POSTER ABSTRACTS

Only abstracts of the posters presented at the Symposium are included in these Proceedings because of space limitations. A companion volume, *IAU Symposium 170: Poster Presentations,* edited by Jeffery G. Mangum. Simon J. E. Radford, and William B. Latter (1996 NRAO), contains expanded versions of many of these presentations.

Using Herbig-Haro Objects to Probe the Interclump Medium of Molecular Clouds

V. P. Alten (University of Colorado)

A recent observational survey of the Perseus molecular cloud complex has resulted in the discovery of a large number of new Herbig-Haro (HH) objects. This implies that the density of shock waves in star forming molecular clouds is much higher than previously thought. Outflows associated with some HH objects are many parsecs in length. It is possible that they pass through the molecular cloud interclump medium so regularly that the gas therein is reprocessed. The short time interval between the passage of subsequent shocks has implications for cloud support and the chemical ages of molecular clouds.

The Chemical Evolution of an Interstellar Cloud Model

M. Y. Amin (Cairo University, Egypt) and M. S. El-Nawawy (UAE University, United Arab Emirates

The aim of the present work is to integrate the chemical rate equations and the hydrodynamic equations simultaneously, where we have used a one-dimensional program to simplify the treatment of contraction as that of a spherically symmetric cloud. The atomic, molecular, and ionic species included in our chemical scheme are altogether 104 species from the families of H, C, O, S, Si, Cl, metals and grains. The involved network contains 622 reactions including 111 reactions for negative ions. The rate coefficients of our system are updated with its most recent values. The central density increases from $n = 10$ cm^{-3} in the diffuse initial cloud model to a dense cloud with central density number of $n \geq 10^5$ cm^{-3} after a time of 1.2×10^7 years.

The results predict that the different molecular species increase in abundance as the contraction proceeds. The species which enhance significantly are CO, HCO, CS and NO. The fractional abundances of many of the other molecular species increase distinctly with contraction, e.g., CH, C_2, CN, SO_2, CO_2, H_2O, C_2, NH_3, HCN, SO, OCS, and SN. The transformation of the initial diffuse cloud model with small abundances of molecular species to a dense molecular cloud with enhancement of the different molecular species is confirmed. Our results are compared with both observations and some recent theoretical works. The comparison shows good agreement of our results with both the observations and the other theoretical studies. Molecules such as the hydrocarbons and related species increase in abundances distinctly. This is because there is a significant abundance of carbon atoms which drive the hydrocarbon chemistry.

The Nitrogen/Oxygen Chemical Network: Observations of NO, HNO, N_2O, NO_2, and NO^+ Towards Sgr B2

A. J. Apponi (Arizona State University)

Unlike that of carbon or oxygen, the chemistry of interstellar nitrogen has yet to be understood even on a qualitative level. One problem is that the observed abundances of several simple nitrogen-bearing molecules such as NH_3 and N_2H^+ cannot be reproduced by the usual "early time" calculations. Another puzzle has been the supposed lack of compounds containing an N-O bond. Here we present recent observations towards the galactic center of N-bearing molecules in the nitrogen/oxygen chemical network that shed light on these problems. The species studied include NO, HNO, N_2O, NO_2, and NO^+. Recently, we have confirmed the presence of HNO in several molecular clouds, including the Sgr B2 complex, by observing transitions of this species at 2 and 1.2 mm. We also have detected N_2O, a new nitrogen-bearing species, in the Galactic center. In conjunction with past work on NO, these observations show that N-O bonds cannot be so rare as previously thought. We additionally have mapped NO and N_2O emission across the Sgr B2 complex. Interestingly, NO, HNO, and N_2O all appear to have peak abundances at the same position, Sgr B2N. Moreover, their abundances are all well-predicted by ion-molecule models, at early times, in contrast to other N-containing species. Such data suggest that nitrogen chemistry involving oxygen differs from that with hydrogen. Other chemical compounds participating in the N/O network are NO^+ and NO_2. We are conducting searches for these species in molecular clouds. The results of this work were reported.

Balanced Finline Mixer in the Millimeter Wave Band

D. S. Armağan (Marmara Research Centre, Turkey)

Rapidly expanding activities in millimeter wave hardware developments have created an urgent need for broad-band mixers for the receivers used in radioastronomy, remote sensing, electronic warfare, surveillance, meteorology, radiometer, and communication systems. Significant improvements have been made in millimeter wave mixers recently. Integrated circuit technologies provide the advantages of low cost, light weight, and small size. These also have the potential of direct translation into monolithic circuits and even large-scale integration. The use of beamlead diodes in integrated circuit mixers avoids a mechanical diode contact in whisker-contacted mixers and, therefore, has better reliability and needs less assembly. This paper describes a balanced finline mixer at 34 GHz frequency. The mixer is the first stage of a radiometer which is aimed to investigate the vegetation canopy. Using the same design technique, it is possible to implement the mixer at the other millimeter wave frequencies. The mixer circuit is etched from a 4×6 cm Duroid-5880 substrate of 0.38 mm thickness and it is placed in a waveguide mount. The signal is fed to the diodes via a symmetrical unilateral finline. The local oscillator power reaches the diodes via symmetrical unilateral finline and transition from finline to coplanar line. This transition works in a similar way to that of a probe type transition from waveguide to coaxial line. For proper operation, a short is placed a quarter wavelength away from the transition, allowing some tuning of the LO input impedance. In a mixer, RF and LO signals produce $nf_{\rm RF} \pm mf_{\rm LO}$ products. The desired IF output is either $f_{\rm RF} + f_{\rm LO}$ or $f_{\rm RF} - f_{\rm LO}$ (upper and lower sidebands) and the IF filter is usually selected to pass only one of these outputs. If it is the desired $\mathrm{f_{RF}} - \mathrm{f_{LO}}$ output, usually the low-pass filter is designed at the IF port. For this finline mixer, the microstrip low-pass filter at 2.8 GHz is connected to the coplanar line. The combination of finline and coplanar line forms a frequency-independent 18° hybrid, giving the basis for this balanced mixer. For the mixer, commercially available GaAs Schottky-barrier beam-lead diodes were used. A first set-up was tested with

AEI diodes DC1306. These diodes have a high noise figure at 34 GHz frequency, so the DSB system noise figure was not good enough. The next step in this study will be to use the HSCH-9101 GaAs Schottky beam-lead mixer diodes.

The Embedded Pre-main Sequence Population in NGC1333-S: $C^{18}O$ Observation

C. Aspin (Joint Astronomy Centre)

We present new JCMT $C^{18}O$ line data towards selected regions in the NGC1333-S molecular cloud/star formation complex. Combined with existing near-IR photometry, we study the relationship between molecular column density (and implied visual extinction) and similar values derived from de-reddening studies. We use the data to provide additional diagnostics for the extractions of the true embedded pre-main sequence stellar population from the distribution seen in the near-IR.

Physical and Chemical Evolution of Dense Cores from Isotopic CO, HCO^+, NH_3, and HC_3N Observations

Peter Barnes (Haystack Observatory), Phil Myers (Center for Astrophysics)

The complex comprising IC 5146 and associated clouds was studied with a variety of molecular line tracers to investigate the properties of the dense cores. Cores associated with the optical cluster (cluster cores) are significantly hotter and somewhat denser than cores far from the cluster (dark cores). The dark cores also have a fairly uniform excitation temperature. Where excitation temperatures are high, optical depths in these low-lying transitions are low, but total CO column densities are comparable in the different cores. Thus the main physical difference between the cluster and dark cores is that molecular populations have been excited to higher J levels. $C^{18}O$ emission correlates well with IR extinction, HCO^+ emission correlates well with star-forming activity, HCO emission occurs only near the H II region, and NH_3 and HC_3N emissions are brightest in the dark cores but are anticorrelated with each other. This anticorrelation is consistent with early-time chemical evolution. Strong fractionation of deuterium has occurred in the dark cores, and fractionation of ^{13}C in the less extincted parts of cores. The intrinsic $^{12}C/^{13}C$ ratio is somewhat less than the terrestrial value ($\sim$60 vs. 89), the double ratio ($^{16}O/^{18}O$)/($^{12}C/^{13}C$) is more than twice terrestrial ($\sim$12 vs. 5.5), and so the $^{16}O/^{18}O$ ratio is also somewhat larger than terrestrial ($\sim$700 vs. 500) in this complex. The warm cluster cores exhibit distinctly different chemical and physical properties from the cool dark cores, but there are also differences among the dark cores.

CO in the Atmospheres of Pluto and Triton

Peter Barnes (Haystack Observatory)

Despite the fact that Pluto has not been visited by a spacecraft, an impressive amount of information has been deduced about its surface, atmosphere, and moon Charon, due in large measure to the mutual occultation events between the two bodies and Pluto's occultation of a star. The latter revealed that Pluto has a thin atmosphere, and subsequent work has suggested that it is composed mainly of nitrogen. In this and other respects, then, Pluto resembles Neptune's moon Triton, as revealed by the Voyager 2 encounter. In addition, both atmospheres contain CO as a minor constituent so, especially in the case of Pluto, CO could be used as a unique probe of atmospheric conditions. Here I give a set of predictions for CO emission from these atmospheres; these can be used, once CO has been detected using ground-based mm-wave radiotelescopes, to derive atmospheric abundances and other properties of these bodies.

Potential Protostars in Cloud Cores: H_2CO Observations of Serpens

Mary Barsony, Robert L. Hurt (UC Riverside), Alwyn Wootten (NRAO)

The Serpens cloud is an active star-forming site. The recent discovery in Serpens of submillimeter continuum sources lacking near-infrared counterparts (a defining characteristic of the youngest observable protostellar phase), has motivated our study of the gas properties of these unique sources. We have chosen H_2CO (formaldehyde) as our molecular probe, because it can trace exceptionally dense gas more sensitively than most other commonly-used molecular species. In the four submm continuum sources which were observed in at least three H_2CO transitions, we present evidence for warm, kinematically active regions surrounded by cooler, more quiescent gas. The temperatures of the embedded cores are warm, ranging from 40–190 K. The gas densities are also high, in the range of $n(H_2) \sim 10^6$–

$10^{6.5}$ cm^{-3}, in general agreement with densities derived from dust emission. Some of the objects exhibit strong self-reversal features which may indicate infall of the cooler outer layers of the core, and two of them possess exceptionally broad linewings which may be associated with molecular flows. Several of these sources may represent extremely young protostars that are in the process of accreting the bulk of their mass from their surrounding envelopes.

Multitransition Submillimeter CO Spectra of Ultraluminous IRAS Galaxies

Dominic J. Benford, Min S. Yun, Todd R. Hunter, Peter M. Bryant, Thomas G. Phillips (California Institute of Technology)

We present submillimeter CO observations of 8 ultraluminous IRAS galaxies as preliminary results from a multitransition survey at the Caltech Submillimeter Observatory. To date, high signal-to-noise spectra have been obtained for all 8 galaxies in the ^{12}CO $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$ transitions. Also, we have recently detected the CO $4 \rightarrow 3$ and $6 \rightarrow 5$ transitions in some of these objects. Observations of the higher frequency lines have been limited by the AOS backend bandwidth (500 MHz = 220 km s^{-1} at CO $6 \rightarrow 5$). As of July 1995, we have begun to extend the high frequency survey using a new AOS that covers the entire 1 GHz receiver bandwidth. We are in the process of preparing an LVG analysis of the multitransition data to better constrain the temperature and density of the molecular gas in these luminous galaxies.

A Comparative Chemical Study of Three Giant Molecular Cloud Cores

E. Bergin (FCRAO, University of Massachusetts)

We discuss the results of a comparative chemical survey of three cloud cores in Orion A, M17, and Cepheus A. The observations were obtained using the FCRAO 15-element array to map the emission of 21 molecules and isotopic variants in > 100 positions in each source. To ascertain if differences in emission are due to abundance variations, we have developed a model of the physical conditions (density and temperature) that determine the molecular excitation. The densities and temperatures are used to derive accurate column densities for each source. The relationship between

the physical and chemical properties for each source will be discussed as well as a discussion of the differences and similarities in the chemical abundances between the three sources. This research is a systematic effort to examine whether current gas phase chemical models can account for observed abundances in GMC cores and, in cases where it fails, to examine other possibilities.

Molecular Oxygen: A New Astrophysical Maser?

P. Bergman (Steward Observatory, University of Arizona)

New excitation calculations for molecular oxygen, which predict maser emission for plausible interstellar conditions, are reported. Collisional rate coefficients for the O_2–He collision system were calculated for several kinetic energies in the range 20 – 500 K. Excitation calculations have been performed for a typical dark cloud and the core and envelope parts of a giant molecular cloud. It is found that for hot ($T_{\text{kin}} \geq 200$ K), dense ($n(\mathrm{H_2}) \approx 10^5\ \mathrm{cm^{-3}}$) interstellar clouds the $N_J = N_{N-1}$ transitions ($1 < N \leq 23$) of O_2 may become significantly inverted, provided that the O_2 abundance (per velocity gradient) is high, $X[\mathrm{O_2}]/(\mathrm{d}v/\mathrm{d}r) > 10^{-4}$ $(\mathrm{km\ s^{-1}\ pc^{-1}})^{-1}$. All these transitions occur at frequencies between 54 and 63 GHz. The physical conditions needed for the masers to exist are similar to, but less severe than, what is required for the 22 GHz water maser line.

CO in the 30 Dor Region of the Large Magellanic Cloud

R. S. Booth (Onsala Space Observatory)

Within the SEST Key Programme an area of approximately $20' \times 23'$, centered on the 30 Dor nebula, has been fully sampled in the ^{12}CO (1–0) line. More than 20 clouds are discernible. A sample of seven clouds have been further investigated in the (2–1) transitions of ^{12}CO and ^{13}CO. Their physical properties are discussed and compared with those observed in other areas of the LMC.

A Highly Collimated Outflow in a Southern Bok Globule

Tyler Bourke (Center for Astrophysics & Dept. of Physics, ADFA, Univ. of NSW), Kimmo Lehtinen (Helsinki University Observatory)

We report the discovery of a highly collimated molecular outflow from the nearby (200pc) low mass young stellar object IRAS 11590–6452 ($L_\star \sim 10\ L_\odot$), located in the isolated southern Bok globule BHR 71 (Bourke et al. 1993, Proc. Astron. Soc. Aust., 10, 236; Bourke et al. 1996, MNRAS, 276, 1052. CO (1–0) observations imply a linear size of ~ 0.5 pc and a mass of 0.5 $M_\odot$ for the outflow, with a degree of collimation of $5:1$. In CO the location of peak emission is not located at the IRAS position, but in the outflow lobes, indicating probable temperature enhancements due to the interaction of shocks and the ambient gas. At these locations, strong emission from CS, HCO^+, and SiO is present, indicating the probable destruction of grains by the passage of the shocks. The widespread presence of vibrational H_2 emission supports this view of shock activity as the cause of these features. This outflow thus belongs to the select group of young outflows from low mass 'Class 0' objects showing a high degree of collimation and enhanced SiO emission.

CO Observations of HII Galaxies

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HII galaxies are gas rich, actively star–forming dwarf galaxies. We know very little about their molecular gas content. Still, they must harbour substantial amounts of H_2 as witnessed by their star formation activity. Several authors have attempted to detect CO in dwarfs (see e.g., Sage et al. 1992, A&A, 265, 19) mostly reporting upper limits or in some cases contradictory results. Several explanations have been put forward why HII galaxies have been so elusive. Because of their low heavy element abundance, the abundances of C and O are down. Moreover, as the dust–to–gas ratio is low, shielding of the UV radiation field will be less effective, suggesting that molecular clouds in irregular galaxies will be more compact than in the Galaxy and that the CO luminosity as a whole can be down by factors of at least 20.

In order to shed more light on this situation we have started a survey in the line of ^{12}CO with the NRAO 12 m telescope of a statistically well defined sample of HII galaxies (Taylor et al. 1995, ApJS, 99, 427). None of our targets were detected during our run in January 1995 at sensitivity levels substantially better than previous studies. One object, Haro 2, which was detected previously with the 30 m IRAM telescope was not seen by us. This could indicate that beam dilution plays a role and would suggest that the CO is indeed highly concentrated in small, dense clumps.

A CS(2–1) Survey of IRAS Point-Sources with Color Characteristics of Ultra-Compact H II Regions

L. Bronfman (Universidad de Chile), L. Nyman (SEST-Onsala Space Observatory, Sweden), J. May (Universidad de Chile)

We have made a complete survey of the CS (2–1) emission toward IRAS point-like sources in the Galactic plane. The observed sources were selected according to their far infrared (FIR) colors, which are characteristic of UC H II regions. They have 25 μm/12 μm flux ratios larger than 3.7 and 60 μm/25 μm flux ratios larger than 19.3. The survey covered from $b = -2°$ to $b = 2°$ in the range $l = 300°$ through $l = 60°$, and from $b = -4°$ to $b = 4°$ elsewhere. The observations were made between 1989 and 1992 with the 15m SEST Telescope at La Silla, Chile, and with the OSO (Onsala Space Observatory) 20m Telescope, Sweden, in May 1993. The angular resolution at 98 GHz is of 50″ for SEST and of 39″ for OSO (main beam FWHM), similar to the IRAS survey angular resolution. Out of 1427 observed sources, 843 were detected. In most cases the observed CS(2–1) profile consisted of a single component, with the VLSR of a known molecular cloud in the line of sight. The IRAS point sources detected in the CS(2–1) line concentrate in the inner Galaxy, forming a "massive star" annulus similar to the molecular annulus that has been previously derived from CO large scale surveys of the Milky Way. The decrease that was then found in the peak molecular gas surface density from the first to the fourth quadrant is compensated by an increase in the FIR surface luminosity due to embedded massive stars.

High Resolution CO Observations of Luminous IR Galaxies

Peter M. Bryant, N. Z. Scoville (Caltech)

We report 2″ – 3″ resolution CO ($1 \rightarrow 0$) observations of six galaxies with infrared luminosities ranging from 3.2×10^{11} to 3.5×10^{12} $L_\odot$; we also report 0.8″ CO ($2 \rightarrow 1$) observations of the most luminous of these objects, Mrk 231. In the five objects previously classified as mergers by their optical morphology, 10^{10} $M_\odot$ or more of molecular gas is contained within a radius of 1.3 kpc or less; in three of these, this gas is within a radius of 0.44 kpc. The only non-merger in our sample — NGC 7674, the larger member of a pair of interacting spirals — shows a massive CO bar of radius 5.6 kpc, roughly coincident with its optical bar in both length and position angle.

In all six objects, the derived nuclear molecular gas masses are comparable to or somewhat greater than the derived dynamical masses. The most serious discrepancy occurs for Mrk 231, where the derived gas mass within a 420 pc radius ($0.5''$) of the nucleus is over seven times larger than the dynamical mass. We have performed a detailed analysis of the behavior of the CO luminosity to gas mass conversion factor in a variety of geometries and physical conditions, and we conclude the molecular gas mass is unlikely to be overestimated by over a factor of seven in Mrk 231; thus, inclination effects are the probable cause of the discrepancy. This implies the mass of the core of Mrk 231 is dominated by molecular gas and the average gas surface density in the core is roughly 7×10^4 $M_\odot$ pc^{-2} — over one hundred times greater than in the center of the Milky Way.

Far-Infrared – CO Study of Star Formation in the Large Magellanic Cloud

Douglas A. Caldwell, Marc L. Kutner (NRAO, Rensselaer Polytechnic Institute)

We present a study of star forming giant molecular clouds (GMC) in the LMC. We have mapped 21 GMCs in both far–infrared (FIR) and CO ($J=1 \rightarrow 0$). FIR observations are from the IRAS high resolution data set. CO observations were made on the SEST (15 m). The resolutions of both data sets correspond to a linear resolution of ~ 10 pc at the LMC. FIR luminosities and virial masses of these clouds are comparable to Milky Way GMCs. The star formation activity, defined here as $L_{\rm FIR}/M_{\rm VIR}$ is comparable to that found for Milky Way clouds, and shows a similar large range for any given $M_{\rm VIR}$. GMCs in the LMC exhibit a range from little to no star formation to robust, massive star star formation, virtually independent of $M_{\rm VIR}$. Despite different physical conditions, some GMCs in the LMC have star formation activities equivalent to all but the most active Milky Way GMCs.

Cosmic Evolution of CI, CII, and CO Luminosity of Galaxies

C. Campbell (Department of Physics, Univ. of Colorado) and John Bally (Center for Astrophysics and Space Astronomy, Univ. of Colorado)

We calculate the gas-phase abundances of neutral carbon (CI), ionized carbon (CII), and carbon monoxide (CO) as functions of cosmic evolutionary time and redshift. In a galactic evolution model using low, intermediate, and high mass stars which includes both Type I and Type II supernovae, infall, and various star formation rates, the interstellar gas phase abundances of carbon and oxygen are computed as functions of the gas mass fraction. For models without infall, the gas phase abundance of carbon bearing species peaks when about 50% of the baryonic mass of a galaxy has been consumed by star formation. The fraction of gas-phase carbon in CI, CII, and CO phases is then determined from models of photon dominated regions. We include the attenuation of radiation by dust grains and self-shielding of CO to find the average column density of CII, CI, and CO. The luminosity of the CO lines is then estimated from an excitation model. Galactic evolution models with varying star formation rates, merging, and the effect of Hubble type are discussed. The analysis of the millimeter and sub-millimeter wavelength lines of all the carbon species may prove to be a powerful probe for studying galactic evolution and cosmology.

CO at $z = 0.724$

F. Casoli, P. Encrenaz, P. Boissé, B. Fort (Observatoire de Paris), Y. Mellier (Observatoire de Toulouse)

We present the probable detection of the CO(2–1) line in the giant arc in the cluster A370 with the IRAM 30m telescope. This very blue arc, 26″ in length, is the image magnified about 15 times of a $z = 0.724$ spiral galaxy located behind the cluster. Without magnification, the galaxy image would have a size of about 0.5″. The line is redshifted to 133.7 GHz and the total integration time was 8 hours. The estimated H_2 mass in this galaxy is a few times 10^9 $M_\odot$. We have searched for CO in 3 other arcs (CL2236–04, CL2244–02, and A2218) but detected none. These objects are more distant so we had to observe high-J lines, which are likely to be weak in normal spirals.

The two other objects detected at cosmological distances, IRAS 10214+4724 and the Cloverleaf, are also amplified by gravitational lensing. Thus, the "gravitational telescope" is likely the best way to study objects in the early Universe, either extreme or normal galaxies.

The Structure of NGC 1333 from ^{13}CO and C^{18}O Observations

A. Castets, S. Warin (Laboratoire d'Astrophysique, Observatoire de Grenoble), and W.D. Langer (Jet Propulsion Laboratory)

This paper presents a study of a dense molecular region, NGC 1333, and the relationship of the embedded infrared sources and young stellar objects to the structure of its molecular core. We use ^{13}CO and C^{18}O J = 1–0 and J = 2–1 observations, along with those of CS J = 2–1 to characterize the structure of the core and to calculate densities and masses. We find from our C^{18}O maps that the core consists of a cavity surrounded by a compressed shell of gas. Many of the infrared and outflow sources in NGC 1333 are located in the cavity. The outflow winds from IRAS2, SSV 13, and several other sources appear to be responsible for creating the cavity and forming the shell. We suggest that sequential star formation is taking place in NGC 1333 with successive generations of young stellar objects providing the energy to expand the cavity, sweep up the material, and compress the shell.

Interferometric Observations of Protostellar Outflows

L. Chernin (University of California, Berkeley)

We present recent high resolution ($3'' - 5''$) ^{12}CO 1–0 interferometer images of the protostellar outflows in the Orion IRc 2, Lynds 1448, NGC 2071, and NGC 2024 regions. We discuss the structures in the individual outflow maps and make comparisions with recent outflow models. The Orion outflow, which is driven by a massive protostar(s), is best described as a wind driven shell, while the other outflows, which are from lower mass stars, appear to be driven by collimated jets. In the low mass outflows, the outflow lobes are conical near the driving star and in some cases there is no known infrared object at the apex of the cone. Thus, we find new evidence of a fundamental difference between outflows from low and high mass stars.

Theoretical Maps of Stellar-wind-powered HII Regions

F. Comeron (Universidad de Barcelona)

HII regions often lie in zones with strong density gradients, such as the interfaces between the cloud and the intercloud medium in a molecu-

lar cloud. Numerical simulations in 2-D carried out in the past by other authors have outlined the process of expansion of the ionized gas when such density gradients are encountered, establishing the framework of the so-called "champagne model."

In this poster, we present the results obtained in a similar scenario when one takes into account the pressure of the shocked stellar wind from the ionizing star in addition to photoionization as a driving agent for the expansion of the HII region. It is shown how the dynamical evolution is modified by the action of a high-pressure, low-density gas inside the photoionized region. In addition, theoretical maps in optically thin wavelengths are presented to allow comparison with radio and infrared observations.

CO Observations of Planetary Nebulae

Aditya Dayal, John H. Bieging (Steward Obs.)

We present NRAO 12-meter observations of CO in 3 planetary nebulae, including the first confirmed detection of a molecular outflow in K 3–35 and the first detection of J=1–0 emission from NGC 2440. We also report a ($\geq 5\sigma$) detection of J=1–0 emission towards IC 418. The J=2–1 spectrum towards K 3–35 shows a strong peak at $\sim$ 10 km s^{-1} ($V_{\rm lsr}$) and $\sim$ 50 km s^{-1} wide high velocity wings. The strong peak is narrow ($<$ 5 km s^{-1}) and is probably associated with a Galactic molecular cloud; the high velocity emission feature indicates an outflow velocity of about 25 km s^{-1}. The CO (J=1–0 and J=2–1) lines towards NGC 2440 are broad and double-peaked, and indicate an expansion velocity of $\sim$ 25 km s^{-1}. The J=1–0 emission towards IC 418 shows a parabolic profile which is indicative of optically thick emission; the expansion velocity is $\sim$ 30 km s^{-1}. The J=2–1 emission is undetected. This suggests that the gas has a fairly low excitation temperature and is consistent with an extended halo of emission, as is also seen in 21 cm observations of neutral H.

Luminosity-to-Mass [$L_{\rm ir}/M(\rm H_2)$] Ratios within GMCs: NGC 7538 and W3

J. R. Deane, D. B. Sanders (Institute for Astronomy, Univ. of Hawaii), E. F. Ladd (Five College Radio Astronomy Observatory, Univ. of Massachusetts)

The star-forming properties of the NGC 7538 and W3 GMCs have been investigated using infrared and millimeter-wave molecular line data. Total molecular gas masses, $M(\mathrm{H_2})$, for W3 (3×10^5 $\mathrm{M_\odot}$) and NGC 7538 (4×10^5 $\mathrm{M_\odot}$) were determined from ^{12}CO(1$\rightarrow$0) and ^{13}CO(1$\rightarrow$0) images of each GMC. After careful subtraction of the Galactic plane far-infrared background emission from the IRAS Infrared Sky Survey Atlas (ISSA), total infrared luminosities, $\mathrm{L_{ir}}$(8 - 1000 μm) for W3 (2.3×10^6 $\mathrm{L_\odot}$) and NGC 7538 (1.1×10^6 $\mathrm{L_\odot}$) were also determined.

The total cloud-integrated $L_{\mathrm{ir}}/M(\mathrm{H_2})$ ratios (W3: 8 $\mathrm{L_\odot/M_\odot}$; NGC 7538: 3 $\mathrm{L_\odot/M_\odot}$) are similar to the mean ratios found for HII-region GMCs from previous surveys of the Milky Way. But when each GMC ($1.5° \times 1.5°$) is mapped at $6'$ resolution, the $L_{\mathrm{ir}}/M(\mathrm{H_2})$ ratios vary by two orders of magnitude. In W3, the three most massive and active cores in the cloud contain 37% of the cloud mass but contribute 85% of the total luminosity ($L_{\mathrm{ir}}/M(\mathrm{H_2})$ = 19 $\mathrm{L_\odot/M_\odot}$). However, most of the cloud, by mass (62%) and by area (75%), is comparatively quiescent ($L_{\mathrm{ir}}/M(\mathrm{H_2})$ = 2.0 $\mathrm{L_\odot/M_\odot}$). In NGC 7538, the most massive cores, which comprise only 30% of the cloud area, contain 60% of the mass and contribute 73% of the total GMC luminosity ($L_{\mathrm{ir}}/M(\mathrm{H_2})$ = 3 $\mathrm{L_\odot/M_\odot}$).

^{12}CO (3–2) and (1–0) Emission Line Observations Of Nearby Starburst Galaxy Nuclei

Nick Devereux (New Mexico State University), Yoshi Taniguchi (Tohoku University), Dave Sanders (University of Hawaii), N. Nakai (Nobeyama Radio Observatory), J.S. Young (FCRAO/UMASS)

New measurements of the ^{12}CO (1–0) and (3–2) line emission are presented for the nuclei of seven nearby starburst galaxies. The new observations capitalize on the coincidence between the beam size of the 45m Nobeyama telescope at 115 GHz and that of the 15m James Clerk Maxwell Telescope at 345 GHz to measure the value of the ^{12}CO (3–2)/(1–0) emission line ratio in a $15''$ ($\leq$ 2.5 kpc) diameter region centered on the nuclear starburst. In principle, the ^{12}CO (3–2)/(1–0) emission line ratio provides a measure of temperature and optical depth for the ^{12}CO gas. The weighted mean value of the ^{12}CO (3–2)/(1–0) emission line ratio measured for the seven starburst galaxy nuclei is 0.64 ± 0.06. The ^{12}CO (3–2)/(1–0) emission line ratio measured for the starburst galaxy nuclei is not as high as would be expected if the molecular gas were hot, $\geq$ 20 K, and optically thin, $\tau \ll 1$. The total mass of molecular gas contained within the central region of the starburst galaxy nuclei ranges between 10^8 and 10^9 $\mathrm{M_\odot}$. While substantial, the molecular gas mass represents only a small percentage, ~ 9 – 16%, of the dynamical mass in the same region. Details in AJ, 107, 2006.

DR21: Highlights over 25 Years

Hélène R. Dickel, Douglas A. Roberts (University of Illinois), W. Miller Goss (National Radio Astronomy Observatory - Very Large Array)

CO observations of the DR 21 region in 1973–4 with the NRAO 36 foot radio telescope at a resolution of $1'$ revealed a giant molecular cloud associated with this continuum source and large CO line wings toward the continuum peak (Dickel *et al.* 1978). CO observations at $15''$ resolution with the Nobeyama 45 m telescope (Garden *et al.* 1991) clearly show this to be the most massive and energetic young stellar bipolar outflow in our Galaxy. Recently we observed the HI absorption with the VLA at $5''$ resolution. DR21 exhibits one of the widest HI absorption lines in our Galaxy. The continuum emission of DR21 is nearly totally absorbed with $\tau > 6$ over about 20 km s^{-1}; the line FWHM $\sim$ 35 km s^{-1}. At least three components are present: two narrow ones at v(lsr) = 5 km s^{-1} and 10 km s^{-1} and a negative-velocity wing whose opacity can be measured out to v(lsr) = -30 km s^{-1} in some places. No positive velocity wing is detected. The negative-velocity wing is detected over most of the HII region core except in the very southwest corner, near the position of the DR 21 H_2O maser. The HI gas appears to be accelerating from this SW position which is therefore taken as the **origin** of the bipolar outflow. Measurements of Zeeman splitting of the HI line reveal a magnetic field of several hundred microgauss in this outflowing gas close to the molecular core; no magnetic field ($B < 50\mu$G) is detected in the narrow line component at v(lsr) = 10 km s^{-1}.

Multitransition Observations of Molecular Clouds in the Far Outer Galaxy

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Millimeter-wave observations of three molecular clouds in the far outer Galaxy, all with apparent Galactocentric distances $R > 20$ kpc, are presented, along with a preliminary analysis of their properties. These clouds, discovered in a survey of H I concentrations in the far outer Galaxy with the CfA 1.2 m telescope, are among the farthest from the Galactic center of any known. Although they are near or beyond the edge of the star-forming disk, one has been found to contain an H II region. The extensive CO maps and observations of lines of ^{13}CO and CS with the NRAO 12 m and IRAM 30 m telescopes presented here indicate that all of the clouds are clumpy at 1–2 pc scales and the dense clumps in the star-forming cloud are distinctly different from those in the other two. The cores of this cloud only are detected in CS. These cores are also apparently warmer and more massive than the others, although the latter distinction may not be significant if the cloud is appreciably closer than its kinematic distance, as a recent spectroscopic study of the star exciting the H II region indicates.

Dust Driven Winds of Pulsating Red Giants

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From numerical calculations of dust driven winds from carbon-rich long period variables (LPVs), it has become clear that both a full treatment of the coupled system of gas and radiation and also time-dependent dust formation and growth is essential to describe the properties of this accelerated and expanding stellar outflow. The stellar pulsation causes shock waves to propagate outwards through the stellar envelope and to lift the stellar atmosphere. The density enhancements in the shock waves followed by a radiative cooling zone provide the physical conditions for an effective nucleation and growth of dust particles. The CO molecule plays a crucial role for these winds since the less abundant element of carbon or oxygen is bound in the CO molecule. This process determines which chemical species are available for the dust condensation. In order to determine the temperature and density structure controlling the dust formation process, the coupled system of radiation, dust, and gas dynamics is solved and provides, e.g., also the modulation of the radiation field due to the compressive motions near the dust-forming region. The mass loss rates and outflow velocities obtained are in agreement with the observed values. The zones of dust formation and growth can be traced in various frequencies leading to a rather complicated geometry within the radiation field because regions of large optical depths alternate with almost transparent zones depending on the grain size and the optical properties of the dust particles.

Compact Objects and Dense Clouds Association

P. Durouchoux (CE-Saclay-DAPNIA-SAP)

Some compact objects, emitting in the gamma-ray range, seem not to be associated with a binary system. The alternative for the accretion is a dust cloud which feeds the disk. We review recent observations conducted at the mm wavelengths that support this idea.

The Evolution of Charged Particles in a Contracting Interstellar Cloud

M. S. El-Nawawy (UAE University, United Arab Emirates), M. Y. Amin (Cairo University, Egypt)

The objective of the present work is to study the evolution of charged particles with time of contraction. This work is part of the calculations carried out on a model of a contracting interstellar cloud. In the first paper by Amin and El-Nawawy (appearing in this volume), we have discussed the results on the neutral species. In this paper, we follow the evolution of the charged particles during contraction. Special care is given to the details of the negative ions. In addition, we have tested the ambipolar diffusion according to the results of the ion density. We have given attention to the chemical reactions of negative ions in three models in steady state before including them in the network of the contracting model.

The results predict the importance of atomic ions in the diffuse regions. H^+ and C^+ are distinctly enhanced in the beginning of contraction but decrease as contraction proceeds. Molecular ions enhance as contraction proceeds and becomes important in dense regions. The most enhanced molecular ions are HCO^+, O_2, C_2H_3, and SO^+. H_3^+ is less abundant. The atomic ions (except metallic ions) decrease noticeably as density increases. In general, the negative ions are of negligible fractional abundances. It has also been found that the time of ambipolar diffusion is shorter than the dynamical time, hence, the magnetic field should be weakened in the central core as the central density increases to $n > 10^4$ cm^{-3}.

Search for CO Emission in High Redshift Powerful Radio Galaxies

Aaron S. Evans (Institute for Astronomy, University of Hawaii)

We present upper limits to the molecular gas masses of 11 high redshift ($1 < z < 4$) powerful radio galaxies (HzPRGs). These observations include some of the most sensitive extragalactic CO observations to date. Our four best studied radio galaxies (3C 368, 4C 23.56, B2 0902+34, and 4C 41.17) have less than one-third the CO luminosity of the hyperluminous infrared galaxy *IRAS* F10214+4724 and, assuming a galactic CO-to-H_2 conversion factor, they have molecular gas masses comparable to or less than the most gas-rich, ultraluminous infrared galaxies (ULIGs) in the local ($z \leq 0.3$) Universe (i.e., $M(\mathrm{H}_2) < 3 \times 10^{10} h^{-2} \mathrm{M}_\odot$; $H_0 = 100h$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$). Spectral energy distributions of 8 HzPRGs show they have UV-to-optical luminosities ranging from ~ 0.1 to 1.0 times that of F10214+4724. Recent submillimeter observations of 3 HzPRGs suggest that one source, 4C 41.17, may have an intense submillimeter-far infrared excess. However, coadded *IRAS* observations suggest that HzPRGs as a class are not hyperluminous at far-infrared wavelengths. We also consider how the possibility that F10214+4724 is a gravitationally lensed galaxy affects our interpretation of the data, as well as what it may mean for gas-rich galaxies in general.

The Bipolar Outflow NGC2264G

Michel Fich (University of Waterloo), Charles J. Lada (Smithsonian Astrophysical Observatory)

Detailed observations in CO(2–1) have been obtained of the highly collimated bipolar outflow NGC2264G. A complete map with 20 arcsec resolution shows rich structural detail in both the spatial morphology and the velocity field of the outflow. The blue outflow lobe extends considerably further than realized by previous authors. The blue lobe appears to interact with a molecular cloud in the foreground that is kinematically distinct from the cloud where the outflow originates. The low velocity gas in the red lobe is contained in a large structure that appears similar to a bow shock. Despite striking differences between the two lobes, essentially every point in either lobe is described by the same kinematic time scale.

Both lobes show an elongated structure at the highest velocities, extending beyond the lower velocity gas and unresolved in the direction perpendicular to the flow direction. These structures may be the molecular component of the jet driving this outflow. The low and intermediate outflowing material exhibits a power-law variation of mass with velocity with index of −1.7, similar to what is seen in several other similar outflows. However, the highest velocity gas that looks like a jet in the position-position plots has a steeper power law variation with the identical index in both lobes.

New estimates of the mass, momentum, and energetics of the outflow indicate that a very high efficiency is required for the source driving the outflow.

Dynamical Models of Circumstellar Dust Shells around Long–period Variables: The Effect of Multiperiodicity

Axel J. Fleischer, Jan Martin Winters, Erwin Sedlmayr (Institut für Astron. & Astrophys., TU Berlin), Andreas H. Gauger (Los Alamos National Laboratory))

We present dynamical models of circumstellar dust shells around carbon–rich long-period variables which include time-dependent hydrodynamics and a detailed treatment of dust formation, growth and evaporation as well as a treatment of chemistry and radiative transfer.

Important effects due to the complex, nonlinear interaction between the dynamics of the pulsating atmosphere and the dust complex are demonstrated. It is shown that in a certain range of the parameter space the dust shell develops its own time scale which is different from the time scale of the interior pulsation. The key parameter which tunes this eigenfrequency of the dust shell is the overabundance of carbon to oxygen. For specific values of the carbon overabundance, the eigenfrequency of the dust shell is an integer multiple of the pulsational period; for other values, irregular or chaotic behavior results from the interaction of the pulsation and the circumstellar shell.

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CO(1-0) Emission at $z = 0.437$ toward 3C 196

D. T. Frayer, R. L. Brown (NRAO, Charlottesville)

We report on CO(1–0) observations at a redshift of $z = 0.437$ corresponding to the 21 cm absorption line system toward the background QSO 3C 196. We have systematically searched several positions at and around

the QSO line of sight and have found evidence for CO emission at two positions. At 1 arcmin south of 3C 196, we detect CO(1–0) emission representing approximately 10^{11} solar masses of molecular gas. We also observe weaker CO emission at the QSO position, but we are currently unable to distinguish between the possibilities that this emission arises from the source which is approximately 1 arcmin south of the 3C 196 or that the CO emission arises from two or more emission regions spread over 200 h^{-1} kpc.

CO Images of IR-luminous Ring Galaxies: Arp 118 and Arp 119

Yu Gao, P.M. Solomon (Astronomy Program, SUNY Stony Brook), D. Downes (IRAM, Grenoble), Min Su Yun (OVRO, Caltech), S.J.E. Radford (NRAO, Tucson)

We present high resolution CO images of Arp 118 and Arp 119 obtained with the IRAM and OVRO mm interferometers, respectively. Both systems are ring-like interacting/merging galaxies with extremely broad CO/HI linewidths of FWZI $\sim 1,000$ km s^{-1}and high molecular masses of 2–5$\times10^{10}$ $M_\odot$. In both systems, most of the molecular gas is associated with the "rings/arcs" or "spiral arms" extending up to $\sim$ 15 kpc around the Seyfert nuclei. Arp 118 shows no nuclear molecular gas and even its strongest extranuclear association, a Giant HII Region that is the dominant 10 μm source, contributes only $\sim$ 15% of the total CO emission. Arp 119 has only $\sim$ 40% of the CO emission from the nuclear region. This is in sharp contrast with most IR-luminous galaxies, which have high nuclear molecular gas concentrations.

Both ring galaxies have high-mass-star formation efficiencies, $L_{\rm IR}/M(\rm H_2) \sim$ 5 $L_\odot/M_\odot$, comparable to the Milky Way's and much lower than those for most IR-luminous interacting galaxies. Arp 119 may be explained as due to a pole-on collision between a gas-rich disk spiral and an elliptical. Arp 118 either involves a collision of an elliptical with an extremely massive spiral of $> 10^{12}$ $M_\odot$ or a merger of two disk spirals followed by a collision with an elliptical. Its molecular morphology demonstrates that not all mergers lead to gas infall into the center. There is no connection between the molecular gas–starburst region and the AGN in this galaxy system.

Dense Molecular Gas and High Mass Star Formation in Galaxies

Yu Gao & Phil M. Solomon (Astronomy Program, SUNY at Stony Brook)

We have carried out systematic HCN (1–0) observations (complementary with CO observations) of a sample of ~ 40 IR/CO bright/luminous galaxies. HCN luminosity, L_{HCN}, is a measure of the mass of dense molecular gas and the ratio $L_{\mathrm{HCN}}/L_{\mathrm{CO}}$ is an indicator of the fraction of dense molecular gas. The principal goal is to compare the dense molecular gas content with the OB star formation rate traced by far infrared emission. We show that the galaxies observed here follow the correlations between L_{IR} and L_{HCN} and between $L_{\mathrm{IR}}/L_{\mathrm{CO}}$ and $L_{\mathrm{HCN}}/L_{\mathrm{CO}}$ proposed by Solomon et al. (1992). In particular, the $L_{\mathrm{IR}}/L_{\mathrm{HCN}}$ ratio is independent of the infrared luminosity, whereas $L_{\mathrm{IR}}/L_{\mathrm{CO}}$ increases with IR luminosity. This suggests the star formation rate depends upon the amount of dense molecular gas, not the total molecular content measured by CO emission. For a few nearby galaxies, we present HCN maps along the major axes so we can determine the total HCN luminosity, map the distribution with radius of HCN emission, and obtain the surface brightness ratio $I_{\mathrm{HCN}}/I_{\mathrm{CO}}$. Dense molecular gas is not confined to ~ 1 kpc nuclear regions. A significant fraction of dense molecular gas is distributed in the inner disks outside the nuclear or inner ring starburst regions, and can be detected to radii as large as a few kpc, perhaps to diameters of $\sim D_{25}/4$. The starburst cores have the highest fraction of dense molecular gas with $I_{\mathrm{HCN}}/I_{\mathrm{CO}}$ ratios comparable to those of ultraluminous IR galaxies, whereas this ratio falls off in the galaxy inner disks at larger radii to be comparable to those of normal galaxies.

Observed and Synthetic CO Line Profiles and the Structure of the IRC+10216 Circumstellar Dust Shell

A. Gauger, J.J. Keady (Los Alamos National Laboratory, Theoretical Division), J.M. Winters, A.J. Fleischer, E. Sedlmayr (Institut für Astronomie und Astrophysik, Technische Universität Berlin)

High resolution infrared spectroscopy of molecular absorption lines, especially of CO, in circumstellar dust shells around AGB stars, such as the prominent carbon-rich Mira IRC+10216, provides a powerful diagnostic probe able to reveal details of the outflow from the photosphere out to more than a hundred stellar radii.

We have performed non-LTE radiative transfer calculations for CO fundamental and $\nu = 2 - 0$ overtone lines using the structure of a dynamical model for the dust shell around IRC+10216, which results from a consistent treatment of hydro- and thermodynamics, radiative transfer, chemistry

and carbon grain formation. Compared to high resolution CO line spectra obtained at the KPNO Mayall 4m telescope, the P–Cygni emission components and the position of the absorption cores of the fundamental lines agree well, implying that the model reproduces the outflow velocity and the dust optical depth of IRC+10216. However, the calculated fundamental line absorption cores are broader and the first overtone line strengths are too high, indicating that the density and thus the mass loss rate of the model is too high and should be closer to the value of $\approx 10^{-5}$ $M_{\odot}$/yr given for IRC+10216 in the literature.
Research at LANL has been performed under the auspices of the U.S. Department of Energy.

CO Observations of Molecular Gas around a Giant HII Region in M101

J. Giannakopoulou and M. Fich (University of Waterloo, Canada)

Using the James Clerk Maxwell Telescope, we observed two rotational transitions of CO (J=2–1 and J=3–2) towards NGC 5461, the brightest giant HII region in the M101 galaxy. The peak temperature of the CO J=2–1 emission line at the centre of the HII region is a factor of two stronger than the corresponding peak seen in the previously observed J=1–0 line. Furthermore, it is intriguing that no CO J=3–2 signals are observed from two positions directly southeast and northwest from the centre of the HII region, even though CO J=2–1 emission has been detected there. The observed large change in the ratio of intensities of the two lines could indicate significant temperature variations. Another interesting feature in the lines is their double-peaked structure. The velocity peaks appear to be spatially separated. Finally, we obtained a marginal detection of ^{13}CO J=2–1.

Cold Dust Emission from the Spiral Arms of M 51: A Reappraisal of the X Conversion Factor

M. Guélin (IRAM), R. Zylka, P.G. Mezger, C.G.T. Haslam, and E. Kreysa (MPIfR)

Using the IRAM 30 m telescope equipped with the MPIfR 7 channel bolometer array, we have mapped the λ 1.2 mm continuum emission of the inner part of M 51. This emission traces the central molecular disk and the inner spiral arms and correlates remarkably well with the ^{12}CO (2–1) line emission. The λ 1.2 mm continuum to CO line intensity ratio, averaged over the 60 GHz wide bolometer band, is 6. The λ 1.2 mm emission arises mostly from cold dust ($T_d \leq 20$K) associated with molecular clouds. Using the local Galactic value of the dust absorption cross section, corrected for the larger metallicity observed near M 51's center, we derive from this emission the gas distribution. The derived molecular masses are 3–5 times smaller than those obtained from the CO luminosity using Strong et al.'s Galactic CO to H_2 conversion factor, but are close to the masses estimated from ^{13}CO and from visual extinction. Considering the approximations inherent to each method, the molecular masses derived from dust, CO and A_V can still be considered as consistent. We wish to stress, however, that the actual gas mass of M 51 may very well be a factor of 4 lower than usually assumed. A similar conclusion was reached for NGC 891, another nearby spiral whose cold dust emission was mapped with the IRAM 30 m telescope (Guélin et al. A&A, 279, L37). It probably also applies to many other galaxies.

The Twin 60 cm CO (J=2–1) Survey Telescopes

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We have constructed twin 60 cm radio telescopes in order to make a survey of the Galactic plane in the CO (J=2–1) line. The scientific targets of the project are to figure out the large-scale density distribution of molecular gas in the Galaxy and the large-scale density structure of giant molecular clouds. These basic observational studies will allow us to establish a link between Galactic and extra-galactic multi-line studies. The telescopes are located at Nobeyama, Japan and at La Silla, Chile. They have the same basic structure and are originaly designed for our survey project. The aperture size is 60 cm and beamsize is 9 arcmin, which is well designed to make direct comparisons with the Columbia Survey (Dame et al. 1987). The optics are offset Cassegrain coudé with 6 mirrors, which gives us a high beam efficiency of 0.93. The receivers are SIS with $T_{\rm sys} = 1100$ K(SSB) and cooled Schottky type with $T_{\rm sys} = 700$ K(DSB). The spectrometers are AOS with 0.25 and 1 GHz bandwidth. The telescopes are controlled by the original system named ASTROS - Automated Small Telescope Remote Operation System, which is designed based upon the distributed processing concept.

A Protoplanetary Gas Disk Search around T Tau Stars – Detection of the CO Emission around DM Tauri

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Sensitive molecular line observations with the Nobeyama 45 m telescope have resulted in the detection of the CO and ^{13}CO emission centered on the young, classical T Tauri star, DM Tau. No C^{18}O emission was detected. The systemic velocity of the emission coincides well with the reported radial velocity of the star. The ^{13}CO profile shows a symmetric double peak, suggesting a Keplerian rotating disk. The derived radius of the disk is about 1000 AU. The mass is between $7 \times 10^{-4}\ M_\odot$ and $1 \times 10^{-3}\ M_\odot$ from the ^{13}CO intensity and the upper limit of C^{18}O intensity. Our results suggest that molecular gas is depleted from the standard gas-to-dust mass ratio or that mass distribution in the disk is steeper than the standard law, $r^{-1.5}$, although our observations cannot detect emission from an optically thick gaseous component inward of $r < 100$ AU, if the emission comes from a Keplerian rotating disk.

Evidence for Selective Photodissociation of CO and an Enhanced C/O Elemental Ratio in the Gas Phase in NGC 253

Andrew Harrison, Peter Brand (University of Edinburgh), Adrian Russell, Phil Puxley (Royal Observatory of Edinburgh)

In the central ~300 pc of the circum-nuclear region of the starburst galaxy NGC 253, the bulk of the molecular gas is hot (T ~100 K) and dense ($n > 10^4$ cm^{-3}) and the chemistry of this gas is dominated by the large UV field from newly born massive stars. Furthermore, in NGC 253:

- standard models of UV photon dominated chemistry can only account for <5% of the observed [CI] emission.
- there is a high C/O elemental ratio in the gas phase.
- C^{18}O is a poor tracer of the bulk of the molecular gas.
- selective photodissociation of CO and its isotopomers is efficient.

A Search for High-Latitude CO

Dap Hartmann (Harvard-Smithsonian Center for Astrophysics), Loris Magnani (University of Georgia), Patrick Thaddeus (Harvard-Smithsonian CfA)

To determine the quantity of molecular gas at high Galactic latitudes, we are surveying CO (1–0) emission at $|b| \geq 30^\circ$. Using the CfA 1.2-meter telescope (beam = $8.7'$ we sampled the sky (at $\delta \geq -17^\circ\!.5$) at these high latitudes, on a $1^\circ \times 1^\circ$ (locally Cartesian) grid, to a sensitivity (3σ) of 0.3 K. The spectra are observed in position-switching mode, where the *off* position is a grid point 1° closer to the nearest Galactic pole. The planned grid has 15,650 points, 44% of which have currently been observed. We have made 53 detections of which some appear to be towards directions never before observed. The grid in the region bounded by $30^\circ \leq l \leq 210^\circ$ and $b \geq +30^\circ$ was fully completed; it comprises 37% of the planned grid. We detected CO emission in 15 of the 5742 directions in this part of the sky, amounting to a detection rate of 0.26%. No detections were found for latitudes higher than $43^\circ\!.$ Monte Carlo simulations of a random distribution of clouds, ranging in size from 0.02 to 2.0 square deg, indicate that our search would typically detect $73.6 \pm 4.5\%$ of all clouds. The undetected clouds fall in the gaps of our sampling pattern. We have only just started sampling the grid at $b \leq -30^\circ$, but the results so far are encouraging. Already we have newly detected CO emission in about a half dozen directions, although it remains to be seen whether this emission originates from large cloud complexes similar to the Polaris Flare in the northern Galactic hemisphere. The region around MBM 54–56 seems to be very rich in CO emission.

Constraints on the Physical and Chemical Conditions of the Molecular Gas in the Magellanic Clouds

Arto Heikkilä, Lars E.B. Johansson (Onsala Space Observatory), Hans Olofsson (Stockholm Observatory)

Physical and chemical conditions of the molecular gas associated with the HII region complex N159 ($\alpha(1950) = 05^{\mathrm{h}}40^{\mathrm{m}}03.0^{\mathrm{s}}$, $\delta(1950) = -69^\circ 47' 03''$) in the Large Magellanic Cloud and the IRAS source LIRS 49 ($\alpha(1950) = 00^{\mathrm{h}}46^{\mathrm{m}}32.9^{\mathrm{s}}$, $\delta(1950) = -73^\circ 21' 50''$) in the Small Magellanic Cloud were derived from results of mm-wave observations of isotopomers of CO, CS and HCO^+ with the SEST by performing statistical equilibrium excitation and radiative transfer calculations. The radiative transfer was treated in the mean escape probability approximation.

Two sets of solutions were found: $T_k = 10 - 25$ K, $n(H_2) = 10^4 - 10^6$ cm^{-3} and $T_k \geq 30$ K, $n(H_2) \approx 3000$ cm^{-3}. Both sets are appropriate for each of the two studied regions.

The derived column densities of all studied molecules are about a factor of 10 lower in LIRS 49 compared to N159, where they are another factor of 10 lower than in Galactic clouds (see Johansson et al. 1994, A&A 291, 89).

The IRAM Key Project: Small-scale Structure of Pre-star Forming Regions Preliminary Analysis of the Structure

A. Heithausen, J. Stutzki (Universität zu Köln), E. Falgarone, J.-F. Panis (Ecole Normale Supérieure, Paris), J.-L. Puget (Université de Paris), and F. Bensch (Universität zu Köln)

Clumpiness is a general property of molecular clouds and is expected to play a key role in the triggering of gravitational instability. The structure found in the three fields selected for the IRAM key project (see their description in the companion poster by Panis et al.) has been decomposed into individual clumps using the Gaussian clump fitting procedure by Stutzki & Güsten (1990, ApJ 356, 513). We analyse the mass spectra and size-line width relation of these clumps and compare the results obtained in each of the three CO isotopes and in each of the fields, which, at large scale, do not present the same level of gravitational binding.

The Dynamical State of High-latitude Molecular Clouds

A. Heithausen (Physikalisches Institut der Universität zu Köln)

The size-line width relation and the size-density relation are analyzed for the molecular clouds from the CfA 1.2m telescope CO survey at high latitudes in the second quadrant. It is found that these clouds follow similar relations as giant molecular clouds. It is also shown that the virial mass is correlated to the CO luminosity, although the high-latitude clouds are not gravitationally bound. The influence of the atomic gas surrounding the high-latitude clouds is analyzed, to study if the clouds are pressure bound.

CO in AGB Stars with Interrupted Mass-Loss

Kenneth Hinkle (NOAO), H. Alwyn Wootten (NRAO), Raghvendra Sahai (JPL)

We have surveyed the CO J=1–0 emission (using the NRAO 12-m) in an IRAS-selected sample of "60 micron excess" AGB stars, in order to look for evidence of interrupted mass-loss. In prototype sources described in the literature (e.g. Olofsson et al. 1988, AA, 196, L1), millimeter wave CO line shapes (doubly-peaked) and maps show the presence of a cold extended hollow shell with radius of a few times 10^{17} cm, implying that mass-loss ceased in these stars a few times 1000 years ago. It has been suggested that mass-loss has been interrupted in these stars by a He-shell flash. For a few stars in our CO J=1–0 survey, we have obtained high resolution spectra of the 4.6 micron CO vibration-rotation fundamental (using the KPNO 4 m FTS). We have used the circumstellar components of the 1–0 lines as a complementary approach to the microwave spectra. By combining both techniques on spectra of the prototype source S Sct, we are able to derive excitation temperatures, velocities, and mass loss rates. These show that the hollow shell model is correct. The excitation temperature of the hollow, outer shell is 10±5 K. The inner circumstellar shell consists of two regions: one at 75 K expanding by 3 km s^{-1} (relative to the stellar center-of-mass velocity) and a second at 200-1000 K contracting by 5 km s^{-1}.

The Distribution of CO in Sa Galaxies

D. E. Hogg, M. S. Roberts (NRAO), J. N. Bregman (U. Michigan)

A recent study of the Sa galaxy NGC 1291 has shown that there is a striking spatial anticorrelation between hot (X-ray) and cold (HI,CO) gas, supporting the suggestion that the hot gas is a bulge phenomenon and the cold gas is concentrated to the disk. Additional observations of the cool gas in the X-ray galaxies NGC 2775 and NGC 3623 have now been completed. The CO in NGC 2775 is concentrated in a ring of approximate radius 5 kpc, a region of the disk which lies outside the prominent central bulge. Both CO (1–0) and CO (2–1) are detected over a large radial range in NGC 3623. There is CO emission from the direction of the nucleus, but a significant part of the emission arises at distances of 6 kpc beyond the bulge.

Atomic and Molecular Gas in Ring Galaxies

Cathy Horellou (Onsala Space Observatory), Fabienne Casoli, Françoise Combes (Observatoire de Paris)

We present a survey of the ^{12}CO(1–0) and HI emission of a sample of 16 collisional ring galaxies (see Horellou et al. 1995, A&A, 298, 767 for more details). Ring galaxies are believed to form when a compact galaxy plunges through the center of a rotating disk system, triggering a set of radially expanding waves in the target disk. We have found that ring galaxies are bright in CO compared to normal galaxies. Their mean HI content, however, is not significantly different. If the standard conversion factor from CO emissivities into H_2 column densities holds for ring galaxies, this indicates that a large amount of molecular gas is available for star formation and that ring galaxies are currently actively forming stars. This result is in agreement with their high far-infrared luminosities. The Cartwheel, often considered as the prototype of ring galaxies, has not been detected. We suggest that the weak CO emission of this galaxy is due to its low metallicity.

Molecular Gas in the Irregular Galaxy NGC 4449

D. A. Hunter (Lowell Observatory), H. A. Thronson (Univ. Wyoming)

We present observations of CO (J=1–0) emission from the irregular galaxy NGC 4449 obtained with the NRAO 12 m. All but 2 of 8 observations coincided with HI complexes with differing levels of star formation. We found the following: (1) The beam (=1.7 kpc at the galaxy) included molecular cloud complexes with $1\text{–}5\times10^7$ $M_\odot$ of $M(H_2)$. (2) The molecular mass, molecular and atomic column densities, and $M(H_2)/M(HI)$ ratios are similar in spite of large variations in the amount of star formation activity. (3) The molecular complexes are associated with considerable atomic gas, and observations are consistent with the picture that the molecular material is protected from UV radiation by atomic material.

The Molecular Disk of IC342: On-The-Fly Mapping of CO with the NRAO 12m Telescope

Robert L. Hurt (UC Riverside), Deborah A. Levine (UCLA/IPAC), Robert N. Martin (Steward Obs/SMTO), Jean L. Turner (UCLA), Paul P.T. Ho (CfA)

We present a map of the ^{12}CO (1–0) emission in the inner disk of the spiral galaxy IC342. This galaxy, at a distance of 1.8 Mpc, is the site of a moderate nuclear starburst and the molecular emission in the central arcminute has been extensively studied interferometrically. Using the newly-implemented spectral line On-The-Fly (OTF) mapping mode of the NRAO 12m telescope, we have observed the extended molecular emission in a $15' \times 15' (8 \times 8$ kpc) region at a resolution of $1'$ (560 pc). In our sensitive maps (RMS $\sim$ 10 mK) we find the CO to be ubiquitous across the entire mapped region, extending to the edges of the optical disk. The emission is strongly peaked at the nuclear starburst while the disk CO tapers off gradually towards the map edges. There is close correlation between the molecular gas and 20 cm continuum emission tracing the nucleus and spiral arms. However, we find a region of reduced star formation efficiency just outside of the inner starburst where the large concentrations of molecular gas show little associated radio continuum emission. This region corresponds to the 'boxy bulge' seen at near infrared wavelengths in IC342.

CO Twin Peaks and Centrally Concentrated H_2 Emission at the Center of the cD Seyfert Galaxy NGC 1275

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We report interferometric observations of 2.6 mm CO and 2 μm spectroscopy of H_2 emission in NGC 1275. The CO emission shows a non-axisymmetric distribution in $r \leq 10$ kpc and a ring-like structure with *twin peaks* at $r \approx 1.4$ kpc. On the other hand, the H_2 emission is concentrated within $r \leq 340$ pc and its velocity-resolved line profile is fitted by a Gaussian with FWHM ≈ 250 km s^{-1}. All these molecular structures are well explained by a non-axisymmetric potential whose existence is implied by our data. Similarities with NGC 1068 propose the importance of non-axisymmetric potential in a process of AGN formation.

CO in the Starburst Nucleus of NGC 3628 – NMA Results

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The edge-on starburst galaxy, NGC 3628, displays spectacular X-ray plumes along its minor axis, indicative of bipolar outflow from the nucleus. We have used the NMA to obtain 3.8″ (123 pc) resolution ^{12}CO (J=1–0) observations of the nuclear molecular disk in this galaxy. The CO distribution can be characterized by three main components, each of which displays a very clumpy distribution. a) A dense, rapidly rotating nuclear disk several hundred pc in radius with a significant velocity dispersion. The kinematic center of the nuclear disk coincides with the radio continuum peak, rather than the offset optical center, confirming that the radio continuum peak is at the galaxy nucleus. b) A low velocity gradient "ridge" that is outside of the rotating disk but within about 1–2 kpc of the nucleus and that may represent part of an inner ring or spiral arm. c) Various arcs/bubbles, most of which appear to originate in the ridge and which collectively contribute to wide line profiles. Expansion energies of order 10^{52}–10^{54} erg are suggested. Extraplanar CO arcs and extensions out to 430 pc from the midplane are also observed.

Mass Loss from OH26.5+0.6

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We present a self-consistent model for the dust and gas outflows from the extreme OH/IR star, OH26.5+0.6. The source has a deep 10 μm absorption, inferring a very high mass loss rate ($\dot{M} = 5.5 \times 10^{-4}$ $M_\odot$/yr) while the CO J=1–0 and 2–1 lines suggest a more tenous mass loss rate in the past ($\dot{M} = 10^{-6}$ $M_\odot$/yr). From these observations plus the recent observations of CO J=3–2 and 4–3 transitions, we have concluded that the star has entered the superwind phase when the mass loss rate increases dramatically during the past 200 yrs.

The Molecular Outflows in NGC 1333

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We present the results of CO(J=3→2) mapping, using the James Clerk Maxwell Telescope, of the active star formation region immediately south of NGC 1333, supplemented by CO($J=1\rightarrow0$) mapping using the Onsala Space Observatory 20 metre telescope.

These spectral line maps provide the first clear overview of the complex cluster of overlapping molecular outflows associated with the Herbig-Haro objects and the far-infrared and (sub)millimetre sources in the region. At least eight molecular outflows are identified, for seven of which we can confidently identify the driving source. Among these are probable "Class 0" protostellar objects driving highly collimated CO jets. Two objects appear to drive outflows which are precessing: IRAS 4A and SSV 13b.

The nature and exciting source of the HH 12 complex is identified for the first time. HH 12 is the working surface of a jet driven by the (sub)millimetre source SSV 13b. This outflow is almost in the plane of the sky, hence the counter-jet also appears blue-shifted.

All of the youngest known members of the current generation of star formation in NGC 1333 are proto-binary or multiple systems. It appears that the hierarchical organisation of multiple systems is present at an extremely early stage.

A cloud-cloud collision model for NGC 1333 is consistent with the structure of the cloud, the arrangement of young objects and their outflows, and the apparently high rate of contemporary star formation activity.

Molecular Absorption Toward the Low-Latitude Radio Source 2023+336

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We have conducted millimeter-wave and centimeter-wave absorption observations toward the low-latitude radio source 2023+336 ($l = 73°$, $b = -2°$) in order to search for cold molecular gas, to compare directly the optical depths of the cool atomic and molecular phases of the ISM, and to characterize the chemical composition of molecular clouds in the Galaxy. We find: 1) Multiple-component, translucent CO, HCN, HCO^+ absorption in the inner Galaxy near 6 km s^{-1}; 2) Only marginal (3σ) evidence for cold gas (CO absorption without emission) in the Galaxy near −55 km s^{-1};

3) CO absorption line widths as broad as the corresponding emission lines, even though the emission beam diameter subtends 0.2 pc and the absorption column subtends $\sim$ 1 AU! We conclude that the emission preferentially arises in denser clumps with small filling factor while the absorption comes from more diffuse regions of subthermal excitation; 4) ^{12}CO absorption and emission spectra indicate low CO excitation temperatures of 4 to 6.0 K; 5) The CO absorption implies an optically thin line of sight, whereas $^{12}CO/^{13}CO$ emission ratios of 13:1 imply a higher optical depth. One resolution to this apparent discrepancy would be that the background source happens to be seen through a "hole" in the molecular clouds so that our measured absorption optical depth is lower than the emission beam average. This solution demands even lower CO excitation temperatures. The alternative solution is a non-standard $^{12}CO/^{13}CO$ ratio.

NMA Observations of Dense Molecular Gas in Messier 51

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We have made aperture synthesis HCN (J=1$\rightarrow$0) observations of M51 using the Nobeyama Millimeter Array with spatial resolutions of $7''$ (340 pc at D=9.6 Mpc). A $4''$ resolution image was also made to resolve the structure of the circumnucleus.

Intense HCN emission was observed in the central $r < 6''$ region, where CO emission is depressed. There is distortion of the HCN velocity field within $r < 4''$ in the nucleus, where a velocity gradient runs from east to west. If this velocity gradient represents rotation, the axis (P.A.$\sim$20°) is just aligned with the direction of the radio jet and bubble. The H_2 column density toward the nucleus is estimated to be 1×10^{23} cm^{-2} from our HCN data, which plausibly accounts for the large absorption reported by X-ray satellites. Considering the large column density toward the nucleus and the alignment of the rotation axis, our observational results imply the presence of a rotating dense molecular disk that obscures the weak Seyfert activity of M51.

In the spiral arm regions, the HCN/CO integrated intensity ratio is in the range of 0.02 – 0.03, whereas the ratio in the central $r < 4''$ area exceeds 0.3, *i.e.*, a factor of 10 larger than those of spiral arm regions. The high HCN/CO ratio means that all the molecular gas in the nuclear region is dense enough to excite HCN (J=1$\rightarrow$0) emission ($n_{H_2} > 10^5$ cm^{-3}).

Structure and Excitation Conditions of the Southern Part of the Orion B Molecular Cloud: A CO Multiline Study

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We present extended maps of ^{12}CO and ^{13}CO (J=2→1 and J=3→2) of the southern part of the Orion B region covering a $\sim 20' \times 60'$ area in ^{13}CO(2→1). They encompass the NGC 2024 H II region, the interface region between NGC 2024 and the optical nebula IC434, the reflection nebula NGC 2023, and the Horsehead Nebula B33. The physical conditions in these different regions vary significantly due to the influence of the OB association lying to the west and due to the embedded stars. The CO emission originates from many clumps, most apparent in individual velocity channel maps. The observed low-J CO and isotopic CO line ratios are inconsistent with the standard interpretation in terms of a single temperature gas component along the line of sight in LTE. They require an outward temperature gradient on the cloud surface, as is naturally expected to arise from external UV heating. A consistent interpretation for both absolute line brightnesses and the intensity ratios can be reached in terms of PDR models. These indicate densities within the bulk of Orion B of at least close to 10^5 cm^{-3}. In addition, we analyse the structure by subdividing the ^{13}CO(2→1) emission of Orion B into clumps using an automated procedure. The shape, orientation, LTE mass, virial mass, and stability of these clumps is examined. The mass spectrum of the clumps follows a power law, $dN/dM \propto M^{-\alpha}$, with $\alpha = 1.65 \pm 0.24$.

Molecular Clouds in the Large Magellanic Cloud

M. L. Kutner (NRAO) and M. Rubio (Universidad de Chile)

We present results of observations of CO(J=1–0) emission form the Large Magellanic Cloud (LMC). These observations were carried out as part of a Key Programme on the Swedish-ESO Submillimeter Telescope (SEST) on La Silla, Chile. The beamwidth at 2.6 mm is 40, or 10 pc at the distance of the LMC, and the maps are fully sampled. The molecular emission in the LMC is dominated by clouds with giant molecular cloud (GMC) dimensions and masses. Cloud properties in two regions of the LMC will be discussed. One is a dark complex extending 2 kpc south of 30 Dor, and the other is associated with the bright HII region N11. We will discuss the cloud size distributions, size-linewidth relations, and the conversion from CO luminosity to virial mass in both regions.

CO Observations of the Carbon-rich Proto-Planetary Nebula IRAS 22272+5435

Sun Kwok (University of Calgary), Typhoon Lee, Shudong Zhou (Academia Sinica, Taiwan), A.W. Woodsworth (Dominion Astrophysical Observatory)

We report recent single-dish and interferometric observations of the PPN IRAS22272+5435, which is one of the few stars that are known to have the unidentified emission feature at 21 μm (Kwok, Volk, & Hrivnak 1989, ApJ, 345, L51). The CO 2–1 and 3–2 lines were detected at JCMT with a beam sizes of 21 and 14 arcsec respectively. The observed profiles are fitted with a LVG model with an inverse-square density distribution, an inner radius of 0.0077 pc, a kinetic temperature law of the form $T(r) = 50K(r/r_in)^{-0.7}$, a mass loss rate of $10^{-5}M_{\odot}\ yr^{-1}$, and a distance of 1050 pc. IRAS 22272+5435 has one of the strongest CO emissions among post-AGB stars, and offers an excellent opportunity to study its morphology with millimeter interferometry. A CO (1–0) image has been obtained with BIMA. The object is found to be marginally resolved by the 3 arcsec beam, with the blue-shifted component to the NE, and the red-shifted component to the SW of the infrared position.

Vibration-Rotation CO in Intermediate Population Miras

Thomas Lebzelter, Josef Hron (Institute for Astronomy, University of Vienna, Austria), Kenneth Hinkle (Kitt Peak National Observatory)

We have observed time-series IR spectra (2.0 – 2.5 μm) of four intermediate population Miras (high velocity, early spectral type, short periods, low metallicity) at high resolution. The covered spectral region includes the CO vibration-rotation first overtone region. The high excitation CO and atomic lines follow the radial velocity curve expected during a pulsation cycle. Amplitude and shape of the rv curves are similar to the results found for disk Miras with longer periods. The low excitation CO lines show only small velocity variations in all objects investigated except in R Vir. We have no definite explanation for the strange behavior of this object at the moment.

For three of our program stars, the carbon isotopic ratio is comparable to the values found for thin disk Miras.

Our results allow two conclusions: (1) The amplitude of the radial velocity variations is almost independent from the period for periods between 150 and 350 days. (2) The amplitude does not depend on metallicity.

PDFs of Centroid Velocities and Centroid Velocity Increments in Supersonic Compressible Turbulence

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We have calculated probability density functions (PDFs) of centroid velocities and centroid velocity increments of line profiles computed from the output of a 512^3 simulation of compressible turbulence (Porter, Pouquet and Woodward 1994, *Phys. Fluids*, 6, 2133). The PDFs of centroid velocities calculated over the whole data cube are roughly Gaussian. On smaller scale, non-Gaussian PDFs are observed in some cases. However, this is far from being the rule, and most of the distributions show only minor deviations from a Gaussian. By contrast, PDFs of centroid velocity increments clearly show non-Gaussian wings for separations comparable to the dissipation scale in the simulation, probably assignable to intermittency. In a recent observational study (Miesch and Scalo 1995, *ApJ Letters*, in press), PDFs of centroid velocities of ^{13}CO line profiles in star-forming regions were shown often to have near exponential wings. We conclude that these wings are unlikely to be a manifestation of intermittency of turbulence. Investigations of PDFs of centroid velocity increments in non-starforming regions, however, would seem a promising avenue for studying the intermittency in the interstellar medium, as an alternative to the line-shape discussion of Falgarone and Phillips (1990, *ApJ*, 359, 344).

A Large-scale High-resolution Survey of CO in the Andromeda Galaxy

Laurent Loinard, Enrico Koper, Patrick Thaddeus (Harvard-Smithsonian Center for Astrophysics), James Lequeux (DEMIRM, Observatoire de Paris)

Although surveys of most of the components of the ISM in M31 (H I, IR, radio-continuum emission, etc.) have already achieved an angular resolution of $\sim 1'$, the only complete CO survey of this galaxy (the CfA survey) has a resolution of $8\rlap{.}'7$. Several small selected areas have been observed at higher resolution, but the overall small-scale structure of the molecular gas in M31 is largely unknown.

We present here a high-resolution CO(1–0) survey of the southern part of the major axis of M31 done with the QUARRY array of receivers on the 14-m FCRAO telescope (angular resolution $\sim 45''$). This survey consists of a 5 arcminute-wide strip along the major axis from the center to about 16 kiloparsecs, covering an area of 360 square arcminutes. Roughly 10 molecular clouds or cloud complexes are fairly well resolved in our data and nearly all are appropriate for higher resolution CO studies. The distribution of the CO emission along the major axis agrees well with previous determinations and shows the same "ring-like" structure as the H I and other tracers of population I, although the H I shows a peak at 13 kpc from the center that only has a very weak conterpart in CO. The velocity distribution of the CO emission is in good agreement with the velocity distribution of the H I.

The Variation of the X-factor in Two Translucent Clouds

Loris Magnani (University of Georgia), Dap Hartmann, Patrick Thaddeus (Harvard-Smithsonian CfA)

We determine the "X-factor" [ratio of $N(\mathrm{H_2})$ to $W(\mathrm{CO})$] for two translucent clouds at high Galactic latitude. The method employed to determine the X-factor involves observations of the hyperfine, ground state, main line transition of CH at 3335 MHz as a tracer for $N(\mathrm{H_2})$. Magnani & Onello (1995) discuss the variation of $\mathrm{X_{CO}}$ in a sample of 28 lines of sight in 18 different translucent clouds. Values of $\mathrm{X_{CO}}$ vary from $0.3 - 6.8 \times 10^{20}$

We determined $\mathrm{X_{CO}}$ for 8 lines of sight in MBM40 and found values ranging from $0.8 - 4.8 \times 10^{20}$, with an average of 1.8×10^{20}. However, the 4.8×10^{20} value is uncertain because the CH spectrum from which $N(\mathrm{H_2})$ is derived is noisy. Discarding this measurement, the range of $\mathrm{X_{CO}}$ in MBM40 is rather constrained: $0.8 - 2.0 \times 10^{20}$. The case of MBM16 is quite different. $\mathrm{X_{CO}}$ was determined for 20 lines of sight and varies more markedly, from 1.2 to 14.9×10^{20}, with an average value of 5.0×10^{20}. For MBM16, determining $\mathrm{X_{CO}}$ on the basis of an observation along a single line of sight could lead to a highly misleading result.

Future work will determine whether translucent clouds taken as an ensemble display a variation of $\mathrm{X_{CO}}$ similar to MBM40 or MBM16.

High Altitude Molecular Clouds: Properties.

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We describe ^{12}CO observations and morphology of a new population of diffuse molecular clouds found far away from the Galactic plane. These high altitude clouds (HACs) are drawn from a sample of 23 clouds identified by Malhotra(1994) as being more than 2.6 scale heights away from the plane. Since these clouds are at tangent point velocities, we know their distances and height above the plane. New observations were carried out in the winter of 1994–95 with the 7 meter telecsope at Bell Laboratories to map these clouds to a noise level of 0.15 K. These observations show that HACs are large—comparable in size to GMC complexes; and arranged in complexes with complicated velocity structure. The HACs have much weaker CO emission than do GMCs, and are not gravitationally bound.

The Dense Gas Structure and Kinetic Temperature in the Serpens Molecular Cloud

Jeffrey G. Mangum (Submillimeter Telescope Observatory), William B. Latter (NASA/Ames), Joseph P. McMullin (Submillimeter Telescope Observatory)

Recent high spatial resolution ($\theta_B \simeq 20''$) measurements of the 800 and 1100$\,\mu$m continuum emission toward the Serpens molecular cloud (Casali, Eiroa, & Duncan 1993) have uncovered six dust continuum cores, four of which have no near-infrared counterparts. With $L_{\rm bol} \lesssim 30\ L_\odot$, Casali *et al.* suggest that these four newly-discovered submillimeter continuum sources are part of a second, younger phase of star formation in Serpens. To investigate the dense gas properties within the Serpens molecular cloud, we have used the newly-developed on-the-fly (OTF) observing technique at the NRAO 12m telescope to map the H_2CO $3_{03} \rightarrow 2_{02}$ and CS $3 \rightarrow 2$ emission toward this region. Our results are the following: (1) With the exception of SMM2, the 800 and 1100$\,\mu$m continuum sources mapped by Casali *et al.* (1993) have CS and H_2CO emission counterparts. (2) Using the analysis described by Mangum & Wootten (1993) for the determination of kinetic temperatures using the $3_{03} \rightarrow 2_{02}$ and $3_{22} \rightarrow 2_{21}$ transitions, we find kinetic temperatures < 55 K for the SMM1 through SMM6 sources. (3) An analysis of the velocity structure in our CS map indicates that the S68N and SMM4 sources possess dense-gas kinematic motion. Given the added properties of high gas density, ($n(H_2) > 1.0 \times 10^5$ cm^{-3}), moderate gas kinetic temperature, and lack of near– or far–infrared emission, we suggest that S68N and SMM4 are Class 0 objects.

Molecular Clouds in the Southern Outer Galaxy

Jorge May, Hector Alvarez, Leonardo Bronfman (Universidad de Chile)

From a deep CO survey of the third galactic quadrant (May et al. 1993, A&A, 99, 105), we derive the physical properties of 177 molecular clouds in the outer Galaxy, beyond 2 kpc from the Sun. Although power-law relations between line widths and sizes of the clouds, and between their densities and sizes have been found, they do not fulfill the requirements to be in strict virial equilibrium. The derived size and mass distributions of the clouds show that they are smaller and less massive than those in the inner Galaxy. A statistical analysis of their CO luminosities and line widths indicates that they appear to be less luminous than those in the inner Galaxy by a factor of 2.4, on the average. Therefore, for the outer Galaxy clouds a CO/H_2 conversion factor 2.4 times larger has been adopted. The warping and flaring of the outer molecular disk is clearly delineated, although no grand design spiral pattern can be visualized from the projection of the clouds on the galactic disk.

Molecular Depletions in NGC 1333 IRAS 4

Joseph P. McMullin (SMTO), Lee G. Mundy (University of Maryland), Geoff A. Blake (Caltech)

We present interferometric observations (BIMA, OVRO) of the young stellar objects NGC 1333 IRAS 4A and 4B, focussing on a comparison between the emission distributions of gas and dust. The strong continuum signature of these sources contrasts with generally weak molecular emission on small scales. We explored the possibility of optical depth effects hiding a larger column density. However, the Blake *et al.* (1994) line survey derives low values for the optical depth in our observed lines while the possibility of temperature increases masking column density increases requires unrealistically large changes in T_K to substantially alter the derived column densities. We conclude that the observed emission may be explained in terms of gas phase depletions by factors of greater than 20, even for CO (based on isotopic information).

Based on the magnitude and scales of the observed depletions, we suggest an extremely youthful stage of development for these sources and attempt to place them within a crude chemical evolutionary sequence based on other sources within the literature and basic model predictions.

Stars and Protostars in NGC 2024

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Mezger et al. (1988, A&A, 191, 44) reported the detection of six "Protostars" in the high density molecular gas *behind* the HII region NGC 2024. We have imaged this region in $J = 1 \rightarrow 0$ $C^{18}O$ and 2.7 mm continuum emission with a resolution of $\sim 10''$ using the Berkeley-Illinois-Maryland Association Array. Continuum emission was detected from dust associated with the sources FIR 3, 5 and 6 (Mezger et al. 1988). The 1.3 mm/2.7 mm spectral indices of these dust cores are all ≥ 4. The upper limits for the 2.7 mm continuum flux densities for FIR 1, 2, 4 and 7 indicate similar spectral indices for these cores.

$C^{18}O$ $J = 1 \rightarrow 0$ emission is observed in 3 slightly extended regions. The two southern peaks are offset by $> 15''$ (6000 AU) from the positions of FIR 5 and FIR 6. The northern peak is located $\leq 4''$ (1700 AU) from the position of FIR 2. For the $C^{18}O$ clouds, H_2 column densities based on the virial theorem imply (CO/H_2) ratios of $\sim 10^{-5}$, about 10% of the normally used value. The low value of the CO fractional abundance can be explained if molecules are depleted onto grains; it is surprising that $X(\mathrm{CO})$ is this *high*, because current models suggest greater depletion in such high density regions. Toward most of the dust cores, no $C^{18}O$ emission is detected and so depletion may be much more severe. On the other hand, if the dust cores contain stars, then molecules may have been destroyed by energetic stellar winds.

BIMA Array CS J=2→1 Observations of Sagittarius B2

David M. Mehringer (Department of Astronomy, University of Illinois)

Observations of the $J = 2 \rightarrow 1$ transition of CS toward the Sgr B2 star-forming region have been carried out using the BIMA (Berkeley-Illinois-Maryland Association) array. The angular and spectral resolutions are $9'' \times 14''$ ($\alpha \times \delta$) and 1.2 km s^{-1}, respectively. Results indicate that a high velocity

(FWZI $\sim$ 60 km s^{-1}) molecular outflow is present in Sgr B2(M), a core which contains more than 20 compact and ultracompact HII regions. The mass of the outflow, derived assuming a normal CS fractional abundance of 2×10^{-9}, is 8000 $M_\odot$. Because this derived mass is much higher than that derived from previous observations, it is likely that the fractional abundance of CS in the Sgr B2(M) outflow is significantly higher than the usual value. No CS emission is observed toward Sgr B2(N), a core/outflow source $\sim$50$''$ north of Sgr B2(M). The absence of CS emission toward this core is due at least in part to self-absorption from the extensive molecular envelope. It is also possible that CS is underabundant toward the Sgr B2(N) core. CS absorption is observed toward both the Sgr B2(M) and (N) continuum sources. Much of the absorbing material is probably located in the extensive envelope of the Sgr B2 molecular cloud and other clouds not associated with Sgr B2 that lie along the same line-of-sight.

Beyond CO – Complex Molecules In Sgr B2(N): The Importance of Grain Chemistry

Y. Miao, D. M. Mehringer, L. E. Snyder, and Y.- J. Kuan (Department of Astronomy, University of Illinois)

The complex molecules methyl formate ($HCOOCH_3$), vinyl cyanide (CH_2CHCN), and ethyl cyanide (CH_3CH_2CN) were observed in the Sgr B2 star-forming region with the BIMA millimeter wavelength array. A region with diameter < 0.1 pc toward the Sgr B2(N) molecular core is found to be the major source of these molecules. Also, this source is coincident with continuum emission from dust and a center of H_2O maser activity. Ultracompact (UC) HII regions are located within 0.1 pc. Strikingly, none of these molecules is detected toward Sgr B2(M), a core located 1$'$ south of Sgr B2(N). The existence of complex molecules, a large mass of dust, high velocity H_2O masers, and UC HII regions strongly suggest that the Sgr B2(N) region has just begun to form stars, while the absence of strong dust emission and large molecules suggest Sgr B2(M) is more evolved. The detection of large molecules coincident with continuum emission from dust supports the idea found in current chemical models that grain chemistry is of crucial importance for the formation of these molecules.

This paper has been accepted for publication. Interested parties may contact the authors for reprints.

S140 - Unravelling the Mystery?

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The complex consisting of the Lynds 1204 molecular cloud and the adjacent S140 HII region, produced by the nearby B0 star HD211880, is somewhat unique. The molecular cloud not only contains one of the best examples of an edge-illuminated PDR, but only 70 – 80 arcsec to the north-east is an embedded cluster of three infrared sources, which lie at the centre of a massive and extensive molecular outflow. Such close association of an archetypical PDR and molecular outflow make this a fascinating region for observational study. Four years ago we began a major observational program to study this region through submillimetre isotopic CO and neutral carbon (CI) emission lines and also broad-band continuum mapping. Selected highlights from our four published/accepted papers are outlined.

Comparison of the continuum emission with high resolution CS, NH_3, isotopic CO and CI observations provides evidence that, for the first time, demonstrates the PDR and outflow are intimately linked. We postulate that the outflow has expanded towards the edge of the molecular cloud such that the edge of the blueshifted outflow lobe is bounded by the expanding HII region. The CI emission originates from the outer edge of the cloud (the PDR), with the CS emission tracing compressed high density gas, sandwiched between the expanding outflow and PDR regions. The NH_3 and continuum emission emanates from the inner edge of the outflow lobe, shielded from the external UV field.

The Star-forming Core of the Monoceros R2 Cloud

George F. Mitchell (Saint Mary's University, Nova Scotia), Jean Giannakopoulou (University of Waterloo, Ontario)

The physical nature of the core of the Mon R2 molecular cloud is investigated using new, high resolution observations. The data include spectral line maps (in CO J = 3–2, HCN J = 4–3, and H_2CO 51,5–41,4), mm/submm continuum maps (at 450, 800, 1100, and 1300 μm), and an M-band absorption spectrum of IRS 3. In addition, spectra of ^{13}CO J = 3–2, H_2CO 50,5–40,4, and H_2CO 52,3–42,2 were obtained at a number of positions. The CO map shows that the cloud core is broken up into numerous clumps (13 in the $3' \times 3'$ field) with masses ranging from 0.01 $M_\odot$ to 3 $M_\odot$. An unusual feature of the clumps is their high velocity dispersion. The formaldehyde line ratio, 50,5–40,4/52,3–42,2, yields a gas kinetic tem-

perature in the range 50 to 70 K. An excitation diagram of 14 rotational lines of the fundamental band of ^{13}CO (from the IR absorption spectrum) is used to find the gas temperature and column density toward IRS 3. Two gas temperatures are found, $T = 45$ K, which we presume to represent the core gas temperature in this line of sight, and $T = 310$ K, which probably is due to gas very close to IRS 3. The HCN and H_2CO emission line maps indicate that the densest core gas is organized into two structures with different radial velocities. We find that IRS 3 is the most active IR source in the core, in the sense that it is producing high velocity gas in its surroundings. There is, however, no evidence for organized, bipolar flow from IRS 3, which might connect it to the well known and very extended bipolar flow in this region. The compactness of the high velocity region around IRS 3 suggests that it may be a young object which has only recently become active.

Molecuar Line Analyses of W49N

Ryosuke Miyawaki (Fukuoka University of Education), Masahiko Hayashi (SUBARU Project Office, National Astronomical Observatory of Japan), Testuo Hasegawa (Institute of Astronomy, The University of Tokyo)

Studies of the W49A molecular cloud complex are difficult not only because it is compact as a result of its large distance but because different molecular lines exhibit different shapes of line profiles. We presented classification of various molecular lines toward W49N using the Nobeyama 45 m telescope. There are three types; deep dip lines, shallow dip lines, and single peak lines. These are charcterized by their optical depths and excitation conditions. From evaluation of physical properties of molecular lines, star formation is taking place between two velocity components. These conclusions are supported by the results of CS (J=1–0) and SiO (J=2–1) emission using Nobeyama Millimeter Array. The 4 kms^{-1} component of CS is surrounded with the 12 kms^{-1} component of CS. SiO has a velocity between two velocities, and its distribution is compact.

3mm SIS Receiver for the Australia Telescope 22 metre Mopra Antenna

G.G. Moorey, M.W. Sinclair (Australia Telescope National Facility, CSIRO), J.M. Payne (National Radio Astronomy Observatory)

As the first step towards equipping the Australia Telescope 3-kilometre array at Narrabri with mm wave receivers covering the 70 to 115 GHz band, a prototype receiver for the 86 to 115 GHz band was built and installed on the 22 metre antenna at Mopra Rock. The antenna is located near the Siding Springs Anglo-Australian Optical Observatory at Coonabarabran in the picturesque Warrumbungle National Park about 450 kilometres north-east of Sydney. To obtain the best possible results from the antenna and site, a dual-frequency , dual-polarisation receiver employing SIS mixers was designed and installed. The receiver is capable of operation in the SSB or DSB mode and has an instantaneous IF bandwidth of 600 MHz centred on 1500 MHz. The initial commissioning tests utilising the inner 15.4 metres of the antenna across the 86-to-98 GHz band gave an average DSB system noise temperature on the sky of 125K with a zenith optical depth $T = 0.1$. The full width to half power beamwidth is $\sim$45 arcsec and the gain is 40 Jy/K which corresponds to an aperture efficiency of $\sim$35%. The initial pointing model gives errors of < 10 arcsec rss of both axis. The flexibility of the ATNF Mopra correlator is demonstrated by the diversity of its configuration modes. These range from 1-bit sampled 256 MHz bandwidth, dual-polarisation, 512 channels down to 2-bit sampled 4 MHz bandwidth, dual-polarisation with 16,384 channels. Initial on/off source observations of SIO, HCN, HCO^+,and CS molecular lines with 20 second integration times, produced good base line spectra with a signal-to-noise ratio of > 20. The initial engineering and observational tests as mentioned above were carried out in the winter months of the last quarter of 1994. For the same period in 1995, the Mopra site will be operated on a shared-risk basis while commissioning tests continue. Commencing in the June quarter of 1996, it is proposed to operate the site as a National Facility. In future development plans we hope to extend the solid surface out to 22 metres, install a nutating subreflector to enable beam switching, improve the pointing and extend the receiver capabilities possibly to cover the 140-to-170 GHz band.

Observation of the Rosette Molecular Cloud in CO(J=2–1) line

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The molecular cloud accompanied by the Rosette Nebula have been observed in the J=2–1 transition of carbon monoxide with $9'$ resolution (4pc at 1600 pc) using the Tokyo-NRO 60 cm telescope. Comparing CO(J=2–1) line intensity with that of CO(J=1–0) line (Blitz and Thaddeus 1980; May and Bronfman 1993), we find that CO(J=2–1) line emission is relatively stronger near the HII region than in other regions. A close comparision with the CO(J=1–0) data of May et al. (1993) in a position-velocity map confirms the tendency that the line intensity ratio, $R_{2-1/1-0}$, is high near the HII region and declines as we move away from it. The gas component with a steep velocity gradient, which we think evidence of interaction with the HII region, exhibits ratios ranging from 1.0 up to 1.2. An LVG line excitation model shows that $R_{2-1/1-0}$ is a good indicator of gas density although it is also slightly dependent on gas kinetic temperature. A possible interpretation for the observed ratio is that the density is enhanced by interaction of molecular gas with the expanding HII region. An alternative interpretation is that the molecular gas near the HII region is made of small clumps surrounded by photodissociation regions as was modeled by Gierens et al. (1992).

The CO-to-H_2 Conversion Factor in Galaxies

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The CO-to-H_2 conversion factor has been evaluated in M51 using visual extinctions and CO data toward 30 HII regions. The derived value is $N(\mathrm{H_2})/\mathrm{I(CO)} = (1.1 \pm 0.1) \times 10^{20}\,\mathrm{cm^{-2}}\,[\mathrm{K\ km/s}]^{-1}$ where $N(\mathrm{H_2})$ is the H_2 column density and $I(\mathrm{CO})$ the CO integrated intensity. The derived value is comparable to the smallest value in our Galaxy or a factor of three smaller than the mean value in our Galaxy. The $N(\mathrm{H_2})/I(\mathrm{CO})$ ratio tends to be larger in the outer region. At very low values of $I(\mathrm{CO})$ of $< 20-40$ K km/s, the ratio shows large values (> 3) in M51 and other galaxies, probably due to the small optical depth of CO emission and low metallicity.

Evidence for Multiple Outbursts from the Cepheus A Molecular Outflow

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We report evidence for multiple episodes of outflow activity in the Cepheus A star-forming region. We present new, high signal-to-noise CSO observations of ^{12}CO J=3–2, ^{13}CO J=3–2, and CS J=7–6 emission. We also present new, high-angular resolution observations of ^{12}CO J=1–0 emission towards the Cepheus A molecular outflow. Using line core velocity centroid maps, we argue that the multiple self-absorption features in the CO J=3–2 line profiles are tracing cool shells of material swept up by an episodic outflow. We present the results of a flexible 3-dimensional LTE outflow model and radiative transfer code that best explains the observations as tracing multiple generations of outflow. The difference in the dynamical time-scales between the "old" and "new" swept-up shells gives an estimate of $\sim 1.6 \times 10^4$ years between the two generations of outbursts. The high resolution ^{12}CO J=1–0 maps obtained by combining single-dish observations with interferometric data clearly show a shell-like morphology at low velocities. This cool shell appears to confine the hot, extremely high-velocity (EHV) winds seen in the J=3–2 transition. The interferometric observations show that the current generation of outflow is being powered by the object Cepheus A-HW2. There is also evidence for redirection of the blueshifted lobe of the current generation of outflow, possibly to the extended NH_3 structure Cep A-3. We present a picture of outflow geometry that can explain most of the observed structures in Cepheus A as the result of the interaction of an intense stellar wind with dense condensations in the parent cloud, and possibly, swept-up shells of previous generation(s) of outflow. The rotating, dense core traced by the CS observations is $\sim$ 0.32 pc in diameter and has an estimated dynamical mass of 330 $M_\odot$. The velocity structure of the core suggests that it is being disrupted by the high-velocity winds driving the molecular outflow. This new technique of extracting information from self-absorbed line profiles could be used to study other deeply embedded protostellar systems. Since outflows are believed to be intimately tied in with accretion, such studies could lead to constraints on mass accretion models for young stellar objects.

The Dust Content and the Kinematics of NGC 4565

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Using the IRAM 30-m telescope, we have mapped the $\lambda\, 1.2$ mm continuum emission and the ^{12}CO J= 1–0 and 2–1 lines in NGC 4565. We selected this edge-on Sb galaxy because, contrary to the nearby galaxies mapped so far at 1.2 mm, it is relatively weak in the CO lines, but strong in the HI λ 21 cm line.

The CO emission shows a ring-like distribution plus a central nuclear source. It peaks between $1'$ and $1.5'$ from the center and tapers off for $R > 2'$; it is much less extended than the HI emission, which remains flat until $R = 5 \ldots 6'$. The $\lambda\, 1.2$ mm continuum, which is mostly thermal emission from dust, has an intermediate distribution. It exhibits the central peak and compact ring observed in CO *plus* a weaker component extending well beyond the limits of the CO map. This is the first time dust emission from extragalactic HI clouds is detected at mm or submm wavelengths.

The velocity field derived from CO can be described in terms of a circular rotation (solid body rotation between 0 and 4 kpc, constant velocity further out) plus non-circular 'streaming' motions near the center and in the molecular ring. The non-circular motions are explained by the presence of a central bar and a spiral density wave. The presence of streaming motions associated with spiral arms was already proposed by Rupen (1991) to explain the HI velocity field. That of the bar could explain the boxy shape of the central bulge.

A 3-position Spectral Line Survey of the Sgr B2 Molecular Cloud

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We are currently, at SEST, performing a spectral line survey towards 3 positions in the Sgr B2 molecular cloud: The hot cores Sgr B2(M) and Sgr B2(N), and the quiescent Sgr B2(NW). By June 1995, the covered frequency band is 218.3 to 263.5 GHz. The spectrum towards the N core, in which we have 1600 identified and unidentified lines, is dominated by emission from complex organic molecules, e.g., C_2H_5CN, CH_3OCHO, whereas M, with 600 spectral lines, is more prominent in sulphur species like SO_2. At present, the number of unidentified lines is 10% in M, but much larger in

N—approximately 25%. Here several U-lines are 1K or stronger. Analysis work is now in progress.

Balloon Observations of the 557 GHz Line of Water Vapour

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We report the first results of PIROG 7, a balloon-borne platform that is equipped with a 60 cm telescope and a heterodyne receiver designed for observations of the ground transition at 557 GHz of ortho-water. Gas-phase water is expected to be one of the primary coolants of dense molecular regions, but its presence in the atmosphere has prevented observations of non-masering low-excitation lines up to now. Observations of this species would provide significant constraints on our knowledge of the chemistry of oxygen-bearing molecules in the ISM, and on the dynamics and energetics of molecular clouds.

The IRAM Key Project: Small-Scale Structure of Pre-Star Forming Regions

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This project consisted of mapping large regions of nearby clouds around dense cores which have not yet formed stars. It has been conceived to fill a gap between two complementary observational approaches of star formation processes: the study of immediate environments of newly born stars and the mapping of molecular clouds over large dynamical ranges to characterize their self-invariant dynamical properties. The objective of our project is, therefore, to extend our knowledge of the molecular gas down to scales as close as possible to that of the protostellar environment, before the apparition of any star.

We present preliminary maps performed with the IRAM 30 m antenna in five transitions (^{12}CO(1–0), ^{12}CO(2–1), ^{13}CO(1–0), ^{13}CO(2–1), and C^{18}O(1–0)) of three fields (L1512, L134A, and a field in Polaris flare). Each contains more than 2500 positions and the resolution of the (2–1) maps is about

2000 AU. The fields extend from the core to the nearest edge of CO cloud emission. The striking results are the large amount of small-scale structure in the ^{12}CO maps, the remarkable differences between the structure seen in ^{12}CO and in the rare isotopes, and the uniformity of the (2–1)/(1–0) ratio (0.65 in T_A^*).

High Resolution ^{13}CO, C^{18}O Observations of NGC 1068, Molecular Gas Properties and an Unusually High I(C^{18}O)/I(^{13}CO) Intensity Ratio

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We have conducted high ($\approx 4'' \times 4''$) resolution observations of ^{13}CO, C^{18}O J=1–0 observations of NGC 1068. We compare the ^{12}CO emission (published maps) with our new ^{13}CO maps and we deduce an average optical depth of $\langle \tau\ (^{13}\mathrm{CO})\ \rangle = 0.07$, which is similar to the ones obtained for disks of quiescent spirals. However, we do find variations of the optical depth for the individual Giant Molecular Associations (GMAs) as a result of varying gas column density, also revealed in recently published UV color-color maps. Finally, we have detected the rare isotope C^{18}O in many positions in NGC 1068 and we have found a ratio of $\langle R \rangle = I(^{18}\mathrm{O})/I(^{13}\mathrm{CO})$ $= 0.4 \pm 0.1$. This is the highest value reported up to date for an extragalactic source. We interpret R as an abundance ratio since both ^{13}CO, C^{18}O are likely to be optically thin and with the same T_{ex}. We argue that such a high abundance is due to the high rate of formation of massive stars, which enhance [^{18}O/^{16}O] without altering [^{13}C/^{12}C].

Star Forming Globules in IC1396

N. Patel (Smithsonian Astrophysical Observatory)

We have mapped the diffuse HII region IC1396 in the J=1–0 transition of CO and ^{13}CO, using the FCRAO 14-meter telescope with the QUARRY focal plane array receiver. The prominent bright rimmed globules are found to lie on a ring of radius 12 pc, expanding with a velocity of 5 km s^{-1}. The dynamical age of the system of globules, as suggested by its expansion, is 2–3 M yrs, consistent with the age estimates of the exciting O6 star, HD206267. Twenty-four IRAS point sources in the mapped field satisfy criteria of young stellar objects; ten of these sources are directly associated with IC1396 globules, suggesting that star formation is occurring within them. In a mass-UV flux parameter space, globules with the IRAS sources are distinct from the globules without IRAS sources, being relatively more massive. The ring of globules itself appears to be embedded in a larger elliptical structure $\sim 9^\circ$ (120 pc) in size, which appears in the IRAS maps of 60 and 100 micron emission. Preliminary results from a CO study of this large-scale region will be presented. We suggest that star formation in this region has proceeded by sequential triggering, and the stars forming in the globules of IC1396 represent the youngest generation of stars in this region.

A Chemical Survey of the Dark Clouds TMC-1 and L134N

Preethi Pratap, Edwin A. Bergin, James Dickens, William M. Irvine, Mari Paz Miralles, F. Peter Schloerb, Ronald Snell (FCRAO, Univ. of Massachusetts)

A large scale chemical study of the dark clouds TMC-1 and L134N is being conducted with the FCRAO 14m telescope. Extended regions of both clouds have been observed in 28 different molecular transitions. The species have been chosen to give us physical conditions such as density (HC_3N) and temperature (CH_3CCH). The conditions derived from these species are used to obtain abundances. Preliminary estimates of the abundances using LTE and assuming optically thin lines show some abundance variations across the sources. However, we find that the LTE approximation may not be valid in these sources. It is clear that we need more accurate estimates of the densities and temperatures in order to determine whether the observed abundance variations are real or due to variations in the physical conditions. In addition, we need to calculate abundances using a full non-LTE analysis.

BIMA Observations of Molecular Spiral Structure in M100

Richard J. Rand (Univ. of Maryland)

We present BIMA observations of CO J=1–0 emission in the grand-design spiral M100 (NGC 4321). Two $100''$ (FWHM) fields have been mapped at resolutions of $7.7'' \times 6.2''$ and $4.6'' \times 3.6''$ and mosaicked together. These fields cover the mild nuclear starburst, the large-scale bar seen in the near-IR, and the main arm which emerges from the north-west end of the bar and swings around to the south. A map of the nuclear region at $3.6'' \times 3.1''$ has also been made. Molecular emission is found along the main arm, showing several GMAs with properties similar to those in M51. The central regions show bright, open arms, in response to the large-scale bar, and a smaller-scale CO bar aligned with a similar structure seen in K-band.

Streaming motions are observed across the arm, consistent with the flow of gas through a density wave compression, but they are of much lower amplitude than in M51. An offset between centroids of the CO and Hα arms is found in the north and west parts of the arm, indicating triggering of star formation, but the offset disappears further along the arm to the south. This location could be near corotation.

An arm-interarm contrast of molecular surface density can be roughly derived from the amplitude of the radial streaming motions, and is found to be 2–3, somewhat lower than in M51. Gravitational instability or collisional agglomeration are both viable ways of building GMAs in the arms. Both theories run into problems, however, if the X-factor in M100 is much different from the standard value. The value of X probably does not vary significantly between arm and interarm regions.

Hydrodynamics and Mass Calibration in the Cepheus Flare

G. P. Remy, I. A. Grenier (EUROPA/Université Paris 7 and DAPNIA/SAp/Centre d'Etudes de Saclay)

The eastern molecular cloud in Cepheus ($111° < l < 118°$, $14° < b < 19°$) coincides with a non-thermal radio spur and displays unusually broad CO lines. Using the 'Mini' telescope of Harvard and POM-2 in France, we have observed this nearby cloud in ^{12}CO and ^{13}CO, in 1–0 and 2–1 transitions, at a resolution of $8'$. A uniform (2–1)/(1–0) line ratio is found over the whole cloud for both isotopomers, implying low excitation temperatures of 10 K and small opacities ($0.1<\tau<3$). The ^{12}CO/^{13}CO line ratios fluctuate by a factor of 5 from point to point, maybe due to *in situ* fractionation. H_2 column densities have been derived using X $\sim 10^{20}$ H_2 cm^{-2} K^{-1} km^{-1} s, as recently obtained from EGRET data on the Cepheus Flare. They agree within a factor of 2 with the column-densities derived from an LVG-model applied to ^{13}CO data, while LTE assumptions yield values too low by a factor of 20.

The velocity field in the cloud is quite singular: it is highly organized on a 10-pc scale, with gradients of 0.4 km s^{-1} pc^{-1} along a plane and rings in the (l,b,v) space. Simple cloud rotation, expansion, or Galactic shearing do not reproduce the data. The observed field is quite consistent with the 'slow flow' of a perfect fluid around a spherical obstacle: 5500 solar masses are carried at a velocity of 3 km s^{-1}, implying a kinetic energy of 5×10^{47} erg. Hydrodynamical simulations of the distortion of a large, dense cloud overtaken by a slow shock wave are underway.

The Bowshocks of the L1582B Molecular Outflow

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High resolution CO 3–2 and 2–1 images of the RNO43/L1582B molecular outflow are presented: these data provide some of the best evidence to date that at least one class of flows are driven by high Mach number optical jets. The CO emission appears to arise in a fragmentary parabolic shell around the optical jet/bow shocks seen in H-alpha and [NII] emission; the CO emission is strongest approximately 30 arcsec upwind of the optical emission, with little emission from the head of the jet. We interpret this as direct evidence that the CO is accelerated in the low velocity wings of the optical jet's working surface; there is little CO at the head of the jet due to molecular dissociation at the high normal shock velocities expected there. The global properties of this outflow are also discussed: a consistent source model is presented in which the observed CO structure is generated by a single intermittent jet whose axis is time dependent; precession of the jet in a cone is one possible explanation for this behaviour.

A Direct Comparison of CO and H_2 from the Orion Molecular Shock

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High resolution long slit spectra of the Orion Peak 2 molecular shock simultaneously detect CO $v = 1 - 0$ P(3) through P(6) and H_2 $v = 0 - 0$ S(9) emission near 4.7 μm. Since the H_2 line has a significantly higher energy upper state, yet is more wide spread than the CO emission, temperature alone is probably not the dominant constraint. More likely is that the CO traces higher densities. The CO lines are displaced further from the cloud rest velocity than the H_2 emission, suggesting the CO may arise in cooled post-shock gas. CO line ratios fail to specify a single temperature and den-

sity, but further study of this wavelength region should prove critical for understanding molecular shocks.

Multiple Winds from the Carbon Star V Hydra: Studying Time-variations Using High-resolution Spectroscopy of the 4.6 μm CO Lines

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Observations of millimeter-wave CO lines have shown the carbon star V Hydra (V Hya) possesses not only a slowly-expanding ($V_{\rm exp} \approx 15$ km/s), largely spherically-symmetrical "normal" circumstellar envelope (CSE), but also a fast ($V_{\rm exp} \approx 120$ km/s) secondary outflow, which is bipolar. Observations of individual P & R-brand lines in the fundamental vibration-rotation band of CO at 4.6 μm over two epochs by Sahai and Wannier (1988, *Astr. Ap.*, 201, L9) showed the presence of several absorption components due to very fast-moving (up to $V_{\rm exp} \approx 120$ km/s) gas. The absorption lines showed significant differences between the two epochs, implying changes in the physical properties of the multiple high-velocity outflow over year-long time-scales. This study provided the first direct evidence of the simultaneous presence of a roughly isotropic, slowly expanding envelope and a very high-velocity stellar wind in a mass-losing AGB carbon star. We are currently performing a detailed study of the high velocity outflow using high-resolution spectroscopic data (obtained with the KPNO 4-m/Fourier Transform Spectrometer) covering the 4.6 μm band of CO (and its isotopomers) taken over 5 epochs. Our analysis, thus far, has yielded several important results. First, the clean separation of the absorption features in our spectra due to the slow and high-velocity outflows, allows us to determine a precise expansion velocity of the slow component ($V_{\rm exp} = 10\pm$ 2 km/s), which is smaller than published results based on mm-wave lines. The high-velocity outflow consists of 4–5 individual kinematic components, covering a velocity range of about 40 km/s. We find structure within the absorption feature due to the slow outflow, indicative of the presence of kinematic perturbations super-imposed on the predominant expansion at 10 km/s. A detailed analysis of the structure of, and variations in, the various absorption components is in progress, aimed at constraining the nature of the high-velocity outflow, and its hydrodynamic interaction with the slow outflow. This study will thus make an important contribution to our understanding of the physical processes mediating the transformation of mass-losing stars like V Hya into bipolar planetary nebulae.

Bar-driven Gas Structure and Star Formation in the Center of M100

K. Sakamoto, S. Okumura (Nobeyama Radio Observatory), T. Minezaki, Y. Kobayashi (National Astronomical Observatory), K. Wada (Hokkaido University)

High resolution (2.5″) CO(1–0) interferometry and near-IR imaging have been made toward the spiral galaxy M100 (NGC 4321). In the central 1′ (5 kpc), there are two-armed molecular spirals which start at each end of the nuclear stellar bar seen in the NIR images, and a central peak of CO emission with a diameter about 3″ (240 pc). The isovelocity map clearly shows distortions of the velocity field at the arms. We attribute the gas arms to the orbit-crowding at the outer inner Lindblad resonance (OILR), and the central peak to the collapsed self-gravitating gas that once piled up at the inner inner Lindblad resonance (IILR). Analytical and numerical models of gas dynamics with two ILRs well reproduced the observed gas structure and kinematics. The surface densities of gas at the OILR arms ($\Sigma > 500$ M$_\odot$ pc^{-2}) are above the threshold for gravitational instability (i.e., Toomre's $Q > 1$), thus the instability may have triggered the active star formation (Hα hotspots) at the arms. In addition, frequent cloud-collisions as a result of orbit-crowding may also be a trigger mechanism. In spite of the similarity to NGC 1068 in gas dynamics, M100 does not show conspicuous AGN activity, indicating that the bar-driven gas fueling to the central ~100 pc is not sufficient for the onset of AGN. The results and the discussion are fully described in Sakamoto *et al.* (1995, *AJ* submitted).

Physical Conditions of Molecular Gas in the Galaxy

Seiichi Sakamoto, Tetsuo Hasegawa, Toshihiro Handa, Tomoharu Oka, Kazuo Sorai (University of Tokyo), Masahiko Hayashi (National Astronomical Observatory)

We carried out an extensive out-of-plane survey of the inner Galaxy ($l = 20°–60°$, $|b| \leq 1°$, $\Delta l = \Delta b = 0.25°$) in CO ($J$=2–1) using the Tokyo-NRO 60 cm survey telescope with the same angular resolution to the Columbia CO (J=1–0) survey.

Distribution of the CO (J=2–1) emission mimics that of the CO (J=1–0) emission both spatially and kinematically, with an average J=2–1/J=1–0 ratio ($\equiv R_{2-1/1-0}$) of 0.66. Through closer comparison of the data, however, we find a radial variation in $R_{2-1/1-0}$. The ratio decreases from $\simeq 0.75$

at 4 kpc to $\simeq 0.6$ at 8 kpc, with a local peak near 6.25 kpc where the Sagittarius arm lies. Gas densities derived through a one-zone model analysis are $\simeq 6 \times 10^2$ at 4 kpc and $\simeq 3 \times 10^2$ cm^{-3} at 8 kpc, respectively. The large-scale variation of $R_{2-1/1-0}$ seems to be ascribed to the variation of the mixing ratio of dense cloud cores and low-density molecular gas. Dense molecular gas marked with large $R_{2-1/1-0}$ was found predominantly along the inner Sagittarius and Scutum arms. This result and the dominance of molecular gas over atomic gas in the inner Galaxy imply that dense molecular gas was formed through compression such as galactic shock compression followed by gravitational collapse, and not through dissociative stripping of low-density molecular gas.

An Isotope Study of Carbon Monoxide in the Edge-on Galaxy NGC 891

Seiichi Sakamoto, Toshihiro Handa, Yoshiaki Sofue, Mareki Honma, Kazuo Sorai (Institute of Astronomy, University of Tokyo)

We carried out high-resolution strip-scan observations along the disk of the edge-on galaxy NGC 891 in ^{12}CO (J=1–0) and ^{13}CO (J=1–0) emissions with very accurate relative calibrations of pointing and intensity scale. Physical properties of molecular gas were examined through an excitation analysis especially with respect to their relation with spiral arms and the galactocentric distance.

There is a radial variation in the ^{12}CO/^{13}CO ratio. The ratio is >10 inside the molecular ring except for the galactic center. It drops to the lowest value of $\simeq$2.5 near the molecular ring, and rises up outward to >5 at 10 kpc from the center. The arm-to-interarm contrast in the ^{13}CO emission is higher than that in the ^{12}CO emission. Nuclear disk emission is almost missing in the ^{13}CO emission. Since the ^{12}CO/^{13}CO ratio in a large scale reflects a fraction of dense gas to total amount of molecular gas rather than opacity of the ^{12}CO emission, observed large-scale variation in the ^{12}CO/^{13}CO ratio is understood in terms of concentration of dense molecular gas to inner spiral arms. This result and the dominance of molecular gas over atomic gas in the inner part of the galaxy imply that dense molecular gas in the inner spiral arms was formed through grand-design compression processes such as shock compression accompanied with density waves followed by gravitational collapse, and not through dissociative stripping of low-density molecular gas.

Structure and Physical Conditions of Molecular Gas in the Orion GMCs

Seiichi Sakamoto, Tetsuo Hasegawa, Junichi Morino, Kumiko Sato, Masumichi Seta, Toshihiro Handa, Tomoharu Oka (Univ. of Tokyo), Masahiko Hayashi (National Astronomical Observatory)

We carried out ^{12}CO (J=2–1) mapping observations of the entire extent of the Orion A and B GMCs using the Tokyo-NRO 60 cm survey telescope with the same beamsize and observation grid as the Columbia survey. Systematic variation in the J=2–1/J=1–0 ratio was found across the cloud. Gas densities extracted by an LVG analysis are $\geq 3 \times 10^3$ cm^{-3} in central ridges and $\sim 2 \times 10^2$ cm^{-3} in peripheries (Sakamoto et al. 1994).

To figure out origins of the systematic variation in physical conditions of molecular gas across the cloud, we conducted an extensive high-resolution imaging of the Orion A cloud in ^{12}CO (J=1–0) emission with the Nobeyama 45 m telescope. We found two distinct populations of molecular gas: "clumps" with larger $T_{\rm b}$, smaller linewidth and sharp boundary, and "interclump gas" with smaller $T_{\rm b}$ and larger linewidth. The surface filling factor of molecular gas is approximately unity throughout the cloud, and the fraction of clump emission to the interclump emission decreases outward. Peripheries of molecular clouds have low CO brightness not because the surface filling factor of molecular gas is small, but because low-density interclump gas dominates the emission.

Effects of Molecular Cloud Properties on the CO-to-H$_2$ Conversion Factor

Seiichi Sakamoto (Institute of Astronomy, University of Tokyo)

Effects of molecular cloud properties on the CO-to-H$_2$ conversion factor are quantitatively examined on the basis of a simple model of radiative transfer and excitation of the CO (J=1–0) emission for clumpy molecular clouds. The model deals with the effects of cloud structure such as elongation, viewing angle, mass distribution, and surface and volume filling factors, in addition to the effects of physical and chemical properties of clouds such as gas density, kinetic temperature, and the CO abundance.

The CO-to-H$_2$ conversion factor is strongly dependent on the CO abundance even when the CO emission is optically thick. It is because most of the molecular gas mass in molecular clouds in galaxies is in the form of low density gas in which even the ^{12}CO (J=1–0) emission is subthermally excited and the degree of photon trapping is reflected in the excitation temperature of the CO emission. Properties of molecular clouds other than the CO abundance have minor effect to the conversion factor.

The numerical results reproduce the empirical relation of the conversion factor to the metallicity found in Galactic and extragalactic molecular clouds (Sofue, Arimoto, & Tsujimoto 1995, this conference). Molecular gas mass in metal-poor galaxies will be severely underestimated if the Galactic value of the conversion factor is assumed.

Observations of the Perseus Arm in CO(J=2–1) line

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We have made extensive observations of the second Galactic quadrant in CO(J=2–1) line with the Tokyo–NRO (Nobeyama Radio Observatory) 60cm survey telescope. The observations were done over the area $l = 130.0°$ to $151.875°$, $b = -3.0°$ to $+3.0°$, which covers 840pc $\times$ 200pc at the distance of the Perseus arm. The previous Galactic plane surveys in the first quadrant show a trend that the intensity ratio between CO(J=2–1) and CO(J=1–0), ($R_{2-1/1-0}$), is about 0.6 at the solar vicinity and increases toward the inner region of the Galaxy. In the Perseus arm at a galactocentric distance of 11.5 kpc, however, the ratio $R_{2-1/1-0}$ is 0.88 ± 0.03 which is higher than that we extrapolate from the previous surveys. Most of the CO luminosity in this region comes from molecular gas associated with HII regions. These results suggest that most of molecular gas we can detect in the CO emission in the Perseus arm is strongly biased the high ratio gas ($R_{2-1/1-0} \sim$ 0.7–0.8) which is adjacent to HII regions, and low ratio gas ($R_{2-1/1-0} \sim 0.5$) such as the Taurus dark cloud is hardly detected. A significant amount of cold or low density molecular gas still can exist in the Perseus arm without being detected in CO lines.

CSO 607-725 GHz Line Survey of the Orion Hot Core

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Using the Caltech Submillimeter Observatory (CSO), we performed a 607 – 725 GHz line survey of the Orion hot core between November 1994 and January 1995, using the 650 GHz facility SIS receiver. Since the weather conditions were excellent, eight nights were sufficient to cover the whole spectrum twice. The single sideband system temperatures were in the range 1500 – 3000 K. The double sideband data were subsequently deconvolved using a MEM method to produce a single sideband spectrum. The achieved sensitivity is sufficiently high to securely identify 0.5 K lines over most of the band. A preliminary analysis revealed around 1500 spectral features. Due to the preliminary stage of the line identification, the fraction of unidentified lines cannot be determined yet, but it appears that it is low. The spectrum is dominated by CO, CS, SO, SiO, HCN, HCO^+, H_2CO, SO_2 and CH_3OH, with many lines from very highly excited states. The sensitivity to these highly excited lines is partly due to the small beam size (about 12″), well matched to the hot core. Evidence for two new molecules was found (SiH and DF), but the identifications are only tentative.

Multi-level CO Observations of Sgr B2

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With the Caltech Submillimeter Observatory (CSO) we mapped a 2′ by 5′ area around SgrB2 in ^{12}CO(2–1), ^{13}CO(2–1), $C^{18}O$(2–1), $C^{17}O$(2–1), ^{12}CO(3–2), ^{13}CO(3–2), $C^{18}O$(3–2), ^{12}CO(6–5), HCO^+(3–2), DCN(3–2), SiO(5–4), H_2S(2,2,0–2,1,1), SO(5,6–4,5), SO_2(11,1,11–10,0,10), H_2CO(3,2,1–2,2,0), OCS(18–17) and several transitions of HNCO(10–9) and $HCOOCH_3$, and a 8′ by 12′ area in ^{13}CO(2–1). The isotopomeric CO maps allow us to model the excitation conditions in the cores and the extended envelope of SgrB2, while the extended ^{13}CO(2–1) map provides information on the large scale kinematic structure of the region. The existence of very widespread, broad ^{12}CO(6–5) line emission indicates elevated temperatures and densities in a large fraction of the cloud envelope. The data permit us to determine the large scale cooling rate more precisely and thus allow a better understanding of heating processes. The maps of the other molecules give important insights into the chemistry of the region: some are peaking on SgrB2(M) (H_2S, SiO, SO, SO_2), some on SgrB2(N) (DCN, $HCOOCH_3$, OCS) and some seem to ignore the cores altogether (H_2CO and HNCO).

The transitions of HNCO allow the determination of the far-IR field in the cores and the answers (150–200 K) agree with earlier estimates.

CO and C^+ Observations in the Rosette Molecular Complex

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Large scale mapping of the Rosette Molecular Complex (RMC) in the 158 μm [CII] fine structure line and lower-J isotopomeric CO transitions reveal the close morphological correspondence between the two tracers. However, there is no simple linear correlation between the CO and C^+ intensities as it was found for Photon Dominated Regions (PDR's) with high volume density and strong UV-flux, F. We found that the C^+ intensity scales with $\log F$. Although the [CII] line was detected on a rather low intensity level of about (1–5)$\times 10^{-4}$ erg s^{-1} sr^{-1} cm^{-2}, there is still significant emission deep in the molecular cloud. Necessarily, the cloud structure is highly inhomogeneous to account for the deep UV penetration creating the observed C^+ intensities.

The large scale molecular cloud structure is traced by $2'$ angular resolution ^{12}CO and ^{13}CO J=2$\rightarrow$1 and $1'$ angular resolution ^{12}CO and ^{13}CO J=3$\rightarrow$2 maps obtained with the KOSMA 3-m telescope. Selected regions of the RMC were observed in isotopomeric J=2$\rightarrow$1 and J=1$\rightarrow$0 CO transitions with the IRAM 30 m telescope. The complex velocity structure of the RMC is revealed in CO channel maps and position-velocity maps. The dynamic of the gas results from the influence of the associated HII region and embedded IR sources. The CO line intensities and ratios are compared with the results of a PDR model, considering a molecular cloud with finite size. The observed line ratios can only be explained by thermalized gas with a local density above 10^4 cm^{-3} and a beam filling factor of about 0.5.

In addition to the CO maps, we took high signal-to-noise (S/N) ^{12}CO and ^{13}CO J=2$\rightarrow$1 spectra with KOSMA. Previous observations reported the detection of 'molecular interclump gas' by identifying CO line wing emission in high S/N spectra and a positionally averaged spectrum in the RMC. We confirm the detection of line wings in the composite spectrum but not reliably in the individual spectra. In contrast to the former interpretation, we show that the wing emission most likely results from embedded outflows and from the superposition of individual high velocity clumps. This finding is based on a study of the excitation conditions of the wing gas derived from a multiline analysis of one high S/N-spectra.

Molecular Clouds Interacting with the Supernova Remnant W44

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The supernova remnant W44 was observed in ^{12}CO(J=1–0),^{13}CO(J=1–0) and HCO$^+$ (J=1–0) lines with 45-m radio telescope at Nobeyama Radio Observatory. Nine giant molecular clouds with masses from 3×10^4 to 4×10^5 solar masses and diameters from 5 to 30 pc are found near the SNR. Each molecular cloud has substructures identified as regions with brighter CO emission. Some of these substructures show morphological anti-correlation with the radio continuum brightness and this suggests that the expansion of supernova remnant is stopped by the molecular clouds. Wings of ^{12}CO emission were discovered at eight positions and they are tightly correlated with bright filaments of radio continuum emission. Broad emission of HCO$^+$ extending to 55 km/s was detected at the positions with strong ^{12}CO wings. These CO and HCO$^+$ wings are considered to be a result of an acceleration of molecular gas in shocks induced by the supernova. Enhanced abundance of HCO$^+$ may have resulted from chemical reactions in the shock.

Observations of the ^{12}CO(J=2–1) emission with the Tokyo-NRO 60 cm radio telescope show that the CO J=2–1/1–0 intensity ratio increases markedly at the GMC/SNR interface. The ratio will offer a new index in identifying regions of GMC/SNR interaction.

Discovery of H_2O Maser Emission Associated with the Supernova Remnant W44

Masumichi Seta, Tetsuo Hasegawa (University of Tokyo), Nobuharu Ukita (Nobeyama Radio Observatory)

We have detected 22 GHz H_2O maser emission in the supernova remnant W44. The 45-m radio telescope at Nobeyama Radio Observatory was used for the observations. Three clear components with intensities from 1.8 to 7.7K were observed in the velocity range from 45km/s to 65 km/s at a position of $l = 34.787°, b = -0.387°$. Line of sight velocities of the maser features fall within the velocity range of the shocked molecular gas observed as broad CO and HCO$^+$ wings (Seta et al. 1996,these proceedings) and the maser spots are adjacent to a radio continuum peak. Because no IRAS point source is catalogued around this position, compact HII regions and late type stars are unlikely to be the source. The possiblity of a young star is also excluded because no point like radio continuum emission nor prominent molecular core is observed. This is possibly the first detection of H_2O maser emission associated with a supernova remnant.

Molecular Gas in M82: High Resolution CO, HCN, and HCO^+ Observations

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We present high resolution BIMA observations of CO(1→0), HCN(1→0), and HCO^+(1→0) emission from the starburst nucleus of M82.

We have identified two molecular rings in the nucleus of M82 and have found outflow motion of part of the molecular gas normal to the plane of the galaxy. The observations suggest that the starbursts took place within the molecular rings (or spiral arms) at some distance from the nucleus; the inner molecular ring is correlated with the ionized gas ring and the starbursts may, in fact, have propagated inwards. The dual molecular ring structure supports the suggestion that M82 may contain a nuclear bar.

We have identified ~60 molecular cloud clumps from the CO emission, with half-power diameters ranging from 20 pc to 100 pc and velocity widths (full-width half power) ranging from 7 km s^{-1} to 65 km s^{-1}. The typical T_b ranges from 13 K to 34 K. We found a power law distribution in the mass spectrum, with an index −1.3 ($dN/dM = -160\ M^{-1.3\pm0.2}$) for cloud masses greater than $4\times10^5\ M_\odot$. The large index indicates that most of the molecular mass is contained in GMCs with large masses.

CO (J=2–1) Mapping of Cygnus X Region with the 60-cm Telescope

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We have observed the Cygnus X region in the CO (J=2–1) line using the Tokyo-NRO 60-cm survey telescope. The observed area covers 6×4 deg^2, $77° < l < 83°$, $-2° < b < 2°$. The beam size of the telescope is about $9'$ and the sampling interval is $7'.5$. We compared our data with the CO(J = 1–0) data taken with 1.2m telescope of CfA (Leung and Thaddeus 1992).

The main conclusions are as follows:
(1) The average CO(J=2–1)/CO(J=1–0) intensity ratio, $R_{2-1/1-0}$, is 0.69± 0.06. This is similar to the values we got for GMCs with massive star forming regions (e.g., $R_{2-1/1-0} = 0.75 \pm 0.01$ in the Orion A cloud).
(2) We found an agglomeration of molecular clouds at $l \sim 78°$ which coincides with the cluster of HII regions. This could be interpreted as a result of the coherent trigger of star formation in a spiral arm.
(3) There are some high ratio clouds not accompained by known HII regions or SNRs. Some other mechanism that compresses or heats the CO-emitting gas is needed there.

The Discovery of Methanol Maser Lines at 1.9 mm

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The series of methanol $J_0{-}J_{-1}E$ lines at 157 GHz has been discovered in galactic sources together with the $2_1 - 3_0A^+$ line of A-type methanol. The observations were made in 1994 March, using the NRAO 12-m radio telescope at Kitt Peak. A 138-173 GHz SIS-mixer, dual-linear polarization receiver was used with system noise temperatures between 250 and 500 K. A hybrid spectrometer with 150 MHz total bandwidth and 768 channels was used providing frequency resolution of 195 kHz (or 0.37 km s^{-1}). Ten methanol transitions were observed by tuning the receiver to appropriate frequencies. In addition to eight lines of the $J_0{-}J_{-1}$E series, the $2_1 - 3_0A^+$ line was observed, and the $6_2 - 7_1A^+$ was observed in one source W3(OH). The E-methanol lines are intense and narrow and are believed to be maser lines. The radial velocities and profiles are similar to those of other class II methanol lines in W3(OH), G345.01+1.79, W48, and Cep A. The intensity of the lines increases with rotational number J, in contrast to thermal methanol features which were detected in the same sources at slightly different radial velocities. In the $2_1 - 3_0A^+$ line, the masers were found only in two sources: G345.01+1.79 and W48. It is suggested that the new maser line sources are the Class II methanol masers, but are excited with higher radiation temperature than the lower frequency Class II masers at 6.7 and 12.2 GHz. The presence of a series of several maser lines confirms an assumption that the whole K=0 ladder of E-methanol is overpopulated in Class II masers, rather than some selected levels. The masers may be related to molecular outflows or cometary bow shocks of ultracompact HII regions as is evidenced by their velocity shift relative to the parent molecular clouds.

Interstellar Acetone

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Acetone is one of the most important molecules in organic chemistry and it was the first 10-atom molecule reported in the ISM (Combes et al. 1987, A&A, 180, L13). The emission lines associated with the original detection were very weak. Thus, this identification was not well-established. Recent BIMA Array observations have shown that the complex species $HCOOCH_3$, CH_2CHCN, and CH_3CH_2CN peak toward the Sgr B2(N) molecular core (Miao et al. 1995, ApJ, 445, L59; Miao et al. these proceedings). Combes et al. (1987) would not have detected acetone emission from Sgr B2(N) because their single-dish pointing position was $1.3'$ away. Because Sgr B2(N) contains other complex organic species, we used the NRAO 12-m to search for new acetone transitions and the BIMA Array to image acetone emission. The blended J=8→7 quadruplets were observed with the BIMA B configuration ($10''\times 5''$ resolution) and the images indicate that, like other complex organic molecules, acetone emission peaks toward Sgr B2(N). We observed these transitions in both Sgr B2(N) and Sgr B2(OH) with the 12-m and found that the acetone emission from Sgr B2(N) is about twice as strong as from Sgr B2(OH). Six new transitions are dectected toward Sgr B2(N). Thus, our results confirm the identification of interstellar acetone and support the conclusion of Miao et al. (1995) that grain-surface chemistry produces complex organic species in Sgr B2(N).

CO-to-H_2 Conversion Factor: Metal Dependency and Radial Variation

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Compiling values of the CO-to-H_2 conversion factor from the literature, we have examined the metallicity dependence and its radial variation in galaxies. The X value (in H_2 cm^{-2} K km s^{-1}) is found to be proportional to the metallicity of galaxies,

$$\log X^* = -1.0(12 + \log \mathrm{O/H}) + 9.30,$$

where $X^* = X \times 10^{-20}$. Since the metallicity is a function of absolute magnitude M_B of galaxies, we obtain a formula to estimate the X value

for a galaxy with known luminosity:

$$\log X^* = 0.20 M_B + 4.44.$$

Since the metallicity is an exponentially decreasing function of the radius within a disk galaxy, the metal dependency would represent a radial gradient, and the data can be fitted by

$$\log X^* = 0.37 + 0.40(r/r_e - 1).$$

This formula can be used for any galaxy if the scale radius of its exponential disk r_e is known. (For details: Arimoto, N., Sofue, Y., Tsujimoto, T. 1995 A&A, submitted).

Inner-CO vs Outer-HI Rotation Curves of Galaxies

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The optical and HI rotation curves concern the kinematics of the outer galaxy. The inner rotation curves can be most accurately obtained by using CO-line position-velocity diagrams. We have compiled CO-line PV diagrams for nearby Sb and Sc galaxies observed with large-aperture mm-wave telescopes and interferometers. The rotation velocity is defined by $V_{\rm rot} = V_{\rm t} - (\sigma_{\rm obs}^2 + \sigma_{\rm ISM}^2)^{1/2}$. Here, $V_{\rm t}$ is the terminal velocity at 20% of max-intensity, $\sigma_{\rm obs} \sim 10$ km s^{-1} is the resolution, and $\sigma_{\rm ISM} \sim 7$ km s^{-1} is the velocity dispersion of gas.

All the RC, without exception, are found to have a steep rising up near the nucleus, and some are very similar to that of the Milky Way. The RC can be fitted by the Miyamoto-Nagai potential with four mass components: (a) the central mass (scale radius ~ 100 pc, mass $3-5\times10^9$ M$_\odot$), (b) the bulge ($0.5-1$ kpc, $\sim 10^{10}$ M$_\odot$), (c) the disk ($5-7$ kpc, $\sim 1-2\times10^{11}$ M$_\odot$), and (d) the massive halo ($15-20$ kpc, $\sim 2-3\times10^{11}$ M$_\odot$). The most striking feature is the steeply rising nuclear peak of RC at $R \sim 100$ to 200 pc observed for all the galaxies, indicating a compact central mass concentration. This nuclear mass, in addition to the bulge, will have an important implication for the formation of the galaxy center and disk. (See for detail, Sofue, Y. 1995, ApJ, in press.)

Molecular Front in Galaxies: Galactic-Scale HI–H_2 Transition

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The major ISM in galaxies comprises the HI and H_2 gases. The HI gas is distributed in the outer galaxy, while the molecular gas is more concentrated toward the center. We examined the HI vs H_2 distributions in galaxies and discuss the galactic scale phase transition of the ISM. We have obtained the radial variation of the molecular fraction, $f_{\rm mol}$, as defined by $f_{\rm mol} = \rho_{\rm H_2}/(\rho_{\rm HI}+\rho_{\rm H_2})$ for nearby Sb and Sc galaxies. (Four face-on galaxies M51, M101, NGC 6946, IC 342; and five edge-on galaxies , NGC 891, NGC 3079, NGC 4565, NGC 5907, MW). The $f_{\rm mol}$-vs-radius diagrams show that the HI to H_2 transition occurs suddenly in a narrow range of radius at 5–10 kpc, which we call the *molecular front* (MF). A galaxy disk is clearly separated by this front: the inner molecular disk, and outer HI disk. The MF is determined by the interstellar pressure P, UV radiation field U, and metallicity Z. We constructed a model galaxy in which P, U and Z decrease exponentially as $\propto \exp(-r/r_e)$, with r_e being the disk scale radius, and applied Elmegreen's theory. The theoretical $f_{\rm mol}$ variation reproduces well the observations, and a clear MF shows up. We find that the Z (metal) gradient is most crucial for the formation of MF. The MF would, therefore, have crucial implications for understanding the chemical evolution of the ISM in galaxies. (References: Sofue, Y., Honma, M., Arimoto, N. 1995, A&A, 296, 33; Honma, Sofue, Y., M., Arimoto, N. 1995, A&A, in press.)

CO-Line Tully-Fisher Relation: mm-Wave Cosmology

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The HI Tully-Fisher relation can reach galaxies with redshifts $cz \sim 10,000$ km s^{-1}. CO-line observations provide us with sharper beams and higher sensitivity to more distant galaxies and the atmospheric noise decreases at red-shifted CO frequencies. Astrophysically, molecular gas is better correlated with the stellar disk, so is less disturbed by tidal interactions than HI. Hence, we may expect that a CO line Tully-Fisher relation could reach farther distances than HI and better determination of H_0 would be possible. We have established the CO-line Tully-Fisher relation for the local calibrators and nearby galaxies from a sample of several tens of galaxies and demonstrated that CO can be used as an alternative to HI.

We have used the Nobeyama 45-m telescope to observe ^{12}CO(J=1–0) line profiles of distant cluster galaxies at $cz \sim 10000-30000\,\mathrm{km\,s^{-1}}$. CO was detected in seven galaxies. We determined the distances to three galaxies from our CO sample by the Tully-Fisher relation using optical data from the Kiso Schmidt CCD images. A preliminary value of the Hubble constant for the galaxies is $H_0 \simeq 106 \pm 30$ km s^{-1}. (References: Dickey J., Kazes I., 1992, ApJ, 393, 530; Schöniger, F., Sofue, Y. 1993, A&A, 283, 21; Sofue Y., 1992, PASJ, 44, L231)

^{12}CO (J=2–1) Emission in the Inner Galaxy

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We have made a survey of the ^{12}CO ($J = 2-1$) line emission from the inner Galaxy covering from 6 to 20 degrees in galactic longitude and from -1 to $+1$ degrees in galactic latitude with the University of Tokyo-Nobeyama Radio Observatory 60 cm radio telescope in Nobeyama. HPBW is $9'$ and sampling grid is $7.5'$.

The distribution of CO ($J = 2-1$) emission is similar to that of CO($J = 1-0$) shown by the Columbia survey (Dame *et al.* 1987). The intensity ratio, $R_{2-1/1-0}$, is 0.73 ± 0.01 averaged over the whole observed region. This value, taken superficially, corresponds to $n(\mathrm{H_2}) \lesssim 10^3$ cm^{-3} and $T_\mathrm{k} \gtrsim 20$ K in a framework of one-zone LVG analysis. The ratio shows a systematic gradient as a function of the galactocentric radius. Adding the data of 20 to 60 degrees in galactic longitude (Sakamoto *et al.* 1995) to our data, the ratio is about 0.5 in the solar vicinity and goes up to about 0.8 at 3 kpc from the galactic center. The ratio of molecular gas that appears to be associated with HII regions is 0.8 on the average markedly higher than average over the whole disk gas, but its contribution to the whole luminosity is small.

References: Dame,T.M. *et al.* 1987, ApJ, **322**, 706; Sakamoto,S. *et al.* 1995, ApJS, in press

Circumstellar Molecular Gas of PV Cephei

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The peculiar young Ae star PV Cephei has been observed in the 1–0 lines of ^{13}CO and C^{18}O and in the 2.7 mm continuum using the Owens Valley Millimeter Array. In all three tracers, circumstellar gas and dust are detected in the $3.9'' \times 3.2''$ beam. The dust continuum emission is spatially unresolved and centered exactly at the stellar position. The flux density (38$\pm$4 mJy at 110 GHz) suggests a circumstellar material mass of 0.3 $M_\odot$. CO isotope emission is also centered at the stellar position, but is spatially resolved with a deconvolved source size of 2600 AU at PA 120° and unresolved in the perpendicular direction. The ^{13}CO emission is seen over the VLSR velocity range 1.8–4.3 km sec^{-1}, but vanishes at the intermediate velocities 2.6–3.0 km sec^{-1} because of self-absorption. The emission peak shifts from the NW side of the star at the lower velocities to the SE side of the star at higher velocities, suggesting rotation. These maps appear to confirm the existence of the circumstellar disk for PV Cephei which has been suggested by previous optical, infrared, and radio work. In contrast to the recent non-detections of other AeBe stars via millimeter interferometry, the results for PV Cephei show that Ae stars can possess massive disks at their earliest evolutionary stages associated with strong bipolar outflow.

The Evolution of Detached Shells in AGB-stars

Lars Stenholm (Uppsala Astronomical Observatory)

Detached shell AGB-stars have experienced a short period of intense mass loss. This massive shell is also faster than the previous normal wind. Observations of S Sct indicate that the shell is thin and to the first approximation spherical. There is, however, also indications of clumping along the shell. This project intends to identify the physical processes involved in the evolution of the shell. We used an 3D hydrodynamic code of SPH type to simulate the shell evolution.

CO^+ in Photon-dominated Regions

Herbert Störzer (Universität zu Köln)

Recent observational studies have shown that molecular clouds in star-forming regions are inhomogeneous and clumpy, and that dense clumps appear to survive or form in clouds exposed to intense stellar far-ultraviolet radiation. These clumps may be studied directly by observing molecular species which are exclusively produced in dense PDRs. The molecular ion CO^+ is such a diagnostic probe.

We present the results of observational studies of CO^+ rotational emission from star-forming molecular clouds in Orion, M17, and S140. We give an interpretation of the results in the context of strong UV/high density PDR regions.

Multiple Winds from the Carbon Star V Hydra: Studying Time-variations Using High-resolution Spectroscopy of the 4.6 μm CO Lines

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Observations of mm-wave CO lines have shown that the carbon star V Hydra possesses a slowly-expanding ($V_{\rm exp}\approx15$ km/s), largely spherically-symmetric "normal" circumstellar envelope, with a fast ($V_{\rm exp}\approx30$ km/s) secondary bipolar outflow. High-resolution spectra of the 4.6 μm P & R-branch CO lines over two epochs by Sahai and Wannier (1988, *Astr. Ap.*, **201**, L9) showed the presence of absorption components due to very fast moving ($\leq V_{\rm exp}\approx120$ km/s) gas. Spectral variations between these epochs implied changes in the high-velocity outflows over $\lesssim1$ yr. We have extended this study by obtaining higher quality data (KPNO 4-m FTS) over 7 epochs. We determine an expansion velocity of the slow component ($V_{\rm exp}\approx10\pm2$ km/s) which is less than that found from published mm-wave results. The high-velocity outflow consists of ≥6 kinematic components over a velocity range of ~70 km/s. Analysis of integrated intensity ratios of the various components imply changes in the high-velocity structure over very short time-scales (~2 days) constraining this outflow to $\sim10^{16}$cm. This study will thus make an important contribution to our understanding of the physical processes which mediate the transformation of mass-losing stars like V Hydra into bipolar planetary nebulae.

An Analysis of the Smoothness of Line Profiles

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It is now generally agreed that molecular clouds are clumpy, i.e., they exhibit large point-to-point density fluctuations. Because individual clumps are observed to emit lines which are narrower than those emitted by their ensemble (the cloud), they must leave an imprint as velocity structure superimposed on ensemble profiles. Thus, a possible route to explore clumpiness is to observe emission lines with very high signal-to-noise ratios and very high velocity resolution, analyze the fluctuations in brightness temperature present on the line shape, and infer from them the properties of the clumps present in the beam. The advantage of this technique is that since a relatively large field of view is sampled, the statistical properties of clumps are obtained directly, without having to go through the process of detecting and mapping each clump as is done with interferometry.

This technique was developed recently and applied to the case of Orion (Tauber, Goldsmith and Dickman 1991), using CO and ^{13}CO lines as tracers. However, in that paper the clumps were assumed to be "black disks", and the beam area filling factor was assumed to be small. We have now generalized the technique to include clumps with an arbitrary central opacity and radial distribution, using as a framework the clumpy cloud model of Martin, Sanders and Hills (1984). We show how with this model, the smoothness of the observed profiles can be used to constrain the parameter space of the unresolved clumps.

Cometary Globules in the Orion Super-Bubble

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We present a preliminary search for cometary globules near the Orion OB associations using IRAS Sky Survey Atlas (ISSA) plates. Coincident ^{12}CO scans of twenty-three of the objects are also presented.

The cometary globules were identified by examining ISSA plates at 25 μm, 60 μm, and 100 μm around the Orion region [R.A. range 7^{h} to 2^{h}, and Dec. range $-24°$ to $+20°$]. The general morphologies (the locations and directions of "tails" in our sample) and kinematics (velocity information from the CO data) suggest that their interactions with the early-type stars in the Orion OB association and older associations in the region are dominated by ionizing radiation originating from a few distinct locations near the center of Barnard's Loop. Using CO observations made from the AT&T Bell Laboratories 7 m offset Cassegrain antenna, we obtain line velocities and line widths for these objects, as well as ^{12}CO and ^{13}CO maps for several of the globules.

Many of the globules with R.A. $> 5^{\mathrm{h}}$ are moving towards the sun with $v \lesssim 25$ km s^{-1} relative to the V_{LSR} of ~ 5 km s^{-1} for the Orion molecular cloud, which is consistent with numerical simulations of super-bubbles large enough to "blow out" of the galactic plane.

The Distribution of Cold Gas in the Flocculent Spiral NGC 5055

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BIMA and FCRAO CO J=1–0 observations are used to assess the properties of the molecular gas distribution in the nearby, flocculent spiral NGC 5055 (7.2 Mpc). As the weak spiral structure in flocculent galaxies may indicate the absence of spiral density wave activity, these observations can help determine the range of cloud sizes and masses that form in spiral galaxies without the influence of strong density waves. With an average surface density one-quarter that of the grand design spiral M51, NGC 5055 exhibits molecular structures with similar properties to the Giant Molecular Associations (GMA) detected in M51. The measured structures have masses between 6×10^6 and 1×10^8 M$_\odot$, and half of these have comparable virial masses. The distribution of CO cloud structures is also compared with the distribution of HI, Hα, and NIR peaks in order to examine the relationship between cold gas and star formation in NGC 5055. This comparison suggests structure organization on kiloparsec scales.

Molecular Clouds in M51

Tomoka Tosaki (Nobeyama Radio Observatory), Yoshiaki Taniguchi (Tohoku University), Ryohei Kawabe (Nobeyama Radio Observatory)

We report results of higher spectral-resolution analyses (3.25 km s^{-1}) of ^{12}CO($J = 1 - 0$) mapping data of the bright arm region in M51 obtained with the Nobeyama Millimeter Array (NMA). We identified 79 clouds as distinct components both spatially and kinematically. The less-massive clouds have the virial masses with a few $\times 10^5$ M$_\odot$, which is just comparable to a typical mass of the Galactic GMCs. We found that for

almost all clouds the ratios of the mass estimated from CO flux using the Galactic CO-to-H_2 conversion factor to the virial mass estimated from the size and velocity width are much larger than 1. The mean ratio in all of the field is 5. This result suggests that the CO-to-H_2 conversion factor is smaller than the Galactic one, and thus implies that in M51 there are many clouds with smaller optical depth than those of the Galactic GMCs. The high temperature and the high metallicity abundance of molecular clouds in M51 may account for the small conversion factor, namely, small optical depth. To investigate the effect of the density wave on the nature of molecular clouds, we divided them into three types by their positions; upstream, on-arm, and downstream clouds. There is a clear difference in the brightness temperatures between the upstream and the downstream clouds. The average brightness temperature for the downstream clouds is high, 8.5 K, which is close to that for the on-arm clouds. This implies that the physical properties of the downstream clouds are closer to those of the on-arm clouds than those of the upstream clouds.

CO(1–0), CO(3–2), and HCN(3–2) Observations of IRAS F10214+4724

Masato Tsuboi (Institute of Astrophysics and Planetary Science, Ibaraki University), Naomasa Nakai (Nobeyama Radio Observatory)

We have observed CO(1–0), CO(3–2) and HCN(3–2) emission from the high redshift galaxy IRAS F10214+4724 using the Nobeyama 45-m telescope. CO(1–0) and CO(3–2) were detected at z=2.286 with integrated intensities of 2.4±0.3 and 5.1±0.3 Jy km s^{-1}, respectively. The intrinsic brightness temperature ratio of CO(3–2) to CO(1–0) is 0.25. HCN(3–2) was not detected, although a weak 3σ emission line was recognized at z=2.286 (1σ=0.8 mK in $T_{\rm MB}$). The 5σ upper limit to the integrated HCN(3-2) intensity is 1.3 Jy km s^{-1}. The 5σ upper limit to the intrinsic brightness temperature ratio of HCN(3–2) to CO(3–2) is 0.2. In addition, we have searched for CO(3–2) from 4 points (east, west, north, and south) 15″ from the center position. There is no significant emission at these points. These results suggest there is a huge mass of low-density molecular gas at $n(H_2)$= 10^2 cm^{-3} in the object.

The Discovery of Methanol Masers at 107 GHz

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A new methanol maser line was discovered in galactic sources in a transition between the K=0 and K=1 ladders at 107 GHz. The observations were carried out, using the radome-enclosed 20 m millimetre wave telescope of Onsala Space Observatory. A cryogenically cooled low-noise SIS mixer was used in the receiver; the single side-band receiver noise temperature was 80 K. The backend was a 64 MHz wide 256-channel filter spectrometer with a frequency resolution of 250 kHz (velocity resolution 0.7 km s^{-1}, at 107 GHz).

All detected sources are known Class II methanol masers. It is similar to the much stronger 6.7 GHz masers. The sources where the new maser line was observed are in general the same sources which are 6.7 GHz Class II line emitters. Toward Class I methanol maser sources, the 107 GHz line was found in absorption, or as rather weak quasi-thermal emission sources.

The detection of the new methanol maser line supports an assumption that the level population inversion is due to overpopulation of some K-ladders relative to neighboring ladders.

Dust and CO in the T Tauri Circumstellar Matter

Huib Jan van Langevelde (Joint Institute for VLBI in Europe, Dwingeloo and NRAO Socorro), Ewine F. van Dishoeck (Sterrewacht Leiden), Geoffrey A. Blake (Geological and Planetary Sciences, Caltech)

The circumstellar material around T Tau shows complicated structure at different scales and different observing frequencies. This is partly due to the fact that the optical star (T Tau N) is accompanied by a close infrared companion (T Tau S). We present sub–arcsecond resolution observations of gas and dust to try to discriminate between several components in the circumstellar material around T Tau. Observations with the Owens Valley Millimeter array at 267 GHz reveal continuum emission, as well as—on the short baselines—HCO^+ J=3→2 emission. The continuum emission indicates an unresolved component (70 AU) at the position of T Tau N, but the emission is at least a factor 4 weaker at the position of T Tau S. Submillimeter interferometer data between the CSO and JCMT taken at 357 GHz are consistent with a single component and provide clues about the spectral energy distribution of the dust around T Tau N. Comparison with single-dish data shows that considerable amounts of gas and dust are present on a larger, circumbinary scale of ≈ 1000 AU. Preliminary estimates indicate a relatively low CO-to-dust ratio in the circumbinary envelope.

CO Observations of NGC 7674

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We have mapped the CO(2–1) and (1–0) emission toward NGC 7674, 1st ranked galaxy of Hickson 96, with the IRAM 30 m radiotelescope (Granada, Spain). The beam sizes were $\sim 13''$ and $22''$, respectively. The molecular gas associated with NGC 7674 is overabundant and extended. Both CO transition maps show enhanced emission that seems to be associated with the spiral arms of the galaxy. We obtained a total mass of 2×10^{10} $M_{\odot}$. A comparison of the masses of the interstellar gas in the molecular and atomic gas phases leads to a value of $M(H_2)/M(HI) \sim 2$ according to the interacting nature of the galaxy and its high infrared luminosity.

CO Emission from QSO Absorption Line Systems

Constance E. Walker, Jill Bechtold, John H. Black (Steward Observ., U. Arizona)

By studying the physical conditions in galaxies at different redshifts, we can begin to understand the evolutionary process of star formation from early epochs to the present. Observations of the mm/submm CO lines in these galaxies provide a way to investigate abundances of, and conditions in, potential star-forming material. Here we report the detection of CO in emission toward 4 galaxies at redshifts of 0.005 to 0.05. Detections were made in two transitions toward each of the four sources: PKS 0038–019, S4 0248+43, 3C 232, and PKS 1327–206. From these observations, we computed the molecular gas mass to be 1.7×10^8 $M_{\odot}$ to 3×10^9 $M_{\odot}$. These estimates used the "standard conversion factor" for H_2 column density to integrated CO intensity ratio, $(N(H_2)/I_{co})$, and an H_0=75km/s/Mpc and $q_0 = 0.5$. We also report upper limits to the molecular gas mass in 33 other systems with redshifts ranging from 0.03 to 2.8 to be $< 4 \times 10^8$ $M_{\odot}$ to $< 5\times10^{11}$ $M_{\odot}$. All four of our sources detected in CO were selected to be metal line systems (with high HI column densities) and possess strong FIR fluxes detected by IRAS at 60 and/or 100 μm. The source possessing the brightest FIR emission among the four is the $z = 0.05$ 21 cm absorber toward S4 0248+43. The total observed FIR luminosity for this source is $L_{\rm FIR} = 3.0 \times 10^{11}$ $L_\odot$. Taking into account its luminosity and the additional correction for the integrated flux from $0.01 - 100$ μm (Sanders et al. 1988), this object can be classified as a transition object between a normal luminous galaxy and an ultraluminous IR galaxy. This absorber galaxy may be the only known starburst in front of a quasar.

An Experiment to Detect Linear Polarization of Millimeter-wave Emission Lines

Christopher K. Walker (Steward Observatory), Phillip R. Jewell (NRAO), Jason Glenn (Steward Observatory)

Using a sensitive, high efficiency polarimeter, we have used the NRAO 12-m to search for linear polarization in the HCO^+ $J = 1 \rightarrow 0$ transition (89.19 GHz) toward the redshifted molecular outflow lobe in DR21. HCO^+ was chosen as the molecular probe because of its high dipole moment (3.3 D). The conditions toward this outflow lobe satisfy many of the excitation requirements for linear polarization. After $\sim$16 hrs of integration, linear polariztaion was *not* observed to the $\sim 0.07\%$ level. This sensitivity level is $\geq 10\times$ higher than what is required to detect line polarization using the most conservative theoretical estimates.

Why was linear polarization not observed? The most plausible explanation is that there are small-scale inhomogeneities in the velocity field along our line of sight that work to randomize the radiation field. Without an anisotropic radiation field, the Zeeman sublevels of a given transition are not differentially populated, and linear polarization is not produced. What is reponsible for the small-scale structure in the velocity field? Turbulence within the material entrained by the stellar wind is the most likely cause. Since no polarization was observed anywhere in the line profile, one is led to conclude turbulent gas is present along the entire line of sight. This result is consistent with a model in which the outflow lobe is filled with turbulent gas.

Shocked Vibration - Rotation CO and H_2 in NGC 2071 IRS1

D. M. Walther and T. R. Geballe (Joint Astronomy Centre/UKIRT)

Two lines of the fundamental vibration-rotation band of CO at 4.7 μm have been detected in emission in the vicinity of NGC 2071/IRS1. Velocity-resolved spectra of these two lines (P(3) and P(4)) as well as the neighboring H_2 0–0 S(9) line are presented. The H_2 line has a velocity width of 110 km s^{-1}. The three lines have similar velocities of maximum line intensity and are broadened, suggesting that the CO emission, like that of H_2, occurs in shocked-heated gas. The CO lines are cut off on their blue-shifted sides by absorption by quiescent CO in the NGC 2071 cloud.

CO Observations of Dust Lane Galaxies: NGC 5866 and NGC 3656

Z. Wang (Smithsonian Astrophysical Observatory)

We present aperture synthesis CO (1–0) observations of early-type galaxies NGC 5866 and NGC 3656. The molecular gases are found to trace the dust lane as seen in optical images of these galaxies, but appear to be unsettled in the gravitational potential. Also, the rotation curves derived from the CO data are found to be rising faster than a simple kinematic model would predict. These results may shed some light on the origin of cold gas and dust in early-type galaxies.

Photodissociation and Rotational Excitation of Interstellar CO

Sophie Warin, Jean-Jacques Benayoun (Observatoire de Grenoble), Yves P. Viala (DEMIRM, Observatoire de Paris, Ecole Normale Supérieur)

We have developed a detailed interstellar cloud model that includes C and O chemistry, as well as ^{13}C and ^{18}O isotopic substitutes. All major processes that modify rotational population of H_2, CO and its isotopes are taken into account: selective photodissociation, UV pumping for H_2, chemical, collisional and radiative processes. Gas and grain temperature distribution can be obtained by solving the thermal equilibrium equation. We have computed a series of models for diffuse, translucent and dense dark clouds. For each type, we consider a "standard" model with a uniform density and temperature. Selective photodissociation of CO leads to a strong dependence on the rotational quantum number and a strong coupling between photodissociation and rotational excitation. In most of the cases, results show that the rotational populations of CO and its isotopes are generally sub-thermally excited with different excitation temperatures for each transition.

We carry out a study of CO abundances as a function of visual extinction to compare to observations. We ran models with uniform density and a distribution temperature computed by solving the thermal balance equation. We found a very good agreement between our model and Frerking et al. (1982) observations. Although we predict too low abundances of both ^{13}CO and $C^{18}O$, the column density ratio R($^{13}CO/C^{18}O$) normalized to the isotopic ratio matches pretty well the Lada et al. (1994) ratio for IC 5146.

A High-resolution Multi-transition Study of CO, CI and Other Lines Towards the Galactic Centre Circumnuclear Disk: A Unique Example of a Photo-dissociation Region

G. J. White (QMW, University of London)

This paper reports the results of a major long-term programme on the JCMT to study the chemical structure and excitation gas in the unique circumnuclear molecular ring (CND) at our Galactic Centre. The CND provides us with our closest view of conditions that may be typical of many external galactic nuclei. The CND has been imaged by the JCMT with beams as small as $10''$ in the CO J = 2–1, 3–2 and 4–3 CO and their isotopic transitions, in atomic Carbon, CI, and in a variety of other strong lines and their isotopes including CS, CN, HCN, HCO^+ and CH_3OH. A well defined rotating ring structure is seen in the CO J = 4–3 transition, and in maps of ^{13}CO and $C^{18}O$. However, the CO isotope line intensities are unusually weak, typically 5–10% those of the main line, suggesting they are surprisingly relatively optically thin. The CO structure is closely correlated to the structures seen in other high density tracers such as CS, CN, HCN, HCO^+ and CH_3OH, but weakly correlated with atomic carbon, CI, which has a distribution quite different from those of any of the molecules. The CO J = 4–3 line intensities exceed 100 K at several points around the ring, as well as showing deep self-absorption features similar to those seen in CN and HCN. A spectral survey in the 200 and 300 GHz windows of two bright points on the ring reveals a simple chemistry, characteristic of photodissociation regions, and dominated by highly excited transitions of simple molecules. Characteristic values of the excitation temperatures and densities are 200 – 400 K and 10^5 cm^{-3} respectively. The material is highly clumped, its morphology and kinematics showing it is closely correlated to ionised gas making up the central 'mini-spiral'. The material at the edge of the CND is clearly being stripped of material, which is feeding along the arms of the mini-spiral into the Centre.

Atomic Carbon, CO and Submillimetre Continuum Studies of the Orion Nebula and the Serpens Star Formation Regions

G. J. White (QMW, University of London)

This paper reports the results of details multi-transition studies of the Orion and Serpens molecular cores in CO and CI lines to study the relationship between atomic carbon and CO, and to attempt to measure the gas-to-dust ratios, and the behaviour of the isotopic abundance ratios of CO. The spatial distributions of the $^3P_1 - ^3P_0$ atomic fine structure of carbon (CI), the CO J=4–3, the CO J=2–1 transitions of CO, ^{13}CO, C^{18}O and C^{17}O and the 790 μm continuum emission have been mapped towards the central region of the Orion molecular cloud (OMC1 cloud), and the Bright Bar ionisation front. The CO data are analysed in a consistent way, allowing the inter isotopomeric abundance ratios to be studied over a wide range of extinction values. The ^{13}CO lines are optically thick; the ^{13}CO abundance being enhanced because of strong isotopic fractionation near the Bright Bar, but less convincingly in the OMC1 cloud. The fractionation occurs mostly in the less opaque regions where N(^{13}CO) may be enhanced by up to one order of magnitude, relative to the more shielded parts. No isotope selective enhancement of the other CO isotopomers was seen; C^{18}O may in fact show a slight depletion in more exposed material. The C^{18}O and C^{17}O lines are optically thin, and correlated with the 790 μm dust continuum emission. The CI emission comes from hot optically thin gas; the abundance ratios of [CI]/[CO] are typically 0.05–0.3, with the larger ratios towards the northern section of the Orion ridge. The CI abundance ratios are also high along the edge of the Bright Bar which is adjacent to the HII region (and the Trapezium cluster which excites it), but decrease in the dense shielded material behind the Bar. The Serpens Molecular cloud is a nearby low/intermediate mass star forming region that is in the final stages of forming a densely packed cluster of stars. Spectra and high angular resolution maps of the CO, ^{13}CO, C^{18}O and C^{17}O J=2–1 and CO J= 4–3 transitions were obtained to study the distribution of molecular gas near the cluster. These are supplemented with data on the J= 4–3 HCO$^+$ line (to probe the denser gas), and $^3P_1 - ^3P_0$ line of atomic carbon. The mass of the region is estimated to be $\sim$ 1450 M$_\odot$, implying that the star formation efficiency in the region to date has been $\sim$ 2.5 percent. Sev-

eral molecular outflows are visible in the maps; some are associated with compact objects visible in millimetre and submillimetre wave continuum maps, as well as more widespread diffuse high velocity gas that extends over much of the nebula. The mass and energy of material in the high velocity gas are relatively small, ~ 0.3 $M_{\odot}$ and 3×10^{45} erg s^{-1}, consistent with the characteristics of outflows seen towards low mass star-formation regions. The directions of the overlapping outflow lobes do not, however, show a clear alignment with the cloud's large scale magnetic field as has been reported towards some other regions. The gas temperatures in the region are warmer ($\sim$ 30–40 K) than typical for dark clouds, suggesting that the Serpens cluster has interacted with, and heated the gas. Estimates of the CO isotopomeric abundance ratios from these data may be strongly affected by opacity and radiative transfer effects. In a comparison of the LTE and LVG techniques, the disagreement between the derived column densities is discussed - with particular relevance to the higher rotational transitions.

CO in Selected Edge-on Galaxies

R. Wielebinski (Max-Planck-Institut für Radioastronomie)

We have made extensive CO maps of numerous northern and southern edge-on galaxies in both the (1–0) and (2–1) line transitions. The observations were made both with the 30m Pico Veleta telescope and with the 15m SEST facility. The maps are made with receivers of good sensitivity so they represent the most extensive studies of these objects so far. Recently, high-angular resolutions studies in CO of nuclear areas of some of 'our' galaxies have been started with the Plateau de Bure interferometer. The main objective in this on-going project, which is being supported by a Max Planck-Forschungspreis (Australian partner John Whiteoak), is to study the dynamics of the galaxies. In particular, we wish to see if the combination of the various dynamic components (optical, HI, dust, molecular component, FIR, X-ray, etc.) will give us a better understanding of the whereabouts of the missing mass at the individual galaxy level. We collaborate with Michel Guélin (Grenoble) in the observation of the 1 mm dust. The HI observations with identical angular resolution come either from the VLA or the Australia Telescope. Optical observations are usually available in publications. We are working towards the adoption of various dynamical codes for galaxies to handle multi-component data (collaboration with Françoise Combes (Paris) and Jan Palous (Prague). The objects being studied (edge-on) are: NGC55, 253, 613, 891, 3034(M82), 3628, 4565, 4594(M104), 4631, 4945, 5907, and 7331. In addition we have observed: NGC1566, 1672, 1808, 2442, 3627, and M51.

The Structure and Evolution of Giant Molecular Clouds

Jonathan P. Williams (University of California at Berkeley)

The relationship between the properties of the molecular gas in a cloud and its star forming nature are investigated and interpreted in terms of an evolutionary scenario for molecular clouds. The internal clumpy structures in two clouds, the Rosette molecular cloud (RMC) and the Maddalena–Thaddeus molecular cloud (MTC) are compared and contrasted with their differing stellar content: the RMC contains the Rosette nebula, a very luminous OB association and, in addition, has several sites of ongoing star formation deeper into the cloud; but the MTC is very "infra-red cold", and there are no O stars, formed or forming, within its molecular boundaries.

Gradients of clump properties across the RMC are found that show gas density, temperature and star forming activity, $L_{\rm IR}/M$, all systematically increase toward the OB association. In the MTC, however, the gas properties are found to be remarkably similar to those in the RMC. The clump mass spectra, size-linewidth relations, clump profiles, *etc.*, share the same slope in the two clouds. Differences between the two are found not in the slopes of the relations, but in the offsets, that is, *not in structure, but in scale*, e.g., the virial mass scales as $M^{2/3}$ in both clouds, but whereas no clumps in the MTC are bound, all the star forming clumps in the RMC are.

The gradients that are seen in the Rosette suggest that star formation in a cloud may not be a purely stochastic process but is influenced by its environment. The structural similarities between the RMC and the MTC possibly reflect common cloud formation/evolutionary processes. Cloud evolution may proceed via clump agglomeration and dissipation in a way that preserves structure but leads to the formation of massive, bound, and ultimately star forming clumps.

BIMA Array Observations of $C^{18}O$ and 2.7 mm Continuum Emission Toward NGC 2024

T. L. Wilson (Max-Planck-Institut für Radioastronomie), D. M. Mehringer, and H. R. Dickel (University of Illinois)

NGC 2024 has been imaged in the J = 1–0 line of $C^{18}O$ and in the 2.7 mm continuum using the BIMA Array with an angular resolution of 10″. The continuum images show four sources which have been observed in previous studies. A 160 mJy point source coincides with the position of IRS 2. The spectral index of this source between 2.7 mm and 6 cm is 1.3. The other three 2.7 mm continuum sources correspond to the 1.3 mm sources FIR 3, 5, and 6 (Mezger et al. 1988, A&A, 191, 44; Mezger et al. 1992, A&A, 256, 637). The spectral indices of these sources between 2.7 and 1.3 mm are ≥ 4. The other continuum sources, FIR 1, 2, 4, and 7, which are not detected in our data, have similar spectral indices. $C^{18}O$ emission is observed in three slightly extended regions. The two southern molecular clumps are offset from the FIR 5 and 6 continuum sources. The northern molecular clump is located ≤ 4 from the FIR 2 continuum source. H_2 column densities derived from a viral analysis of the $C^{18}O$ clumps indicate that the CO relative abundance is only about 10% of the usual value. Depletion of CO in the gas phase may be due to "freezing out" of this molecule onto grain surfaces.

Dynamical Models of Circumstellar Dust Shells around Long-period Variables: Spectrum, Lightcurves, Intensity Profiles, and Visibilities of IRC+10216

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Based on dynamical models for circumstellar dust shells (CDS) around long–period variables, including time–dependent hydrodynamics and a detailed treatment of carbon grain formation, continuum radiative transfer calculations have been carried out for a model which is capable of explaining several different observations of the prominent carbon star IRC+10216. It is shown that the resulting theoretical lightcurves exhibit the superposition of different oscillations: The oscillation with the period of the interior pulsation of the star is superposed by an oscillation with a longer period which is produced by the dynamical structure of the CDS. This dust shell model also causes a pronounced non–monotonic course of the spatial intensity distribution across the CDS, leading to the occurrence of wavelength–dependent internal structures of the calculated visibility functions. A quantitative comparison with specific observations obtained for IRC+10216 shows the layered distribution of dust across the CDS might be a natural physical explanation of the multiperiodic photometric lightcurves, the step–like behaviour of the brightness profile, and the internal structures present in the measured visibilities. **Acknowledgements:** This work has been supported by the BMBF, the DFG, and the DOE.

The Monoceros OB1 Dark Cloud: A Comparison of ^{13}CO, C^{18}O, and CS Observations of Outflow Regions

Grace A. Wolf-Chase (NASA/Ames Research Center)

We compare ^{13}CO and C^{18}O J=1→0 observations of four massive outflows in the Mon OB1 dark cloud with CS J=2→1 (Wolf-Chase, Walker, & Lada 1995; Wolf-Chase & Walker 1995) and CO J=1→0 (Margulis, Lada, & Snell 1988) observations. We find the ^{13}CO J=1→0 transition to be optically thin almost everywhere and derive a ^{13}C^{16}O/^{12}C^{18}O abundance ratio of $\sim$ 8.1. Comparison of ^{13}CO and CS column densities in the line cores indicates that the relative CS abundance may be enhanced by a factor of two to four over the typical abundance in quiescent clouds. However, comparison of the column densities derived from the outflowing gas in the line wings indicates the CS abundance may be enhanced by one or two orders of magnitude in these regions. The CS abundance is correlated with the mechanical luminosity of the outflows, suggesting a possible correlation of CS abundance with the strength of the shocks where the wind impacts the ambient cloud material. The CS abundance is about an order of magnitude higher in the redshifted outflowing gas than in the blueshifted outflowing gas. We speculate this may be due to the higher velocities observed in the redshifted gas associated with these outflows.

Ammonia and Formaldehyde Gas Temperatures and Kinematics in Protostellar Cores

Alwyn Wootten (NRAO), Jeffrey G. Mangum (SMT)

Protostellar cores can be distinguished by possession of accompanying dust concentrations equalling or exceeding in mass the stellar mass inferred

from the observed luminosity of the source. We have imaged a number of these cores to compare dust and gas distributions on scales of several thousand AU. Neither thermal nor kinematic properties of the near-protostellar region can be easily measured using dust emission measurements alone. We have employed radiation from symmetric (NH_3) or slightly asymmetric (H_2CO) top molecules to measure temperature variations on these scales and to explore core velocity structure. In more luminous sources, (e.g., DR21(OH) or S106FIR) there appears to be a close correlation between properties derived from all of these constituents of the core. In less luminous cores (e.g., L1448-IRS3 or IRAS16293), ammonia emission correlates poorly with properties deduced from dust or formaldehyde emission. In some regions (e.g., L1448-IRS3 or VLA1623), dust emission peaks at saddle points in the ammonia distribution, possibly indicating that ammonia is processed into other forms in regions of sufficiently high density and low temperatures. We suggest that gas temperatures measured from formaldehyde more securely probe the region near low luminosity protostars than either blackbody-derived dust temperatures or modeled ammonia temperatures.

Ammonia Observations for Dense Cores of High Velocity Molecular Outflow

Yuefang Wu (Geophysics Department, Peking University), M. Miller (I. Physikalisches Institut, Universität zu Köln), G. Winnewisser (I. Physikalisches Institut, Universität zu Köln)

Observations with the 100 m telescope at Effelsberg in the NH_3 (1,1) and (2,2) lines towards eight molecular outflows were reported. All sources were mapped with the two lines except L1582B in which only weak NH_3(1,1) emission was detected. The NH_3 cores detected are coincident with the corresponding flow center sources. In the previous known source IRAS 00338+6312, our data agree with the previous results. In L1535, L483, and possibly in B361, the condensations are elongated in the direction perpendicular to the outflow axis. In other sources, the cores are between the two lobes or overlapped with the lobes. In L1535, L483, and L1251A, there are velocity gradients along the major axis of the condensation, showing evidence that the outflow material may be accelerated and collimated by rotation of the disk. The NH_3(1,1) line widths in these cores are wider than those of the cores without outflows on the whole. Our analysis also shows that the gas in the cores with high luminosity sources has high kinetic temperature and vice versa. The line width and gas temperature comparisons suggest that the perturbation of the dense gas produced by moment coupling with strong winds may be more than by the radiation of the center source. Core masses were derived with different methods. The stability of the cores is analysed.

Observational Studies of Molecular Outflows in Star Forming Regions

Yuefang Wu (Geophysics Department, Peking University)

Molecular outflows were searched widely towards young stellar objects. With surveys which were in unbiased (e.g., Margulis and Lada 1986; Fukui 1989) or guided by IRAS data (e.g., Levreault 1985; Morgan and Bally 1991) or other star forming activities (e.g., Evans et al. 1994), many new outflows were found. According to Wu, Huang and He (1995), there were 252 outflows observed until May of 1995. Resulting from high sensitivity and spatial resolution measurements, weak outflows were detected and polar or more collimated flows increase compared with those in the early period of the outflow discoveries. The velocity range, emission size and mass of EHV gas were investigated. Physical parameter ranges are summarized: ΔV: 3–320 km s^{-1}; Size: $0.01 - 2$ pc; mass: $0.008 - 600$ M$_\odot$; energy: $10^{41} - 10^{47}$ erg; mass loss: $2 \times 10^{-9} - 10^{-5}$ M$_\odot$/yr; $L_{\rm mech}$: $0.0002 - 2600$ L$_\odot$; $\tau : 1 \times 10^3 - 4.6 \times 10^5$ yr; $L : 0.2 - 10^5$ L$_\odot$. The ranges tend to be wider than the earlier sources on the whole (Lada 1985). And some statistics based on the large number of samples may be meaningful. There were 80 molecular outflows associated with water masers and 59 flows associated with HH objects. The correlations between the outflows with these associated objects and the source bolometric luminosities were analysed. New observational advances in infall or inflow detection was presented. The flow region structures which show evidence for theoretical driving models are also discussed.

Water Vapor Masers in Envelopes of Late Type Stars

Yuefang Wu (United Radio Labs, Academic Sinica & Peking Univ.), Jing Lu (Purple Mountain Obs.), Huawei Zhang (Peking Univ.)

A survey was made of 98 sources to study the occurrence of water maser emission in the circumstellar shells of late-type stars. The sample was selected from the IRAS PSC with new colour criteria resulting from analyses of known water masers: [12]–[25]: –1.5 – 0.5, [25]–[60]: –2.3 – (–1.0); here

$[\lambda_1]$–$[\lambda_2]$= $2.5\times[\log(f_{\lambda 2}\ /f_{\lambda 1})]$. The survey was carried out with the 13.7m telescope at De Lin Ha, Qinghai province of China during August of 1993 to January of 1994. We detected weak water maser emission with S/N>4 or $\simeq$4 in 33 sources for the first time. The detection rate was 34%. Considering that a number of H_2O masers detected previously were excluded from the sample, one can see that the water maser occurrence rate is rather high in this two color region. Maser emission was also detected in IRAS LRS class 4n sources, which exhibit the 11μm SiC future. Combining the known water masers, the dependence of the detection rate on IRAS LRS class, variability and colour index is analysed. Results show that stellar H_2O masers occurrence most frequently in thick oxygen-rich envelopes or those with a variable star. However water masers were detected in IRAS LRS 1n and 4n objects. It may suggest that water masers can also occur in thin oxygen-rich envelopes which may be forming and diffusing. Since the S/N of our results is low, more sensitive observations are needed.

Water Maser Search in Candidate HII Regions

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Water maser emission has been searched for in 63 sources chosen from the IRAS PSC. The infrared index of the sample satisfies the criteria suggested by Wood and Churchwell (1989) for being associated with ultracompact HII regions. We used $f(60\mu\mathrm{m}) > 150$ Jy to limit number the number of objects observed and to choose objects with a high expected detection rate. We also limited the declination to $\geq -25°$ so the source elevation was high enough. The observations were made with the 13.7m telescope of the Purple Mountain Observatory at De Lin Ha in Qinghai Province from June to December of 1993. The pointing accuracy is 20″. The efficiency of the antenna is 47%. All the spectra were taken with a 1024 channel acousto-optical spectrometer. Its total bandwidth is 12.38 MHz. The system noise temperature was 320-350 K. For most of the observations, frequency switching was used. We observed 16 sources with signal-to-noise ratios ≥ 4, including IRAS 18110–1854, which was also detected by Brand et al. (1993). The primary result is a 25% detection rate. It may be not typical that some sources satisfying the WC criteria were found with water masers already (Palla et al. 1991). Combining known maser statistics shown in sources with high LRS and VAR index, masers may occur rather frequently but that is not the necessary condition. And water maser emission may be easily excited around strong infrared sources.

CO Observations for High Velocity Gas in Molecular Clouds

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Searches for high velocity gas were made in six molecular clouds with the CO J=2–1 transition line. One (S64) of the observed sources is in a high mass star formation region and five are low mass cores in nearby dark clouds. The core TMC2A is an IRAS source, but the others (L1512, L1523, L1582A, and L1681A) are without associated infrared sources (Beichman et al. (1986). The observations were carried out with the 3m KOSMA telescope of the Gornergrat Observatory of I. Physics Institute, Universität zu Köln, near Zermatt from February to September of 1992. Both blue and red wings were detected in L1582A and L1681A. The maps indicate the wings are probably bipolar outflows, showing star forming activity. There may be weak infrared sources in these clouds that need to be investigated further. There is also a bipolar outflow in the low mass source TMC2A. The $V_{\rm lsr}$ distribution in this core shows there is rotation with the axis along the northeast to southwest direction. Strong red wings were measured in S64. The observed area is $12' \times 12'$, which shows there is a red monopolar outflow in the cloud. It suggests the infrared source is located near the surface of the molecular region. The result confirms the layer structure consisting of an optical HII region, a CII radiation region, and a molecular region (Sharpless 1959; Vallee 1987; Zelik & Lada 1978). Since our maps are not complete, more observations are needed for further analysis.

The Giant Molecular Cloud Monoceros R2: A Large "Wok-Shaped" Shell Possibly Resulting from a Champagne Flow

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We present abundant data at millimeter wavelengths which show that the nearby Giant Molecular Cloud Monoceros R2 is largely a giant, massive expanding "wok" shell with its open side pointing away from us. This type of structure is expected in the "champagne flow" phenomenon when stars form on one side of a molecular cloud. Of particular interest is the large scale (over 30 pc) and the apparent longevity (over a few millions years) of this structure. Our observations show that the wok shell incorporated almost all the available molecular gas in this GMC ($\sim 40,000\,\mathrm{M}_\odot$). The age of the structure is consistent with the age of a cluster of main sequence stars in this GMC. The existence of numerous younger stellar objects with an age on the order of 10^5 years or younger on the shell strongly suggest the occurrence of triggered star formation. Overall, it seems that existing theories on the development of molecular shells and the subsequent triggered star formation contain essential physical elements to confront the wealth of molecular data on a large scale, but some discrepancies in details between theories and observations remain to be explained.

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Molecular Line Surveys of Dense Cores in Regions of High Mass Star Formation

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We analyze further the observational data for dense cores in regions of high mass star formation (HMSF) obtained recently with the SEST and Metsähovi radio telescopes. The statistical distributions of the core sizes, masses, mean densities, CS line widths and CO temperatures are constructed.

The galacto-centric dependence of these parameters in the range $R \approx 7 - 11$ kpc is investigated. There is a trend to a systematic decrease of the mean density of the cores with increasing galacto-centric distance.

We have attempted to investigate the radial dependence of some physical parameters in several cores which have a simple structure. The CS line areas drop rather quickly with r, corresponding to $r^{-1.5}$ to r^{-2}. The CS line widths decrease towards the core edges as well, sometimes below the $C^{34}S$ line width (measured at the CS peak position). The ratios of the CS and $C^{34}S$ line widths and intensities are described preferably by the models with density inhomogeneities in the cores.

We investigate the $L - \Delta V$ and $L - \bar{n}$ relationships for the CS cores. Although there is a trend for increasing line width with increasing size, the correlation is very weak. There is, in general, a higher velocity dispersion in HMSF cores than in CO clouds and dense cores in dark clouds.