

Abstract Book

Transformational Science with ALMA: The Birth and Feedback of Massive Stars, Within and Beyond the Galaxy

A science workshop sponsored by the
North American ALMA Science Center
of the
National Radio Astronomy Observatory
and the
University of Virginia
Department of Astronomy
in
Charlottesville, Virginia, USA
on
September 25-27, 2008

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Program

Wednesday, September 24:

7:30 - 9:00p - Set up posters and pick up workshop registration materials in Conference Room 225, Omni Hotel.

Thursday, September 25:

Session 1

8:00 - 9:00a - Continental breakfast; set up posters and pick up workshop registration materials.

9:00-9:15a “*Welcome and scientific overview*” - Fred Lo

9:15-9:45a “*The formation of molecular cores from turbulent flows*” - Paolo Padoan

9:45-10:15a “*Observed properties of massive molecular cores*” - Neal Evans

10:15-10:35a “*Properties of high-mass protostars and massive pre-stellar cores at the dawn of Herschel and ALMA*” - Frédérique Motte

10:35-11:05a - Coffee break

Session 2

11:05-11:35a “*The formation of high mass stars from cores*” - Jonathan Tan

11:35-12:05p “*Observational constraints on massive star formation*” - Crystal Brogan

12:05-12:25p “*Fragmentation in (pre)cluster forming regions*” - Qizhou Zhang

12:25-12:35p - Discussion

12:35-2:05p Lunch

Session 3

2:05-2:25p “*Probing the earliest stages of massive star formation in cluster-forming clumps*” - Philippe André

2:25-2:55p “*Scaling relations for star formation and feedback on galaxy scales*” - Daniela Calzetti

2:55-3:15p “*The star formation efficiency in nearby galaxies: results from THINGS++*” - Adam Leroy

3:15-3:45p - Coffee break

Session 4

3:45-4:05p “*Using cosmological simulations to connect star formation in molecular clouds with observations on galactic scales*” - Konstantinos Tassis

4:05-4:25p “*Constant SFR/M in high-mass star-forming clumps*” - Yancy Shirley

4:25-4:45p “*Molecular star formation rate indicators in galaxies*” - Desika Narayanan

4:45-5:05p “*Evidence that the top end of the IMF varies in nearby star-forming galaxies*” - Guinevere Kauffmann

5:05-5:15p - Discussion

6:00 - 8:00 - Director’s reception/tour of NRAO Technology Center.

Friday, September 26:

Session 5

8:00-9:00a - Continental breakfast

9:00-9:20a “*Chemical evolution of massive star-forming regions*” - Floris van der Tak

9:20-9:40a “*What are the best (molecular) tracers of physical conditions in regions of massive star formation?*” - Peter Schilke

9:40-10:00a “*Submillimeter Array observations of magnetic fields in massive star-forming regions*”
- Ramprasad Rao

10:00-10:20a “*Outflow feedback in cluster formation*”
- Zhi-Yun Li

10:20-11:00a Coffee break

Session 6

11:00-11:20a “*Submillimeter Array observations of molecular outflows in massive star forming regions*” - Keping Qiu

11:20-11:40a “*When and how does protostellar dynamical feedback matter?*” - Christopher Matzner

11:40a-12:00p “*The formation of massive star clusters by cooperative accretion*” - Eric Keto

12:00-12:20p “*What does it take to make a massive star?* ” - Mark Krumholz

12:20-12:30p Discussion

12:30-2:00p Lunch

Session 7

2:00-2:20p “*Feedback from massive stars*” - John Bally

2:20-2:40p “*Dusty, wind-blown bubbles: Not your classical HII region*” - Ed Churchwell

2:40-3:00p “*Star formation triggered by Galactic HII regions*” - Annie Zavagno

3:00-3:20p “*X-ray observations of massive star formation and feedback* ” - Leisa Townsley

3:20-4:00p Coffee break

Session 8

4:00-4:20p “*Spatially-resolved studies of super star cluster feedback in starburst galaxies*” - Mark Westmoquette

4:20-4:50p “*What drives galaxy-scale feedback?*” - Tim Heckman

4:50-5:10p “*Tracing nuclear star formation and feedback*” - Eva Schinnerer

5:10-5:30p “*Triggered star formation in M81 group dwarf galaxy IC2574* ” - Daniel Weisz

5:30-5:40p Discussion

5:40 PM - 7:00 PM - Poster viewing session with wine and cheese, Omni Hotel, Room 225.

7:00 PM - 9:00 PM - Conference dinner, sponsored by UVA Department of Astronomy, Omni Hotel Atrium.

Saturday, September 27:

Session 9

8:00-9:00a - Continental breakfast

9:00-9:20a “*Current status of ALMA*” - Alison Peck

9:20-9:40a “*Turbulence, feedback, and star formation in the G333 molecular cloud complex*” - Maria Cunningham

9:40-10:00a “*A potential bonanza for ALMA in the Carina Nebula*” - Nathan Smith

10:00-10:20a “*Star formation in the Galactic center region*” - Farhad Yusef-Zadeh

10:20-10:50a Coffee break

Session 10

10:50-11:10a “*What are the conditions for forming massive star clusters: lessons in the GC and the LMC*” - Yasuo Fukui

11:10-11:30a “*The properties of extragalactic GMCs*” - Alberto Bolatto

11:30-11:50a “*Massive star formation in extreme environments*” - Chris Wilson

11:50a-12:00p Discussion

12:00-1:30p Lunch

Session 11

1:30-2:00p “*The future evolution of ALMA*” - Adrian Russell

2:00-3:30p Discussion (thematic groups on development science drivers)

3:30-4:30p Discussion (all)

Talks

Fred Lo (NRAO)

Welcome and scientific overview

Paolo Padoan (UCSD)

The formation of molecular cores from turbulent flows

Supersonic turbulence is ubiquitous in star-forming regions, causing their fragmentation into complex structures with density ranging over many orders of magnitude. Being the dominant fragmentation mechanism, supersonic turbulence must play a fundamental role in the process of star formation. In this presentation, I will discuss recent results from numerical simulations of turbulent flows related to the formation and dynamical state of molecular cores. I will start with a brief introduction of the numerical methods and of the statistical comparison of the simulations with the observations. I will then review some results on the formation and dynamical state of molecular cores, focusing on their kinematics, lifetime, magnetic field, and thermal balance. I will discuss recent results suggesting that turbulence may be a dominant heating source in massive star-forming cores, an idea that could be tested with ALMA.

Neal Evans (University of Texas)

Observed properties of massive molecular cores

This talk will center on massive molecular cores, but will draw in recent results on low mass star formation and connect to issues of extragalactic star formation. The basic theoretical scenarios for massive star formation will be contrasted. The properties of a set of well-studied massive molecular cores will be reviewed and compared to initial results from the Bolocam Galactic Plane Survey (BGPS). The BGPS, a survey of the Galactic Plane in the continuum at 1.1 mm, is finding thousands of cores. Follow-up studies with ammonia and CS are underway, and the goals of the program will be discussed. The talk will conclude with discussion of the role that ALMA will play in elucidating the formation process of massive stars.

Frédérique Motte (AIM/SAP, CEA Saclay, France)

S. Bontemps (OASU/LAB, Observatoire de Bordeaux, France)

N. Schneider (AIM/SAP, CEA Saclay, France)

P. Schilke (Max-Planck-Institut für Radioastronomie, Germany)

J. Hora (Harvard Smithsonian Center for Astrophysics, USA)

et al.

Properties of high-mass protostars and massive pre-stellar cores at the dawn of Herschel and ALMA

We have started searching, in an unbiased way and in the 6 closest (< 3 kpc) high-mass star-forming complexes, for the high-mass analogs of low-mass pre-stellar cores and class 0 protostars. We will here present the extensive millimeter continuum mappings of the Cygnus X and NGC 6334-6357 complexes that have already revealed 40 new, cold (or IR-quiet) dense cores that should correspond to the earliest phases of high-mass star formation: *FWHM* size ~ 0.1 pc, gas mass $\sim 100 M_{\odot}$, volume averaged density $\sim 2 \times 10^5 \text{ cm}^{-3}$, mass averaged temperature ~ 20 K, undetected by *MSX*. We will also show that the *Herschel* imaging planned for the closest high-mass star-forming complexes (Key Program HOBYS by Motte, Zavagno, Bontemps et al., see <http://starformation-herschel.iap.fr/hobys/>) and the forthcoming ALMA studies of further-away regions will undoubtedly find many more of these massive and extremely dense, cold dense cores.

Furthermore, thanks to several complementary surveys done by us in Cygnus X, we have started to statistically characterize high-mass protostars and massive pre-stellar cores. We will detail our first fundamental result, which is, that the statistical lifetimes of high-mass protostars and pre-stellar cores could be one and two order(s) of magnitude smaller, respectively, than what is found in nearby, low-mass star-forming regions (see Motte, Bontemps, Schilke et al. 2007, *A&A*, 476, 1243).

We will also present the recent *Spitzer*/MIPS imagings (at 24 and 70 μm , from the *Spitzer* Legacy program by Hora, Bontemps, Megeath, et al.) and CSO/SHARC II maps (at 350 μm , project Motte, Bontemps, Lis et al.) that nicely complement the IRAM 30m/MAMBO-2 mosaicking of Motte et al. (2007). We will derive the first luminosity estimates of the cold (or IR-quiet) dense cores that are the precursors of high-mass stars in Cygnus X, estimates which are expected to be refined by future *Herschel* far-infrared to submillimeter (75 – 500 μm) flux measurements.

We will also give some evidence that high-mass stars may form in free-falling clumps where highly turbulent processes dominate: their short lifetimes and some global infall traced on parsec scales by HCO^+ or CS imagings (cf. Csengeri et al.). Finally, we will assess the effect of subfragmentation on the above results, using the very recent interferometric survey of 12 Cygnus X dense cores at the IRAM Plateau de Bure (Bontemps et al.).

Jonathan Tan (University of Florida)

The formation of massive stars from cores

I review the evidence for whether or not massive stars form from massive cores and whether this process can be described by a scaled-up version of our standard theories of low-mass star formation. As part of this discussion we need to introduce precise definitions of the star-forming core and also the tolerance we allow for fragmentation of the core. I describe the abilities of ALMA to help resolve these questions.

Crystal Brogan (NRAO)

Todd Hunter (NRAO)

Observational constraints on massive star formation

Many of the fundamental questions regarding how massive stars form are poorly understood, even in our own Galaxy. Among these are: where, how, and under what conditions do high mass stars form? Fortunately, we are entering a new era in the exploration of massive star formation using new mm/submillimeter arrays like the SMA and CARMA, as well as new high resolution and sensitivity mid-IR data from *Spitzer*. In this talk, I will present results from recent high resolution mid-IR to centimeter wavelength studies of massive star forming regions and their precursors: infrared dark clouds (IRDCs). I will concentrate in particular on which molecular tracers have proven to provide the best diagnostics in these regions (at high angular resolution). I will also discuss how the tremendous advances offered by ALMA at mm/submm wavelengths and the EVLA at cm wavelengths at the beginning of the next decade will allow us to probe the secrets of massive star birth with unprecedented frequency coverage, sensitivity, and resolution.

Qizhou Zhang (Harvard-Smithsonian Center for Astrophysics)

Fragmentation in (pre)cluster forming regions

Recent studies of massive (pre)cluster forming clouds begin to provide the first glimpses of conditions in these regions. Spectral line and dust continuum images with spatial resolutions better than the Jeans length reveal hierarchical fragmentation and heavy chemical depletion. Comparison with Jeans fragmentation indicates the importance of turbulence in structure formation. ALMA, which represents a significant leap in both imaging speed and sensitivity over the current (sub)mm interferometers, will bring major advances in this area.

Philippe André (CEA/SAP Saclay)

Nicolas Peretto (University of Manchester)

Patrick Hennebelle (ENS Paris)

Anaëlle Maury (CEA/SAP Saclay)

Probing the earliest stages of massive star formation in cluster-forming clumps

Since massive stars may be able to form only in closely-packed protoclusters, detailed millimeter studies of massive cluster-forming clumps are of great interest to gain insight into the initial conditions and earliest phases of the high-mass star formation process. We will present recent results obtained with the IRAM 30m telescope and Plateau de Bure interferometer toward nearby cluster-forming clumps such as NGC2264-C (cf. Peretto et al. 2006, 2007) and Aquila Rift/Serpens South. Comparison of these observational results with numerical simulations suggests that large-scale collapse is a key feature of the initial phases of protocluster evolution and points to a picture of intermediate- to high-mass star formation which is halfway between the massive turbulent core model of McKee & Tan and the competitive accretion scenario of Bonnell & Bate. In our picture, the large-scale, dynamical collapse of a massive unstable clump leads to the formation of a turbulent, ultra-dense core with properties reminiscent of the McKee & Tan model, through the gravitational merger of two or more intermediate-mass Class 0 protostellar cores in the central part of the clump. Although this picture is highly dynamic like the Bonnell & Bate scenario, competitive accretion does not play a major role (cf. André et al. 2007). While our results are presently limited to relatively nearby, intermediate-mass protoclusters, ALMA will make it possible to carry out similar studies in more extreme cluster-forming clumps at larger distances. I will also present preliminary results obtained with a prototype of the ArTéMiS bolometer array on APEX which illustrate how wide-field submm continuum imaging can be used to select potential protocluster targets for future detailed ALMA studies.

Daniela Calzetti (University of Massachusetts)

Scaling relations for star formation and feedback on galaxy scales

I review recent results on SFR measurements, and their impact on our understanding of the star formation in nearby galaxies. For the purpose of accurately determining the scaling laws of star formation in a range of environments and the underlying physics, we need to achieve more accurate measurements of the gas distribution in galaxies, a task that will be superbly accomplished by ALMA and other upcoming millimeter facilities. I discuss a few examples of such applications, highlighting, in the process, the limitations of current data.

Adam Leroy (MPIA)

Fabian Walter (MPIA)

Elias Brinks (University of Hertfordshire)

W.J.G. de Blok (University of Cape Town)

Michele Thornley (Bucknell University)

The star formation efficiency in nearby galaxies: results from THINGS++

I will present results relating massive star formation to the atomic and molecular ISM on Galactic scales. From the combination of THINGS (The HI Nearby Galaxy Survey), our new CO survey with the IRAM 30m, SINGS, and the GALEX Atlas of Nearby Galaxies, we have estimated the atomic and molecular gas content, kinematics, stellar surface density, and star formation surface density (both embedded and unobscured) across the disks of 24 nearby galaxies — 13 spirals and 11 dwarf galaxies. Using this database, we study what sets the star formation efficiency — the star formation rate per unit gas — in these galaxies. Our basic observational results are that the star formation per unit molecular gas is strikingly constant across the disks of spiral galaxies, even when considered as a function of changing orbital timescales, shear, pressure, and gas or stellar surface density. On the other hand, the ratio of atomic to molecular gas is a strong function of many of these quantities. This leads the star formation efficiency to decline steadily with increasing radius where HI dominates the ISM and suggests that giant molecular cloud (GMC) formation depends sensitively on environment. We combine environment-dependent timescales for GMC formation with thresholds that predict where GMCs can form and find that several such recipes are able to reproduce the observed star formation efficiency with factor of 2 accuracy. The common element in successful recipes is that they incorporate the influence of the stellar potential, which brings gas to higher densities, thus increasing pressure, decreasing the free fall time in the disk, inducing instability to large-scale collapse, and aiding the formation of a cold phase in the ISM.

Konstantinos Tassis (KICP)

Using cosmological simulations to connect star formation in molecular clouds with observations on galactic scales

We investigate, using cosmological simulations of galaxy formation, the physics behind established scalings between galactic-scale observables (such as the star formation rate, gas density, and metallicity) in star-forming galaxies. To this effect, we follow the formation of molecular hydrogen in the ISM in a self-consistent way, including the effects of nonequilibrium chemistry and cooling, as well as radiative transfer. We develop subgrid starformation models tied to molecular hydrogen. We find that, under such implementations of star formation, the observed scalings of the star formation rate with molecular and atomic hydrogen in galactic scales arise naturally.

Yancy Shirley (The University of Arizona)

Constant SFR/M in high-mass star-forming clumps

I shall review the evidence for a constant star formation rate per unit mass in dense molecular gas within in the Milky Way. Single-dish observations of molecular gas tracers with critical densities above 10^4 cm^{-3} , such as HCN, HCO^+ , and CS, toward high-mass star-forming clumps have revealed that SFR (determined from bolometric luminosity and the assumption of a universal IMF) per unit mass traced by dense, molecular gas is constant over two orders of magnitude in mass. I shall critically analyze the assumptions that are used to derive this result.

Desika Narayanan (Harvard-Smithsonian Center for Astrophysics)

Thomas J. Cox (Harvard-Smithsonian Center for Astrophysics)

Yancy Shirley (University of Arizona)

Romeel Dave (University of Arizona)

Lars Hernquist (Harvard-Smithsonian Center for Astrophysics)

Christopher K. Walker (University of Arizona)

Molecular star formation rate indicators in galaxies

Observed correlations between the infrared luminosity (L_{IR}) and molecular line luminosity in the Galaxy and galaxies from $z = 0 - 6$ have suggested a more "fundamental" SFR "law" than the canonical Kennicutt-Schmidt relations such that the SFR is linearly related to the dense molecular gas mass. Utilizing a series of both hydrodynamic and radiative transfer simulations as well as submillimeter-wave observations, I investigate the relationship between the physics controlling star formation rates on molecular cloud scales and the observed properties of SFR relations in galaxies. Using this physical model, I provide direct observational tests for ALMA for directly observing the Schmidt law both in star forming regions in local galaxies and at high redshift ($z > 2$).

Guinevere Kauffmann (Max Planck Institute for Astrophysics)

Timothy Heckman (Johns Hopkins University)

Evidence that the top end of the IMF varies in nearby star-forming galaxies

We present evidence that the relative number of massive stars that are formed from a given amount of gas depends systematically on local conditions within a galaxy. By analyzing samples of tens of thousands of galaxies from the SDSS, we quantify these dependences and place constraints on the allowed changes in the IMF. We discuss the implications of our findings for star formation at high redshift.

Floris van der Tak (SRON)

Chemical evolution of massive star-forming regions

This talk gives an outline on how the chemical composition of massive star-forming regions may be used to infer parameters that are otherwise hard to constrain. Examples are their ages, ionization rates, and the strength of energetic radiation fields (e.g., X-rays). Observed variations in composition between regions will be discussed as well as within regions (e.g., disk vs envelope). Which molecules should we use to search for massive circumstellar disks? Special emphasis will be given to differences between massive and low-mass star-forming regions. The talk concludes with a comparison to extragalactic starburst systems, where conditions are even more extreme.

Peter Schilke (MPIfR)

What are the best (molecular) tracers of physical conditions in regions of massive star formation?

Instruments like ALMA, with their high sensitivity, large frequency range and large instantaneous bandwidths, will make almost any observation an involuntary line survey. This is true almost everywhere, but particularly in regions of massive star formation. This offers great possibilities in selecting exactly the right combination of tracers to determine the physical, dynamical or chemical state of the region in question, if the observations are planned, executed and analyzed in the right manner. If not, we will end up with archives full of uninterpretable data. In this talk, I'll review some of the current knowledge on specific tracers, and discuss strategies for efficient planning and analysis.

Ramprasad Rao (Submillimeter Array/ASIAA)

Submillimeter Array observations of magnetic fields in massive star-forming regions

Magnetic fields are believed to play an important role in the formation of stars. Submillimeter Array (SMA) observations of polarized dust continuum at 345 GHz are able to detect magnetic field structures consistent with theoretical predictions especially for regions of low mass star formation. However, massive star forming regions are significantly more complicated and it is not always possible to disentangle the field structure. The nearest region of massive star formation is in Orion, particularly the OMC1 core. Recent SMA observations of this region significantly improve on both the resolution and sensitivity. These observations show ordered magnetic fields and that their effects must be considered to be important in the star formation process especially in this region. In addition, observations of a sample of selected sources by the SMA show different structures which may be related to the evolutionary state of these objects.

Zhi-Yun Li (UVa)

Fumitaka Nakamura (Niigata University, Japan)

Outflow feedback in cluster formation

Protostellar outflows are ubiquitously observed around forming stars. They are expected to be particularly important in regions of cluster formation (such as NGC 1333), where the efficiency of star formation is relatively high and the outflows are crowded into a relatively small volume of space. There is enough outflow energy and momentum to unbind the cluster forming clump if the stars form in a single burst. If stars form over several generations (as indicated by the co-existence of prestellar cores and Class 0-III objects in embedded clusters), their outflows can in principle replenish the turbulence dissipated in the clump, and keep the star formation at a low rate for more than one dynamical time. I will present numerical simulations to illustrate the main features of the outflow-driven protostellar turbulence in regions of active cluster formation, and speculate on possible implications for massive star formation.

Keping Qiu (Harvard-Smithsonian Center for Astrophysics)

Qizhou Zhang (Harvard-Smithsonian Center for Astrophysics)

Submillimeter Array observations of molecular outflows in massive star forming regions

Molecular outflows are known to ubiquitously exist in massive star forming regions. Given the intrinsic coupling of jet-like outflows and accretion disks in low-mass star formation, the growing number of well-collimated outflows in $< 10^4 L_{\odot}$ star forming regions provide strong arguments that stars up to early B types could form via disk-mediated accretion. However, high-angular-resolution observations of outflows in more luminous objects ($> 10^5 L_{\odot}$) are still rare. Are molecular outflows in most massive O stars collimated? How are their kinematics and energetics different from those in low-mass to moderate massive stars? Answering these questions is an essential step toward understanding the formation mechanisms of the most massive O stars. We are undertaking a survey of $^{12}\text{CO}/^{13}\text{CO}$ outflows in a small sample of deeply embedded O stars with the Submillimeter Array, and simultaneously obtaining complementary short spacings with single-dish observations. Here we present the most recent results from the survey, with an emphasis on the comparison with low-mass outflows and potential implications on massive star formation.

Christopher Matzner (University of Toronto)

When and how does protostellar dynamical feedback matter?

Protostars alter their own birth environment through radiative and dynamical effects. Dynamical feedback is potentially important for regenerating turbulence and regulating the star formation efficiency as gas is consumed – hence, for the duration, appearance, and result of star cluster formation. I will discuss two physical criteria for feedback to be important, and use these to evaluate the feedback from protostellar outflows. I will also consider the observational properties of outflow-driven turbulence, and the differences between low-mass and massive-star feedback. Time permitting, I will address GMC-scale feedback from multiple star clusters as well.

Eric Keto (Harvard-Smithsonian Center for Astrophysics)

The formation of massive star clusters by cooperative accretion

Infrared observations of ultracompact H II regions often indicate the presence of several massive stars within the same H II region. How do these clusters of massive stars embedded in ionized gas form? VLA and SMA observations show that these H II regions are surrounded by cluster-scale molecular accretion flows that continue into the common H II region as ionized accretion flows. The spatial scales are large enough that the combined mass of the stars in the cluster is required to pull the large-scale accretion flow through the thermal and radiative pressure within the H II region toward the stars in a phenomenon of cooperative accretion. Why do these massive accretion flows not form a single massive star? What sets the mass scale of the stars and the cluster itself? Calculations suggest that radiation pressure limits the growth of the most massive stars to their Eddington luminosity. This encourages the formation of several rather than a single massive star. The cluster-scale accretion flow itself is ultimately reversed by the thermal pressure of ionized gas beyond the sonic-gravitational radius. Because the location of this radius is also a function of radiation pressure, the radiation of the massive stars emerges as the limiting factor for the size of the cluster as well. Extragalactic super-star clusters may be scaled up versions of the smaller Galactic clusters that we currently observe with the VLA and SMA. These observations suggest that ALMA will provide fascinating observations of Galactic and extragalactic cluster-scale accretion flows in the near future.

Mark Krumholz (UC Santa Cruz)

What does it take to make a massive star?

Massive stars are extremely rare, which suggests that only rare and unusual protostellar clouds are capable of forming them. In this talk I examine two significant barriers to massive star formation: fragmentation, which tends to break clouds up into clusters of low mass stars rather than single massive ones, and feedback, which inhibits accretion of mass onto stars larger than $\sim 20 M_{\odot}$. I discuss the physical mechanisms by which these barriers can be overcome, and sketch a theoretical model for what conditions must be present in a prestellar core for these mechanisms to operate and allow the formation of a massive star.

John Bally (University of Colorado, Boulder)

Feedback from massive stars

Massive stars dominate feedback in star formation. Their UV radiation forms expanding H II regions, stellar wind bubbles, and supernova explosions drive the ecology of the interstellar medium (ISM). Massive stars can disrupt clouds, or trigger their collapse to initiate a wave of propagating star formation that can lead to the birth of a sequence of clusters and associations. While super-bubbles tend to blow-out orthogonal to the Galactic plane to drive the Galactic fountain, in the plane they can sweep-up millions of solar masses into dense shells that can eventually fragment into new generations of molecular clouds. I will compare observations of three complexes; Orion, Carina, and the W3/4/5 complex.

Orion contains the closest active sites of star formation, and a spatially segregated sequence of OB association sub-groups. Orion and its super-bubble, created by the explosion of at least a dozen massive stars, provide the closest environment where the impacts of massive stars on the ISM can be evaluated in detail. The Carina Nebula contains several massive star clusters, and nearly half of known Galactic O2 and O3 stars. W3/4/5 is a northern analog to the Carina Nebula. Located at about 2 kpc, both regions have similar distances, comparable number of OB stars (around 80), and similar sized H II region complexes. While Carina contains the unusual massive LBV Car, W4 contains at least one exotic compact object, LSI +61-303 a TeV gamma ray source thought to originate from the central cluster in W4. Multiple supernovae in W4 portion have powered a kpc-scale chimney that is blowing out of the Galactic plane. The superbubble may have triggered the birth massive stars and star cluster in the younger W3 region, and possibly in portions of W5. There is evidence that the famous double cluster in Perseus may represent an earlier generation of stars that predates the W3/4/5 complex and may have triggered the formation of the W4 complex.

In the Carina region, we are looking partially along a spiral arm (the Carina arm). As a result, several complexes are superimposed along the line of sight. It is clear from our studies that the Tr 14 cluster is considerably behind Tr 15 that hosts Car itself. Thus line-of-sight confusion abounds in Carina. In contrast, the W3/4/5 complex is stretched orthogonal to our line of sight in the Perseus arm. The youngest stars are located along the projected periphery of the H II regions while the older clusters are centered in the various bubbles. Thus, the W3/4/5 complex is an ideal laboratory for the study of massive star formation feedback and propagating star formation.

Ed Churchwell (University of Wisconsin-Madison)

John Everett (University of Wisconsin-Madison)

Dusty, wind-blown bubbles: Not your classical H II region

Massive stars play a major role in determining the ionization, density, temperature, and velocity structure of the ambient interstellar medium in their neighborhoods. Recent results from radio, submm, and IR are showing that the classical picture of H II regions associated with O and early B stars must be modified. Evidence for triggered star formation is often evident, especially at MIR wavelengths around the periphery of H II bubbles. We will review the new results that are forcing reconsideration of the environs of massive young stars and the importance of triggered star formation. In particular, we will examine the structure of a wind-blown IR bubble to illustrate some of the new ideas and puzzles raised by current observations and speculate on how ALMA may be able to address some of the puzzles.

Annie Zavagno (LAM, Marseille, FRANCE)

Deharveng (LAM)

Pomares (LAM)

Star formation triggered by Galactic H II regions

Massive stars have a profound impact on their environment, impact that can be either destructive or constructive. In the constructive case, we have shown (Deharveng et al. 2004, 2005, 2008; Zavagno et al. 2006, 2007) that the expansion of Galactic H II regions trigger the formation of young stars, of all masses, observed on the borders of these regions. I will present examples showing the various "faces" of triggering associated with expanding H II regions. I will show how new (and forthcoming) mid-IR and submillimeter surveys of the Galaxy can help us to understand and quantify the impact of massive stars on their surroundings. I will also show examples on how small-scale, high-resolution studies are so usefully complementary to the above-described global approach. I will end my presentation by suggesting how ALMA can be used to make further progress in this field.

Leisa Townsley (Penn State University)

X-ray observations of massive star formation and feedback

The *Chandra X-ray Observatory*, with its sub-arcsecond spatial resolution and hard X-ray response, is an excellent probe of massive star formation and feedback and will remain the only sub-arcsecond X-ray telescope available when ALMA and *JWST* come on-line. *Chandra* is revealing that very young massive stars are often hard X-ray emitters, in addition to standard expectations of soft X-rays due to microshocks in their fast winds. These unexpected hard X-rays may come from magnetically-channeled wind shocks around magnetic O stars, but in some cases there is compelling evidence that colliding winds from binary O stars are the cause. To add to the mystery, *Chandra* shows that these hard X-rays are not present in cluster O stars aged more than about 2 million years – do fossil B fields die away, or are massive binary systems somehow disrupted early on? Whatever the cause, these hard X-rays reveal early stages of massive star formation behind 150 magnitudes of visual extinction and from half-way across the Galaxy.

Because *Chandra* can separate stellar X-ray emission from hot plasma emission generated by O-star winds, we can finally detect the 1–10 million degree plasma that fills some H II regions and distinguish it from harder X-ray emission due to cavity supernovae that have exploded inside the bubbles blown by these young massive stellar clusters. These observations clearly illustrate massive star feedback and show how massive clusters push material around, triggering further star formation in their natal clouds.

Mark Westmoquette (University College London)

Linda Smith (STScI/UCL)

Jay Gallagher (University of Wisconsin-Madison)

Spatially-resolved studies of super star cluster feedback in starburst galaxies

I will focus on the programme we are undertaking to investigate the state of the ionized gas surrounding super star clusters (SSCs) in starburst environments. Our ultimate aims are to better understand the mechanisms of how SSCs drive gas outflows and superwinds, and how they affect the continuing evolution of the starburst. I will discuss recent results from a number of high spatial and spectral resolution integral field spectroscopic studies of local-group starbursts (NGC 1569, M82, NGC 5253). Through these we have been able to identify multiple components in the optical emission lines and map out their properties (dynamics, excitations, densities, etc). Ubiquitous in our sample (and seen in many other intense star-formation sites) is a broad (200–300 km/s) component underlying the main narrow, bright emission line. We conclude that this broad component represents turbulent gas created by the interaction between the winds and ionizing photons from nearby star clusters and individual ISM clumps, and therefore embodies clear observational evidence of small-scale massive star-driven feedback. Furthermore, since these effects become compounded on larger scales, I will show how we have used the broad component to trace the dynamics of galaxy-wide feedback mechanisms such as superwinds.

Timothy Heckman (Johns Hopkins University)

What drives galaxy-scale feedback?

The mass spectrum for dark matter halos is a scale-free power-law, but the galaxy stellar mass function has a strongly preferred mass scale of around 10^{12} solar masses. Current models explain this by invoking strong feedback to suppress the cooling of baryons and their subsequent conversion into stars in a mass-dependent way. For very low halo masses photoelectric heating by the metagalactic ionizing background can keep gas above the virial temperature. For moderately low halo masses heating by mechanical energy from supernovae and stellar winds can drive galaxy-scale winds. For high halo masses heating due to supermassive black holes (radio sources and/or thermally-driven winds) are thought to be important. I will review the observational evidence as to whether these various feedback processes are both wide-spread and powerful enough to have had the required effects, and will discuss how ALMA and other future facilities will clarify the picture.

Eva Schinnerer (MPIA)

Tracing nuclear star formation and feedback

Using the PdBI we have observed the central massively star forming regions (inner 300 pc) of the two nearby late-type spiral galaxies IC 342 and NGC 6946 in multiple molecular lines and transitions. These unique data sets are used together with dynamical models for the gas flow to locate the regions where stars will, are and have been forming. Adding chemical tracers at ≤ 50 pc resolution allows us to distinguish between kinematic shocks, photon-dominated regions and embedded star formation. Combination with high angular resolution images from *HST* suggests feedback of the star formation onto the molecular gas providing evidence that the gas flow to the very nucleus might be self-regulating.

Daniel Weisz (University of Minnesota)

Evan Skillman (University of Minnesota)

John Cannon (Macalester College)

Fabian Walter (MPIA)

Triggered star formation in M81 group dwarf galaxy IC 2574

Using a combination of *HST*/ACS and THINGS HI observations, we present a movie of triggered star formation (SF) and the creation of an HI super giant shell (SGS) in interstellar medium (ISM) of the M81 Group dwarf irregular galaxy IC 2574. From the HI observation, we find an elliptically shaped SGS with a diameter of ~ 1 kpc. Optical *HST*/ACS observations of the same region allow us to measure the SFH using a color-magnitude diagram fitting technique and create a movie using the spatial component of blue helium burning stars. The central SF event of the SGS occurred ~ 30 Myr ago and induces SF on the rim within the last 10 Myr, in excellent agreement with H α observations and the dynamical age of ~ 15 Myr from HI kinematics. Additionally, we compute the energetics necessary to create such a large disturbance in the ISM.

Alison Peck (ALMA)

Richard Hills (ALMA)

Rick Murowinski (ALMA)

Tony Beasley (ALMA)

Thijs de Graauw (ALMA)

Current status of ALMA

The Atacama Large Millimeter/submillimeter Array (ALMA) is an international radio telescope under construction in the Atacama Desert of northern Chile by North America, Europe, Japan, Chile and associated partners. ALMA will be situated on the high altitude Chajnantor plateau, which provides excellent atmospheric transmission over the instrument wavelength range of 0.3 to 3 mm. ALMA will be comprised of an array of 12-m diameter antennas arranged in multiple configurations ranging in size from 0.15 to ~ 14 km, plus a closely-packed array of 7-m diameter antennas known as the Atacama Compact Array. This combination will provide sensitive interferometric and total-power astronomical information over a broad range of angular scales. Array control and support will primarily be carried out at the Operations Support Facility at 3000 m, and ALMA Regional Centers in the US, Europe and Japan will provide the scientific portals for the use of the instrument.

In this talk we will review the current construction schedule of ALMA facilities at the site and elsewhere, describe the status of antenna and equipment integration and outline upcoming major events in 2008/2009.

Maria Cunningham (University of New South Wales, Australia)

Turbulence, feedback, and star formation in the G333 molecular cloud complex

The Mopra telescope (Australia) has been used to map a 1.2×0.6 degree region of the southern Galactic plane (the G333 molecular cloud complex) in rotational transitions of 20 different molecules with a velocity resolution of 0.2 km/s. The survey, made possible by the new 8-GHz bandwidth, 64,000 channel MMIC receiver/ UNSW MOPS backend combination, has produced a unique dataset that is being used to answer observationally some of the key questions about the dynamical processes surrounding massive star formation (e.g., massive stellar winds and large-scale galactic flows) and their relative importance in regulating the star formation process. These dynamical processes drive the turbulent motions which are ubiquitous in giant molecular clouds (GMCs). The multi-molecular line nature of this survey is what distinguishes it from similar surveys, and is crucial for gaining a clear picture of the energetics and dynamics of the gas. Different molecular transitions trace different regions of gas in terms of density and excitation, and so can be used to follow energy transfer through the molecular cloud complex.

Our initial investigation of the spatial power spectrum, using a number of molecules that trace different critical densities, shows a picture where turbulence is injected at large scales (hundreds of parsecs), and passes through to smaller parsec scales without significant dissipation. This scenario is supported by other analyses which suggest that the initial wave of star formation in the complex may have been triggered by a merger between two large scale Galactic flows, but that the majority of current star formation has clearly been triggered by relatively nearby dynamic events associated with massive star formation, such as expanding shells.

Nathan Smith (UC Berkeley)

A potential bonanza for ALMA in the Carina Nebula

As the nearest and visually brightest giant HII region in the southern sky, the Carina Nebula offers a phenomenal – but largely untapped – reservoir of information about the birth and feedback of massive stars that ALMA can exploit. Carina contains over 65 O-type stars, including some of the most massive stars known. Feedback from these stars has sculpted the surrounding fledgling superbubble, and has triggered a second generation of stars. In fact, Carina is arguably our best nearby laboratory for studying triggered and self-propagating star formation in detail. In addition to its proximity (only 2.3 kpc), one of the great advantages of Carina, as compared to other regions where extremely massive stars have recently formed, is that it is unobscured at visual wavelengths, so a great deal is already known about the stellar content and nebulosity. The main missing component in our observational census of Carina is at long wavelengths. I will summarize the global picture of the Carina nebula and its stellar content gleaned from work over the past few decades (including limited radio surveys), as well as recent work with *Spitzer*, *HST*, *Chandra*, and large ground-based telescopes, and I will point to some regions of particular interest where ALMA can make valuable contributions. Finally, I will present some ideas about how Carina came to be in its present state, its future evolution, and its larger relevance as a prototype for triggered star-forming regions.

Farhad Yusef-Zadeh (Northwestern University)

Star formation in the Galactic center region

I will first discuss the origin of one or two discs of massive stars found within 0.5 pc of Sgr A*. The disk formation can be interpreted in terms of the partial accretion of extended Galactic center clouds that temporarily pass through the central region. I will then discuss on-going star formation in the circumnuclear molecular ring which extends from 2 to 7 pc from Sgr A*. Star formation in the ring itself has been thought to be inhibited by the strong tidal force in the gravitational potential of the black hole and nearby stars; this force can only be overcome by self-gravity for densities in excess of $\sim 10^7 \text{ cm}^{-3}$. We report the detection of several narrow and broad methanol and water lines observed with GBT. The presence of methanol emission suggests that massive star formation in the molecular ring is in its infancy. On a larger scale, I will then turn to recent *Spitzer* measurements indicating the presence of a large number of YSO candidates in the inner 200 pcs of the Galactic center.

Yasuo Fukui (Nagoya University)

What are the conditions for forming massive star clusters: lessons in the GC and the LMC

Massive stellar clusters are still being formed in the Local Group galaxies. There are two regions of particular interest, i.e., the Galactic center and the LMC, where young super clusters are observed. I present the molecular properties of the two regions and discuss the common properties and differences which may affect the cluster mass. I discuss that the key factor is the accumulation of massive dense gas into a small volume, a necessary condition to form super clusters and present how the accumulation is realized in the two regions.

Alberto Bolatto (University of Maryland)

Adam Leroy (MPIA)

Fabian Walter (MPIA)

Erik Rosolowsky (UBC)

Leo Blitz (UCB)

Karl Gordon (STScI)

The properties of extragalactic GMCs

Giant molecular clouds (GMCs) are the major reservoirs of molecular gas in galaxies, and the starting point for star formation. As such, their properties play a key role in setting the initial conditions for the formation of stars. I will discuss the results from a comprehensive combined far-infrared and interferometric/single-dish study of the resolved GMC properties in a number of extragalactic systems, including both normal and dwarf galaxies. We find that the extragalactic GMC properties measured across a wide range of environments, characterized by the Larson relations, are to first order remarkably compatible with those in the Milky Way. We use these data to investigate trends due to galaxy metallicity. I will discuss: 1) how these measurements compare with simple expectations from photoionization-regulated star formation theory, 2) metallicity trends in the virial CO-to-H₂ conversion factor on the spatial scales studied, and 3) measurable departures from the Galactic Larson relations. The Small Magellanic Cloud — the object with the lowest metallicity in the sample — appears to host GMCs with velocity dispersions that are too small for their sizes. I will discuss the stability of these clouds, and I will contrast the results of the virial and high-resolution far-infrared studies on the issue of the CO-to-H₂ conversion factor and what they tell us about the structure of molecular clouds in primitive galaxies.

Chris Wilson (McMaster University)

Daisuke Iono (NAOJ)

Andrew Baker (Rutgers)

Glen Petitpas (CfA)

Alison Peck (ALMA)

Massive star formation in extreme environments

Luminous and ultraluminous infrared galaxies represent the most extreme star formation environments that can be studied in the local universe. Understanding the physical and environmental conditions which enable these intense bursts of star formation provide strong tests of theoretical models of star formation. Probing the molecular gas which is the fuel for star formation is an important focus.

In my talk, I will review recent, high resolution observations for a sample of 14 nearby luminous and ultraluminous infrared galaxies observed with the Submillimeter Array. I will focus on how the observed star formation rates may be understood in the context of the physical properties of the molecular gas on roughly kiloparsec scales. I will also put these galaxies into the broader context of global star formation properties ranging from normal galaxies in the local universe to quasars and submillimeter galaxies at high redshift.

Adrian Russell (NRAO)

The future evolution of ALMA

Posters

P1. Intermediate-mass star formation regions in the field of W51

Michael Alexander (University of Wyoming)

Henry A. Kobulnicky (University of Wyoming), Charles Kerton (Iowa State University), Kim Arvidsson (Iowa State University)

We present a multi-wavelength study of two star forming regions on the periphery of the W51 complex near $l = 49.5$, $b = 0$. *Spitzer Space Telescope* infrared photometry from the GLIMPSE and MIPS GAL surveys reveals two regions of active intermediate-mass star formation within several tens of parsecs of the W51 core. One of these harbors several dozen young stellar objects embedded in a network of filamentary IR dark clouds seen for the first time in *Spitzer* IRAC images at arcsec resolution. The other region exhibits condensations of young stellar objects (YSOs) lining the rim of an IR-bright cloud seen prominently in 8 micron PAH emission. The velocities of associated CO features place both SF regions near the tangent point distance of ~ 5.6 kpc, suggesting a proximity to the W51 complex of massive star formation. The latter of these two regions may be an example of star formation triggered by feedback from earlier generations of massive SF activity in or near W51. Using IR color diagrams we classify the evolutionary state of ~ 150 probable Class I and Class II YSOs in these two regions. Based on the adopted distances and measured IR luminosities, we present luminosity functions and estimate stellar masses for these newly identified YSOs.

P2. Chandra observations of IRAS 20126+4104

Crystal Anderson (NRAO)

Peter Hofner (New Mexico Institute of Mining and Technology; NRAO), Debra Shepherd (NRAO), Michelle Creech-Eakman (New Mexico Institute of Mining and Technology)

We present preliminary results of *Chandra* ACIS-I observations of the massive star forming region, IRAS 20126+4104. This region harbors a deeply embedded massive protostar, as well as a young stellar cluster. The early B protostar in this region is a prime candidate for accretion through a disk. The primary goal of this project is to search for X-ray emission toward the center of the young stellar cluster. 150 X-ray sources were detected with *Chandra*, most of which are pre-MS stars. We do not detect X-ray emission from the massive protostar. We do, however, detect very strong X-ray emission from a jet (I20S) located just south of the early B protostar. We found that 13 out of 150 sources are variable and four have flare-like behavior, characteristic of a low-mass, pre-main sequence star. Spectral analysis is currently in progress for this region and so far the spectrum of most of the sources detected around the central object emit hard X-rays. Preliminary results of the I20S spectrum indicate a contribution from both thermal and nonthermal emission.

P3. On the complexities of massive star formation: The case of G31.41+0.31

Esteban Araya (NRAO & University of New Mexico)

Peter Hofner (New Mexico Tech & NRAO), Stan Kurtz (CRyA, UNAM Morelia)

Massive stars form in cluster environments within regions located at typical distances of several kpc, and reach the zero age main sequence while still highly embedded. All this makes the study of massive star formation a formidable challenge that requires high angular resolution observations. In this work we discuss the case of G31.41+0.31, where an ultracompact H II region and a prominent hot molecular core are found in a region of extended radio continuum emission. High angular resolution ($\sim 0.5''$) VLA observations of thermal methanol are discussed in detail. Our data suggest the presence of a wide-angle bipolar outflow from the hot molecular core. The outflow shows a remarkable morphological similarity to outflows detected toward low-mass young stellar objects.

P4. Star formation in molecular clouds associated with H II regions

Mohaddeseh Azimlu (University of Waterloo)

Michel Fich (University of Waterloo)

Star formation in a cloud occurs in different modes and is highly affected by high mass stars, stellar winds and internal dynamics of the cloud. We are looking at the star formation near a sample of 12 H II regions to examine these effects. Our sample is selected from the outer regions in the Galaxy primarily along the Perseus spiral arm to reduce the confusion with background sources. For each object we are using the JCMT sub-millimeter telescope to make 7×7 arcmin ^{12}CO (2-1) maps of H II regions to study the clumpy structure and to find the dense cores. We then use pointed observations in ^{13}CO (2-1) and CS (5-4) in dense cores to measure physical properties such as density, temperature, optical depth, clump masses, velocity structure and line widths that may affect the star formation process. We already have detected evidence of triggered star formation in a layer *Collected and Collapsed* by shock fronts from ionized gas around S104. Number of clumps in this cloud is twice than the similar regions. This project is followed by near infra red observation at CFHT to detect the stellar clusters embedded within the clouds. We will study how the star formation and stellar mass distribution (IMF) has been affected by various physical conditions in different regions. The observation for five sources have been completed and we have detected five embedded clusters within three of the observed regions.

P5. The impact of CHaMP

Peter Barnes (University of Florida)

Yoshinori Yonekura (Osaka Prefecture University), Yasuo Fukui (Nagoya University), Stuart Ryder (Anglo-Australian University)

The *Census of High- and Medium-mass Protostars* (CHaMP) is surveying the earliest phases of massive star formation by compiling the largest, most uniform, and least biased database of such regions at multiple wavelengths. We are bootstrapping from the Nanten Galactic Plane surveys using the 128k-channel digital filterbank on the Mopra antenna of the Australia Telescope, covering a $20^\circ \times 6^\circ$ region in Vela, Carina, and Centaurus. In 2005–07 we efficiently mapped over 100 cores in this region with multiple tracers, identifying all the dense gas, and we are now characterising their physical state (temperature, density, mass, luminosity, etc.). At the same time, we have begun near-IR imaging spectroscopy of these dense cores with the IRIS2 imager on the Anglo-Australian Telescope, and are also surveying the 1 mm dust continuum with ASTE.

These data will allow us to take an unbiased census of all massive protostars and protostellar clusters in our $20^\circ \times 6^\circ$ survey region on both large and small scales, as well as identifying massive starless cloud cores, and for the first time (a) uniformly identify the normal evolutionary stages of higher-mass star formation, (b) characterise the physical conditions in the dense gas at each stage, (c) directly compute the lifetimes of each stage, and (d) compare these results with other biased surveys. While we plan to further expand the survey’s scope and coverage, we consider the impact CHaMP will have on studies of massive star formation with ALMA and other instruments, potentially providing definitive answers to many of the questions on this meeting’s wish list.

P6. Massive star formation in nearby galaxies: From the star-forming disks into the outskirts of galaxies

Frank Bigiel (UC Berkeley)

Fabian Walter (MPI for Astronomy), Adam Leroy (MPI for Astronomy), Elias Brinks (University of Hertfordshire), Erwin de Blok (University of Cape Town), Barry Madore (OCIW)

I will present results from THINGS (‘The HI Nearby Galaxy Survey’) on scaling relations between gas and massive star formation (SF) in nearby galaxies. The survey was carried out at the VLA and provides the currently best sensitivity and highest resolution HI survey data available. It covers 34 nearby galaxies and spans a wide range in galaxy parameter space, e.g. in metallicity and star formation activity. I will present a detailed pixel-by-pixel study of the star formation law on 500 pc resolution for 19 THINGS galaxies, spirals and dwarfs, using ancillary IRAM CO, *Spitzer* 24 micron and *GALEX* UV data. This is the first time that the scaling relation between gas and SF has been measured at high resolution across the entire star forming disks of a large sample of galaxies in a systematic way. I will show that a Schmidt law with power law index $N = 1.0 \pm 0.2$ relates star formation surface density and molecular gas surface density in the star forming disks and that the ratio of HI to H₂ is a strong function of radius and thus environment in a galaxy.

Both THINGS and *GALEX* detect extremely extended distributions of gas and SF in our sample, often reaching out to twice the canonical optical radius r_{25} . I will present new results

comparing SF to gas in the extreme environments of outer galaxy disks. At around the edge of the star forming disk, there is a strong correlation between the two. Both drop with increasing radius in the outer disk. However, SF traced by FUV emission drops substantially faster than HI and I'll talk about possible drivers for this behavior. I will highlight the extreme case of M83, which is the first result of a GALEX program to obtain some of the deepest UV images ever taken on nearby galaxies. In M83, the new GALEX images and a 1 degree field-of-view THINGS map reveal ongoing SF at more than 3 optical radii.

P7. Physical conditions in the innermost 1000 AU of massive protostars

Vivien Chen (National Tsing Hua University)

Sheng-Yuan Liu (ASIAA, Taiwan), Yu-Nung Su (ASIAA, Taiwan), Qizhou Zhang (CfA), Wm. J. Welch (UC Berkeley), T. K. Sridharan (CfA)

The large distances of high-mass protostellar objects require high angular resolution observations with (sub)millimeter interferometers to resolve the structures in their innermost region, where different formation scenarios can be distinguished. Although highly collimated bipolar outflows are indicative of mass accretion via disks, well resolved observations that can provide information about kinematics and even density and temperature distributions in the innermost 1000 AU of massive protostellar objects are desired. In this talk, we report the results of our line and continuum studies with sub-arcsecond angular resolutions toward a nearby massive protostar, IRAS 20126+4104. Previous studies of a well-collimated bipolar outflow observed in SiO and HCN strongly suggest the presence of an accretion disk. Our observations with BIMA and SMA allow us to resolve the central region of this source and to study the physical conditions of the rotating structure that has been previously proposed to be a Keplerian disk.

P8. Extended Green Objects (EGOs) in the GLIMPSE survey: A new sample of massive young stellar object outflow candidates

Claudia Cyganowski (University of Wisconsin Madison)

C.L. Brogan (NRAO), T.R. Hunter (NRAO), E. Churchwell (University of Wisconsin Madison)

Using images from the *Spitzer* GLIMPSE legacy survey, we have identified more than 300 sources with extended 4.5 μm emission, thought to trace shocked molecular gas in protostellar outflows (called EGOs, Extended Green Objects, for the common coding of the [4.5] band as green in 3-color composite IRAC images). Extended 4.5 μm emission is thought to trace shocked molecular gas in protostellar outflows. We present results of VLA surveys of EGOs for two types of masers associated with outflow activity in massive star forming regions: 6.7 GHz Class II CH₃OH masers (using the new EVLA receivers) and 44 GHz Class I CH₃OH masers. These high resolution observations allow detailed comparison with IRAC and MIPS images. We also present high-resolution mm line and continuum data for selected EGOs. Several EGOs lie on the rims of infrared-bright dust bubbles,

and may be examples of triggered star formation: we present a GBT NH_3 study of the large-scale molecular environment of one such EGO.

P9. Wide-field H_2D^+ observations of starless cores

James Di Francesco (National Research Council of Canada)

Rachel Friesen (University of Victoria (UVic)), Paola Caselli (University of Leeds (UL)), Philip C. Myers (Harvard-Smithsonian Center for Astrophysics (CfA)), Floris van der Tak (Dutch National Institute for Space Research (SRON)), Cecilia Ceccarelli (Laboratoire d’Astrophysique de Grenoble (LAOG))

In recent years, isolated starless cores have been revealed to have significant chemical differentiation with very low abundances of carbon-bearing molecules (such as CO and its isotopologues) in their cold, dense interiors. The inner regions of such cores, however, may be quite interesting, e.g., if contraction or collapse begins there. To explore these regions, we present detections of six isolated starless cores in the 1_{11} - 1_{10} line of H_2D^+ at 372 GHz using the new HARP instrument at the James Clerk Maxwell Telescope. Since the detection of this line requires very dry conditions on Mauna Kea (i.e., $\tau_{225\text{GHz}} < 0.05$), only a multi-beam receiver system like the 4×4 HARP array can locate H_2D^+ emission across such cores in a practical amount of observing time. In all cases, the brightest line emission is coincident with the local peak of submillimetre continuum emission, but significant H_2D^+ emission is detected offset from the continuum peak in some. In addition, we describe the thermal and turbulent velocity fields in these cores revealed by these lines.

P10. Clustered star formation in the Ophiuchus molecular cloud

Rachel Friesen (University of Victoria)

James Di Francesco (National Research Council of Canada), Yancy Shirley (University of Arizona), Philip C. Myers (Harvard-Smithsonian CfA)

Comprehensive studies of isolated low mass star forming cores have greatly enhanced our understanding of the structure and evolution of these objects. Massive star formation, however, occurs in clustered environments, which are characterized by more complex geometries and kinematics. In this detailed study, we present combined single-dish and interferometric NH_3 (1,1) and (2,2) observations in the Oph B, C and F filaments in the intermediate mass cluster-forming Ophiuchus molecular cloud. We find surprising differences in the physical properties of the filaments. Dense gas in Oph B is extremely “clumpy”, but kinetic temperatures vary little and are warmer than those observed in isolated cores, and over most of the filament non-thermal motions dominate the observed linewidths. Several localized emission peaks are associated with higher NH_3 column density, near-thermal linewidths and moderately cooler gas temperatures. In contrast to isolated cores, however, these NH_3 peaks are not coincident with the millimeter continuum emission peaks. Conversely, in Oph C, the NH_3 and dust continuum emission correlate well. In addition, we find

Oph C is significantly colder than Oph B, with near-thermal linewidths. Oph F is warmer than both Oph B and C, and shows complicated velocity structure possibly caused by embedded protostars. Additional single-dish detections of transitions from the early-time molecules CCS and HC₅N provide evidence that Oph C may be in a younger evolutionary state than B or F.

P11. Small H II regions and their role in massive star formation

Roberto Galvan-Madrid (Harvard-Smithsonian CfA)

Qizhou Zhang (Harvard-Smithsonian CfA), Eric Keto (Harvard-Smithsonian CfA), Luis F. Rodriguez (CRyA-UNAM, Mexico), Paul Ho (ASIAA, Taiwan and Harvard-Smithsonian CfA), Stan Kurtz (CRyA-UNAM, Mexico)

It is unknown if in the formation of massive (O) stars, accretion is halted with the appearance of an H II region, preventing the young star from ever reaching higher masses. We have started a program with the aim of characterizing the different evolutionary stages of small H II regions formed by young, massive stars, from the first appearance of detectable radio-continuum emission (objects that are likely to be still accreting) to the stage in which accretion is completely shut off. Hypercompact H II regions are of special interest for our study. We present here the results of our first SMA and VLA observations in a subsample of our sources, where the kinematics of both the molecular and ionized components is revealed.

P12. ²⁸SiO ($v = 0, 1, 2$), ²⁹SiO, and ³⁰SiO ($v = 0$) $J = 1 - 0$ maser emission from Source I in Orion BN/KL

Ciriaco Goddi (Harvard-Smithsonian Center for Astrophysics)

L. J. Greenhill (Harvard-Smithsonian Center for Astrophysics), C. J. Chandler (National Radio Astronomy Observatory), E. M. L. Humphreys (Harvard-Smithsonian Center for Astrophysics), L. D. Matthews (Harvard-Smithsonian Center for Astrophysics)

We have conducted a line survey of Orion BN/KL in the band 42.2-43.6 GHz with the GBT. Several molecular species were identified, including SiO, SO₂, C₂H₅CN, HC₇N, NH₂D, CH₃OCH₃. Five transitions from three SiO isotopologues were observed: ²⁸SiO $v = 0, 1, 2$ $J = 1 - 0$ and ²⁹SiO and ³⁰SiO $v = 0$ $J = 1 - 0$. Using the VLA, we imaged the emission from all five transitions. For the first time, we have been able to map the ²⁹SiO and the ³⁰SiO $v = 0$ $J = 1 - 0$ emission in BN/KL and confirm its association with the high-mass YSO Source I. We confirm the maser nature of the the ²⁹SiO and ³⁰SiO emission. In this poster, we compare maps of the different maser transitions and discuss how the results may affect theoretical SiO pumping scenarios and interpretation of data from the KaLYPSO project (<http://www.cfa.harvard.edu/kalypso/>), which aims to map the structure and dynamical evolution of gas 10-1000 AU from the nearest high-mass YSO, radio source I in BN/KL. Joint study by ALMA and EVLA would extend this work, covering $J = 1 - 0$, $2 - 1$, and $3 - 2$ transitions in 3 vibrational states and 3 isotopologues, greatly broadening

the foundation for pump models, and better constraining physical conditions in close proximity to source-I. Results may also be applied to investigations of physical conditions in late-type stellar envelopes.

P13. Recent star formation history of selected regions in the M81 outer disk and their relation to H α and UV emission timescales

Stephanie Gogarten (University of Washington)

We have measured resolved stellar photometry from Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) observations of a field in the outer disk of M81 as part of the ACS Nearby Galaxy Survey Treasury (ANGST). Motivated by the recent discovery of extended UV (XUV) disks around many nearby spiral galaxies, we use the observed stellar population to derive the star formation histories of five 0.5 kpc-sized regions within this field. These regions were selected on the basis of their UV luminosity from GALEX and include two HII regions, two regions which are UV-bright but H α -faint, and one "control" region faint in both UV and H α . As expected, the HII regions contain massive main sequence stars (in the mass range 18-27 Msun, based on our best extinction estimates), while these massive main sequence stars are not found in the UV-bright/H α -faint regions. The observations are consistent with stellar ages < 10 Myr in the HII regions, and > 16 Myr in the UV-bright/H α -faint regions. Thus, our results are consistent with an age difference being sufficient to explain the observed discrepancy between star-forming regions detected in H α and those detected exclusively in UV. However, our data cannot conclusively rule out other explanations, such as a strongly truncated initial mass function (IMF).

P14. What physical conditions in molecular clouds are required for the formation of massive stars?

Jennifer Hatchell (University of Exeter)

Mark Thompson (University of Hertfordshire), Friedrich Wyrowski (Max-Planck-Institut fuer Radioastronomie, Bonn), Thushara Pillai (CfA), Andy Gibb (University of British Columbia), Michele Pestalozzi (University of Gothenburg)

In the observational pursuit of SCAMPs (SCubA Massive Precluster cores) we have been considering what physical conditions qualify a molecular core as the precursor to a massive star formation region. Given measurements of mass, size, luminosity, temperature, linewidth, deuteration, etc., how do we identify which regions have the correct properties to go on to form massive stars? Our approach is an observational one. Clear pointers on masses and sizes come from the massive clusters which are the required end product. For example, we can extend the relationship between the mass of the most massive star in a cluster and the cluster mass (Weidner & Kroupa 2004) to predict the required precluster core mass necessary to produce a star of a particular spectral type. Sizes of cores are required to be similar to the sizes of the clusters which they form. Further clues come from nearby star forming regions which we know are forming O and/or B stars (e.g., Orion, NGC1333 in

Perseus). We simulate continuum observations of these well-known regions as they would appear if they lay at various distances across the Galaxy. Finally, we use this distance modification tool to correct for flux-limited samples and decreasing spatial resolution and test if the apparently large masses, sizes and luminosities of more distant regions truly indicate more extreme properties.

P15. A study of the physical relation between embedded clusters and their natal clumps using the Nobeyama 45m telescope

Aya Higuchi (Nobeyama Radio Observatory/Tokyo Institute of Technology)

Yoshimi Kitamura (Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency), Norio Ikeda (Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency)

We have carried out a survey of the dense clumps associated with 11 embedded clusters in the H^{13}CO^+ (1–0) line emission with the Nobeyama 45m telescope to reveal the physical relation between clusters and their natal clumps. In this survey we made typically $5'' \times 5''$ maps in H^{13}CO^+ around the center of the 11 regions. The target sources were selected from the catalog by Lada & Lada (2003) and the results of the $\text{NH}_3(1,1)$ and H_2O maser survey with the 45m telescope by Sunada et al. (2007). We have succeeded in obtaining the maps of all the H^{13}CO^+ clumps with the radii of 0.3 - 1 pc, LTE masses of 60 - 850 M_\odot , and velocity widths in FWHM of 1.6 – 4.5 km s^{-1} . Previously, we also carried $\text{C}^{18}\text{O}(1-0)$ line observation toward the same objects and obtained the clumps which cover the whole clusters (Higuchi et al. in prep). On the other hand, the H^{13}CO^+ ones are located shifted from the central position of the clusters. Our analysis showed that all the clumps are most likely to be in virial equilibrium, suggesting that the dense clumps have the potential for cluster formation. We have discovered an interesting correlation between the cluster mass and the degree of the central concentration of the clumps. We defined the central concentration as the ratio of the mass above the 6σ levels to the mass above the 3σ of the clumps. We considered that the relation shows the progress of the clusters: the larger the cluster masses, the smaller the central concentration of the H^{13}CO^+ clumps. In conclusion, we understood that the H^{13}CO^+ clumps are really sensitive to the on-going star formation.

P16. Identifying the chemistry of cold cores

Tracey Hill (University of Exeter)

M. R. Cunningham (University of New South Wales, Australia), M. G. Burton (University of New South Wales, Australia), V. Minier (CEA, Saclay, France)

We have undertaken a large-scale spectral line study of millimetre continuum cores identified in a survey with the SIMBA bolometer on the Swedish ESO Submillimetre Telescope (Hill et al. 2005). These mm-only cores are devoid of typical star formation identifiers such as methanol maser and UC H II regions and are thus detected solely from their millimetre continuum emission as measured

by SIMBA. Spectral energy distribution modelling and analysis reveals these mm-only cores to be cooler and less luminous, but of comparable mass to cores where star formation is known to be taking places - i.e. those cores associated with methanol maser and/or radio continuum sources. These data suggest that the mm-only core is a possible precursor of massive star formation, prior to the onset of methanol maser emission. We have embarked upon a millimetre spectral line study of a sample of mm-only cores, with the Mopra telescope, in order ascertain their physical and chemical properties and ultimately to address whether they display evidence of massive star formation and can thus fill the role of a younger stage of massive star evolution. Results from this spectral line study and hence the chemistry of these mm-only cores will be presented here.

P17. Preliminary modeling results of Orion Source I from the KaLYPSO project

Liz Humphreys (Harvard Smithsonian CfA)

Lincoln Greenhill (Harvard Smithsonian CfA), Lynn Matthews (Harvard Smithsonian CfA), Ciriaco Goddi (Harvard Smithsonian CfA), Mark Reid (Harvard Smithsonian CfA), Claire Chandler (NRAO)

Radio Source I in the Orion BN/KL region is the nearest example of a high-mass YSO, and one of only a few star-forming sources known to power both H₂O and SiO masers. The KaLYPSO Project (<http://www.cfa.harvard.edu/kalypso>) is capitalizing on this combination to map the structure and dynamical evolution of material within 10 - 1000 AU of a high-mass YSO in unprecedented detail. In this poster, we present examples of the KaLYPSO dataset, including maser spectra, interferometric maps and proper motions, that we have used to inform preliminary geometric and dynamical models of Source I. We show a comparison of simple models aimed at establishing the YSO geometry, that include treatments of maser (un)saturation, and varying density and velocity fields. The model can be applied to any maser source, and, if Source I represents an evolutionary stage common to other high mass objects, it will be more broadly applicable to studies likely to be done with ALMA.

P18. Ammonia study of the high-mass star-forming region G111.6+0.3

Nancy Irisarri Méndez (Universidad de Puerto Rico, Rio Piedras Campus)

M. Lebrón (UPR-RP)

Observations of the UC HII region G111.61+0.3, and its associated PDR, suggest that a hot molecular core may be present, and nearby coincident with the arc of the cometary HII region. The NH₃(3,3) and NH₃(4,4) were observed in order to determine the presence of a hot molecular core. This observations also give us the opportunity to study physics of the interaction between ionized, neutral and molecular gas components. The results of this study are summarized in this poster.

P19. Search for ionized gas towards millimeter clumps and cores: uncovering nearby intermediate- and high-mass protostars suitable for followup with the eVLA and ALMA.

Katharine Johnston (University of St Andrews)

Debra Shepherd (NRAO), James Aguirre (University of Pennsylvania), Kenny Wood (University of St Andrews)

We have performed a 3.6 cm continuum survey of selected intermediate- and high-mass millimeter clumps and cores. Using these observations, we wish to increase the number of nearby (< 4 kpc) intermediate and massive protostars available for future observation with both the eVLA and ALMA. This survey has also allowed us to study the relationship between the properties and morphologies of the ionized gas and neutral gas component traced by dust, providing more insight into the observable evolutionary sequence, and aiding our understanding of the effect a forming HII region has on the formation of a massive star. We present our findings in this poster, including several of the most interesting objects this survey has uncovered.

P20. Molecular gas in the interacting galaxy pair NGC4567/8

Hiroyuki Kaneko (The Graduate University for Advanced Studies (SOKENDAI))

KUNO Nario (National Astronomical Observatory of Japan), TOSAKI Tomoka (National Astronomical Observatory of Japan), SAWADA Tsuyoshi (National Astronomical Observatory of Japan), IONO Daisuke (National Astronomical Observatory of Japan), NAKANISHI Hiroyuki (Kagoshima University)

We present a $^{12}\text{CO}(J=1-0)$ mapping observation of the interacting galaxy pair NGC 4567/8 performed with the Nobeyama 45 m telescope. The aims for this study are to investigate the response of cold molecular gas during the early stage of collision of galaxies, and to understand why interacting systems are stimulated to violent star formation. Combining with previous HI observations, we found high molecular fractions (f_{mol} ; ratio of the molecular to total gas surface densities) in NGC 4567 and the overlap region in spite of their low total gas column densities. The large f_{mol} is explained due to two possibilities. One is the collision of galaxies. The collision increases the pressure that encourages to produce H_2 gas. Another is ram pressure, because the NGC4567/8 pair is located in the Virgo cluster. Ram pressure may affect selective HI gas stripping and help the production of H_2 gas as a result of the interaction with ISM. These regions also show high star formation efficiency (star formation rate per solar mass of total gas) that may lead to explosive star formation of the latter stage of collision.

P21. Molecular clouds and star formation in the Magellanic Clouds by NANTEN and NANTEN2

Akiko Kawamura (Nagoya University)

Yoji Mizuno (Nagoya University), Tetsuhiro Minamidani (Hokkaido University), Norikazu Mizuno (Nagoya University), Toshikazu Onishi (Nagoya University), Yasuo Fukui (Nagoya University)

We have made a catalog of about 300 molecular clouds in the Large and Small Magellanic Clouds through the 12CO(1-0) observations by NANTEN, a 4 m telescope at Las Campanas Observatory in Chile. We have utilized the catalog of GMCs to compare the cloud distribution with signatures of massive star formation, stellar clusters, and classical H II regions. We find that the molecular clouds are classified into three types according to the associated activities of massive star formation; Type I shows no signature of massive star formation, Type II is associated with relatively small H II region(s) and Type III with both H II region(s) and young stellar cluster(s). Among possible ideas to explain the GMC Types, we favor that the Types indicate an evolutionary sequence; i.e., the youngest phase is Type I, followed by Type II and the last phase is Type III, where most active star formation takes place leading to cloud dispersal. We estimate a lifetime of a GMC of 20–30 Myrs for those with a mass above the completeness limit, 5×10^4 solar masses, in the LMC by assuming a steady state of massive star and cluster formation and adopting a time scale of the youngest stellar clusters, 10 Myrs. We have been extending our observations to higher transition lines in CO and its isotopes as well as CI in submm by NANTEN2 and ASTE. We will present these results from comparisons of the cloud and massive star forming activities. These new results together with recent IR observations of the YSOs will bring us deeper understanding of the molecular cloud properties as well as star and cluster formation processes in the Magellanic Clouds.

P22. Neutral gas content of galaxies in the local universe

Brian Kent (Cornell University)

The neutral and molecular gas components of nearby galaxies at the present epoch provide important information for studies of galaxy evolution. Wide-field extragalactic surveys are making use of the 21-cm line of neutral hydrogen to measure properties of some 20,000 galaxies in the local Universe. Statistics on the gas content of this population ($cz < 18000$ km/s) are very useful in understanding the star formation potential for nearby galaxies. The link between high M_{HI}/L galaxies observed with HI surveys and actively star forming galaxies will be explored. In more extreme cases for resolved gaseous self-gravitating HI clouds with no optical counterparts, limits can be placed on the star formation threshold. The database of global HI profiles will complement the high resolution ALMA CO studies of molecular clouds in targeted nearby galaxies.

P23. Bridging the gap: A Spitzer census of intermediate-mass star-forming regions

Charles Kerton (Iowa State University)

Chip Kobulnicky (University of Wyoming), Kim Arvidsson (Iowa State University), Michael Alexander (University of Wyoming)

We present the initial results of a census of intermediate-mass (IM) star-forming regions (SFRs) in our Galaxy. These relatively unknown and unstudied sources are SFRs where the most massive star is in the 4-8 solar mass range and thus they straddle the boundary between traditional high- and low-mass SFRs. They are identified from their IRAS colors and subsequently studied using Spitzer legacy Galactic surveys (GLIMPSE and MIPS GAL) along with CO, 21 cm line, and radio continuum surveys. By identifying and subsequently studying such regions we hope to understand what controls the transition from low- to high-mass star formation. We are also investigating the evidence for sequential or triggered star-formation on the periphery of these regions, the prevalence of bipolar outflows, and the mass and velocity structure of the molecular and atomic interstellar medium associated with these regions.

P24. Triggered and clustered star formation in W5

Xavier Koenig (CfA)

We present images and results from our extensive *Spitzer* imaging survey of the W5 H II region with IRAC and MIPS. We detect dense clusters of stars infrared excess sources, centered on the O stars. At 24 microns, substantial extended emission is visible from heated dust grains that survive in the ionizing environment of the H II region. With photometry of more than 18000 point sources, we analyze the clustering properties of objects classified as young stars by their IR SEDs across the region using a minimal-spanning-tree algorithm. We find $\sim 40 - 70\%$ of infrared excess sources belong to clusters with > 10 members. We find that within the evacuated cavities of the H II regions that make up W5, the ratio of Class II to Class I sources is ~ 7 times higher than for objects coincident with molecular gas as traced by ^{12}CO emission and near-IR extinction maps. We attribute this contrast to an age difference between the two locations, and postulate that at least two distinct generations of star formation are visible across W5. Our analysis shows that triggering is a plausible mechanism to explain the multiple generations of star formation in W5.

P25. Massive stellar clusters in the Galaxy: Multi-wavelength observations of new candidate clusters

Cornelia Lang (University of Iowa)

Maria Messineo (Rochester Institute of Technology), Lucy Hadfield (Rochester Institute of Technology), Don Figer (Rochester Institute of Technology), Zhu Qingfeng (Rochester Institute of Technology)

Due to their rarity and short lifetimes, massive stars are predominantly observed in young (few Myrs) massive (10^4 solar mass) clusters. In the Milky Way, only a handful of such clusters have been detected thus far, including the spectacular Arches, Quintuplet, Central clusters in the Galactic center, and Westerland 1+2. Recent multi-wavelength surveys have suggested that many more candidates may be hiding behind dust and gas in the Galactic plane. Here, I summarize observational efforts to uncover these candidates, using high-resolution data from optical, near- and mid-infrared, radio and X-ray instruments. In particular, I will report on recent radio continuum observations of a small sample of candidate massive clusters and present multi-wavelength analysis of the impact that such massive clusters have on the surrounding interstellar medium in our Galaxy. In addition, I will compare these candidate massive stellar clusters to the well-known clusters in the Galactic center region.

P26. Molecular study of the starburst galaxy Arp 220

Mayra Lebron (Universidad de Puerto Rico, Rio Piedras)

C. Salter (NAIC), T. Ghosh (NAIC), M. Lerner (NAIC), B. Catinella (MPIfA), R. Minchin (NAIC), E. Momjian (NRAO)

An on-going Arecibo line search between 1.1 and 10 GHz of the prototypical starburst/megamaser galaxy, Arp 220, has revealed a spectrum rich in molecular transitions. These includes methanamine (CH_2NH) in emission, HCN lines in absorption, and OH absorption lines. In this presentation, we compare the results of the extreme environs of Arp 220 with Galactic star-forming regions.

P27. High-mass star formation in the IRAS 17233-3606 region: a new nearby and bright hot core in the southern sky

Silvia Leurini (ESO)

A. Belloche (MPIfR), L. Zapata (MPIfR), P. Schilke (MPIfR), F. Wyrowski (MPIfR)

In a recent survey of massive YSOs carried out with the APEX telescope, we detected exceptionally strong and rich molecular emission towards the star forming region IRAS 17233-3606. These observations were followed up with the SMA at 1.3 mm, which show a bright single object on a scale of 0.04 pc with a mass of $120 M_\odot$. These observations reveal a well collimated outflow (collimation factor ~ 4) originating from the source, and a velocity gradient along a direction probably perpendicular to the axis of the outflow, suggesting a rotating molecular toroid. All these results (collimated outflow, rotating molecular toroid, hot core chemistry) strongly suggest that I17233 is in a very early evolutionary phase. In addition, I17233 is relatively close (probably at ~ 1 kpc)

and in the southern sky, thus a perfect target for ALMA. These considerations increase the importance of this star forming region, making it one of the best laboratories in which to investigate the processes leading to the formation of massive stars.

In our contribution, we will present our SMA data, and concentrate on the analysis of the molecular outflow originating from IRAS 17233, based on CO and ^{13}CO (2-1) lines from the SMA, and on the CO(6-5) and (7-6) transitions observed with the APEX telescope (and with a resolution of 8.9'' and 7.6'', respectively).

P28. The Galactic magnetic field anchors in turbulent molecular clouds

Hua-bai Li (CfA)

Turbulence and magnetic field are almost ubiquitous in molecular clouds, and the relative importance between them is the main different assumption between the “rapid” and “quiescent” star formation theories, that are long under debate. Is turbulence scrambling magnetic fields? Or it is magnetic field that channels mass flows and forces turbulence anisotropic? Simulated cluster star formation rate, efficiency, and IMF are sensitive to this difference. We show that polarimetry observations can put a crucial constraint on star formation theories and simulations.

P29. Spectral band studies of molecular cores in IRDCs

Sheng-Yuan Liu (Academia Sinica, Institute of Astronomy and Astrophysics)

Contrary to the low-mass cases, our understanding of the massive star formation processes is rather limited. In particular, what constitutes the initial conditions for massive star formation is hardly known. While both hot molecular core sources and ultracompact (UC) HII regions are recognized as signposts of the early phases in the massive star formation processes, infrared dark clouds (IRDCs), objects seen in absorption against the bright diffuse Galactic mid-infrared background, have drawn significant attention recently since they are very likely to be the gas condensations harboring massive stars in formation. Here, we present the preliminary results from a multi-band line study of molecular cores in IRDCs. We discuss in particular their chemical signatures as compared to other indicators of star formation activities in these regions, and the implication of their evolutionary stages.

P30. HOPS and the SMA

Steve Longmore (CfA)

In this contribution I will present 1) a project underway to survey the southern Galactic plane for dense molecular gas and 2) follow-up SMA observations to uncover the physical properties of the youngest identified massive star formation regions. HOPS is a survey of the southern Galactic

plane ($|l| \leq 0.5^\circ$, $b = 300^\circ \rightarrow 30^\circ$), simultaneously covering the 12 mm band (18 to 26 GHz) in 16 bandpasses at $\sim 0.4 \text{ km s}^{-1}$ spectral resolution using the MOPS back-end on the Mopra telescope. With a third of the survey complete, I will focus on initial results from the multiple inversion transitions of ammonia accessible in the 12 mm band. Ammonia is an excellent probe of the physical properties and kinematic structure of the dense gas in young massive star formation regions. We have previously shown this can be used to separate MSF regions into relative evolutionary stages and hence isolate the youngest regions for further study, as laboratories of the initial conditions under which a molecular cloud will form massive stars. Once complete, HOPS will provide a list of the brightest southern massive dense molecular clouds and their physical/kinematic properties for follow-up with ALMA. Finally, I will show SMA observations aiming to determine the properties of a sample of the youngest identified MSF regions.

P31. Global star formation with the Hi-GAL HERSCHEL multiband far-IR survey of the Galactic plane

Sergio Molinari (Istituto Nazionale di Astrofisica - IFSI, Rome)

Leonardo Testi (ESO, Garching), Riccardo Cesaroni (INAF - Osservatorio di Arcetri, Firenze), Jan Brand (INAF - Istituto di Radioastronomia, Bologna), Fabiana Faustini (INAF - Istituto Fisica Spazio Interplanetario, Roma), Hi-GAL Team

Measuring the star formation rate and efficiency in a galaxy rests on the characterization of the massive star formation timeline and its dependence on local galactic environmental conditions. Most of the uncertainties come from the lack of diagnostic tools to evolutionarily classify large samples of candidate massive protostellar objects that can then be studied in more detail.

Preliminary results based on relatively low resolution IR and submillimeter data suggest that the shape of the SED and the bolometric luminosity are indeed capable of tracing different classes of massive YSOs according to a scheme that resembles the classical Class 0-I-II classification established for the low-mass regime. The bolometric luminosity, in particular, appears to be a very sensitive evolutionary indicator; its exact measure over a wide dynamical range, for which the *Herschel* satellite is the optimum facility, has the potential to distinguish between different competing star formation theories. The full potential of these diagnostic tools can only be expressed if applied to Galaxy-wide samples of YSOs of different envelope masses and evolutionary stages.

Hi-GAL is the *Herschel* Key Project for the 60-600 micron 5-band imaging survey of the inner 120 longitude degrees of the Galactic plane; it will be the keystone of the set of new-generation Galactic plane surveys including *Spitzer's* GLIMPSE/MIPSGAL in the mid-IR, and ATLASGAL/JPS in the submillimeter. Hi-GAL will provide the ultimate census and SED properties of virtually every intermediate and high-mass star forming region over most of the Galaxy, that is the essential foundation to build a predictive bottom-up model for an entire spiral galaxy.

In spite of its 30-fold increase in spatial resolution with respect to *IRAS* or *DIRBE*, however, *Herschel* will still be insufficient to isolate single massive YSOs further away than a few kpc, a challenge that will be met by ALMA and by the next generation of large space-borne far-IR facilities with photometric and spectroscopic capabilities.

P32. Evidence of jet/outflow triggered star formation traced by kinematics of H₂O masers in a massive star forming region

Kazuhito Motogi (Hokkaido University)

Yoshimasa Watanabe (Hokkaido University), Kazuo Sorai (Hokkaido University), Mareki Honma (National Astronomical Observatory of Japan), Hiroshi Imai (Kagoshima University), Kenta Fujisawa (Yamaguchi University)

We have made multi-epoch VLBI observations of H₂O maser emission in the massive star forming region IRAS 06061+2151 with the Japanese VLBI network (JVN) from 2005 May to 2007 October. The detected maser features are distributed within an 1''×1'' (1500 AU×1500 AU at the source position) area around the ultra-compact H II region detected in radio continuum emission. Their distribution and expanding motion traced through relative proper motions indicate that they are excited by an energetic bipolar outflow. Our three-dimensional model fitting shows that the maser kinematics in IRAS 06061+2151 is able to be explained by a biconical outflow with a large opening angle of 50°. The position angle of the flow major axis coincides very well with that of the large scale jet seen in 2.1 μm hydrogen emission. Moreover, there are two nearby B-type protostars located on the flow axis near the UCH II region, which suggests that the jet and molecular flow are related to the formation of these young stellar objects. A sub-arcsecond image of molecular gas and thermal emission from dust obtained with ALMA will make clear the relation between the molecular outflow and jet, and triggering star formation.

P33. NANTEN2 project: CO and CI survey of the Local Group

Toshikazu Onishi (Nagoya University)

Norikazu Mizuno (Nagoya University), Akira Mizuno (Nagoya University), Akiko Kawamura (Nagoya University), Yasuo Fukui (Nagoya University), NANTEN2 Consortium

In order to understand the galactic evolution, we need to have comprehensive knowledge on atomic/molecular gas distribution and massive star formation in an entire galaxy. Only in the Local Group we can make such a detailed study of individual clouds. We summarize the results of molecular observations of the Galaxy and the Magellanic system with NANTEN telescope in terms of massive star formation. I also present a project overview and the observational results of NANTEN2, which is an upgrade of NANTEN to Atacama at an altitude of 4,800 m, aiming at realizing large-scale surveys in the Local Group in molecular lines and atomic carbon lines at sub-mm.

P34. Bridging the H⁺/molecular divide: Panchromatic studies of stellar feedback in giant star forming regions

Eric Pellegrini (Michigan State University)

Jack A. Baldwin (Michigan State University), Gary J. Ferland (University of Kentucky), Margaret M. Hanson (University of Cincinnati)

We are conducting a series of detailed, panchromatic studies on active star forming regions of various size and metallicity to answer important questions like:

- What is the feedback of a stellar cluster on its parent molecular environment?
- How does star cluster formation in extreme environments, such as starbursts, compare to more quiescent small scale star formation?
- What fundamental physics is responsible for star formation feedback on local and galactic scales? Are supernova, stellar winds or radiation dominant?
- How does stellar feedback in low metallicity environments like 30 Doradus differ from stellar feedback at galactic metallicities.

By looking at a variety of star forming regions, ranging from the Orion nebula with one O star, to M17 with about 10, and 30 Doradus and NGC 3603 with up to 100 O stars, we are beginning to answer these questions. We are combining X-ray, optical, IR and radio observations to form self-consistent models from the H⁺ region to the molecular gas, to detail the interaction of stars and their parent molecular cloud. This work has already shown, among other things, that magnetic fields are important in the PDR interface region between the hot H⁺ region and cold molecular gas. The density of cosmic rays may be enhanced along with the magnetic field, strongly affecting the ionization fraction in the molecular gas. We currently are carrying out optical and NIR studies of 30 Doradus and NGC 3603, two local examples which begin to approach a starburst environment. The observations are designed to complement future observations with ALMA, and provide valuable insight to stellar feedback in giant star forming regions.

P35. What molecular cloud properties influence massive star formation?

Thushara Pillai (SAO)

The earliest stage in the evolution of a high mass star would be a “pre-protocluster stage”, which is hard to find. There is no bona fide high mass pre-protocluster core yet! A recent large scale mm survey of the entire Cygnus-X region has not revealed a single such object! The knowledge of their properties is crucial in establishing an evolutionary paradigm and constraining any theoretical calculations on collapse. We selected candidate pre-protocluster cores within high mass infrared dark clouds, from three large dust emission surveys that are massive, very dense, highly deuterated and depleted (single dish results). The objects were then observed with high angular resolution with the SMA, VLA, and PdBI in molecular tracers like N₂H⁺, NH₃, NH₂D. Extinction maps from *Spitzer* observations have also been derived. By the time of this conference, we will have

already obtained high angular resolution data also in N_2D^+ , and CO isotopologues. The modeling of the N_2H^+ ($J = 1 - 0$ and $3 - 2$) data is underway. We will present the results of this multi-wavelength study of high mass pre/protocluster candidates, which combines the large scale (parsec size) and small scale (sub-parsec) structure of molecular clouds in high mass star forming regions. By studying the excitation, velocity structure, stability, deuteration, and depletion in the earliest stage, we will be able to outline the physical properties that influence high mass star formation.

The recent observations of high mass proto-star/clusters with pseudo-disks, and driving outflows point towards a formation scenario similar to that of low mass stars. We will devote some attention whether such a similarity also holds for the pre-protostellar stage by combining simulations, and observations of low and high mass pre-stellar cores.

P36. Molecular line observations of infrared dark clouds: The physical conditions in massive pre-protostellar cores

Rene Plume (University of Calgary, Centre for Radio Astronomy)

David Gibson (University of Calgary, Centre for Radio Astronomy), Edwin Bergin (University of Michigan), Sarah Ragan (University of Michigan)

Using a source selection biased towards high mass star forming regions, we used a Large Velocity Gradient (LVG) code to calculate the H_2 densities and CS column densities for *Midcourse Space Experiment (MSX)* $8 \mu\text{m}$ infrared dark cores. From comparing the observed physical conditions (i.e., line widths, masses, densities, column densities) to previous low mass star formation studies and high mass star formation studies, we have identified 28 of the selected cores as potential high mass pre-protostellar objects. We found these, on average, to be $1.14 \times 10^6 \text{ cm}^{-3}$ and $1.21 \times 10^{13} \text{ cm}^{-2}$, respectively. In addition, we have calculated the Jeans mass and virial mass for each core to get a better understanding of their gravitational stability. We found that masses calculated from the column densities of N_2H^+ $J = 1 \rightarrow 0$ and C^{18}O $J = 1 \rightarrow 0$ calculated in Ragan et al. 2006 (Paper 1) were large enough that there is sufficient mass for collapse, though most regions are likely to form protoclusters. However, two of these cores, G37.44+0.14 ($M_{\text{molecular}} = 90 M_{\odot}$) and G37.89-0.15 ($M_{\text{molecular}} = 60 M_{\odot}$), have physical properties that could indicate the possibility of isolated massive star formation.

P37. The initial conditions of massive star formation in IRAS 23033+5951

Michael Reid (McMaster University)

Brenda Matthews (Herzberg Institute of Astrophysics)

We present the results of an interferometric study of the kinematics of the young star-forming region, IRAS 23033-5951. The interesting feature of this region is that its kinematic characteristics are very much like those of claimed massive star-forming disks, yet on far larger spatial scales. The dense gas tracers in the region, namely, N_2H^+ and H^{13}CO^+ , trace a geometrically thin object which

lies perpendicular to the main outflow in the region and which has a velocity gradient of several kilometers per second along its long axis. However, this long axis is some 10^5 AU long! We discuss several plausible interpretations of this object and put it in context among those objects claimed to be disks forming massive stars. We also identify two massive, apparently pre-stellar sources in the field which merit further investigation as candidate “Class 0” massive cores.

P38. A new view of the super star clusters in the low-metallicity galaxy SBS 0335–052

Amy E. Reines (University of Virginia)

Kelsey E. Johnson (University of Virginia), Leslie K. Hunt (INAF)

We present a study of the individual super star clusters (SSCs) in the low-metallicity galaxy SBS 0335–052 using new near-infrared and archival optical *Hubble Space Telescope* observations. The physical properties of the SSCs are derived from fitting model spectral energy distributions (SEDs) to the optical photometry, as well as from the $H\alpha$ and $Pa\alpha$ nebular emission. Among the clusters, we find a significant age spread that is correlated with position in the galaxy, suggesting successive cluster formation occurred in SBS 0335–052 triggered by a large-scale disturbance traveling through the galaxy at a speed of ~ 35 km/s. The SSCs exhibit I -band ($\sim 0.8 \mu\text{m}$) and near-IR ($\sim 1.6 - 2.1 \mu\text{m}$) excesses with respect to model SEDs fit to the optical data. We hypothesize that the I -band excess is dominated by a photoluminescent process known as Extended Red Emission; however, this mechanism cannot account for the excesses observed at longer near-IR wavelengths. From the cluster SEDs and colors, we find that the primary origin of the near-IR excess observed in the youngest SSCs (< 3 Myr) is hot dust emission, while evolved red supergiants dominate the near-IR light in the older (> 7 Myr) clusters. We also find evidence for a porous and clumpy interstellar medium (ISM) surrounding the youngest, embedded SSCs: the ionized gas emission underpredicts the expected ionizing luminosities from the optical stellar continuum, suggesting ionizing photons are leaking out of the immediate vicinity of the clusters before ionizing hydrogen. The corrected, intrinsic ionizing luminosities of the two SSCs younger than ~ 3 Myr are each $\sim 5 \times 10^{52} \text{ s}^{-1}$, which is equivalent to each cluster hosting ~ 5000 O7.5 V stars. The inferred masses of these SSCs are $\sim 10^6 M_{\odot}$.

P39. Submillimetre line mapping of star formation in molecular clouds

John Richer (Cavendish Laboratory, Cambridge, UK)

We present some of the first degree-scale images of submillimetre line emission from GMCs at high angular resolution using the HARP array on the JCMT. HARP allows for the first time rapid line mapping in the 325–375 GHz band, with an angular resolution of about 14 arcseconds. We will present images of several local molecular clouds complexes, and discuss the utility of these datacubes in constraining models of molecular cloud structure and star formation. The 350 GHz band is of vital importance to ALMA: with its higher angular resolution, ALMA will be able to

image GMCs on similar linear scales to those in HARP images out to distances of 10 kpc or more, so these images serve as a template to ALMA's capabilities for studying GMCs throughout the galaxy.

P40. GEMINI near-infrared spectroscopic observations of young massive stars

Alexandre Roman-Lopes (Universidad La Serena - Astronomy Group - La Serena - Chile)

Zulema Abraham (IAG-USP), Roberto Ortiz (EACH-USP), Alberto Ardila (Laboratório Nacional de Astrofísica - LNA)

K-band spectra of young stellar candidates in four southern hemisphere clusters have been obtained with the near-infrared spectrograph GNIRS in Gemini South. The clusters are associated with IRAS sources that have colors characteristic of ultracompact HII regions: IRAS09149-4743, IRAS15408-5356, IRAS16132-5039 and IRAS16177-5018. Spectral types were obtained by comparison of the observed spectra with those of a NIR library; the results include the spectral classification of nine massive stars and seven objects confirmed as background late-type stars. One young stellar object (YSO) was found in each cluster, associated with either the main IRAS source or a nearby resolved MSX component. The distances to the stars were derived from their spectral types and previously determined *JHK* magnitudes; they agree well with previously determined kinematic distances, except in the case of IRAS15408-5356, for which the spectroscopic distance is about a factor two smaller than the kinematic value.

P41. Super molecular clouds associated with super star clusters in Henize 2-10?

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In the extragalactic context, compact galaxies with intense star formation that produces the so called Super Star Clusters (SSCs) are particularly interesting. Compared to high mass star formation regions in our Galaxy, the properties of these clusters are extreme and suggest that also the associated molecular clouds should be extremely dense and compact. Henize 2-10 is a blue compact dwarf galaxy, located at a distance of about 9 Mpc, dominated by a powerful episode of star formation. This is an exceptionally rich molecular environment and an ideal target to study the molecular clouds associated with SSCs. We present the results of IRAM 30 m and SMA observations at millimeter wavelengths of HCN(1-0), ¹³CO(2-1), and CO(2-1) toward Henize 2-10.

P42. The APEX Telescope Large Area Survey of the Galaxy (ATLASGAL)

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Submillimeter continuum emission traces high molecular column densities and, thus, dense cloud regions in which new stars are forming. Surveys of the Galactic plane in such emission have the potential of delivering an unbiased view of high-mass star formation throughout the Milky Way. The location of the Atacama Pathfinder Experiment (APEX) telescope on the Chajnantor plateau in Chile is ideally suited for mapping the inner Galaxy. After a brief introduction to this telescope and its instruments, our ongoing Galactic plane survey, ATLASGAL, will be described. Its scope, current status and first results will be presented. Aimed at mapping 360 square degrees with a uniform sensitivity of 50 mJy/beam using the Large APEX Bolometer Camera (LABOCA), this survey will provide the first unbiased sample of cold dusty clumps in the Galaxy at submillimeter wavelength - targets for molecular line follow-up observations and high resolution studies with ALMA and the EVLA. Our mid-term strategy for this project will be described, and preliminary results will be shown.

P43. Observational evidence for outflow-triggered star formation in the OMC-2 FIR 3/4 region

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We have carried out millimeter interferometric observations of the Orion Molecular Cloud-2 (OMC-2) FIR 3/4 region at an angular resolution of $\sim 3'' - 7''$ with the Nobeyama Millimeter Array (NMA) in the H^{13}CO^+ ($J=1-0$), ^{12}CO ($J=1-0$), SiO ($v=0, J=2-1$), and CS ($J=2-1$) lines and in the 3.3 mm continuum emission. Submillimeter single-dish observations of the same region have also been performed with Atacama Submillimeter Telescope Experiment (ASTE) in the ^{12}CO ($J=3-2$) and CH_3OH ($J_K=7_K-6_K$) lines. Our NMA observations in the H^{13}CO^+ emission have revealed 0.07 pc-scale dense gas associated with FIR 4. The ^{12}CO ($J=3-2,1-0$) emission shows high-velocity blue and redshifted components at both the north-east and south-west of FIR 3, suggesting a molecular outflow driven by FIR 3 nearly along the plane of the sky. The SiO ($v=0, J=2-1$) and the submillimeter CH_3OH ($J_K=7_K-6_K$) emission, known as shock tracers, are detected around the interface between the outflow and the dense gas. Furthermore, the ^{12}CO ($J=1-0$) emission shows an L-shaped structure in the P-V diagram. These results imply presence of the shock due to the interaction between the molecular outflow driven by FIR 3 and the dense gas associated with FIR 4. Moreover, our high angular-resolution ($\sim 3''$) observations of FIR 4 in the 3.3 mm continuum emission with the NMA have first found that FIR 4 consists of eleven dusty cores with a size of

$\sim 1500 - 4000$ AU and a mass of $\sim 0.2 - 1.4 M_{\odot}$. The separation among these cores ($\sim 5 \times 10^3$ AU) is on the same order of the Jeans length ($\sim 13 \times 10^3$ AU), suggesting that the fragmentation into these cores has been caused by the gravitational instability. The time scale of the fragmentation ($\sim 3.8 \times 10^4$ yr), estimated from the separation divided by the sound speed, is similar to the time scale of the interaction between the molecular outflow and the dense gas ($\sim 1.4 \times 10^4$ yr). We suggest that the interaction between the molecular outflow from FIR 3 and the dense gas at FIR 4 triggered the fragmentation into these dusty cores, and hence the next generation of the cluster formation in FIR 4.

P44. Observations of a compact (< 1000 AU) MYSO cluster with HST

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Observations show that most, if not all, massive stars form in clusters. This combination of massive stars and clusters has led to the suggestions that massive stars form by coalescence after stellar collisions or by enhanced accretion due to the gravitational potential of the cluster instead of the simple accretion through a disk embedded in an isolated natal cloud that is the current paradigm for low-mass star formation. We have been studying the massive young stellar objects (MYSOs) in the nearest star-forming regions using 2 micron polarimetry with the $0.2''$ resolution of NICMOS on Hubble Space Telescope. These stars, which are still embedded in dense envelopes, have cones of scattered light along their outflow axes. Through polarimetry we can infer the orientation and illuminating star of each observed outflow; thanks to our high spatial resolution we can also observe twists in the outflow axes (possibly due to precession) and other asymmetries and irregularities that indicate the outflows are episodic or are influenced by neighboring stars. Mon R2 IRS3 is one of the most interesting of our targets. This compact stellar group is found in the center of the Mon R2 star cluster just east of the well-known Mon R2 IRS1 H II region. The region is also known for its massive molecular outflows, the source(s) of which may no longer be actively ejecting mass and which cannot be identified with any of the currently known YSOs. In IRS3 itself at least three early B stars (total luminosity $1.4 \times 10^4 L_{\odot}$) are found within a core of $< 1.2''$ (< 1000 AU). Our polarimetry shows that the outflow axes of the two brightest stars are perpendicular in the plane of the sky, although much of the dust appears to envelope all the IRS3 cluster ($20''$). Moreover, the brightest star is sufficiently embedded in its envelope plus disk that it appears extended in the NICMOS resolution. We will discuss the three stars and their interaction using models of our data and archival NICMOS images at other wavelengths. Clearly high spatial resolution is needed to distinguish these MYSOs. Stars of much younger ages than those in Mon R2 will not be visible in the near infrared; instead observations will need to be done with mm interferometers such as ALMA.

P45. High-velocity molecular outflows from massive young stars

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Although bipolar molecular outflows have been recognized as a common phenomenon of star formation, it is not clear how the bulk of the outflowing gas is accelerated. Also the composition of the primary jet/wind which is responsible for accelerating the ambient material has not been identified. High-velocity ($v_{\text{flow}} > 10 \text{ km s}^{-1}$) outflowing gas often demonstrates distinguished behaviors with low-velocity counterparts and hence is a potential candidate of the outflow driving agent. We present here a millimeter and submillimeter study of high-velocity molecular outflows from massive young stellar objects at resolutions of $2''$ – $3''$. We will describe the physical conditions of the high-velocity gas, discriminate theoretical outflow driving mechanisms based on the observed outflow characteristics (morphology and kinematics), and lastly, discuss the relationship between the high-velocity outflow gas and the outflow driving agent (i.e., the primary jet/wind). Our results indicate that high-velocity CO gas is a good tracer to probe the primary jet.

P46. An investigation of the initial conditions of massive star formation

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The mass of a star is the single most important parameter in determining how it will interact with its environment, how long it will live, and the nature of its death. In the low-mass regime, observed mass distributions of dense molecular cores appear similar to the stellar initial mass function suggesting that the mass of a star is determined by the fragmentation of dense molecular gas. Our recent numerical results show that current observations of dense cores cannot imply any particular evolutionary pathway from cores to stars, and that the statistical trends seen in the low-mass regime cannot be extrapolated to high-mass stars.

Direct observations of the pristine conditions preceding high-mass star formation are needed to discriminate between conflicting formation paradigms and to determine the physical conditions required for the formation of massive stars. Unfortunately, these conditions are difficult to assess due in part to the large distances to high-mass star-forming regions and the propensity for massive stars to quickly and severely alter their environment.

The observational technique of interferometric mosaicking is a powerful tool for investigating wide fields at high-resolution in the wavebands most relevant for the very early phases of star formation. Two massive, quiescent Galactic clouds have been selected for intensive study to better understand the conditions leading to the formation of massive stars. Our $850 \mu\text{m}$ continuum images span $\sim 3'$ fields with $2''$ resolution and reveal in one cloud several cores free of MIPS $24 \mu\text{m}$ sources with masses between ~ 10 and $50 M_{\odot}$. A single $\sim 70 M_{\odot}$ quiescent core dominates the small scale structure of the other cloud.

Together with single-dish data and infrared imaging, we use these observations to characterize these clouds and assess the likelihood that they are Galactic proto-clusters. We also briefly discuss the potential for mosaic observations with ALMA to vastly improve our knowledge of the initial conditions of massive star formation.

P47. Optical and near-infrared IFU kinematics and the interplay with the ISM phases in the prototype H II galaxy II Zw 40

Eduardo Telles (University of Virginia)

I present the results of Integral Field spectroscopy on the prototype H II galaxy II Zw 40 from a combination of two complementary collaborations. Using Gemini GMOS-IFU in the red part of the visible spectrum Bordalo, Plana & Telles (2008) derived H α monochromatic, velocity and dispersion maps on the central star forming knot. We show that II Zw 40 has a kinematic core which is dominated by random motions with a core velocity dispersion of 34 km s⁻¹. It also shows a lower limit supersonic velocity dispersion of $\sigma \sim 26$ km s⁻¹, unaffected by stellar evolution, which permeates the whole star forming region, likely to represent the dispersion associated with gravity. Diagnostic diagrams, such as the Intensity versus σ diagram, are used to identify the kinematic features as shells and filaments due to the stellar driven winds. A single Gaussian fit to the integrated spectrum H α line over the whole star forming region will measure exactly the same width as a single Gaussian fit to the one pixel core H α line.

Using SINFONI integral field in the near-infrared with adaptive optics on the VLT, Vanzi, Cresci, Telles & Melnick (2008) analysed the spatial distribution of extinction, ionized Hydrogen, Helium, [Fe II] and molecular hydrogen (H₂) emission and velocity fields. We show that II Zw 40 is solely powered by one super stellar cluster (knot A) producing all the present ionizing radiation. It is also responsible for the photo-excitation of H₂, although this has a peculiar velocity field detached from Br γ and [Fe II].

Both of these studies are in good agreement revealing that the age of the stellar population in the main cluster is such that no supernova (SN) should be present yet so that the gas kinematics must be dominated by the young stars with a dominant turbulent random component in the core. We do not see, in the starbursting region, any geometrical or dynamical structure that can be related to the large scale morphology of the galaxy.

P48. Two-fluid turbulence in molecular cloud cores

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We investigate the behaviour of molecular cloud core turbulence in the presence of ion-neutral friction, using the RIEMANN code. We utilize a two-fluid formulation of the ambipolar drift coupled with an adiabatic equation of state that allows us to characterize the frictional reheating of the molecular gas. We measure the correlation between the density clumping and the magnetic field, and cross-compare with the single-fluid case.

P49. High mass star forming regions: Turbulent support or gravitational collapse?

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We present numerical simulations of driven hydrodynamic, isothermal turbulence, providing evidence that at least part of the nonthermal linewidth observed in molecular clouds consist of coherent, inwards motions. This result implies that a significant fraction of the kinetic energy in MCs is not available for support against gravitational collapse, but rather promotes it, or is a consequence of it. The evidence is provided by the existence of an anti-correlation between the mean density of clumps and the mean divergence of the velocity field. We then show that the clumps and cores appearing in regions of dynamic collapse in a numerical simulation of the evolution of a dense cloud formed by a transonic compression in the diffuse atomic ISM exhibit physical properties comparable to those observed in the clumps and cores of high-mass star forming regions. This result suggests that such regions may at sites of large-scale collapse of a cloud.

P50. H₂CS emission in regions of massive star formation

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Jeff Mangum (NRAO)

Using arguments parallel to those used in support of using H₂CO as a sensitive probe of temperature and density in molecular clouds, we measured the $J = 7 \rightarrow 6$ and $J = 10 \rightarrow 9$ transitions of thioformaldehyde (H₂CS) in several hot core sources. The goal here was to investigate more closely the conditions giving rise to H₂CS emission in cloud cores containing young stars by modelling several transitions. As a slightly asymmetric rotor, many H₂CS transitions occur closely spaced in frequency, though they are substantially separated in energy. Transitions of H₂CS originating from the $K = 0, 1, 2, 3,$ and 4 ladders in the 230 and 345 GHz windows can productively be used to constrain densities and temperatures. As a first step in developing the use of these transitions as thermometers and densitometers, we surveyed and modeled the emission from well known warm dense cores.

P51. Studying massive star-forming clumps using dense molecular tracers with single-dish & the SMA

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Massive star formation occurs in very dense, turbulent, Giant Molecular Cloud (GMC) clumps. We have mapped a sample of more than 50 massive dense GMC clumps with multiple dense gas tracers (HCN 1-0, 3-2, CS 2-1, 5-4, 7-6) with single-dish telescopes, to study the conditions of massive star-forming regions, and to analyse the difference between these tracers. We found that the molecular line luminosity of all these dense gas tracers has a nearly linear correlation with their star formation rate (indicative by their infrared luminosities) for these dense GMC clumps; some correlations can be connected to extragalactic star formation.

To deeply explore the density structure and internal dynamics of individual massive dense clumps, we have started a project to use the SMA to follow-up observing a sample of about 10 massive dense clumps, most of which are best infall candidates from our single-dish study. Maps of good molecular infall tracers, HCN 3-2 and HCO⁺ 3-2, as well as many other molecules and high resolution continuum were obtained in this survey. Here we also report the early result of this study.

P52. Inflow motions in massive star formation regions

Yuefang Wu (Peking University)

After a brief review of the recent progress of searches for inflow motion in high-mass star forming regions, we focus on “blue profile”, one of the collapse signatures. We talk about the statistical characteristics of “blue profile”, then mention the mapping studies of inflow motions. Then we summarize the detections of the red-shifted gas absorption, which is a stronger characteristic of inflow motion. Next we compare the studies of collapse motions in high-mass and low-mass star forming regions. We elaborate on molecular lines sensitive to collapse signatures. Finally we discuss the problems in current research and the questions left for future study.

P53. Theoretical modeling and observations of FIR/sub-mm/mm line emission in massive star-forming regions

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Studying the physical properties of molecular gas in galaxies is of fundamental importance for understanding the processes leading to star formation and the effect of star formation on the physical conditions of the neutral ISM at low and high redshifts. Multiple molecular line excitations in the nuclei of nearby starburst galaxies can yield important information (e.g., physical state and evolutionary sequence) on active star-forming phenomena.

I will present theoretical modeling and observation of FIR/sub-mm/mm molecular line emission in massive star-forming regions. We have developed a new set of Evolving Starburst Model (ESbM)

for the neutral ISM. The models consist of a standard dynamical model of the bubble/shell structure around a young star cluster, a time-dependent stellar population synthesis method, a fully time-dependent chemistry for the PDR regions, and a non-LTE line radiative transfer calculation. We follow the evolution of an ensemble of giant molecular clouds (GMCs) and expanding shells, and model multiple line emissions for various molecular and atomic species (CO, HCN, HCO⁺, C, O, C⁺). This work allows us for the first time to be able to relate line emission properties of molecular gas in a starburst galaxy to its age and star formation history. This study provides potential answers to several key science questions related to massive star formation at low and high z universe. It is a complementary study to the Starburst Models for dusty media. The predictions made by our models promise to be useful for the interpretation of future high resolution maps of molecular gas on small and large scales in starburst galaxies, to study the structure, dynamics, and evolution of the neutral ISM in these objects.

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