Chemical evolution of massive star-forming regions

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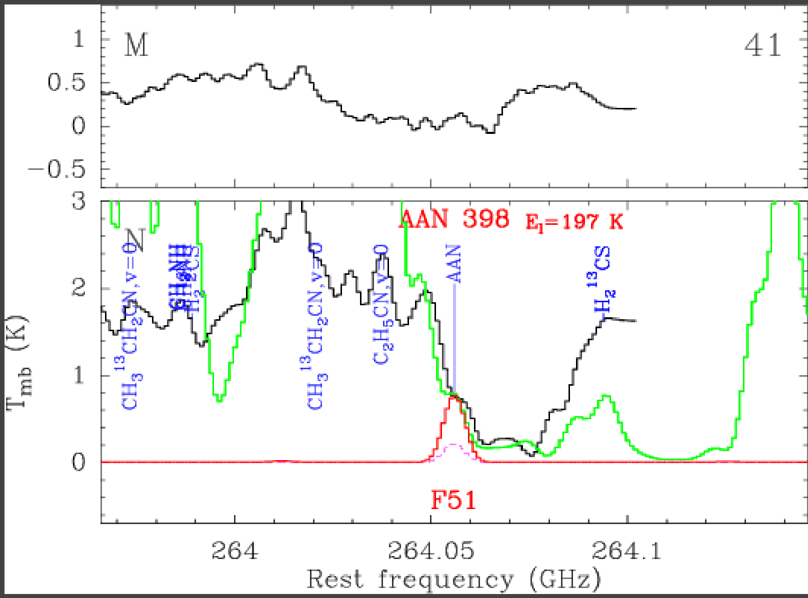
Two roles of chemistry in star formation studies

- Submm line radiation unique probe of
  - kinematics
  - temperature, density, ...
- Need to know which molecules are abundant under which conditions



- Active astrochemistry: use chemical models to learn about
  - ages of objects
  - invisible (ionizing) radiation
  - temperature history
- Parameters hard to obtain otherwise!

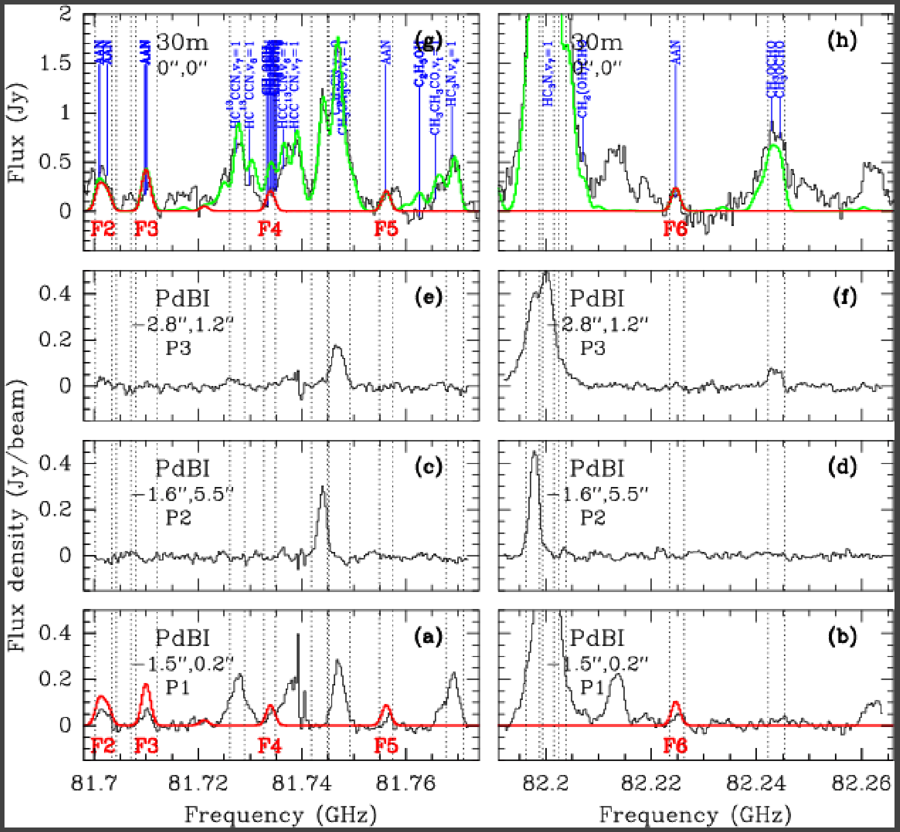
Currently >140 molecules known in space (38 extragalactic, 10 in solid state). Detection rate = a few per year!

Basic chemical processes in star formation

- **Cold gas: ion-molecule reactions**
  - no barriers, e.g., $CO + H_3^+ \rightarrow HCO^+ + H_2$ (ions from CR)
  - production rates OK, recombination rates / products uncertain
- **Warm gas: neutral-neutral reactions**
  - uncertain rates and barriers, e.g., $O + OH \rightarrow O_2 + H$
  - Odin detection in Oph << prediction: need lab data at low *T*
- **Cold dust: catalyst for H or O addition**
  - $CO \rightarrow CH_3OH$ route efficient in lab
  - uncertain *T* dependence (surface roughness)
- **Warm dust: ice evaporation**
  - CO, N_2 at 20 K, bulk H_2O at 110 K
  - rearrangement during warm-up key to complexity

New molecules 2008

- **Negative ions**
  - C_8H^- (Agúndez / Sakai et al 2008)
  - C_3N^- (Thaddeus et al 2008)
- **Phosphorus compounds**
  - CCP (Halfen et al 2008)
  - PH_3 (Tenenbaum & Ziurys 2008; Agúndez et al 2008)
- **Complex organics**
  - CH(O)CN (Remijan et al 2008)
  - NH_2CH_2CN (Belloche et al 2008)
- No D-molecules so far …



Reliable line ID: (1) full-spectrum analysis; (2) imaging information

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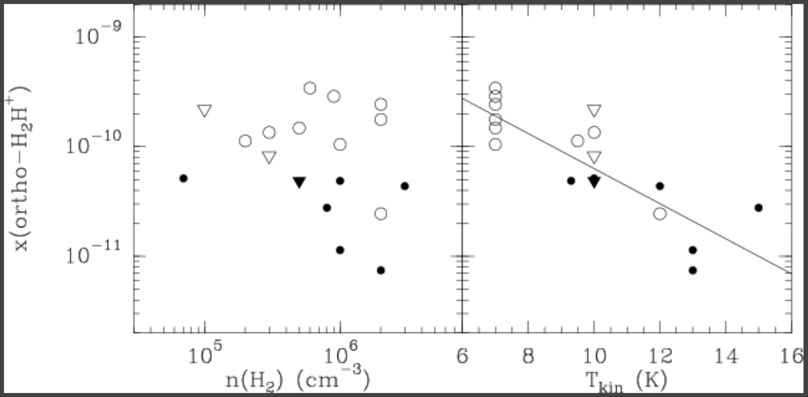
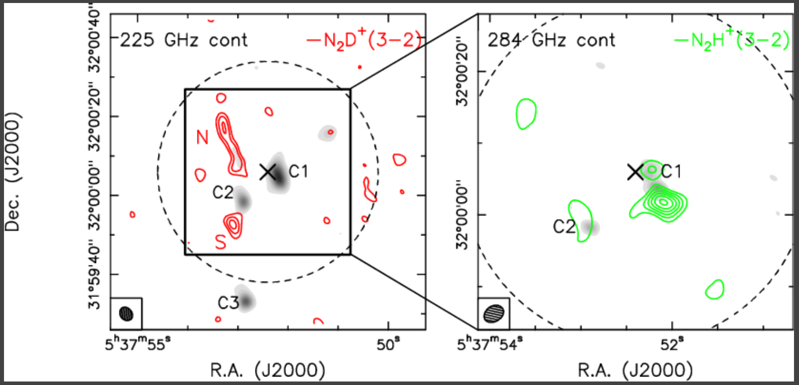
Deuterium fractionation in low- and high-mass cores

- **Survey of 16 low-mass pre/protostellar cores:**
  - [D/H] ~0.1 in densest cores
  - >99% of CNO freezes out
  - as *n* ↑, *T* ↓ *below* 10 K
  - when star turns on, [D/H] drops quickly
  - chance to constrain grain size
- **High-mass cores:**
  - 10-100x lower [D/H]
  - higher in low-*M* neighbours





High-mass pre-stellar cores: short time scales, high temperatures

Caselli et al 2008; Fontani et al 2008; posters DiFrancesco, Pillai

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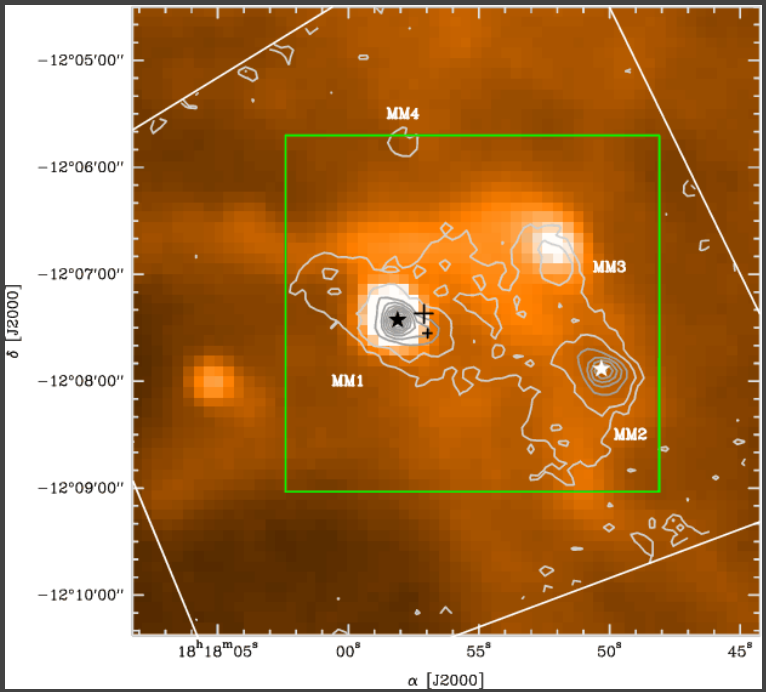
Ages of protostars in the IRAS 18151-1208 region

- **MM1: mature protostar**
  - strong outflow
  - bright in mid-IR
- **MM2: young protostar**
  - small outflow
  - weak mid-IR source
- **MM3: pre-stellar core**
  - weak line emission
  - narrow lines without wings



Systematic decrease of N_2H^+ / CS abundance ratio MM3 → MM1: Evolutionary indicator?

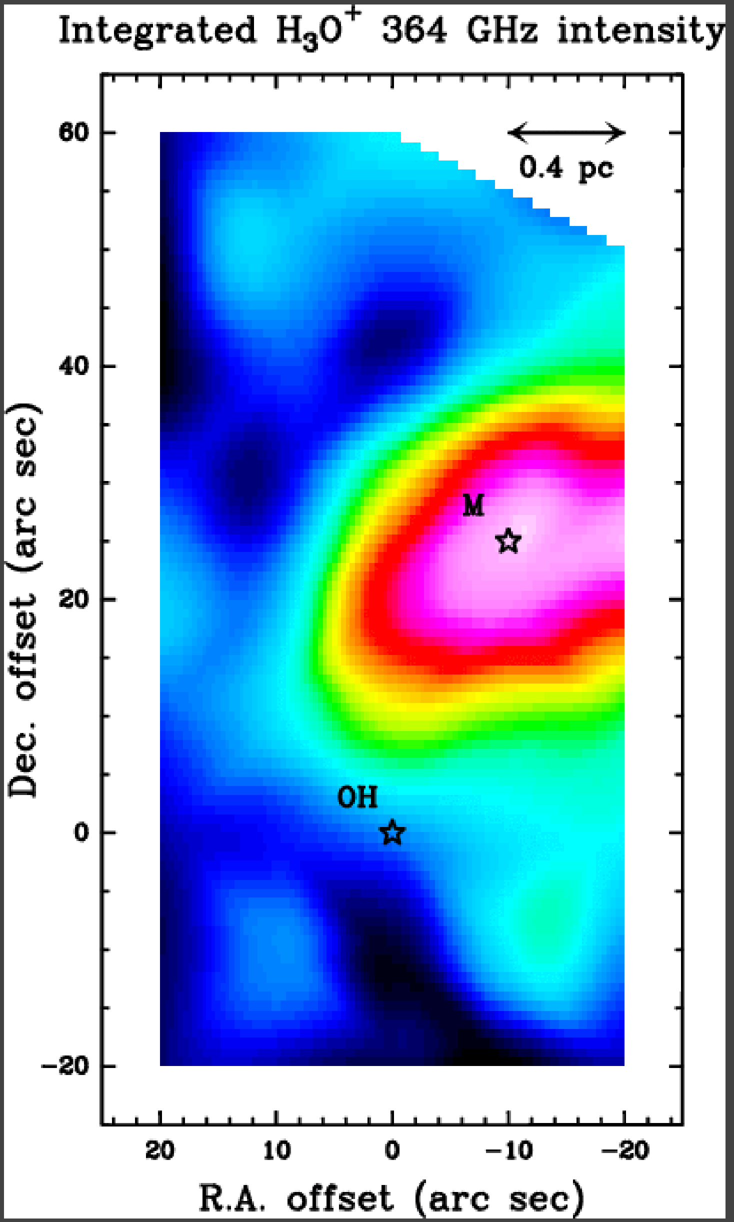
Marseille et al 2008

Enhanced cosmic-ray density in SgrB2

- **ζ_{CR} key for cloud dynamics and chemistry**
  - locally $\zeta_{CR} = 3 \times 10^{-17}\ s^{-1}$
  - factor -/+3 variation: extinction or location?
- **APEX: $H_3O^+ / H_2O = 1/50$**
  - ζ_{CR} 10x higher than local clouds
  - even higher ζ_{CR} in SgrA

Variation of cosmic-ray density by factor ~10 across Galaxy; and by factor ~3 due to attenuation / energy loss

Van der Tak et al 2006



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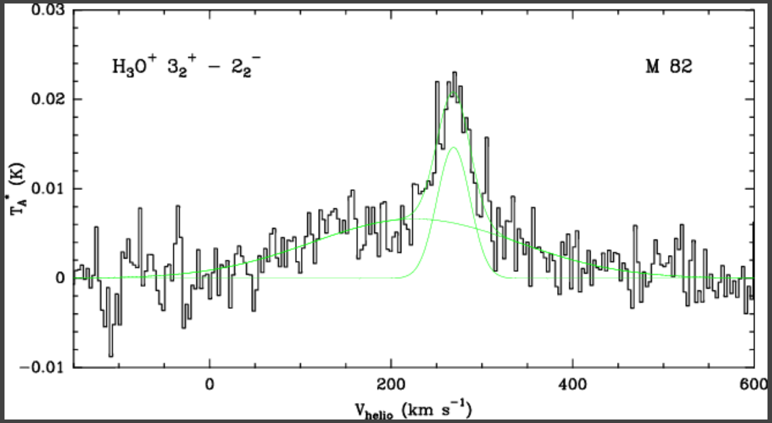
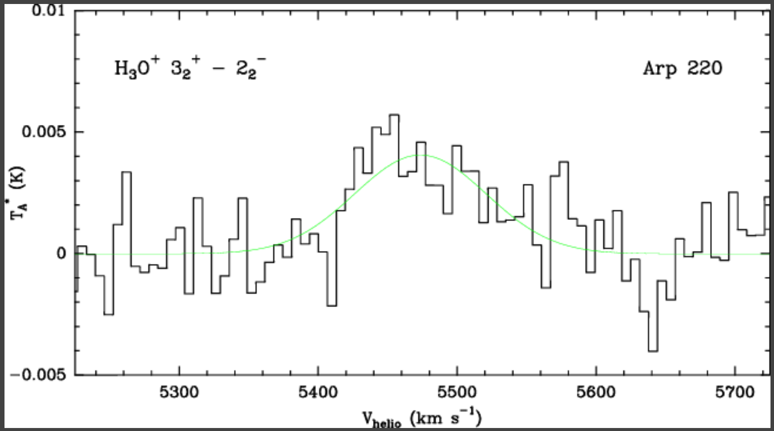
Detection of extragalactic H_3O^+

- **M82: prototype starburst**
  - *d* = 4 Mpc
  - IRAM 30m detection of CO^+
  - Emission likely extended
- **Arp 220: prototype merger**
  - *d* = 72 Mpc
  - ISO detection of H_2O
  - Emission confined to W nucleus?





For M82 need PDR with $\zeta_{CR} \sim 100\ \zeta_0$: evolved starburst. For Arp 220 need X-rays: from AGN (?) or from HMXB in starburst

Van der Tak et al 2008; see poster Pellegrini

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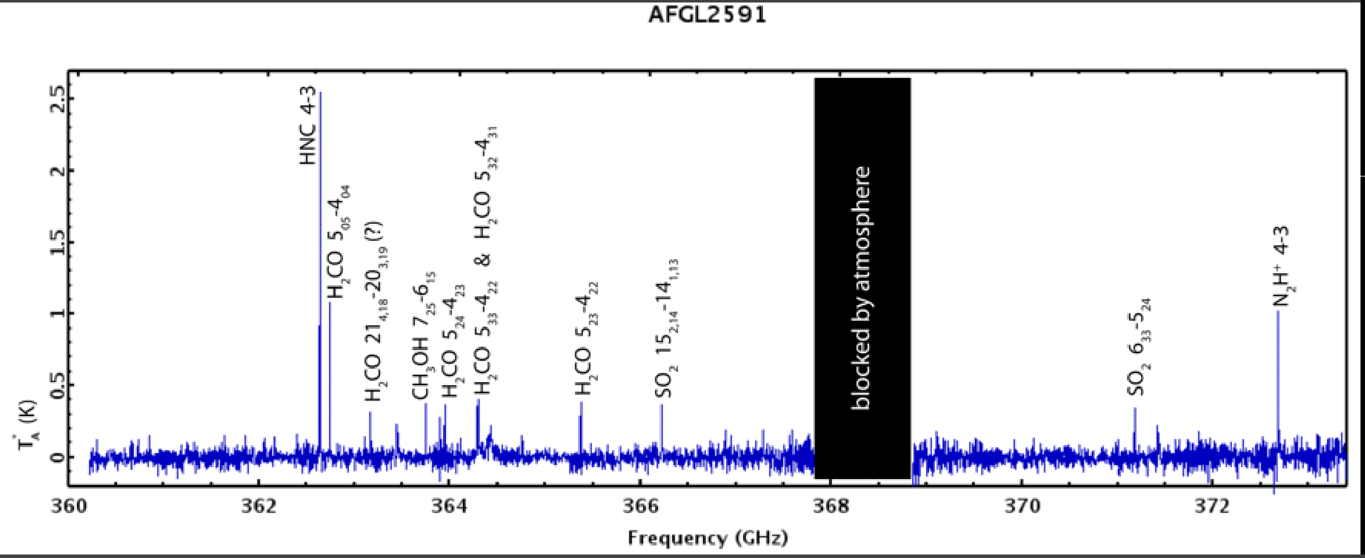
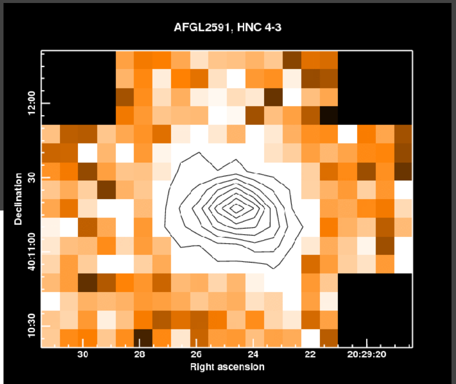
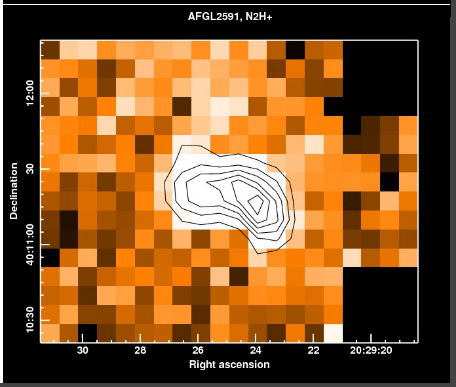
The JCMT Spectral Legacy Survey





HNC 4-3



N_2H^+ 4-3

- **Five star-forming regions, 330-373 GHz, 2x2 arcmin, 15 arcsec**
  - PDR: Orion Bar
  - Low mass core: NGC 1333 IRAS 4A
  - Intermediate mass core: IRAS 20126
  - High mass core: AFGL 2591
  - Starburst template: W49N

Van der Wiel et al 2008; see poster Richer

JCMT-SLS Spectral Legacy Survey

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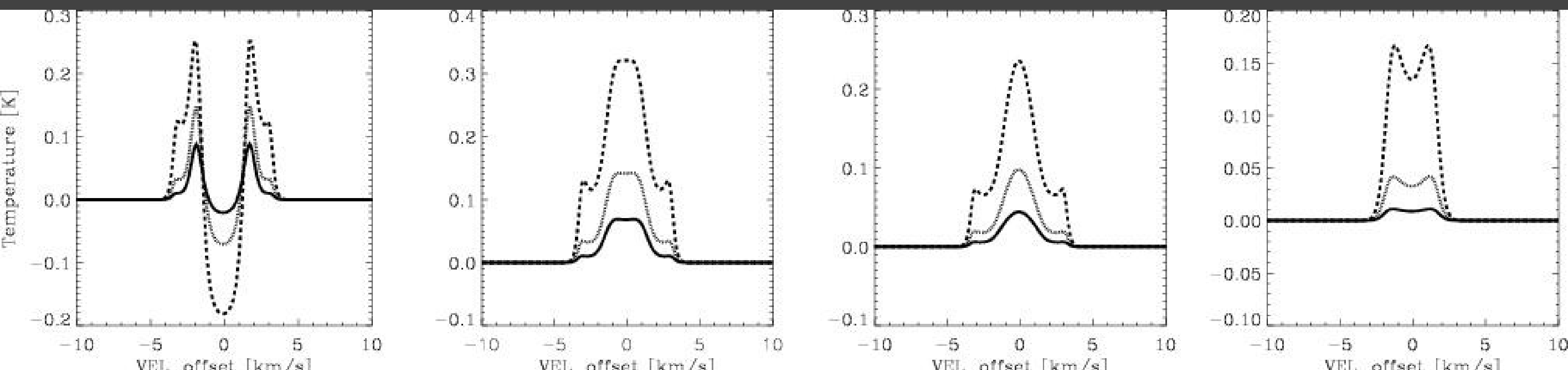
Future opportunities 1: *Herschel*-HIFI

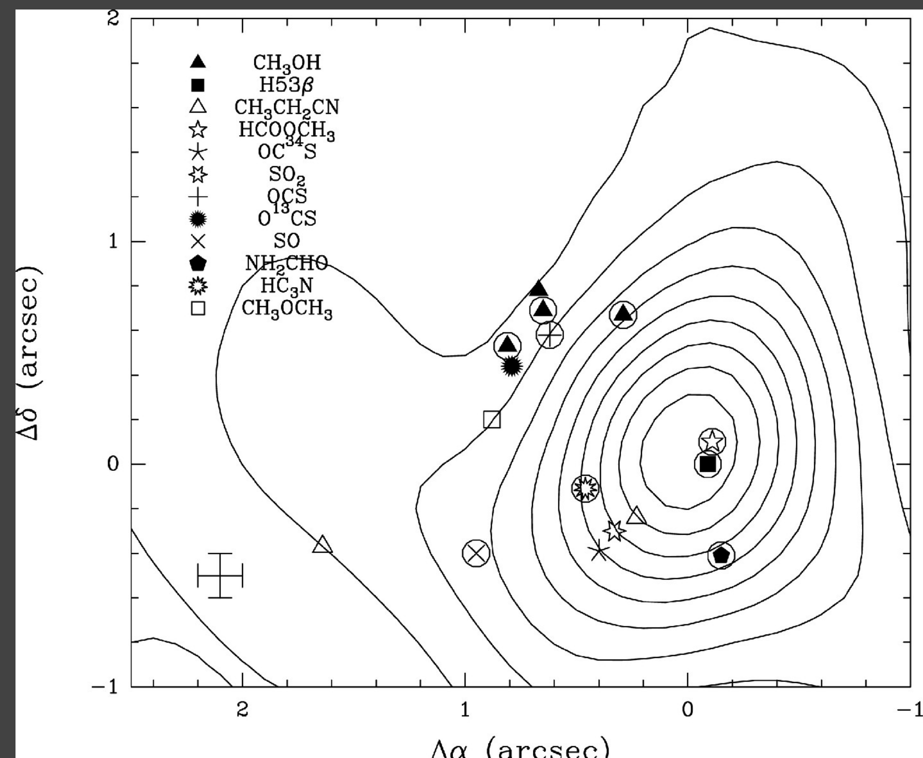
- **WISH**: follow water trail through star formation
- **HS3F:** molecular inventory of star-forming regions
- **PRISMAS**: measure composition of interstellar gas along line of sight toward bright Galactic objects (in absorption)
- **HOP**: measuring excitation and abundance of O_2 in a range of interstellar environments



Water line profile predictions for L = 2/7/25 L_0: Van Kempen et al 2008

Future opportunities 2: ALMA

- Resolve small-scale differentiation
- Sensitivity to detect isotopic lines → optical depth
- Bandwidth for multi-line studies → excitation
- Separate envelope / outflow / disk chemistry



BIMA observations of G34.26: Mookerjea et al 2007

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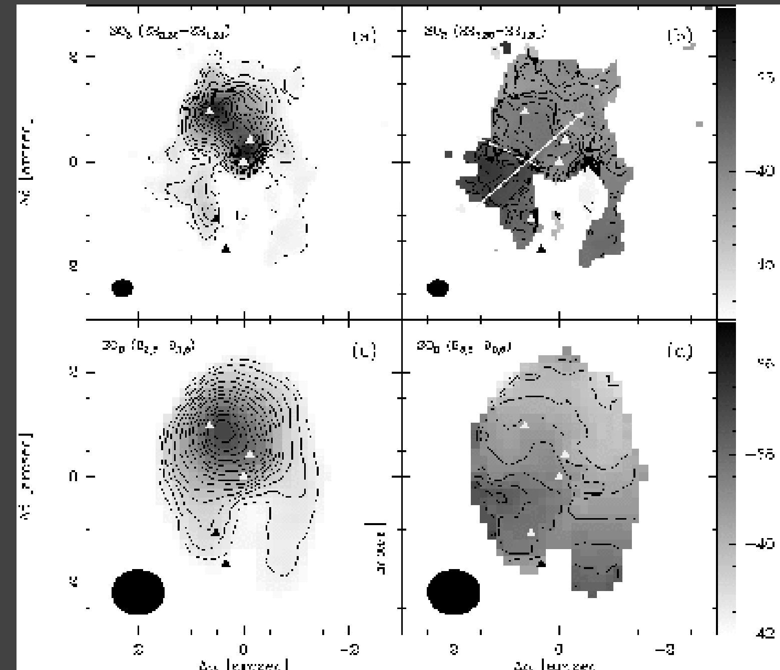
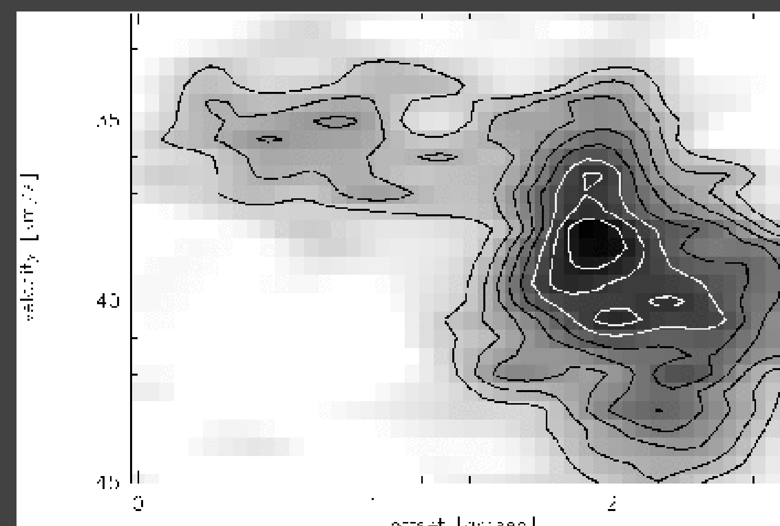
Converging flows in W3 IRS5?

- **Protocluster of 4-5 OB stars**
  - separation 0.1 pc
  - $L = 10^5\ L_0$, $d = 2$ kpc
- **Velocity jump in SO_2 emission**
  - PdB data, beam 0.36 arcsec
  - also seen in SMA data
- **Protostars close to front**
  - triggered by collision?

Rodón et al 2008





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