Massive Star Formation at the SMA
SMA publications on massive stars:

- 2005: 4 / 12
- 2006: 4 / 22
- 2007: 9 / 27

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17 / 61 = 28%
What did we do? 2005 2006 2007

- 5 papers on Orion
  - 3 papers from a PhD thesis
- 6 papers searching for disks in outflow sources
- 4 papers on Multiplicity in HMSFR
- 1 paper on 321 GHz H$_2$O maser
- 1 paper on recombination lines in HCHII regions
PhD thesis on Orion

- Luis Zapata supervised by Paul Ho
- Study the relationship of molecular outflows to HH outflows
- Suggestion that SiO(5-4) is a tracer of “young” outflows

CO(2-1)          SiO(5-4)
Search for rotating disks assoc.
with outflows

- Search through 6 outflow regions and ~30 lines for a reliable tracer showing evidence of rotation and hence a disk

- IRAS 18089-1732 HCOOCH$_3$ Beuther et al 2005
- IRAS 18182-1433 None found Beuther et al 2006a
- IRAS 2315+5912 CH$_3$OH($7_{1,7} - 6_{1,6}$)$_{v=1}$ Beuther et al 2006b
- G29.96+0.02 HN$_{13}$C
- HC$_3$N(37-36)$_{v=7}$ Beuther et al 2007
- Ceph A East CH$_3$CN Patel et al 2005
- AFGL 5142 CH$_3$CN Zhang et al 2007
Disk+Outflow: Motivation

- 2 Theories of Massive Star Formation

- Bate, Bonnell, Zinnecker 1998
  - Massive stars cannot form by accretion because of radiation pressure.
  - Therefore they form by stellar captures/collisions

- McKee & Tan 2003
  - Massive stars form the same way as Larson (1969) suggested for low mass stars (Jeans mass in a free-fall time), but high mass stars form in higher density gas
Search for disks

• Observers decided that if you could find one example of a massive star forming by accretion, then this would demonstrate that massive stars form by fragmentation and gravitational collapse.

• 5 articles in Nature about disks around stars 10 - 20 $M_\odot$.
  – Chini et al 2004
  – Sako et al 2005
  – Beltran et al 2005
  – Jiang et al 2005
  – Patel et al 2005 (SMA) Ceph A
Disk + outflow observations

Patel et al 2005 (SMA) Ceph A

CH$_3$CN $J=18-17$

-20 0 20 kms

Sep 4-5, 2007

SMA Advisory Committee
Multiplicity

- 5 papers on multiplicity in massive star formation
  - NGC6334 Hunter et al 2006
  - S255 Cyganowski et al 2007
  - AFGL5142 Zhang et al 2007
  - IRAS 05358+3543 Beuther et al 2007
  - Ceph A Brogan et al 2007
A complex flow

• Ceph A

Brogan et al 2007
Rotation and Multiplicity

Spin-Up and Fragmentation?

- As a cloud contracts, both spin-up and fragmentation occur simultaneously. Fragments may contain stars of different mass and evolutionary times and therefore different chemistries.

Krumholz et al 2007
SMA / VLA

- Comparison of SMA vs VLA lines as diagnostics
  - 22 / 321 GHz masers
  - mm / cm radio recombination lines
- New techniques: One paper each
22 / 321 GHz H$_2$O Maser

- H$_2$O maser emission is associated with shocked gas

- Excitation is not entirely understood
  - 22 and 321 by collisions (Neufeld & Melnick 1990)
  - 183 by radiation (Kuiper et al 1984)

- One SMA observation of Ceph A suggests
  - 321 GHz masers in outflows
  - 22 GHz masers in disks
  - 321 without 22 ??

**Patel et al 2007**
Radio Recombination lines

• RRL broadening
  – Gas density
    • $1 / \text{Frequency}^{4}$th power
  – Gas motions
    • Frequency independent

• SMA / VLA
  – H30α (SMA) no broadening up to $10^{8} \text{ cm}^{-3}$
    • Supersonic velocities in HII regions
  – H76α (VLA) excess width
    • High density in optically thick ionized gas
SMA Accomplishments in Massive Star Formation 2005-2007

- PhD Thesis on outflows in Orion

- Observations of Multiplicity and rotating accretion flows
  - A better understanding of how to use the information in multiple molecular lines?
  - A possibility of clustered massive star formation by spin-up and fragmentation ??
  - SMA / VLA diagnostics