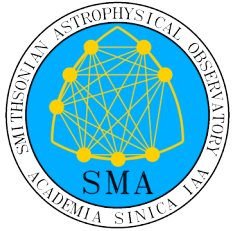


Massive Star Formation at the SMA

Sep 4-5, 2007

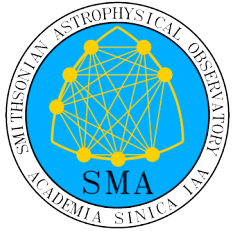
SMA Science Committee



SMA publications on massive stars:

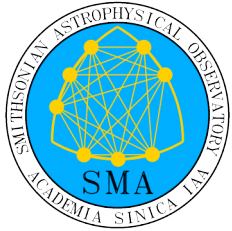
Massive Stars / Total Publications

- 2005 4 / 12
- 2006 4 / 22
- 2007 9 / 27
- -----
- 17 / 61 28%



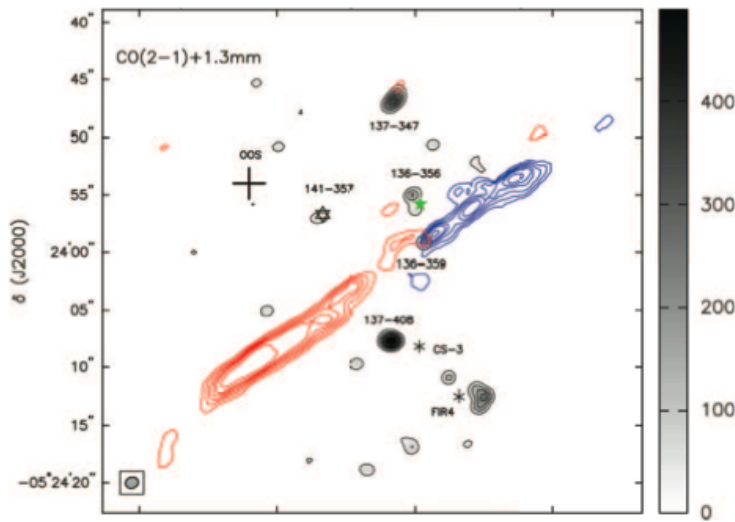
What did we do? 2005 2006 2007

- 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 H₂O maser
- 1 paper on recombination lines in HCHII regions

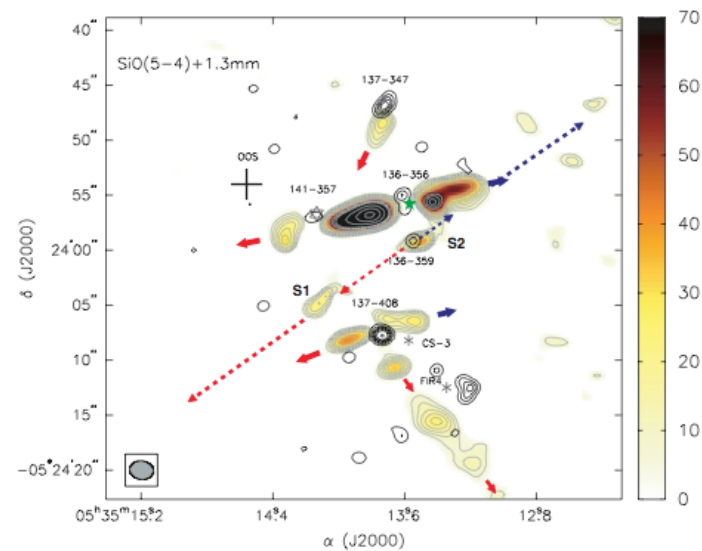


PhD thesis on Orion

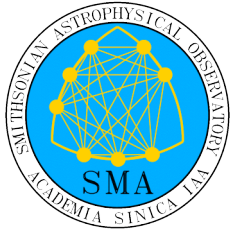
- Luis Zapata supervised by Paul Ho
- Study the relationship of molecular outflows to HH outflows
- Suggestion that SiO(5-4) is a tracer of “young” outflows



CO(2-1)



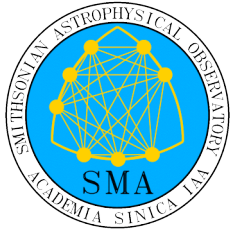
SiO(5-4)



Search for rotating disks assoc. with outflows

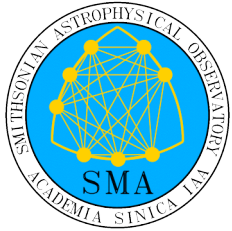
- Search through 6 outflow regions and ~30 lines for a reliable tracer showing evidence of rotation and hence a disk

• 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



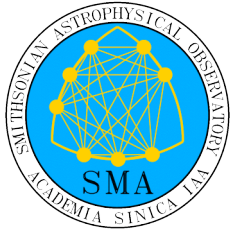
Disk+Outflow: Motivation

- 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



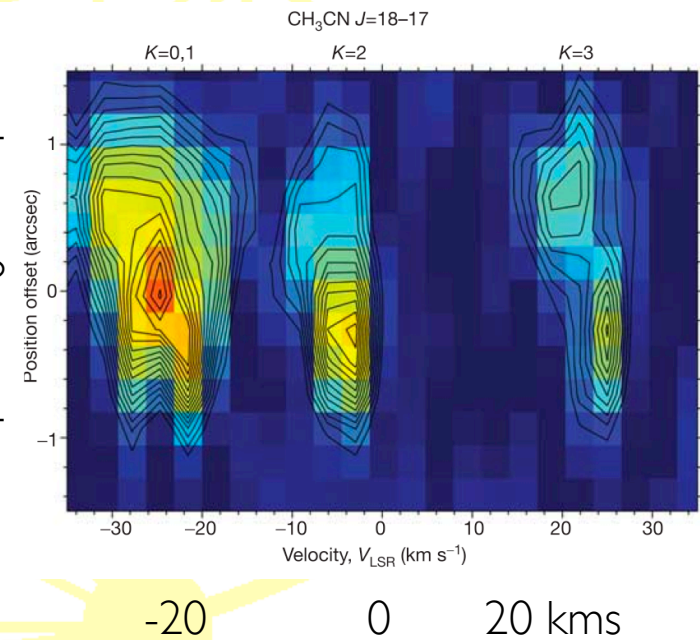
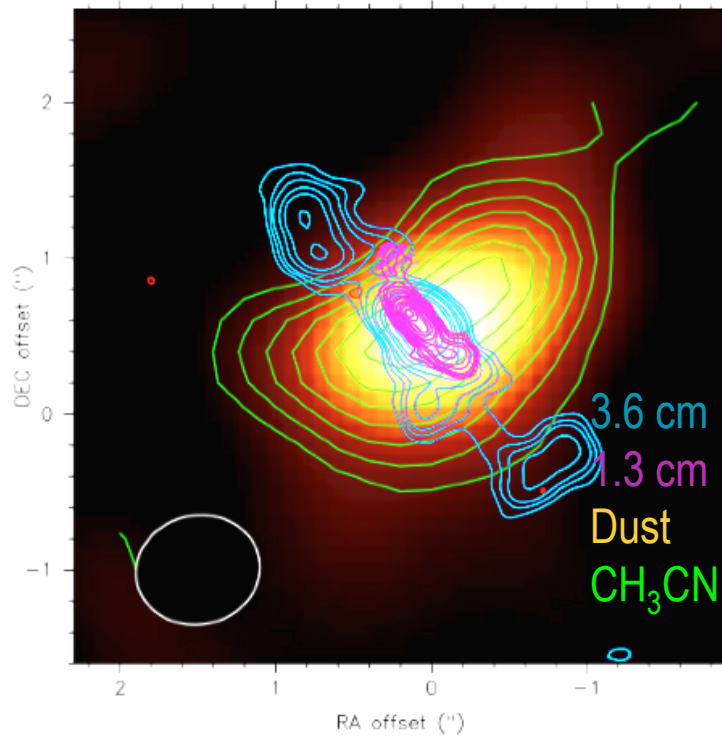
Search for disks

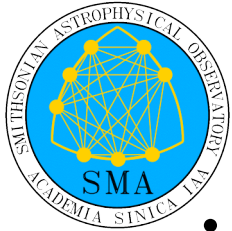
- Observers decided that if you could find one example of a massive star forming by accretion, then this would demonstrate that massive stars form by fragmentation and gravitational collapse.
- 5 articles in Nature about disks around stars 10 - 20 M_{\odot} .
 - Chini et al 2004
 - Sako et al 2005
 - Beltran et al 2005
 - Jiang et al 2005
 - Patel et al 2005 (SMA) Ceph A



Disk + outflow observations

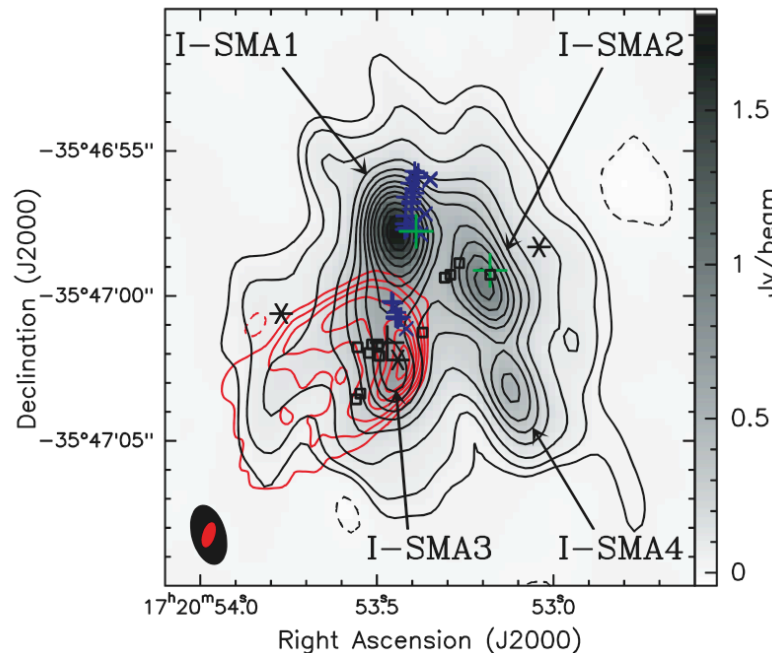
Patel et al 2005 (SMA) Ceph A



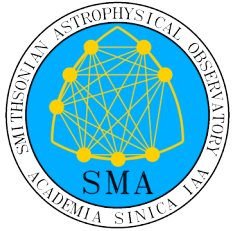


Multiplicity

- 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](#)



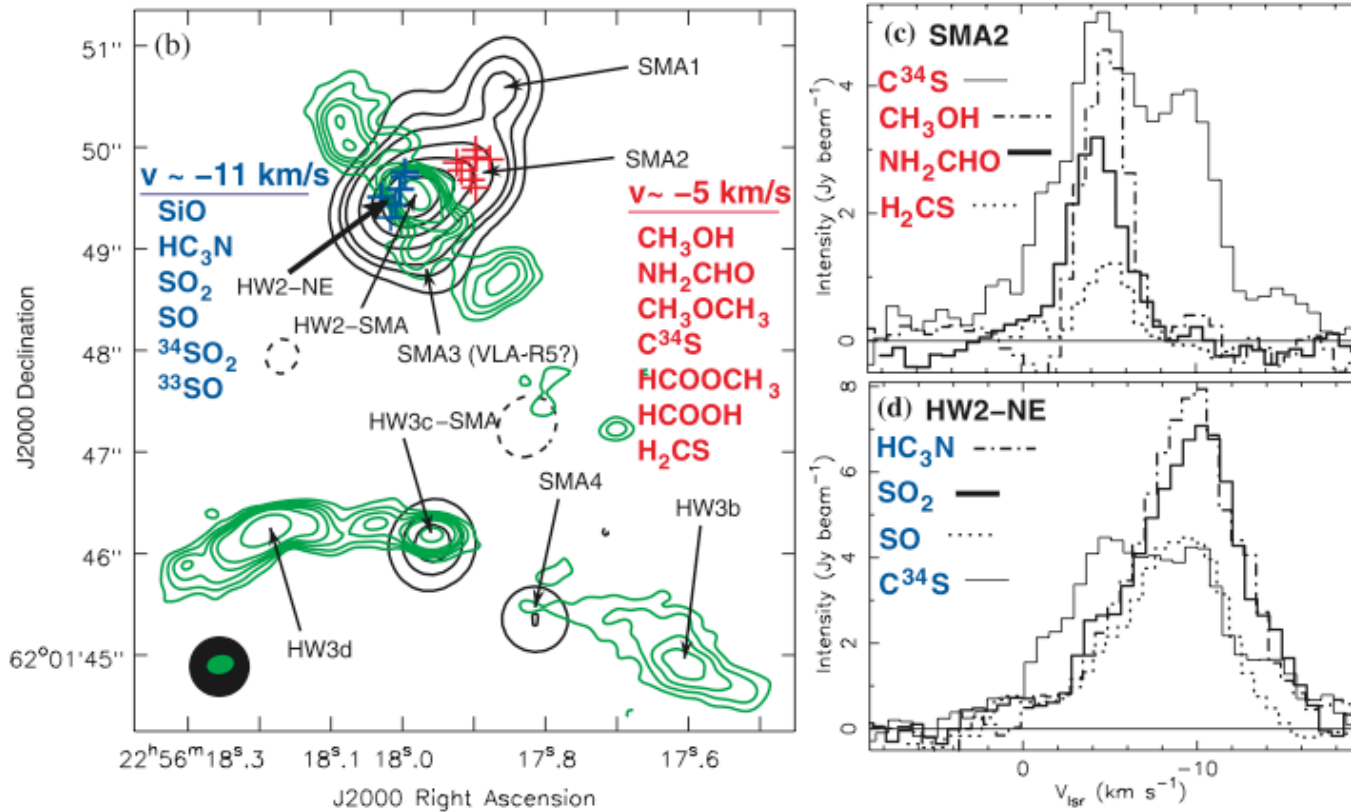
NGC6334 Hunter et al 2006

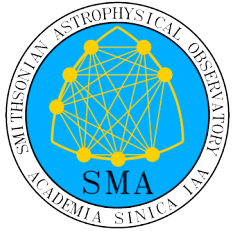


A complex flow

• Ceph A

Brogan et al 2007

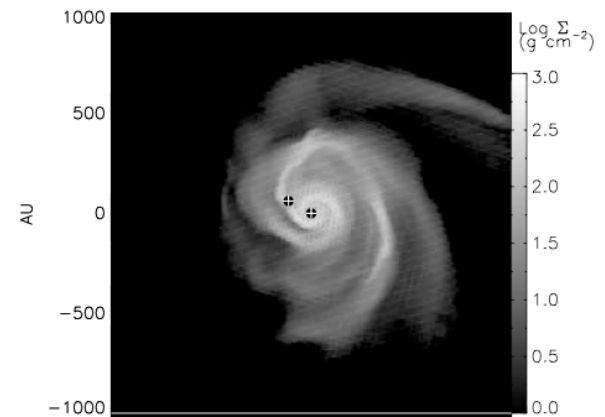
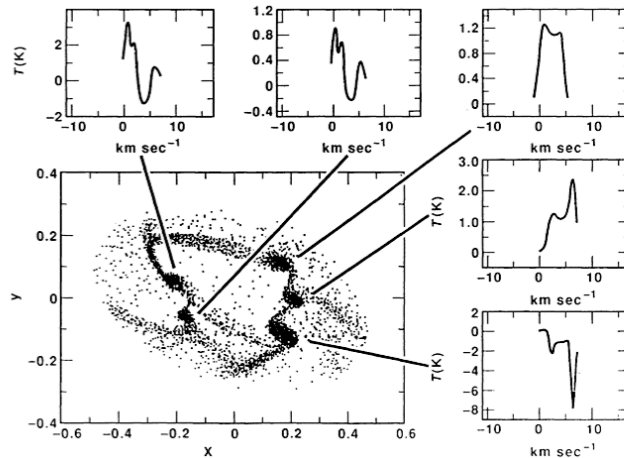
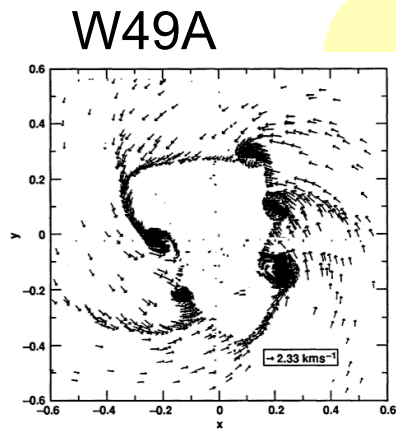




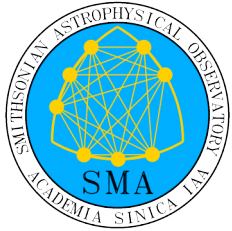
Rotation and Multiplicity

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.

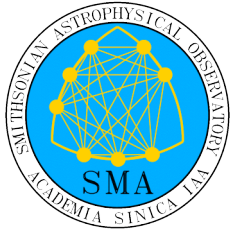


Krumholz et al 2007



SMA / VLA

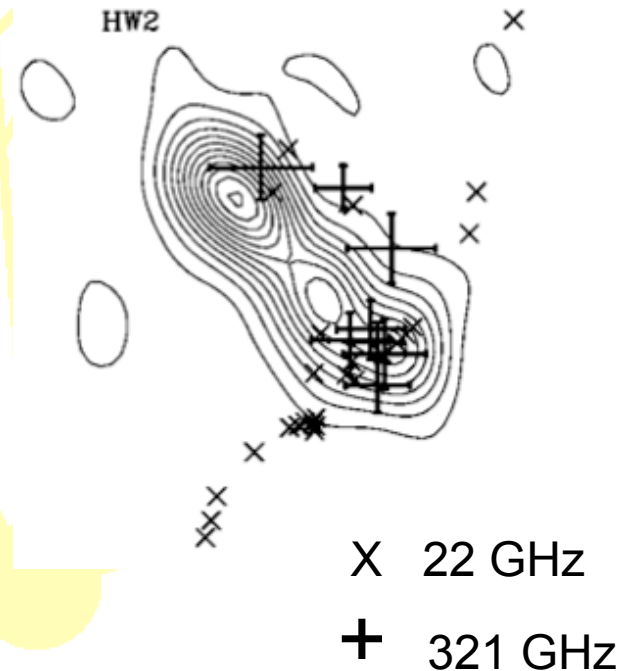
- Comparison of SMA vs VLA lines as diagnostics
 - 22 / 321 GHz masers
 - mm / cm radio recombination lines
- New techniques: One paper each

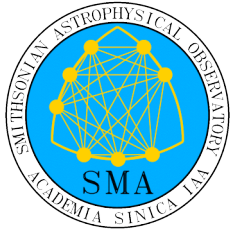


22 / 321 GHz H₂O Maser

- H₂O 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 ??

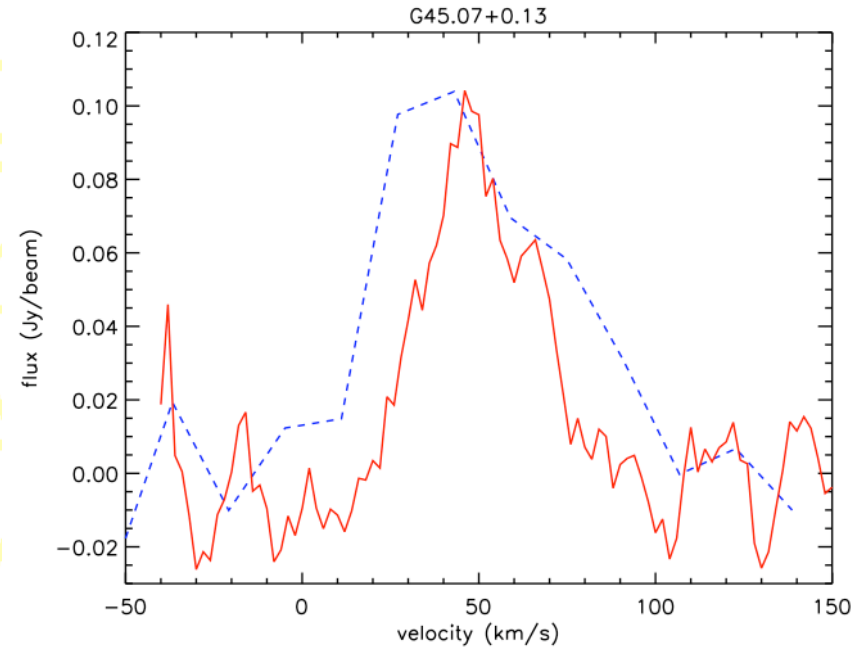
Patel et al 2007

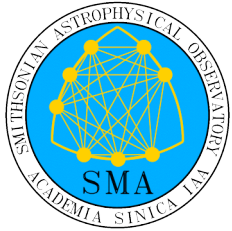




Radio Recombination lines

- RRL broadening
 - Gas density
 - $1 / \text{Frequency}^4$ power
 - Gas motions
 - Frequency independent
- SMA / VLA
 - H30 α (SMA) no broadening up to 10^8 cm^{-3}
 - Supersonic velocities in HII regions
 - H76 α (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