Gas dynamics 20-1000 AU from Orion BN/KL source *I* (a high mass YSO)

L. Greenhill

How do stars of ~ 10 $M_\odot$ form?

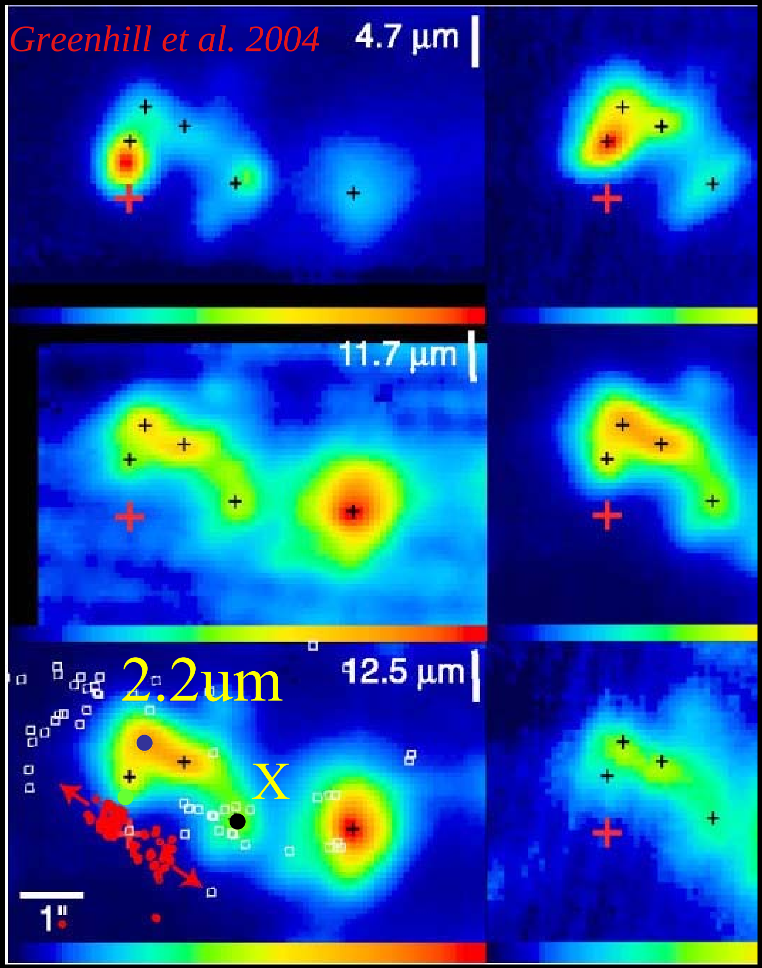
— What lies inside 1000, 100, and 10 AU ?

— What drives and collimates assoc. outflows?

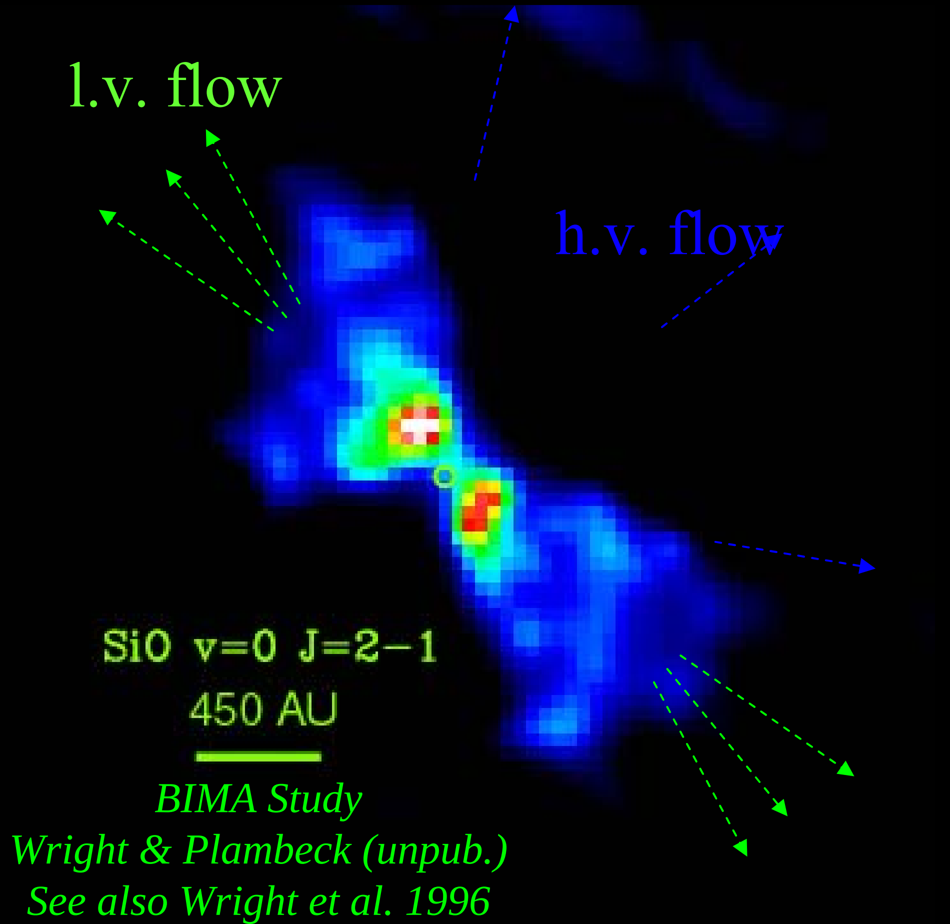
- L_*, B_*, B_{disk}, *etc?*

What is going on in Orion BN/KL?

Source *I* - amid a v. dense part of the BN/KL cluster and obscured even in the midIR



Keck LWS mid-IR images of BN/KL



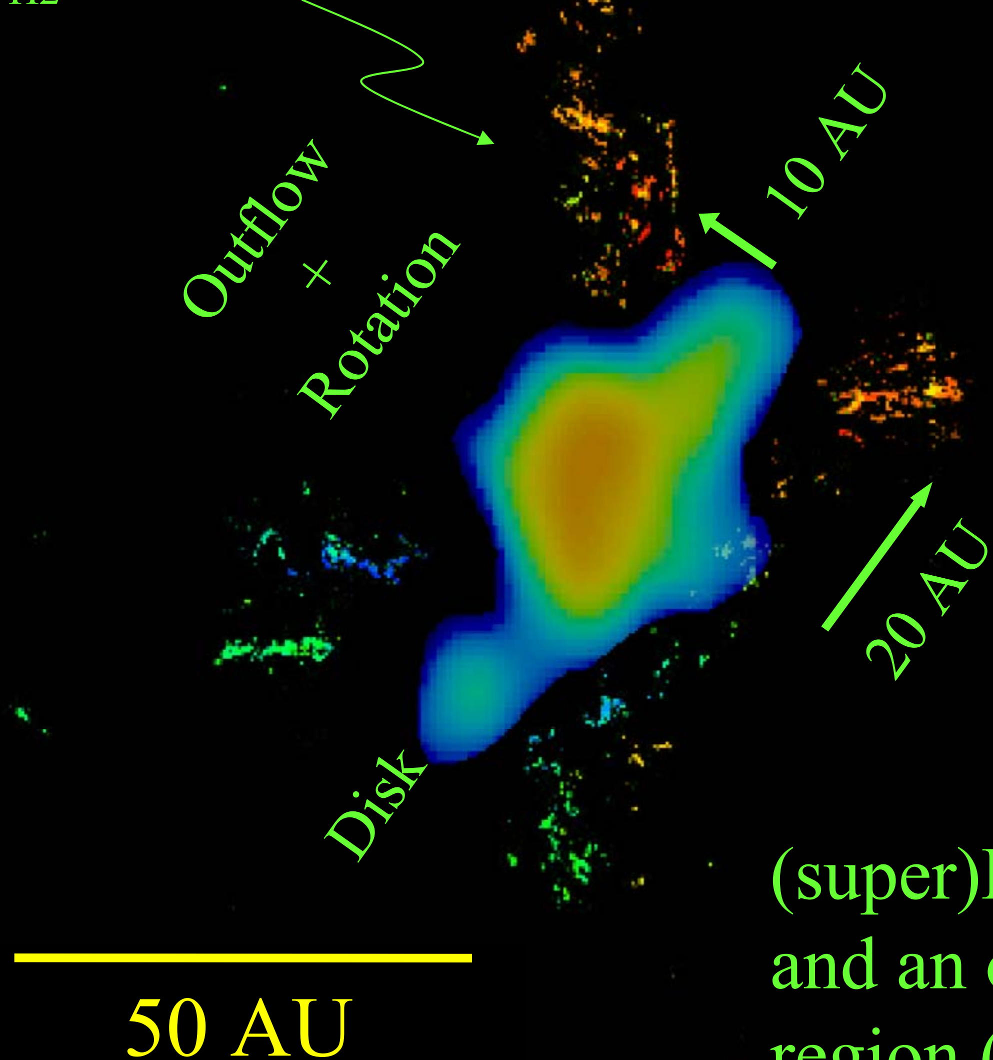
SiO, v=1, 2

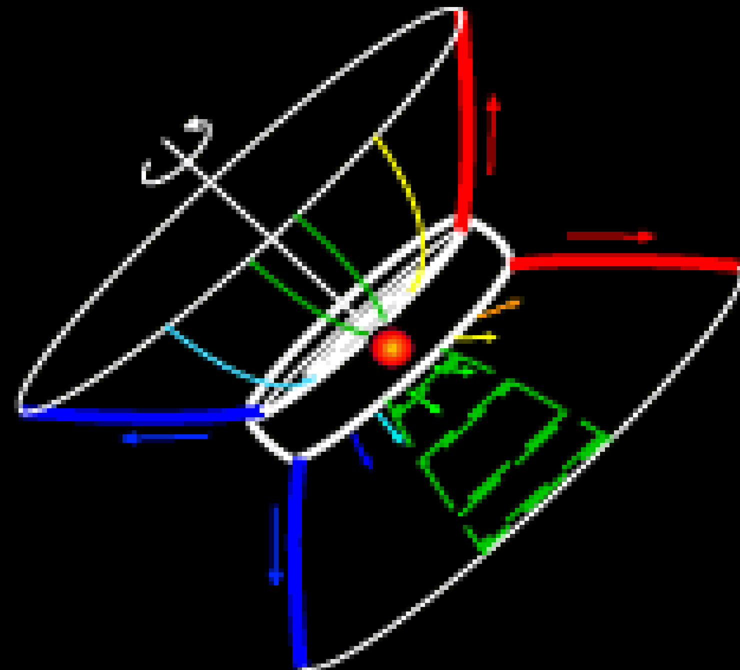
T~1000-2000 K

n_{H2}~$10^{10\pm1}$ cm^{-3}

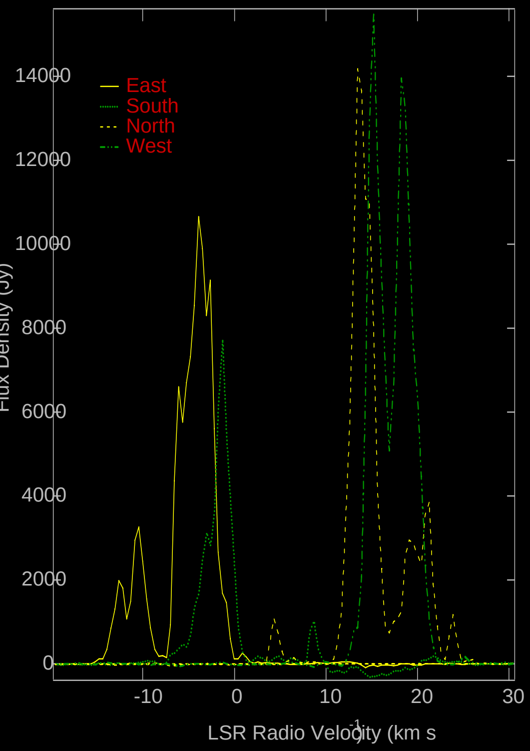
Source *I*

R<100 AU



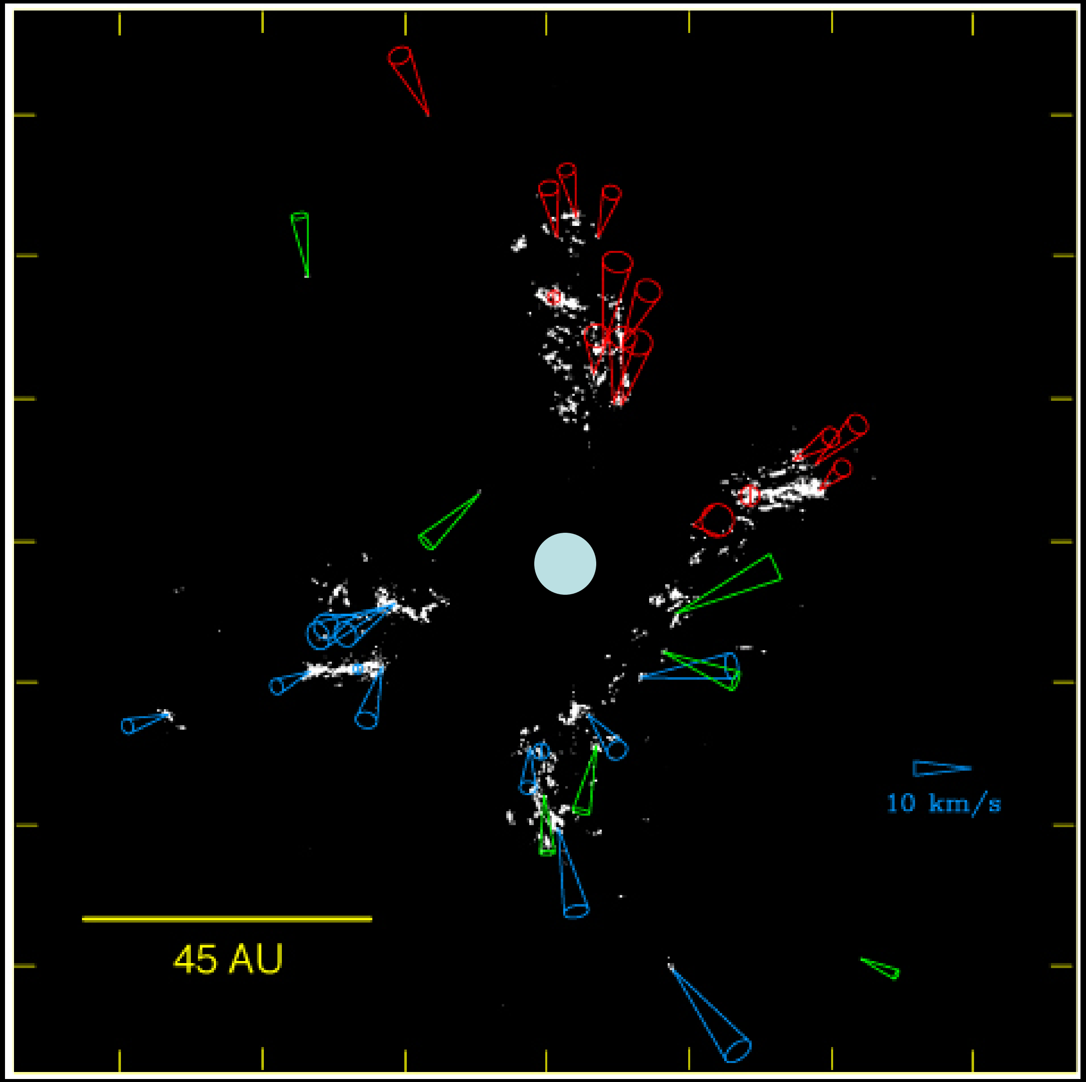


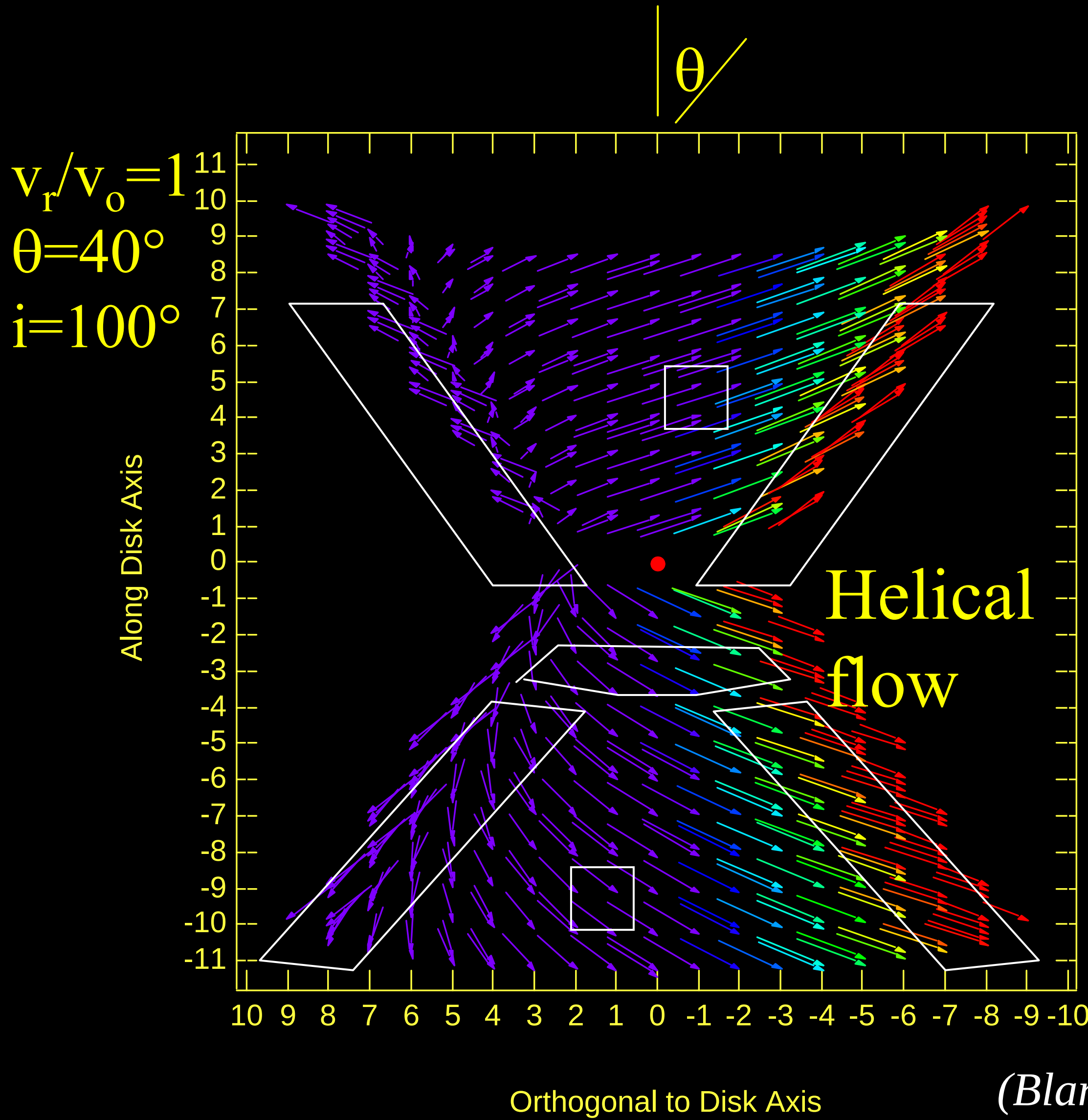
(super)Resolution of a compact disk and an outflow launch/collimation region ($\theta/\Delta\theta$ ~10^3, $\nu/\Delta\nu$ ~10^2)



SiO (v=1,2)
motion over
4 months

Proper Motion of Dense Hot Gas



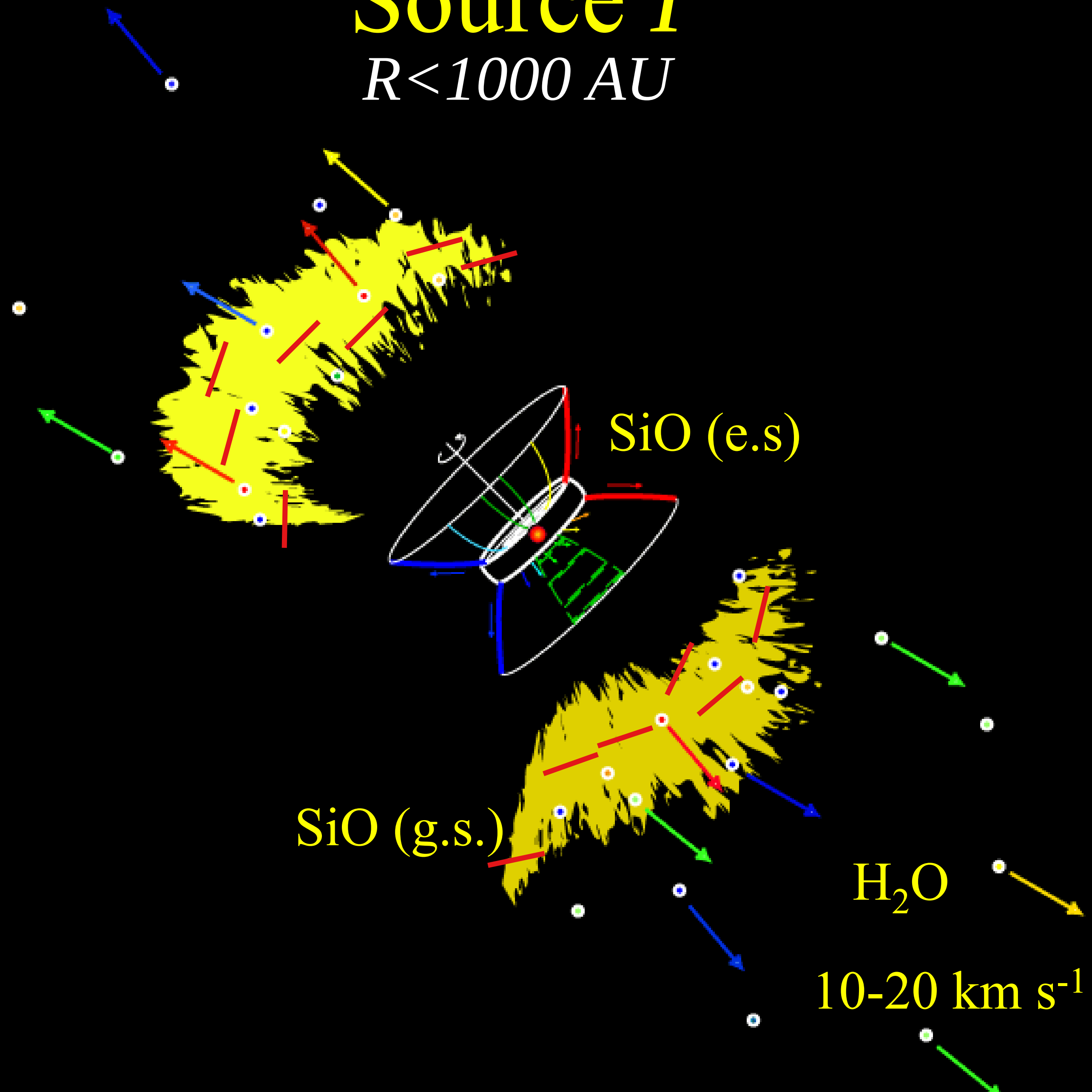


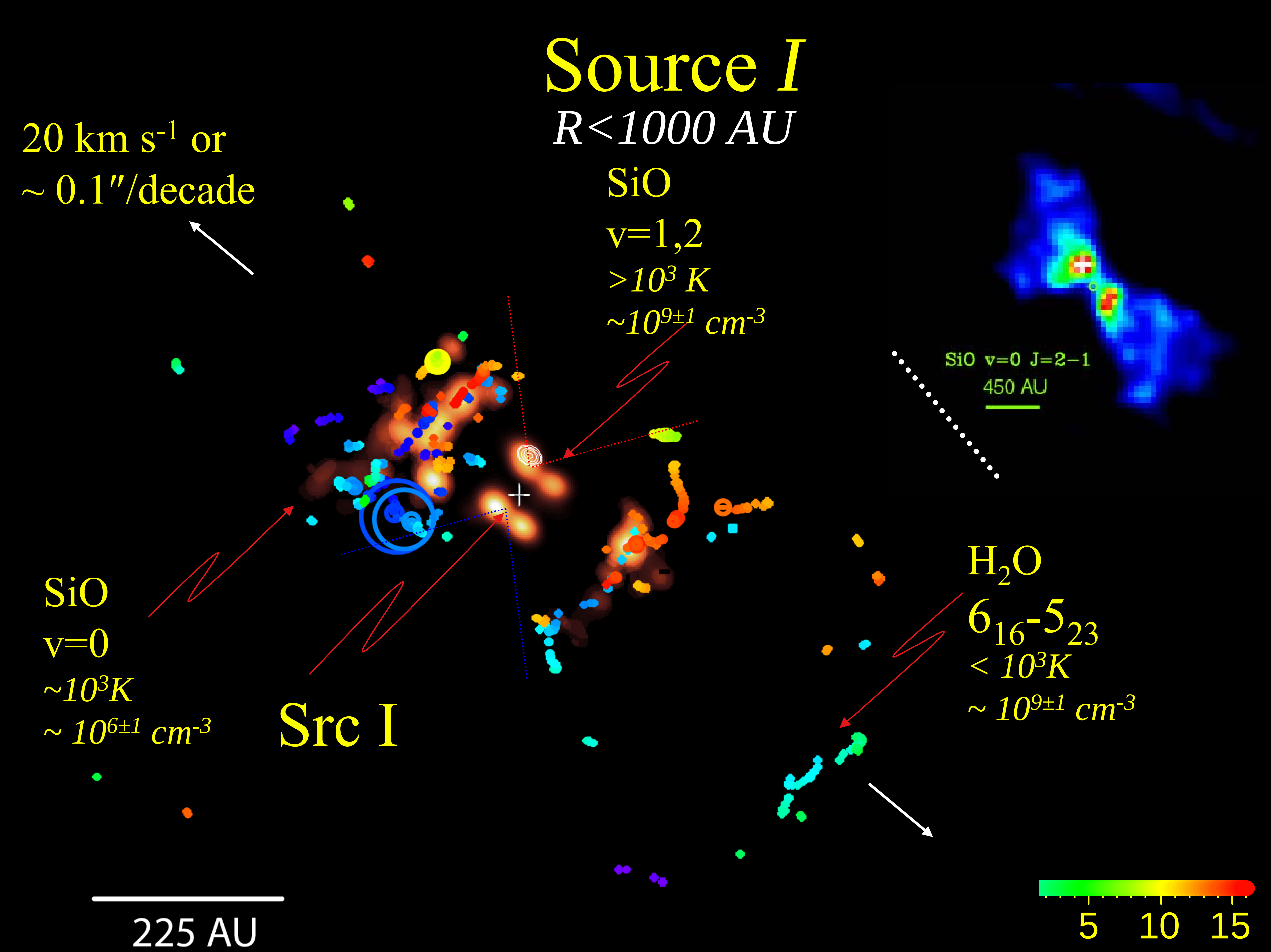
- 3-D velocity and accel of gas inside 100 AU.
  - helical flow?
  - ballistic flow?
- 3-yr VLBA time monitoring will lay out 3-D dynamics.

(Blandford & Payne 82, Pudritz & Norman 86, Ouyed, Pudritz & Stone 97)

Source *I*

R<1000 AU

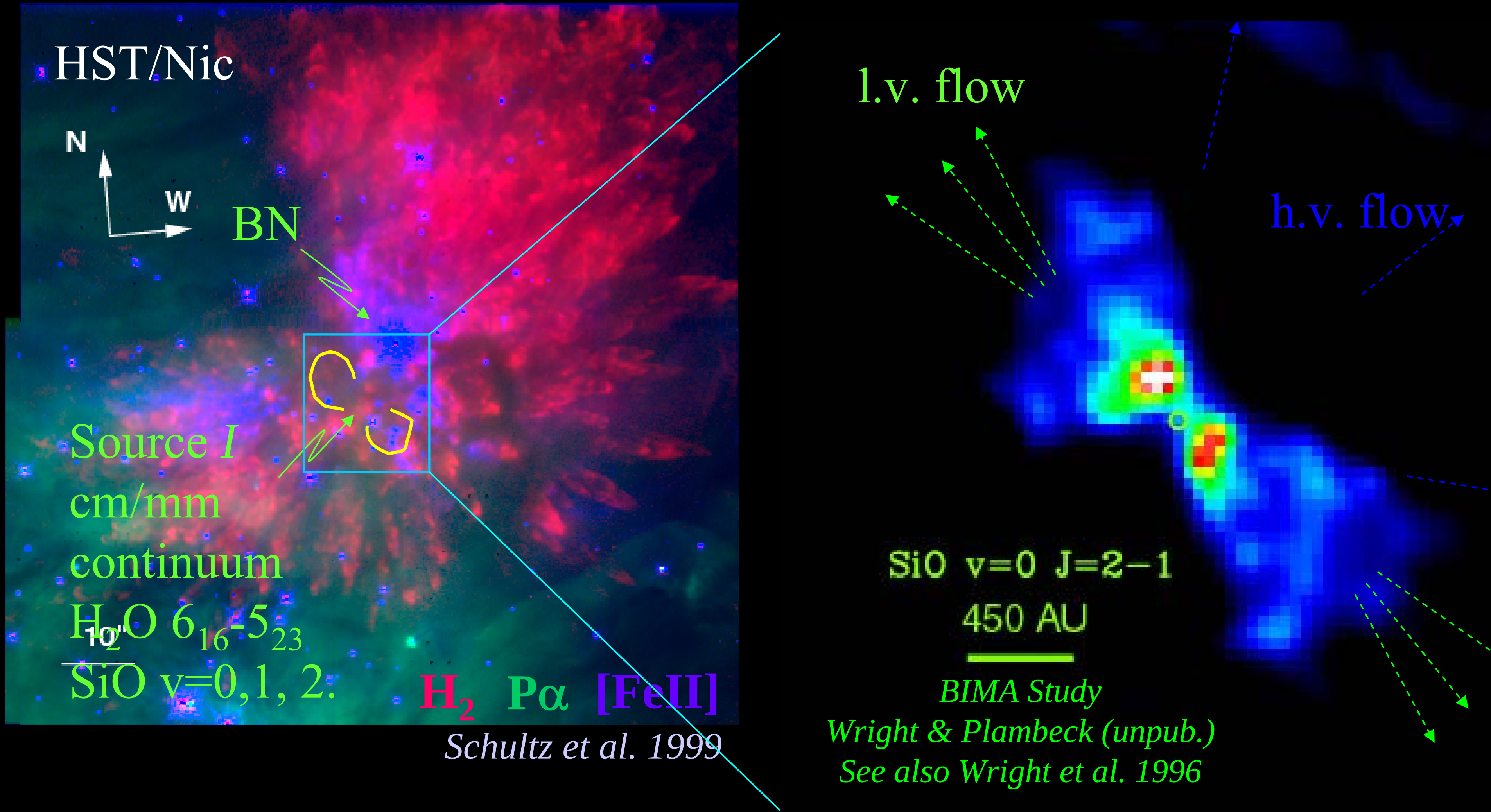



Source I
R<1000 AU
20 km s^{-1} or
~ 0.1″/decade
SiO
v=1,2
>10^3 K
~$10^{9\pm1}$ cm^{-3}
SiO v=0 J=2−1
450 AU
SiO
v=0
~10^3K
~ $10^{6\pm1}$ cm^{-3}
Src I
H_2O
6_{16}-5_{23}
< 10^3K
~ $10^{9\pm1}$ cm^{-3}
225 AU
5 10 15

Summary

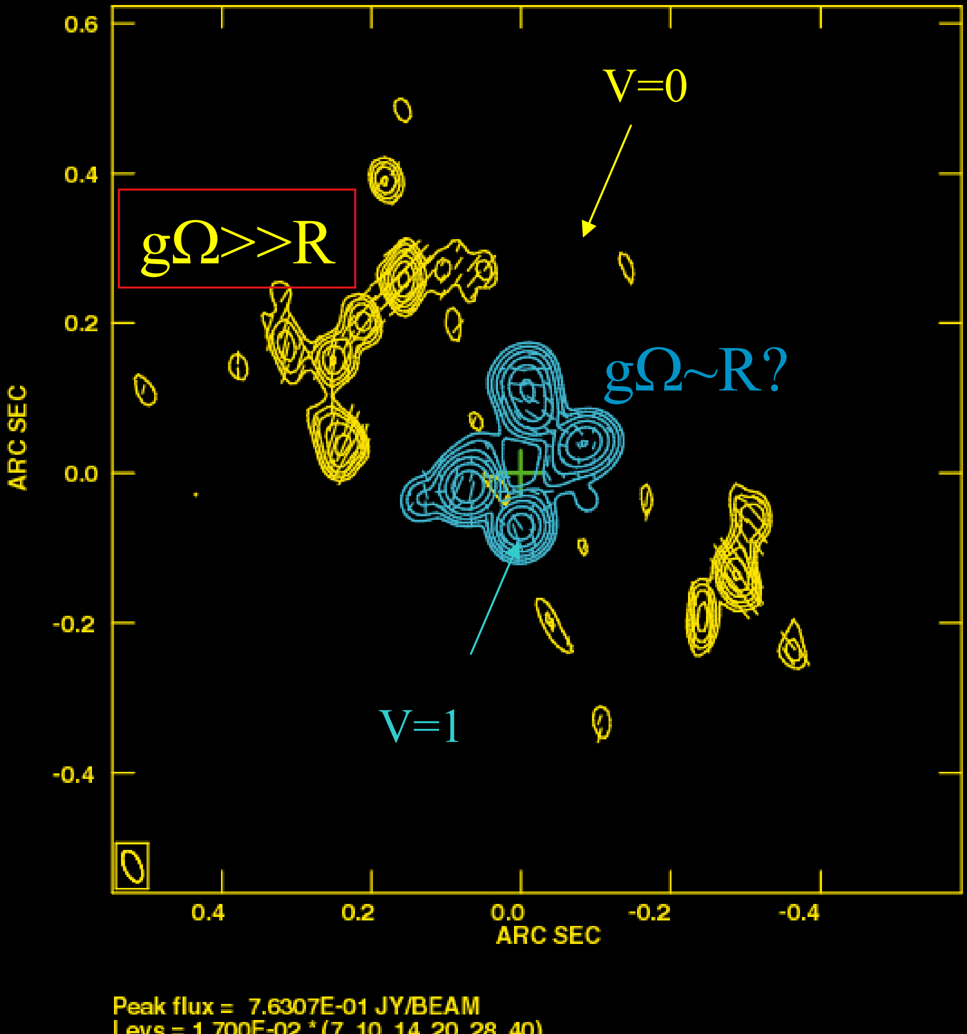
- (super)Resolution of structures inside ~100 AU.
- Evidence for a disk inside ~50 AU *(Reid/Menten).*
- Bipolar, funnel-like outflow in rotation.
- Inferred YSO dynamical mass:
  - max $|V_{3D}|^2 \sim 2GM/r$ $M_* \sim 10\ M_\odot$ (cf. $V_{shock} \neq V_{kin}$?)
- Source *I* is the ***best*** source known for testing how inflowing material is collimated to form outflow
    - entrainment of accreting material by a high-speed wind?
    - MHD disk wind?
  - e.g., measurement of v_{3D} and a_{3D} fields. $B_\perp$ field too?
- Do we understand Orion BN/KL yet?
  - Are you kidding? Quixotic hope?
- Next steps: modeling / process time series of data.

End



– Crowded.
– Incomplete ID of YSOs. Multiple sources of outflow?
– Patchy obscuration, A_V of a few to 500.

Is there a detectable magnetic field?



Greenhill et al., in prep

- Polarization maps trace **B** at 200 AU.
- **B** is || or ⊥ to polarization.
- Where would the field come from?
  - Presumably not stellar.
  - Sweeping up of ambient field?
    - –Ambipolar diffusion
- Does anisotropic pumping contaminate the polz?
  - –Nedoluha & Watson 1994
  - – Wiebe & Watson 1998…

Masers trace hot, dense gas…

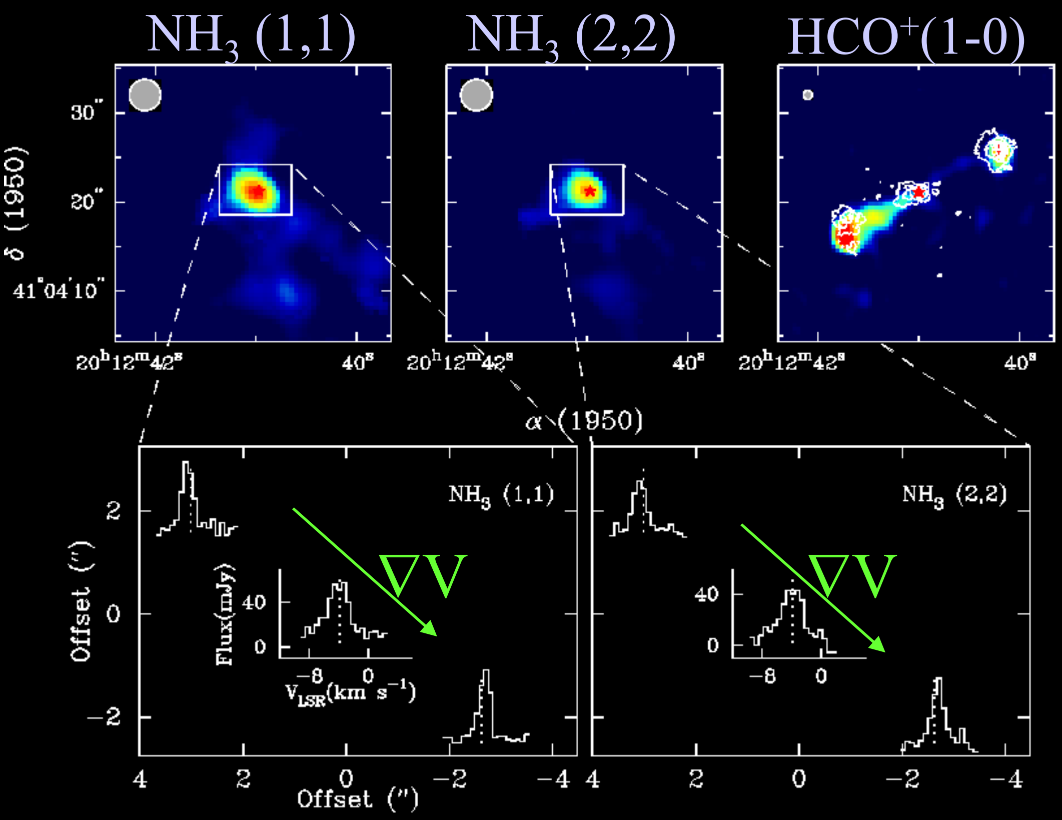
- H_2O
  - $n_{H2} \sim 10^9 - 10^{10}$ cm^{-3}
  - T ~ 300 - 800 K
    - *Dusty regions. Collisional pump (shocks).*
- SiO (v=1, 2)
  - $n_{H2} \sim 10^9 - 10^{11}$ cm^{-3} ; $N_{SiO} \sim 10^{19} - 10^{20}$ cm^{-2}
  - T > 1200 K
    - *Dust-free regions. Collisional and radiative pumps.*
- SiO (v=0)
  - $n_{H2} \sim 10^5 - 10^6$ cm^{-3} ; $N_{SiO} \sim 10^{16}$ cm^{-2}
  - T ~ 800 - 1600 K

- *Close association with young stars.*
- *Quiescent gas.*

Are Magnetic Fields Important?

- Evaluate 3-D gas dynamics
  - v=1, 2 SiO masers @ R<10^2 AU
  - Radiation-driven disk winds?
  - Hydromagnetic disk winds?
    - Blandford & Payne 82, Pudritz & Norman 86, Ouyed, Pudritz & Stone 97
  - Where would the field come from?
    - Presumably not stellar.
    - Sweeping up of ambient field?
      - Ambipolar diffusion
- Measure linear polarization
  - v=0, 1, 2 SiO masers @ R<10^3 AU

A Typical Best Case - High-Mass Star Formation via Accretion



Few examples of disks known

- Zhang, Hunter, & Sridharan 1998,
- Shepherd & Kurtz 1999,
- Cesaroni et al. 1999.

None resolved below 10^3 AU.

- A lot can hide in 10^3 AU

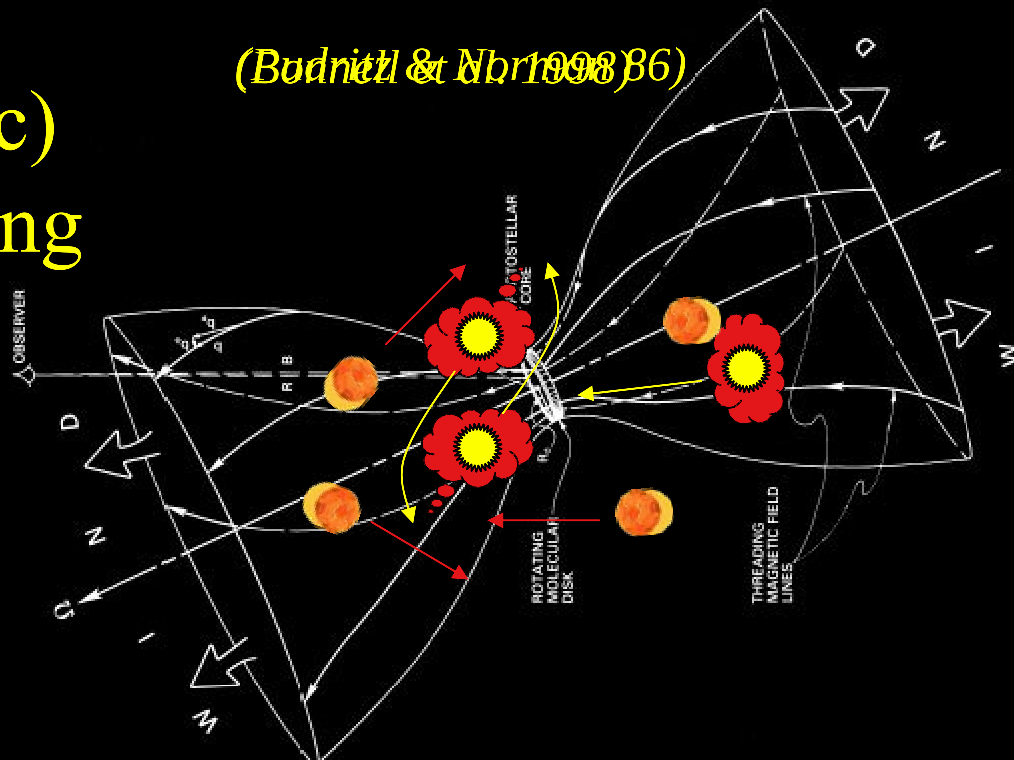
Limit of imaging thermal gas.

Why is high-mass star formation poorly understood?

Good examples of accreting massive YSOs are rare.

- Declining IMF
- Distance (> 500 pc)
- Confusion/crowding
- Rapid evolution
- Obscuration
- Poor thermal tracers of gas

(Bonnell et al. 1998) *(Pudritz & Norman 1986)*



Proposed MHD *disk winds* in high-mass star formation