A beautiful example of disk-mediated accretion in massive star formation

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Rationale

A detailed picture of high-mass (≥10 $M_\odot$) star formation has remained elusive, largely owing to difficulties in observing the earliest stages of massive protostars, which are on average distant (>1 kpc), form in clusters, and ignite quickly whilst still enshrouded in dusty envelopes, making optical and NIR observations impracticable.

Orion BN/KL is the closest (~410 pc) known region with ongoing massive star formation and it is generally considered the archetype (Fig. 1a,b). Radio Source I in the region (Fig. 1c,d), although undetected in the NIR-MIR, exhibits cm-wave continuum (thermal free-free emission from a HII region) and powers a rich variety of molecular masers in the surrounding, indicating a deeply embedded, luminous, massive protostar.

Long baseline radio interferometry monitoring of different SiO maser transitions, enabled to map the structure, 3-D velocity field, and dynamical evolution of the circumstellar gas within 1000 AU from Source I on scales of only a few AU. The bulk gas flow traces a compact disk and the base of a wide-angle wind at radii <100 AU from the protostar, and a well-collimated bipolar outflow at radii of 100-1000 AU from Source I.
This provides convincing evidence that high-mass star formation can occur via disk-mediated accretion.

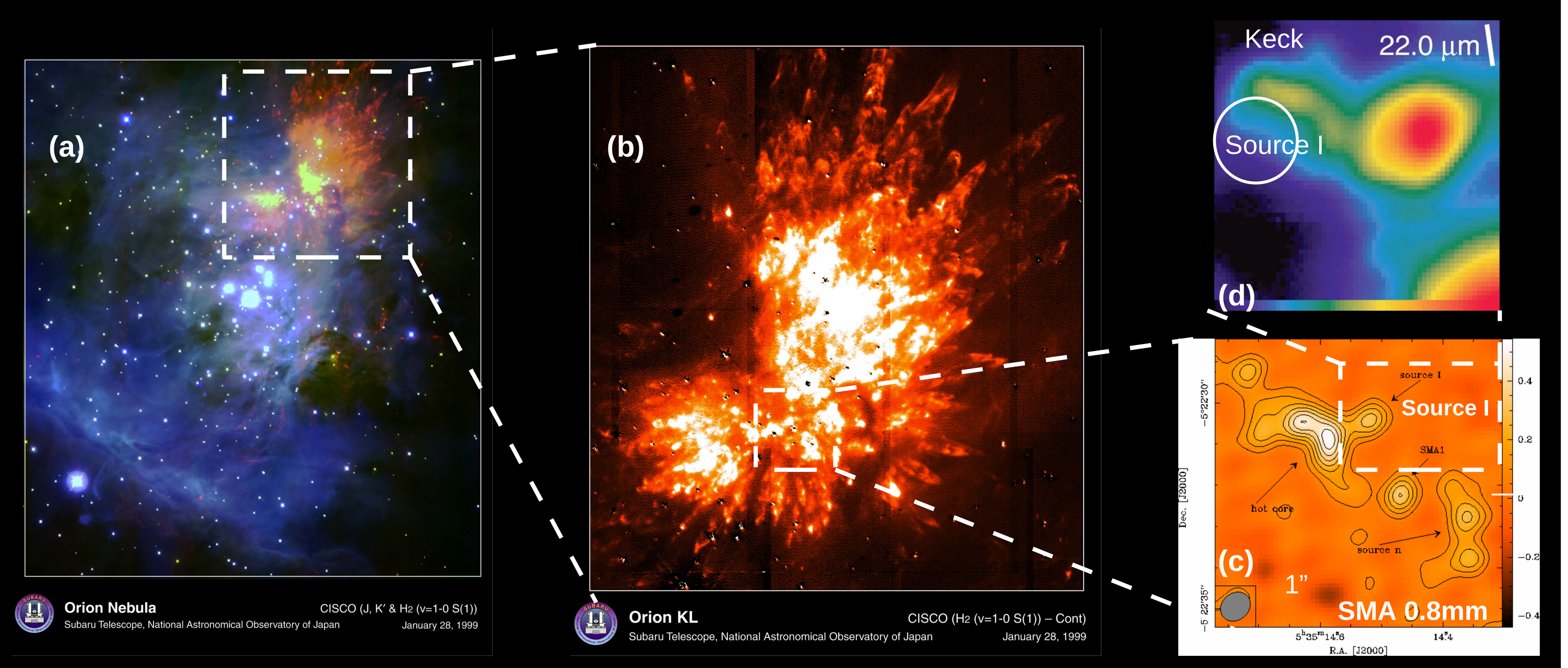


Fig. 1. A NIR view of the Orion Nebula (a) and the BN/KL region (b) with the Subaru Telescope; zoom at the center of BN/KL in mm-wave emission with the SMA interferometer (c) and MIR emission with the Keck telescope (d)

R=100-1000 AU

Instrument: VLA (θ~0.05”)

Tracers: λ7mm cont, 7mm SiO J=1-0 v=0, 1.3 cm H_2O

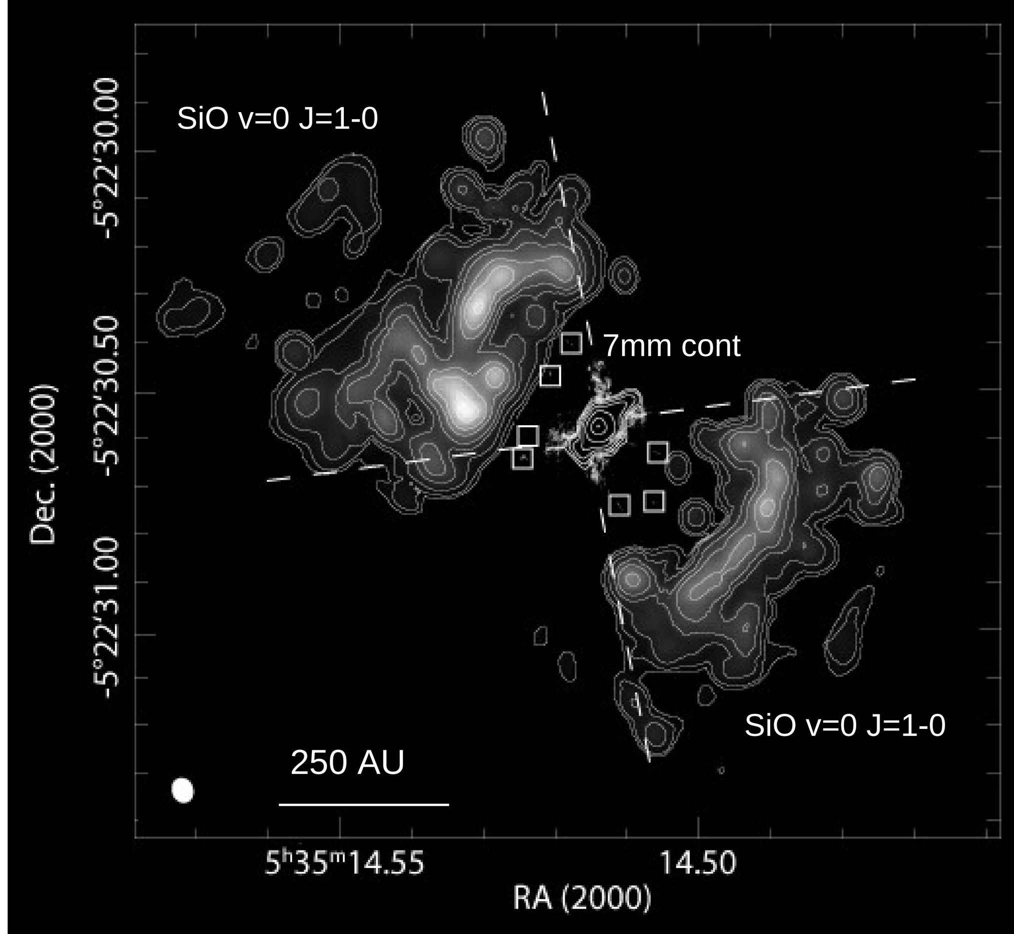


Fig. 2: Velocity-integrated emission from SiO v=0 J=1-0 (*grey-scale + contours*) brackets λ7mm continuum emission from Source I (*contours at center*).

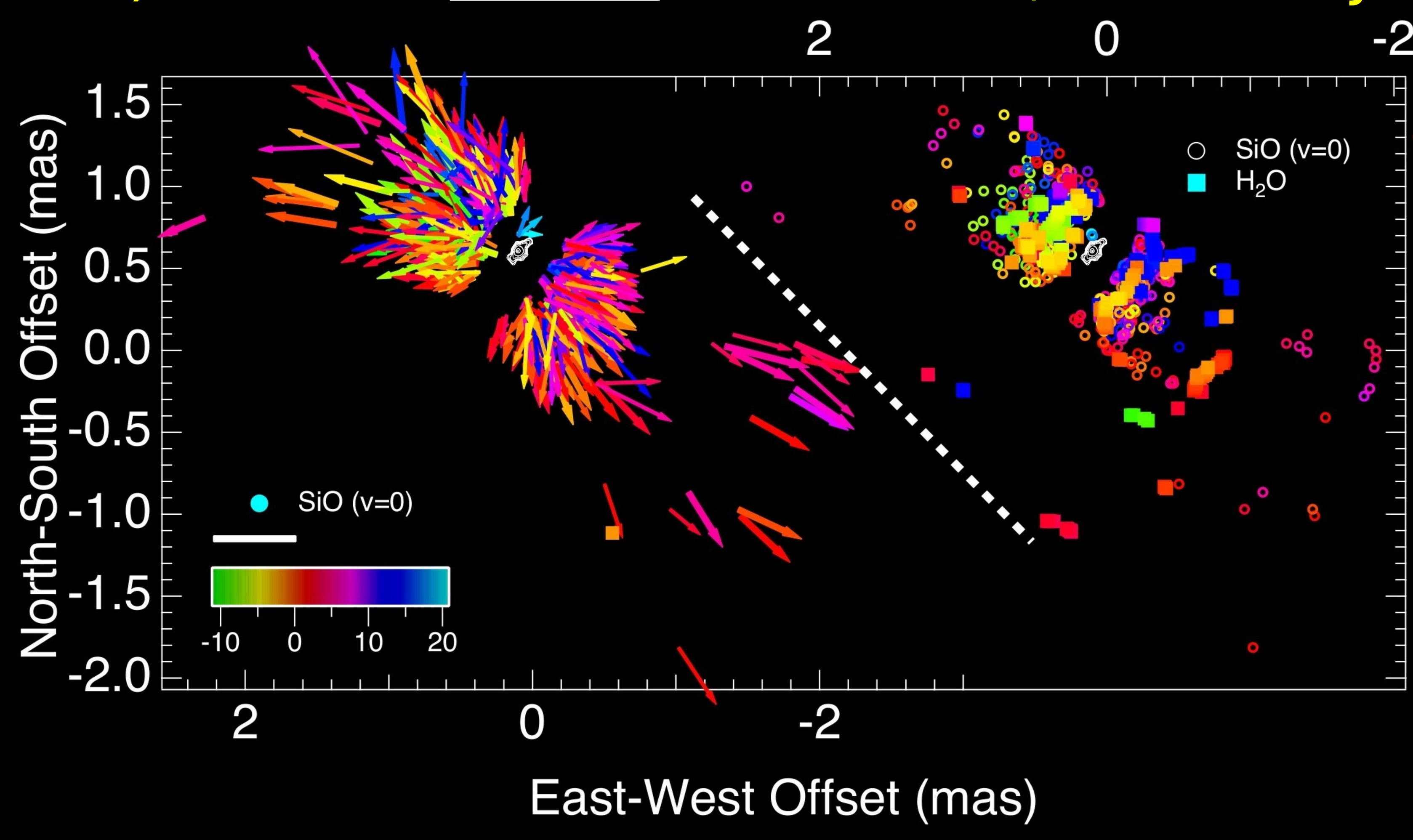


Fig. 3: Proper motions (*arrows*) of individual SiO v=0 maser spots (*left*). Positions and V_{LOS} of the 7mm SiO v=0 and 1.3cm H_2O maser spots (*right*). λ7mm continuum emission from Source I (*contours at center*).

NE-SW Bipolar Outflow

$\langle V_{outflow} \rangle$	18 km s^{-1}
max $V_{outflow}$	35 km s^{-1}
R_{inn}	~100 AU
R_{out}	~1000 AU
T_{dyn}	~500 yrs
Mass-loss rate	<10^{-5} $M_\odot$ yr^{-1}
disk cont.	e-p free-free
disk EM	>10^5 pc cm^{-6}

R=10-100 AU

Instrument: VLBA (θ~0.0002”)

Tracers: λ7mm SiO J=1-0 v=1 and v=2

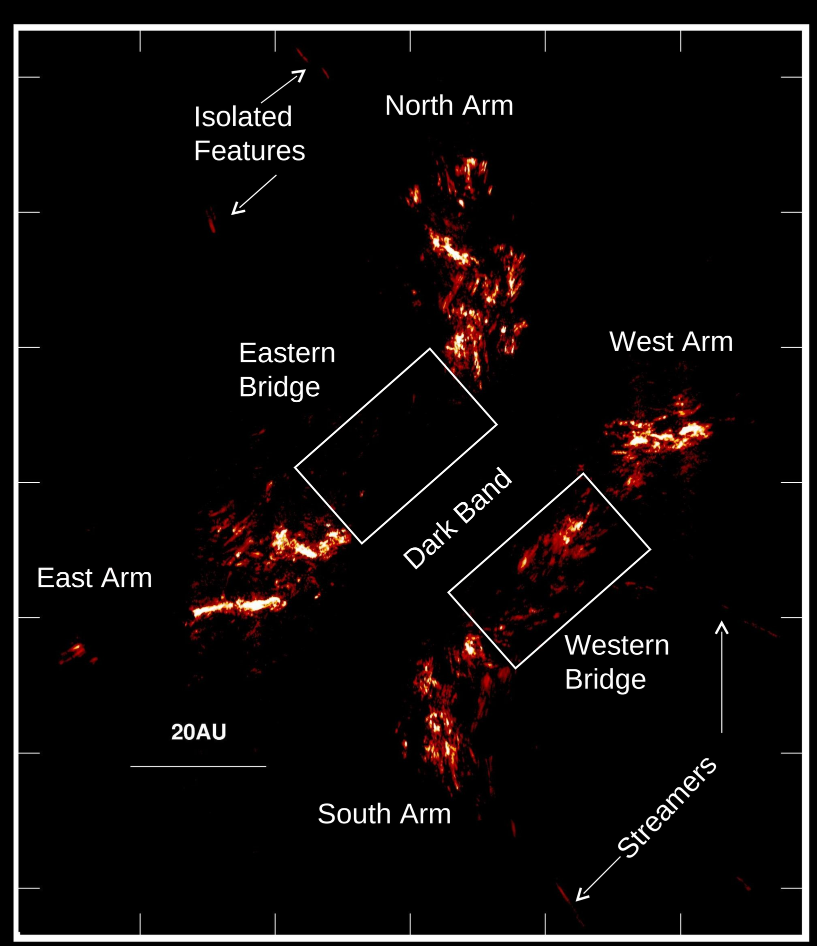


Fig. 4: Combined velocity-integrated emission (MOM0) from SiO J=1-0 v=1 and v=2, summed over 20 epochs spanning over two years .

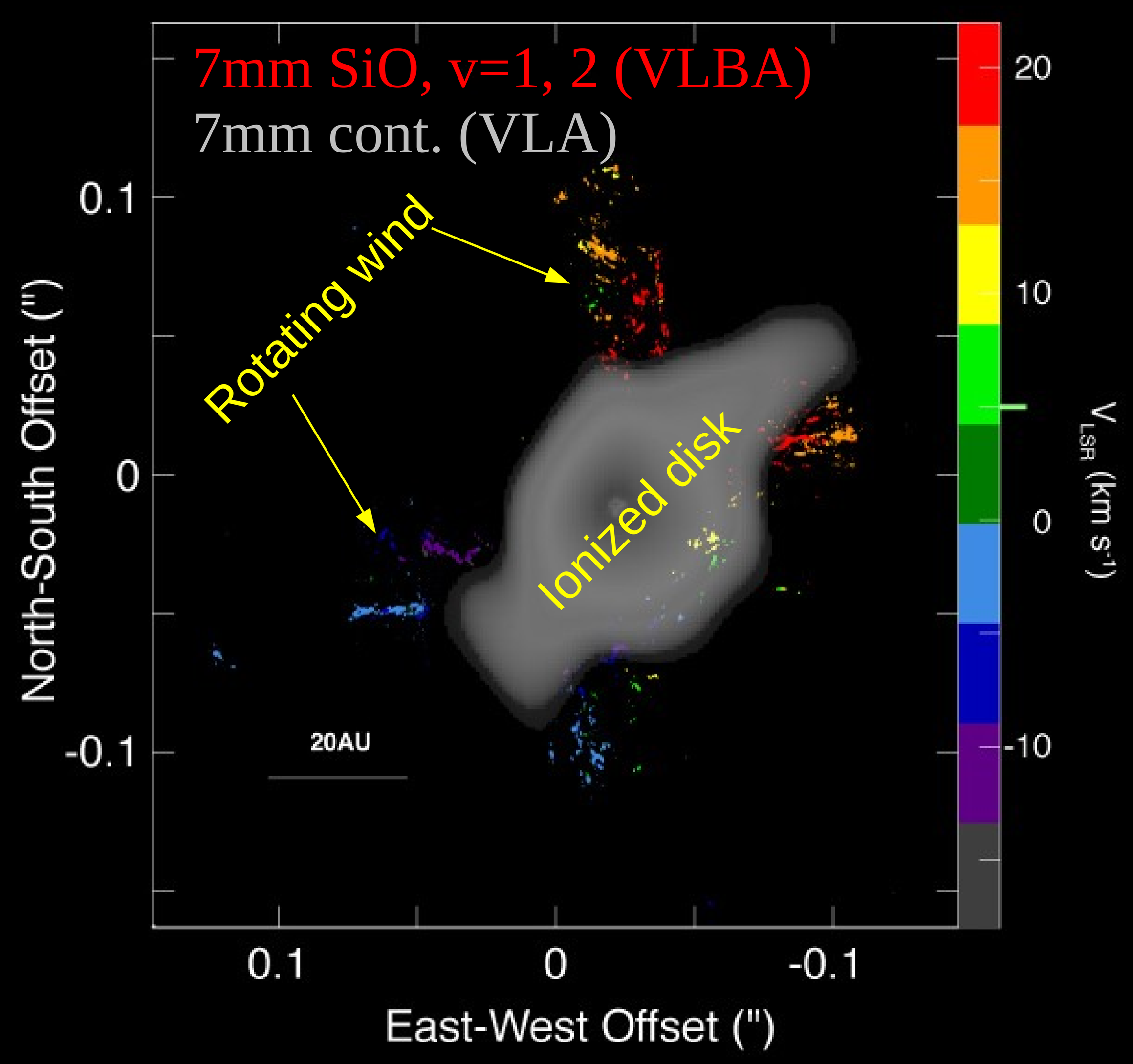


Fig. 5: Combined intensity-integrated velocity map (MOM1) from SiO J=1-0 v=1 and v=2 at one epoch (*color image*), overlayed the λ7mm continuum emission from Source I (*greyscale*).

- Funnel-like, rotating wind
- Rotating and expanding disk

M_{dyn} YSO	10 $M_\odot$
M_{disk}	>0.002 $M_\odot$
V_{rot} (20 AU)	9 km s^{-1}
$\langle V_{outflow} \rangle$	16 km s^{-1}
Max $V_{outflow}$	25 km s^{-1}
h_{half}/R	~0.2
$\Omega/4\pi$	~0.2
h_{half}	7 AU
Mass-loss in Arms	<10^{-4} $M_\odot$ yr^{-1}
Disk cont.	e-p free-free
Disk EM	>10^5 pc cm^{-6}

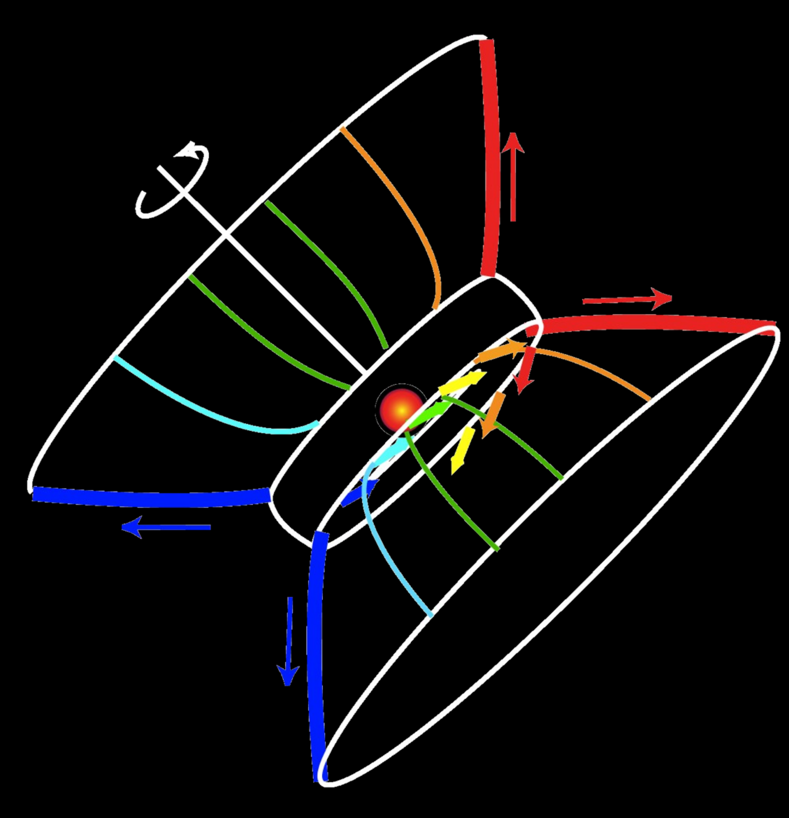


Fig. 6: Toy-model of the rotating disk/wind structure in Source I.

Summary

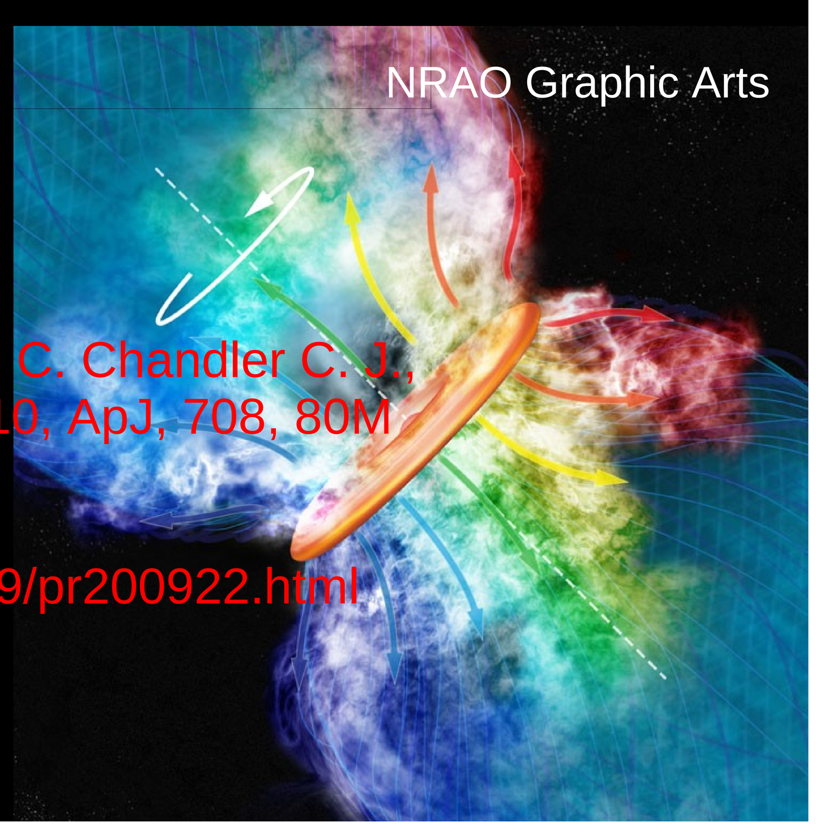
Detailed mapping of circumstellar gas with O(AU) resolution within 1000 AU from a massive protostar

demonstrate existence of a disk (R<100 AU)

resolve outflow at/near launch and collimation (R<100 AU)

Collimated bipolar outflow along the disk-axis (100<R<1000 AU)

=> identified a good example of disk-mediated accretion at M ≥ 8 M⊙



Reference Article:
Matthews L. D., Greenhill L. J., Goddi C. Chandler C. J., Humphreys E. M. L., Kunz, M. W. 2010, ApJ, 708, 80M

Press Release:
http://www.cfa.harvard.edu/news/2009/pr200922.html