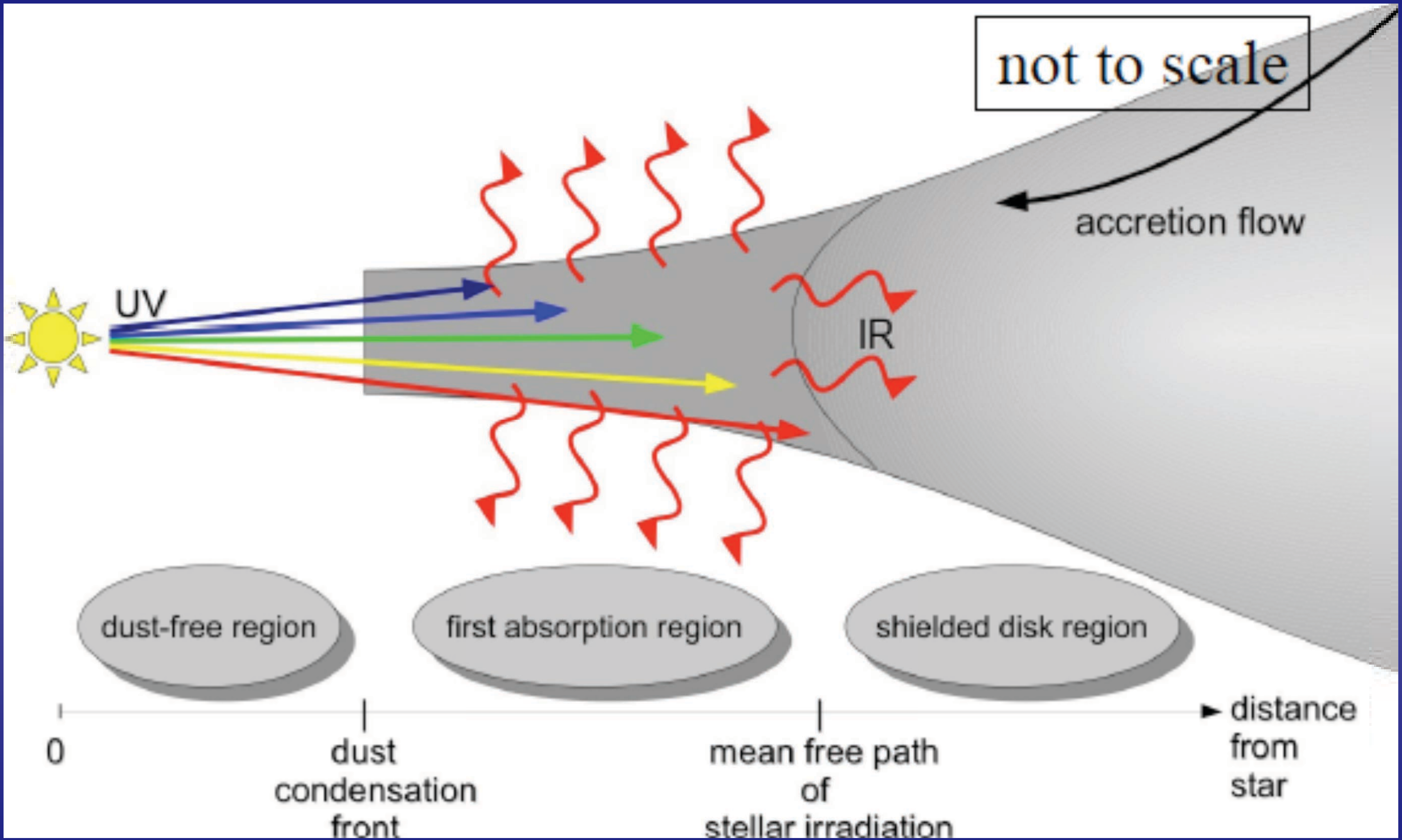
Rotation, disks and infall in High-Mass Star Formation:

Henrik Beuther

Conceptual ideas



Courtesy of Rolf Kuiper

Potential tracers

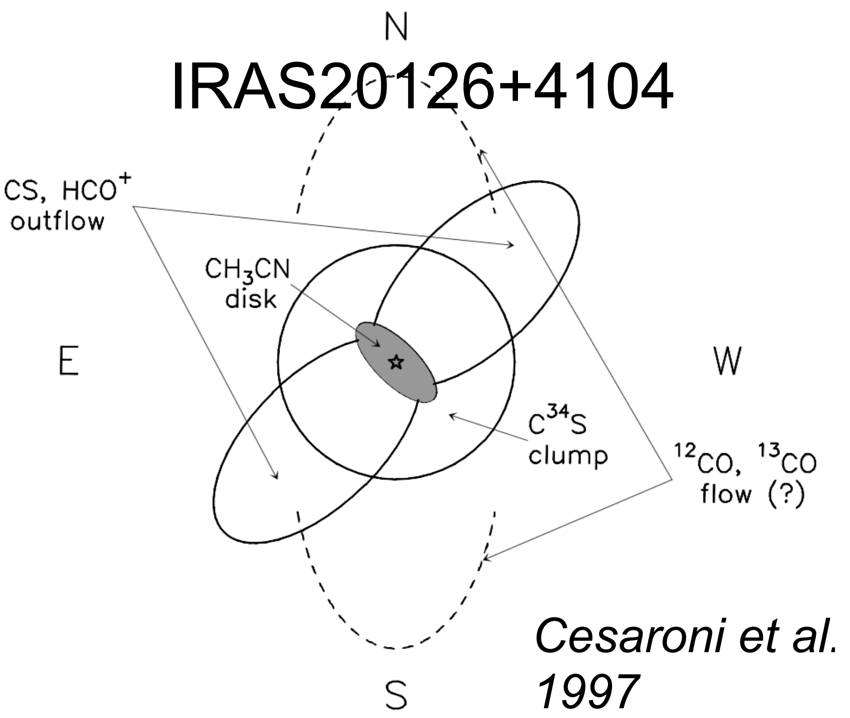
- (sub)mm continuum
- (sub)mm thermal spectral lines
- maser emission (mainly CH_3OH ?)
- near-infrared imaging
- near-/mid-infrared interferometry
- near-infrared spectroscopy

Talk bias: Only observational constraints, no theory.

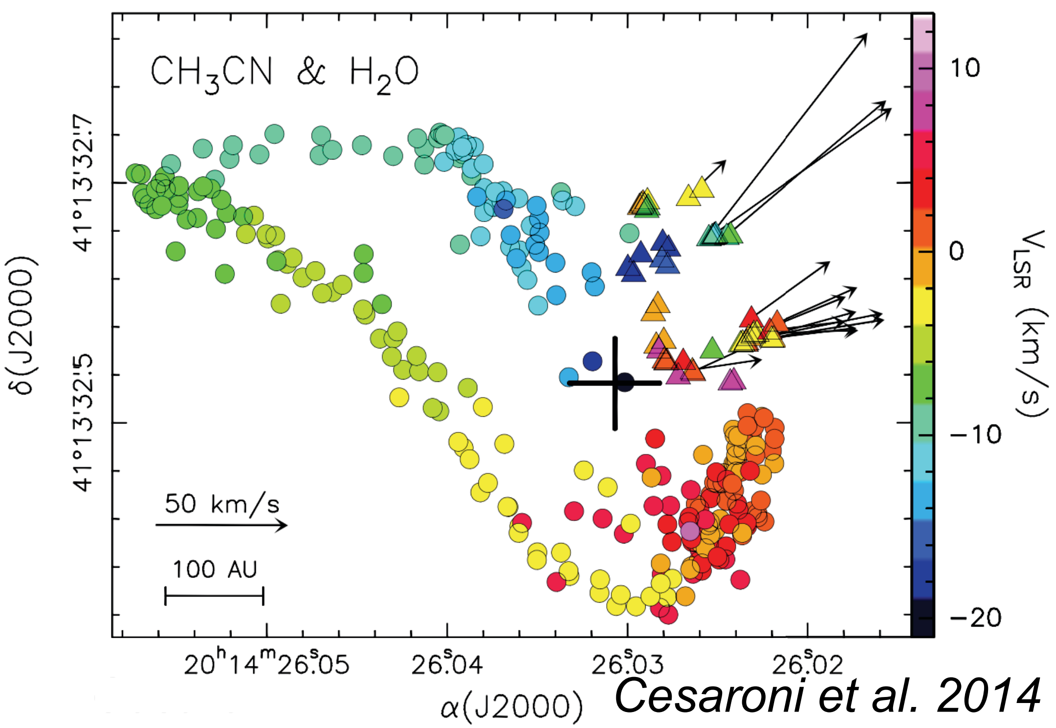
Topics

- Pre-2010 Townsville Meeting
- Where do we see rotational signatures first?
- Rotation and collapse on many scales
- State of the art with SMA, PdBI and ALMA
- State of the art in the near-infrared

Disks around B-type protostars



Cesaroni et al. 1997

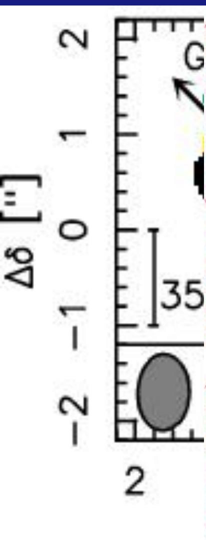


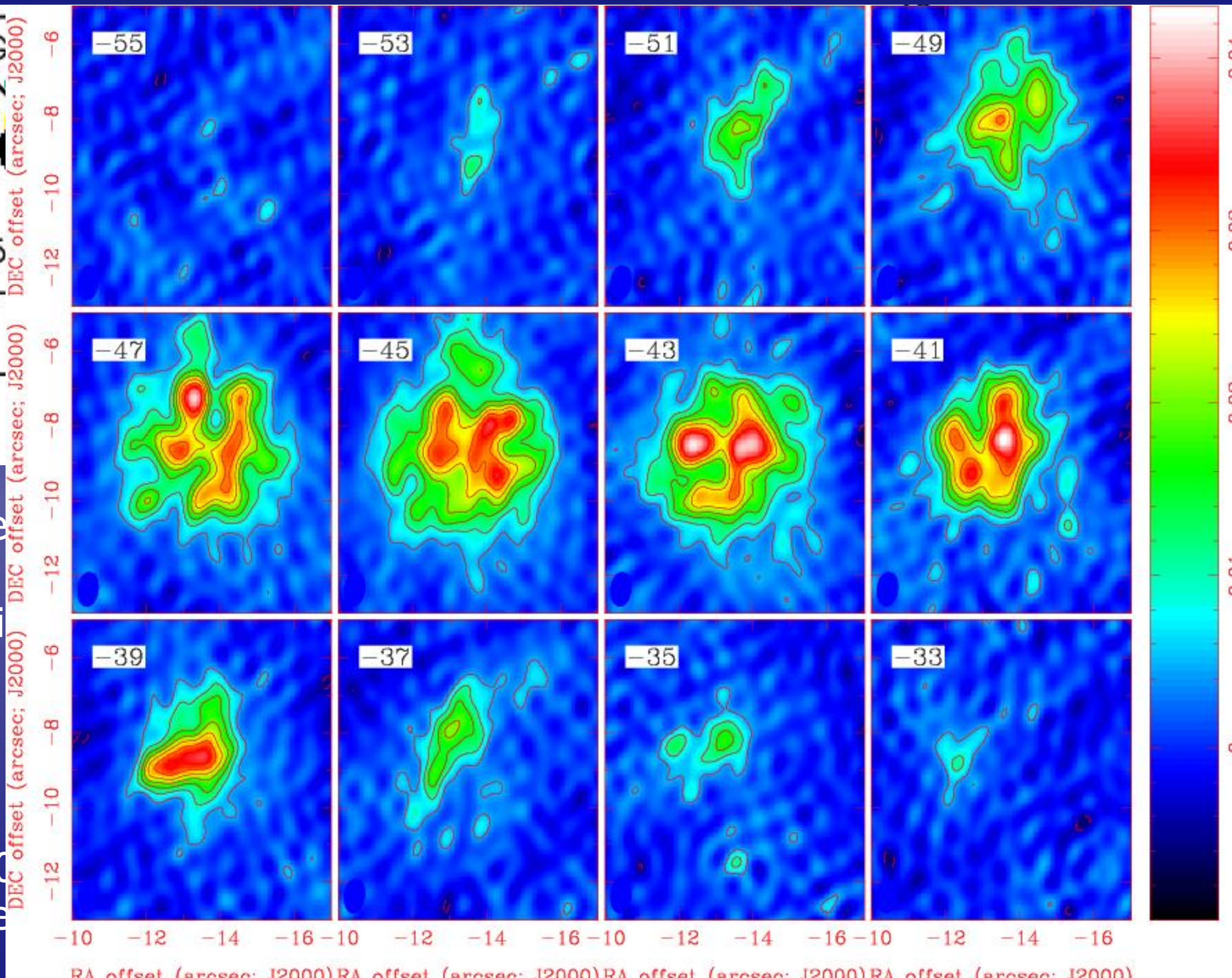
Cesaroni et al. 2014

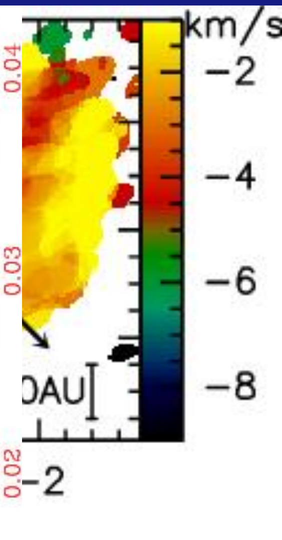
- Disks around B-type objects with Keplerian rotation established.
- Famous example IRAS20126+4104, work by *Cesaroni et al., Keto & Zhang 2010, Johnston et al. 2011, Surcis et al. 2014, Moscadelli et al. 2011 … and more*
- Other examples exist for B-type objects

→ But what about more massive stars?

A sample of 12 massive disk candidates







- Sample ... resolution.

- Excitati

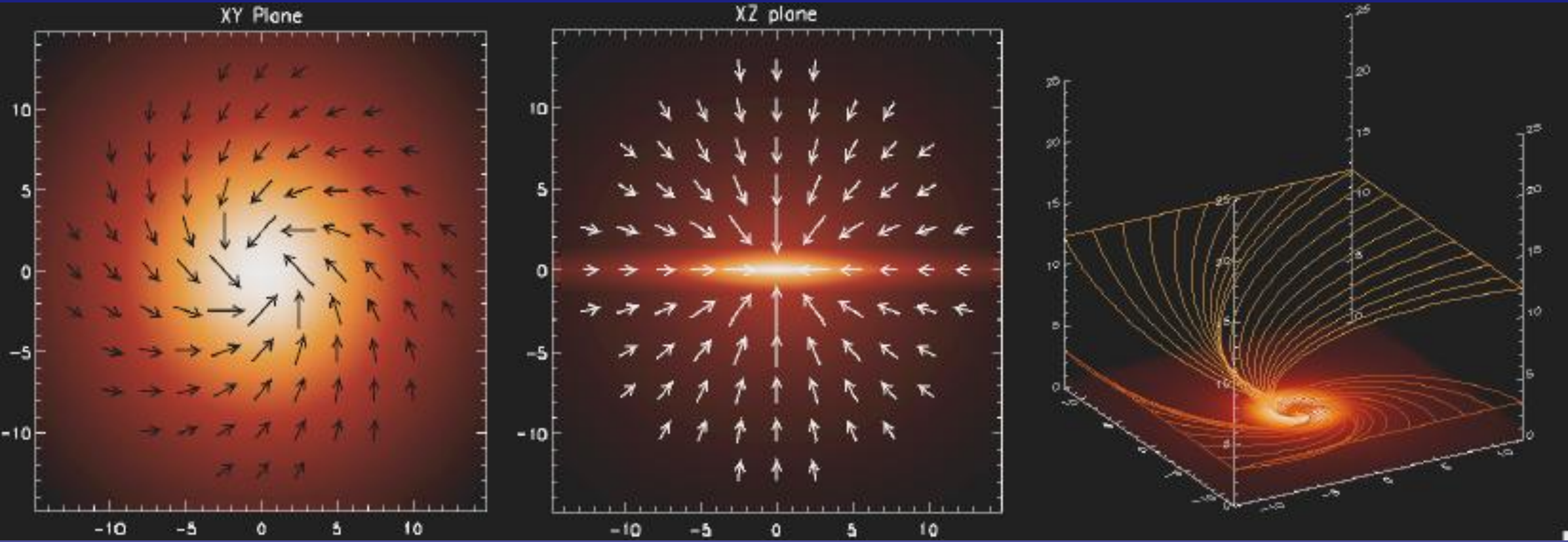
- 11 out

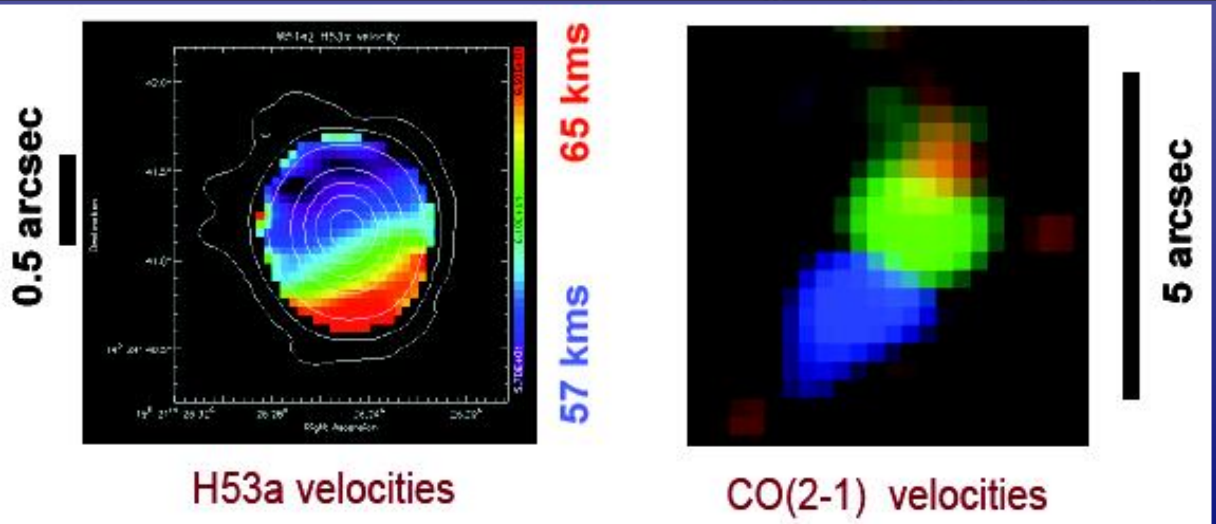
- At 1000
  → Re

- Channel maps show clumpy sub-structure

Beuther, Walsh & Longmore 2009

Accretion through HCHII regions

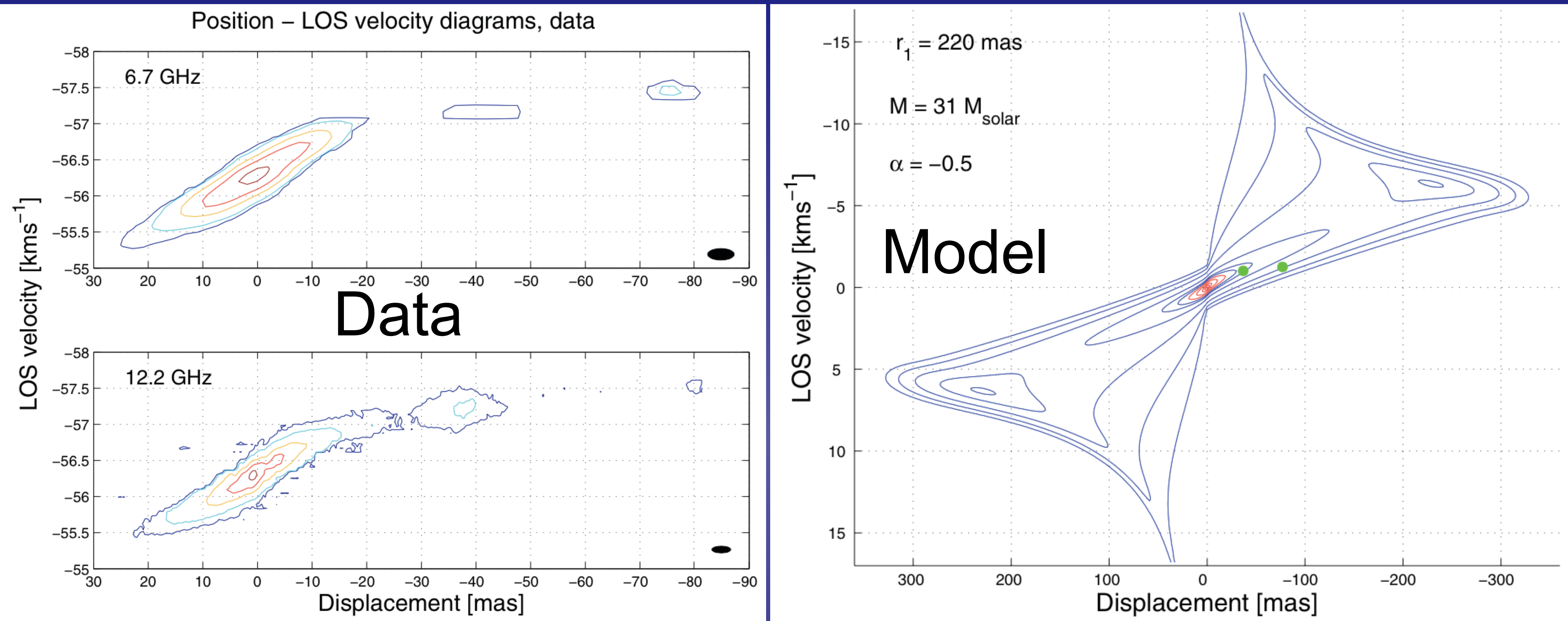




Inspiralling trajectories continue from the molecular to the ionized gas (grav. trapped HIIs).

Keto 2002, 2003, Keto & Klaassen 2008

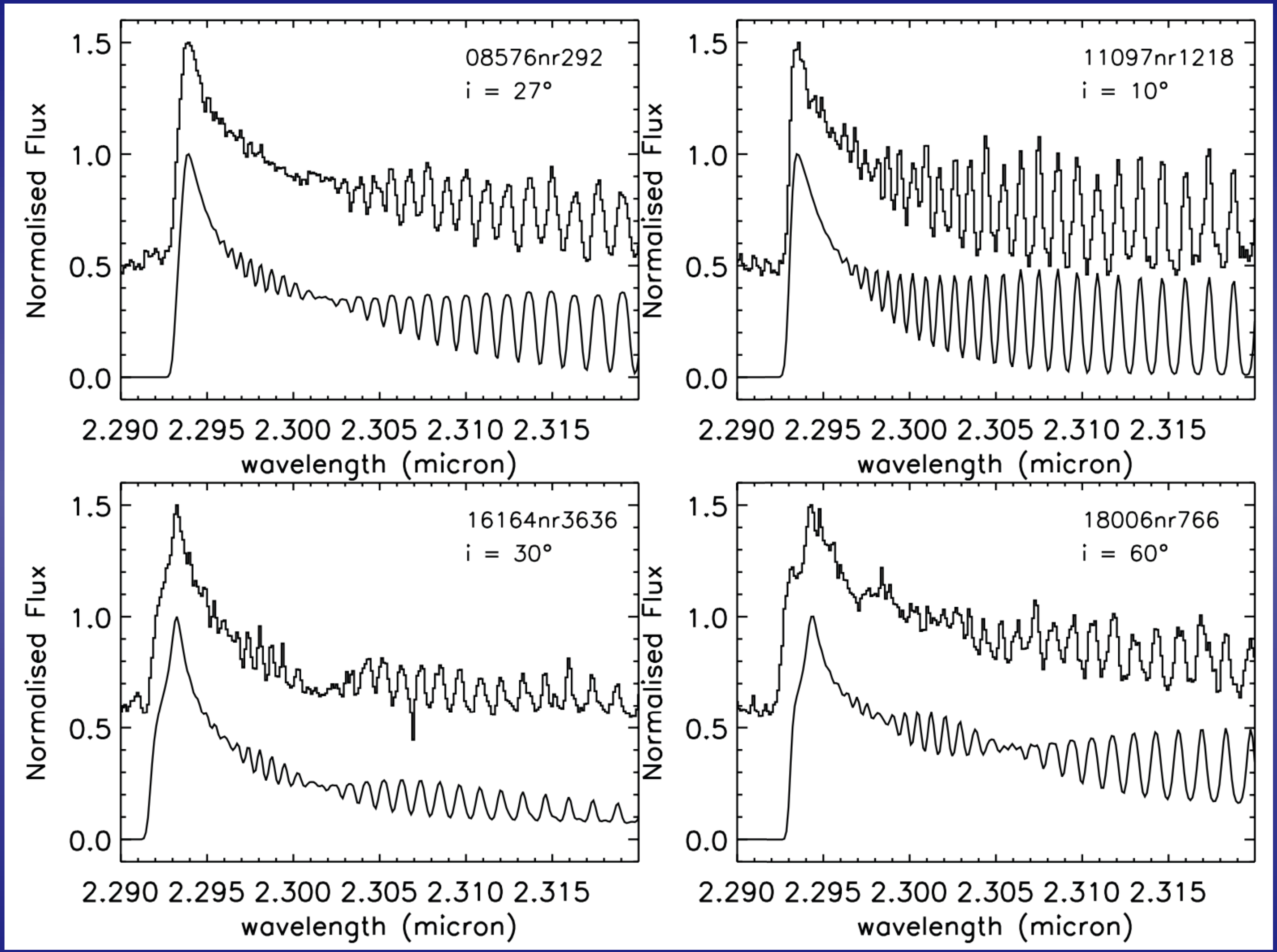
CH_3OH maser disk



- Strongly debated whether the masers trace a disk or outflow
- The model favors the differentially rotating disk around a $30M_{sun}$ star.

Pestalozzi et al. 2009

Hot molecular disks at 2.3μm in CO



Top: Data

Bottom: Model

Modeled with hot (1500 to 4500K) Keplerian disk in the inner few AU.

Bik & Thi 2004

Topics

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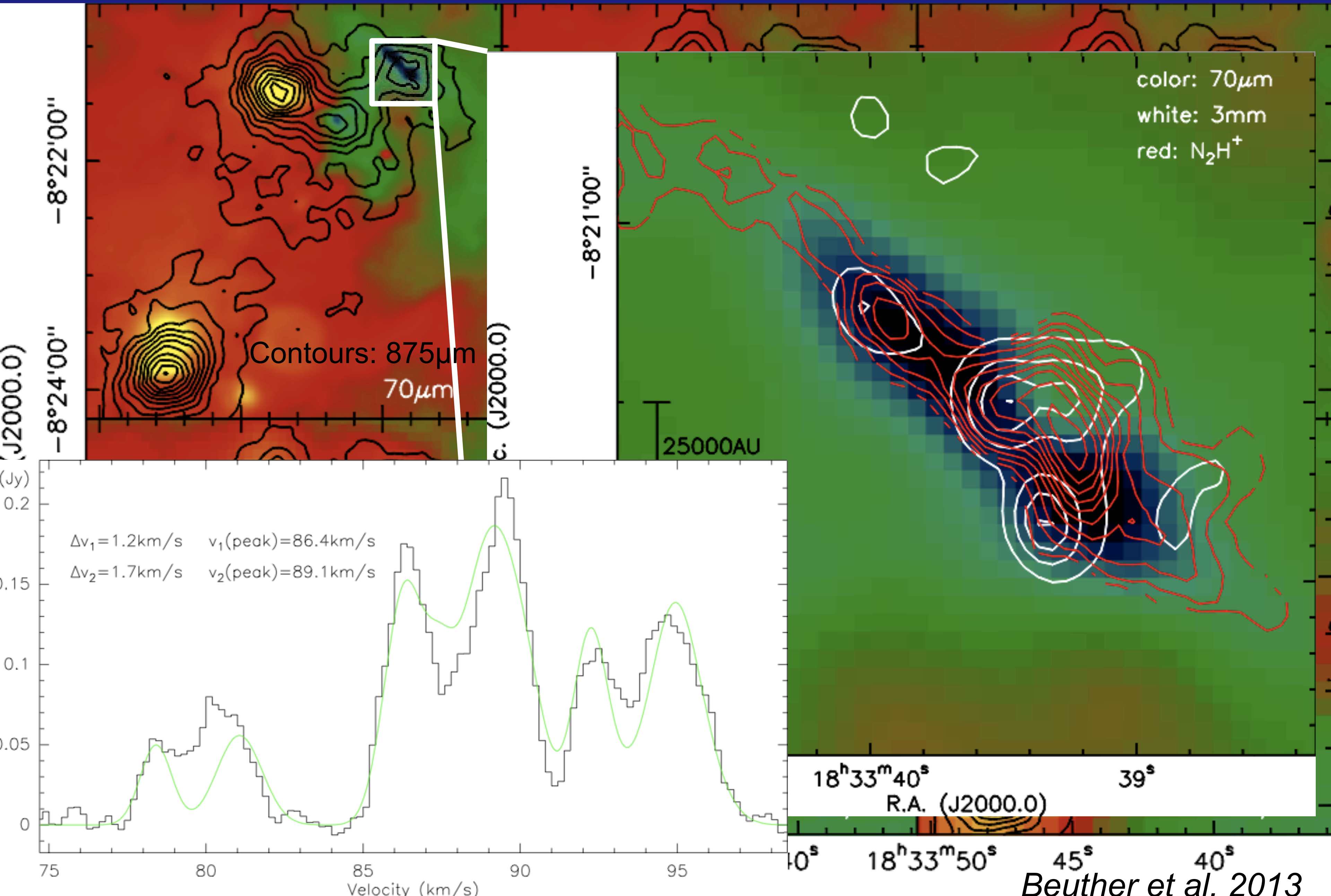
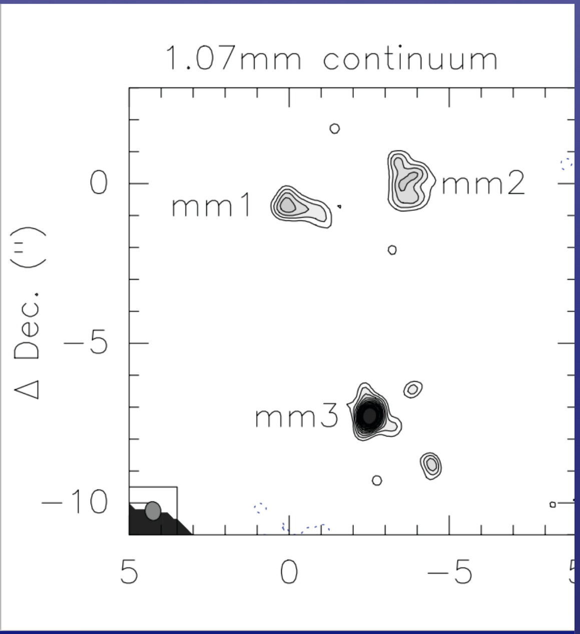
Hierarchical fragmentation in high-mass star-f.



Beuther et al. 2013

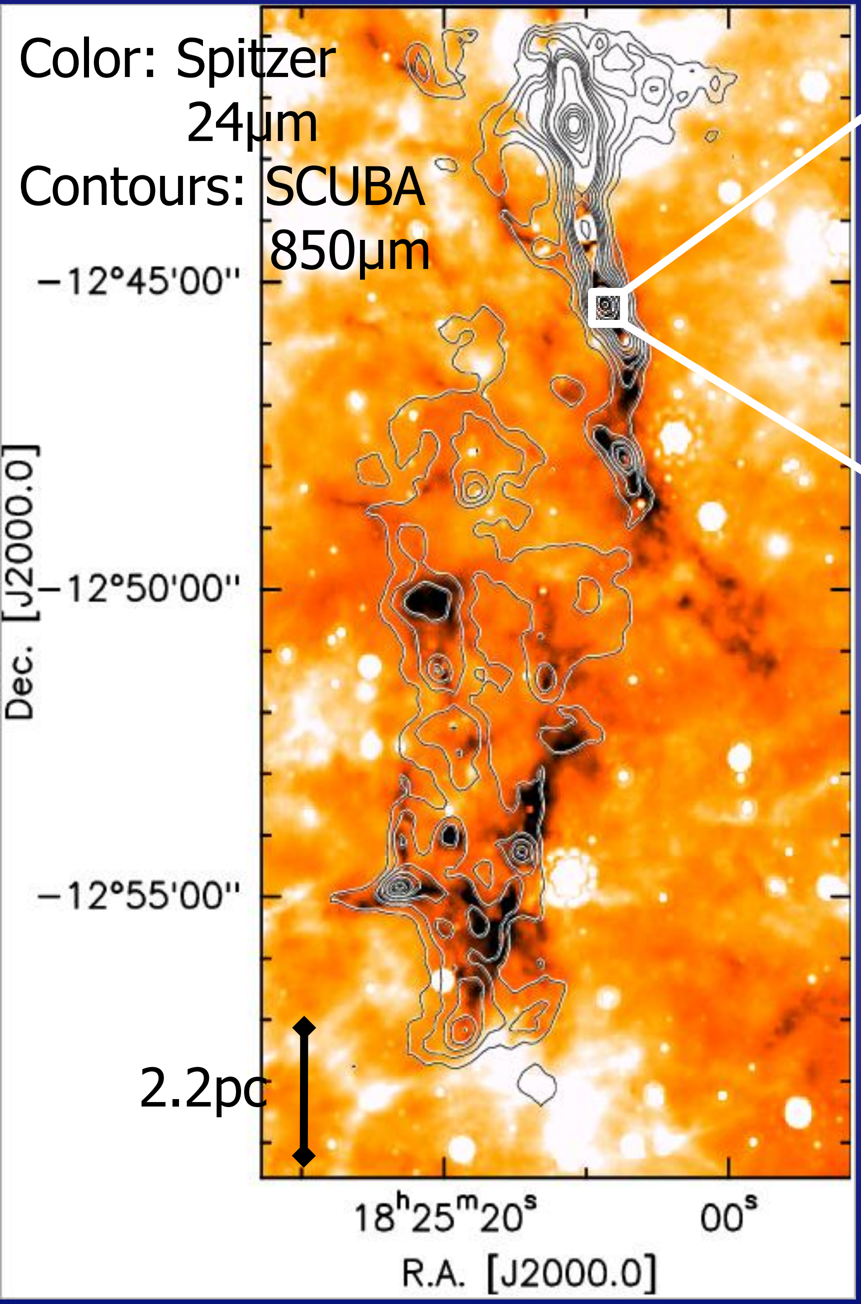
Multiple velocity components

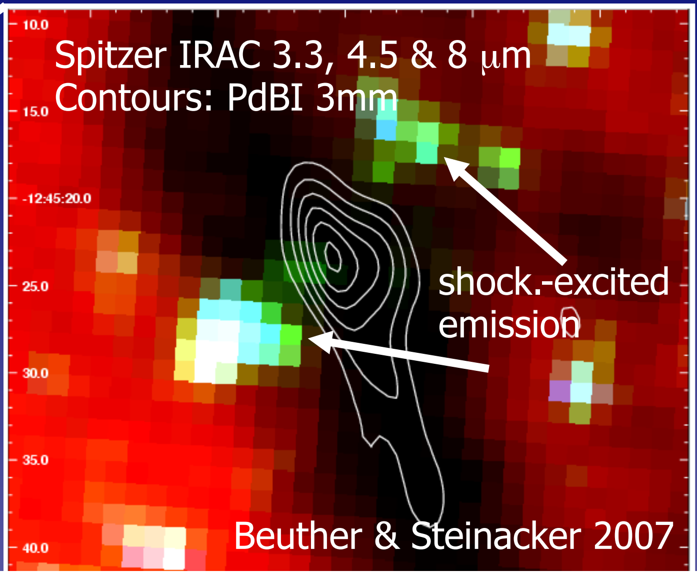


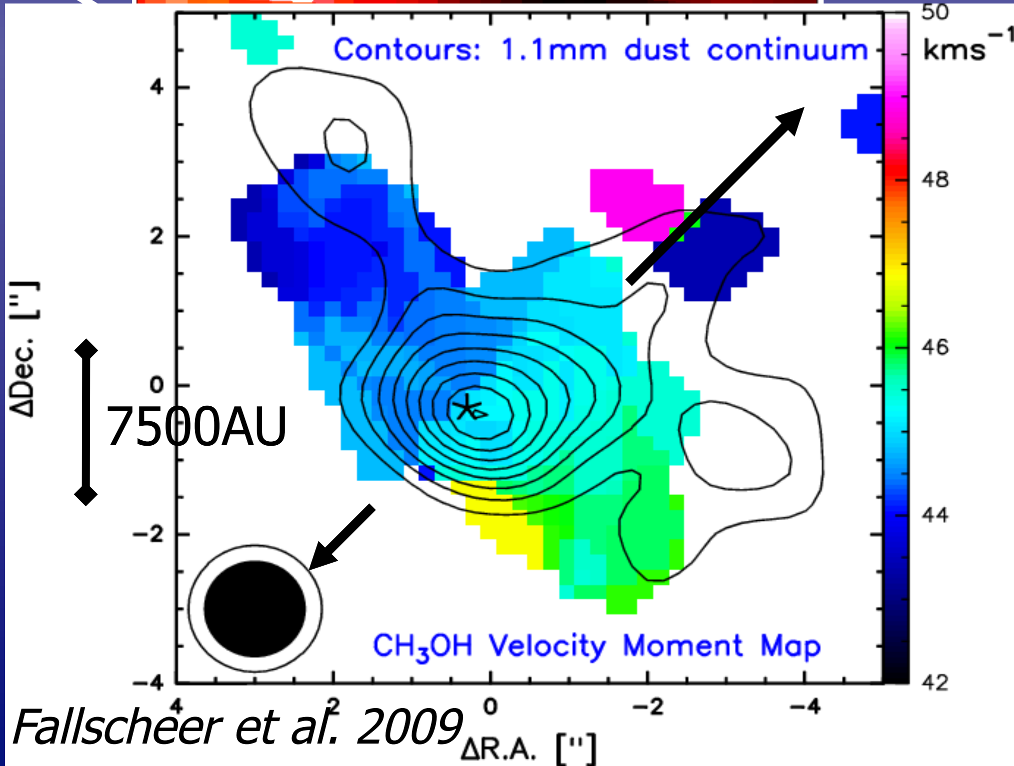
Linewidth Δv between 0.3 and 1.3km/s

Beuther et al. in prep.

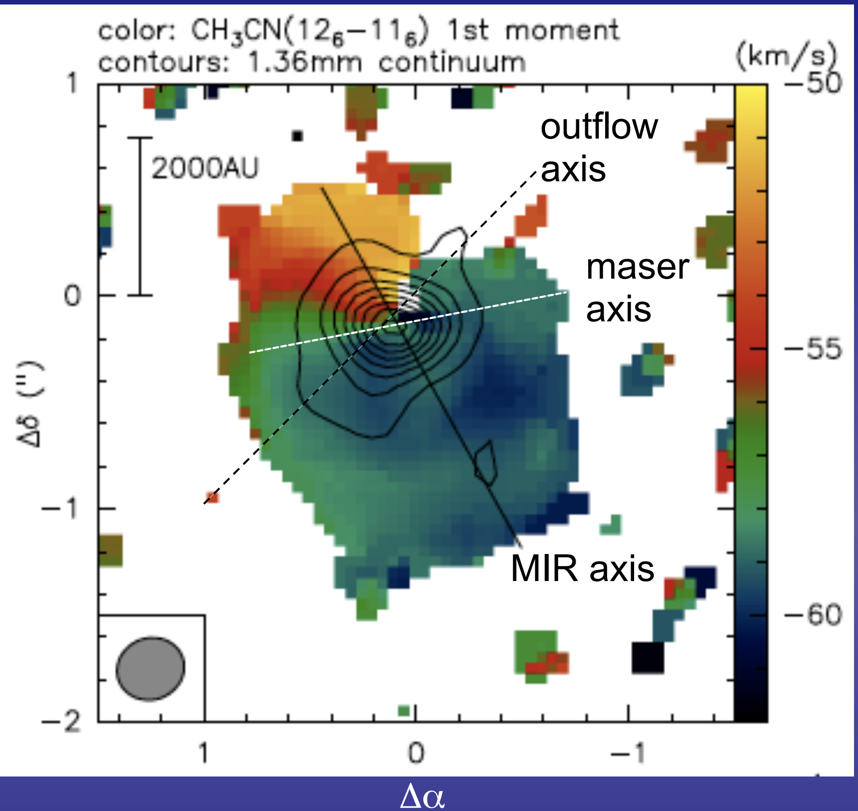
Rotation at the earliest evolutionary stages

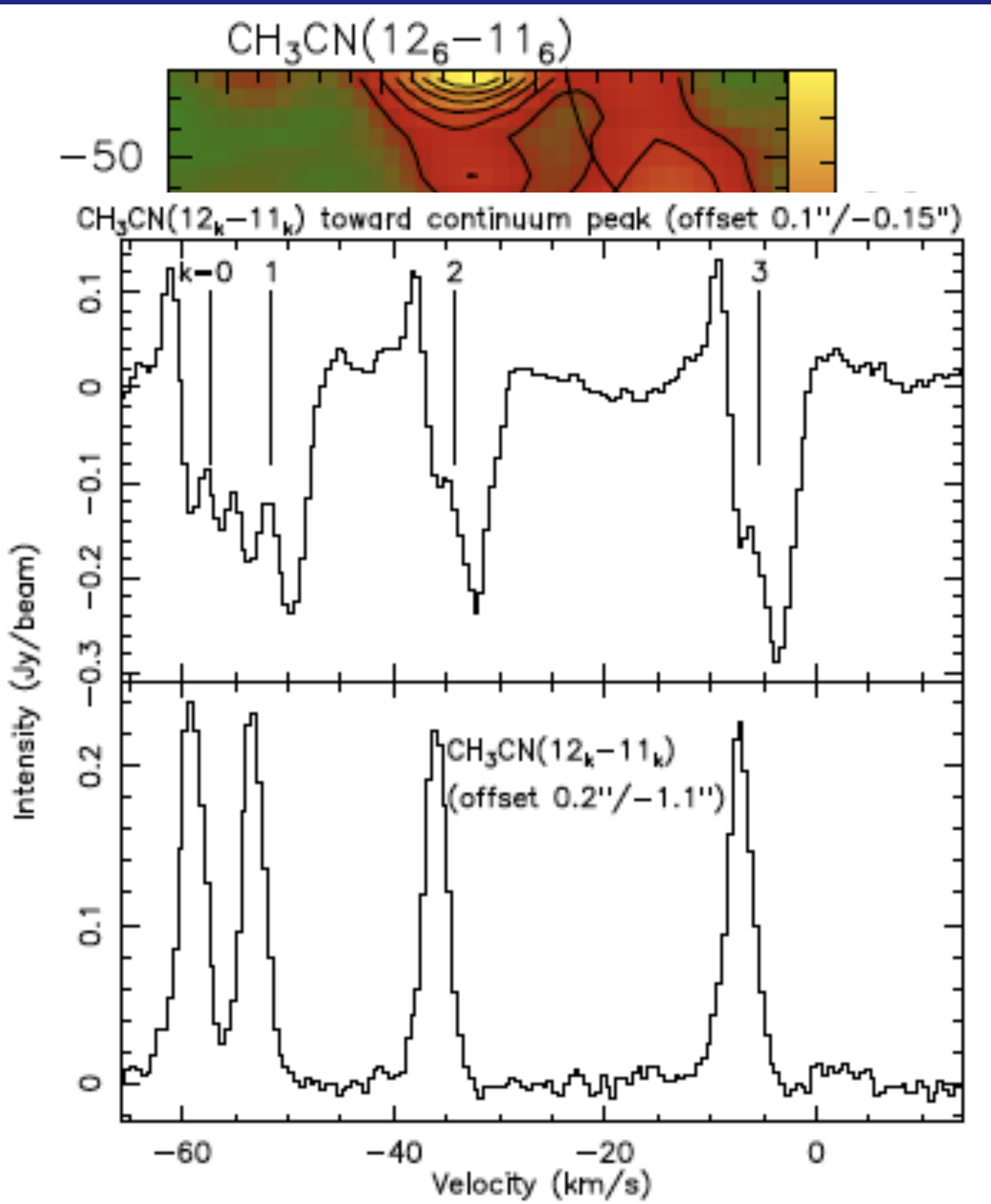






Infall and rotation around NGC7538IRS1

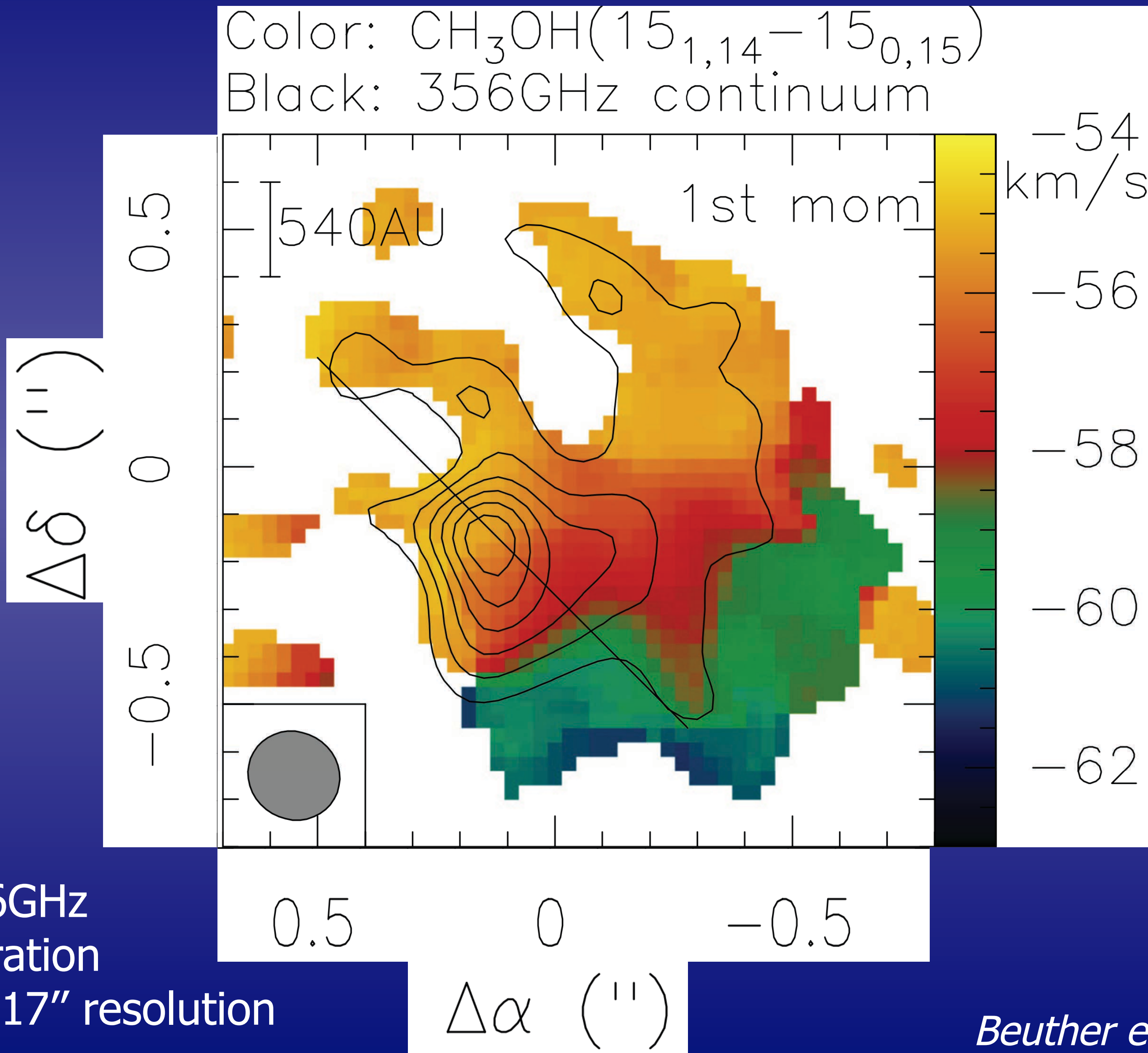




Infall rates: ~$10^{-3} M_{sun}$/yr

Beuther et al. 2012

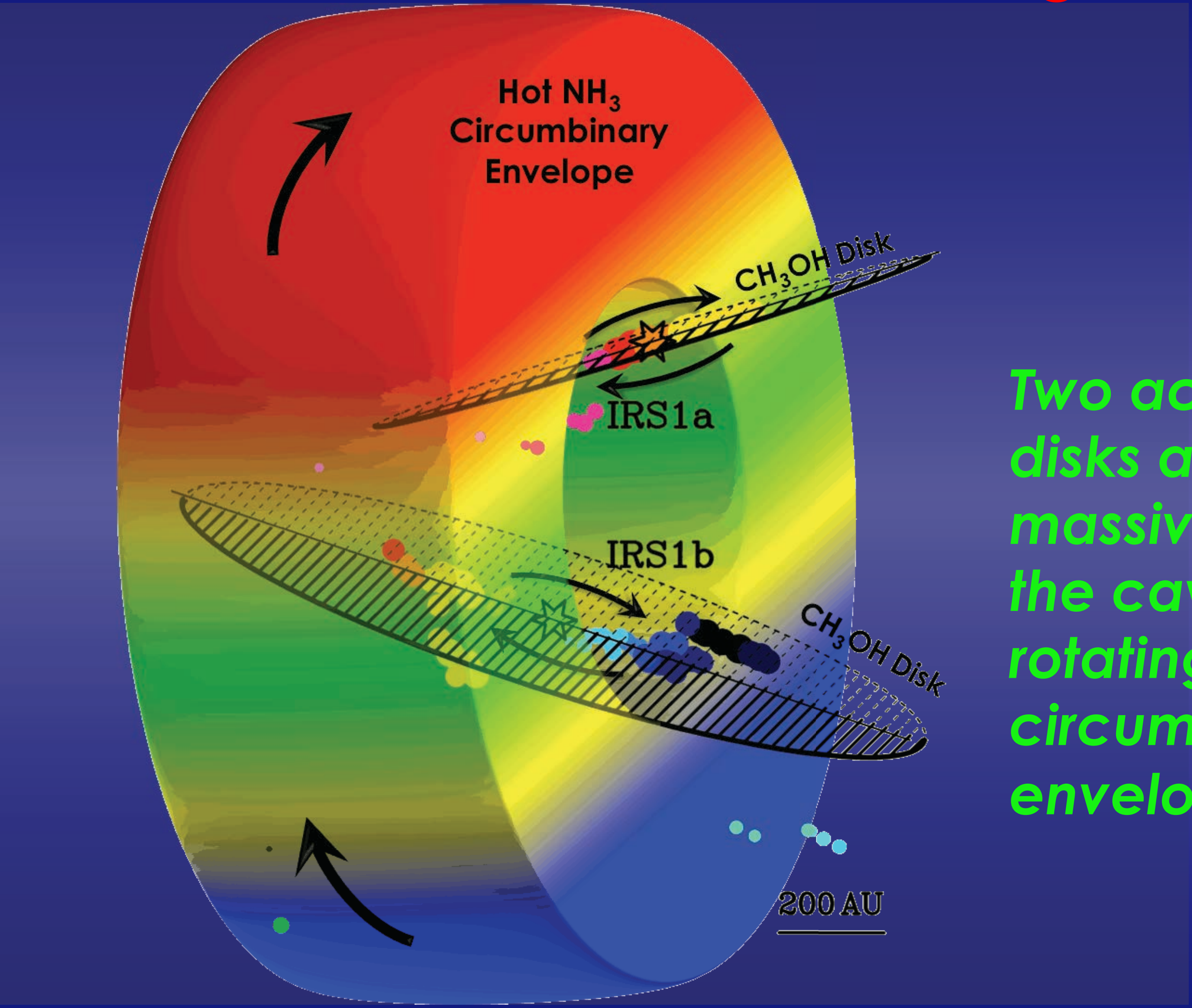
Fragmentation of the inner disk in NGC7538IRS1



PdBI@356GHz
A-configuration
→ 0.2″x0.17″ resolution

Beuther et al. 2013

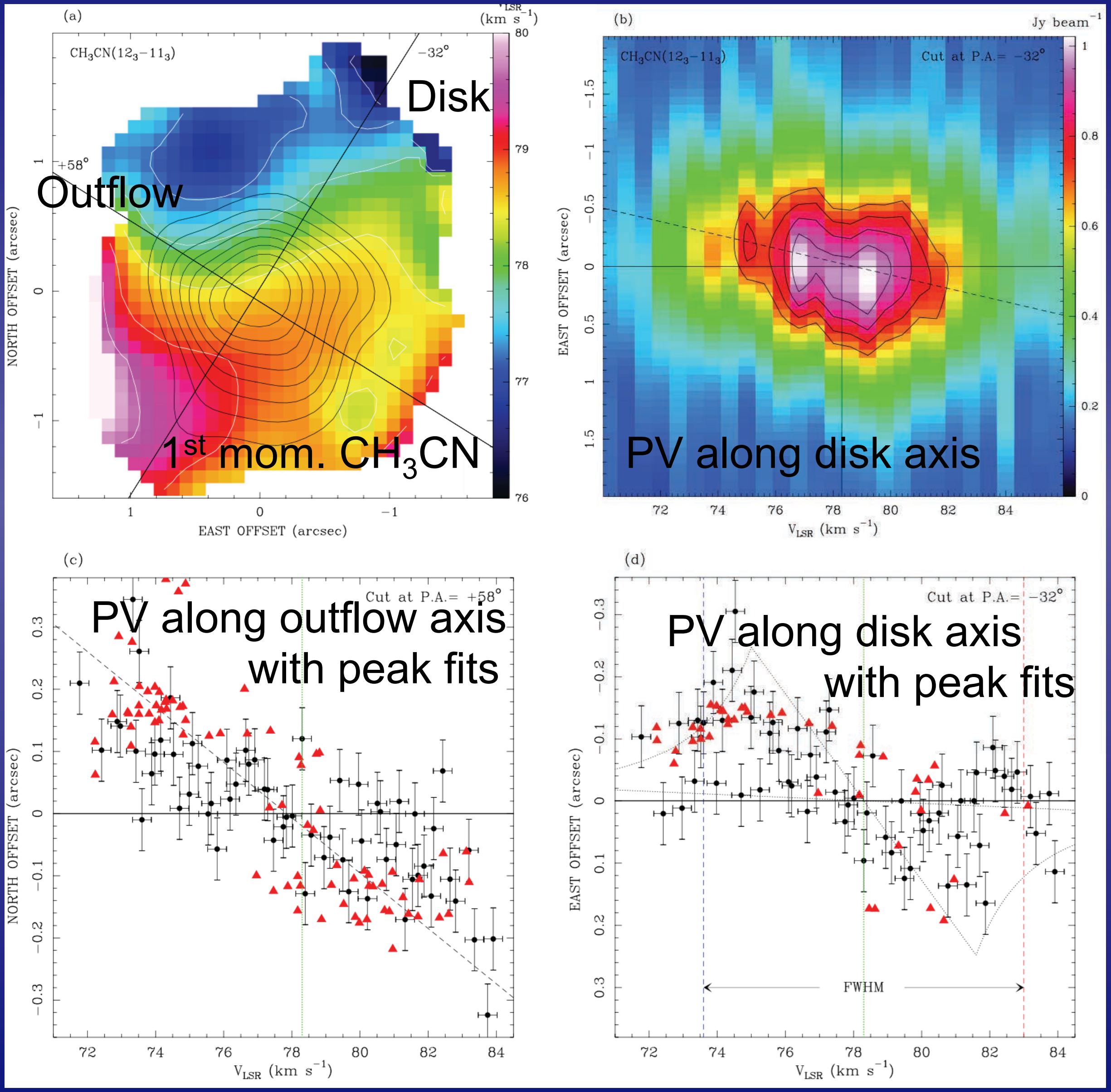
I. NGC7538 IRS1: an accreting O-type Star



Two accretion disks around two massive YSOs in the cavity of a rotating circumbinary envelope

Goddi, Zhang, & Moscadelli, 2015, A&A, 573, 108

Subarsecond SMA study of G023.01

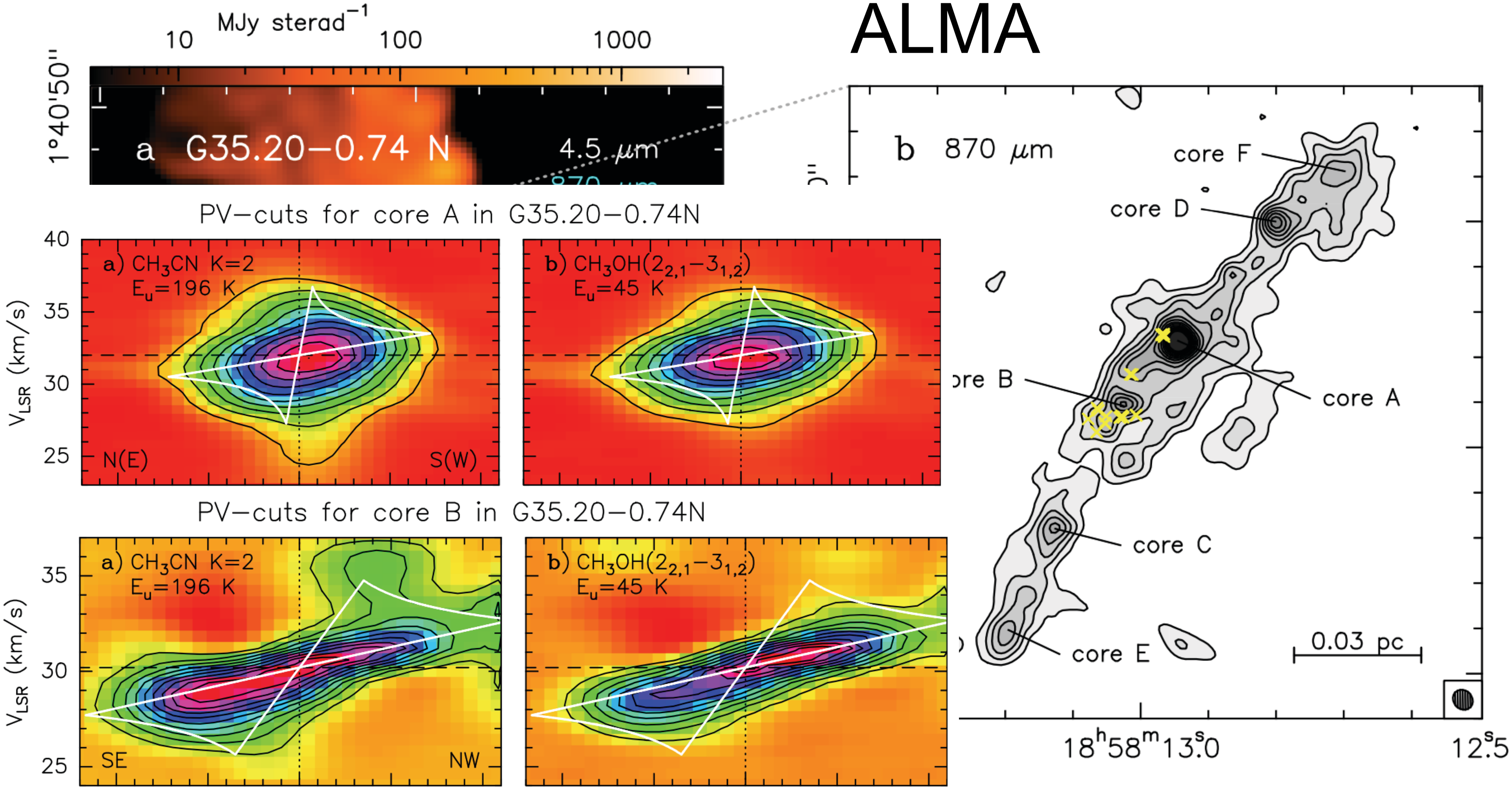


- CH_3CN traces disk & outflow
- Outflow Hubble law
- Rotation consistent with dyn. mass $19M_{sun}$

Sanna et al. 2014

Multiple disks within filaments

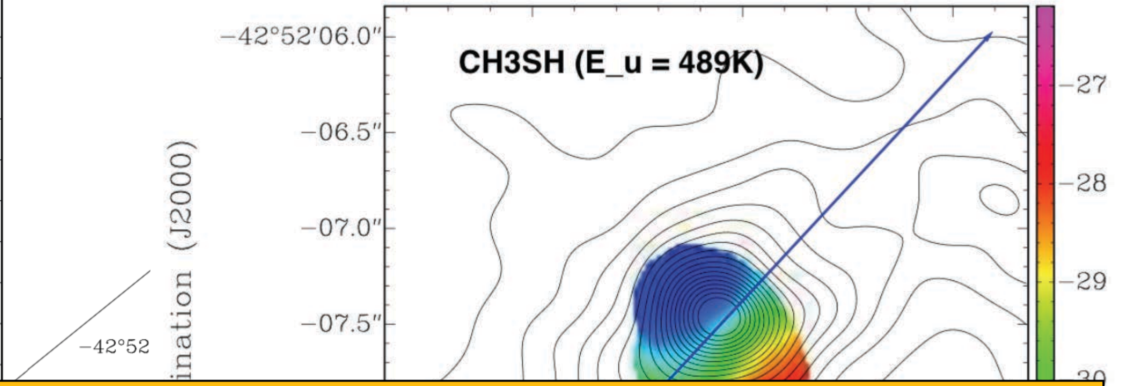
ALMA



- Filamentary chain of cores
- Rotation signatures consistent with Keplerian rotation around 4-18M_{sun} stars

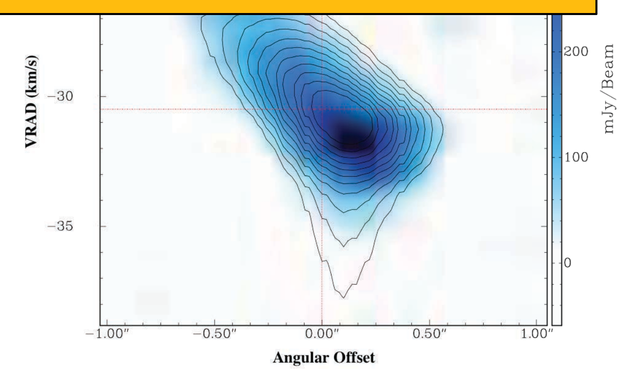
Sanchez-Monge et al. 2013, 2014, see also Beltran et al. 2014

A precessing disk/jet system



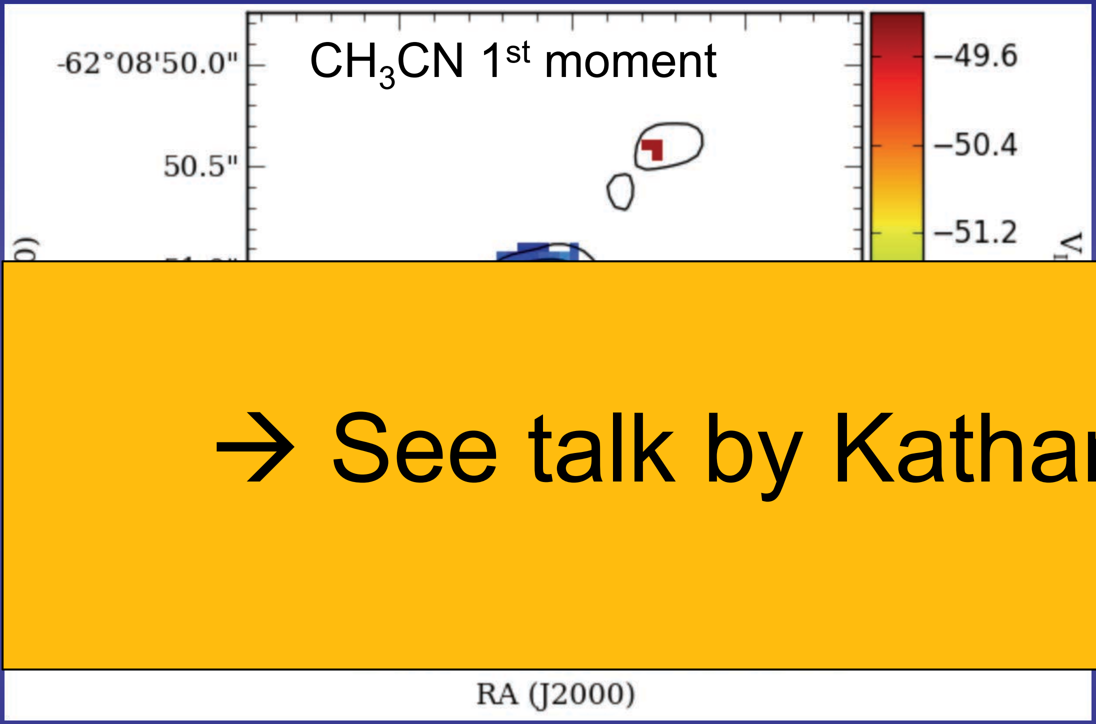
→ See talk by Luis Zapata

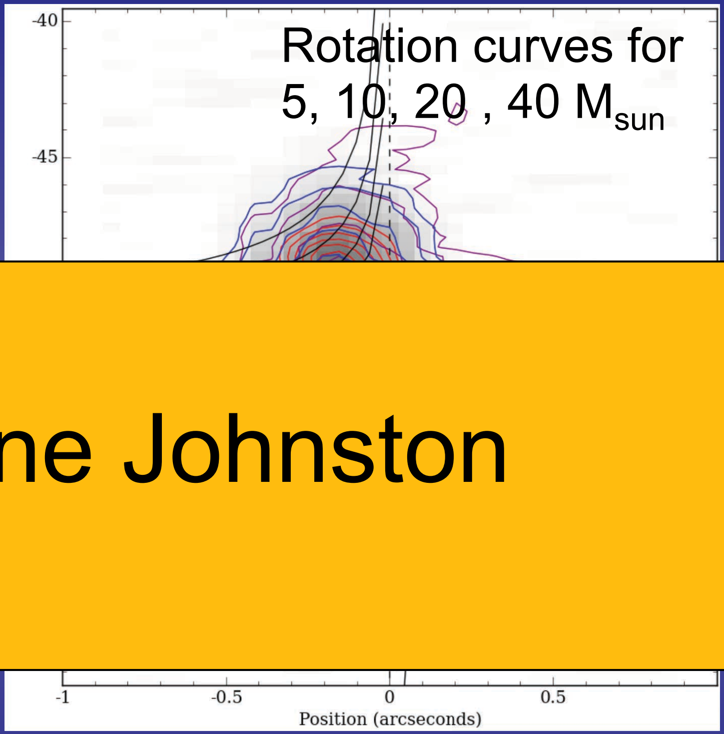
20M_{sun} central object (fits bolometric luminosity)



Zapata et al. 2015, see also Higuchi et al. 2015

ALMA observations of AFGL4176



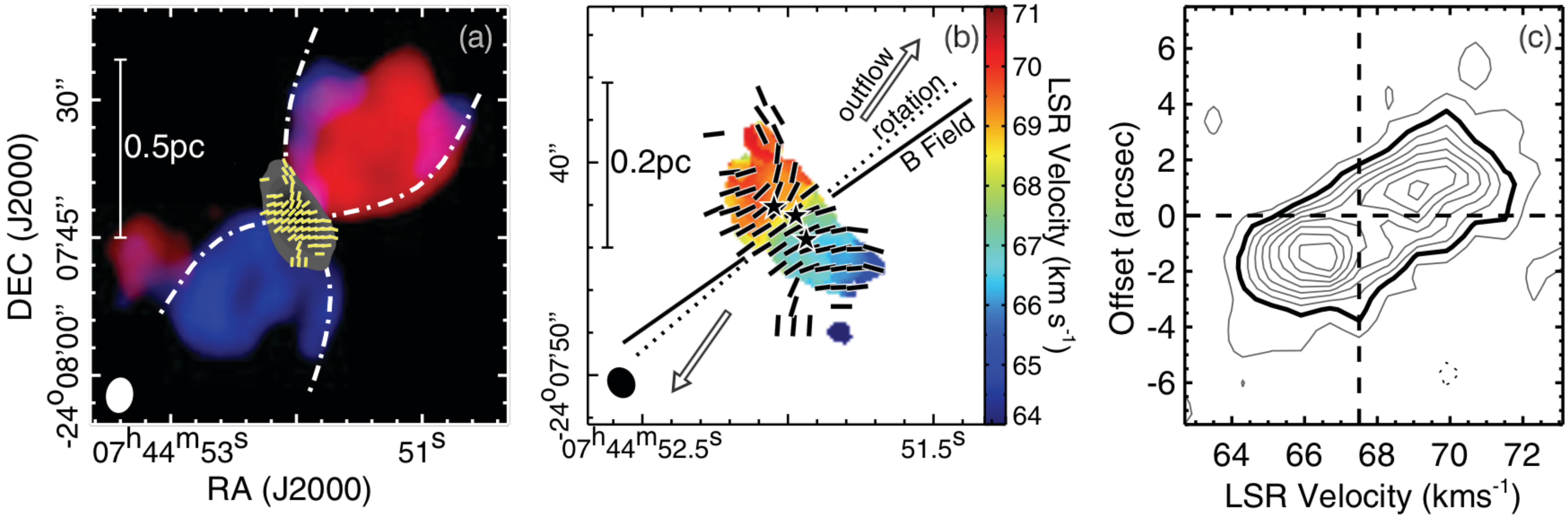


→ See talk by Katharine Johnston

Johnston et al. in prep.

Magnetic disk/outflow system

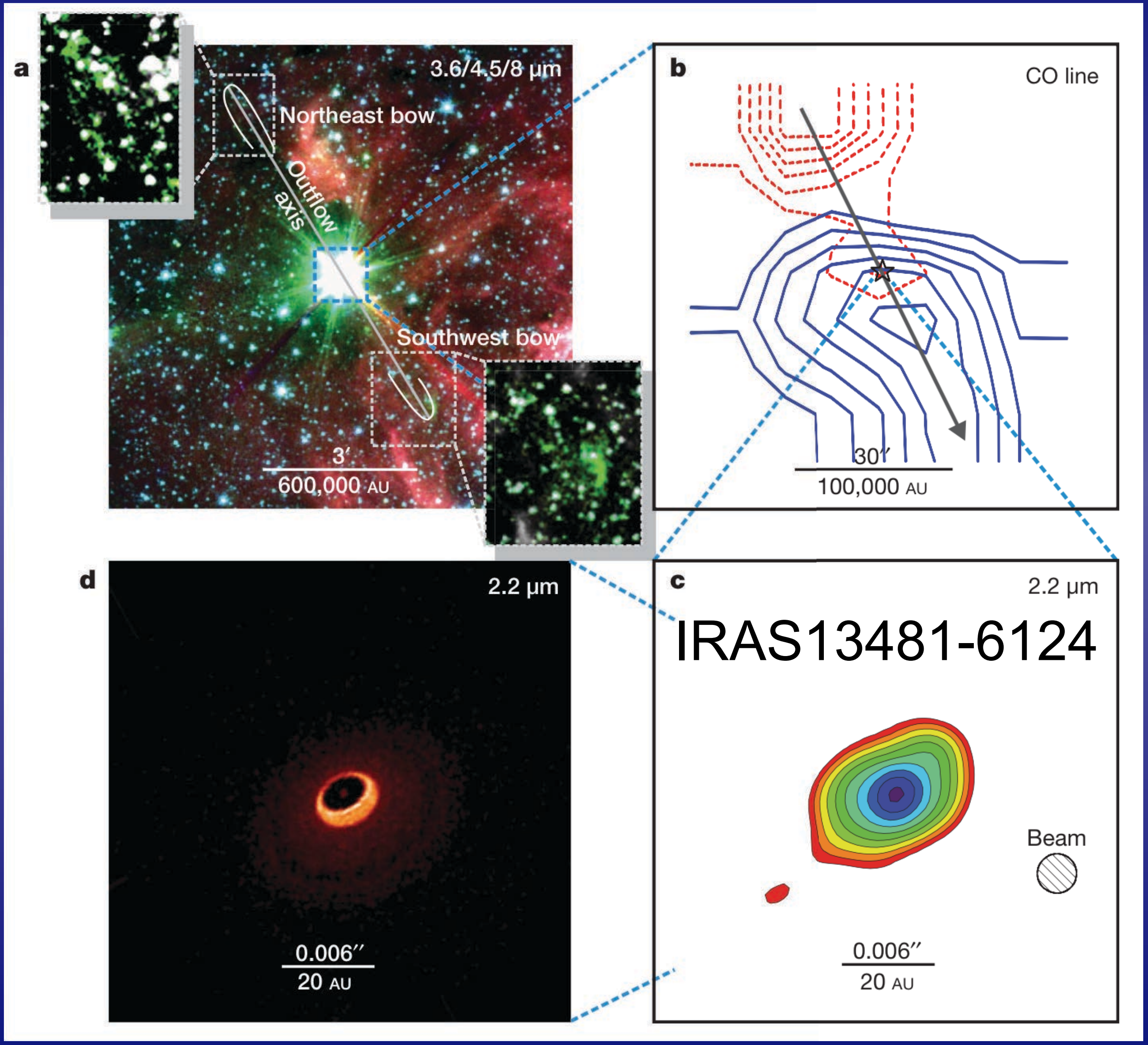
G240.31+0.07



Magnetic field, disk and outflow system consistent with low-mass picture.

Qiu et al. 2014

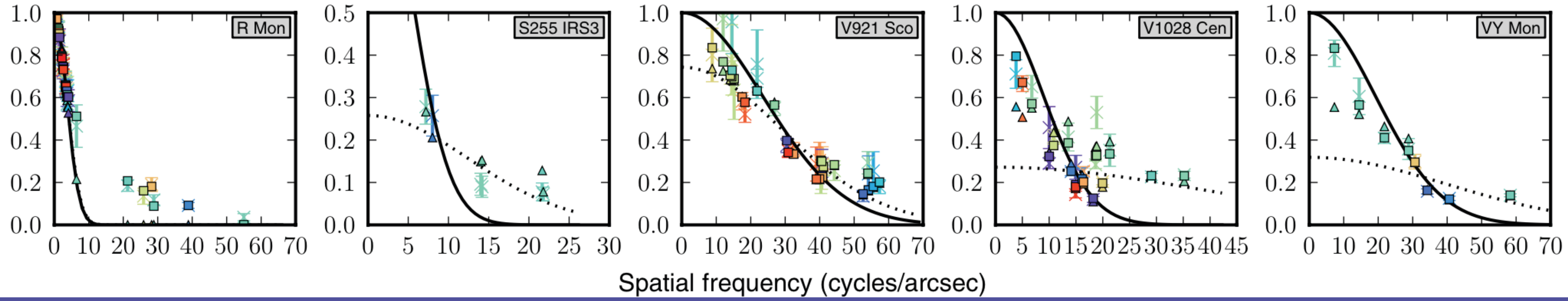
NIR interferometric disk imaging



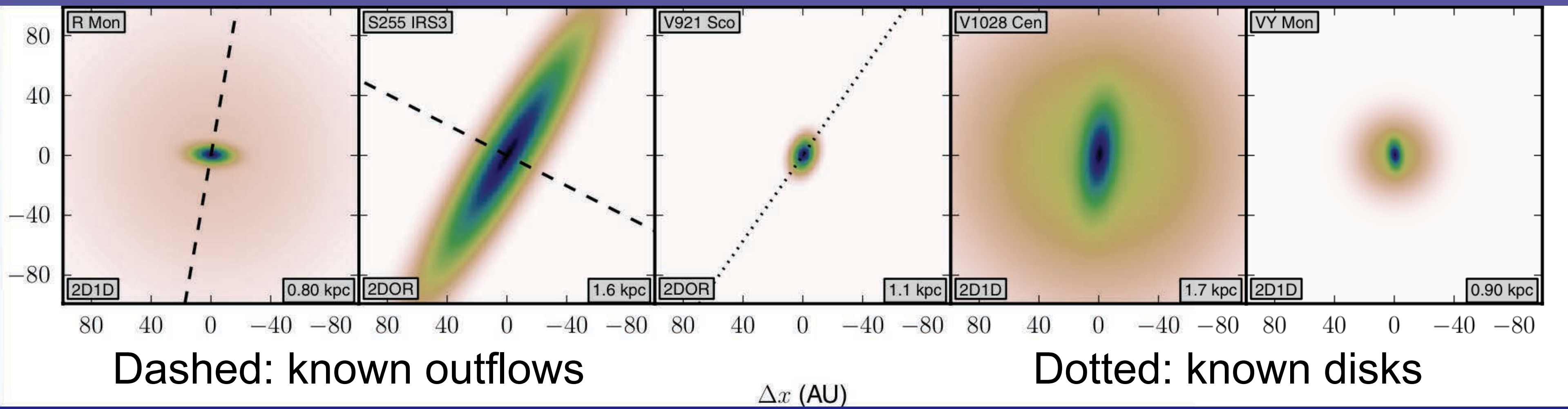
Kraus et al. 2010

Mid-infrared interferometry

Visibilities



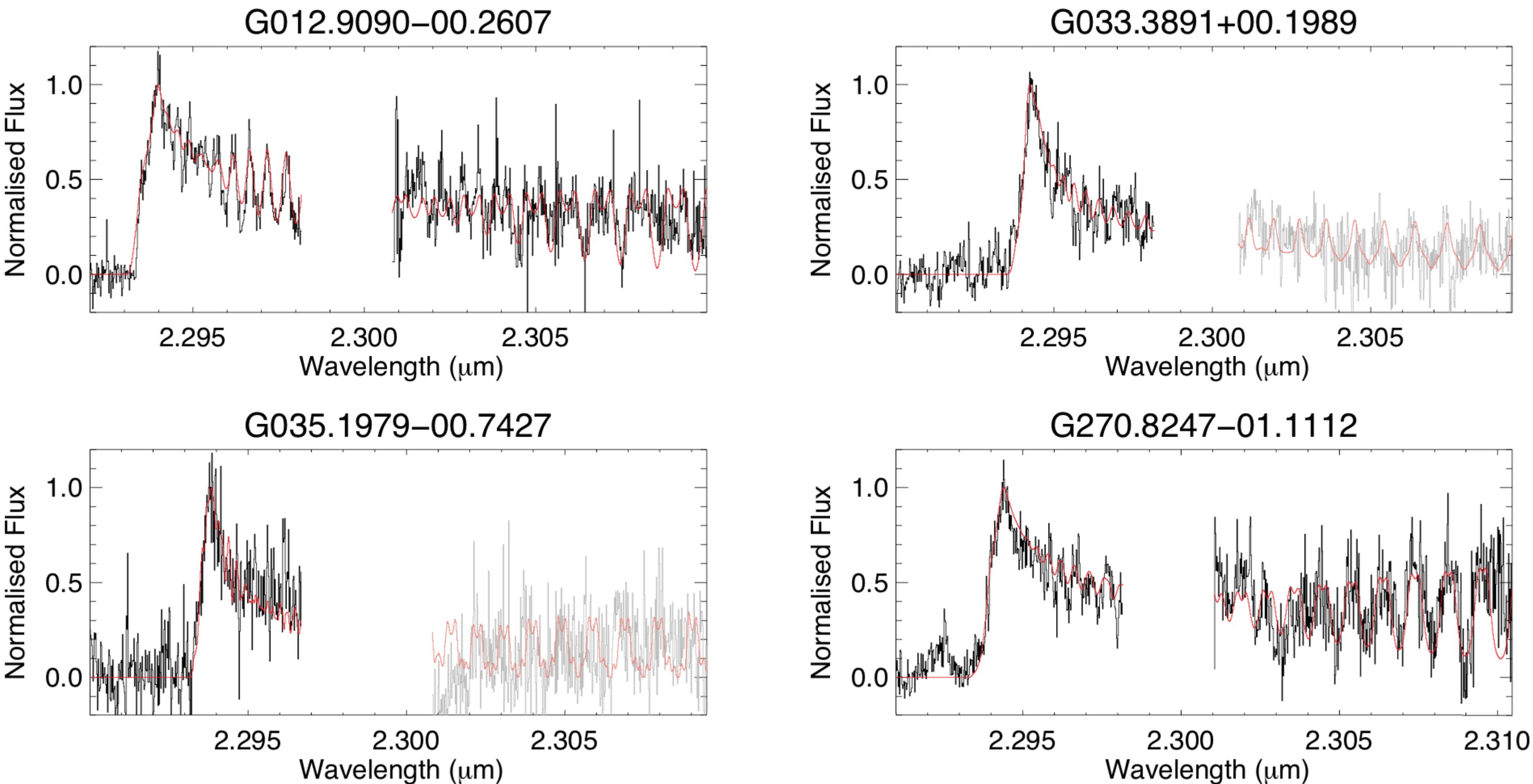
Best fit models



- MIR can trace disks and outflows, often hard to disentangle

Boley et al. 2013

NIR spectroscopy



- 2.3μm CO bandhead emission of 20 MYSOs
  → emission fitted assuming Keplerian disk
  → Data fitted with geometrically thin disks within dust sublimation radius on AU scales.

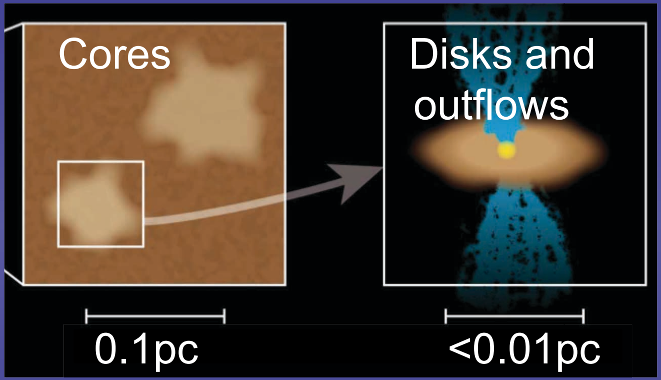
Ilee et al. 2013

Fragmentation and disk formation during high-mass star formation

Survey (PI: H. Beuther):

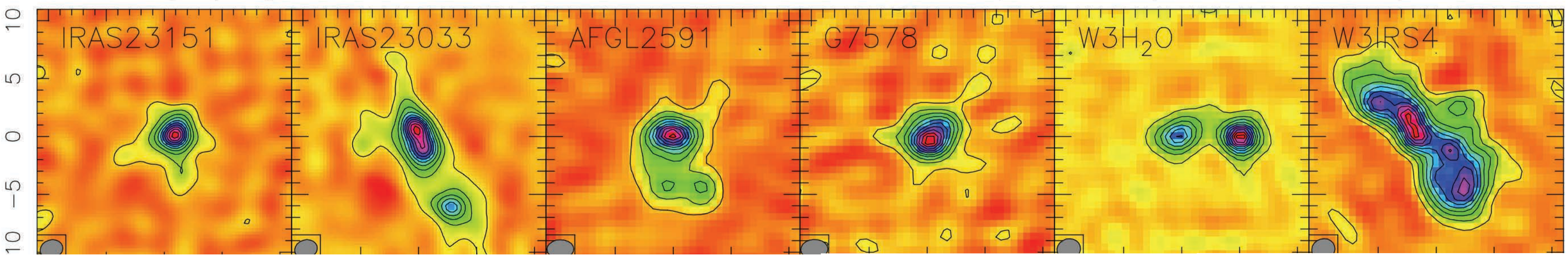
- Large sample of high-mass star-forming regions
- 0.2″ ~ 500AU
- (sub)mm line and continuum emission

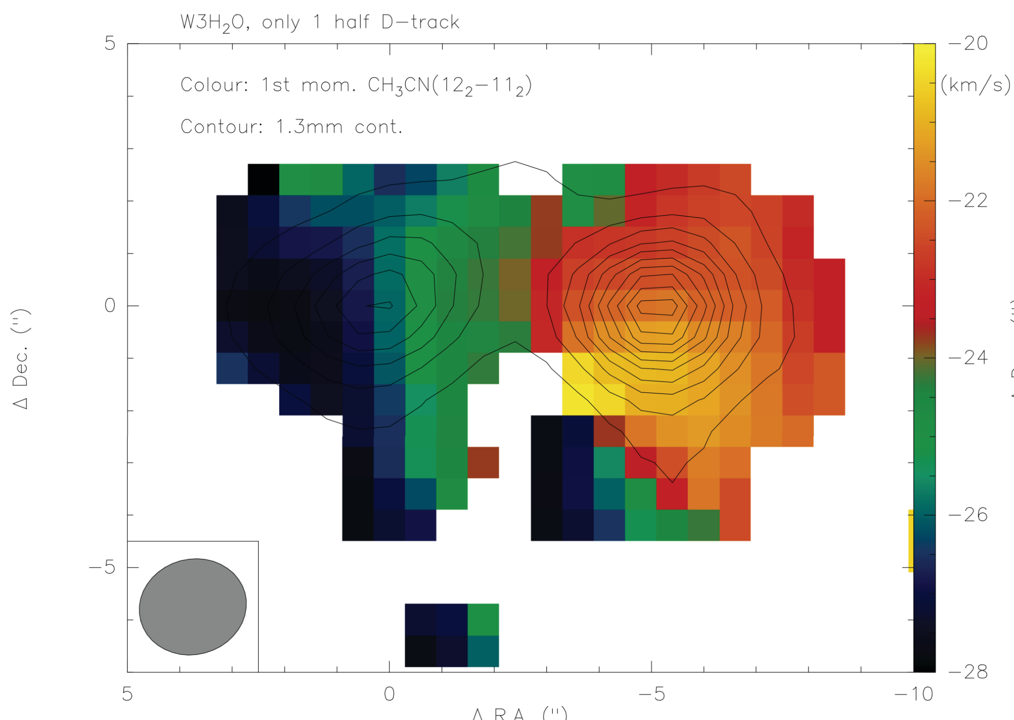
- >300 hours large program at PdBI
- Only large program in that field

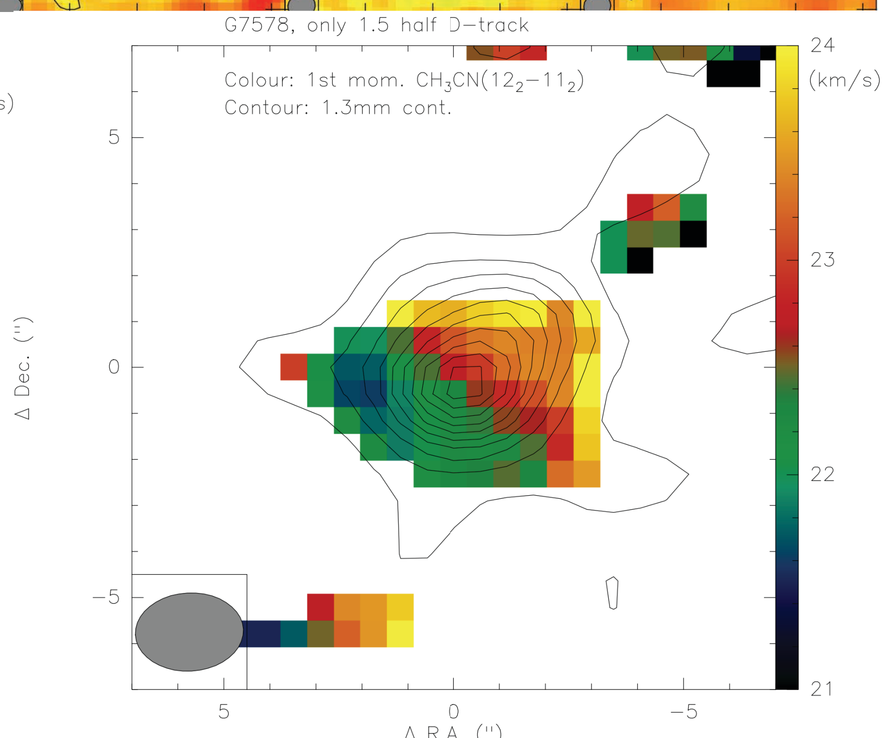


Fragmentation and disk formation during high-mass star formation

PdBI large program CORE: 1.3mm continuum emission of sample. Usually 0.5 D–tracks per source





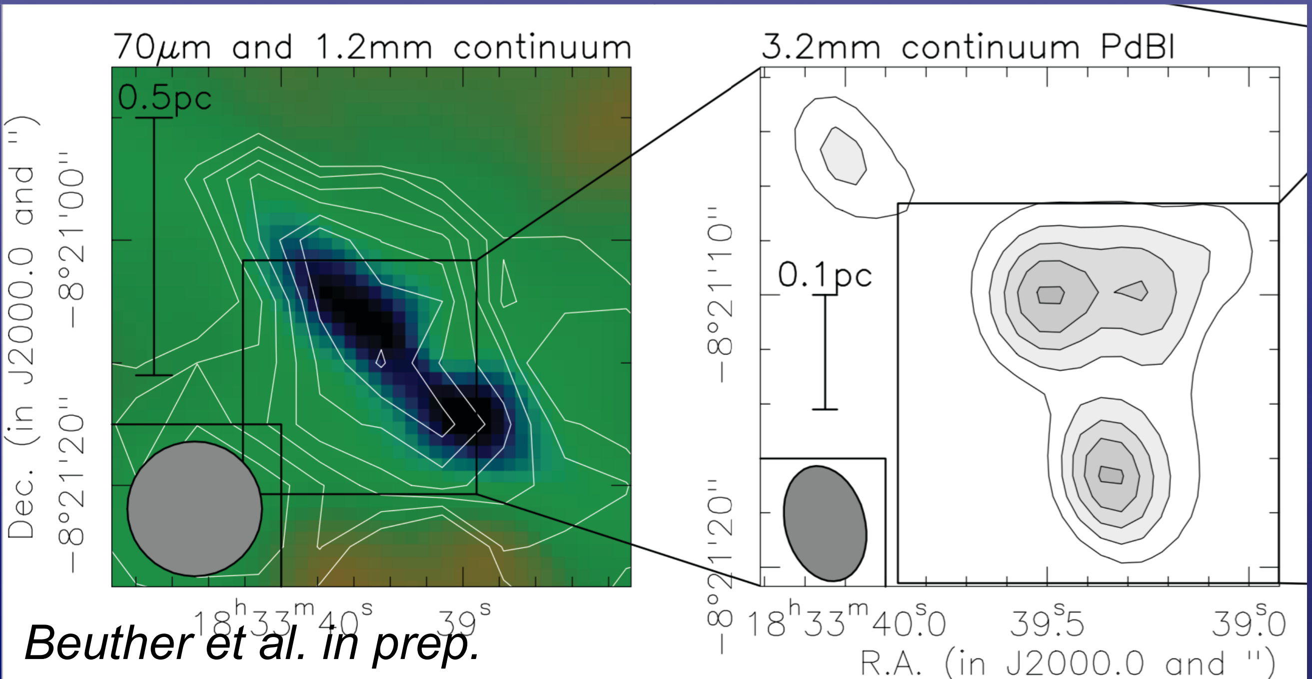


Summary

- Disks around early B-stars well established
- More difficult in O-star regime
- Early interesting examples of disk candidates in 20M_{sun} regime
- However statistics still poor
- Multi-wavelength approach likely to be very important

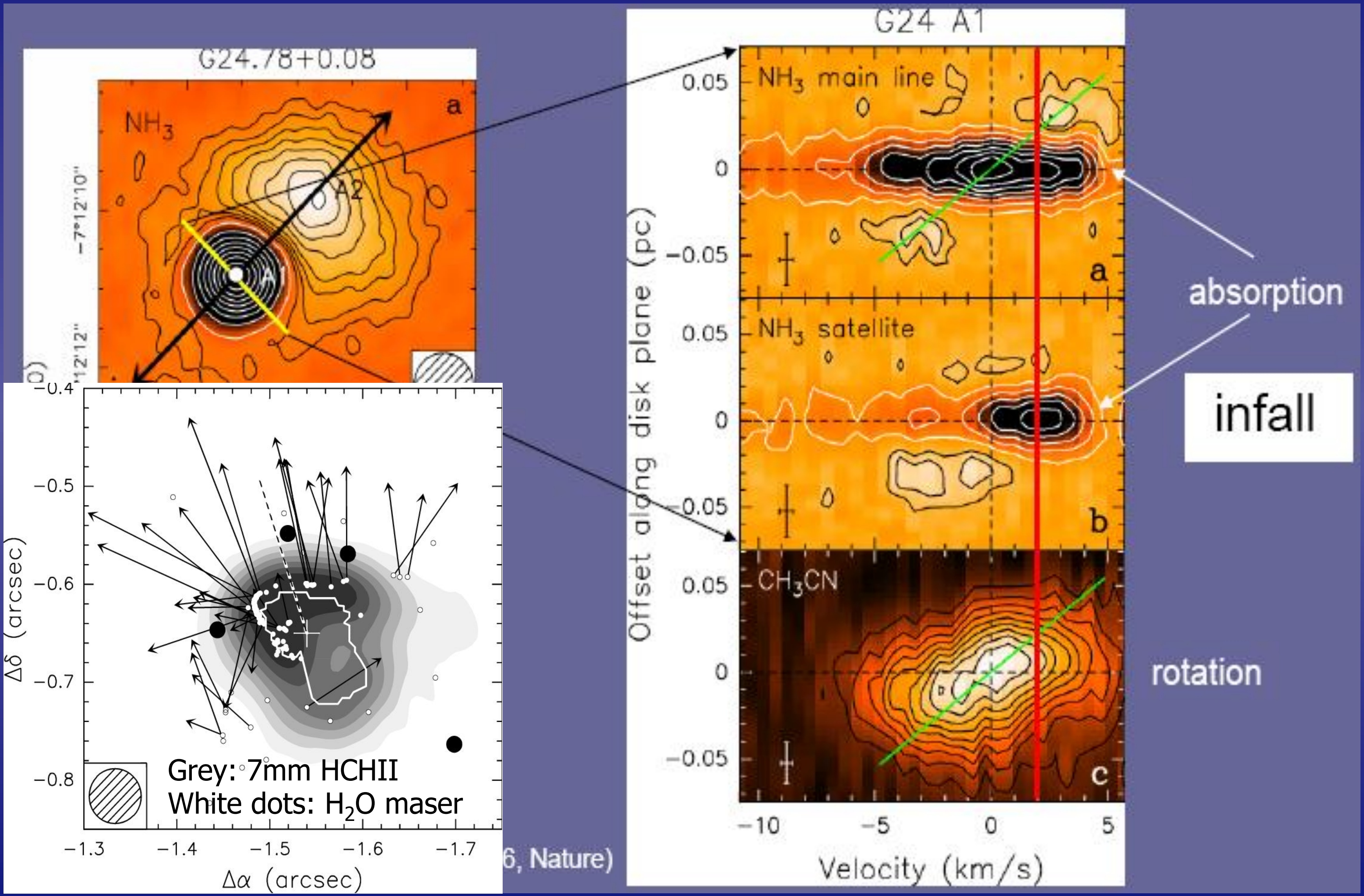
- Lots to come in the field with NOEMA, ALMA, JWST, MATISSE …

Hirarchical fragmentation



Beuther et al. in prep.

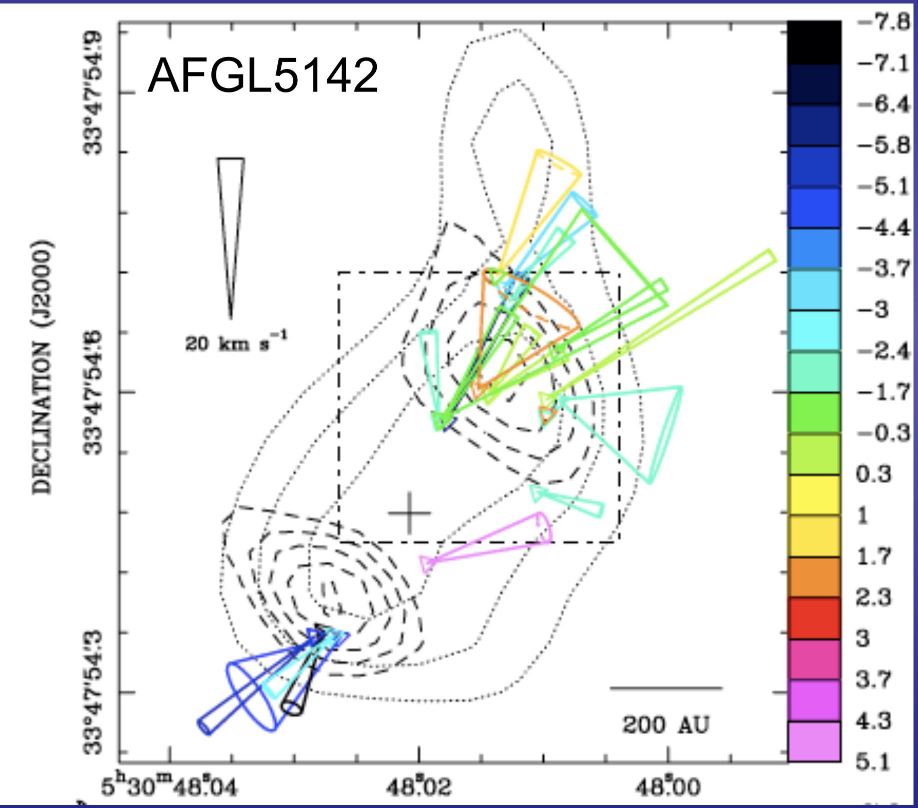
Rotation, Infall and Outflow motions

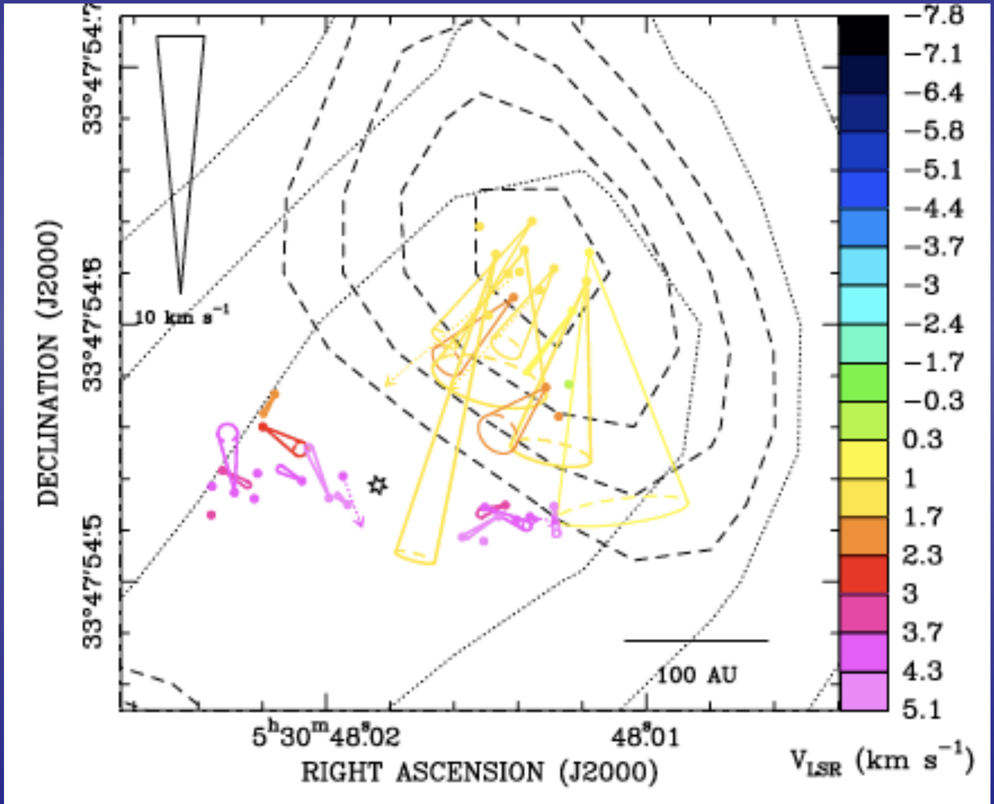


Beltran et al. 2006, 2007

Infall and outflow at 400AU scales

Proper motios: H_2O maser CH_3OH maser

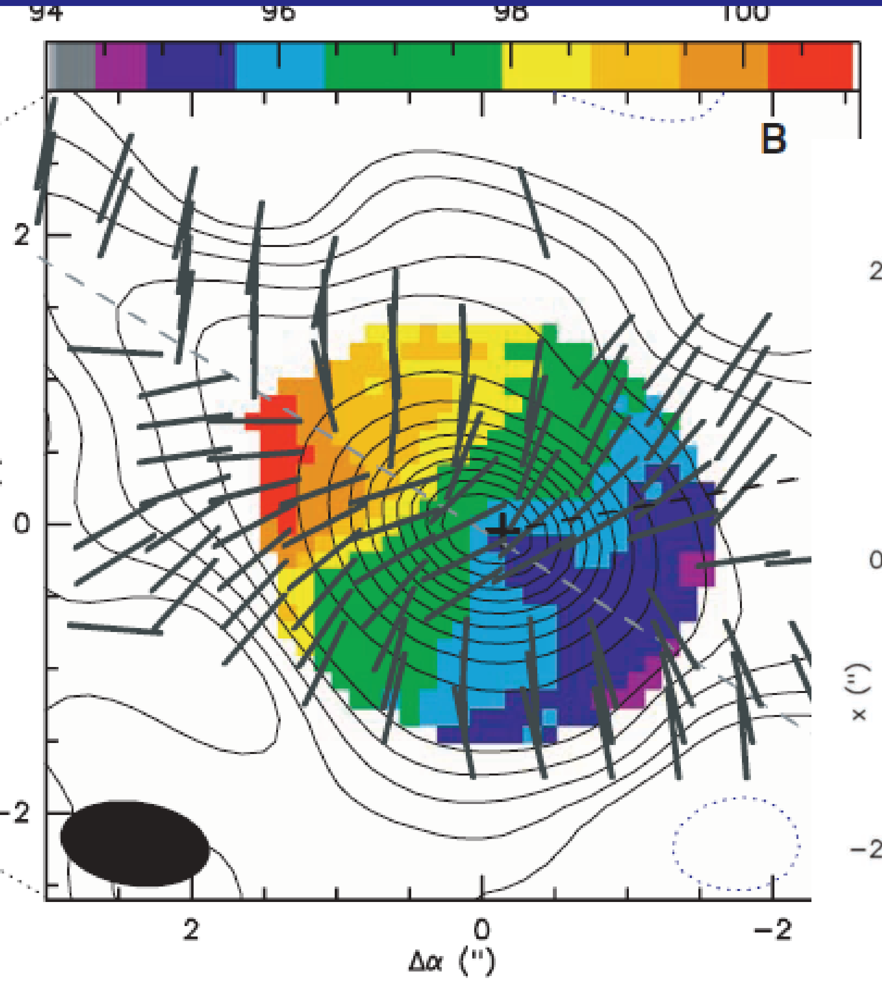


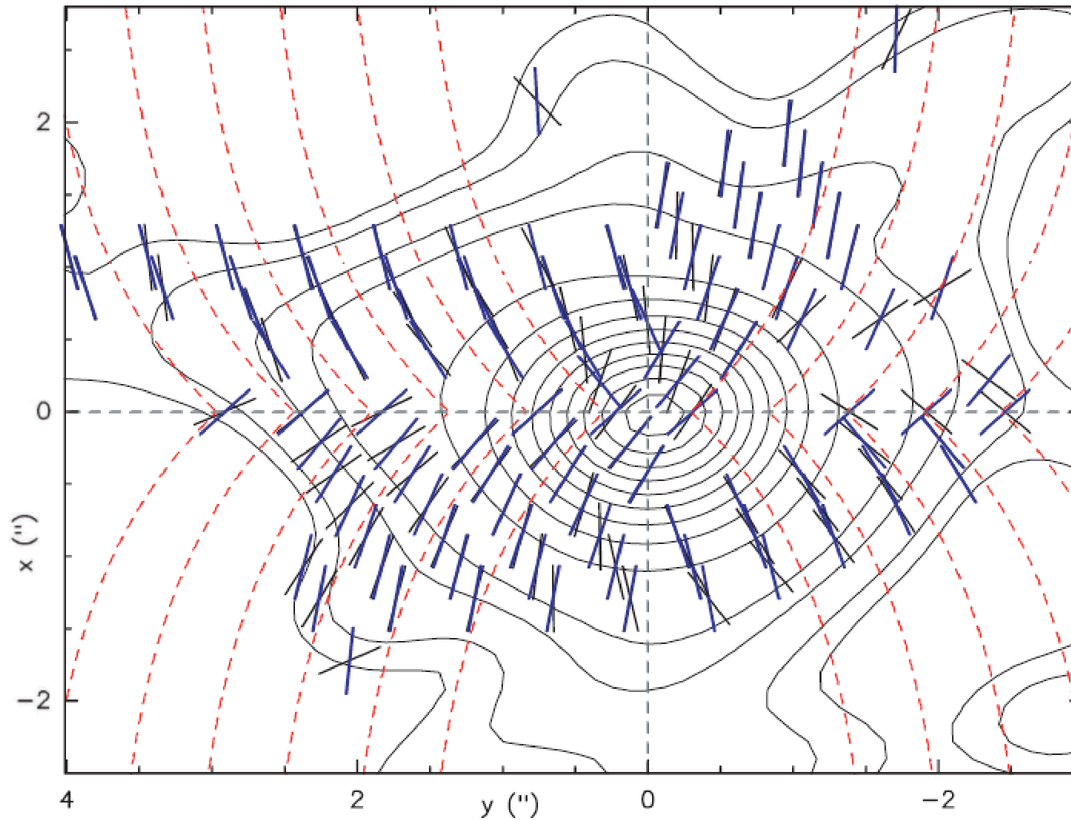


Goddi et al. 2011

Magnetic field in the hot core G31.41

Color: 1st moment CH_3OH, contours: 879µm
bars: orientation of magnetic field
red: best fit field

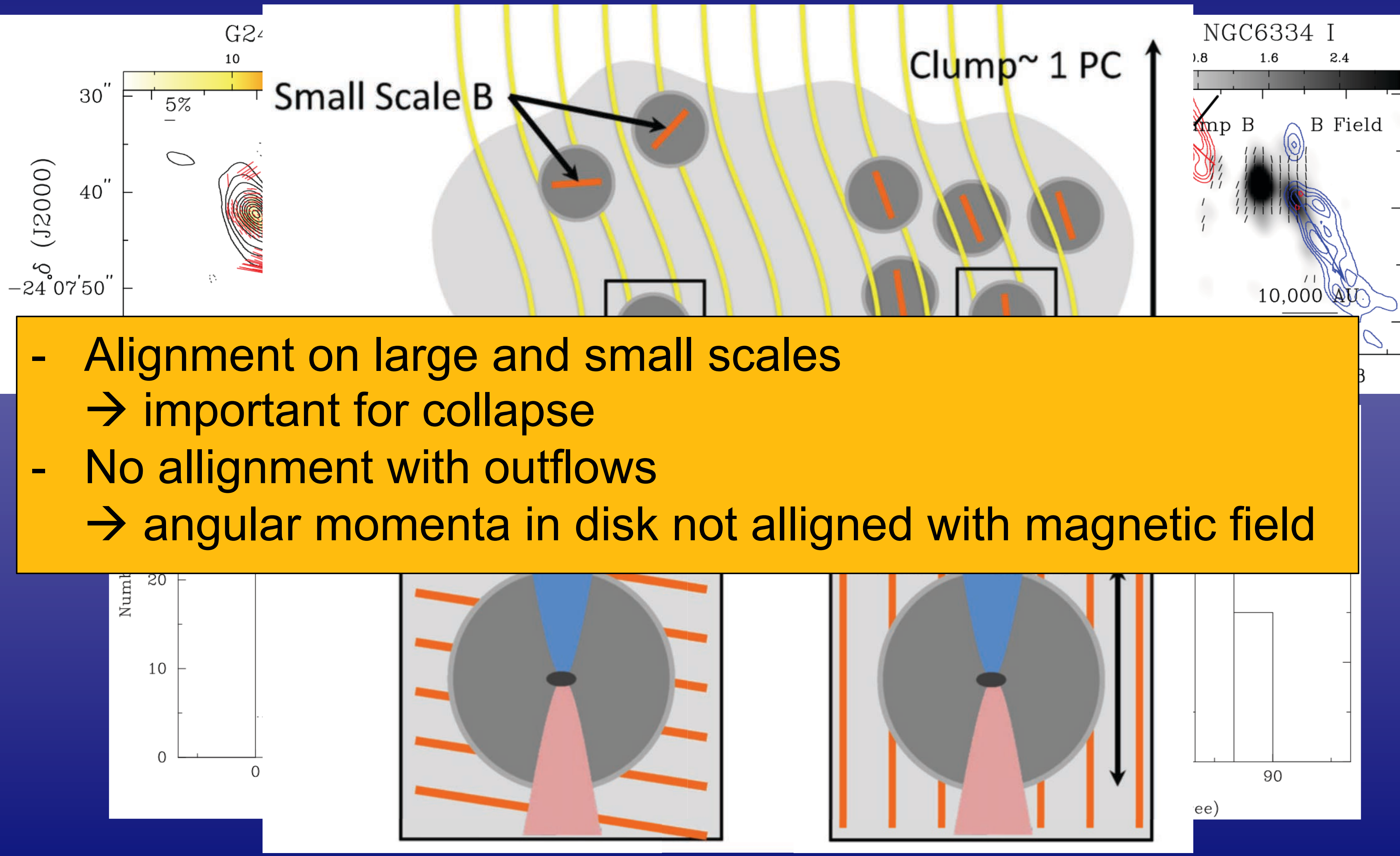




Collapse dominated by magnetic field
Magnetic energy dominates over turbulent and centrifugal energy

Girart et al. 2009

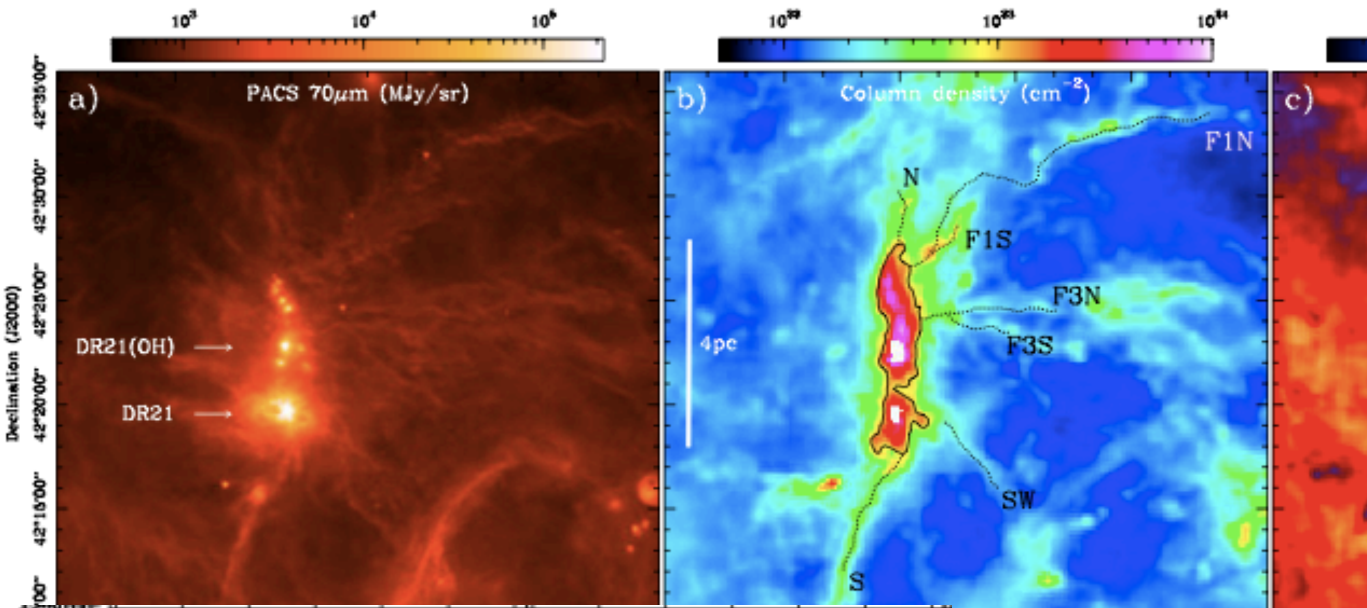
Magnetic fields in a sample of 14

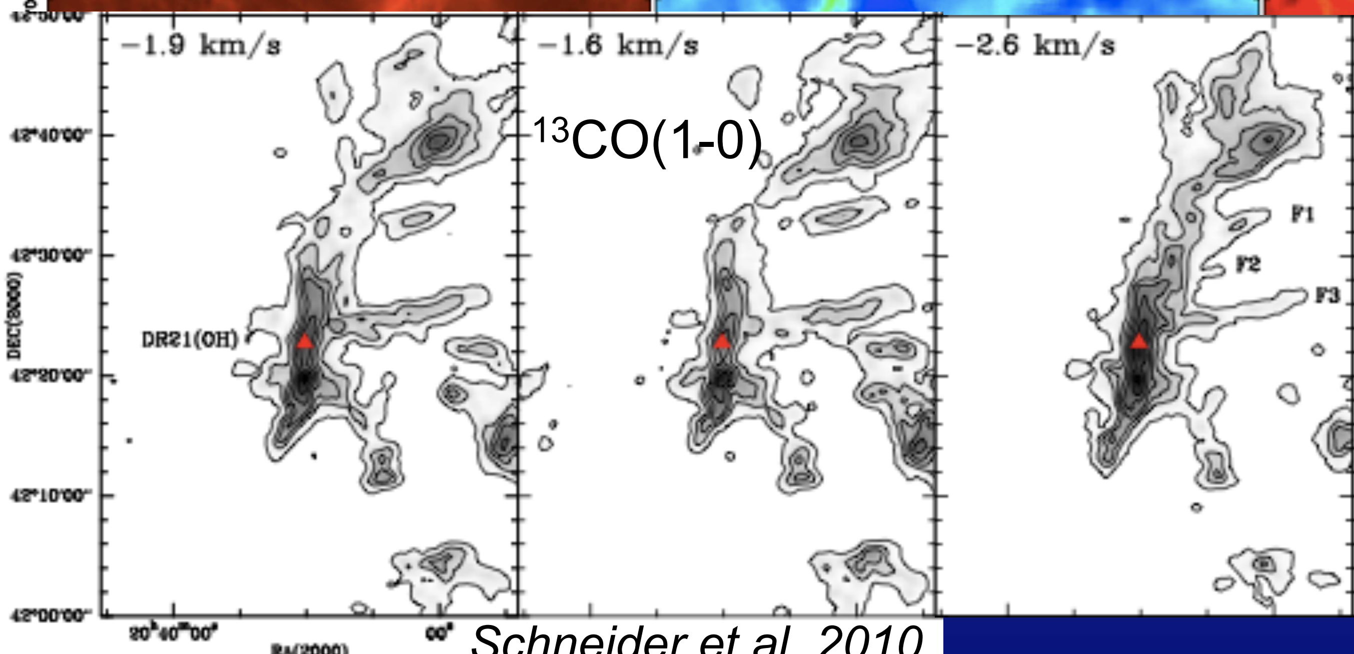


- Alignment on large and small scales
  → important for collapse
- No allignment with outflows
  → angular momenta in disk not alligned with magnetic field

Zhang et al. 2014

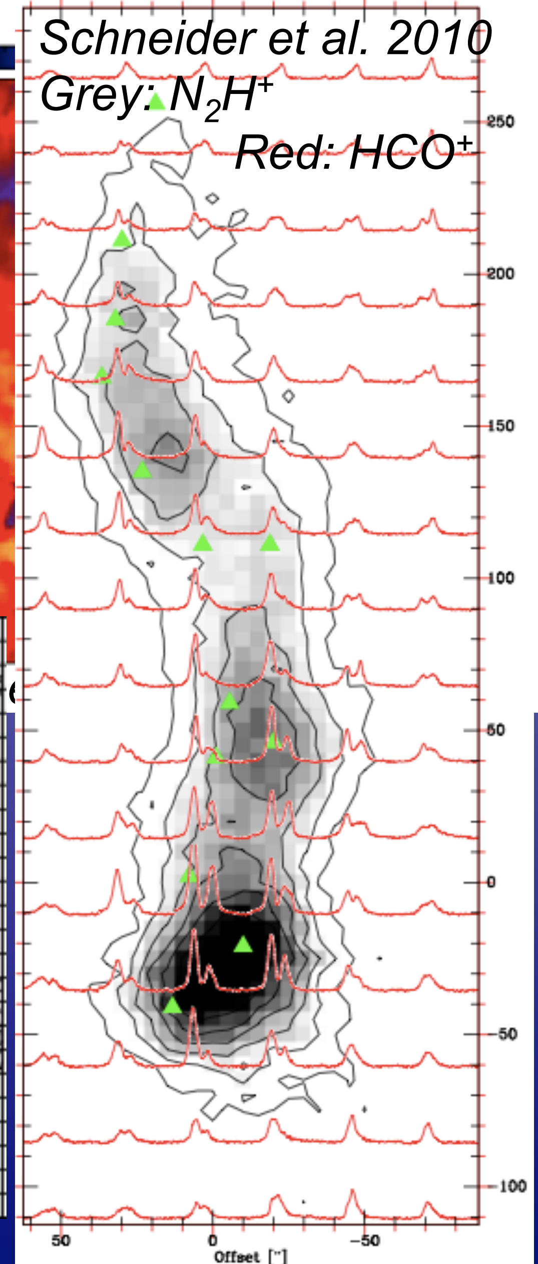
Converging flows



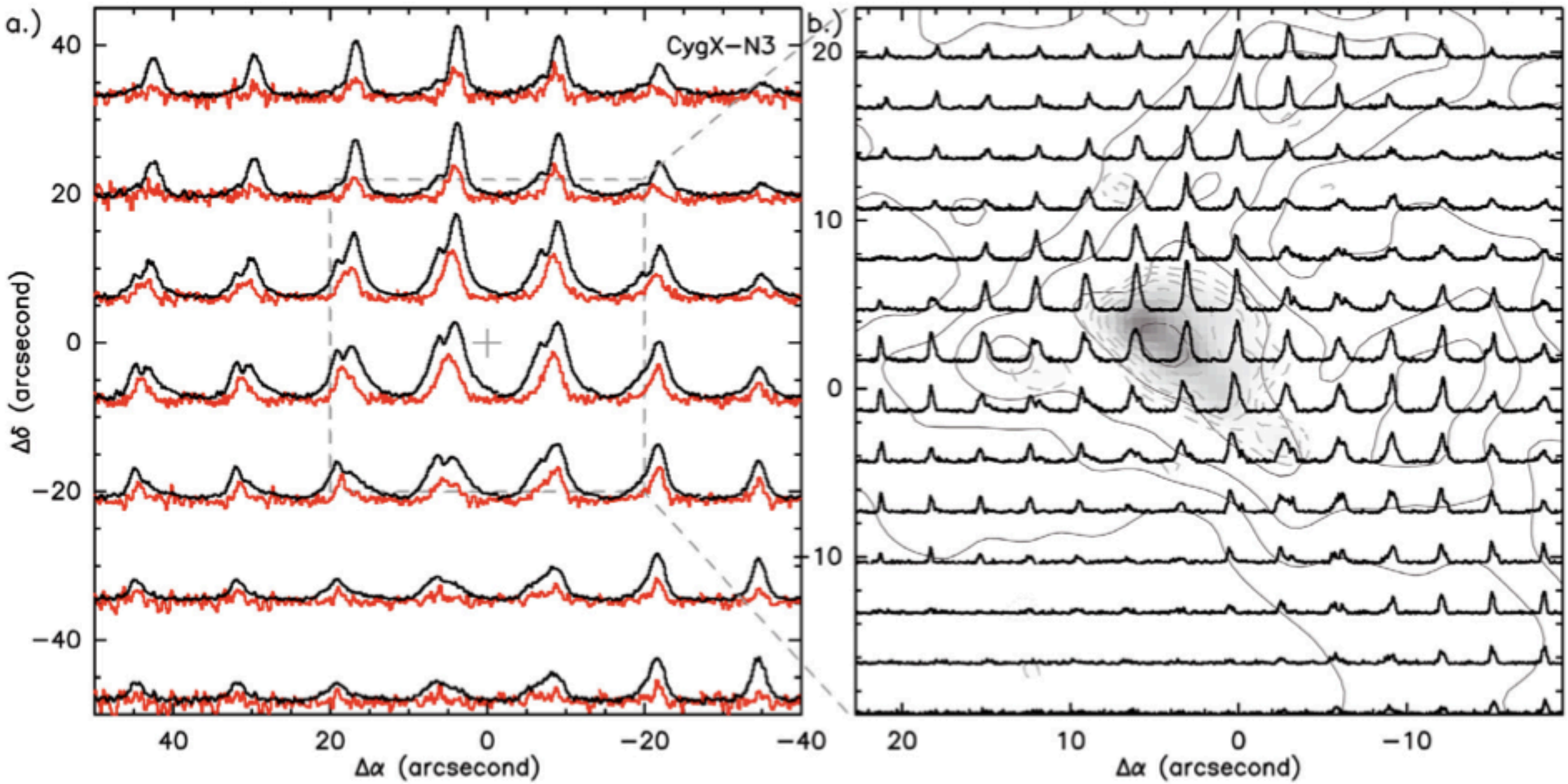


^{13}CO(1-0)

Schneider et al. 2010



Gas dynamics on clump scales

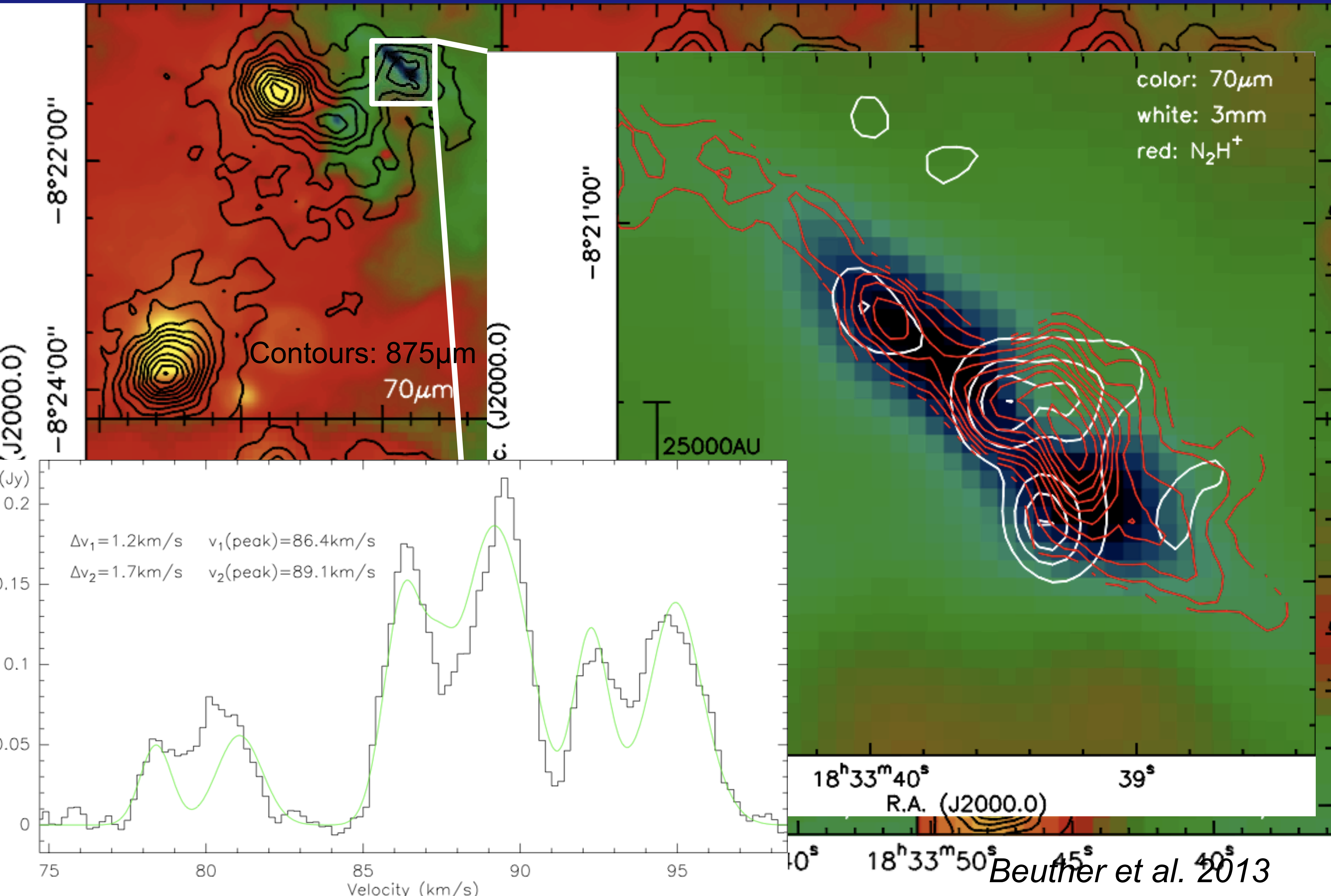


Black: HCO^+, Red $H^{13}CO^+$ (30m)

$H^{13}CO^+$ (PdBI)

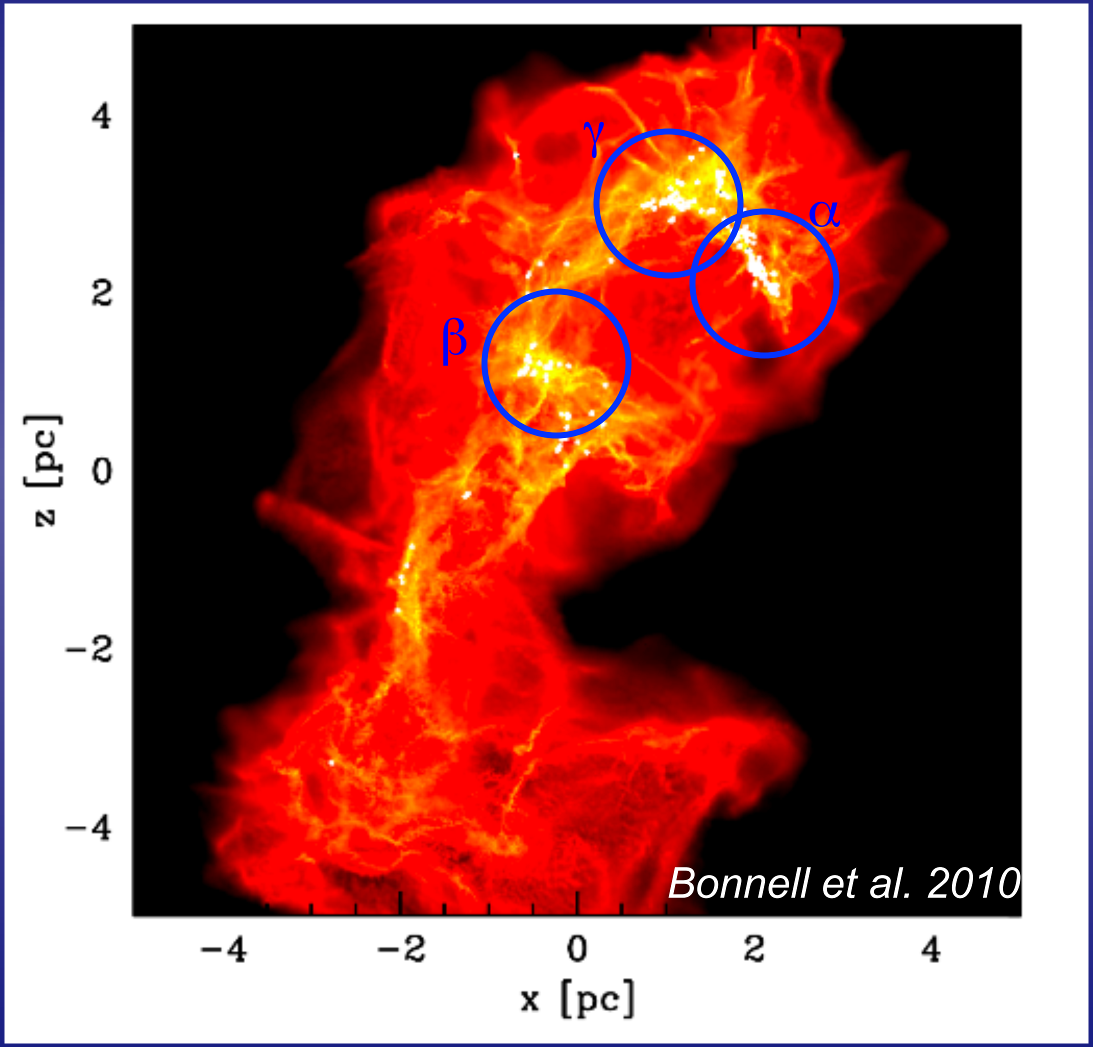
Csengeri et al. 2011a,b

A very massive starless clump in IRDC18310-4



Beuther et al. 2013

Simulation results



- From the global simulation three **clumps** are assigned.

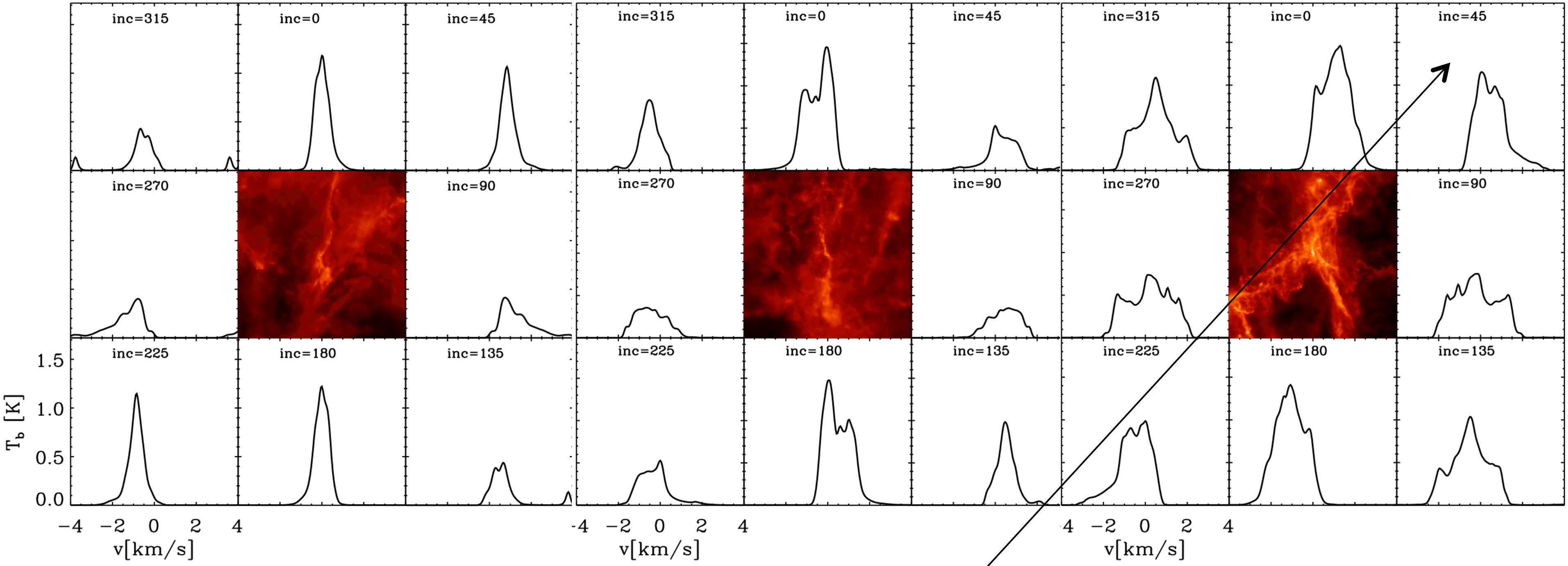
- Each forms a star cluster and has a massive star at its centre.

- Consists of all the mass within 1pc of the precursor of the most massive sink.

Smith et al. 2013

Simulation results

N_2H^+ lines are **non-gaussian** when viewed with a narrow beam (0.02pc half-width).



Example: Peak separation 0.9km/s
dv_1=0.9km/s & dv_2=0.7km/s

Smith et al. 2013