Circumstellar disks in young stellar objects

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  - Accretion versus coalescence/merging of low mass stars;
  - Observations of intermediate star forming regions;
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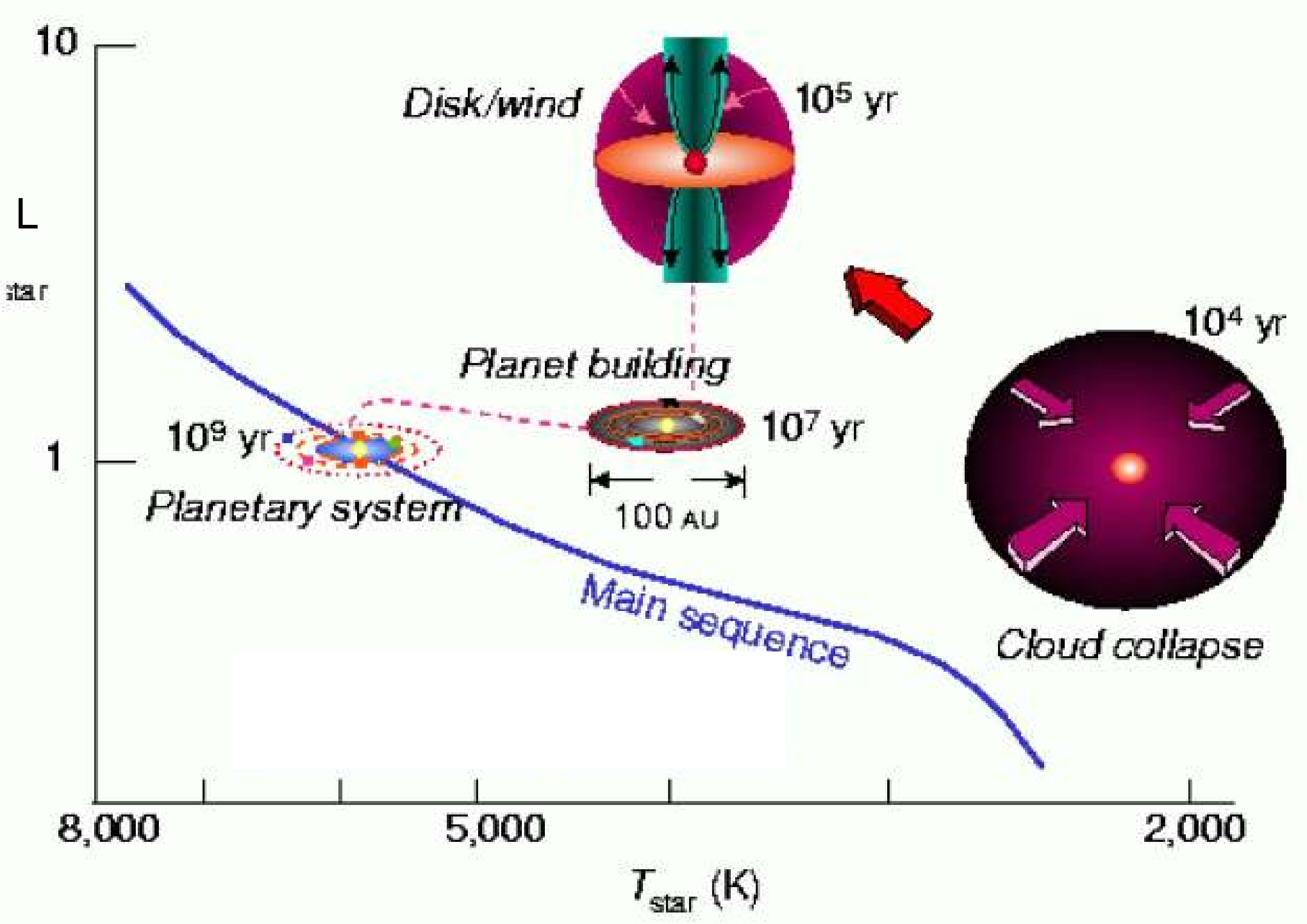
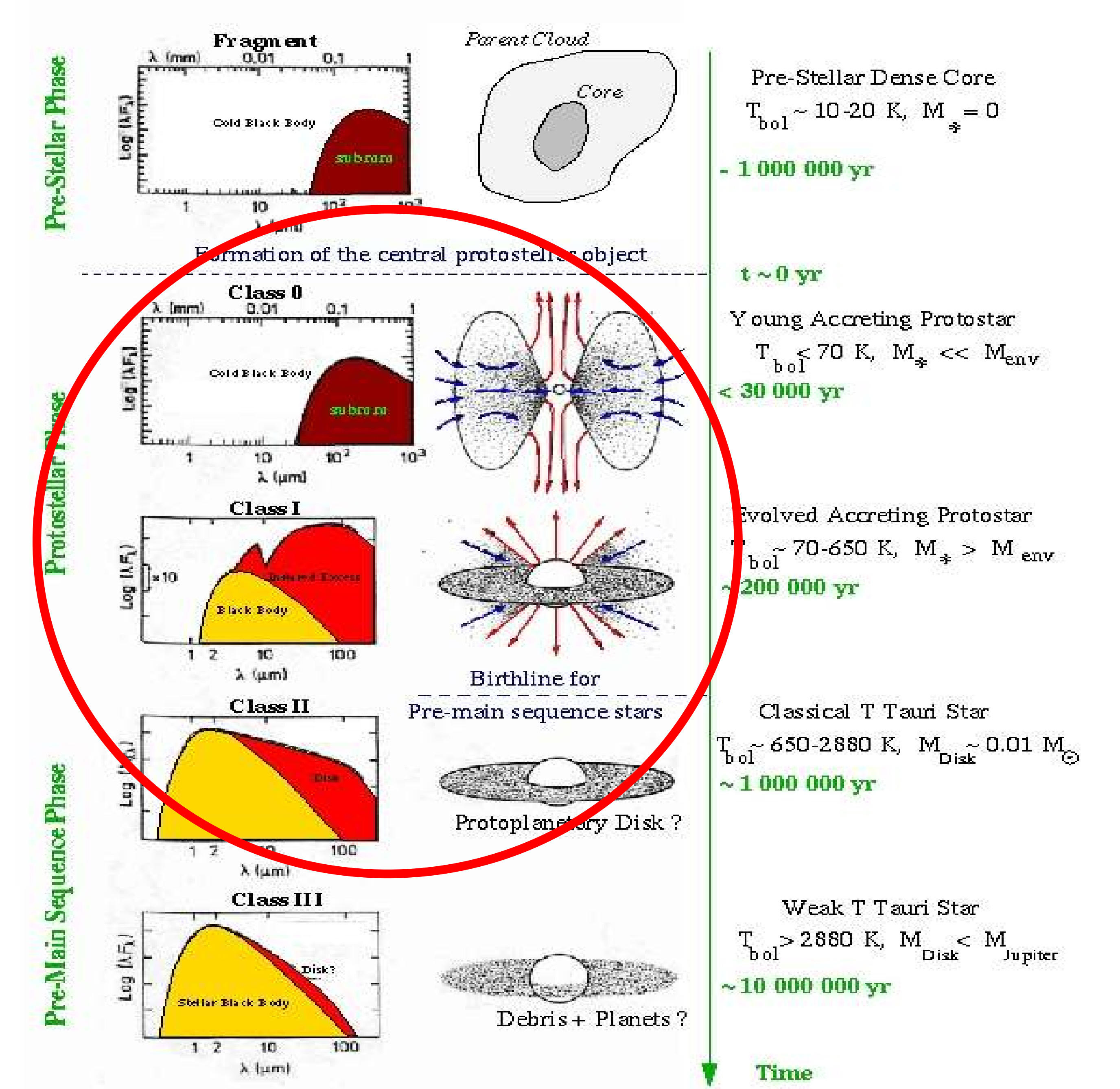
    - B type stars
    - O type stars

Star formation paradigm, the low mass star case. I



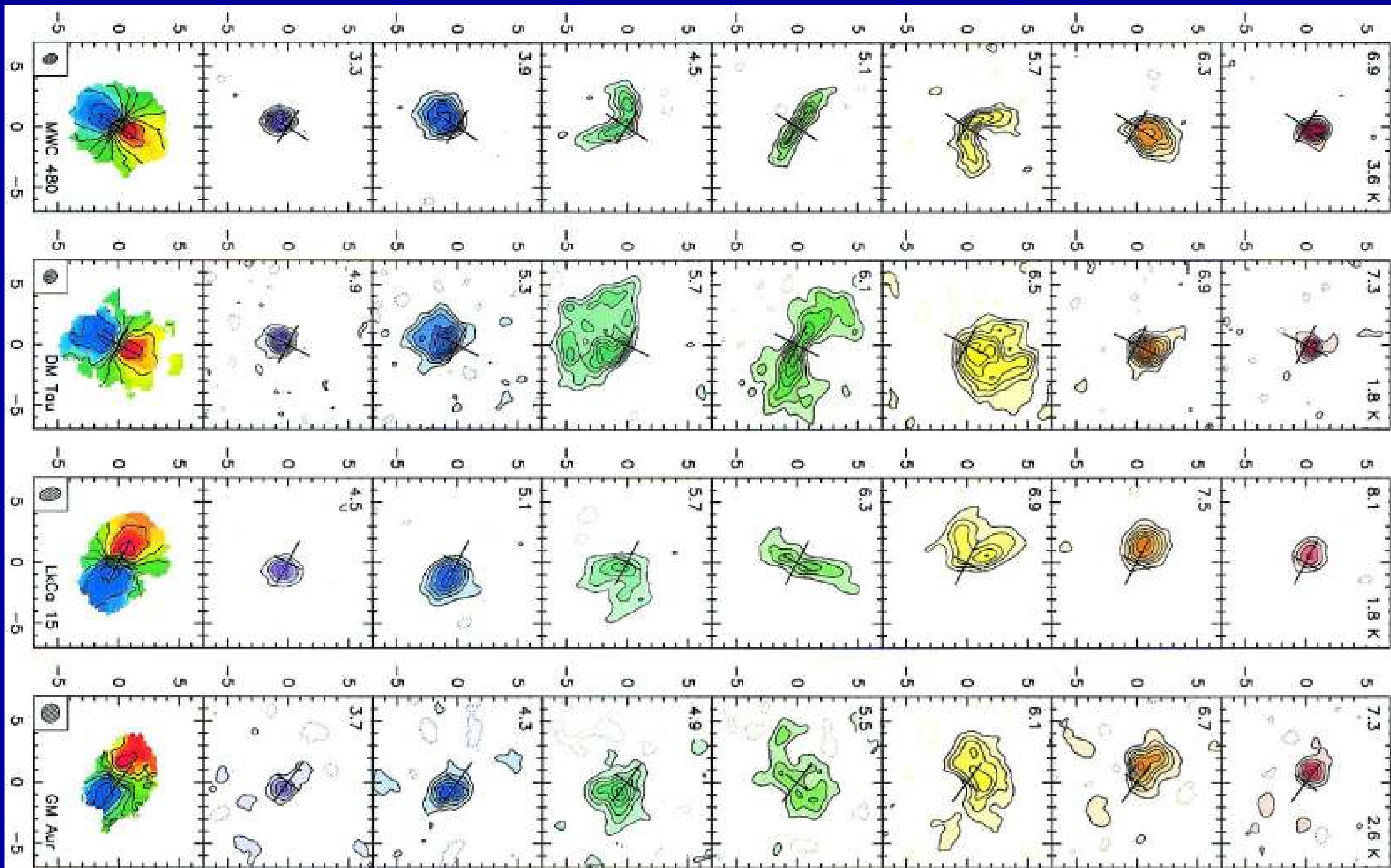
Star formation paradigm, the low mass star case. II



P. André 2002

Circumstellar disks in low mass PMS stars

^{12}CO (2-1) PdBI observations, Simon et al. (2000)



Circumstellar disks in low mass PMS stars

Interferometric (sub)mm observations resolved the dust continuum and line emission from the disk and found that:

•Large disks (outer radius from CO(2-1) ~200-1000 AU)

•The surface density decreases as R^{-1}

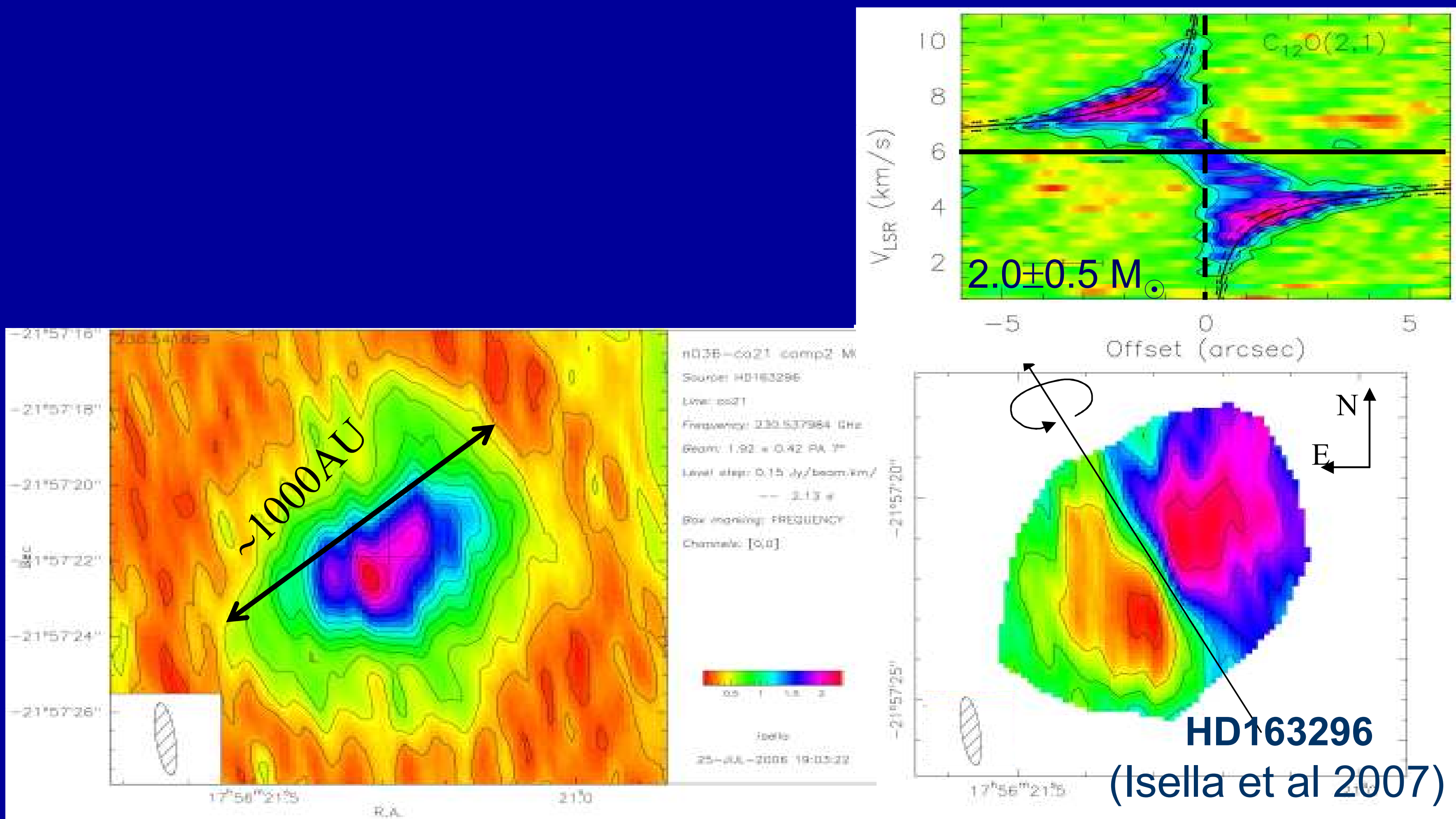
• $F_\nu \sim B_\nu(T_{dust})\, k_\nu\, M_D \Rightarrow$ dust mass $\Rightarrow \Rightarrow$ gas mass

$M_D \sim 0.01\text{-}0.1\ M_\odot$

$M_D/M_* \sim 0.03$

•Most of the disks are in Keplerian rotation (but AB Aur does not)

Circumstellar disks in low mass PMS stars



Disks and the formation of stars

Disks are formed in the early stages of core collapse and are an essential ingredient of the standard paradigm for star formation

Is this paradigm applicable to the most massive stellar objects?

The high mass stars problem

<u>Infall</u> of circumstellar material onto protostar

Two relevant timescales:

- **accretion:** $t_{acc} = M_{star}/(dM/dt)_{acc}$
- **contraction:** $t_{KH} = GM_{sta}r/R_{star}L_{star}$

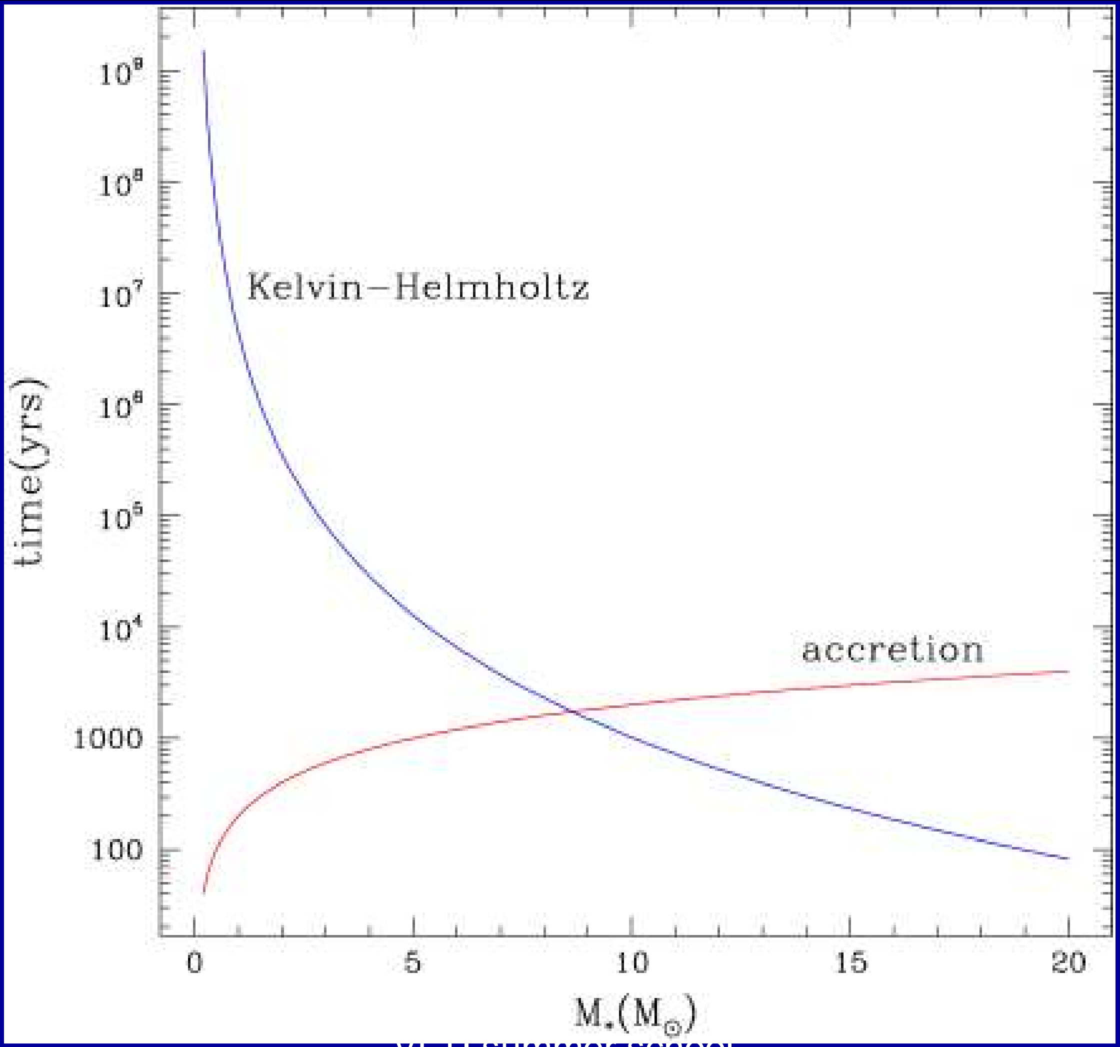
M_{star} **>** 6-10 $M_{\odot} \Rightarrow t_{acc}$ **>** t_{KH} (Palla & Stahler 1993)

High-mass stars reach ZAMS still accreting!

Spherical symmetry $\Rightarrow P_{radiation}$ **>** P_{ram}

$\Rightarrow \Rightarrow$ stars **>** 6-10 $M_{\odot}$ should not form**!??**

The high mass stars problem



Massive star formation

Formation of massive stars. Two solutions:

- I. merging of low-mass stars (Bonnell et al 1998; 2002; 2003;Stahler 2000)
- II. non-spherical accretion (Behrend & Maeder 2001; Yorke & Sonnhalter 2002; Tan & McKee 2003)

Merging

- Theory: coalescence of stars with masses below ~8 $M_\odot$ to form more massive stars.

- Observational features:
  - No isolated massive stars should form; ✓
  - High density of stars (>10^6-10^8 pc^{-1});
  - Collimated outflows and circumstellar disks would be disrupted in the merging;

Accretion

- Theory: overcoming radiation pressure through non spherical accretion ($\Rightarrow$ disk). Predicts a system **disk+outflow**

- Observational features:
  - Collimated outflows ✓ **BUT in early B object AND when observed at high resolution**
  - accretion disks **What do the observations say?**

$\Rightarrow \Rightarrow$ Detection of accretion disks is crucial to the understanding of O-B star formation

Intermediate / High-mass stars observations

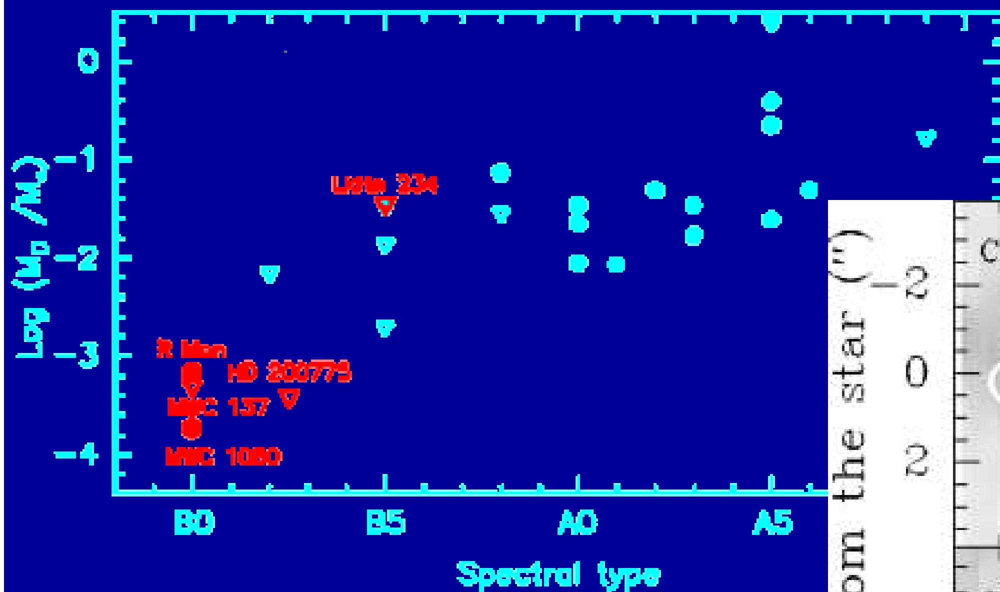
- Observational problems:
  - IMF → high-mass stars are rare
  - rapid evolution: $t_{acc}=50\ M_\odot/10^{-3} M_\odot yr^{-1}=5\ 10^4 yr$
    → **high-mass protostars are even rarer**
  - large distance >450 pc → a few kpc (even more for O type stars)
    ALMA sensitivity and resolution!
  - formation in clusters → confusion
    ALMA resolution!

Intermediate / High-mass stars observations

Typical linear sizes:	**At 3 kpc (average distance):**
UC HII: 70000 AU	~20 arcsec
Protostar: ~a few AU	~0.001 arcsec
Outflow: up to several parsecs	
Disk: $\geq$ 100-500 AU	~0.03-0.15 arcsec

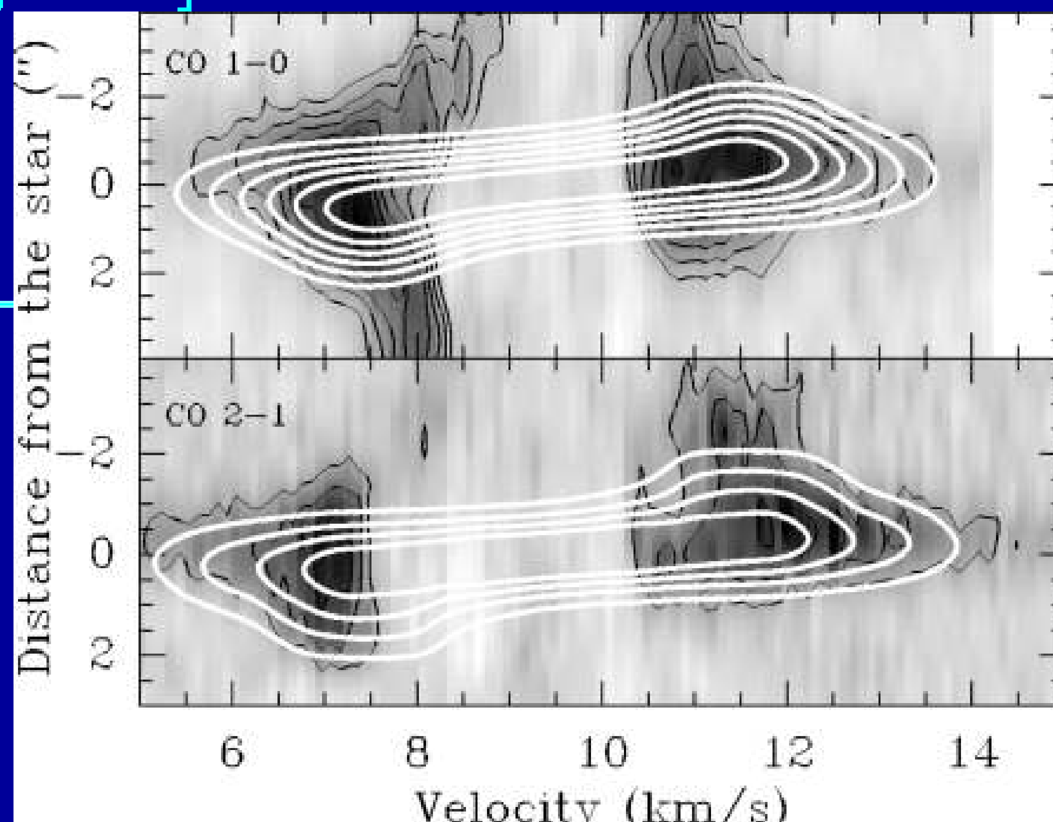
ALMA at 300 GHz (~1 mm) will have a resolution down to 0.016"

Observation of circumstellar disks in intermediate mass (>3-10 $M_{\odot}$) pre MS stars



(Fuente et al. 2006)

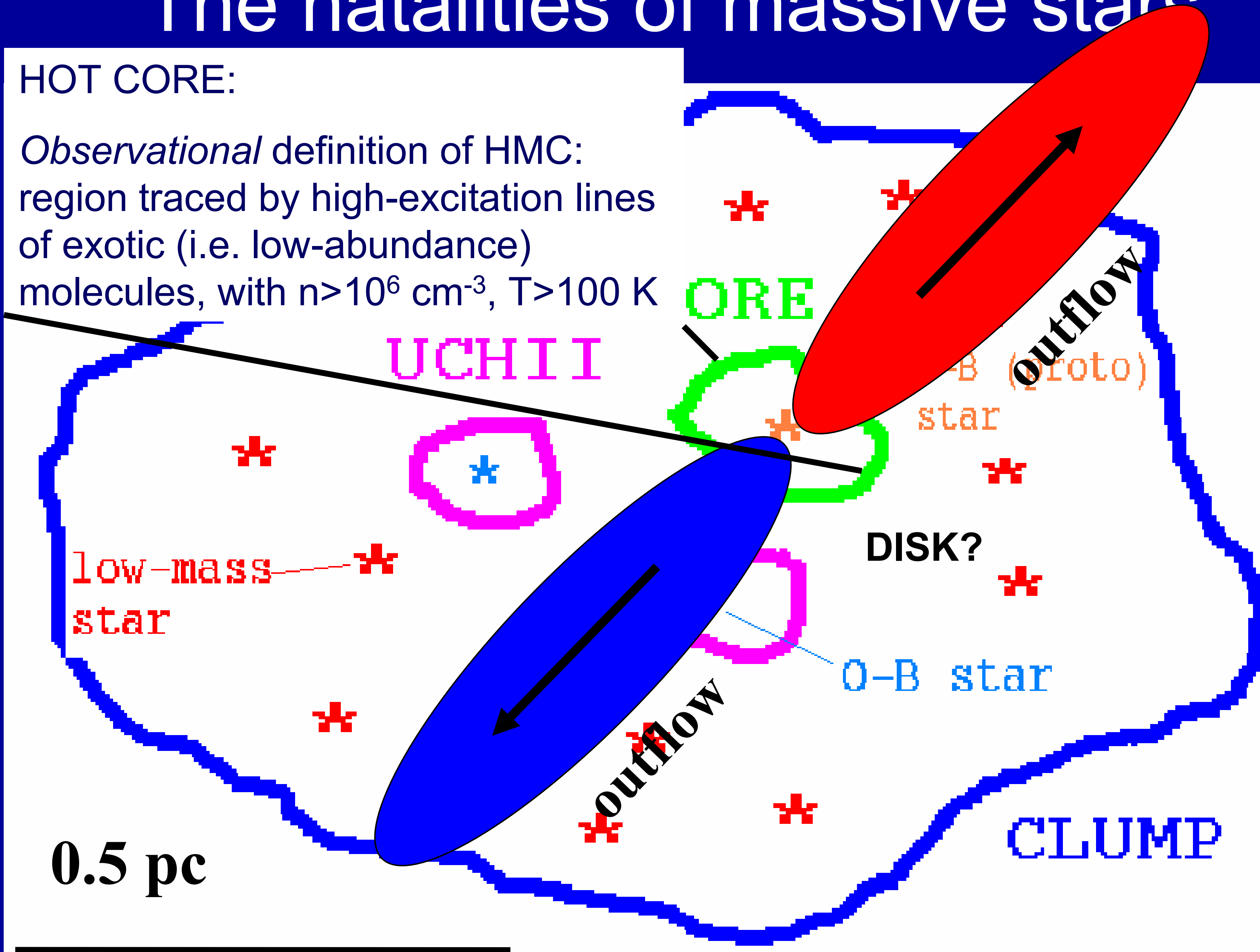
(Fuente et al. 2003)



The natalities of massive stars

HOT CORE:

Observational definition of HMC: region traced by high-excitation lines of exotic (i.e. low-abundance) molecules, with $n>10^6$ cm^{-3}, $T>100$ K

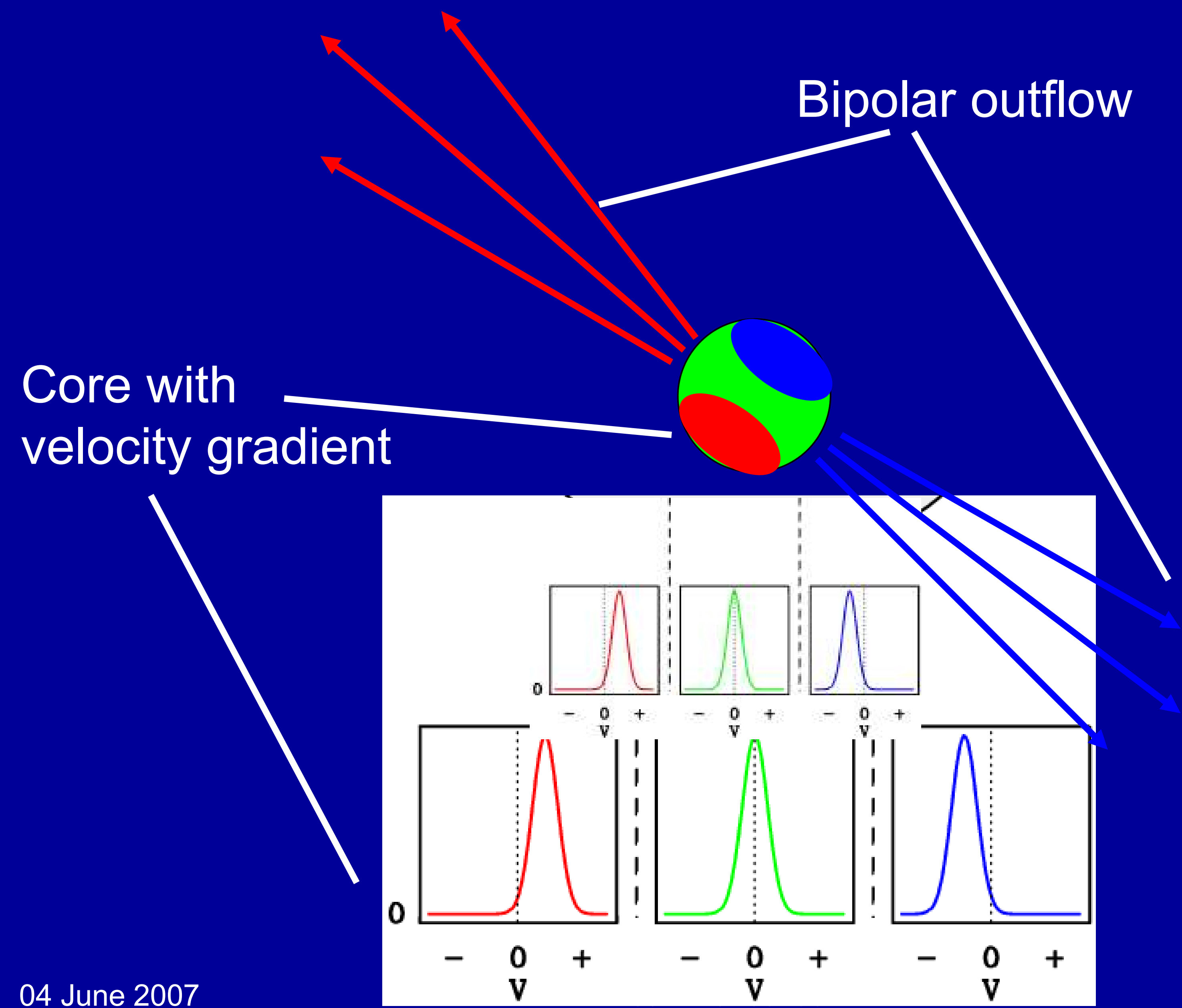


The search for disks in massive (proto)stars I.

- **Where:** hot cores (<0.1 pc, 10-10^3 $M_\odot$, 100 K) **with** jet/outflow
- **What:** low-abundance, high energy molecular lines ⇒ ⇒ optically thin (CH_3CN or other complex molecules)

Probable detection of a disk:

Compact hot core located at the center of an outflow ***and*** with a velocity gradient perpendicular to outflow axis.

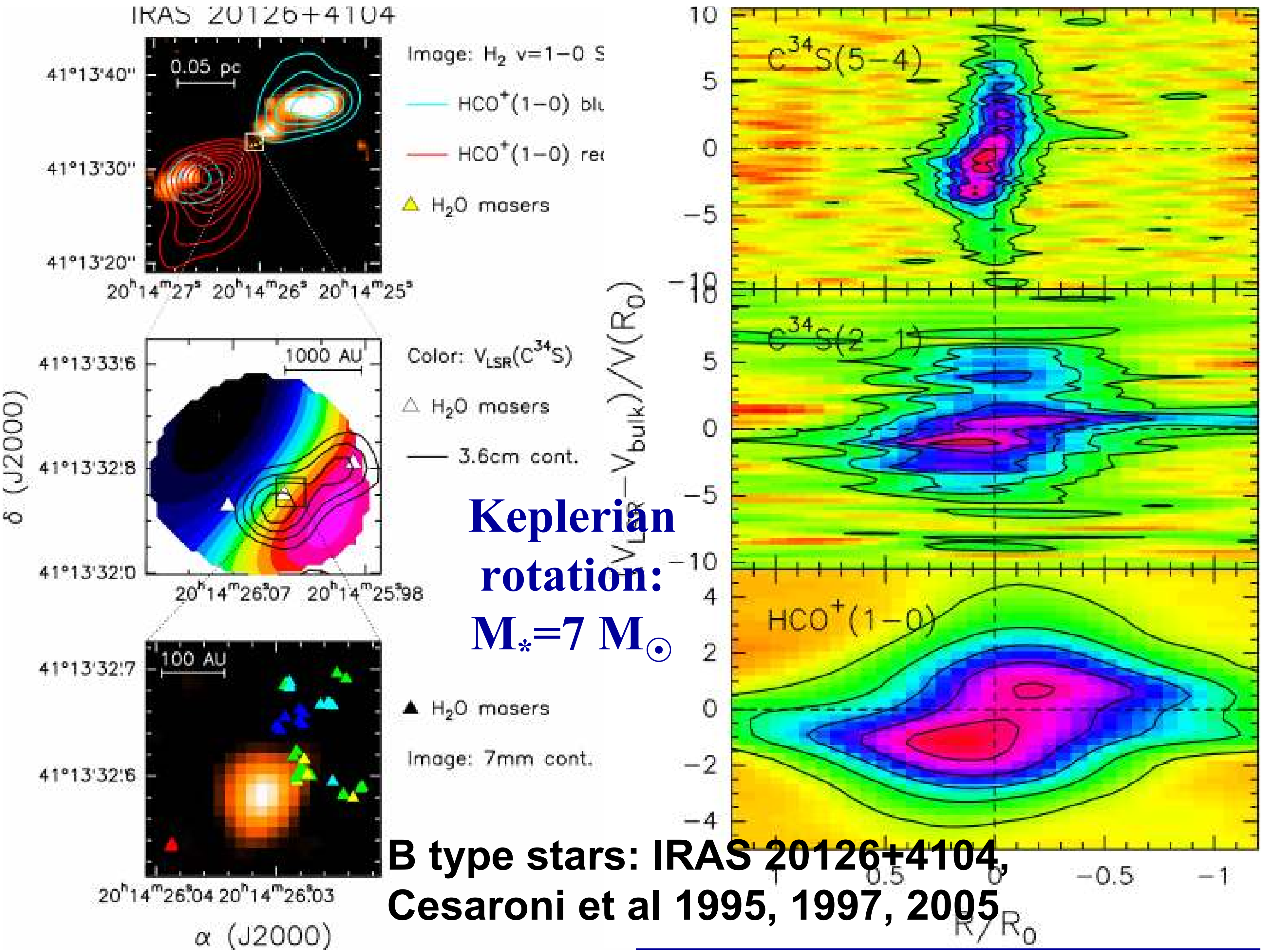

Bipolar outflow
Core with
velocity gradient
0
− 0 +
V
− 0 +
V
− 0 +
V
0
− 0 +
V
− 0 +
V
− 0 +
V

The search for disks in massive (proto)stars II.

Tentative detection best examples:

- IRAS 20126 (Cesaroni et al. 1997-2005)
- G192.16 (Shepherd & Kurtz 1999)
- NGC 7538S (Sandell et al. 2003)

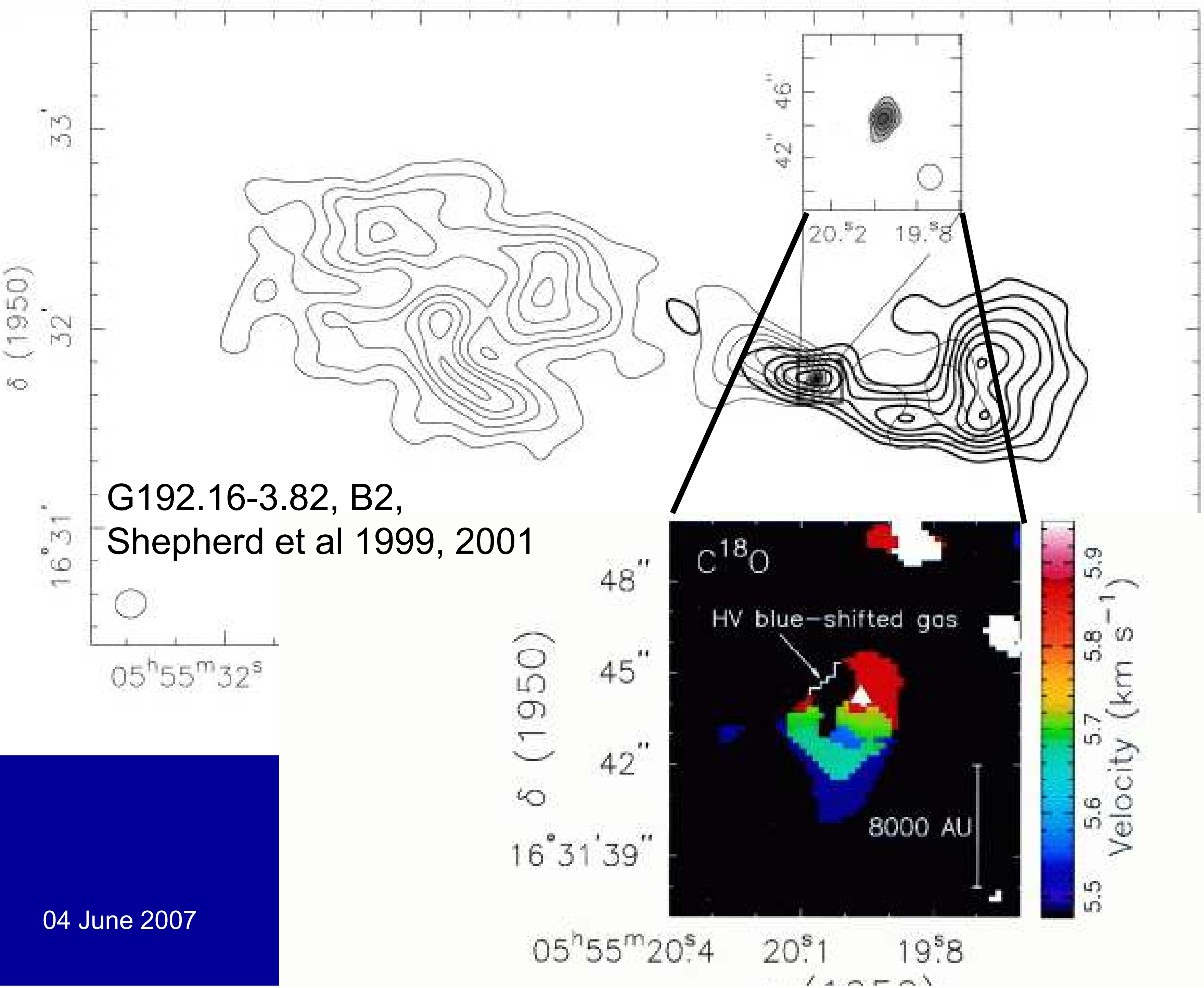
They are all B type stars with Keplerian rotation



Keplerian rotation: $M_* = 7\ M_\odot$

B type stars: IRAS 20126+4104, Cesaroni et al 1995, 1997, 2005

G192.16-3.82, B2,
Shepherd et al 1999, 2001



…and tentative detections of double-peaked profiles

NGC6334 I(N): compact object, outflow(s) and double peaked profile in NH_3(6,6) (Megeath & Tieftrunk 1999, Beuther et al. 2007)

IRAS 05358+3543: compact object, outflow(s), velocity gardient and double-peaked profile (Beuther et 2002, Leurini et al. subm.)

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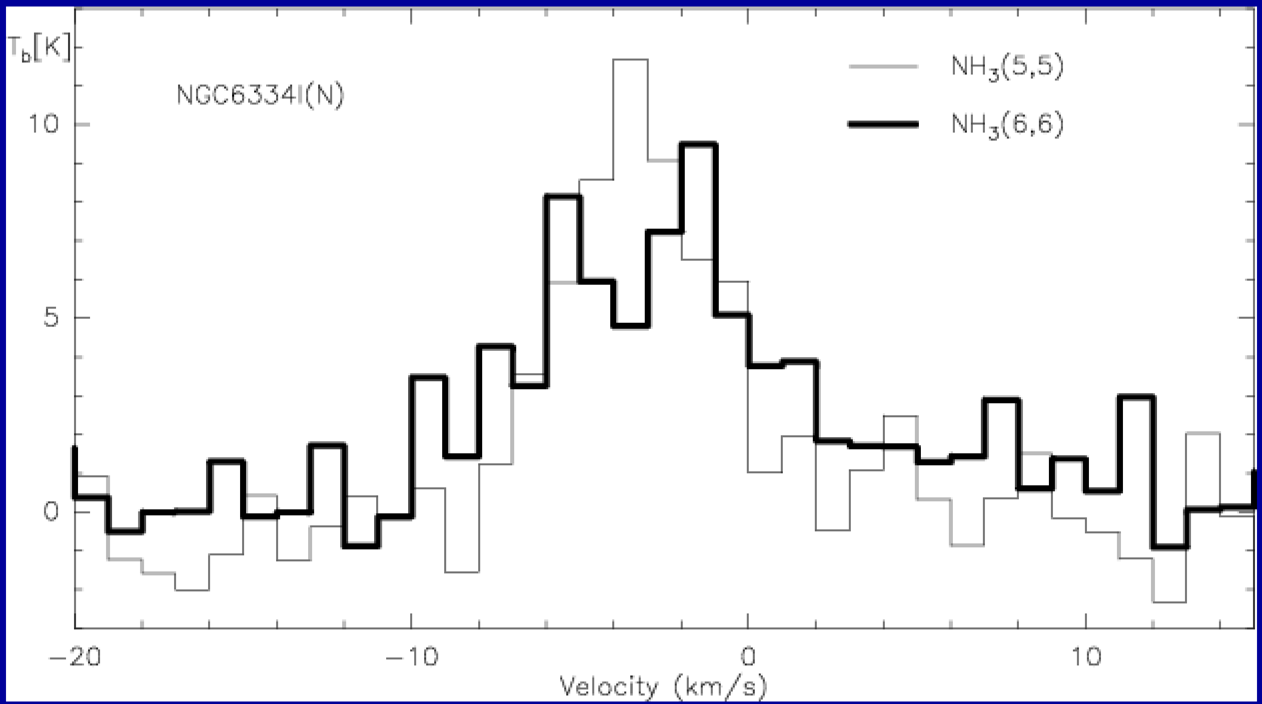

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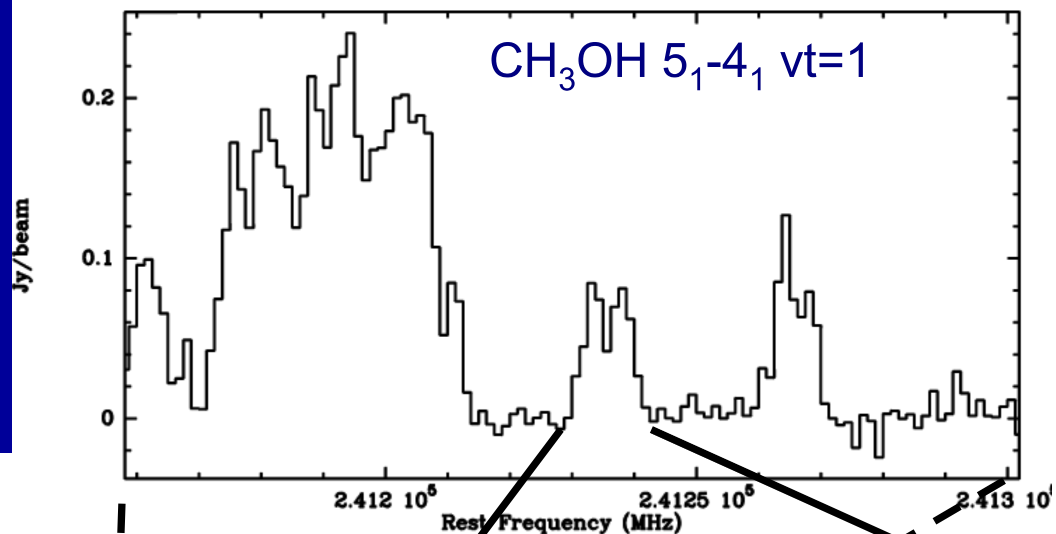
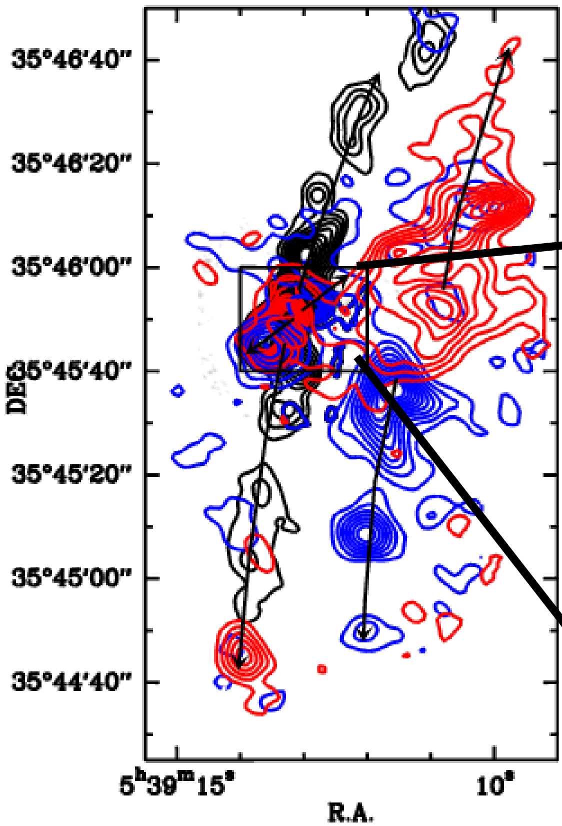
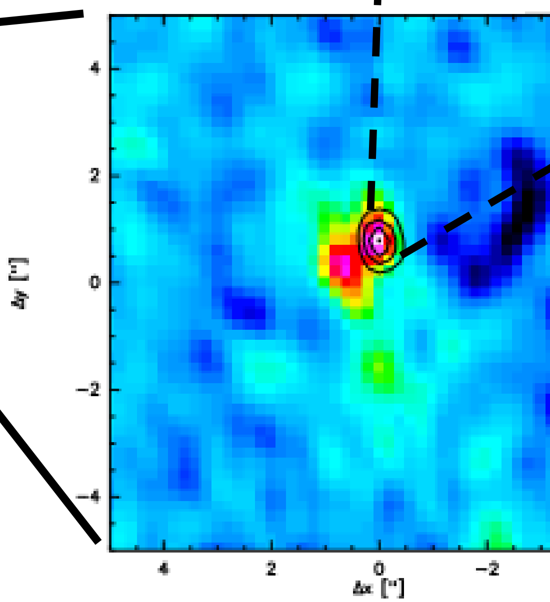
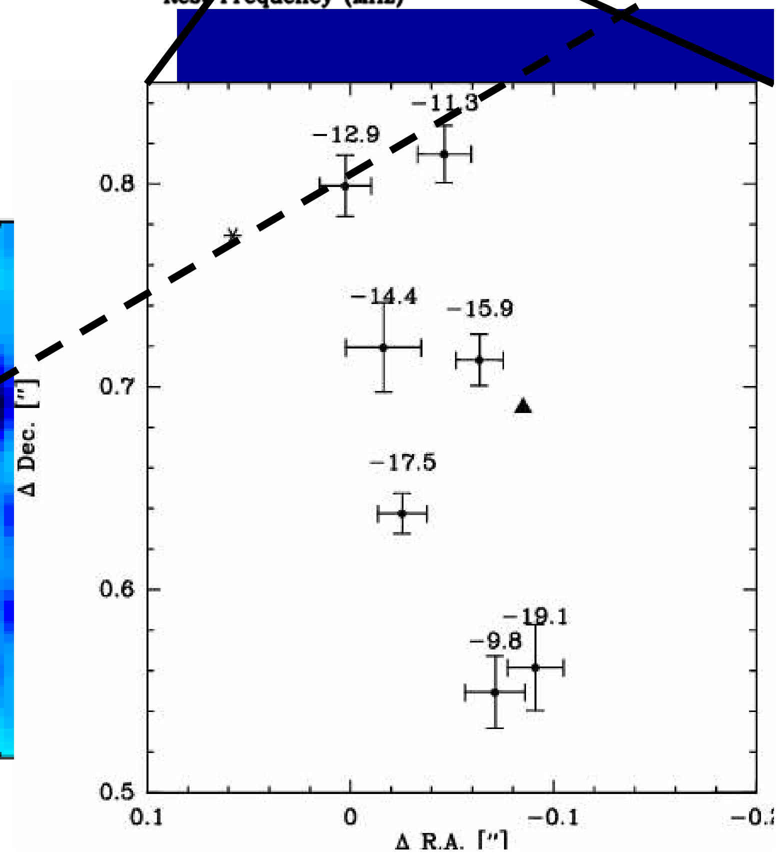








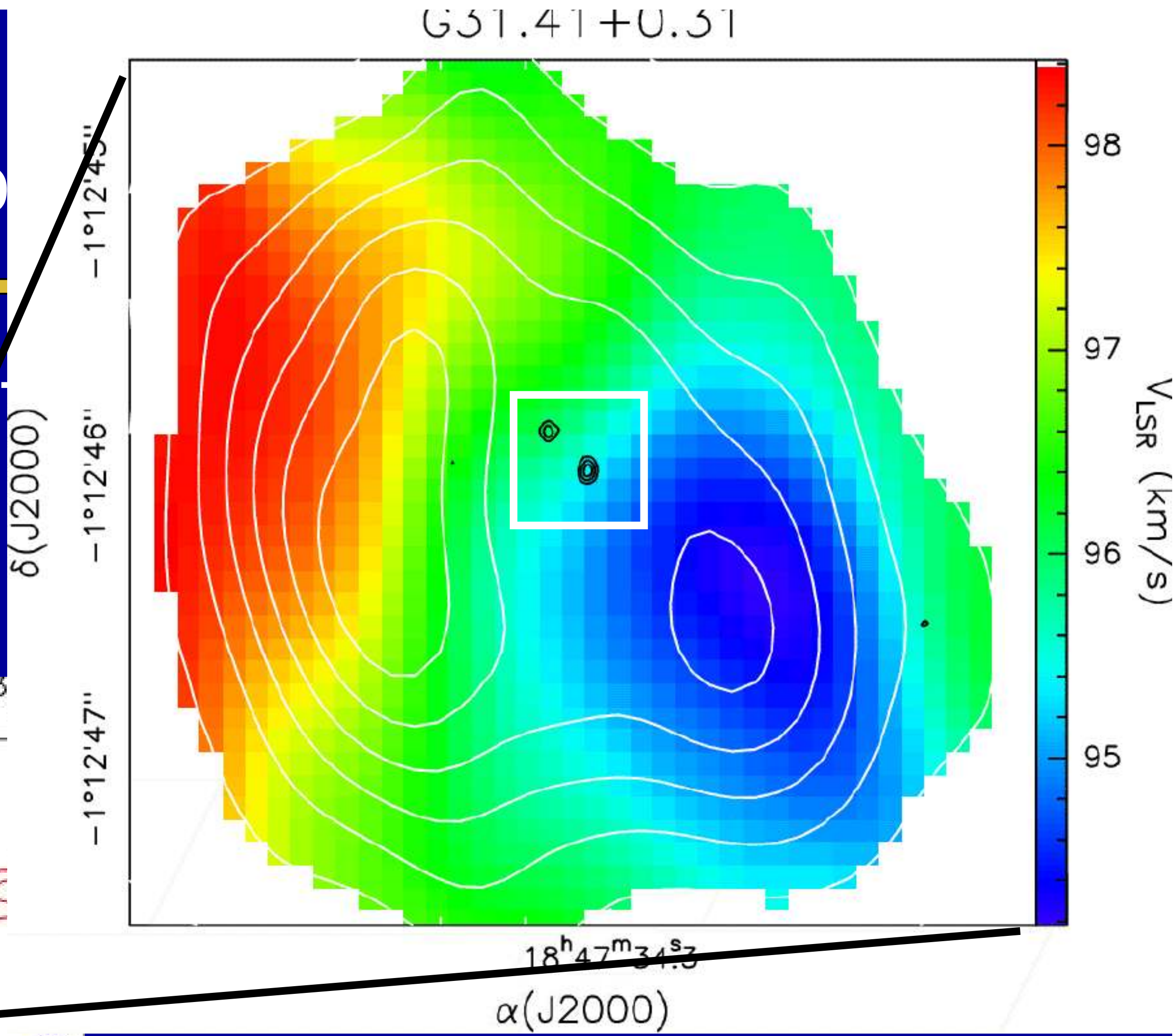
Search in more massive (O type) stars

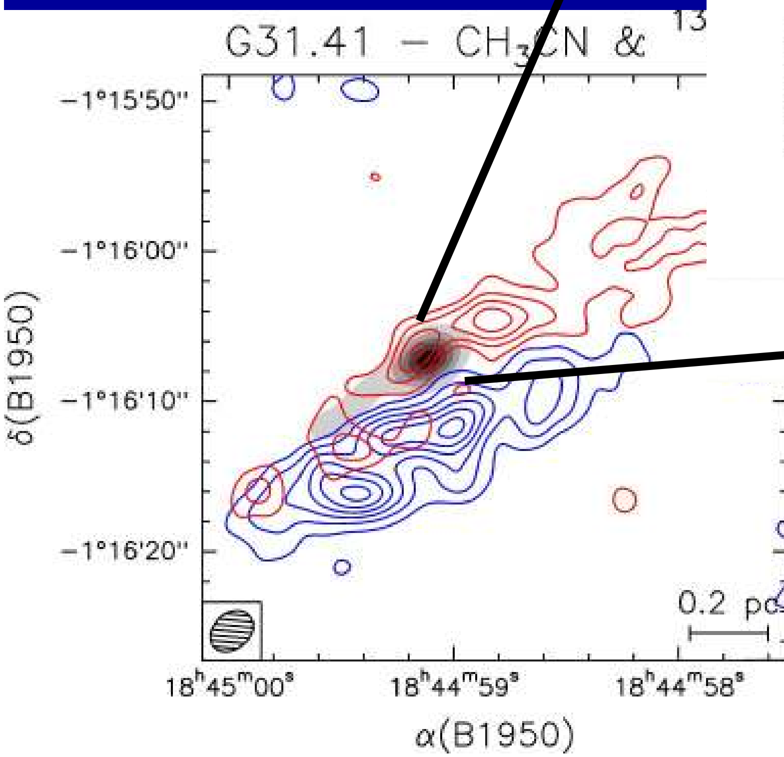
G31.41+0.31, G24.78+0.08 (Furuya et al. 2002, Beltran et al. 2004, 2005)

- distant (~7 kpc, linear resolution~5000 AU)
- luminous ($L \gg 10^4 L_\odot$)
- detection of outflows
- detection of hot-cores

Search in mo

Example: G31.41+





Search in more massive (O type) stars

BUT these are structures of ~8000–16000 AU and masses ~80–500 $M_\odot$: they are **not in equilibrium! Toroids and not Keplerian disks**

e.g. G31.41:

Dynamical mass assuming equilibrium between centrifugal and gravitational force:

$$M_{dyn} = v_{rot}^{\ 2} \frac{R}{G \sin^2 i} \approx 87\, M_{sol}$$

Mass of the core (from the mm continuum):

$$M = \frac{F_\nu d^2}{B_\nu(T) k_\nu} \approx 490 M_{sol}$$

Search in more massive (O type) stars

Toroids (O type protostars)

- $M > 100\ M_\odot$
- $R \sim 10000$ AU
- **$L > 10^5\ L_\odot$**
- $t_{rot} \sim 10^5$ yr
- $t_{acc} \sim M/(dM/dt)_{star} \sim 10^4$ yr

→ **$t_{acc} \ll t_{rot}$**

Disks (B type protostars)

- $M < 10\ M_\odot$
- $R \sim 1000$ AU
- **$L \sim 10^4\ L_\odot$**
- $t_{rot} \sim 10^4$ yr
- $t_{acc} \sim M/(dM/dt)_{star} \sim 10^5$ yr

→ **$t_{acc} \gg t_{rot}$**

Is this an observational bias?

The sensitivity and linear resolution of current mm interferometers SHOULD allow us to detect a massive circumstellar disk (~1”) up to 8 kpc!

BUT:

•rarity of O stars (they are in average more distant than B stars) $\Rightarrow$ ALMA sensitivity
•Short timescales, and disks should evaporate fast
•confusion with envelope (they form in richer clusters: multiple outflows, disks?) $\Rightarrow$ ALMA resolution
•Chemistry (we still do not have a final answer on which is the best tracer) $\Rightarrow$ ALMA spectral coverage

Is this an observational bias?

ALTERNATIVELY the formation of disks in O stars may be inhibited

We have to wait for ALMA (early science 2012) for a better understanding of star formation in O stars