TOWARD UNDERSTANDING THE FORMATION OF MULTIPLE SYSTEMS : A PILOT PDBI SUB-ARCSECOND SURVEY OF CLASS 0 PROTOSTARS

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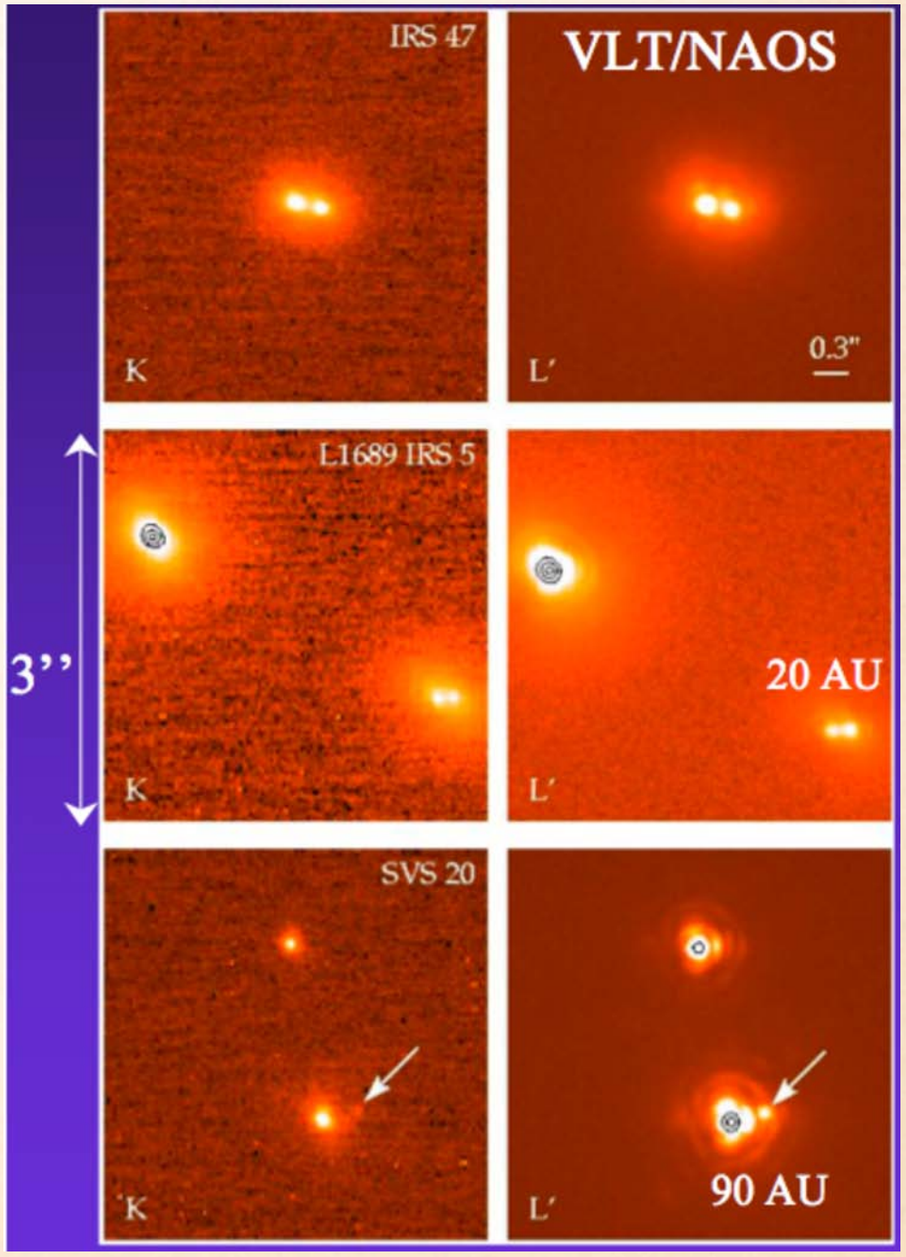
Context

❖ Formation of multiple systems

- MS and pre-MS stars :
50% - 70% are observed in multiple systems
typical separations ~10-500 AU.
(Duquennoy & Mayor 1991; Patience & Duchêne 2001)

- Deep IR images :
show that 30% - 60% of Class I protostars are observed in multiple systems, with similar separations.
(Duchêne et al. 2007, Connelley et al. 2008)



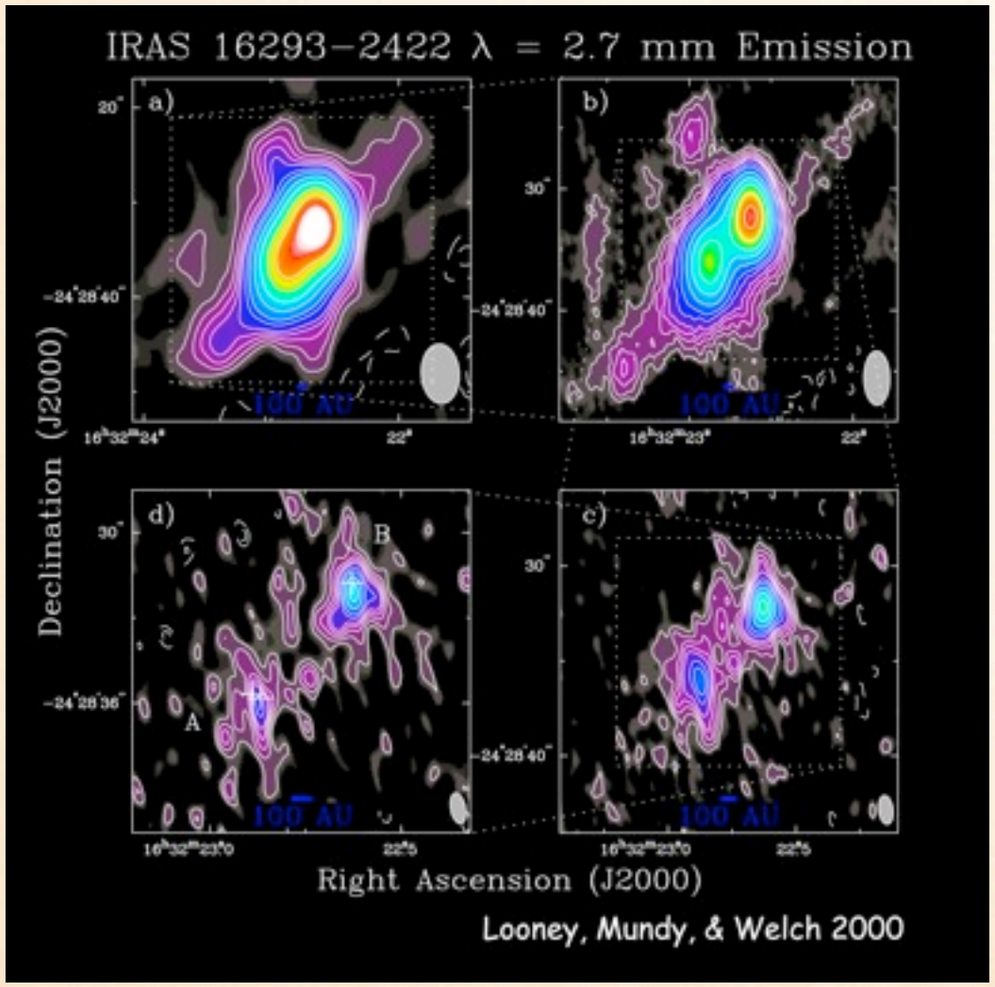
(Duchêne et al. 2003)

Context

❖ Formation of multiple systems

<u>At Class 0 stage : memory of fragmentation</u>

✳ Class 0 protostars the most luminous are sometimes found in multiple systems with separations ~500-4000 AU.
(Looney et al. 2000 / Jorgensen et al. 2007)



✳ SMA / VLA :
some close multiple sources recently detected :
L723 : Girart et al. 2009,
IRS16293 : Loinard et al. 2007, Rao et al. 2009

BUT
no comprehensive sample so far,
with resolutions and sensitivities
allowing to detect the bulk of multiple systems
given by Class I observations.

Multiplicity rate of Class 0 protostars : Observations

✳13 Class 0 protostars :

5 sources observed in 2008 (Maury et al. 2010)

+ 8 sources observed in 2010 (Maury et al. in prep)

✳ Maps of continuum emission at 1.3 mm

+ maps of ^{12}CO(2-1) emission

✳ With the Plateau de Bure interferometer (IRAM) within its most extended configuration (A).

PdB-A :

✳ Achieved resolutions : ~ 0.3'' - 0.6''

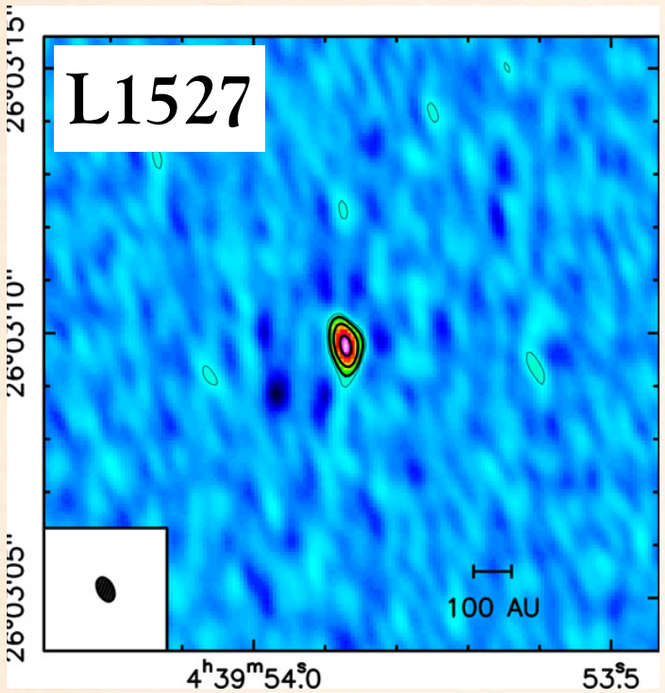
~ 40 - 80 AU for Taurus sources (140 pc)

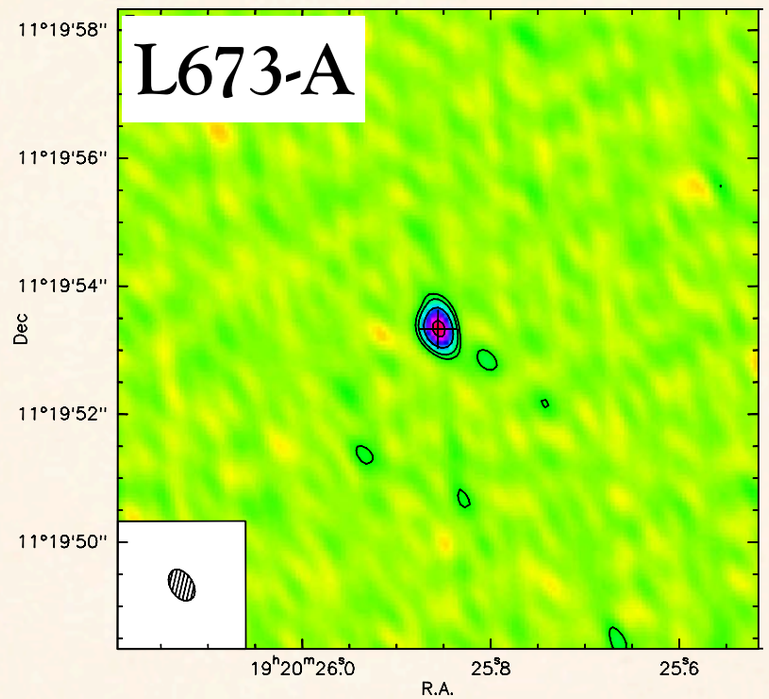
~ 70 - 120 AU for Perseus sources (250 pc)

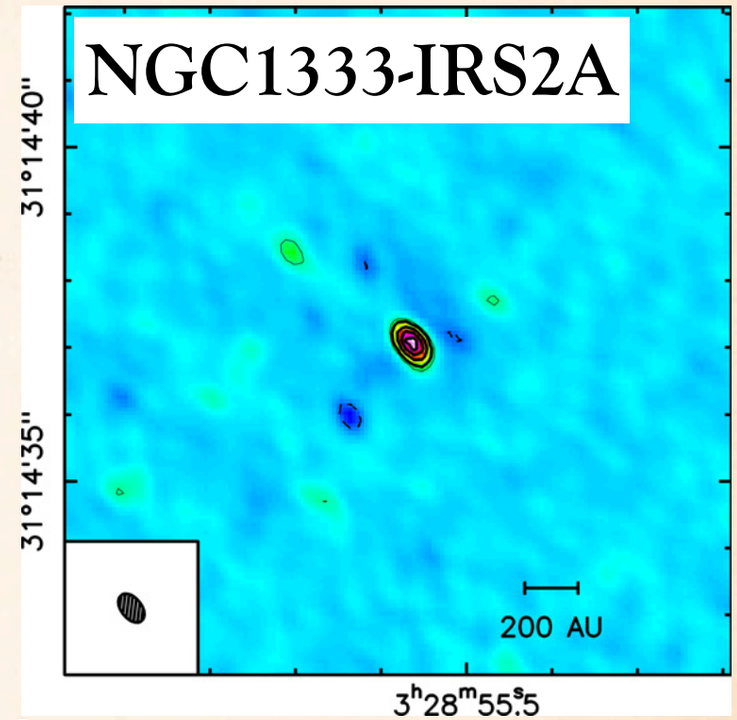
✳ rms noise values in continuum maps :

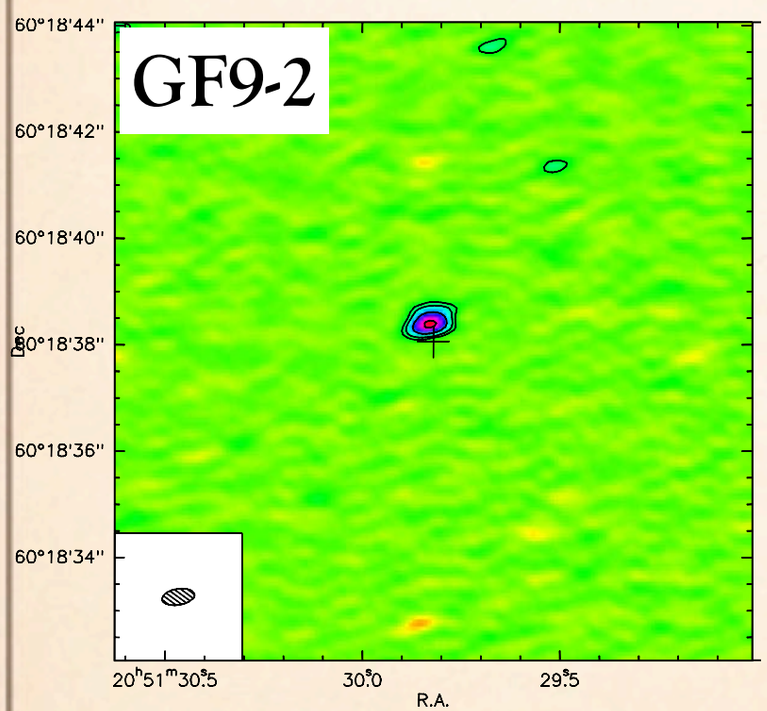
0.12 - 1.2 mJy/beam @ 1.3 mm

High-resolution 1.3 mm continuum maps

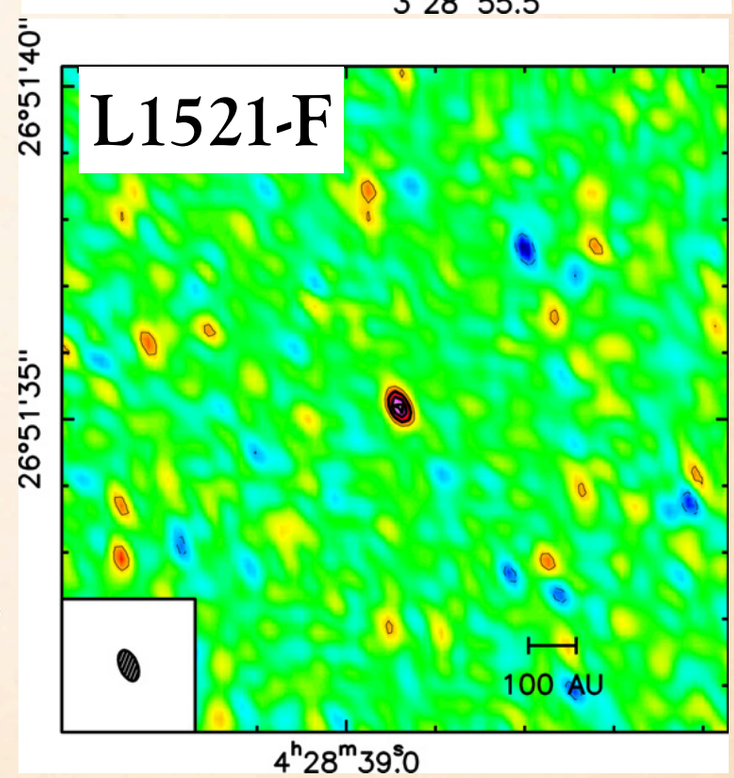




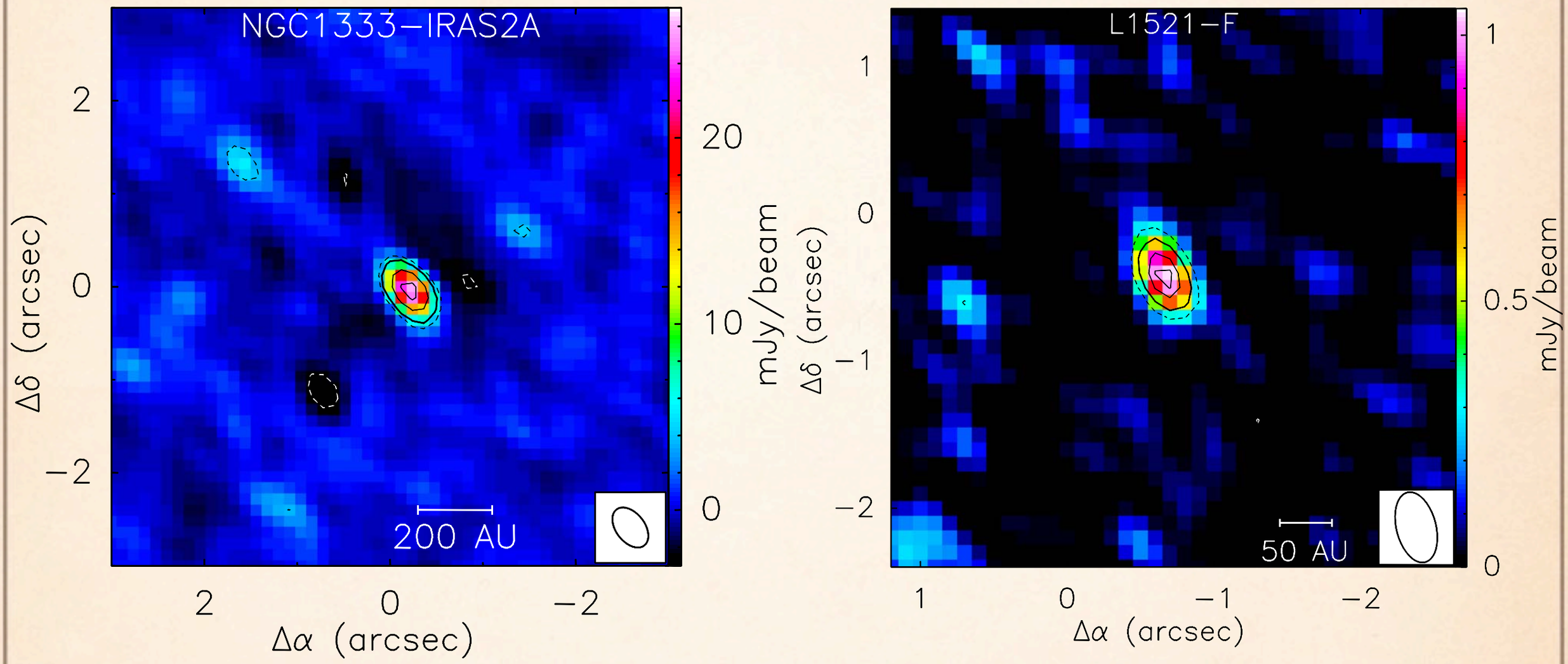




Most of the
1.3 mm continuum maps
of Class 0 protostars
show SINGLE sources



Source structure in high-resolution continuum maps :

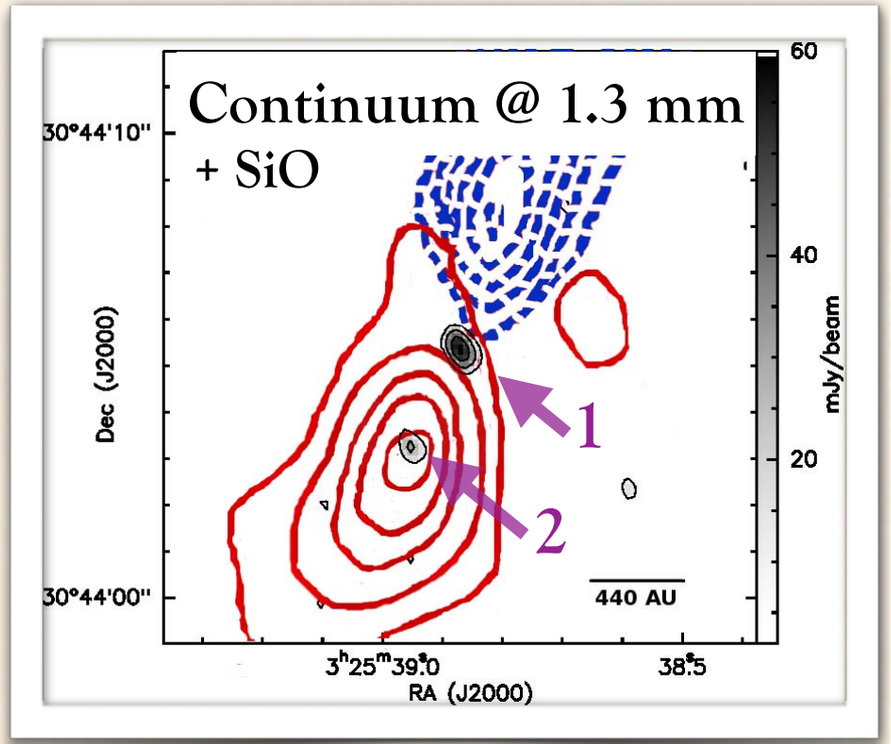


Most of the 1.3 mm continuum maps of Class 0 protostars show single COMPACT sources

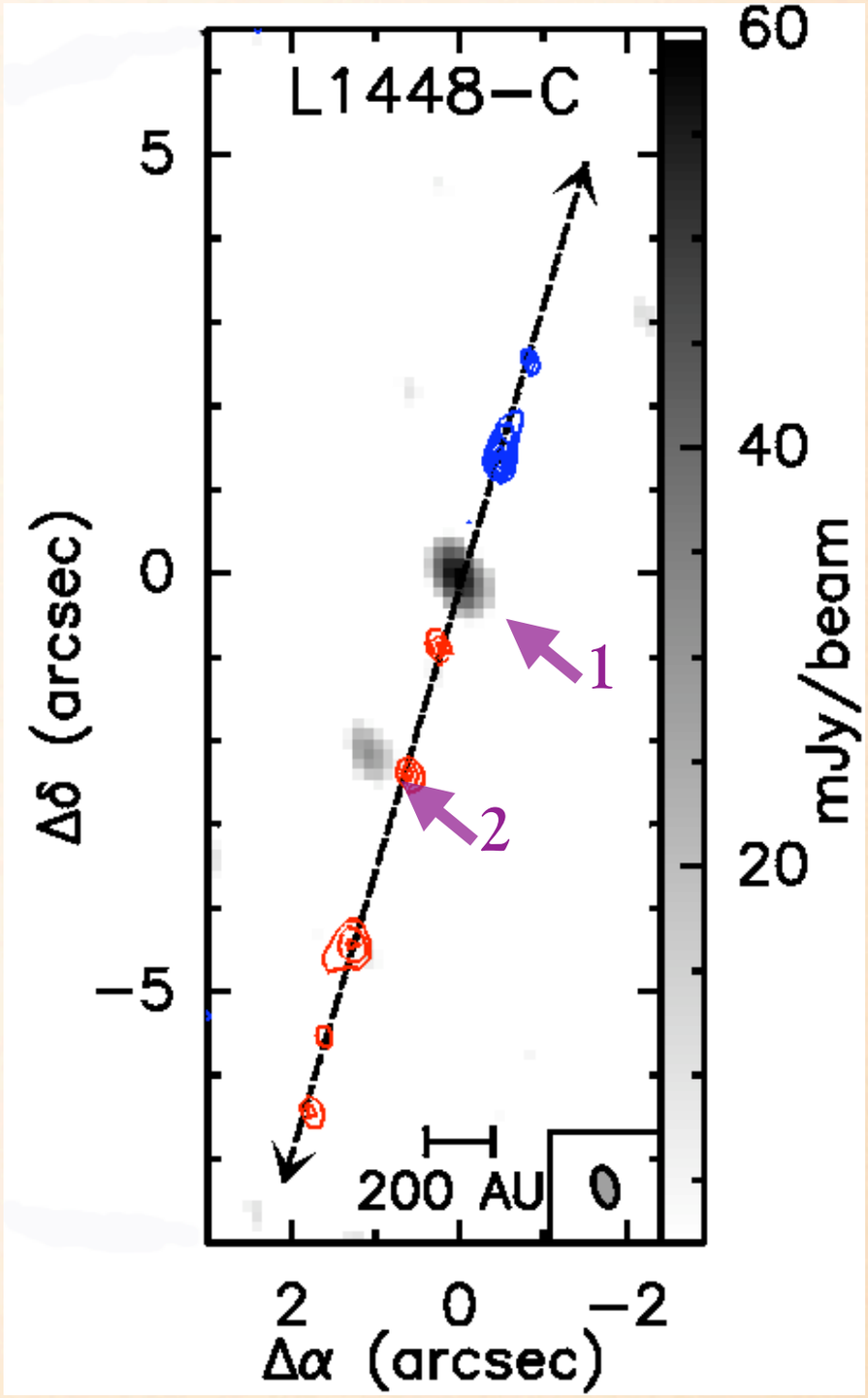
Maury, André, Hennebelle et al. (2010)

The L1448 case : candidate companion ?

❖ PdB-A 1.3 mm continuum map :
secondary source with F_{peak} =11 mJy/beam
about 2'' south-east of L1448-C
aligned with jet axis



SiO map : Guilloteau et al. (1992)



❖ Comprehensive analysis :
CO high velocity bullet
SiO shock
too close to be separated by Spitzer images
Very likely to be an outflow feature

Multiplicity : conclusions

❖ PdB-A first sample
5/5 Class 0 protostars **single** at scales 50-1500 UA

❖ Multiplicity rate of Class I protostars is well-known at similar scales :
30% - 40 % (Duchêne et al 2007, Connelley et al. 2008)

❖ Taking into account the results of Looney et al. (2000), and applying our methods: more significant (but inhomogeneous) sample of 14 sources.

Tentatively suggests that the multiplicity rate of Class 0 protostars at scales 50-1500 AU is smaller than the one for Class I protostars at similar scales. (2σ confidence level)

❖ Typical separation evolves from Class 0 to Class I stages ?
❖ Dynamical scenarii for the formation of multiple systems ?

Maury, André, Hennebelle et al. (2010)

Class 0 with PdB : what can we say about $\vec{B}$?

❖ Hard to measure magnetic fields at small scales during earliest phases of collapse

❖ Polarization measurements doable, but :

- only very few instruments
- and a few sources

❖ Idea : rather than trying to measure magnetic fields, track magnetic fields effects :

Use typical predictions of magnetized scenarii for protostellar collapse and test them

❖ Perfect case here :

2 major outcomes of magnetized collapse scenarii can be tested :

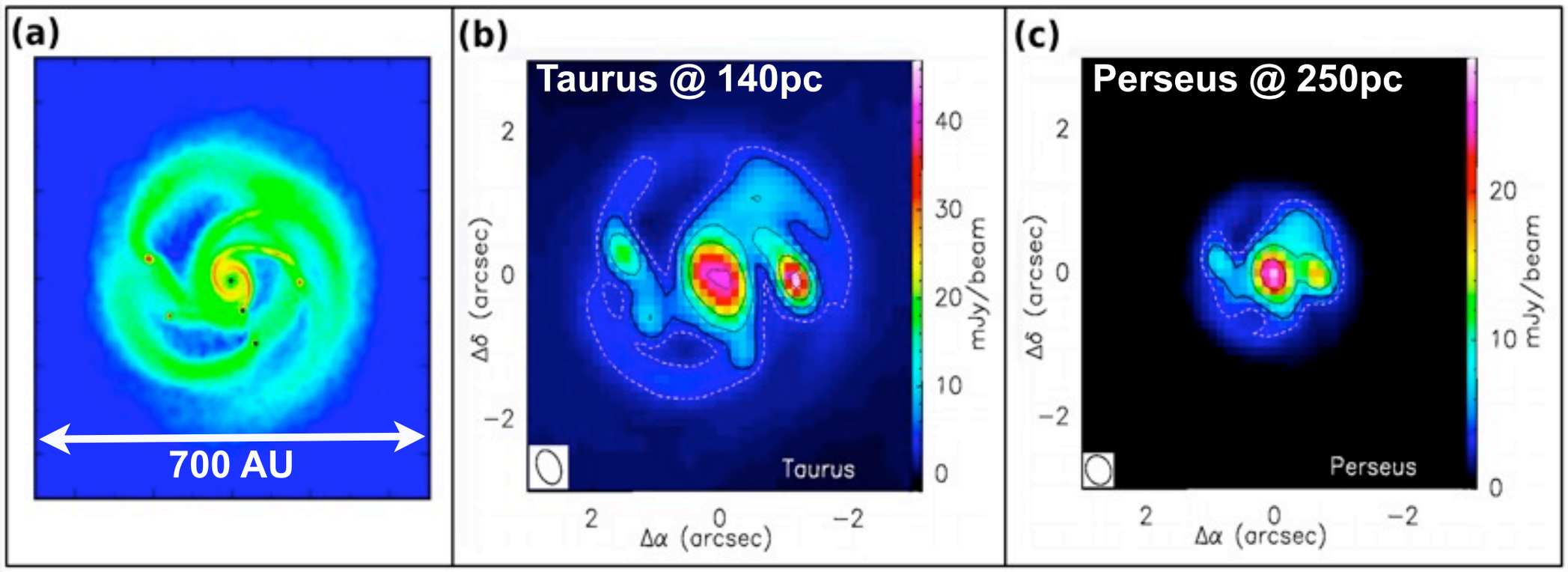
- suppression of large scale rotating structures (so-called accretion disks)
- and therefore suppression of fragmentation at small (50-1000 AU) scales

Such predicted properties seem to match our observations.
Deeper analysis involves quantitative comparison of models and observations

Comparison with numerical simulations of SF

Simulations by Stamatellos & Whitworth (2009) : hydrodynamic disk of 0.7 $M_\odot$

HD numerical simulations : synthetic images



White contour : 3σ level. Thick black : 5σ level.

Synthetic images : <u>extended, multiple</u> structures with typical FWHM ~1.8" - 3.8"

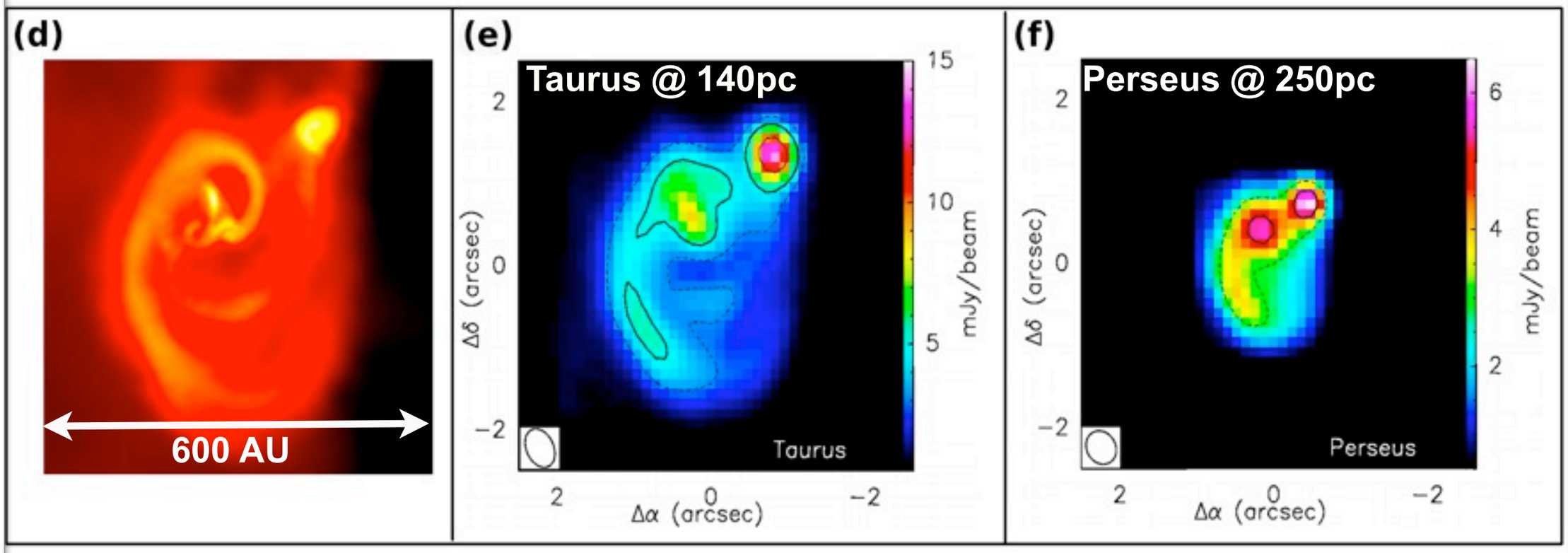
BUT

The 5 Class 0 protostars as seen with PdB-A are <u>single</u>, <u>compact</u> sources with typical FWHM ~0.25" - 0.9".

Comparison with numerical simulations of SF

Simulations by Bate (2009) : hydrodynamics + radiative feedback

HD numerical simulations : synthetic images



White contour : 3**σ** level. Thick black contour : 5**σ** level.

Synthetic images : <u>extended, multiple</u> structures with typical FWHM ~1.9" - 3.4"

BUT

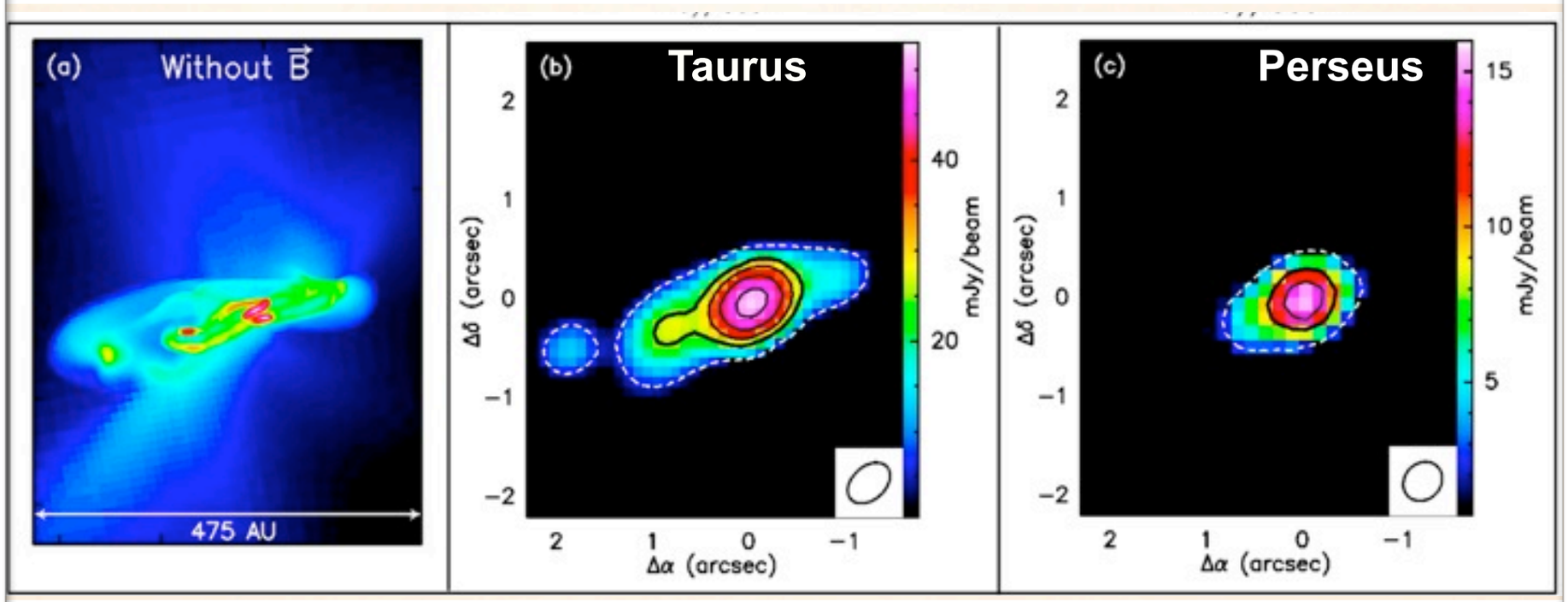
The 5 Class 0 protostars as seen with PdB-A are <u>single</u>, <u>compact</u> sources with typical FWHM ~0.25" - 0.9".

Comparison with numerical simulations of SF

HD and MHD simulations by Hennebelle & Teyssier (2008) :

Without magnetic fields :
extended, fragmented structures

Hydro numerical simulations : synthetic images



White contour : 3σ level. Thick black contour : 5σ level.

Maury, André, Hennebelle et al. (2010)

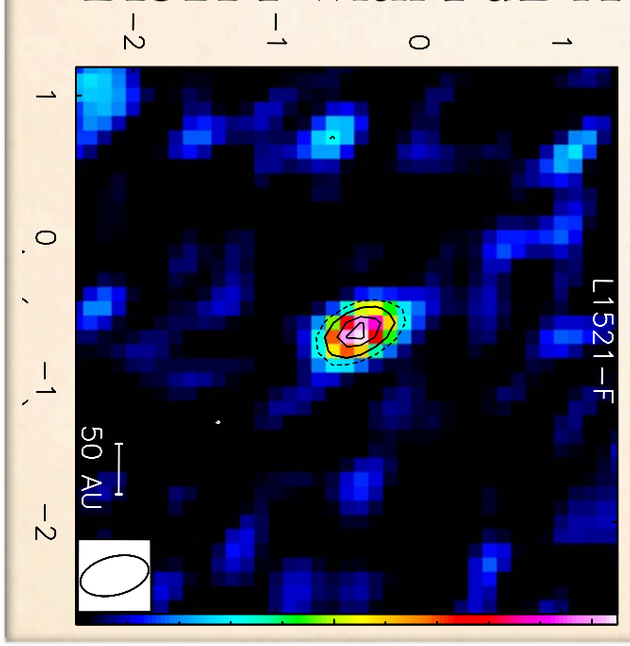
Comparison with numerical simulations of SF

MHD simulations by Hennebelle & Teyssier (2008) :
magnetic field = half the critical value (initial μ=3.2)

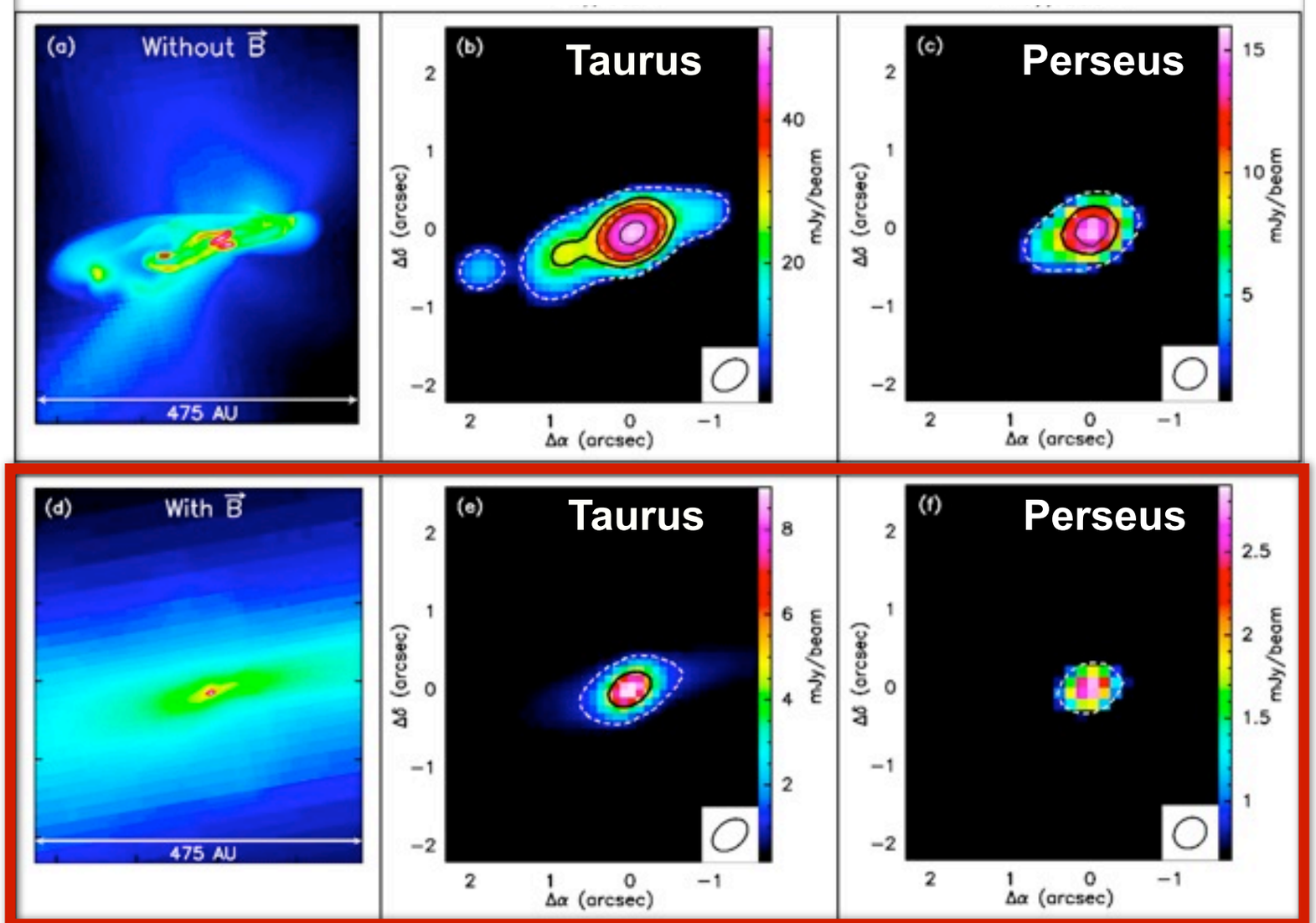
synthetic images
with typical FWHM
~ 0.2" - 0.6"

Similar to the PdB-A
observations of Class 0
protostars.

L1521-F with PdB-A



MHD numerical simulations : synthetic images



White contour : 3σ level. Thick black contour : 5σ level.

Concluding remarks

✳ Pilot study : sample of 5 Class 0 protostars

✳ First sample : 5 single protostars at small scales (50 - 1500 AU).

✳ Tentative evolution of binary fraction at ~ 50-1500 AU from Class 0 to Class I stage ?

Dynamical scenarii for the formation of multiple systems.

✳ Numerical simulations of protostellar formation :

only magnetized models reproduce high-resolution observations of Class 0 protostars.

✳ To be continued :

8 more sources observed during Winter 2009-2010

✳ Question of disks : no massive, extended disks resolved so far !

Deeper analysis in progress ...

The near future ...

PdBI Large Program

- more than 300 hours observing time starting this summer
- targeting 17 Class 0 protostars
- will provide a comprehensive set of high-resolution observations
- putting constraints on small scales :

enveloppe properties and chemistry
disk existence and properties
accretion/ejection phenomena
role of bipolar outflows in angular momentum removal

ALMA

- will perform highly sensitive magnetic fields measurements :

polarization & Zeeman

- will allow to test the ohmic dissipation scenario : tiny (20 AU) disks ?
- Call for Early Science expected in less than one year ....

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