Star-forming regions with the SKA and its precursors

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Outline

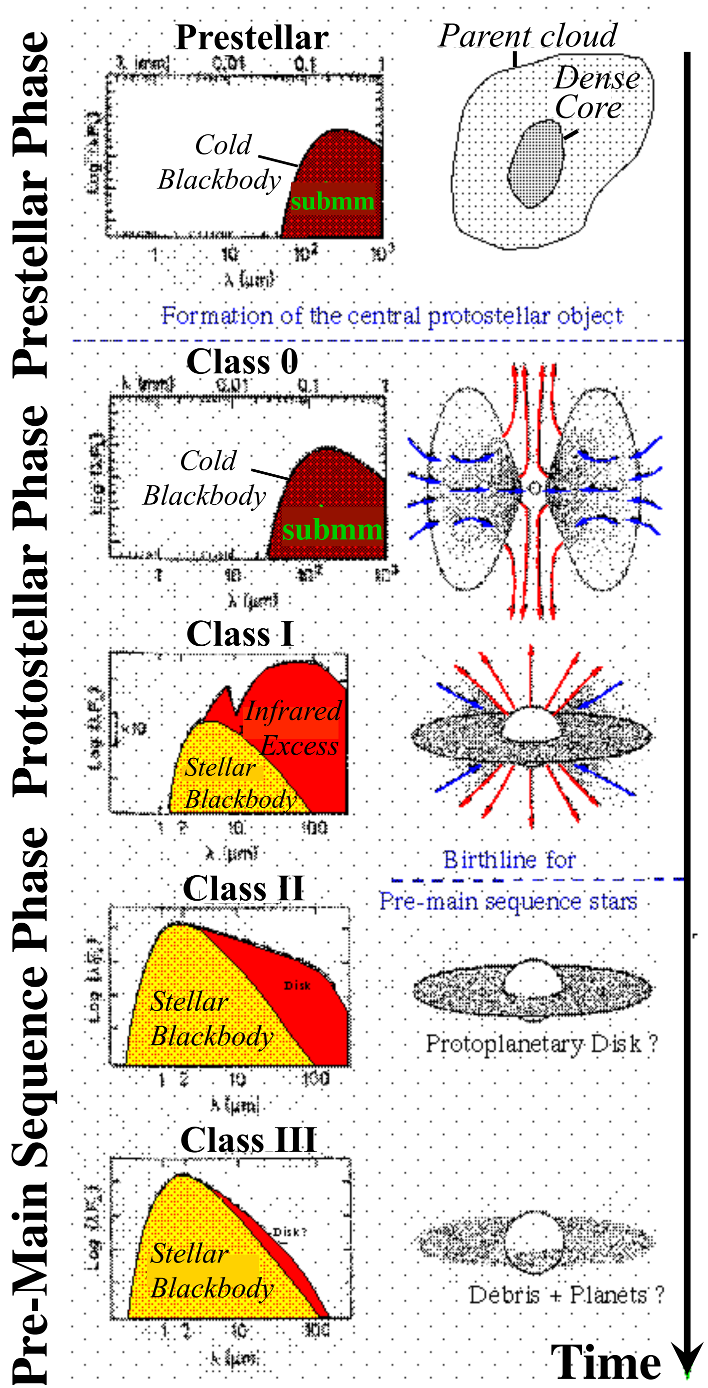
- **Radio continuum emission from young stellar objects:**

  - nonthermal gyrosynchrotron emission associated with magnetic activity and magnetospheres

  - (thermal) free-free emission from the shock-ionized base of protostellar jets

- **Origin of the filamentary structure of star-forming clouds:**

  - imaging the texture of the cold atomic component of SF clouds at high-resolution in HI



Lada 1987 + André, Ward-Thompson, Barsony 2000

Radio (cm) emission along the evolutionary sequence of solar-type young stellar objects

Class 0 ($M_{env} > M_\star$)

protostars

Class I ($M_{env} < M_\star$)

Class II (CTTSs)

YSOs/T Tauri stars

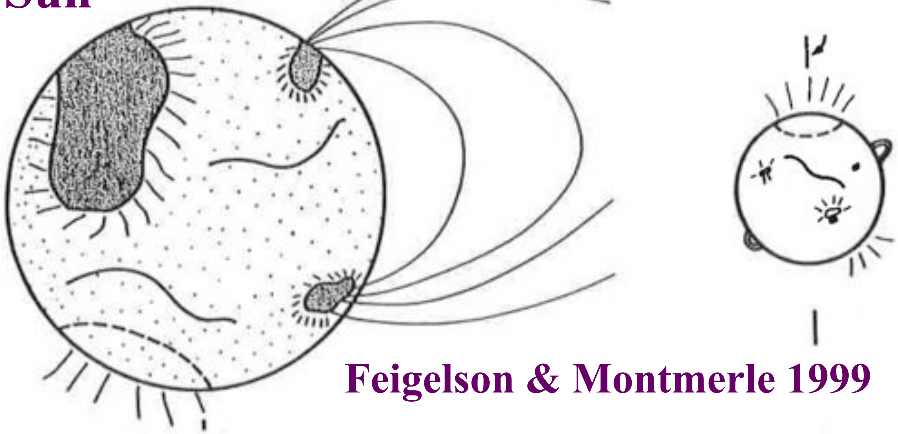
Class III (WTTSs)

Thermal (free-free) radio emitters

Nonthermal (gyrosynchrotron) radio emitters

Nonthermal cm radio emission from large-scale magnetic structures around YSOs

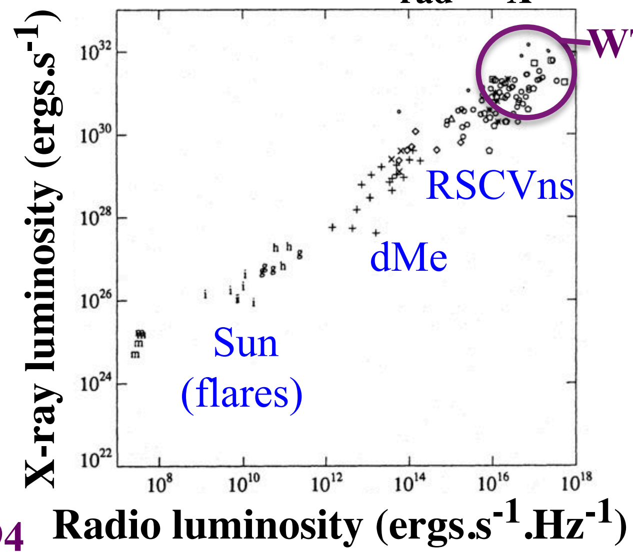
Young Sun ⌽ Sun



Feigelson & Montmerle 1999

Feigelson+1991

Correlation L_{rad} - L_X



Benz & Güdel 1994

- **Enhanced solar-type magnetic activity of weak-lined T Tauri stars:** variable, circularly polarized (~5-20%) gyrosynchrotron emission from MeV e- in giant flares

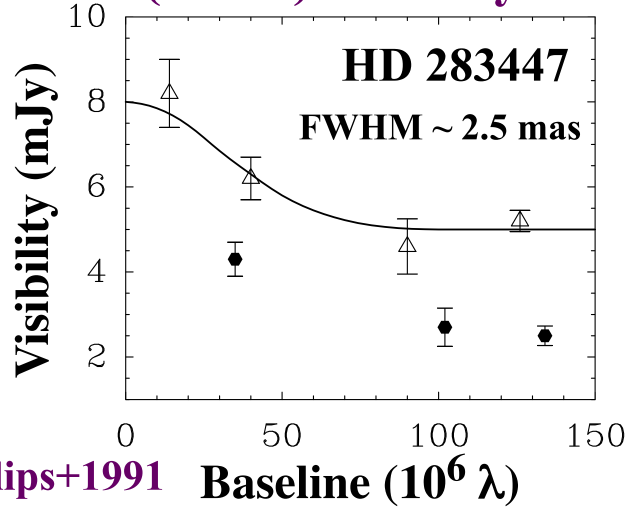
[B ~ 1-10 G in emitting region

→ $B_\star$ ~ 0.1-1 kG (dipole)]

- **At low frequencies with LOFAR + SKA-low:** can expect to detect coherent emission (e.g. plasma radiation) like on the Sun

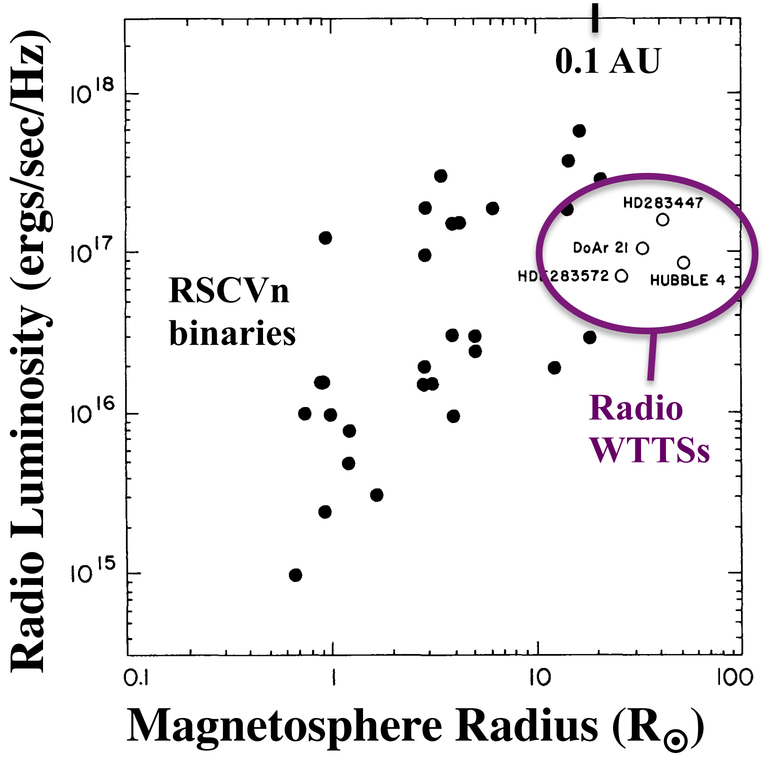
Nonthermal cm radio emission from large-scale magnetospheres around YSOs

VLBI (5GHz) visibility curve

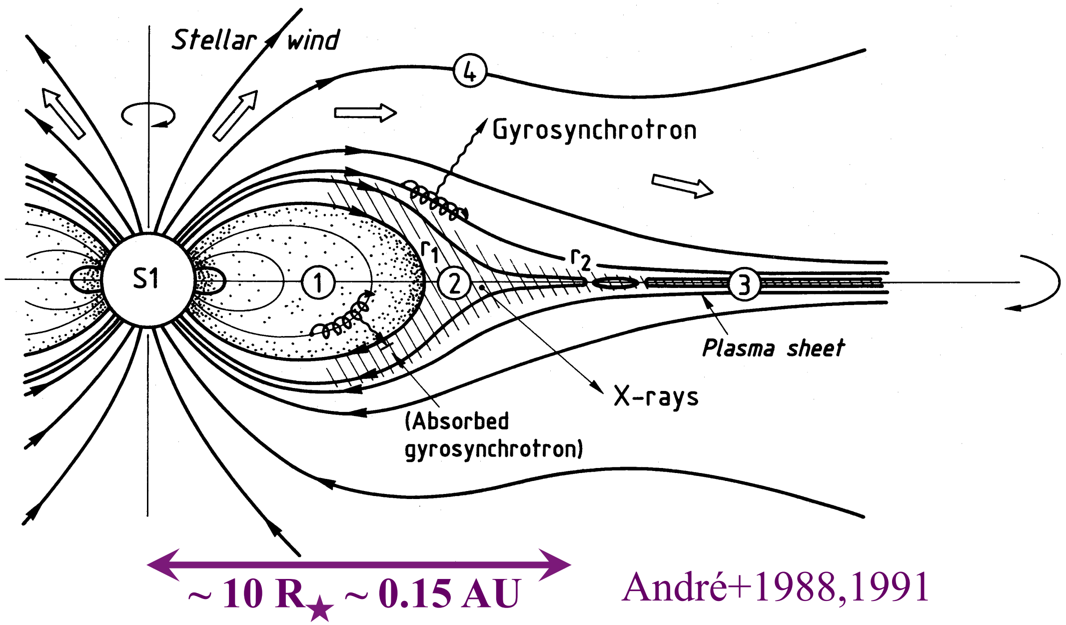


Phillips+1991

Parallax measurements with VLBA (Loinard et al. 2007, 2008)



Phillips et al. 1991

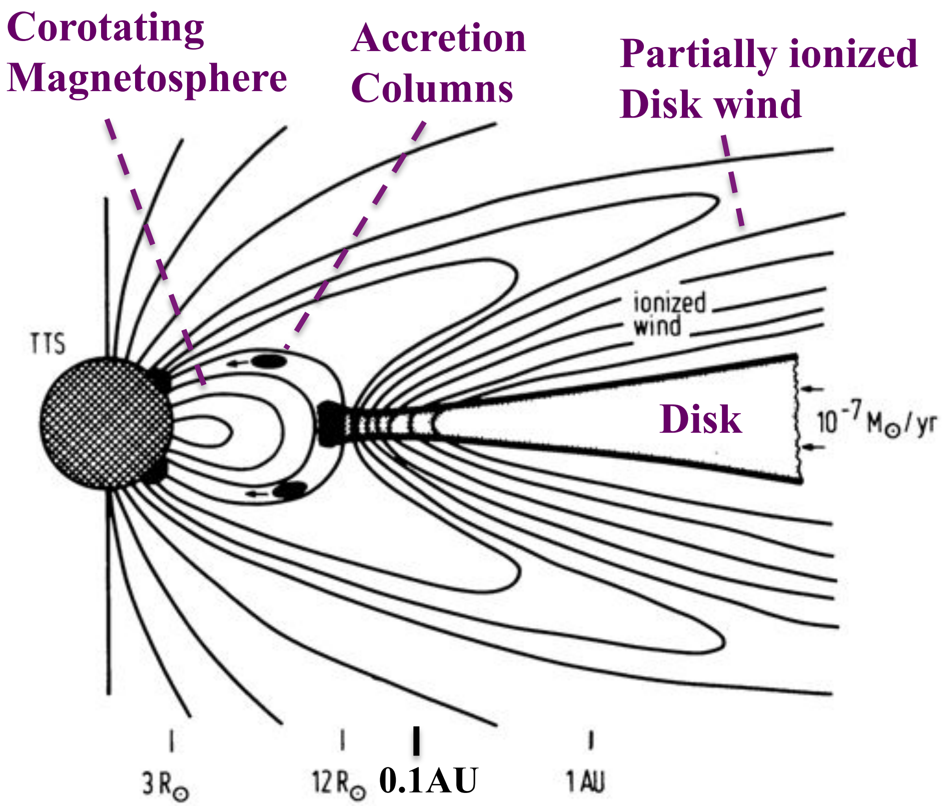


André+1988,1991

- **The largest of these magnetospheres may be resolved/imaged (?) with SKA2 at ν ~ 20 GHz**

Probing magnetospheric accretion and the launching zone of T Tauri winds/jets with SKA2 at ~ 5-20 GHz

Magnetospheric accretion paradigm



Camenzind 1990
Bouvier et al. 2007

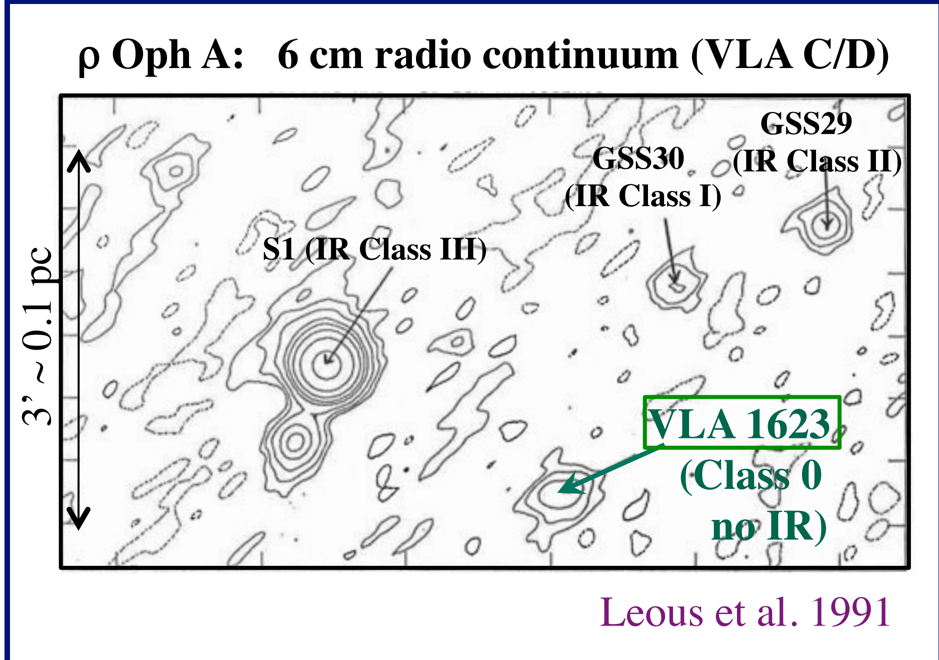
- **Magnetosphere disrupts inner disk of CTTSs at a few $R_\star$ (up to ~ 0.1 AU)**
- **Helps to regulate angular momentum and to power ejection in CTTSs**

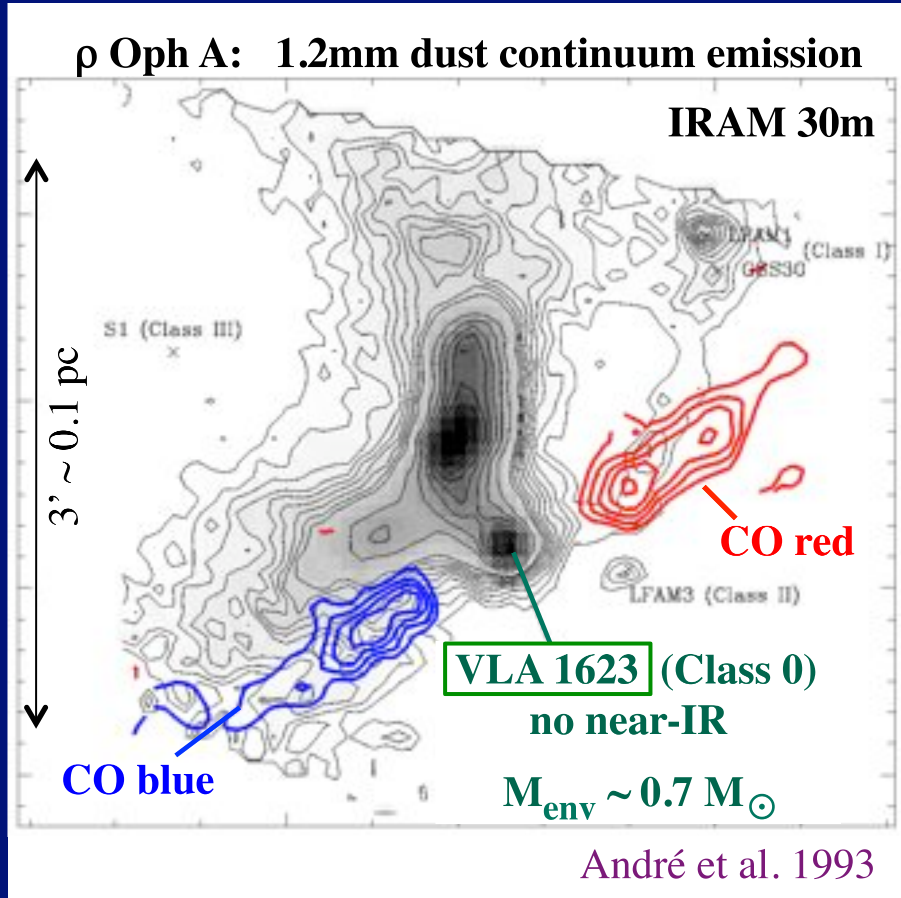
➢ **High-resolution imaging at ~ 5-20 GHz with SKA2 can provide a good diagnostic**

➢ **Potential problem: Free-free optical depth of wind**

Radio cm emission is one of the best tracers of the youngest protostars (Class 0 objects)

Free-free emission from shock-ionized base of accretion-driven protostellar jets (cf. Anglada 1996)

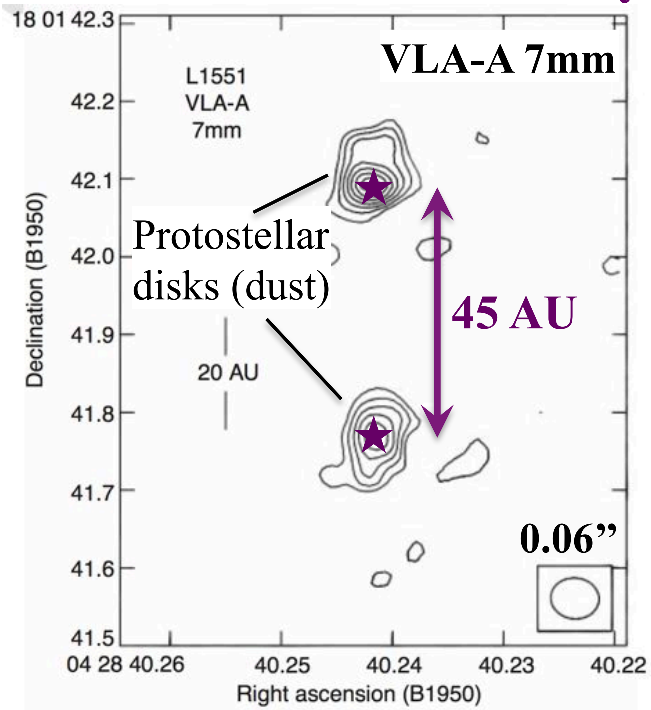




Jets/outflows more powerful at Class 0 stage than at Class I IR stage (Bontemps et al. 1996)

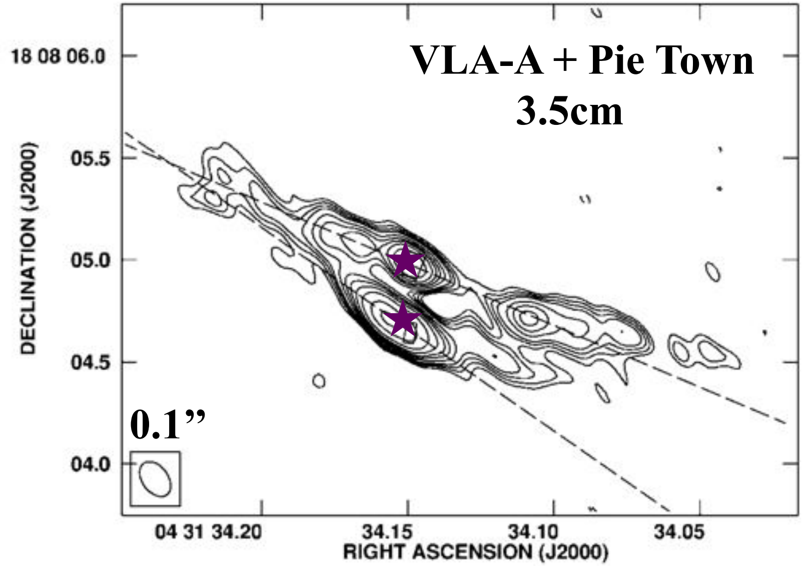
High-resolution surveys of protostars with SKA2 at ~ 5-20 GHz can help probe their multiplicity down to < 1 AU

L1551-IRS5 Protobinary



Rodriguez et al. 1998

L1551 Binary jets

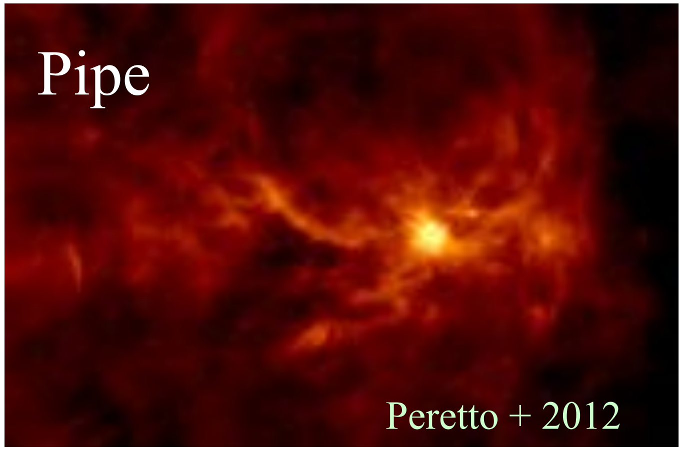


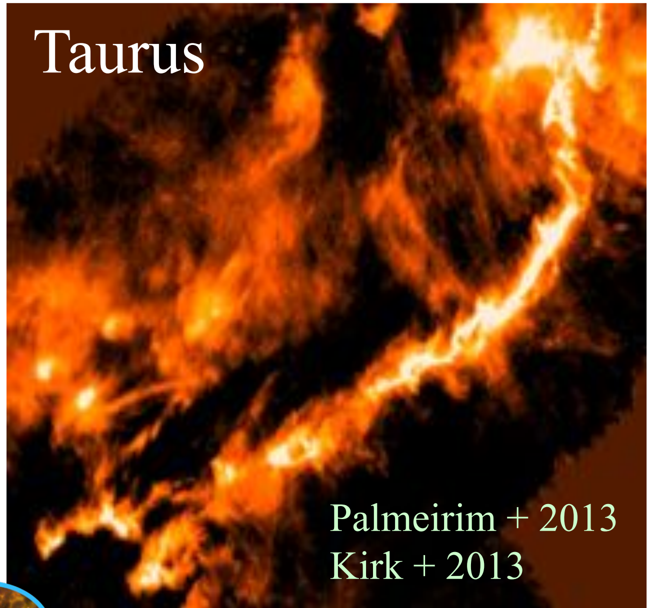
Rodriguez et al. 2003

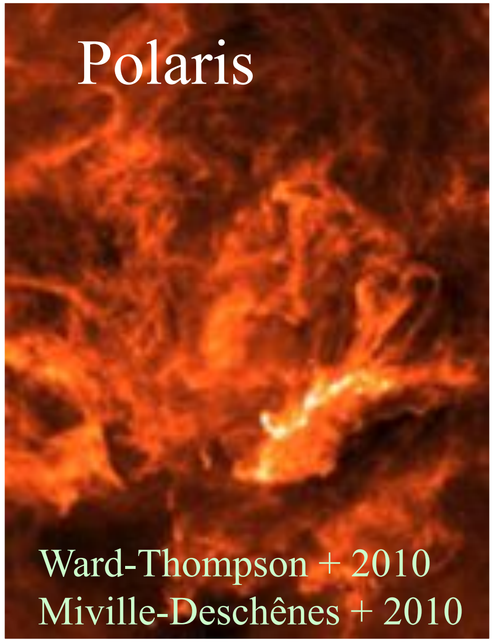
- **High-resolution imaging of protostars at ~ 5-20 GHz can give insight into the formation of multiple protostars**

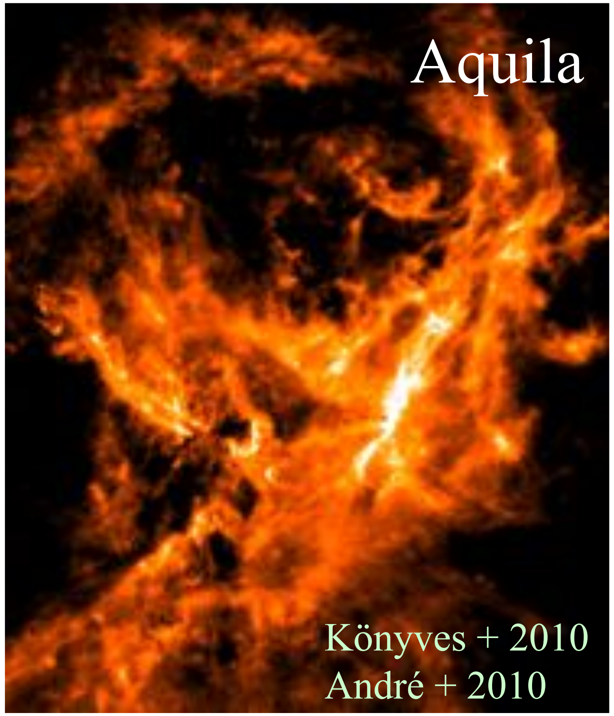
Growth of structure in the cold ISM leading to star formation in molecular clouds

Herschel has revealed a “universal” filamentary structure in the cold ISM



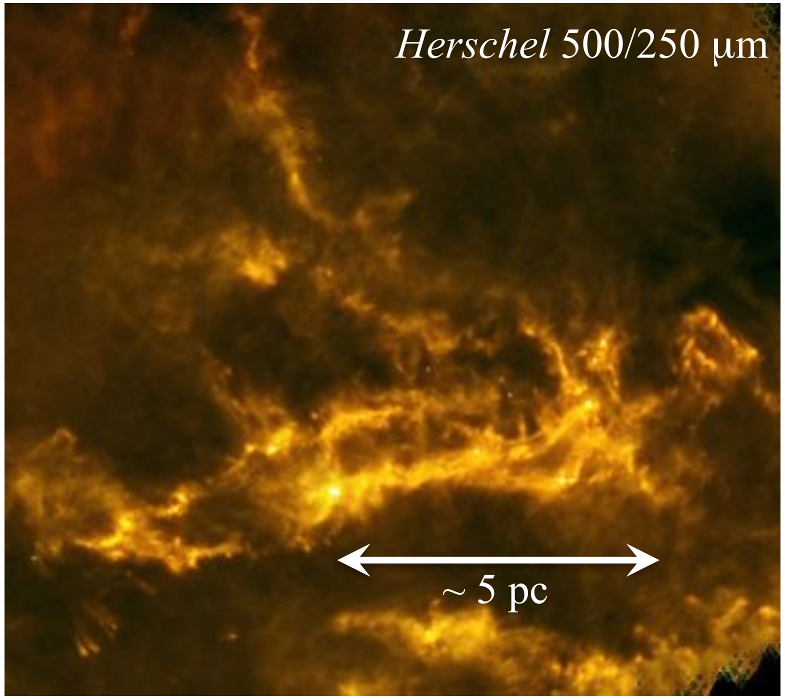




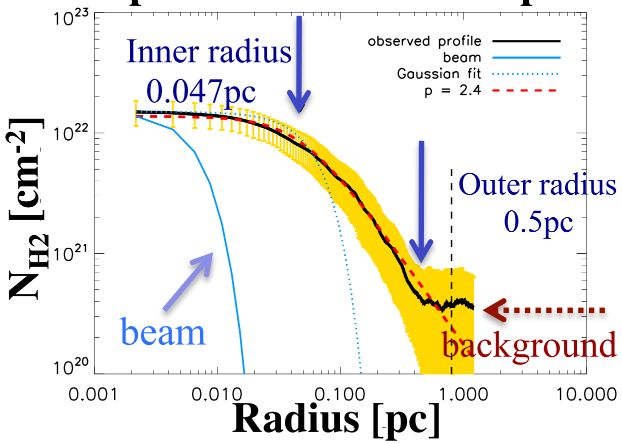


Filaments have a characteristic width ~ 0.1 pc

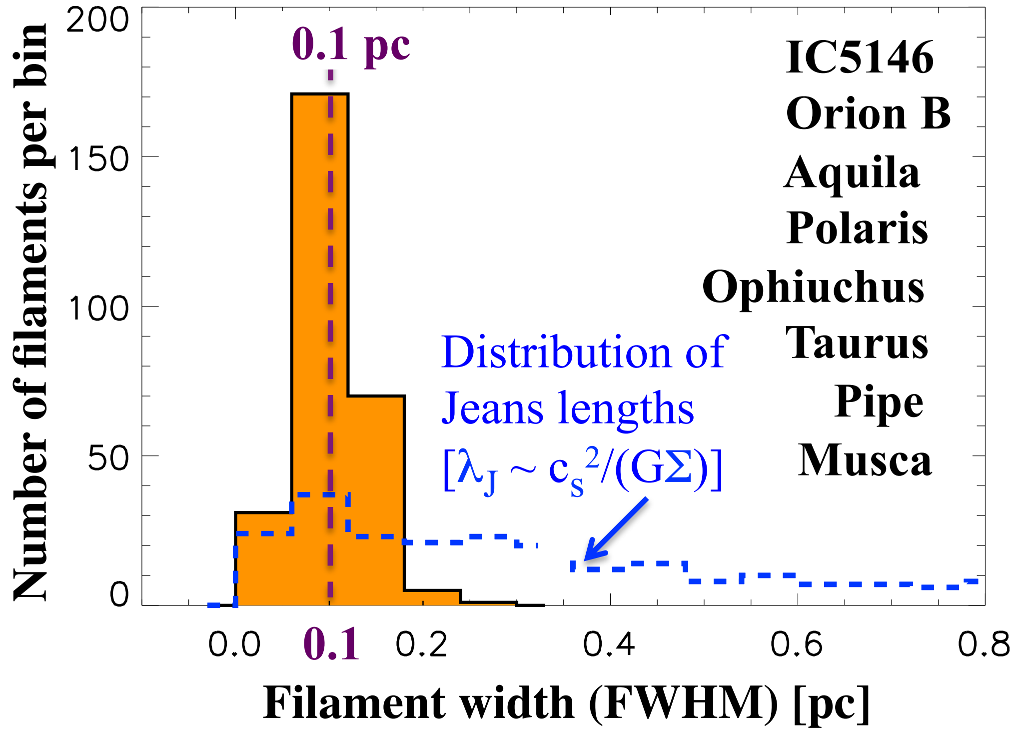
Network of filaments in IC5146



Example of filament radial profile



Statistical distribution of widths for > 270 nearby (d< 450 pc) filaments



Arzoumanian et al. 2011, A&A, 529, L6
D. Arzoumanian' s PhD thesis

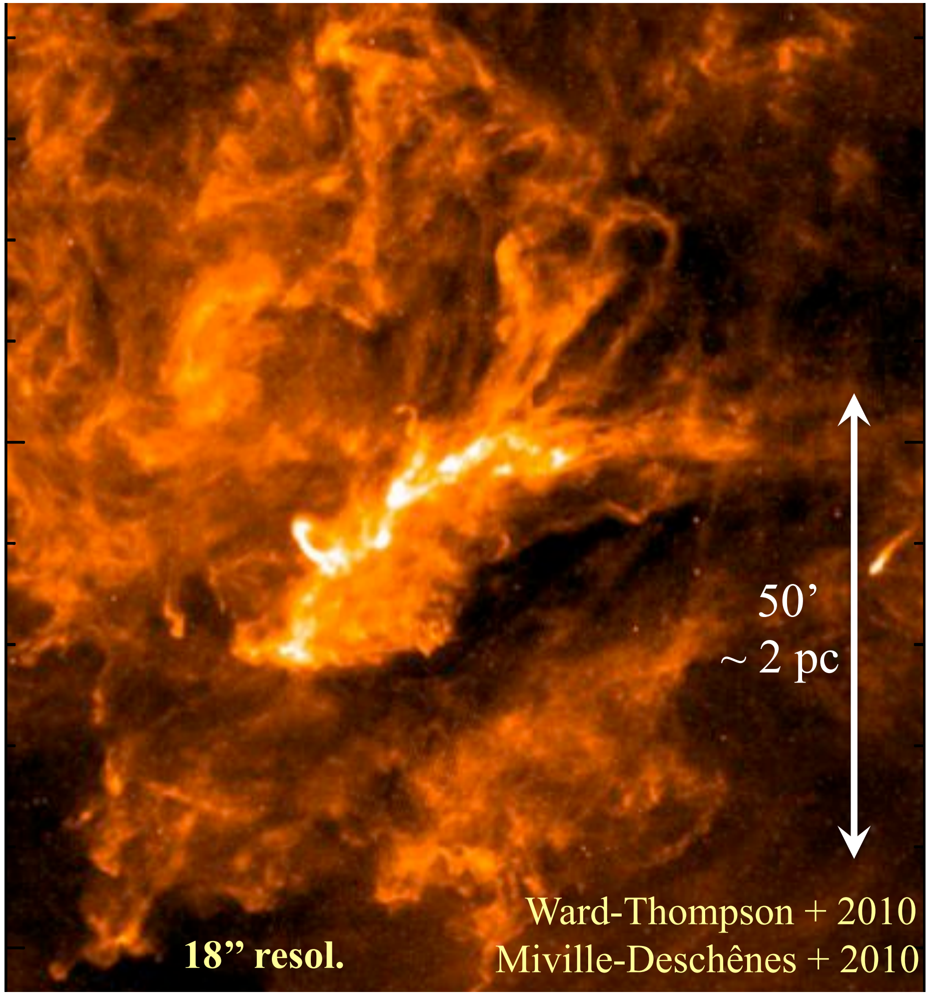
- **Toward a new paradigm for star Formation**

Review for PPVI (André et al. - astro-ph/1312.6232)

Toward a 'universal' scenario for star formation ?

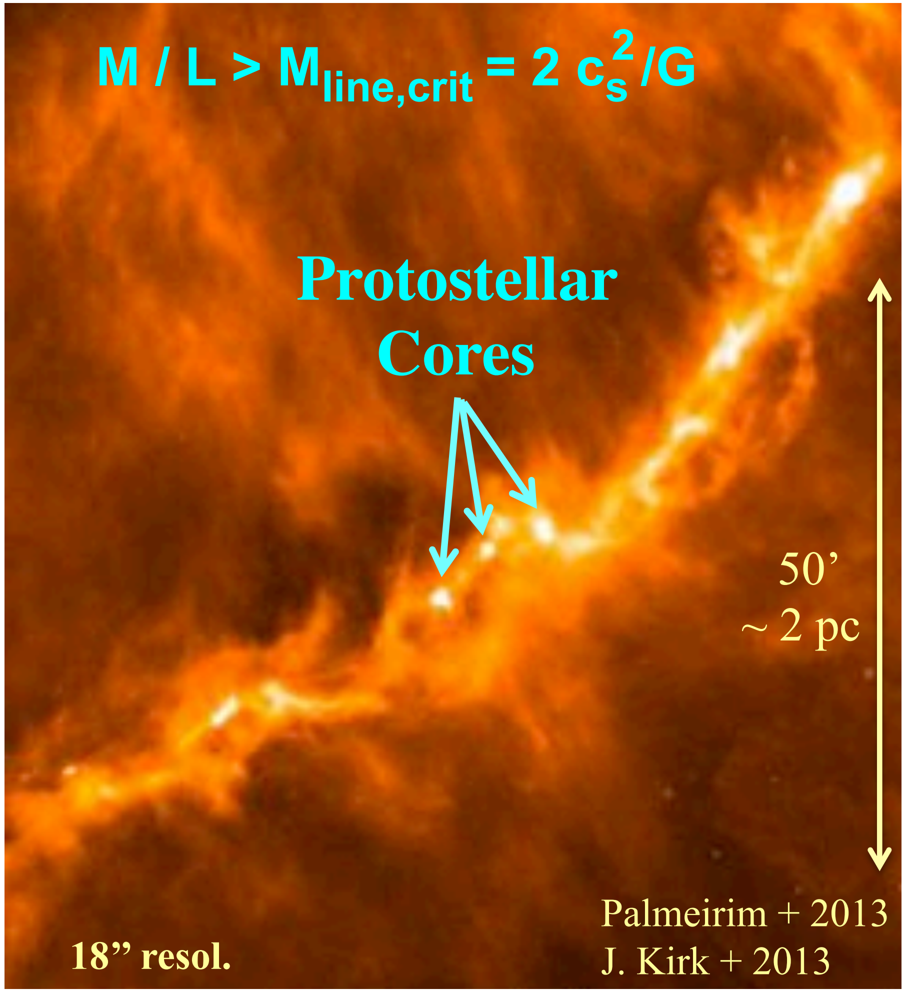
See chapter for « Protostars & Planets VI » (astro-ph/1312.6232)
by André, Di Francesco, Ward-Thompson, Inutsuka, Pudritz, Pineda

1) The dissipation of large-scale MHD 'turbulence' generates filaments



Polaris – *Herschel*/SPIRE 250 μm

2) Gravity fragments the densest filaments into prestellar cores

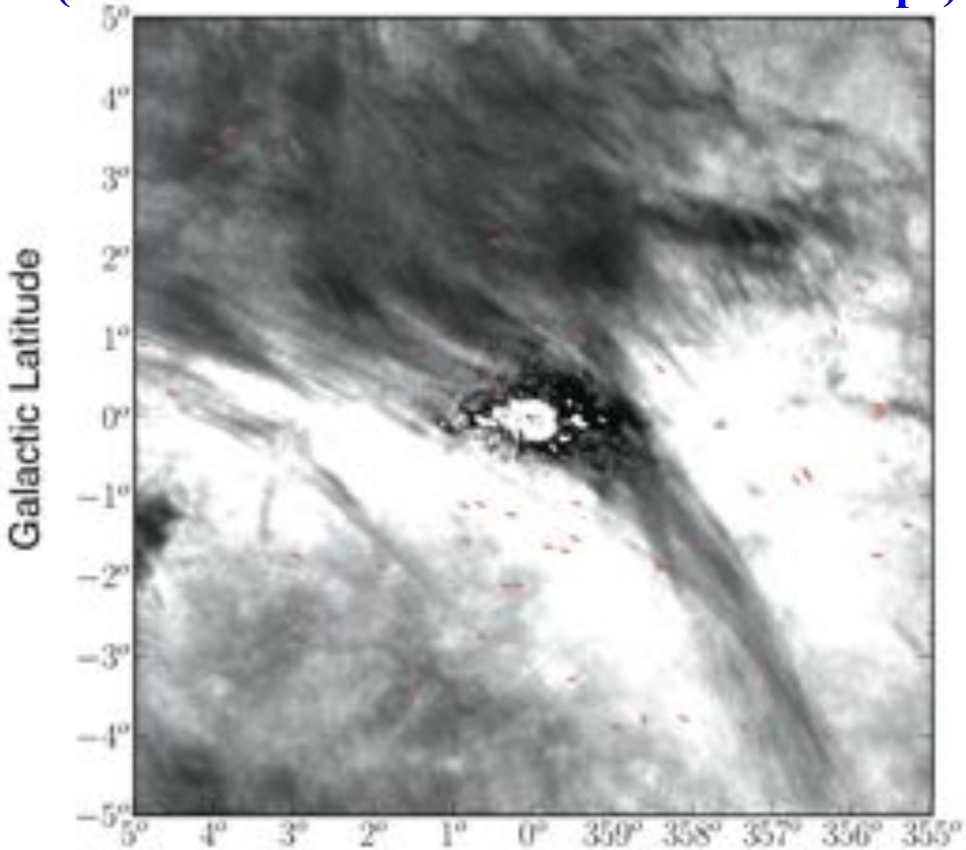


Taurus B211/3 – SPIRE 250 μm

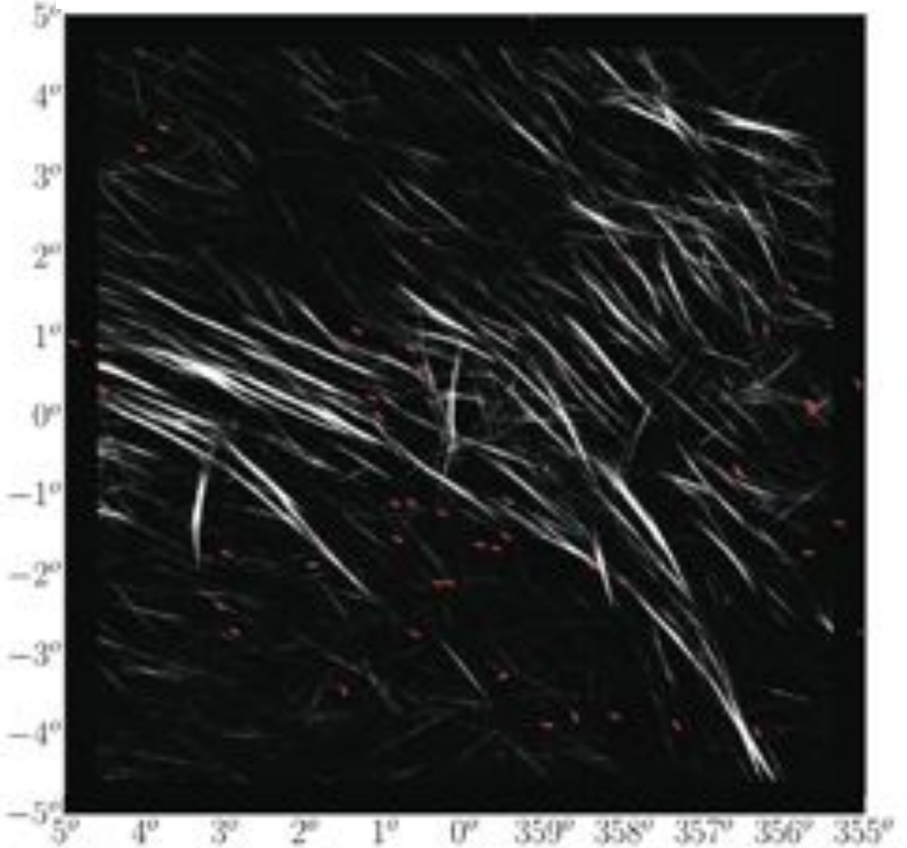
Formation of filament structures in the cold ISM ?

Hint: Prominent filaments are also seen in HI absorption (CNM)

The Riegel-Crutcher cloud in HI asborption
(ATCA+ Parkes – Resolution: 100” ~ 0.1 pc)



HI filaments traced with the
“Rolling Hough Transform”

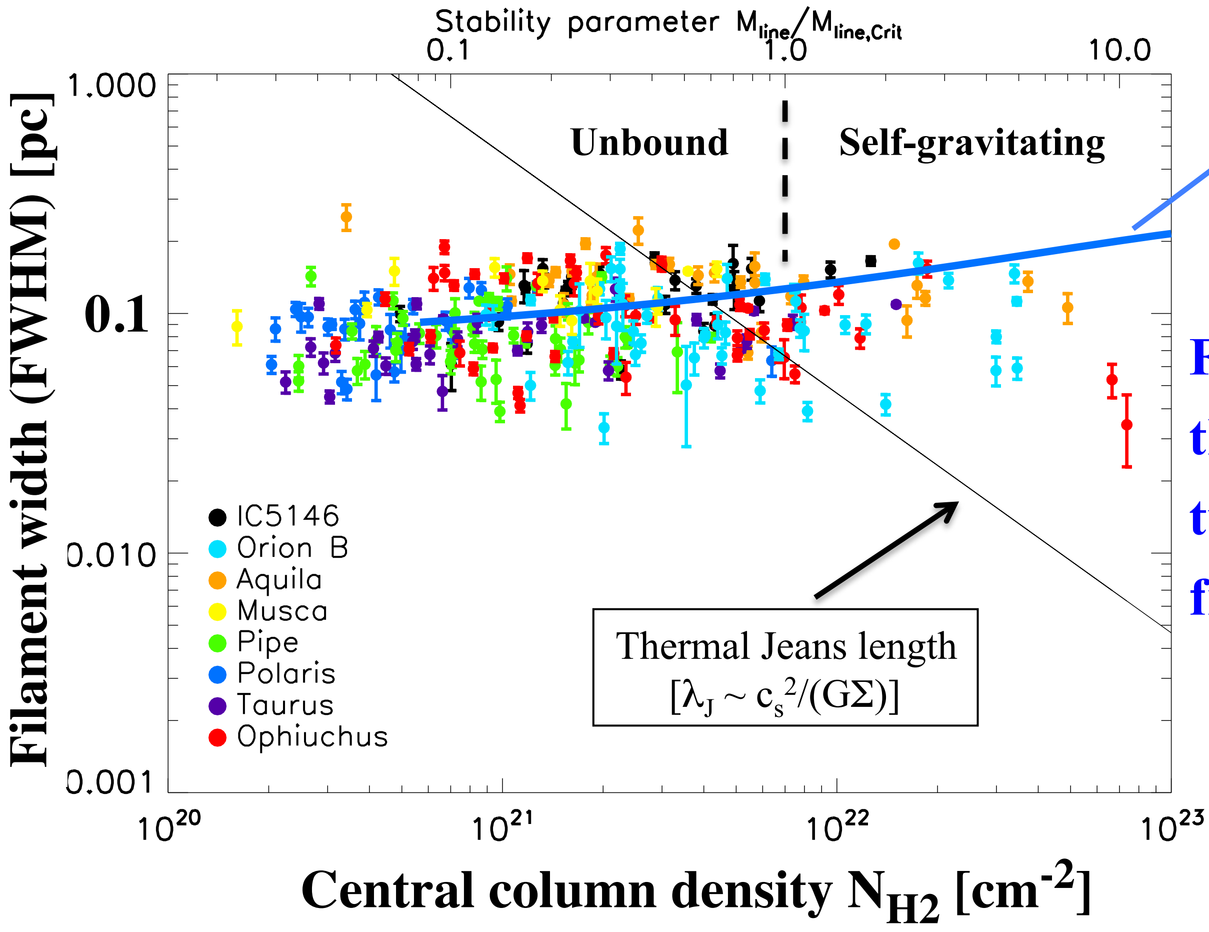


McClure-Griffiths et al. 2006

Galactic Longitude

Clark et al. 2014

Filament width vs. Column density (*Herschel*)



At high densities, consistent with a model of accreting filaments (Hennebelle & André 2013)

Filament width may be set by the dissipation of MHD turbulence due to ion-neutral friction (Hennebelle 2013)

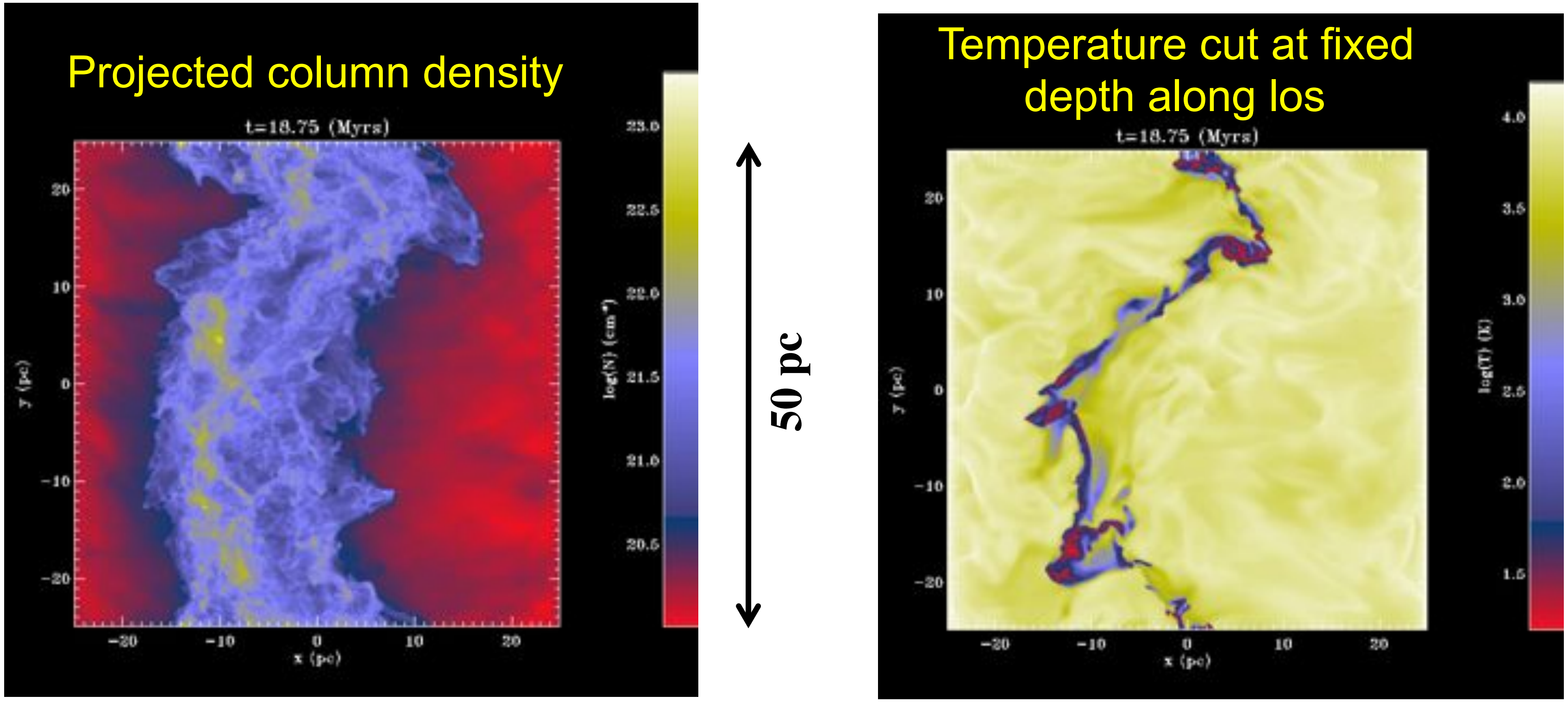
↓

Expect the width of HI filaments to be ~ 10 times smaller due to higher ionization degree 0.01pc ⇔ ~15" @ d=150pc

Arzoumanian et al. 2011
D. Arzoumanian's PhD thesis

Star-forming clouds have a 2-phase structure (CNM/WNM)

Numerical simulations of molecular cloud formation out of atomic gas



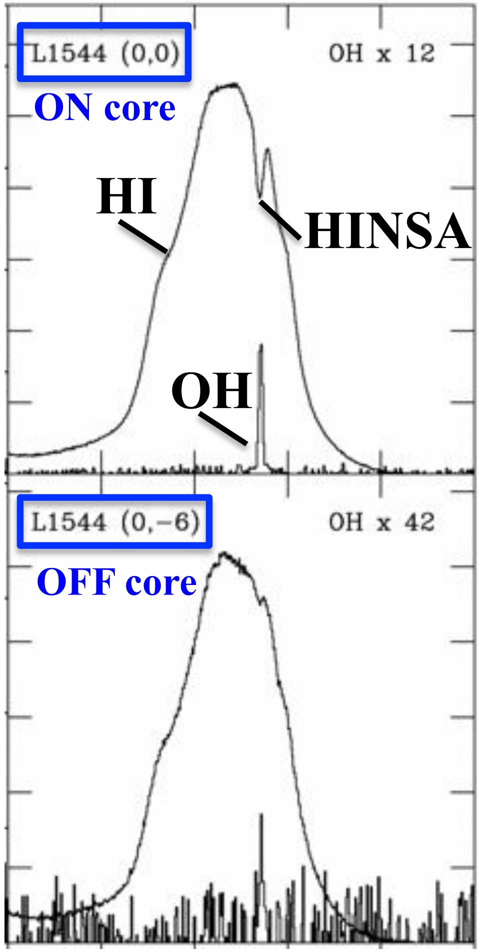
Hennebelle et al. 2008

- **Complex 2-phase structure with WNM (= warm HI) inter-mixed with CNM (= cold H_2)**

- **Turbulence in molecular clouds (CNM) may be maintained by constant interaction with WNM**

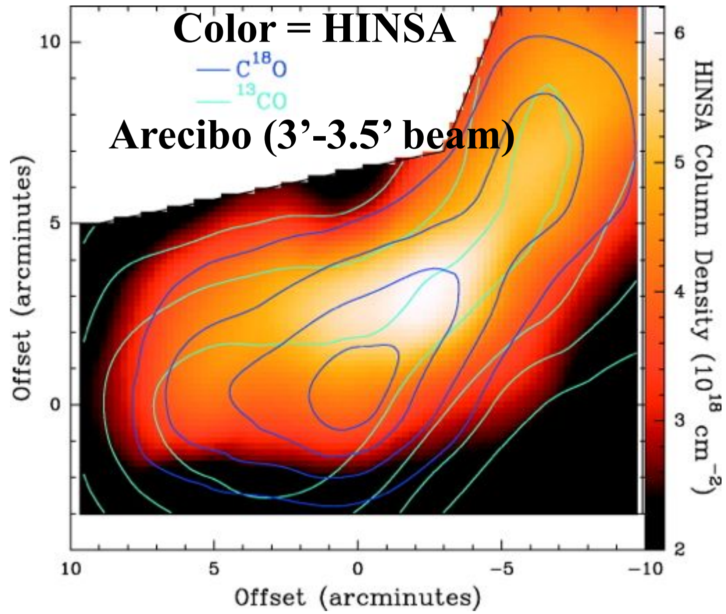
Observational evidence of the 2-phase structure of star-forming clouds

- Close correlation between HI narrow self-absorption (HINSA) and molecular emission in dark clouds



Li & Goldsmith 2003
Goldsmith & Li 2005

L1544 prestellar dense core in Taurus



- Existing HI observations of nearby star-forming clouds are too scarce/low resolution
- Wide-field HI imaging at high resolution (< 20") needed to probe interactions between atomic and molecular medium

Summary

- **Magnetic activity of young stars:** low-frequency continuum studies of known young (nonthermal) radio stars

- **Census and multiplicity of the youngest protostars:** mid-frequency surveys for (shock-ionized jets from) Class 0 protostars + multiplicity studies at the highest resolution

- **Origin of the filamentary structure of star-forming clouds:** resolving the texture of the cold atomic component of SF clouds in HI