Herschel Overview of the Link Between Clouds and Star Formation: *a PPreVIew*

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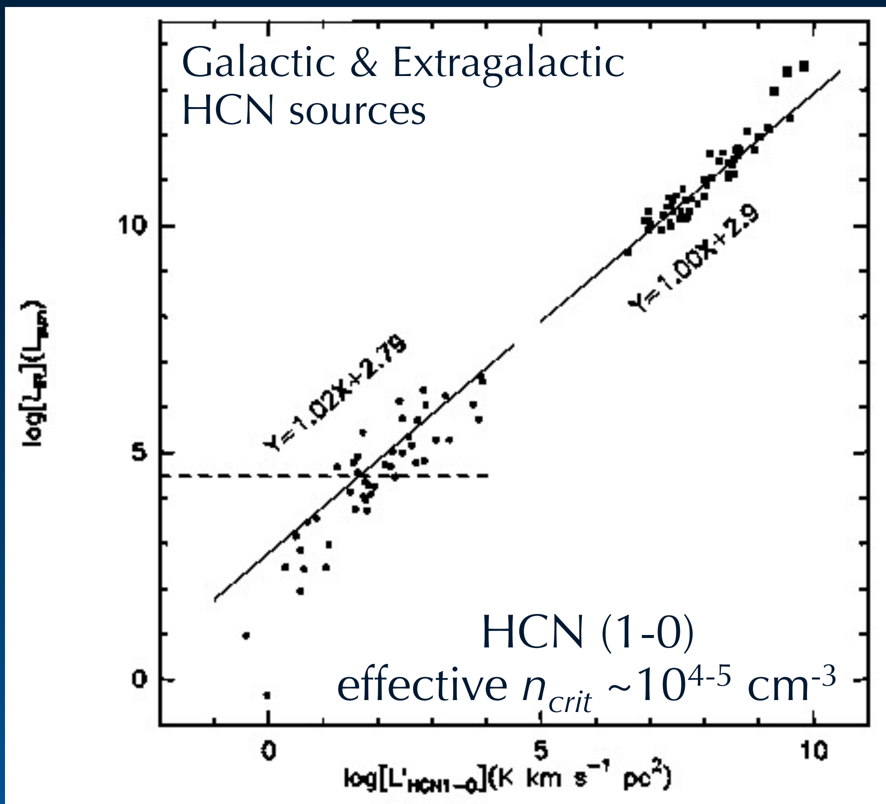
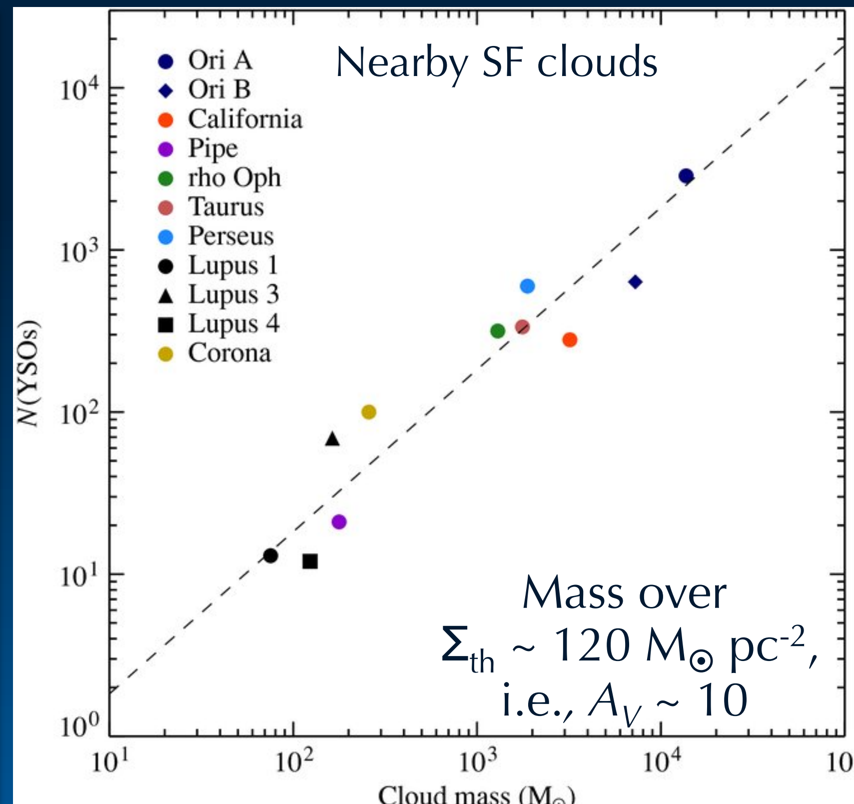
Star Formation Occurs in **Dense** Gas

L_{IR} (SFR) vs. L_{HCN} (**Dense** Gas)



Wu et al. (2005); Gao & Solomon (2004)

N(YSOs) vs. **Dense** Cloud Mass



Lada et al. (2010); Gutermuth et al. (2011)

How does Dense Gas Originate?

- 3.5 m diameter telescope at Sun-Earth L2 point
- apparently still going strong! ☺

Herschel Reveals Substructure in Clouds

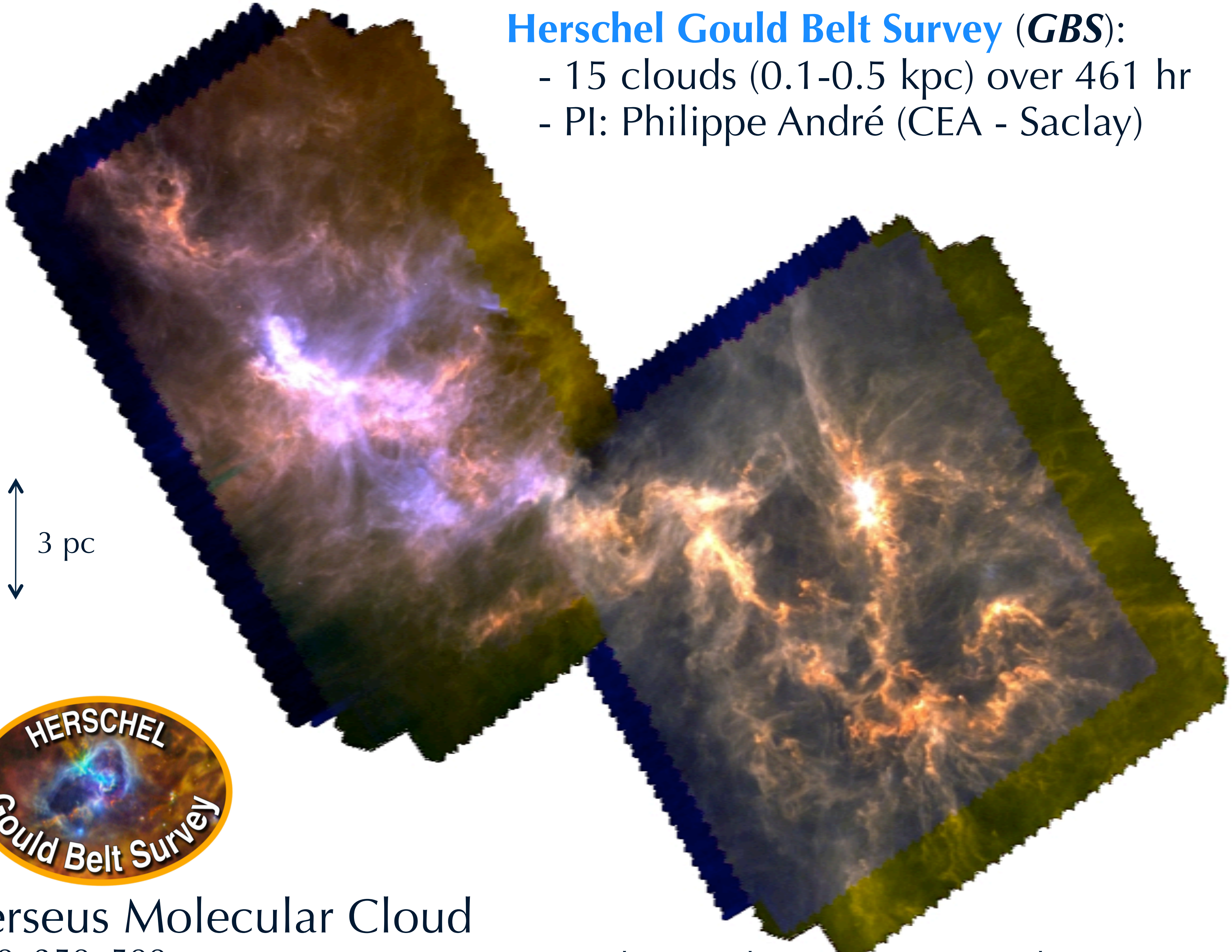
Herschel Space Observatory

PACS and **SPIRE** (in parallel):

- probe thermal emission from dust at high resolution (5″-36″)
- have wide dynamic range, probing link between diffuse and compact emission (cores)
- detect 70-500 μm, where cold cores are brightest, gives multi-λ data to constrain T_{dust}
- have high sensitivity for maps, samples low column densities

Herschel Gould Belt Survey (***GBS***):

- 15 clouds (0.1-0.5 kpc) over 461 hr
- PI: Philippe André (CEA - Saclay)



3 pc

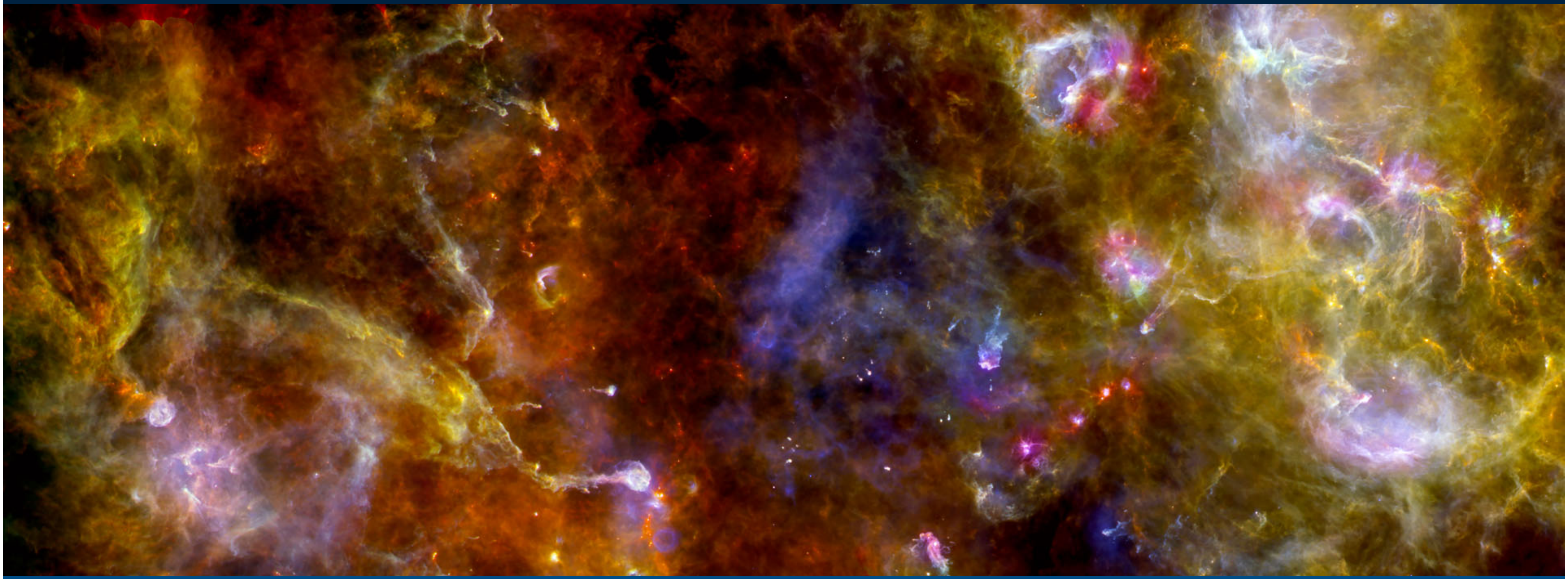
Perseus Molecular Cloud

160, 250, 500 μm

Sadavoy et al. (2012); Pezzuto et al. (2012, in prep)

Herschel OB Young Star Survey (***HOBYS***):

- 15 clouds (0.7-3.0 kpc) over 126 hr
- PI: Fréderique Motte (CEA - Saclay)



Hennemann et al. (2012, in press)

Cygnus X - North

70, 160, 250 μm

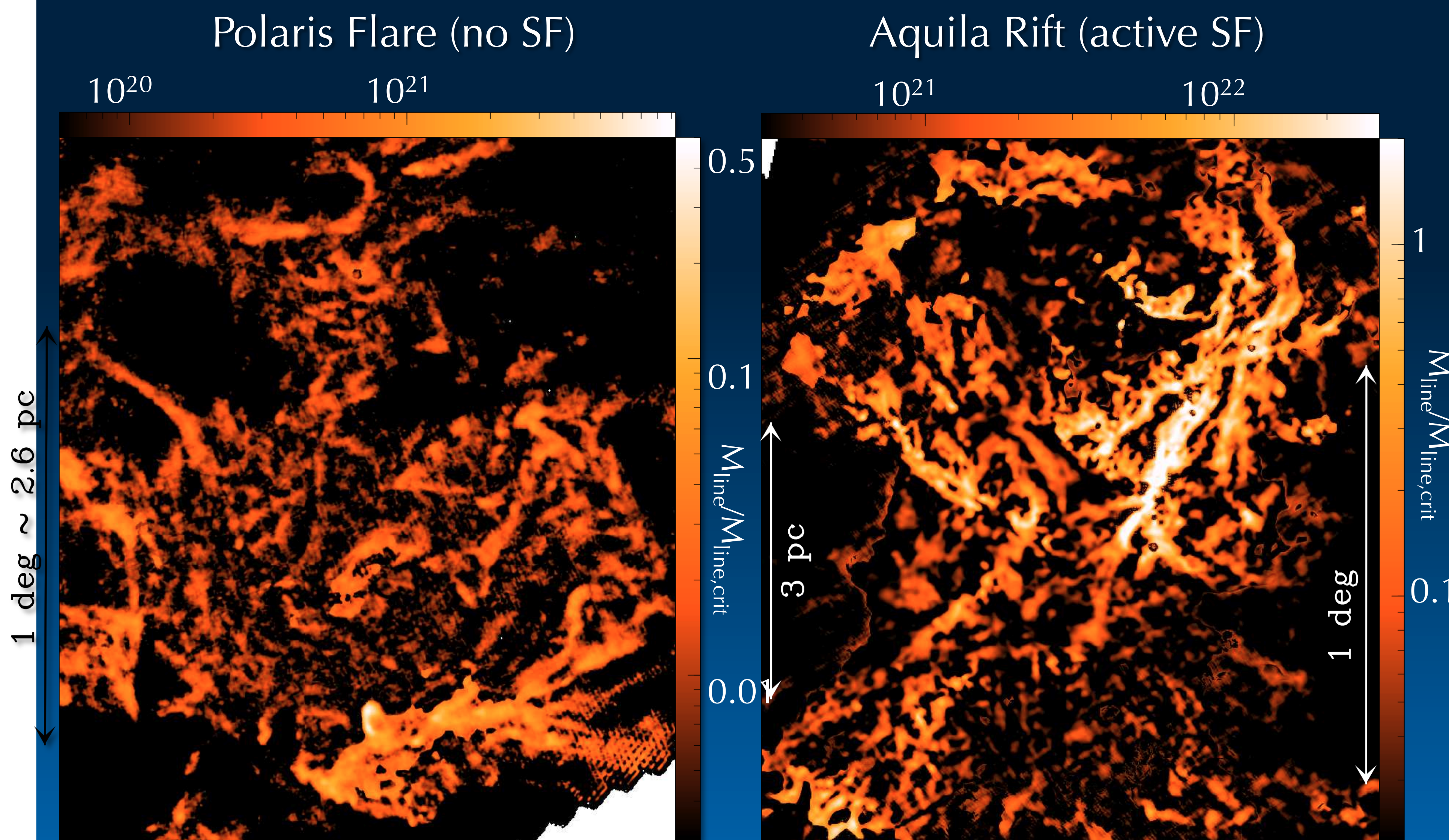
Key Points from Herschel Continuum SF Surveys

1. **Filamentary structure is ubiquitous in molecular clouds**

2. **Only dense filaments appear to form cores, stars**

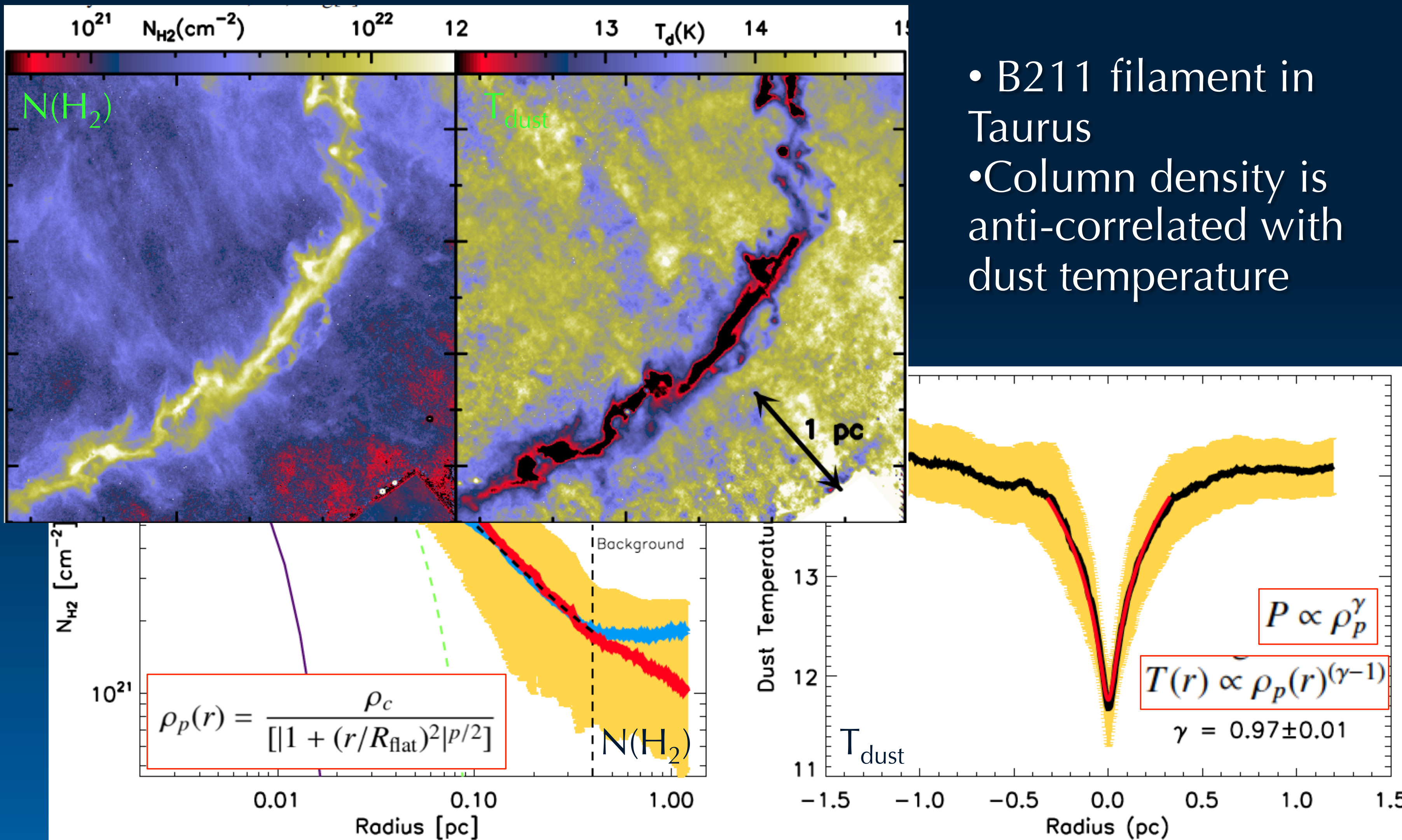
3. **Core mass function very similar in shape to stellar IMF**

1. Filaments are Ubiquitous in MCs



Mid-scale curvelet component of column density map (H_2/cm^2)

Characterization of Filaments



- B211 filament in Taurus
- Column density is anti-correlated with dust temperature

- Plummer fits; p ~ 2 ± 0.4 (cf. p = 4 isothermal cylinder; Ostriker 1964)

Palmerim et al. (2013); also Arzoumanian et al. (2011), Nakamura & Umemura (1999).

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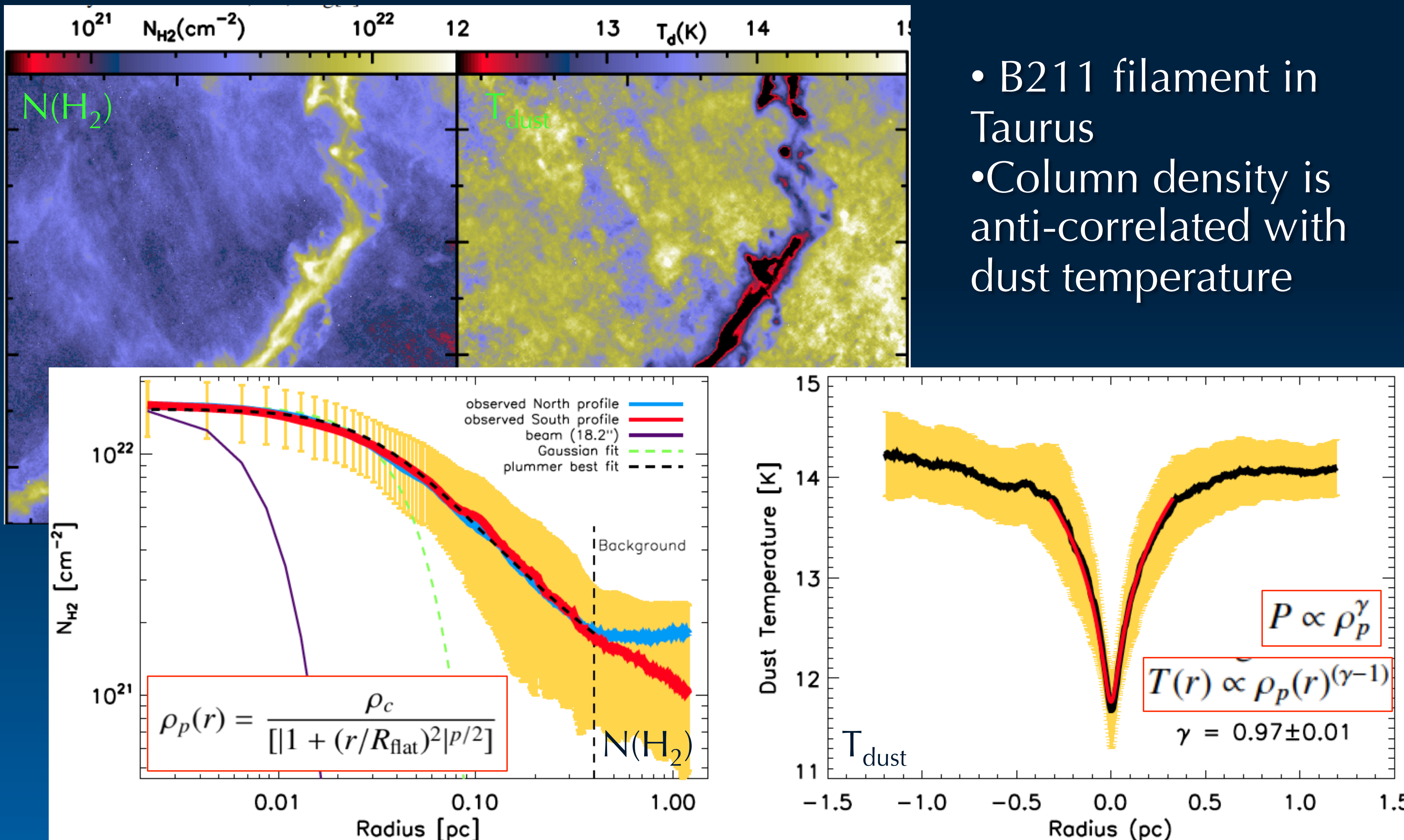

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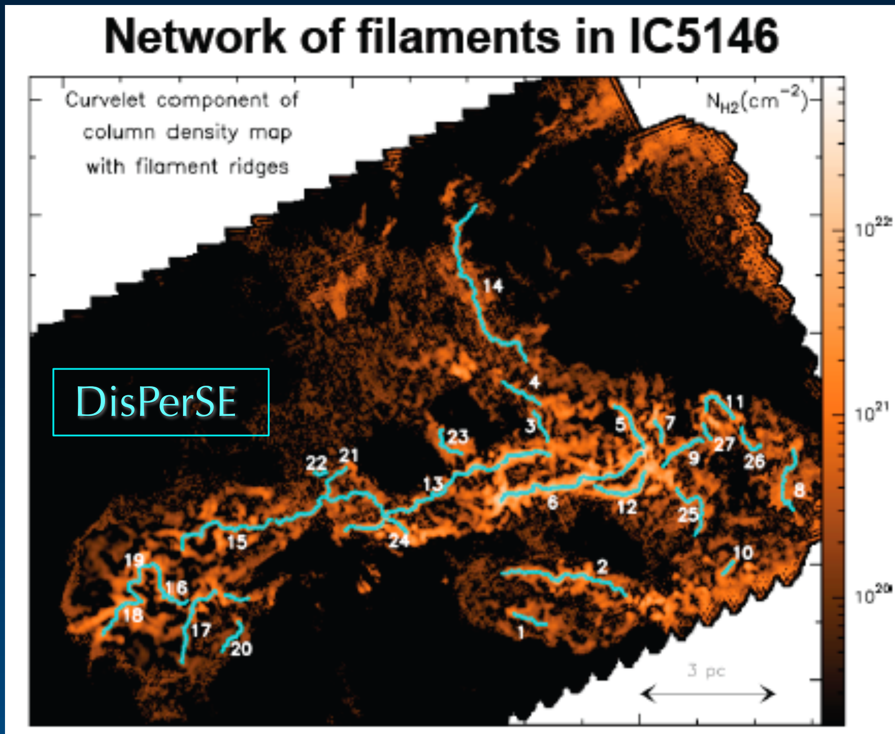
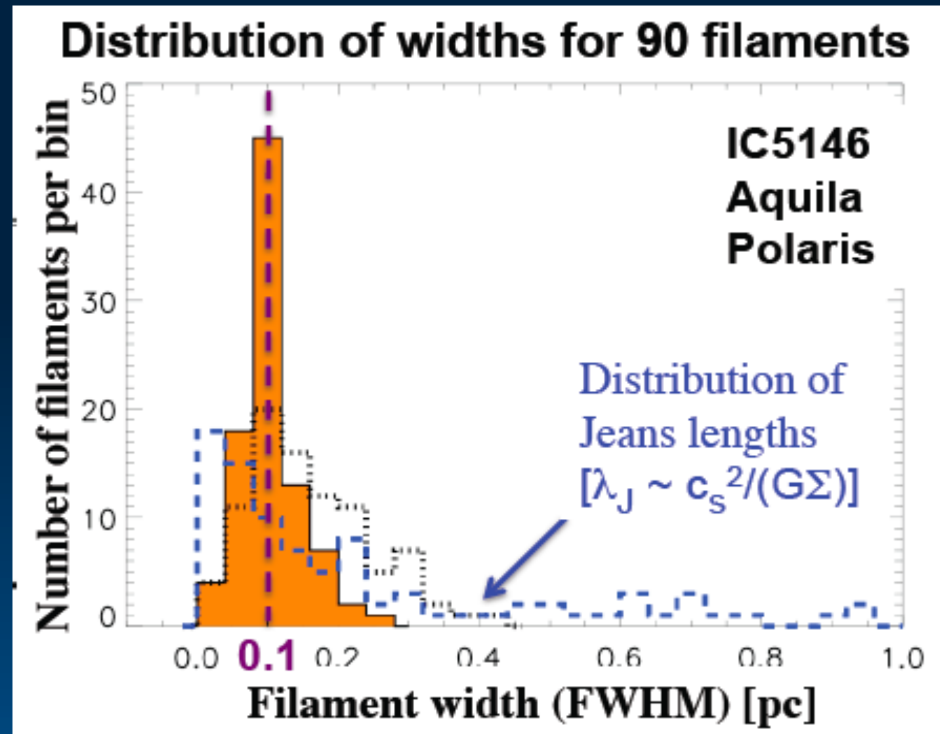
Filaments have Constant Widths

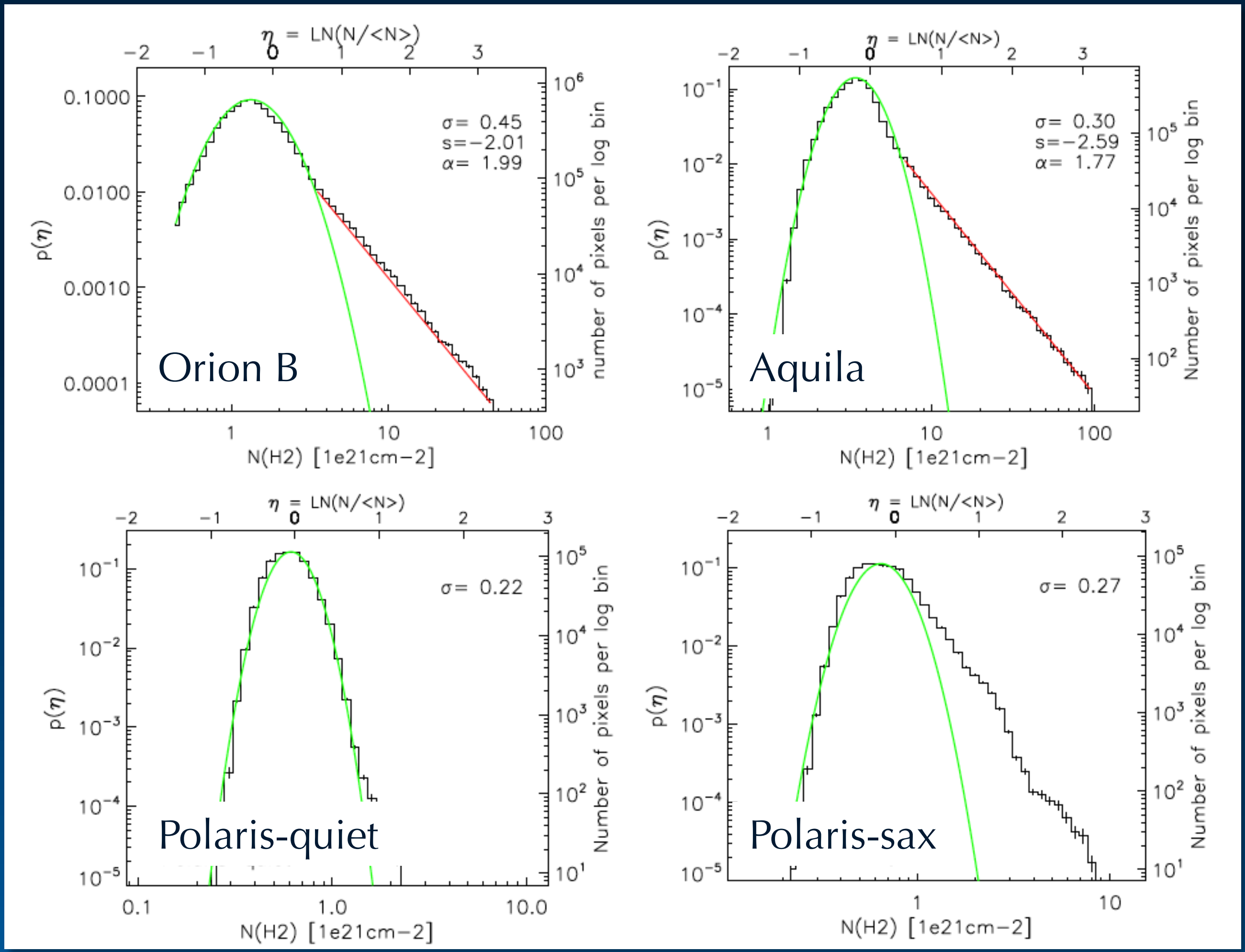




- filament central column densities vary over ~2 orders of magnitude
- widths vary little around ~0.1 pc, similar to sonic scale
- stagnation points in a turbulent velocity field?

Arzoumanian et al. (2011, 2013) + André et al. (2013; PPVI); GBS

Probability Column Density Functions

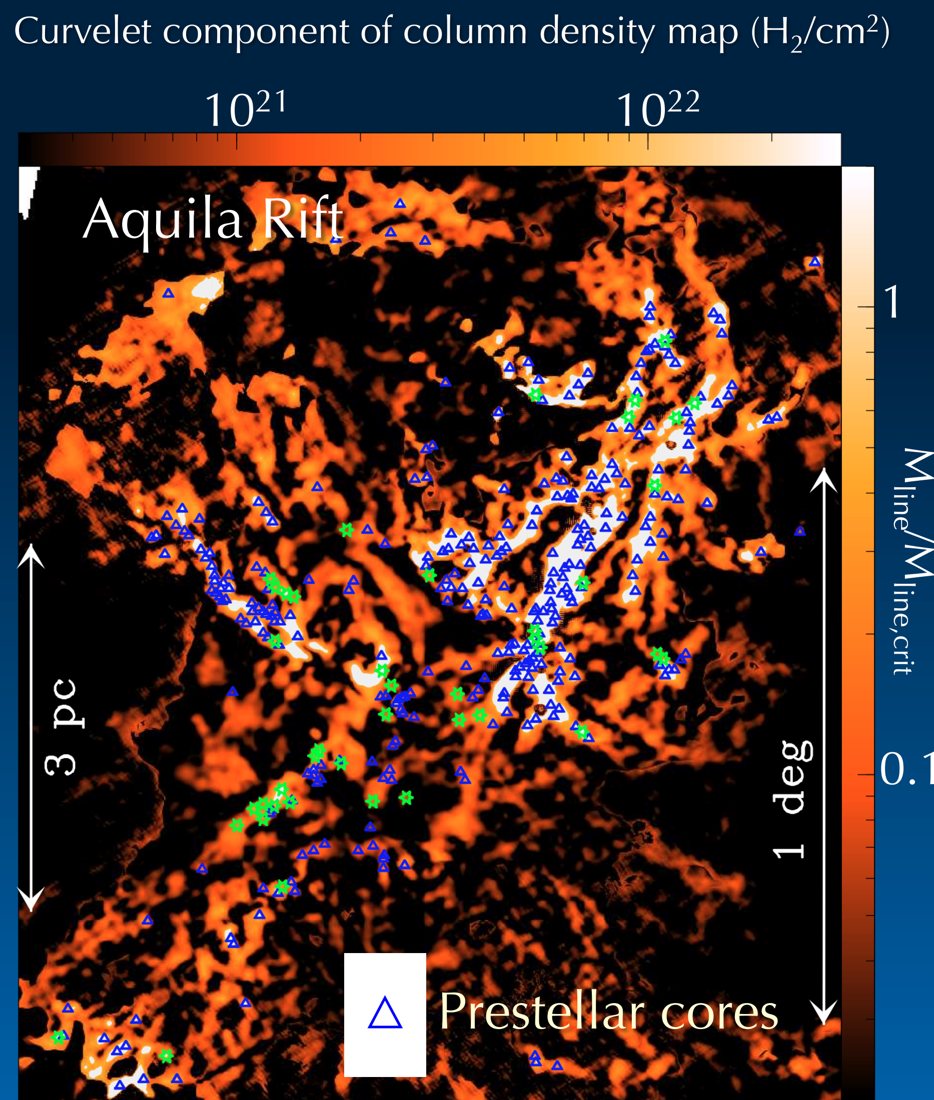


- lognormal part from turbulence, high column tail from gravity
- width ~ external compression, tail slope ~ r^{-2} density distribution

Schneider et al. (2013, GBS); also Russeil et al. (2013, HOBYS)

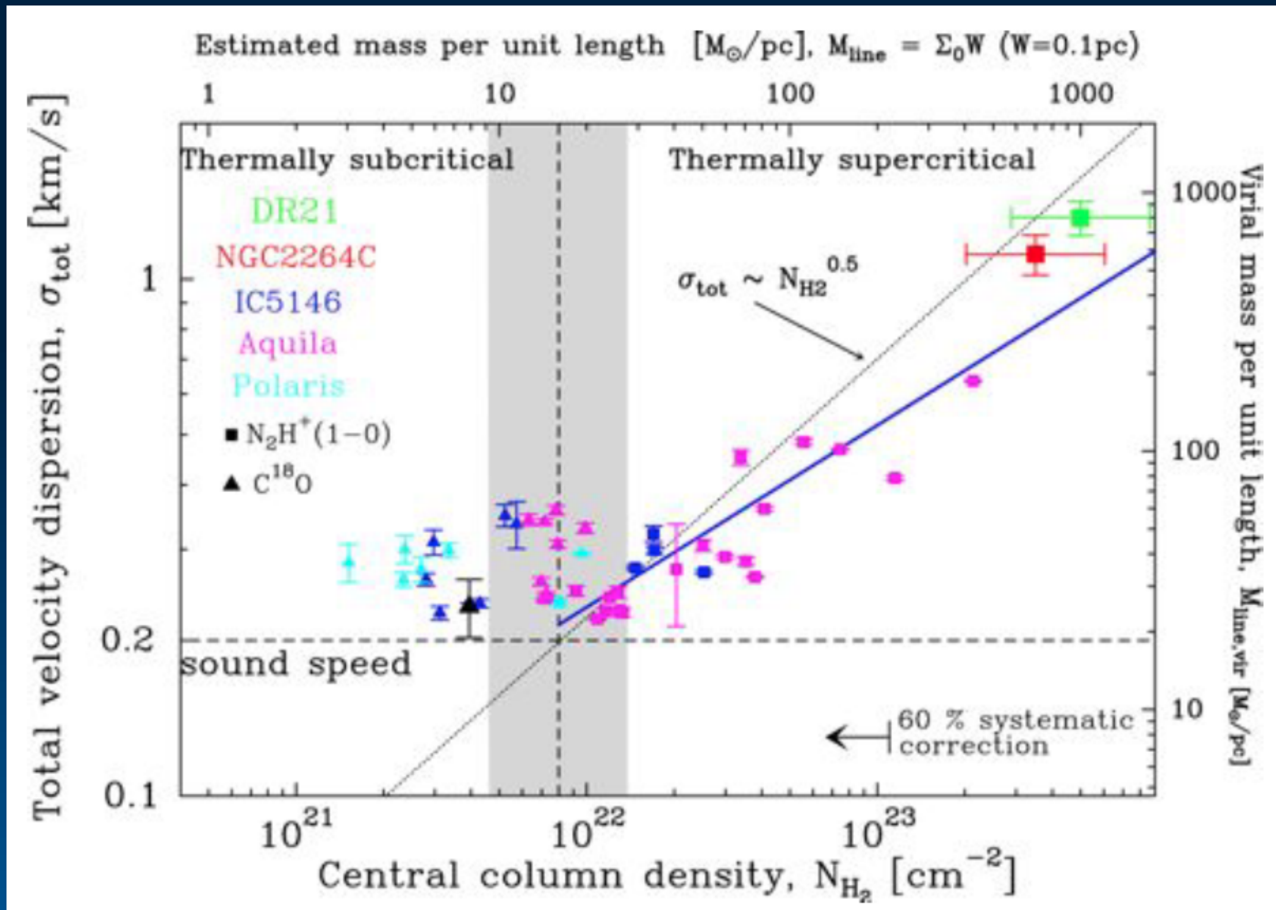
2. Only Dense Filaments Fragment into Cores

- Filament stability depends on **mass per unit length** M_{line} (cf. Inutsuka & Miyama 1997)
- unstable if $M_{line} > M_{line,\,crit} = 2c_s^2/G \sim 16\ M_\odot/pc$ at 10 K
- networks of filaments form via **turbulence**
- filaments at $\boldsymbol{A_V > 6}$ are dense enough to fragment into cores (expl. extinction threshold)



André et al.; Könyves et al. (2010); GBS

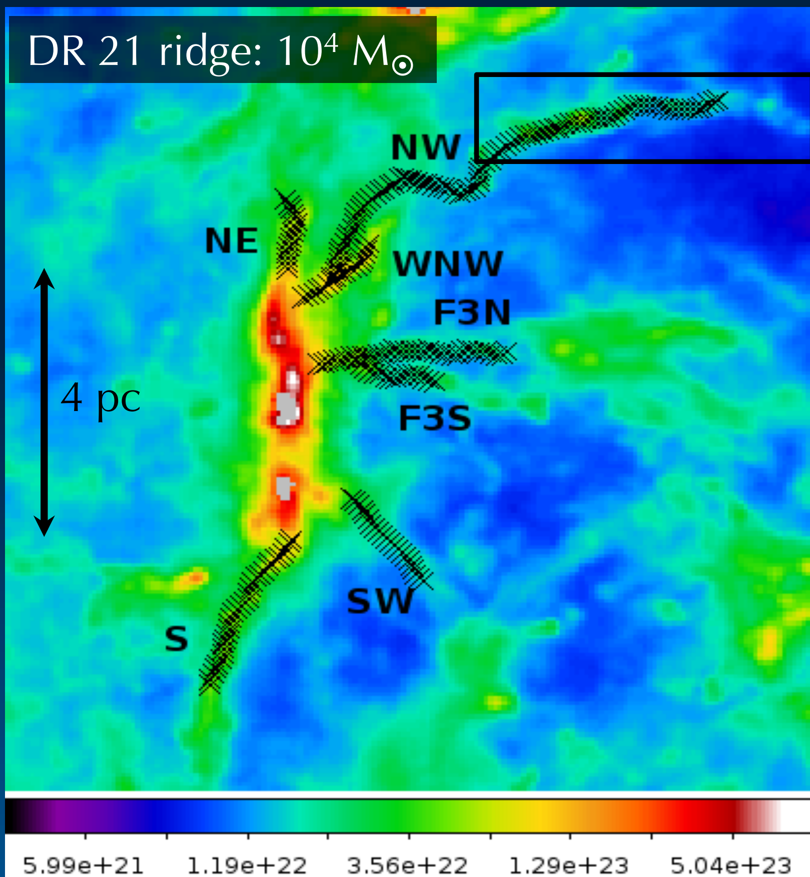
Evidence of Supercritical Filament Accretion?

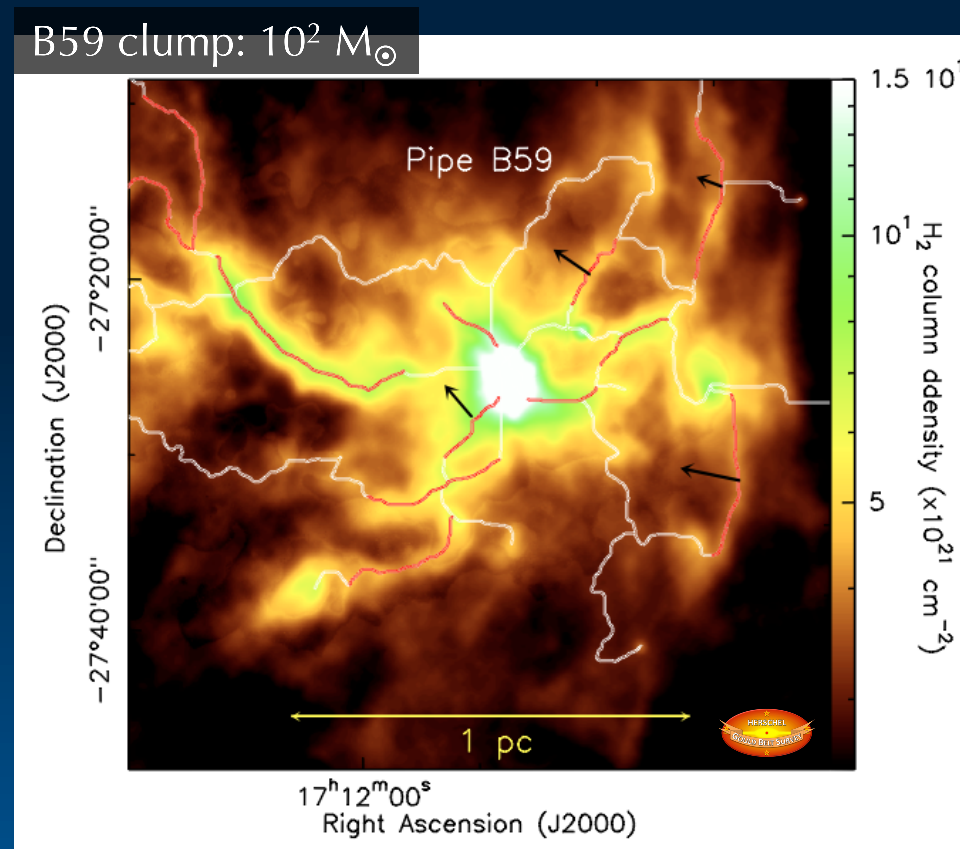


- thermally subcritical filaments have trans-sonic dispersions
- thermally supercritical filaments have larger dispersions... not turbulent motions but background material accretion?

Arzoumanian et al. (2013)

Clusters form at Intersections of Filaments



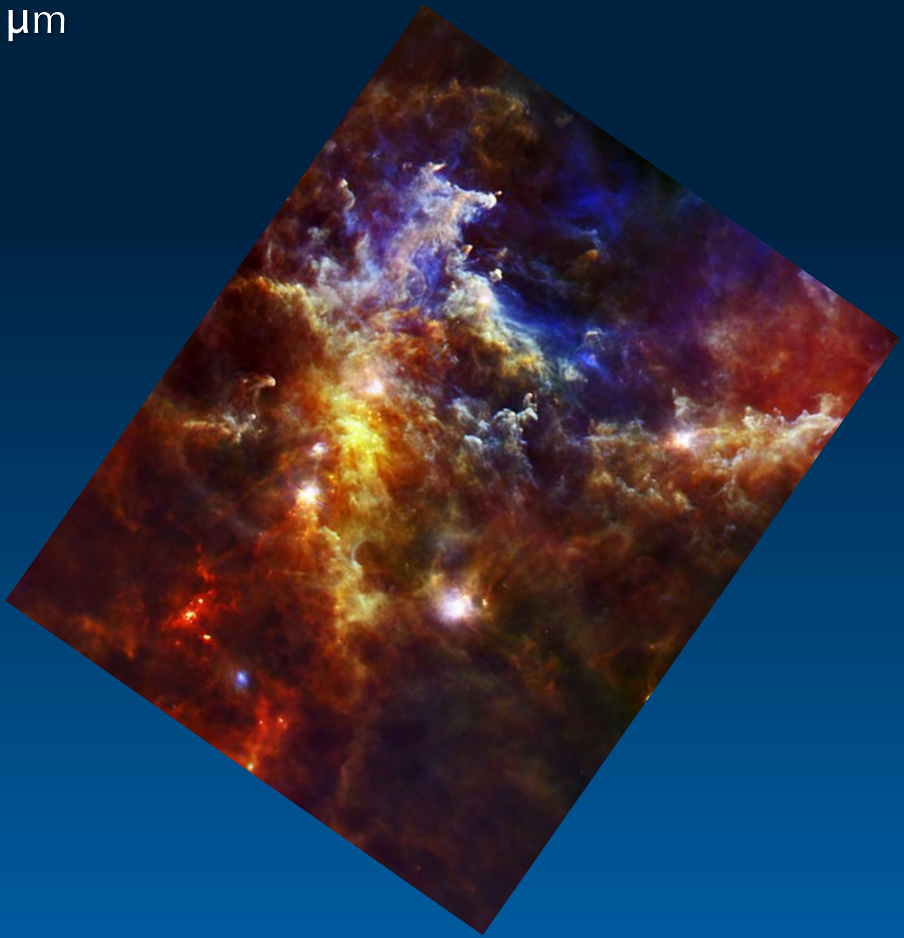


- ridges formed and fed by sub-filament merging (Hill et al. 2011)
- sub-filaments also surround (feed?) dominant clump in Pipe Nebula

Hennemann et al. (2012), Marston et al. (2013), in prep.; HOBYS; Peretto et al. (2012); GBS

Filament Intersections: Origins of Clusters

Rosette Molecular Cloud
70, 160, 250 μm



Schneider et al. (2012); HOBYS

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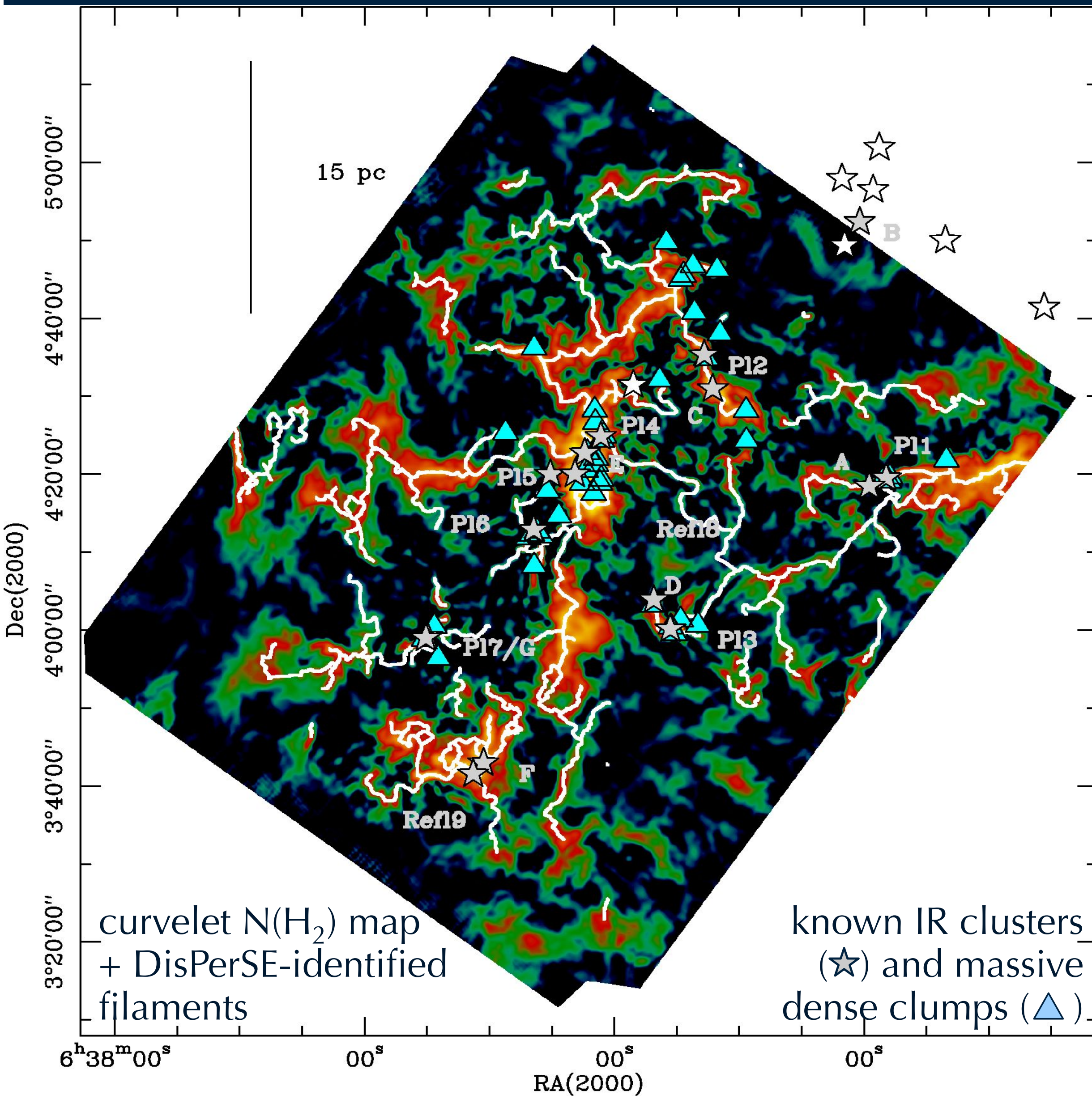
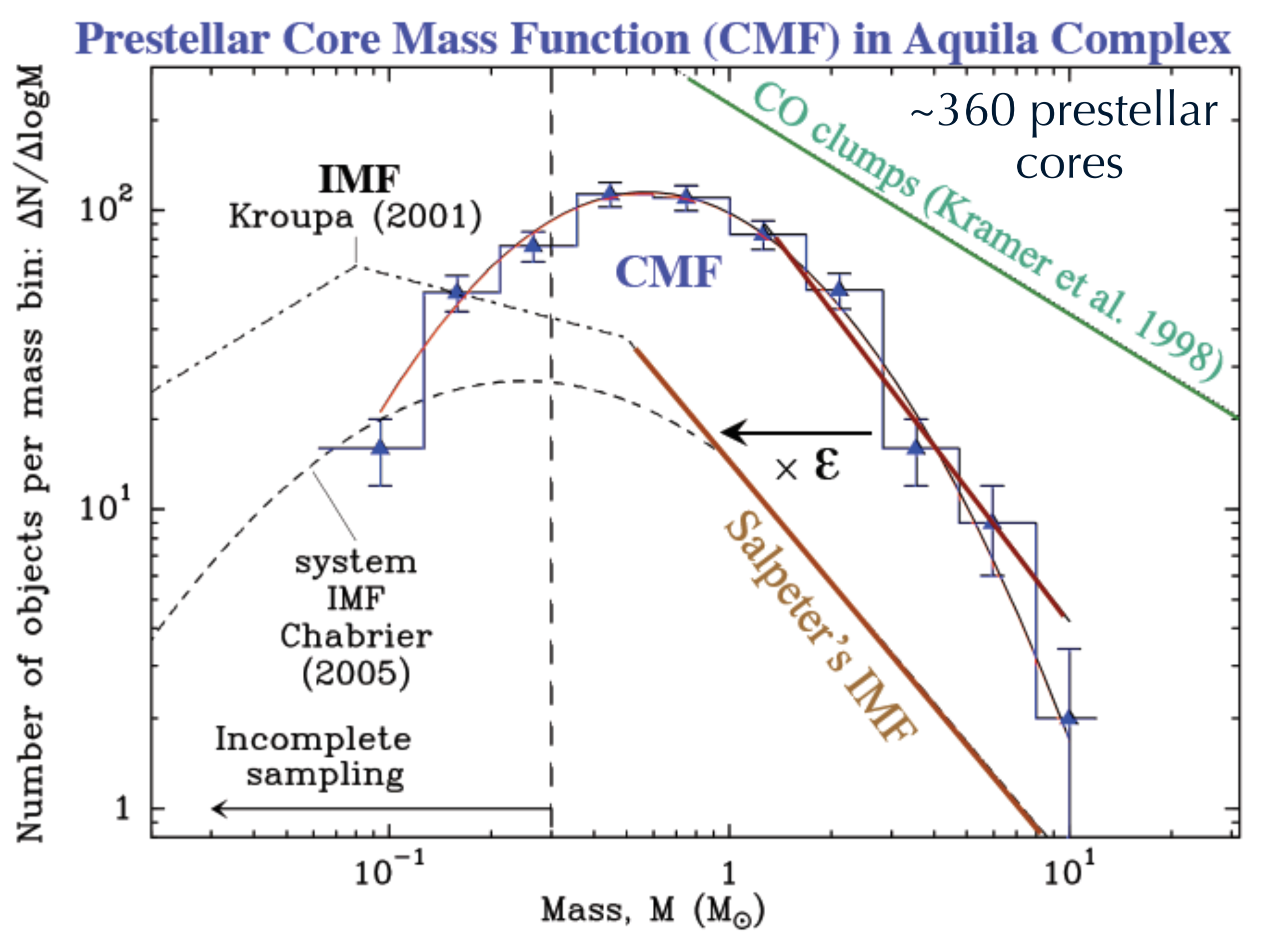


- massive clumps and IR clusters found at filament junctions
- mass flow into junction regions ➔ more clustered star formation

Schneider et al. (2012); HOBYS

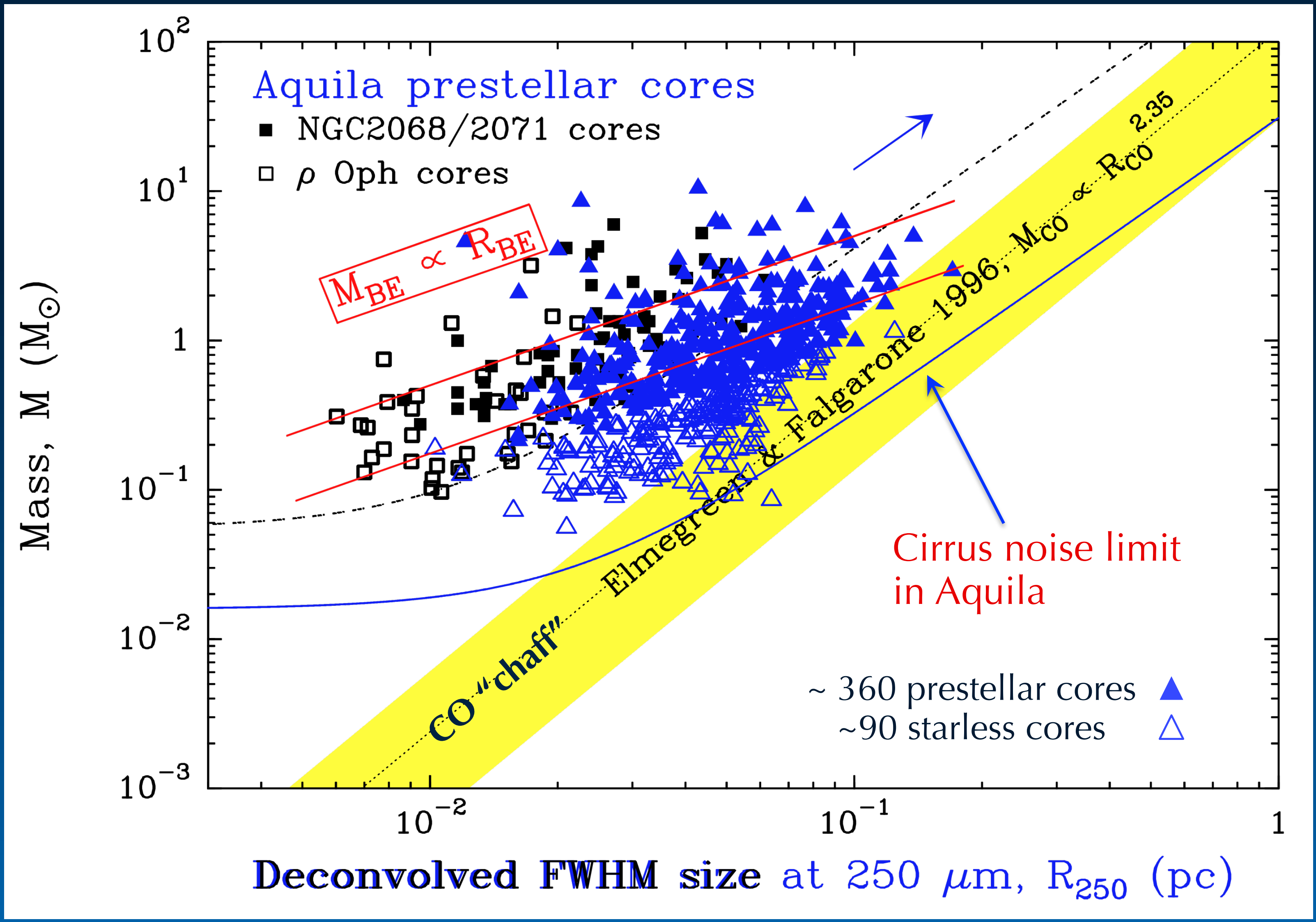
3. The CMF looks like the IMF



- shape of CMF very similar to IMF (ε ≈ 0.3)
- slope of high-mass end ≈ -1.5 ± 0.2 and Salpeter = -1.35

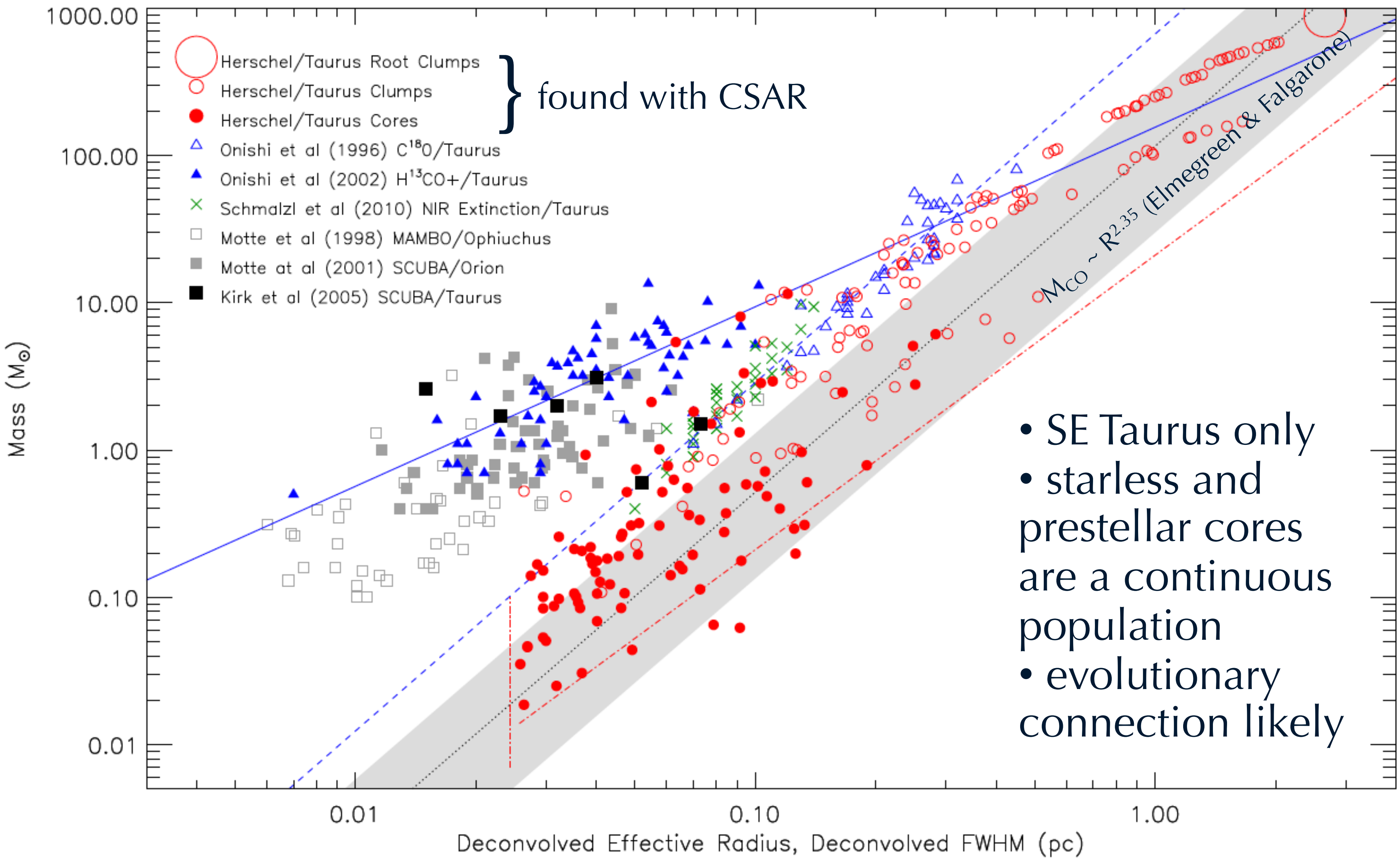
André et al. (2010); GBS

Differentiating Starless and Prestellar Cores



André et al. (2010); GBS

Differentiating Starless and Prestellar Cores

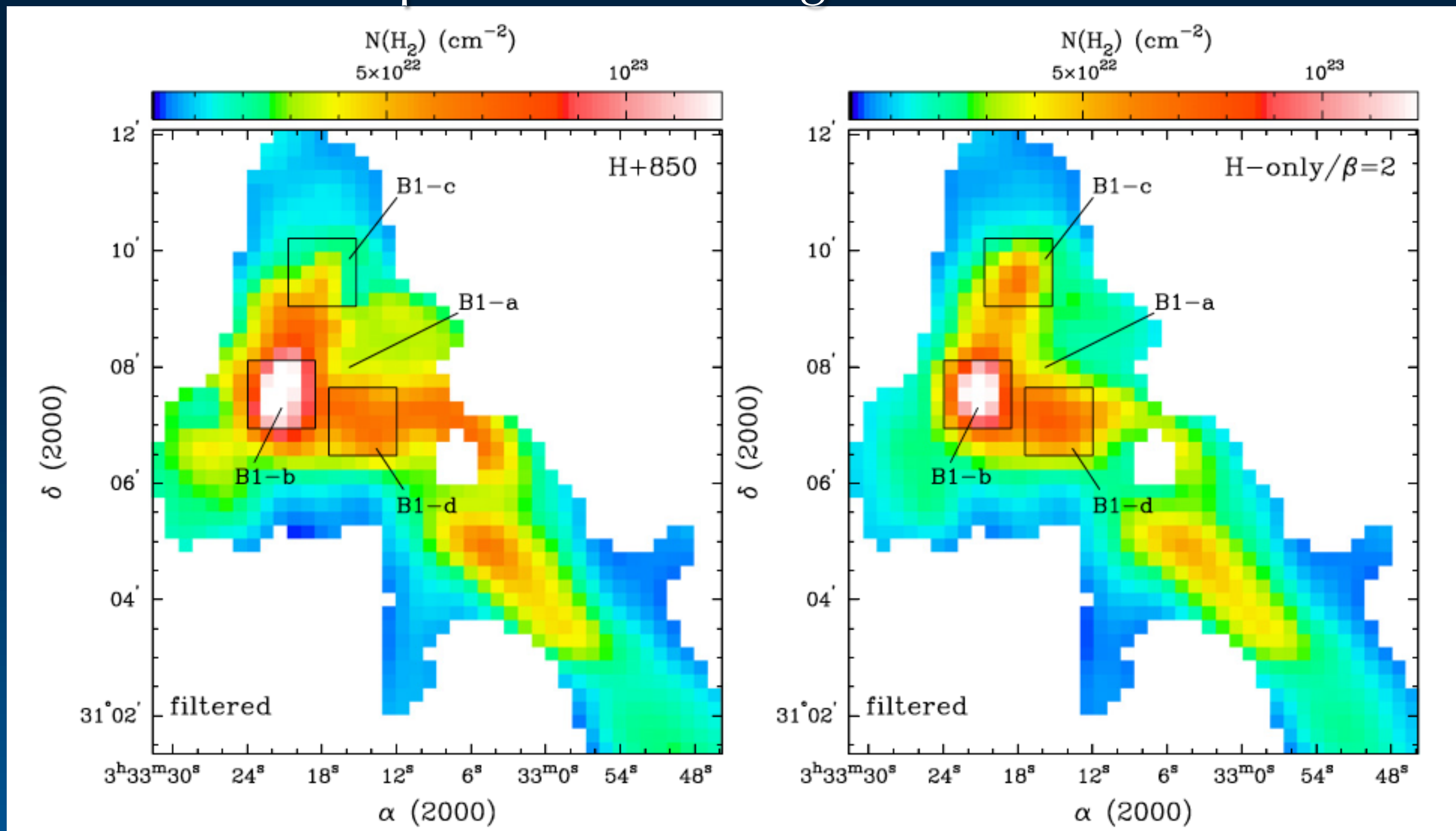


- SE Taurus only
- starless and prestellar cores are a continuous population
- evolutionary connection likely

Kirk et al. (2013); GBS

H+JCMT: Improving Core Mass Estimates

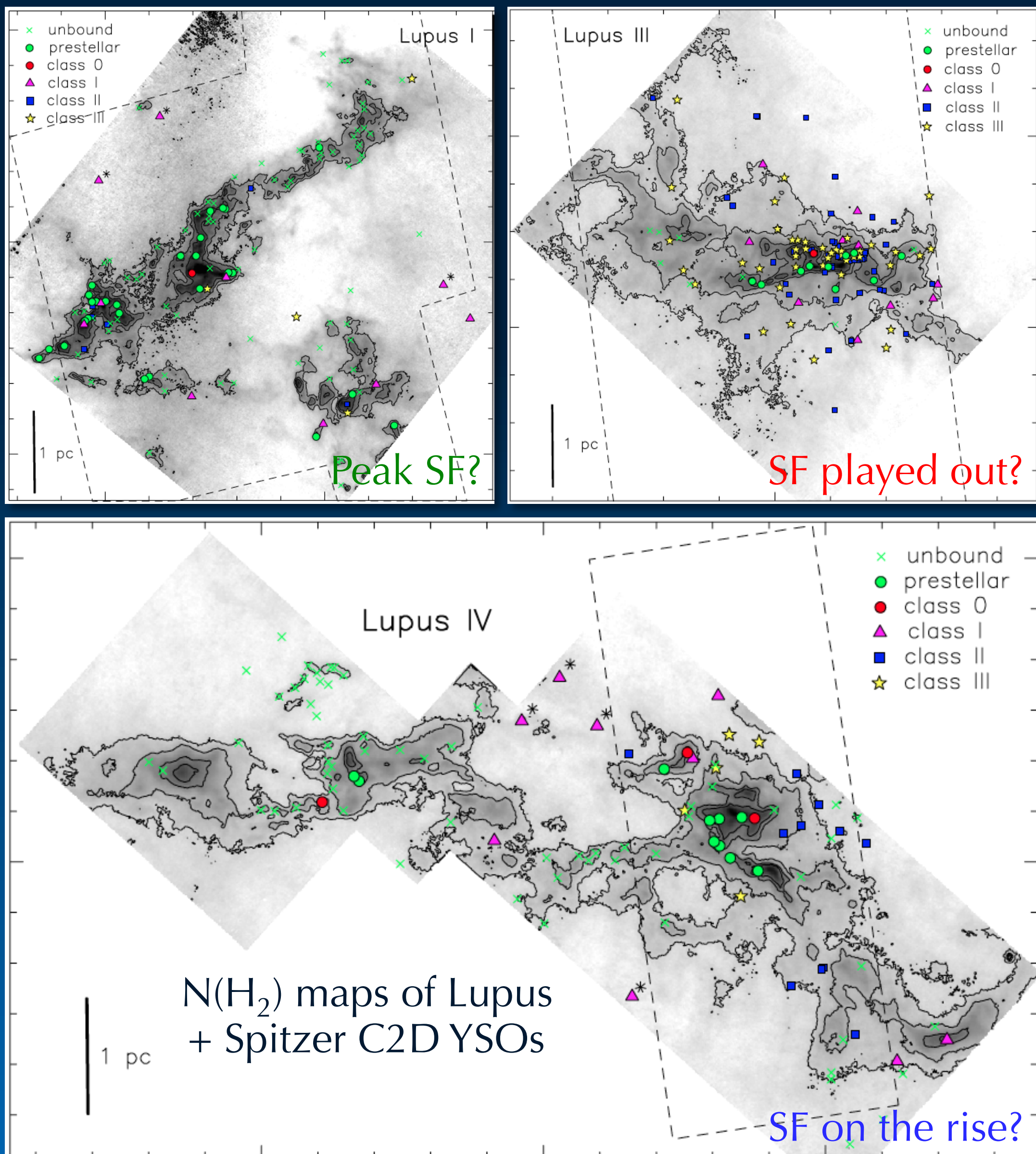
Perseus B1 Clump: effect of adding SCUBA-2 data



- Herschel GBS assuming $\beta = 2$ for core mass calculations
- adding SCUBA-2 850 μm data yields more accurate β but core masses only change <30%

Sadavoy et al. (2013); GBS

H+c2d: Tracing Star Formation Histories



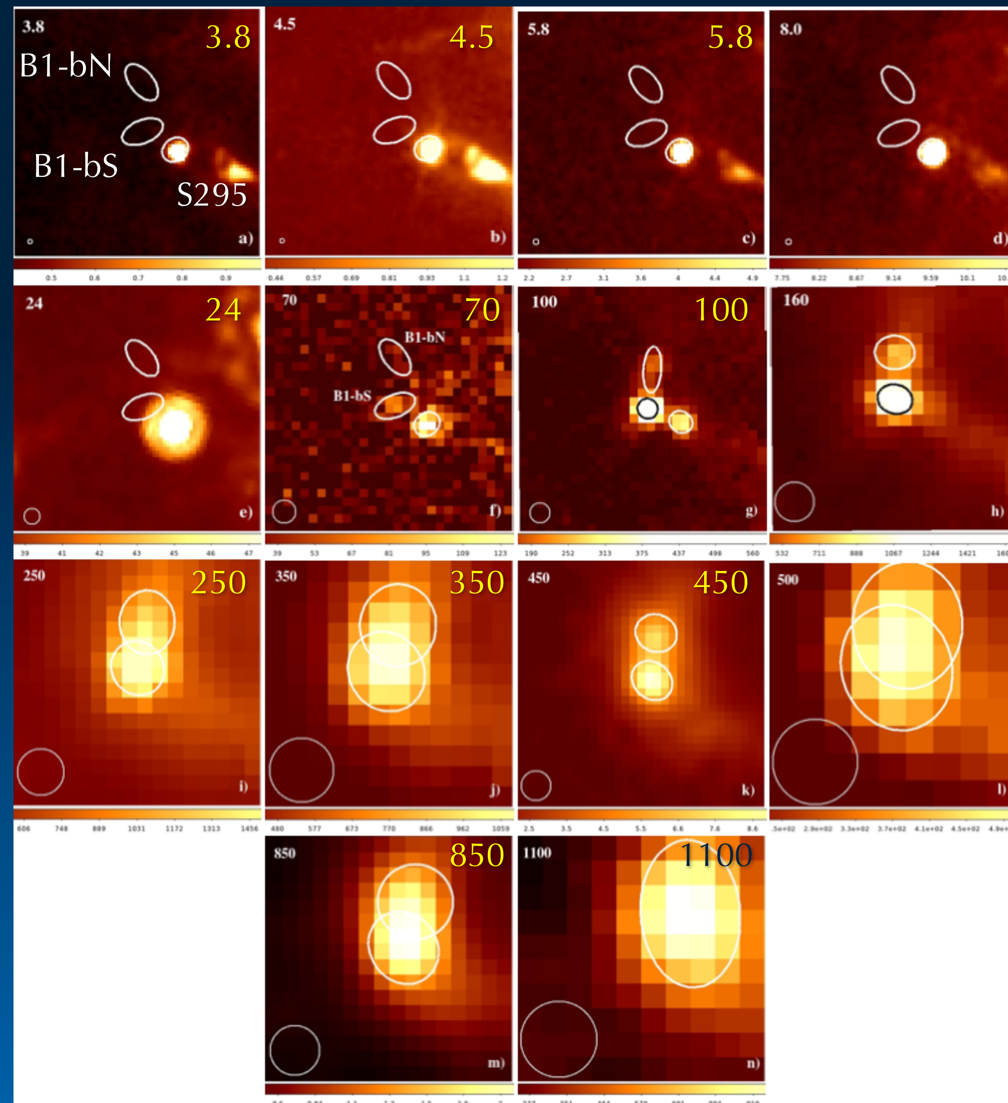
Given source counts and expected lifetimes (from c2d):

- Lupus I has increasing SFR, high columns, SF peaking?
- Lupus III has decreasing SFR, large core to YSO ratio, SF ending?
- Lupus IV has increasing SFR, few prestellar cores, SF not yet at peak?

Rygl et al. (2013),
also Sadavoy et al. (2013); GBS

H+c2d: a First Hydrostatic Core in Per B1-b?

- Omukai (2007):
  FHSC SED deviates from greybody at $\lambda \leq 200\ \mu m$
- Commerçon et al. (2012):
  1 $M_\odot$ FHSC should be
  - detected $\lambda \geq 70\ \mu m$
  - undetected $\lambda < 70\ \mu m$
- B1-bS *only* source of 40 (in Perseus West) meeting Commerçon criteria
- B1-bN like B1-bS *except* undetected at 70 μm



Pezzuto et al. (2012)

Summary

• Star formation in a molecular cloud appears related to the amount of dense gas within the cloud

• **filaments are ubiquitous, a key aspect of cloud substructure**

• filaments have common width **~ 0.1 pc**, possibly related to origin in turbulent shocks

• **if dense enough, these filaments fragment into star-forming cores**

• where filaments intersect, clusters may form due to increased access to dense gas reservoirs

• **CMFs look like IMF more than ever, work is ongoing**

• comparisons with Spitzer c2d data can lead to estimates of SF histories, reveal FHSC candidates