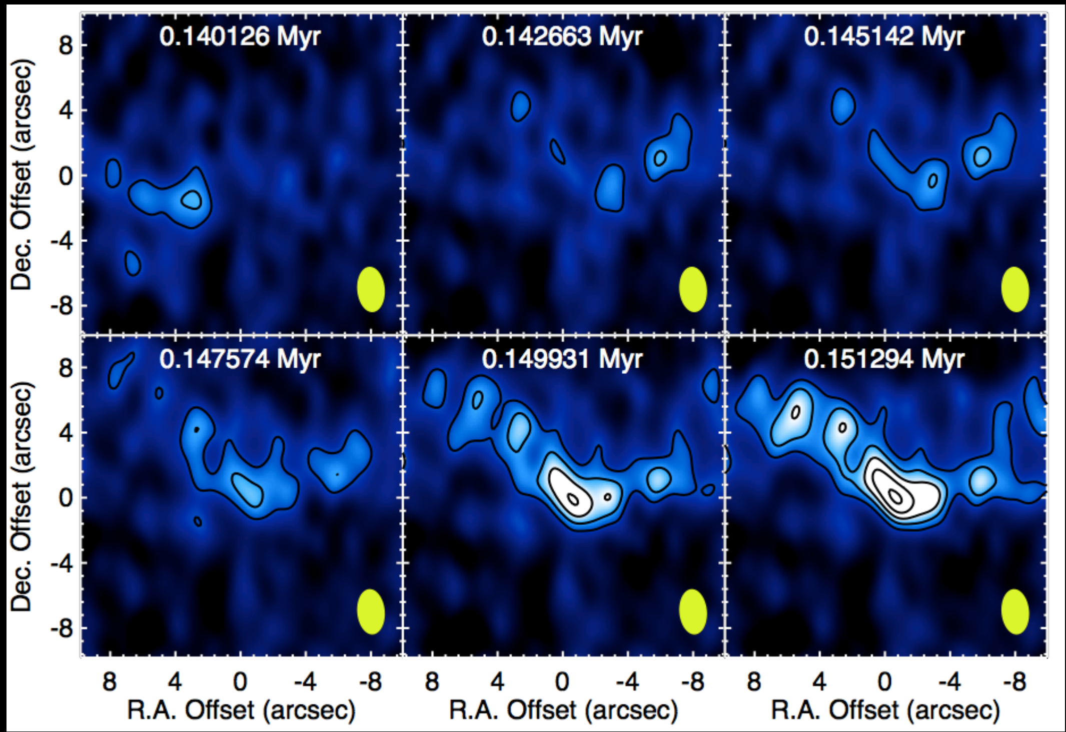
A Complete Census of Dense Cores in Chamaeleon I

Results from an ALMA Cycle 1 Survey



John Tobin, Leiden Observatory

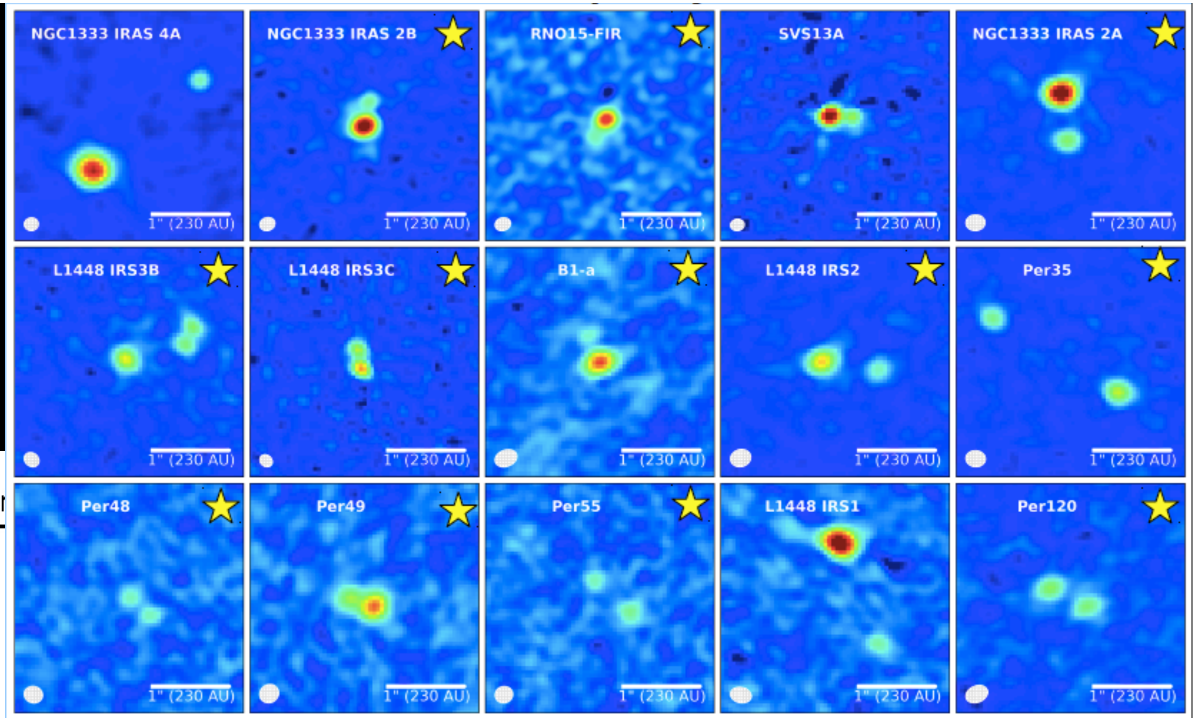
Mike Dunham (CfA), Scott Schnee (NRAO), Stella Offner (UMass Amherst), Jaime Pineda (ETH), Héctor Arce (Yale), Tyler Bourke (SKA), Xuepeng Chen (PMO), James Di Francesco (HIA), Doug Johnstone (HIA), Daniel Price (Monash)

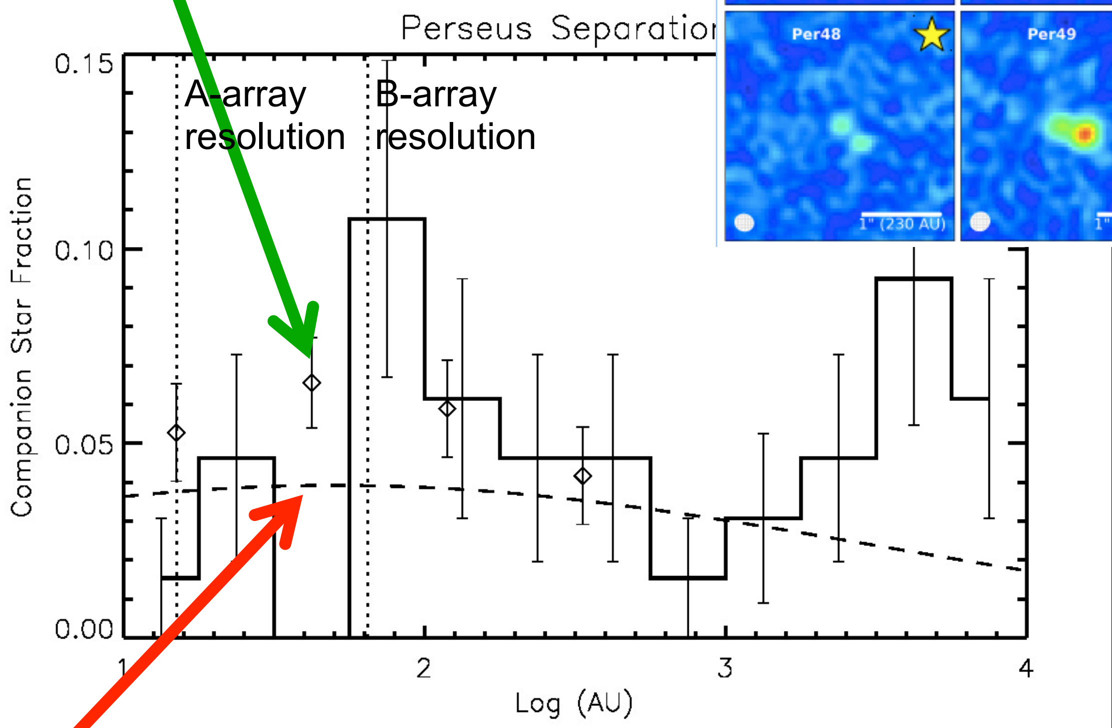
Star Formation Across Space and Time
Noordwijk, Netherlands
November 11, 2014

Multiplicity

T Tauri stars (Patience et al. 2002)

Tobin et al. (in prep)





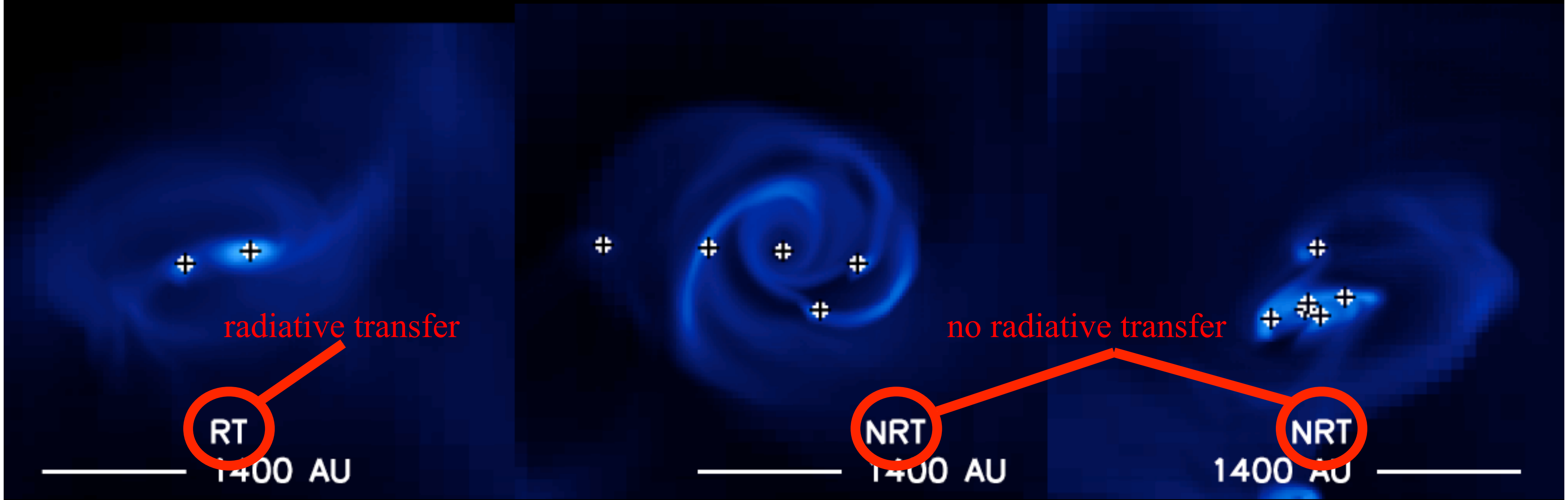
Solar-type field stars (Raghavan et al. 2010)

Multiplicity is common in protostars, and declines with evolutionary stage

Origins of Multiplicity?

Turbulent Fragmentation

Offner et al. (2010)



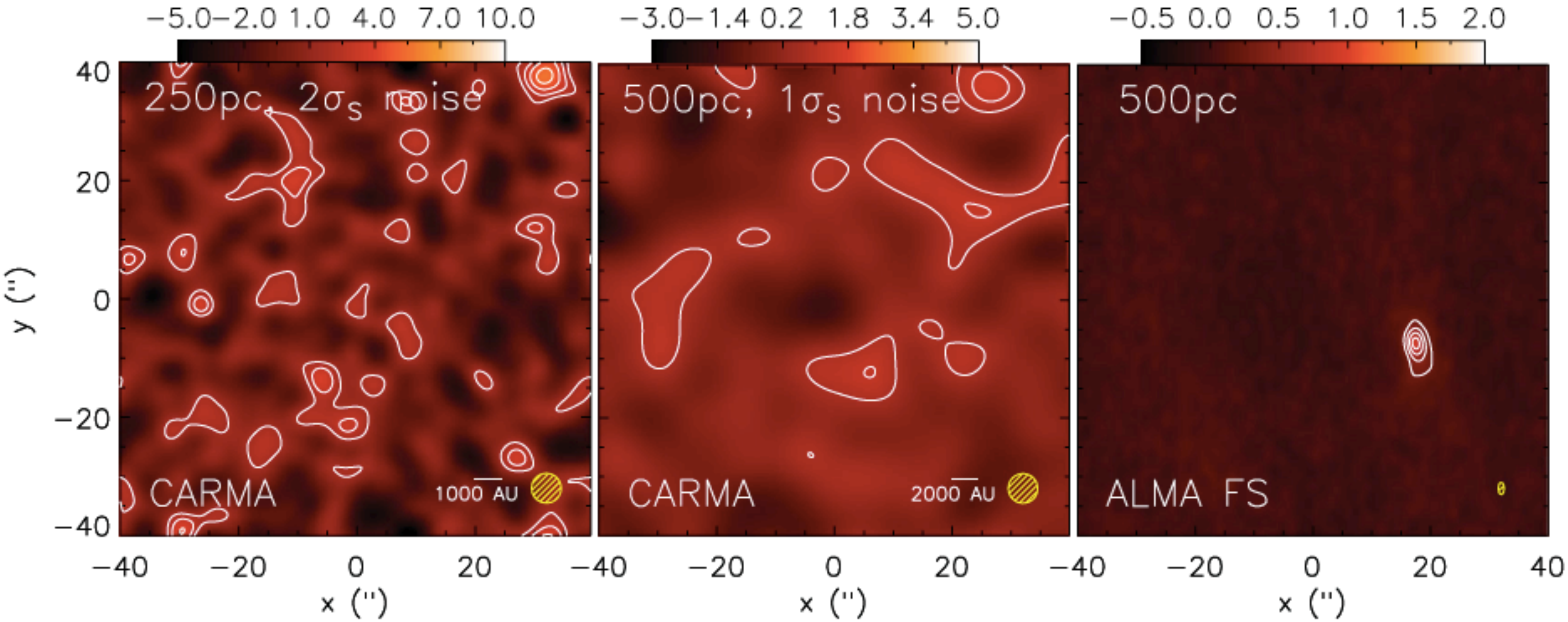
<u>Predictions of Simulations (Offner et al. 2010):</u>
Radiative feedback promotes disk stability
Turbulent fragmentation is the dominant channel for multiplicity
Fragmentation begins in the starless phase

Turbulent Fragmentation

Schnee et al. (2010) - CARMA observations of 9 starless cores in Perseus, all undetected

Consistent with predictions of turbulent fragmentation

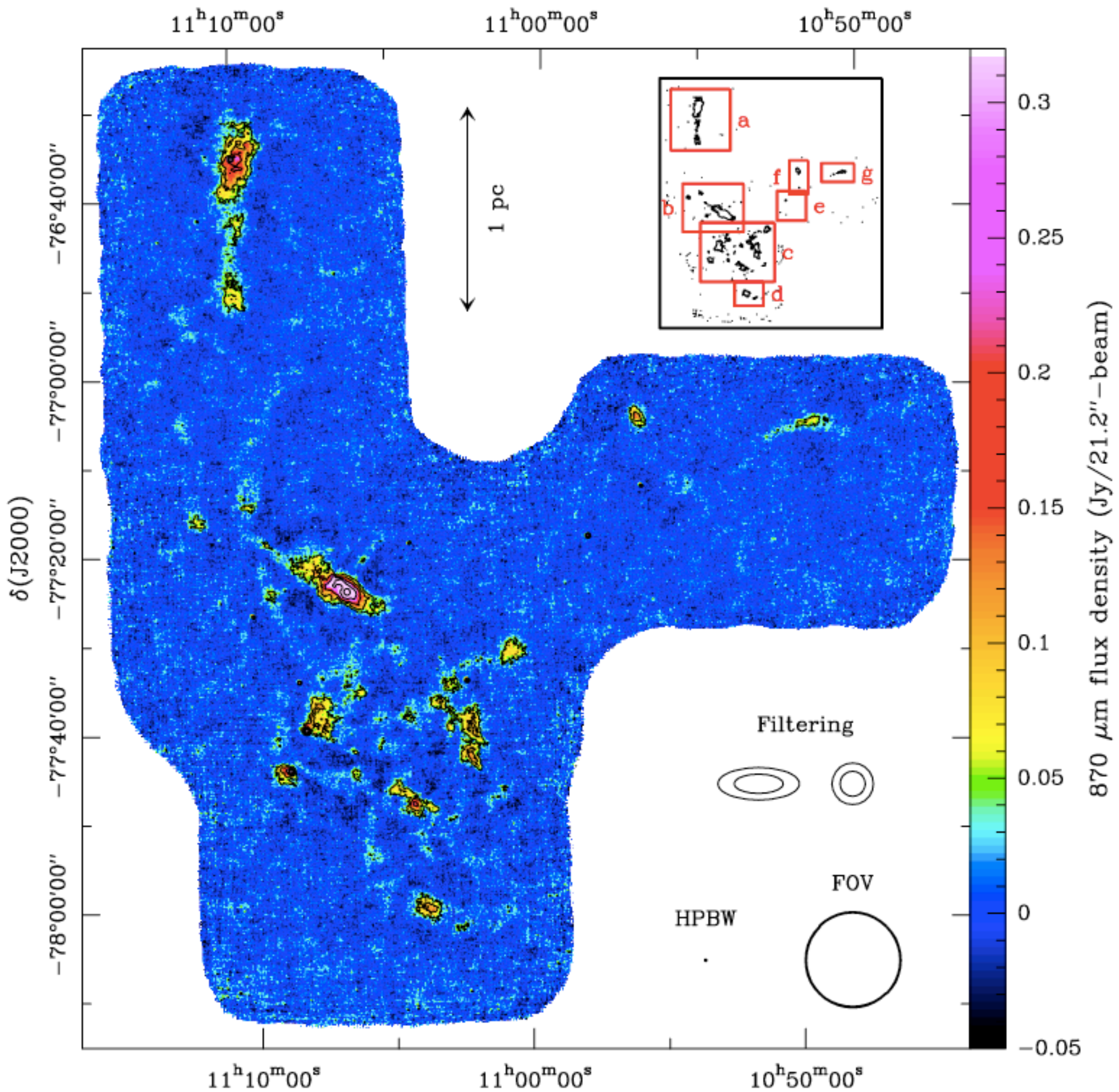
ALMA should be capable of detecting fragmenting starless cores



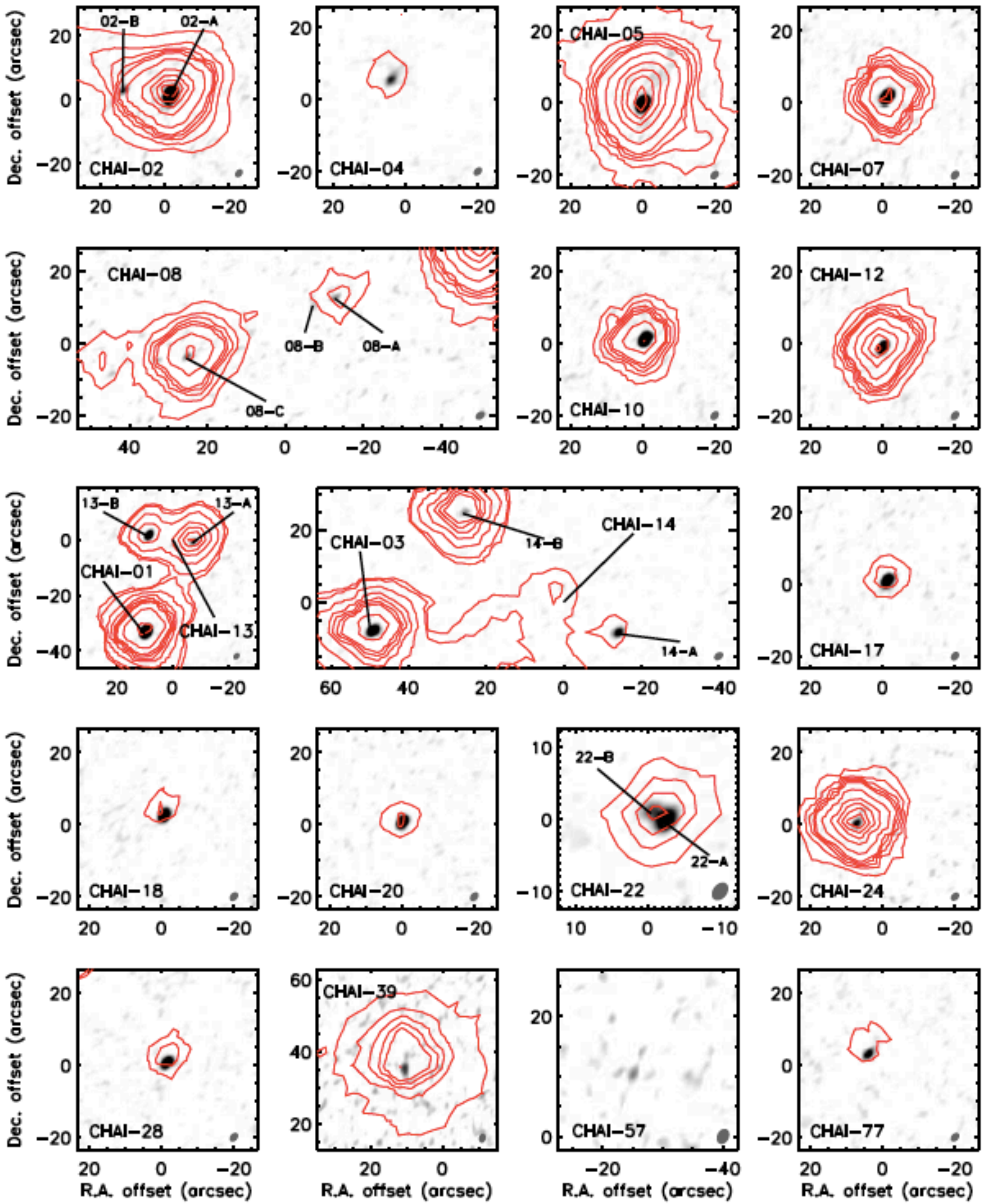
Offner et al. (2012); see also Mairs et al. (2014)

ALMA 3 mm Survey of Chamaeleon I

- Cycle 1 observations of 73 starless and protostellar cores in Chamaeleon I (d = 150 pc)
- Complete population of cores selected from single-dish submm LABOCA survey
- Band 3 (3 mm) continuum + CO (1-0) single pointings
  ~3" resolution
  rms = 0.1 mJy/beam
  ~ 2 x 10^{-3} M_{sun}



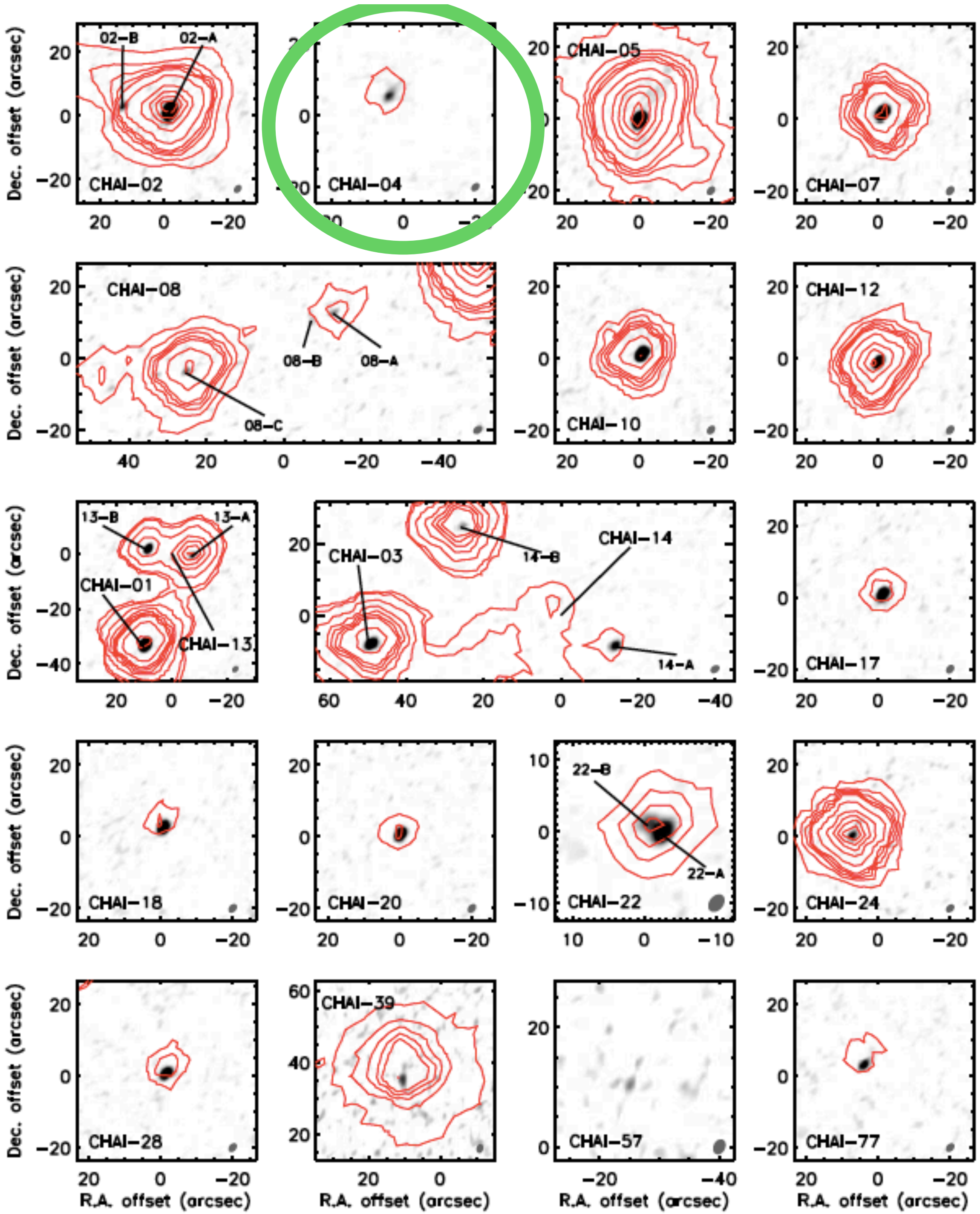
Belloche et al. (2011)



Detection Statistics

- 26 continuum detections
  1 Class 0 / FHSC
  6 Class I in 4 cores
  (2 multiple, 1 new)
  17 flat-spectrum / Class II
  2 new
- All known Class 0/I detected
- One new Class I (02B), unresolved by Herschel
- New sources are not associated with cores
  extra-galactic?

Grayscale: ALMA 106 GHz Continuum
Red Contours: *Herschel* 70 um continuum
(GB Survey, Winston et al. 2012)
Dunham et al. (in prep)



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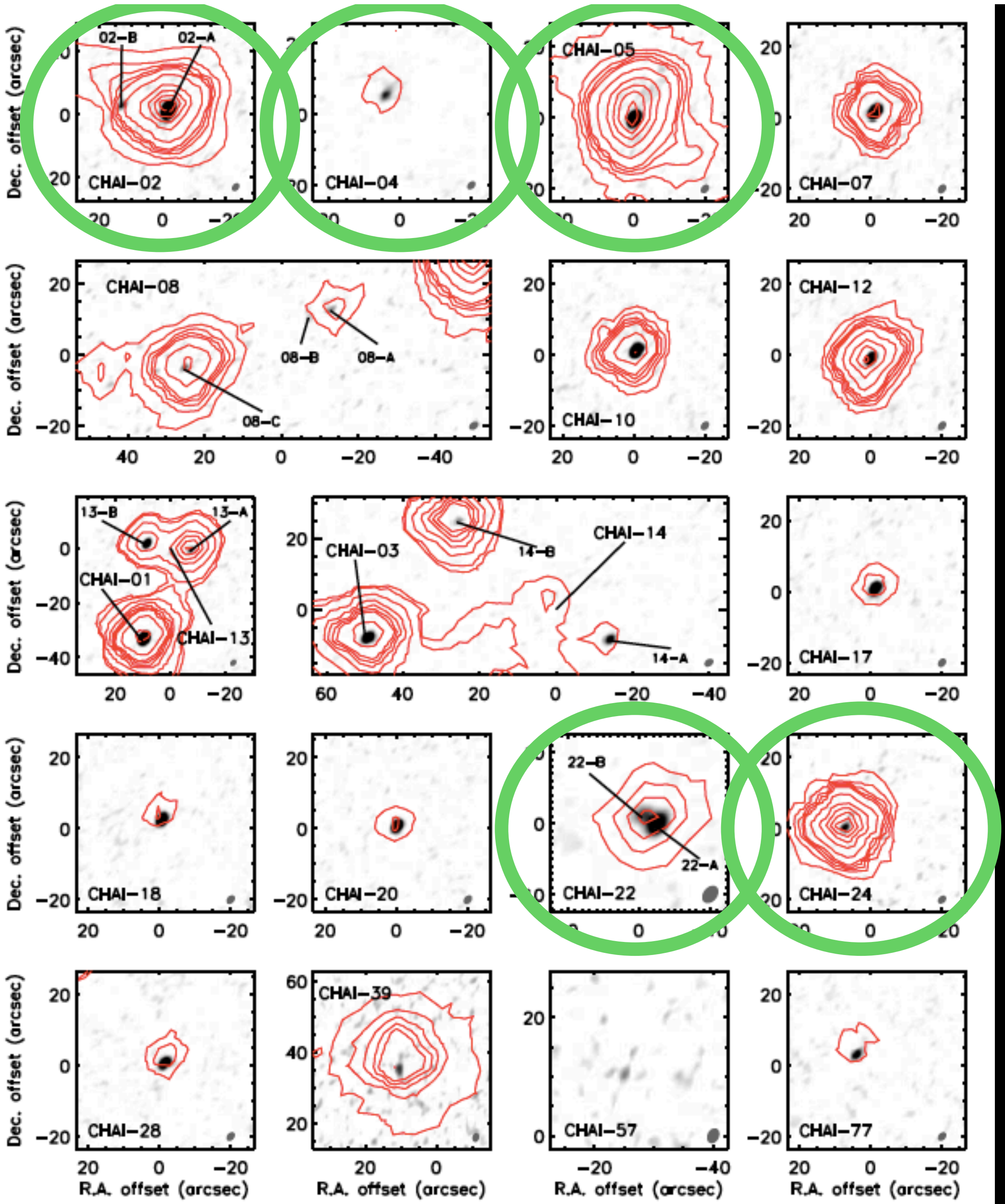

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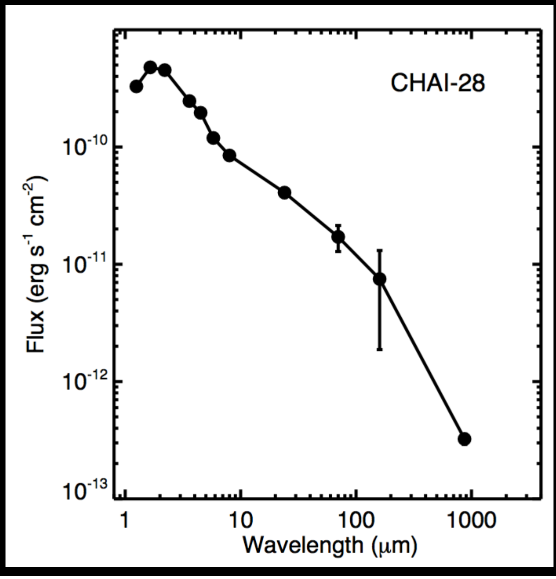
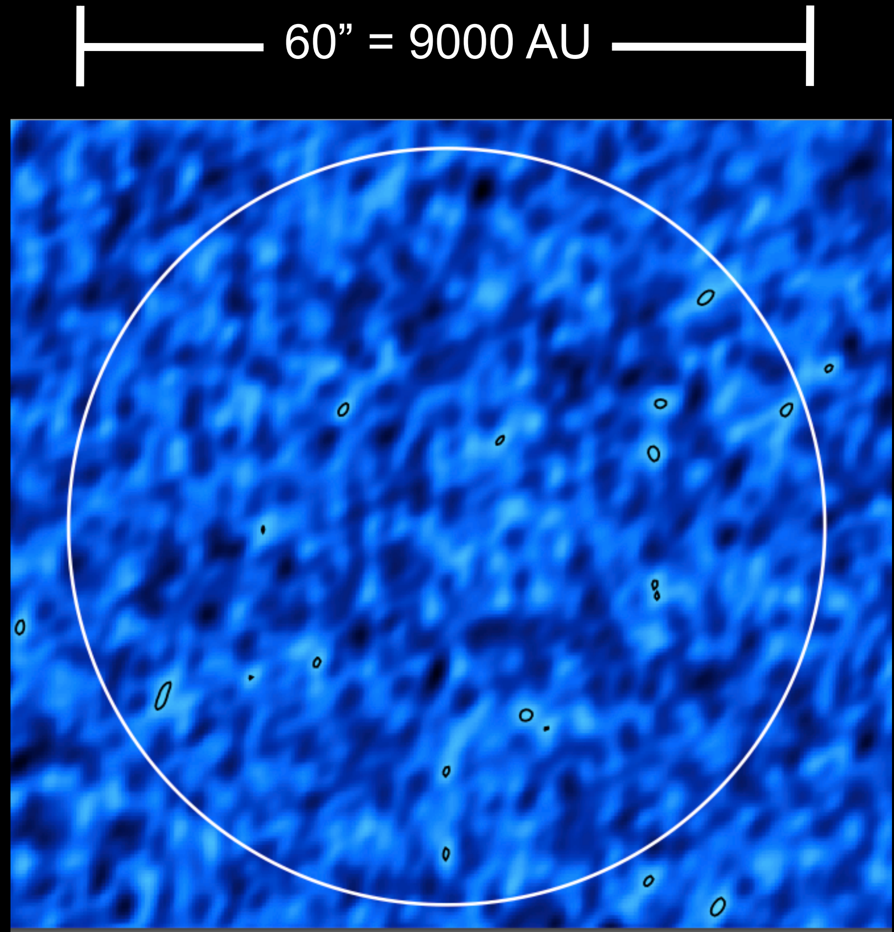
Starless Cores

73 LABOCA cores
– 1 Class 0 core
– 4 Class I cores
– 11 disk detections
– 1 disk non-detection

56 starless cores

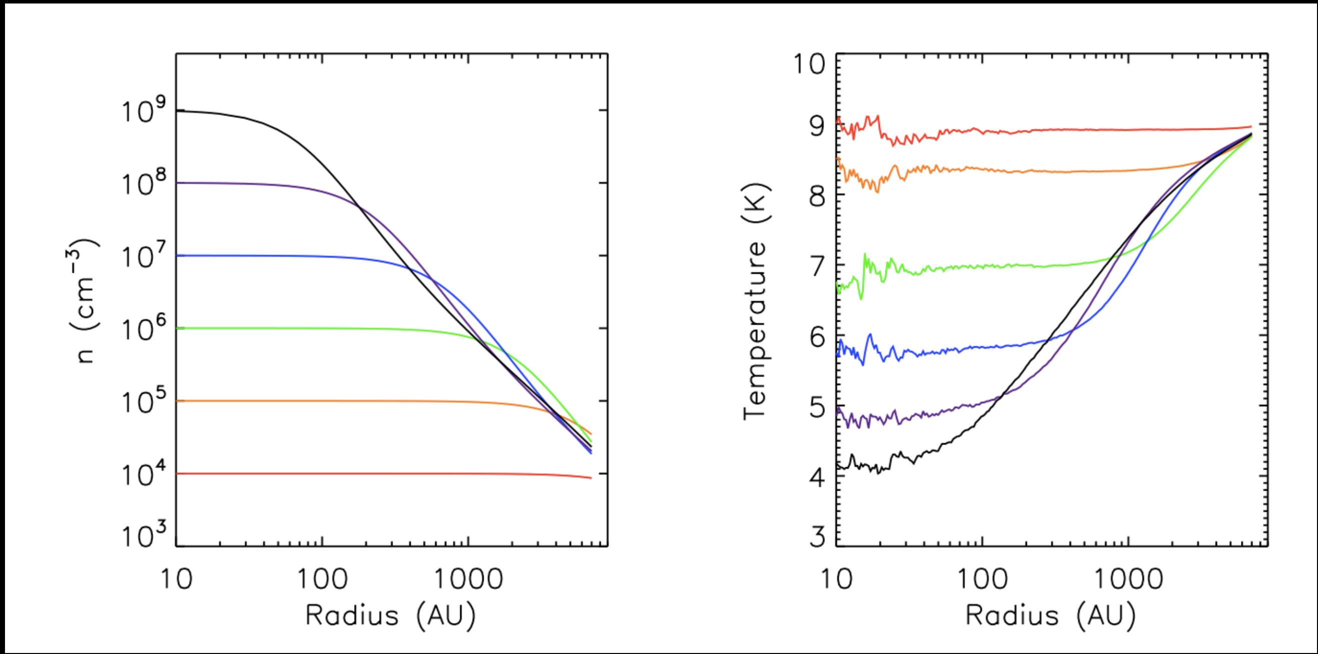




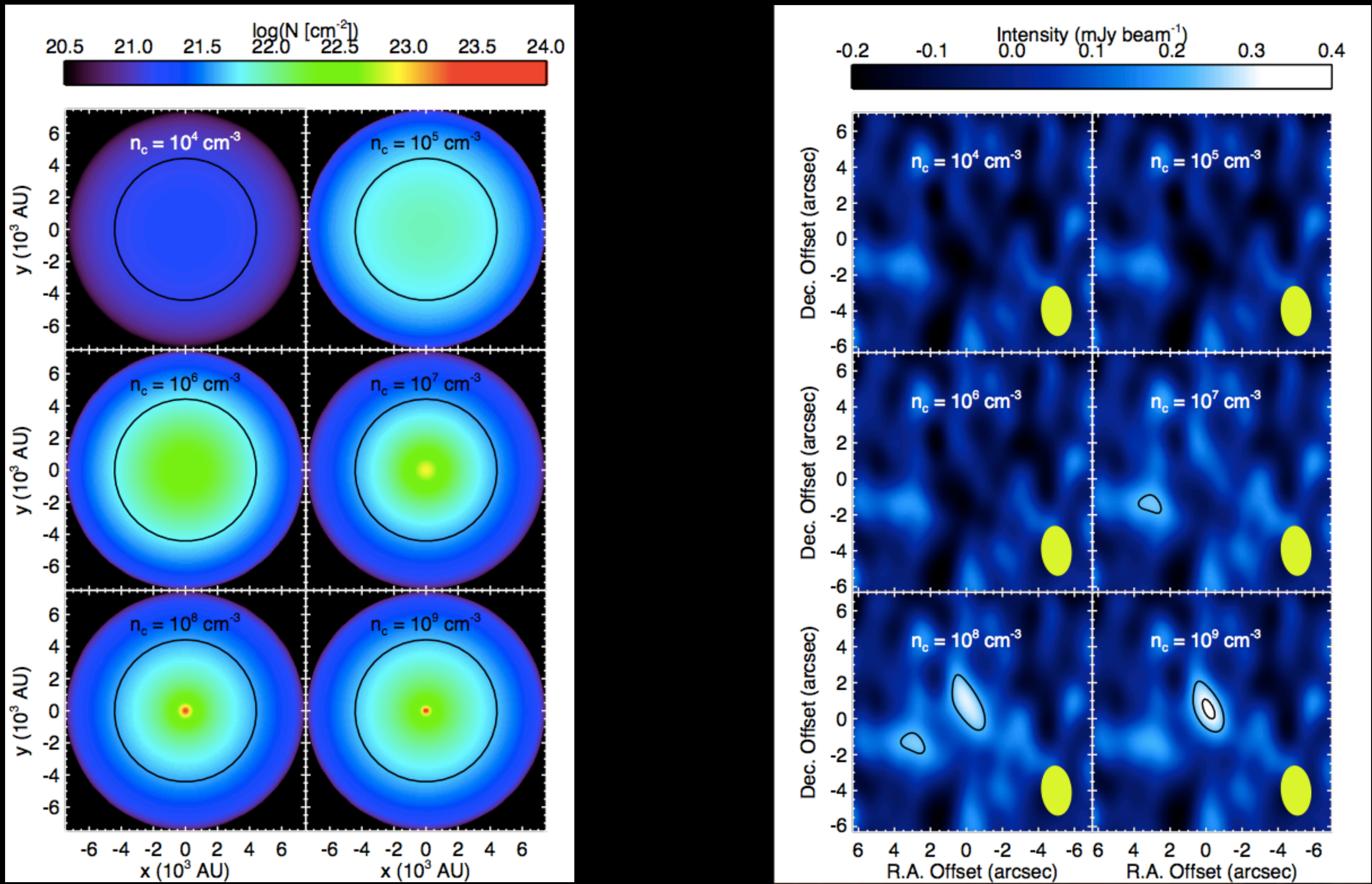
Dunham et al. (in prep)

Simulated Starless Cores: Bonnor-Ebert Spheres

Generate 106 GHz images of Bonnor-Ebert spheres (RADMC-3D)
Central density = $10^4 - 10^9$ cm^{-3}
Heated externally by ISRF attenuated by A_V = 3
Simulate ALMA Cycle 1 observations (same beam and rms)



Simulated Starless Cores: BE Spheres

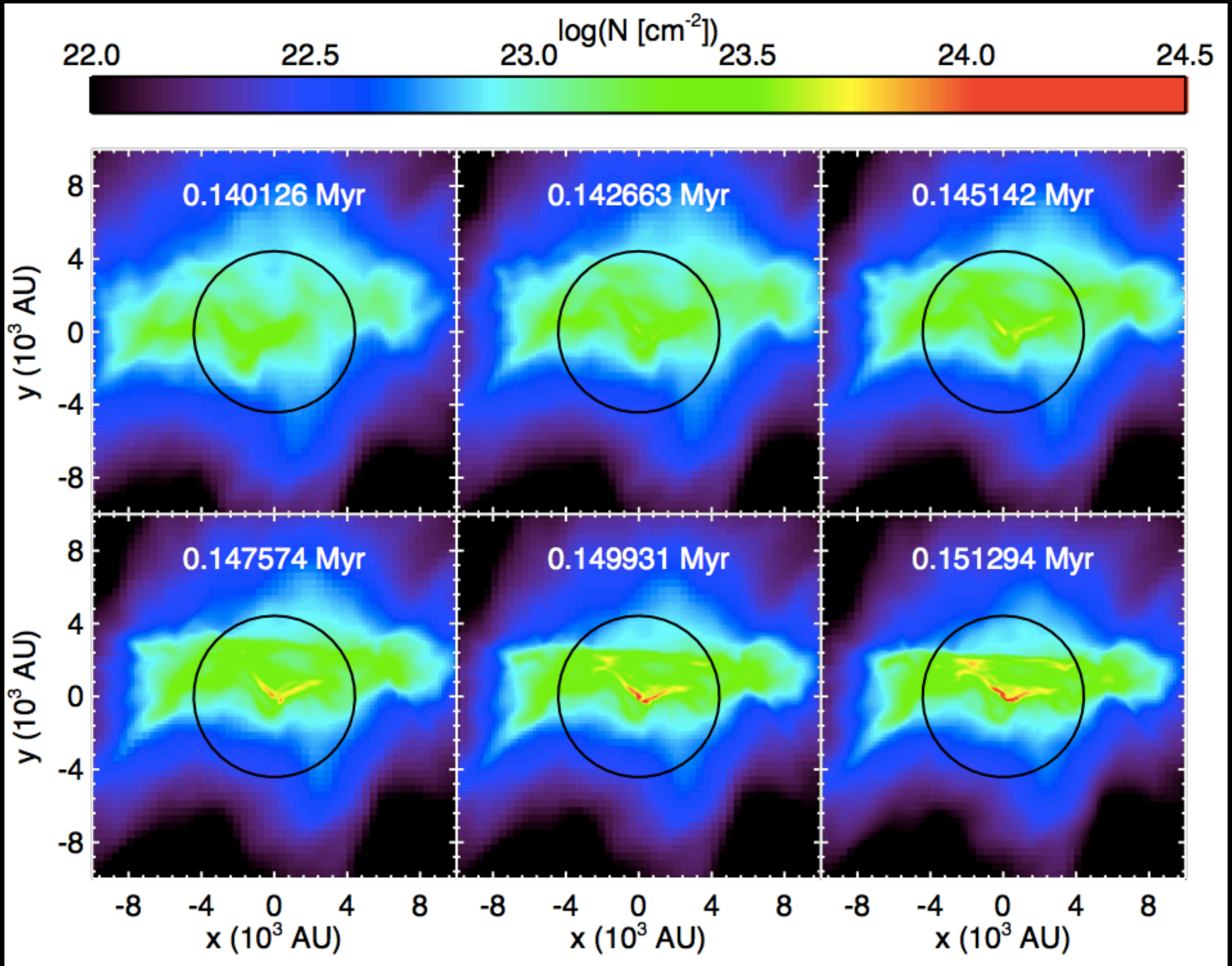


Dunham et al. (in prep)

>3 sigma detections for $n_{central}$ >= 10^8 cm^{-3}

Simulated Starless Cores: MHD Simulations

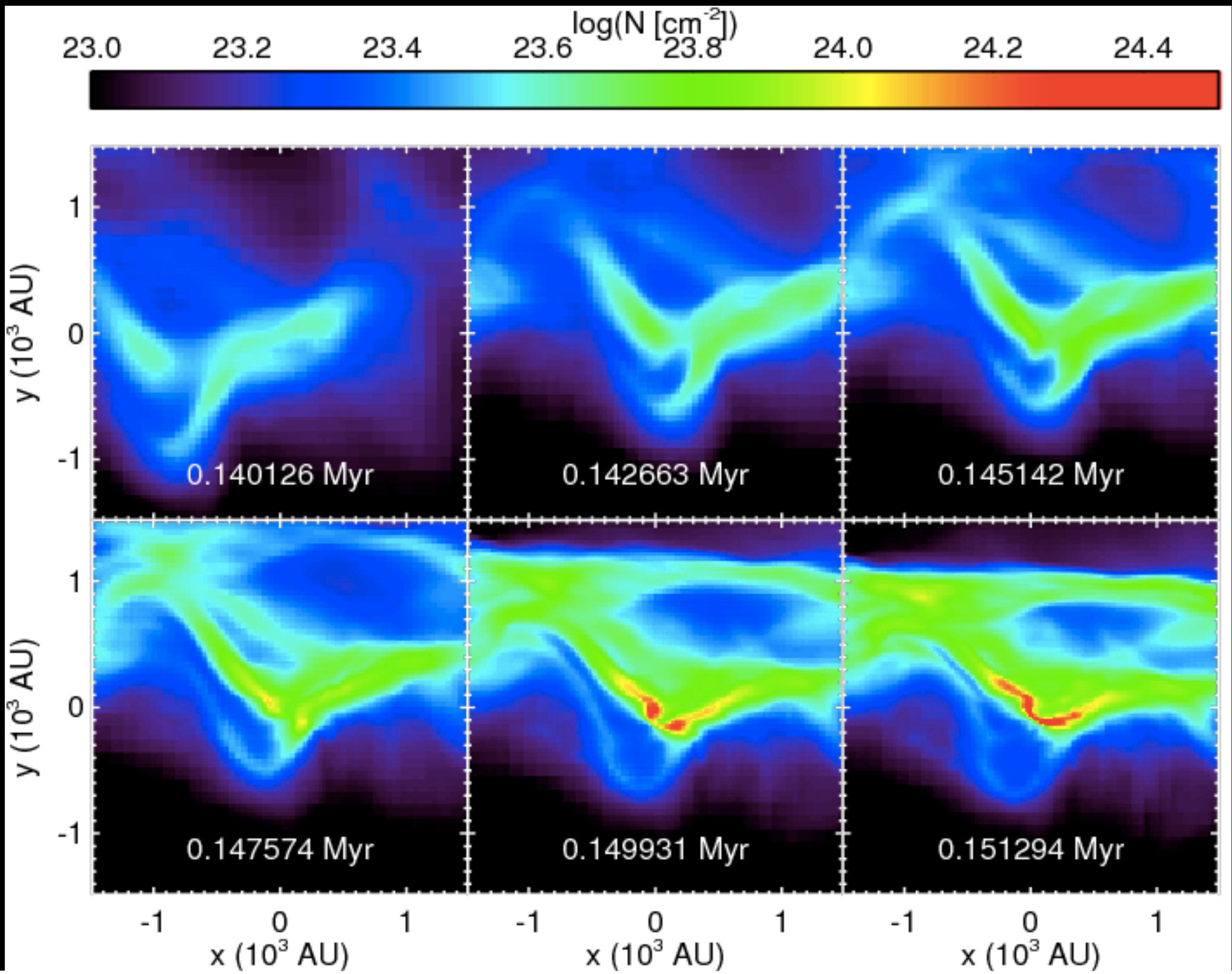
Offner & Arce (2014) + magnetic fields
M = 4 M_{sun}, L ~ 0.065 pc, n = 6 x 10^4 cm^{-3}



Dunham et al. (in prep), Offner et al. (in prep)

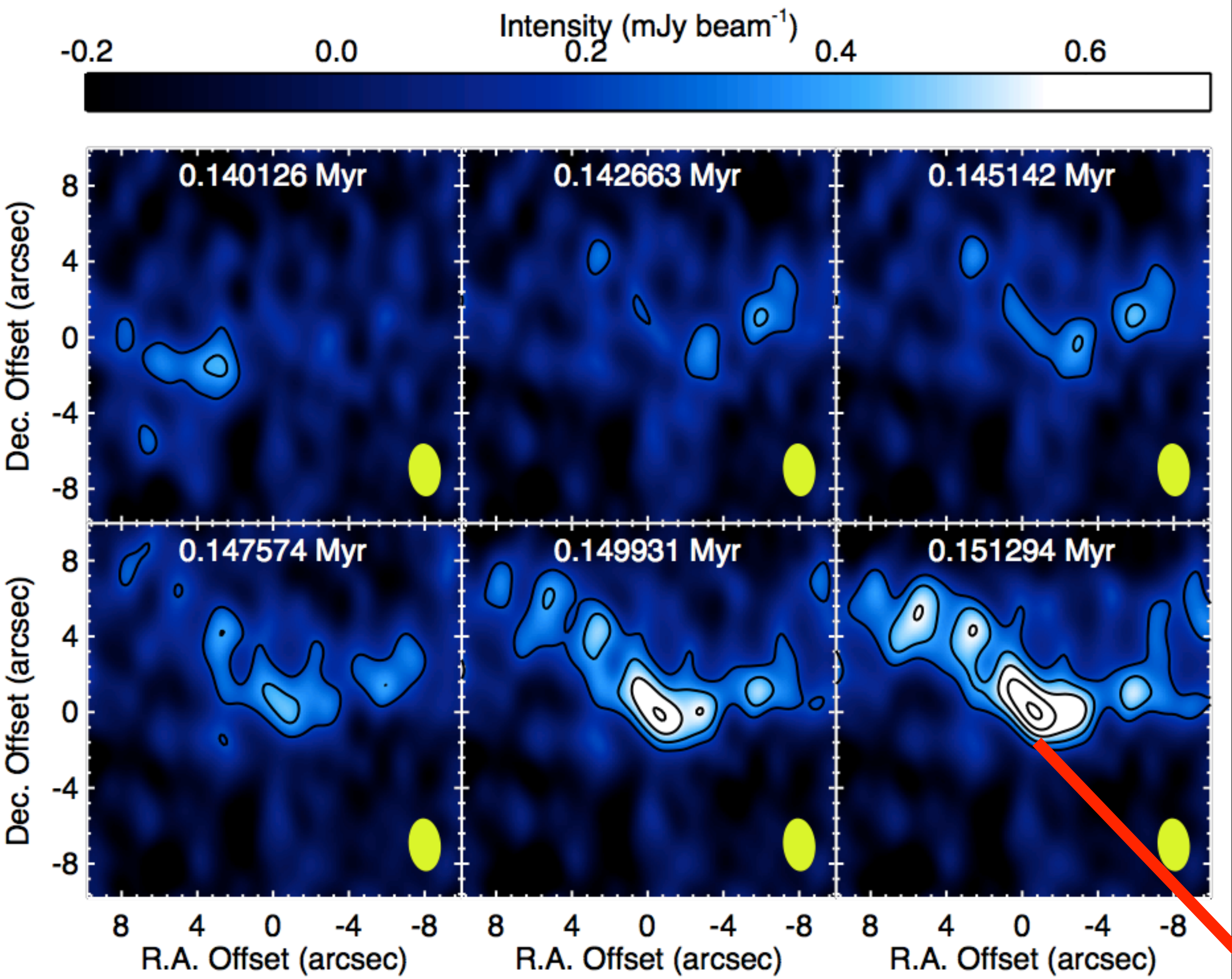
Simulated Starless Cores: MHD Simulations

Offner & Arce (2014) + magnetic fields
$M = 4\ M_{sun}$, $L \sim 0.065$ pc, $n = 6 \times 10^4\ cm^{-3}$



Dunham et al. (in prep), Offner et al. (in prep)

Simulated Starless Cores: MHD Simulations



Predictions:

starless cores detected for n > 3 x 10^7 cm^{-3}

Fragmentation and filamentary structure detectable with these ALMA observations

First cores detectable

Simulated ALMA cycle 1 observations
Same resolution and sensitivity

Sink inserted
First hydrostatic core forms

Dunham et al. (in prep)

56 Undetected Starless Cores: Implications

Lower limit to mean central density of the 56 starless cores:
$\langle n_{central} \rangle = 1.4 \times 10^5 \text{ cm}^{-3}$
(M and R from peak mass per beam)

Fragmenting starless cores should be detectable for:
$n_{central} > 3 \times 10^7 \text{ cm}^{-3}$

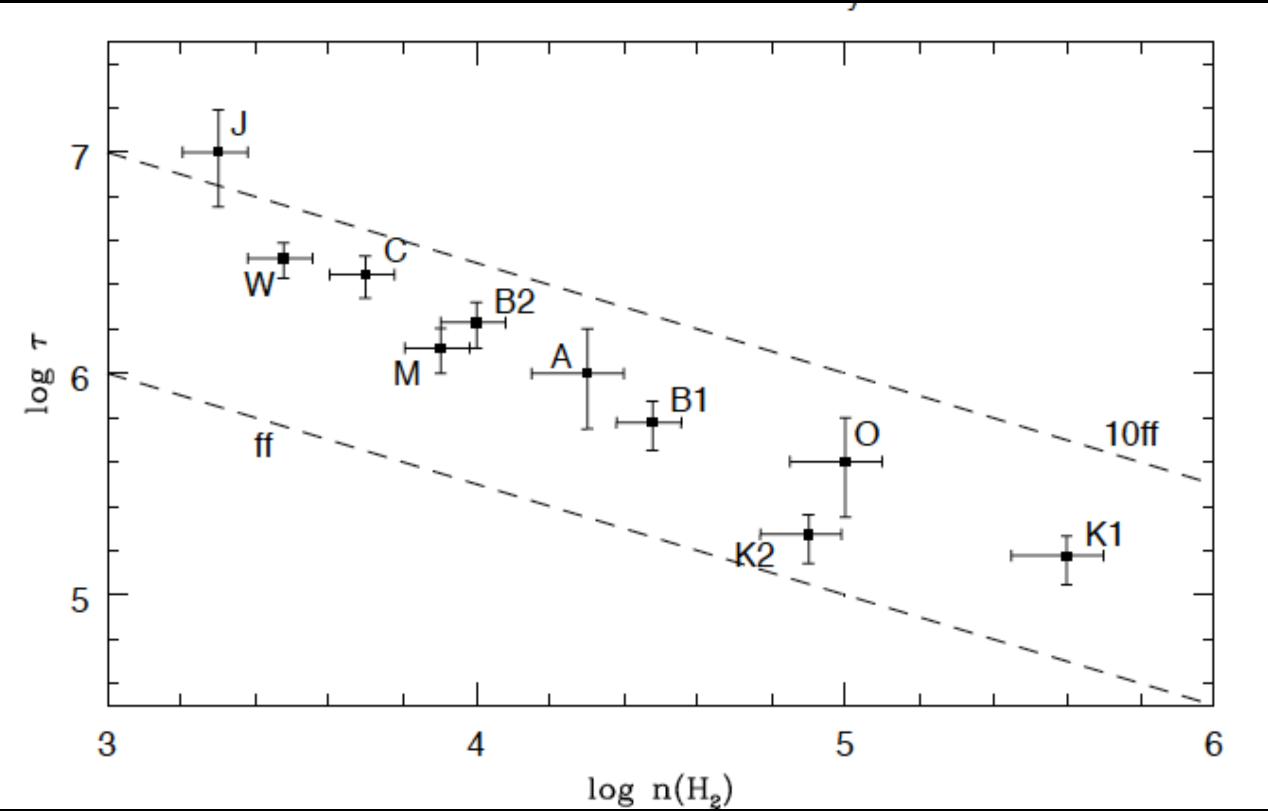
Assume cores evolve on free-fall timescale ($t_{ff} \sim n^{[-1/2]}$)
Assume star formation is continuous
Expected number of detections = $56 * (3d7/1.4d5)^{-1/2}$

Should detect ~ 4 starless cores

Why are no starless cores detected?

56 Undetected Starless Cores: Implications

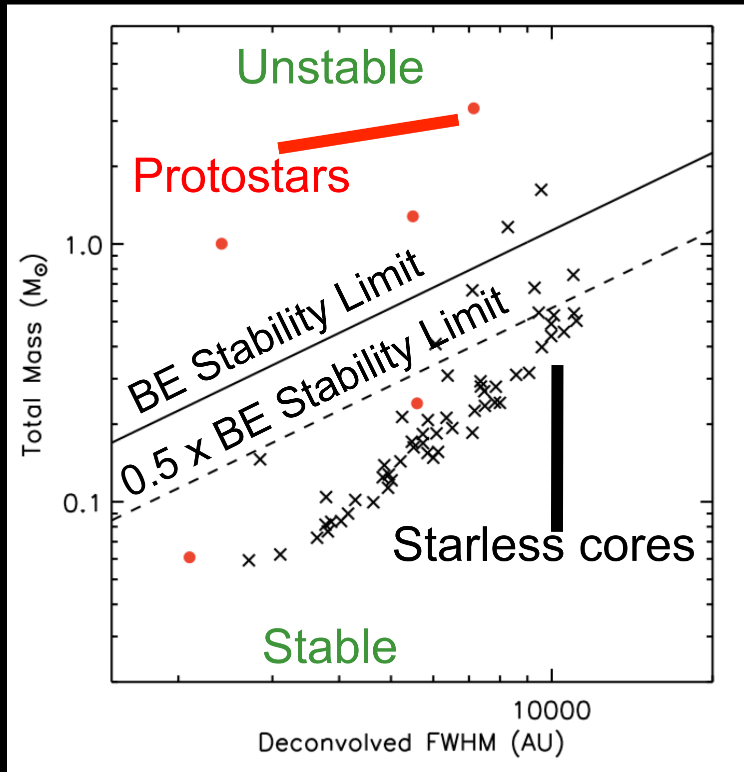
Assumption that all cores evolve on free-fall timescale is bad?
Lifetime / Free-fall time not constant, higher at lower n?
Maybe, although little evidence either way at $n > 10^5$ cm^{-3}



Ward-Thompson et al. (2007), PPV Review

56 Undetected Starless Cores: Implications

Assumption that star formation is continuous is bad?
Most starless cores aren't going to form stars?
Is star formation ending in Cham I?
$N_{protostar} / N_{pre\text{-}main\ sequence} = 0.045$
Mean of all GB clouds = 0.09



Adapted from Belloche et al. (2011)

Summary

Simulations predict turbulent fragmentation in the starless phase
is the dominant channel for the formation of multiple systems

Fragmenting starless cores should be detectable w/ALMA cycle 1 observations

None detected in sample of 56 starless cores in Chamaeleon I
~4 should be detected if star formation is continuous
and starless cores evolve on free-fall timescale

Star formation may be ending or pausing in Chamaeleon I
Starless cores may spend >> free-fall timescale at low densities
Simulation may not be applicable to Chamaeleon I cores

No new protostars or candidate first cores despite sufficient sensitivity
Spitzer+Herschel census of protostars is complete in Chamaeleon U