Herschel Gould Belt Survey

(the Herschel low-mass star forming region survey)

filaments, cores and young stellar objects in the Musca & Chaemeleon dark clouds.

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Insights from the Herschel Gould Belt Survey

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Filaments and striations – super vs. sub critical

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Cold cores – bound vs. relaxed

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Bound cores primarily located within densest filaments

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Pre-stellar cores, proto-stars and YSO mass-functions

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Density threshold (A_V > 6-9 mag) for SF to ensue

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Active accretion of diffuse matter onto dense filaments along magnetic field lines

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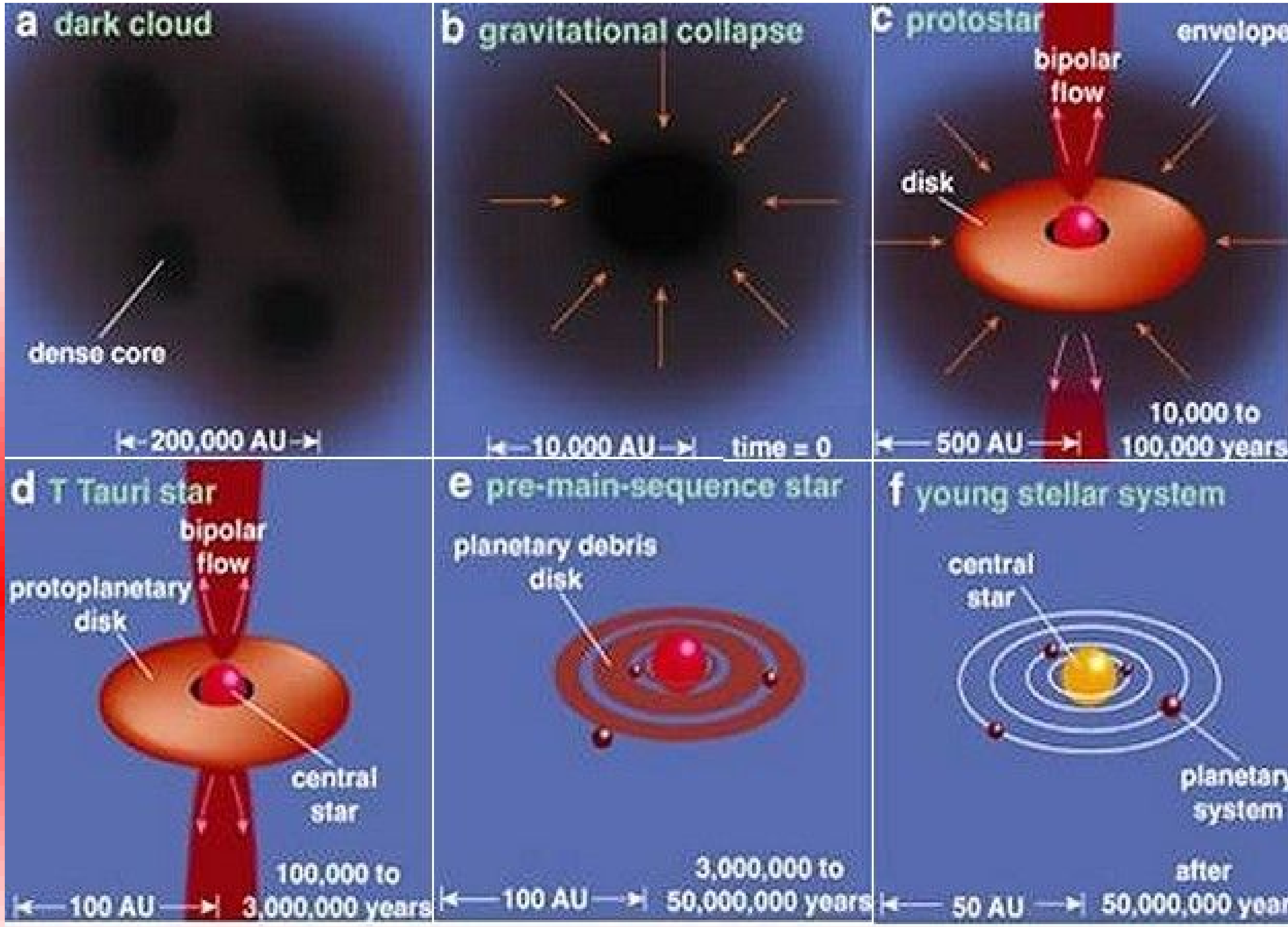
Structure of this presentation

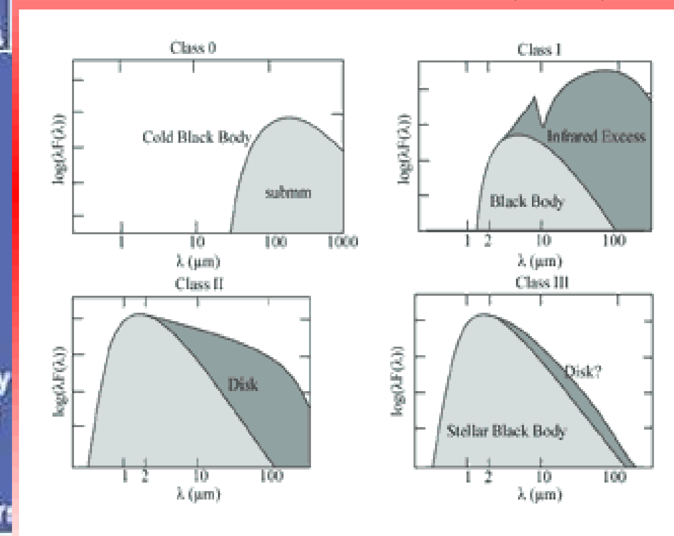
1. Introduction (star formation / molecular clouds)
2. Filaments – a new view with Herschel
3. Musca: a special cloud with filaments, striations, and cold cores
4. Herschel's view on YSOs in Chamaeleon I
5. Individual objects: HD97300, Bok Globules
6. Prospects and plans

low-mass star-formation scenario



Source: Spitzer Science Center: Based on Lada et al. 1993.

Source: M. Burton (UNSW)



SED evolution during low mass star formation.

Class 0: cold core of ~20-30K, peaking in the sub-mm
Class I: IR excess, peaks in the far-IR, emission from a warm envelope heated by the accretion luminosity.
Class II: Peak shifts to mid-IR as a disk forms. Shape depends on whether disk is passive or active.
Class III: The disk dissipates.

Molecular 'dark' clouds

Key references:

Bergin & Tafalla 2007, ARA&A, “Cold dark clouds: initial conditions for star-formation”
McKee & Ostriker 2007, ARA&A, “Theory of star formation”
Evans 1999, ARA&A, “Physical conditions in regions of star formation”

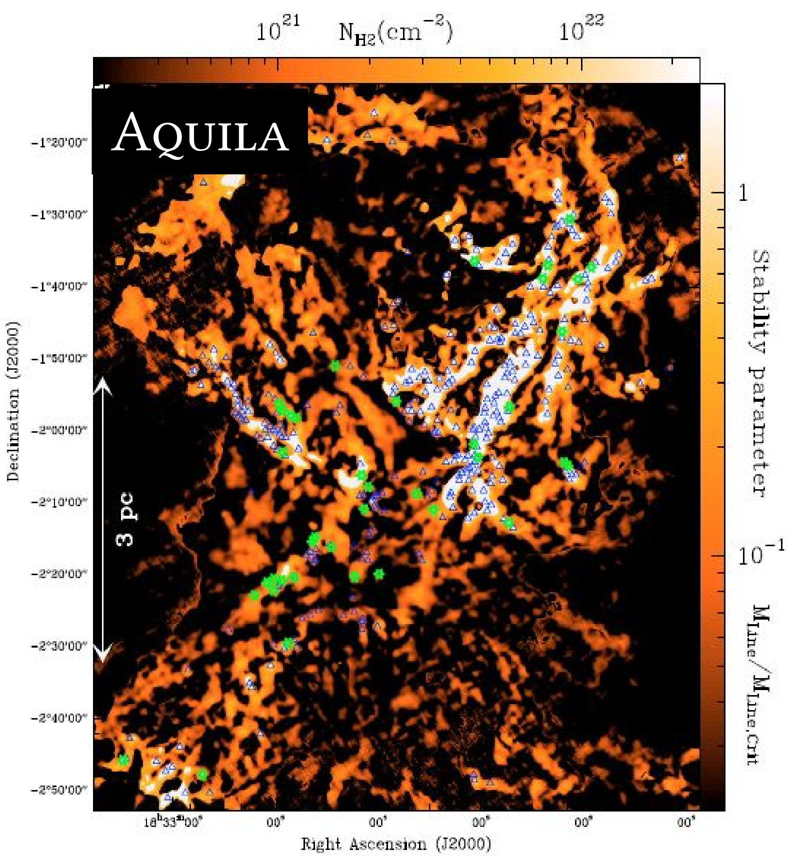
	Clouds	**Clumps**	**Cores**
Mass (M_{sun})	10^3 - 10^4	50-500	0.5-5
Size (pc)	2-15	0.3-3	0.03-0.2
Density (cm^{-3})	50-500	10^3 - 10^4	10^4 - 10^5
Tgas (K)	~10	10-20	8-12
Examples	Taurus, Oph, Musca, Cham.	B213, L1709	L1544, B68

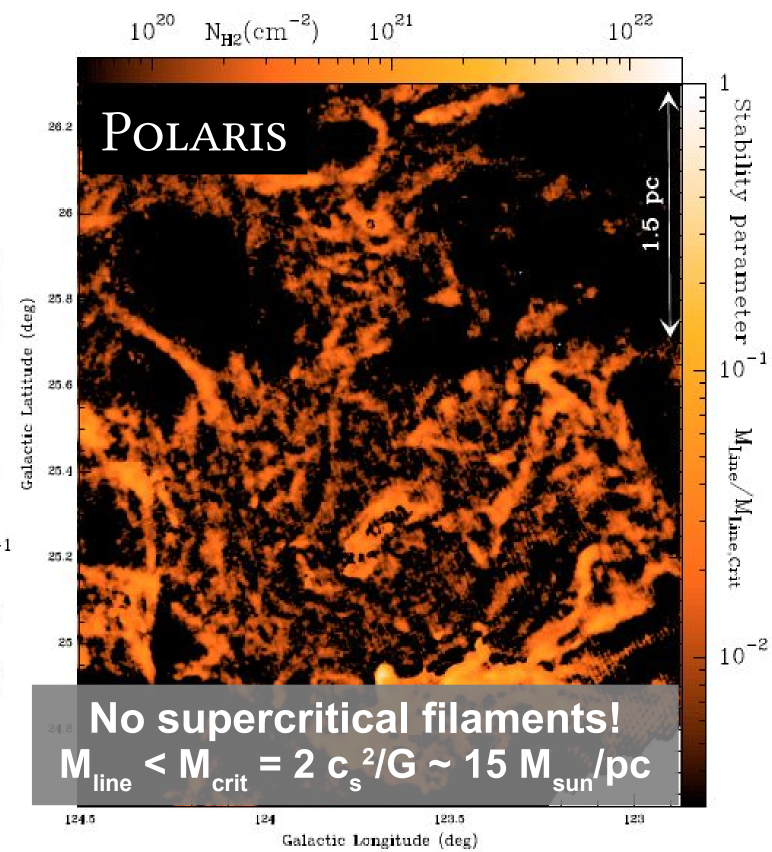
Bergin & Tafalla, 2007

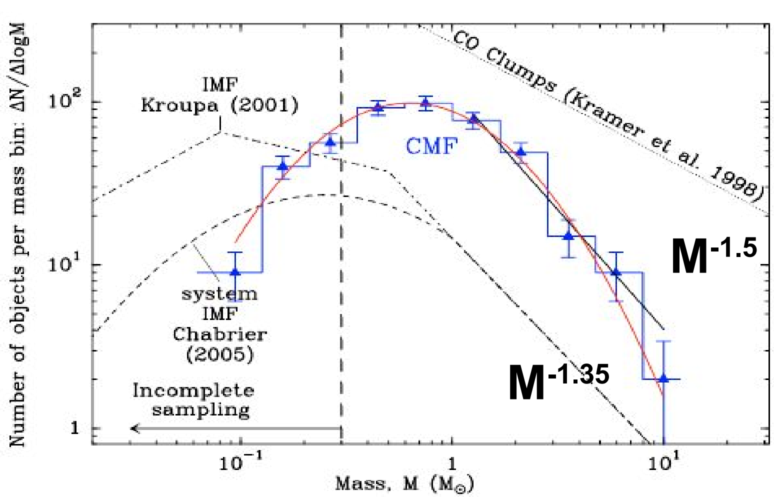
¿Sterile and fertile parts of a cloud? How to distinguish? Where does isolated SF occurs?

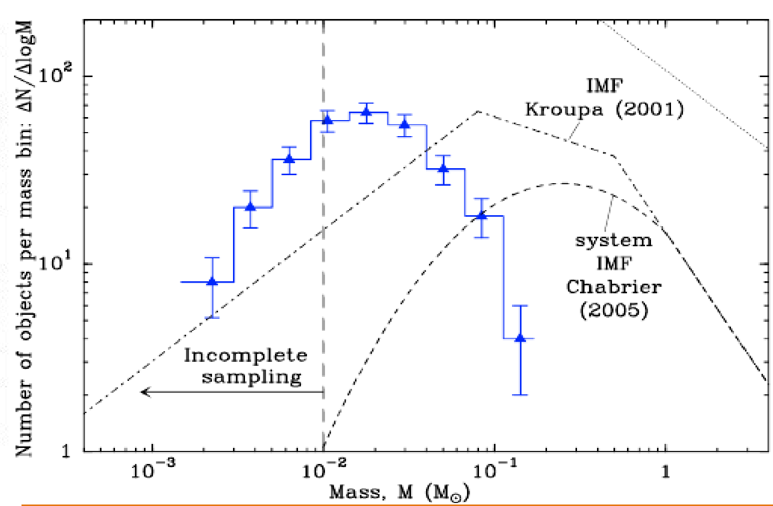
¿Isolated (e.g. Taurus) versus clustered (e.g. Ophiucus) star-formation of low-mass stars?

The Aquila Rift cloud complex









Completeness:

prestellar cores 75% for core mass of > 0.2 M_{sun}.
protostars 90% for L_{bol} > 0.2 L_{sun}.

AQUILA:
541 starless cores (0.01-0.1 pc); 341 (63%) are bound.

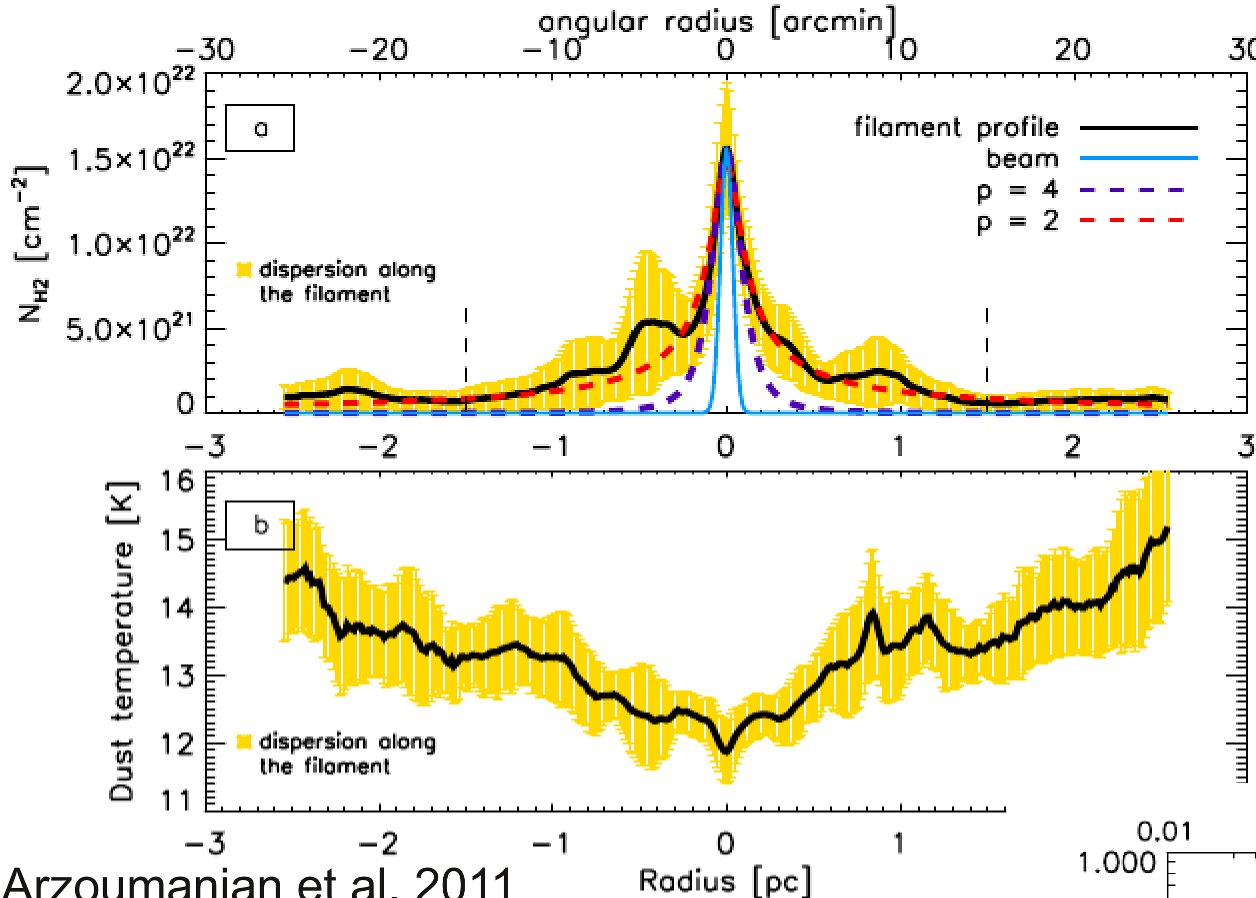
POLARIS:
302 unbound cores.

Results for Aquila & Polaris suggest that prestellar cores result from the gravitational fragmentation of filaments in cold ISM.

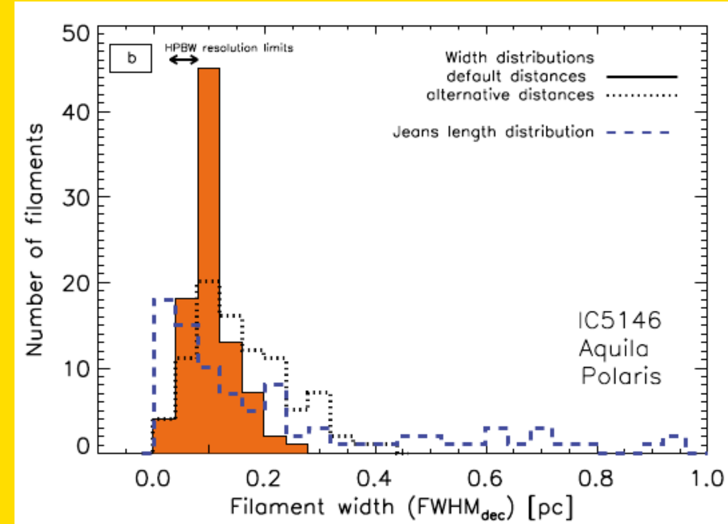
→ CMF 'initializes' IMF.

KONYVES ET AL. 2010, BONTEMPS ET AL. 2010, ANDRE ET AL. 2010

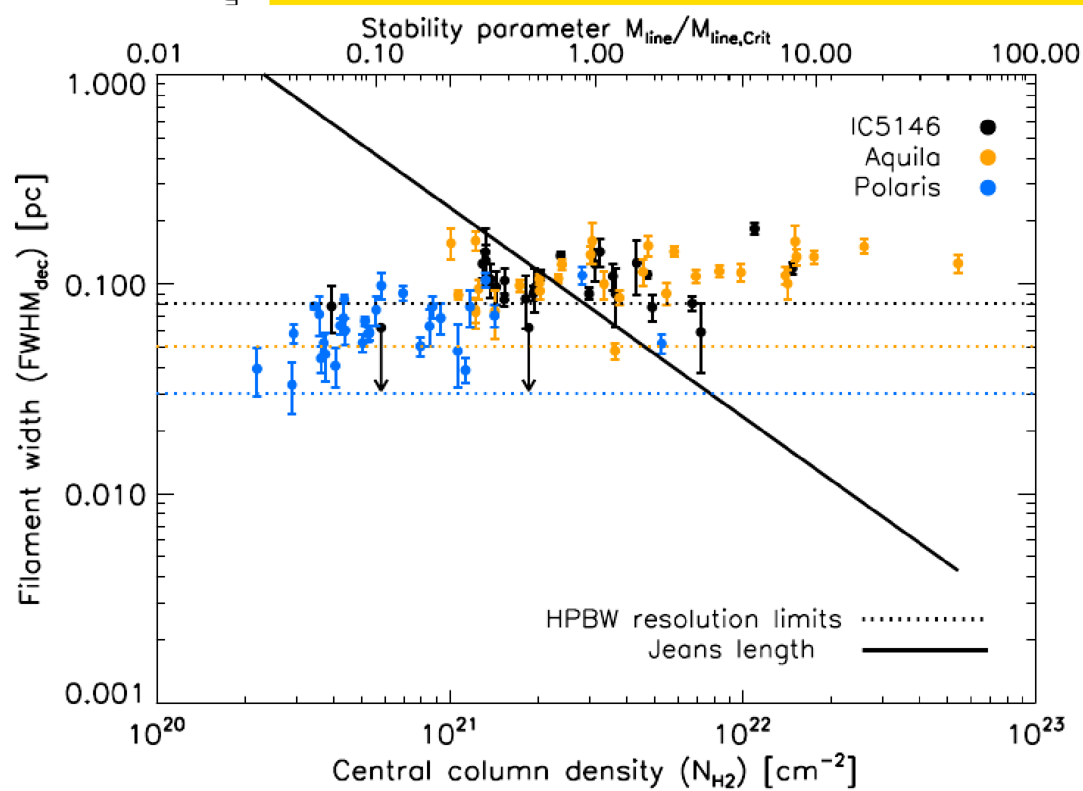
Filament widths



Arzoumanian et al. 2011



Median filament width ~ 0.10±0.03 pc



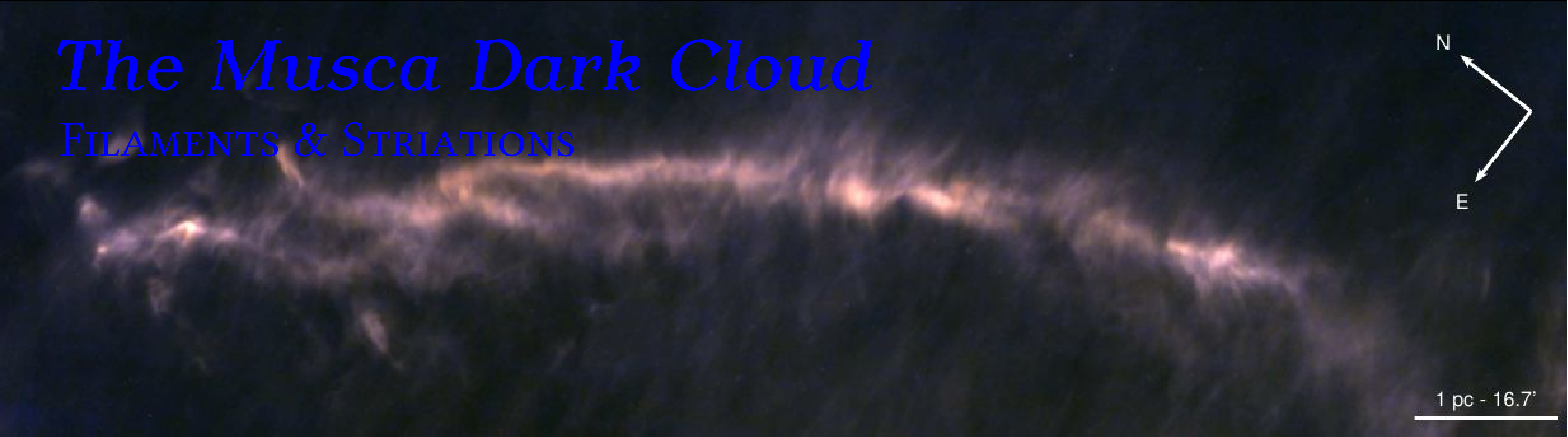
Most bound prestellar cores appear to be located within supercritical, gravitationally unstable filaments. Similar result for Aquila (André et al. 2010).

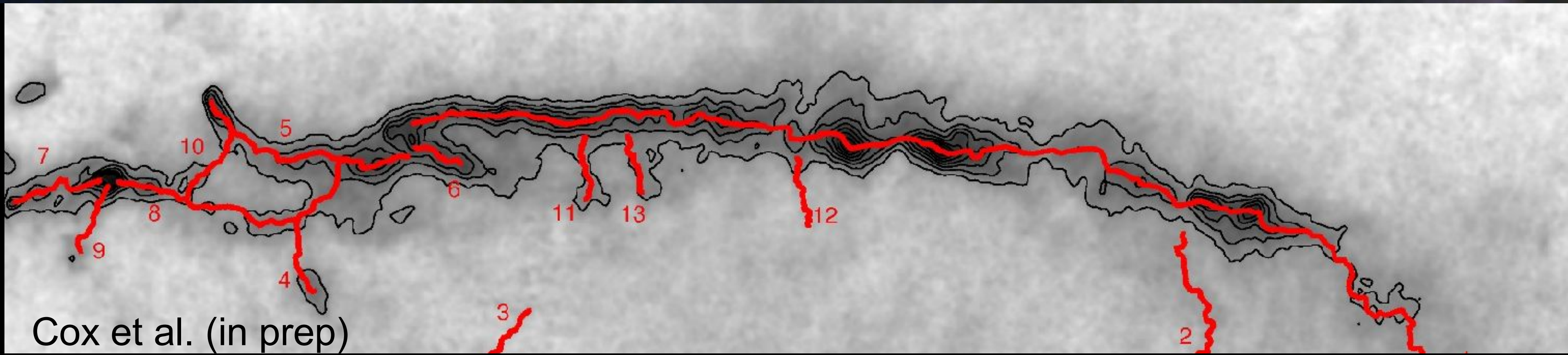
No anti-correlation between filament width and central column density

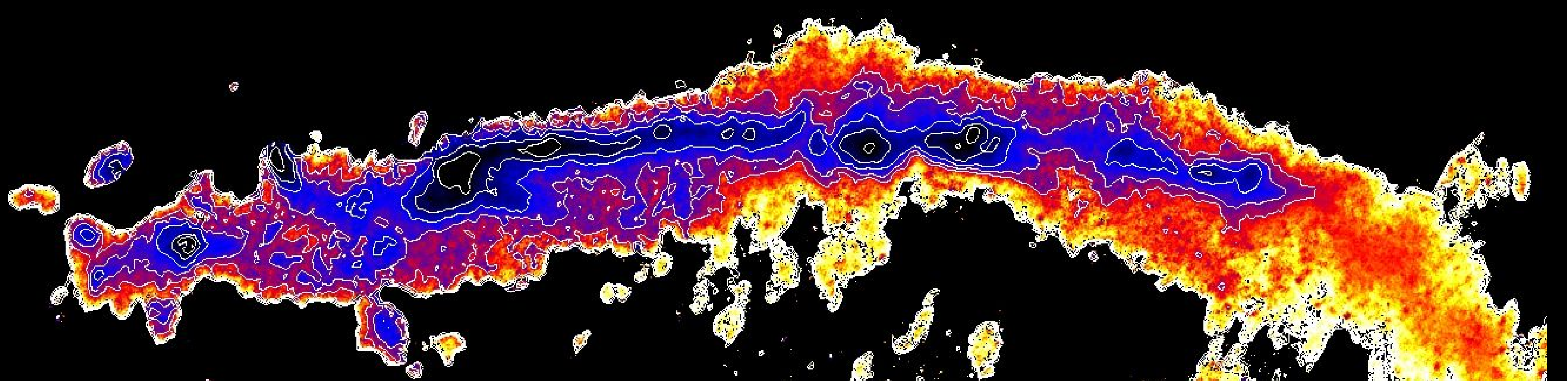
Large-scale turbulence is main mechanism to *form* filaments, but gravity is driving their *evolution*, as evidence by cores forming in gravitationally unstable filaments.

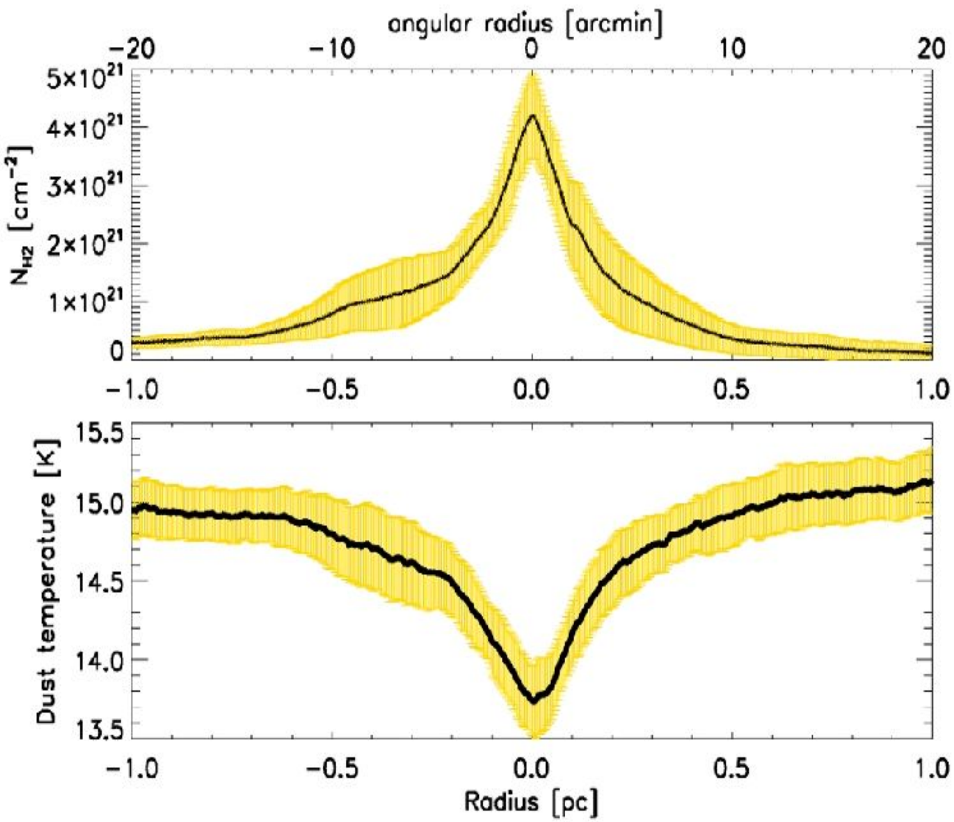
The Musca Dark Cloud

Filaments & Striations

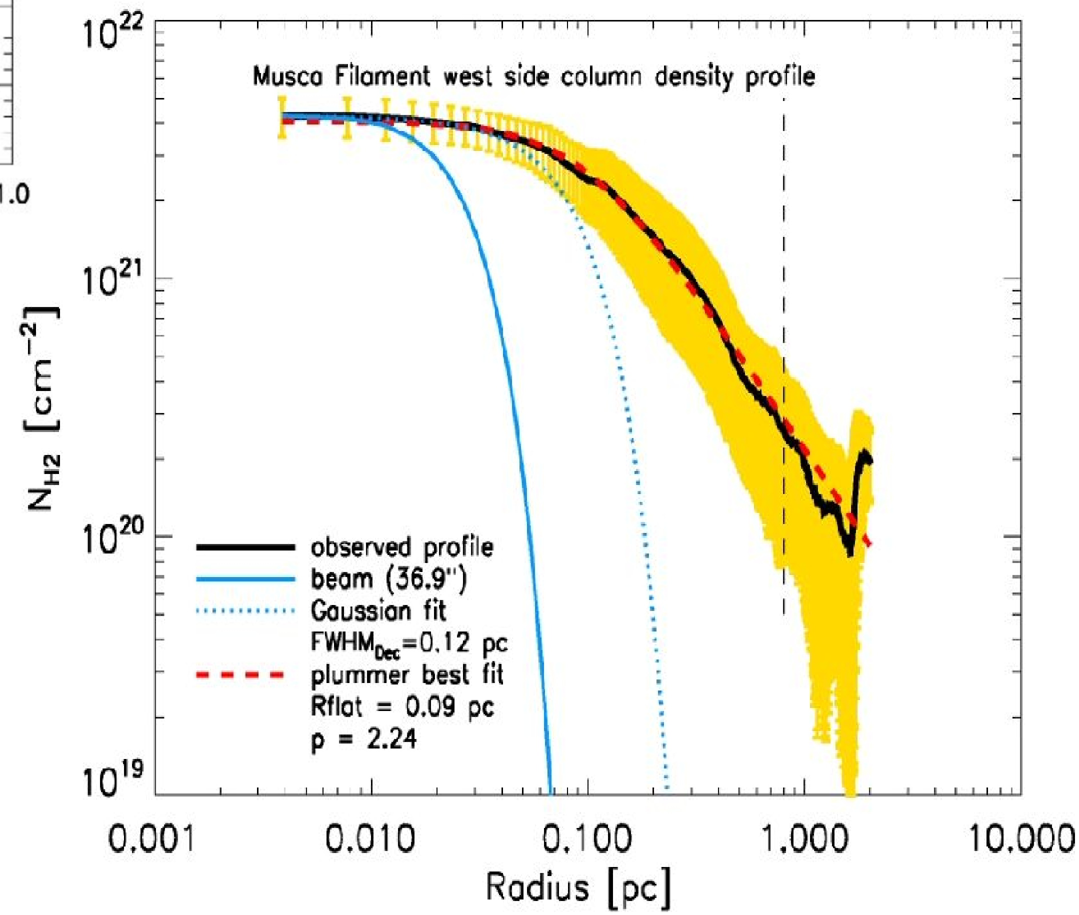








$$F(r) = \frac{\rho_c \, R_{\rm flat}}{\left[1 + (r/R_{\rm flat})^2\right]^{\frac{p-1}{2}}}$$

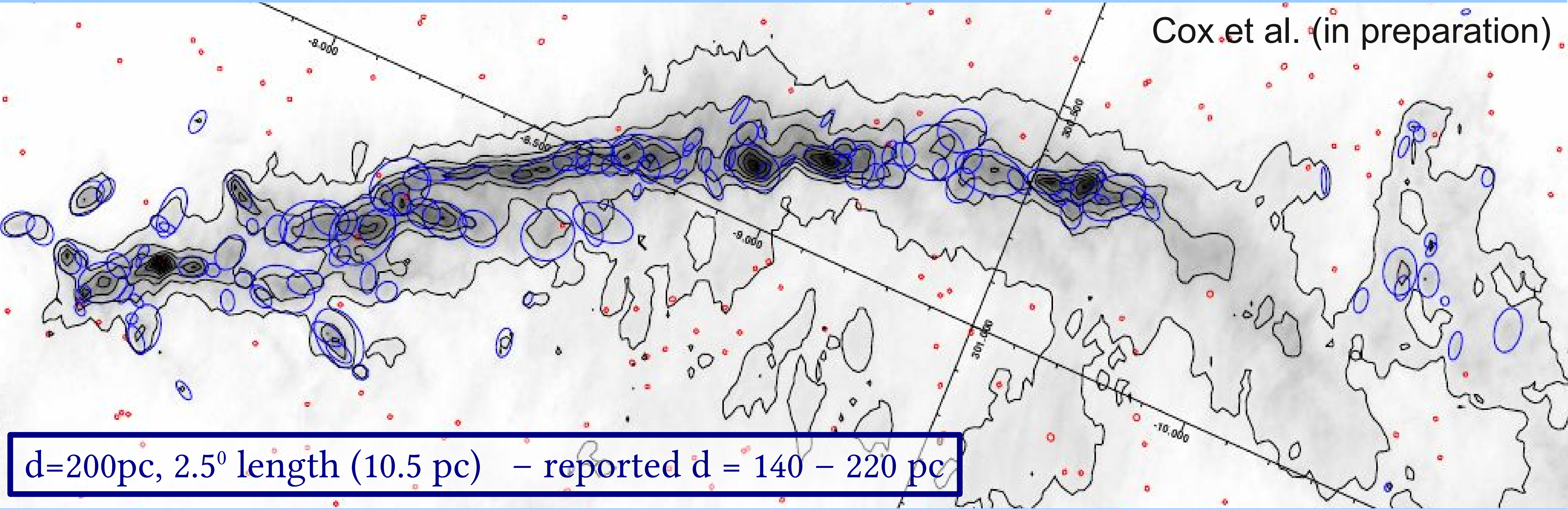


Filament width is 0.08-0.12 pc

p ~ 2.0

Cox et al. (in preparation)

Extended & point-like sources in Musca



d=200pc, 2.5^0 length (10.5 pc) – reported d = 140 – 220 pc

~47 extended 'cold' condensations (with F_{250}>F_{160})

~12 cores matched of 16 CO cores (Vilas-Boas et al. 1994)
→ elongated || main filament.

→ $M_{BE}/M_{dust+gas}$ < 2 → bound!?

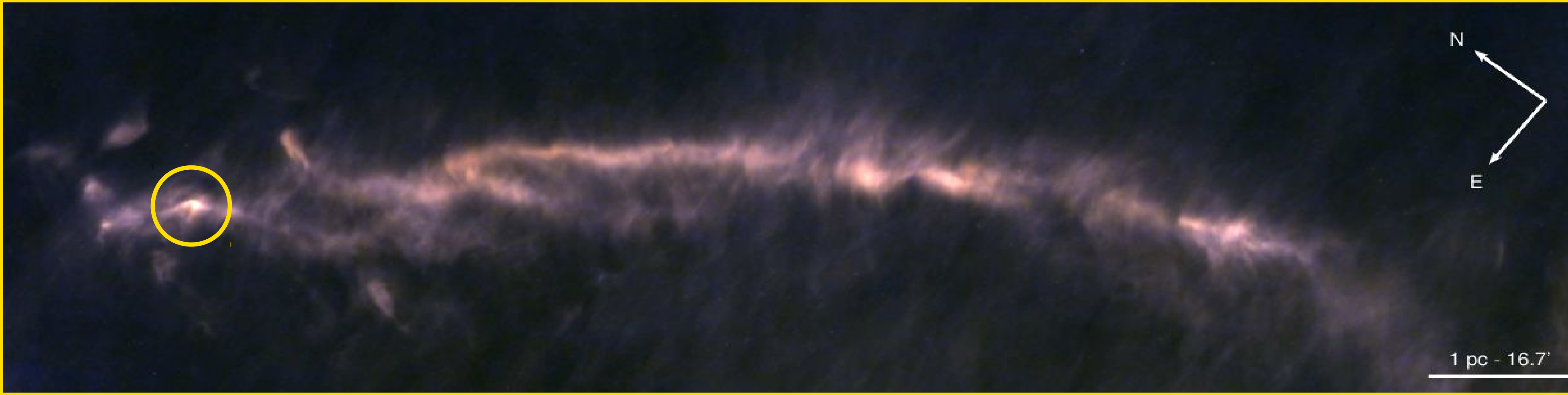
Total mass:
$M_{dust+gas}$ (A_V>2) ~ 300 M_{sun}
$M_{A(V)>2}$ ~ 160 M_{sun}

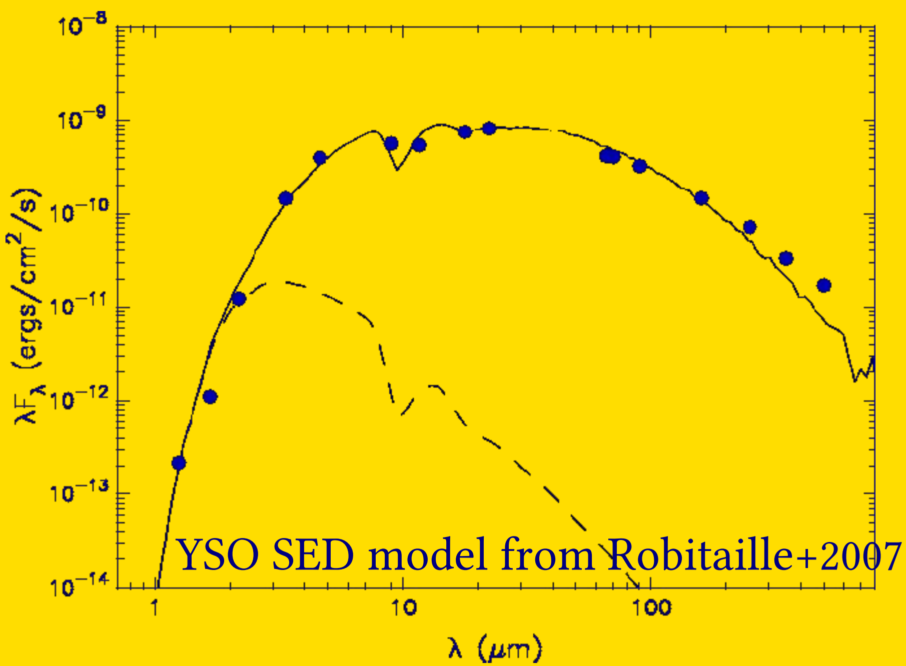
Measured linear mass density ~30 Msun/pc. Similar, within factor 2, to theoretical critical density for self-gravitating cylindrical cloud (Ostriker 1967)

Progressive evolution along the Musca main filament?

Oldest (yso + #cores higher) → Youngest – in-falling

Candidate YSO

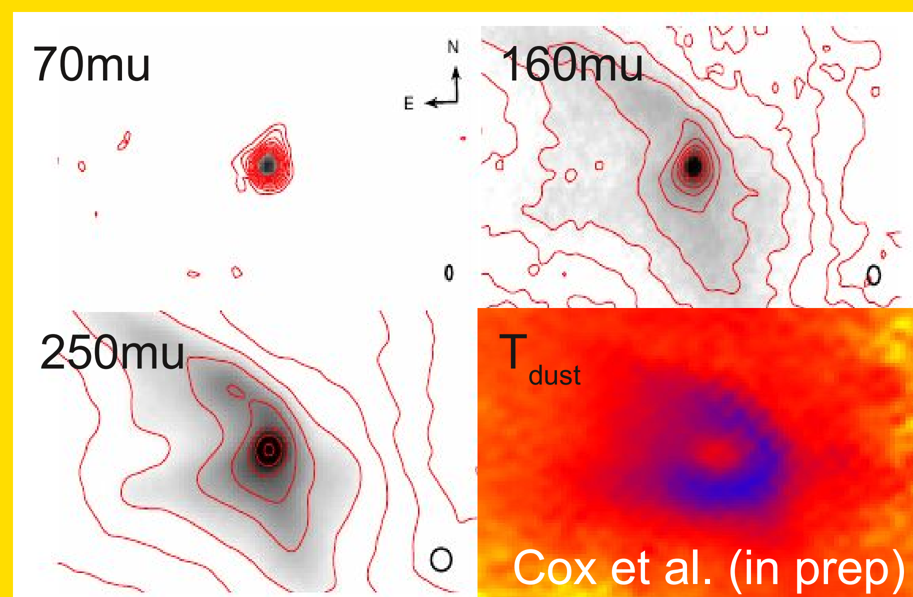




M_* = 2.55 M_{sun}, T_{eff} = 9700 K

M_{disk} = 0.05 M_{sun}, M_{env} = 8 10^{-9} M_{sun} → SFE ~ 1.5%

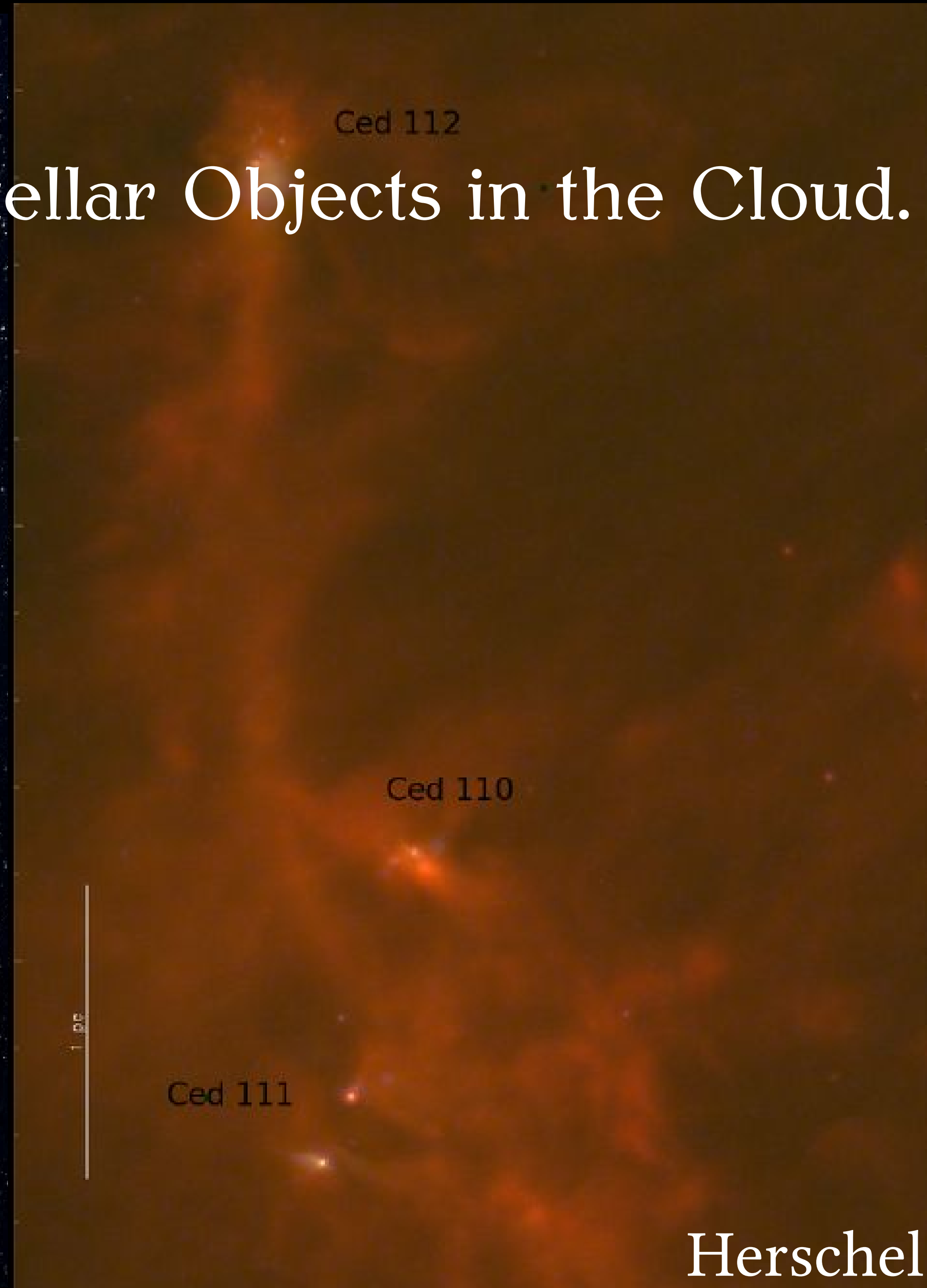
L_{tot} = 44.7 L_{sun} Age = 4 Myr.



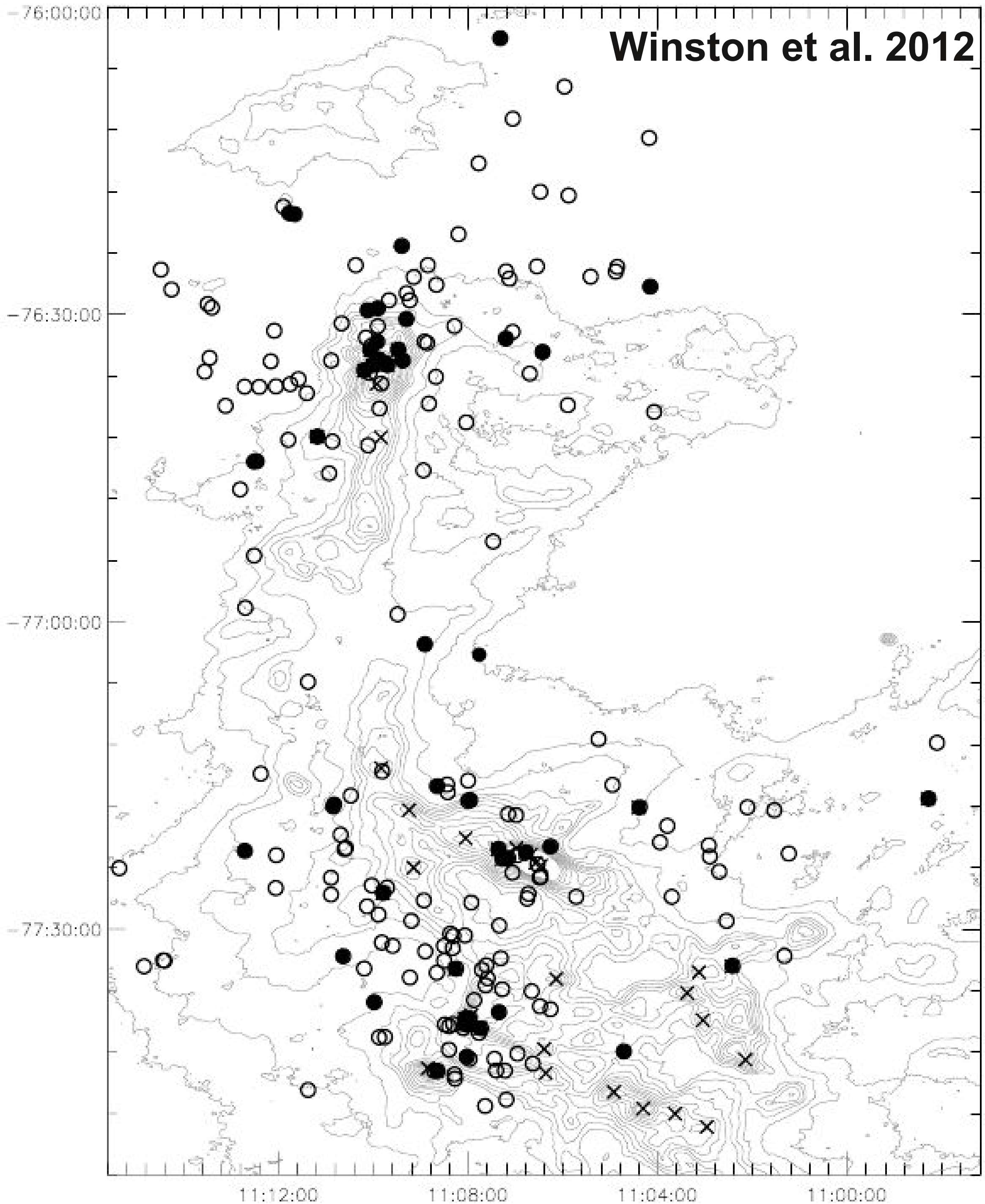
'colder' (T~12.2 – 12.8 K) dust ring embbeded in 'warmer' (T~13.5-14 K) environment.

Chamaeleon I

A first view of Young Stellar Objects in the Cloud.



Known YSOs in Cham I



SPIRE 500 micron grey scale contour

Circles indicate 237 YSOs detected by Luhman et al. 2008

Filled circles are those 47 YSOs also detected with Herschel

5 class I,
6 flat spectrum,
32 class II,
3 transition disks (CZ Cha, SZ Cha, T54),
1 class III (Ced110 IRS 2).

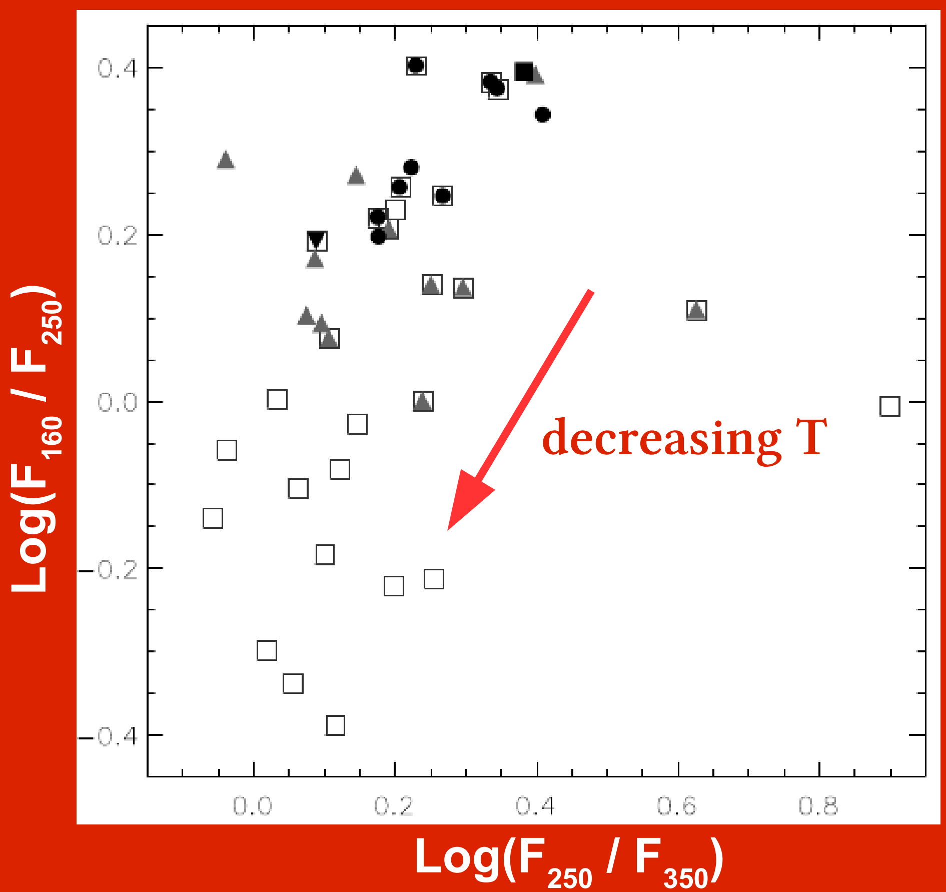
X's mark 30 Herschel detected Belloche et al 2011sources.

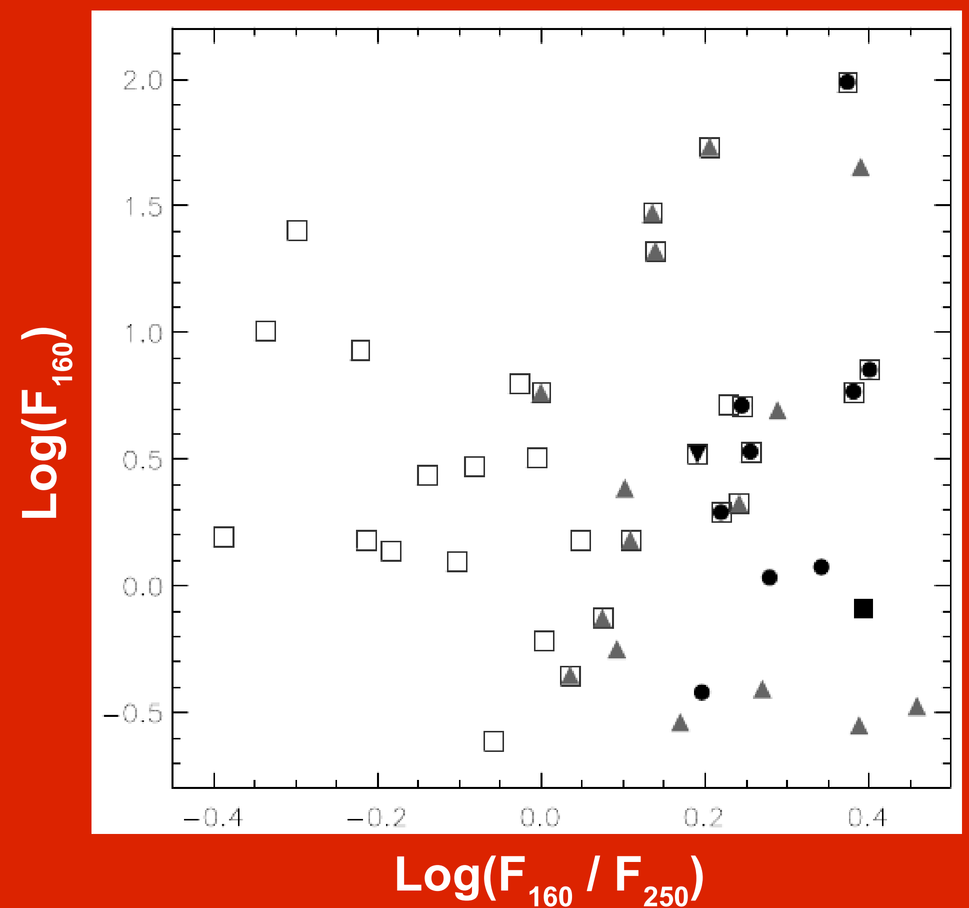
Herschel sources are more clustered and are coincident with regions of dense dust

300 unidentified point-like sources – galaxies? – detected mainly in low-density region (A_V<1).

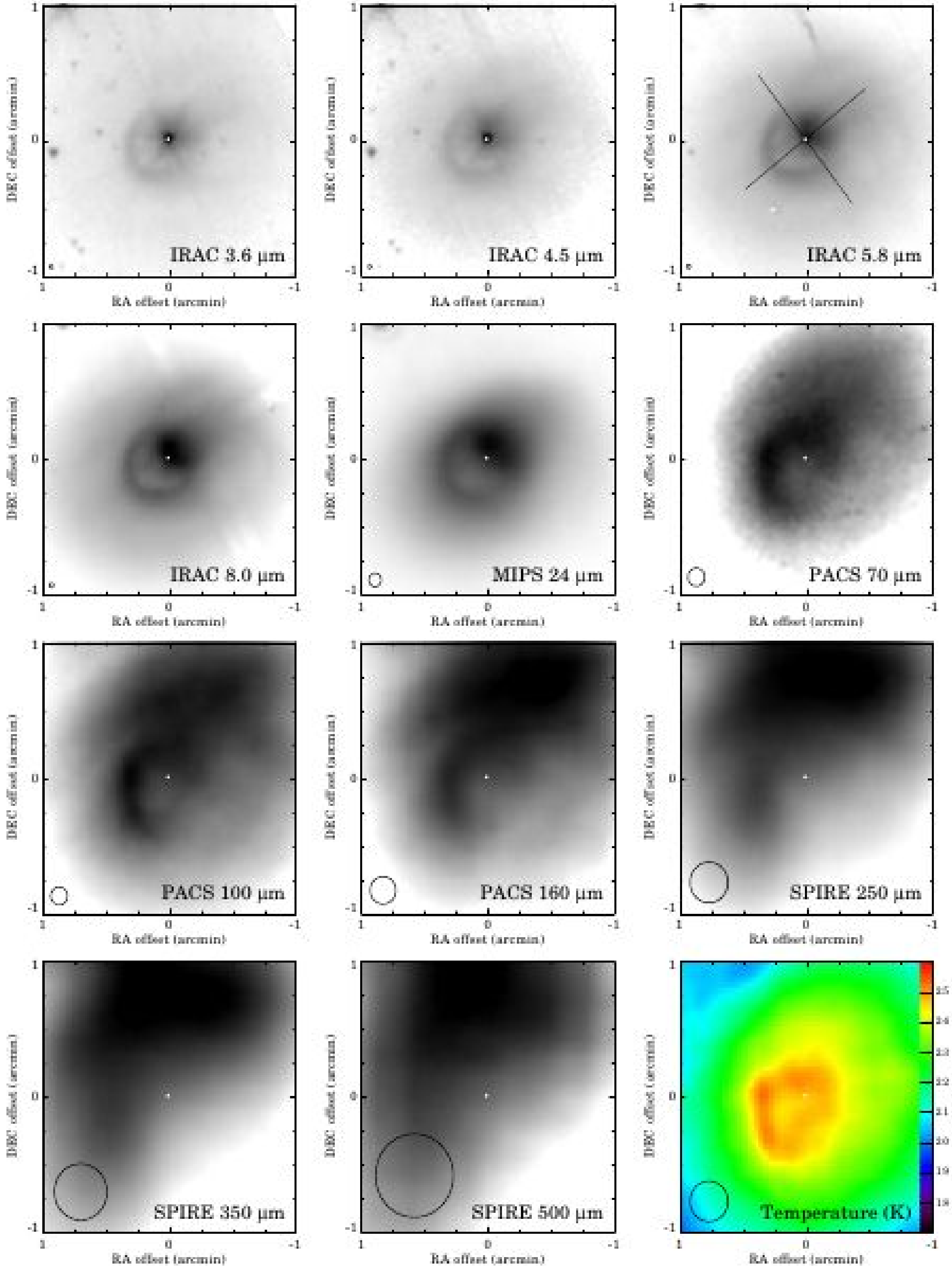
YSOs properties

YSOs bluer than the cores, but no difference in 160mu flux (ie. Mass / Luminosity).





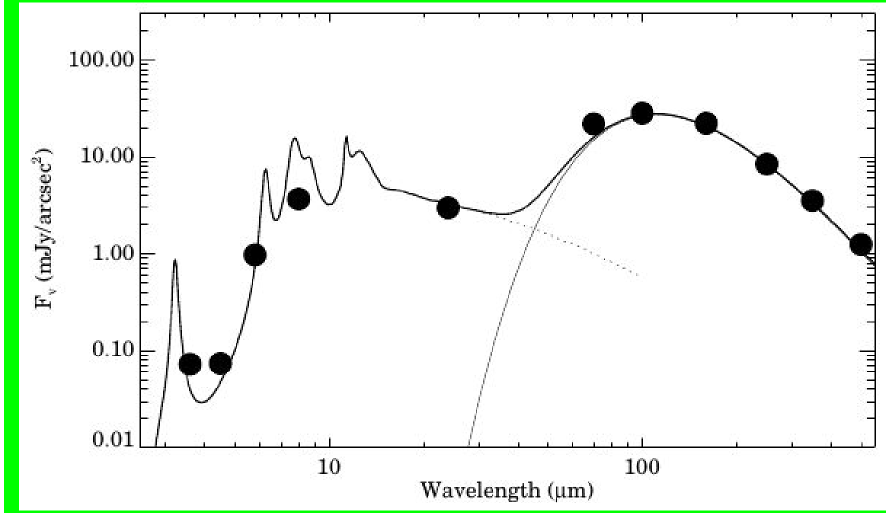
Black Circles:	●	Class I / Flat Spectrum
Grey Triangles:	▲	Class II
Inverted Triangles:	▼	Transition Disks
Filled Square:	■	Class III
Open Squares:	□	Sub-mm cores (Belloche et al.)



HD97300 in Cha I

Kospal et al. 2012

Bubble blown into surrounding medium and heated by the star

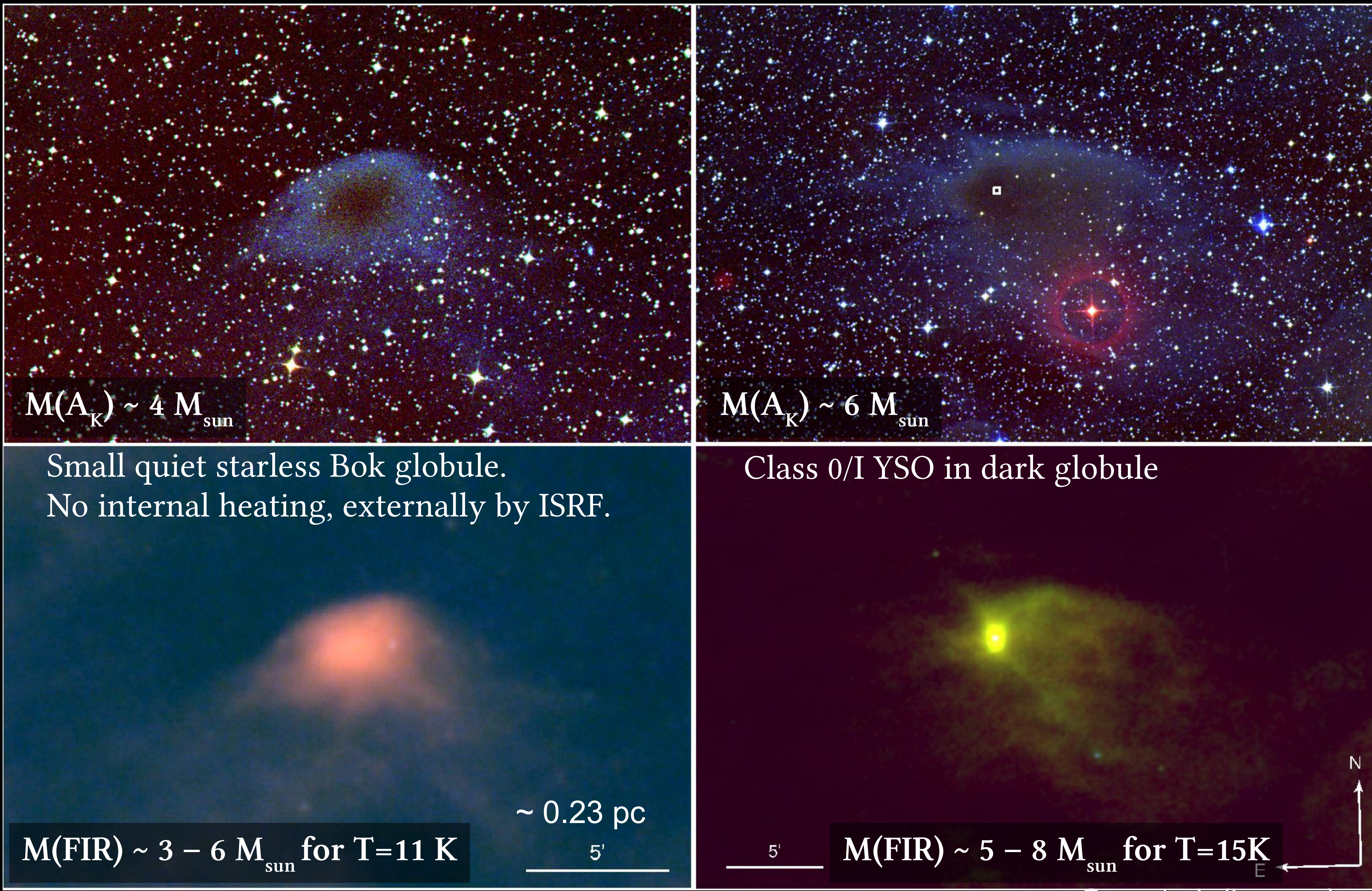


Siebenmorgen et al. 1998 model for dust ring (ring 50"x36") and grey-body T~26 K.

Total mass in large grains in the ring ~0.001 M_{sun}

From mid-IR (PAHs – VSGs) the inferred mass in ring is ~0.03 M_{sun}

Isolated star-formation in Bok globules



Cox et al. (in prep)

Prospects & challenges

- Filamentary evolution from Cha III → Cha II → Cha I?

  → definition of (sub)filaments? → refinement filament definition and extraction in crowded regions with "filament networks".

- Pre-stellar cores in Cha III: bound versus unbound?

  → Detailed analysis of 'coldest condensations' identified w/ SPIRE & LABOCA

- Detailed mid-to-far-IR SED modeling of YSOs in Cha I & II.

- Velocity dispersion and kinematic of (molecular) gas in the Musca filament?

- Magnetic field orientation and strength WITHIN the filaments AND striations?