THE PIPE NEBULA IN HIGH RESOLUTION WITH SOFI AND ISAAC

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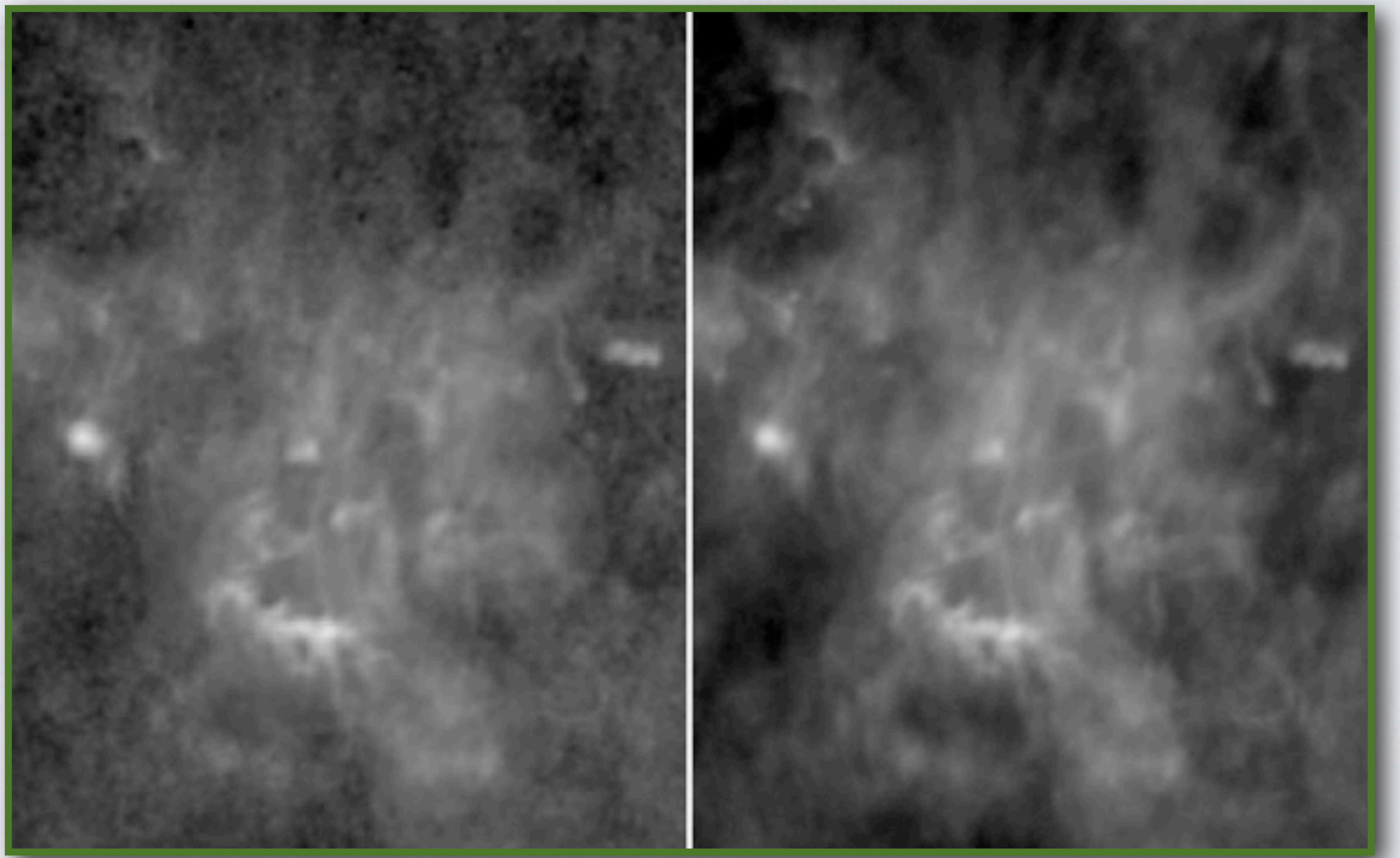
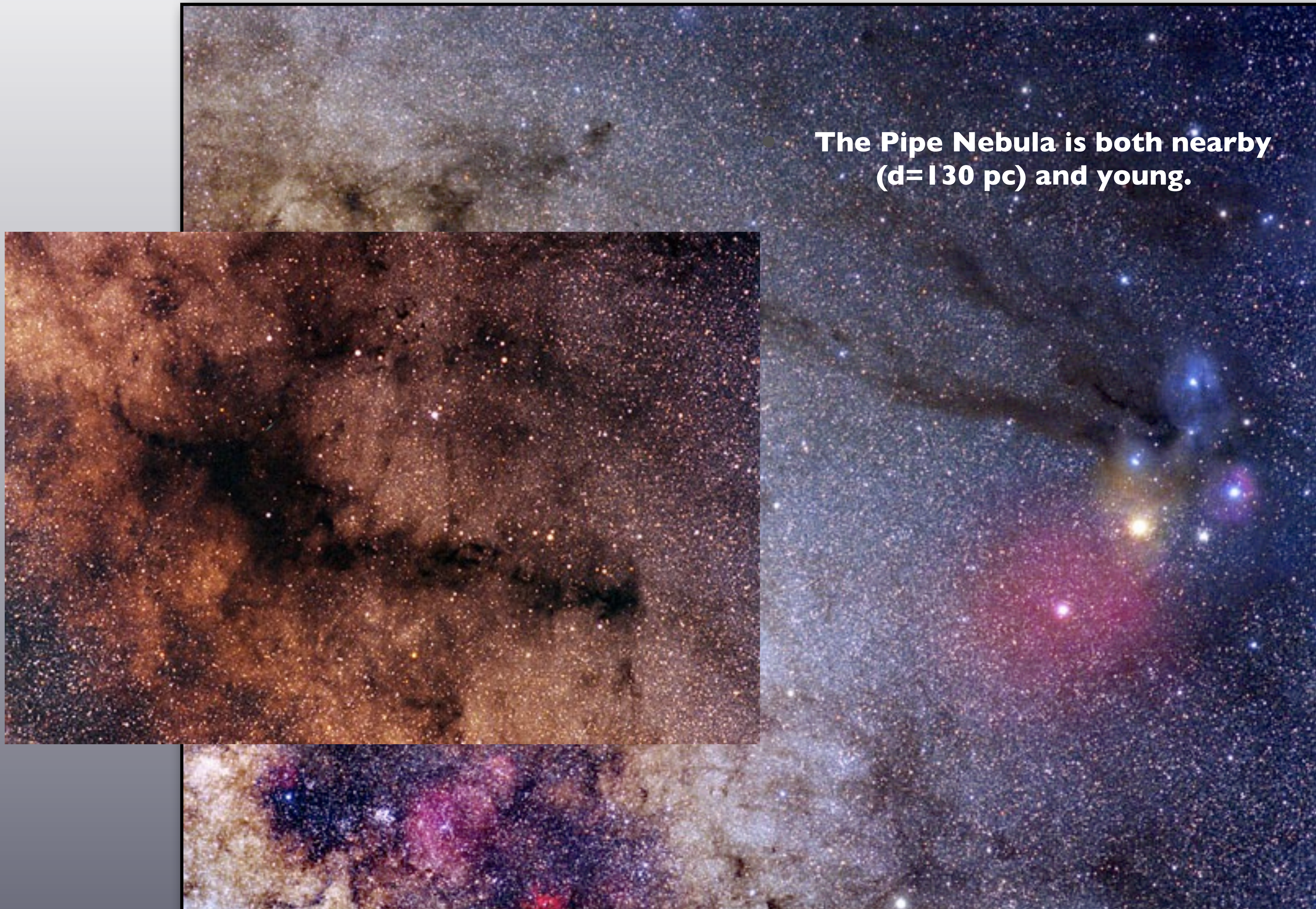


ESO: 50 years. Garching, Germany, 090312

QUICK OVERVIEW



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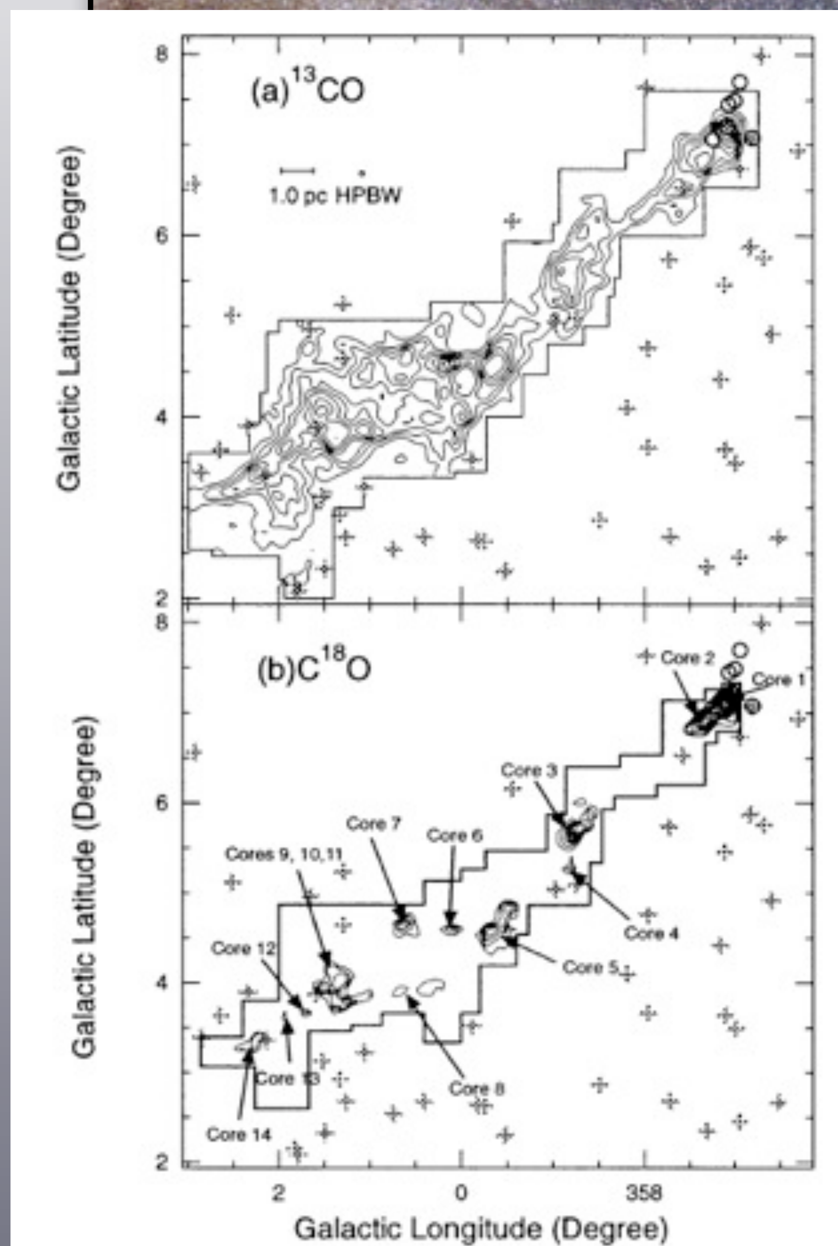

- The Pipe Nebula is both nearby (d=130 pc) and young.
- Minimum star formation activity, thus unevolved
- Fragmentation into star forming core has just began.
- Early: Onishi et al 99 radio map suggested at least 14 cores, 1 outflow.

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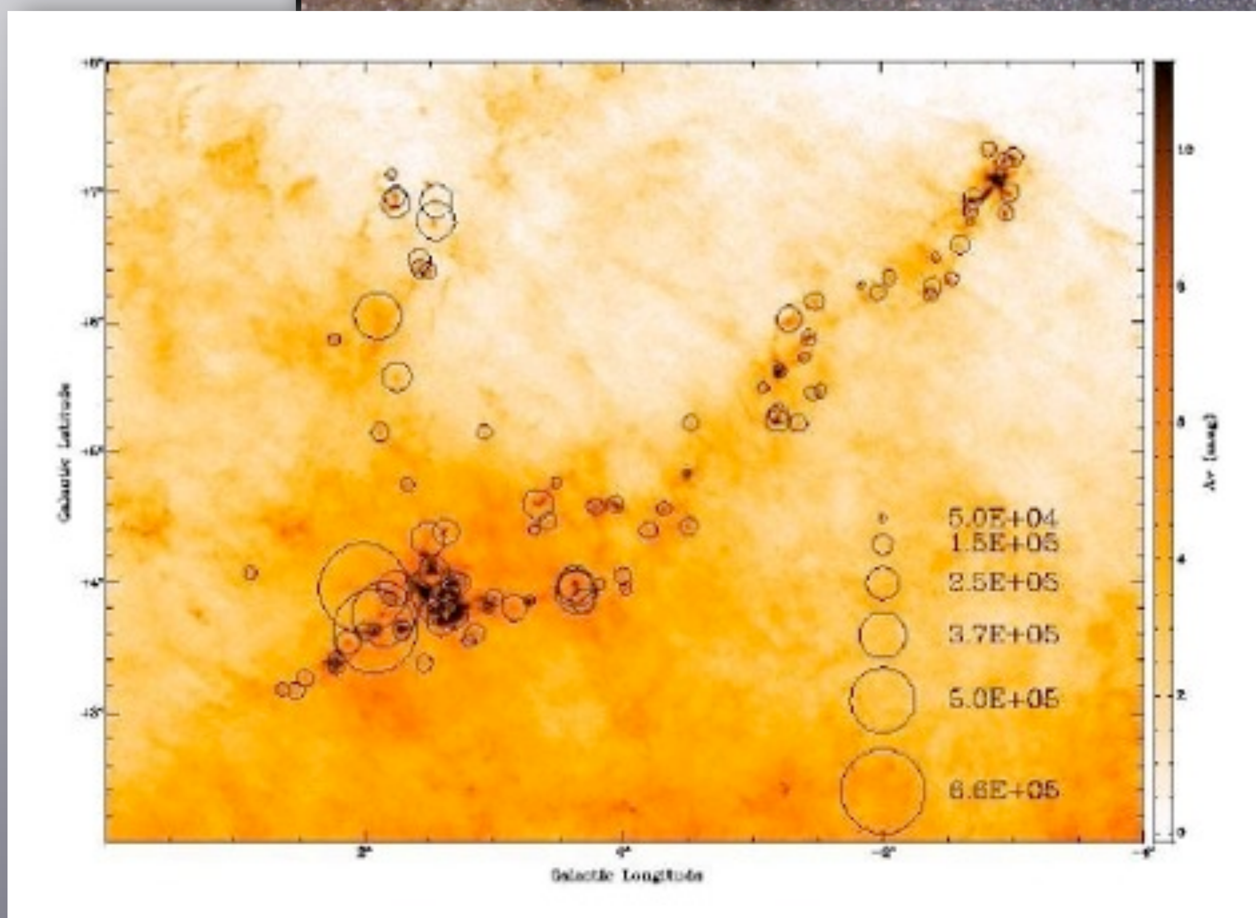

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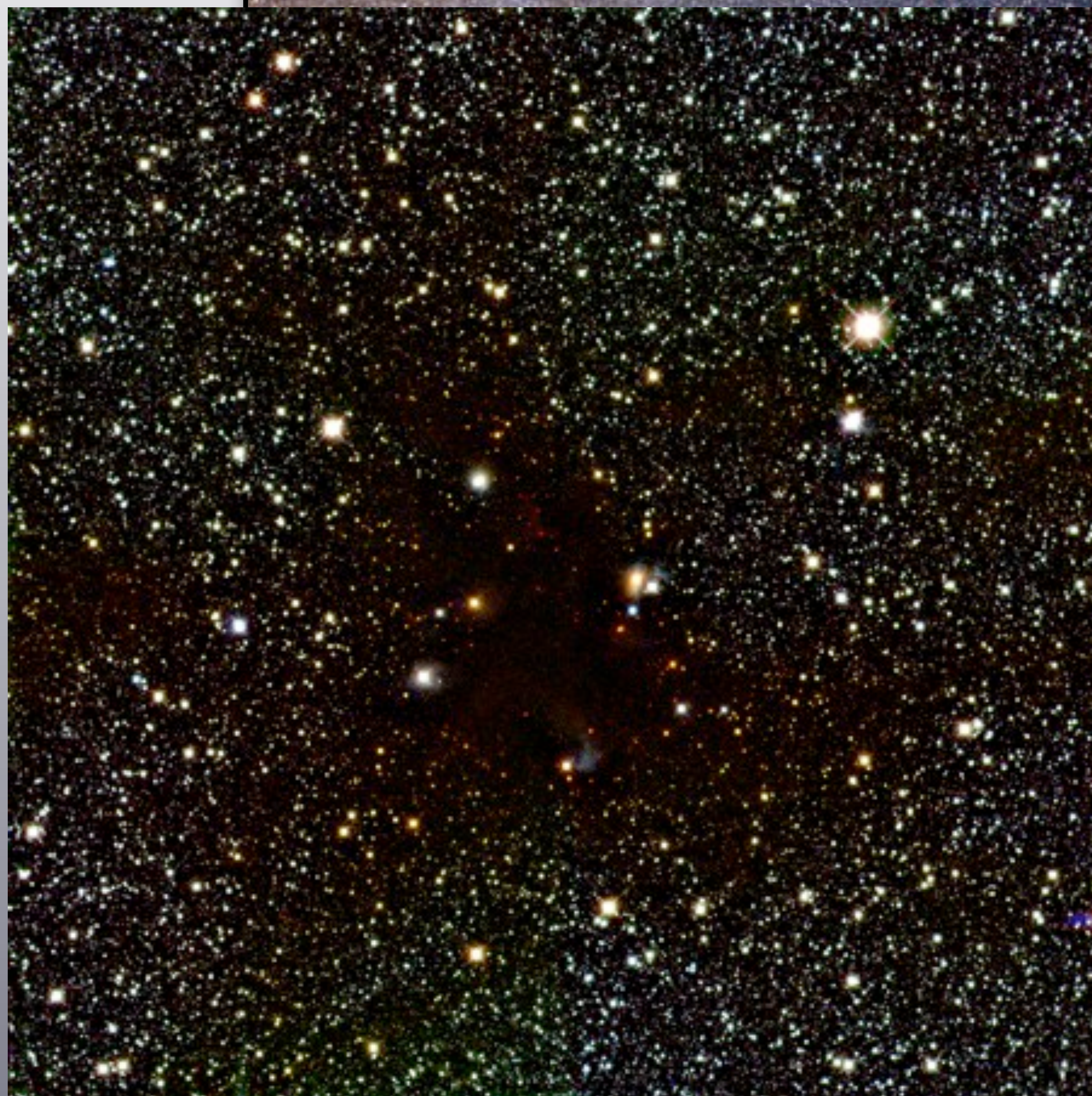

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- Spitzer data revealed a cluster with >14 members (Brooke et al 2008) in B59.

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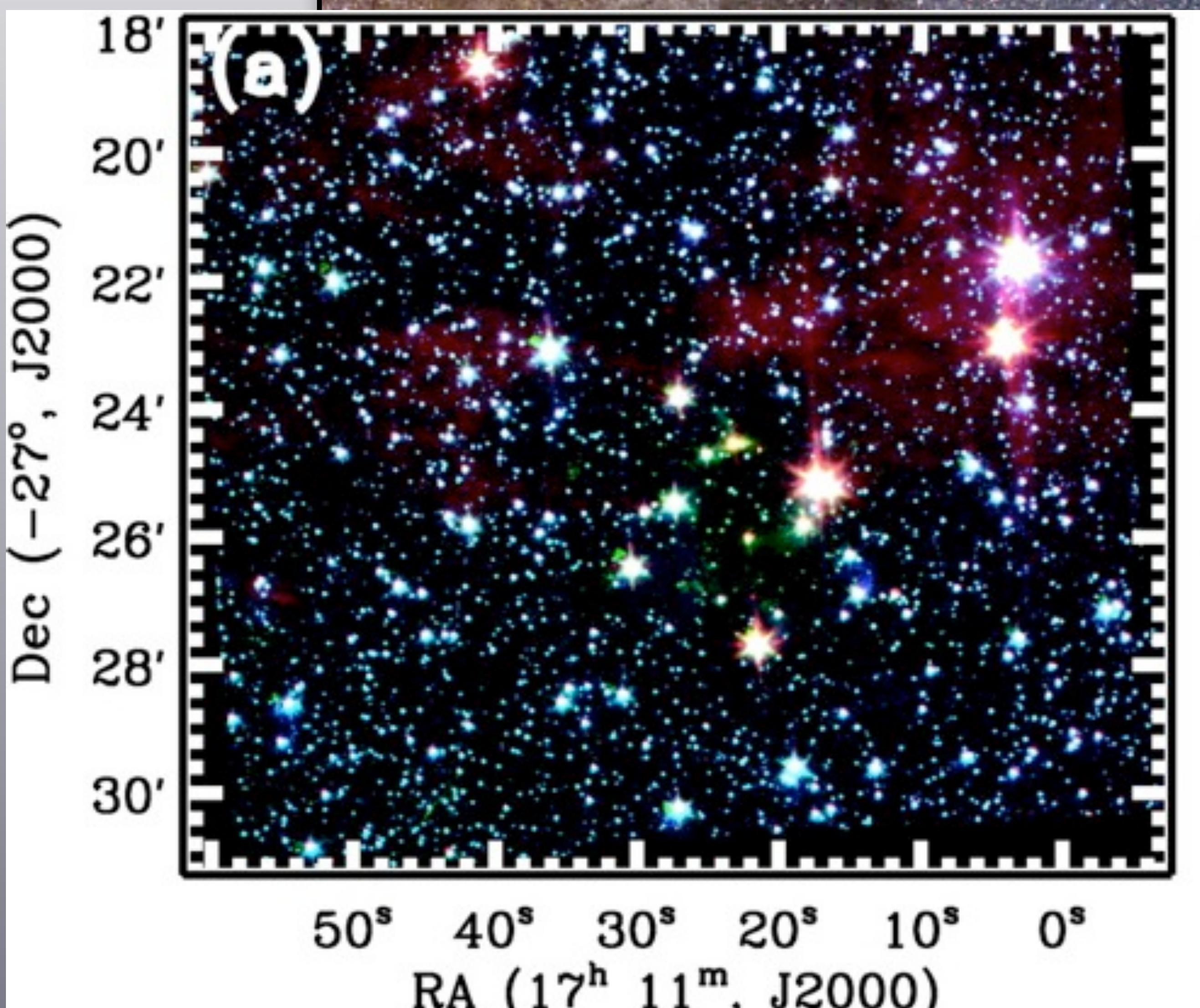

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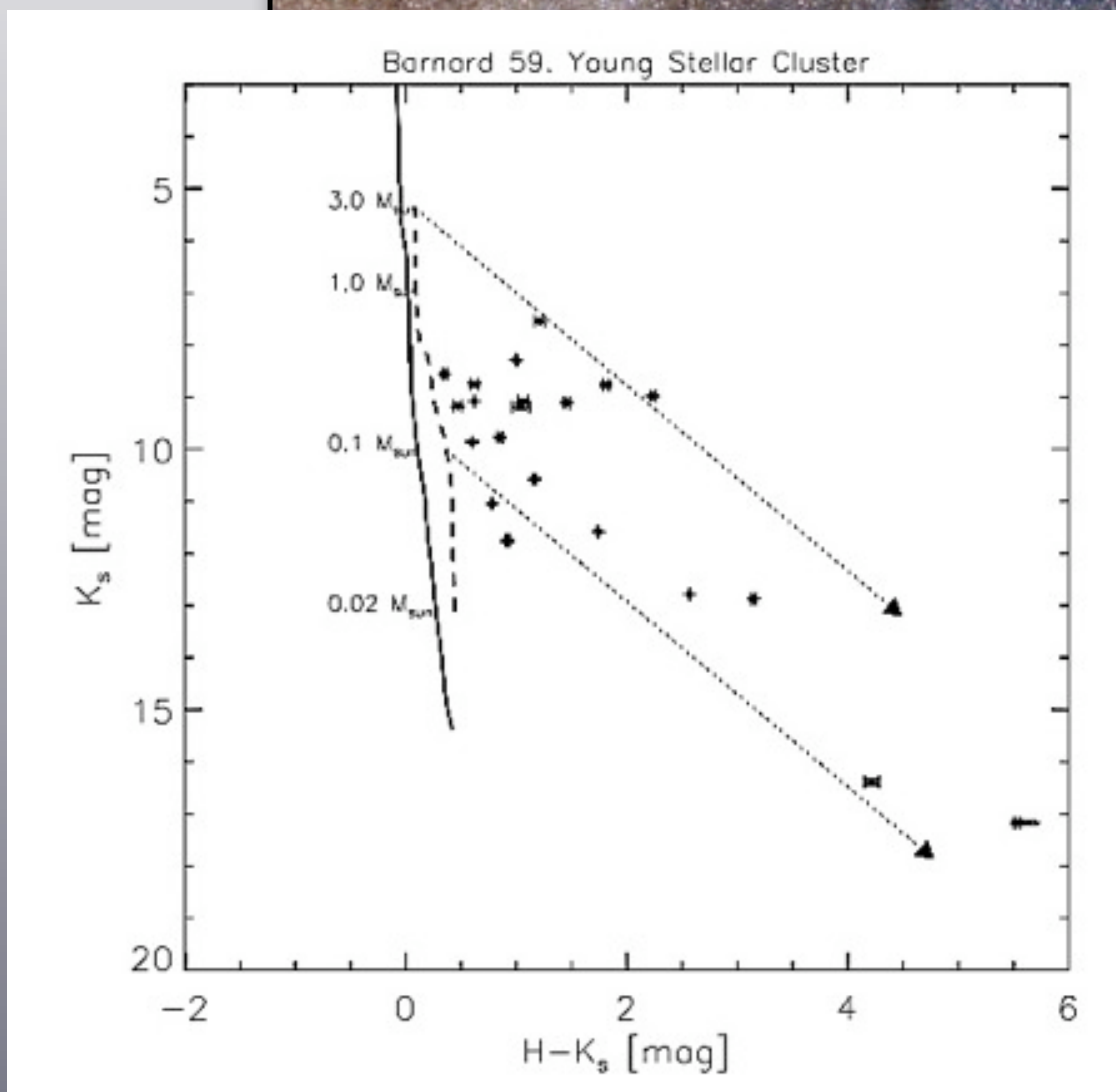

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MOLECULAR CLOUD CORES

and why so much hype...

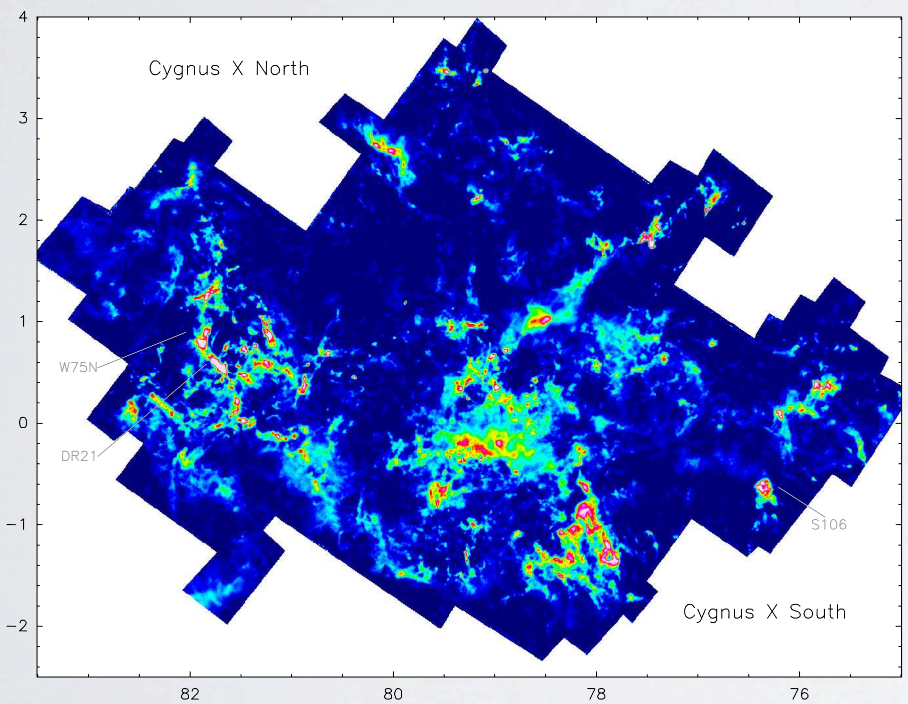
Giant Molecular Clouds → Fragmentation → Gravitational Collapse

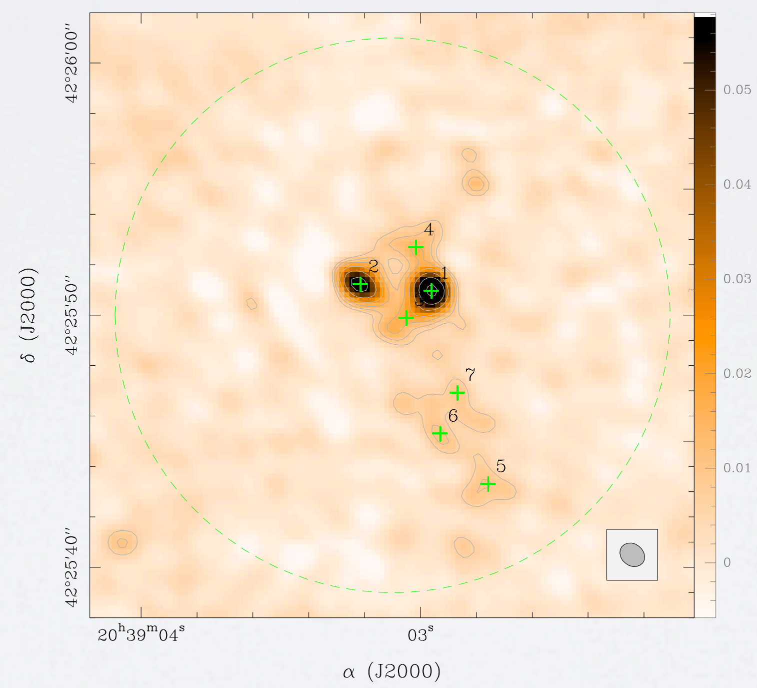
mostly uncertain (Giant Molecular Clouds → Fragmentation)

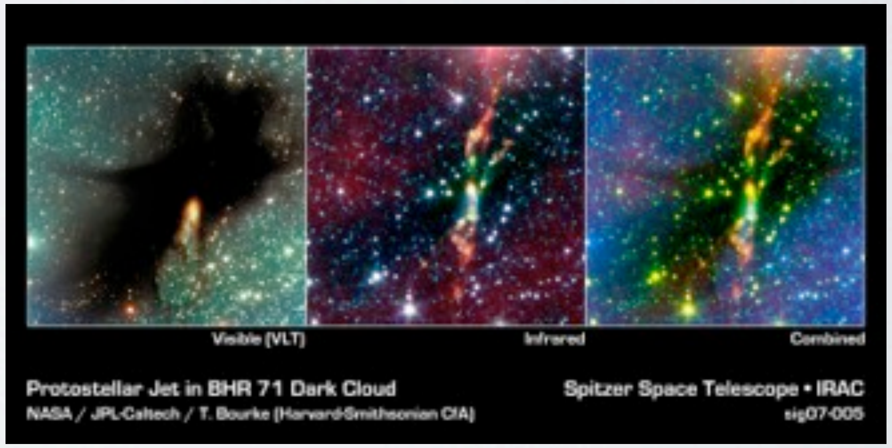
How important is turbulence
How important are magnetic fields
What is the mass distribution of fragments
How do you define a clump?
What is a core?

under discussion (Fragmentation → Gravitational Collapse)

How important is turbulence
How important are magnetic fields
What is the role of feedback
How fast is the process
What is the standard efficiency of transformation?







The younger the cloud, the better we understand initial conditions

MOLECULAR CLOUD CORES

and why so much hype...

Giant M

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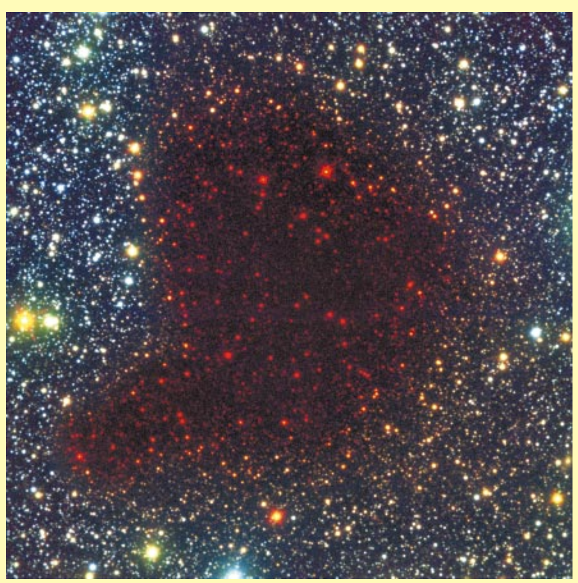
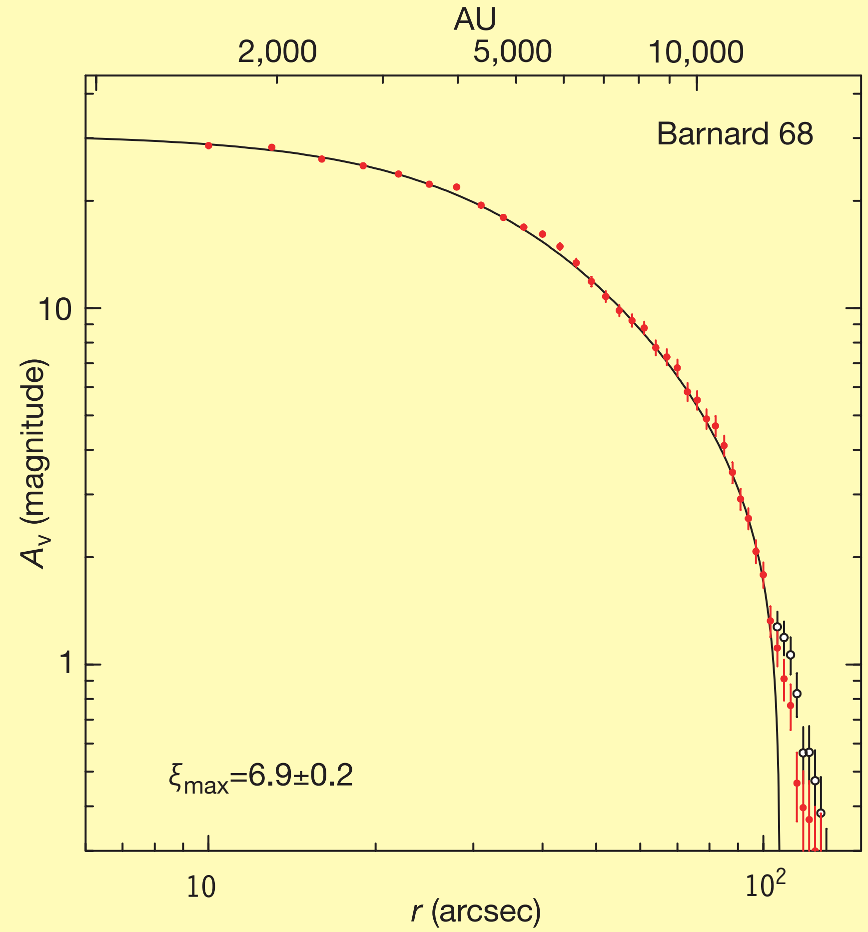
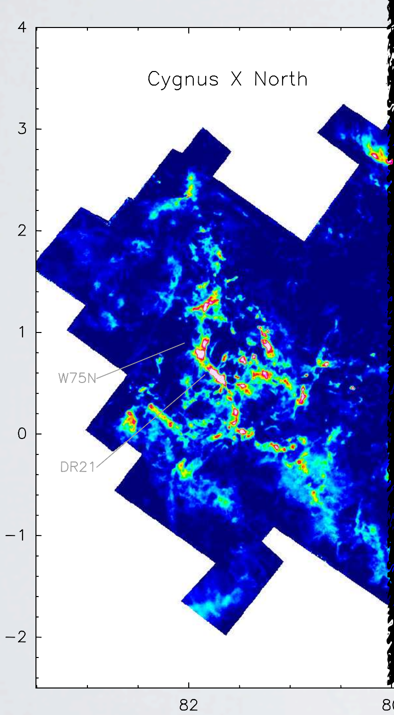
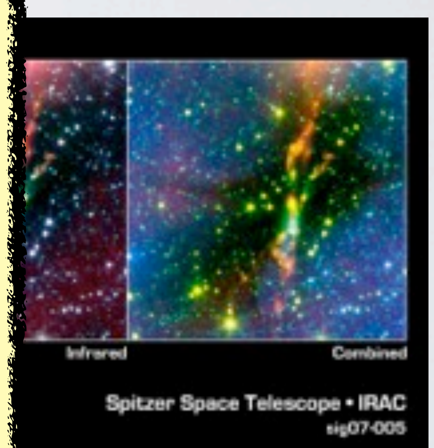




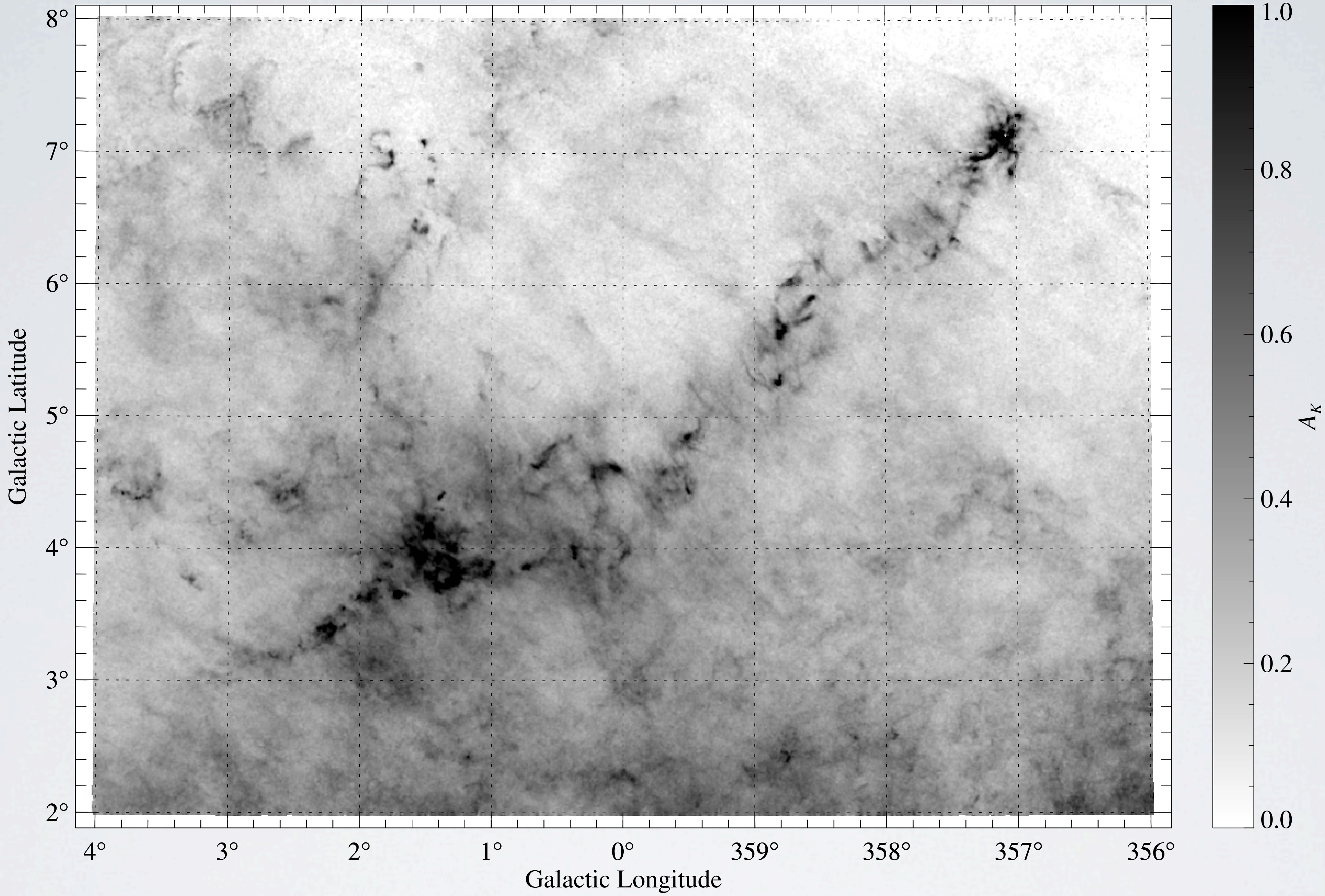
B68: ESO icon





The younger the cloud, the better we understand initial conditions

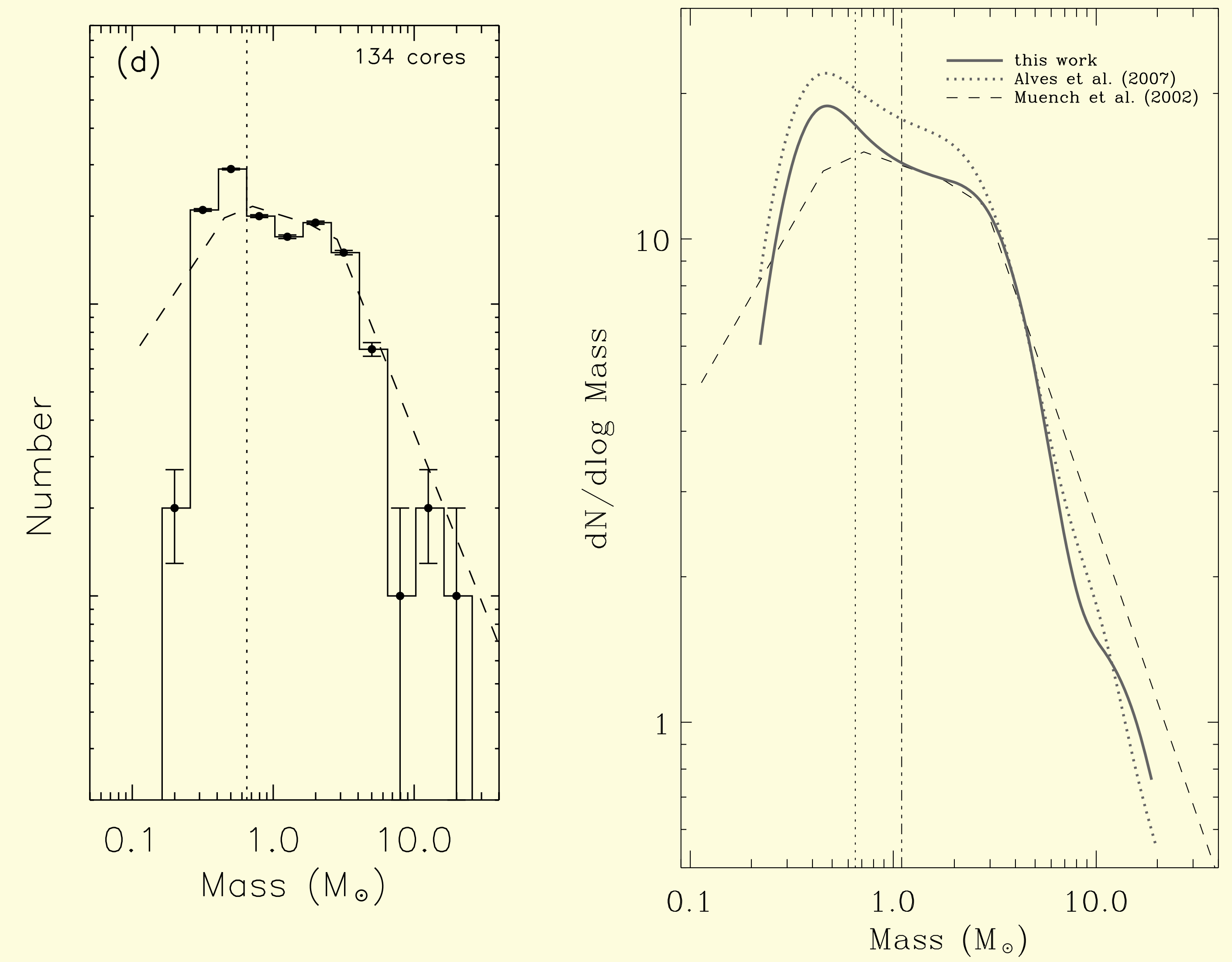
2MASS PIPE NEBULA



Distance, morphology and projection of cloud against galactic bulge allowed to resolve cloud down to the scale of prestellar cores. Near IR excess method to estimate extinction, then column density

Lombardi et al. 2006

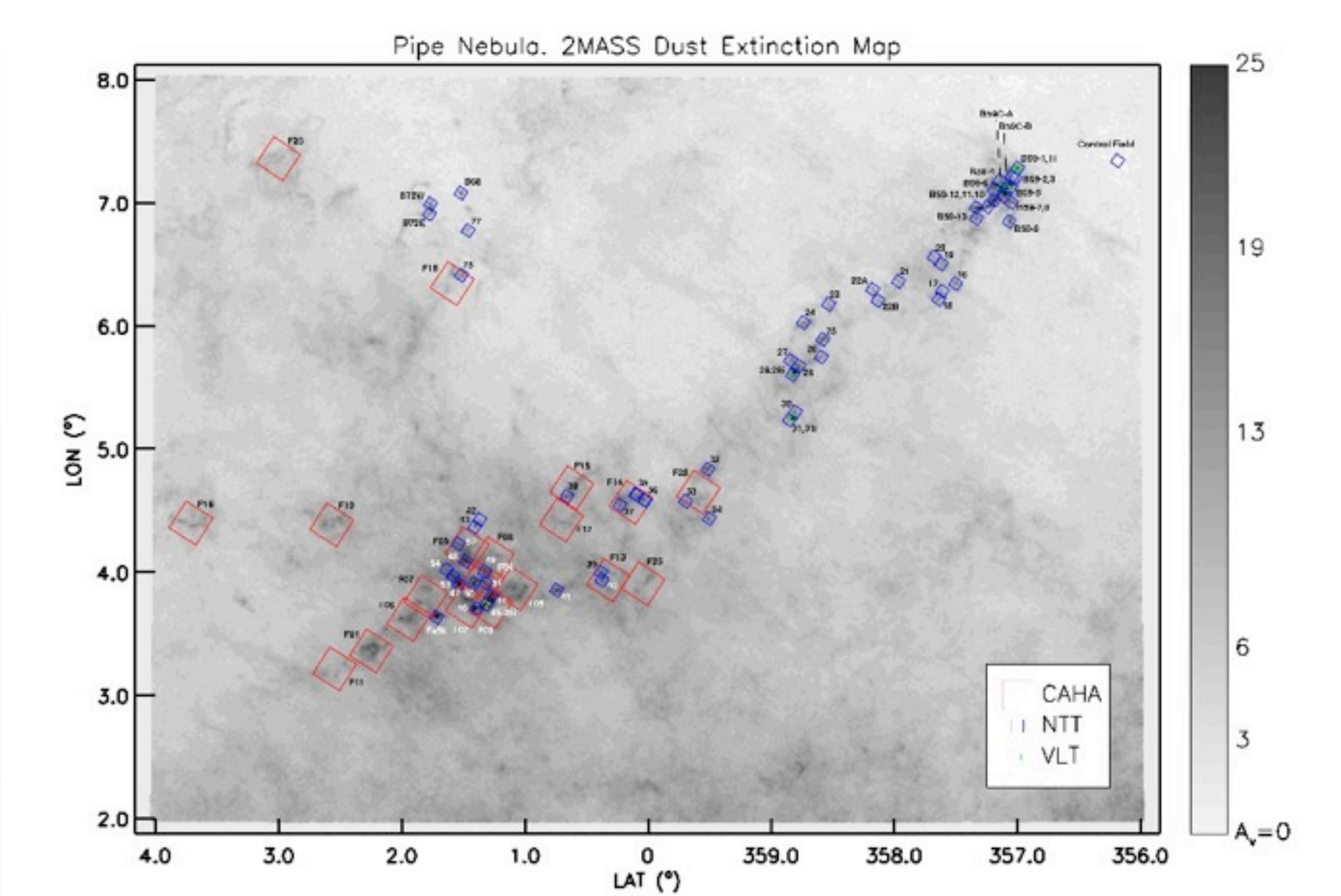
2MASS PIPE NEBULA



Core initial mass function: clue for initial conditions of IMF

Rathborne et al 2008

HI-RES NEAR-IR SURVEY



Roman-Zuniga, Alves, Lada & Lombardi, 2010

•While the map of LAA06 permitted a great "in bulk" view of the core population, higher spatial resolutions are needed to resolve the internal structure of the cores themselves. That step is crucial to determine the physical properties of individual cores and their possible stage of evolution towards collapse into stars.

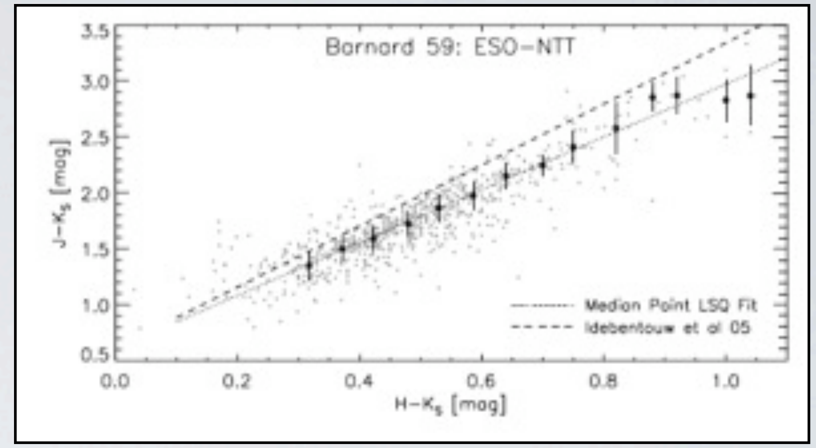
•ESO SURVEY: 55 FIELDS OBSERVED WITH SOFI@NTT-3.6m, 7 FIELDS WITH ISAAC@VLT-8.2m, and 21 FIELDS OBSERVED with OMEGA2000@CAHA-3.5m

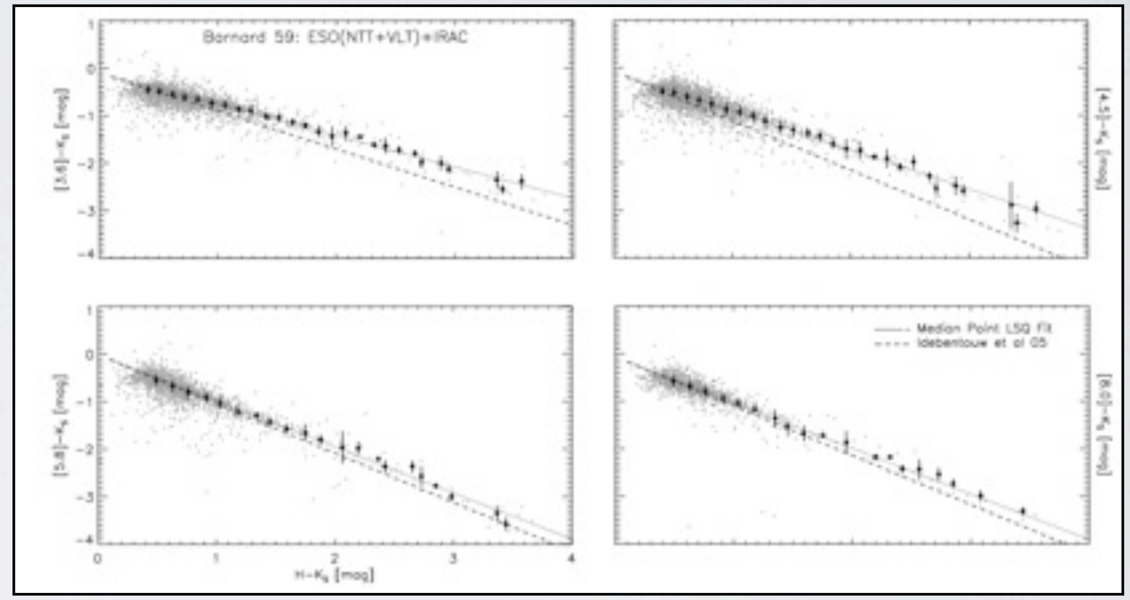
•5-7 magnitudes deeper than 2MASS -> ~5-20x increase in background source density, allow for 2-5 fold in spatial resolution

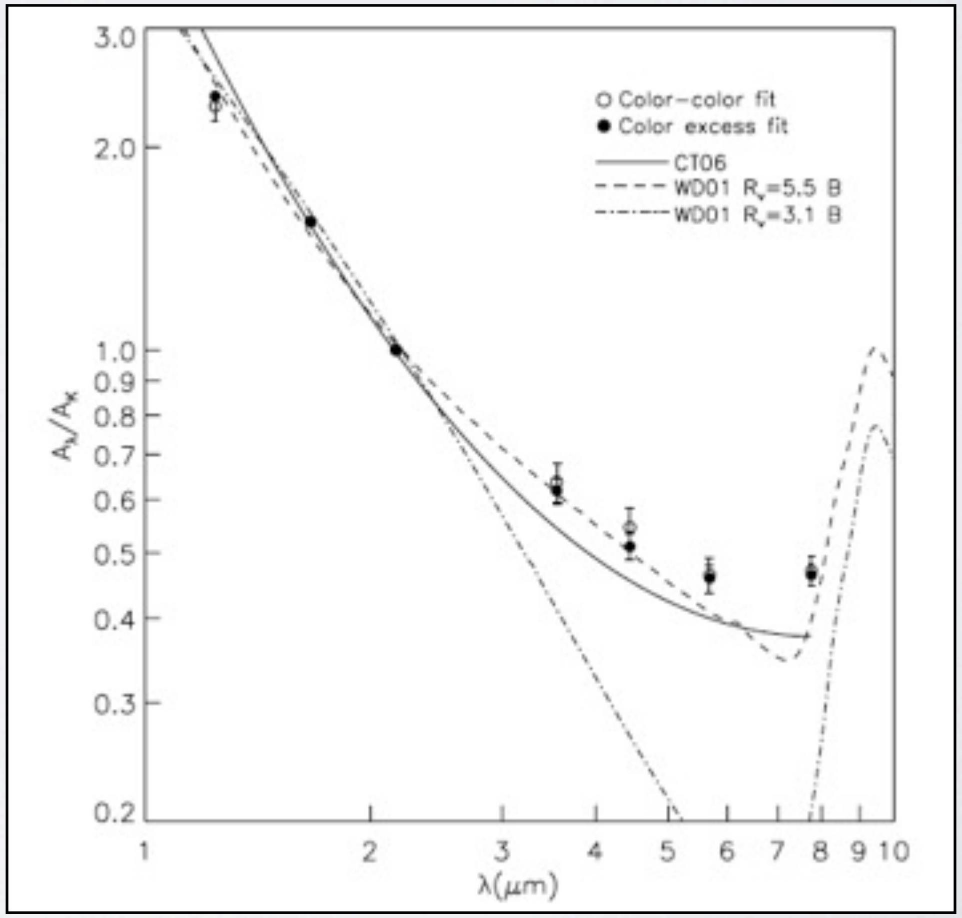
EXTINCTION LAW IN B59

- Calculate the relative extinction wr to K band using the slope of the distribution of color excess. Pivot at A_H/A_K=1.55 (Indebetouw et al. 2005), down to Av=60 mag!
- The extinction law towards the dense cloud of B59 shows at most a moderate departure from the one inferred in previous studies mixing observations of thin and thick clouds.
- We find no evidence of significant grain growth as a function of density in a cloud.

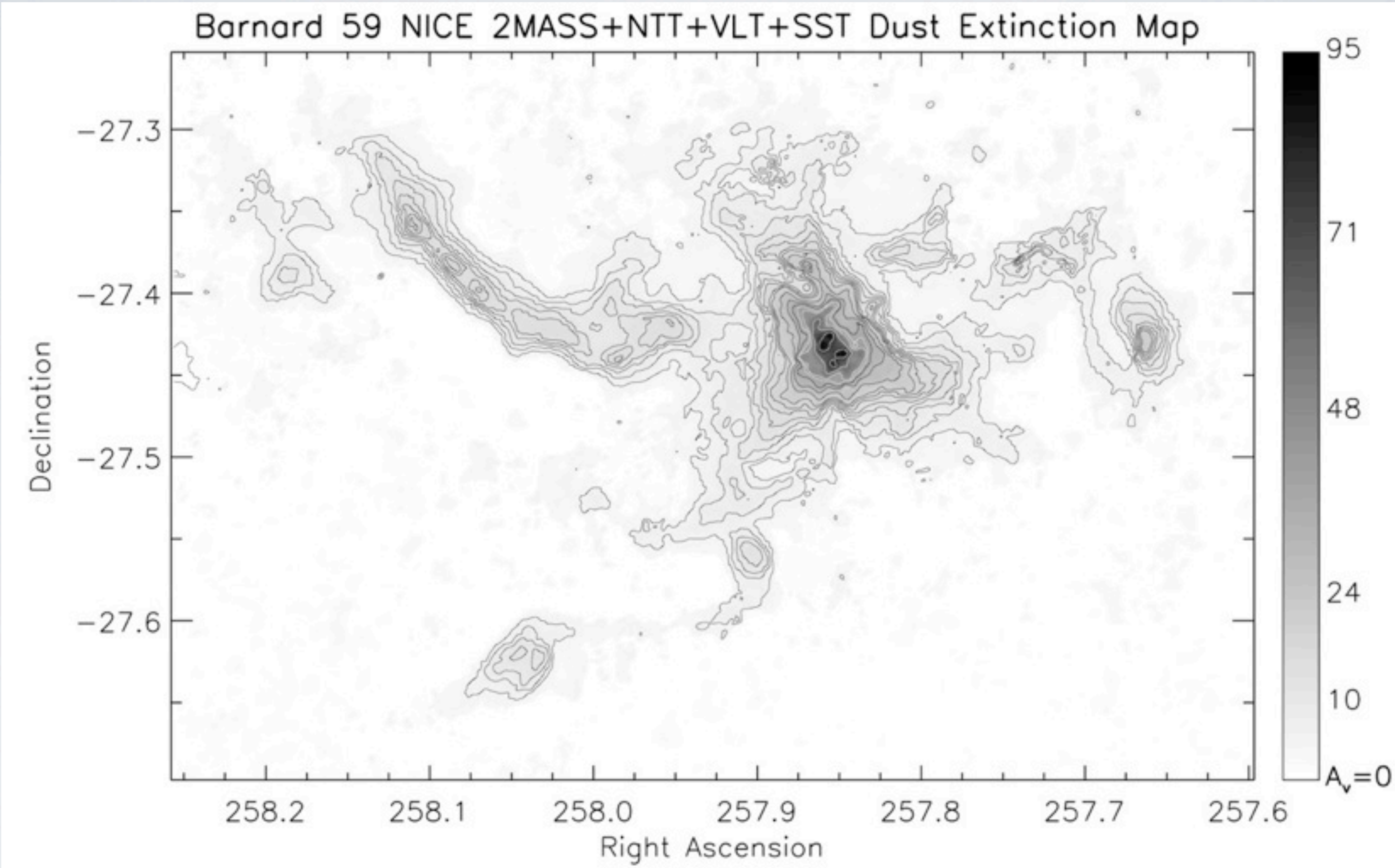
Román-Zúñiga et al 2008







B59 IN HIGH RESOLUTION

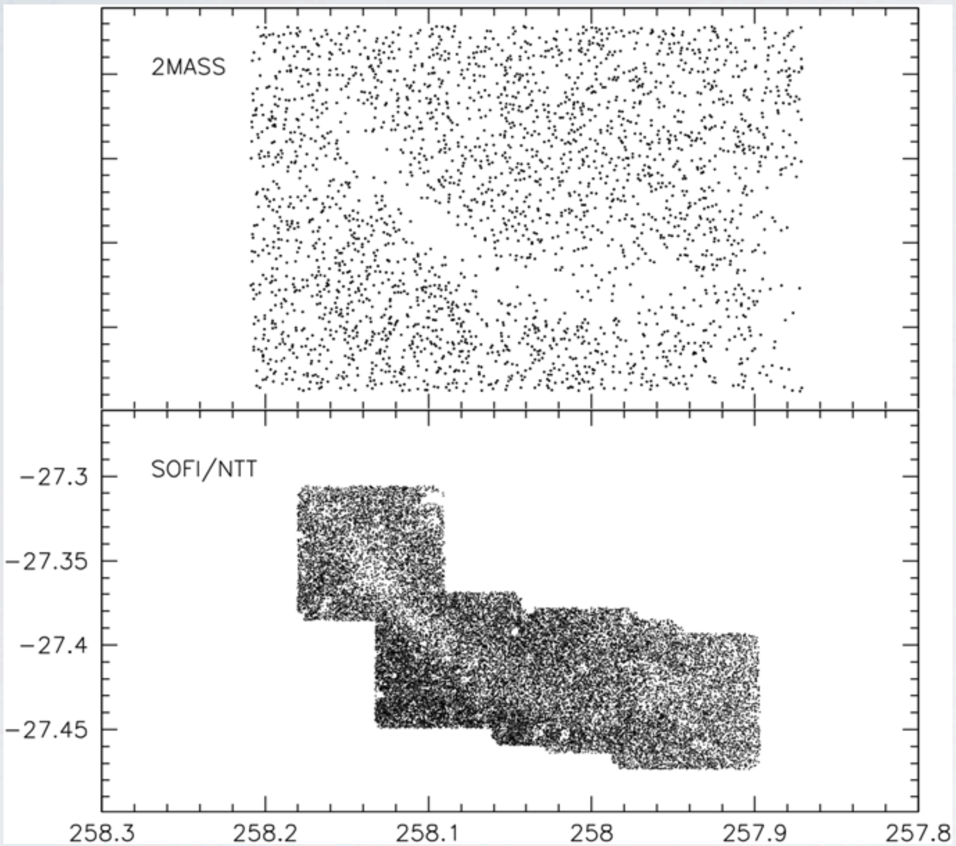


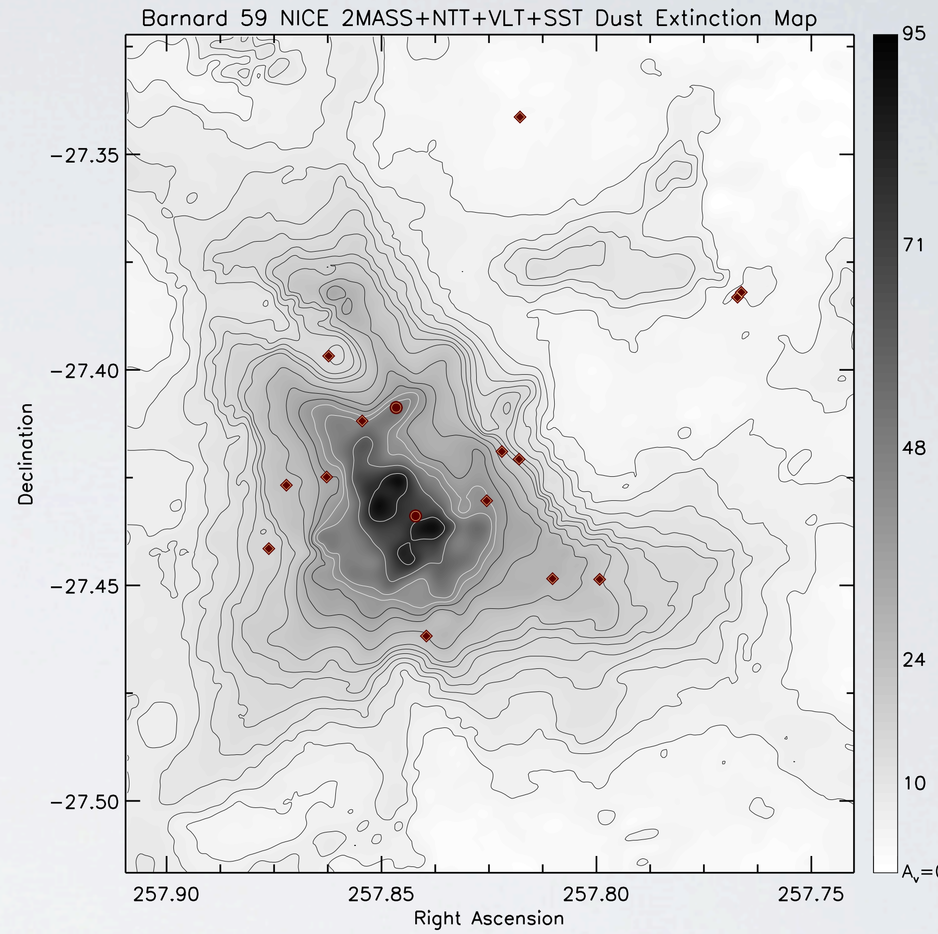
Main features fully resolved
Abundant substructure
High Dynamic Range: $A_V < 89$ mag or $N(H_2) < 8.45 \times 10^{22}$ cm^{-2}

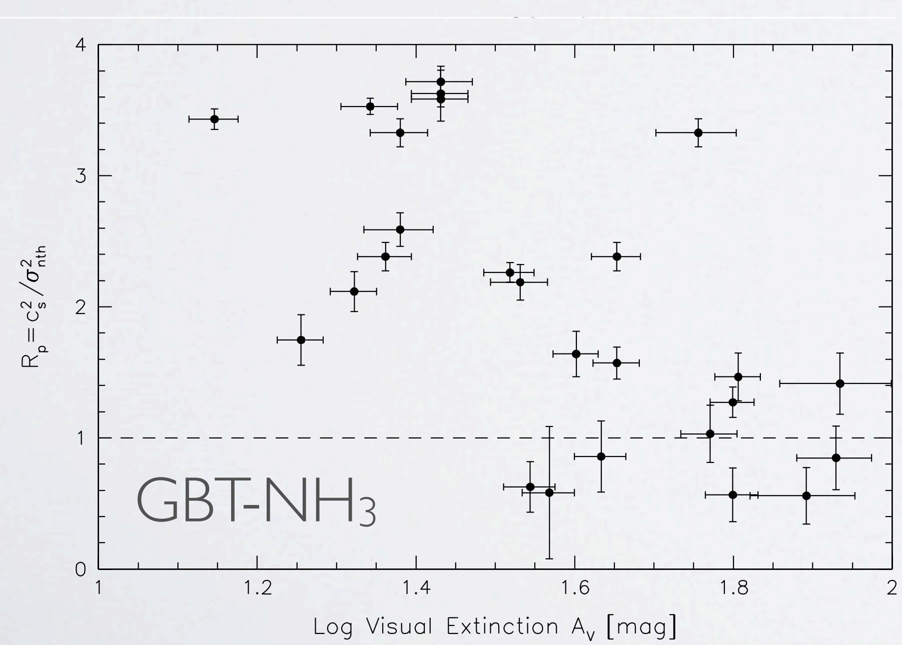
Román-Zúñiga et al 2010

B59 IN HIGH RESOLUTION

ESO vs 2MASS







Context of B59 young cluster in its forming cloud

Evidence of feedback effects

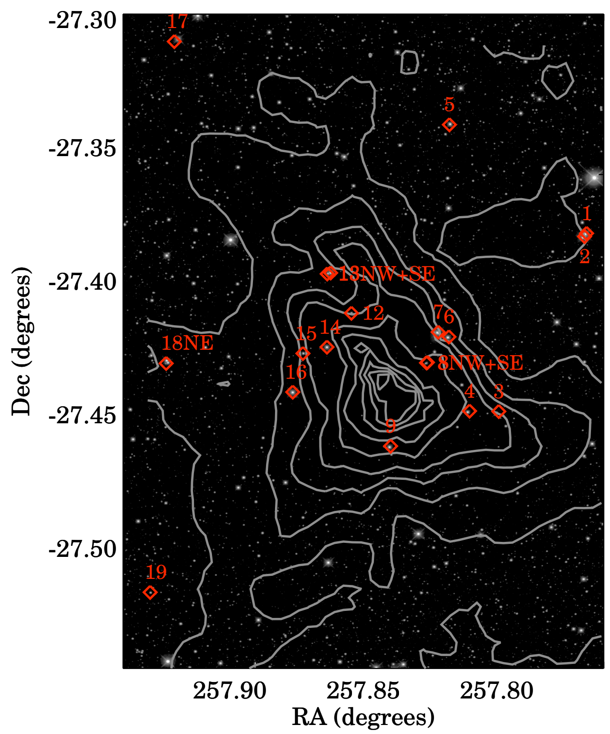
Little structure in central core

Dense gas mostly quiescent!

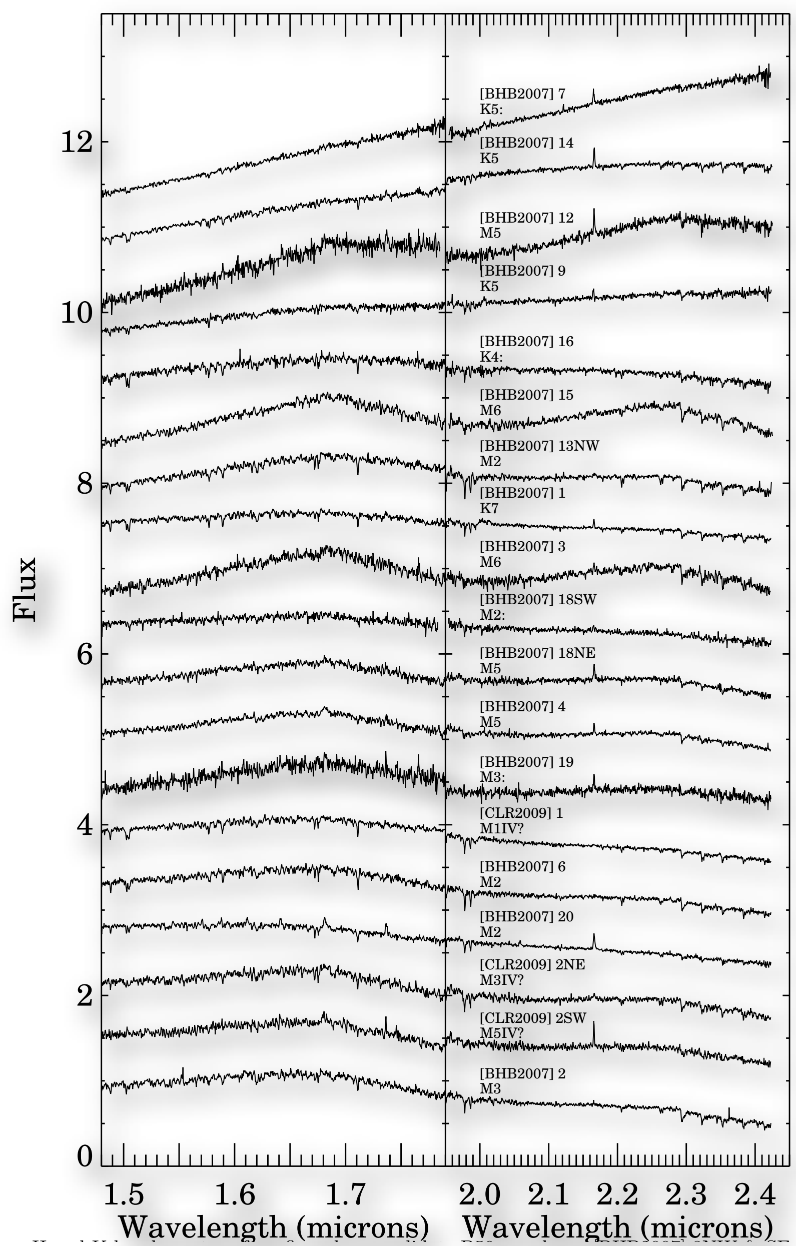
Román-Zúñiga et al 2010

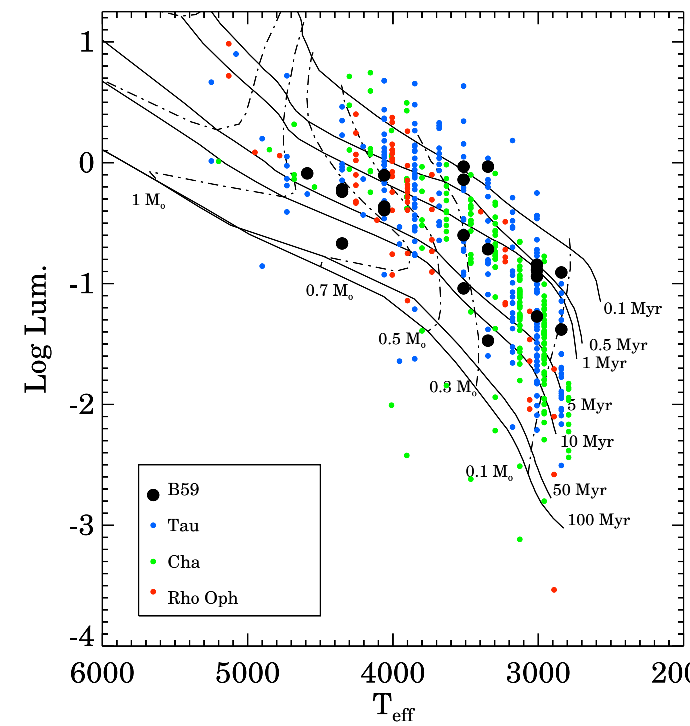
SPEX SURVEY OF B59

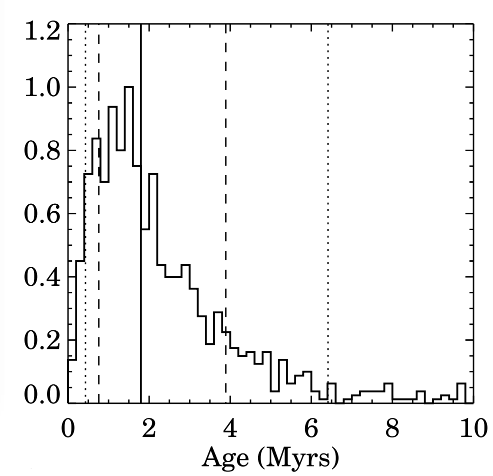
- An spectroscopic survey of YSOs in B59 was performed with SpeX@IRTF.
- Most members were classified as M and K stars
- Age of B59 estimated to be ~2.6 Myr => 6 t_{ff}, SFE/t_{dyn} ≈ 6%
- Agrees well with SF simulations that include a B field + feedback

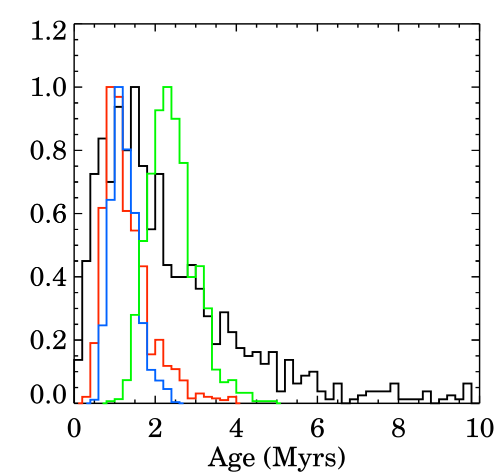


Covey et al 2009









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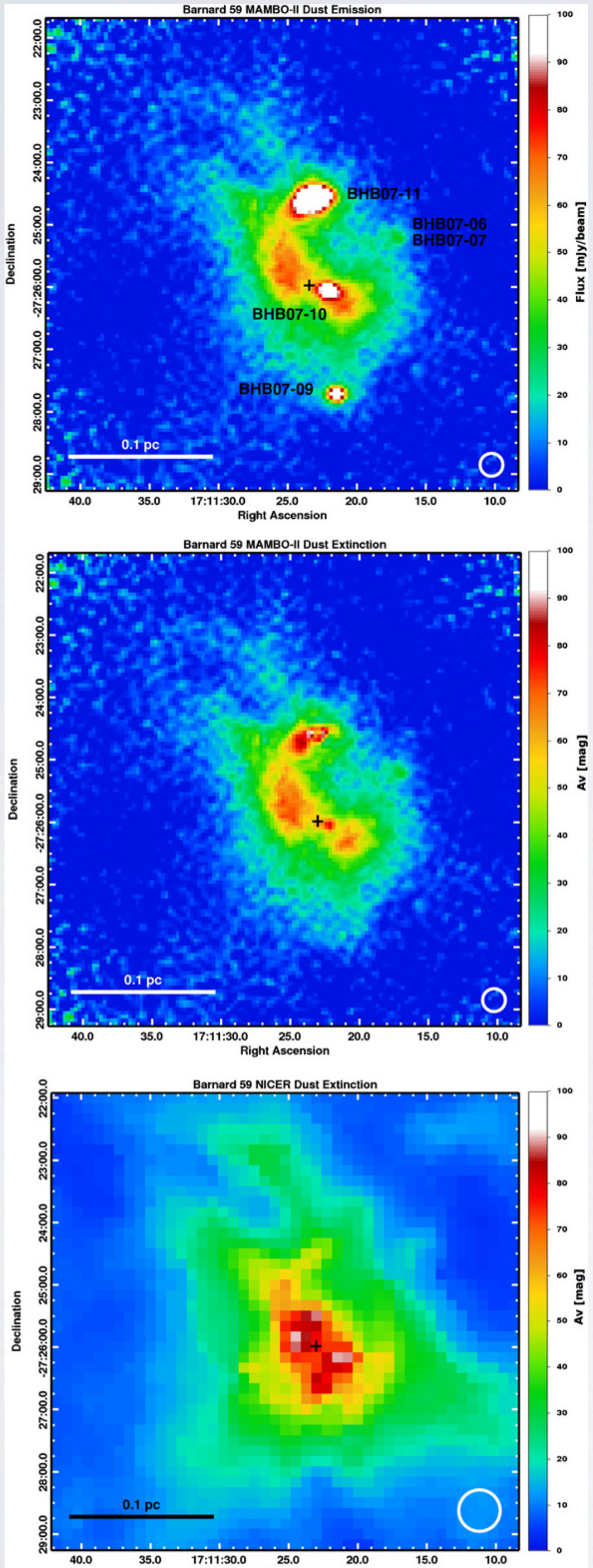
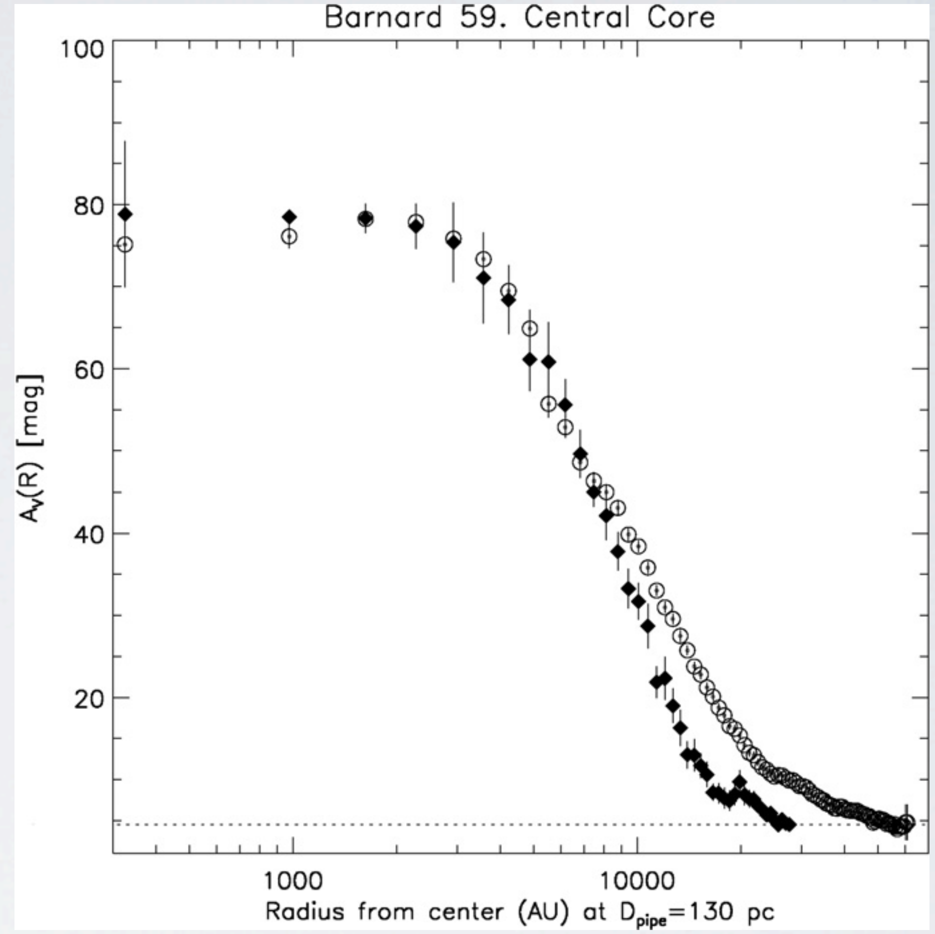




Radio continuum map, IRAM 30m doubles resolution.

Confirms absence of significant substructure in the central core down to 2000-5000 AU

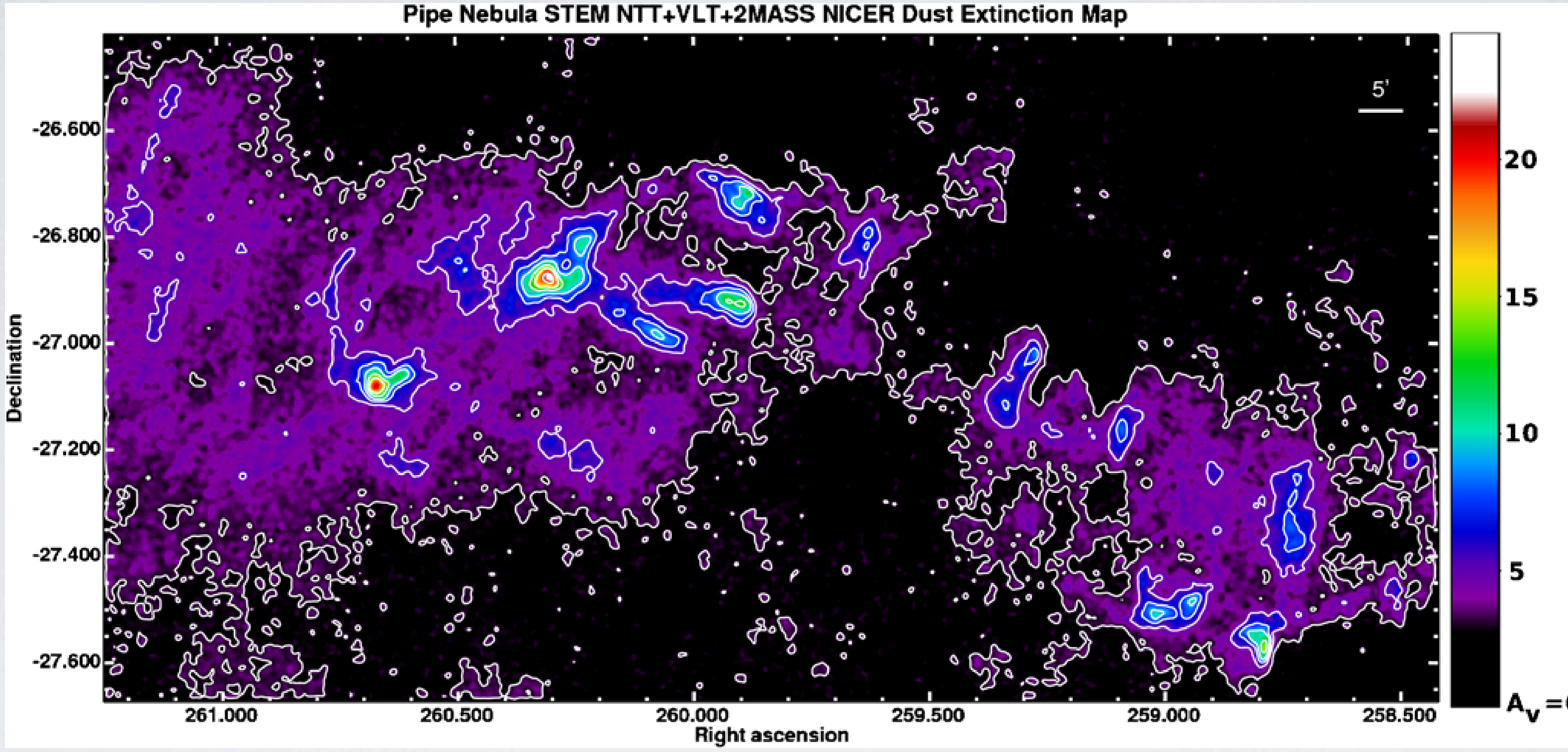
Monotonic radial profile

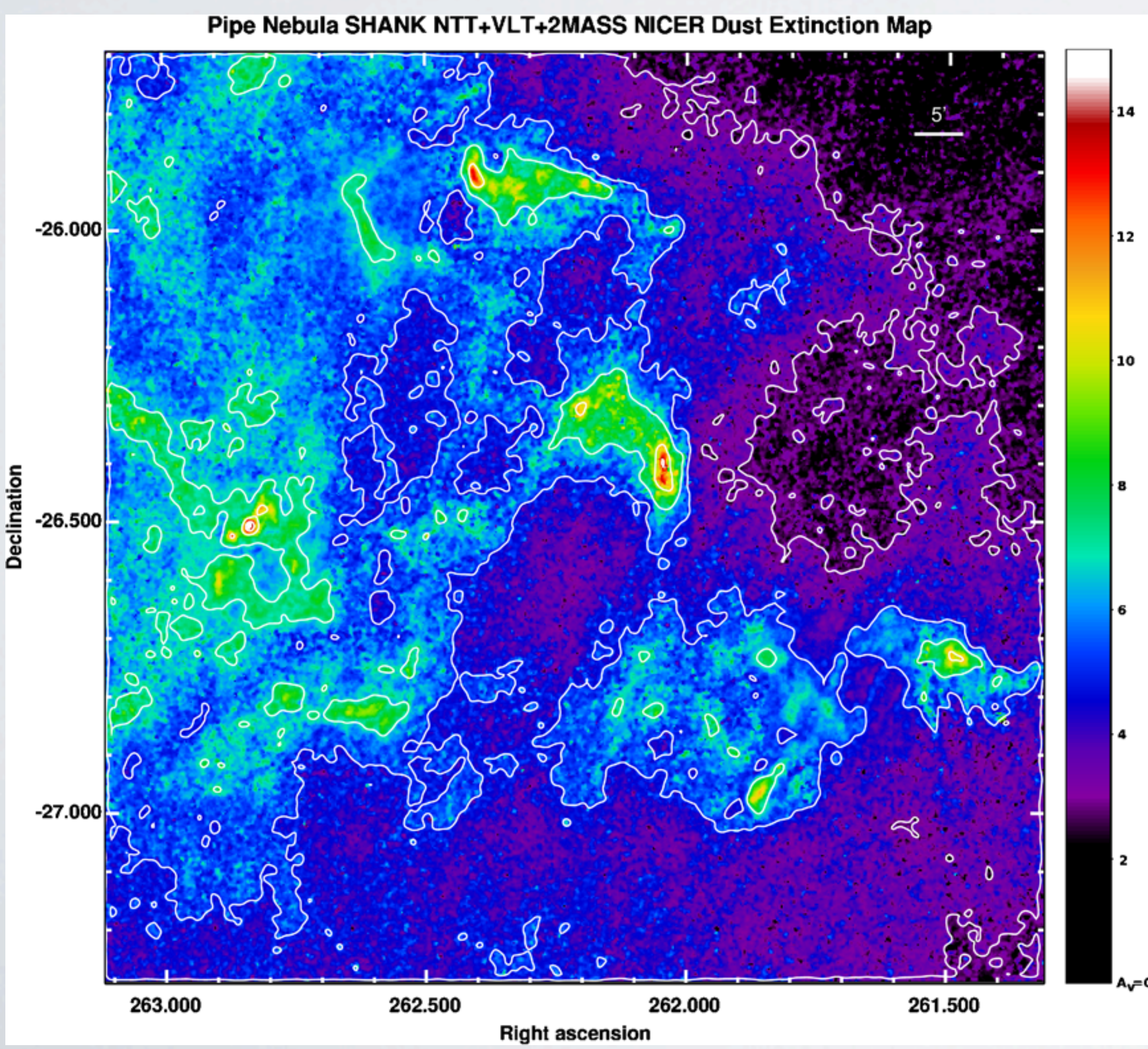
No evidence for further clump fragmentation in B59

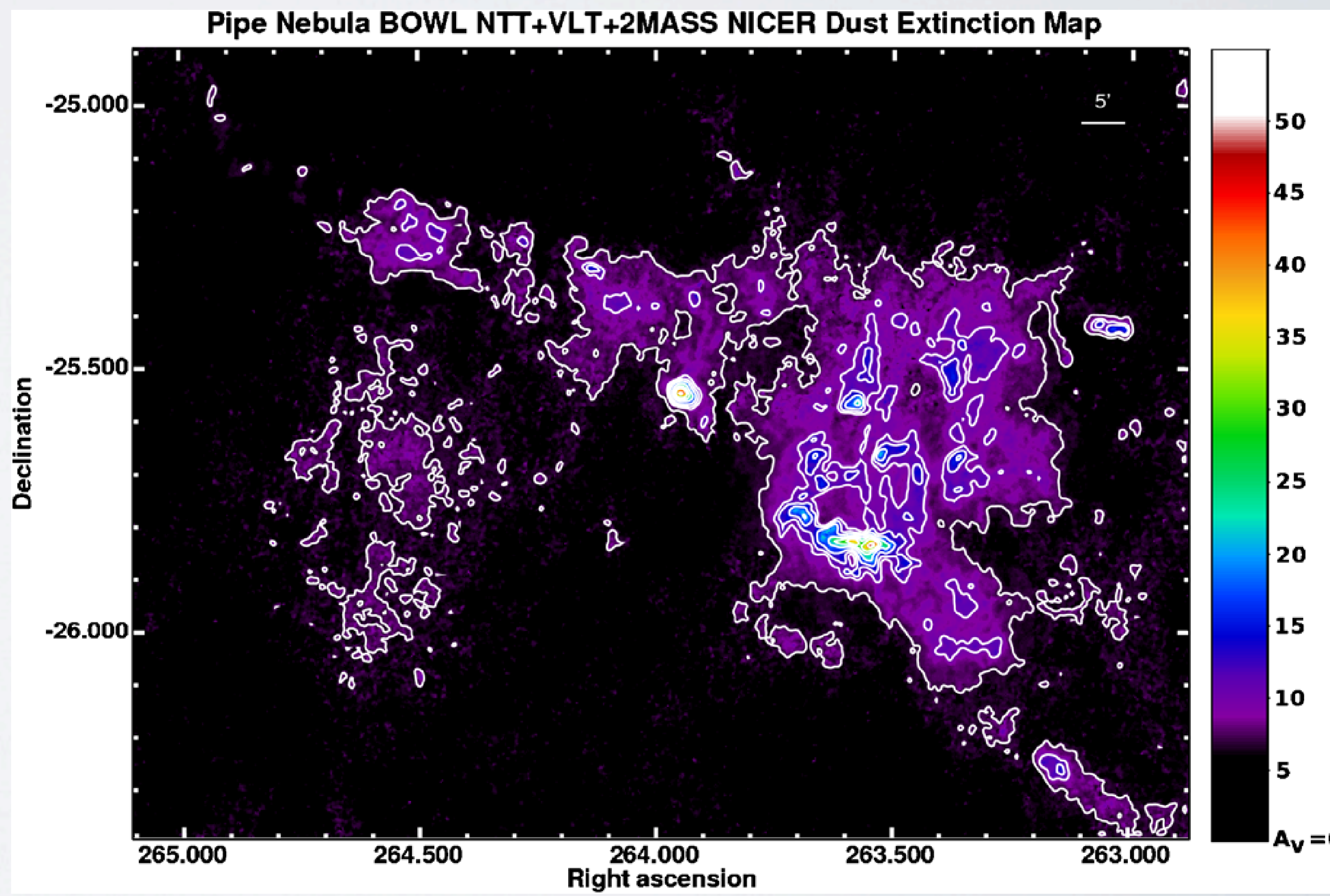
Action of magnetic field to retard collapse?

Román-Zúñiga et al 2012

PIPE NEBULA: MOSTLY STARLESS







Román-Zúñiga et al 2011

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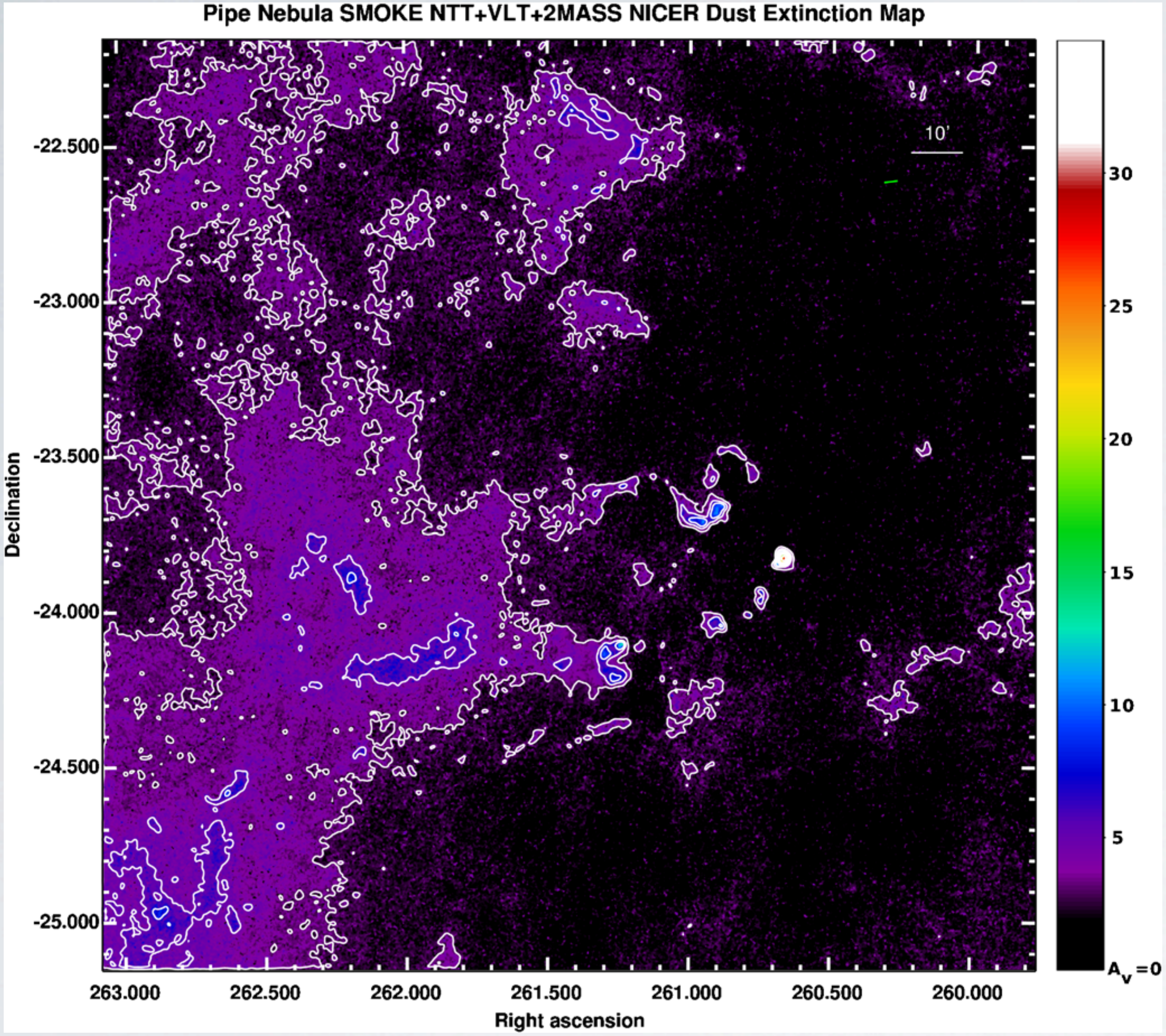
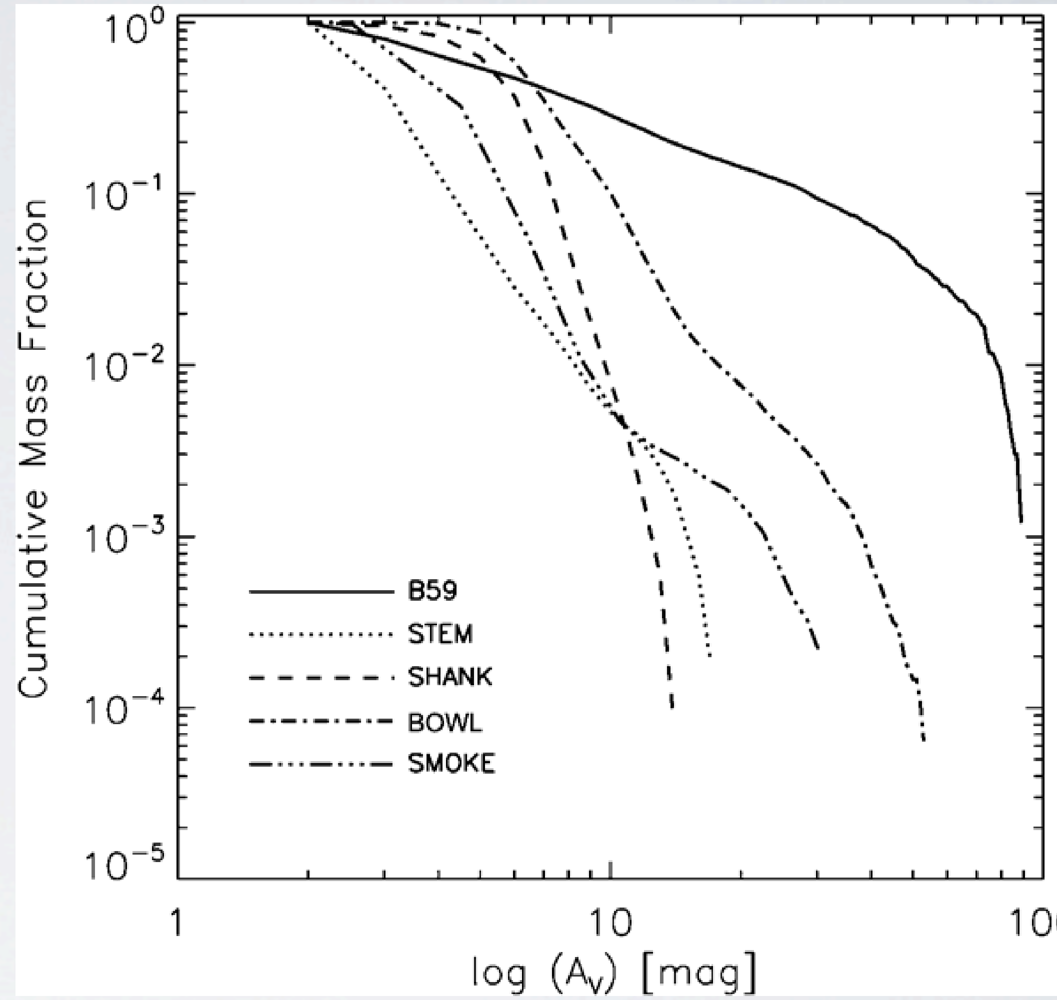




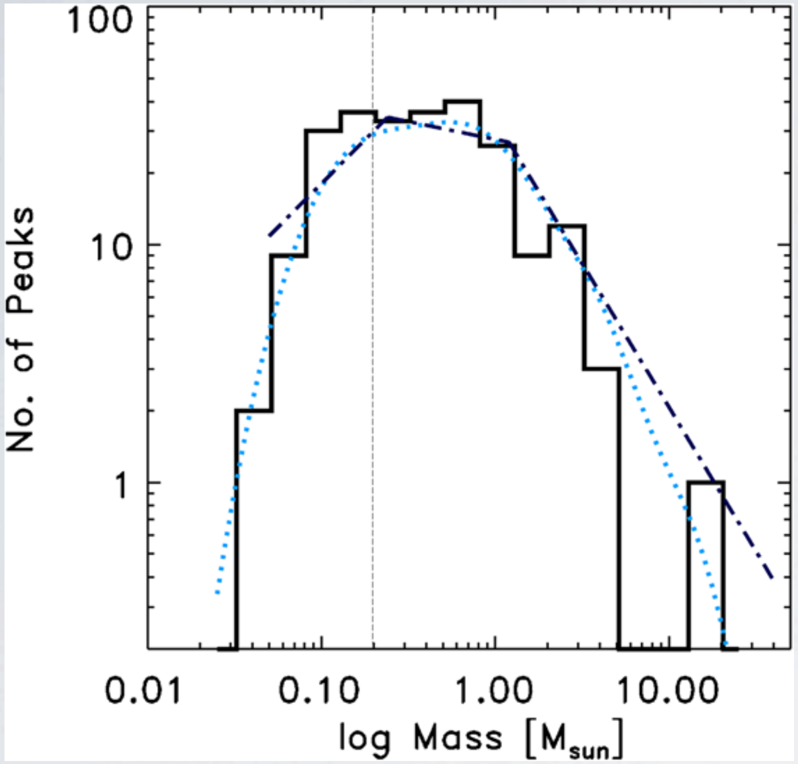
Different regions of the cloud reveal slightly different evolutionary states within the cloud

B59 has already organized towards collapse, but the rest of the cloud is still in a very early stage. Bowl may be next.

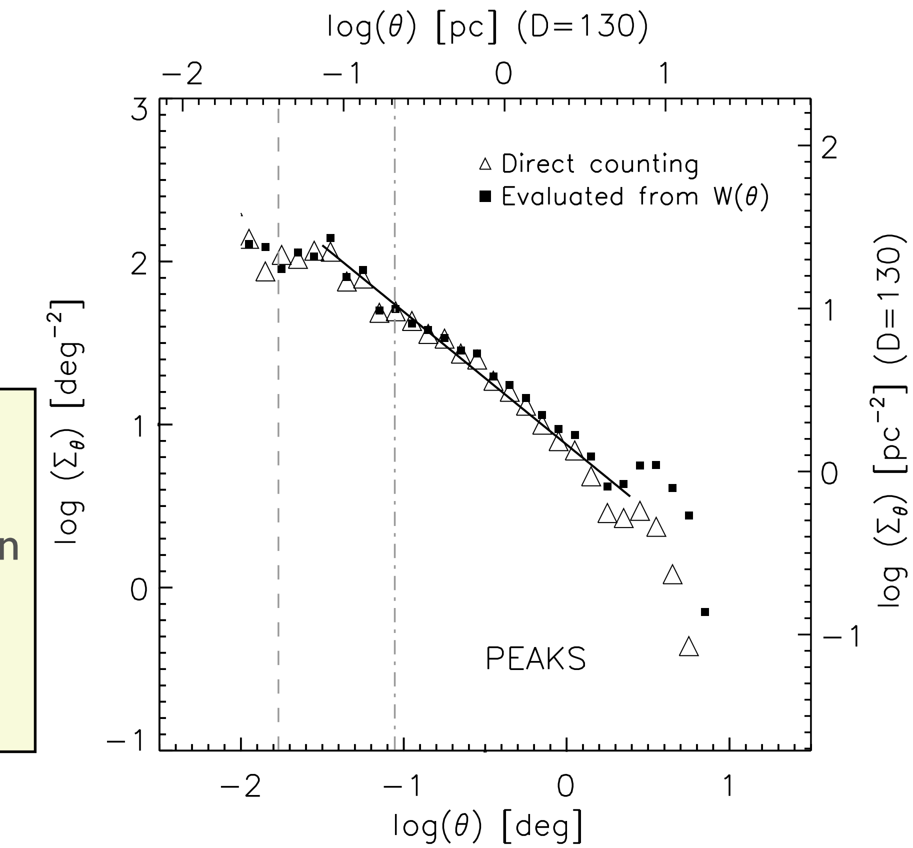
Cores show significant substructure, below Jeans length

Román-Zúñiga et al 2011

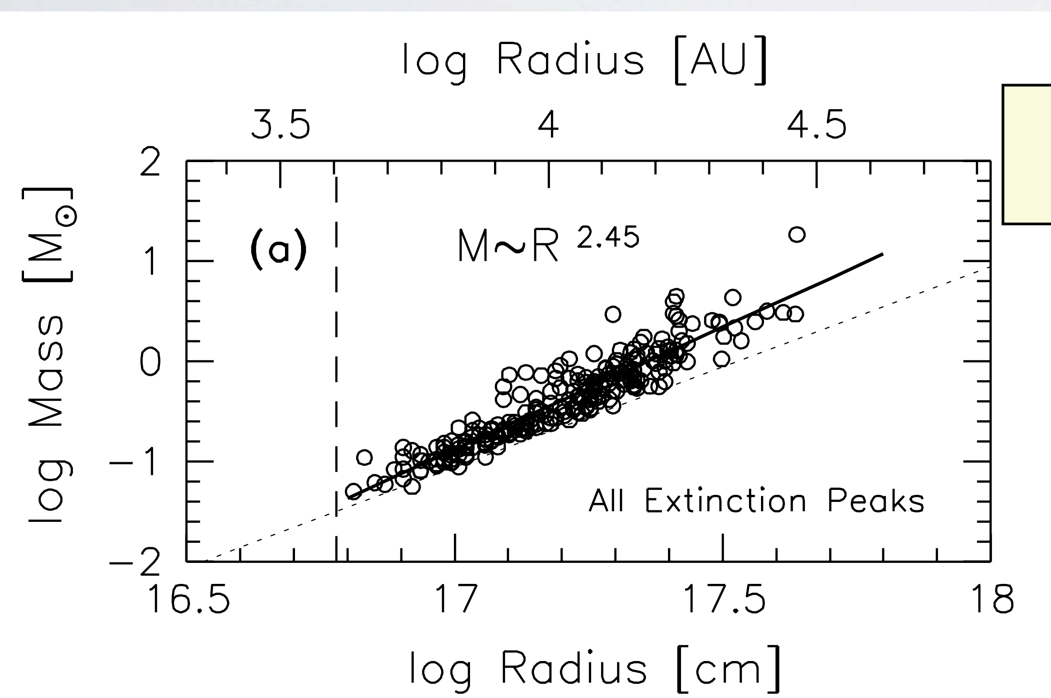
STRUCTURE



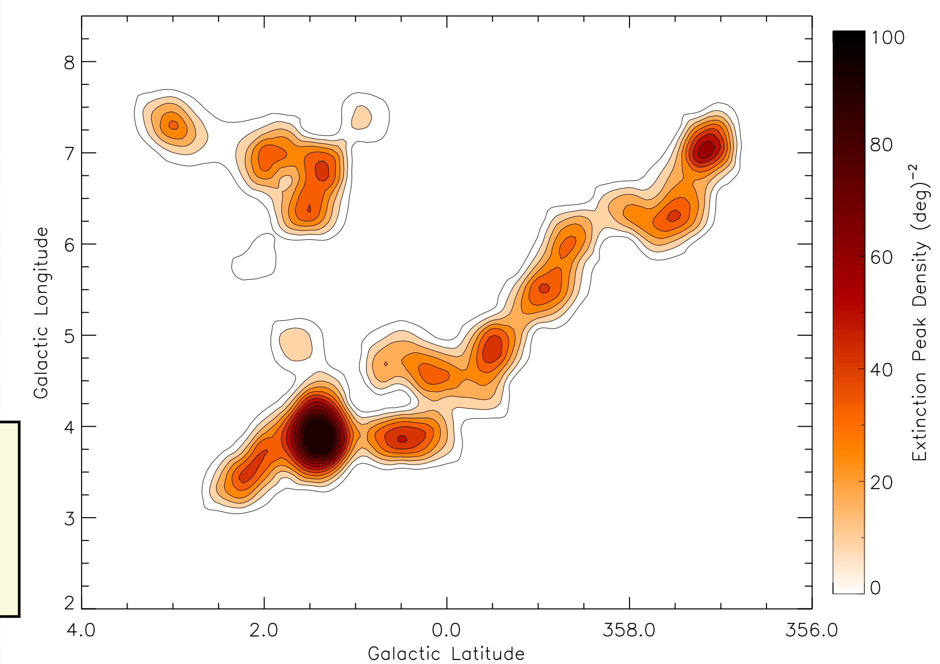
Distribution of mass for extinction peaks shows appears to mimic core mass function.



Mean surface density of companions: peaks distribute along filaments, in the same manner as stars in Taurus. Also, a maximum at 14500 AU appears to mark a limit for the scale of fragmentation



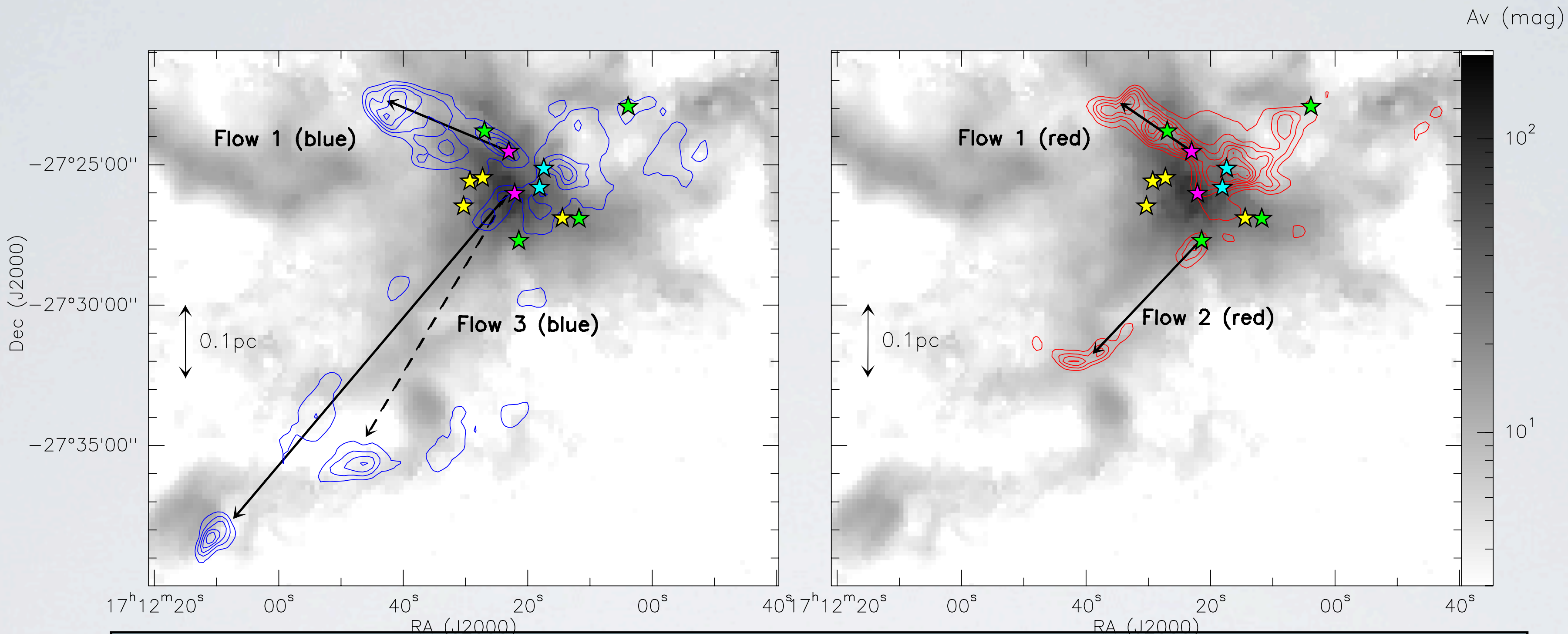
tight mass-radius relationship



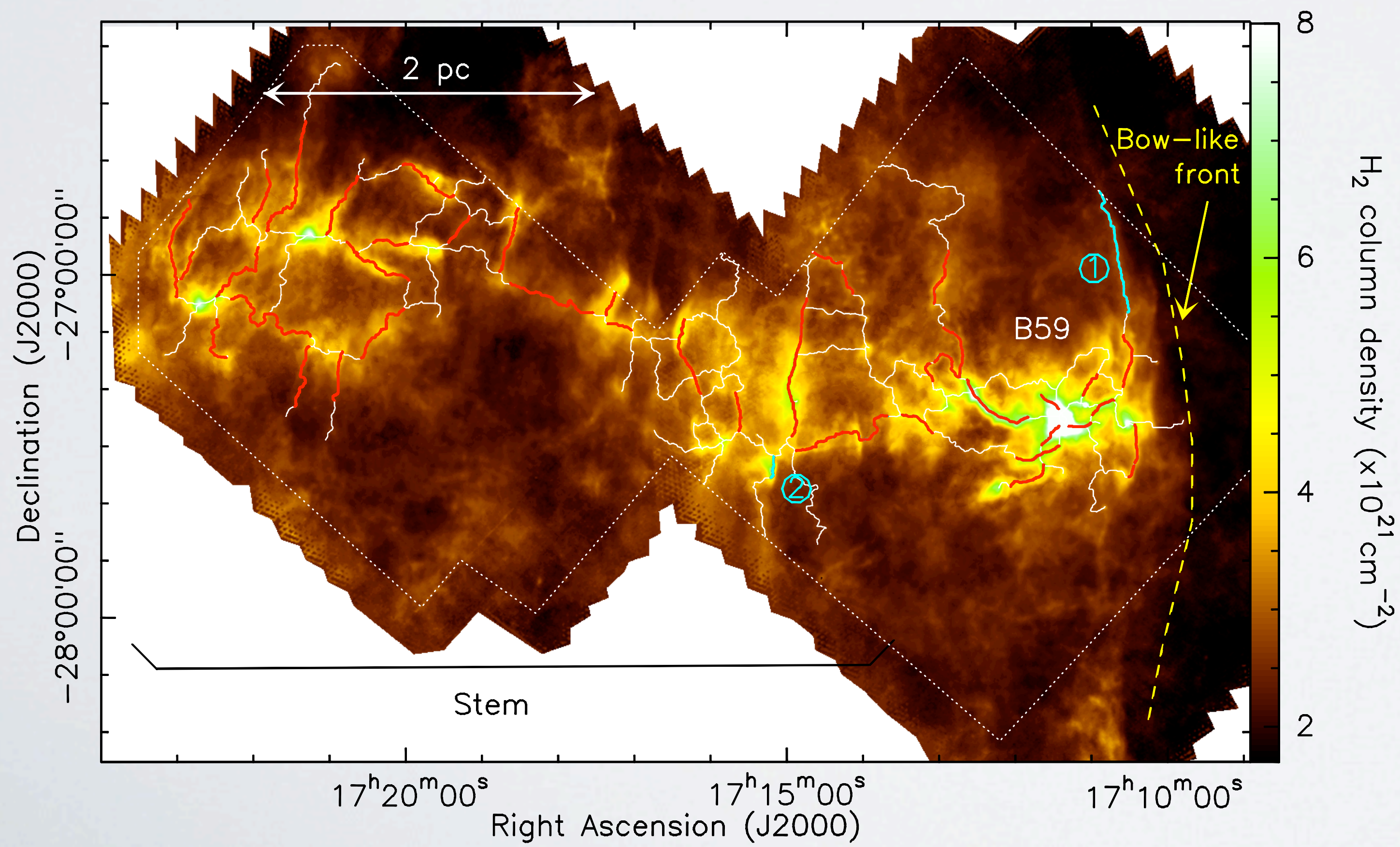
"clustering" of peaks: primordial organization of stars?

Román-Zúñiga et al 2011

PIPE NEBULA: MORE CLUES

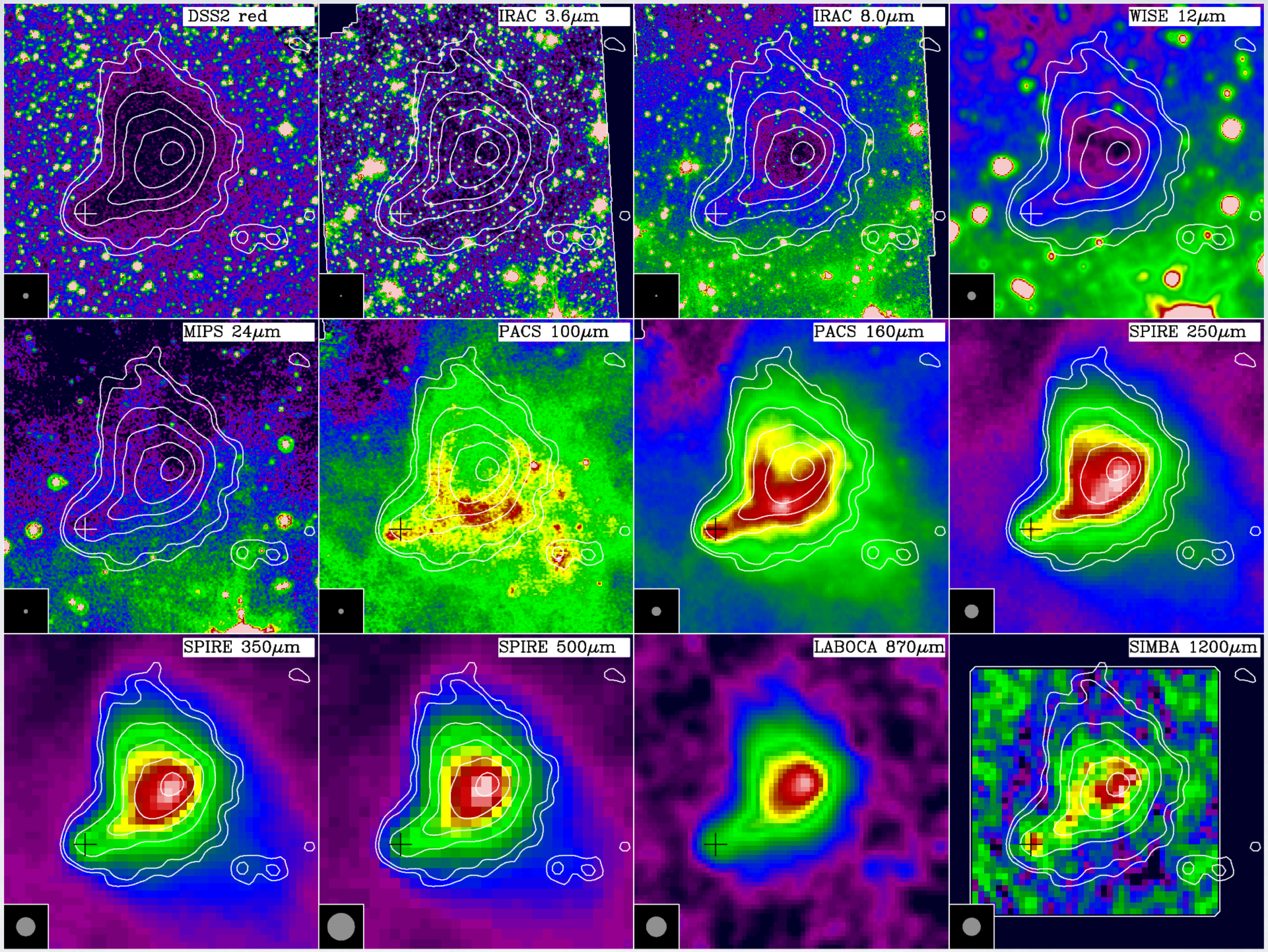


Duarte-Cabral et al 2012: outflows from YSOs revealed in 12CO emission maps. Relation to structures observed in maps are now more clear. Outflows may be increasing turbulent energy to the cloud, effectively retarding collapse.



Peretto et al 2012: Herschel maps reveal the complex structure of filaments in the B59 and Stem regions of the Pipe Nebula. Large scale, primordial gravitational compression may be the origin of the structure we observe nowadays.

PIPE NEBULA: MORE CLUES



Nielbock et al 2012. EPoS Barnard 68. Globule dissected from optical to sub-mm

SMOKING THE PIPE...

•The NTT and VLT high resolution near-IR imaging allowed to create exquisite, highly detailed maps of column density of a nearby molecular cloud.

•The high spatial resolution achieved has allowed us to peek at the interior of prestellar cores and clumps.

•The Pipe Nebula is a very young cloud and it may contain some crucial keys for the puzzle of the initial conditions of star formation. Some of those keys have already been revealed.

•B59, a small stellar clusters with no massive members is also the only spot in the Pipe Nebula that has collapsed into multiple stars.

•What has hold the rest of the Pipe Nebula against protostellar collapse for almost 3 Myr?

• How does the Pipe Nebula compare to other clouds observed in similar conditions?

•ESO capabilities for large scale infrared surveys at high resolution will allow us to do comparative studies in other complexes.

•Evidently, HERSCHEL and ALMA will play a main role in the near future.

•Nowadays the Pipe Nebula stands as one prime target in virtually all major surveys. 30+ major publications have started to dissect its properties. Not bad for a molecular cloud that until 2006 had been barely observed.

Román-Zúñiga et al 2012 (in. p.)