Diversity in the OB Cluster-Forming Molecular Clouds

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2016 Aug 13

Our Big Questions

How Young Massive Cluster or Globular Cluster Form?

HST Image of 30 Doradus (NGC2070; Credit: NASA, ESA, etc)

The origin of scatterings In the star-formation law

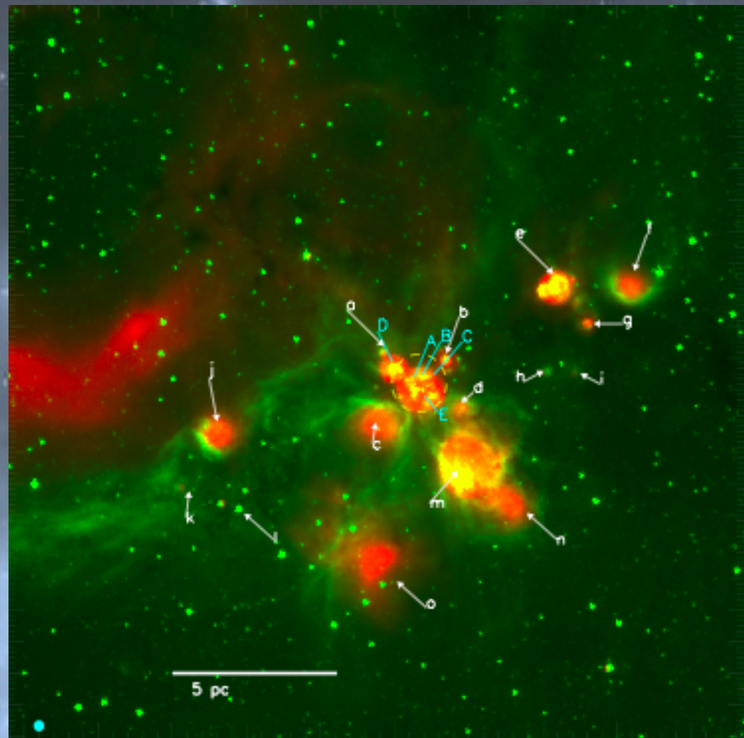
VLT image (I suppose) of antenna galaxies

Our approach: Detailed Studies of Galactic Cases

A Young Massive Cluster

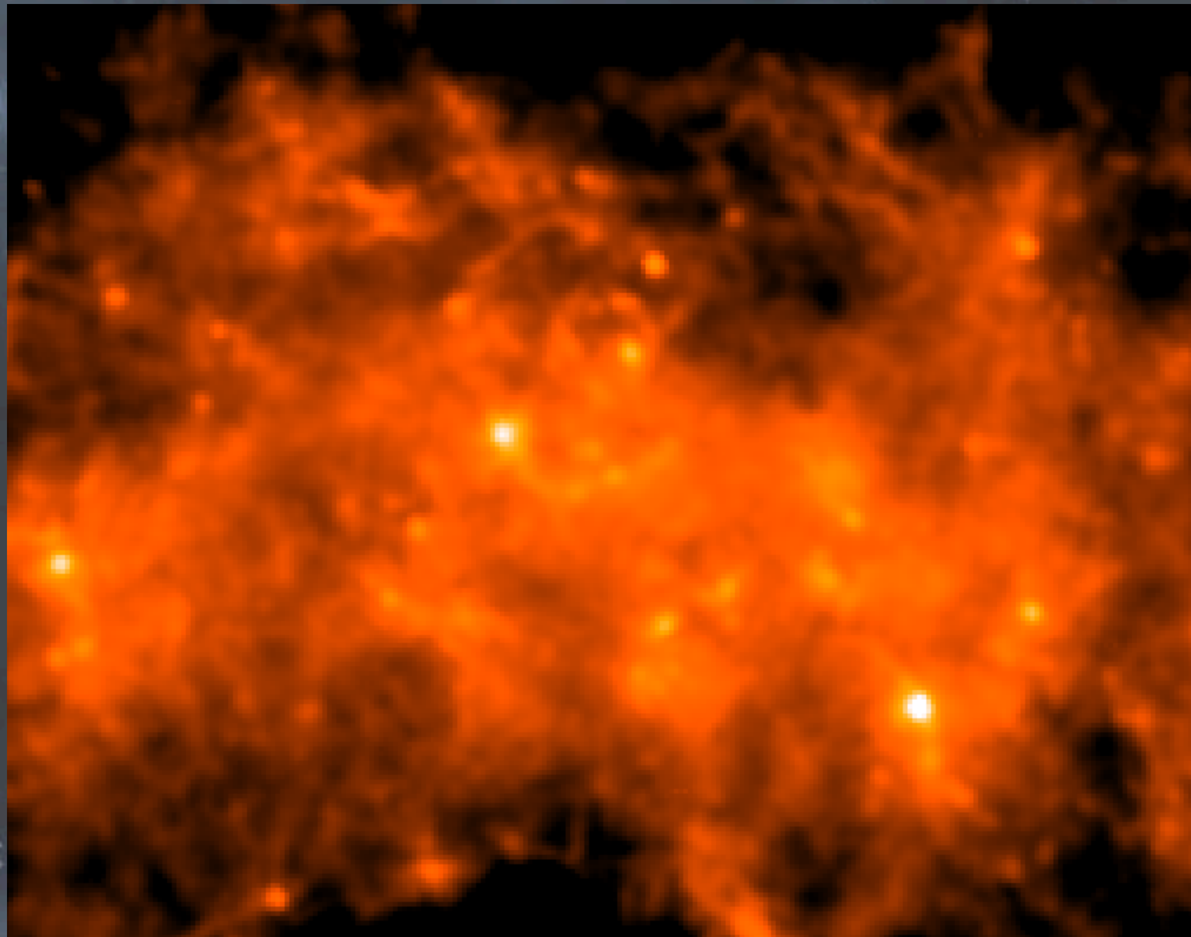
HST Image of 30 Doradus (NGC2070; Credit: NASA, ESA, etc)

Targets: Candidates of Young Massive Cluster in the Making



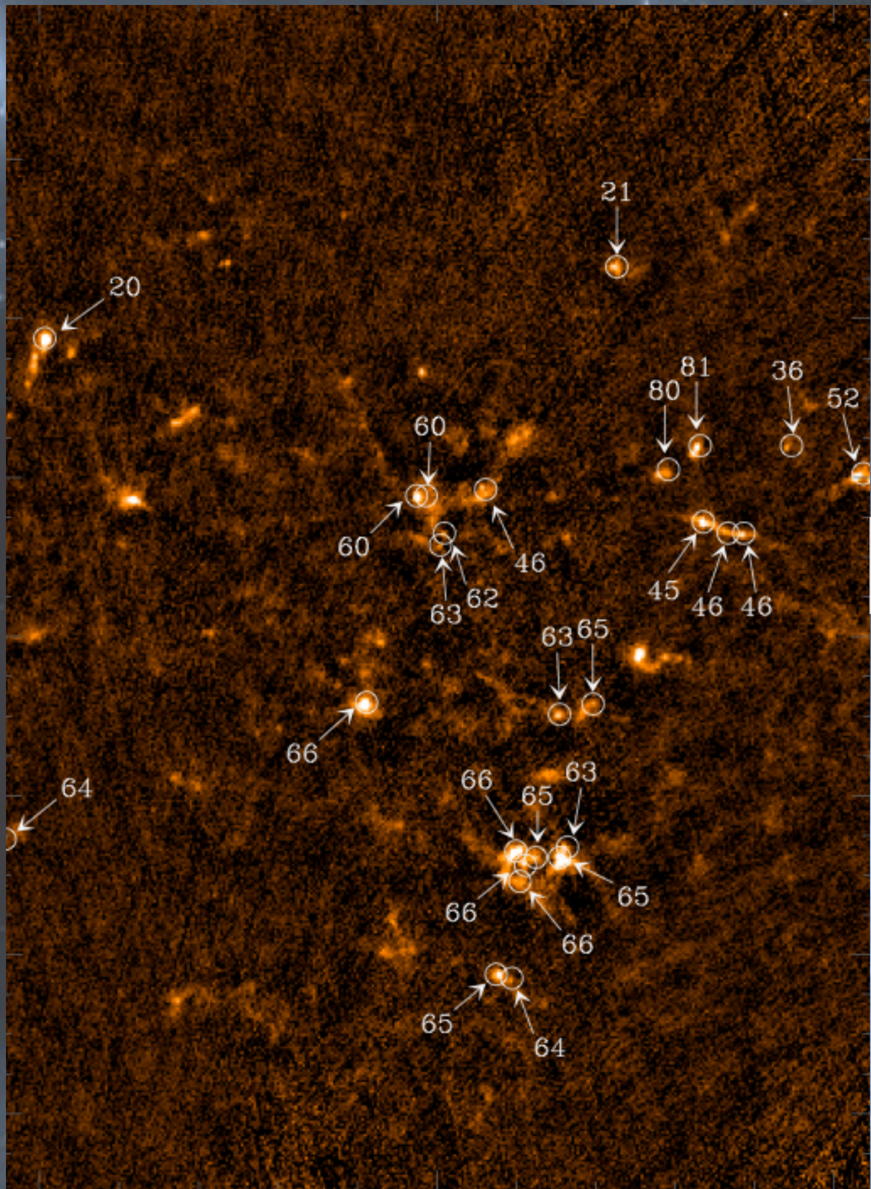
Red : *Spitzer* MIPS 24 um (Indicator for HII regions)
Green: *Spitzer* IRAC 8 um
(Liu et al. 2012, ApJ, 745, 61)

Our Difficulties: Molecular Clouds Look Similarly Incomprehensive in Poor Quality Images + Too Difficult to Beat Confusion



Herschel 350 um image of a random field in the Galactic plane

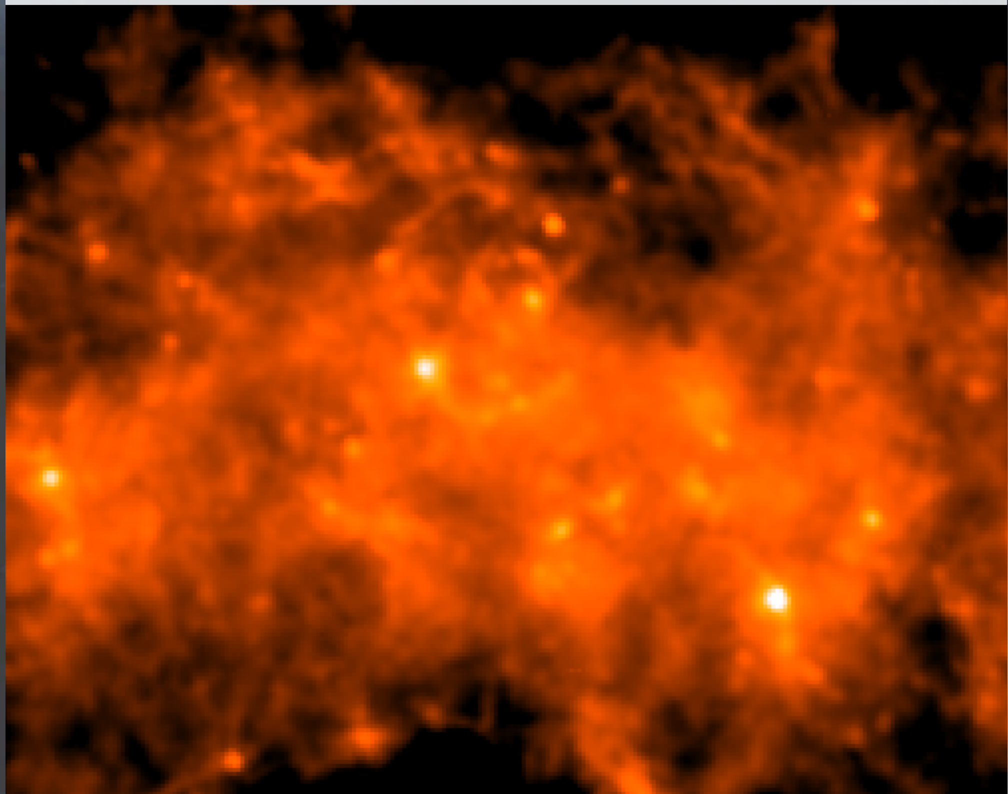
Non-trivial to Quantify High Resolution Images Either



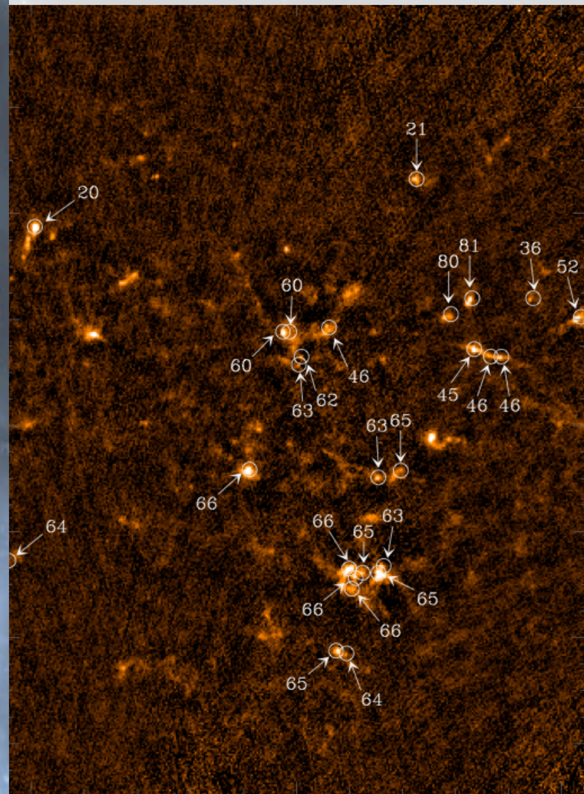
APEX-ATLASGAL 870 um Galactic Plane Survey
Schuller et al. 2009

Image Quality is the Key to Learn Beyond the Central Limit Theory!

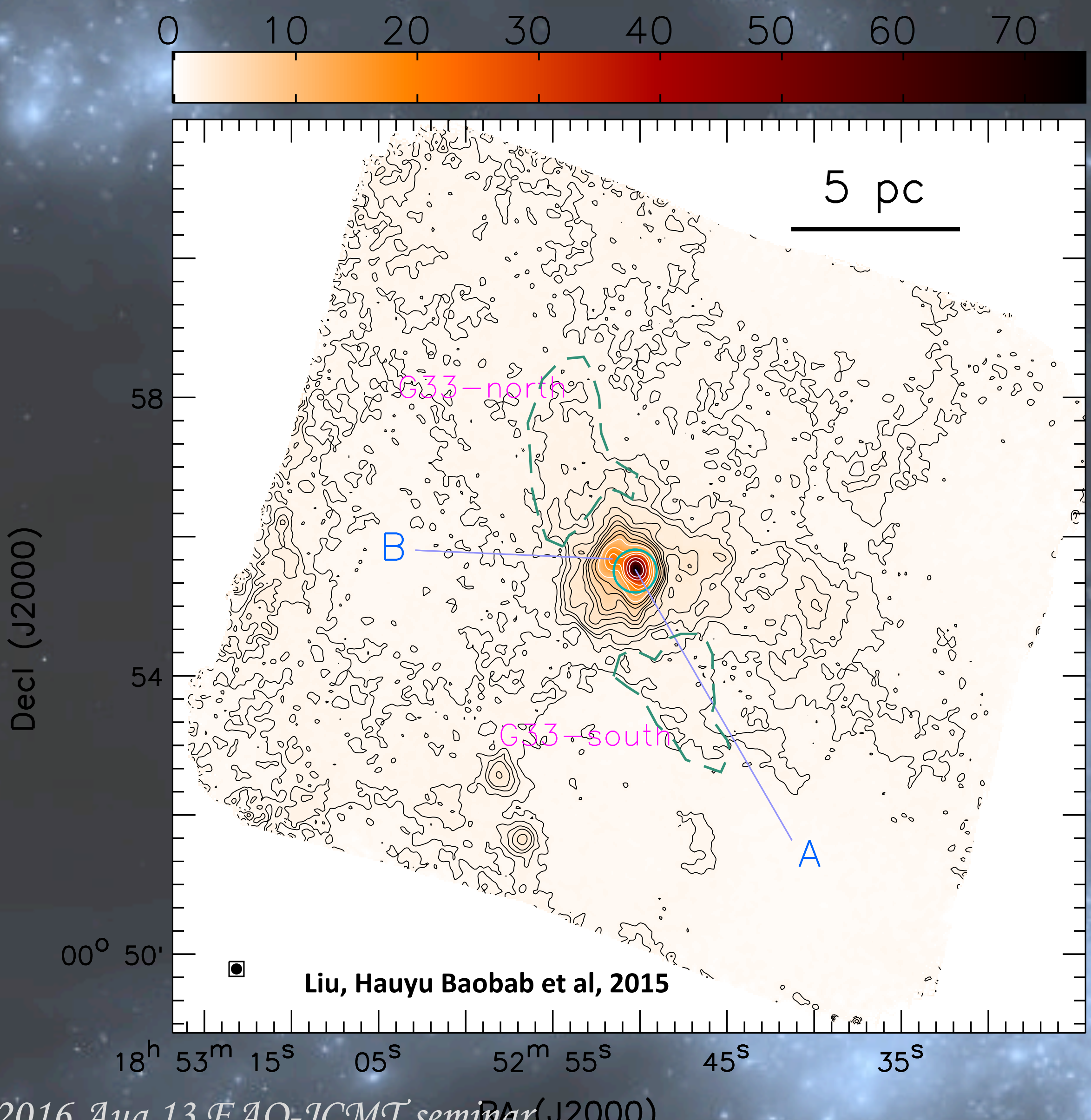
Herschel 350 um image

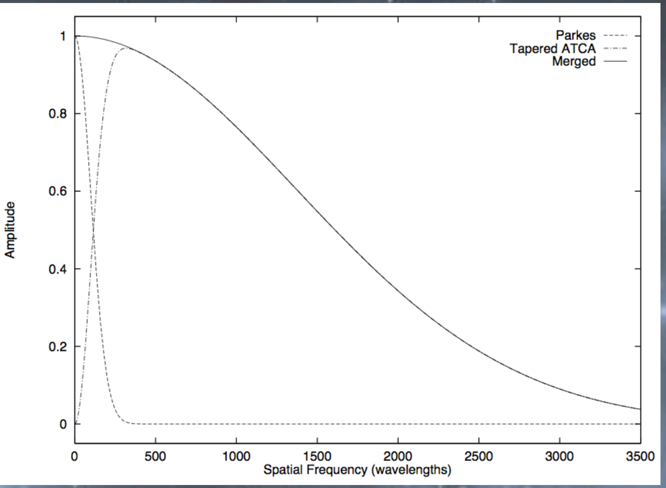


APEX 870 um Galactic Plane Survey

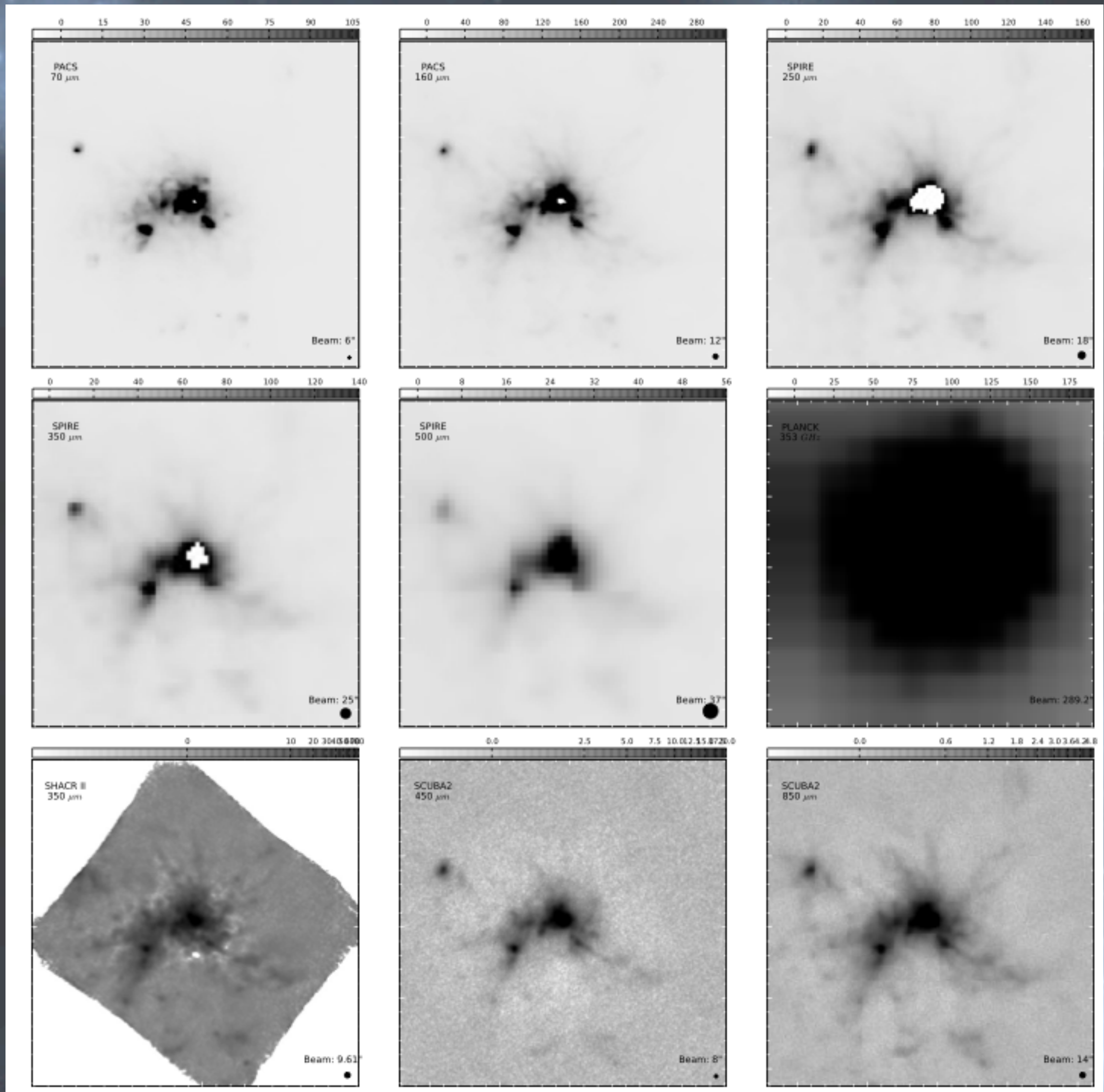


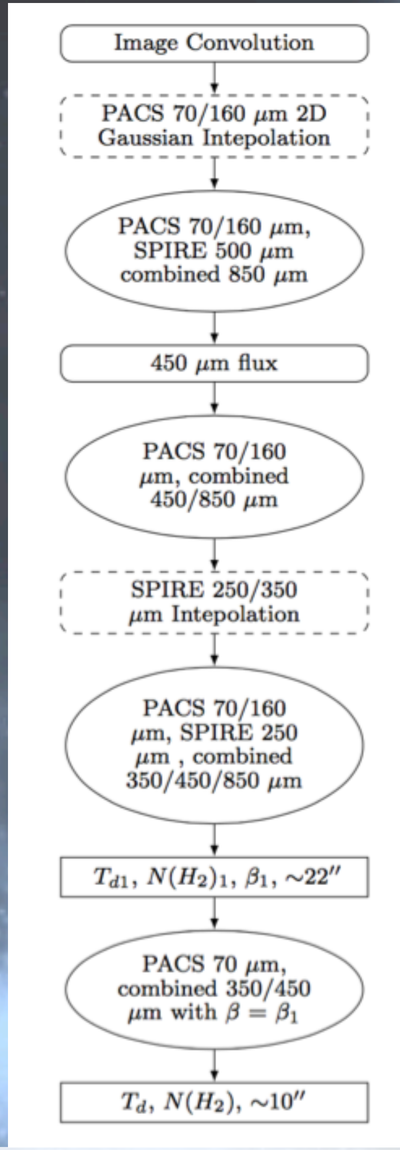
Proof of Concept





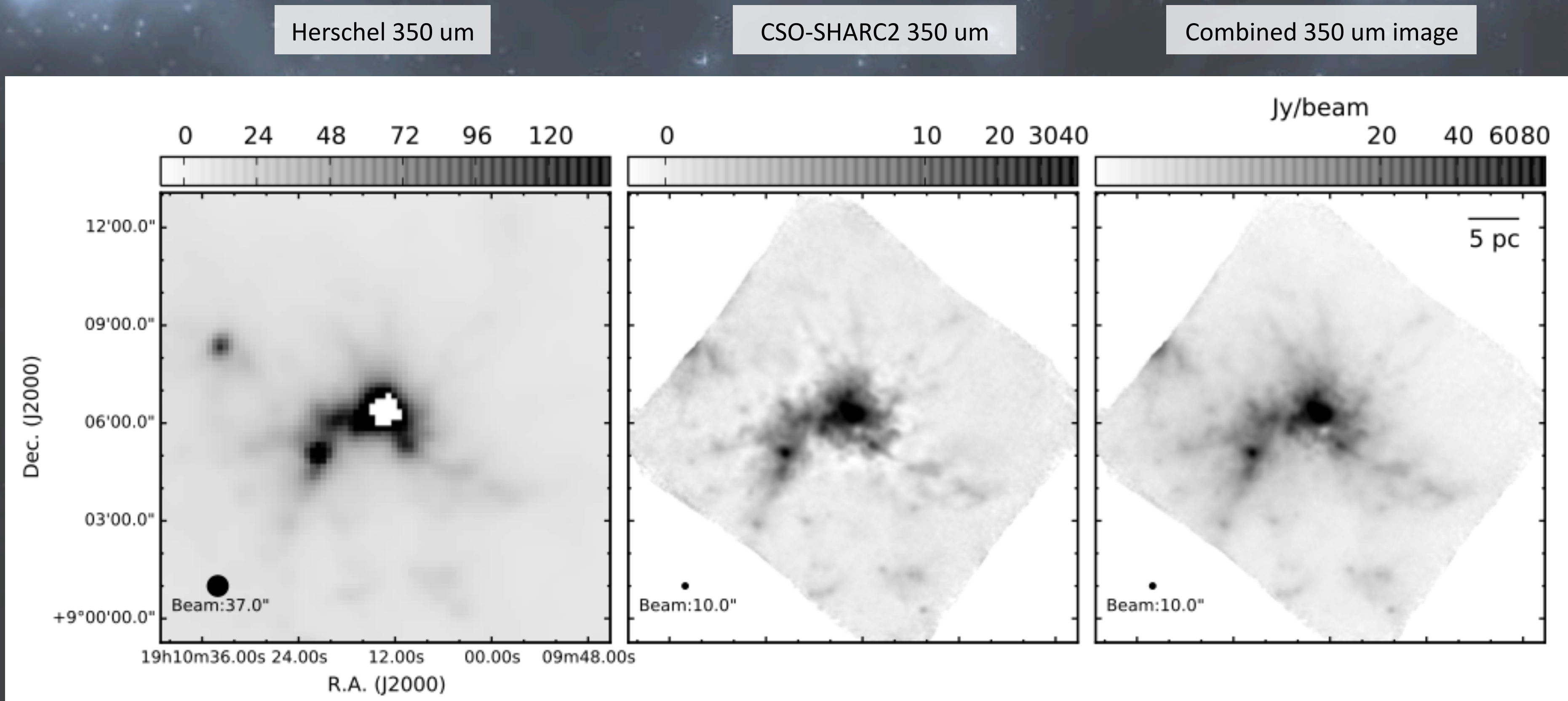
Iterative Procedure to Derive Dust Temperature and Column Density with ~10” Resolution





I can understand if she hates me. Lin et al. (2016)

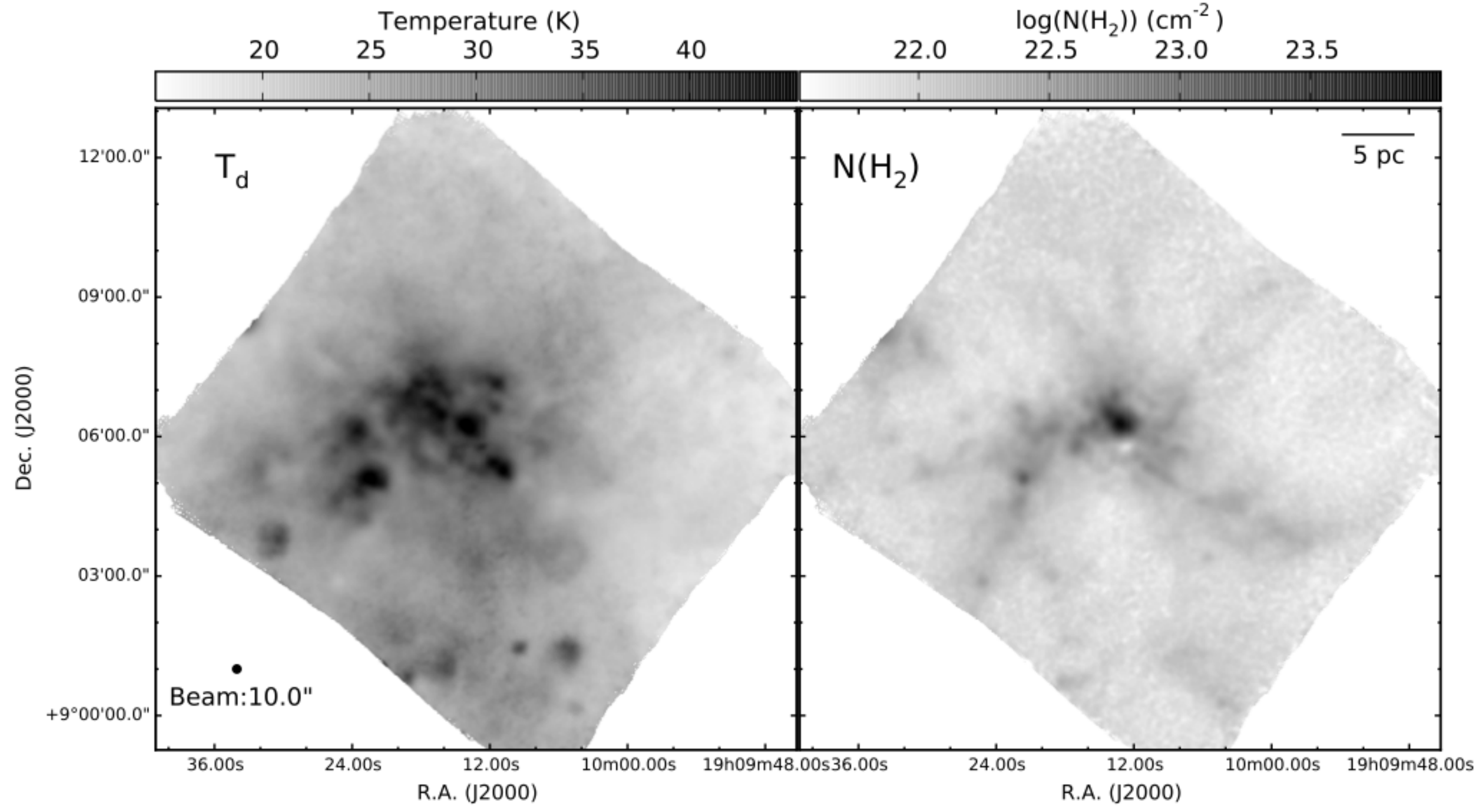
Tedious? Worth it.



Lin et al. (2016)

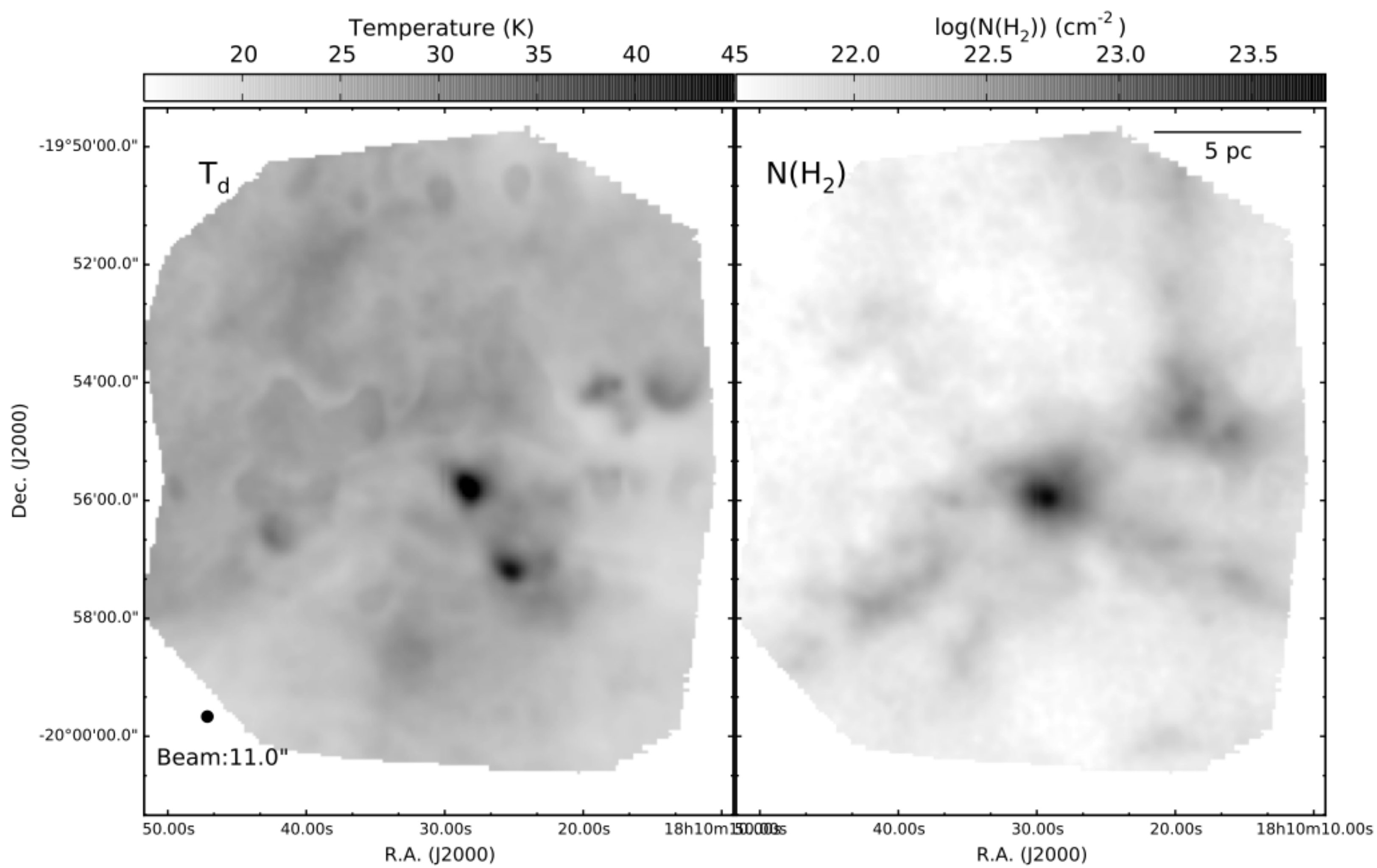
A Gallery of L>10^6 L$_\odot$ OB Cluster-Forming Clouds

W49A



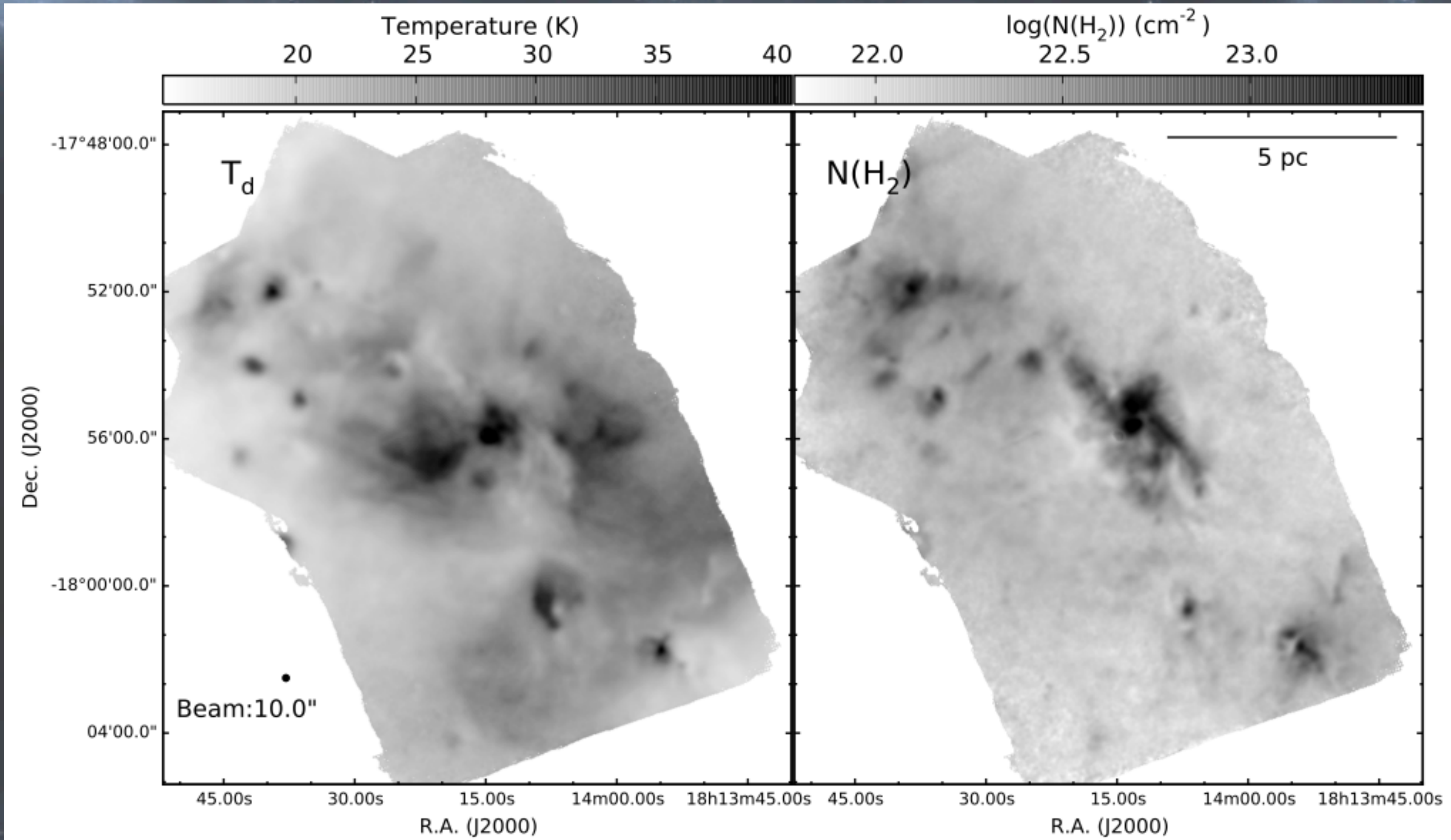
A Gallery of $L>10^6 L_\odot$ OB Cluster-Forming Clouds

G10.6-0.4



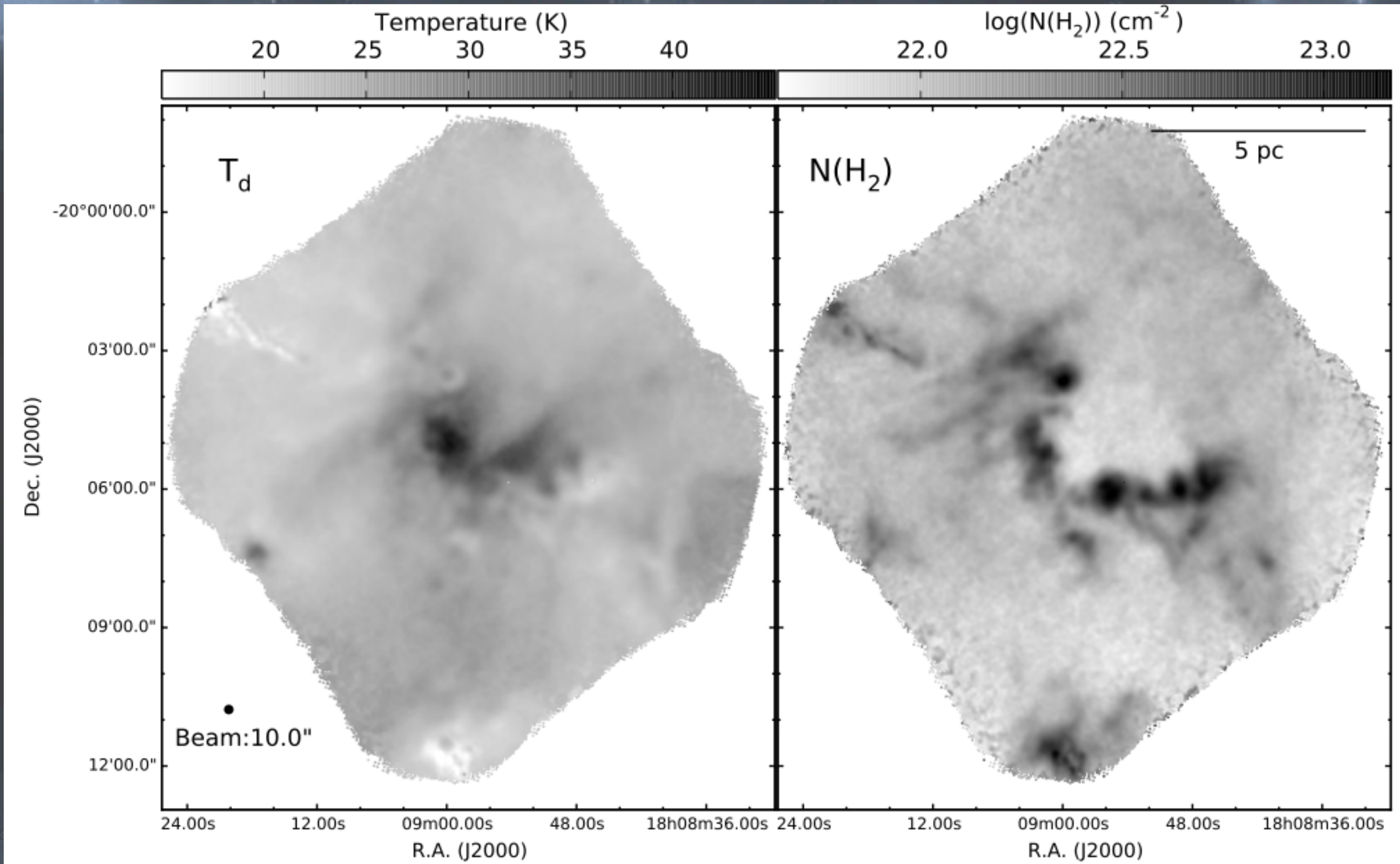
A Gallery of L>10^6 $L_\odot$ OB Cluster-Forming Clouds

W33



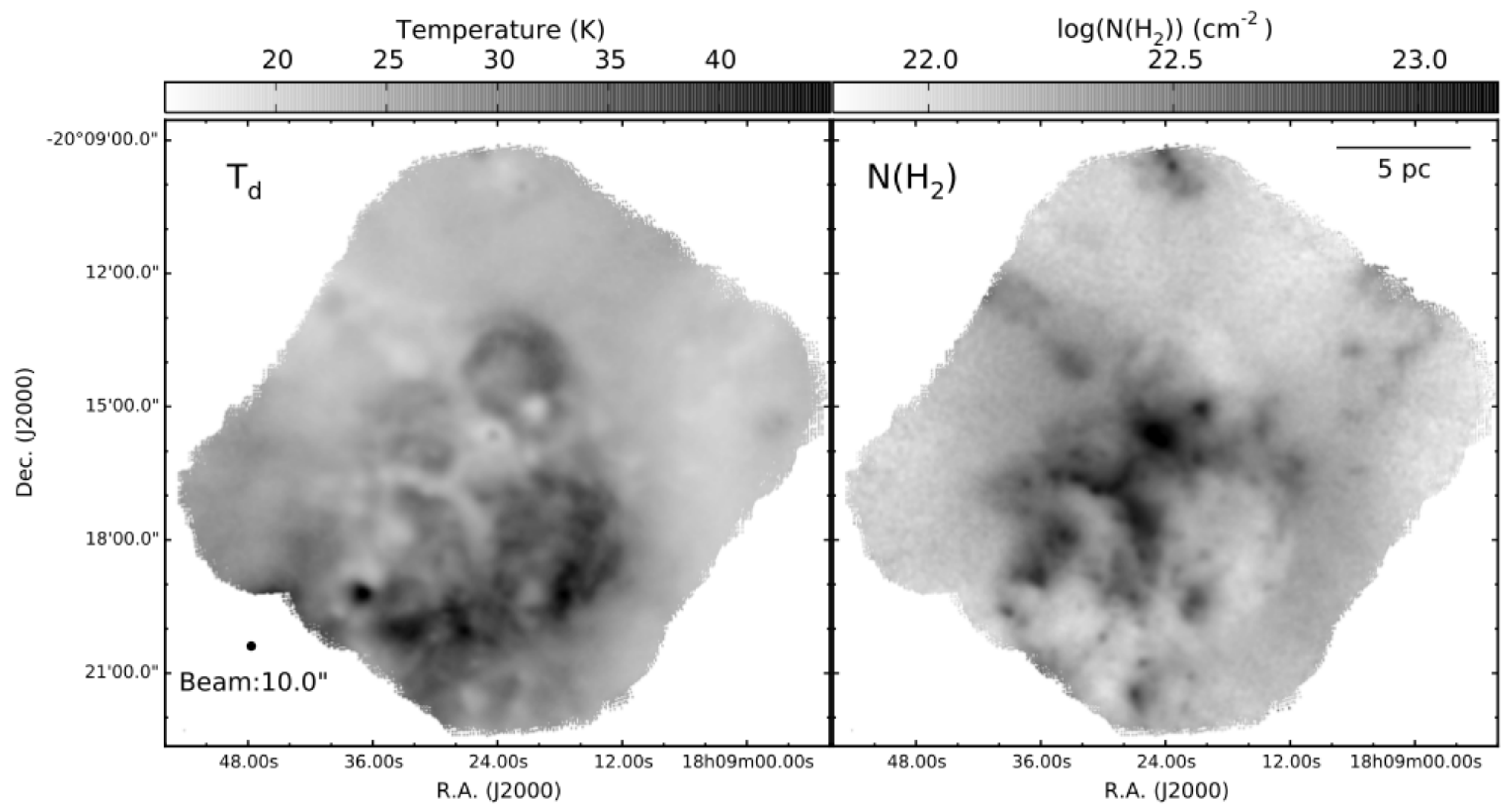
A Gallery of L>10^6 L$_\odot$ OB Cluster-Forming Clouds

G10.3-0.1



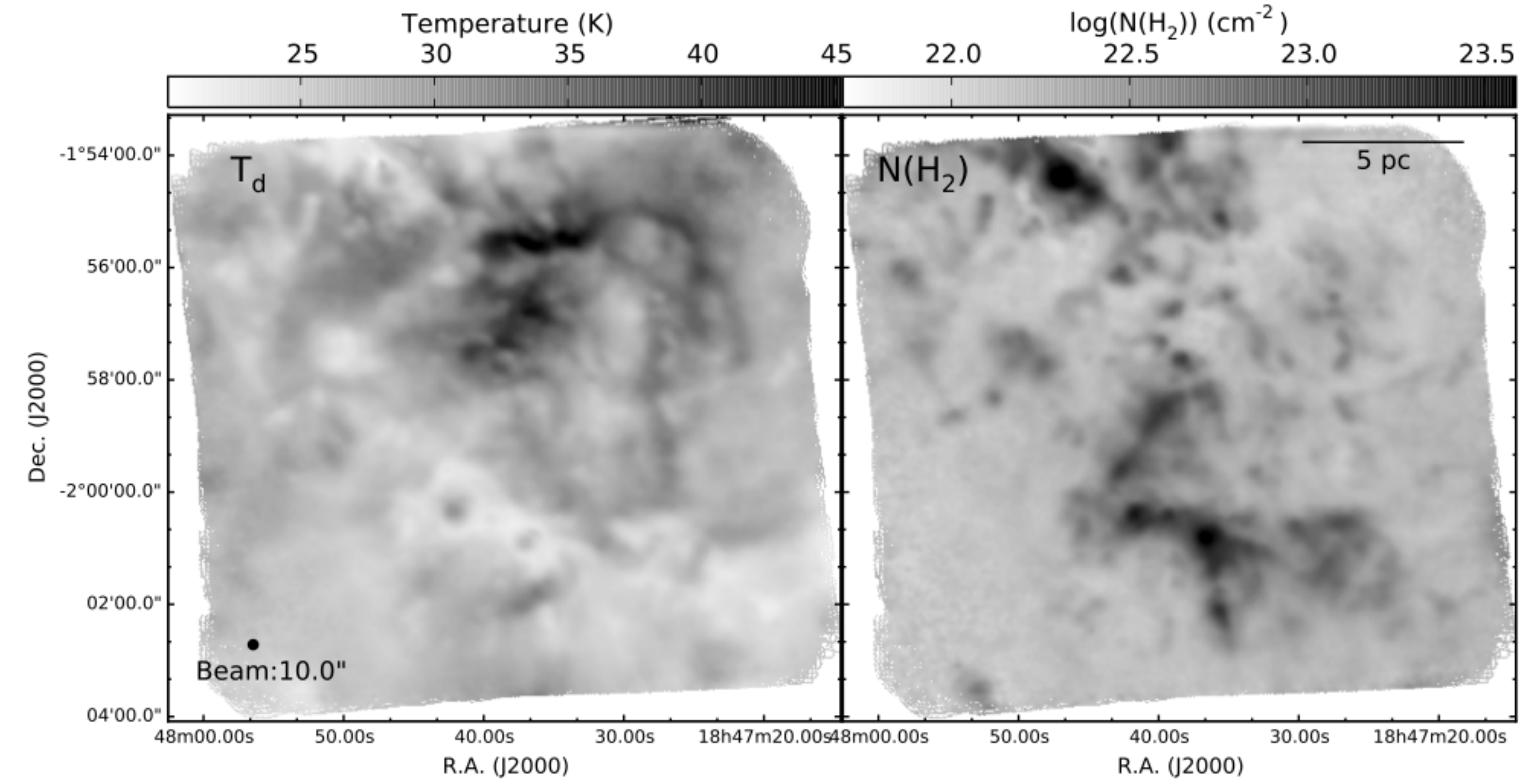
A Gallery of L>10^6 $L_\odot$ OB Cluster-Forming Clouds

G10.2-0.3



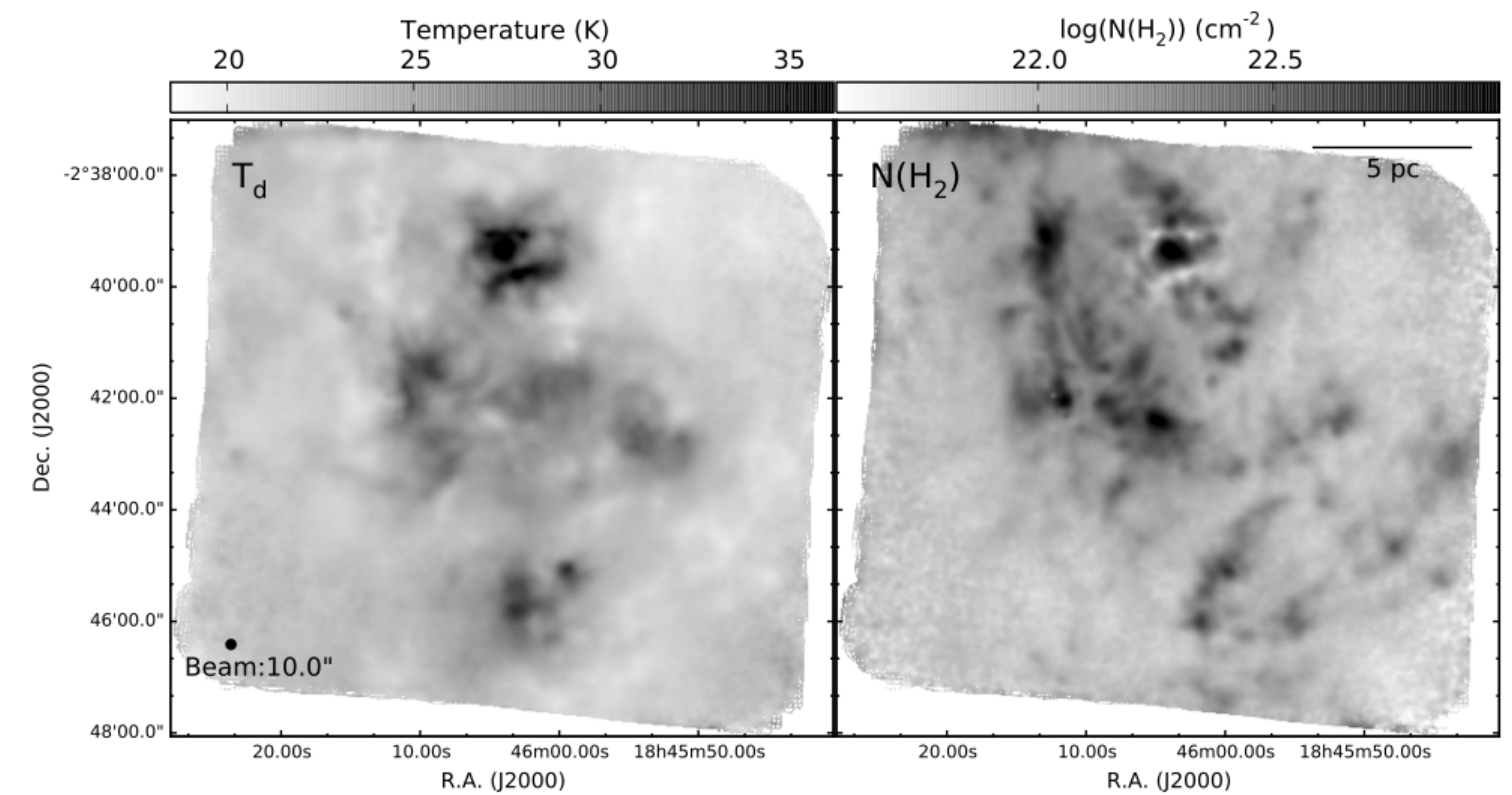
A Gallery of L>10^6 $L_\odot$ OB Cluster-Forming Clouds

W43-Main

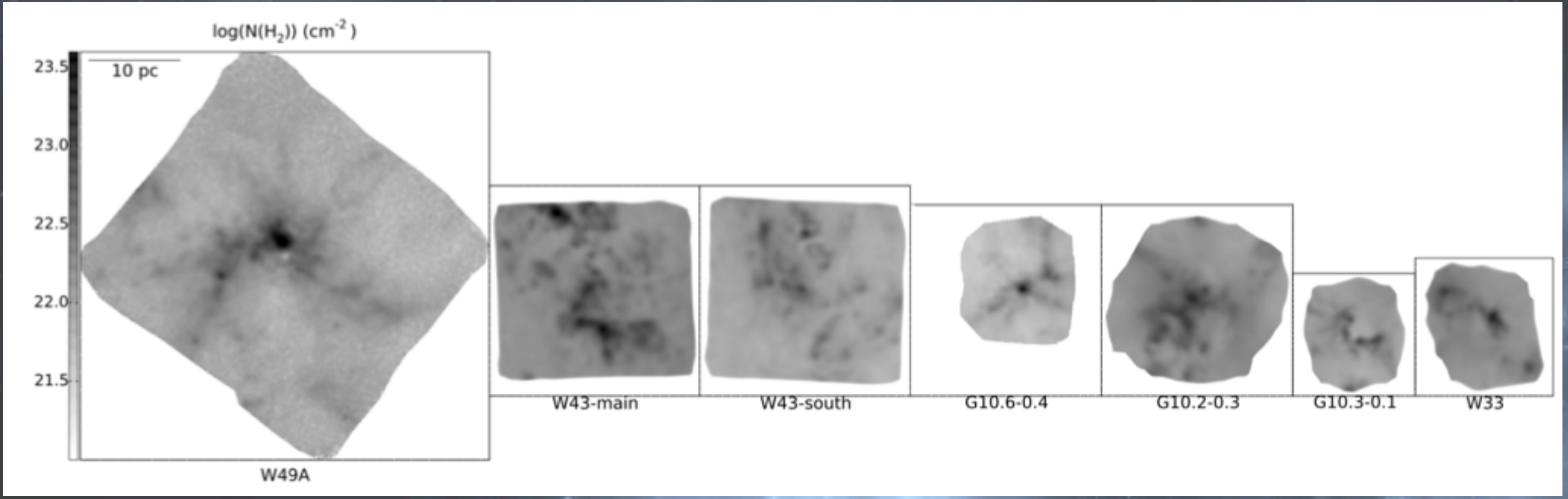


A Gallery of L>10⁶ $L_\odot$ OB Cluster-Forming Clouds

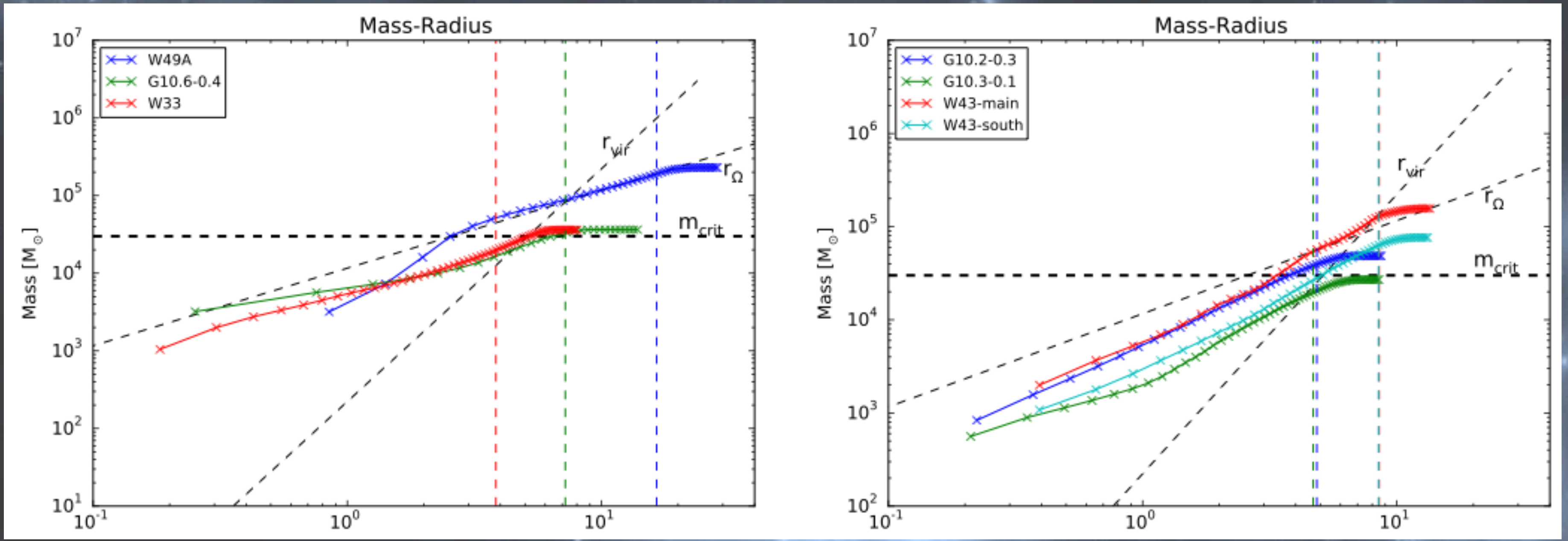
W43-South



No Simple Linear or Spherically Symmetric Structure
They are Different



Enclosed Mass Profile



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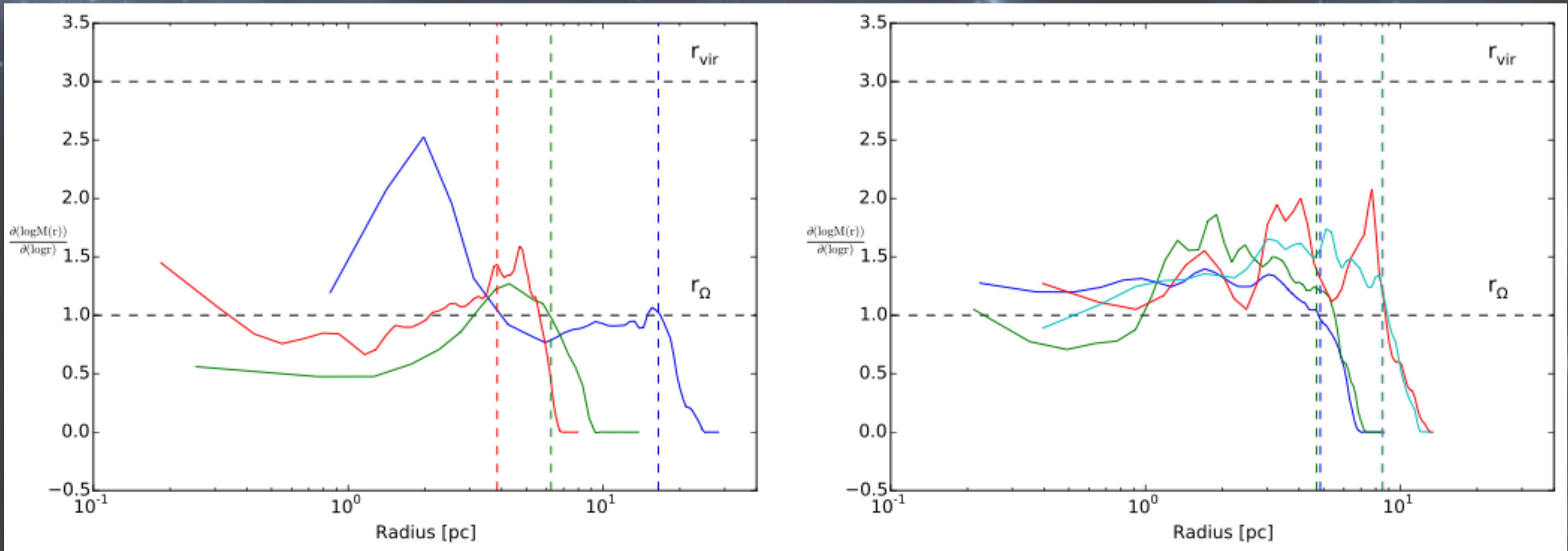
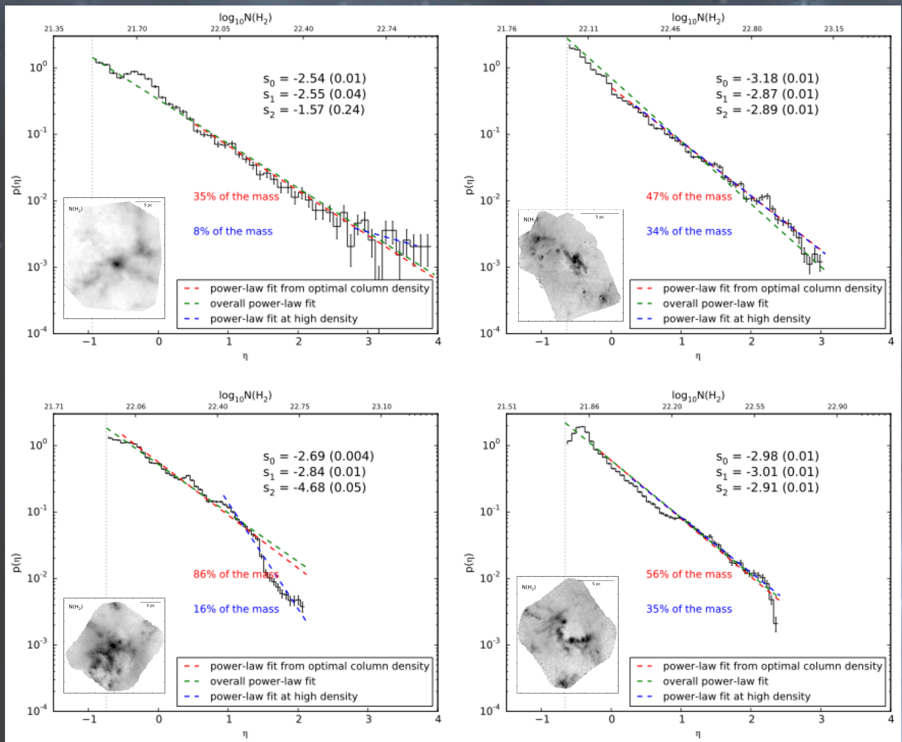
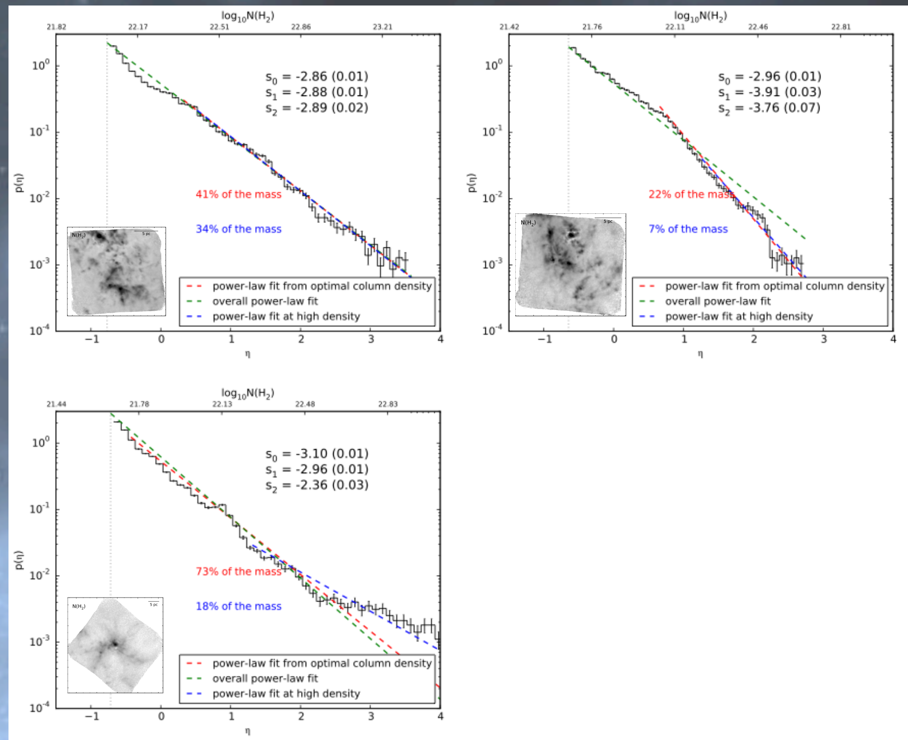
Slopes of Enclosed Mass Profile



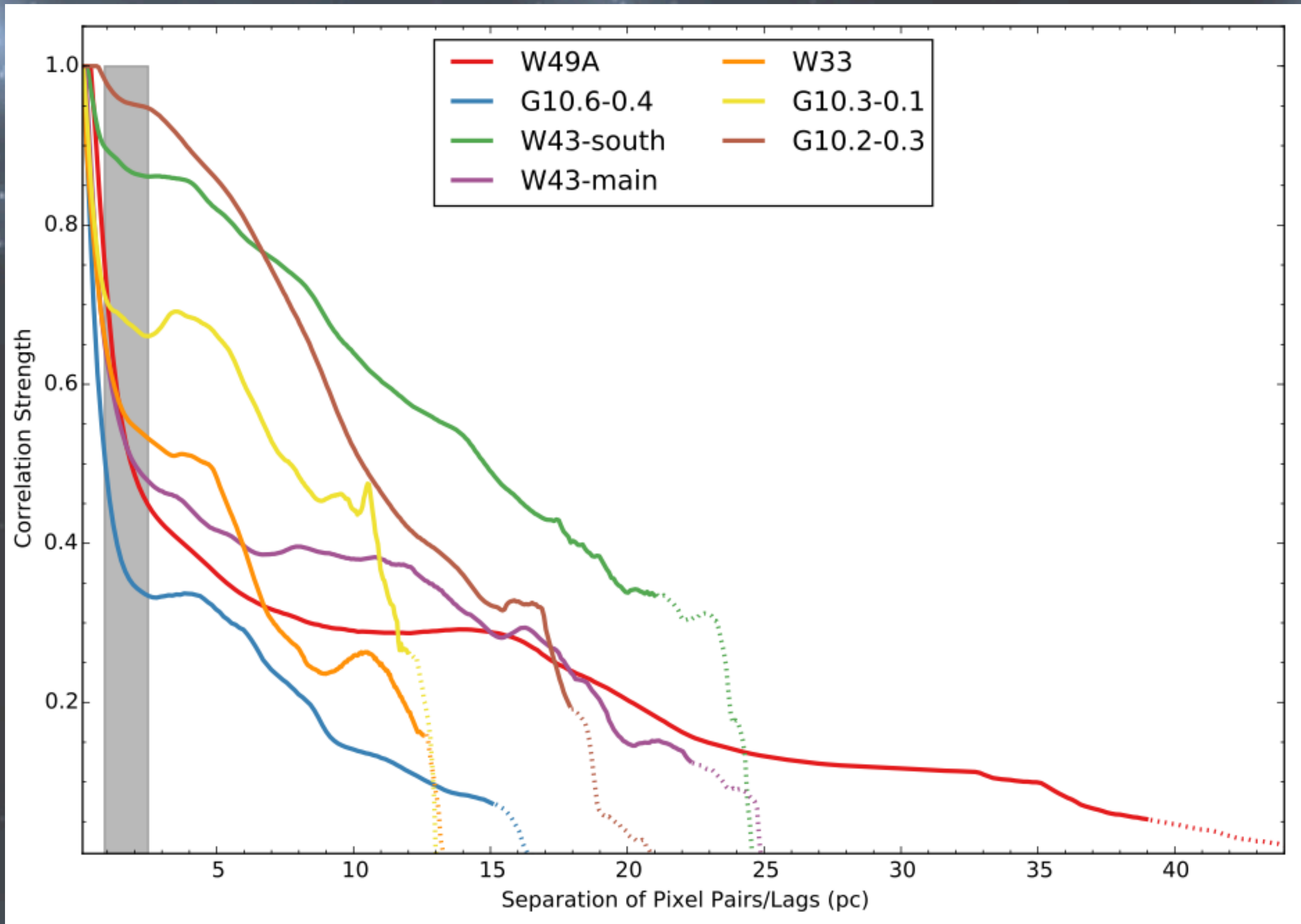
Column Density Probability Distribution Function

Nothing is consistent with log-normal distribution. Clearly, we are beyond the central limit theory confusion.

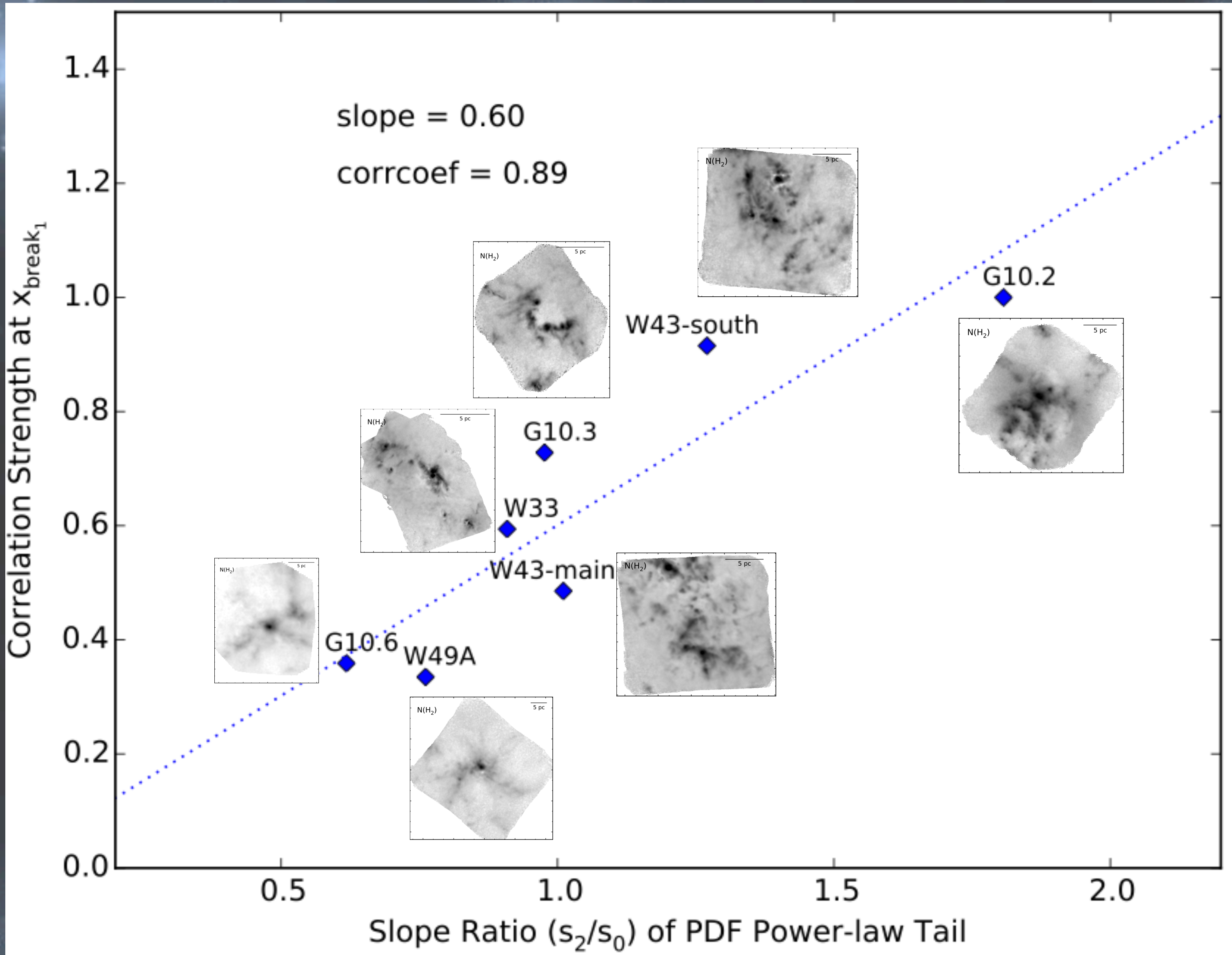




1-Dimensional Auto-correlation Funcion

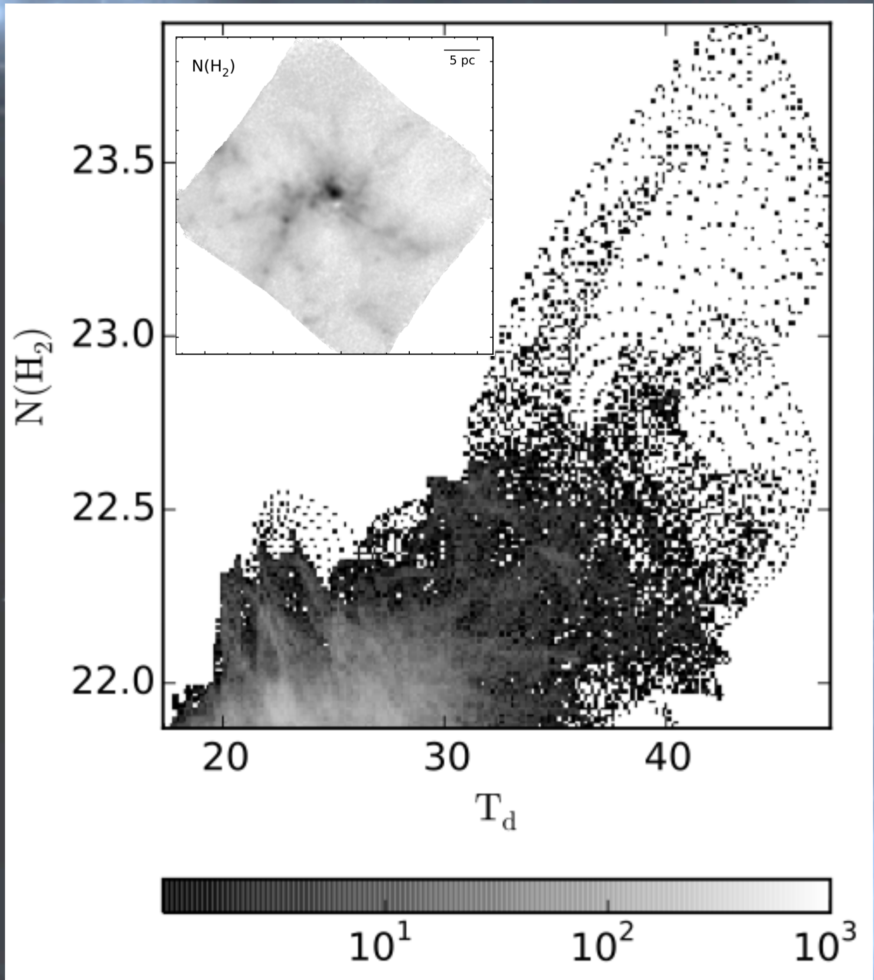


Correlation of Statistical Properties

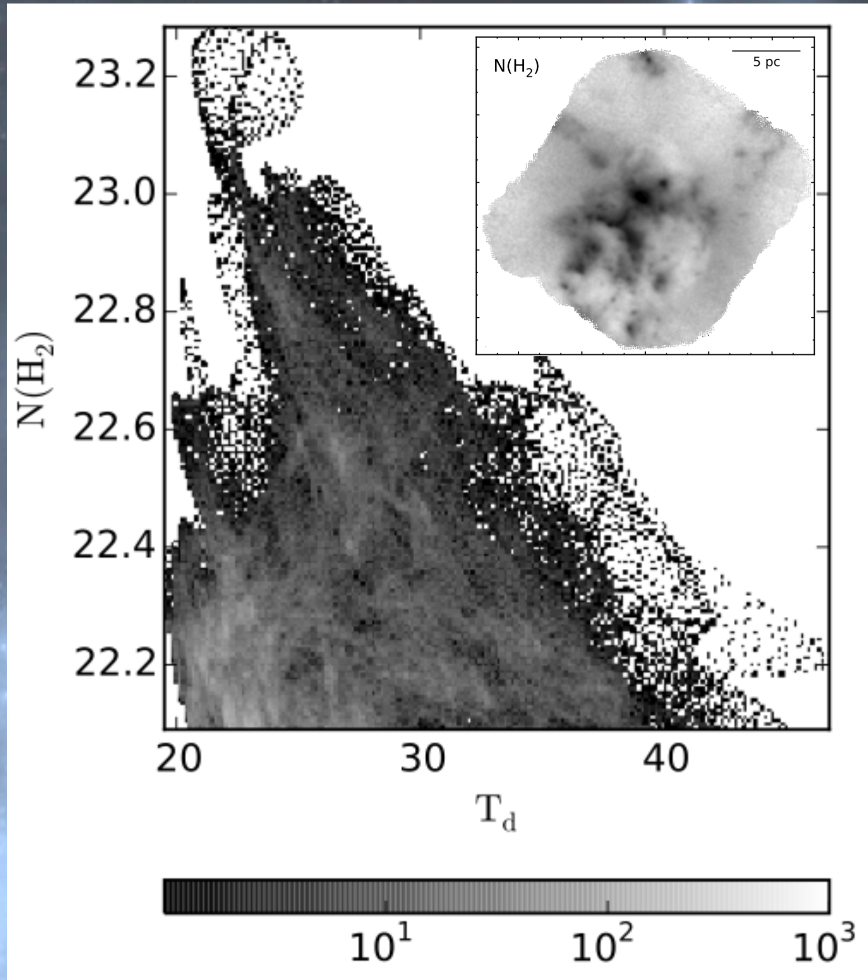


Different Role of Stellar Feedback?

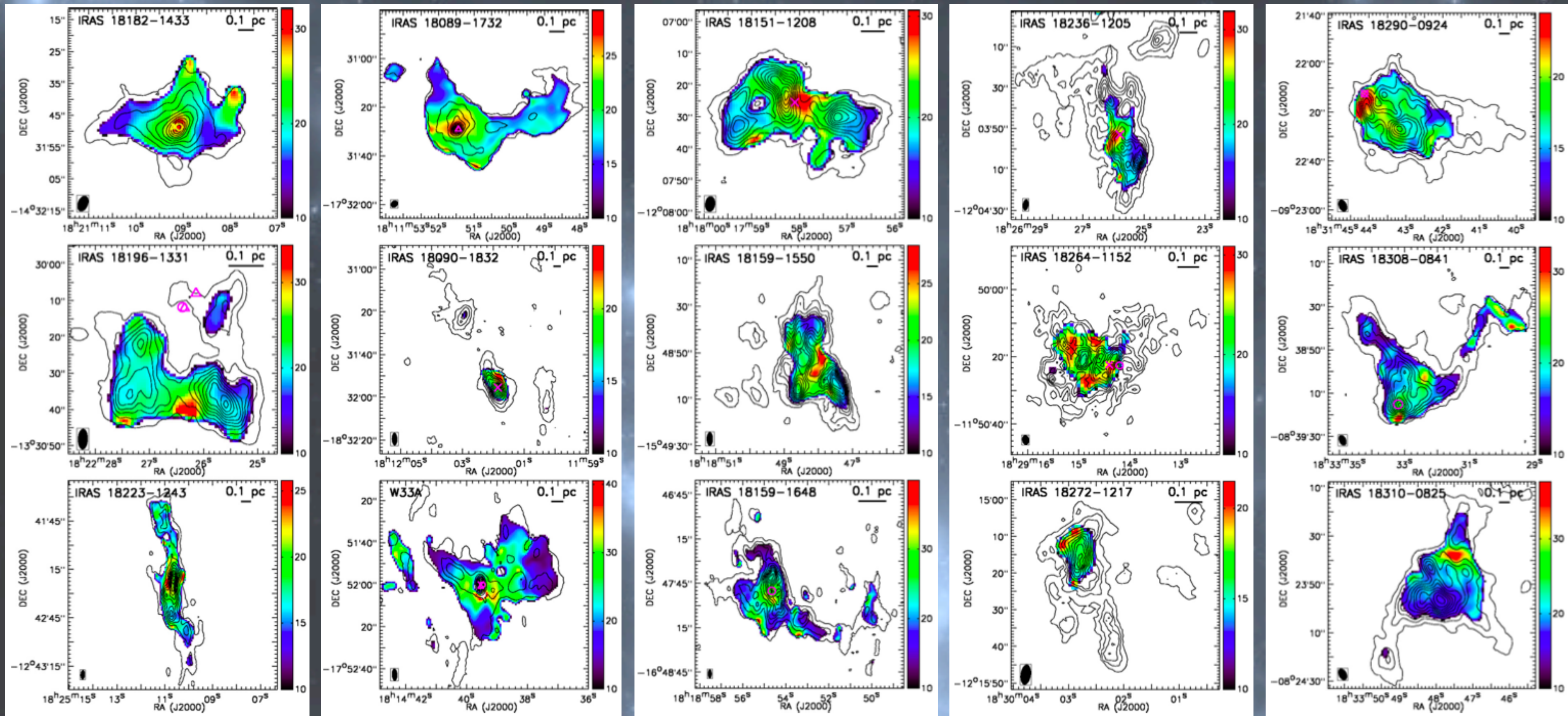
W49A



G10.2-0.3

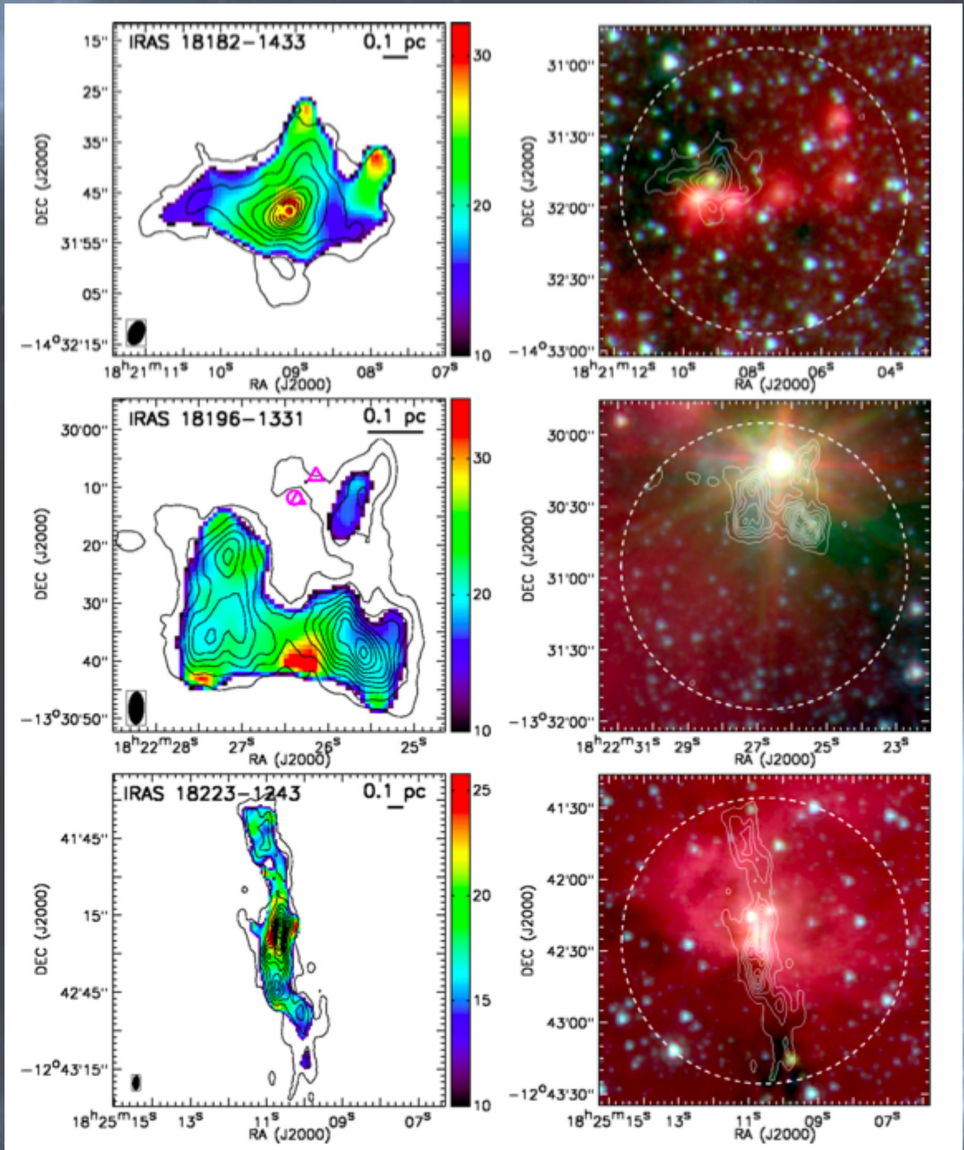


A Gallery of 62 L~10^4 $L_\odot$ OB Cluster-Forming Regions



Lu et al. (2014)

Morphological Classification for L~10^4 $L_\odot$ Regions

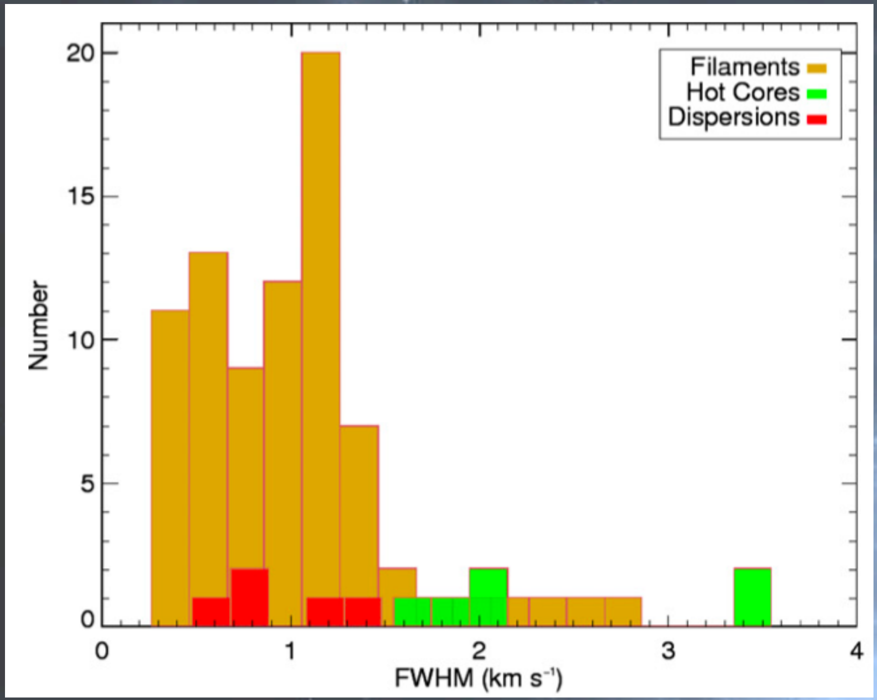


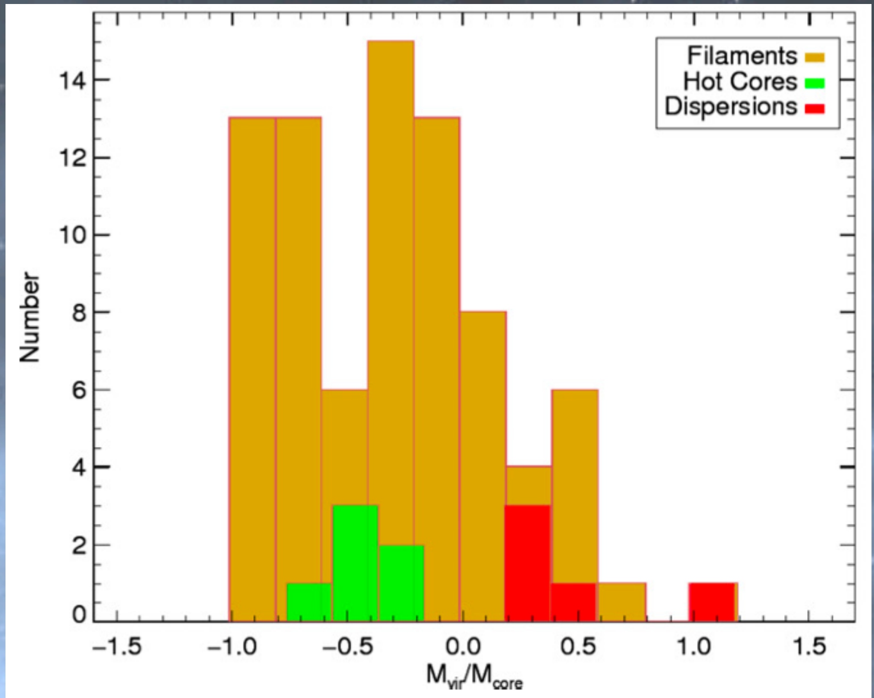
Concentration

Dispersed

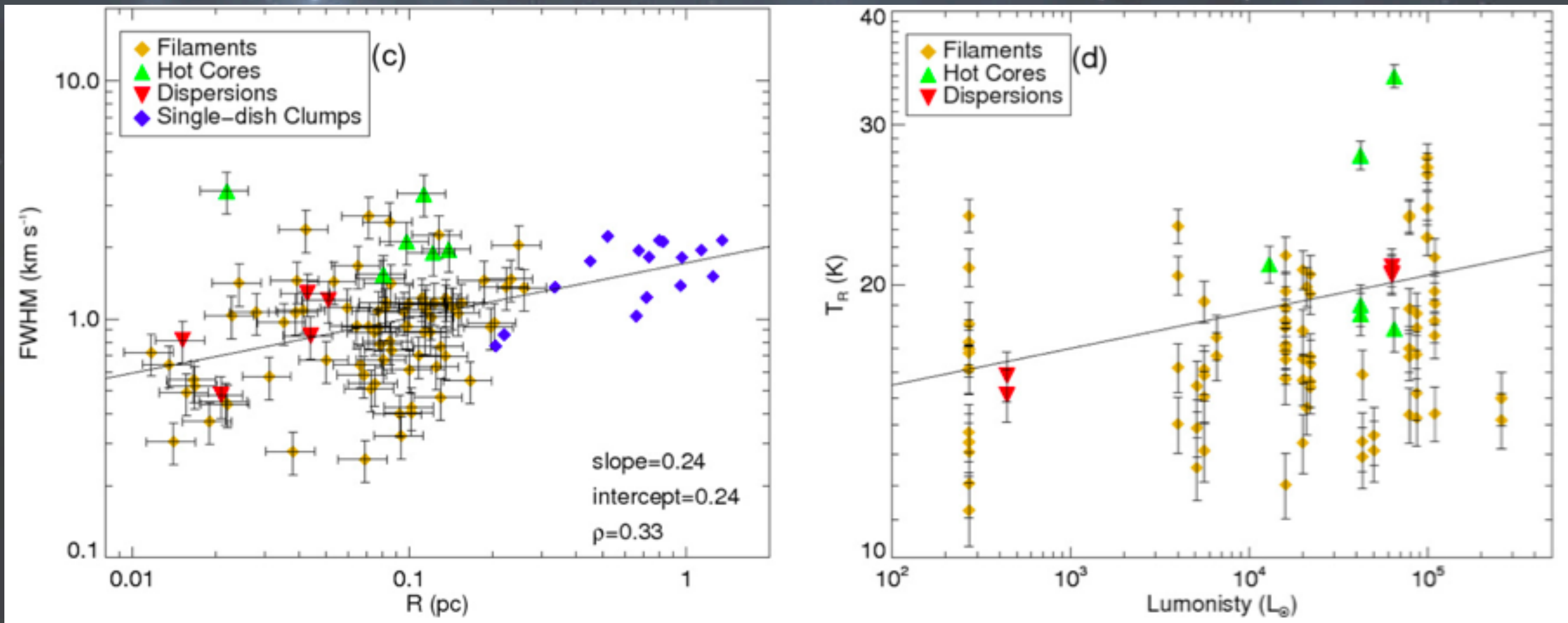
Filaments

Cores Embedded in the samples of L~10^4 $L_\odot$ OB Cluster-Forming Regions



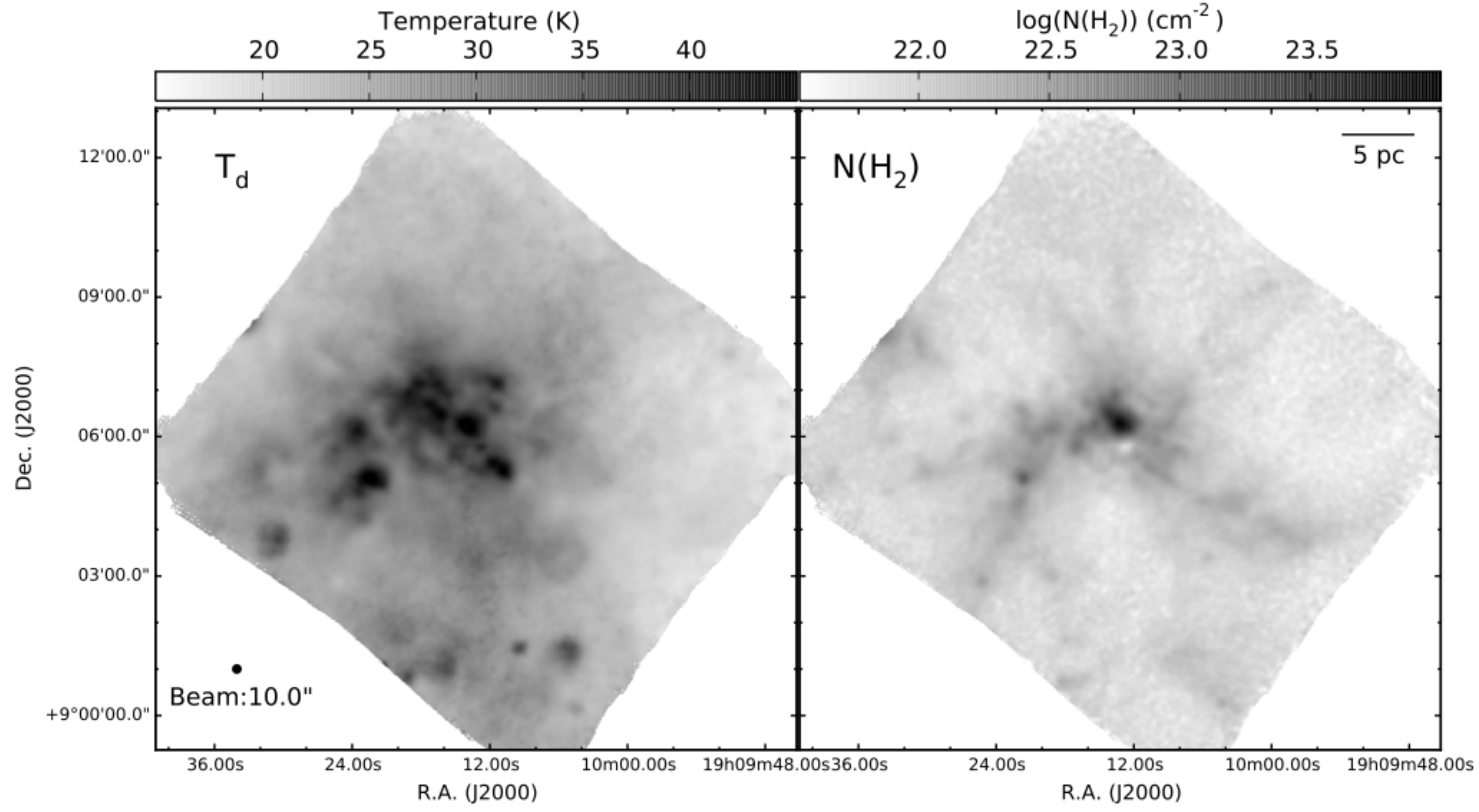


Cores Embedded in the samples of L~10^4 $L_\odot$ OB Cluster-Forming Regions



Cloud Global Gravitational Collapse?

W49A

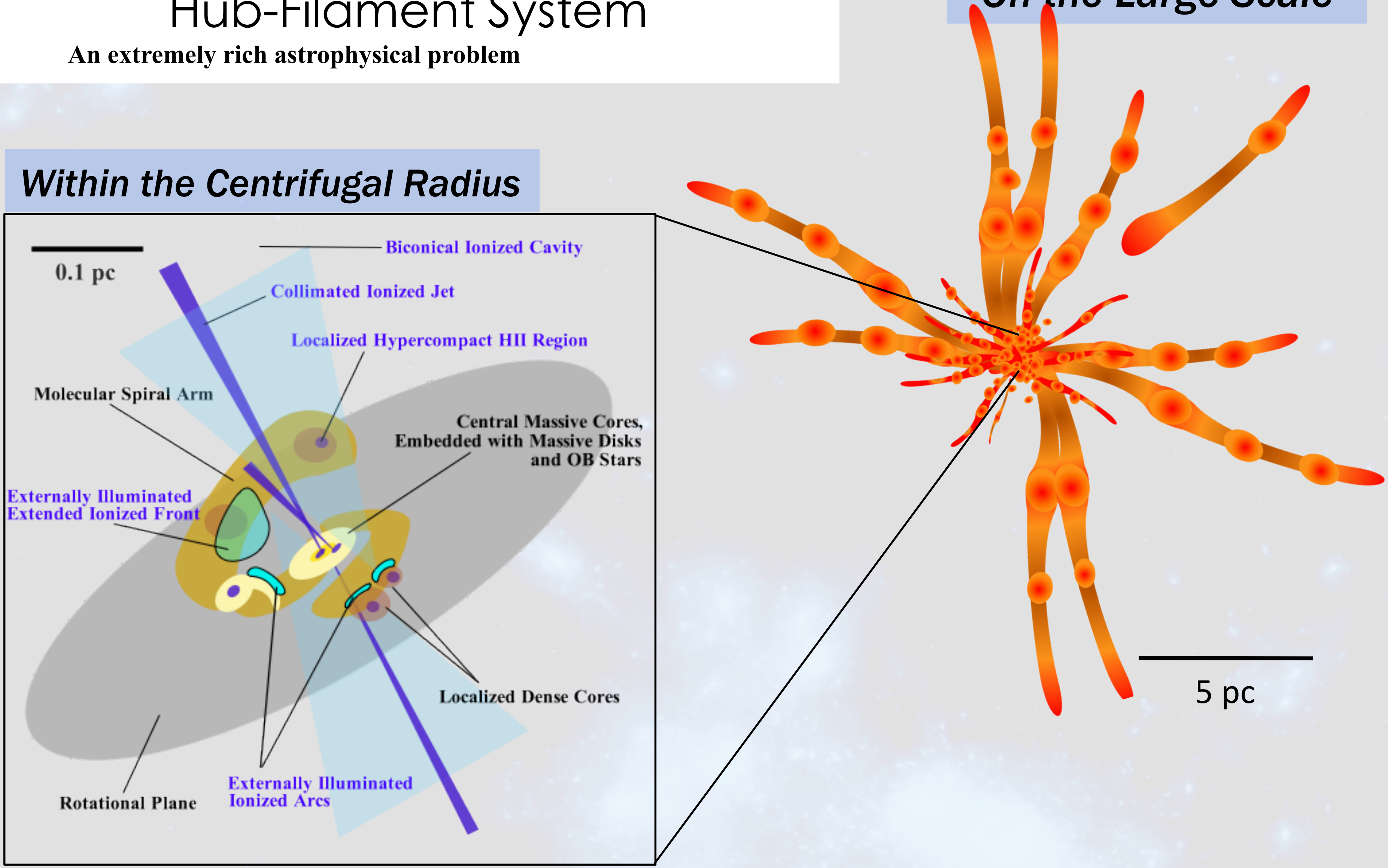


OB Cluster-Forming Molecular Hub-Filament System

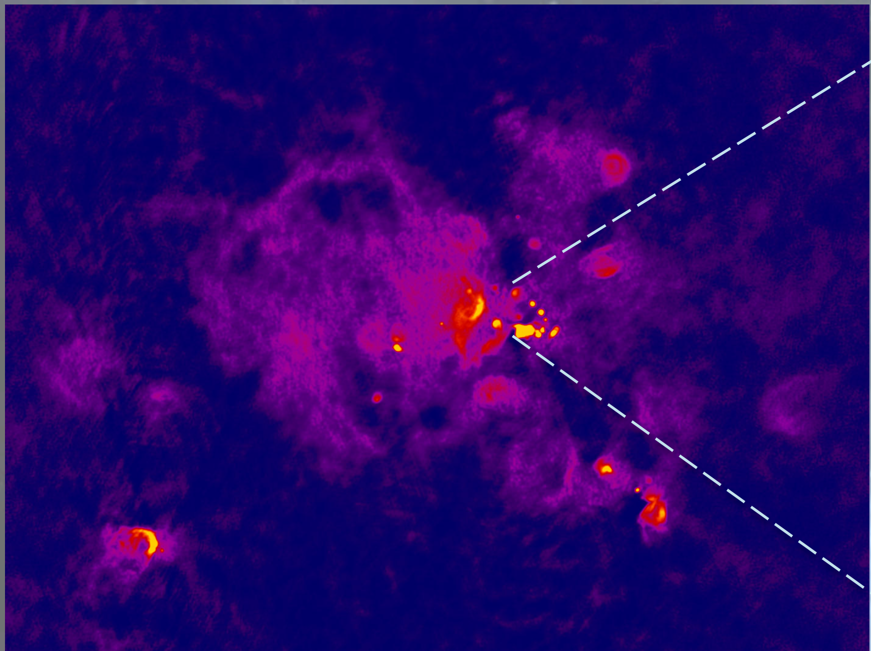
An extremely rich astrophysical problem

Within the Centrifugal Radius

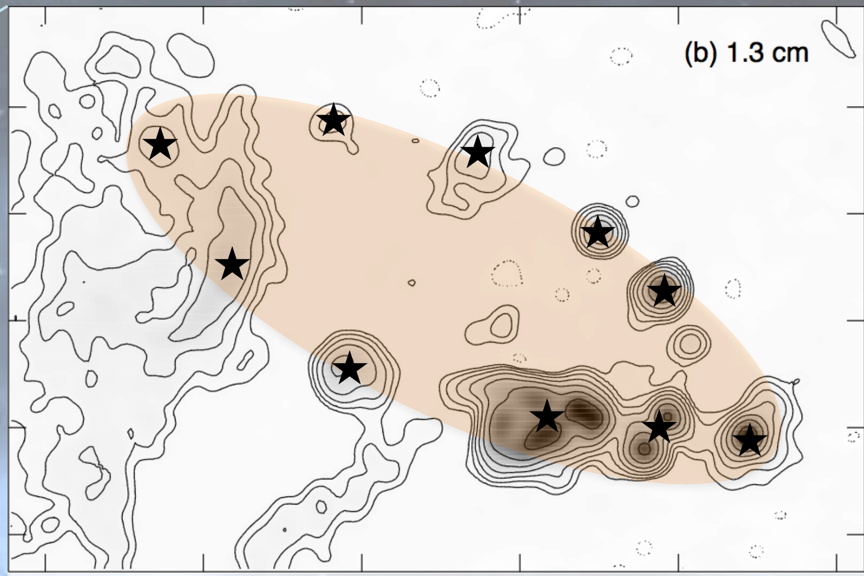
On the Large Scale



A Ring Like Distribution of UC HII Region Gave Implication to the Parent Molecular Toroid

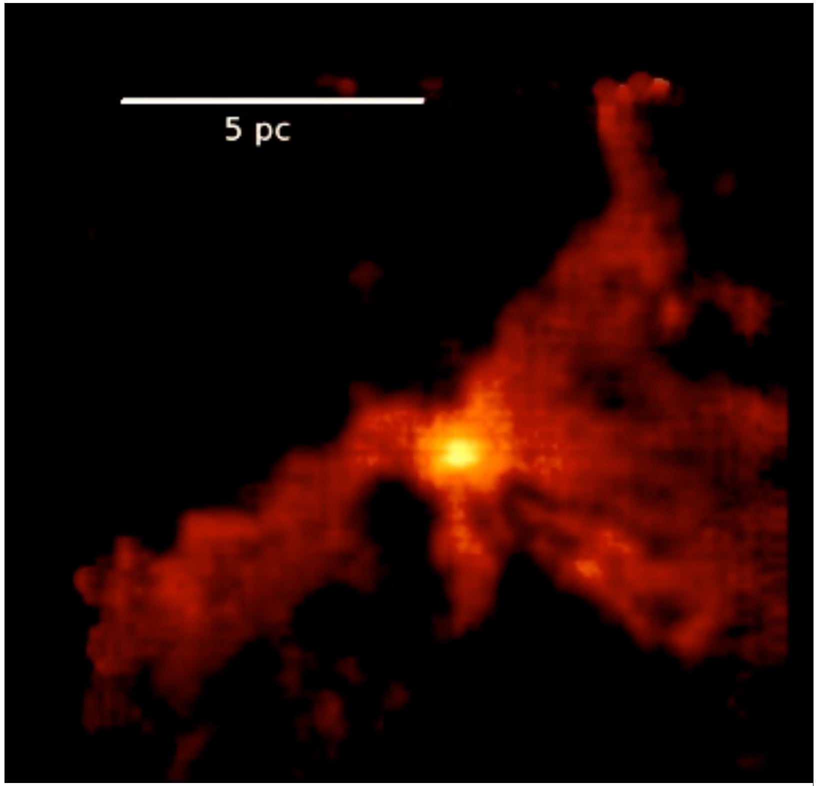


VLA 3.6 cm image of W49A (De Pree et al. 1997, ApJ, 482, 307)

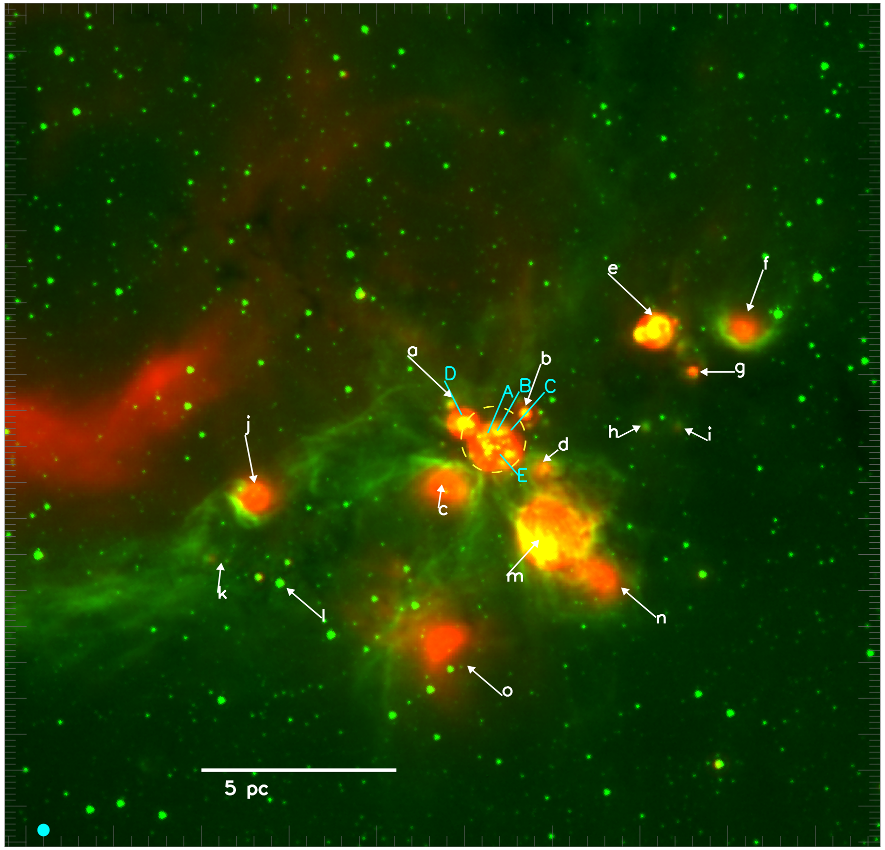


VLA 1.3 cm image of W49A (De Pree et al. 1997, ApJ, 482, 307)

The Case of the
Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4

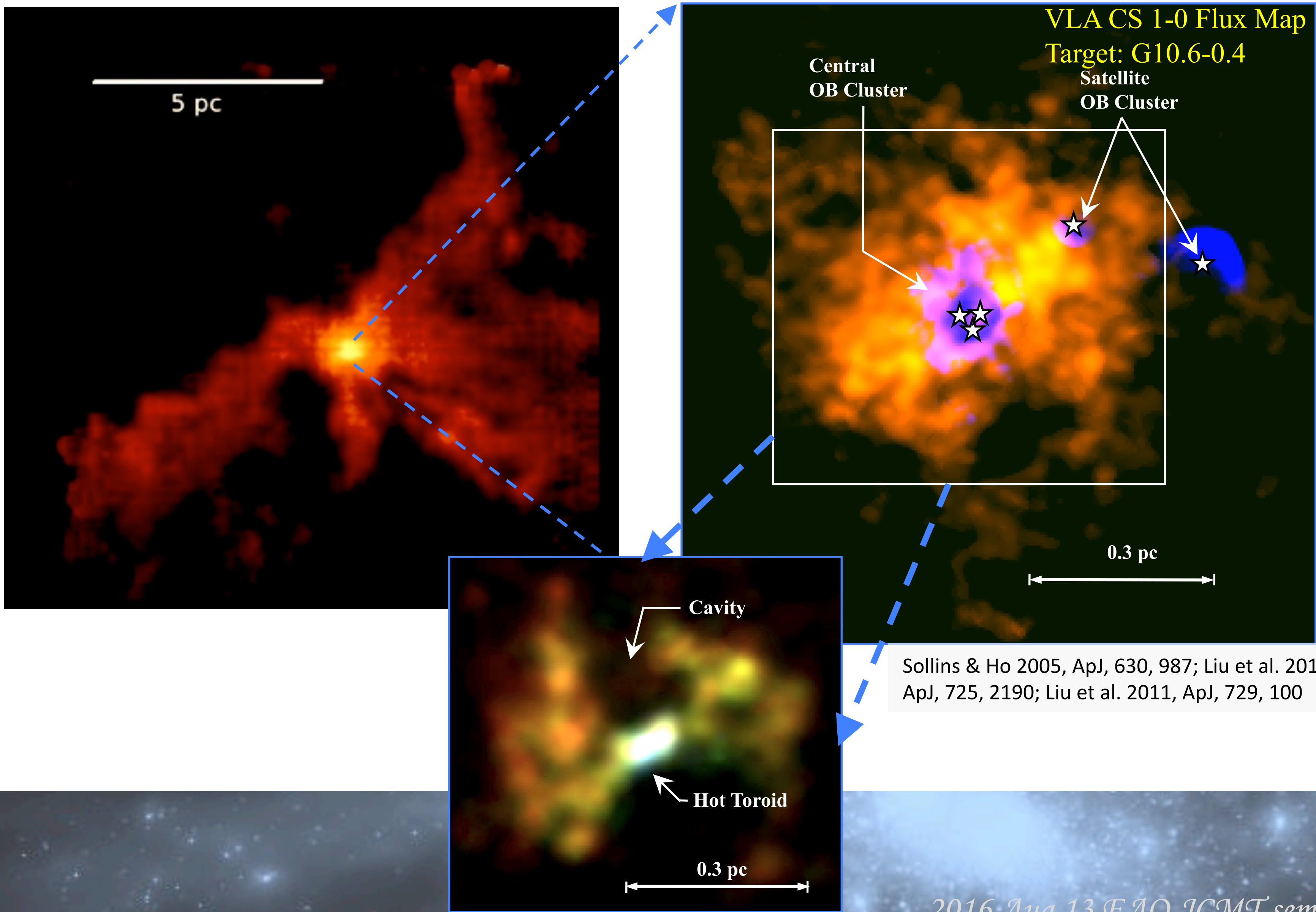


Molecular Gas Distribution
IRAM-30m Telescope OTF Mapping
Observations of ^{13}CO 2-1.



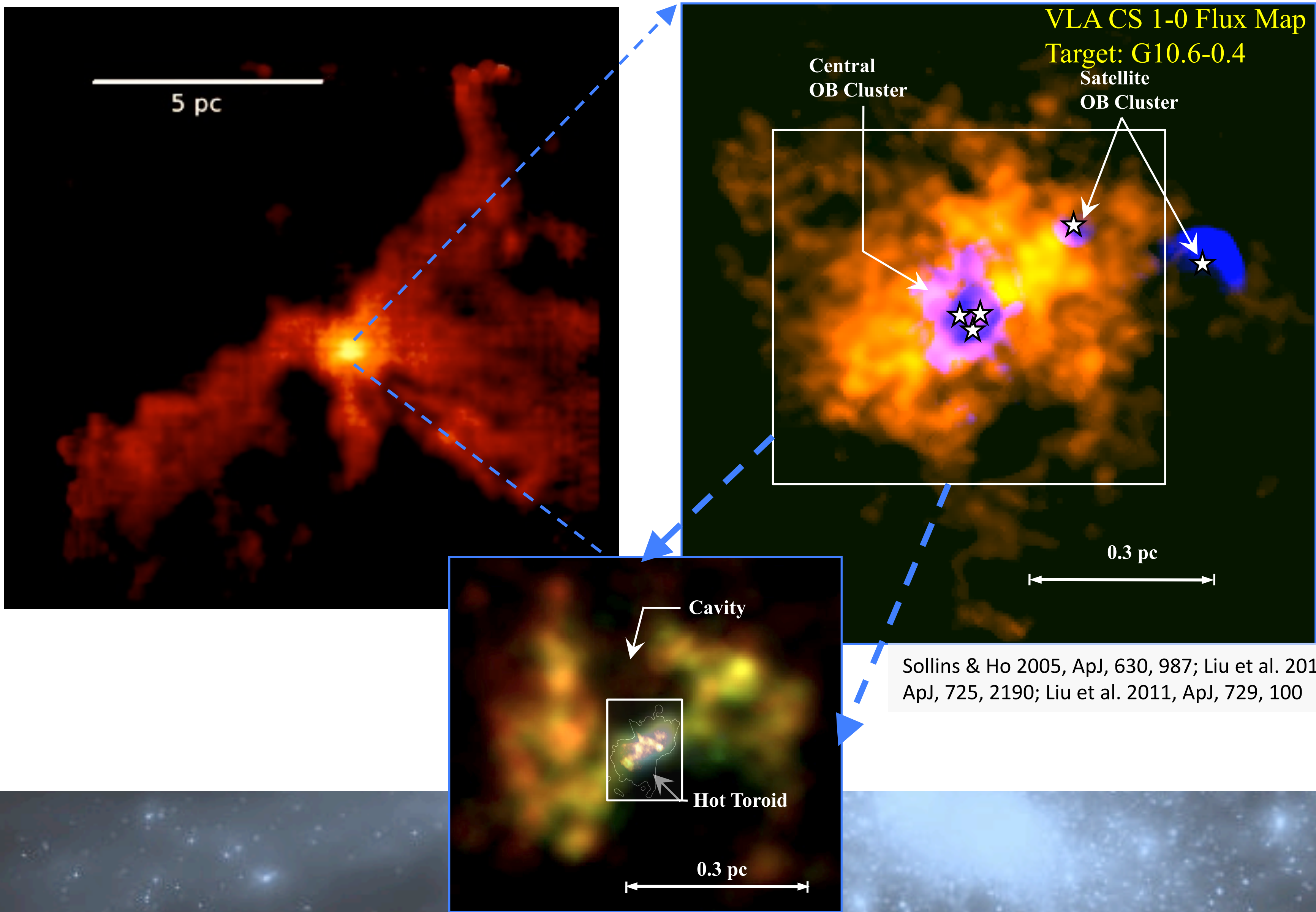
Red : *Spitzer* MIPS 24 um (Indicator for HII regions)
Green: *Spitzer* IRAC 8 um
(Liu et al. 2012, ApJ, 745, 61)

Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4



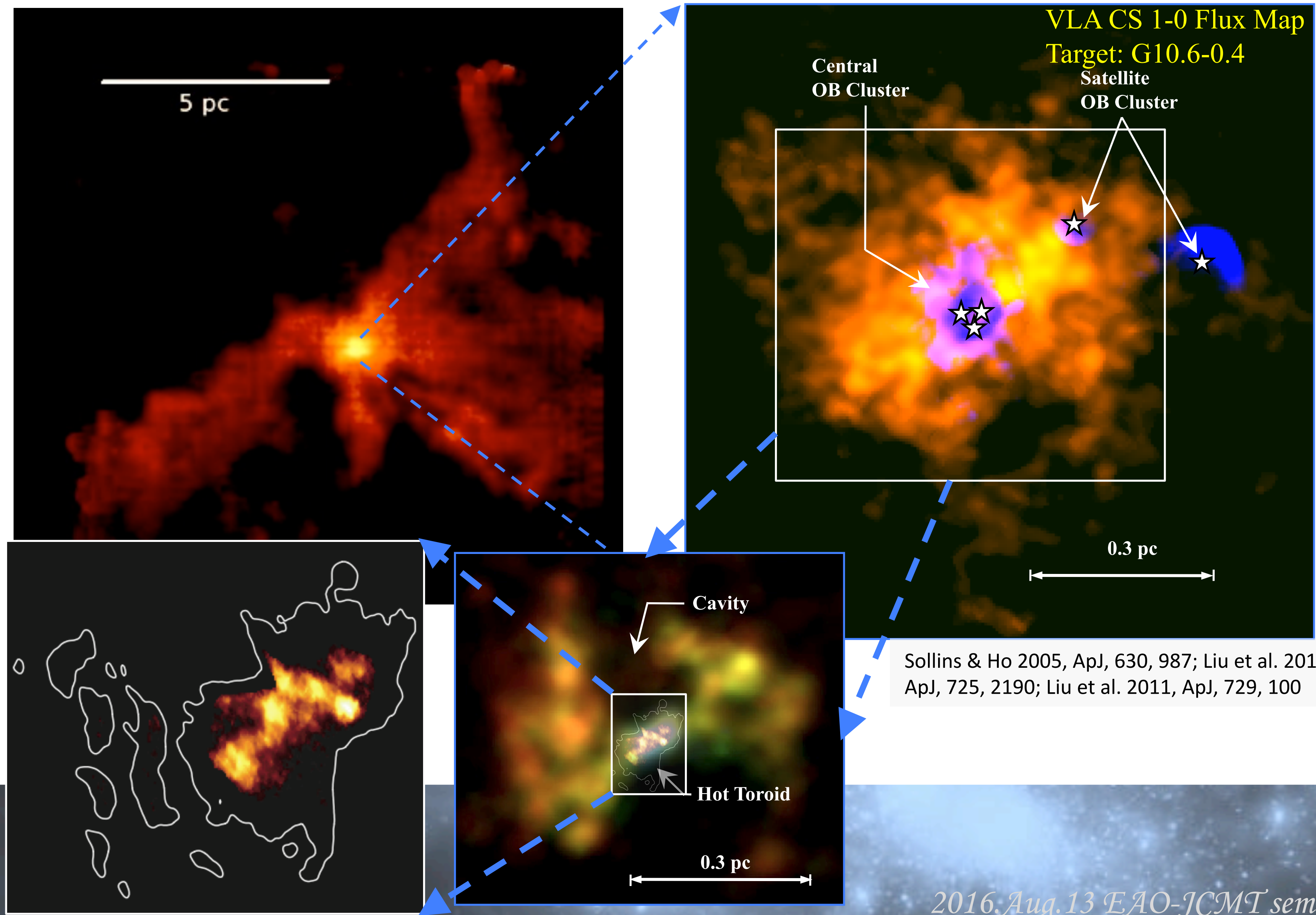
Sollins & Ho 2005, ApJ, 630, 987; Liu et al. 2010, ApJ, 725, 2190; Liu et al. 2011, ApJ, 729, 100

Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4



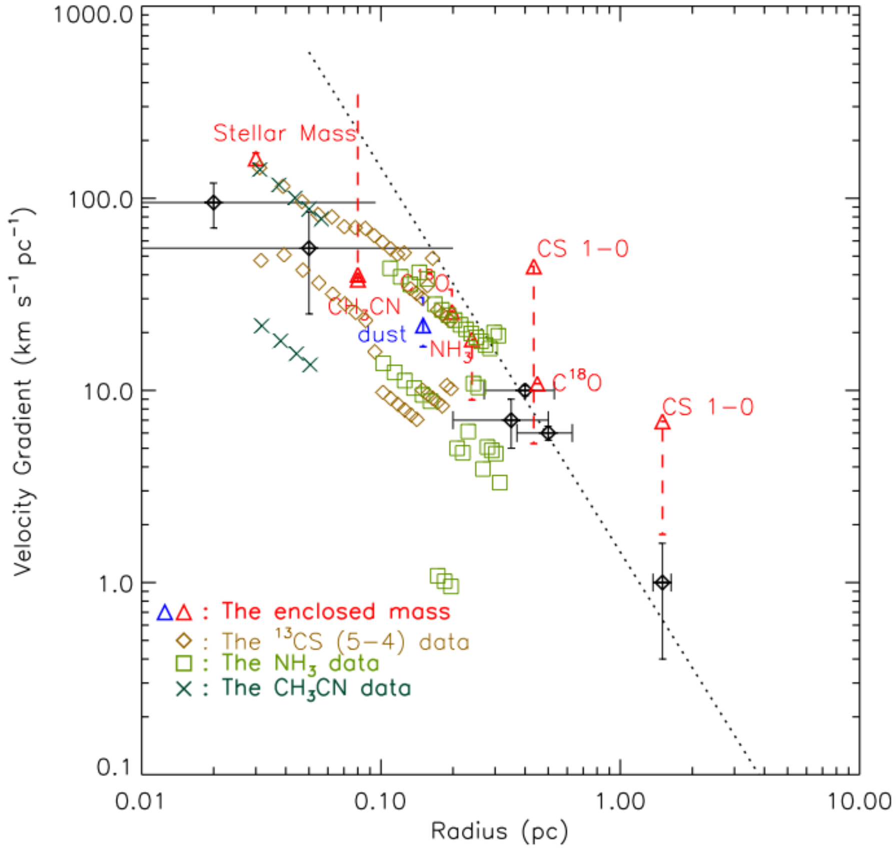
Sollins & Ho 2005, ApJ, 630, 987; Liu et al. 2010, ApJ, 725, 2190; Liu et al. 2011, ApJ, 729, 100

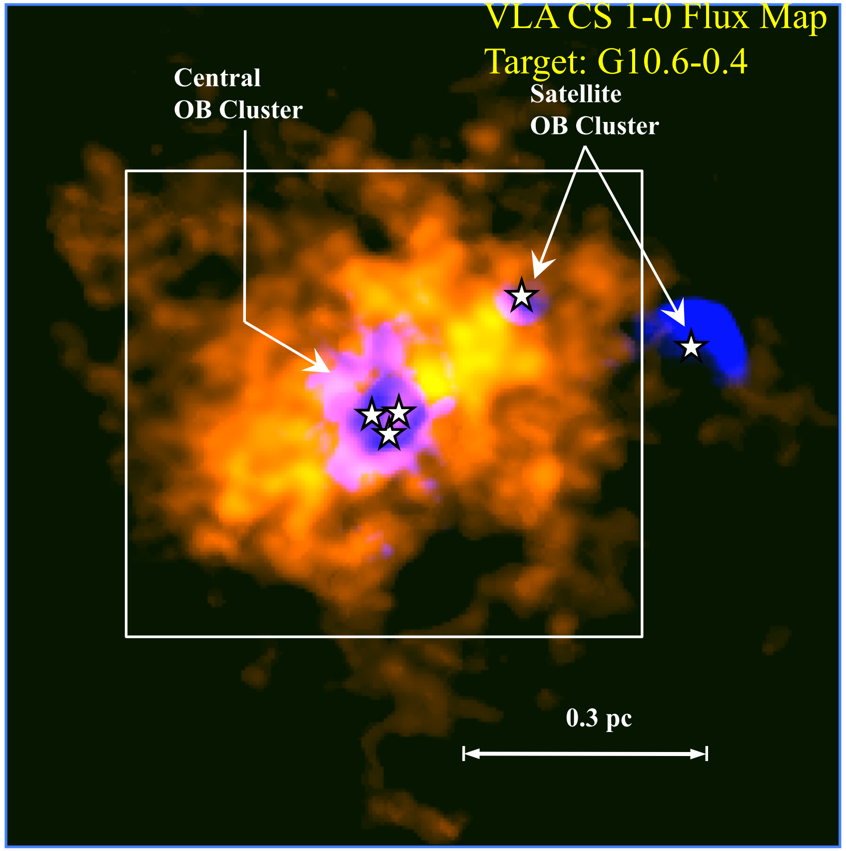
Aggressively Zooming-In to the Galactic L~10^6 OB Cluster-Forming Region G10.6-0.4



Sollins & Ho 2005, ApJ, 630, 987; Liu et al. 2010, ApJ, 725, 2190; Liu et al. 2011, ApJ, 729, 100

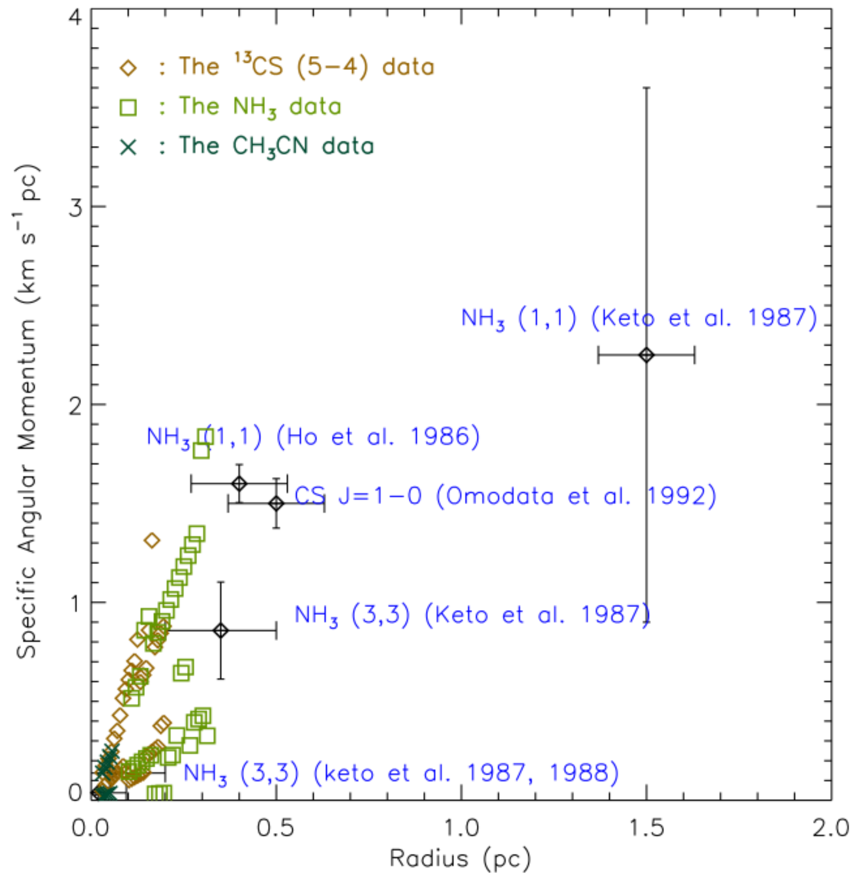
Progressively Tracing the Rotation Curve From Outer to Inner Region by Observing Multiple Molecular Line Tracers

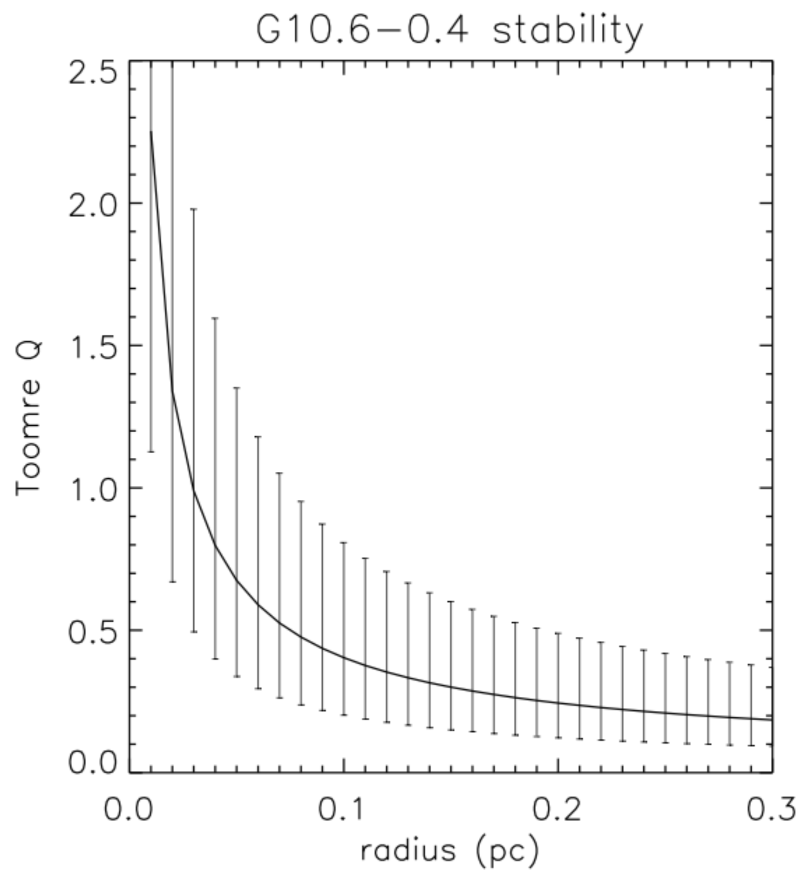




Liu et al. 2010, ApJ, 722, 262; Liu et al. 2010, ApJ, 725, 2190; Liu et al. 2011, ApJ, 729, 100

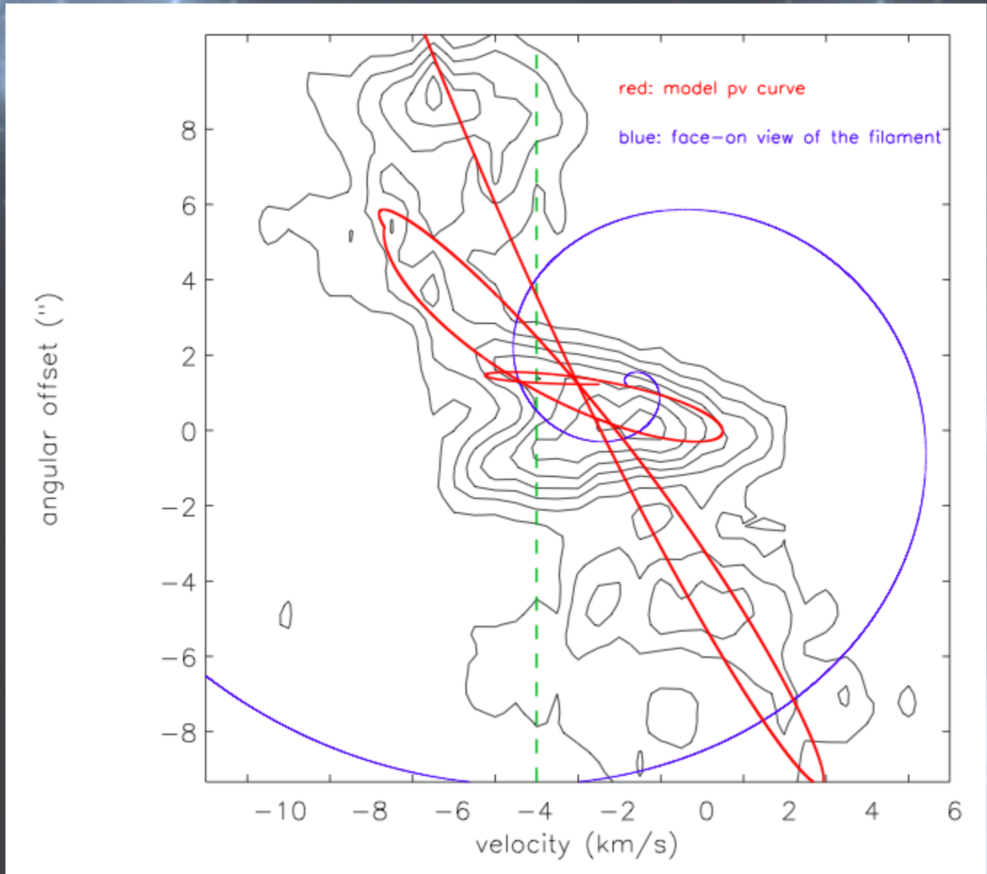
Decreasing Specific Angular Momentum in a Toomre Unstable Flattened Rotating Accretion Flow

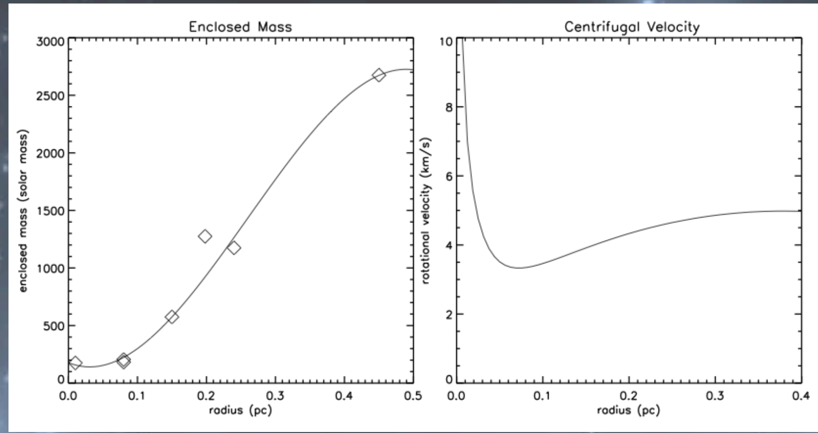


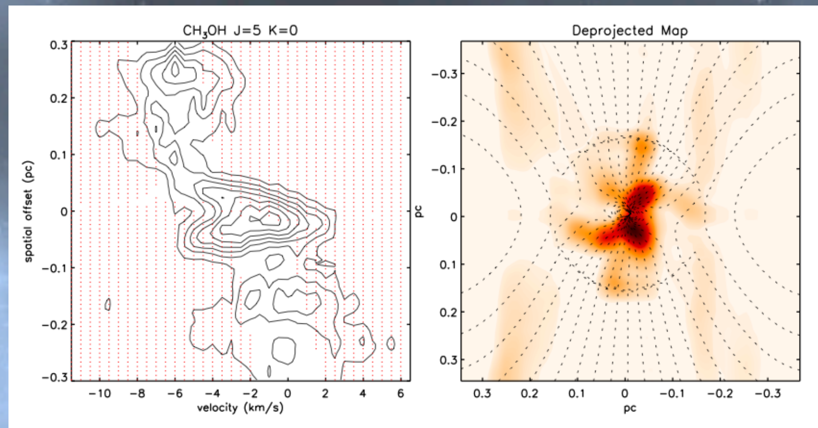


Liu 2012, PhD, Thesis

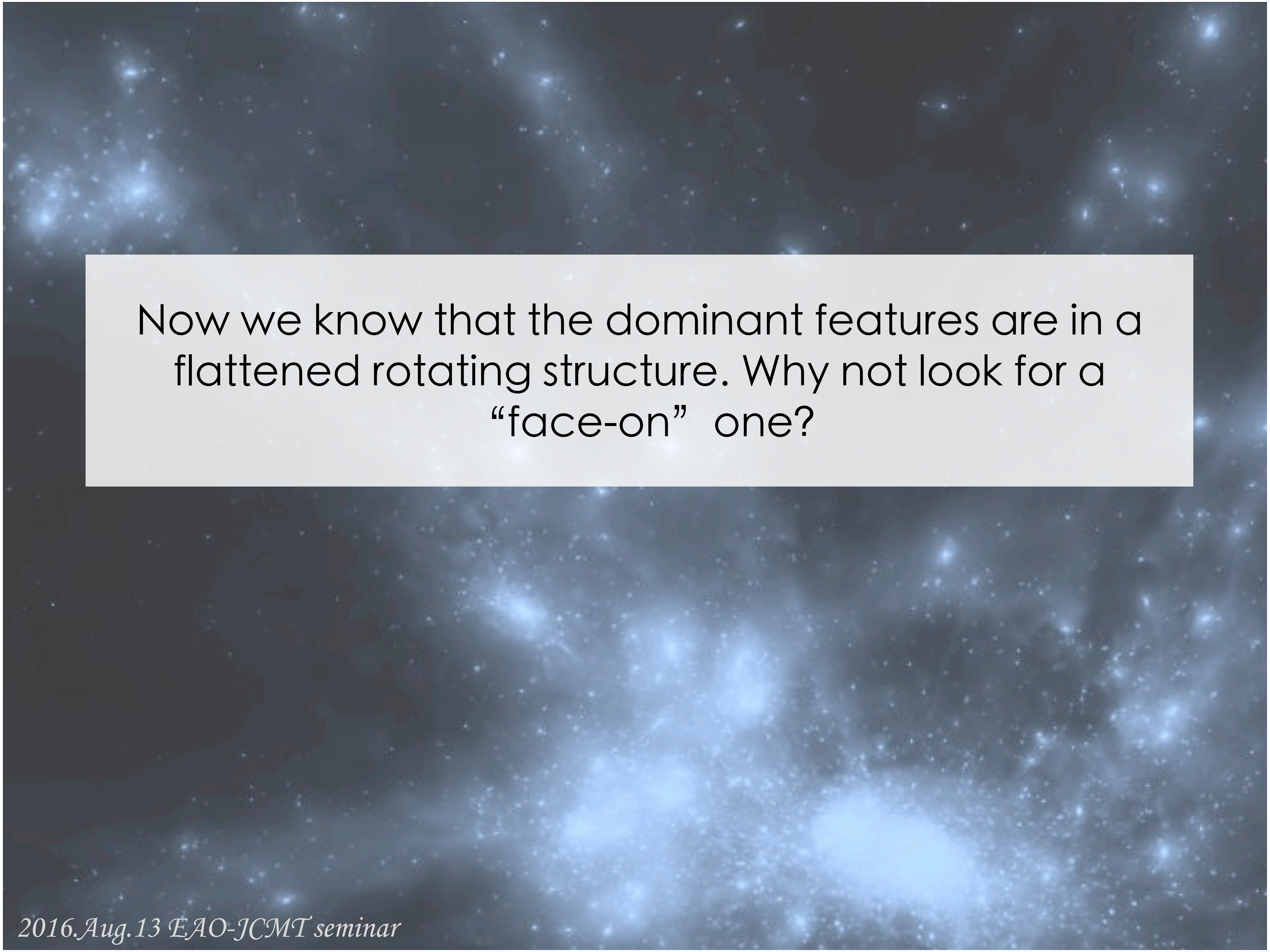
Showing Significant Asymmetry in Position-Velocity Diagram







Liu 2012, PhD, Thesis


Now we know that the dominant features are in a flattened rotating structure. Why not look for a “face-on” one?
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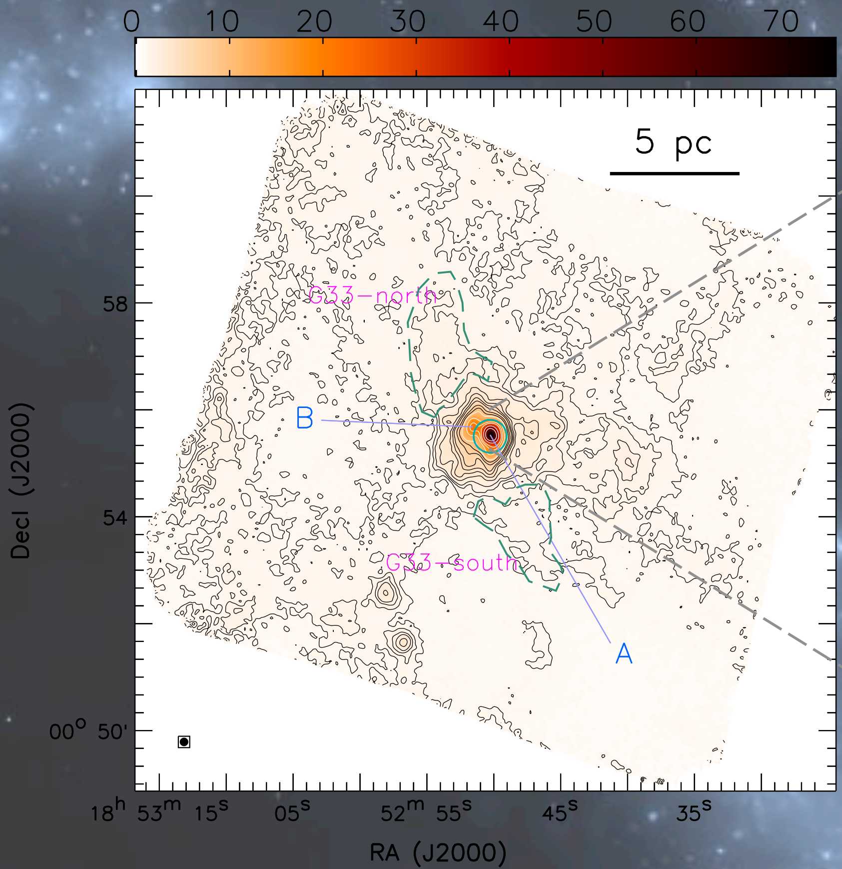
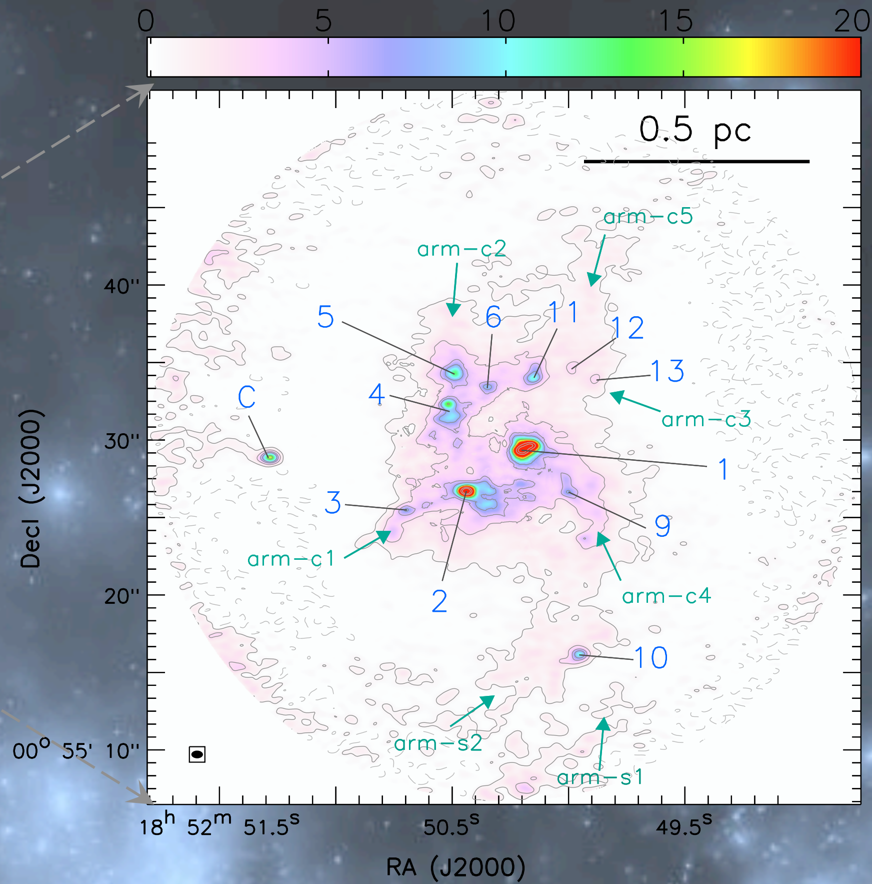
The Unified Power of CSO and ALMA in Studying OB Cluster-Forming Molecular Cloud: The Case of G33.92+0.11



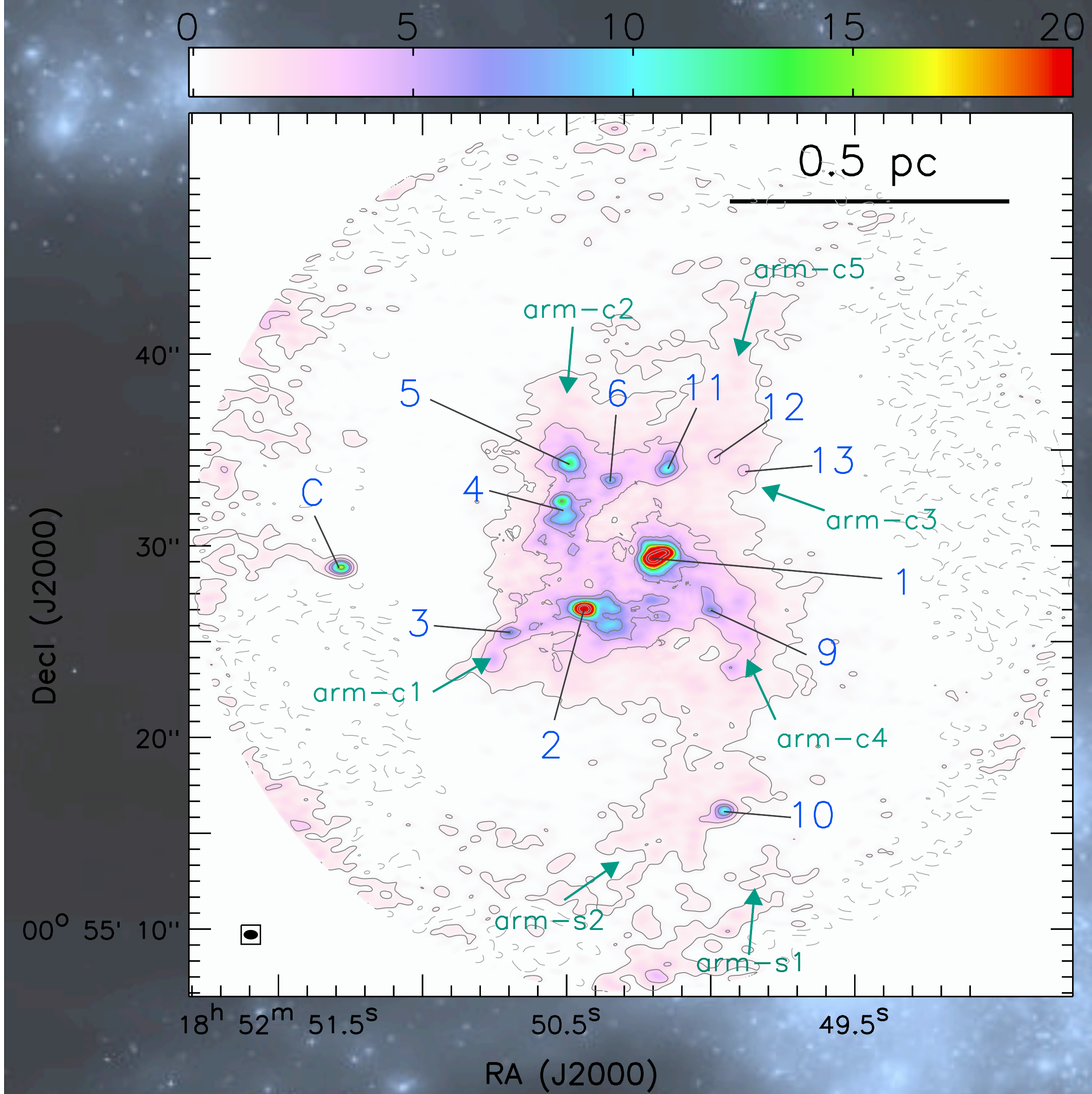
CSO-SHARC2 0.35 mm imaging resolved the accreting molecular filaments towards the sub-parsec scale, ~3000 Msun OB cluster-forming molecular clumps G33.92+0.11 A and B.



ALMA Cycle-1 observations of 1.3 mm dust continuum showed that the <0.5 pc scale spiraling arm-like structures are cradles to form massive molecular cores.

Liu, Hauyu Baobab et al, 2015

The Unified Power of CSO and ALMA in Studying OB Cluster-Forming Molecular Cloud: The Case of G33.92+0.11



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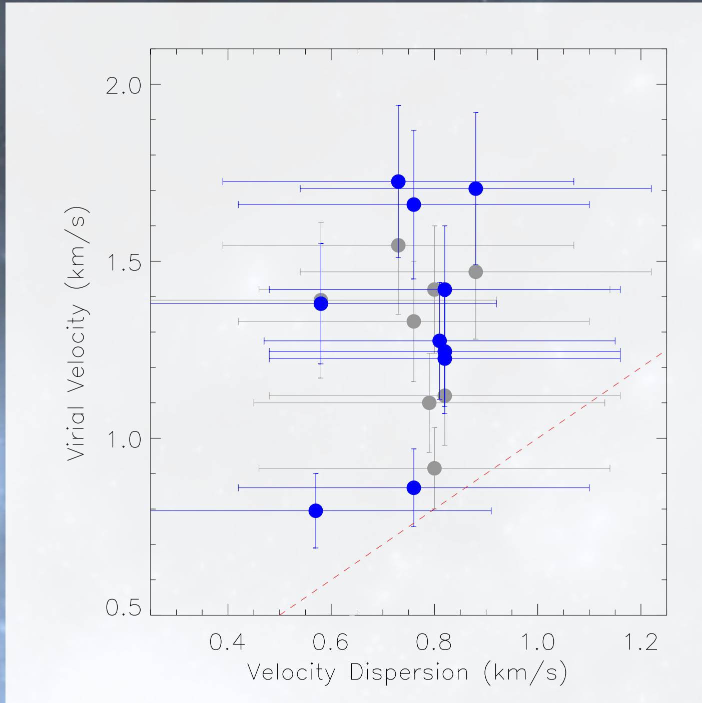
Liu, Hauyu Baobab et al, submitted to ApJ

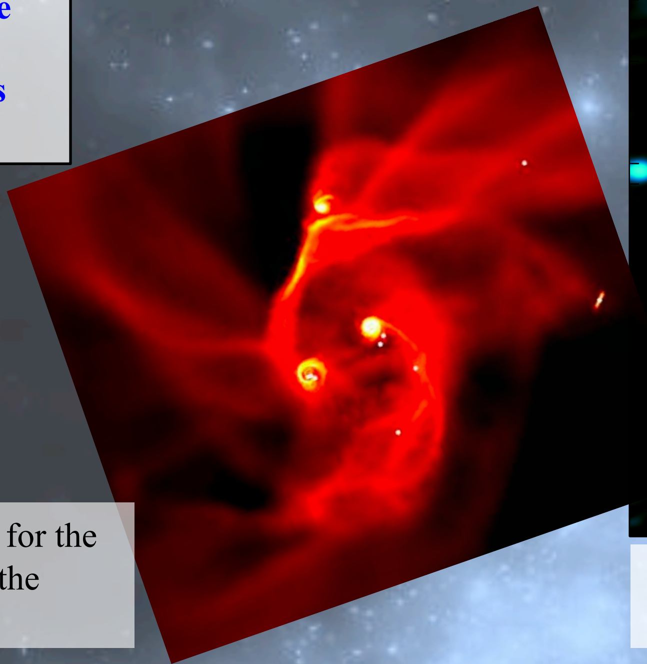


(Liu et al. 2015)

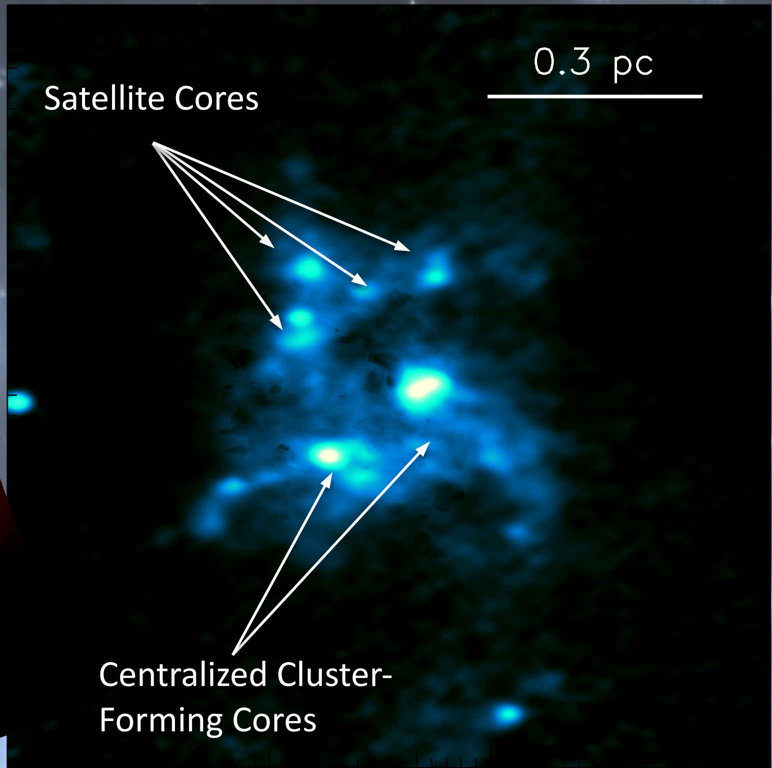
2016.Aug.13 EAO-JCMT seminar

ALMA Cycle-1Image on The Center of OB Cluster-Forming Region G33.92+0.11

Gas structure is flattened in the central 0.3 pc radius, and formed spiraling gas arms. These gas arms are indeed the cradles of *satellite* dense molecular cores and intermediate/high-mass stars.

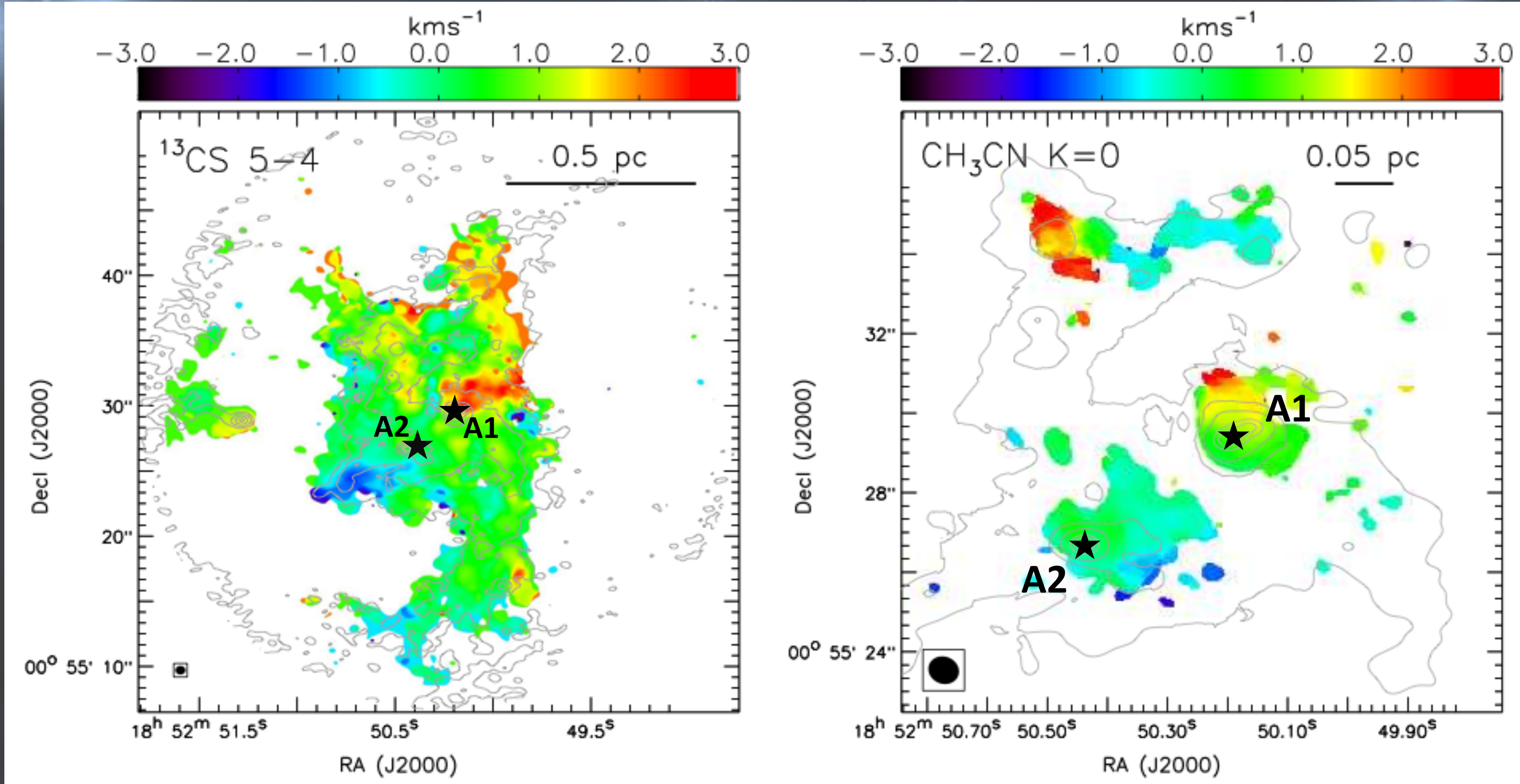


Numerical Simulation for the Cluster-Formation on the Much Smaller Scale



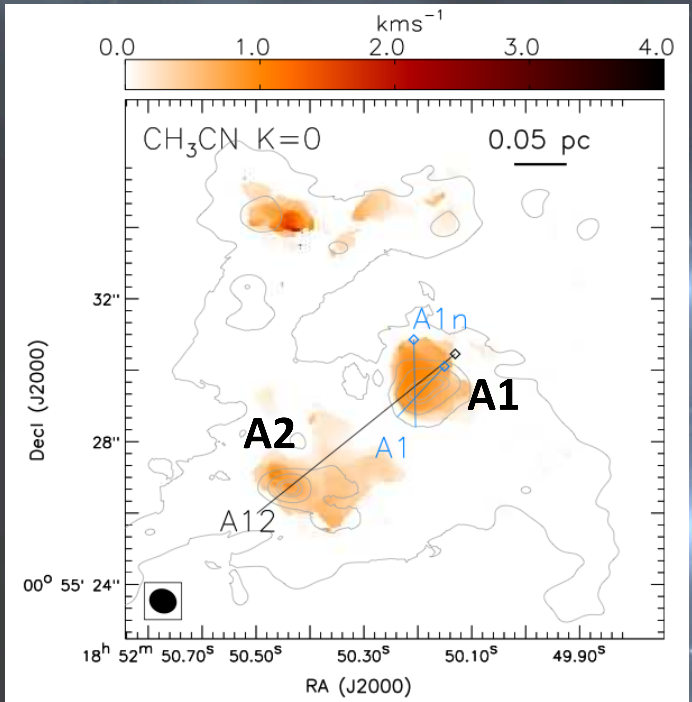
ALMA Cycle-1 Image of 1.3 mm Dust Continuum Emission (Liu et al. submitted.)

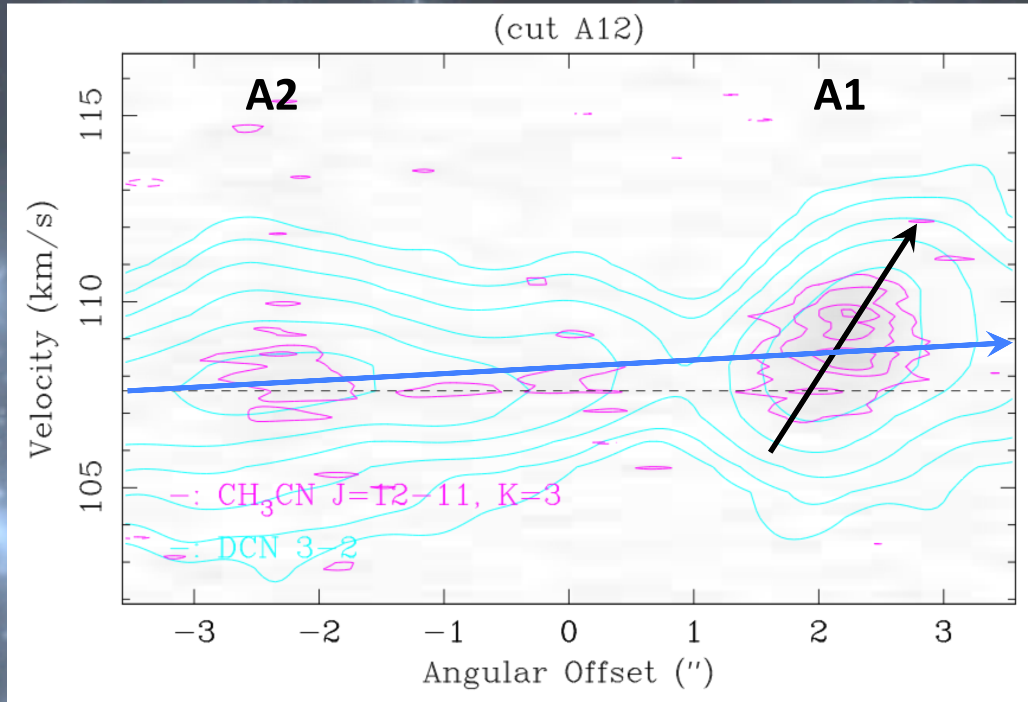
Velocity Maps From Different Tracers



(Liu et al. 2015)

Velocity Gradient: Hot Cores and Massive Molecular Clump

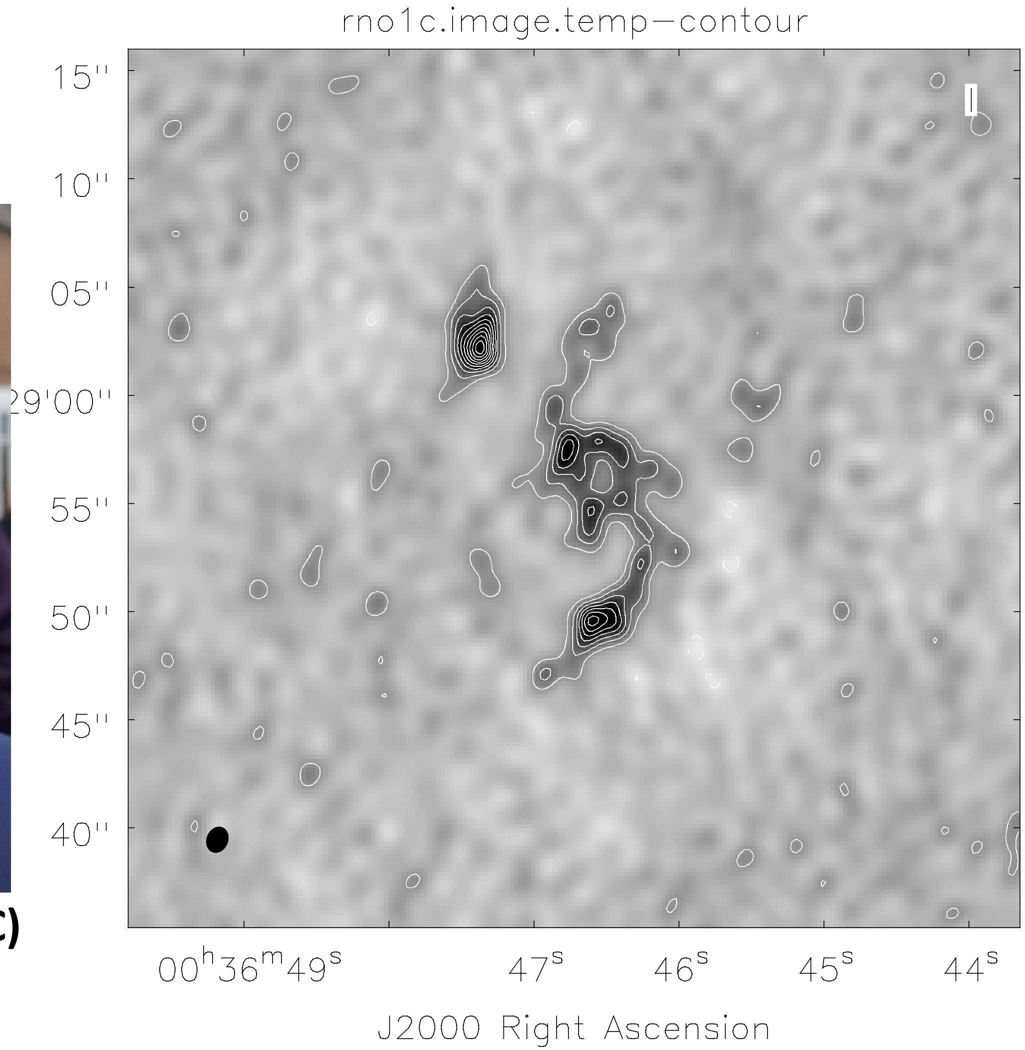




(Liu et al. 2015)

Low-mass Cluster-Forming Region L1287

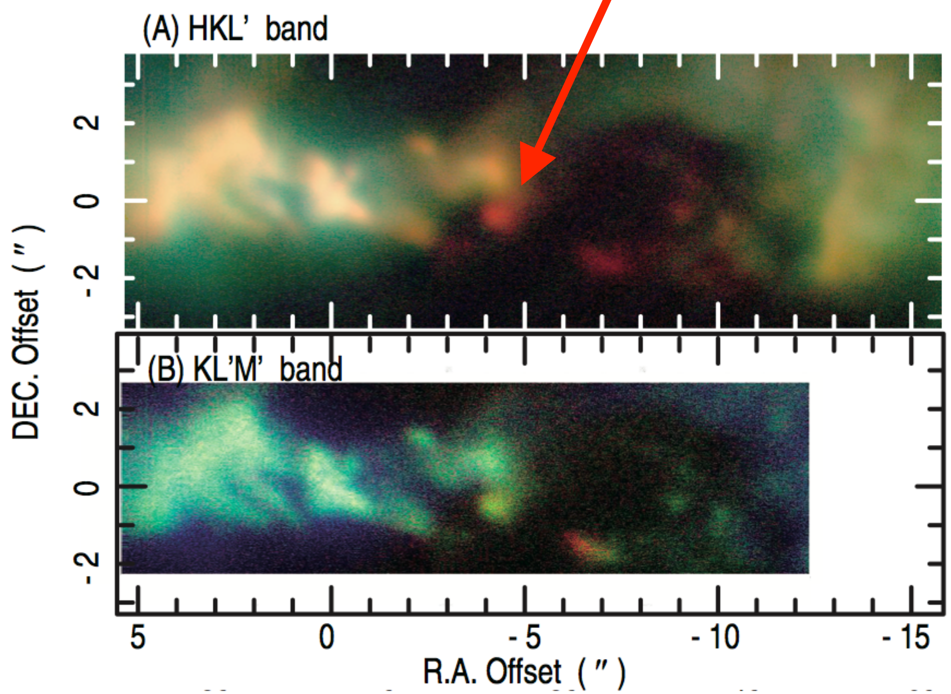
Carmen Juarez Rodriguez (IEEC)



Juarez & Liu et al. in prep.

The Case of Intermediate Star-Forming Region NGC6334V

Location of embedded intermediate mass stars

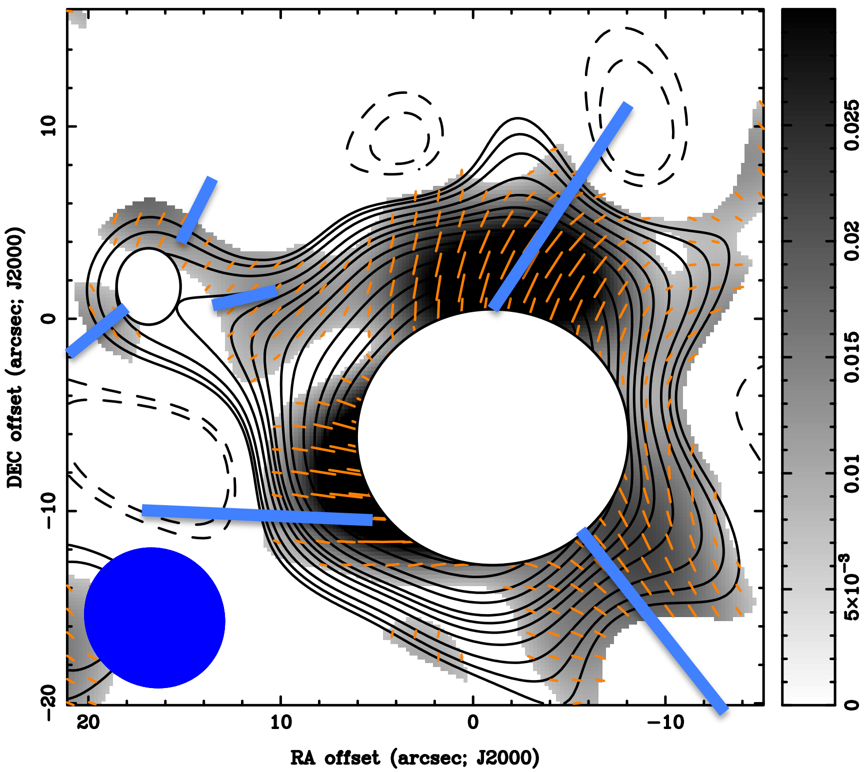


Hashimoto et al. 2007, PASJ, 59, 221

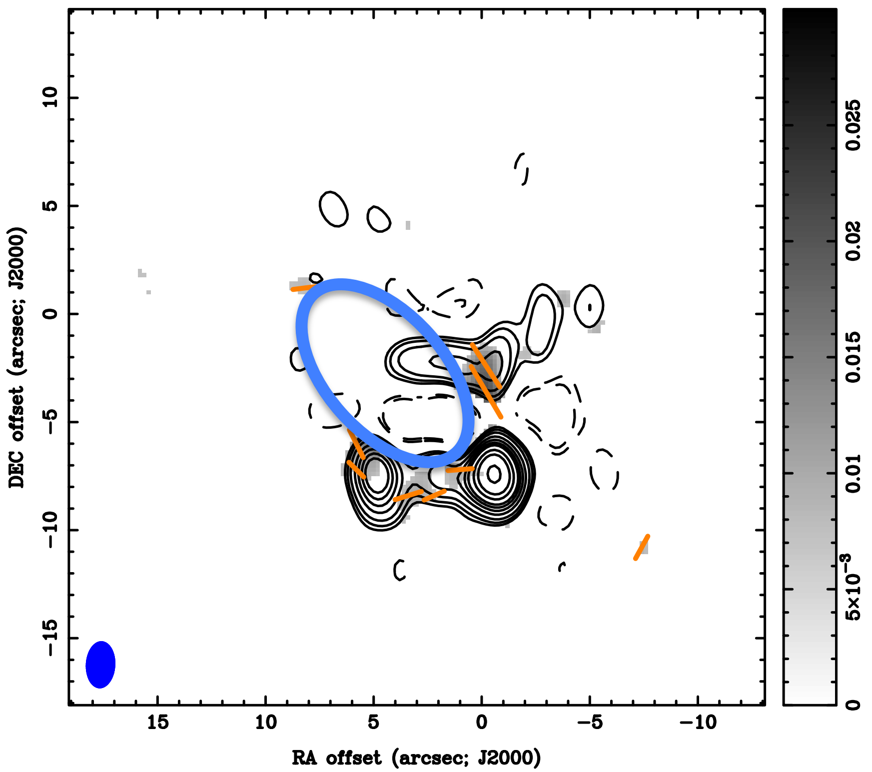
Carmen Juarez Rodriguez (IEEC)

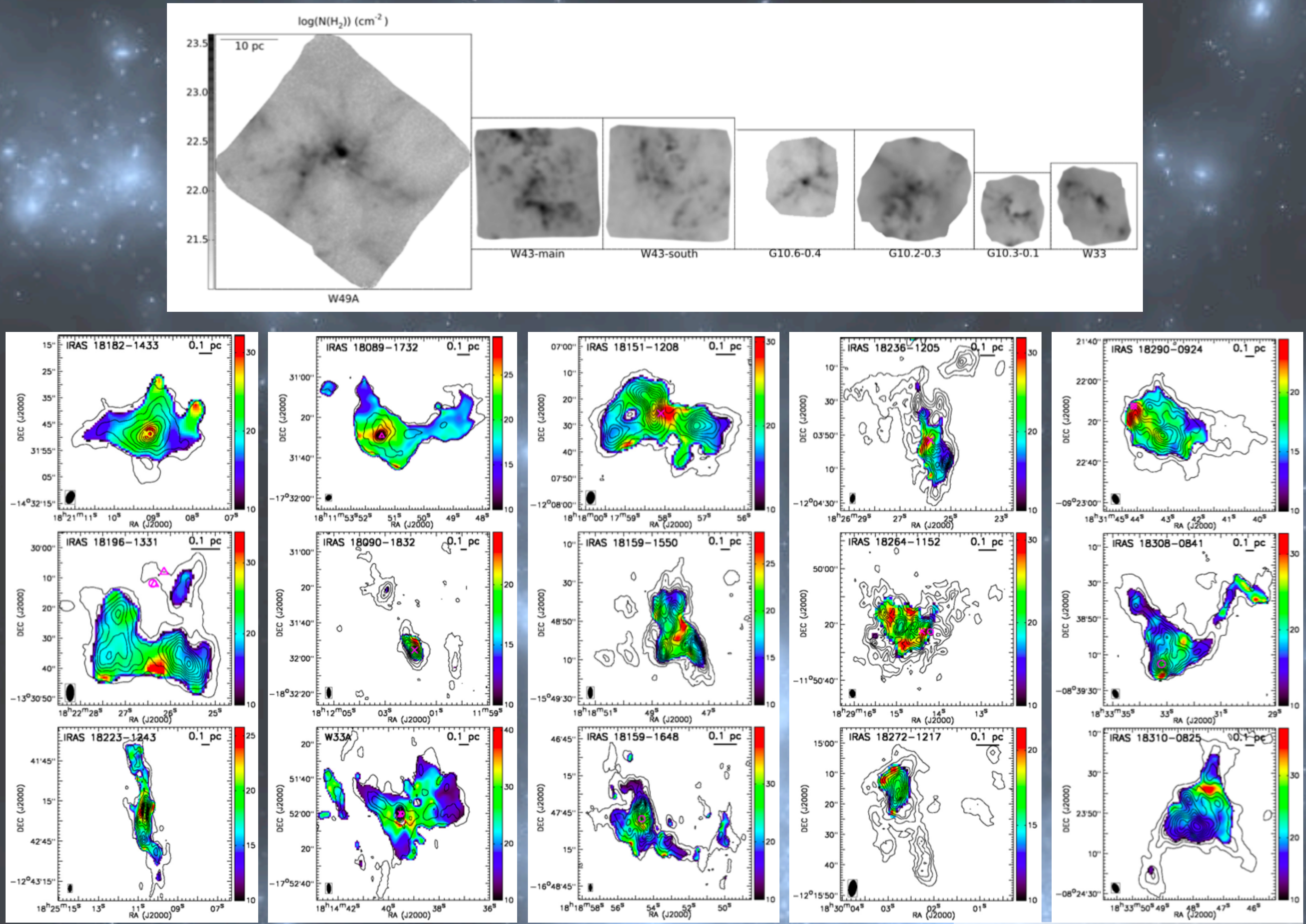
The Case of Intermediate Star-Forming Region NGC6334V

Poloidal Field on large scale

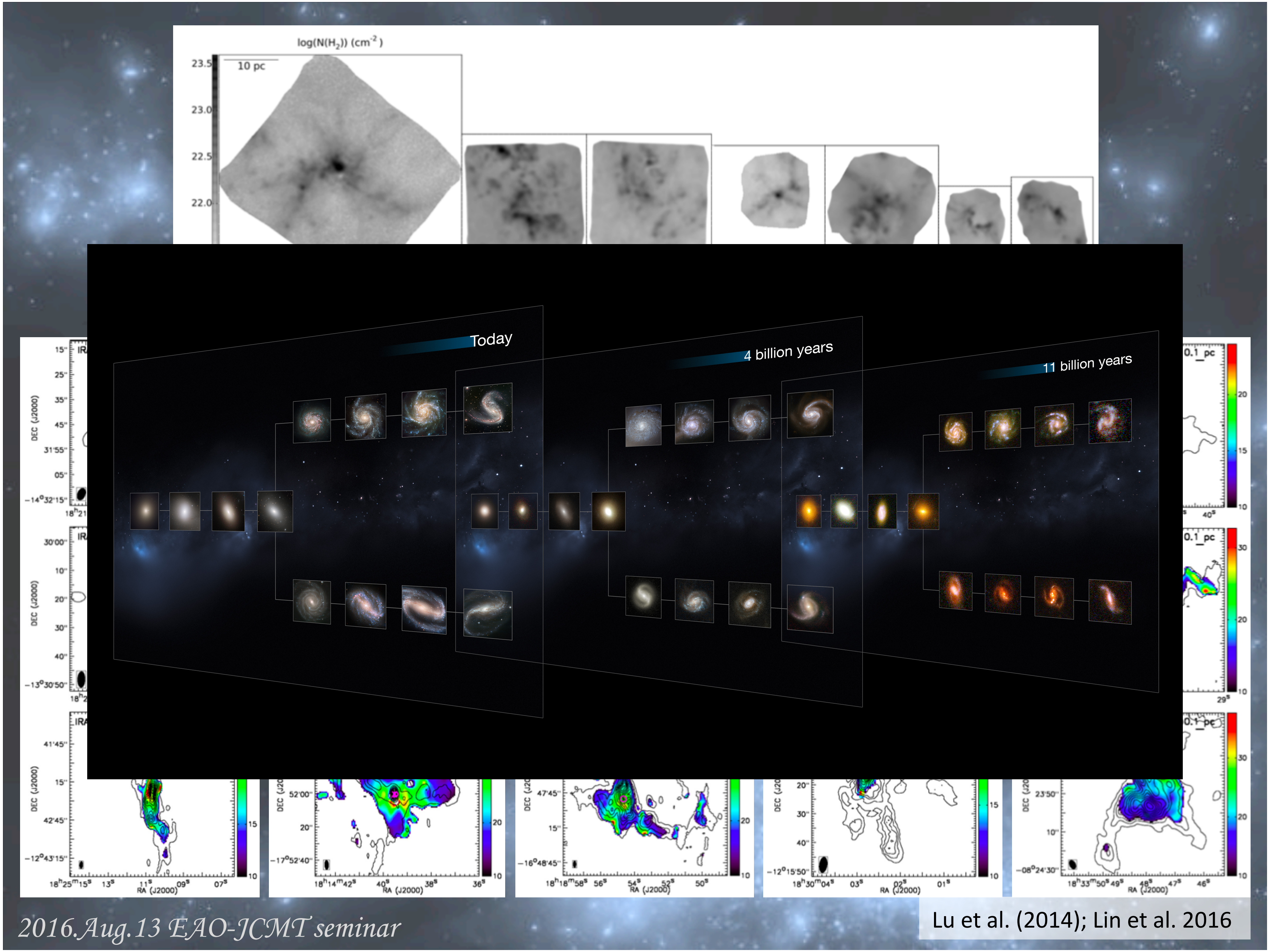


Toroidal Field at the center





Lu et al. (2014); Lin et al. 2016


log(N(H2)) (cm-2)
10 pc
Today
4 billion years
11 billion years
0.1 pc
2016.Aug.13 EAO-JCMT seminar
Lu et al. (2014); Lin et al. 2016

Conclusion

1. We develop a routine to iteratively fit and yield ~10" resolution dust temperature and column density maps, with little or no loss of extended structures.
2. The high quality, high resolution images are pointing us to a new way of looking at the problem. Molecular clouds form in different physical condition may have different geometry/ morphology, and the subsequent star-forming activities. (Obvious, since stellar clusters are not all the same either)
3. Very dense, parsec scale molecular gas clumps may only form when there is a highly centrally concentrated molecular cloud structure, which is conducive or is a consequence of cloud global gravitational collapse. Molecular gas in such system seems relatively well self-shielded, and therefore has a better chance to form gravitational bound stellar cluster.


Thank You Very Much