RECONSTRUCTING HISTORIES OF CLUSTER FORMATION

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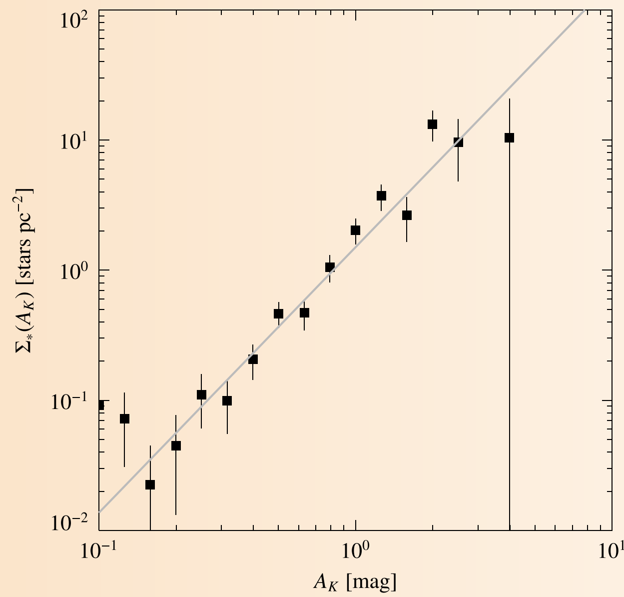
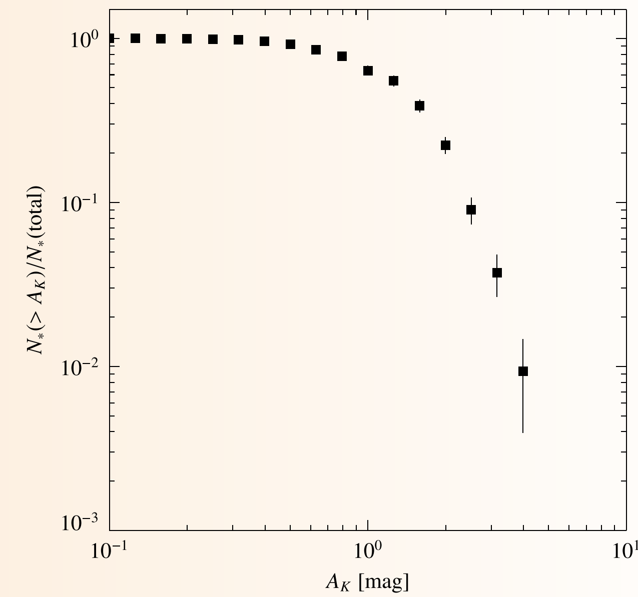
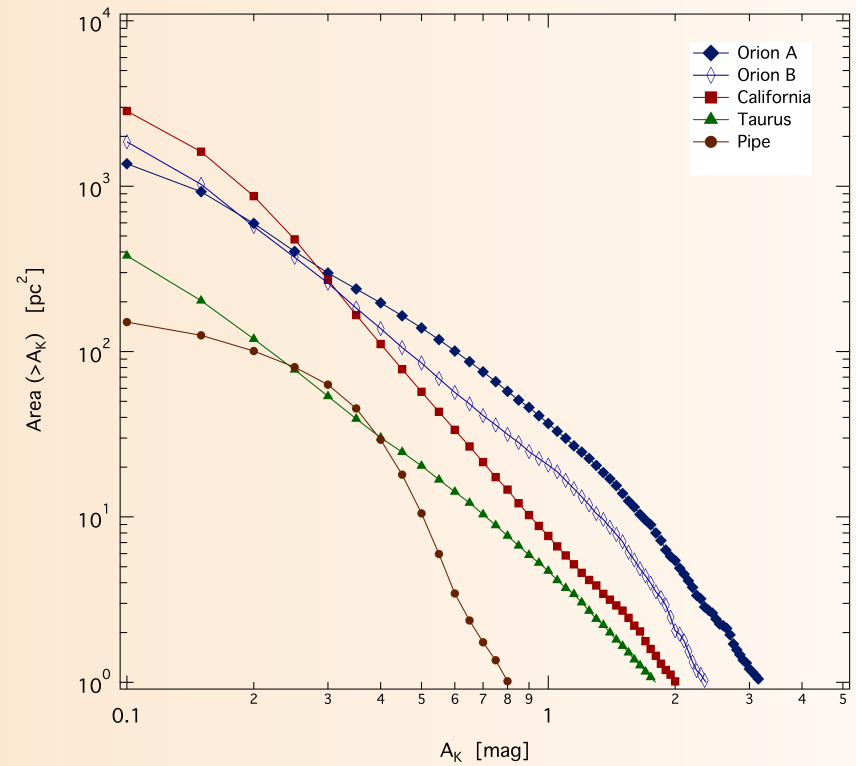
SOUL OF HIGH-MASS STAR FORMATION

PROGRESSION OF STAR FORMATION IN MOLECULAR COMPLEXES

- Schmidt's Law: a local relation of the form $\Sigma_*(A_K) = \kappa A_K^{\beta}$ (protostars pc^{-2}) exists in (but not within) GMCs (L13).
- SL is not sufficient to describe or to predict SF in active GMCs but it shows that *the structure of the cloud* plays a crucial role in the level of SF activity it will be developed.
- S ($>A_K$) declines and truncates effectively for most clouds, constraining current episodes of formation to the highest density regions, with little or no diffusion of protostars toward low density regions.
- However, once protostars evolve and gas clears, it is more difficult to reconstruct the history of star formation. The picture is more complicated.





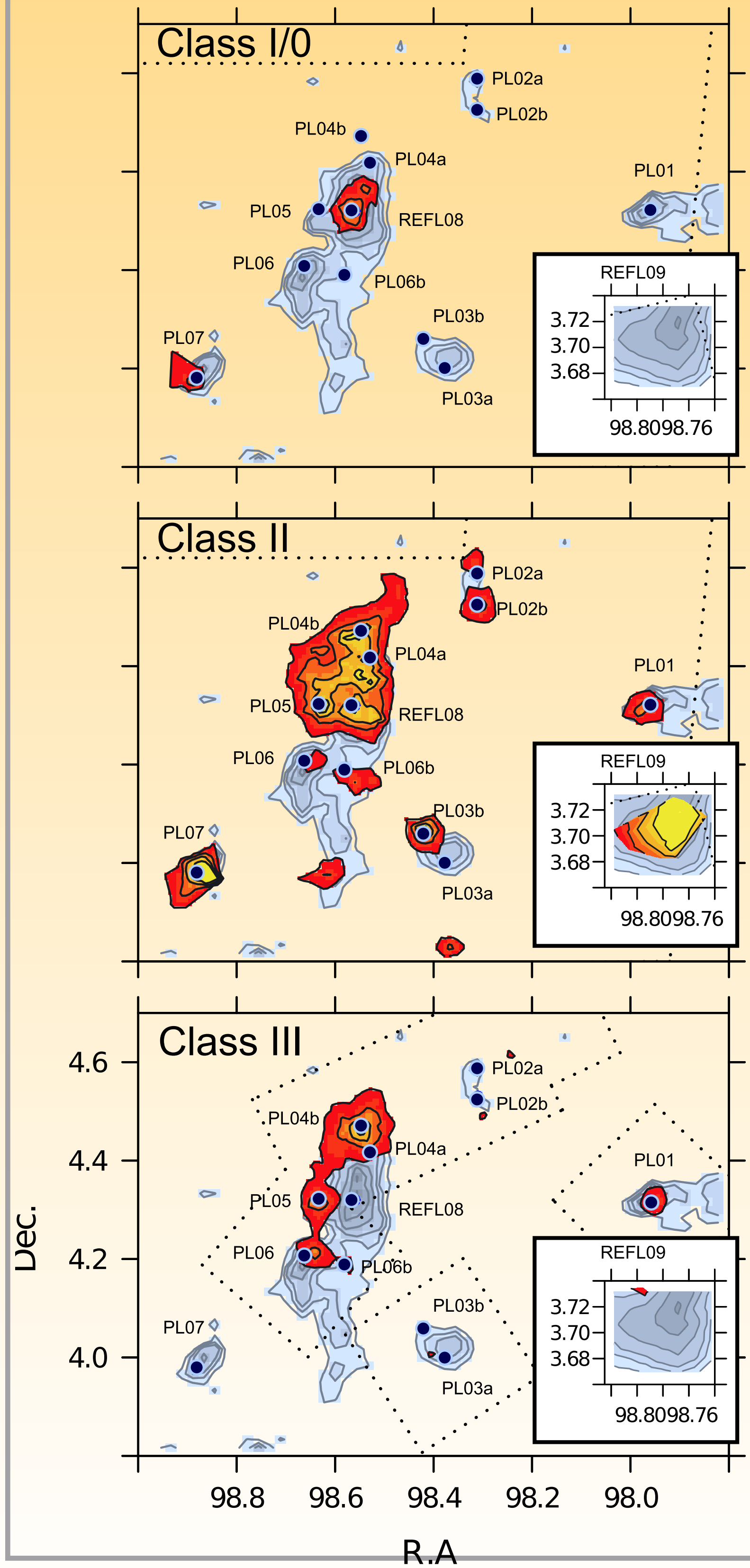


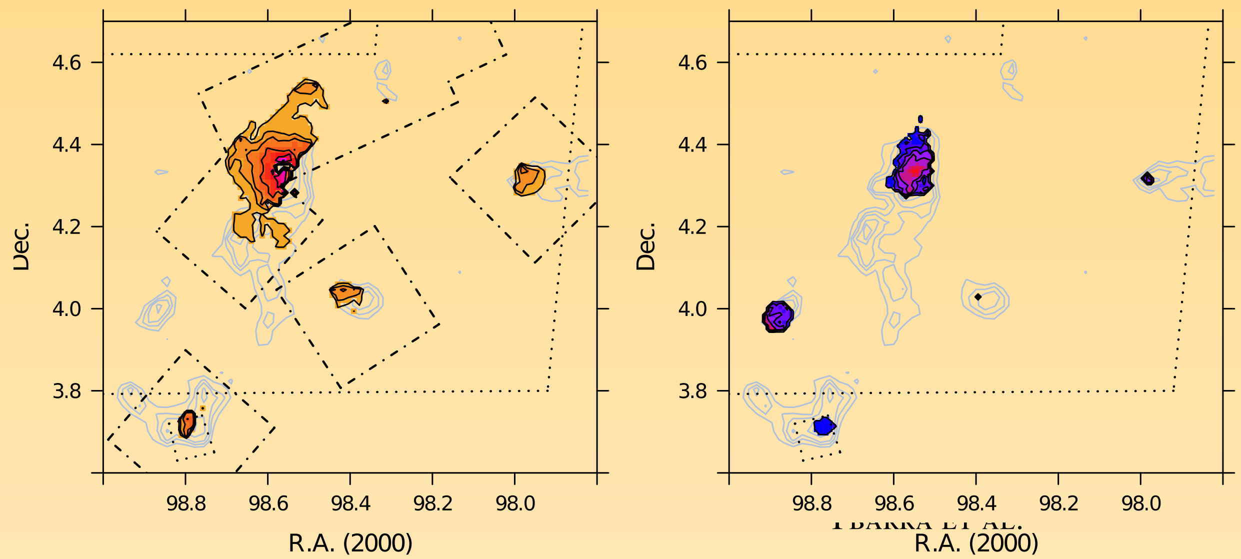
LADA ET AL 2013

cluster forming histories

Rosette GMC

RMC, Ybarra et al. 2013





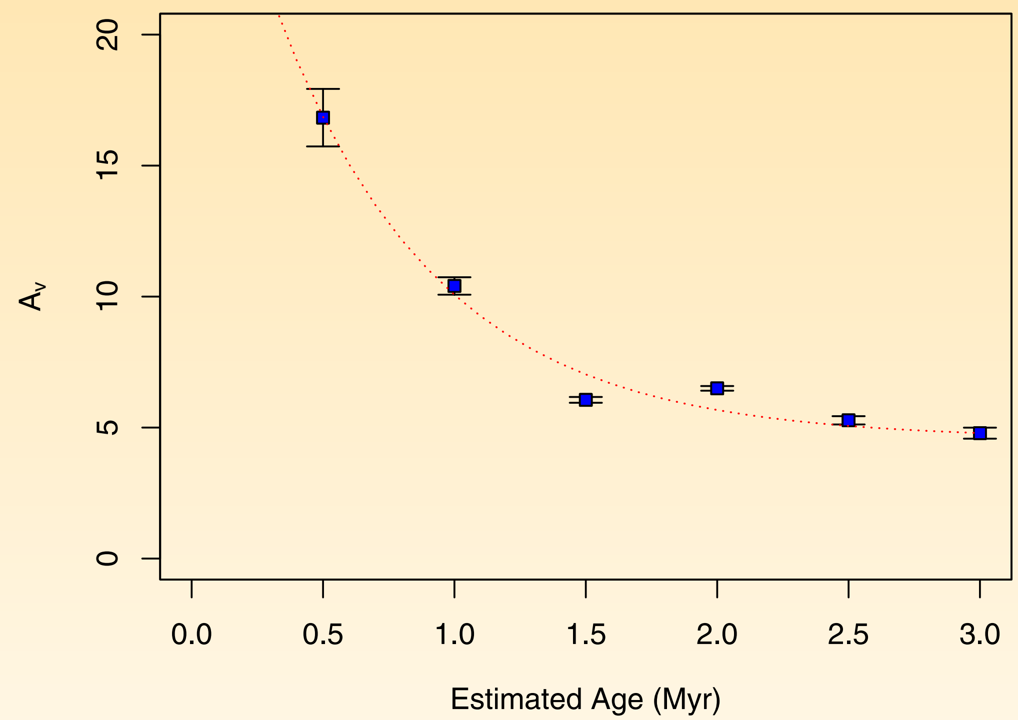


Figure 8. Plot of estimated age vs. mean extinction. The age is estimated from the Class II to Class III ratio. The red dotted line shows the exponential fit with half-life, $t_{1/2} = 0.4$ My, above $A_V = 5$ mag.

- Combining near-IR, Spitzer and Chandra catalogs, we were able to use evolutive classes and evolutive class number density ratios to reconstruct the progression of cluster ages as a function of extinction
- Rosette layout is favorable: minimal overlap of individual clusters.
- Rapid gas removal
- Nice correlation between age and extinction.

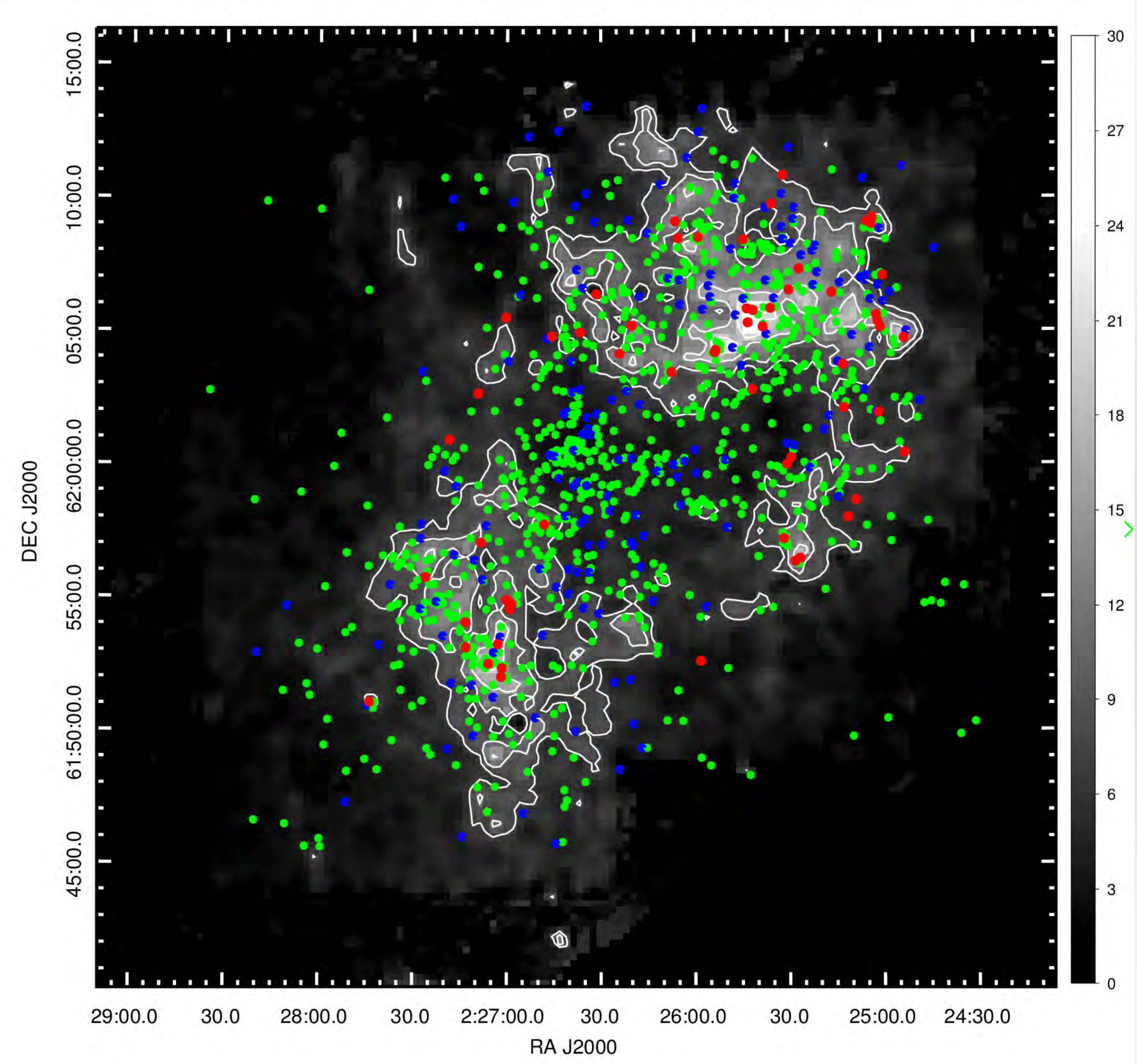
Towards understanding modes of cluster formation

W3

- Same idea for W3 region. However this one is more entangled.
- Separation into evolutive classes (0/I.II.III) allows to determine the spatial distribution of young sources and the early evolution of the region.

Román-Zúñiga et al 2015 (subm; in revision)

Rivera-Ingraham 2011,13



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- Separation into evolutive classes (0/I.II.III) allows to determine the spatial distribution of young sources and the early evolution of the region.
- We identify five principal clusters.

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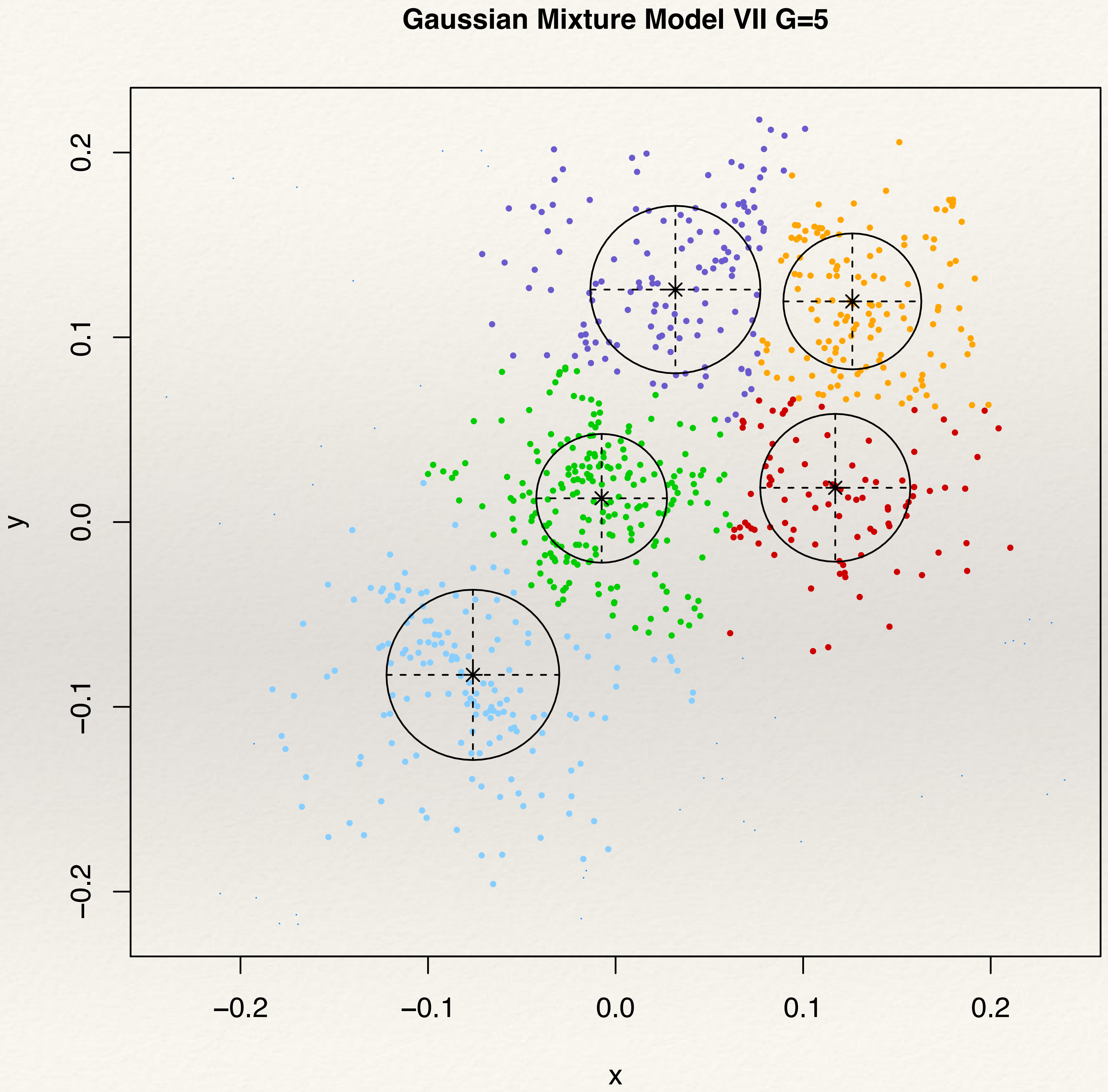

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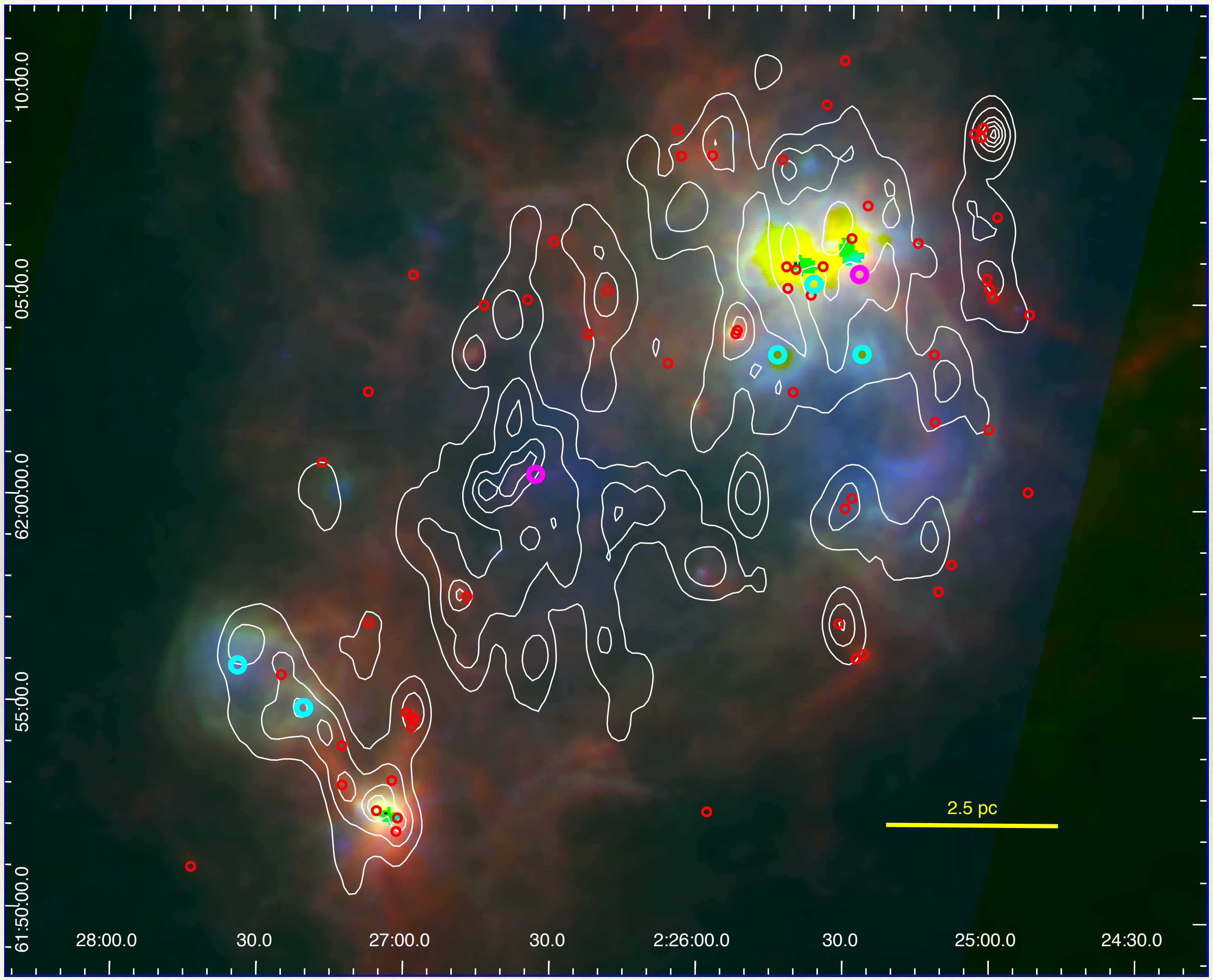

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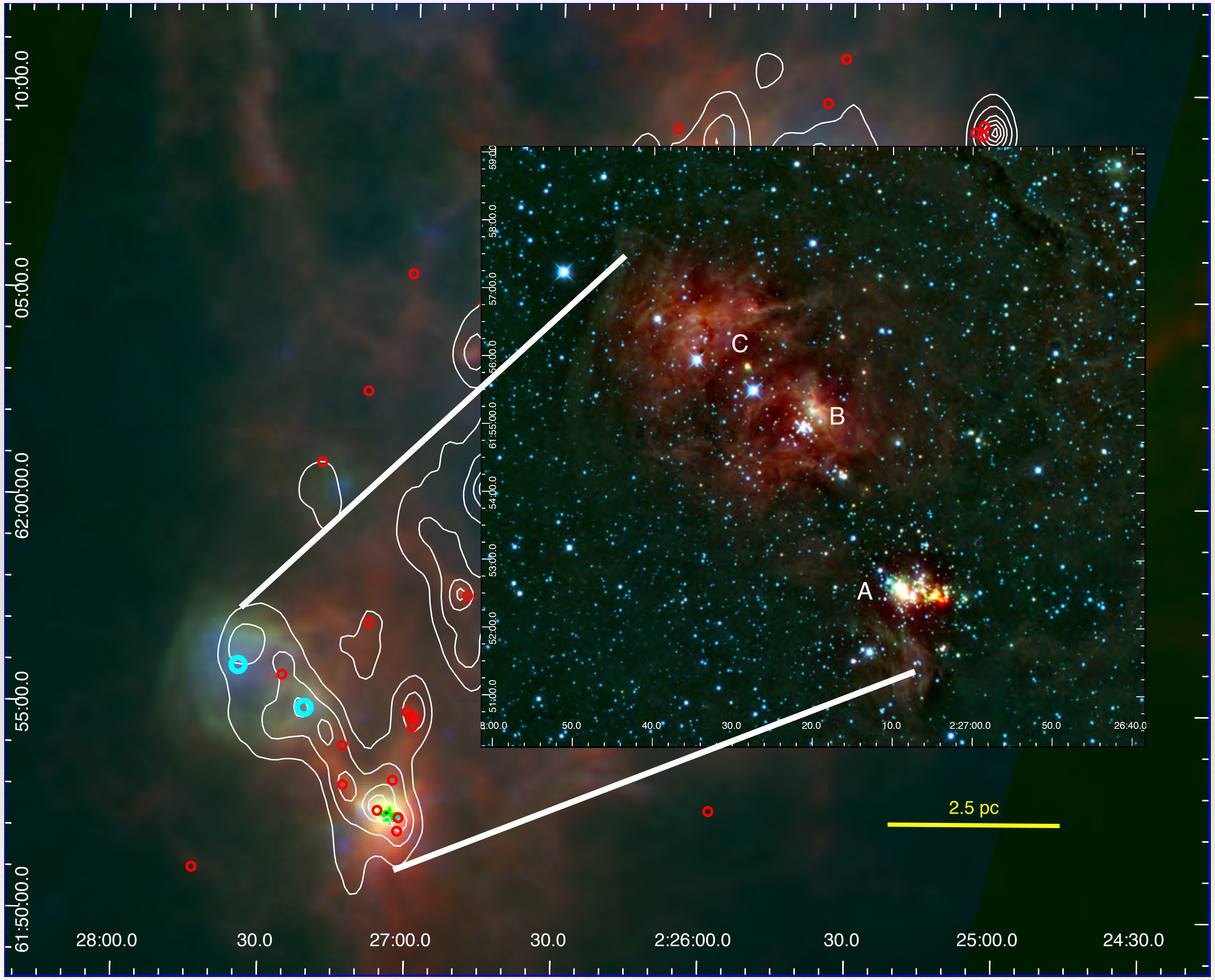

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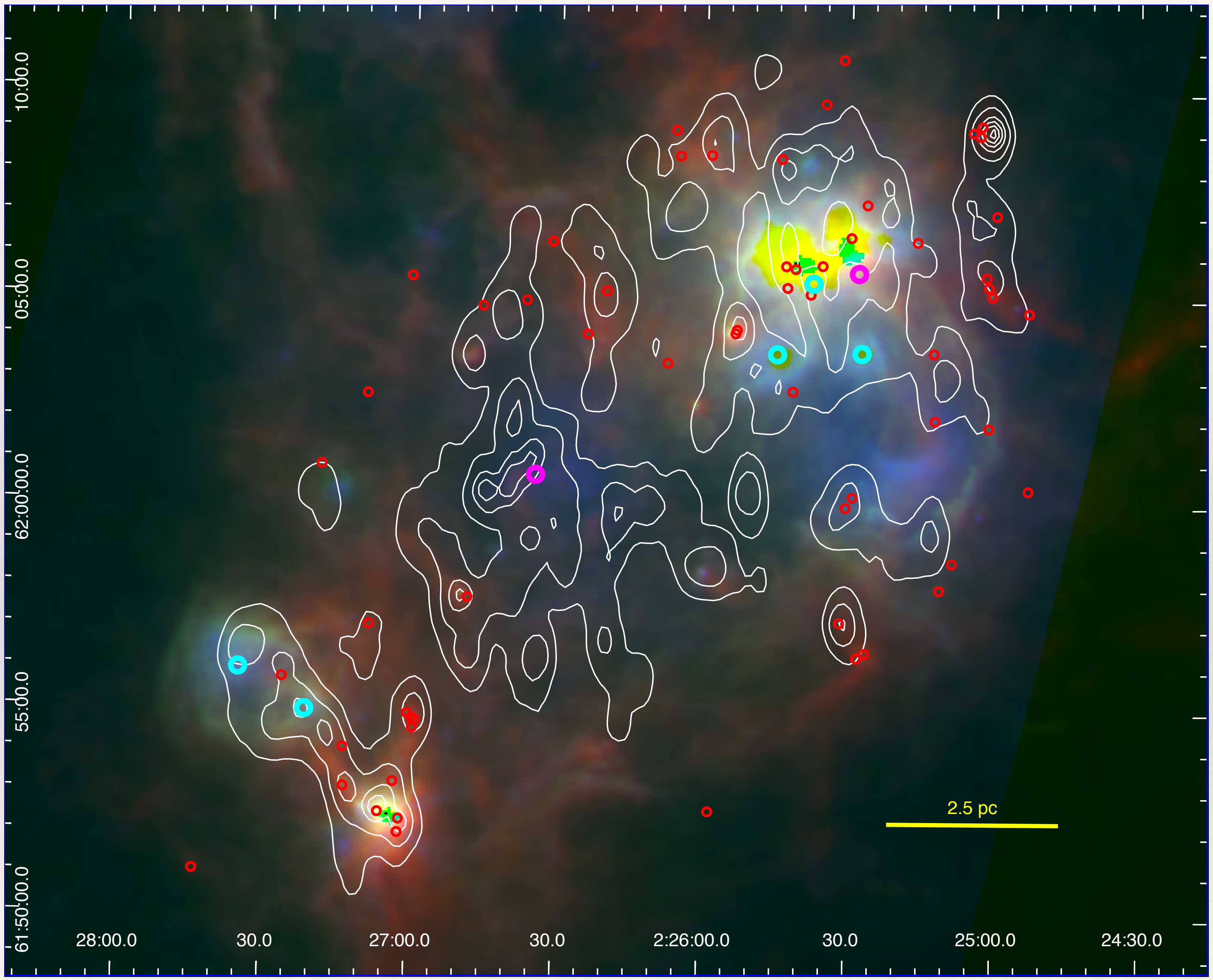

- YSO surface density analysis provides evidence of sub-structure.
- Many groups associated with Class I sources and thus represent some of the most recent event of formation.

see also talk by Daniel Walker!!

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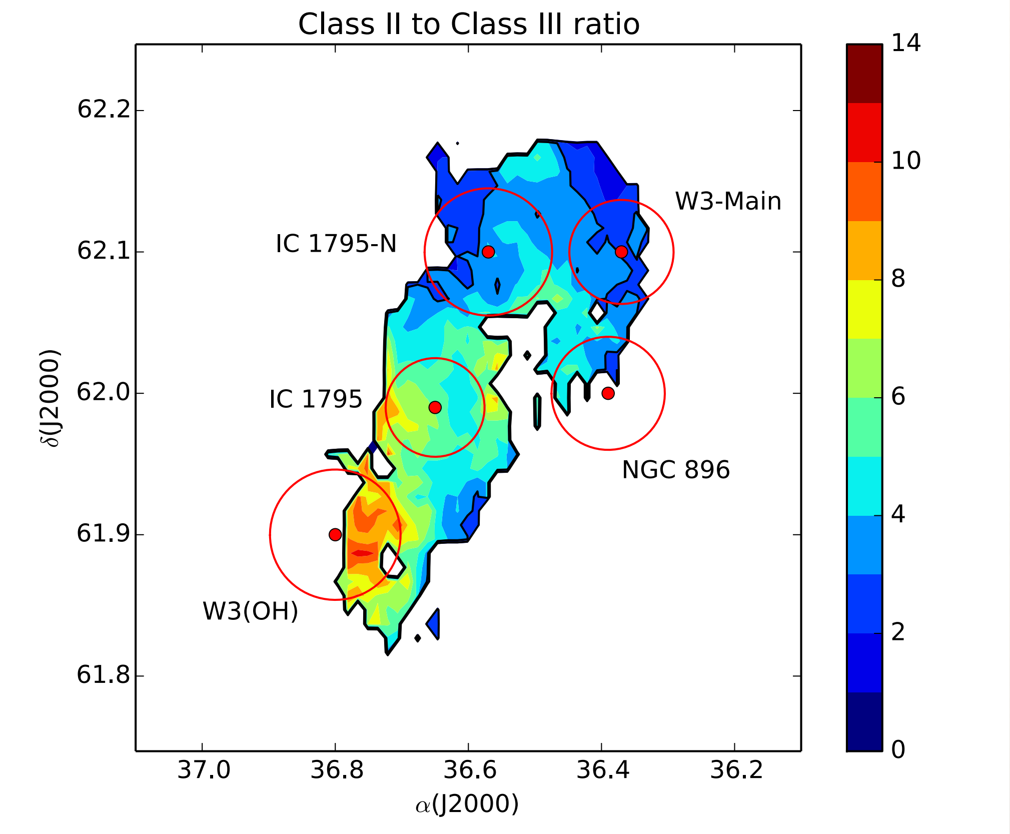

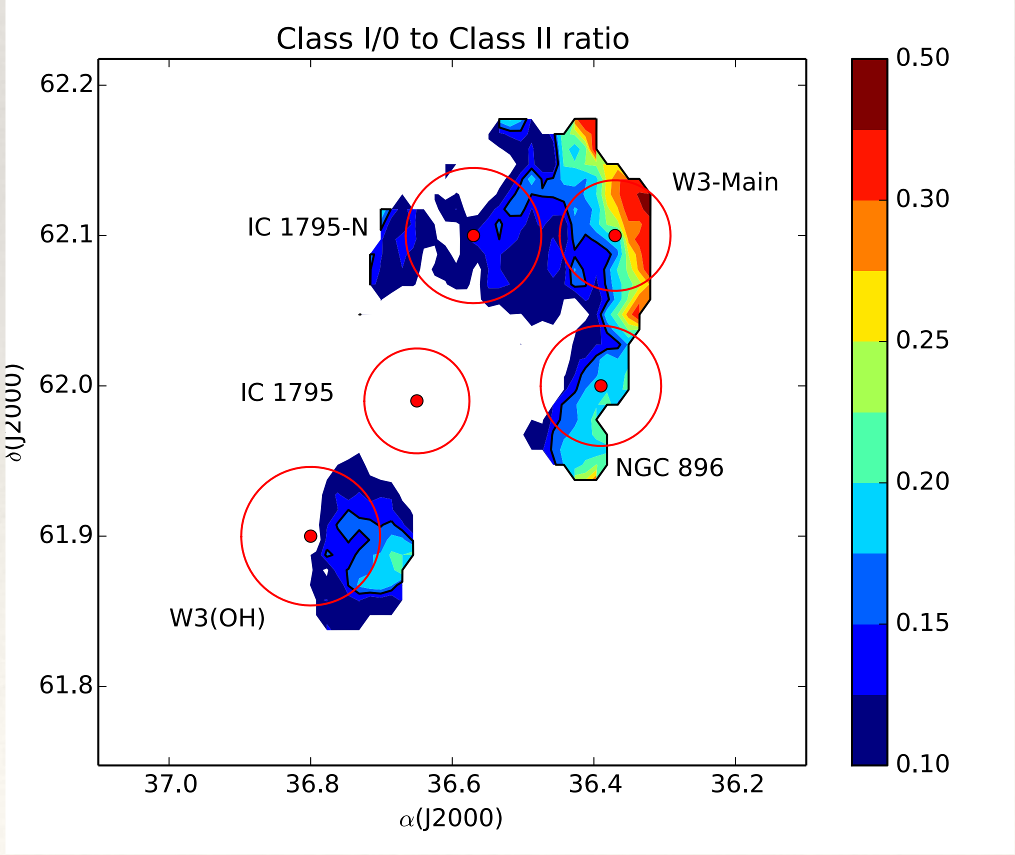

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- Class ratio maps allows us to attempt a rough reconstruction of the history of star formation in W3.
- Absence of Class 0/I sources and gas in IC1795 is indicative of a slightly older population.

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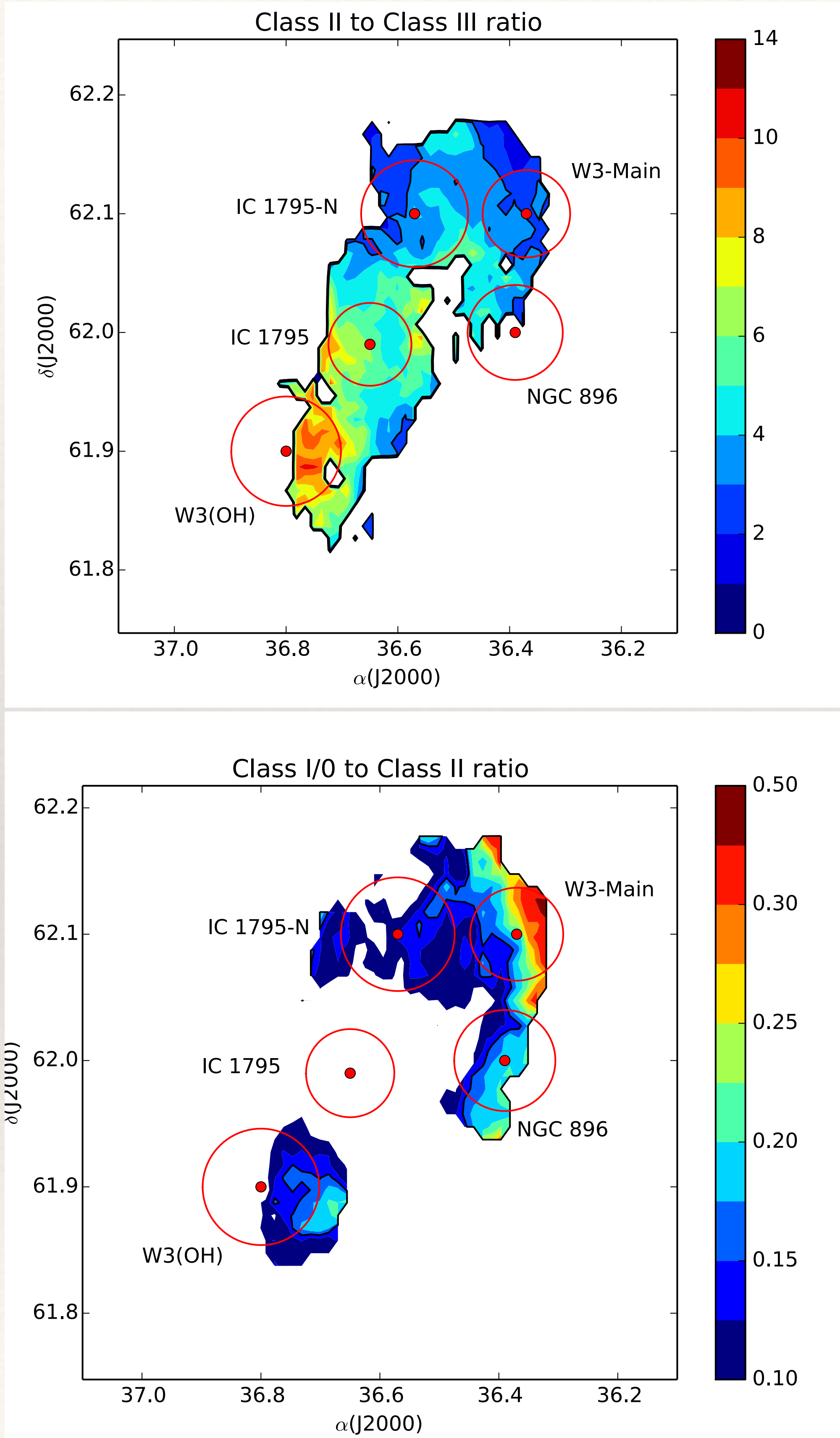

- YSO surface density analysis provides evidence of sub-structure.
- Many groups associated with Class I sources and thus represent some of the most recent event of formation.
- Class ratio maps allows us to attempt a rough reconstruction of the history of star formation in W3.
- Absence of Class 0/I sources and gas in IC1795 is indicative of a slightly older population.
- Class II are overabundant across the complex, and the large number of Class III candidates in W3-main may point towards rapid dispersion of disks.
- The large number of disk bearing sources in IC 1795 could be reinforce scenario sub-structured formation. If subgroup episodes are not simultaneous, could explain large age spread.

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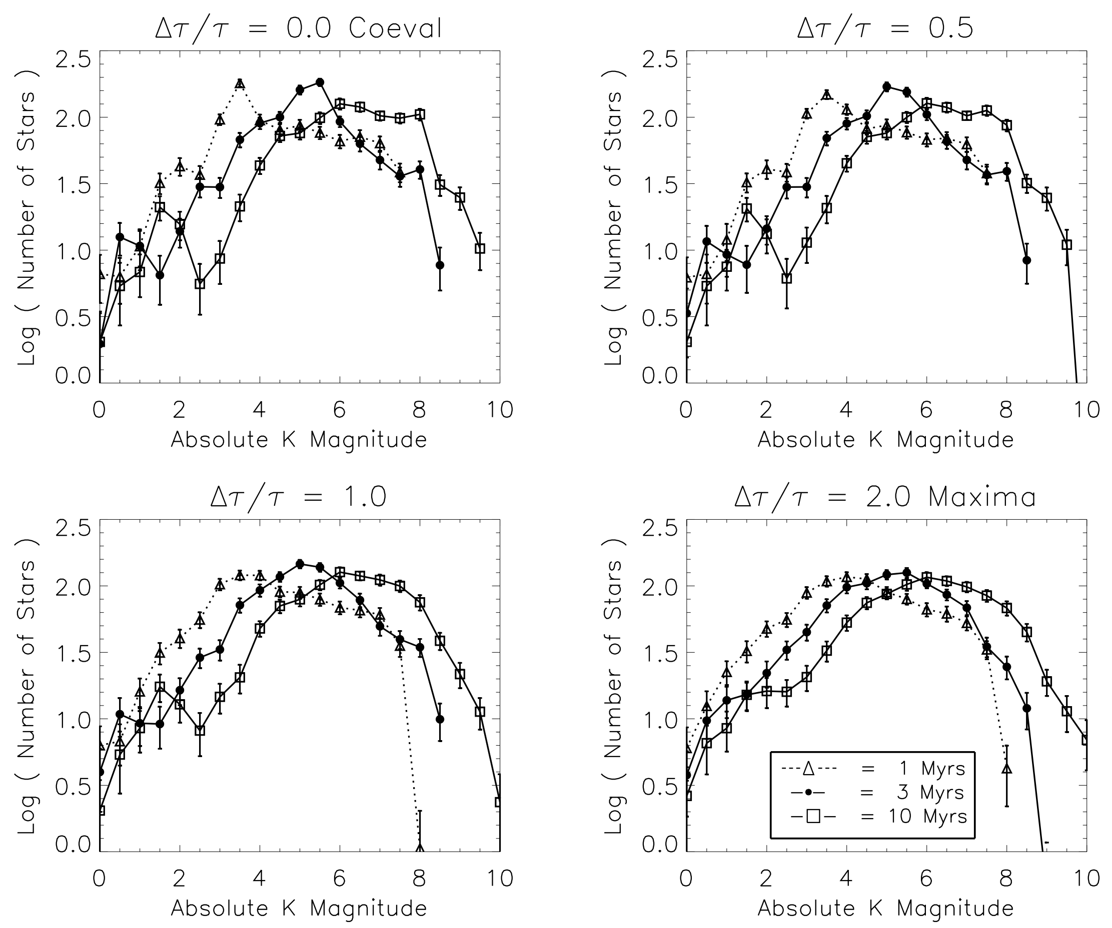

- Comparison of KLFs from an Av-limited sample with models of young clusters. Sample is complete to about 0.2 Msun
- Monte Carlo engine (Muench et al 2001) to generate an artificial population based on PMS evolution models (DM94)
- Observed KLF for all populations in the W3 complex compare well with cluster models with t_f<4.5 Myr.
- IC 1795 has only recently removed gas and still presents a large fraction of young stars. W3OH appears also to have a mixed population in a larger spread
- W3-Main, has a much larger gas reservoir, and is still forming a cluster about twice as massive.

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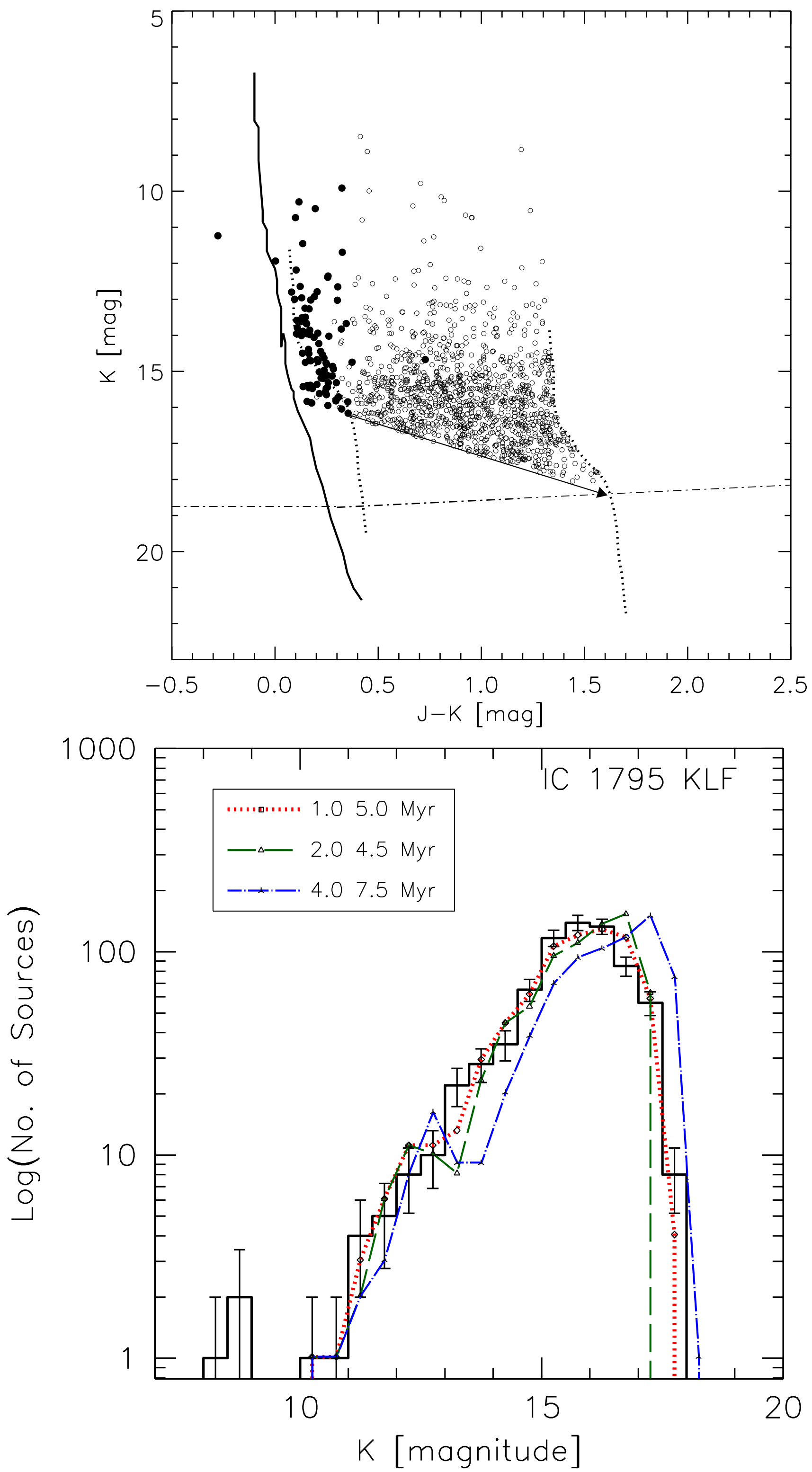

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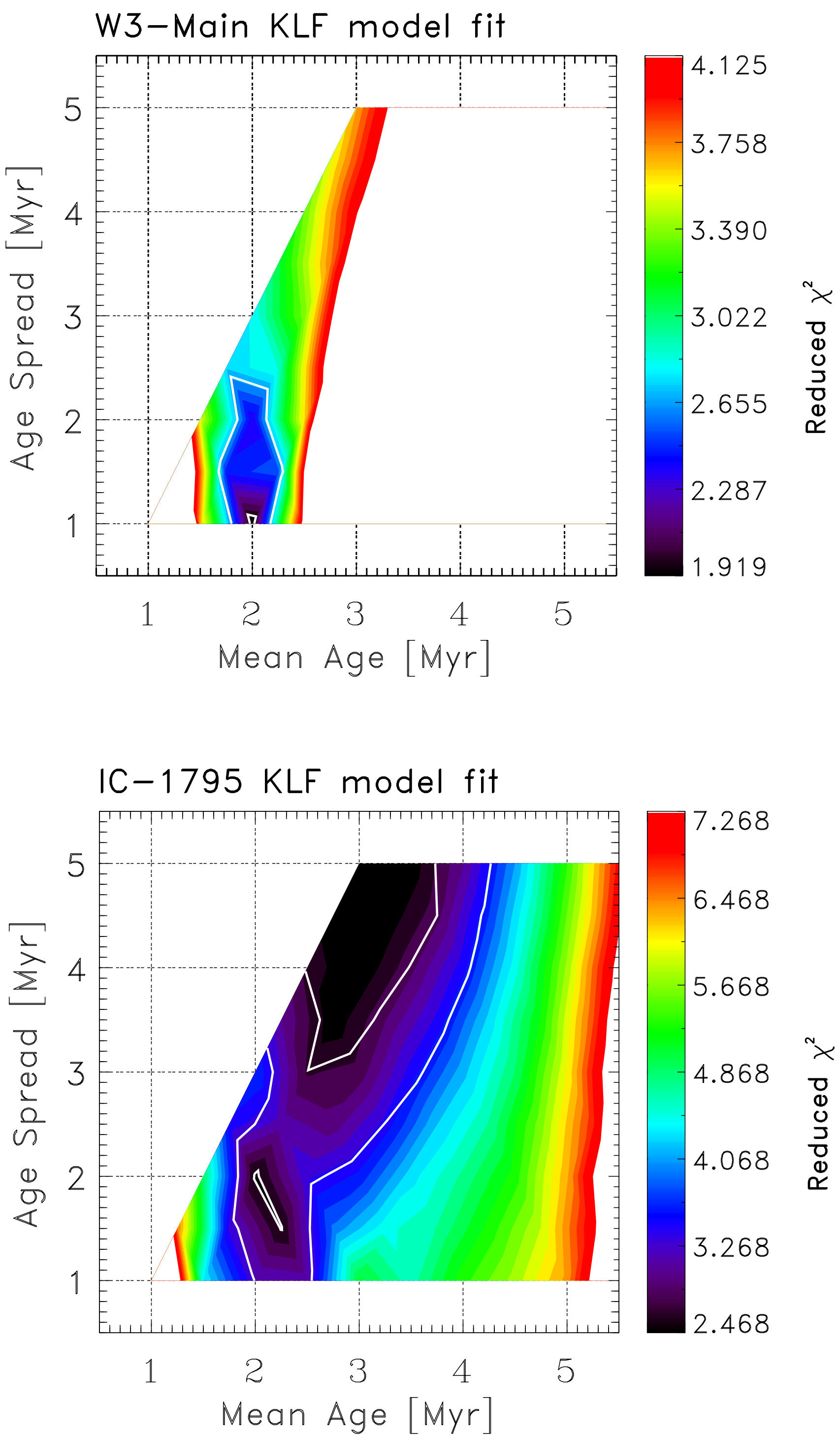

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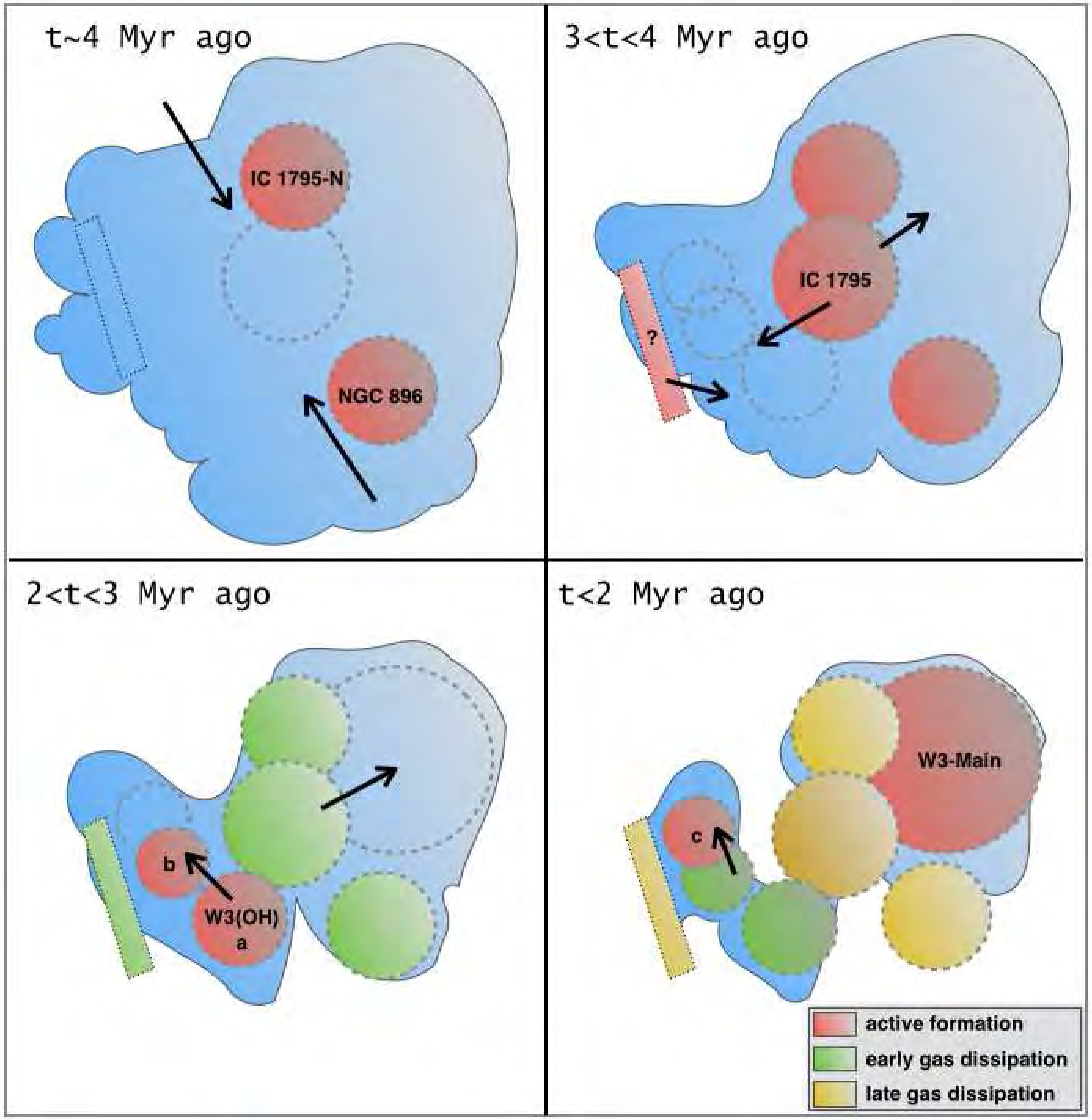

A possible scenario for the progression of cluster formation in the W3 Complex

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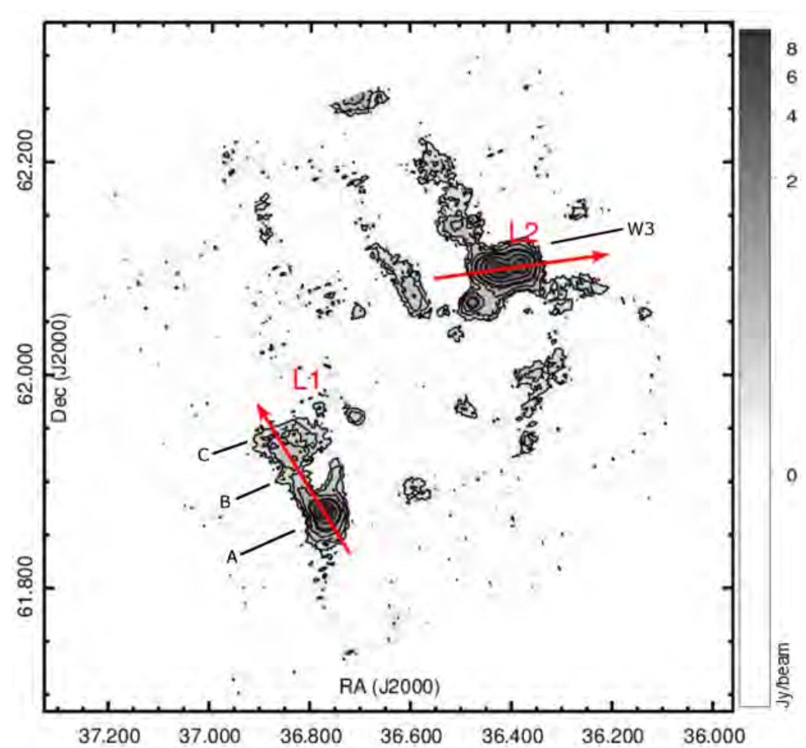

- p-v plots in W3(OH) and W3-Main from Bieging's ARO $^{13}CO(3\text{-}2)$ map.
- Ejection of material from the main molecular clumps at the location of the clusters. Resolve opening flows
- In W3(OH) we find a peak to peak velocity difference of 15-20 km/s within less than 0.5 pc
- In W3-Main, we find a peak to peak velocity difference of 25-30 km/s within less than 0.7 pc
- Mass loss rate at W3-Main, $\dot{M}_{out}$= ~ 7.2×10^{-4} $M_\odot$ yr^{-1} . **This is sufficient to remove 10^3 $M_\odot$ of gas in about 1.5 Myr**
- This is consistent with a **rapid gas removal** scenario, which may occur in a period comparable to the T Tauri timescale.

^{13}CO *J=3-2***

**Bieging et al 2012

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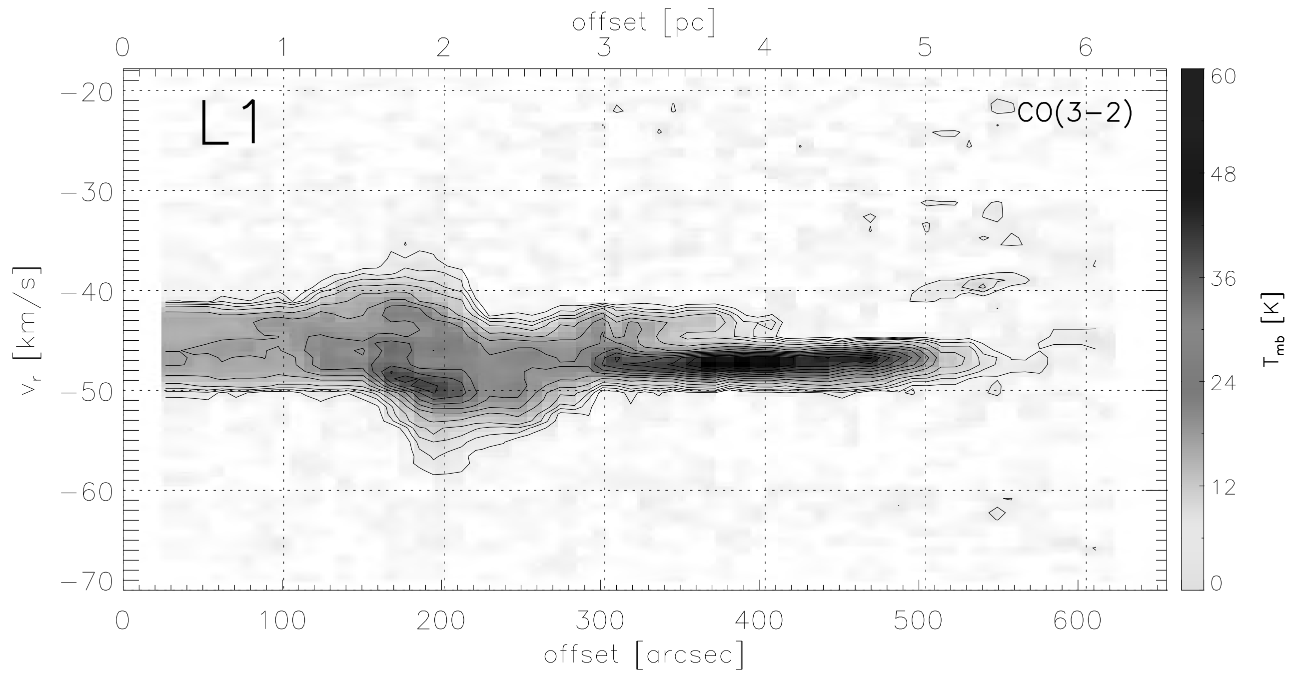

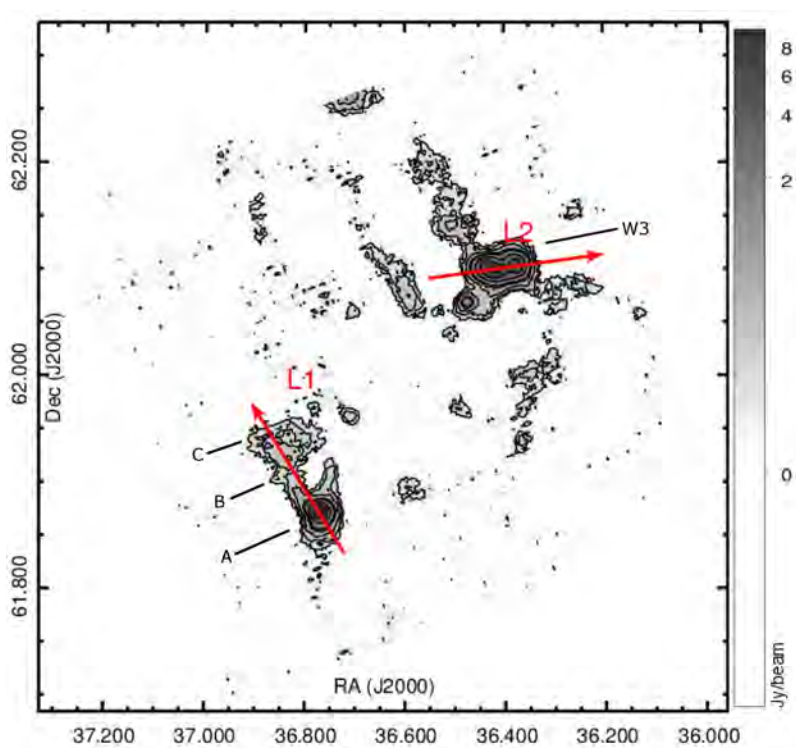

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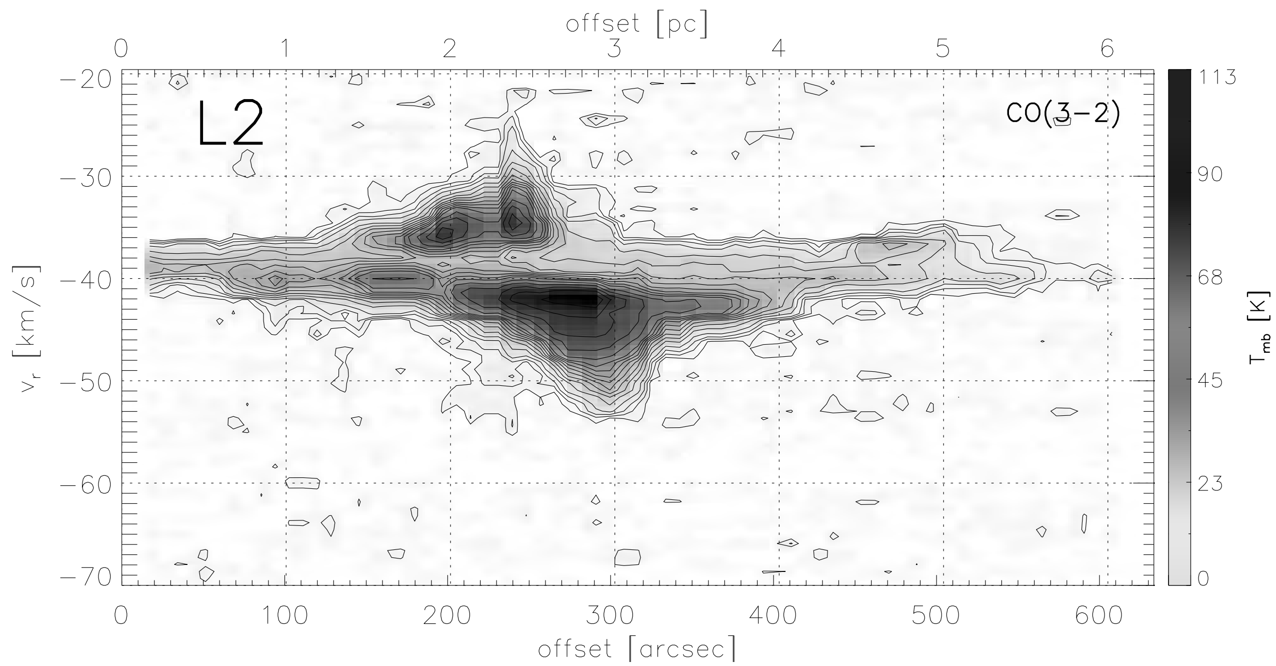

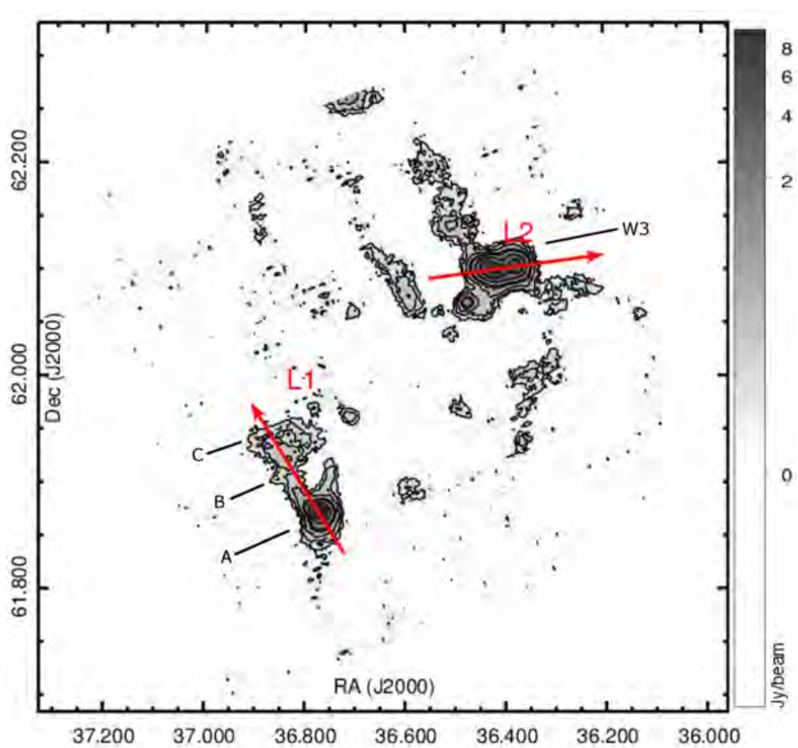

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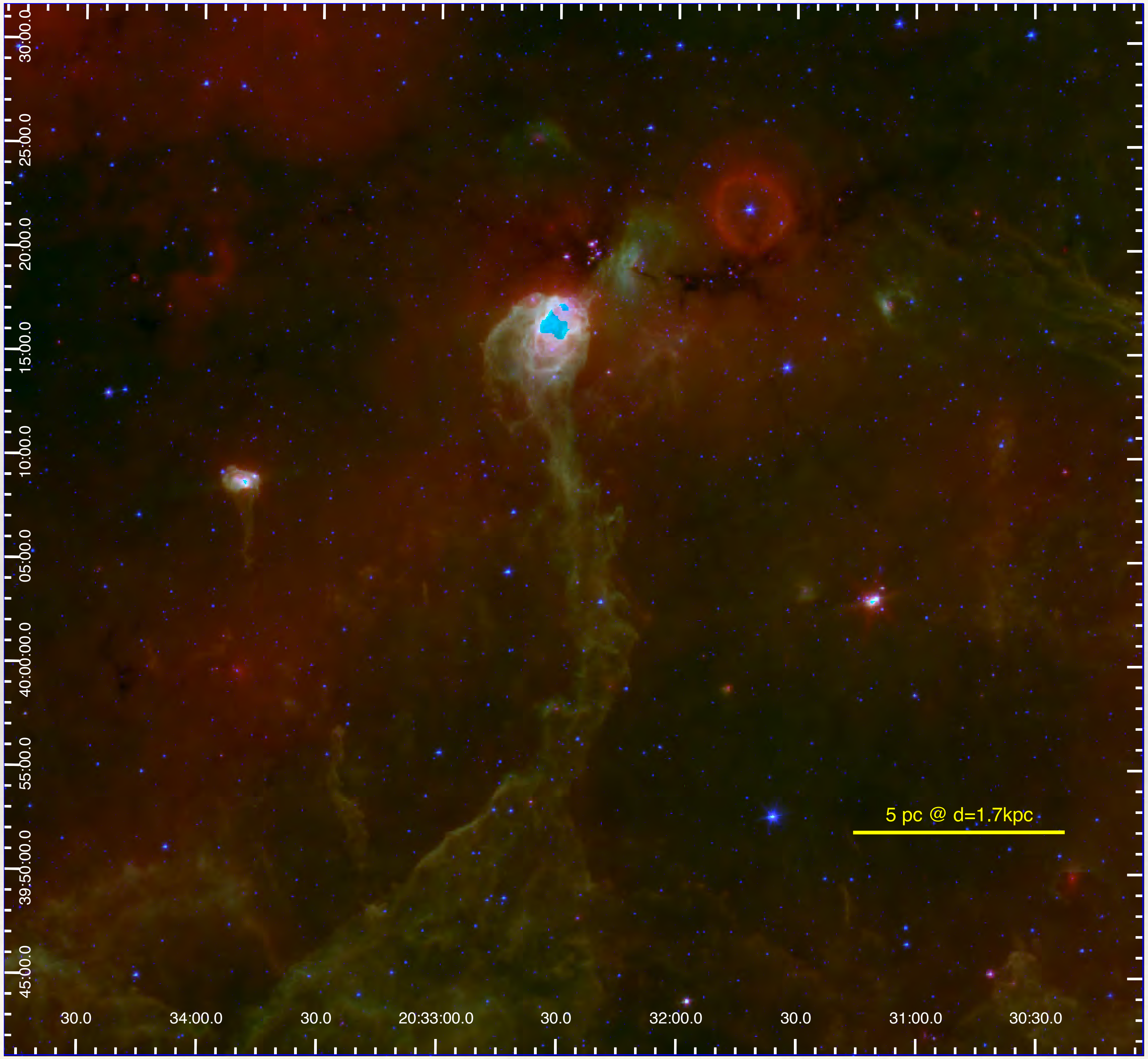
CYG-X DR15



- Cygnus-X DR15 was chosen first because of its staggering beauty :)
- However, it also has one of the most interesting layouts in the complex.
- The cluster has formed at the tip of a thick carved pilar in the southwest area of the complex.
- It lies next to a dark infrared cloud which is currently forming two clusters.
- Not shown here, the other cluster was possibly triggered by the expansion of a LBV G79.29+0.46 (d=1.4 kpc, see Rizzo et al. , Palau et al 2014)

Roman-Zuniga, Rivera-Gálvez et al 2015, in prep

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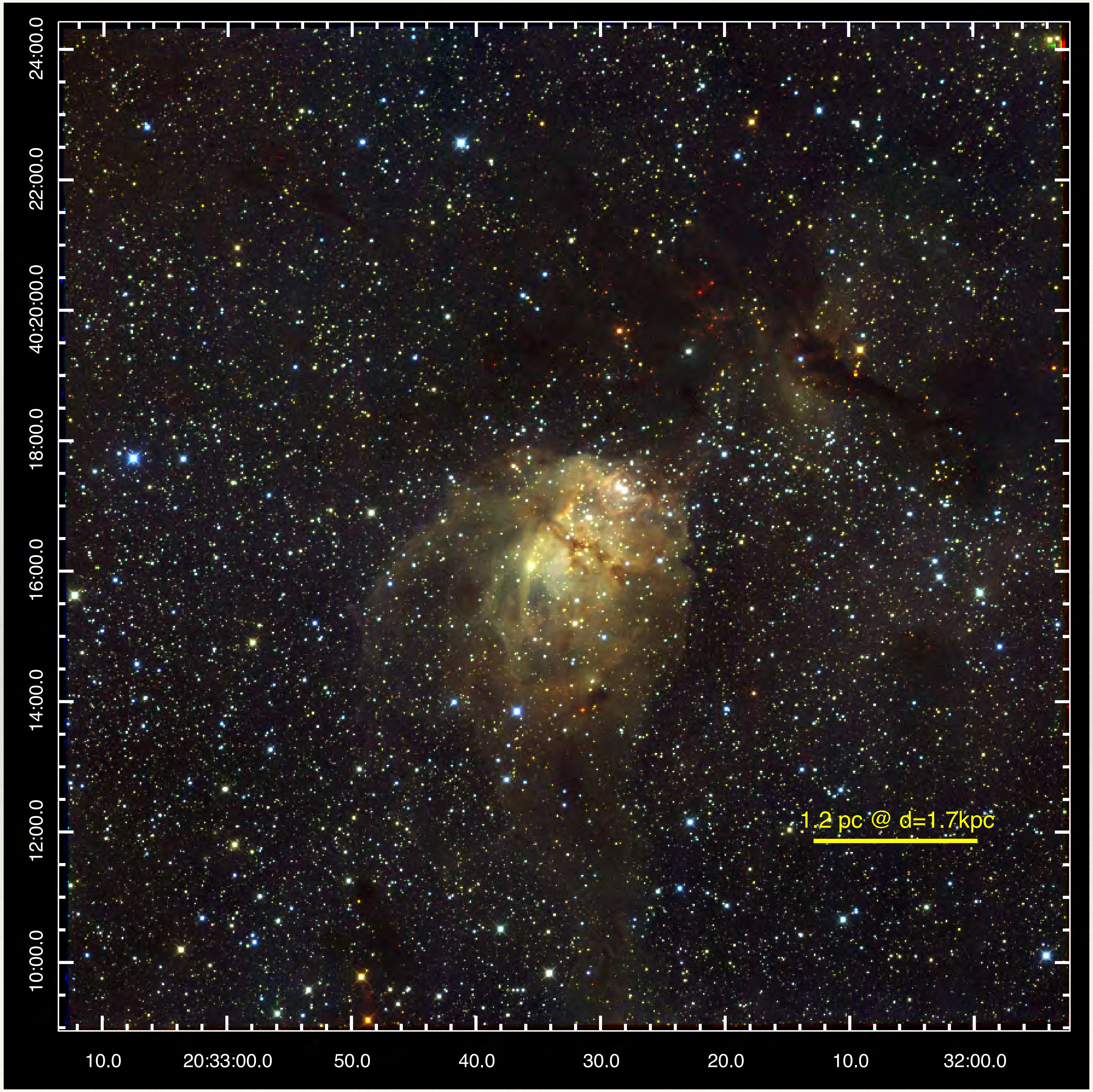

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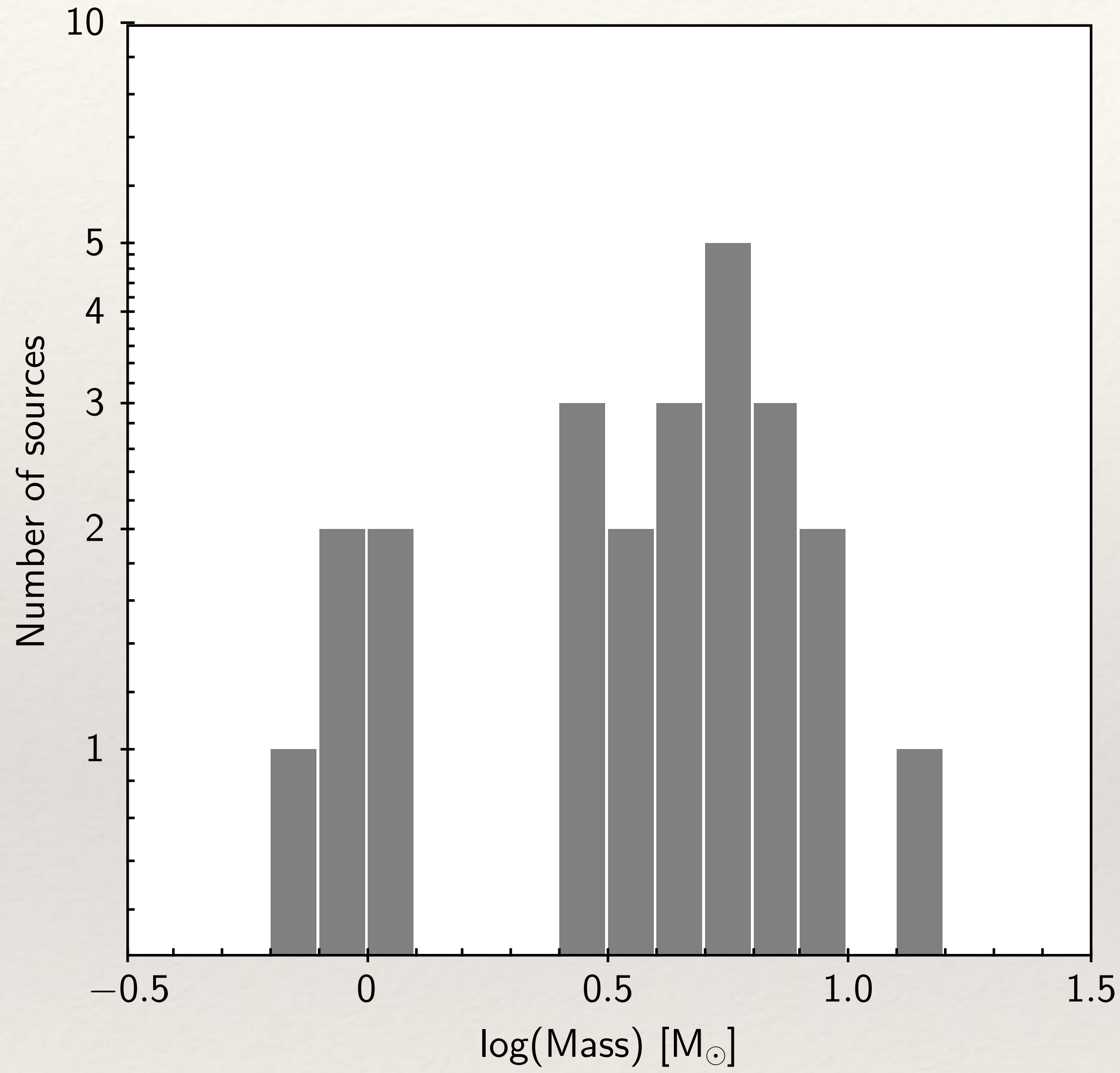

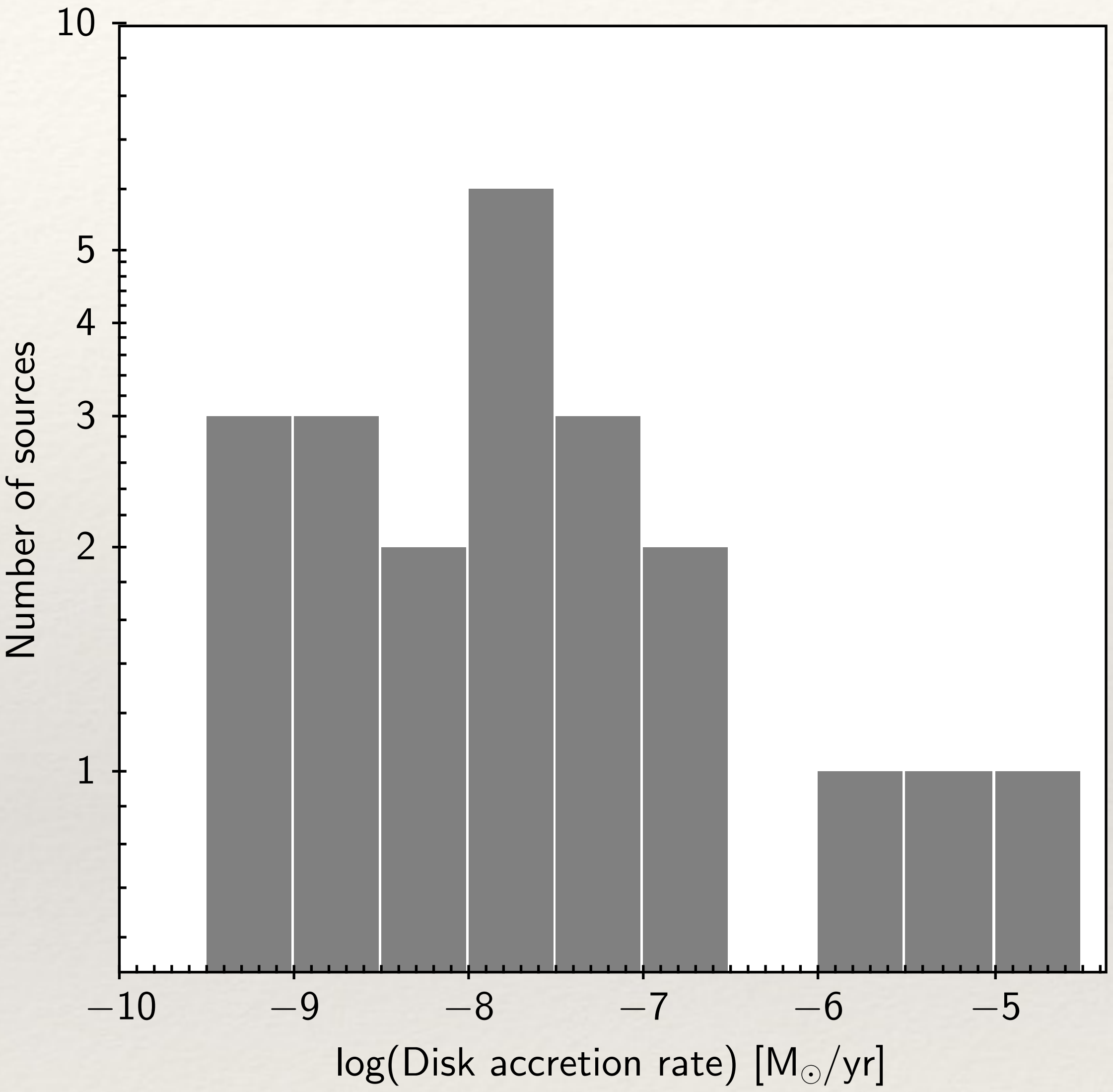

- We modeled Class I SEDs for JHK+IRAC photometric observations using Robitaille et al Fitting Tool. Models provide best fit YSO model based on $\chi 2$. Not perfect but one can obtain a quick estimate of YSO properties, like a poor-man's spectroscopic survey. For a good number of cases, models suggest that stars forming in DR15 are moderate to massive, with relatively large circumstellar disks accretion rates. Cygnus-X childs are not small, at least compared with clusters like the RMC.

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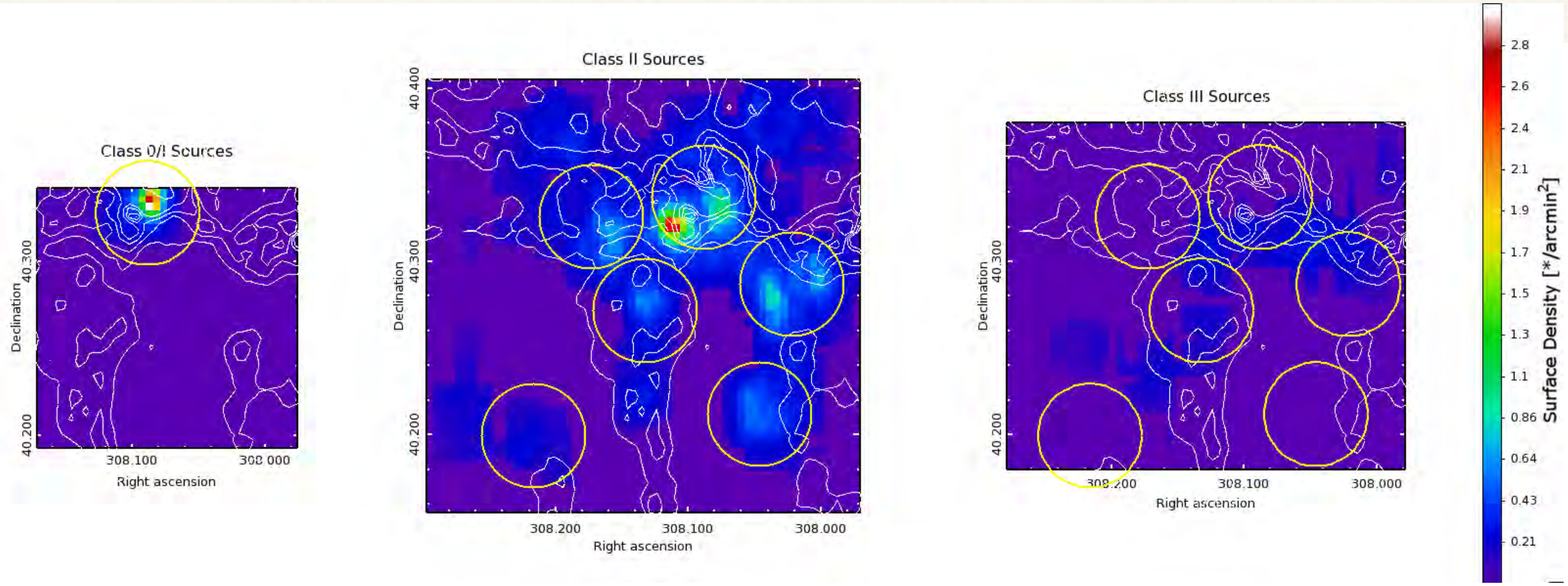

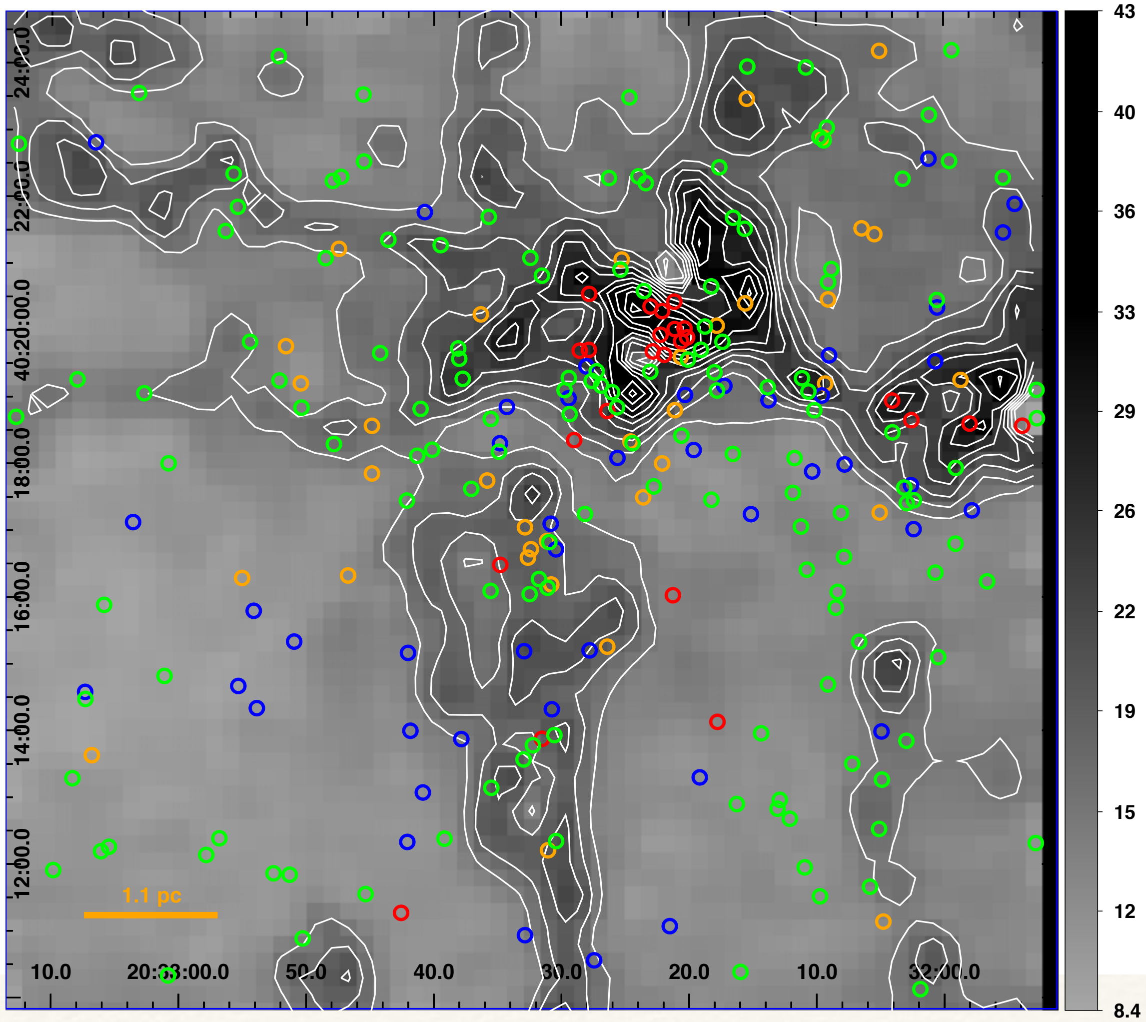

- Class II and Class III sources reveal a rapidly dispersed population, possibly formed in advance.
- Class I sources are mostly confined to the IRDC, as expected.
- **Reconstruction of SFH using KLF samples show that DR15-C may be 3-4 Myr old!**
- The cluster shows a very clear formation history, with a population mainly composed of WTTS in the hatching central cluster. Expansion of the main cluster envelope has proceeded relatively slowly.
- DR15c shell mass ~1500 Msun, expanding shell mass ~100 Msun. $\dot{M}_{out} \sim 2.5\times10^{-4}\,M_\odot\,yr^{-1}$. **Should require 3.5-4 Myr to remove the shell.**

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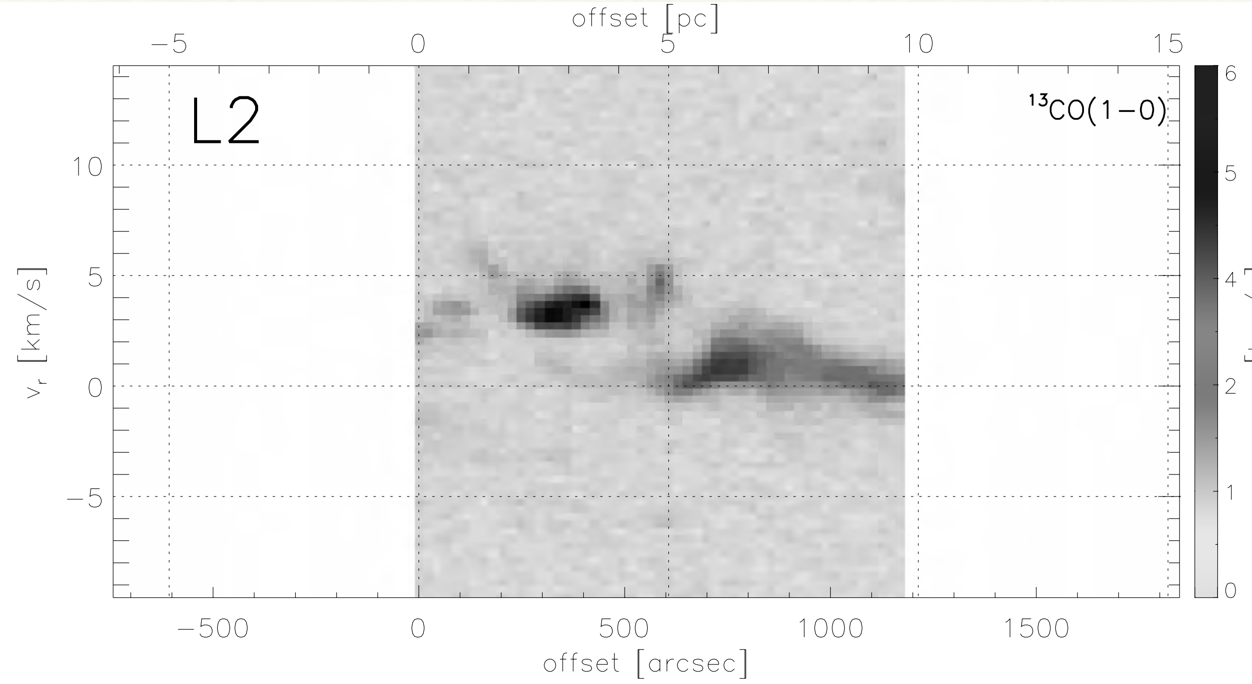
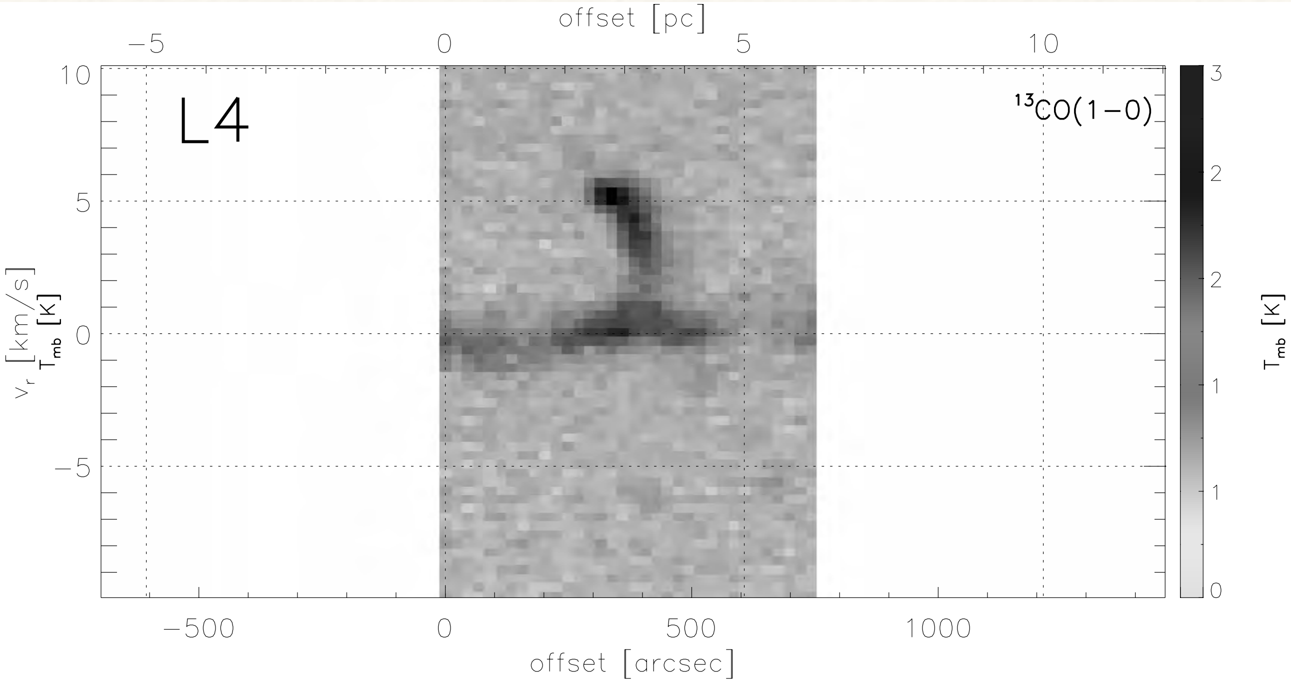
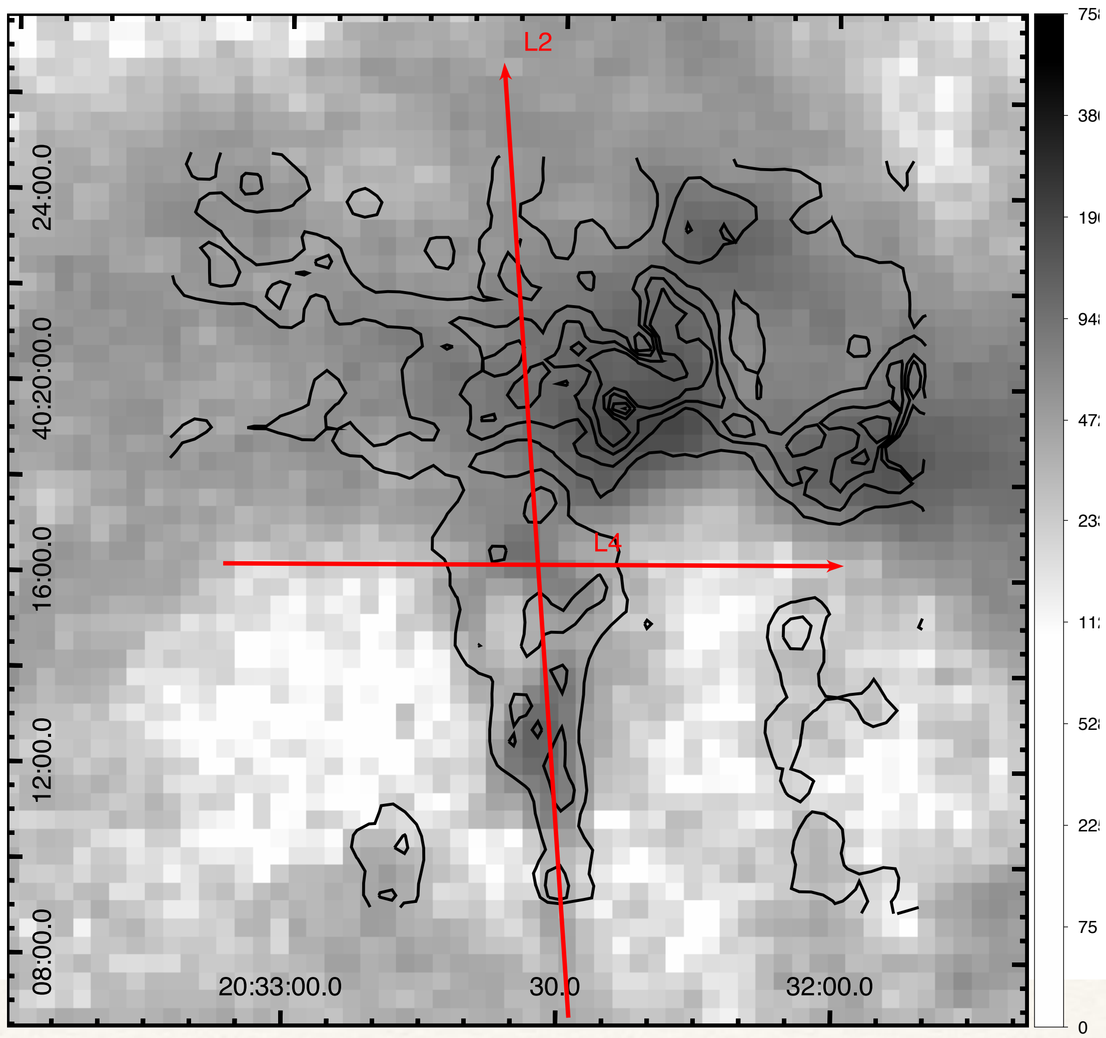
CYG-X DR15

recall talk by Anna McLeod!







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thoughts, questions

- Cluster formation modes are not independent of the local environment. However, effects of triggering and sequential formation may be more important at unity scales (clusters) rather than group scales (complexes).
- Cluster formation proceeds preferentially following primordial structure of cloud. Like in Rosette. Triggering is a large scale process, like in W3
- Massive stars are possibly responsible for rapid gas removal in large complexes.
- Is substructure (possibly related to potentials) more important than triggering? To what point is substructure related -or not- to global collapse processes?
- What dominantes in DR15? erosion or feedback? why is the envelope removal slow?