Hints on Star Formation Histories in Cluster-forming regions from multi-wavelength IR Continuum

Sergio Molinari
INAF/IFSI, Roma

F. Faustini – IFSI
R. Cesaroni - Arcetri
L. Testi - Arcetri/ESO
J. Brand - IRA
S. Pezzuto - IFSI

Context and Motivations

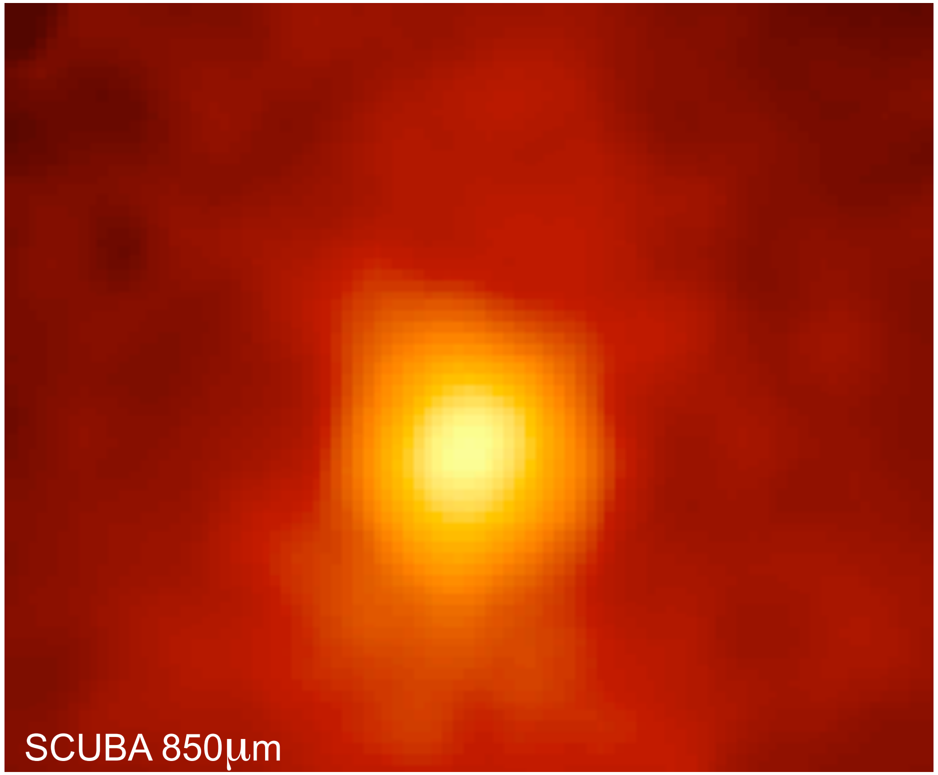
- Star formation histories may be crucial to predict the emergent integrated SED of galaxies
- Massive stars are critical in this respect not only as they dominate the ISRF input, but more because are associated with clusters of low-mass stars; probably most low mass stars are born in this way.
- Slow vs Fast star formation is still an open debate, and something can be learned considering low and high mass star formation together: <u>are low and high-mass YSOs coeval in a given region ?</u>

Context and Motivations

- Effort up to now concentrated toward few OB associations with mostly optically visible objects (e.g. Preibisch & Zinnecker 2007; Briceño et al. 2007): suggestions are that low/high mass are born as part of the same burst.
- Here we want to extend this type of investigation toward more embedded systems which are presumably younger. Fields investigated are from Palla et al. (1991) and Molinari et al. (1996)

Hints of Evolutionary Complexity

Clusters-forming regions harbor objects in seemingly different evolutionary stages. Test case: IRAS23385+6053 (Molinari et al. 1998, 2008b)



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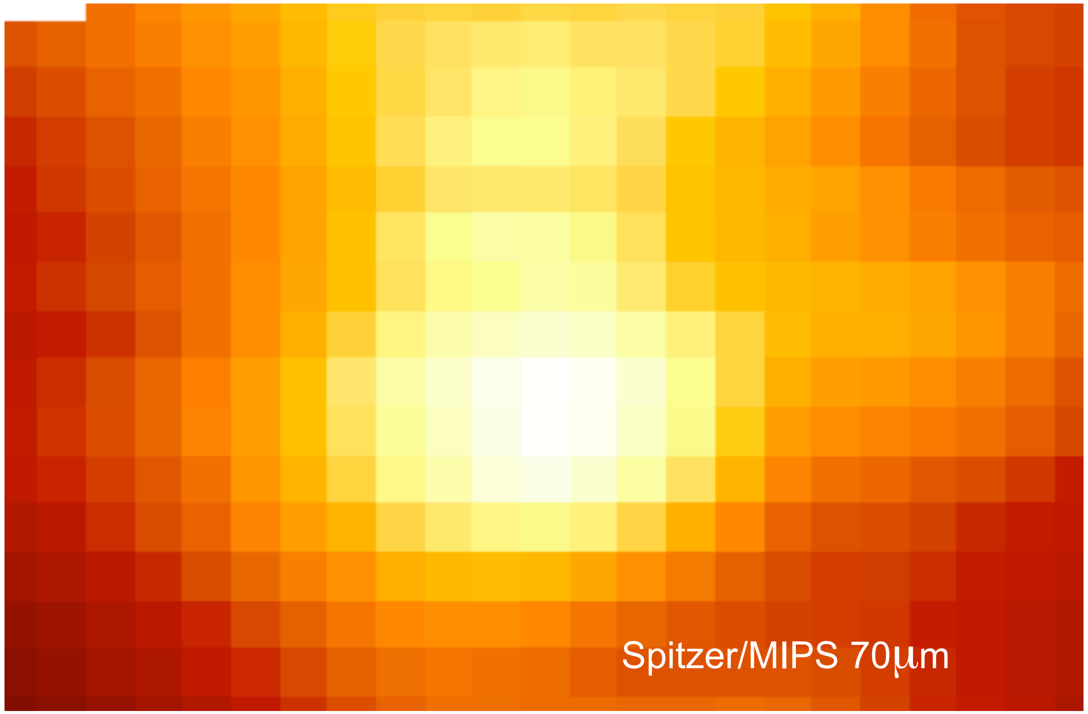

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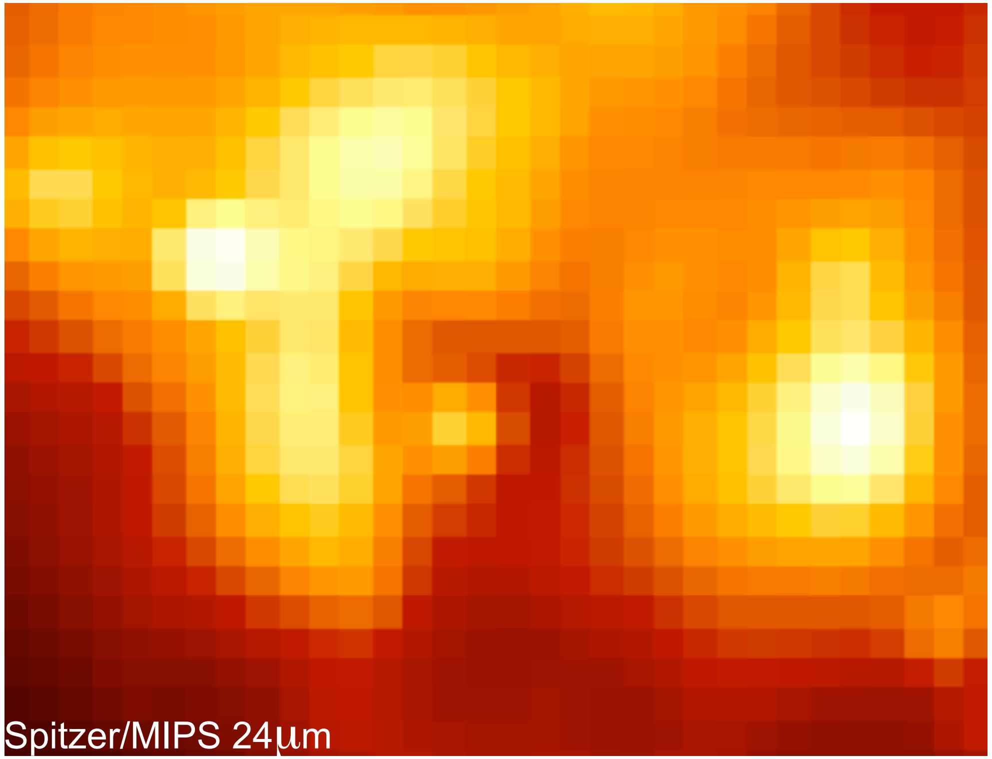

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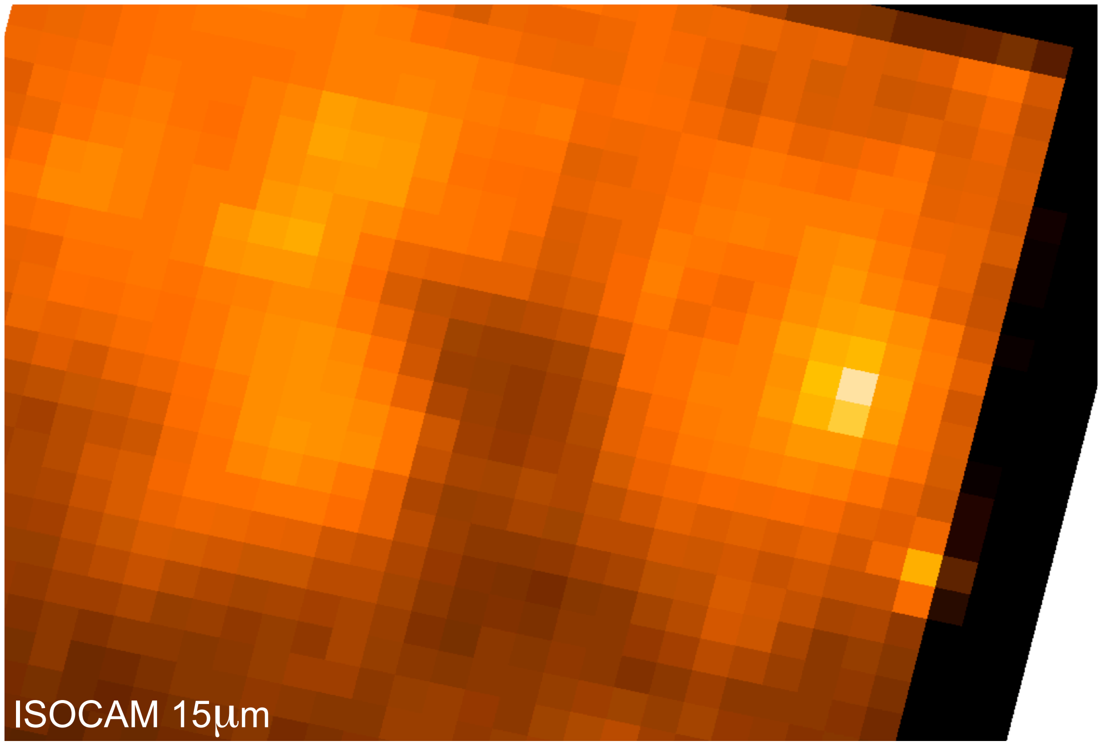

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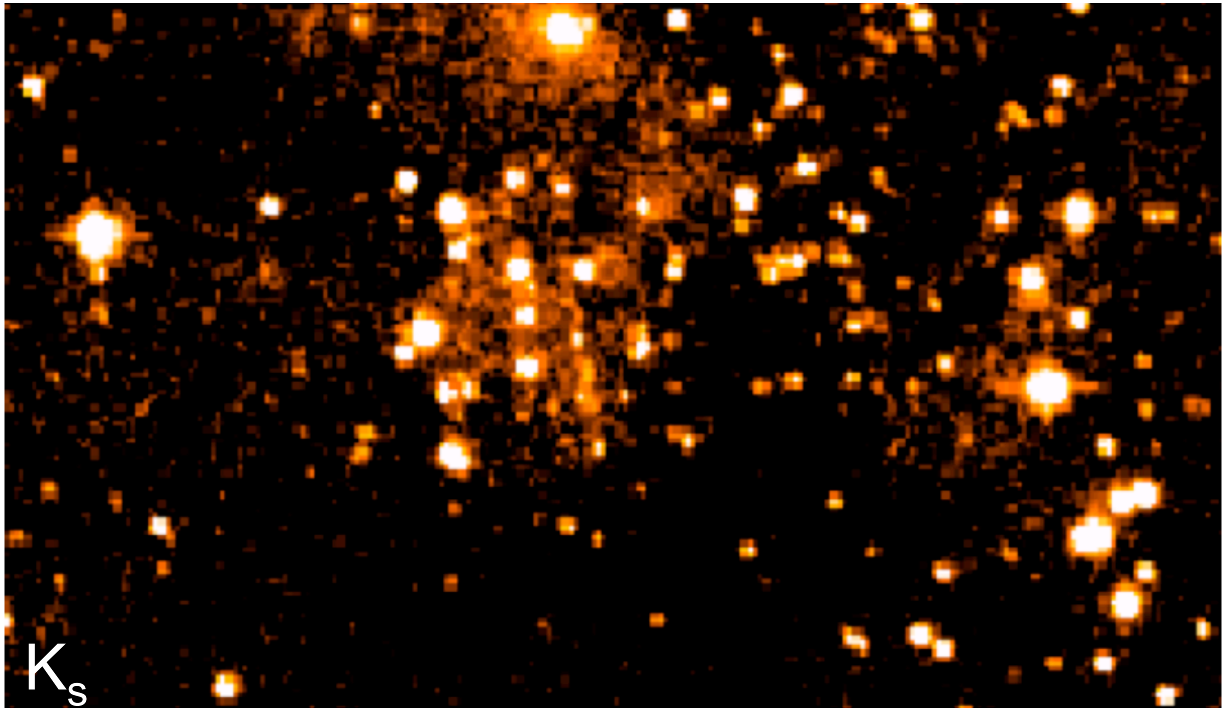


Hints of Evolutionary Complexity

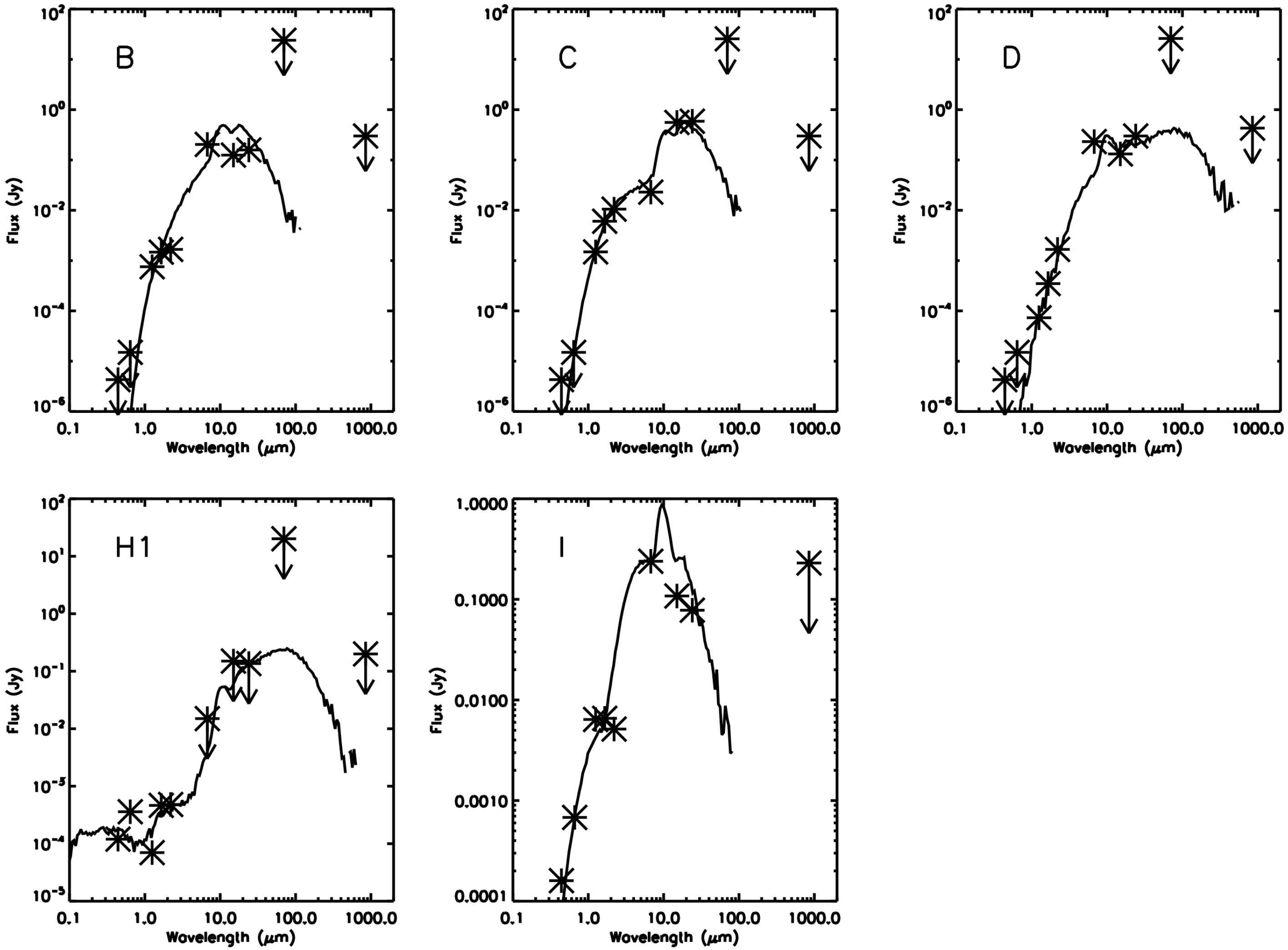
• The most massive object has an SED which dominates at $\lambda \geq 70\mu$m and which can be fit to a very young "birthline" object accreting at rates $\approx 10^{-3}$ $M_{\odot}$/yr (Robitaille et al. 2007); end-product could be a B0-O9.5 star.

• The objects dominating the mid-IR emission have an SED which can be fit with embedded ZAMS B stars

• Lower luminosity objects apparent in the Ks image are pre-MS YSOs…but what's their age ?

YSO coeval in the same Star Forming Region?

Hints of Evolutionary Complexity

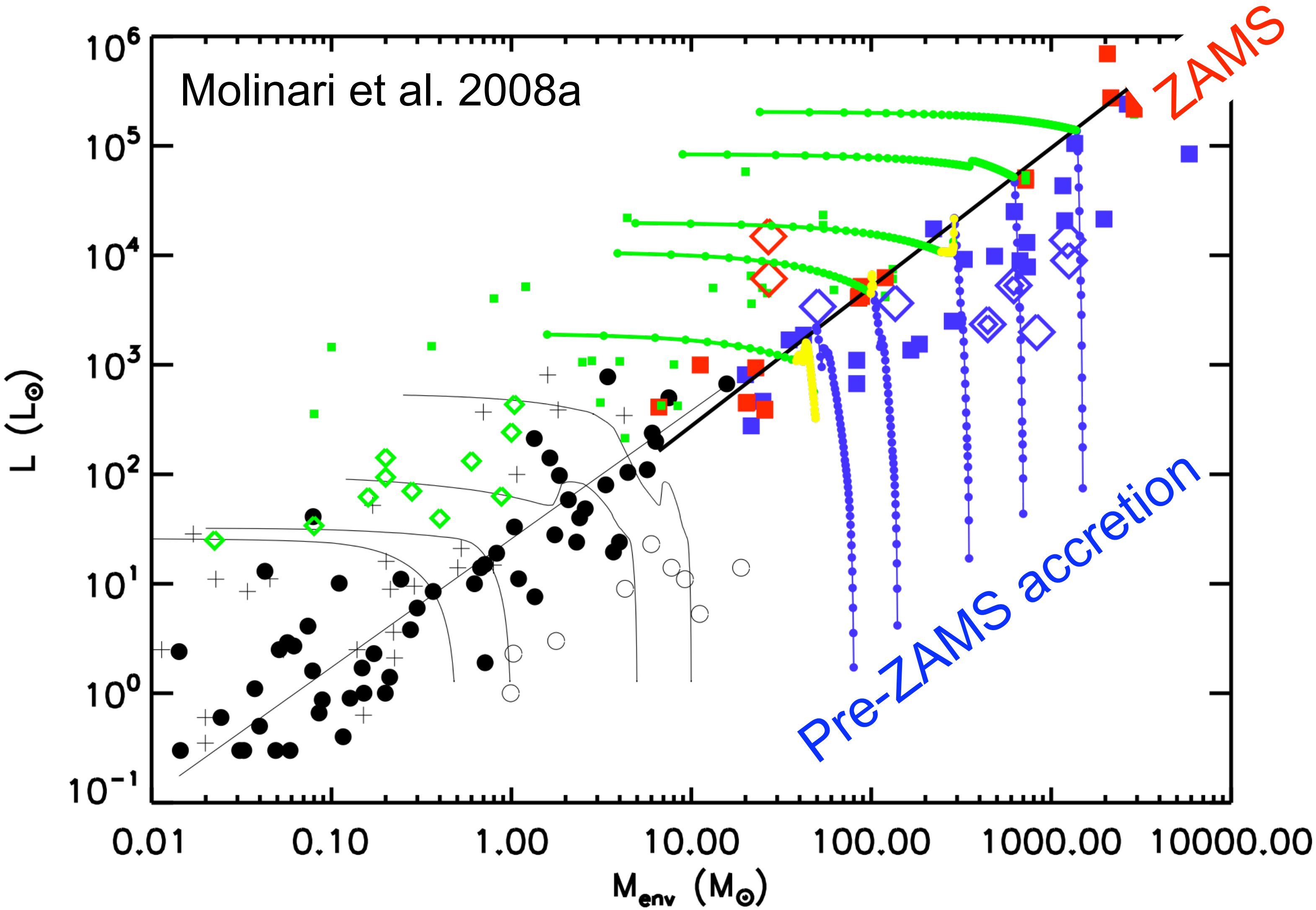


SED-based Modeling of Massive YSO Evolution (Molinari et al. 2008a)

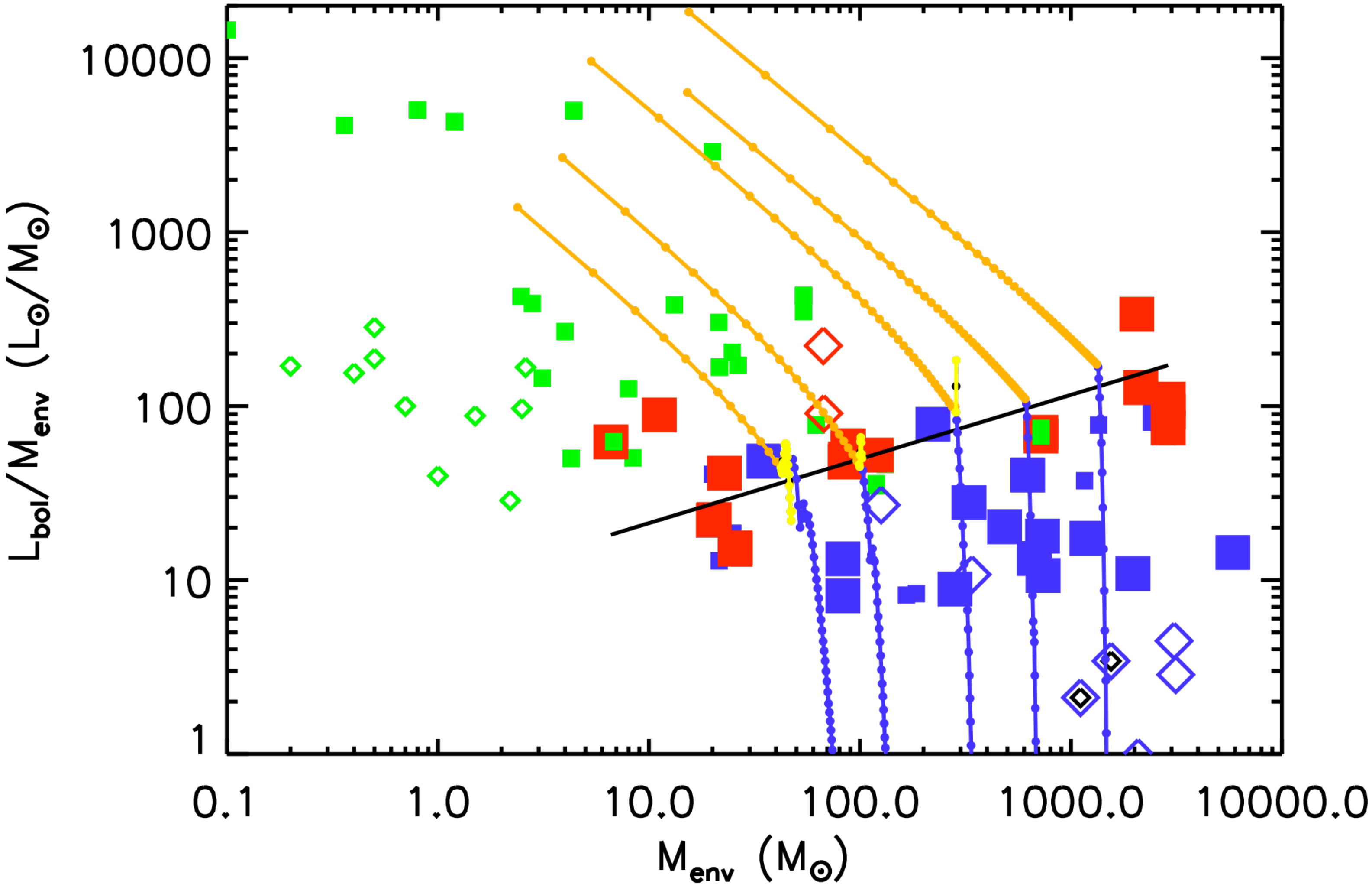
- Build SEDs for the most prominent YSOs found toward each of the IRAS sources of our sample (42 objects)
  - Identify components in mid-IR (MSX) and submm images (SCUBA, SIMBA), where resolution is higher
  - …much easier if Spitzer data are available
  - Fit to grid of SED models (Whitney et al. 2003; Robitaille et al. 2007) for central YSOs (ZAMS and not-ZAMS)+disk+envelope.
- Estimate Bolometric Luminosity and Circumstellar Mass to be used as evolutionary tracers.
- Build Evolutionary Tracks based on Turbulent Core model prescriptions (McKee & Tan 2003)

$$\dot{M}_* \propto M_{*f}^{3/4} \Sigma_{cl}^{3/4} \sqrt{\frac{M_*}{M_{*f}}}$$

Massive YSO Evolution in the L_{bol}-M_{env} diagram



Massive YSO Evolution in the L_{bol}-M_{env} diagram



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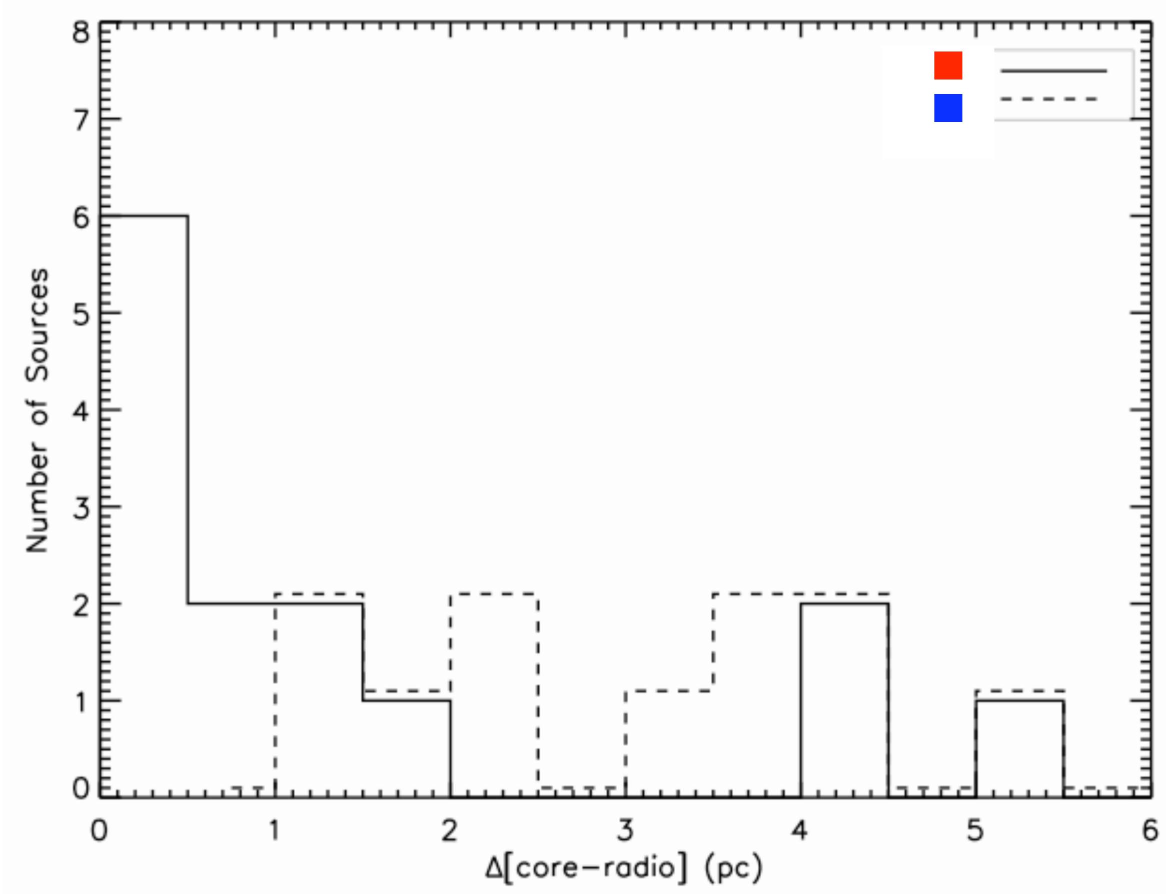
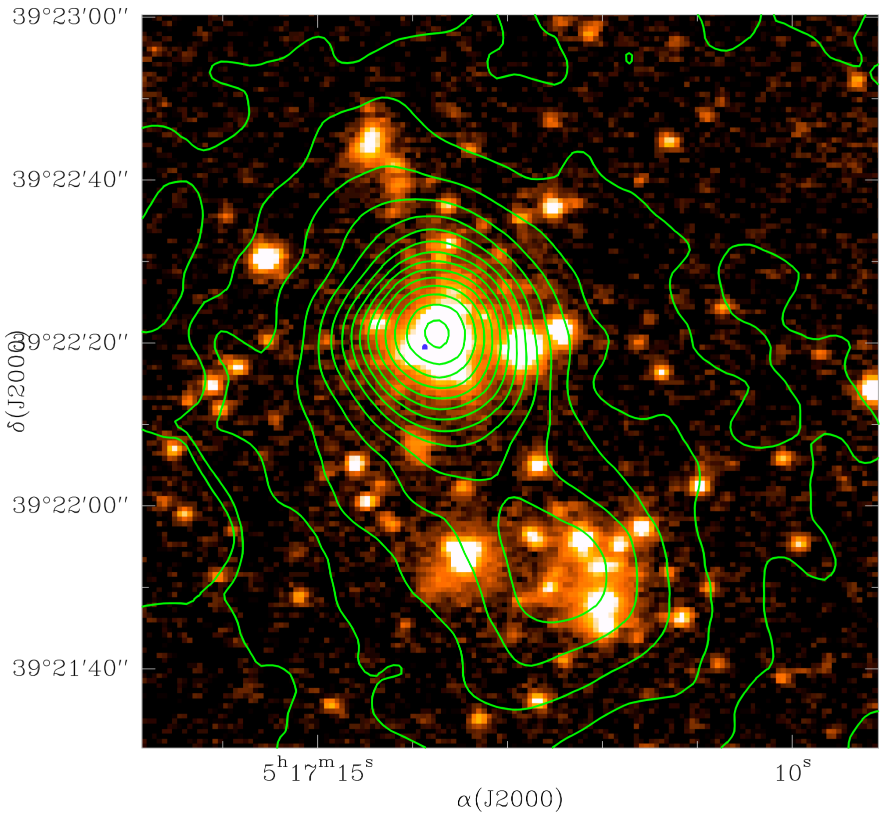


Modeling the low-mass YSO fraction

(Faustini et al. 2009)

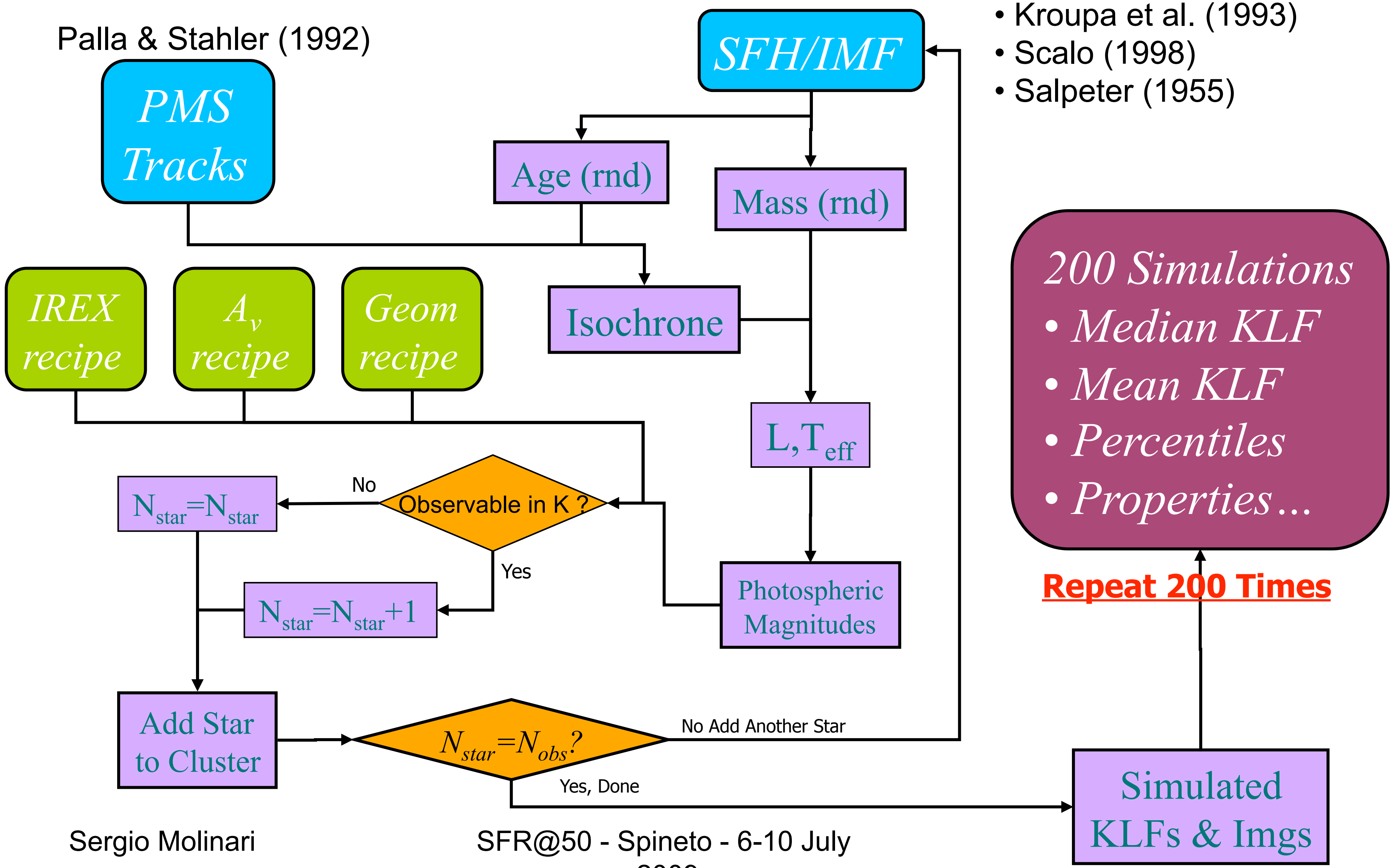
• A near-IR cluster is revealed in more than 80% of the observed fields (Palomar, NTT); this is much higher detection rate than obtained using 2MASS (Kumar et al. 2007) or Spitzer (Kumar & Grave 2008)



• Deriving cluster properties directly, requires detailed knowledge of virtually every star in the field to be able to assign it to the cluster or to place it in the H-R diagram (e.g. Hillenbrand 1997)

• Or we can try to invert a background-subtracted KLF aided by a statistically significant comparison with grids of synthetic young clusters models.

MonteCarlo Synthetic Cluster Generator



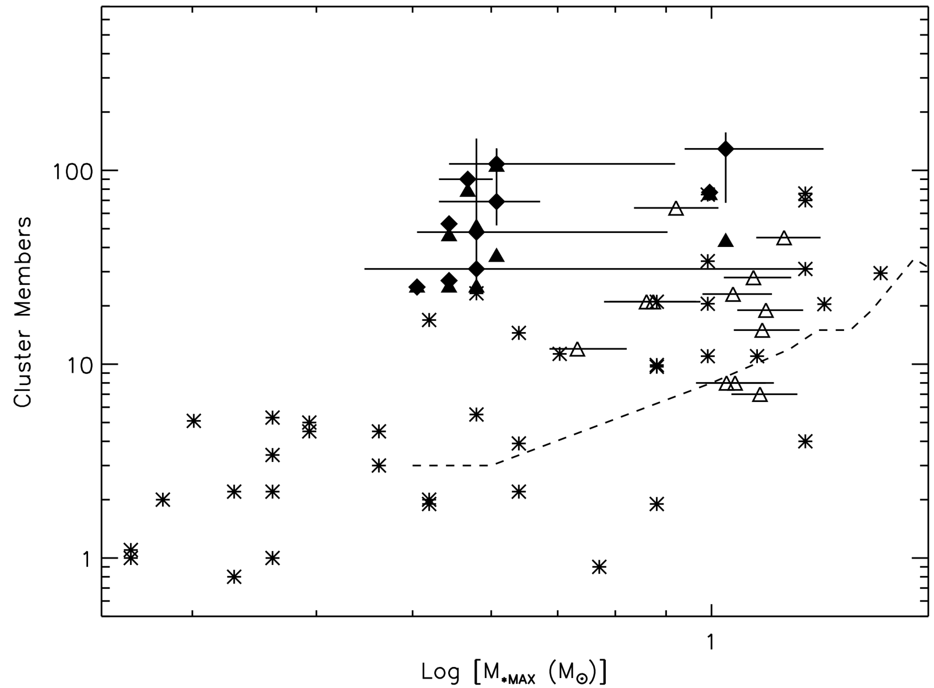
Modeling the low-mass YSO fraction

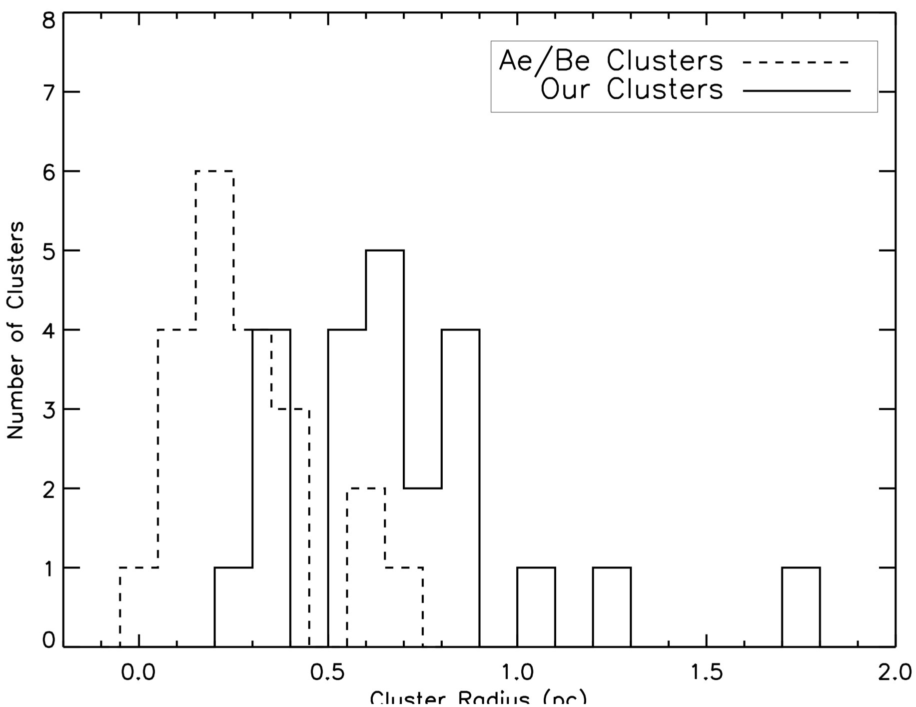
Comparison of observed KLFs to synthetic models grid has a level of degeneracy, but significant trends can be identified, especially for the SFHs

Source Mol	IMF	$t_{10\%}$	t_{med} yrs	$t_{90\%}$	$N_\star$	$M_{\star Max}$ $M_\odot$	$M_{\star Tot}$ $M_\odot$
3	1	$10^{4.98}$	$10^{5.40}$	$10^{5.81}$	91	3.7	61
8A	2-3	$10^{4.71}$	$10^{5.38}$	$10^{5.83}$	31	3.8	30
11	1-2-3	$10^{6.06}$	$10^{6.41}$	$10^{6.82}$	48	3.8	47
28	3	$10^{6.03}$	$10^{6.12}$	$10^{6.24}$	77	9.9	105
50	1	$10^{6.16}$	$10^{6.48}$	$10^{6.66}$	53	3.5	36
103	1-2	$10^{6.57}$	$10^{6.70}$	$10^{6.83}$	115	4.0	80
139	3	$10^{5.34}$	$10^{5.96}$	$10^{6.46}$	25	2.9	16
143	2	$10^{6.57}$	$10^{6.70}$	$10^{6.82}$	27	3.1	21
160	1-2-3	$10^{6.57}$	$10^{6.7}$	$10^{6.83}$	89	4.3	63

Evolutionary indications in cluster properties

• Our observed clusters tend to be richer than clusters around typical AeBe stars (e.g. Testi et al. 1999) for a given mass of the most massive object.





• … and smaller

• in agreement with expectations if intra-cluster medium is lost in the final stages of evolution (Baumgardt & Kroupa 2007)

Bringing the pieces together...

- Massive YSOs form on timescales of 1 to few **10^5** years (depending on mass). Each observed field has at least one massive YSO which is either in a Hot Core/UCHII stage, or in a pre-ZAMS phase.

- Massive YSOs are found in association with clusters of lower mass stars with median ages of a few **10^6** years, and with a comparable ages spread.

Conclusions

• Modeling both the low and high mass members of a star forming region allow us to obtain a very interesting perspective.

• Our findings are difficult to reconcile with a “dynamical” star formation scenario.

• There are indications that star formation may be a “slow” process lasting several free-fall timescales, and the most massive objects are the last ones to (rapidly) form. A mechanism has to be in place to support the massive core against collapse for several free-fall times.