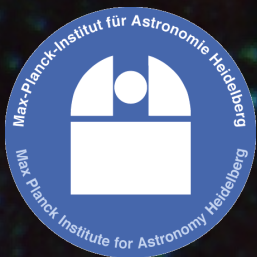
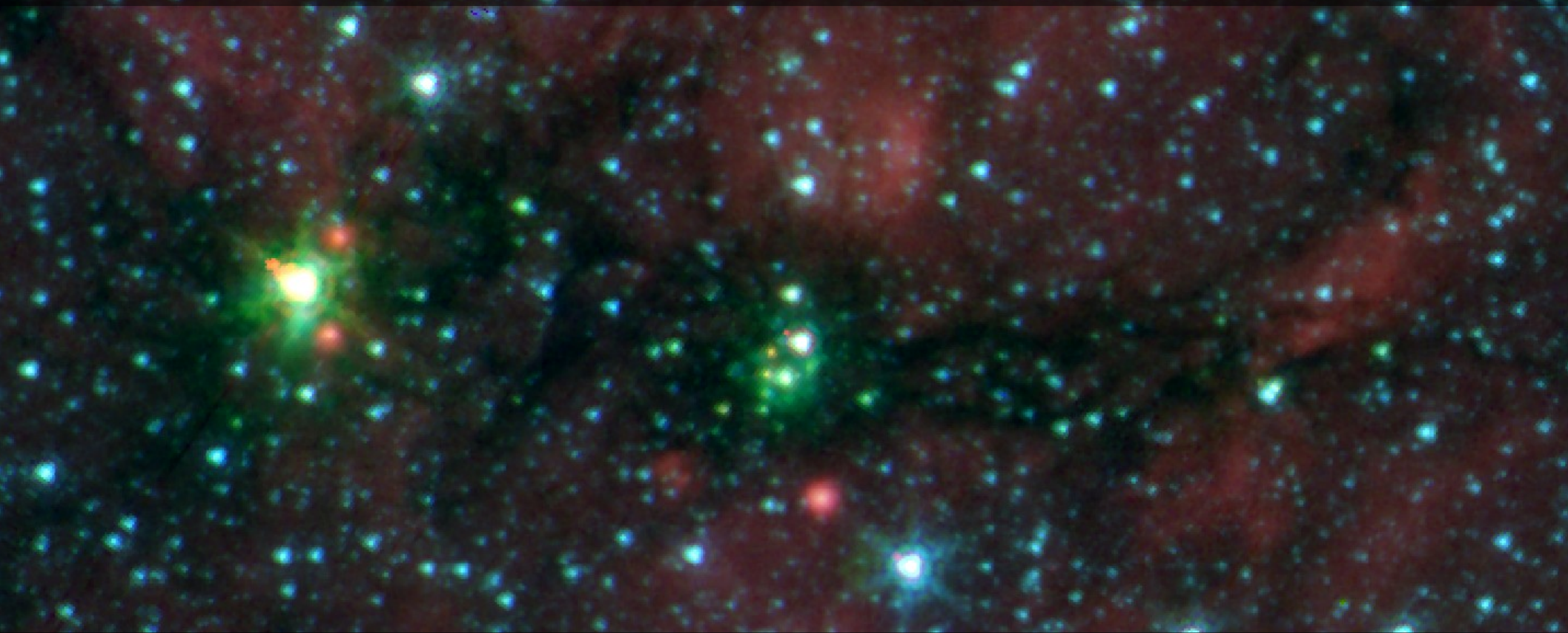


Embedded clusters and young stellar objects (YSOs) in the Galactic plane



Esteban Morales
Max Planck Institute for Astronomy

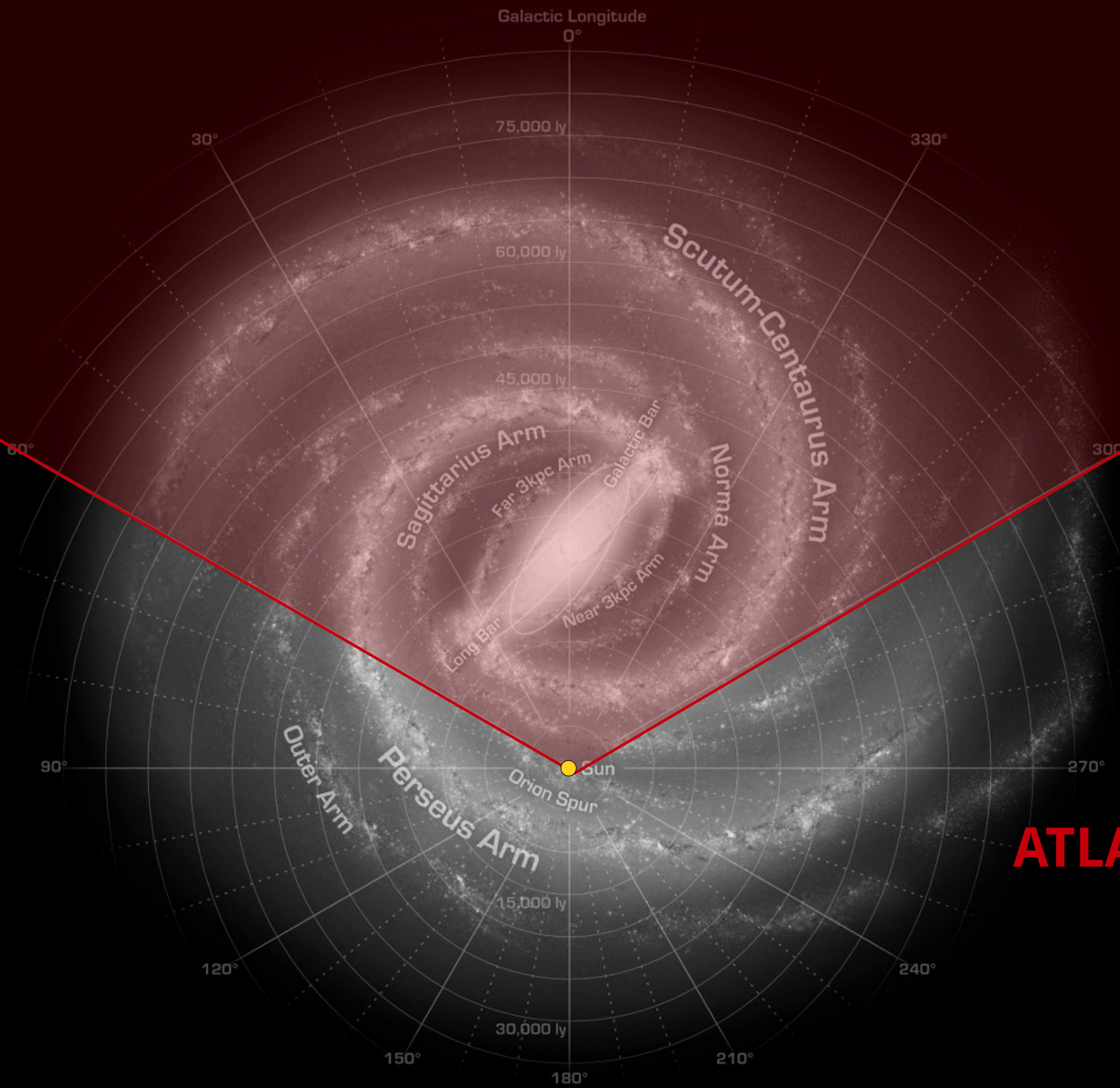
and T. Robitaille, F. Wyrowski, K. Menten, F. Schuller

Observations: Galactic plane surveys

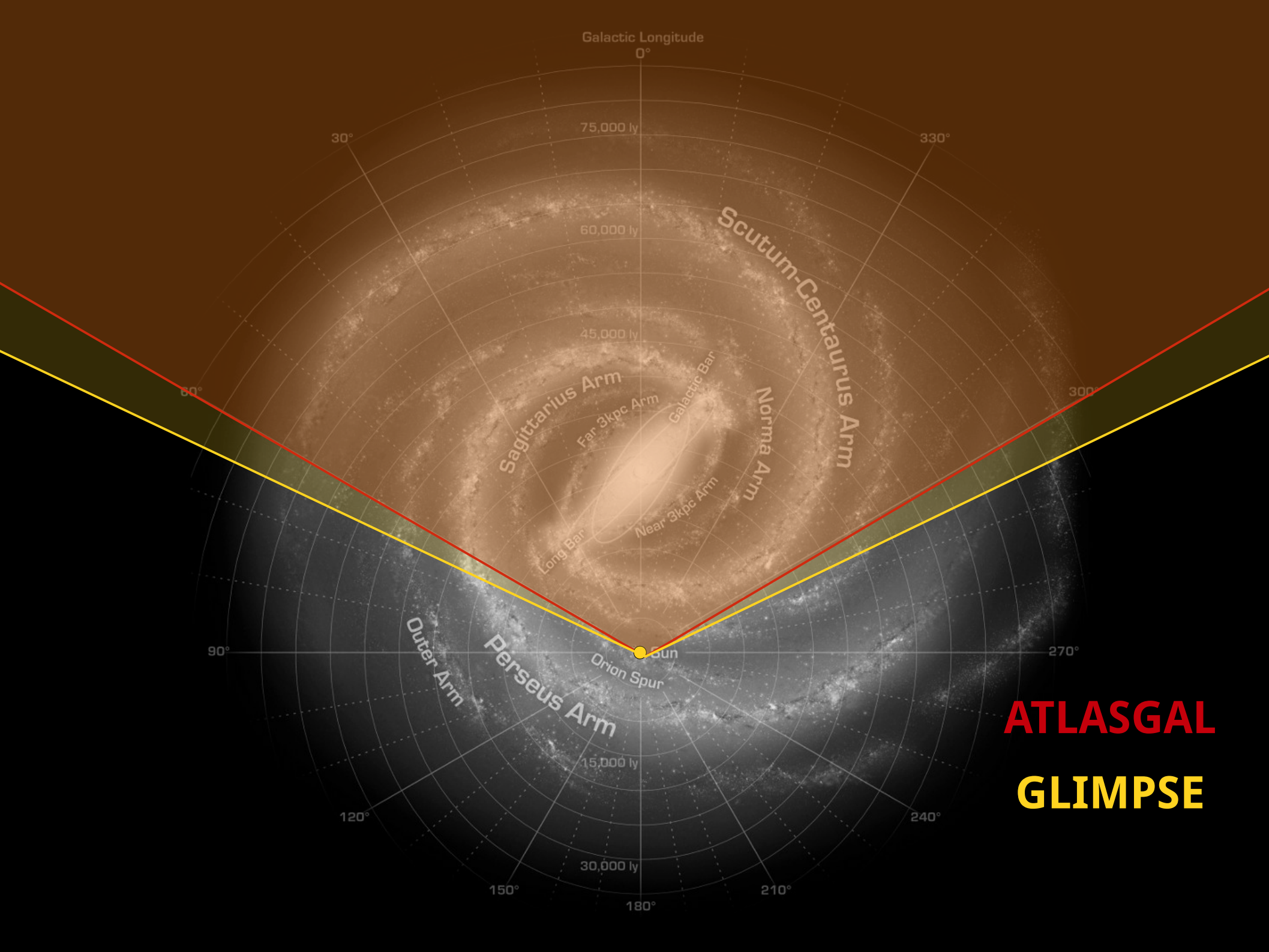
- Bolocam GPS → 1100 μm , 33"
- ATLASGAL → 870 μm , 19.2"
- Hi-GAL → 70 - 500 μm , ~ 5" - 36"
- MIPS GAL → 24 μm , 6"
- GLIMPSE → 3.6 - 8.0 μm , 2"
- UKIDSS GPS → 1.2 - 2.2 μm , 0.8"
- VVV → 0.9 - 2.1 μm , 0.9"

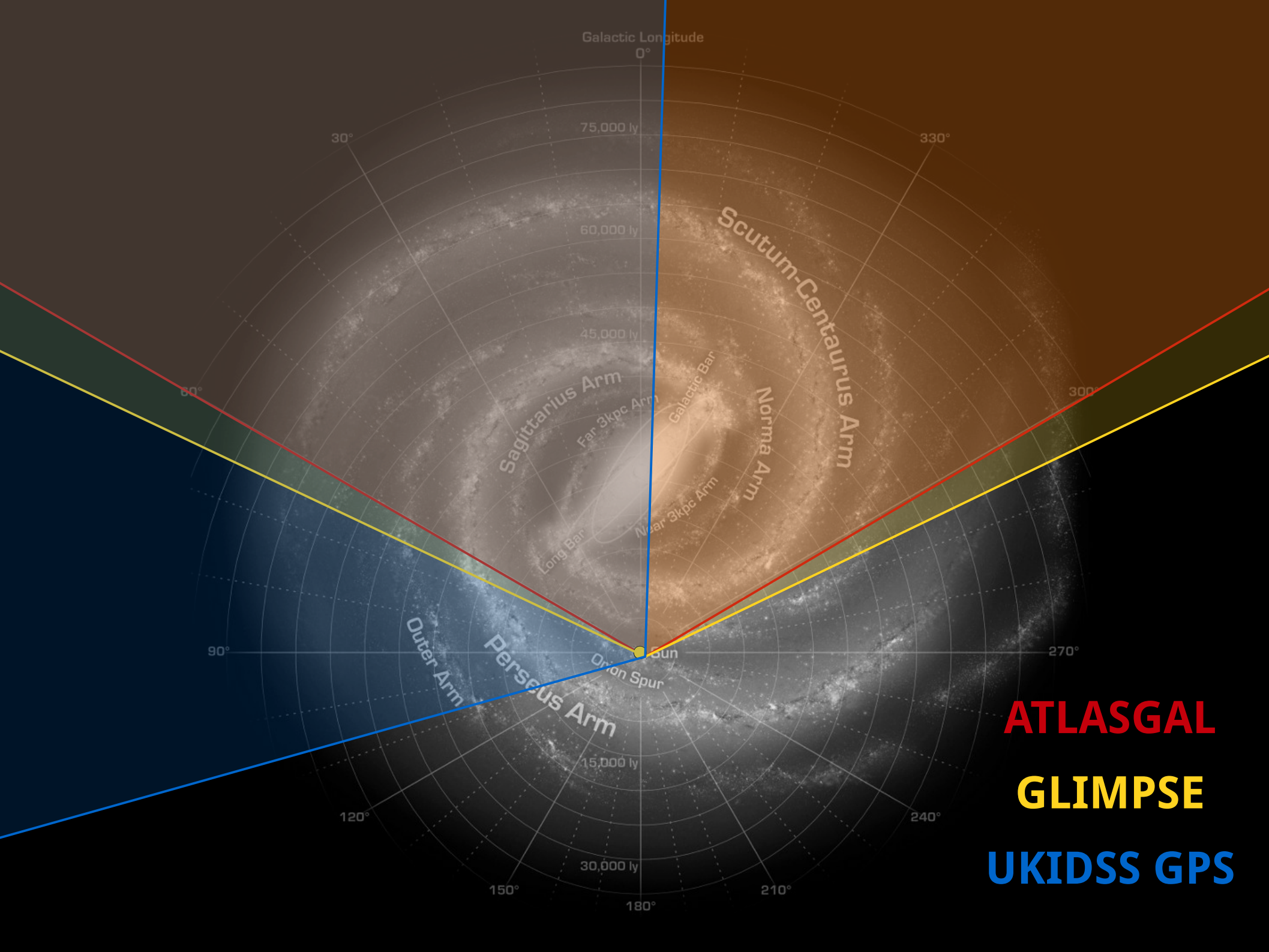
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ATLASGAL

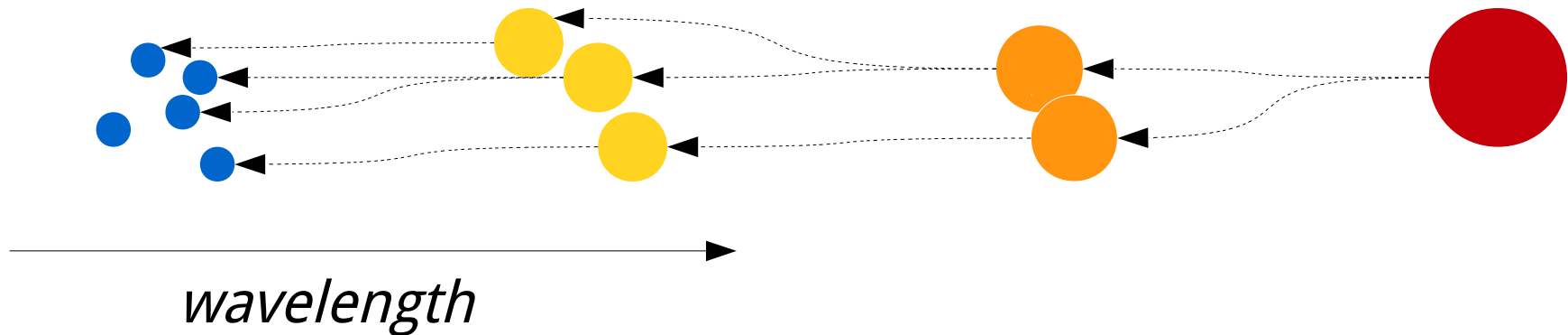




ATLASGAL
GLIMPSE
UKIDSS GPS

Tracing (massive) star formation

- How can we use these surveys to **directly** trace (massive) star formation in the Galactic plane?
- Ideal (long-term) plan: **Hierarchical YSO catalog**

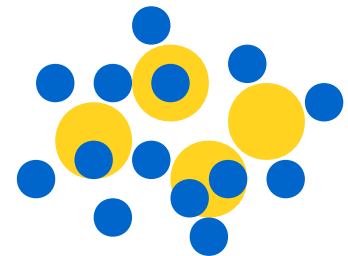
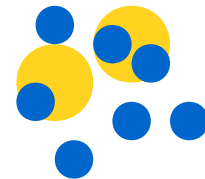
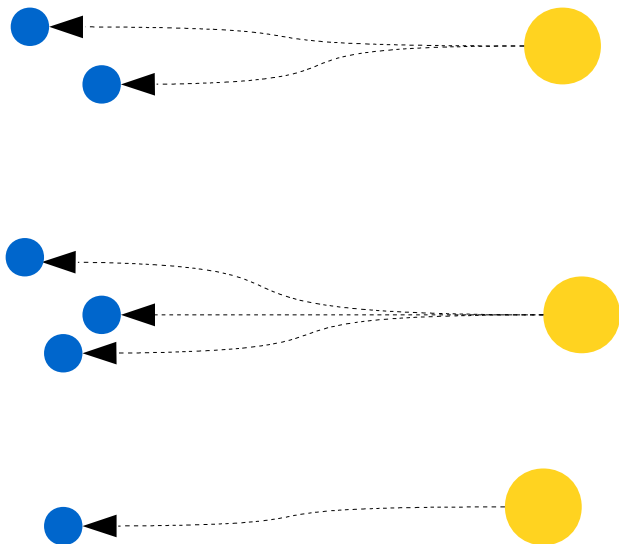


Tracing (massive) star formation

- For the moment:

GLIMPSE catalog of YSOs
(Robitaille+08)
+ UKIDSS GPS

Compilation of
embedded clusters
(Morales+13)



“Stellar cluster” definitions



3 pc

Open cluster *Pleiades*
(credit: ESO/S. Brunier)



Embedded cluster VV CL015 (to scale)
(Borissova et al. 2011)

"Stellar cluster" definitions

Bound open cluster (lifetimes ~ 100 Myr)

Star formation process +
dynamical evolution +
interaction with residual gas

(Unbound) association

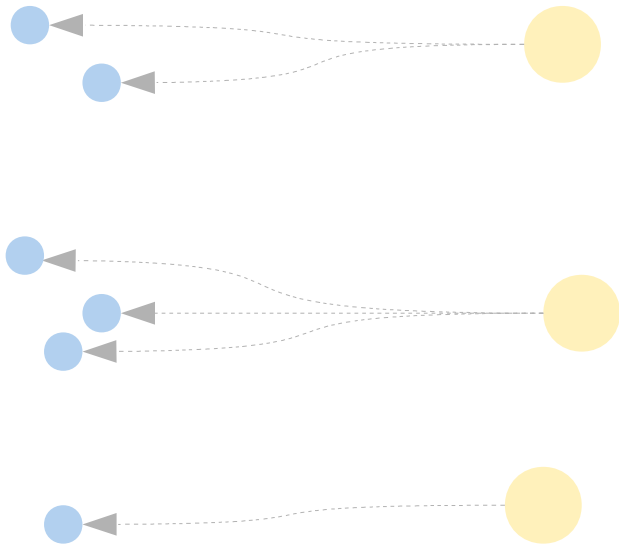


Embedded cluster

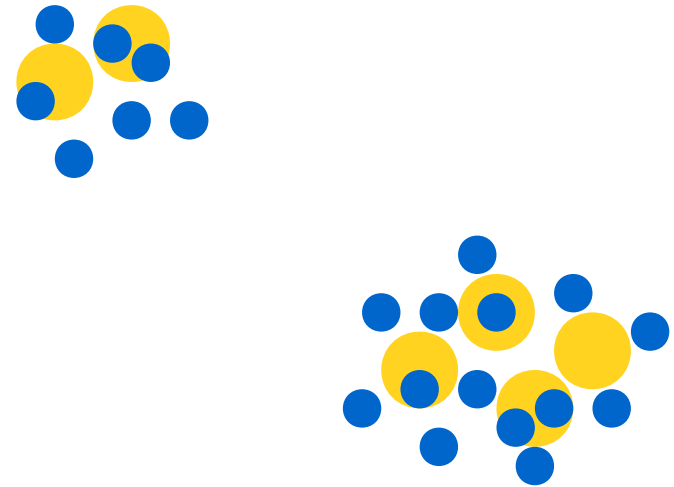


Field stars

GLIMPSE catalog of YSOs
(Robitaille+08)
+ UKIDSS GPS



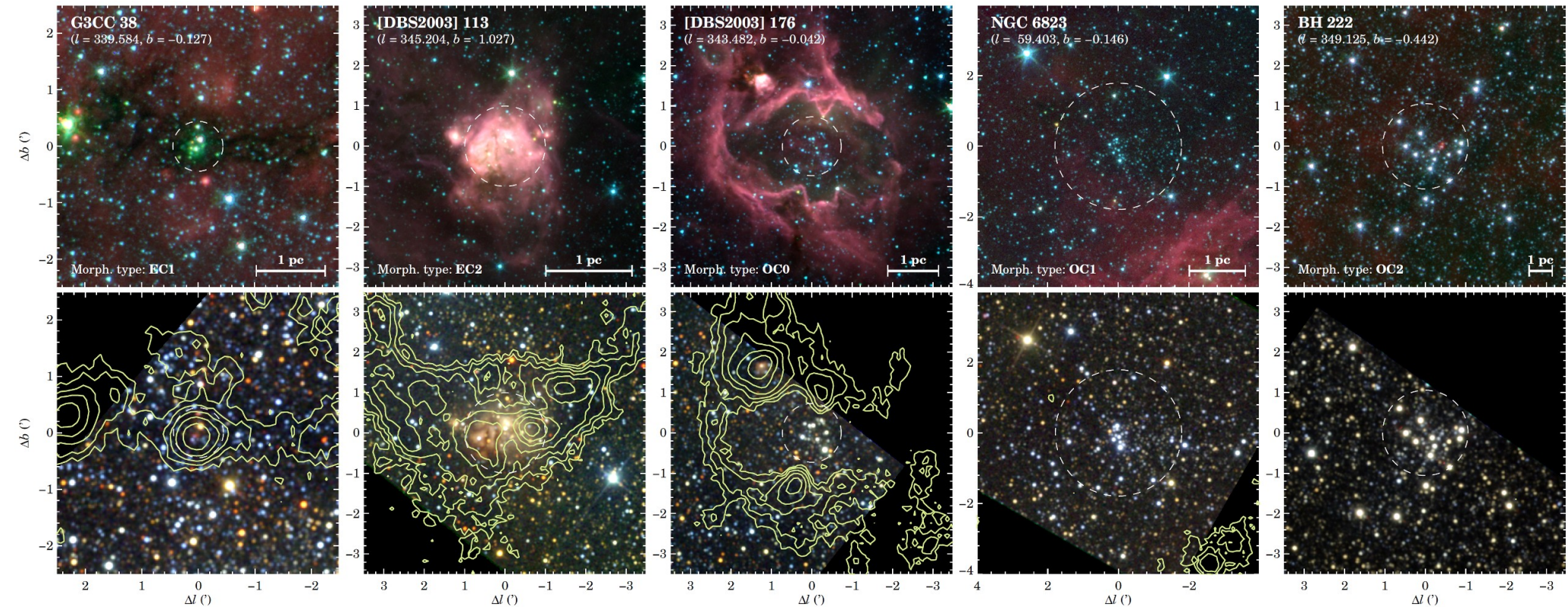
Compilation of
embedded clusters
(Morales+13)



The cluster sample

- Compilation of 695 embedded and open clusters in the ATLASGAL Galactic range
- Catalog in [VizieR: J/A+A/560/A76](#) → includes some distances (kinematic and/or stellar) and ages, correlation with known objects, etc.
- 90% of the embedded clusters are associated with [H II regions](#) and/or are within [clumps with \$M > 500 M_{\odot}\$](#)

Using ATLASGAL to probe embeddedness



Top: [8.0][4.5][3.6] μm Bottom: 2MASS $K_s H J$ + ATLASGAL (870 μm) contours

EC1

Deeply
embedded
cluster

EC2

Partially
embedded
cluster

OC0

Emerging
open
cluster

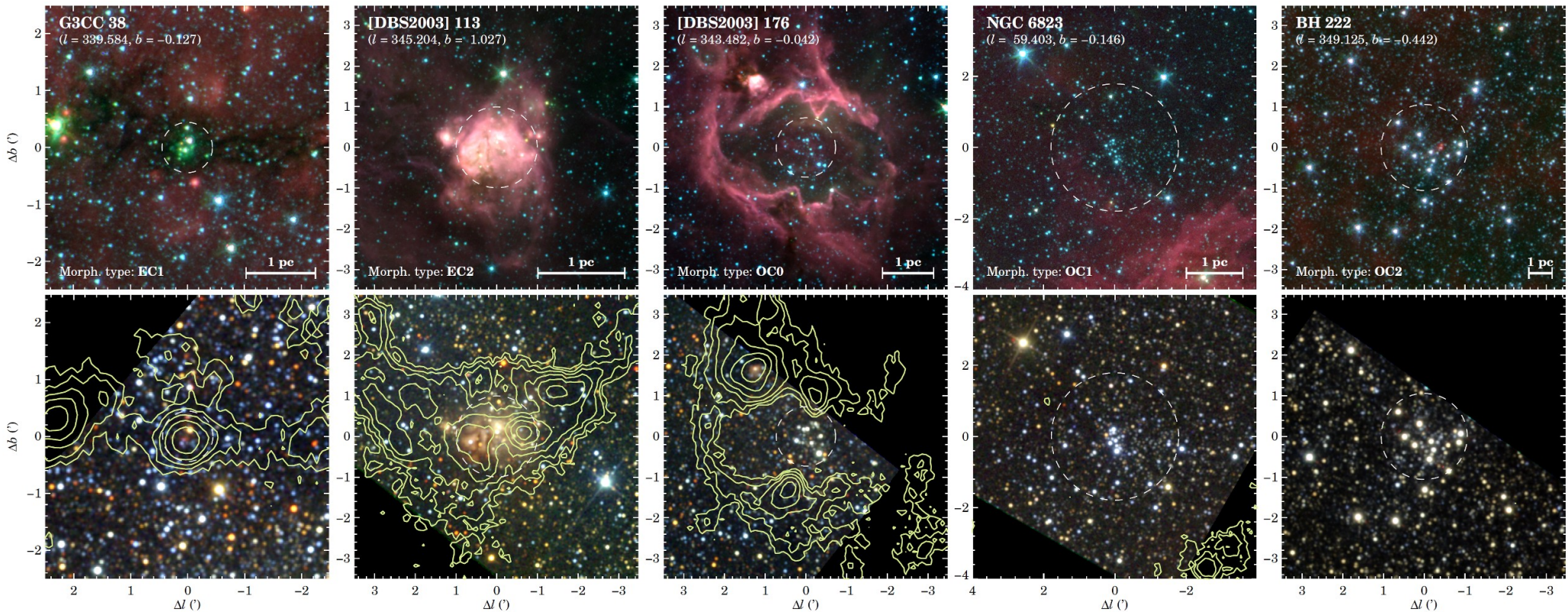
OC1

Fully exposed
cluster +
nearby submm
emission

OC2

All the
remaining
exposed
clusters

Using ATLASGAL to probe embeddedness



EC1

EC2

327 Embedded clusters (ECs)

OC0

OC1

OC2

+ *confirmed* → **191** open clusters (OCs)

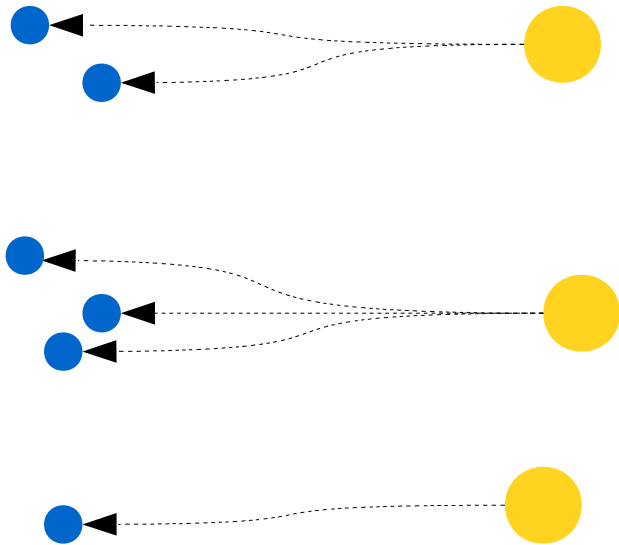
(observational definition of OC → not necessarily bound)

Some results (I)

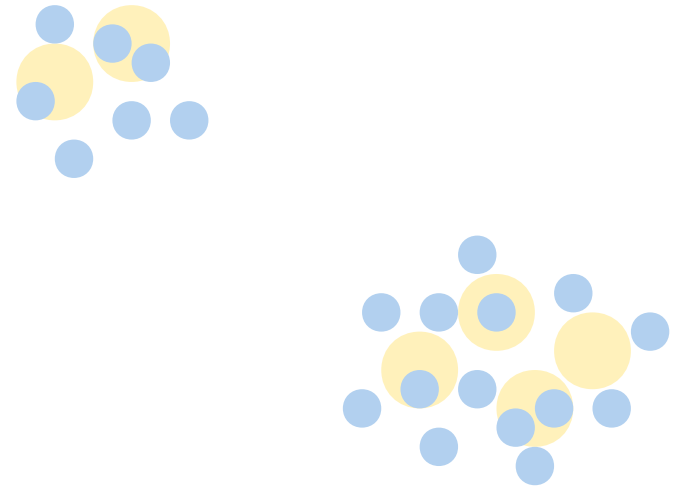
- OCs: Observational definition = physical definition for an age $\gtrsim 15$ Myr. Younger OCs can be associations
- Completeness distance: 1 kpc for OCs, 1.8 kpc for ECs
- Upper limit duration of ~ 3 Myr for the embedded phase
- Excess of young OCs with respect to a simple model \rightarrow consistent with presence of associations in the OC sample for age $\lesssim 15$ Myr
- EC dissolution fraction of $\sim 90\%$

*For details, check the paper
(Morales+13)*

GLIMPSE catalog of YSOs
(Robitaille+08)
+ UKIDSS GPS



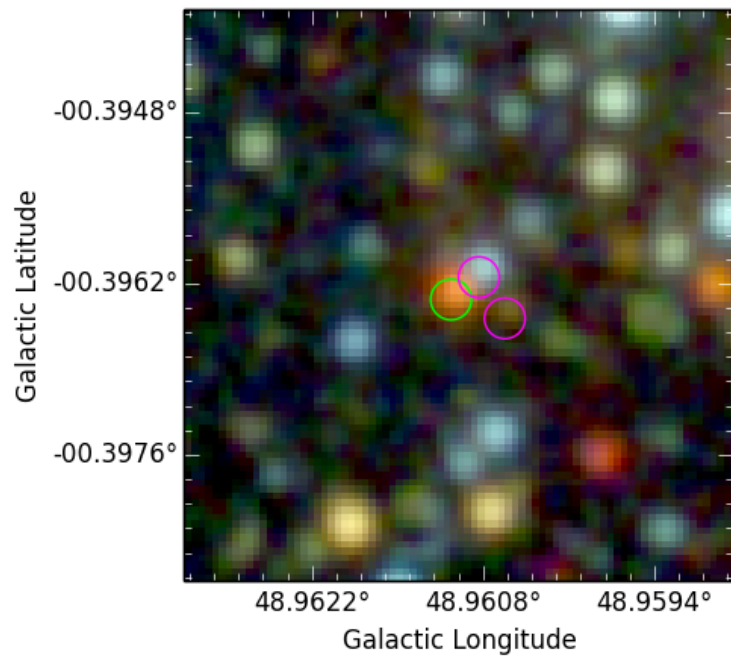
Compilation of
embedded clusters
(Morales+13)



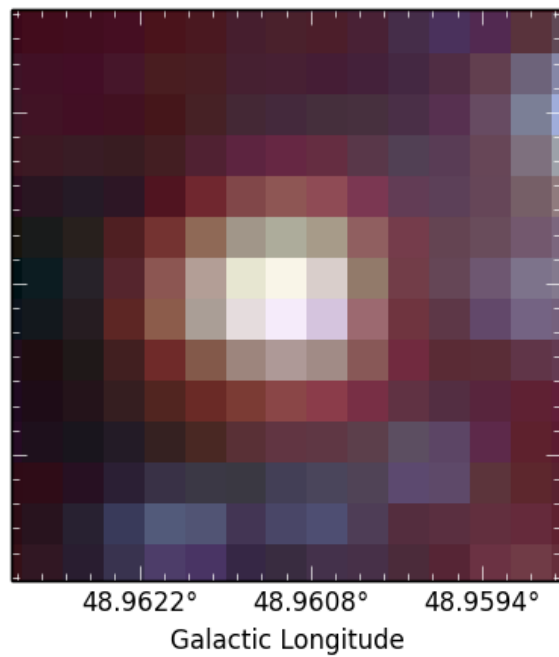
The GLIMPSE YSO sample

- From GLIMPSE catalog → Robitaille+08 (R08): catalog of 18,949 intrinsically red sources
- They are thought to be high- and intermediate-mass YSOs (50% - 70%) and AGB stars (30% - 50%)
- In UKIDSS GPS DR8: 8,325 sources from the R08 catalog
- UKIDSS point source catalog: aperture photometry → we performed PSF-fitting photometry

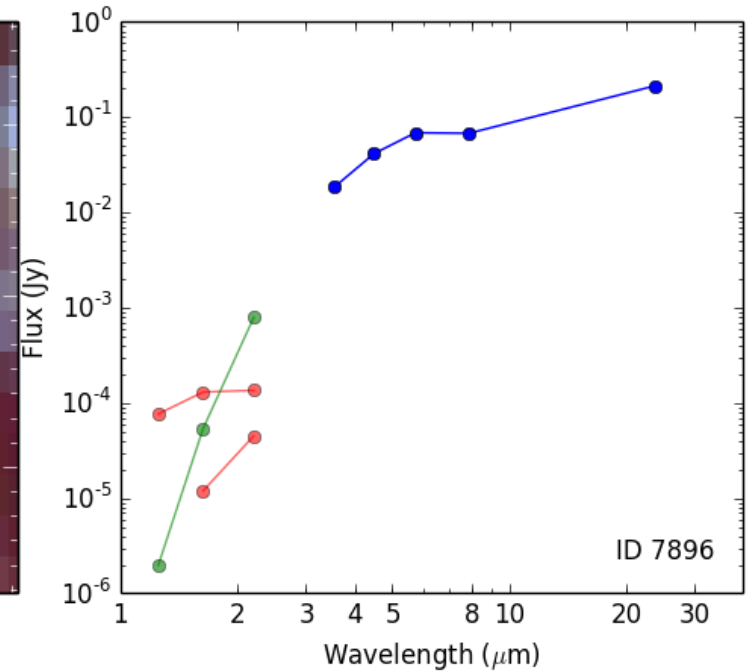
Spectral energy distributions (SEDs)



UKIDSS JHK

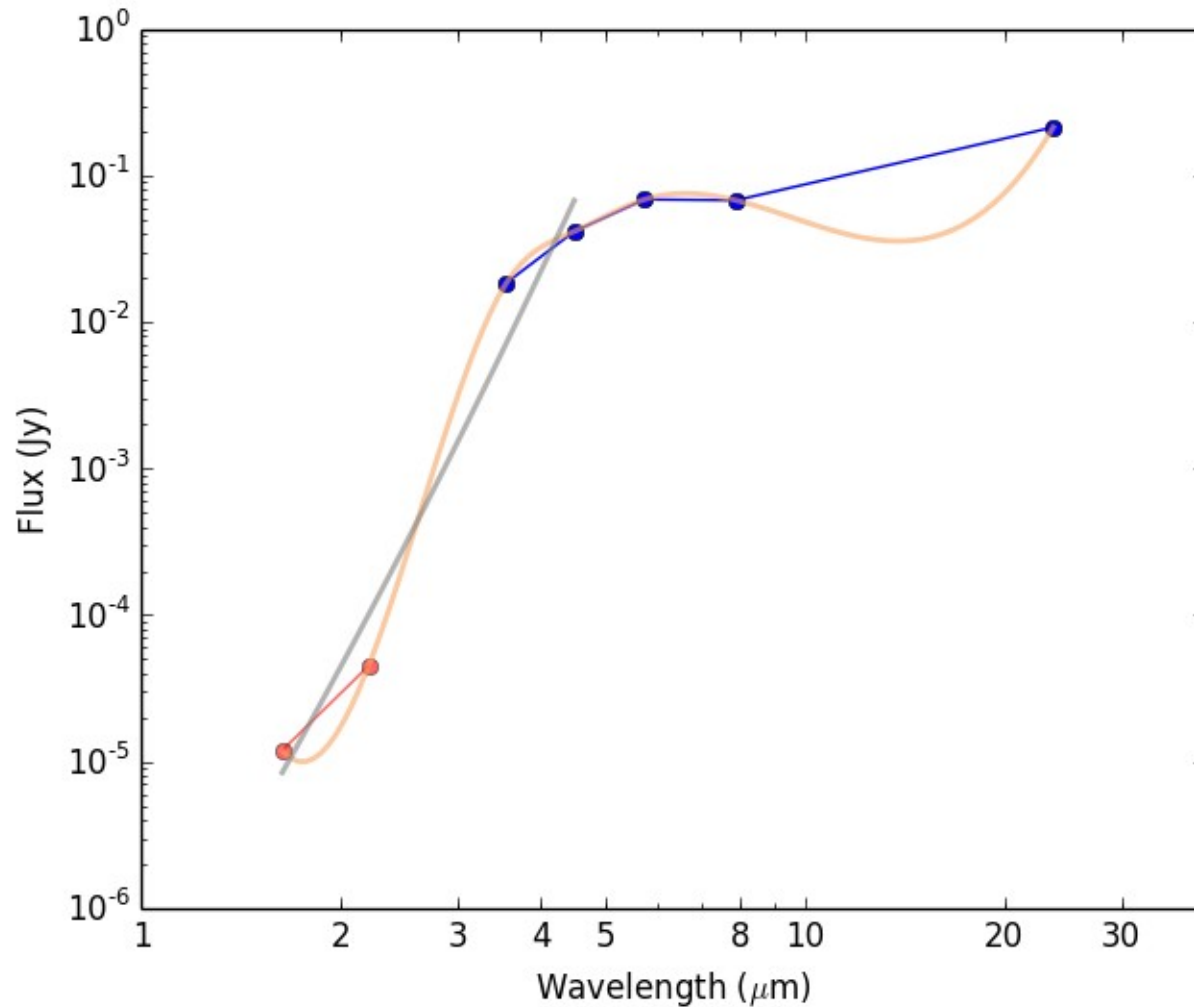


GLIMPSE [3.6][4.5][8.0]



(Morales+15, in prep.)

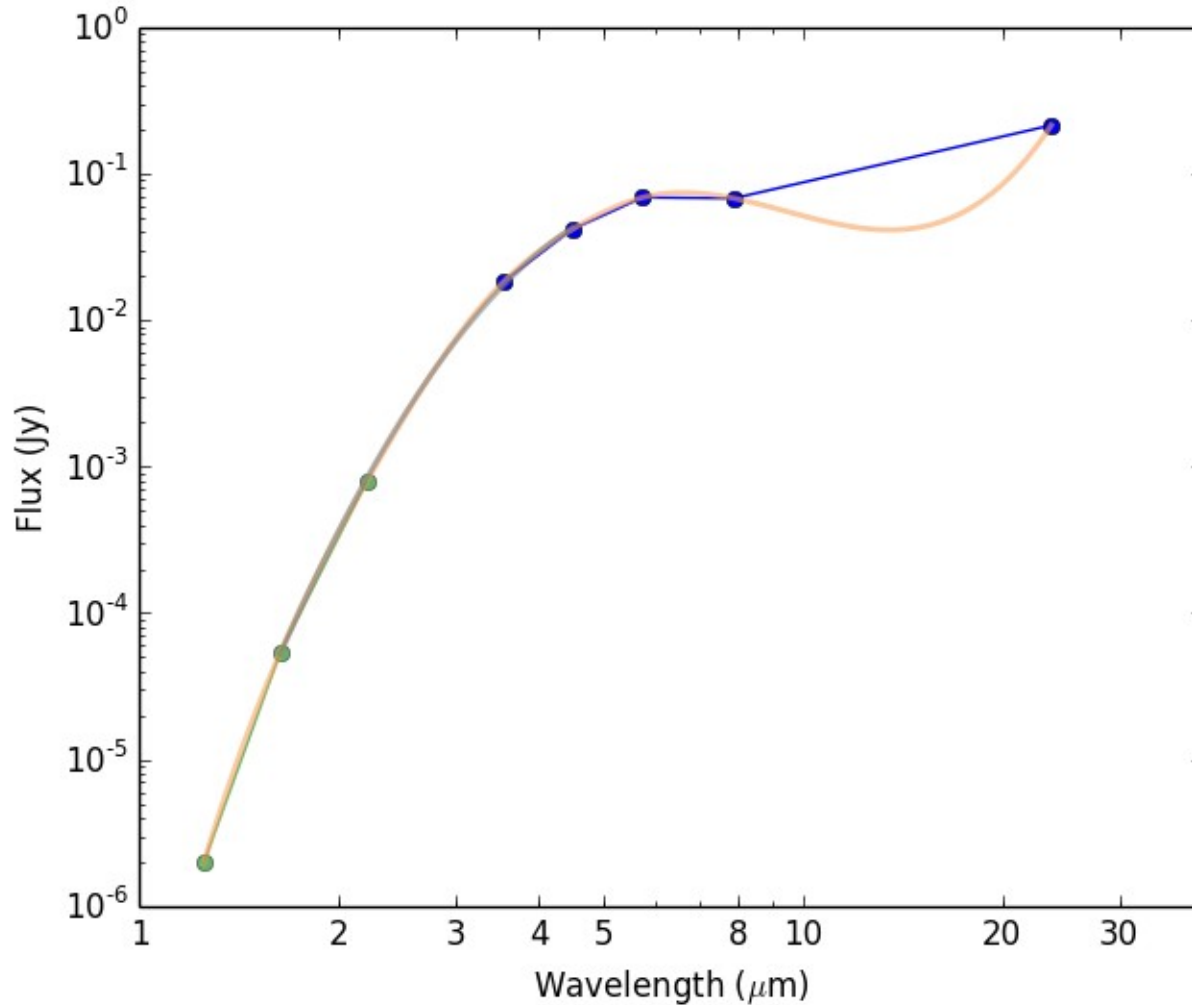
Quantifying the SED match



— Spline fit

— Quadratic fit to the 4 “middle points”

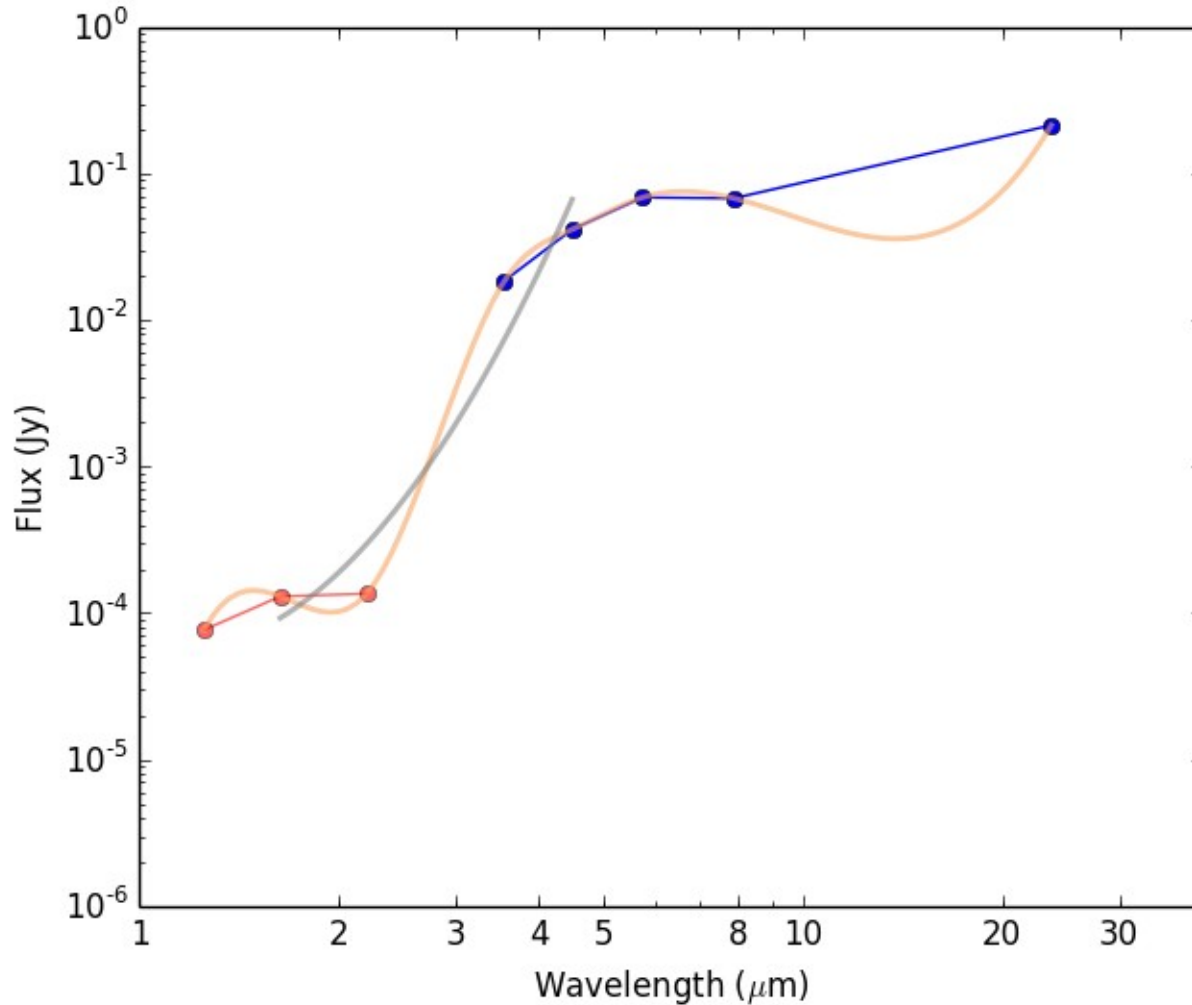
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Quantifying the SED match



— Spline fit

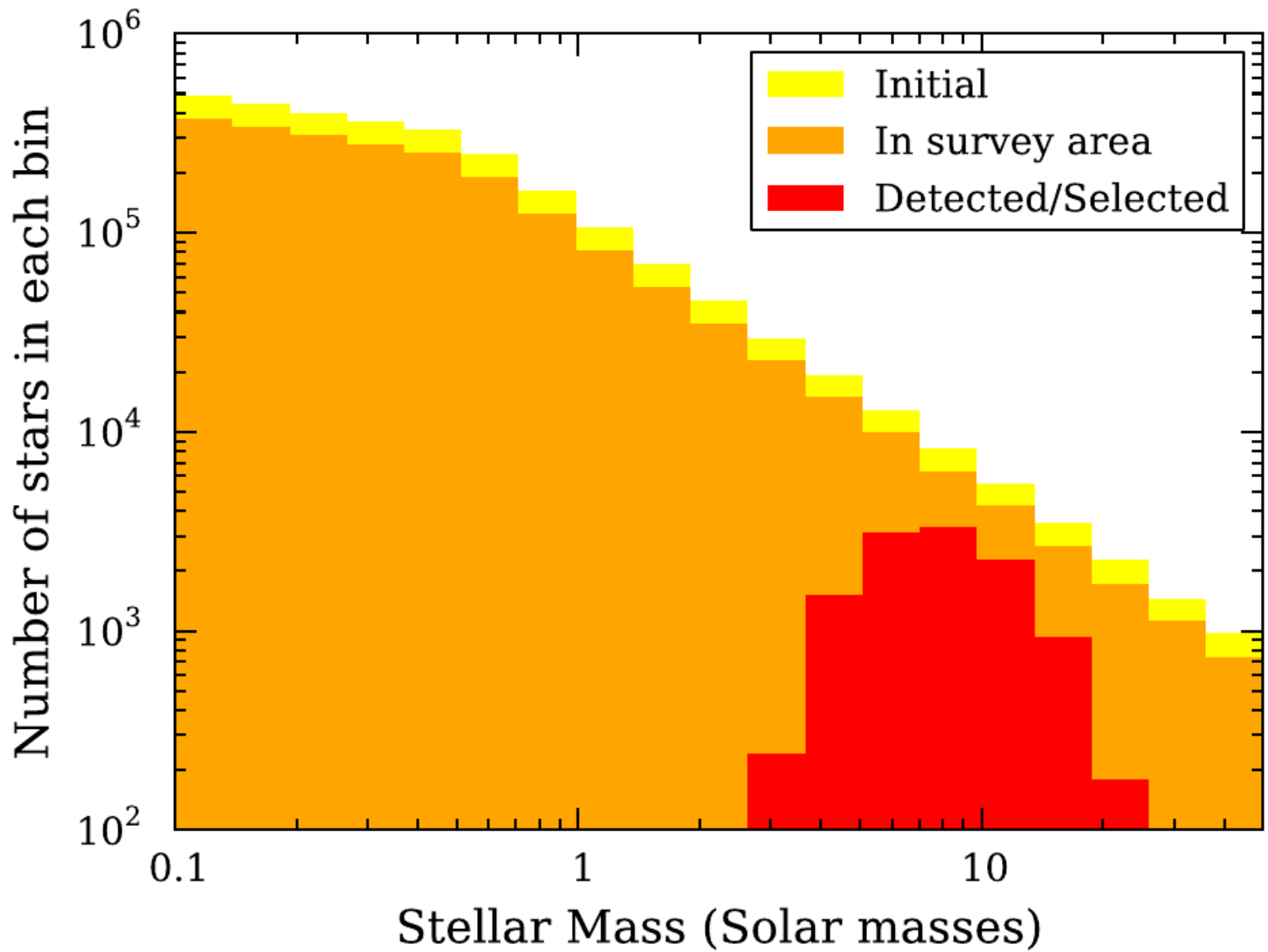
— Quadratic fit to the 4 "middle points"

Some results (II)

- From the 8,325 R08 sources → 4,923 are not saturated and with good quality PSF photometry in UKIDSS.
- From these, at least 85% present only one dominant UKIDSS source which matches the SED.
- Possible explanation: within the mass range covered by the R08 catalog, clustering at the GLIMPSE resolution is unlikely
- No significant corrections are needed to apply to SFR estimates based on GLIMPSE YSOs counts (e.g., Robitaille & Whitney 2010)

Are the GLIMPSE YSOs in embedded clusters?

- EC sample complete up to 1.8 kpc
- 140 R08 sources are in ECs or OCs younger than 3 Myr, for clusters within 1.8 kpc
- From population synthesis model (Robitaille & Whitney 2010) → 141 synthetic YSOs within 1.8 kpc
- Probably all GLIMPSE YSOs are members of embedded clusters!



(Robitaille & Whitney 2010)