# Mass Segregation in Small Clusters/Groups

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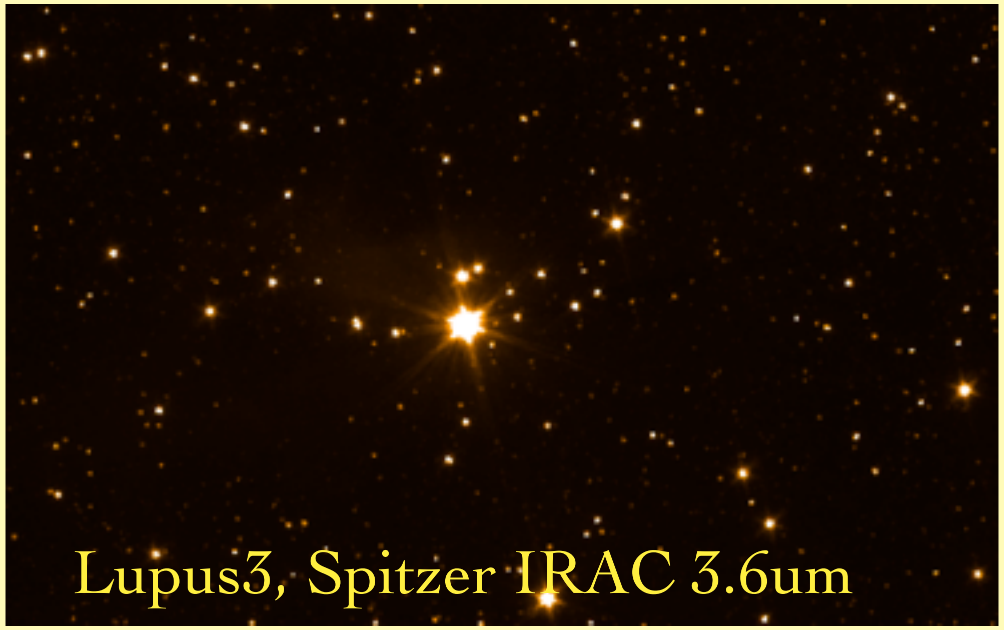
Phil Myers (CfA) (observations)

# Small & young stellar groups

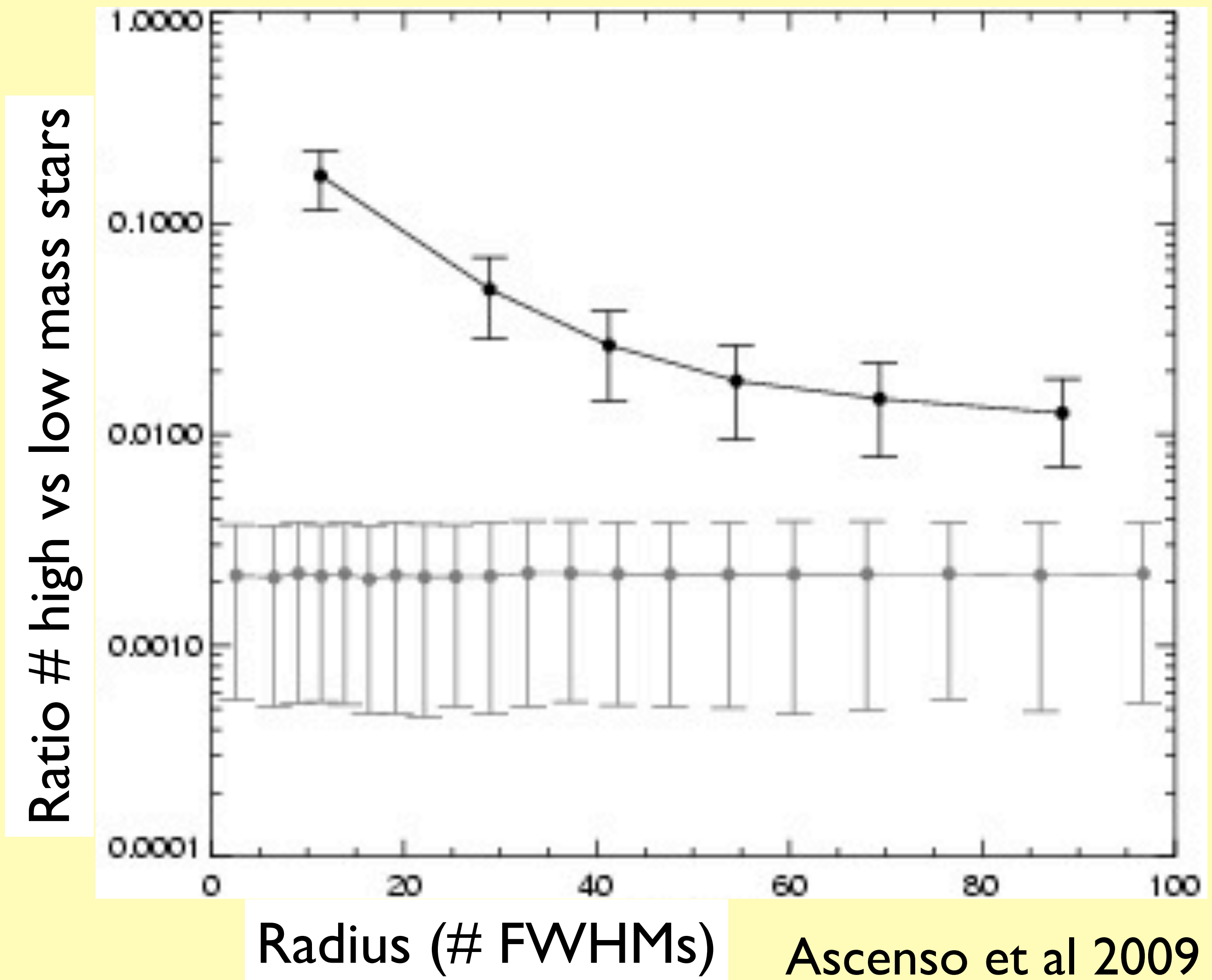
- A relatively un-explored regime of 'clustered' star formation
- How sparse do regions have to be before they no longer form like clusters? (e.g., Testi et al 1999)
- Our observational results (next slides) show that some properties typically associated with clusters extend to very small, sparse groups

groups in sample have 10's of members, surface densities ~1-10/pc$^2$, ages 1-2Myr, within ~300pc, with spectral types complete to late M



# Advangatges of small groups?

- Ascenso et al 2009: tightly packed (large) clusters can give an artificial appearance of mass segregation - not an issue for us
- dynamical interactions, etc, decrease with sparser, smaller groups, allowing an easier association to be made with primordial state



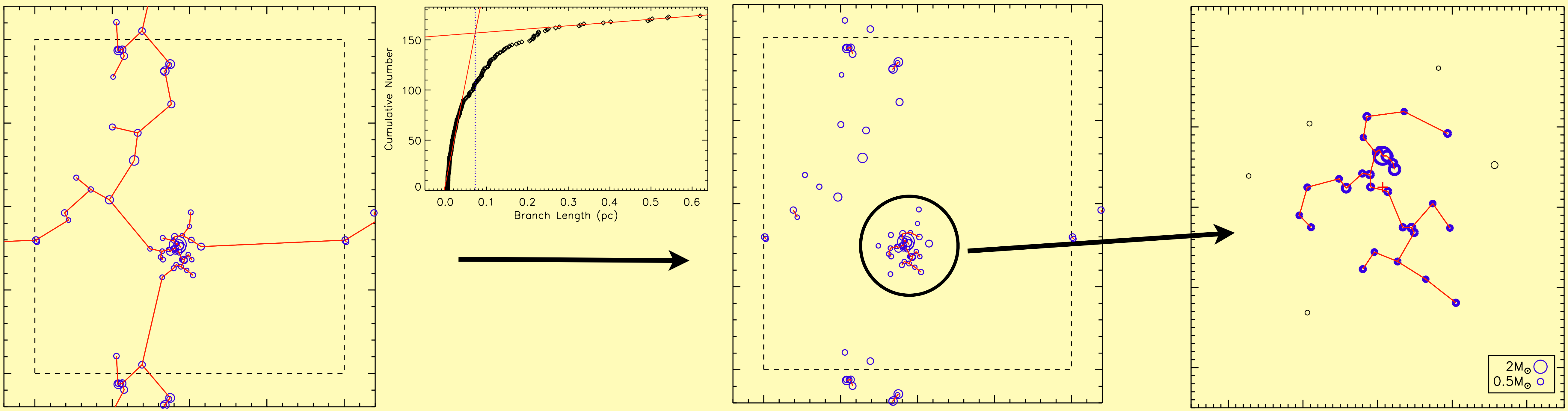

Ascenso et al 2009

synthetic cluster with equally distributed masses of stars

# Identifying Groupings - MSTs

## Minimal Spanning Trees used to identify groups / clusters

e.g., Gutermuth et al 2009, Kirk & Myers 2011, Maschberger et al 2011



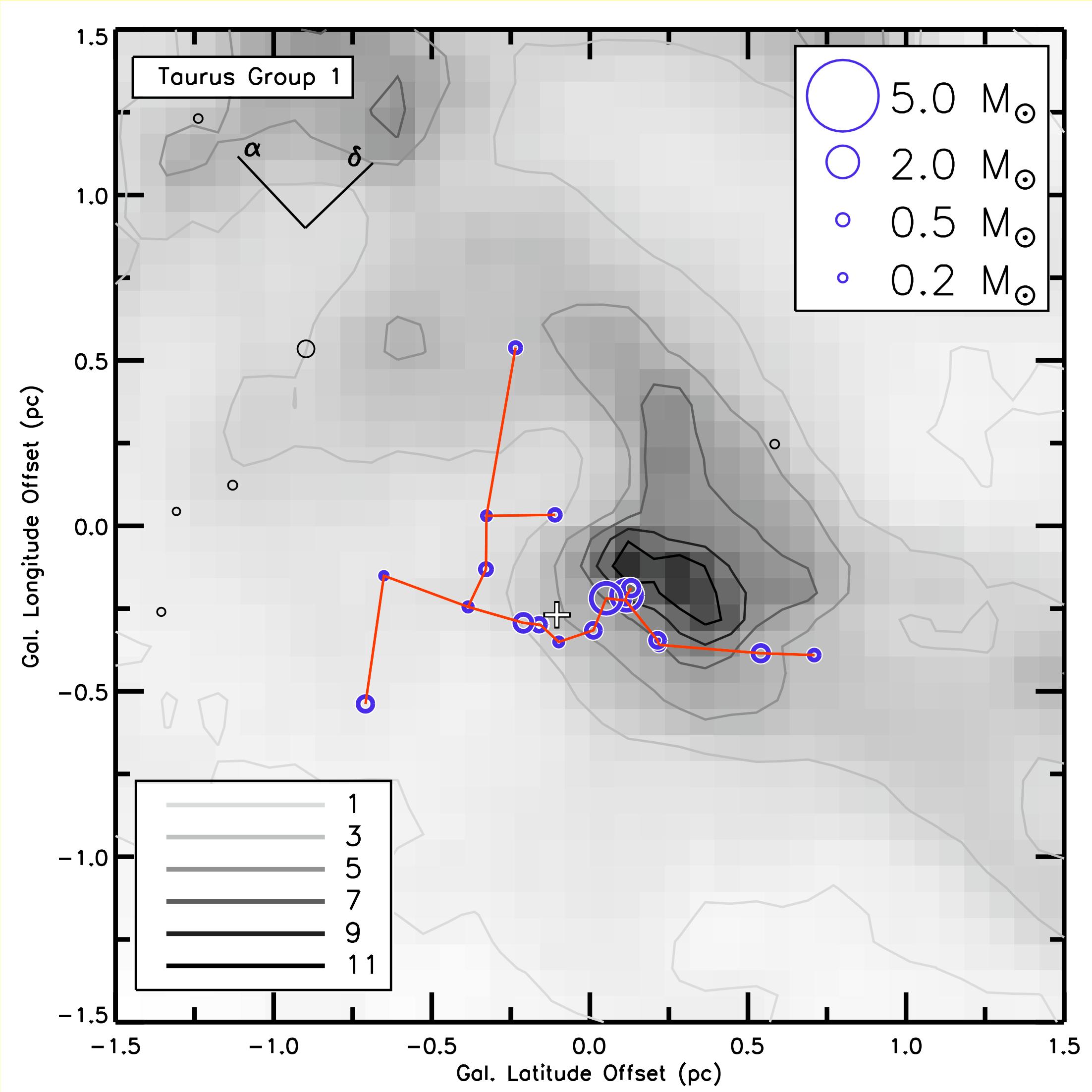

1) connect all stars by shortest path

1b) determine max branch length for groupings

2) chop out long branches

3) keep remaining groupings with > N members

# Observational results




Kirk & Myers 2011

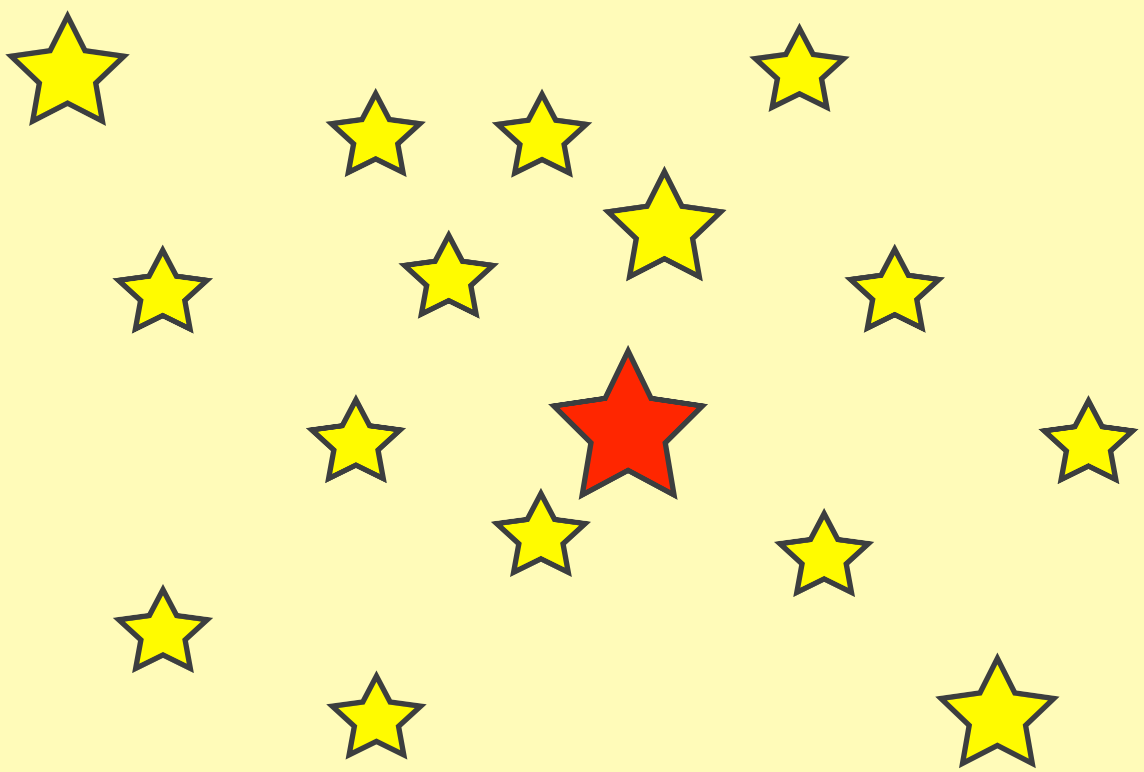
background = extinction / column density, circles = stars

- most massive member tends to be centrally located
- higher surface density around most massive star
- higher likelihood of higher masses in higher surface density environments

full observational sample: Taurus, Lupus3, ChaI, IC348

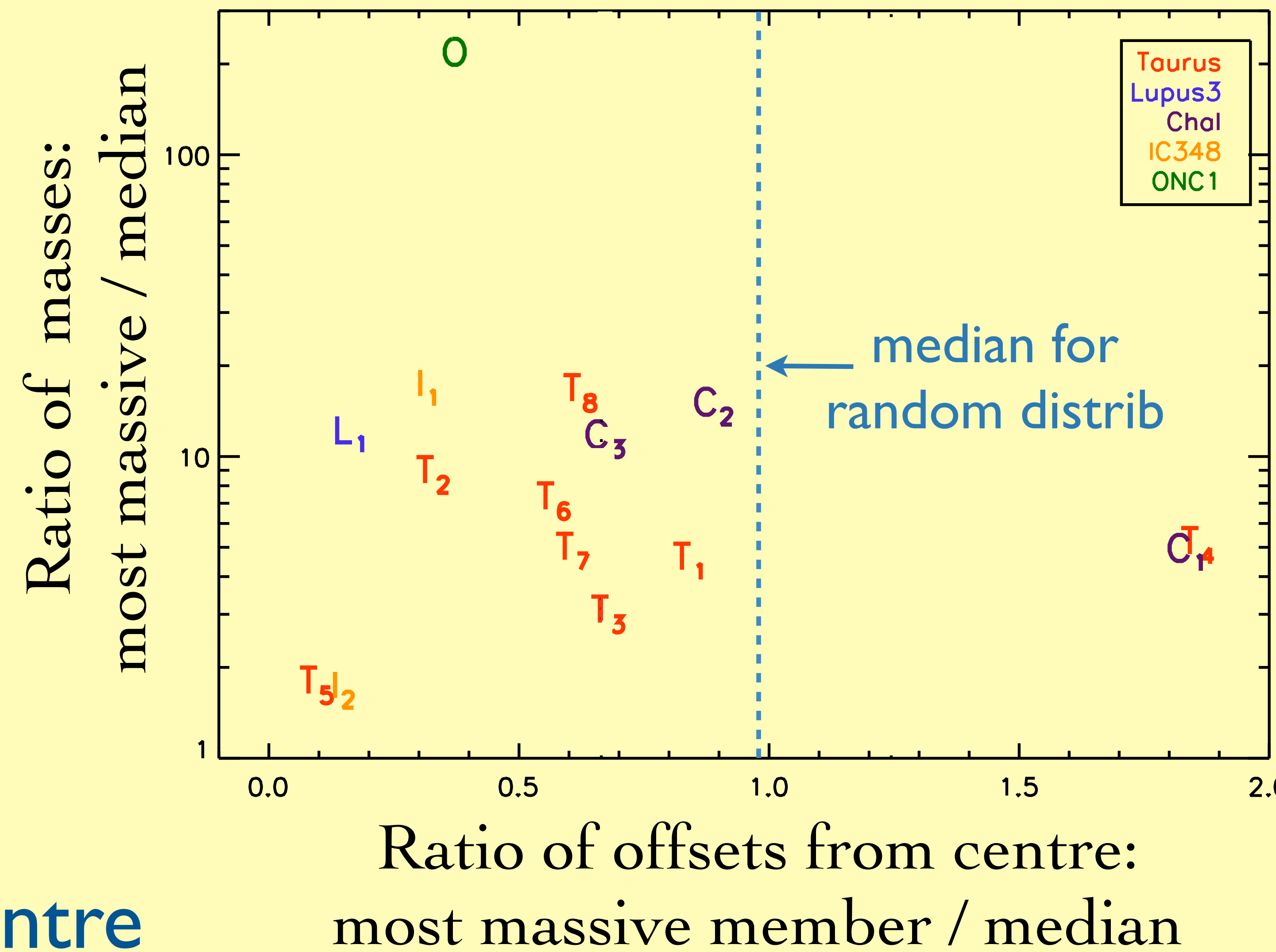
# Observational results

## measuring mass segregation



1) centre = median position
2) measure all offsets from centre
3) take ratio of most massive star's offset to median

## central location of most massive member:




Kirk & Myers 2011

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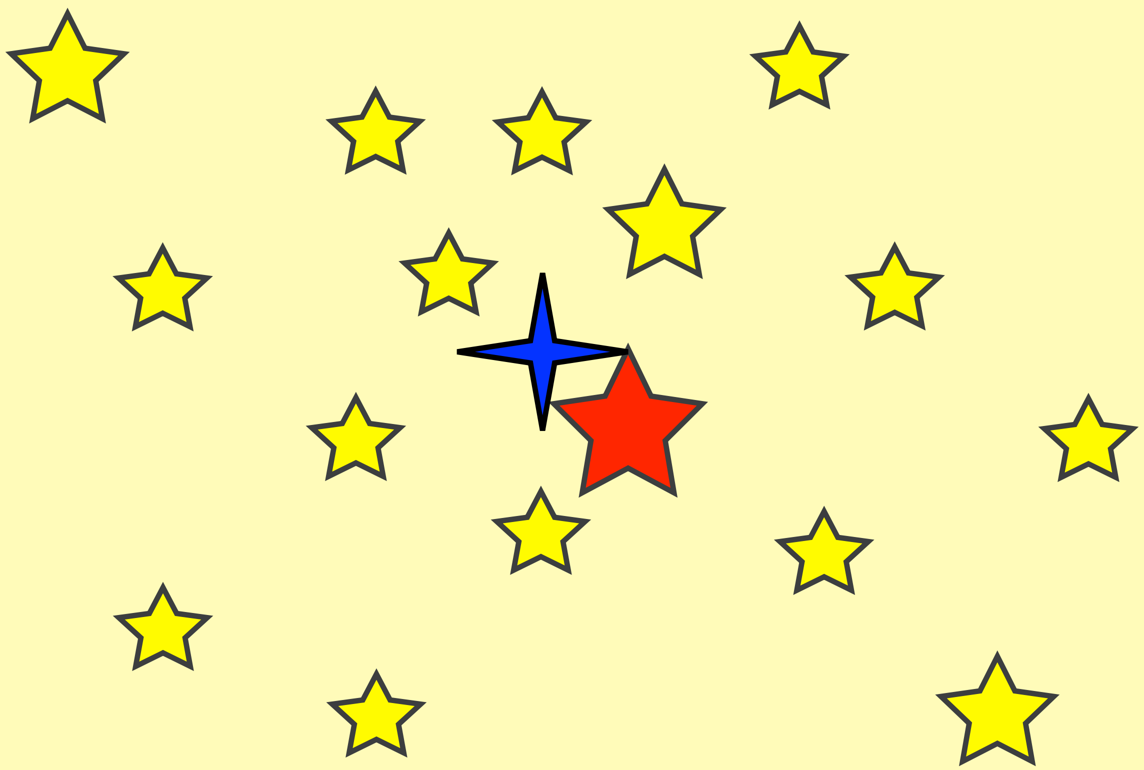

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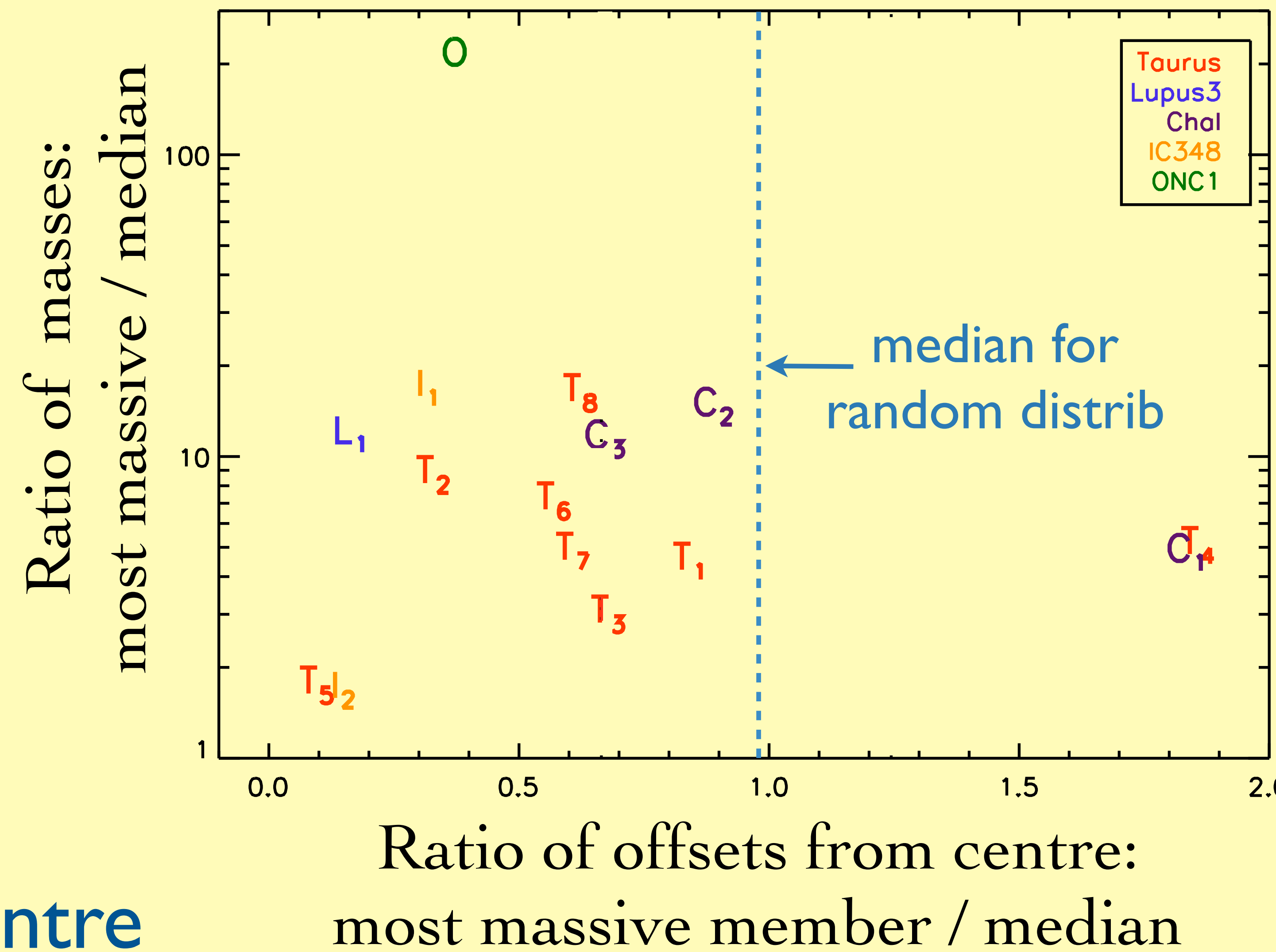


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Kirk & Myers 2011

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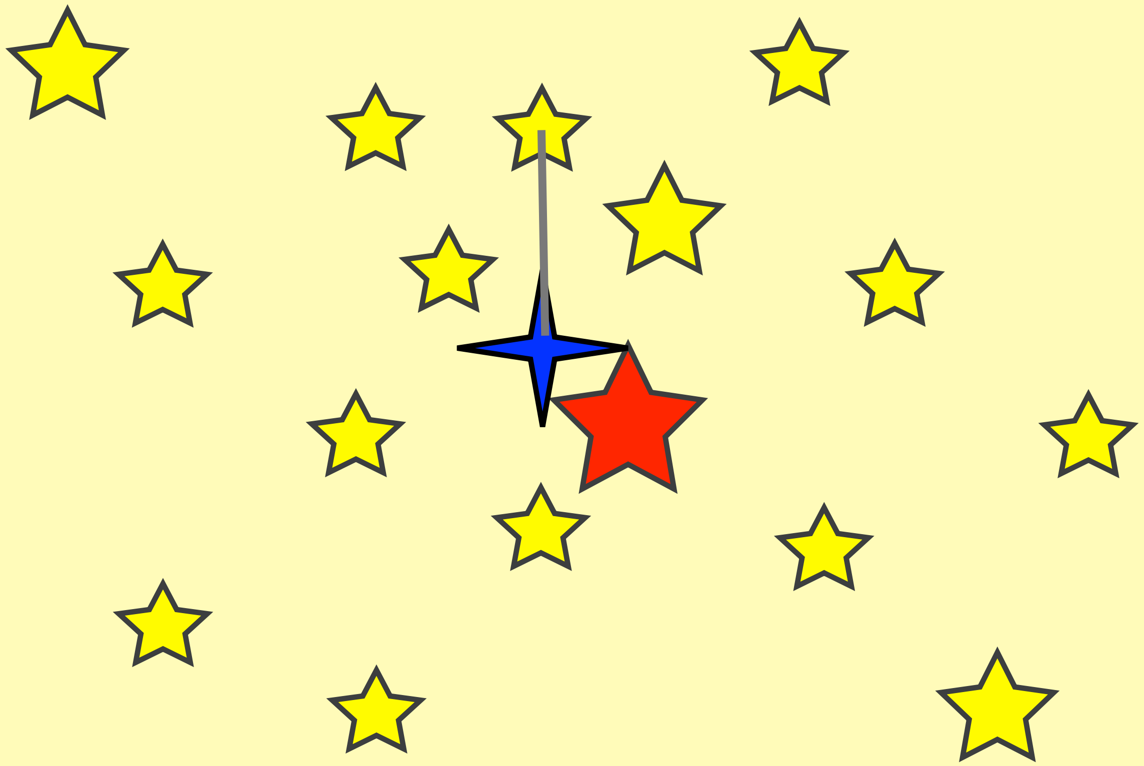

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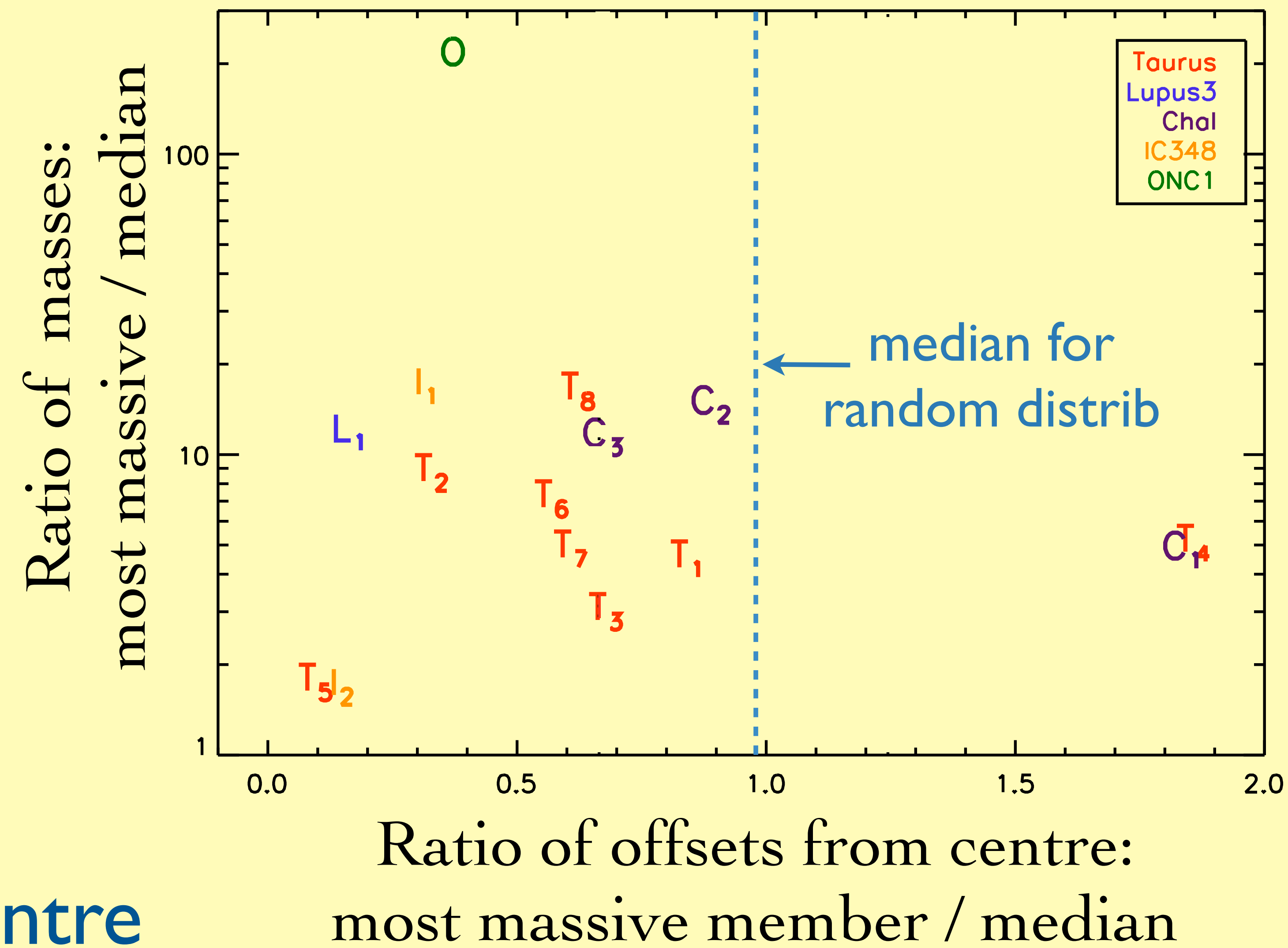


Kirk & Myers 2011

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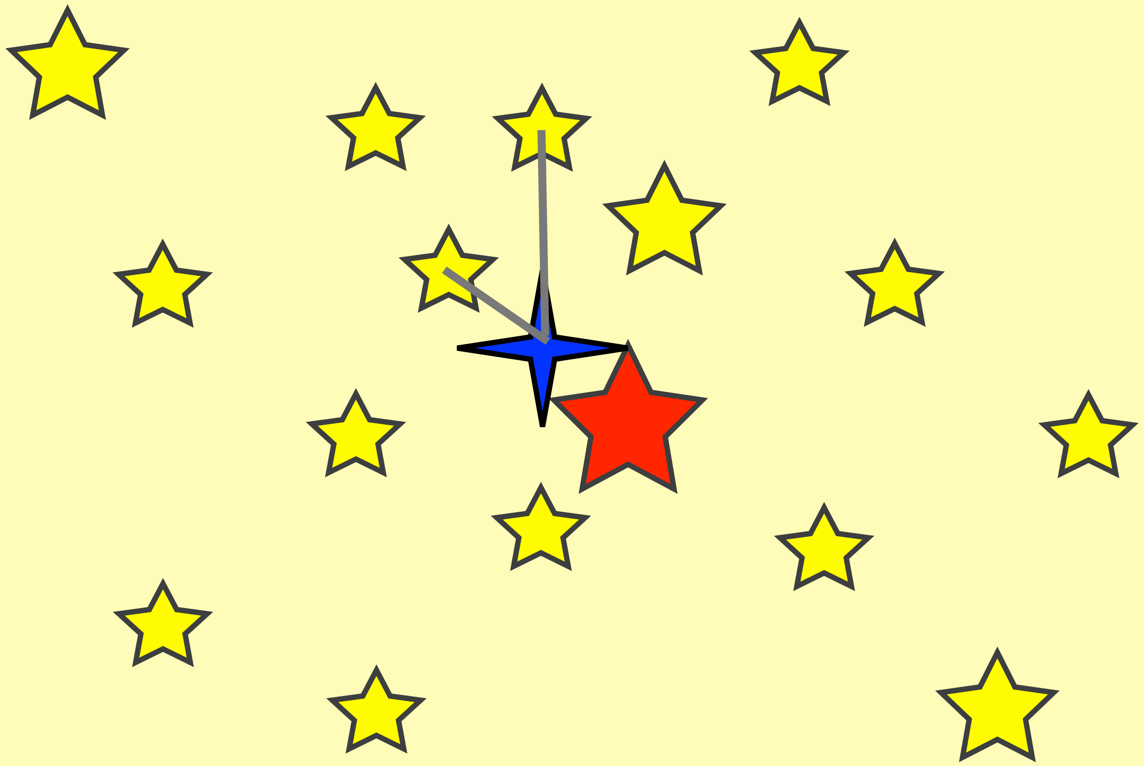

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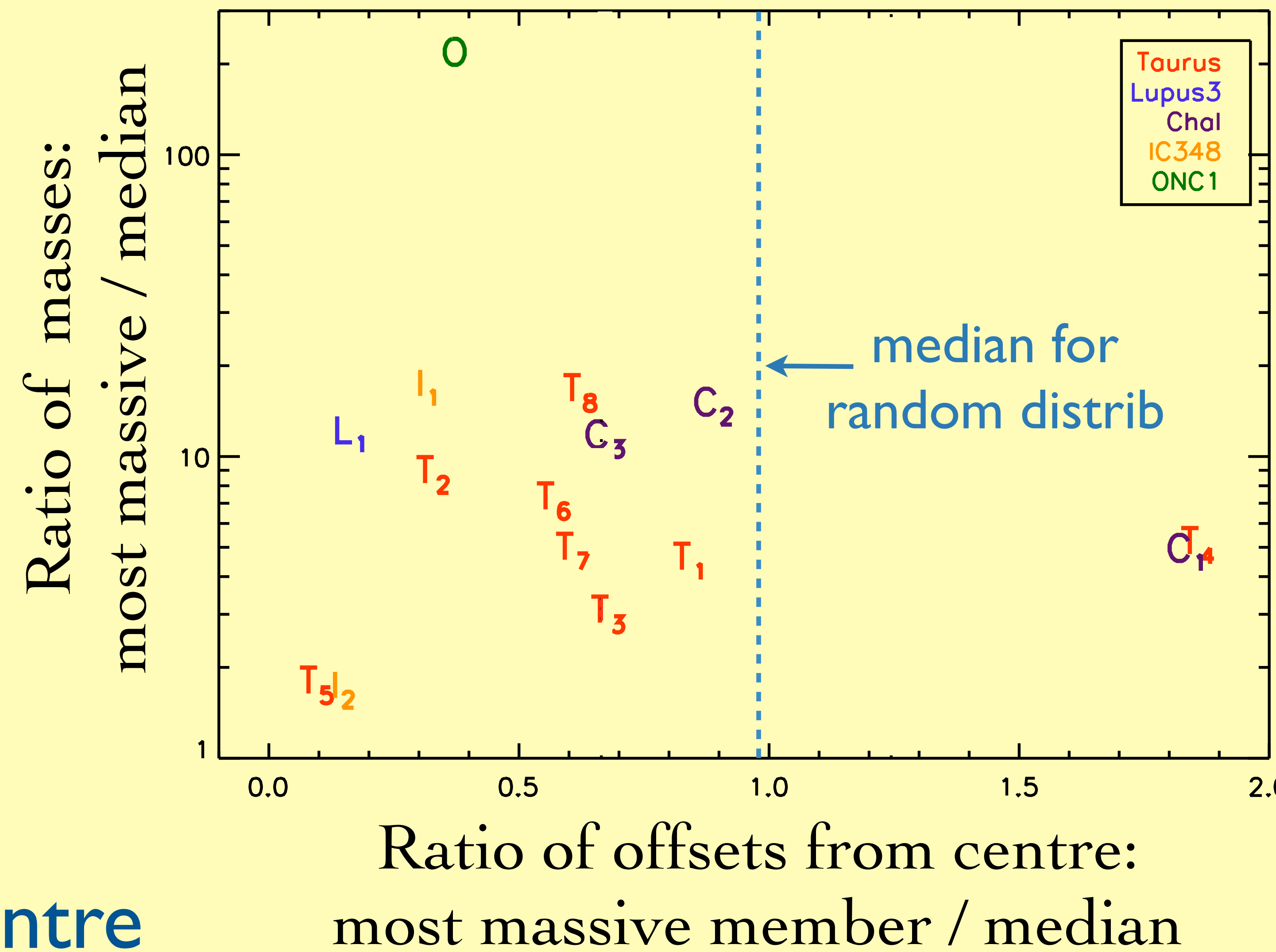


Kirk & Myers 2011

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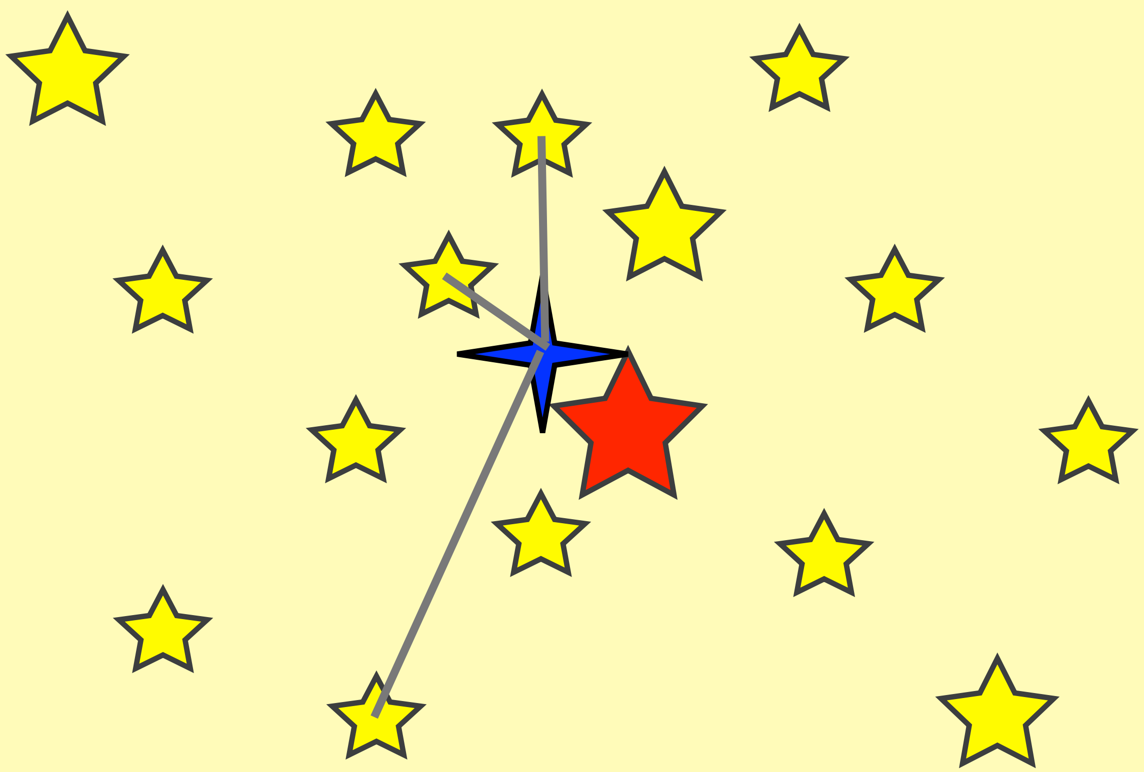

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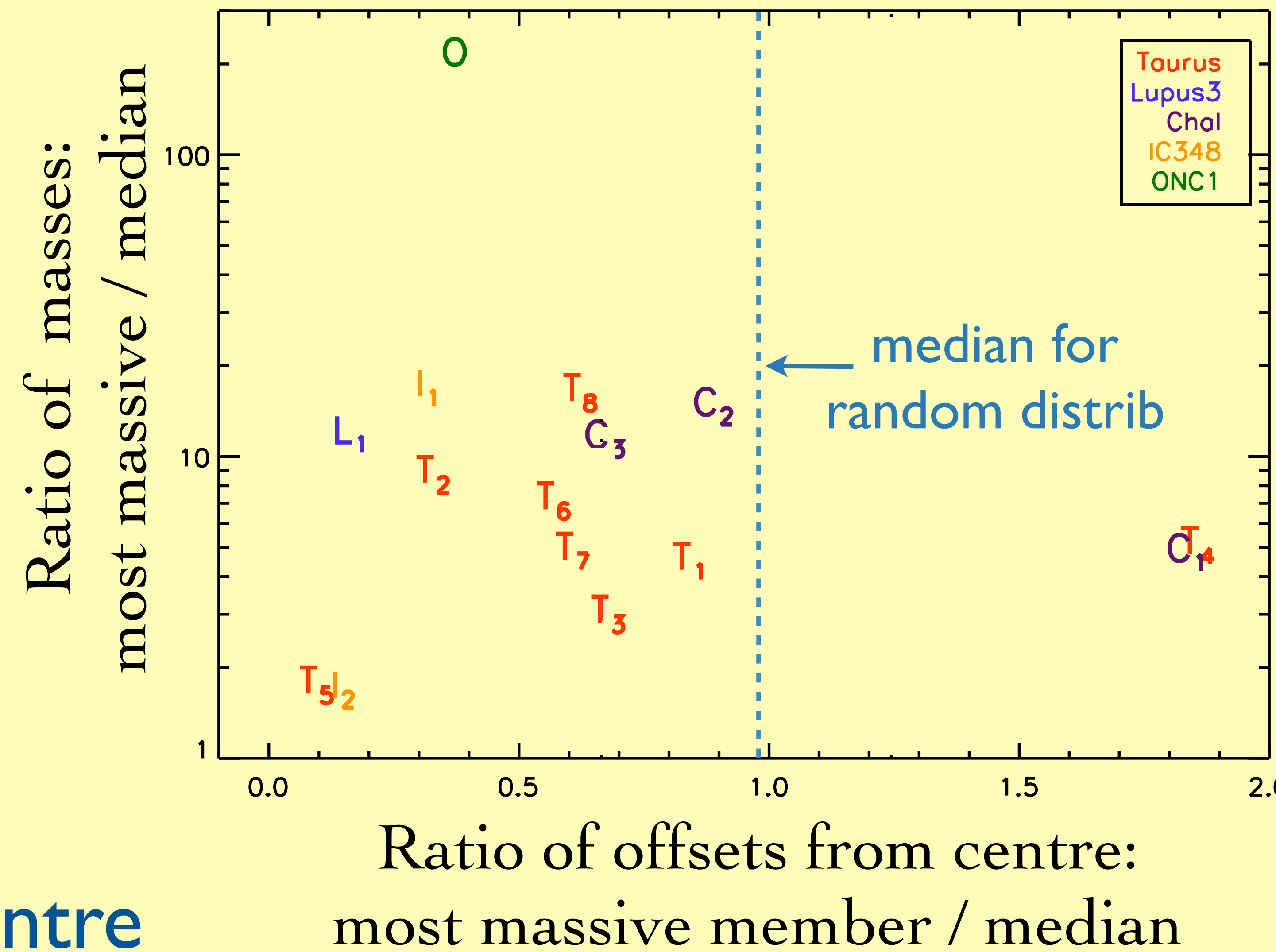


Kirk & Myers 2011

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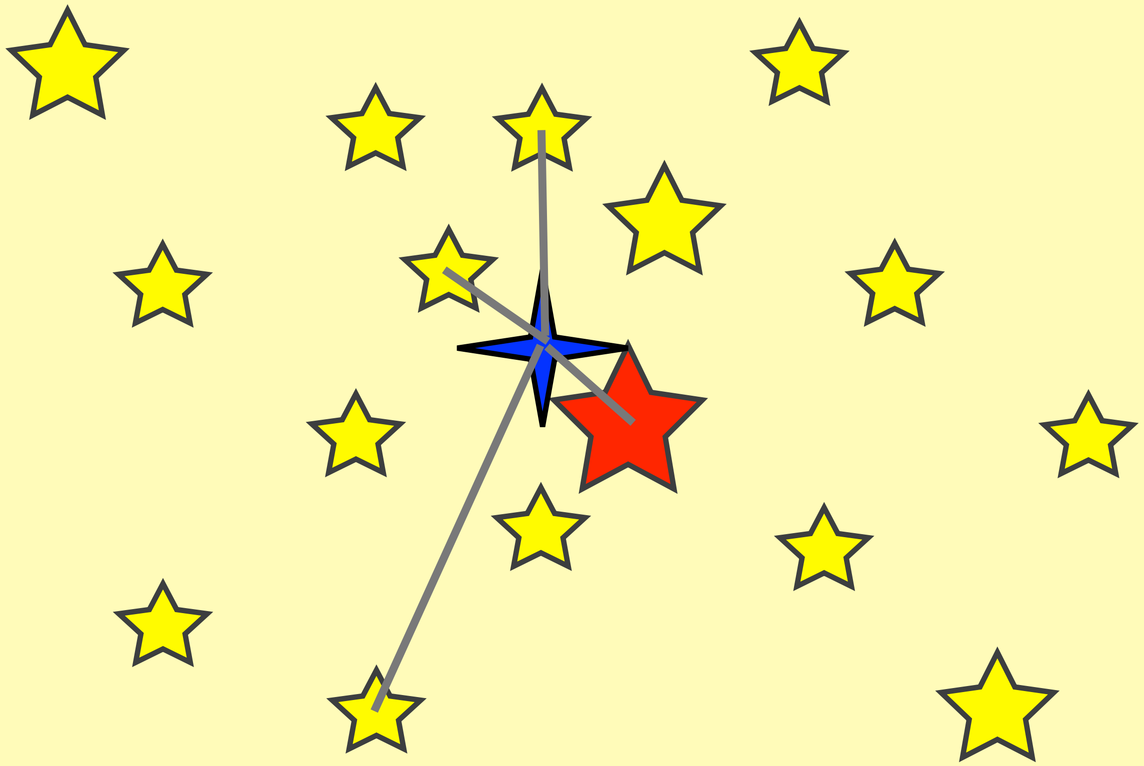

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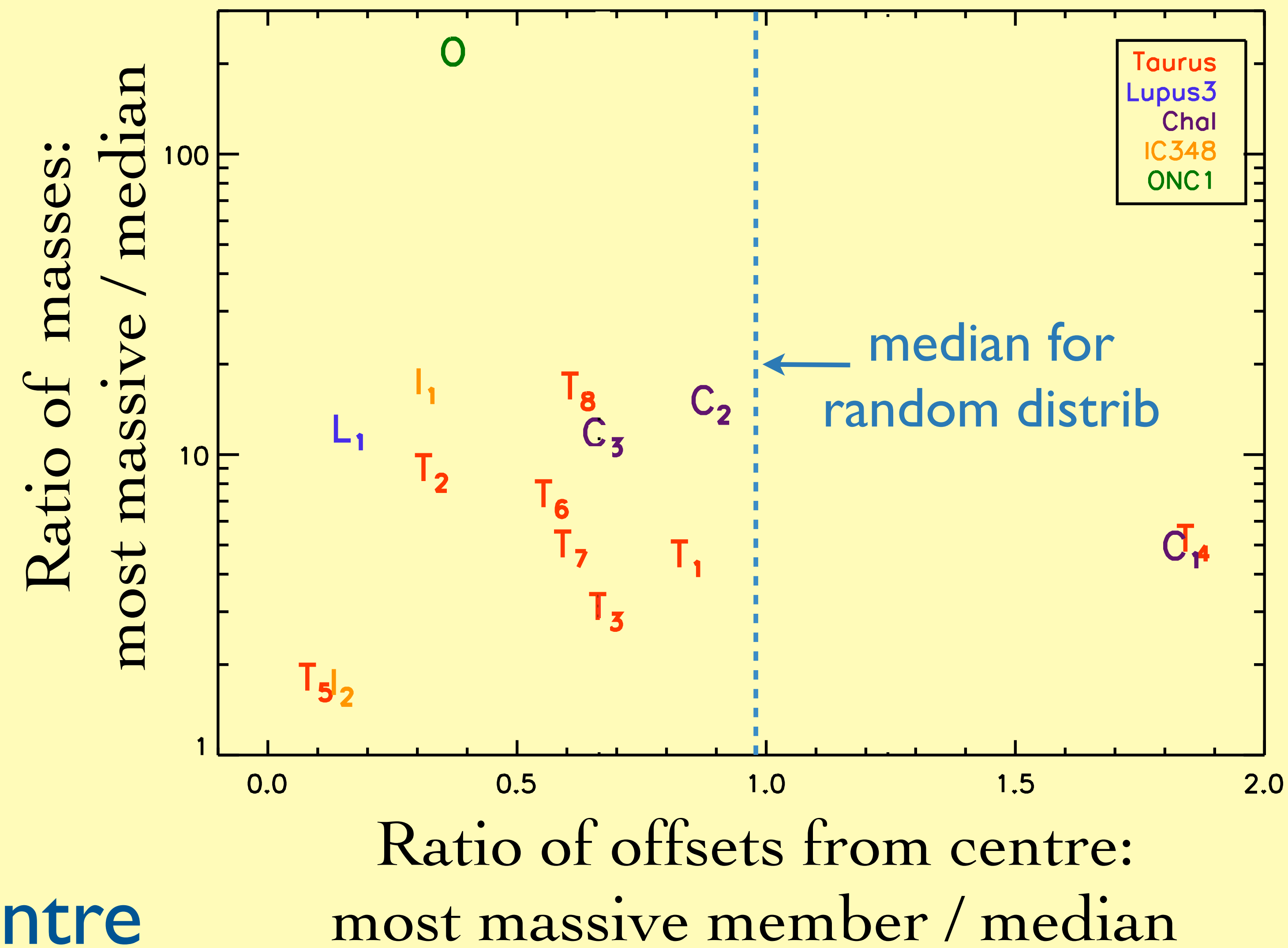


Kirk & Myers 2011

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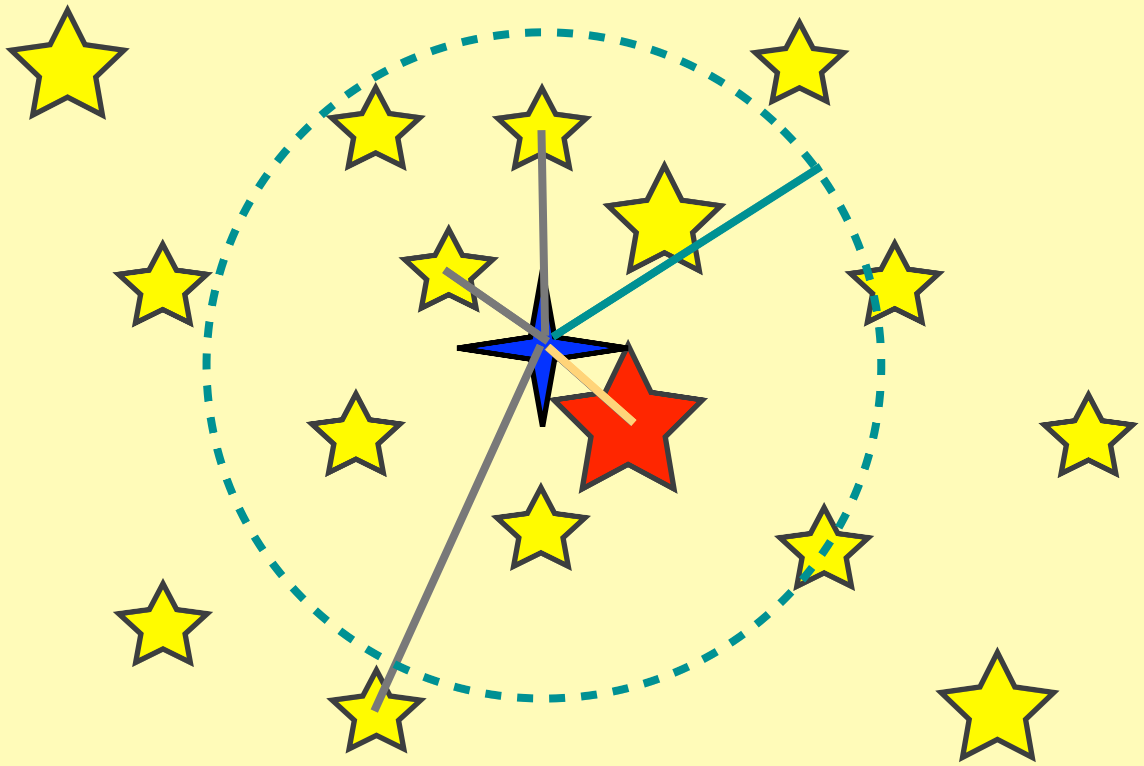

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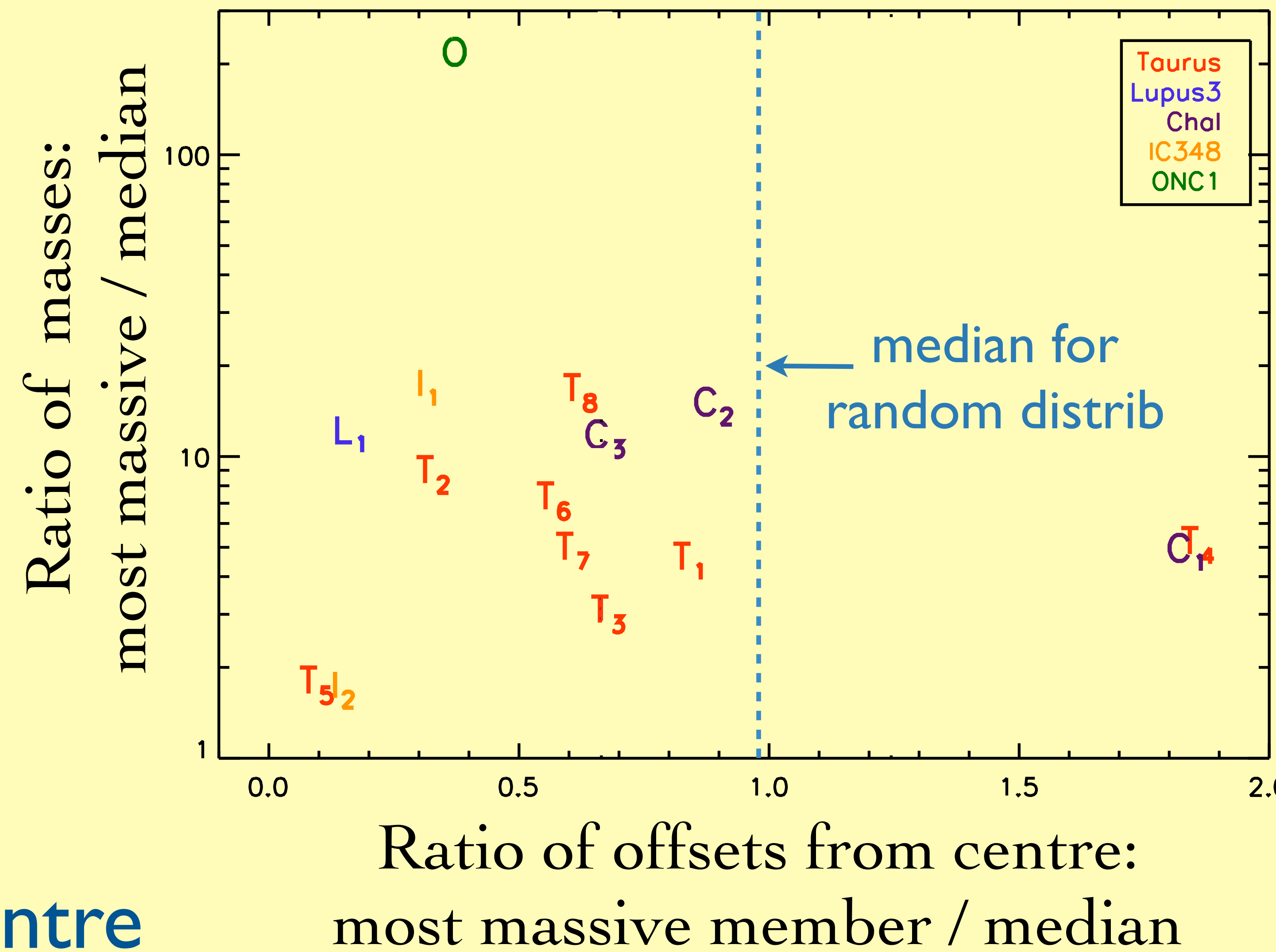


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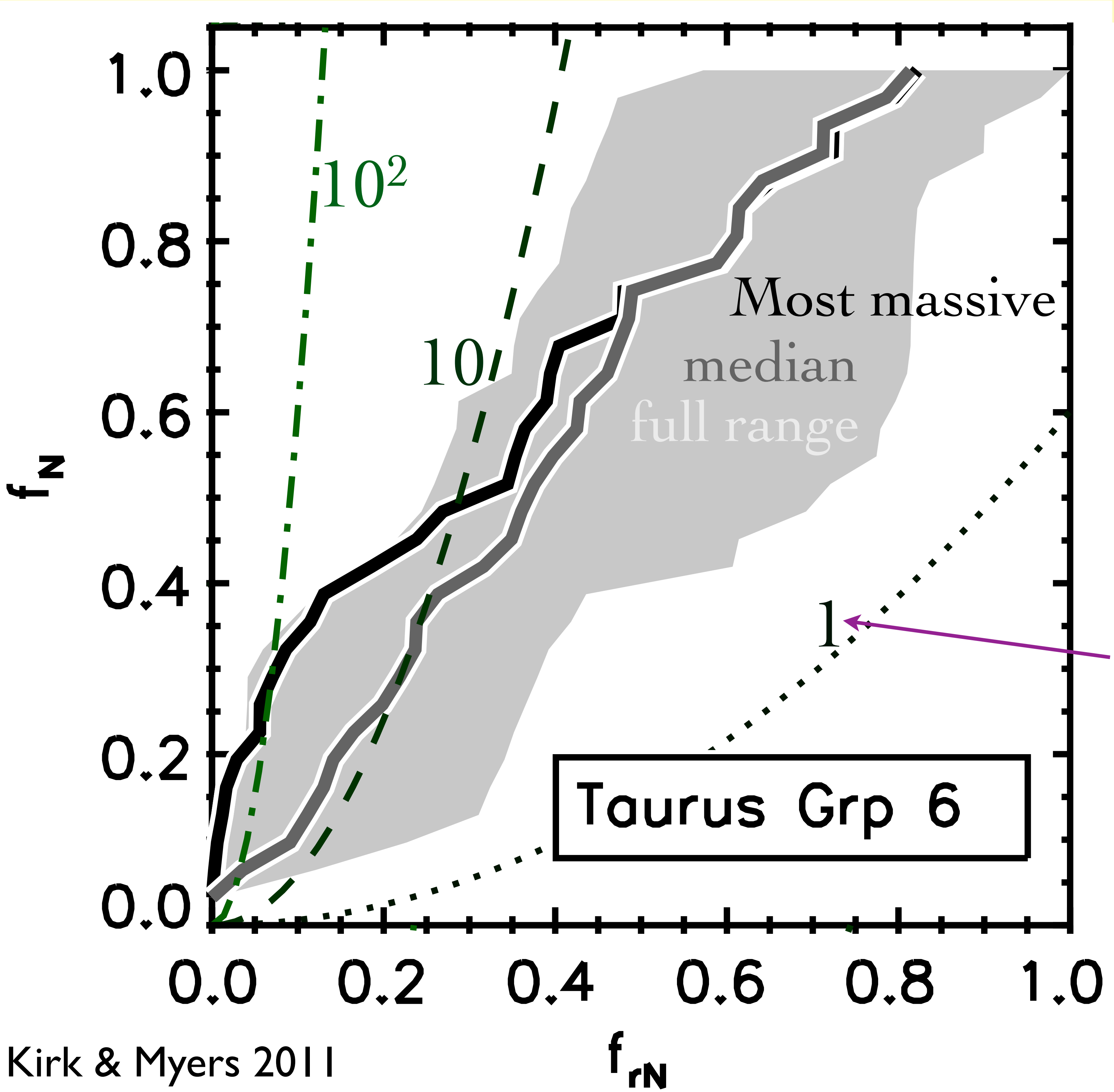
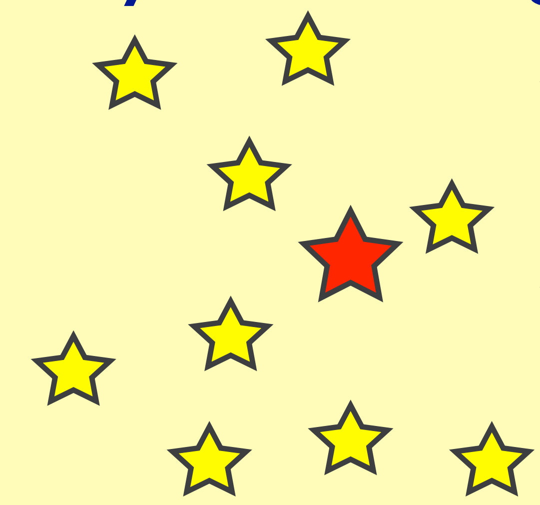



Kirk & Myers 2011

calculate surface density as a function of radius for every star in a group



surface density in #/pc$^2$

Surface density tends to be higher than typical around the most massive group members

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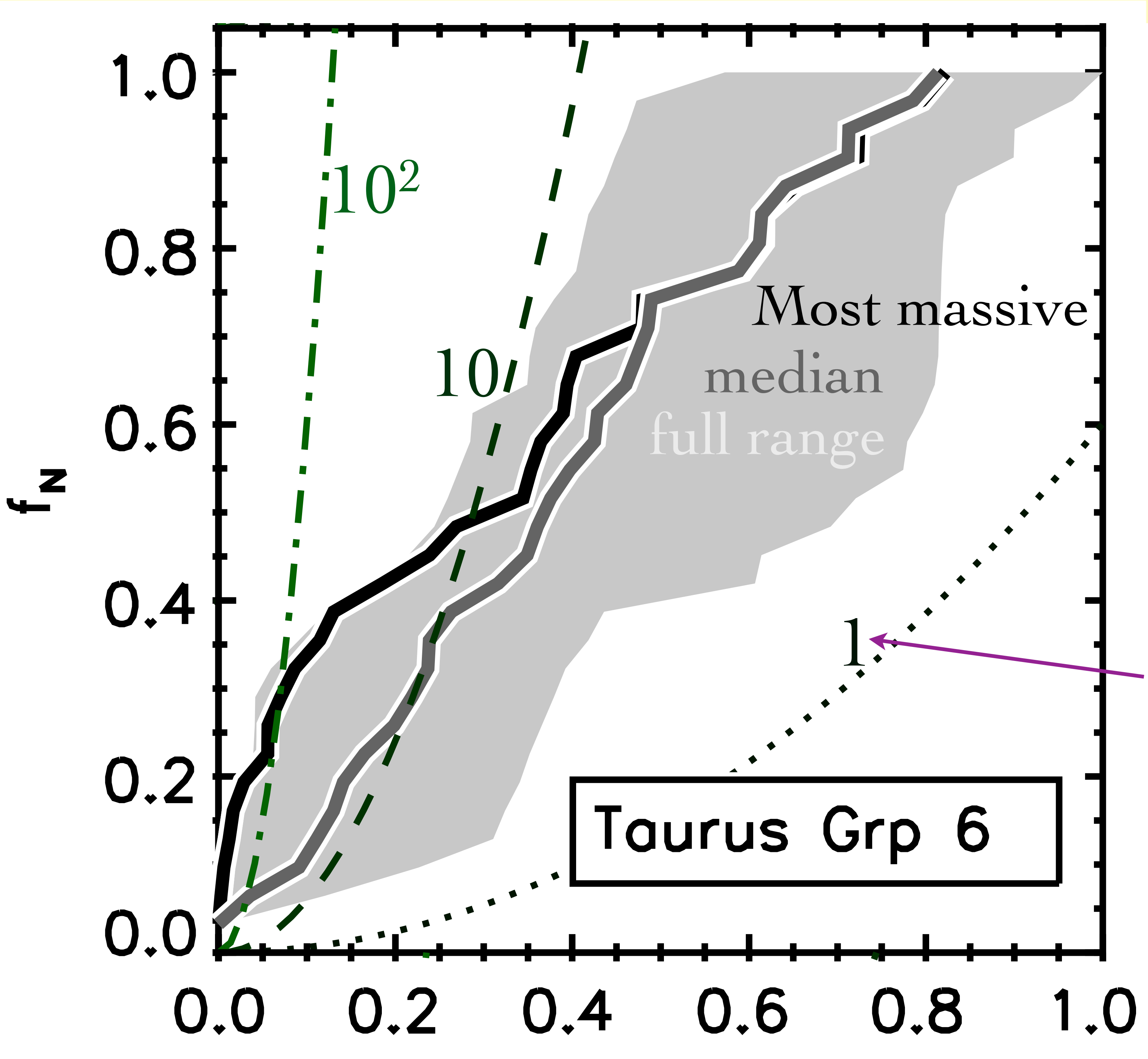


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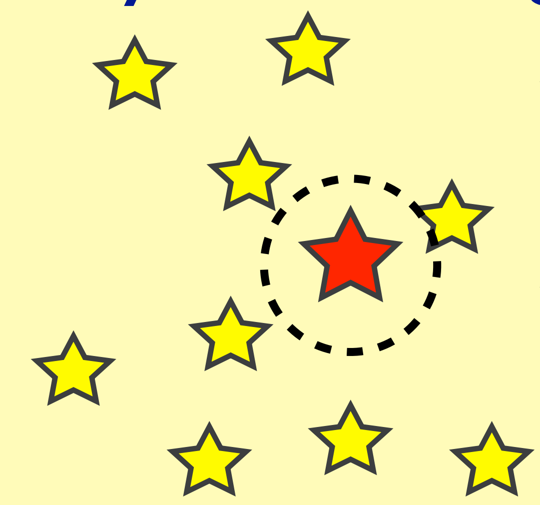

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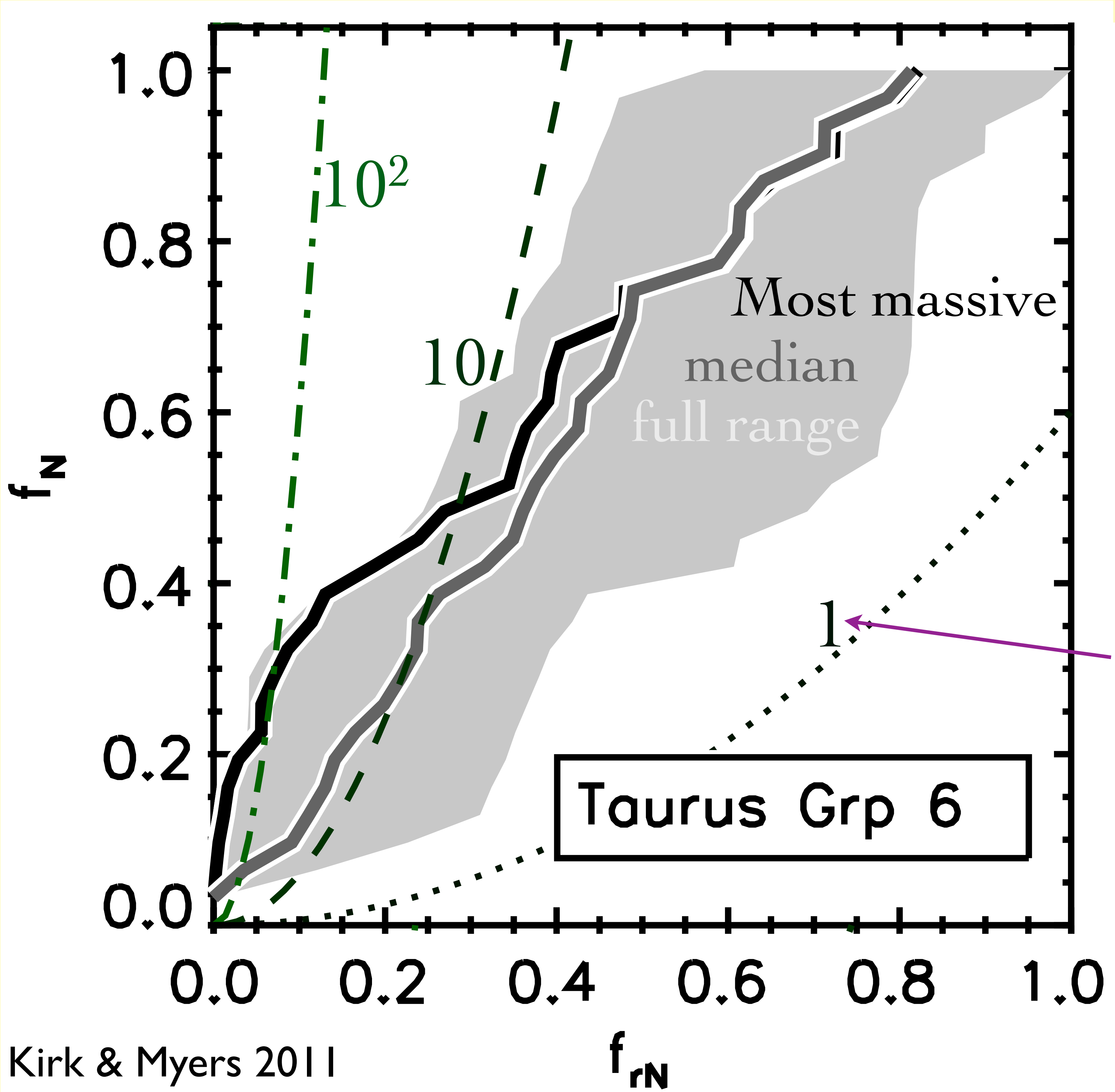
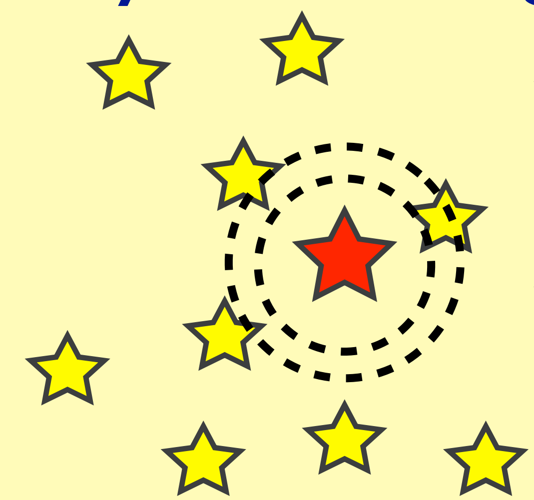



calculate surface density as a function of radius for every star in a group



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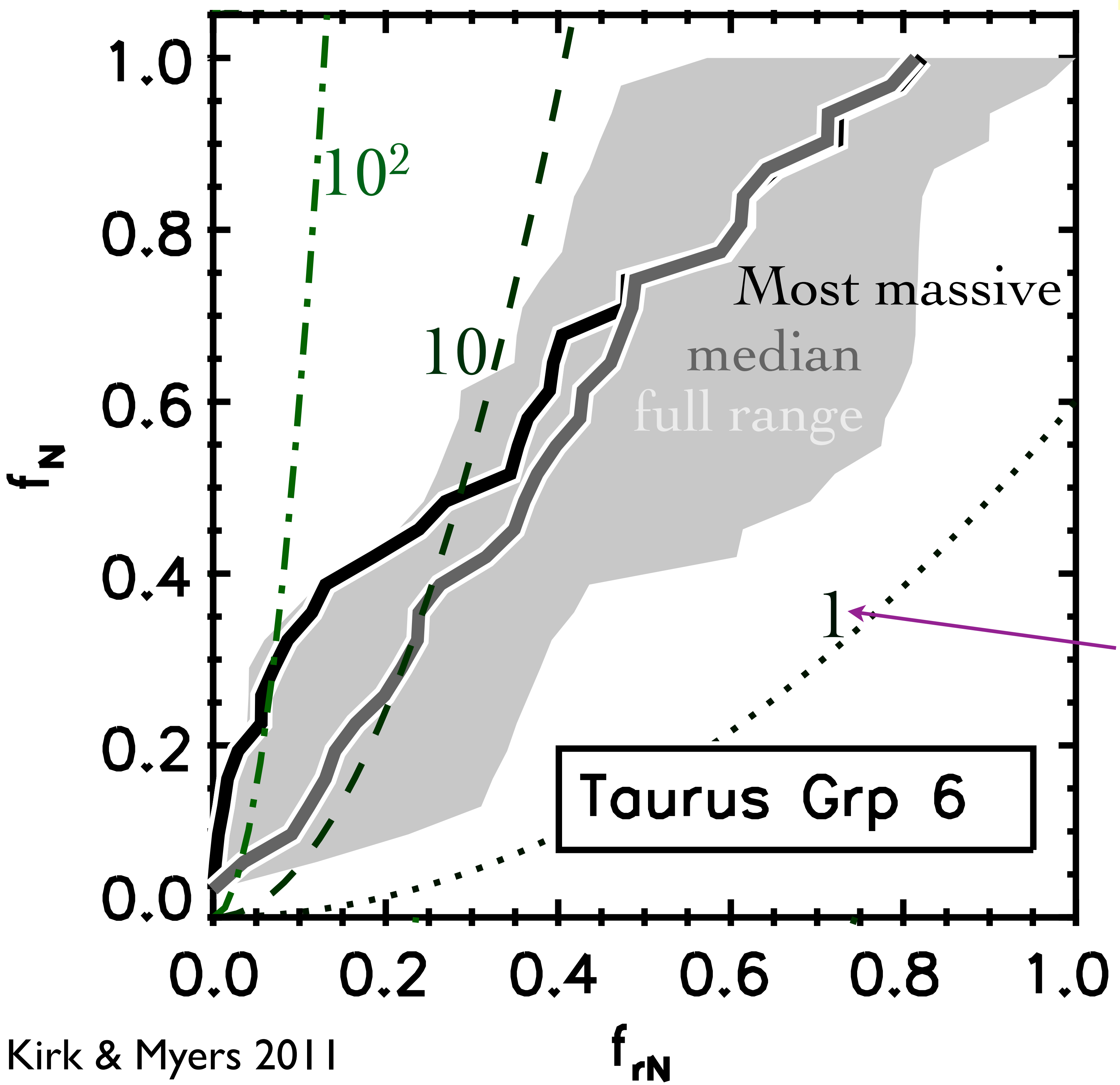


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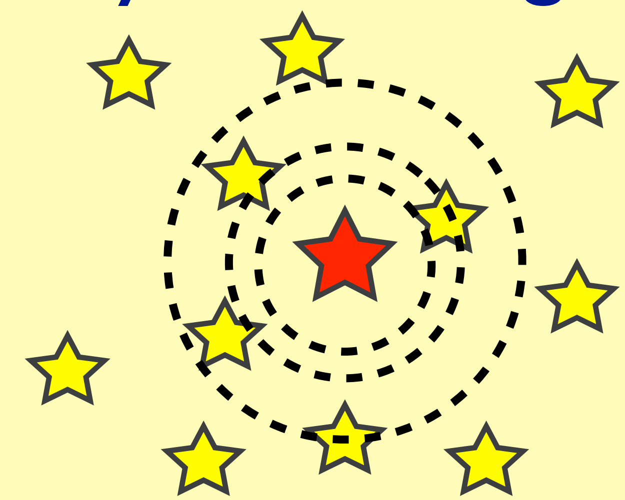

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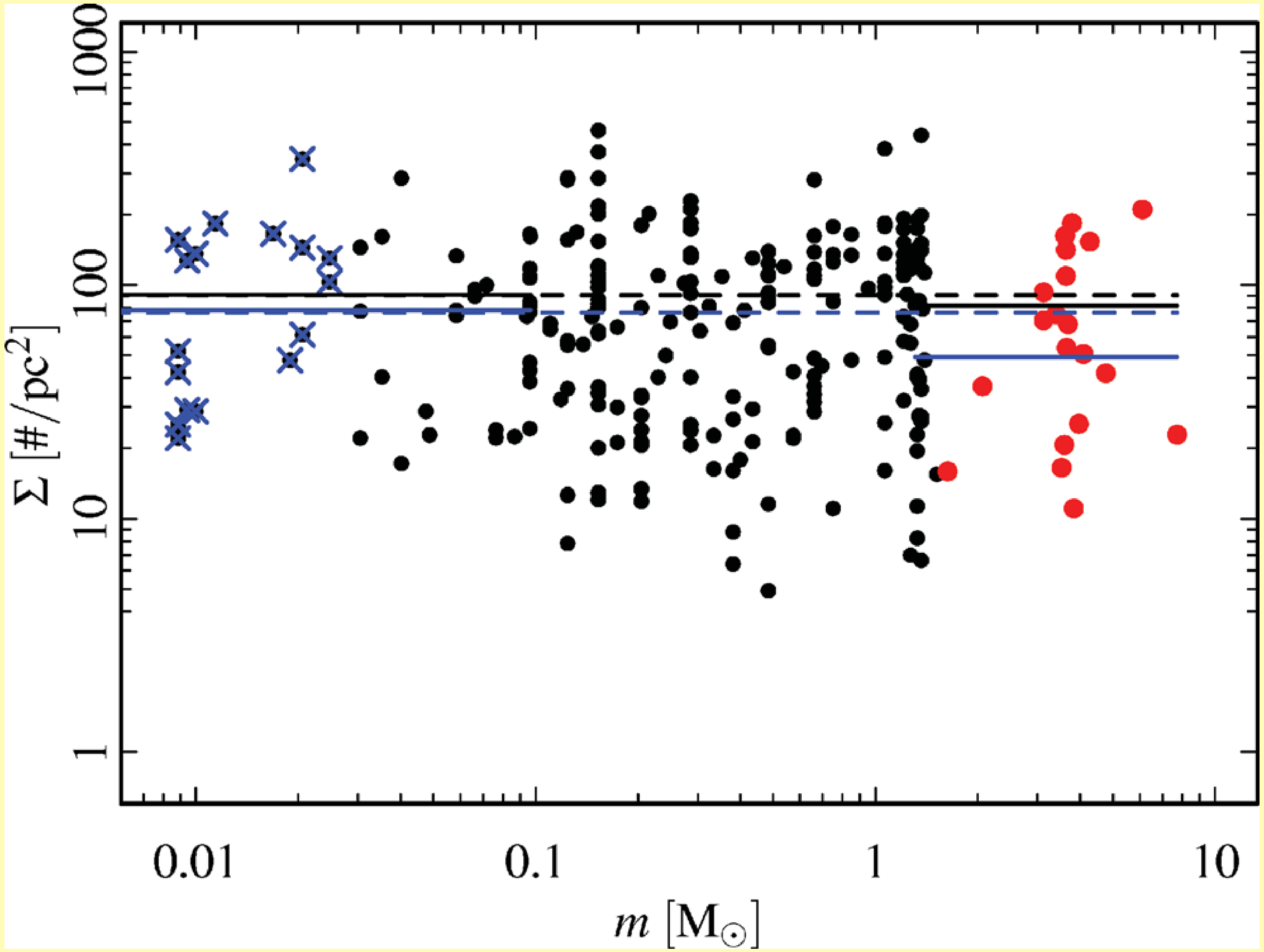
# Aside: alternate m-Σ



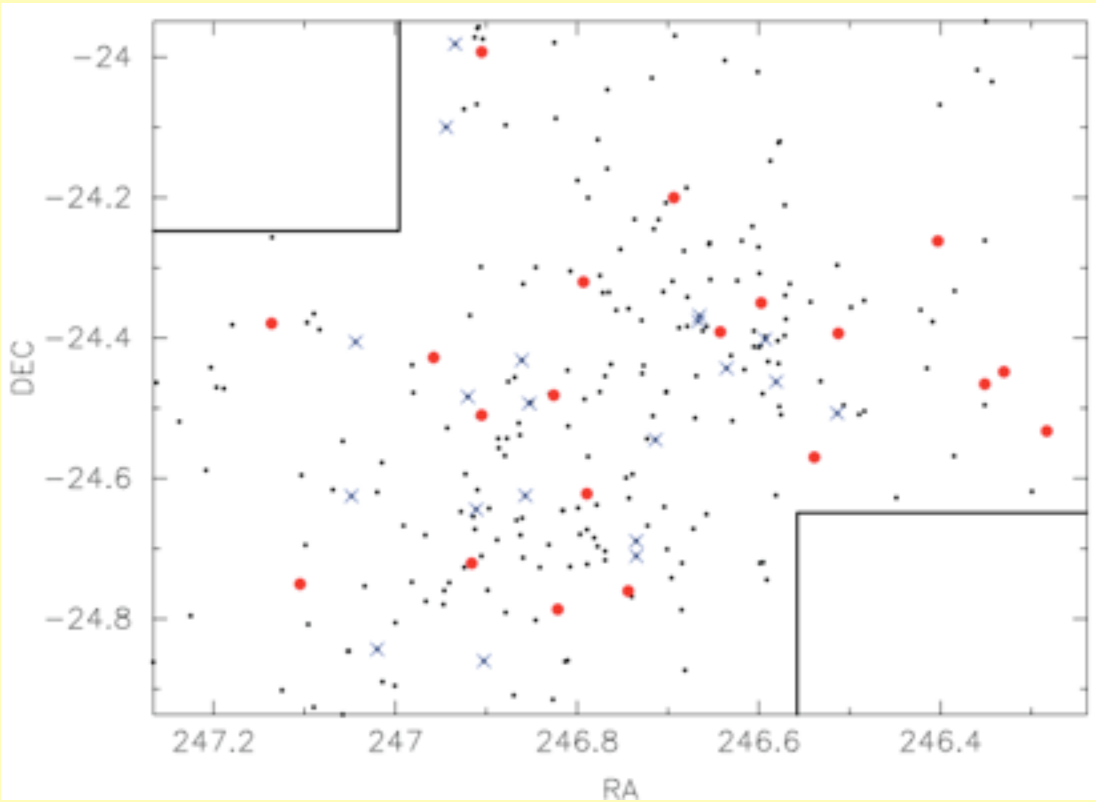

Parker, Maschberger, & Alves de Oliviera 2012

1) Calculate single surface density for each star (radius to enclose 10 nearest neighbours).
2) Compare mean surface density for different mass regimes.

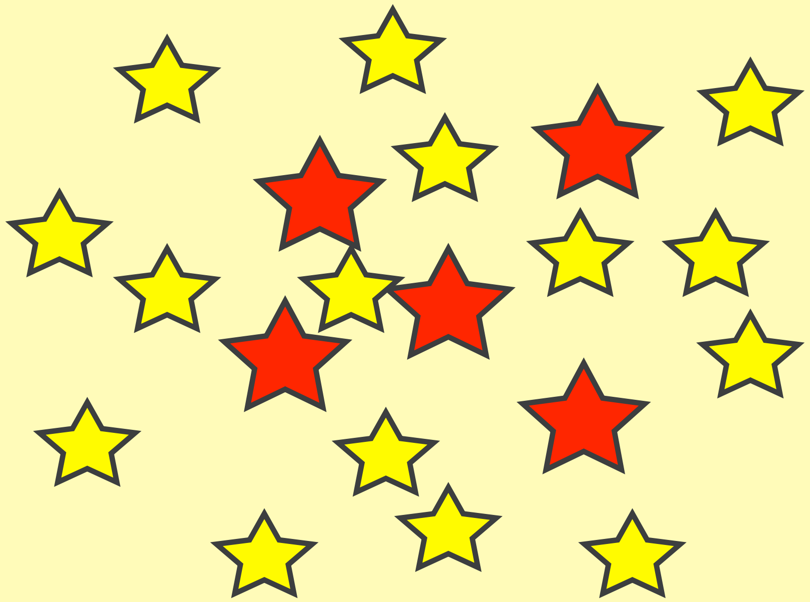
No significant difference found in Ophiuchus (more soon)

# Other Techniques

ΛMSR (mass seg. ratio; Allison et al 2009, Maschberger et al 2011) : measure branch lengths typical of N randomly-selected stars vs N most massive stars : ratio > 1 for mass segregation




Ophiuchus, Parker et al 2012



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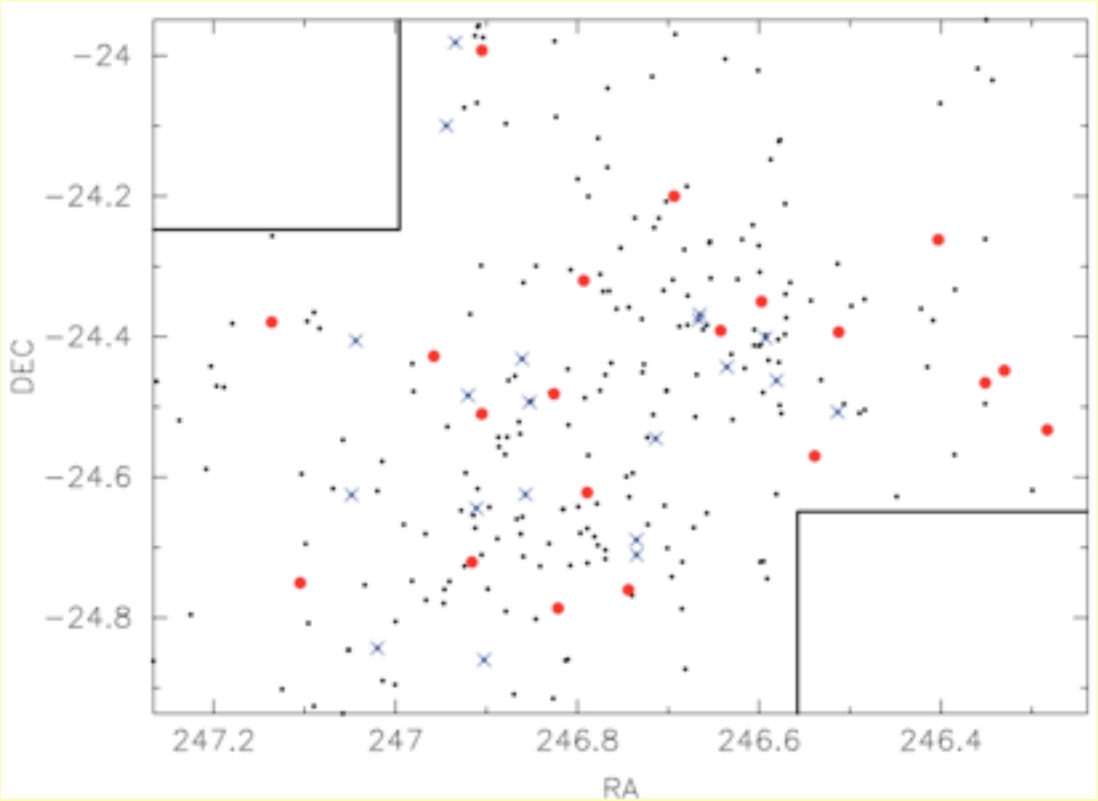


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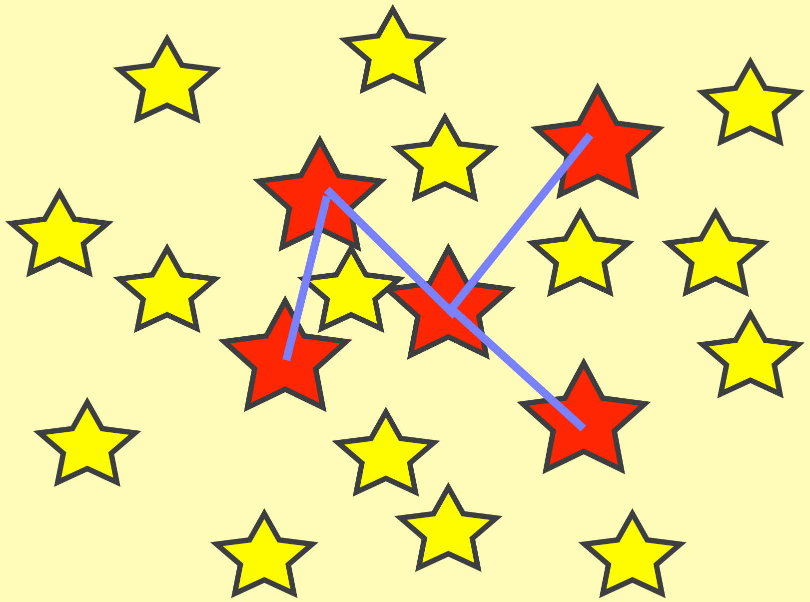

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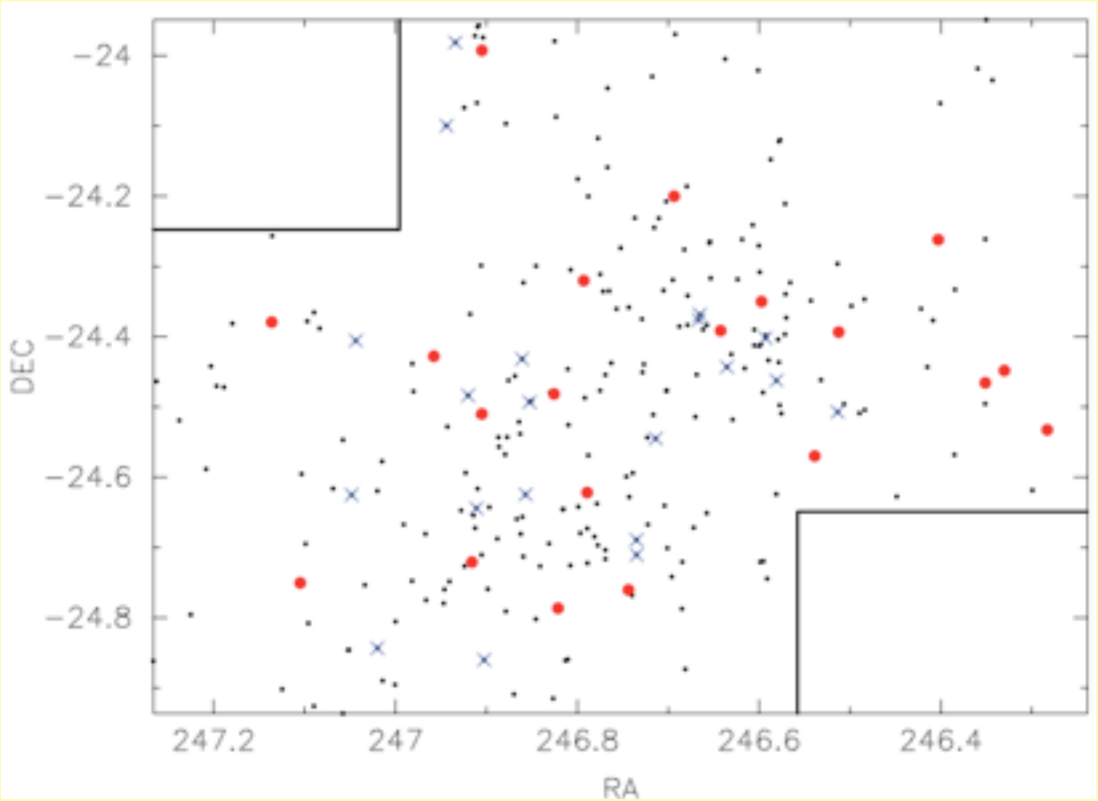


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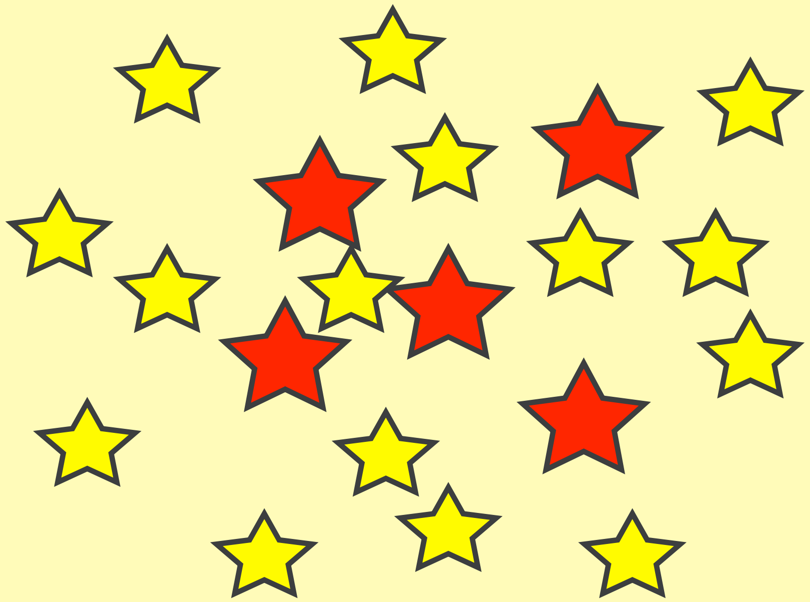

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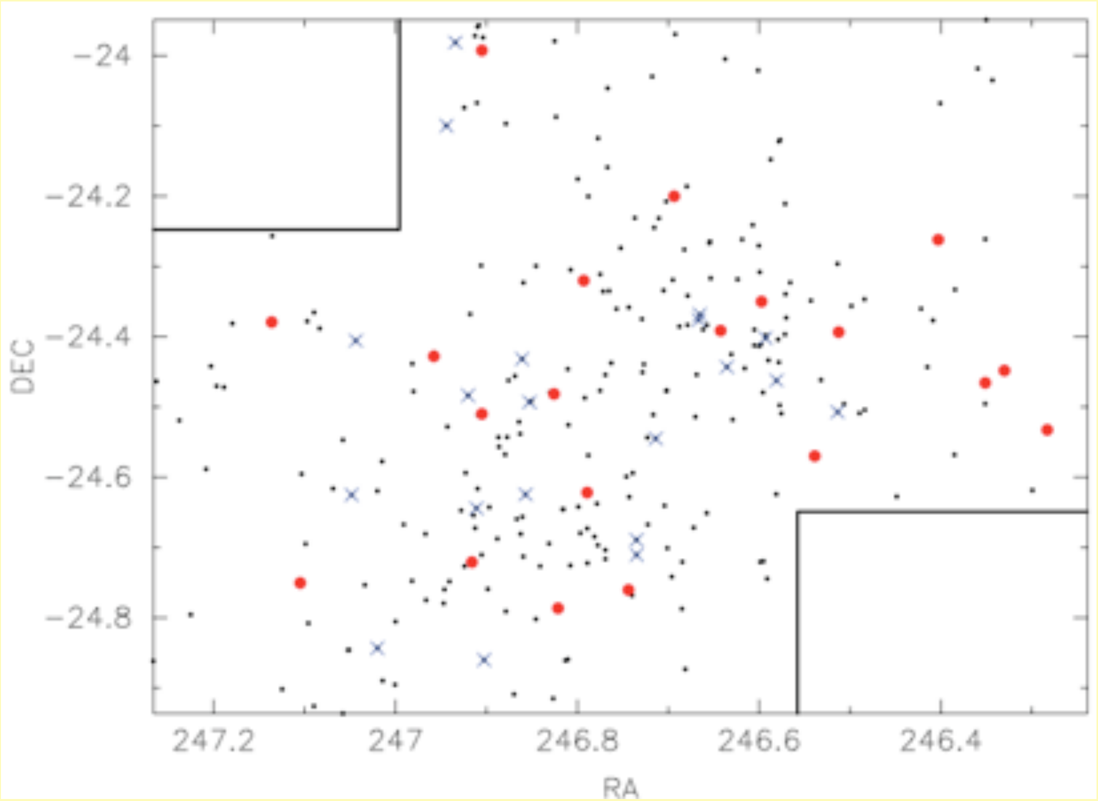


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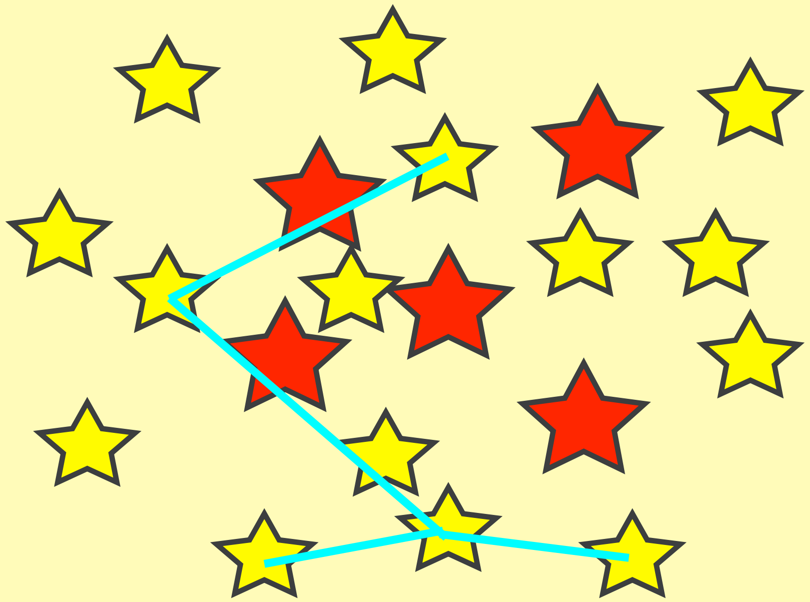

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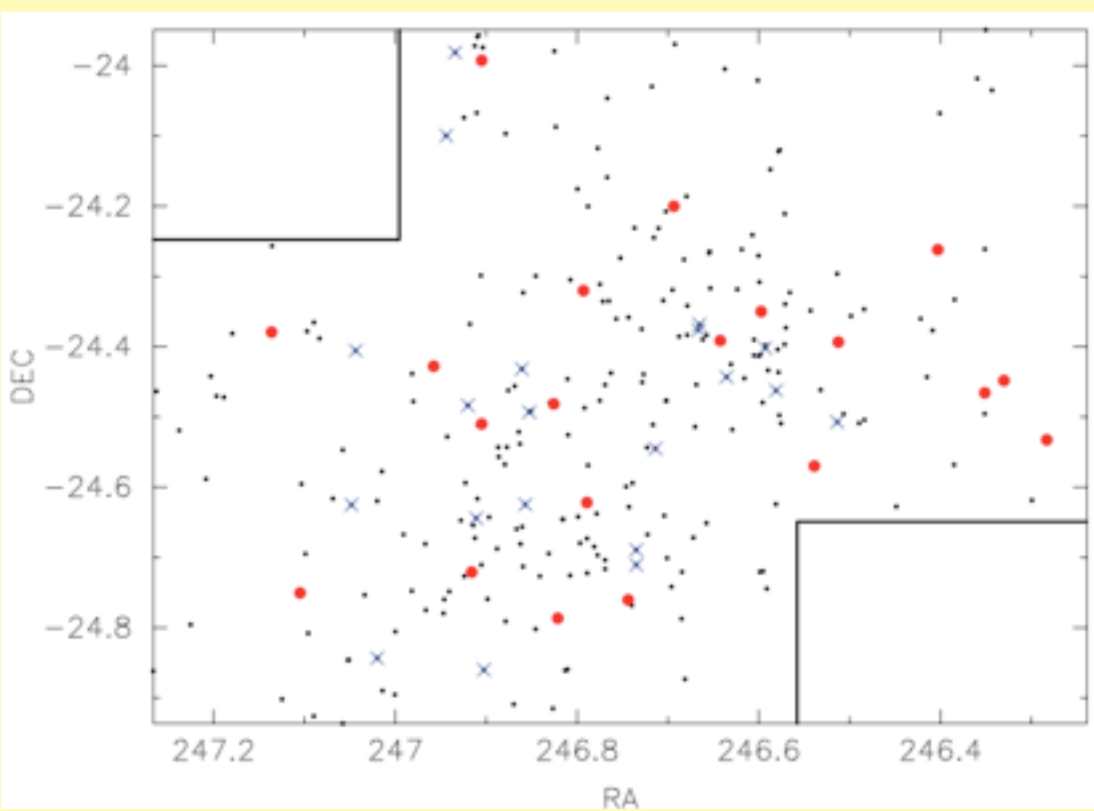
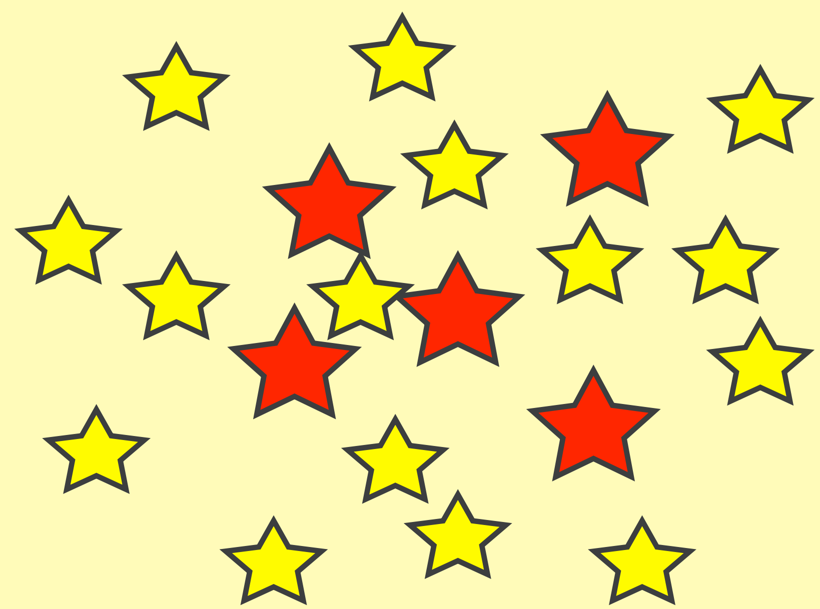



Ophiuchus, Parker et al 2012



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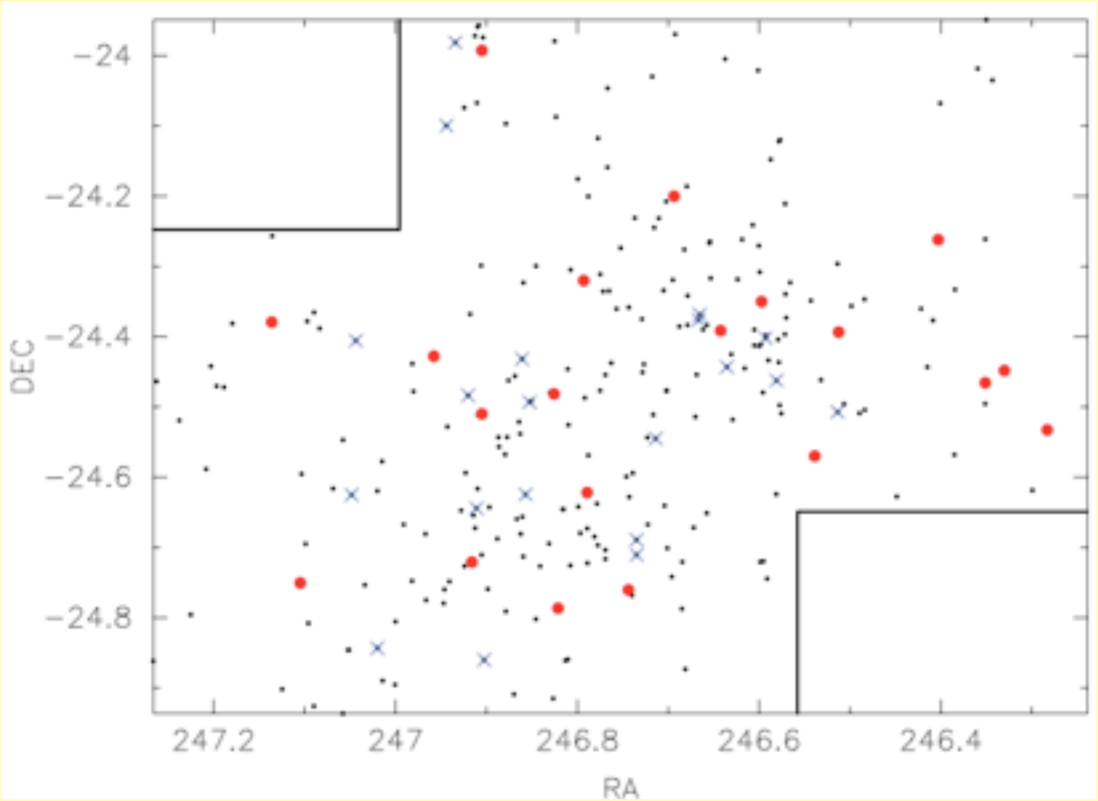
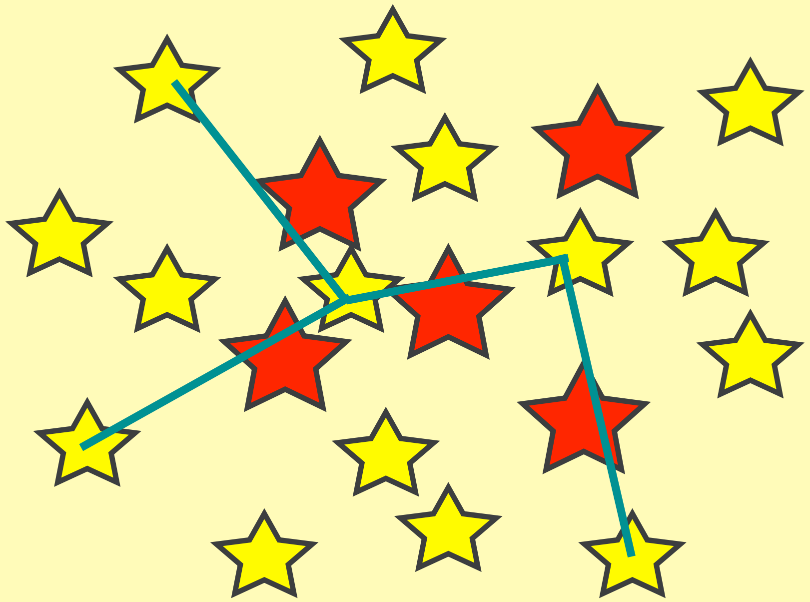



Ophiuchus, Parker et al 2012



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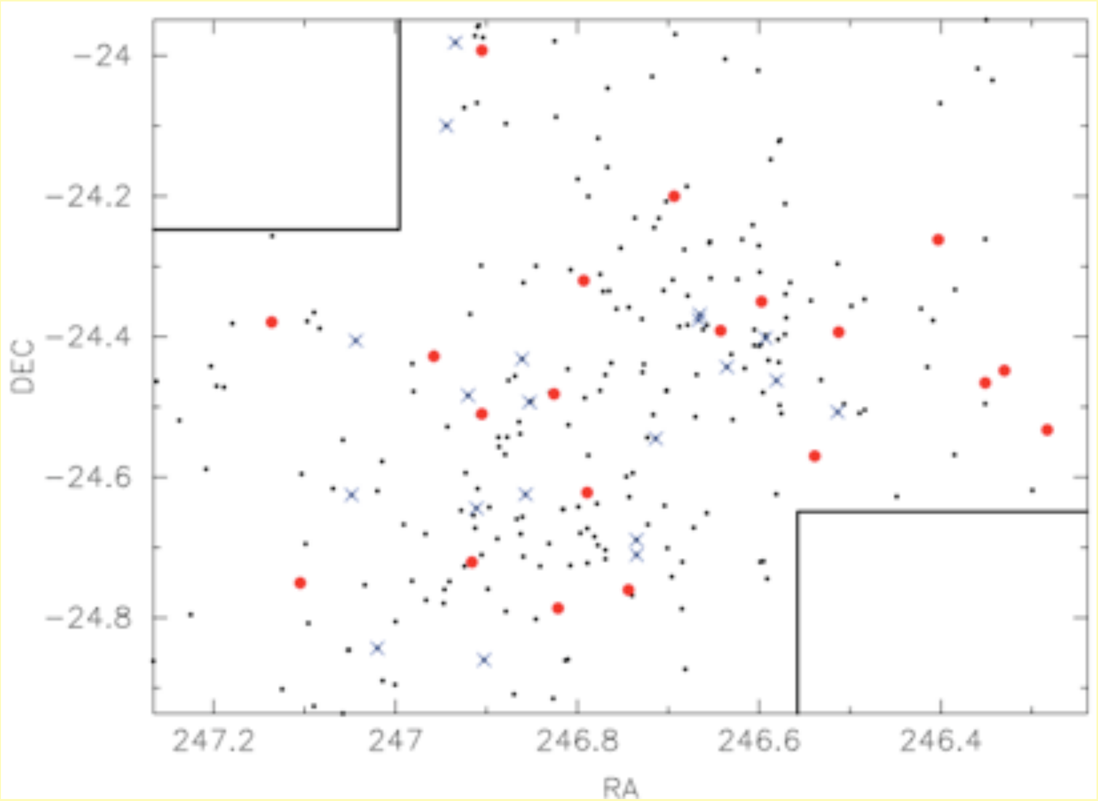
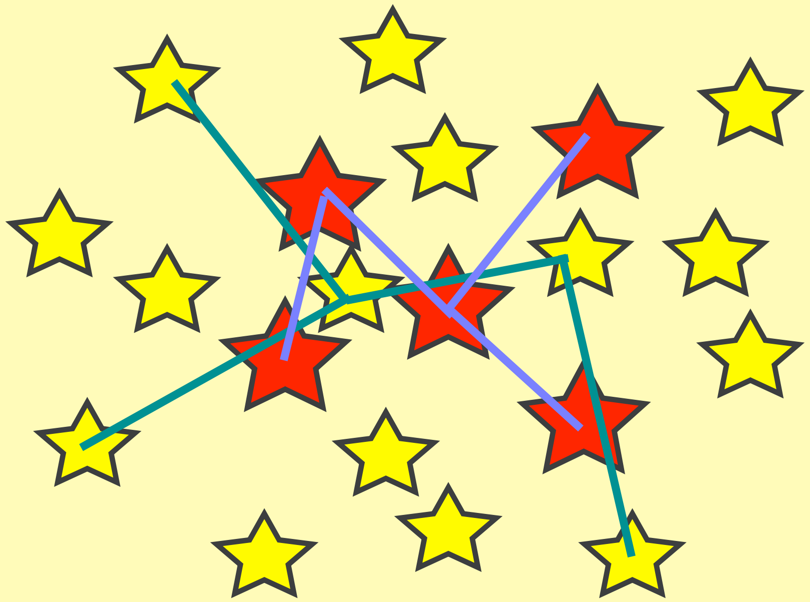



Ophiuchus, Parker et al 2012



# Other Cluster Techniques

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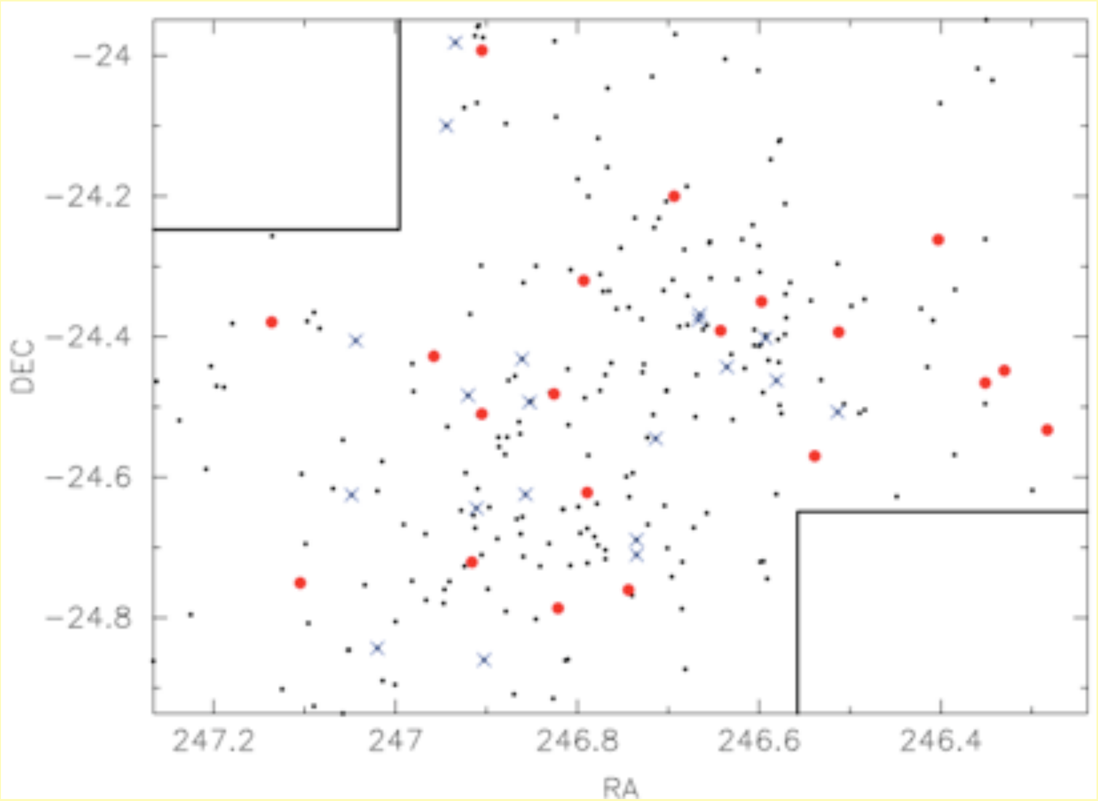


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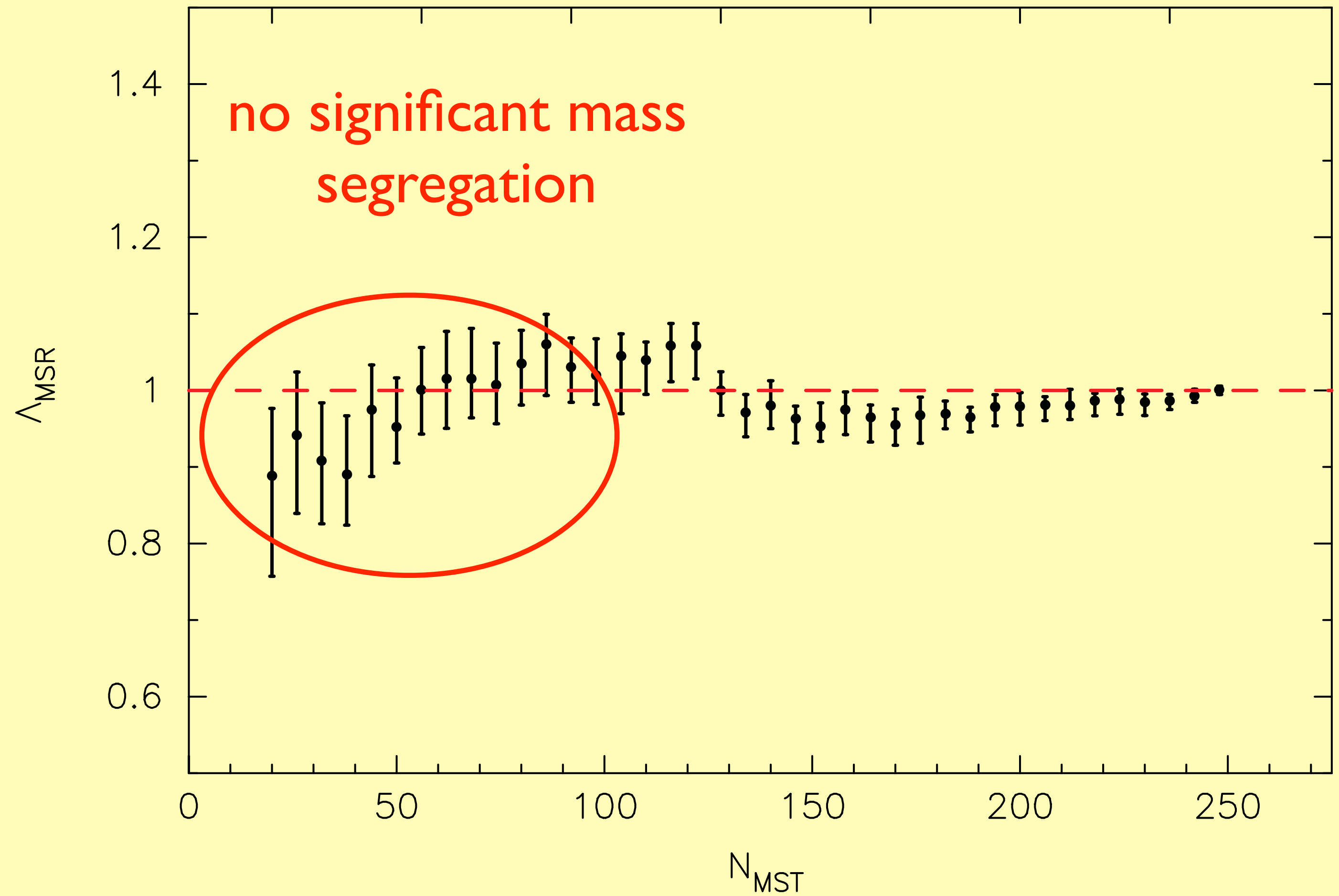
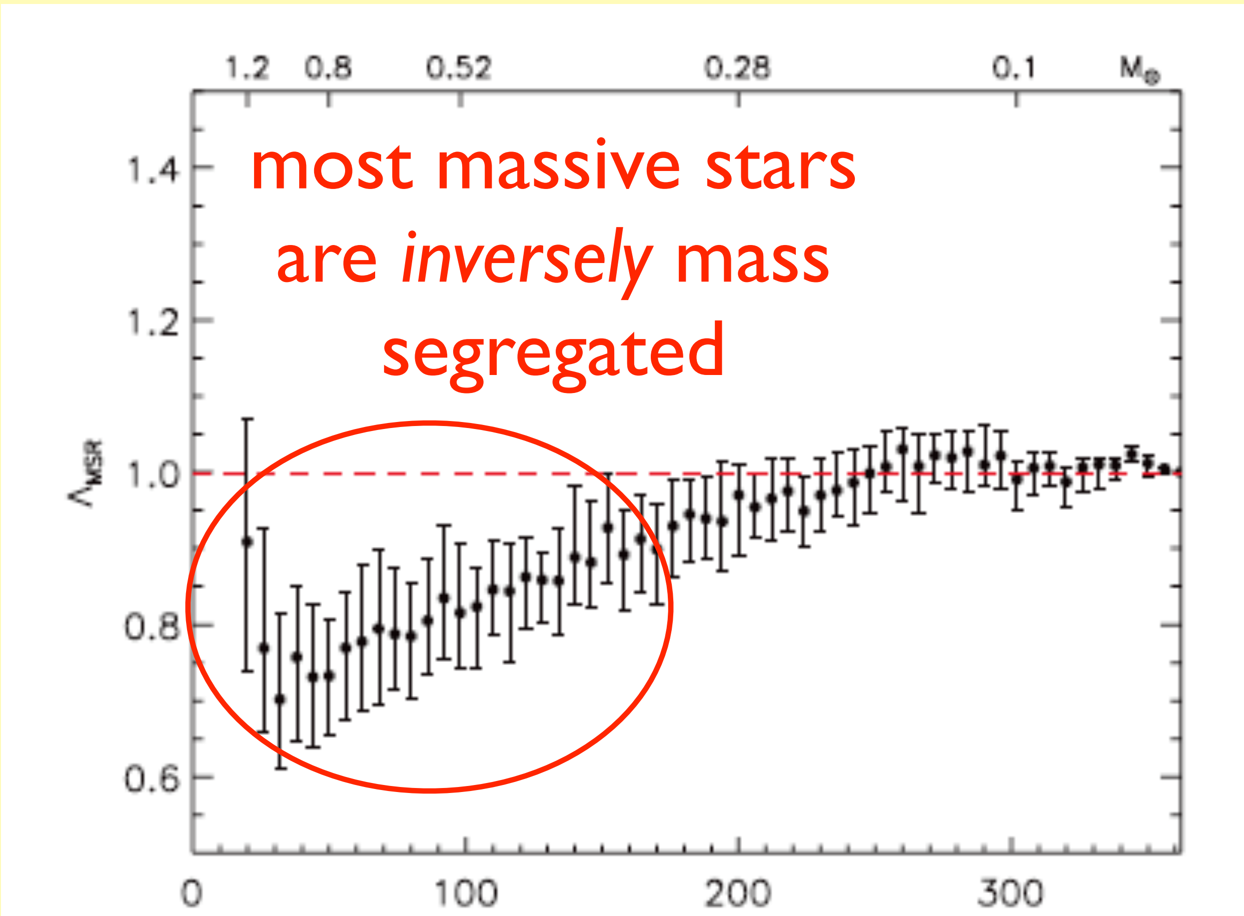
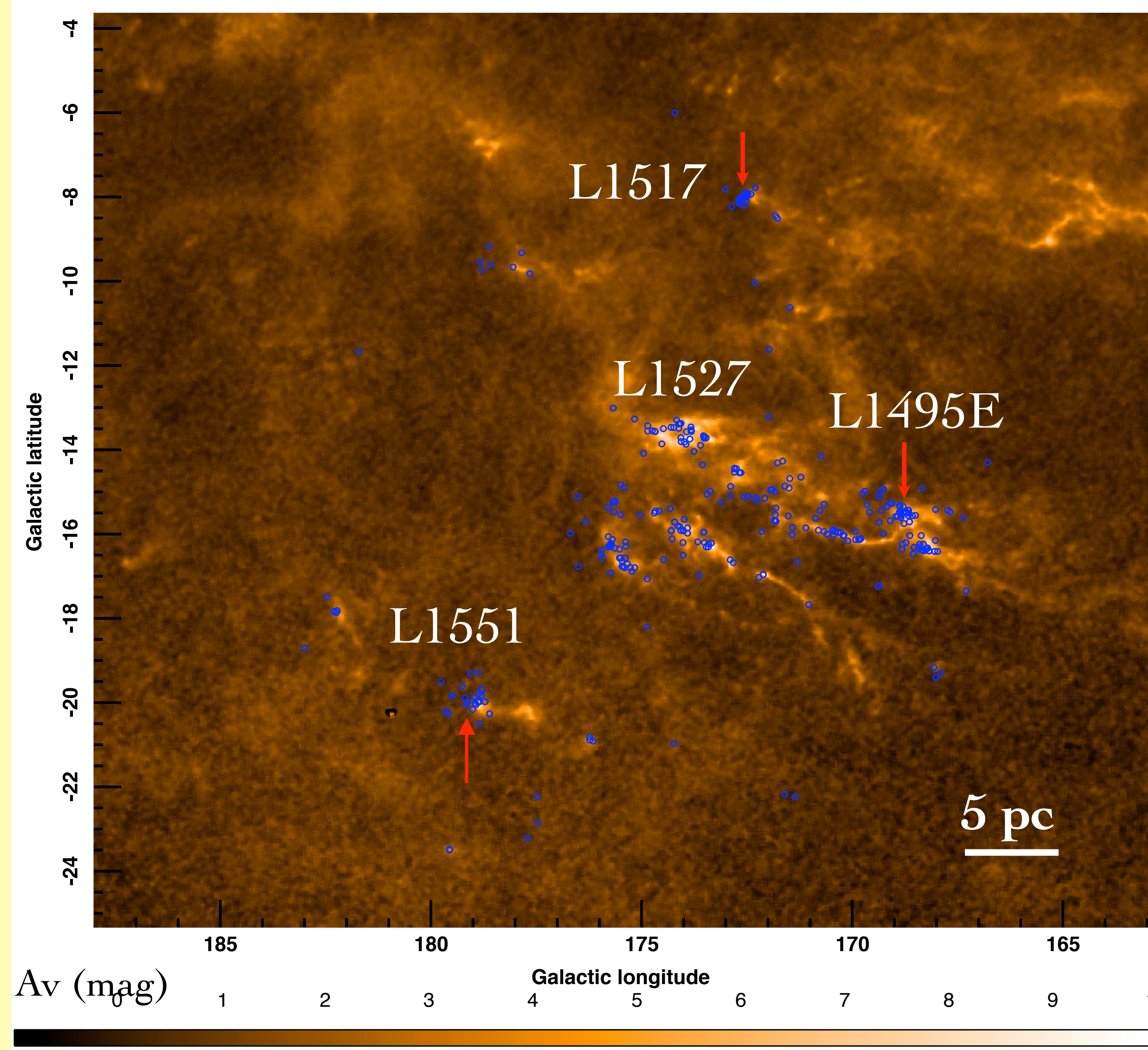


# Taurus Comparison



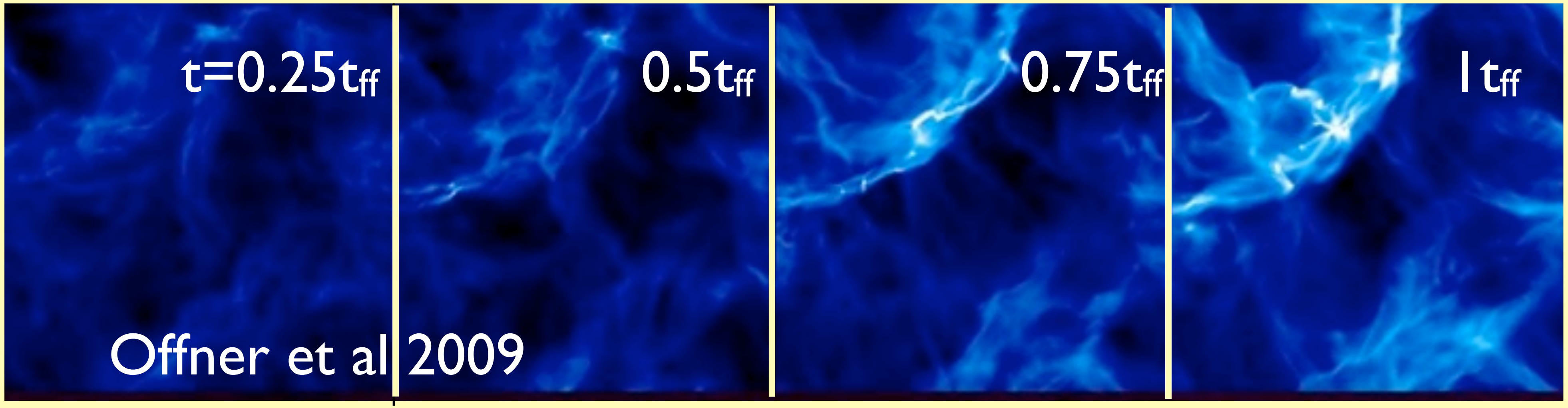

Parker et al 2011




- Why the difference?
  Size scales examined

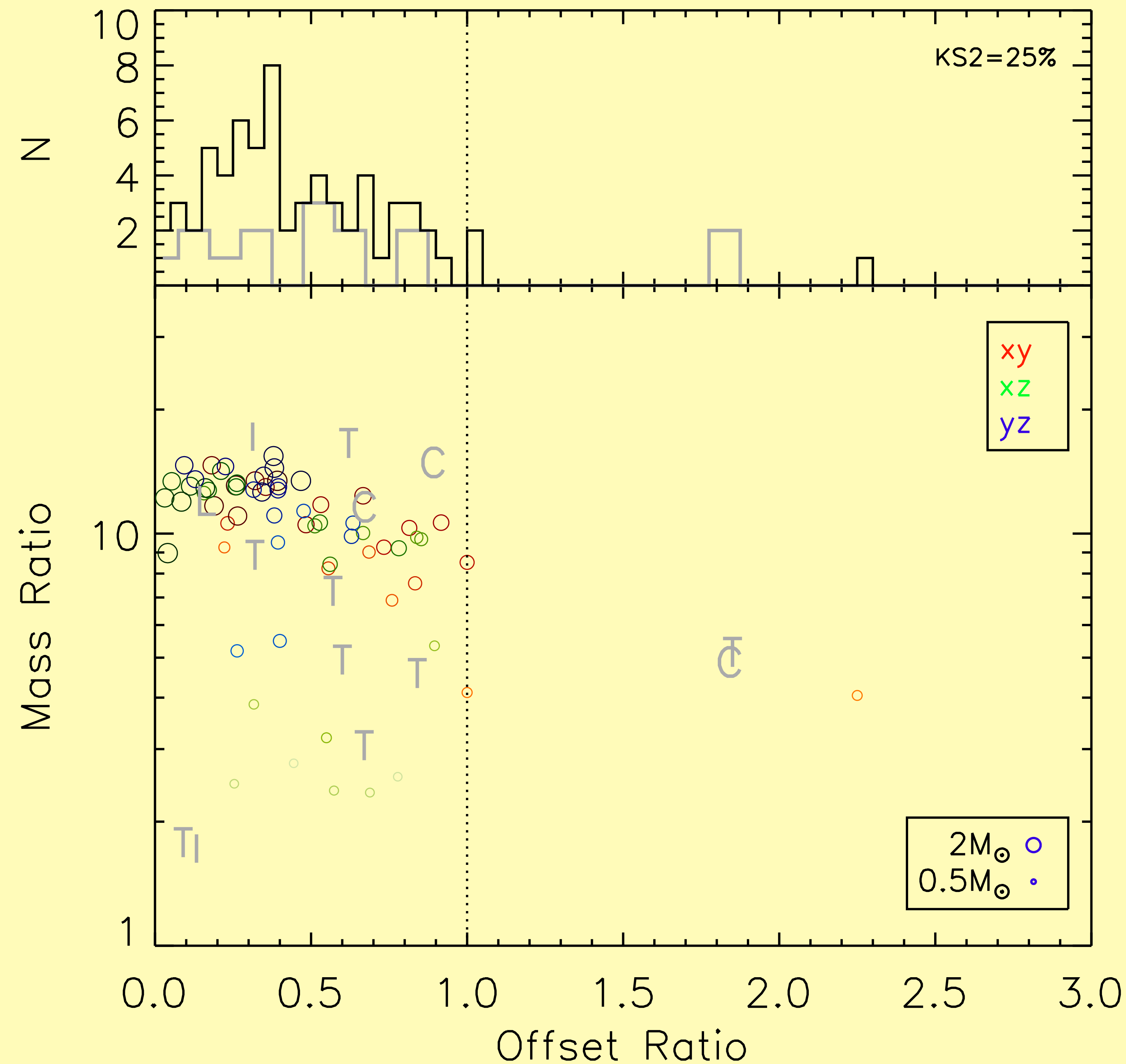
# Simulation Comparison

- allows examination in 3D, time evolution, effect of initial conditions, dynamics
- Our setup: periodic box, AMR, gravity + turbulence, different initial conditions (Mach, T, turbulent driving scale) - fiducial: 2pc box, 600Msol, 10K, large-scale driving
- use same MST method as Kirk & Myers 2011, with 3 viewing angles, account for observational limits (mass & spatial resolution)



# Simulation Results

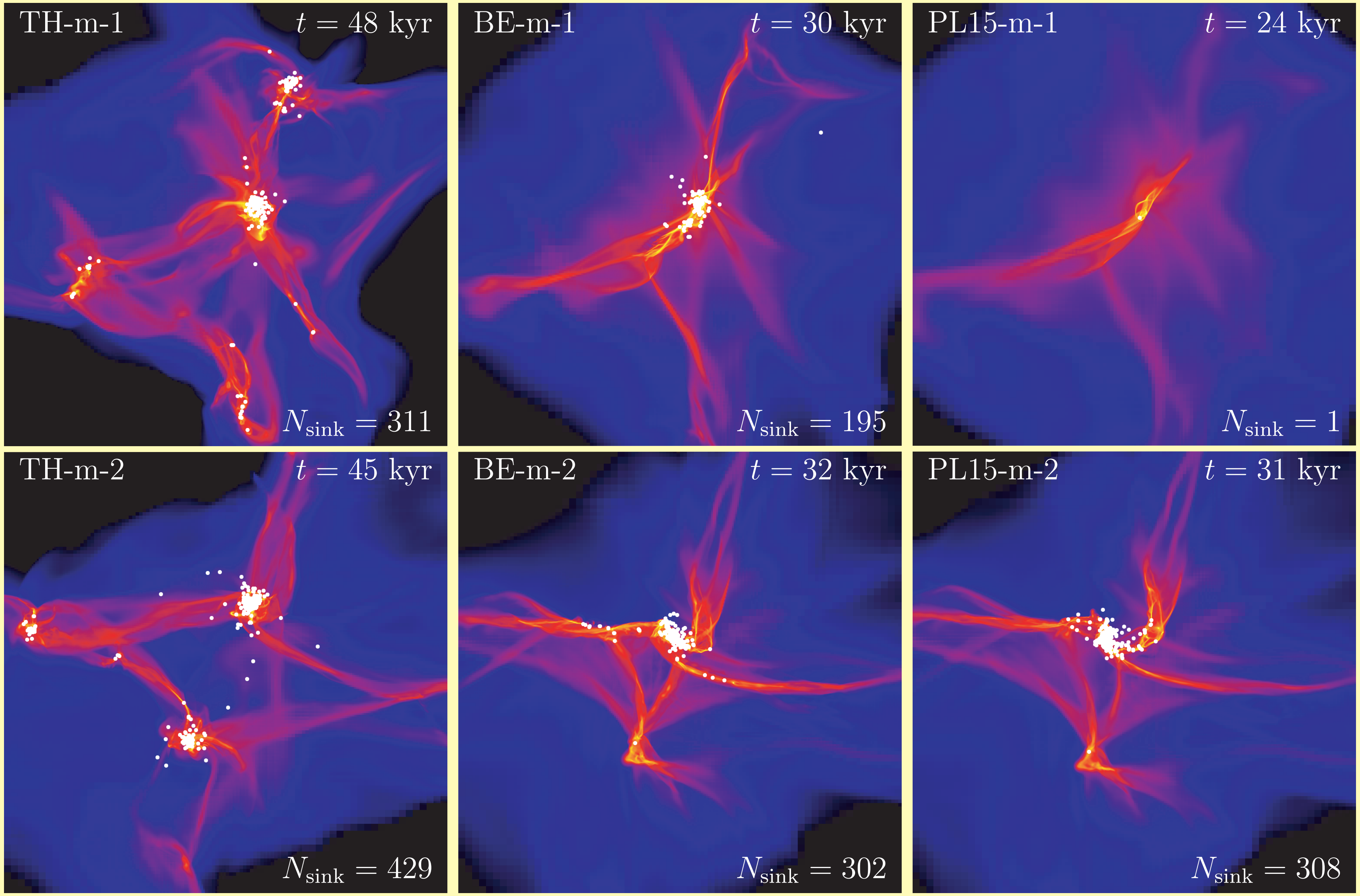
- fiducial simulation: similar distribution of offset ratios to observations
- other simulations: no clusters with same KM11 criterion, but relaxing those gives similar trend
- no time evolution: as soon as cluster appears, has central most massive
- little time for dynamics to cause this




Kirk, Offner, & Redmond 2014

# Simulation Side Note

- Girichidis et al 2011: the mass & spatial distribution of stars is strongly influenced by initial conditions (cloud density profile & turbulence)

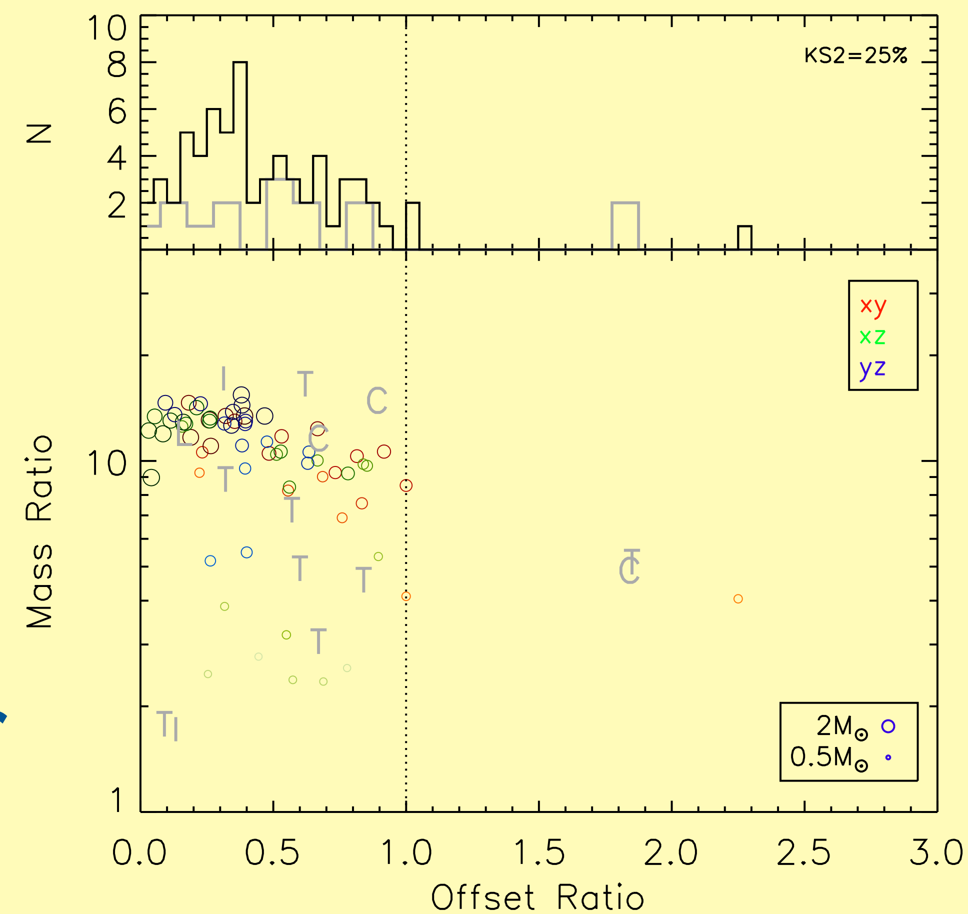



Difference between unif density and Bonnor Ebert or power law (left to right); initial turbulent seed also (top vs bottom)

Girichidis et al 2011

# Conclusions

- Young sparse systems offer a promising avenue to explore in clustering studies
- Observed systems exhibit centrally located most massive member in higher surface density environment
- Simulations in same regime show similar result, as early as can be analyzed, for all tested parameter space




simulated vs observed small groups; Kirk et al 2014

## What does the future hold?

- observe: younger systems (Herschel, JCMT), motions (Gaia)
- simulate: explore a wider parameter space!

# Thank You!