Properties of hierarchically forming star clusters

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with
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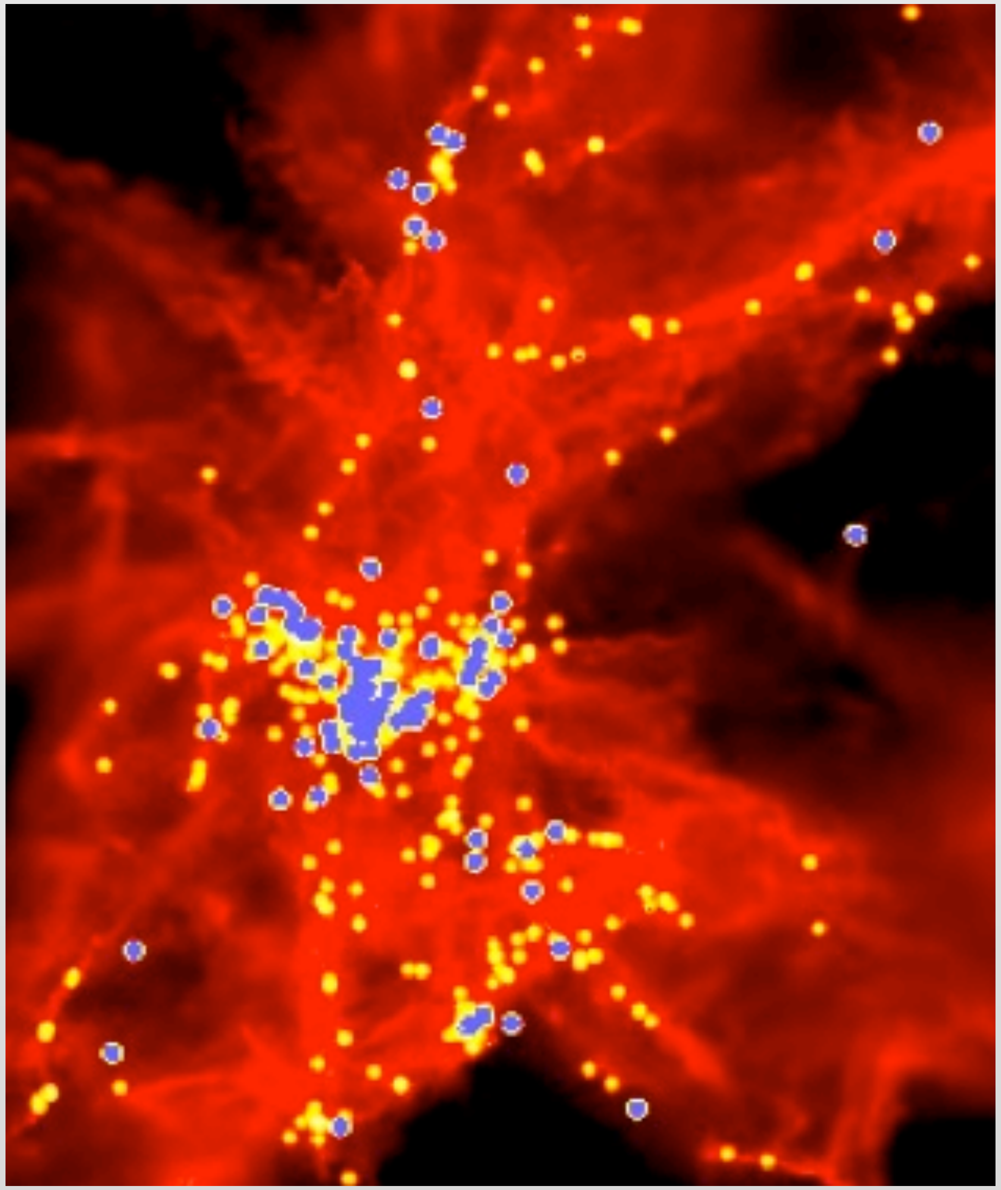
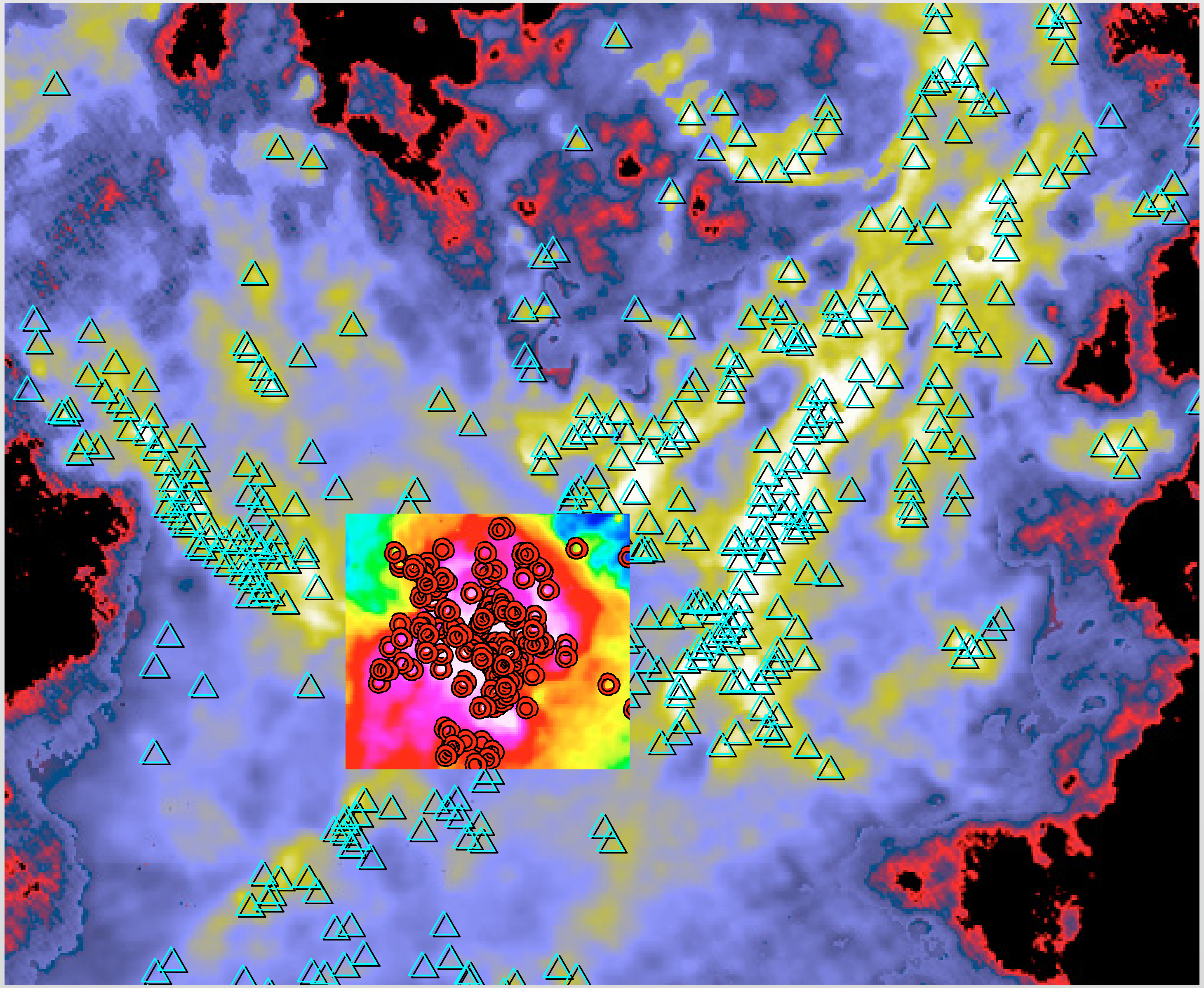
Simulation and Observation

SPH:
10 000 $M_\odot$ gas
2300 “stars” at end



Bonnell et al. 2008

Aquila (Herschel):
10 000 $M_\odot$ gas
100(?) stars+210 protostars + 500 cores



Könyves et al. 2010, Bontemps et al. 2010

Outline

Determine observationally detectable properties in a star formation simulation:

- Structure and appearance
- Mass segregation
- Mass functions

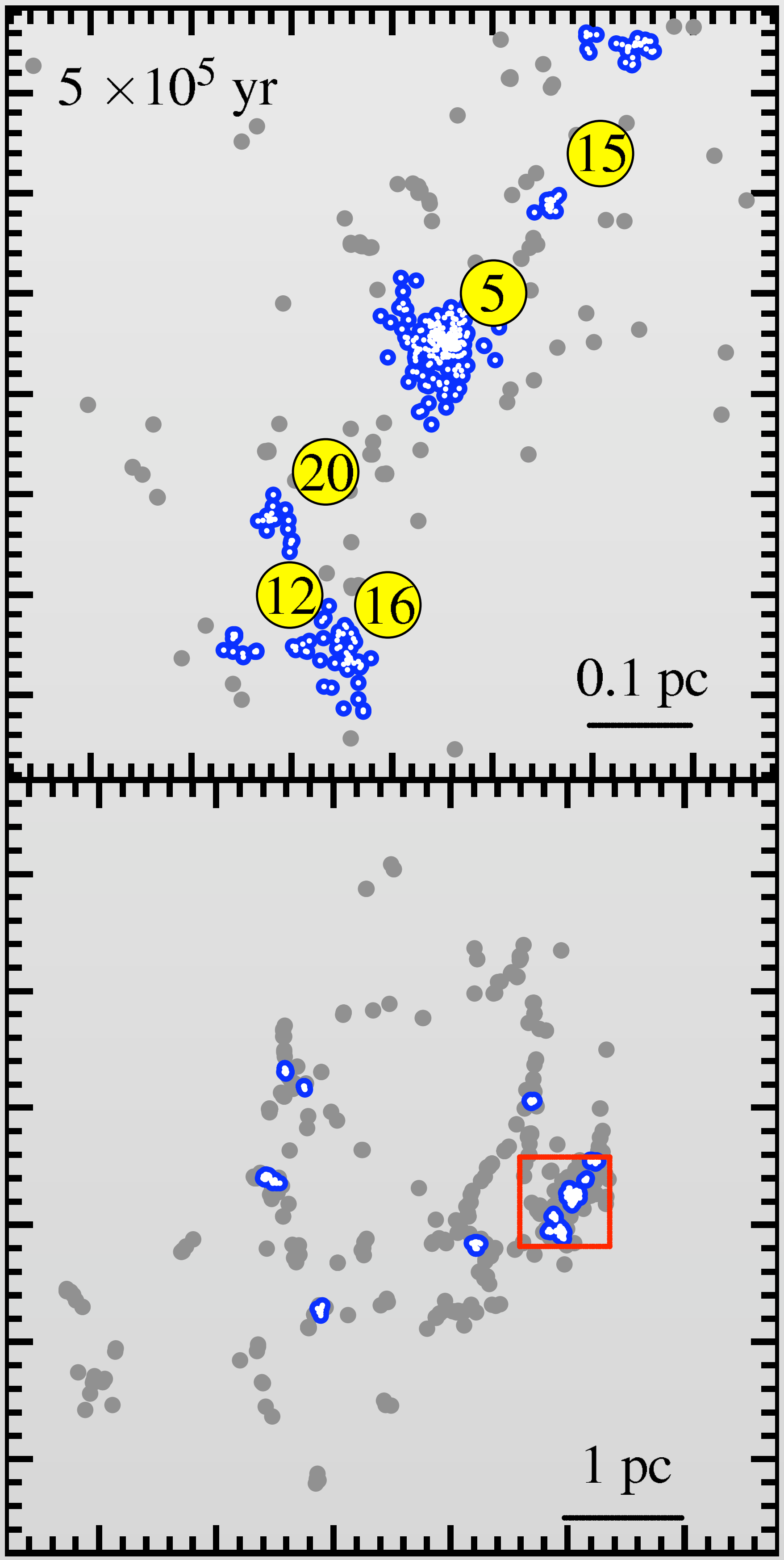
SPH calculations of Bonnell et al (2003, 2008)

1000 $\mathrm{M}_{\odot}$ gas, 550 sink particles, 1 final cluster, 5 subclusters
10000 $\mathrm{M}_{\odot}$ gas, 2300 sink particles, 3-5 clusters, 20 subclusters
Simulation time 0.5 Myr

Subcluster identification

Use the minimum spanning tree to find subclusters

Several clusters are formed by merging subclusters in the filaments.

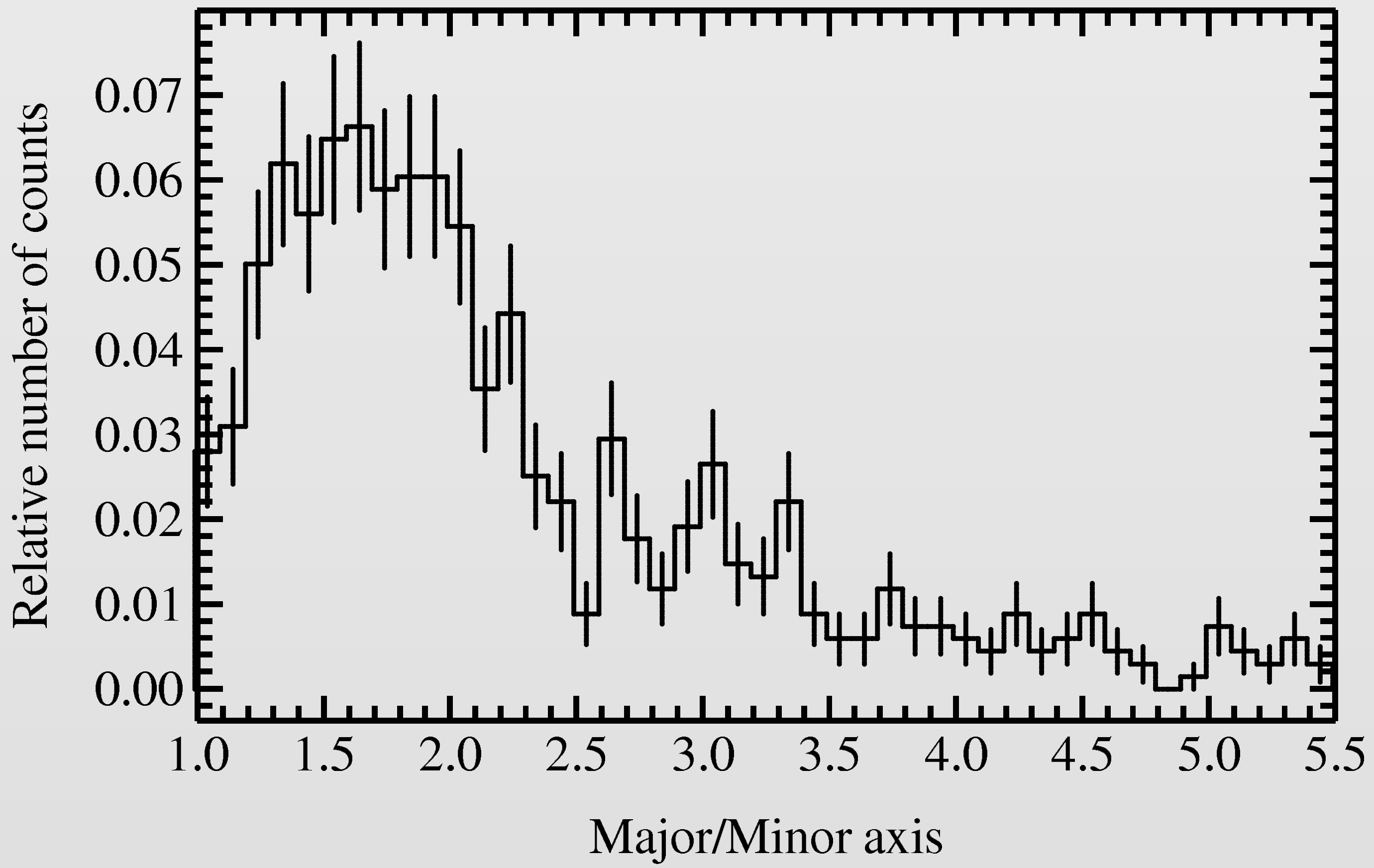


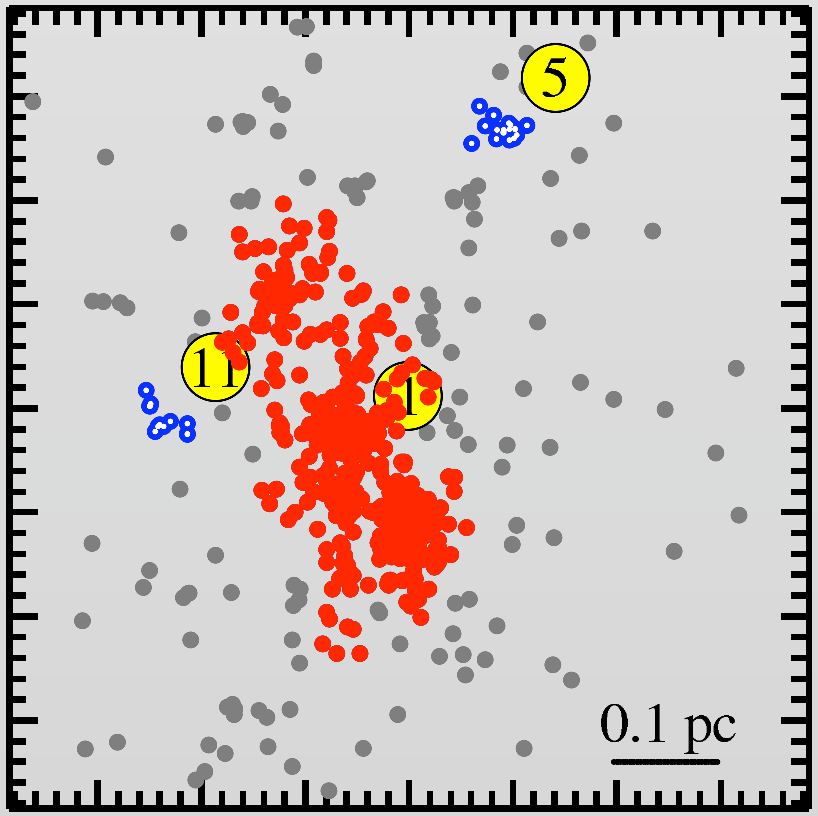
Subcluster shapes

Derived from fitting a 2D Gaussian.

Most subclusters are most of the time roundish.

Elongated clusters appear during mergers.





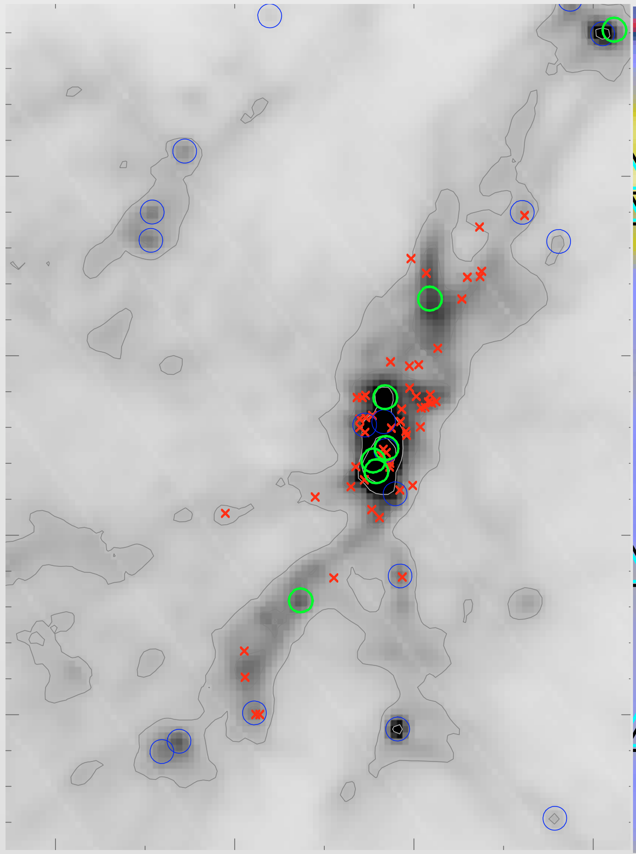
Where do new stars form?

Only 50-60% of stars form within a subcluster.

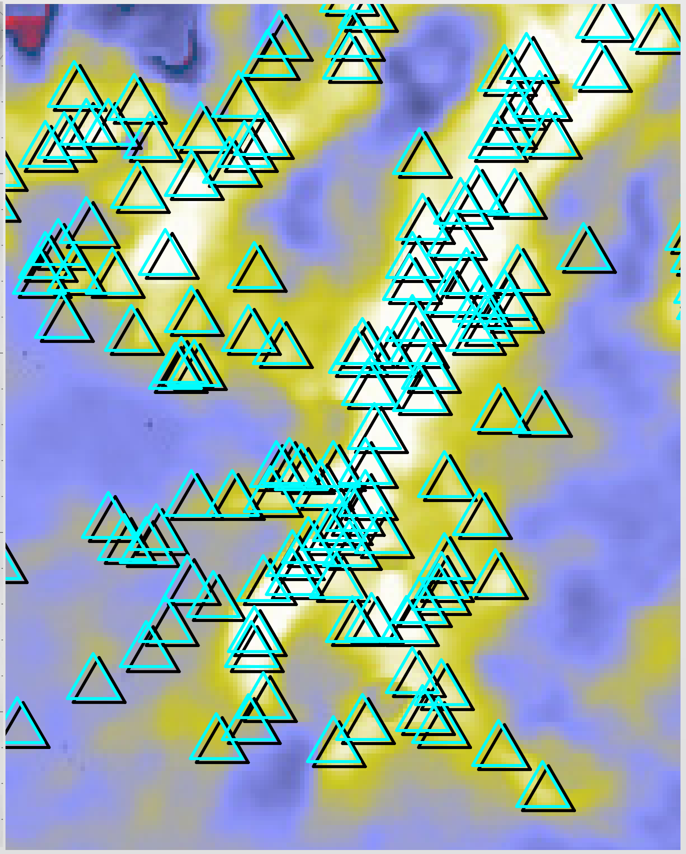
No central concentration of new stars.

Older stars (i.e. longer accreting, i.e. more massive) are at the centres of subclusters.

Perhaps observational evidence?



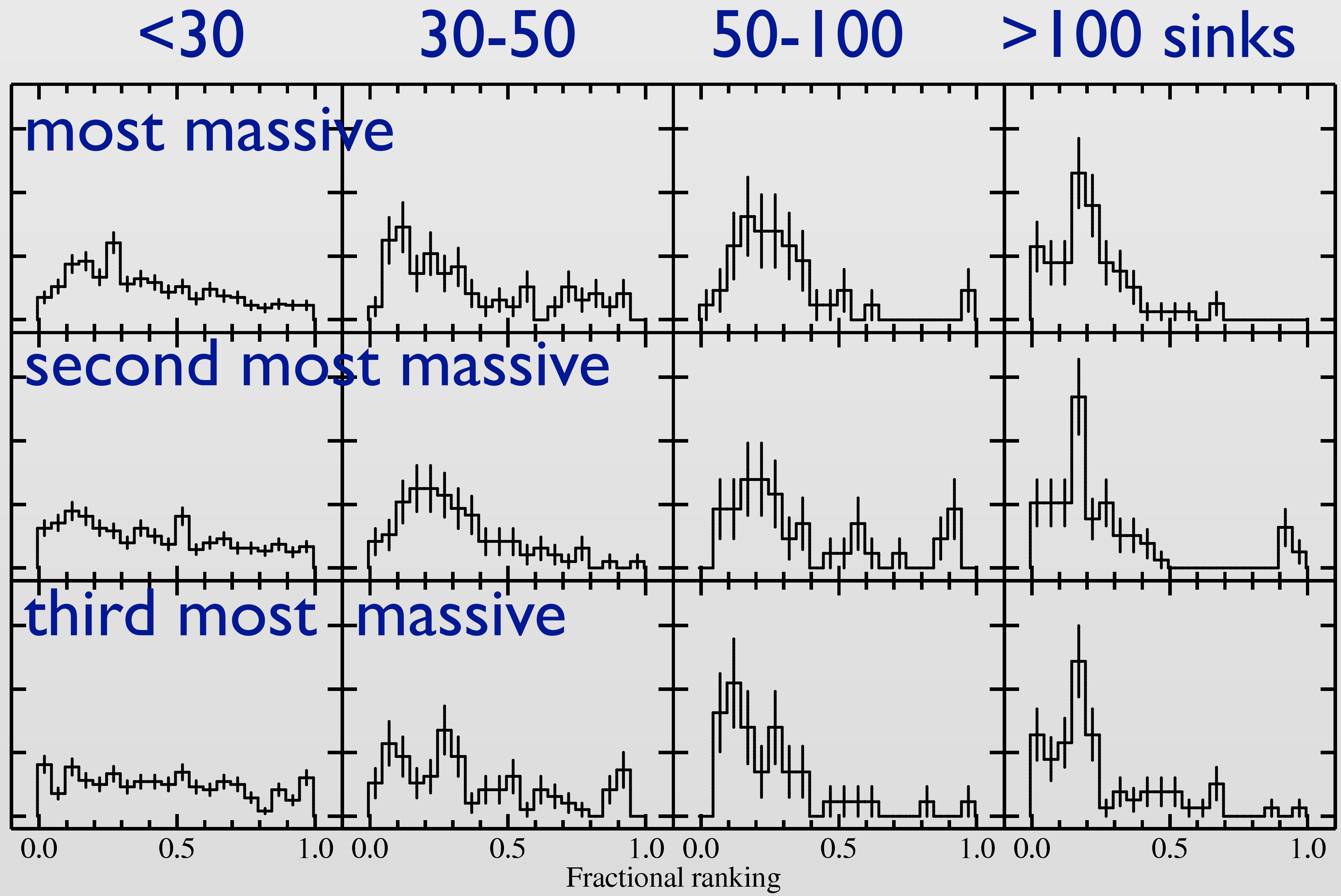
Bontemps et al. 2010



Könyves et al. 2010

Mass segregation

Histogram of ranks in distance from the geometrical cluster centre.



distance from geometrical centre

Evolutionary sequence:
n increases - age increases

Upper stellar mass function

Is the IMF universal?

or rather

Which bit of the IMF is universal?

$$\frac{\mathrm{d}P(m)}{\mathrm{d}m} \propto m^{-\alpha}$$

$$\alpha = 2.35$$

$$m > 0.5 \ \mathrm{M}_\odot$$

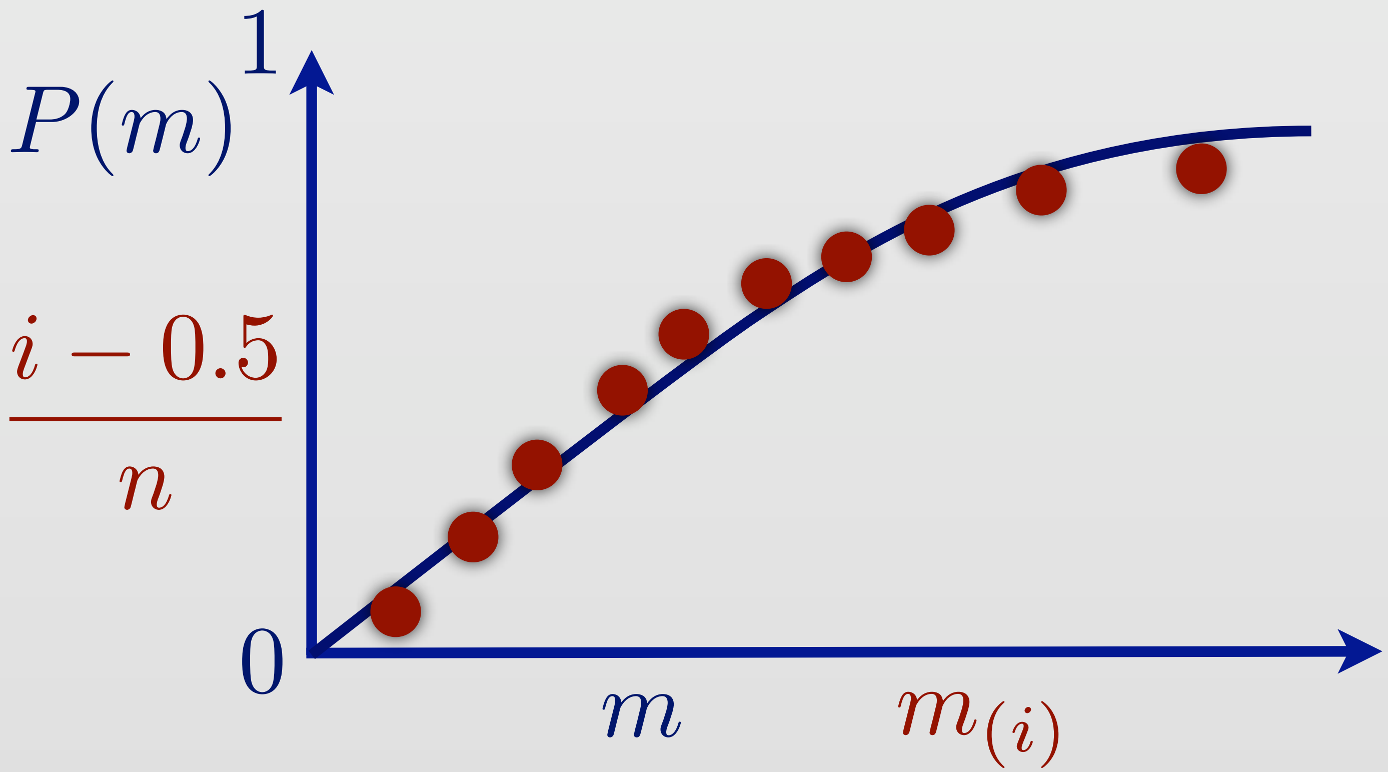
$$m <?$$

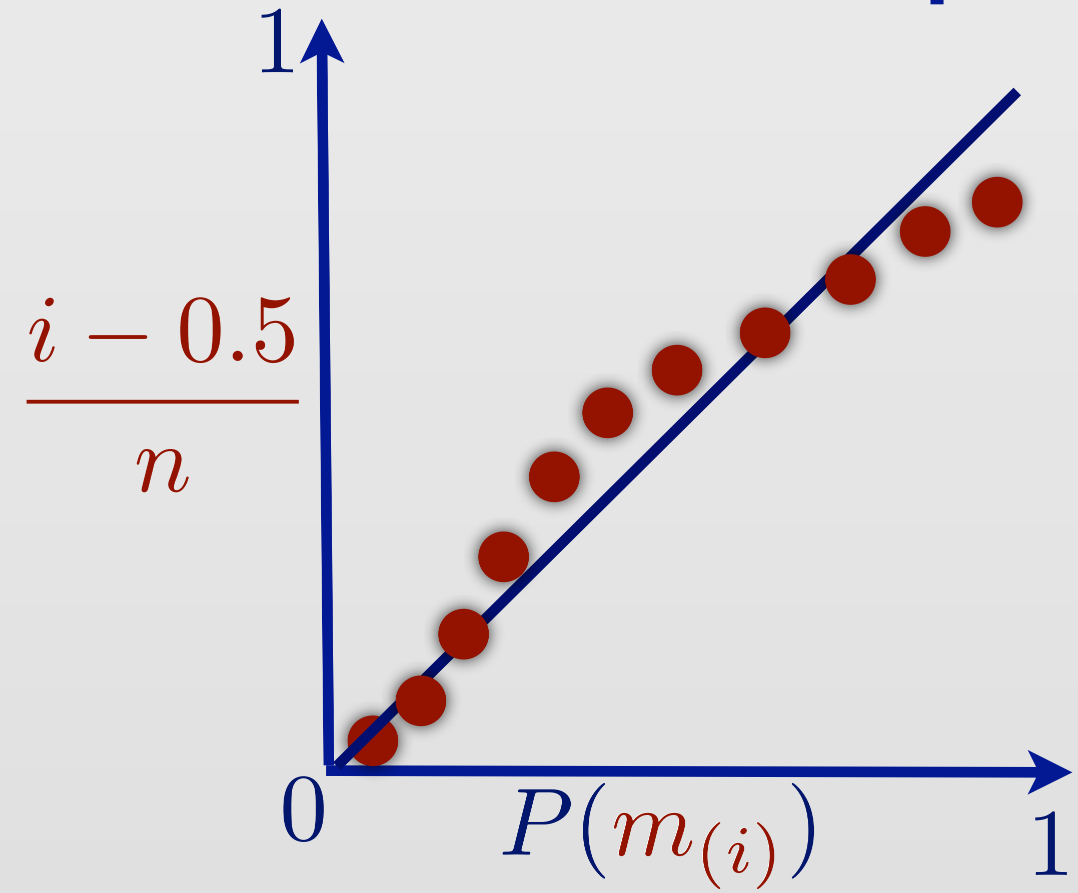
The Exponent?
The Upper limit?
(cf. work of Weidner & Kroupa)

Method of data analysis:

1. Assume Model (truncated power law)
2. Estimate parameters
3. Check agreement of data and best-fit model

A tool for the upper mass end: the SPP plot





Cumulative distributions vs. m show all data points but are hard to read (curvature).

Solution:
plot cumulative distribution of data vs. cumulative distribution of model.
Compare data to a straight line.
Can even show KS test.

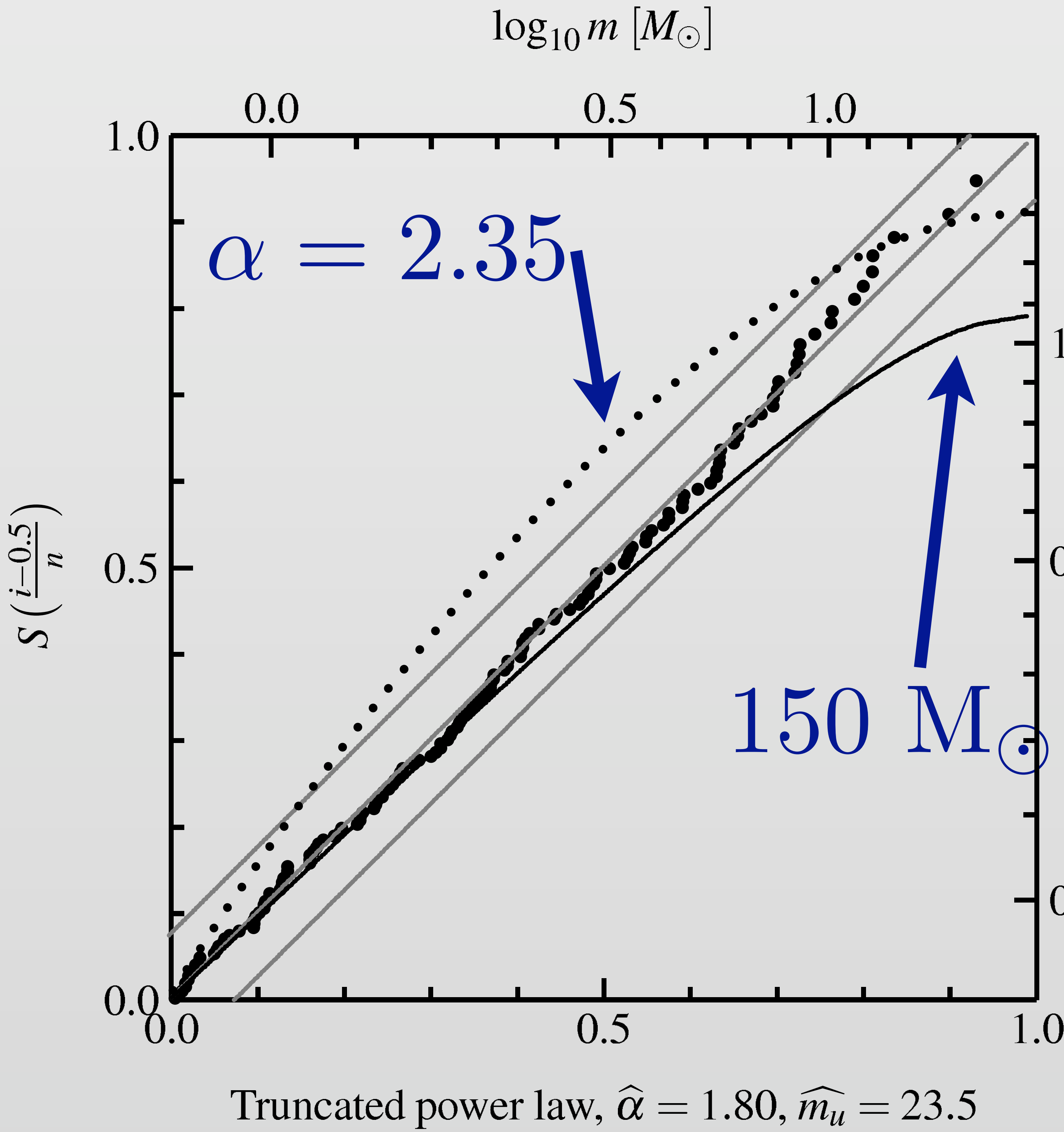
Mass function in one Cluster

Mass function follows a truncated power law!

Estimated exponent: 1.80

Estimated upper limit: 23.5 Msun.

Not consistent with 150 Msun.

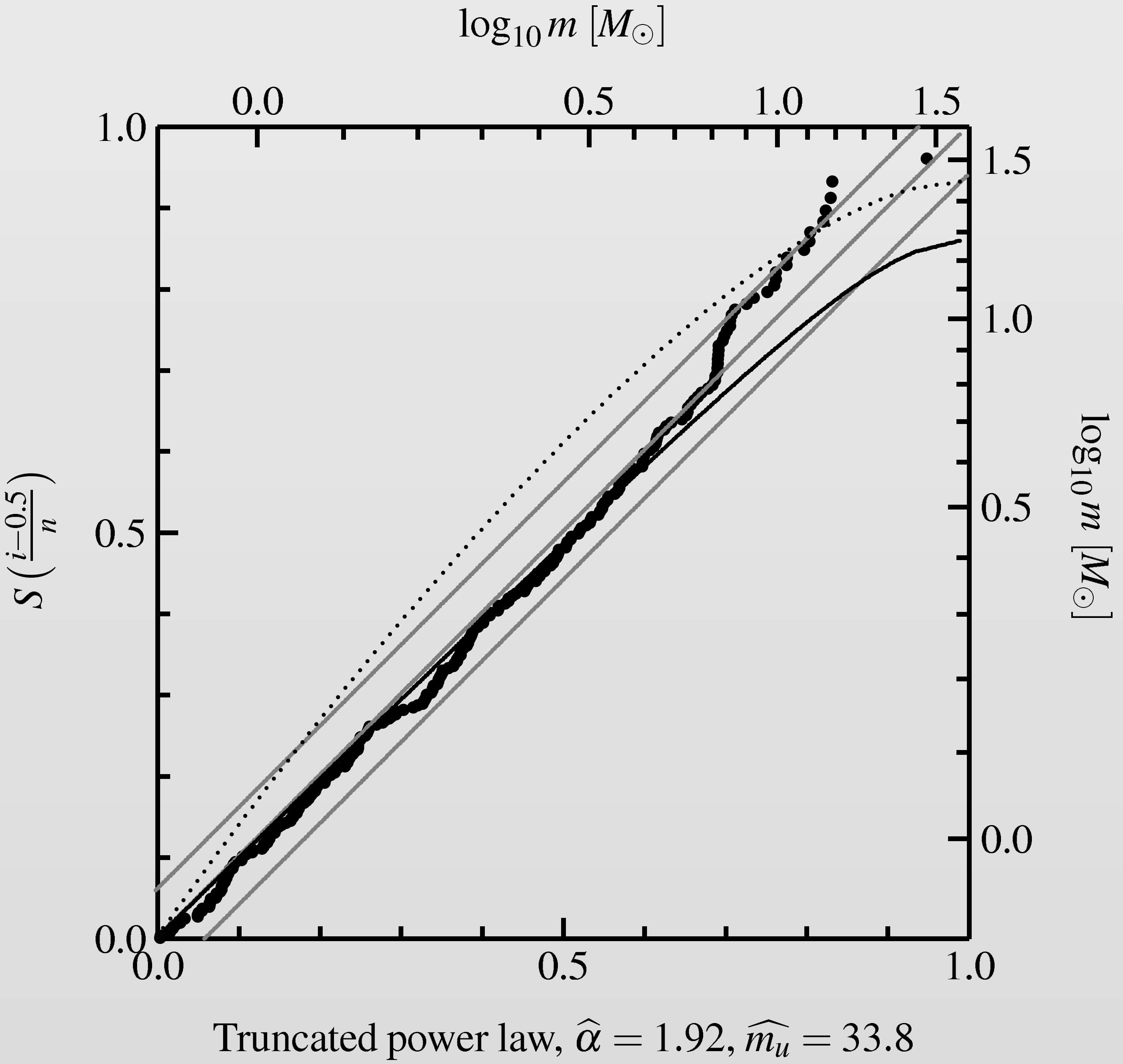


Mass function of all stars

Adding up all stars in clusters to have a homogeneous sample.

Truncated power law not a good fit.
Data curve towards a turn-down at high masses.

A sign of the IGIMF effect?



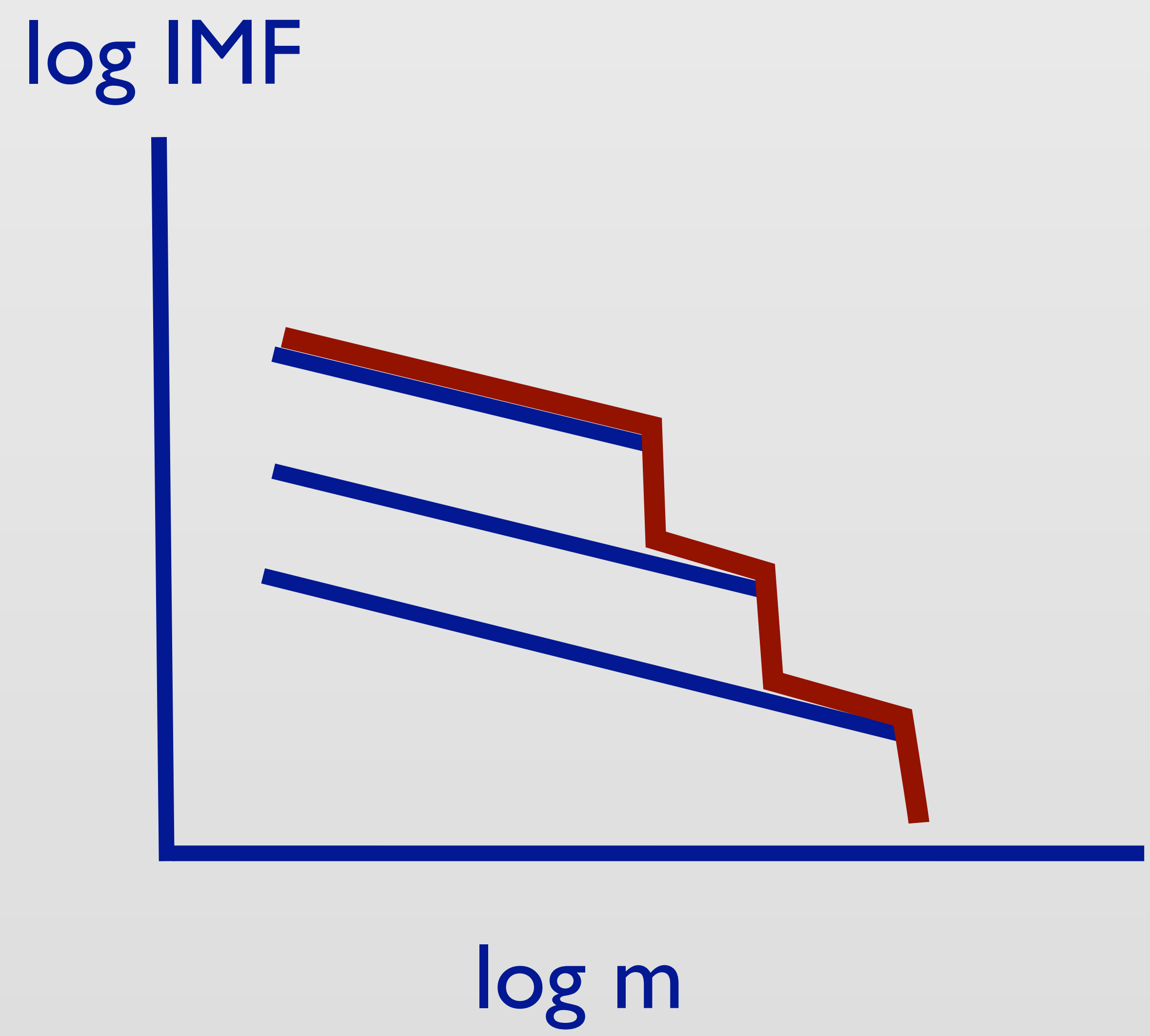
IGIMF effect?

Consequence of a “non-universal” IMF

Large simulation produces several clusters.

If you add up mass functions with different truncation masses, the resulting mass function will have a different shape.

Steepening of the high-mass slope or turn-down.



Conclusions

Subclusters are usually round.
Mergers can disturb the shape.
Subclusters quickly reach a central concentration.

Future massive stars are seeds of subclusters.
Subclusters are mass segregated at an age of 0.5 Myr.

The mass function in a subcluster is rather flat.
The mass function in a subcluster is strongly truncated.

There might be signs of the IGIMF effect.

Further reading: Maschberger, Clarke, Bonnell & Kroupa 2010, MNRAS 404, p.1061