Quantifying the boundness of star clusters with Gaia data

Villa Galileo, 22.11.23

Emily L. Hunt[1,2]

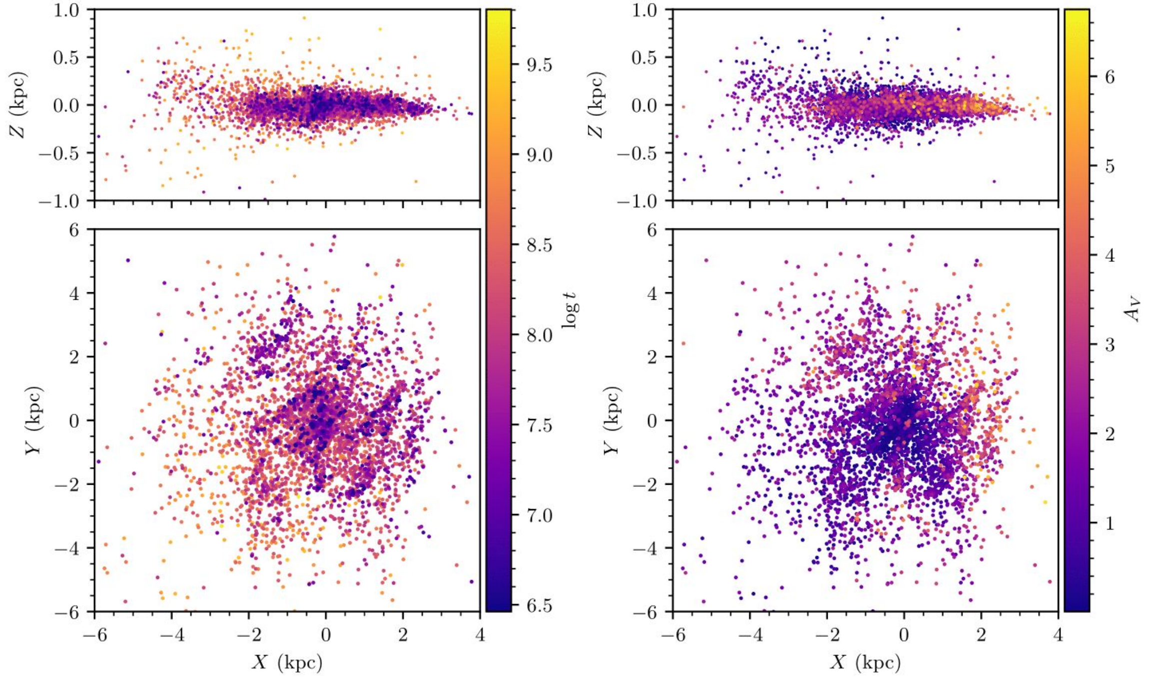
1. LSW, Universität Heidelberg // 2. IMPRS-HD Fellow

Milky Way impression: Nick Risinger

The context: Hunt & Reffert 2023

After the largest ever search in Gaia data for star clusters…

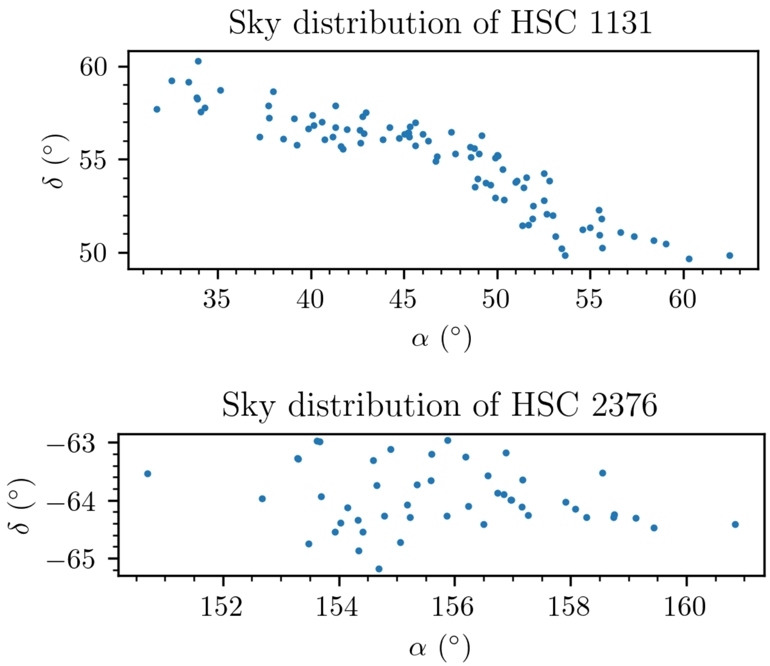
- **7167** clusters in total
  4105 highly reliable
- **Largest ever** (deduplicated) catalogue!
- **Parameters & quality criteria** for every cluster



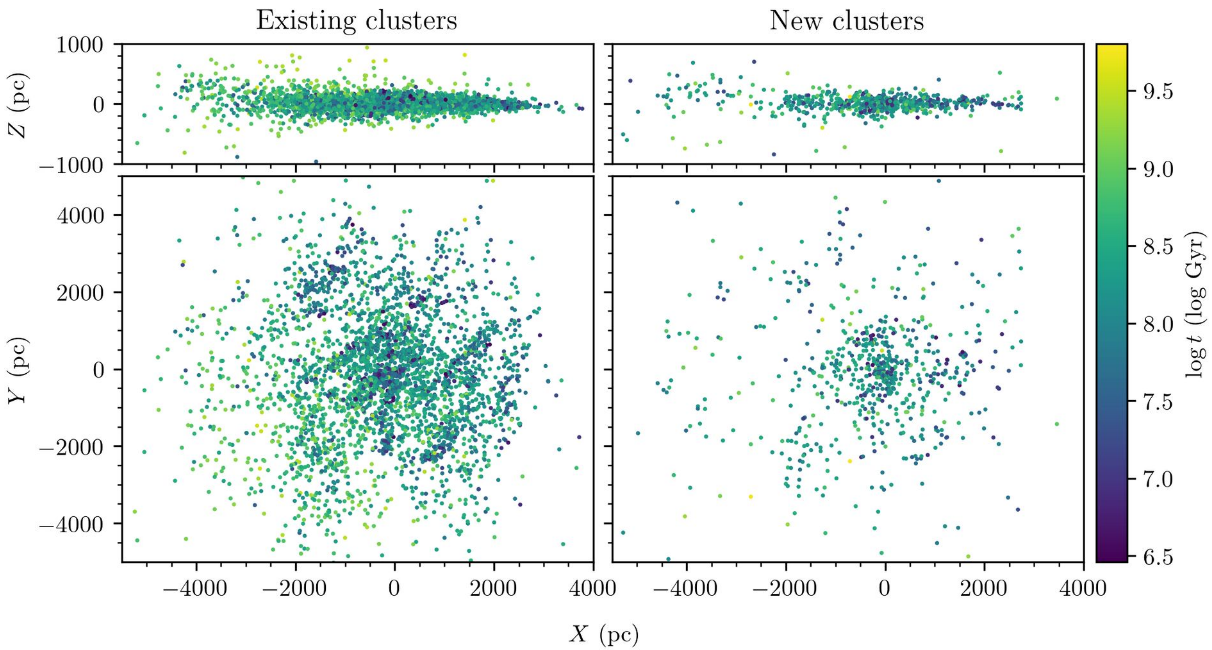
The problem…

Many of the new clusters look more like **moving groups (unbound clusters)…**
… and there isn't an easy way to **classify** them

'Unclumpy' distributions:

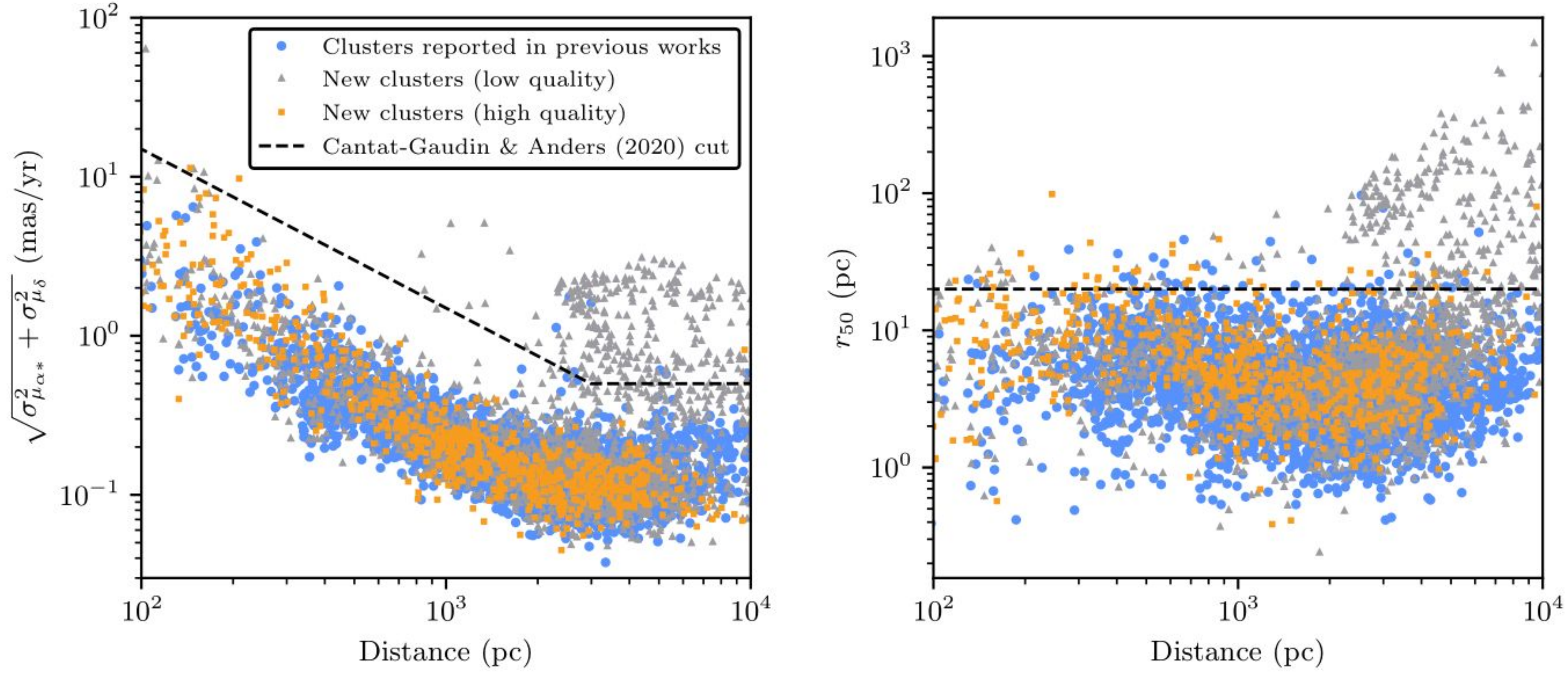


Mostly near to the Sun:



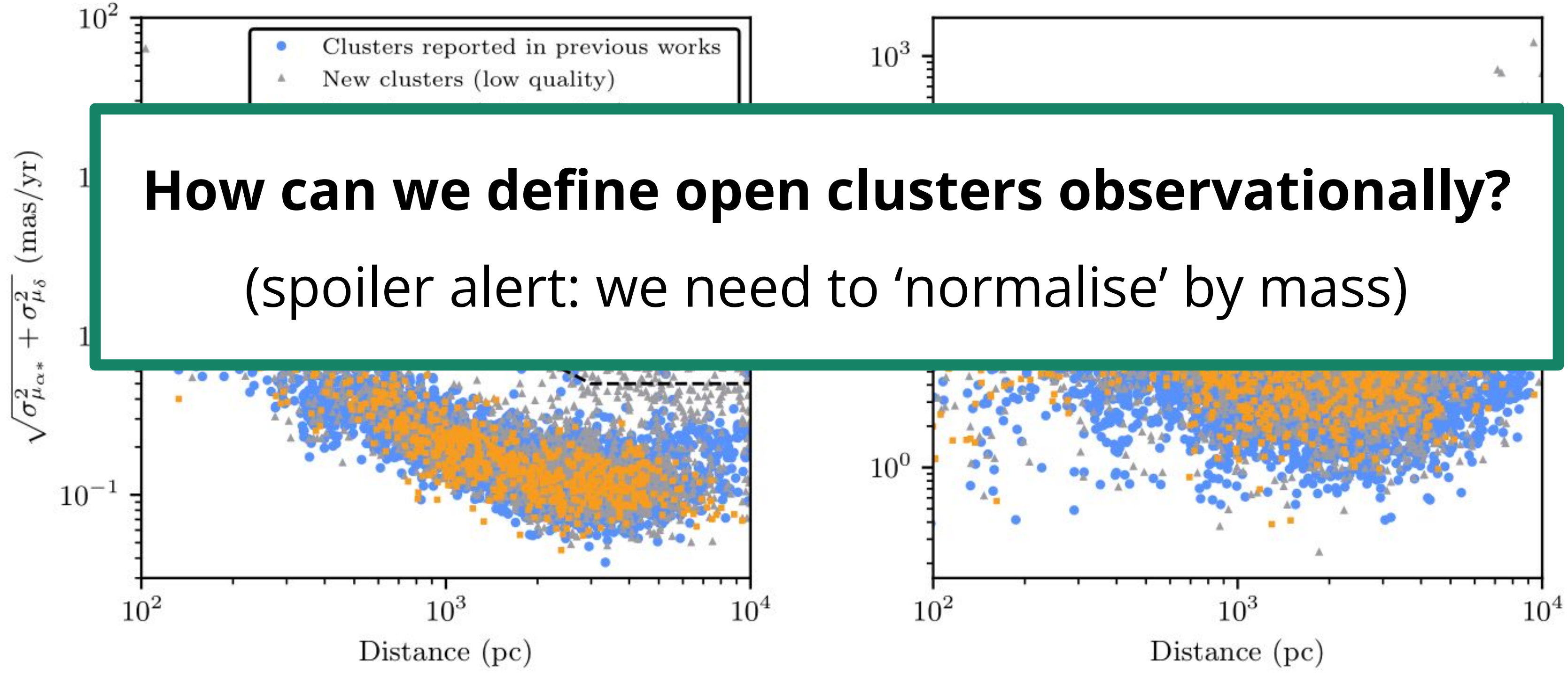
The previous best approach

Cantat-Gaudin & Anders 2020: constraints on proper motion dispersion & radius
=> but most of our clusters pass them! (including what I just showed you)



The previous best approach

Cantat-Gaudin & Anders 2020: constraints on proper motion dispersion & radius
=> but most of our clusters pass them! (including what I just showed you)



How can we define open clusters observationally?

(spoiler alert: we need to 'normalise' by mass)

What is a bound cluster?

Virial theorem: $2 \cdot E_{Kinetic} = |E_{Potential}|$ for a bound object

$$E_{Kinetic} \sim \frac{1}{2} M v^2$$

$$Q = \frac{E_{Kinetic}}{E_{potential}} \sim 0.5$$

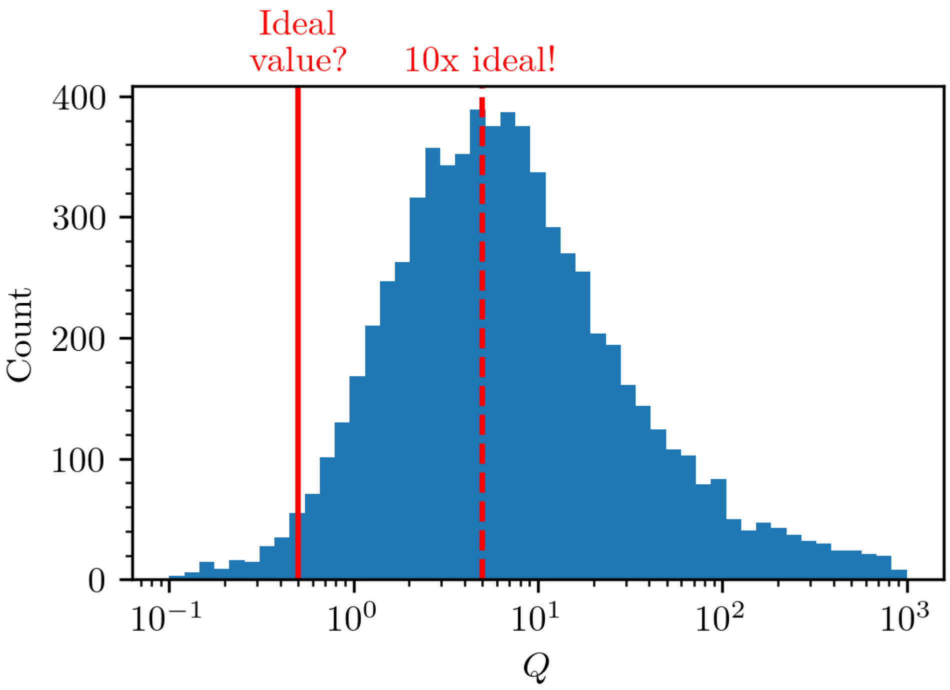
$$E_{Potential} \sim \frac{1}{2} \frac{GM^2}{R_{50}}$$

Need the following:

R_{50} v M

That didn't work...

_Q_ was always _way_ too high:



- **Velocity dispersions** seemed consistently too high
- **Effectively impossible** to decontaminate all clusters of **binary stars** and measure **Q** accurately ~7000 times
- Hard to make a **physically motivated** cut – bound clusters can be **supervirial** at different stages!

We needed another way...

Any **gravitational system** has a **Jacobi radius** $\boldsymbol{r_J}$ within which its potential is stronger than that of its host's potential

$$r_J = \left(\frac{GM}{4\Omega^2 - k^2} \right)^{\frac{1}{3}}$$

where ***M*** is the cluster's mass and ***Ω*** and ***k*** are the circular and epicyclic frequencies of the cluster's orbit.

If a cluster has no valid $\boldsymbol{r_J}$

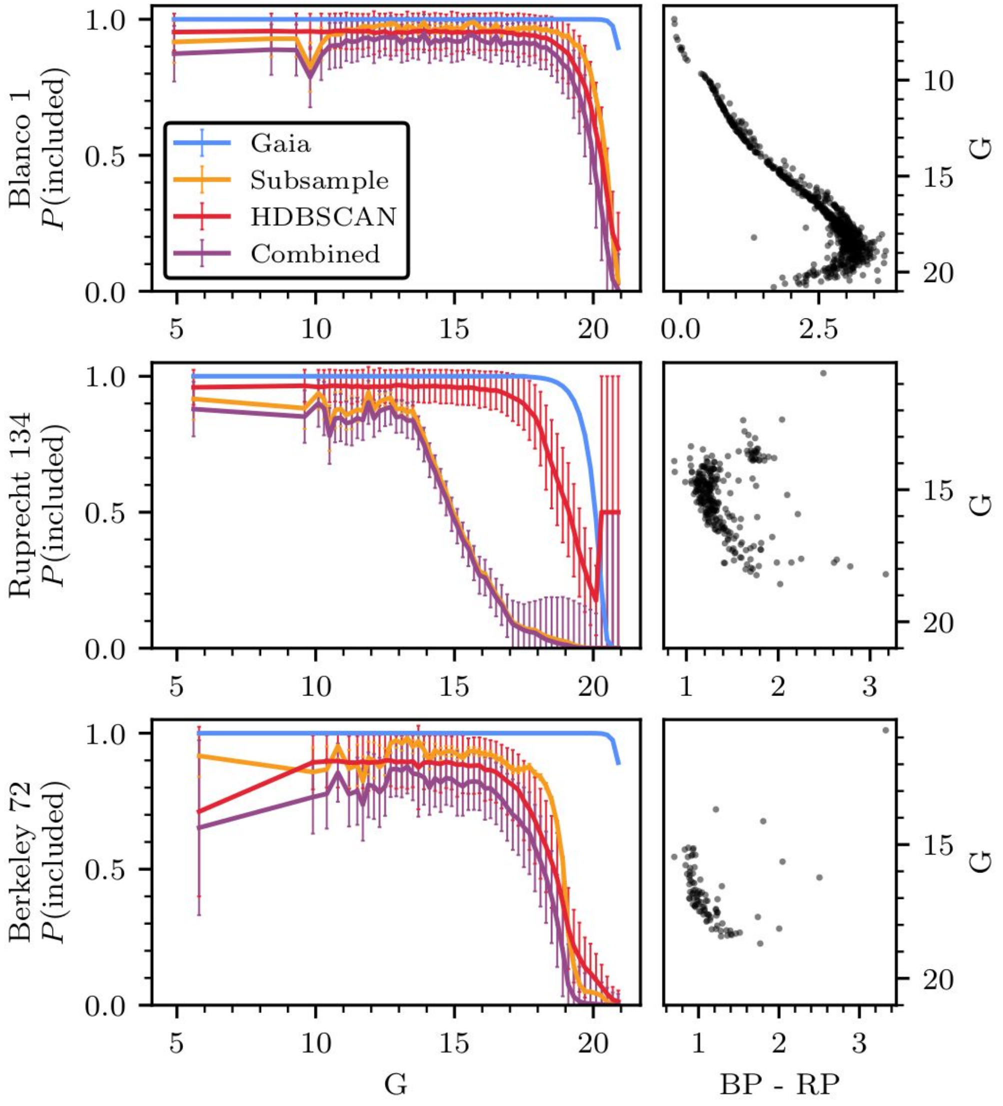
→ cannot be bound

Measuring masses: selection effects

Incompleteness of our membership lists is accounted for due to:

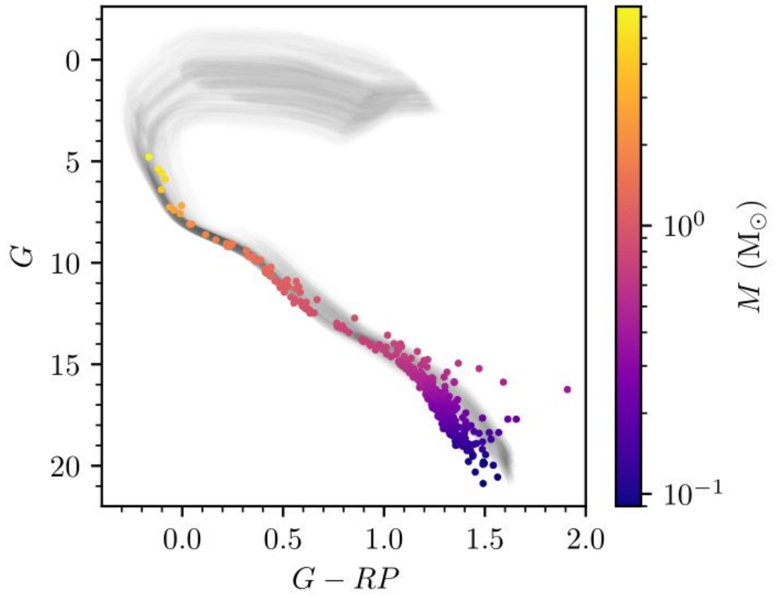
- **Gaia**
- **Subsample**
- **Clustering algorithm**

Very important step that changes final results a lot!



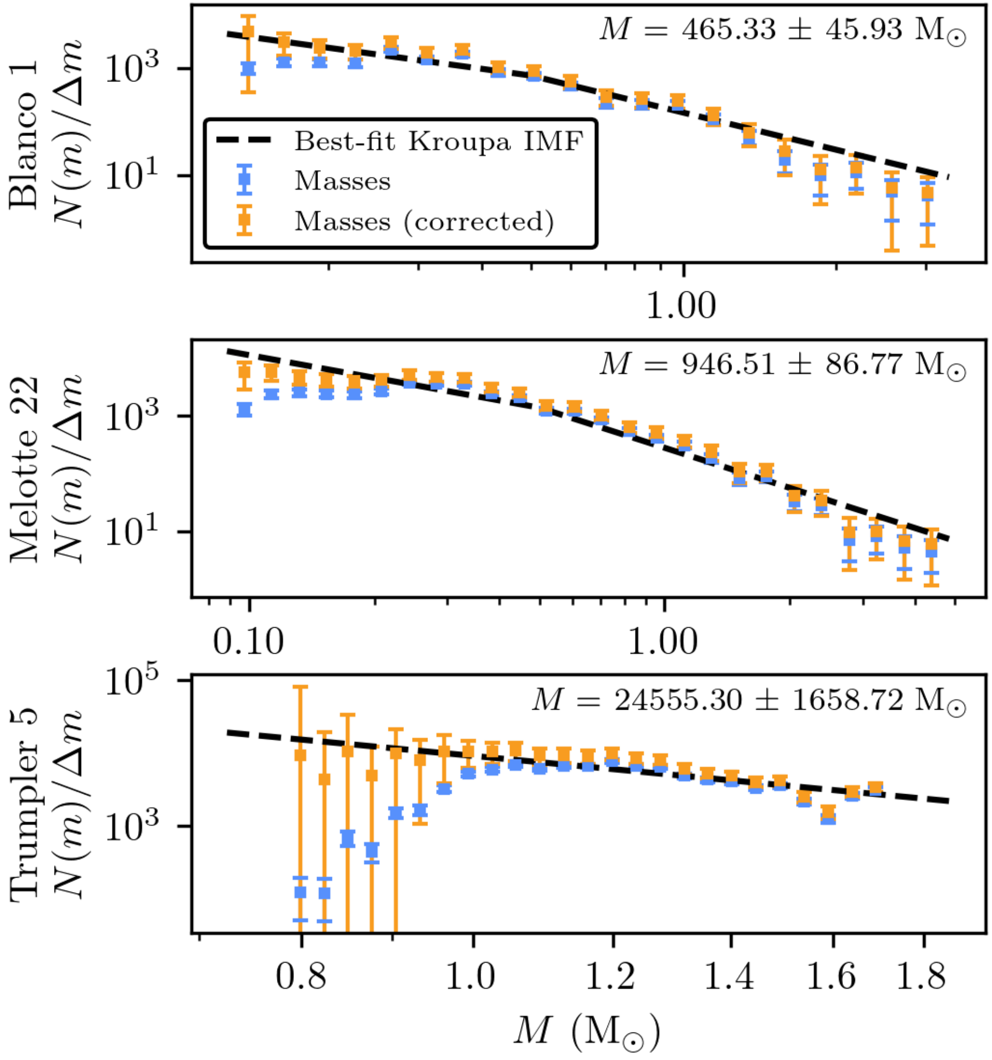
Binary stars & total mass

- Interpolate to **PARSEC** isochrones to get primary star masses
- …but difficult to correct for **unresolved binary stars** accurately for all ~7000 clusters → assume field-like population of binaries from Moe & Di Stefano 2017*
  *completeness-corrected q(m), P(m) distributions
- **Simulate** if binaries resolved or not
- **~10% to ~30%** mass increase to each cluster mass function
- We then fit a **Kroupa IMF** to each cluster's mass function → **integral of this is the total mass**

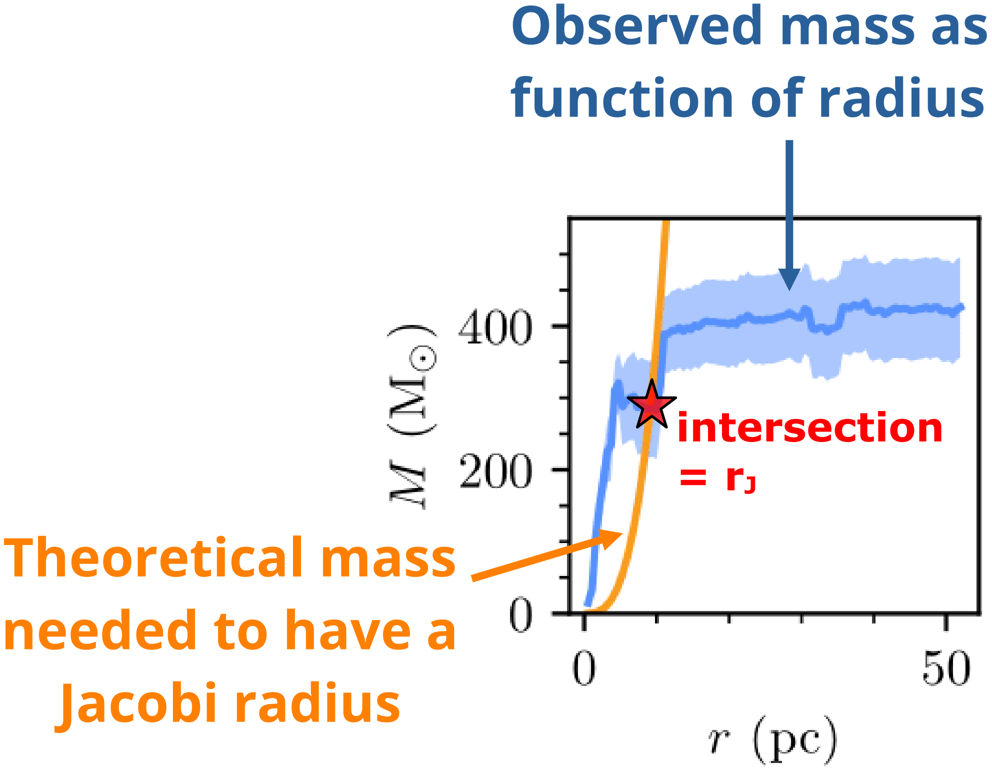


Is assuming a Kroupa IMF a good assumption?

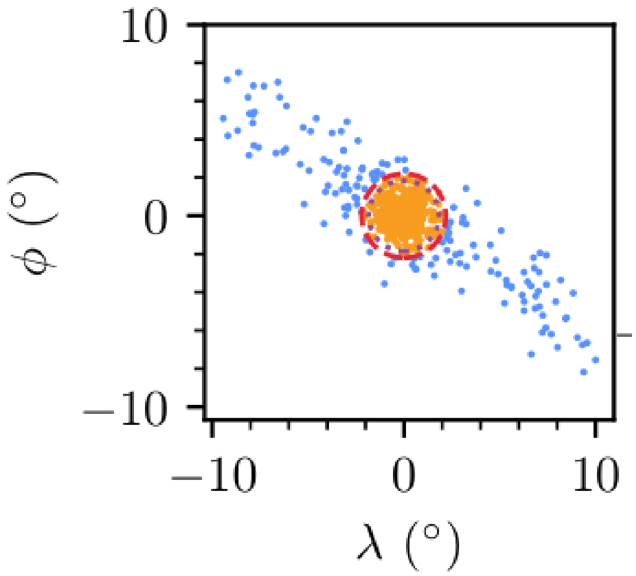
- After applying all corrections… most clusters have a **Kroupa-like** mass function (!!!!)
- **Exception:** old clusters (age of ~1 Gyr) where more deviation from IMF visible below 0.5 $M_\odot$
- **Cannot reproduce** recent results suggesting most clusters are best fit by a **bespoke** mass function (e.g. Cordoni+23)



Measuring Jacobi radii

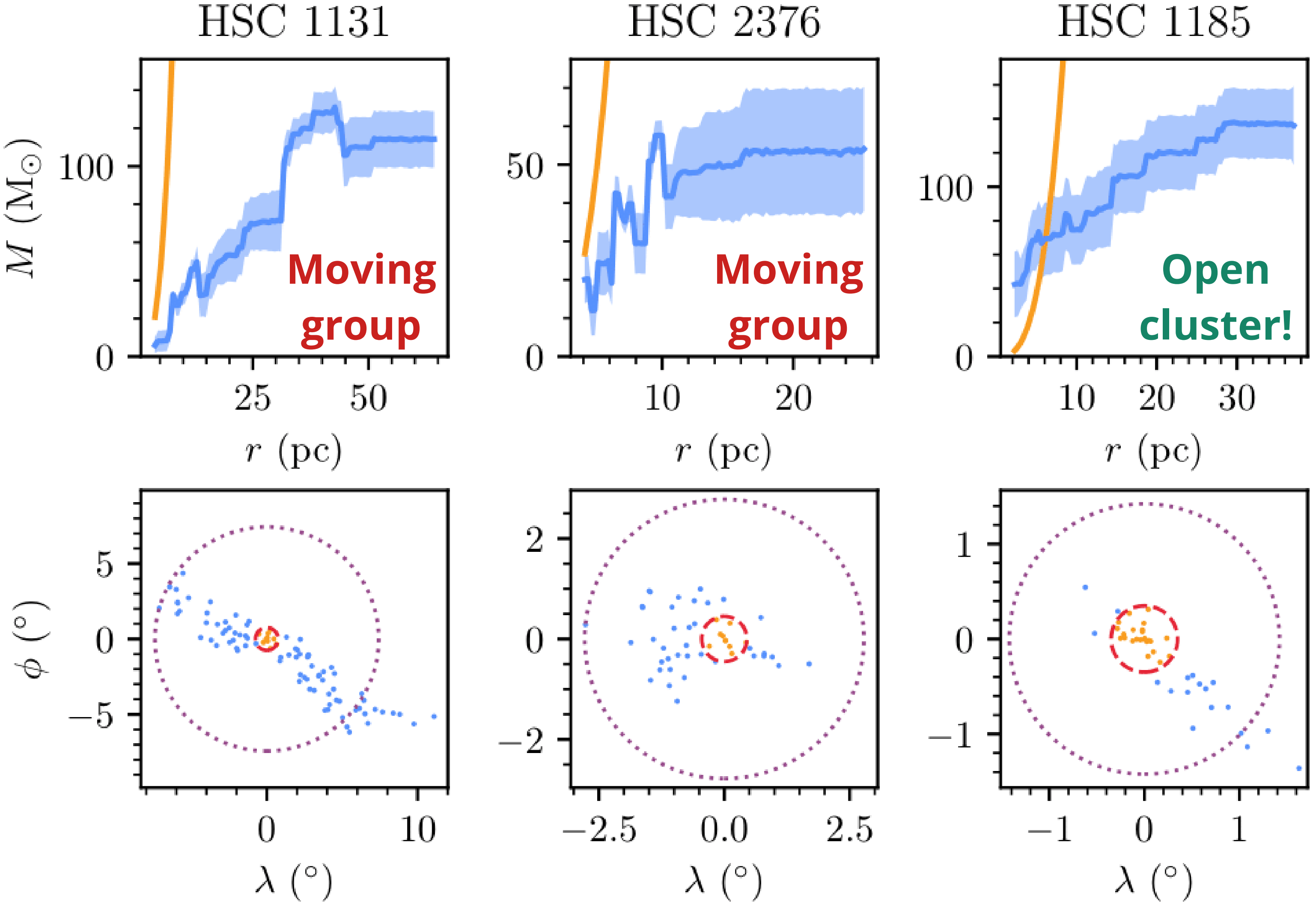


On-sky distribution:



(This approach is from **Meingast+2020**)

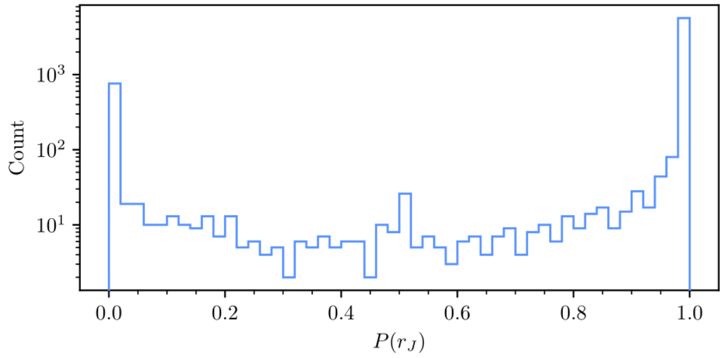
Does it work?

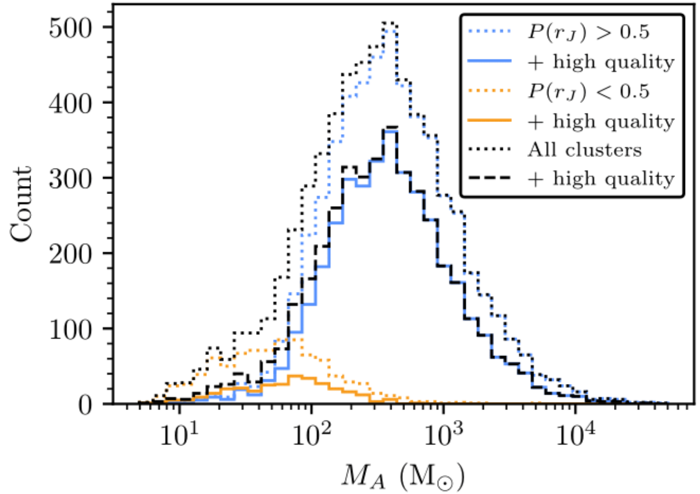


HSC 1131
HSC 2376
HSC 1185
M (M$_\odot$)
Moving group
Moving group
Open cluster!
r (pc)
r (pc)
r (pc)
ϕ (°)
λ (°)
λ (°)
λ (°)

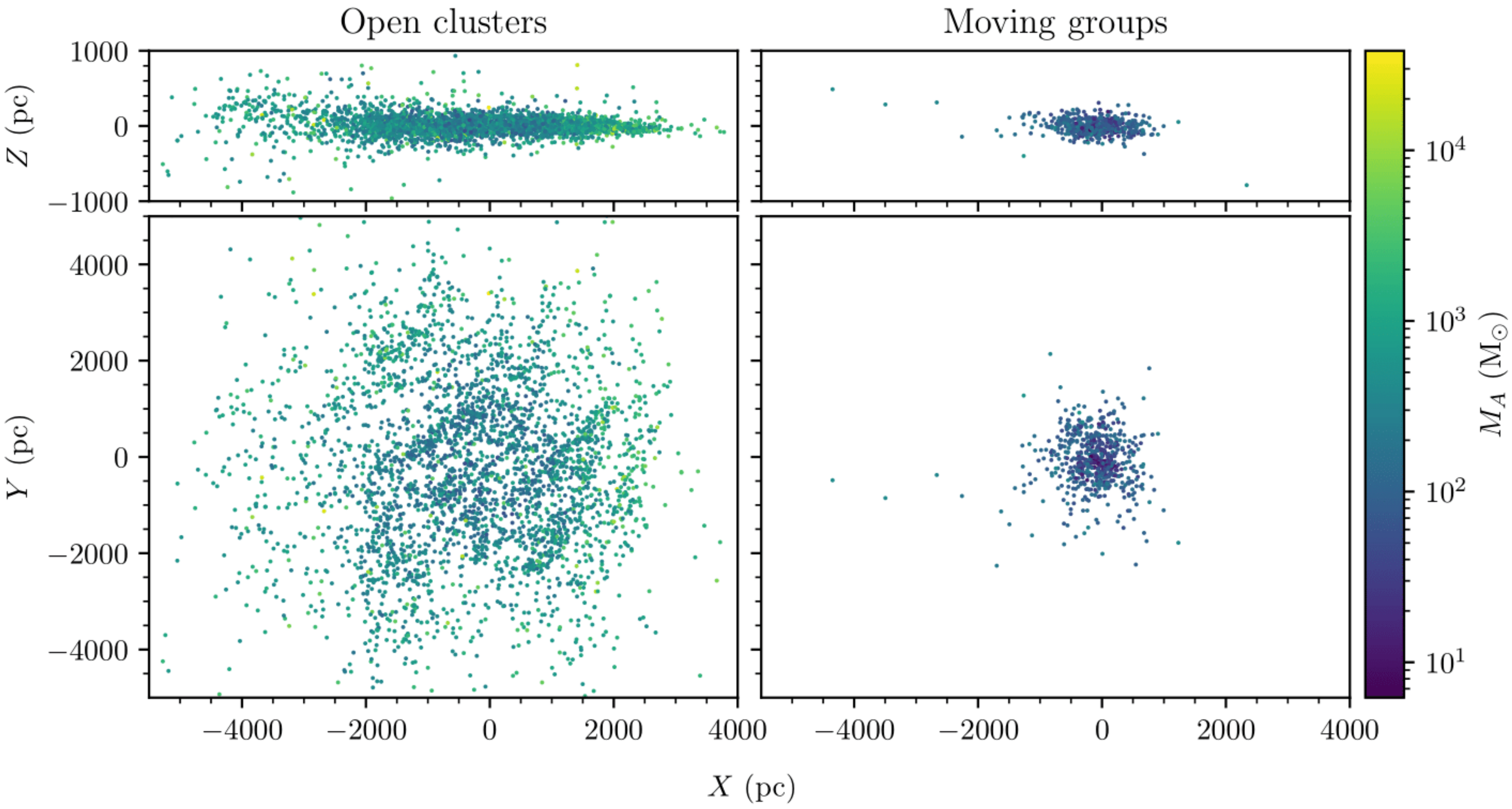
A definition of bound clusters

- Probability of having a Jacobi radius: **strong** indicator!
- Some objects seem to have a low-mass Jacobi radius (e.g. of ~15 $M_\odot$)
  - May be due to limitation of method
  - Multiple star system?
  - Either way… that's really small
- **Suggested cut:** $P(r_J) > 0.5$ **and** $M > 40\ M_\odot$





How does it change our catalogue?



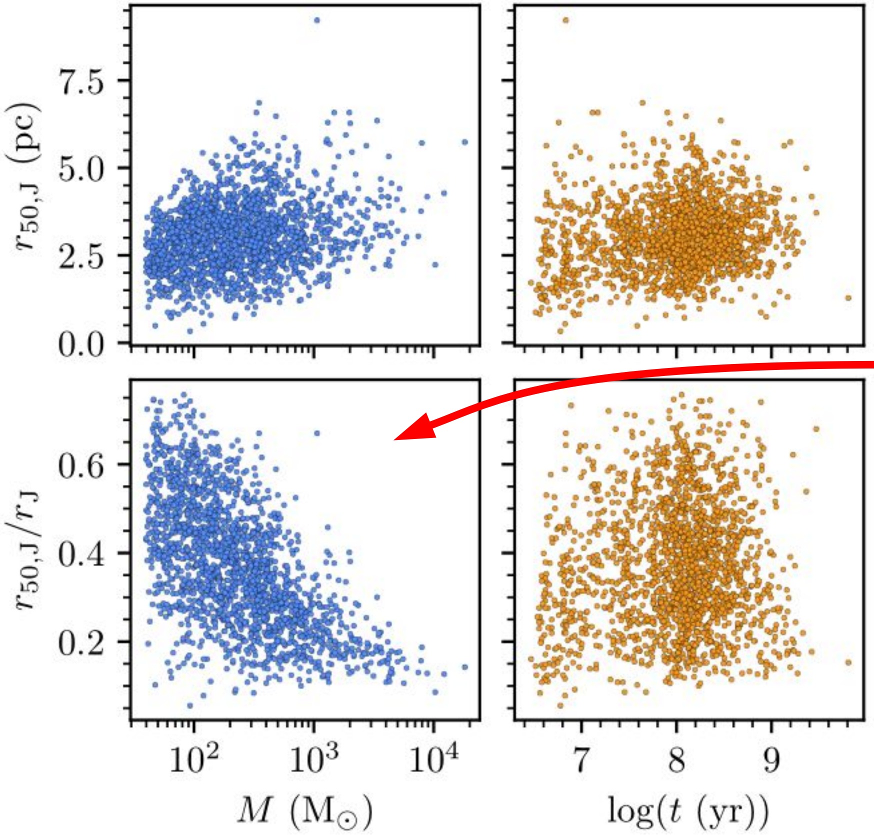
Catalogue contains **3530 high-quality OCs** (5648 total)

Plus: **1309 moving groups, 131 globulars**

84% of clusters within **250 pc** are **moving groups!**

Looking for correlations

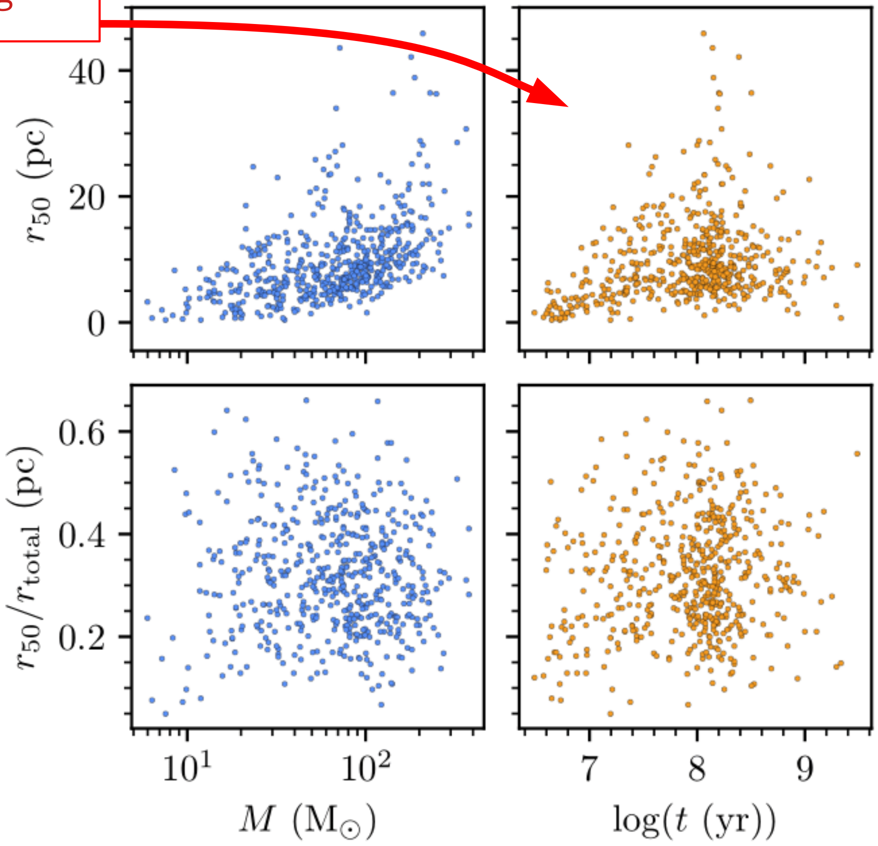
Open clusters



Get bigger with age?
⇒ expanding

Concentration a strong function of mass

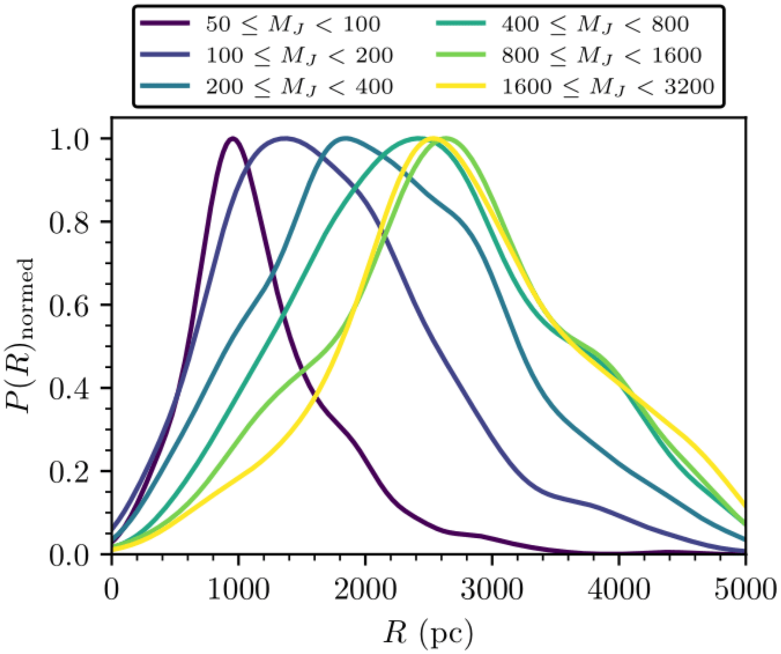
Moving groups

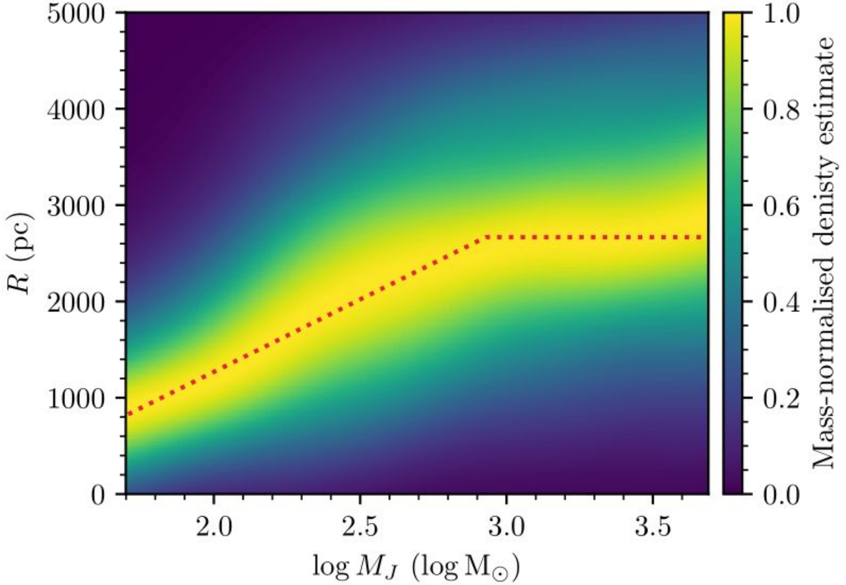


Completeness with masses

Masses are a **strong** predictor of cluster census completeness

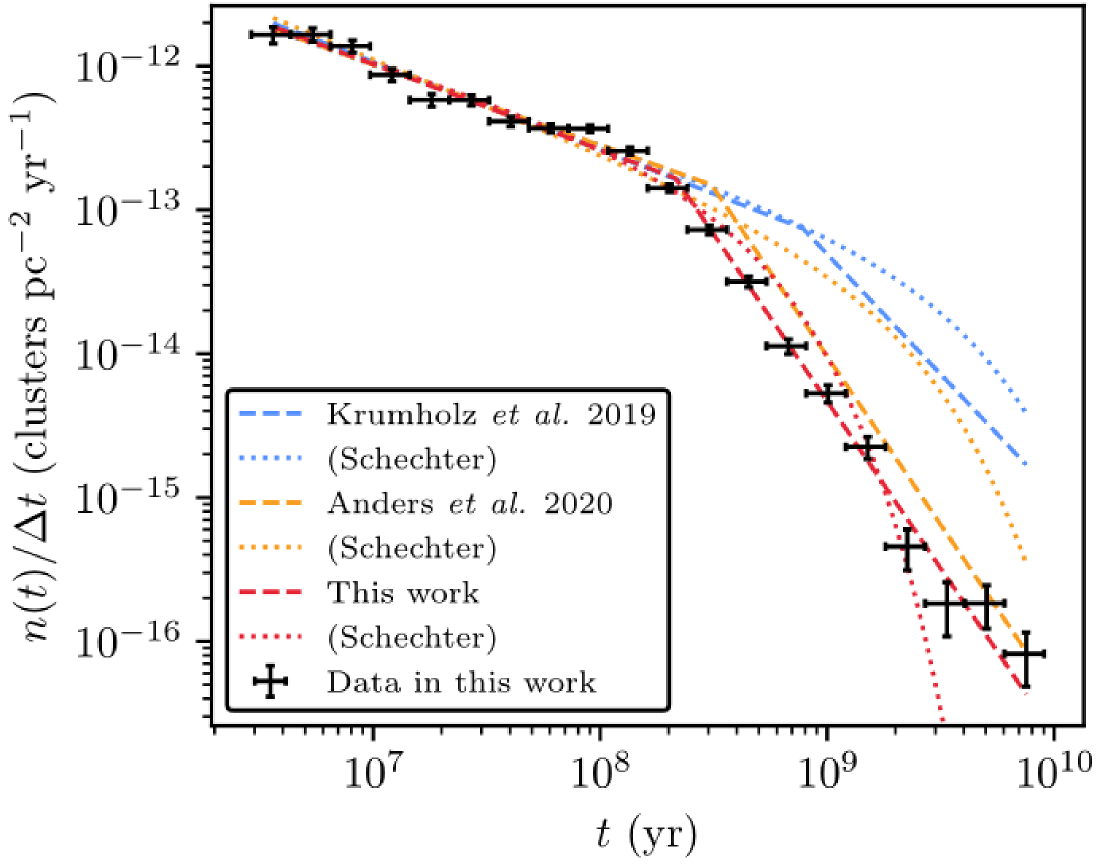
→ Estimate completeness from distribution peaks





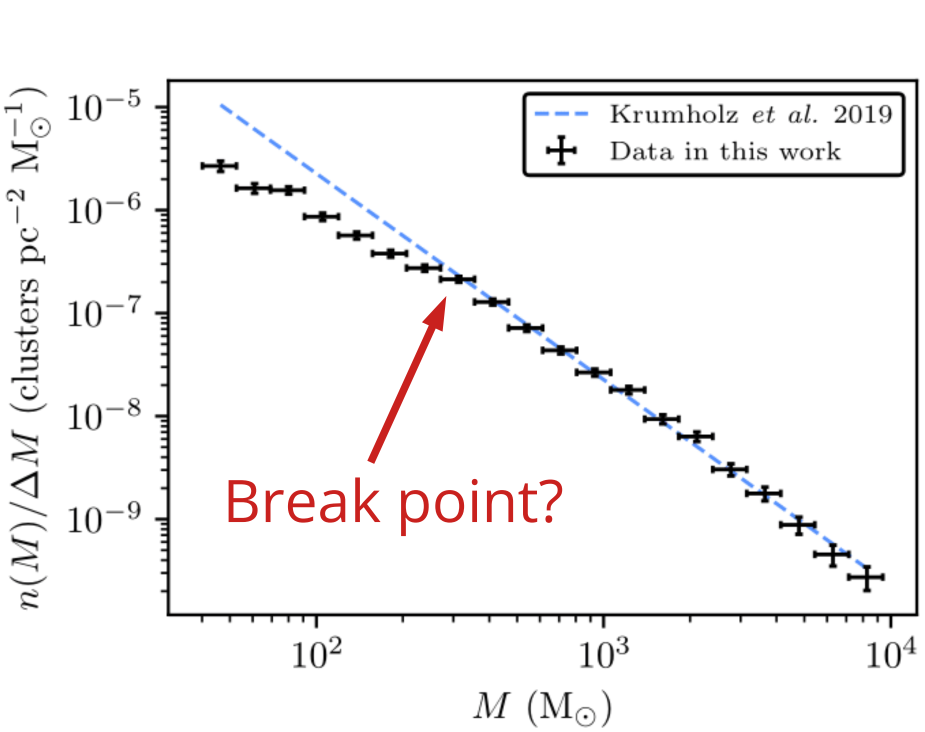
The catalogue age function

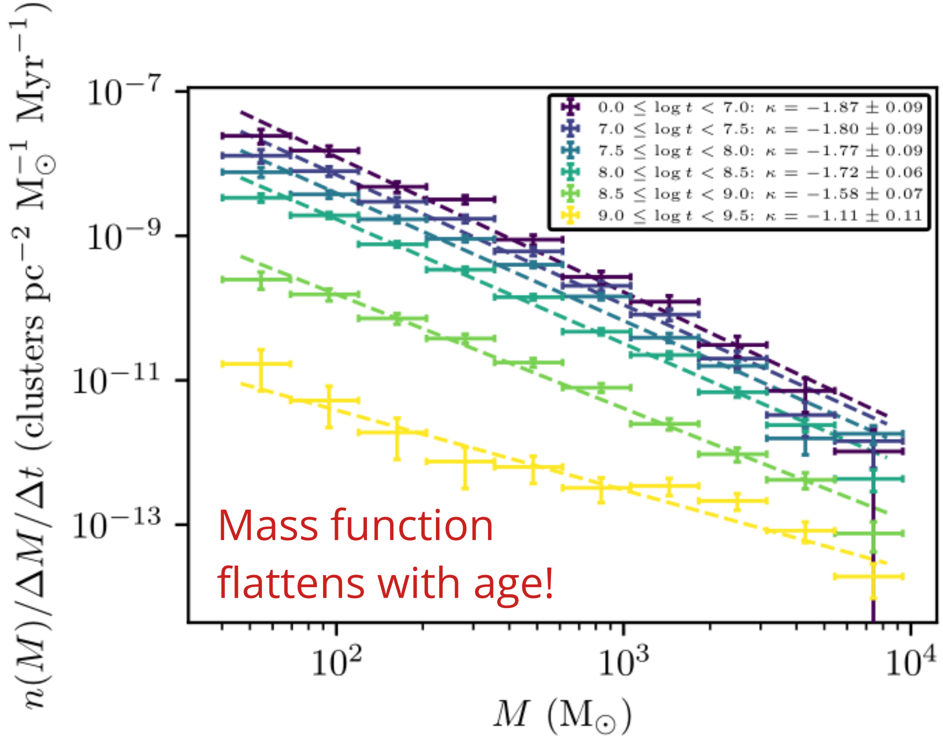
- Very **similar** result to Anders+2020 (Gaia DR2)
- Very **different** to pre-Gaia works
- There are **fewer old open clusters** than previously thought
  (we would have found them if they're real!)



The catalogue mass function

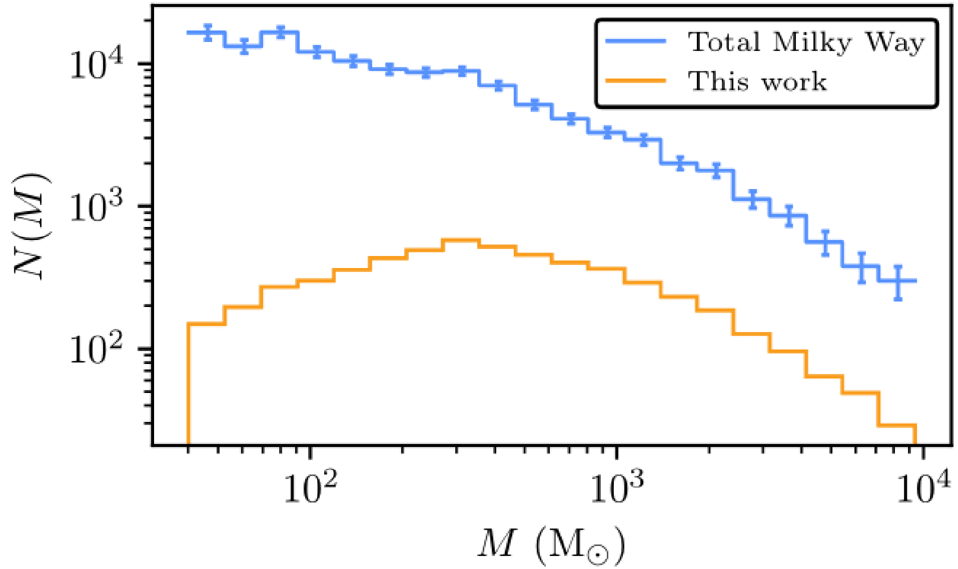
- **First measurement** of Gaia open cluster mass function
- Krumholz+19: **all galaxies** have a κ ≈ -2 power-law mass function at age=0
- We can measure cluster population mass function down to **40 $M_\odot$!**





How much of the Milky Way is open clusters?

- **Dias *et al.* 2002: ~10^5** open clusters in Milky Way
- **This work: ~1.3×10^5**
  → Very similar!
  → Just 4% of open clusters known
- **Total stellar mass: ~4.8×10^7 $M_\odot$**
  → ~0.1% of Milky Way's stars are in an open cluster
  (based on Cautun+20 DR2 stellar mass)



Open cluster open questions

- Can the **observed rates of cluster dissolution** be explained?
  Which processes are dominant? GMC collisions? Tidal disruption? Or a bit of everything?

- What are the **moving groups** we detect?
  They have good photometry, clear overdensities... Dissolved open clusters? Never bound? Or both?

- Why is **cluster concentration** a function of mass?
  Do the outskirts of clusters dissolve first? Is there a connection to how populated cluster tidal tails are?

P.S. paper is submitted!

Key takeaways

1. We measure **cluster masses** for ~7000 star clusters
2. Find that **Jacobi radii** can be used to cut a star cluster catalogue
   We have **three** quality criteria now – please use them all!
3. **Cluster mass** traces many interesting things about cluster lives

Get in touch:
ehunt@lsw.uni-heidelberg.de
Web: https://emily.space

I'm currently on the job market!
CV: https://cv.emily.space