Clusters Across Time

GG and CS

From Krumholtz et. al. 2019

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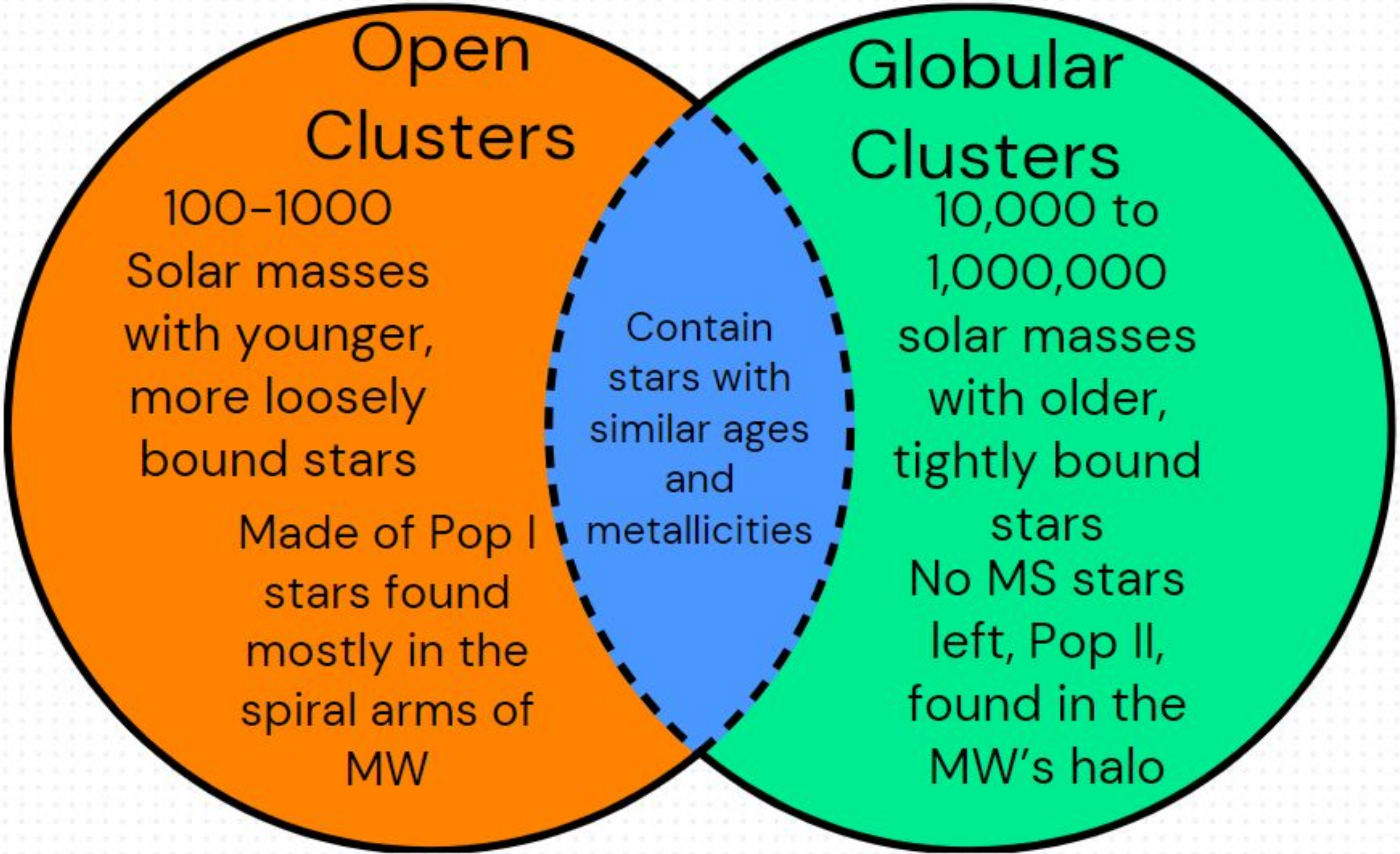
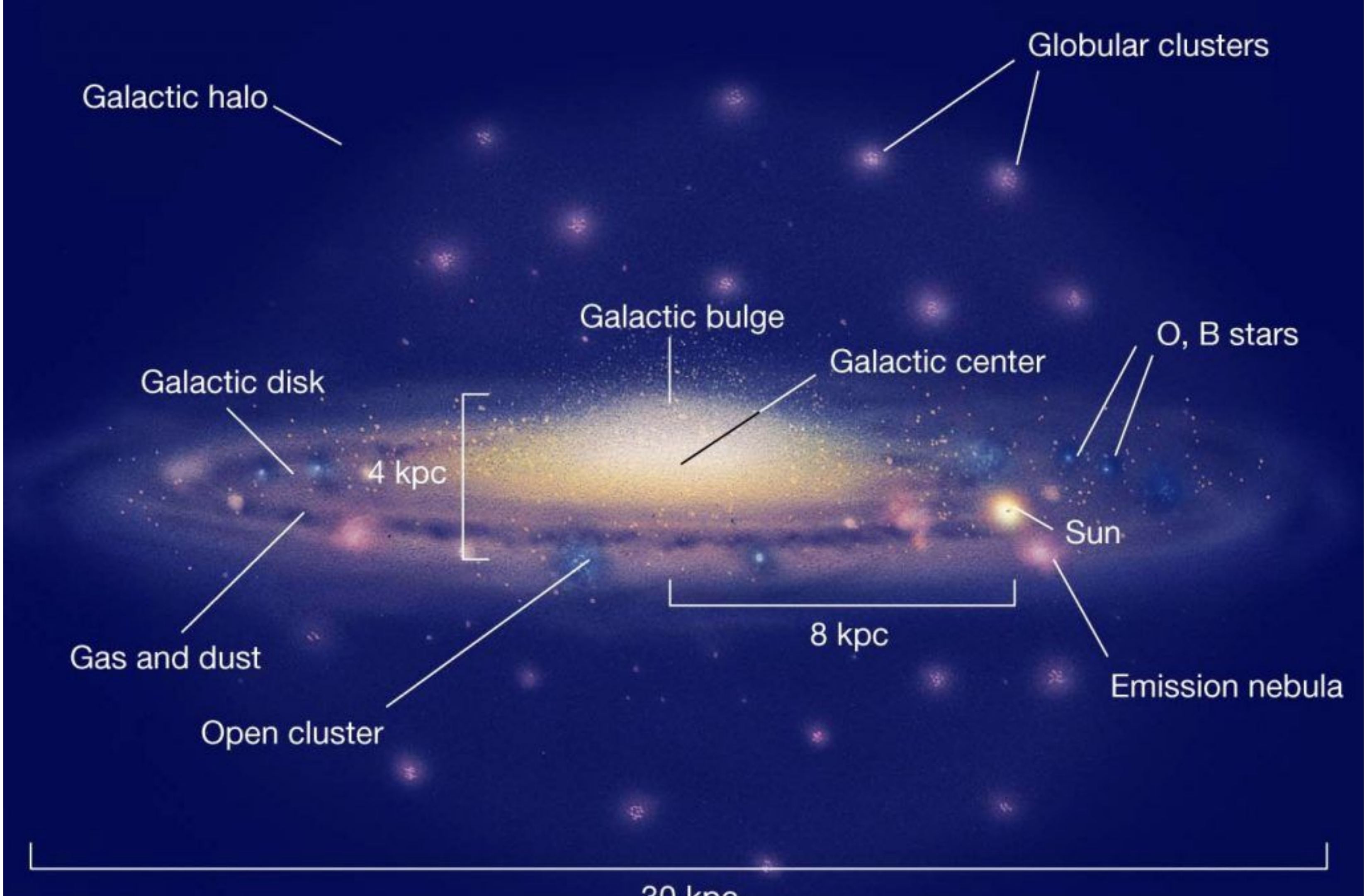
Dr. Dale says: Looks cool!

Star Cluster Overview

- 10^2 to 10^6 $M_\odot$
- 1Myr to >10Gyr
- d>1Mpc is hard to resolve anything but the brightest of stars
- Globular Clusters vs Open Clusters?
  - Separate classifications in the past, but recent research points to significant overlap in Z and density.
  - May indicate similar formation mechanism, but different cosmological history


Open Clusters
100-1000 Solar masses with younger, more loosely bound stars
Made of Pop I stars found mostly in the spiral arms of MW
Contain stars with similar ages and metallicities
Globular Clusters
10,000 to 1,000,000 solar masses with older, tightly bound stars
No MS stars left, Pop II, found in the MW's halo


Globular clusters
Galactic halo
Galactic bulge
O, B stars
Galactic center
Galactic disk
4 kpc
Sun
8 kpc
Gas and dust
Emission nebula
Open cluster

Classification

"...newly discovered star clusters, open or globular, within the Galaxy have designations following the convention "Chhmm±ddd", always beginning with the prefix C, where h, m, and d represent the approximate coordinates of the cluster centre in hours and minutes of right ascension, and degrees of declination, respectively, with leading zeros. The designation, once assigned, is not to change, even if subsequent measurements improve on the location of the cluster center."- XVIIe IAU Assemblee Generale,1979

Exclusive vs Inclusive Cluster Catalogs

- Unresolved Cluster Classification
  - *Exclusive* catalogs:
    - Symmetric and compact objects
    - Non-symmetric but still compact objects
  - *Inclusive* catalogs:
    - Symmetric and compact objects
    - Non-symmetric but still compact objects
    - Multi Peaked, non-symmetric objects

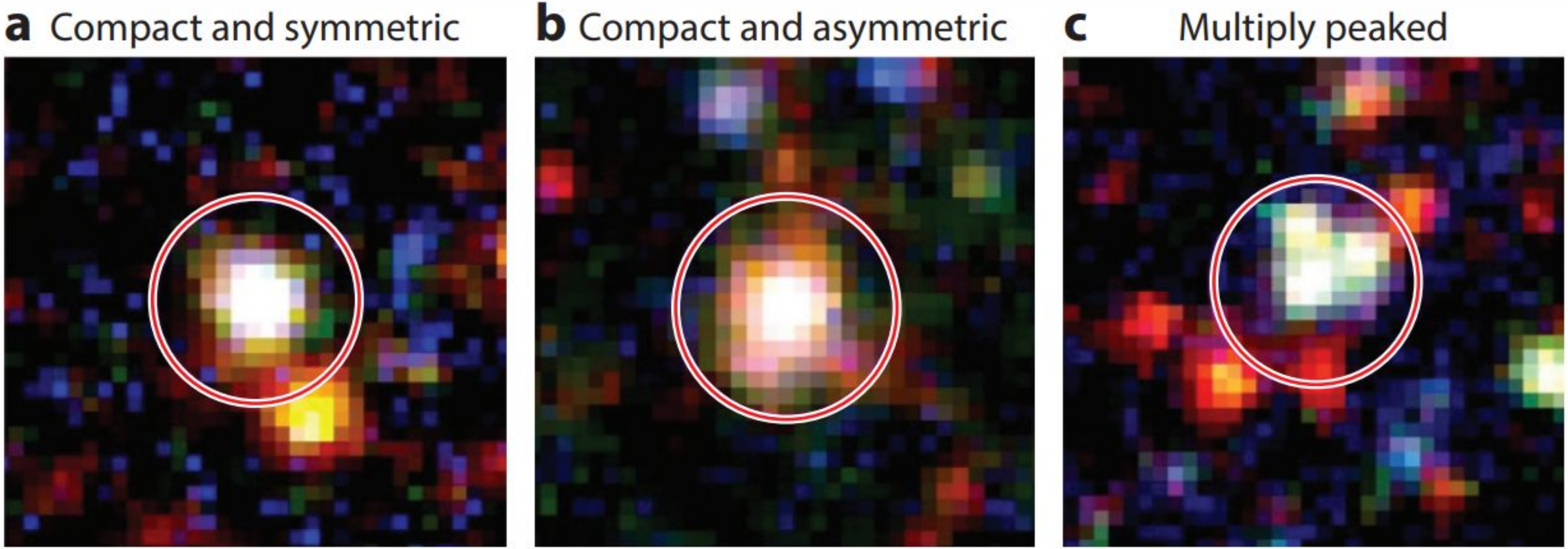
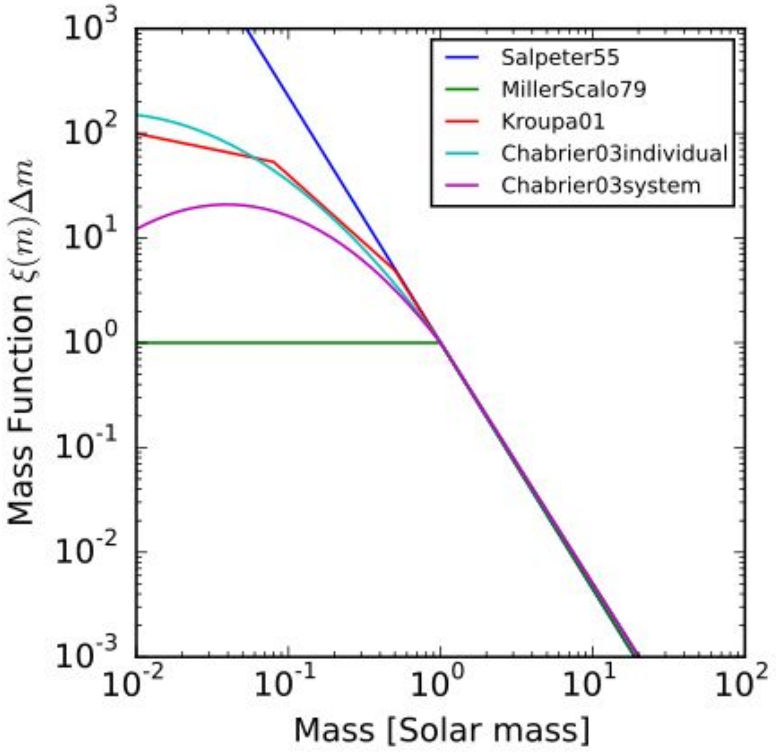


Figure 4

Examples of unresolved clusters of different morphological classes. Each panel shows a three-color UBV image of a star cluster in NGC 628. The ring shows a radius of 0.28 arcsec, approximately 13.4 pc at the distance of NGC 628. The morphologies are classified as (*a*) compact and symmetric, (*b*) compact and asymmetric, and (*c*) multiply peaked. An exclusive catalog, in the sense used in this review, would include the two objects in panels *a* and *b* but exclude the one in panel *c*, whereas an inclusive catalog would include all three. A comparison with **Figure 2** suggests that the Orion Nebula Cluster might well be excluded from an exclusive catalog. Figure adapted from Adamo et al. (2017), copyright AAS.

Initial Mass Function

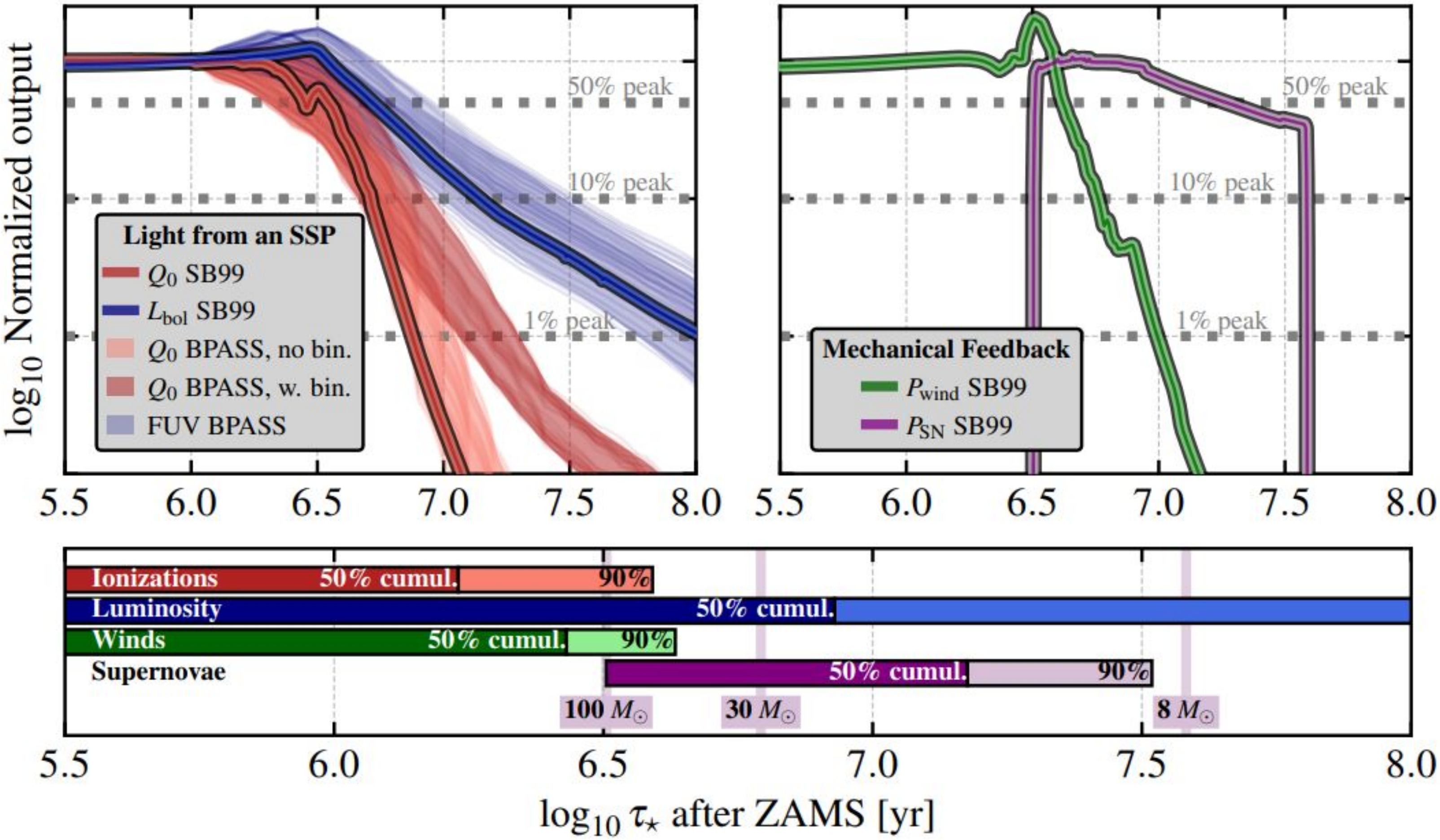
- The vast majority of ionizing photons come from OB stars
- The initial mass function defines the distribution of stars of different masses created from some input mass.
    - I.e., one would expect far less O or B stars than K and M stars



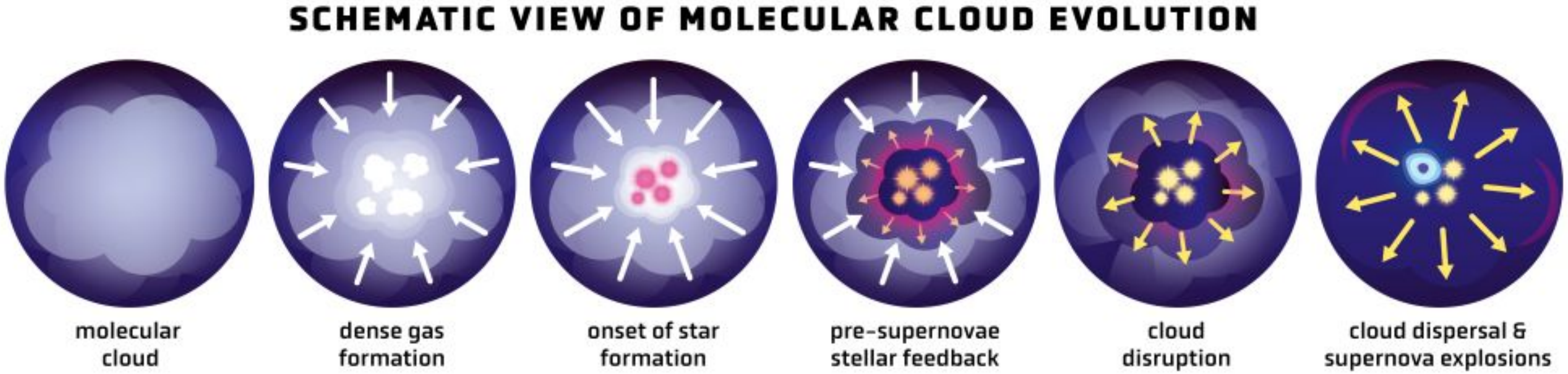
HII Regions and Cluster Populations

- For a SSP from a *fully-sampled* IMF, ionizing photons are produced at a rate of 10^{46} per second per solar mass.
- Ionizing photons heat the star forming clouds to 10,000K, and expand the HII region
- If not trapped by surrounding material or the clusters own gravity, the gas will flow outward and burst into the ISM in a process known as champagne flow.

Schinnerer & Leroy 2024

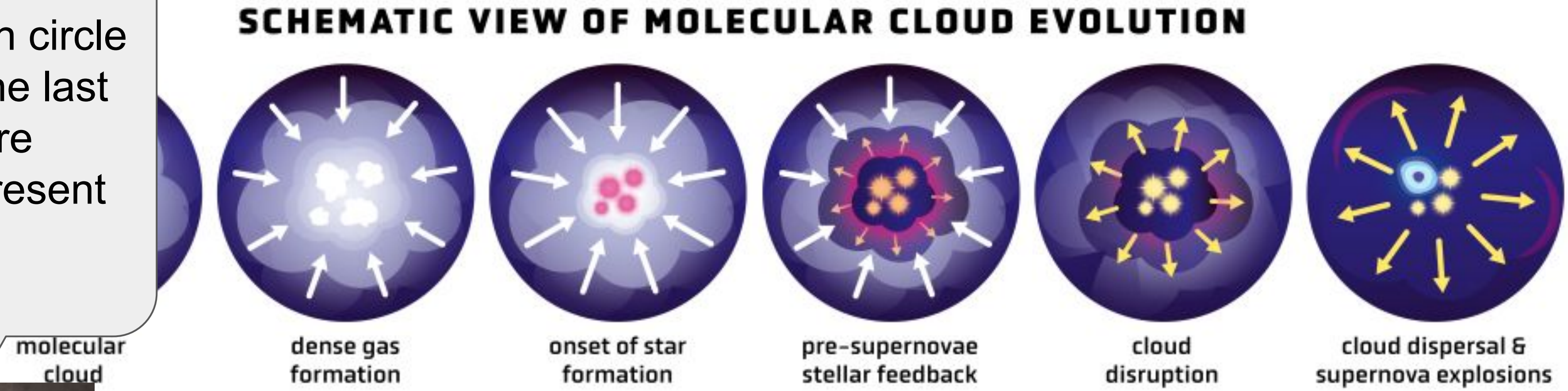


Schinnerer & Leroy 2024



Schinnerer & Leroy 2024

Dr. Dale says: The cyan circle in the last figure represent SN!



Undersampling IMF

- For clusters of masses lower than $10^4\ M_\odot$, the IMF is *undersampled.*
- What does this do to our amount of PAH-exciting ionizing photons?

Cluster Mass Function

Probability distribution function of observed mass distribution of star clusters:

$$dN/dM \propto M^{\alpha}$$

In normal star-forming galaxies, the mass function slope (α) is generally measured over the range of ≈10^3–10^5 $M_\odot$

If we are undersampling the IMF for clusters of masses lower than 10^4 $M_\odot$, how does this affect the value of α we determine for a galaxy?

Cluster Age Function

$$\frac{Probability\ destroyed}{T} = \frac{1}{aT}$$

Where T=Time, N=Num Clusters

$$\frac{dN}{dT} = \frac{-N}{aT}$$

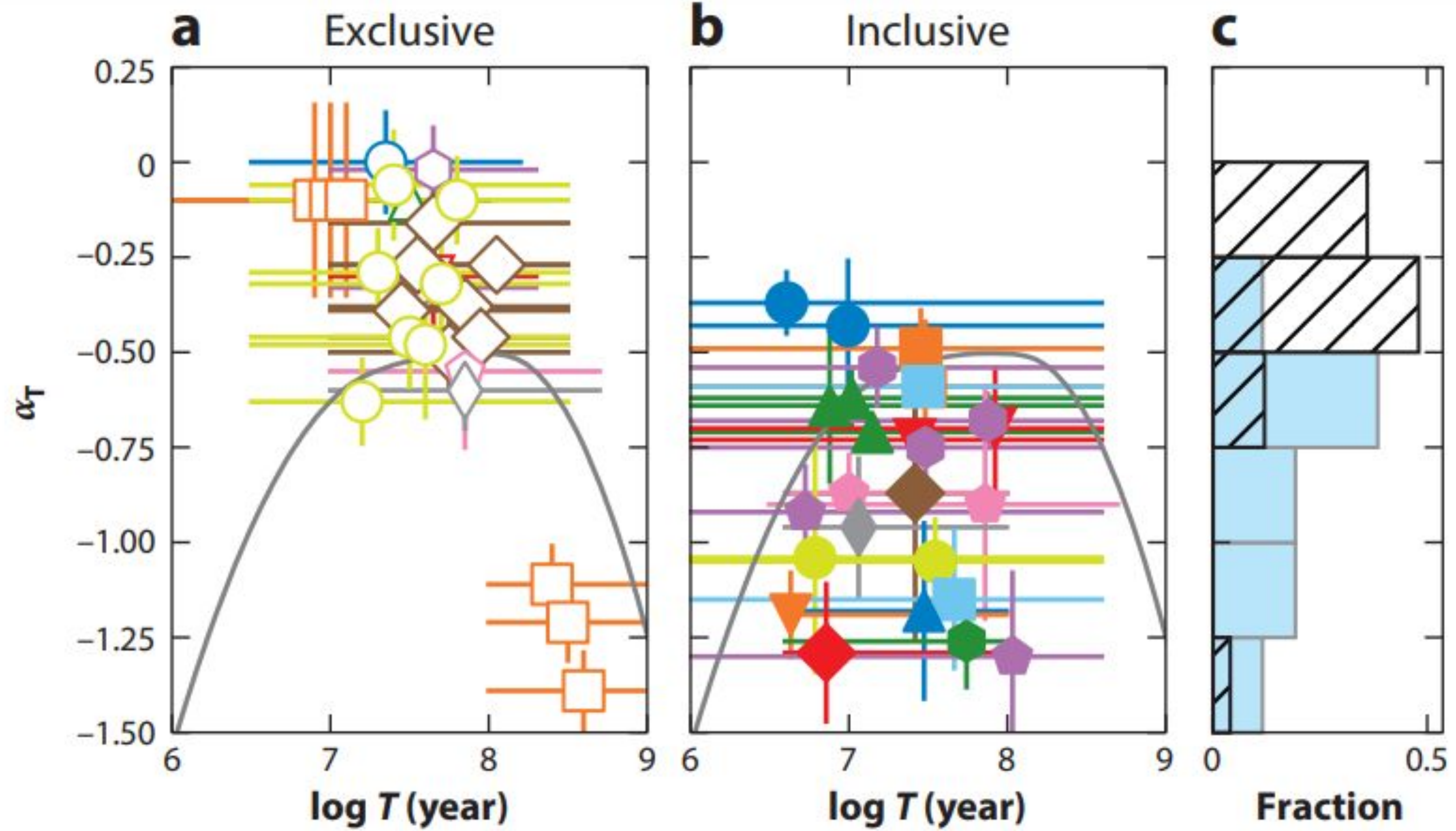
$$N = N_0\left(\frac{T}{T_0}\right)^{-\frac{1}{a}} = N_0\left(\frac{T}{T_0}\right)^{-\alpha_T}$$

Thus…

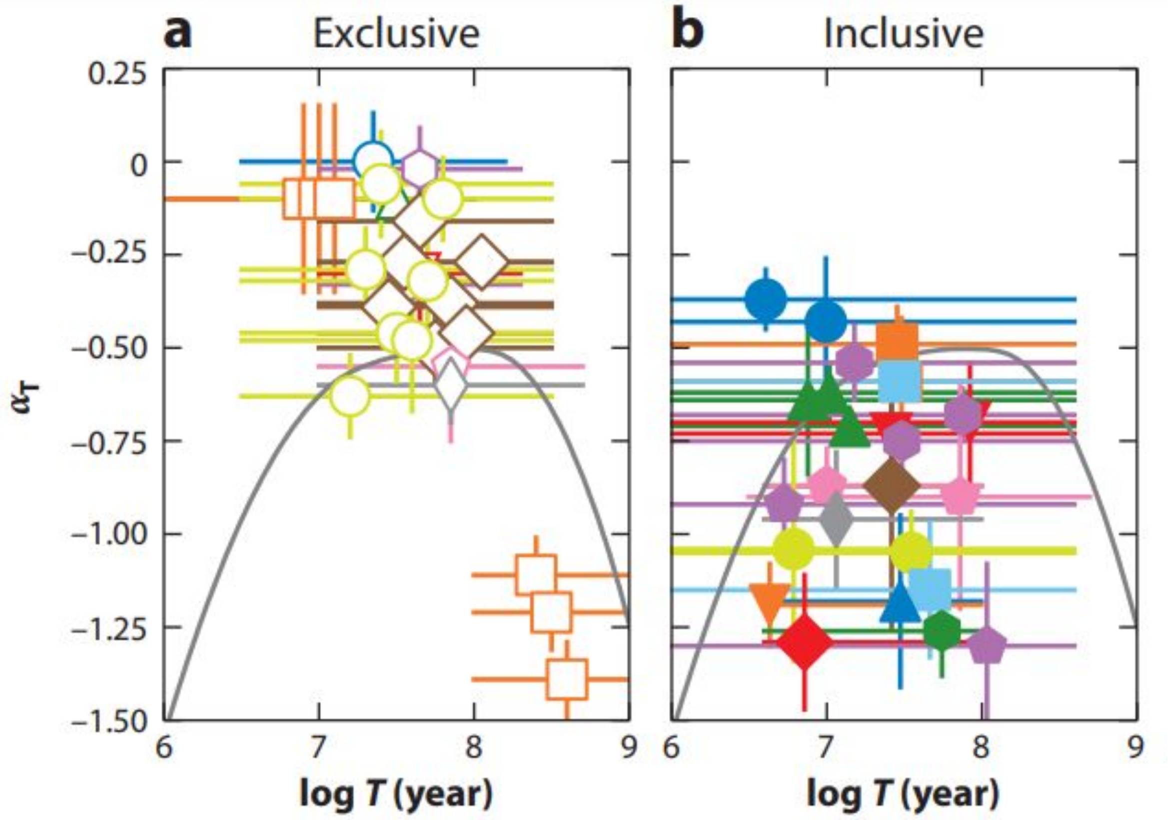
- As $\boldsymbol{\alpha}_T$ approaches 0, clusters liver a lot longer than their current age
- If $\boldsymbol{\alpha}_T$ = -1, the average time to destroy a cluster is equal to its current age

$$N = N_0\left(\frac{T}{T_0}\right)^{-\frac{1}{a}} = N_0\left(\frac{T}{T_0}\right)^{-\alpha_T}$$

CAF on Inclusive and Exclusive Cluster Surveys

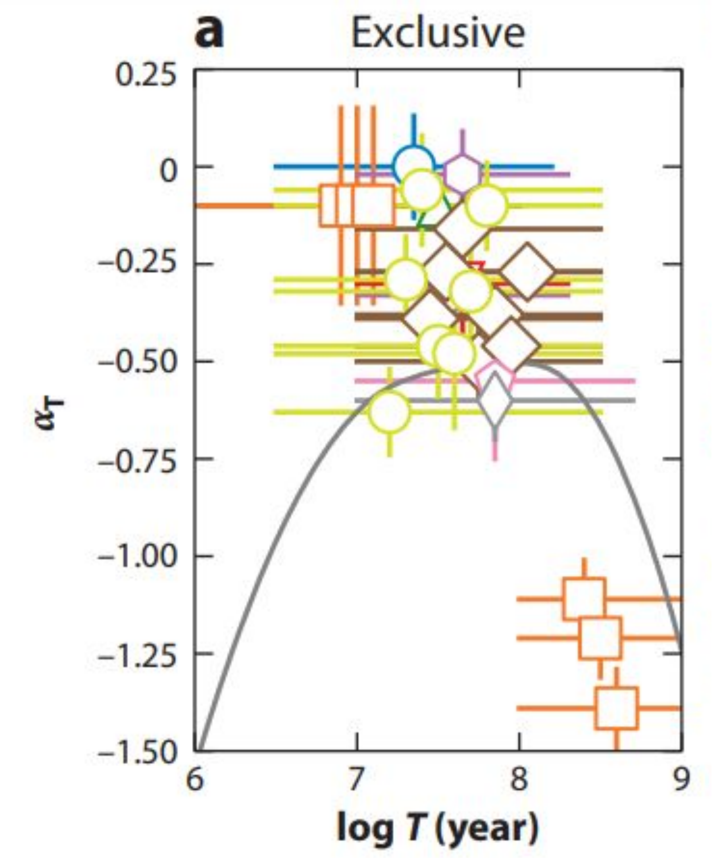


CAF on Inclusive and Exclusive Cluster Surveys

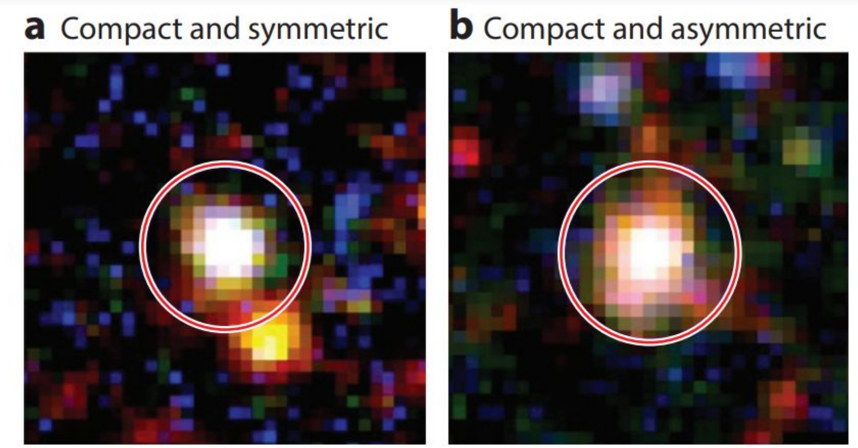


Exclusive catalogs suggest that clusters have long survival times compared to their current ages, whereas inclusive catalogs imply survival times comparable with cluster ages

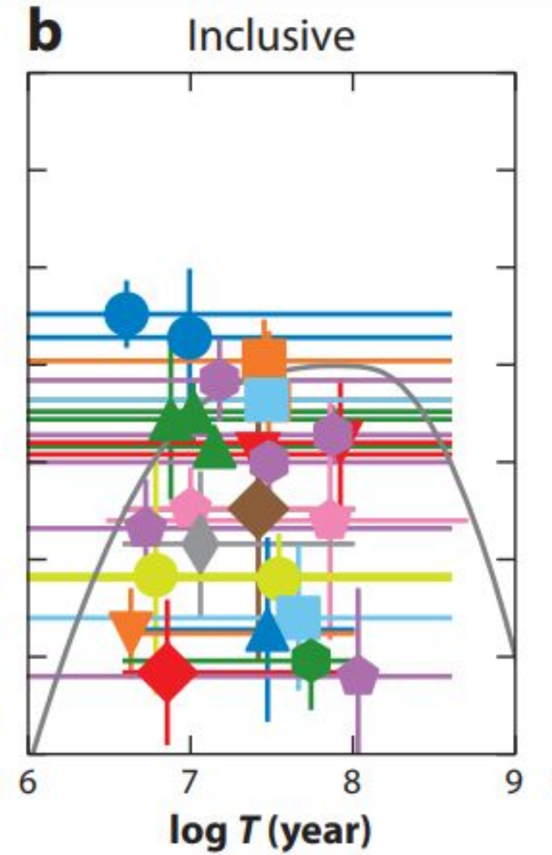
CAF on Inclusive and Exclusive Cluster Surveys



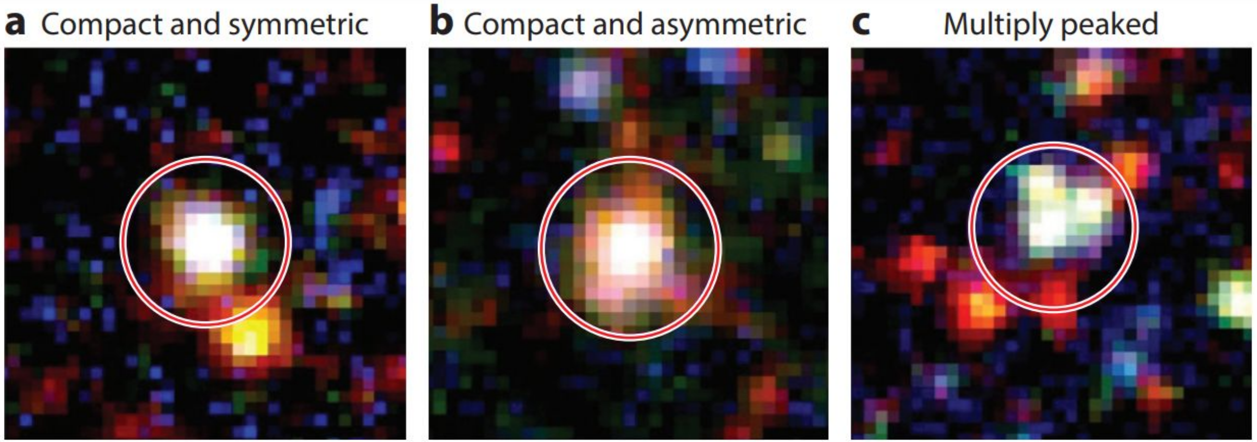
When we exclude extended sources in *Exclusive* catalogs, we exclude older clusters that have drifted apart more, biasing our sample to younger clusters



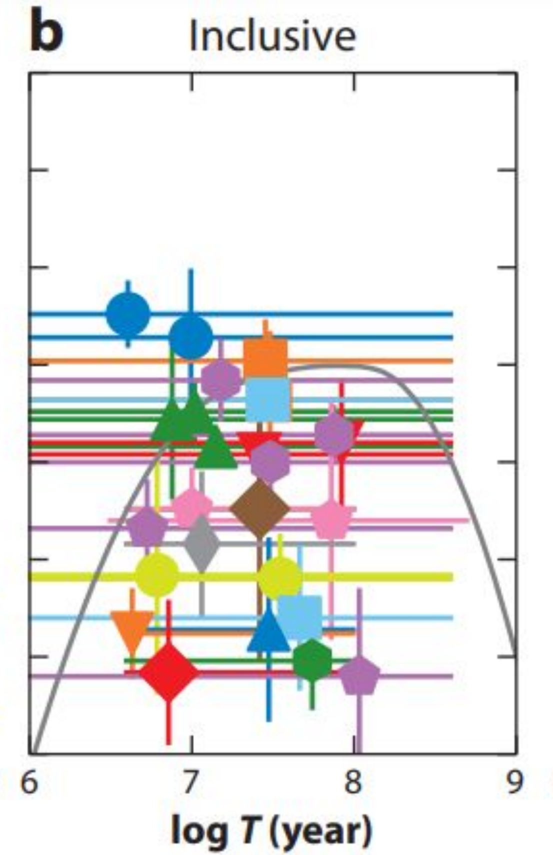
CAF on Inclusive and Exclusive Cluster Surveys



Conversely, when we include extended sources in *Inclusive* catalogs, we retain those older clusters that have drifted apart more



CAF on Inclusive and Exclusive Cluster Surveys



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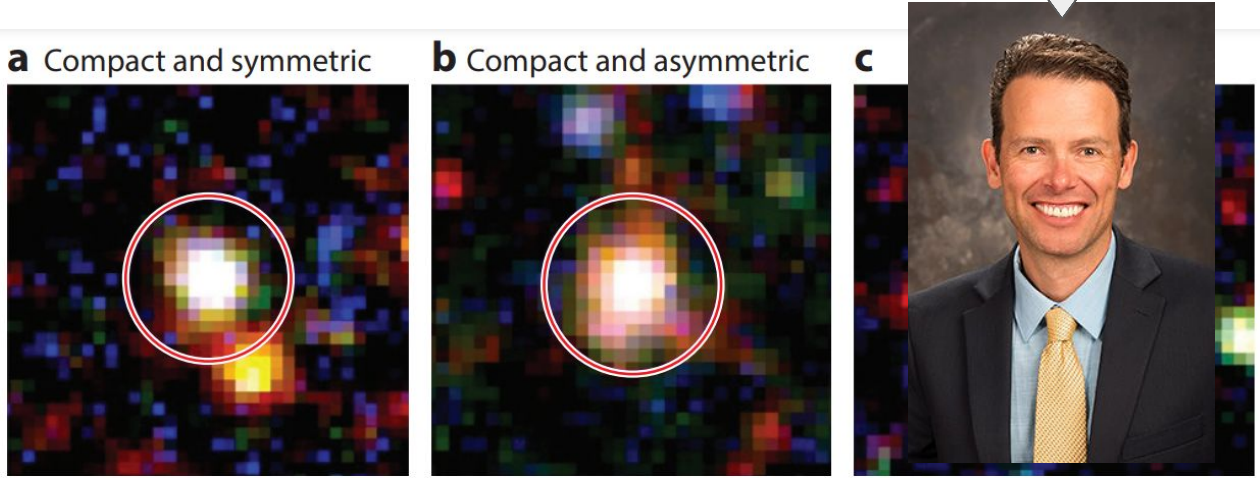
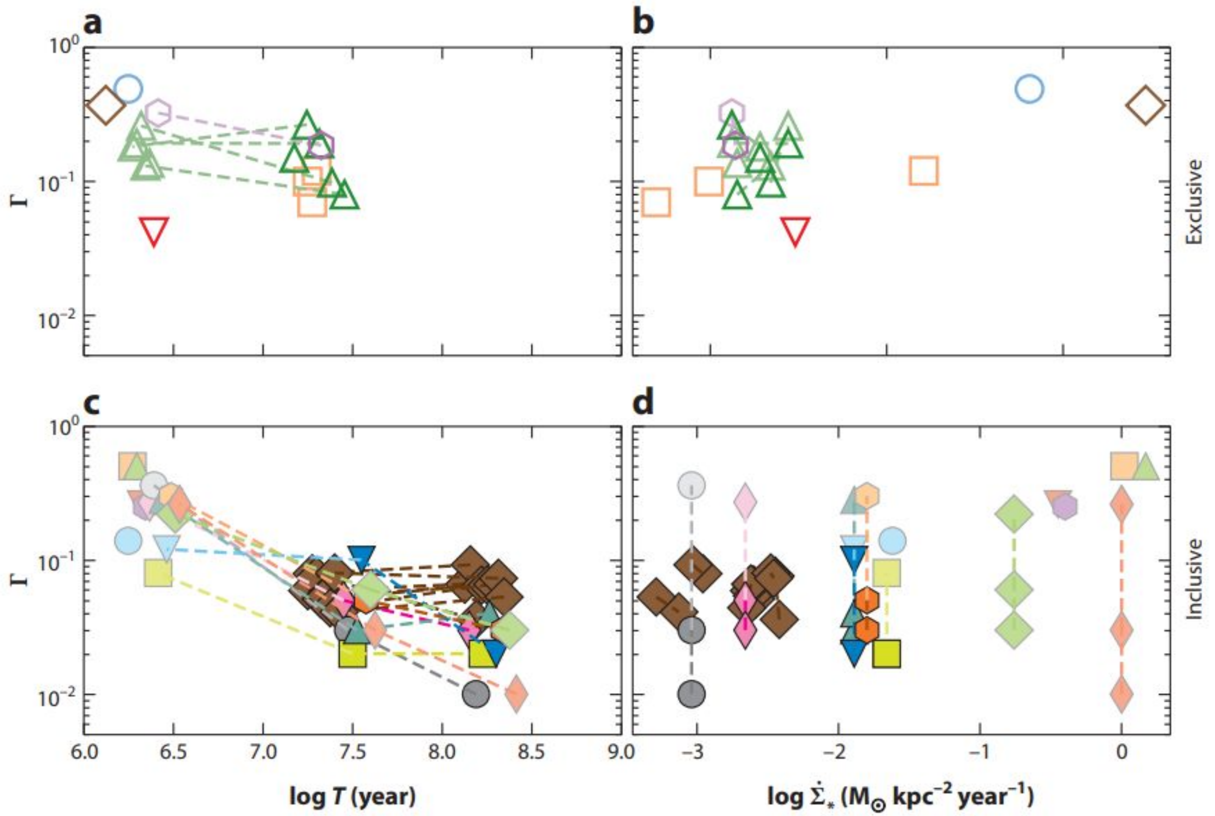
Dr. Dale says: The MW's α_T is ~-0.5!



Bound Mass Function

- Γ = The total amount of stellar mass bound in a cluster
- Changes as a function of time due to stellar winds leaving the cluster
- For ages <10 Myr, Γ becomes unreliable.
  - These are more likely to be heavily contaminated by the presence of non-bound structures that have simply not yet had time to disperse.



(a,b) values taken from exclusive catalogs, (c,d) from inclusive. Measurements in multiple age ranges are connected by dashed lines. Faded points are dubious measurements, <10Myr

JWST and CMF, CAF, and Γ

- Cluster mass, age, and Γ all have significant uncertainties when determined photometrically.
- JWST can give more accurate CMDs for nearby clusters
  - Still struggles with unresolved clusters as IR cluster color is fairly constant >6 Myr, as it is dominated by red giants
- Cigale…?