Formation of the first massive star clusters and their feedback on galaxies at \( z > 3 \)

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with Andrey Kravtsov (Chicago), Jose Prieto (Ohio State), and Sasha Muratov (Michigan)
every old cluster was young sometime

how?
when?
where?
globular clusters are old and low (but non-zero) metallicity
globular clusters are dense

Average density at half-light radius $\sim 10^2 - 10^5 \, M_\odot \, \text{pc}^{-3}$
The Monoceros R2 Molecular Cloud Complex
Use hydrodynamic simulations to find molecular clouds

300 kpc (physical)

14 kpc

20 pc

Kravtsov & OG (2005)
Masses and sizes of model GCs are in excellent agreement with the observations of young clusters.
young star clusters in the Galaxy form in self-gravitating cores of molecular clouds with $\rho_{\text{gas}} > 10^4 \, M_\odot \, pc^{-3}$

these cores contain only a few % of the H$_2$ mass $\Rightarrow$ globular clusters probe the highest peaks of the density field
Globular clusters at redshifts above 3 or 4?
peak of global SF

density!
metallicities at $z > 3$ are barely high enough for blue GCs

large range of metallicities of GCs formed at the same epoch: up to two orders of magnitude
Dynamical evolution removes most low-mass clusters

Jose Prieto & OG (2007)

Stellar evolution + relaxation + tidal shocks

final/initial mass = 0.46  final/initial number = 0.16
Mergers of host galaxies of GCs result in a spheroidal distribution of the overall GC system \textit{now}.

Number density is consistent with a power-law, slope $\approx -2.7$

(observed $\approx -3$)
Luminosity-metallicity distribution is also ok

Sasha Muratov & OG, in prep.
Feedback of young star clusters on their host galaxies

Young clusters for 5 Myr after formation have ionizing luminosity $\lambda L_{\lambda} \sim 10^8 L_\odot$ ($\sim 10^7 L_\odot$ for 10 Myr)

Luminous O and B stars ionize and heat the high density regions of parent molecular cloud. Subsequent supernovae expand into the reduced density, partially ionized medium $\Rightarrow$ superbubbles

$$M_{\text{all GC}} \sim 3 \times 10^6 M_\odot \left( \frac{M_{\text{halo}}}{10^{11} M_\odot} \right) \sim 3 \times 10^6 M_\odot \left( \frac{M_{\text{bar}}}{10^{10} M_\odot} \right)$$

Young GCs can be directly detected in Ly$\alpha$ searches (for low [Fe/H] not much absorption by local dust)
– analogs of local super-starburst regions [Roderik Overzier talk]

Most massive clusters contain most massive stars:

- Likely sites for gamma-ray bursts and hypernovae
- Intermediate-mass black holes (gas accretion may lead to mini-quasars)