Dense Star Clusters from Multi-scale Simulations of Magneto-turbulent Molecular Clouds

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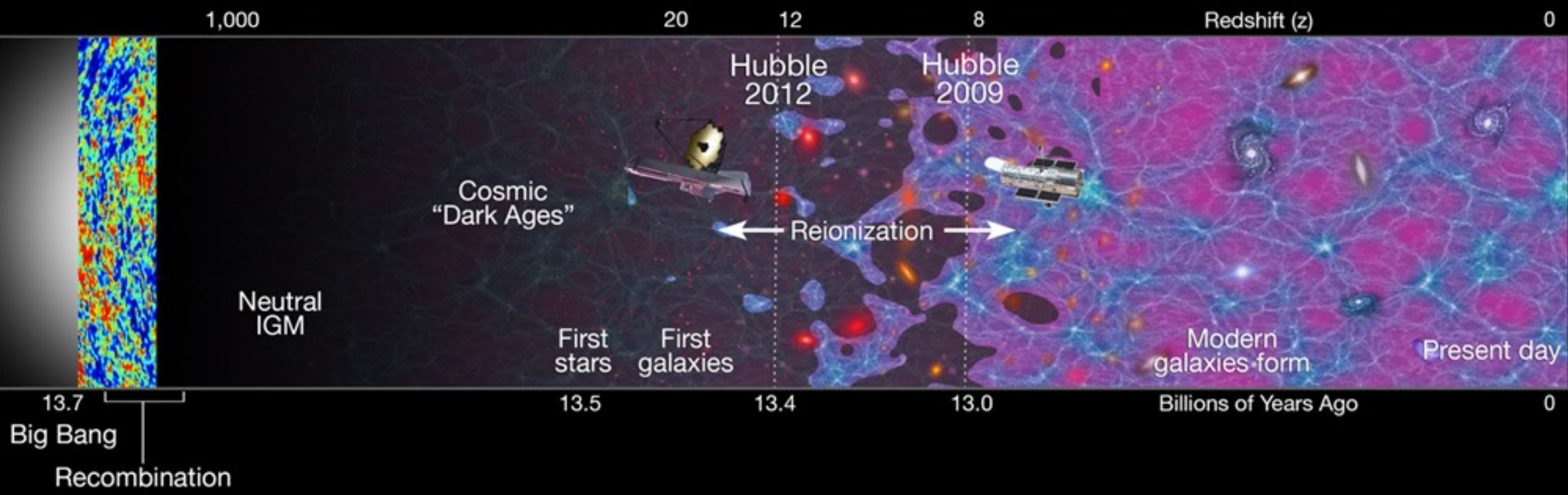
“Illuminating Galaxy Formation with Ancient Globular Star Clusters and Their Progenitors"
Tue, Mar 15, 2022



- What reionized the universe? How much do globular clusters contribute to cosmic reionization?
- How to probe it with JWST?

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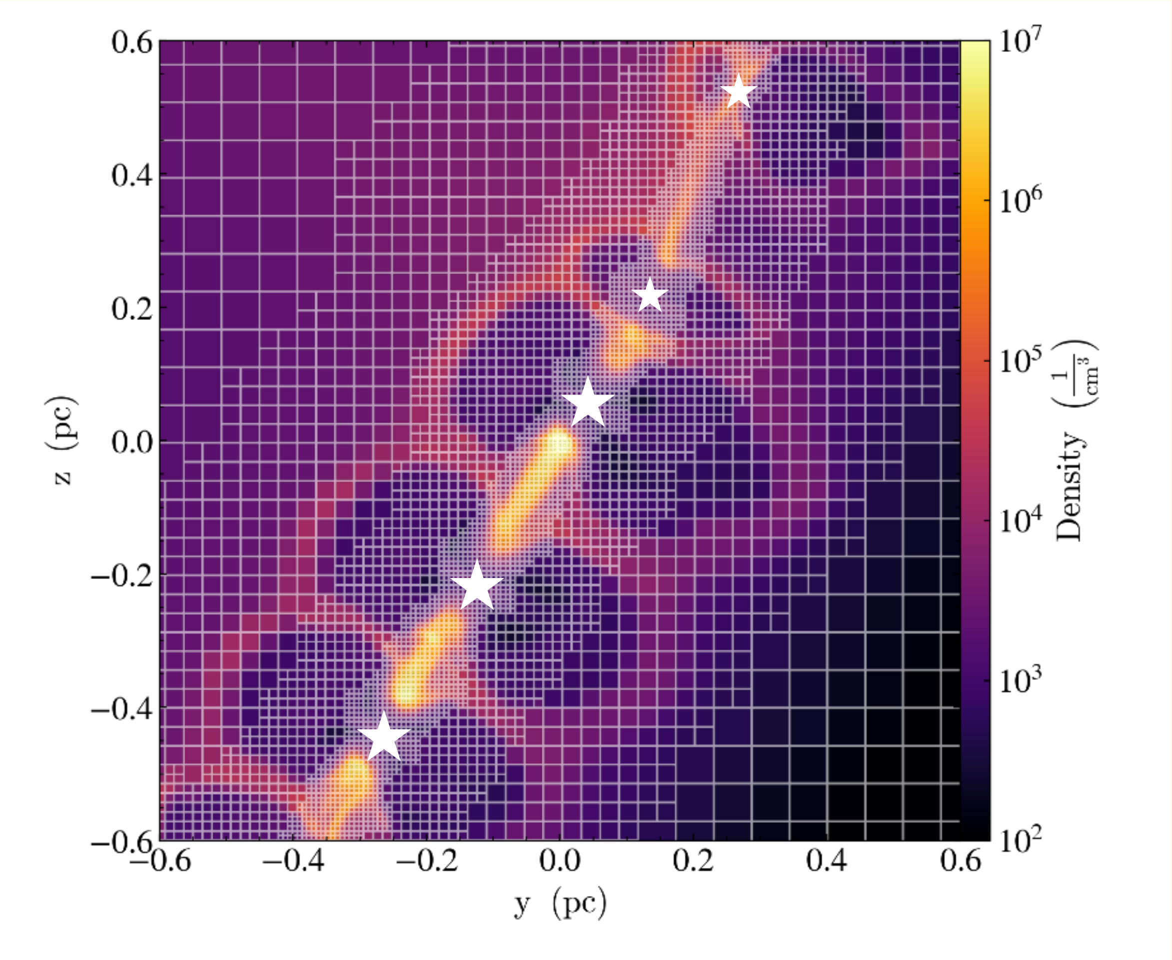
- Q: **Can globular cluster progenitors contribute a significant fraction of ionizing photons?**
  - How abundant are globular cluster progenitors as a function of luminosity and redshift?
  - **How many ionizing photons escaped from these clusters into the IGM?**

Method: Simulating star cluster formation from GMCs

RAMSES: MHD + UV feedback + (out of equilibrium) cooling + heating due to radiation

Adaptive Mesh Refinement and UV feedback



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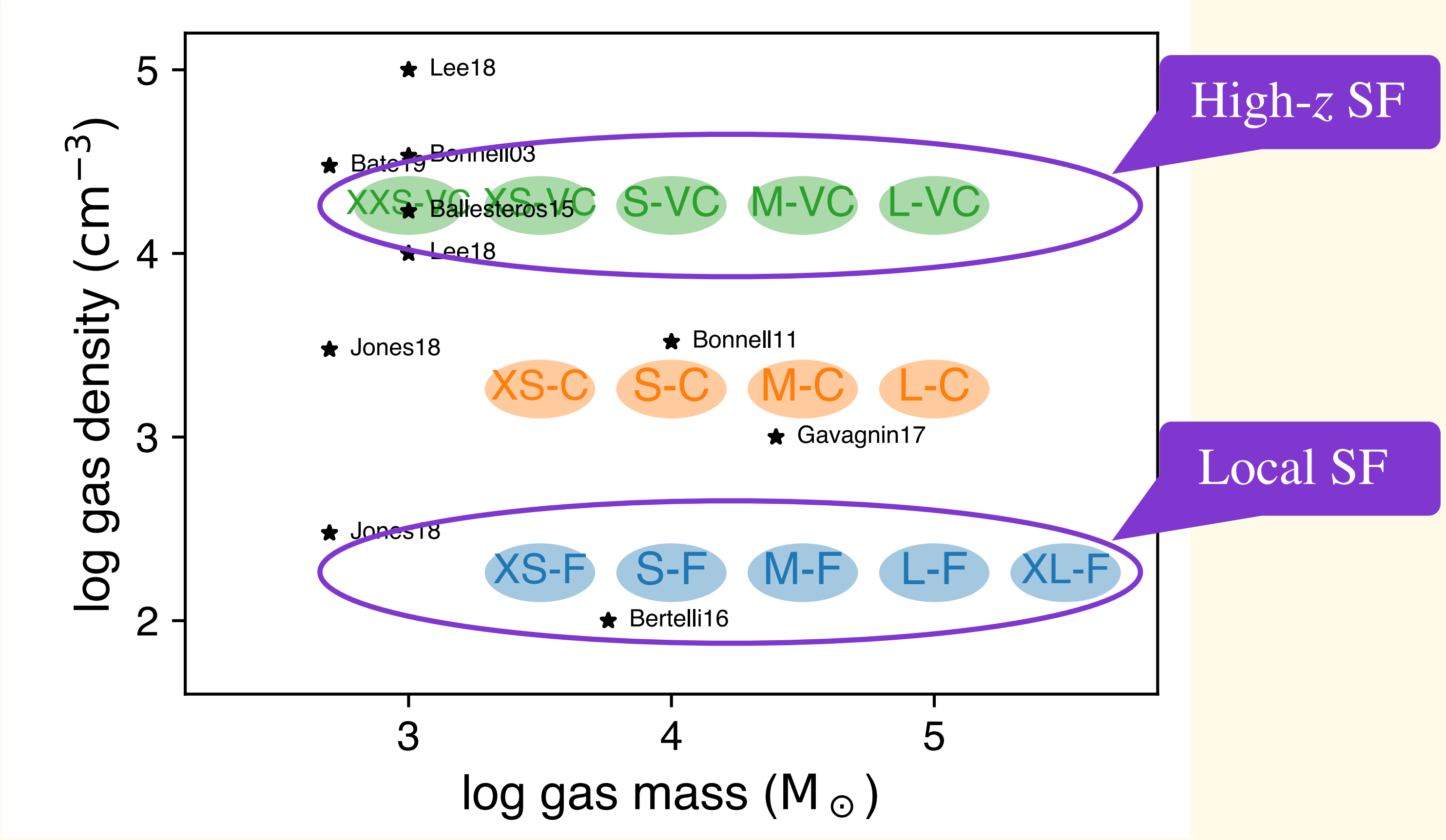
Grid of simulations



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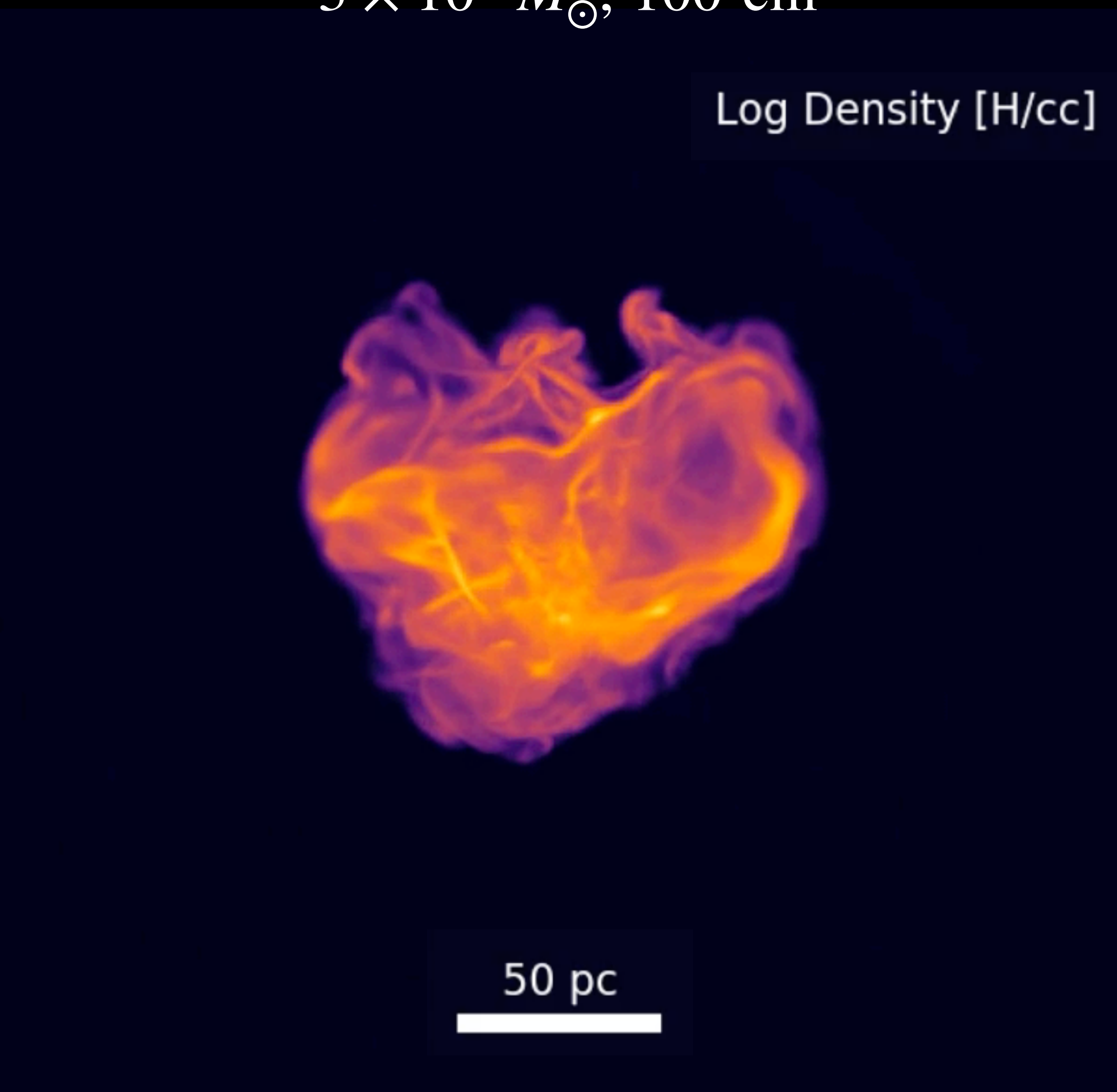
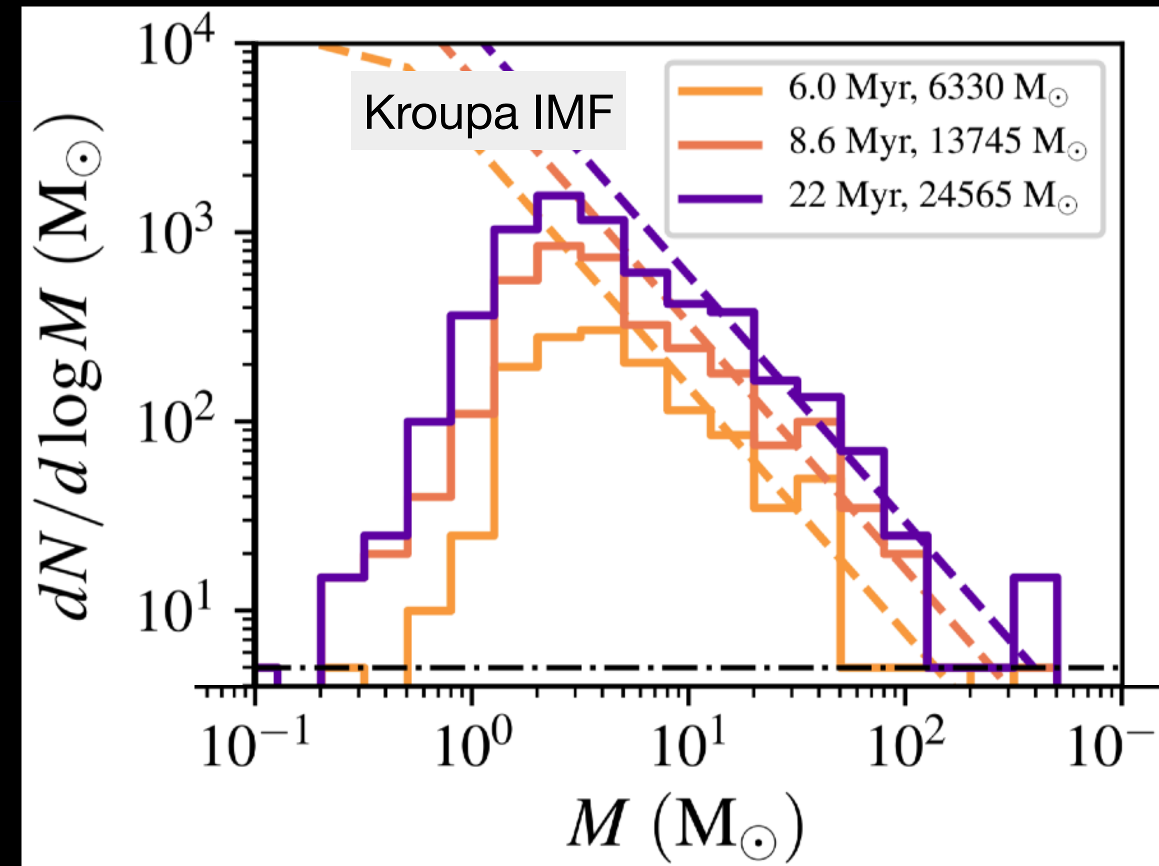
$3 \times 10^5\ M_\odot$, $100\ \mathrm{cm}^{-3}$





- Reproduces Kroupa IMF at high mass end ($\gtrsim 2\ M_\odot$) of the mass function
- The MF resembles Kroupa IMF at any time during star formation (Universal to the whole grid of simulations.)
- Low-mass stars form first followed by low-mass and high-mass stars.

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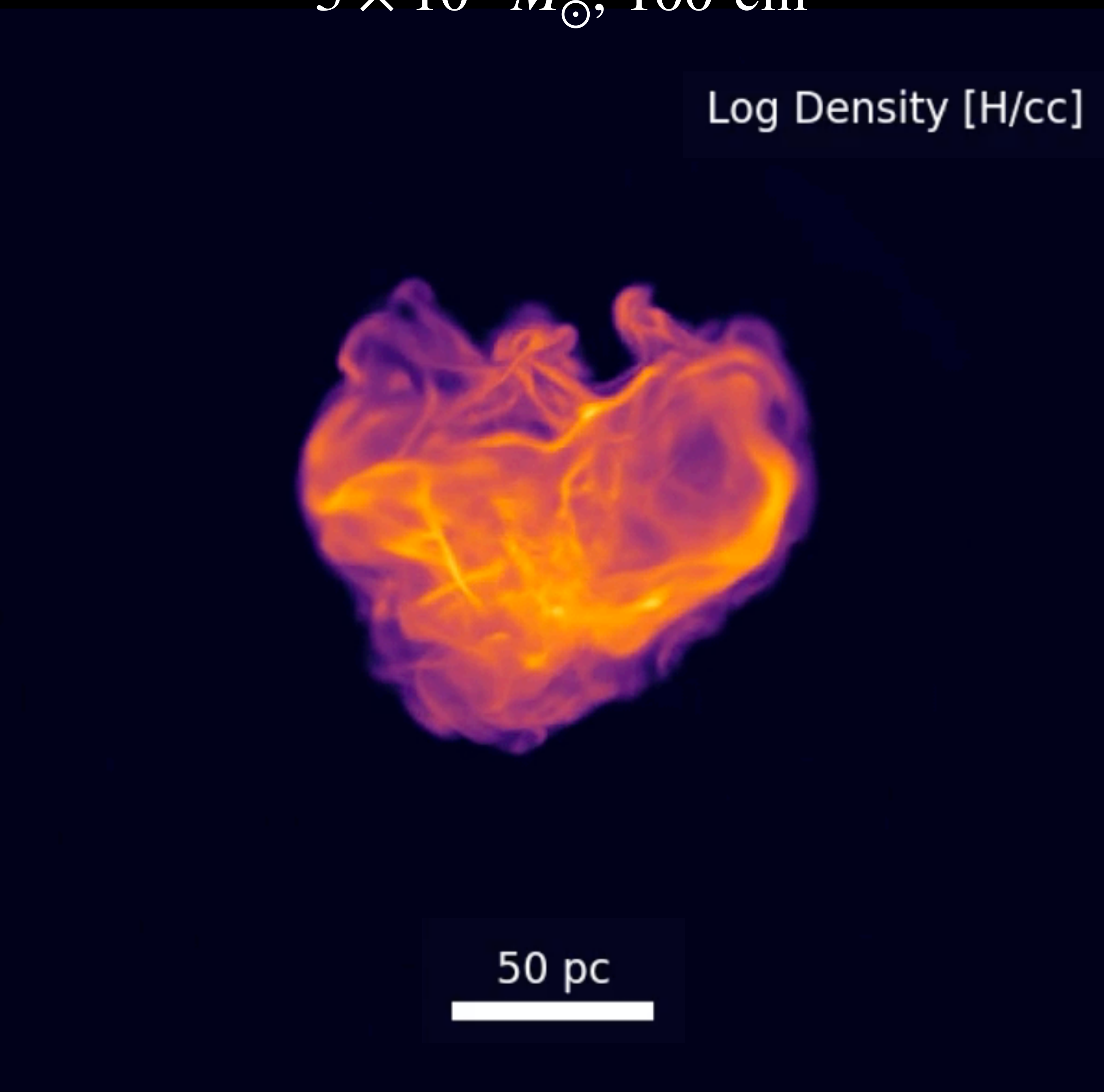

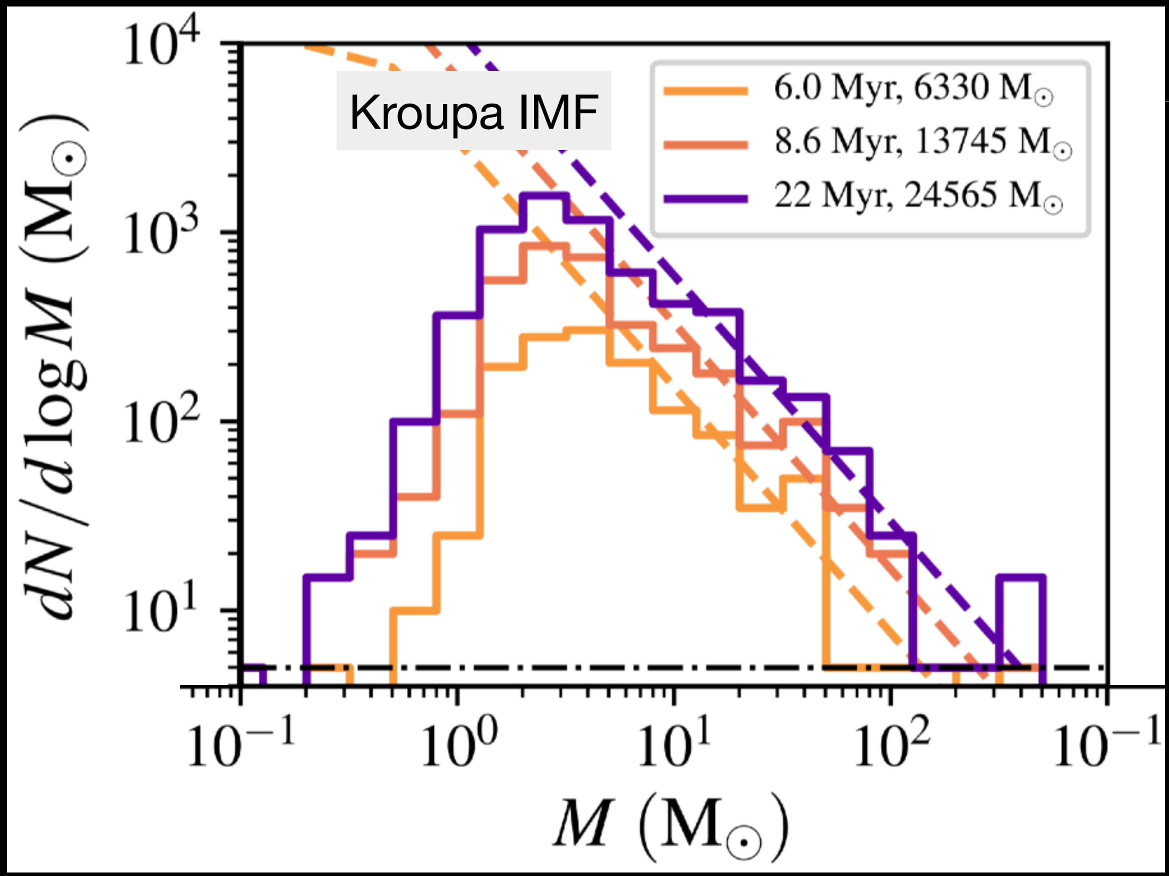

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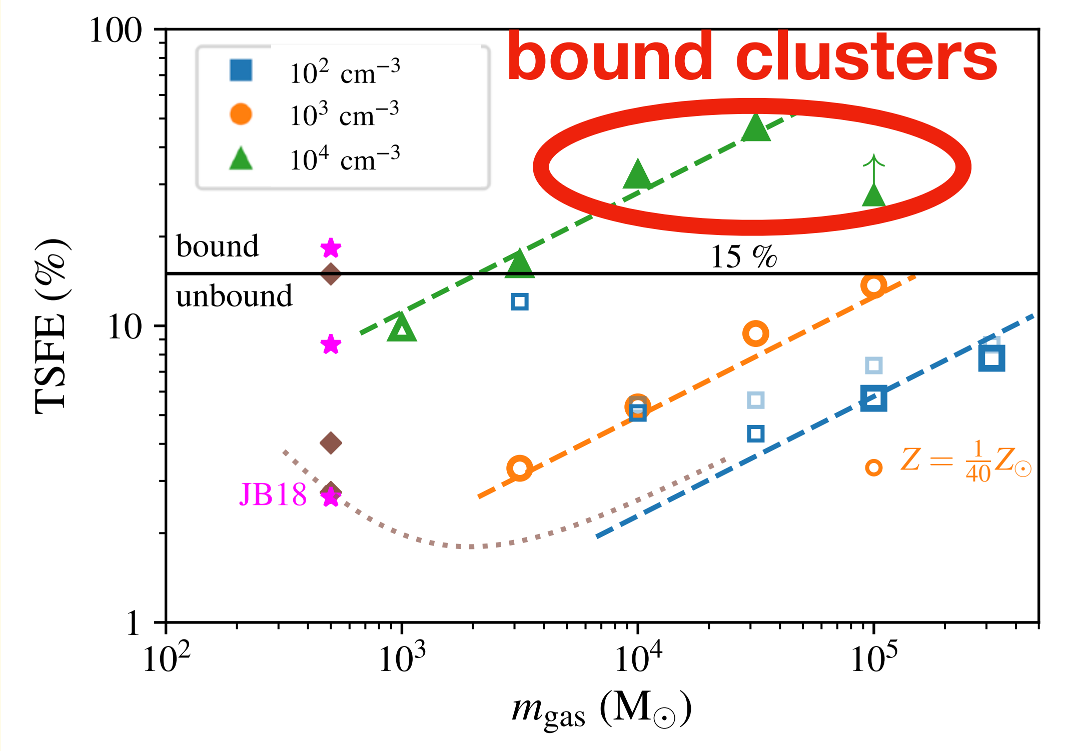

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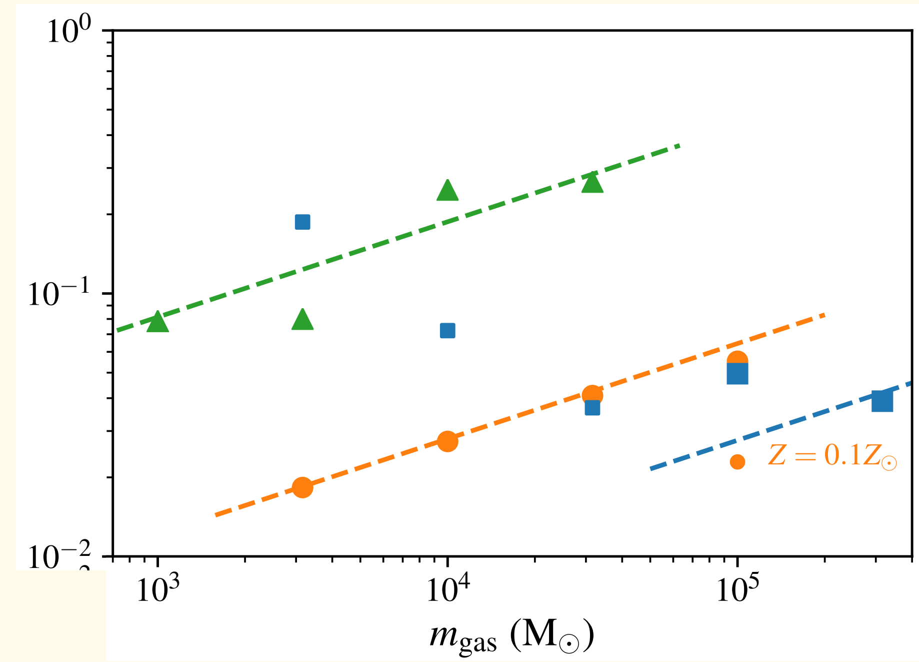
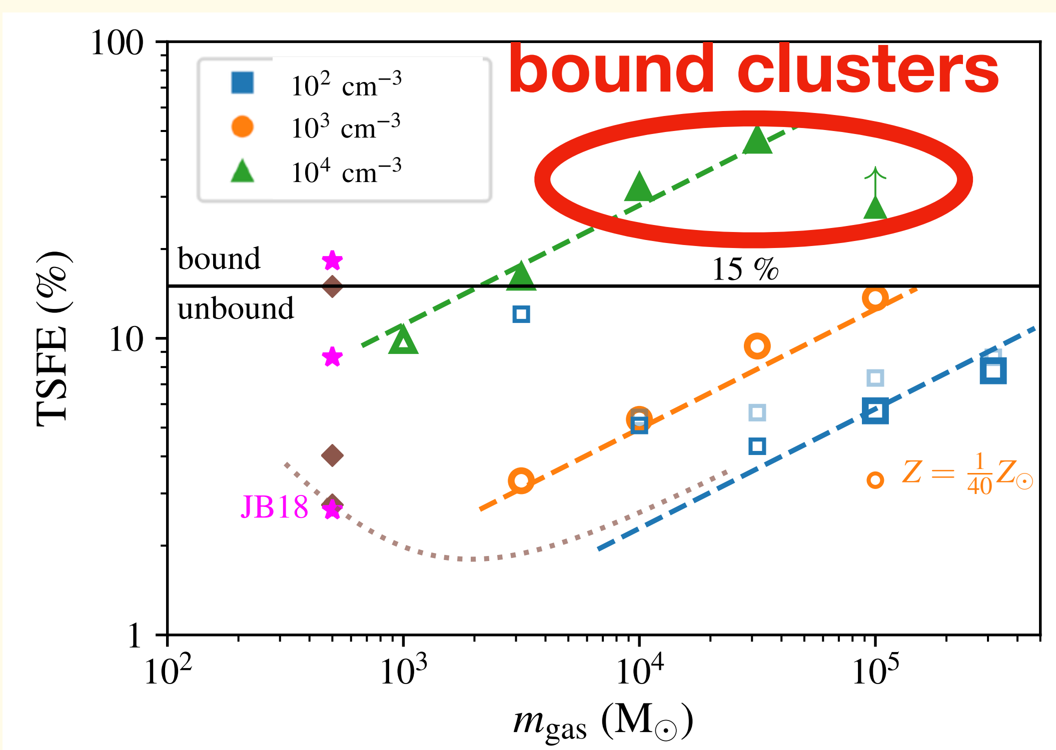
What GMCs are able to give birth to GC progenitors?

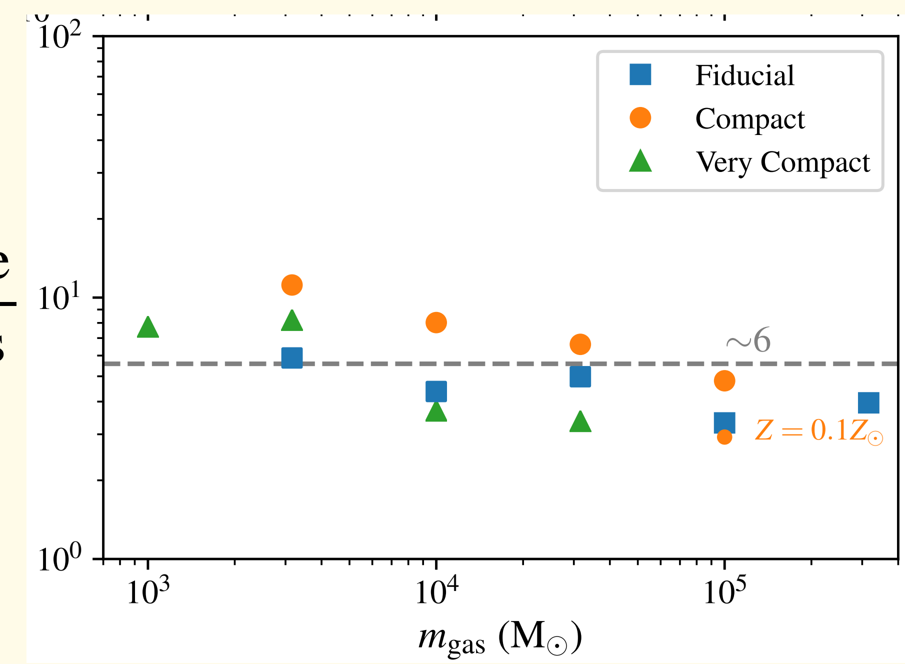
- $t_{SF} \approx$ a few $\times\ R\ /\ 10$ km/s
- $t_{ff} \approx R\ /\ v_{esc}$
- $\tau_{SF} \equiv t_{SF}/t_{ff} \sim$ a few times $\dfrac{v_{esc}}{10\ \text{km/s}}$
- SFE $= \tau_{SF}\ \epsilon_{ff} \propto v_{esc}\ \epsilon_{ff}$
- **Dense and massive GMCs with high escape velocities are efficient at converting gas into stars and form globular cluster progenitors**

$2\epsilon_{ff}$





$\dfrac{\text{SF timescale}}{R\ /\ 10\ \text{km/s}}$



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So, what fraction of ionizing photons emitted by the star cluster escapes from its parental molecular cloud?

He, Ricotii & Geen 20’

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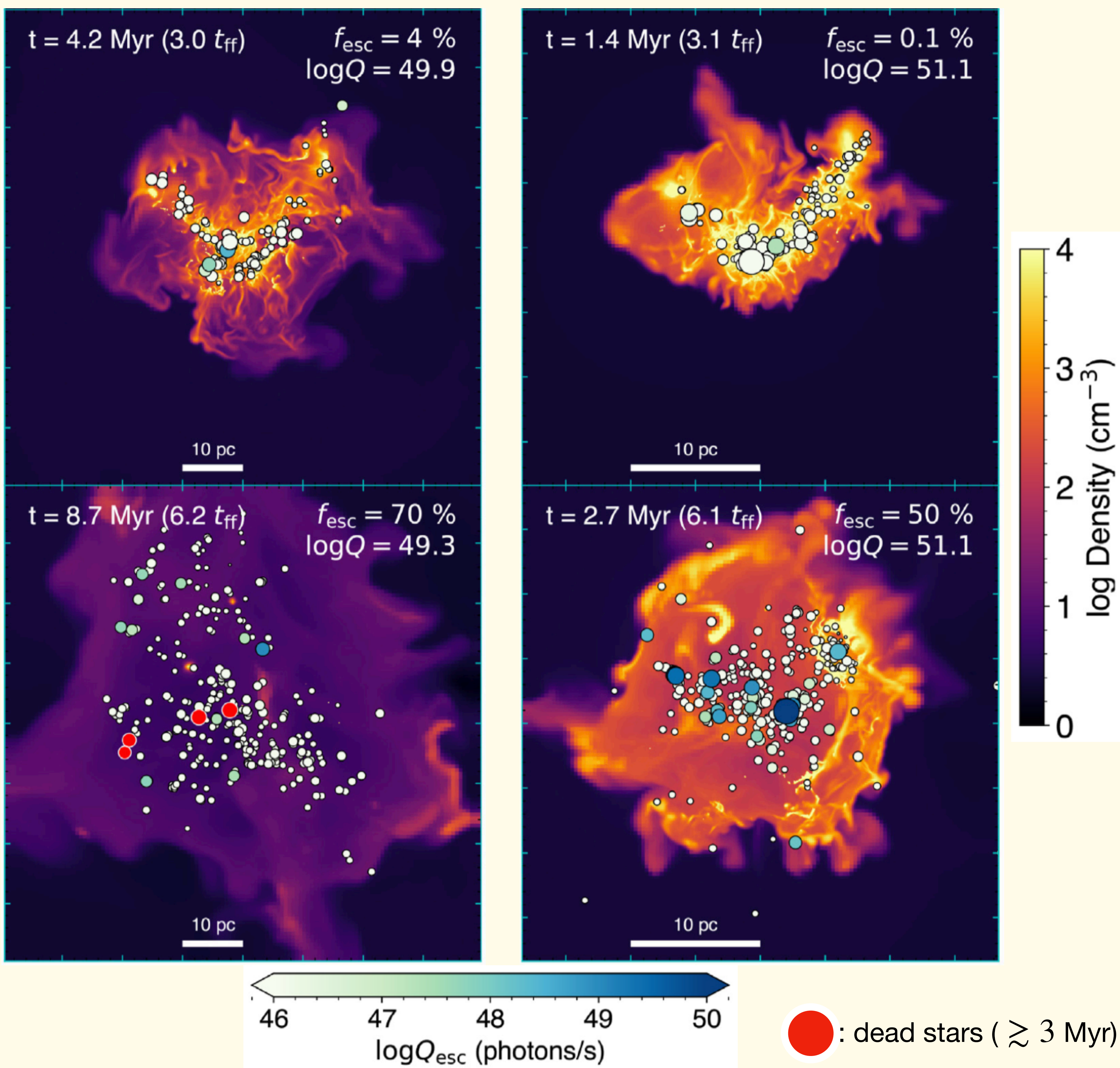
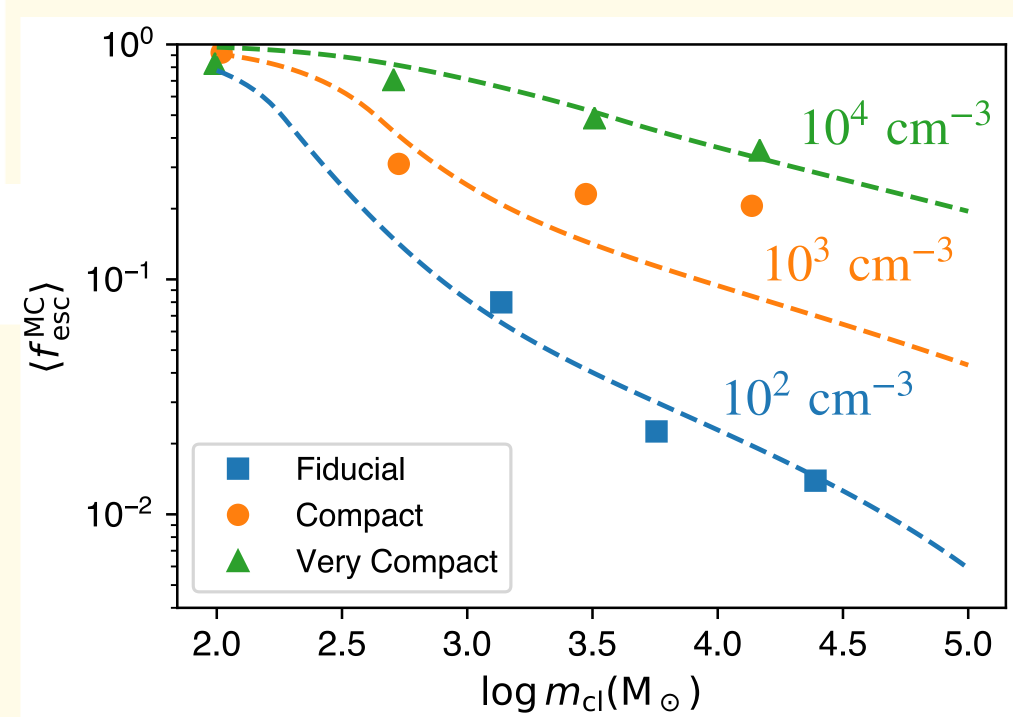
Less dense | More dense



- The quicker the stars are able to ionize and destruct the parental cloud, the higher the f_{esc} is.
- Since globular cluster progenitors form from compact GMCs with high f_{esc}, they could provide significant amount of photon budget for cosmic reionization.



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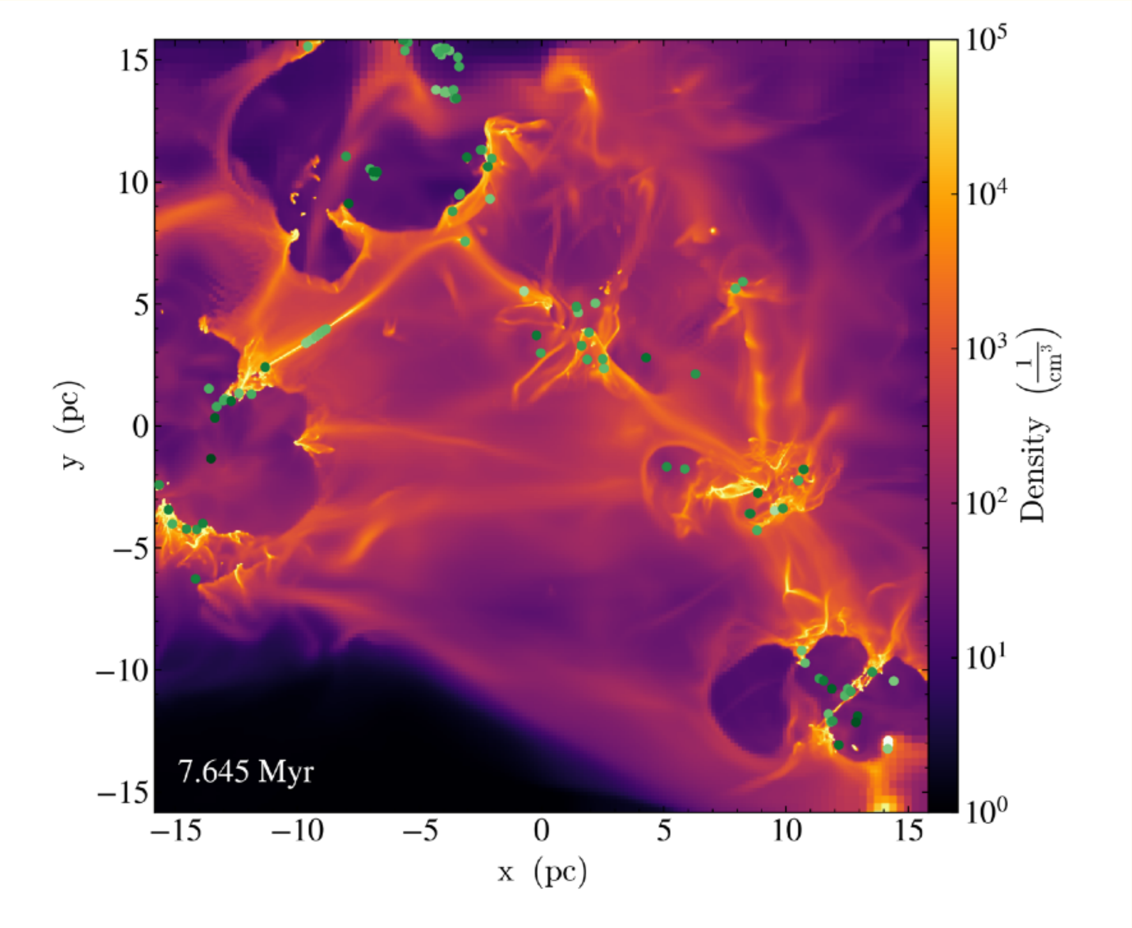
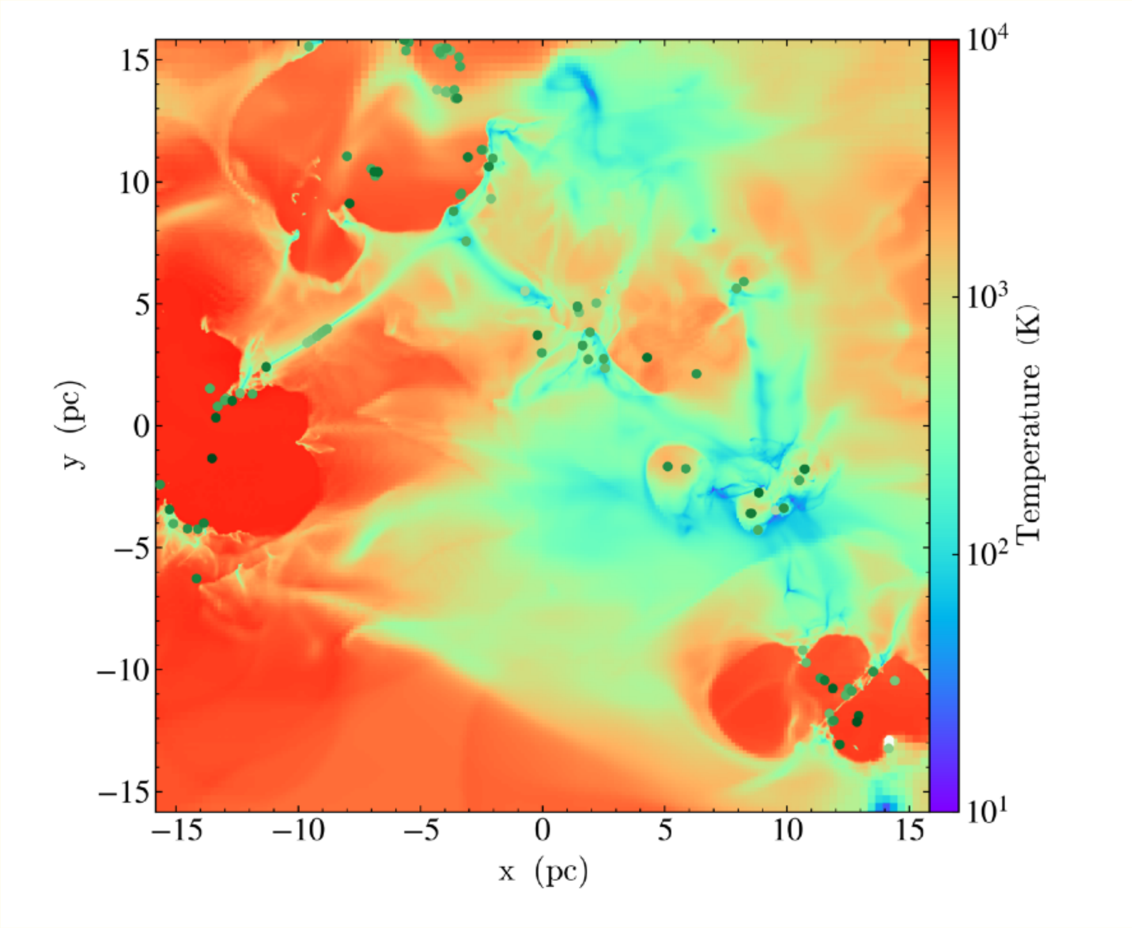
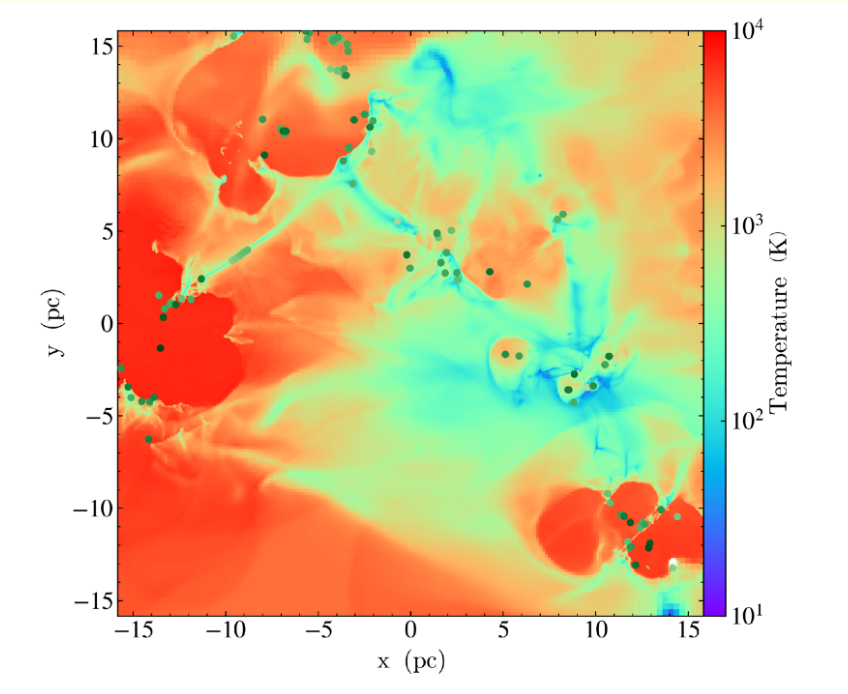
Part 2: How do we probe $f_{\rm esc}$ from dense star clusters at high-z with JWST?





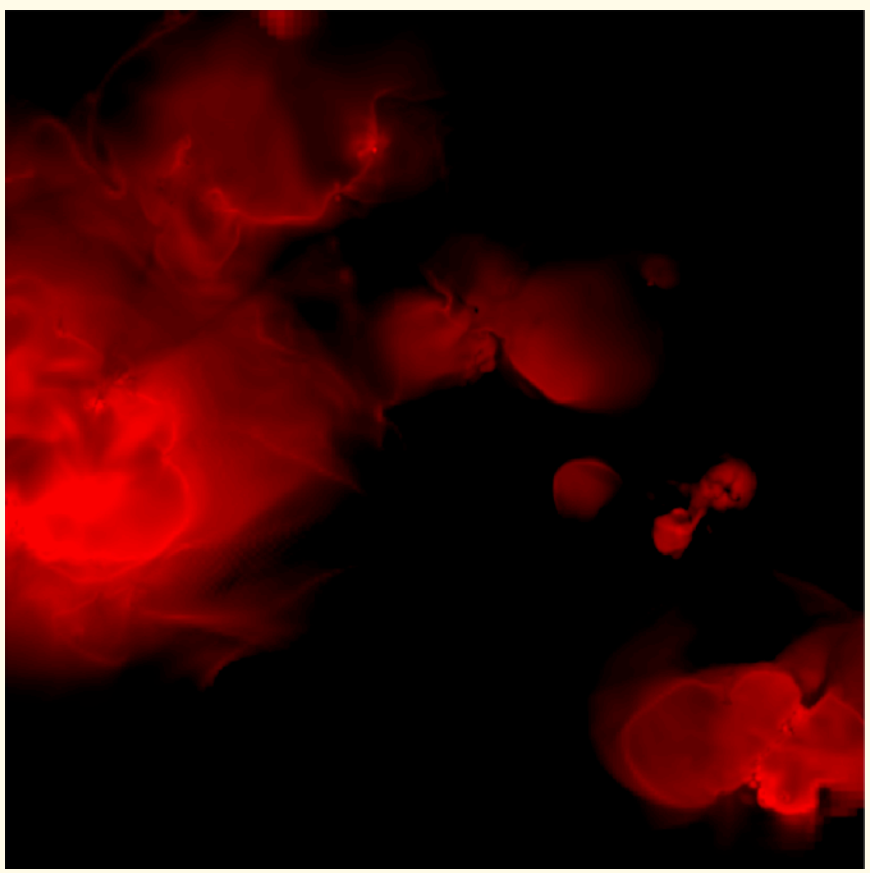
Temperature projection



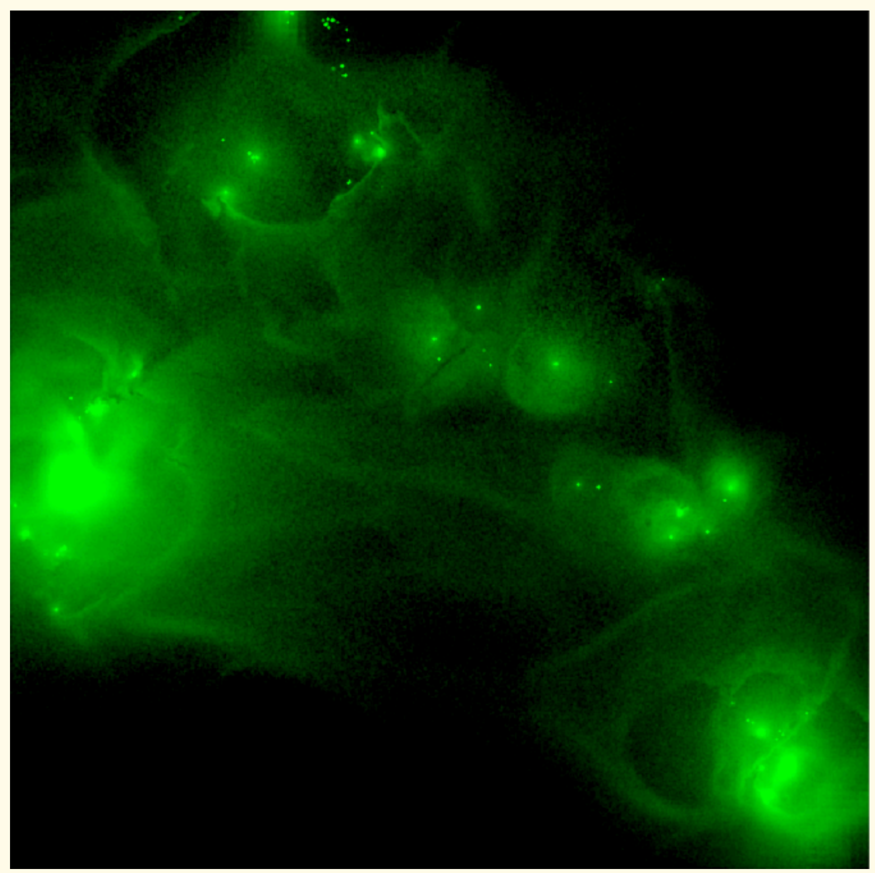
Stellar Population Synthesis

- Continuum: stellar emission (realistic spectrum based on their mass and age) + dust extinction and scattering
- Hα: proportional to recombination rate inside HII region with dust extinction
- What we get: spectra at each pixel (line of sight)

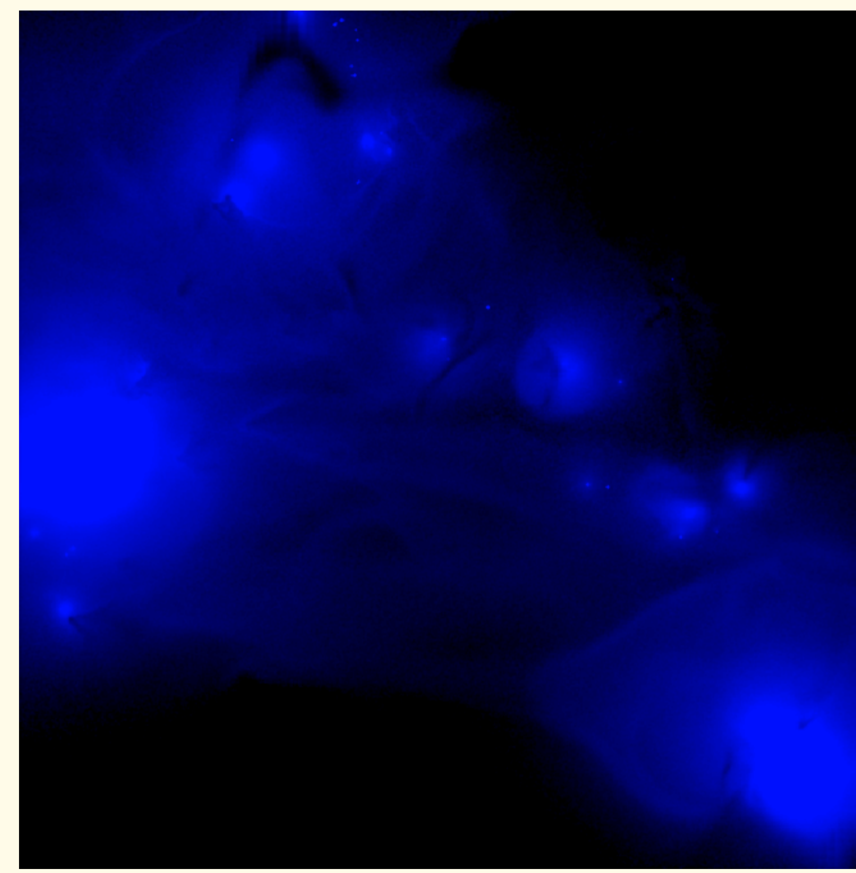
r (Hα, 6560 Å)



g (visible, ~6000 Å)



b (UV, ~1500 Å)



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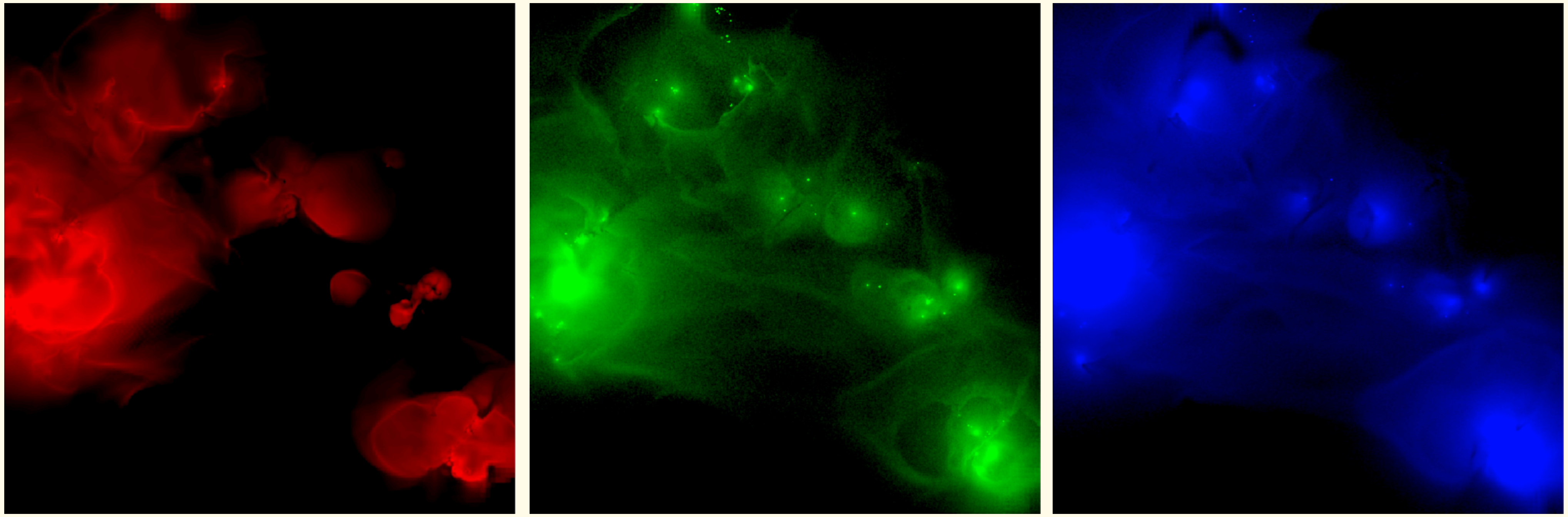

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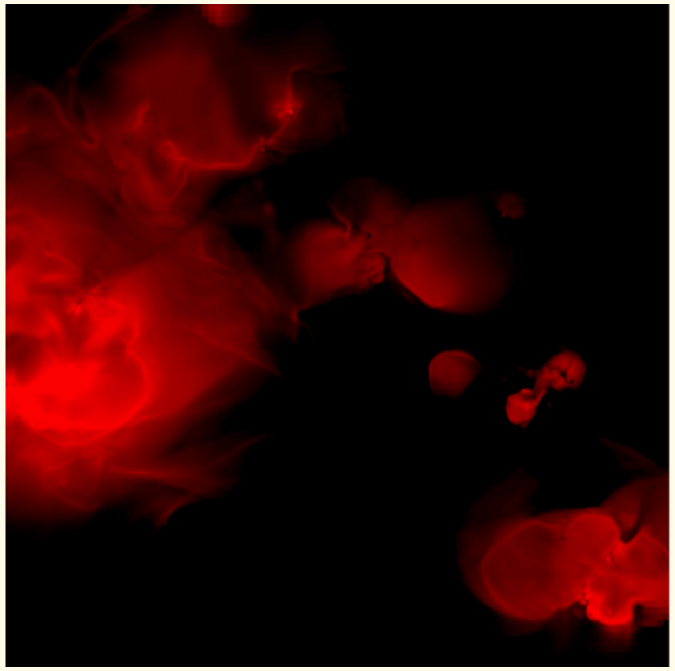

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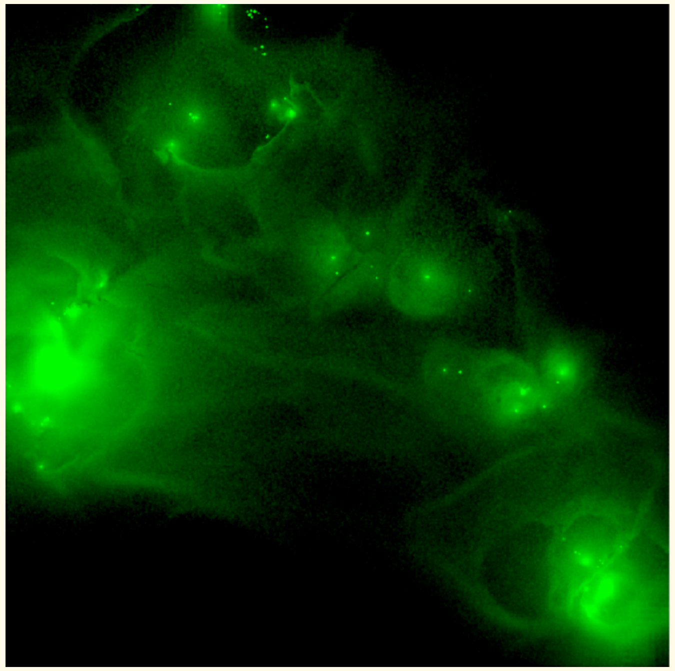

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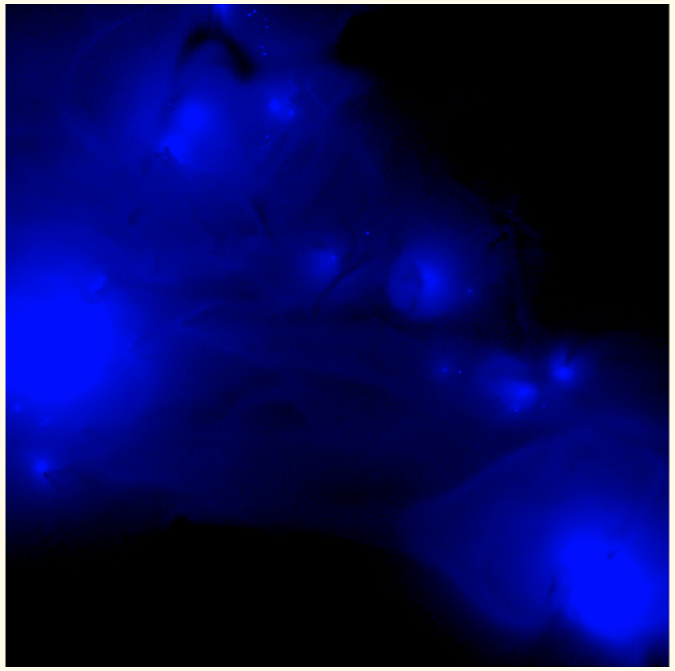
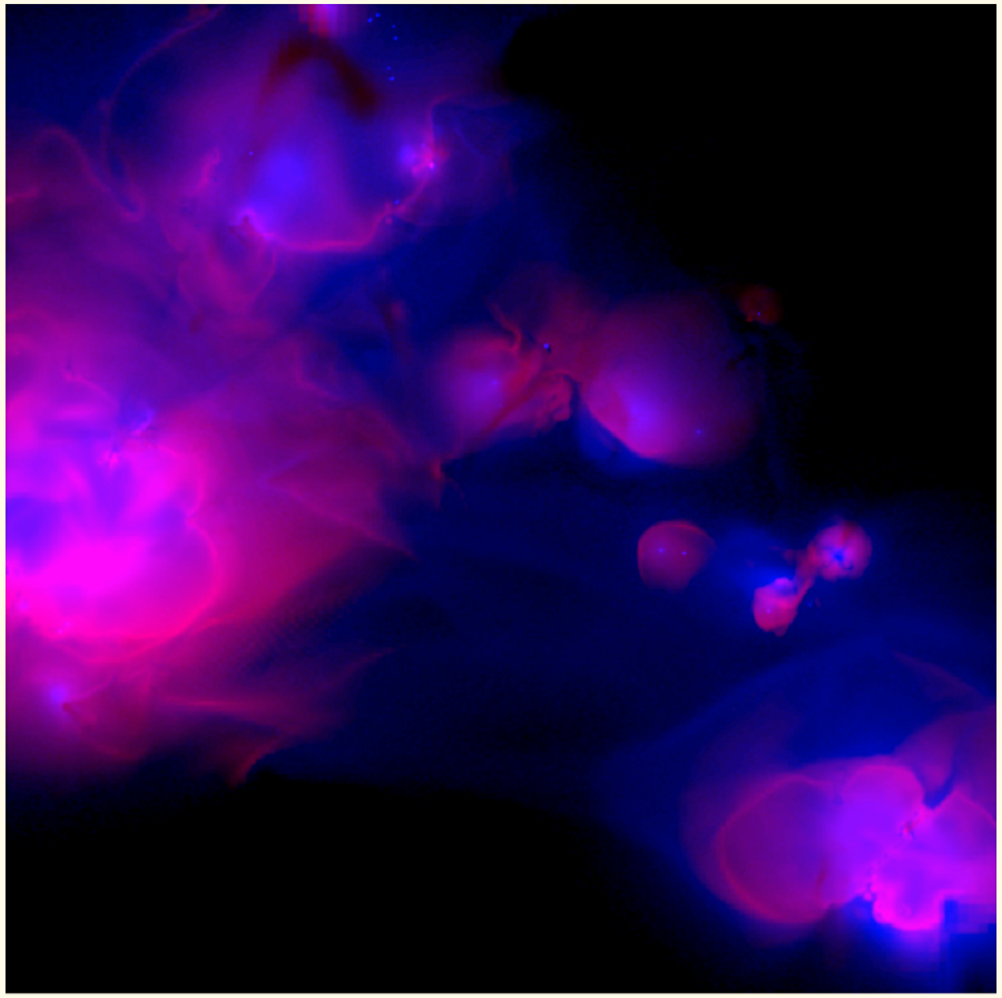


r + b



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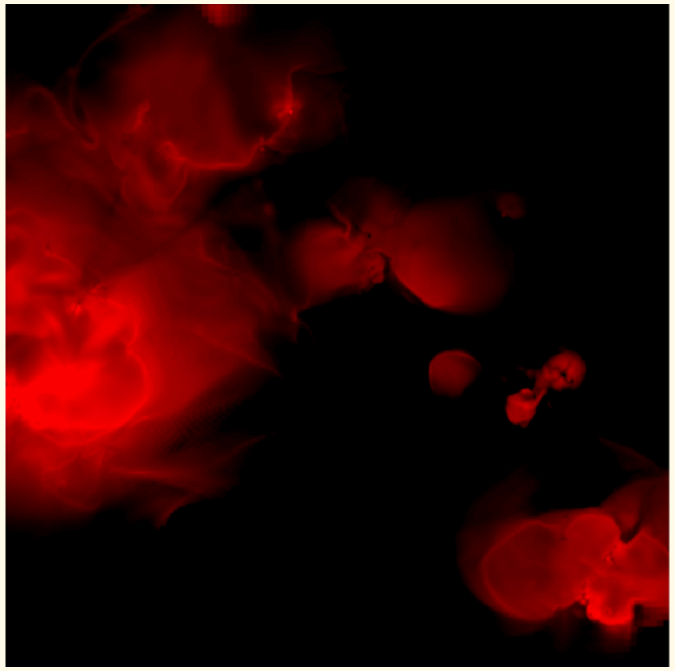

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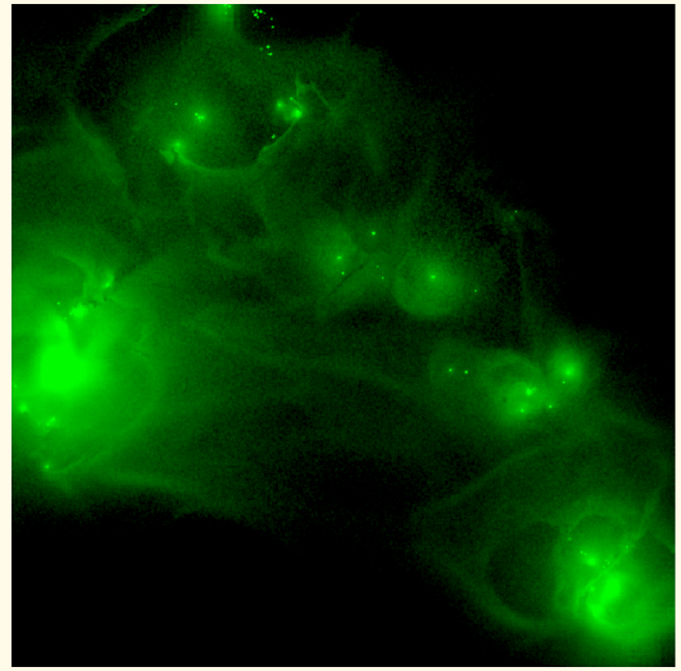

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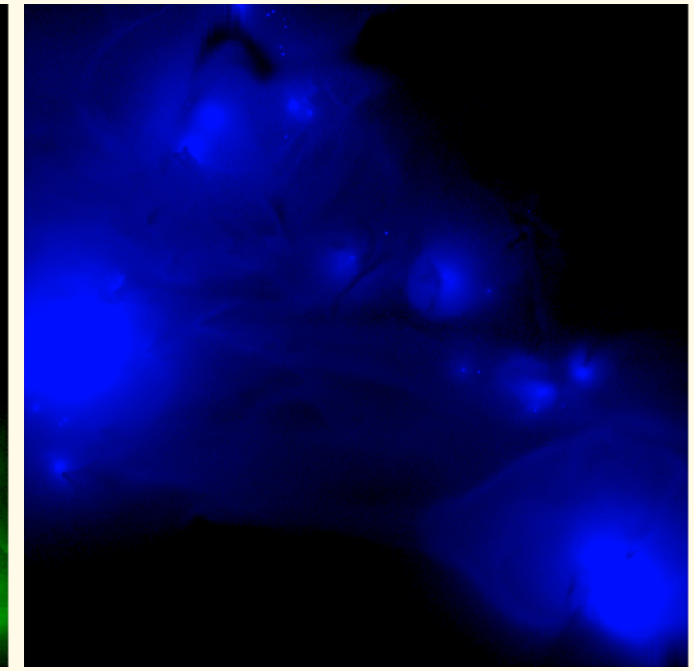

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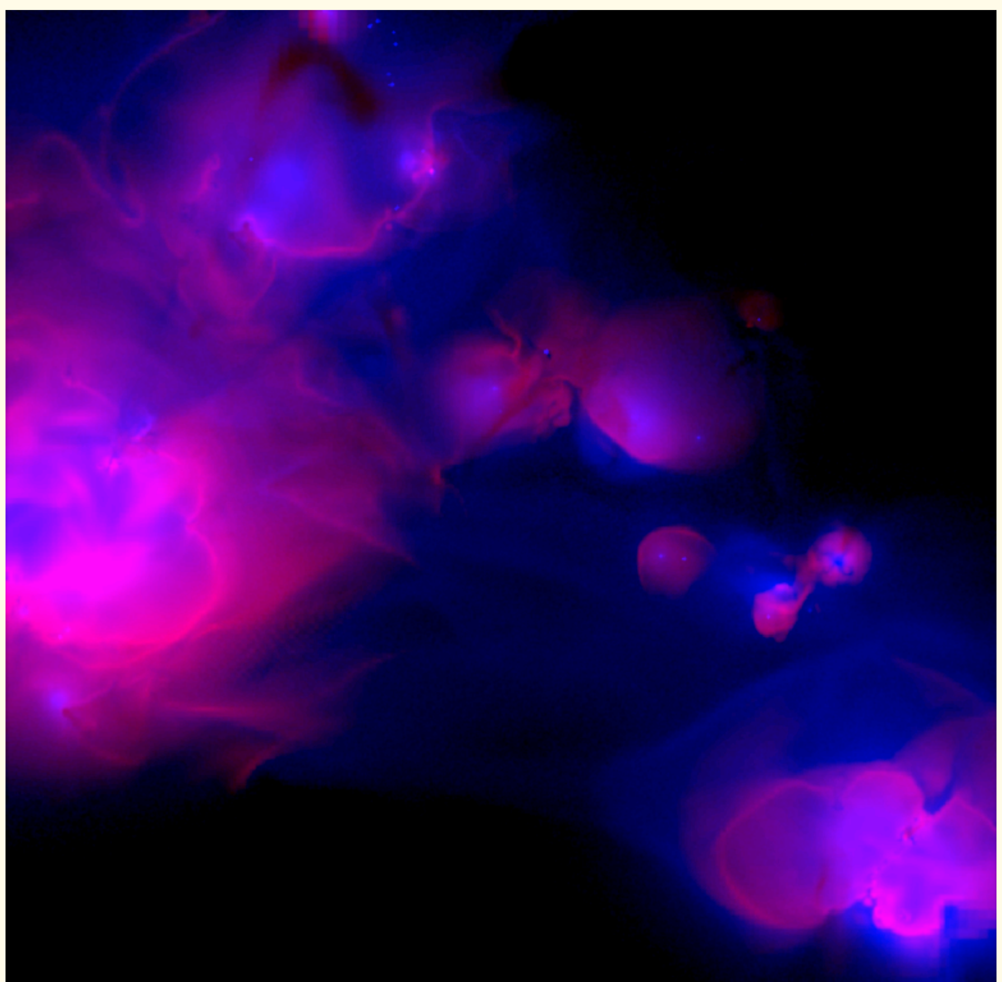
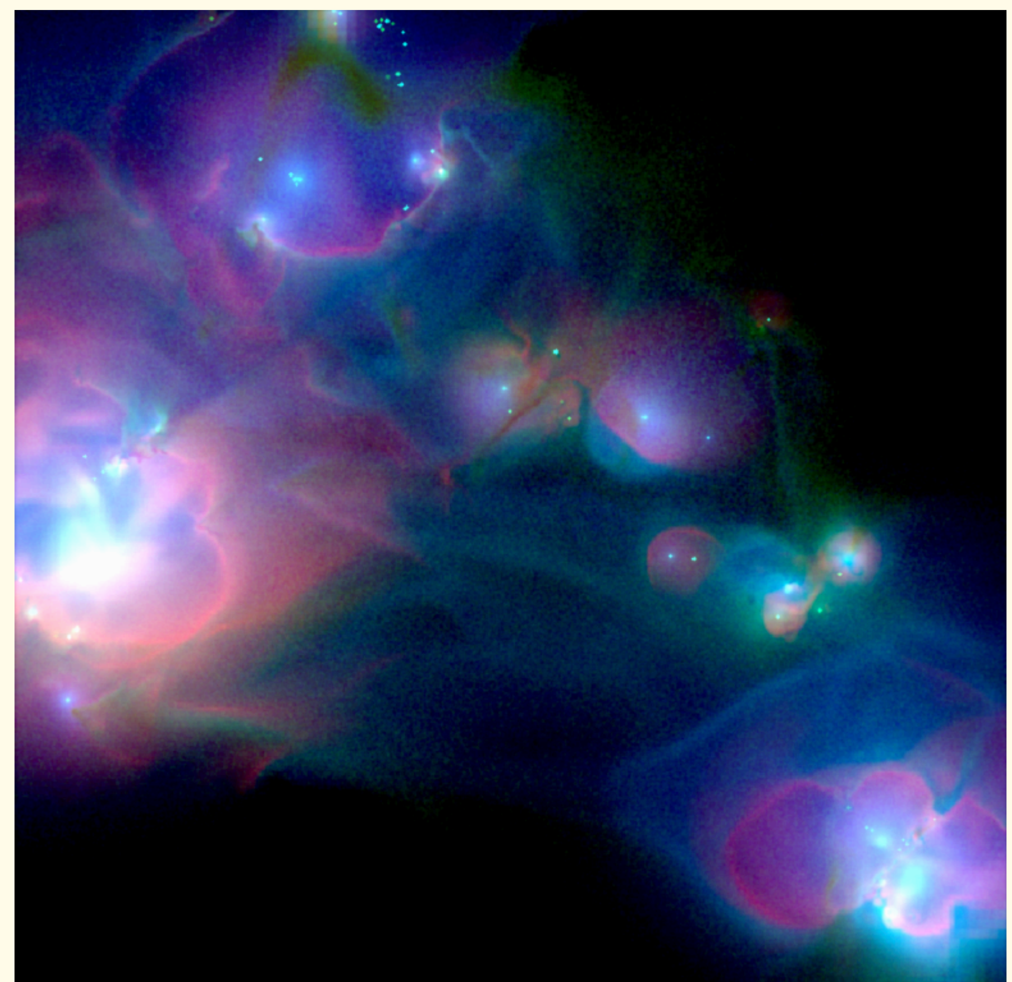


r + b + g



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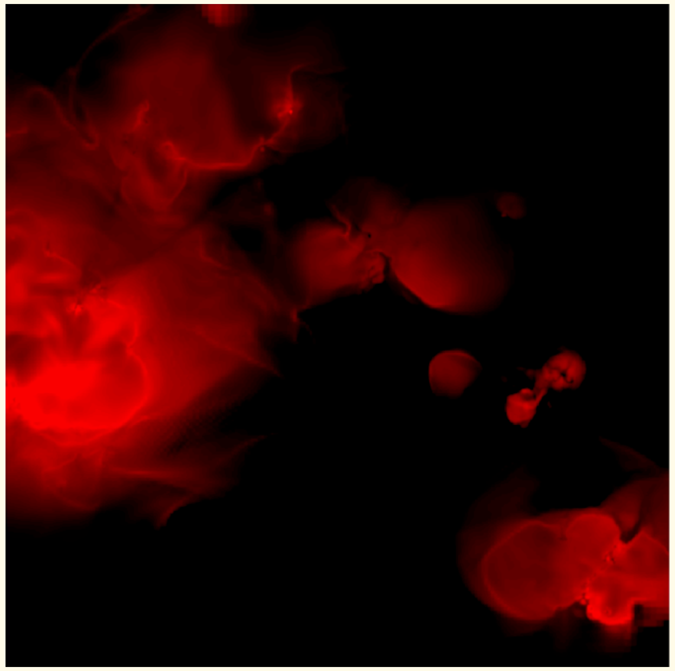

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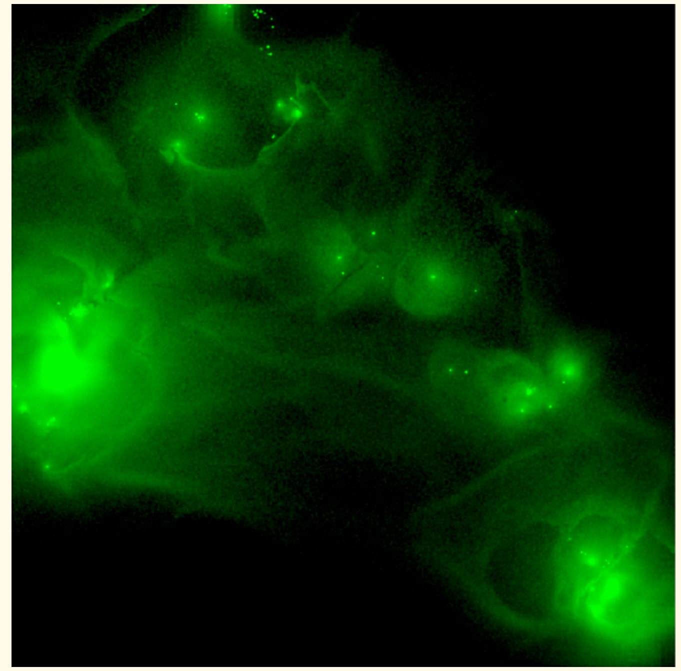

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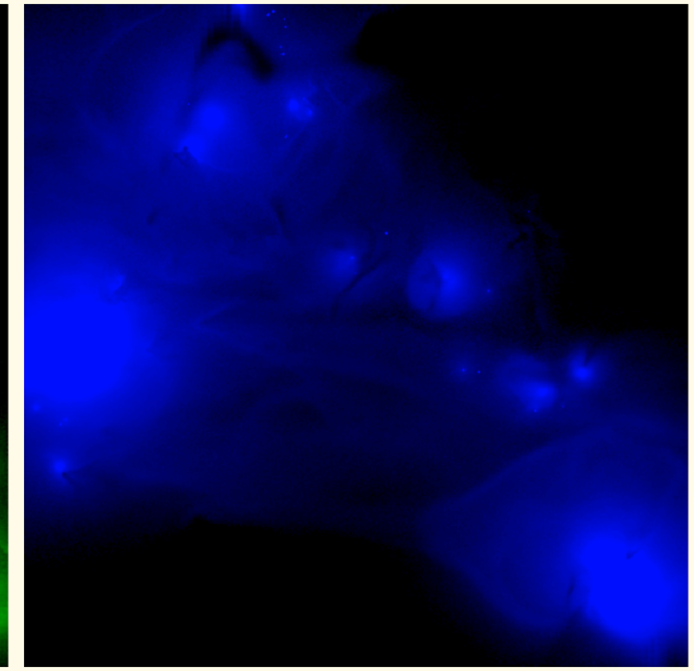

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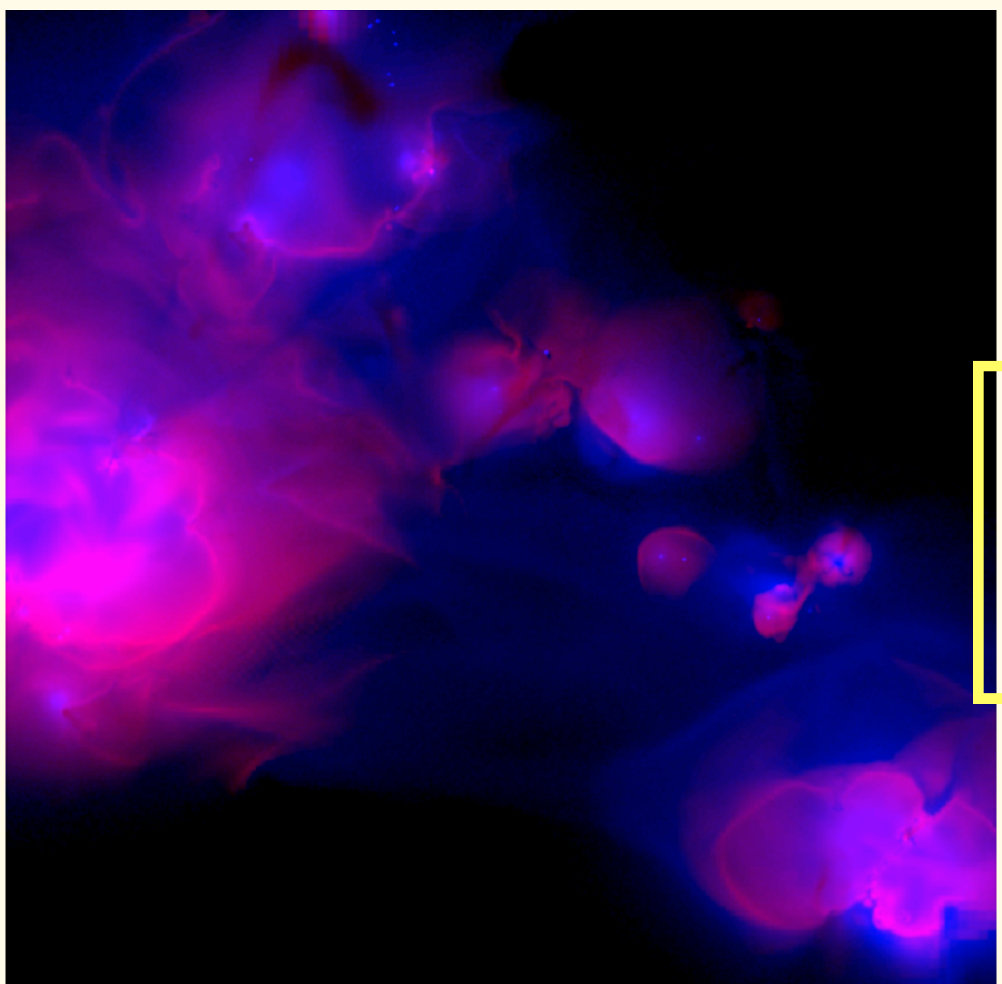
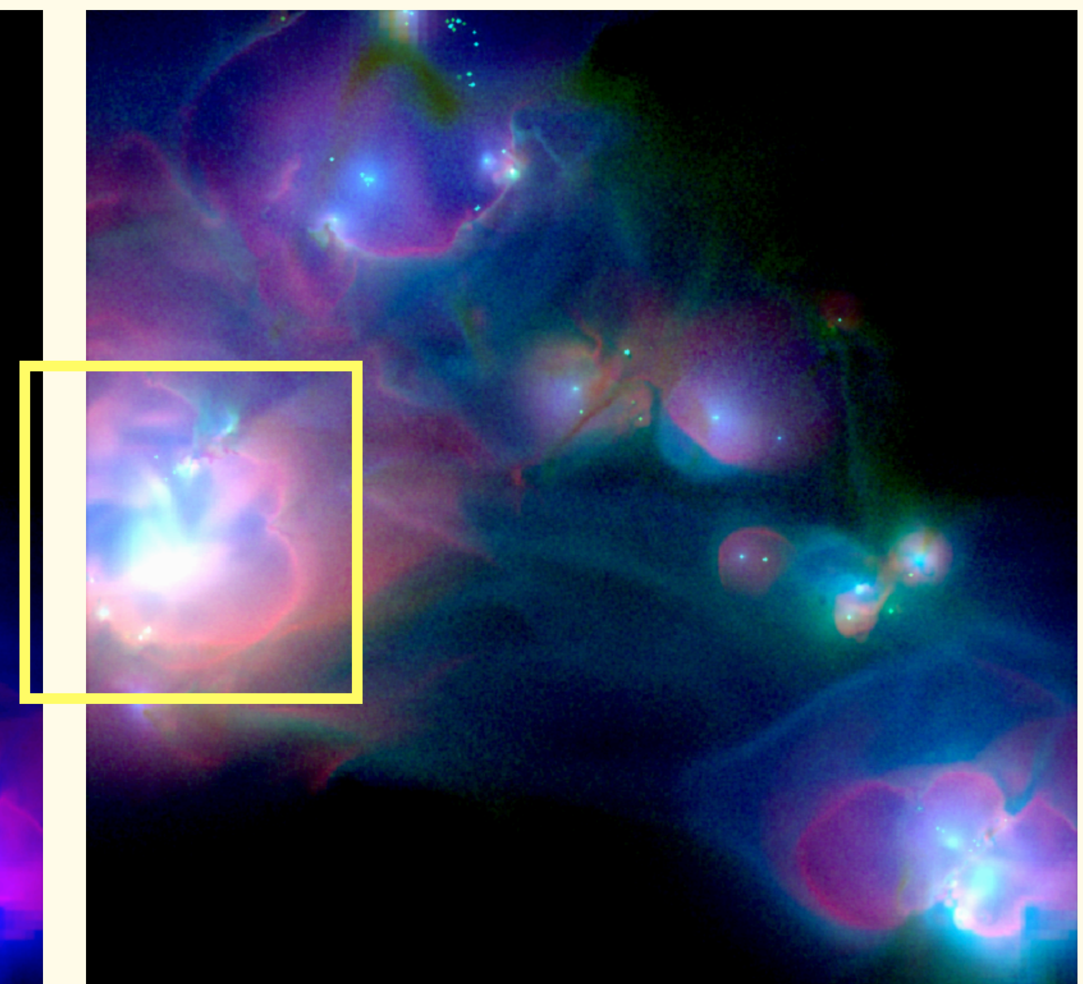
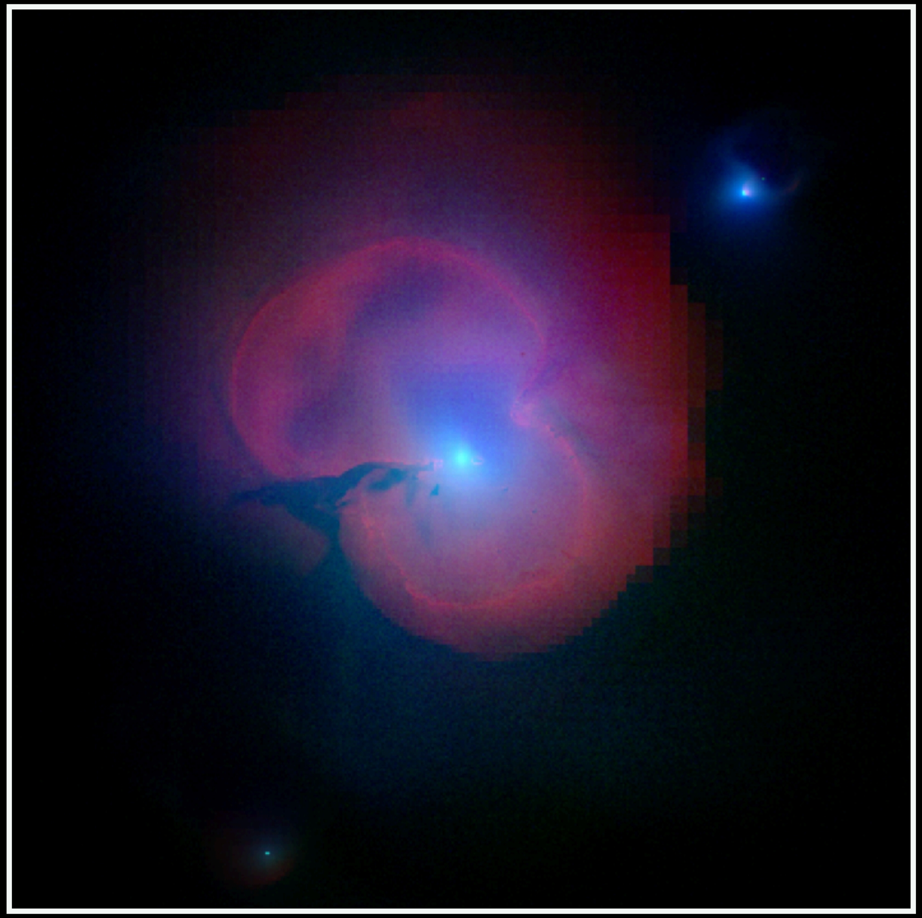
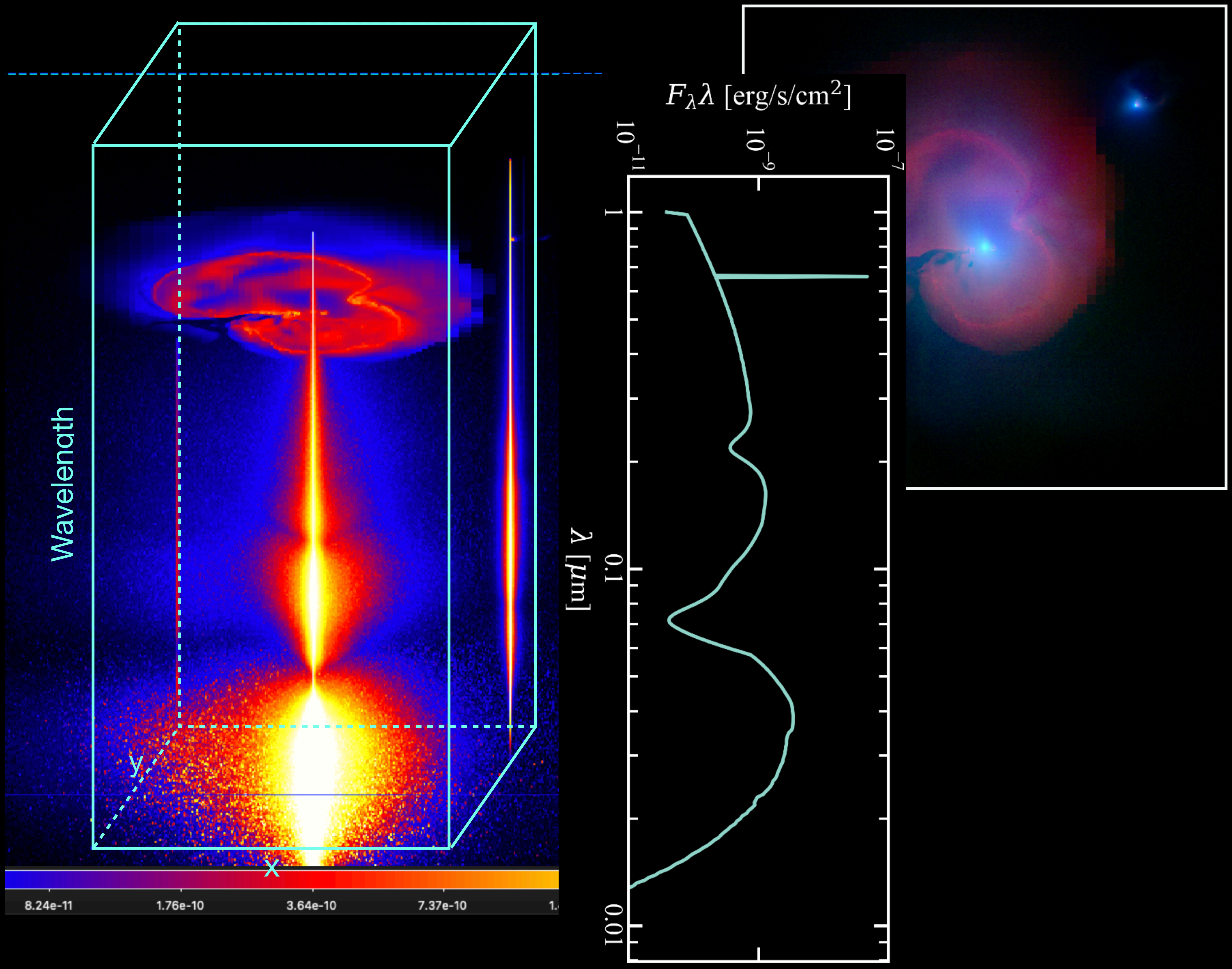


r + b + g



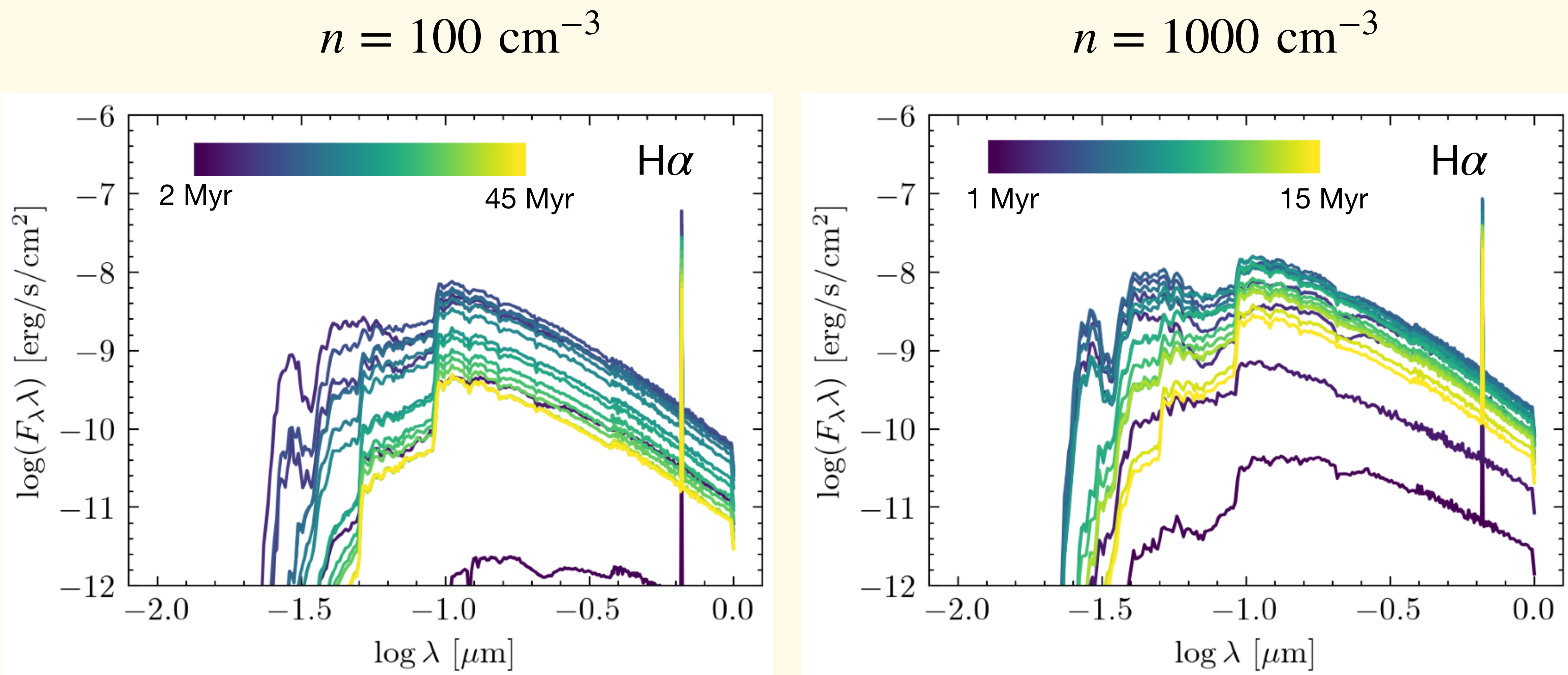
r (Hα, 6560 Å) + g (6000 Å) + b (UV, 1500 Å)





Wavelength
y
x
8.24e-11
1.76e-10
3.64e-10
7.37e-10
$F_\lambda \lambda$ [erg/s/cm^2]
10^{-11}
10^{-9}
10^{-7}
λ [μm]
1
0.1
0.01

Mock spectrum for JWST



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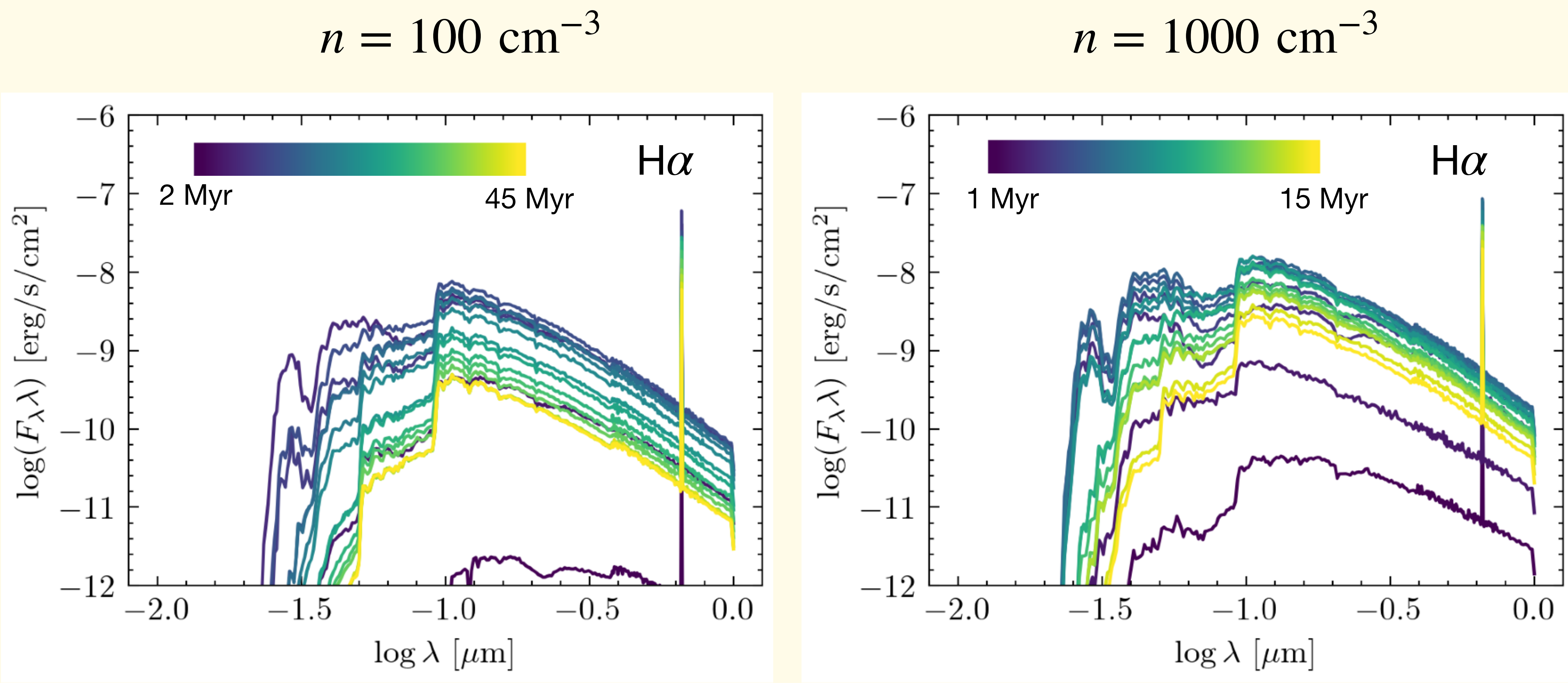

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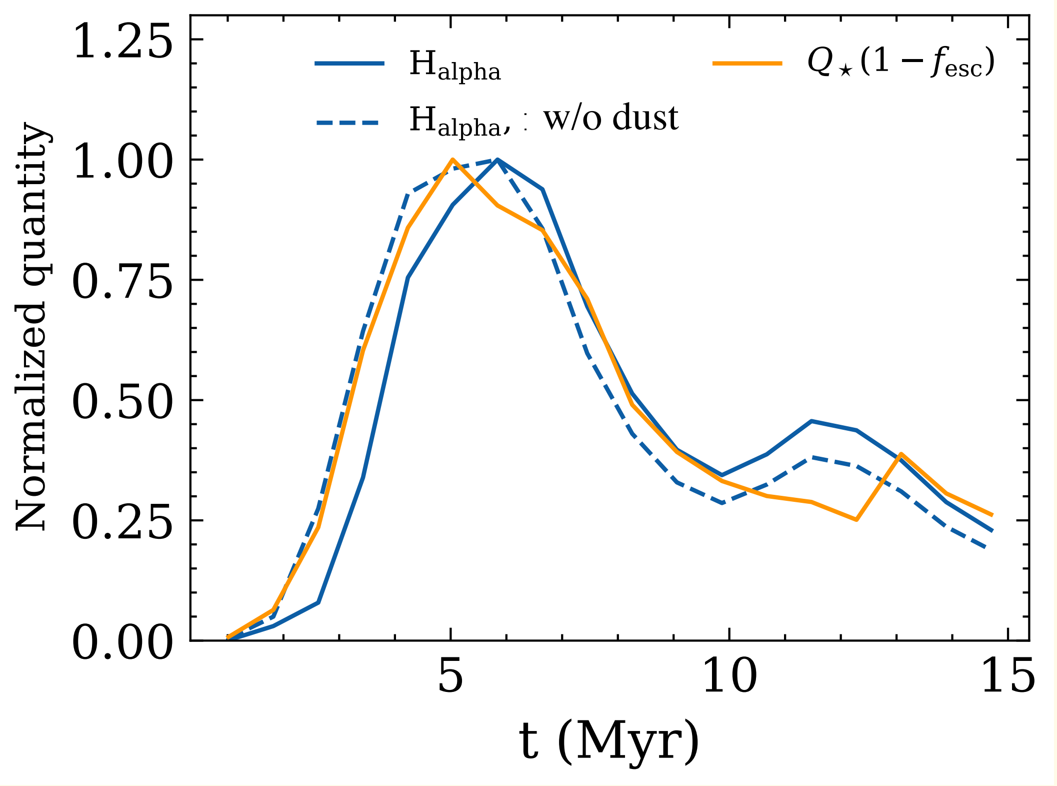
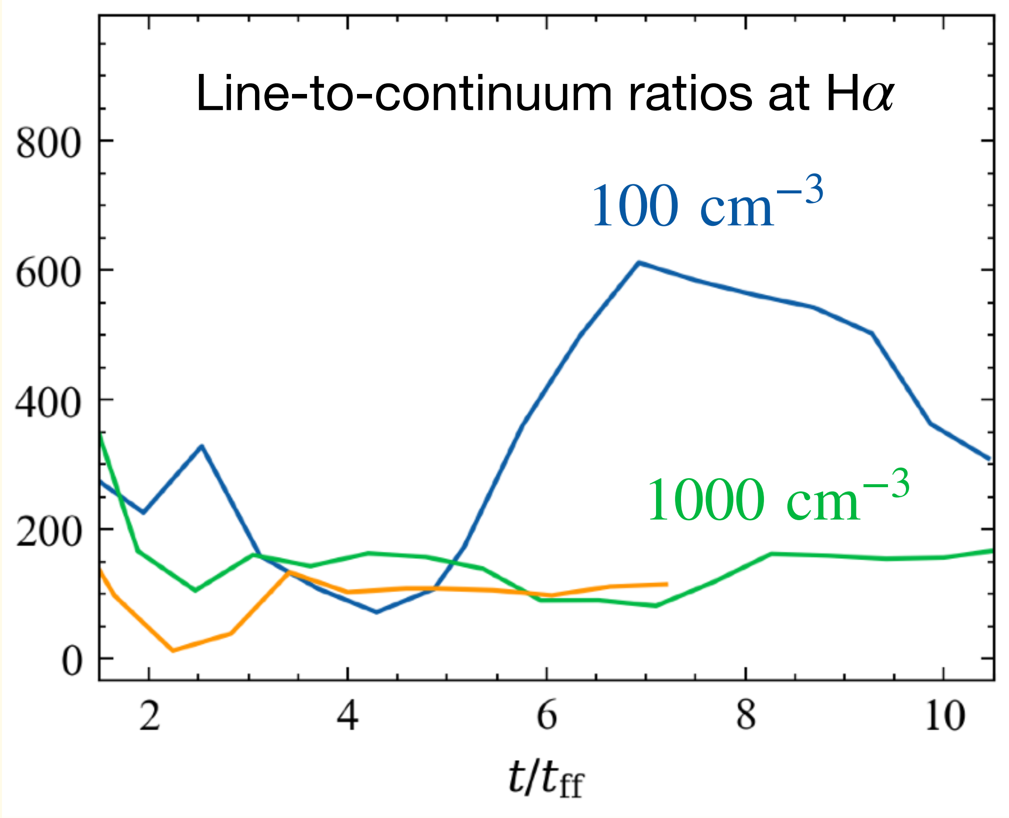
Work in progress. A lot to be done.

What do different line-to-continuum ratios tell us?





The line strength at H-alpha is proportional to the ionizing photon absorption rate, which is roughly proportional to the continuum strength times $1 - f_{esc}$. i.e.

- The line strength at $H\alpha$ is proportional to $Q_{ion}(1 - f_{esc})$.
- The line-to-continuum ratio at $H\alpha$ is roughly proportional to $1 - f_{esc}$. Probe of f_{esc}.
- High density clouds have lower line-to-continuum ratios at $H\alpha$ which could work as a diagnostics of cluster density by JWST.

He & Ricotti 2022, in prep.

Conclusions

- Dense and massive GMCs with high escape velocity are efficient at converting gas into stars and form globular cluster progenitors.
- Globular cluster progenitors escape a high fraction of ionizing photons into IGM and thus could potentially provide significant amount of photon budget for cosmic reionization.
- The line-to-continuum ratio at Hα is a good tracer of ionizing photon escape fraction that JWST could use to measure $f_{\rm esc}$ from lensed star clusters at $z \approx 6$.