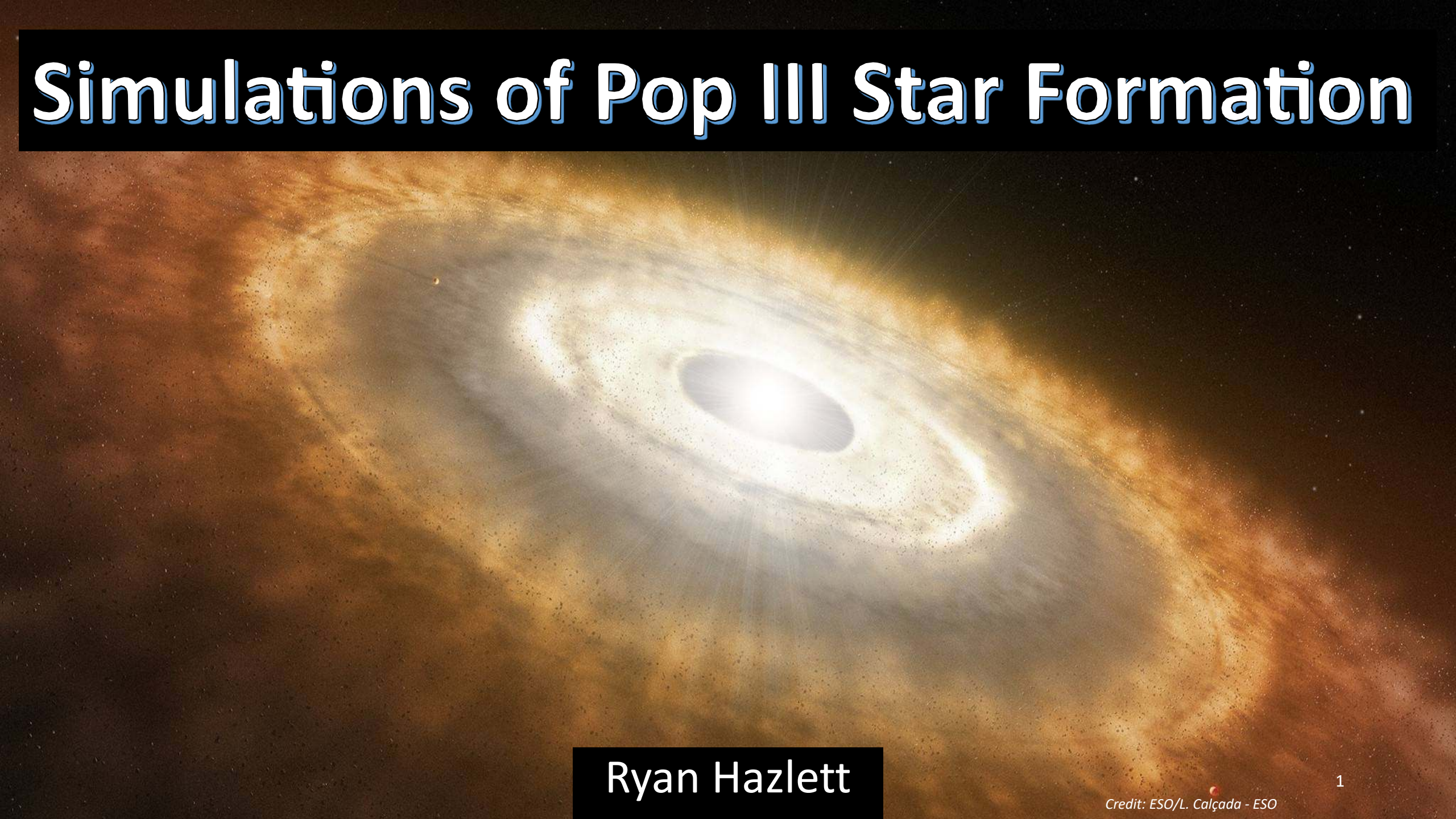
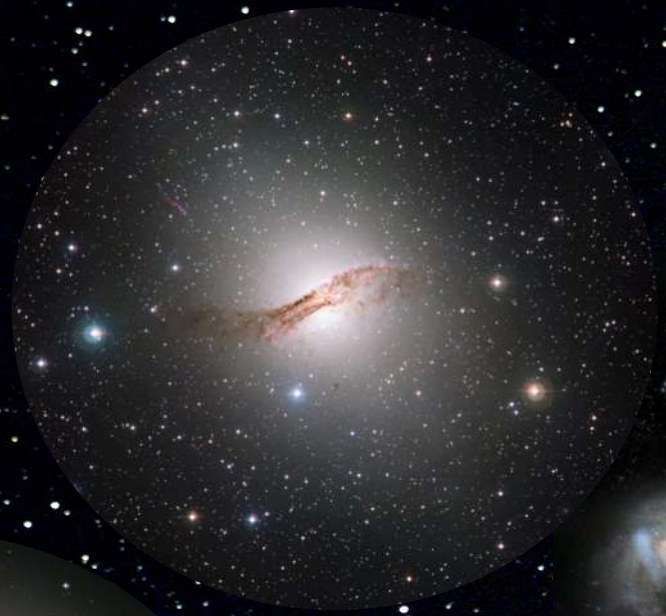
Simulations of Pop III Star Formation



Ryan Hazlett

Credit: ESO/L. Calçada - ESO

How do Galaxies Form and Evolve?



Credit: ESO/IDA/Danish, R. Gendler

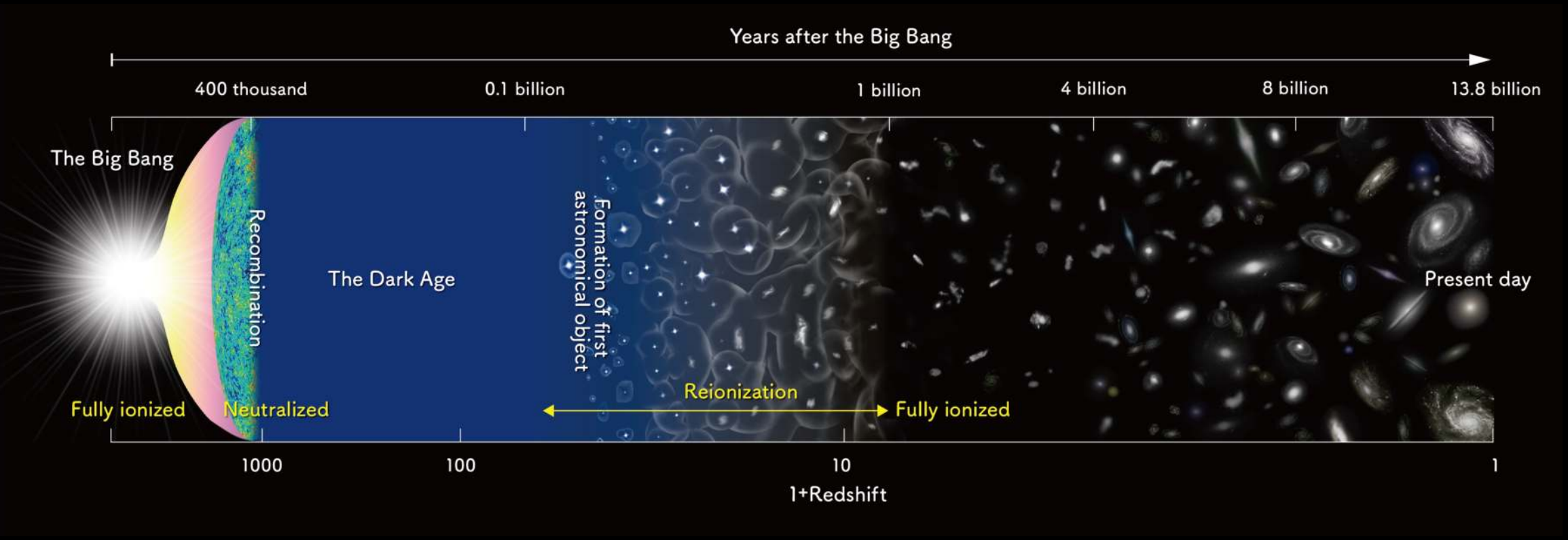
Credit: NASA/STScI/AURA

Credit: ESA/Hubble

Credit: NRAO/AUI/NSF, S. Dagnello

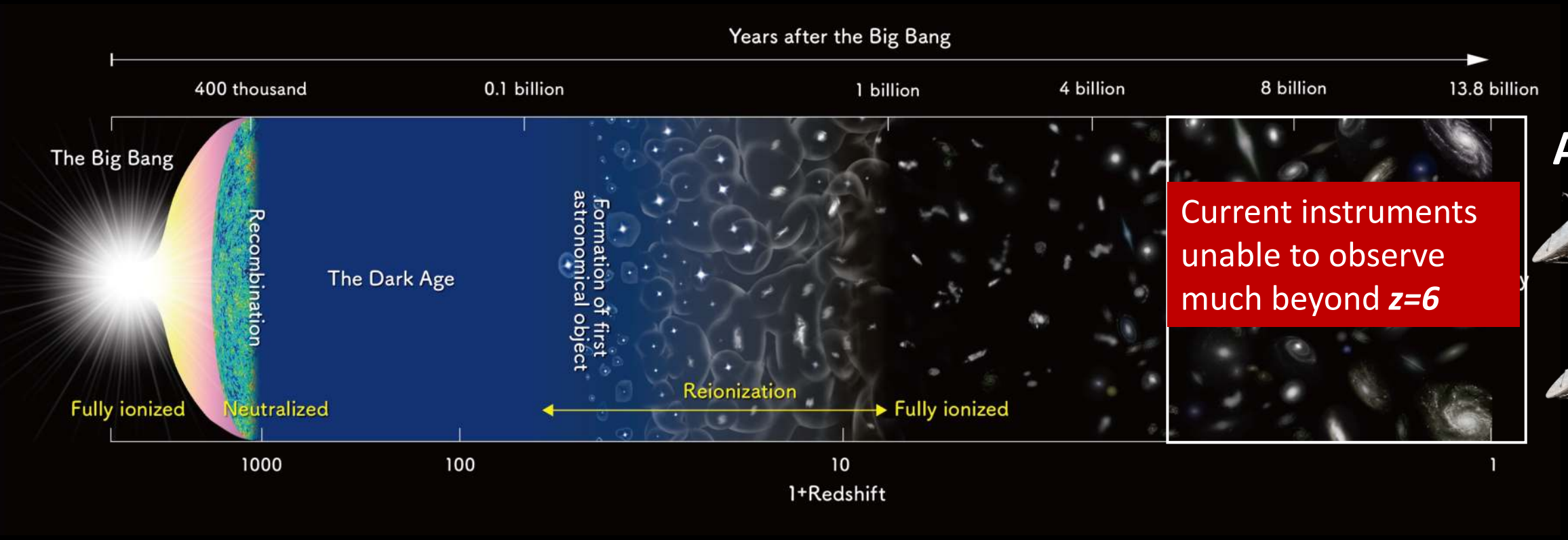
How does this relate to Population III Stars?

When do Pop III Stars Form?



Credit: NOAJ

Difficulties in Observing Pop III Stars

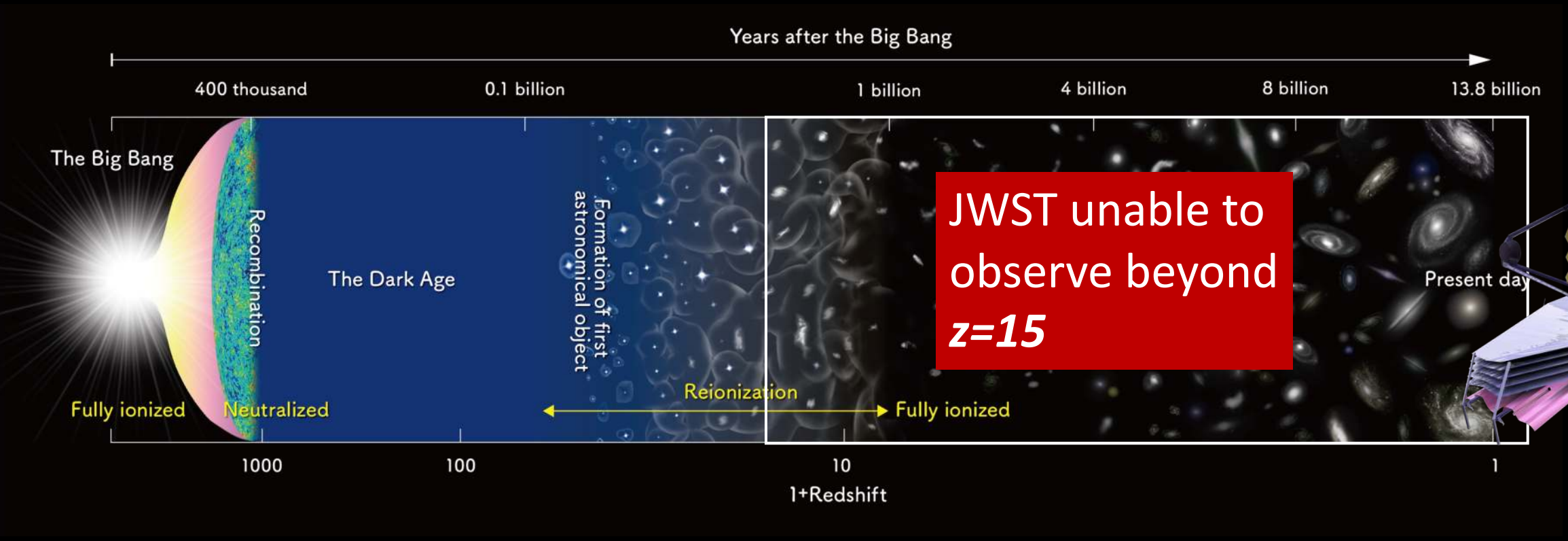


Current instruments unable to observe much beyond ***z=6***

ALMA

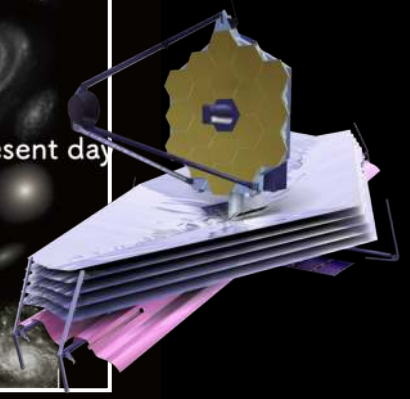
Credit: NOAJ

Difficulties in Observing Pop III Stars



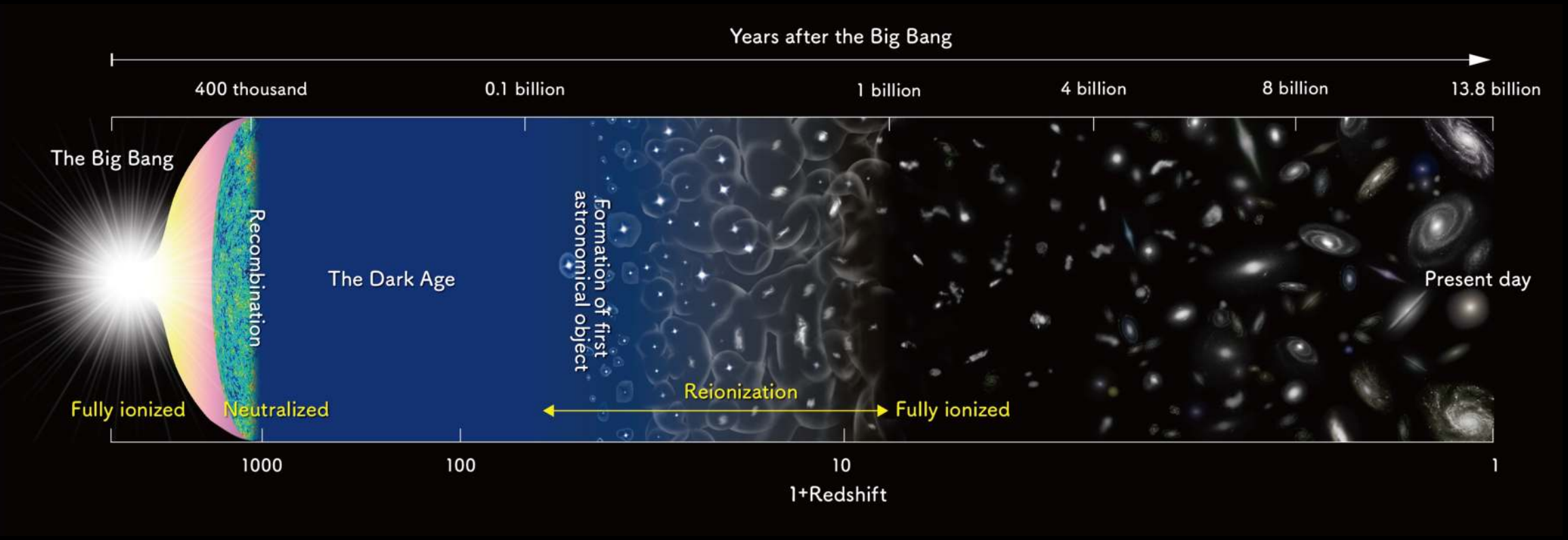
JWST unable to observe beyond ***z=15***

JWST



Credit: NOAJ

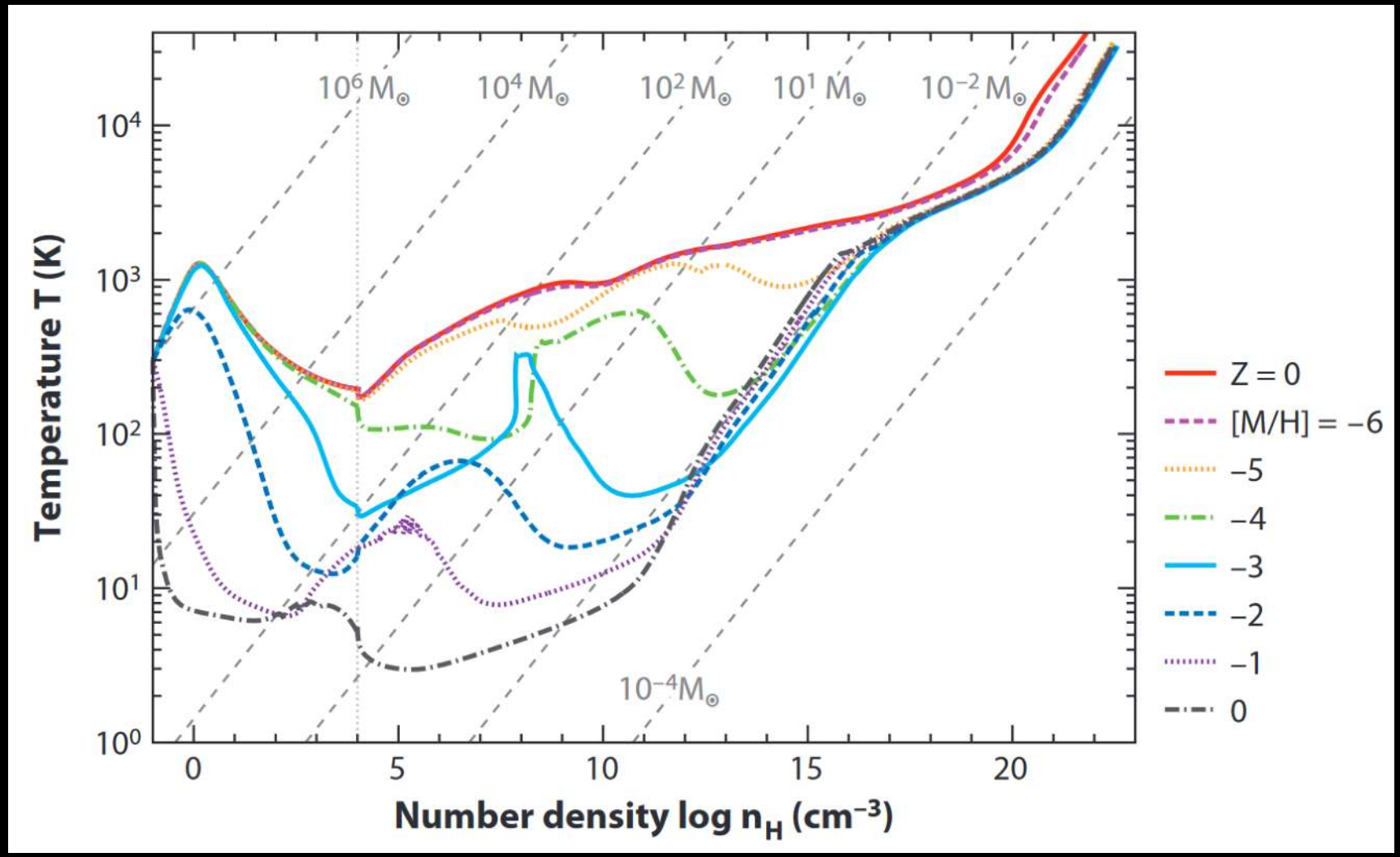
Are Pop III Stars out of Reach?



Credit: NOAJ

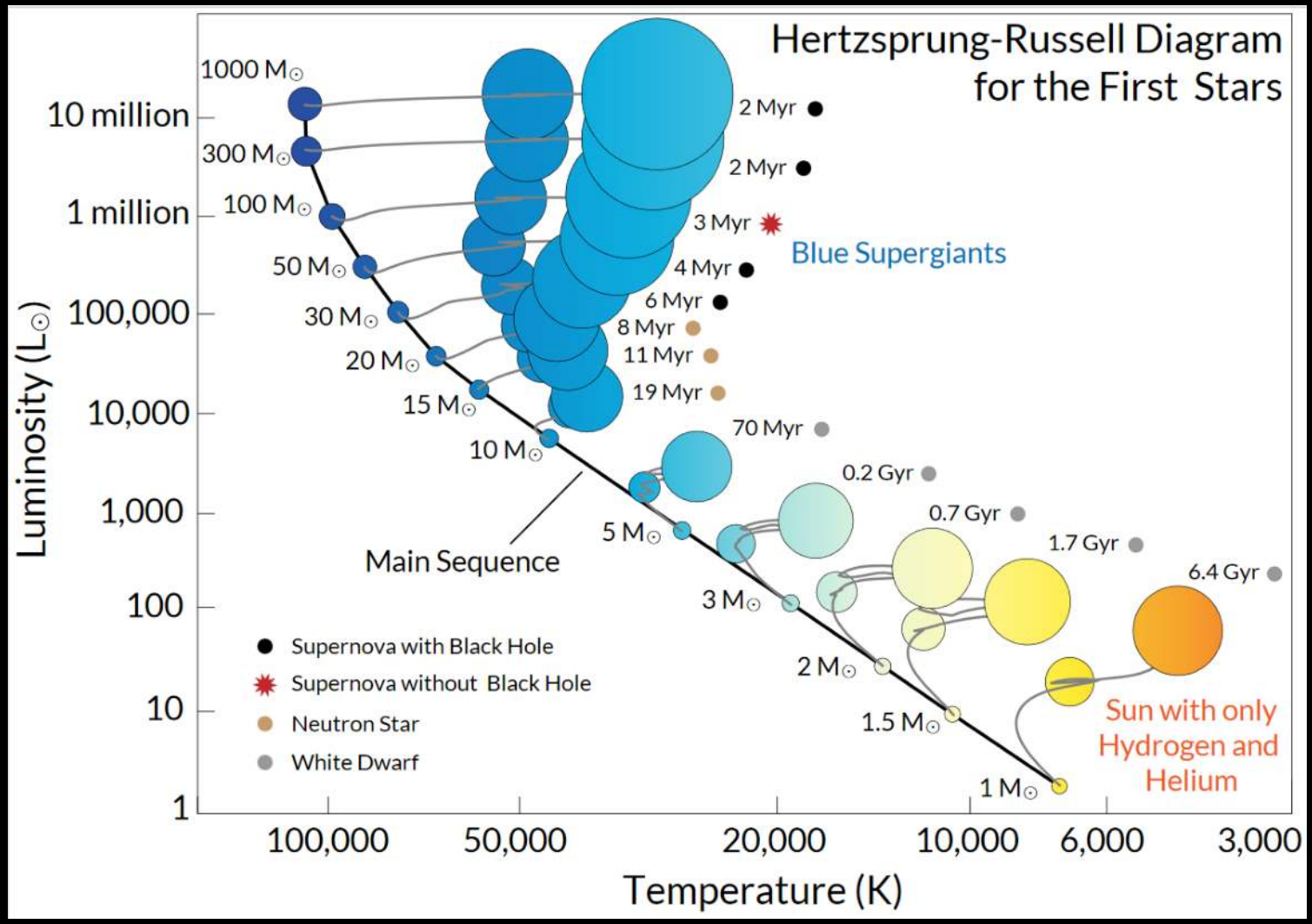
Use simulations to understand the impact of Pop III stars

Where do Pop III Stars Form?



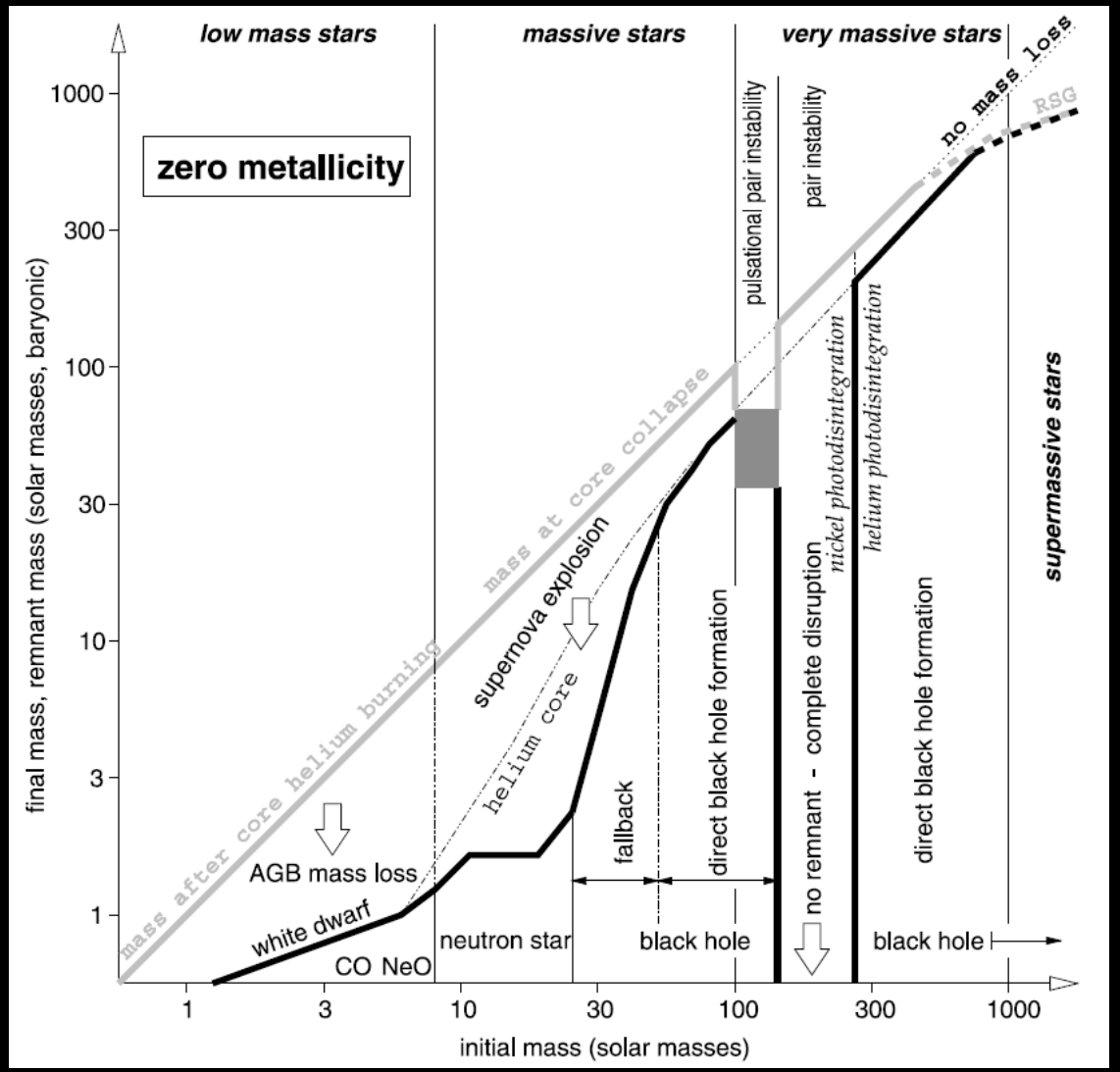
Adapted from Omukai, Hosokawa & Yoshida (2010)

Evolution of Pop III Stars



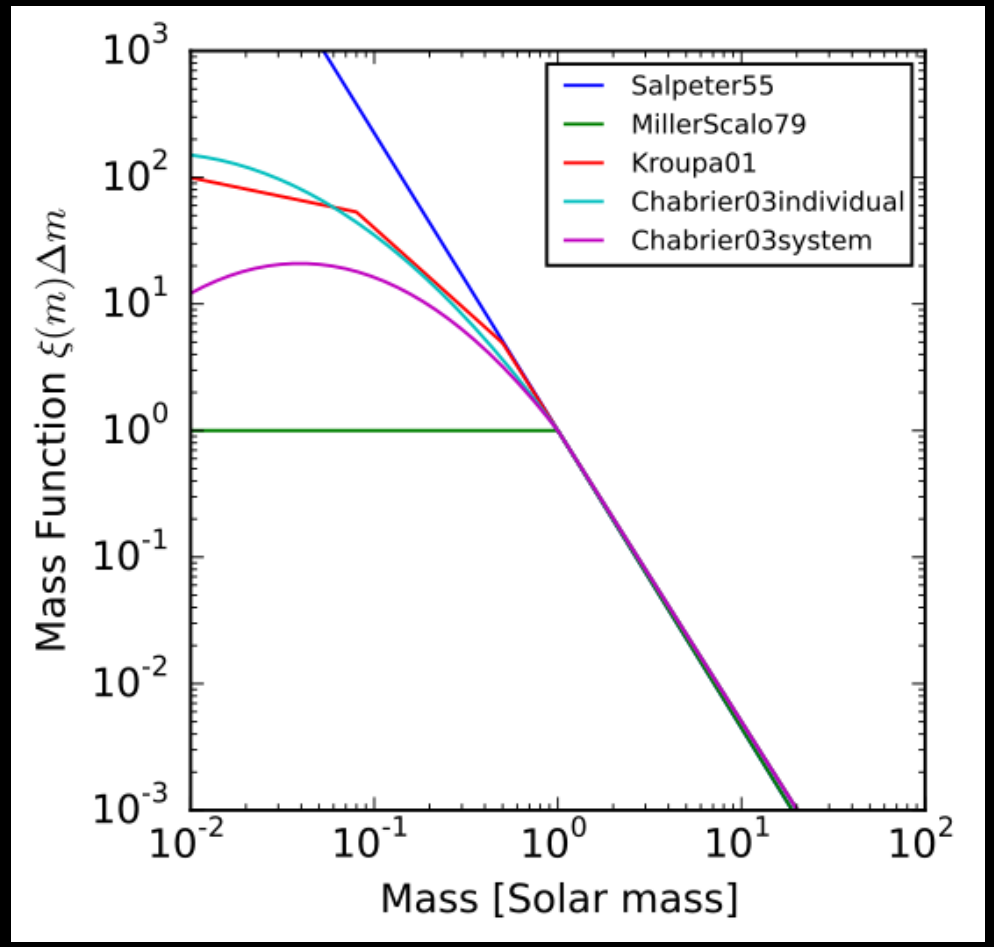
Adopted from Windhorst et al. (2018)

The Remains of Pop III Stars



Adopted from Figure 9 Greif (2015)

What is the Pop III Initial Mass Function?



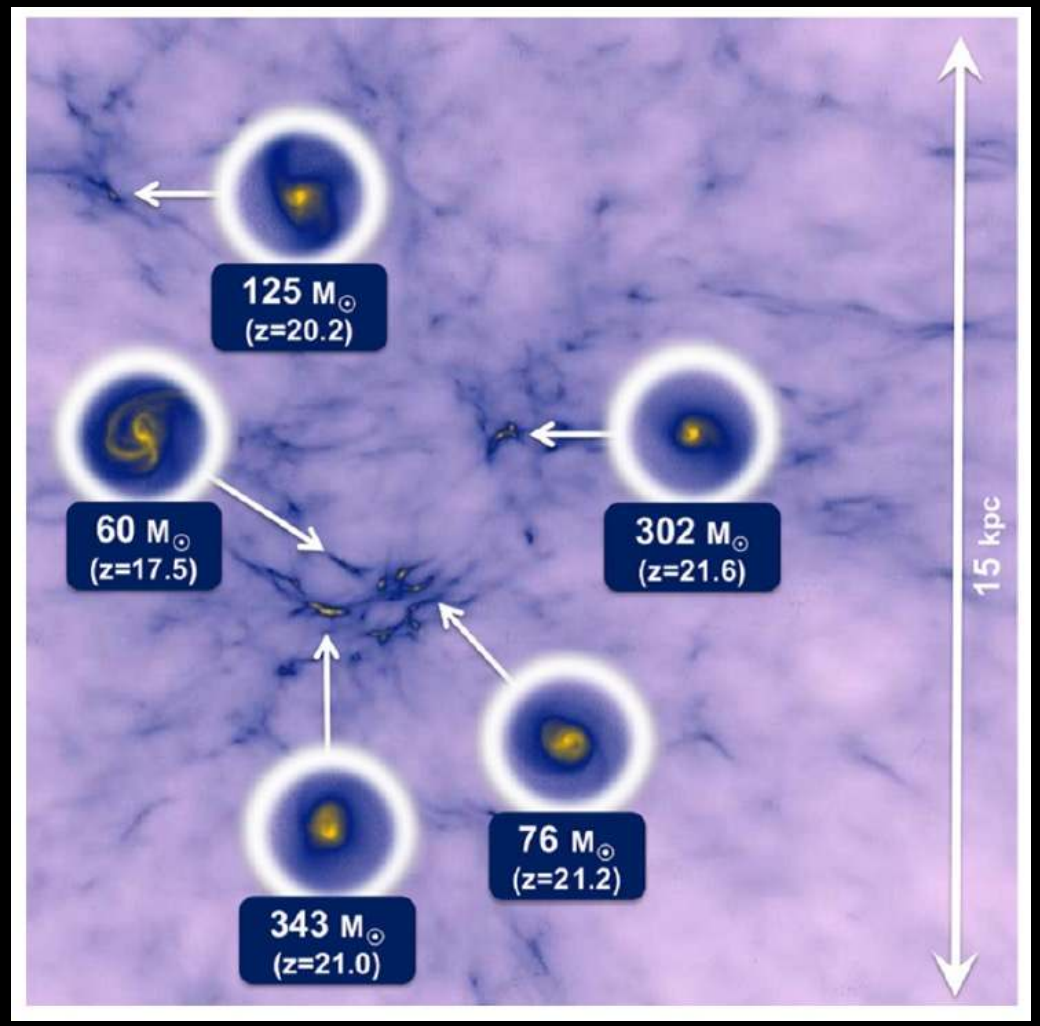
Pop III IMF?

Need to know for Pop III:

- Number of Stars
- Masses
- How late can they form

Simulate the formation of Pop III stars to determine the IMF

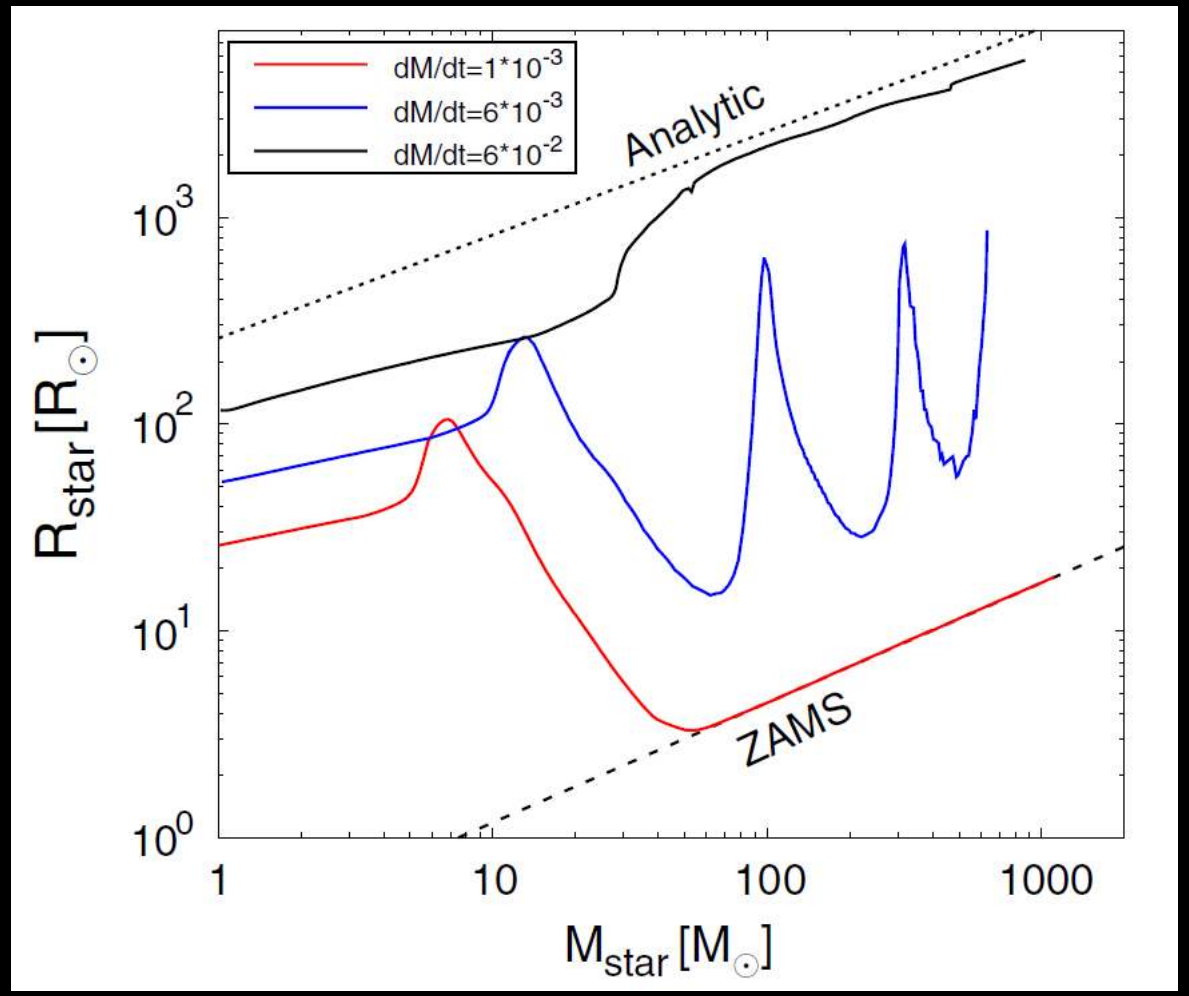
Simulation of Pop III Formation



Adopted from Hirano et al. (2014)

- Chemical and radiative processes in primordial gas.
- Structure and evolution of accreting star.
- Hydrodynamics of accreting gas irradiated by stellar radiation.

How does accretion impact ZAMS mass?

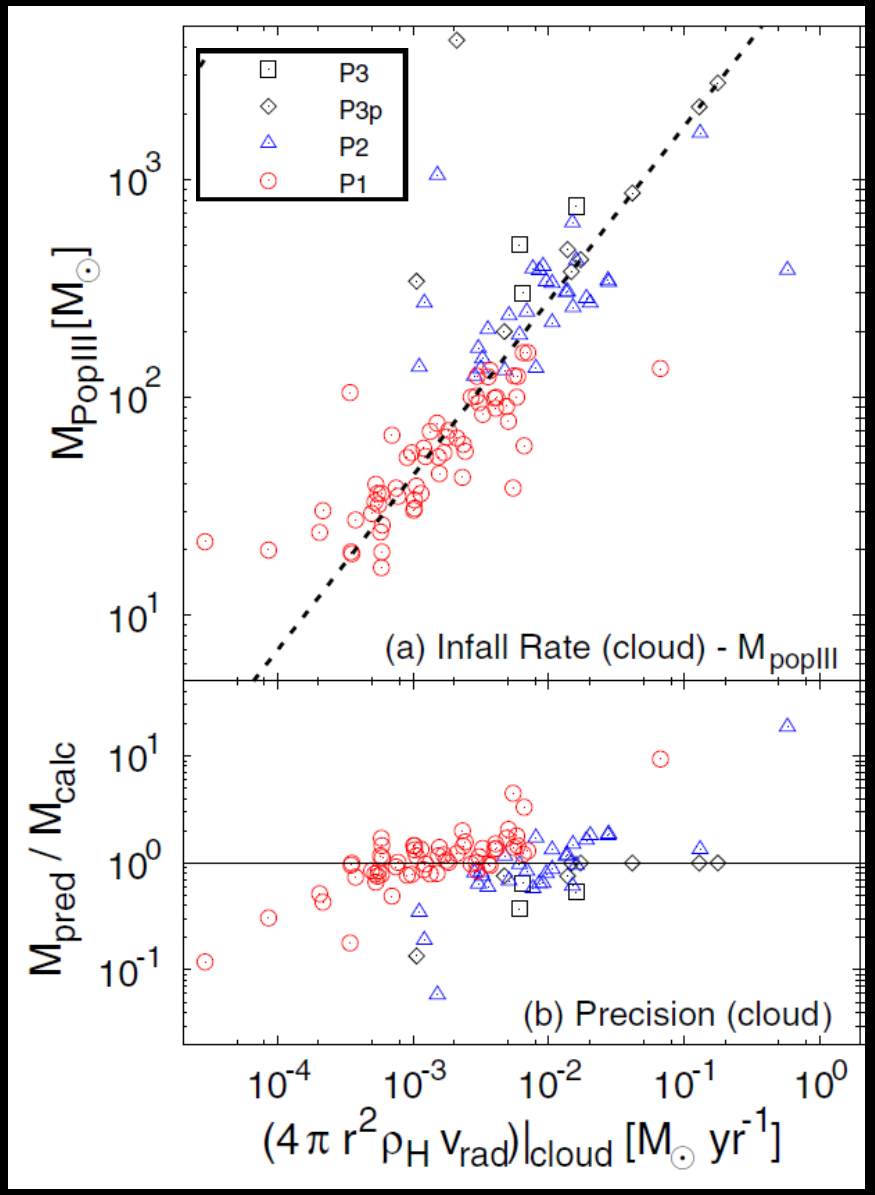


- Red curve, interplay between KH contraction and accretion.
- Blue curve, Eddington limit reached during contraction, star must expand.
- Black curve, contracting core and bloated envelope.

Adopted from Hirano et al. (2014)

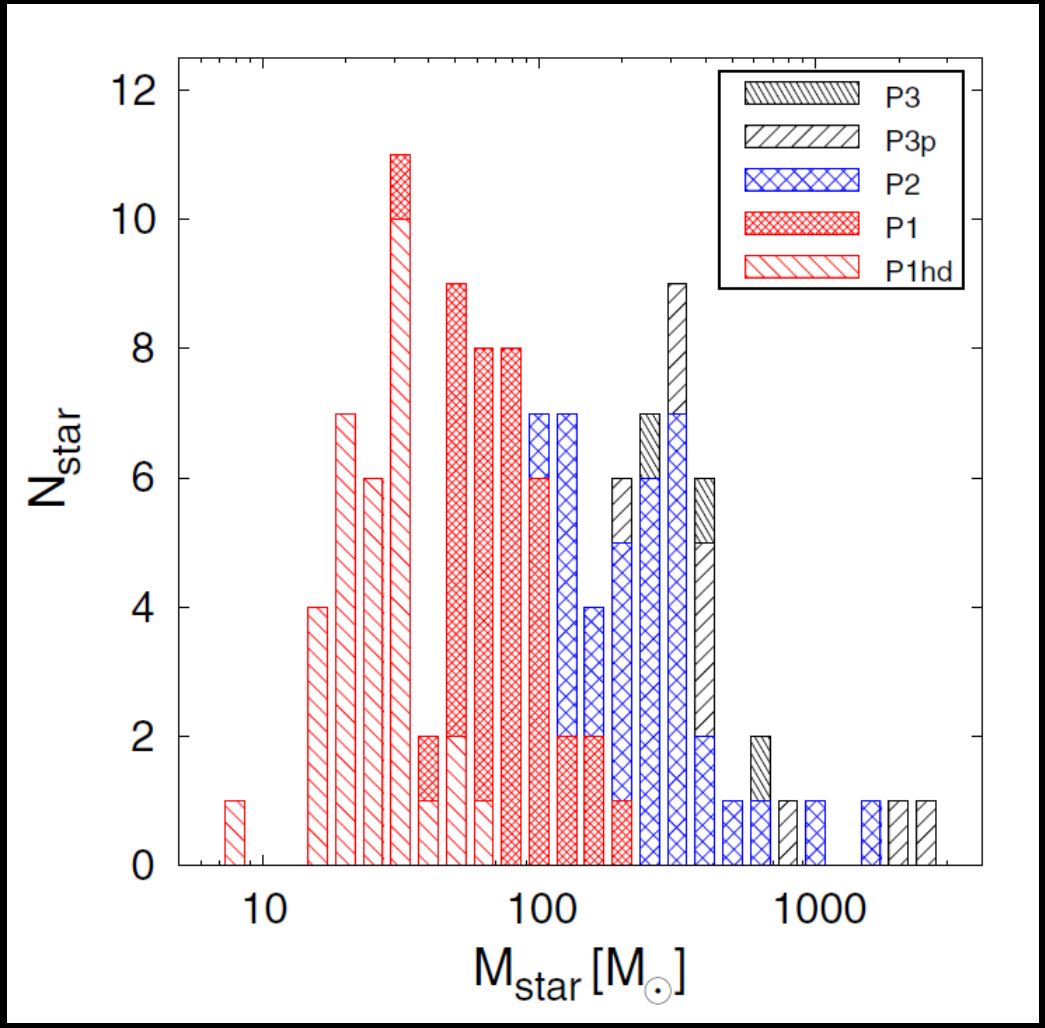
Accretion Rate Determines Mass

- High accretion rate corresponds to larger Pop III mass.
- Pop III mass also related to mass of the host halo.



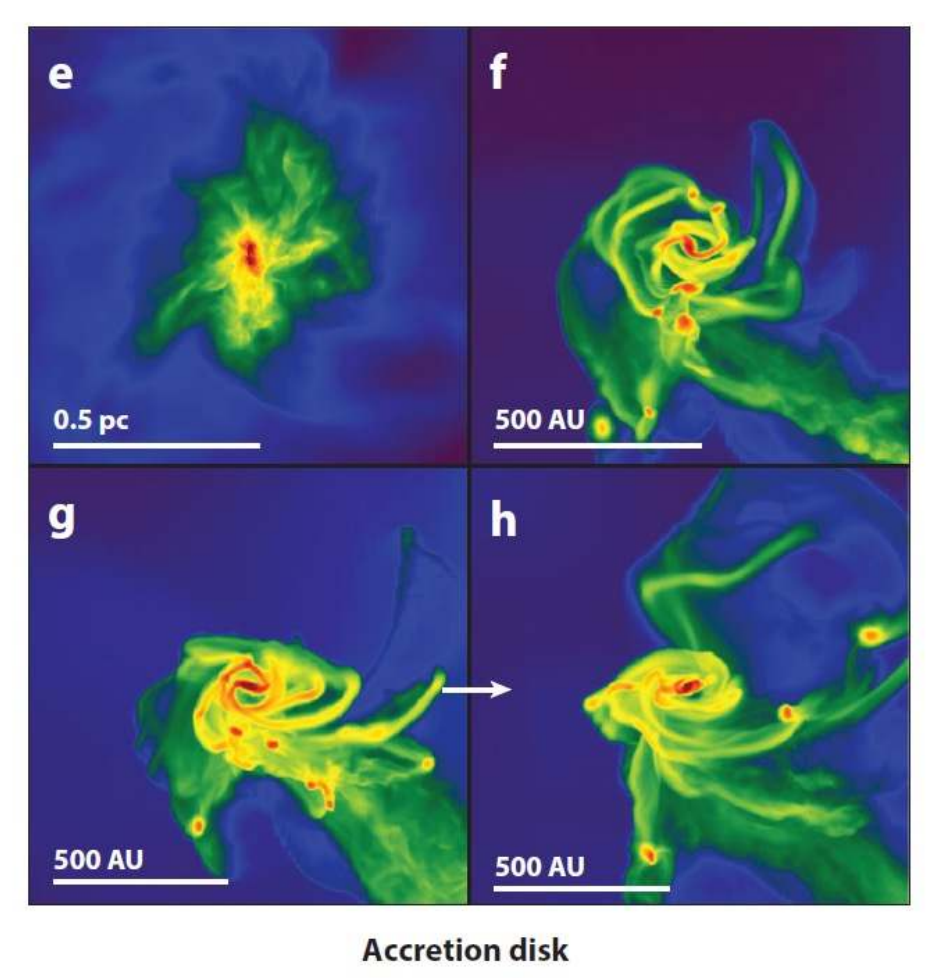
Adopted from Hirano et al. (2014)

A "Top-Heavy" Pop III IMF



Adopted from Hirano et al. (2014)

Some limitations of this simulation

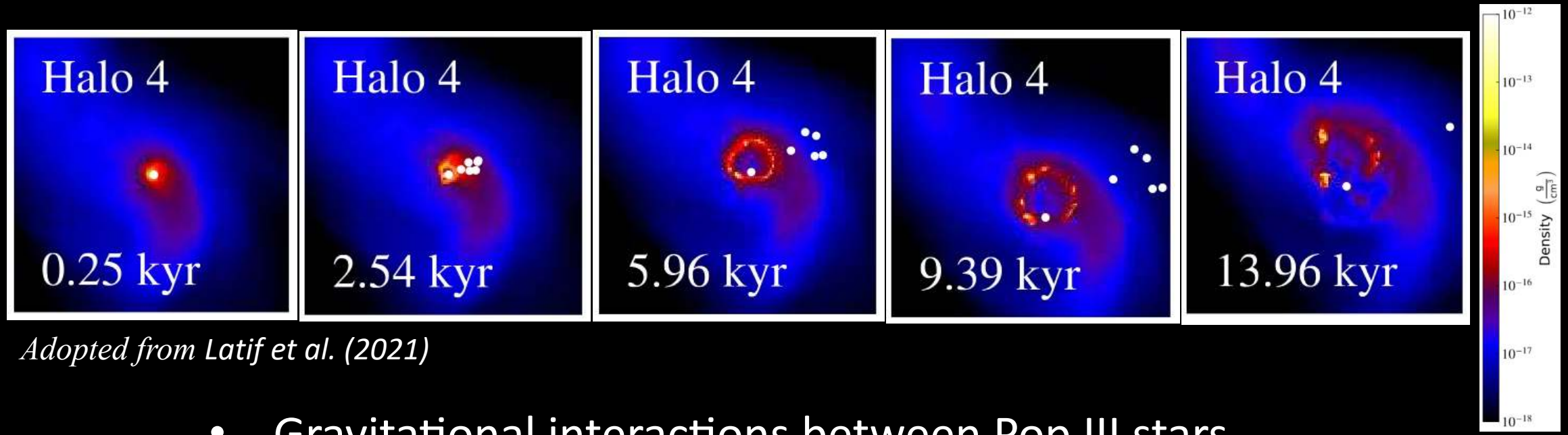


Adopted from Regan et. al. (2014a)

- Only a single star forming per minihalo.
- Fragmentation during accretion could result in smaller stars.
- However, magnetic fields might hinder fragmentation.

Compare with a different simulation

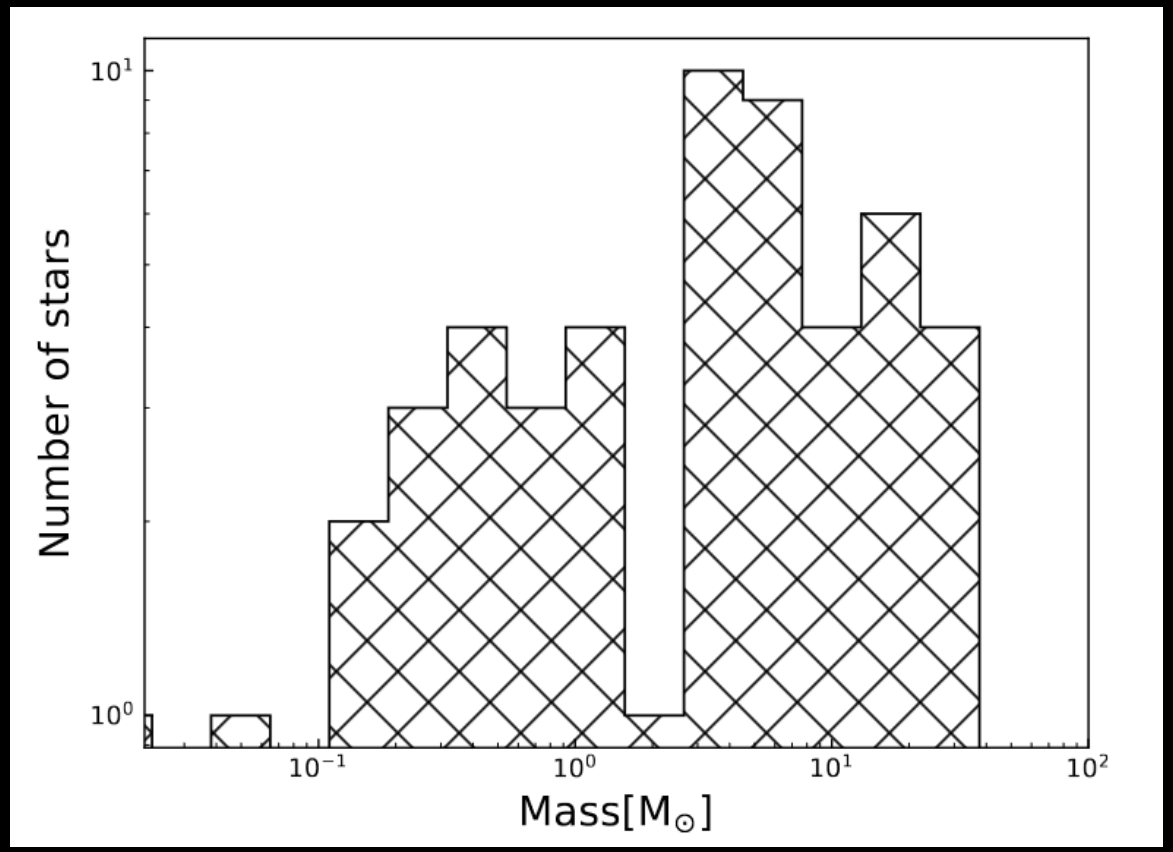
Three-Body Interactions Eject Protostars



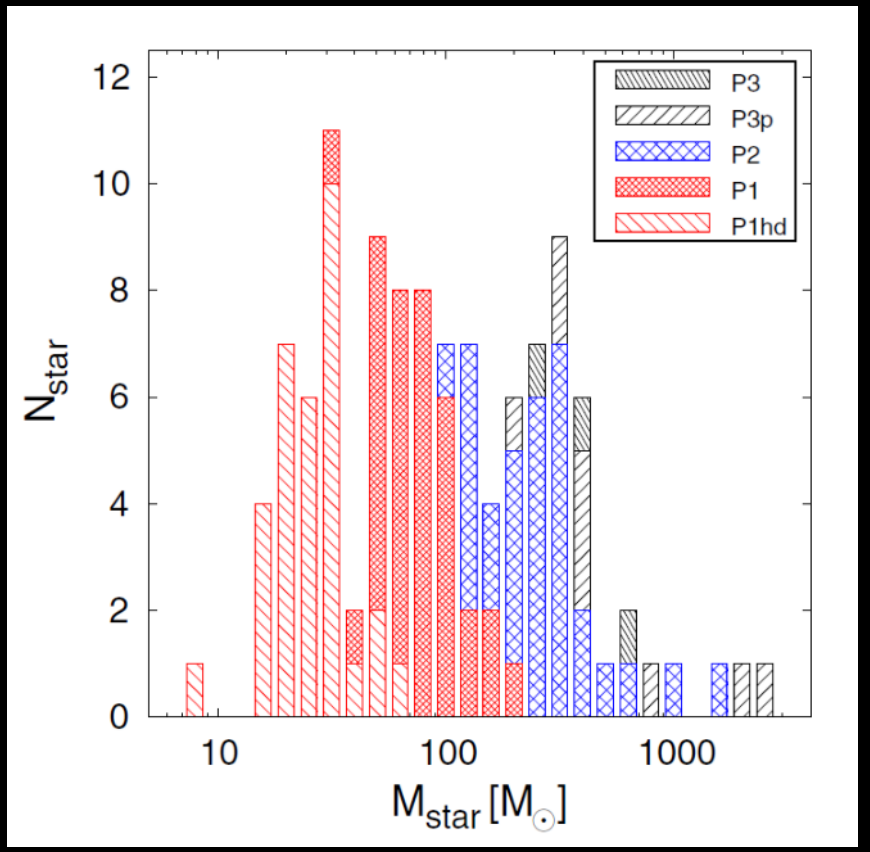
Adopted from Latif et al. (2021)

- Gravitational interactions between Pop III stars.
- Stars are ejected from gas rich regions.
- Radiation from nearby stars limits accretion.

Very Different Pop III IMFs



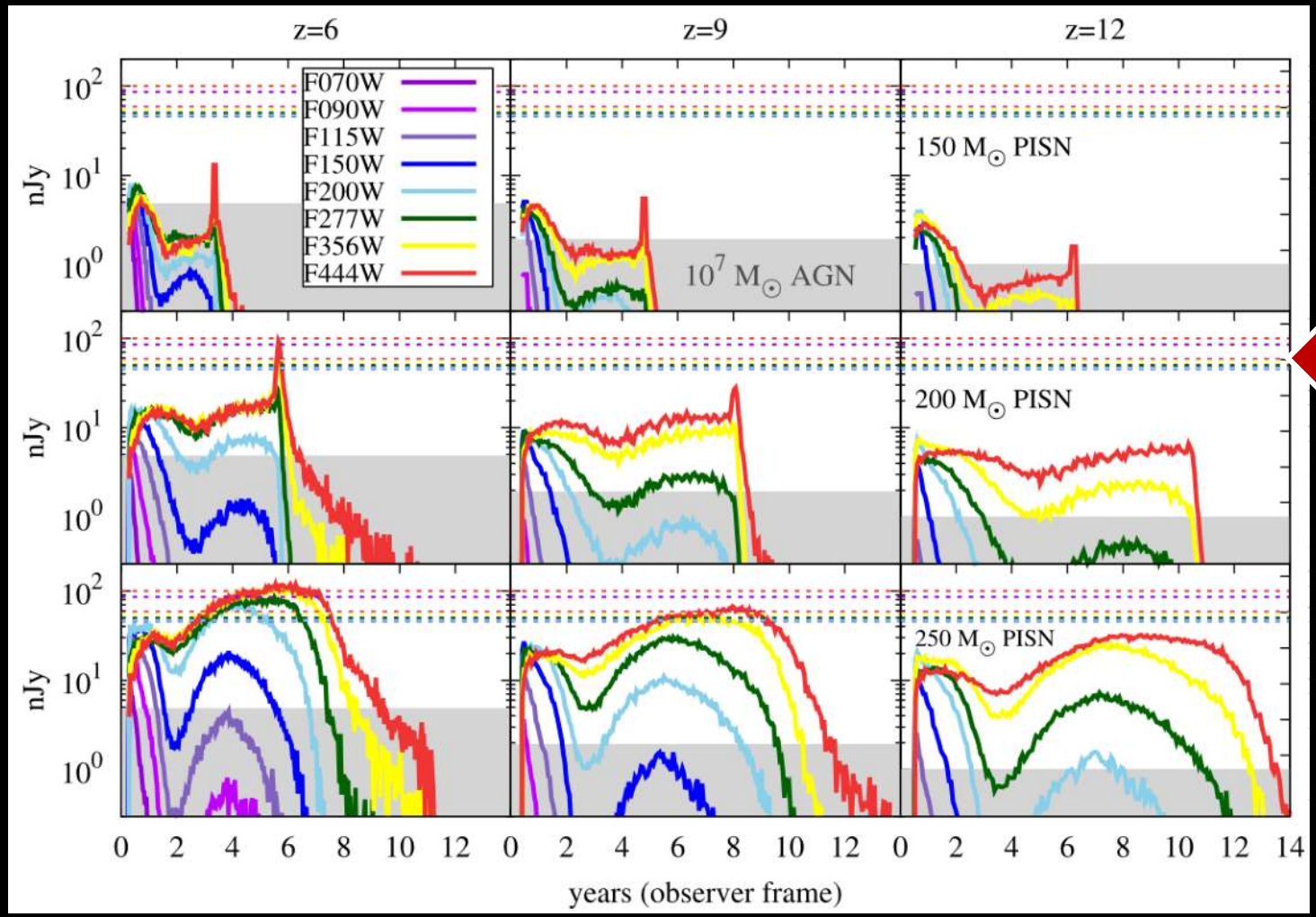
Adopted from Latif et al. (2021)



Adopted from Hirano et al. (2014)

Observational evidence for Pop III Stars

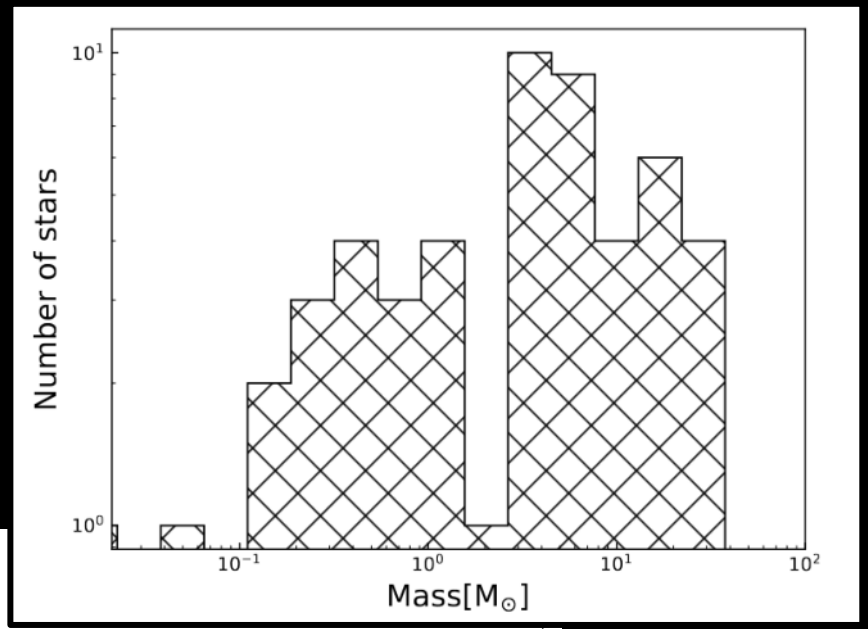
JWST observations of Pair Instability SN

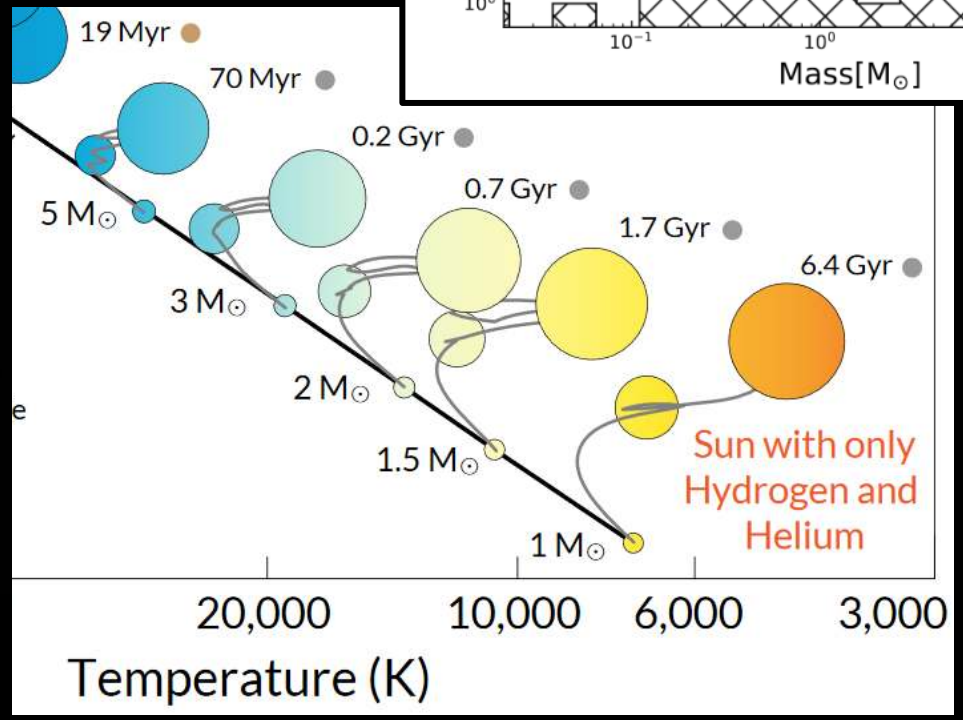


JWST can detect emission from PISN

Adopted from Hartwig et al. (2018)

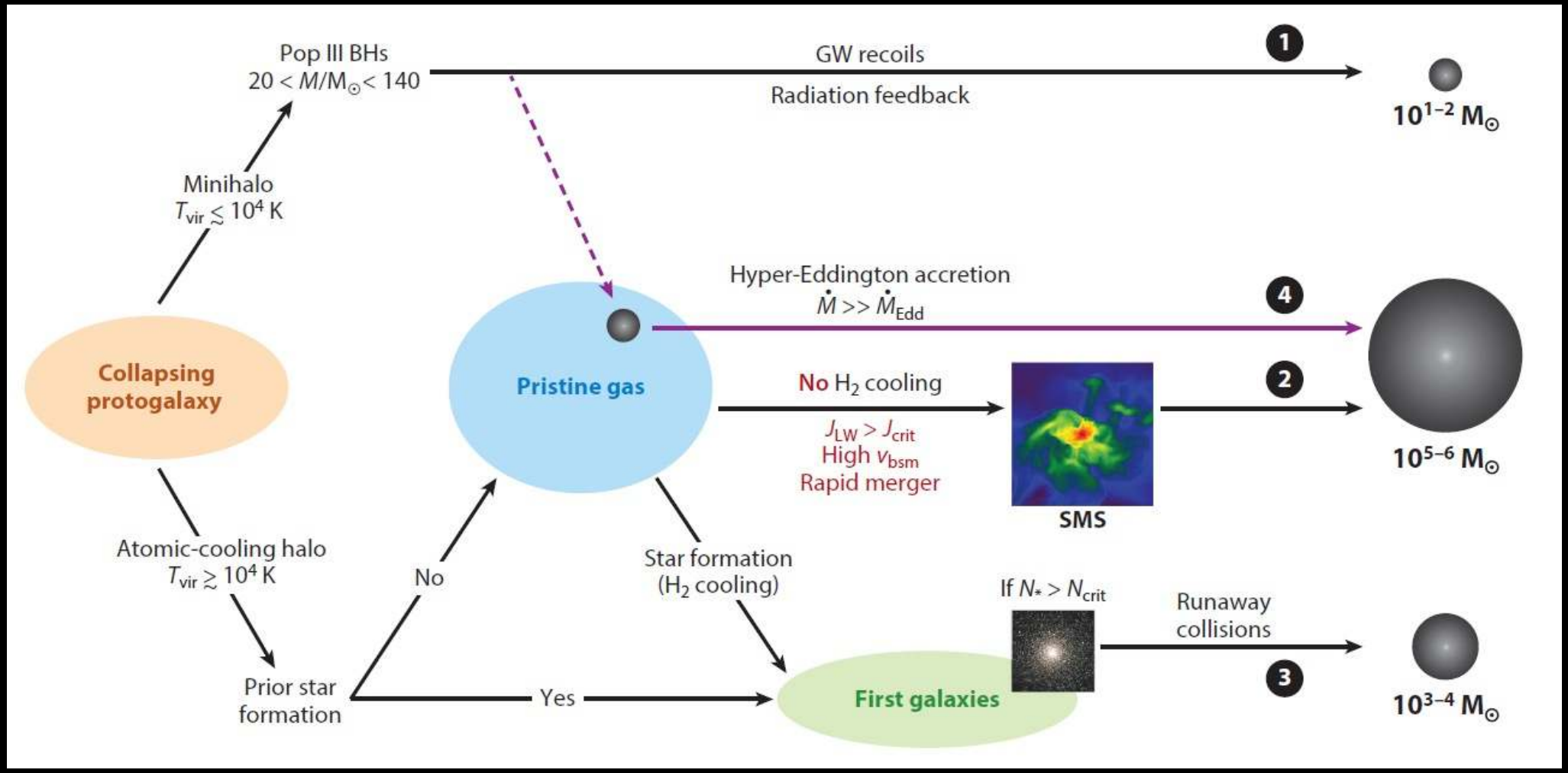
Stellar Archaeology





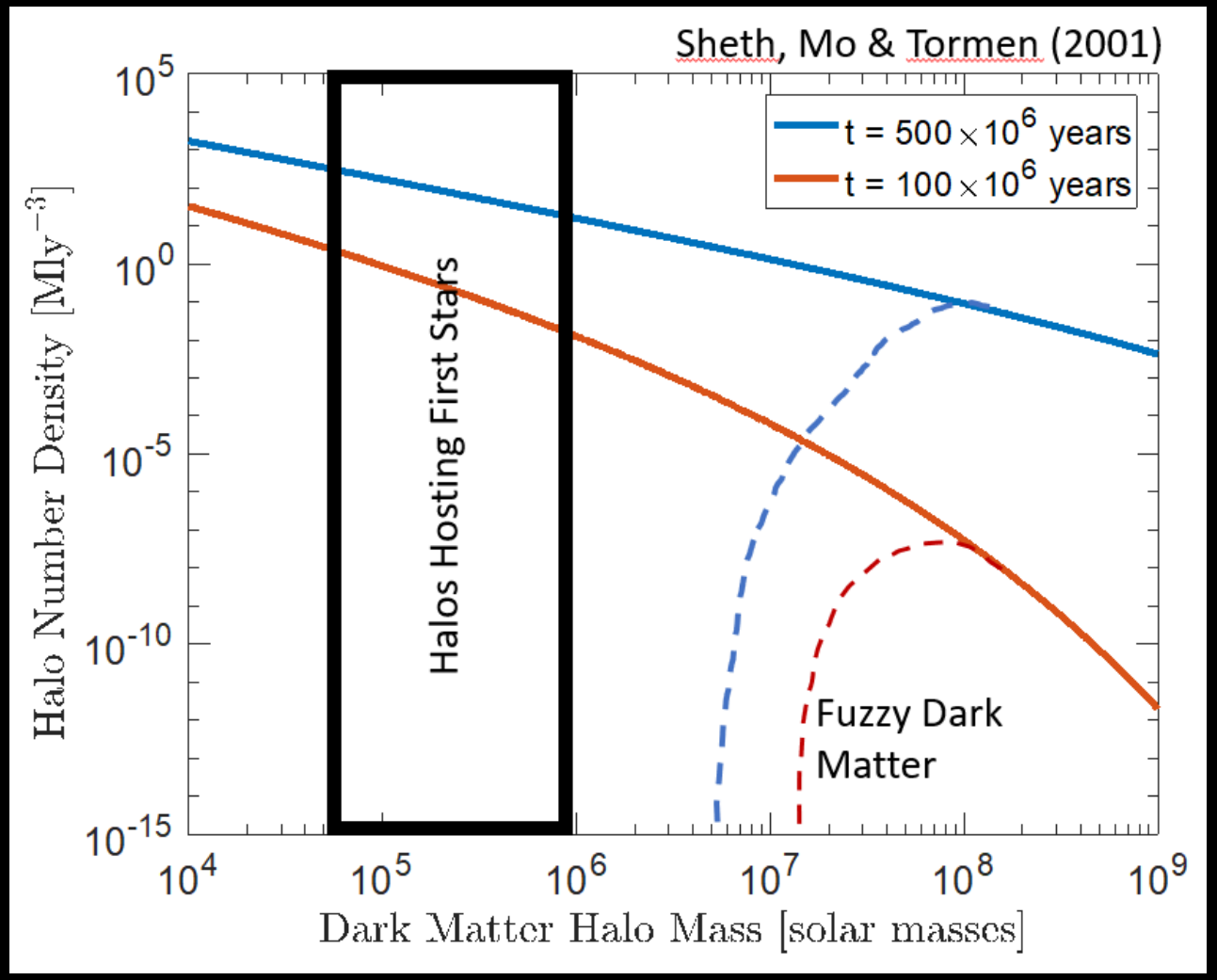
Implications of the Pop III IMF

The Seeds of Supermassive Black Holes



Adopted from Inayoshi, Visbal, Haiman (2020)

Constraints on Dark Matter Models



- Number of low mass halos dependent on DM model.
- Can use Pop III stars to test models for dark matter!

Courtesy of Eli Visbal

Take away

- JWST will provide the first opportunity to look for evidence of Pop III stars.
- Simulations can constrain the properties of the first stars.
- Understanding Pop III stars will provide new insights into galaxy evolution, SMBHs, and dark matter.

References

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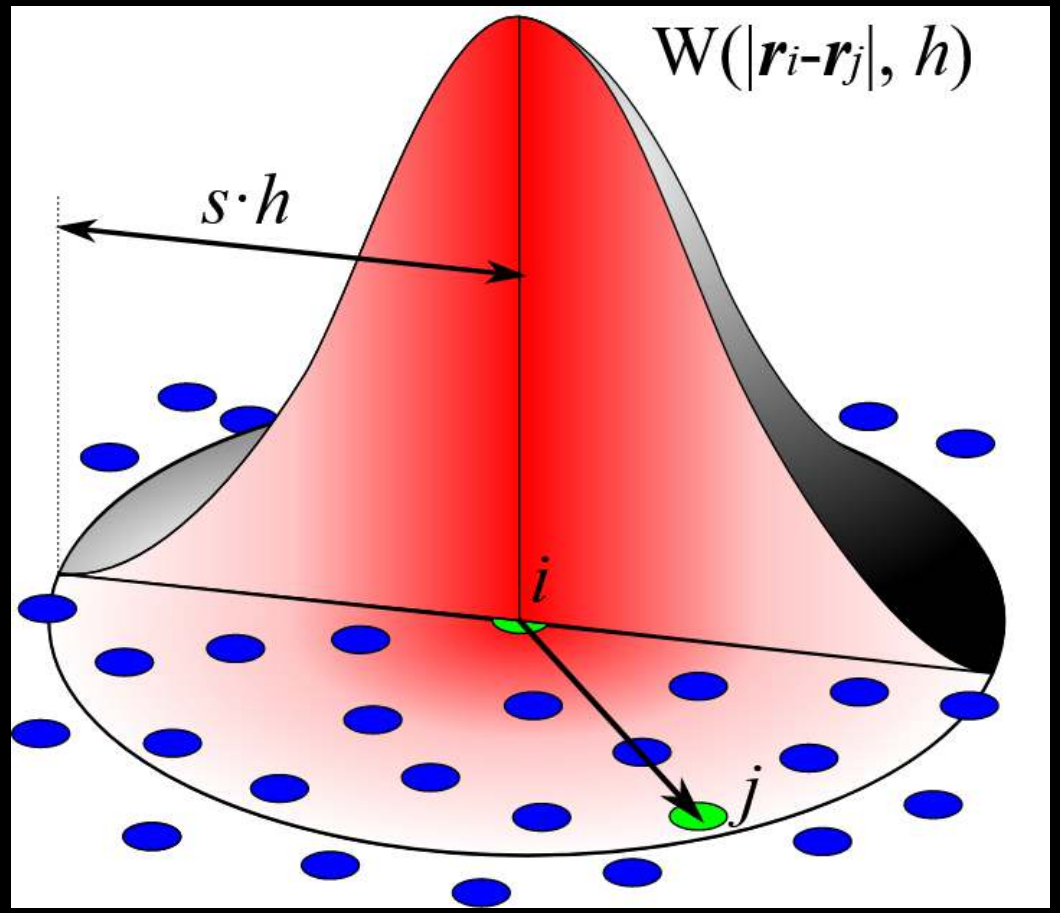
Smoothed Particle Hydrodynamics



- Reconstruct a continuous field from cloud of discrete particles.
- Conserves physically conserved properties.
- Physical quantities varying by many orders of magnitude.

Adaptive Mesh Refinement