THE FORMATION OF THE FIRST STARS AND GALAXIES

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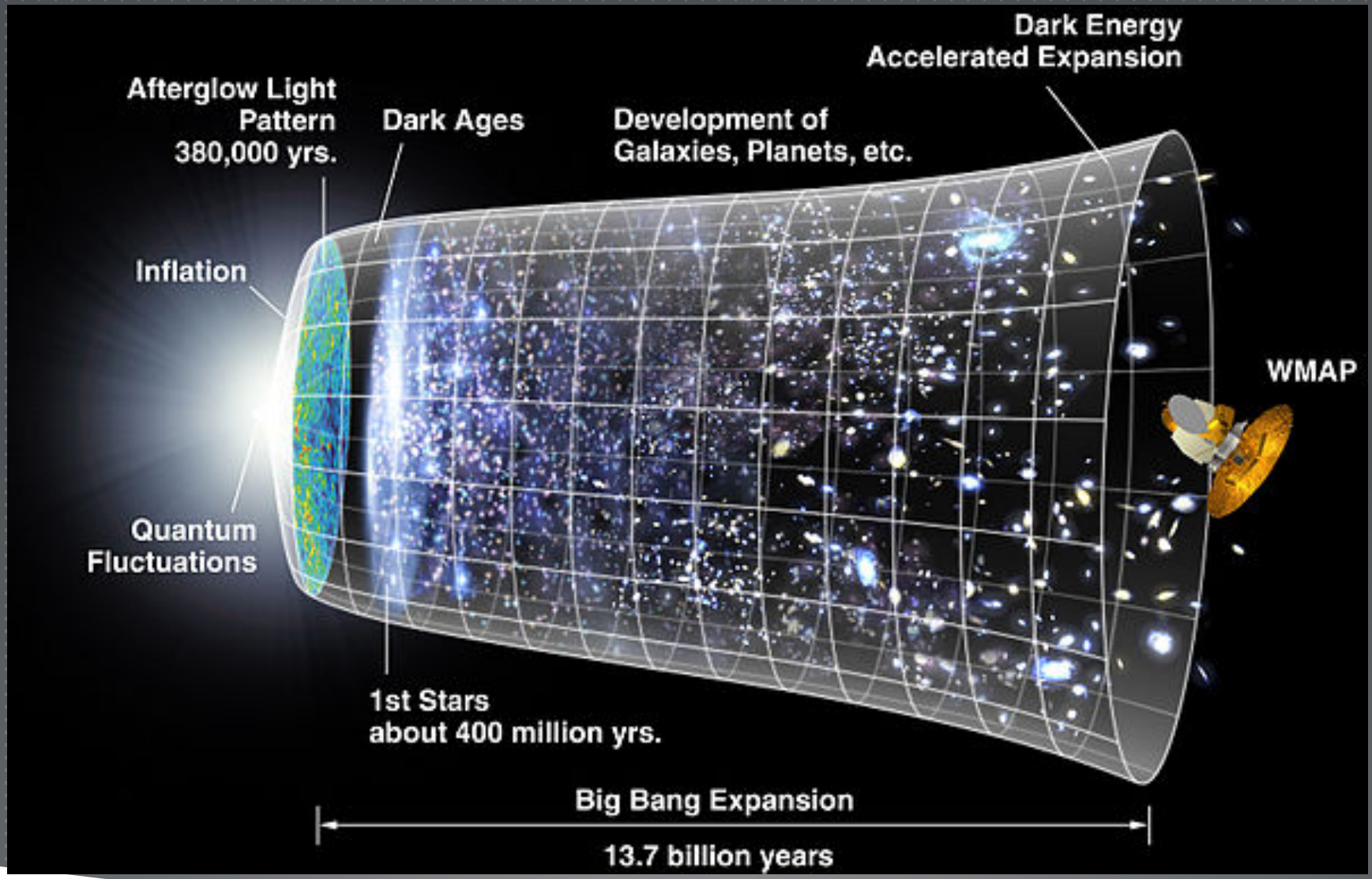

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

ΛCDM

- Λ – vacuum "dark" energy
- Cold Dark Matter (CDM) – slow moving (non-relativistic) particles
  - Allows collapse early in Universe
  - Can have bottom-up or Hierarchical galaxy formation

THE FIRST STARS

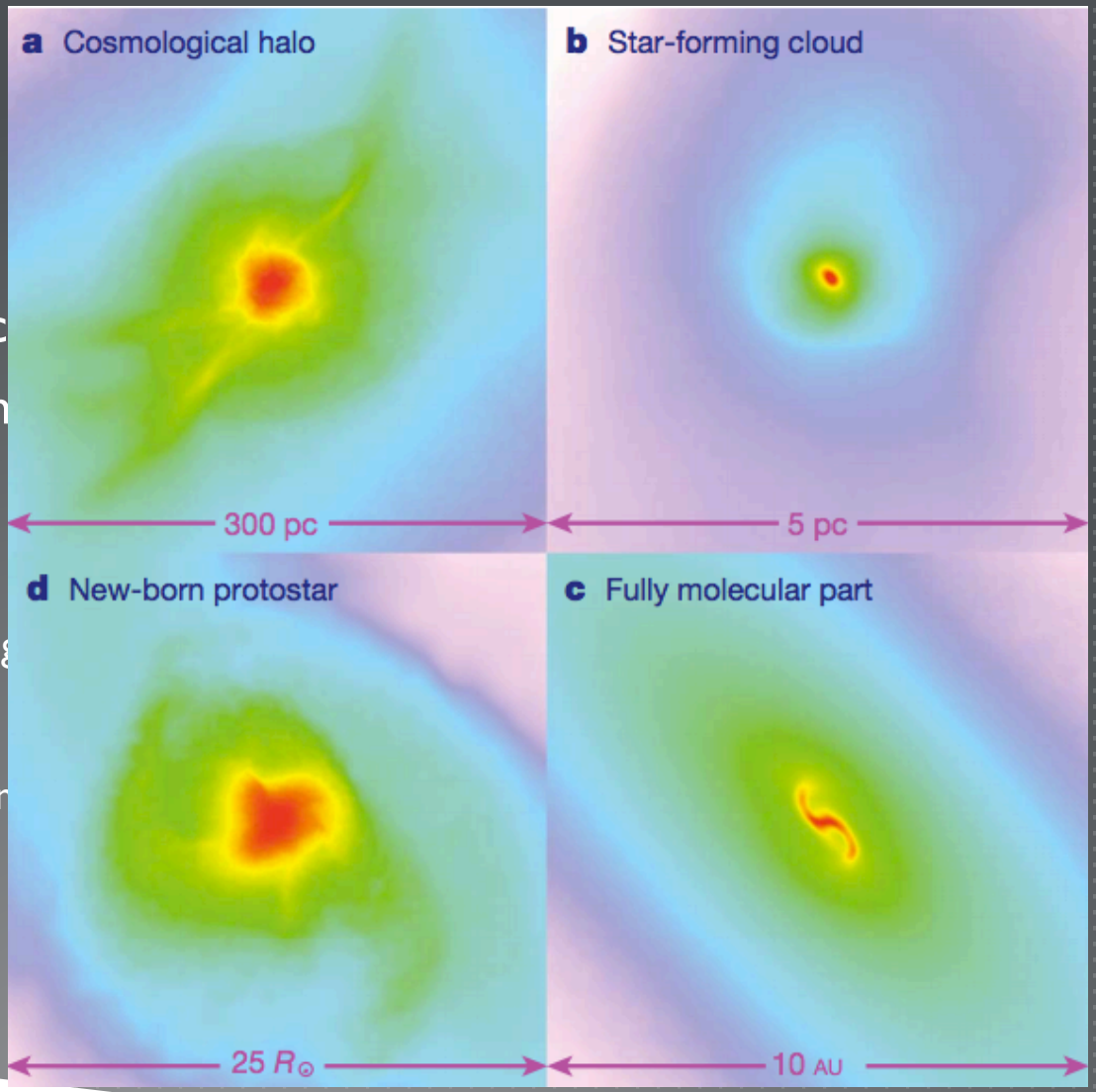
- Population III
  - Pop. III.1
  - Pop. III.2
- Population II
  - extremely metal poor for metallicities $10^{-4} < Z/Z_{\odot} < 10^{-3}$
  - ultra-metal poor for $10^{-5} < Z/Z_{\odot} < 10^{-4}$
  - hyper-metal poor for $10^{-6} < Z/Z_{\odot} < 10^{-5}$

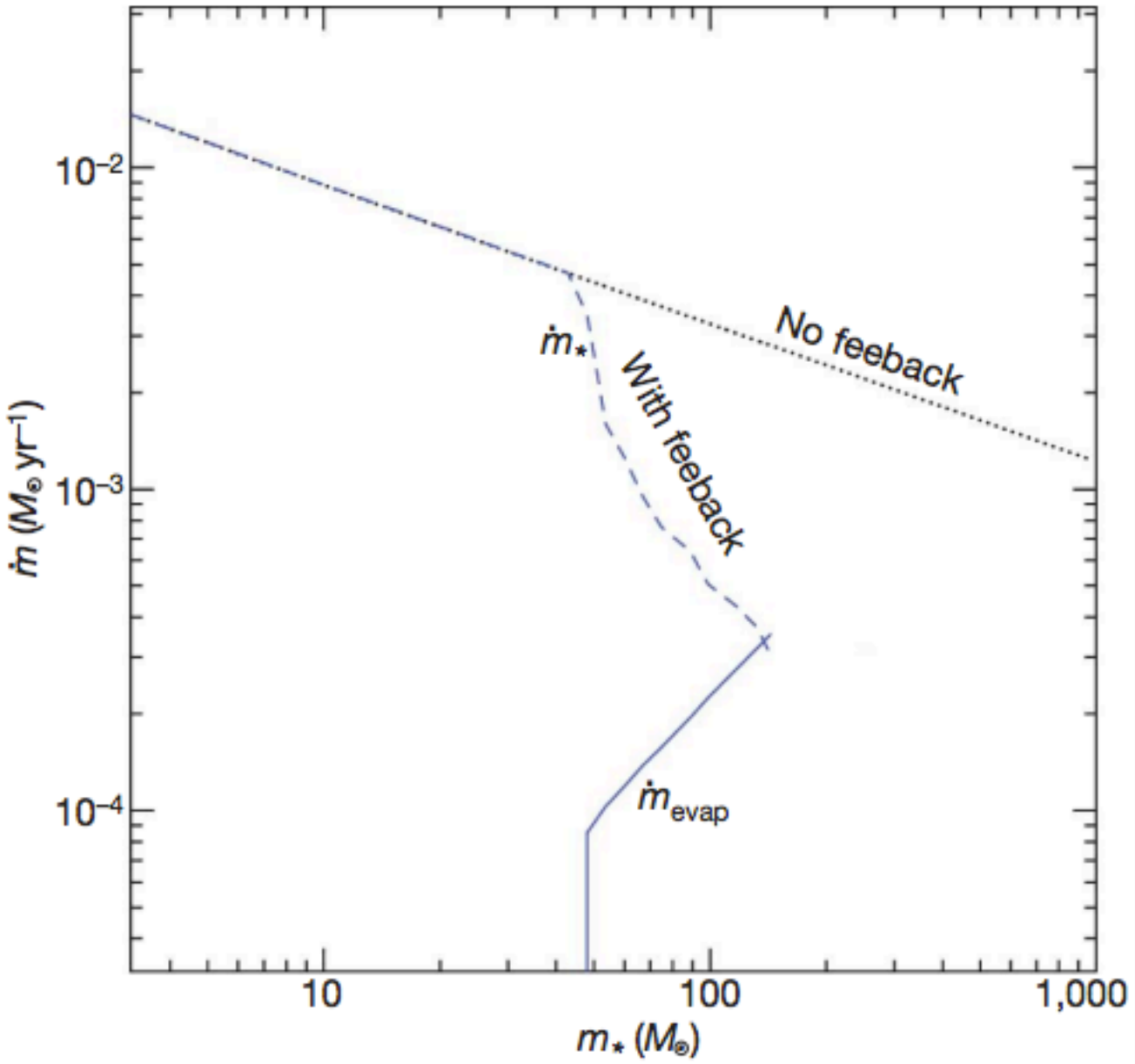
THE FIRST STARS

- Dark matter "minihalos"
  - 1000K and $10^6 M_\odot$
- Gas must cool in order to collapse into stars
  - $H + e^- \rightarrow H^- + \gamma$
  - $H^- + H \rightarrow H_2 + e^-$
- Collapse when Jean's mass exceeded
  - $M_J = 500 M_\odot \left(\frac{T}{200}\right)^{3/2} \left(\frac{n}{10^4}\right)^{-1/2}$

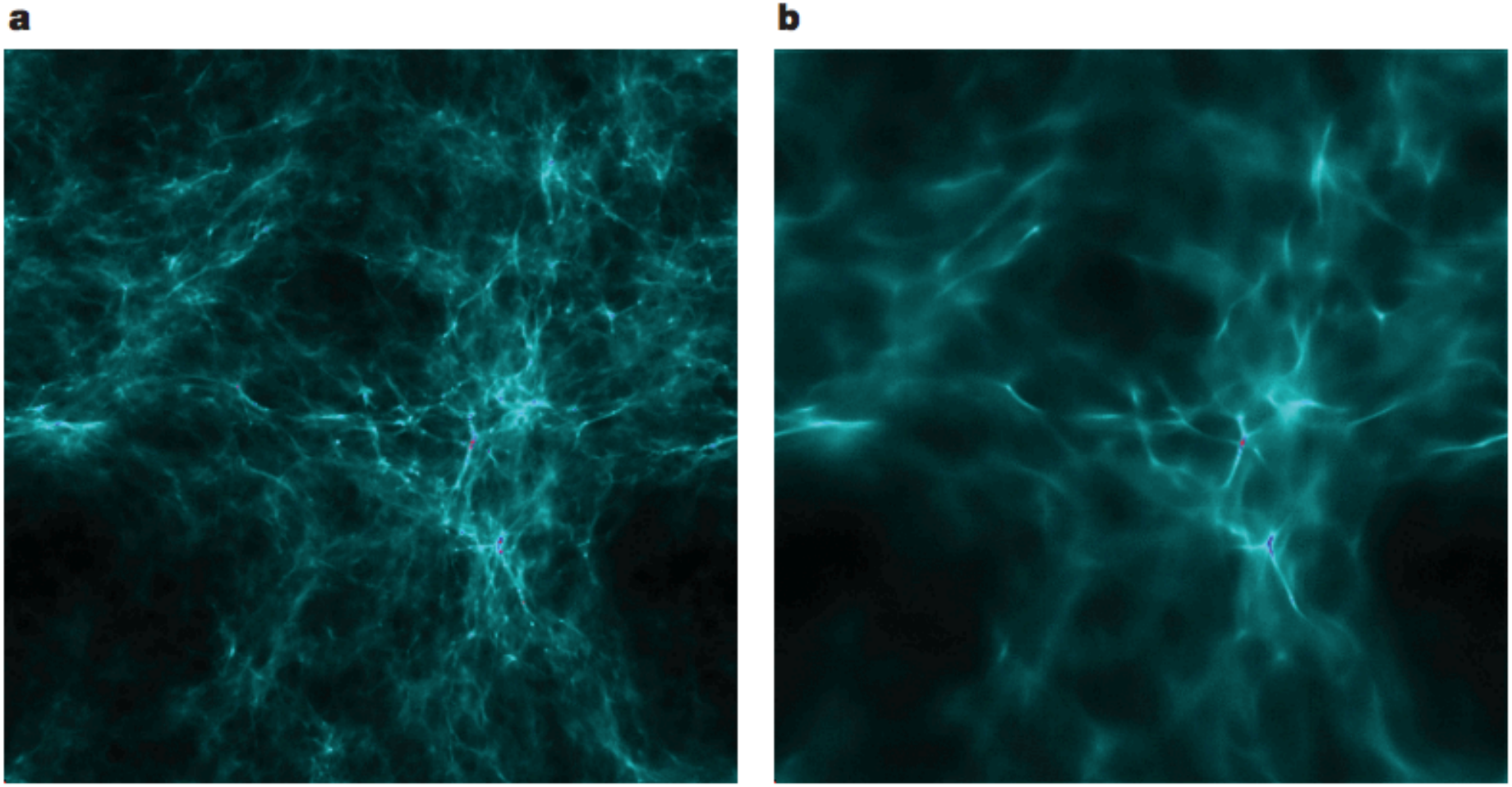
PROPERTIES

- Single stars
- Clustering due to feedbac
- Formation of protostar th
- Final mass 60-300 $M_\odot$
- No dust
  - Less radiation pressure on g
- Weaker magnetic fields
  - Less dissipation of angular r
  - No outflows




10^{-2}
10^{-3}
10^{-4}
$\dot{m}$ ($M_\odot$ yr^{-1})
$\dot{m}_*$
With feeback
No feeback
$\dot{m}_{evap}$
10
100
1,000
m_* ($M_\odot$)

WDM?



NEUTRALINOS?

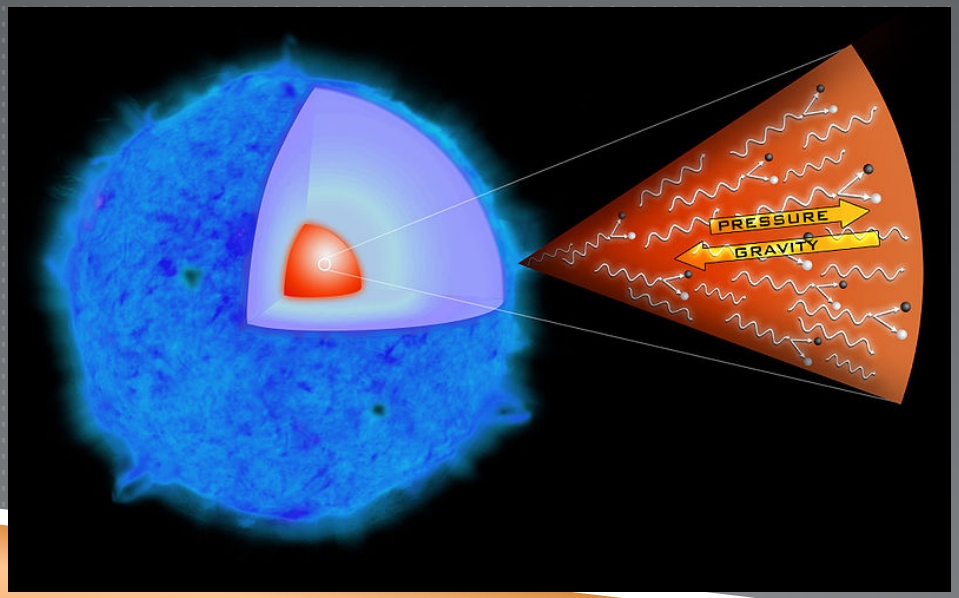
- Self-annihilation produces high-energy particles and high-energy photons
- Heating the collapsing gas
- Effects?
  - Heating gas means it takes longer for it to cool enough to collapse
  - First stars will form later than if CDM is not neutralinos.

FEEDBACK

- H II regions left behind after the central star has died, catalyse the reformation of molecules, allowing the primordial gas to cool leading to the formation of population III.2 stars
- Process takes of the order of the local Hubble time, thus imposing a 100 Myr delay in star formation.
- Increasing volume filling fraction of H II, suggests high optical depth to Lyman–Werner photons, acting to suppress the build-up of a background Lyman–Werner radiation field, and mitigating negative feedback on star formation
- Strongly clustered nature of early star formation
- Movie

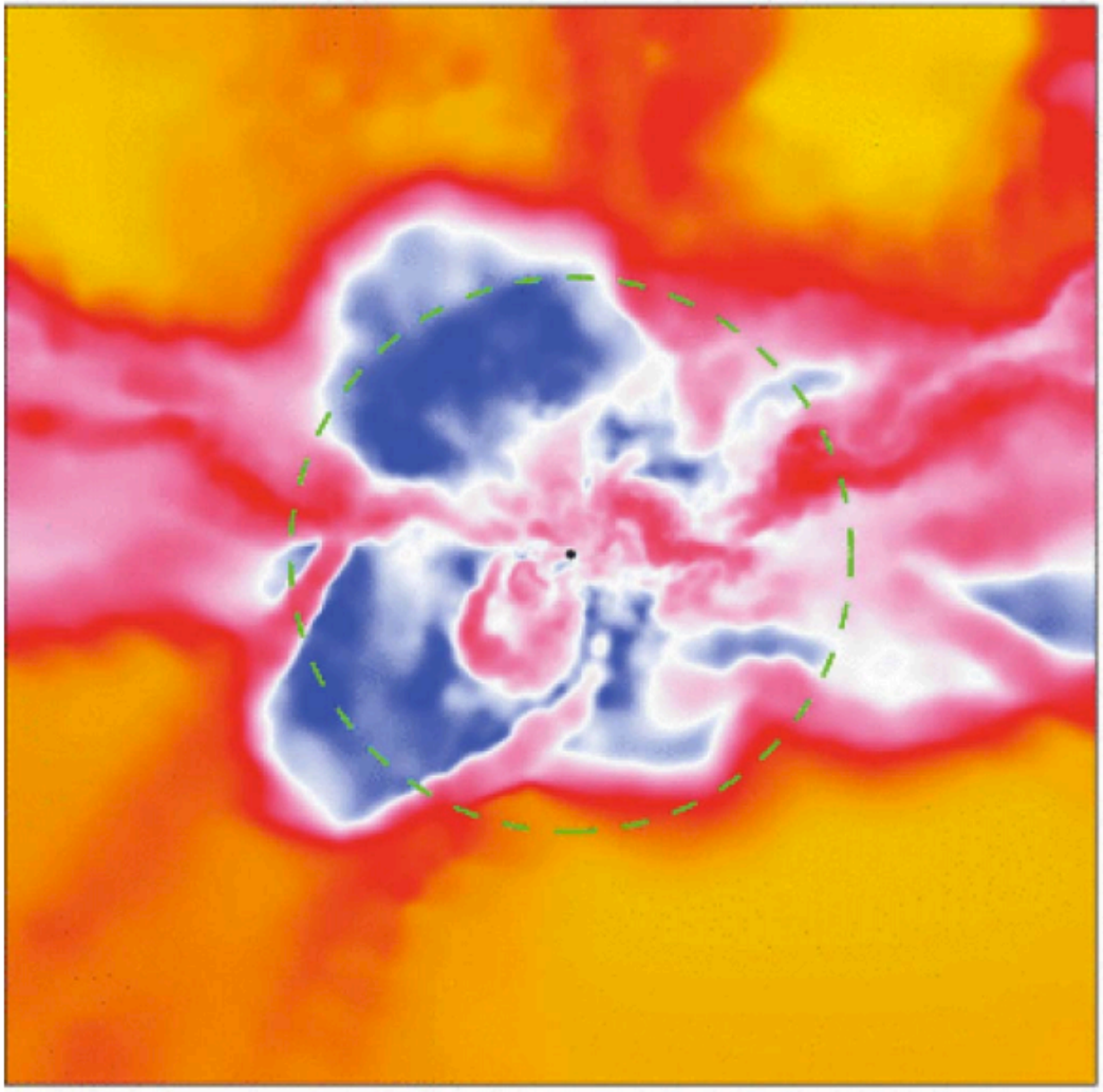
FEEDBACK

- Many pop III stars collapse into black holes
- Pop III stars 140-260$M_{\odot}$ explode as pair-instability supernovae
  - Release a lot of energy (10^{51}erg to 10^{53}erg)
  - Release metals – enriching surrounding medium



FIRST GALAXIES

- More massive dark matter halos – $10^8 M_\odot$
- Higher temperatures – $10^4 K$
- Feedback from first generation of stars
- Gas re-incorporation time is as long as 10^8 years


log Ma
−1
0
1
2
Size: 40 kpc (comoving)
x–y plane
z = 10.62
t_H = 429.4 Myr

FUTURE

- OBSERVE some of this stuff
- What kinds of things could we possibly observe?