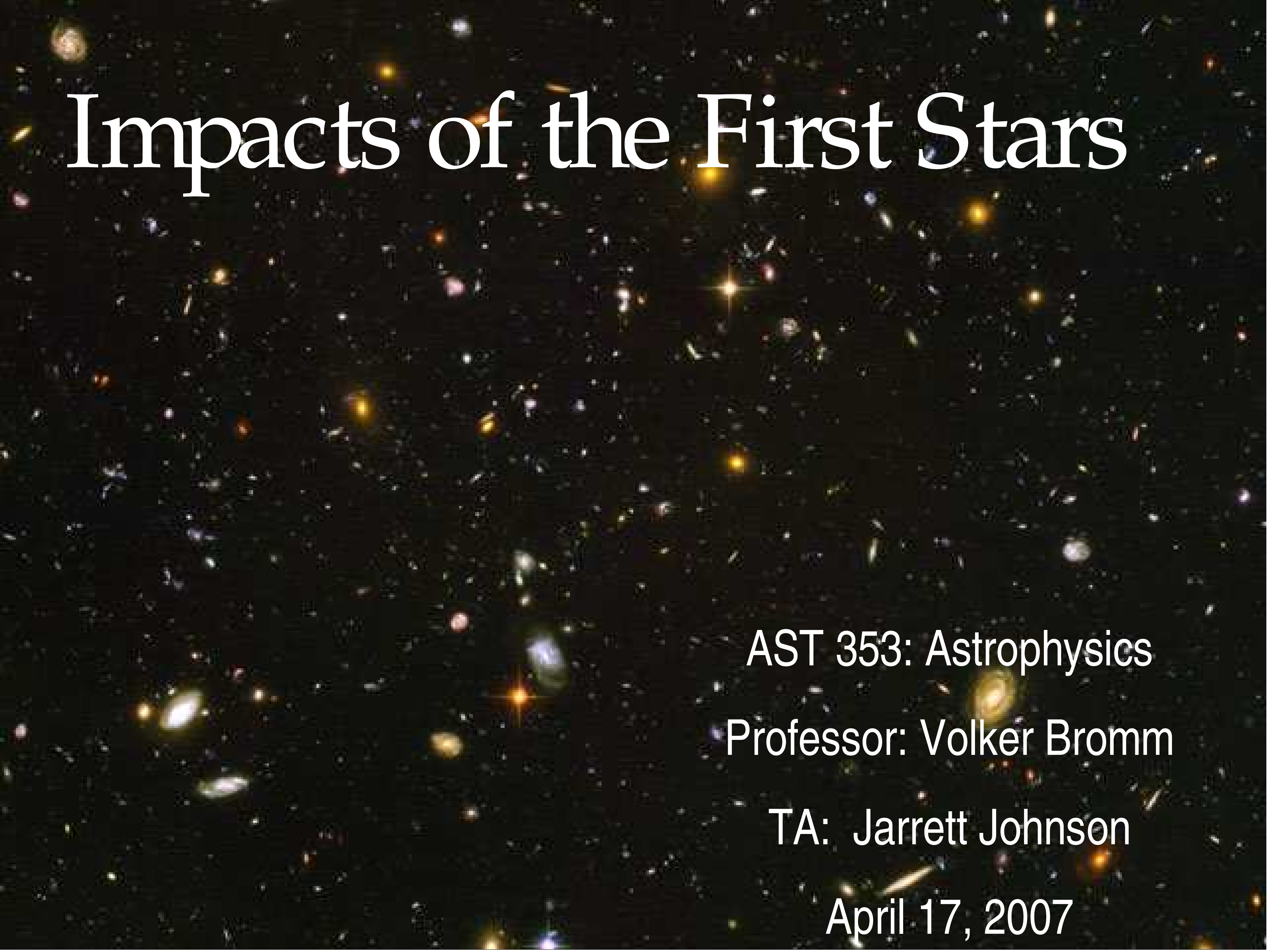


Impacts of the First Stars

AST 353: Astrophysics

Professor: Volker Bromm

TA: Jarrett Johnson

April 17, 2007

Pop III Star Formation in Dark Matter Minihalos

- Mass of the dark matter minihal determines the temperature needed for gas to collapse to form stars:

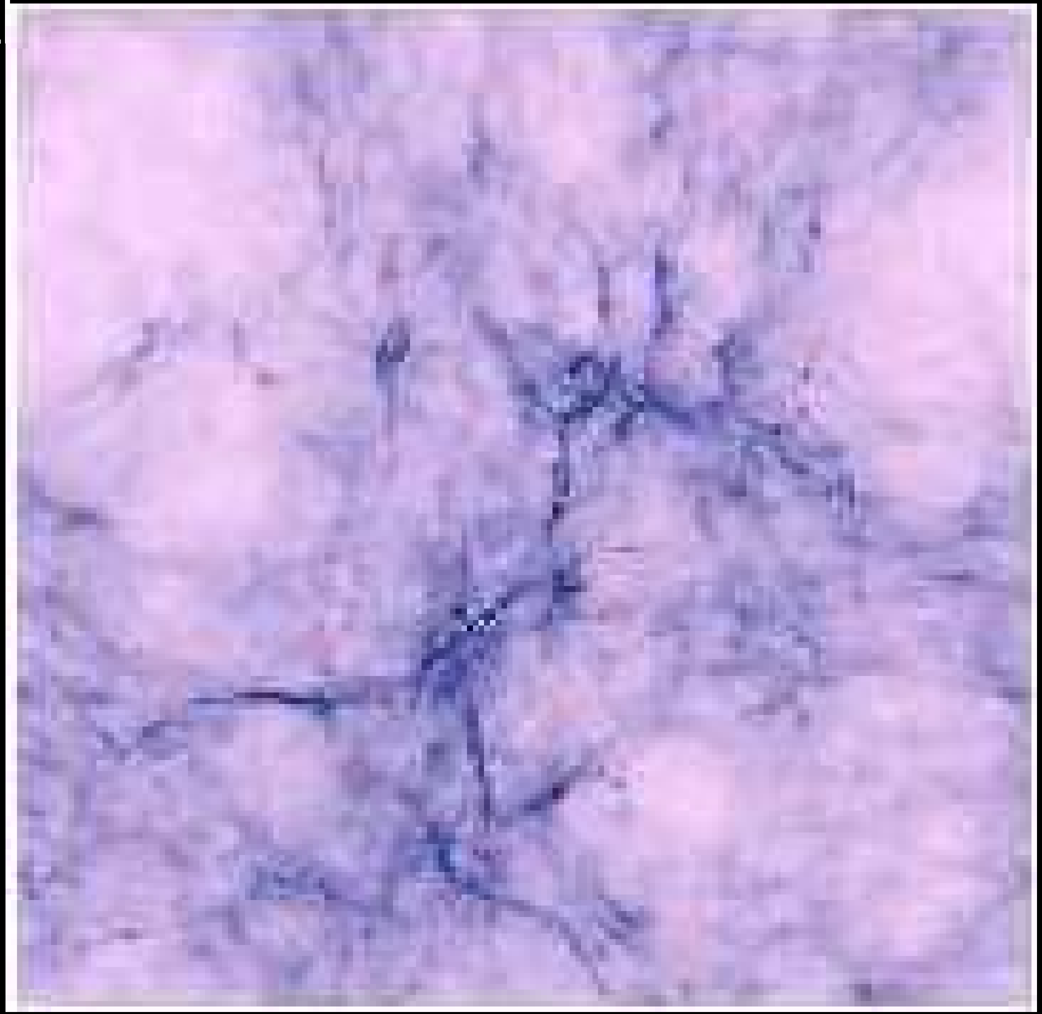
$k_B T_{vir} \sim G M_{halo} m_H / R_{vir}$

$R_{vir} \sim 100$ pc

$M_{halo} \sim 10^6$ M_solar

$\Rightarrow T_{vir} \sim 10^3$ K

$\Rightarrow$ For collapse of gas, need H_2 cooling



Yoshida et al. (2003)

Massive Population III

- With only H and H_2 as the available coolants, primordial gas is unable to cool to below ~200 K in minihalos

- Detailed calculations of the collapse of primordial gas into minihalos show that the gas reaches a characteristic density of $n \sim 10^4$ cm^{-3}

$$M_J \simeq 700 \mathrm{M}_\odot \left(\frac{T_{\mathrm{final}}}{200\,\mathrm{K}}\right)^{3/2} \left(\frac{n_{\mathrm{final}}}{10^4 \mathrm{cm}^{-3}}\right)^{-1/2}$$

Radiation from the First Stars

- With masses of ~ 100 M_solar, Pop III stars would have surface temperatures of T ~10^5 K and radii of R > 4 R_solar

  => $L_{PopIII} \sim 10^6 L_{Sun}$

- Pop III stars thus would have emitted many photons with E > 13.6 eV, which are able to ionize neutral hydrogen and heat the primordial gas

- The first HII regions were thus very large and hot:

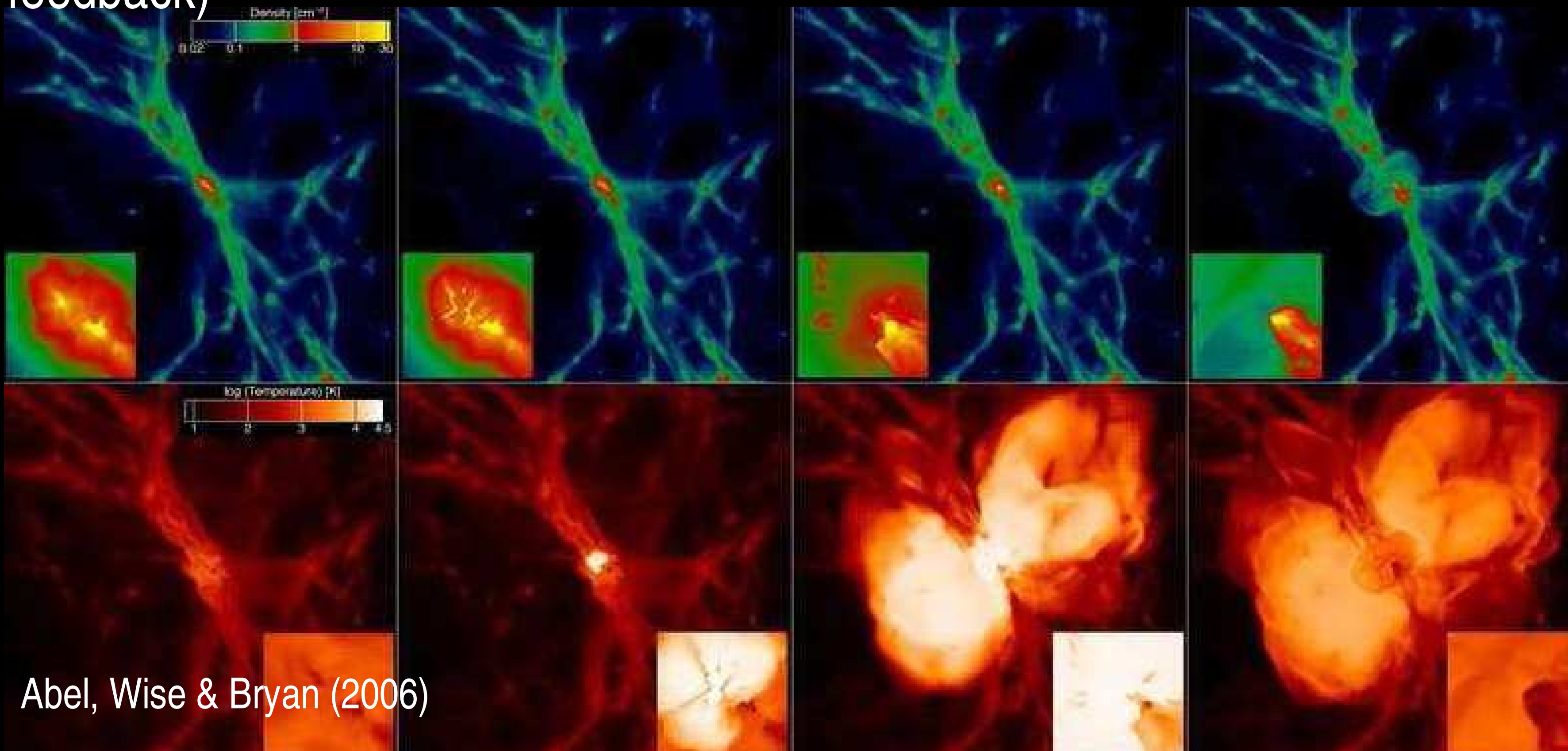
  R_{HII} ~ 5 kpc

  T_{HII} ~ 30,000 K

The First HII Region

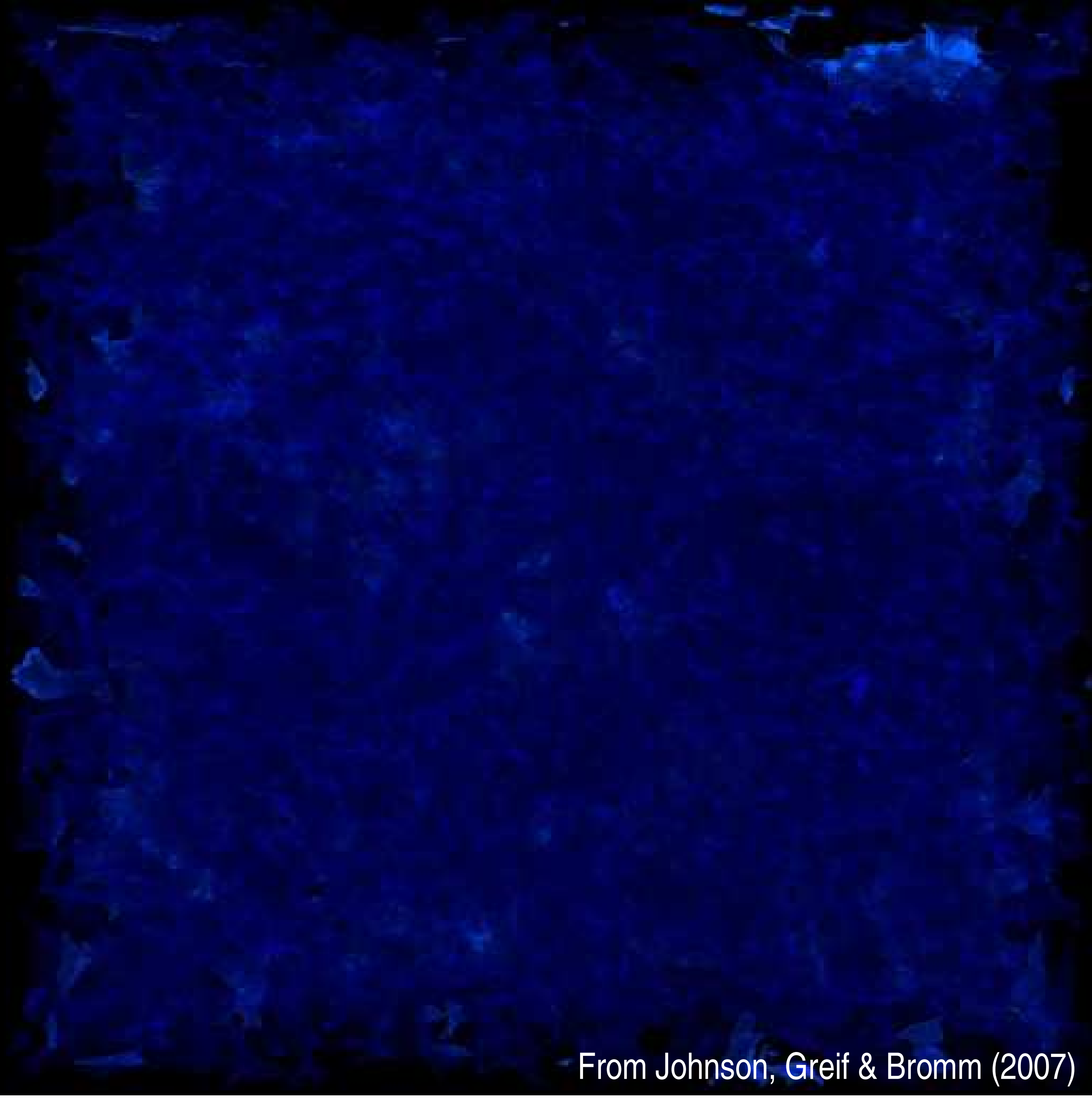
• The gas in the minihalo of the star is blown out, $T_{HII} > T_{vir}$

$\Rightarrow$ Further star formation in this minihalo is hindered (Negative feedback)



Abel, Wise & Bryan (2006)

• Begins the process of the *reionization* of the Universe


From Johnson, Greif & Bromm (2007)

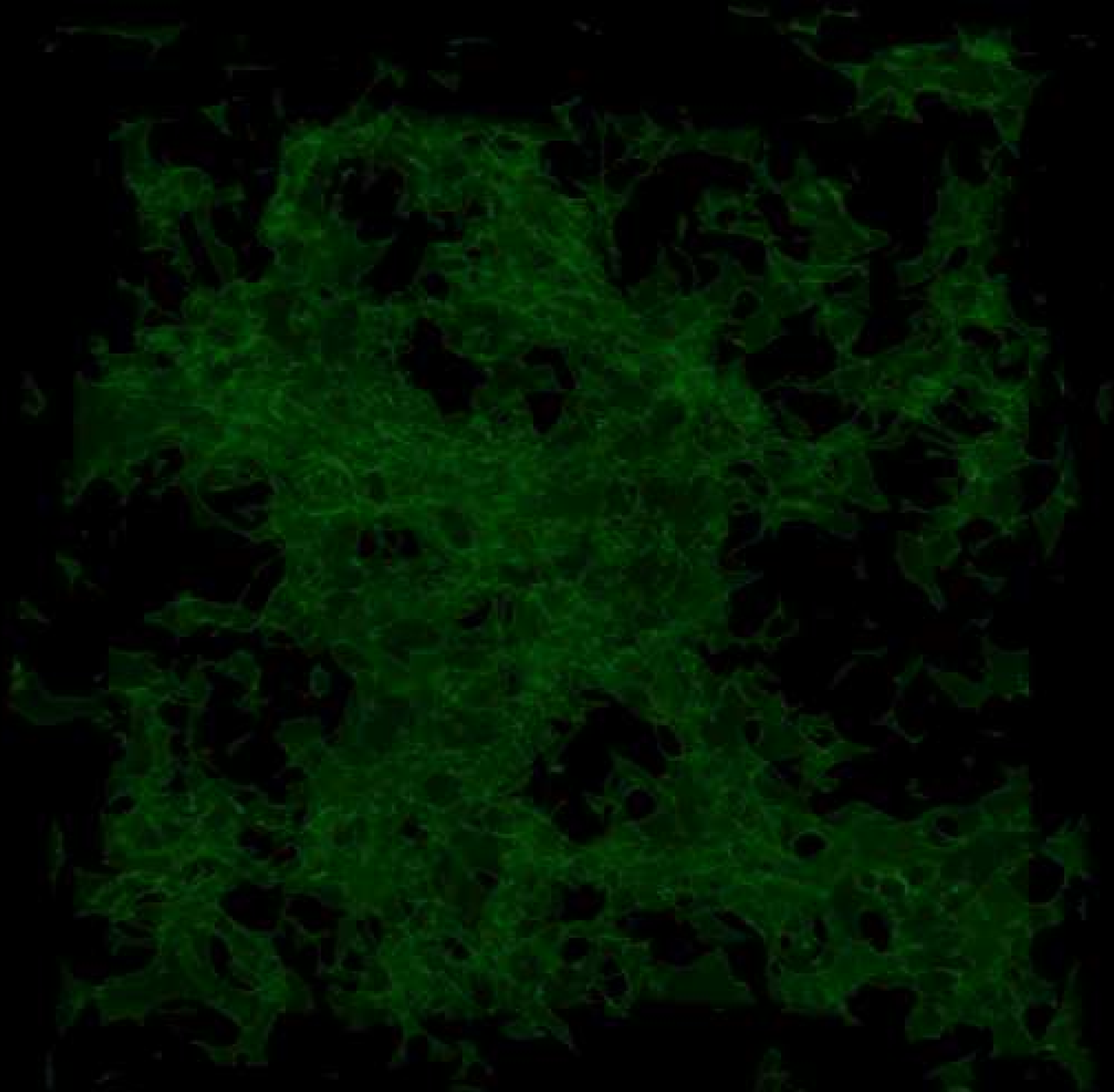
Radiation from the First Stars

- Photons with 11.2 eV < E < 13.6 eV can excite and dissociate H_2 molecules

- But these are the main coolants that allow for Pop III star formation in minihalos

  => Negative feedback on star formation

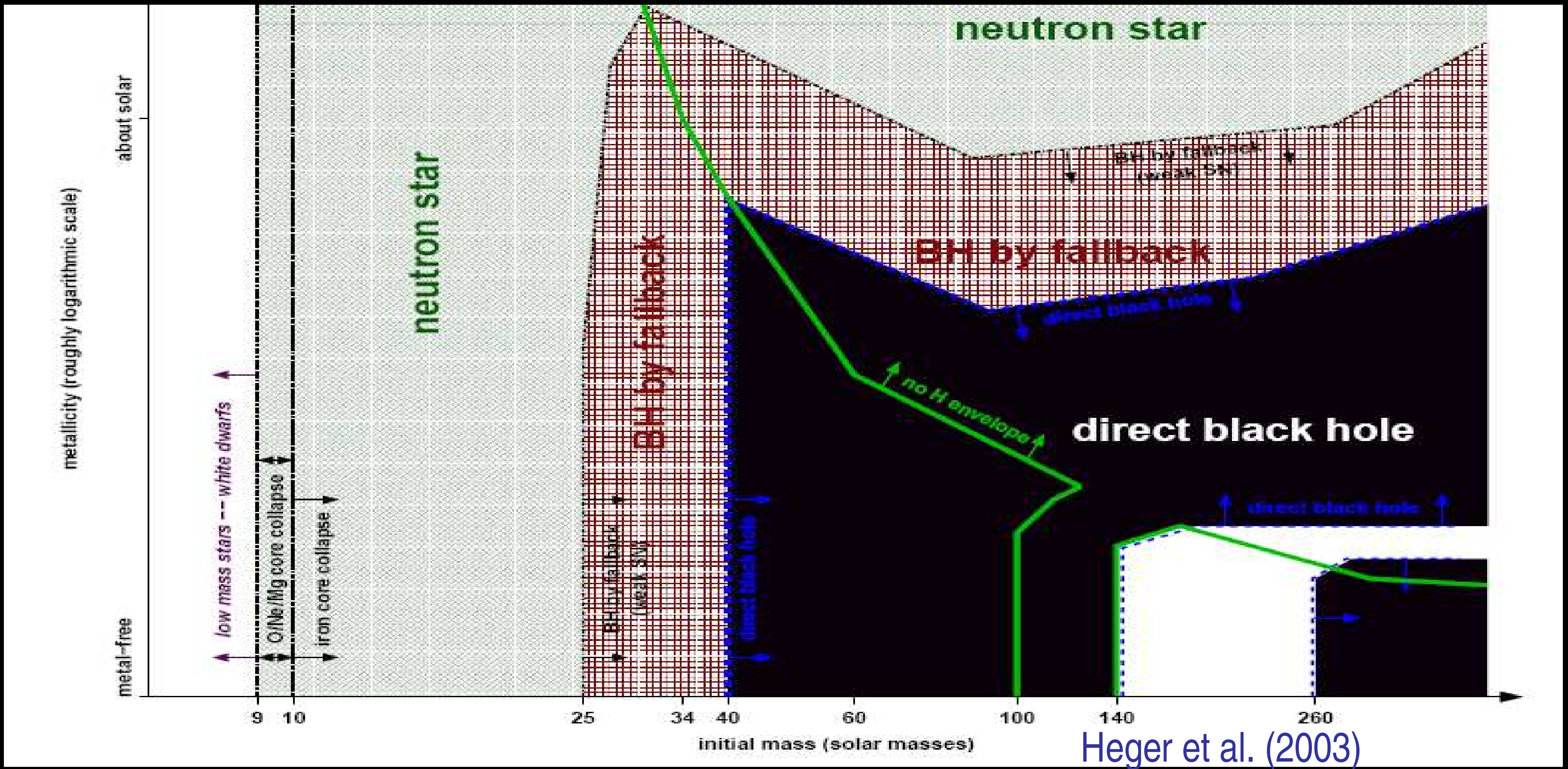
- Note that after the star dies, H_2 can quickly reform, as the ionized gas cools!



From Johnson, Greif & Bromm (2007)

The Endpoints of the First Stars

- Massive Pop III stars end their lives as one of the following:
  - Black holes (Possibly type II supernovae and/or GRBs)
  - Pair-instability supernovae



Heger et al. (2003)

The First Supernovae

- The explosions of the first stars release the first heavy elements into the Universe
- The presence of heavy elements (C, O, Fe, etc.) changes the nature of star formation
- Heavy elements act as effective coolants, allowing gas to achieve lower temperatures

=> *Low-mass* stars are more easily formed!

Movies from class can be found at the following websites:

Supernova movies:
www.tacc.utexas.edu/~vega/supernova/

Radiation movies:
http://www.tacc.utexas.edu/~pnav/FirstStars/