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 minihalo determines the temperature needed for gas to collapse to form stars:

\[ k_B T_{\text{vir}} \sim \frac{GM_{\text{halo}} m_H}{R_{\text{vir}}} \]

- \( R_{\text{vir}} \sim 100 \text{ pc} \)
- \( M_{\text{halo}} \sim 10^6 \text{ M}_{\odot} \)

\[ \Rightarrow T_{\text{vir}} \sim 10^3 \text{ K} \]

\[ \Rightarrow \text{For collapse of gas, need } \text{H}_2 \text{ cooling} \]
Massive Population III

- With only H and H$_2$ as the available coolants, primordial gas is unable to cool to below $\sim$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$^{-3}$

\[
M_j \approx 700 M_\odot \left( \frac{T_{\text{final}}}{200 \text{ K}} \right)^{3/2} \left( \frac{n_{\text{final}}}{10^4 \text{ cm}^{-3}} \right)^{-1/2}
\]
Radiation from the First Stars

• With masses of ~ 100 M\_solar, Pop III stars would have surface temperatures of T \sim 10^5 K and radii of R > 4 R\_solar

\[ L_{\text{PopIII}} \sim 10^6 L_{\text{Sun}} \]

• 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:
  \[ R_{\text{HII}} \sim 5 \text{ kpc} \]
  \[ T_{\text{HII}} \sim 30,000 \text{ K} \]
The First HII Region

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

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

- Begins the process of the reionization of the Universe

Radiation from the First Stars

- Photons with $11.2 \text{ eV} < E < 13.6 \text{ eV}$ can excite and dissociate $\text{H}_2$ molecules

- But these are the main coolants that allow for Pop III star formation in minihalos
  $\Rightarrow$ Negative feedback on star formation

- Note that after the star dies, $\text{H}_2$ can quickly reform, as the ionized gas cools!
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/