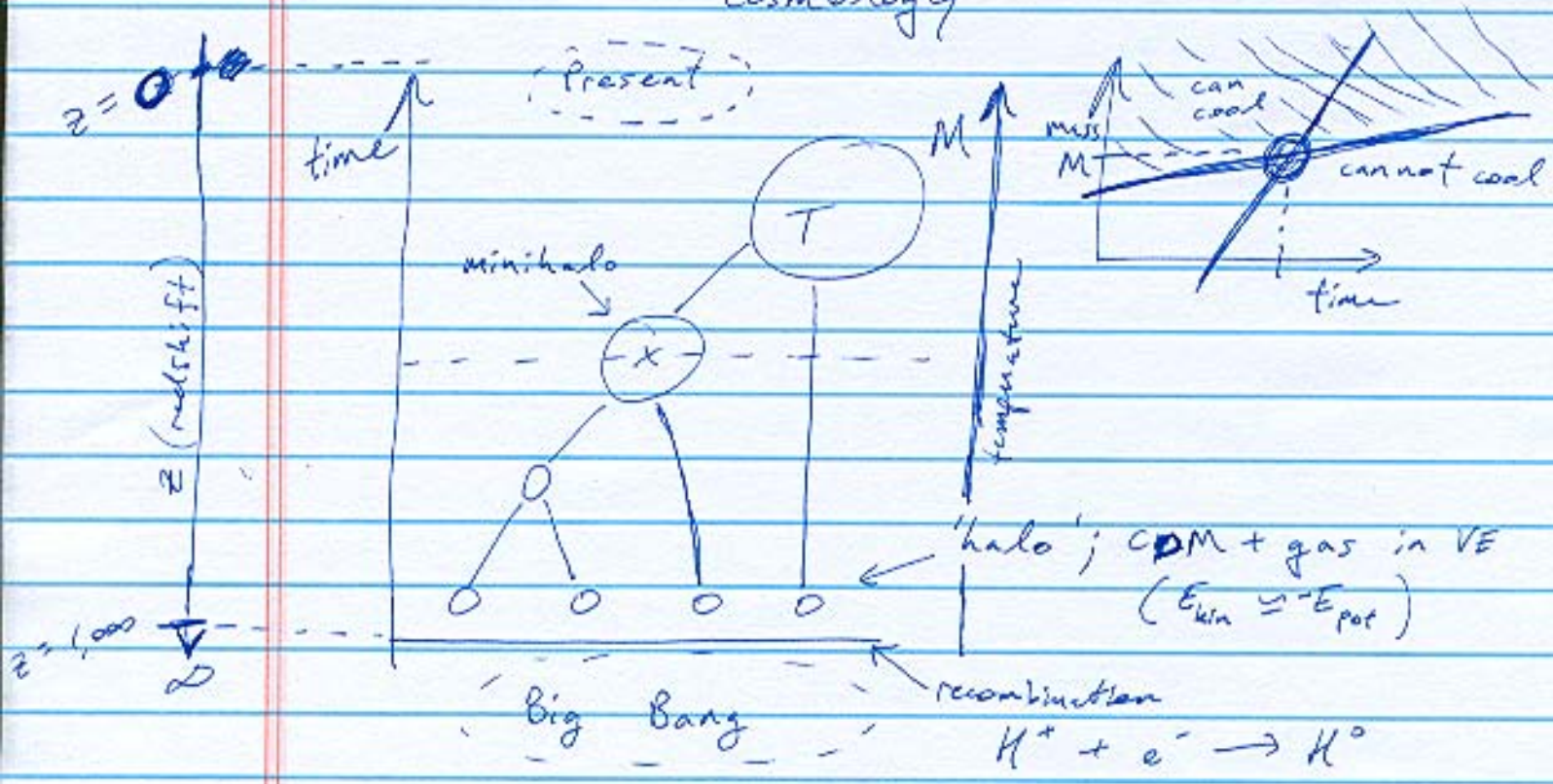
April 22, 2008

First Stars : Formation

• Cosmological Context

Q: Where and when did the first stars form ?

→ consider: cold dark matter (CDM) cosmology

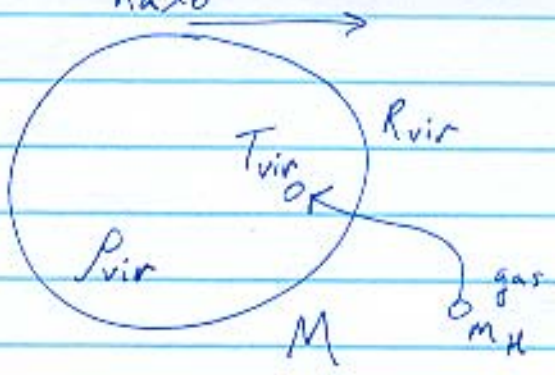


- For stars to form, need gas to cool !
- In early Universe pure H/He (= primordial gas)

A: $\boxed{\tau_{cool} < \tau_{ff}}$ (Rees - Ostriker criterion)

$\Rightarrow M \sim 10^6 M_\odot$
$z \sim 20-30$
} minihalo $(M \ll M_{\text{milky way}})$

Q: Typical temperature in minihalos ?



gravitational potential

$$\varphi = -\frac{GM}{R_{vir}}$$

$$\epsilon_{pot} = m_H \varphi$$

$$= -\frac{GM m_H}{R_{vir}} = -\epsilon_{kin}$$

and $\epsilon_{kin} = -k_B T_{vir}$

Now, $M = \frac{4\pi}{3} R_{vir}^3 \rho_{vir} = R_{vir}^3 \rho_{vir}$, and

$\rho_{vir} = 200\, \rho_b$

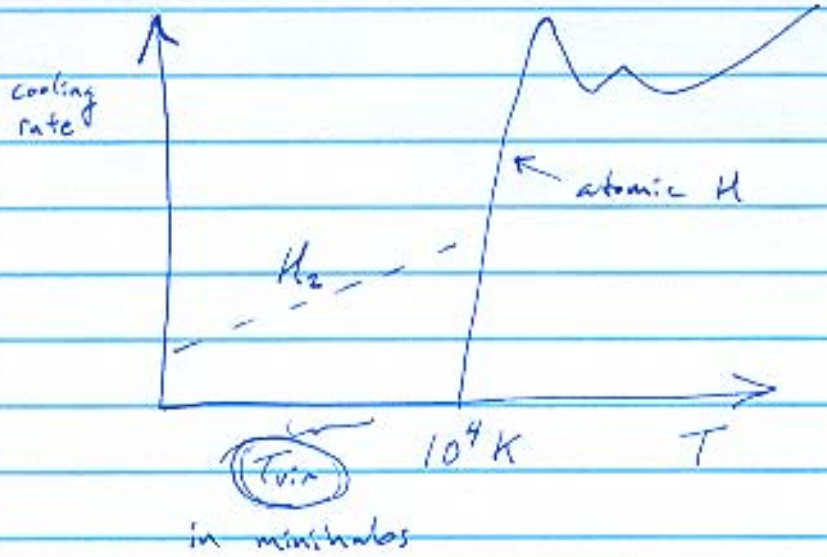
ρ_b: background density of universe

$$\rho_b = \rho_{b,0} (1+z)^3$$

$$\rho_{b,0} = 2.5 \times 10^{-27}\ \text{kg m}^{-3}$$

$$\Rightarrow \boxed{T_{vir} \simeq 2{,}000 \left(\frac{M}{10^6 M_\odot}\right)^{2/3} \left(\frac{1+z}{20}\right)}$$

- Cooling in the Early Universe



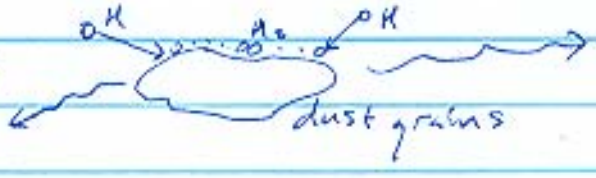
Q: How to form H_2 in the early universe?

$$H + H \xrightarrow{?} H_2$$

→ Doesn't work; molecule bounces back elastically!

Reason: H_2 is a very bad radiator!

Today (in MW):



- Dust-catalyzed formation

But: No dust in the early Universe!

Solution: "gas-phase" reactions

$$H + e^- \longrightarrow H^- + \text{photon}$$

$$H^- + H \longrightarrow H_2 + e^-$$

Notice: Free electrons act as catalyst!

→ Find for minihalos: $\frac{n[H_2]}{n_H} \sim 10^{-3}$

Q: How does H_2 cooling work?

Transition energies