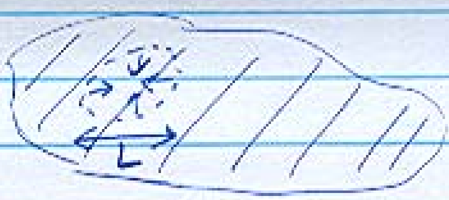
April 24, 2008

First Stars (cont'd)

- Gas Fragmentation



$L = c_s \tau_{sound}$, where c_s is the speed of sound

Q: When can perturbations collapse = stars form?

gravity > thermal pressure

$\downarrow$

$$\tau_{ff} < \tau_{sound} = \frac{L}{c_s}$$

"sound-crossing time"

$$c_s = \sqrt{\frac{k_B T}{m_H}}$$

$\rightarrow$ more convenient : $\frac{1}{G\rho} \simeq \tau_{ff}^2 < \tau_{sound}^2 \simeq \frac{L^2 m_H}{k_B T}$

$$\Rightarrow L > L_J = \frac{c_s}{G\rho} = \frac{\sqrt{\frac{k_B T}{m_H}}}{G\rho} \quad \text{(Jeans length)}$$

$$\Rightarrow M_J = \frac{4\pi}{3} L_J^3 \rho \simeq L_J^3 \rho \propto T^{3/2} \rho^{-1/2}$$

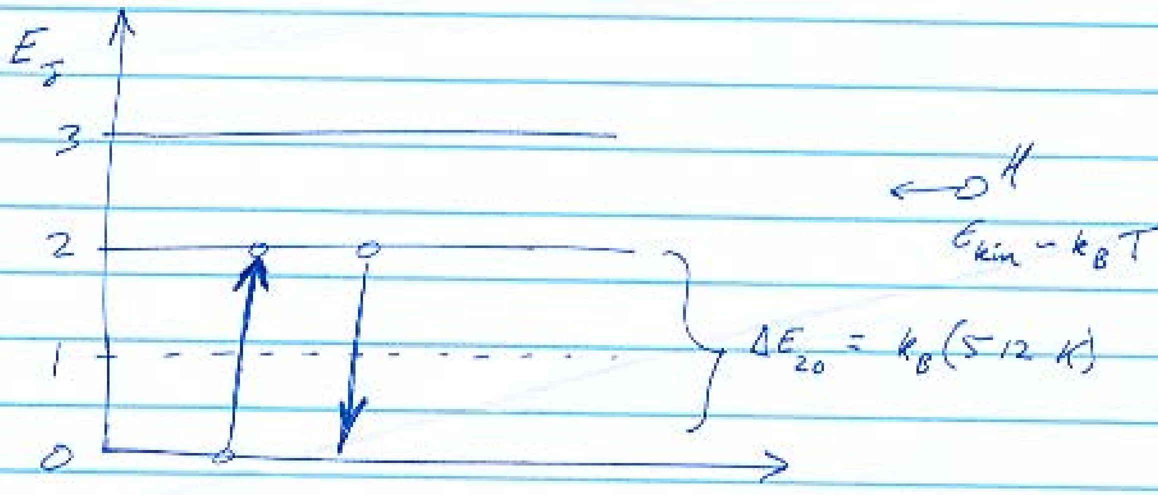
(Jeans Mass)

<u>Note</u> : $M_* \leq M_J$

→ <u>in general</u>, for star formation, need low T and high ρ (density)

(1) <u>Q: T_{min} 'achievable' with H_2 cooling ?</u>

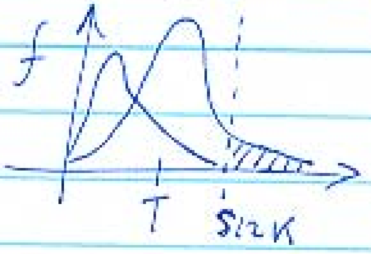
→ consider rotational transitions



$J = 0 \rightarrow 1$ is forbidden!

→ for H_2, need $\Delta J = 2$

→ Can cool a bit below 512 K, because impacting particles (H atoms) have thermal distribution of energies

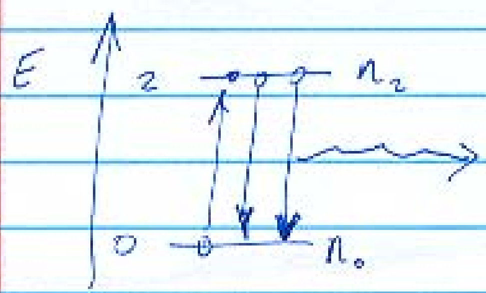


$\Rightarrow$ Find: $T_{min} \simeq 200\,K$

(2) What is ρ_{max}?

$\rightarrow$ Consider detailed balance!

(up = down)



$$\underbrace{\gamma_{02} n_0 n_H}_{\text{collisional excitation}} = \underbrace{A_{20} n_2}_{\text{radiative decay}} + \underbrace{\gamma_{20} n_2 n_H}_{\text{collisional de-excitation}}$$

collisional coefficients

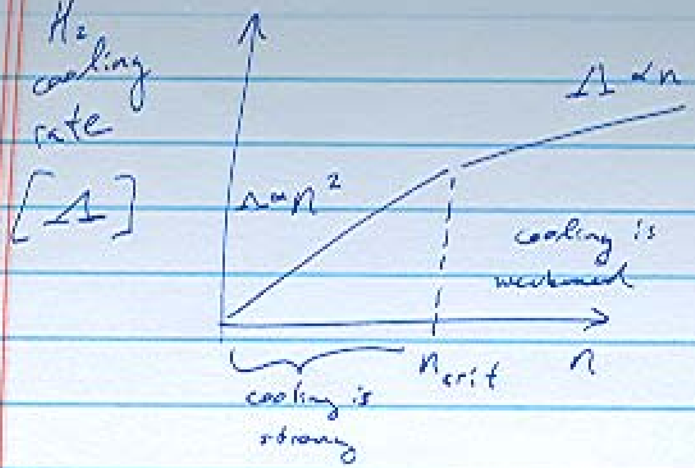
$$\gamma_{02} = \gamma_{20} \exp\left[-\frac{\Delta E_{20}}{k_B T}\right]$$

$\rightarrow$ critical density:

collisional de-excitation similar to radiative decays

$$\Rightarrow A_{20} \cancel{n_2} = \gamma_{20} \cancel{n_2} n_H$$

$$\Rightarrow n_{crit} \simeq \frac{A_{20}}{\gamma_{20}} \sim 10^4\,cm^{-3}$$



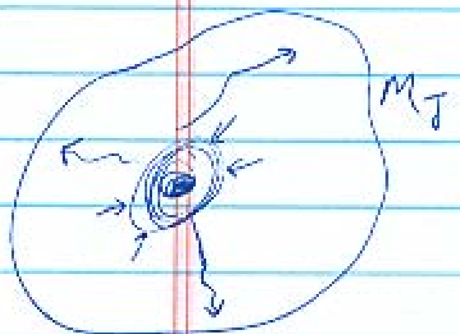
- At $n > n_{crit}$: cooling "saturates"

(= becomes inefficient)

$\Rightarrow$ primordial gas in minihalos has a characteristic state

$$\left.\begin{array}{l} T_{min} \simeq 200\,K \\ n_{max} \simeq n_{crit} \simeq 10^4\,cm^{-3} \end{array}\right\} \text{microphysics of } H_2$$

$\Rightarrow$ Find: $$\boxed{M_J \simeq 1{,}000\, M_\odot \left(\frac{T}{200\,K}\right)^{3/2} \left(\frac{n}{10^4\,cm^{-3}}\right)^{-1/2}}$$



$$M_{Pop\,III} = \alpha_{accretion}\, M_J$$

$(\alpha_{accretion} \sim 0.1 - 0.5)$ $\quad \simeq$ few $\times$ 100 $M_\odot$