Lecture 20

Formation of First stars (cont'd)

- Microphysics of H_2 cooling:

$$T_{char} \simeq 200\ K$$

$$n_{char} \simeq 10^4\ cm^{-3}$$

($\rightarrow$ "characteristic" $\hat{=}$ typical values of T and n in primordial gas, when cooling is due to H_2)

$\rightarrow$ Plug into formula for Jeans mass

$$M_{J,Pop\,III} \simeq 1\,M_\odot \left(\frac{200K}{10K}\right)^{3/2} \left(\frac{10^4\ cm^{-3}}{10^5\ cm^{-3}}\right)^{-\frac{1}{2}} \simeq 500\ M_\odot$$

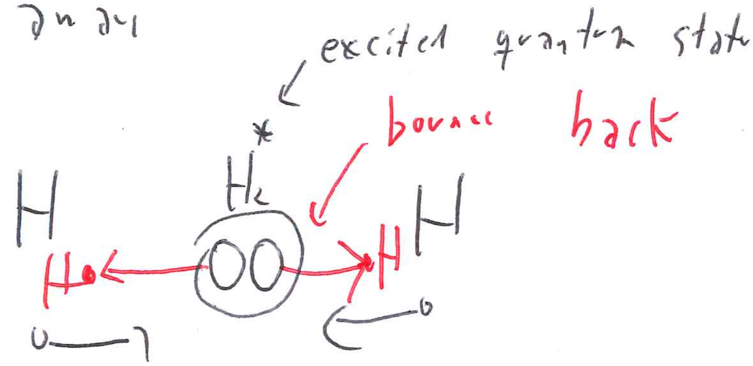
$\Rightarrow$ First (Population III) stars are very massive!

- Big remaining Q: How does H_2 form?

→ Why not just: $H + H \to H_2$?

<u>Problem</u>: Because of high symmetry, H_2 cannot radiate away binding energy of $H + H$ collision.

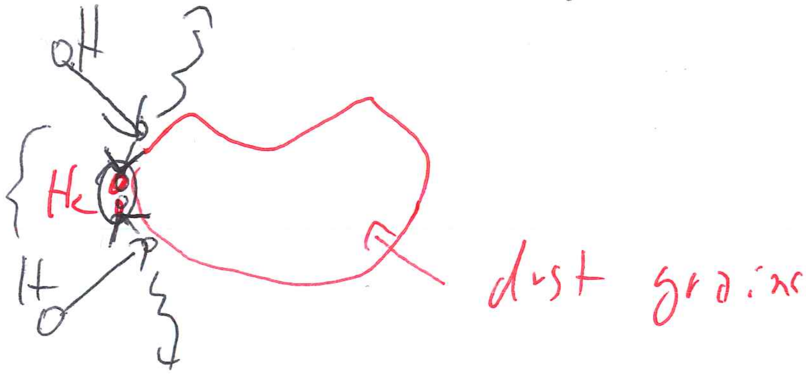
⇒ H_2^* just bounces back right away



→ in present-day universe (Milky Way, say), H_2 formation is straightforward:

dust radiates energy of impact

Two H atoms move along grain surface, meet and form H_2



→ But: No dust in early universe !

- Way out: sequence of reactions that involve charged species

(→ those can more easily radiate photons!)

$$\mathrm{H} + e^- \longrightarrow \underbrace{\mathrm{H}^-}_{\text{negative H ion}} + h\nu \quad \text{photon energy}$$

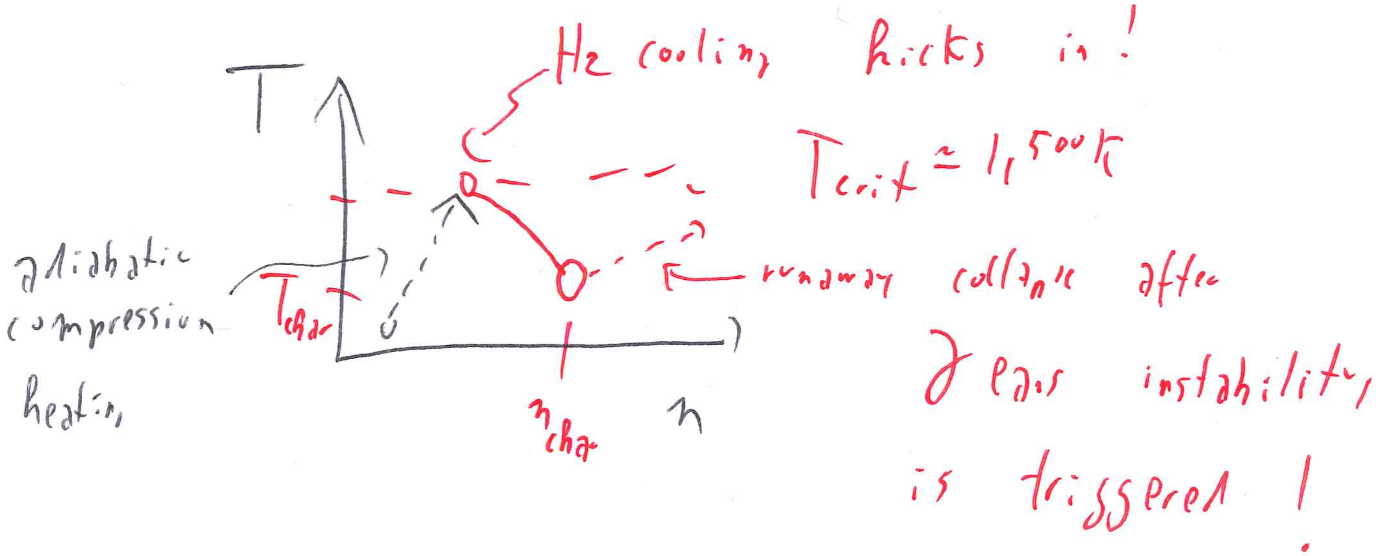
$$\mathrm{H}^- + \mathrm{H} \longrightarrow \mathrm{H}_2 + e^-$$

free electrons act as catalyst

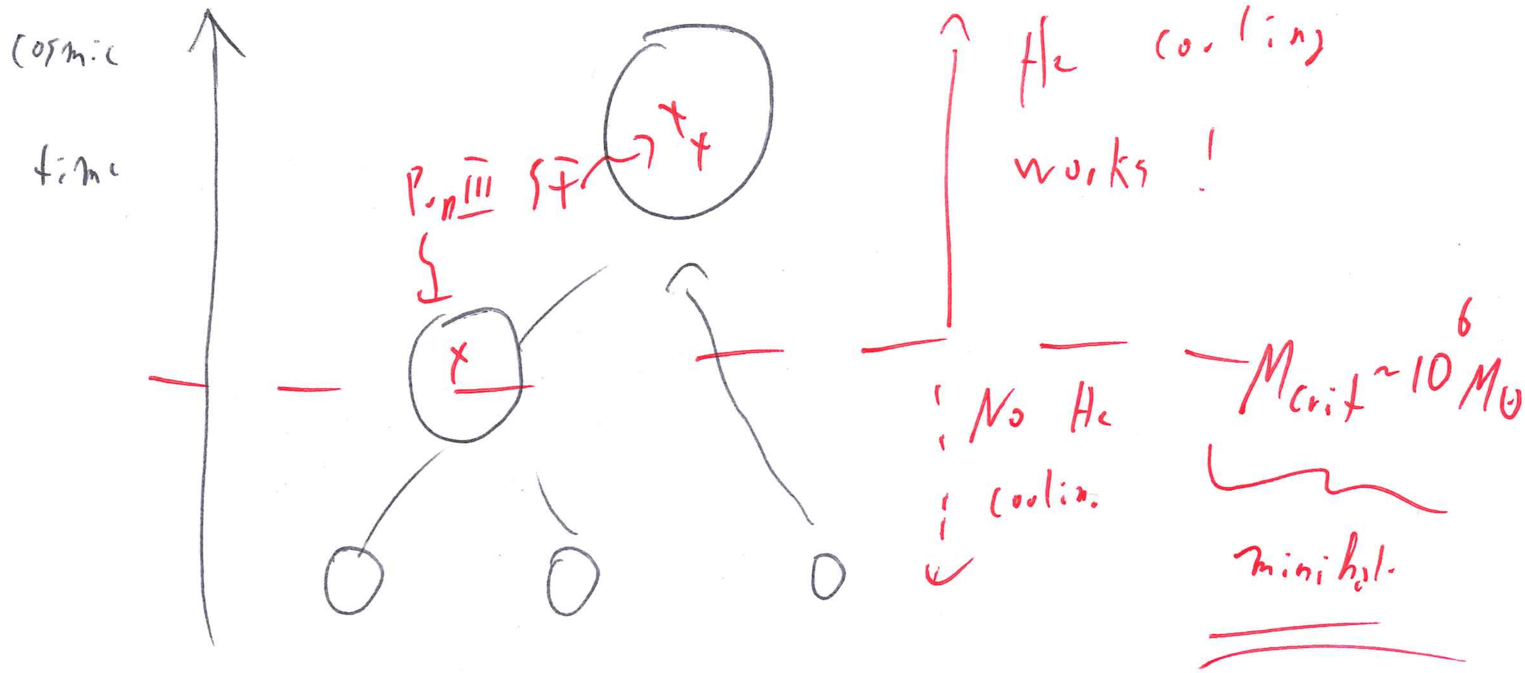
- Key Q: Which DM halos manage to form enough H_2 via the H^- sequence?

- A: Need to heat gas sufficiently to $T_{crit} \simeq 1{,}500\,K$, so that chemical reactions can happen sufficiently rapidly!

→ For successful halo:



→ Need sufficiently massive DM halo to trigger H_2 cooling!



- recall: halo's gravitational potential well can be expressed via "virial temperature" $T_{vir} \propto M_{halo}^{2/3}(1+z)$
- Thus: condition for onset of Pop III SF:

$$\boxed{T_{vir} \gtrsim T_{crit} \simeq 1{,}500\,K}$$

$$\Rightarrow \boxed{M_{halo} \simeq 10^6 M_\odot \text{ at } z_{vir} \simeq 20-30}$$

⇒ so-called "minihalos"