Week 11 Tuesday

<u>Today's Agenda</u>

- Fusion
- ISM intro
- Group problem
- ISM emission

<u>Announcements / Reminders</u>

- HW 8 (& 7.3) due Friday 1min before midnight
- Read Chapters 16.1-2 & 17

- HEAP talk at 4pm on Thursday
  - CFTs Blueshift Tensor Fluctuations Universally 🤷‍♀️
- Colloquium at 2pm on Friday
  - Lithium-ion Batteries

HW 6 Problem 3

3. Imagine that you make observations of 2 stars, determining their V-band magnitudes to be $m_1 = 12$ and $m_2 = 14.5$, colors to be $(B - V)_1 = 0.5$ and $(B - V)_2 = -0.3$, and V-band bolometric corrections to be $BC_1 = -0.05$ and $BC_2 = -0.25$. From other measurements, you know that star 2 has a parallax $\pi'' = 0.005''$.

   (a) What are the approximate temperatures of the stars? Why is the BC of star 2 more negative than that of star 1?

   (b) Assuming these are effective temperatures, what is the radius of star 2?

   (c) If interferometric measurements limit the angular size of star 1 to be $\theta < 10^{-4}$ arcsec, place a constraint on how far away star 1 is assuming the two stars are the same physical size.

   (d) Is this distance constraint consistent with the distance estimated from its $T_{\rm eff}$ under the same assumption about their relative sizes?

Energy Generation

<u>First idea</u>: light is the latent heat from the formation of the Sun due to the conversion of gravitational potential energy to kinetic energy (heat) during collapse

$$U = -q\frac{GM^2}{R}$$

q is a factor of order unity that depends on the density distribution $\rho(r)$

Lifetime of a star is simply this energy divided by the rate that energy is emitted, i.e., the luminosity

$$t_{\rm KH} \equiv \frac{U}{L} \qquad t_{\rm KH,\odot} = \frac{U_\odot}{L_\odot} \approx 50 \text{ Myr}$$

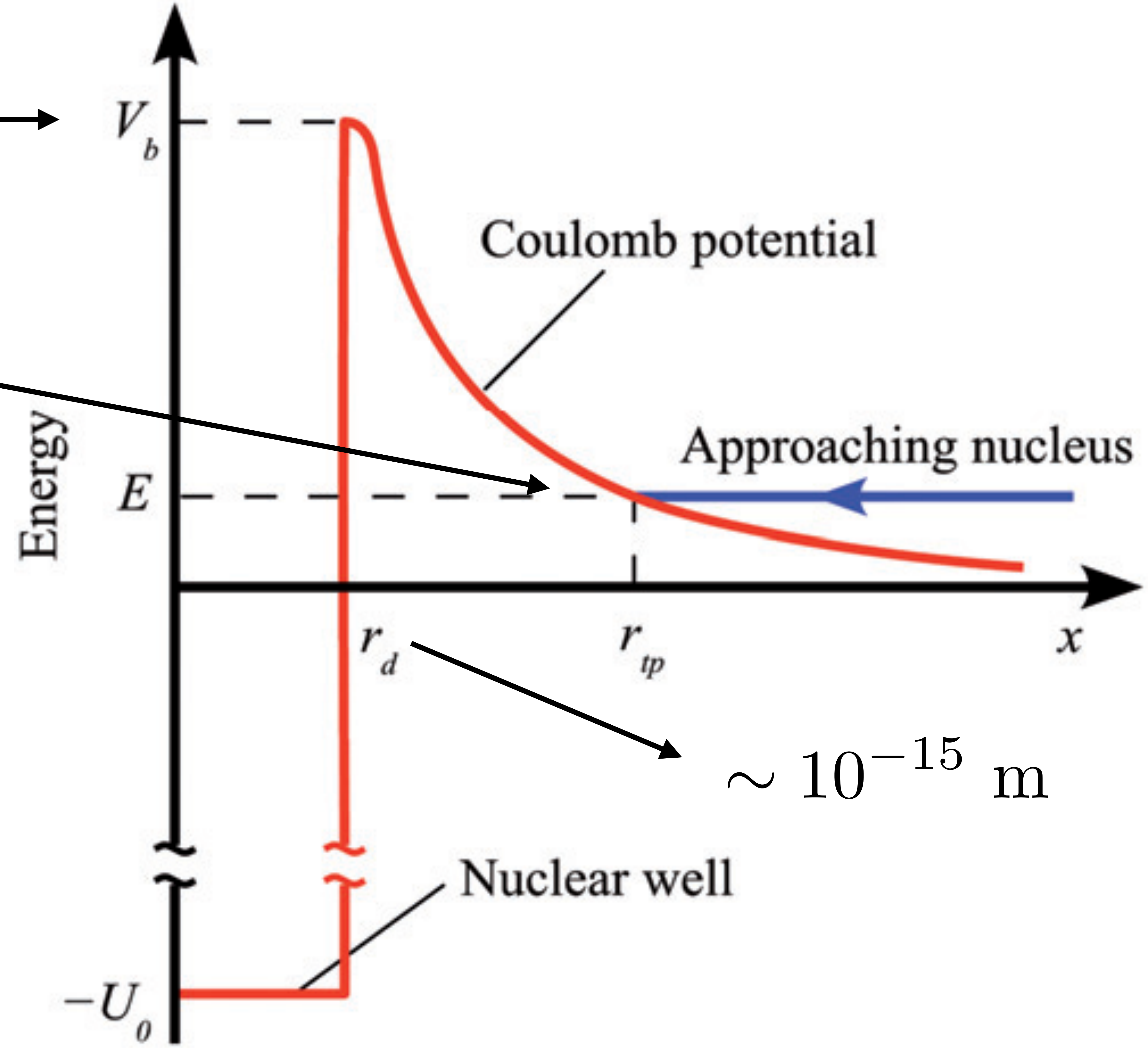
Fusion possible b/c of QM

$$U \approx \frac{e^2}{4\pi\epsilon_0 r} = 1.4 \text{ MeV}$$

$$\langle E \rangle = \frac{3}{2} k T_c \approx 2 \text{ keV}$$

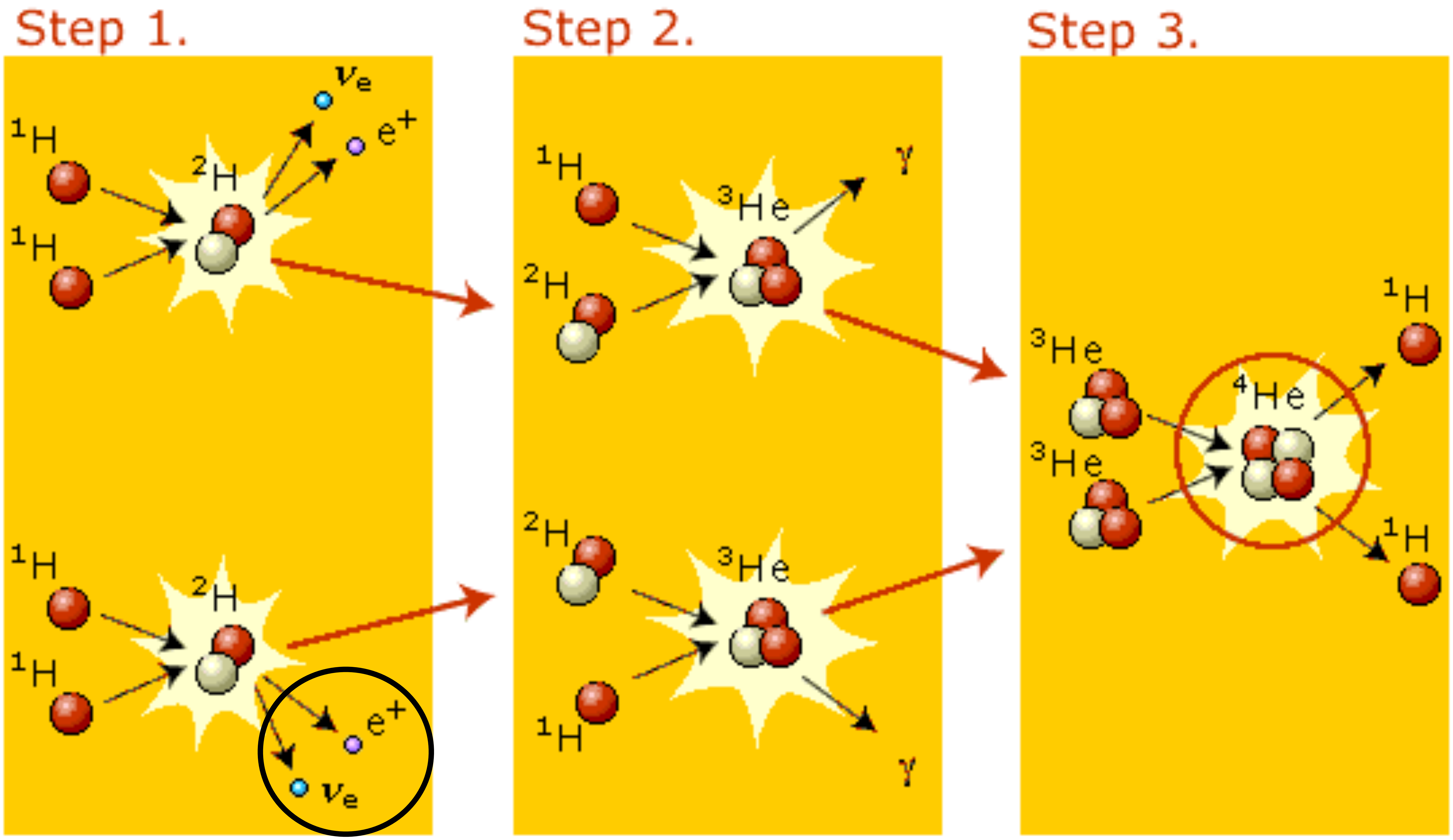
Particles are waves!

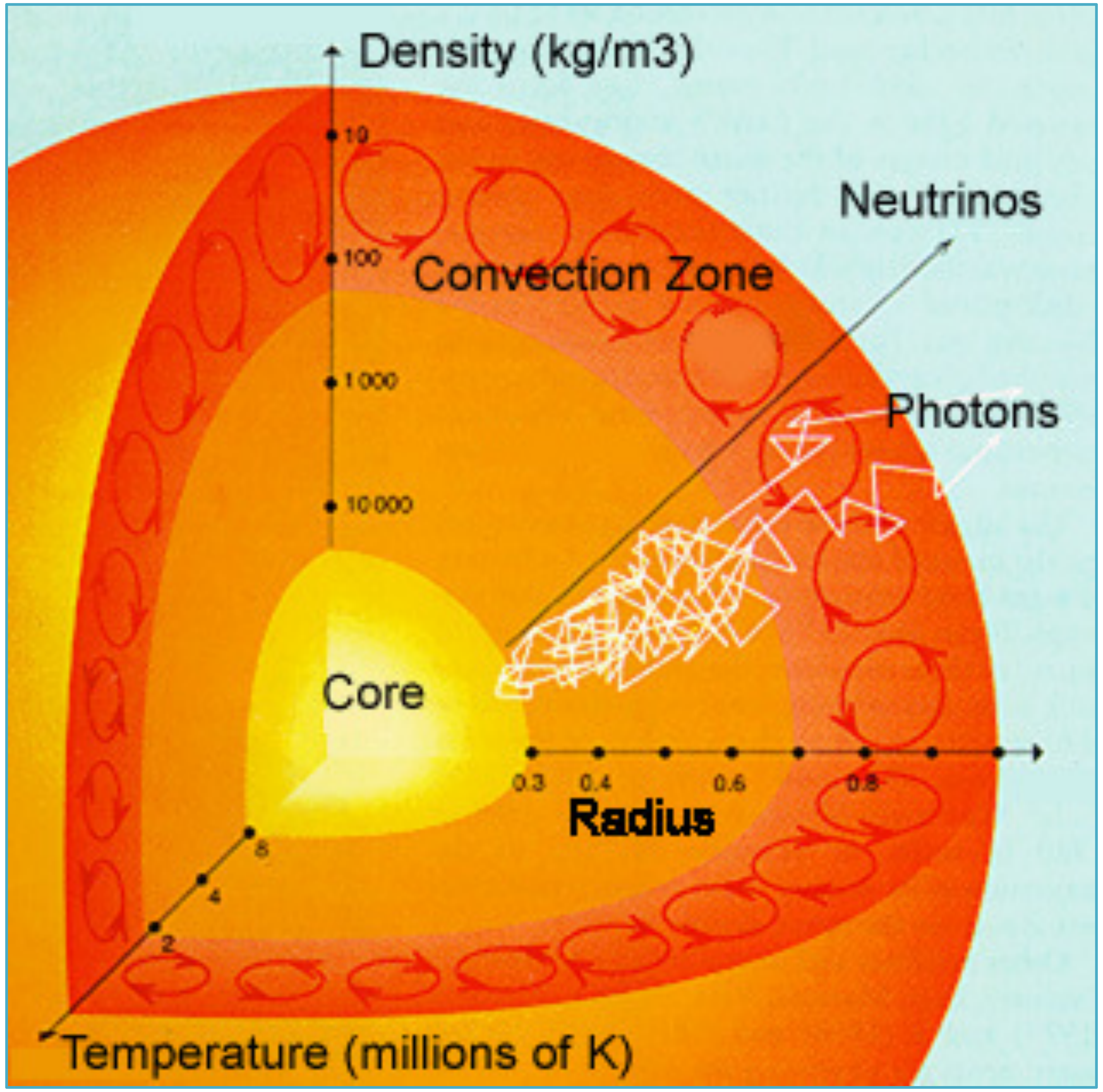
$$\lambda_{\text{prot}} = \frac{h}{p} = \frac{h}{m_p v} \approx 10^{-13} \text{ m}$$



$\sim 10^{-15}$ m

Proton-proton chain: $T_c < 1.8 \times 10^7$ K

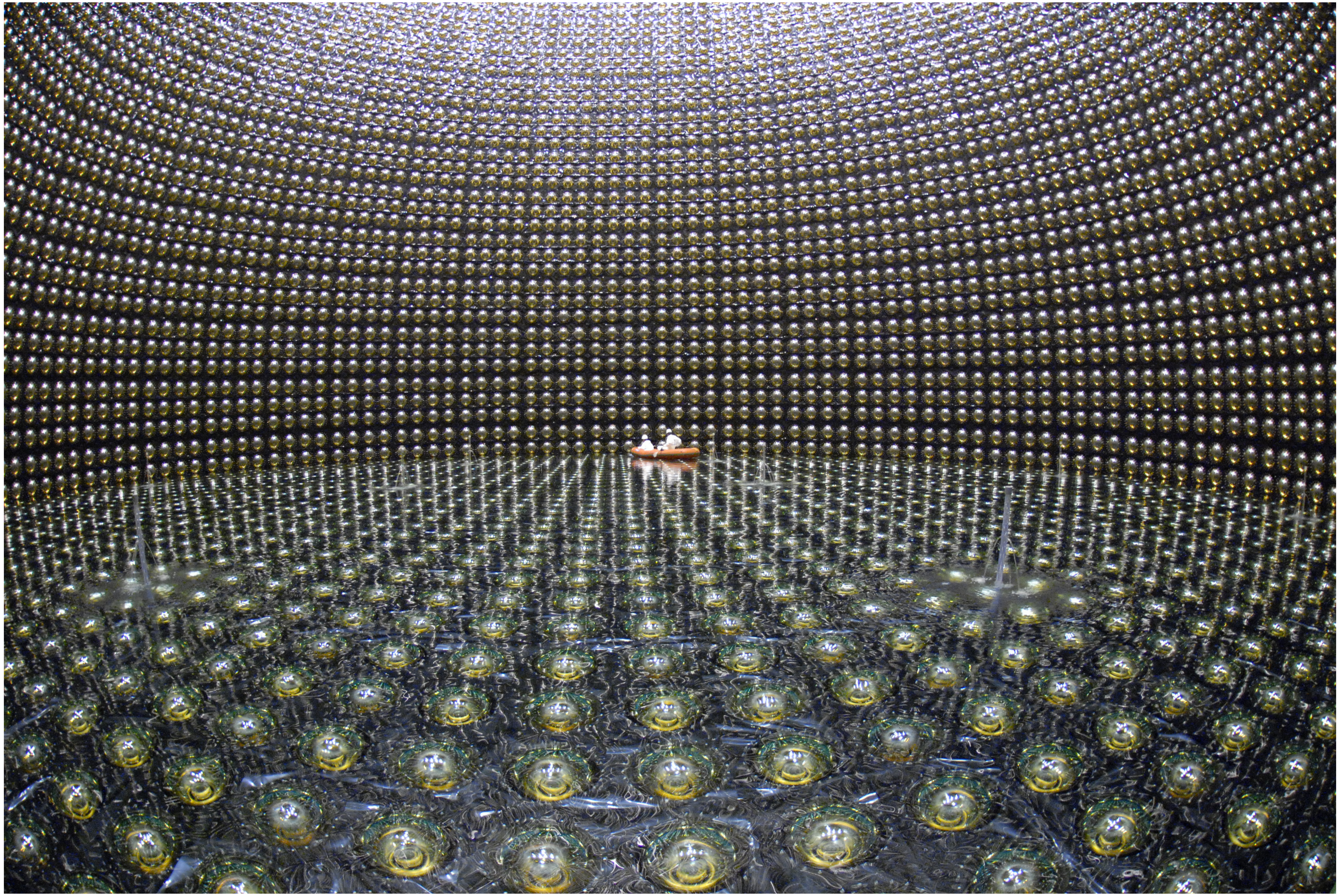




$$4\ \mathrm{p} \rightarrow {}^4\mathrm{He} + 2\gamma + 2\mathrm{e}^+ + 2\nu_\mathrm{e}$$

$$\mathrm{e}^+ + \mathrm{e}^- \rightarrow 2\gamma$$

Neutrino Detector



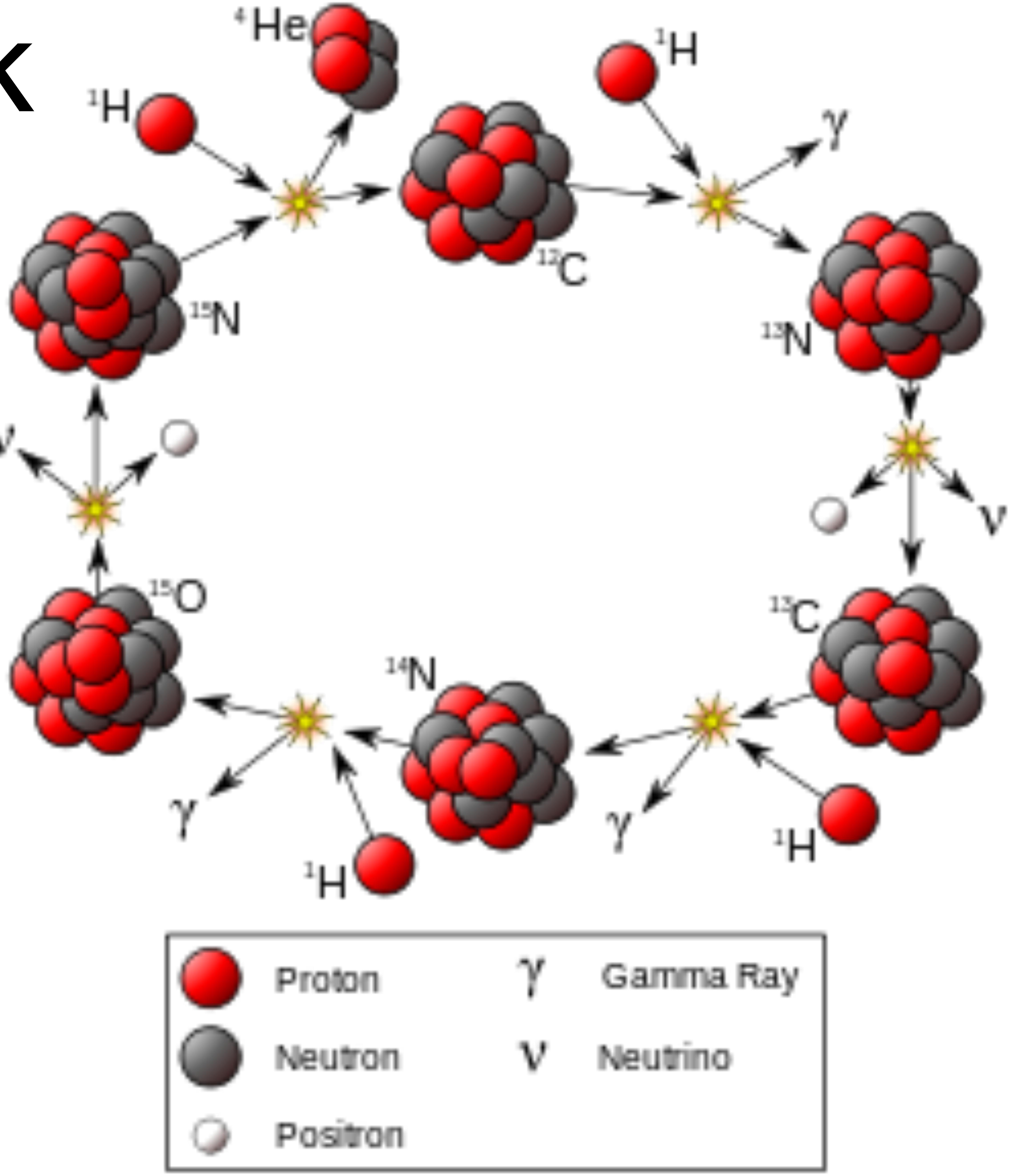
Super Kamiokande, Japan

CNO cycle: $T_c > 1.8 \times 10^7$ K

Carbon, Nitrogen, Oxygen used as catalysts

$$^{12}\mathrm{C} + 4\mathrm{p} \rightarrow {}^{12}\mathrm{C} + {}^{4}\mathrm{He}$$

plus photons, neutrinos, and positrons



Triple Alpha Process

$$^{4}\mathrm{He} + {}^{4}\mathrm{He} \rightarrow {}^{8}\mathrm{Be} + \gamma$$

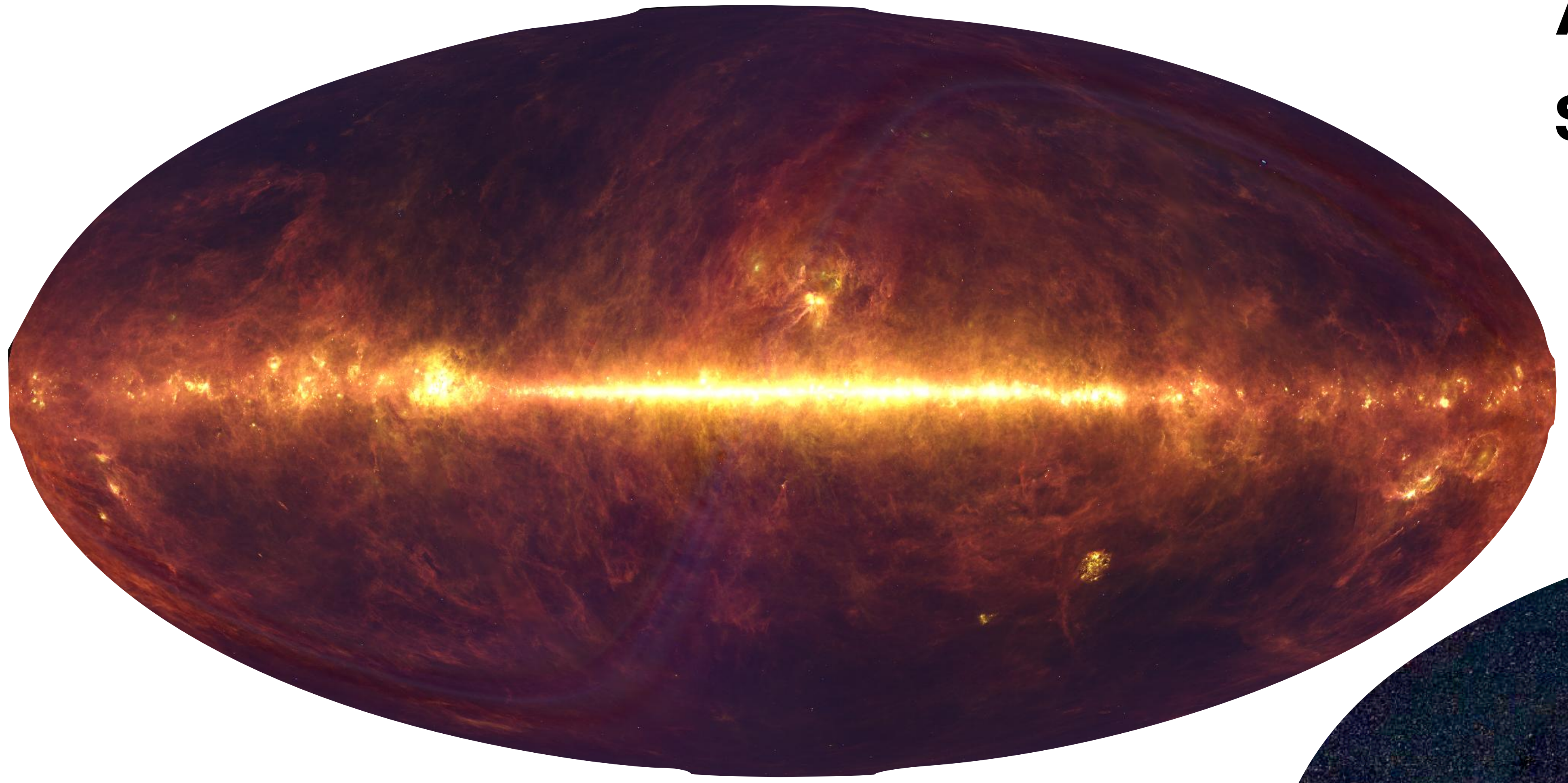
$$^{8}\mathrm{Be} + {}^{4}\mathrm{He} \rightarrow {}^{12}\mathrm{C} + \gamma$$

Decays quickly, needs $T > 10^8$ K and high density so it encounters another helium nucleus (alpha particle) before it does

Interstellar Medium
(ISM)

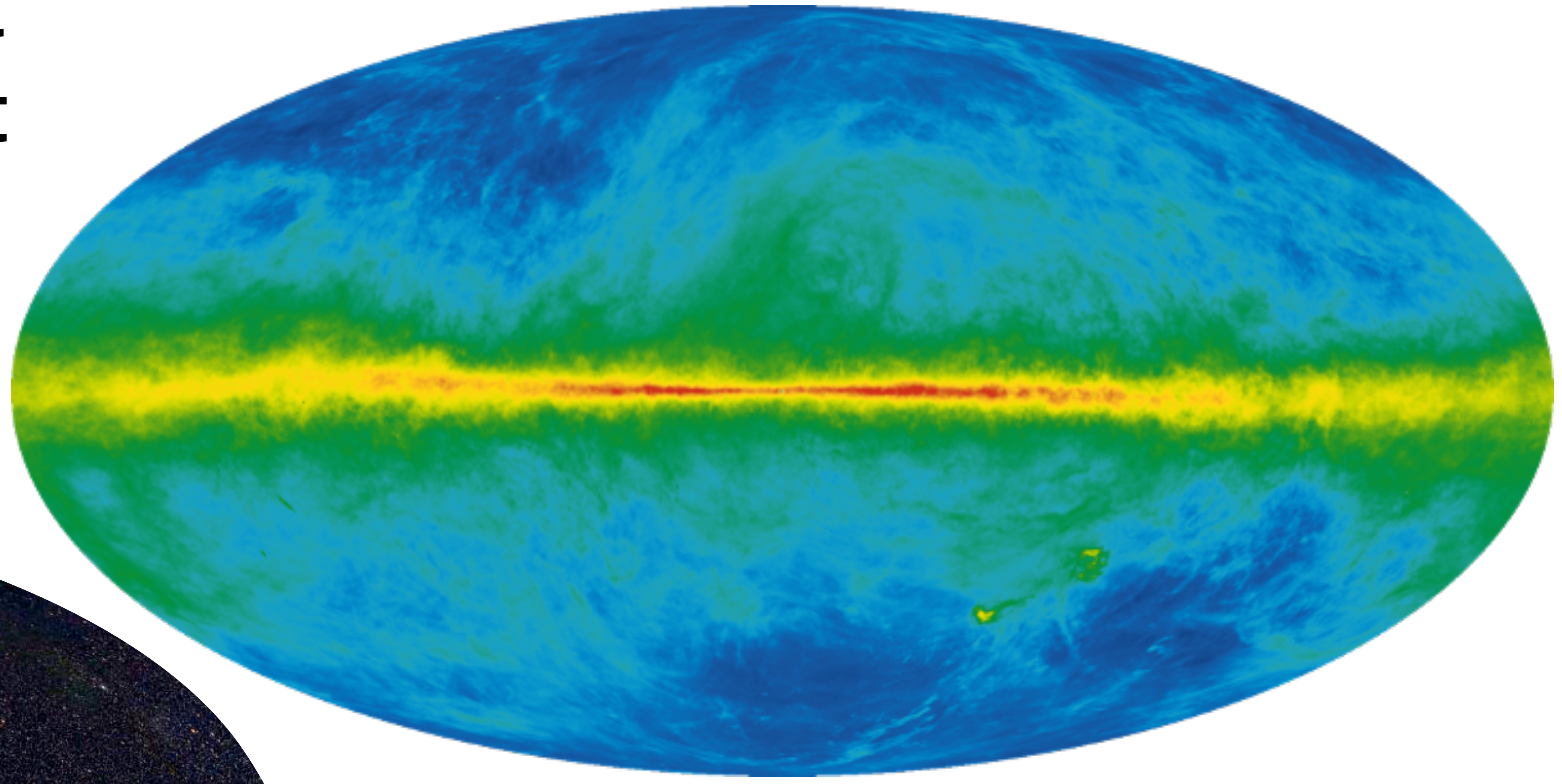
Interstellar Medium (ISM)

Hot Dust (far IR)

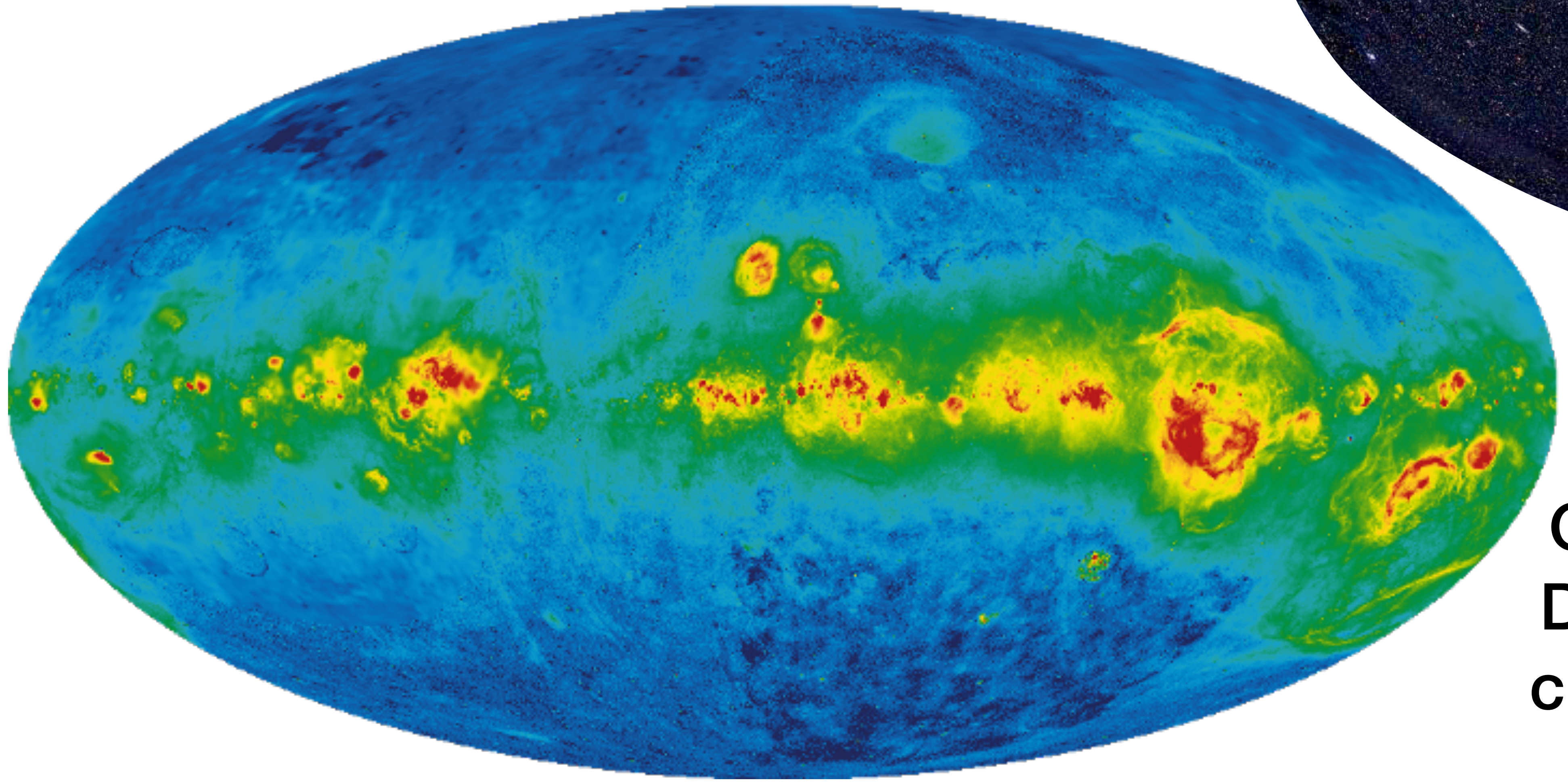


All the diffuse stuff in b/t stars and other compact objects in the MW

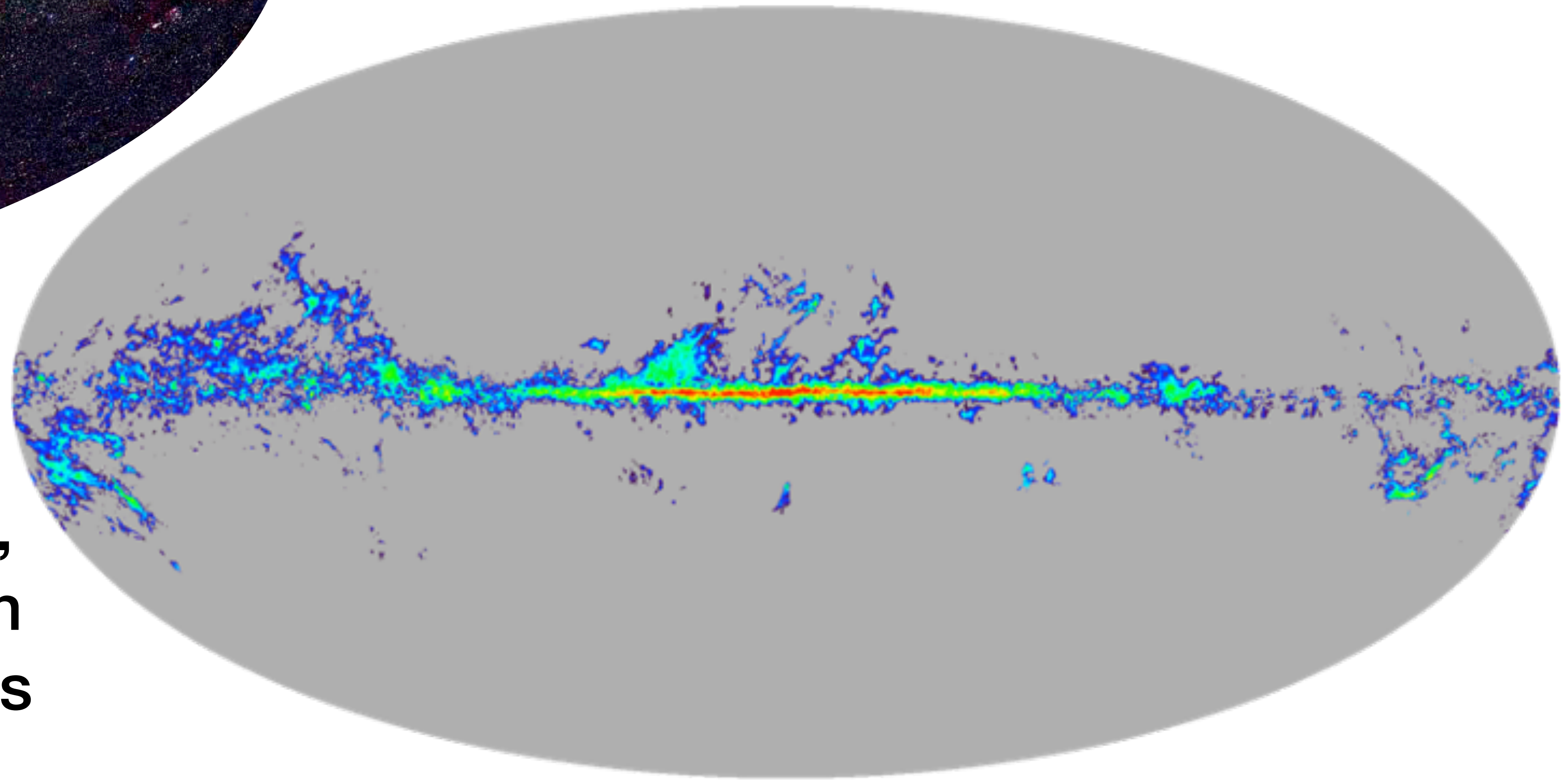
Neutral H (21cm; radio)



Balmer line n=3->2 (656.3 nm)



CO (2.6 mm; microwave)



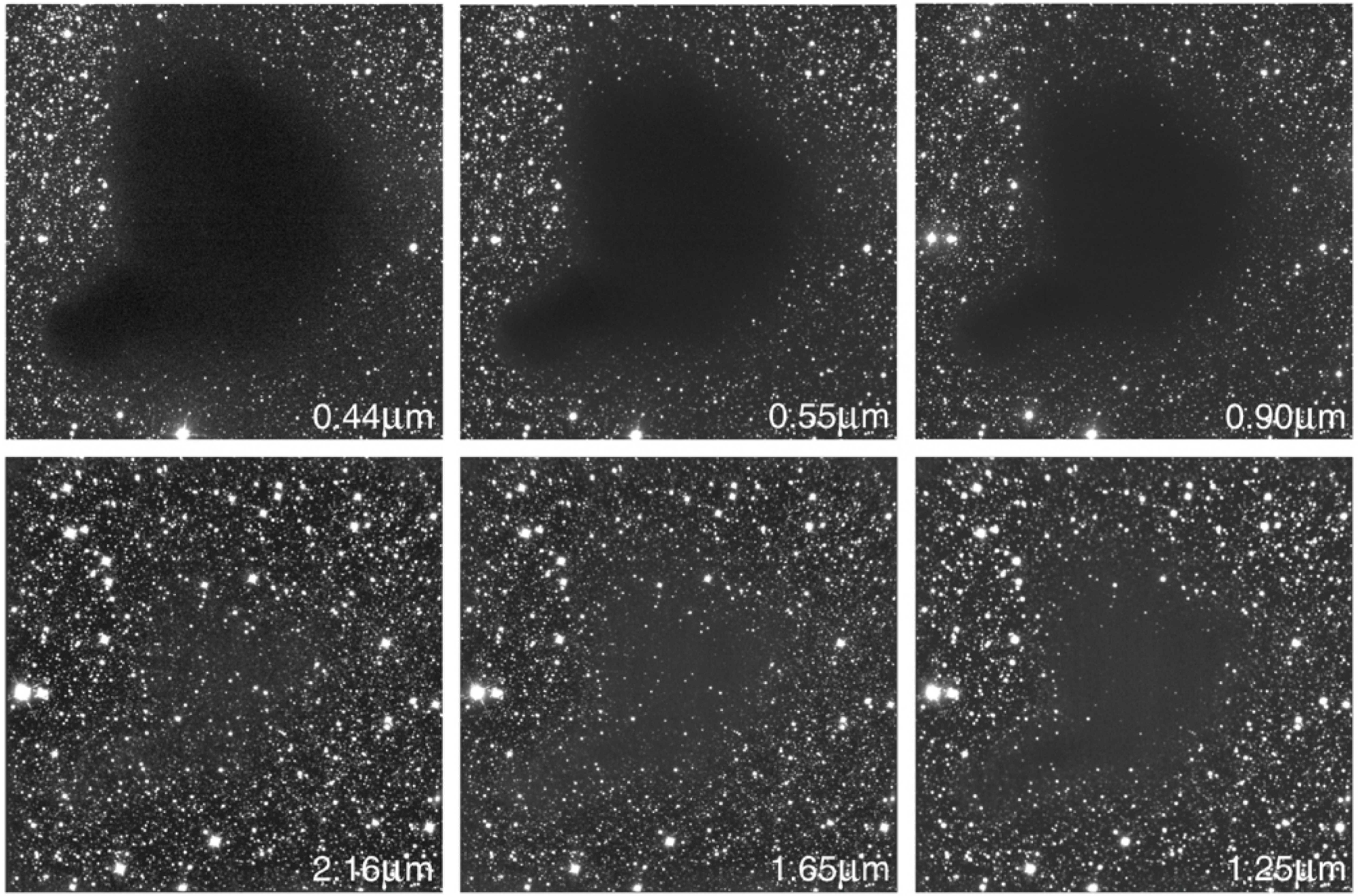
Stars (visible)

Gas (ionized, neutral, molecules), Dust (large molecules, singly or in clumps), & relativistic components (magnetic fields, cosmic rays)

Dust blocks starlight: Extinction

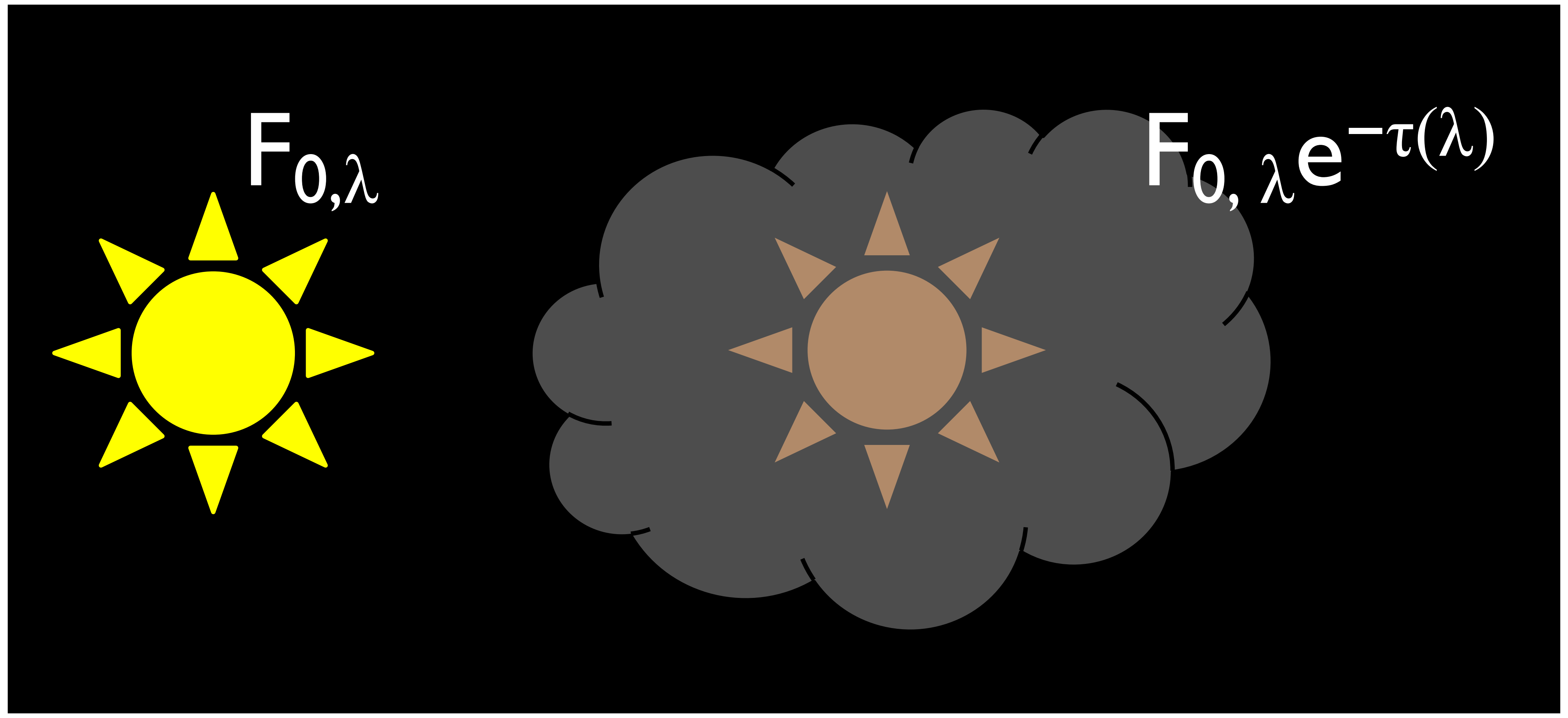
Barnard 68

Blue | Green | Red



<————————————IR————————————>

Extinction messes up magnitudes AND colors



$$F_\lambda = F_{0,\lambda}e^{-\tau} = F_{0,\lambda}e^{-n\sigma r}$$

$$\begin{aligned} m_{\rm obs} &= C - 2.5\log(F) \\ &= C - 2.5\log(F_0) - 2.5\log(e^{-\tau}) \\ &= m_0 + 2.5\tau\log e \\ &= m_0 + 1.086\tau \end{aligned}$$

Correcting Magnitudes

$$m_{\rm obs}(\lambda) = m_0(\lambda) + A(\lambda)$$

$$\begin{aligned} \text{e.g., } m_{V,\rm obs} &= m_V + A_V \\ &= V_0 + A_V \end{aligned}$$

Correcting Colors

$$\begin{aligned} (B-V)_{\rm obs} &= (B-V)_0 + (A_B + A_V) \\ &= (B-V)_0 + E(B-V) \end{aligned}$$

$$R \equiv \frac{A_V}{E(B-V)} \approx 3.1$$

Group Problem

Imagine you observe 2 stars that have the same spectral (but not necessarily luminosity) type.

$$m_{V,1} = 15 \qquad m_{V,2} = 21$$

$$m_{B,1} = 15.5 \qquad m_{B,2} = 22.5$$

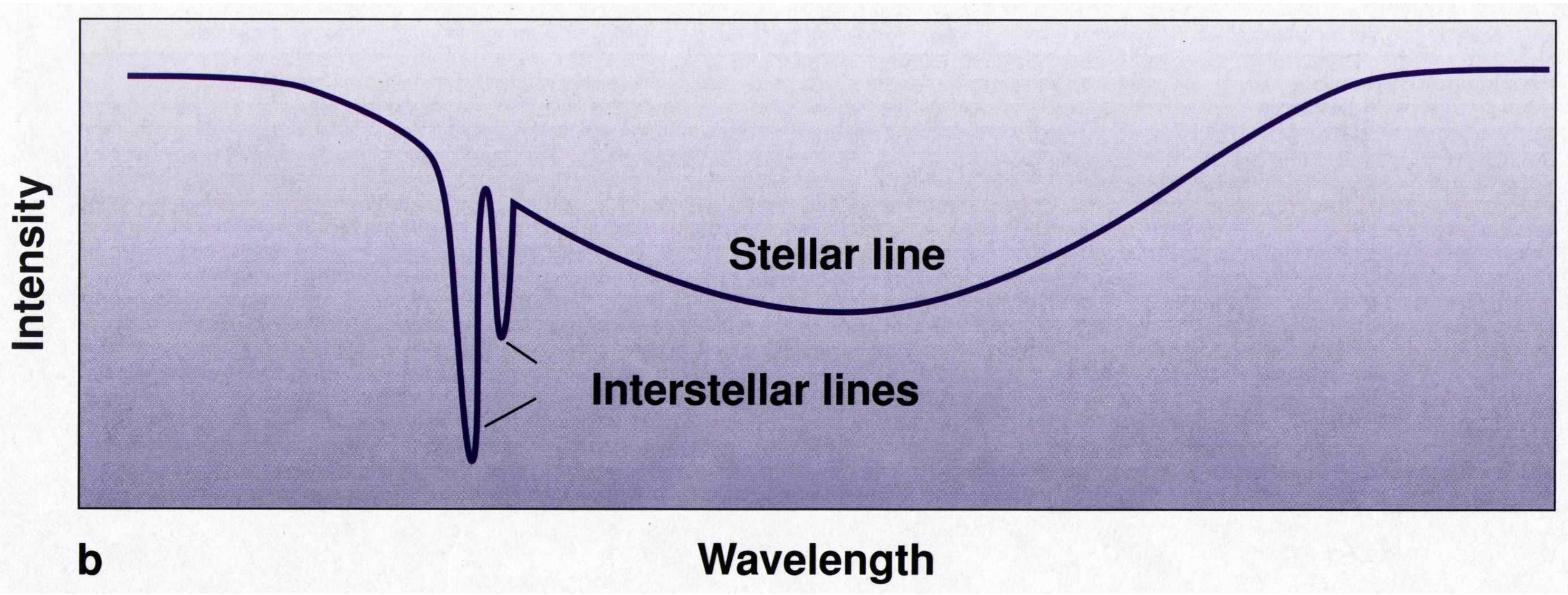
Assuming one of the stars has an $A_V = 0$, what is the extinction toward the other star?

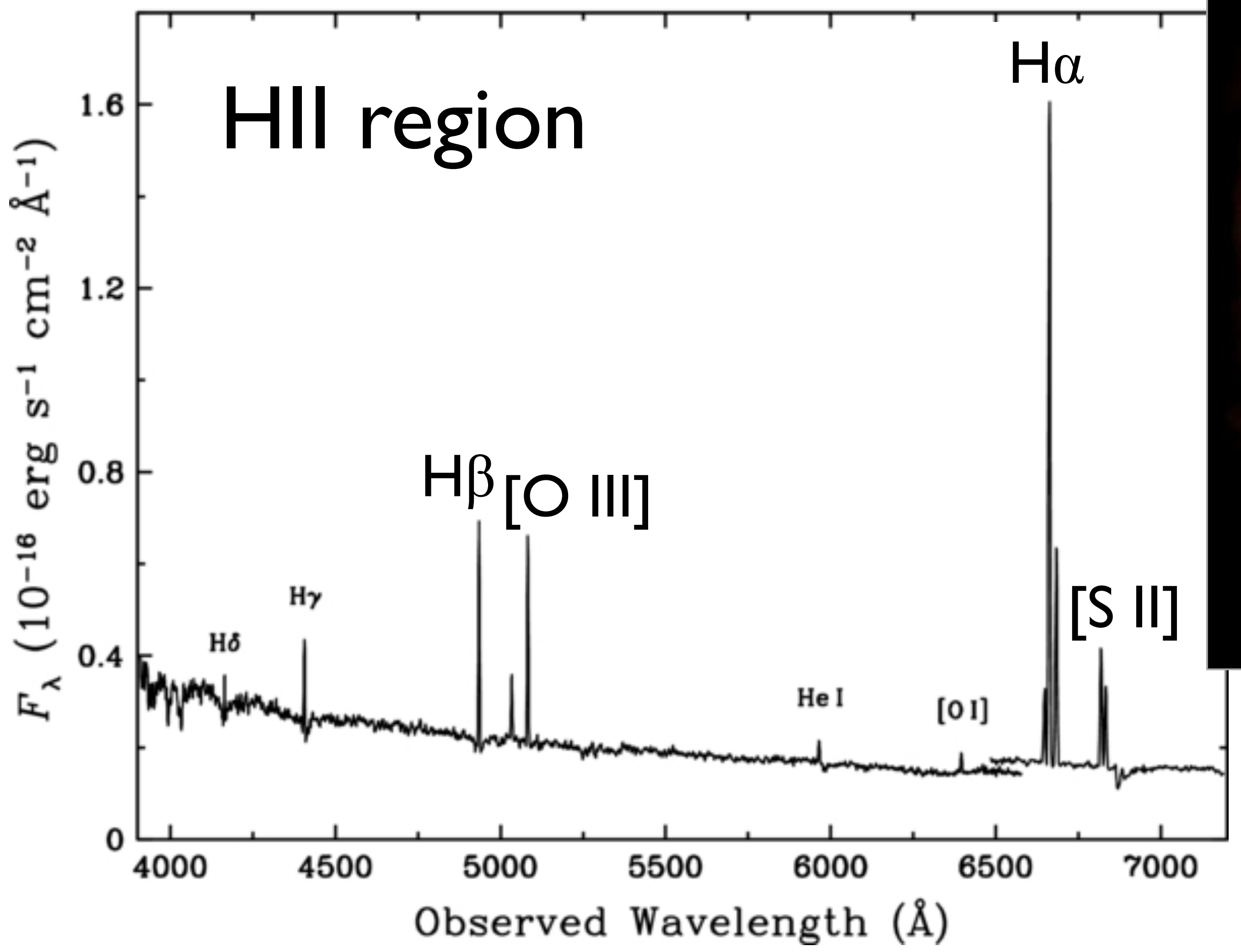
What is the optical depth toward that star in the B band?

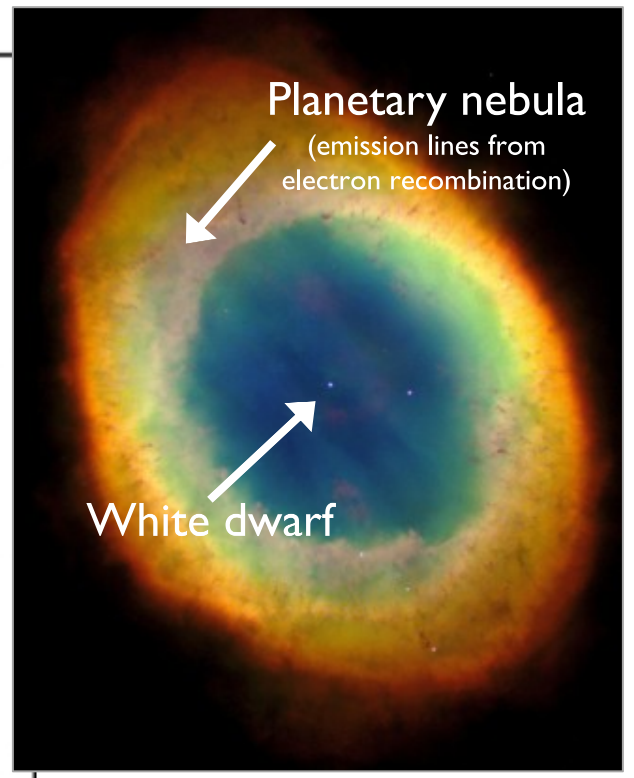
Assuming both stars have the same distance from us, what can you say about their luminosity classes?

Detection of gas is generally more direct

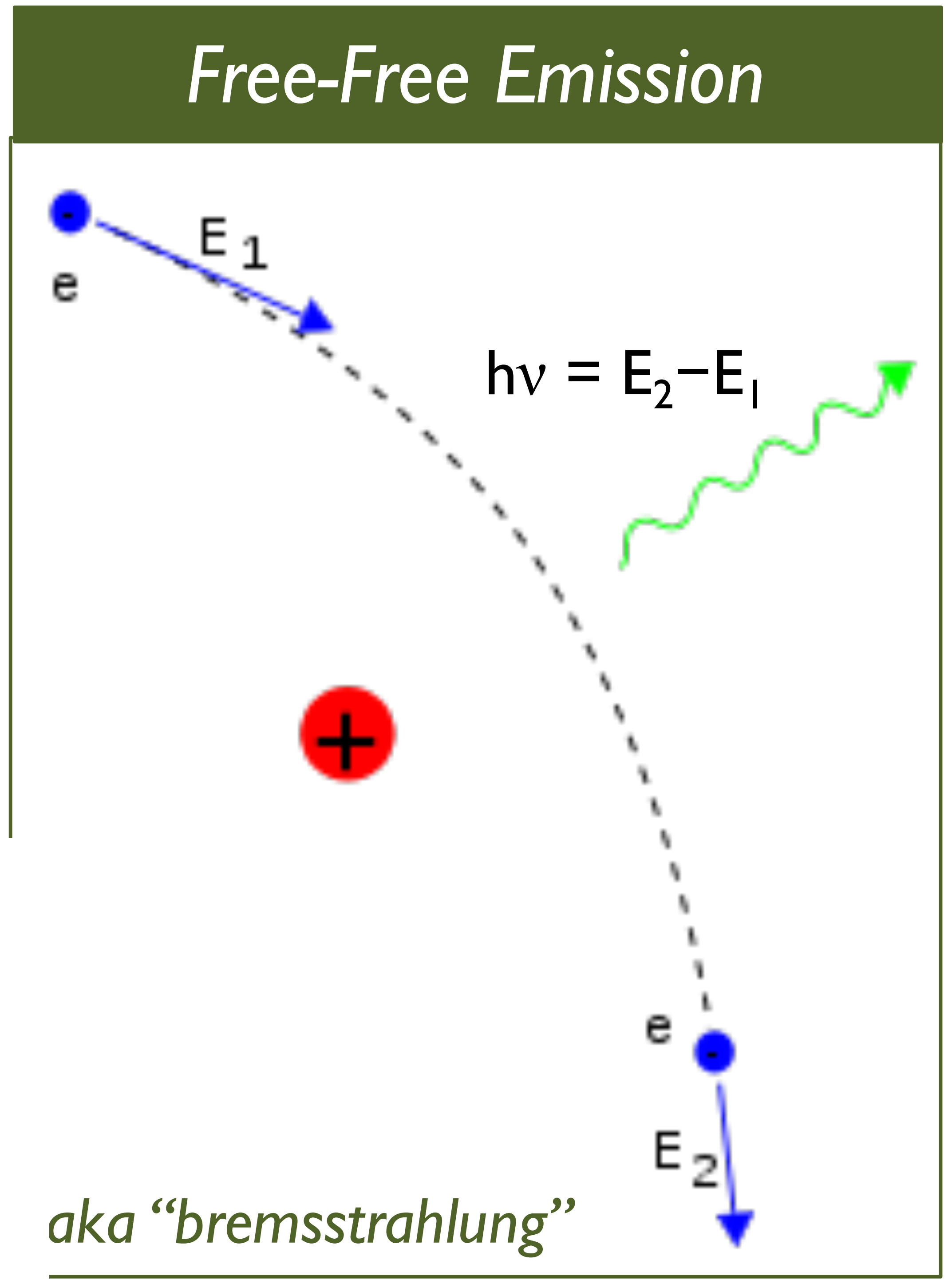
Absorption & Emission Lines (Kirchoff's laws)



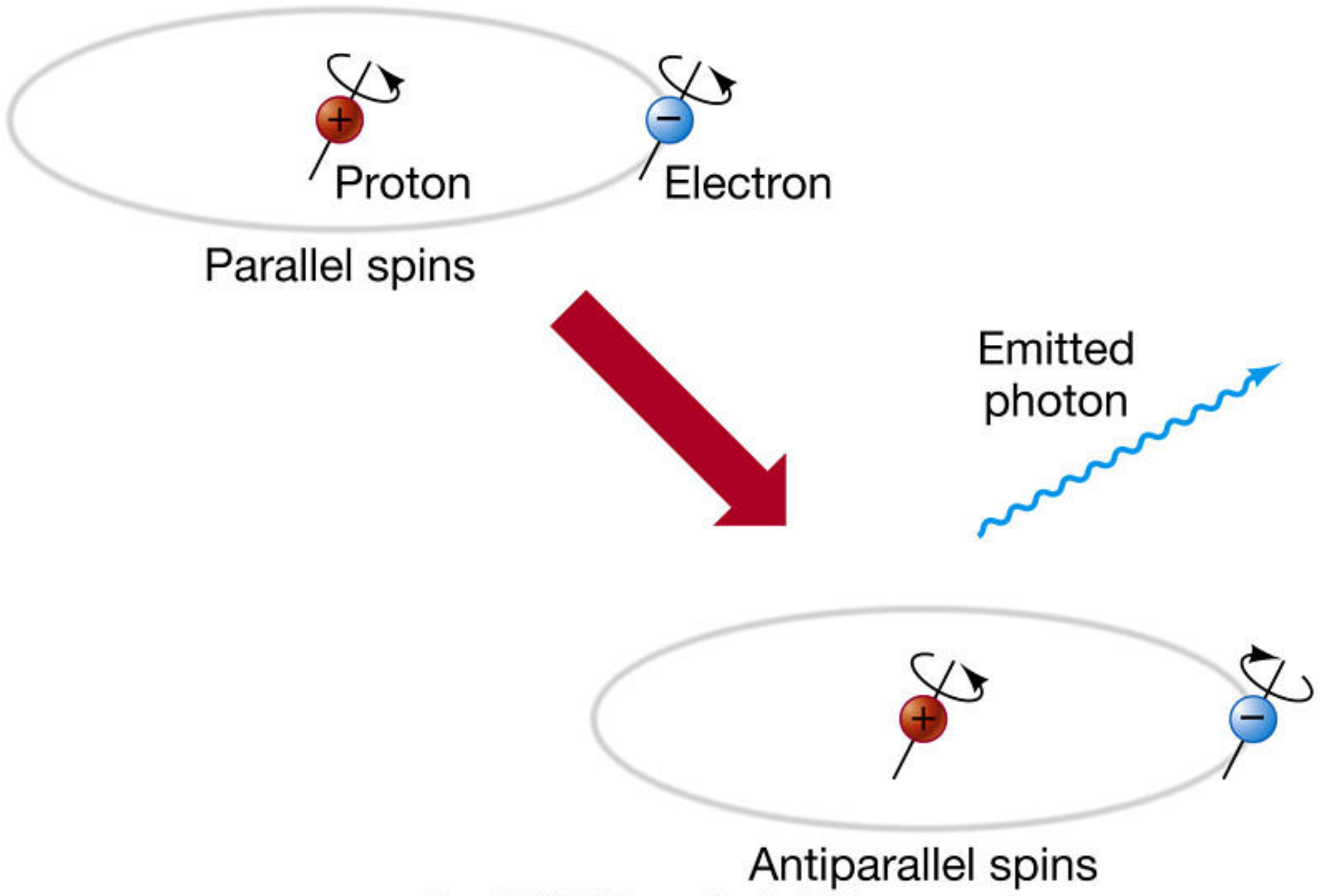




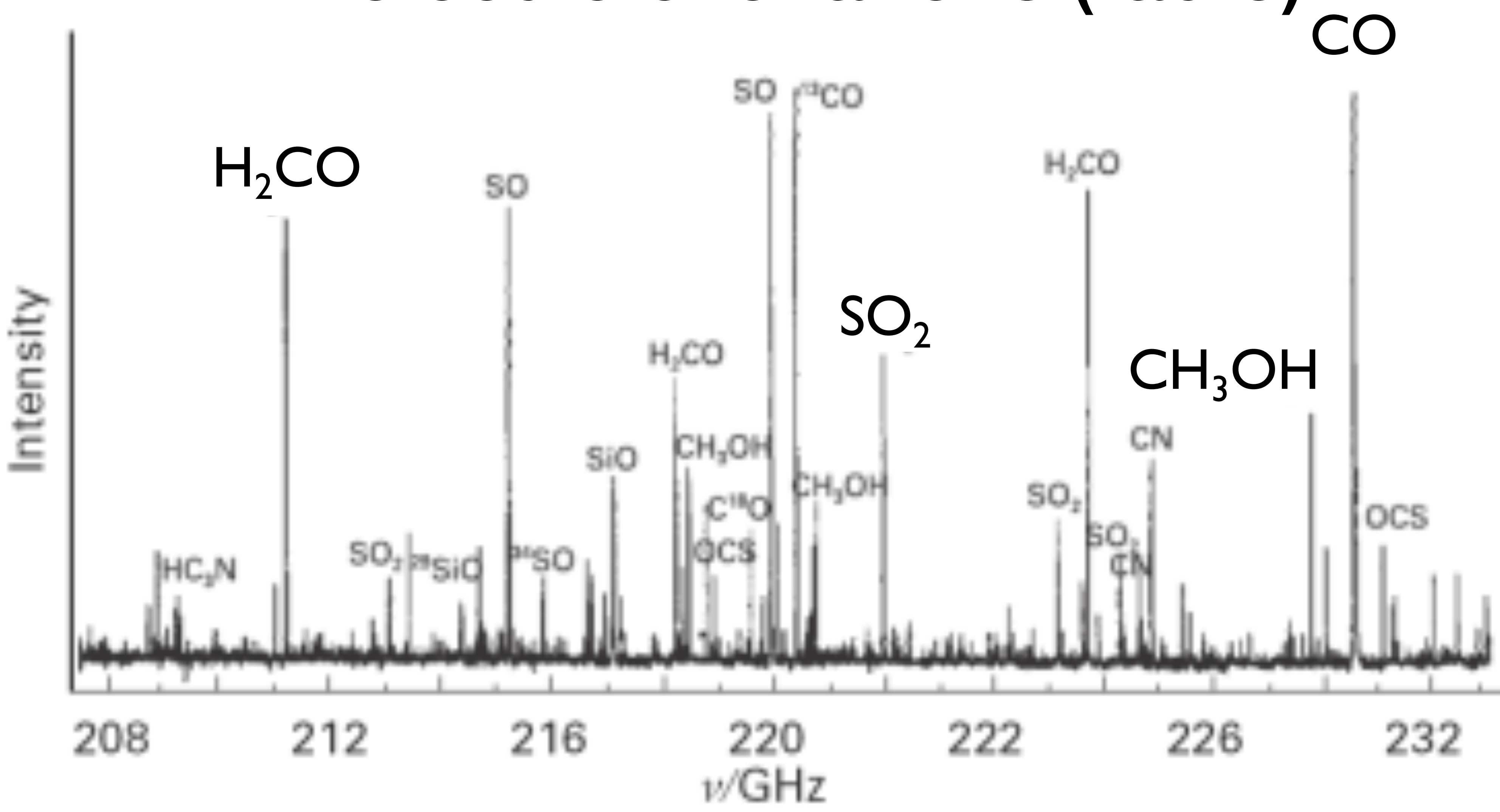
Radio continuum

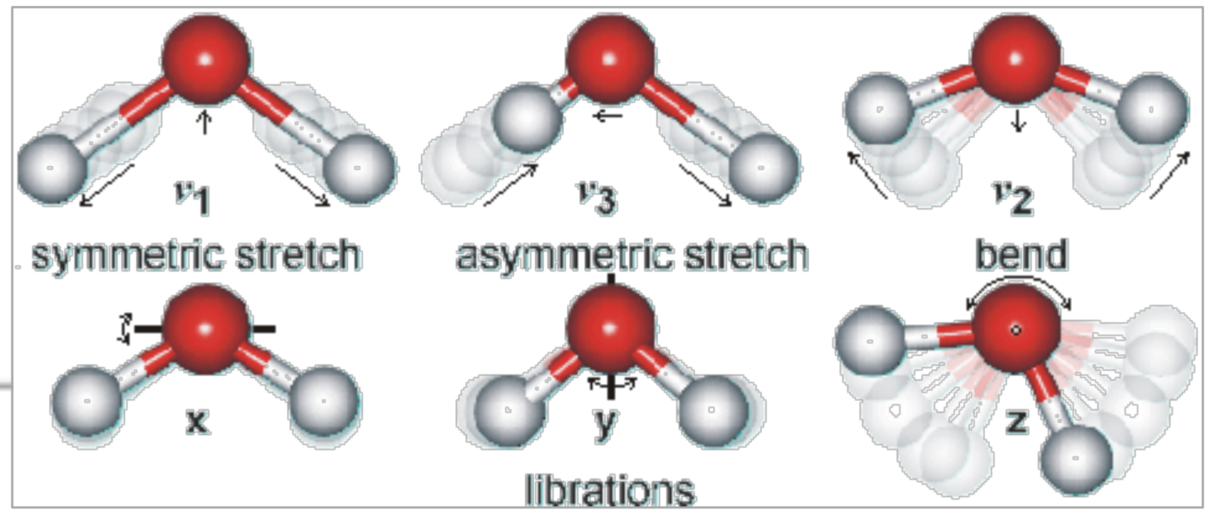


Neutral H "spin-flip": 21cm emission



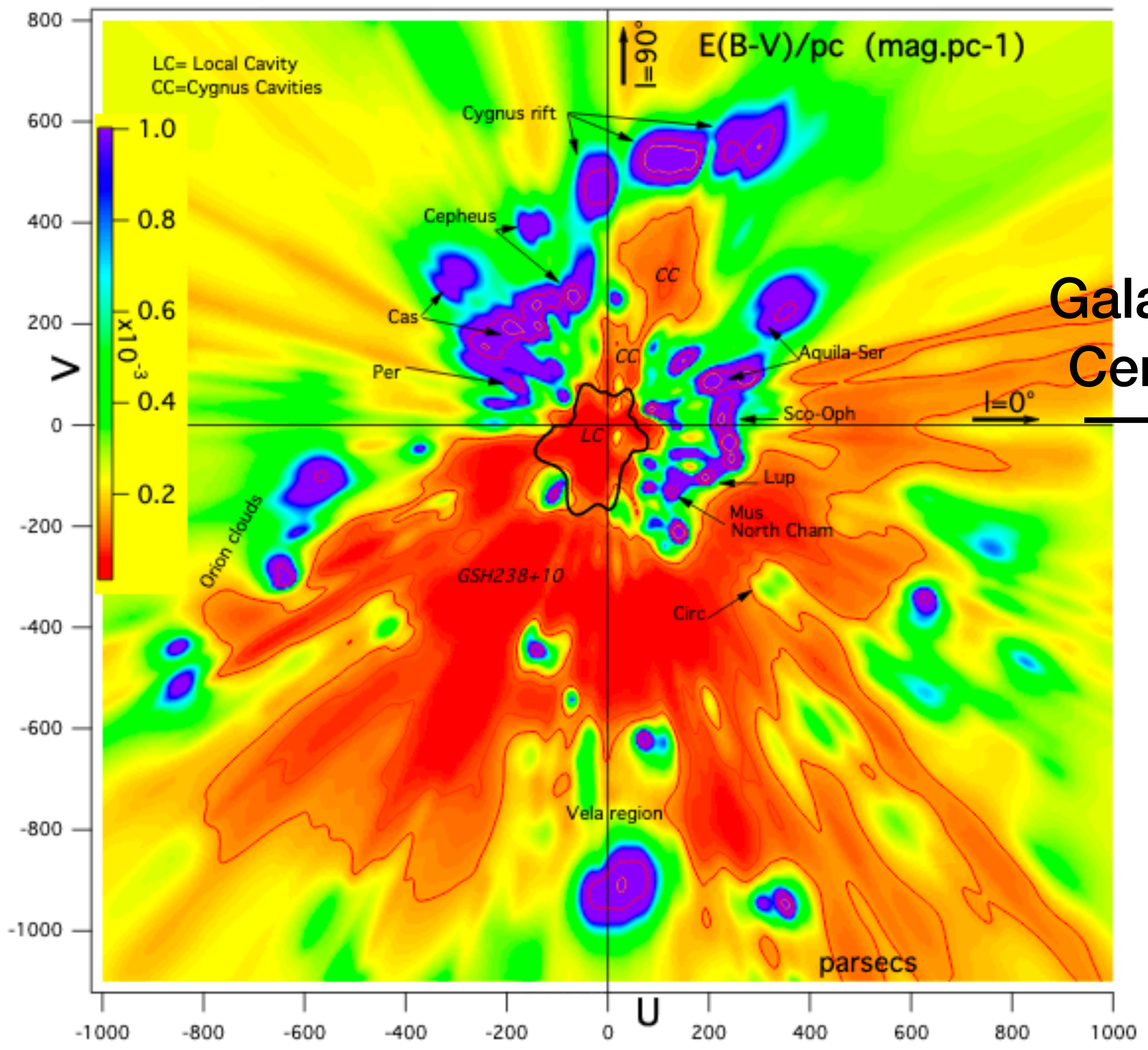
Molecule excitations (radio)





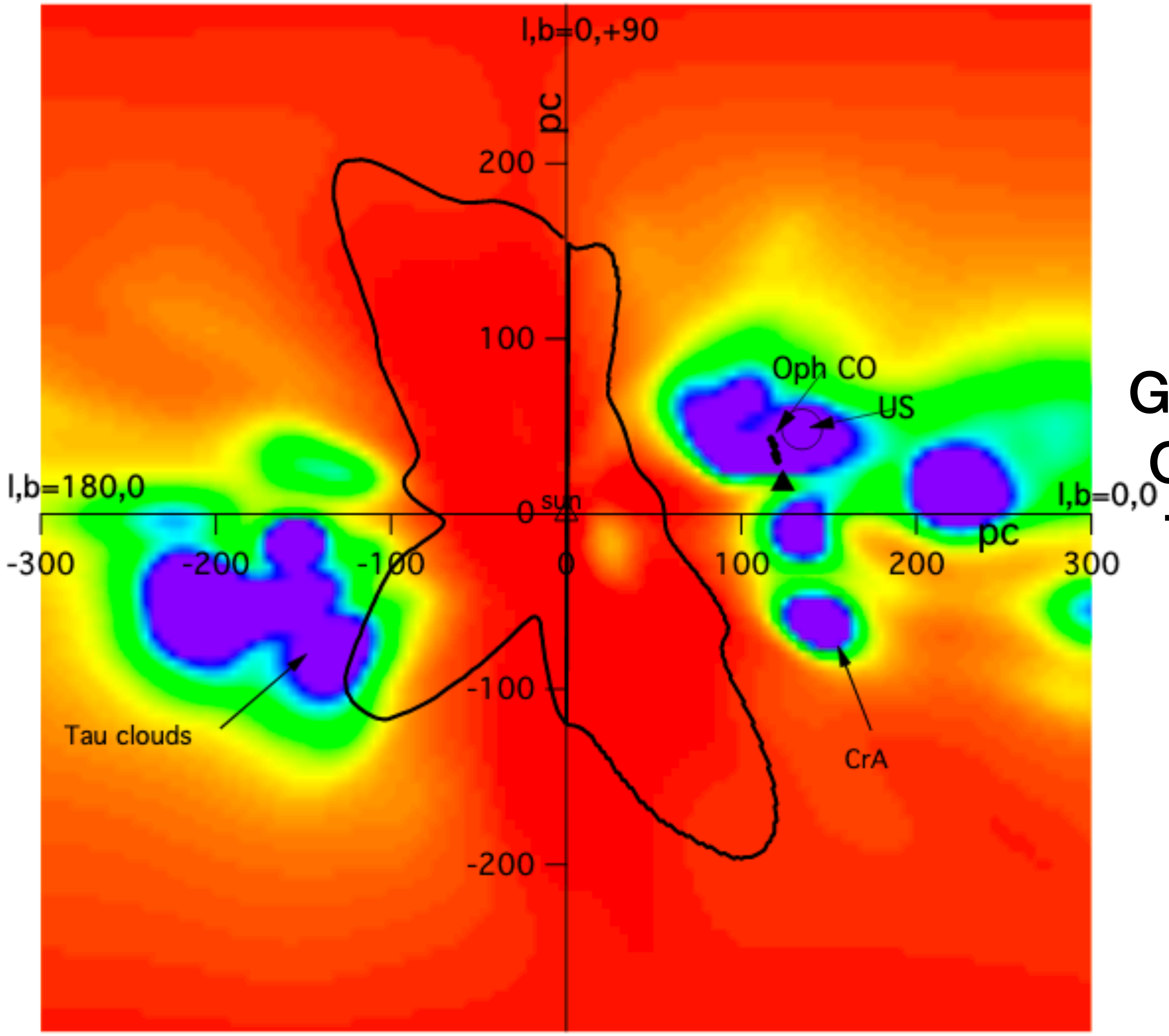
ISM also contains very hot gas heated by SNe

Face-on disk view



Galactic Center →

Edge-on disk view



Galactic Center →

All these gas “phases” are in pressure equilibrium

Cold Molecular Clouds:
$T \sim 10$ K, $n \sim 10^9$ m^{-3}
Cold Neutral Medium:
$T \sim 100$ K, $n \sim 10^8$ m^{-3}
Warm Neutral Medium:
$T \sim 7000$ K, $n \sim 10^5$ m^{-3}
Warm Ionized Medium:
$T \sim 10{,}000$ K, $n \sim 10^6$ m^{-3}
Hot Ionized Medium:
$T \sim 1{,}000{,}000$ K, $n \sim 10^4$ m^{-3}

$P \sim nkT \sim$ const.