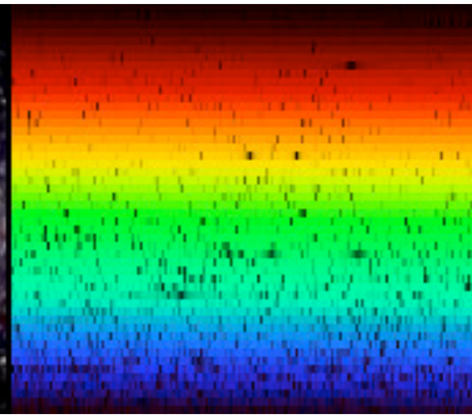
ASTR/PHYS 3070: Foundations Astronomy



Week 10 Thursday

Today's Agenda

- Chemical composition of stars
- Stellar interiors
- Energy generation in the core
- Group Problem!
- Fusion

Video of Friday's colloquium & Q&A on careers: https://uofu.box.com/s/hve526edej6p4m7wax1lgot59wc6ff0d

Announcements / Reminders

- HW 7 due Friday 1min before midnight
- Read Chapters 16.1-2 & 17 for next week

- HEAP talk at 4pm on Thursday
  - Theoretical dark matter candidate particle
- Colloquium at 2pm on Friday
  - Condensed matter theory, material properties in Earth's mantle

Luminosity vs Temperature

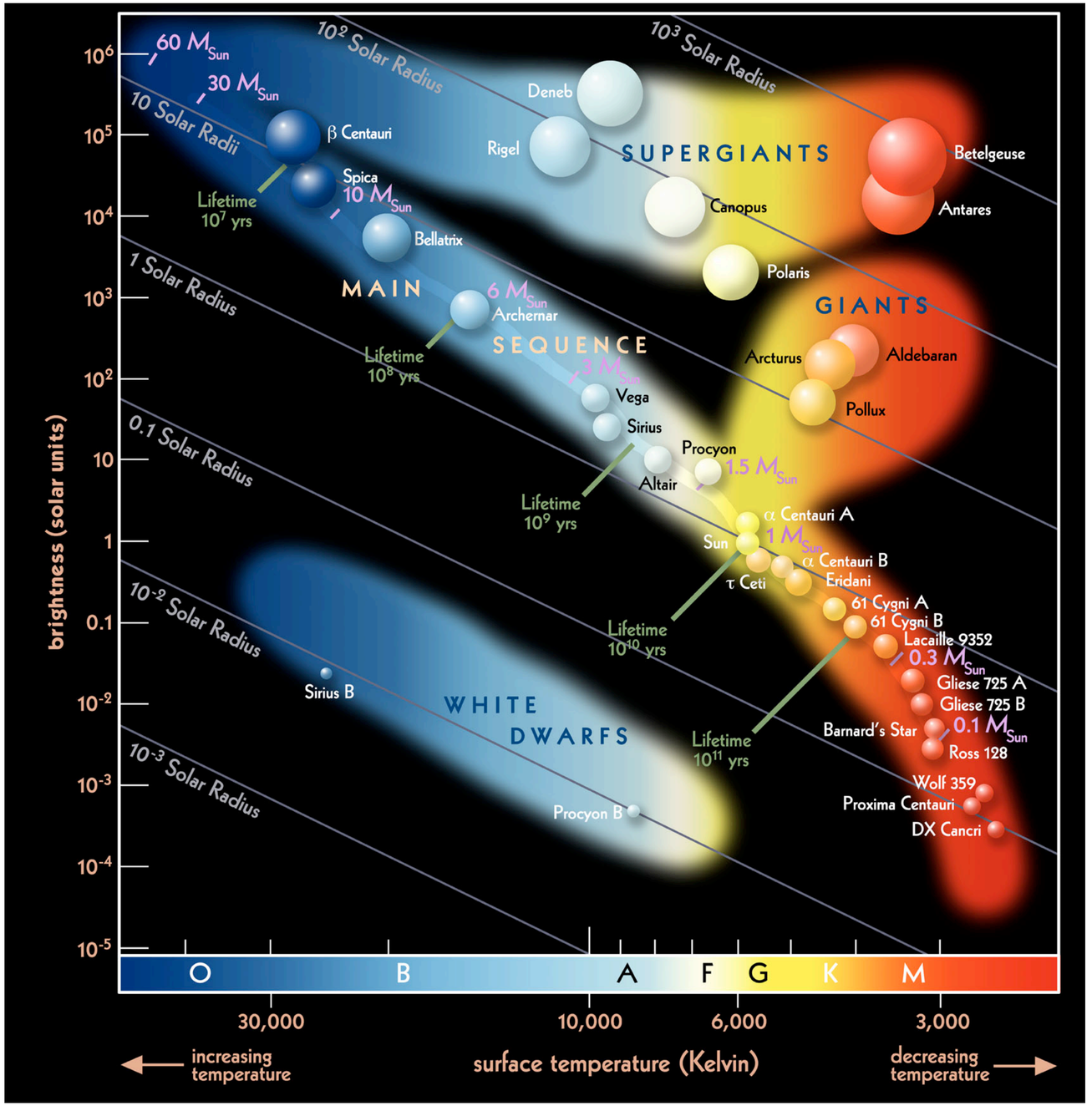
$$T_{\rm eff} = \left(\frac{L}{4\pi R^2 \sigma_{\rm SB}} \right)^{1/4}$$

Hydrostatic Equilibrium

$$\frac{dP}{dr} = -\frac{GM(<r)\rho}{r^2}$$

Ideal Gas Law

$$P = nkT = \frac{\rho kT}{\mu m_p}$$



Characterizing Composition of Stars

$$\rho = \rho_{\rm H} + \rho_{\rm He} + \rho_{\rm metals}$$

$$X \equiv \rho_{\rm H}/\rho$$

$$Y \equiv \rho_{\rm He}/\rho$$

$$Z \equiv \rho_{\rm metals}/\rho = 1 - X - Y$$

$$X_\odot = 0.734,\ Y_\odot = 0.250,\ Z_\odot = 0.016$$

$$X_{\rm BB} \sim \frac{3}{4},\ Y_{\rm BB} \sim \frac{1}{4},\ Z_{\rm BB} \sim 0$$

$$P = nkT = \frac{\rho kT}{\mu m_p}$$

Mean molecular mass

$$\mu_{\rm H} = \begin{cases} 1 & \text{neutral} \\ \frac{1}{2} & \text{ionized} \end{cases} \qquad \mu_{\rm He} = \begin{cases} 4 & \text{neutral} \\ \frac{4}{3} & \text{ionized} \end{cases}$$

$$\mu(\text{ionized}) = \frac{\rho}{n m_p} = \left(2X + \frac{3}{4}Y + \frac{1}{2}Z\right)^{-1}$$

$$\mu_\odot(\text{ionized}) = 0.60$$

Stellar Interiors (same as atmospheres)

$$\frac{dP}{dr} = -\frac{GM(<r)\rho(r)}{r^2}$$

$$\frac{\Delta P}{\Delta r} \approx -\frac{G\langle M\rangle\langle\rho\rangle}{\langle r\rangle^2}$$

Energy Generation

First idea: 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

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

Group Problem

Mars is now tectonically dead, because it has cooled sufficiently that heat from its formation is no longer available to drive convention and activity like plate tectonics.

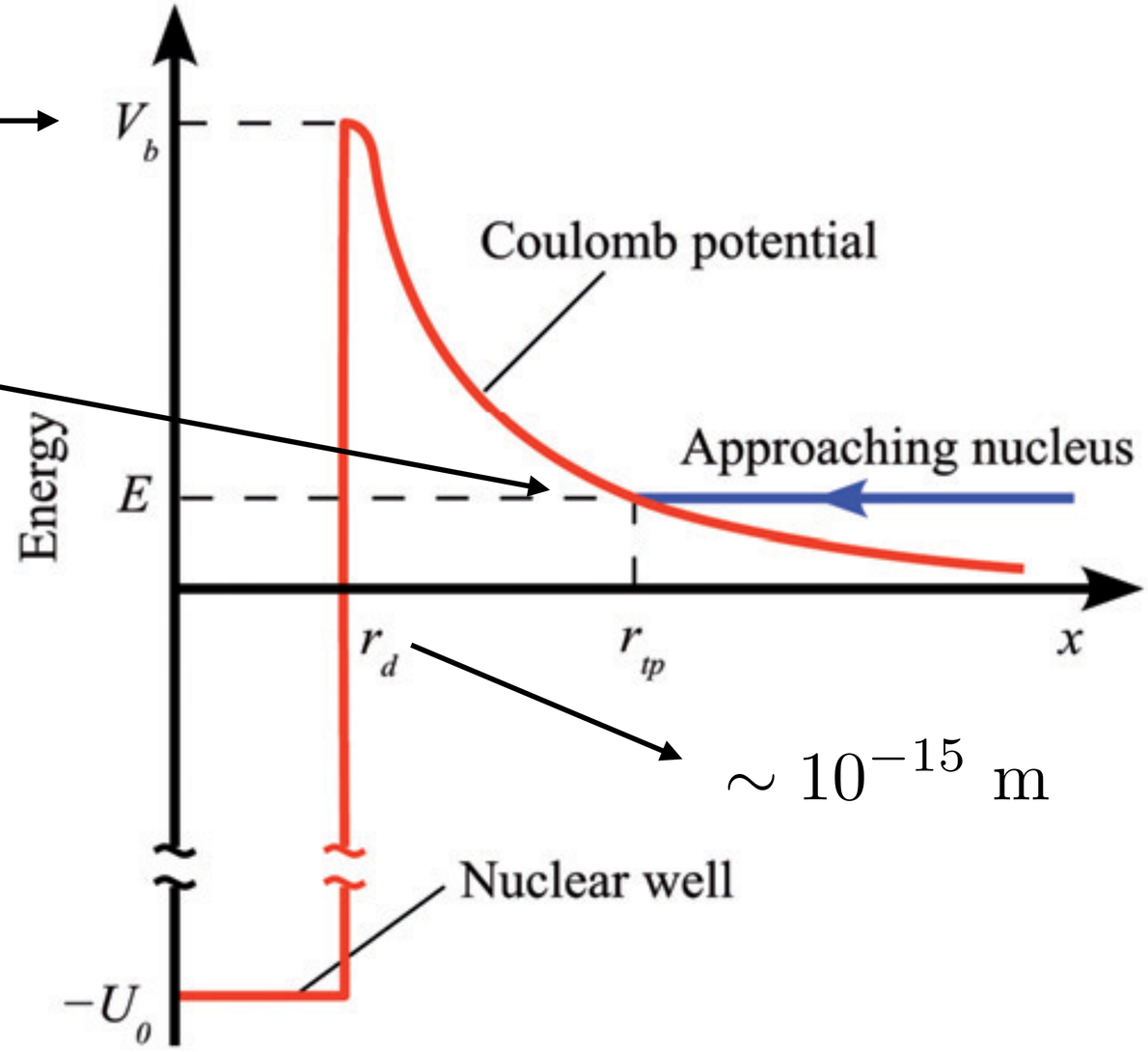
Using Lord Kelvin & Helmholtz's arguments, should 🌎 Earth 🌍 still be tectonically active today?

If the answer is no, why do we have earthquakes, volcanoes, and active plate tectonics???

Fusion possible b/c of QM

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

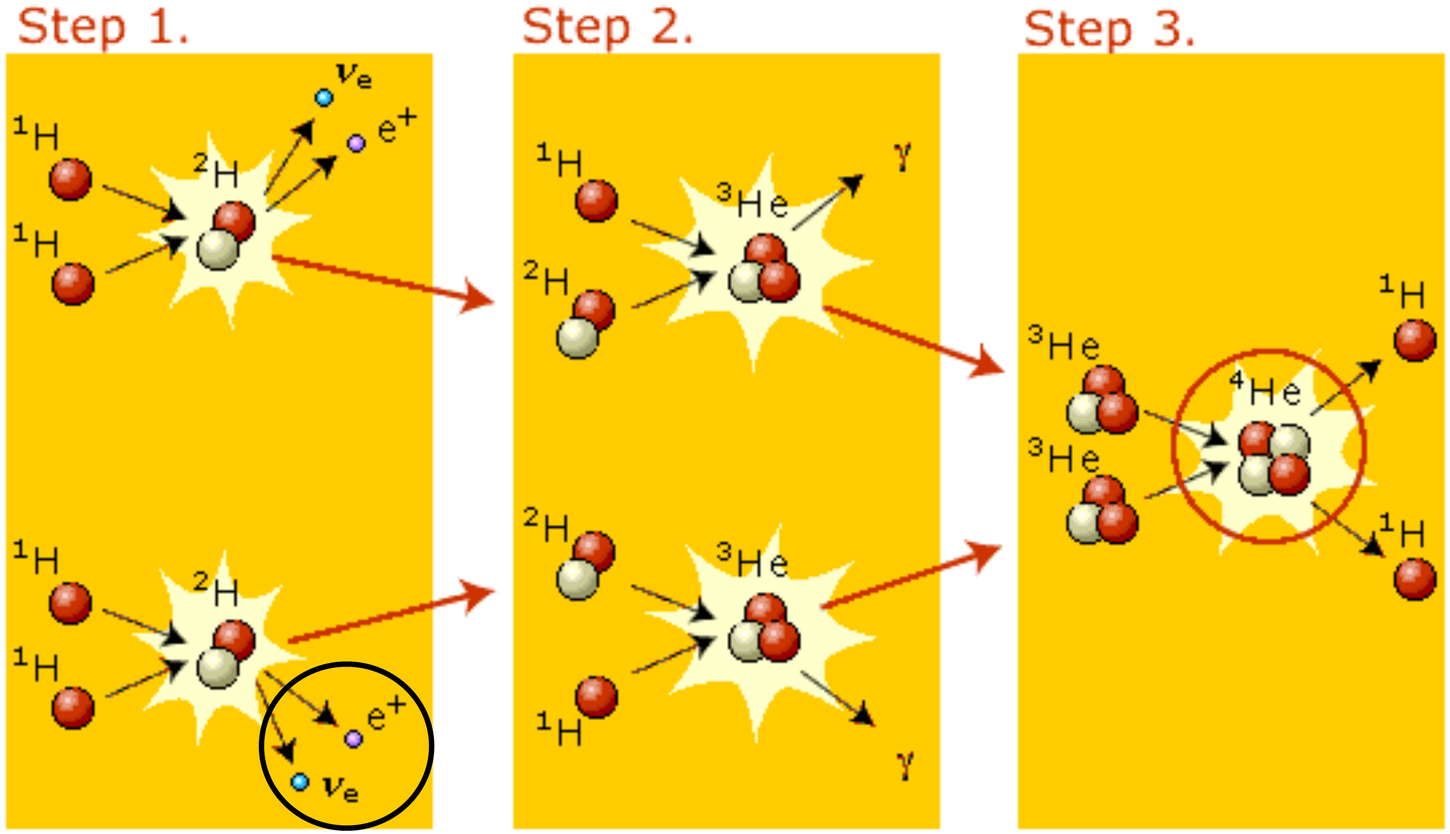
$$\langle E \rangle = \frac{3}{2} k T_c \approx 2 \text{ keV}$$

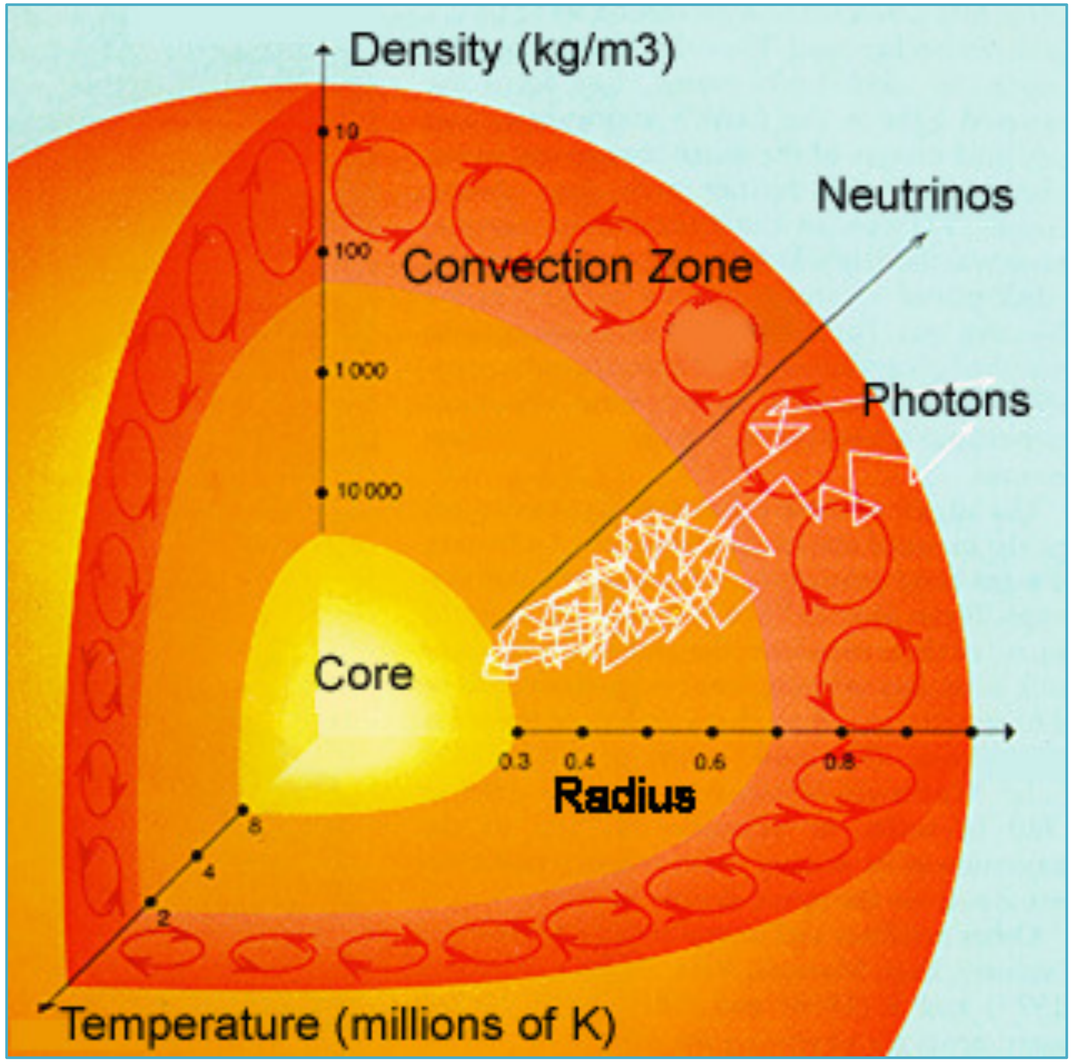


Particles are waves!

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

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

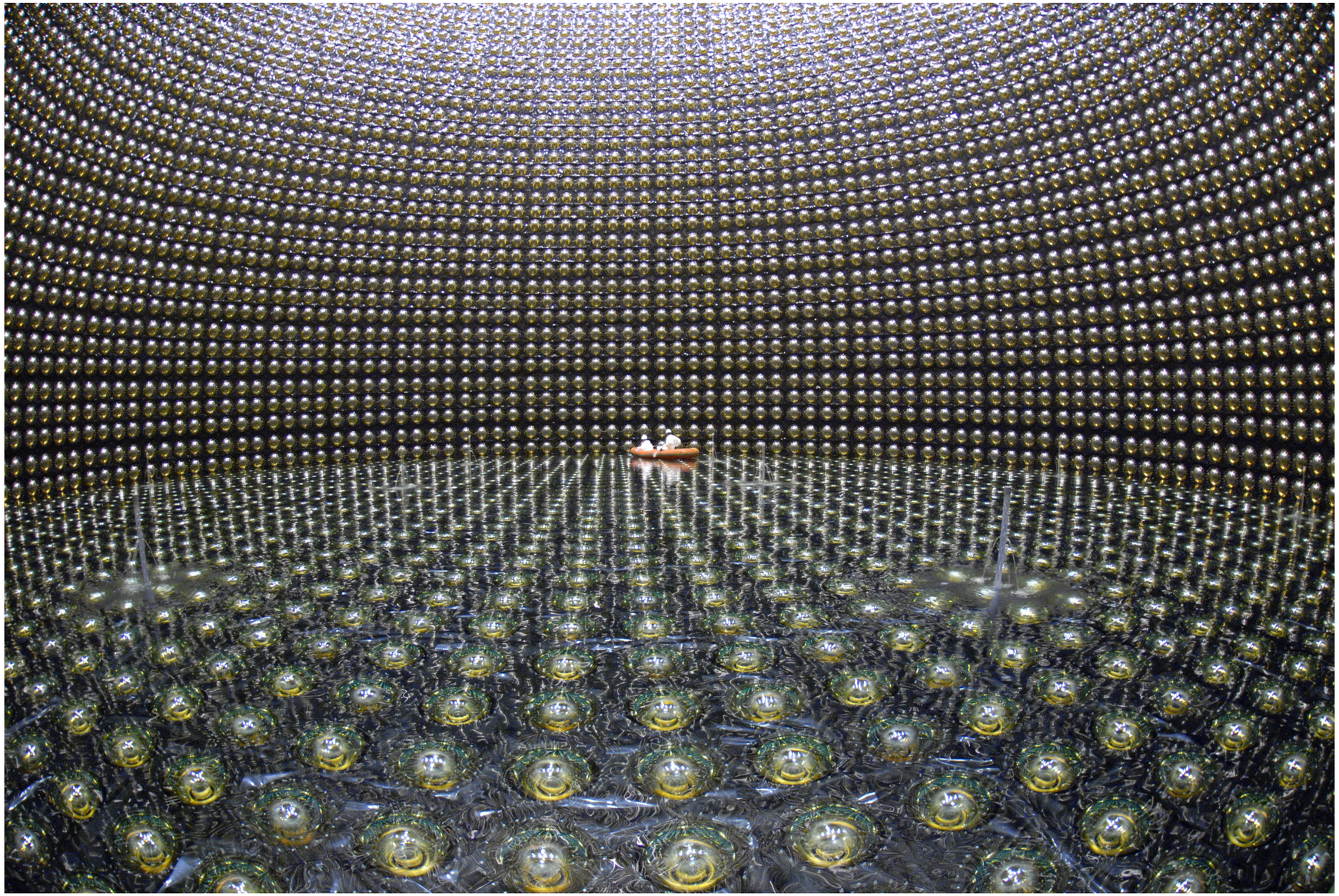




$$4\ \mathrm{p} \rightarrow {}^4\mathrm{He} + 2\gamma + 2\mathrm{e}^+ + 2\nu_\mathrm{e}$$

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

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