Timescales of stellar evolution

1. Dynamical time scale

Measure of the time scale on which a star would expand or contract if the balance between pressure gradients and gravity was suddenly disrupted (same as free-fall time scale):

$$\tau_{dyn} \equiv \frac{\text{characteristic radius}}{\text{characteristic velocity}} = \frac{R}{v_{esc}}$$

Escape velocity from the surface of the star: $v_{esc} = \sqrt{\frac{2GM}{R}}$

$$\tau_{dyn} = \sqrt{\frac{R^3}{2GM}} \approx \text{(for Sun) } 1100 \text{ s}$$

In terms of mean density: $\tau_{dyn} \propto \frac{1}{\sqrt{G\rho}}$ ← mean density of the star, molecular cloud, etc

2. Kelvin-Helmholtz time scale (or thermal time scale)

Suppose nuclear reaction were suddenly cut off in the Sun. Thermal time scale is the time required for the Sun to radiate all its reservoir of thermal energy:

$$\tau_{KH} \equiv \frac{U}{L}$$

← Virial theorem: the thermal energy U is roughly equal to the gravitational potential energy

$$\Rightarrow \quad \tau_{KH} \approx \frac{GM^2}{RL} = 3 \times 10^7 \text{ yr (for the Sun)}$$

Important time scale: determines how quickly a star contracts *before* nuclear fusion starts - i.e. sets roughly the pre-main sequence lifetime.

3. Nuclear time scale

Time scale on which the star will exhaust its supply of nuclear fuel if it keeps burning it at the current rate:

Energy release from fusing one gram of hydrogen to helium is 6 x 10^{18} erg, so:

$$\tau_{nuc} = \frac{qXM \times 6 \times 10^{18} \text{ erg g}^{-1}}{L}$$

…where:

- X is the mass fraction of hydrogen initially present (X=0.7)
- q is the fraction of fuel available to burn in the core (q=0.1)

$$\tau_{nuc} \approx 7 \times 10^{9} \text{ yr}$$

Reasonable estimate of the main-sequence lifetime of the Sun.

Ordering of time scales:

$$\tau_{dyn} << \tau_{KH} << \tau_{nuc}$$

Most stars, most of the time, are in hydrostatic and thermal equilibrium, with slow changes in structure and composition occurring on the (long) time scale τ_{nuc} as fusion occurs.

Do observe evolution on the shorter time scales also:

- Dynamical - **stellar collapse / supernova**
- Thermal / Kelvin-Helmholtz - **pre-main-sequence**