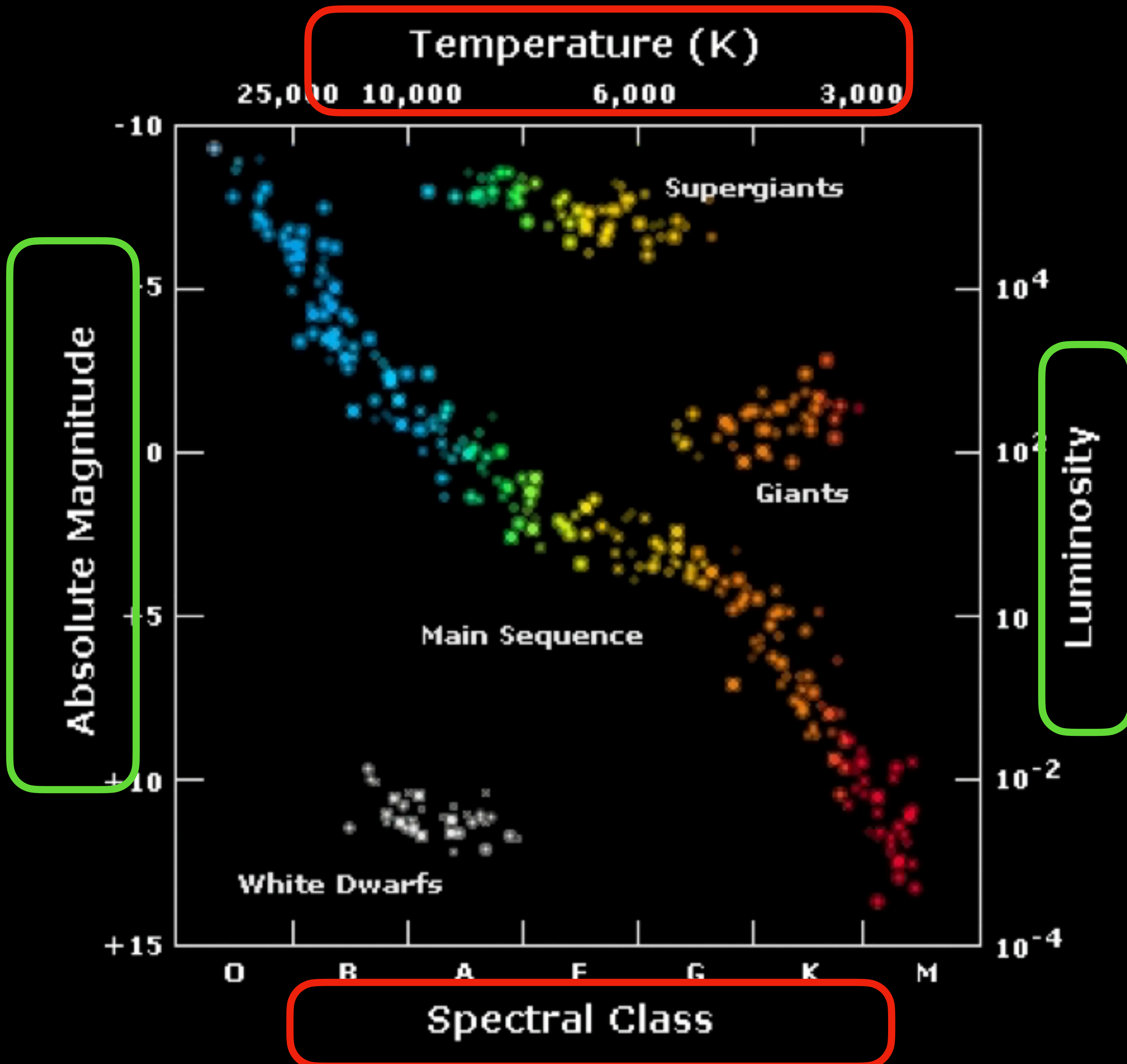
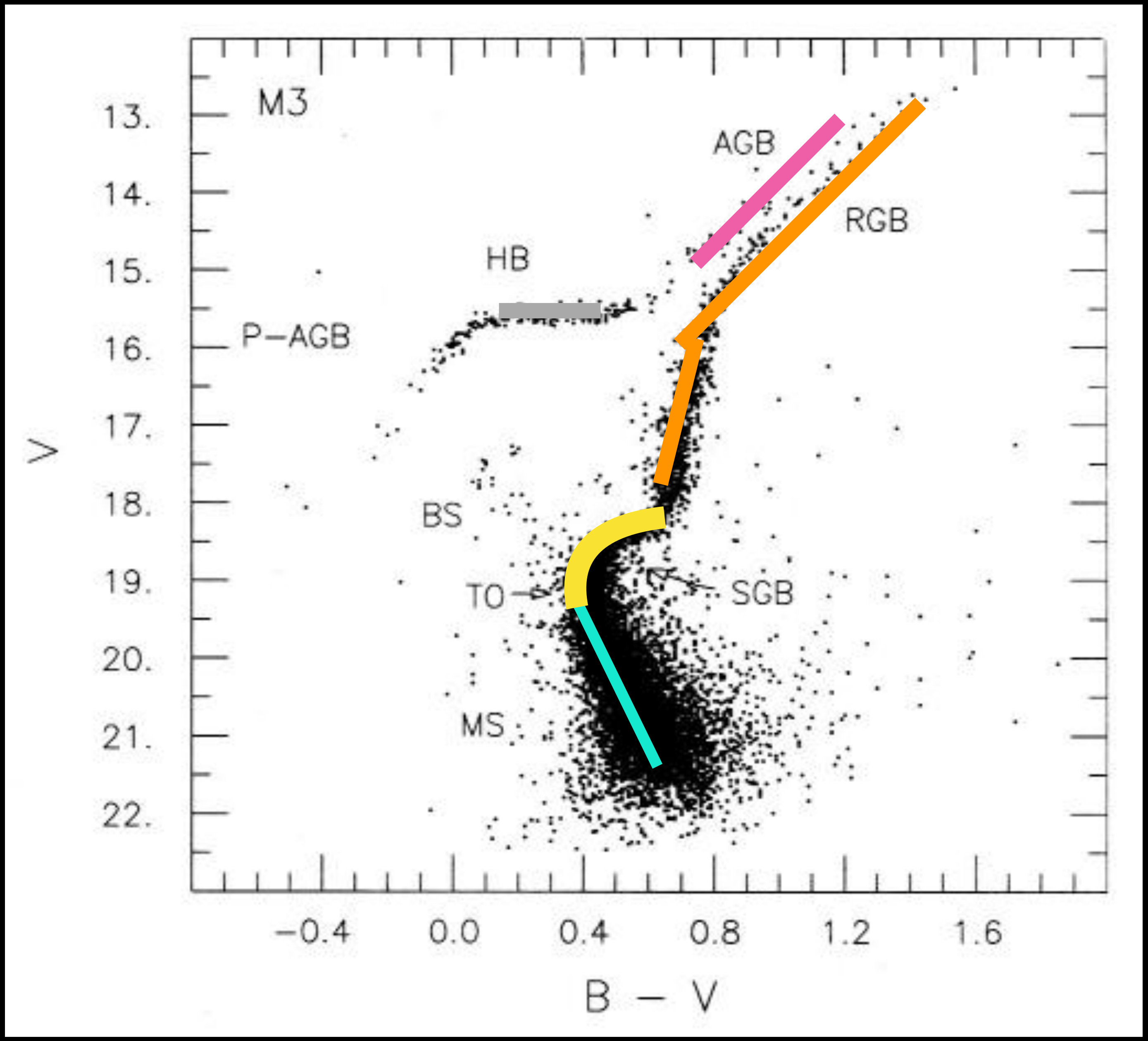
Recap: lecture 12

Hertzsprung Russell (H-R) diagram



Recap: lecture 12

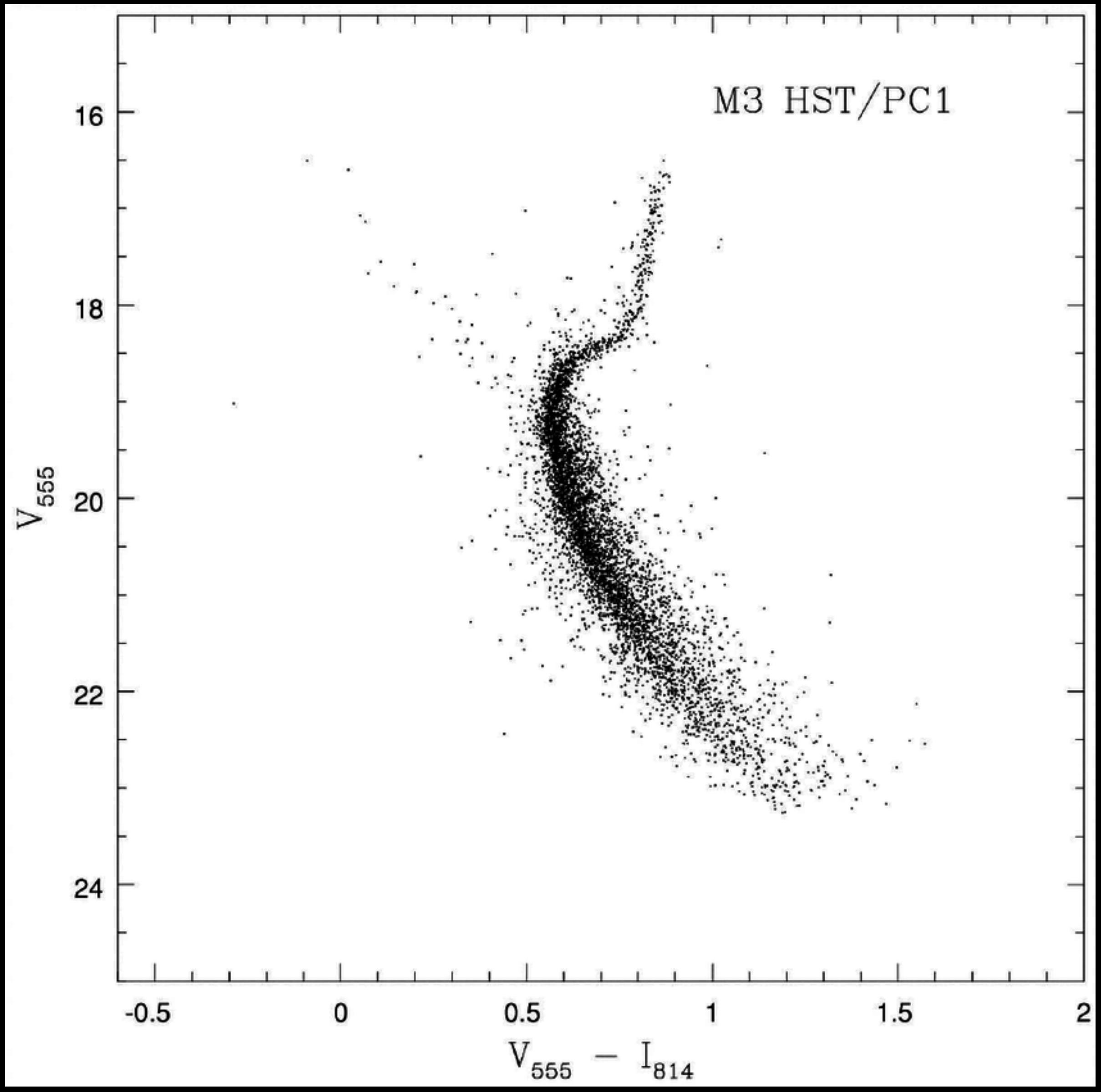
HR diagram

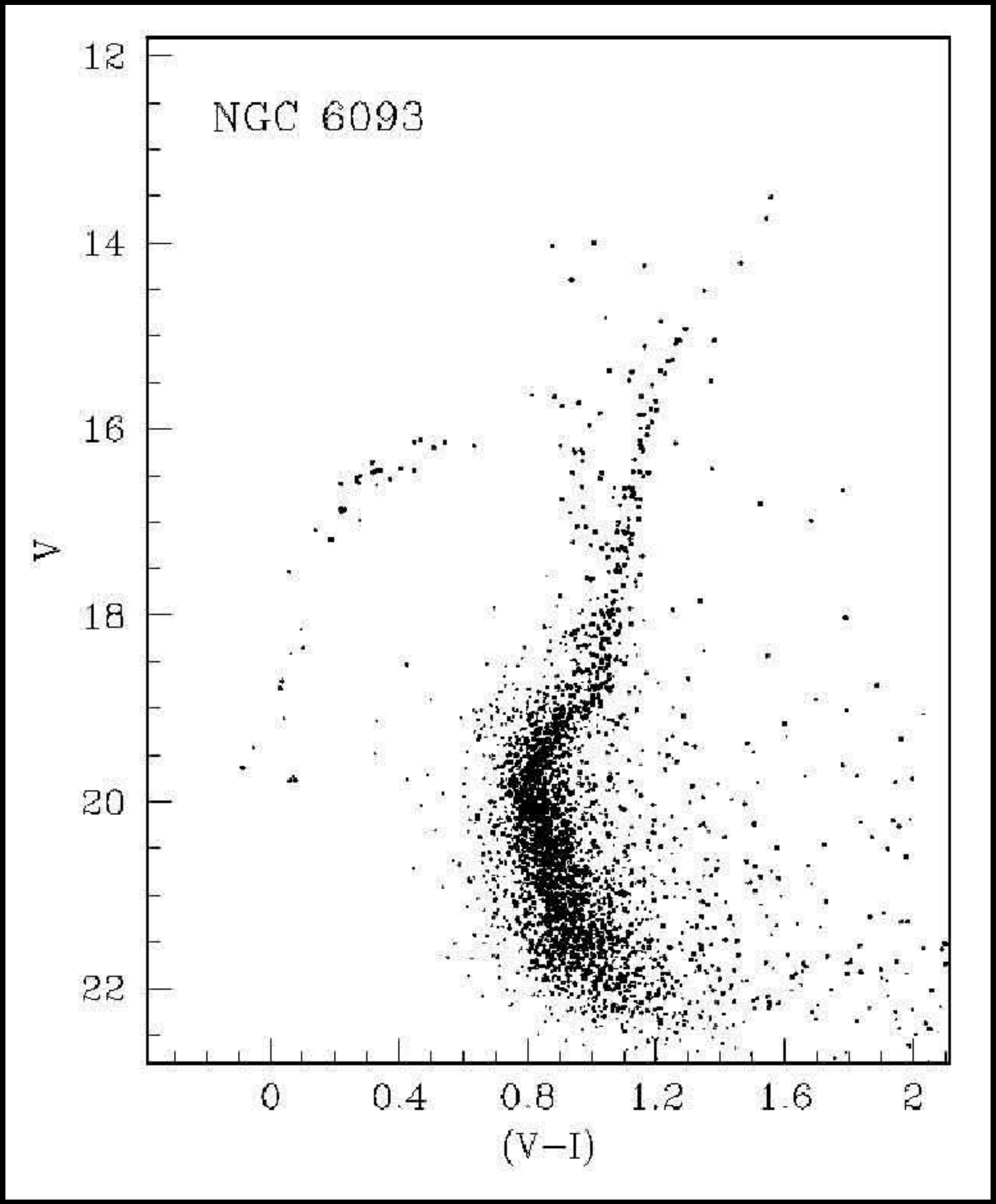


- **MS = Main Sequence**
- **TO = Main sequence Turn off**
- **RGB = Red Giant Branch**
- **AGB = Asymptotic Giant Branch**
- **HB = Horizontal Branch**

Recap: lecture 12
Star Cluster

Star cluster, either of two general types of stellar assemblages held together by the mutual gravitational attraction of its members, which are physically related through common origin. The two types are open (formerly called galactic) clusters and globular clusters.





H-R diagram

- More luminous stars are more massive.
- More massive stars live shorter.
- Main sequence is where stars spend most of the time.
- From bottom-left to up-right stars have larger radius
- HR diagram can give us information on the age of the system

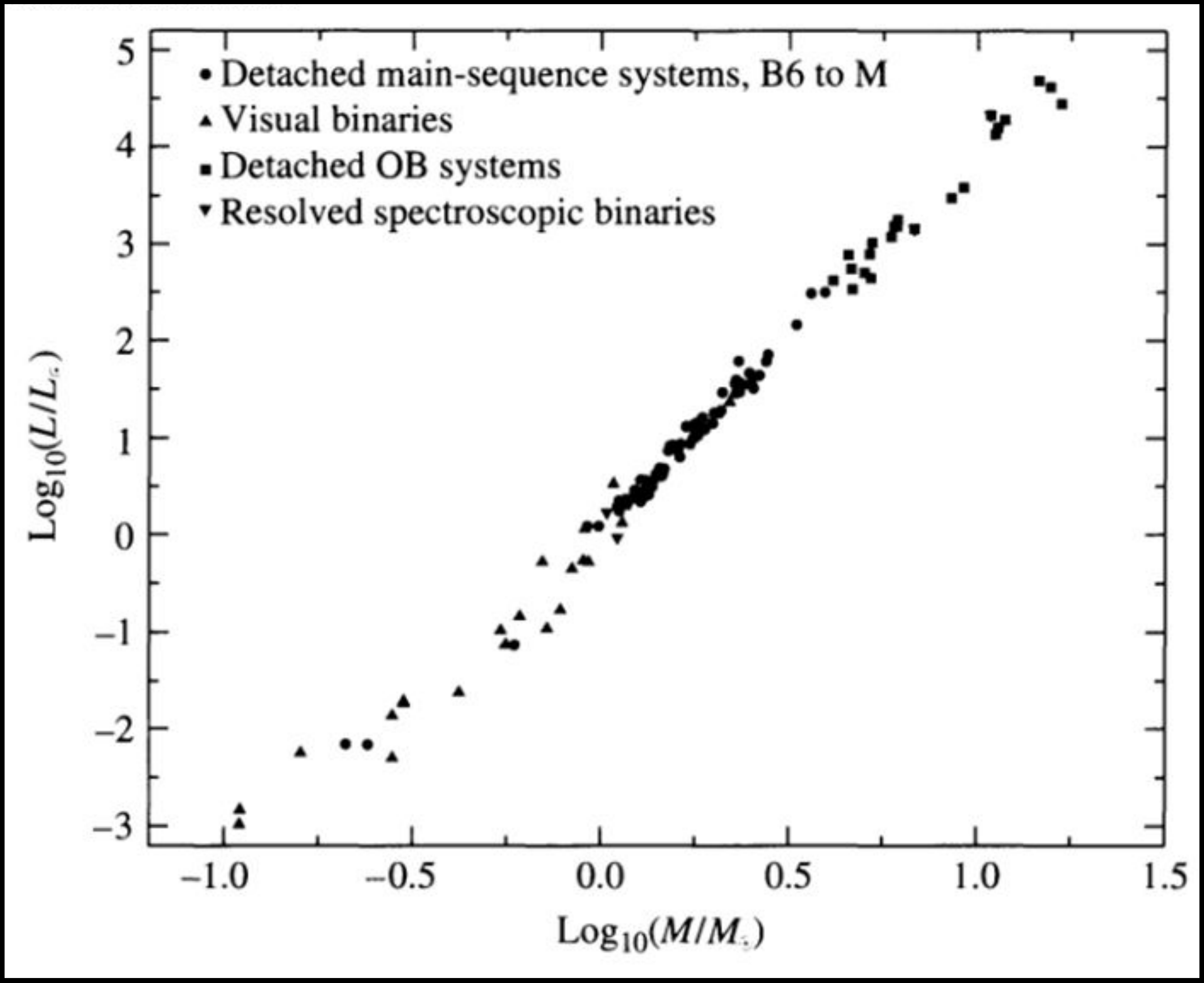
Life time of a star

$$\textbf{life of a star} \propto \frac{Total\ Energy\ can\ release}{Power}$$

Mass vs Luminosity relation

$$L \propto M^x$$

where x > 1



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Life time of a star

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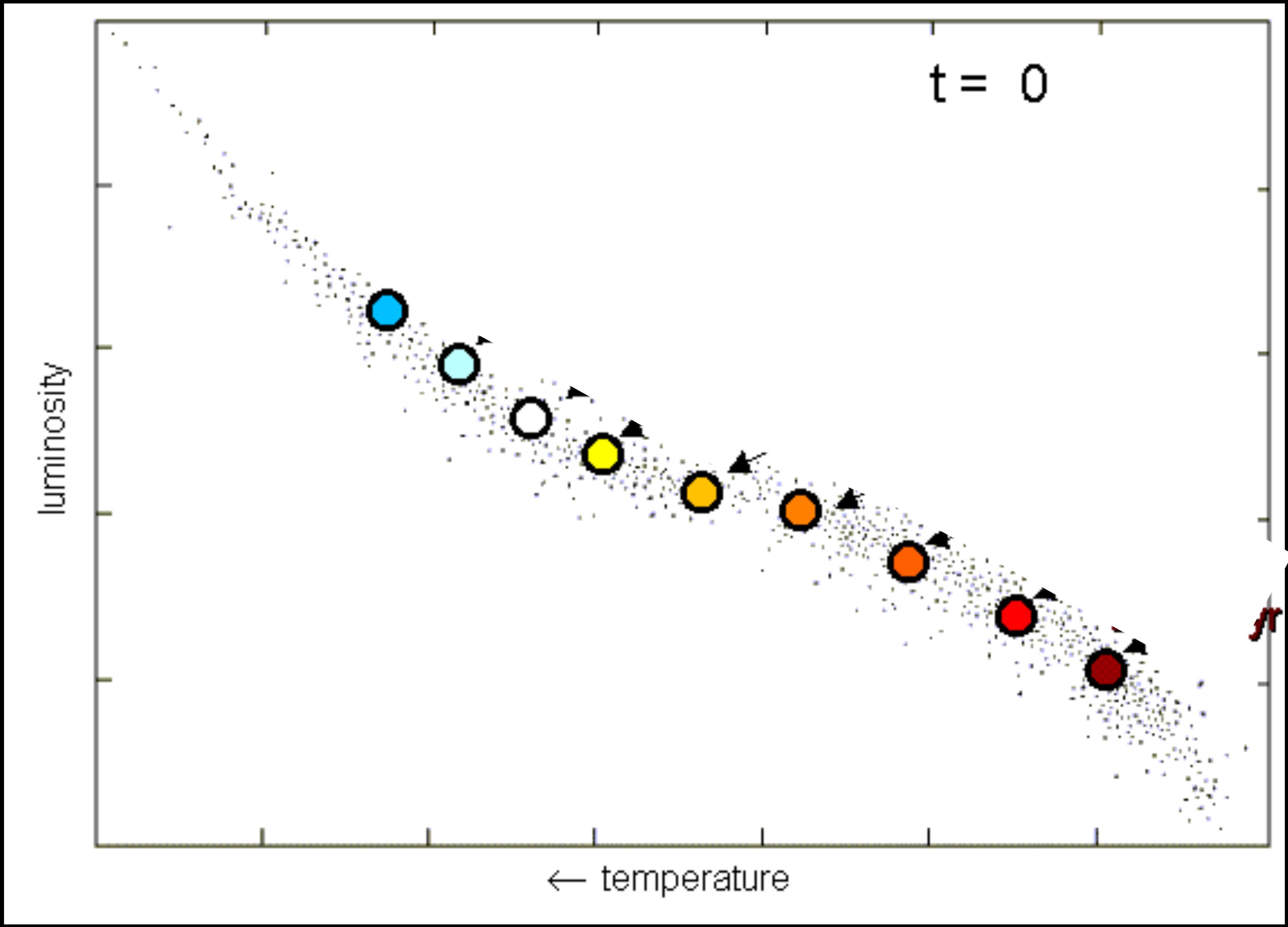
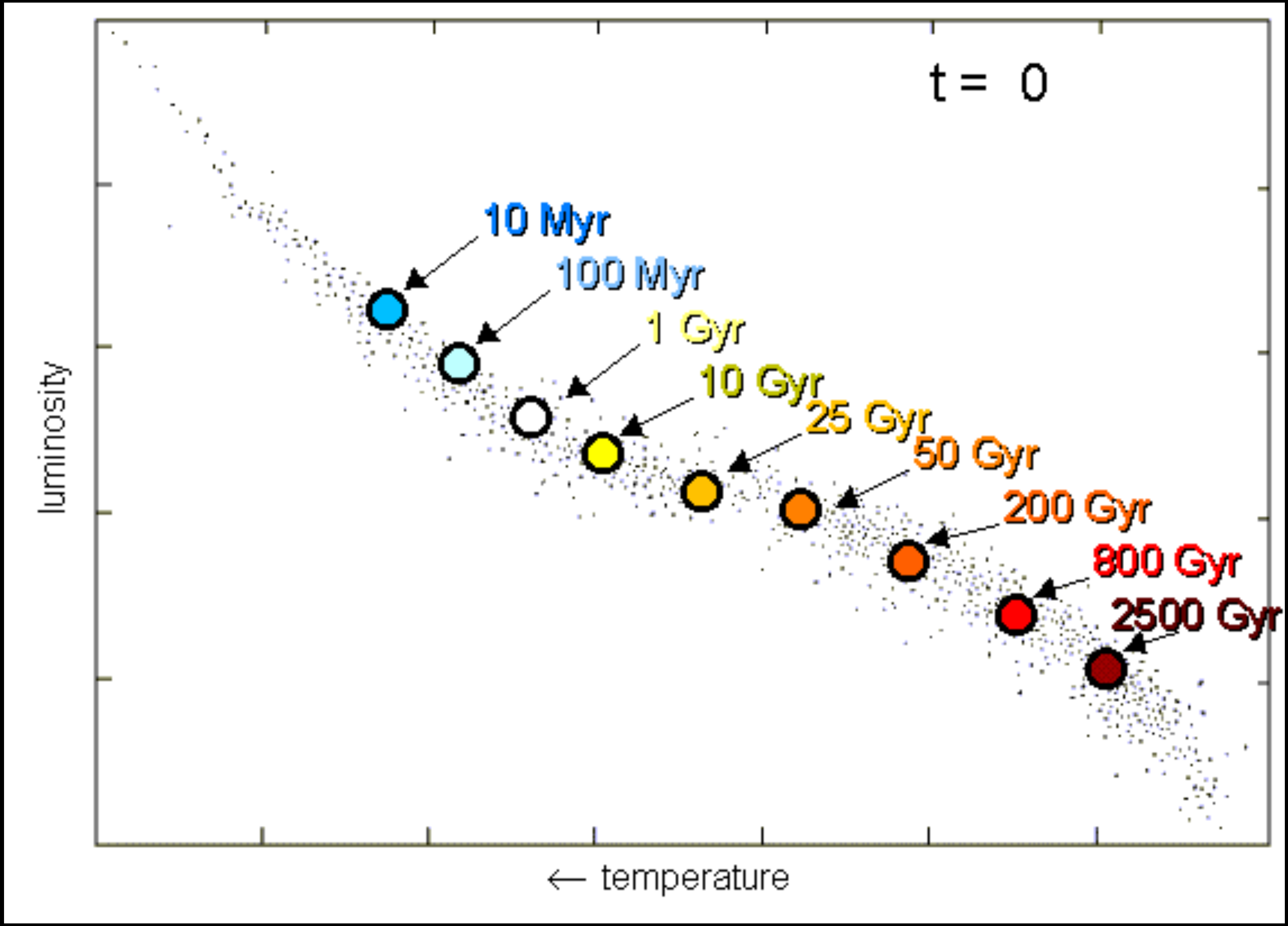
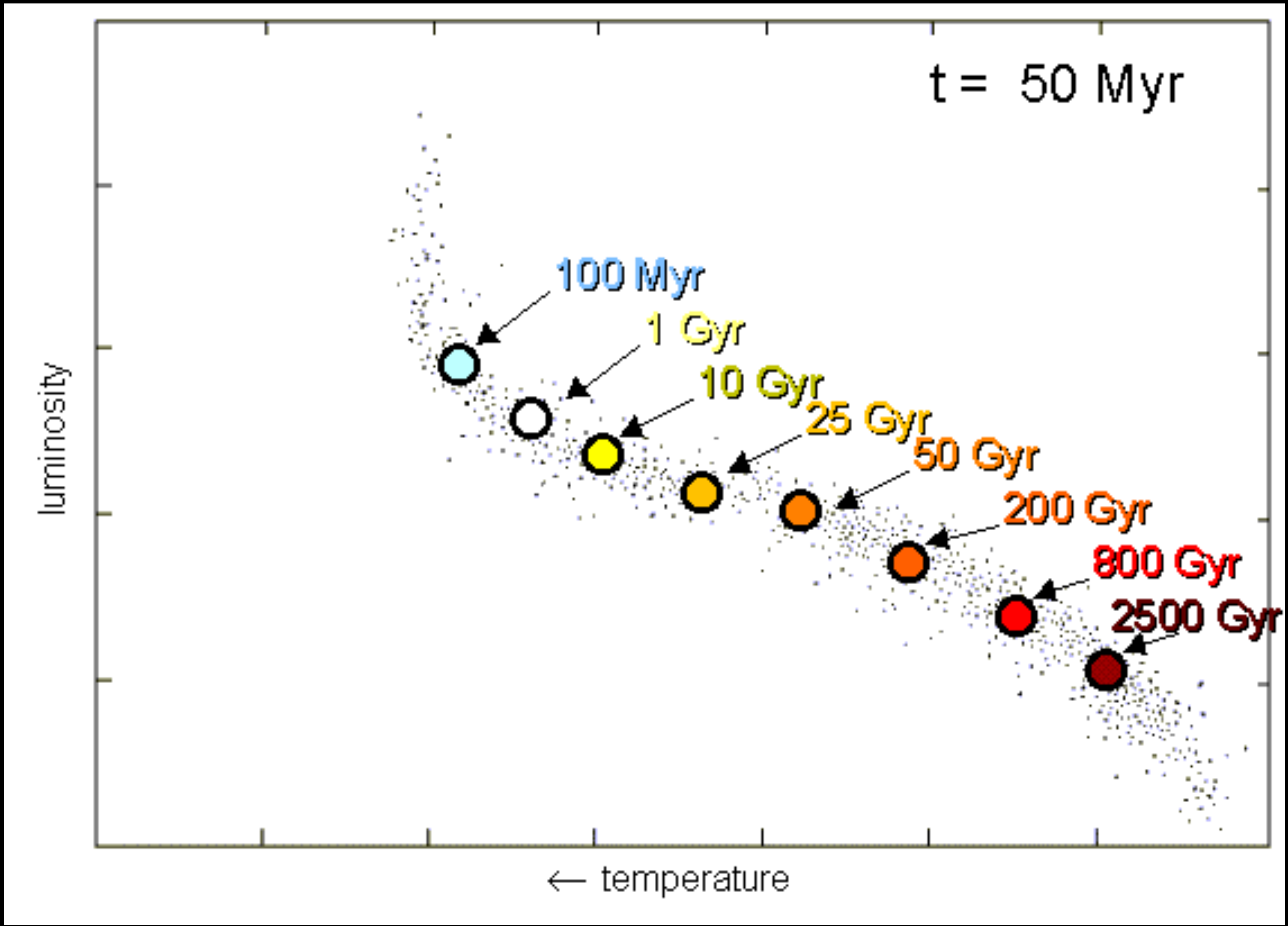
mass-luminosity relation also tell us that more massive stars live shorter

Main sequence

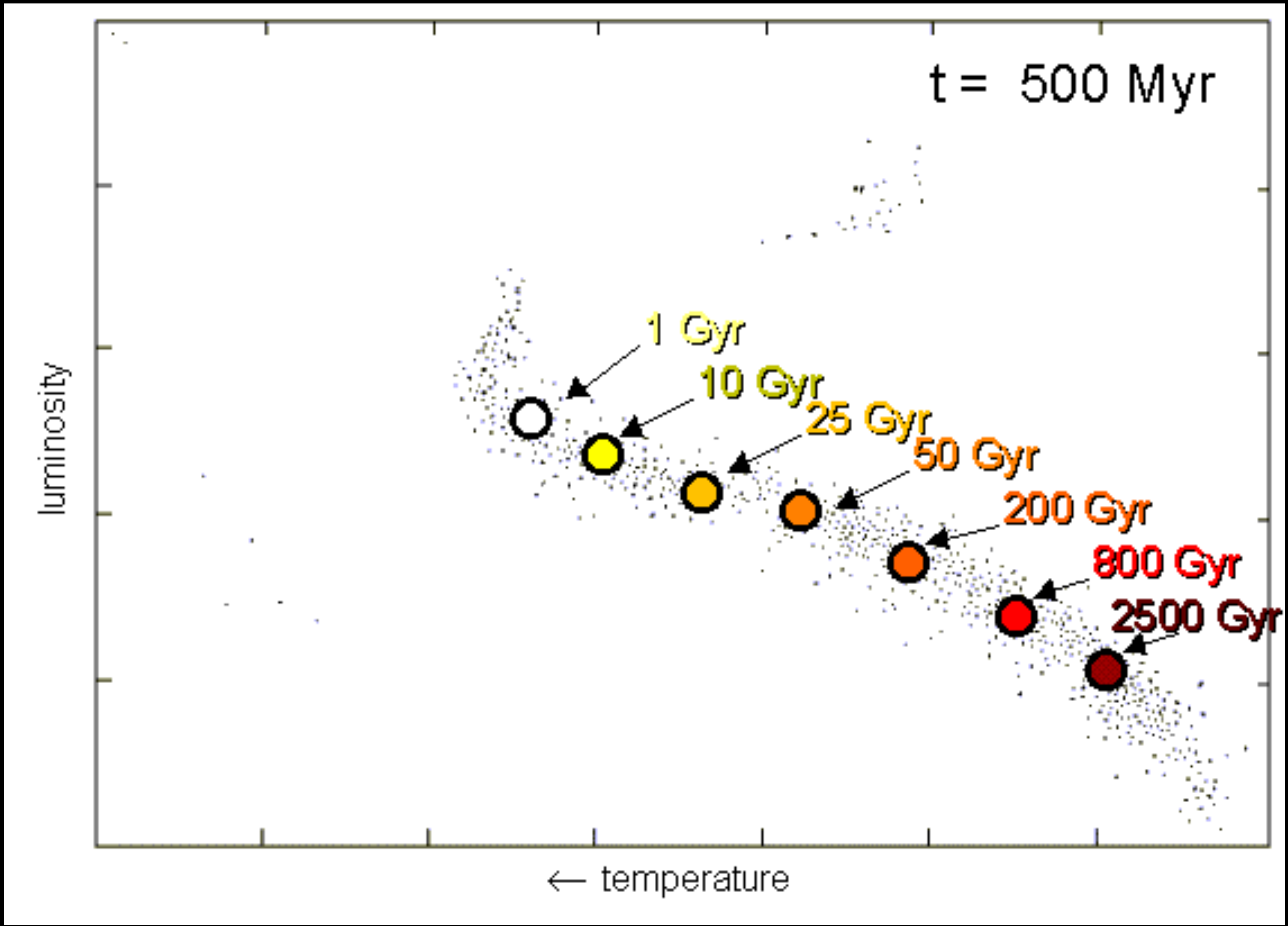


Stars evolution on the HR





t = 50 Myr
100 Myr
1 Gyr
10 Gyr
25 Gyr
50 Gyr
200 Gyr
800 Gyr
2500 Gyr
luminosity
← temperature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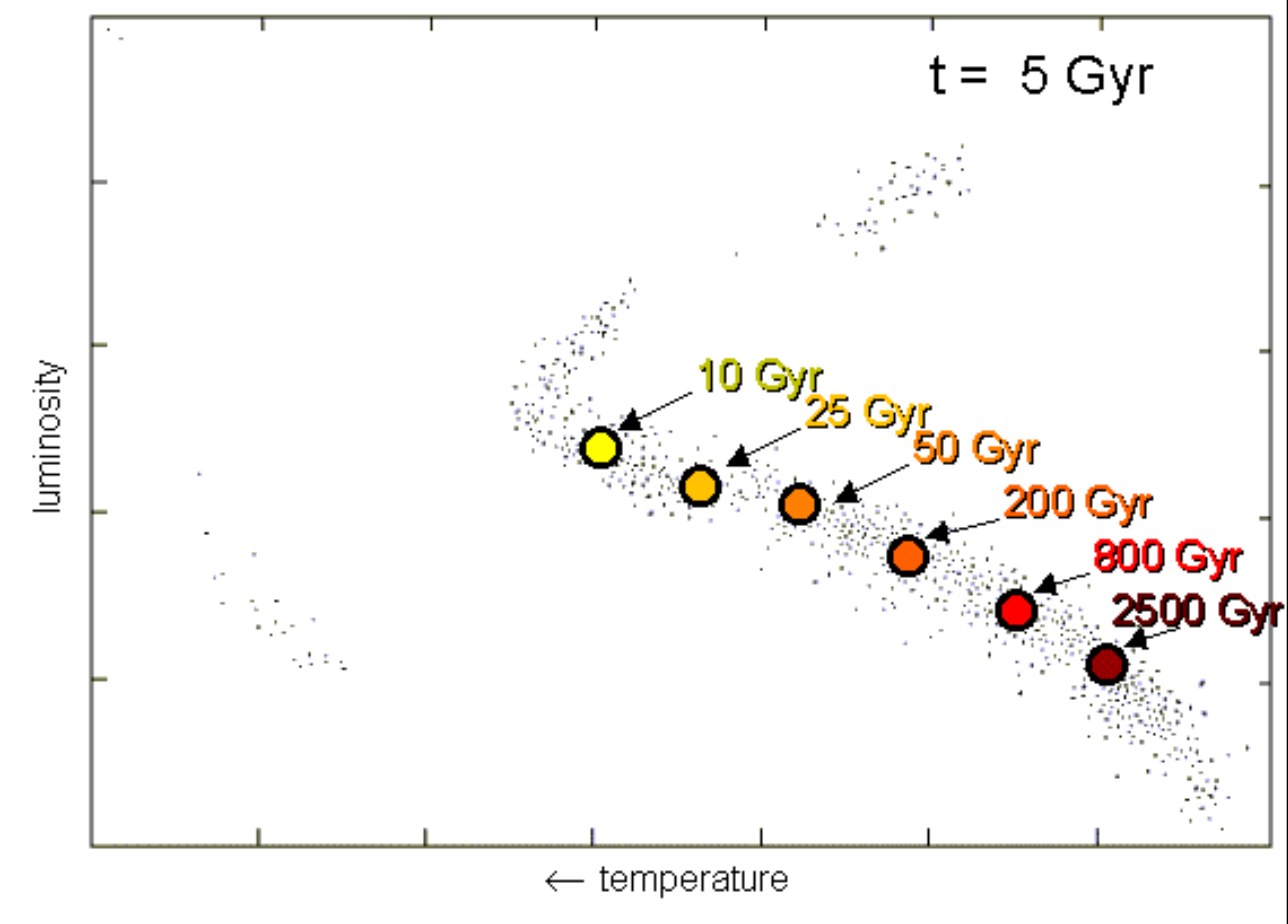

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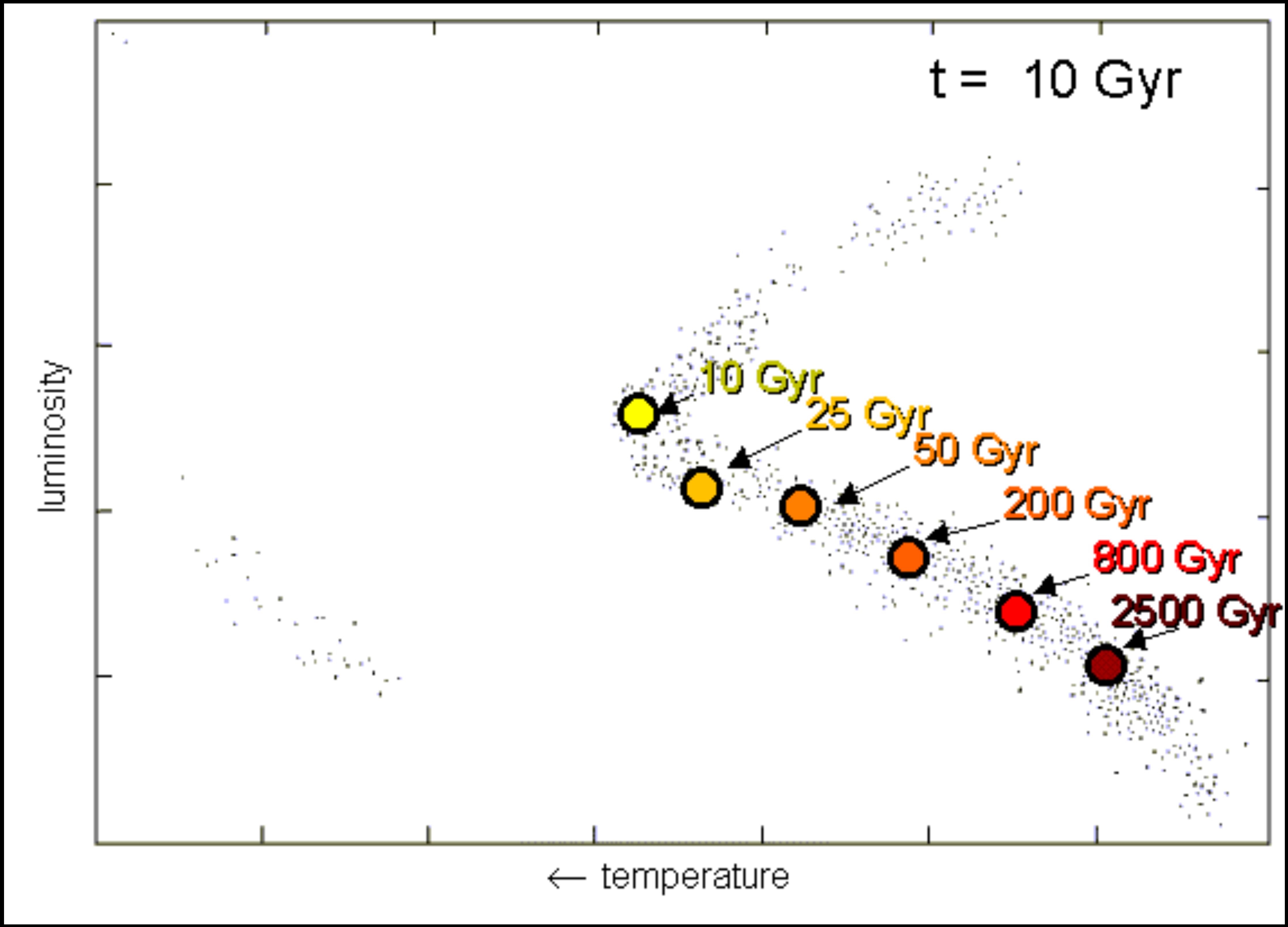
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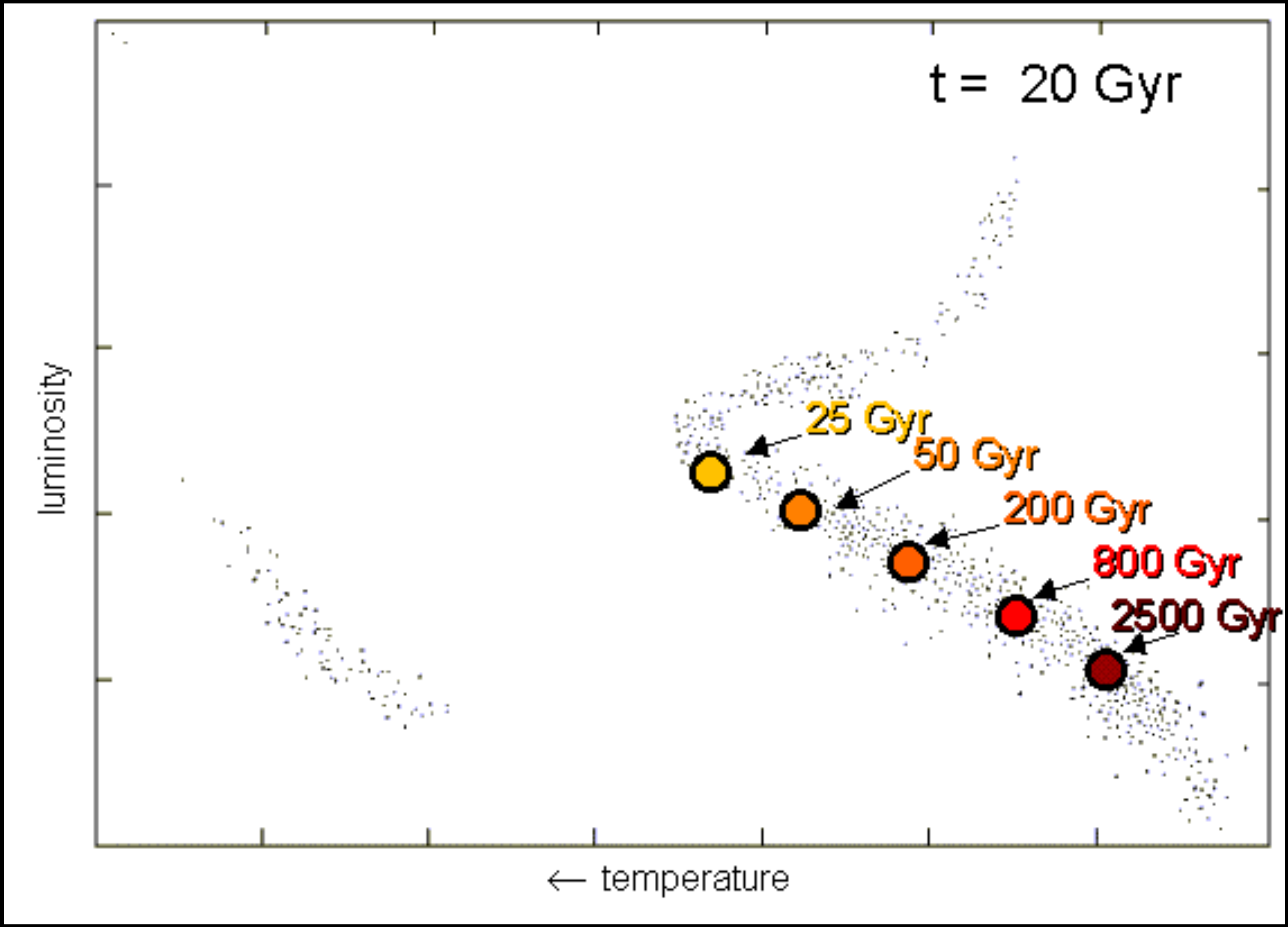
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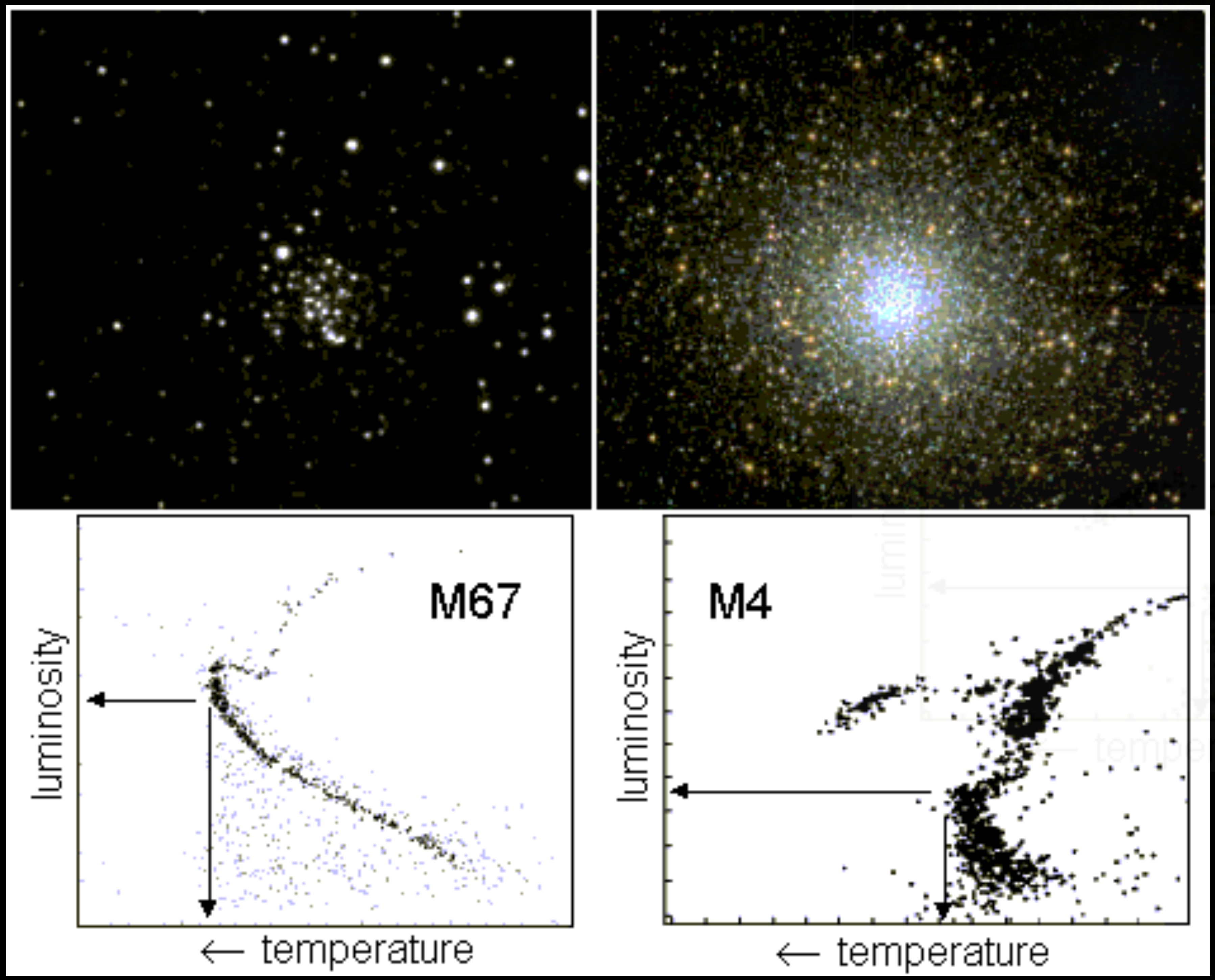
Clusters



Open Cluster

Globular Cluster

age, composition, distance

H-R diagram

- **More luminous stars are more massive.**
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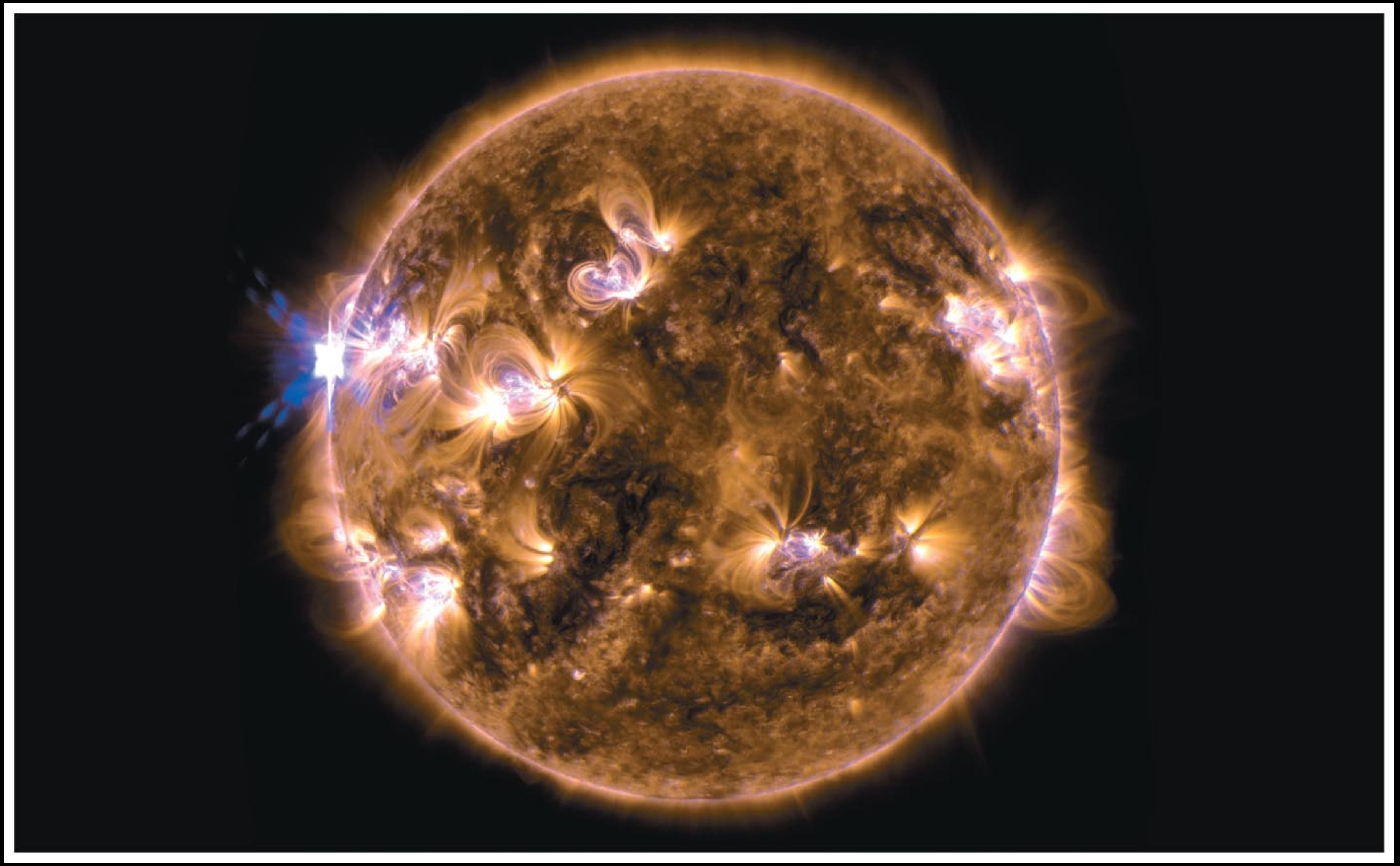
- **From bottom-left to up-right stars have larger radius**
- **HR diagram can give us information on the age of the system**

Questions

1. **Why don't stars have just any luminosity and temperature?**
2. **Why is there a distinct Main Sequence?**
3. **What makes on main-sequence star different from another?**
4. **Are giants, supergiants, and white dwarfs born that way, or is something else going on?**

Patterns on the H-R Diagram are telling us about the internal physics of stars.

Time Scale of stellar evolution



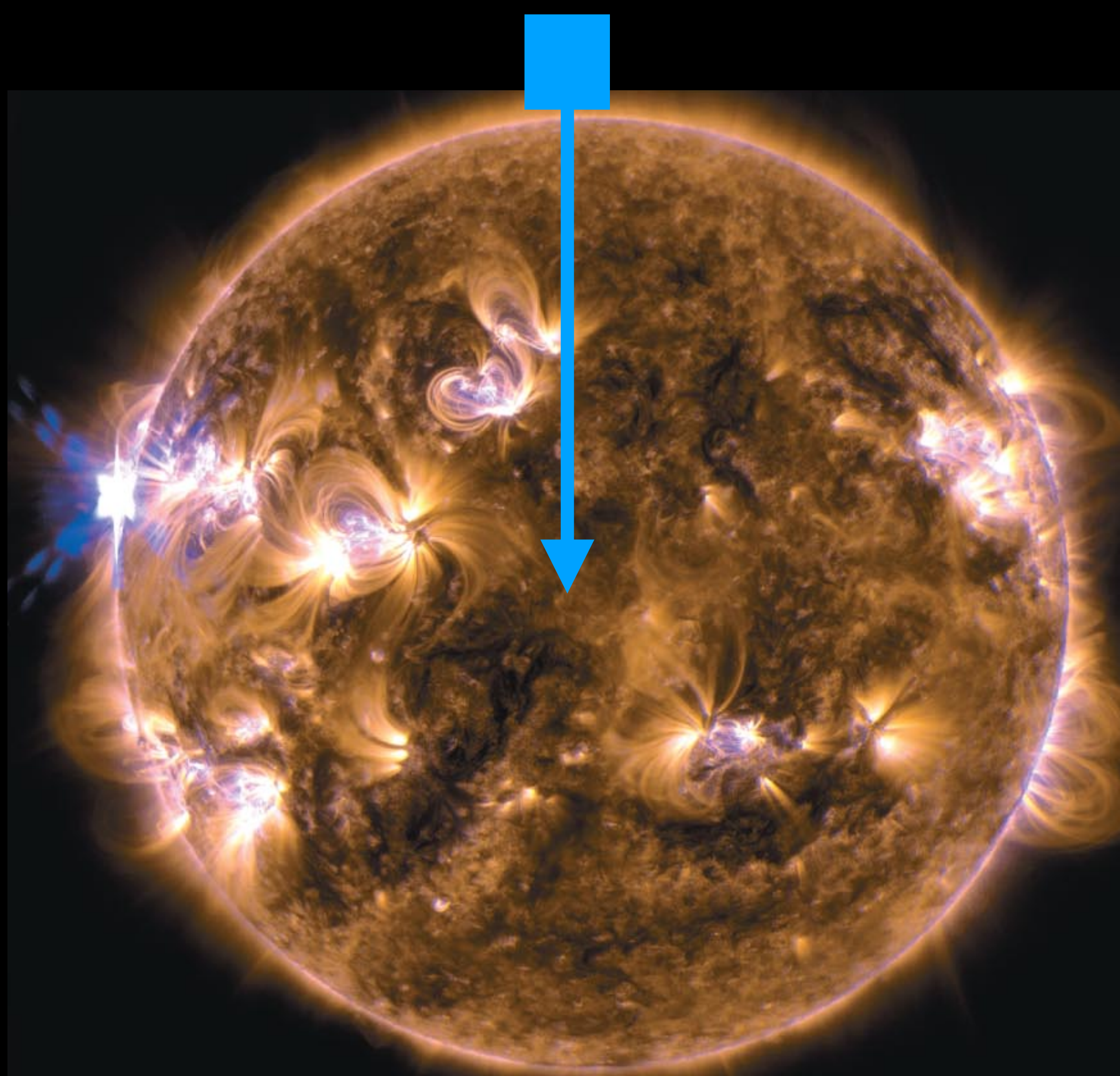
- The Sun is hot $\sim$ 5800 K

- The Sun is there since 4.6 billions year

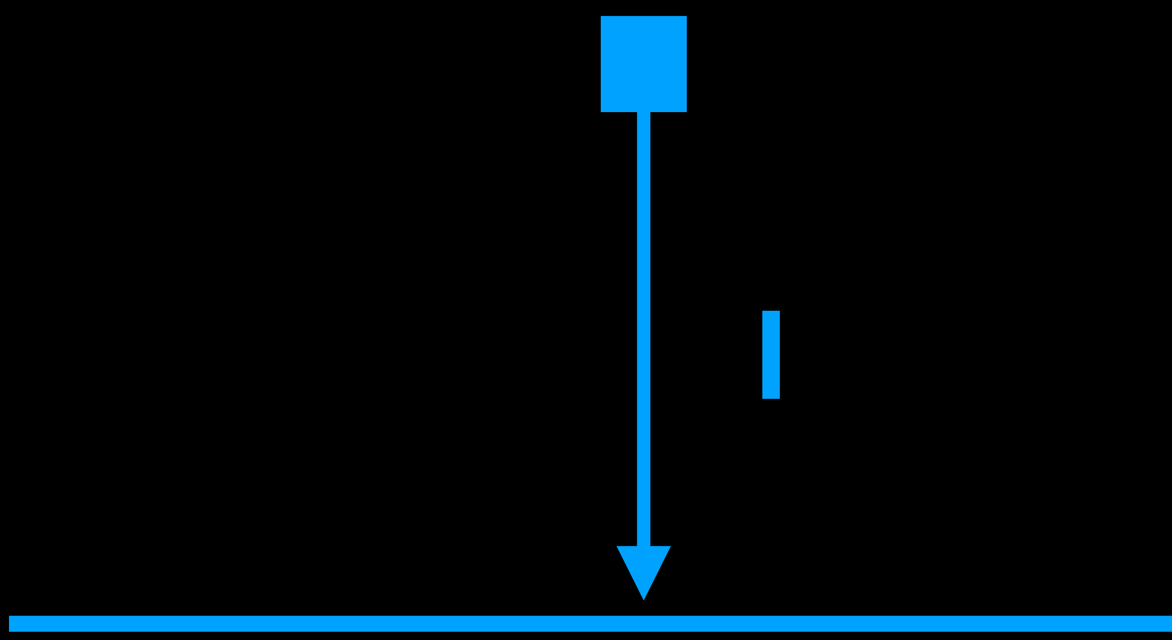
What is the time scale of the Sun evolution?

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):



what is the time of free-fall (from kinematic)?



t=?

Dynamical time scale

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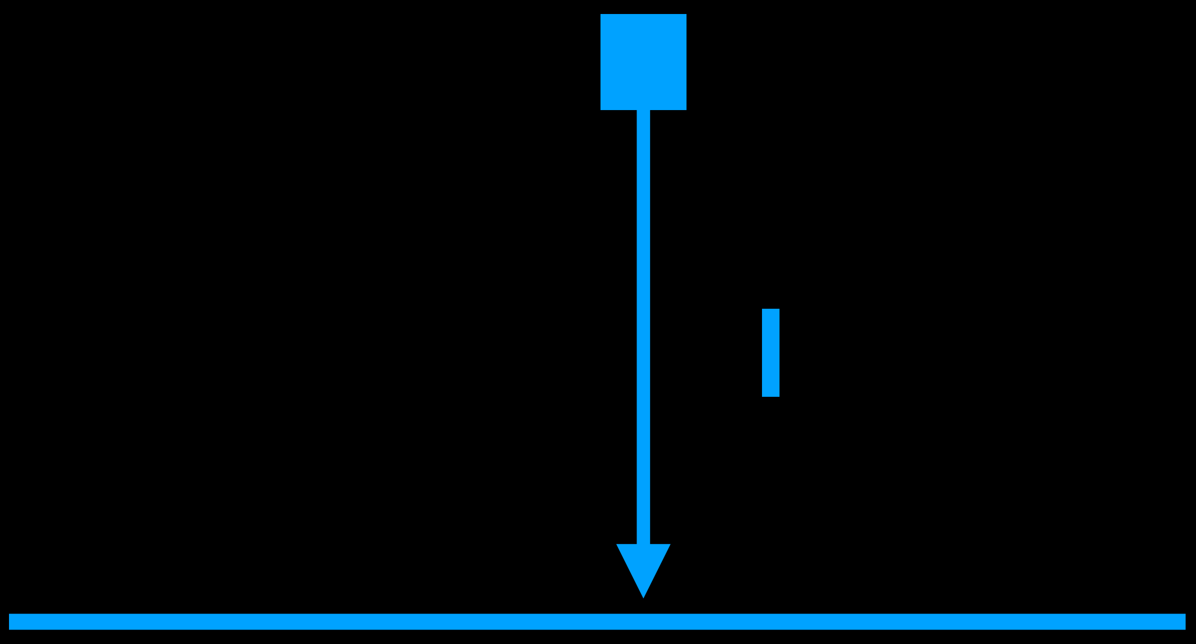
a = gs gravitational accelerations
v(t) = v0 + a t
x(t) = x0 + v0 t + 1/2 a t^2



$$t = \left(\frac{2l}{g_s}\right)^{1/2} = \left(\frac{2lR^2}{GM}\right)^{1/2}$$

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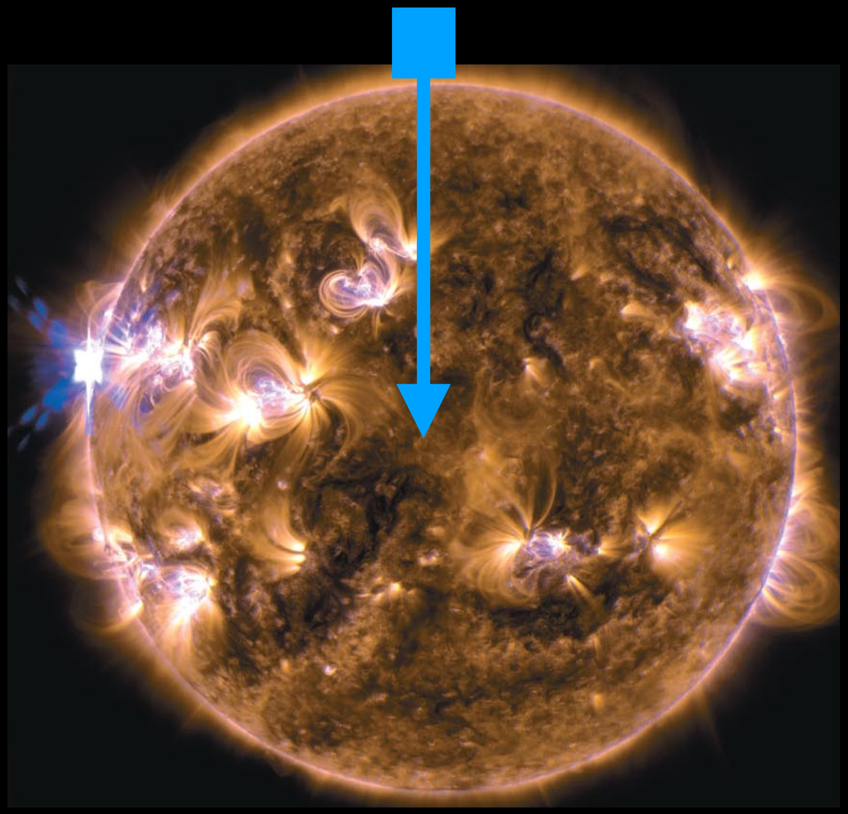

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$$t_{dyn} = \left(\frac{2R^3}{GM}\right)^{1/2} \approx 30\ minutes\ \left(\frac{R}{R_\odot}\right)^{3/2}\left(\frac{M}{M_\odot}\right)^{-1/2}$$

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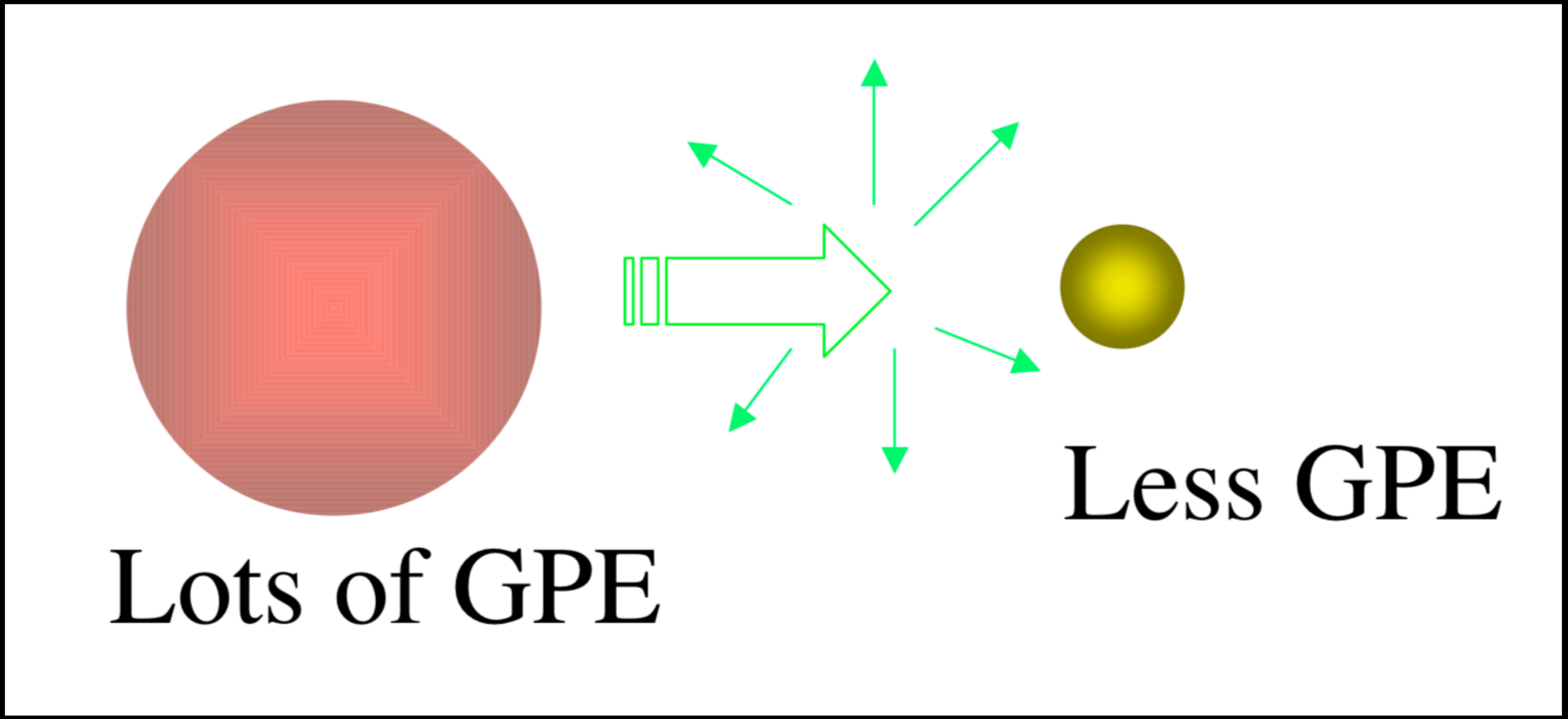
Stellar radii vary over a range from roughly 0.01 $R_\odot$ to roughly 1000 $R_\odot$, whereas the mass ranges from 0.1 $M_\odot$ to 100 $M_\odot$. Hence the dynamical timescale ranges from seconds to years.

Thermal time scale

If a star has no internal sources of energy, it can still radiate energy by contracting. In this way it gets gravitationally more tightly bound; its gravitational potential energy (GPE) decreases (i.e., becomes of larger negative magnitude), and the star has to get rid of the excess energy somehow



Thermal time scale

Suppose the Sun were not in equilibrium: there were no forces opposing gravitational collapse. In order for the collapse to proceed, the pressure supporting the Sun against collapse, provided by the hot gas, would have to be lost. As the gas radiates its energy away, pressure support would decrease, and the Sun would contract. But the release of gravitational potential energy would reheat the Sun (at a slightly smaller radius).

total gravitational energy $$GPE = \frac{-GMm}{r}$$

Luminosity of the Sun L

$$T_{KH} = \frac{GPE}{L} =$$

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~ 20-30 million years

Kelvin-Helmhotz Time Scale

Thermal time scale

Kelvin-Helmhotz Time Scale

- protostars to collapse to the main sequence
- main sequence stars to evolve into giants

Nuclear time scale

How long the sun can burn Hydrogen?

$$\frac{\text{Nuclear Energy}}{\text{Luminosity}}$$

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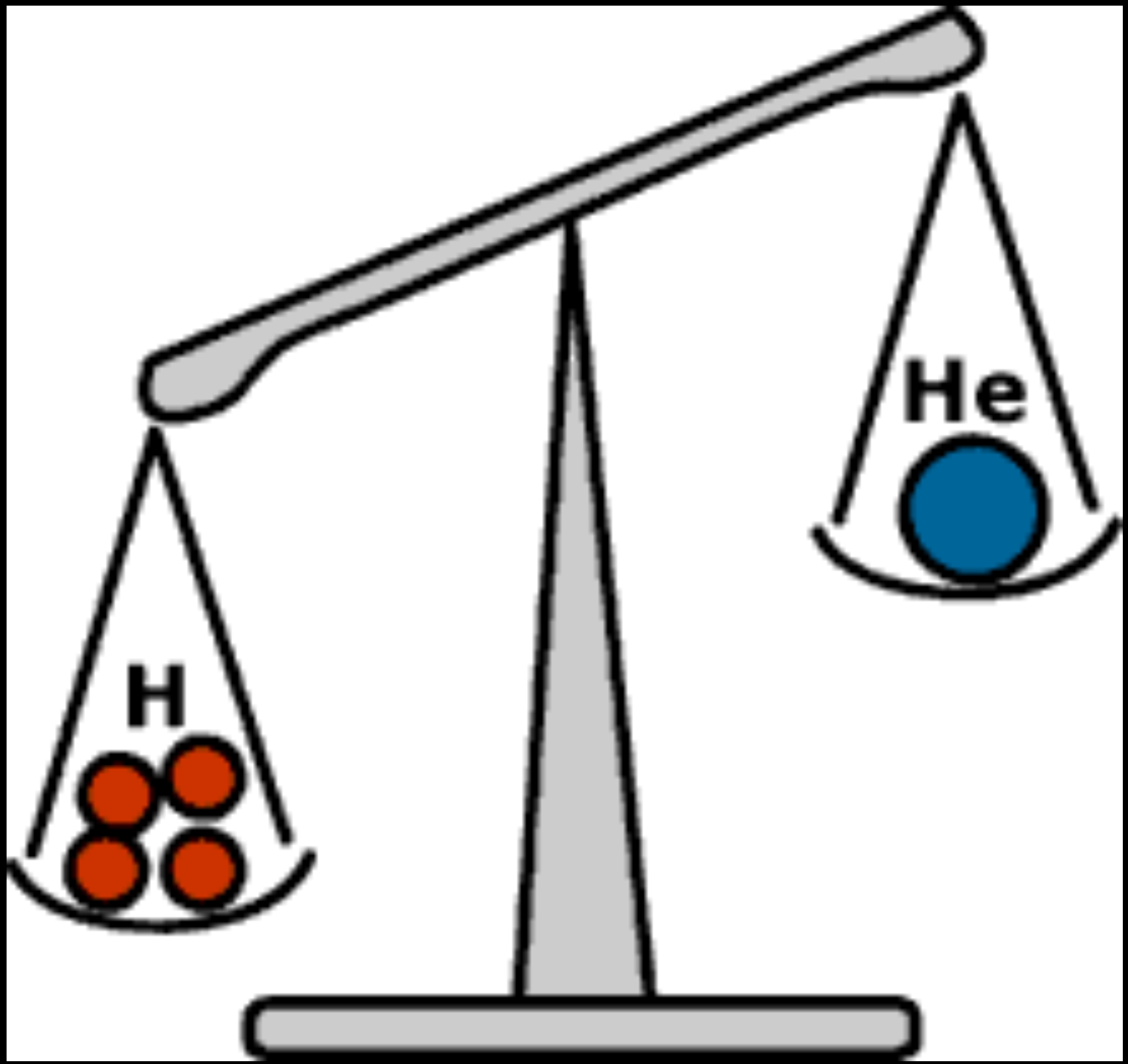
When we burn Hydrogen in Helium we are transforming their difference in mass in energy.



Nuclear time scale

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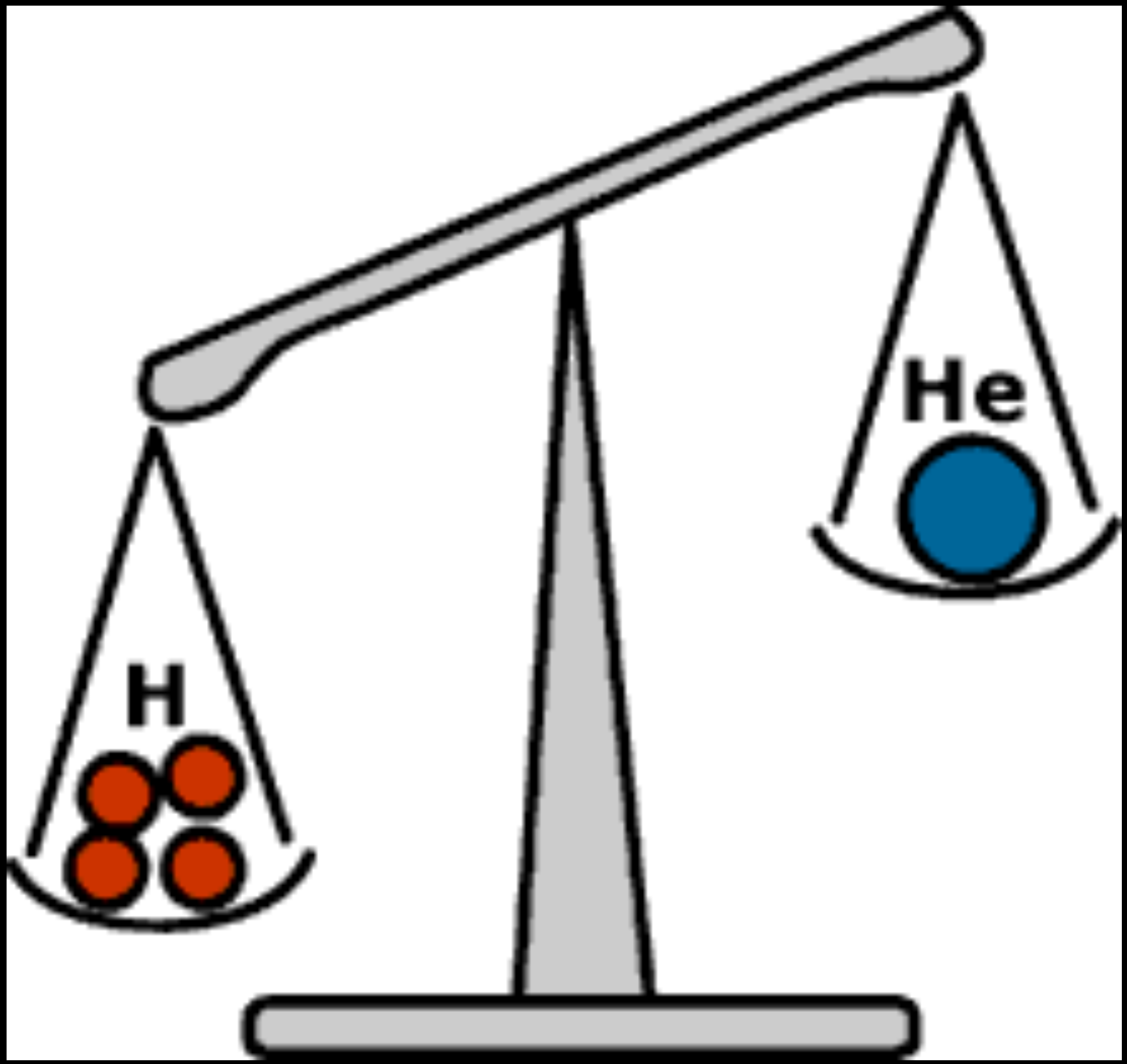
m = 0.02869 u
(where u is the atomic mass = 1.66053873 x 10-27 kg)



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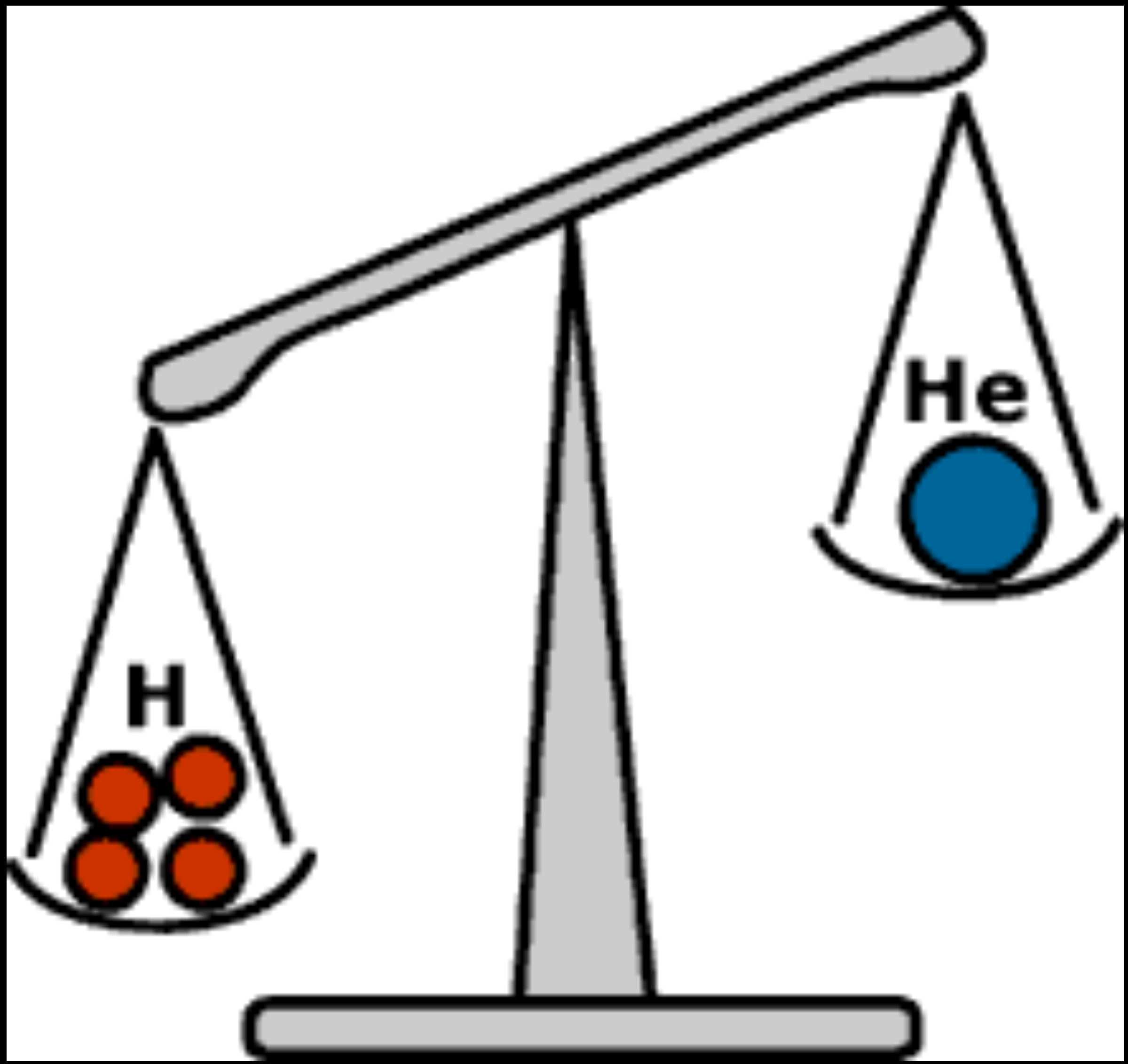

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Energy released is
mc^2 = 26.MeV

Nuclear time scale

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$$t_N = \frac{\Delta mc^2}{L_s} \times M_{\odot} X$$

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X is the fraction of hydrogen in the Sun (70%)

Nuclear time scale

How long the sun can burn Hydrogen?

$$t_N = \frac{\Delta mc^2}{L_s} \times M_{\odot} X = 10^{10} (\frac{M}{M_{\odot}})^2 (\frac{L}{L_{\odot}})^{-1}$$

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~ 10 billions years

Time Scale of stellar evolution

$$t_{dyn} < < t_{KH} < < t_N$$

Stars evolve at different time scales depending in which phase they are

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Stars evolve at different time scales depending in which phase they are

burning	nuclear time scale
contraction	KH time scale
explosions	dynamic time scale

Virial Theorem

For ideal gas

For relativistic particles

Virial Theorem

For ideal gas

$$\Omega = -2U_{tot} \qquad E = \Omega + U_{tot} = -U_{tot} = \frac{1}{2}\Omega$$

For relativistic particles

$$\Omega = -U_{tot} \qquad E = \Omega + U_{tot} = 0$$

Gravitational potential energy (Ω)

total internal energy (U_{tot})

Virial Theorem

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Gravitational potential energy

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- If the total energy is negative, the system is bound (the star is stable)
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For ideal gas

$$\boxed{L_G} = \frac{dE}{dt} = -\boxed{\frac{1}{2}\frac{d\Omega}{dt}}$$

- The amount of energy lost by radiation is equal to 1/2 of the gravitational potential energy

Virial Theorem

Whenever the star is in one of those phases in which does not produce energy with burning, the star contract releasing half of the gravitational energy in luminosity and using the other half to increase the internal energy and increasing the temperature. Every star alternate phases of contraction and heating with phases in which energy is provided by burning stages.

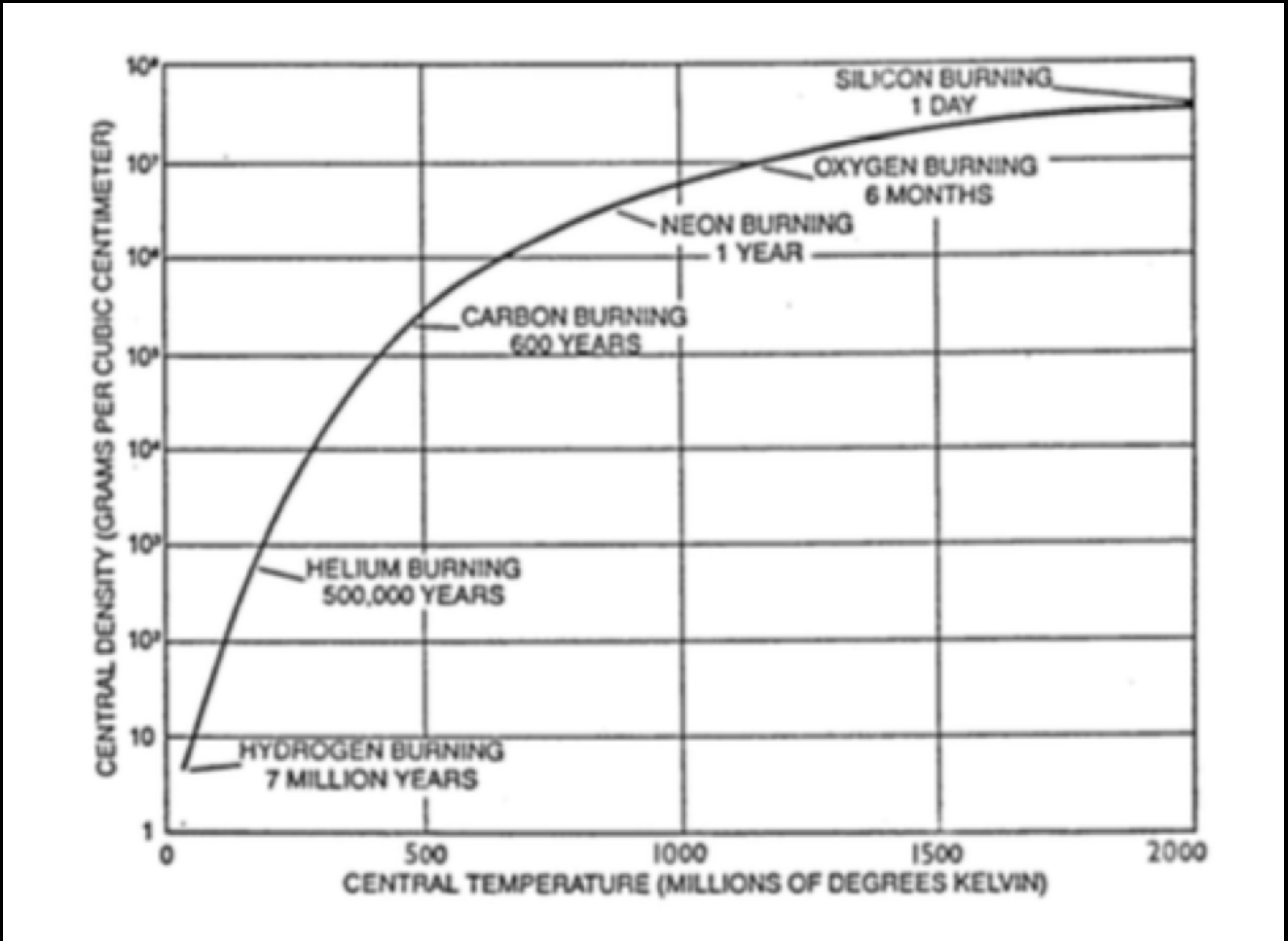
For ideal gas

$$\boxed{L_G} = \frac{dE}{dt} = -\boxed{\frac{1}{2}\frac{d\Omega}{dt}}$$

- **The amount of energy lost by radiation is equal to 1/2 of the gravitational potential energy**

Virial Theorem

The star contract while not producing enough energy with nuclear burning. Temperature increase and start to burn a different element.



Burning Stages

Burning Stages in High-Mass Stars

Core Burning Stage	9 $M_{\odot}$ Star	25 $M_{\odot}$ Star	Typical Core Temperatures
H burning	20 million years	7 million years	$(3–10) \times 10^7$ K
He burning	2 million years	700,000 years	$(1–7.5) \times 10^8$ K
C burning	380 years	160 years	$(0.8–1.4) \times 10^9$ K
Ne burning	1.1 years	1 year	$(1.4–1.7) \times 10^9$ K
O burning	8 months	6 months	$(1.8–2.8) \times 10^9$ K
Si burning	4 days	1 day	$(2.8–4) \times 10^9$ K

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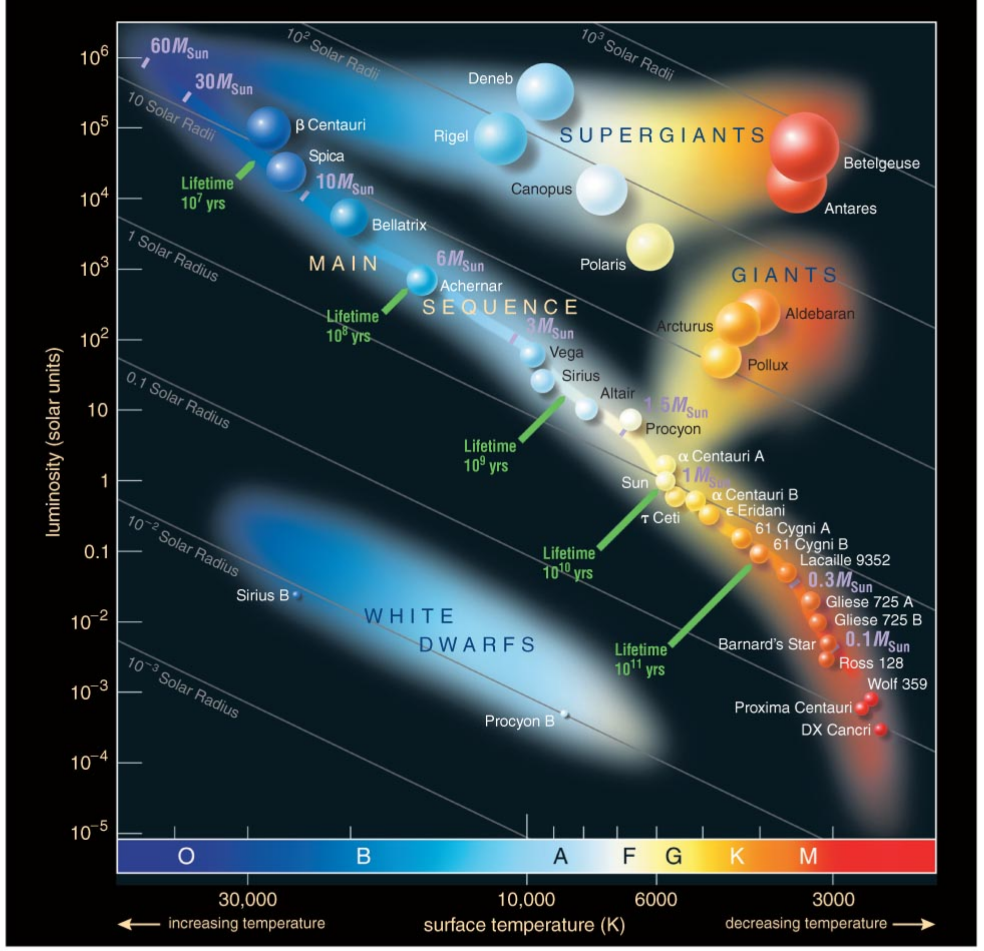

if you have a cluster of stars of 25 solar masses how many stars burning Silicum we will see compared to the stars that burn Hydrogen?

$$\frac{N(Si)}{N(H)} = ?$$

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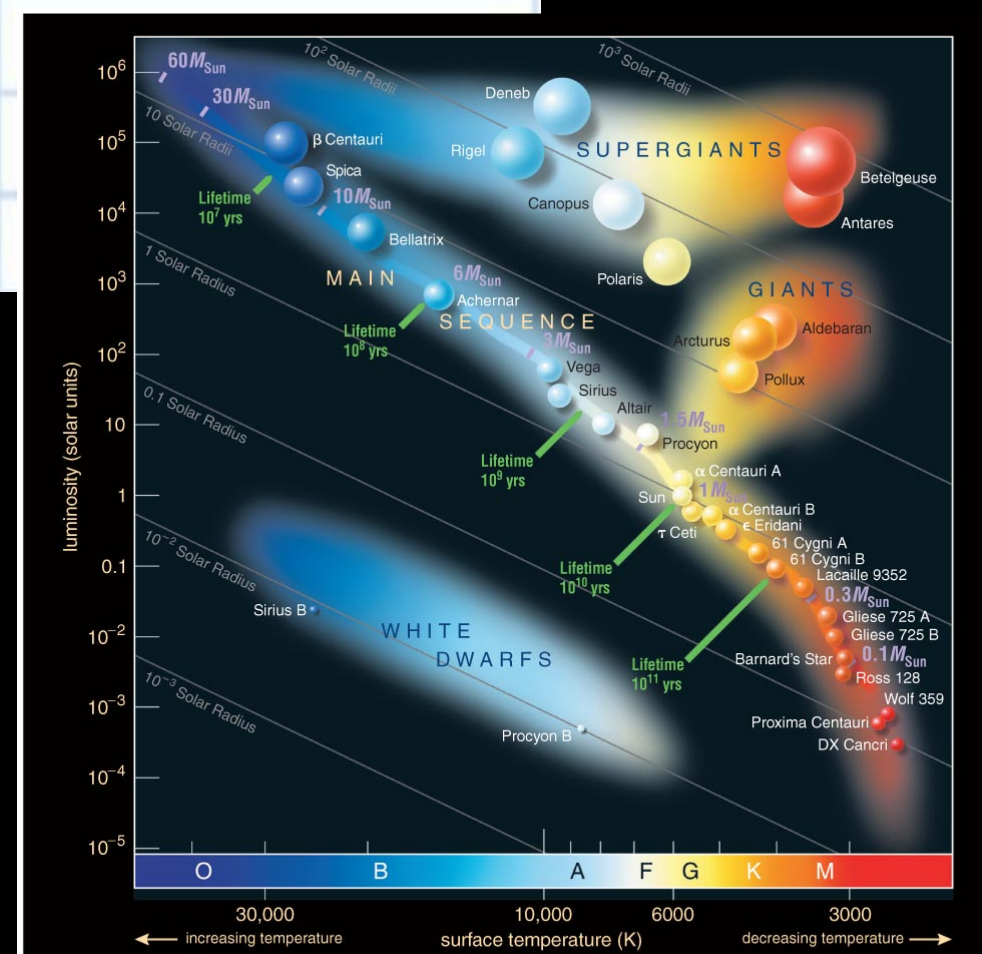

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$$\frac{N(Si)}{N(H)} = \frac{1}{2.555x10^{12}}$$