Summary: Physical Properties of Stars

Photospheric ("Surface") Temperatures

3,000°K (Red M stars) **to 40,000°K** (Blue-White O stars)

Luminosities

Main Sequence: $L_{M5V} \approx 10^{-2} L_{Sun}$ **to** $L_{O5V} \approx 10^{+6} L_{Sun}$

Also red supergiants at $10^{+5} L_{Sun}$ to white dwarfs at $10^{-4} L_{Sun}$.

Stellar Radii

Main Sequence: $R \approx 0.3$ to $18\ R_{Sun}$ (M5V to O5V)

Giants & Supergiants: $R \approx 1{,}000$ to $18\ R_{Sun}$ (M5V to O5V)

White Dwarfs, Neutron Stars: $R_{wd} \approx 10^{-2} R_{Sun}$ & $R_{ns} \approx 10^{-5} R_{Sun}$

Stellar Masses

$M \approx 0.1\ M_{Sun}$ **to** $M \approx 30\ M_{Sun}$

Also white dwarfs at 0.6 to 1.2 M_{Sun}

The Mass-Luminosity Relation for main sequence stars:

$$L_{Star}/L_{Sun} \approx [M_{Star}/M_{Sun}]^{3.5}$$

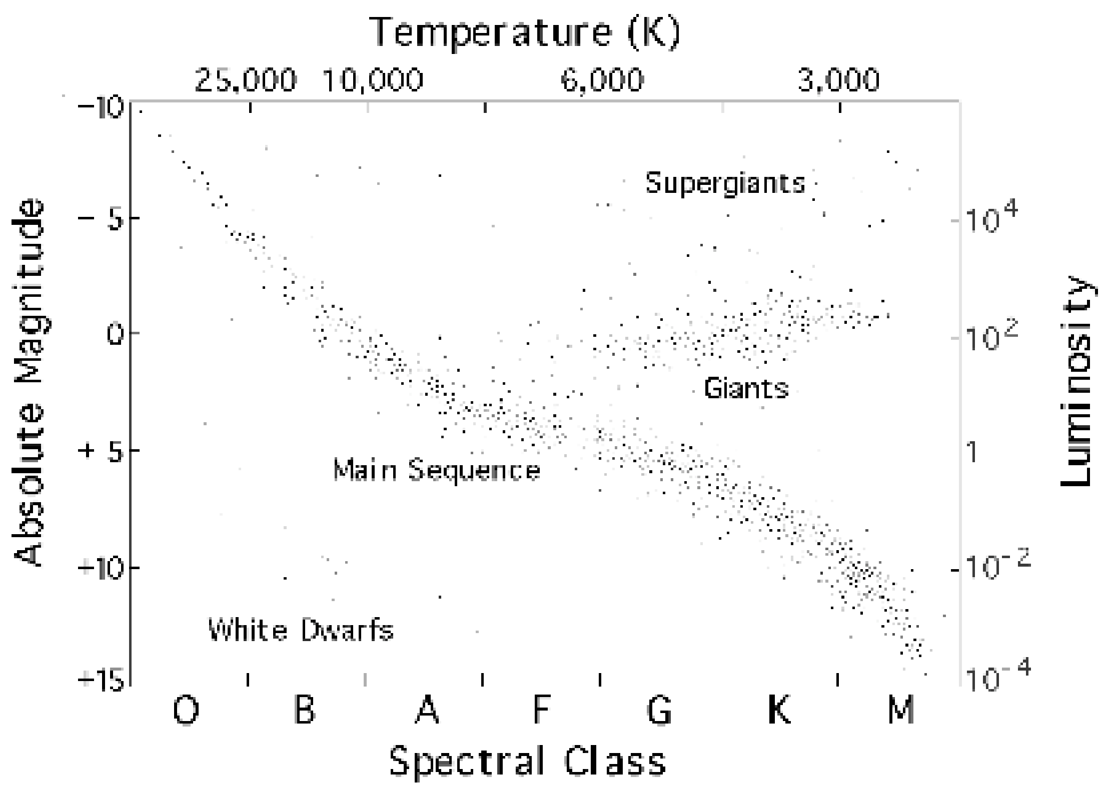
Some Empirical Relationships Among Stellar Properties

Surface Temperature - Spectral Type - Star Color

(4,000°K to 3,000°K) (OBAFGKM) (Blue to Red)

Surface Temperature - Luminosity - Radius

(The Hertzsprung Russell Diagram)



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What Makes the Stars Shine?

Estimating Stellar Lifetimes

<u>**Assumptions**</u>

1. All stars "run" on the same basic process.
... whatever that may be.
(The "efficiency" is the same for all stars)

2. A star's fuel reserves are contained within the star
... and proportional to the star's <u>initial</u> mass.
(Stars are not "refueled" from external sources.)

3. A star's energy production rate is given by its luminosity
... with no other sources of energy loss.
(The luminous output is the only energy output.)

Remember, these <u>are</u> assumptions.............

Estimating Stellar Lifetimes

Then stellar lifetimes τ_{star} are proportional to M_{star}/L_{star} or

$\tau_{star}/\tau_{Sun} = M_{star}/L_{star}$ **(solar units)**

It is observed that, <u>for main sequence stars</u>

$L_{star} = M_{star}^{3.5}$ **(solar units)**

(This is the "Mass-Luminosity Relation")

So that

$\tau_{star}/\tau_{Sun} = M_{star}^{-2.5}$ **(solar units)**

Implications:

<u>Low-mass stars are long-lived, high-mass stars short-lived.</u>

Examples:

$M_{star} = 10\ M_{Sun}$ gives $\tau_{star} = 0.003\ \tau_{Sun}$

$M_{star} = 0.1\ M_{Sun}$ gives $\tau_{star} = 0.316\ \tau_{Sun}$

But what is τ_{Sun}?

What Makes the Stars Shine?
Consider the Sun:

Estimating the Energy Production Requirement

The Sun's Luminosity is L_{Sun} = 3.8 x 10^{26} watts

The Sun's Lifetime is τ_{Sun} > 1.4 x 10^{17} seconds
(i.e., at least 4.5 Billion Years)

The energy produced is $E_{Sun} = L_{Sun}\tau_{Sun}$ > 5.5 x 10^{43} joules
(at least 1.5 x 10^{37} kilowatt-hours)

Question:

What processes might be able to produce at least this amount of energy from, at most
1 M_{Sun} = 2 x 10^{30} kilograms
of fuel?

What Makes the Sun Shine?

POSSIBILITIES

Residual Heat? $\tau_{Sun} \approx MTc_v/L$ τ_{Sun} ~ 20,000 yr
(c_v = Specific heat, T = Temperature) **...but....**

Chemical Reactions? $\tau_{Sun} \approx M\varepsilon_C/L$ τ_{Sun} ~ 5,000 yr
(ε_C = Specific energy production rate; Assume H + F → HF) **...but...**

Gravitational Energy? $\tau_{Sun} \approx GM/RL$ τ_{Sun} ~ 5 x 10^7 yr
(G = Gravity Constant; Assume contraction to radius R.) **...but...**

Nuclear Fission? $\tau_{Sun} \approx M\varepsilon_U/L$ τ_{Sun} ~ 1 x 10^{10} yr
(ε_U = Specific energy production rate; Assume U→ Pb.) **...but...**

but finally

Nuclear Fusion $\tau_{Sun} \approx M\varepsilon_N/L$ τ_{Sun} ~ 1 x 10^{11} yr
(ε_N = Specific energy production rate; Assume 4H→ He.)

Fusion: Historical Motivation

Einstein's Theory of Relativity ($E = Mc^2$)
Atomic Masses (H &He), the Solar Composition (H & He)

Nuclear Reactions

Nomenclature

Atomic Number (Z)→ $_{6}C^{12}$ ←Atomic Weight (A)
Chemical Symbol ↑ (C for Carbon)

Atomic Number = Number of Protons(+)
(Identifies the <u>element</u>: 6 → "Carbon")
Atomic Weight = Number of Protons (+) plus Neutrons (o)
(Identifies the <u>isotope</u>: "Carbon-12")

<u>Nuclear Reaction Examples</u>

Nuclear Fusion: $_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{92}U^{236}$

neutron ↑

Nuclear Fission: $_{92}U^{236} \rightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + {}_{0}n^{1} + {}_{0}n^{1} + \gamma$

gamma ray ↑

The Simplest Fusion Reaction:

$_{1}H^{1} + {}_{1}H^{1} \rightarrow {}_{1}H^{2} + e^{+} + \nu$ ←a "neutrino"

"deuterium" ↑ ↑a "positron"

also Matter-Antimatter Annihilation:

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

electron↑ ↑positron