



# Universidad Nacional de Río Negro

## Int. Partículas, Astrofísica & Cosmología - 2017

- **Unidad** 02 – Astrofísica
- **Clase** UO2 C04 – 10
- **Fecha** 12 Oct 2017
- **Cont** Estrellas 2
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# Contenidos: un viaje en el tiempo

## HOW DID OUR UNIVERSE BEGIN?

Some 13.8 billion years ago our entire visible universe was contained in an unimaginably hot, dense point, a billion times the size of a nuclear particle. Since then it has expanded—a lot—fighting gravity all the way.

**Inflation**  
The universe expands, cools a repulsive energy field inflates space faster than light fills it with a soup of subatomic particles called quarks.

**Age:**  $10^{-3}$  milliseconds  
**Size:** Infinitesimal to golf ball

**Early building blocks**  
Quarks clump into protons and neutrons, creating blocks of atomic nuclei. Perhaps dark matter forms.

**Age:** .01 milliseconds  
**Size:** 0.1-millionth present size

**First nuclei**  
As the universe continues to cool, the lightest nuclei of hydrogen and helium arise. A thick fog of particles blocks all light.

**Age:** .01 to 200 seconds  
**Size:** 1-billionth present size

**First atoms, first light**  
As electrons begin orbiting nuclei, creating atoms, the glow from their infalling orbits is unveiled. This light is as far back as our instruments can see.

**Age:** 380,000 years  
**Size:** .0009 to 0.1 present size

**The “dark ages”**  
For 300 million years this collection of gas and dust is the only light. Clumps of matter that will become galaxies glow brightest.

**Age:** 380,000 to 300 million years  
**Size:** .0009 to 0.1 present size

**Gravity wins: first stars**  
Dense gas clouds collapse under their own gravity. Puffs of dark matter eventually form galaxies and stars. Star fusion lights up the stars.

**Age:** 300 million years  
**Size:** 0.1 present size

**Antigravity wins**  
After being slowed for billions of years, gravity, cosmic expansion accelerates again. The culprit: dark energy. Its nature: unclear.

**Age:** 10 billion years  
**Size:** .77 present size

**Today**  
The universe continues to expand, becoming ever less dense. As a result, fewer new stars and galaxies are forming.

**Age:** 13.8 billion years  
**Size:** Present size

## COSMIC QUESTIONS

In the 20th century the universe became a story—a scientific one. It had always been seen as static and eternal. Then astronomers observed other galaxies flying away from ours, and Einstein's general relativity theory implied space itself was expanding—which meant the universe had once been denser. What had seemed eternal now had a beginning and an end. But what beginning? What end? Those questions are still open.

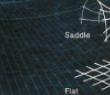
## WHAT IS OUR UNIVERSE MADE OF?

Stars, dust, and gas—the stuff we can discern—make up less than 5 percent of the universe. Their gravity can't account for how galaxies hold together. Scientists figure about 23 percent of the universe is a mysterious dark matter—perhaps exotic particles formed right after inflation. The rest is dark energy, an unknown energy field or property of space that counters gravity, providing an explanation for observations that the expansion of space is accelerating.



## WHAT IS THE SHAPE OF OUR UNIVERSE?

Einstein discovered that a star's gravity curves space around it. But is the whole universe curved? Might space close up on itself like a sphere or curve the other way, opening out like a saddle? By studying cosmic background radiation, scientists have found that the universe is poised between the two: just dense enough with just enough gravity to be almost perfectly flat, at least the part we can see. What lies beyond we can't know.



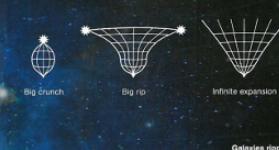
## Unidad 2 Astrofísica Cálido y frío

### DO WE LIVE IN A MULTIVERSE?

What came before the big bang? Maybe other big bangs. The uncertainty principle holds that even the vacuum of space has quantum energy fluctuations. Inflation theory suggests universes exploded from such a fluctuation—a random event that, odds are, had happened many times before. Our cosmos may be one in a sea of others just like ours—or nothing like ours. These other cosmos will very likely remain forever inaccessible to observation; their possibilities limited only by our imagination.

## HOW WILL IT END?

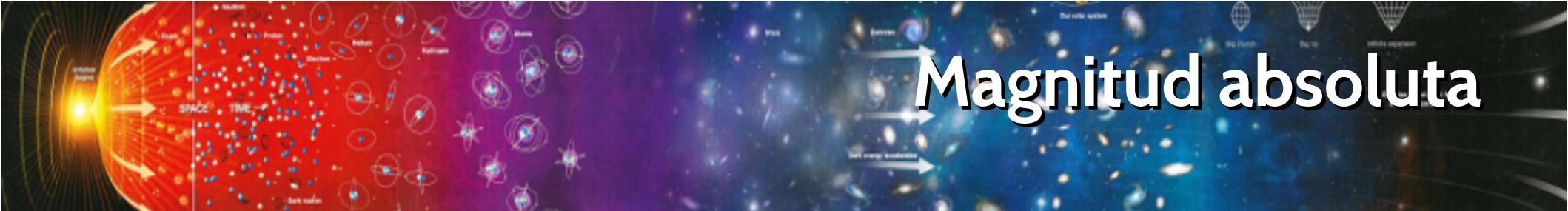
Which will win in the end, gravity or antigravity? Is the density of matter enough for gravity to halt or even reverse cosmic expansion, leading to a big crunch? It seems unlikely—especially given the power of dark energy, a kind of antigravity. Perhaps the acceleration in expansion caused by dark energy will trigger a big rip that shreds everything, from galaxies to atoms. If not, the universe may expand for hundreds of billions of years, long after all stars have died.



## Unidad 1 Partículas 1 todo es relativo



Fly through the universe on our digital edition.  
LONDON PHOTOS: ANDREW STONE; FERNE GOLDBECK; ART: WOZNIAK/INTERACT DESIGN SOURCE: CHARLES BENNETT, JOHN HESKETH, AND JEFFREY KATZ, NIST; DAVID TURNER, UNIVERSITY OF CHICAGO; COURTESY OF THE NATIONAL GEOGRAPHIC SOCIETY



# Magnitud absoluta

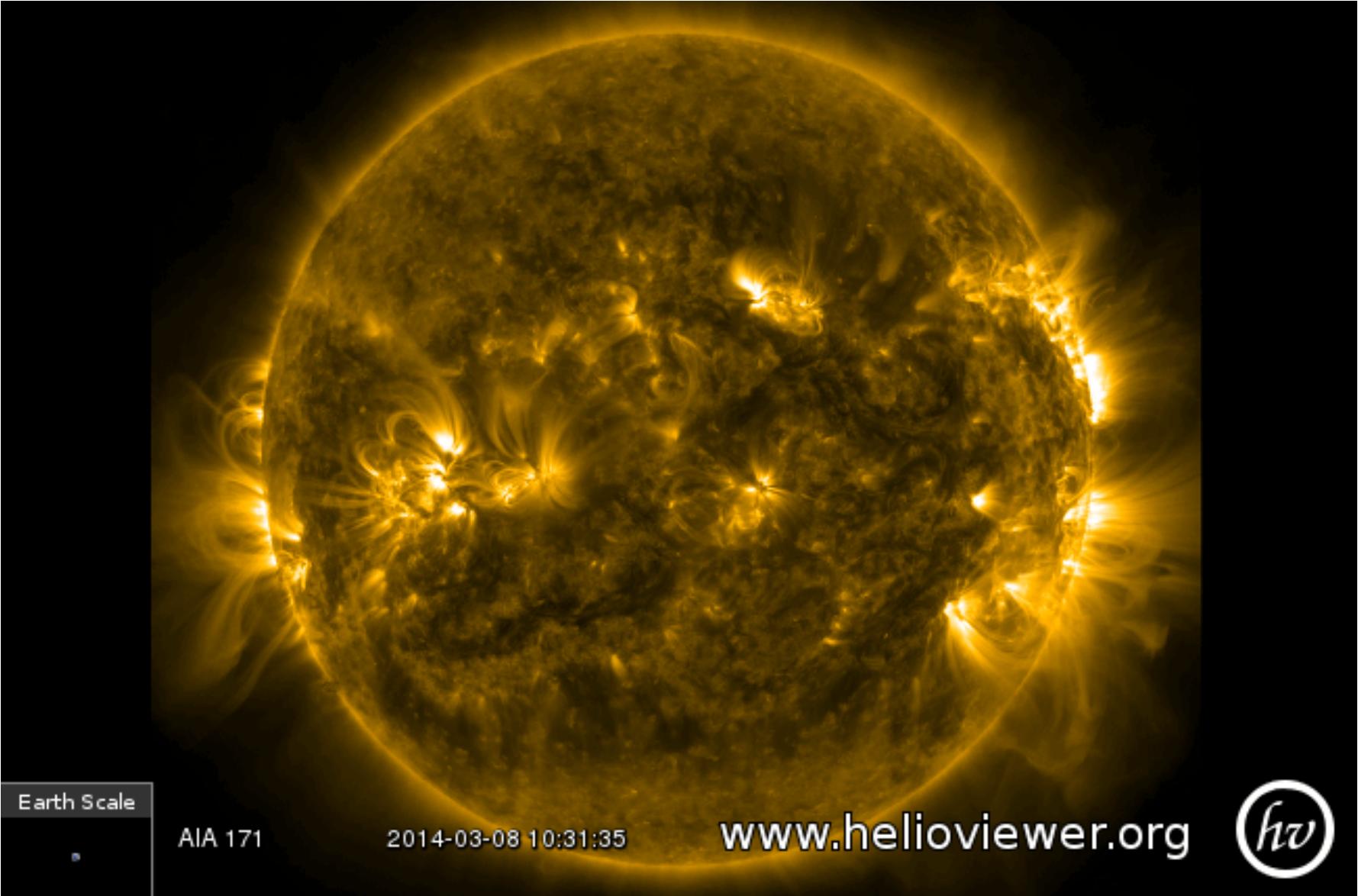
- **Magnitud absoluta  $M$ , es la magnitud aparente que tendría una estrella si su distancia fuera de 10pc**

- Relación con la magnitud aparente  $m$  y la distancia  $d$ : (medida en parsecs):

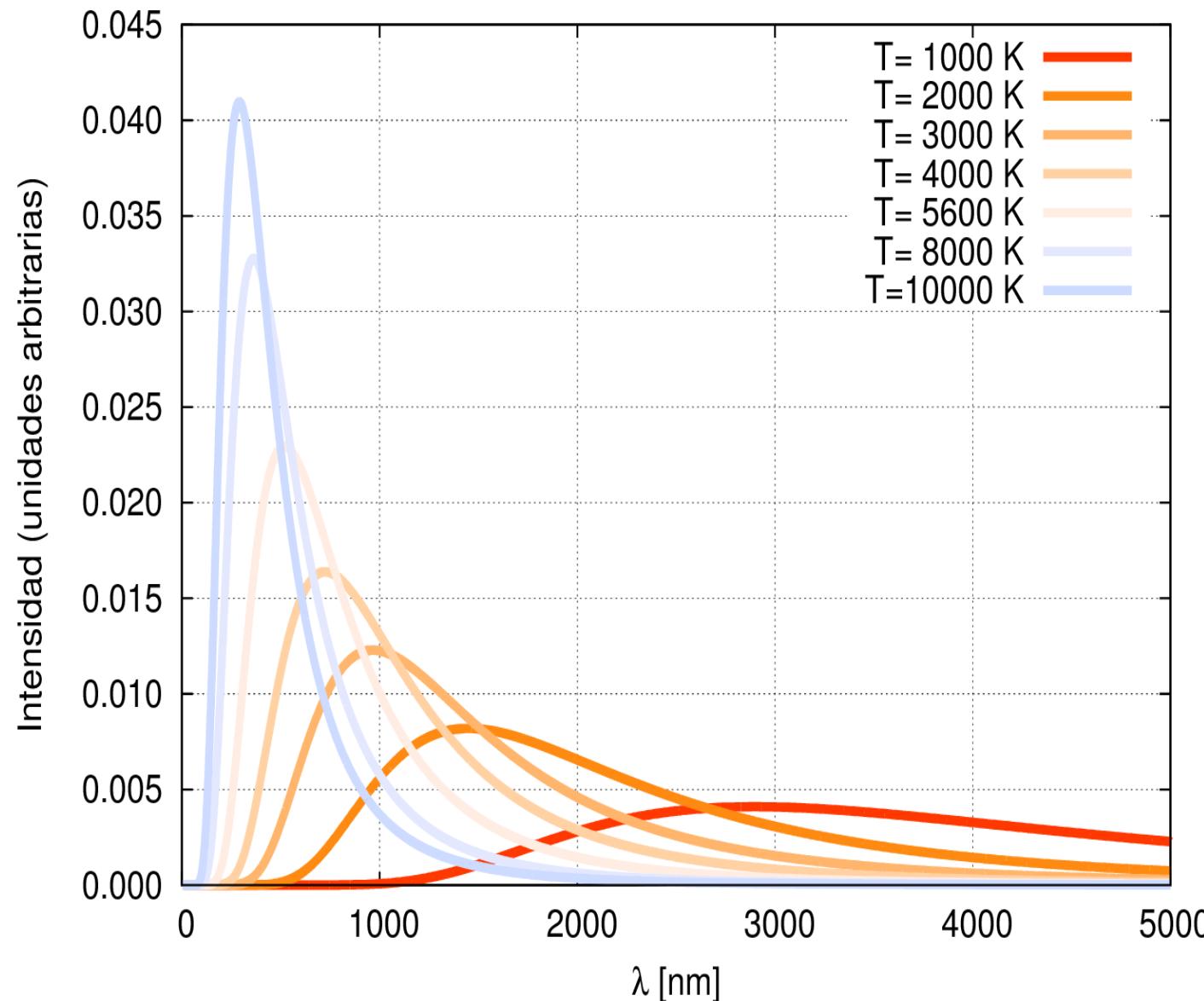
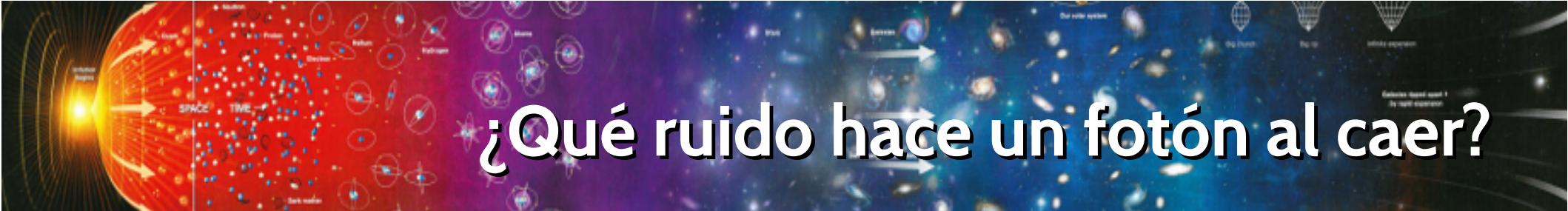
$$M = m - 5(\log_{10}(d) - 1)$$

- P.ej.: Si  $d=10$  pc,  $M = m - 5 [1-1] = m - 5(0) = m$
- Magnitudes absolutas y aparentes:
  - Sol:  $m=-26.73$ ,  $M=4.75$
  - Mintaka ( $\delta$ Ori):  $m=2.4$ ,  $M=-4.84$
  - Sirio (aCMa):  $m=-1.45$ ,  $M=1.44$

# Mirando en otras longitudes de onda



# ¿Qué ruido hace un fotón al caer?



- Ley de Wien
  - Posición de  $\lambda_{\max}$

$$\lambda_{\max} = \frac{b}{T}$$

$$b = 2.9 \text{ mm K}$$

- Ley de Stefan-Boltzmann

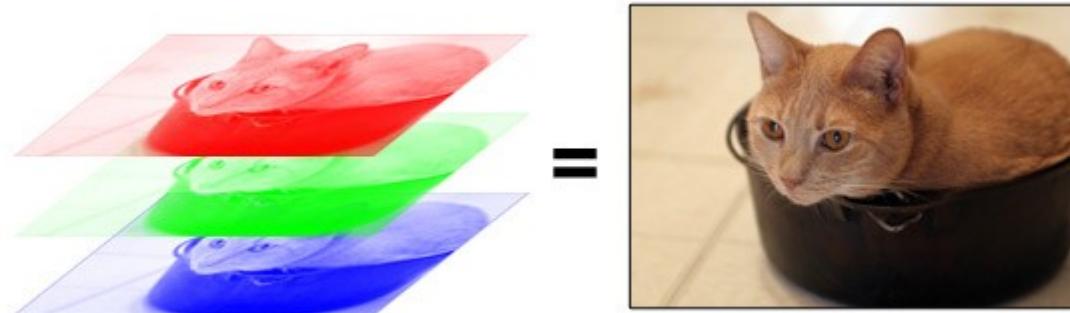
$$L \equiv \frac{\Delta E}{\Delta t} = \sigma A T^4$$

$$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$



“Color” → Temperatura

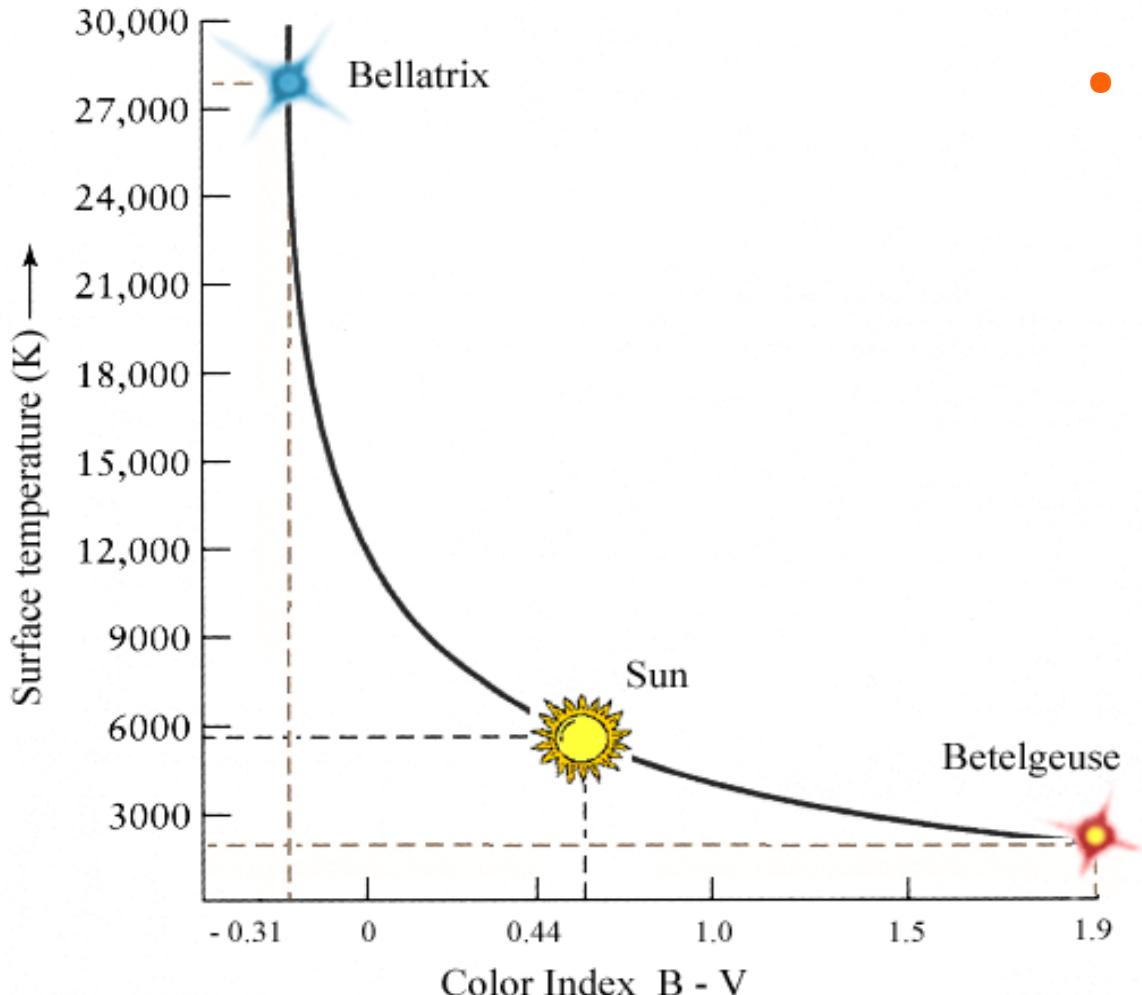
- ¿Cómo cuantificar el color?



Para las estrellas → magnitudes



# Se observa que para estrellas, $B-V \rightarrow T$



- Índice  $B-V$

- $m_B$ =magnitud en el canal B
- $m_V$ =magnitud en el canal V

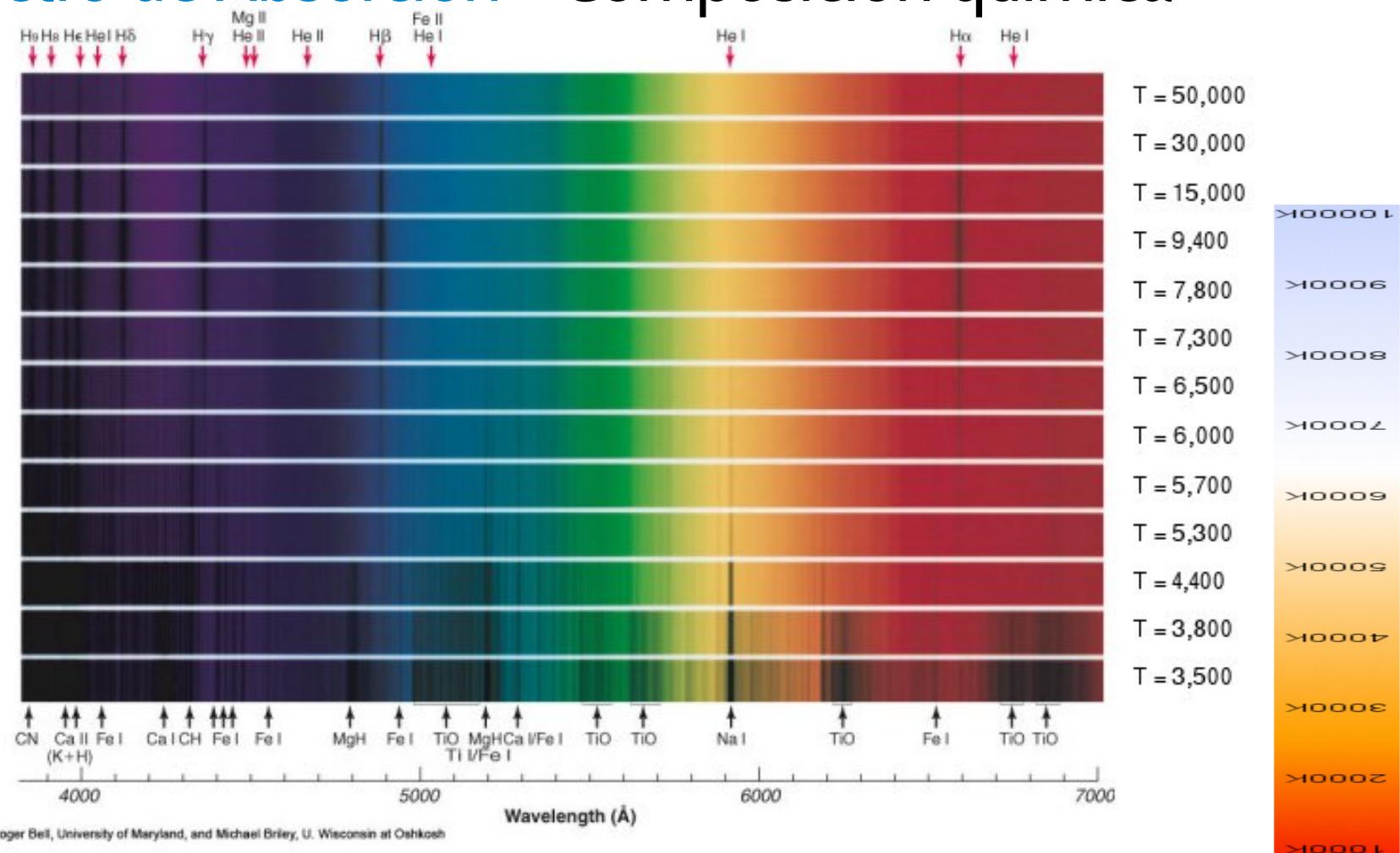
$$(B-V) = m_B - m_V$$

(Recordar que m es logarítmica)

$$T = 4600 \left( \frac{1}{0.92(B-V)+1.7} + \frac{1}{0.92(B-V)+0.62} \right) K$$

# Espectros estelares

- Emisión continua → Cuerpo Negro → Color → Temp.
- Espectro de Absorción → Composición química





# ¡Podemos clasificarlas!

- La “lógica”: A B C... por temperatura superficial



# ¡Podemos clasificarlas!

- A B C... por temperatura superficial

O B A F G K M R N S

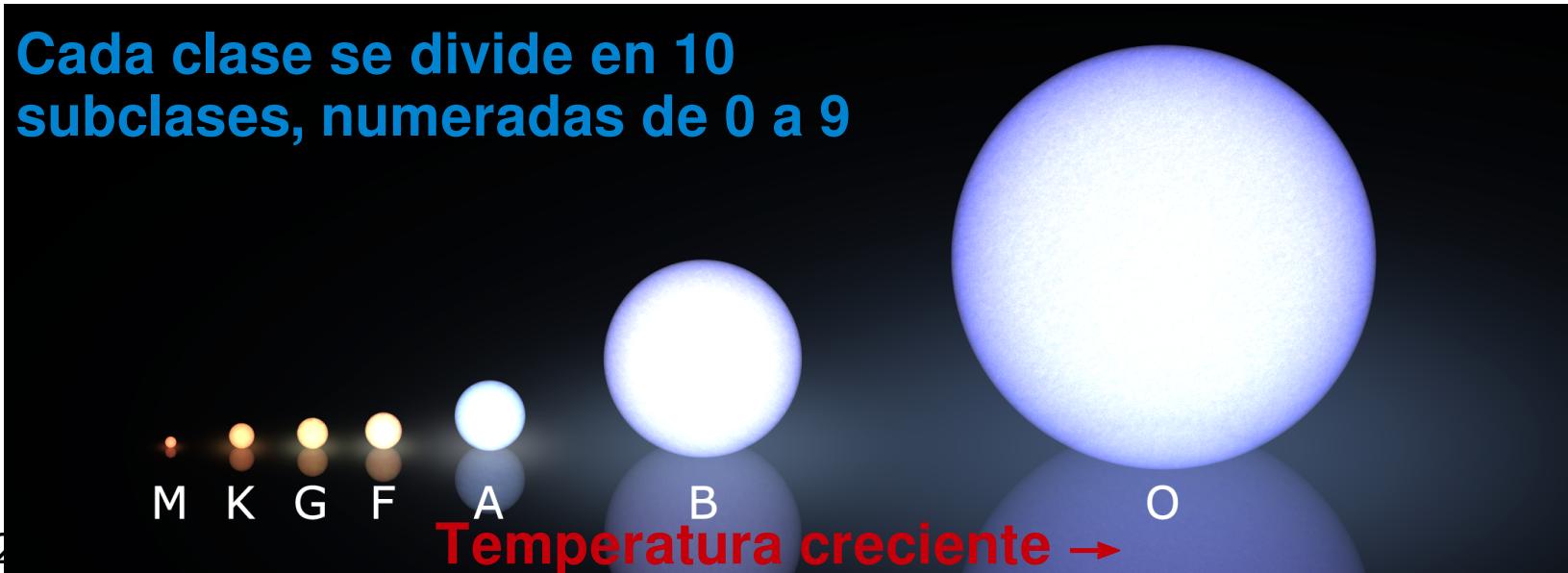
# ¡Podemos clasificarlas!

- A B C... por temperatura superficial

O B A F G K M R N S

- Oh Be A Fine Girl and Kiss Me Right Now Sweet
- Oh Besame Amor, Fasinadora Gitana, Kilómetros Median Rompiendo Nuestros Sueños

Cada clase se divide en 10 subclases, numeradas de 0 a 9

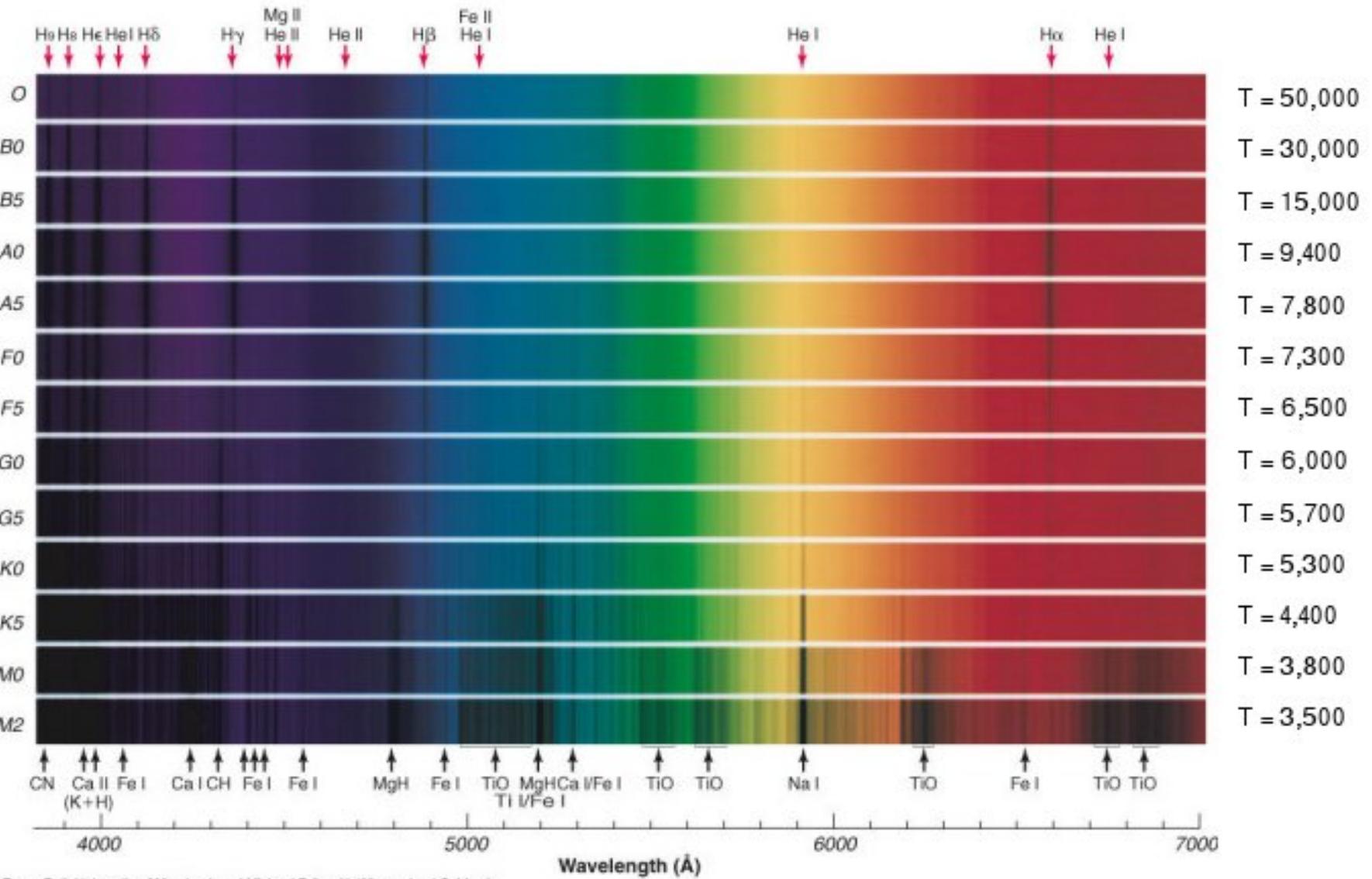




Para decirle a un ser amado

Oh Besame Amor,  
Fasinadora Gitana,  
Kilómetros Median  
Rompiendo Nuestros  
Sueños

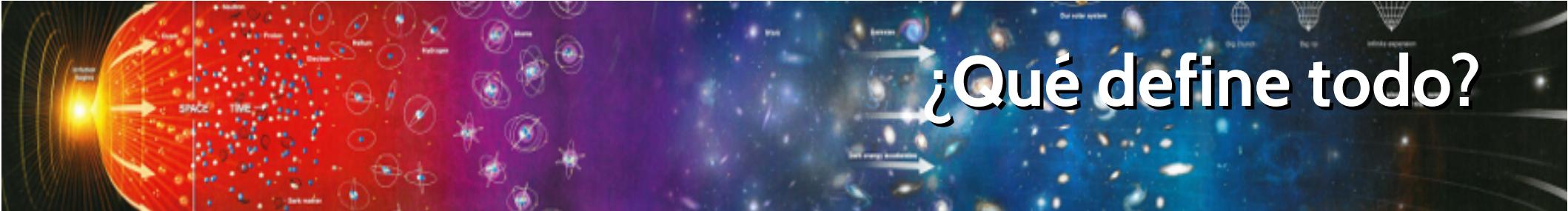
# Clasificación espectral



Roger Bell, University of Maryland, and Michael Briley, U. Wisconsin at Oshkosh

# Algunos ejemplos

Todo expresado en unidades solares (Radio, Masa, Luminosidad)			
O Azul; T > 33000 K	M > 16; R > 7; L > 30000	Mintaka (d-Ori)	
B Blanco Azulado; 10000 < T < 30000 K	2 < M < 16; 2 < R < 7; 25 < L < 30000	Rigel (b-Ori)	
A Blanco; 7500 < T < 10000 K	1.4 < M < 2; 1.4 < R < 2; 5 < L < 25	Sirio (a-CMa)	
F Blanco Amarillo 6000 < T < 7500 K	1.04 < M < 2; 1.1 < R < 1.4; 1.5 < L < 5	Canopus (a-Car)	
G Amarillo 5200 < T < 6000 K	0.8 < M < 1.04; 0.9 < R < 1.1; 0.6 < L < 1.5	Sol (el nuestro)	
K Naranja 3700 < T < 5200 K	0.5 < M < 0.8; 0.7 < R < 0.9; 0.08 < L < 0.6	Arturo (a-Boo)	
M Rojas T < 3700 K	M < 0.5; R < 0.7; L < 0.08	Gliese 581 (Lib)	



# ¿Qué define todo?

- **Relaciones entre parámetros:**

- Luminosidad (L)
- Masa (M)
- Temperatura (T)
- Radio (R)

$$L = \frac{\Delta E}{\Delta t} = 4\pi\sigma R^2 T^4$$

$$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$

- **¿Cuál es el más importante en condiciones normales?**

- **Cantidad de materia → Masa**
- Está fijada por condiciones externas → Nacimiento

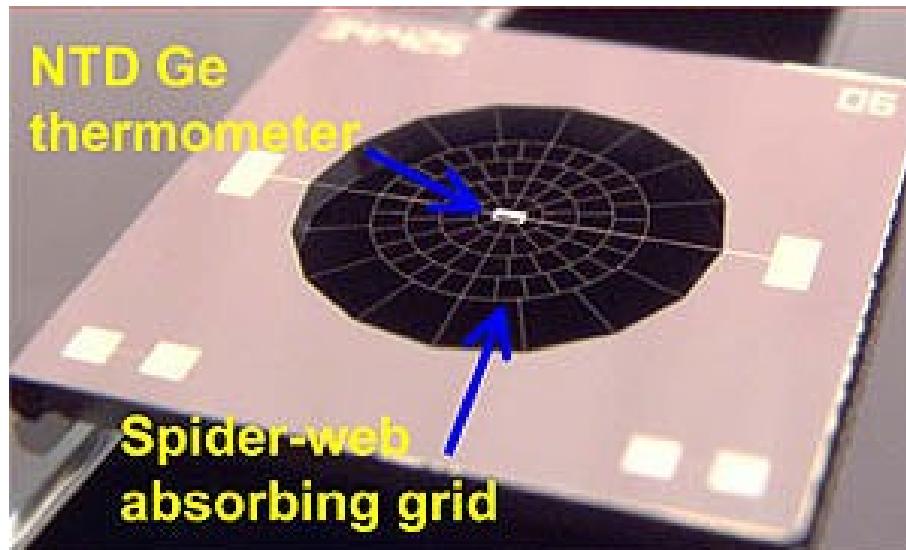
# Para entender la estrella

- Debemos averiguar estos parámetros:
  - Temperatura (T), Luminosidad (L), Radio estelar (R), Masa (M)



# ¿Cómo se mide la luminosidad?

- **Bolómetro: instrumento para medir el flujo de radiación electromagnética en distintas bandas (IR,V,UV...)**



- Uso la definición del flujo sobre la superficie esfera:

$$F = \frac{L}{4\pi d^2}$$

- Conociendo la distancia  $d$  (próxima unidad), puedo calcular la luminosidad:

$$L = 4\pi d^2 F$$

- Ó, conociendo  $L$ , calculo  $d$

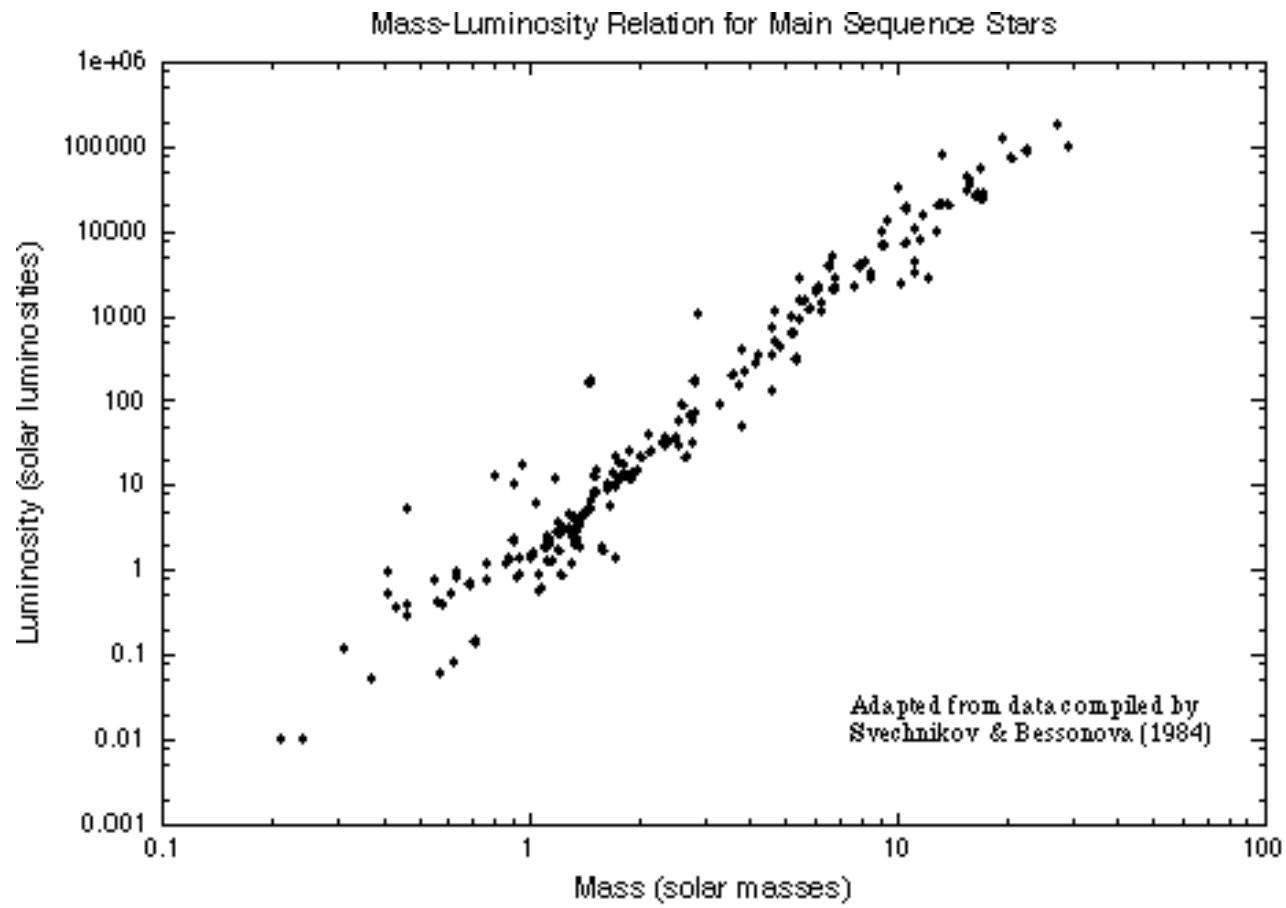
$$d = \sqrt{\frac{L}{4\pi F}}$$

# Luminosidad → Masa

- Si:  $(0.1 < \text{Masa Estelar} < 50)$  masas solares:  
**L es proporcional a la  $M^4$**
- Nota: En general,  $M^a$ , con a entre 3 y 4 (~ masa)

$$\left( \frac{L_{\text{Estrella}}}{L_{\text{Sol}}} \right) = \left( \frac{M_{\text{Estrella}}}{M_{\text{Sol}}} \right)^4$$

Oct 12, 2017

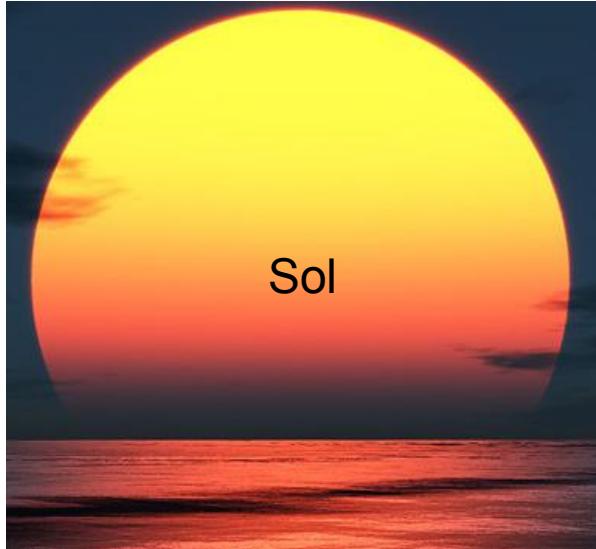




# Luminosidad → Masa

- Ejemplo

# $Y: (\text{Luminosidad, Temperatura}) \rightarrow \text{Radio}$



- $T = 5700 \text{ K}$  (Amarilla)
- $L = L_S$
- $T = 3400 \text{ K}$  (Roja)
- $L = 135000 L_S$

# Y: (Luminosidad, Temperatura) → Radio



Sol



Betelgeuse

- $T = 5700 \text{ K}$  (Amarilla)
- $L = L_S$
- $T = 3400 \text{ K}$  (Roja)
- $L = 135000 L_S$

**Menor temperatura,  
menos emisión  
Pero, la emisión es  
mucho mayor**

# Y: (Luminosidad, Temperatura) → Radio

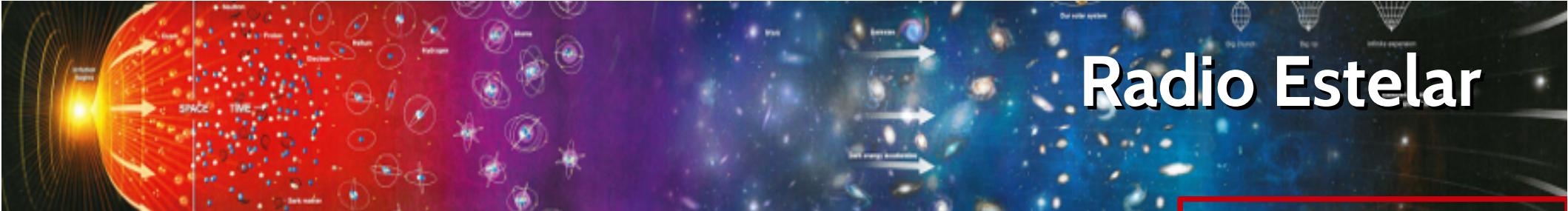


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Menor temperatura,  
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- $T = 3400 \text{ K}$  (Roja)
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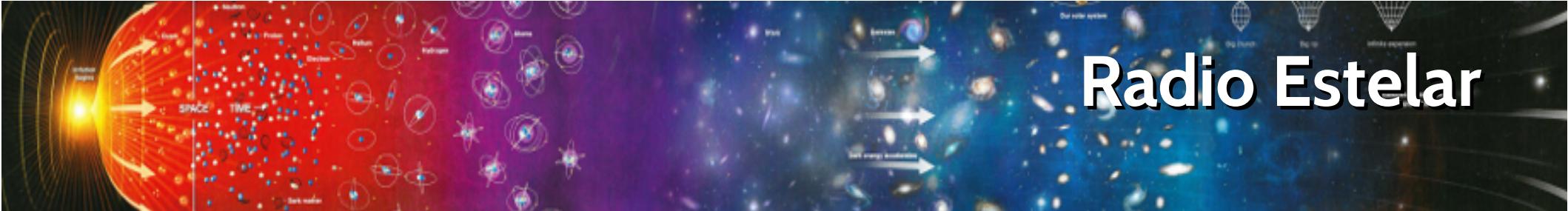
**Betelgeuse debe  
ser mucho más  
grande que el  
Sol**



# Radio Estelar

$$L = 4\pi\sigma R^2 T^4$$

- Comparando las temperaturas
- ¡Pero también depende del radio!



# Radio Estelar

- Veamos....  $(T_B/T_S)^4$ 
  - $(3400 / 5700)^4 \sim = 1/7.8$
  - Si dependiera sólo de T, el Sol sería 7.8 veces más luminoso que Betelguese
- Pero...

$$L_B / L_S = [(4\pi R_B^2) \sigma T_B^4] / [(4\pi R_S^2) \sigma T_S^4]$$

$$135000 = (R_B/R_S)^2 (T_B/T_S)^4$$

$$135000 = (R_B/R_S)^2 / 7.8$$

$$1.053 \times 10^6 = (R_B/R_S)^2$$

- Veamos....  $(T_B/T_S)^4$

$$R_B = 1026 R_{\text{Sol}}$$

**Betelgeuse es una supergigante roja**

mas luminoso que Betelgeuse

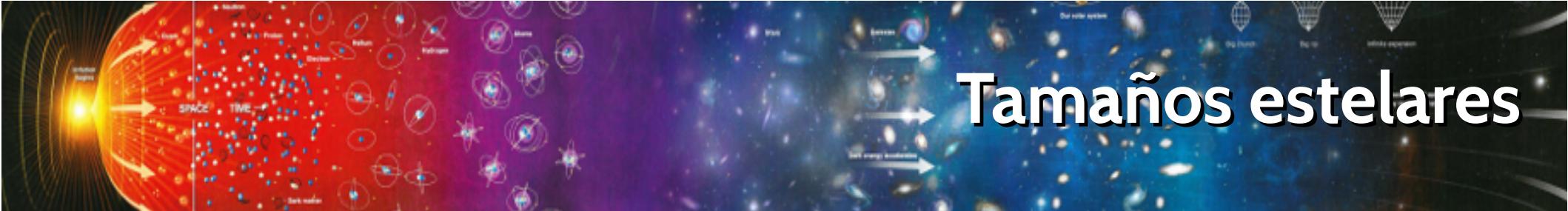
- Pero...

$$L_B / L_S = [(4\pi R_B^2) \sigma T_B^4] / [(4\pi R_S^2) \sigma T_S^4]$$

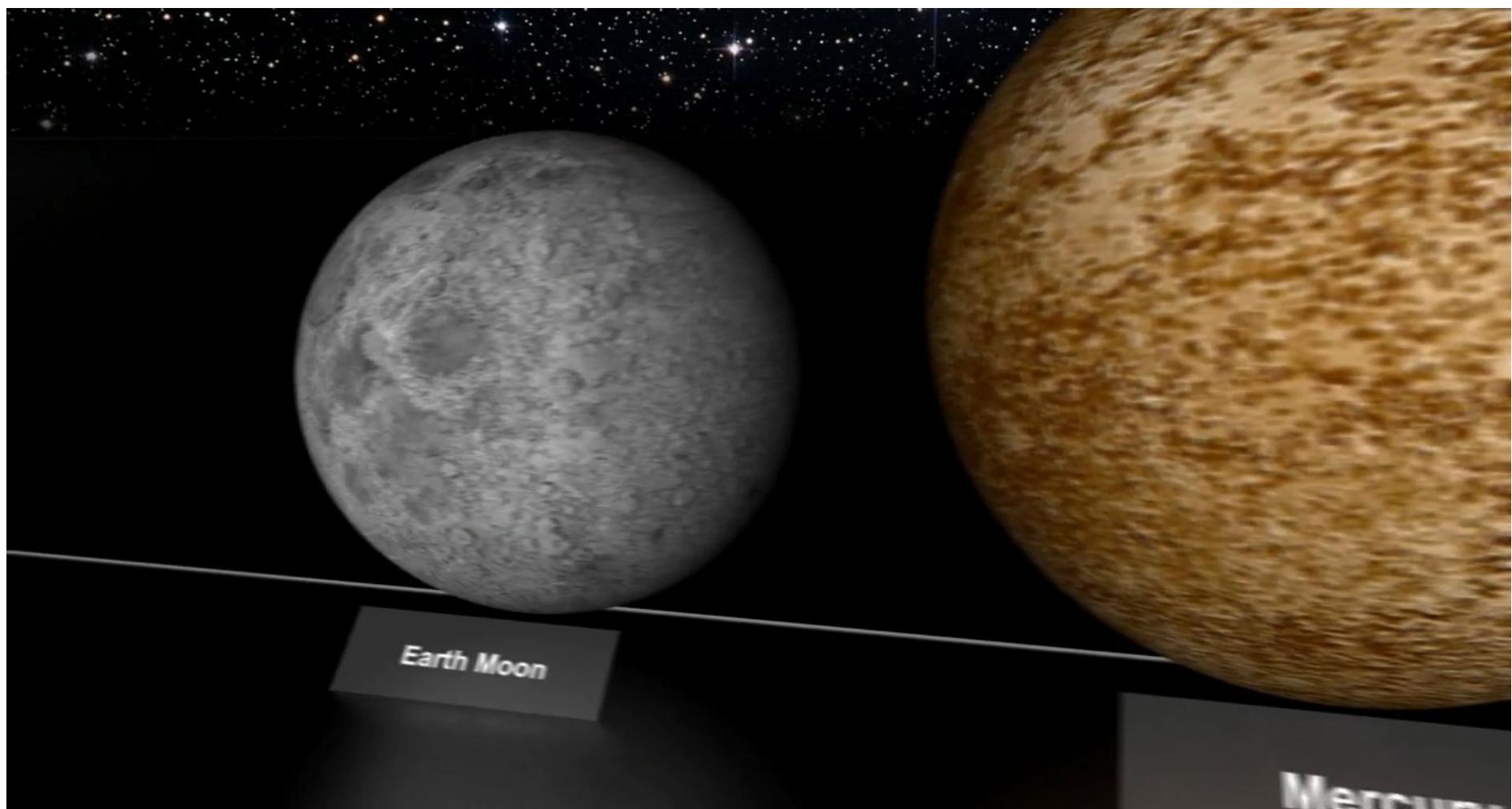
$$135000 = (R_B/R_S)^2 (T_B/T_S)^4$$

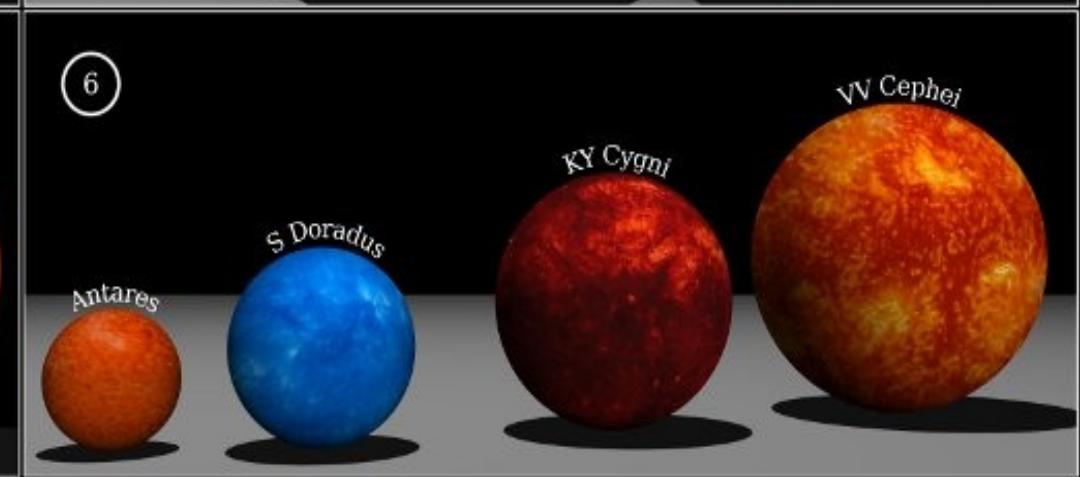
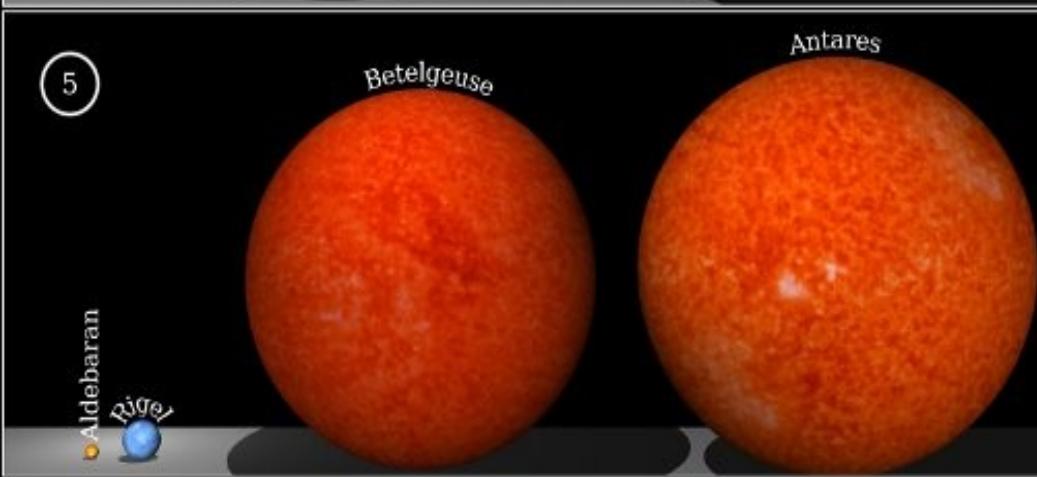
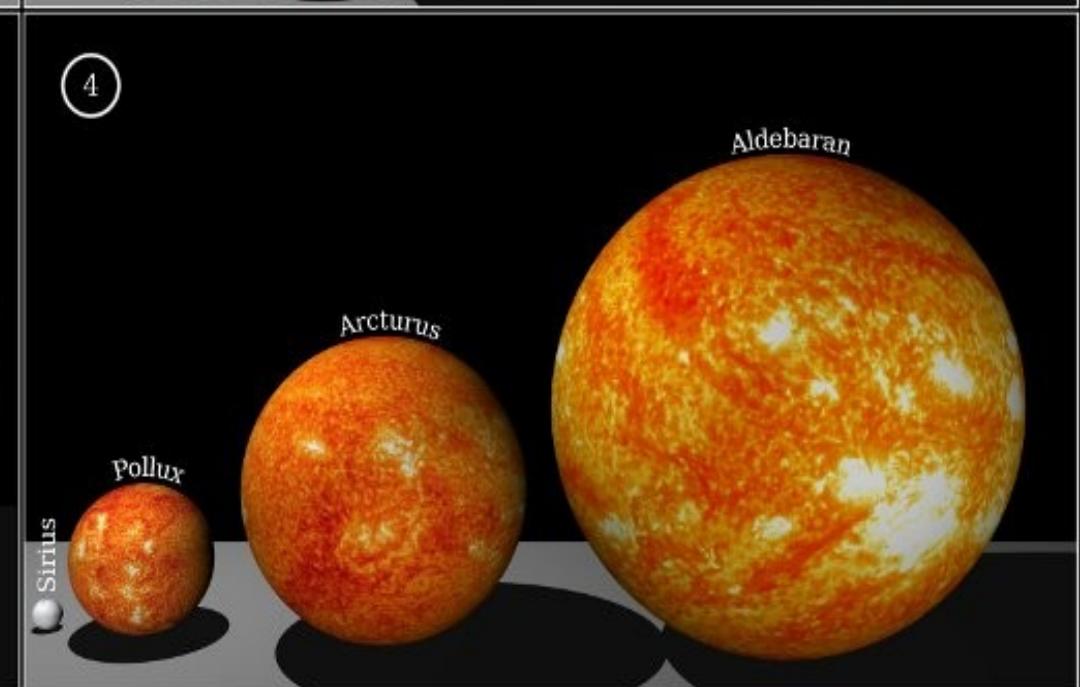
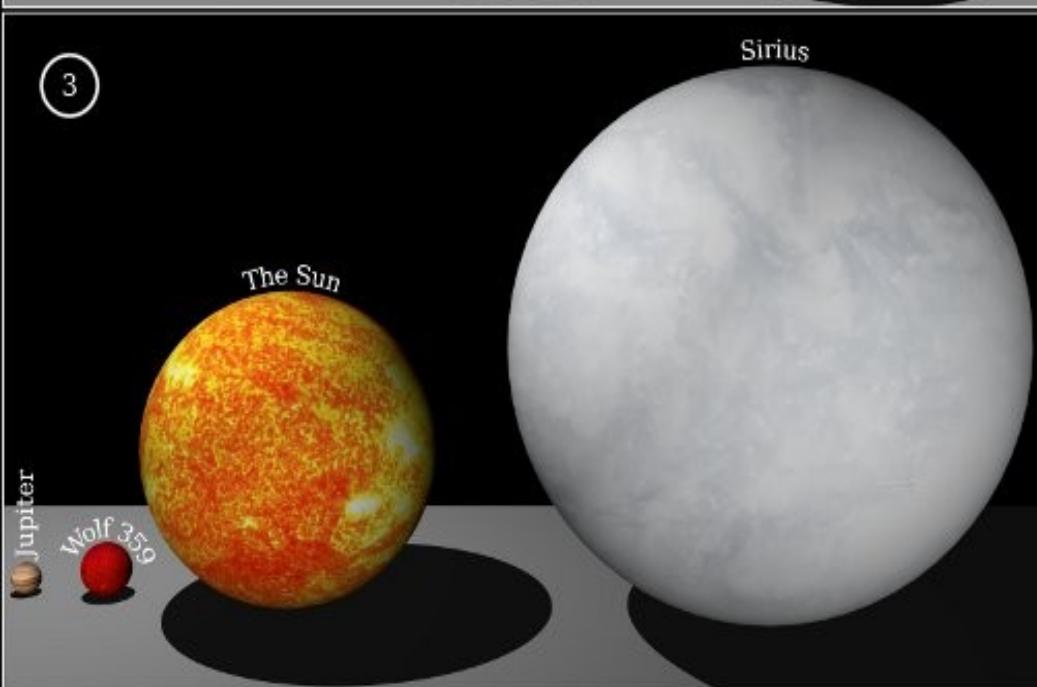
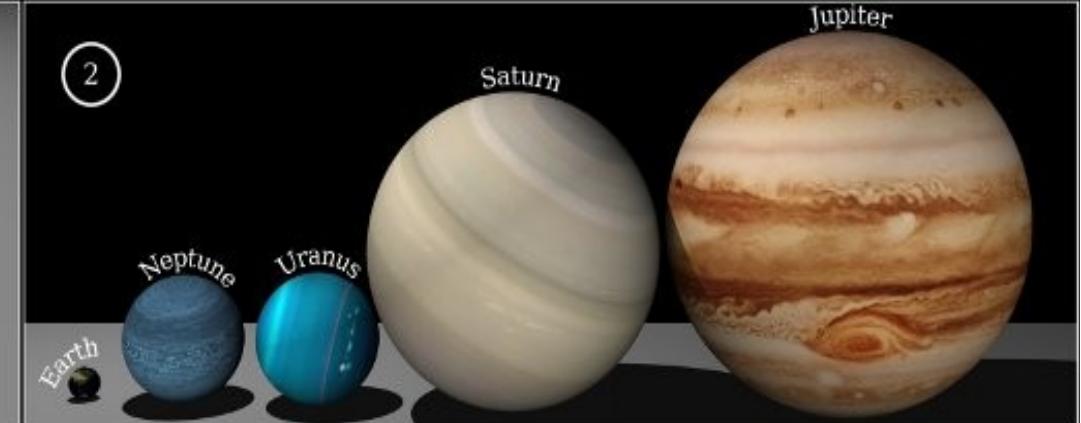
$$135000 = (R_B/R_S)^2 / 7.8$$

$$1.053 \times 10^6 = (R_B/R_S)^2$$



# Tamaños estelares







# Es cómodo medir las cosas en términos solares

- Masa Solar:

$$M_{\text{Sol}} = 1.989 \times 10^{30} \text{ kg} \simeq 1000 M_{\text{Júpiter}} \simeq 333000 M_{\text{Tierra}}$$

- Radio Solar:

$$R_{\text{Sol}} = 6.96 \times 10^8 \text{ m} = 696000 \text{ km}$$

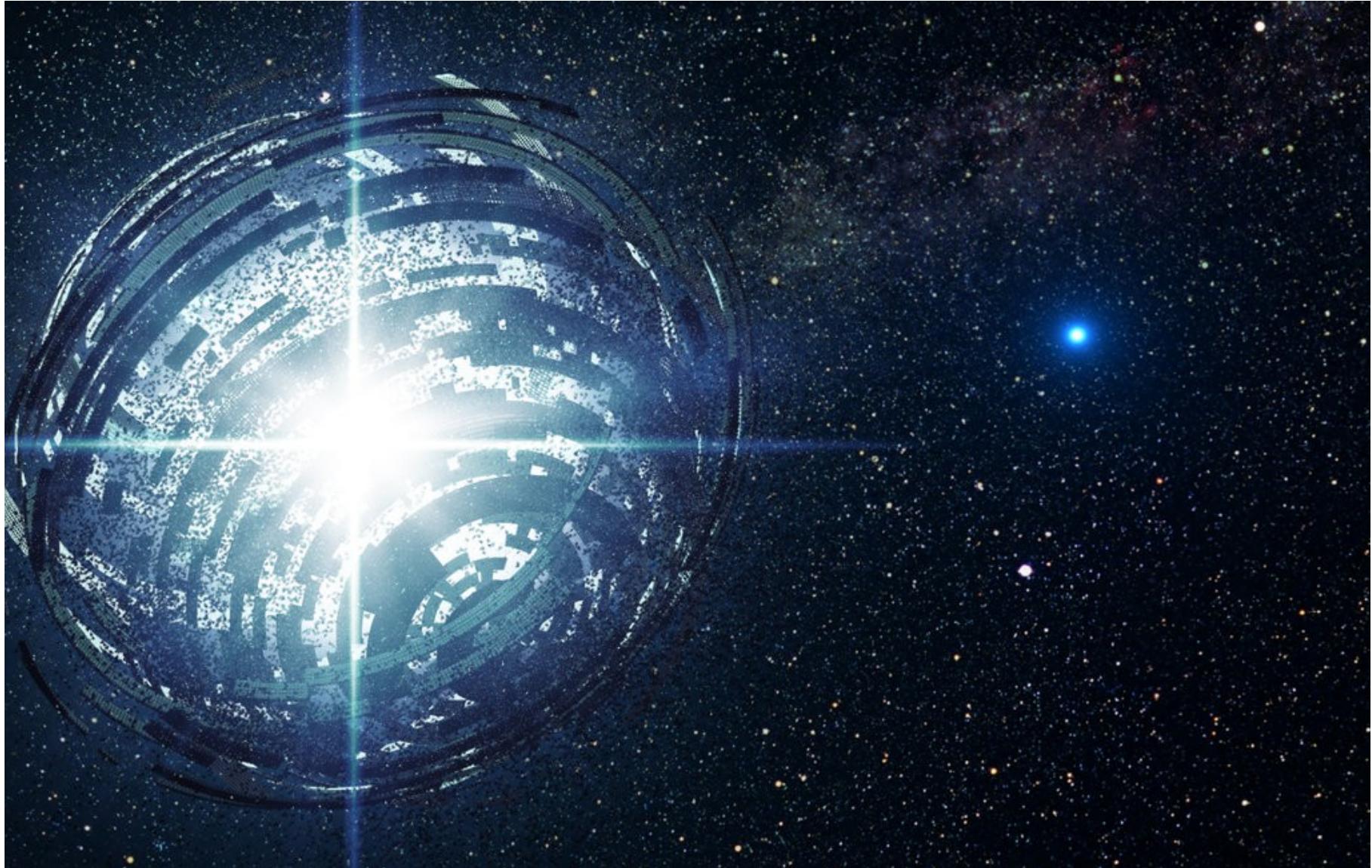
- Luminosidad Solar:

$$L_{\text{Sol}} = 3.83 \times 10^{26} \text{ W}$$

- Alto:

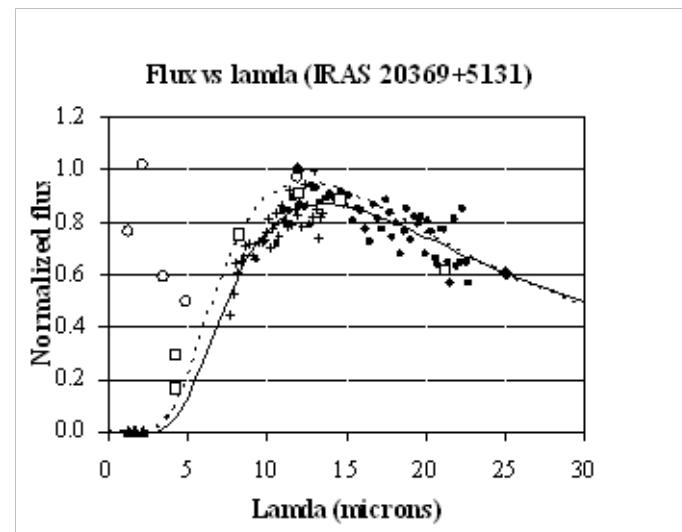
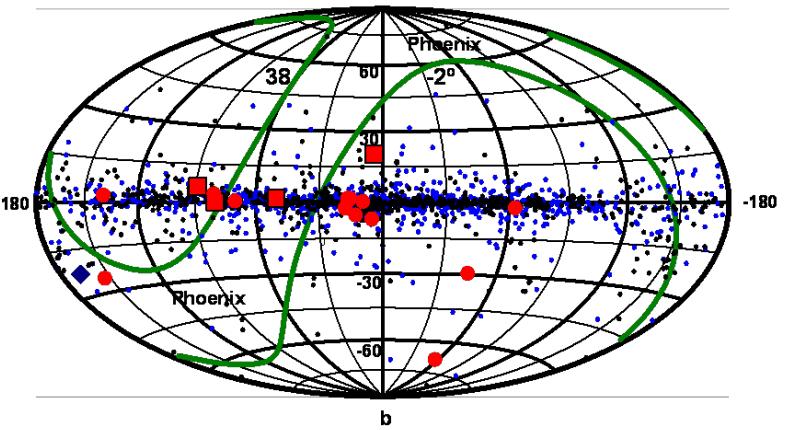
**1 segundo de energía liberada en el Sol  
equivale a 800000 años de consumo humano (2013)**

# Esferas de Dyson

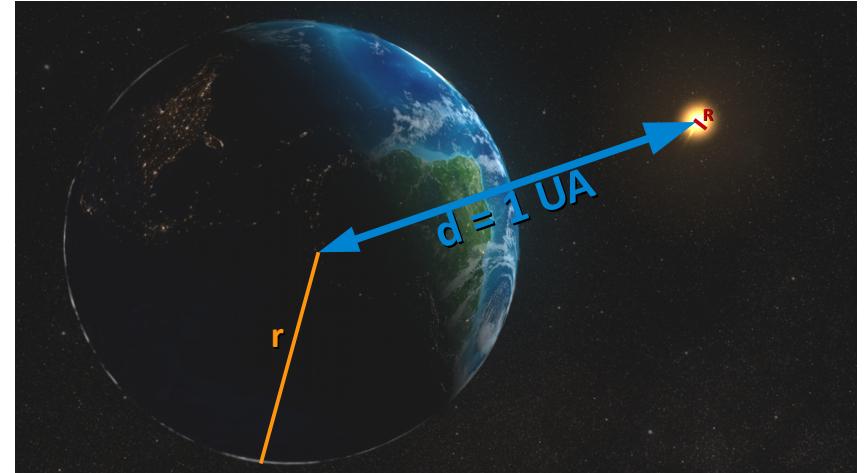


# IRAS (InfraRed Astronomical Satellite)

[http://home.fnal.gov/~carrigan/infrared\\_astronomy/Fermilab\\_search.htm](http://home.fnal.gov/~carrigan/infrared_astronomy/Fermilab_search.htm)



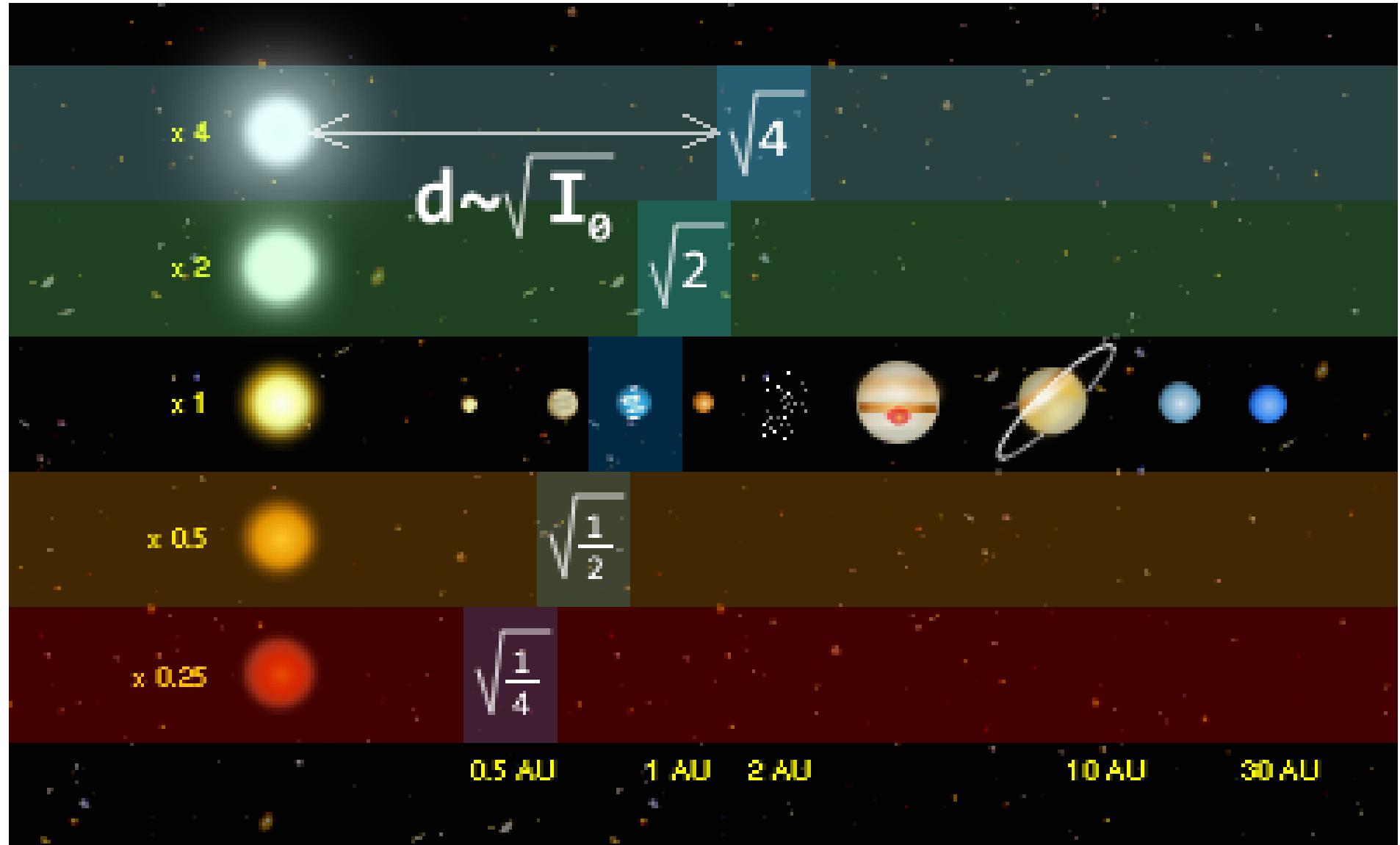
# ¿Y si fuera un planeta?



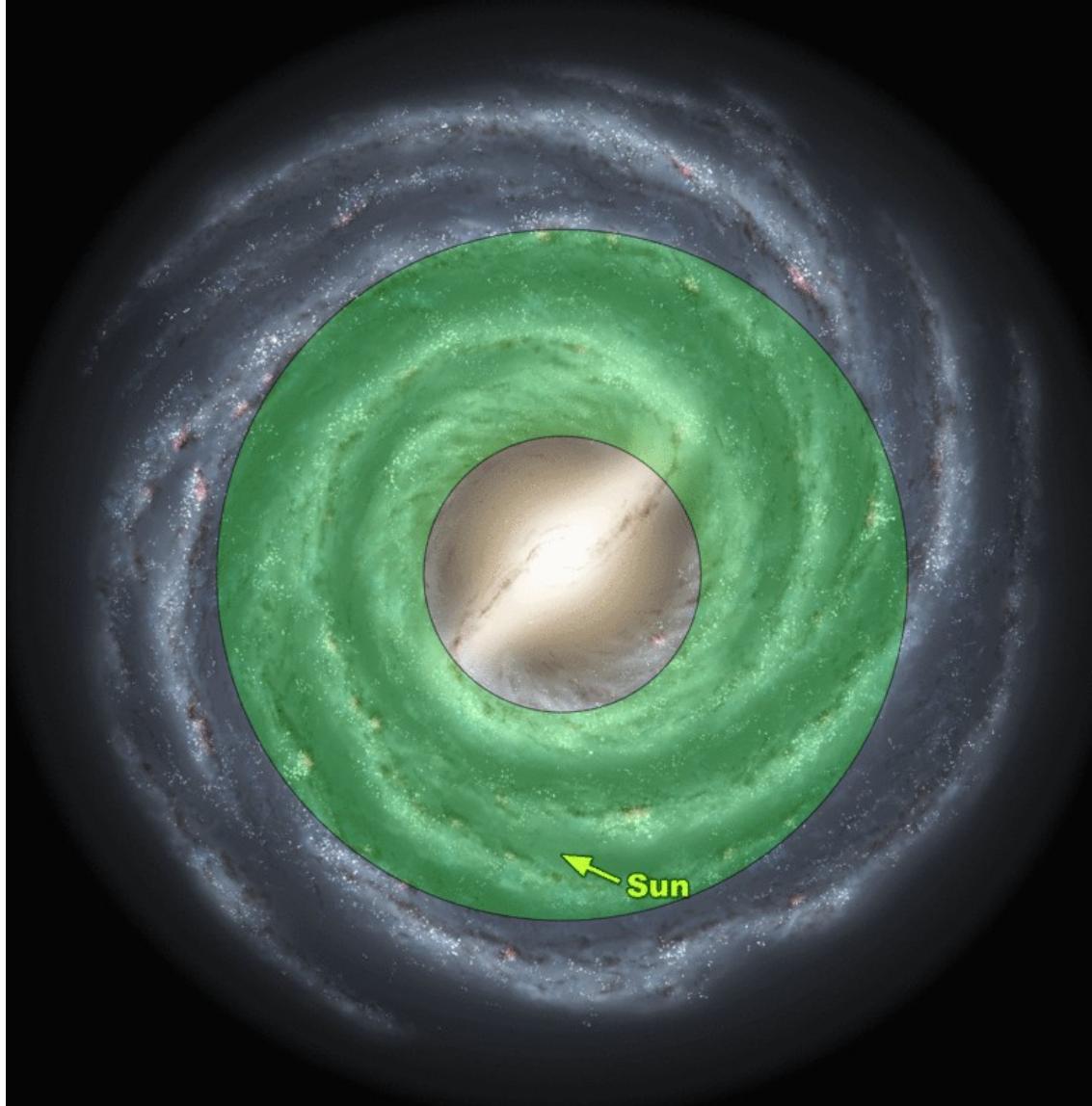
- ¿Qué fracción de la energía captura un planeta de radio  $r$ ?

$$T_{\oplus} = \sqrt[4]{\frac{L_{\odot}}{16\pi\sigma d^2}}$$
$$T_{\oplus} = \sqrt{\frac{R_{\odot}}{2d}} T_{\odot}$$
$$d = \frac{1}{2} \left( \frac{T_{\odot}}{T_{\oplus}} \right)^2 R_{\odot}$$

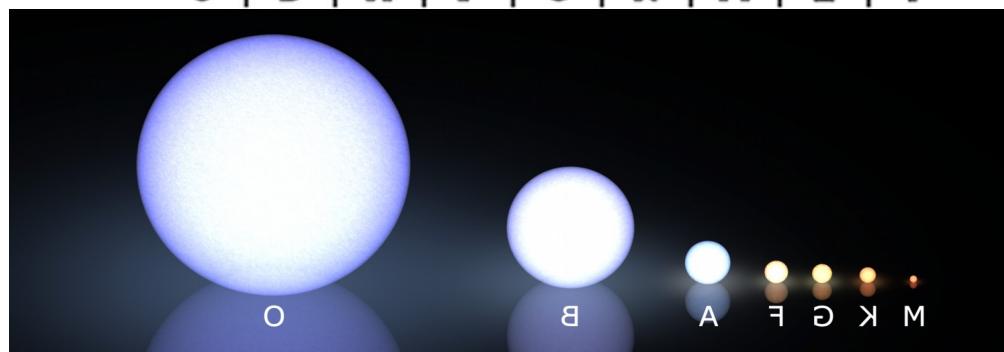
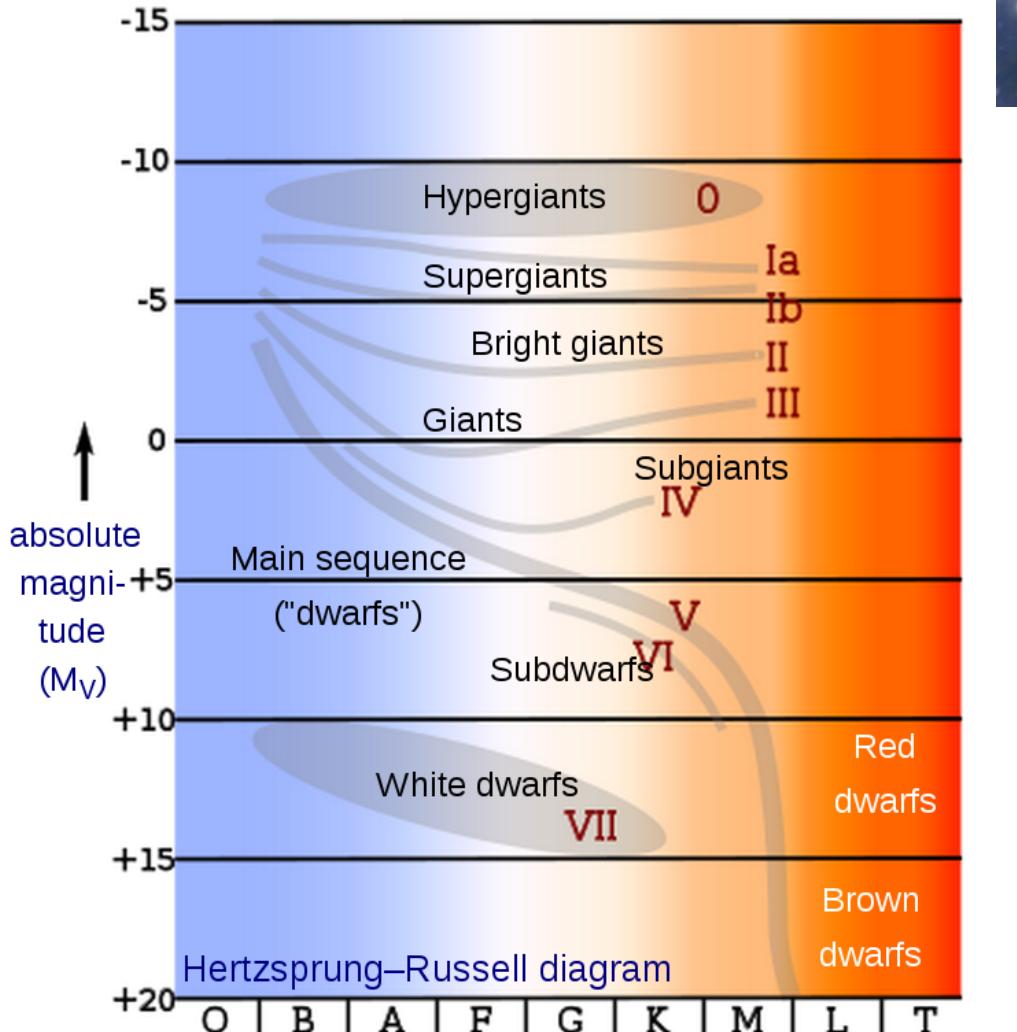
# Zona habitable: Agua líquida (volveremos...)



zona habitable... galáctica



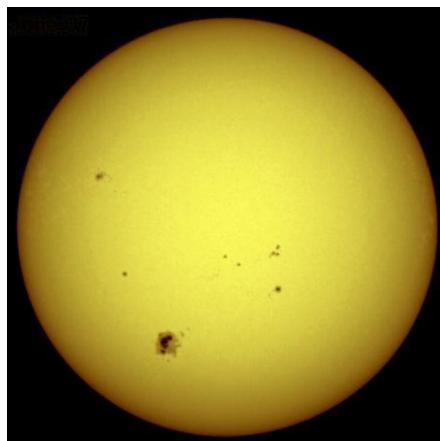
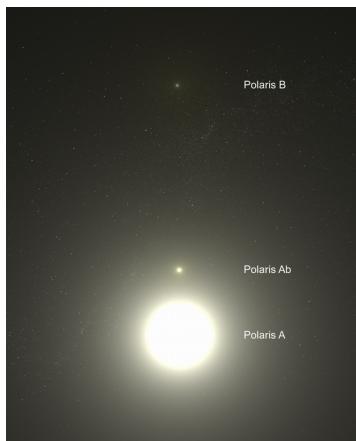
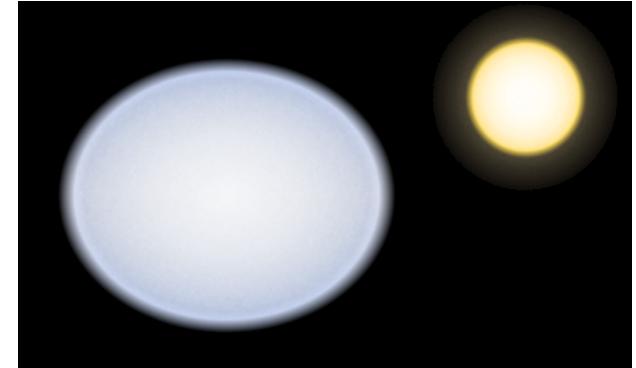
# Dijimos que la masa define todo



Surface temperature ranges for different stellar classes<sup>[134]</sup>

Class	Temperature	Sample star
O	33,000 K or more	Zeta Ophiuchi
B	10,500–30,000 K	Rigel
A	7,500–10,000 K	Altair
F	6,000–7,200 K	Procyon A
G	5,500–6,000 K	Sun
K	4,000–5,250 K	Epsilon Indi
M	2,600–3,850 K	Proxima Centauri

# Secuencia principal → OBAFGKM





**SPECTRAL CLASS O**

Dark Blue  
28,000 - 50,000 K  
Ionized Atoms, especially helium  
Example: Mintaka (O1-3III)



**SPECTRAL CLASS B**

Blue  
10,000 - 28,000 K  
Neutral helium, some hydrogen  
Alpha Eridani A (B3V-IV)



**SPECTRAL CLASS A**

Light Blue  
7,500 - 10,000 K  
Strong hydrogen, some ionized metals  
Sirius A (A0-1V)



**SPECTRAL CLASS F**

White  
6,000 - 7,500 K  
Hydrogen and ionized metals,  
calcium and iron  
Procyon A (F5V-IV)

Yellow  
5,000 - 6,000 K  
Ionized calcium, both neutral and  
ionized metals  
Example: Sol (G2V)

**SPECTRAL CLASS G**

Orange  
3,500 - 5,000 K  
Neutral Metals  
Alpha Centauri B (K0-3V)

**SPECTRAL CLASS K**



Red  
2,500 - 3,500 K  
Ionized atoms, especially helium  
Wolf 359 (M5-8V)

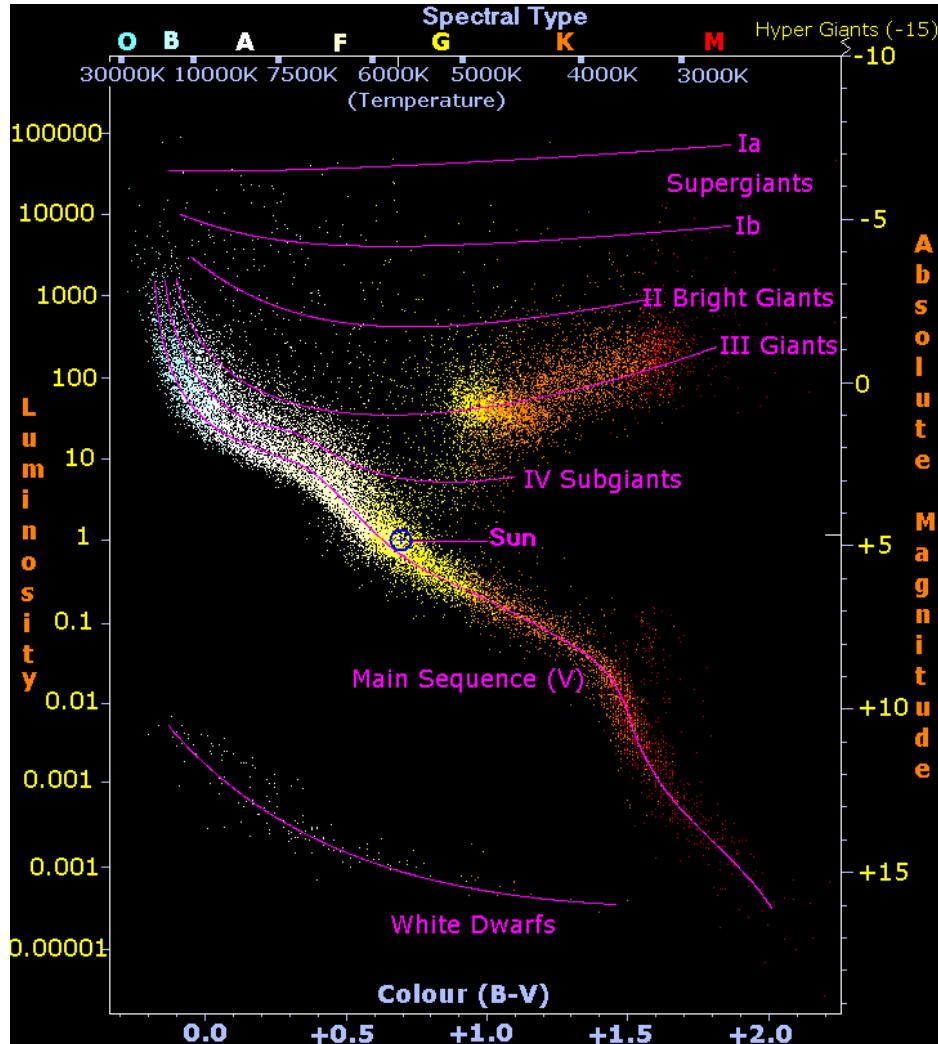
**SPECTRAL CLASS M**



**Non-Main Sequence Types**

Class W: Wolf-Rayet Star  
Up to 70,000 K  
Carbon, nitrogen, or oxygen  
Gamma Velorum A (WC)  
Class L: Dwarf Star  
J,300 - 2,000 K  
Metal hydrides and alkali metals  
VW Hyi  
Class T: Methane Dwarf  
700 - 1,000 K  
Methane  
Epsilon Indi Ba  
Class Y: Ammonia Dwarf  
<700 K  
Ammonia  
Not yet observed  
Class C: Carbon  
Class S: Zirconium Oxide  
Classes MS and SC  
Class D: Dwarf

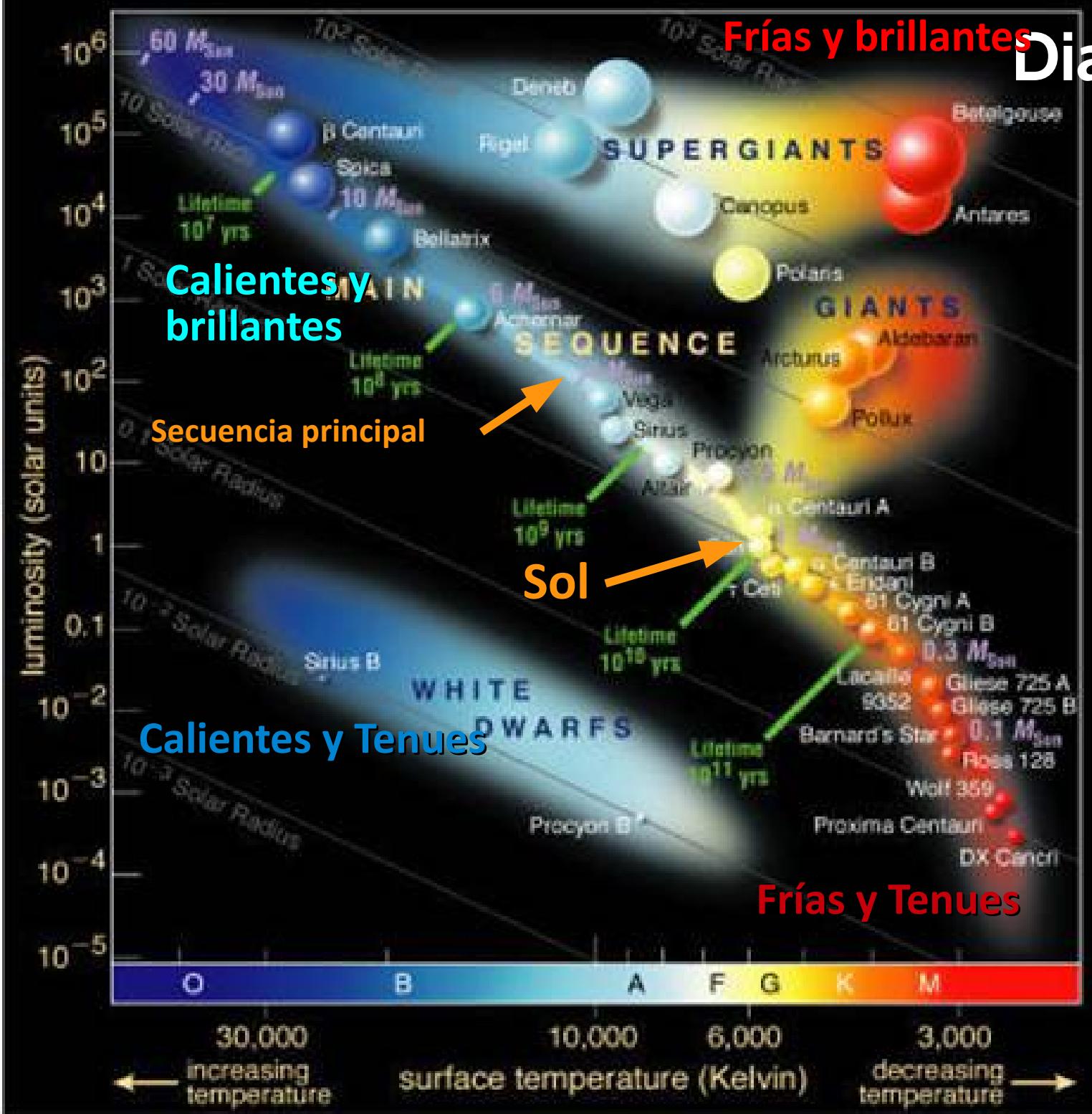
# Secuencia principal



- Estrellas que están en su fase normal de quema de combustible:  
 $H \rightarrow He$
- 90% del tiempo de vida las estrellas permanecen en este estadio
- **Metalicidad: contenido de elementos más masivos que el Helio**

Frías y brillantes

# Diagrama H-R

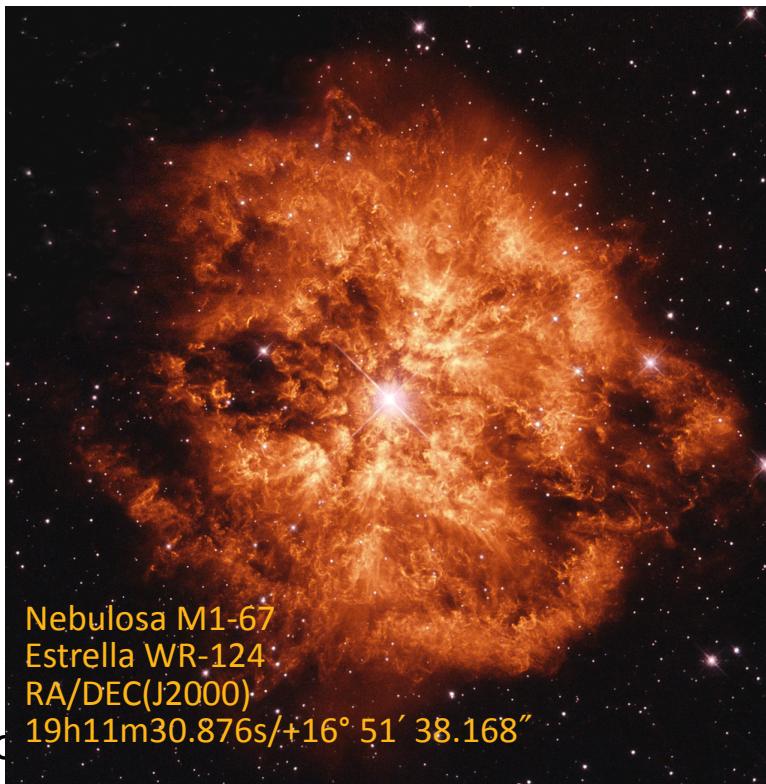


$$L \propto R^2 T^4$$

# Otros tipos de estrellas

- **W: Wolf-Rayet**

- **Estrellas masivas ( $>20M_s$ )**
- **Excesivamente calientes**



- **Los nuevos: L, T, Y**

- **L: Enanas frías o subestrellas, temperaturas  $1300K < T < 2400K$**
- **T: Enanas marrones (subestrellas, sin fusión H) con prominencia de metano y  $500K < T < 1300K$**
- **Y: enanas marrones ultra frías (superplanetas?) c/amoníaco y  $T < 600K$ , y  $10 < M/M_{Júp} < 90$**