

Evolución estelar y agujeros negros

Gil Jannes

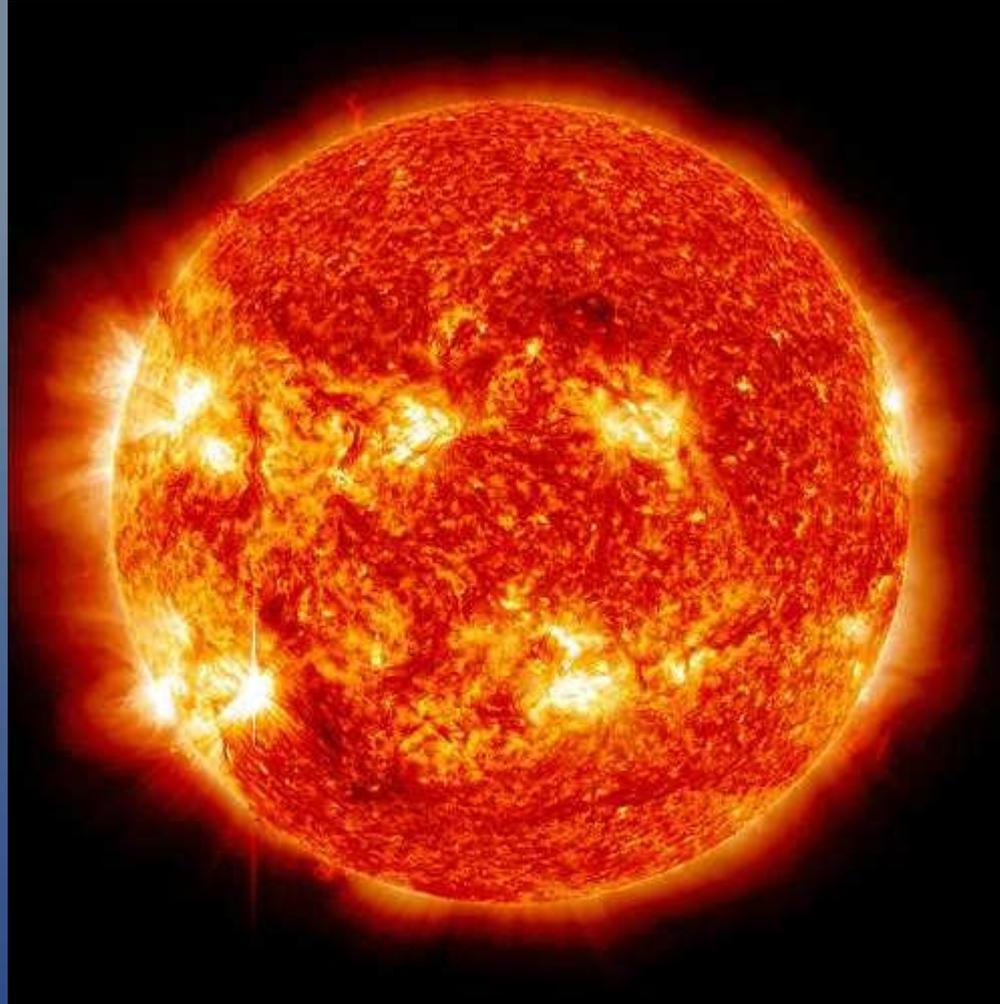
Universidad Europea de Madrid
Universidad Complutense de Madrid



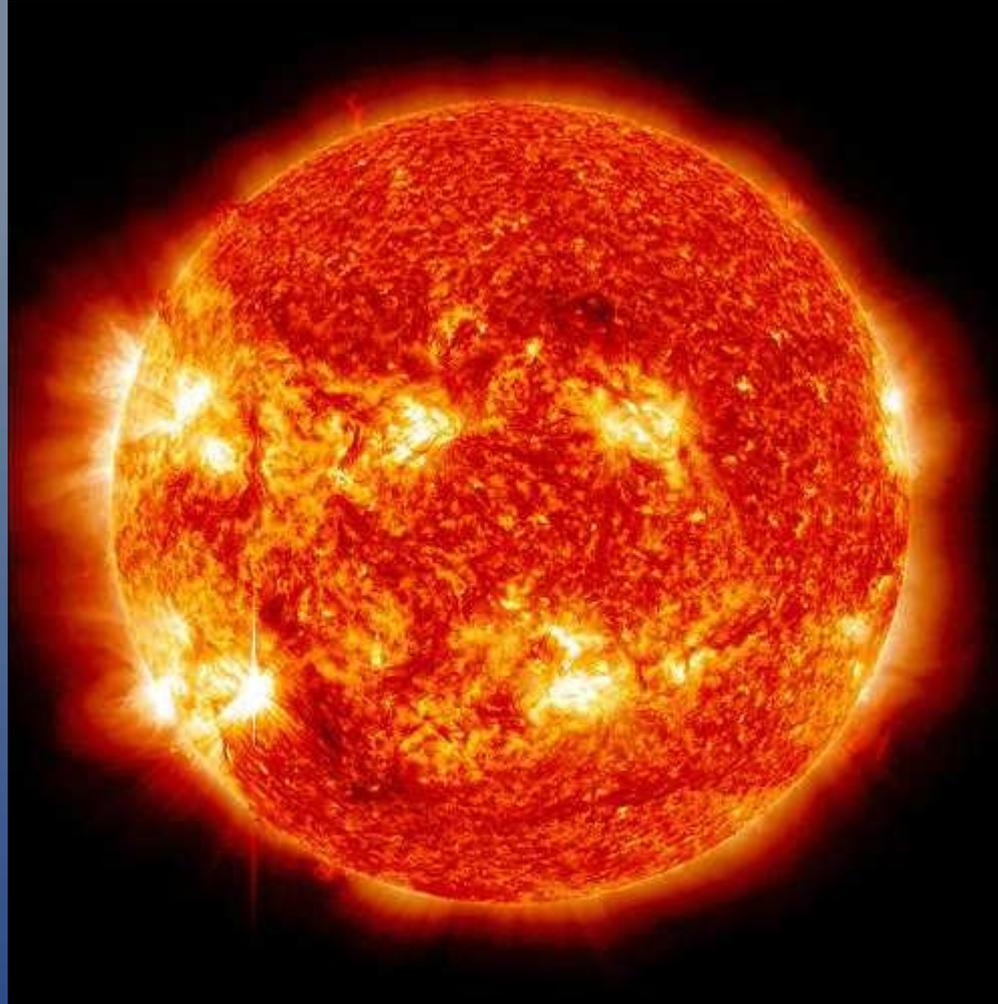
Contenido

- ¿Qué es una estrella?
- El nacimiento de las estrellas
- Evolución estelar
- La muerte de las estrellas
- Enanas blancas, estrellas de neutrones y...
- Agujeros negros

¿Qué es una estrella?

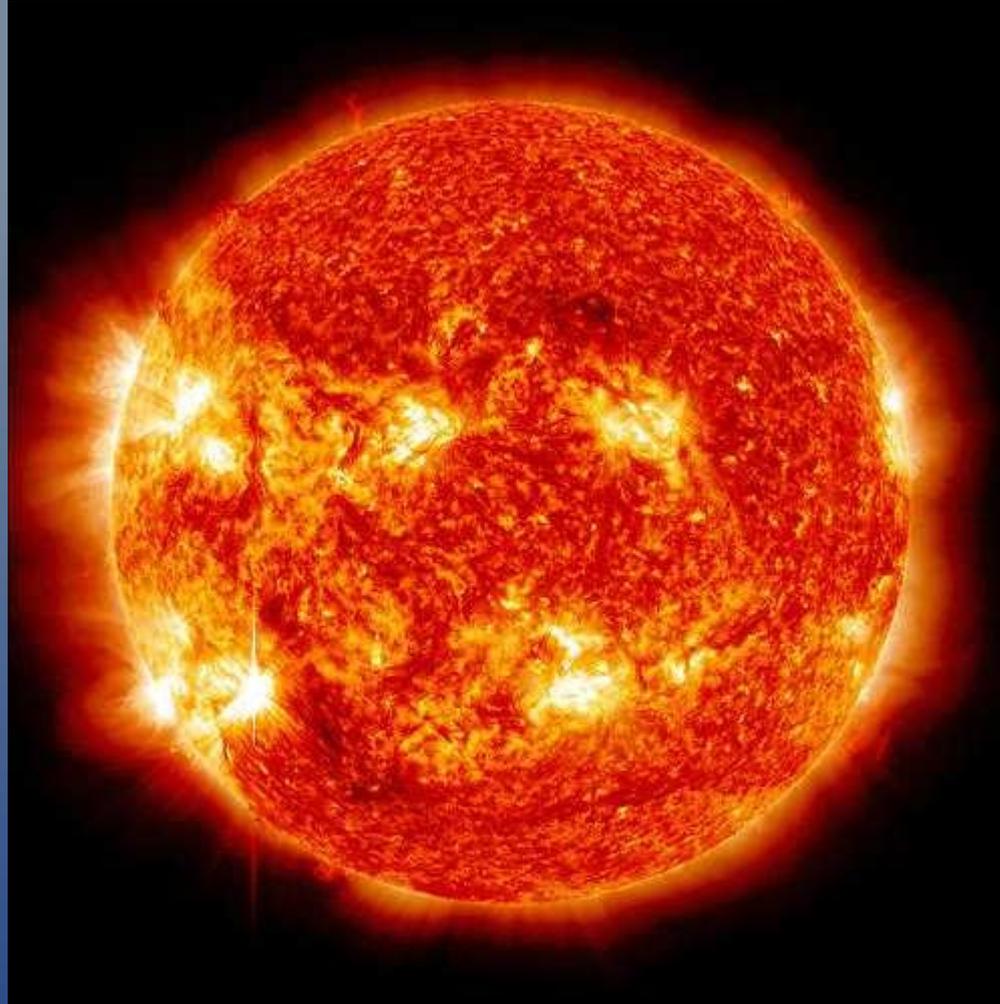


¿Qué es una estrella?



[wikipedia] UNA ESTRELLA (DEL LATÍN: STELLA) ES UNA ESFERA LUMINOSA DE PLASMA QUE MANTIENE SU FORMA GRACIAS A SU PROPIA GRAVEDAD.

¿Qué es una estrella?

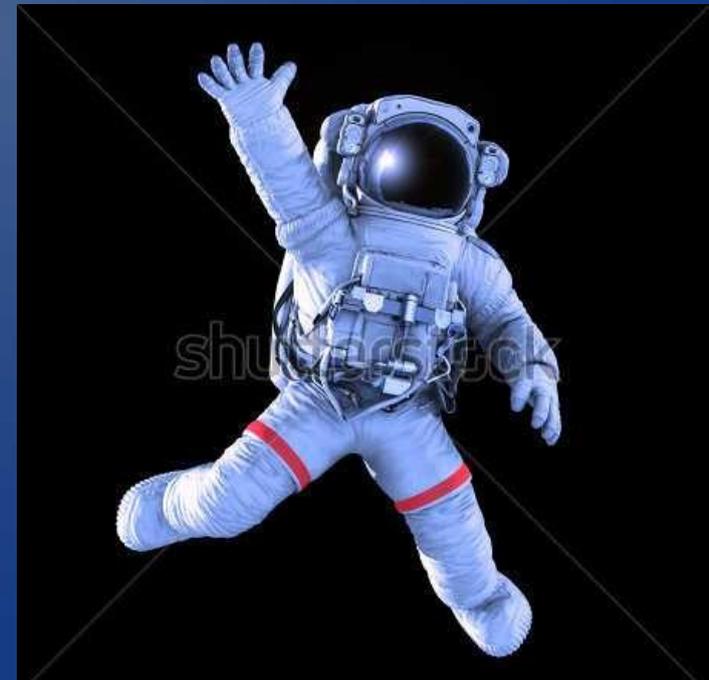


BOLA DE FUEGO

Triángulo del fuego



Combustible → GAS (plasma)
Calor ??? (-270.5°C)
Oxígeno ???

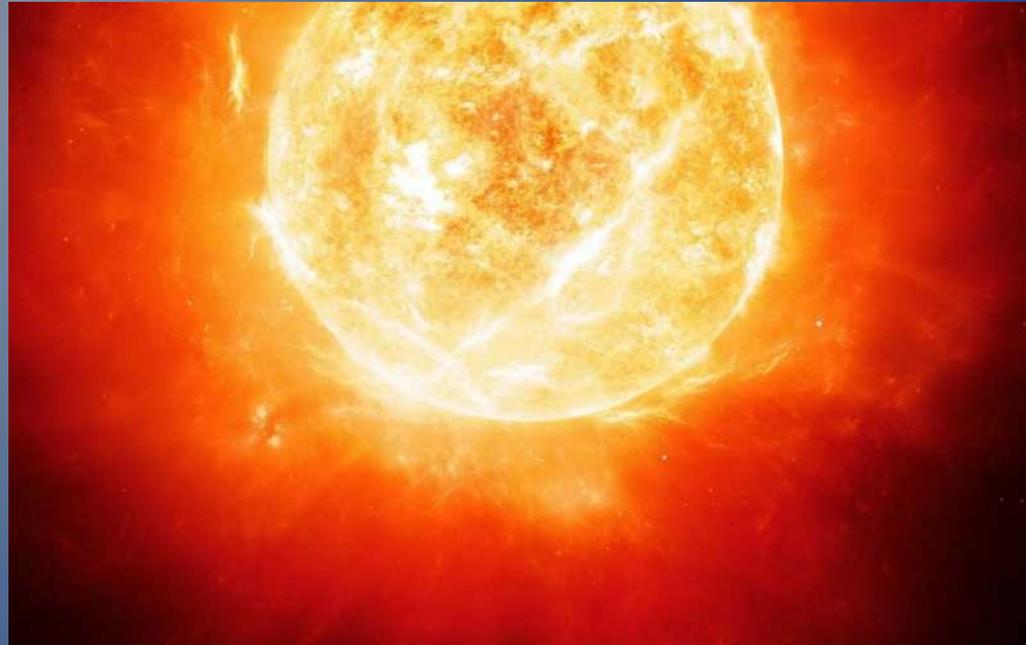


Las estrellas están hechas de gas



¿Qué gas?

Las estrellas están hechas de gas



¿Qué gas?



¿butano o
propano?

¿Por qué arden las estrellas?



¿Cómo se encienden?

¿Qué tipo de fuego?



¿De dónde viene el oxígeno?
o ¿no hace falta?

NACIMIENTO

NACIMIENTO

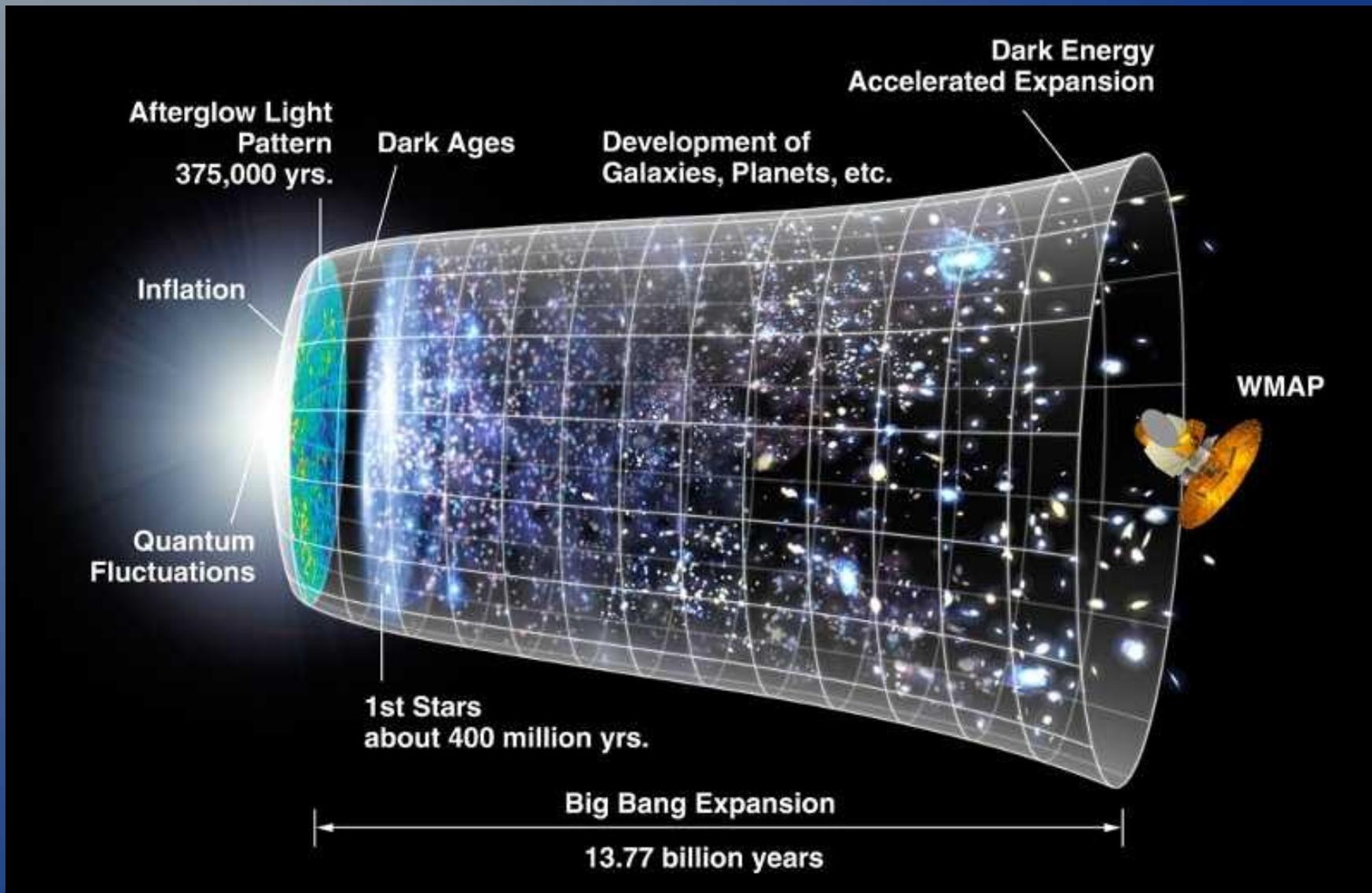


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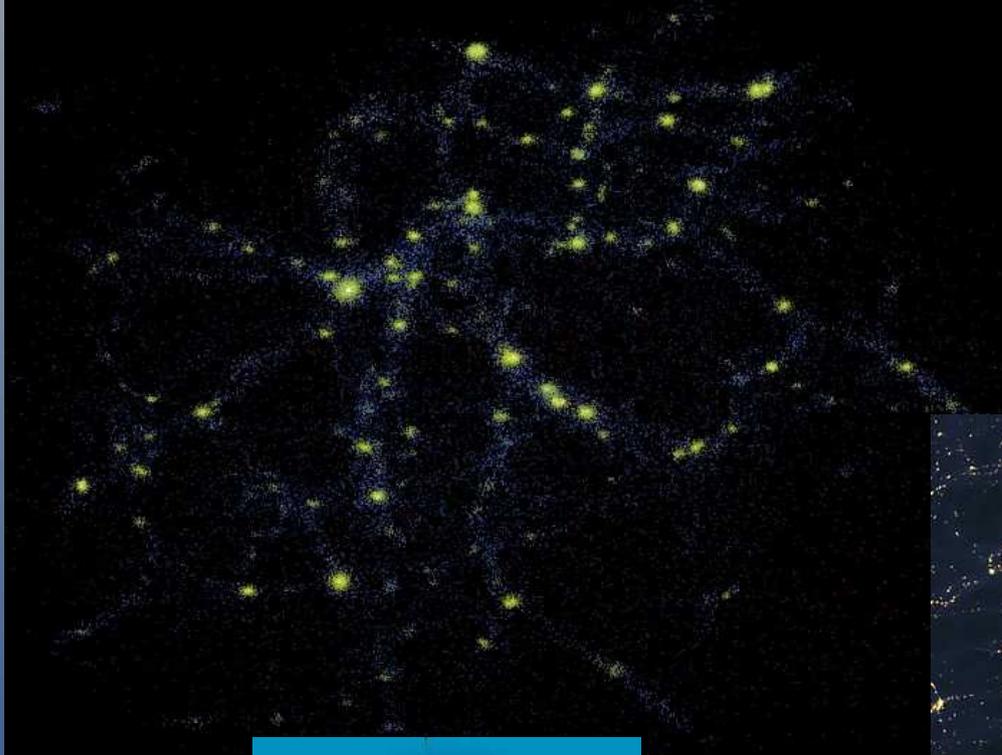


Hilarity
by Default...

Universo primigenio



FORMACIÓN DE ESTRUCTURA

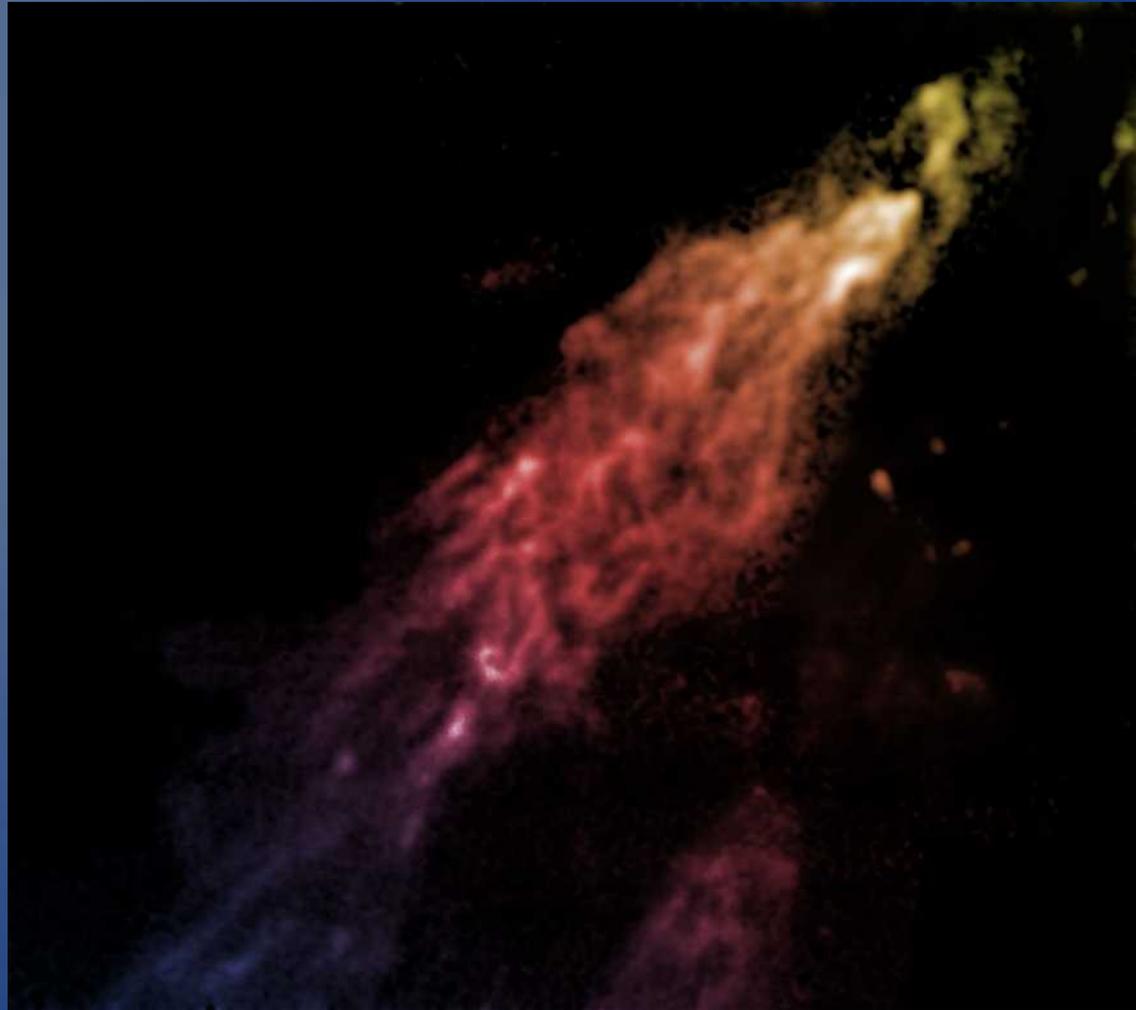


GRAVEDAD

NUBES PRIMORDIALES



Vision artística



Nube de Smith

NUBES ACTUALES (nebulosas interestelares)



Bow shock nebula



Lagoon nebula

Más nebulosas interestelares



Horse head
nebula



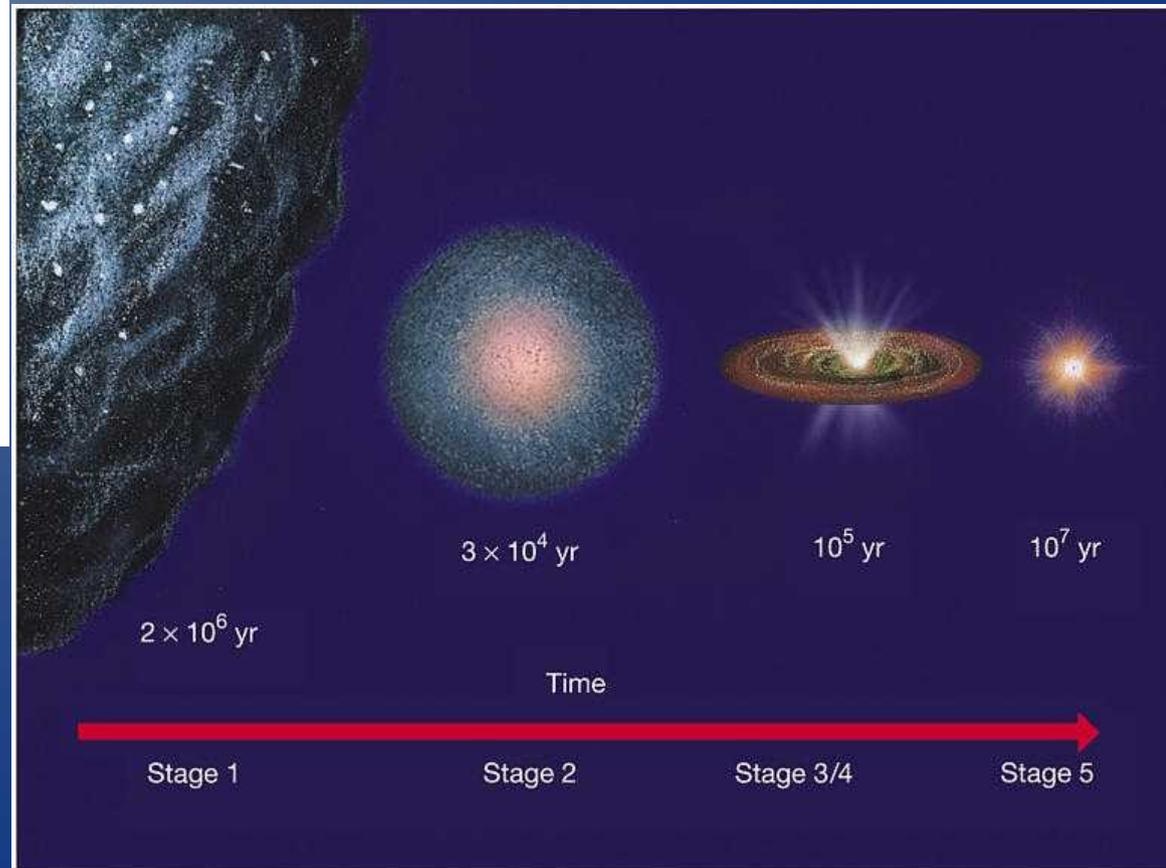
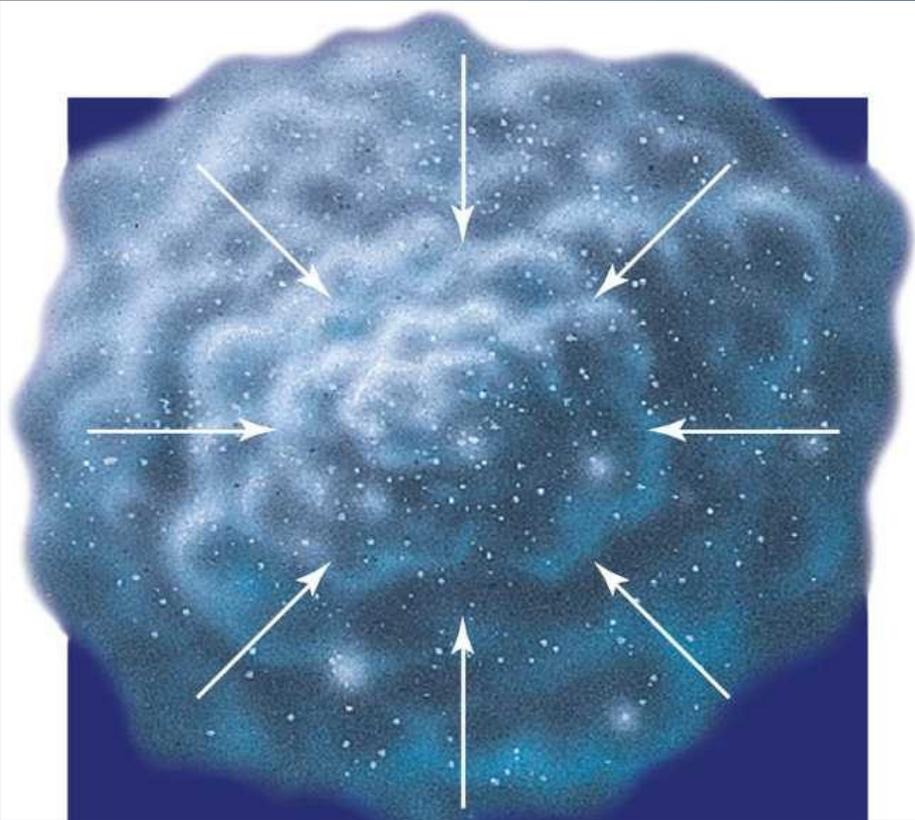
Más nebulosas interestelares



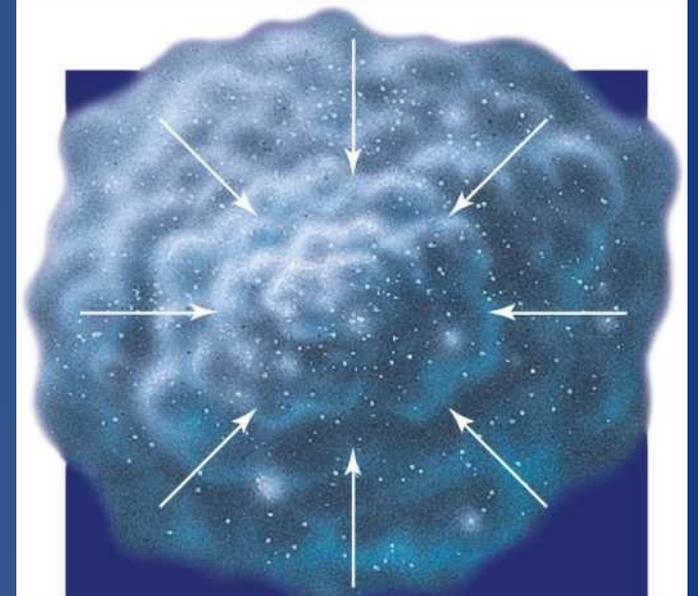
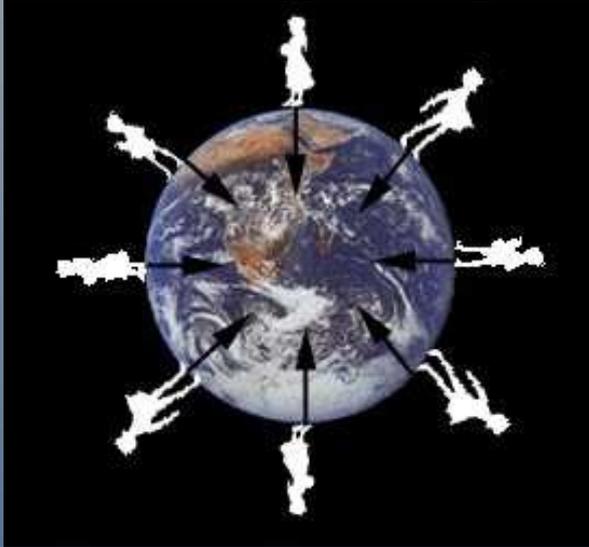
“Pilares de la creación”

tamaño: 5 años luz
distancia: 7000 años luz
(5M veces distancia al sol)
se especula que ya no existe
(destruido en explosión supernova hace 6000 años)
lo sabremos con seguridad dentro de 1000 años...

NUBES COLAPSAN (autogravedad)



Autogravedad



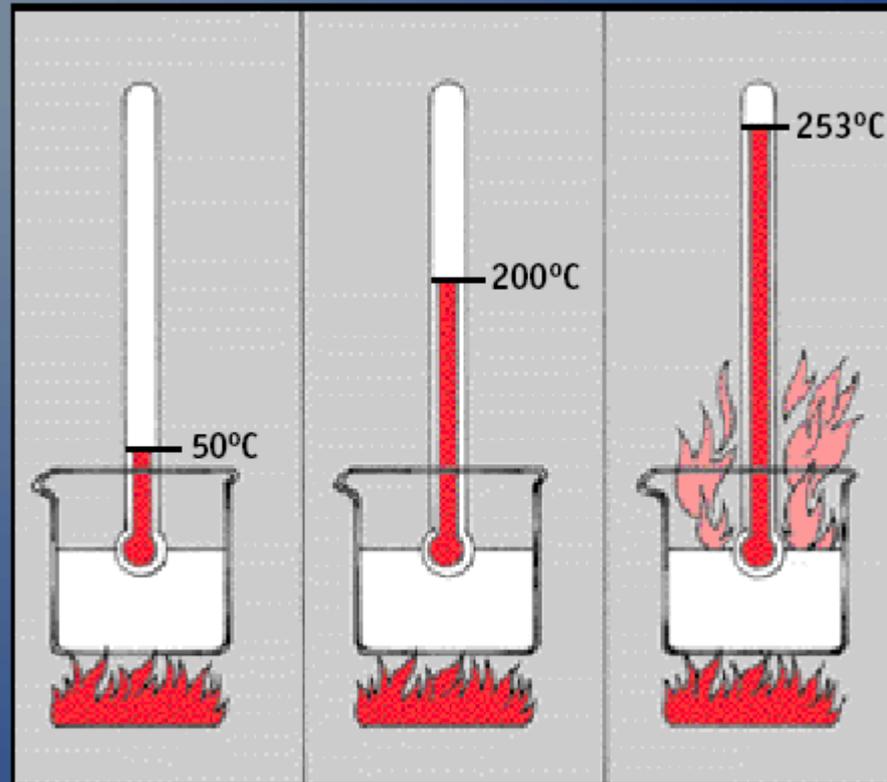
$$F = G \frac{M_1 M_2}{r^2}$$

nube suficientemente grande
siempre termina colapsando ($M \sim r^3$)

IGNICIÓN



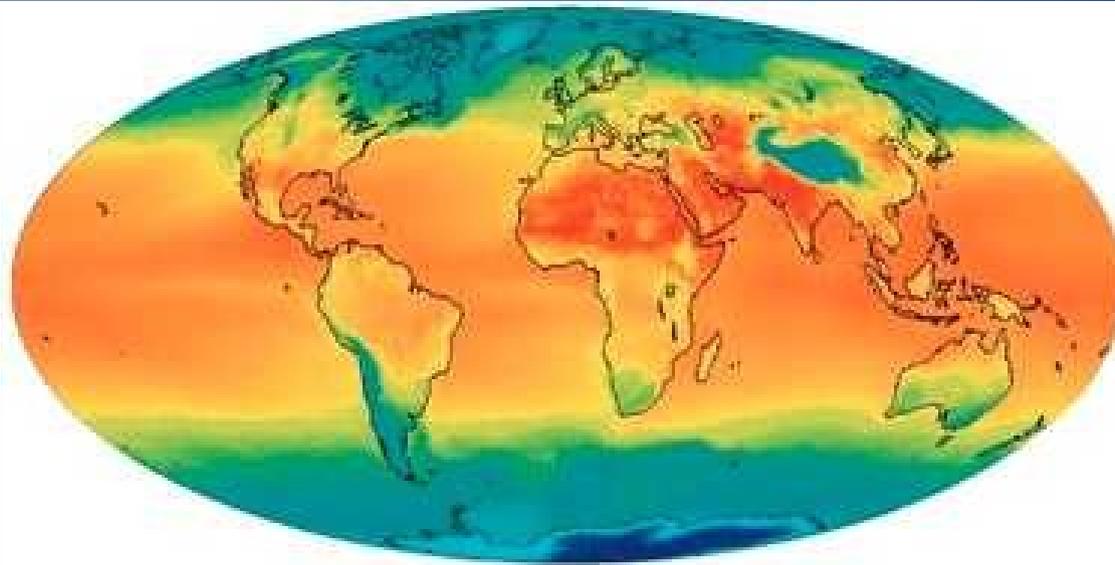
IGNICIÓN



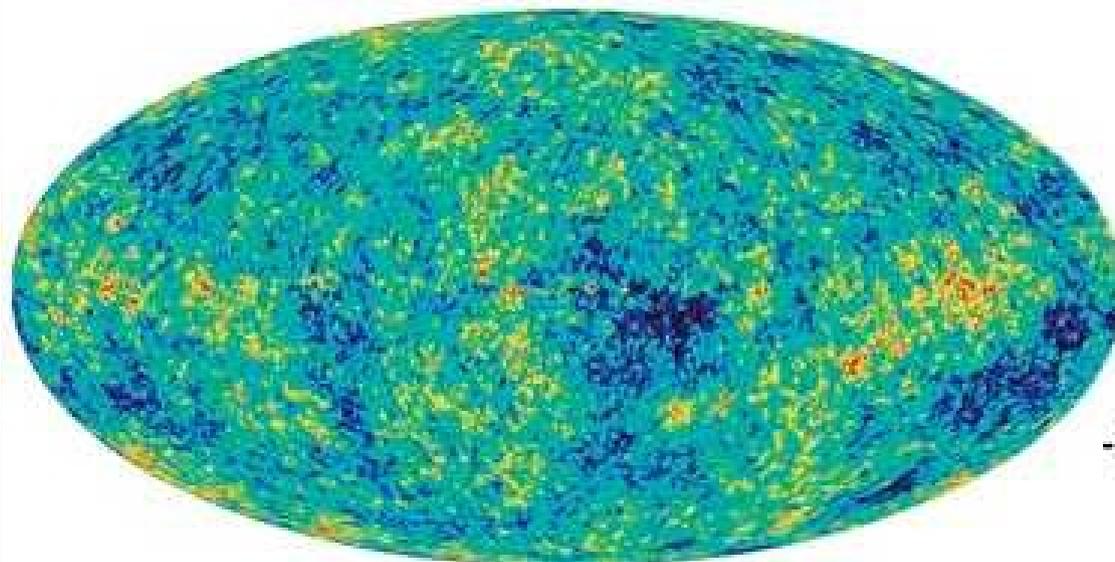
IGNICIÓN ESPONTÁNEA

IGNICIÓN ESPONTÁNEA
REQUIERE TEMPERATURA ALTA

IGNICIÓN ESPONTÁNEA REQUIERE TEMPERATURA ALTA



Earth
Temperatures



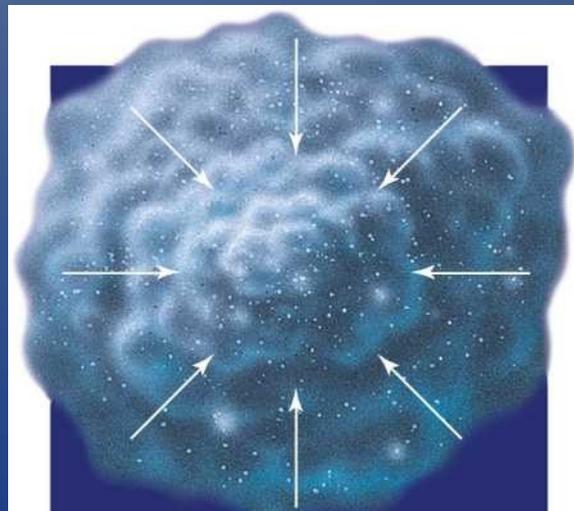
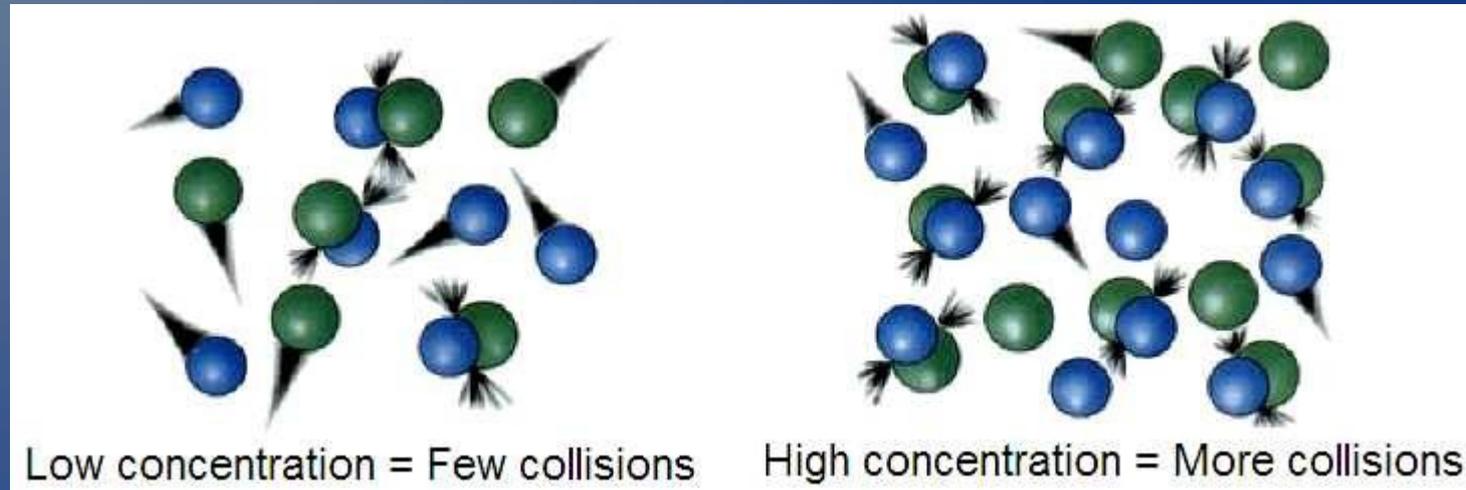
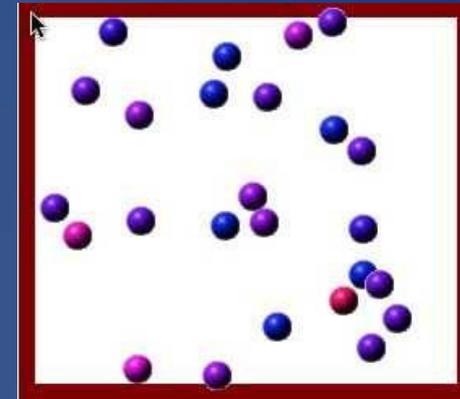
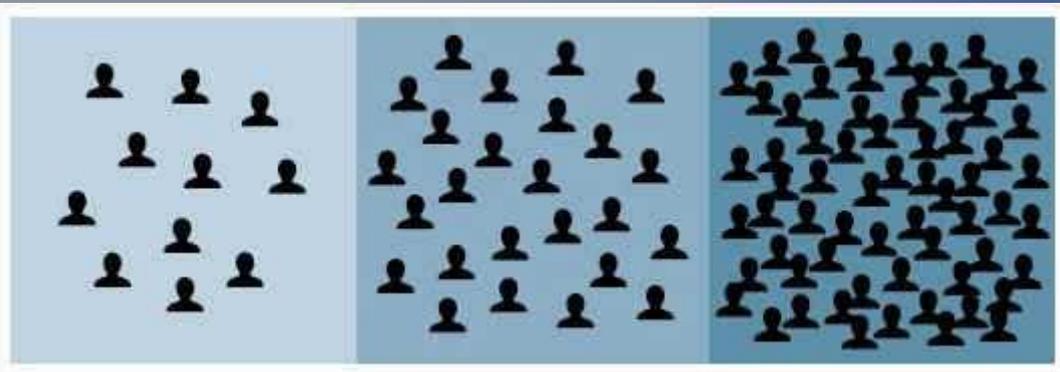
Microwave Sky
Temperatures



IGNICIÓN ESPONTÁNEA REQUIERE TEMPERATURA ALTA

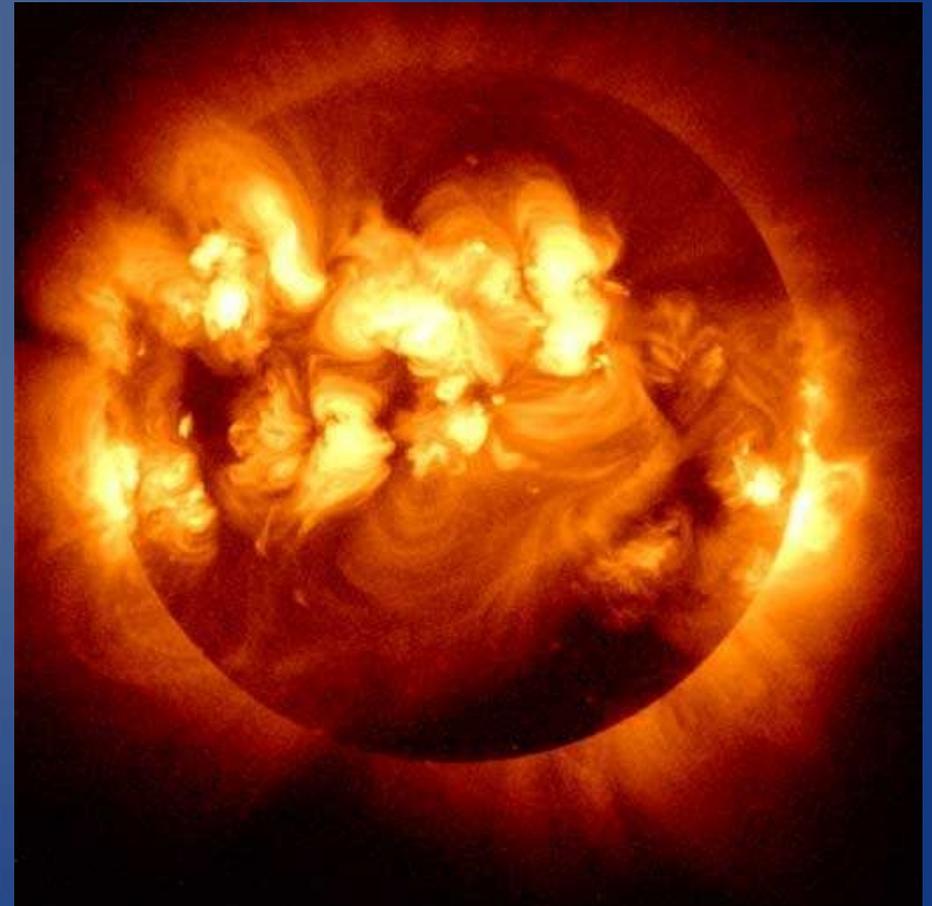
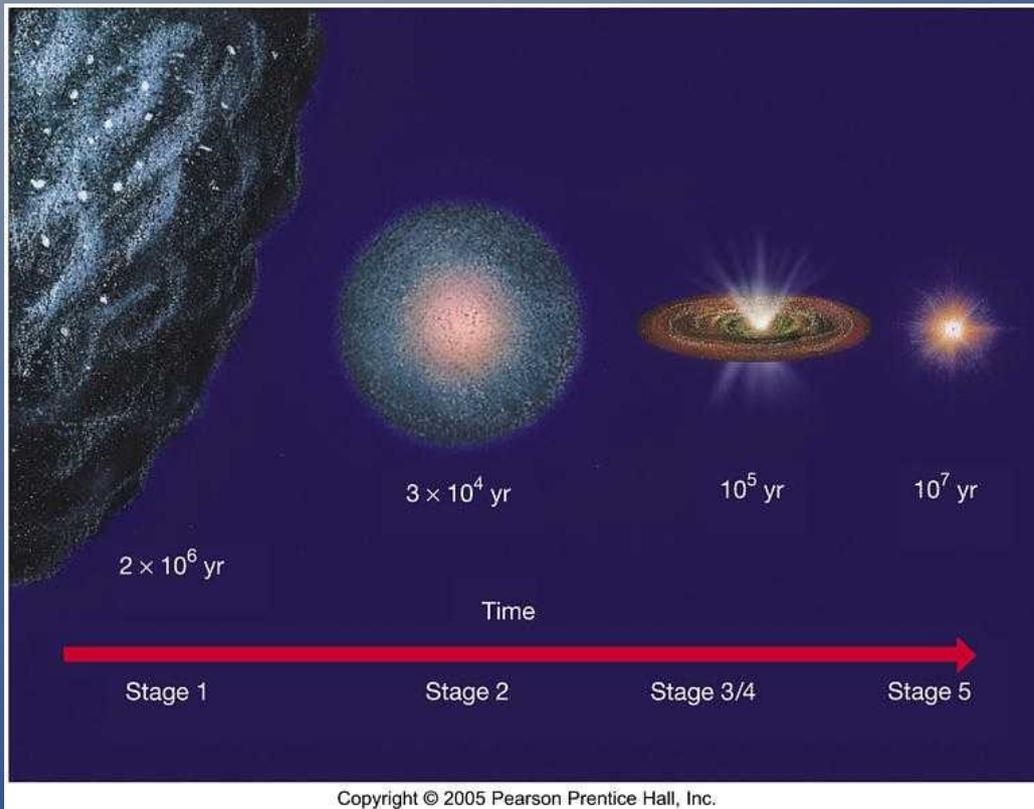


IGNICIÓN ESPONTÁNEA REQUIERE TEMPERATURA ALTA



Autogravedad

Ignición estelar



¿Qué tipo de fuego?



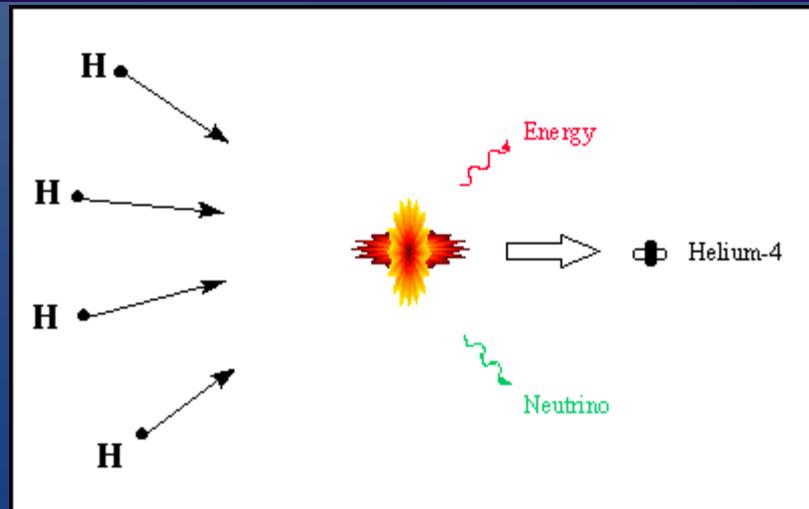
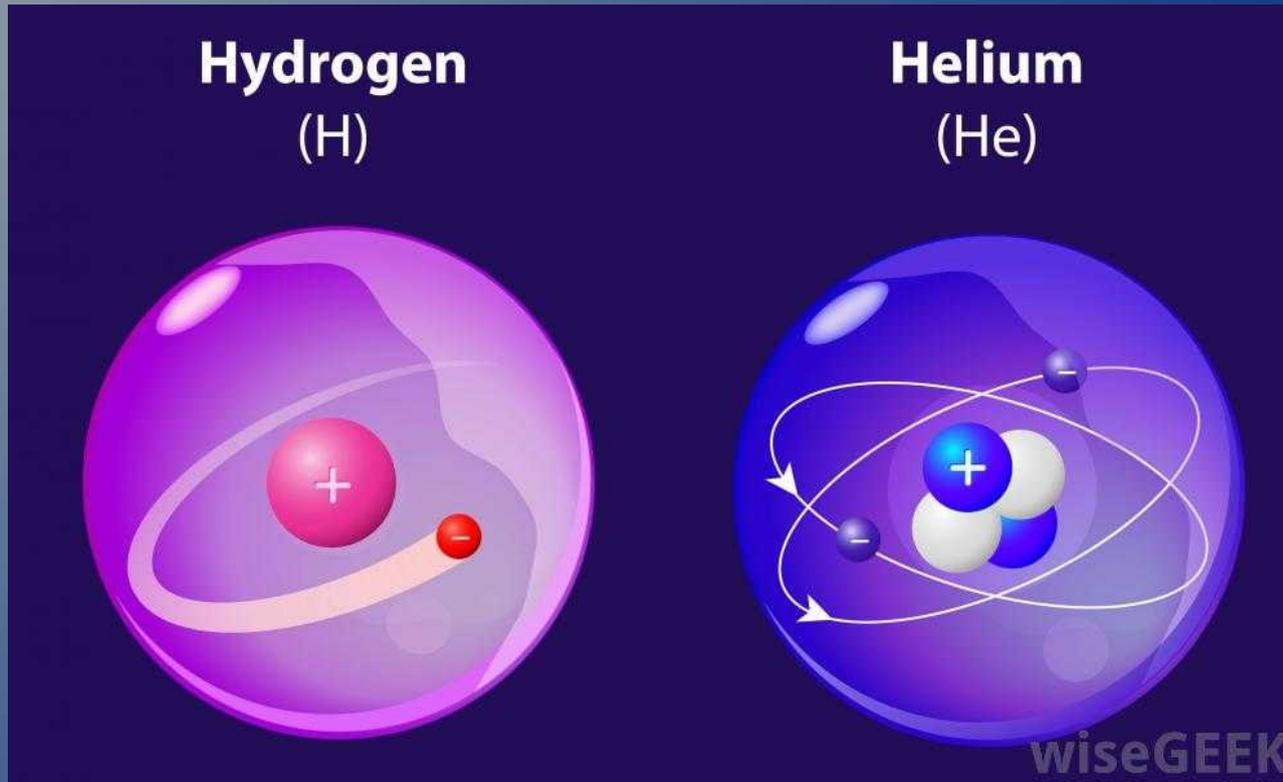
¿De dónde viene el oxígeno?
o ¿no hace falta?

¿Qué tipo de fuego?



¿De dónde viene el oxígeno?
o ¿no hace falta?

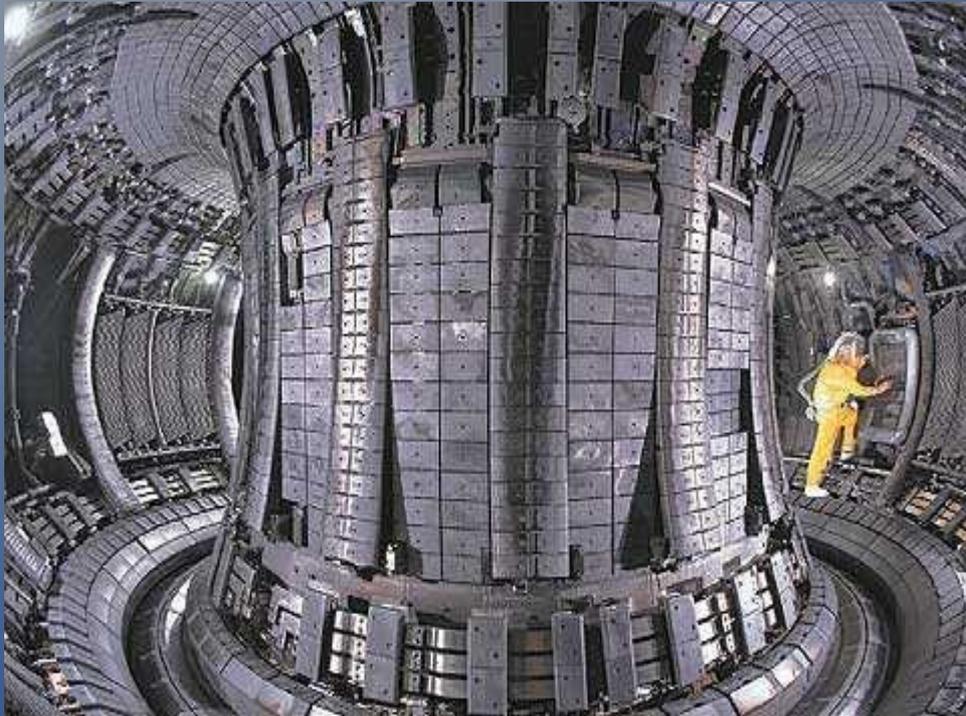
“Fuego” → Fusión nuclear (1930)



$$E=mc^2$$

($c=300\,000\text{ km/s}$)

Fusión nuclear



ITER



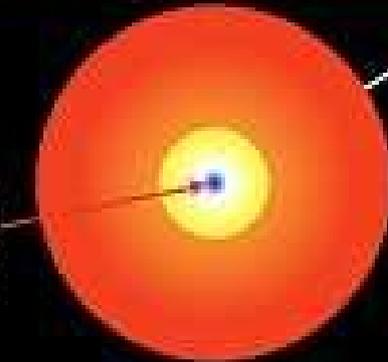
Bomba H

Stellar evolution

(sizes not to scale!)

Helium core fusion

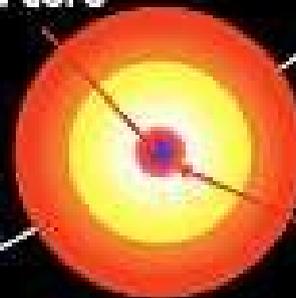
He fusion
(He \Rightarrow C)



Helium core

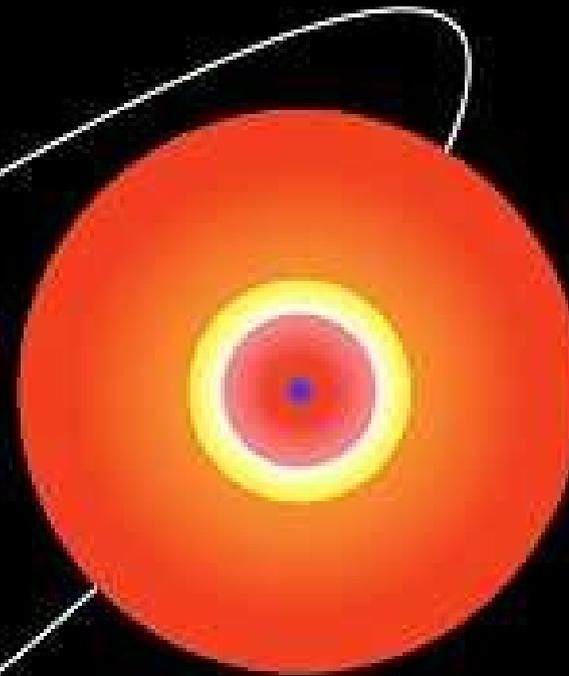
Hydrogen shell fusion

Hydrogen shell

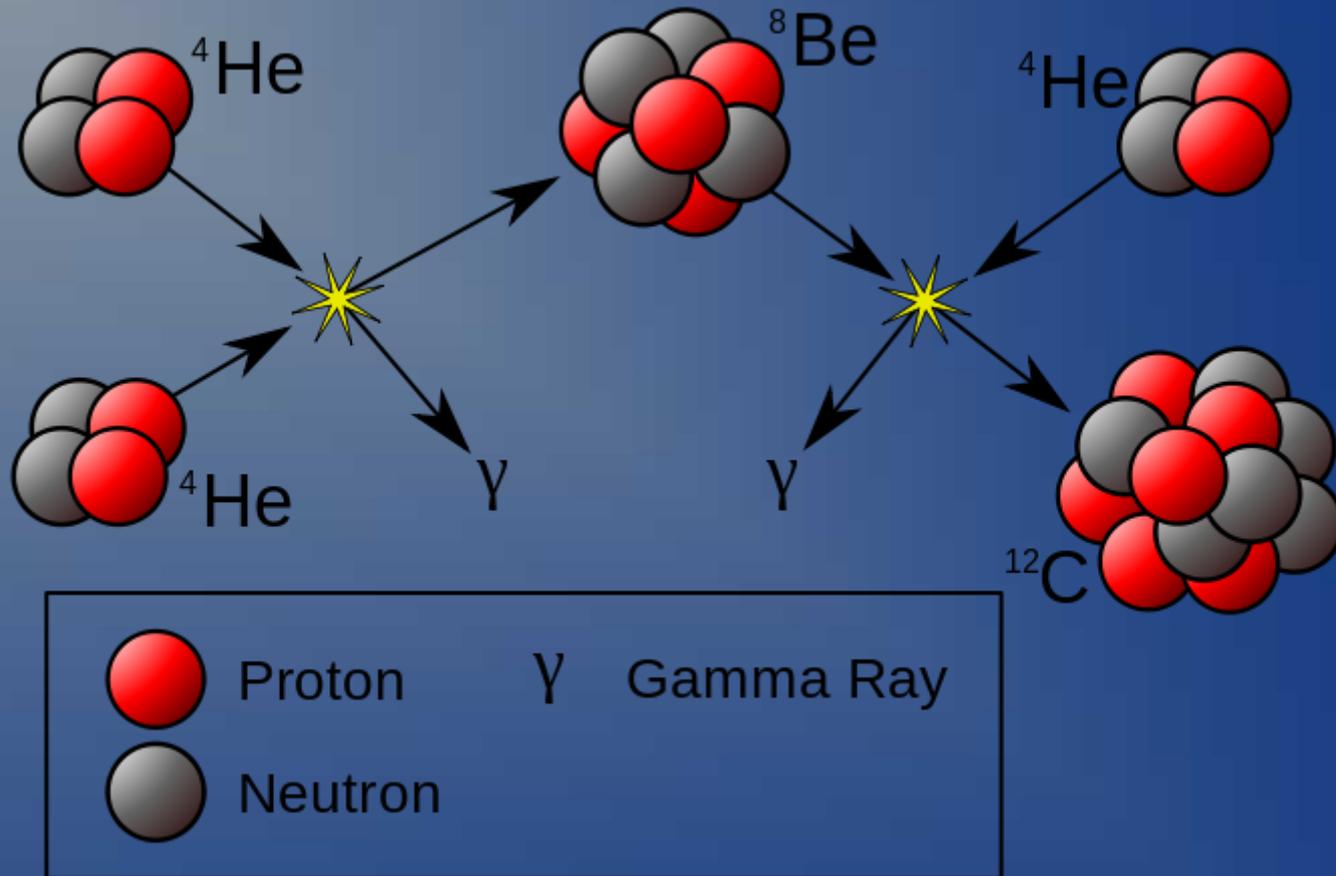


Hydrogen core fusion

Hydrogen core
(H \Rightarrow He)



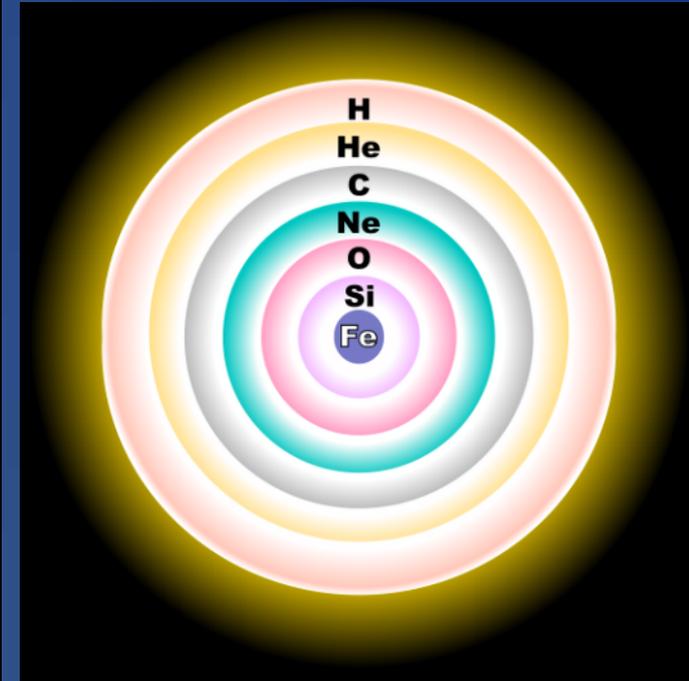
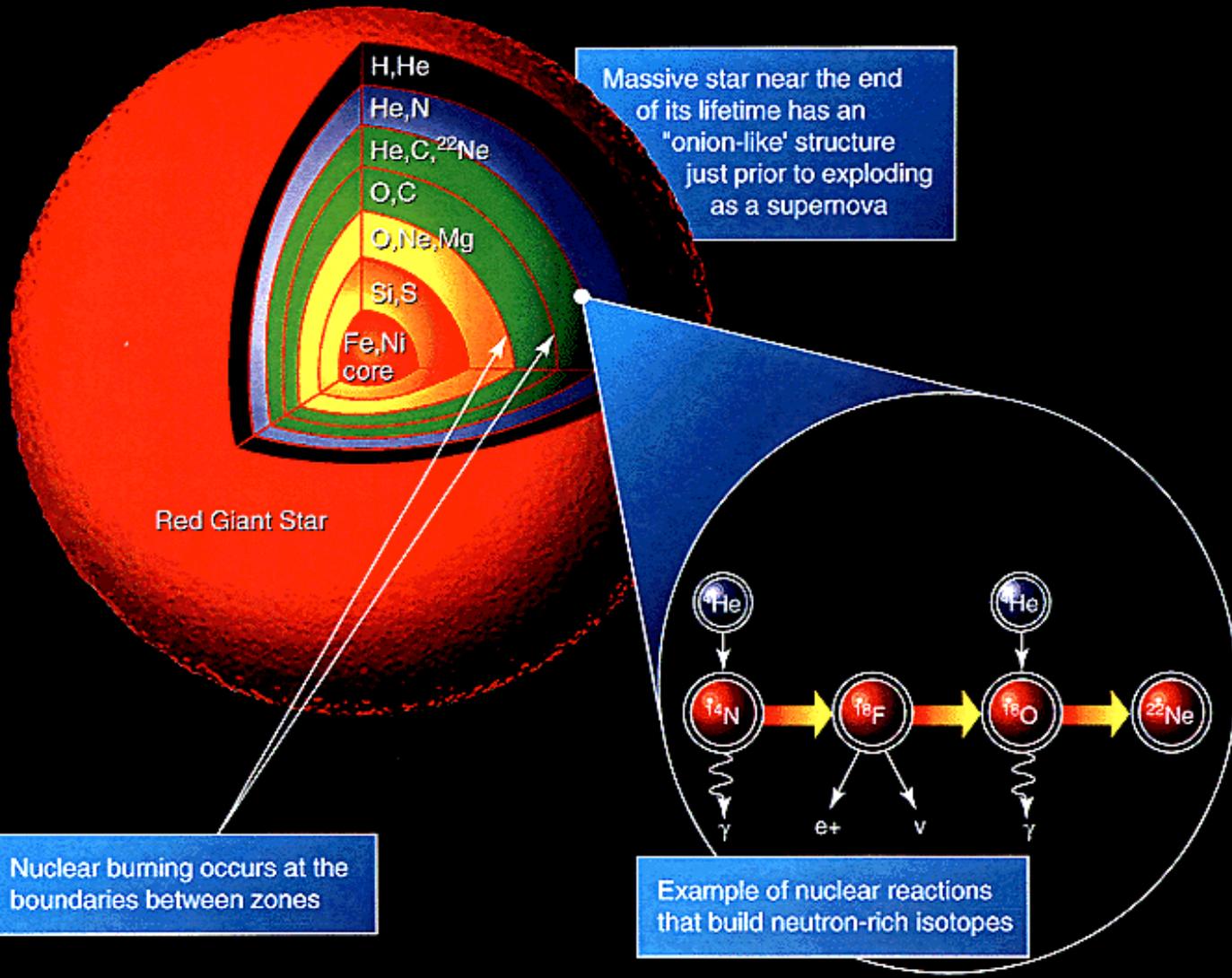
Fusión de Helio



“Triple Alfa”

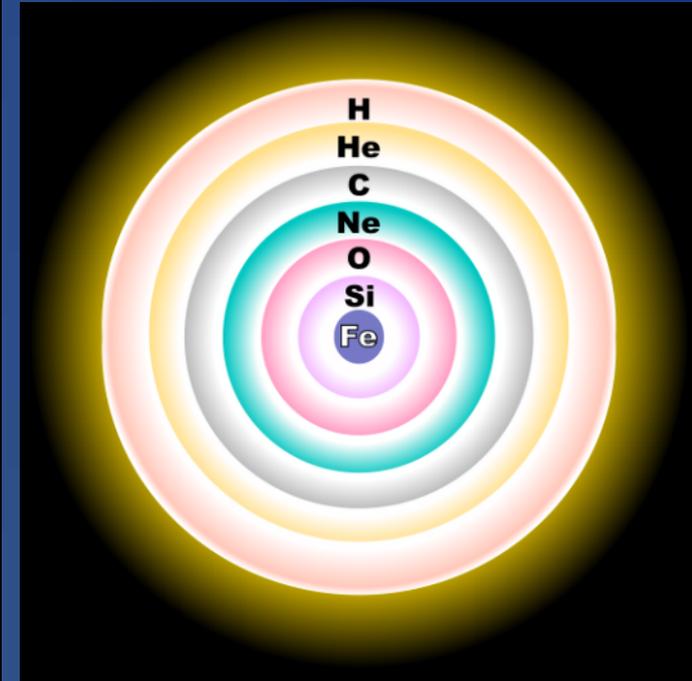
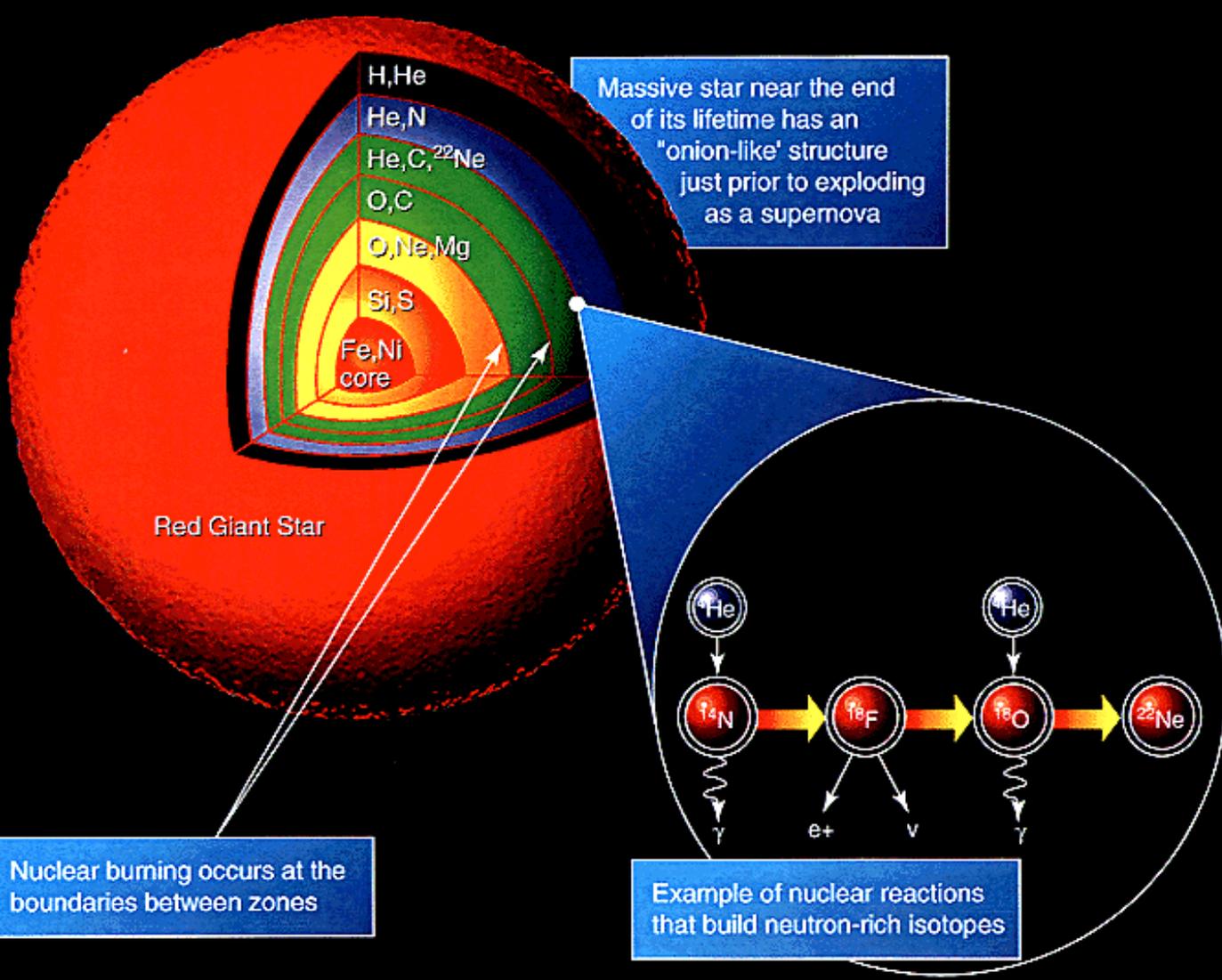
Requiere una T incluso mucho mayor

Etcétera



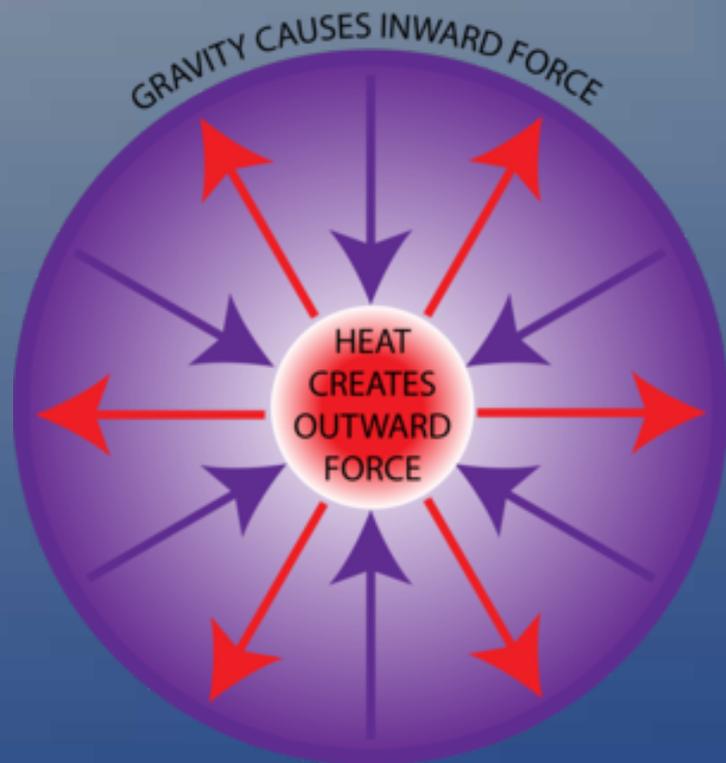
Cada paso requiere T mayor

Etcétera

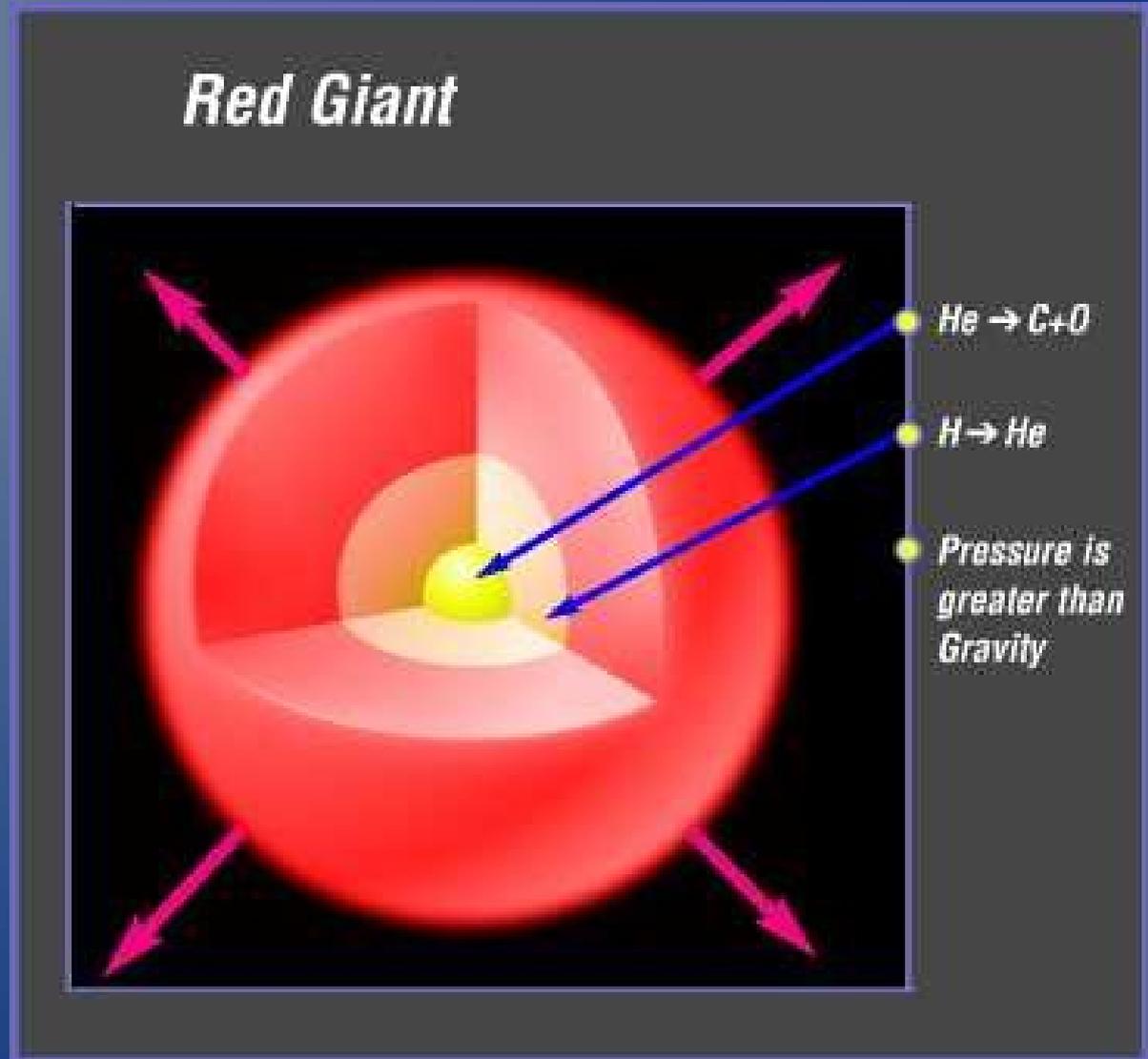


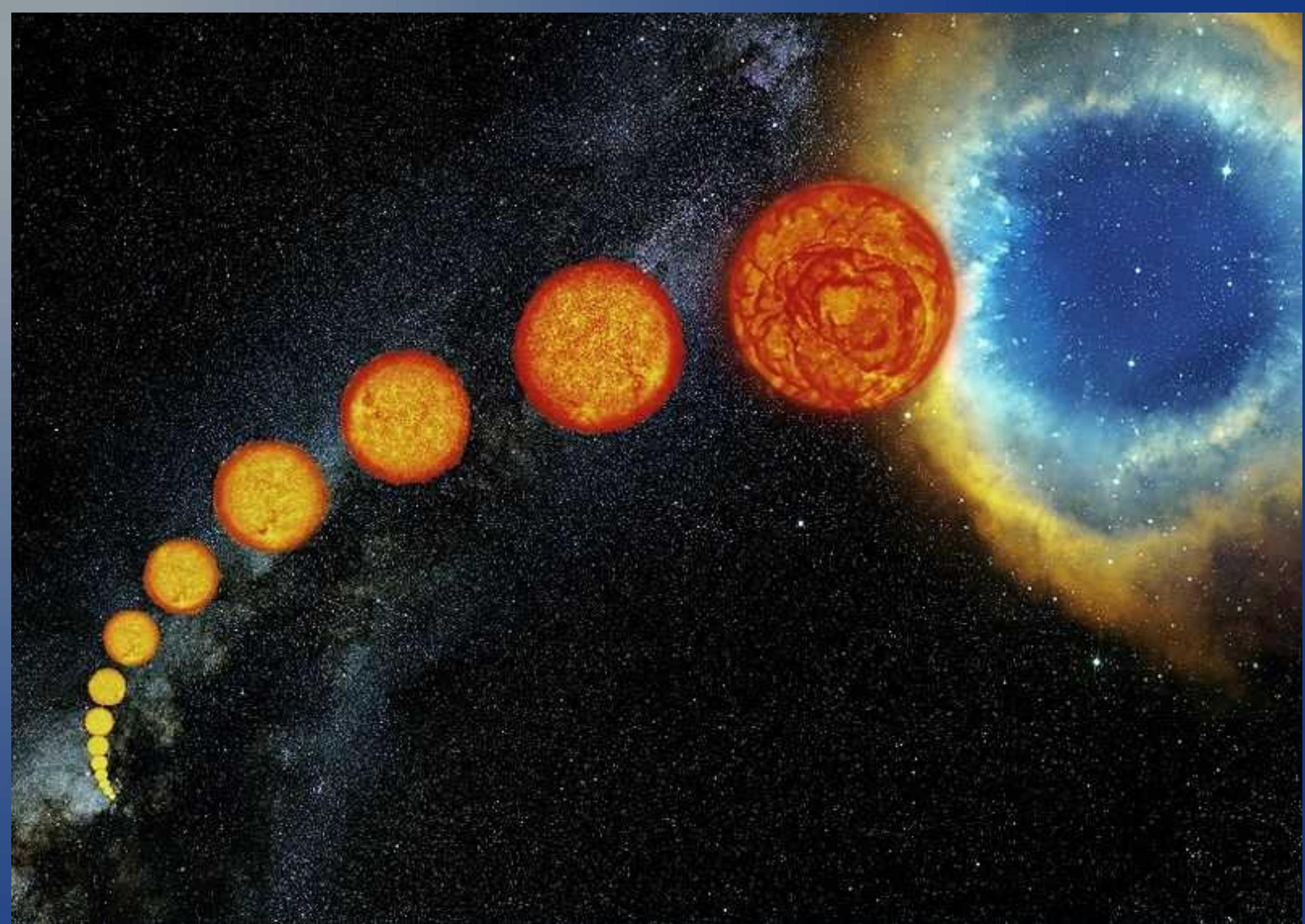
Cada paso requiere T mayor

Entre etapas: colapso parcial + expansión

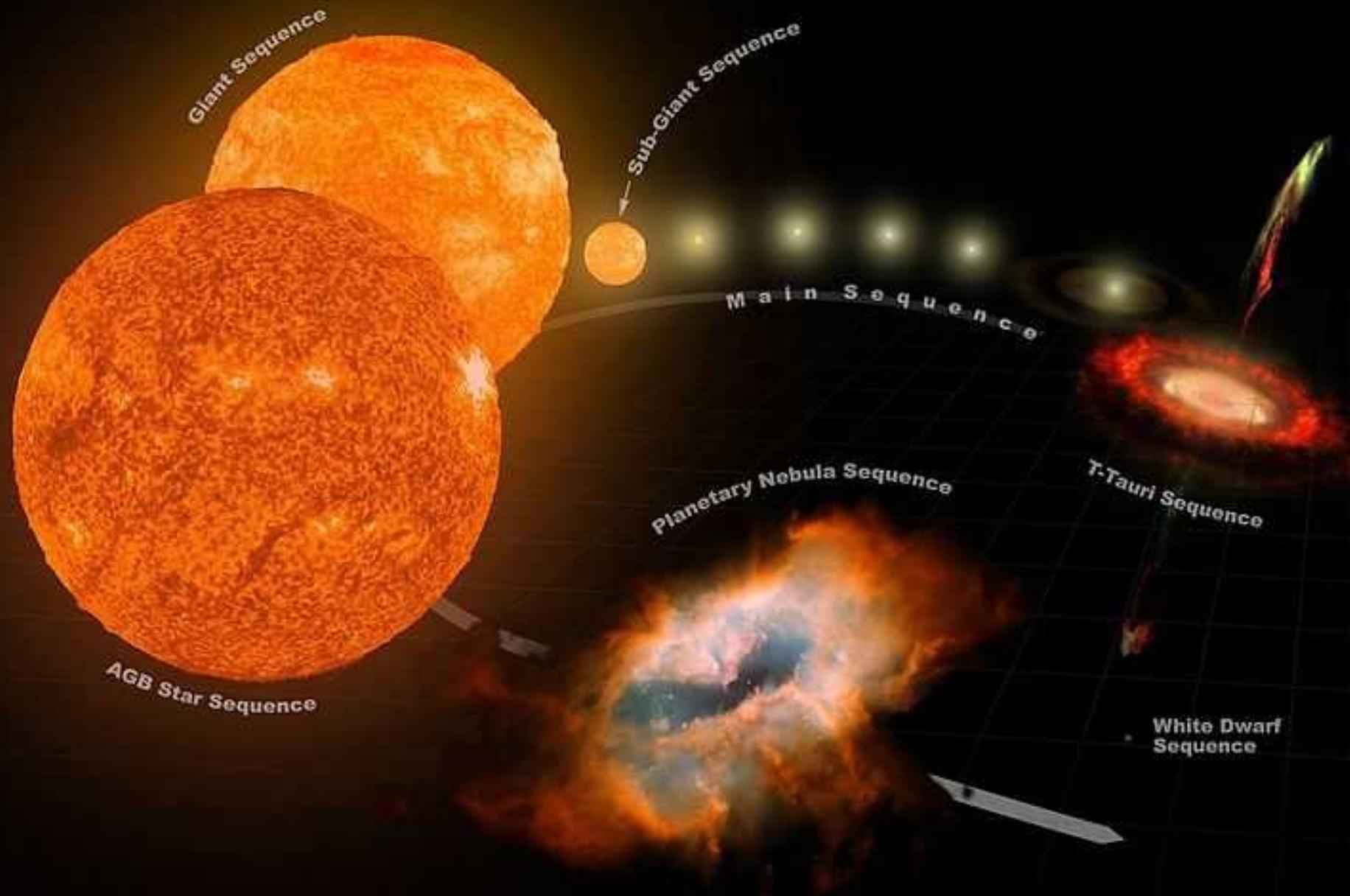


Equilibrio





Stellar Evolution (0.8 - 8 M_{\odot})

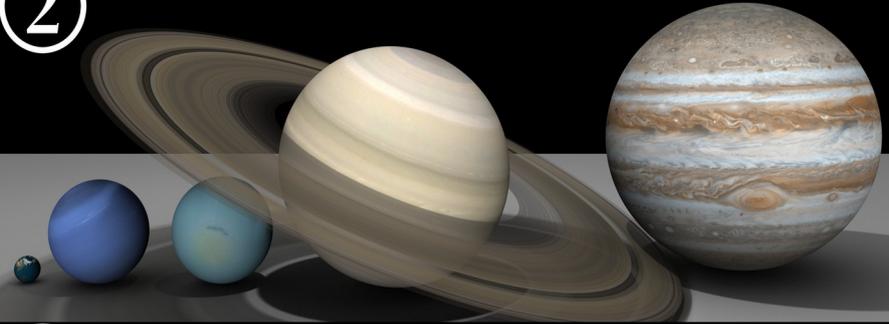


¿“Gigantes” rojas?

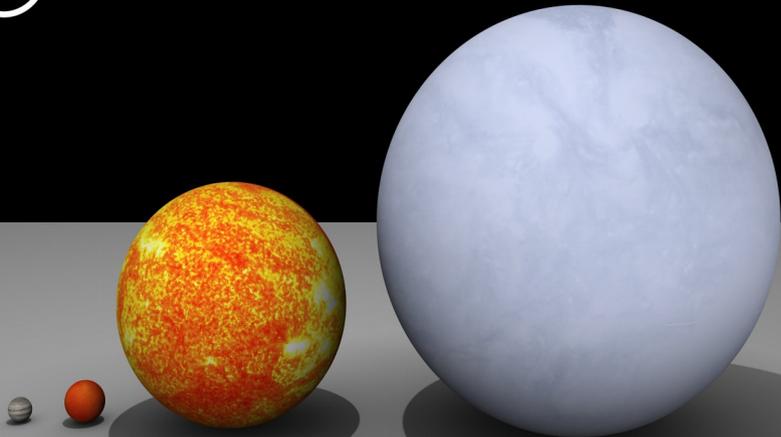
① Mercury < Mars < Venus < Earth



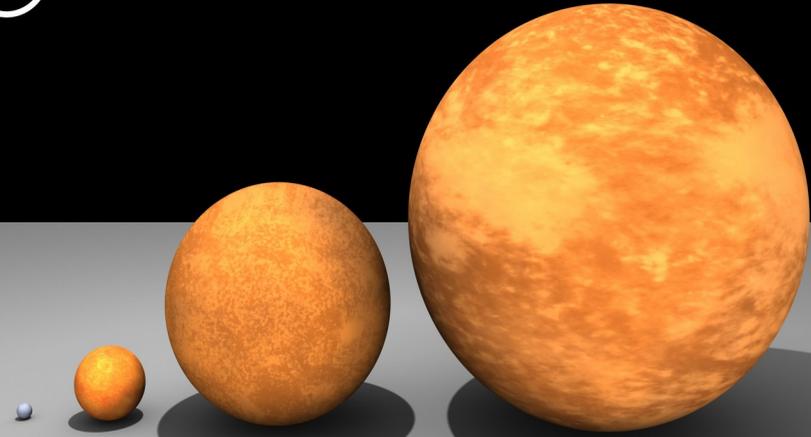
② Earth < Neptune < Uranus < Saturn < Jupiter



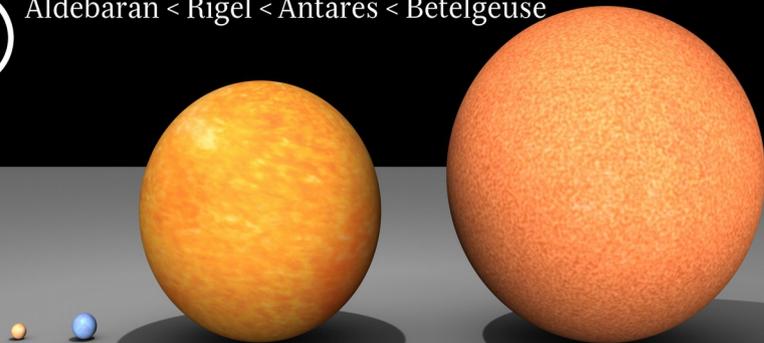
③ Jupiter < Wolf 359 < Sun < Sirius



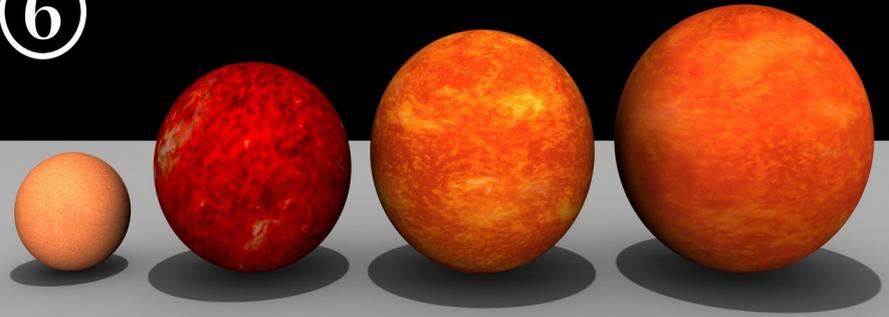
④ Sirius < Pollux < Arcturus < Aldebaran



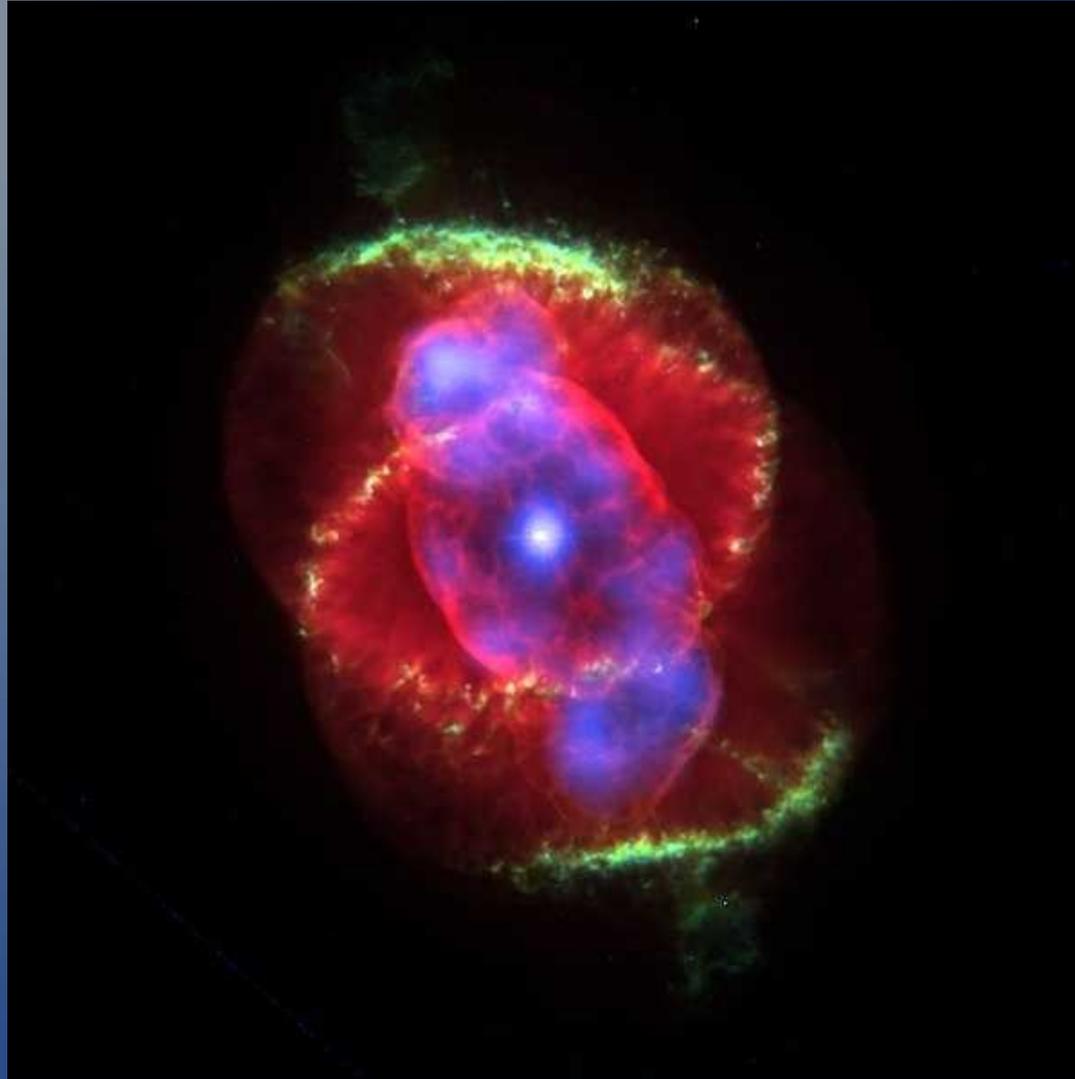
⑤ Aldebaran < Rigel < Antares < Betelgeuse



⑥ Betelgeuse < Mu Cephei < VV Cephei A < VY Canis Majoris

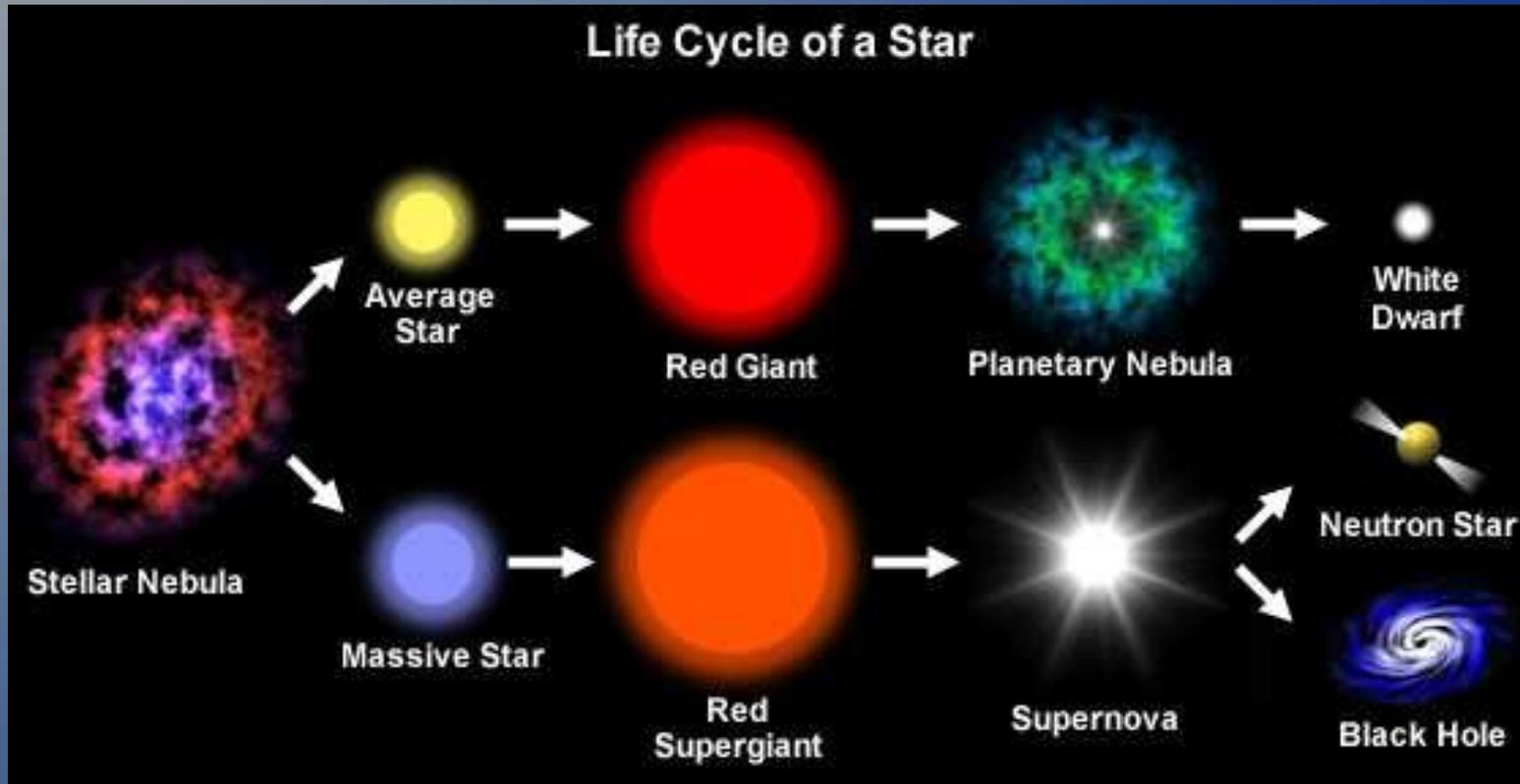


Nebulosa “planetaria” (1780)



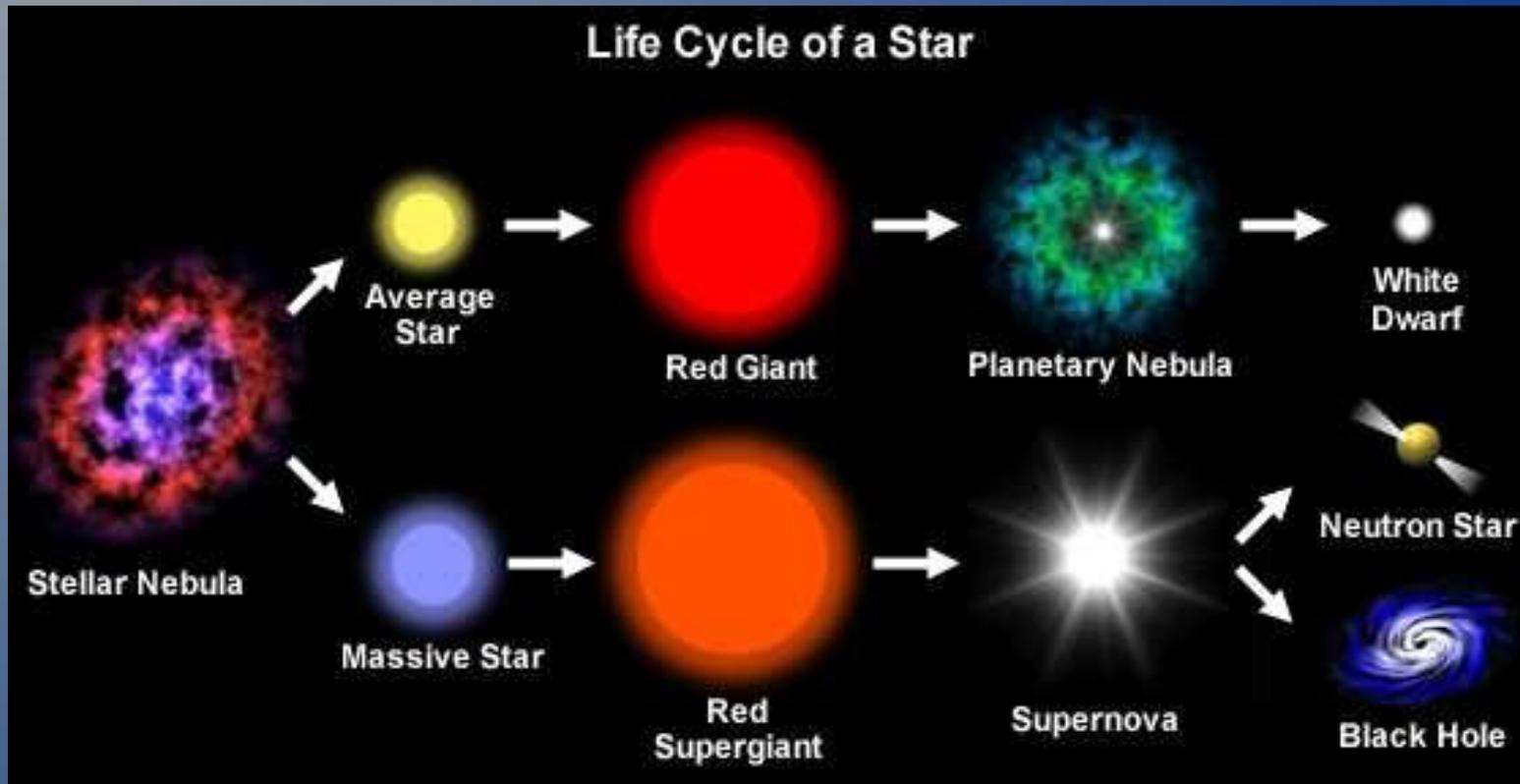
“Ojo de gato”

¿Todas las estrellas terminan así?

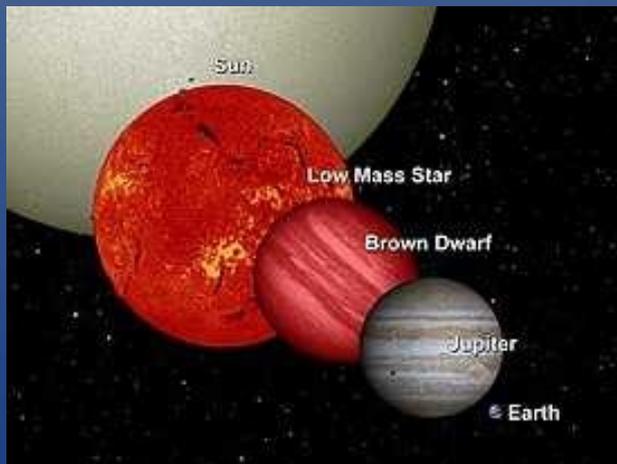


+

¿Todas las estrellas terminan así?

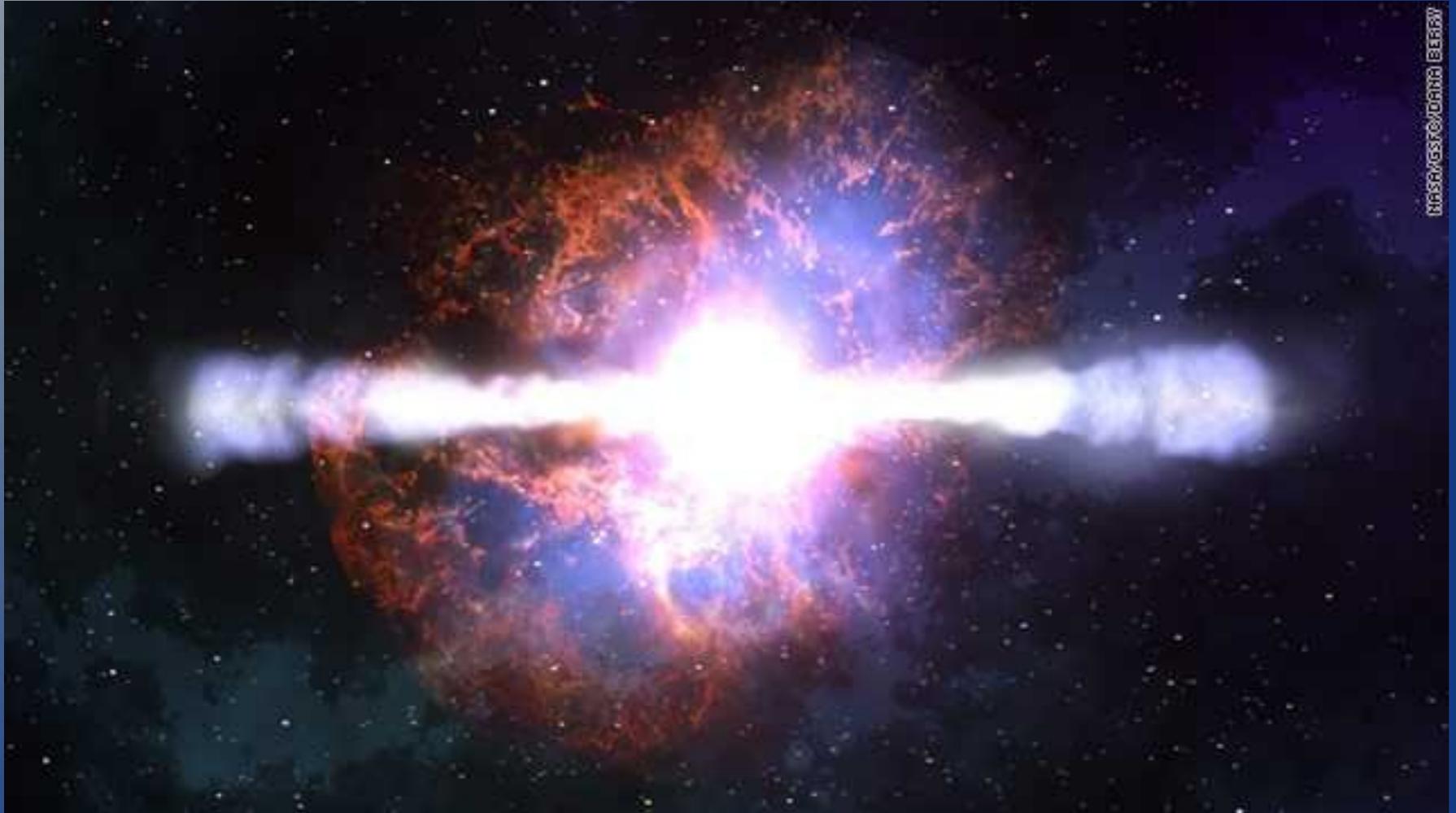


+



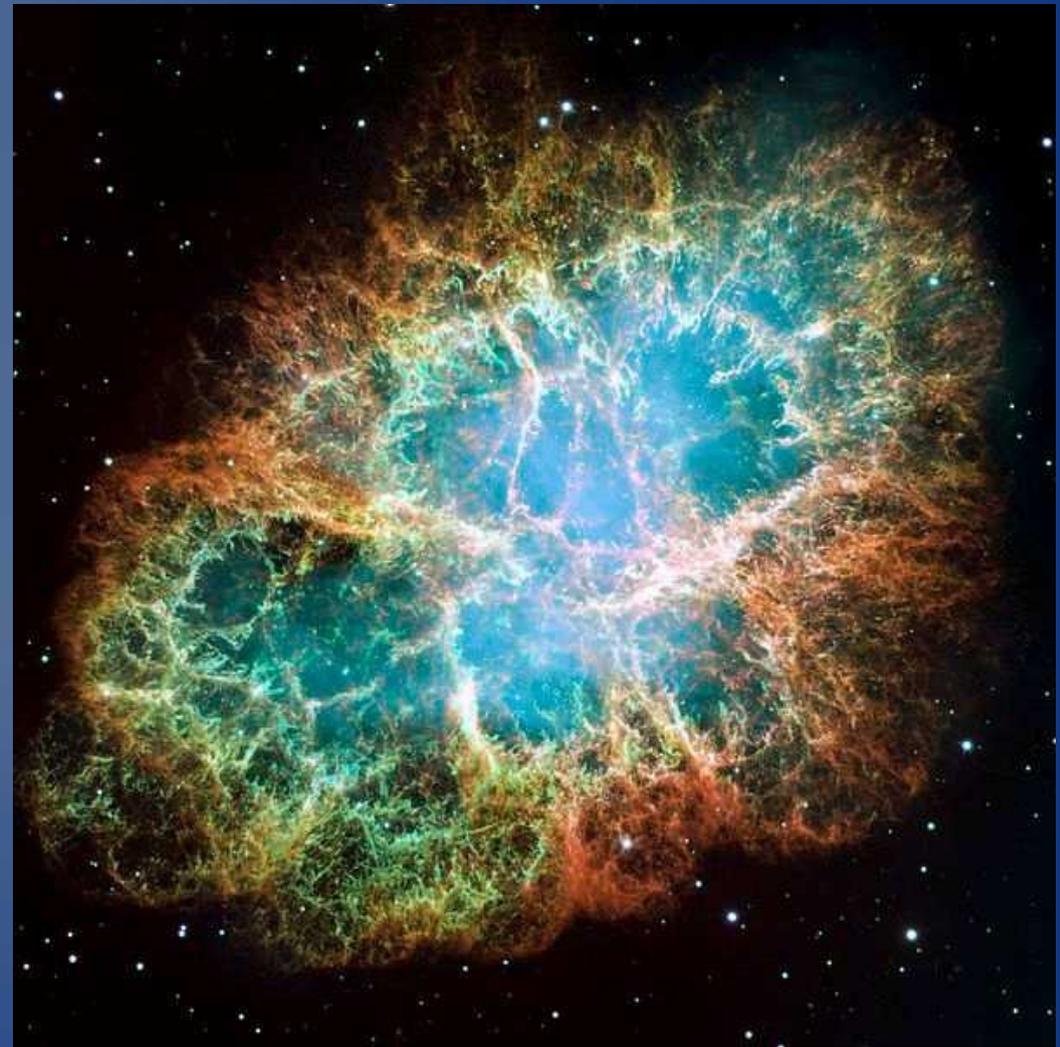
(IAC 1995)

Supernova





Luminosidad $>$ galaxia

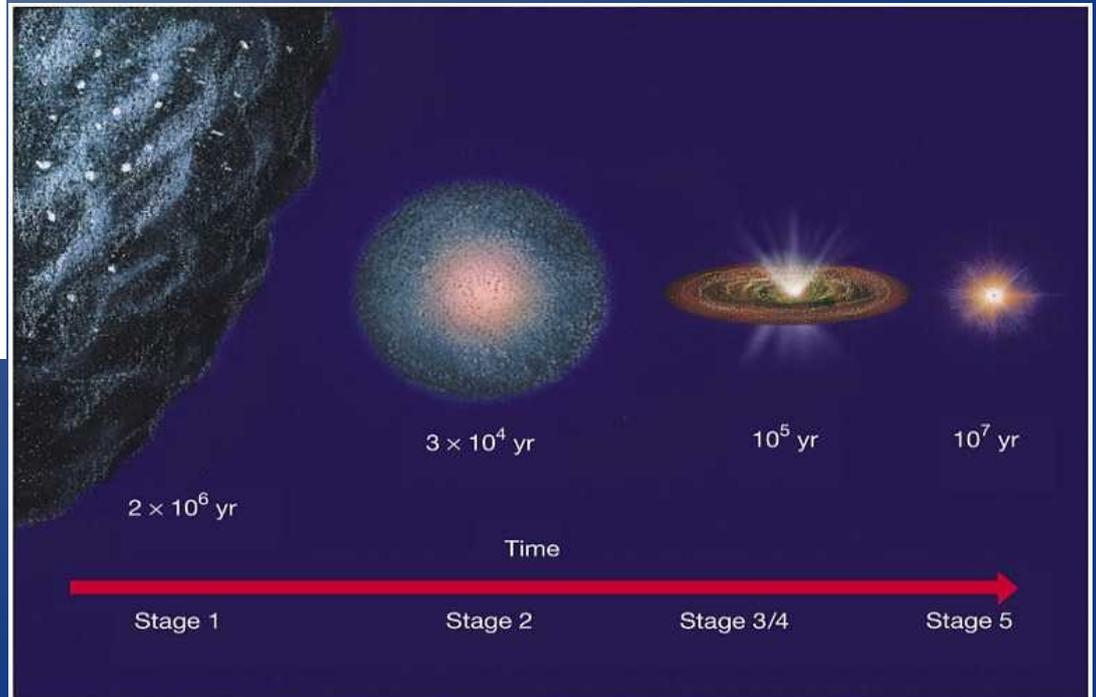
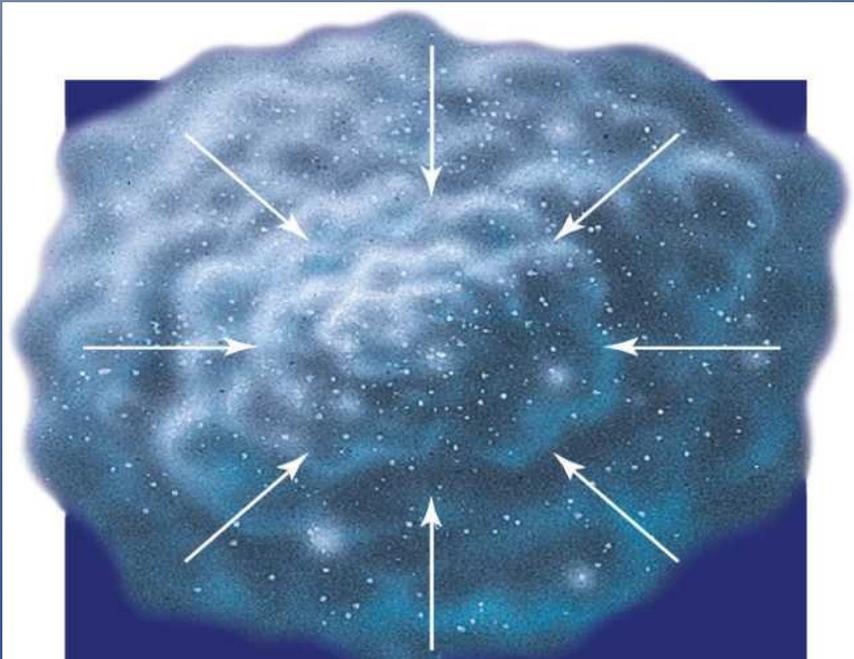


“Nebulosa del Cangrejo”
(resto de SN)

Y empezamos de nuevo...

Y empezamos de nuevo...

NUBES COLAPSAN (autogravedad)



Etcétera...

“Sol = estrella de 3^a generación”

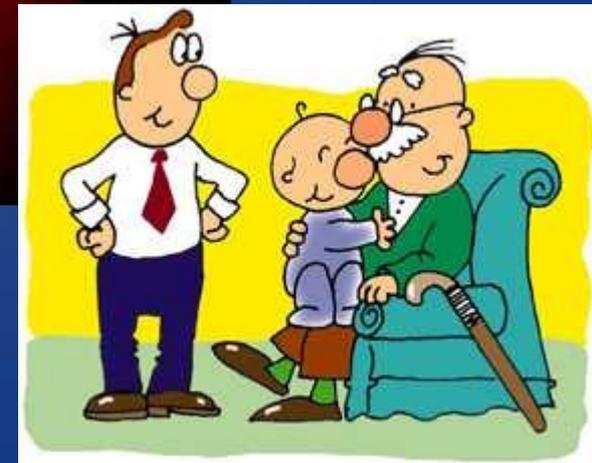
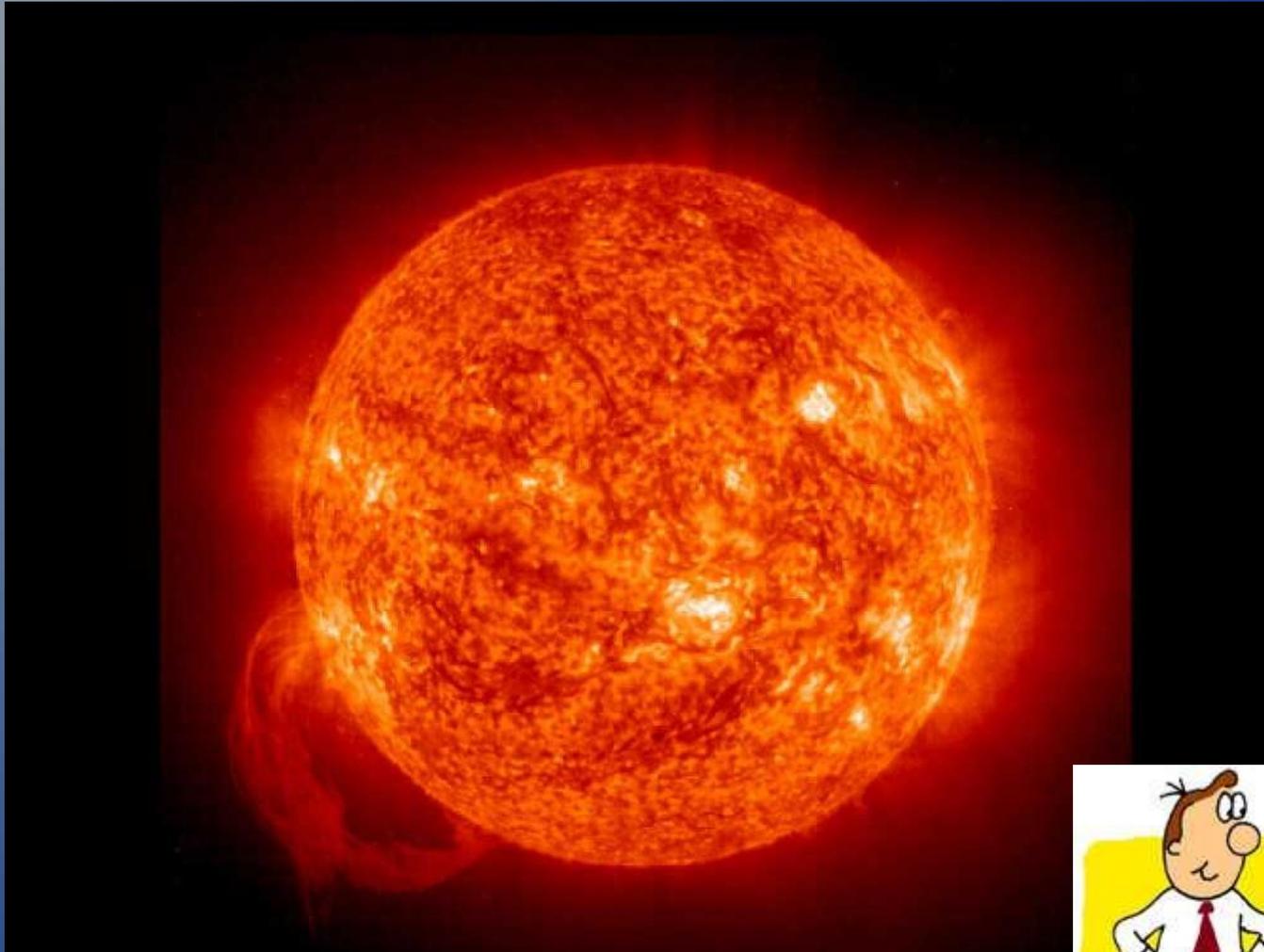
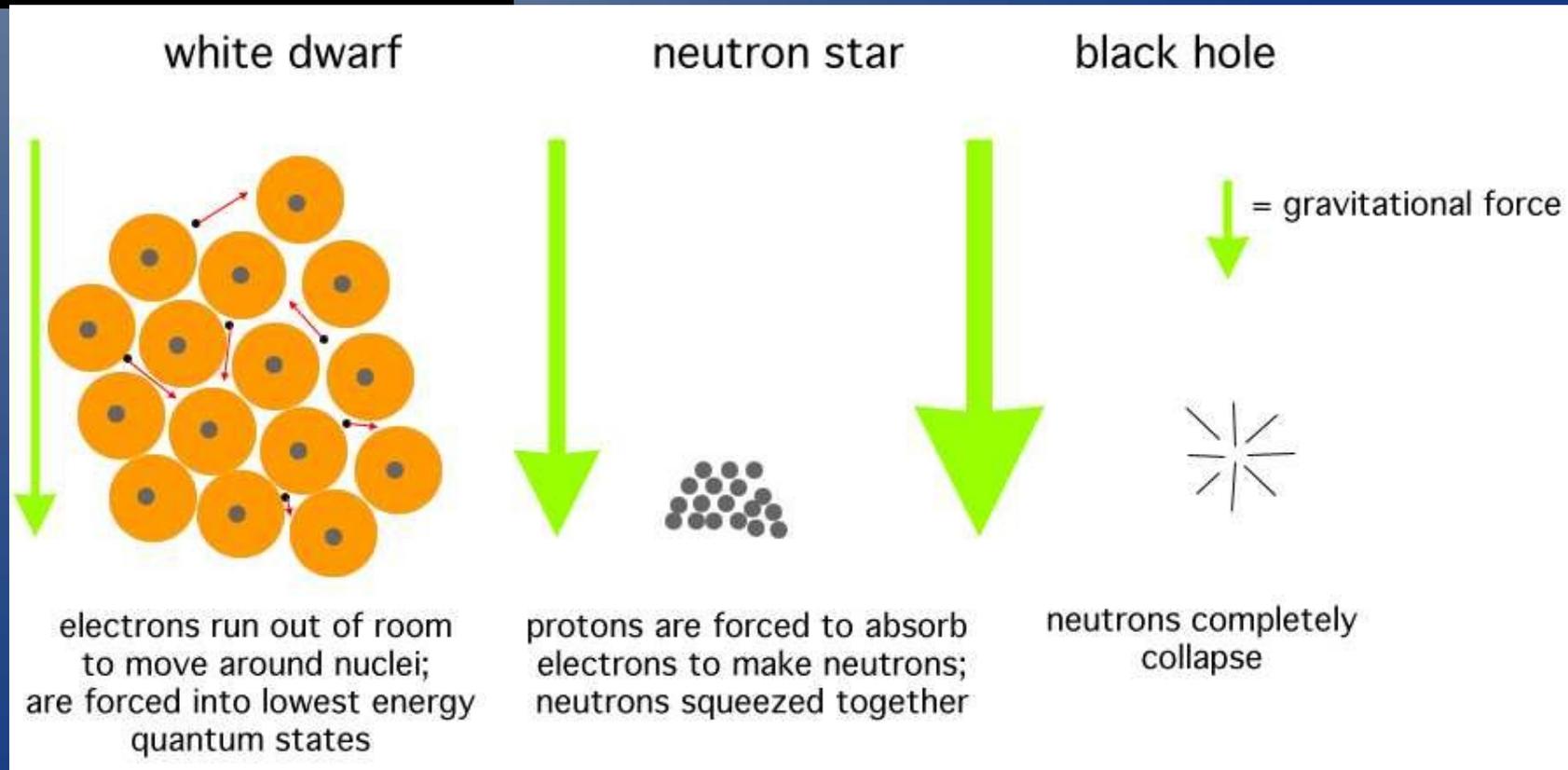
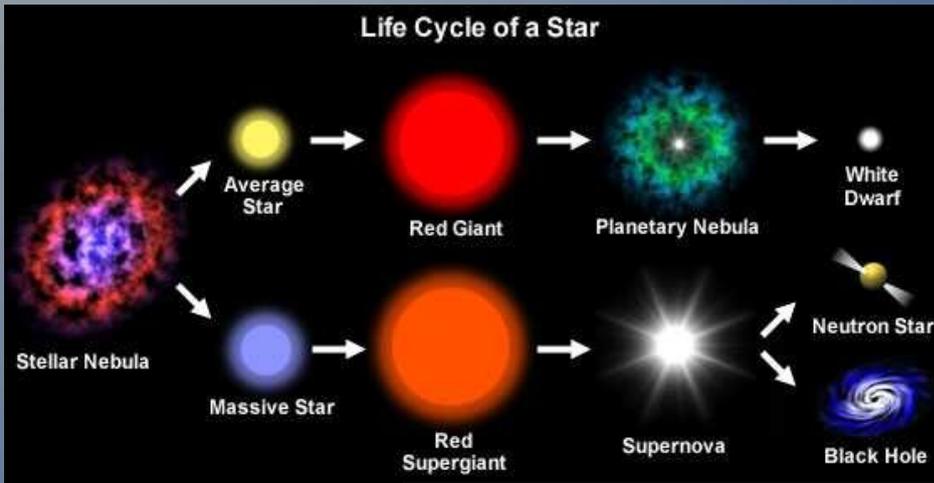


Tabla periódica

H B																	He B						
Li C	Be C																	B C	C S L	N S L	O S L	F L	Ne S L
Na L	Mg L																	Al \$ L	Si \$ L	P L	S S L	Cl L	Ar L
K L	Ca L	Sc L	Ti \$ L	V \$ L	Cr L	Mn L	Fe \$ L	Co \$	Ni \$	Cu L	Zn L	Ga \$	Ge \$	As L	Se \$	Br \$	Kr \$						
Rb \$	Sr L	Y L	Zr L	Nb L	Mo \$ L	Tc L	Ru \$ L	Rh \$	Pd \$ L	Ag \$ L	Cd \$ L	In \$ L	Sn \$ L	Sb \$	Te \$	I \$	Xe \$						
Cs \$	Ba L	Hf \$ L	Ta \$ L	W \$ L	Re \$	Os \$	Ir \$	Pt \$	Au \$	Hg \$ L	Tl \$ L	Pb \$	Bi \$	Po \$	At \$	Rn \$							
Fr \$	Ra \$	La L	Ce L	Pr \$ L	Nd \$ L	Pm \$ L	Sm \$ L	Eu \$	Gd \$	Tb \$	Dy \$	Ho \$	Er \$	Tm \$	Yb \$ L	Lu \$							
		Ac \$	Th \$	Pa \$	U \$	Np \$	Pu \$	Am M	Cm M	Bk M	Cf M	Es M	Fm M	Md M	No M	Lr M							

B Big Bang	L Large stars	\$ Super-novae
C Cosmic rays	S Small stars	M Man-made

¿Qué queda de la estrella original?



Constituyentes

Building blocks



proton

Charge = +1



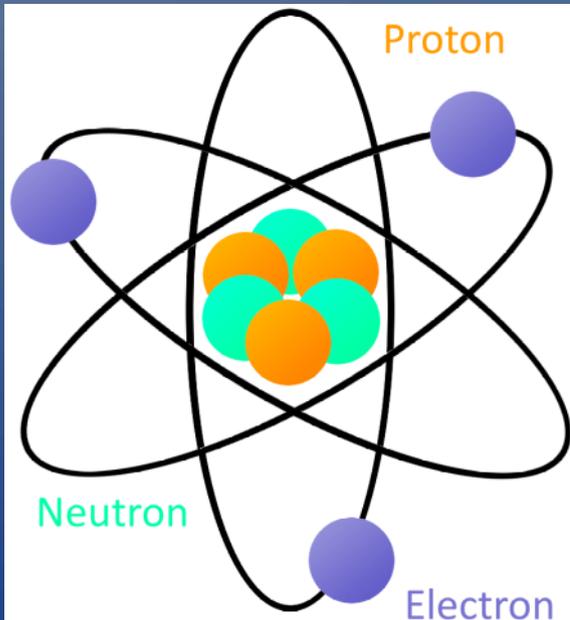
electron

Charge = -1

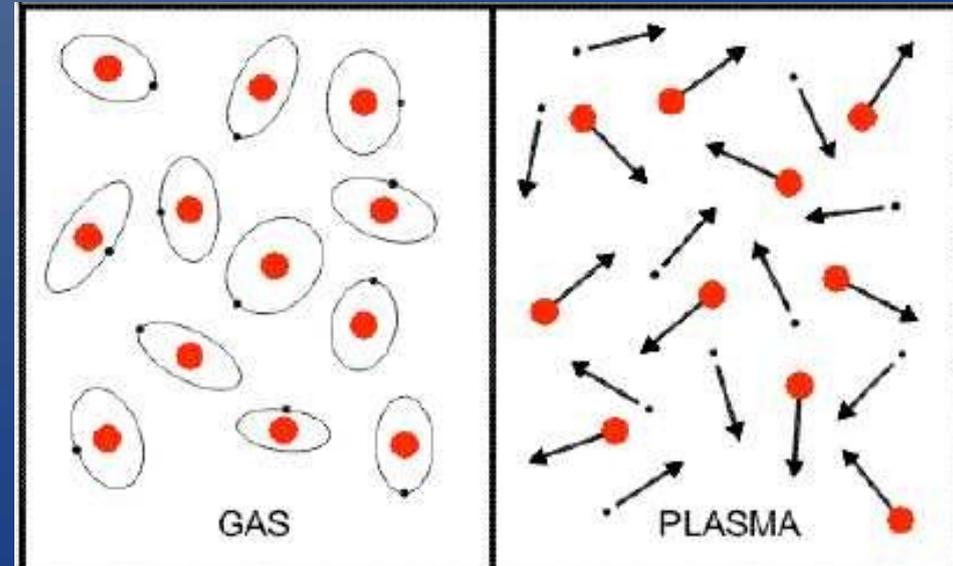


neutron

Charge = 0

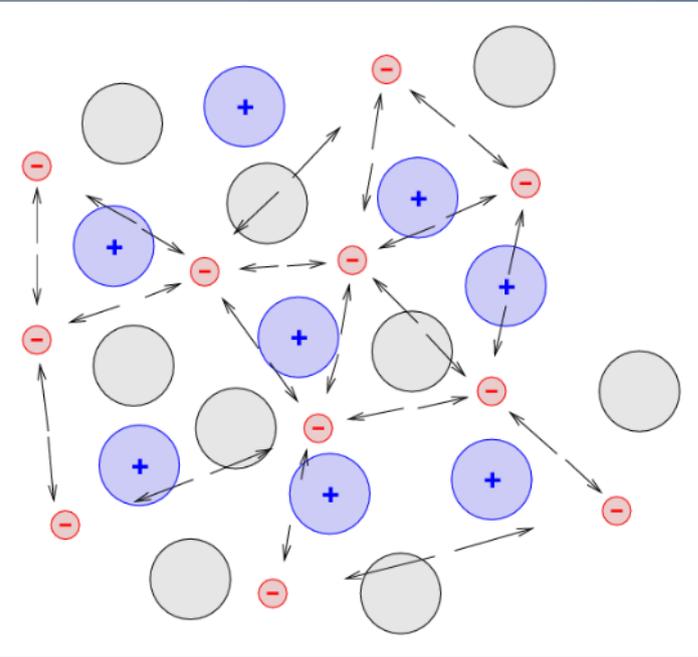


Materia "normal"

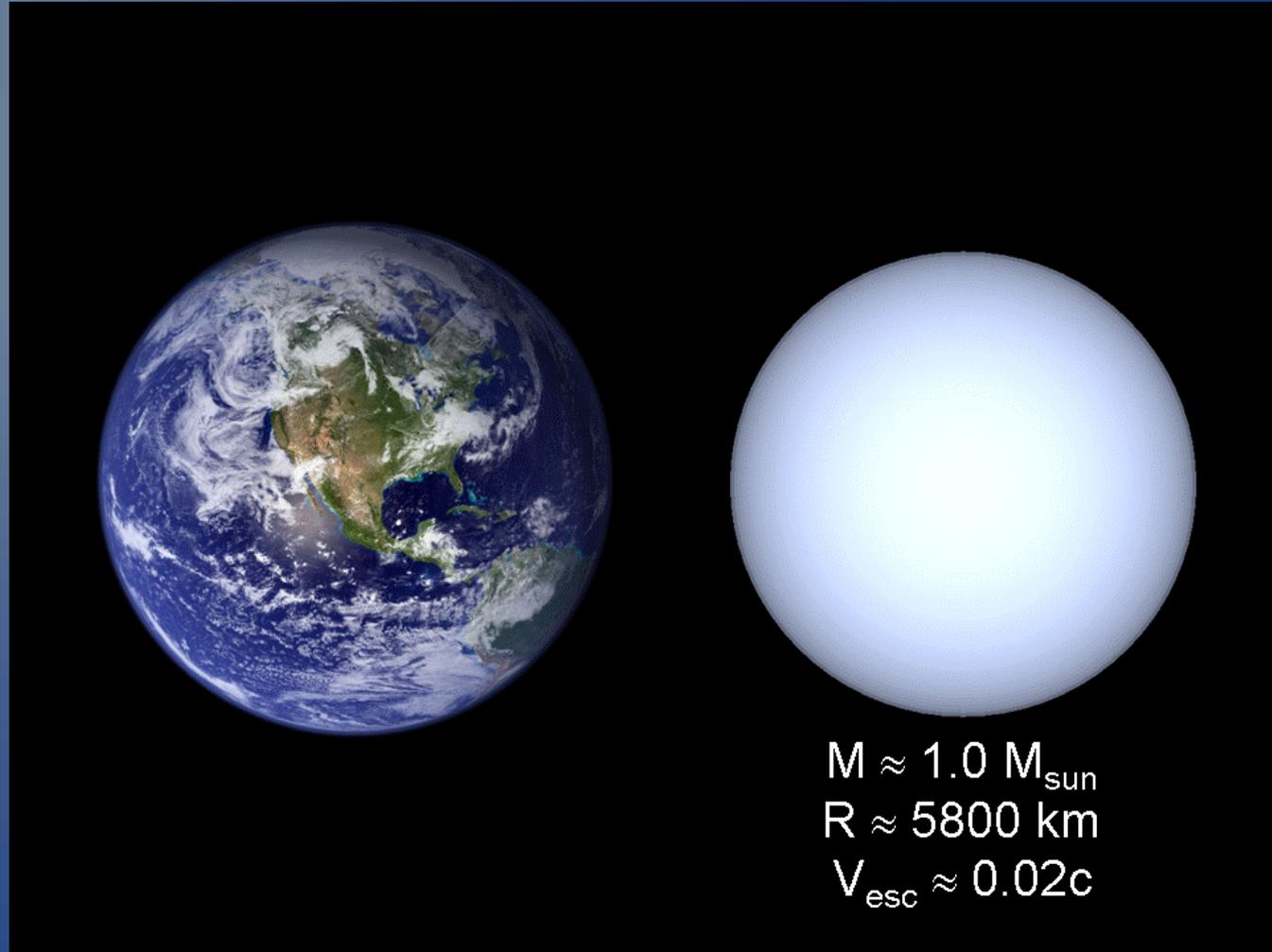


Plasma: e⁻ libres

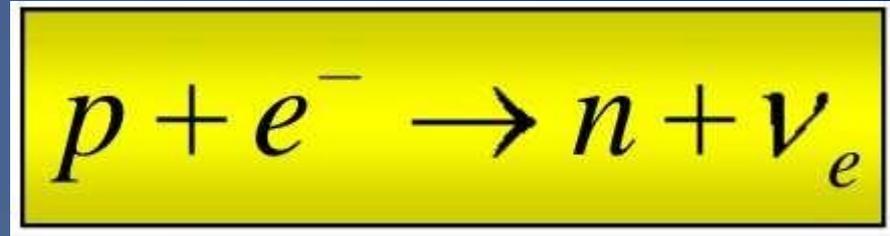
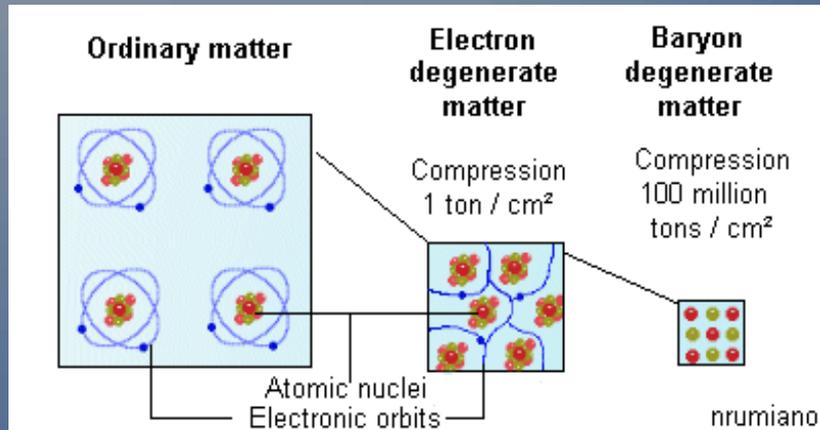
Enanas blancas



Presión de degeneración
electrónica

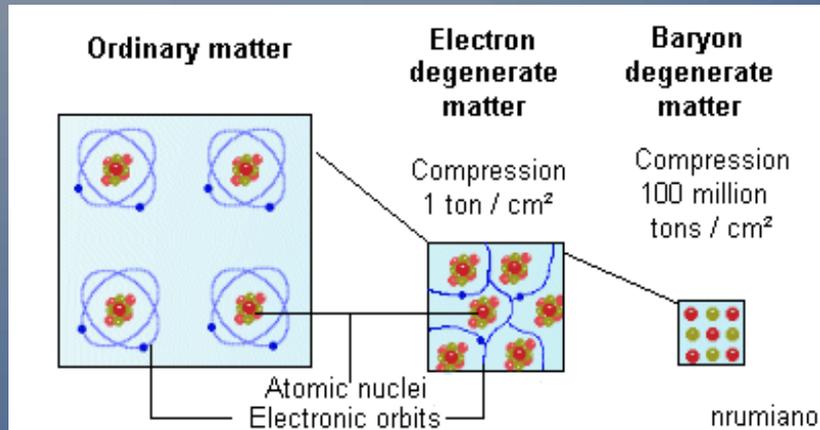


Estrella de neutrones

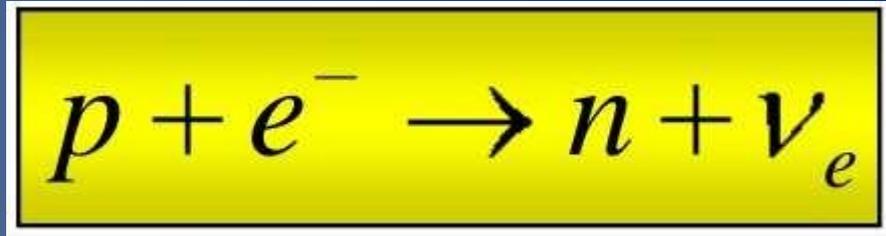


Presión de degeneración
de neutrones

Estrella de neutrones



Presión de degeneración de neutrones



There are 3 types of people:

Proton



"I'm Positive"

Electron

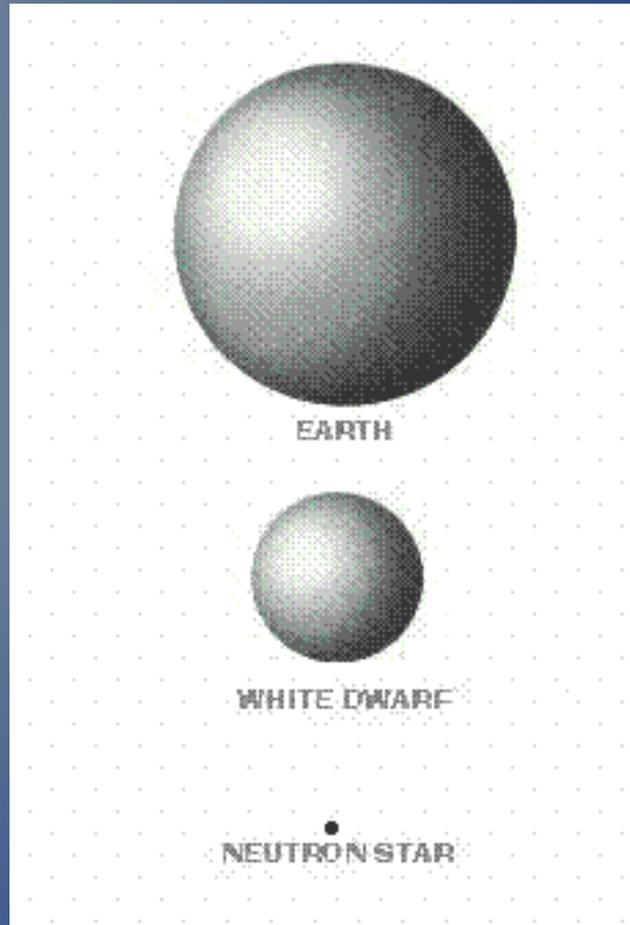


"I'm Negative"

Neutron



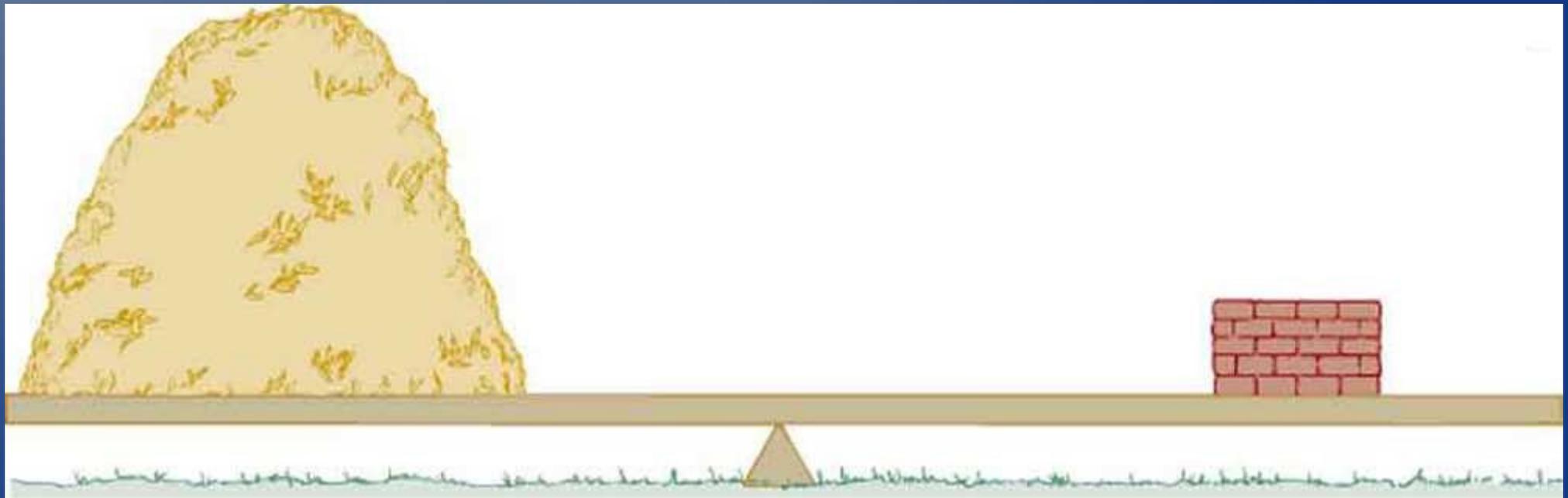
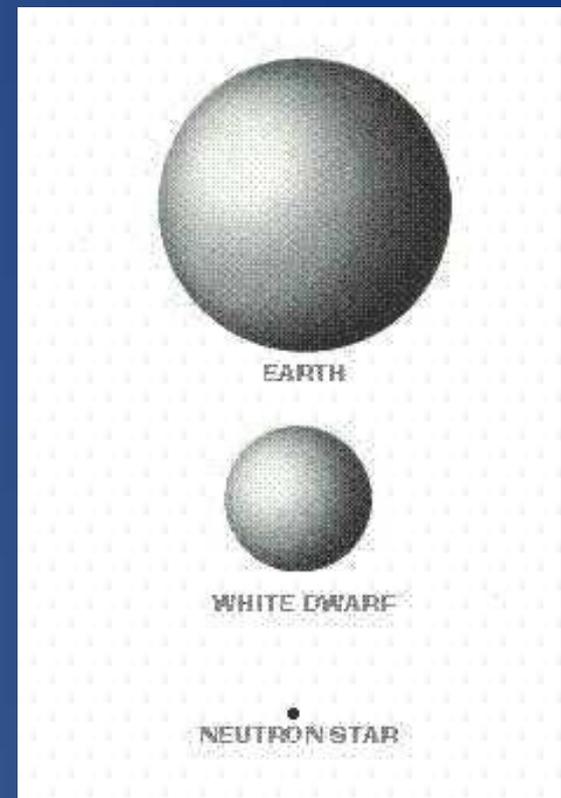
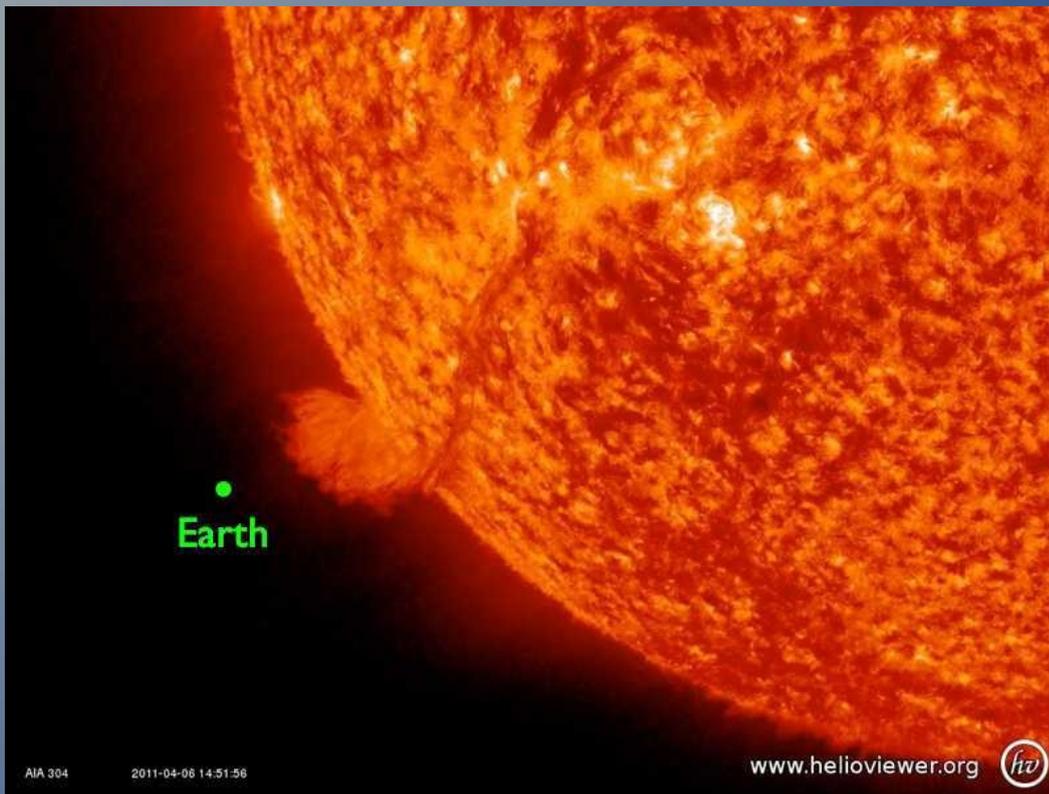
"I don't give a f*ck"



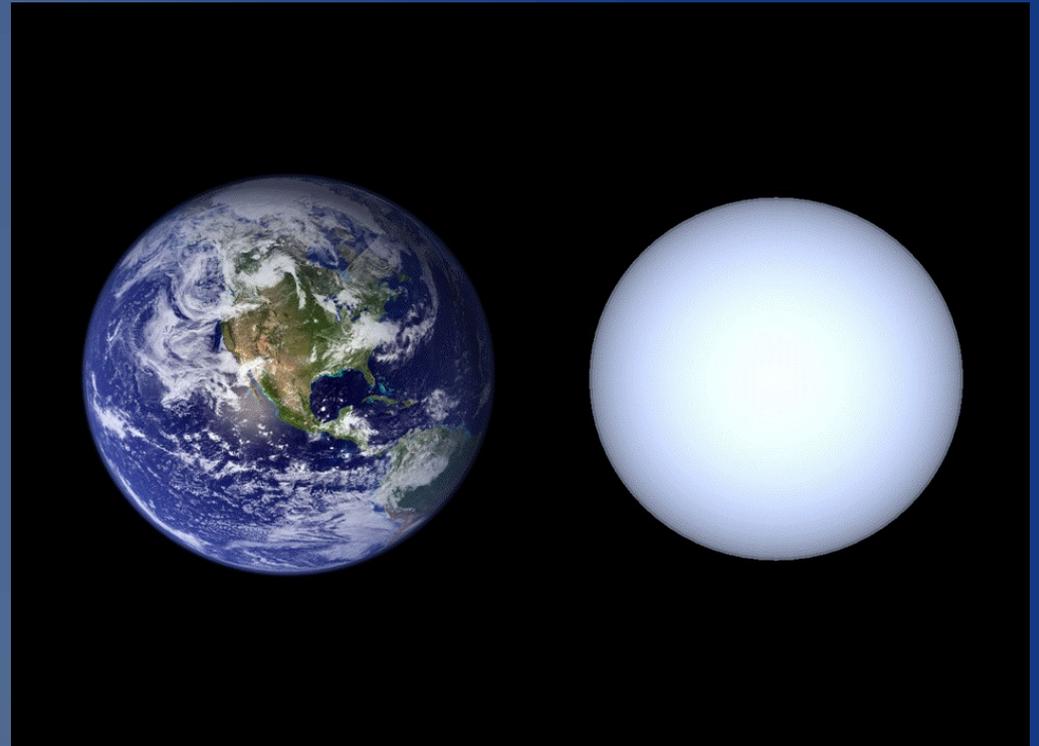
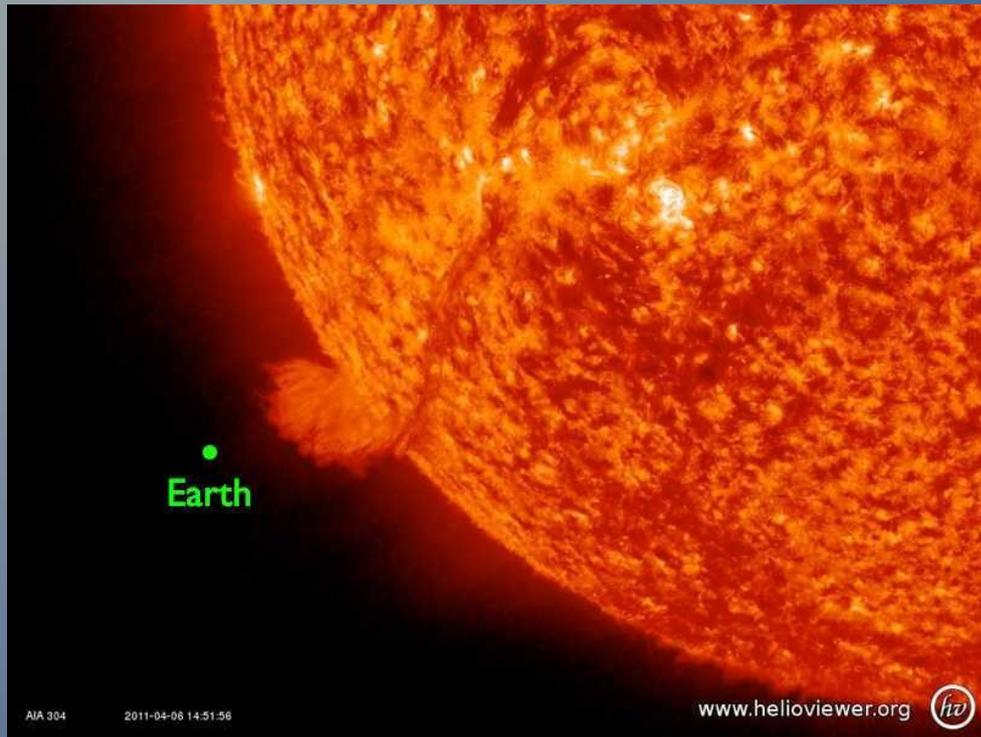
TIERRA: $d=12.000$ km
ENANA BLANCA: $d=10.000 - 15.000$ km
ESTRELLA DE NEUTRONES: 20 km

Agujero negro

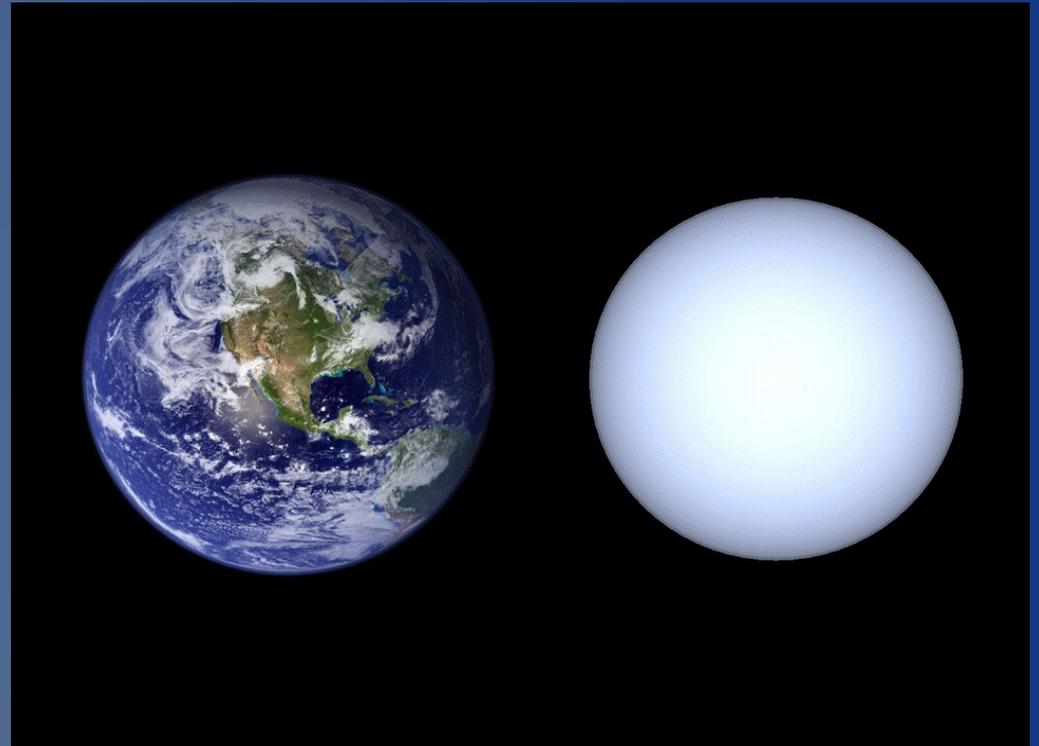
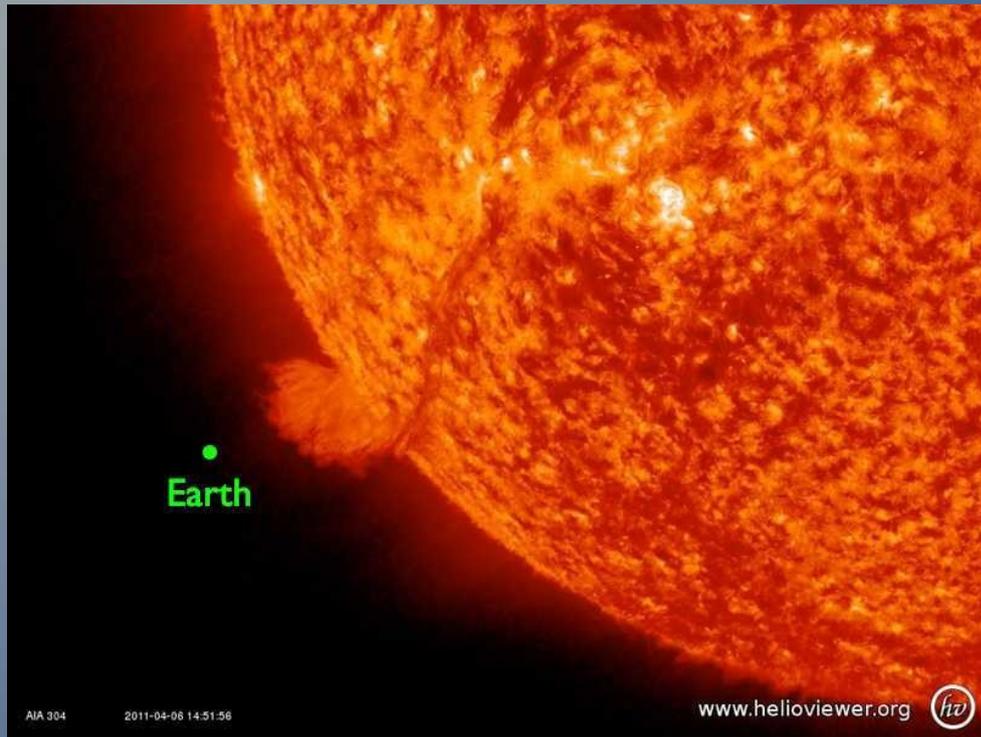






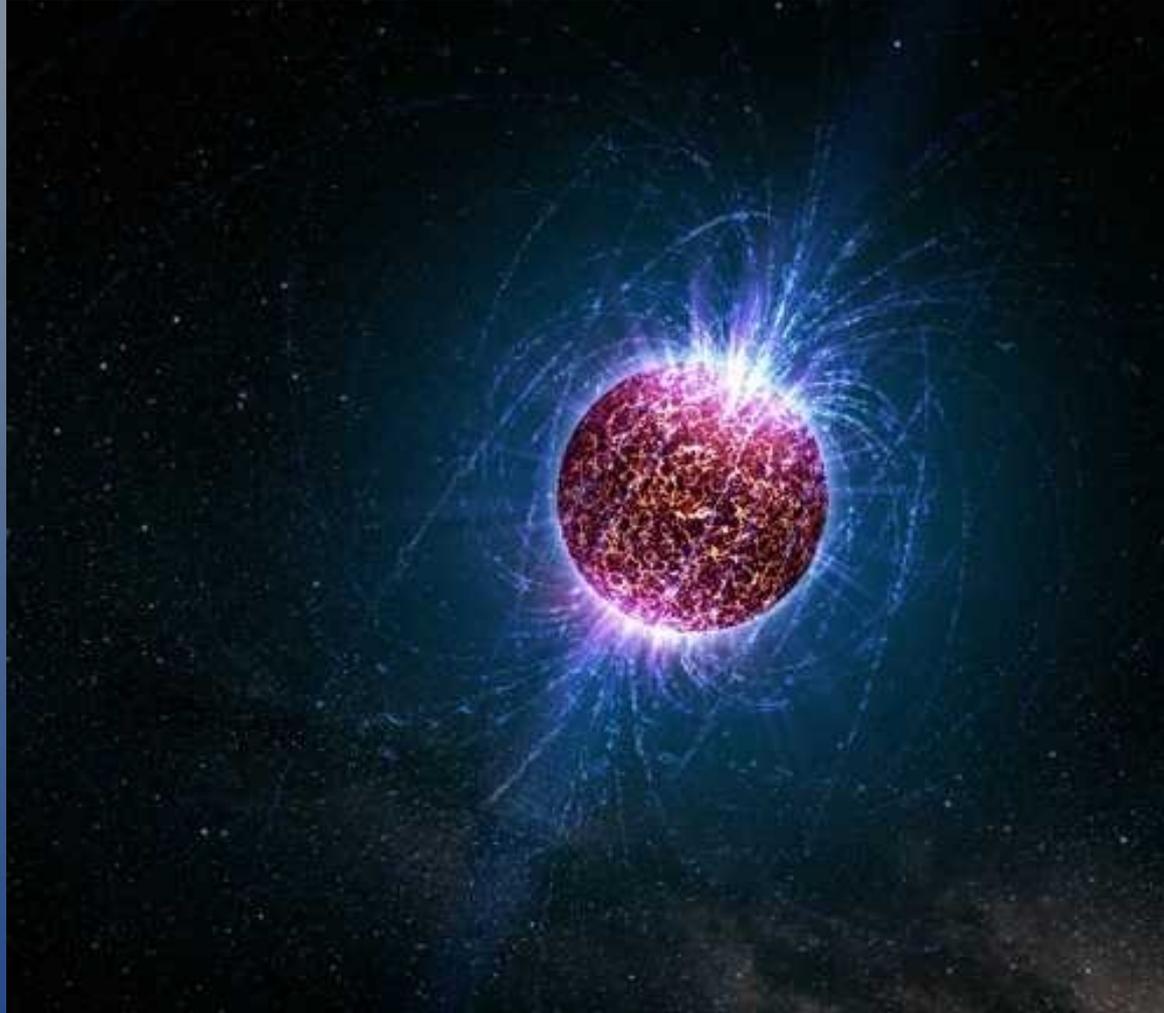


ENANA
BLANCA

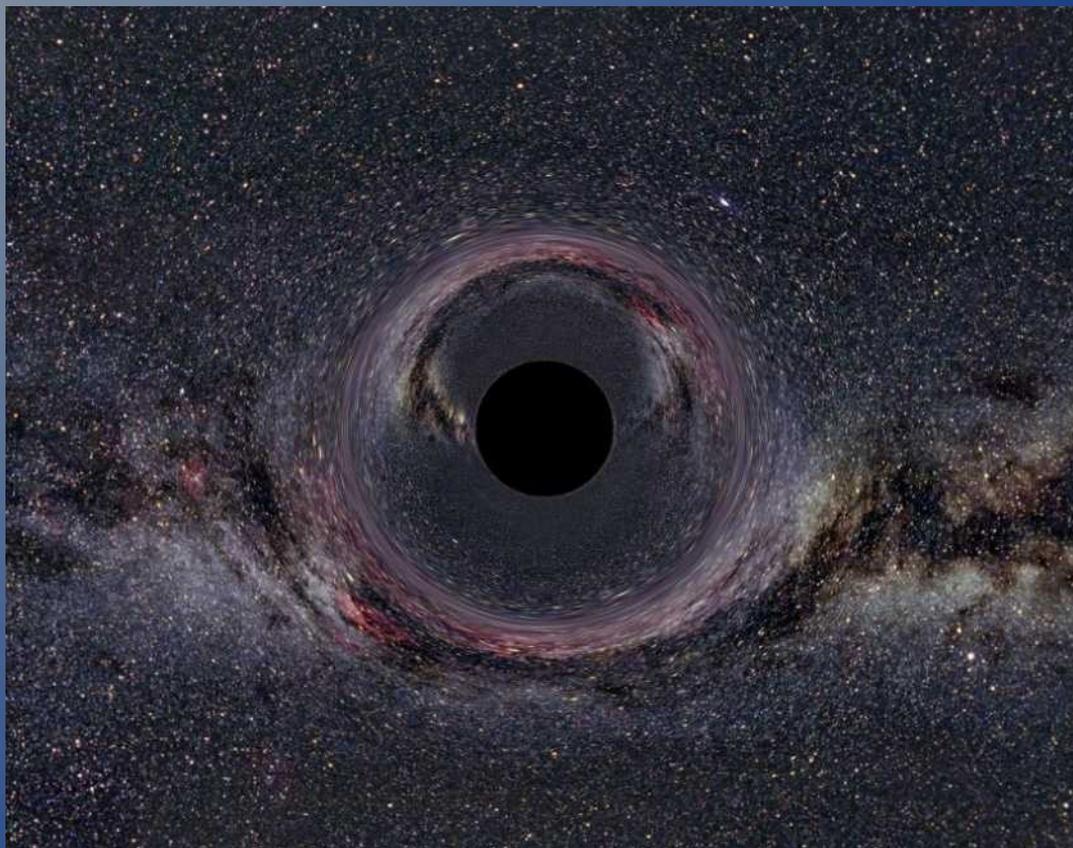


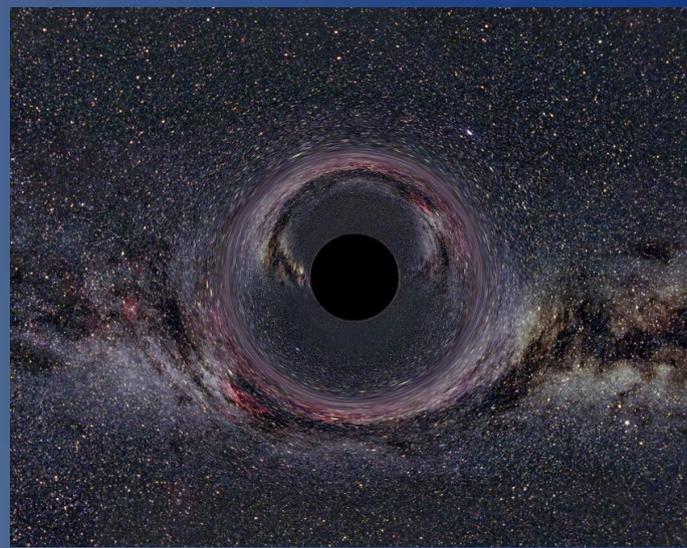
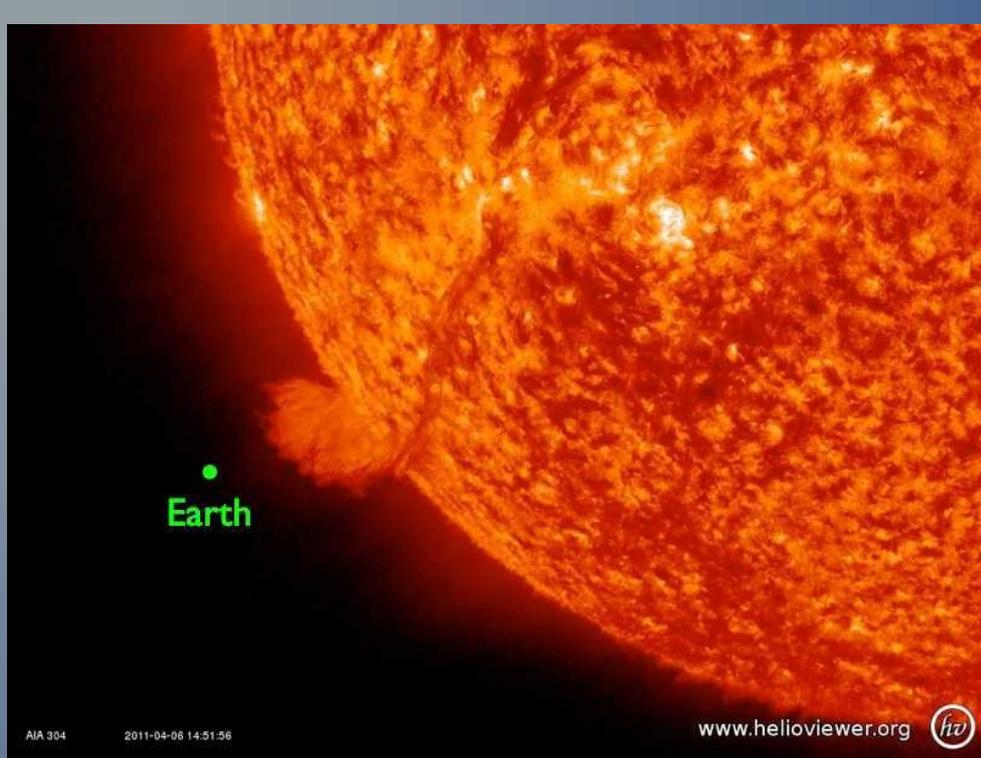
ENANA
BLANCA

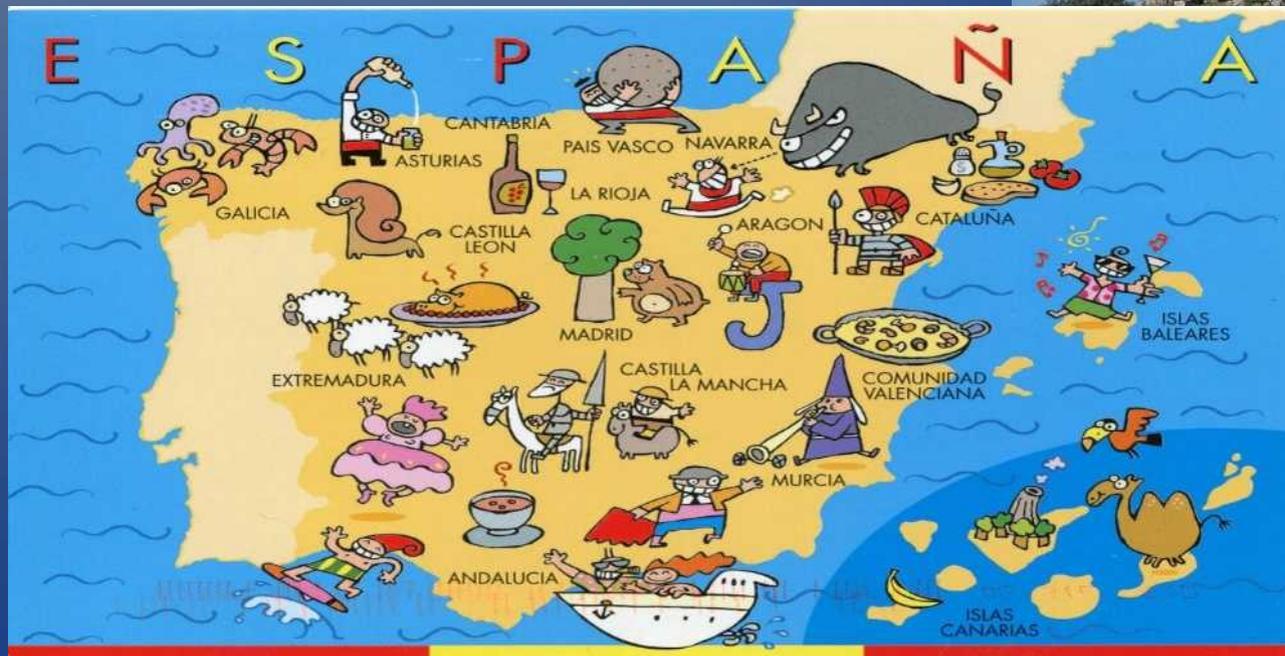
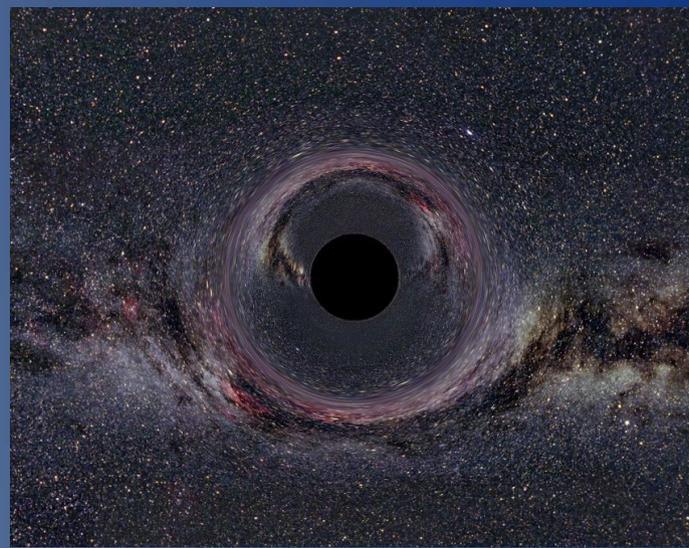
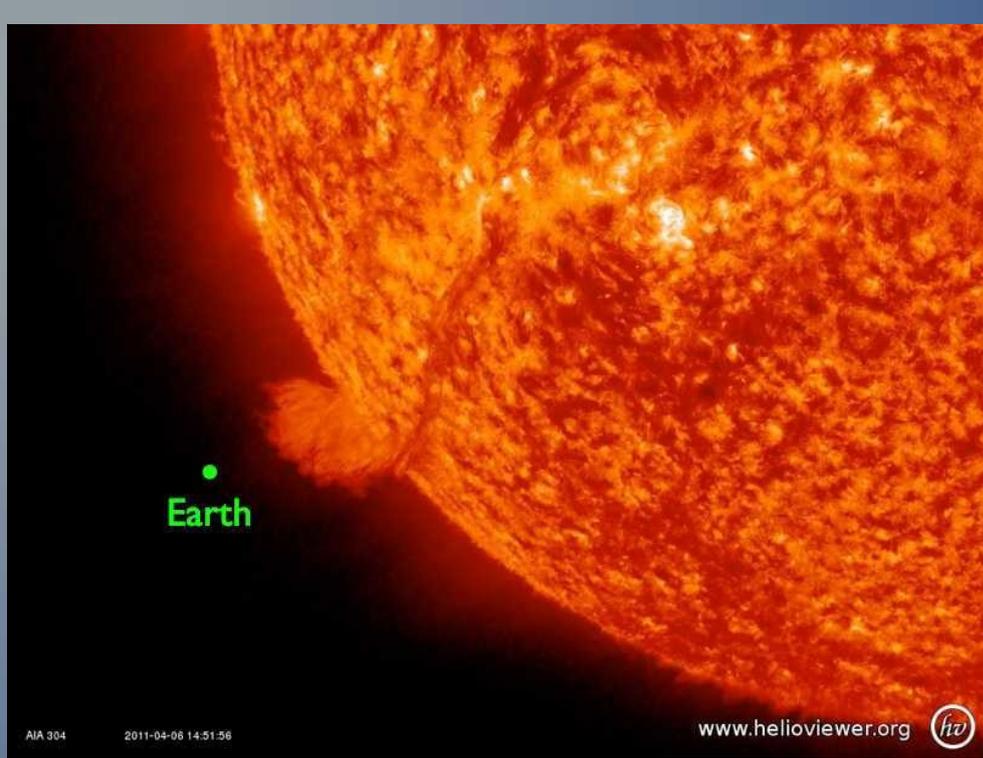
ESTRELLA DE NEUTRONES



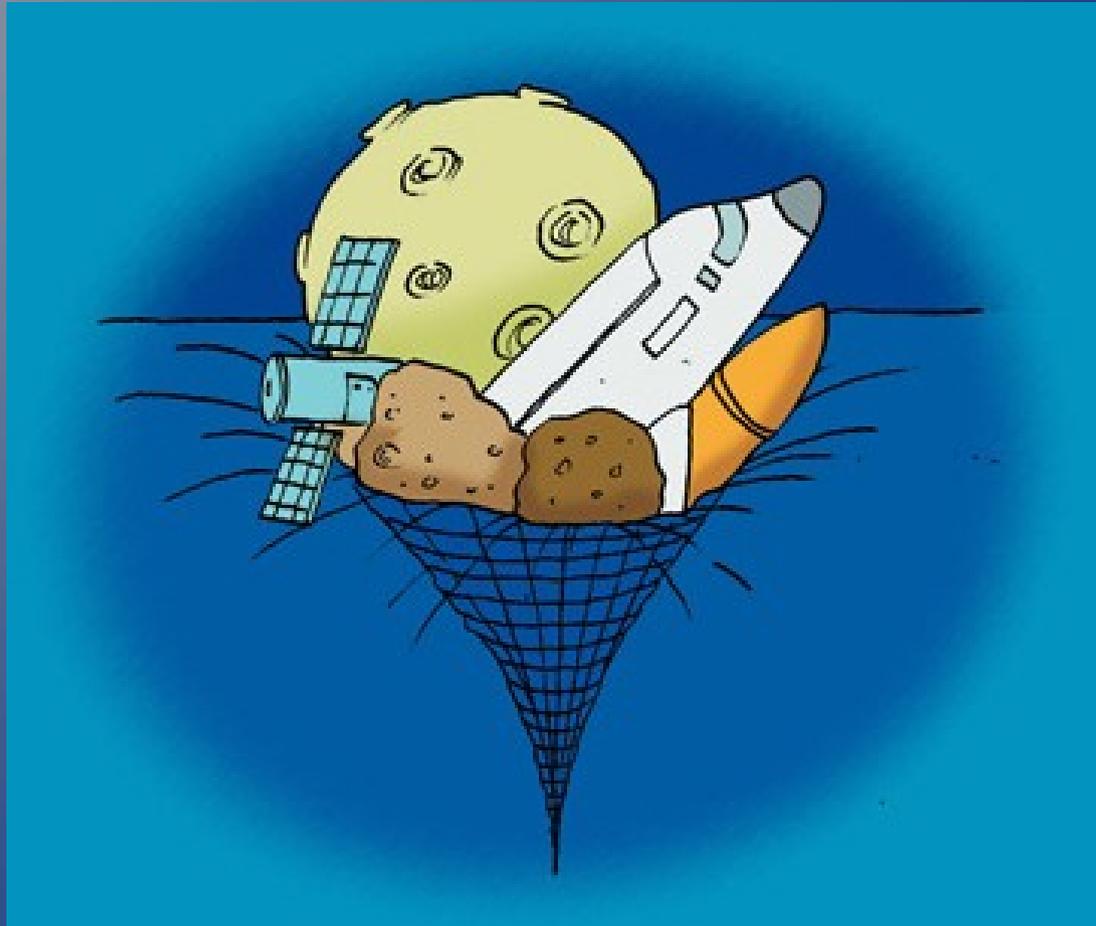
AGUJERO NEGRO



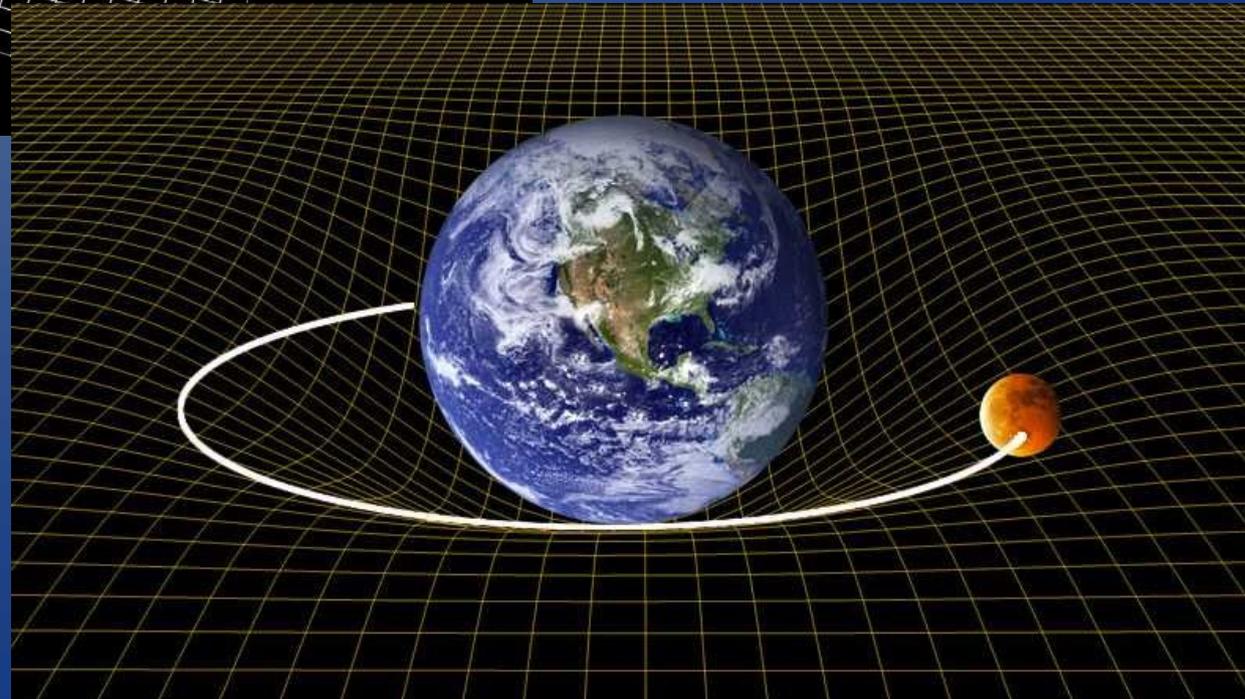
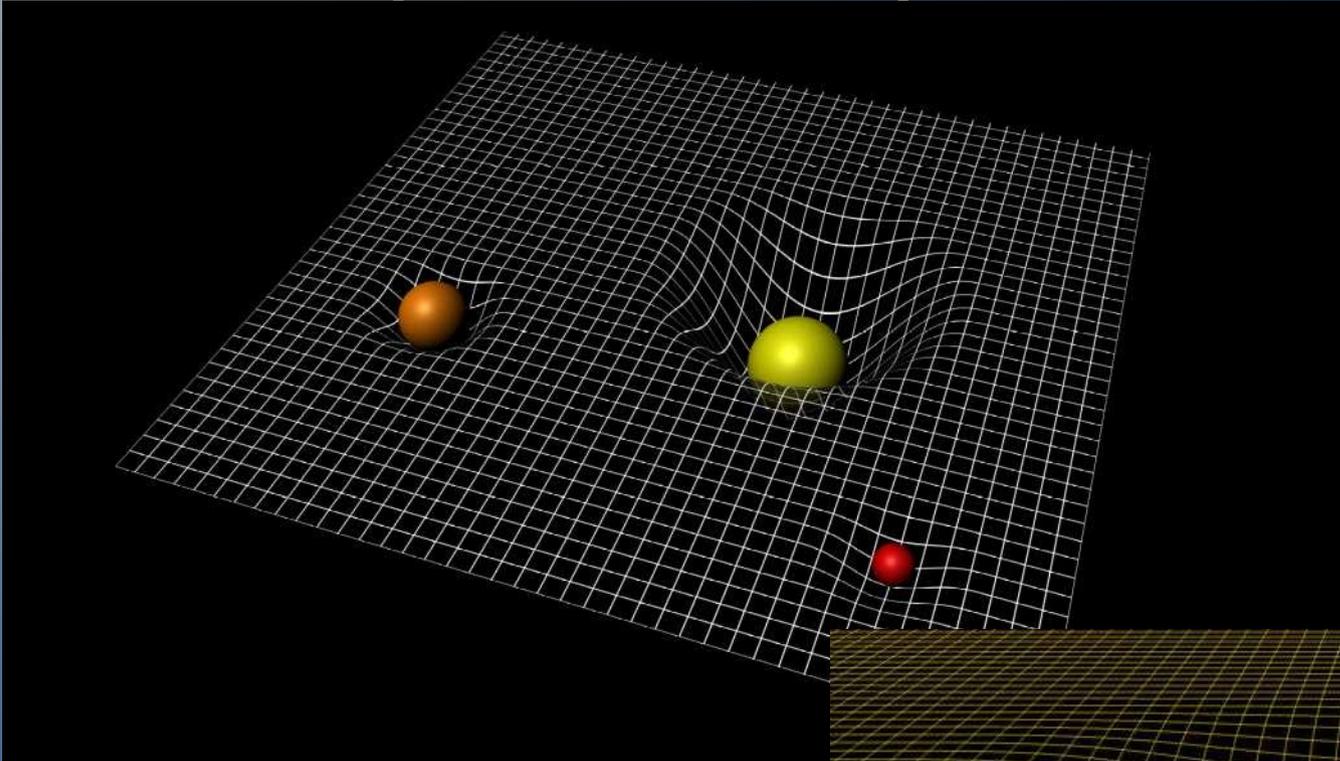




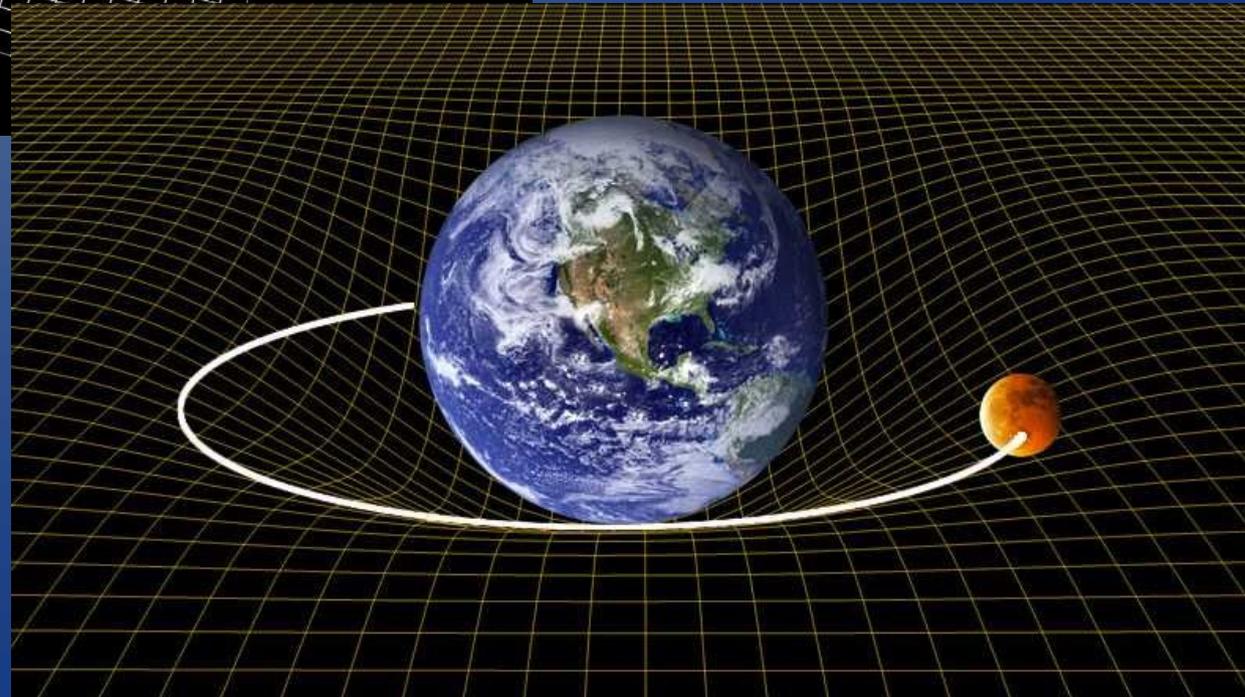
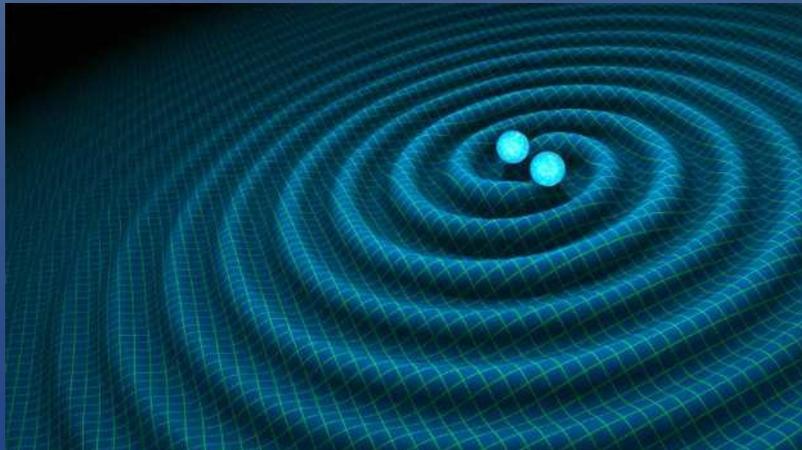
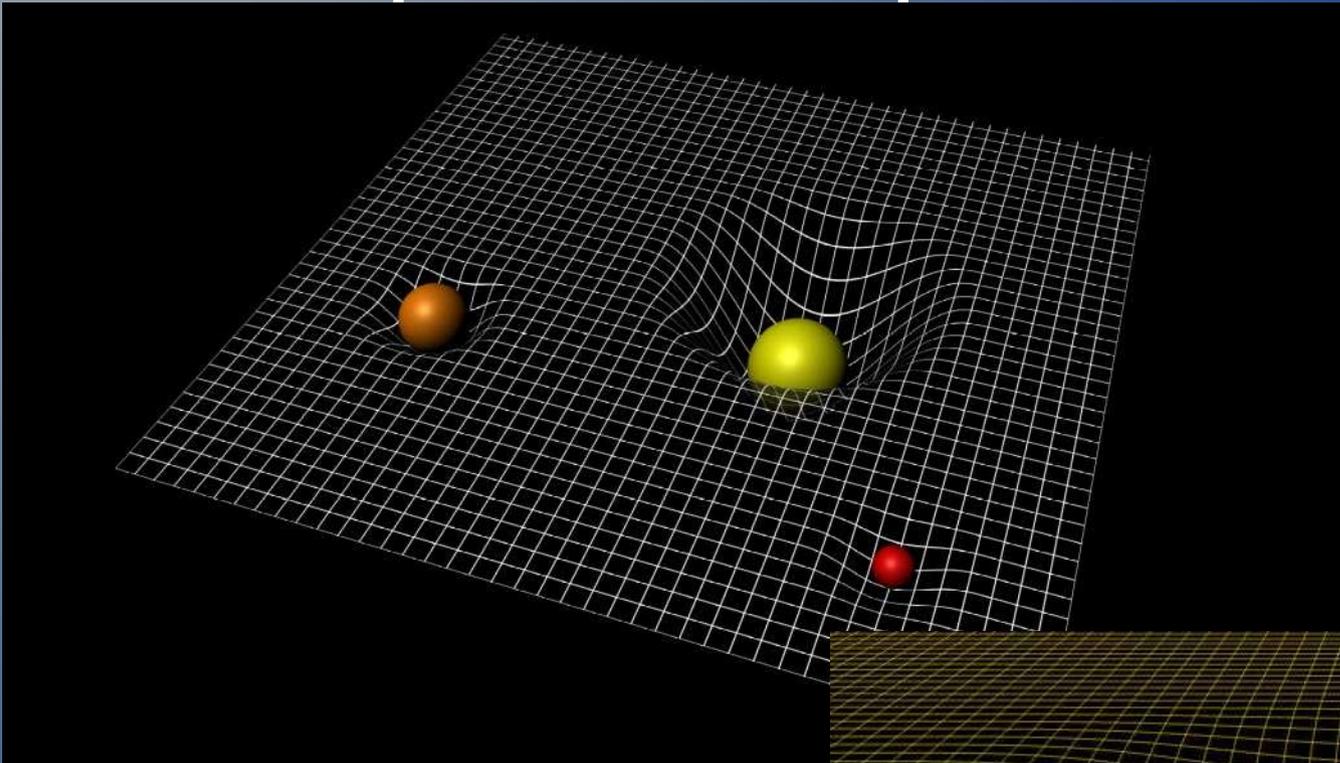
¿Por qué “agujero negro”?

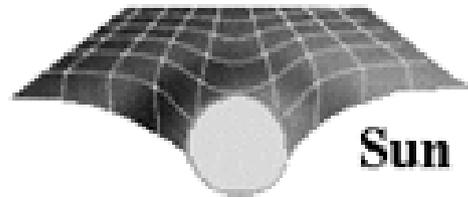


Espaciotiempo en Relatividad

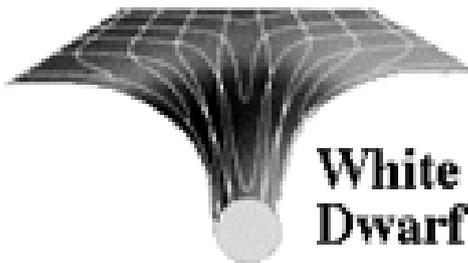


Espaciotiempo en Relatividad

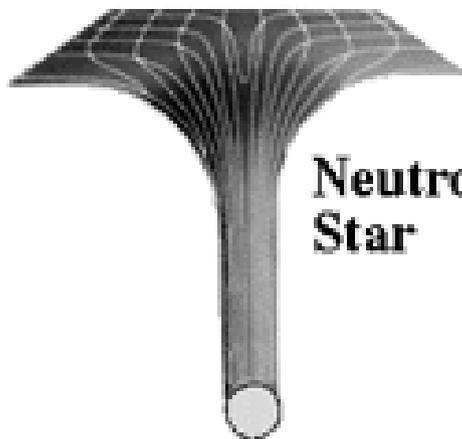




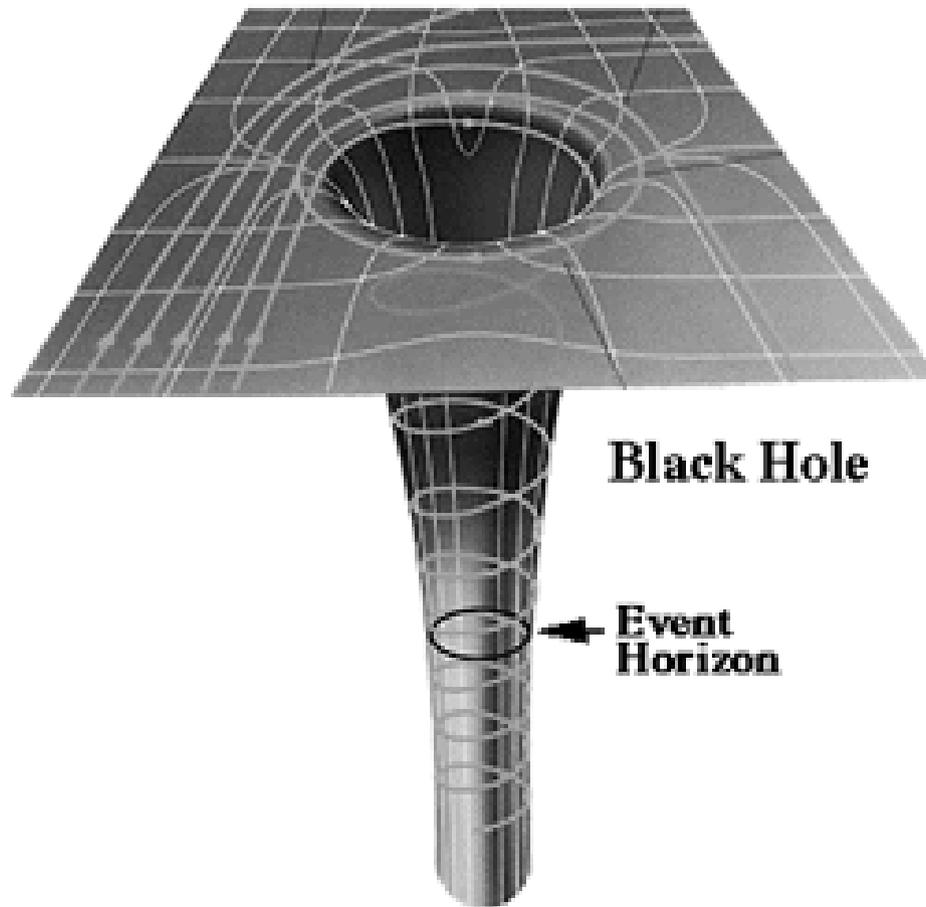
Sun



White Dwarf



Neutron Star



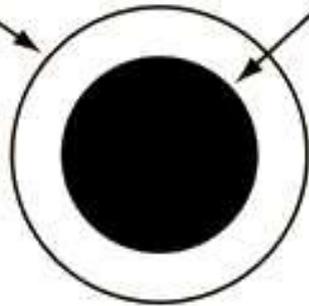
Black Hole

Event Horizon

Radio de Schwarzschild

For 3 solar mass black hole

"Photon sphere",
orbit of light at
13.5 km, 3/2 x the
event horizon radius.



Event horizon or
Schwarzschild radius at

$$R = \frac{2MG}{c^2}$$

or 9 km for 3 solar
masses.

R = 9 km for three solar masses

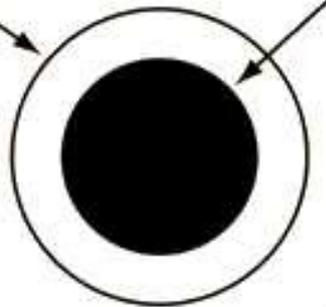
R = 3 km for Sun

R = 9 mm for Earth's mass

Radio de Schwarzschild

For 3 solar mass black hole

"Photon sphere", orbit of light at 13.5 km, 3/2 x the event horizon radius.

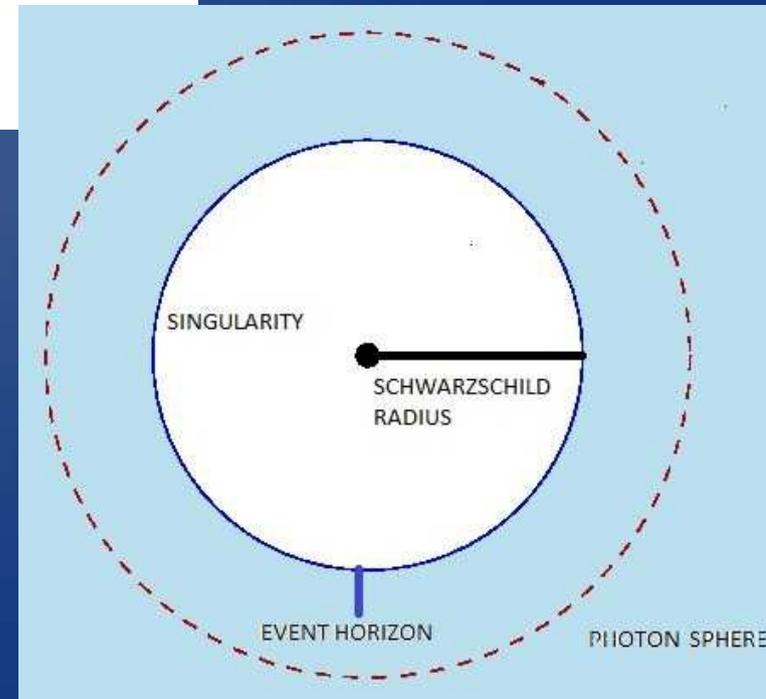


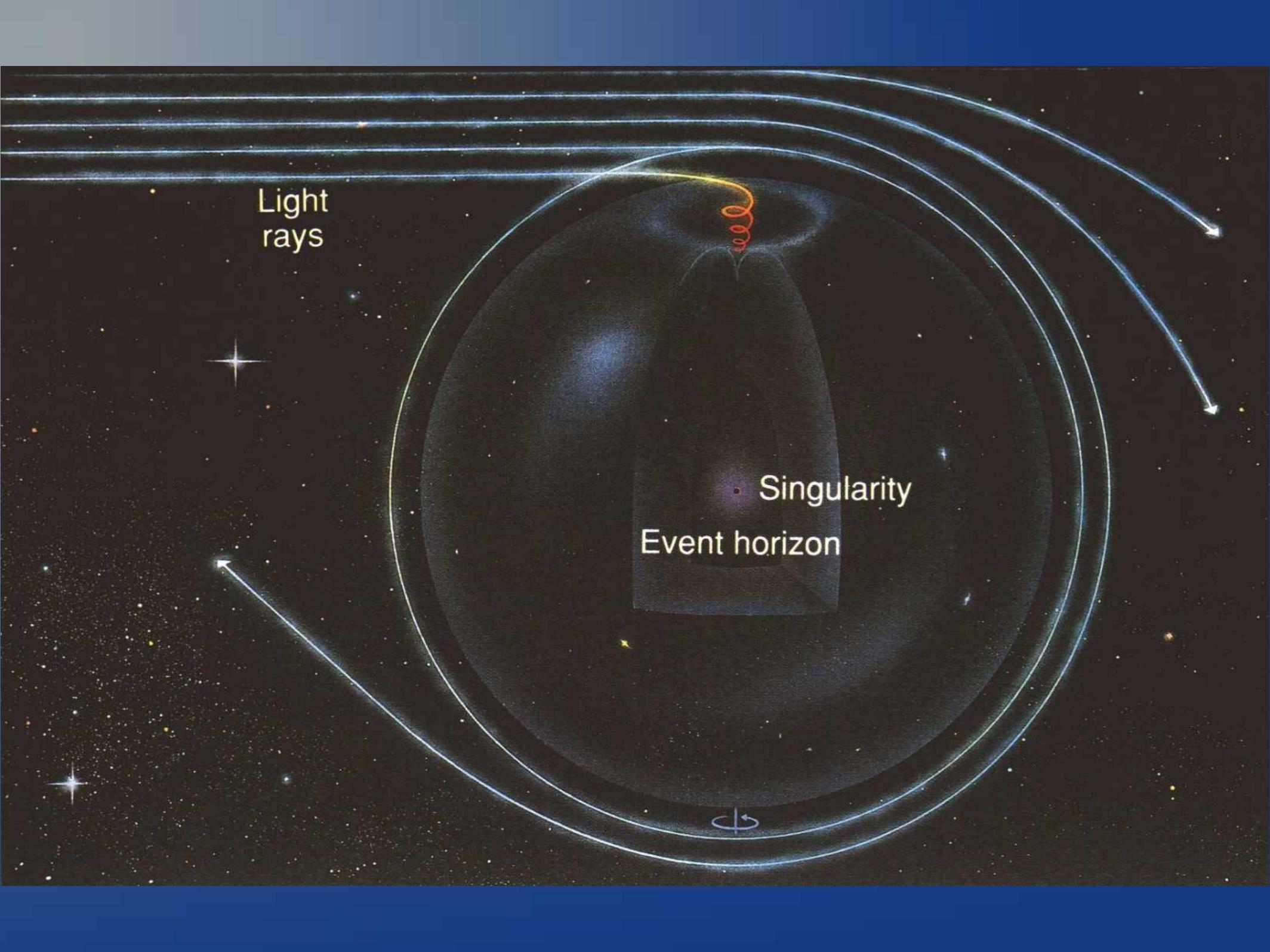
Event horizon or Schwarzschild radius at

$$R = \frac{2MG}{c^2}$$

or 9 km for 3 solar masses.

R = 9 km for three solar masses
R = 3 km for Sun
R = 9 mm for Earth's mass

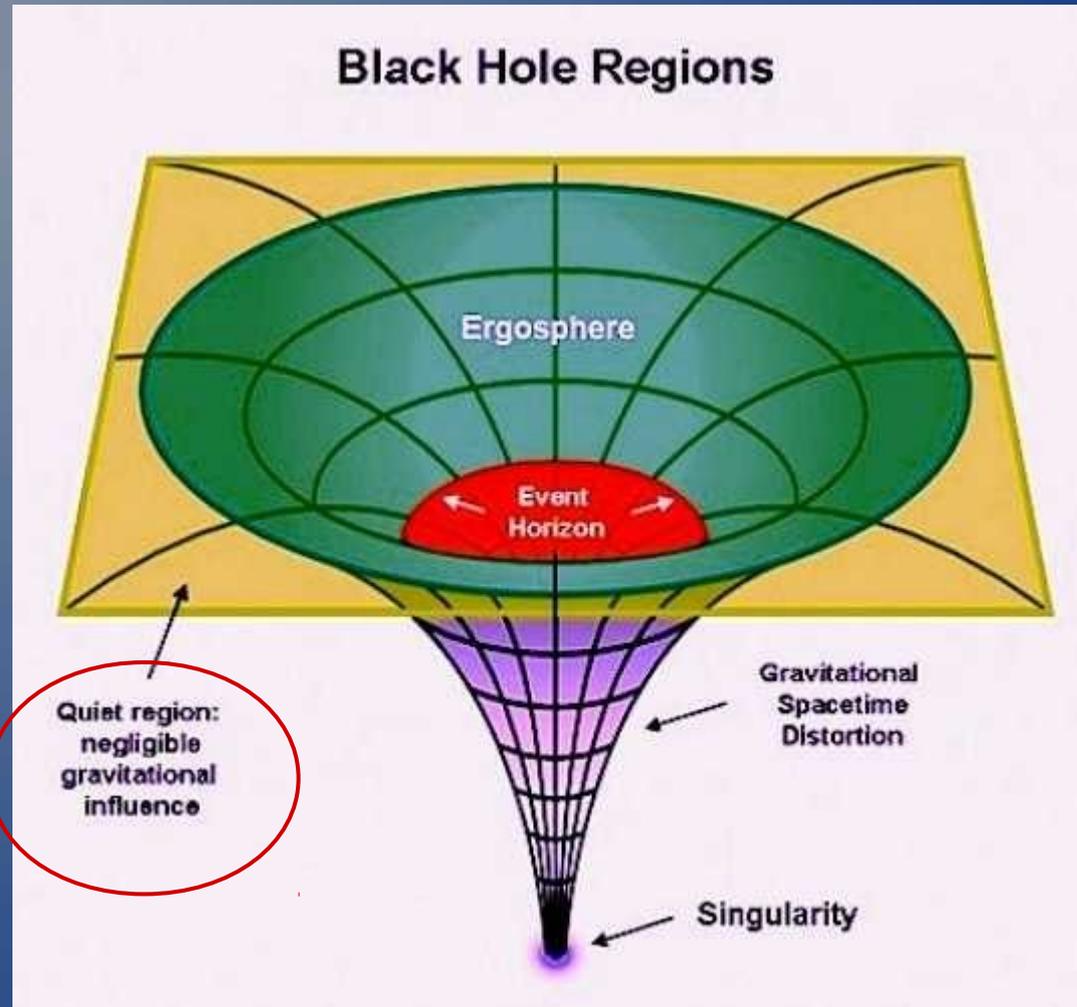




Light rays

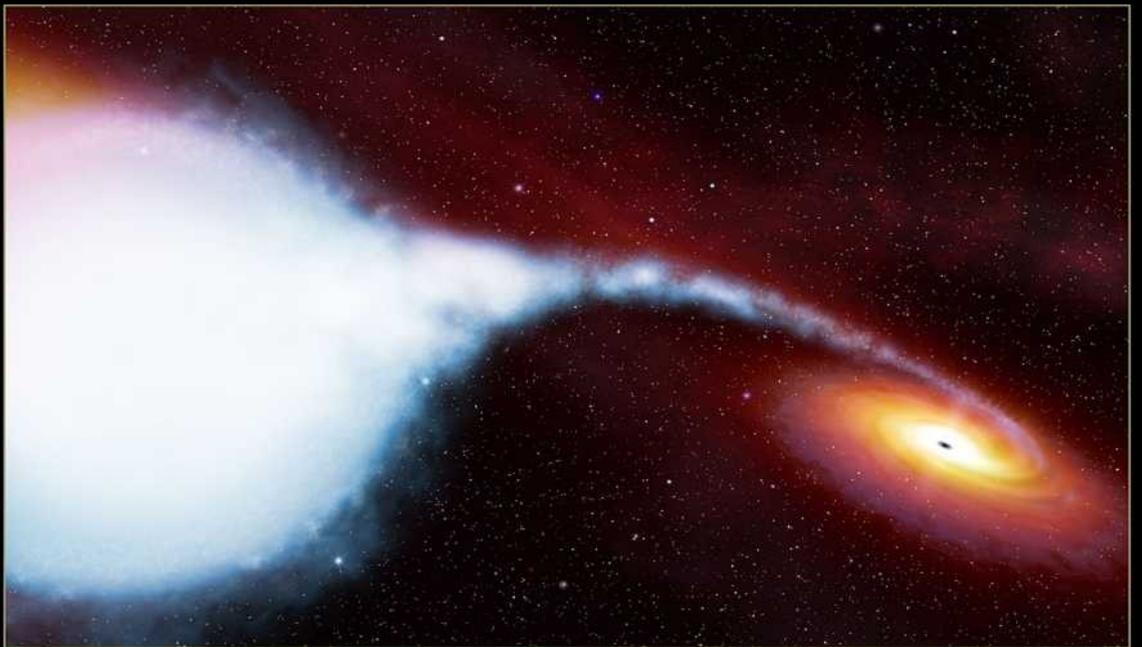
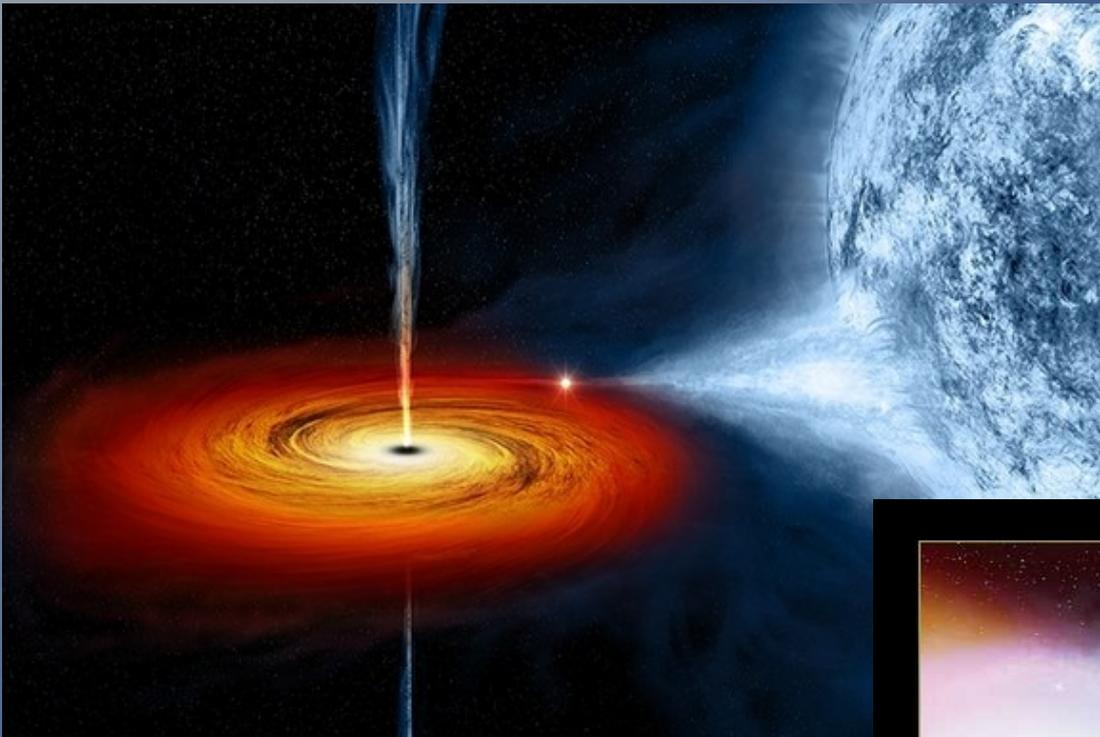
• Singularity
Event horizon

¿Un AN absorbe todo?



Sí, pero sólo lo que está suficientemente cerca

Cygnus X-1



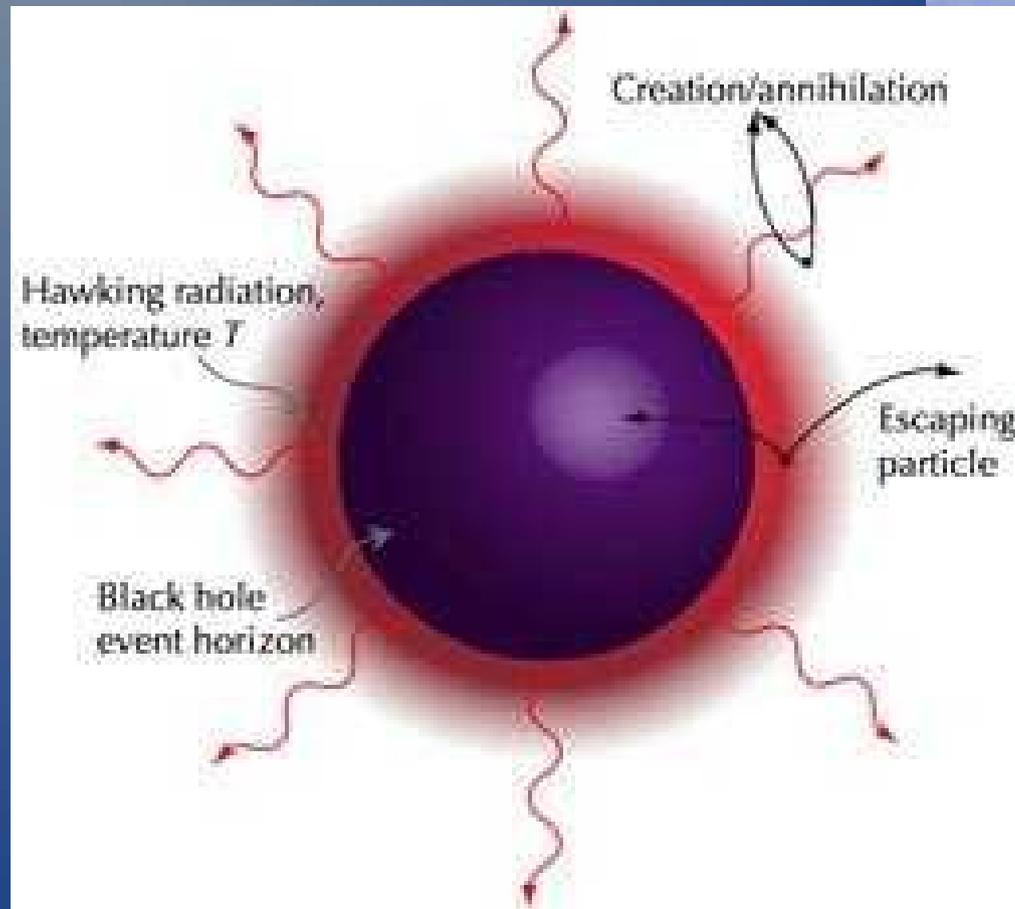
CYGNUS-X1 *Black hole*



Radiación de Hawking



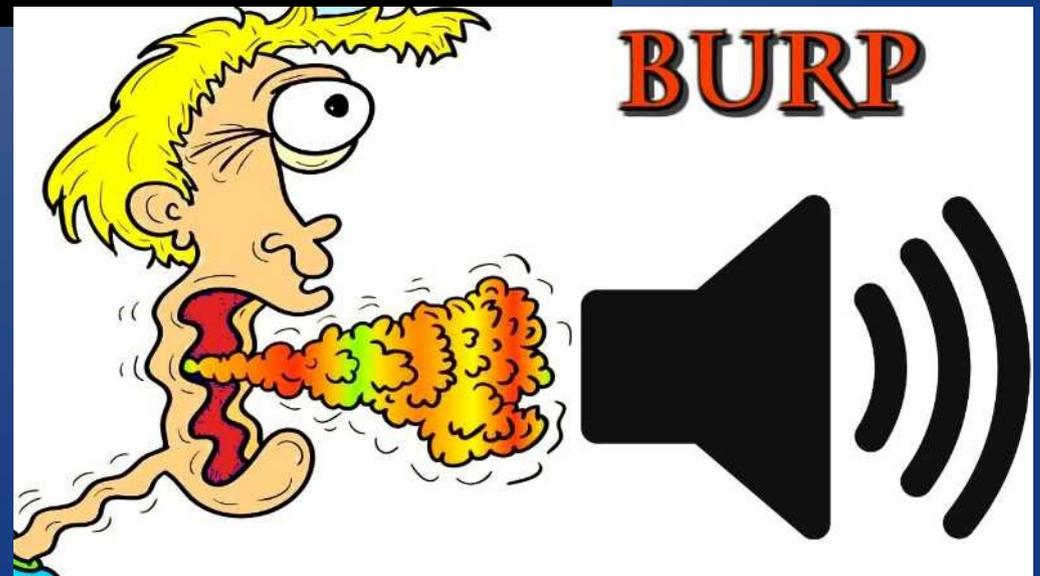
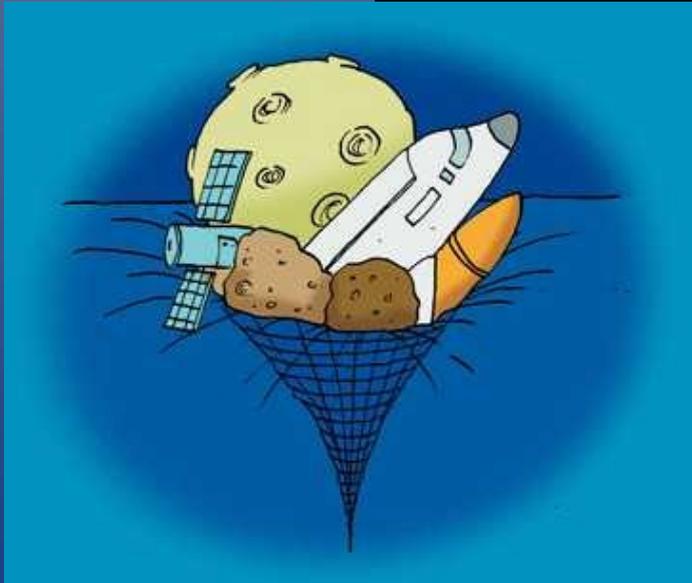
Radiación de Hawking



Radiación de Hawking



Radiación de Hawking

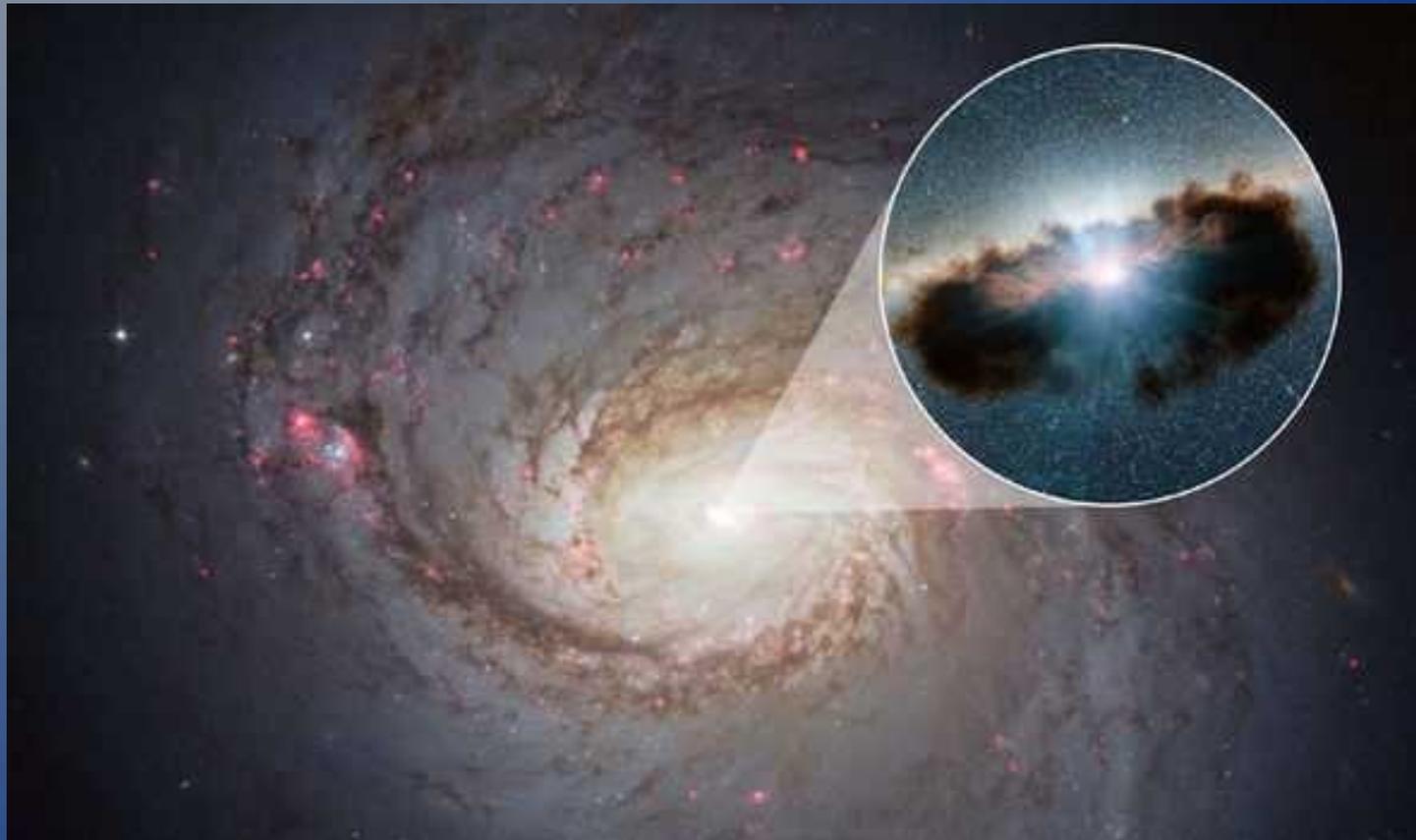


Radiación de Hawking

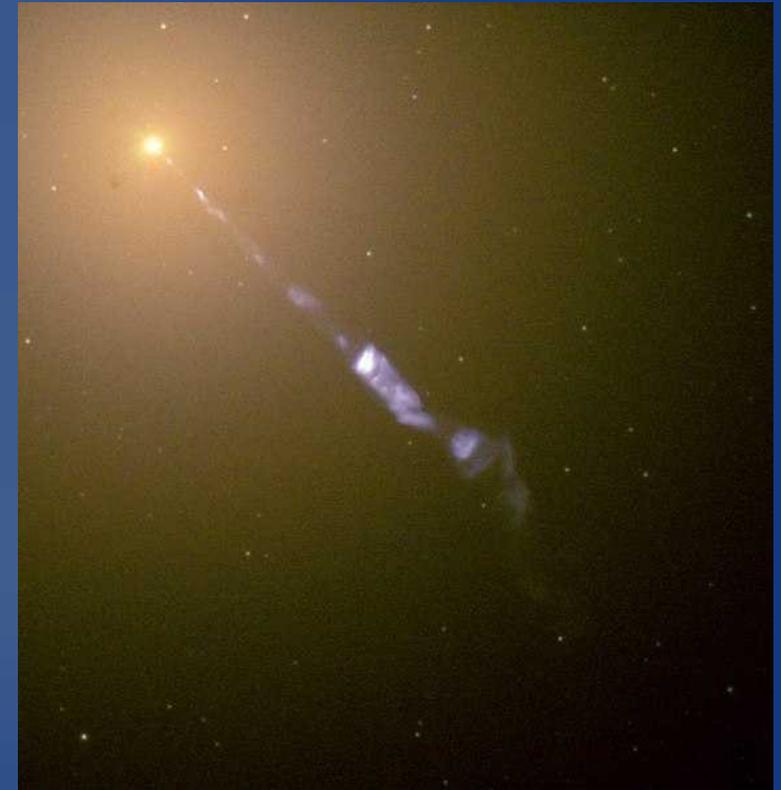
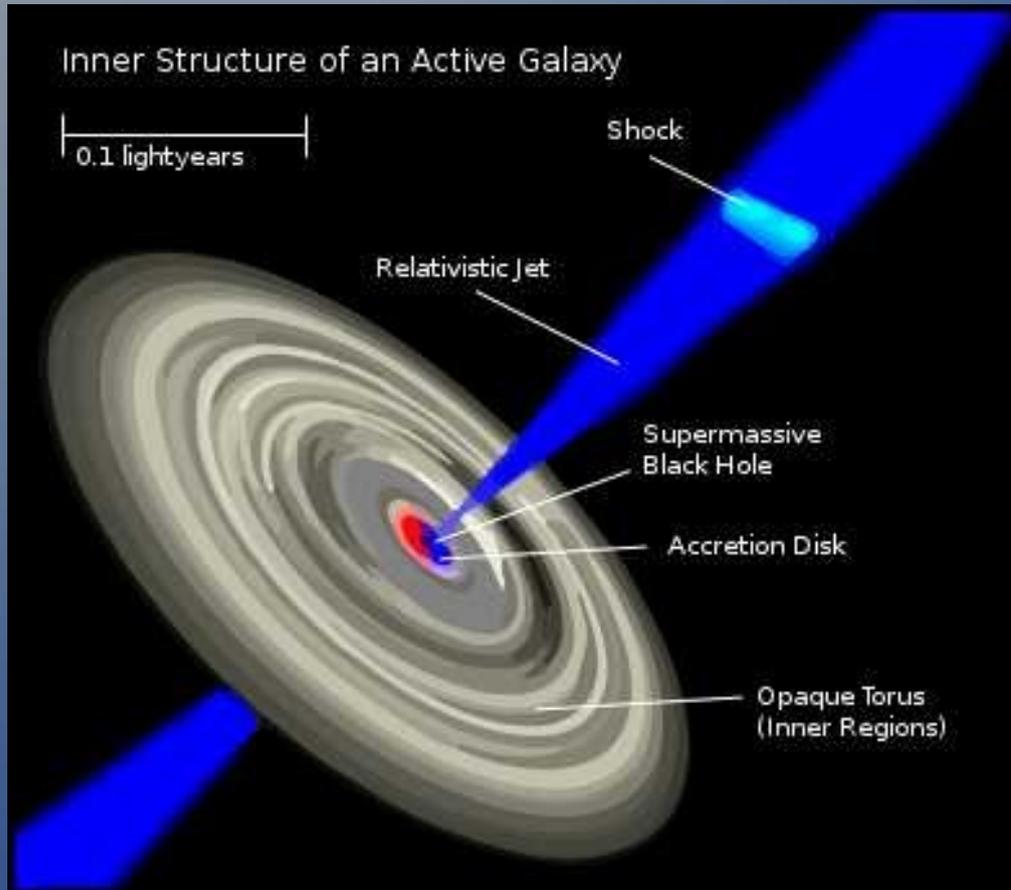


$T(\text{Hawking}) \sim 0.000001 \text{ K}$ vs $T(\text{CMB}) = 2.7 \text{ K}$
(evaporación total tardaría miles de M de años)

AN Supermasivos

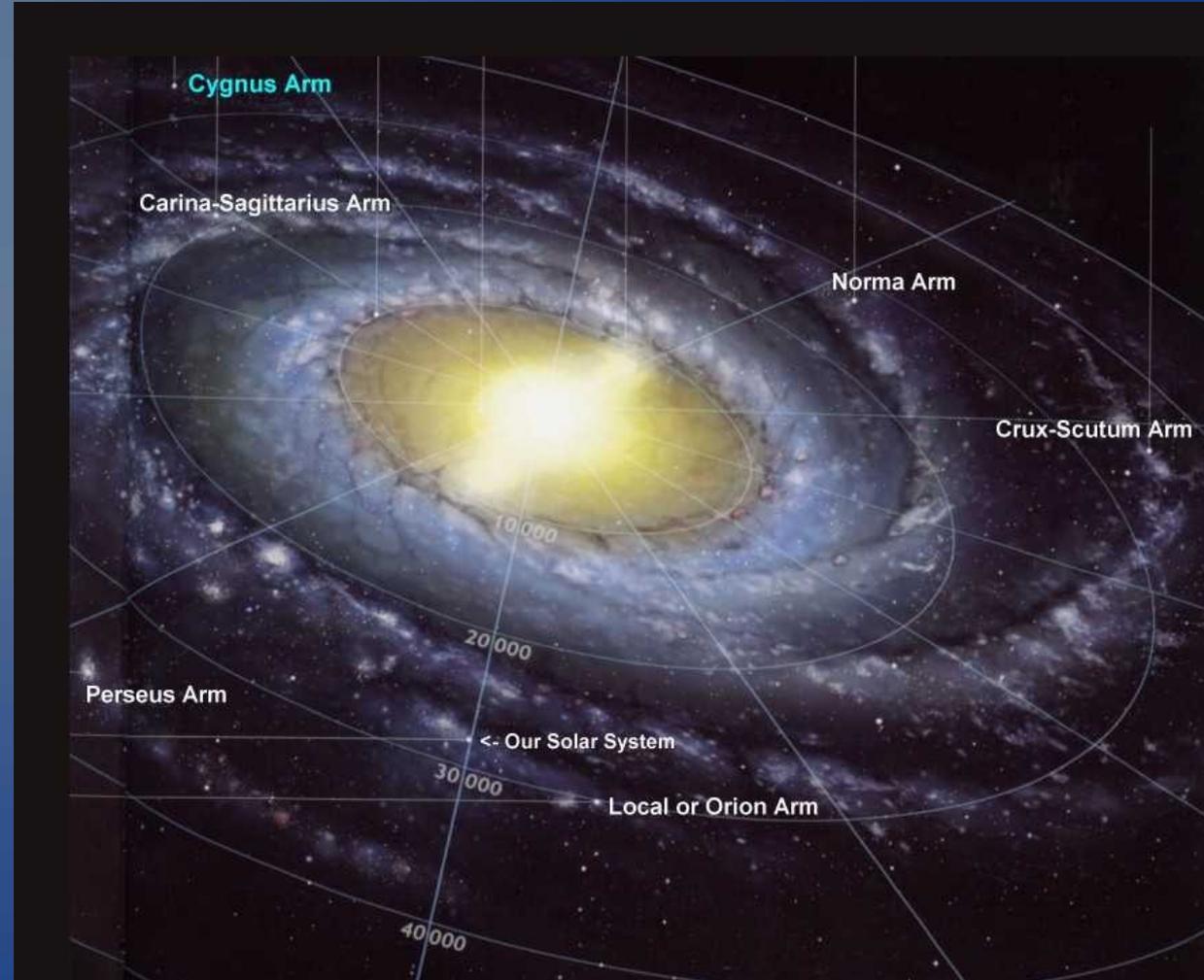
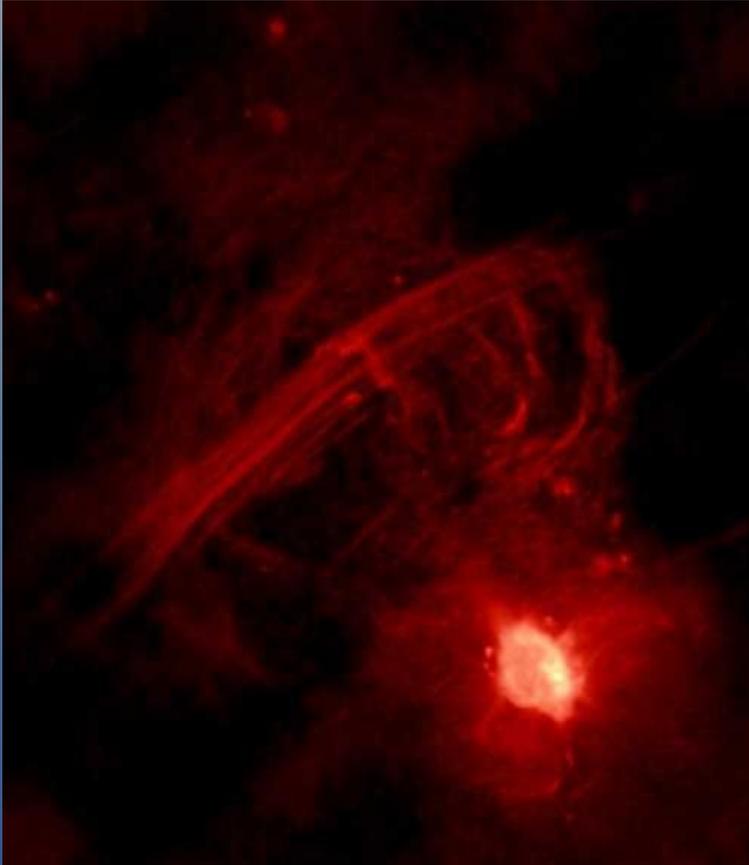


AN Supermasivos y Núcleos Activos de Galaxia



Galaxia M87
Jet de longitud: 5000 años luz

AN en el centro de la Vía Láctea



Sagitario A*

FIN.

