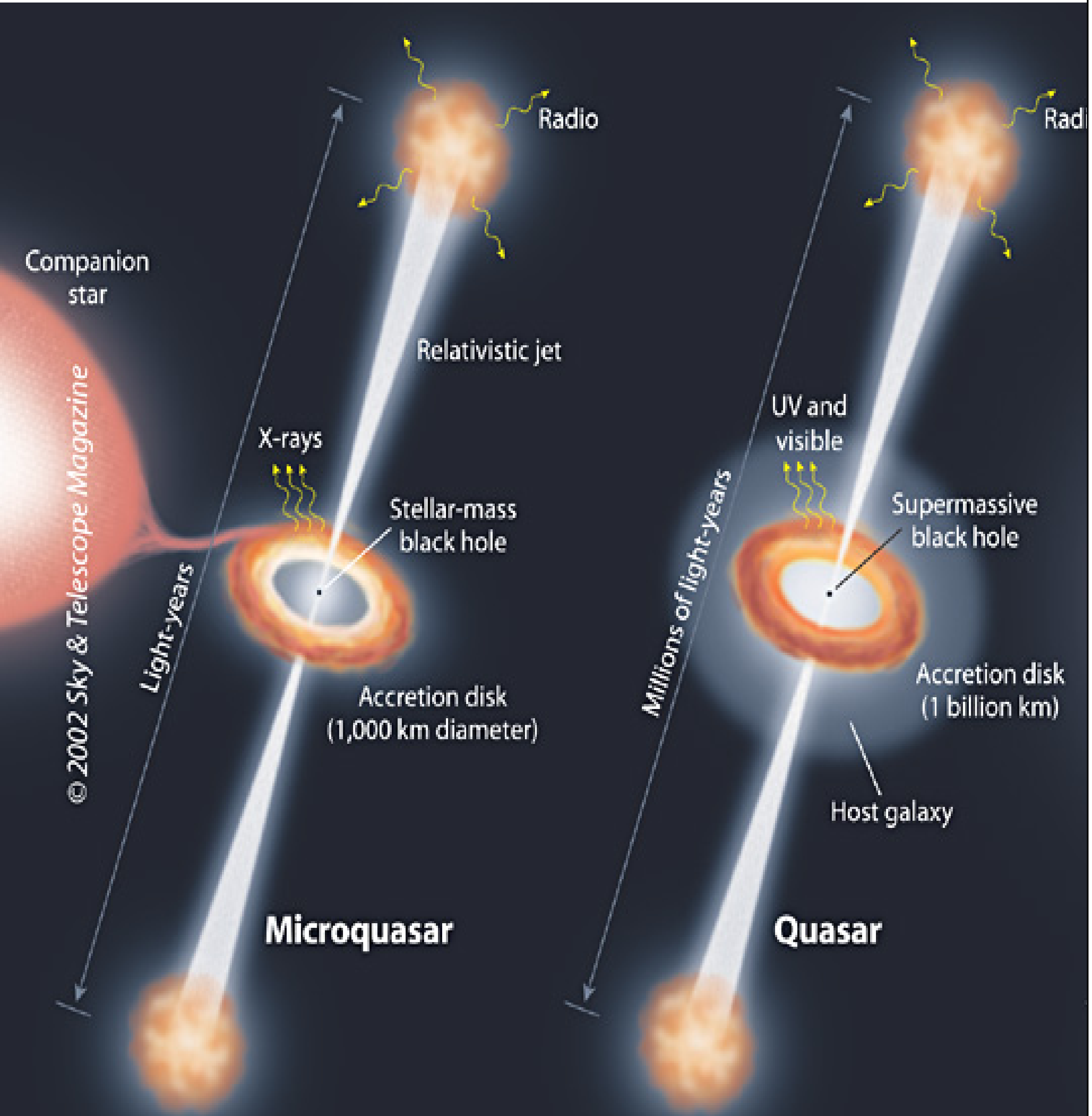


(Mirabel & Rodriguez; Sky & Telescope, May 2002)

QUASARS

and

MICROQUASARS

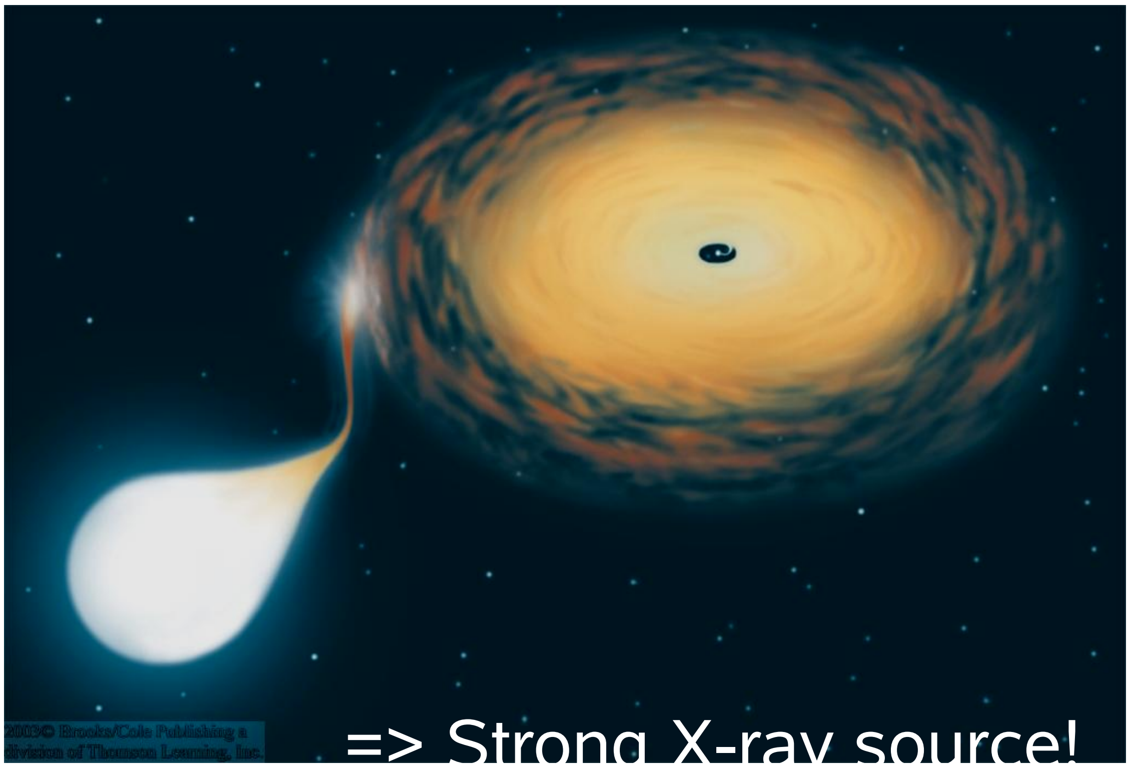
Microquasars:

subclass of the X-ray binary class

X-ray binaries are a class of stellar systems containing two stars of very different nature. One is a normal star
of mass < 1 solar Mass (Low mass X-ray binary LMXB)
or mass >5 solar masses (High mass X-ray binary HMXB).

whereas the other star is a compact object:
either a neutron star or a black hole

Accreting neutron stars and black holes

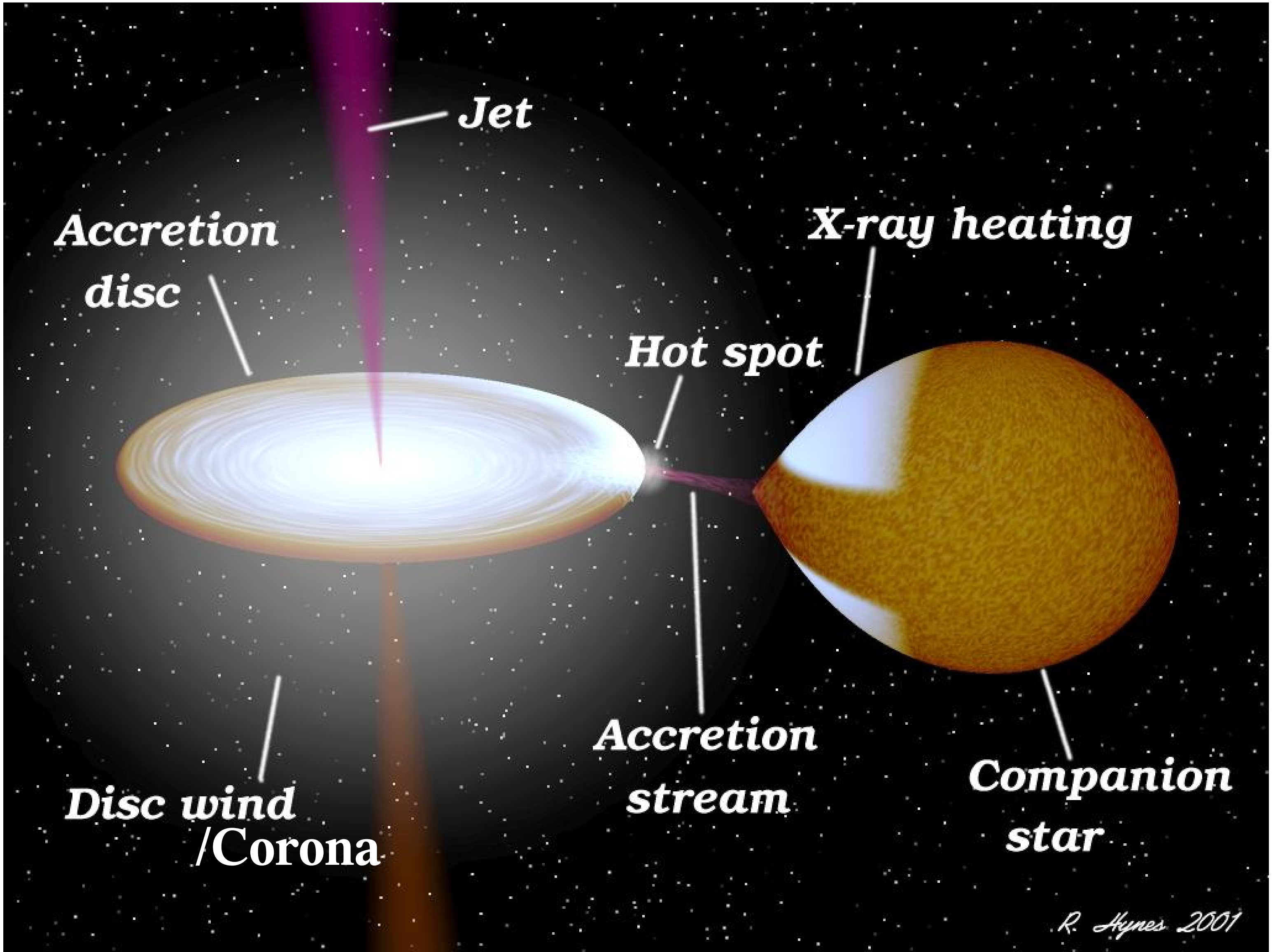


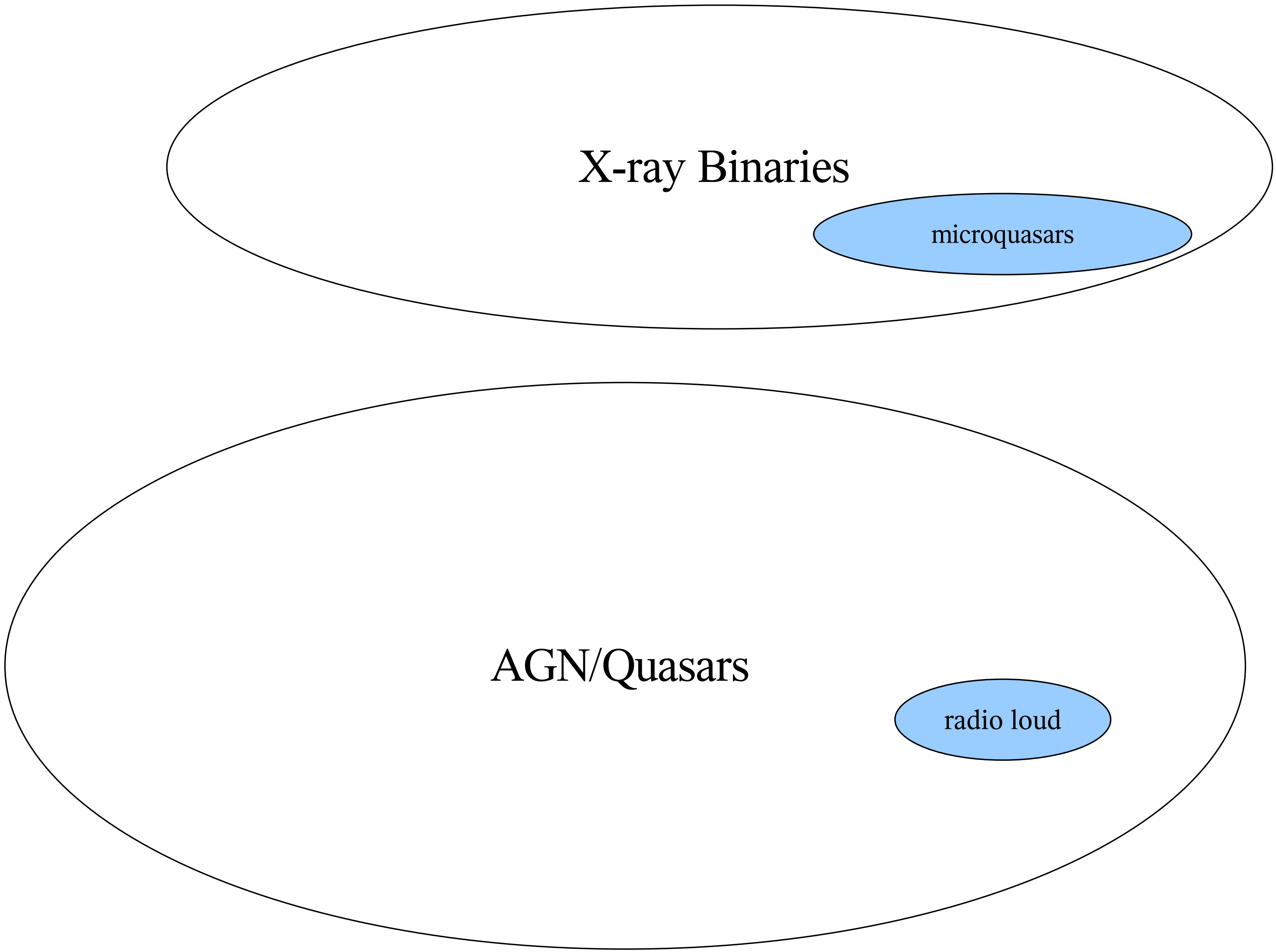
=> Strong X-ray source!

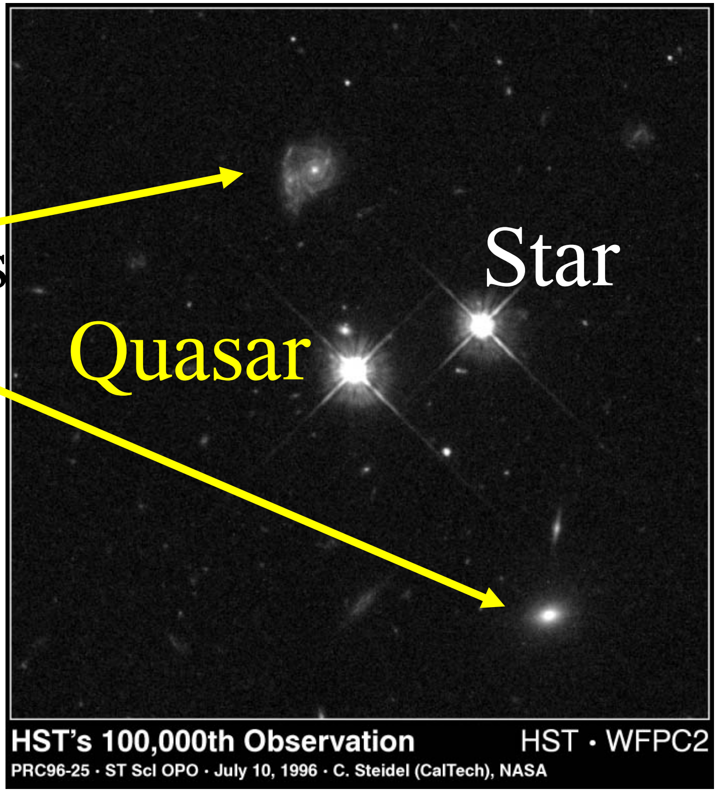
Matter gets pulled off from the companion star, forming an **accretion disk.**

Infalling matter heats up to 10^7 K.
Accretion is a very efficient process of energy release.

X-ray Binary + Jet = Microquasar




X-ray Binaries
microquasars
AGN/Quasars
radio loud



Star and quasar point-like sources (diffraction spikes)

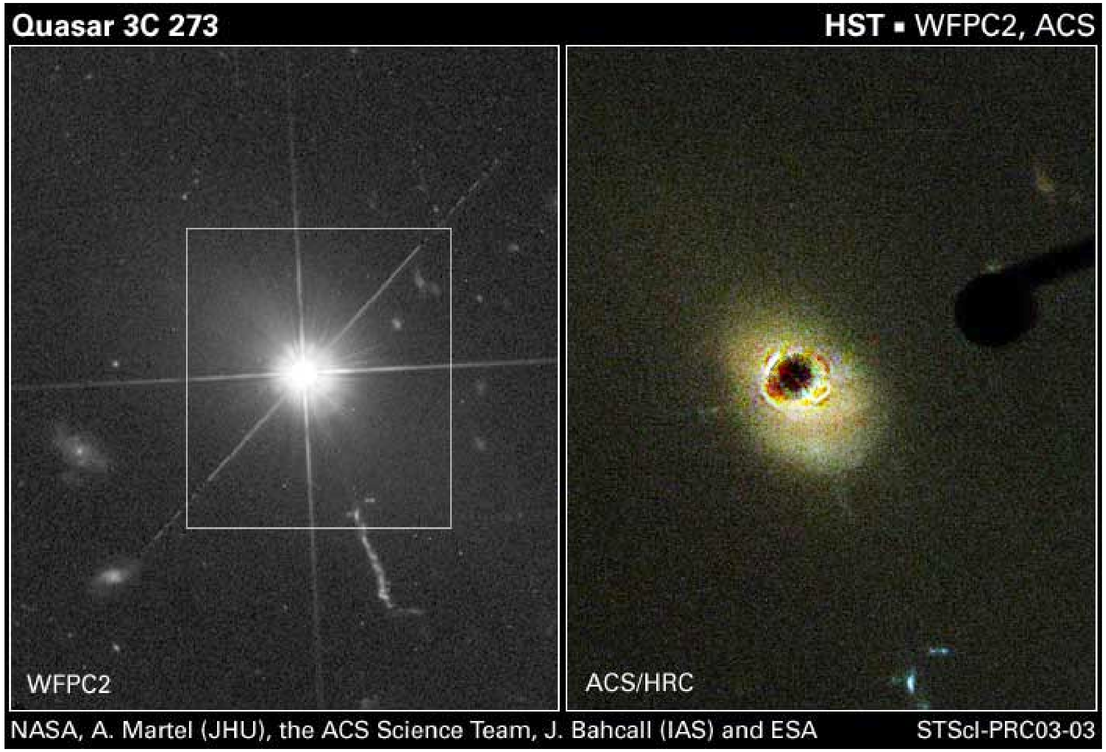
QUASi-stellAR

radio source

= **QUASAR**

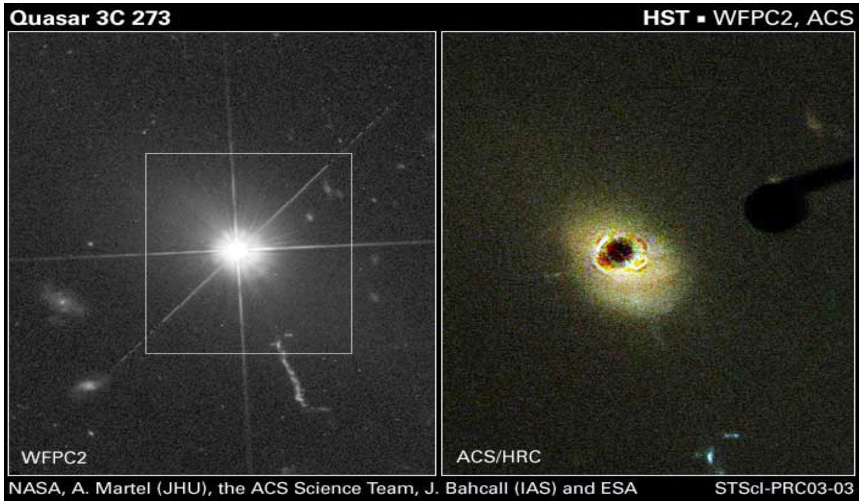
1960 Third Cambridge Catalogue
-looking for the optical counterparts.
In 1960, radio source 3C 48 was finally tied to an optical object.
faint blue star at the location of the radio source and obtained its spectrum. Containing many unknown broad emission lines, the anomalous spectrum defied interpretation — a claim by John Bolton of a large redshift was not generally accepted.

NLR 500 km/sec Broad Line Region 10000 km/sec

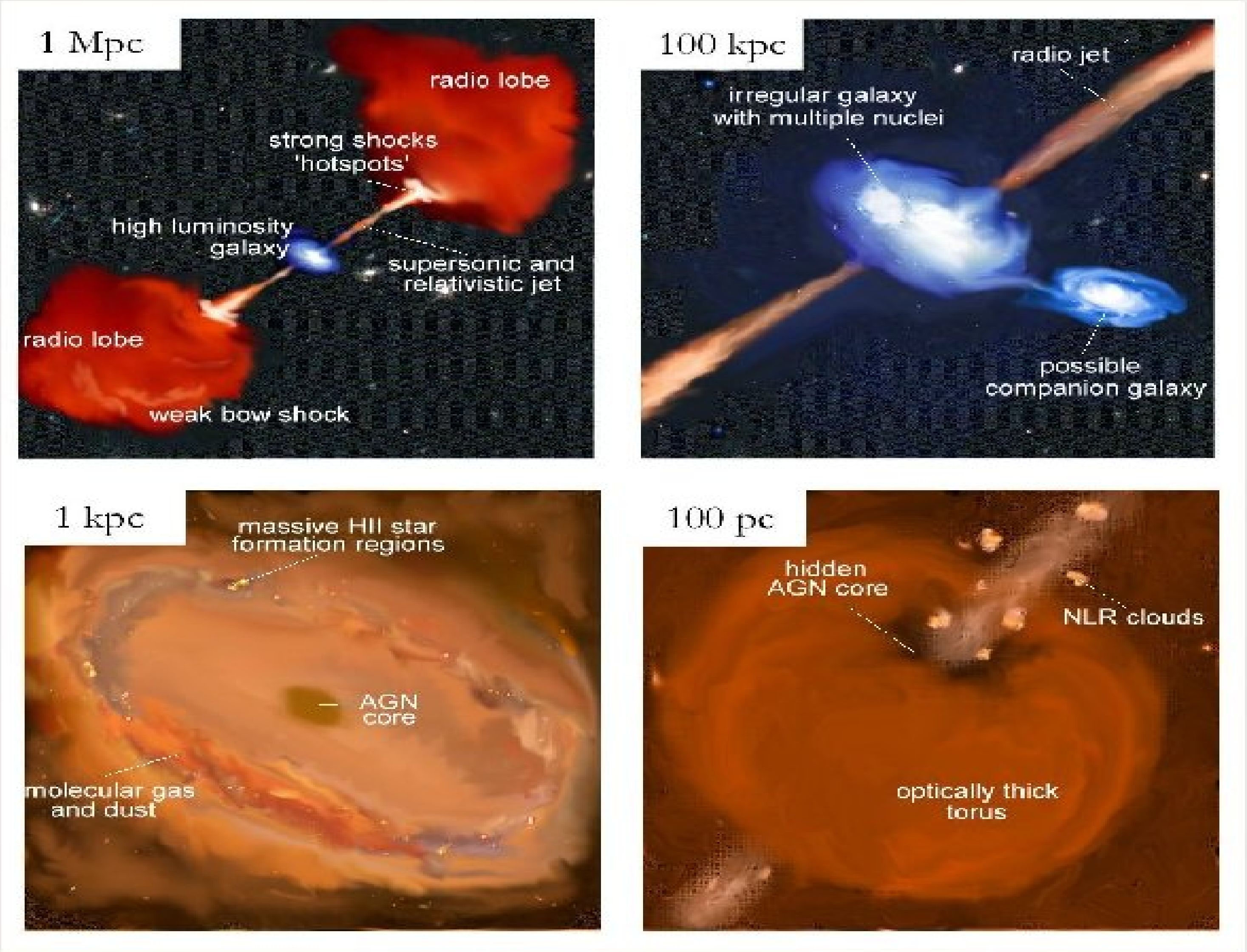


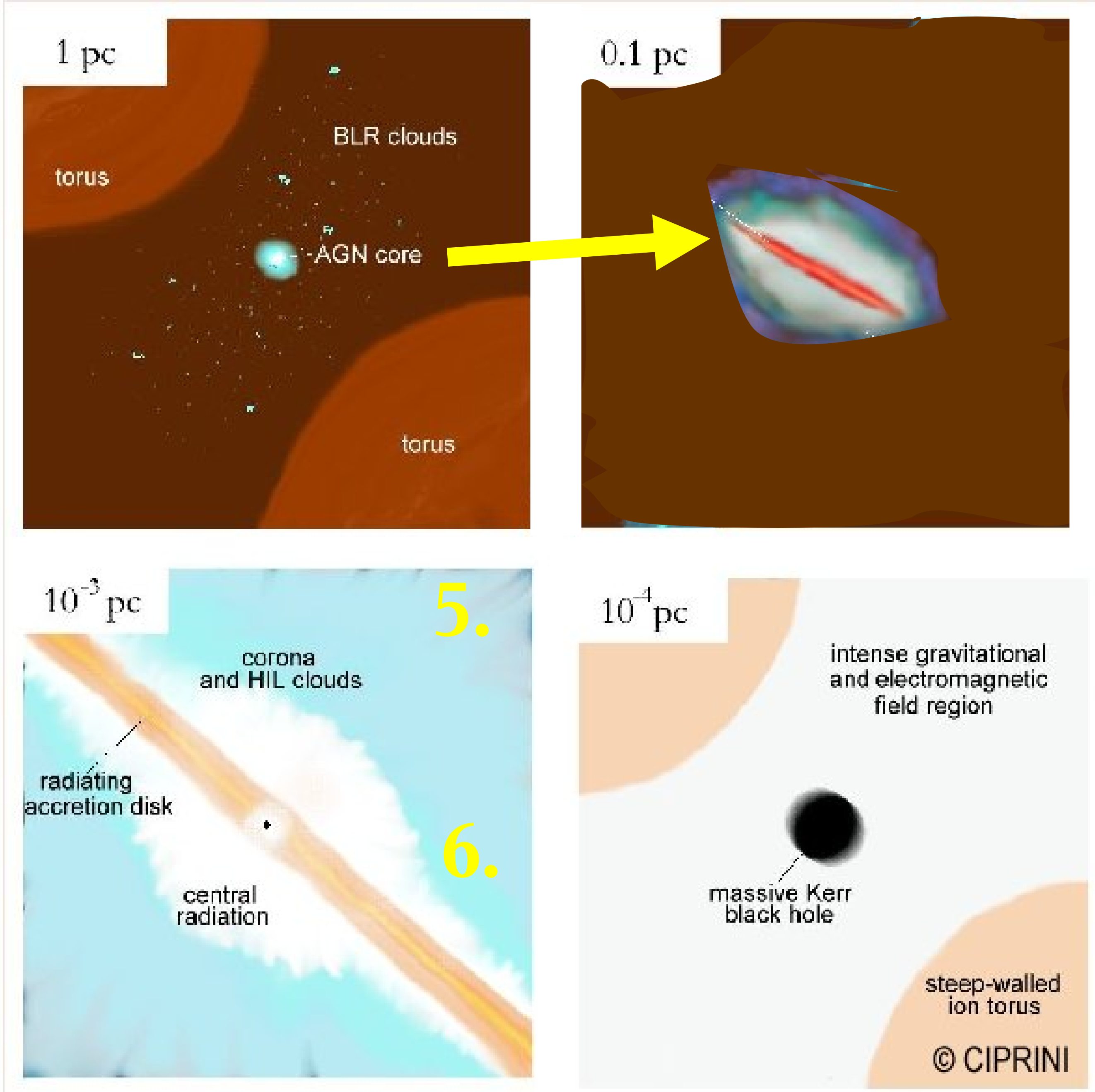
Left: Hubble image taken with the Wide Field Planetary Camera 2. Right: The quasar's home galaxy comes into view only when the coronagraph of the Advanced Camera for Surveys (ACS) blocks the light from the brilliant central quasar.

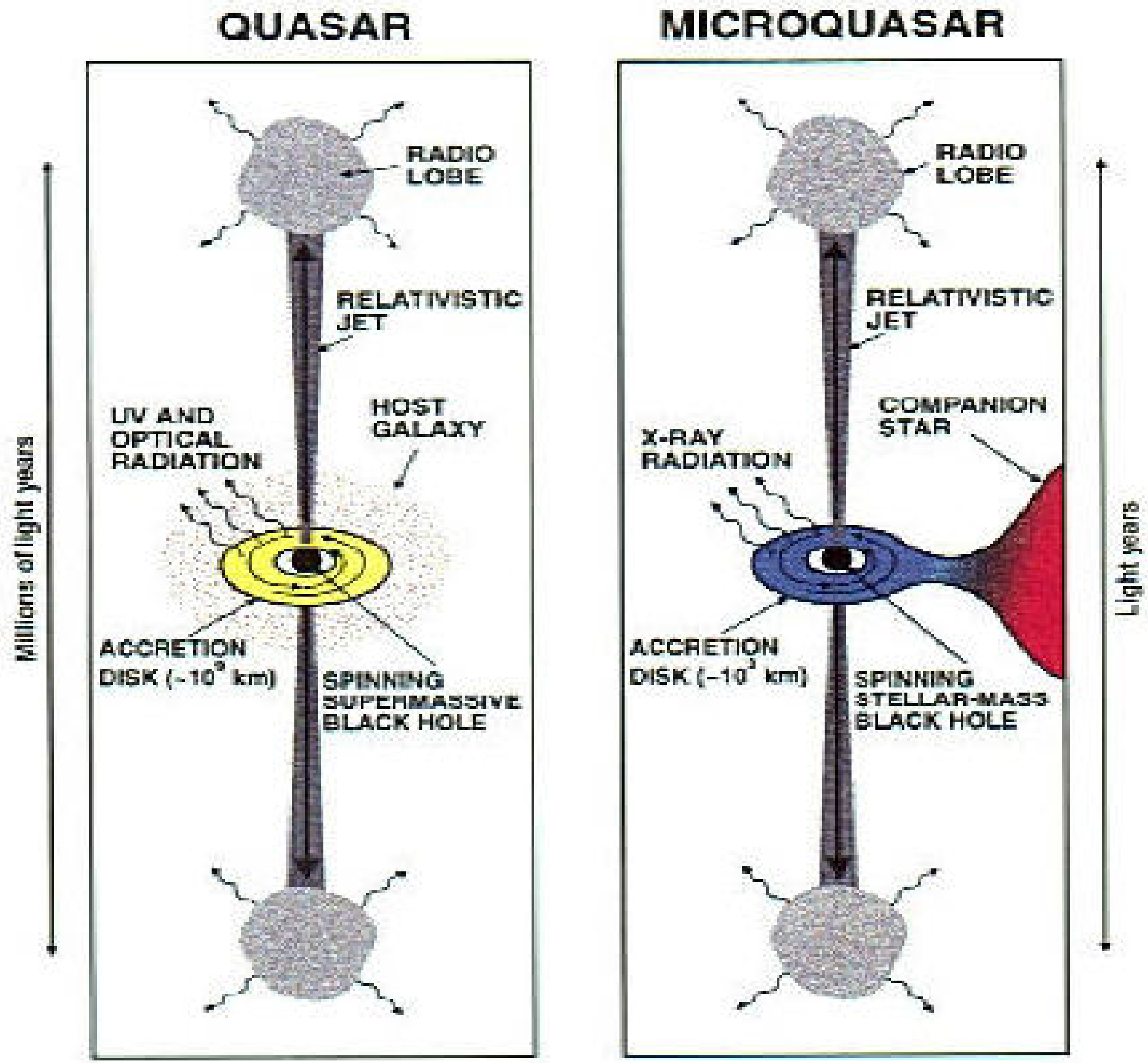
$$L_{\text{Quasar}} = 10^{13} \, L_{\text{Sun}} \sim 100 \, L_{\text{Galaxy}}$$



As the light of the Sun overshines the corona..... the Quasar overhines the host Galaxy


1 Mpc
radio lobe
strong shocks 'hotspots'
high luminosity galaxy
supersonic and relativistic jet
radio lobe
weak bow shock
100 kpc
radio jet
irregular galaxy with multiple nuclei
possible companion galaxy
1 kpc
massive HII star formation regions
AGN core
molecular gas and dust
100 pc
hidden AGN core
NLR clouds
optically thick torus


1 pc
BLR clouds
torus
AGN core
torus
0.1 pc
10^{-3} pc
5.
corona
and HIL clouds
radiating
accretion disk
6.
central
radiation
10^{-4} pc
intense gravitational
and electromagnetic
field region
massive Kerr
black hole
steep-walled
ion torus
© CIPRINI

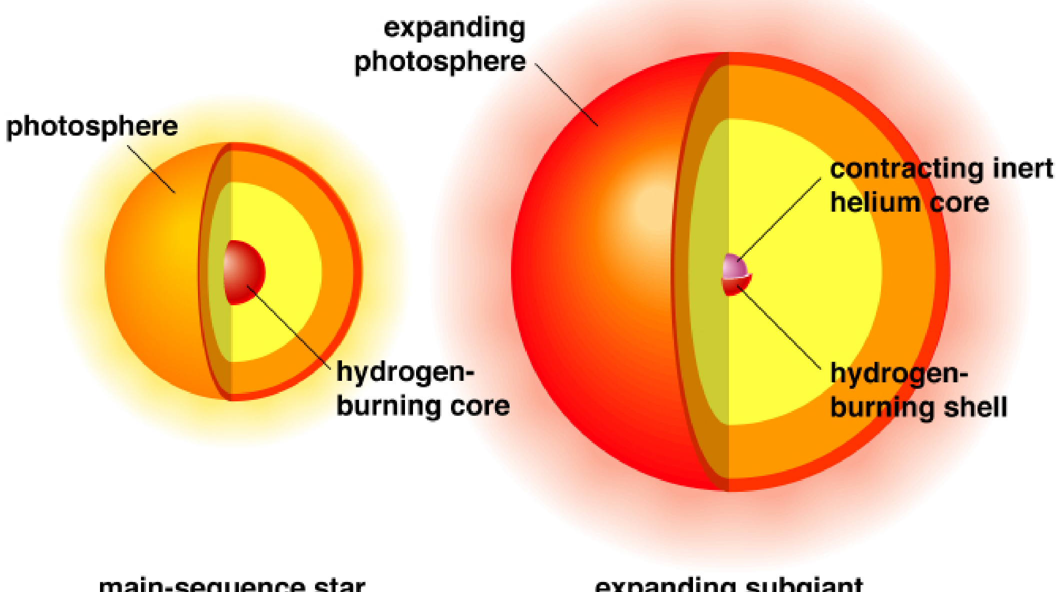

QUASAR
MICROQUASAR
RADIO LOBE
RELATIVISTIC JET
HOST GALAXY
UV AND OPTICAL RADIATION
ACCRETION DISK (~10^9 km)
SPINNING SUPERMASSIVE BLACK HOLE
Millions of light years
RADIO LOBE
RELATIVISTIC JET
COMPANION STAR
X-RAY RADIATION
ACCRETION DISK (~10^3 km)
SPINNING STELLAR-MASS BLACK HOLE
Light years

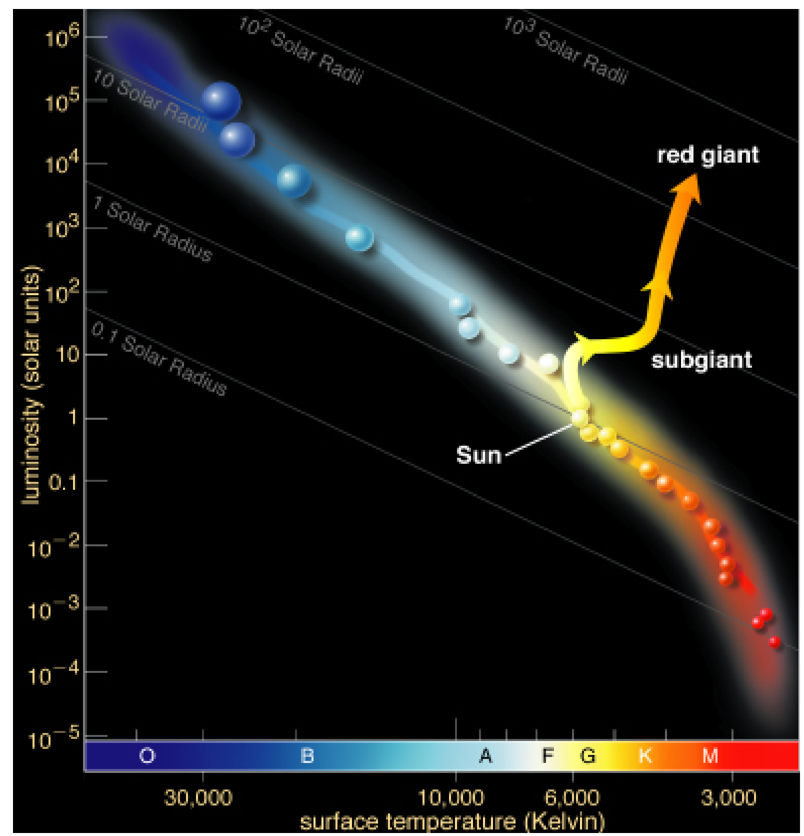
Stellar evolution:

white dwarf, neutron stars and black holes

- After approximately 10 billion years of steady core hydrogen burning, a Sun-like (1 solar mass) star begins to run out of fuel.
- Source of energy is gone, gravity finally wins.
- Contraction leads to increase in density and temperature in the core.

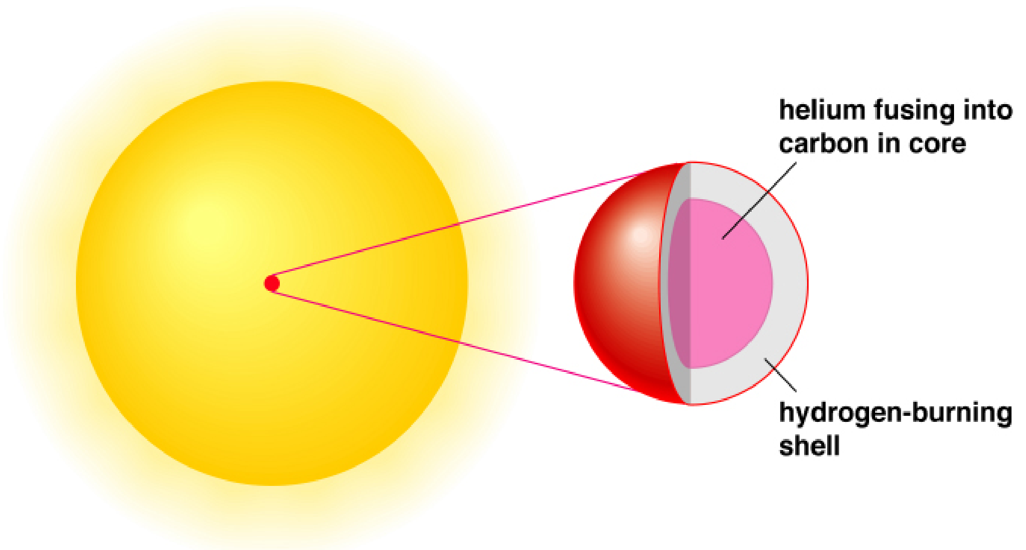
Hydrogen fusion (T>1.4 10^7 K) begins in a <u>shell</u> outside the original core as the temperature increases.

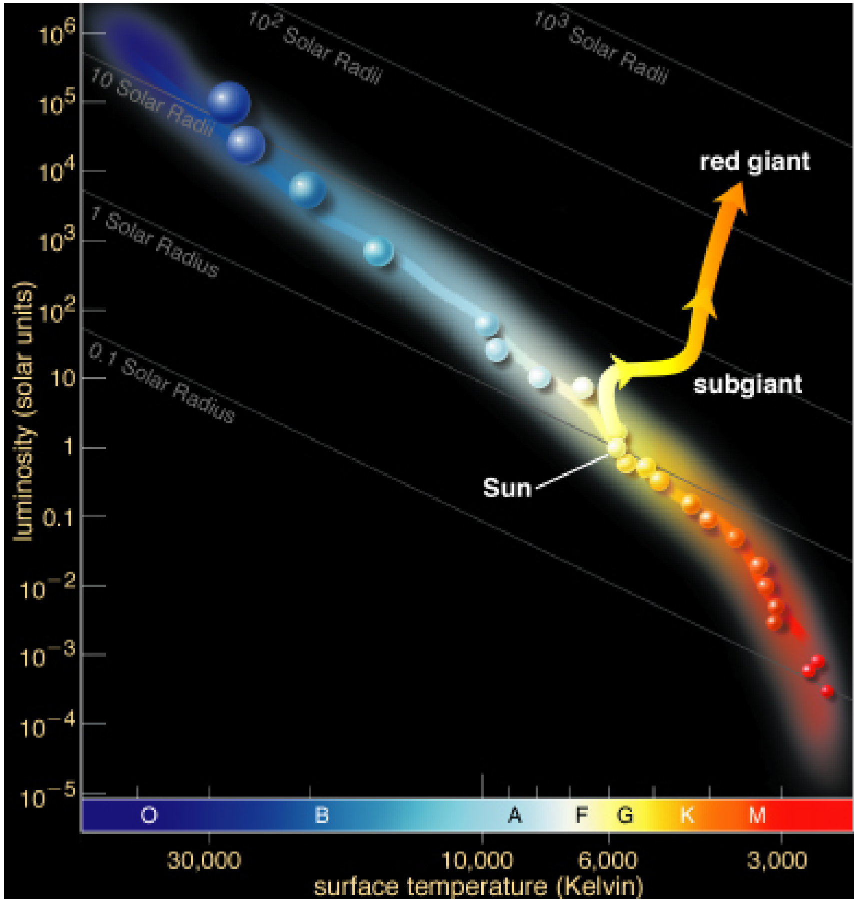




Helium-Carbon burning

Helium fusion begins in the core at a high enough temperature. (10^8

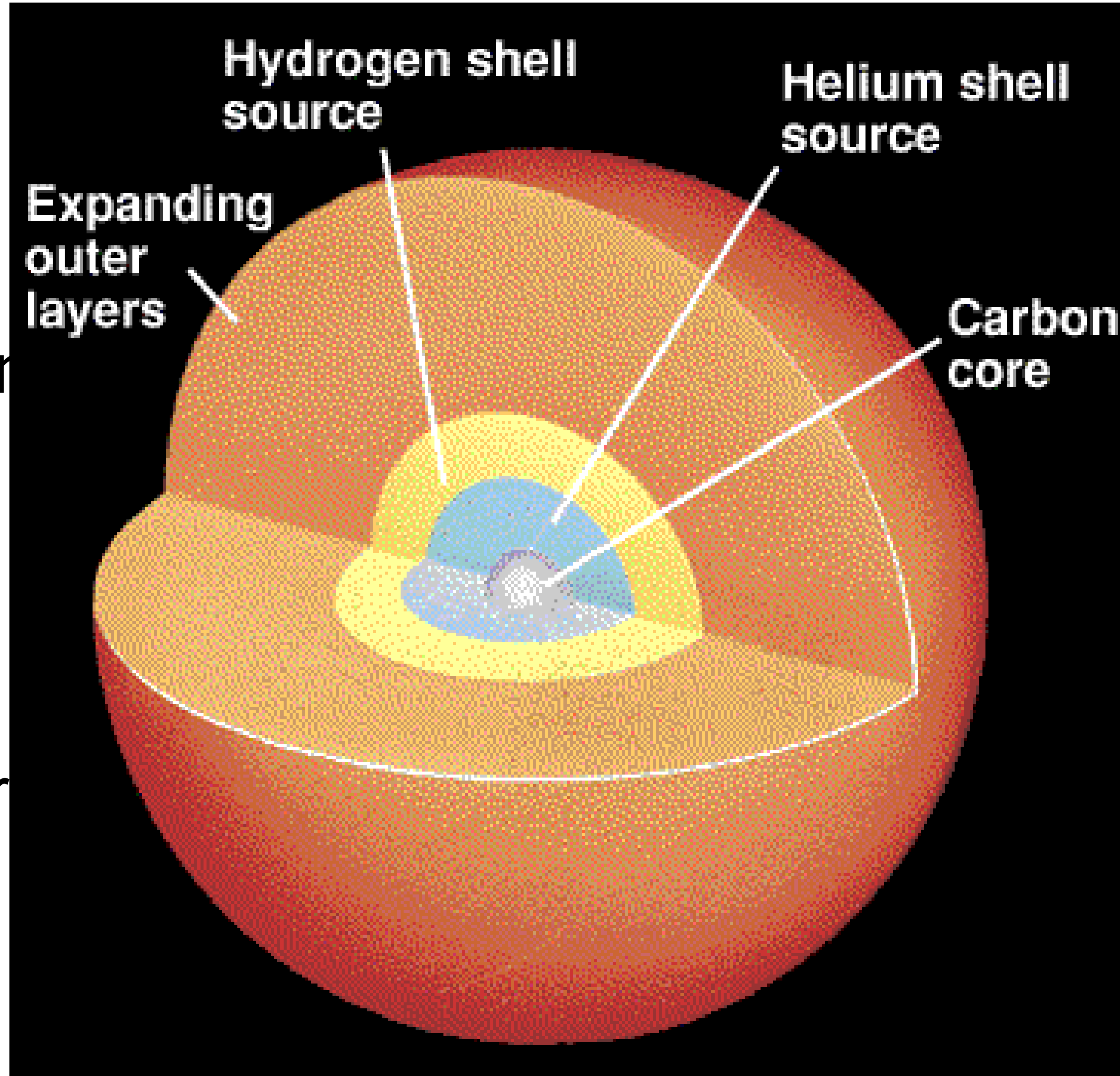




H-He, He-C shell burning

Once the star runs out of helium in the core, contraction begins again.

Eventually the core temperatur allows helium shell fusion.



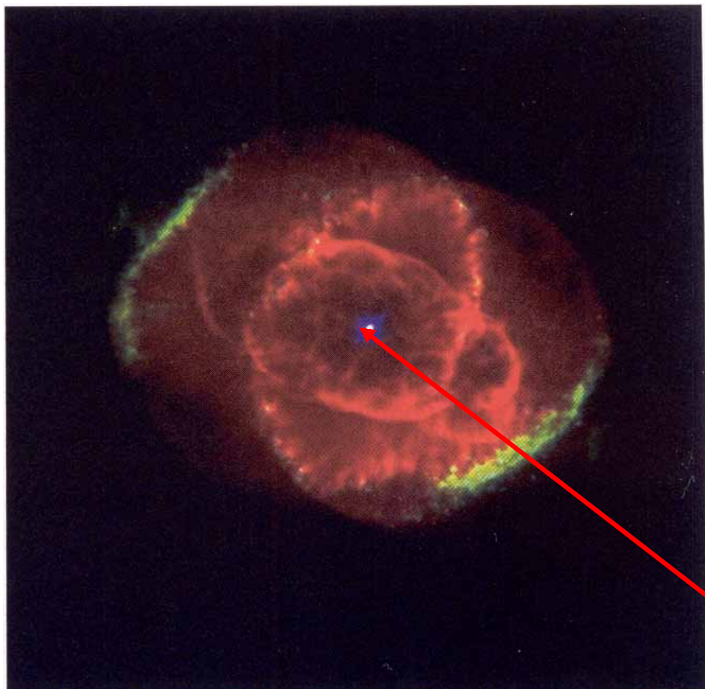
The End

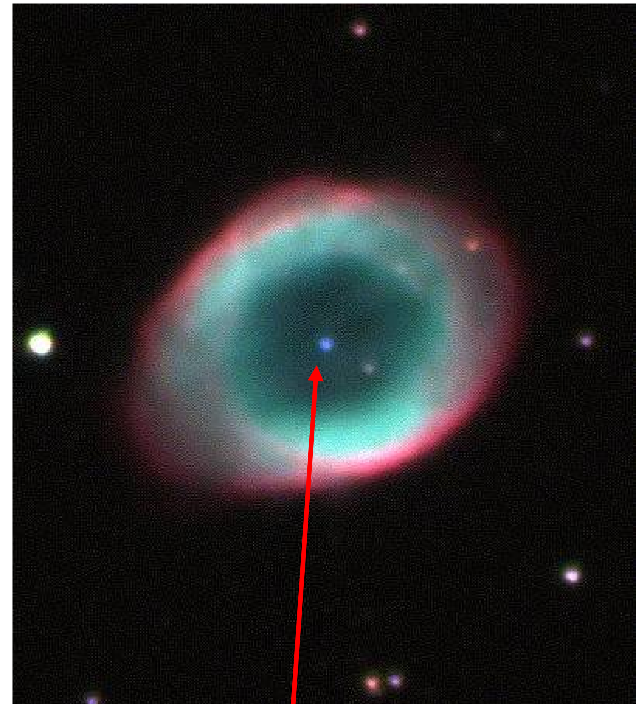
If the central temperature could become high enough for carbon fusion to occur, the newly generated energy might again support the star, temporarily restoring for a time the equilibrium between gravity and radiation.

For a 1 solar-mass star, however, this does not occur. The temperature never reaches the **6 10^8** K needed for a new round of nuclear reactions to occur.

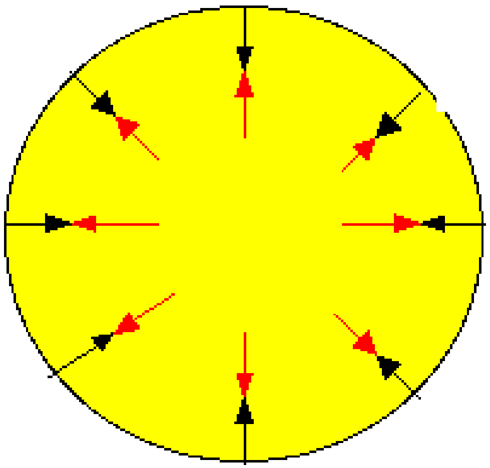
Planetary Nebula

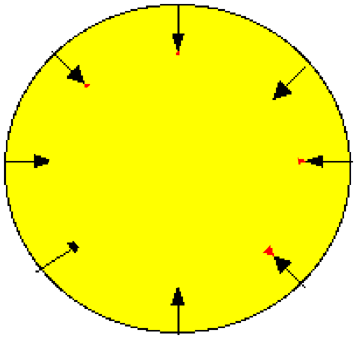
Planetary Nebulae

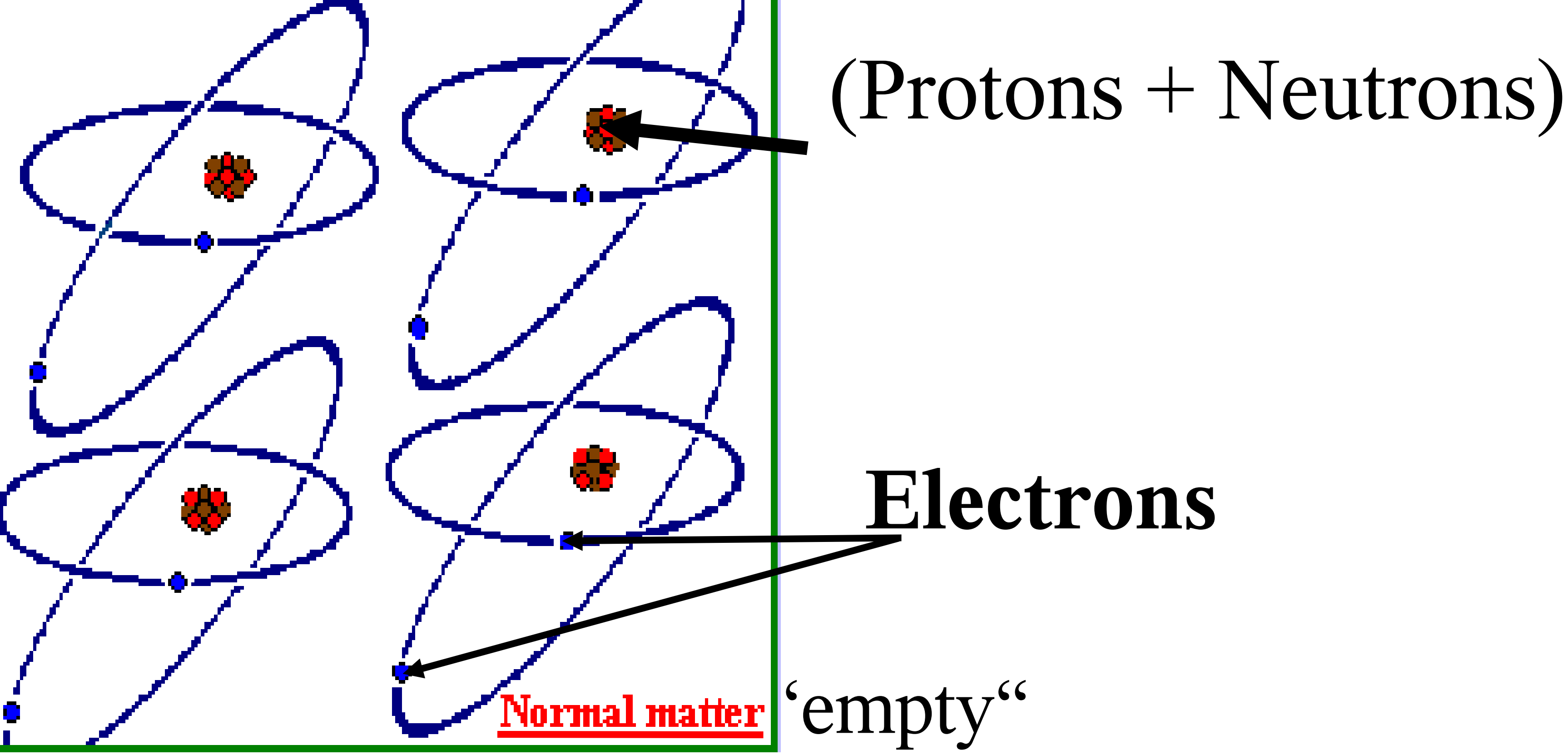




The collapsing Carbon core becomes a White Dwarf







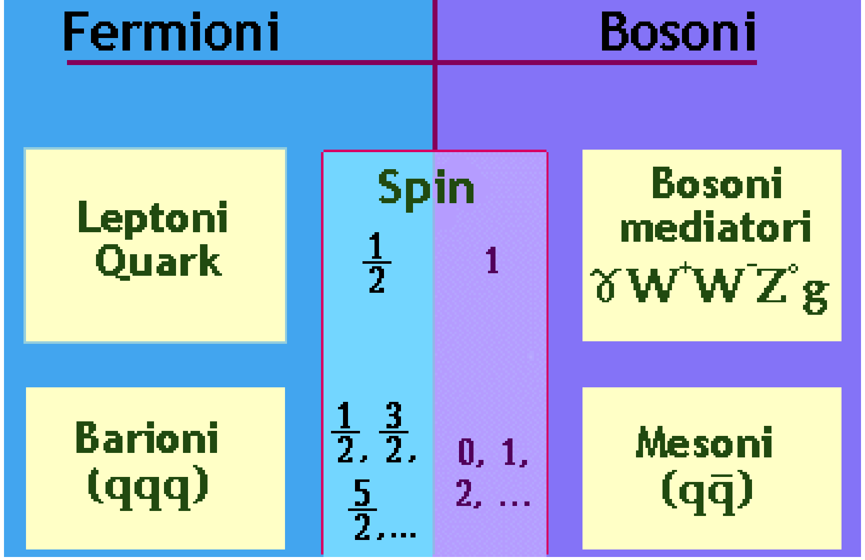
Large inter-atomic distances
become compressed during the collapse

Normal matter: nearly“empty“
The usual atomic structure is disrupted by the large gravitational force

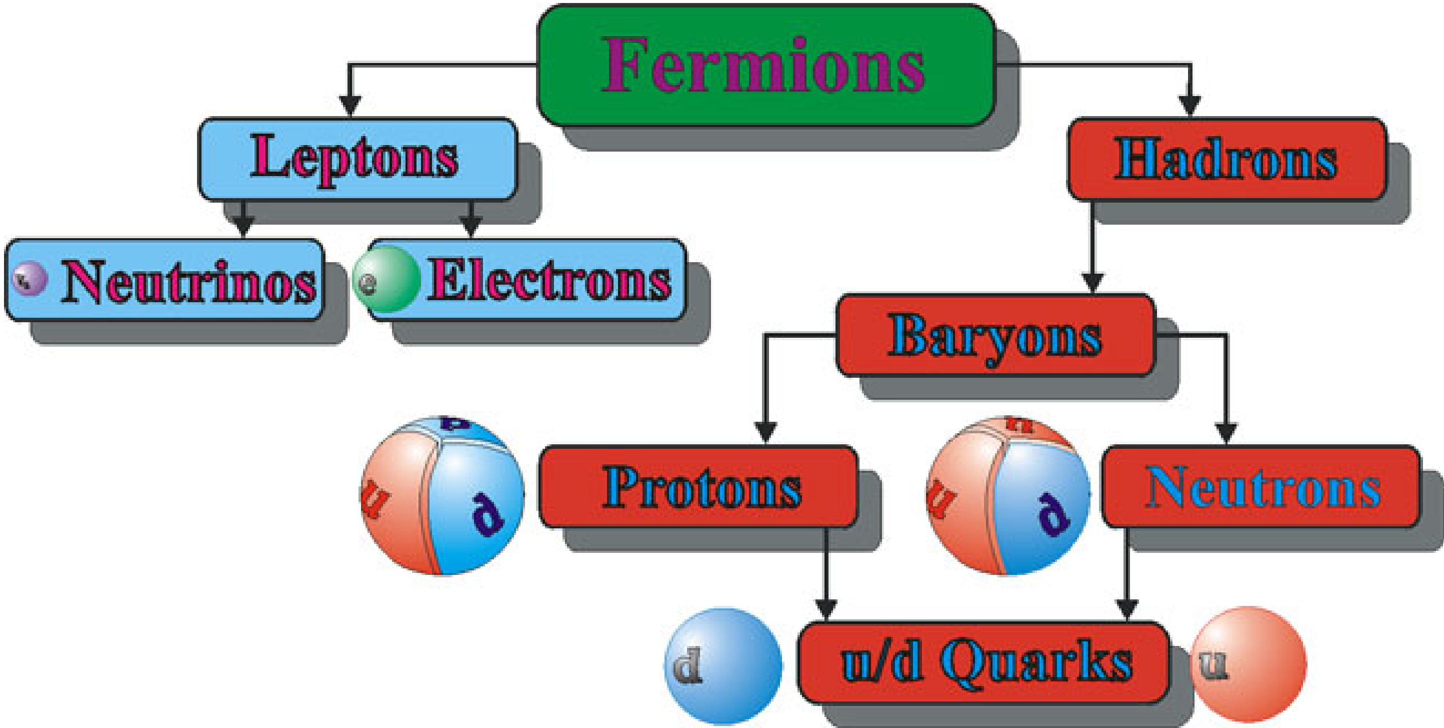
Pauli exclusion principle:

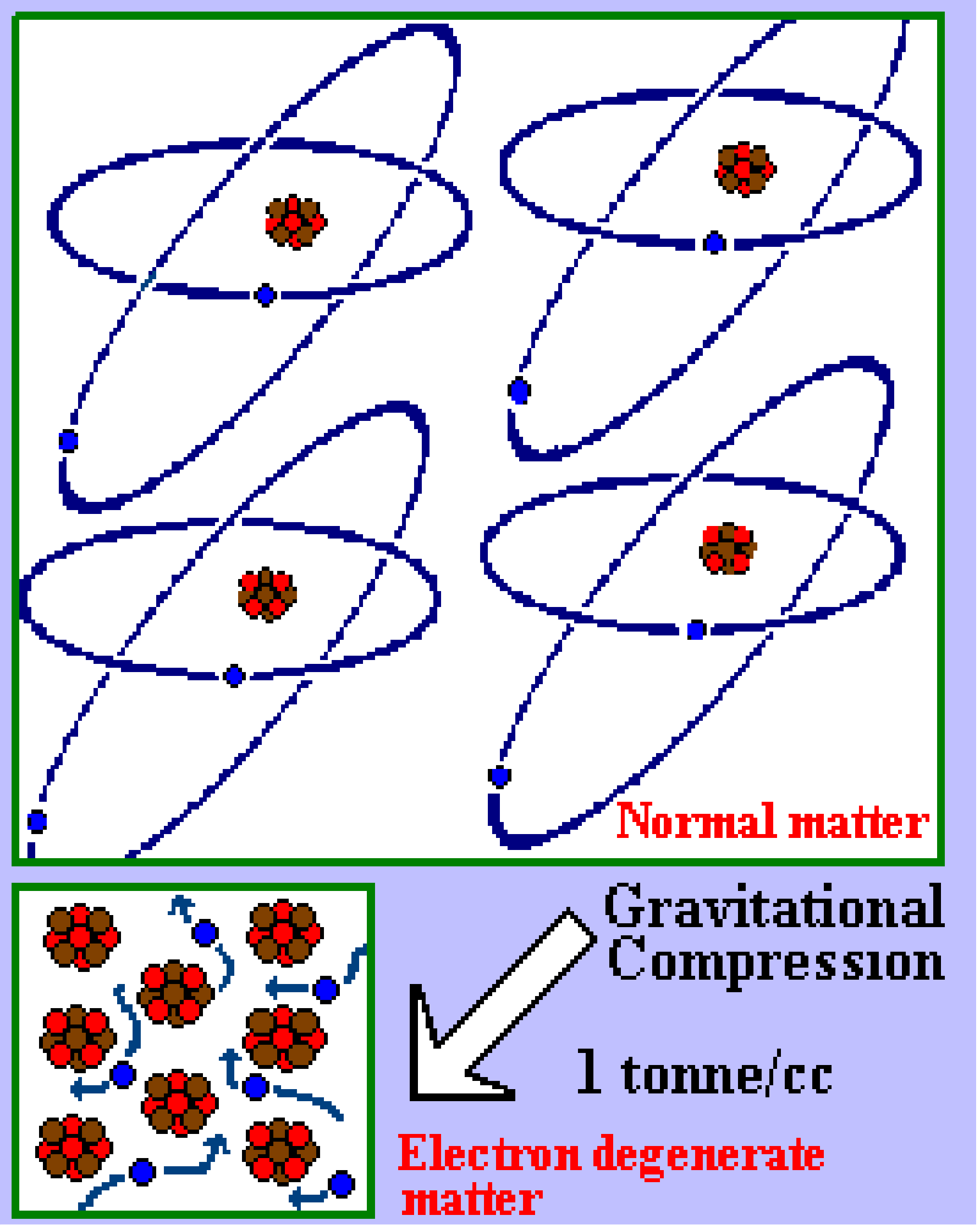
It states that no two identical fermions may occupy the same quantum state simultaneously.

Fermions : particles with a half-integer spin, such as protons,neutrons. electrons



Fermions : particles with a half-integer spin, such as protons,neutrons. electrons



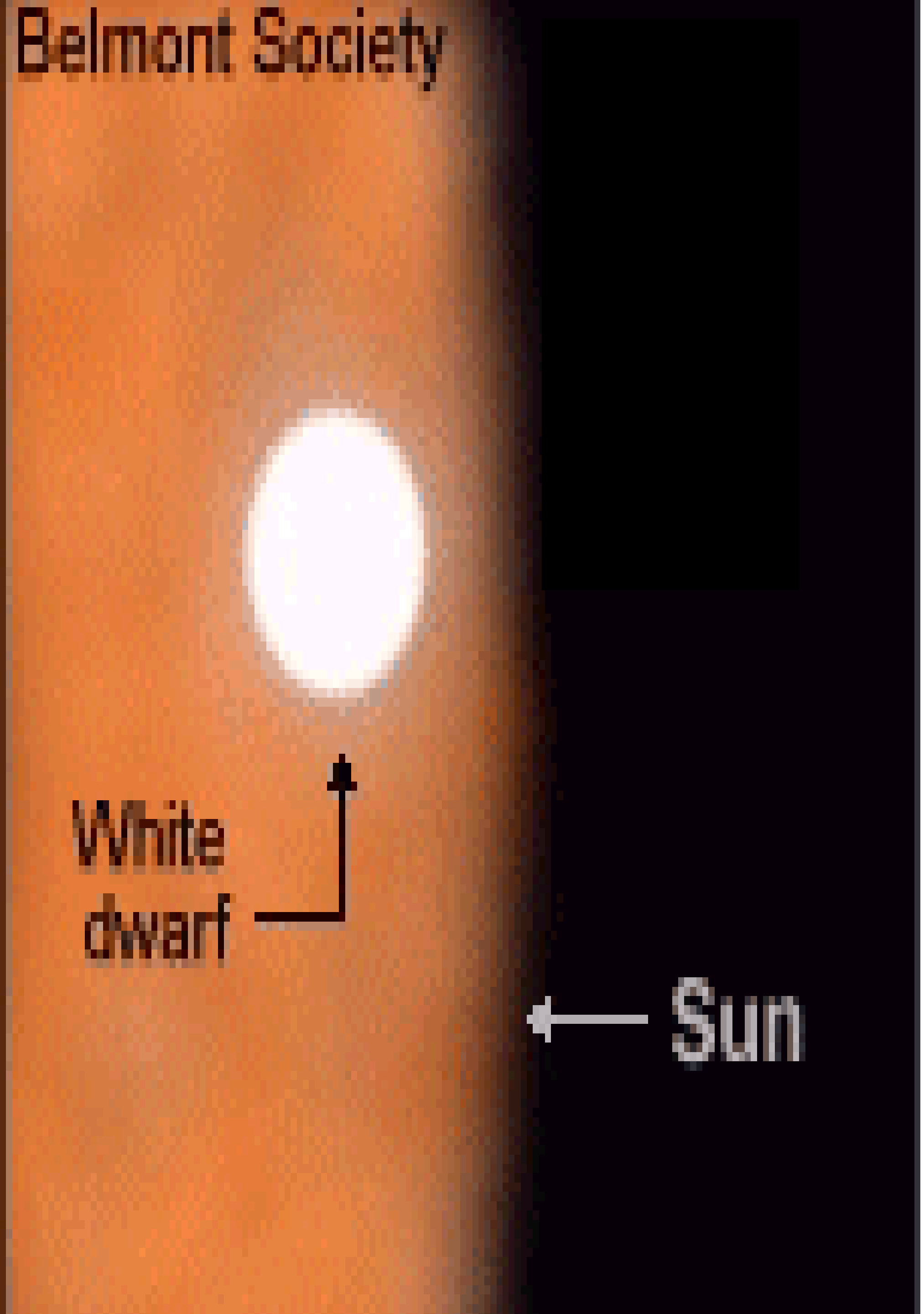


Pauli exclusion principle:

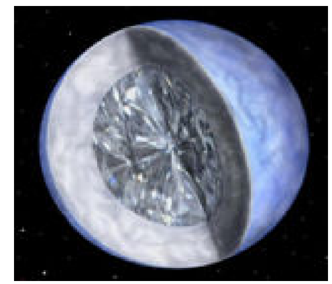
no two identical electrons may occupy the same quantum state simultaneously.

- The degenerate-electron pressure supports the star against further collapse

STOP of the collapse



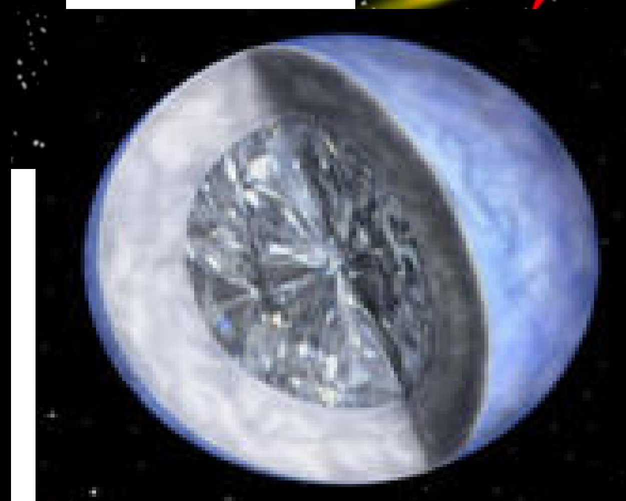
In white dwarfs, the atoms are held apart by the degenerate-electron pressure

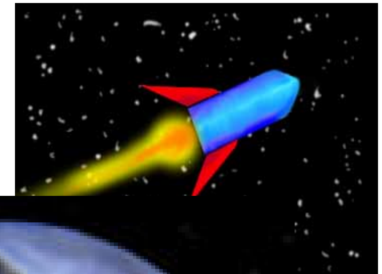


-Mass of the Sun
-about the size of the earth

- A cool white dwarf is a giant diamond made of crystallized (the ions do not move anymore freely but tend to form a rigid lattice) carbon

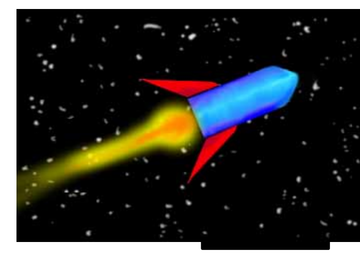
11 km/s

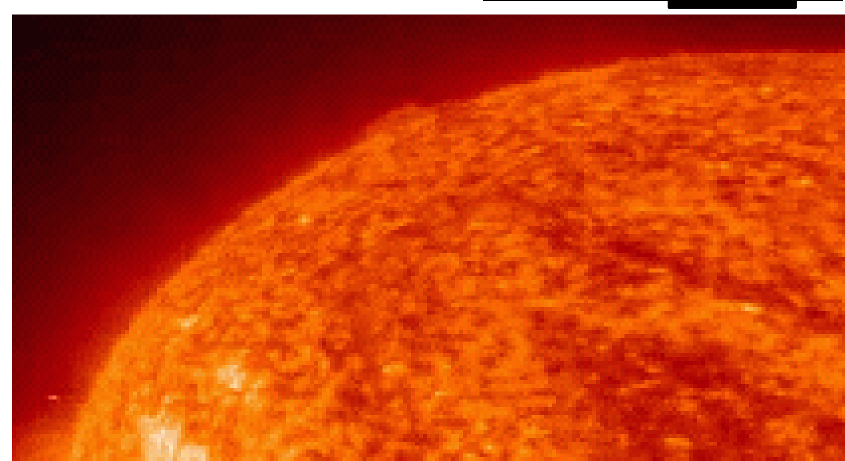




5.000 km/s

617 km/s





$$v = \sqrt{\frac{2GM}{R}}$$

Escape velocity

High Mass Stars ($M_{initial}$ >8 Msun)

- A low mass star (< 8 Msun) follows the evolution track of
  - Main sequence
  - Red Giant -→ Horizontal Branch -→ AGB star
  - Planetary Nebula
  - White Dwarf

- But, a high mass star (>8 Msun) has different evolution
  1. Main
  2. Supergiant
  3. Supernova
  4. Neutron star or black hole

- Unlike a low-mass star, a high mass star undergoes an extended sequence of thermonuclear reactions in its core and shells
- These include carbon (^{12}C) fusion, neon (^{20}Ne) fusion, oxygen (^{16}O) fusion, and silicon (^{28}Si) fusion

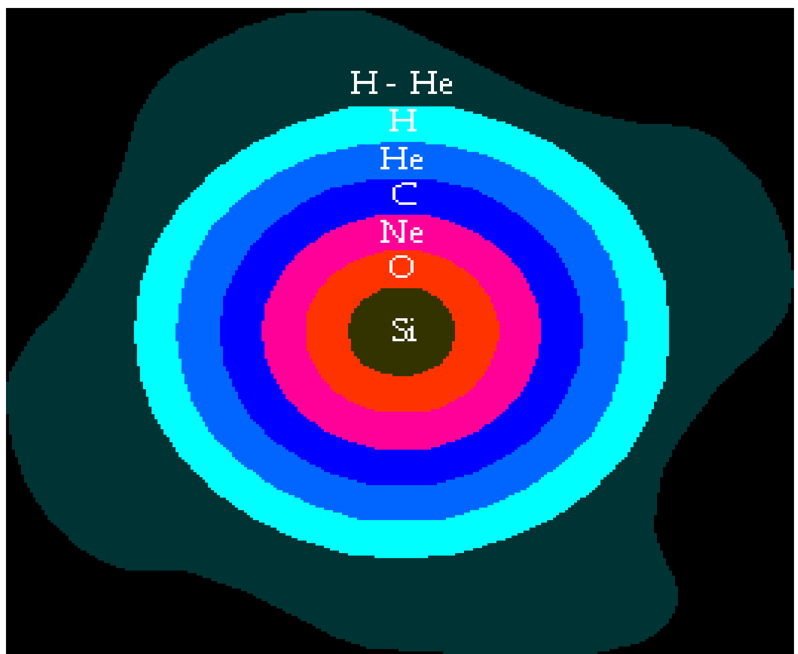
table 22-1 Evolutionary Stages of a 25-$M_\odot$ Star

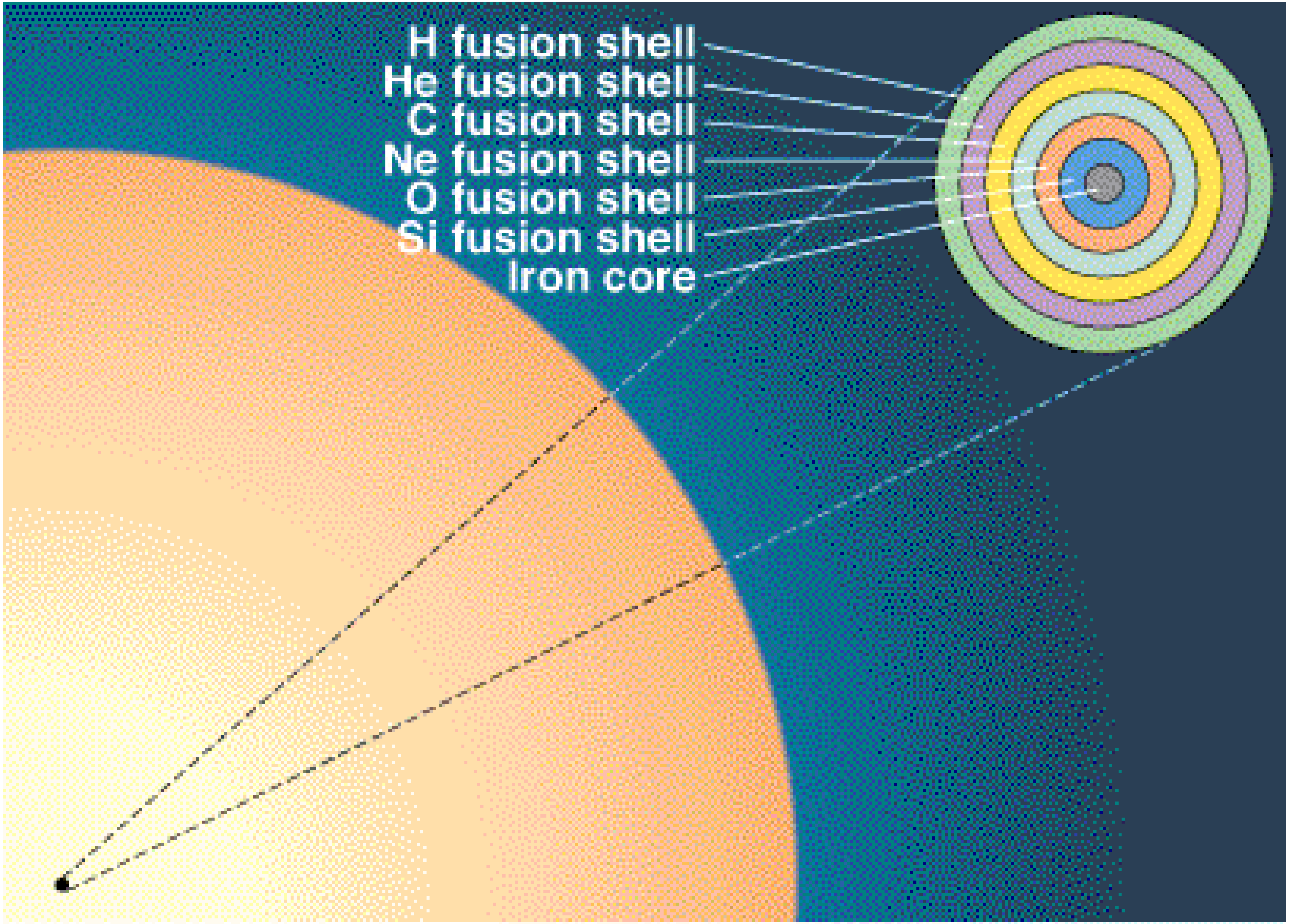
Stage	Core temperature (K)	Core density (kg/m^3)	Duration of stage
Carbon fusion	6×10^8	2×10^8	600 years
Neon fusion	1.2×10^9	4×10^9	1 year
Oxygen fusion	1.5×10^9	10^{10}	6 months
Silicon fusion	2.7×10^9	3×10^{10}	1 day
Core collapse	5.4×10^9	3×10^{12}	¼ second
Core bounce	2.3×10^{10}	4×10^{15}	milliseconds
Explosive (supernova)	about 10^9	varies	10 seconds

Massive stars
Shell structure

If each reaction has time to reach equilibrium, the stellar interior will consist of shells of different composition and reactions

- Oxygen is ignited next producing a Silicon core.

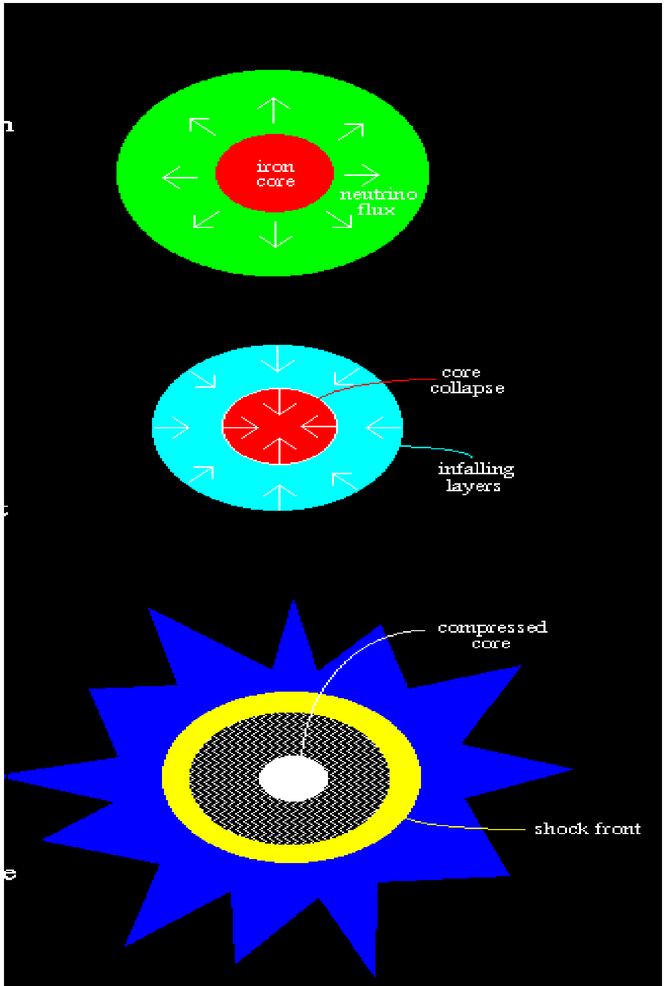


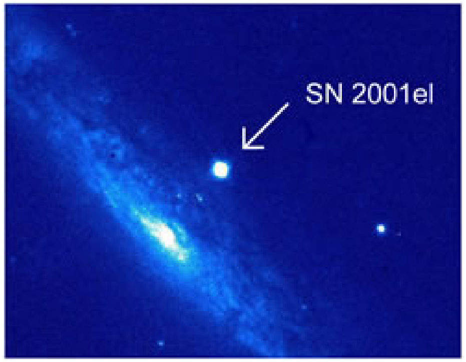

H fusion shell
He fusion shell
C fusion shell
Ne fusion shell
O fusion shell
Si fusion shell
Iron core

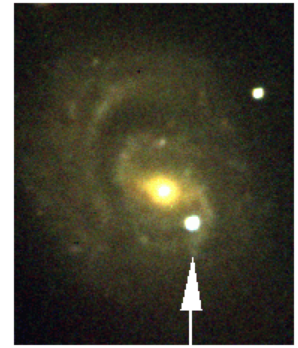
The Iron (Fe) Problem: Iron burning is an endothermic reaction

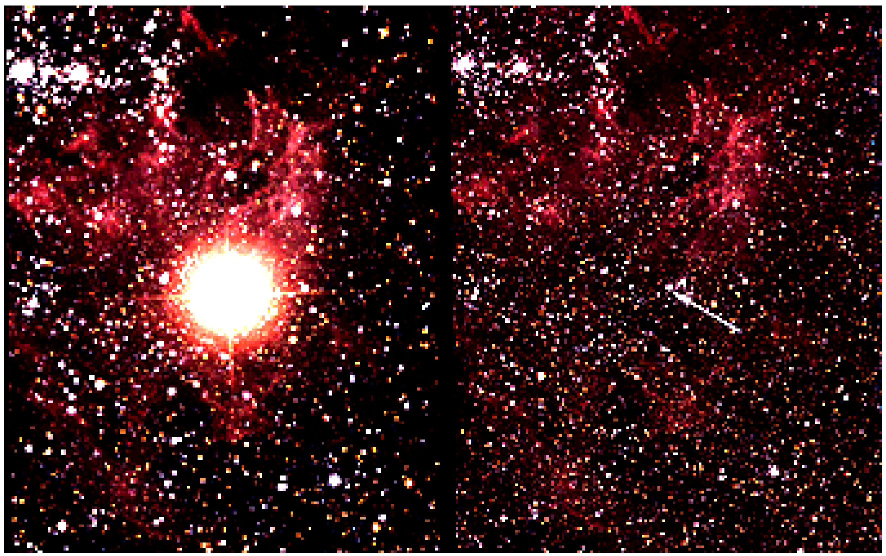
Iron is the last element that can be produced by nuclear fusion, exothermically. All nuclear fusion reactions from here on are endothermic and so the star loses energy.

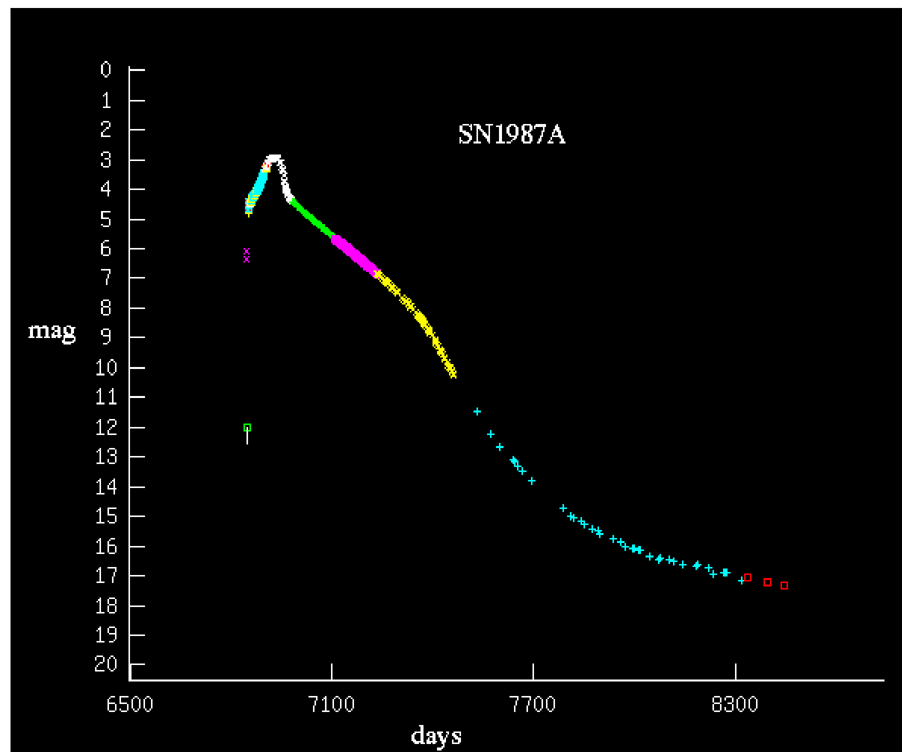
Core collapse




SN 2001el






SN1987A
mag
0
1
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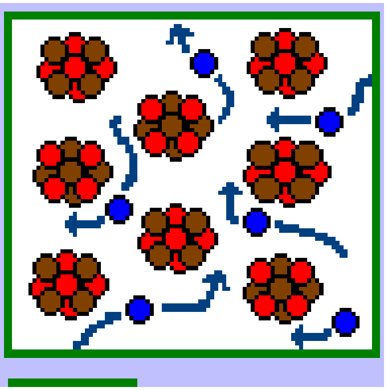
16
17
18
19
20
6500
7100
7700
8300
days

Subrahmanyan Chandrasekhar predicted while a very young man in the 1930s that there was a limiting mass for white dwarf stars:
no white dwarf could be stable against gravitational collapse if it exceeded this mass, which is about
1.4 solar masses,

Chandrasekhar won a Nobel Prize for his deep theoretical contributions to astrophysics.

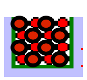


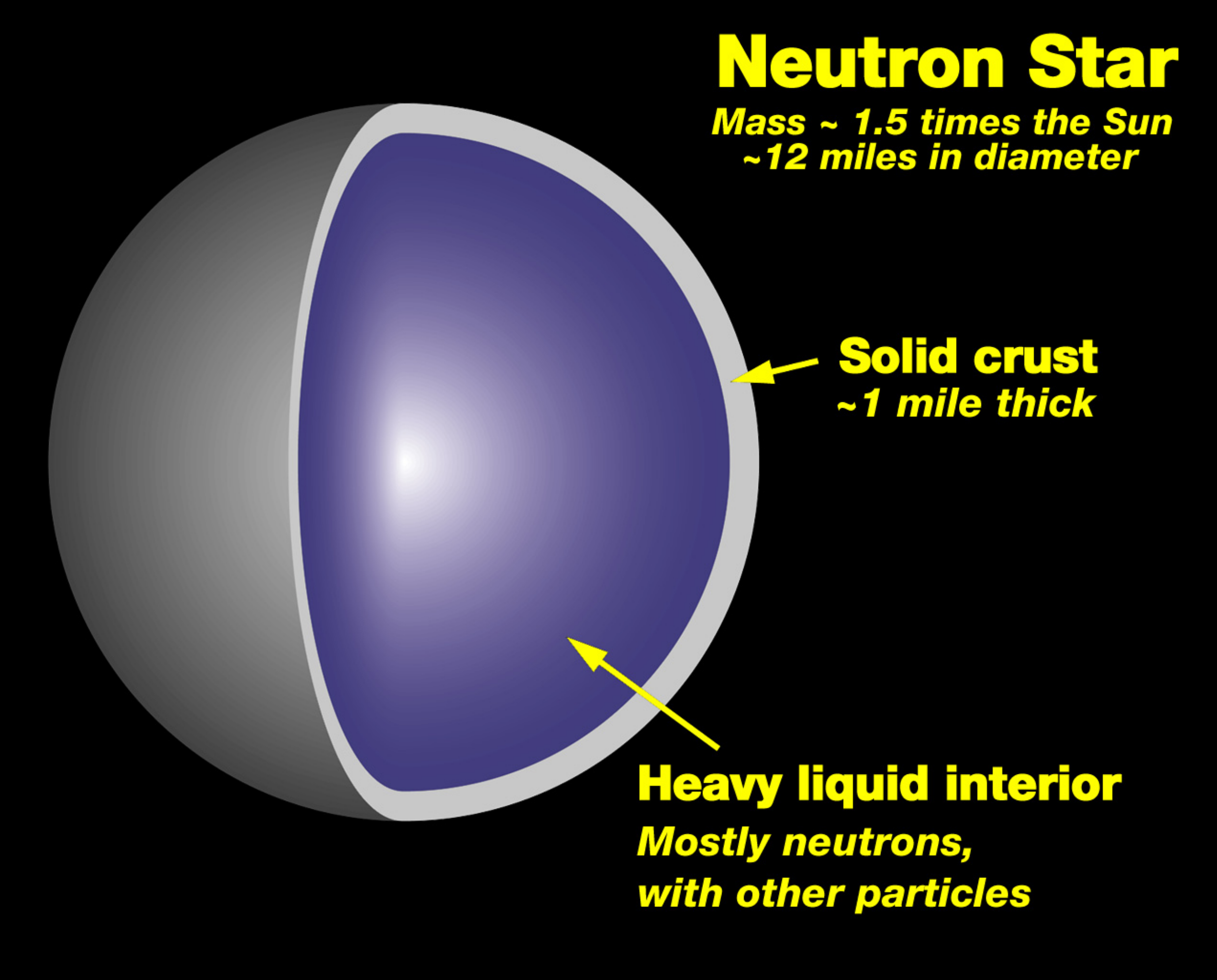
Elektrons and Protons form

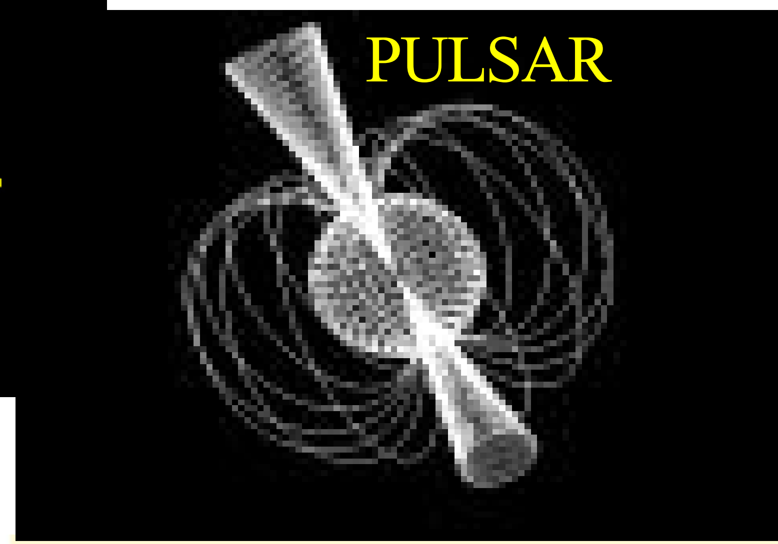
<u>Neutrons.</u>

Pauli exclusion principle

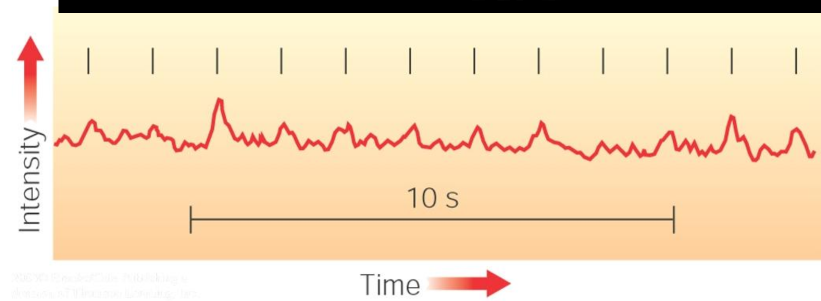
STOP of the collapse



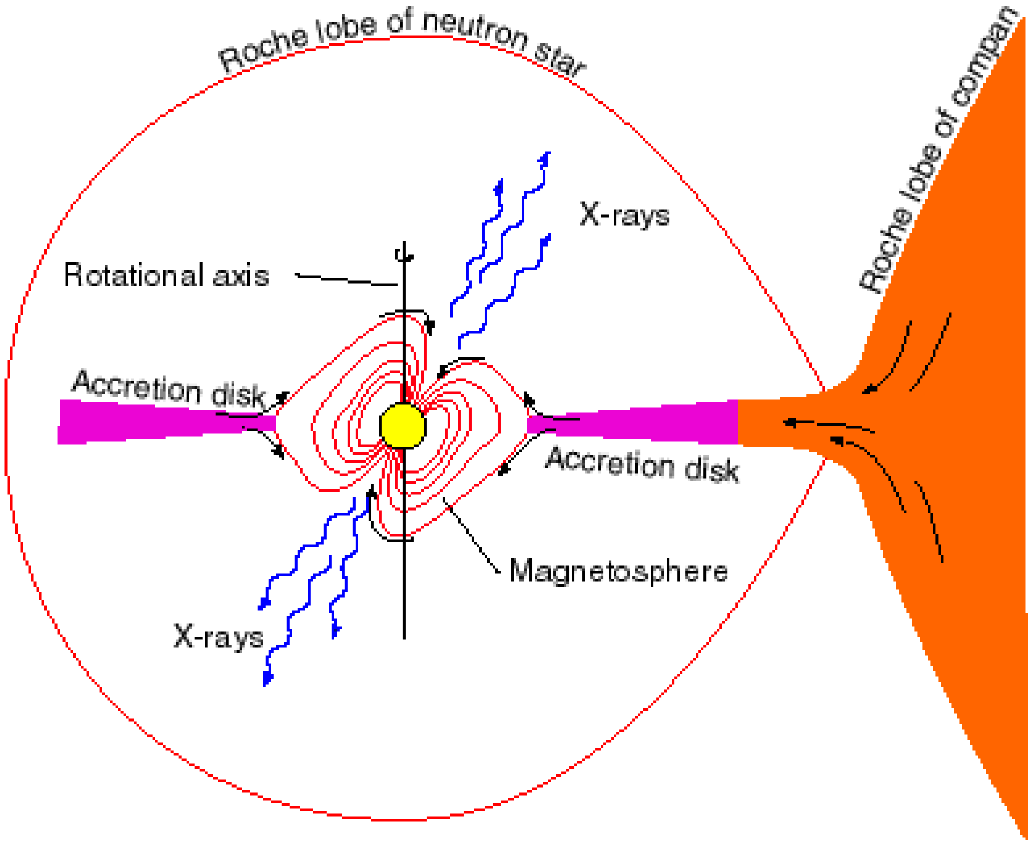


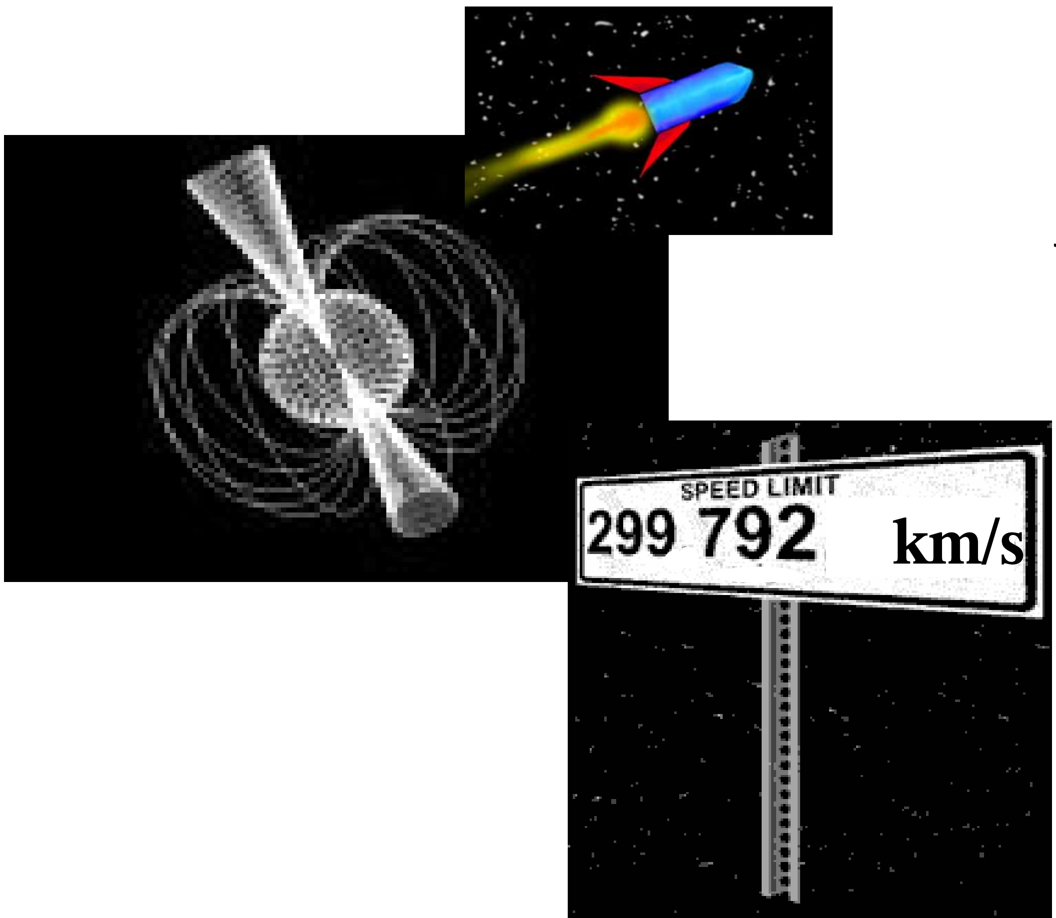


Radio pulsar



X-ray pulsar: an accreting neutron star





Escape velocity

v = 250.000 km/s

just as there is an upper limit on the mass of a white dwarf, there is an upper limit on the mass of a neutron star.

White dwarfs can't have **M > 1.4 Msun**; above this mass, the degenerate-electron pressure is insufficient to prevent collapse.

Neutron stars can't have **M > 3 Msun**; above this mass, the degenerate-neutron pressure is insufficient to prevent collapse (the upper mass limit for neutron stars is fairly uncertain).

Escape Velocity and Black Holes

No physical object can travel faster than light. The speed of light, according to special relativity, is an absolute upper limit.

What is the radius of an object of given mass that has an escape velocity equal to the speed of light?

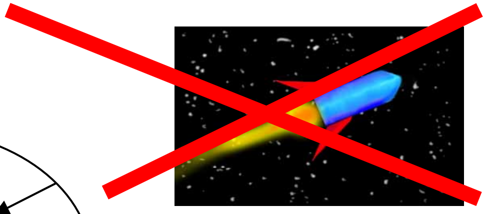
$$v_e = \sqrt{\frac{2GM}{R}} \qquad c = \sqrt{\frac{2GM}{R_s}} \qquad R_s = \frac{2GM}{c^2} \qquad R_s = \frac{2GM_e M}{c^2 M_e}$$

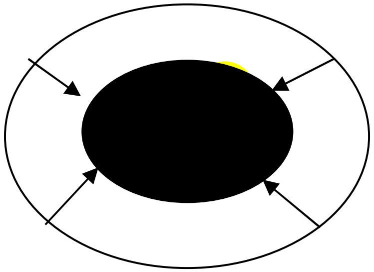
$$R_s = \frac{2GM_e}{c^2}\,\frac{M}{M_e}$$

$$\frac{2GM_e}{c^2} = \frac{2\left(6.67 \quad 10^{-11}\right)\left(1.99 \quad 10^{30}\,\mathrm{kg}\right)}{\left(2.998 \quad 10^{8}\,\mathrm{m/s}\right)^2} = 3.0 \quad 10^3\,\mathrm{m} = 3.0\,\mathrm{km}$$

$R_s = (3.0\,\mathrm{km})\,M$ M in solar masses and R_s in km

Schwarzchild Radius





The radius where

escape speed = the speed of light.

$$R_s = 2\,GM/c^2$$

$R_s = 3 \times M$ (R_s in km; M in solar masses)

A sphere of radius R_s around the black hole is called the **event horizon**.

Object	Mass (solar)	Black Hole Event Horizon
Star	10	30 km
Star	3	9 km