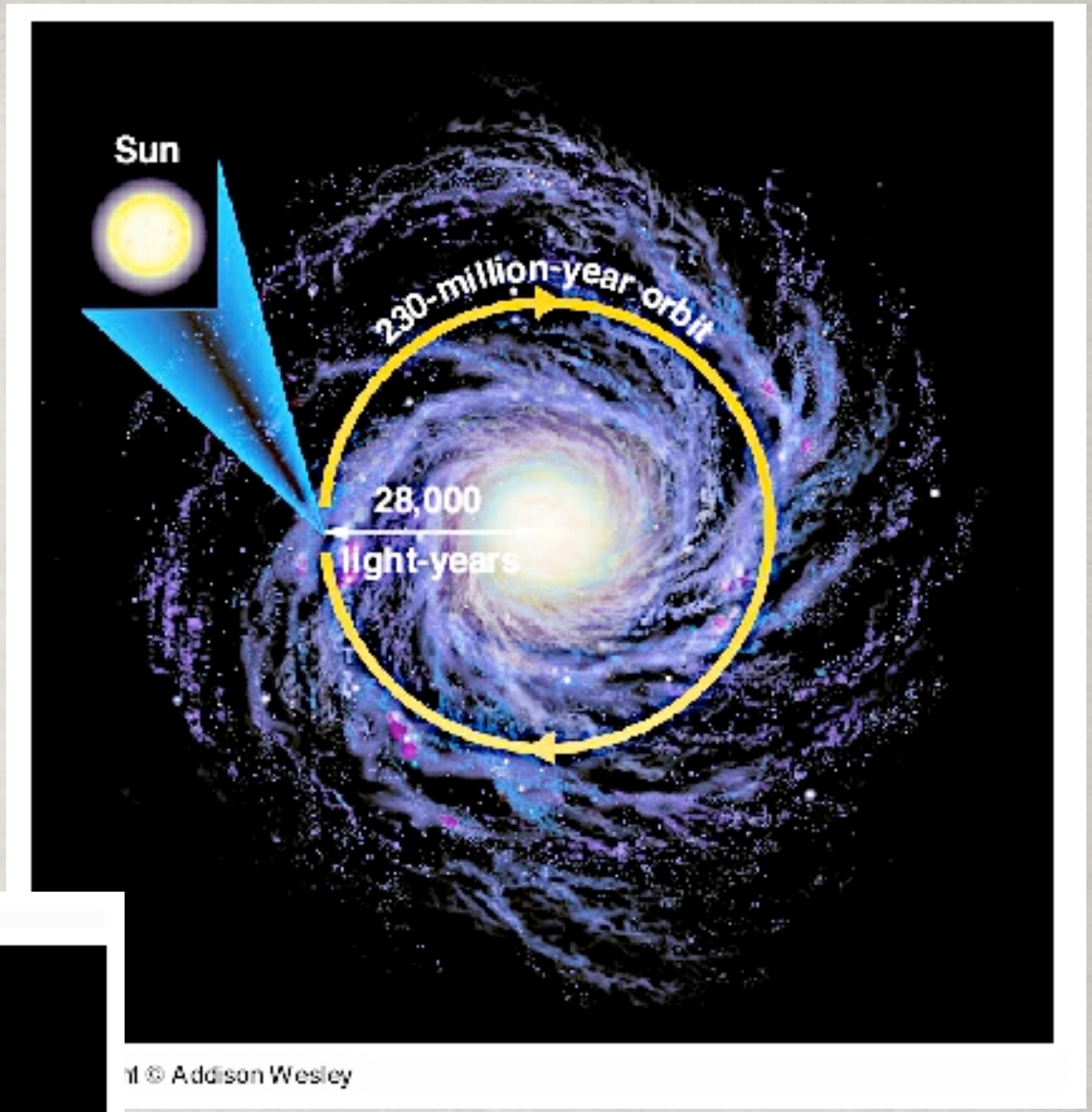
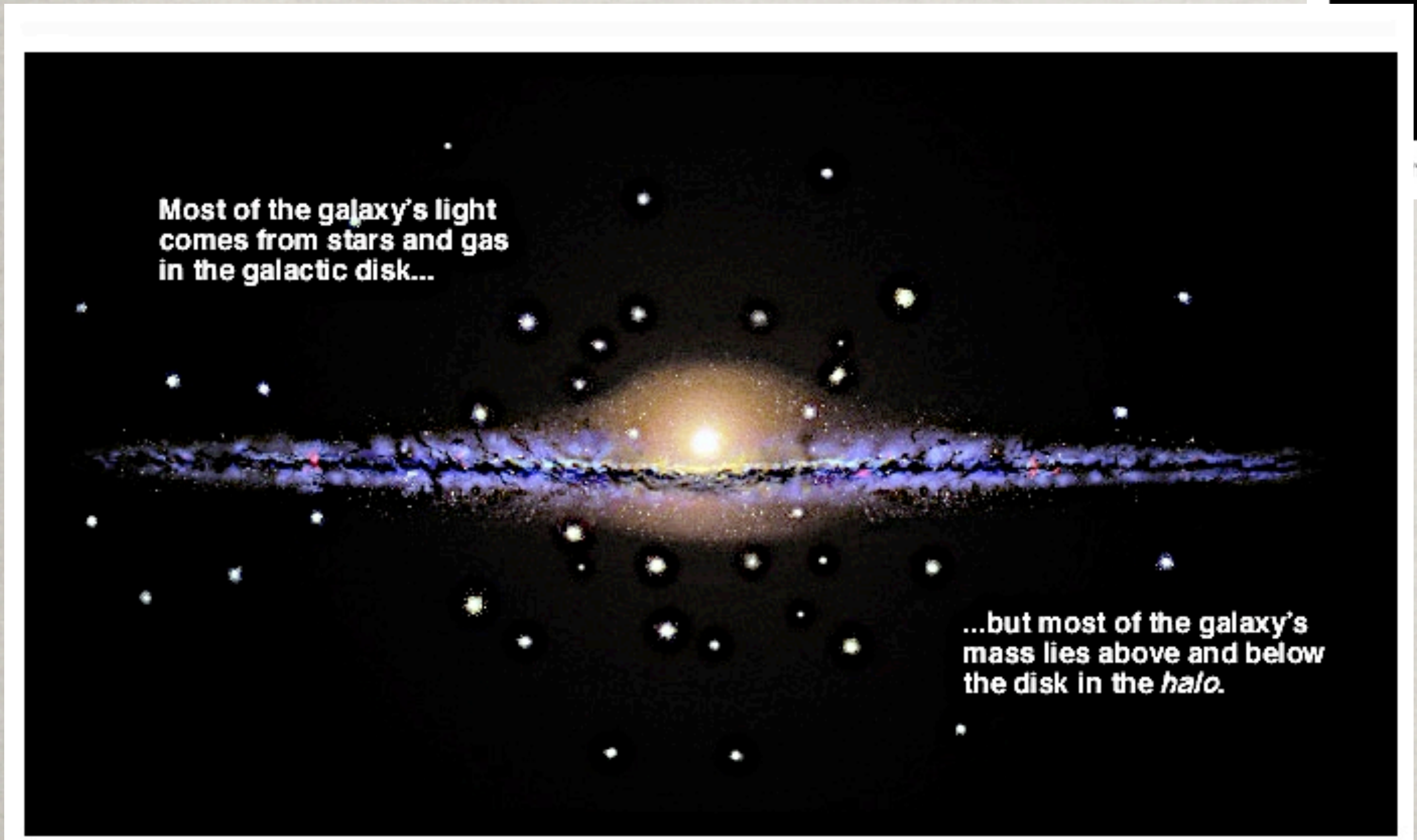
# Star Formation

# Main Components of our Galaxy

Disk, Bulge, Halo



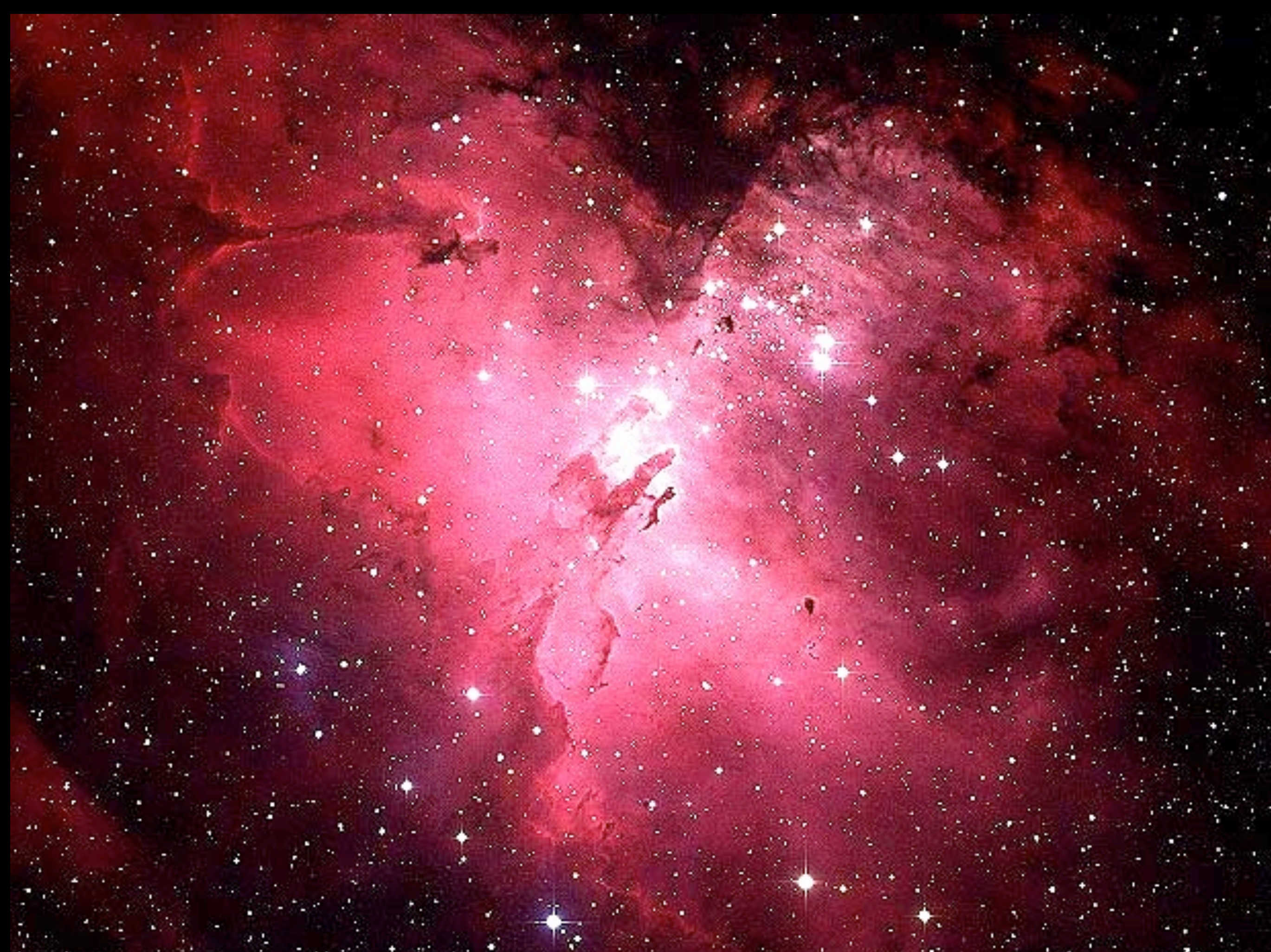



## Distances:

1pc - typical distance between stars.
8,500pc - distance to the center

# Giant Molecular Clouds: places where stars form

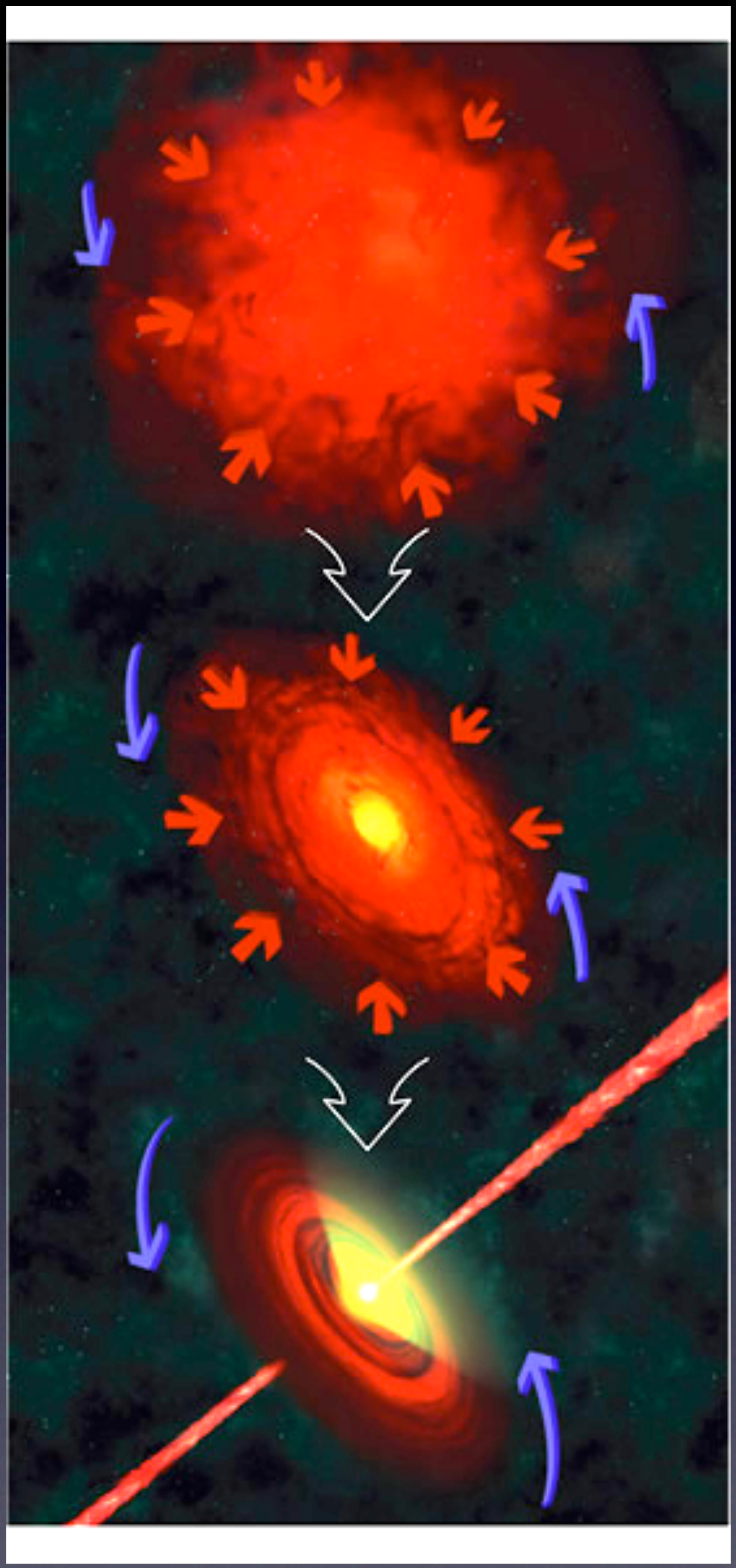
SIZES: 10-100 PC
MASSES: $10^5$-$10^6$ SOLLAR MASSES
TEMPERATURE: 100K



M16 © Anglo-Australian Observatory Photo by David Malin

The whole process of formation of stars is very inefficient: only few precent of mass of the cloud is converted into stars

Eagle nebula

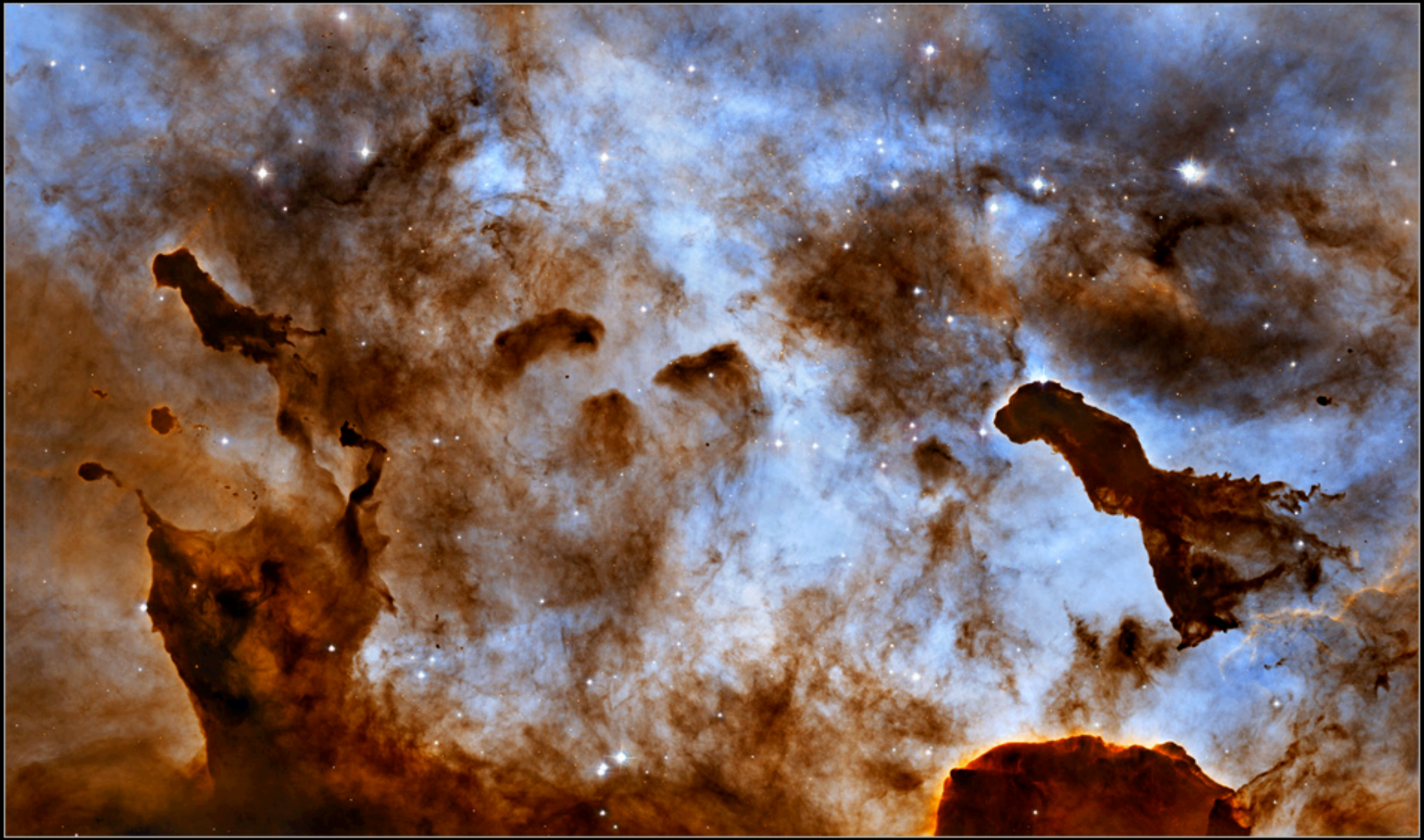


# Stages of star formation:

1. Molecular Cloud forms.
2. A small clump in the cloud starts to collapse under the force of gravity. This initial collapse proceeds very fast.
3. Once the clump gets relatively dense, radiation cannot easily escape. The collapse gets slow
4. At some moment the temperature and density at the center of gradually shrinking protostar get so large that nuclear reactions switch on and arrest the collapse. The star is on the main sequence.

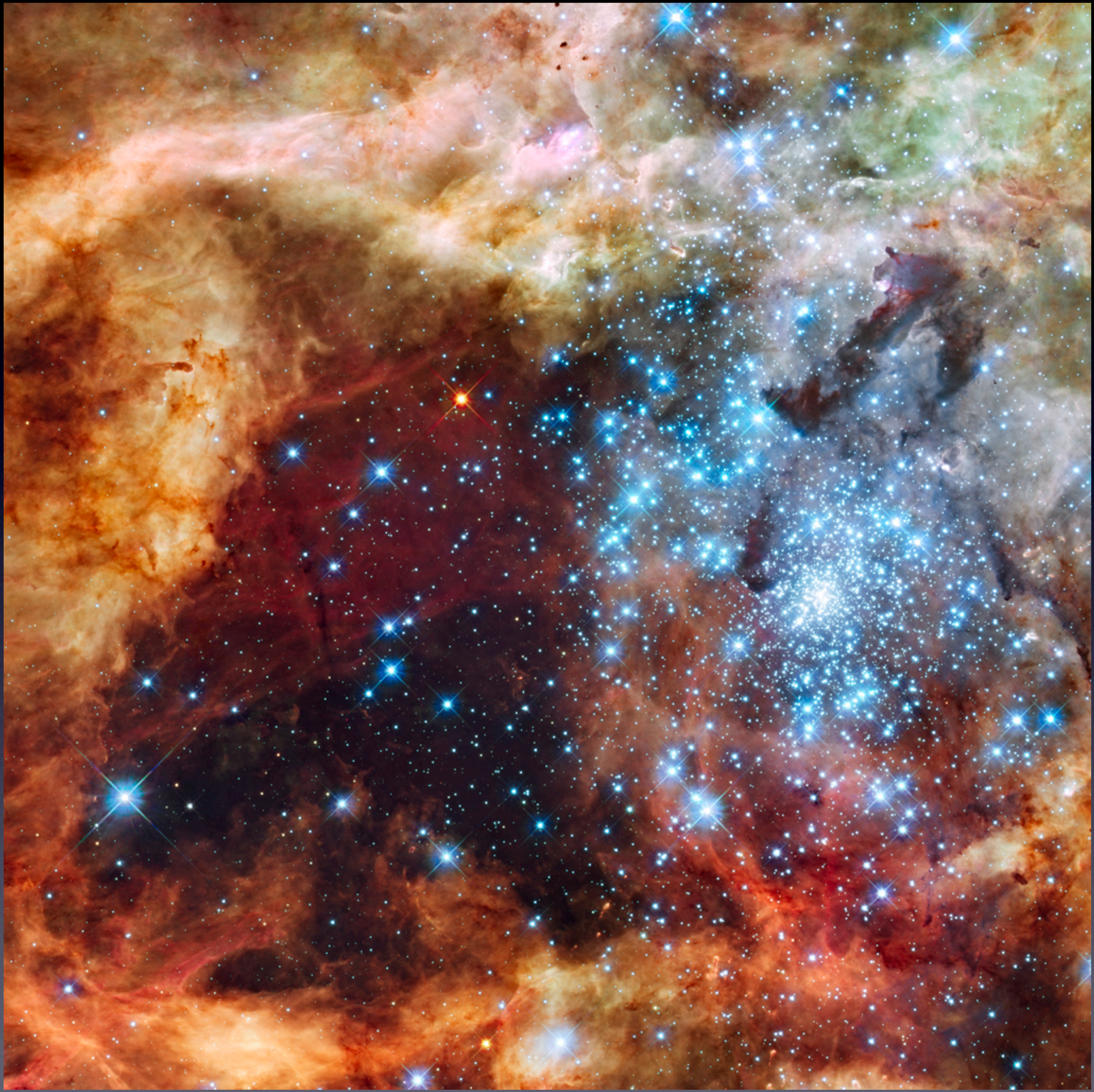
# Carina Nebula

# Carina Nebula



Hubble Heritage

NASA, ESA, and the Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS/WFC • STScI-PRC10-29

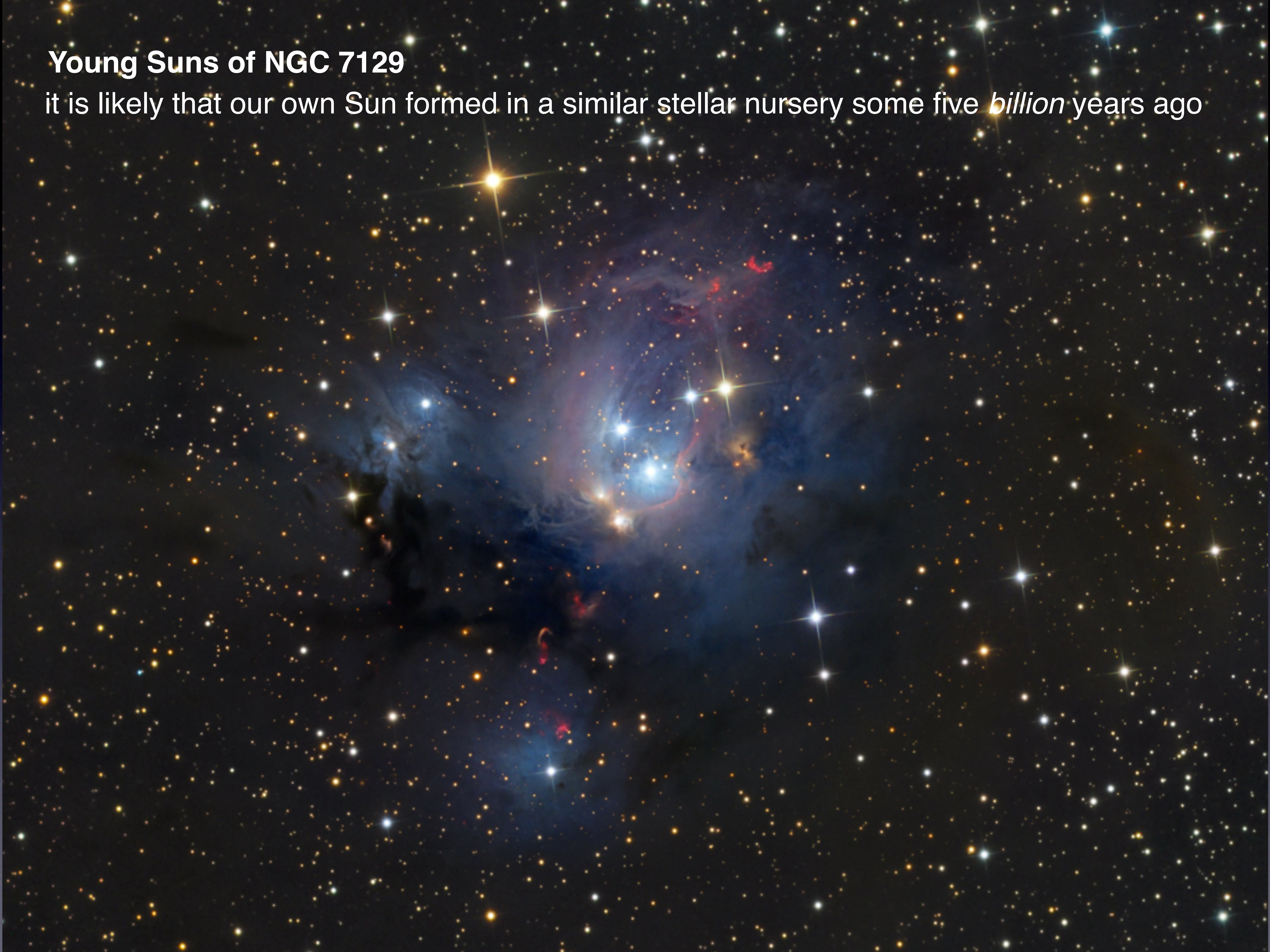


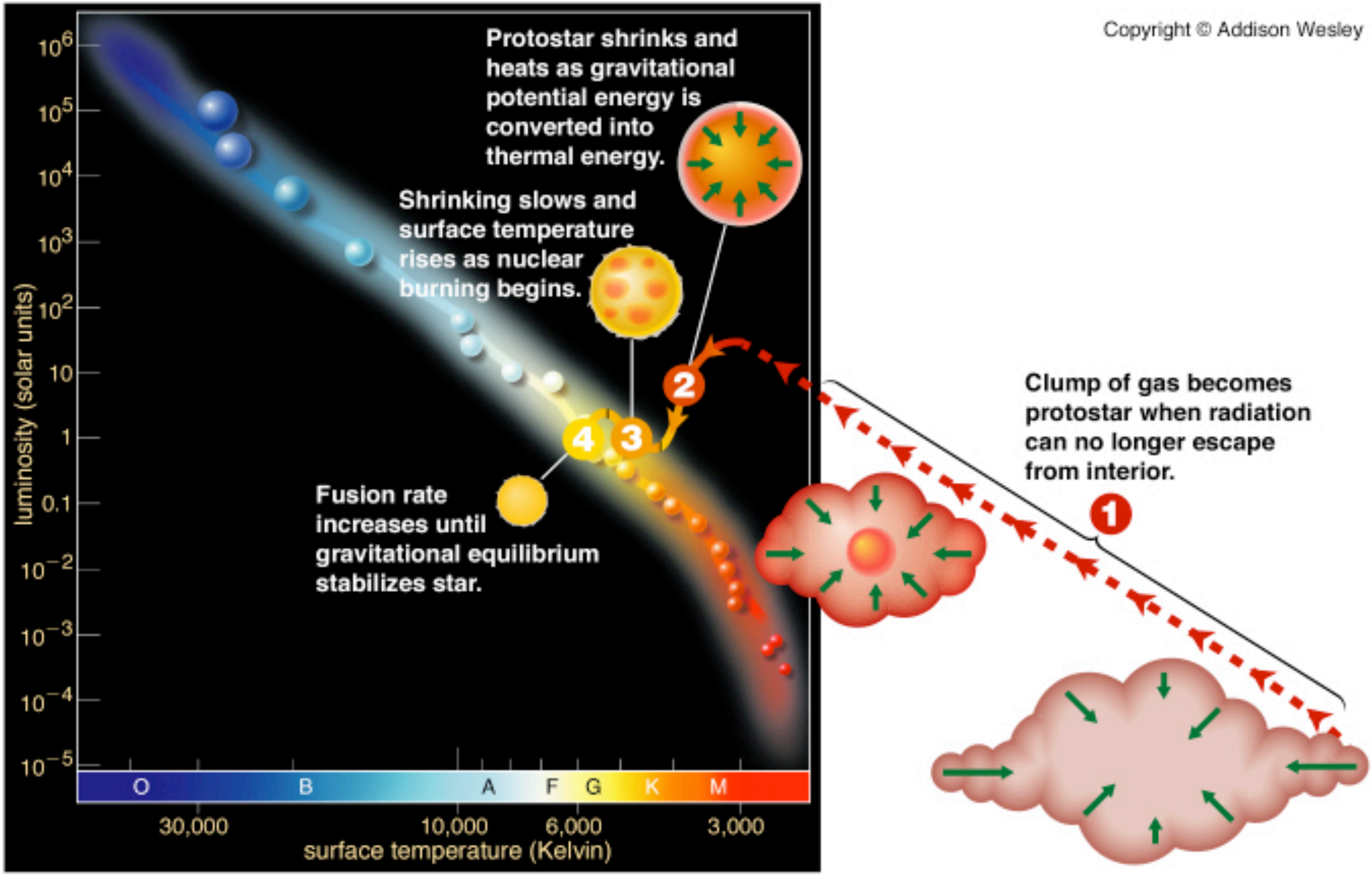
NGC 602 in the Small Magellanic Cloud

Hubble

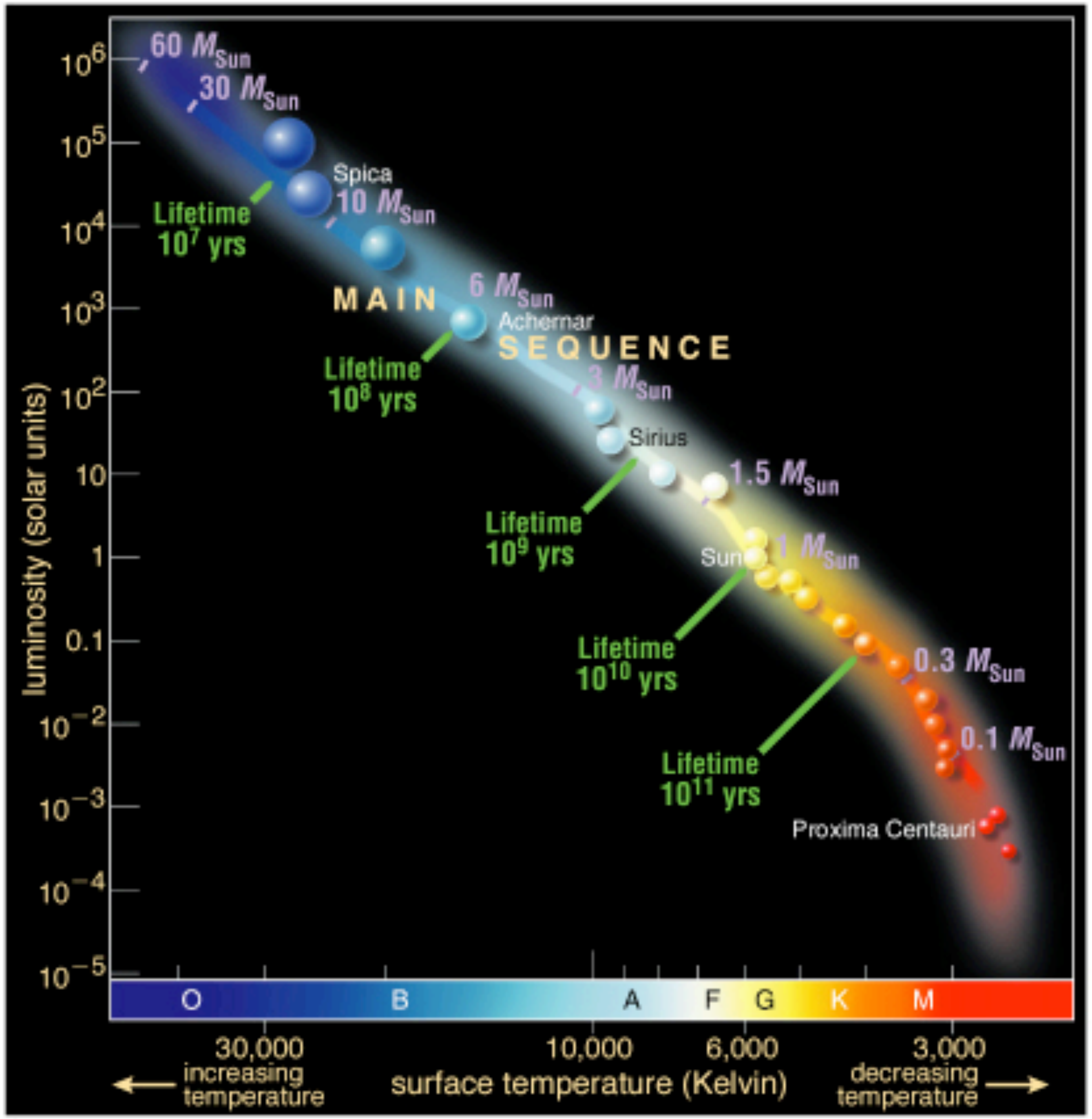
## Young Suns of NGC 7129

it is likely that our own Sun formed in a similar stellar nursery some five *billion* years ago

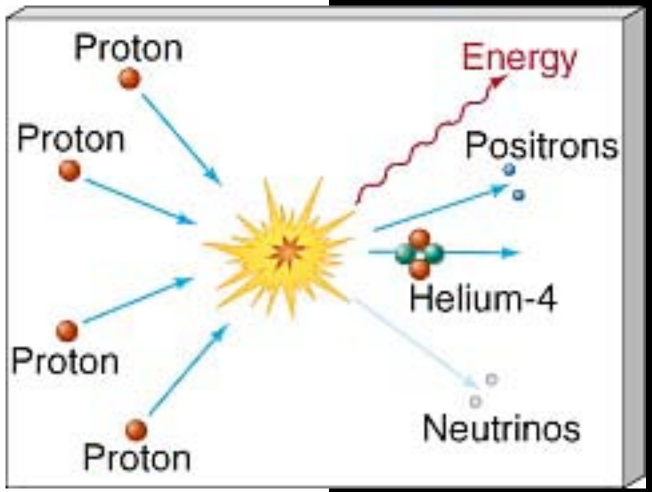




Protostar shrinks and heats as gravitational potential energy is converted into thermal energy.
Shrinking slows and surface temperature rises as nuclear burning begins.
Fusion rate increases until gravitational equilibrium stabilizes star.
Clump of gas becomes protostar when radiation can no longer escape from interior.
1
2
3
4
luminosity (solar units)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
0.1
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
surface temperature (Kelvin)

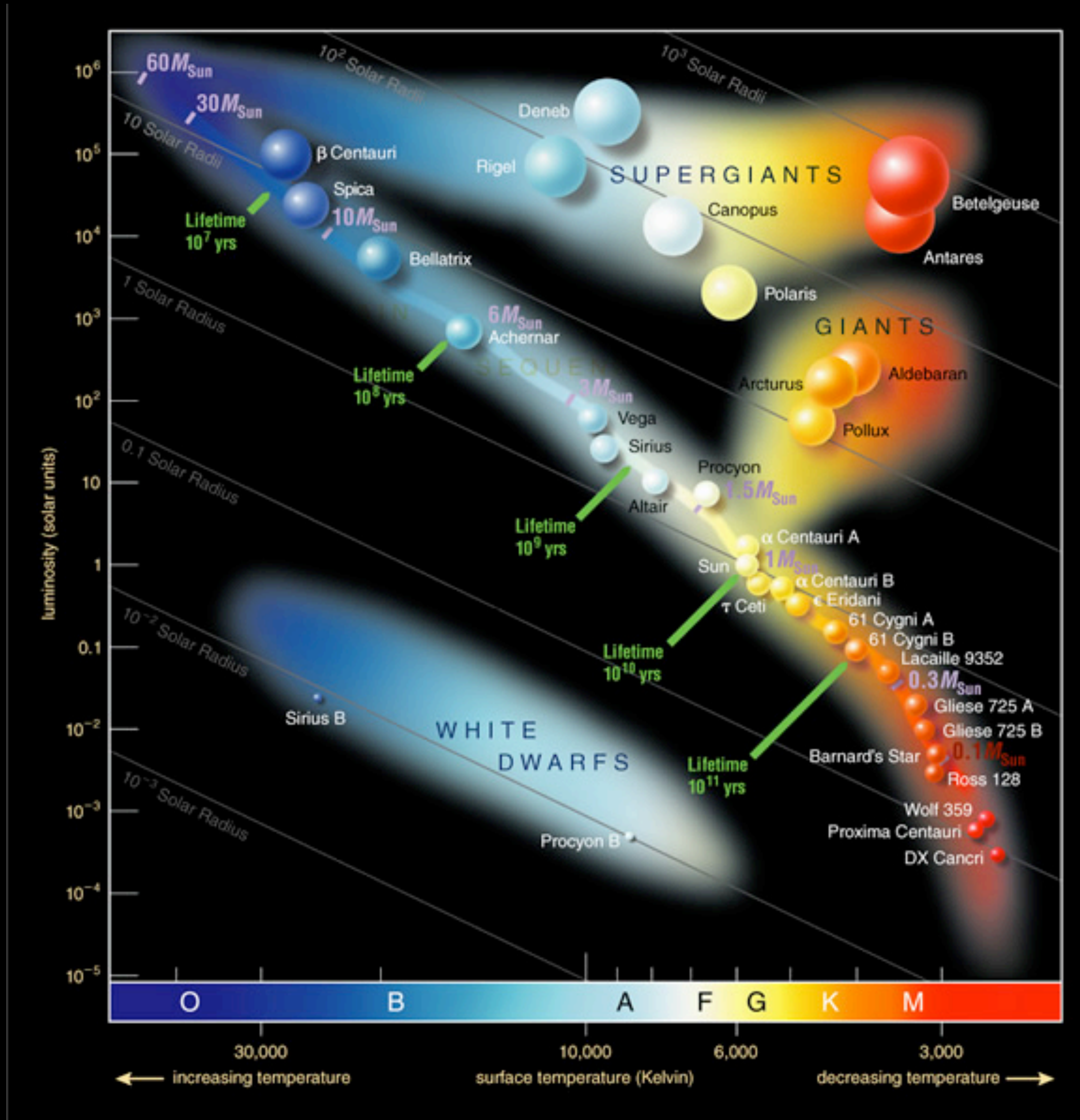


60 $M_{Sun}$
30 $M_{Sun}$
Spica
10 $M_{Sun}$
Lifetime $10^7$ yrs
MAIN
6 $M_{Sun}$
Achernar
SEQUENCE
Lifetime $10^8$ yrs
3 $M_{Sun}$
Sirius
1.5 $M_{Sun}$
Lifetime $10^9$ yrs
Sun
1 $M_{Sun}$
Lifetime $10^{10}$ yrs
0.3 $M_{Sun}$
Lifetime $10^{11}$ yrs
0.1 $M_{Sun}$
Proxima Centauri
luminosity (solar units)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
0.1
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

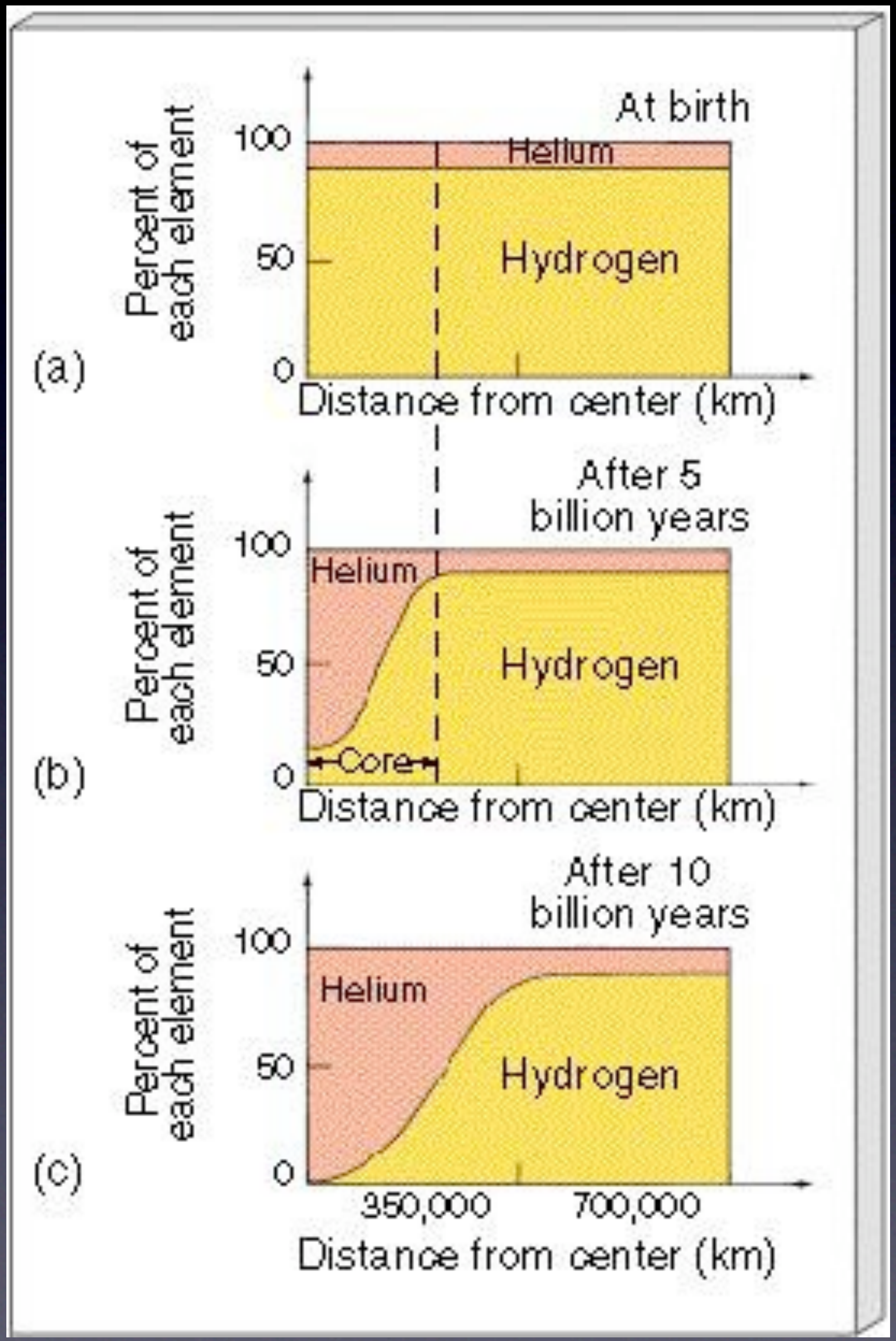
Proton
Proton
Proton
Proton
Energy
Positrons
Helium-4
Neutrinos

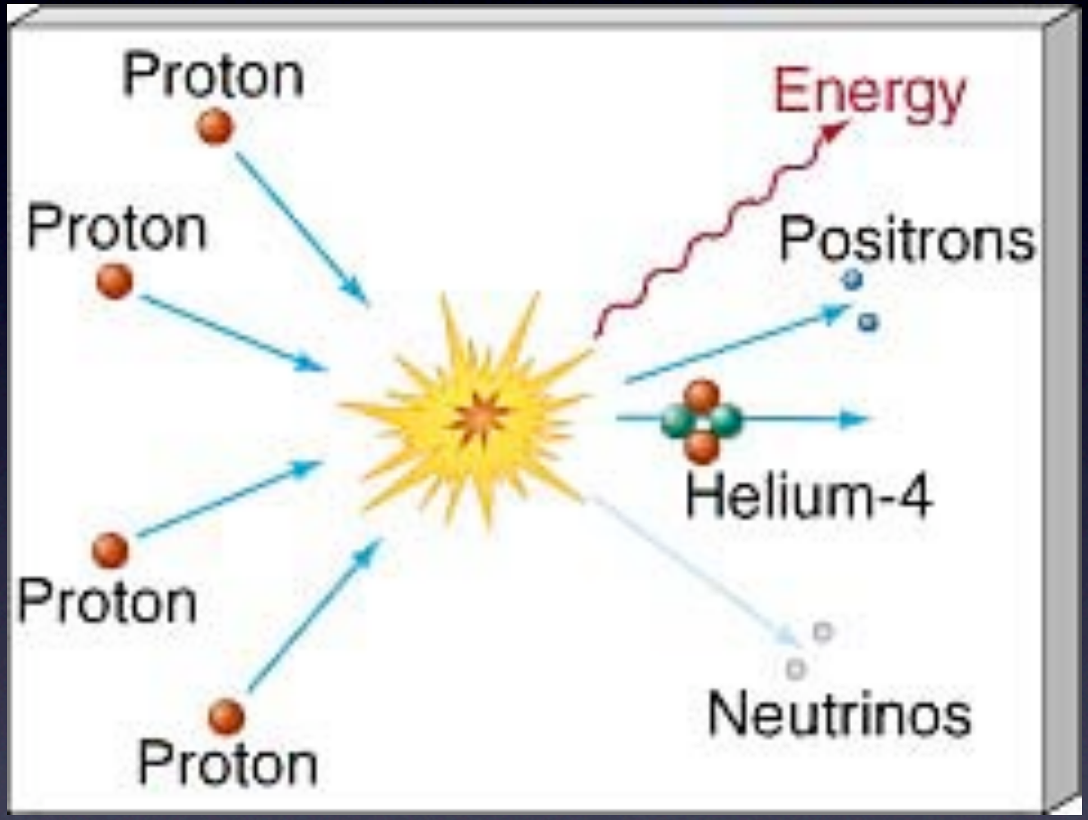
# Late Stages of Stellar Evolution



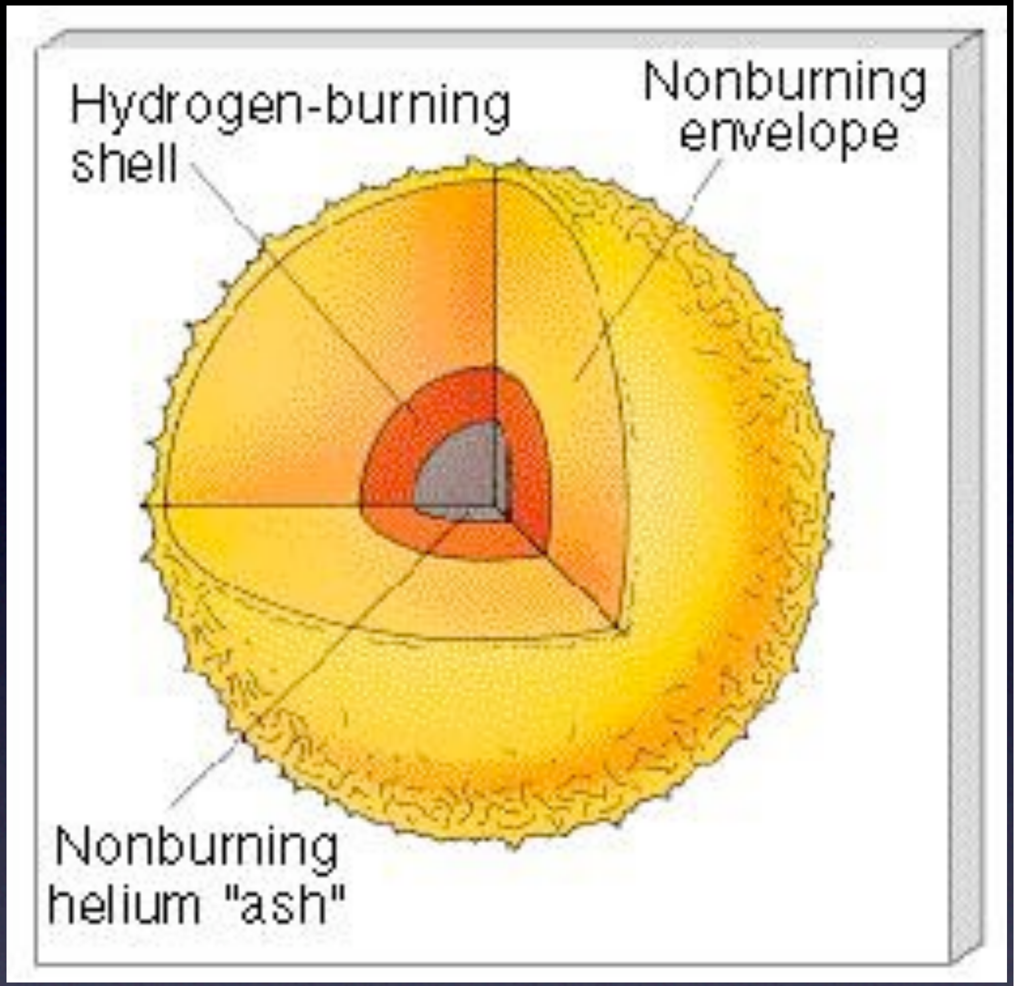
luminosity (solar units)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
0.1
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^2$ Solar Radii
$10^3$ Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
$10^{-2}$ Solar Radius
$10^{-3}$ Solar Radius
$60 M_{Sun}$
$30 M_{Sun}$
$10 M_{Sun}$
$6 M_{Sun}$
$3 M_{Sun}$
$1.5 M_{Sun}$
$1 M_{Sun}$
$0.3 M_{Sun}$
$0.1 M_{Sun}$
Lifetime $10^7$ yrs
Lifetime $10^8$ yrs
Lifetime $10^9$ yrs
Lifetime $10^{10}$ yrs
Lifetime $10^{11}$ yrs
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Altair
Procyon
α Centauri A
Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Deneb
Rigel
SUPERGIANTS
Canopus
Betelgeuse
Antares
Polaris
GIANTS
Arcturus
Aldebaran
Pollux
Sirius B
WHITE DWARFS
Procyon B
O B A F G K M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

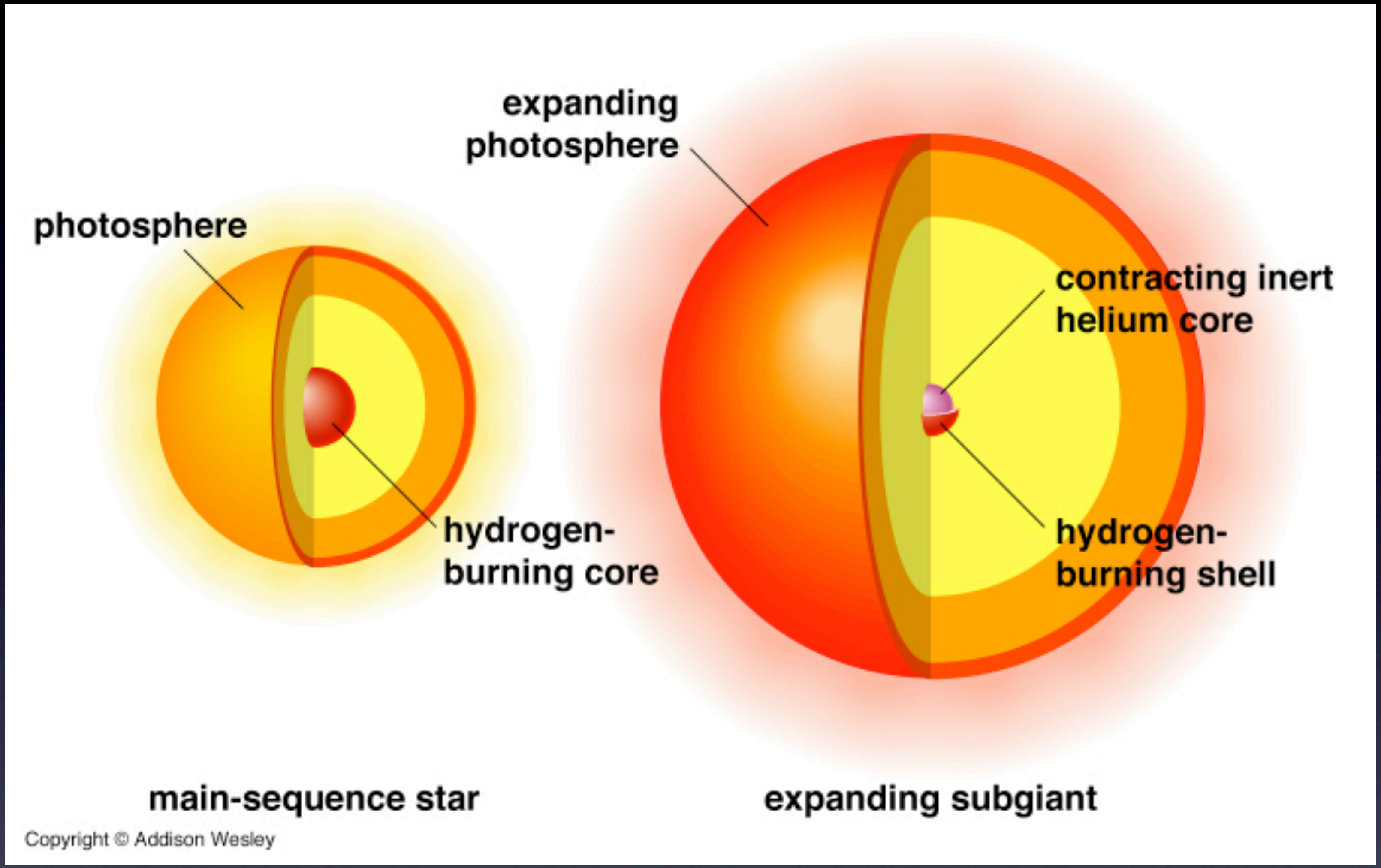
# Core of Stars on the Main Sequence



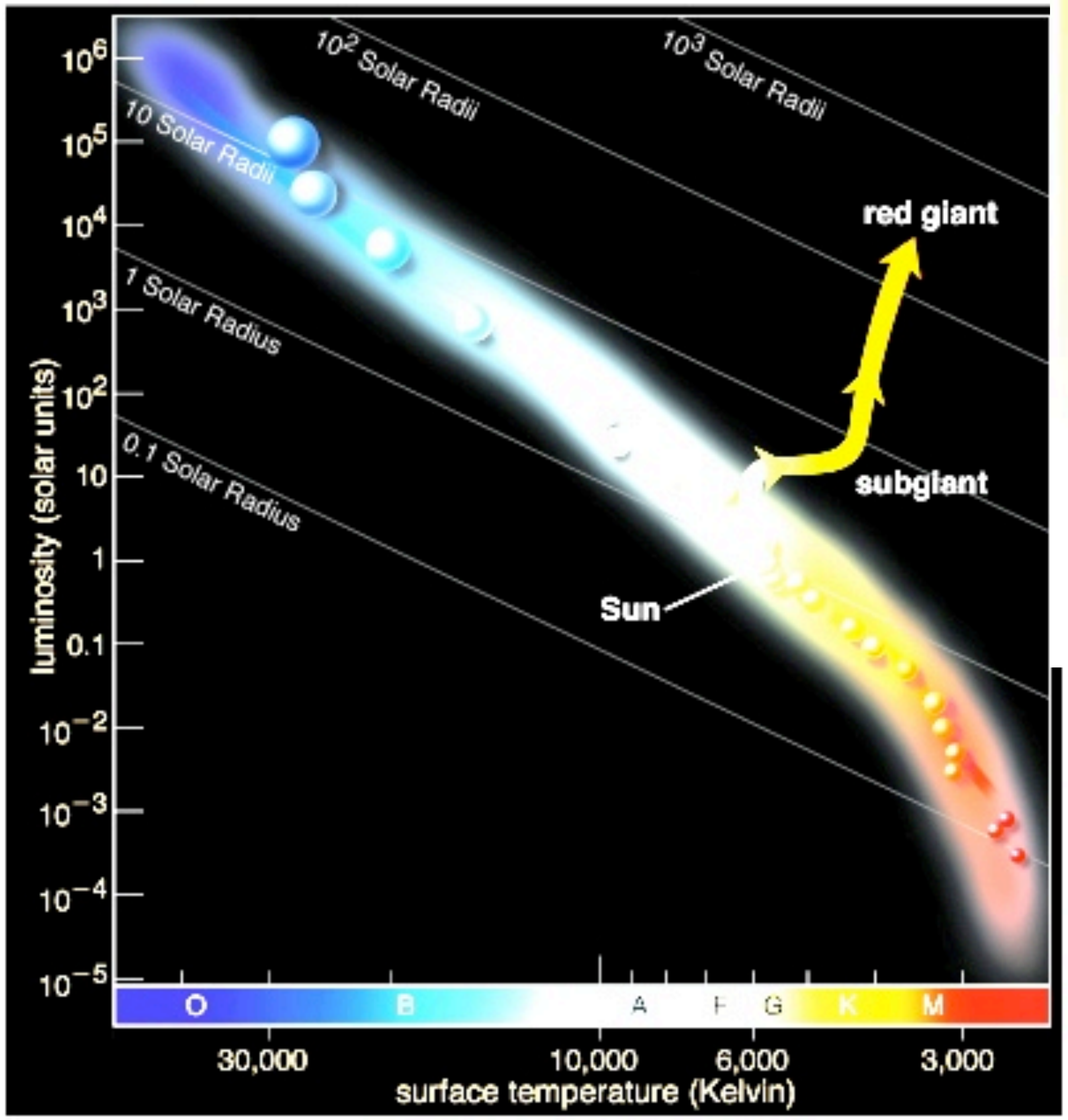



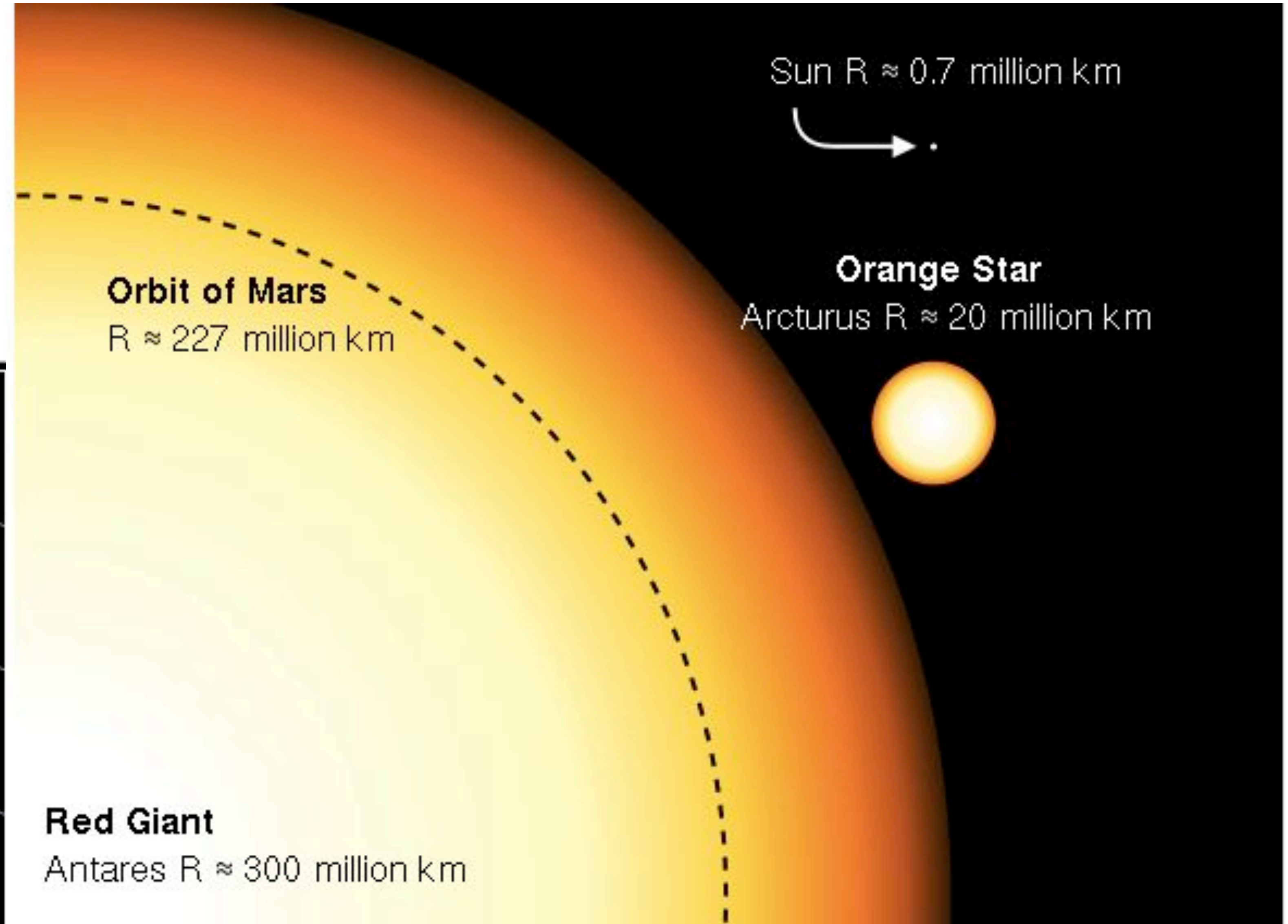
# When hydrogen is exhausted in the core:




# Formation of a Red Giant



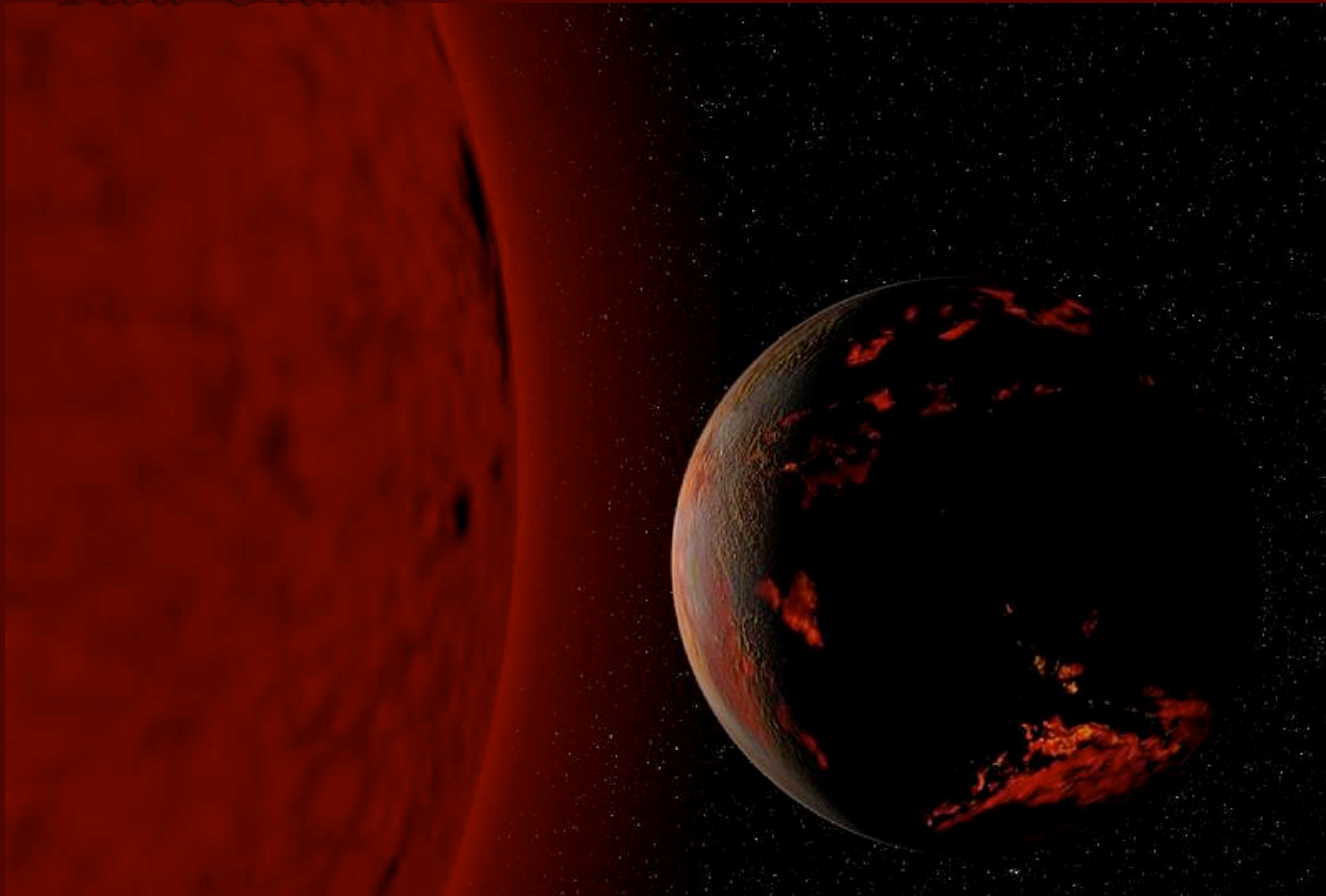



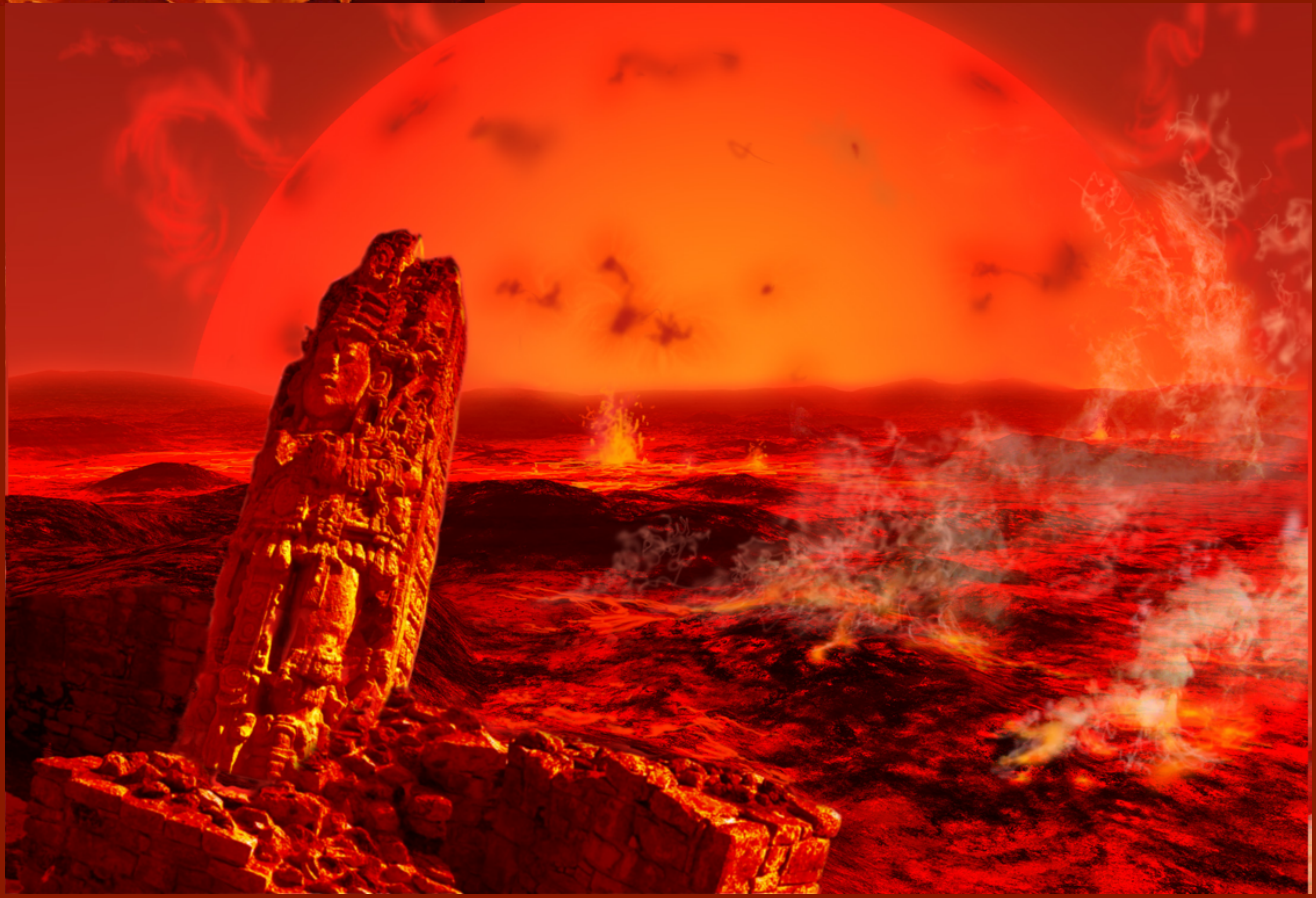

Sizes of stars

# *Formation of a Red Giant*

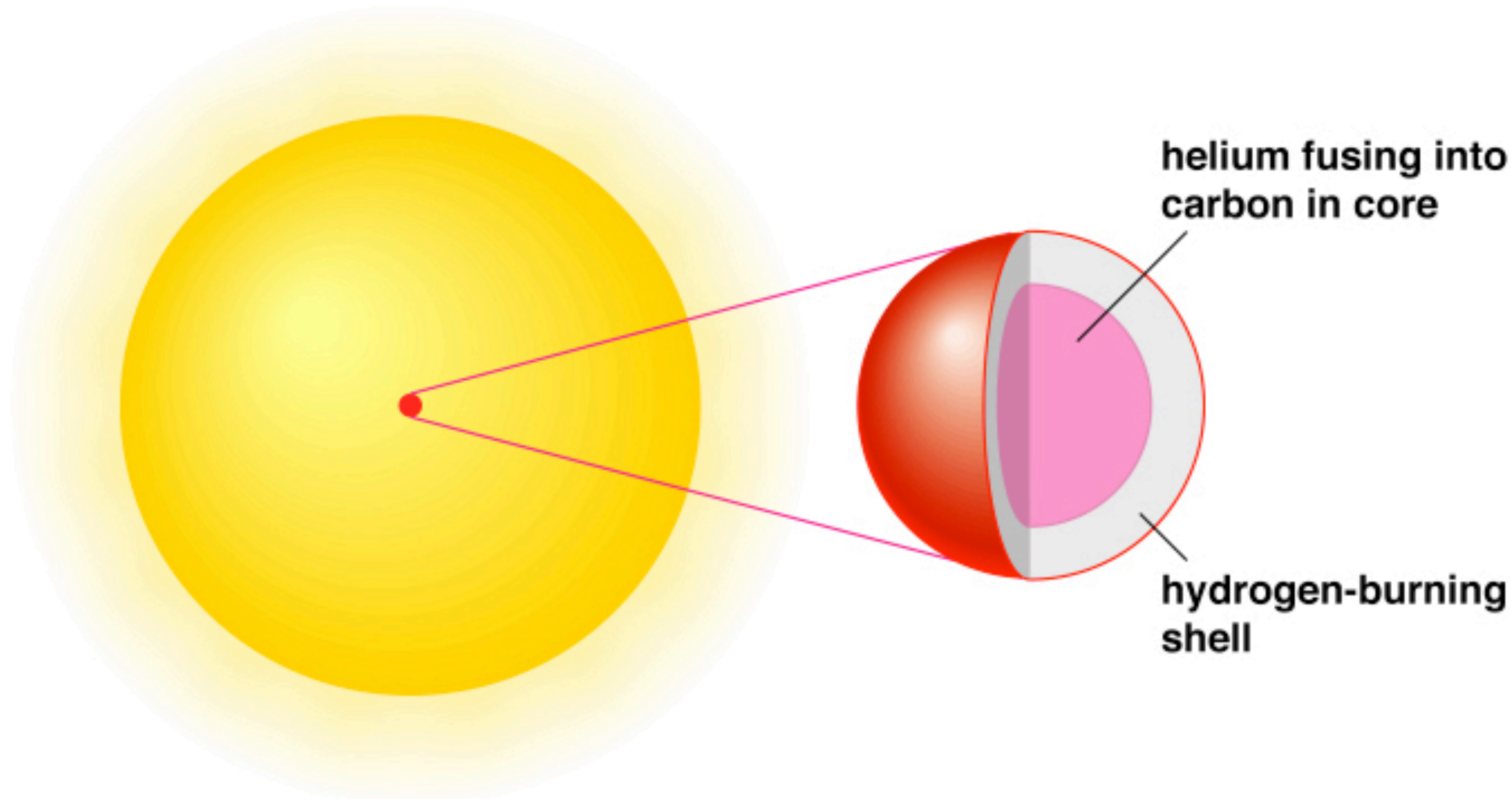
Red Giant

Planet



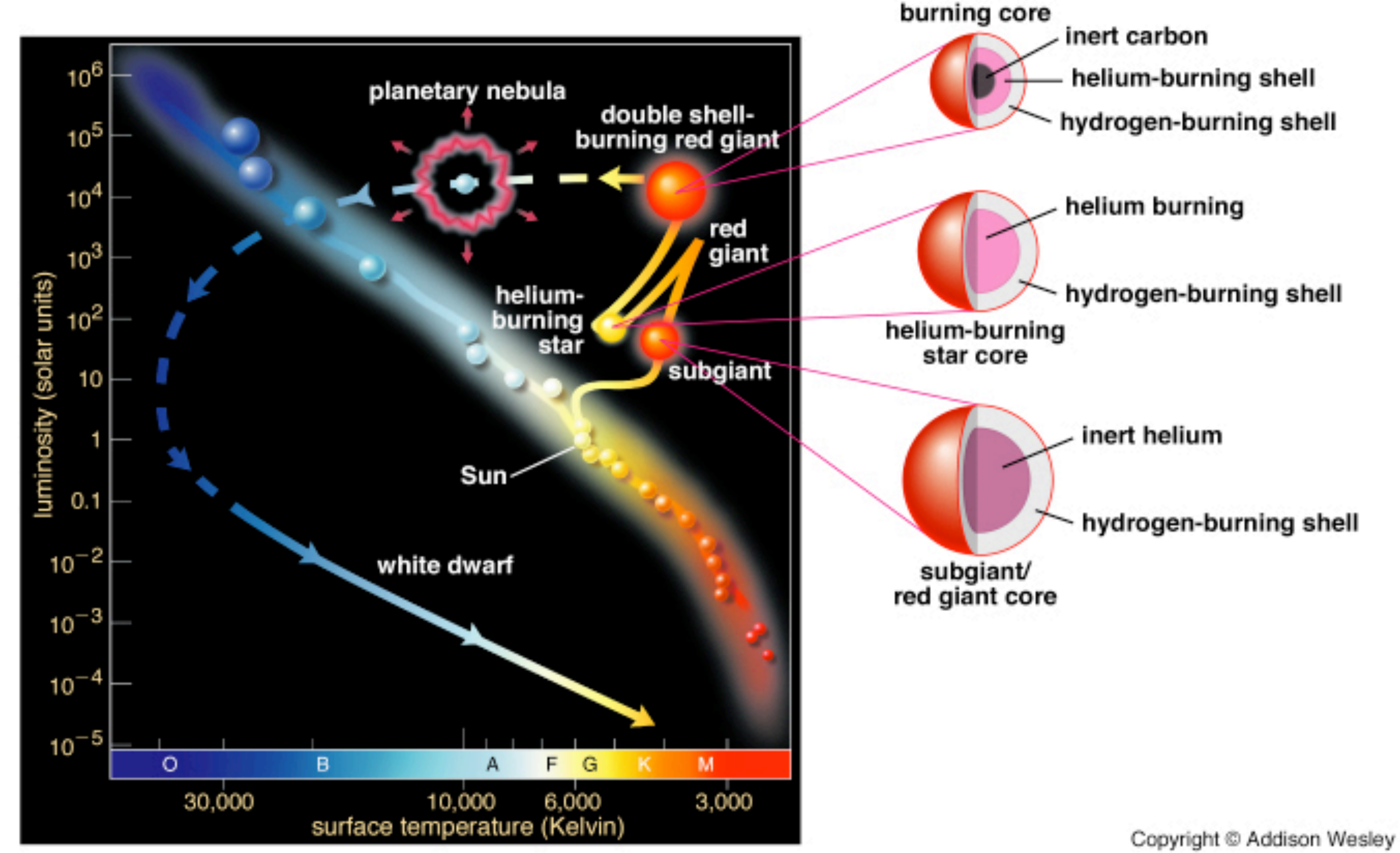

© Mark A. Garlick / space-art.co.uk
No unauthorized usage


# When helium core becomes too large, helium starts to burn into carbon



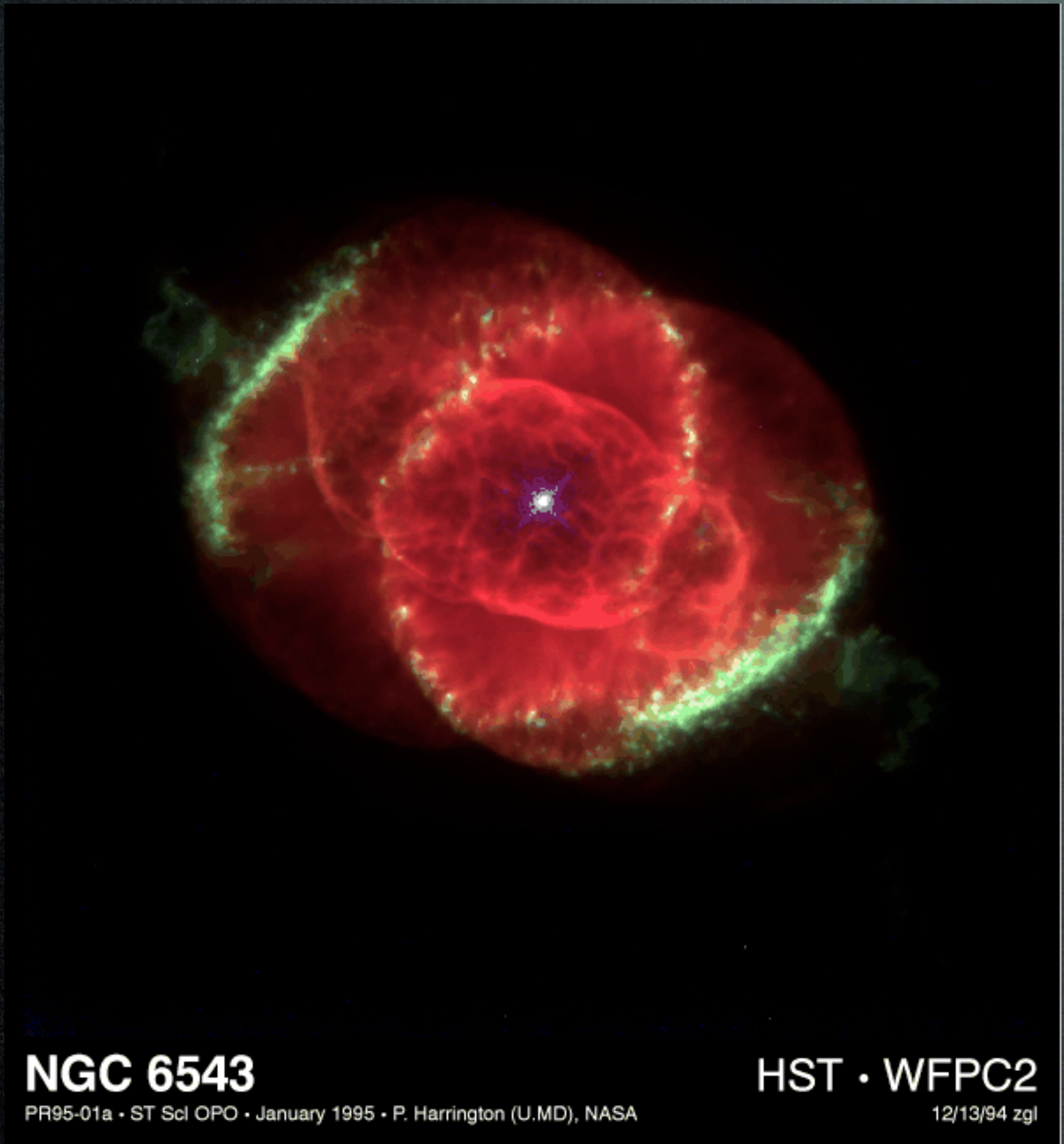


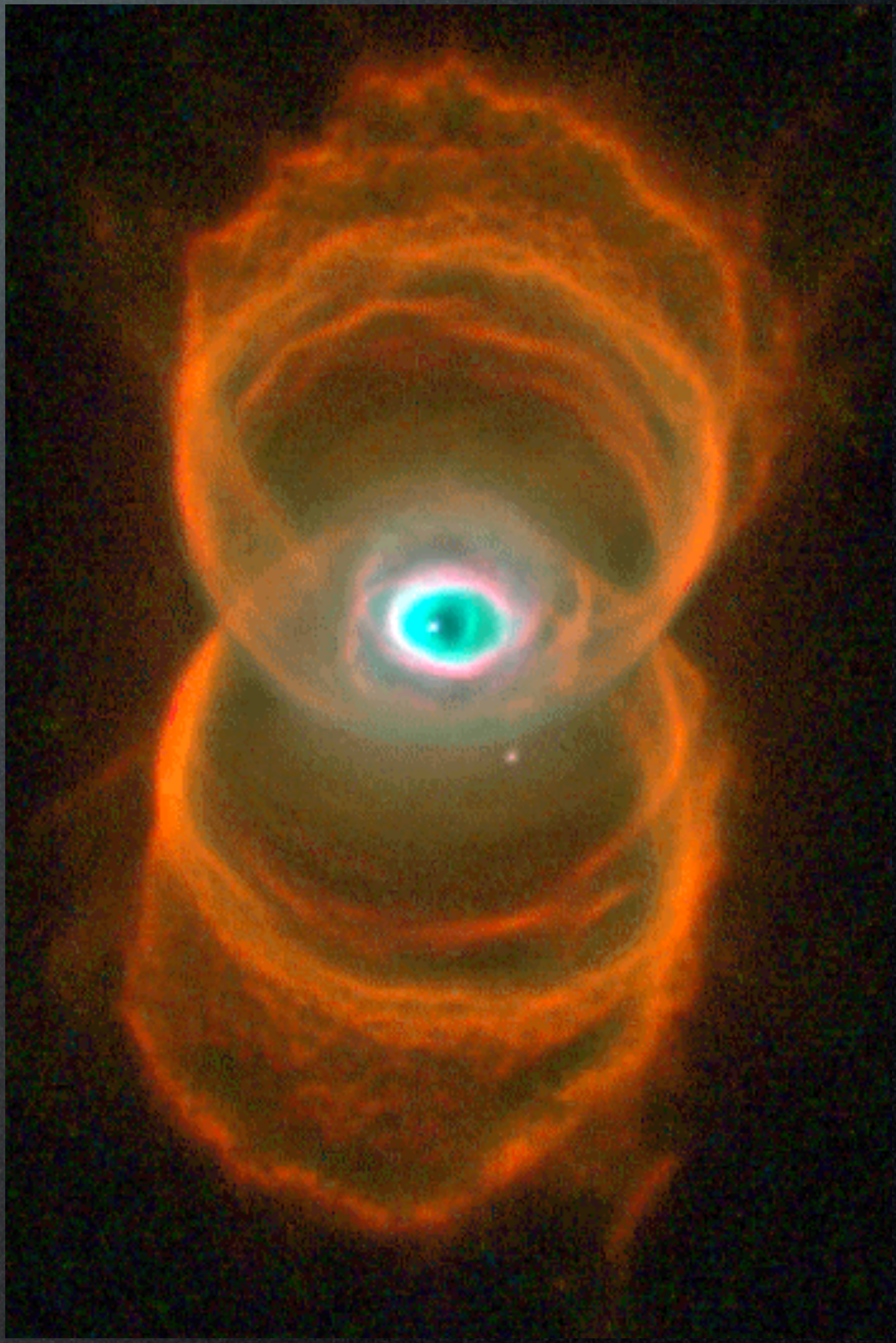

Now the star evolves very fast, because
(a) there is not much energy left and because
(b) the star generates that energy very efficiently



burning core
inert carbon
helium-burning shell
hydrogen-burning shell
planetary nebula
double shell-burning red giant
red giant
helium-burning star
subgiant
Sun
white dwarf
helium burning
hydrogen-burning shell
helium-burning star core
inert helium
hydrogen-burning shell
subgiant/ red giant core
luminosity (solar units)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
0.1
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
surface temperature (Kelvin)

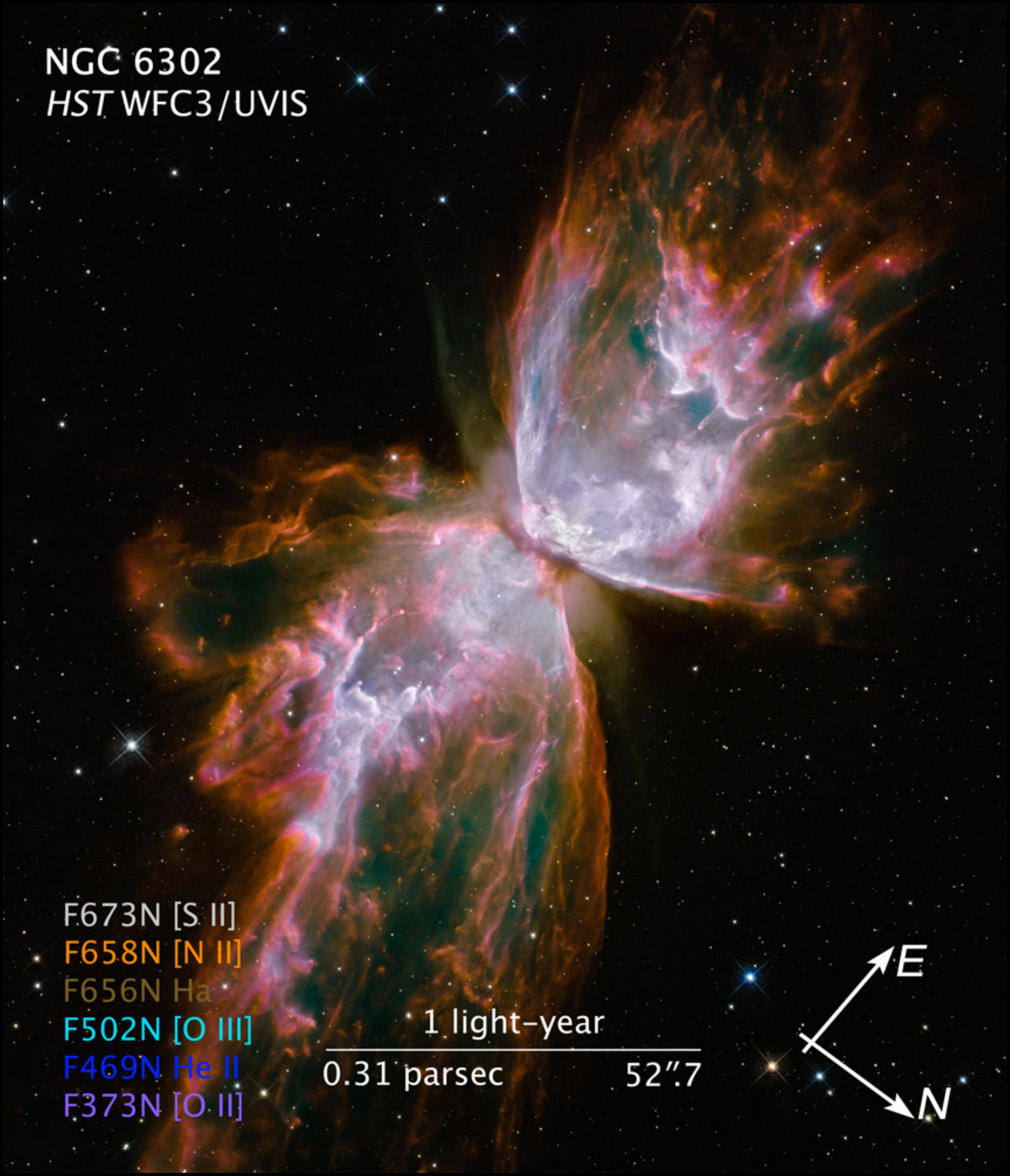
# *Planetary Nebulae: intermediate - mass dying stars produce white dwarfs*

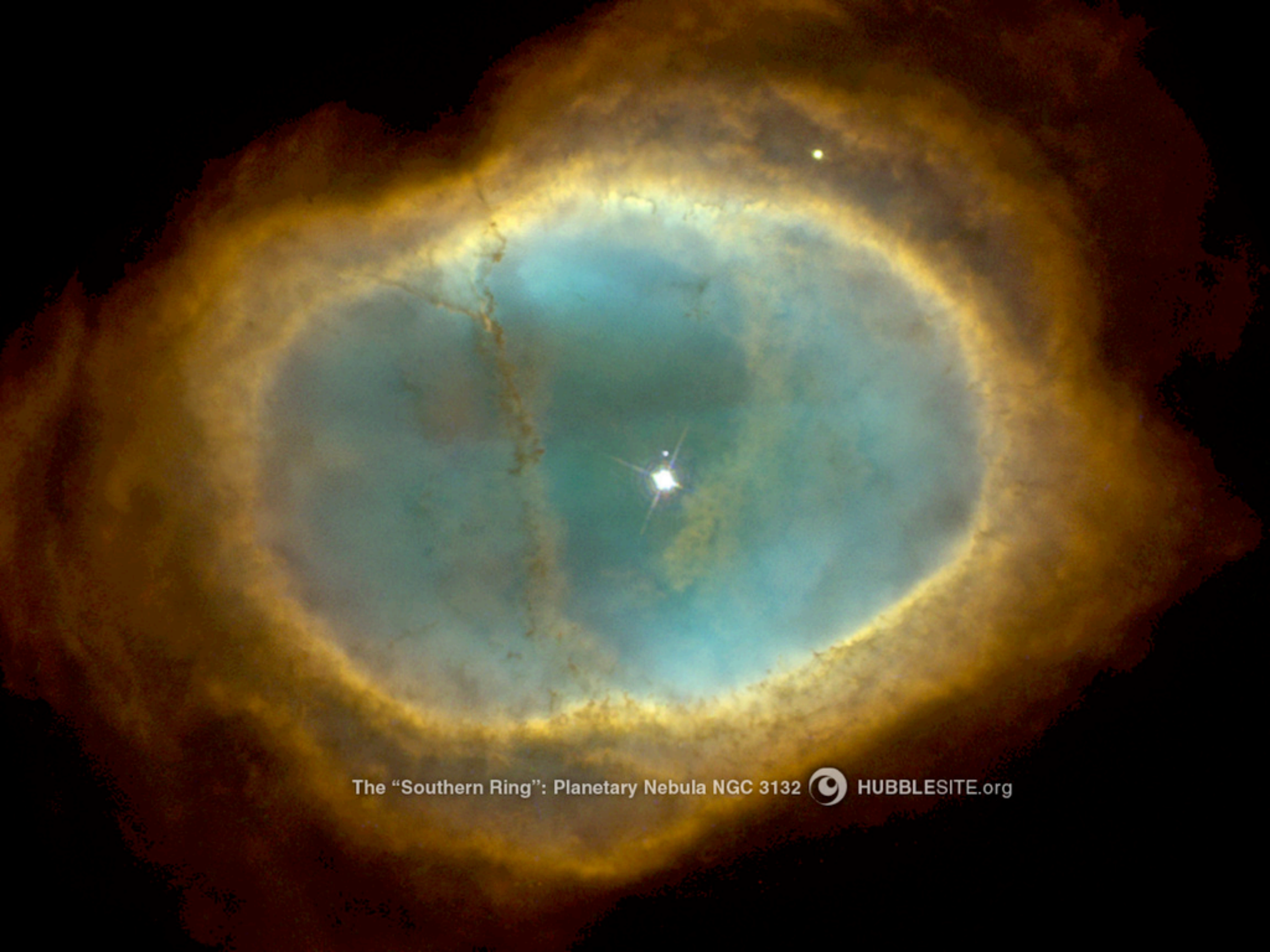



**Helix Nebula • NGC 7293**
**Hubble Space Telescope** • Advanced Camera for Surveys
**NOAO 0.9m** • Mosaic I Camera

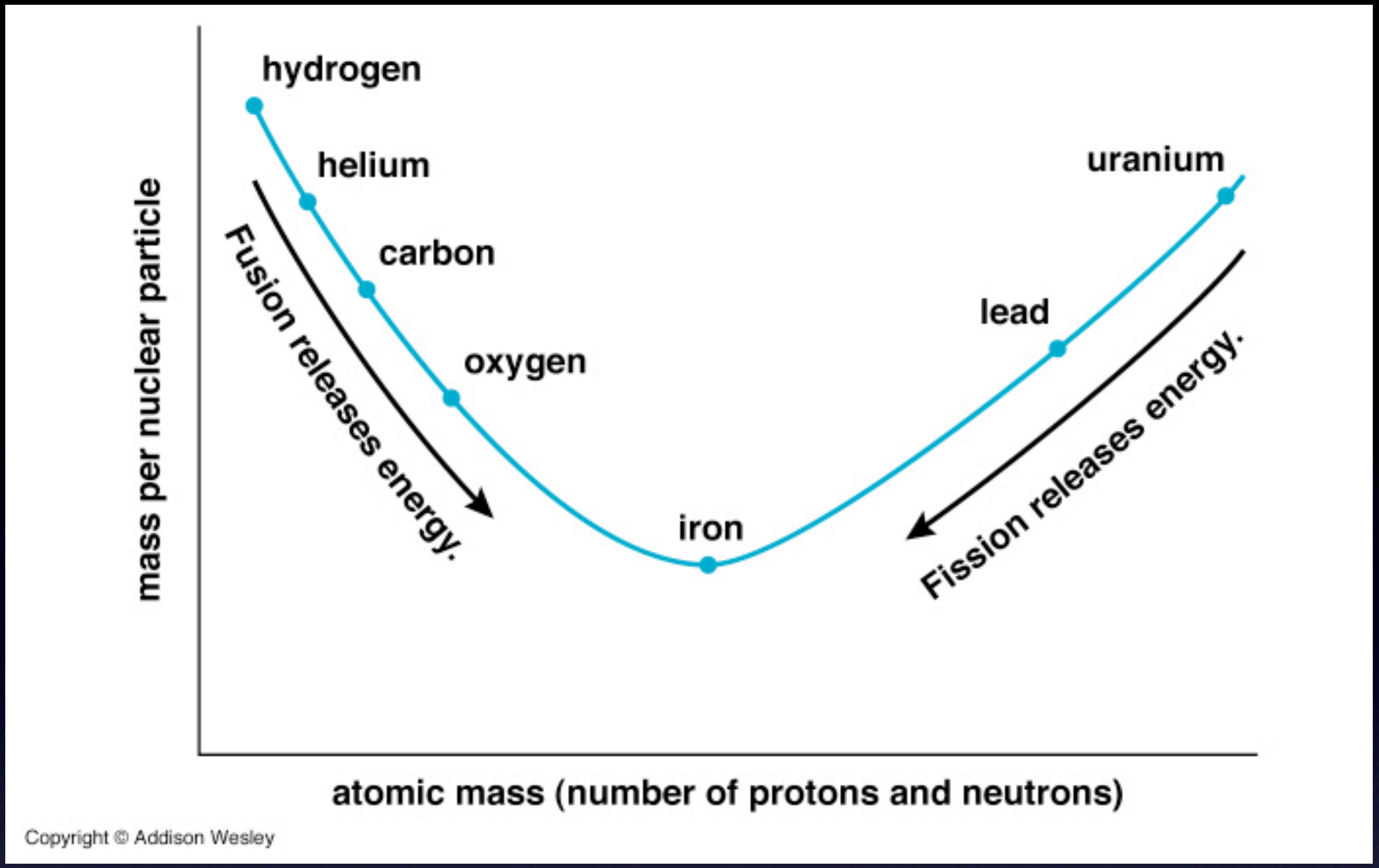
NASA, NOAO, ESA, The Hubble Helix Team, M. Meixner (STScI), and T.A. Rector (NRAO) • STScI-PRC0

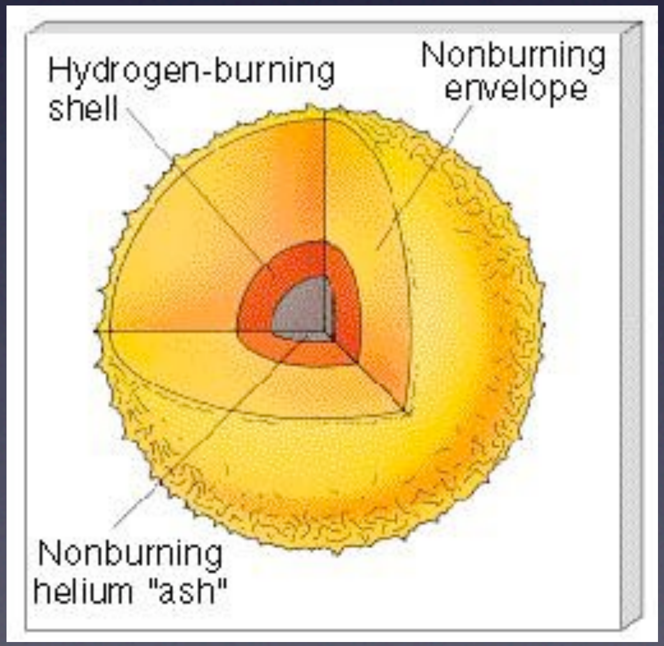

NGC 6302
*HST* WFC3/UVIS
F673N [S II]
F658N [N II]
F656N Ha
F502N [O III]
F469N He II
F373N [O II]
1 light-year
0.31 parsec
52″.7
E
N

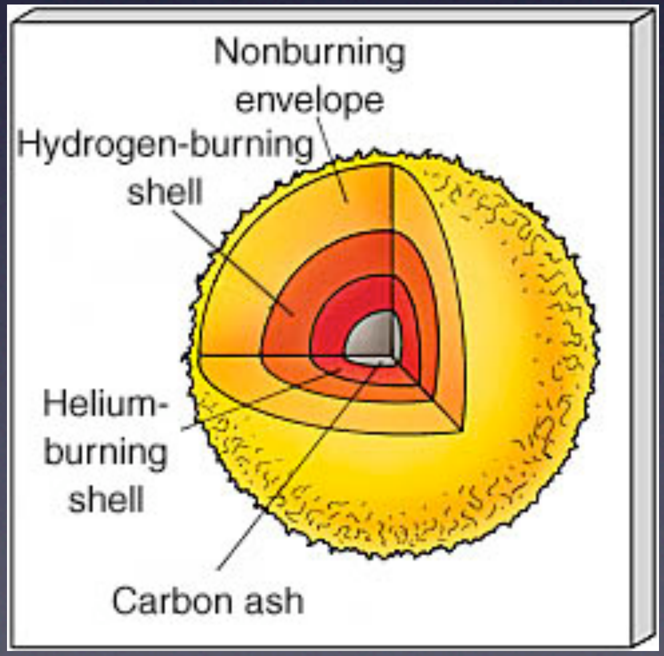

The “Southern Ring”: Planetary Nebula NGC 3132
HUBBLESITE.org

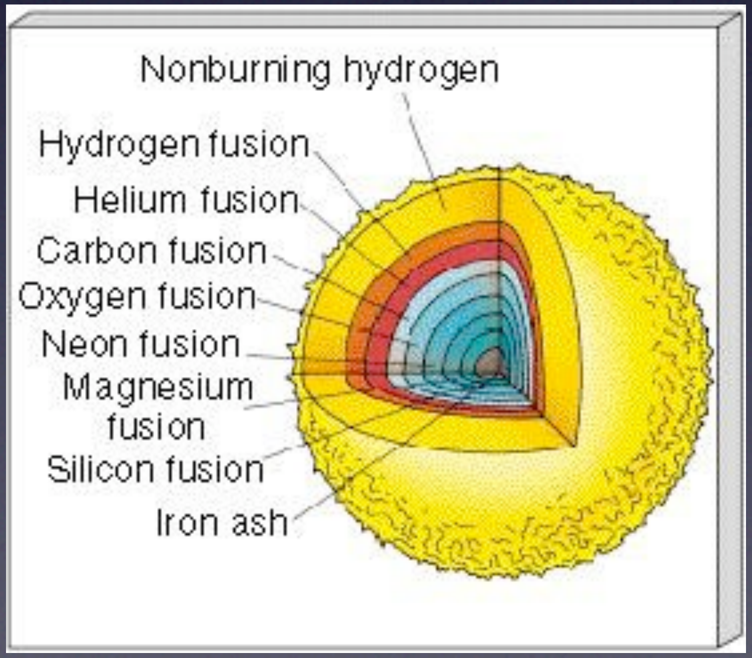

Hubble

# Evolution of a very massive (more than 10Msun) star

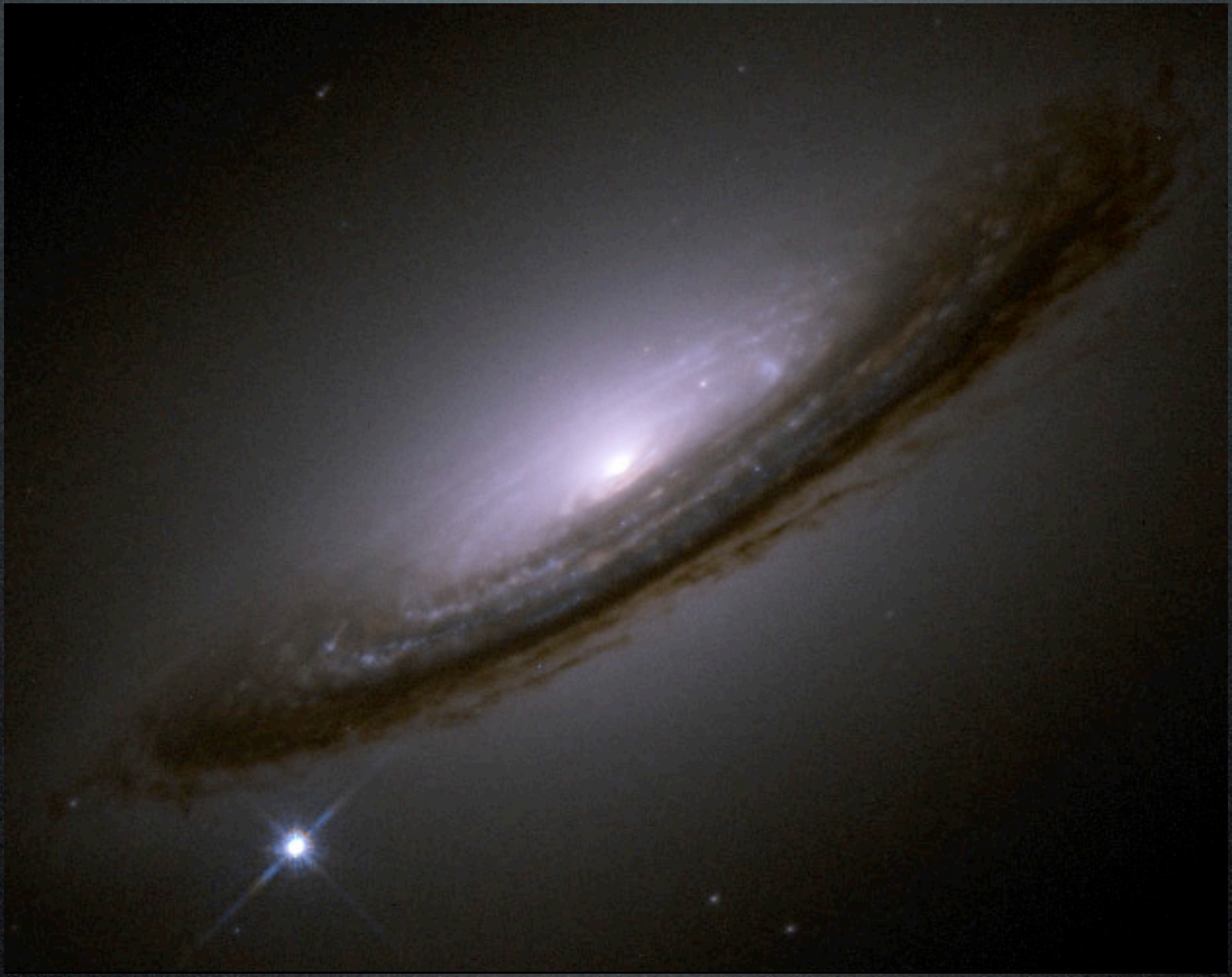


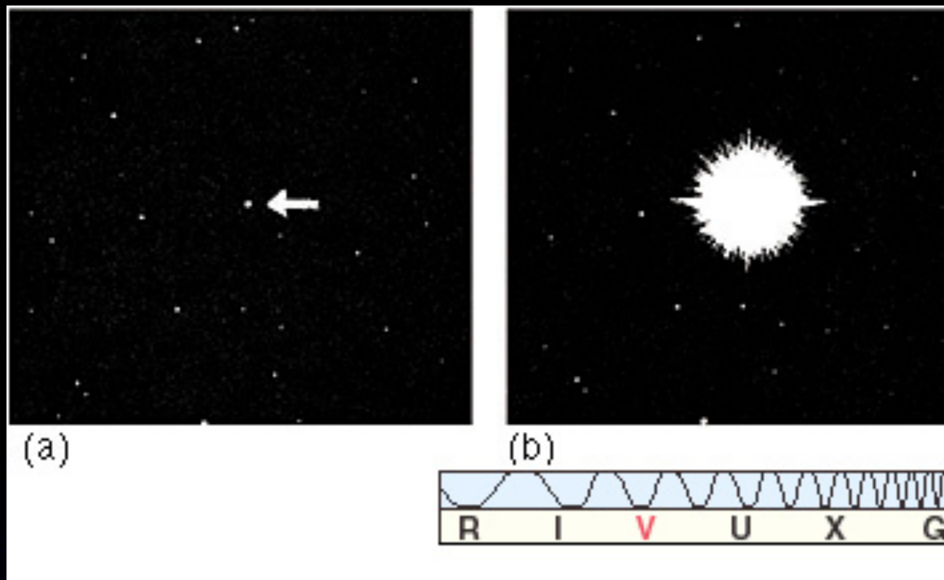



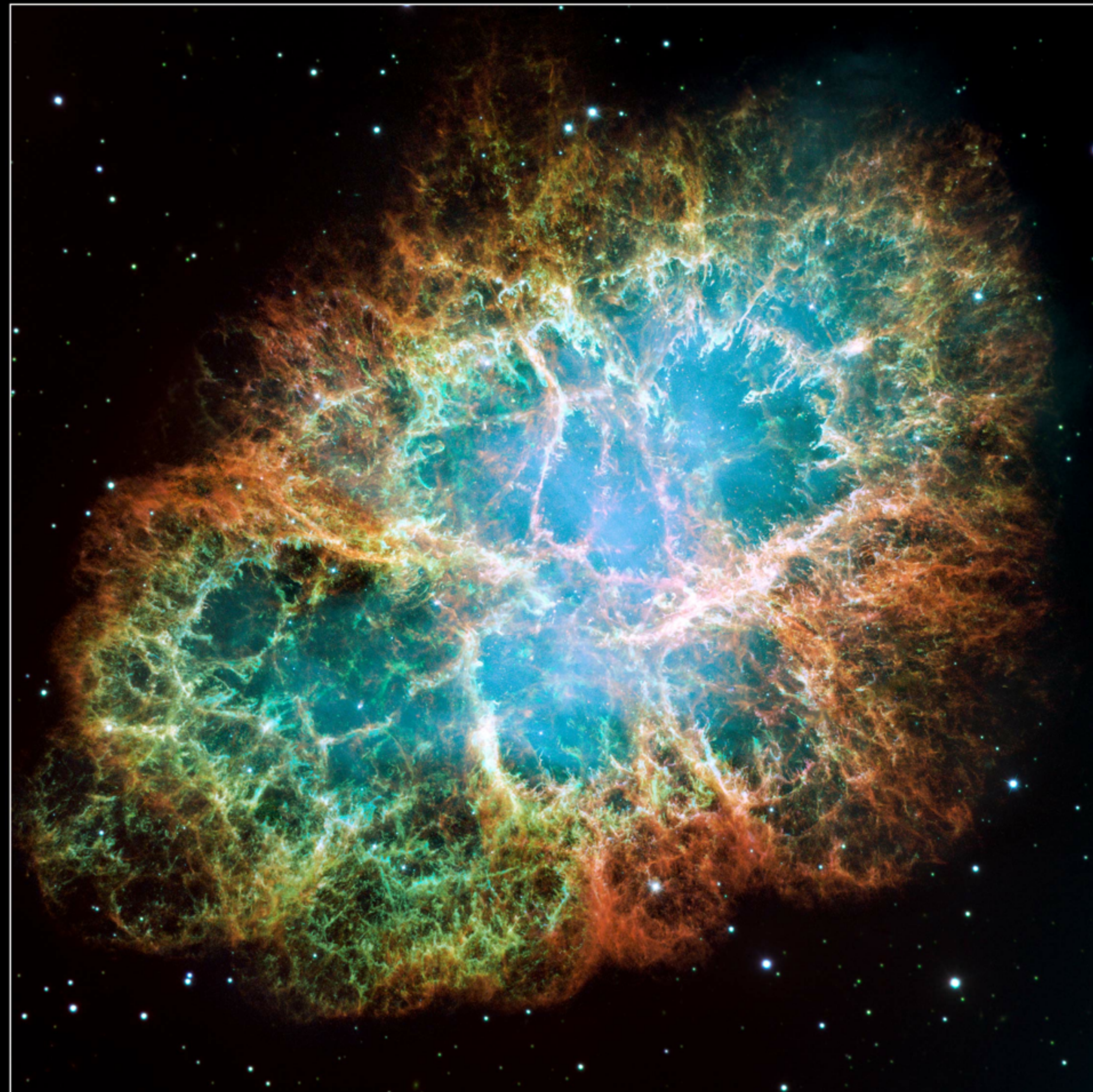



# Supernova in another galaxy



*When a large star dies, it explodes*

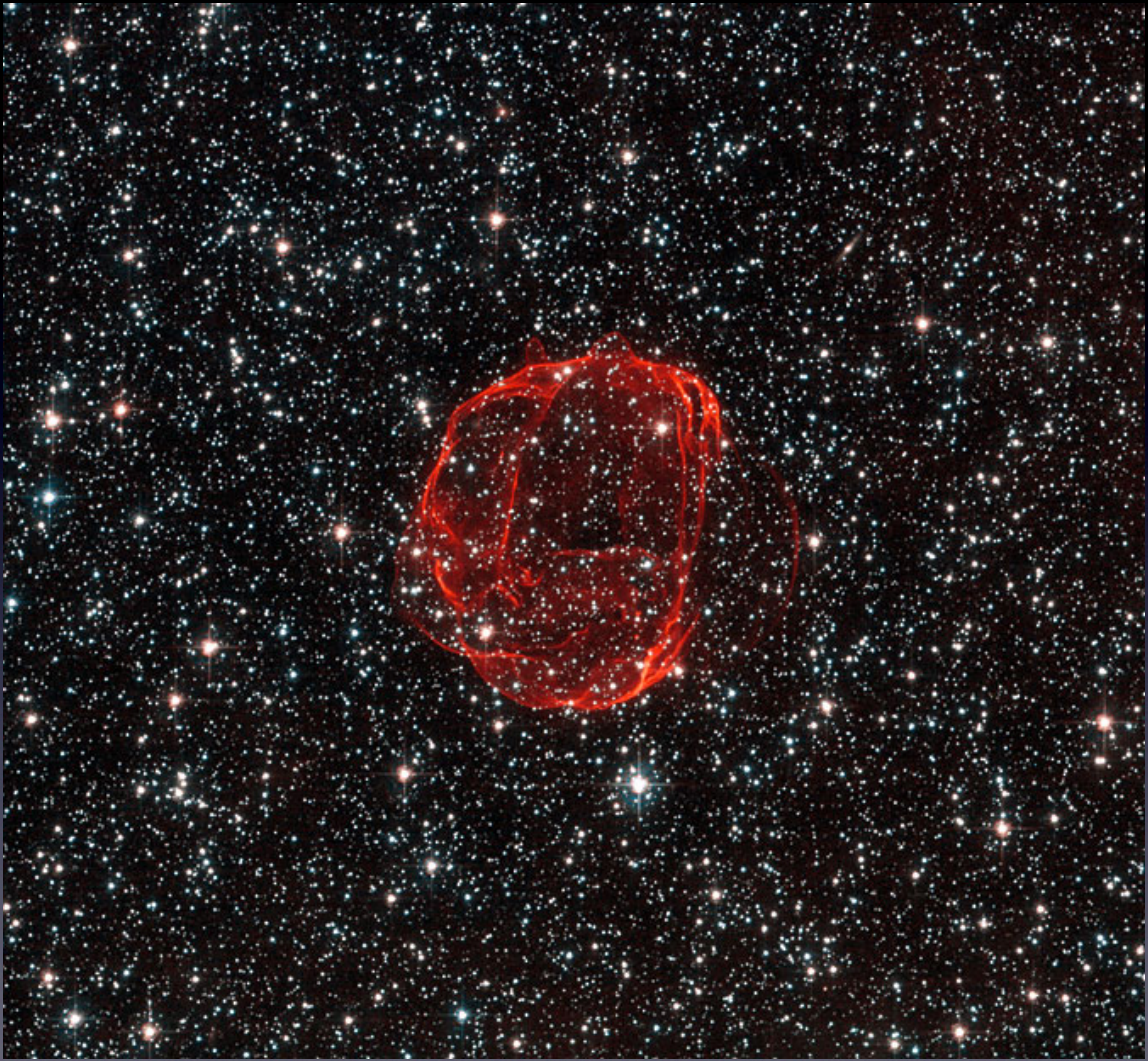


Crab Nebula • M1
Hubble Space Telescope • WFPC2

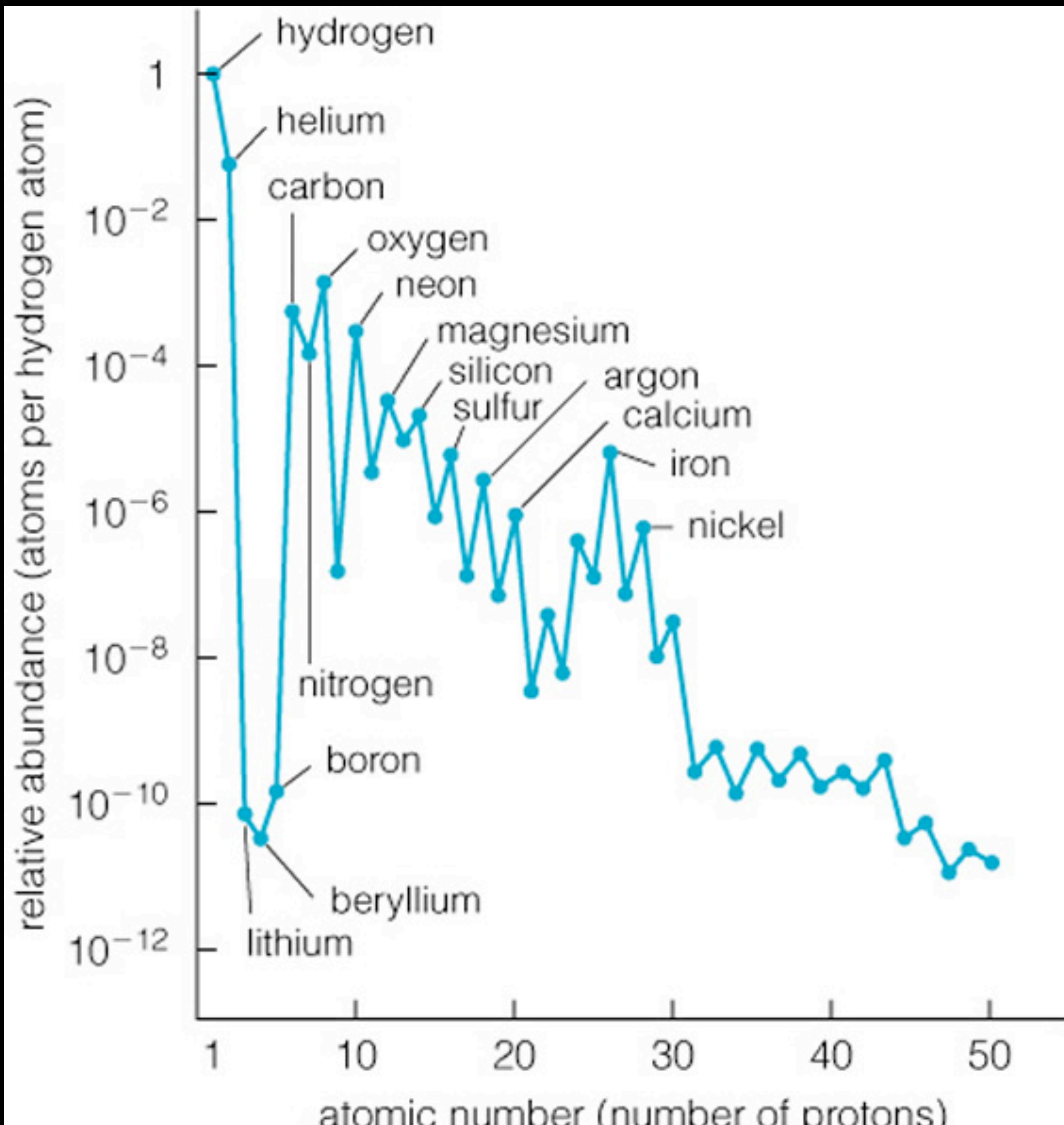
NASA, ESA, and J. Hester (Arizona State University)

STScI-PRC05-37

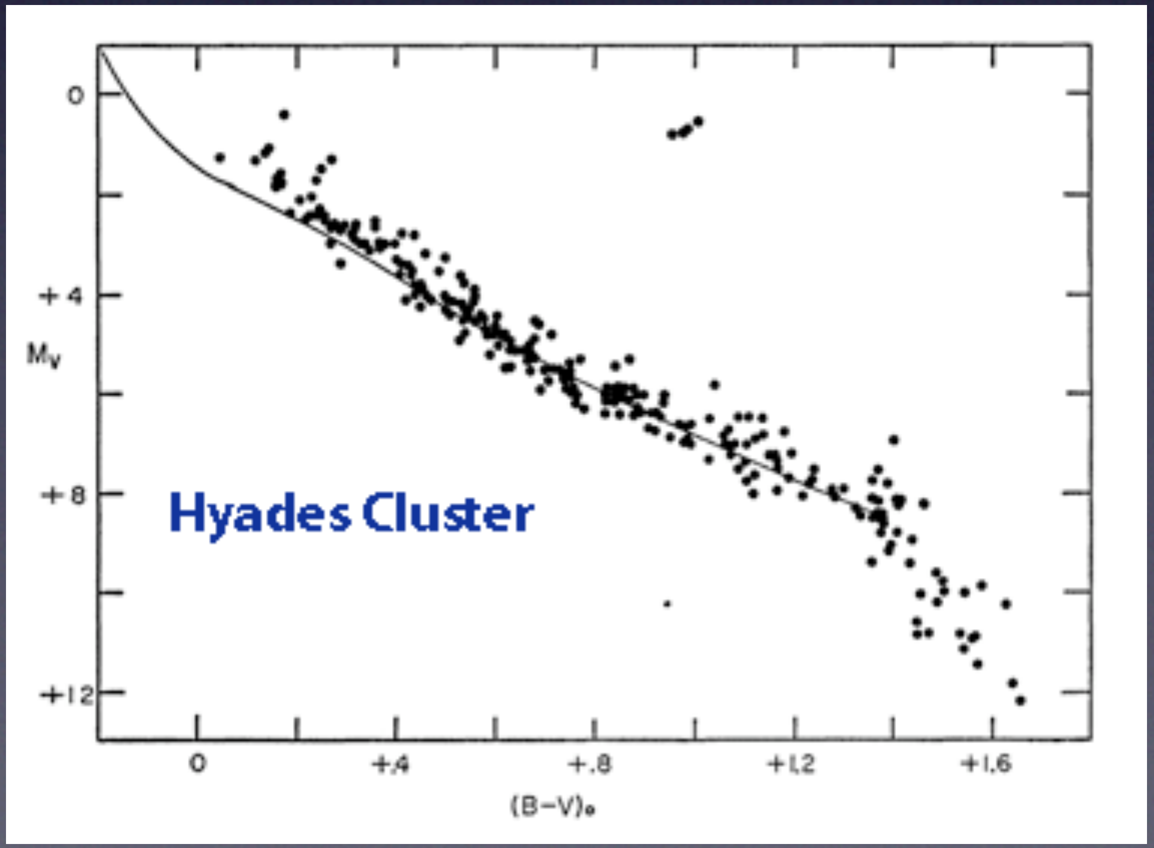


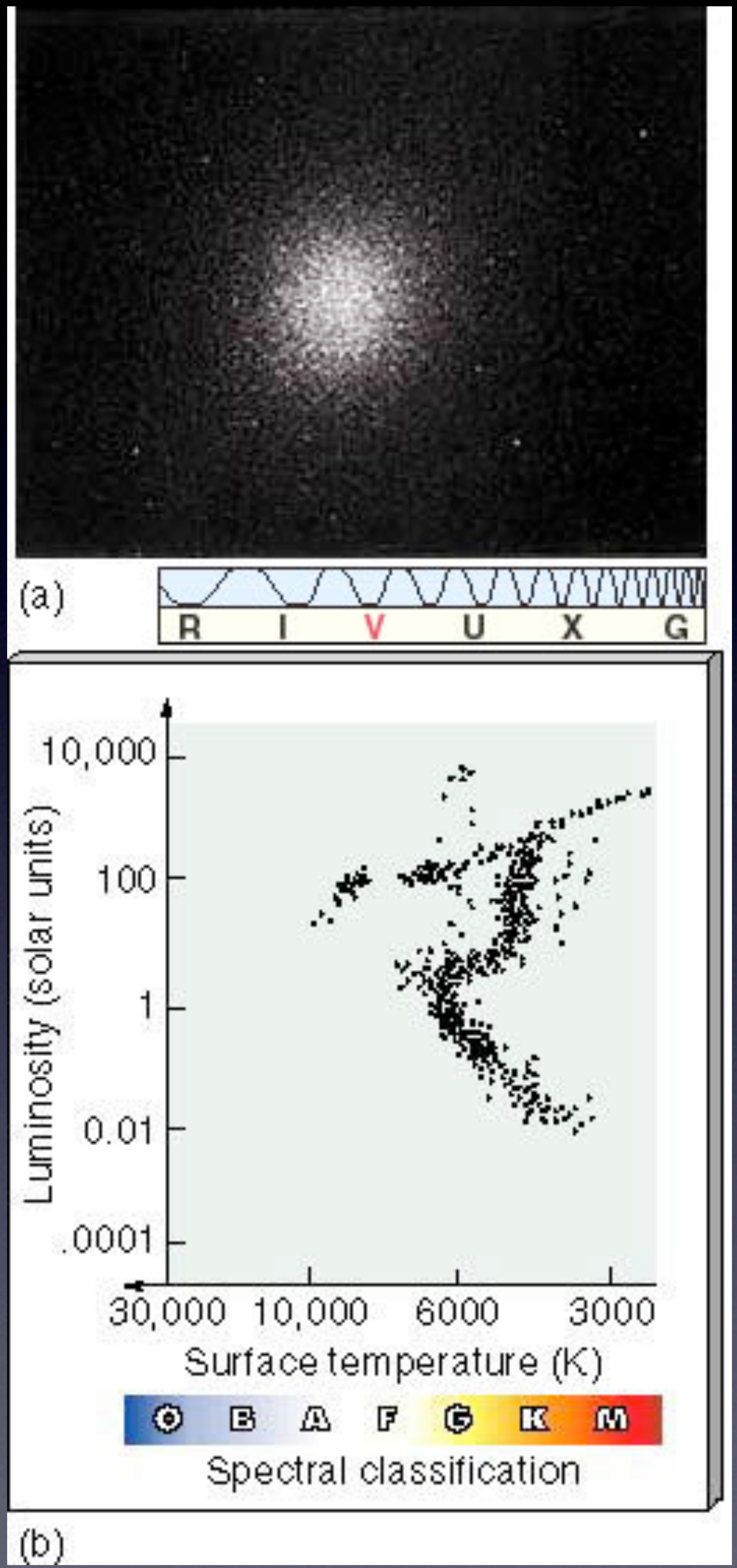
Cygnus Loop: gas thrown in space by a large stellar explosion, which happened long ago

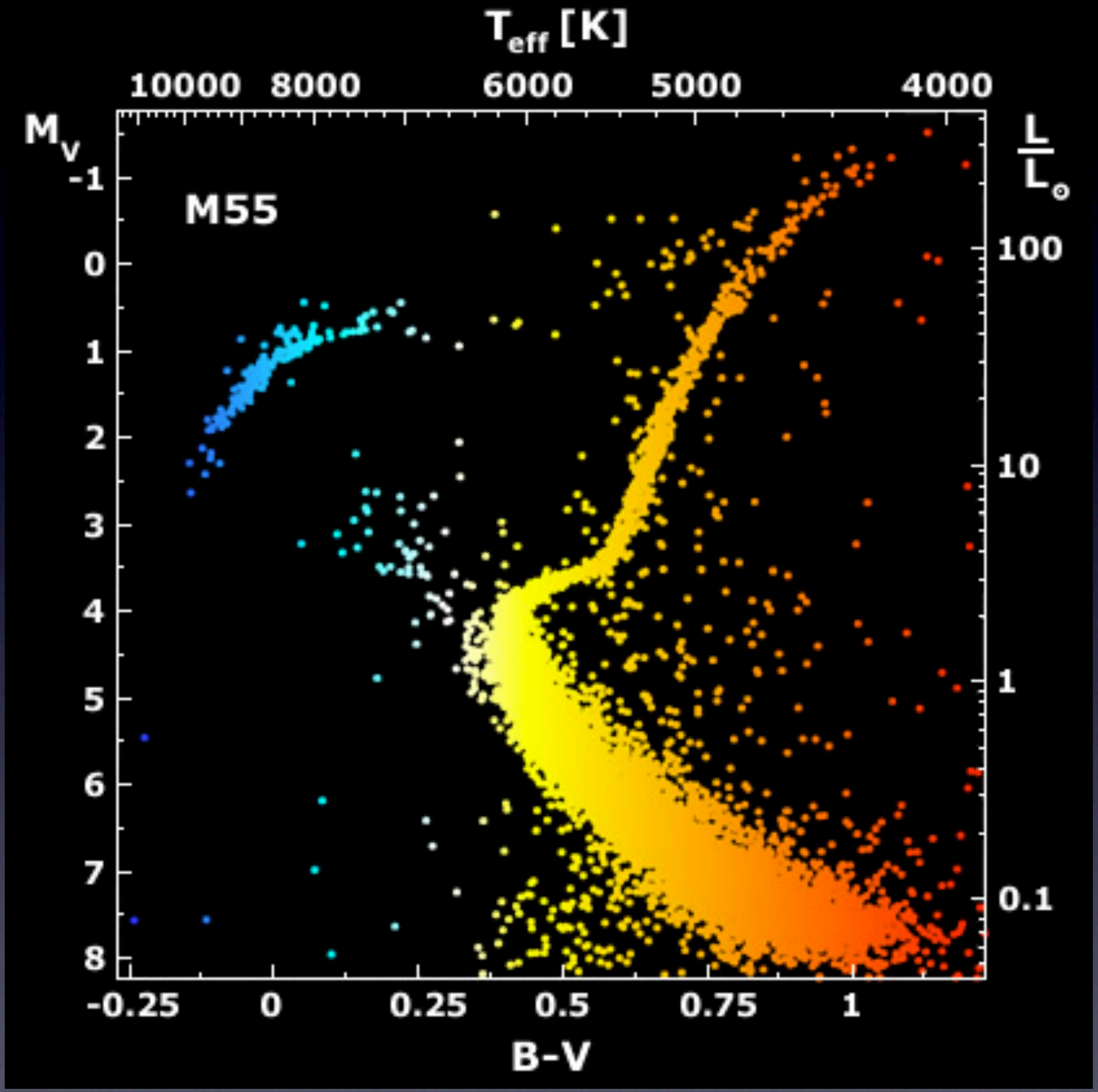
# Origin of elements



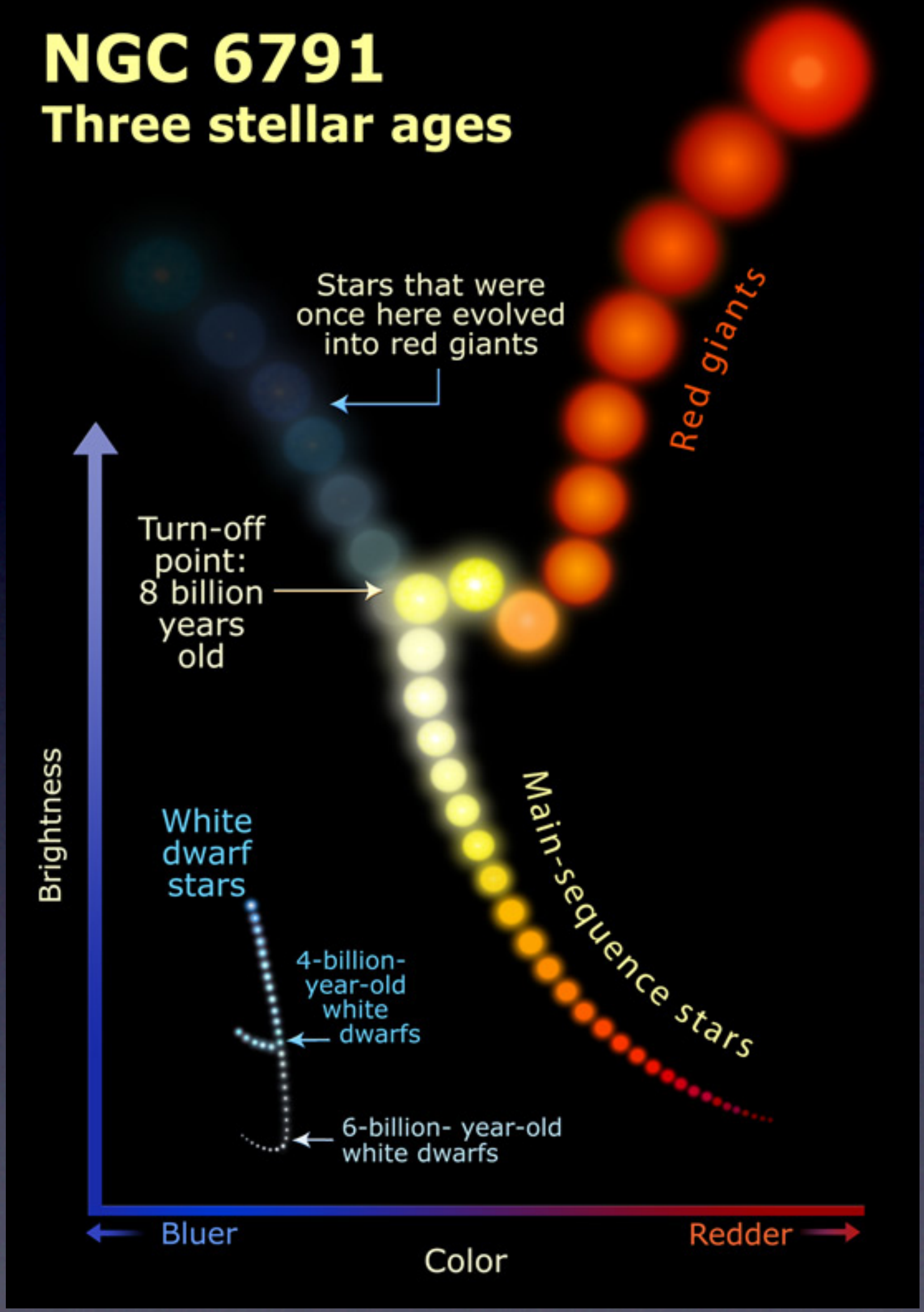
# Measuring ages of stars

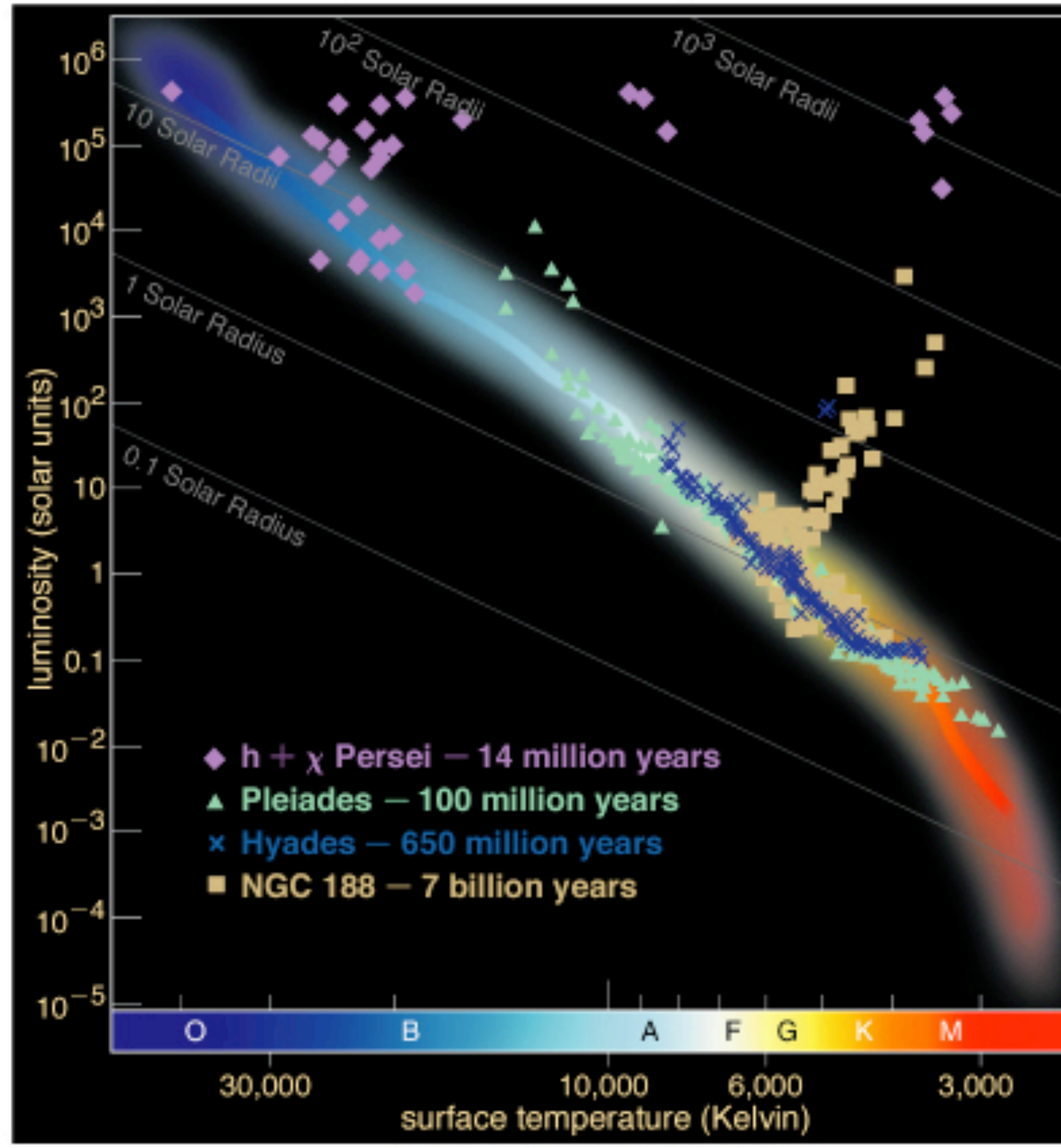


$T_{eff}$ [K]
10000 8000 6000 5000 4000
$M_V$
-1
0
1
2
3
4
5
6
7
8
M55
$\frac{L}{L_\odot}$
100
10
1
0.1
-0.25 0 0.25 0.5 0.75 1
B-V

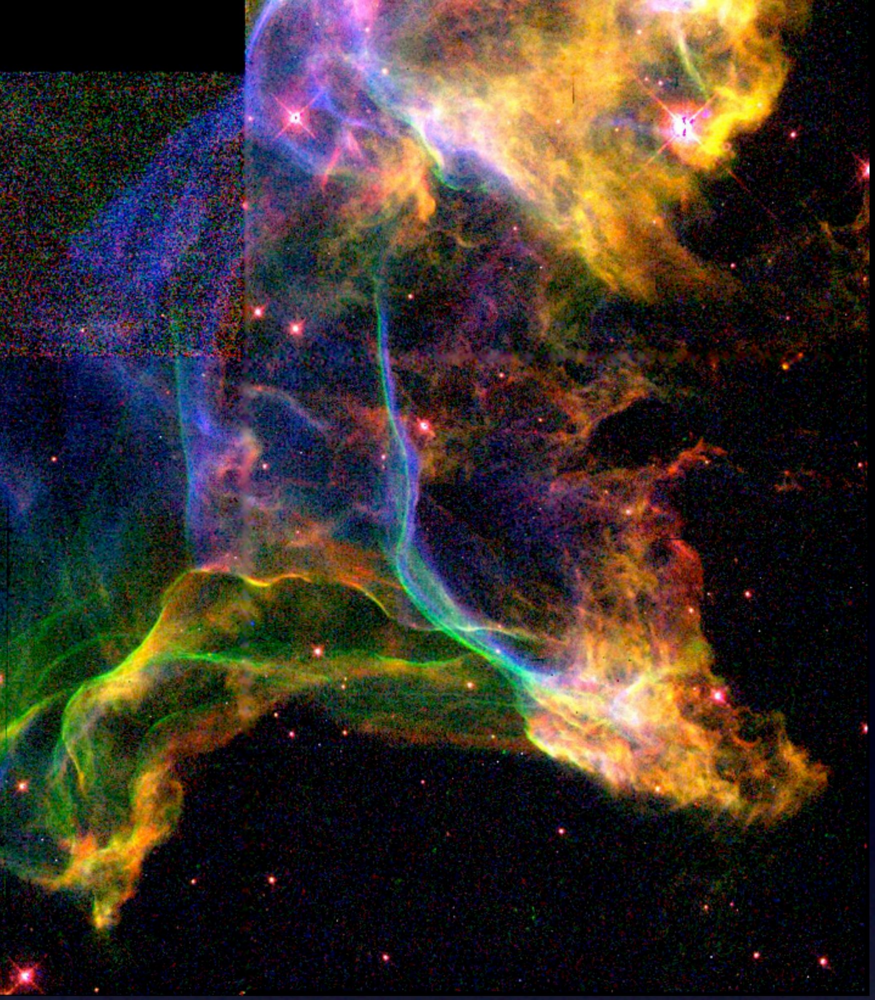



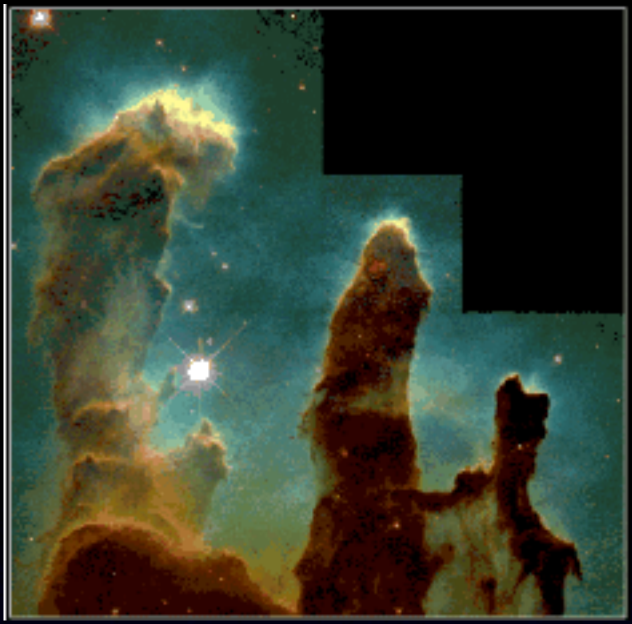
NGC 6791
Three stellar ages
Stars that were once here evolved into red giants
Red giants
Turn-off point: 8 billion years old
Brightness
White dwarf stars
4-billion-year-old white dwarfs
6-billion- year-old white dwarfs
Main-sequence stars
Bluer
Color
Redder

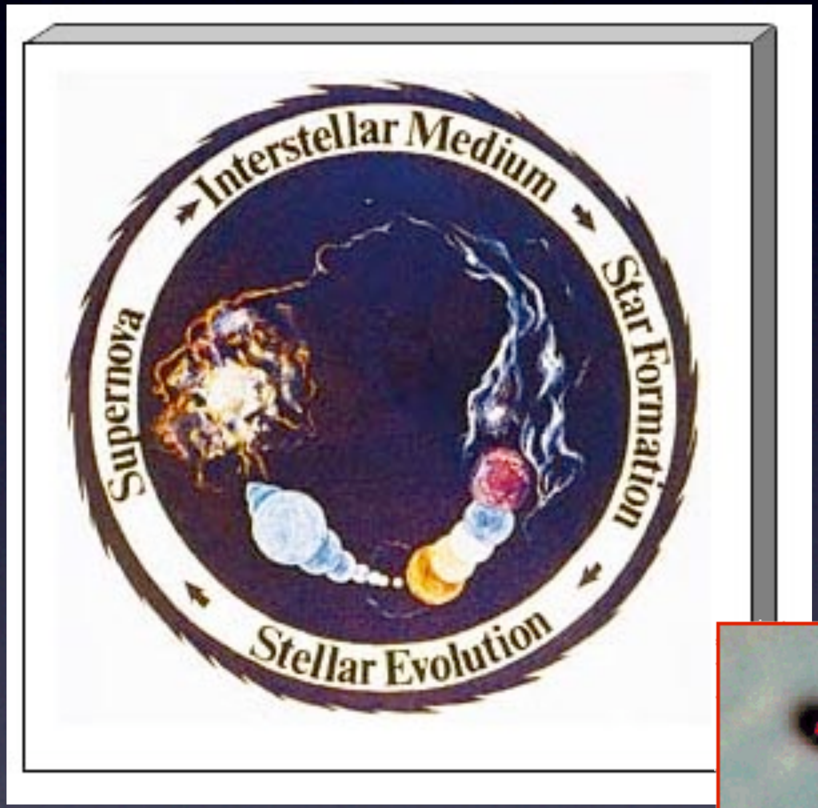




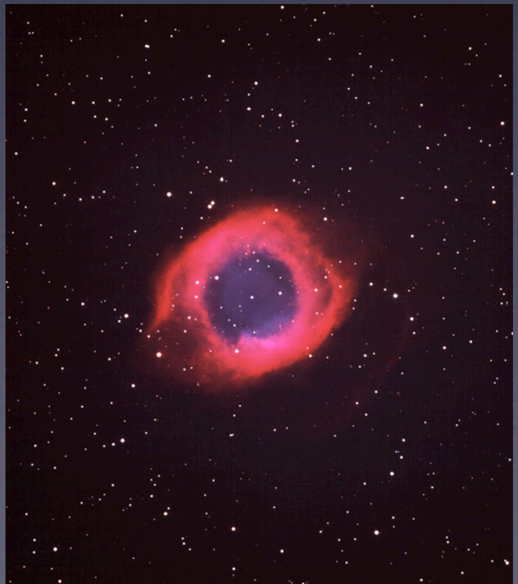

Oldest globular clusters have age of 12Gyrs:
almost as old as the Universe itself.
Age of our Sun is 4.6Gyrs

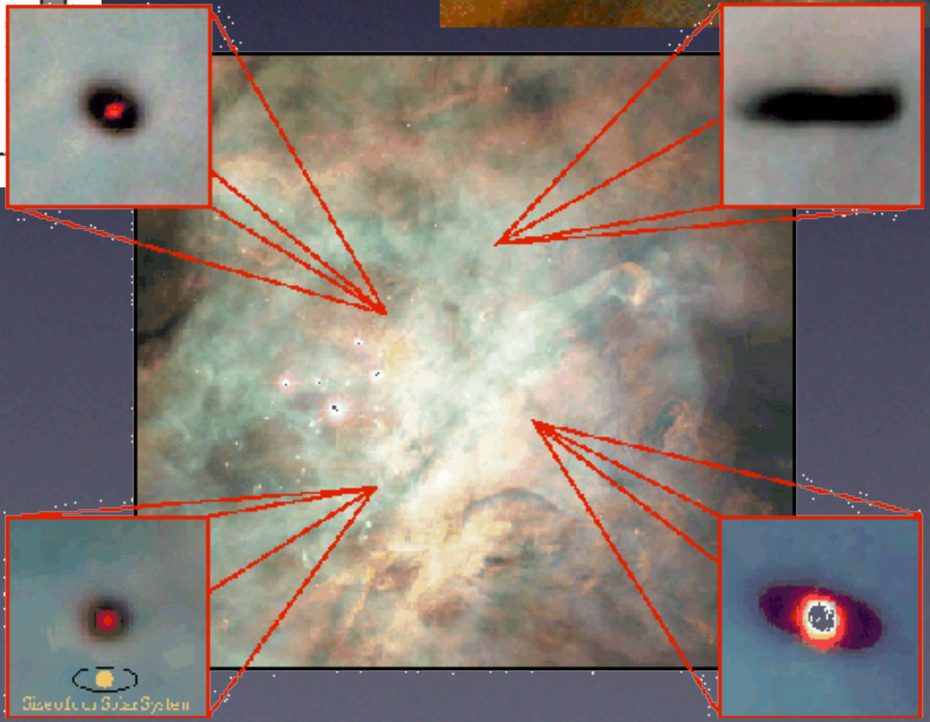


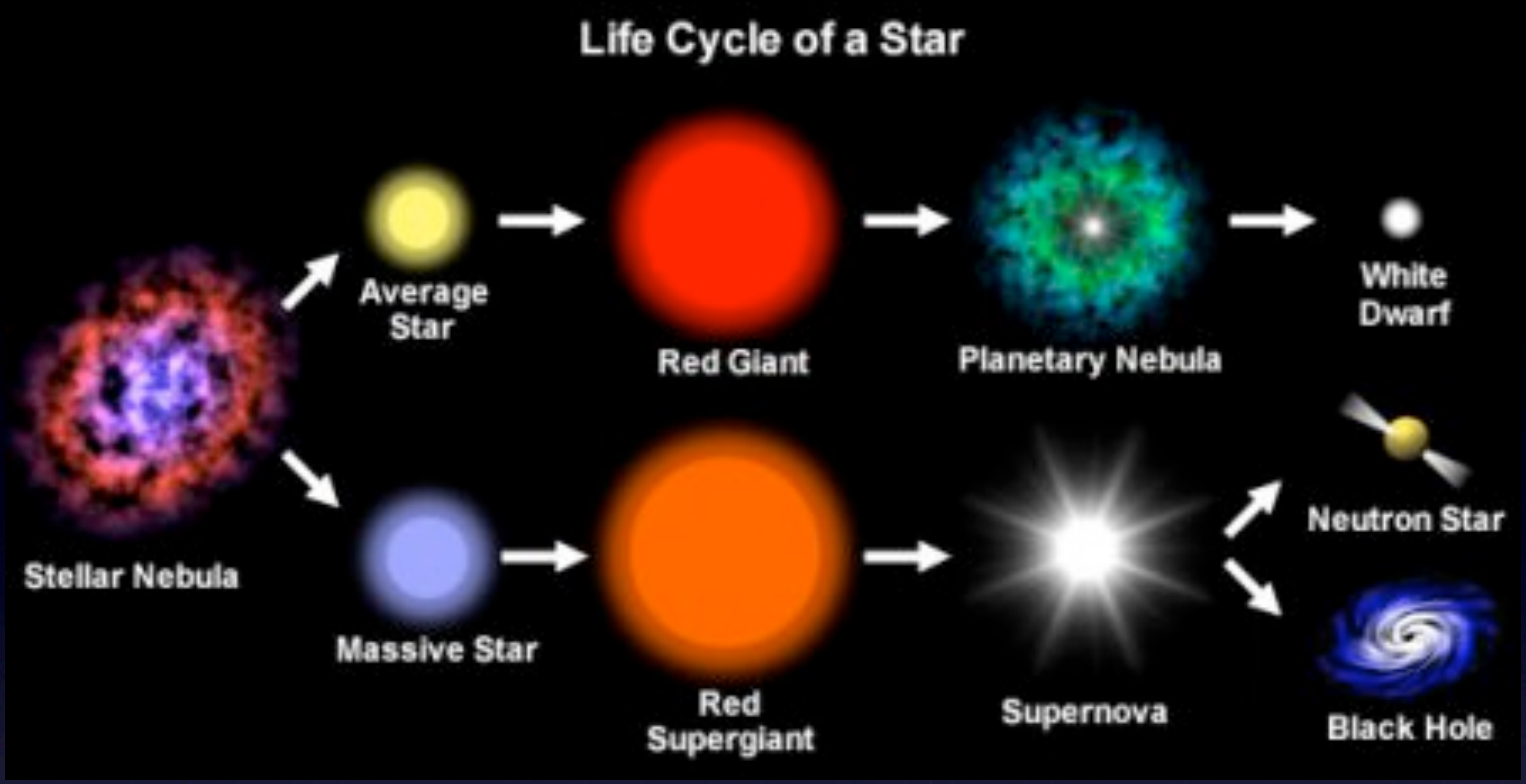


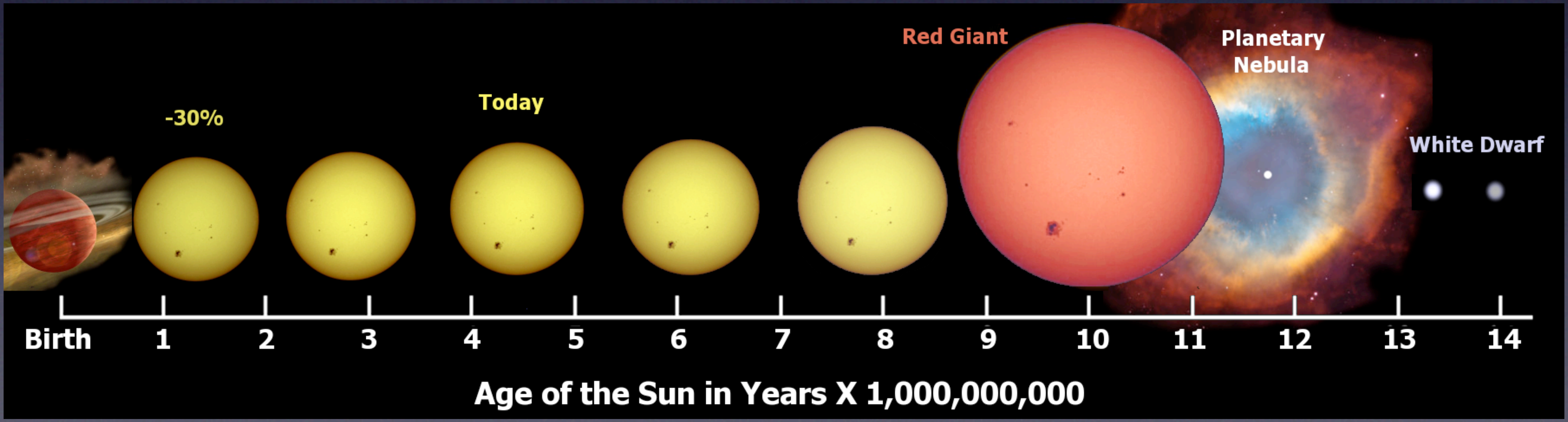

Interstellar Medium
Star Formation
Stellar Evolution
Supernova


Crab Nebula • M1
Hubble Space Telescope • WFPC2
NASA, ESA, and J. Hester (Arizona State University)
STScI-PRC05-37






Life Cycle of a Star
Average Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Nebula
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole


Red Giant
Planetary Nebula
-30%
Today
White Dwarf
Birth
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Age of the Sun in Years X 1,000,000,000

The mass of a star has an important role in determining its evolution. **The larger the mass, the more quickly the star will evolve** onto and off of the Main Sequence. A $1M_{sun}$ star takes about 30 million yrs to evolve onto the Main Sequence, but a $15M_{sun}$ takes only about 160,000 yrs and a $0.2M_{sun}$ star takes about 1 billion yrs.

**Massive stars consume their fuel quickly & live relatively short lives on the Main Sequence whereas low mass stars conserve their fuel & shine for billions of years.** For example, a $25M_{sun}$ will live only 7 million yrs on the Main Sequence, whereas a $0.5M_{sun}$ can continue to burn its nuclear fuel for 17 billion yrs.

Main Sequence stars ``shine" by fusing hydrogen into helium. When about 90% of that hydrogen has been exhausted, great changes occur in the structure, luminosity, & size of the star. The star begins to evolve off of the Main Sequence.

Once the hydrogen in the core is depleted, proton-proton nuclear reactions cease and the helium core begins to contract (thermal pressure no longer can offset gravity). The core temperature begins to rise. The larger core temperature results in the ignition of a shell of hydrogen which surrounds the core.

The star moves toward the upper right portion of the H-R diagram - the Giant Branch. The *hydrogen shell burning* has caused the star's envelope or atmosphere to rapidly expand with the outermost layers cooling due to the expansion. After another 5 billion yrs, our Sun will become a *Red Giant*. A star can remain a Red Giant only for about 10% of its total lifetime.

Meanwhile, the helium core continues to contract & heat. Once the core temperature reaches 100 million K, nuclear reactions begin again. This time, three helium nuclei fuse to produce a carbon nucleus in what's called the Triple Alpha process.

# What is the fate of our Sun?

**For a** medium-mass star like the Sun**, the triple-alpha process is the last nuclear reaction in the core. Once the core has been converted into carbon, the star begins to collapse again and becomes a white dwarf, where degenerate gas pressure halts the collapse. It moves to the lower left portion of the H-R diagram. As the white dwarf radiates its energy into space, the star cools off and the luminosity declines. Eventually the star becomes a cold & dark carbon cinder called a black dwarf.**

# What is the fate of a very massive star?

For stars with mass larger than 10 Msun, the end can be quite spectacular. Such a star is layered like an onion with an iron core, surrounded by a layer of silicon, then oxygen, then carbon, then helium, and finally an outer ``skin" of hydrogen. The evolution then proceeds as follows:

- As the star develops an iron core, the energy production declines (iron has a very tightly bound nucleus) and the core contracts. As the core reaches 5 billion K, the photons have reached gamma-ray energies which break up iron nuclei and cause the core to collapse VERY rapidly.

- This rapid collapse triggers a star-destroying explosion called a supernova. The contraction of the innermost degenerate core allows the rest of the core to fall inward producing a huge shock (or compression) which propagates outward and blows off the outer part of the star. This explosion results in a rapid rise in luminosity, for a brief period of time.

- The core collapse transforms iron to heavier nuclei, all the way to the end of the periodic table. A supernova is the ONLY way that elements heavier than iron can be produced in nature.

- The remaining core of the star may be either a neutron star (which can produce a pulsar) or a black hole.