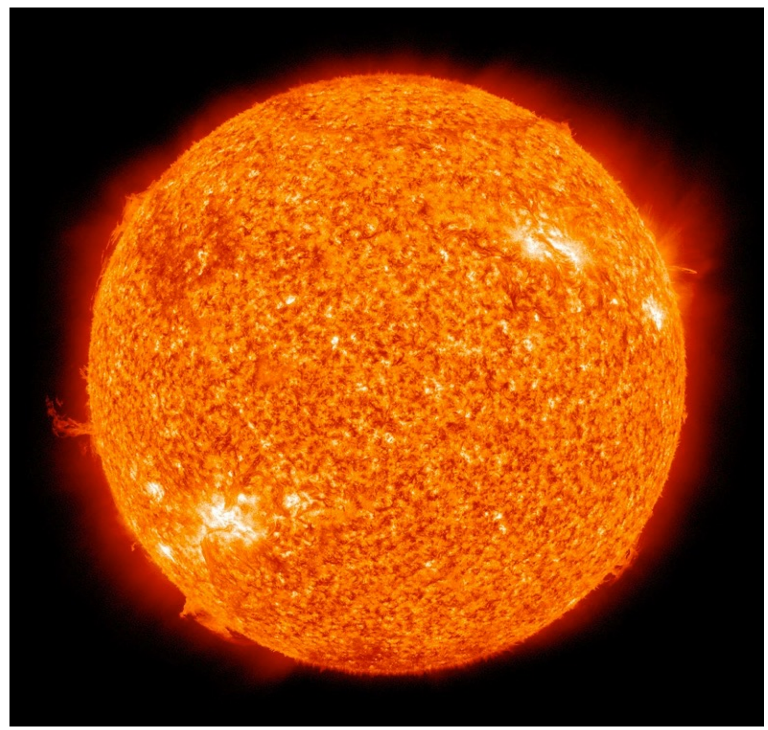
THE SUN & THE STARS

CONTENT EXPECTATIONS

E5.2 The Sun

Stars, including the Sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. Solar energy is responsible for life processes and weather as well as phenomena on Earth. These and other processes in stars have led to the formation of all the other chemical elements.

E5.2A Identify patterns in solar activities (sunspot cycle, solar flares, solar wind).

E5.2B Relate events on the Sun to phenomena such as auroras, disruption of radio and satellite communications, and power grid disturbances.

E5.2C Describe how nuclear fusion produces energy in the Sun.

E5.2D Describe how nuclear fusion and other processes in stars have led to the formation of all the other chemical elements.

E5.2x Stellar Evolution

Stars, including the Sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. These and other processes in stars have led to the formation of all the other chemical elements. There is a wide range of stellar objects of different sizes and temperatures. Stars have varying life histories based on these parameters.

E5.2e Explain how the Hertzsprung-Russell (H-R) diagram can be used to deduce other parameters (distance).

E5.2f Explain how you can infer the temperature, life span, and mass of a star from its color. Use the H-R diagram to explain the life cycles of stars.

E5.2g Explain how the balance between fusion and gravity controls the evolution of a star (equilibrium).

E5.2h Compare the evolution paths of low-, moderate-, and high-mass stars using the H-R diagram.

STARS

What are stars?

Are they all the same?

What makes them different?

What is our nearest star?

THE SUN

Why is it important?

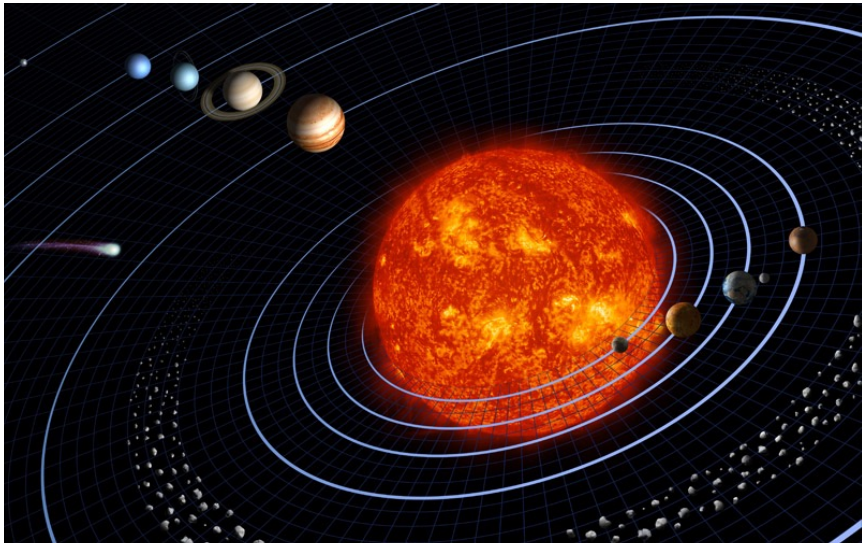
provides heat and light that we need for life

governs the motions in our solar system

Is it special?

No! It's a pretty normal middle-aged star

There are lots of stars now known with planets



THE SUN: FACTS

How big?

109 times radius of Earth, or 430,000 miles

How heavy?

300,000 times the mass of the Earth

How far away?

93 million miles, or 8 light minutes

How hot?

10000 F at the surface (photosphere)

How old is it?

4.5 billion years!

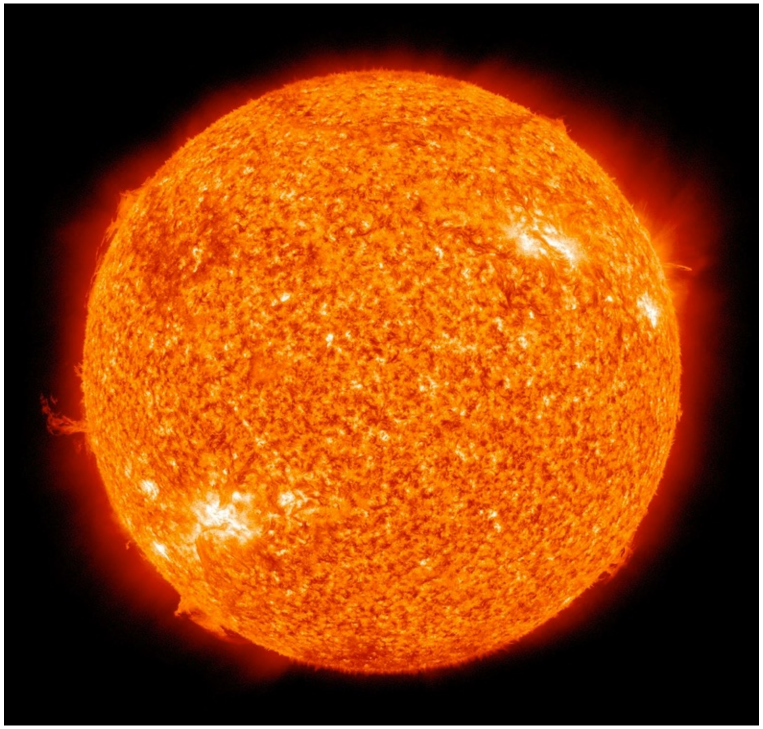
What is it made of?

Gas, mostly H (70%) and He (28%)

Does it rotate?

Yes, once about every 26 days (rotates faster at the equator)

The Sun is always changing!

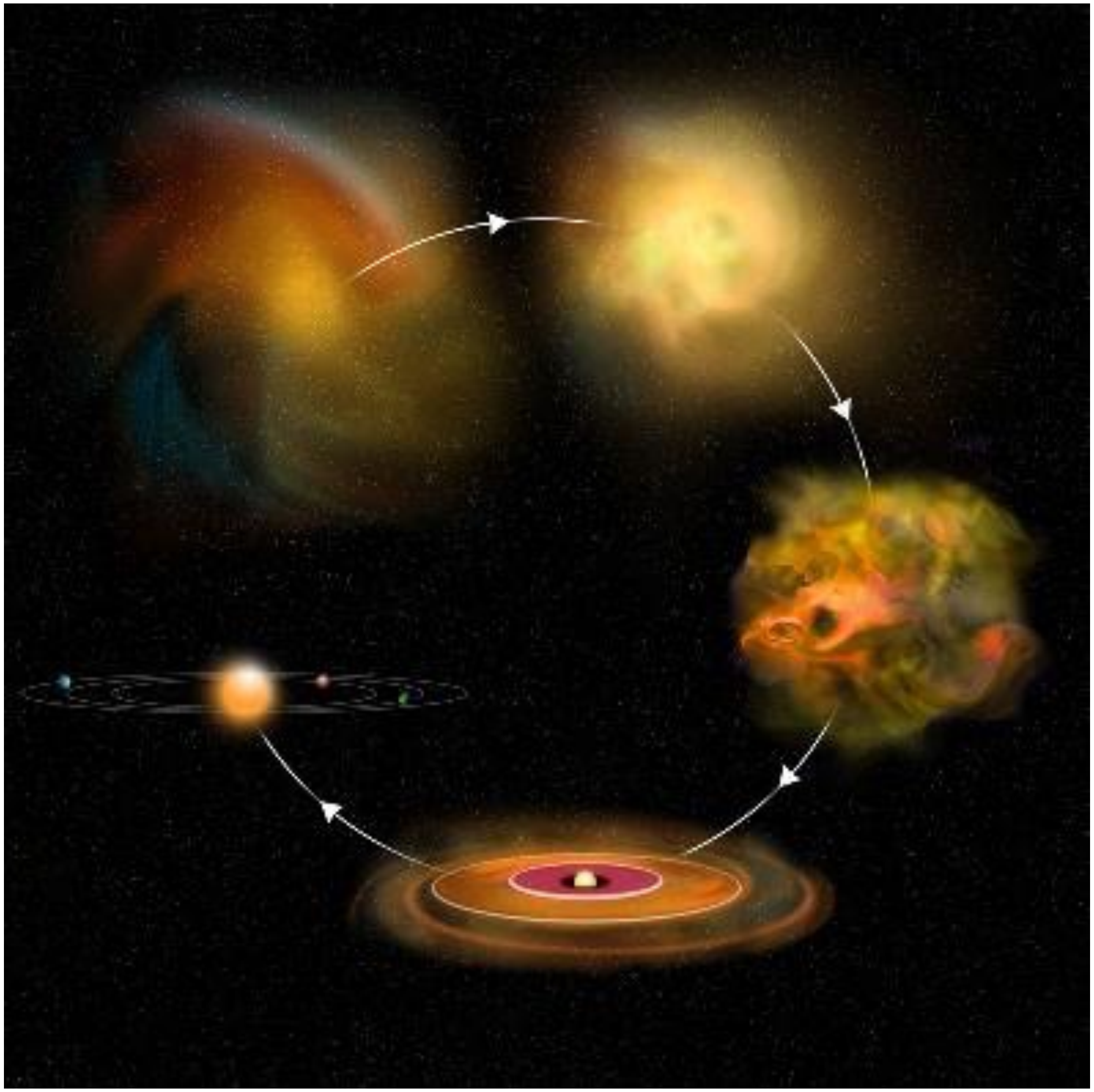


HOW DID THE SUN (AND OTHER STARS) FORM?

Huge clouds of cold gas and dust in space collapse under their own gravity

They heat up as they collapse

Get hot enough to start burning hydrogen: nuclear fusion!

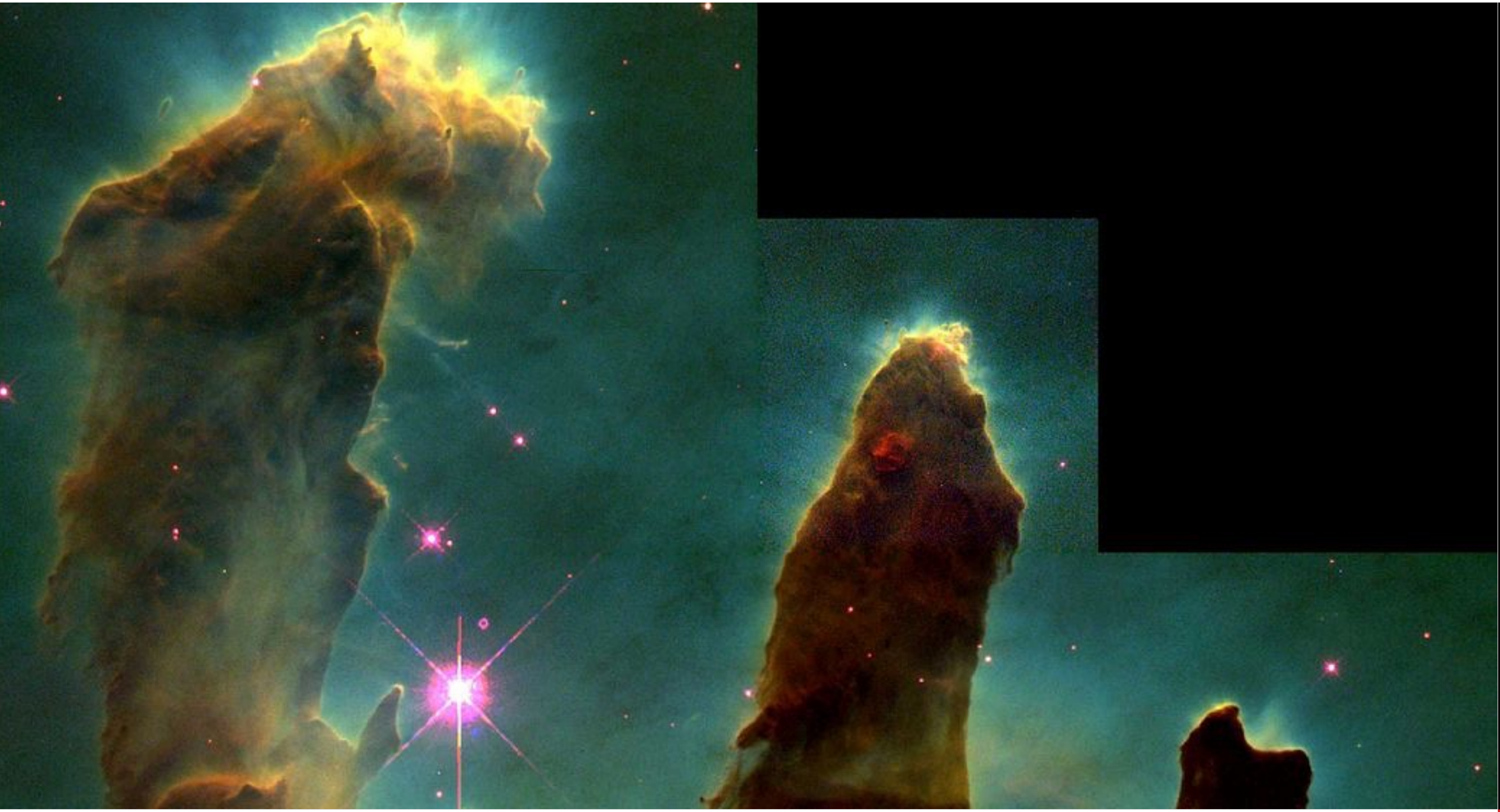


THE ORION NEBULA

Nearest large star forming region

HORSEHEAD NEBULA

Giant molecular cloud



PILLARS OF CREATION

Eagle Nebula, as seen by Hubble Space Telescope

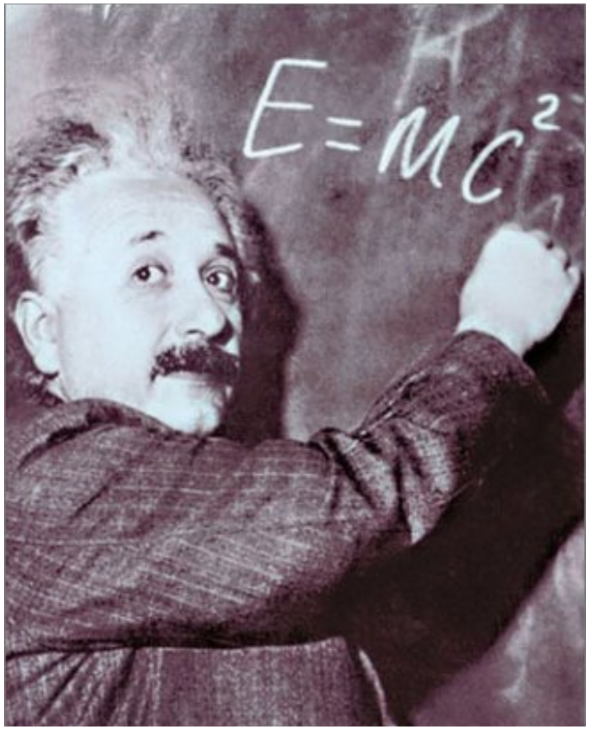
THERMONUCLEAR FUSION

Process by which (most) stars get their energy

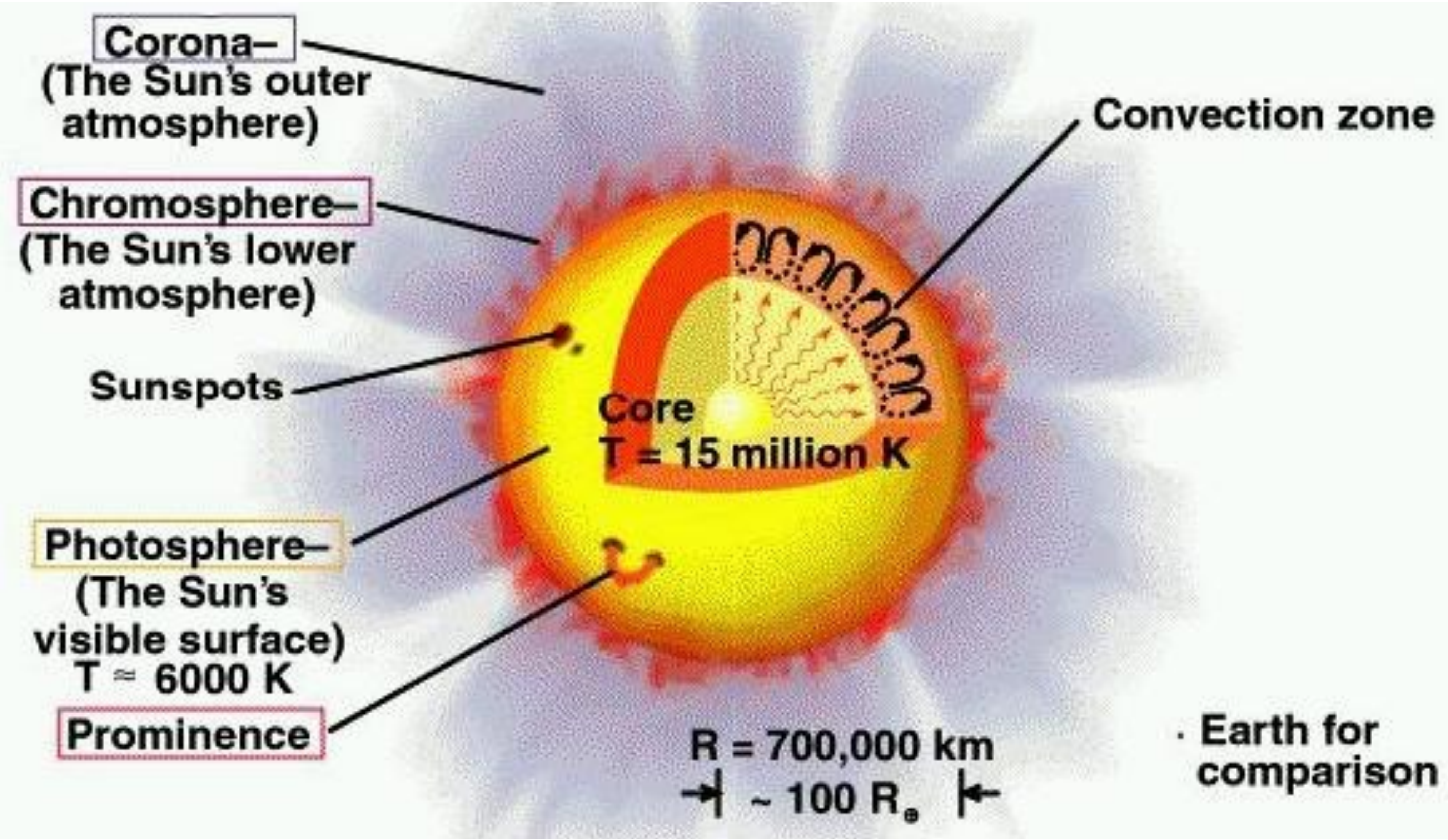
Light elements *fuse* together to become heavier elements

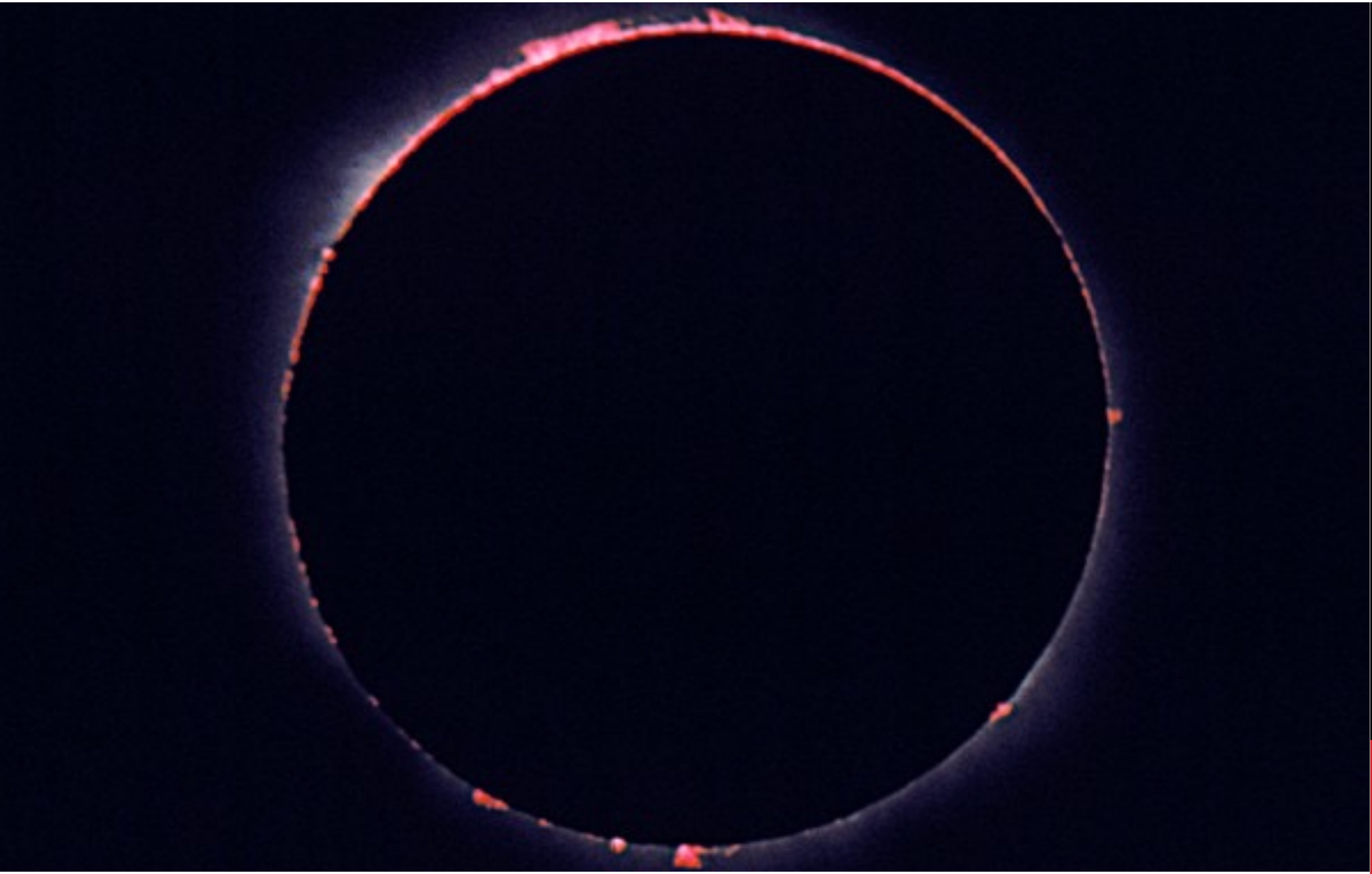
E.g., 4 H join to become He

He has slightly less mass than 4 H – the lost mass is converted to energy



STRUCTURE OF THE SUN



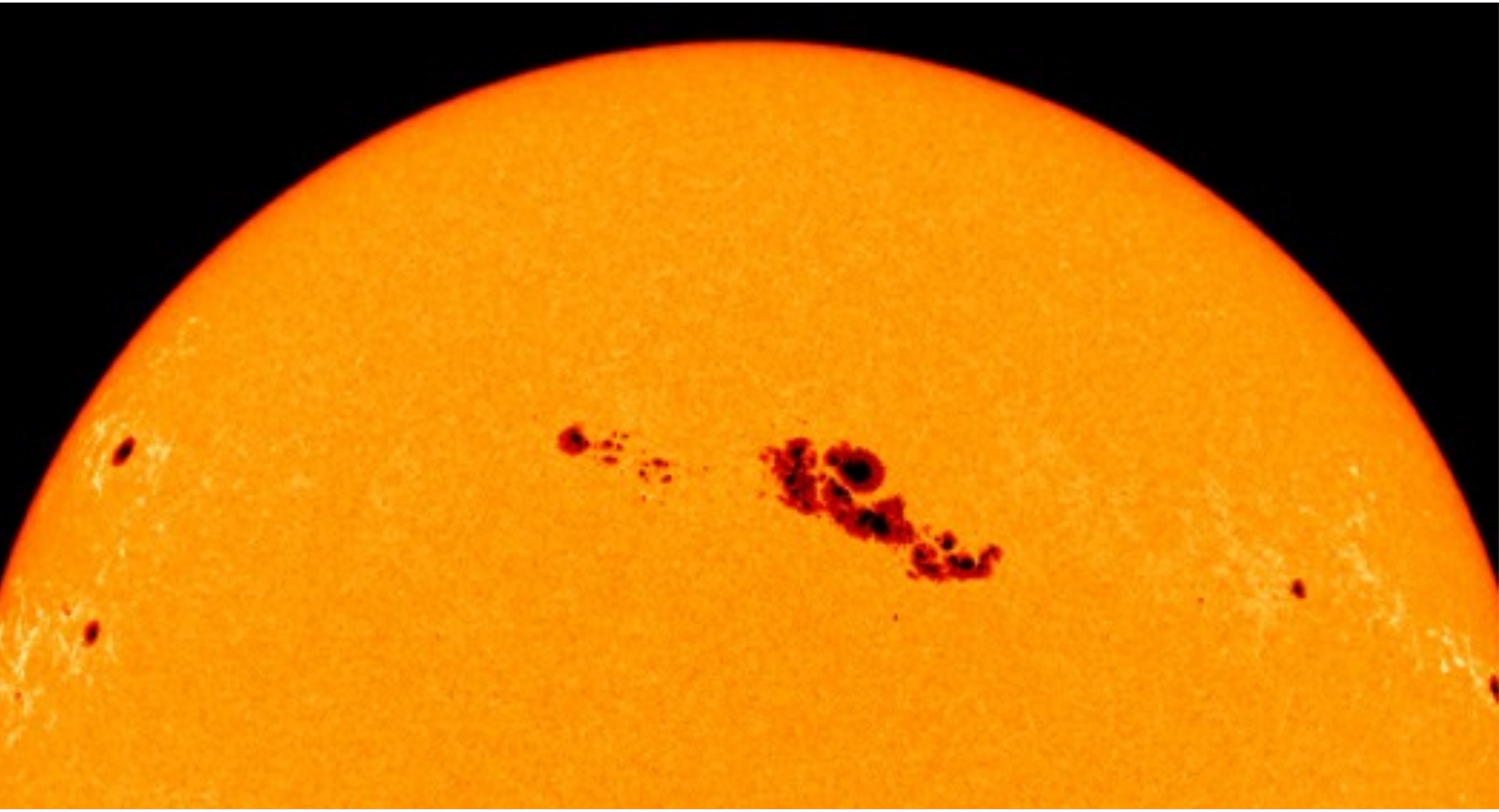


CHROMOSPHERE

seen during a total solar eclipse

THE SOLAR CORONA

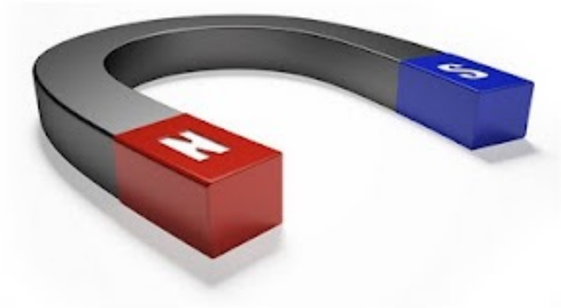
as seen during a total solar eclipse

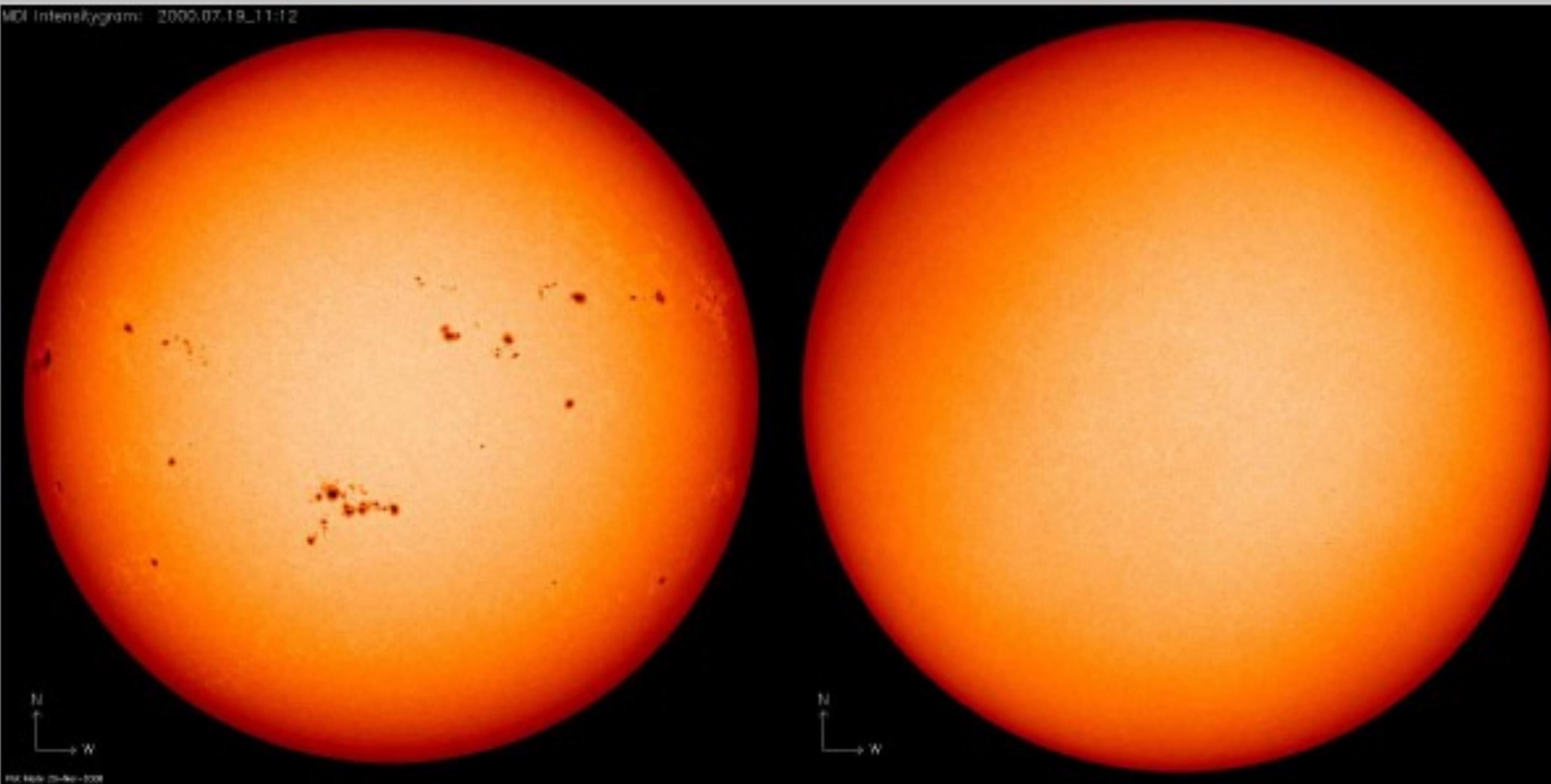


SUNSPOTS

Appear darker because they are cooler

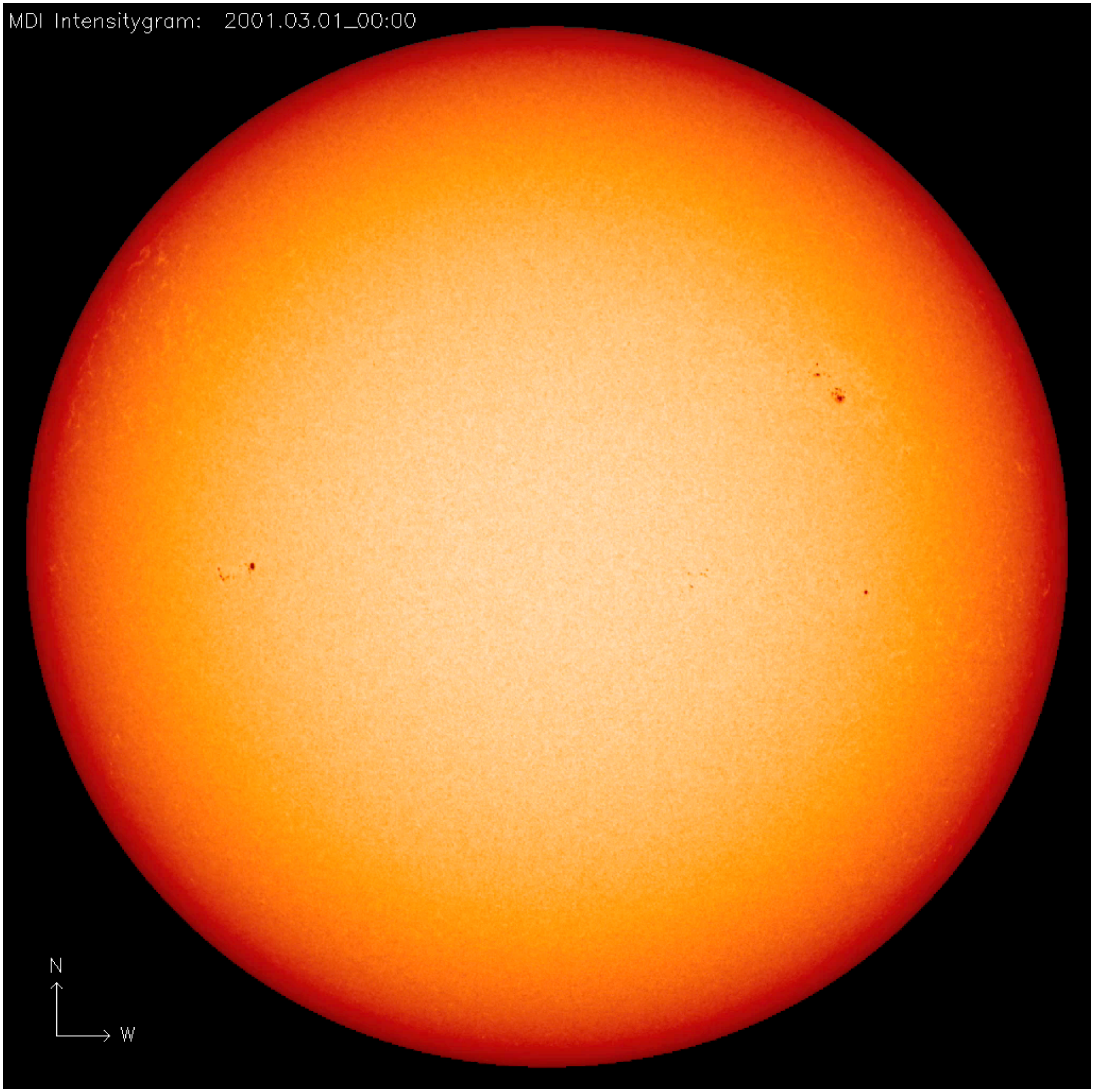
Where the Sun’s magnetic field breaks out of the surface





SUNSPOTS

Constantly changing – 11 year cycle of sunspot activity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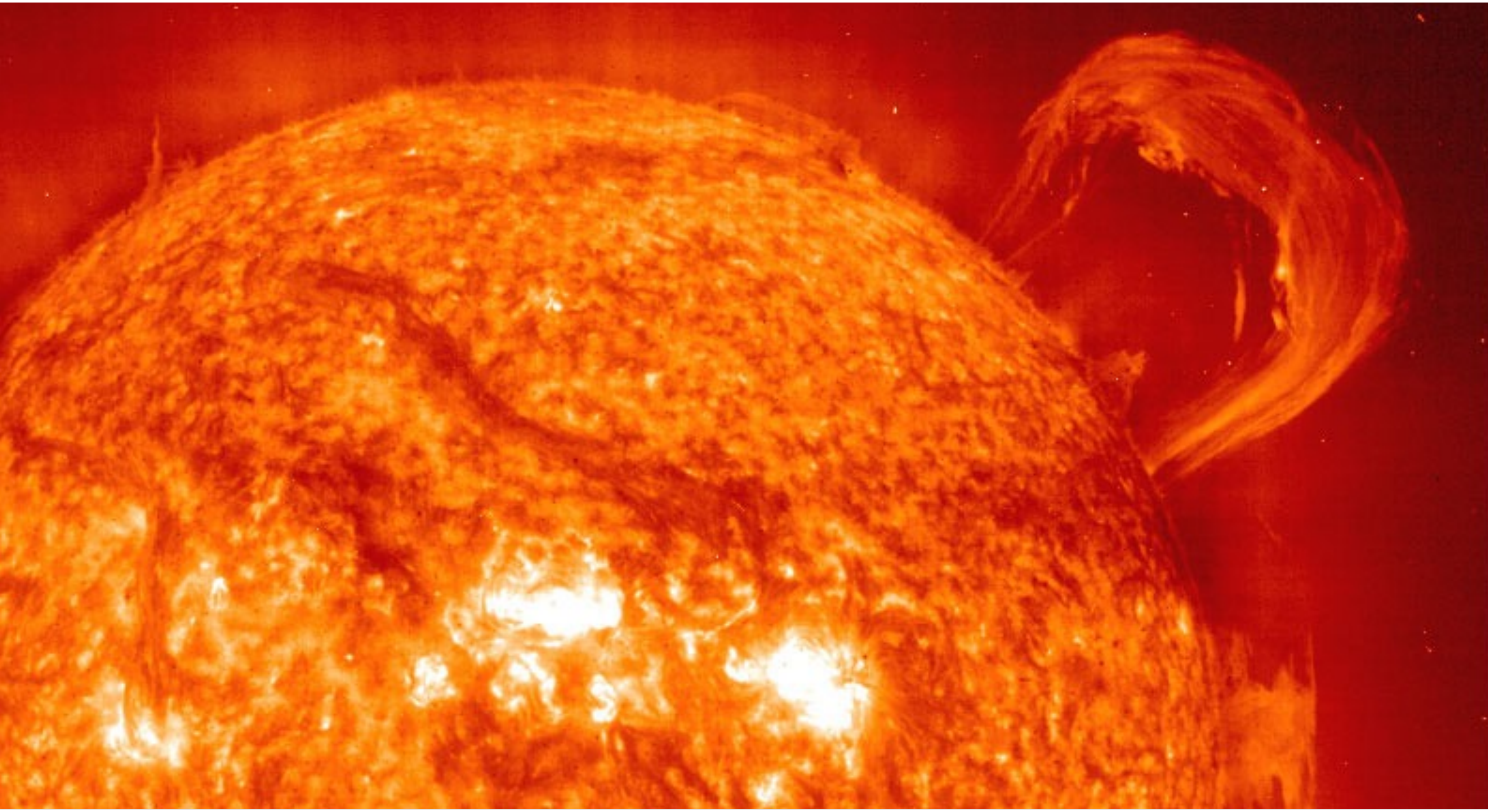
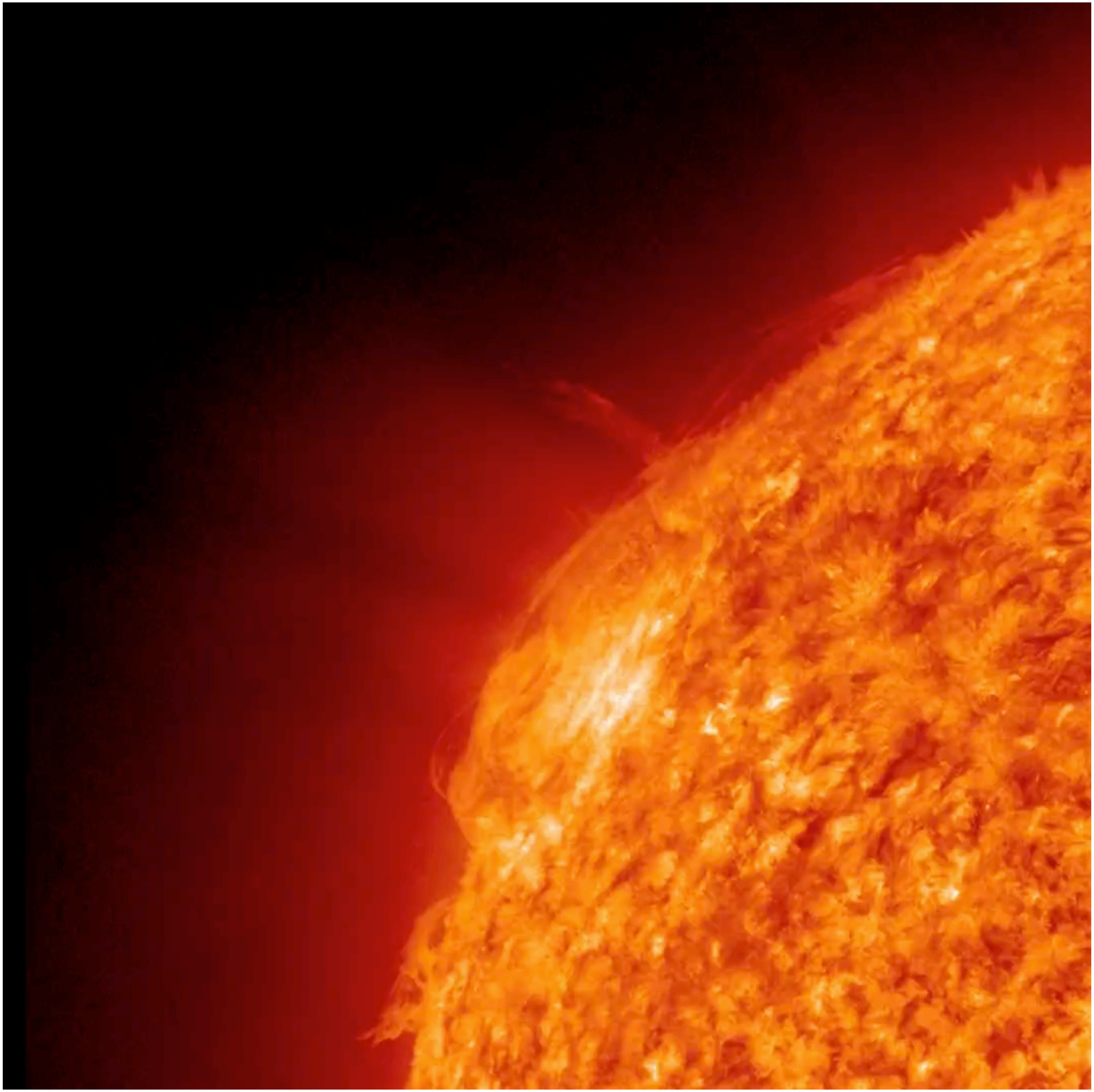
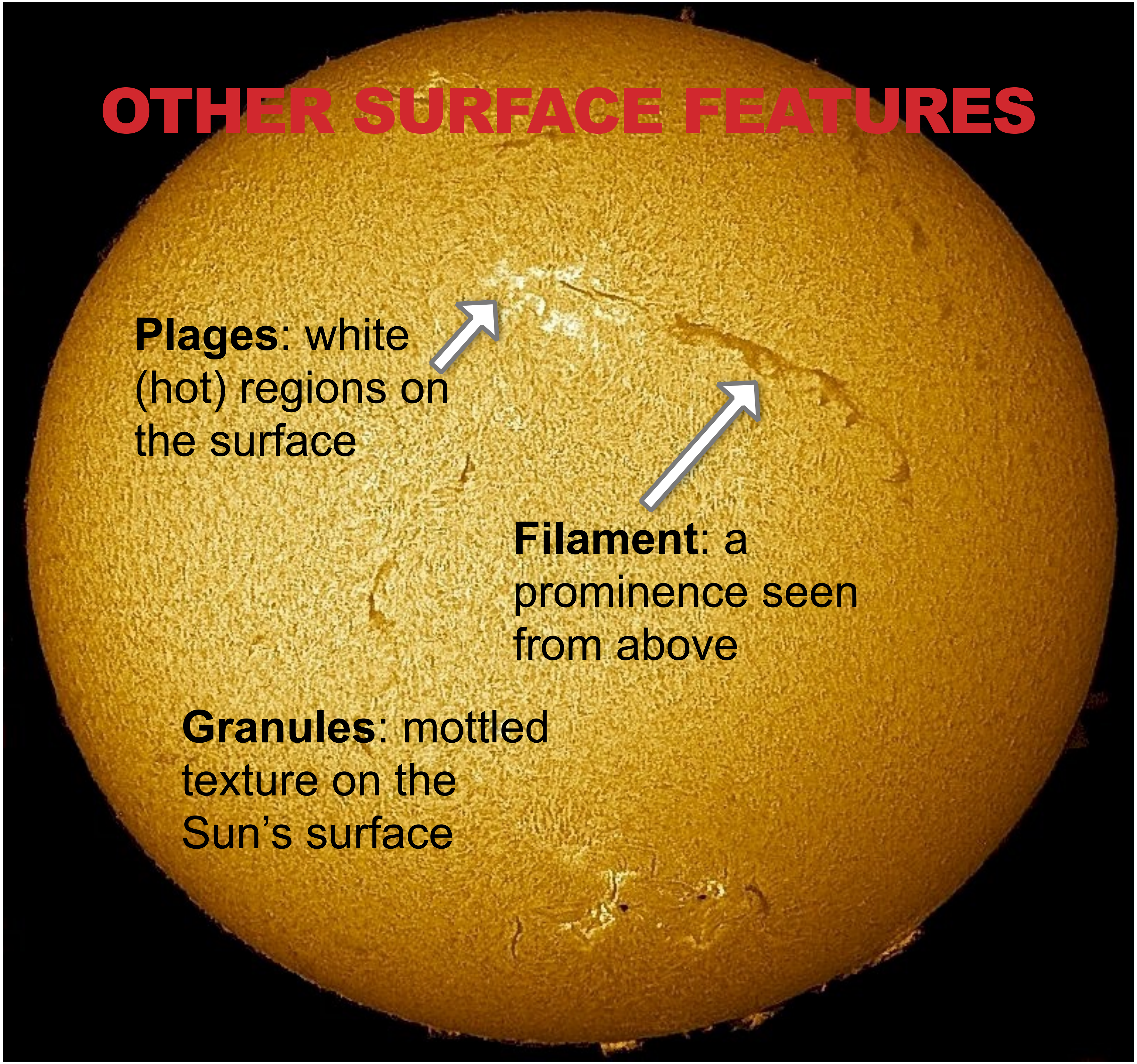


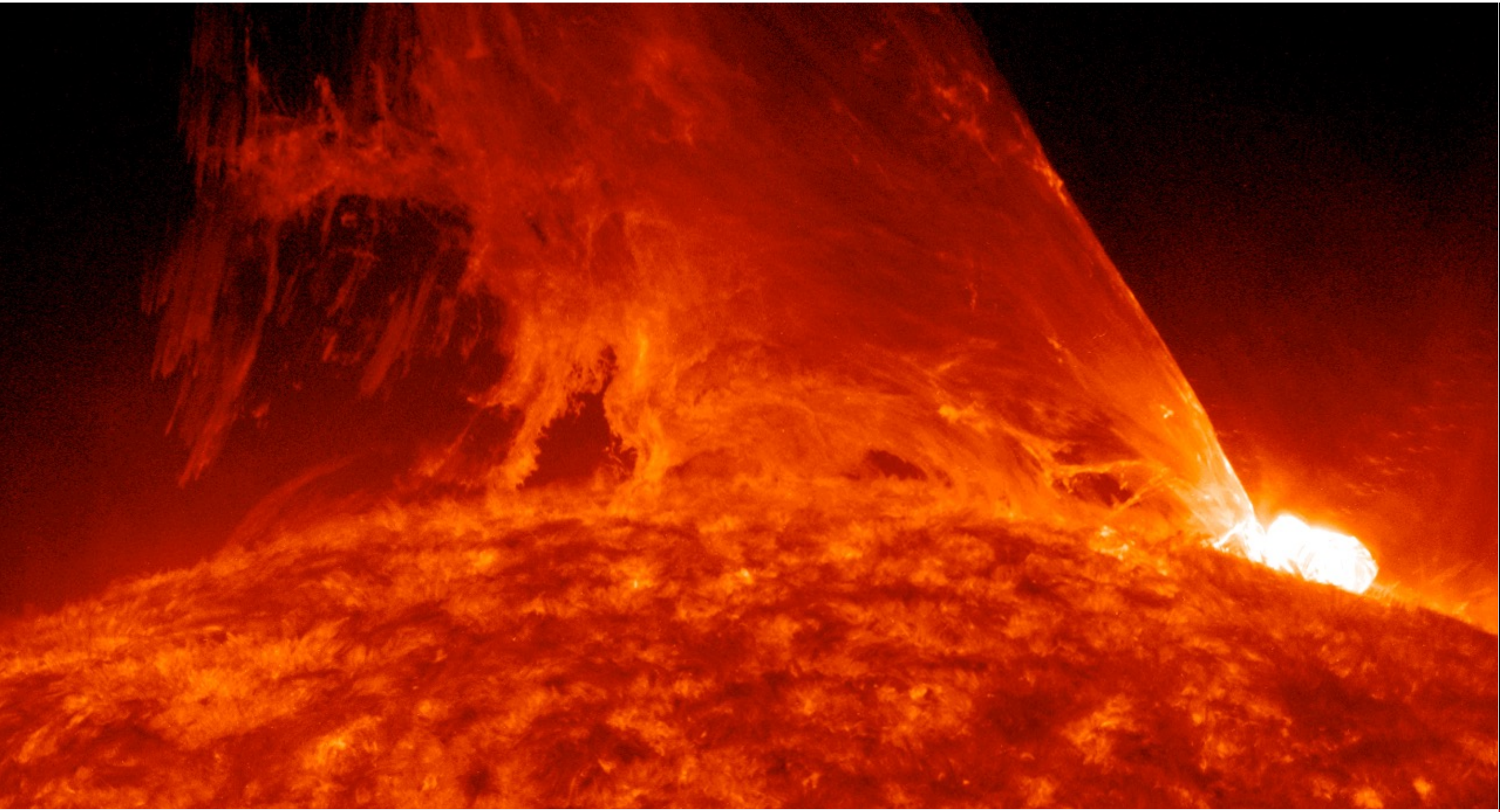
SOLAR PROMINENCES

Arches of gas aligning with the magnetic field of sunspot pairs that can last for months.



OTHER SURFACE FEATURES



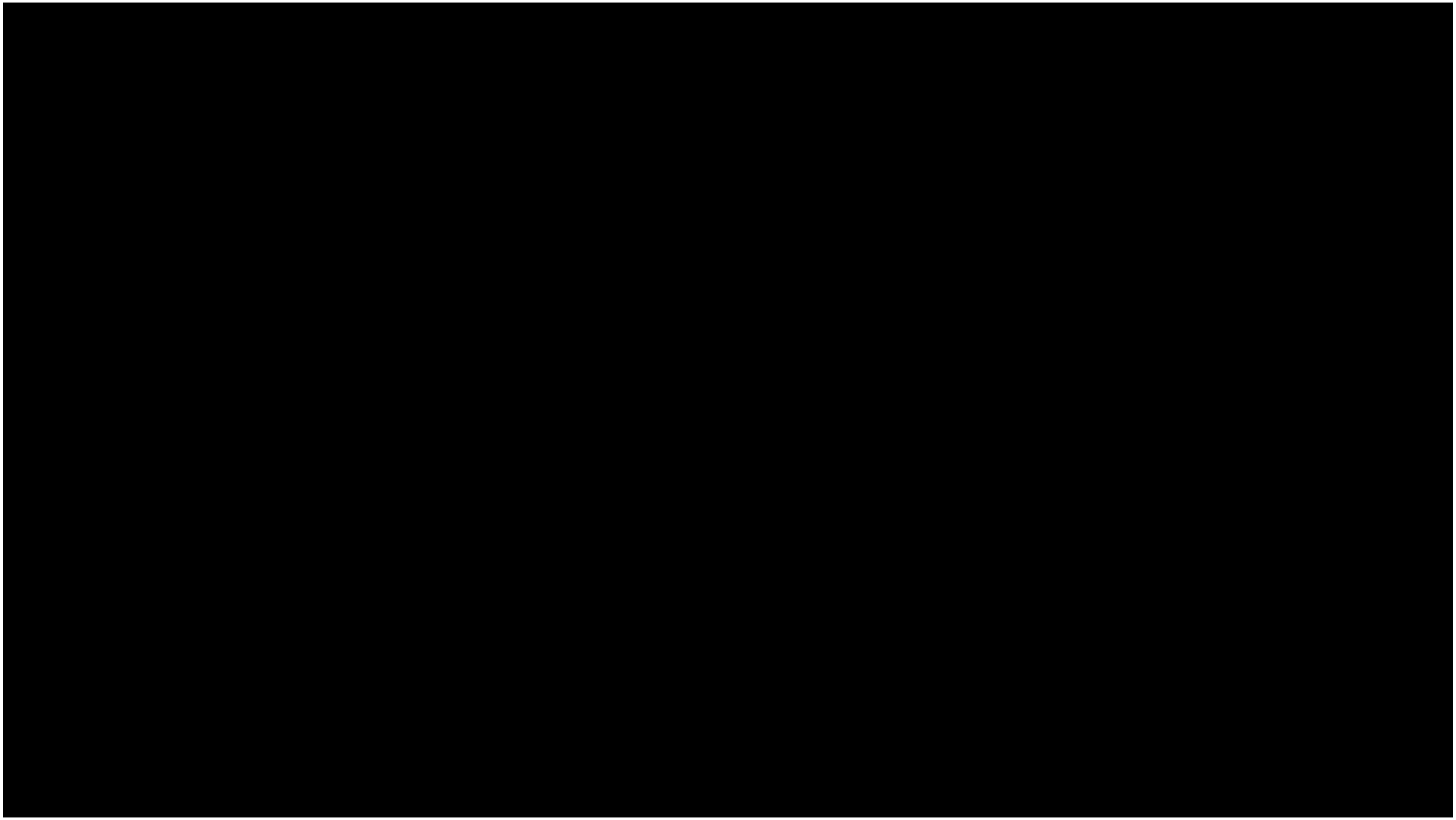


SOLAR FLARE

Abrupt, violent explosions

AURORA

Interaction of solar wind with Earth’s magnetic field. The solar wind is the energetic particles (e and p) streaming off the Sun at 400 km/s.



Movie from NASA’s Solar Dynamic Observatory

SOHO

10 years of operations

1995-2005

STARS OTHER THAN THE SUN

When you look at stars do you see them as different colors?

- take a look a Betelgeuse and Rigel in Orion
- or, with a telescope look at Alberio

Why the different colors?

HOW DO STARS DIFFER?

They have different:

temperatures (colors)

sizes

masses

compositions

Their brightness in the sky depends on:

how intrinsically bright they are

their distance

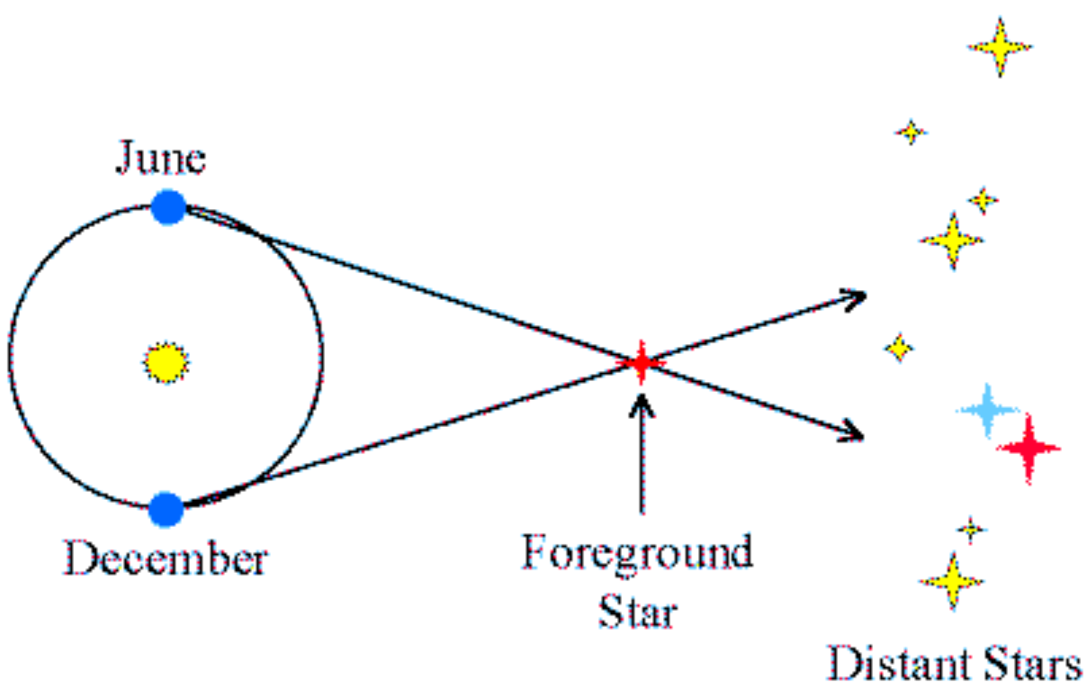
DISTANCE TO STARS

Around 200 billion stars in galaxy

Nearest star (other than Sun) is about 4 light years away

Center of the Galaxy is about 26,000 light years

Get distance to nearest stars using *parallax*

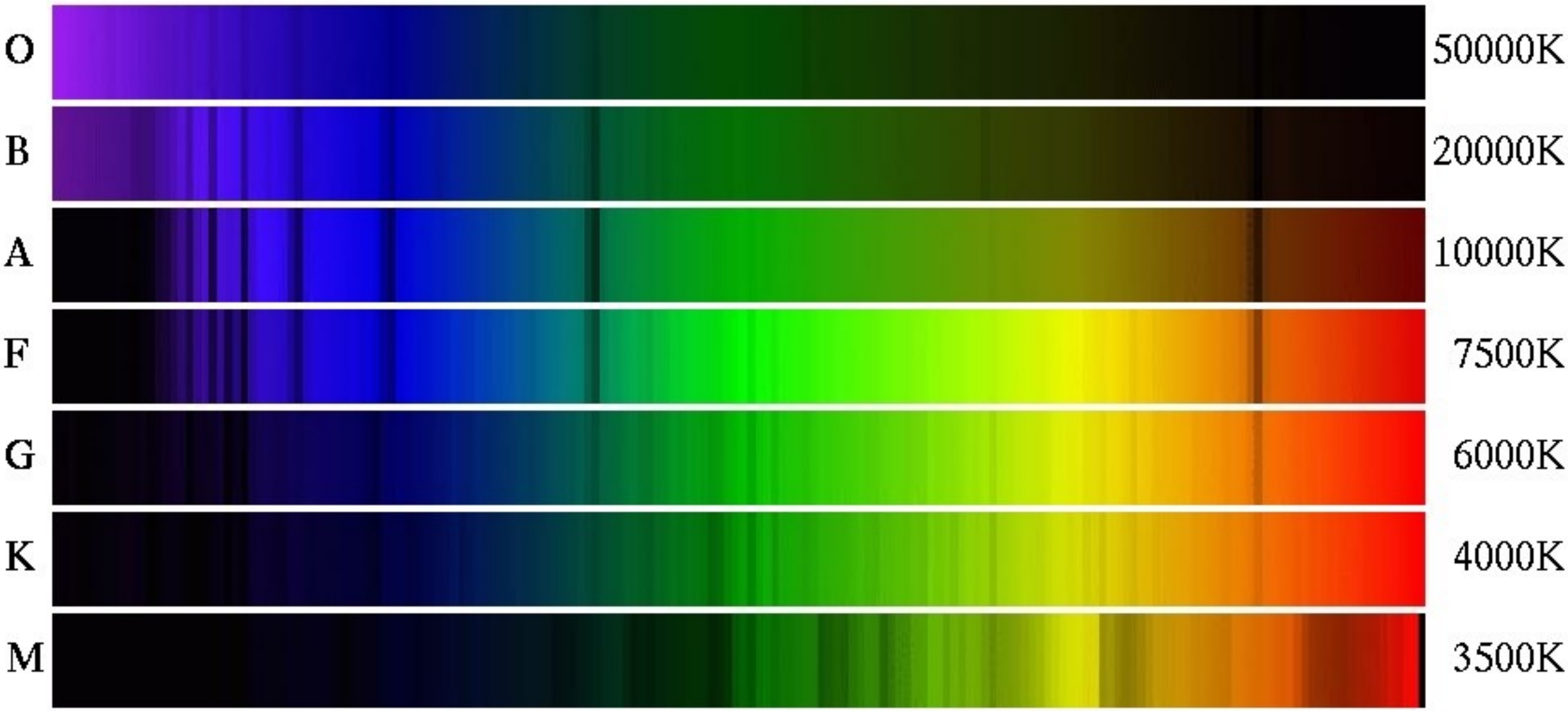


HOW HOT ARE STARS?

Their color tells us their temperature.

Cooler stars are redder, hotter stars are blue/white

We can measure the exact temperature by looking at how much light there is in different colors



HOW BIG ARE STARS?

If we measure the brightness, distance and temperature we can get the radius

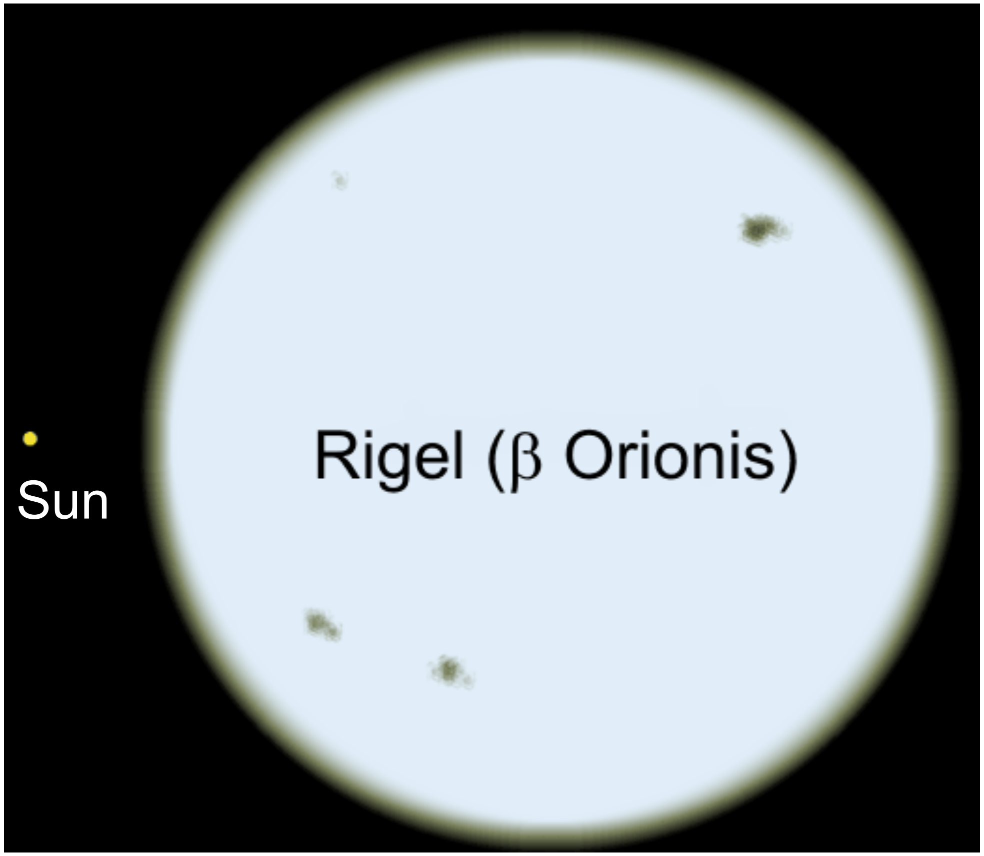
Distance: as you move something away, it gets fainter

Radius: if an object is bigger, it emits more light

HOW BIG ARE STARS?

<u>Radius</u> can range from:

10 km (neutron star) to 1000 times the Sun's radius (supergiant)



<u>Mass</u> can range from:

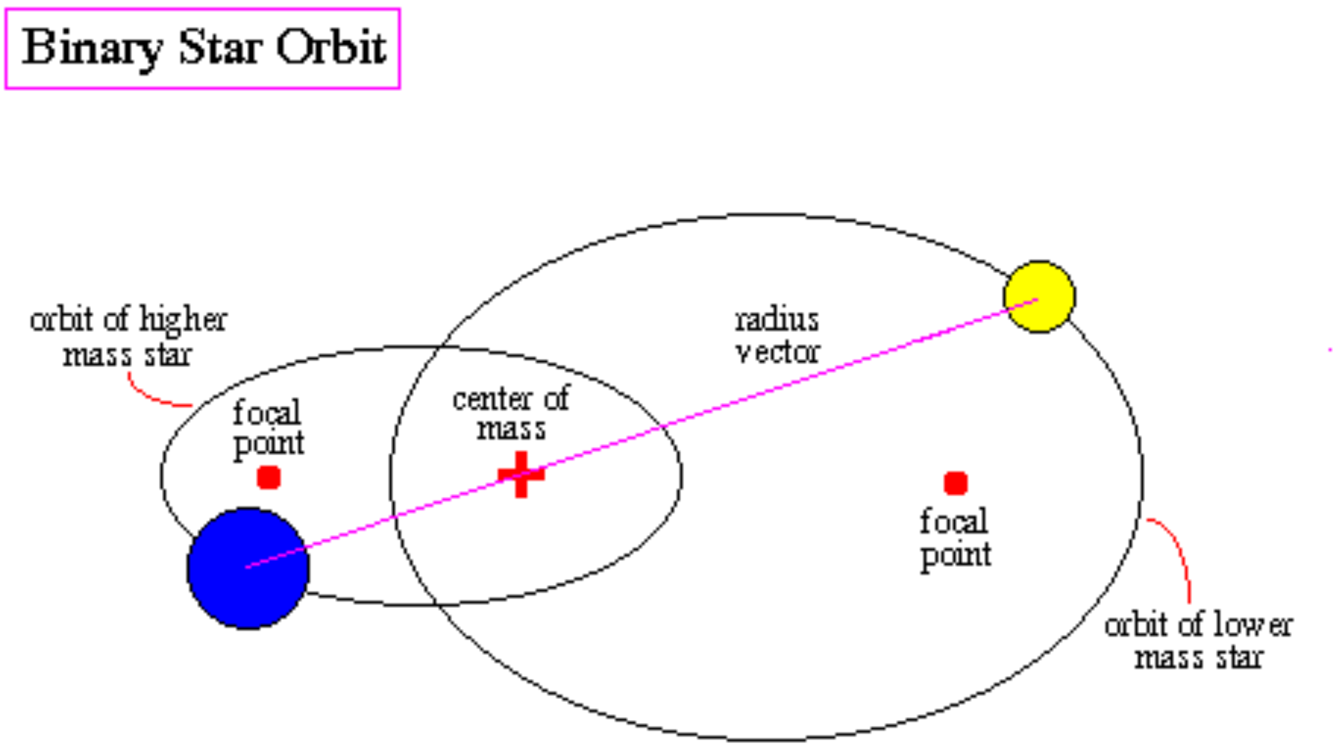
10% of the Sun (red dwarf) to 70 (?) times the Sun (supergiant).

< 0.08 $M_{\odot}$: cannot fuse H - brown dwarf (failed star)

Most stars are in the range 0.2 to 20 $M_{\odot}$

BINARY STARS

Many stars have a companion!



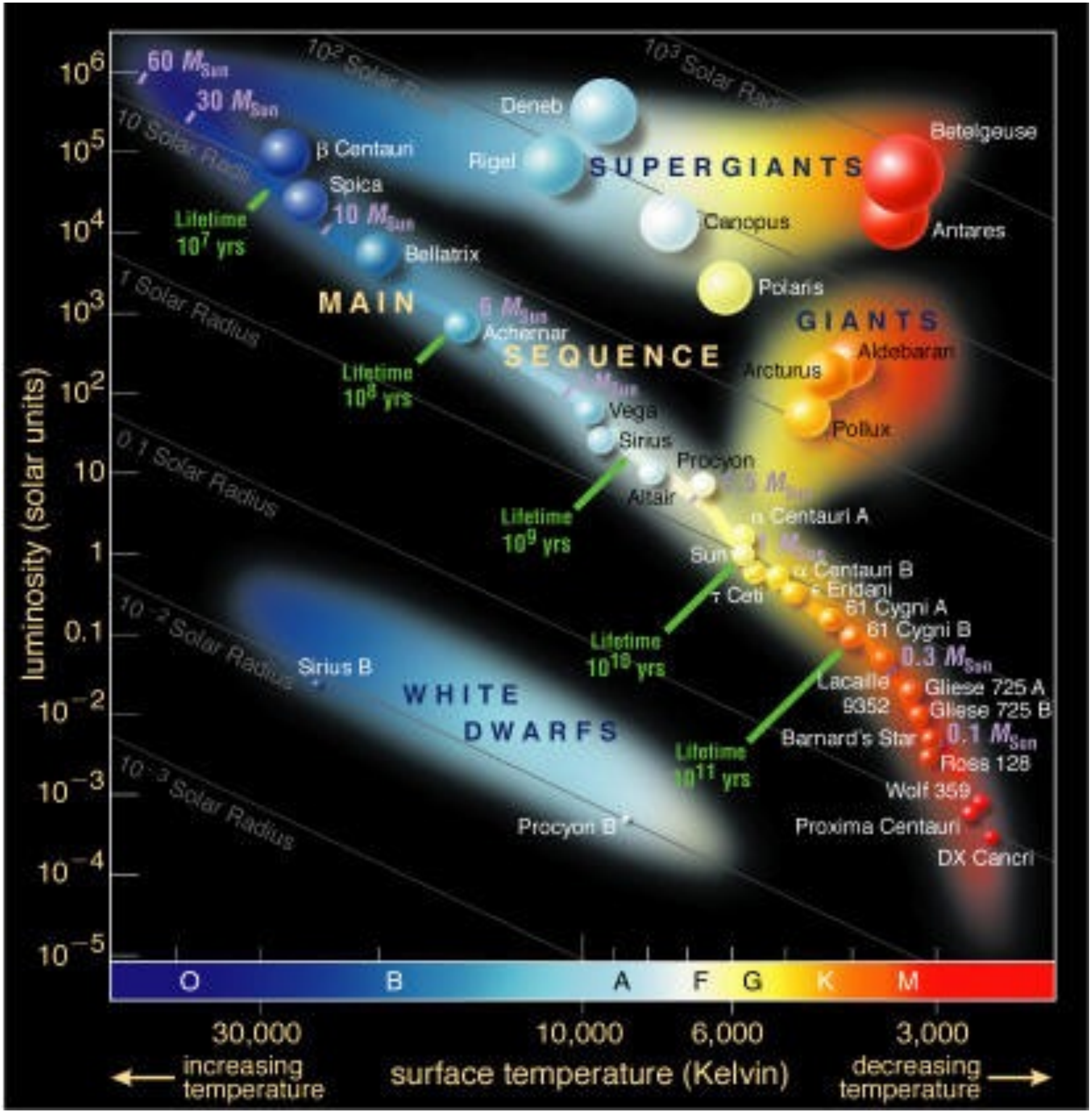
STAR CLASSIFICATION

Classify based on color (temperature) and brightness

O B A F G K M

Blue → Red

Can learn a lot about stars from the Hertzsprung-Russell (HR) diagram



luminosity (solar units)
surface temperature (Kelvin)
increasing temperature
decreasing temperature
30,000
10,000
6,000
3,000
O
B
A
F
G
K
M
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
Aldebaran
Arcturus
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Procyon
Altair
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
Sirius B
Procyon B
60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 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
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
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}

HR DIAGRAM

Stars evolve around the HR diagram as they age.

The position on the HR diagram depends on both the mass and age of a star

Mass is very important **since it determines which nuclear fusion reactions will take place in the center of the star**

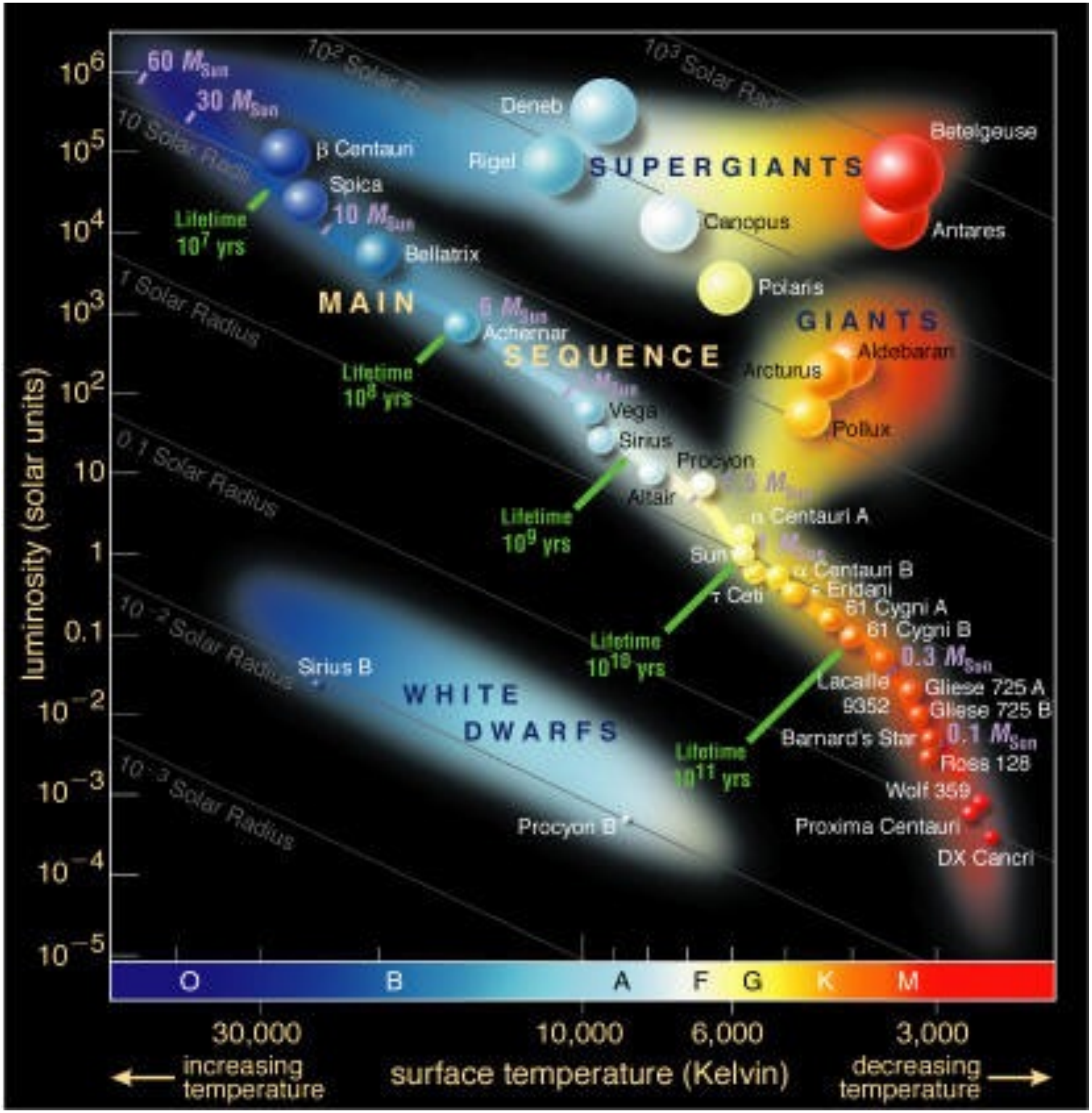
Low-mass stars (< 2 $M_\odot$) only fuse hydrogen

Medium-mass stars (2 $M_\odot$ < M < 8 $M_\odot$) will fuse helium (to C and O) but nothing heavier

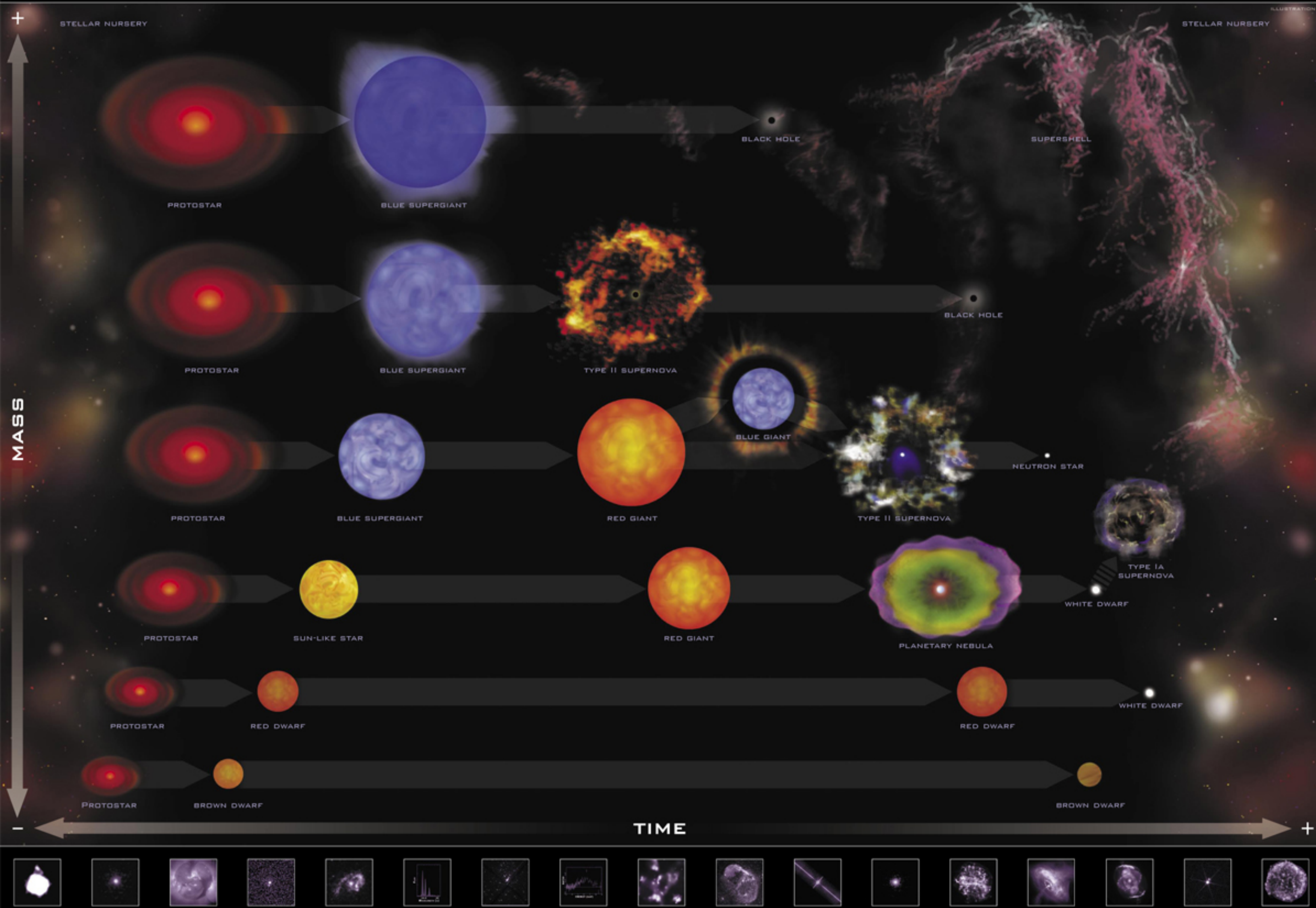
High-mass stars (>8 $M_\odot$) can fuse all the way up to iron

<u>Main sequence:</u> stars that are fusing hydrogen.

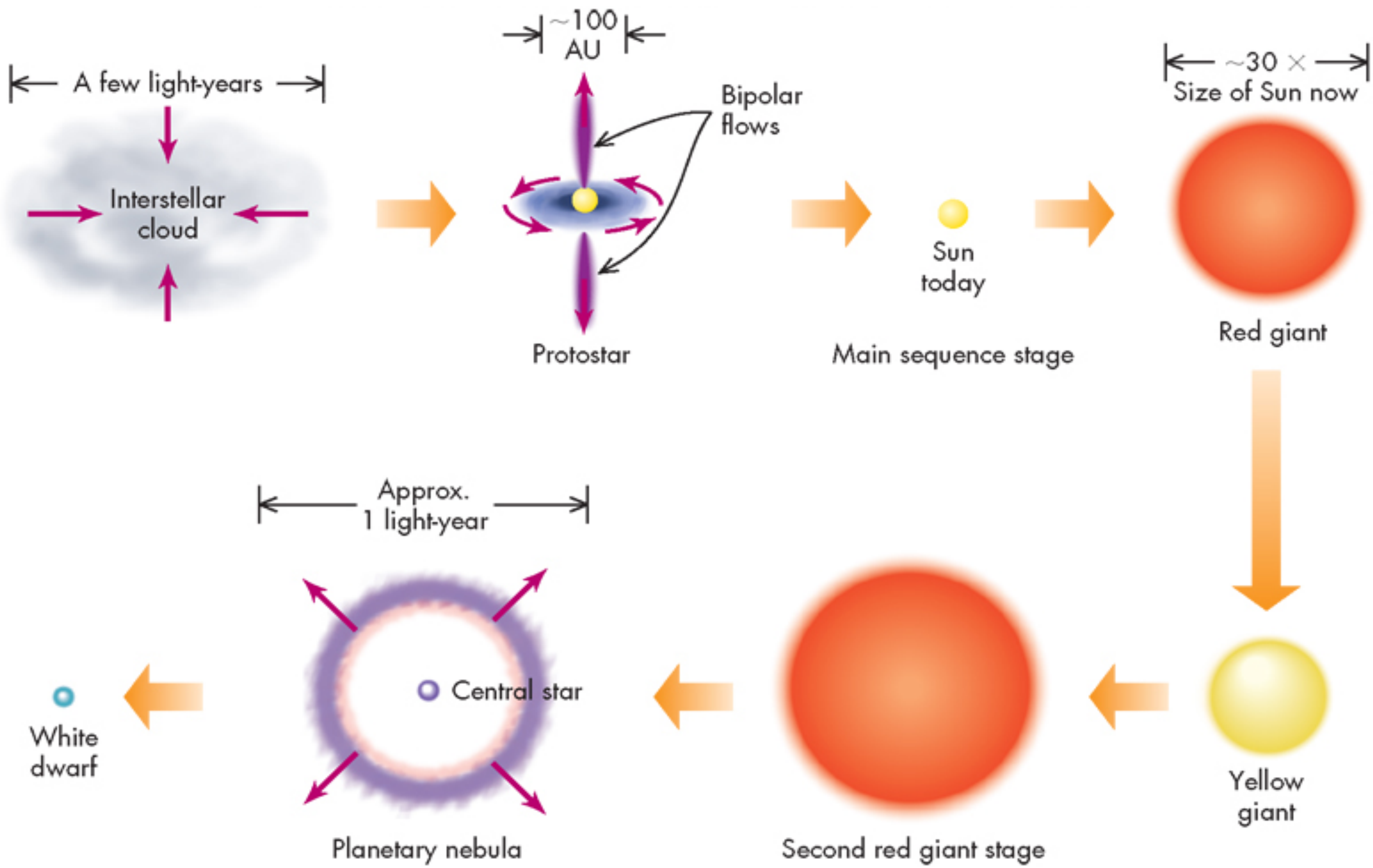
Stars spend ~90% of their lifetime fusing hydrogen. Only move off the main sequence when they run out of hydrogen in their center.


luminosity (solar units)
surface temperature (Kelvin)
increasing temperature
decreasing temperature
30,000
10,000
6,000
3,000
O
B
A
F
G
K
M
60 M_Sun
30 M_Sun
10 M_Sun
6 M_Sun
0.3 M_Sun
0.1 M_Sun
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
10^2 Solar Radii
10^3 Solar Radii
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
β Centauri
Spica
Bellatrix
Achernar
Aldebaran
Arcturus
Pollux
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
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
Sirius B
Procyon B
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs

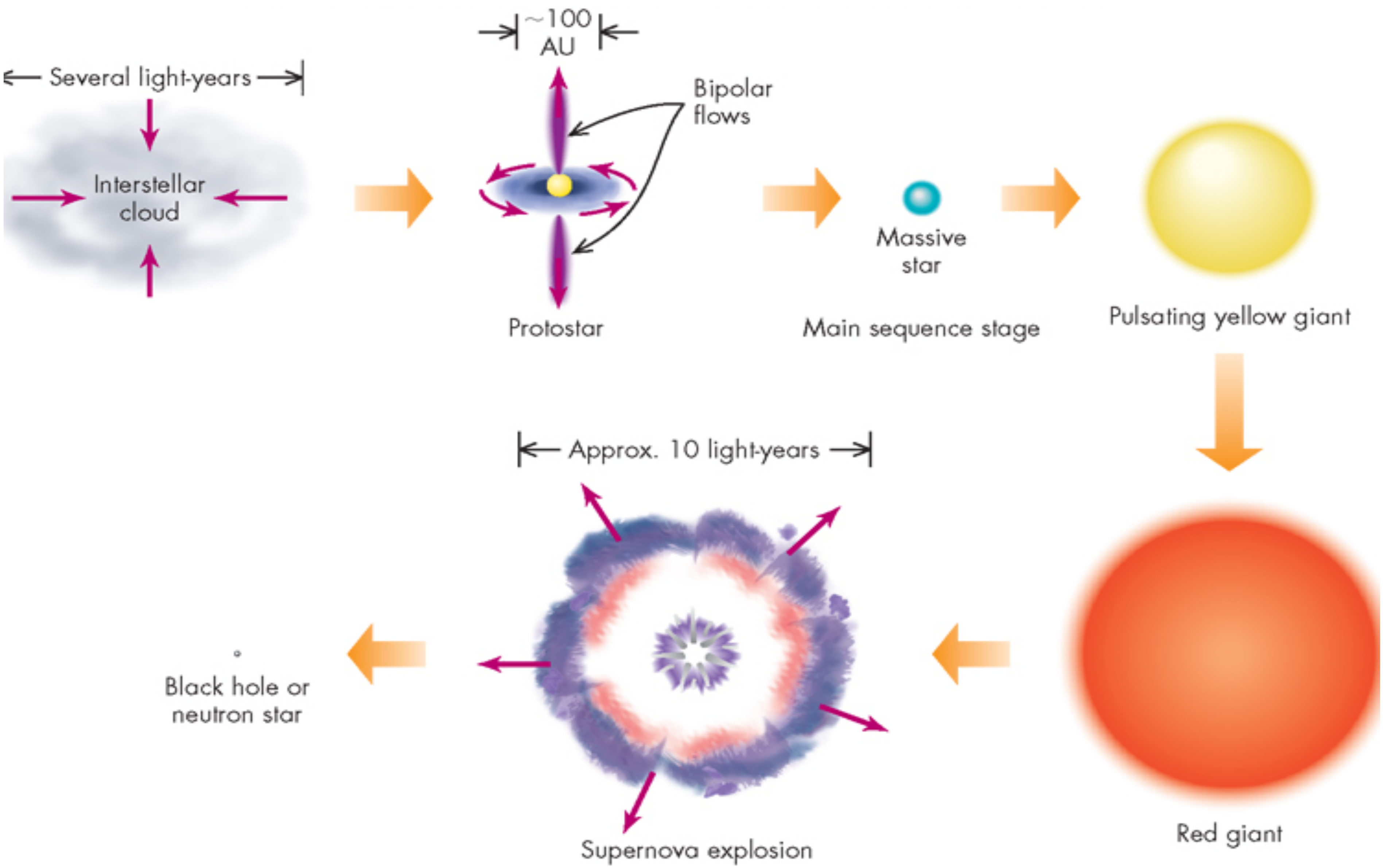
STELLAR EVOLUTION: A JOURNEY WITH CHANDRA



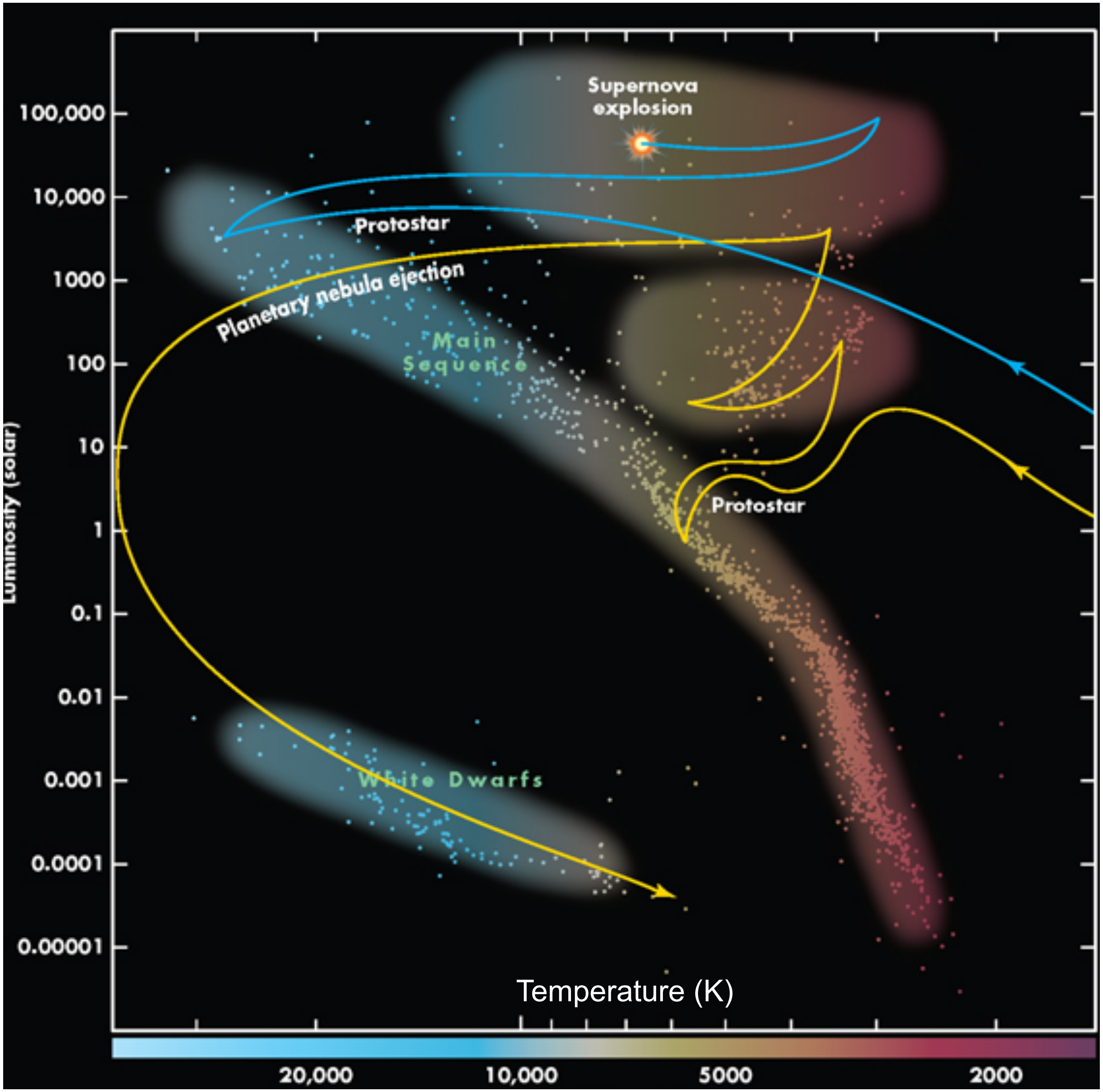
EVOLUTION OF A SUN-LIKE STAR



EVOLUTION OF A MASSIVE STAR



EVOLUTION ON THE HR DIAGRAM



Massive

Sun-like

DEATH OF STARS

For low mass stars, the outer layers of the star get expelled in a ‘planetary nebula’ leaving a dense core that becomes a:

white dwarf

For the most massive stars, they end their life with a supernova explosion, which can leave behind a:

black hole

neutron star

Much more later…….