The Sun

I. **Basic Features**
   Mass, Size, Elemental make-up, 8 major Parts: CRCPCTCW

II. **Quiet Sun**
   Continuous Features, Energy Production, Fusion Rx's

III. **Active Sun**
   Solar Cycle, Sunspots, Transient Features, Magnetic Dynamo

	The student will be able to:	HW:
1	Describe the overall structure of the Sun in terms of its core, radiation zone, convection zone, photosphere, chromosphere, transition zone, corona, and solar wind.	1 – 8
2	Describe the basic properties and composition of each part of the Sun listed above.	
3	Explain and describe granulation and supergranulation.	
4	Explain what is meant by helioseismology and describe how it has yielded information about the Sun's structure.	9, 10
5	Define, explain, and state the approximate values of the solar constant and the Sun's luminosity.	11 – 19
6	Describe mechanisms by which energy is transported from the core of the Sun to its exterior.	
7	Explain the process by which the Sun produces energy – fusion and relate this to the law of conservation of mass and energy and the strong nuclear force.	
8	Describe and explain the steps of the proton-proton chain in terms of reactions involving fundamental and subatomic particles.	
9	Describe efforts to obtain experimental evidence of the fusion process thought to power the Sun including measurements of solar neutrinos.	
10	Compare and contrast the concepts quiet Sun and active Sun.	20 – 23
11	Describe the appearance of sunspots and explain their formation in terms of the Sun's magnetic field.	
12	Define and explain the following concepts: sunspot cycle, solar cycle, solar minimum, and solar maximum.	
13	Describe and explain active regions of the Sun including prominences, and flares, spicules, and coronal mass ejections.	

What ***is*** the Sun?

- For astronomers the Sun is the nearest star – an extremely important subject of study to help us understand *all* stars.
- The Sun is a body of “energized gas” that supplies the bulk of our energy on Earth.
- The Sun is by far the most massive object in our solar system and its gravity holds all planets in orbit.

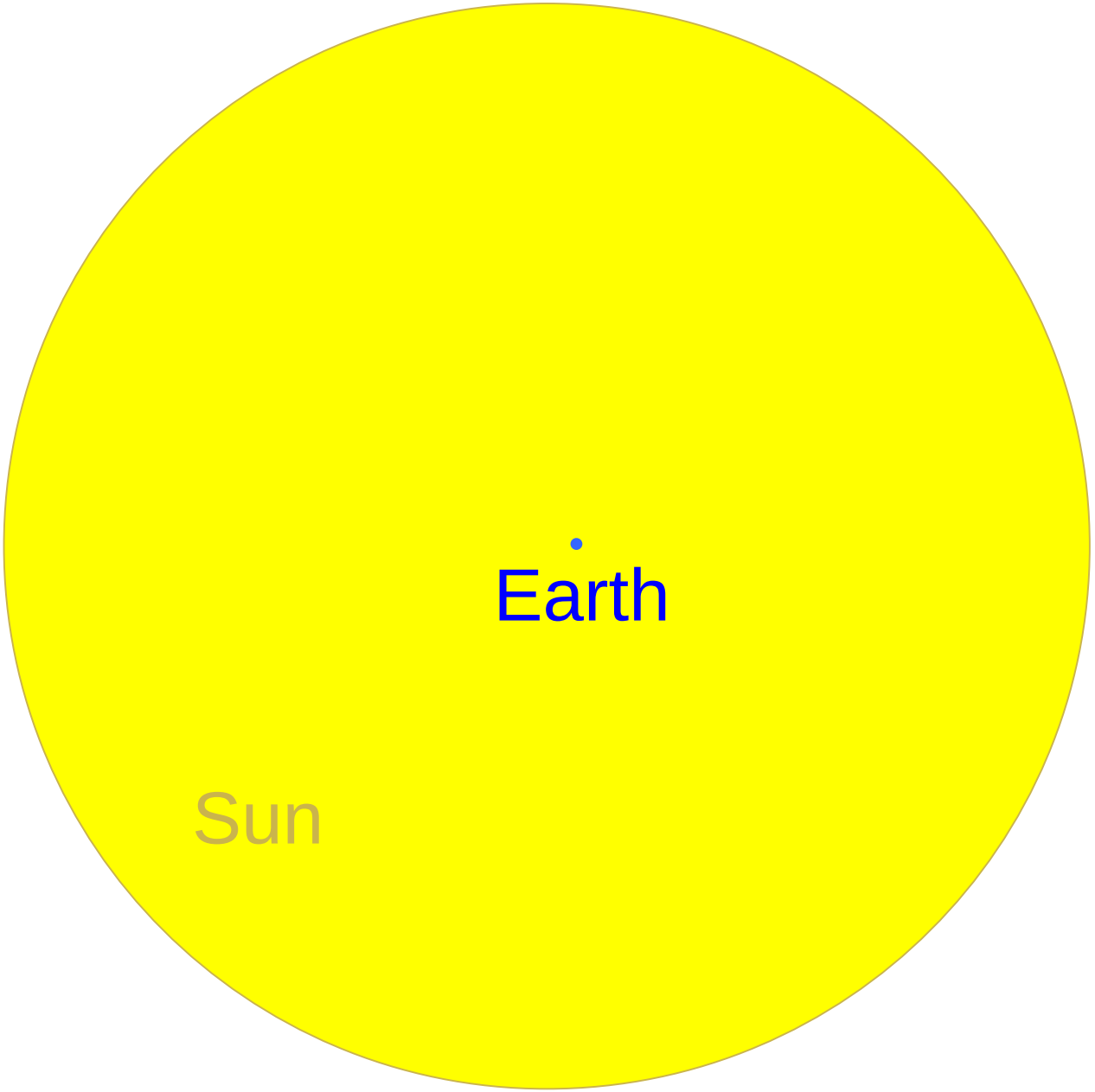
Basic Properties

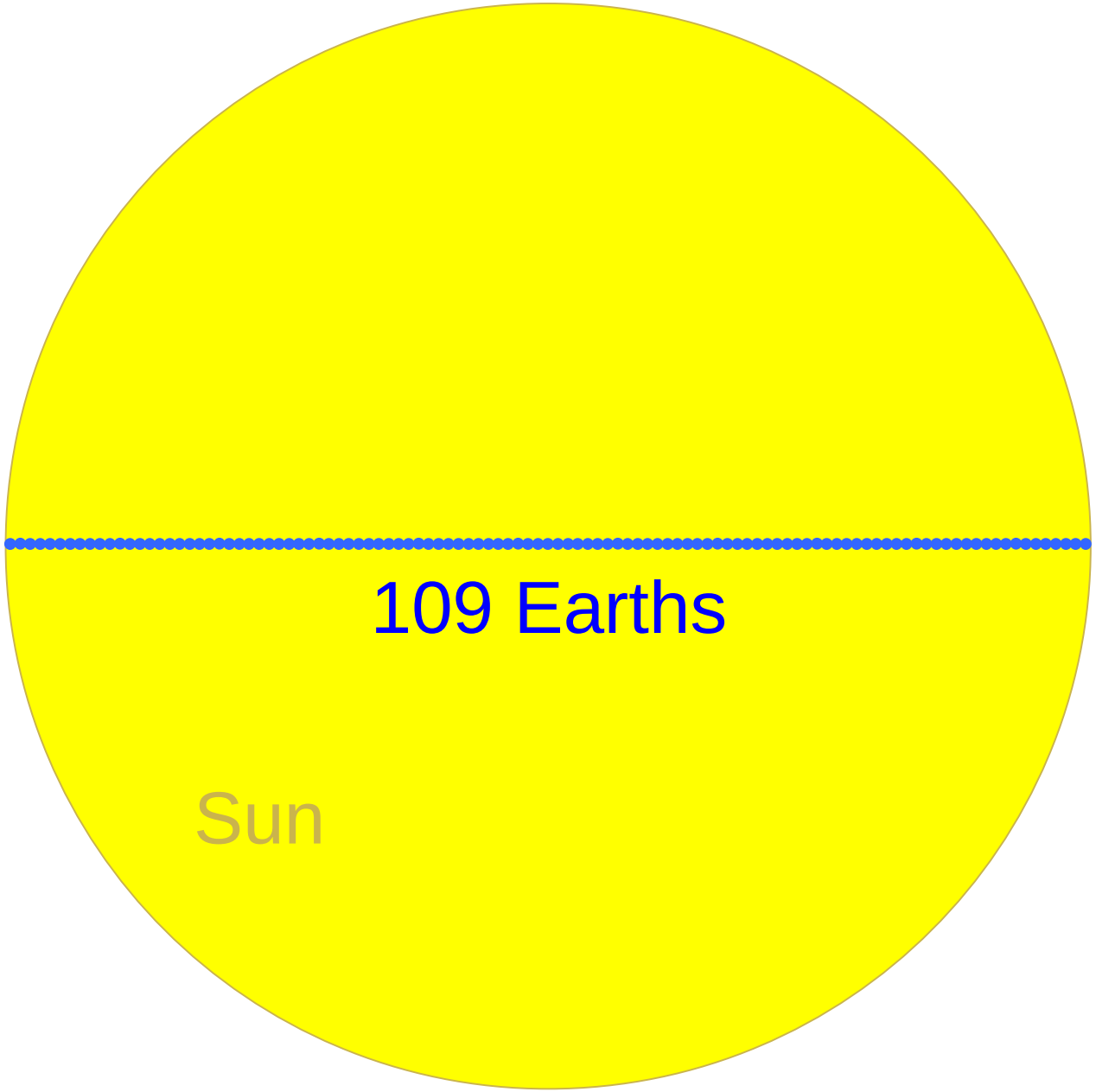
- Diameter = 1.39×10^6 km
- Mass = 1.99×10^{30} kg
- Bulk Density = 1410 kg/m^3
- Effective Temperature = 5800K

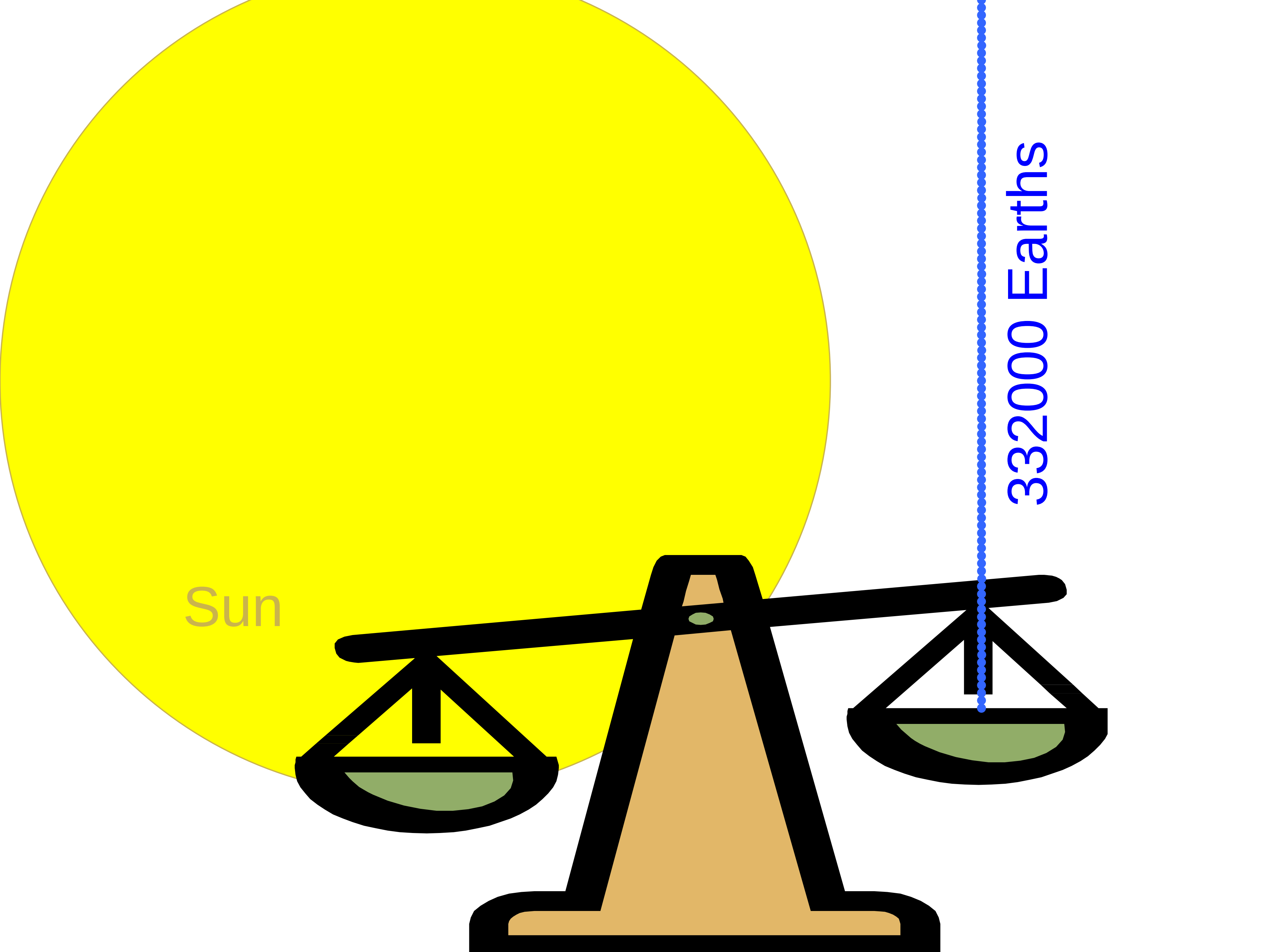
But how can we comprehend these values?

Basic Properties

- Diameter = 1.39×10^6 km
- Mass = 1.99×10^{30} kg
- Bulk Density = 1410 kg/m^3
- Relative to Earth the Sun is 109 times the diameter, 332000 times the mass.
- In terms of volume, the Sun could hold 1.3 million Earths!
- Density is similar to Jupiter's (1330 kg/m^3) but much less than Earth's (5520 kg/m^3). (Water: 1000 kg/m^3; Honey: 1420 kg/m^3)

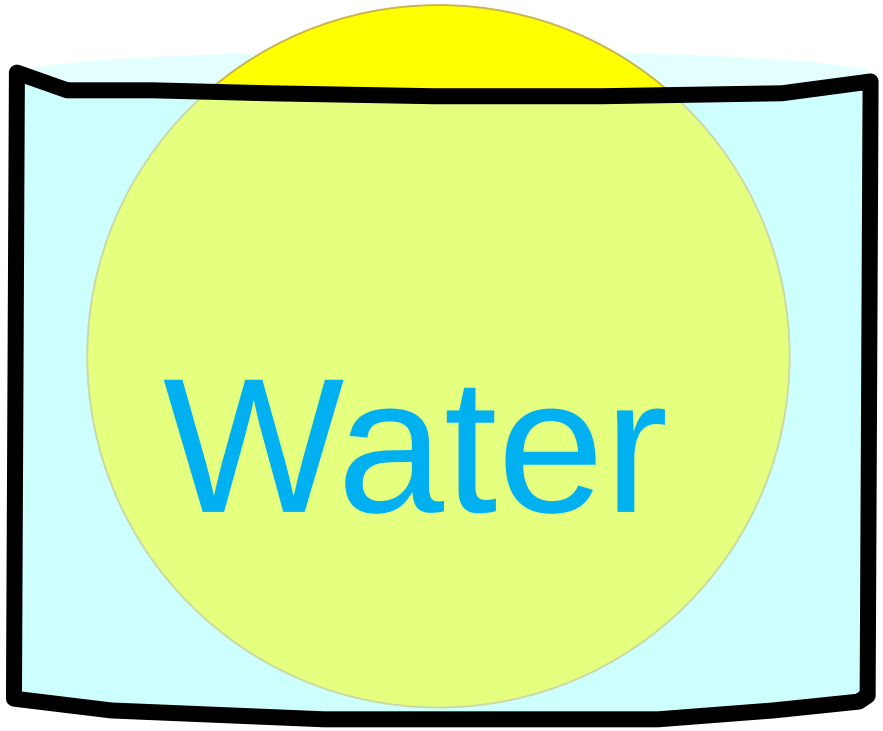


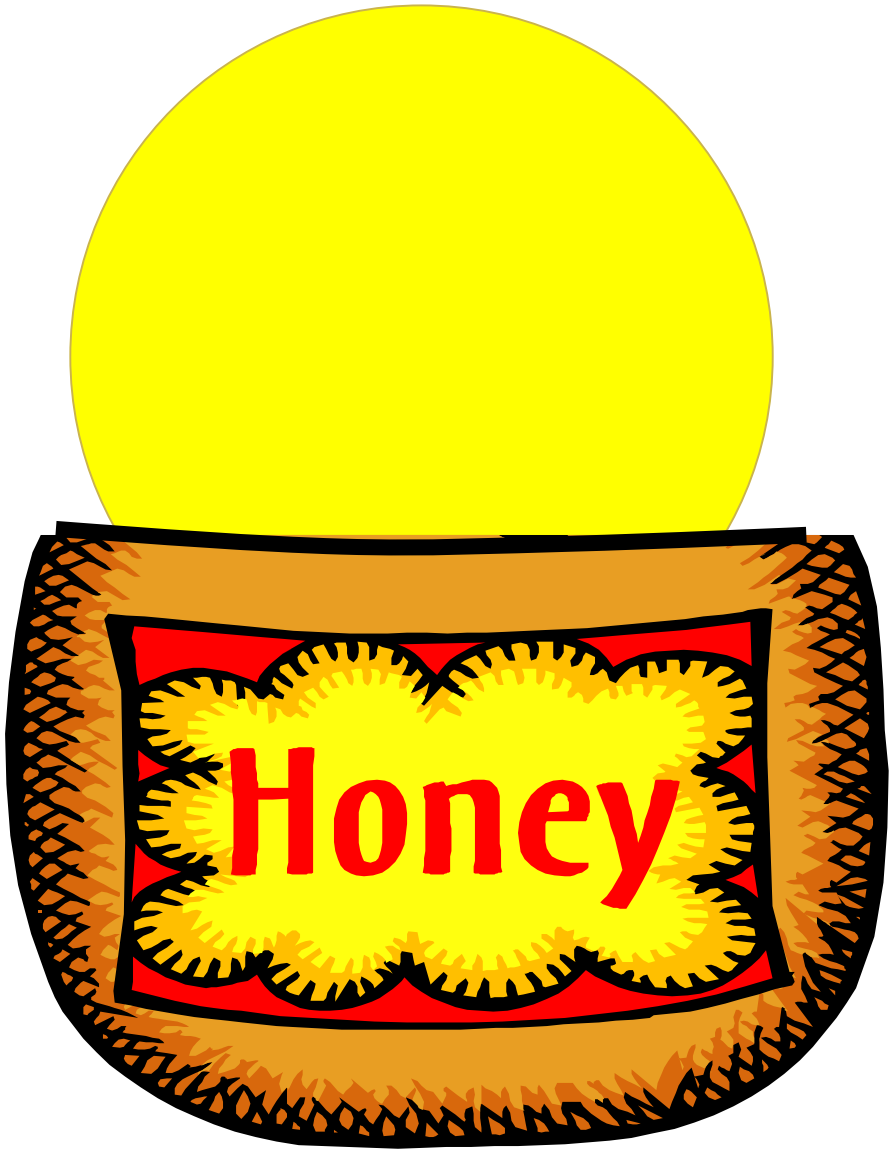



Sun
332000 Earths

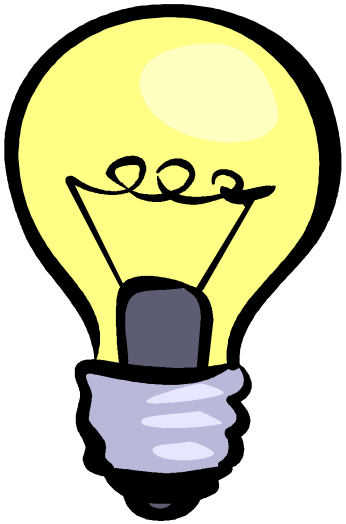
a little less dense than honey

denser than water



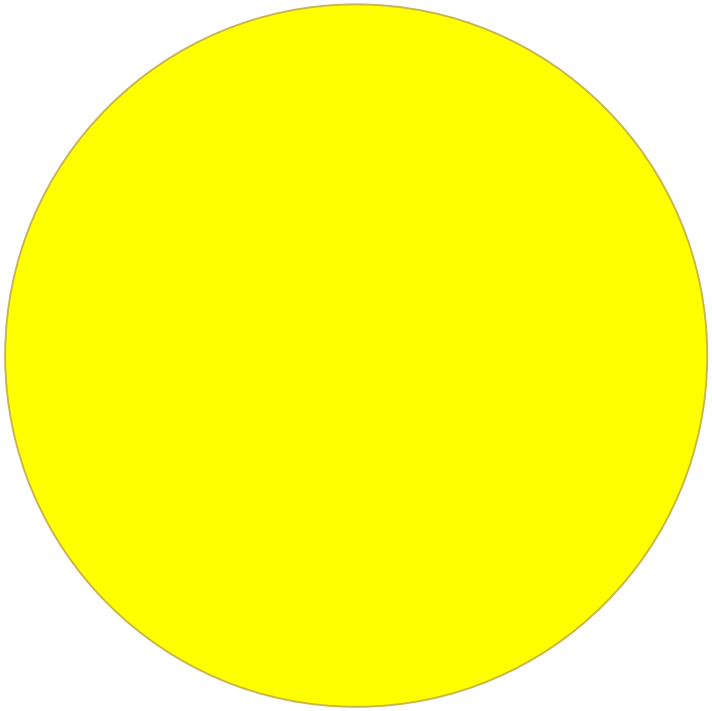


incandescent filament



3000 K

surface of Sun



6000 K

lightning bolt

30000 K

What is the Sun made of?

	% atoms	% mass
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

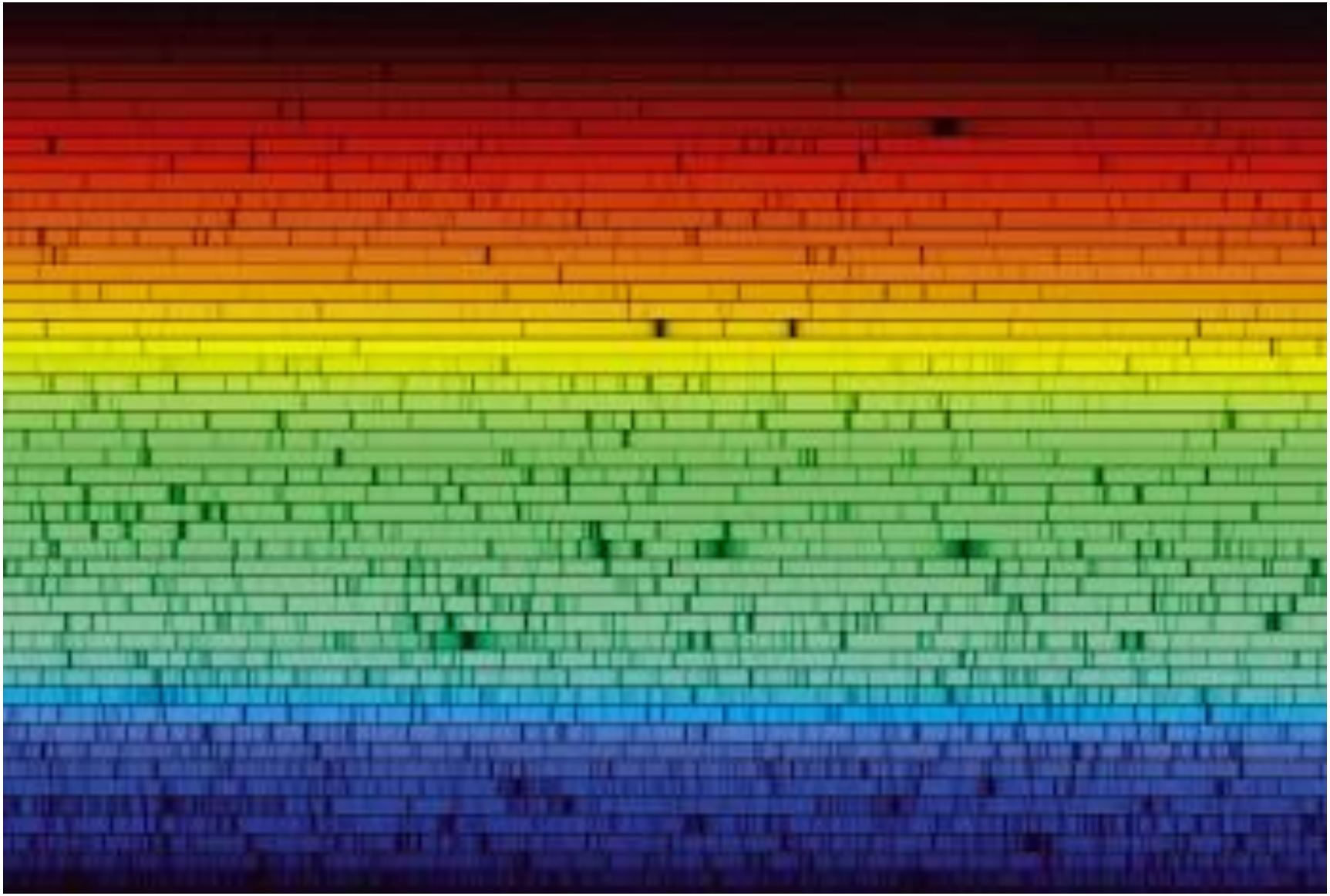
At least 67 different elements have been identified in the Sun – there are probably more!

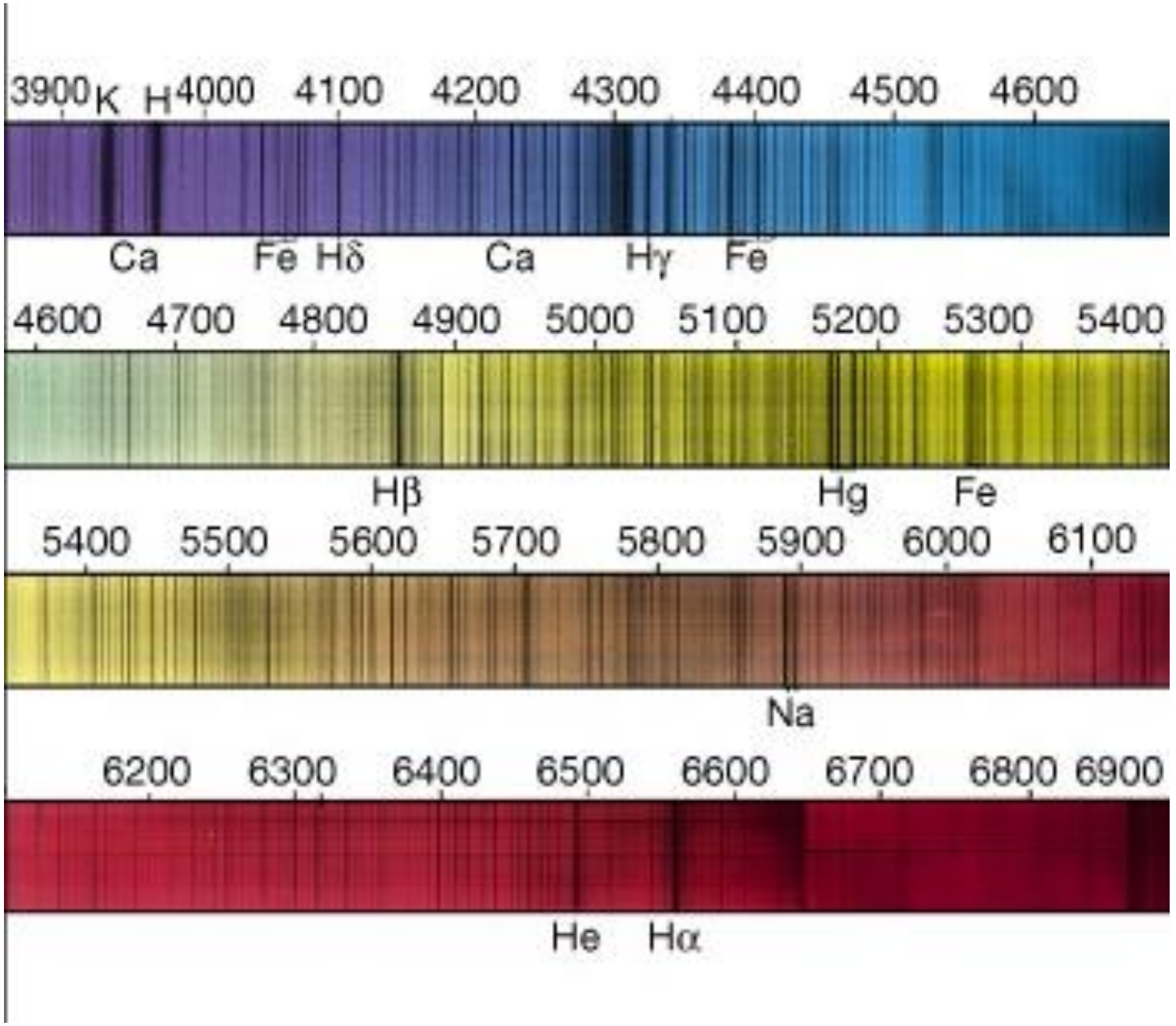
Because the Sun is so huge, even a small percentage of it is a large amount. Example: find the total number of kg of iron in the Sun (0.14% of its mass).

Total iron in Sun = 2.8×10^{27} kg

(466 Earth masses! 1.5 Jupiter masses!)

Fraunhofer Lines



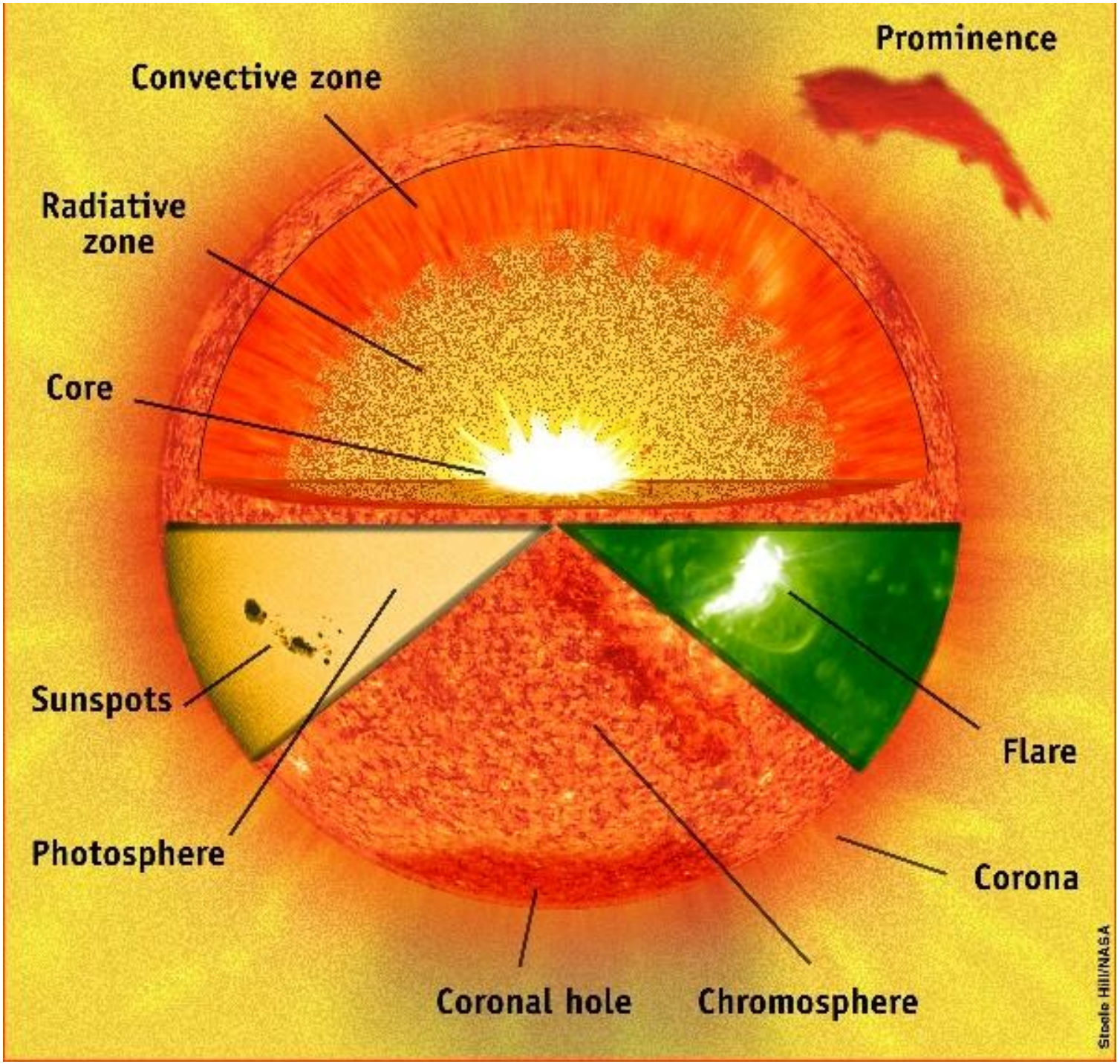

3900 K H 4000 4100 4200 4300 4400 4500 4600
Ca Fe Hδ Ca Hγ Fe
4600 4700 4800 4900 5000 5100 5200 5300 5400
Hβ Hg Fe
5400 5500 5600 5700 5800 5900 6000 6100
Na
6200 6300 6400 6500 6600 6700 6800 6900
He Hα

Notes on Spectral Lines

- The sun emits all colors of visible light except its spectrum reveals dark line absorption features.
- The dark lines are referred to as Fraunhofer lines, honoring the scientist that first analyzed the properties.
- A simple model is to assume the photosphere of the Sun emits a continuous blackbody spectrum and then cooler higher layers of gas in the chromosphere absorb certain outward bound photons.

Notes on Spectral Lines

- Helium's spectral lines were observed in the Solar spectrum before helium was ever discovered on Earth! (Hence the name)
- "Coronium" was thought to be another mysterious substance in the Sun as implied by odd spectral lines in the light of the corona (observed during total eclipse).
- It was later determined that these lines were from highly ionized iron atoms in the corona at very high temperatures.


Prominence
Convective zone
Radiative zone
Core
Sunspots
Photosphere
Flare
Corona
Coronal hole
Chromosphere
Steele Hill/NASA

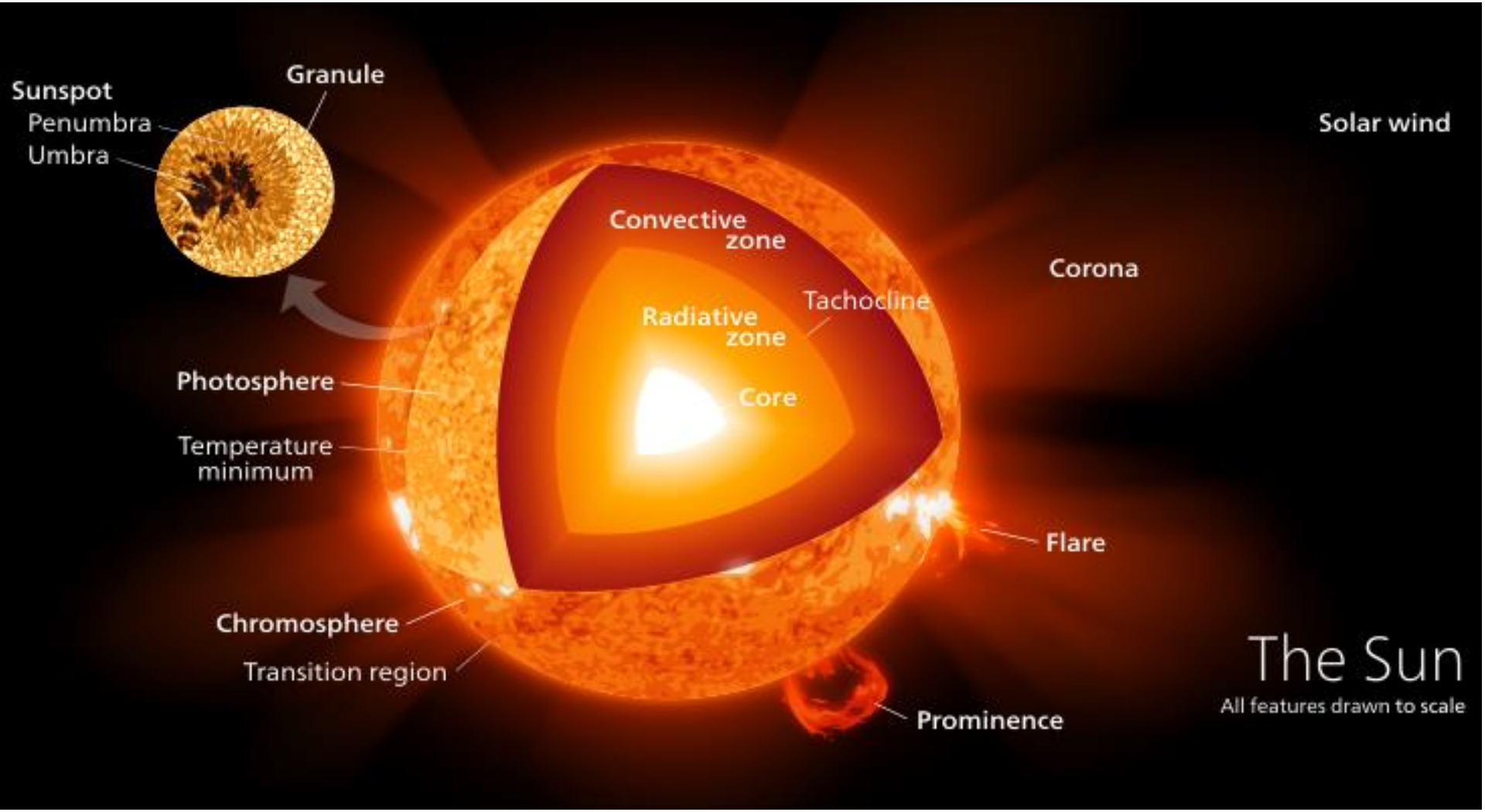
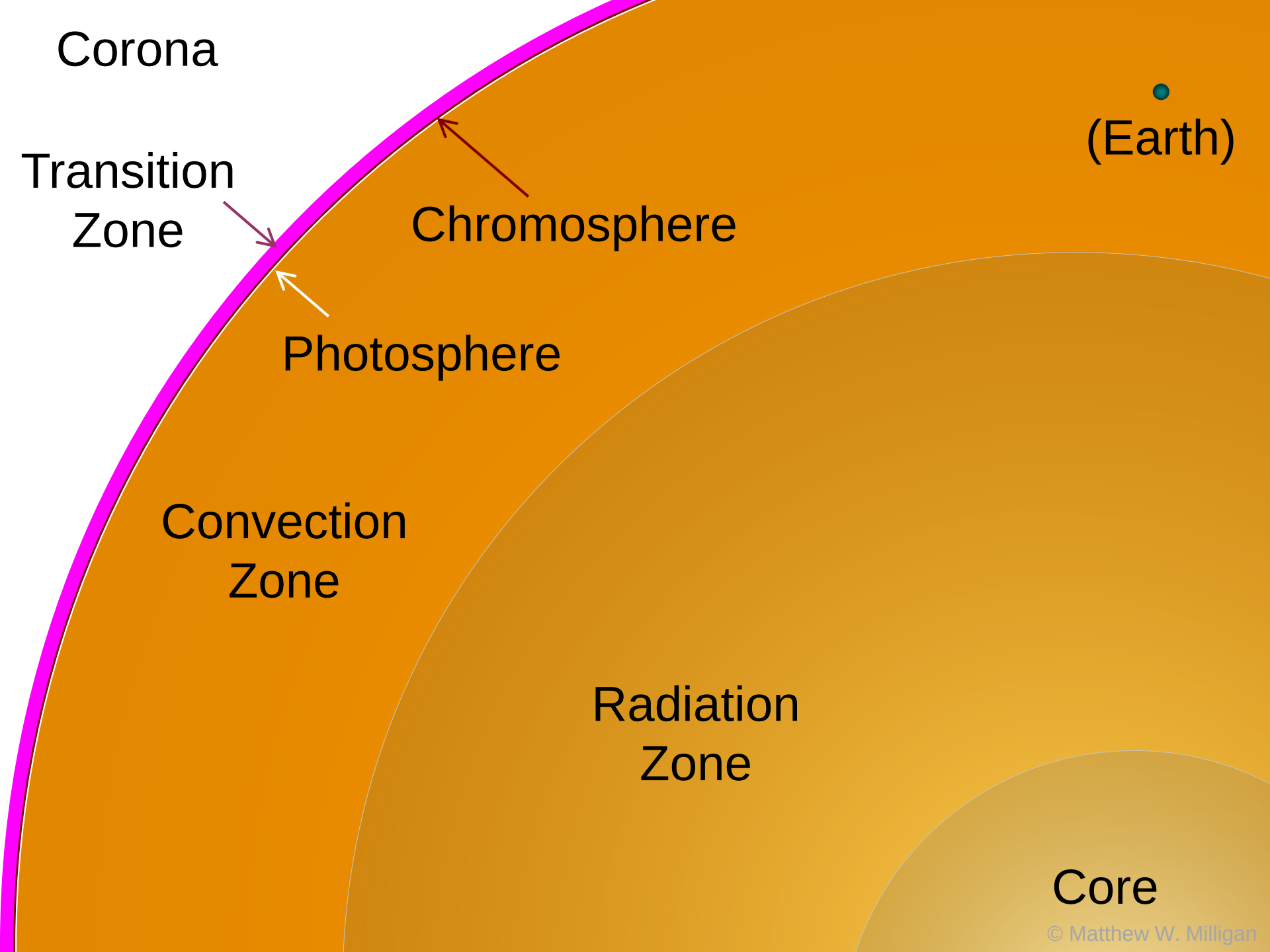
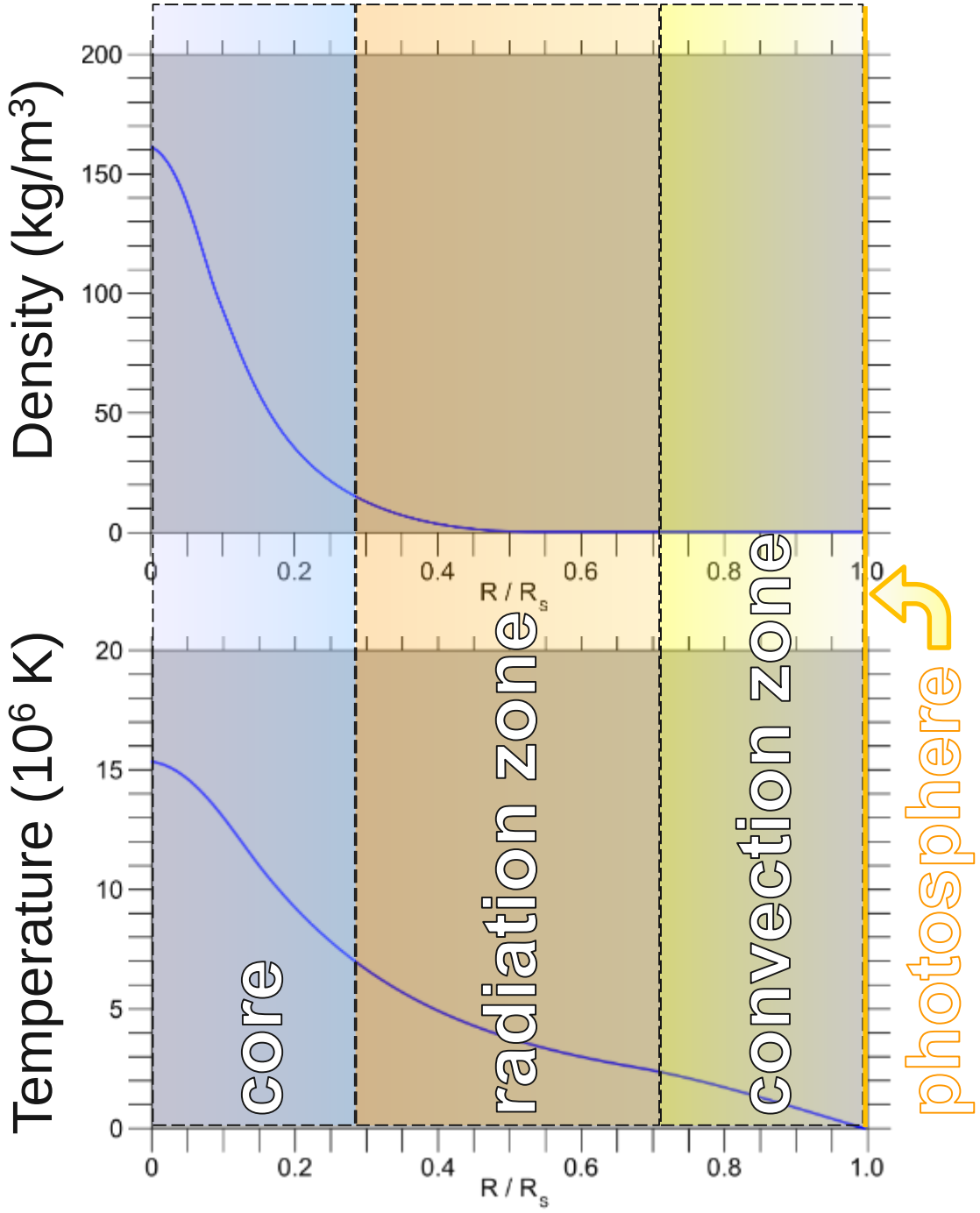


image: Kelvin Ma, Wikipedia



	Defining Properties
Core	Energy produced by fusion
Radiation Zone	Energy transport by EMR
Convection Zone	Energy transport by convection
Photosphere	Radiates visible light into space
Chromosphere	Coolest part, reddish color
Transition Zone	Temperature transition
Corona	Pale “crown-like” atmosphere
Solar Wind	Energetic particles escaping Sun

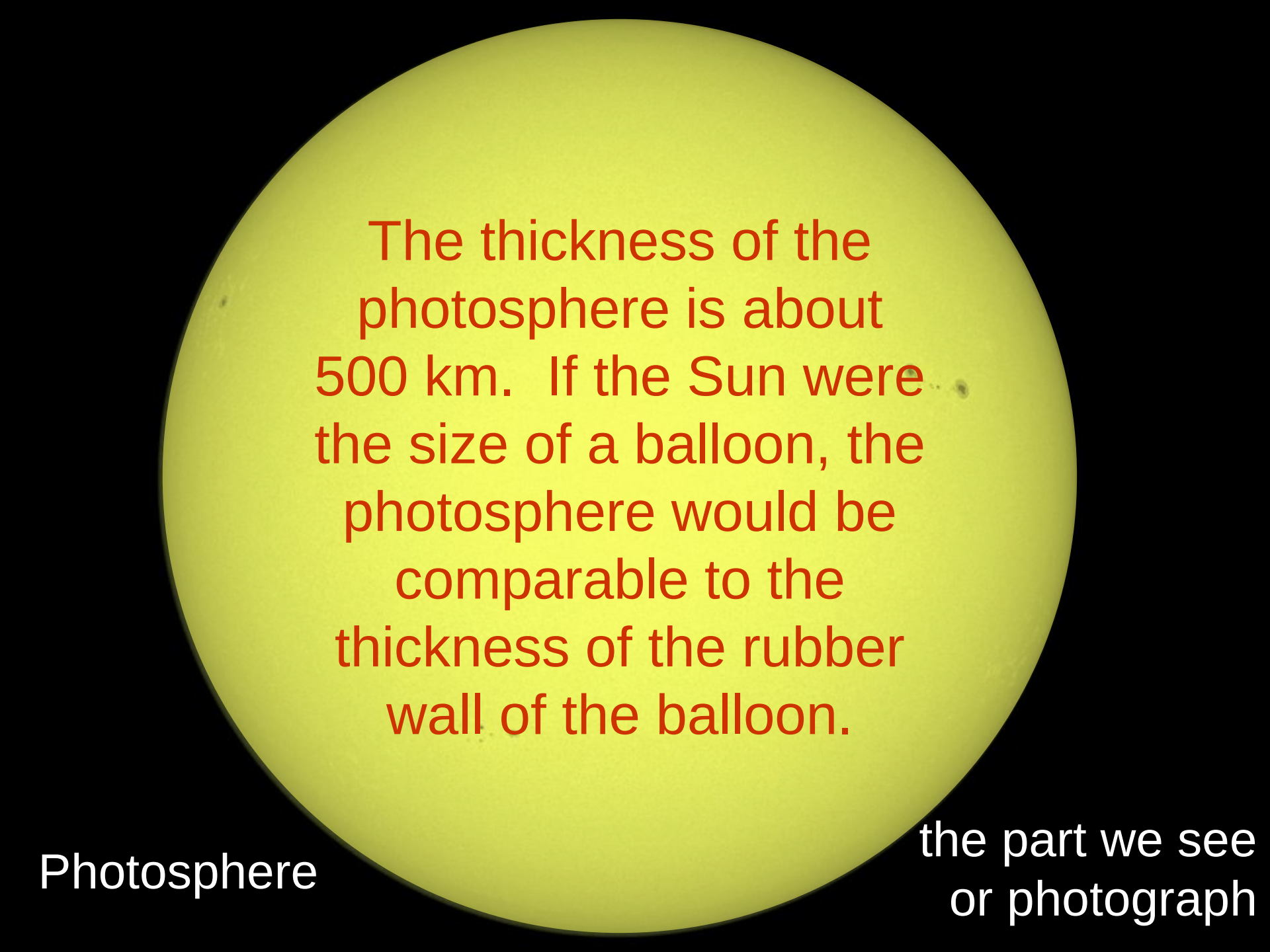
	Temperature (K)	Density (kg/m^3)
Core	15,000,000	150,000
Radiation Zone	7,000,000	15,000
Convection Zone	2,000,000	150
Photosphere	5800	2×10^{-4}
Chromosphere	4500	5×10^{-6}
Transition Zone	8000	2×10^{-10}
Corona	1,000,000	10^{-12}
Solar Wind	2,000,000	10^{-23}

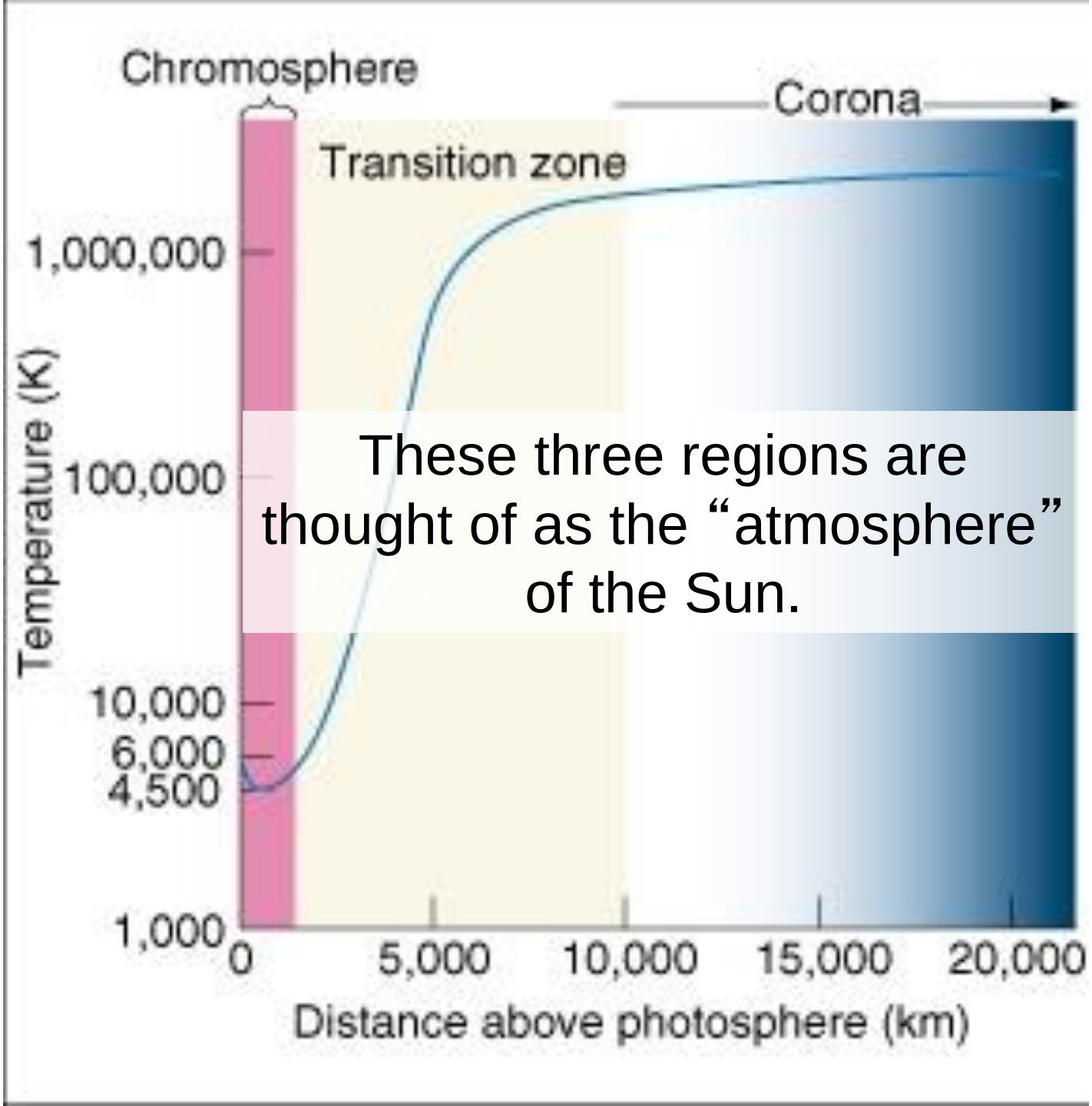


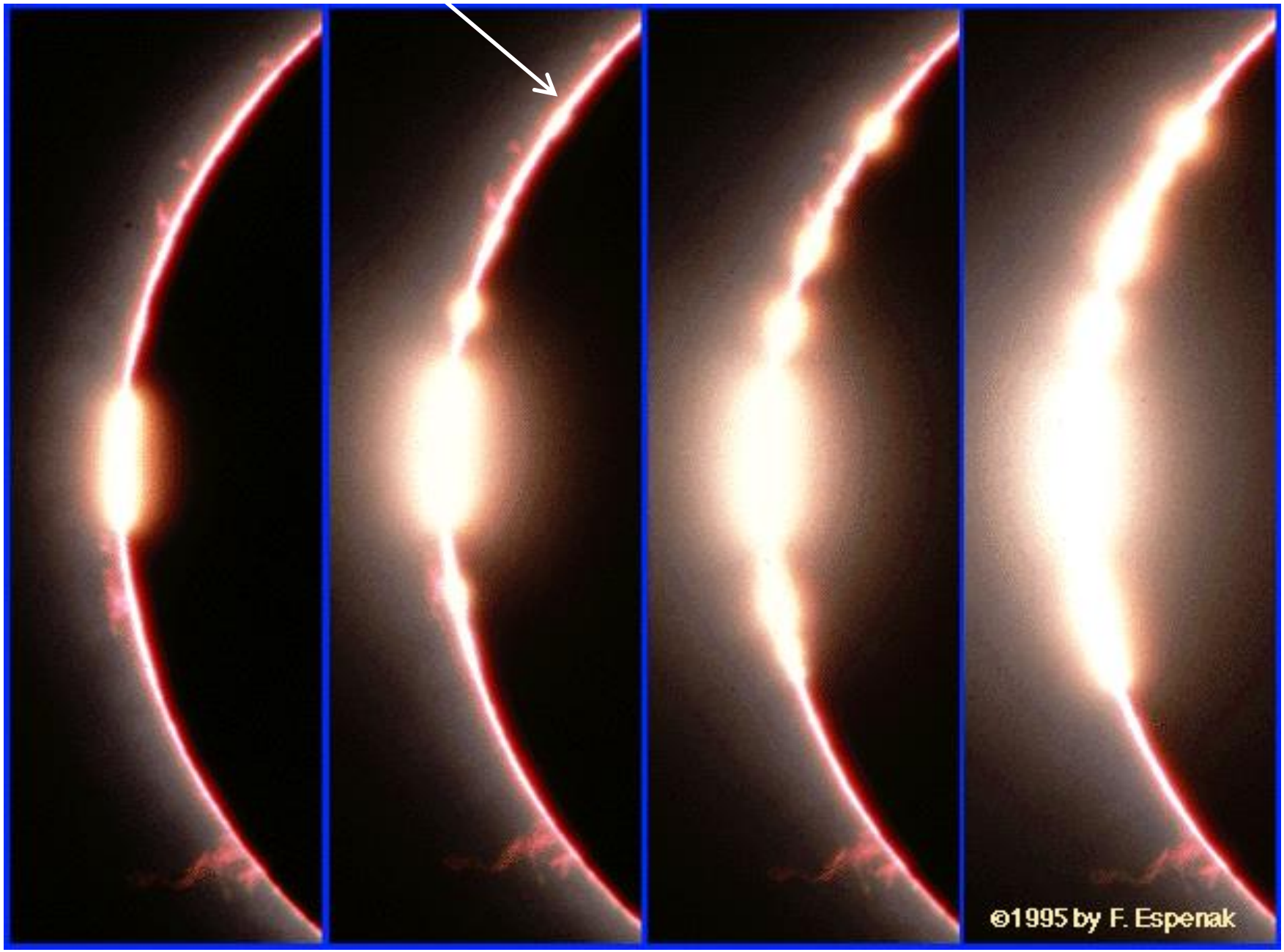
These four layers are thought of as the "body" of the Sun – the photosphere being the "surface".

However, the Sun has no solid or liquid parts – it is entirely made of matter in the plasma phase – an "energetic gas".

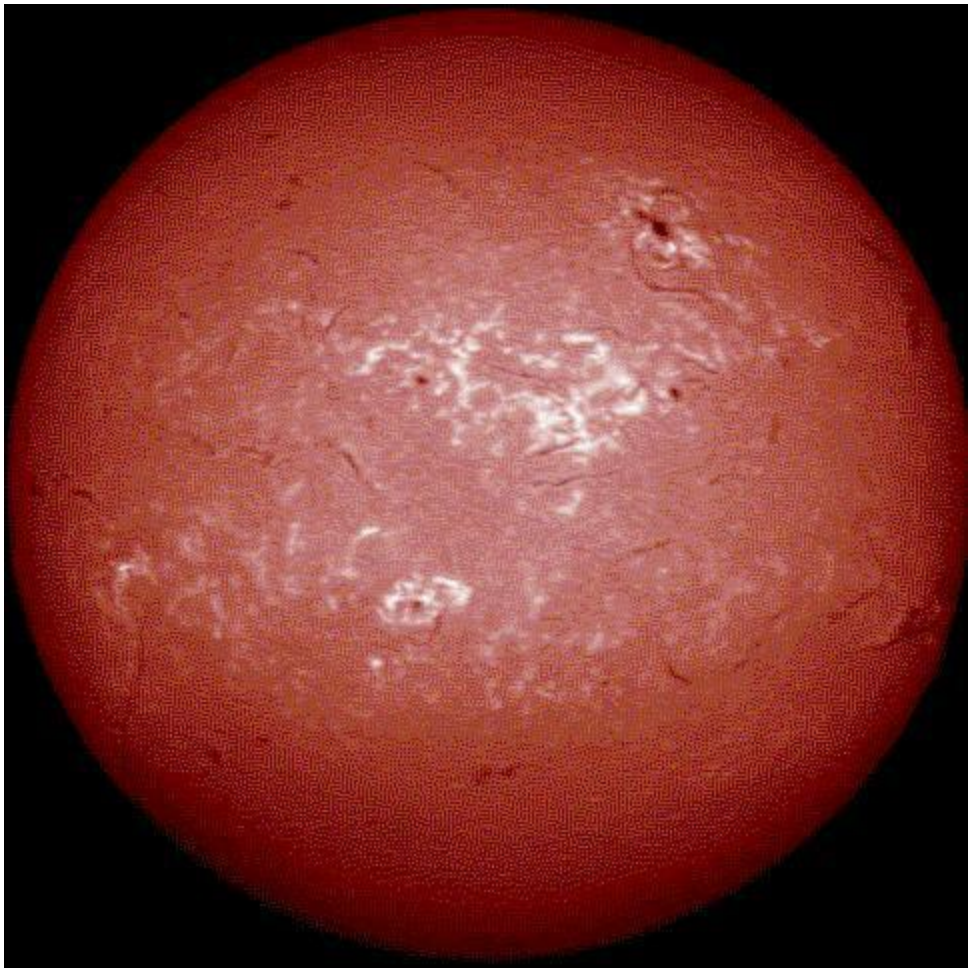
graphs: Michael Oestreicher, Wikipedia

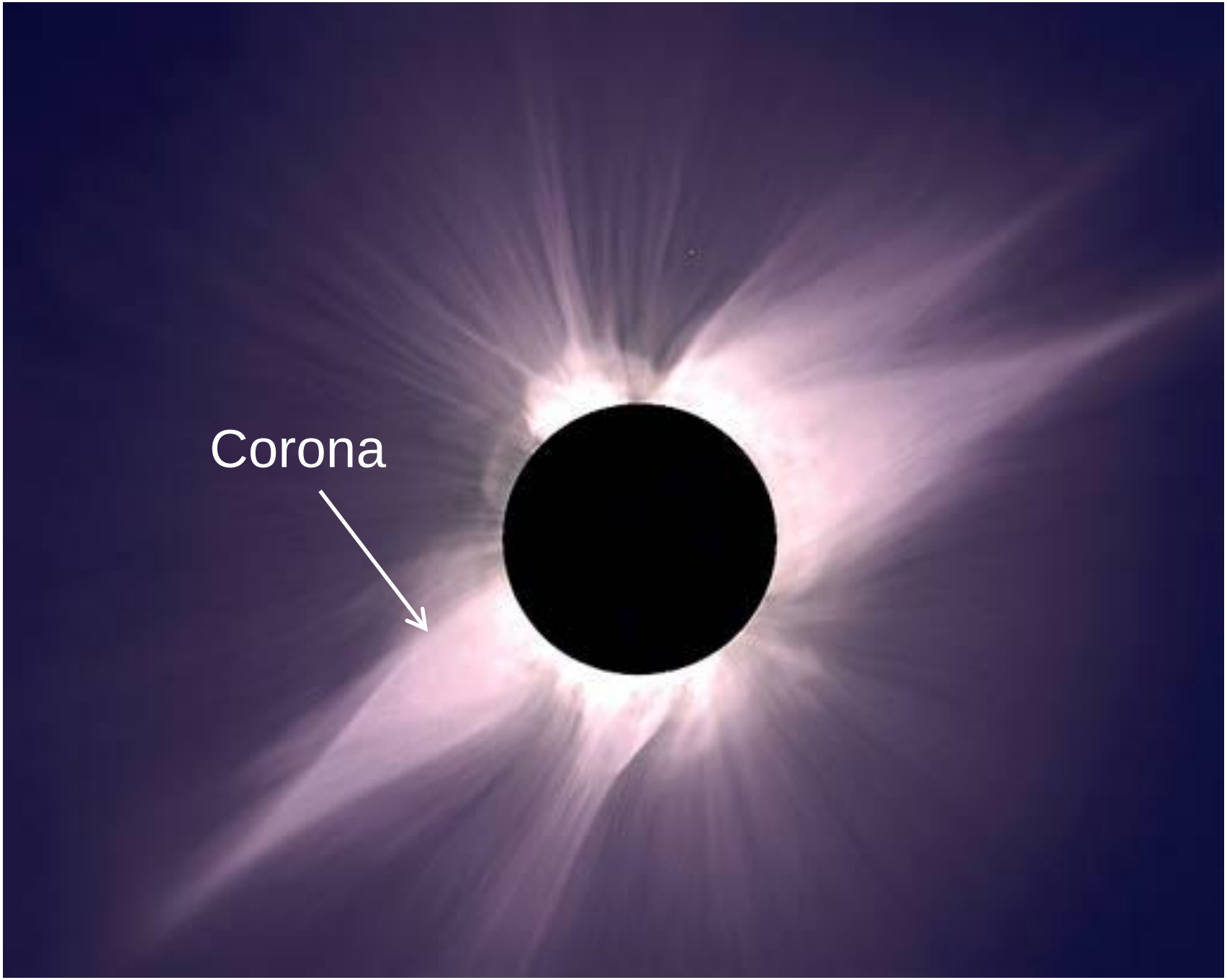

The thickness of the photosphere is about 500 km. If the Sun were the size of a balloon, the photosphere would be comparable to the thickness of the rubber wall of the balloon.
Photosphere
the part we see or photograph

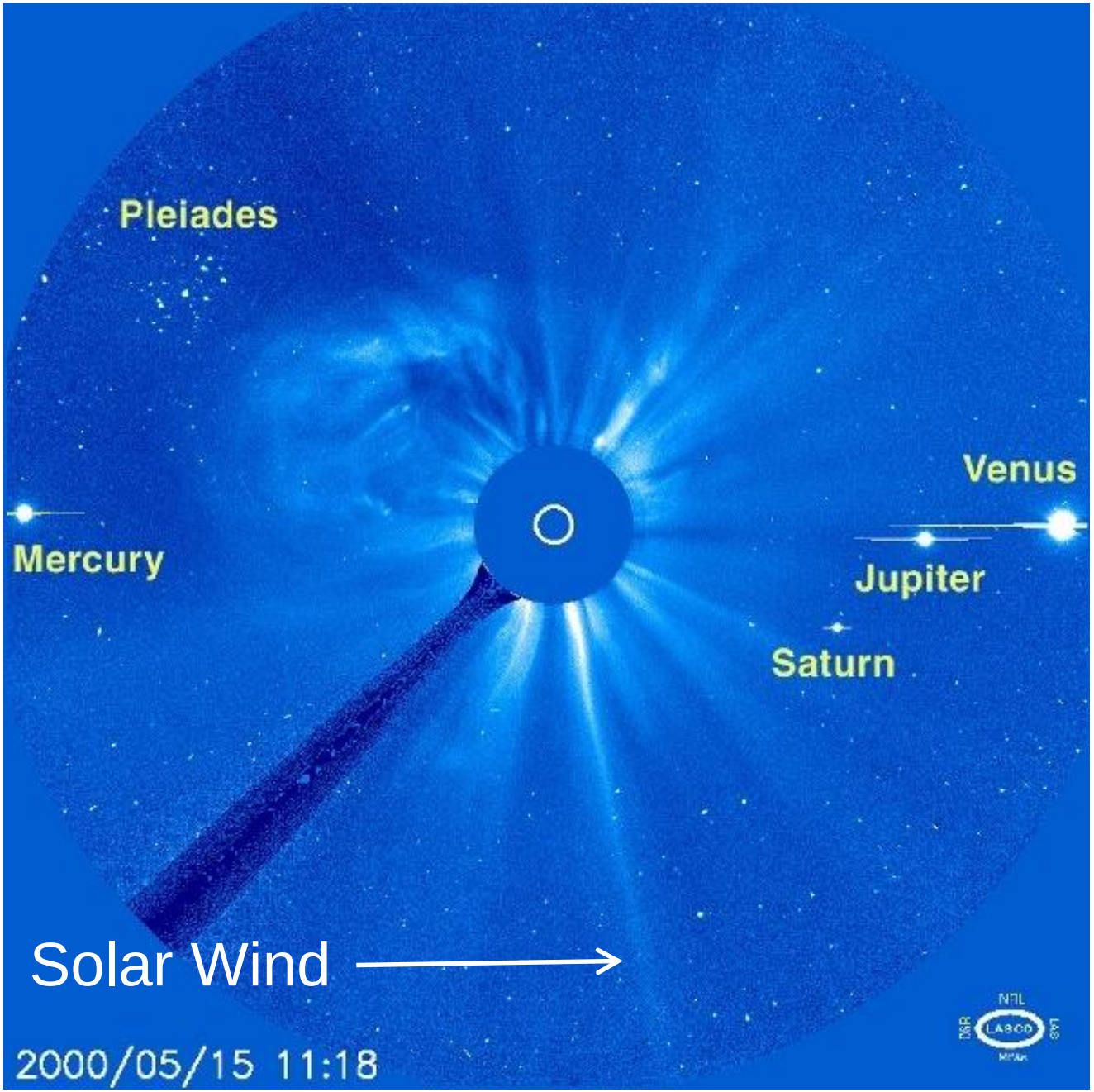

Chromosphere
Corona
Transition zone
1,000,000
100,000
10,000
6,000
4,500
1,000
Temperature (K)
0
5,000
10,000
15,000
20,000
Distance above photosphere (km)
These three regions are thought of as the “atmosphere” of the Sun.


Chromosphere
©1995 by F. Espenak

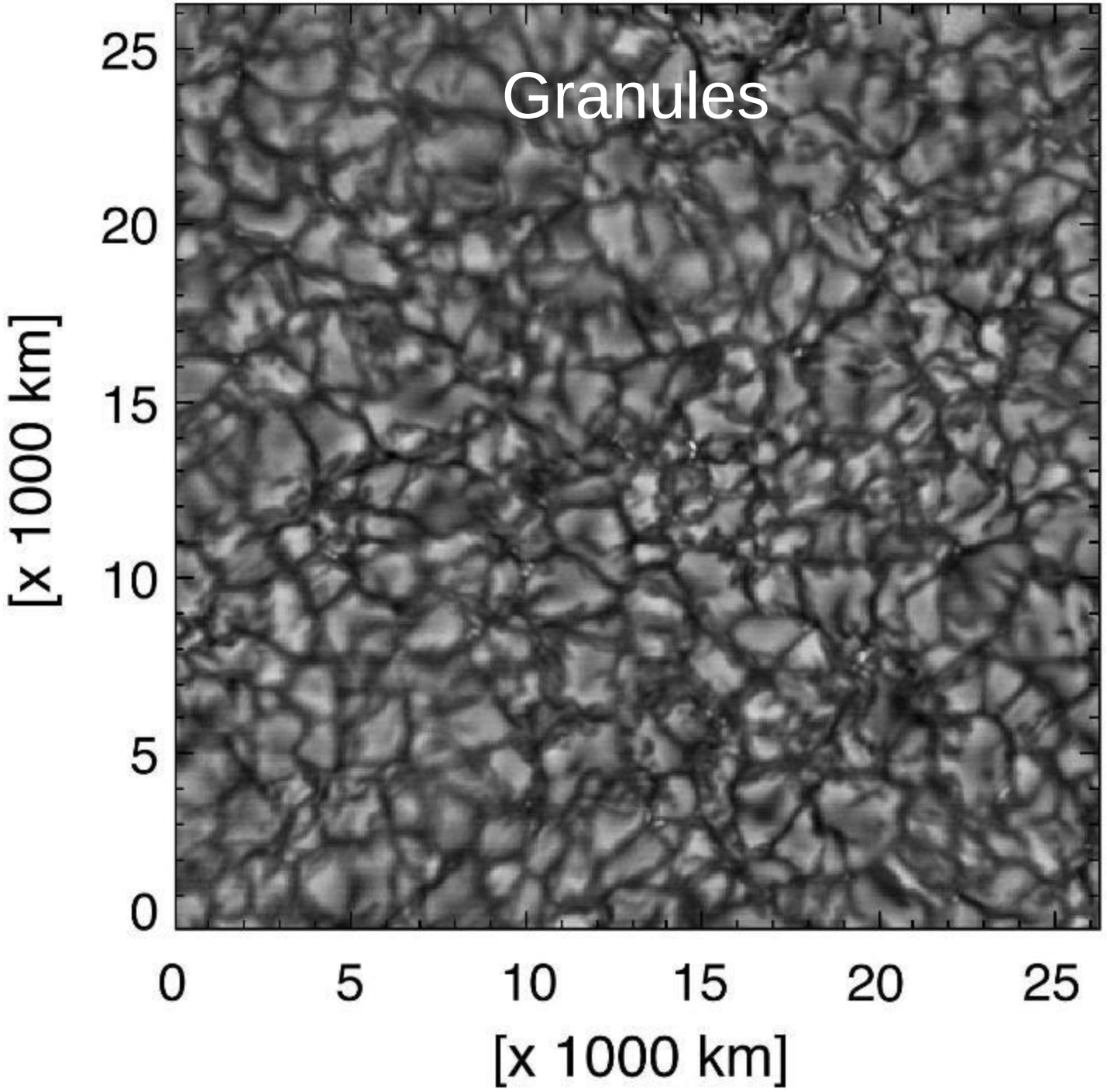
the Chromosphere as seen through hydrogen-α filter

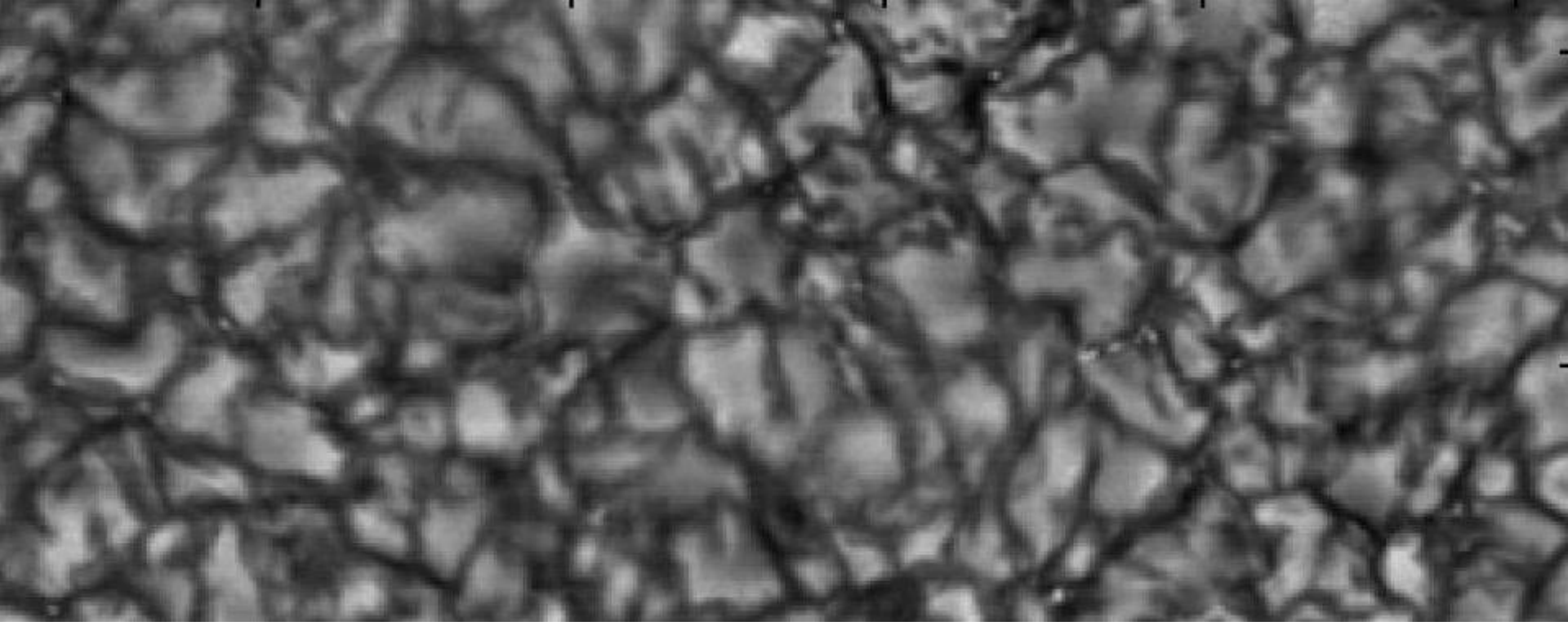



Corona

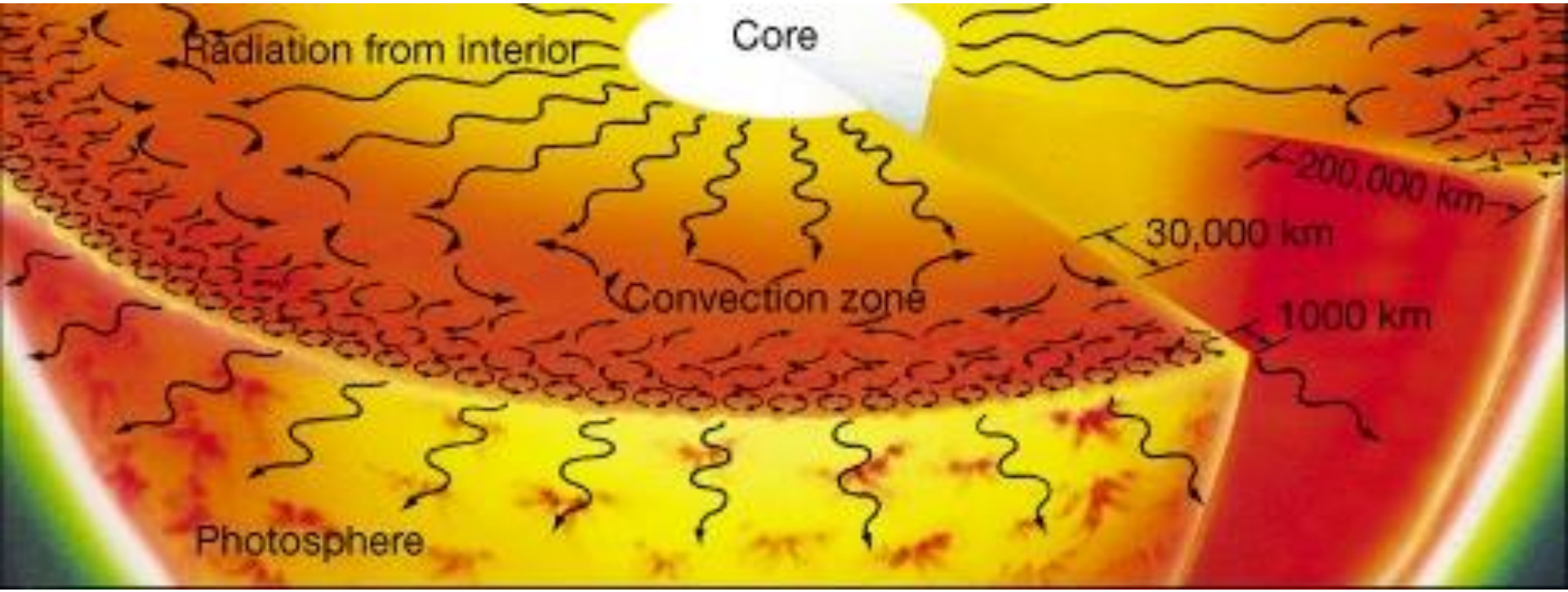

Pleiades
Venus
Mercury
Jupiter
Saturn
Solar Wind
2000/05/15 11:18
NRL
LASCO
SOHO

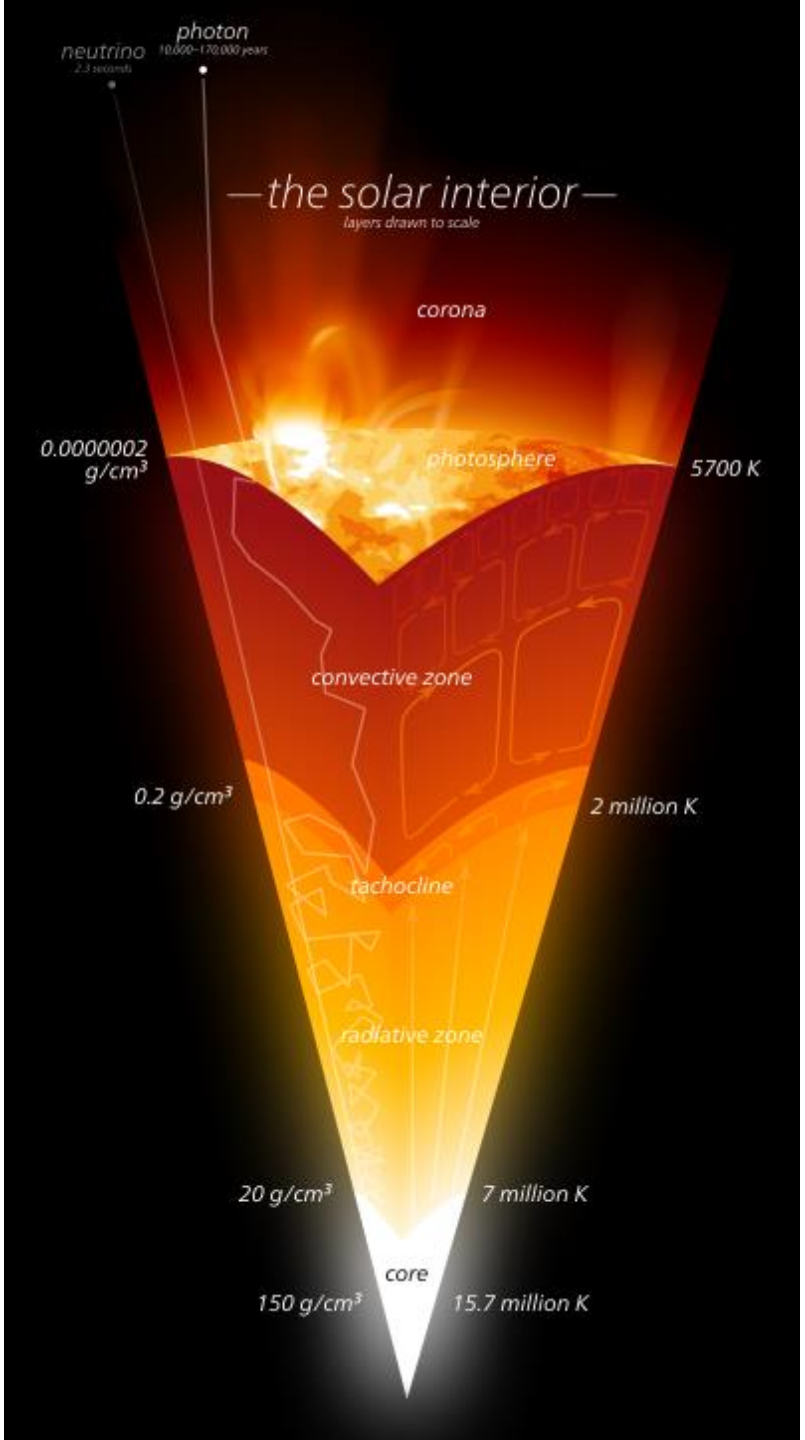
How do we know what is below the Photosphere?


Granules
25
20
15
10
5
0
[x 1000 km]
0
5
10
15
20
25
[x 1000 km]



Granulation refers to the grainy appearance of the photosphere. The granules are evidence of the underlying process of convection.


Radiation from interior
Core
200,000 km
30,000 km
Convection zone
1000 km
Photosphere



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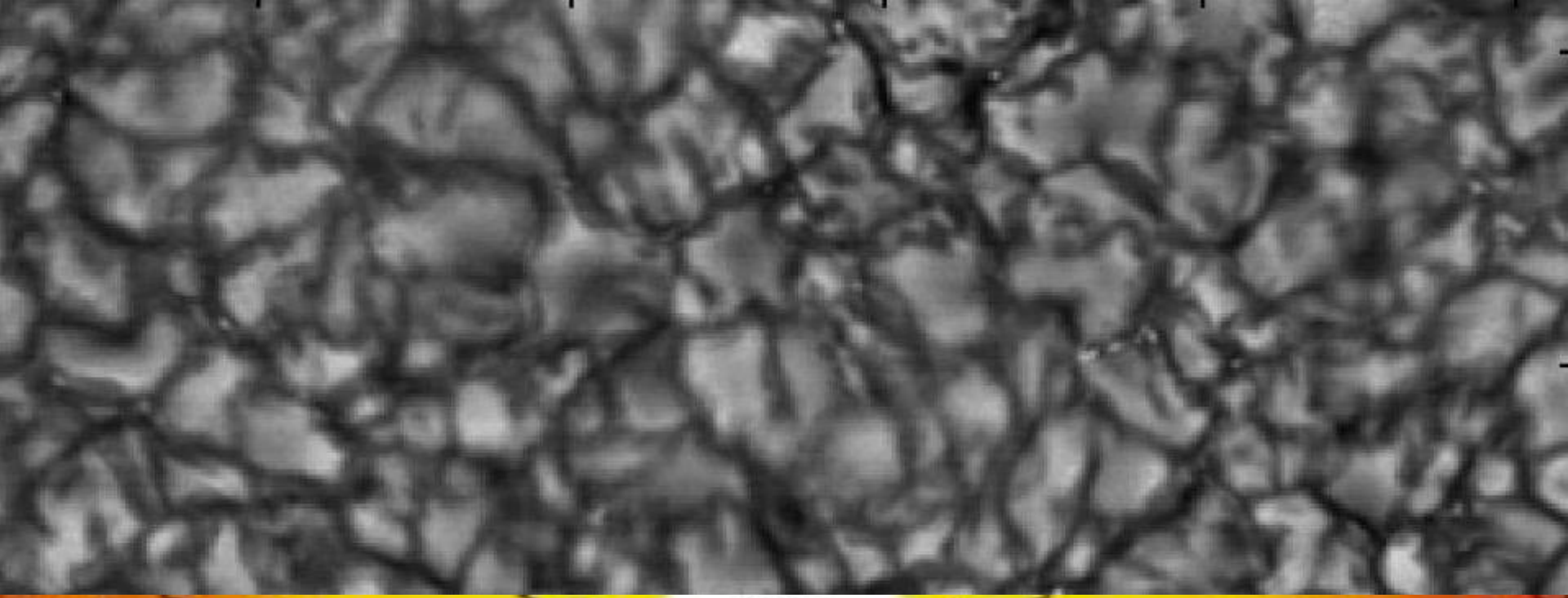
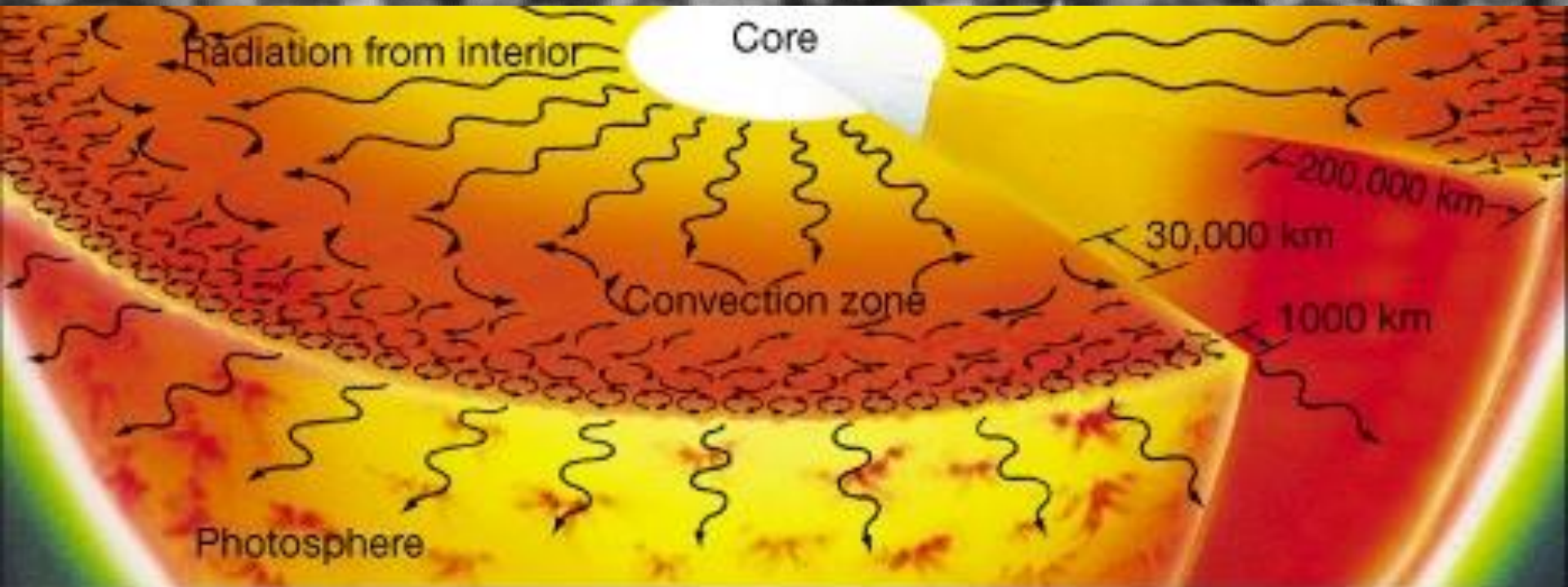
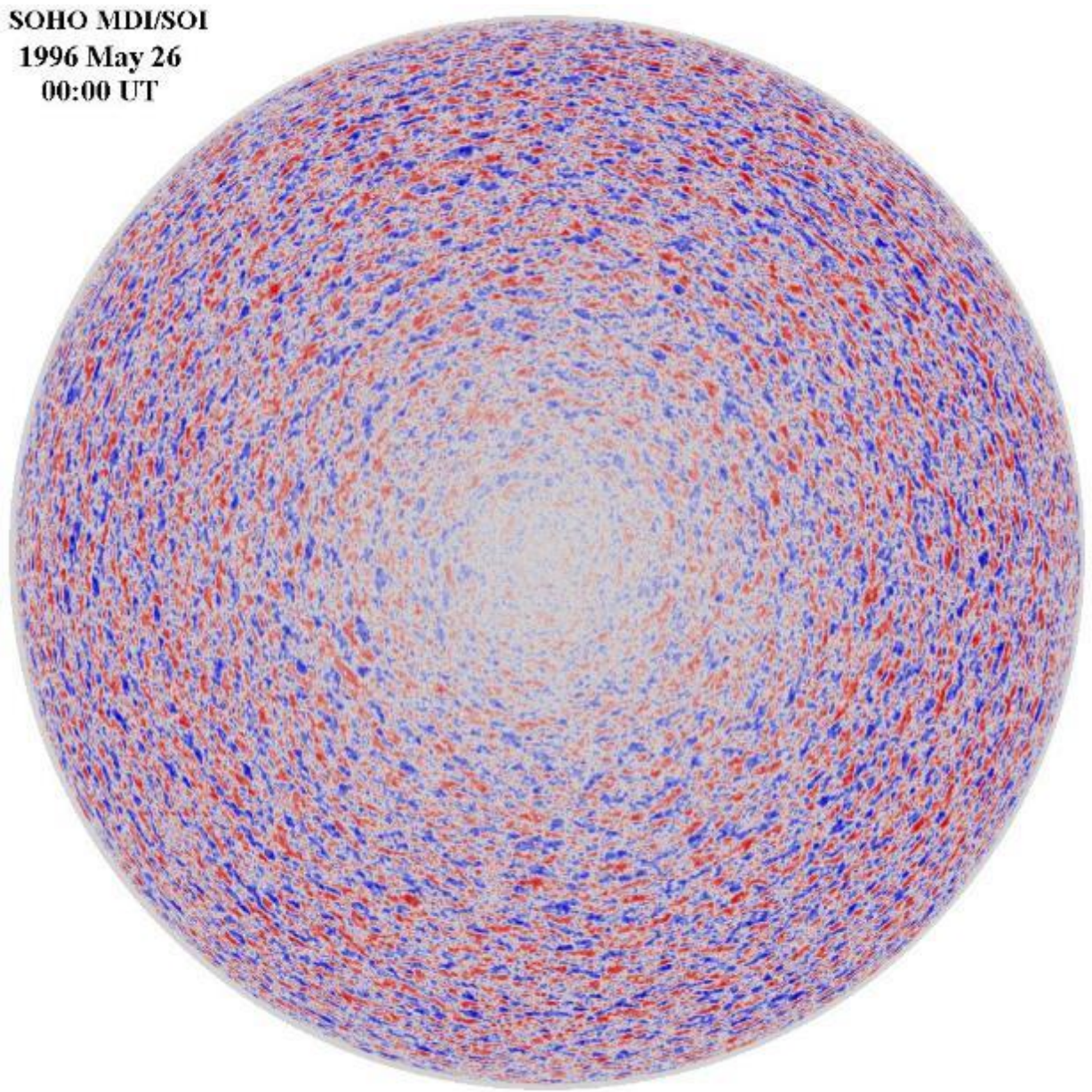



Radiation from interior
Core
200,000 km
30,000 km
Convection zone
1000 km
Photosphere

Super-Granulation



How do we know what is below the Convection Zone?

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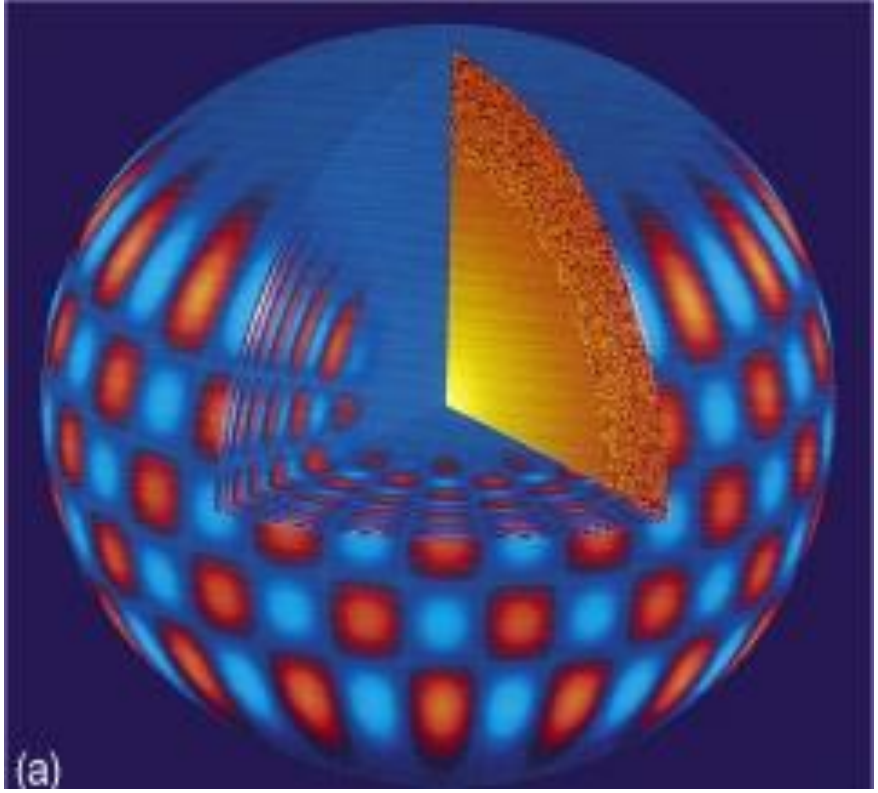
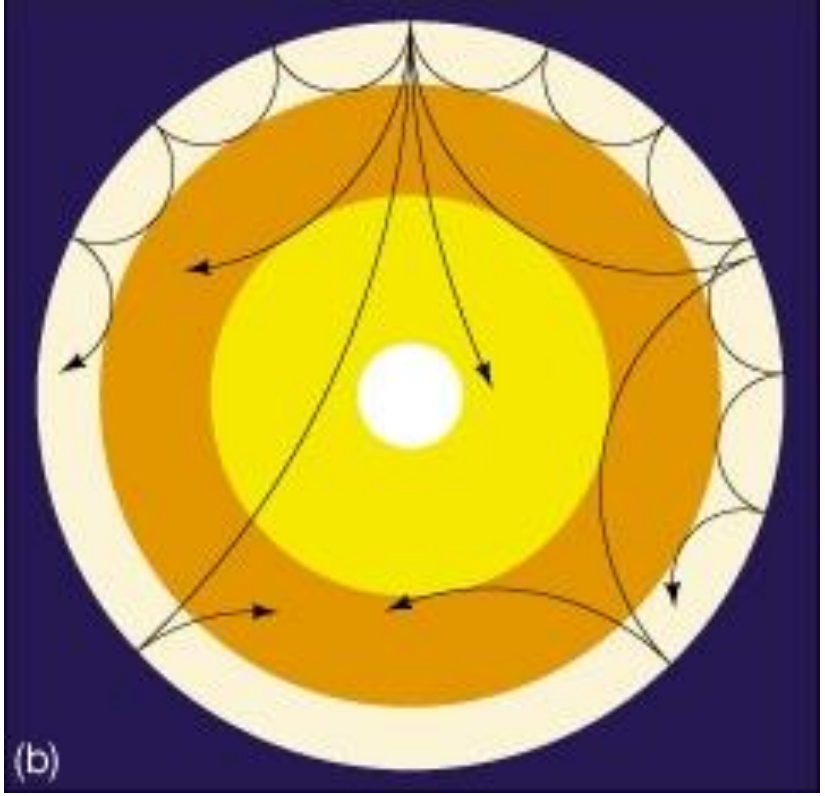
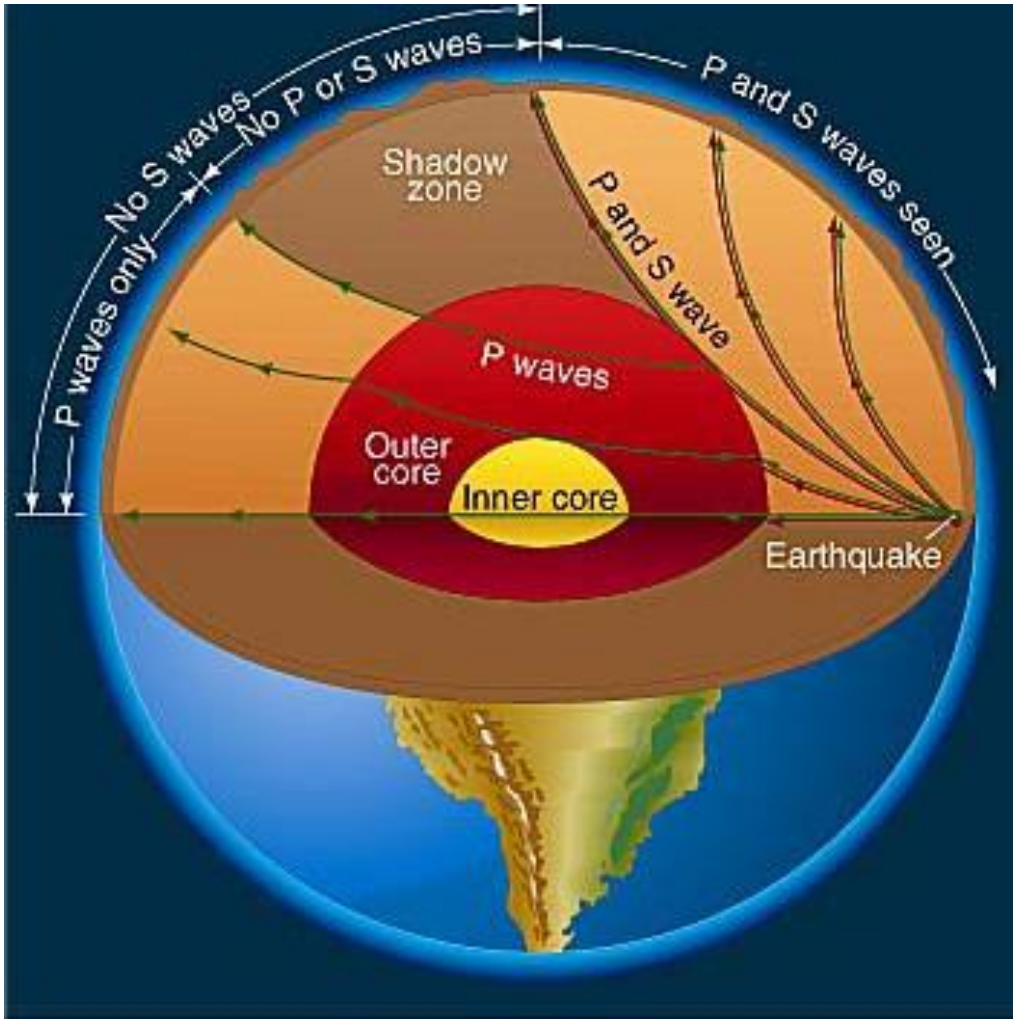
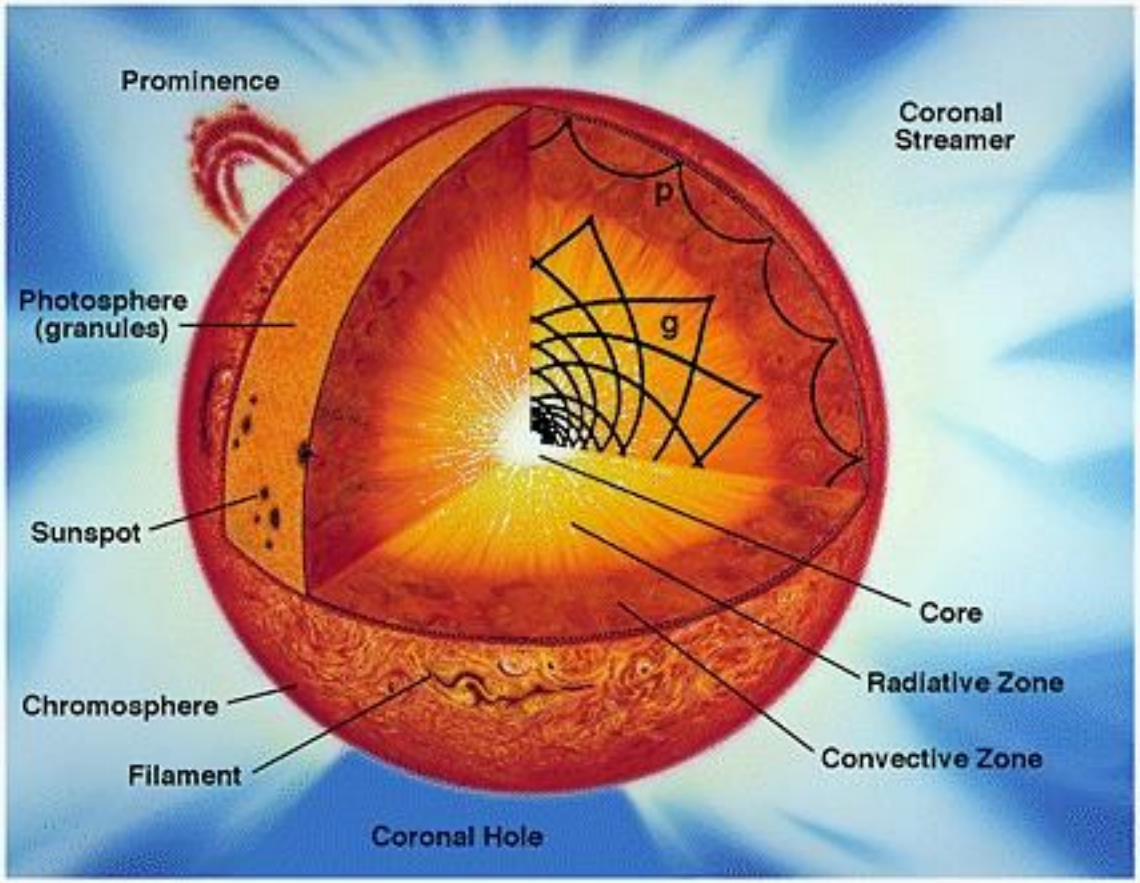


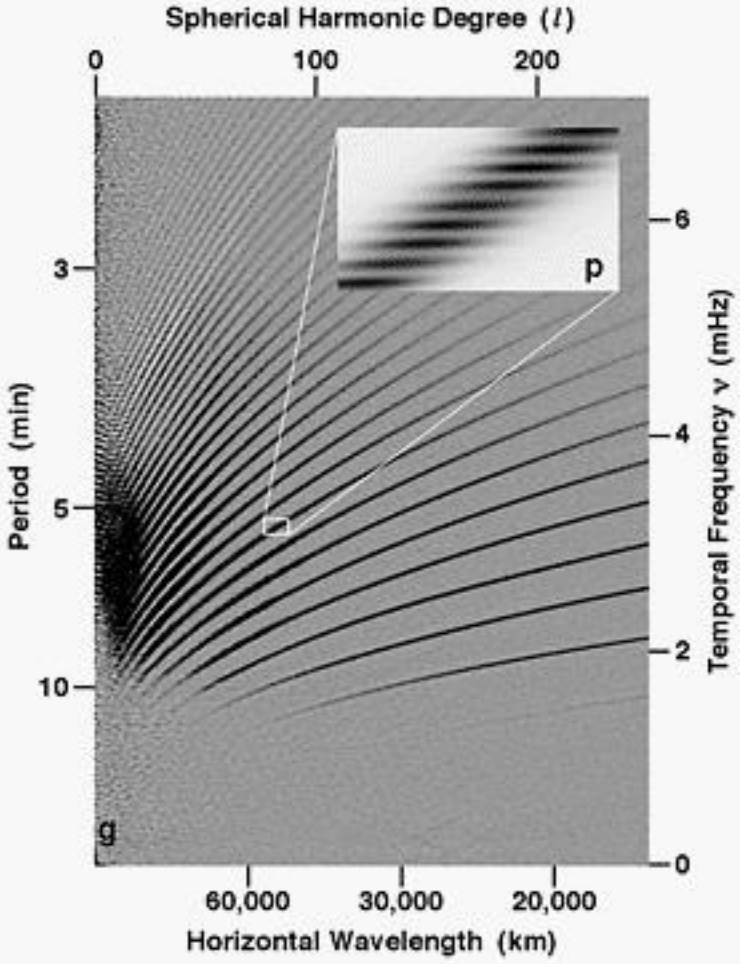


Helioseismology is the study of sound-like waves that travel through the Sun's interior, as evidenced by oscillations observed on the surface. This yields vital info about density, temperature, consistency, etc.



“Regular seismology” is the study of waves that travel through the Earth’s interior, as measured by seismographs when an earthquake occurs


Prominence
Coronal Streamer
p
g
Photosphere (granules)
Sunspot
Core
Radiative Zone
Chromosphere
Convective Zone
Filament
Coronal Hole


Spherical Harmonic Degree (l)
0
100
200
3
5
10
Period (min)
6
4
2
0
Temporal Frequency ν (mHz)
p
g
60,000
30,000
20,000
Horizontal Wavelength (km)