

ASTR 1P01

Brock University

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# Lecture 9: The Sun

# We will learn about...

- The composition and structure of the Sun.
- Solar phenomena such as sunspots and flares.

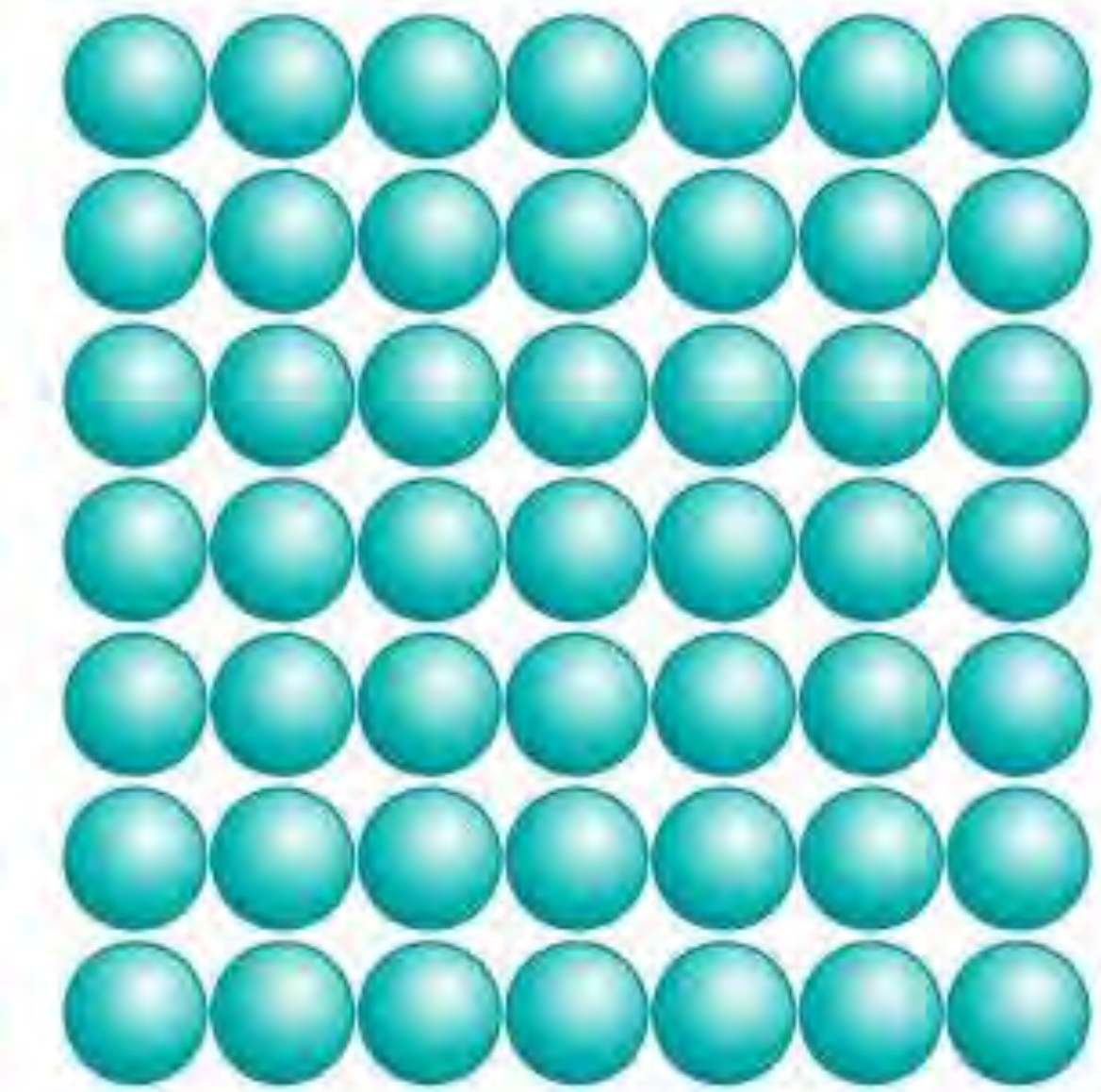


# The Sun

- The **Sun** is composed mainly of the two lightest elements: ~73% **hydrogen** (H) and ~25% **helium** (He).
- The other ~2% are heavier elements like **oxygen** (O), **carbon** (C), **iron** (Fe), and **neon** (Ne).
- These elements in the Sun are in the form of **plasma**.
  - Plasma is the 4<sup>th</sup> fundamental **state of matter**, after **solid**, **liquid**, and **gas**.
  - It's similar to gas, but it's so hot that atoms break down into individual electrons and nuclei.

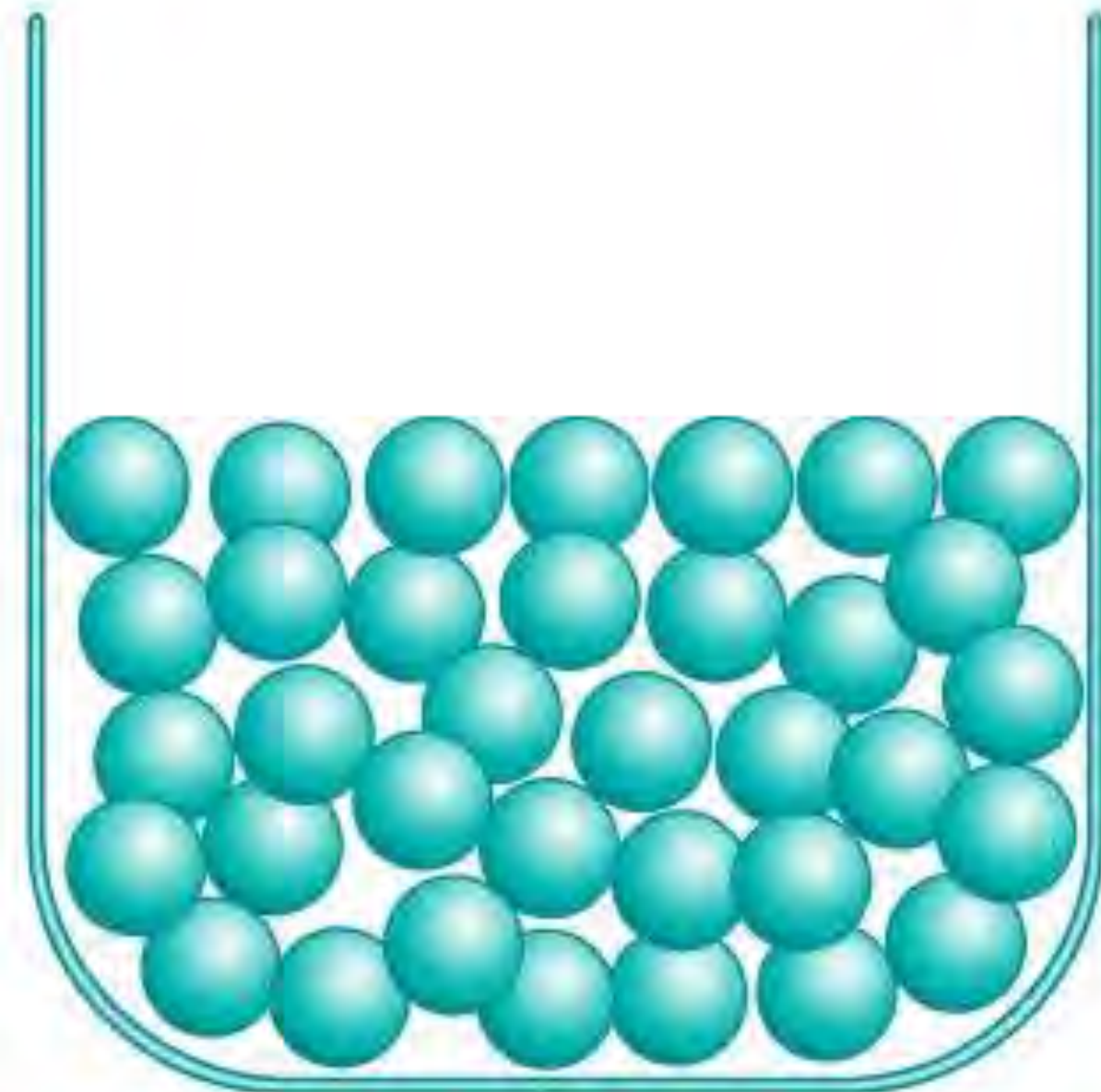


increasing energy



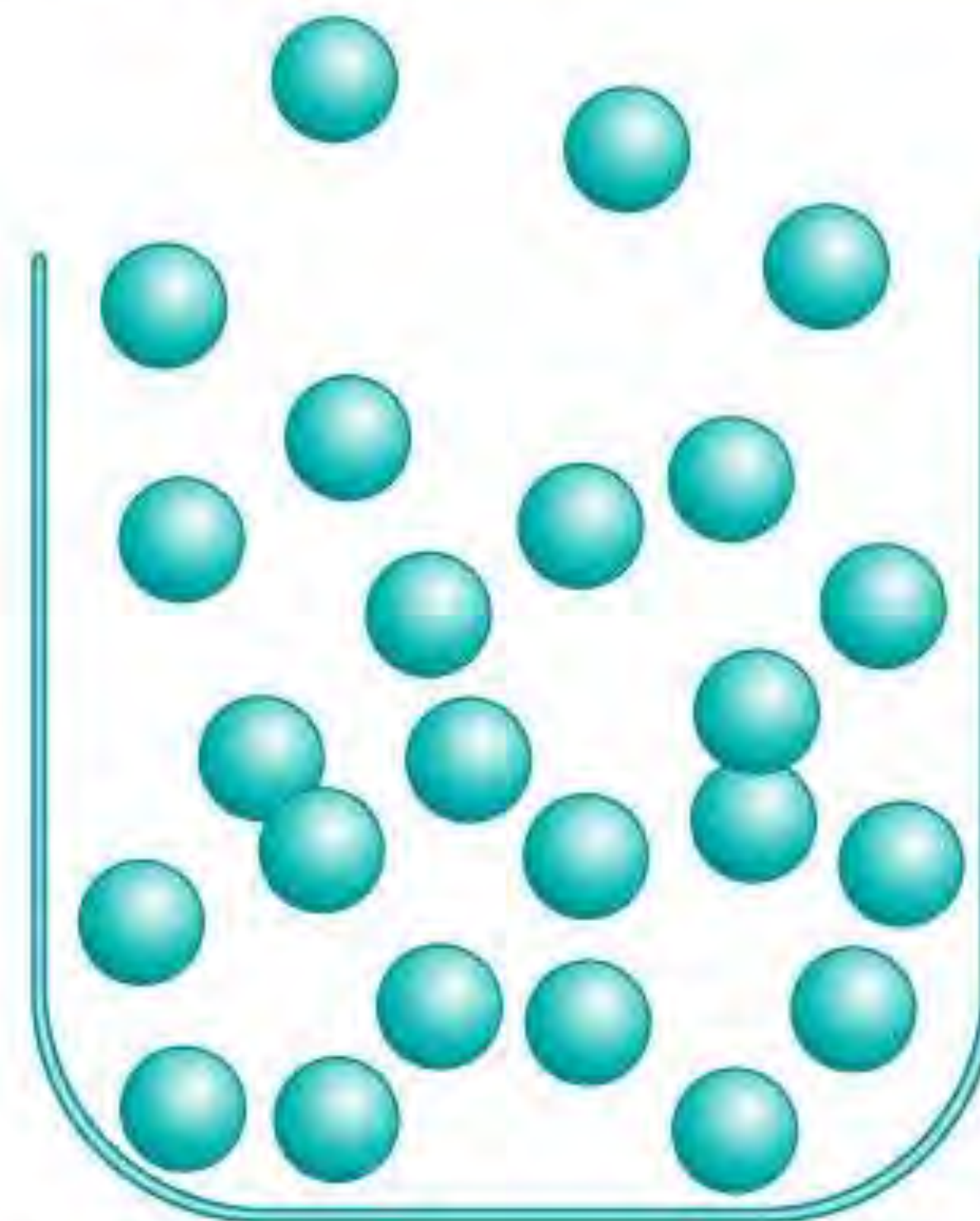
## Solid

The molecules that make up a solid are arranged in regular, repeating patterns. They are held firmly in place but can vibrate within a limited area.



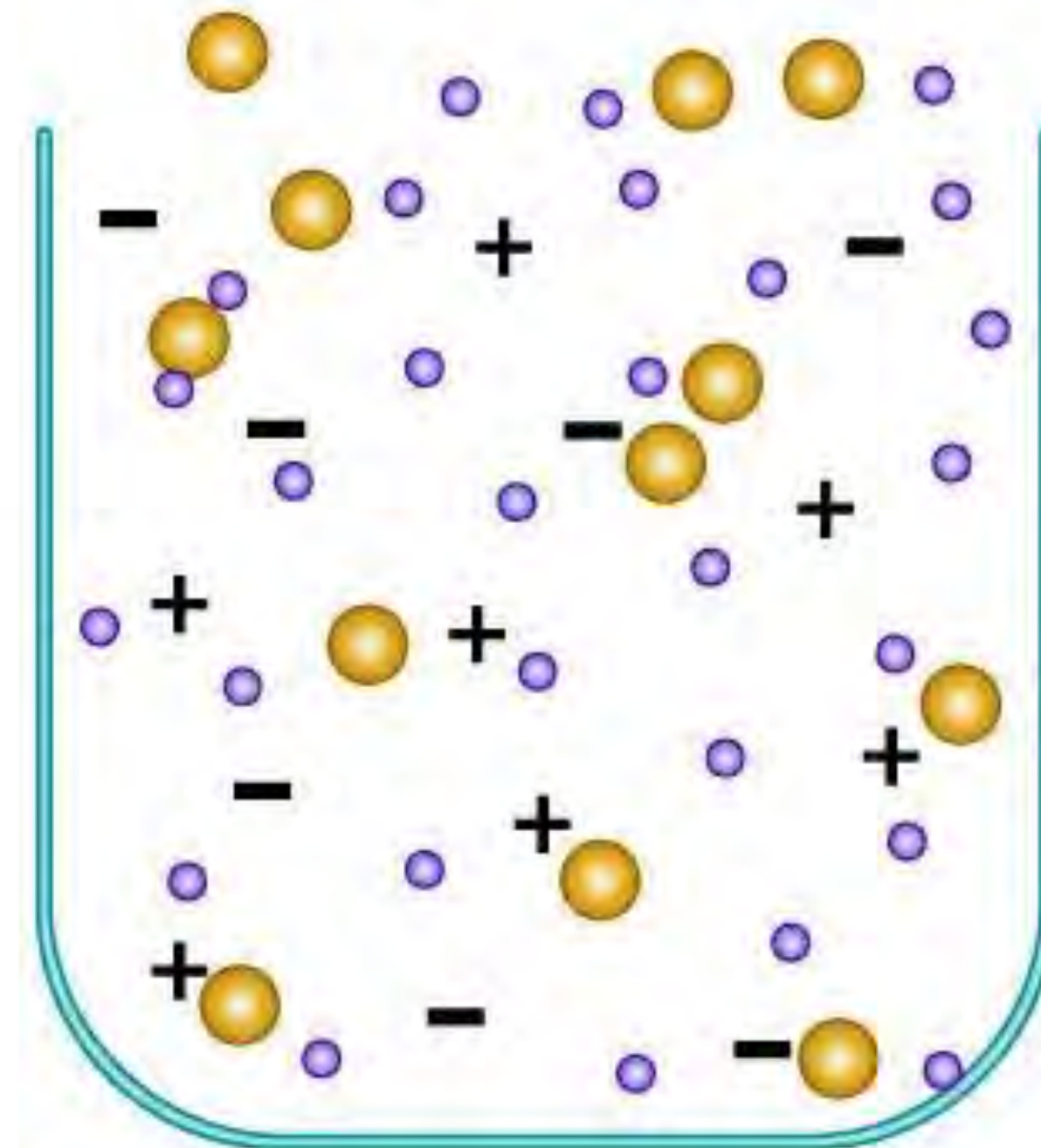
## Liquid

The molecules that make up a liquid flow easily around one another. They are kept from flying apart by attractive forces between them. Liquids assume the shape of their containers.



## Gas

The molecules that make up a gas fly in all directions at great speeds. They are so far apart that the attractive forces between them are insignificant.



## Plasma

At the very high temperatures of stars, atoms lose their electrons. The mixture of electrons and nuclei that results is the plasma state of matter.



# Periodic Table of the Elements

Group 1																	18		
Period 1	1.008 1312.0 2.20 <b>H</b> Hydrogen 1s <sup>1</sup>																	4.0026 2372.3 <b>He</b> Helium 1s <sup>2</sup>	
2	6.94 520.2 0.98 <b>Li</b> Lithium 1s <sup>2</sup> 2s <sup>1</sup>	9.0122 899.5 1.57 <b>Be</b> Beryllium 1s <sup>2</sup> 2s <sup>2</sup>																	20.180 2080.7 <b>Ne</b> Neon 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup>
3	22.990 495.8 0.93 <b>Na</b> Sodium [Ne] 3s <sup>1</sup>	24.305 737.7 1.31 <b>Mg</b> Magnesium [Ne] 3s <sup>2</sup>																	39.948 1520.6 <b>Ar</b> Argon [Ne] 3s <sup>2</sup> 3p <sup>6</sup>
4	39.098 418.8 0.82 <b>K</b> Potassium [Ar] 4s <sup>1</sup>	40.078 589.8 1.00 <b>Ca</b> Calcium [Ar] 4s <sup>2</sup>	44.956 633.1 1.36 <b>Sc</b> Scandium [Ar] 3d <sup>1</sup> 4s <sup>2</sup>	47.867 658.8 1.54 <b>Ti</b> Titanium [Ar] 3d <sup>2</sup> 4s <sup>2</sup>	50.942 650.9 1.63 <b>V</b> Vanadium [Ar] 3d <sup>3</sup> 4s <sup>2</sup>	51.996 652.9 1.66 <b>Cr</b> Chromium [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	54.938 717.3 1.55 <b>Mn</b> Manganese [Ar] 3d <sup>5</sup> 4s <sup>2</sup>	55.845 762.5 1.83 <b>Fe</b> Iron [Ar] 3d <sup>6</sup> 4s <sup>2</sup>	58.933 760.4 1.91 <b>Co</b> Cobalt [Ar] 3d <sup>7</sup> 4s <sup>2</sup>	58.693 737.1 1.88 <b>Ni</b> Nickel [Ar] 3d <sup>8</sup> 4s <sup>2</sup>	63.546 745.5 1.90 <b>Cu</b> Copper [Ar] 3d <sup>10</sup> 4s <sup>1</sup>	65.38 906.4 1.65 <b>Zn</b> Zinc [Ar] 3d <sup>10</sup> 4s <sup>2</sup>	69.723 578.8 1.81 <b>Ga</b> Gallium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	72.630 762.0 2.01 <b>Ge</b> Germanium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	74.922 947.0 2.18 <b>As</b> Arsenic [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	78.971 941.0 2.55 <b>Se</b> Selenium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	79.904 1139.9 2.96 <b>Br</b> Bromine [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	83.798 1350.8 3.00 <b>Kr</b> Krypton [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>	
5	85.468 403.0 0.82 <b>Rb</b> Rubidium [Kr] 5s <sup>1</sup>	87.62 549.5 0.95 <b>Sr</b> Strontium [Kr] 5s <sup>2</sup>	88.906 600.0 1.22 <b>Y</b> Yttrium [Kr] 4d <sup>1</sup> 5s <sup>2</sup>	91.224 640.1 1.33 <b>Zr</b> Zirconium [Kr] 4d <sup>2</sup> 5s <sup>2</sup>	92.906 652.1 1.60 <b>Nb</b> Niobium [Kr] 4d <sup>4</sup> 5s <sup>1</sup>	95.95 684.3 2.16 <b>Mo</b> Molybdenum [Kr] 4d <sup>5</sup> 5s <sup>1</sup>	(98) 702.0 1.90 <b>Tc</b> Technetium [Kr] 4d <sup>5</sup> 5s <sup>2</sup>	101.07 710.2 2.20 <b>Ru</b> Ruthenium [Kr] 4d <sup>7</sup> 5s <sup>1</sup>	102.91 719.7 2.28 <b>Rh</b> Rhodium [Kr] 4d <sup>8</sup> 5s <sup>1</sup>	106.42 804.4 2.20 <b>Pd</b> Palladium [Kr] 4d <sup>10</sup>	107.87 731.0 1.93 <b>Ag</b> Silver [Kr] 4d <sup>10</sup> 5s <sup>1</sup>	112.41 867.8 1.69 <b>Cd</b> Cadmium [Kr] 4d <sup>10</sup> 5s <sup>2</sup>	114.82 558.3 1.78 <b>In</b> Indium [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>1</sup>	118.71 708.6 1.96 <b>Sn</b> Tin [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup>	121.76 834.0 2.05 <b>Sb</b> Antimony [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup>	127.60 869.3 2.10 <b>Te</b> Tellurium [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup>	126.90 1008.4 2.66 <b>I</b> Iodine [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup>	131.29 1170.4 2.60 <b>Xe</b> Xenon [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup>	
6	132.91 375.7 0.79 <b>Cs</b> Caesium [Xe] 6s <sup>1</sup>	137.33 502.9 0.89 <b>Ba</b> Barium [Xe] 6s <sup>2</sup>	138.91 538.1 1.10 <b>La</b> Lanthanum [Xe] 5d <sup>1</sup> 6s <sup>2</sup>	* <b>Hf</b> Hafnium [Xe] 4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup>	* <b>Ta</b> Tantalum [Xe] 4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup>	* <b>W</b> Tungsten [Xe] 4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup>	* <b>Re</b> Rhenium [Xe] 4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup>	* <b>Os</b> Osmium [Xe] 4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup>	* <b>Ir</b> Iridium [Xe] 4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup>	* <b>Pt</b> Platinum [Xe] 4f <sup>14</sup> 5d <sup>9</sup> 6s <sup>1</sup>	* <b>Au</b> Gold [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>1</sup>	* <b>Hg</b> Mercury [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup>	* <b>Tl</b> Thallium [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>1</sup>	* <b>Pb</b> Lead [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>2</sup>	* <b>Bi</b> Bismuth [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>3</sup>	(210) 812.1 2.00 <b>Po</b> Polonium [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>4</sup>	(210) 890.0 2.20 <b>At</b> Astatine [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>5</sup>	(220) 1037.0 <b>Rn</b> Radon [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>6</sup>	
7	(223) 380.0 0.70 <b>Fr</b> Francium [Rn] 7s <sup>1</sup>	(226) 509.3 0.90 <b>Ra</b> Radium [Rn] 7s <sup>2</sup>	(227) 499.0 1.10 <b>Ac</b> Actinium [Rn] 6d <sup>1</sup> 7s <sup>2</sup>	* <b>Rf</b> Rutherfordium [Rn] 5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup>	* <b>Db</b> Dubnium [Rn] 5f <sup>14</sup> 6d <sup>3</sup> 7s <sup>2</sup>	* <b>Sg</b> Seaborgium [Rn] 5f <sup>14</sup> 6d <sup>4</sup> 7s <sup>2</sup>	* <b>Bh</b> Bohrium [Rn] 5f <sup>14</sup> 6d <sup>5</sup> 7s <sup>2</sup>	* <b>Hs</b> Hassium [Rn] 5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup>	* <b>Mt</b> Meitnerium [Rn] 5f <sup>14</sup> 6d <sup>7</sup> 7s <sup>2</sup>	* <b>Ds</b> Darmstadtium [Rn] 5f <sup>14</sup> 6d <sup>8</sup> 7s <sup>2</sup>	* <b>Rg</b> Roentgenium [Rn] 5f <sup>14</sup> 6d <sup>9</sup> 7s <sup>2</sup>	* <b>Cn</b> Copernicium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup>	* <b>Nh</b> Nihonium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>1</sup>	* <b>Fl</b> Flerovium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>2</sup>	* <b>Mc</b> Moscovium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>3</sup>	* <b>Lv</b> Livermorium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>4</sup>	* <b>Ts</b> Tennessine [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>5</sup>	* <b>Og</b> Oganesson [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>6</sup>	

standard atomic weight or most stable mass number: 55.845

1st ionization energy in kJ/mol: 762.5

electronegativity: 1.83

atomic number: 26

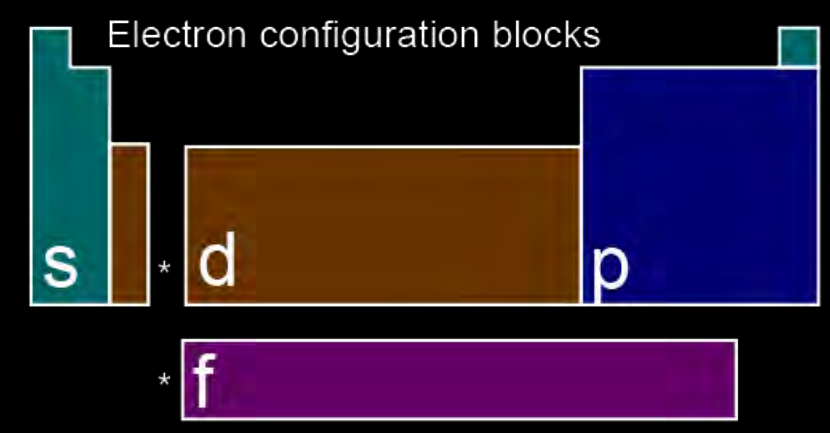
chemical symbol: **Fe**

name: Iron

electron configuration: [Ar] 3d<sup>6</sup> 4s<sup>2</sup>

oxidation states: +6, +5, +4, +3, +2, +1, -1, -2 (most common are bold)

radioactive elements have masses in parenthesis



140.12 534.4 1.12 <b>Ce</b> Cerium [Xe] 4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>	140.91 527.0 1.13 <b>Pr</b> Praseodymium [Xe] 4f <sup>3</sup> 6s <sup>2</sup>	144.24 533.1 1.14 <b>Nd</b> Neodymium [Xe] 4f <sup>4</sup> 6s <sup>2</sup>	(145) 540.0 <b>Pm</b> Promethium [Xe] 4f <sup>5</sup> 6s <sup>2</sup>	150.36 544.5 1.17 <b>Sm</b> Samarium [Xe] 4f <sup>6</sup> 6s <sup>2</sup>	151.96 547.1 <b>Eu</b> Europium [Xe] 4f <sup>7</sup> 6s <sup>2</sup>	157.25 593.4 1.20 <b>Gd</b> Gadolinium [Xe] 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	158.93 565.8 <b>Tb</b> Terbium [Xe] 4f <sup>9</sup> 6s <sup>2</sup>	162.50 573.0 1.22 <b>Dy</b> Dysprosium [Xe] 4f <sup>10</sup> 6s <sup>2</sup>	164.93 581.0 1.23 <b>Ho</b> Holmium [Xe] 4f <sup>11</sup> 6s <sup>2</sup>	167.25 589.3 1.24 <b>Er</b> Erbium [Xe] 4f <sup>12</sup> 6s <sup>2</sup>	168.93 596.7 1.25 <b>Tm</b> Thulium [Xe] 4f <sup>13</sup> 6s <sup>2</sup>	173.05 603.4 <b>Yb</b> Ytterbium [Xe] 4f <sup>14</sup> 6s <sup>2</sup>	174.97 523.5 1.27 <b>Lu</b> Lutetium [Xe] 4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>
232.04 587.0 1.30 <b>Th</b> Thorium [Rn] 6d <sup>2</sup> 7s <sup>2</sup>	231.04 588.0 1.50 <b>Pa</b> Protactinium [Rn] 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	238.03 597.6 1.38 <b>U</b> Uranium [Rn] 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(237) 604.5 1.36 <b>Np</b> Neptunium [Rn] 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(244) 584.7 1.28 <b>Pu</b> Plutonium [Rn] 5f <sup>6</sup> 7s <sup>2</sup>	(243) 578.0 1.30 <b>Am</b> Americium [Rn] 5f <sup>7</sup> 7s <sup>2</sup>	(247) 581.0 1.30 <b>Cm</b> Curium [Rn] 5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(247) 601.0 1.30 <b>Bk</b> Berkelium [Rn] 5f <sup>9</sup> 7s <sup>2</sup>	(251) 608.0 1.30 <b>Cf</b> Californium [Rn] 5f <sup>10</sup> 7s <sup>2</sup>	(252) 619.0 1.30 <b>Es</b> Einsteinium [Rn] 5f <sup>11</sup> 6s <sup>2</sup>	(257) 627.0 1.30 <b>Fm</b> Fermium [Rn] 5f <sup>12</sup> 7s <sup>2</sup>	(258) 635.0 1.30 <b>Md</b> Mendelevium [Rn] 5f <sup>13</sup> 7s <sup>2</sup>	(259) 642.0 1.30 <b>No</b> Nobelium [Rn] 5f <sup>14</sup> 7s <sup>2</sup>	(262) 470.0 <b>Lr</b> Lawrencium [Rn] 5f <sup>14</sup> 7s <sup>2</sup> 7p <sup>1</sup>



# The Sun

- The Sun is basically a huge ball of plasma.
- It has no solid parts, like a surface or core, and no liquid parts like oceans either.
- However, it is divided into several layers.

# The Sun

- The first layer, the **core**, extends from the center to  $\sim 20\text{-}25\%$  of the solar radius.
- The core is where the Sun's energy (and light) is produced via **nuclear fusion** reactions.
  - We will learn more about how this works when we learn about stars.
- It is extremely dense, and its temperature is  $\sim 15.7$  million K.
  - This is compared to the surface temperature of  $\sim 5,800$  K.



# The Sun

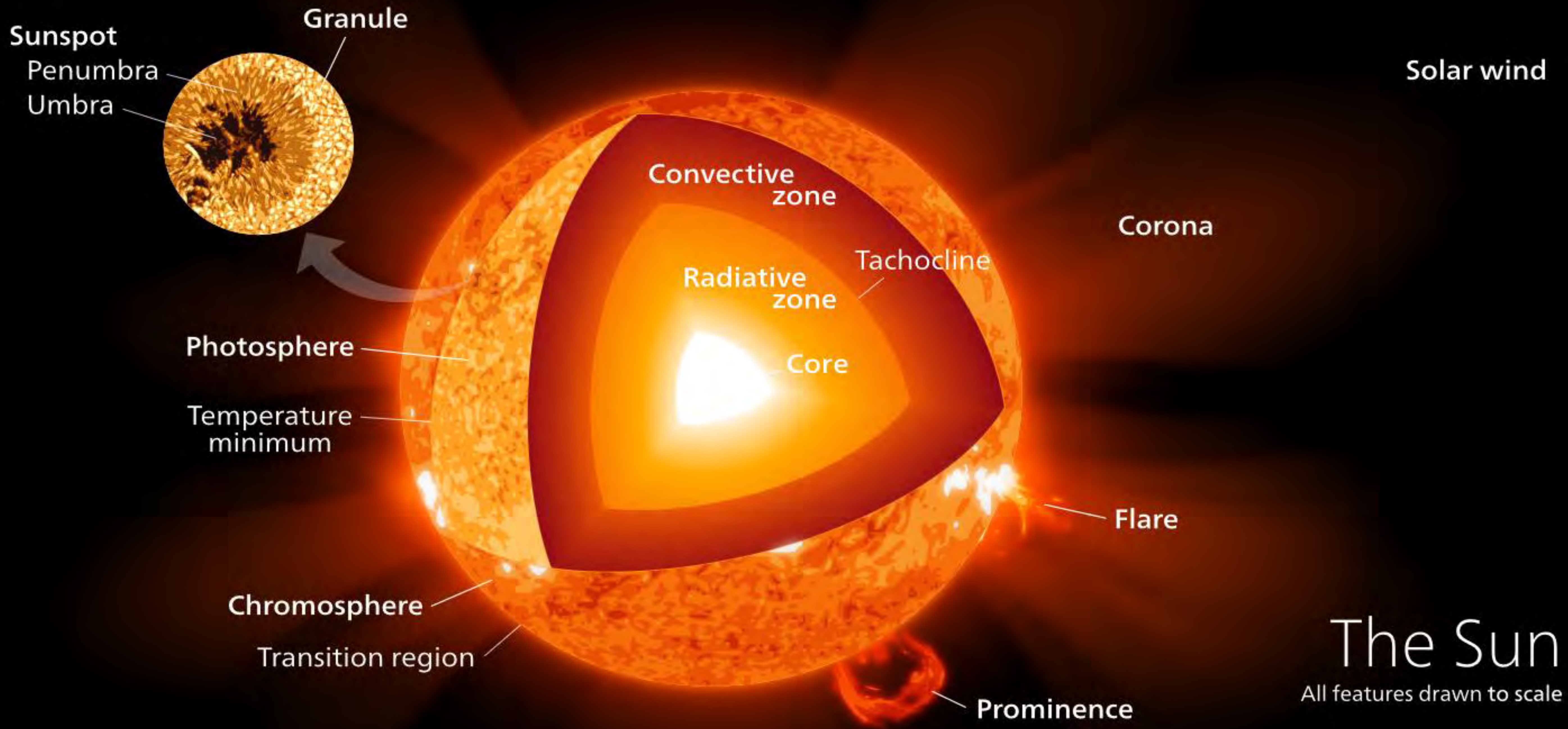
- The next layer is the **radiative zone**, extending up to 45% of the solar radius.
- It transports energy from the core outwards via **radiation** (in the form of photons, or particles of light).
- It is also very dense, so energy is transported very slowly.
  - The photons keep bumping into other particles on the way, changing direction, and losing energy in the process.
- The temperature drops across the radiative zone, down to ~2 million K at the largest distance from the core.



# The Sun

- Next we have the **convective zone**, the outermost layer of the solar interior, extending up to the surface.
  - It is separated from the radiative zone by the **tachocline**.
- The convective zone is not dense or hot enough to transfer heat outward via radiation.
- Instead, heat is transferred via **convection**, or the movement of fluid (in this case plasma).







# The Sun

- The visible and opaque surface of the Sun is the **photosphere**.
- It's where we actually see the photons that originated in the core.
- This layer is only a  $\sim 400$  km thick. The diameter of the Sun is defined as the size of the region surrounded by the photosphere.
- The temperature of the photosphere is  $\sim 5,800$  K.
- The photosphere is not a solid surface. If you fell through it (and didn't mind the heat) it would be like falling through air.
- In fact, its density is  $1/10,000$  the density of Earth's atmosphere at sea level.



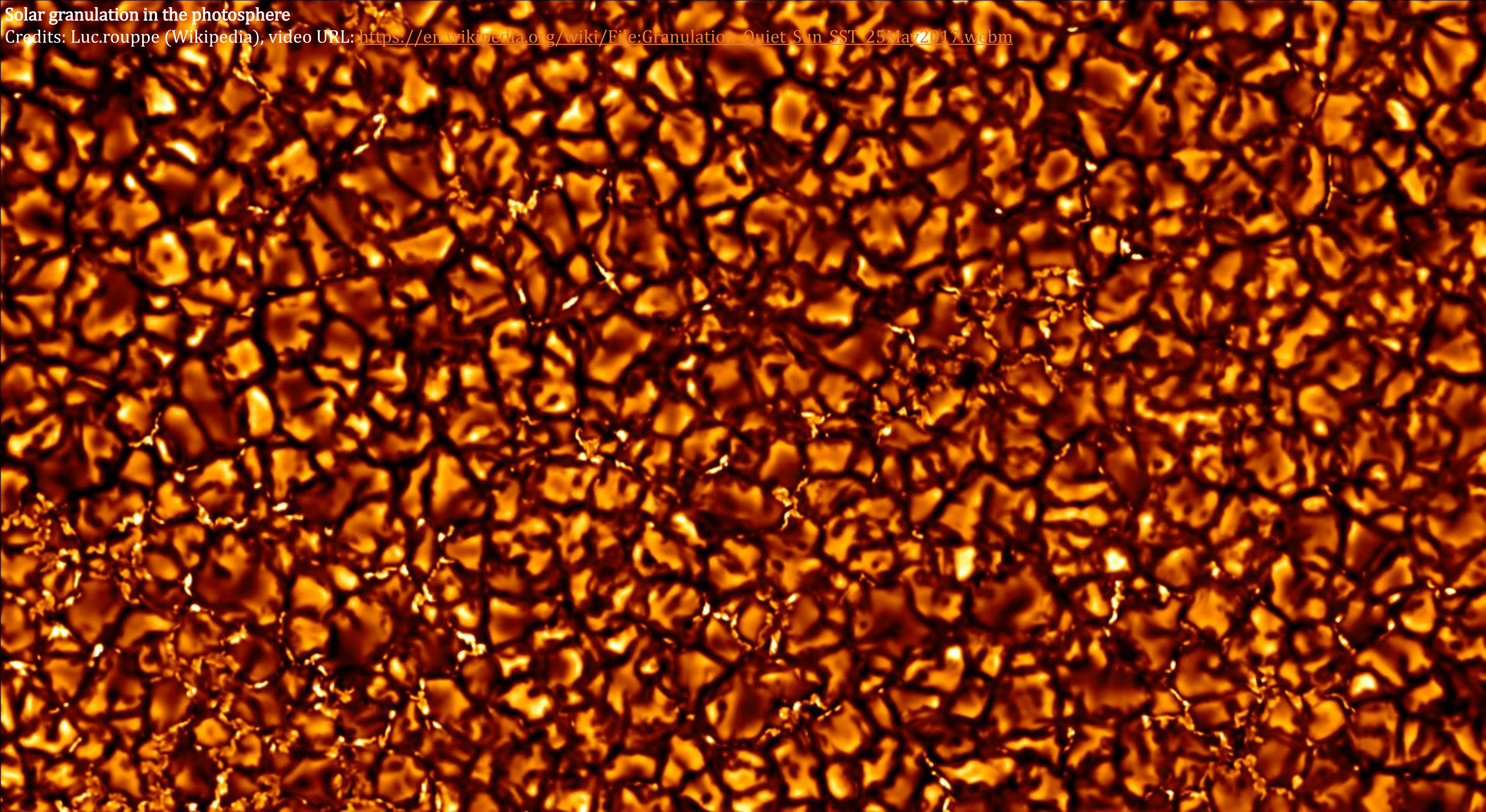
# The Sun

- The photosphere is composed of **granules**, ~700-1000 km in diameter (roughly the size of Alberta).
- They appear as bright areas surrounded by narrow, darker, and cooler regions.
- The lifetime of an individual granule is only 5 to 10 minutes.
- **Supergranules** are ~35,000 km across (about the size of two Earths) and last about 24 hours.
- The granules are a result of **convective motion** of bubbles that rise from the solar interior, like in boiling soup.



# Solar granulation in the photosphere

Credits: Luc.roupe (Wikipedia), video URL: [https://en.wikipedia.org/wiki/File:Granulation\\_Quiet\\_Sun\\_SST\\_25May2017.webm](https://en.wikipedia.org/wiki/File:Granulation_Quiet_Sun_SST_25May2017.webm)





# The Sun

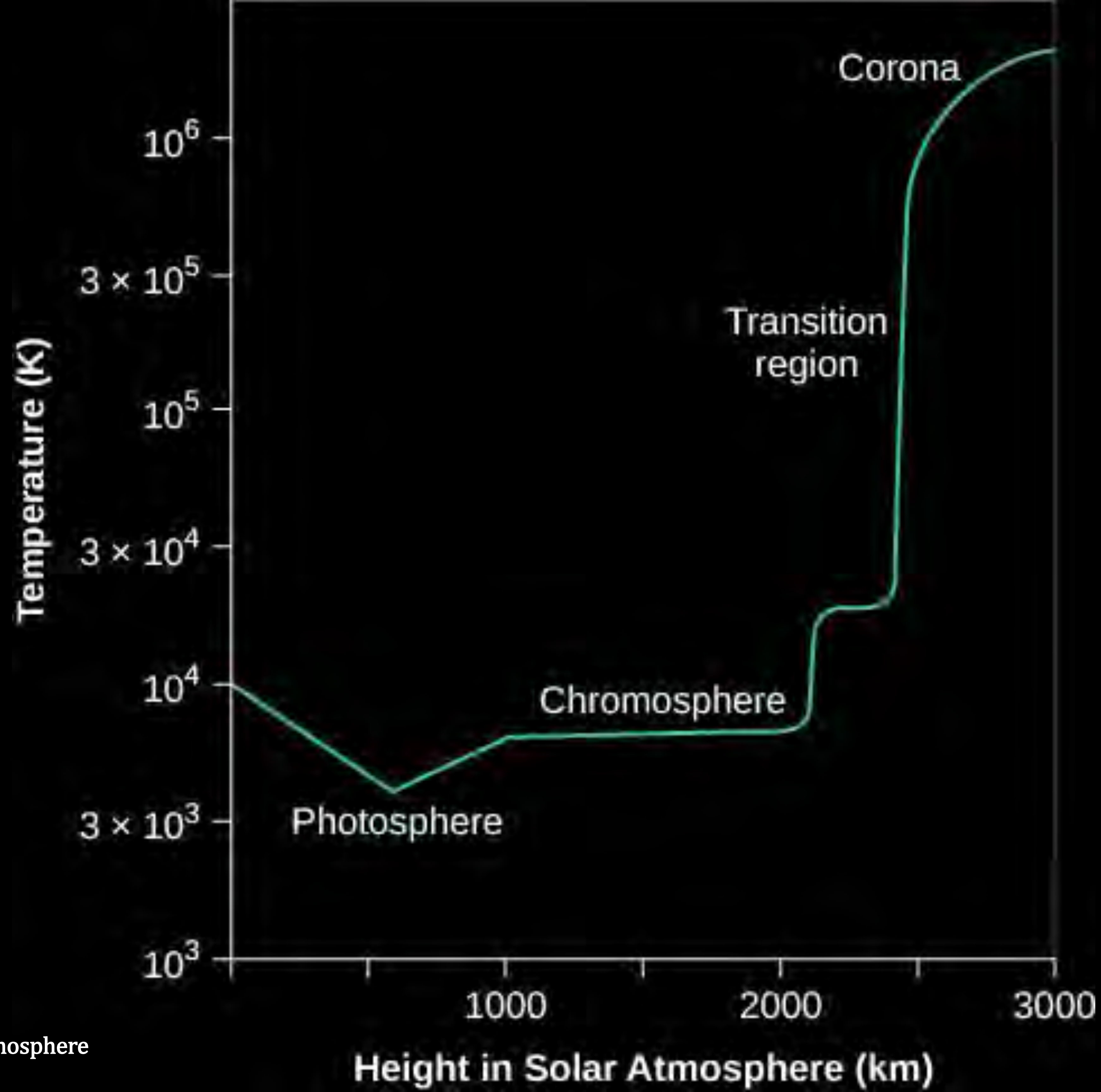
- The region of the Sun's atmosphere immediately above the photosphere is called the **chromosphere**.
- It is ~2,000-3,000 km thick and ~10,000 K hot.
- Note that it is hotter than the photosphere (~5,800 K). This is surprising, since it is farther from the core.
- The chromosphere is visible when the photosphere is concealed by the Moon during a total solar eclipse.



# The Sun

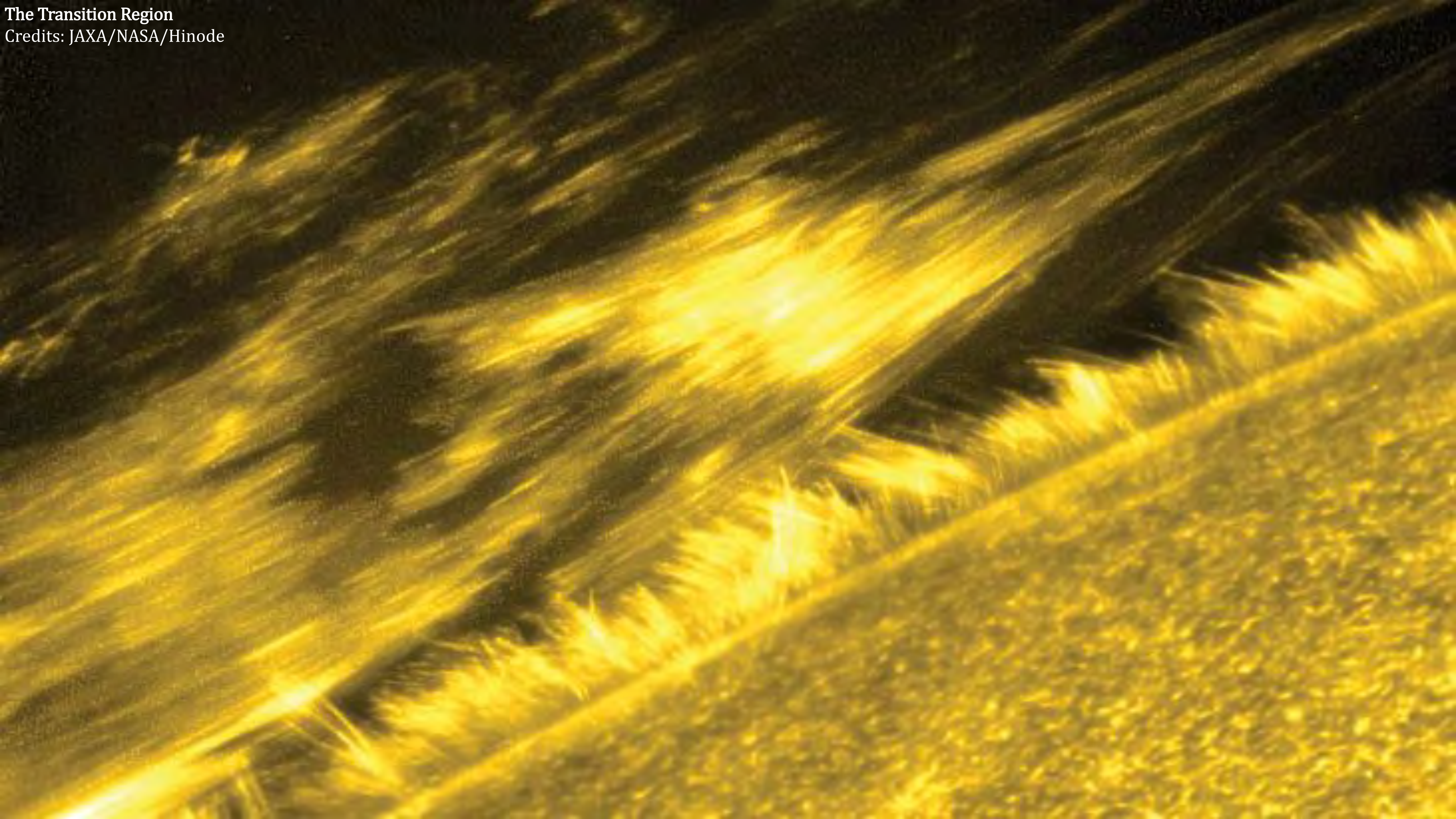
- Above the chromosphere is a region called the **corona** where the temperature increases rapidly from  $\sim 10,000$  K to  $\sim 1$  million K!
- The part of the Sun where the rapid temperature rise occurs is called the **transition region**. It is only a few tens of km thick.







The Transition Region  
Credits: JAXA/NASA/Hinode





# The Sun

- The **corona** is the outermost part of the Sun's atmosphere.
- Like the chromosphere, the corona can be seen during total eclipses.
- The corona extends millions of km above the photosphere and emits about half as much light as the full moon.
- The reason we don't see this light until an eclipse occurs is that it is much fainter compared to the photosphere.
- The corona can also be photographed with a special instrument called a **coronagraph** that removes the Sun's glare from the image with a circular piece of material held in front of the Sun.

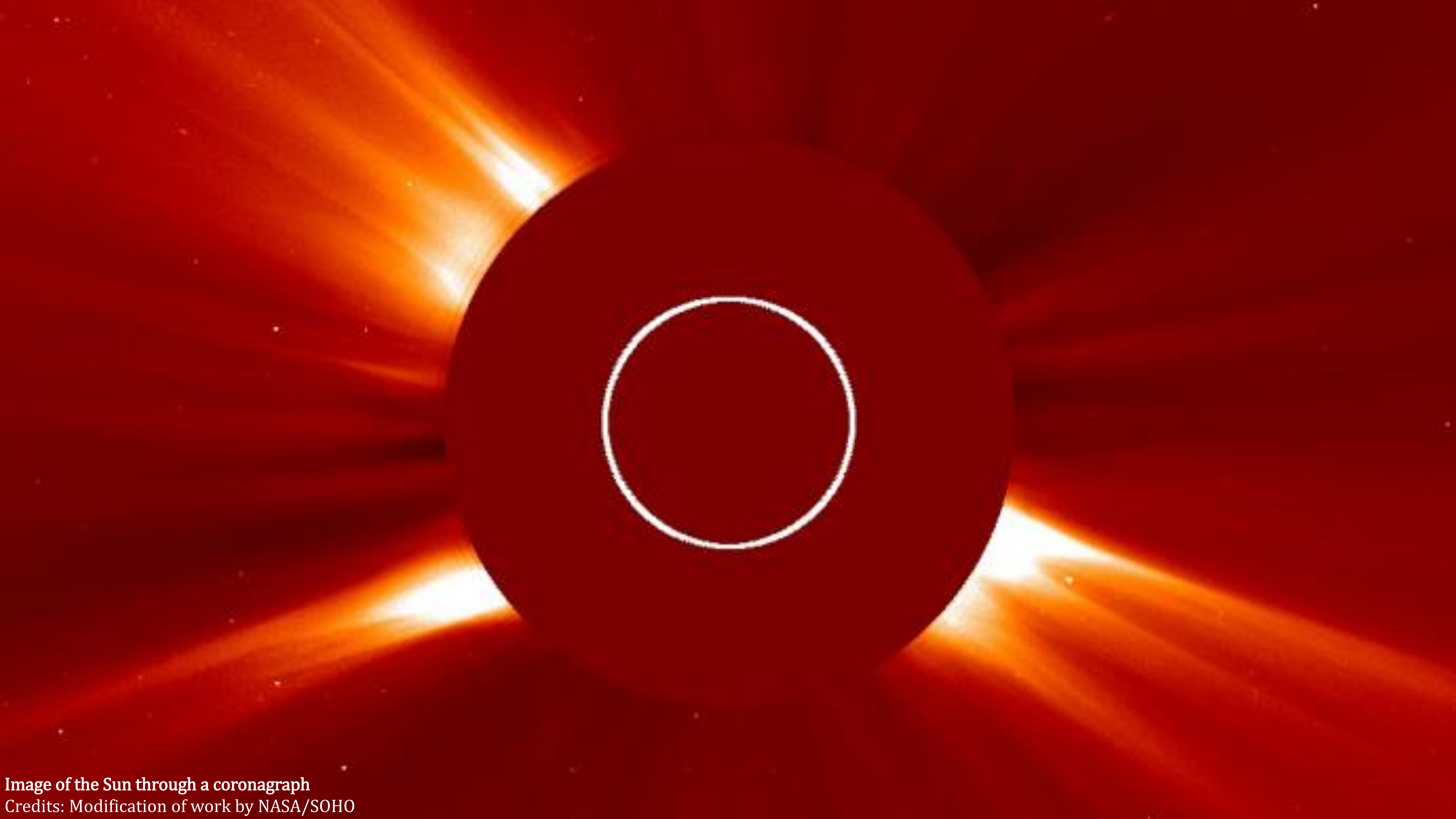




The Sun's corona as seen during a total solar eclipse

Credits: NASA/Aubrey Gemignani





**Image of the Sun through a coronagraph**  
Credits: Modification of work by NASA/SOHO



# The Sun

- The corona has very low density and thins out very rapidly at greater heights.
- At the bottom of the corona, there are only  $\sim 10^{15}$  atoms/m<sup>3</sup>.
- Compare with:
  - $\sim 10^{22}$  atoms/m<sup>3</sup> in the upper photosphere.
  - $\sim 10^{25}$  molecules/m<sup>3</sup> at sea level in Earth's atmosphere.
- The corona extends far past Earth – we are technically living **inside** the Sun's atmosphere!

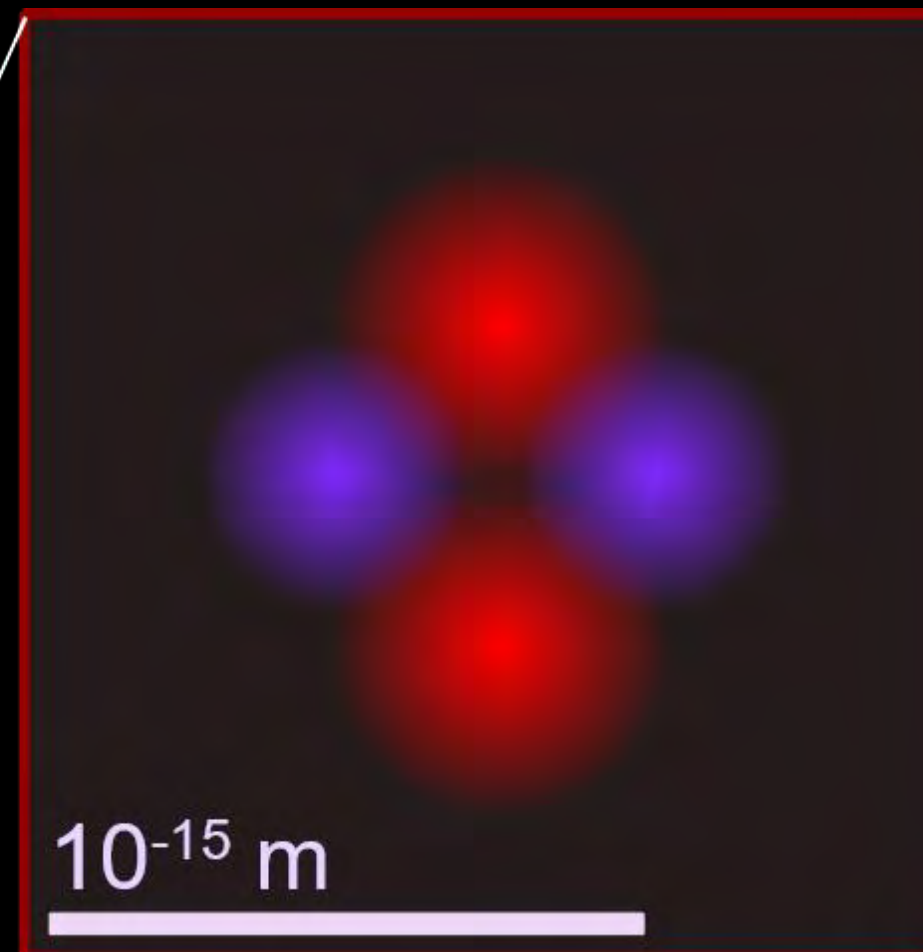


# The Sun

- The Sun's atmosphere produces a stream of charged particles, mainly protons and electrons, called the **solar wind**.
  - Recall: an atom is made from a **nucleus** containing **protons** and **neutrons**, surrounded by a cloud of **electrons**.
- These particles flow outward from the Sun at  $\sim 400$  km/s.



Electron  
Cloud



Nucleus  
(Enlarged)

$10^{-10}$  m





# The Sun

- The solar wind exists because the gases in the corona are so hot and moving so rapidly that they cannot be held back by gravity.
- The Sun is losing ~1–2 million tons of material each second through the solar wind.
- This sounds like a lot, but it's so small compared to the enormous mass of the Sun that it doesn't affect it in a noticeable way.





Stellar wind from the star LL Orionis generating a bright arc (called a bow shock), about half a light-year across, as it collides with flowing material in the surrounding Orion Nebula.  
Credits: NASA





The Auroras, or polar light, result from charged particles in the solar wind interacting with Earth's magnetic fields


Credits: Moyan Brenn



# The Sun

- **Prominences** are large and bright eruptions from the surface of the Sun, often in the shape of a loop.
- They can extend over thousands of km, sometimes hundreds of thousands.



Approx. size of Earth → 



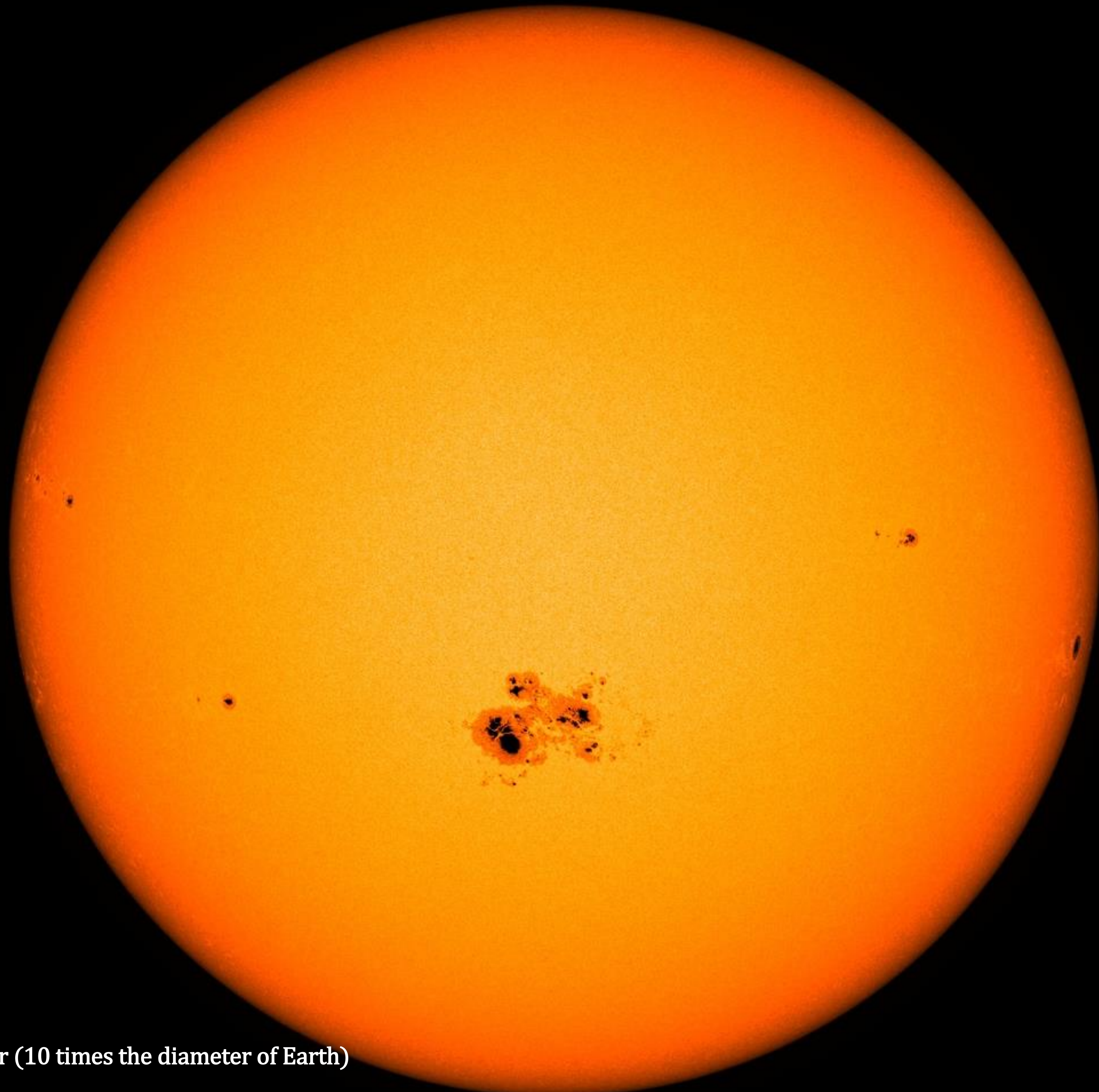
A solar prominence  
Credits: NASA/SDO



# The Sun

- **Sunspots** are dark “spots” on the Sun’s photosphere. They are places where the magnetic field is stronger.
- This inhibits heat transport from the solar interior to the surface. This means sunspots are colder, and hence appear darker.
- The central and darkest part of the sunspot is called the **umbra**. It is where the magnetic field is the strongest.
- The outer and brighter part is called the **penumbra**.
- The temperature of the umbra ( $\sim 3,000\text{-}4,500\text{ K}$ ) is much colder than the penumbra and the surrounding regions ( $\sim 5,800\text{ K}$ ).

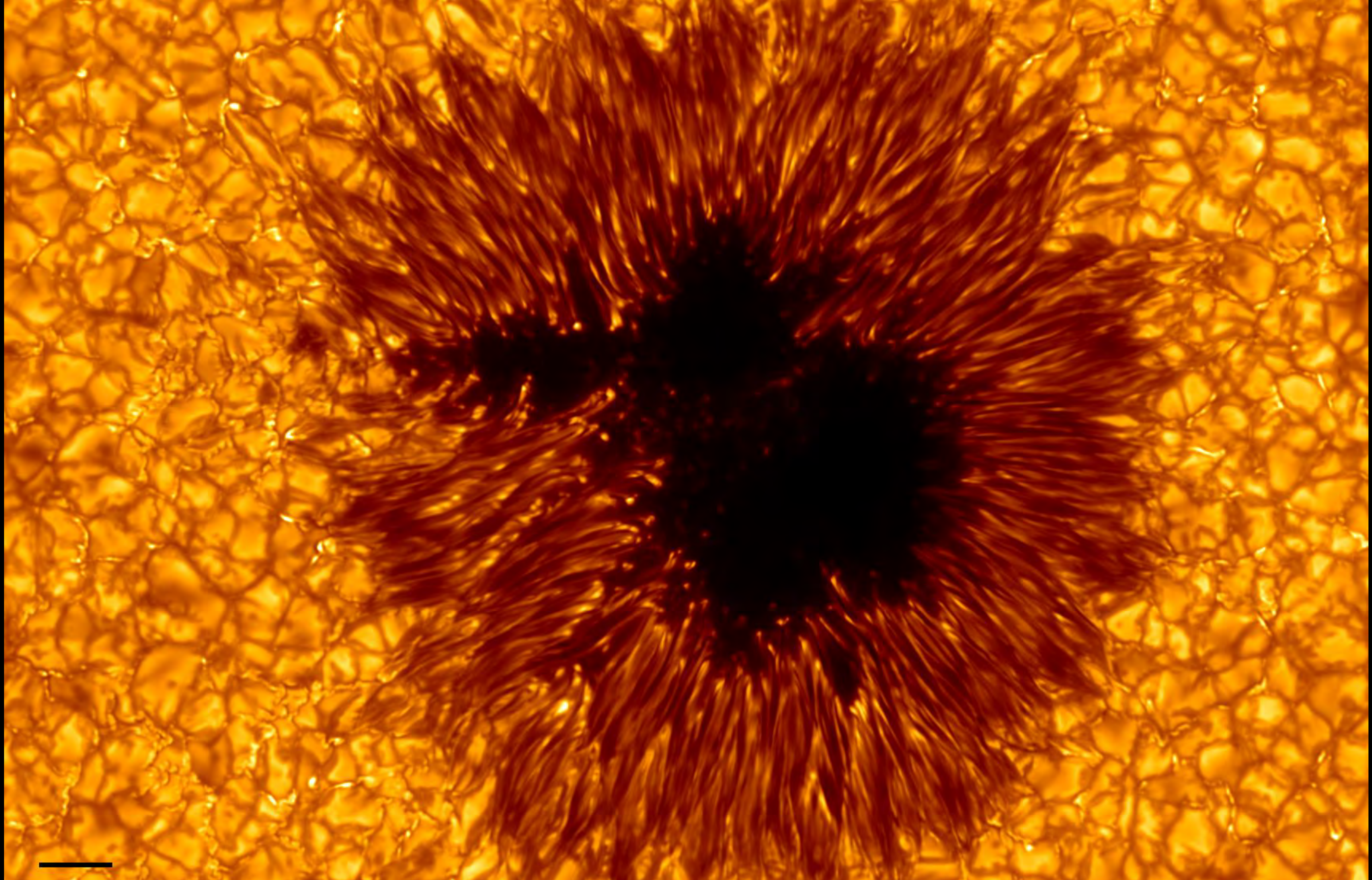




A large sunspot, ~130,000 km in diameter (10 times the diameter of Earth)

Credits: NASA/SDO





**A sunspot observed by the Swedish Solar Telescope. The black line on the lower left is 2,500 km long.**

Credits: Luc Rouppe van der Voort and Shahin Jafarzadeh

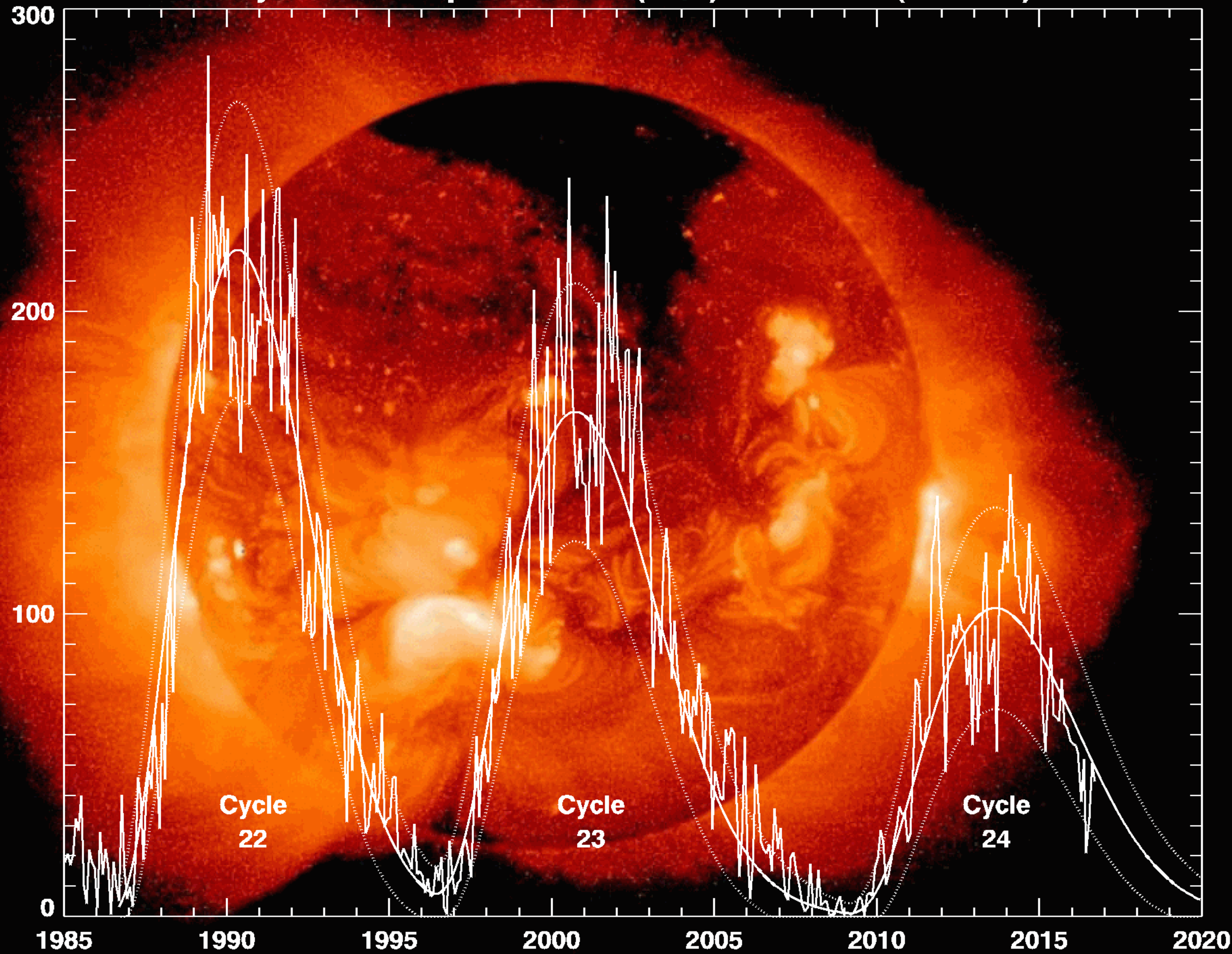


# The Sun

- Many solar phenomena change periodically over ~11 years on average. This is called the **solar cycle** (or the **sunspot cycle**).
- During a solar cycle, the number of sunspots observed on the Sun's surface varies.
- A **solar maximum/minimum** is the time with most/least sunspots.
- Each solar cycle starts and ends with a solar minimum.
- We are currently (2022) in **cycle 25**, which began December 2019 and is expected to end around 2030.
- The previous cycle, number 24, started in January 2008.



# Cycle 24 Sunspot Number (V2.0) Prediction (2016/10)



The last 3 solar cycles

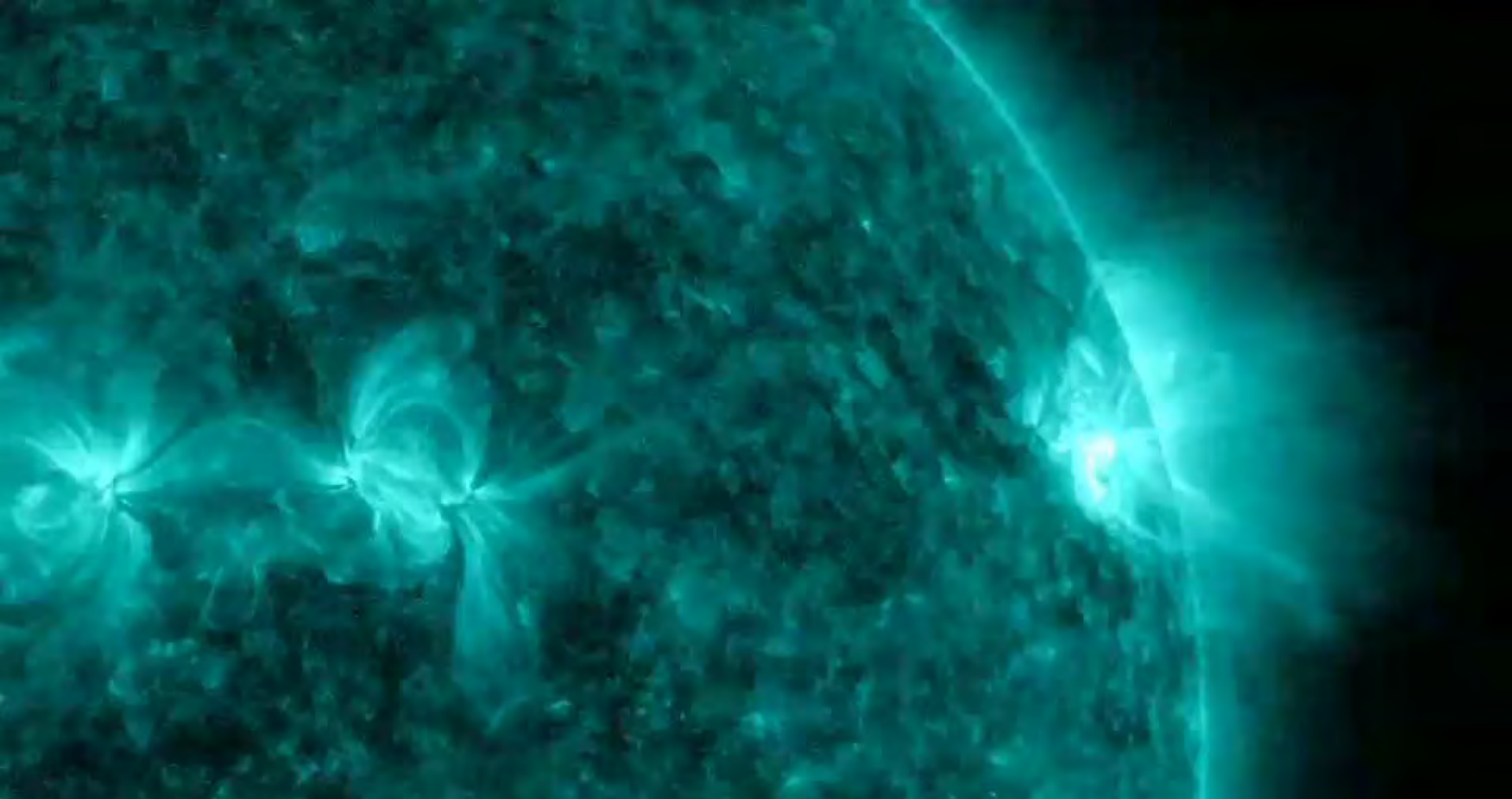
Credits: David Hathaway, NASA, Marshall Space Flight Center



# The Sun

- Several other phenomena vary during a solar cycle.
- A **solar flare** is a rapid eruption lasting minutes to hours and releasing an enormous amount of energy.
- Near solar maximum, solar flares occur several times per day. Near solar minimum, they can occur less than once per week.
- More powerful flares are less frequent than weaker ones.





A solar flare bursts from the sun on August 9, 2011, as seen by NASA's Solar Dynamics Observatory (SDO) satellite.  
Credits: NASA/Goddard Space Flight Center; video URL: <https://svs.gsfc.nasa.gov/vis/a010000/a010800/a010833/>



# The Sun

- A **coronal mass ejection (CME)** is a massive burst of solar wind and magnetic fields rising above the solar corona.
- The Sun produces 3 CMEs every day during a solar maximum, but only 1 CME every 5 days during a solar minimum.
- CMEs are often associated with solar flares, but the exact relationship is not understood.
- Some CMEs can reach Earth and even damage electrical power grids (but this only rarely happens).

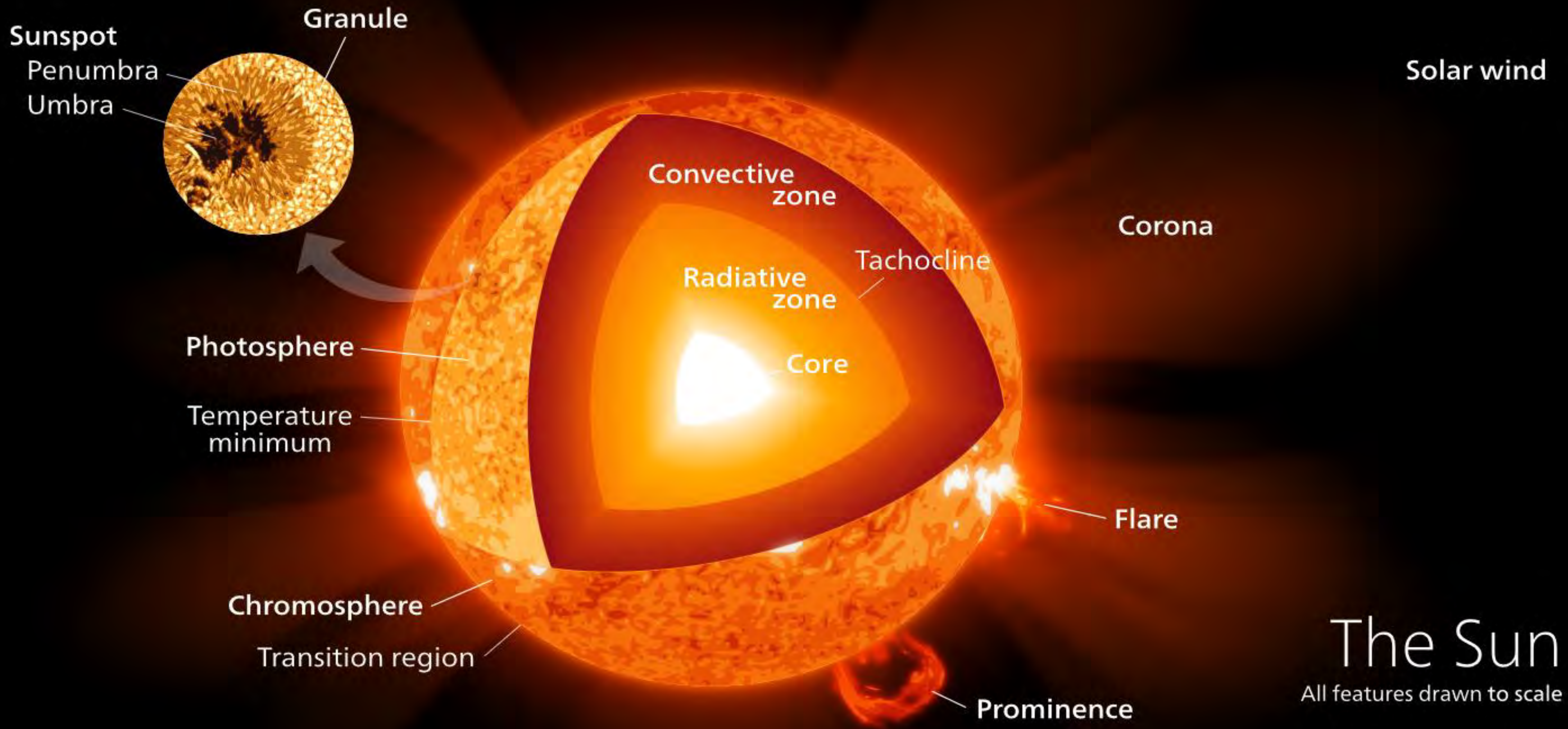


# Video

- This video shows a coronal mass ejection recorded by the Solar Dynamics Observatory on June 18, 2015.
- The video is available at this URL:

<https://youtu.be/icitZubDmFI>







# The Sun

- The radius of the Sun (at the Equator) is  $\sim 696,000$  km.
  - This is called the **solar radius** and denoted  $R_{\odot}$ .
  - It is 109 times the radius of Earth.
- The mass of the Sun is  $\sim 2 \times 10^{30}$  kg.
  - This is called the **solar mass** and denoted  $M_{\odot}$ .
  - It is 333,000 times the mass of Earth.
- The average density of the Sun is  $\sim 1400$  kg/m<sup>3</sup>.
  - It is about 1/4 of the average density of Earth.



# Video

- I will show a video with some nice animations and illustration of the composition of the Sun and relevant phenomena from National Geographic.
- The video is available at this URL:

[https://youtu.be/2HoTK\\_Gqi2Q](https://youtu.be/2HoTK_Gqi2Q)



# Conclusions

- In this lecture, we learned about the Sun, the star at the center of our solar system.
- The Sun isn't just a yellow ball in the sky. There's a lot going on there, both inside and outside!
- Reading: OpenStax Astronomy, chapter 15.
- Exercises: Practice questions will be posted on Teams.