IE350
Alternate Energy Course

Lecture # 4

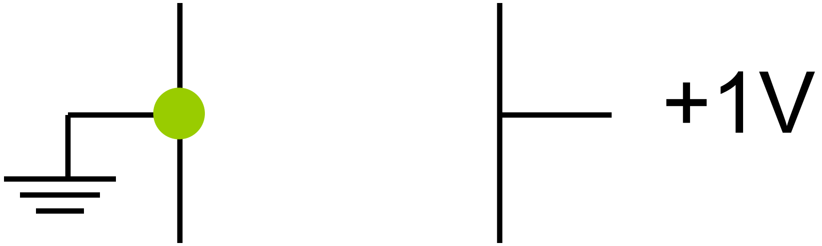
Energy and Power, Solar Astronomy

Energy Units - Calorie

- Calorie (cal) = heat to increase by 1°C the 1 gram of water.
- 1 cal ≈ 4.184 Joules

Very Small Energy Unit, eV

- Electronvolt (eV) - the amount of kinetic energy gained by a single unbound electron when it passes through an electrostatic potential difference of one volt, in vacuum.



- 1 eV = 1.6×10^{-19} J

Energy unit conversion factors

Relationships between different units of measurment for Energy

	INPUT	Calory	Joule	Kilowatt-hour	Erg	Electron-volt	kG*m
Calories	1	1	4.19E+00	1.16E-06	4.18E+07	2.61E+19	4.27E-01
Joules	1.00E+00	2.39E-01	1	2.78E-07	1.00E+07	6.24E+18	1.02E-01
Kilowatt-hours	1	8.60E+05	3.60E+06	1	3.60E+13	2.25E+25	3.67E+05
Ergs	1	2.39E-08	1.00E-07	2.78E-14	1	6.24E+11	1.02E-08
Electron-volts	1	3.83E-20	1.60E-19	4.45E-26	1.60E-12	1	1.63E-20
kG*m-s	1	2.34E+00	9.81E+00	2.73E-06	9.81E+07	6.12E+19	1

Energy and Power

- If power is constant

$$\mathbf{E = P \cdot t, \qquad P = E/t}$$

- If power is variable and depends on time

$$\mathbf{E = \int P(t)dt, \qquad P(t) = dE(t)/dt}$$

Power Units

- Watt (W) = using one J in one second.
- kW = 1000 W
- Horsepower = 735 W
= 0.735 kW
- MW = 1000 kW

Power vs. Energy

- Thus, power is the rate of the energy use.
- Energy is what you pay for repeatedly, as much as you use the energy, the kWh-s – ***variable***, operational cost.
- Power is the capacity to use the energy
- You pay for the capacity usually upfront, ***fixed*** or installation cost.
- E.g. if you decide to buy an air conditioner, you need to solve a power sizing problem. You pay the fixed amount. Later you usually use only a fraction of the total capacity.

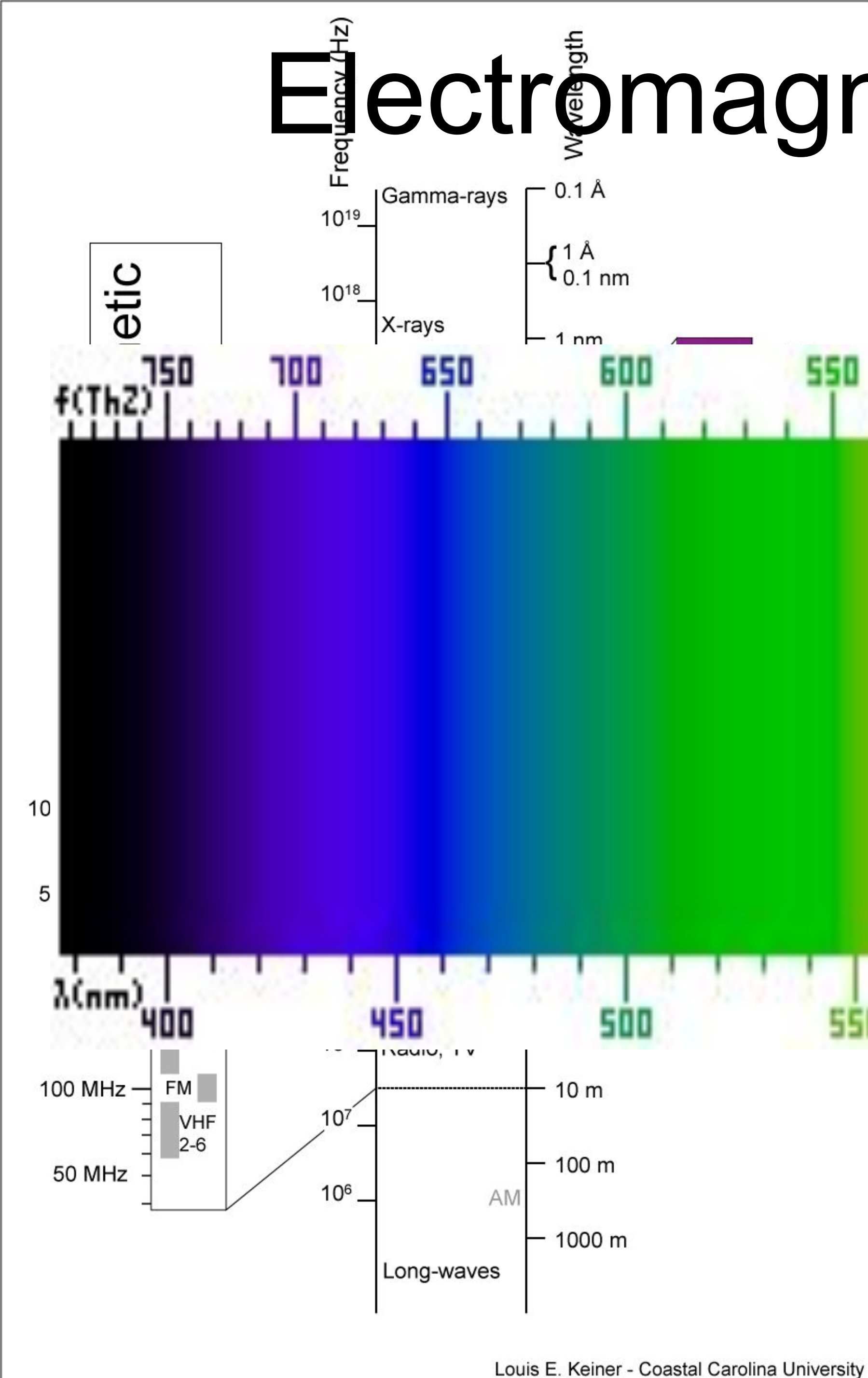
Solar Energy

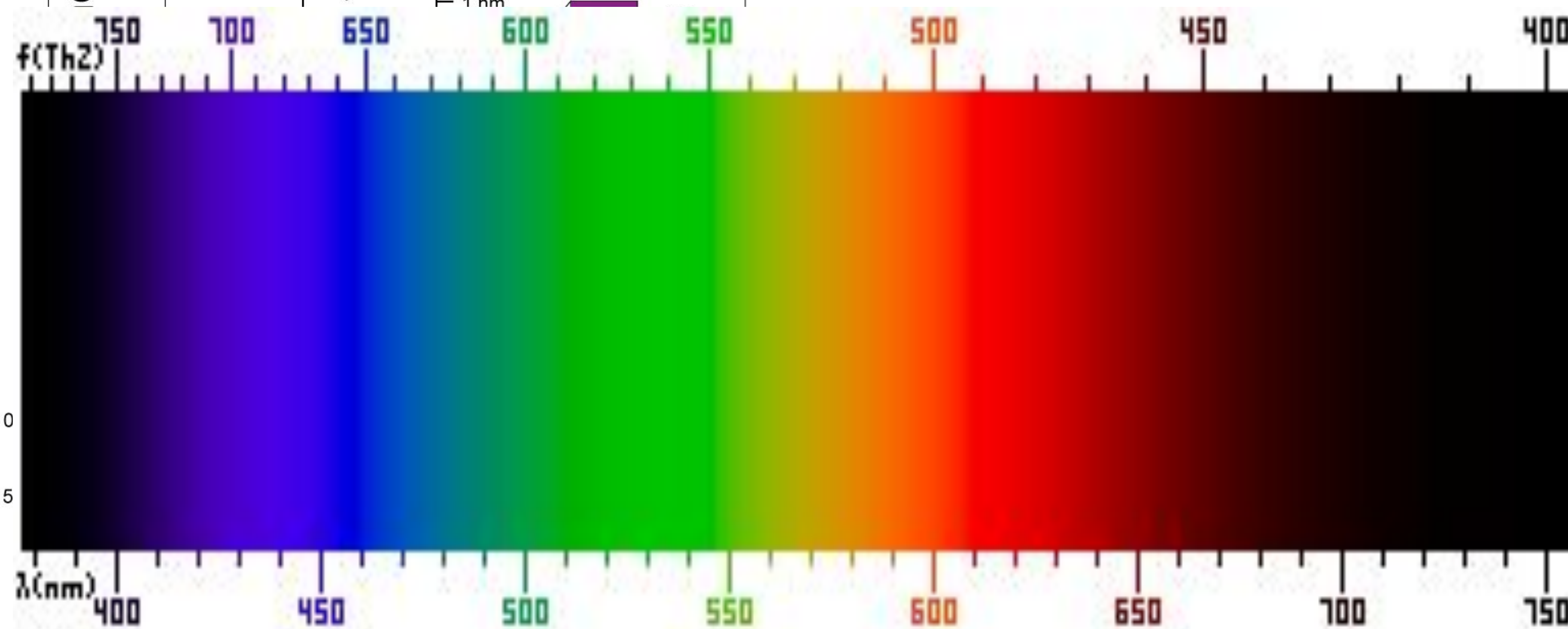
- The SUN:
- Fusion in the sun – the process
- Temperature of the suncrust, black-body radiation – BBR
- Photon energy, light speed, duality
- Electromagnetic Spectrum
- The solar radiation spectrum
- Solar constant = 1366 W/m^2.

The light: particle, wave

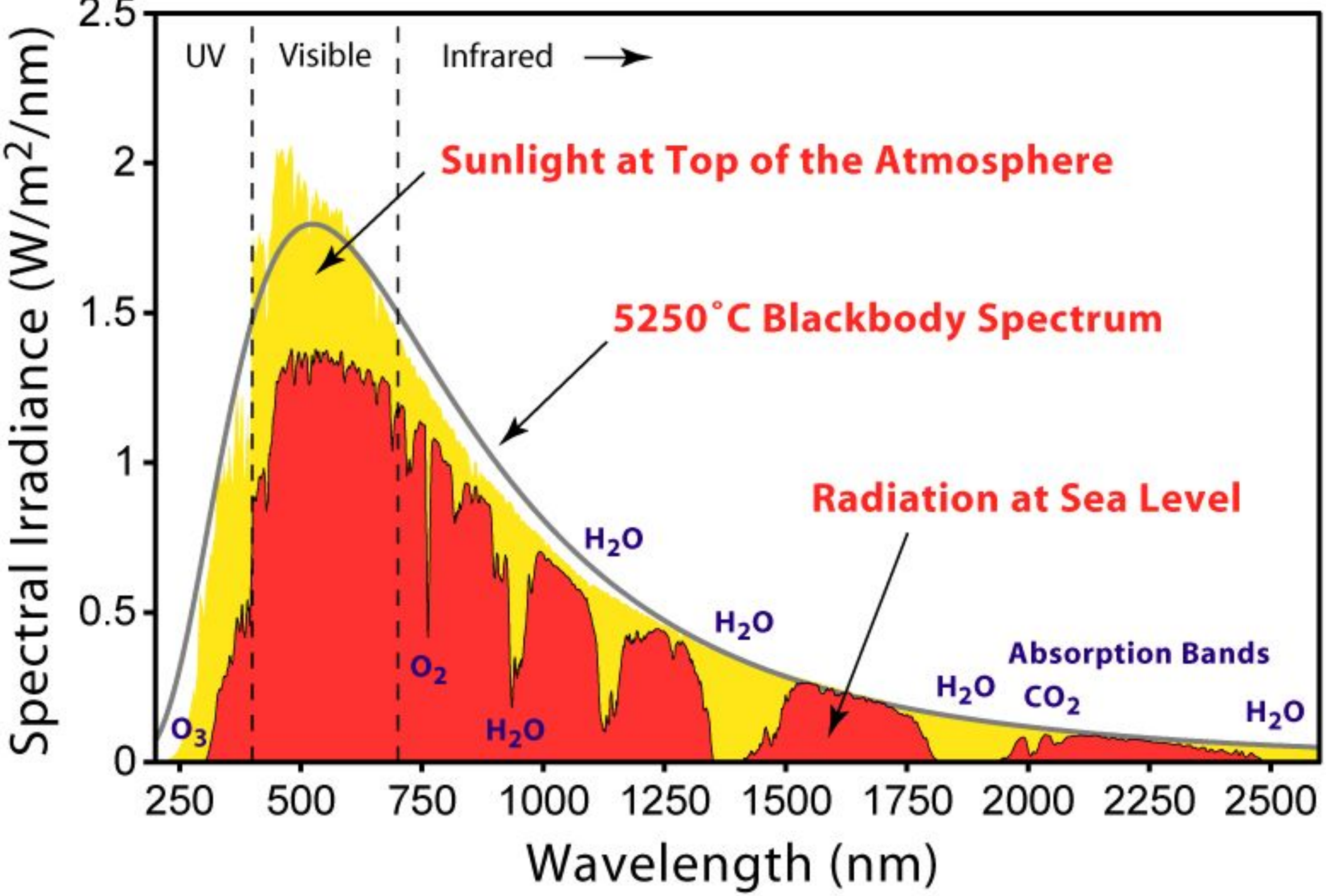
- Particle and wave
- Light speed, $c = 299{,}792{,}458$ m/s
  $c \approx 300{,}000$ km/s
- Photon energy, $E = h\nu$, ν = frequency,
- h is Planck's constant, $h = 6.626\ 10^{-34}$ J s
  $h = 4.135\ 10^{-15}$ eV s.
- $\lambda = c/\nu$
- $E = hc/\lambda$

Electromagnetic Spectrum



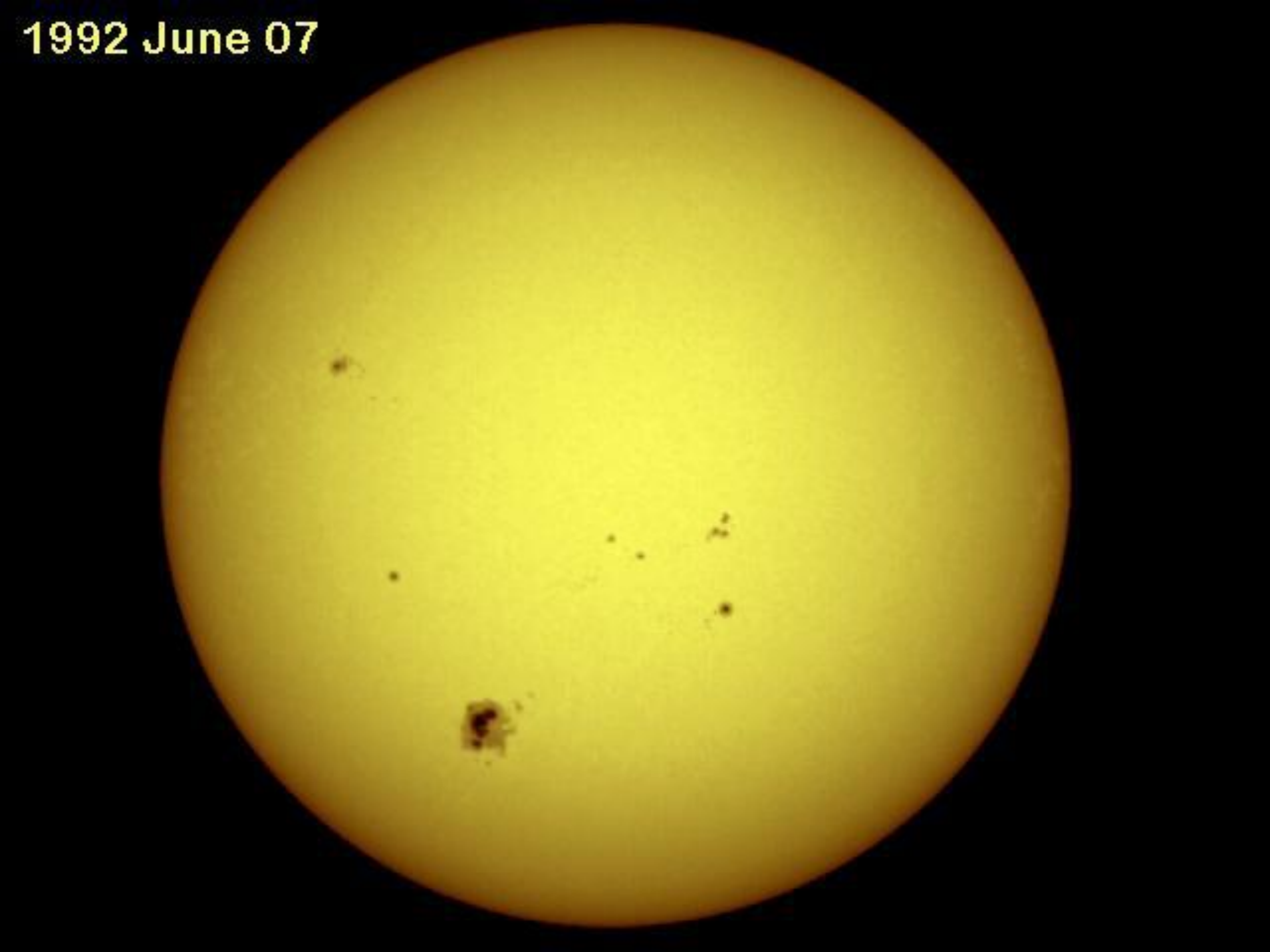


Solar Radiation Spectrum



The Sun

- Sun has a capacity of 3.86×10^{26} W
  3.86×10^{8} EJ/s
- Earth gets only two-billionth part of it.
- 127,400,000 km² - Earth cross-section
- $1.740\ 10^{17}$ W = 0.174 EJ/s
- Armenian annual energy consumption: 0.1752 Quads
- Solar Constant =1366 W/sq.m.
- Average Insolation = ¼ of solar const.
  = 342 W/sq.m.


1992 June 07

How this energy is generated?

- About 74% of the Sun's mass is hydrogen, 25% is helium, and the rest is made up of trace quantities of heavier elements.

How this energy is generated?

- The Sun has a surface temperature of approximately 5,500 K, giving it a white color, which, because of atmospheric scattering, appears yellow.

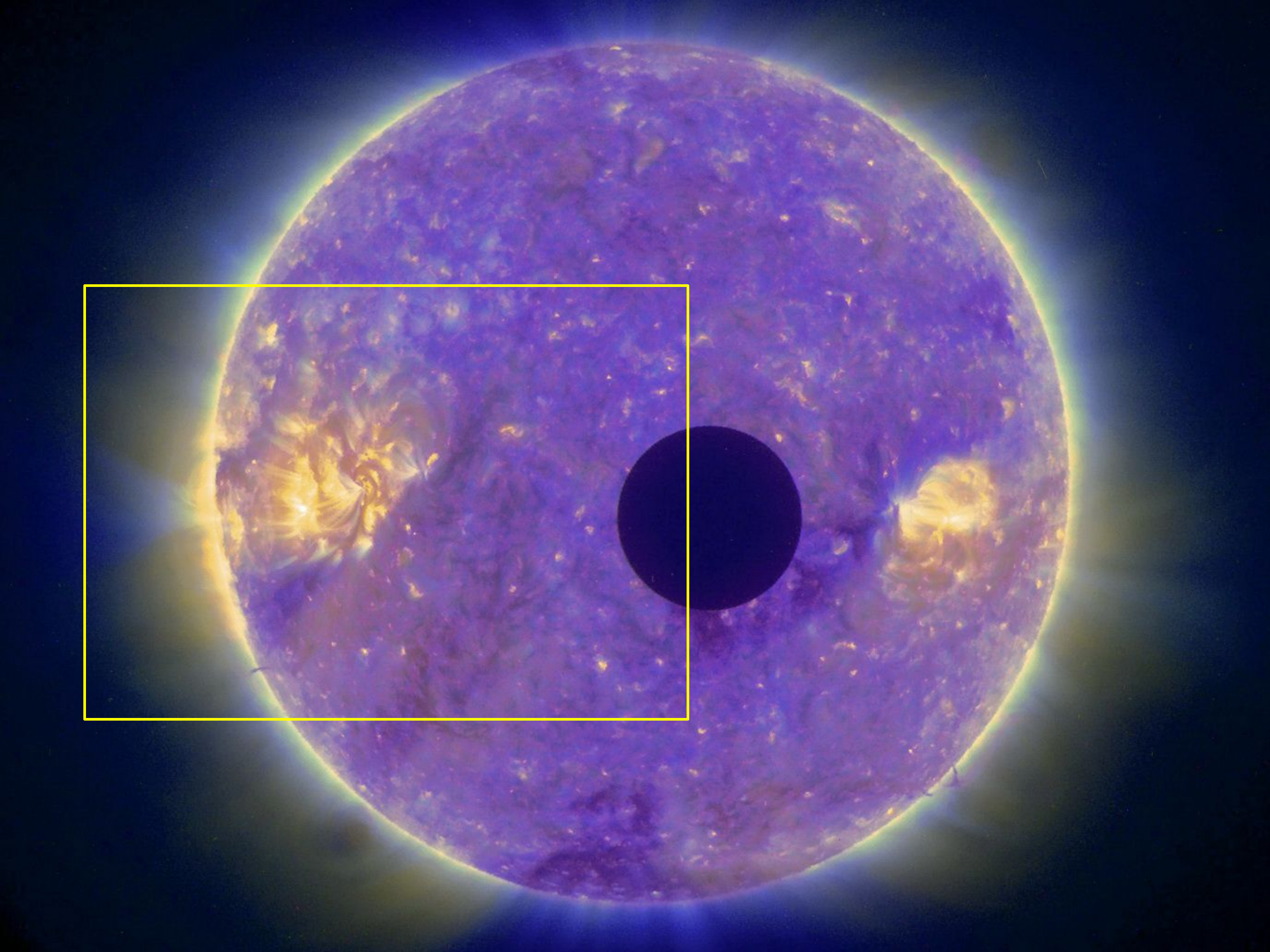
How this energy is generated?

- The Sun diameter:
  1.4 10^6 km = 109 that of the earth.
- Distance from Earth:
  1.5 10^8 km, = 8.31 min at light speed

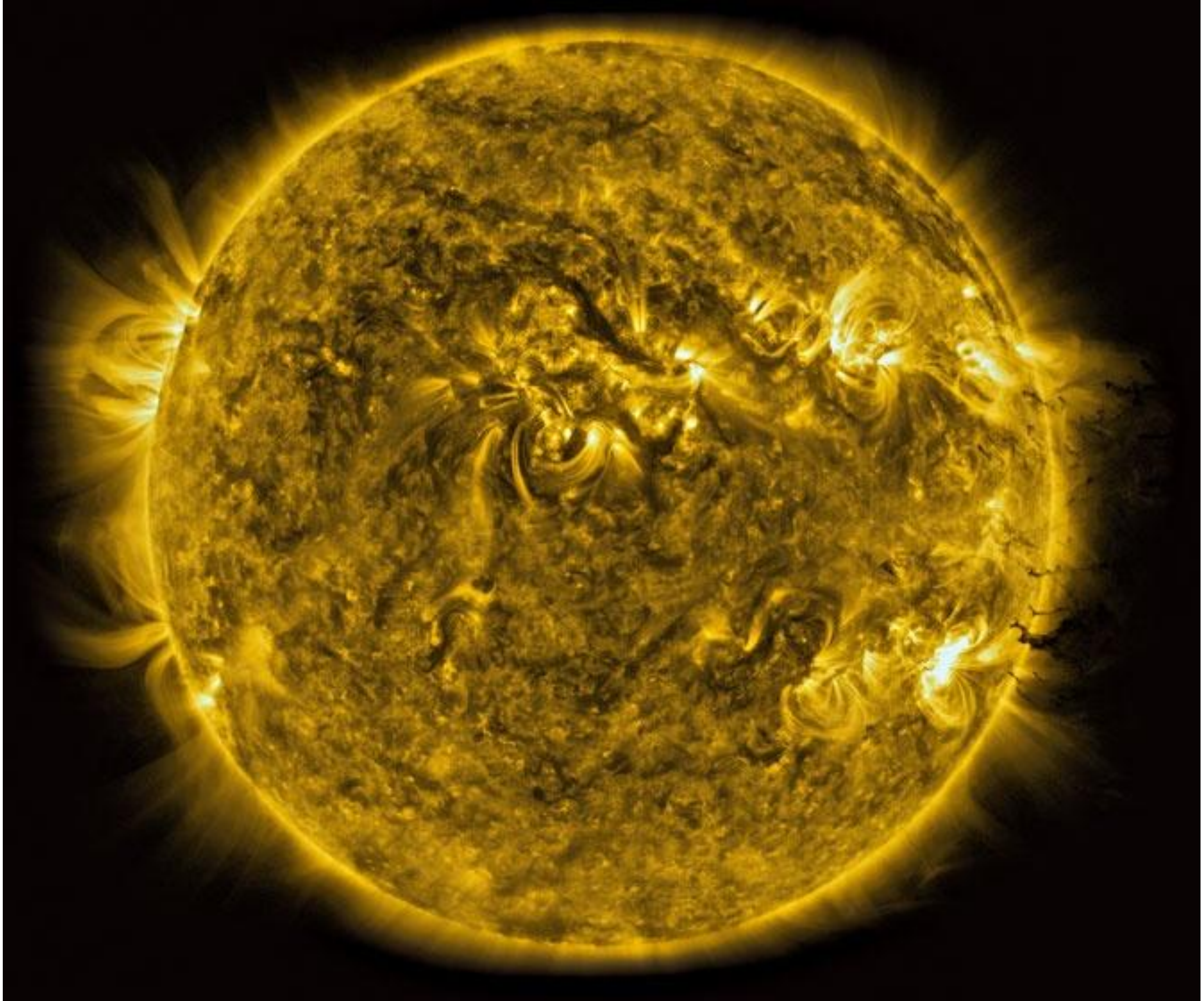
How this energy is generated?

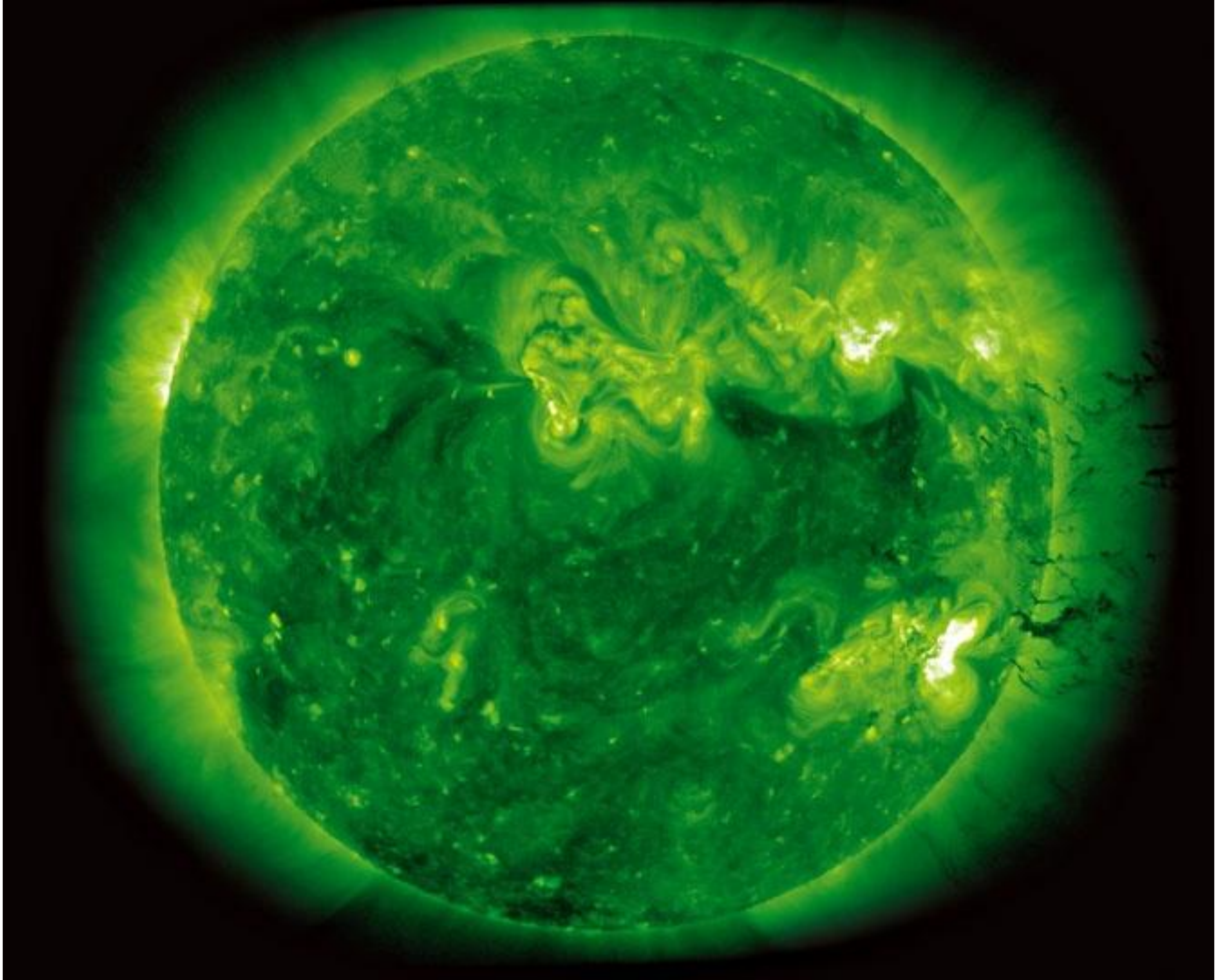
It was *Albert Einstein* who provided the essential clue to the source of the Sun's energy output with his mass-energy relation:

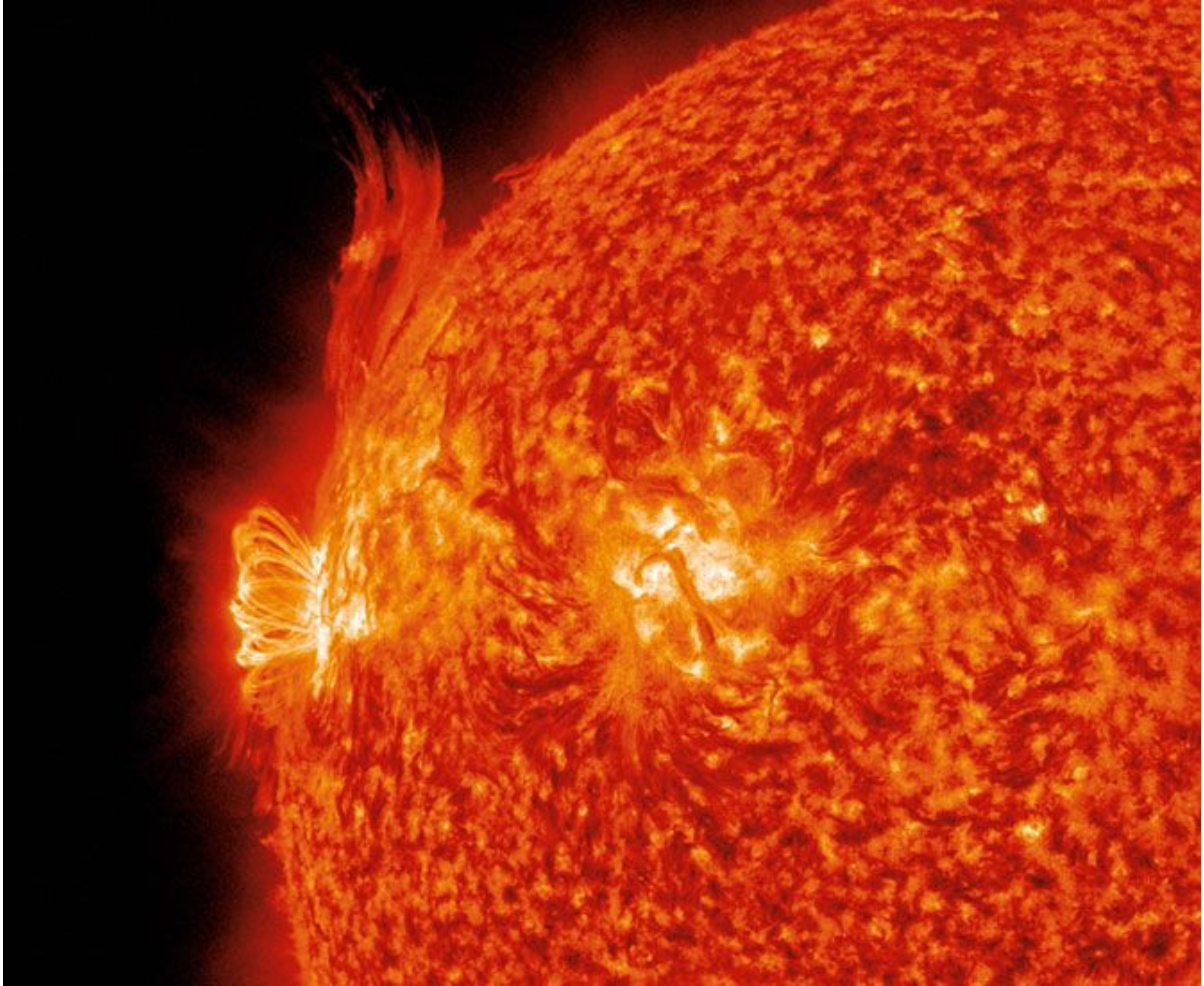
$$\mathbf{E=mc^2}$$

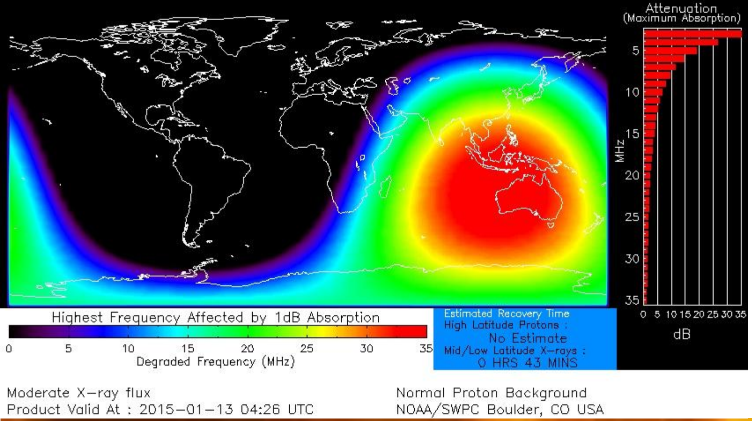


The Sun



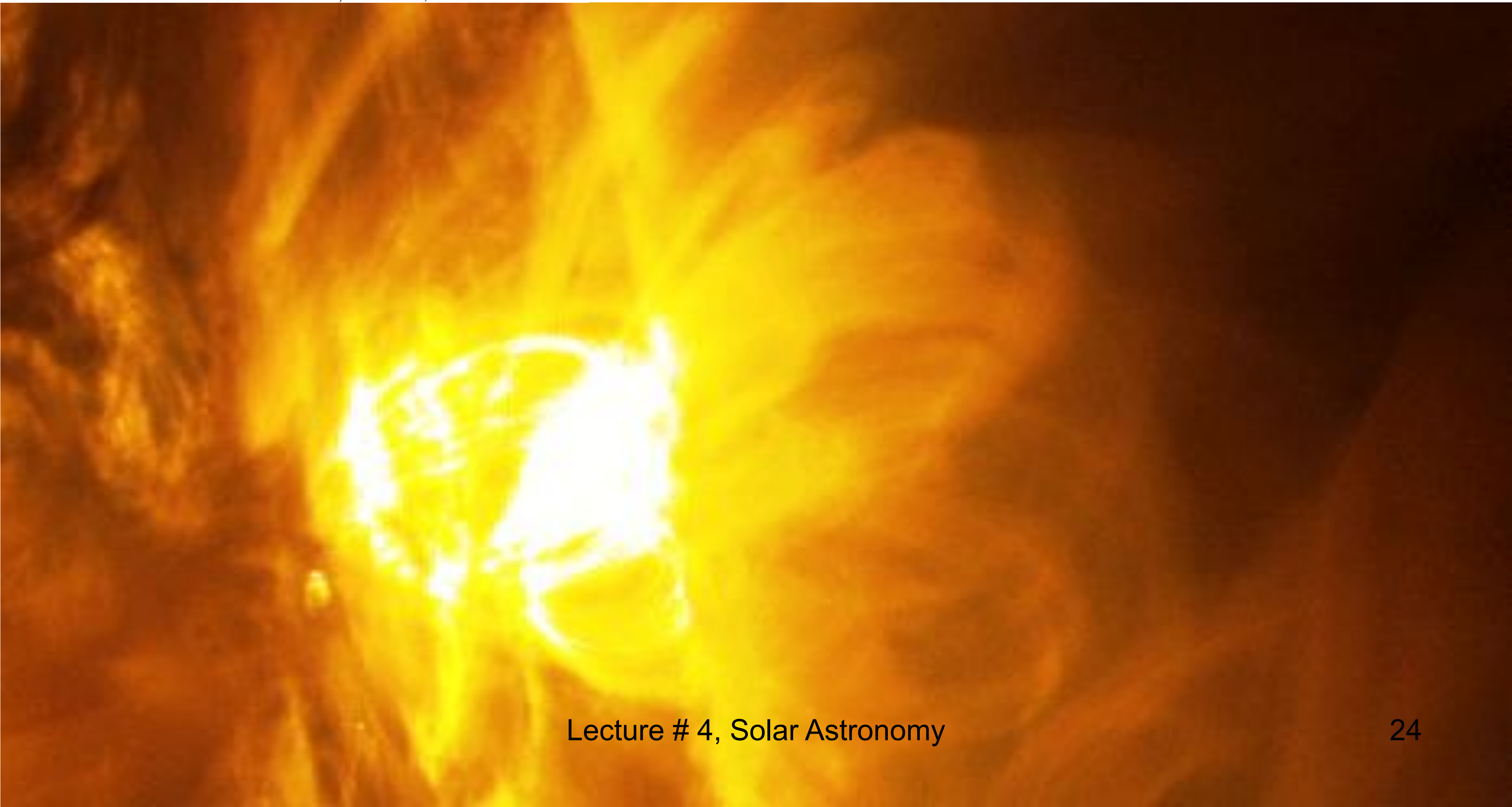


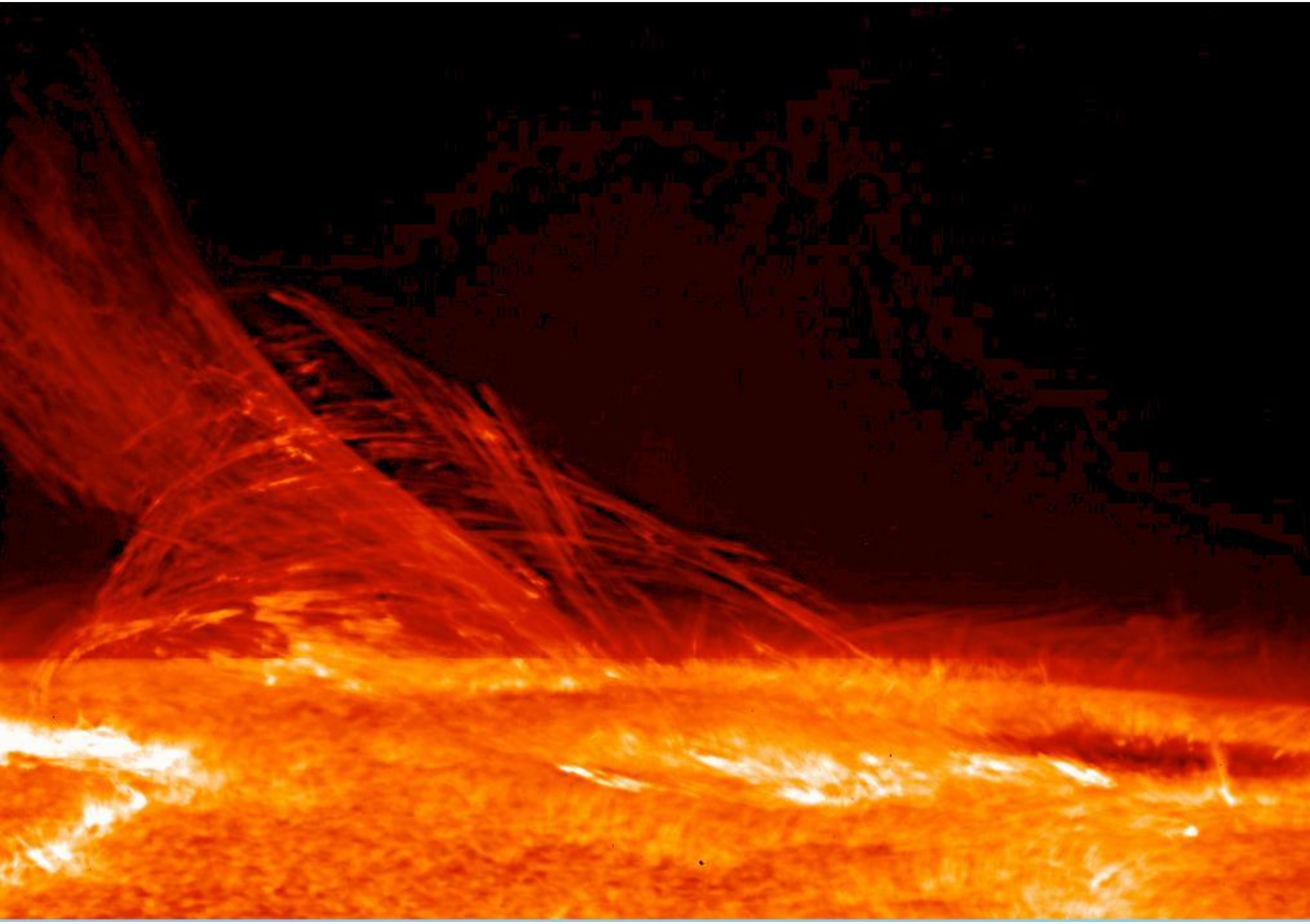


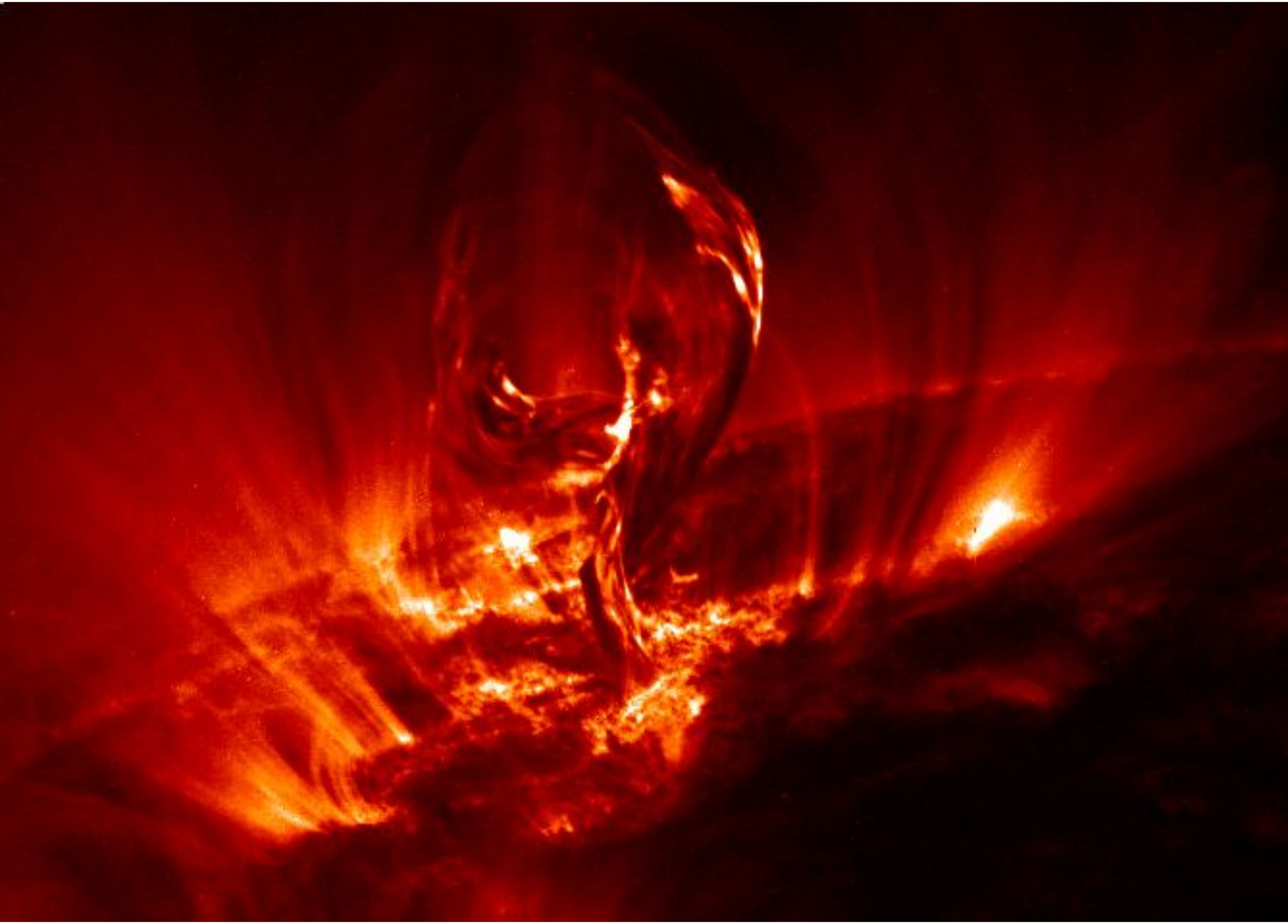


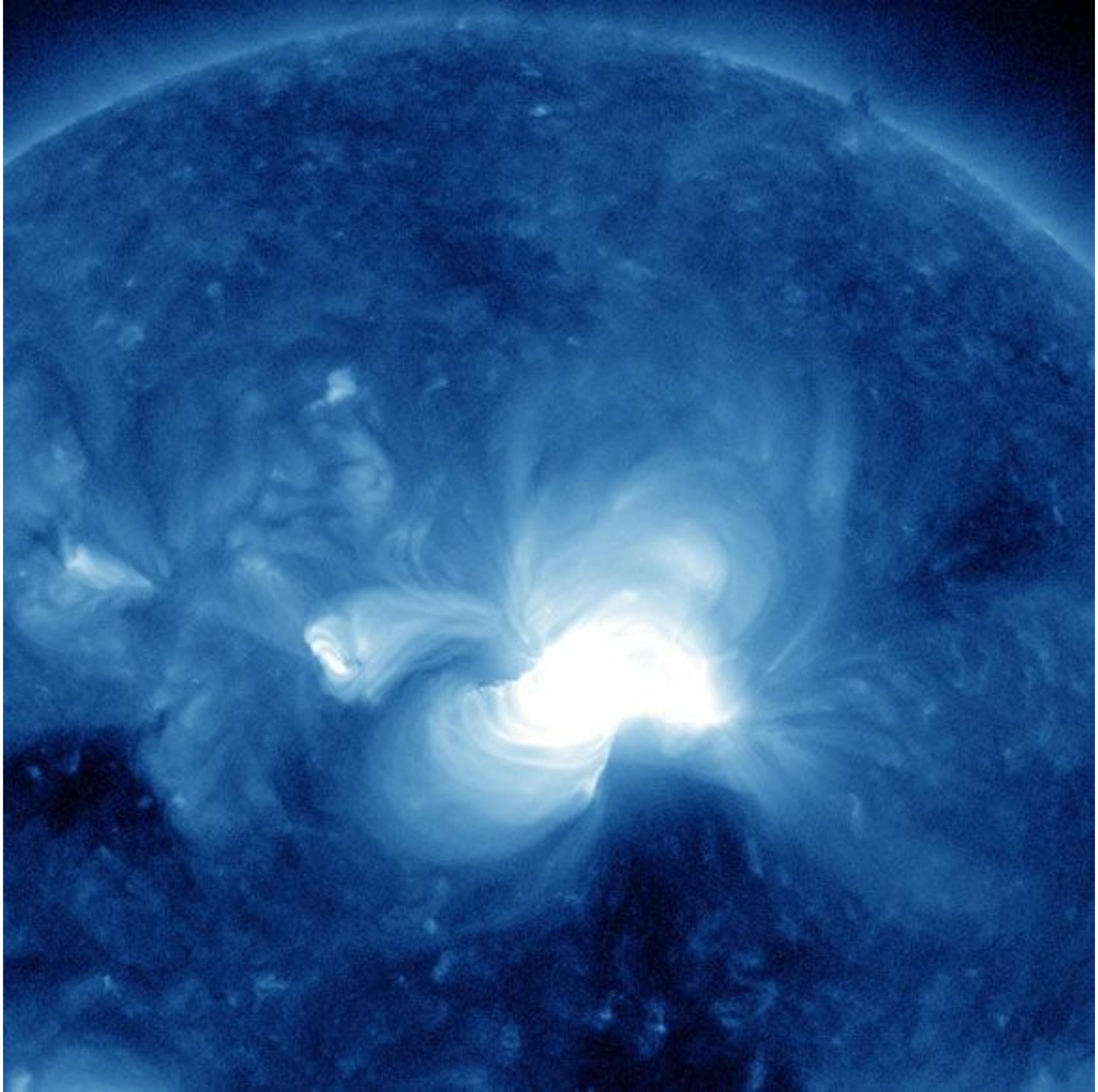
NASA caption: Giant magnetic loops dance on the sun's horizon in concert with the eruption of a solar flare—seen as a bright flash of light—in this imagery from NASA's Solar Dynamics Observatory, captured Jan. 12-13, 2015.

Image Credit: NASA/SDO







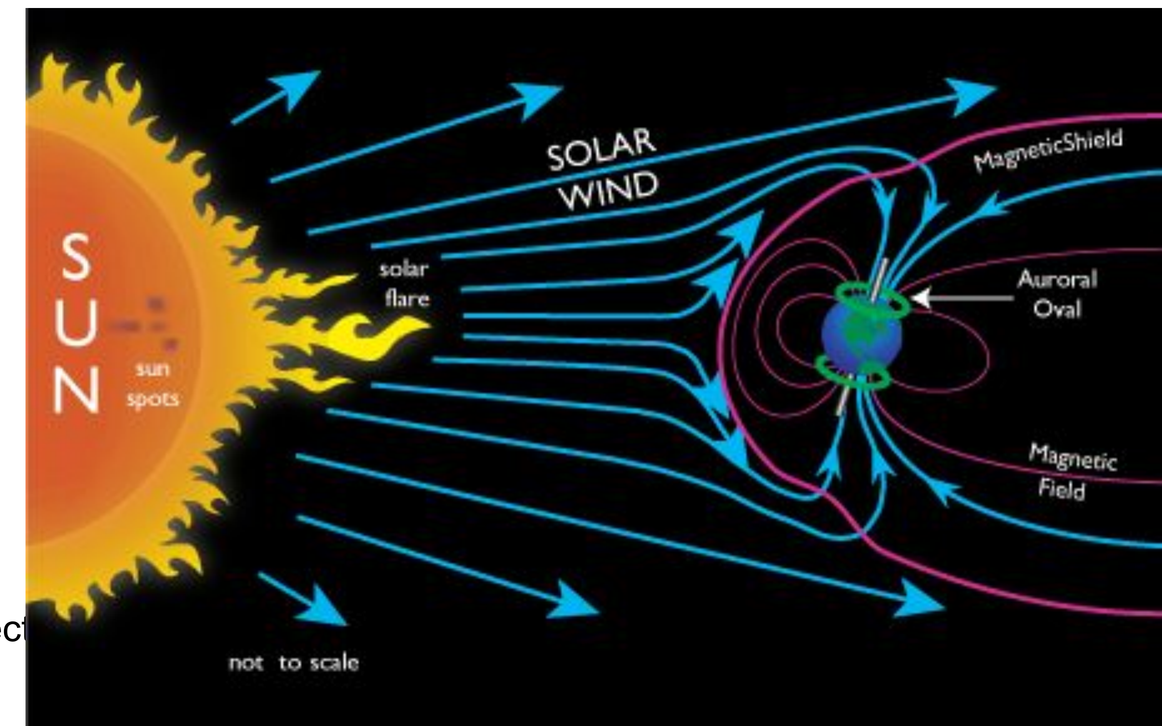


Sun surface videos

- https://www.youtube.com/watch?v=ipvfwPqh3V4
- https://www.youtube.com/watch?v=0WW1HN0iG0M
- https://www.youtube.com/watch?v=lpzCSZ7Eerc
- https://www.youtube.com/watch?v=nmDZhQAleXM

Solar wind

- The total number of particles carried away from the Sun by the solar wind is about 1.3 $\times 10^{36}$ per second.
- Thus, the total mass loss is about 4–6 billion tons per hour.
- Composed of:
  - electrons,
  - protons
  - alpha particles



Elementary particles flow from Sun – Solar Wind

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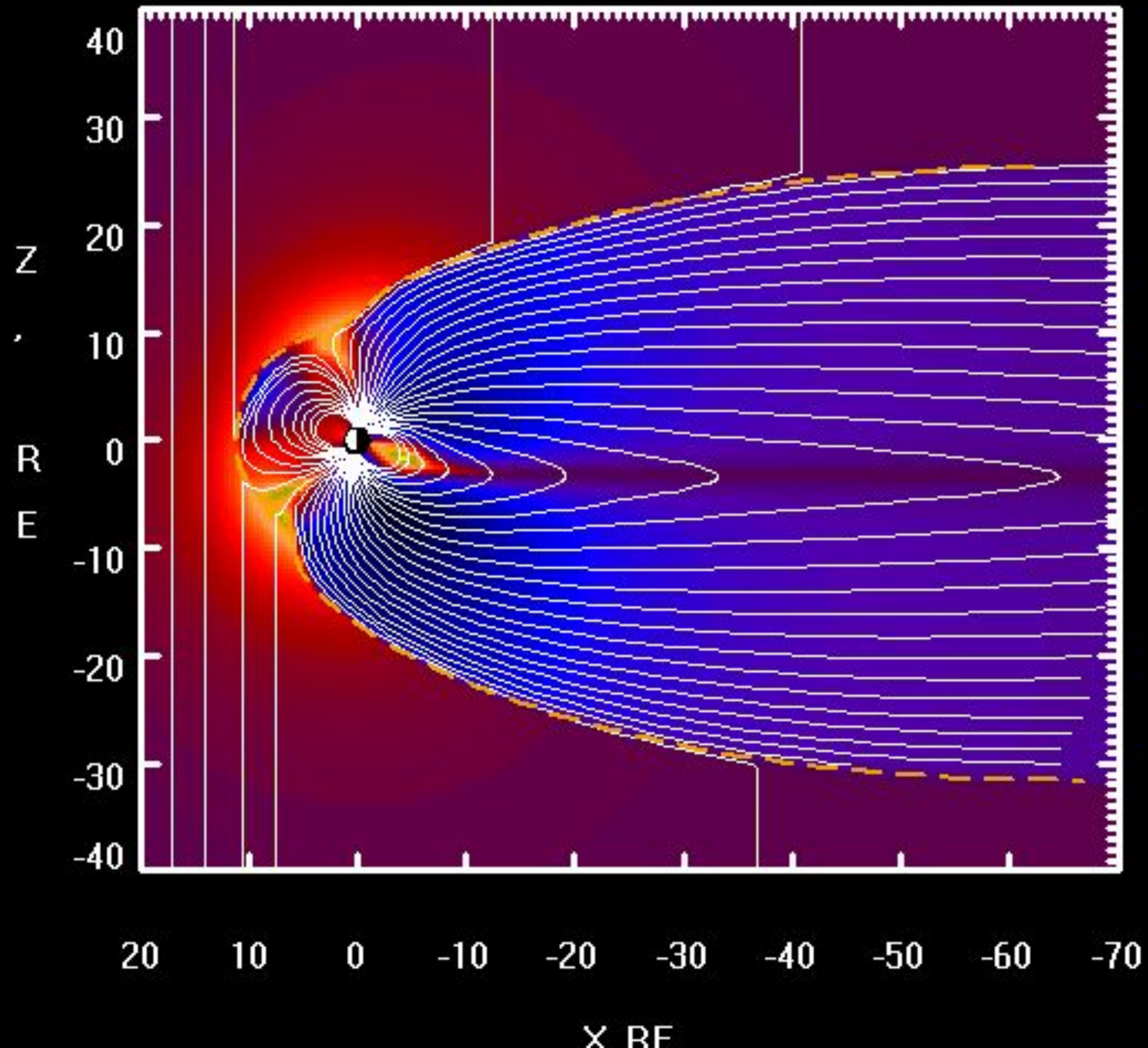
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X RE

Aurora Borealis

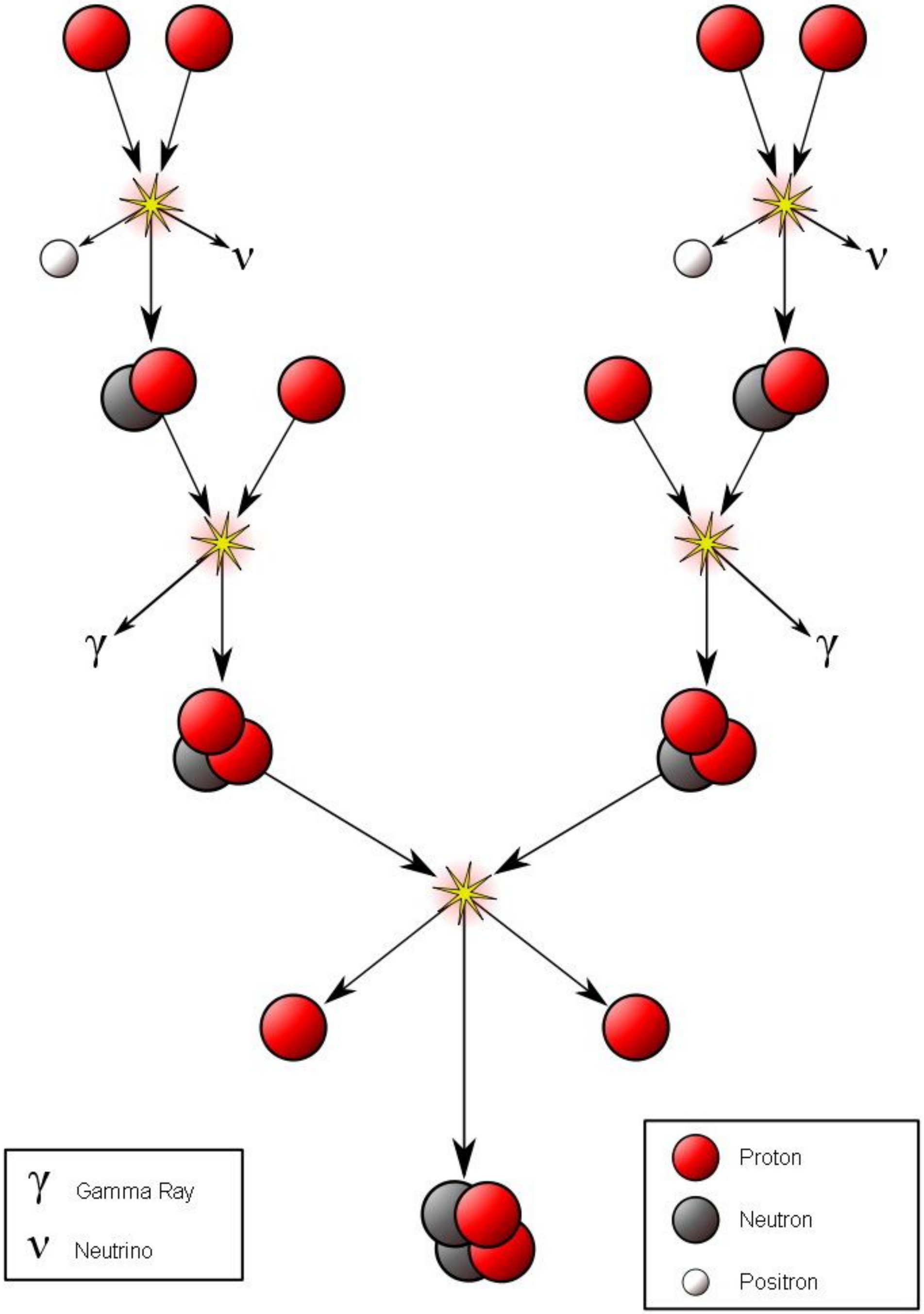
- https://www.youtube.com/watch?v=hsMW7zbzsUs
- https://www.youtube.com/watch?v=Vdb9IndsSXk
- https://www.youtube.com/watch?v=pjgvGiEHlNs

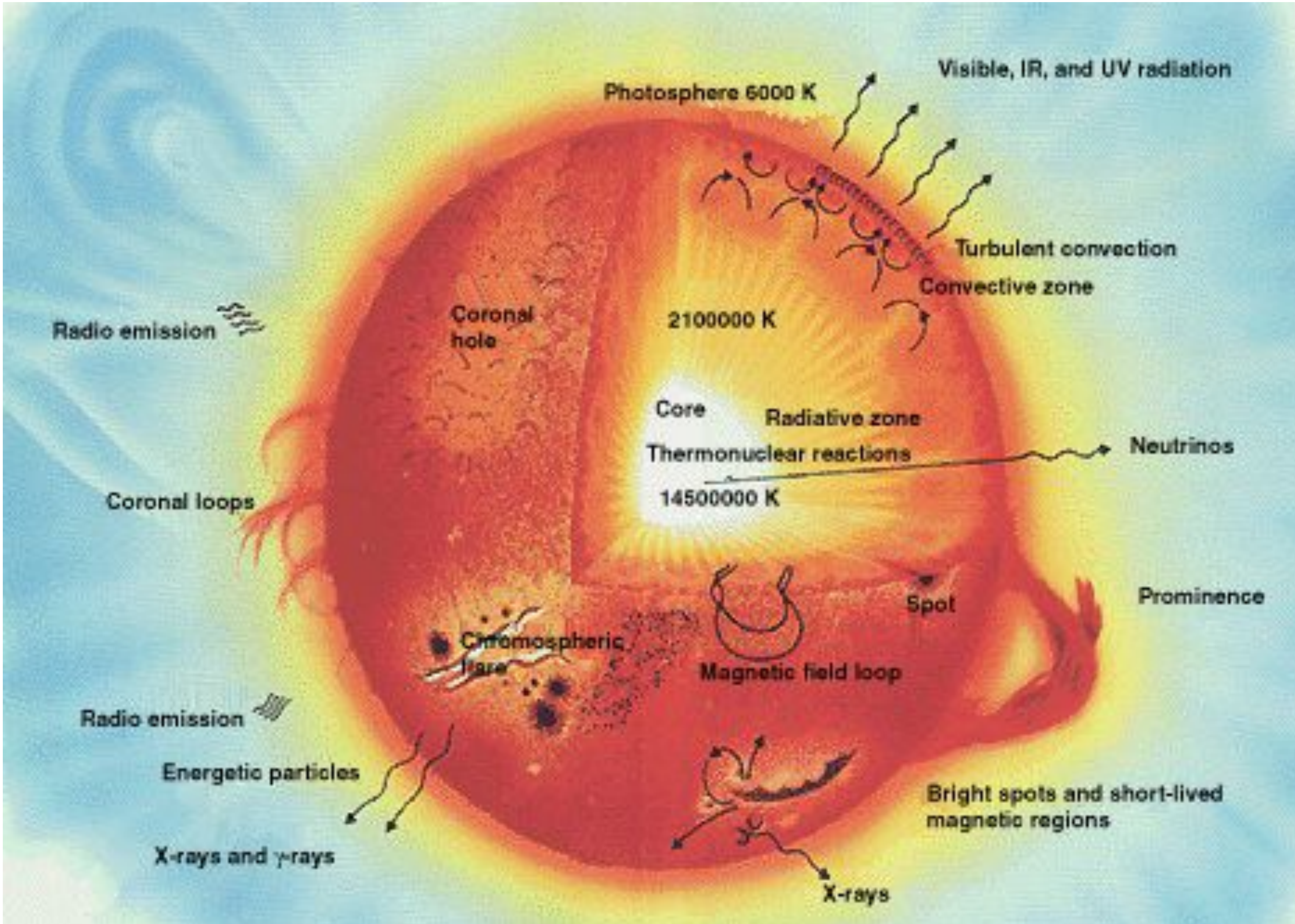
How this energy is generated?

In 1920 Sir Arthur Eddington proposed that the pressures and temperatures at the core of the Sun could produce a nuclear ***fusion*** reaction that merged hydrogen into helium, resulting in a production of energy from the ***net change in mass***.

This actually corresponds to a surprisingly low rate of energy production in the Sun's core—about 0.3 μW/cm³ (microwatts per cubic cm), or about 6 μW/kg of matter.

For comparison, the human body produces heat at approximately the rate 1.2 W/kg, roughly a million times greater per unit mass.





Visible, IR, and UV radiation
Photosphere 6000 K
Turbulent convection
Convective zone
Coronal hole
2100000 K
Radio emission
Core
Radiative zone
Neutrinos
Thermonuclear reactions
Coronal loops
14500000 K
Spot
Prominence
Magnetic field loop
Radio emission
Energetic particles
Bright spots and short-lived magnetic regions
X-rays and γ-rays
X-rays

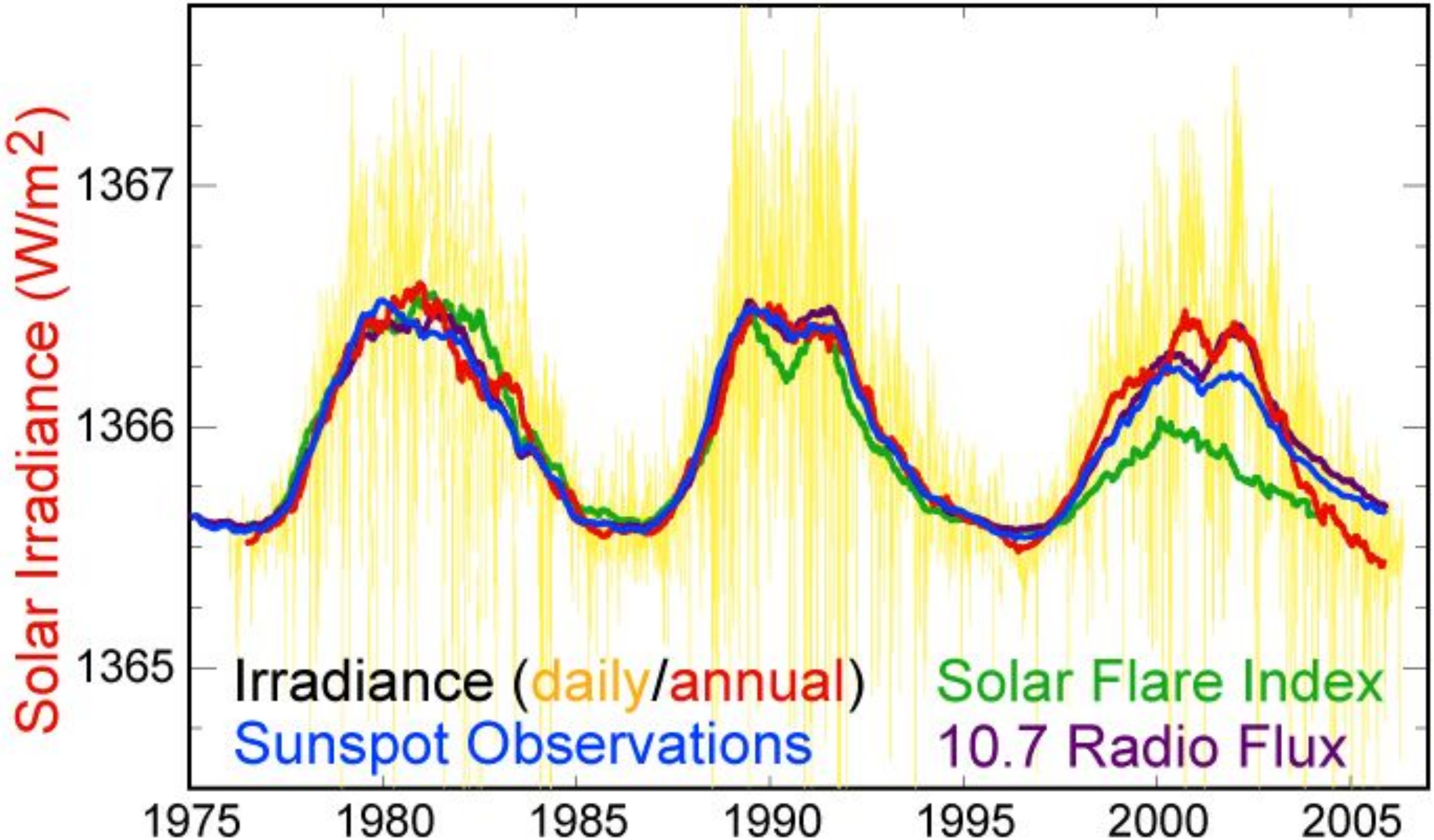
How this energy is generated?

most of the elements in the universe had been created by nuclear reactions inside stars like the Sun.

1.5 The future of energy resources

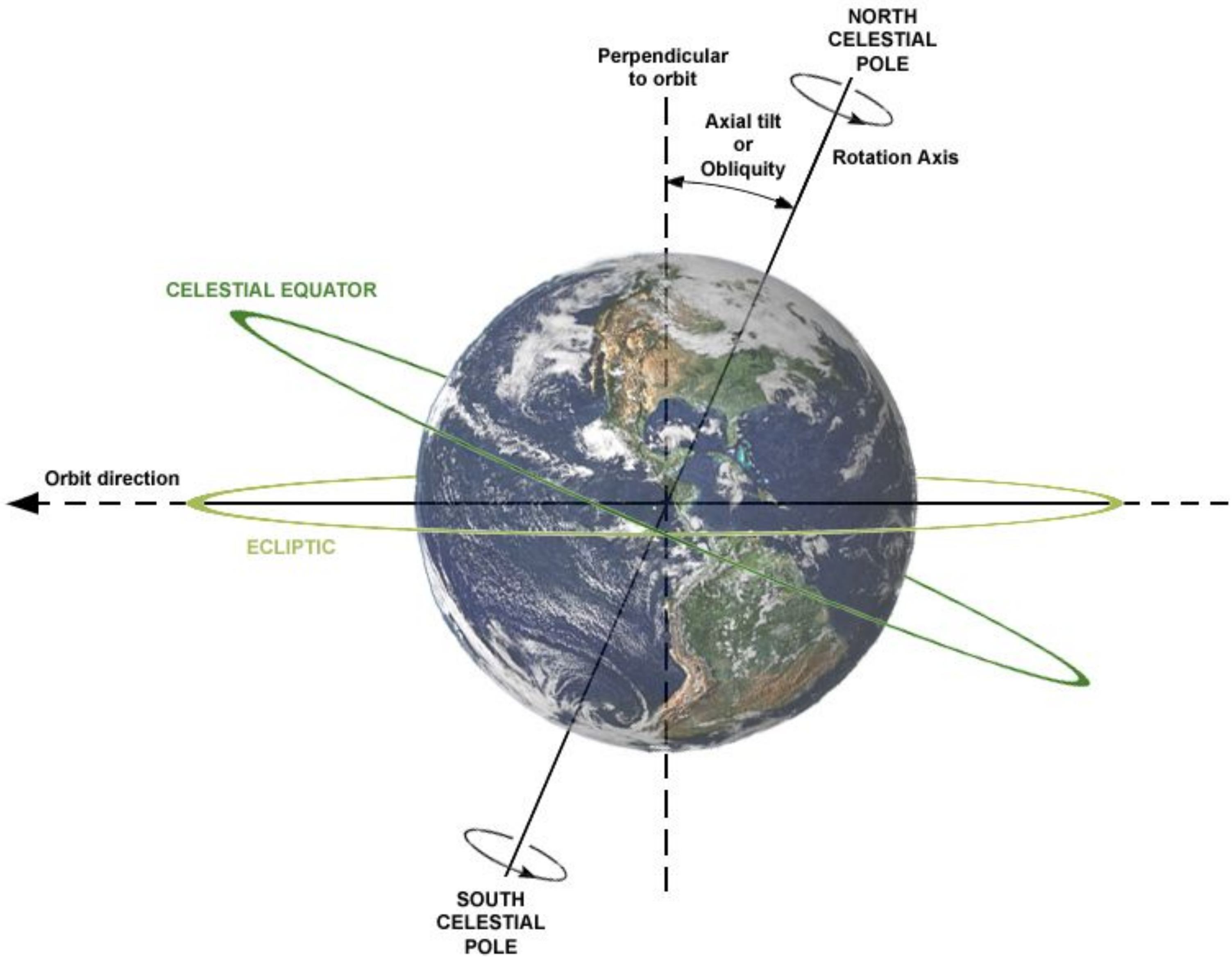
- Solar Constant = 1366 W/sq.m.
- Sahara's surface area = 9,000,000 sq.km.
- If we use 10% of Sahara with 12.5% efficiency, we will get 1000 Exajoules/year!
- This is twice as much as current world consumption.
- I can see the future «Ocean Solar Power Plants», that produce Hydrogen!
- However, population grows exponentially!

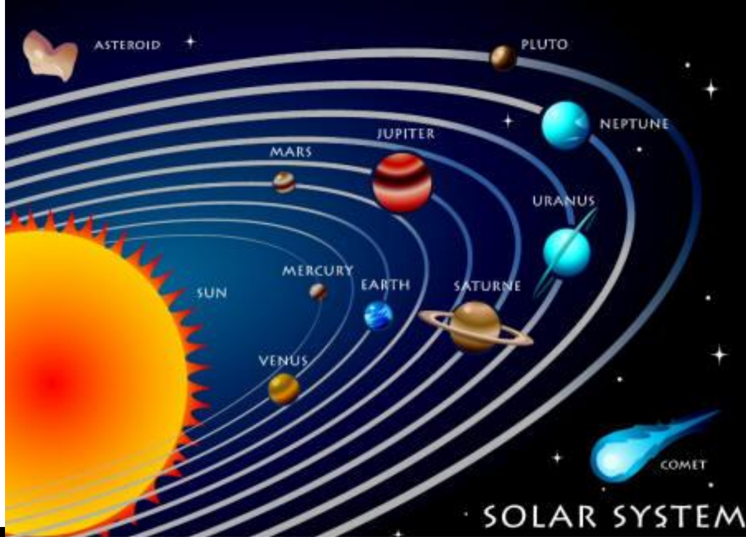
Solar Cycle Variations



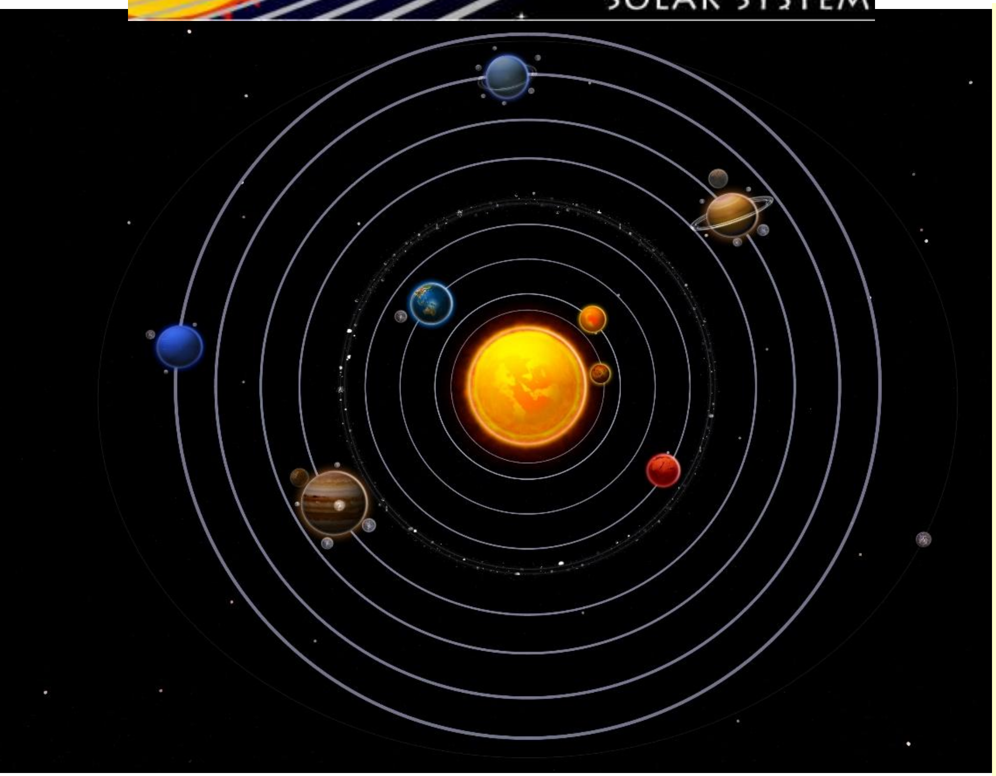
Earth's rotation

- Earth's rotation tilts about 23.5 degrees on its pole-to-pole axis, relative to the plane of Earth's solar system orbit around our sun.
- As the Earth orbits the sun, this creates the 47-degree peak solar altitude angle difference, and the hemisphere-specific difference between summer and winter.


NORTH CELESTIAL POLE
Perpendicular to orbit
Axial tilt or Obliquity
Rotation Axis
CELESTIAL EQUATOR
Orbit direction
ECLIPTIC
SOUTH CELESTIAL POLE

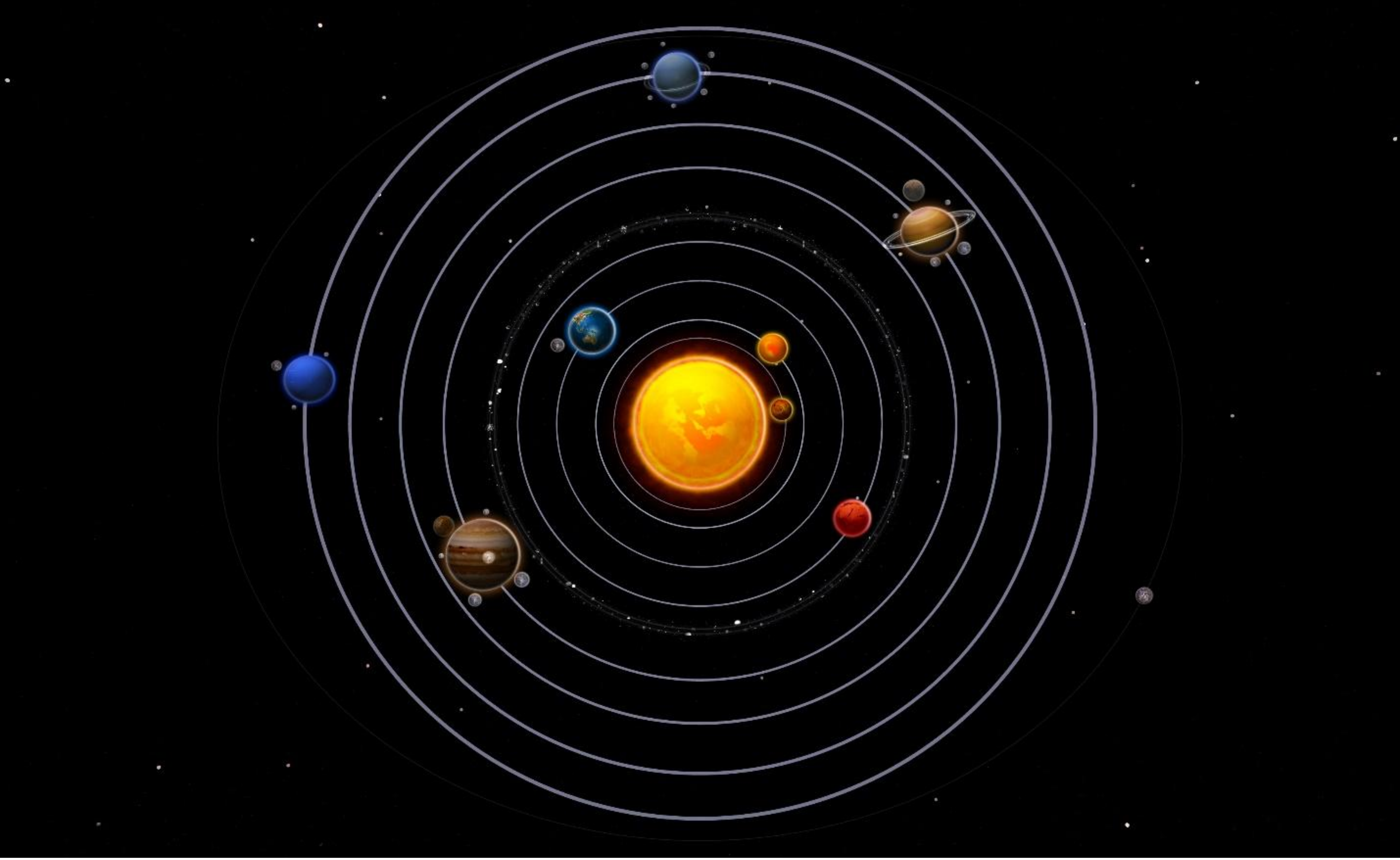


Solar Constant



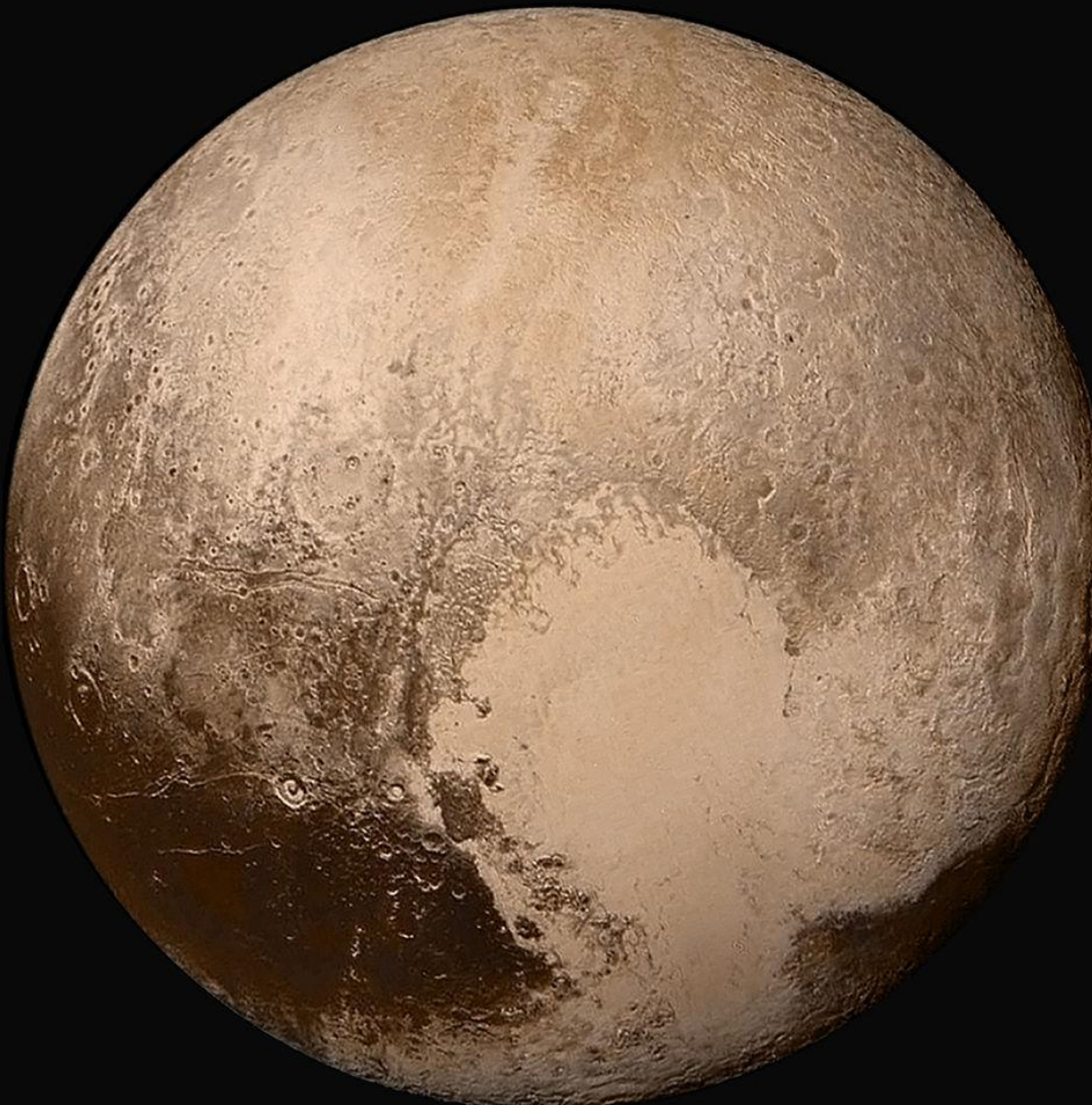
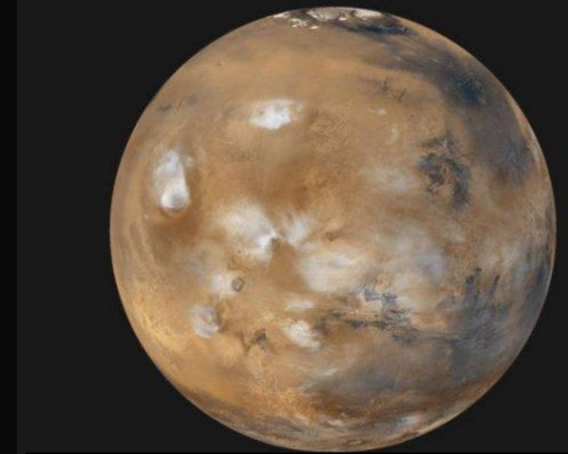
Planets, Distances and Incidences

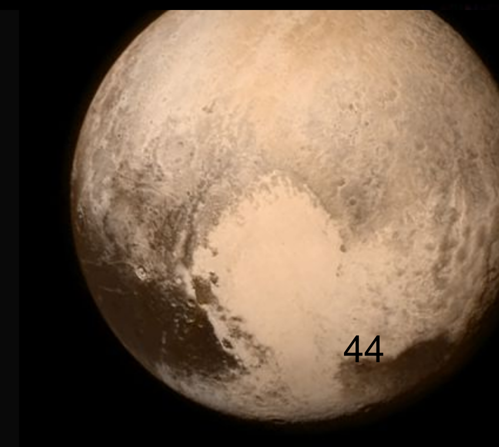
Planet	Mean Radius (AU)	Solar Radiation Incidence (W/m^2)
Mercury	0.387	9,121
Venus	0.720	2,635
Earth/Moon	**1.000**	**1,366**
Mars	1.520	591
Asteroid Belt	2.500	219
3.5 AU Distance	3.500	112
Jupiter	5.190	51
7 AU Distance	7.000	28
Saturn	9.510	15
Uranus	19.000	4
Neptune	30.000	1.5
Pluto	39.480	0.9

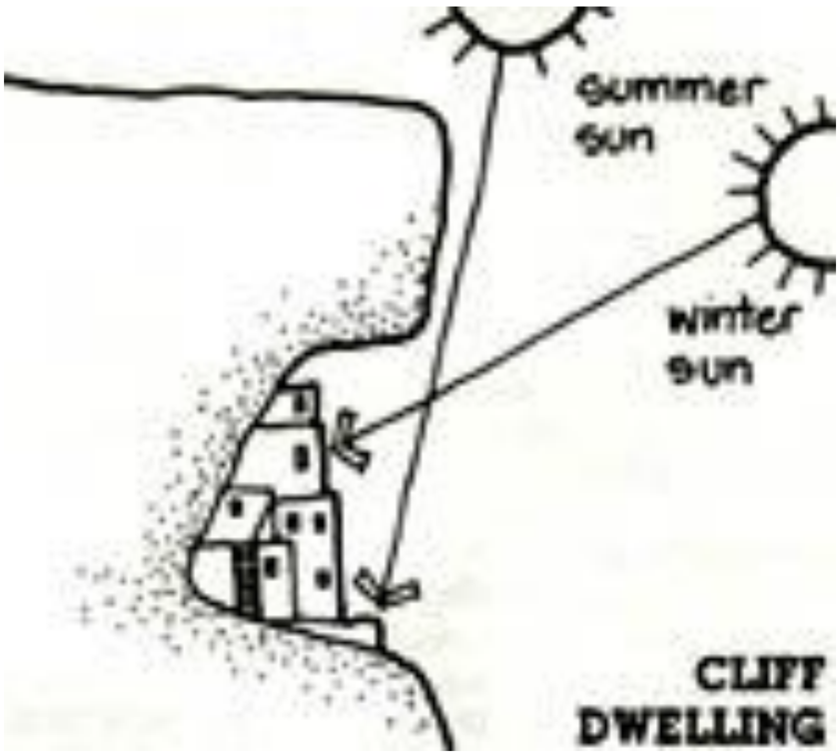


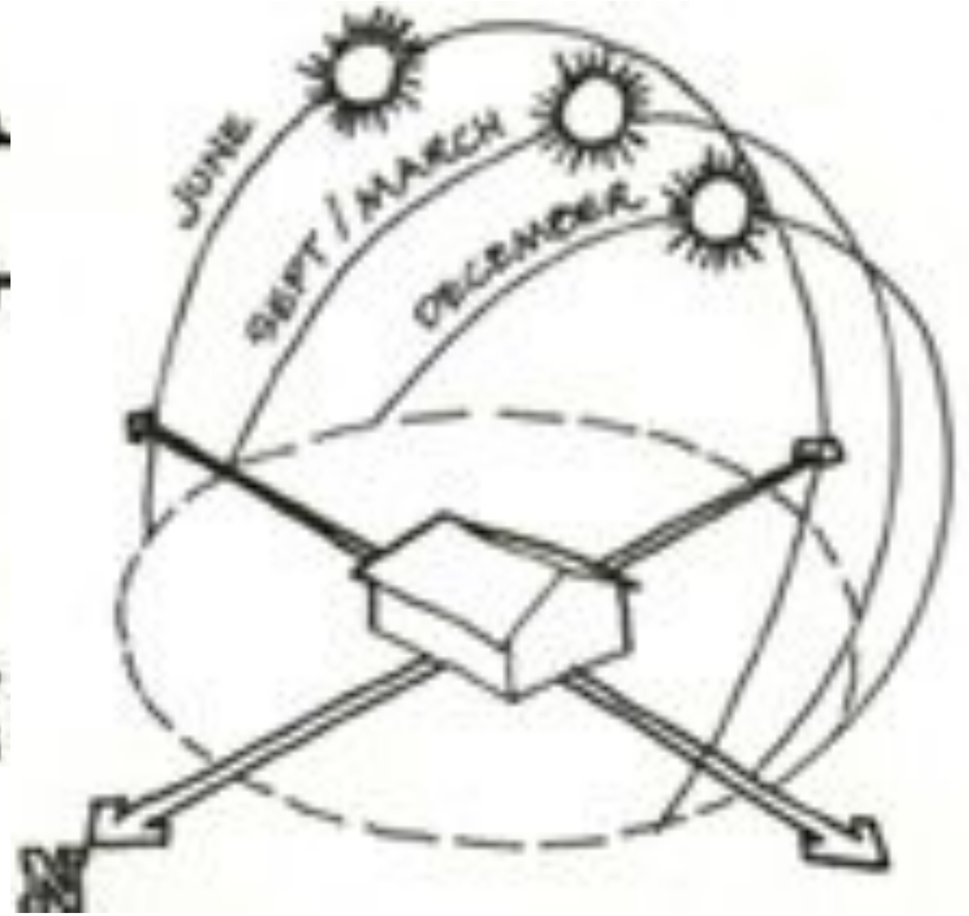
Now: go to the article
http://www.wired.com/2015/07/pluto-new-horizons-2/


NEW HORIZONS'
LONG, DARK, AMAZING
JOURNEY TO PLUTO...
AND BEYOND
BY SARAH ZHANG




summer sun
winter sun
CLIFF DWELLING


JUNE
SEPT / MARCH
DECEMBER

Airmass

- In astronomy, airmass is the optical path length through Earth's atmosphere for light from a celestial source.
- As it passes through the atmosphere, light is attenuated by scattering and absorption; the more atmosphere through which it passes, the greater the attenuation.
- Consequently, celestial bodies at the horizon appear less bright than when at the zenith.

Earth Atmosphere

Rayleigh scattering

$$\sigma_s = \frac{2\pi^5}{3}\frac{d^6}{\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2$$

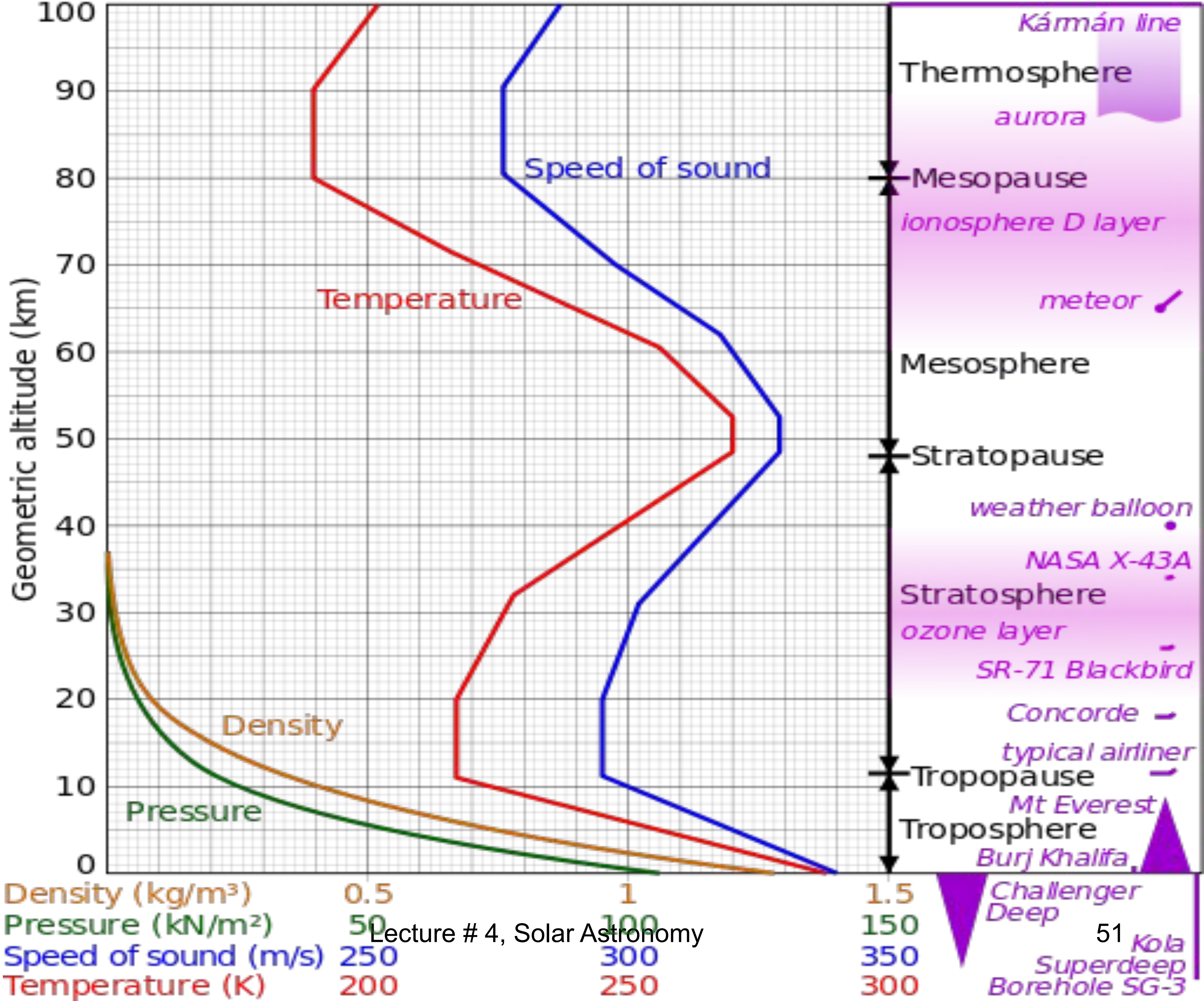
Airmass

- "Airmass" normally indicates relative airmass, the path length relative to that at the zenith at sea level, so by definition, the sea-level airmass when the sun is at the zenith is 1.
- Airmass increases as the angle between the source and the zenith increases, reaching a value of approximately 38 at the horizon.
- Airmass can be less than one at an elevation greater than sea level.

Airmass

- Atmosphere height = 8.5 ÷ 11 km.
- Earth's mean radius is 6371 km.
- Airmass abbreviation: AM##.
- E.g. at angle of approximately 60 degrees over horizon we have AM2, = 62% of solar constant.
- The solar panels are often rated at AM1.5
- The maximum airmass at horizon is: AM35.5 ÷ AM39
- At sea level, AM1 attenuates @ 27%.
- At AM10 we have 23X attenuation
- At AM20 we have >10000X attenuation

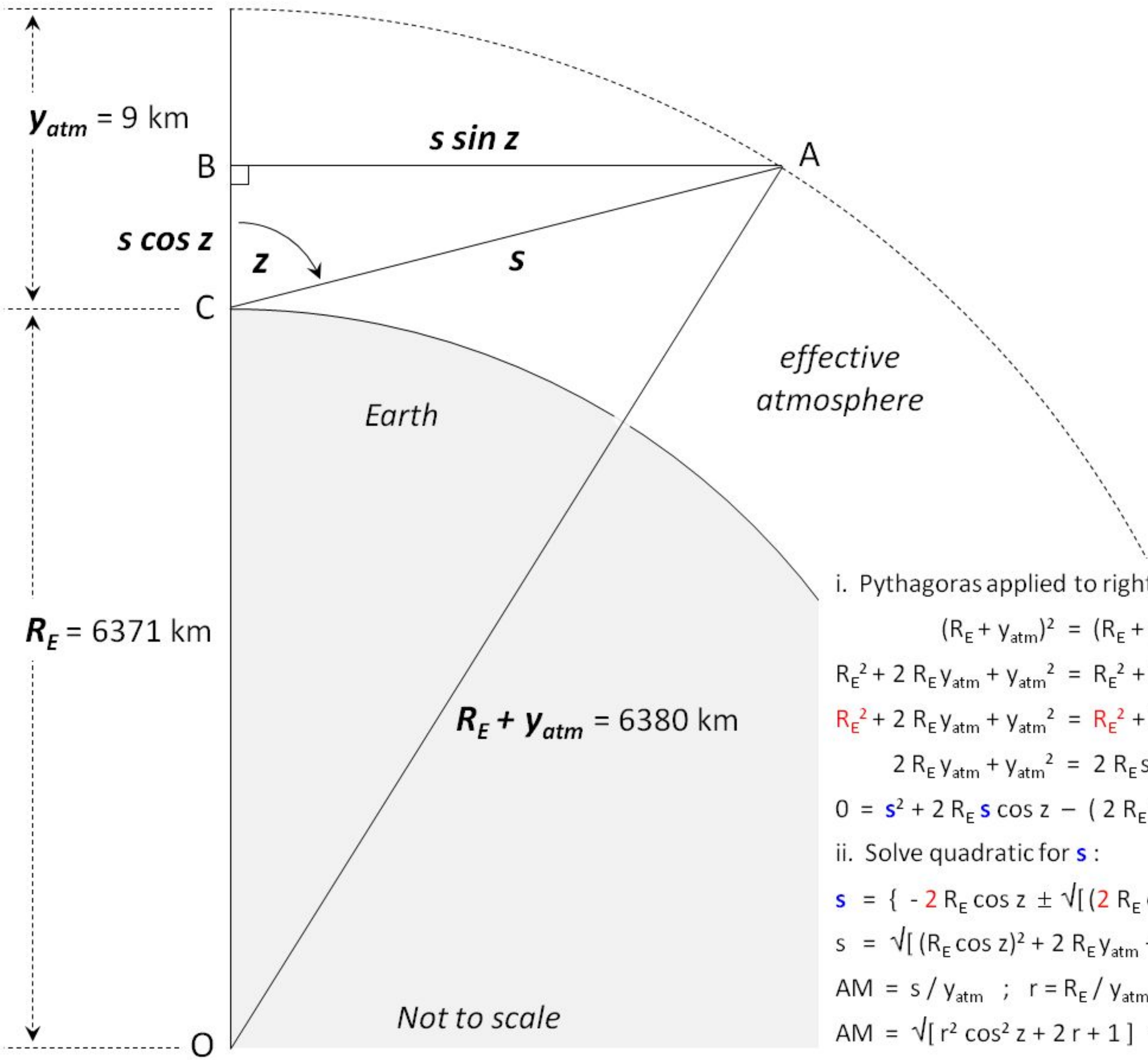
Earth Atmosphere



Numbers to remember

- Solar constant = $1366 W/m^2$
- Attenuation at AM1 = 27%
- Scattered light capacity
  = $1366 W/m^2$ x 27% = $369 W/m^2$
- Intensity at AM1 = $1366 W/m^2$ - $369 W/m^2$
  = $997 W/m^2 \approx 1000 W/m^2$
- Reference Intensity = $1000 W/m^2$

Air mass calculations



i. Pythagoras applied to right-angle triangle OAB :

$$(R_E + y_{atm})^2 = (R_E + s\cos z)^2 + (s \sin z)^2$$

$$R_E^2 + 2\,R_E y_{atm} + y_{atm}^2 = R_E^2 + 2\,R_E s \cos z + s^2\cos^2 z + s^2 \sin^2 z$$

$$R_E^2 + 2\,R_E y_{atm} + y_{atm}^2 = R_E^2 + 2\,R_E s \cos z + s^2\,(\cos^2 z + \sin^2 z)$$

$$2\,R_E y_{atm} + y_{atm}^2 = 2\,R_E s \cos z + s^2$$

$$0 = s^2 + 2\,R_E\, s \cos z - (\,2\,R_E y_{atm} + y_{atm}^2\,)$$

ii. Solve quadratic for **s** :

$$s = \{\, -2\,R_E \cos z \pm \sqrt{[\,(2\,R_E \cos z)^2 + 4(2\,R_E y_{atm} + y_{atm}^2)\,]}\,\} / 2$$

$$s = \sqrt{[\,(R_E \cos z)^2 + 2\,R_E y_{atm} + y_{atm}^2\,]} - R_E \cos z$$

$$AM = s / y_{atm} \quad ; \quad r = R_E / y_{atm} \approx 708$$

$$AM = \sqrt{[\,r^2 \cos^2 z + 2\,r + 1\,]} - r \cos z$$

Notion of the Cost per peak watt installed

- "Peak Watt" = 1000W = 1kW
- Is the power produced at normal incidence of solar radiation @ 1000W/m^2.
- \$/W_p - Easy way to compare various solar conversion devices.
- Mostly useful for electric power generation devices, such as for: Hydro; PV; Wind, Solar Thermal Electric, etc.