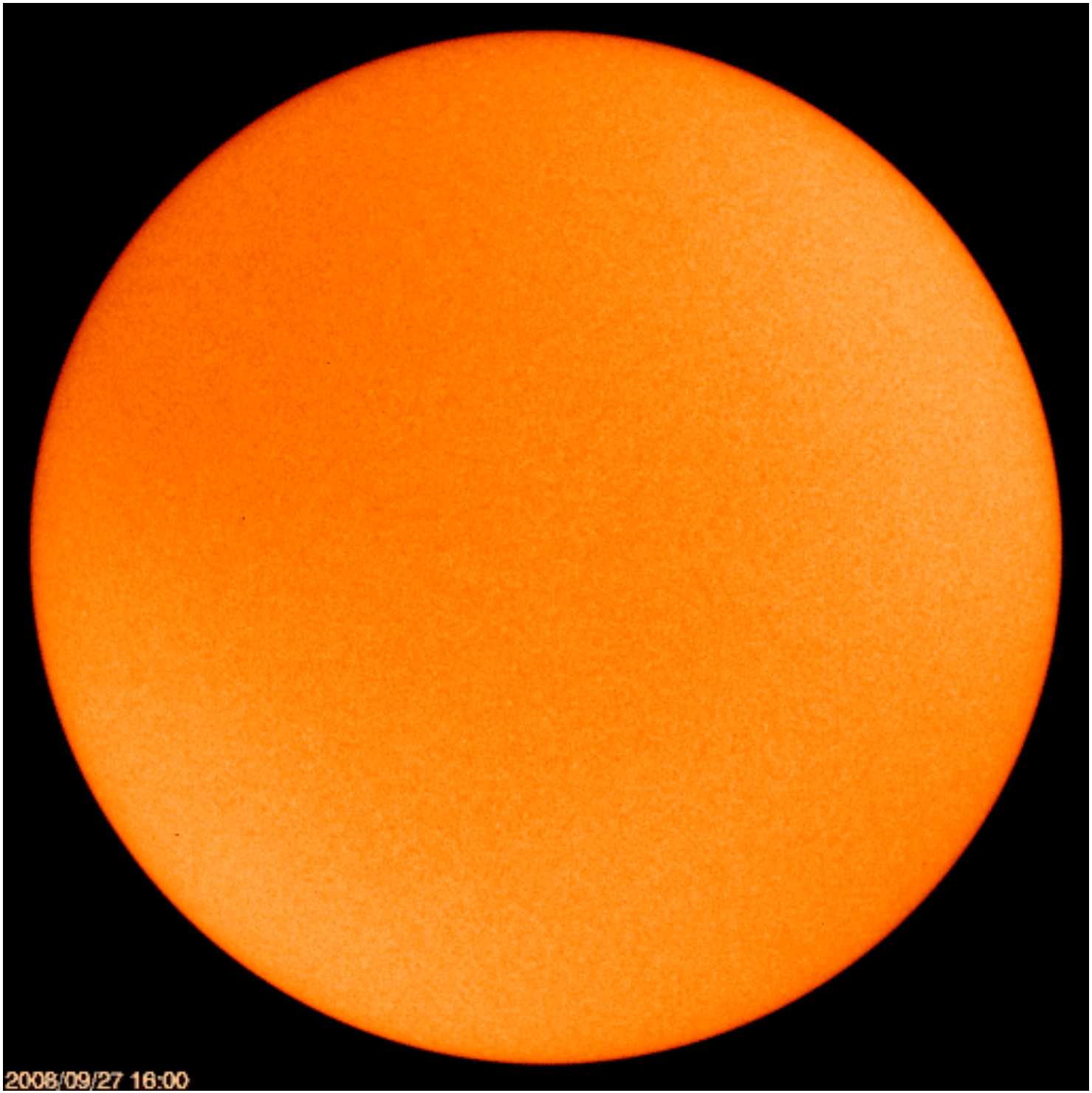
Introduction to Astrophysics

1. The Sun; starlight
2. Spectra; magnitudes
3. HR diagram; star clusters
4. Stellar structure; stellar evolution
5. Milky Way; Galaxies
6. Interstellar gas; dust
7. Star formation; planet formation
8. Orbits; exoplanets
9. Active galaxies; jets
10. Radio telescopes; interferometry

The Sun

- Properties
- Lifetime
- Energy Source
- Solar Atmosphere



science.nasa.gov

Properties

- Mass = 2×10^{30} kg = 1 $M_\odot$
  - (Kepler's Laws – later in module)
- Distance = 1.5×10^{11} m = 1 au
  - (Kepler's Laws)
- Radius = 7×10^{8} m = 1 $R_\odot$
  - (θ and d)
- Luminosity = 4×10^{26} W = 1 $L_\odot$
  - (Flux and d)

Lifetime

- Geological evidence

  $\rightarrow$ at least 5 x 10^9 years
- Stellar evolution theory

  10 x 10^9 years
- Energy required

$$E = L\tau$$
$$= 4.10^{26} \times 10.10^{9} \times 3.10^{7}$$
$$= 1.10^{44}\ \mathrm{J}$$

Nuclear Fusion

- In the core of the Sun

  $T=1 \times 10^7$ K

  $P=10^9$ atmospheres

- Sufficient for fusion of hydrogen nuclei into helium

$$4\,^1\mathrm{H} \rightarrow {}^4\mathrm{He} + \nu + \gamma$$

- Energy arises from mass difference

$$\mathrm{m}(4^{1}\mathrm{H}) - m(^{4}\mathrm{He}) = 0.0286\ \mathrm{amu}$$

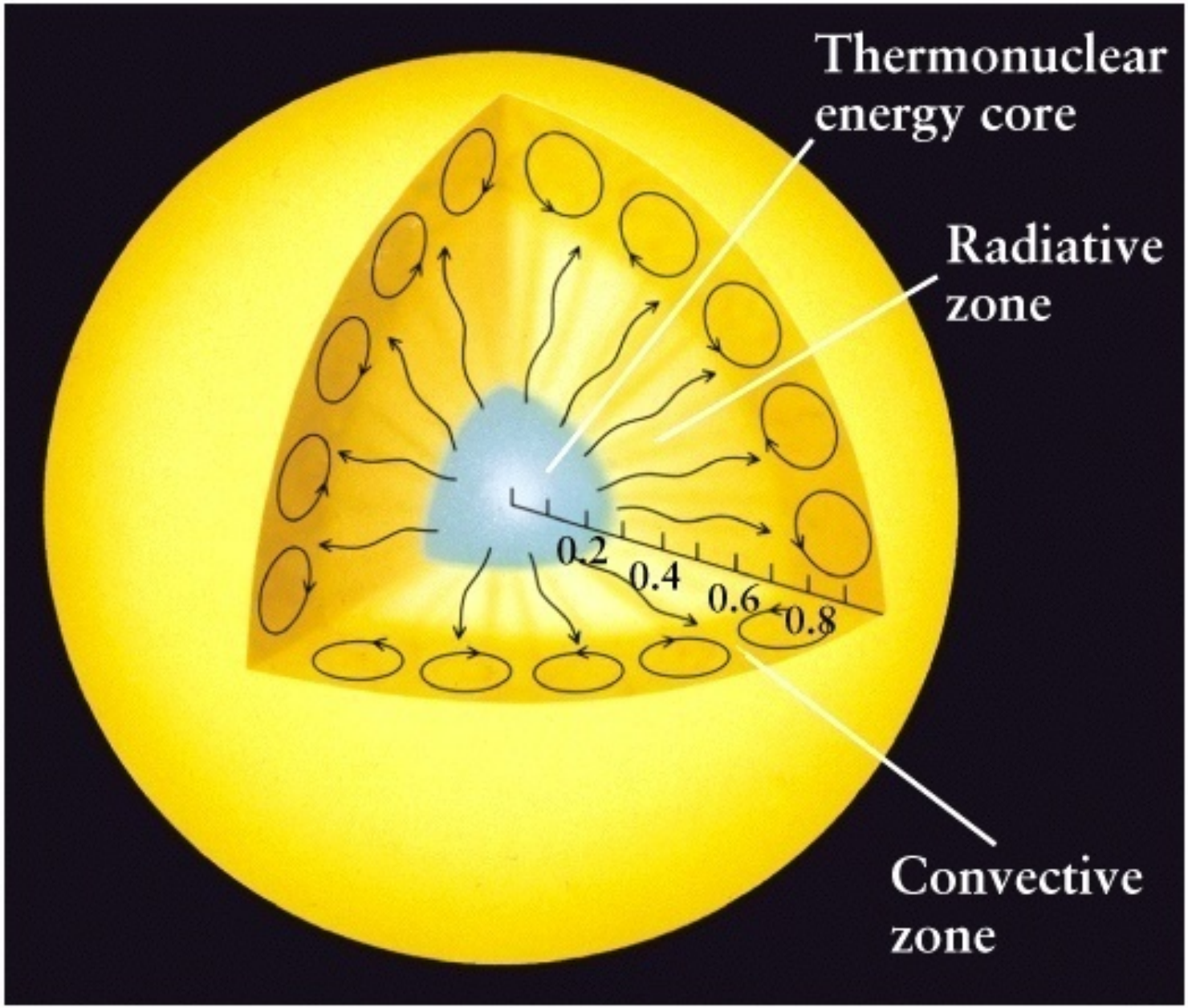
$$\mathrm{or}\ 0.7\%\ \mathrm{of\ the\ mass.}$$

- Core of the Sun contains about 10% of the total mass
- Total energy available

$$= \Delta mc^2$$

$$= 0.10 \times 0.007 \times 2 \times 10^{30} \times \left(3 \times 10^{8}\right)^2$$

$$= 1 \times 10^{44}\ \mathrm{J}$$

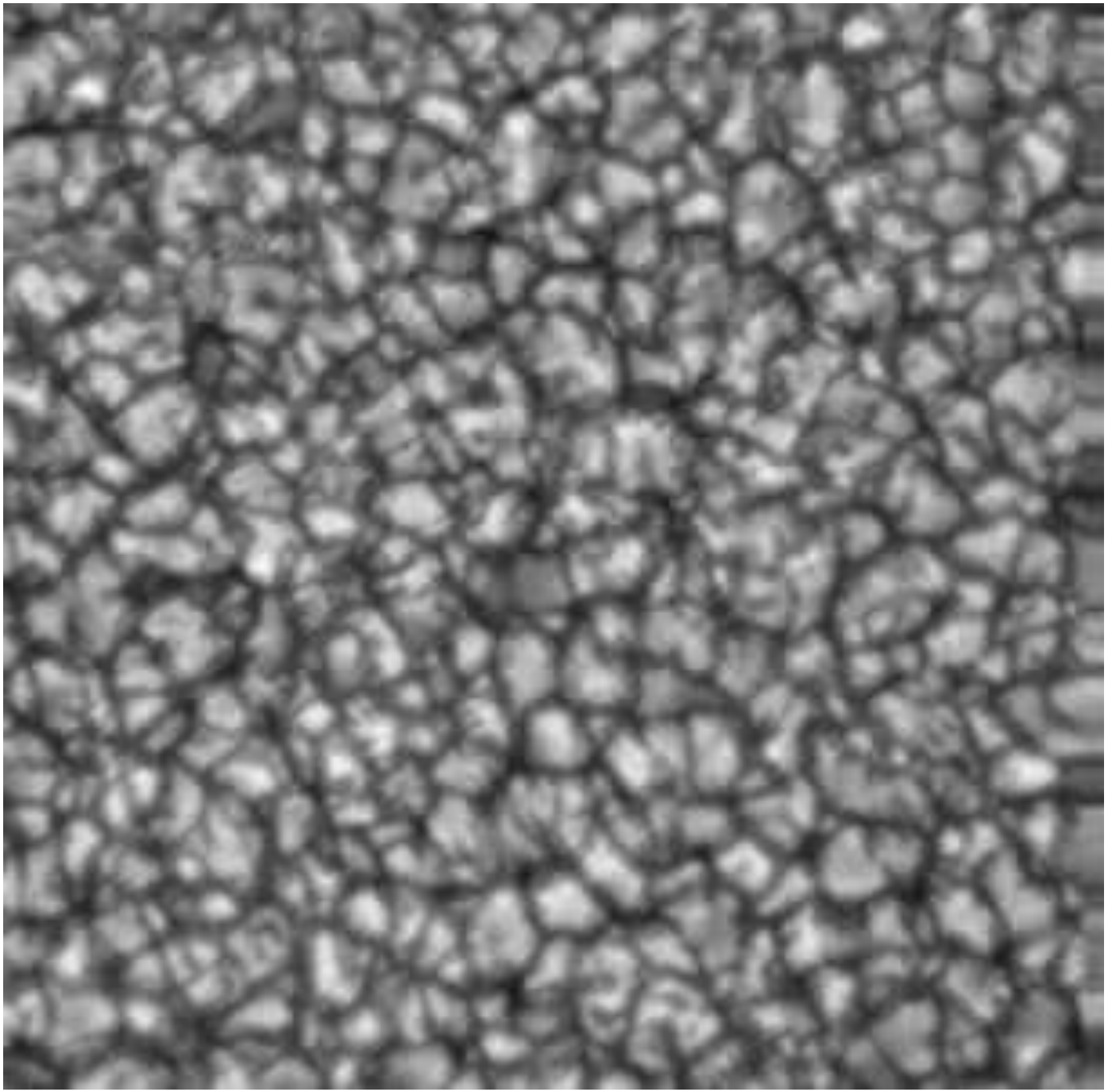


Energy Transport

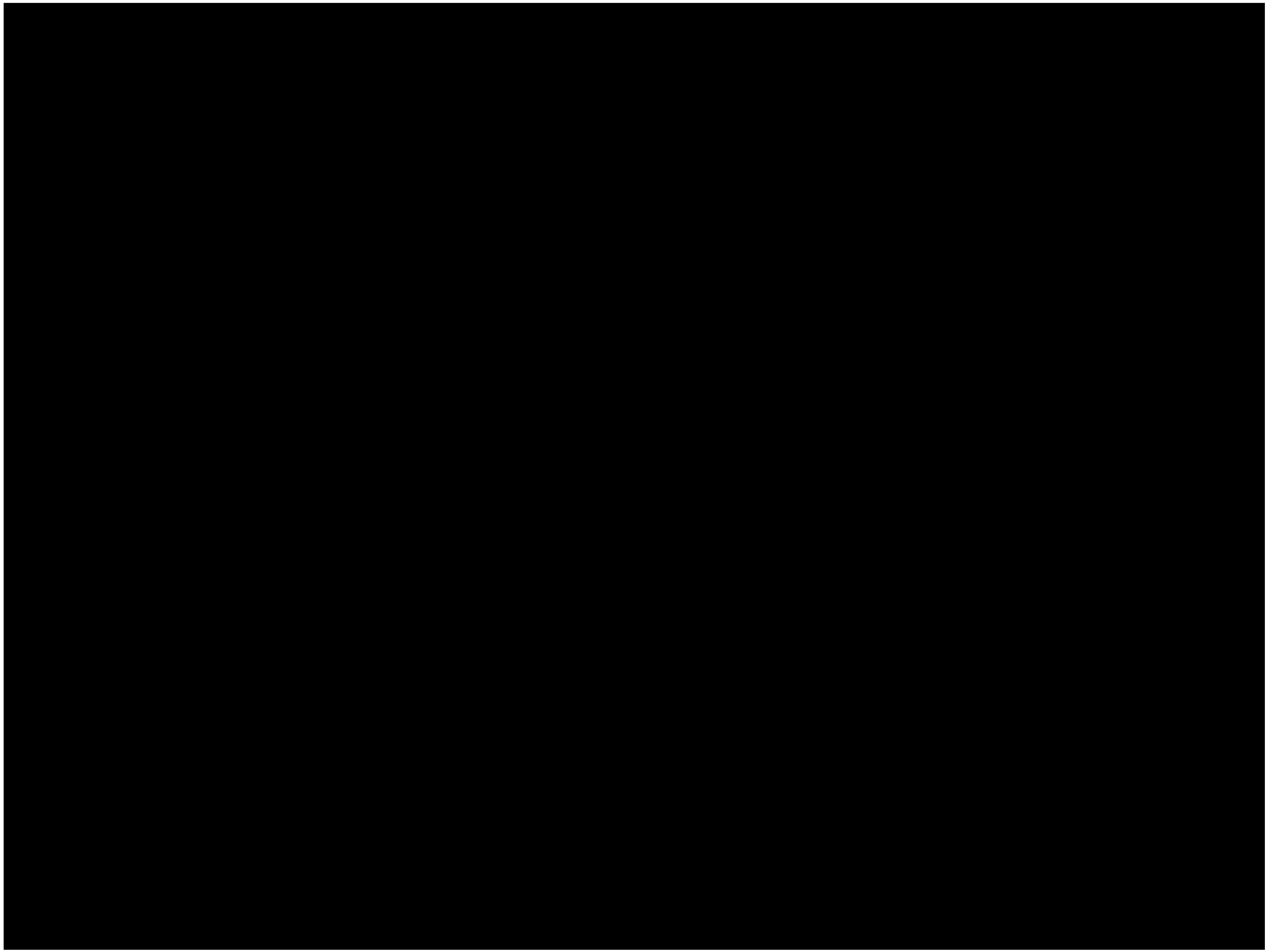
- Heat energy generated in the core is transported to the surface
- Firstly by radiation and then by convection
- The outer third of the Sun is in constant convective motion

Granulation

- Columns of hot gas rise up to the surface, cool, and then fall again
- Tops of convection cells give the photosphere a granular appearance



Close-up of granulation. Credit: Royal Swedish Academy of Sciences www.solarphysics.kva.se

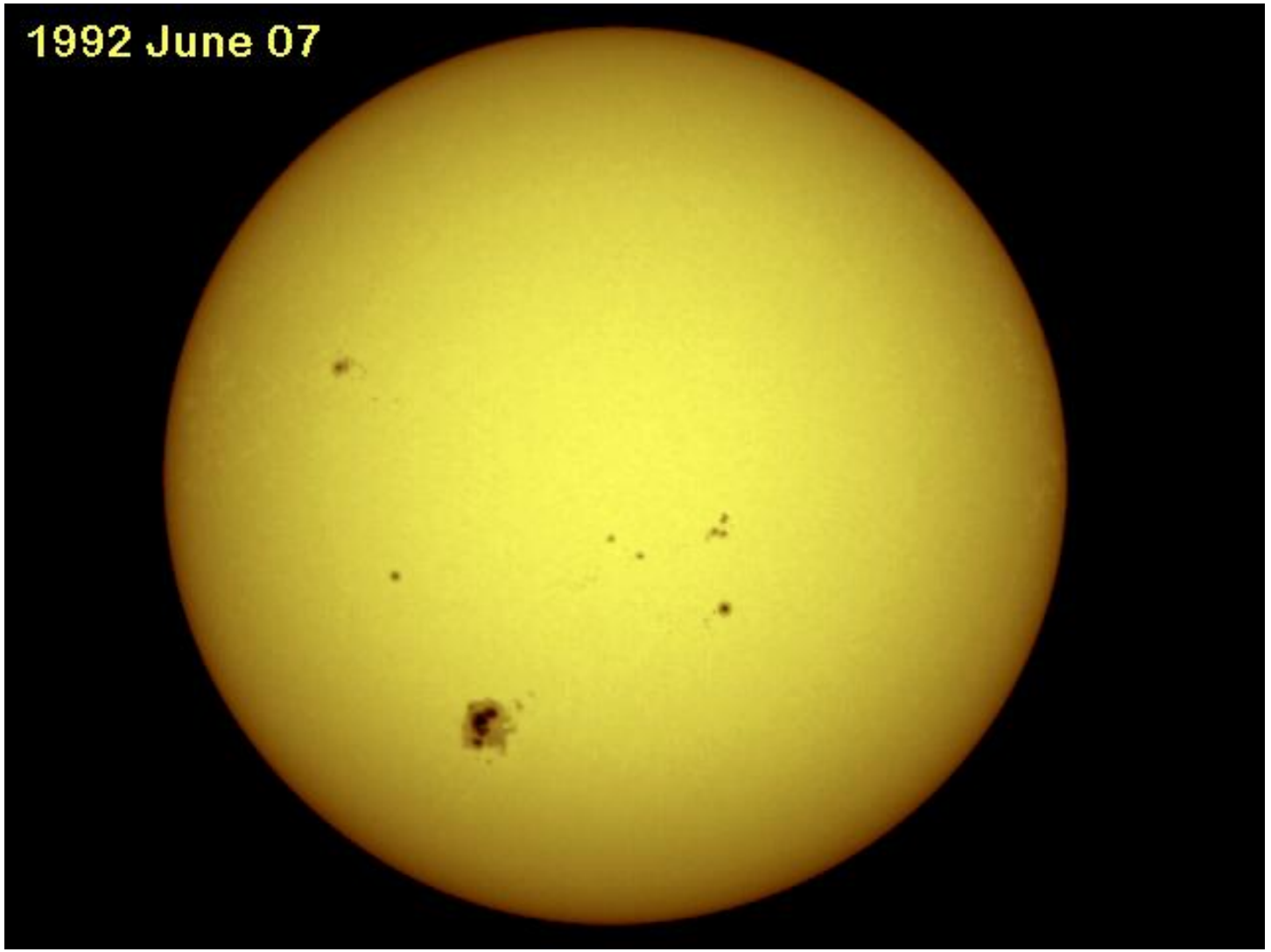


Hinode satellite movie
https://svs.gsfc.nasa.gov/3412

Photosphere

- ‘Visible surface’ of the Sun
- No solid surface – density and temperature of the gas just fall steadily with height through the photosphere
- ‘Effective’ temperature of 5800 K

Sunspots



http://solarscience.msfc.nasa.gov/

- Spot cooler and lower than surroundings
- Strong (B~0.1T) vertical magnetic field prevents heat transfer from convective flow

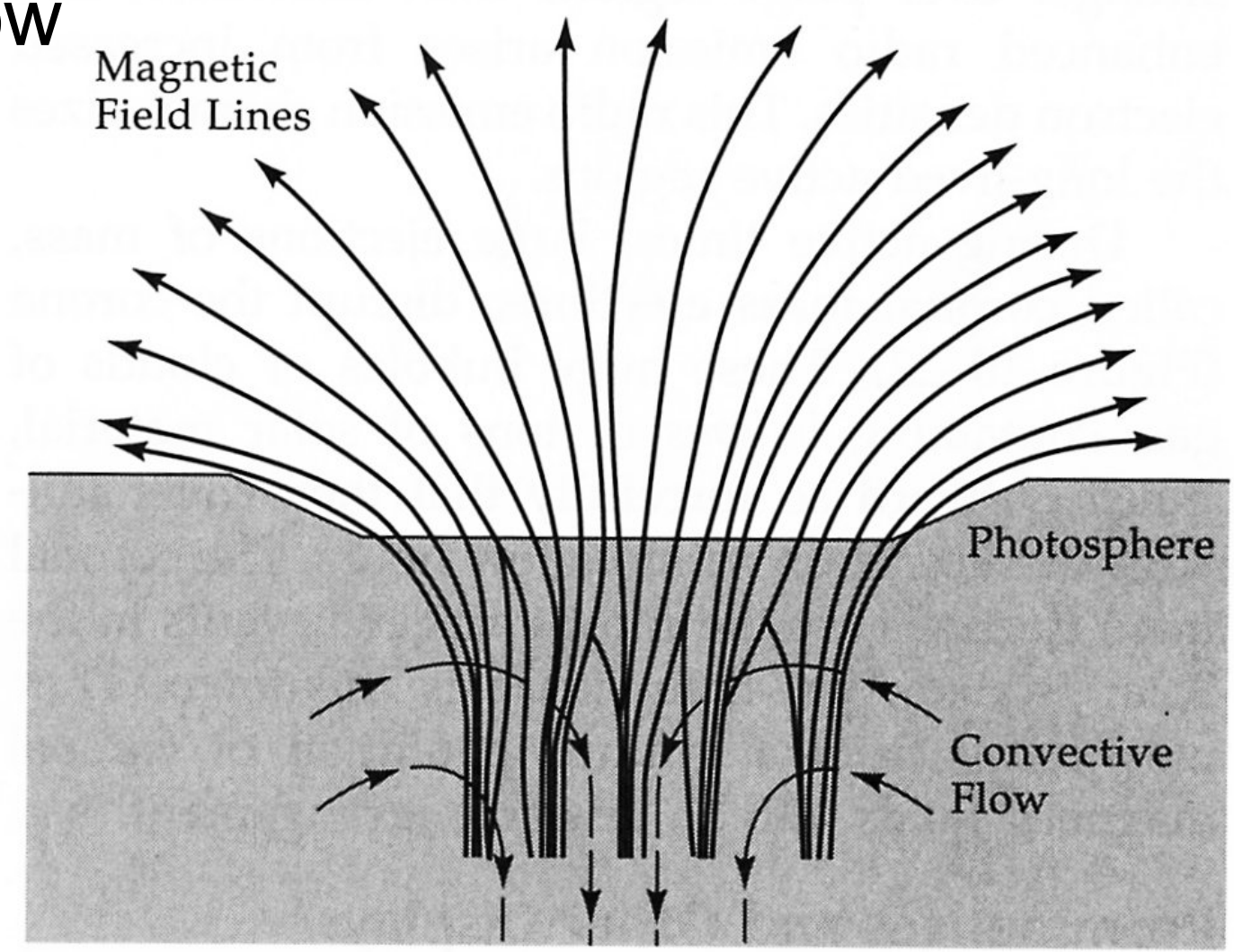


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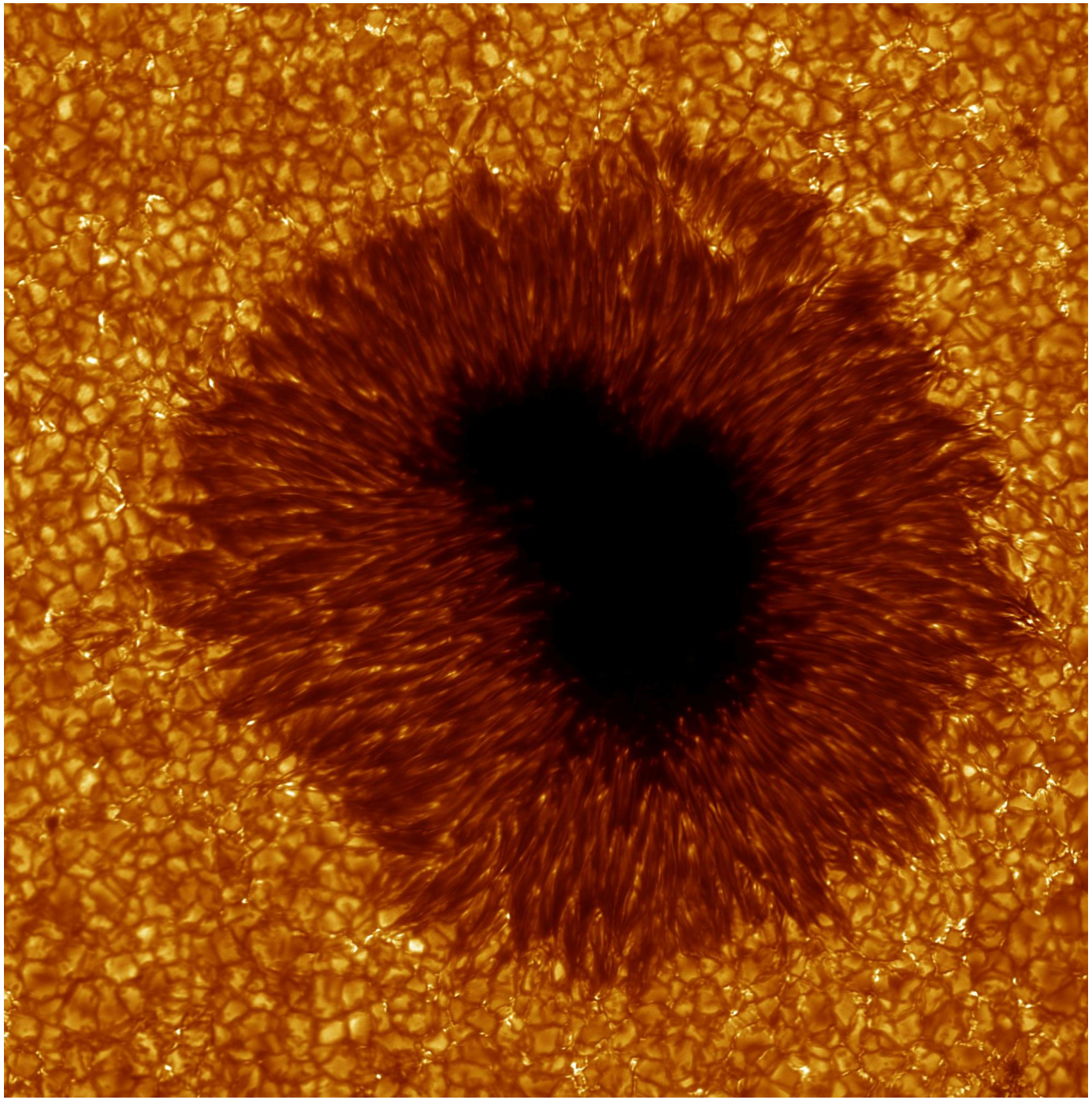
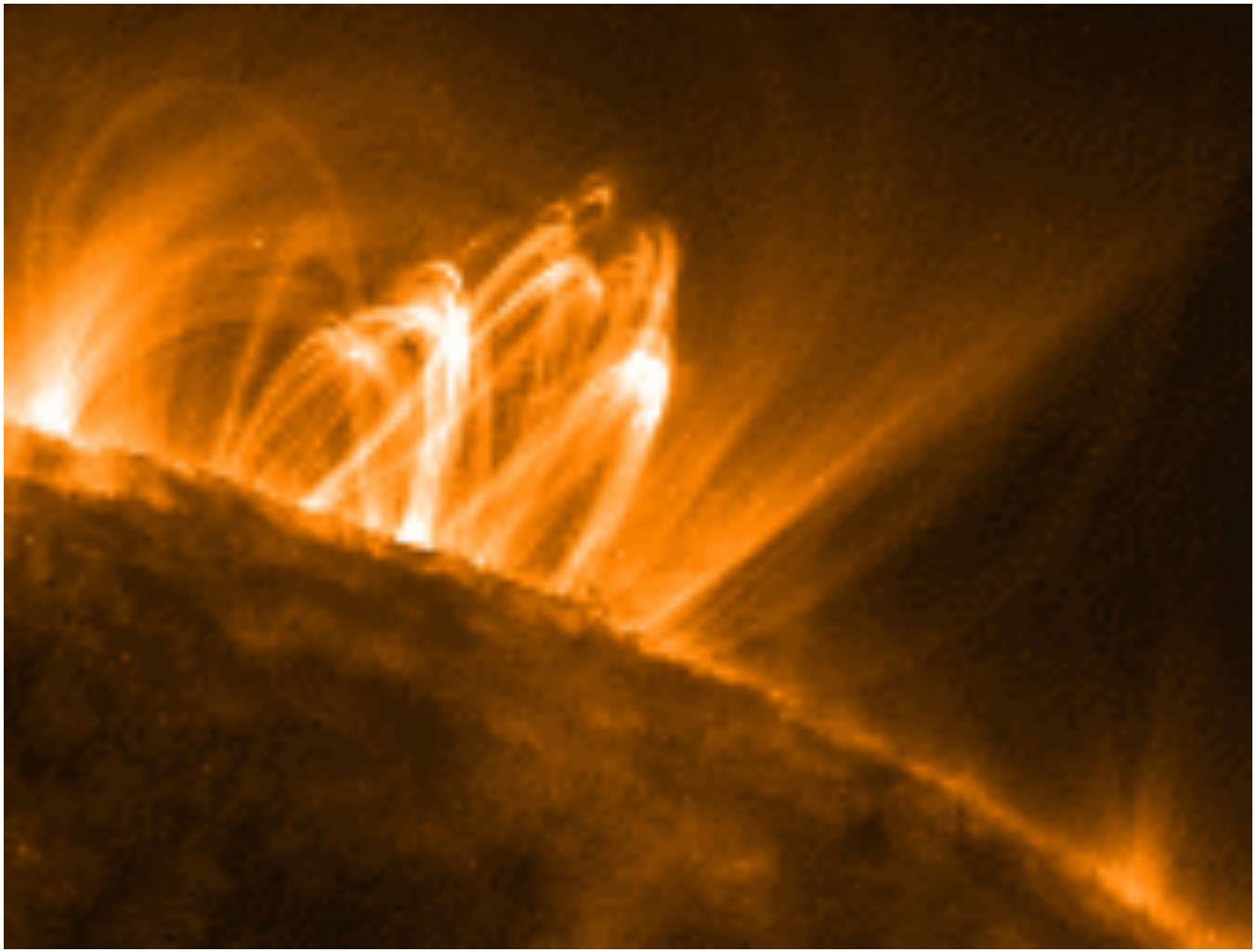
Fig 10-21

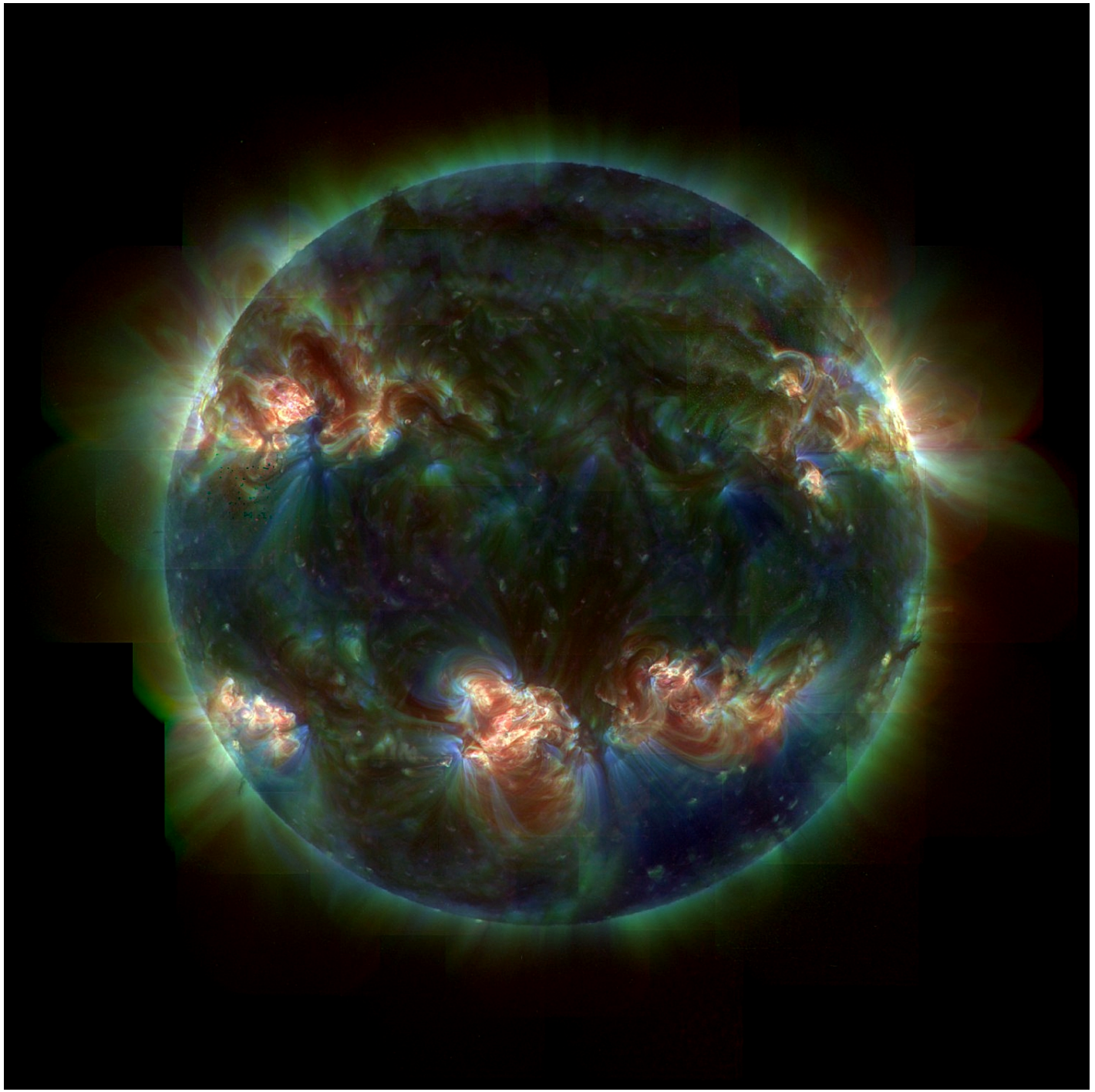


Close-up of sunspot. Credit: Royal Swedish Academy of Sciences www.solarphysics.kva.se

- Pairs of spots usually linked by loop of hot, magnetic plasma



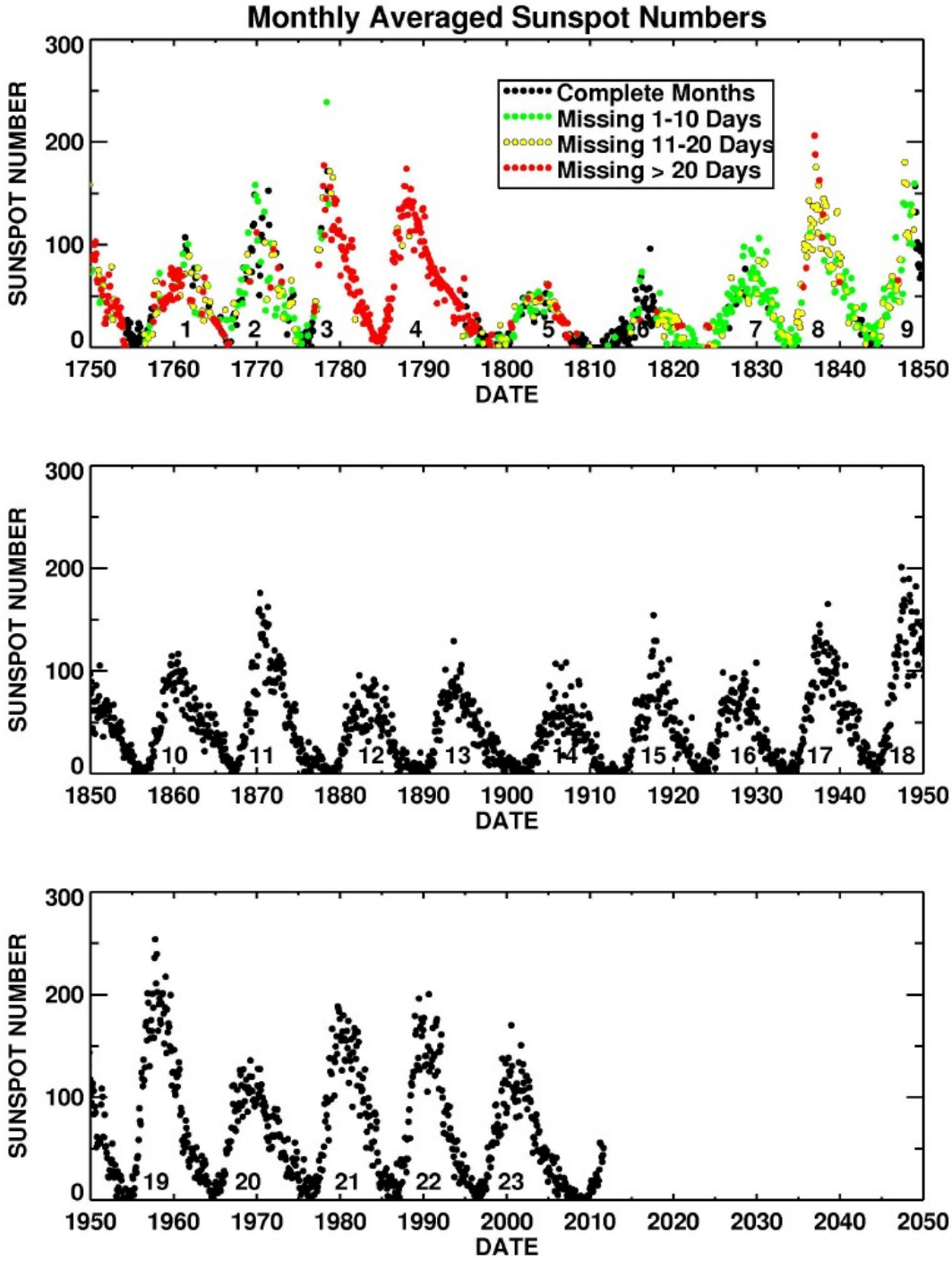
TRACE Satellite Stanford-Lockheed Institute for Space Research & NASA (trace.lmsal.com/POD/images)



TRACE Satellite Stanford-Lockheed Institute for Space Research & NASA (trace.lmsal.com/POD/images)

Solar Cycle

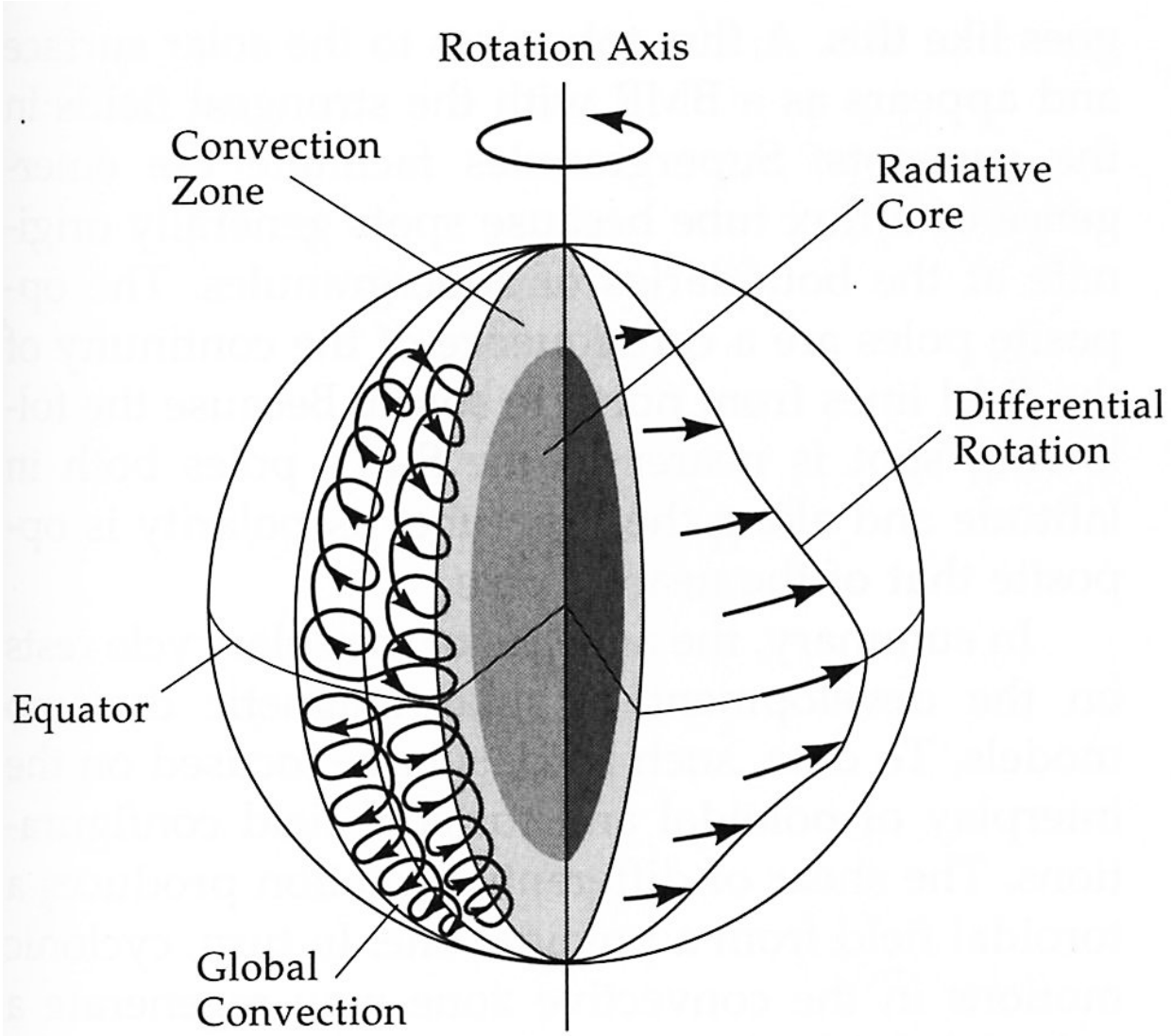
- Level of magnetic activity reaches a maximum every 11 years



solarscience.msfc.nasa.gov

Model for Solar Activity

- Combination of differential rotation and convection generates strong magnetic field around the equatorial regions
- Field lines get wound up and very twisted
- Global magnetic field flips over every 11 years and cycle starts again



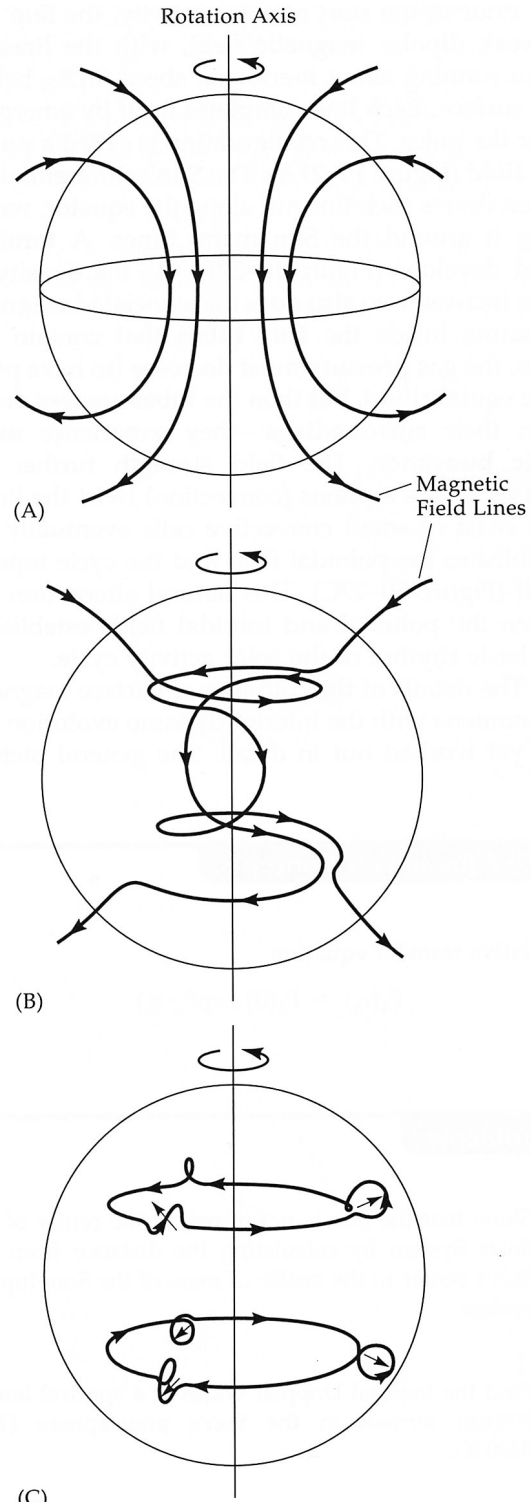


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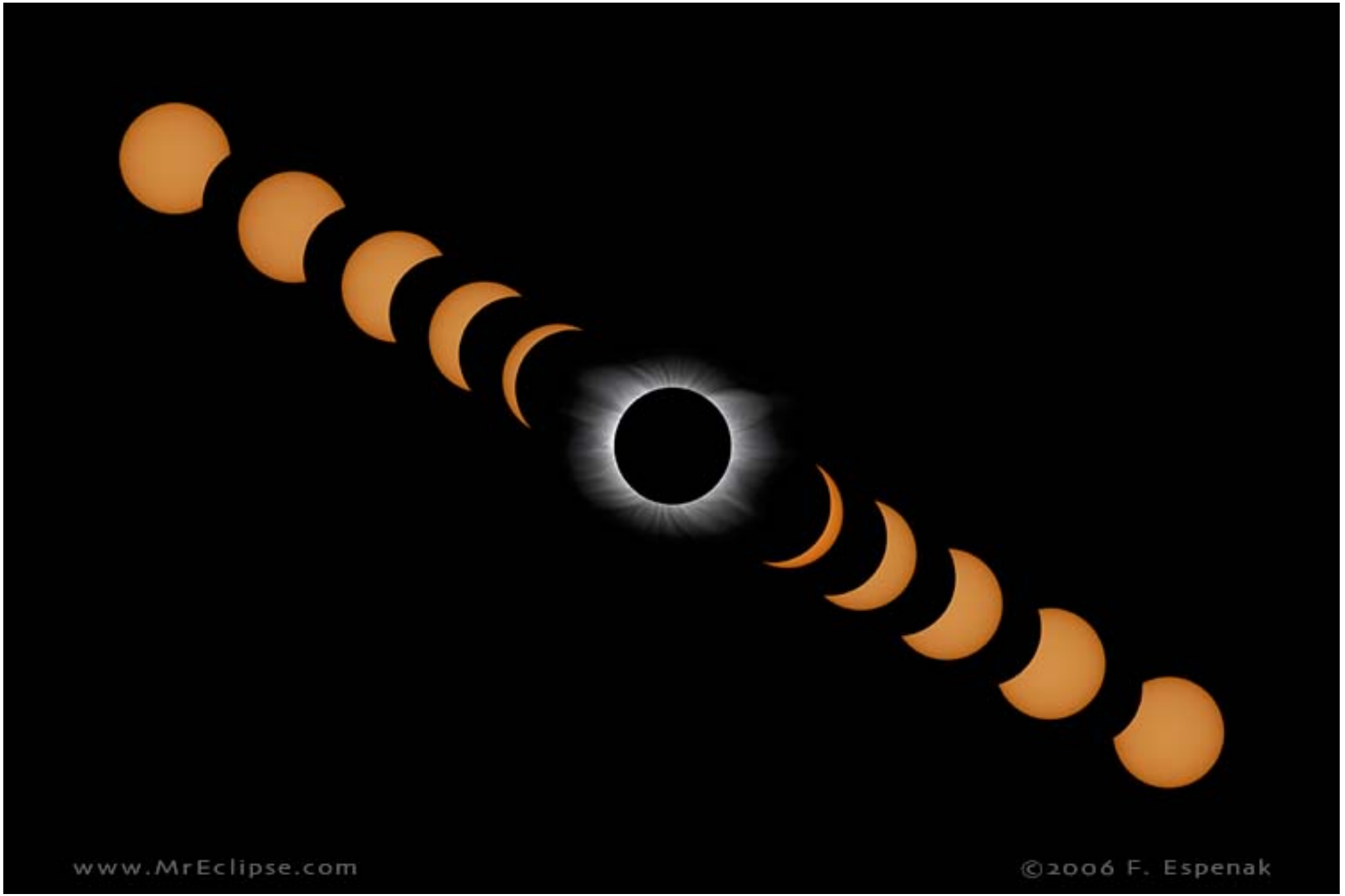
Fig 10-26

Corona

- The outer atmosphere of the Sun is very hot (T~10^6 K) and tenuous
- White halo seen during eclipses extends several solar radii
- Also emits strongly in UV and X-rays observed from satellites and at radio wavelengths


www.MrEclipse.com
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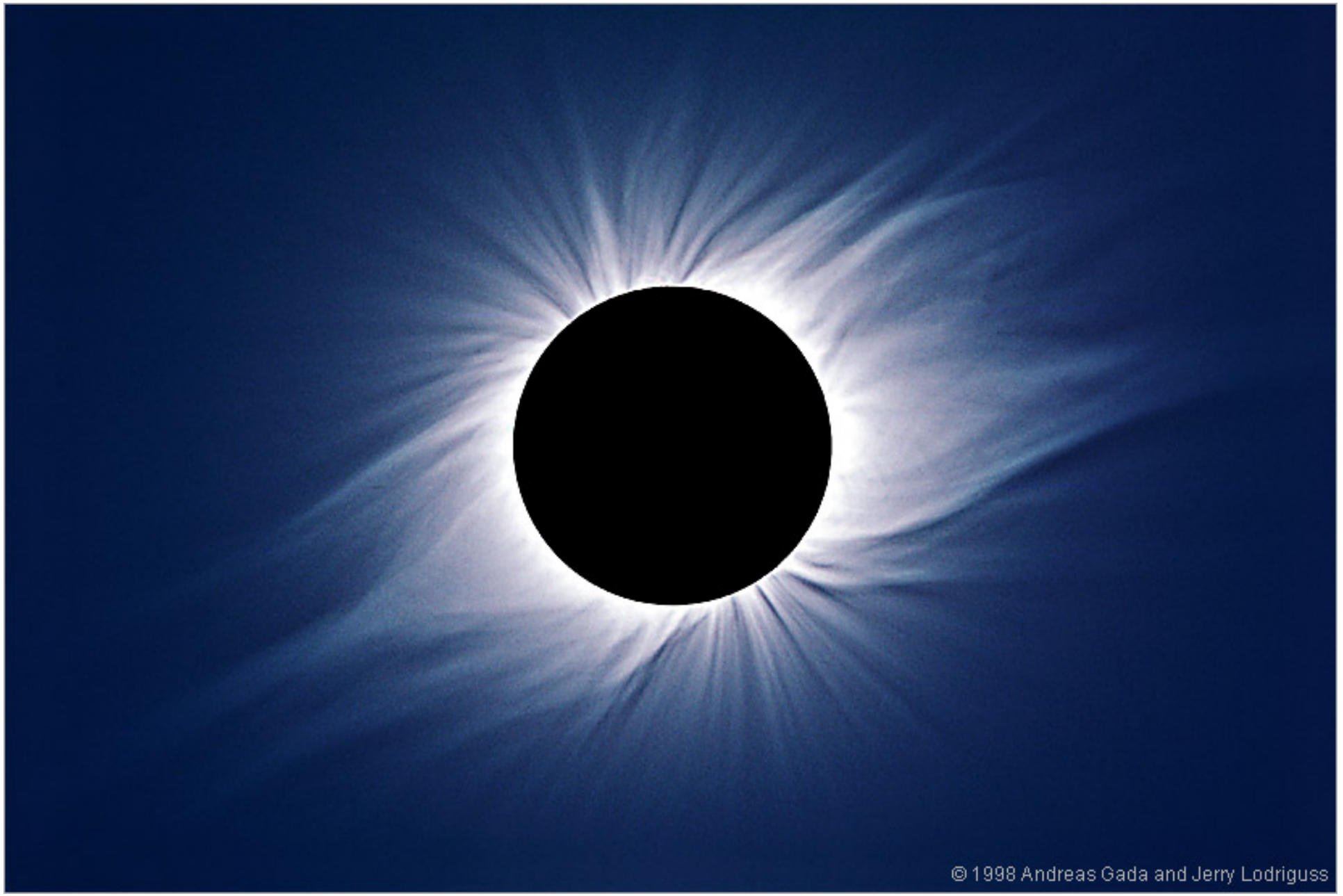
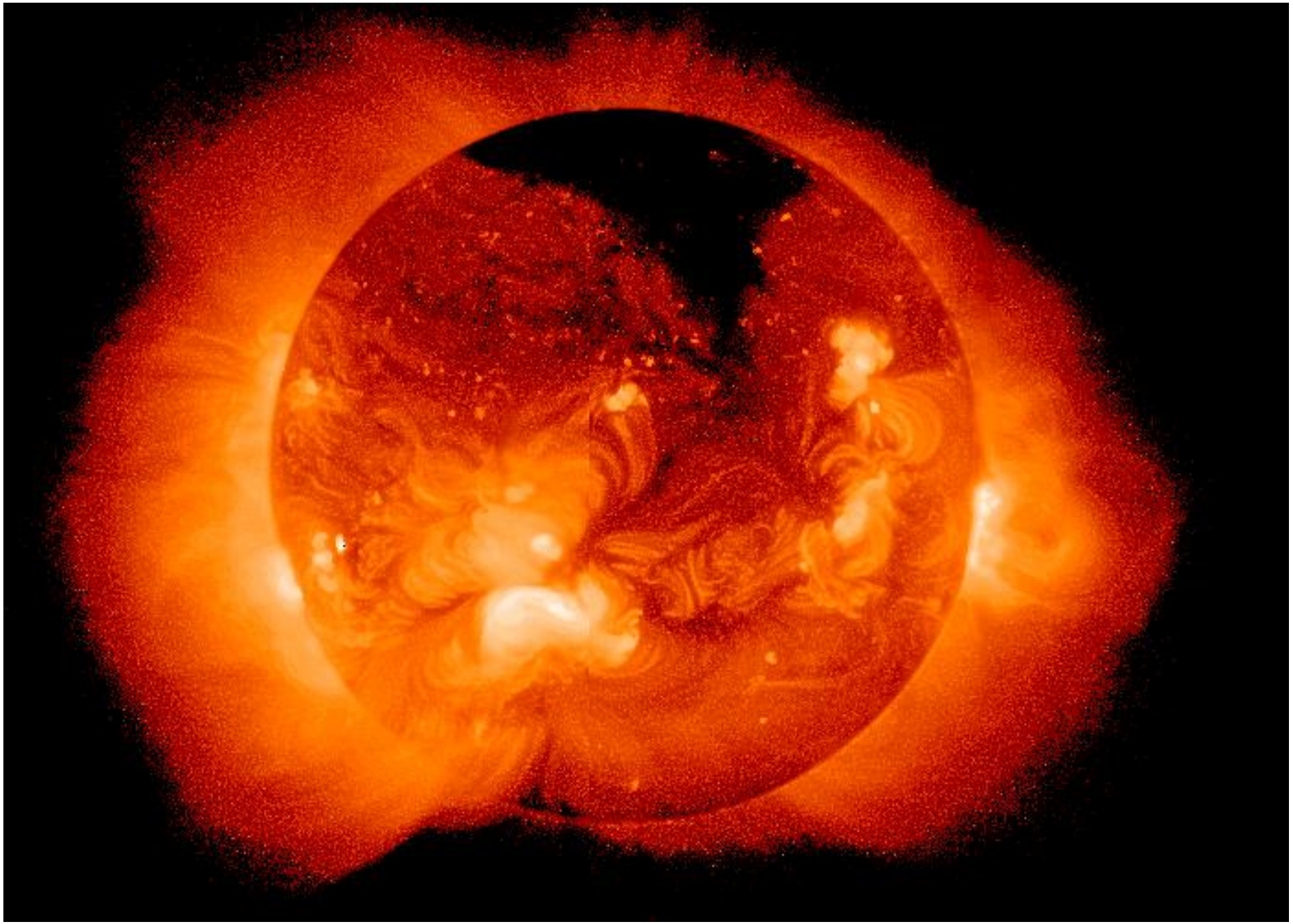
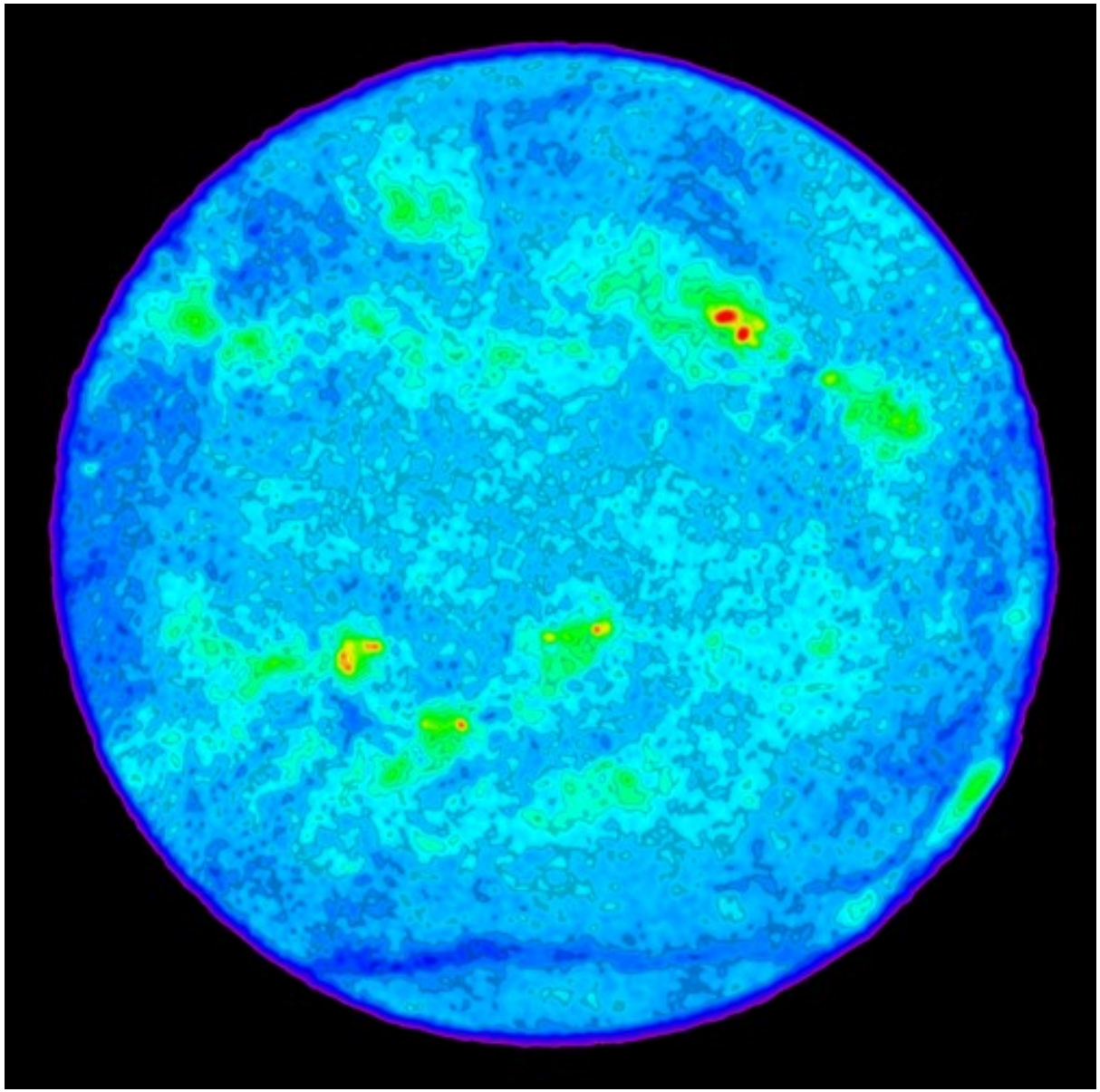


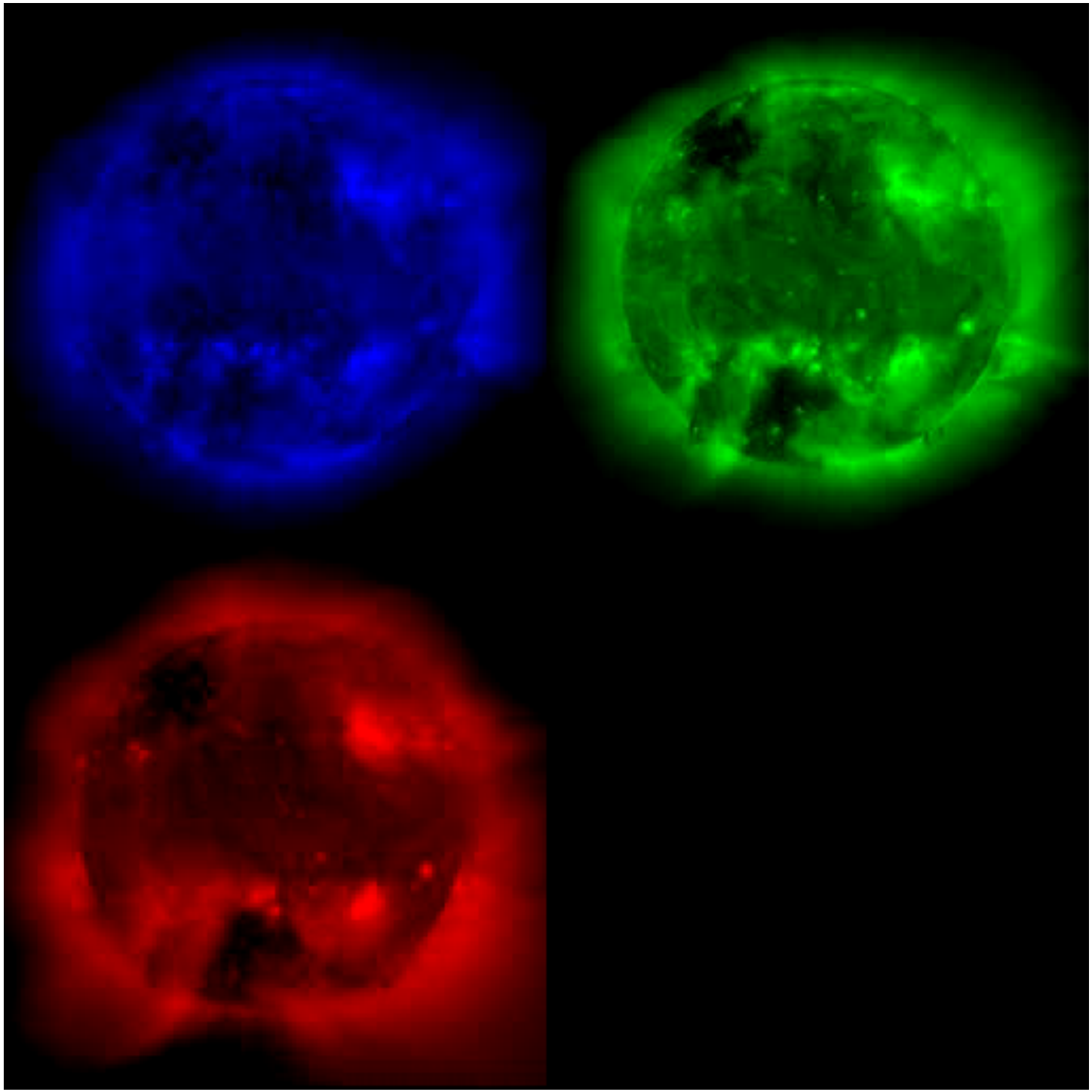


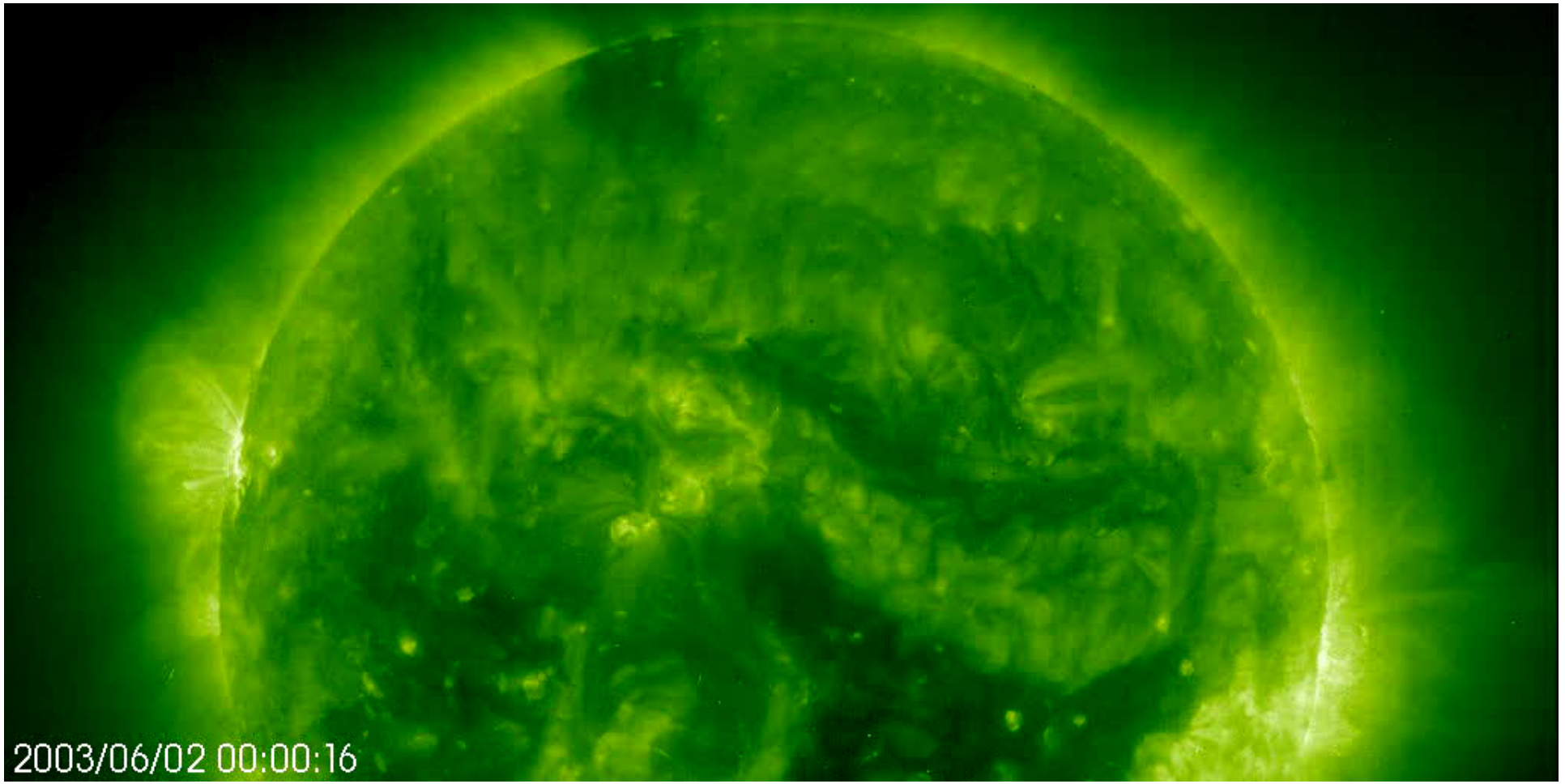


VLA radio image at 5 GHz
http://images.nrao.edu/506

Summary

- The Sun is a very average star about half way through its 10 billion year lifetime
- Energy generated in core by nuclear fusion is transported by radiation and convection to the photosphere
- Surface activity is powered by magnetic fields generated by dynamo action through convection and differential rotation

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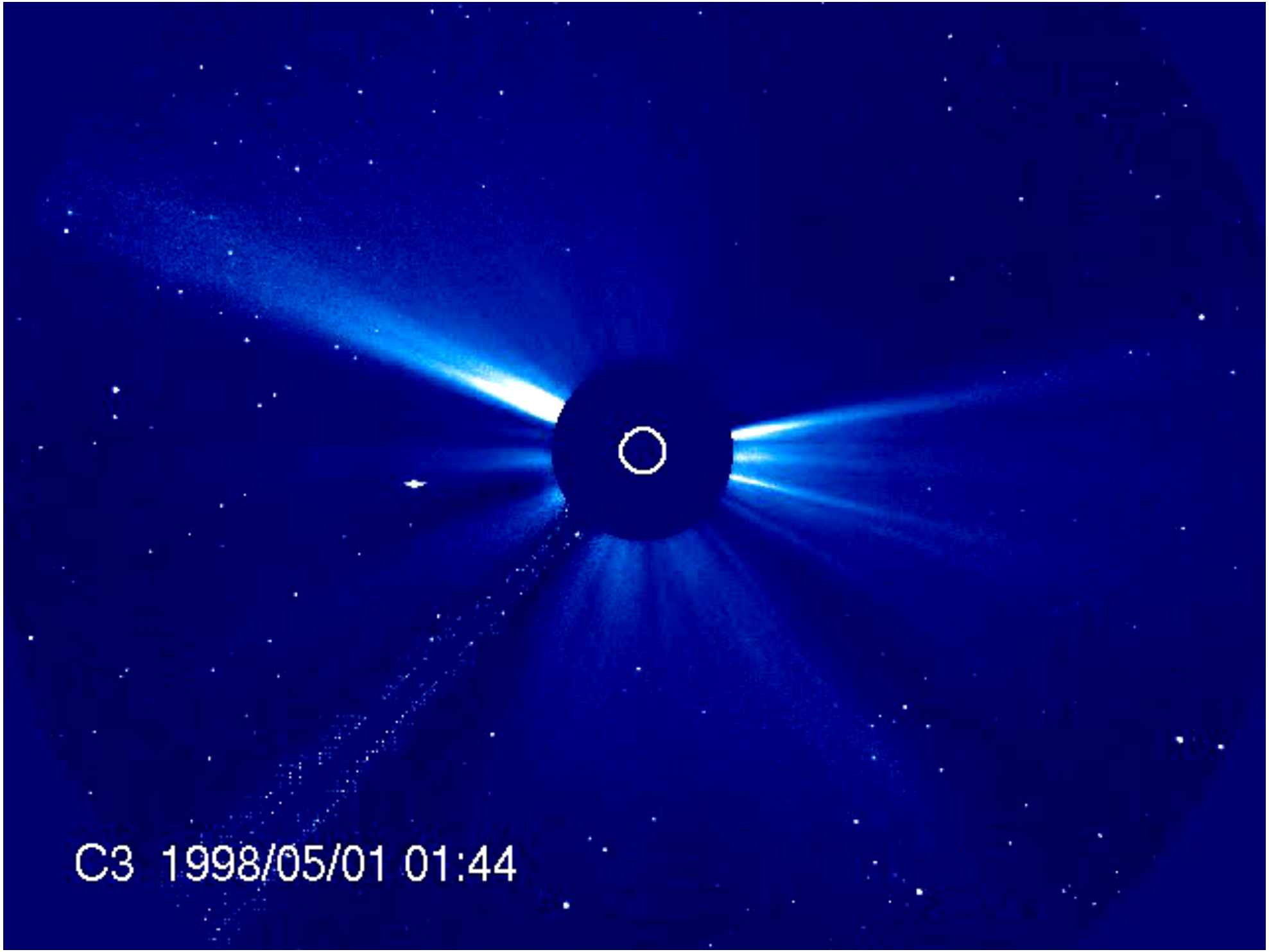
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