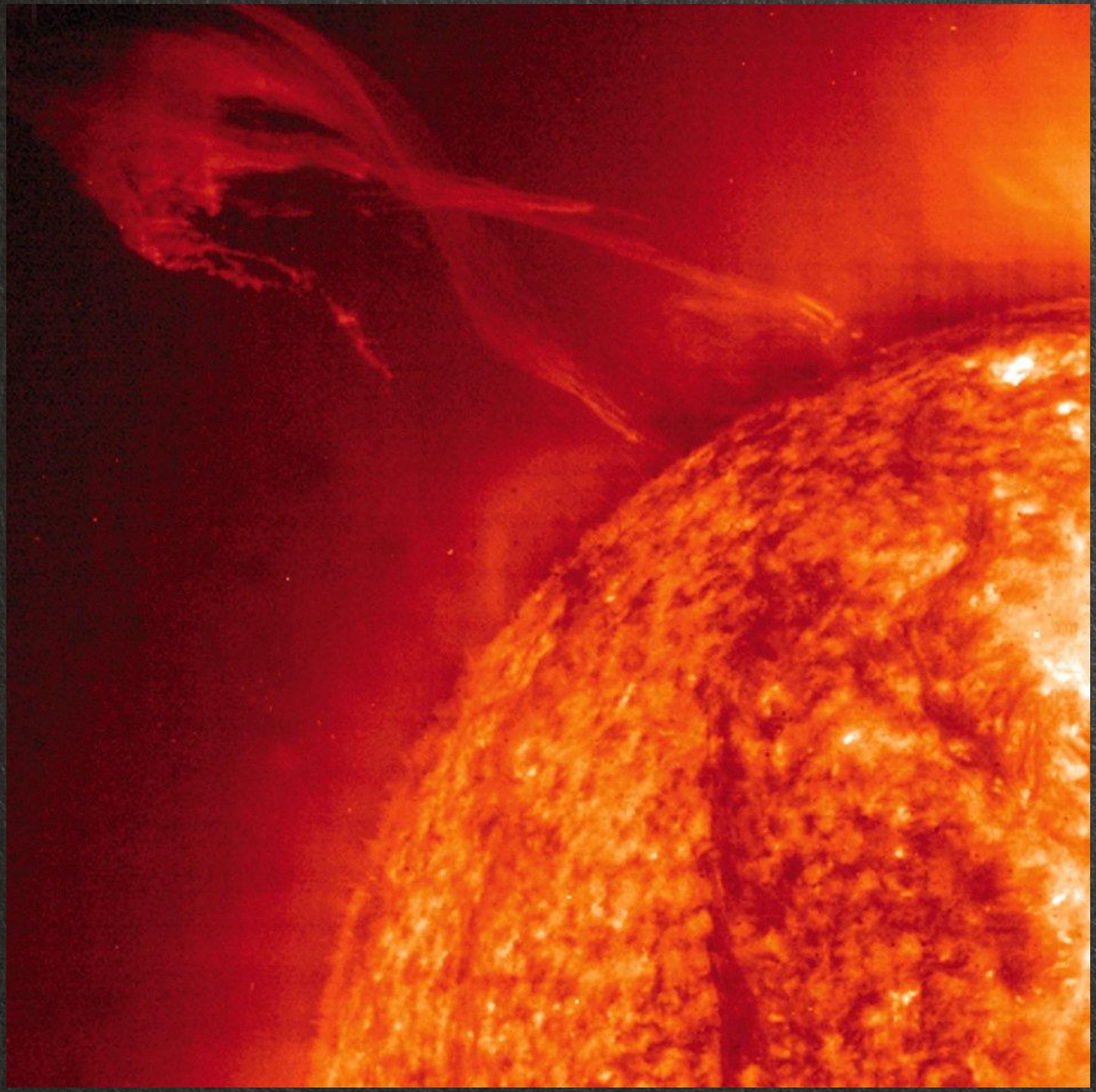
TIME-DOMAIN ASTRONOMY

Science Case 1: Sunspot Number

Stefano Covino
INAF / Brera Astronomical Observatory

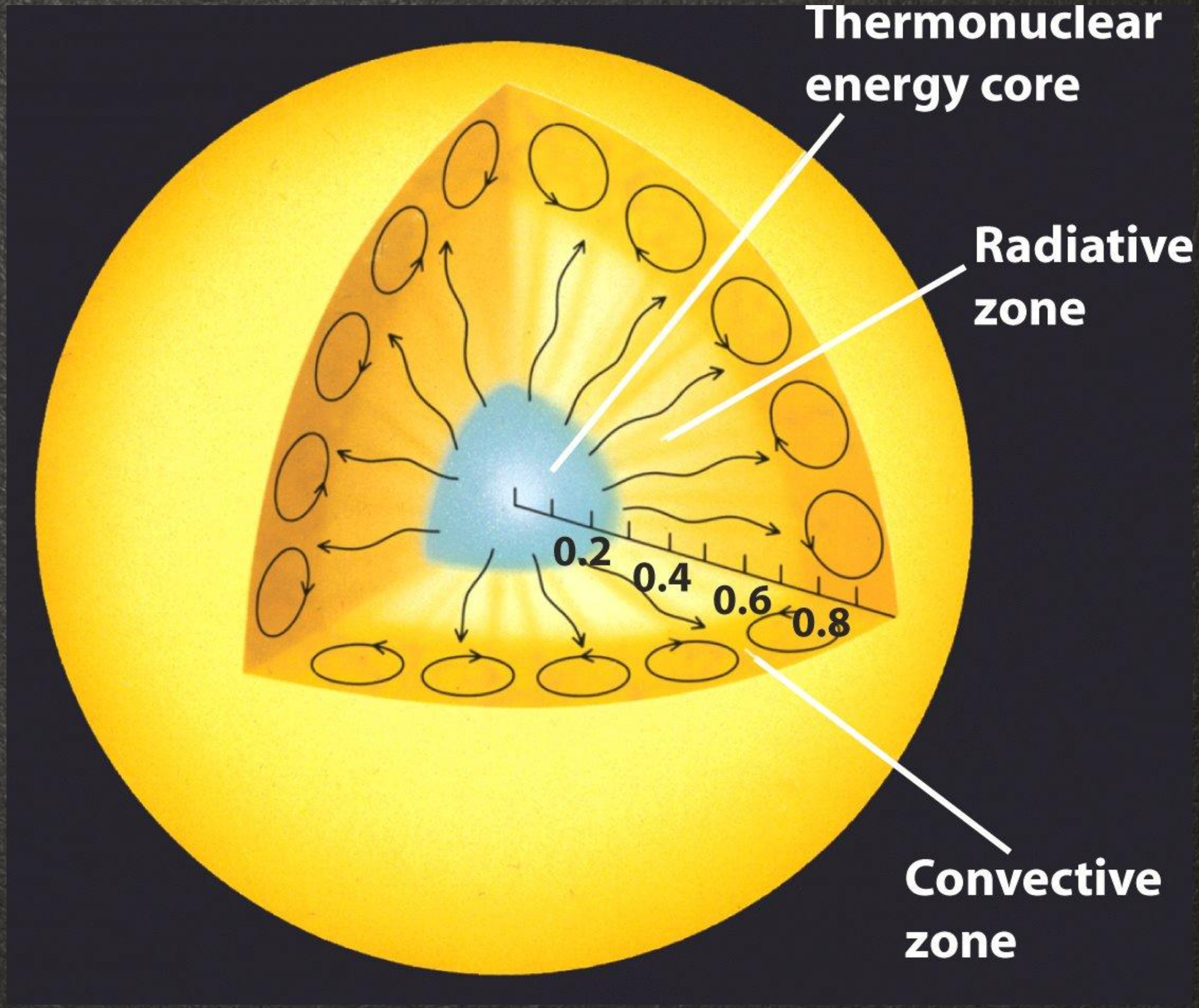
The Sun's energy is generated by thermonuclear reactions in its core



- The energy released in a nuclear reaction corresponds to a slight reduction of mass according to Einstein's equation $E = mc^2$
- Thermonuclear fusion occurs only at very high temperatures; for example, hydrogen fusion occurs only at temperatures in excess of about 10^7 K
- In the Sun, fusion occurs only in the dense, hot core

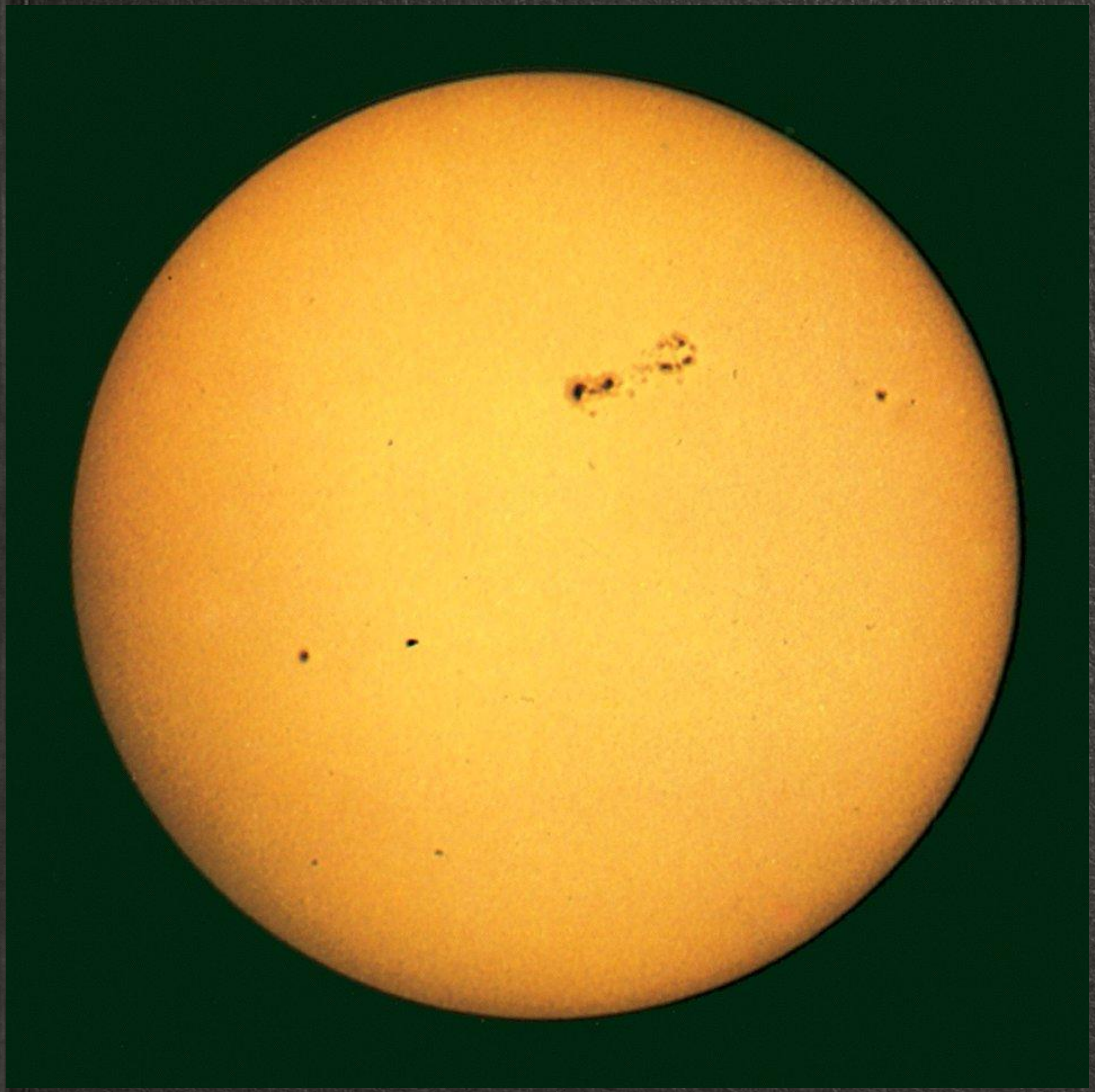
A THEORETICAL MODEL OF THE SUN SHOWS HOW ENERGY GETS FROM ITS CENTER TO ITS SURFACE

- Hydrogen fusion takes place in a core extending from the Sun's center to about 0.25 solar radius.
- The core is surrounded by a radiative zone extending to about 0.71 solar radius.
- In this zone, energy travels outward through radiative diffusion.
- The radiative zone is surrounded by a rather opaque convective zone of gas at relatively low temperature and pressure.
- In this zone, energy travels outward primarily through convection.



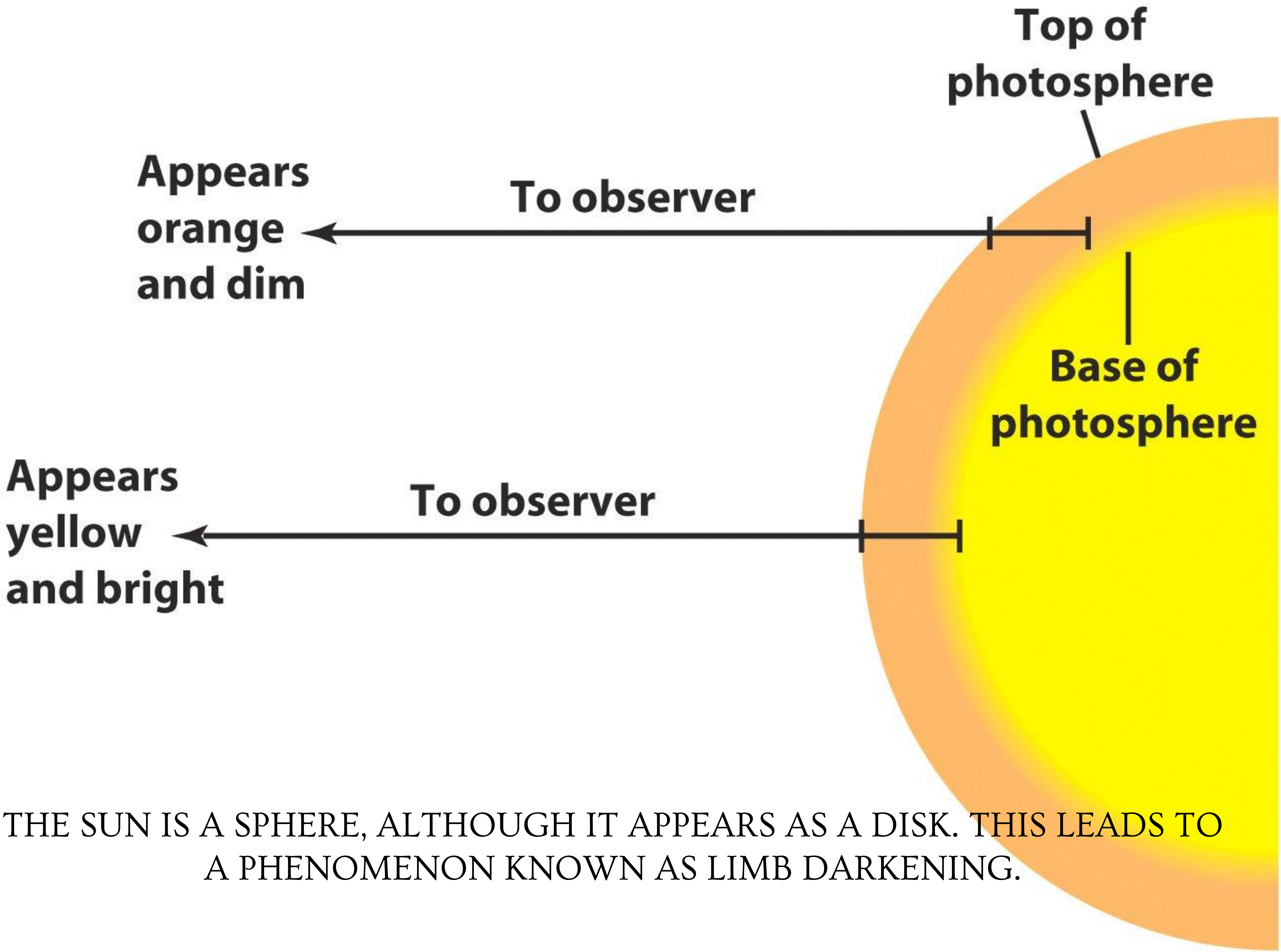
THE PHOTOSPHERE

THE LOWEST OF THREE MAIN LAYERS IN THE SUN'S ATMOSPHERE



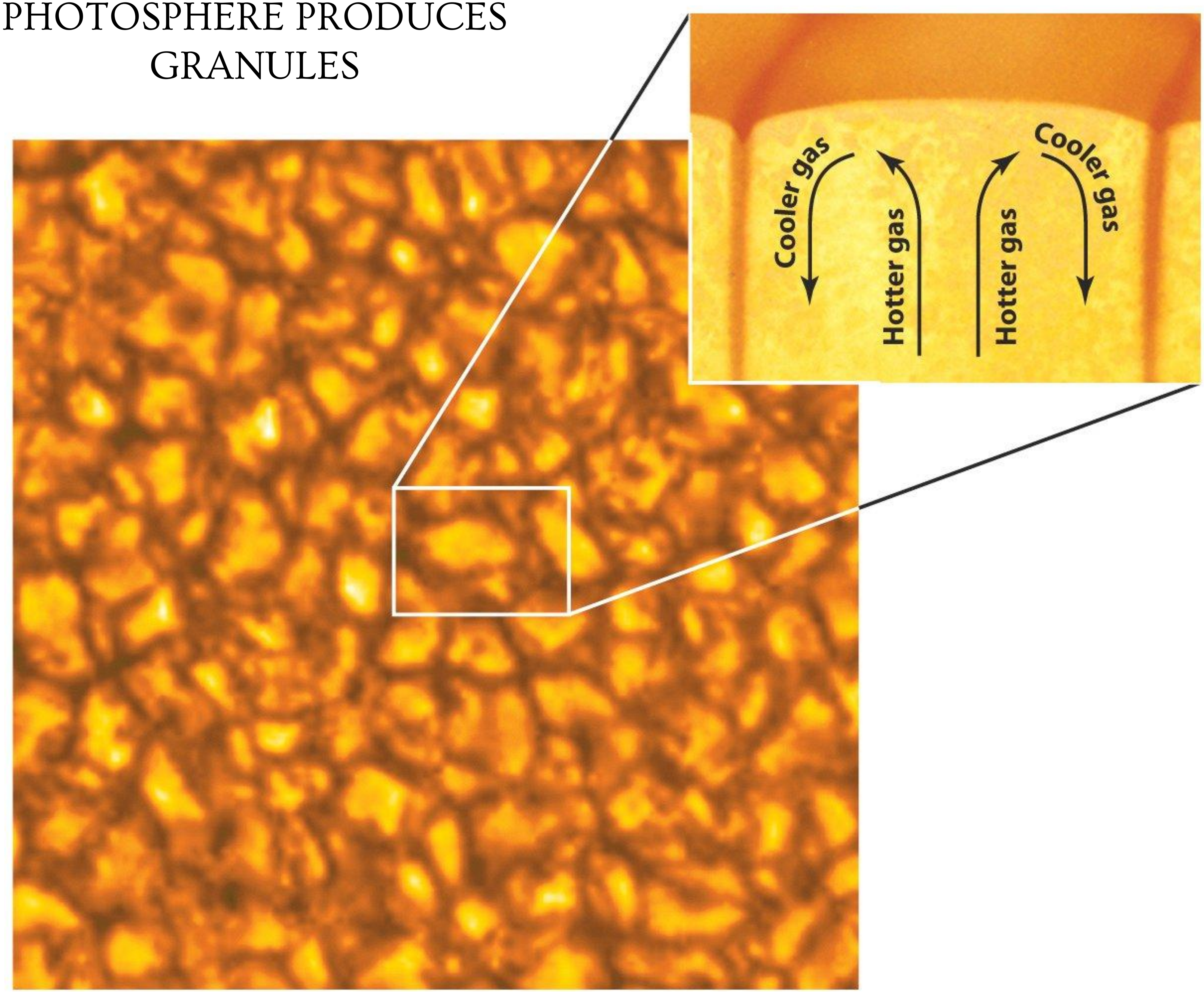
- The Sun's atmosphere has three main layers:
  - the photosphere
  - the chromosphere
  - the corona
- Everything below the solar atmosphere is called the solar interior.
- The visible surface of the Sun, the photosphere, is the lowest layer in the solar atmosphere.

The spectrum of the photosphere is similar to that of a blackbody at a temperature of 5800 K

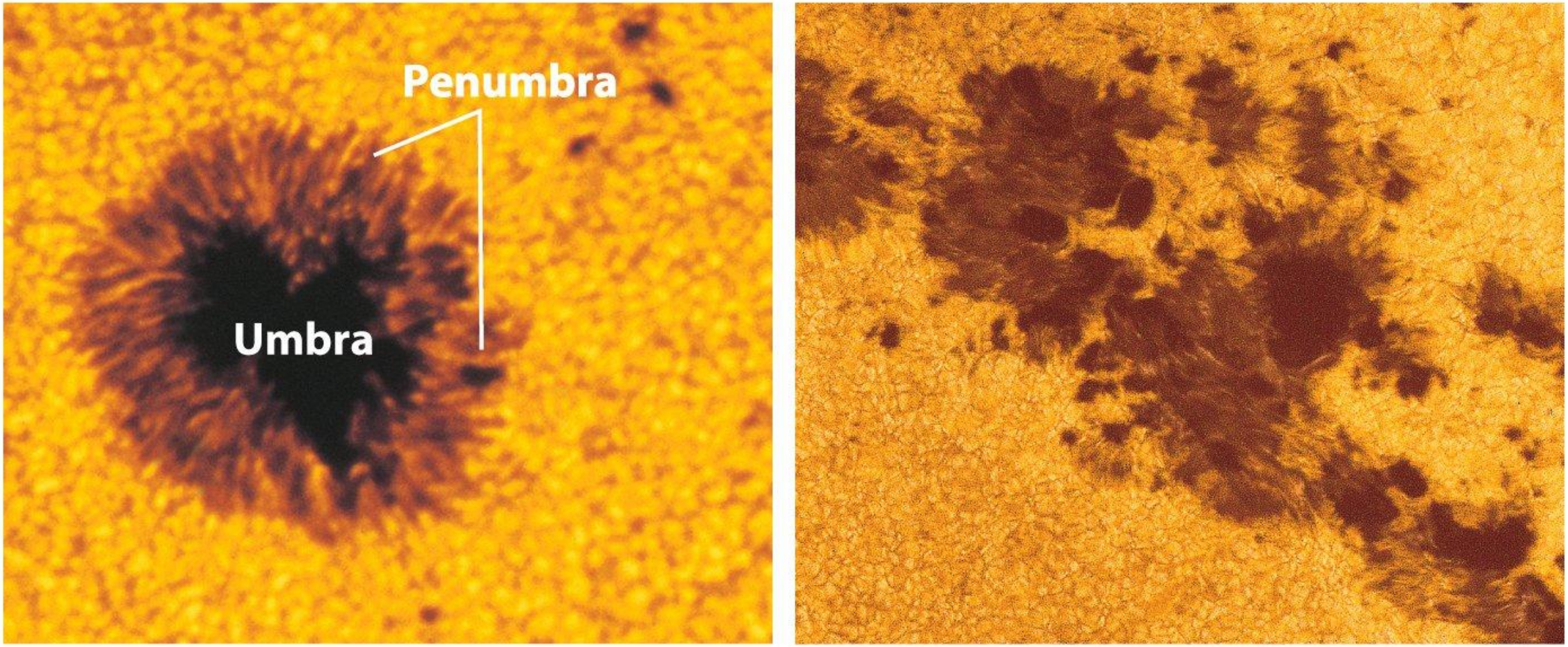


THE SUN IS A SPHERE, ALTHOUGH IT APPEARS AS A DISK. THIS LEADS TO A PHENOMENON KNOWN AS LIMB DARKENING.

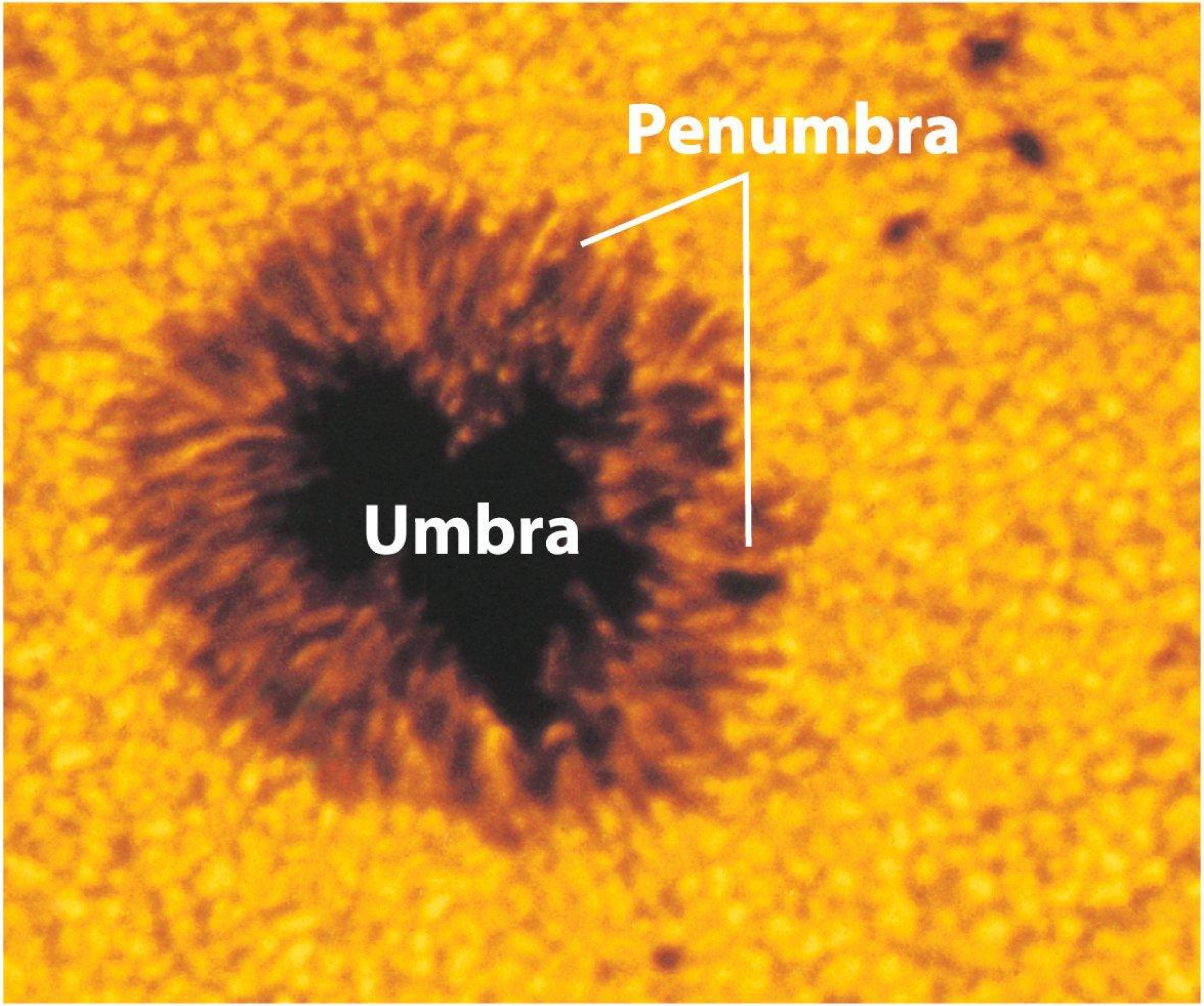
CONVECTION IN THE PHOTOSPHERE PRODUCES GRANULES

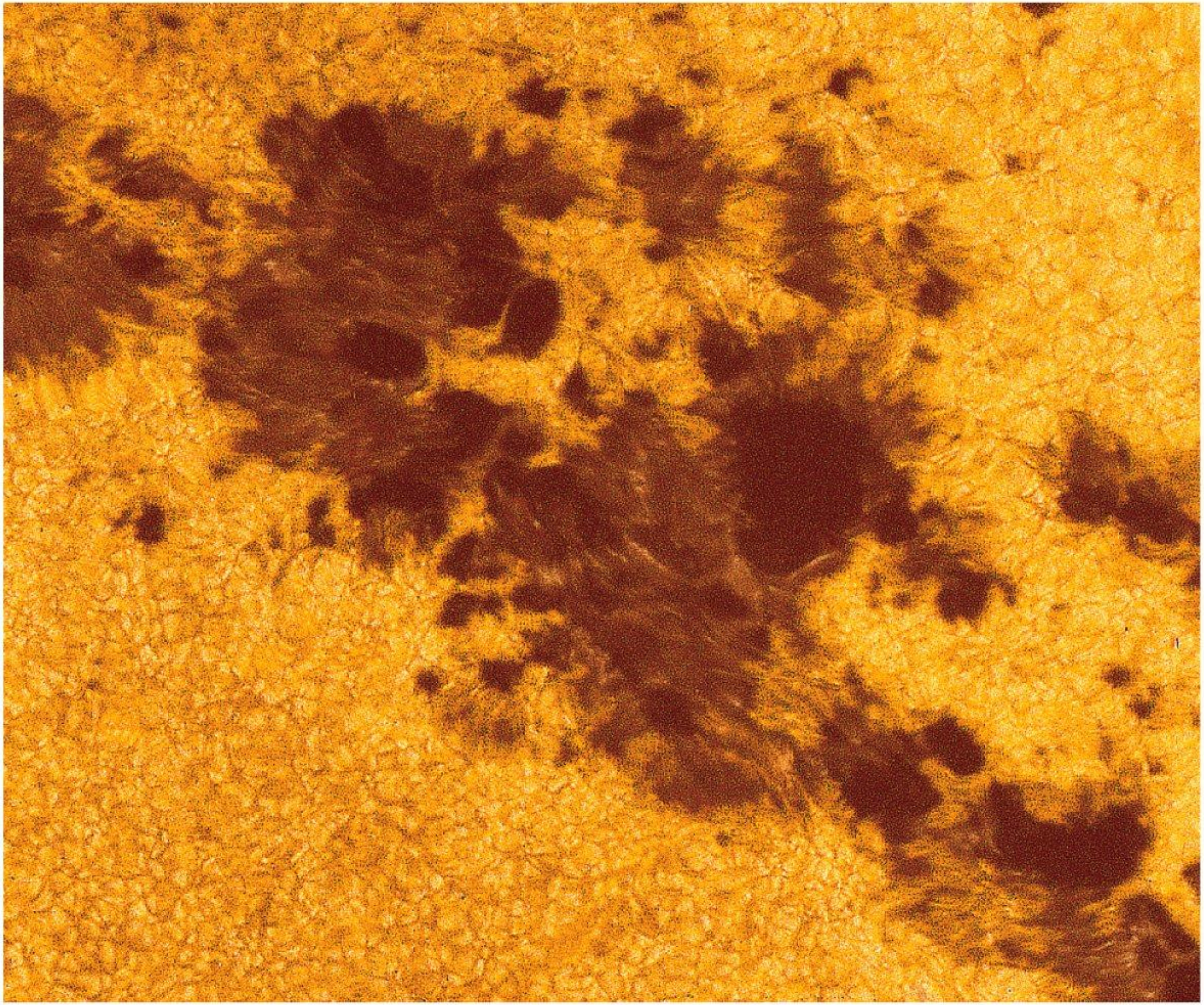


Sunspots:

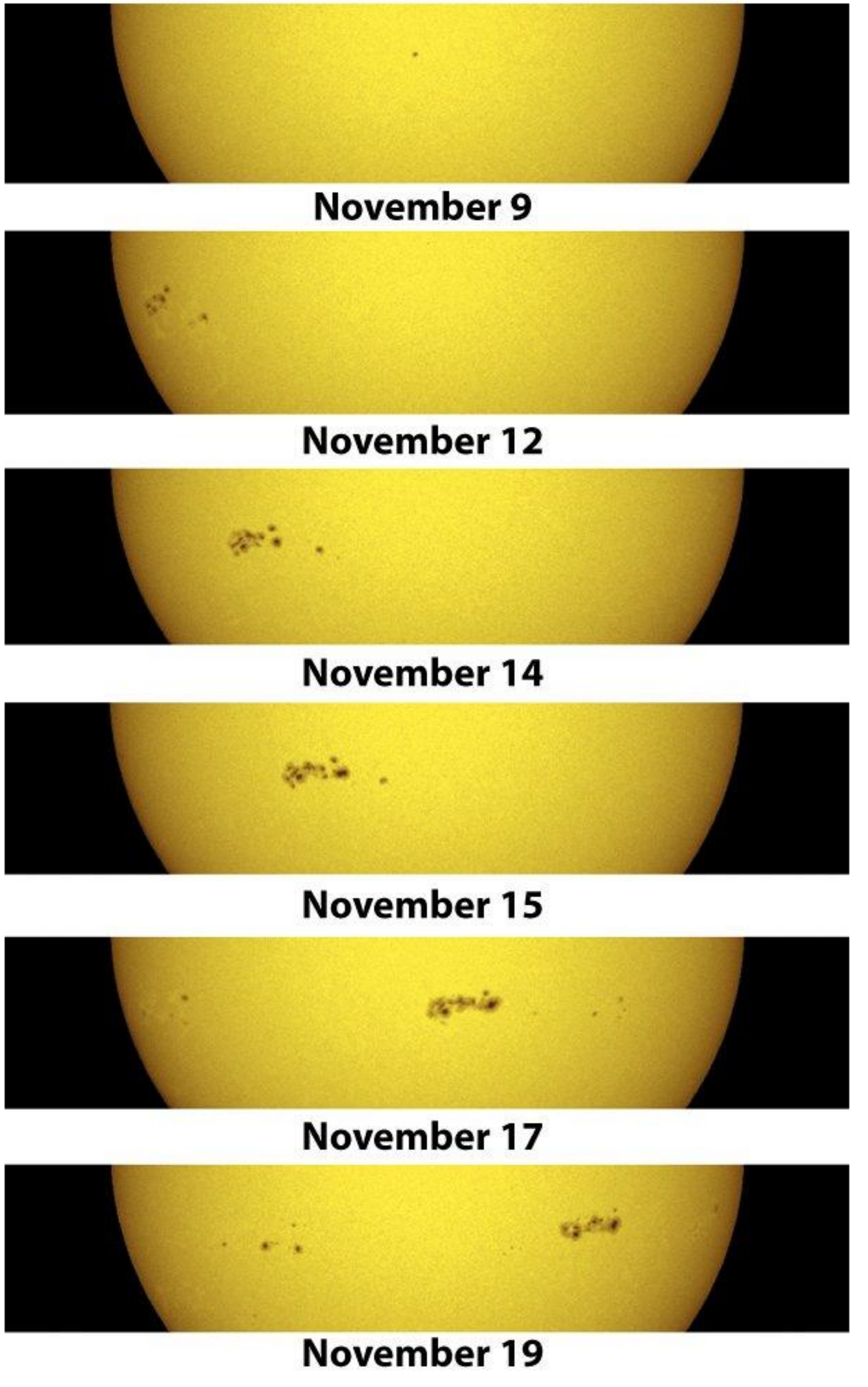


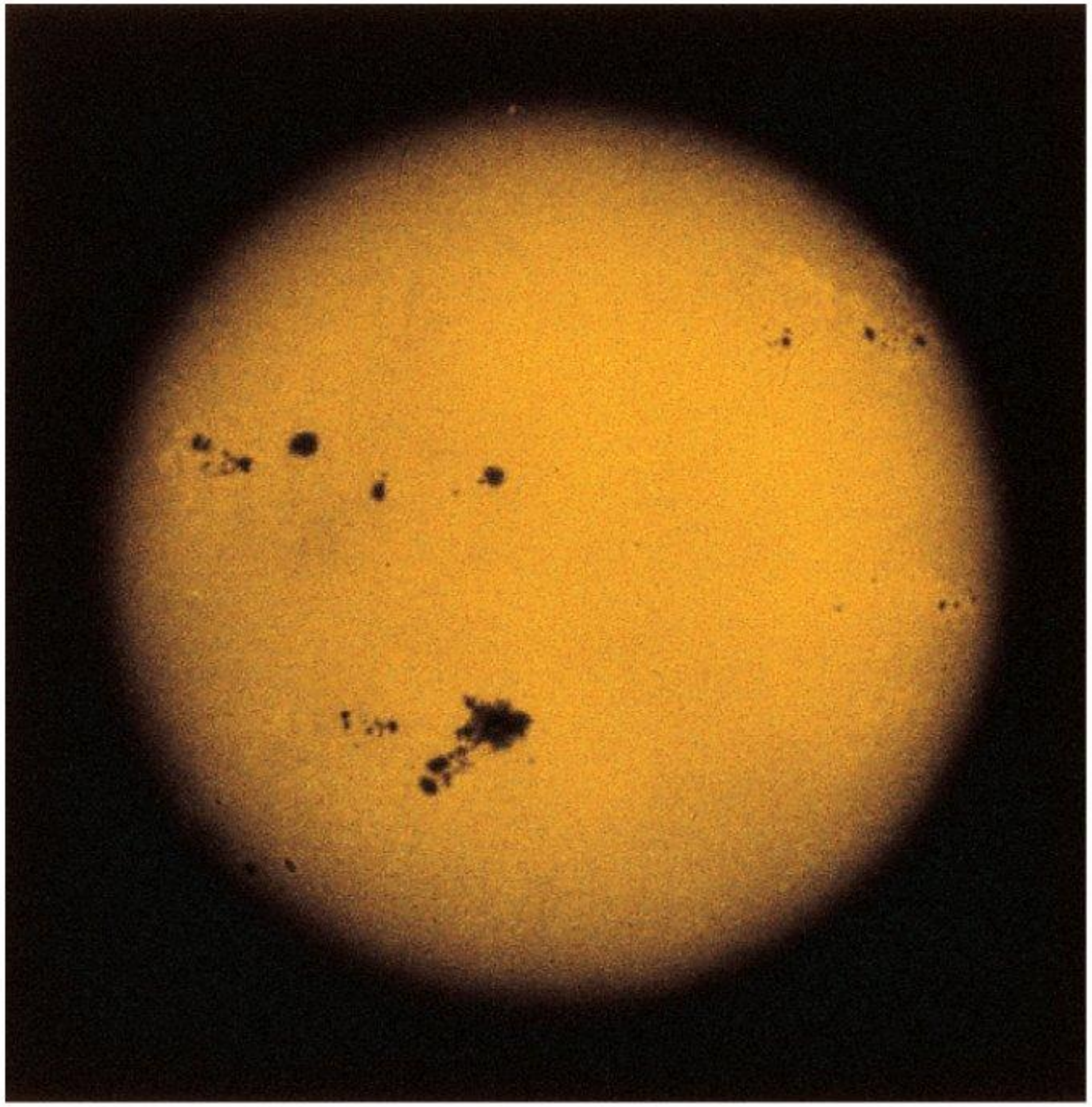
(a) (b)


Penumbra
Umbra

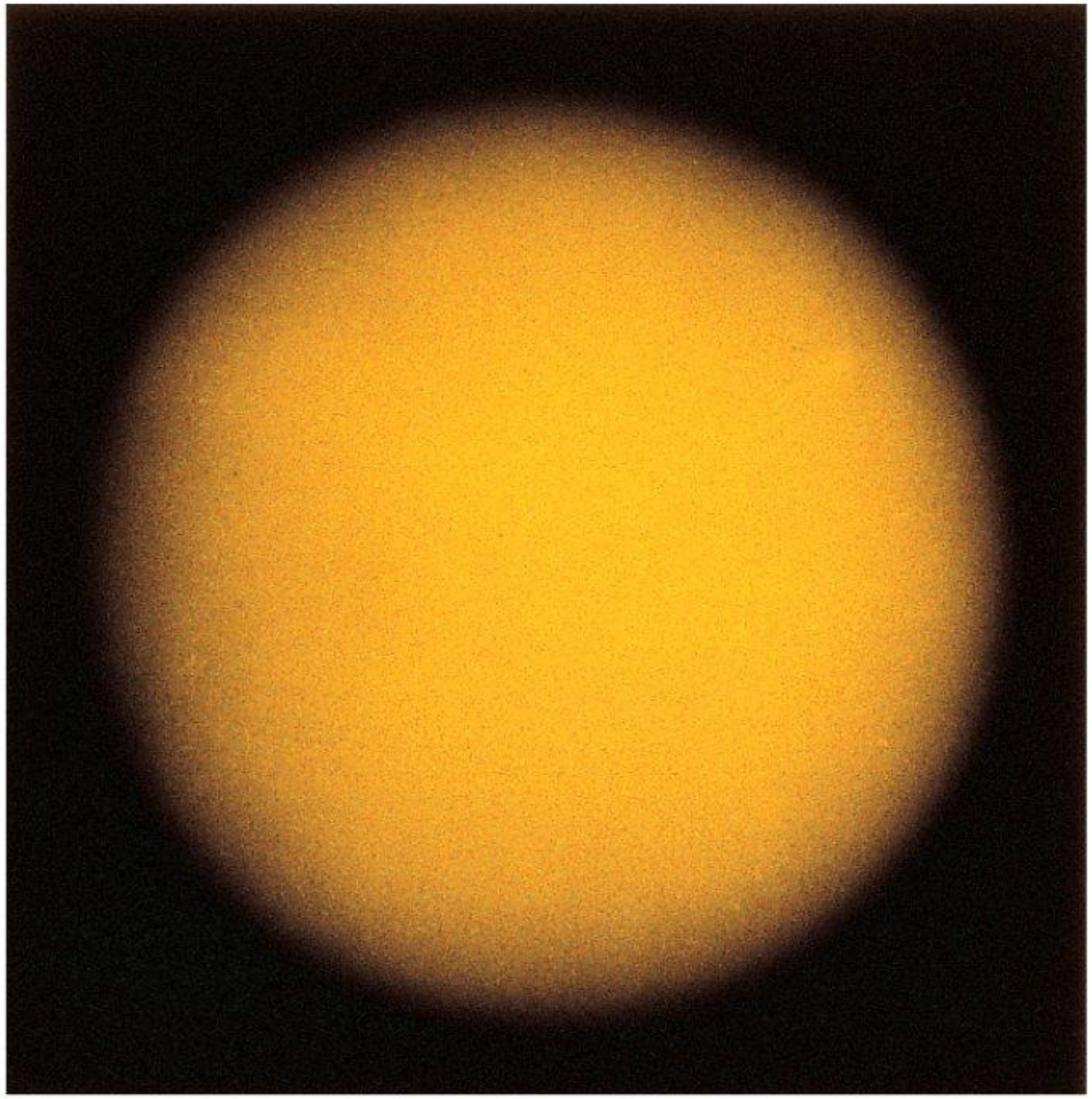


Sunspot Cycle



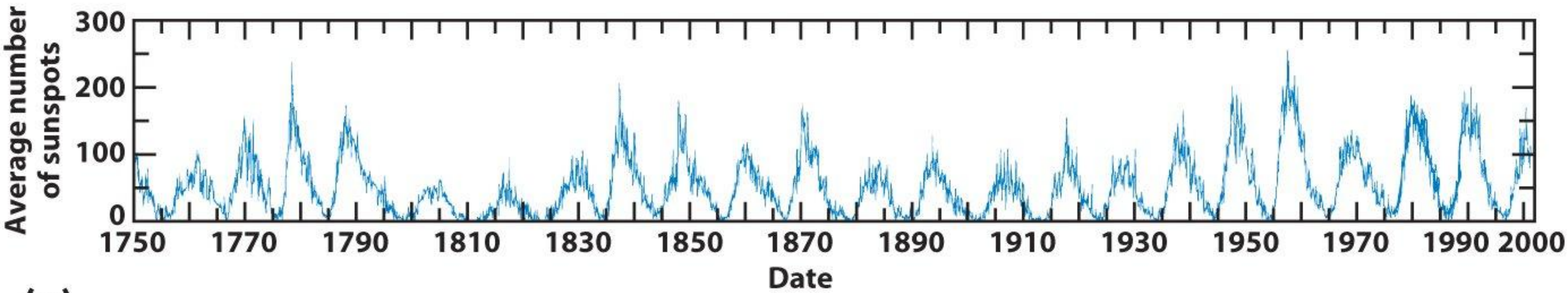


Near sunspot maximum

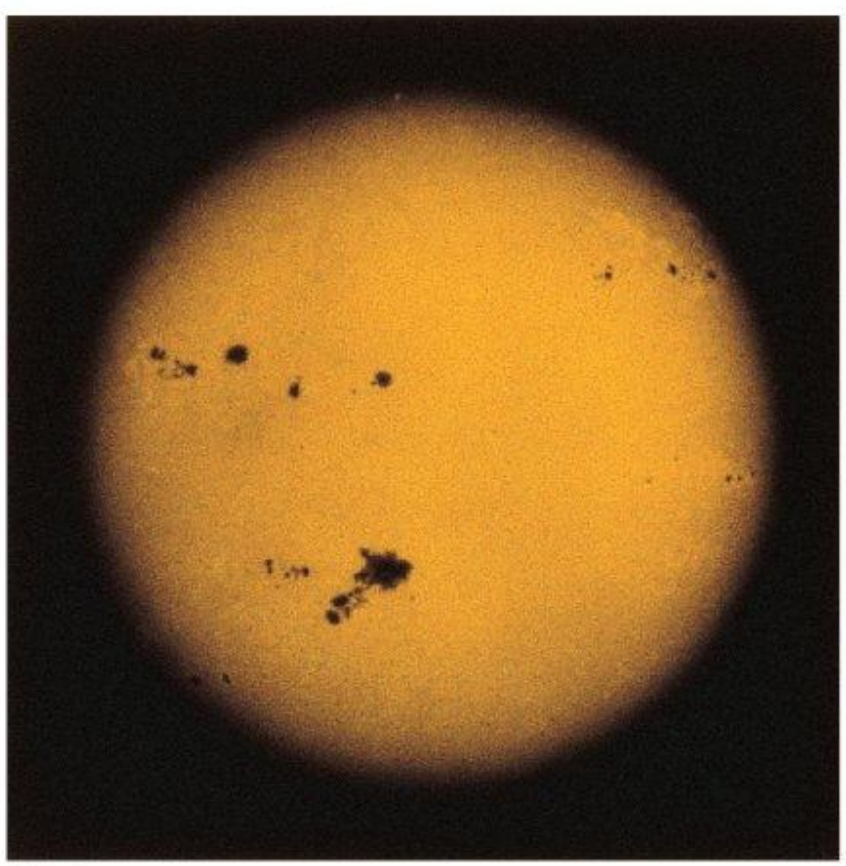


Near sunspot minimum

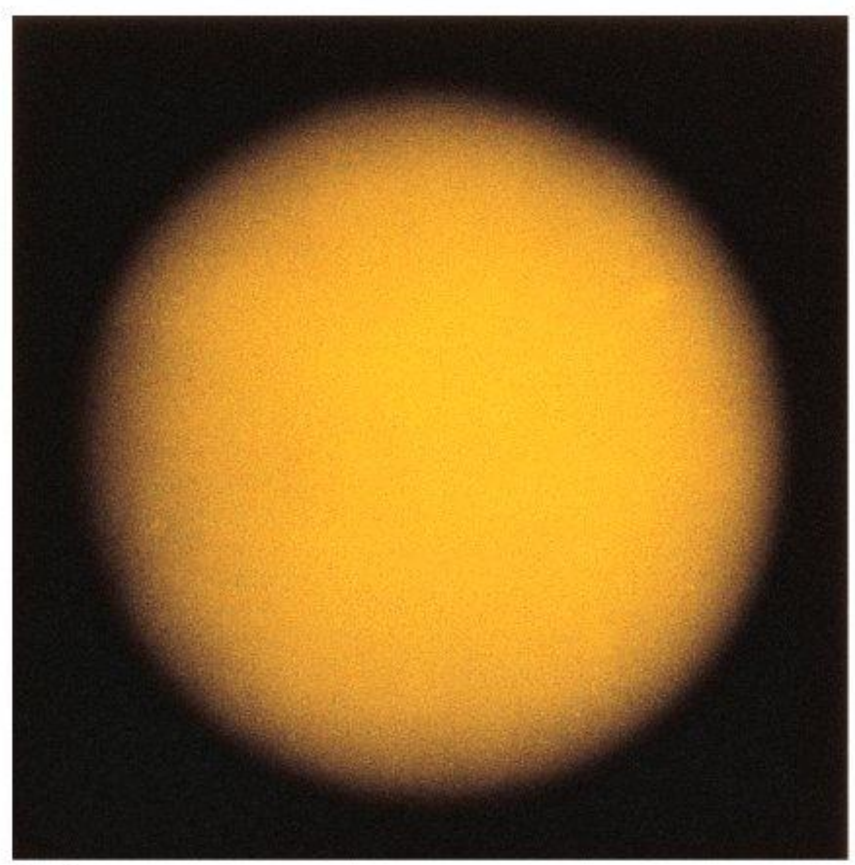
Sunspots are produced by a 22-year cycle in the Sun's magnetic field



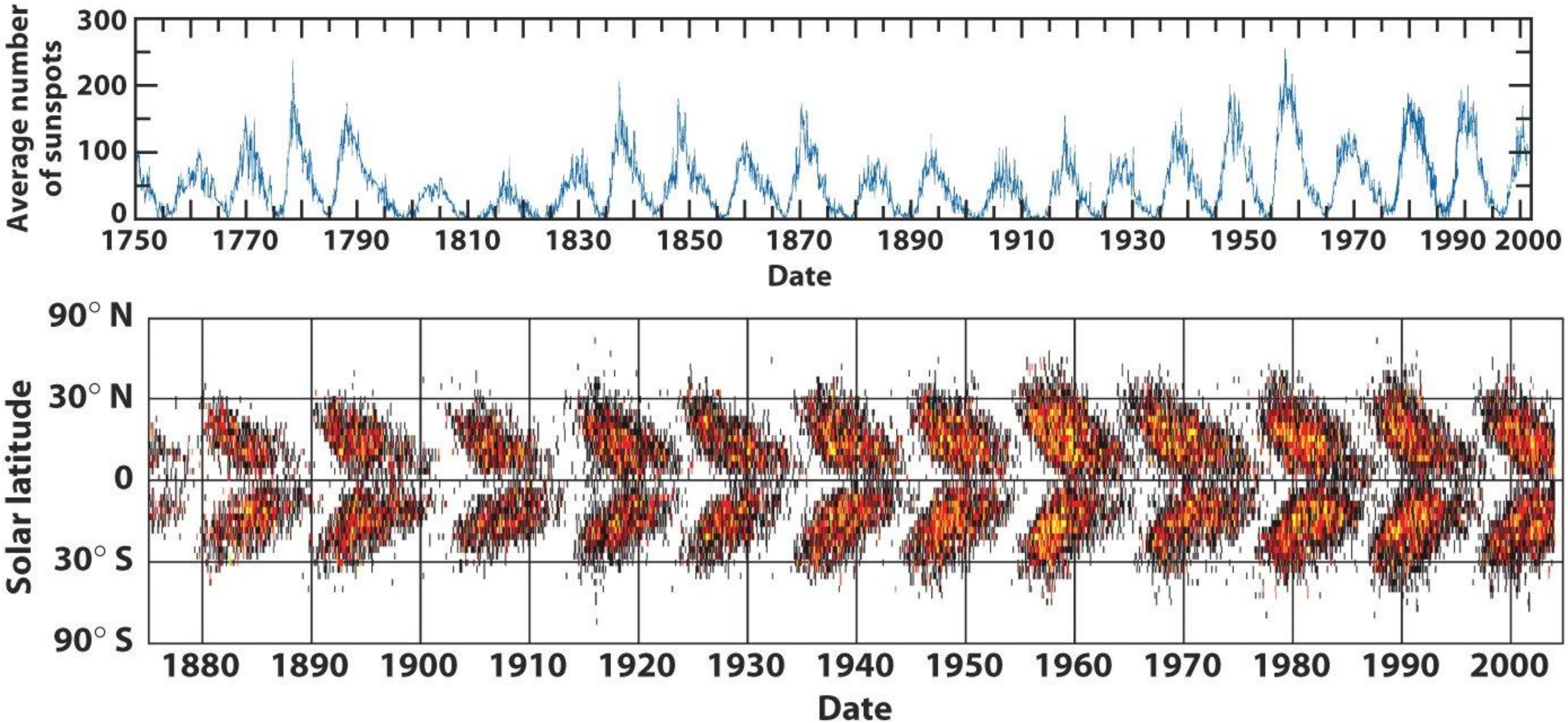
(a)



(b) Near sunspot maximum

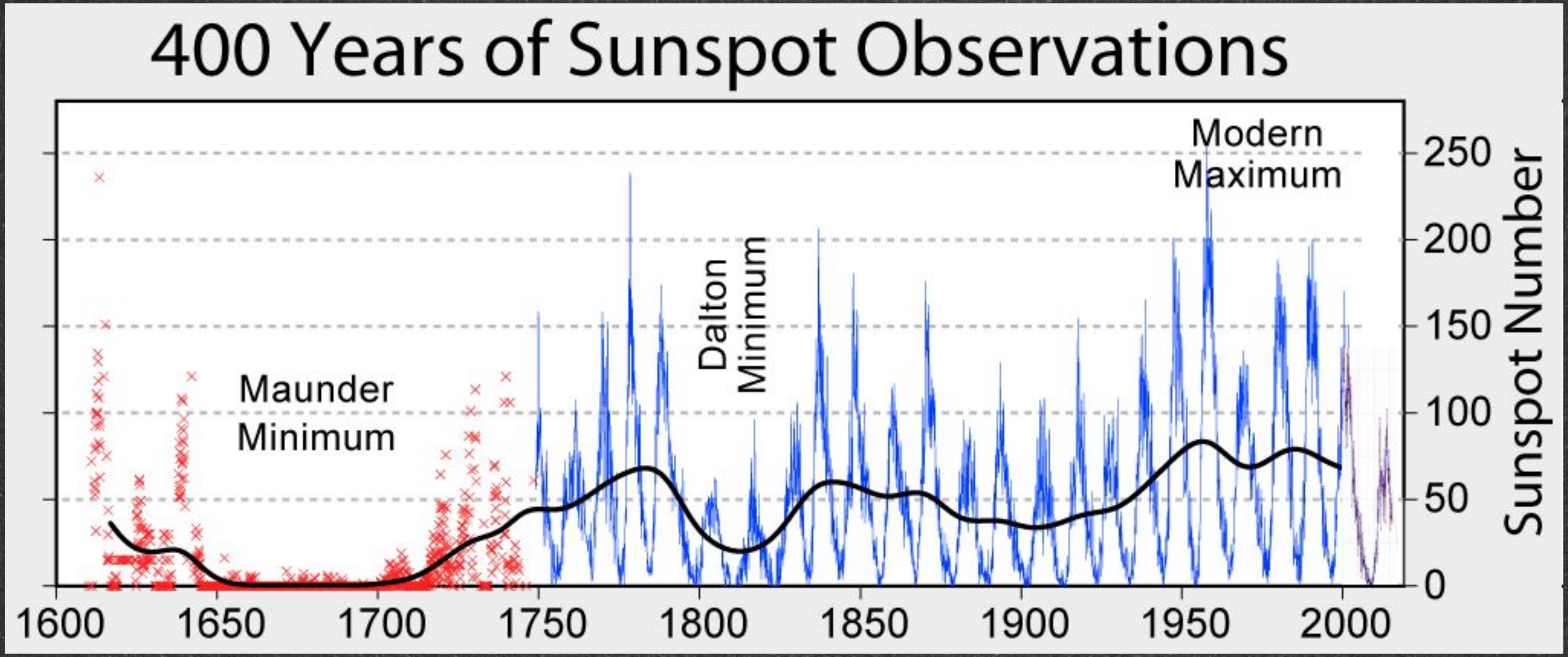


(c) Near sunspot minimum



- The Sun's surface features vary in an 11-year cycle – the sunspot cycle.
- The average number of sunspots increases and decreases in a regular cycle of approximately 11 years, with reversed magnetic polarities from one 11-year cycle to the next.
- This is related to a 22-year cycle (the solar cycle) in which the surface magnetic field increases, decreases, and then increases again with the opposite polarity.
- Two sunspot cycles make up one 22-year solar cycle.

Notebook: SunspotNumber



REFERENCES AND DEEPENING

Aimee A. Norton

Solar and Astrophysical Dynamos and Magnetic Activity
Proceedings IAU Symposium No. 294, 2012
A.G. Kosovichev, E.M. de Gouveia Dal Pino, & Y. Yan, eds.
doi:10.1017/S1743921313002172

How much more can sunspots tell us about the solar dynamo?

Aimee A. Norton[1], Eric H. Jones[2], Y. Liu[1], K. Hayashi[1], J. T. Hoeksema[1] and Jesper Schou[1]

[1]HEPL, Solar Physics, Stanford University,
CA 94305 USA,
email: aanorton@stanford.edu

[2]Centre for Astronomy, University of Southern Queensland,
Toowoomba, QLD, Australia
email: eric.jones@jcu.edu.au

Abstract. Sunspot observations inspired solar dynamo theory and continue to do so. Simply counting them established the sunspot cycle and its period. Latitudinal distributions introduced the tough constraint that the source of sunspots moves equator-ward as the cycle progresses. Observations of Hale's polarity law mandated hemispheric asymmetry. How much more can sunspots tell us about the solar dynamo? We draw attention to a few outstanding questions raised by inherent sunspot properties. Namely, how to explain sunspot rotation rates, the incoherence of follower spots, the longitudinal spacing of sunspot groups, and brightness trends within a given sunspot cycle. After reviewing the first several topics, we then present new results on the brightness of sunspots in Cycle 24 as observed with the Helioseismic Magnetic Imager (HMI). We compare these results to the sunspot brightness observed in Cycle 23 with the Michelson Doppler Imager (MDI). Next, we compare the minimum intensities of five sunspots simultaneously observed by the Hinode Solar Optical Telescope Spectropolarimeter (SOT-SP) and HMI to verify that the minimum brightness of sunspot umbrae correlates well to the maximum field strength. We then examine 90 and 52 sunspots in the north and south hemisphere, respectively, from 2010 - 2012. Finally, we conclude that the average maximum field strengths of umbra 40 Carrington Rotations into Cycle 24 are 2690 Gauss, virtually indistinguishable from the 2660 Gauss value observed at a similar time in Cycle 23 with MDI.

Keywords. Sunspots, dynamo, magnetic fields