The Sun

Our Star
What we know about the Sun

• **Angular Diameter** $\theta = 32$ arcmin (from observations)
• **Solar Constant** $f = 1.4 \times 10^6$ erg/sec/cm$^2$ (from observations)
• **Distance** $d = 1.5 \times 10^8$ km (1 AU).
  (from Kepler's Third Law and the trigonometric parallax of Venus)
• **Luminosity** $L = 4 \times 10^{33}$ erg/s.
  (from the inverse-square law: $L = 4\pi d^2 f$)
• **Radius** $R = 7 \times 10^5$ km. (from geometry: $R = \pi d$)
• **Mass** $M = 2 \times 10^{33}$ gm. (from Newton's version of Kepler's Third Law:
  $M = (4\pi^2/G) d^3/P^2$)
• **Temperature** $T = 5800$ K. (from the black body law: $L = 4\pi R^2 \sigma T^4$)
• **Composition** about 74% Hydrogen, 24% Helium, and 2% everything else (by mass). (from spectroscopy)
The Solar Photosphere

Galileo observed sunspots (earlier noted by Chinese observers)

- Sunspots are regions of intense magnetic fields
- Sunspots appear dark because they are cooler than the photosphere
- A large sunspot is brighter than the full moon.
Solar Photosphere
Solar Granulation

Real time: 20 minutes
Naked-eye Sunpots
Sunspots

**Pressure balance:**
Gas pressure + magnetic pressure in spot =
gas pressure outside spot

$B_s \sim 2\text{kG}$
$T_s \sim 4500\text{K}$
Photospheric Magnetic Fields

Zeeman Effect
The Solar Magnetic Field
The Solar Magnetic Field

- Magnetic fields trap gas.
- sunspots $T \approx 4,500 \text{ K}$
- convection cells $T \approx 5,800 \text{ K}$
- Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.
The Solar Magnetic Field
Temperature Profile

![Temperature Profile Graph](image_url)
Solar Atmospheric Structure

- Photosphere: 5760K; 0 km
- Temperature minimum: ~4000K, 500 km
- Chromosphere: 8000-20000K, 500-2000 km
- Transition Region: .02 - 1 MK, 2000 km
- Corona: $>10^6$ K, $>2000$ km
- Wind: $>10^6$ K, $>2000$ km

- Note heights are mean, and density-dependent
• First noticed in total solar eclipses.
• Name from the red color (from an emission line of Hydrogen)
• Hot (8000-20,000K) gas heated by magnetic fields.
• Bright regions known as plage.
The Corona
The diffuse outer atmospheres of the Sun.

The X-ray corona
The white-light corona

Also, the K corona - sunlight scattered from interplanetary dust
The Corona

Yohkoh  SXT: 1993-1994
Flares
The Magnetic Cycle

Spot cycle ~11 years
Magnetic cycle ~22 yrs
The Magnetic Cycle

The Butterfly Diagram

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

DATE


EQ

90N 30N 30S 90S

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

HATHAWAY NASA/ARC 2016/10
Solar Irradiance

ACRIM Composite Total Solar Irradiance Time Series: nnaa3

TSI trend between minima: + 0.037 %/decade
Nimbus7/ERB, ACRIM1, ACRIM2, VIRGO & ACRIM3 Results
ACRIM3 Scale - Nimbus7/ERB Comparisons of ACRIM1/ACRIM2

RC Wilson, composite nnaa3 09/11/2003
Coronal Mass Ejections
Coronal Mass Ejections
Coronal Mass Ejections
6/22/15 Flare
Solar Flares come with

- Solar Proton Events (SPE)
- Coronal Mass Ejections (CME)
The 1 Sept 1859 Flare

• 9/1: Carrington observed white-light flare
• 9/2: Brilliant auroras seen (as far south as the Caribbean)
• Telegraphs functioned w/o batteries
• Telegraph operators shocked

• First solar flare recorded
• Strongest in ~500 years
• Today it would
  – Bring down the electrical grid
  – Fry satellites
The 23 July 2012 Flare

- At least as energetic as the 1859 Carrington event
- Missed by about 1 week
The 23 July 2012 Flare

- At least as energetic as the 1859 Carrington event
- Missed by about 1 week
The 23 July 2012 Flare

- 2 CMEs recorded
- At least as energetic as the Carrington 1859 event
- Missed the earth by about 1 week

- Estimated economic impact:
  - $2 trillion ($2 \times 10^{12}) – 20 x greater than Katrina
  - Heavy-duty transformers destroyed; take years to manufacture
  - Power grid impacted for years

The Odds

12% in the next decade…

And in any decade following
Current Economic Impact

Insurance claims, 2000-2010

• Claims increase with geomagnetic activity
• ~4% of US power grid disturbances due to geomagnetic storms and GICs
  – 59% caused by “electrical surges”
  – Implies about 500 disturbances/year
• Estimated losses $118-188 Billion/year

Superflares

- Brightest ☉ flare observed \( \sim 10^{32} \text{ erg} \)
- Maehara et al. (2012) conclude a \( 10^{35} \text{ erg} \) flare could be expected every 5000 years
More Pictures and References

- Solar Data Analysis Center (SDAC): [http://umbra.nascom.nasa.gov/](http://umbra.nascom.nasa.gov/) includes links to SOHO, SDO, HINODE, and YOHKOH

Other Solar Missions:


- TRACE: [http://trace.lmsal.com/](http://trace.lmsal.com/)

Solar Storms