Today:

Flares,
CMEs and
Solar Wind
Flare can release $10^{31}$ ergs

Compare to: lightning? ($10^{11}$ ergs) Or Solar flux at Earth? ($3 \times 10^{24}$ ergs/s)
Composite Solar Flare Spectrum

Fluence (photons keV^{-1} cm^{-2})
(Duration = 100 s)

- Thermal Bremsstrahlung
  - T = 2 \times 10^5 K, E \nu = 10^{49} \text{cm}^{-3}\text{s}^{-1}
  - T = 4 \times 10^5 K, E \nu = 10^{49} \text{cm}^{-3}\text{s}^{-1}

- Nonthermal Bremsstrahlung

- Positron and Nuclear Gamma-Ray Lines

Photon Energy

1 keV, 10 keV, 100 keV, 1 MeV, 10 MeV, 100 MeV
CME = coronal mass ejection

Earth shown for size comparison
A large coronal mass ejection (CME) as observed by SOHO's LASCO C2 instrument over a two-hour period.
### Solar Wind Parameters

#### Table 4.1: Observed Properties of the Solar Wind near the Orbit of the Earth (1 AU)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton density</td>
<td>6.6 cm⁻³</td>
</tr>
<tr>
<td>Electron density</td>
<td>7.1 cm⁻³</td>
</tr>
<tr>
<td>He⁺⁺ density</td>
<td>0.25 cm⁻³</td>
</tr>
<tr>
<td>Flow speed (nearly radial)</td>
<td>450 km·s⁻¹</td>
</tr>
<tr>
<td>Proton temperature</td>
<td>1.2 × 10⁹ K</td>
</tr>
<tr>
<td>Electron temperature</td>
<td>1.4 × 10⁹ K</td>
</tr>
<tr>
<td>Magnetic field (induction)</td>
<td>7 × 10⁻⁹ Tesla (T)</td>
</tr>
</tbody>
</table>

#### Table 4.2: Solar-Wind Flux Densities and Fluxes near the Orbit of the Earth

<table>
<thead>
<tr>
<th>Flux Density</th>
<th>Flux Through Sphere at 1 AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>8.4 × 10³⁵ s⁻¹</td>
</tr>
<tr>
<td>Mass</td>
<td>1.6 × 10¹² g·s⁻¹</td>
</tr>
<tr>
<td>Radial momentum</td>
<td>7.3 × 10¹⁴ newton (N)</td>
</tr>
<tr>
<td>Kinetic energy</td>
<td>1.7 × 10²⁷ erg·s⁻¹</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>0.05 × 10²⁷ erg·s⁻¹</td>
</tr>
<tr>
<td>Magnetic energy</td>
<td>0.025 × 10²⁷ erg·s⁻¹</td>
</tr>
<tr>
<td>Radial magnetic flux</td>
<td>1.4 × 10¹⁵ weber (Wb)</td>
</tr>
</tbody>
</table>
First Direct measurements of the Solar Wind

Luna 1 (Metchta)

Launched in 1959 on a direct orbit to Moon

Discovered outer radiation belts and made first measurements of energetic Solar Wind particles.

(missed the moon, and went into solar orbit)
Magnetic and Electric Fields in Space
A X-ray image of the Sun made with the Hinode satellite on February 20, 2007. The insets show the flow of gas away from the bright region marked on the left. The blue image indicates material flowing towards us that will eventually make up the solar wind and the red image shows material flowing away from us back towards the surface of the Sun. L. Harra/JAXA/NASA/ESA
Frozen-in B-field
Results in
Garden Hose Angle

Spiral Locus of Fluid Parcels Emitted from a Fixed Source on Rotating Sun

Location of Source when First Parcel Left Base of Corona

Location of Source when Last Parcel Left Base of Corona

Sun Rotating with Angular Speed $\omega$
FIGURE 5.3 The so-called "ballerina skirt" model of the solar-interplanetary current sheet. (Courtesy of S.-I. Akasofu, Geophysical Institute, University of Alaska.) The sun is the center of an extensive and warped disk-like sheet in which electric currents flow azimuthally, that is, around the sun. The average plane of the disk is approximately the plane of the equator of the sun's average dipole magnetic field, which may be tilted with respect to its equator of rotation. The sheet separates solar-interplanetary magnetic-field regimes of nearly opposite or at least greatly different average direction, as shown in the inset, which is a meridian cross section of the current sheet and magnetic field lines on each side.
**South Hemisphere (40°–60° lat.)**

- **Electron Density (cm$^{-3}$)**
  - $0.64 \pm 0.04$
  - $2.00 \pm 0.01$

**Heliocentric distance (A.U.)**
FIGURE 5.2 One possible model of the heliosphere. The plane of the figure is the plane of the sun's equator, which is approximately the general plane of planetary orbits. The details of the outer regions are in doubt: they are based on theoretical extrapolations of the only region (less than halfway out to Neptune's orbit) in which measurements have been made.
Fig. 11. A model of transients propagating into the outer heliosphere. A kinematic model is used to follow the distortions in the heliospheric magnetic field with time and distance. Six high-speed streams of limited temporal and spatial extent intended to simulate flare ejecta were launched at the sun over an interval of 19 days. The resulting dramatic effect of the transients on the pre-existing spiral structure of the heliosphere is apparent. The dark bands correspond to interaction regions and the light areas with more radially directed field lines correspond to rarefaction regions. The region out to 15 AU is shown at intervals from 7 to 25 days [Akosyfu and Hikumoto, 1983].
Fig. 1. (Left) Schematic of corotating flow [from Pizzo, 1978]. (Right) Flare-associated transient flow [from Hundhausen, 1972]. Both figures show a cross section of the flow in the solar equatorial plane, with the light spiral lines representing the magnetic field; the heavy dark arrows denote the bulk flow vector. The large open arrows in the corotating flow indicate the nonradial flows driven by the pressure gradients built up in the stream interaction. The internal structure of the transient flow can be quite complex. For a more recent schematic, see Zwicki et al. [1983].