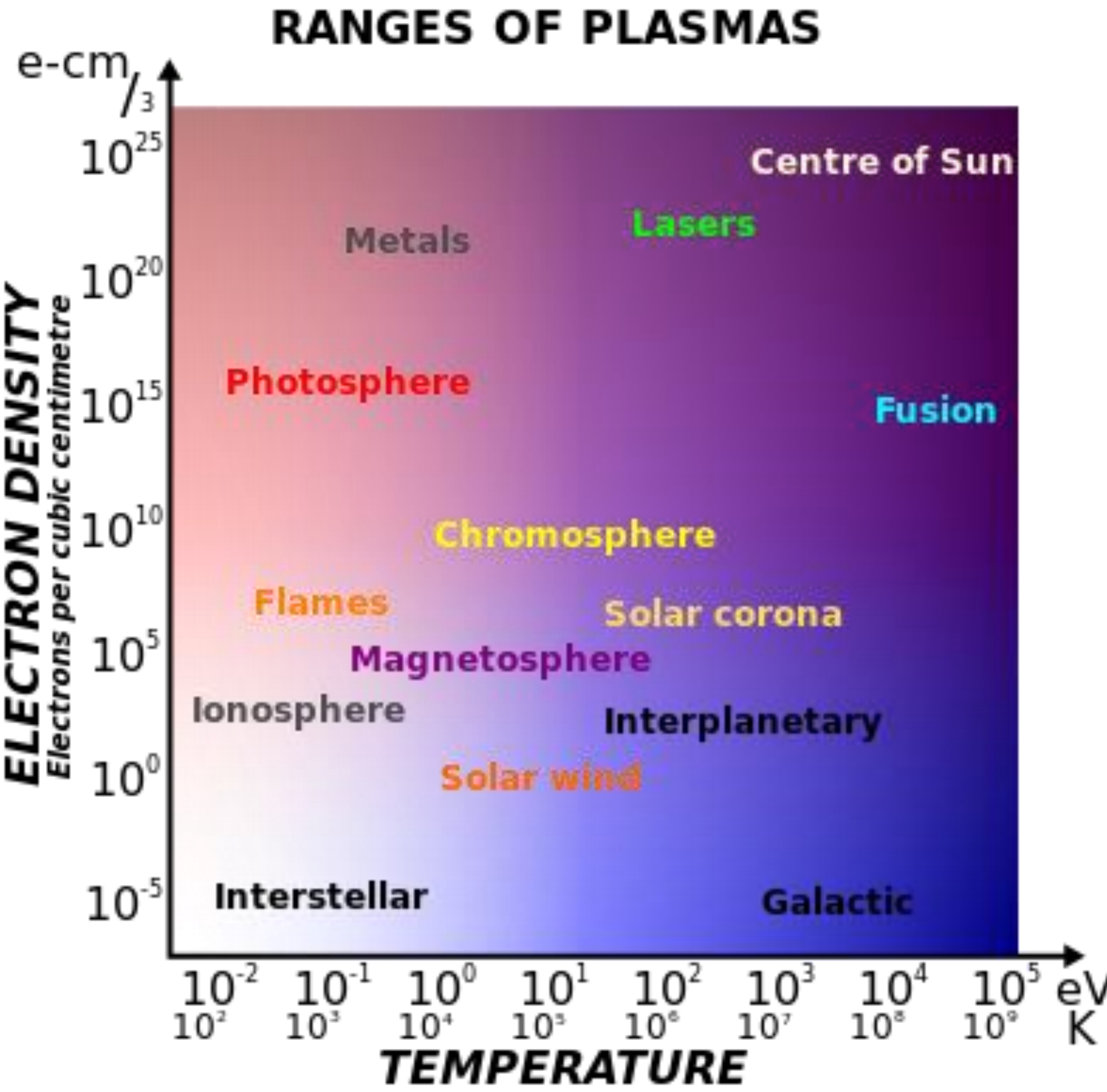
Last time…

- Electric field in tail
- ExB drift
  - Vector algebra with double cross product
  - Interaction with Earth’s corotating plasma
  - Kelvin-Helmholtz instability
- Different plasma regimes
  - Neutral Earth’s atmosphere: n_e low, E low

Plasma Characteristics & behaviors

Knipp's book
pp. 244-247



Lecture 35

- Comments on homework
  - – Double epsilons
  - – integrals
- Space weather stories
- CMEs

Double epsilons

Application of last time

$$[\mathbf{E}\times\mathbf{B}]_i = -[(\mathbf{u}\times\mathbf{B})\times\mathbf{B}]_i = [\mathbf{B}\times(\mathbf{u}\times\mathbf{B})]_i = \varepsilon_{ijk}B_j\varepsilon_{klm}u_lB_m$$

Which one is correct?

A. $\varepsilon_{ijk}\varepsilon_{klm} = \delta_{ij}\delta_{lm} - \delta_{ji}\delta_{ml}$

B. $\varepsilon_{ijk}\varepsilon_{klm} = \delta_{ji}\delta_{ml} - \delta_{ij}\delta_{lm}$

C. $\varepsilon_{ijk}\varepsilon_{klm} = \delta_{il}\delta_{jm} - \delta_{im}\delta_{jl}$

D. $\varepsilon_{ijk}\varepsilon_{klm} = \delta_{im}\delta_{jl} - \delta_{il}\delta_{jm}$

Integrations

$$\int_{-1}^{1} \mu \, \mathrm{d}\mu = ?$$

Which one is correct?

A. $\tfrac{1}{2}\mu^2$

B. $\tfrac{1}{2}$

C. 1

D. 0

…from Lecture 3

Need to know

$$\int_0^\infty \frac{x^3}{e^x - 1}\,dx = \frac{\pi^4}{15}$$

definition

$$\frac{2\pi k_B^4}{15h^3c^2} = \sigma_{SB}$$

so

$$S = \frac{\sigma_{SB}}{\pi} T^4$$

Which one is the Boltzmann constant?

A. $k_B = 1.38 \times 10^{-23}$ J/K

B. $\sigma_{SB} = 5.67 \times 10^{-8}$ J/m2/s/K

…from Lecture 32

Hydrostatic equilibrium

$$\frac{dP}{dr} = -\rho\frac{GM}{r^2}$$

$$\frac{d\ln P}{dr} = -\frac{\rho}{P}\frac{GM}{r^2} = -\frac{\mu}{\mathfrak{R}T}\frac{GM}{r^2} = -\frac{\mu}{\mathfrak{R}T_0}\left(\frac{r}{r_0}\right)^{2/7}\frac{GM}{r^2}$$

integrate

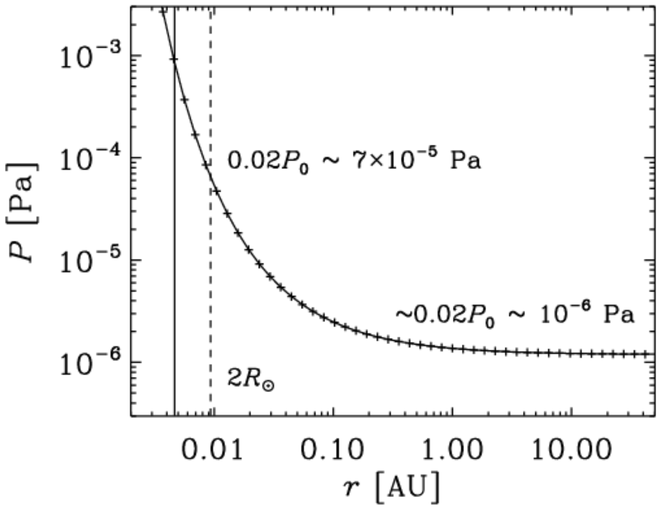
$$\int d\ln P = \frac{\mu}{\mathfrak{R}T_0}\frac{GM}{r_0}\int (r/r_0)^{-12/7}\, d(r/r_0)$$

so

$$\ln(P/P_0) = \underbrace{\tfrac{7}{5}\frac{\mu}{\mathfrak{R}T_0}\frac{GM}{r_0}}_{C_2\approx 4}\left[(r/r_0)^{-5/7}-1\right]$$

gives

$$P = P_0\exp\left\{4\left[\left(\frac{r}{r_0}\right)^{-5/7}-1\right]\right\}$$



…from lecture 10

Increased pressure $p = 2n_{\mathrm{H}}k_{\mathrm{B}}T$ 2 particles per H atom

Ionized hydrogen $\rho = \frac{n}{2}m_{\mathrm{H}}$ Gas density

$$p = \rho\frac{k_B}{m_{\mathrm{H}}/2}T = \rho\frac{\Re}{\mu}T$$

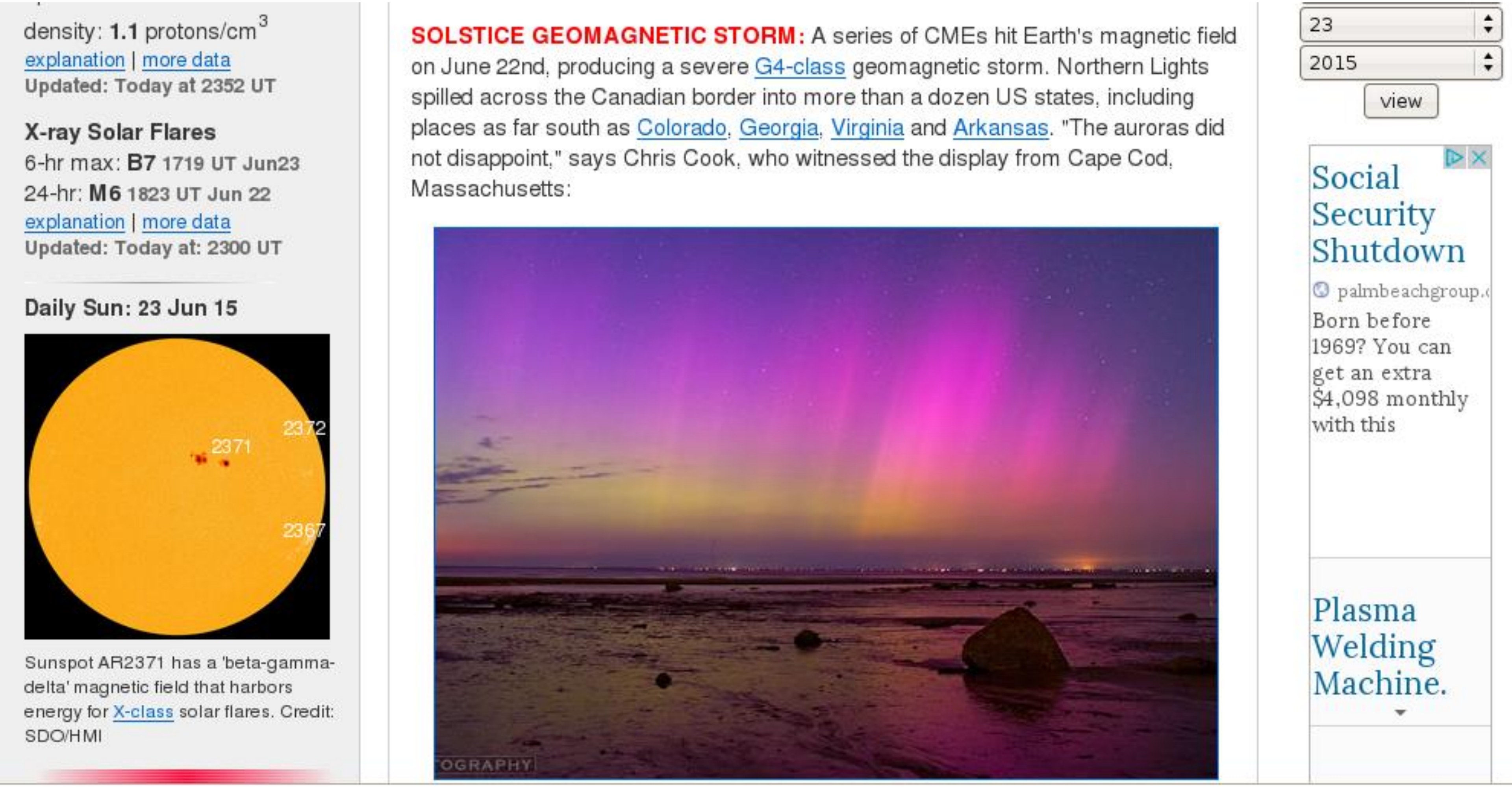
so $\mu = 1/2$

Neutral helium $\rho = 4nm_{\mathrm{H}}$ so $\mu = 4$

Space weather stories

- 1972 Aug 2, 400 rem event
- 1989 Mar 13, CME 10^{12} kg
- 2000 Jul 14, Bastille Day Event
- 2001 Sep 4, Mars global dust storm
- 2003 Oct 28, Halloween event
- 2012 Jul 23 (~to Carrington event)

23 June 2015



density: **1.1** protons/cm^3
explanation | more data
Updated: Today at 2352 UT

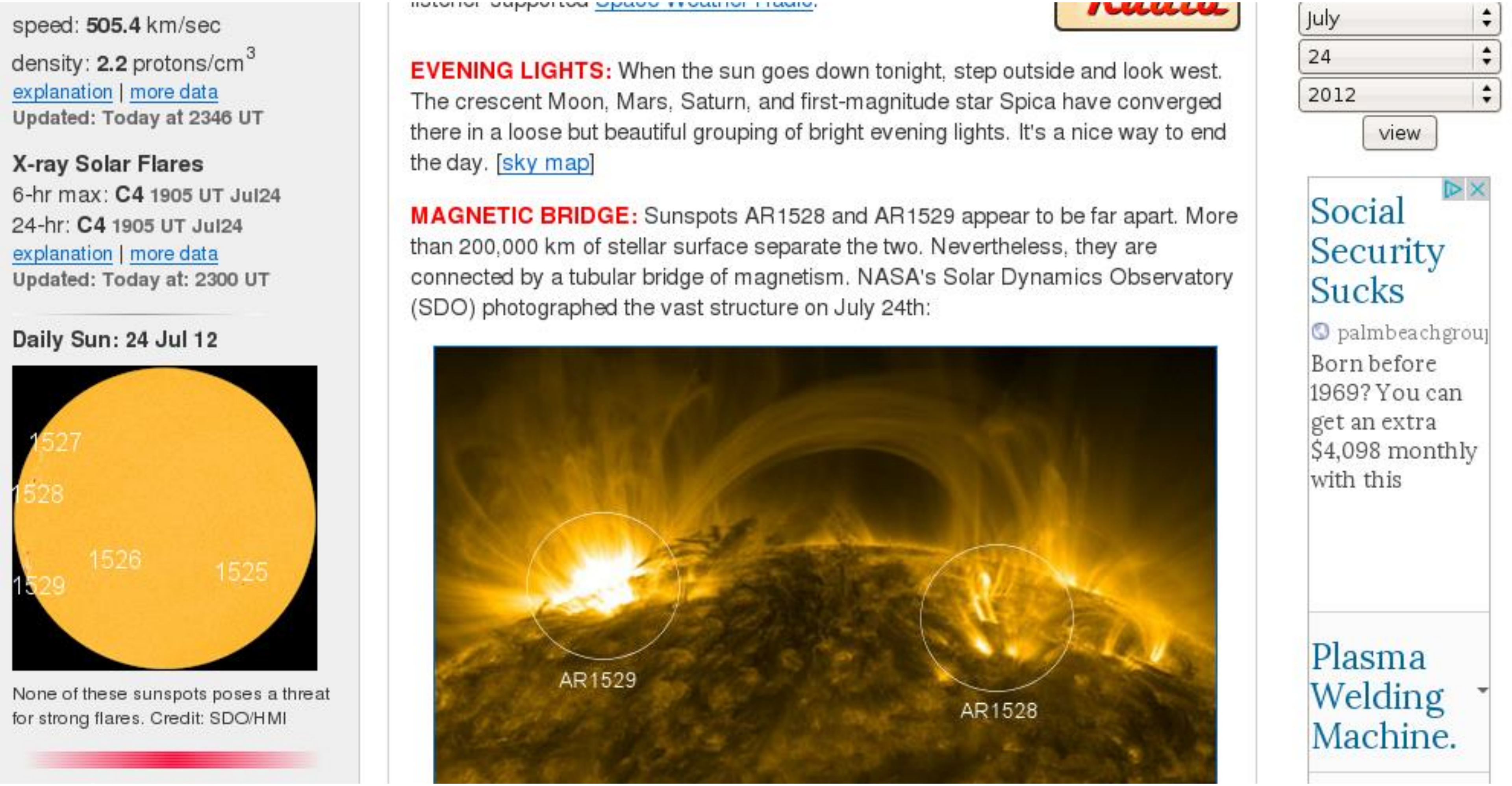
X-ray Solar Flares
6-hr max: **B7** 1719 UT Jun23
24-hr: **M6** 1823 UT Jun 22
explanation | more data
Updated: Today at: 2300 UT

Daily Sun: 23 Jun 15

Sunspot AR2371 has a 'beta-gamma-delta' magnetic field that harbors energy for X-class solar flares. Credit: SDO/HMI

SOLSTICE GEOMAGNETIC STORM: A series of CMEs hit Earth's magnetic field on June 22nd, producing a severe G4-class geomagnetic storm. Northern Lights spilled across the Canadian border into more than a dozen US states, including places as far south as Colorado, Georgia, Virginia and Arkansas. "The auroras did not disappoint," says Chris Cook, who witnessed the display from Cape Cod, Massachusetts:

23 July 2012



speed: **505.4** km/sec
density: **2.2** protons/cm^3
explanation | more data
Updated: Today at 2346 UT

X-ray Solar Flares
6-hr max: **C4** **1905 UT Jul24**
24-hr: **C4** **1905 UT Jul24**
explanation | more data
Updated: Today at: 2300 UT

Daily Sun: 24 Jul 12

None of these sunspots poses a threat for strong flares. Credit: SDO/HMI

EVENING LIGHTS: When the sun goes down tonight, step outside and look west. The crescent Moon, Mars, Saturn, and first-magnitude star Spica have converged there in a loose but beautiful grouping of bright evening lights. It's a nice way to end the day. [sky map]

MAGNETIC BRIDGE: Sunspots AR1528 and AR1529 appear to be far apart. More than 200,000 km of stellar surface separate the two. Nevertheless, they are connected by a tubular bridge of magnetism. NASA's Solar Dynamics Observatory (SDO) photographed the vast structure on July 24th:

Bastille Day Event

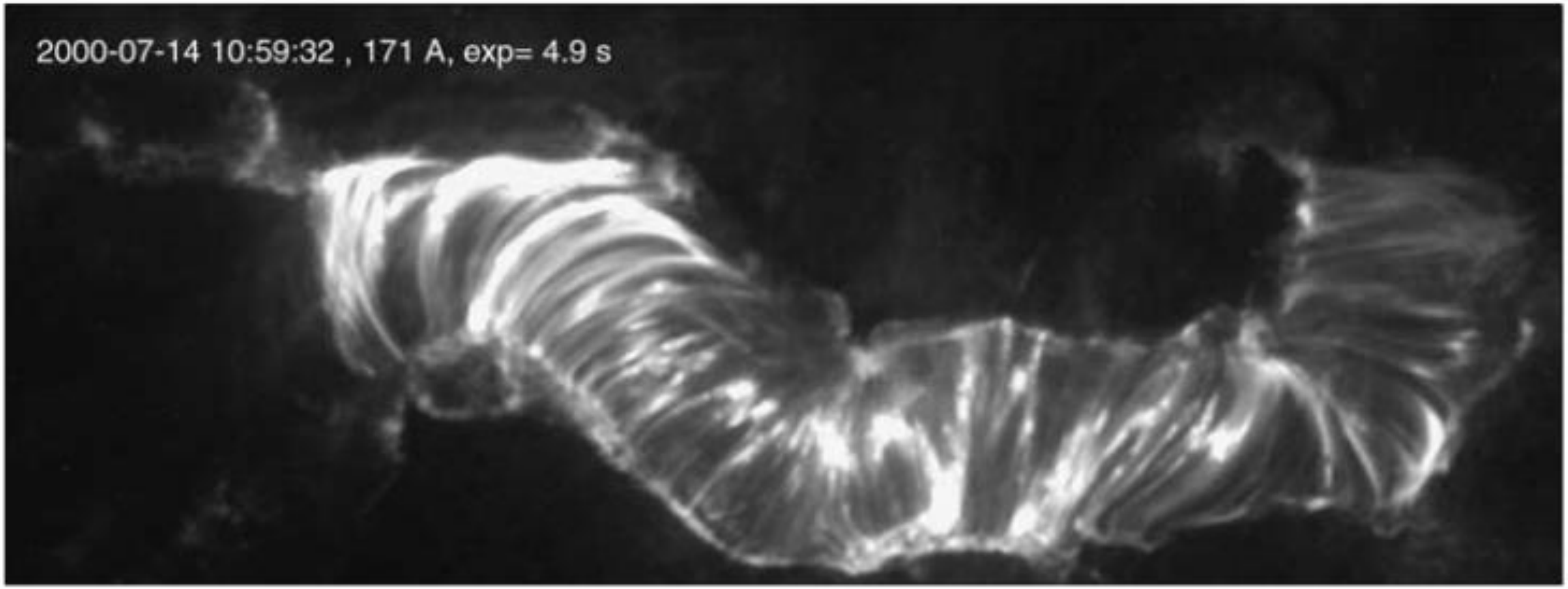
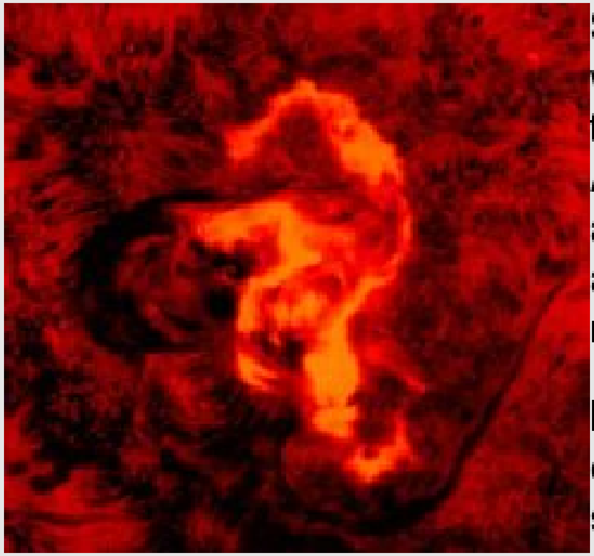


Figure 6. TRACE 171 Å image of the Bastille Day flare about 40 min after the flare peak, when the entire arcade of this double-ribbon flare is illuminated with cooling plasma in the $T = 1 - 2$ MK range, showing a curved sequence of closely-spaced loops with the appearance of a '*slinky*'. The field of view is 640 × 256 pixels (with pixel size of $0.5''$), which corresponds to $320'' \times 128''$ or 232 × 93 Mm.

Cucinotta estimates that a moonwalker caught in the August 1972 storm might have absorbed 400 rem. Deadly? "Not necessarily," he says. A quick trip back to Earth for medical care could have saved the hypothetical astronaut's life.

Below: One of the August 1972 solar flares. Click to view a 2-MB mpeg movie → of the explosion, which solar physicists call "the seahorse flare." [More →]



Surely, though, no astronaut is going to walk around on the Moon when there's a giant sunspot threatening to explode. "They're going to stay inside their spaceship (or habitat)," says Cucinotta. An Apollo command module with its aluminum hull would have attenuated the 1972 storm from 400 rem to less than 35 rem at the astronaut's blood-forming organs. That's the difference between needing a bone marrow transplant âŚ or just a headache pill.

Modern spaceships are even safer. "We measure the shielding of our ships in units of areal density--or grams per centimeter-squared," says Cucinotta. Big numbers, which represent thick hulls, are better:

The hull of an Apollo command module rated 7 to 8 g/cm^2.

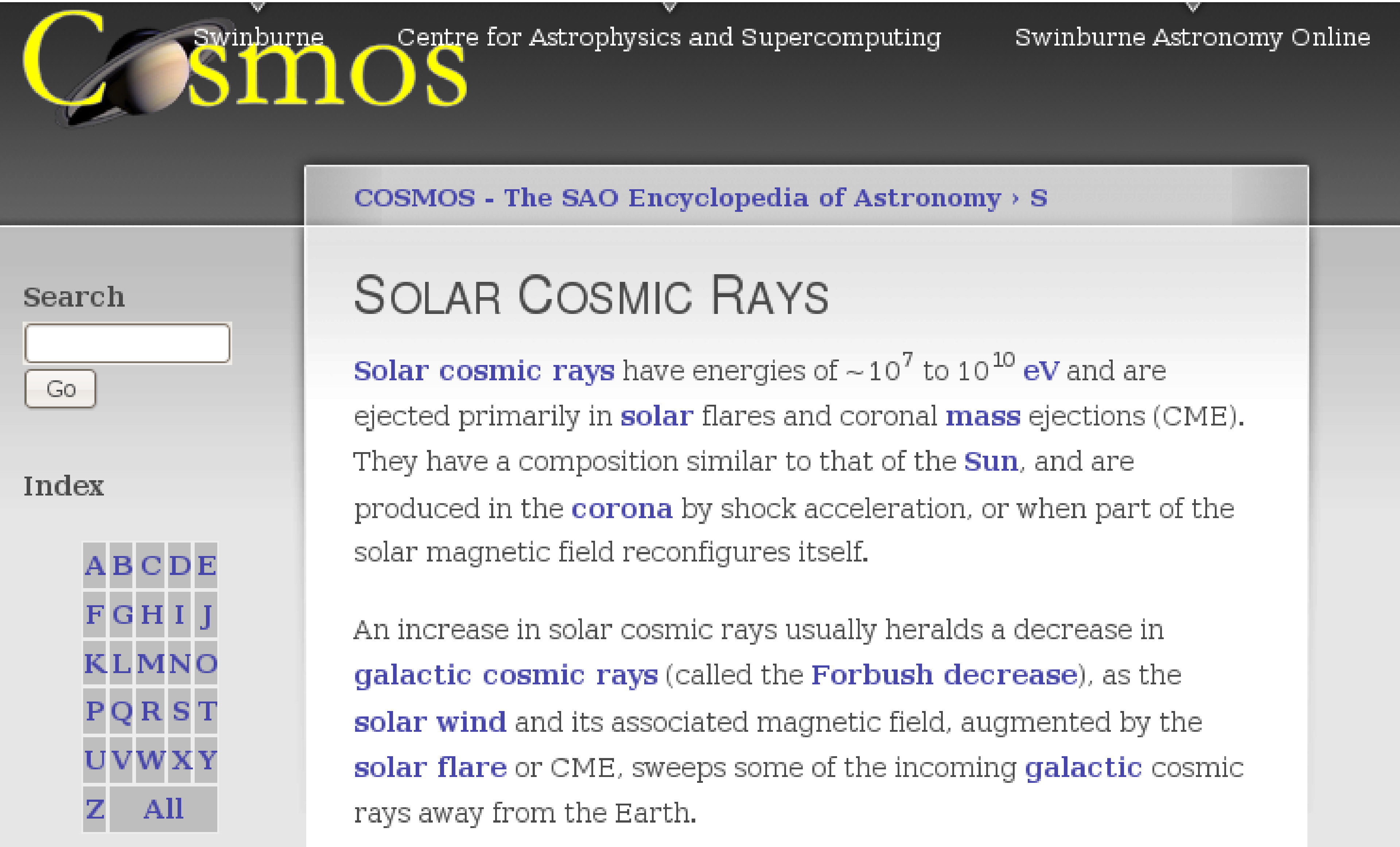
A modern space shuttle has 10 to 11 g/cm^2.

The hull of the ISS, in its most heavily shielded areas, has 15 g/cm^2.

Future moonbases will have storm shelters made of polyethelene and aluminum possibly exceeding 20 g/cm^2.

A typical space suit, meanwhile, has only 0.25 g/cm^2, offering little protection. "That's why you want to be indoors when the proton storm hits," says Cucinotta.

Solar cosmic rays

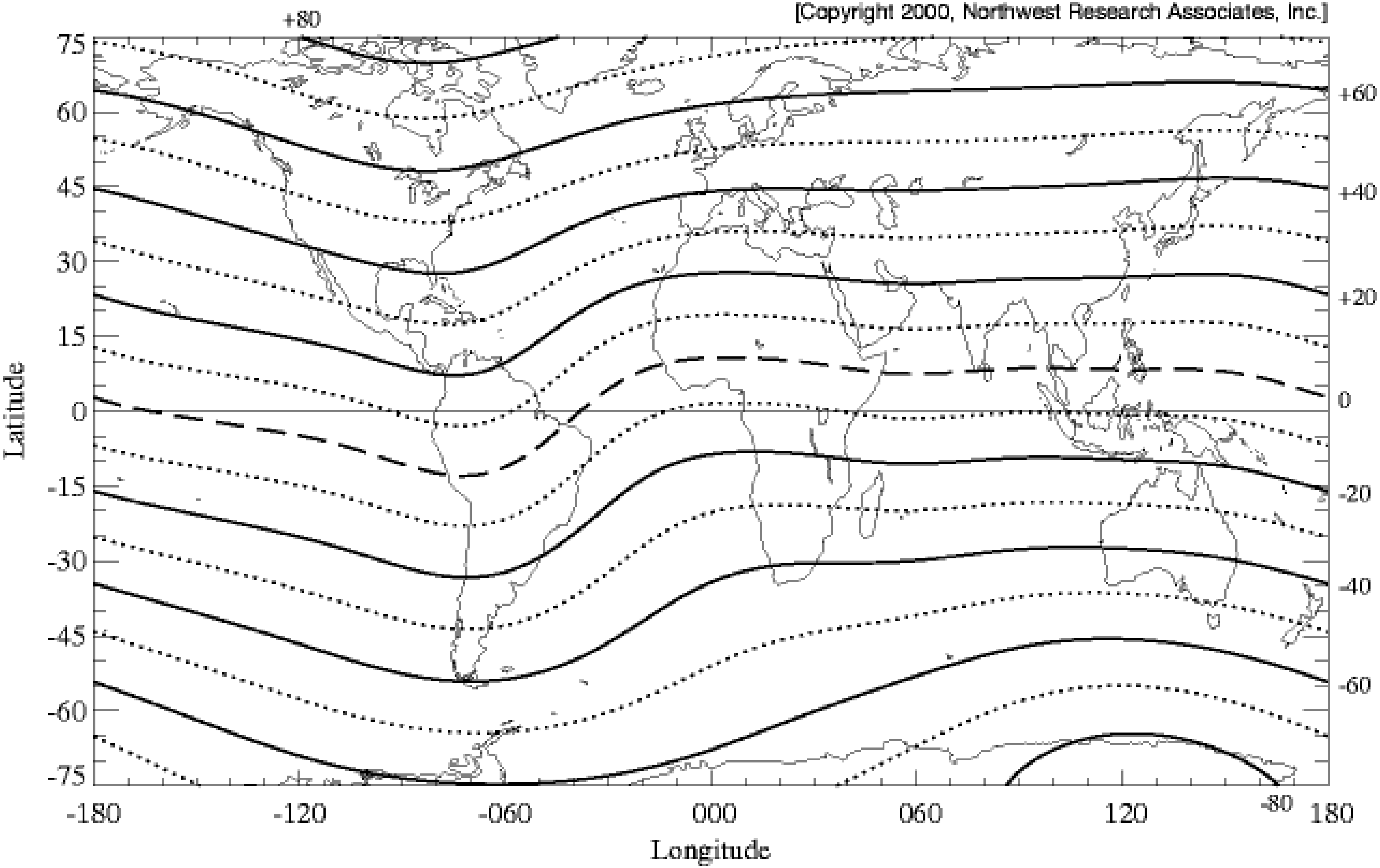


SOLAR COSMIC RAYS

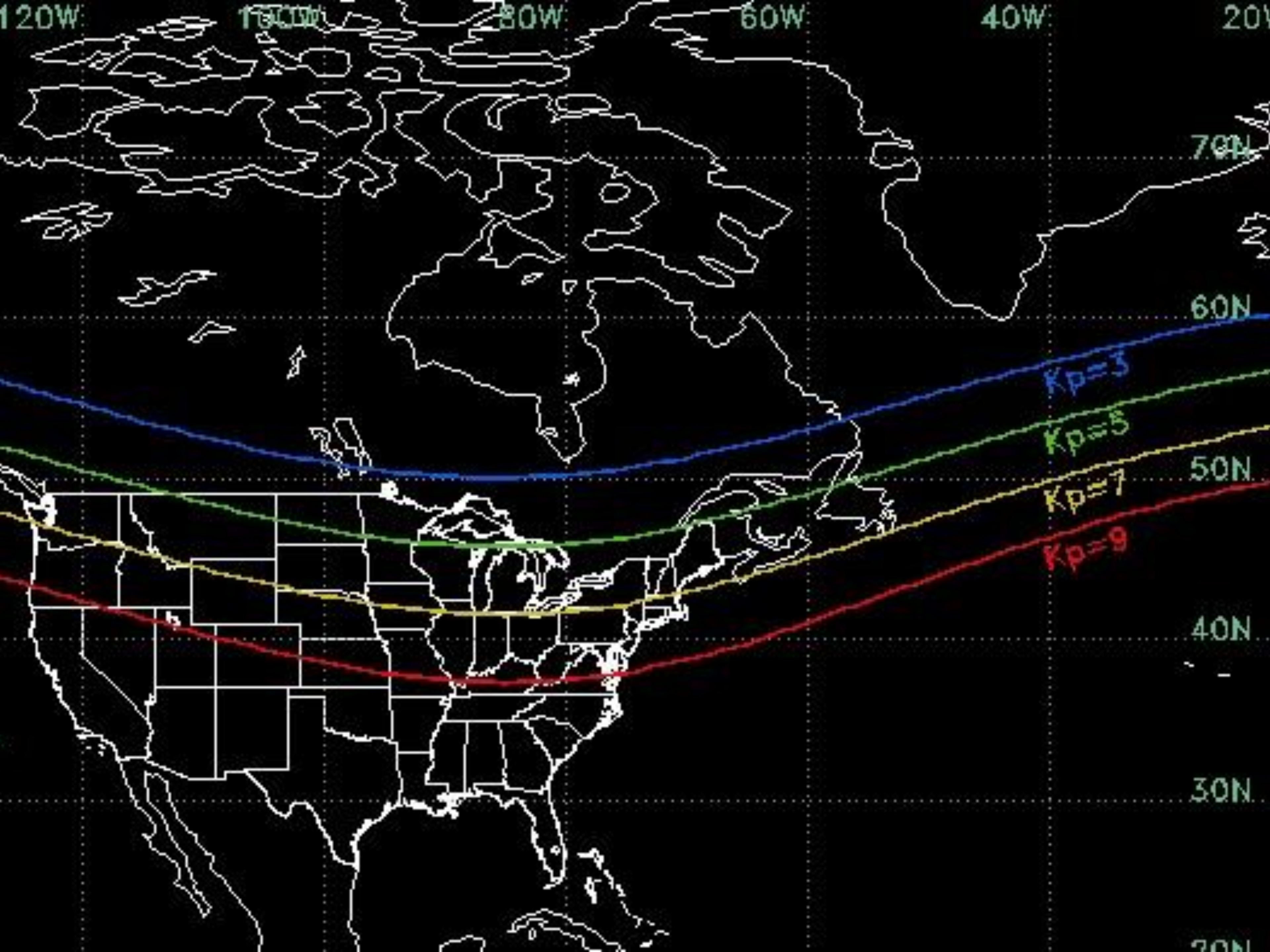
Solar cosmic rays have energies of ~10^7 to 10^{10} **eV** and are ejected primarily in **solar** flares and coronal **mass** ejections (CME). They have a composition similar to that of the **Sun**, and are produced in the **corona** by shock acceleration, or when part of the solar magnetic field reconfigures itself.

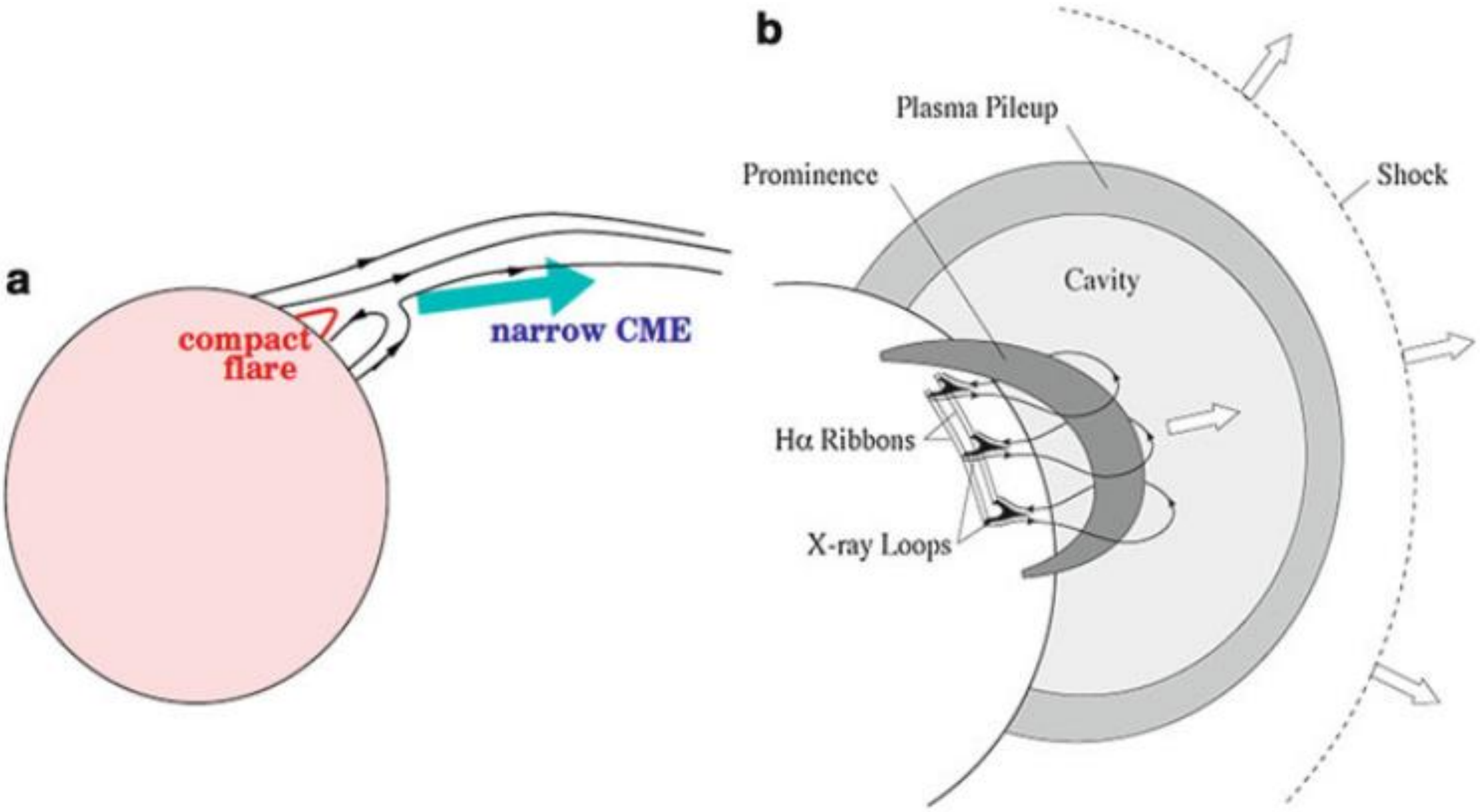
An increase in solar cosmic rays usually heralds a decrease in **galactic cosmic rays** (called the **Forbush decrease**), as the **solar wind** and its associated magnetic field, augmented by the **solar flare** or CME, sweeps some of the incoming **galactic** cosmic rays away from the Earth.

Geomagnetic (350km Apex) Latitudes



Based on modified apex coordinates at 350km altitude

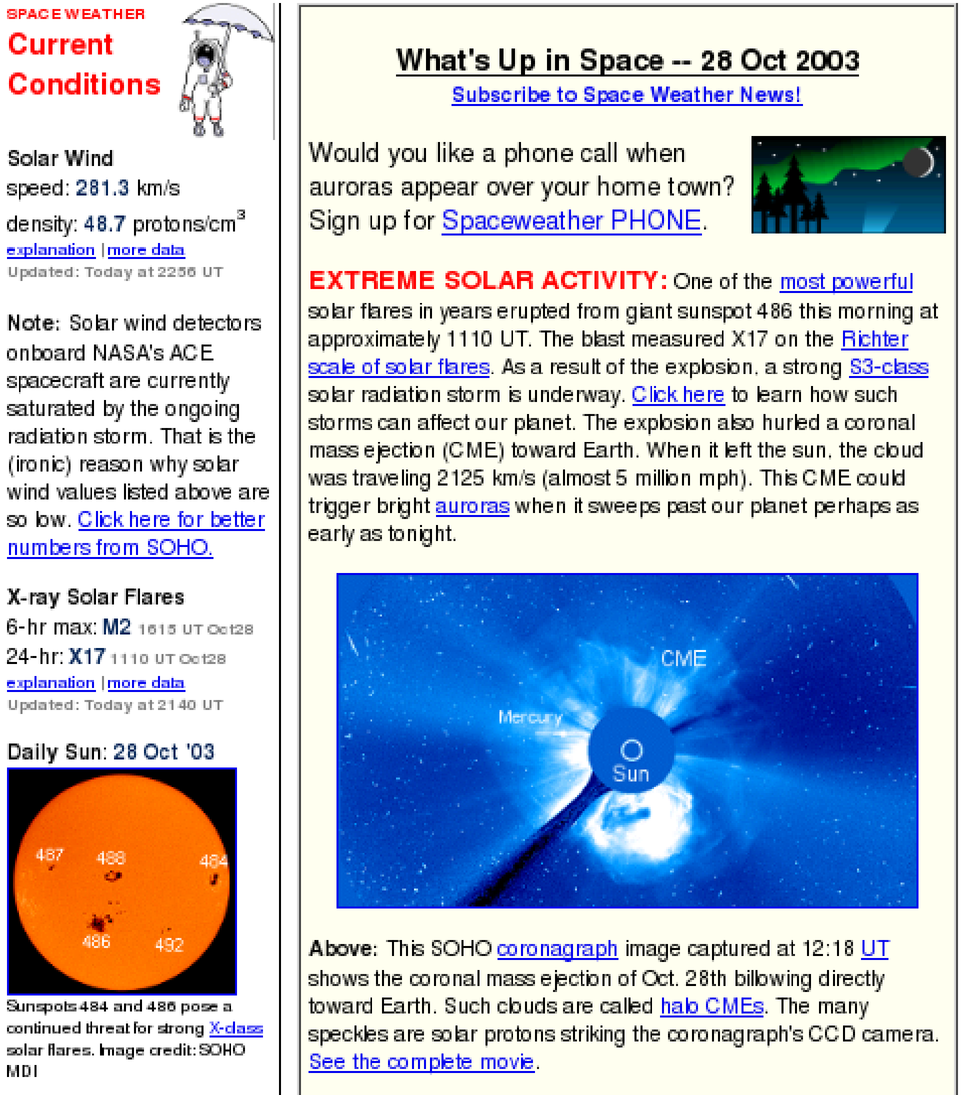

120W
100W
80W
60W
40W
20
70N
60N
50N
40N
30N
20N
Kp=3
Kp=5
Kp=7
Kp=9



Although visually different, almost certainly due to projection effects, CMEs have a number of common physical characteristics that will be discussed below. The mass range of ejected ions that occur during a CME ranges from 1 × 10^{11} kg (i.e., 100 million metric tons) up to 4 × 10^{13} kg (e.g., 40 billion metric tons), with an estimated average of about 3 × 10^{12} kg (i.e., 3 billion metric tons). Its

Precursors from local helioseismology

cf. Ilonidis et al. (2013)   NOAA 10488, 2003 Oct 26



SPACE WEATHER

Current Conditions

Solar Wind
speed: 281.3 km/s
density: 48.7 protons/cm^3
explanation | more data
Updated: Today at 2256 UT

Note: Solar wind detectors onboard NASA's ACE spacecraft are currently saturated by the ongoing radiation storm. That is the (ironic) reason why solar wind values listed above are so low. Click here for better numbers from SOHO.

X-ray Solar Flares
6-hr max: M2 1615 UT Oct28
24-hr: X17 1110 UT Oct28
explanation | more data
Updated: Today at 2140 UT

Daily Sun: 28 Oct '03

Sunspots 484 and 486 pose a continued threat for strong X-class solar flares. Image credit: SOHO MDI

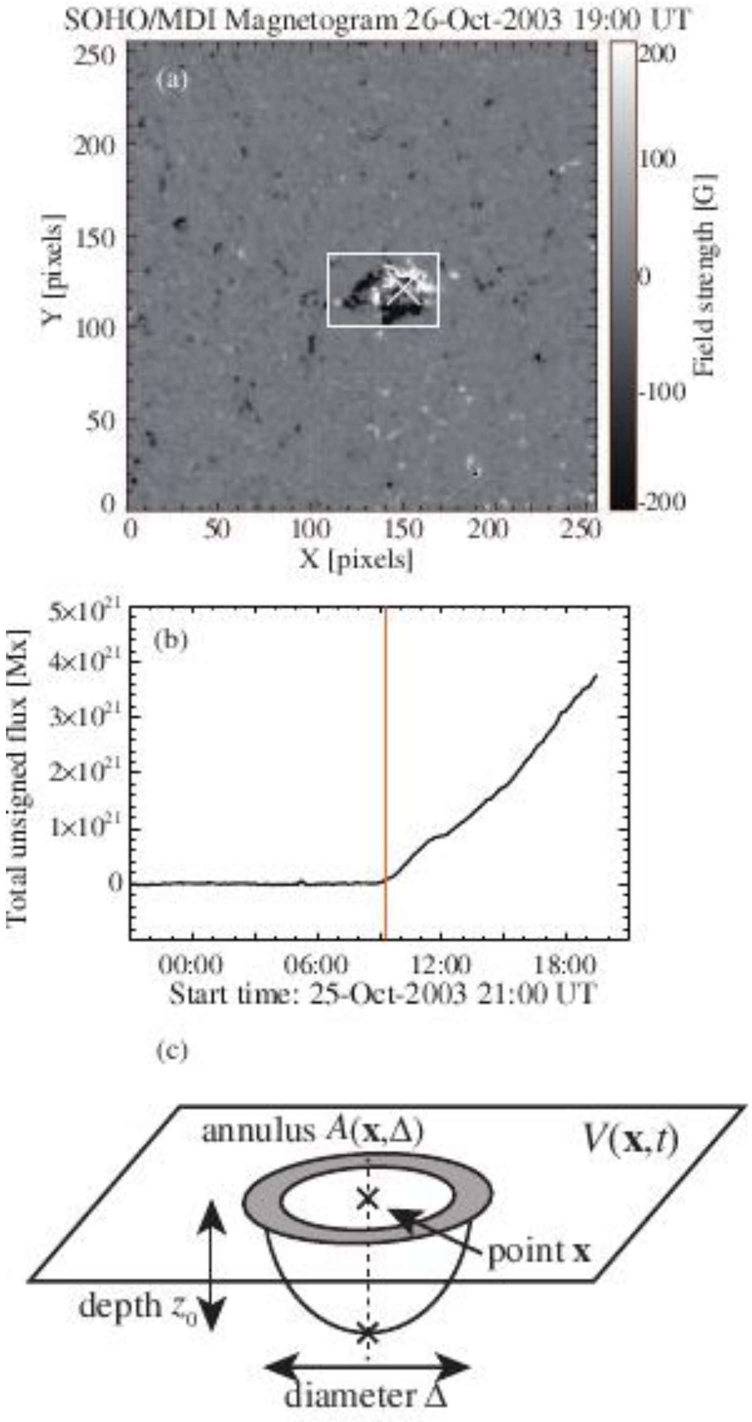
What's Up in Space -- 28 Oct 2003

Subscribe to Space Weather News!

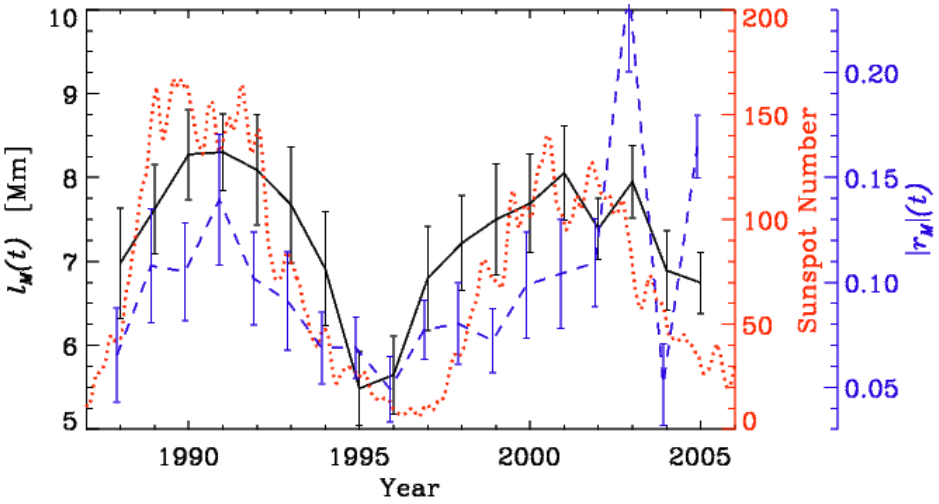
Would you like a phone call when auroras appear over your home town? Sign up for Spaceweather PHONE.

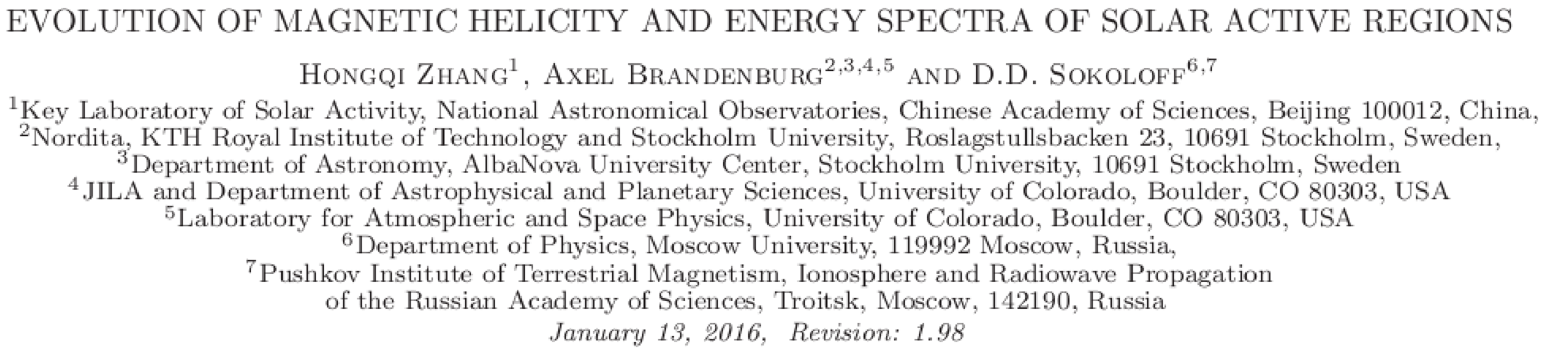
EXTREME SOLAR ACTIVITY: One of the most powerful solar flares in years erupted from giant sunspot 486 this morning at approximately 1110 UT. The blast measured X17 on the Richter scale of solar flares. As a result of the explosion, a strong S3-class solar radiation storm is underway. Click here to learn how such storms can affect our planet. The explosion also hurled a coronal mass ejection (CME) toward Earth. When it left the sun, the cloud was traveling 2125 km/s (almost 5 million mph). This CME could trigger bright auroras when it sweeps past our planet perhaps as early as tonight.

Above: This SOHO coronagraph image captured at 12:18 UT shows the coronal mass ejection of Oct. 28th billowing directly toward Earth. Such clouds are called halo CMEs. The many speckles are solar protons striking the coronagraph's CCD camera. See the complete movie.



Interesting spike in magnetic helicity from 10484, 10486, and 10488 in Huaiou vector magnetograms





EVOLUTION OF MAGNETIC HELICITY AND ENERGY SPECTRA OF SOLAR ACTIVE REGIONS

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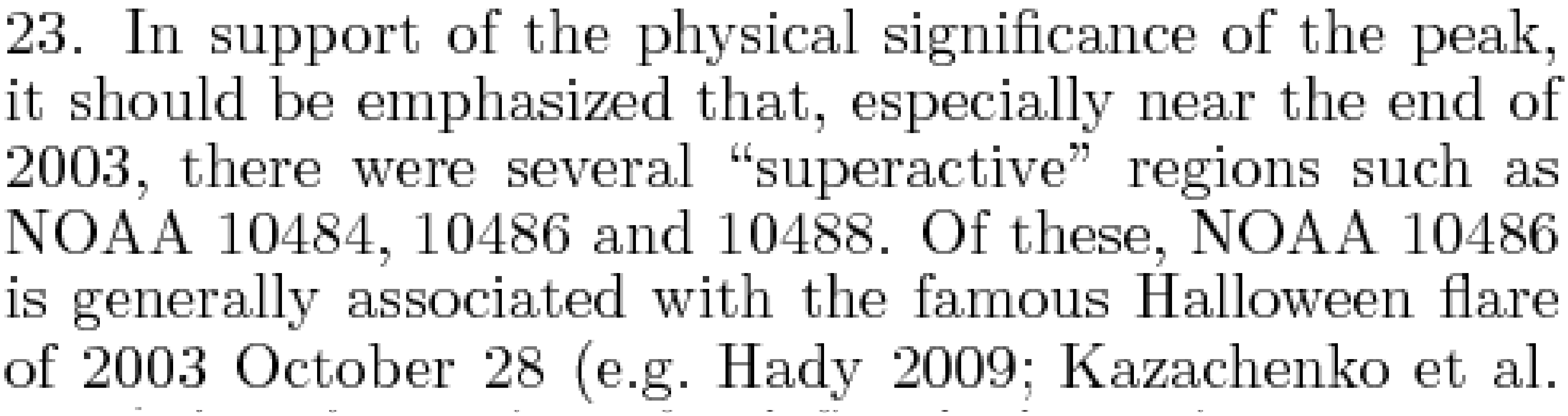
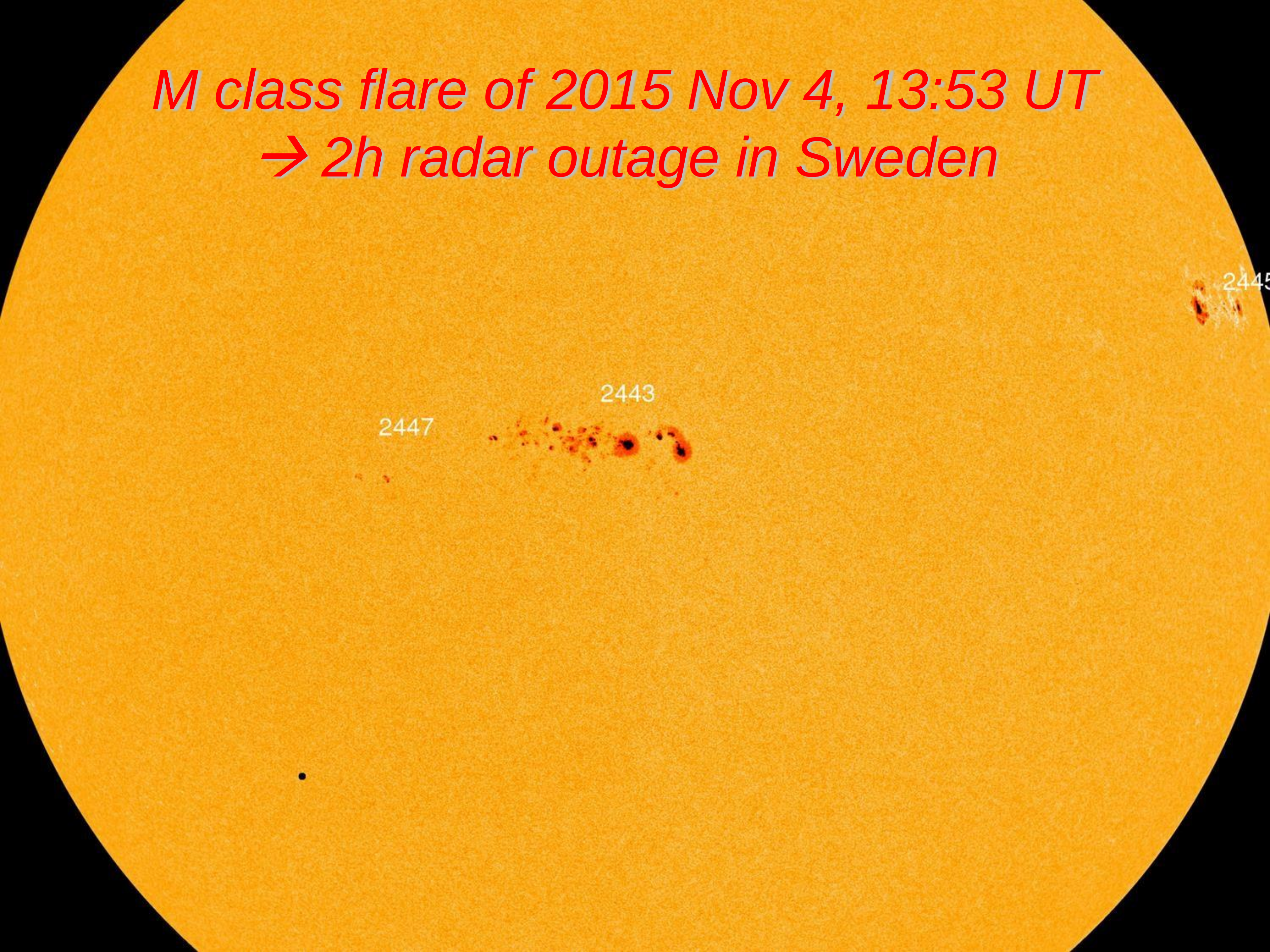
January 13, 2016, Revision: 1.98



23. In support of the physical significance of the peak, it should be emphasized that, especially near the end of 2003, there were several "superactive" regions such as NOAA 10484, 10486 and 10488. Of these, NOAA 10486 is generally associated with the famous Halloween flare of 2003 October 28 (e.g. Hady 2009; Kazachenko et al.

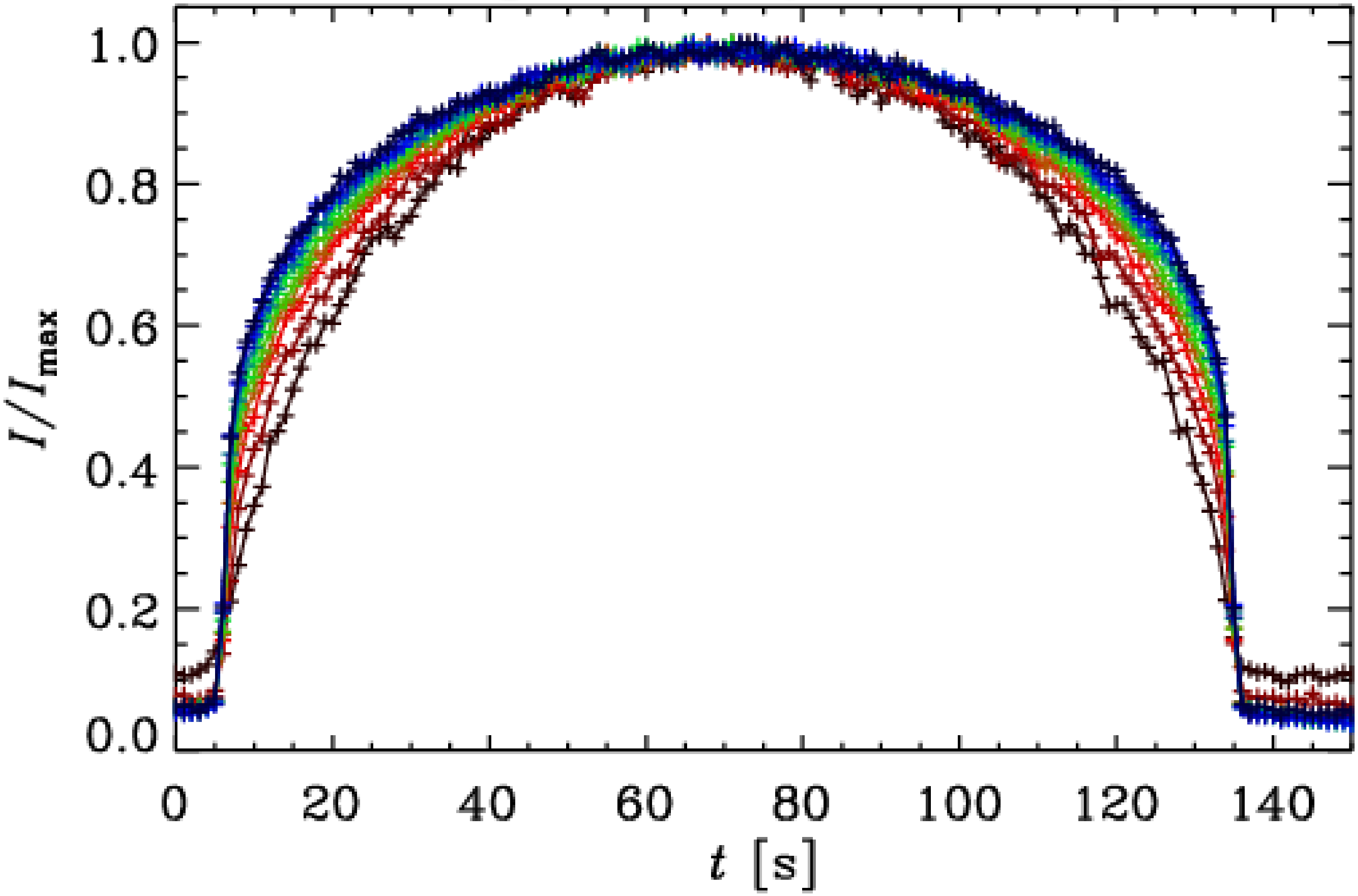
M class flare of 2015 Nov 4, 13:53 UT → 2h radar outage in Sweden

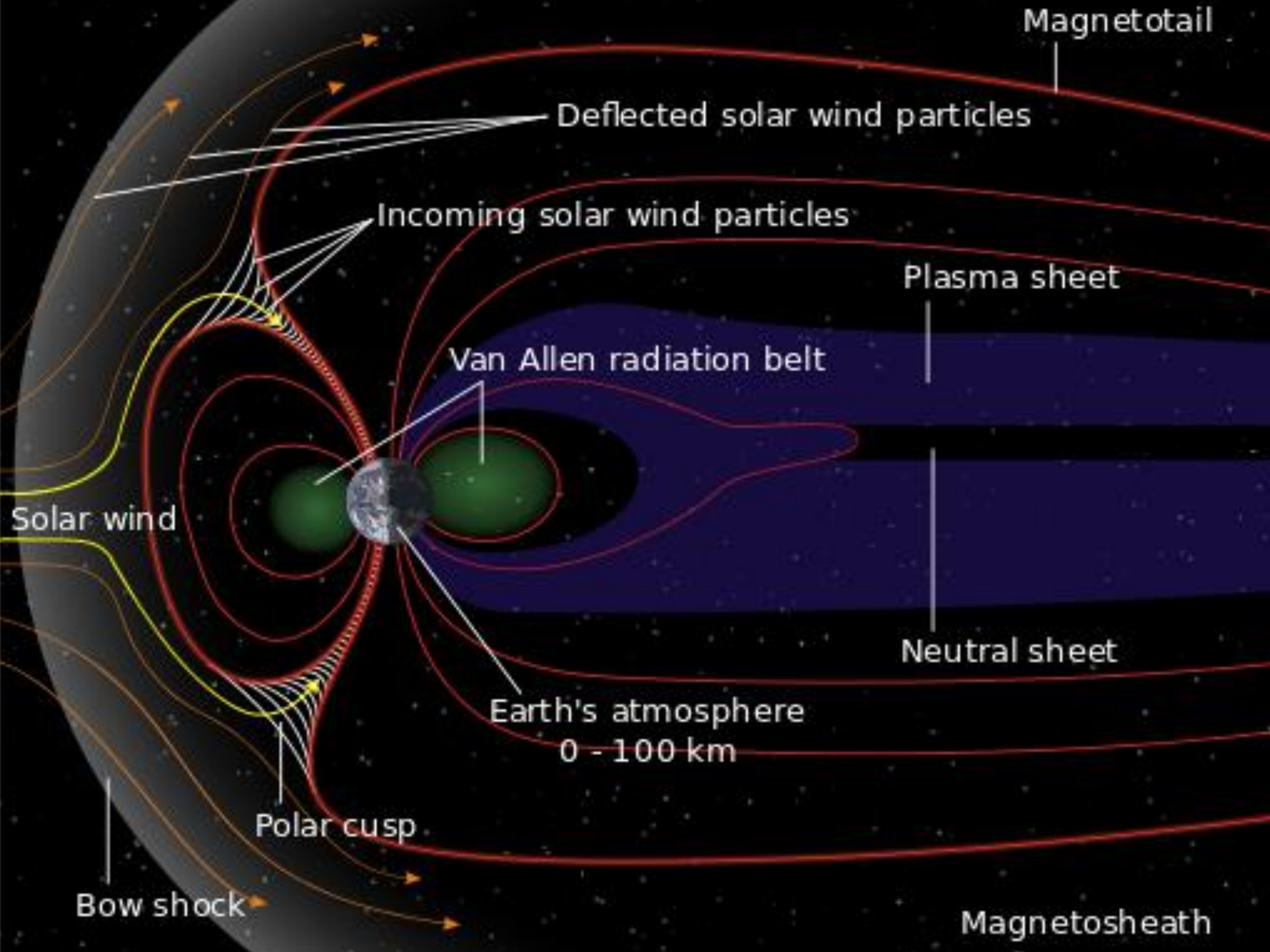


What we learned today

- Comments on homework
  - Double epsilons
  - integrals
- Space weather stories
- CMEs

Letting sun pass by




Magnetotail
Deflected solar wind particles
Incoming solar wind particles
Plasma sheet
Van Allen radiation belt
Solar wind
Neutral sheet
Earth's atmosphere
0 - 100 km
Polar cusp
Bow shock
Magnetosheath