Extremes of solar storms:

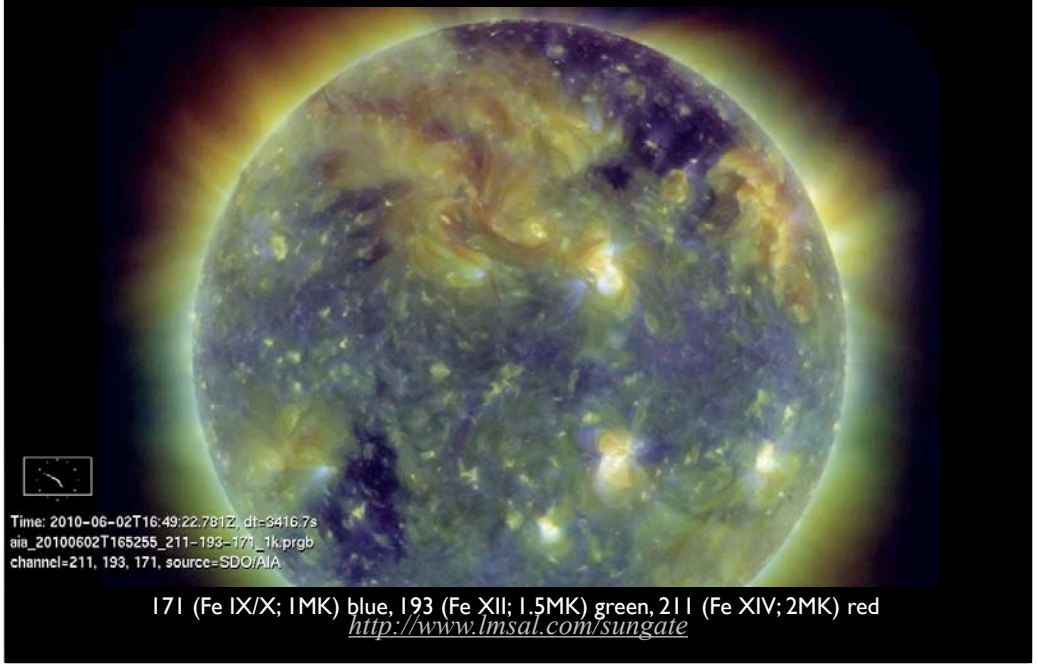
how to determine statistics of rare solar events based on existing or obtainable records or models?

Karel Schrijver
Lockheed Martin Advanced Technology Center

Solar Dynamics Observatory
Atmospheric Imaging Assembly

2TB/day

4096x4096 image/1.5s

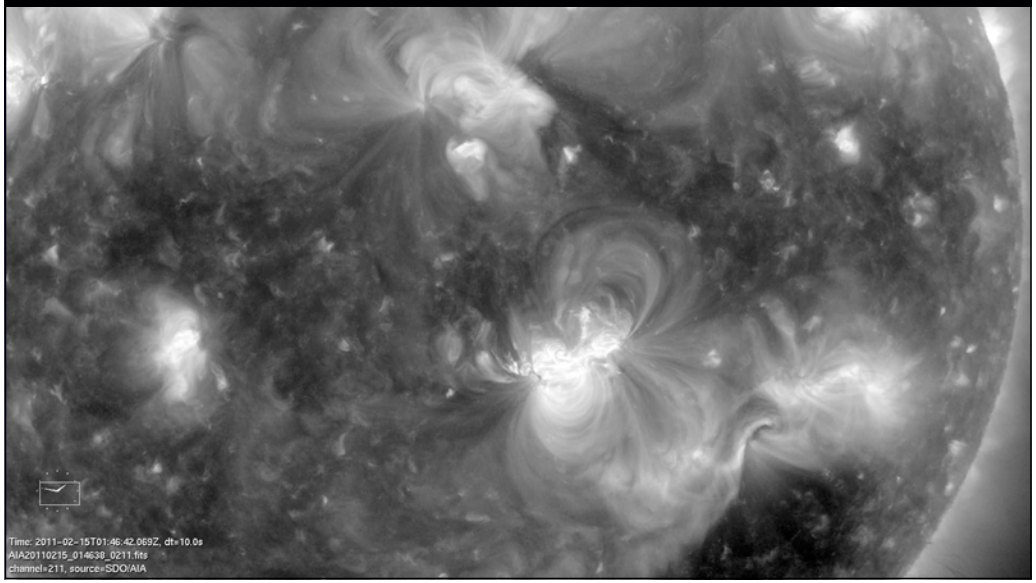


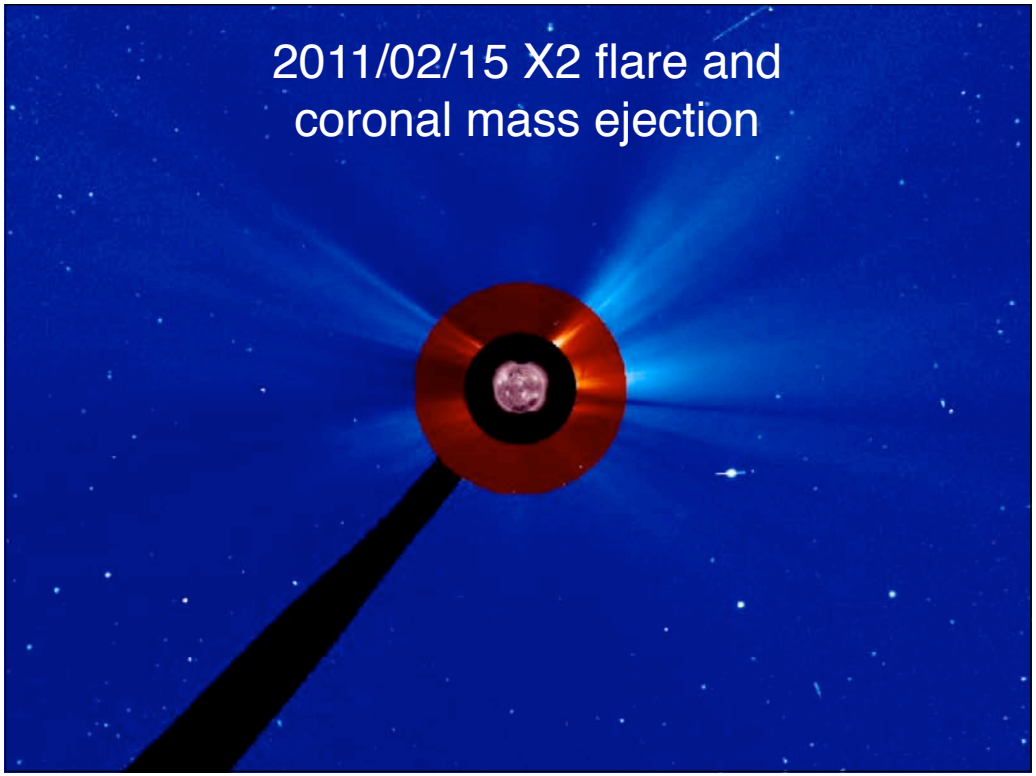
171 (Fe IX/X; 1MK) blue, 193 (Fe XII; 1.5MK) green, 211 (Fe XIV; 2MK) red

http://www.lmsal.com/sungate

X2.2* flare and eruption

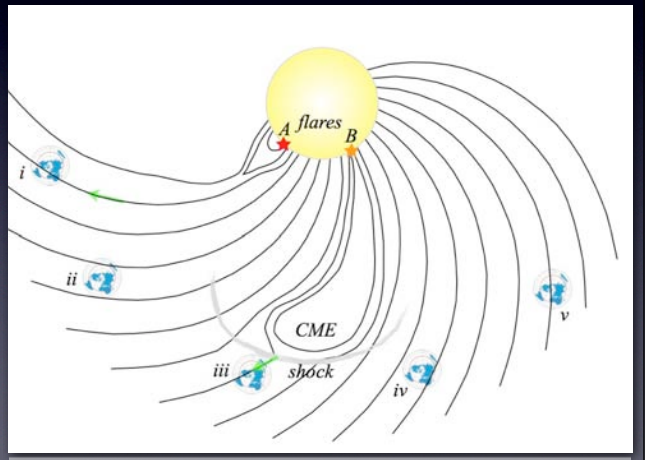
* ~100 billion Hiroshima bombs




2011/02/15 X2 flare and
coronal mass ejection

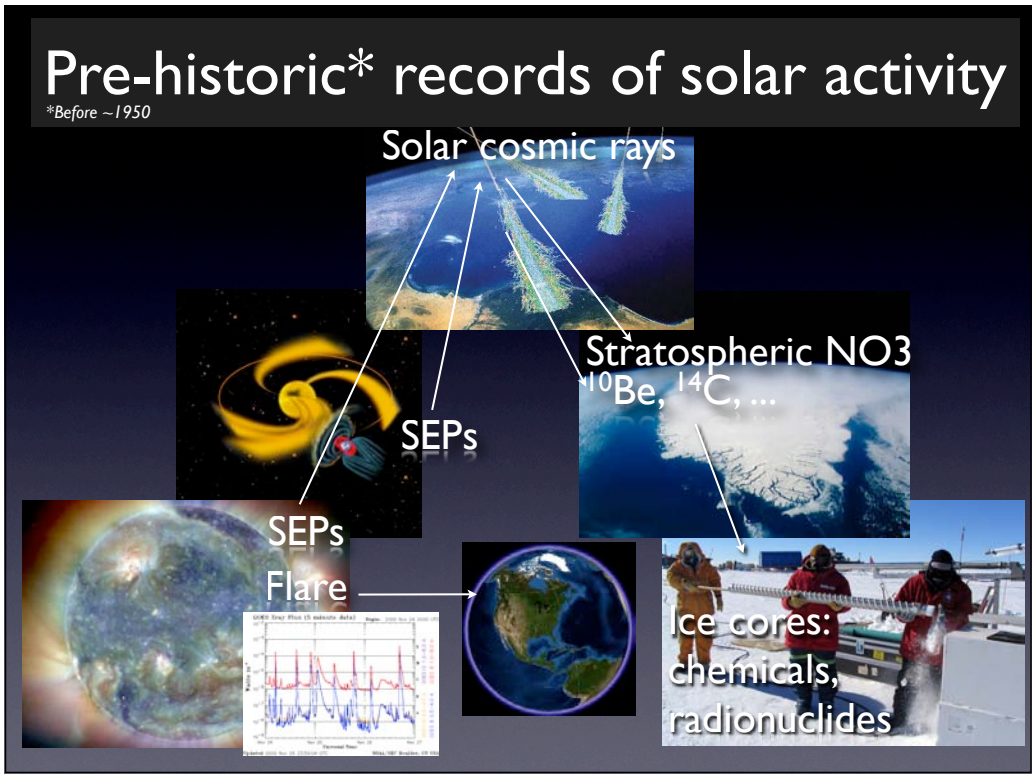
Flares, coronal mass ejections (CMEs) and solar energetic particles (SEPs, SPEs, solar cosmic rays, ...)

- Flares (X-rays, (E)UV, radio, + visible light): visible from the Earth-facing side of the Sun (i-v).
- CMEs: "halo-CME" directed towards Earth, and "glancing blows" (ii-iv)
- SEPs: sensible for events from solar central meridian to far side (i-iii), and after passage of Earth orbit (co-rotating interaction regions, CIRs; iv-v).



Pre-historic* records of solar activity

*Before ~1950



Solar energetic particles (SEPs)

SEP statistic can be obtained from:

- Spacecraft particle instruments and ground-based neutron monitors;

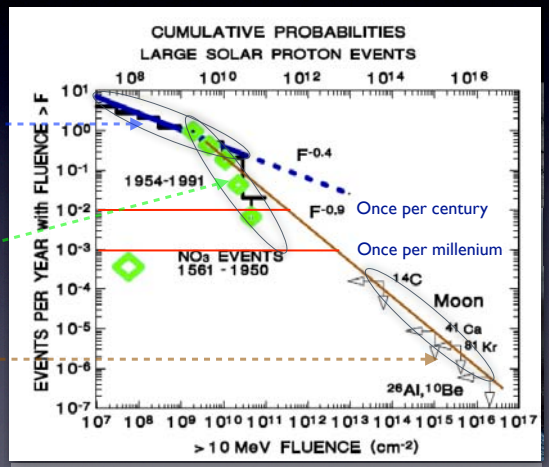
  Records since ~1950s; too short

- Chemical signatures (NO_3 in ice)

  Only one ice core published; atmospheric scientists question pathways

- Radionuclides in biosphere, ice, rocks (Earth, Moon), meteorites.

  Lunar rocks & meteorites: cumulative dose only. Biosphere: washes out signal. Ice: limited resolution (~3y) on background of galactic cosmic rays.

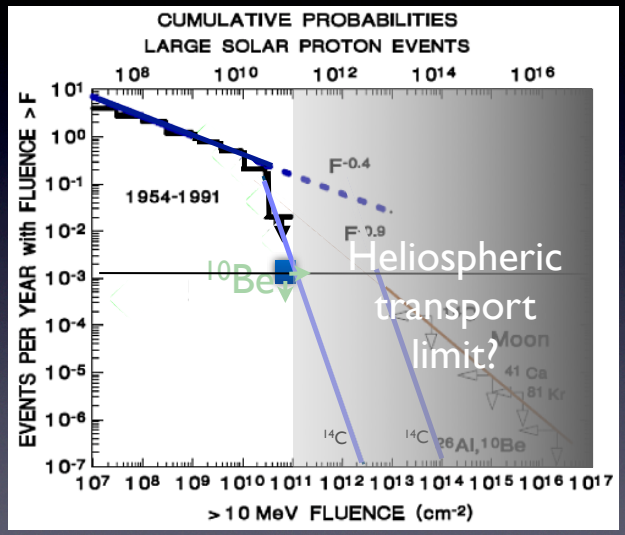


ISSI* study team tasks

- Review statistics of direct observations of solar and stellar coronal magnetic storms.
- Establish cross-calibration of diagnostics in various wavelength bands (and their uncertainties) to yield distributions as a function of total energy for both solar and stellar data.
- Review statistics and significance of "geological" records of major coronal magnetic storms.
- Assess consistency of solar, stellar, and geological data and derive information on transport and impact processes from solar flares, through heliospheric ICMEs, to storage and analysis in, primarily, snow/ice deposits in polar regions.

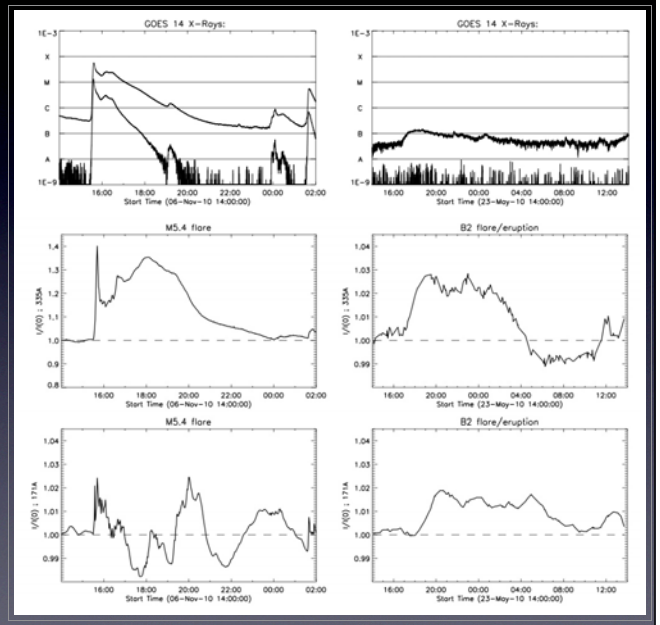
** International Space Science Institute, Bern, CH*

Revised SEP-event statistics after 1st ISSI meeting

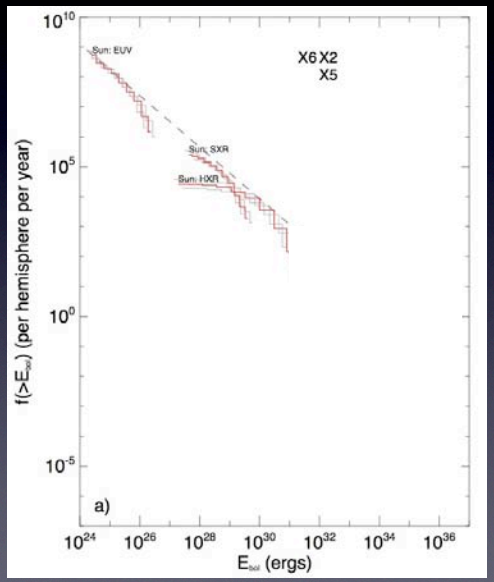


Chameleon behavior of solar storms

- GOES class provides a very uncertain measure of the energy in a solar coronal storm event.
- Example: GOES light curve peaks for an active-region flare and quiet-Sun filament eruption differ by factor of ~250 for comparable 'bolometric' energies in the X-ray/(E) UV domain.

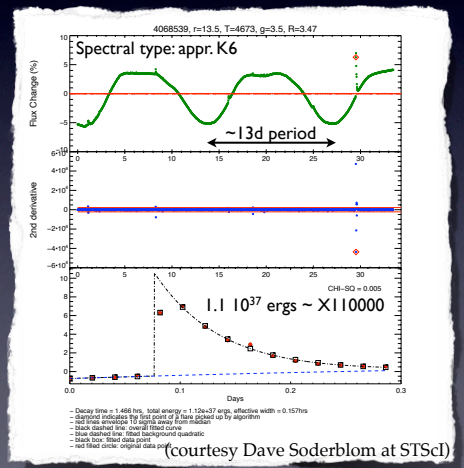


Statistics of solar flares

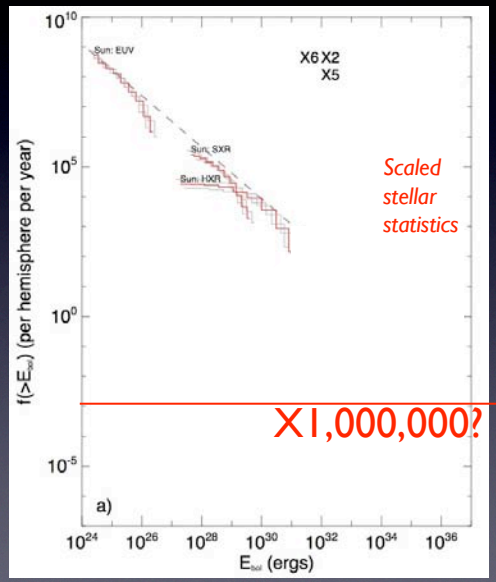


Statistics of solar/stellar flares

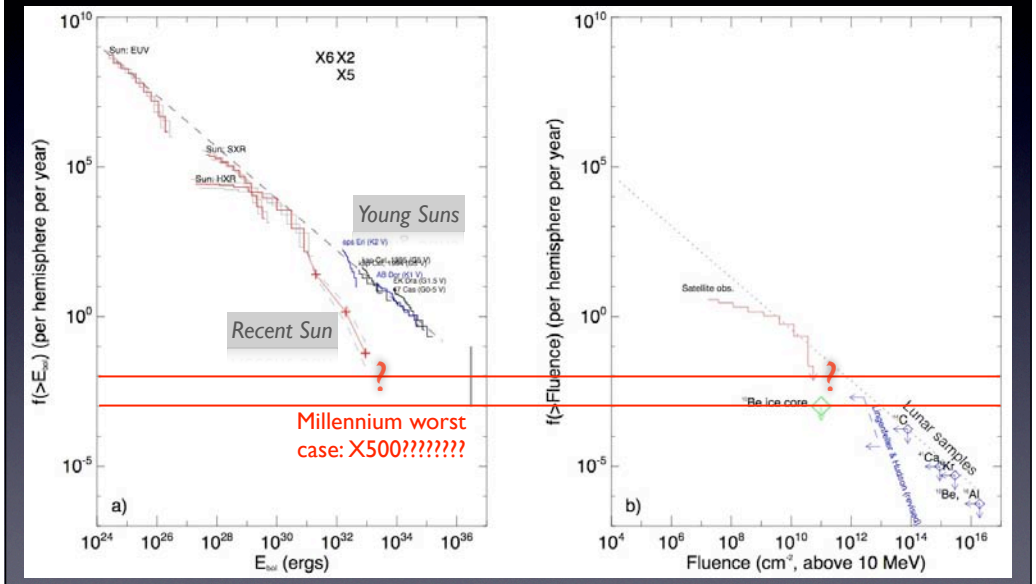
Kepler: monitoring 150,000 stars!



(courtesy Dave Soderblom at STScI)



Statistics of solar flares and SEP events



Lessons learned ... so far

- Interdisciplinary approach is critical: this example project involved Sun-Stars-heliosphere-geospace-atmosphere-ice.
- Concerns from neighboring disciplines about "known facts" must be investigated
- Need to combine solar-stellar data to increase statistical basis within years rather than millenia
- Need to include Sun-to-ice in portfolios

Now what?

- Consult society about what is needed most:

  (a) solar spectral irradiance variability (σ_{SSI}) for ionospheric perturbations, or

  (b) solar energetic particle spectral distribution (f_{SEP}) for design of satellites and protection of astronauts

if (a) Collect and study panchromatic observations of solar neighborhood stars

if (b) Revisit atmospheric studies and ice-core analysis; utilize differential exposure of stationary rocks on rotating Earth, Moon, asteroids, and multiple radionuclides

Formulate pathways for implementation of the possible and affordable research to sponsoring organizations.

Integrate knowledge as information becomes available.