A Really Brief Introduction to Space Weather

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What is space weather?

- Any perturbation to the "steady state" of the:
  - solar radiative output
  - solar energetic charged particle output
  - solar mass and magnetic field outflow (solar wind changes, coronal mass ejections)
- and how these changes are perceived
  - at earth
  - at the Moon or other planets
  - anywhere else in the heliosphere

Where it all starts

- The Sun
  - source of radiative output (sunshine)
  - source of magnetic field and mass outflow
  - source of dynamic events

Forms space weather can take

- At the Sun:
  - Solar flares
  - Coronal mass ejections
  - Solar energetic particles

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Flares (I)

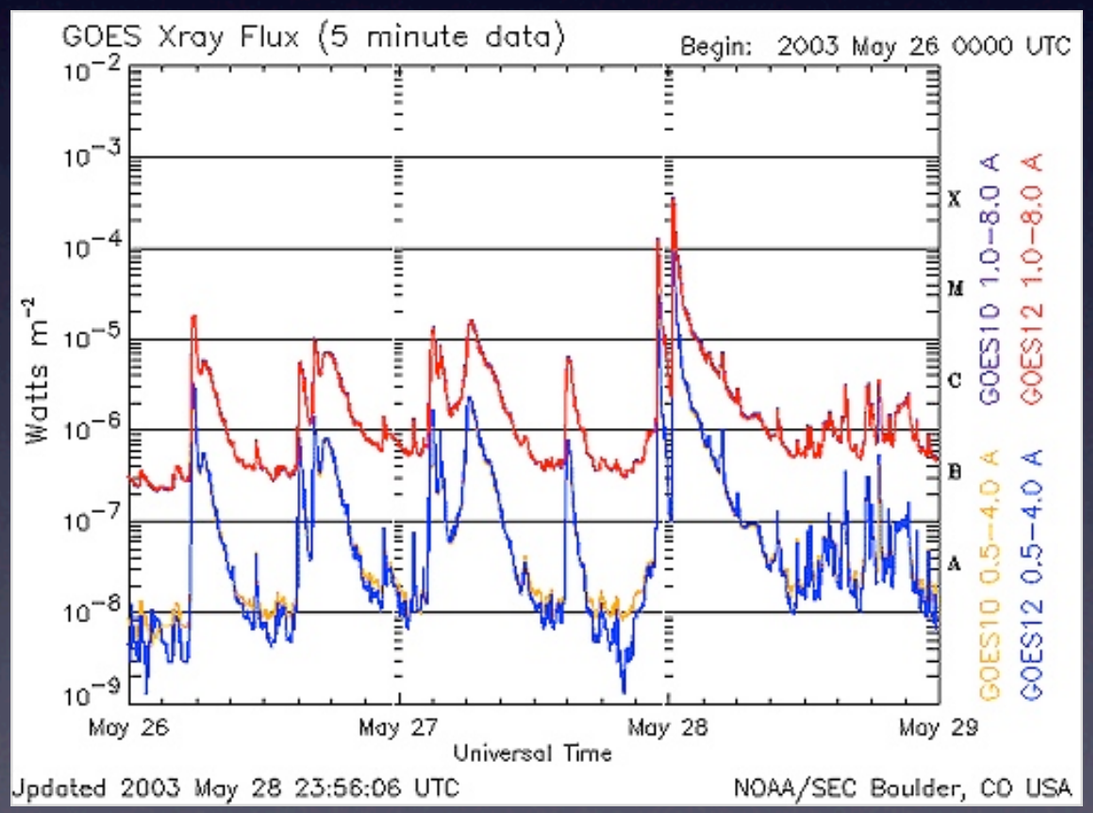
- Solar flares
  - high *power* events
    - to a physicist, power is *energy per unit time*
  - some dynamics associated with them, but primarily
    - bright in the upper solar atmosphere
    - lots of extra radiation in the extreme ultraviolet (EUV) and soft X-ray (SXR) ranges
      - only accessible from space
        - absorbed by earth;s atmosphere

Flares (II)

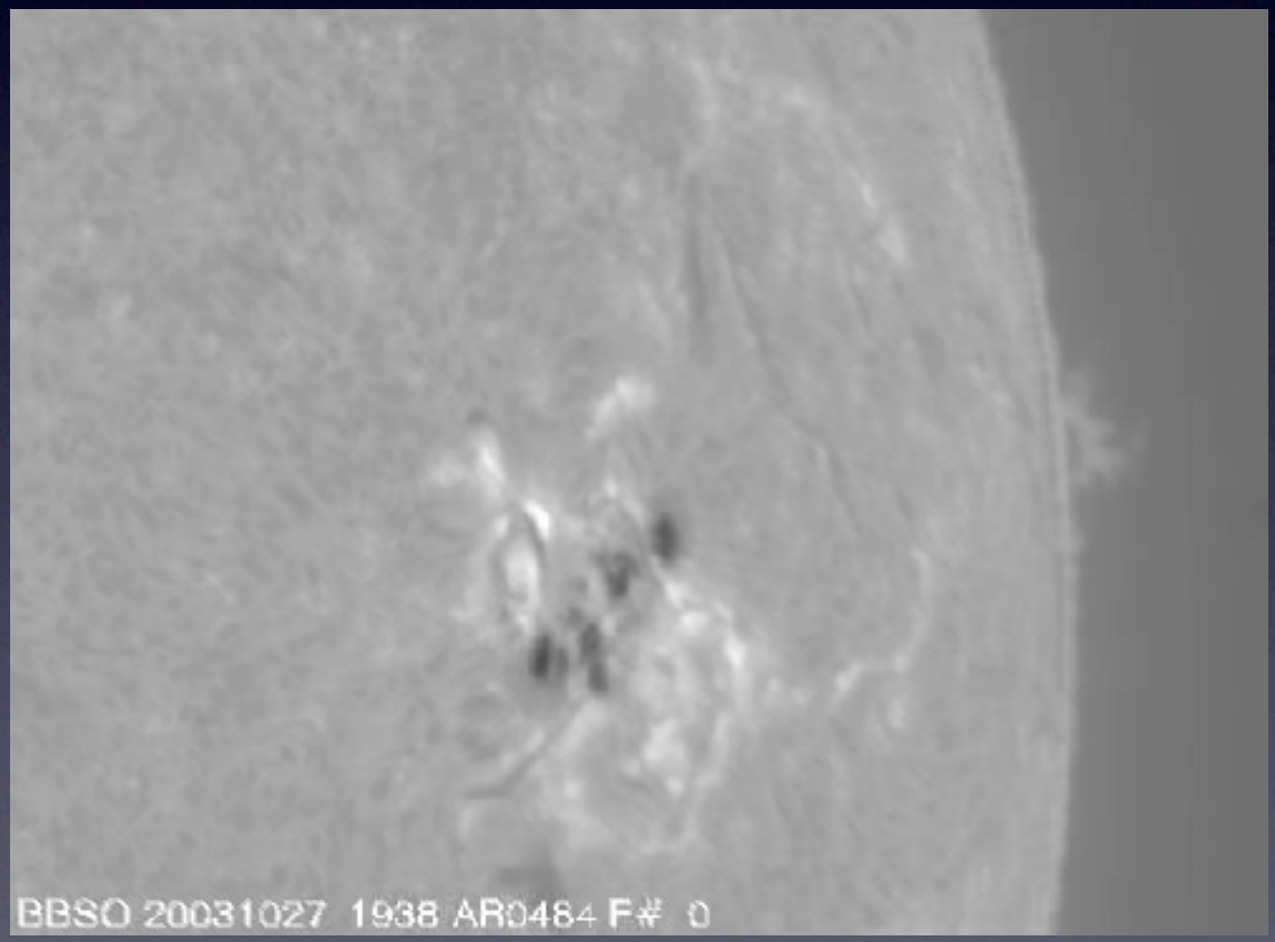
- Flares can last from tens of seconds to hours
  - Most of the power is delivered in a few minutes
  - Power comes from *changes in the magnetic field* above the surface of the Sun
  - Proximate cause is beaming of electrons from above the Sun's surface into higher density plasma farther down in the atmosphere
  - Can also accelerate solar energetic particles

How solar astronomers think of flares (I)

- Soft X-ray plots from NOAA GOES spacecraft

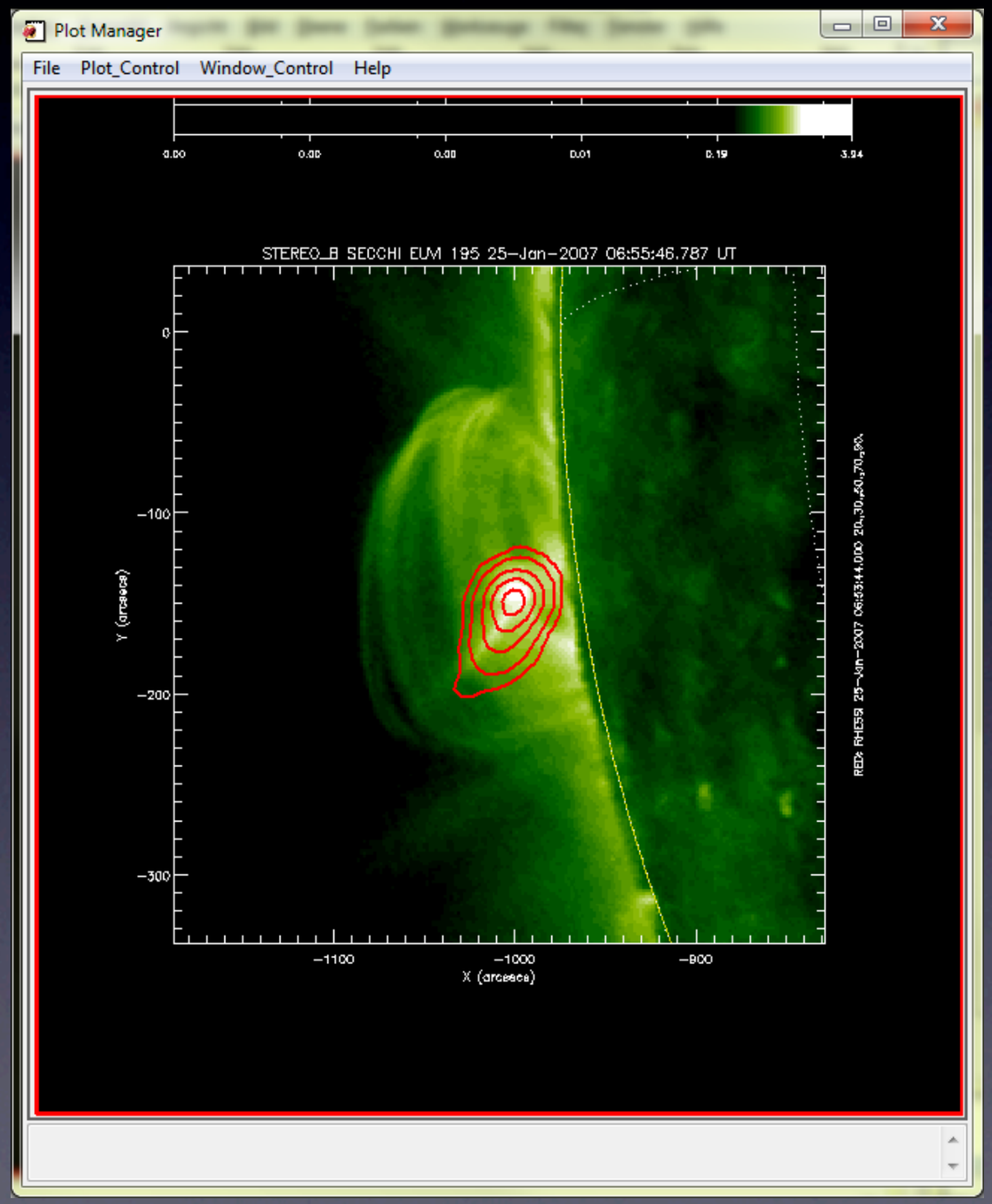


- Something near the solar surface getting brighter



How solar astronomers think of flares (II)

- Hard X-ray and gamma-ray imaging from RHESSI



Flares: Effects on earth

- Prompt:
  - Increase in EUV radiation changes the height in the earth's atmosphere at which atoms are ionized
    - Changes heights at which most radio waves are reflected
- Intermediate-term:
  - EUV heats the thermosphere, the outermost part of the earth's atmosphere, and causes it to expand
  - Increased drag on LEO satellites

Local Resources

- Flare mission:
  - RHESSI
- Goddard scientists to talk to about flares
  - Dr. Brian Dennis / 671
  - Dr. Gordon Holman / 671
  - anyone they deisgnate
  - Dr. Alex Young / 671 and ADNET

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Coronal Mass Ejections (I)

- CMEs
  - Low *power* events, but generally more energy than in flares associated with them
  - "A million tons of matter moving at a million miles and hour"
    - but are enormous, so densities are very low
  - Driven by:
    - Changes in magnetic fields

Coronal Mass Ejections (II)

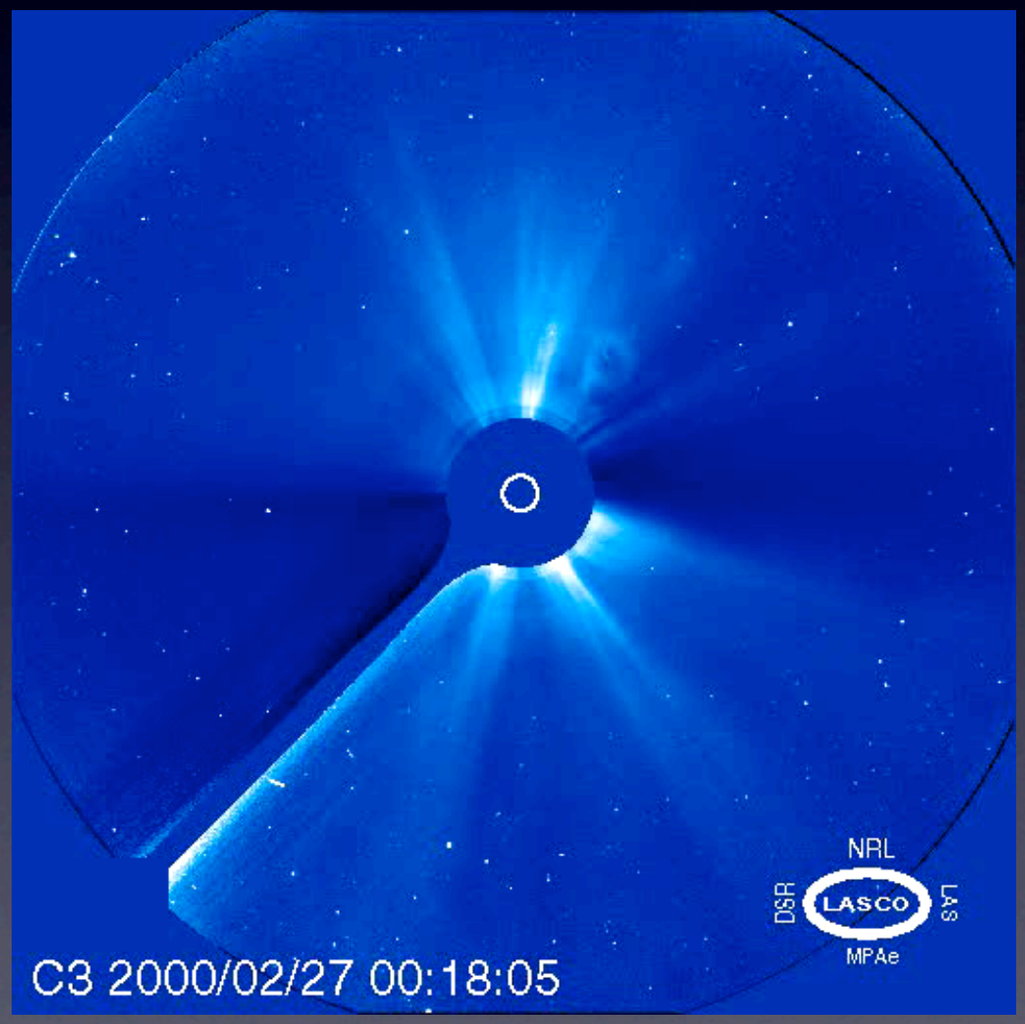
- Speeds vary from a few hundred km/s to > 2000 km/s
- Can take 1 - 3 days to reach earth
- If faster than ambient solar wind speed
  - slow down on their way out from the Sun
  - drive *shocks* (like a bow wave)
    - have distinct radio signatures (WIND & STEREO WAVES)
    - shocks can accelerate solar energetic particles
    - can propagate across the solar system
      - effects have been observed as far away as Jupiter and Saturn

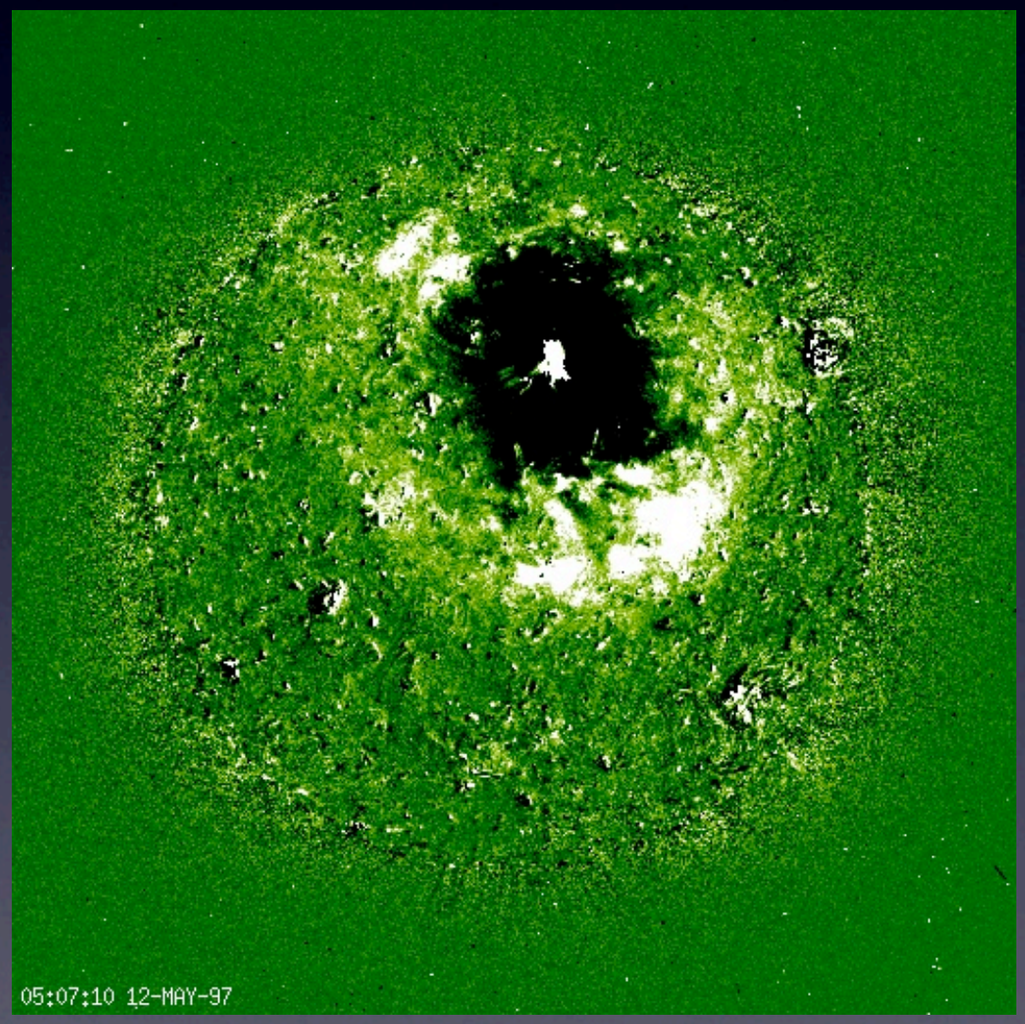
Flares and CMEs

- Most flares have no associated CME
- A few CMEs have no associated flares, but most CMEs are associated with some sort of flare
- The fastest CMEs are generally associated with very intense flares

How solar astronomers think of CMEs

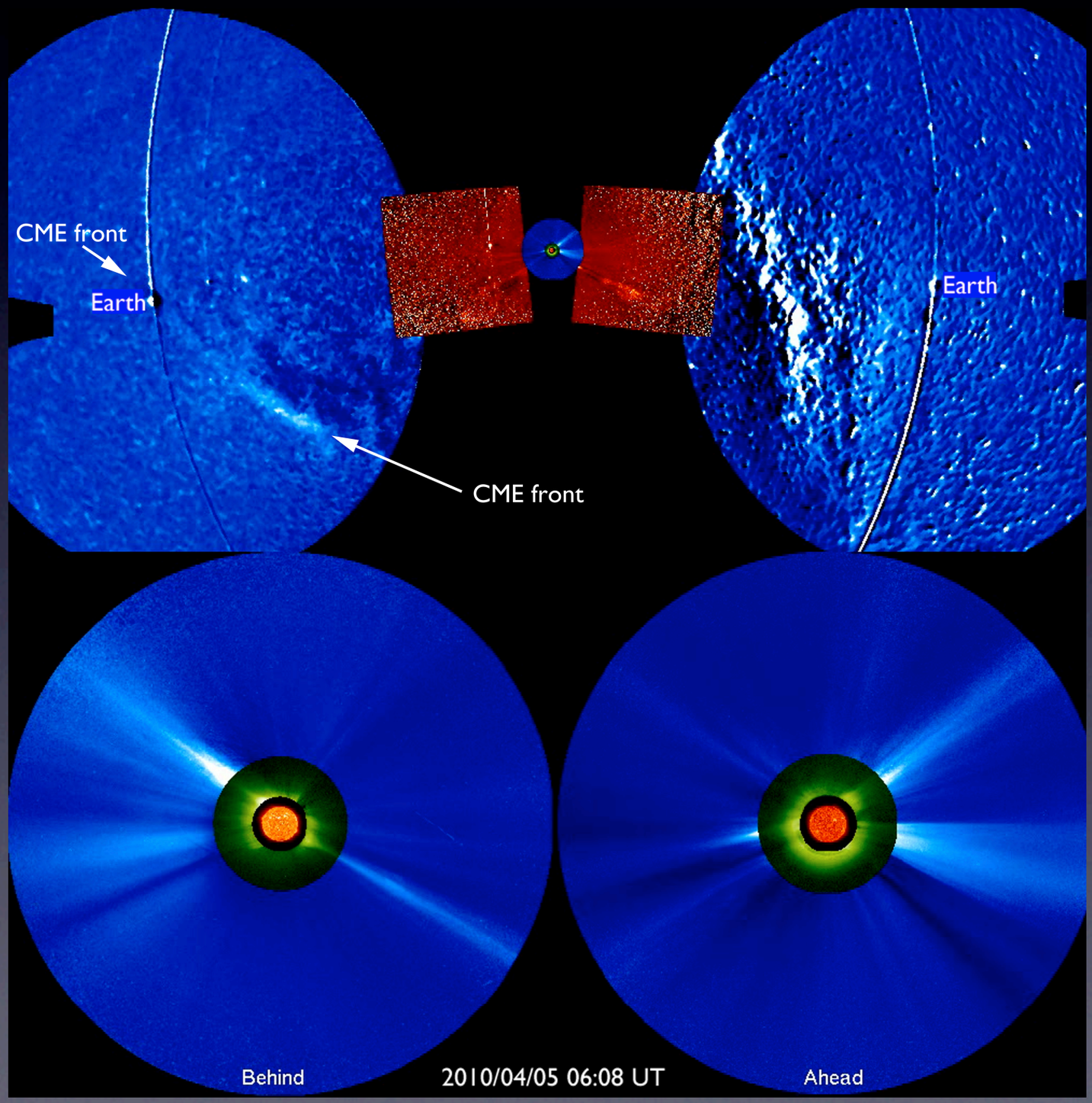
- Coronagraph images
- EUV waves



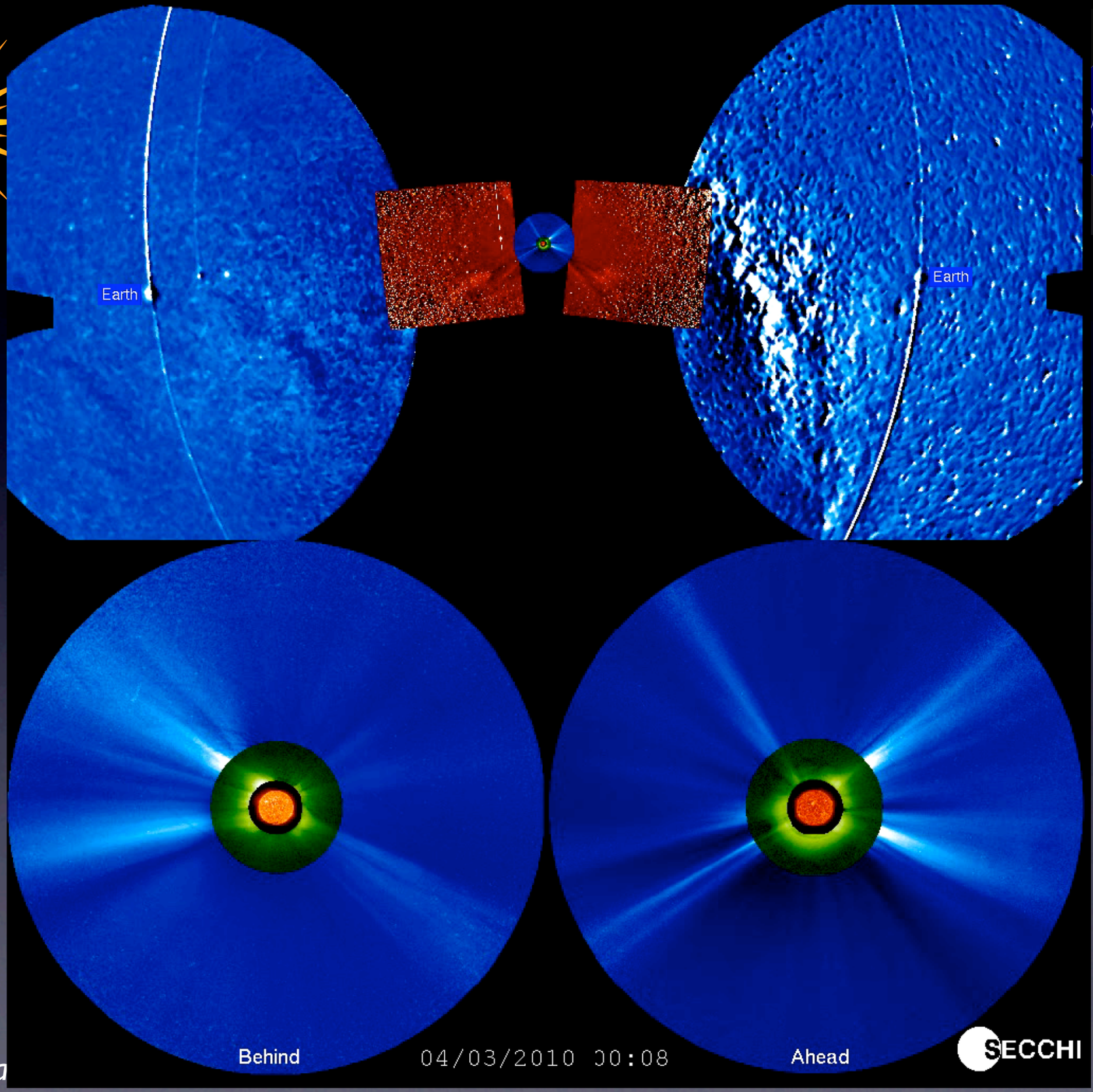


How solar astronomers think of CMEs

- STEREO SECCHI composite images/ movies with Heliospheric Imager (HI) detail on event passing the earth



J.B. Gurman, 2010•08•10


Earth
Earth
Behind
04/03/2010 00:08
Ahead
SECCHI

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Solar Energetic Particles

- What are they?
  - Subatomic particles (electrons, protons) and nuclei of light elements (e.g. He)
  - Electrically charged
  - Accelerated to a sizable fraction (> 0.2 for protons) of the speed of light

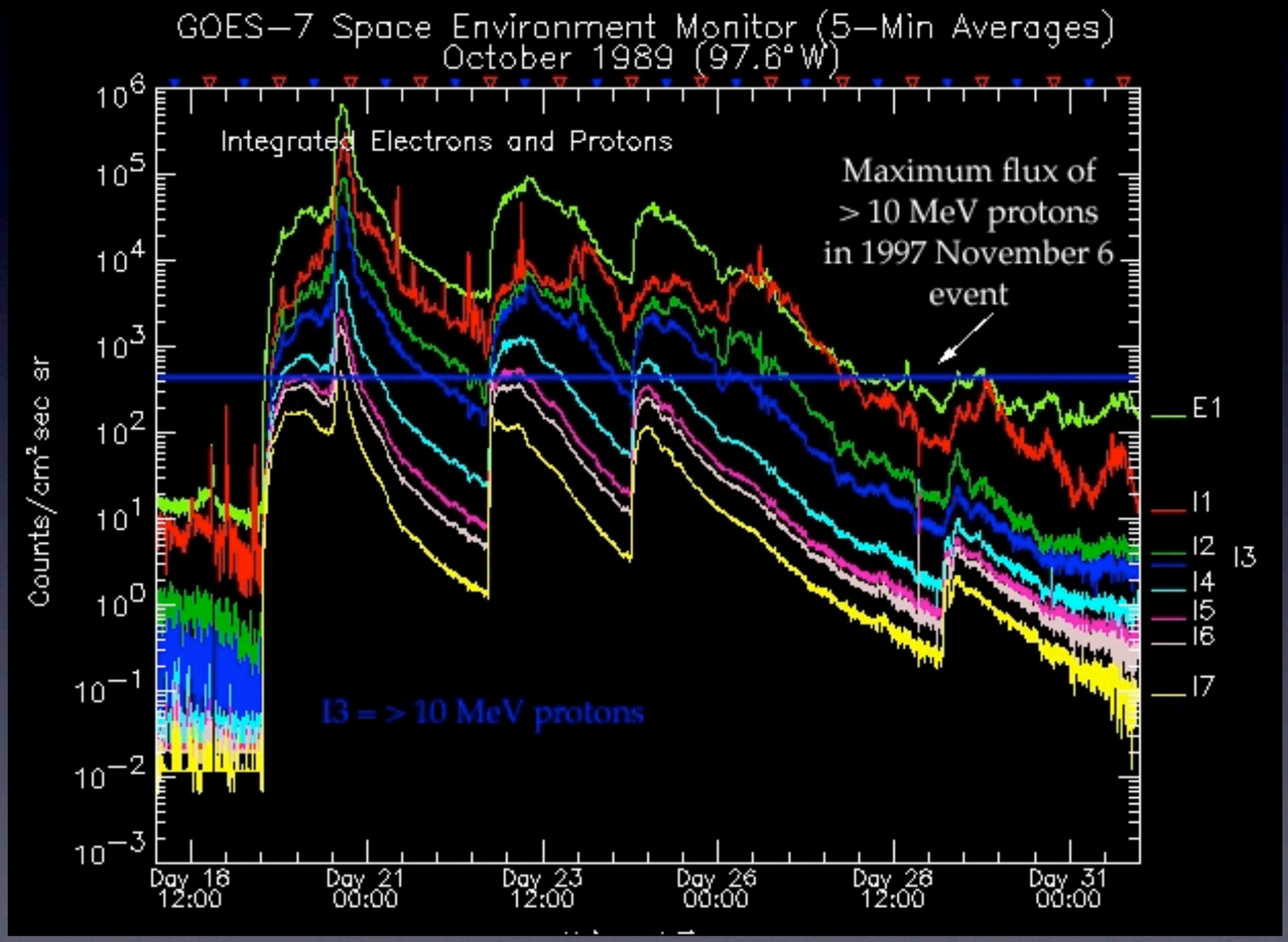
Solar Energetic Particles

- How are the accelerated?
  - In flares, possibly in the same way that the electron beams that are the primary energy release mechanism are
  - By "shock acceleration" on the outside of fast CMEs
    - Twisted magnetic field acts like a bottle
    - At each reflection by the magnetic field, a charged particle gains kinetic energy = moves faster
    - Eventually, particles leak out; by that time, they're going very fast

Solar Energetic Particles

- Electrons are 1800 times lighter than protons, so they're accelerated to much higher speeds than protons
  - Relativistic electrons get "here" (1 AU) faster and are the only known precursor of SEP protons
  - Relativistic protons have enough energy to disrupt cell nuclei; they're the *primary health hazard* to spacefarers from space weather

How a solar astronomer thinks of SEP events



Effects of space weather at earth

- Usual:
  - auroral displays
  - lots of hits on space weather Websites
  - occasionally, storms of PAO contacts
- Occasionally:
  - Interruption of RF communications near geomagnetic poles (air transport) - flare ionizing radiation
  - More widespread RF issues - flares as well
  - Geomagnetically induced currents - CMEs

Worst case scenarios

- Geomagnetically induced currents are an issue for:
  - electric power generation (ground phase) - need warning or extra protective measures to mitigate
  - long oil and natural gas pipelines at hugh geomagnetic latitudes - no real mitigation other than maintenance (BP in Alaska)
- Absolute worst case:
  - Interconnected, deregulated power grids fail; millions without power; generation equipment takes year to replace (very, very unlikely)

Resources/contacts in the Solar Physics Laboratory (671)

- SDO
  - Dean Pesnell, Barbara Thompson, Phil Chamberlin (near realtime, high resolution, multichannel imagery, including magnetic fields of earthward-facing side of Sun)
- RHESSI
  - Brian Dennis, Gordon Holman
- SOHO, STEREO
  - Joe Gurman, Terry Kucera, Bill Thompson
  - STEREO: wide-angle and "side" views, *but not in near realtime*