INNER HELIOSPHERE “HURRICANE SEASON”: OBSERVATIONS OF CORONAL MASS EJECTIONS DURING SOLAR MAXIMUM

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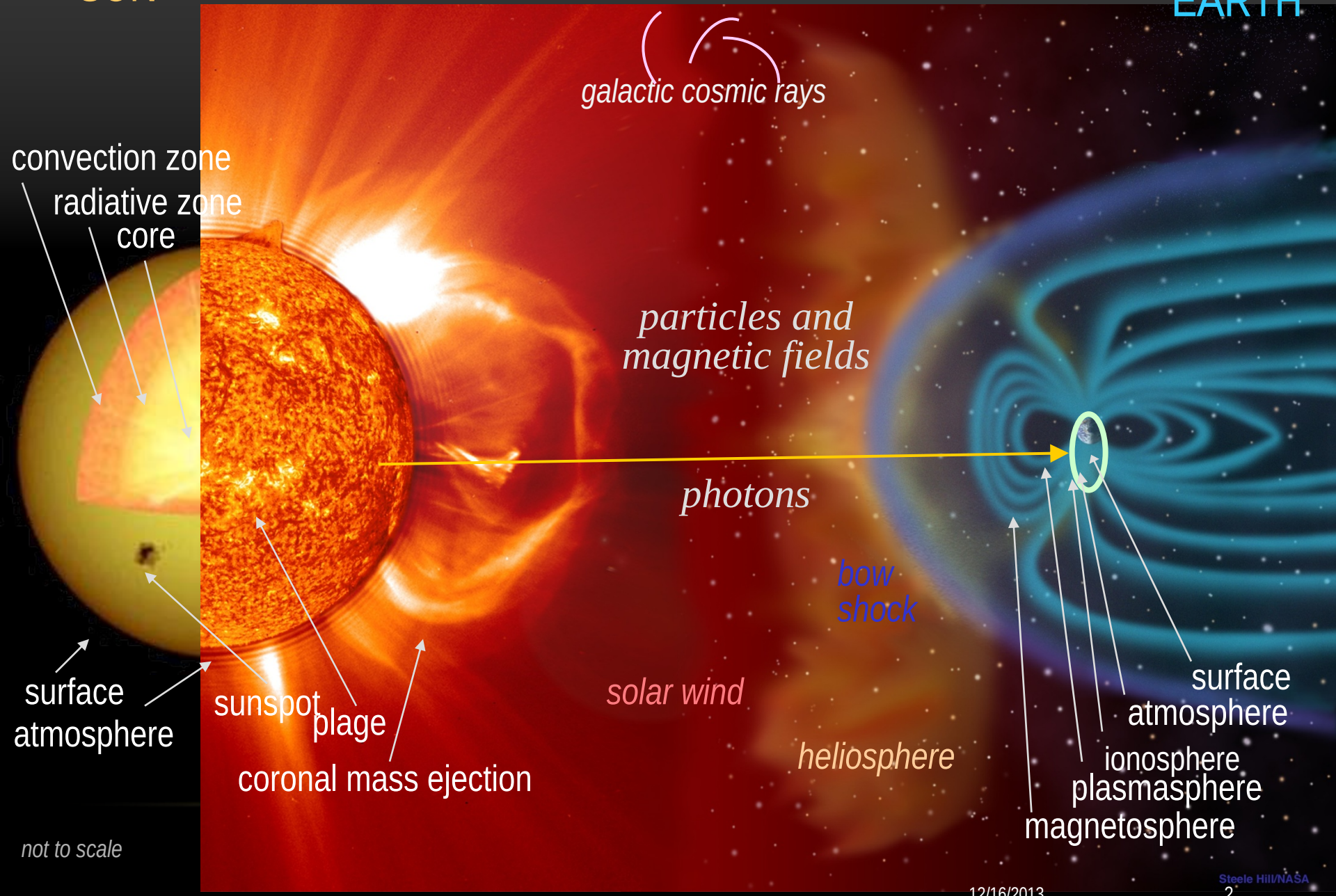
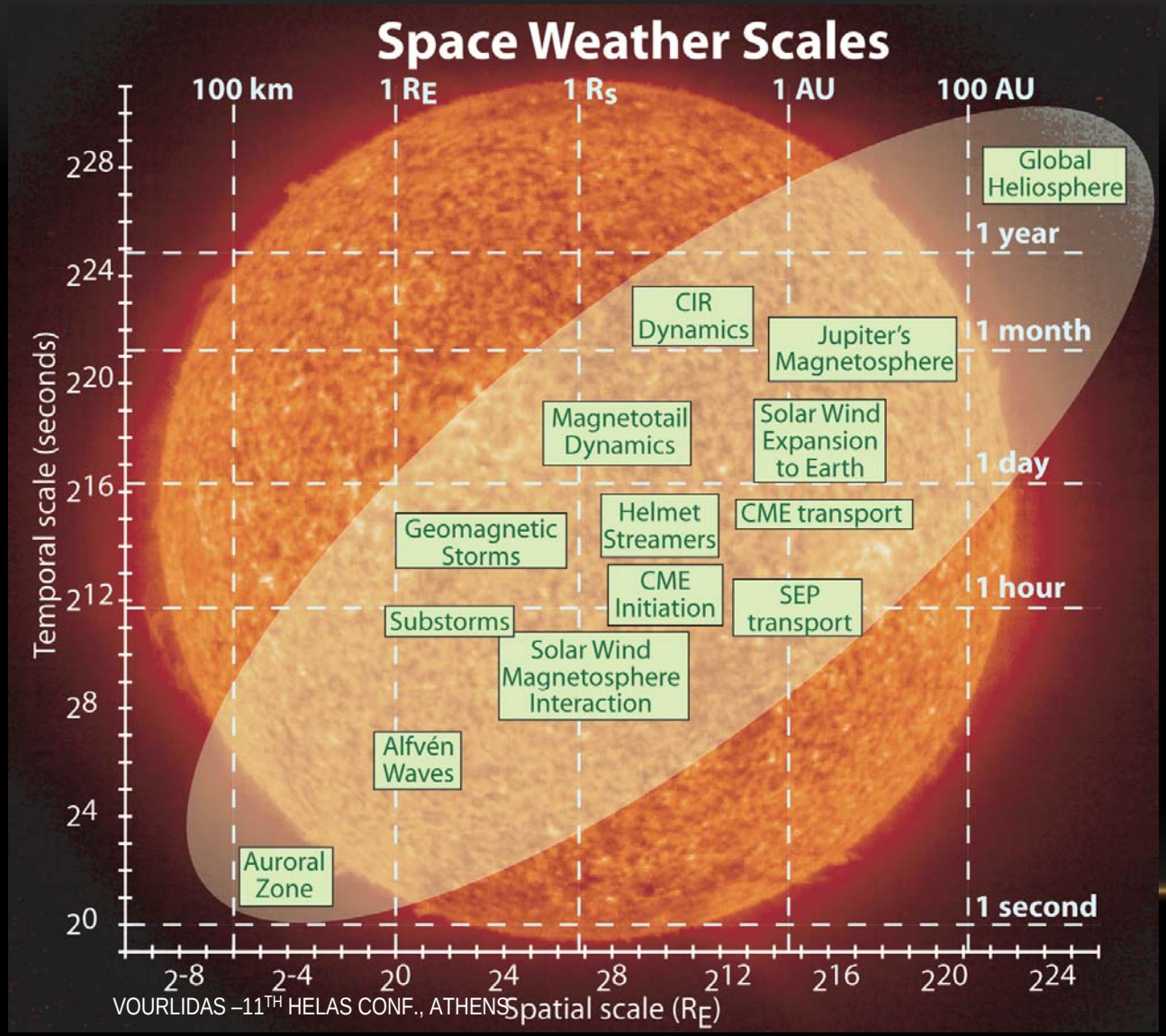
Space Science Division
Naval Research Laboratory, USA



Slide courtesy M. Guhathakurta

SPACE WEATHER IS DRIVEN BY A MULTI-SCALE SYSTEM WHICH COUPLES BETWEEN SCALES



Processes operating at one scale can influence phenomena at other scales.

- A quantitative, predictive understanding of a complex system
- Microphysical processes regulate global & interplanetary structures
- Multi-constituent plasmas and complex photochemistry
- Non-linear dynamic responses

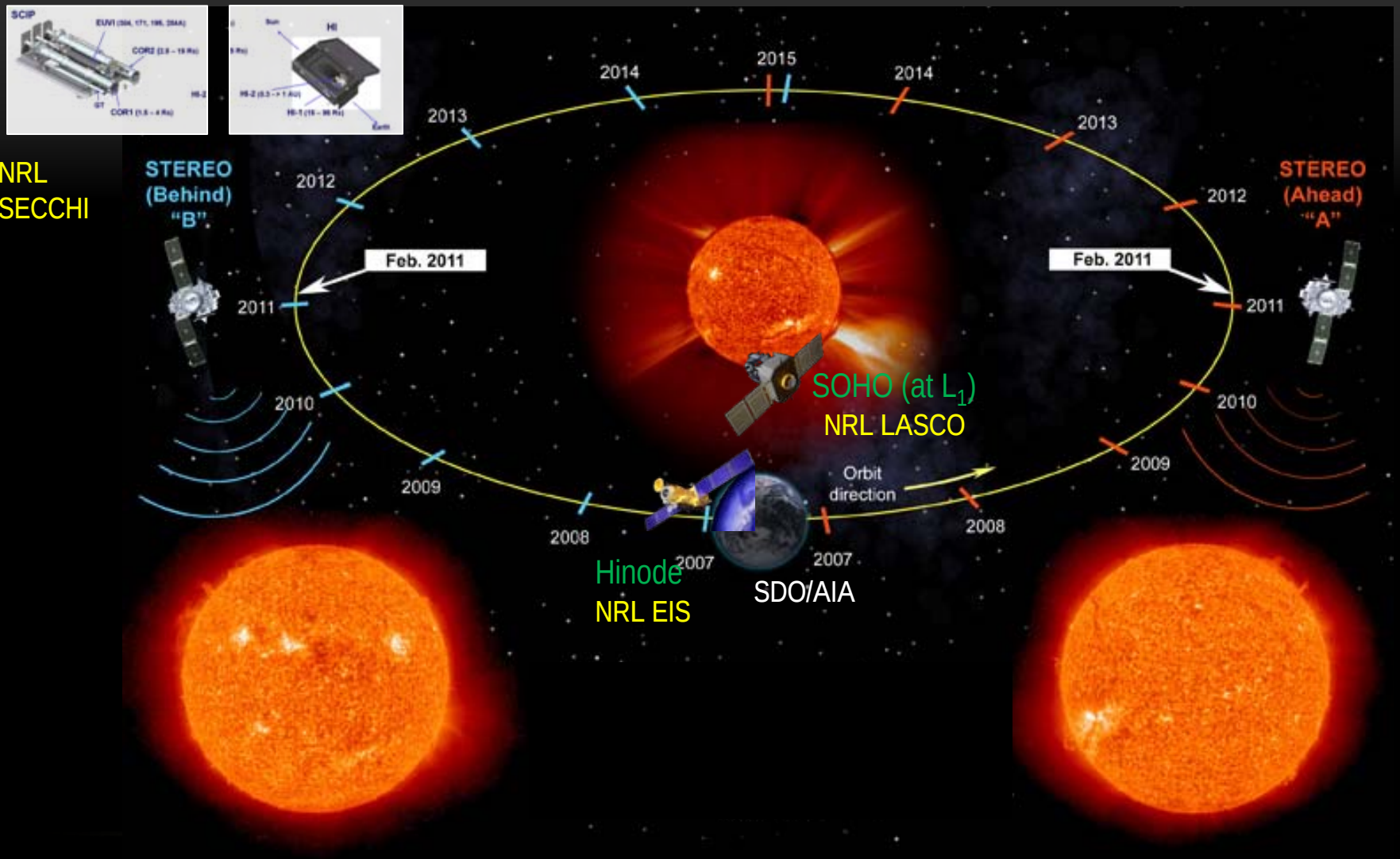
- **Integration** and synthesis of multi-point observations.
- **Data** assimilative models & theory.

Interdisciplinary communities and tools

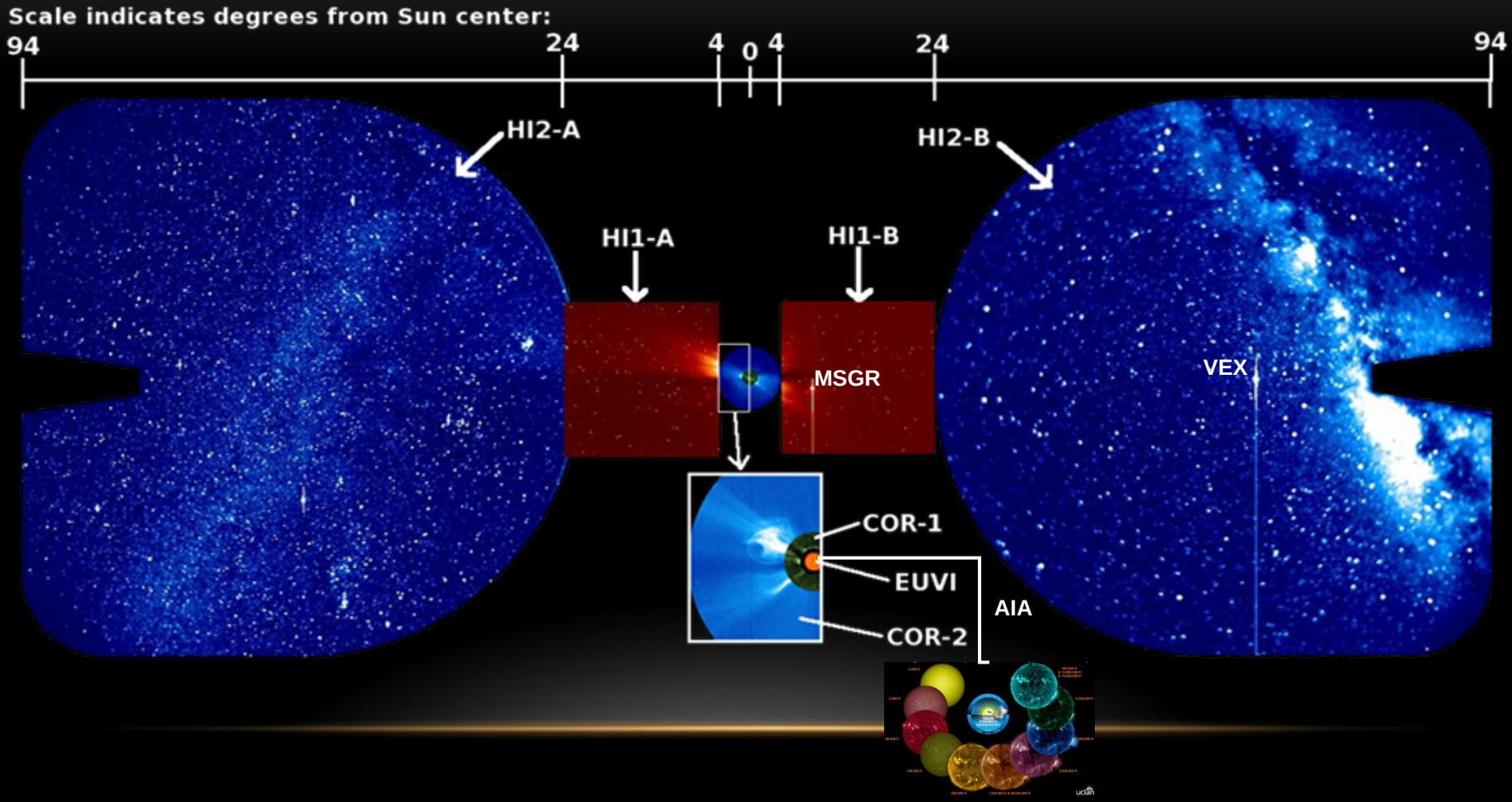
Image credit: T. Gombosi, CSEM, U of Mich

TOOLS: IMAGING FROM THE AIA ON SDO MISSION

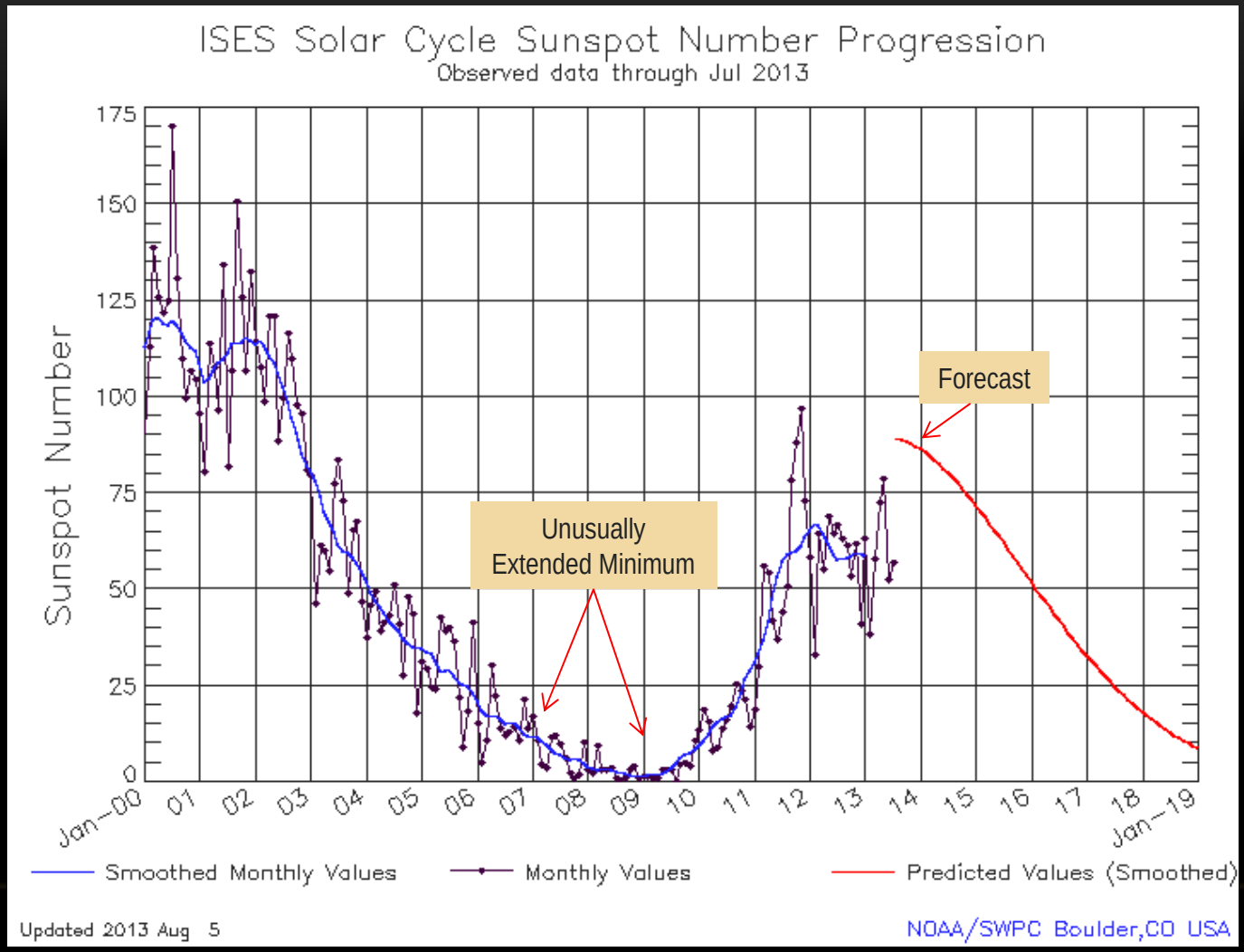
TOOLS: IMAGING FROM STEREO & SOHO MISSIONS



TOOLS: COMPLETE COVERAGE OF THE INNER HELIOSPHERE

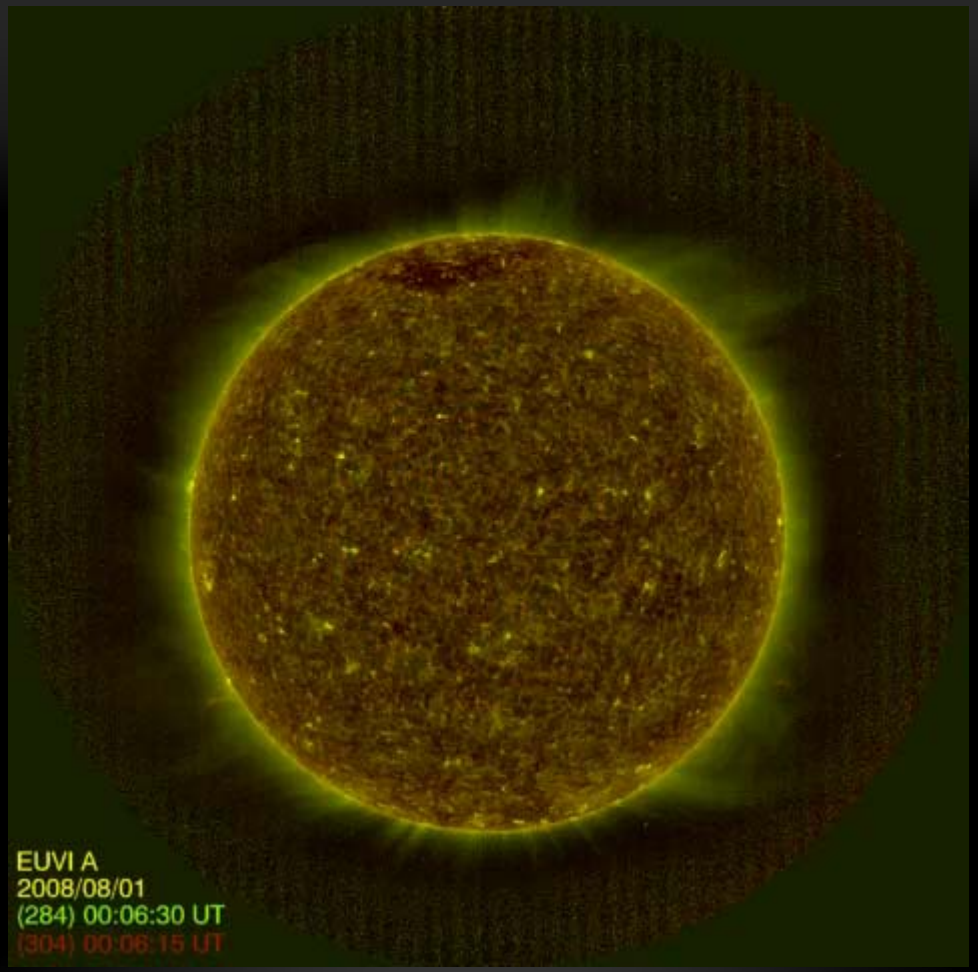


JUST WHEN YOU THOUGHT IT WAS SAFE TO PREDICT THE SOLAR CYCLE….



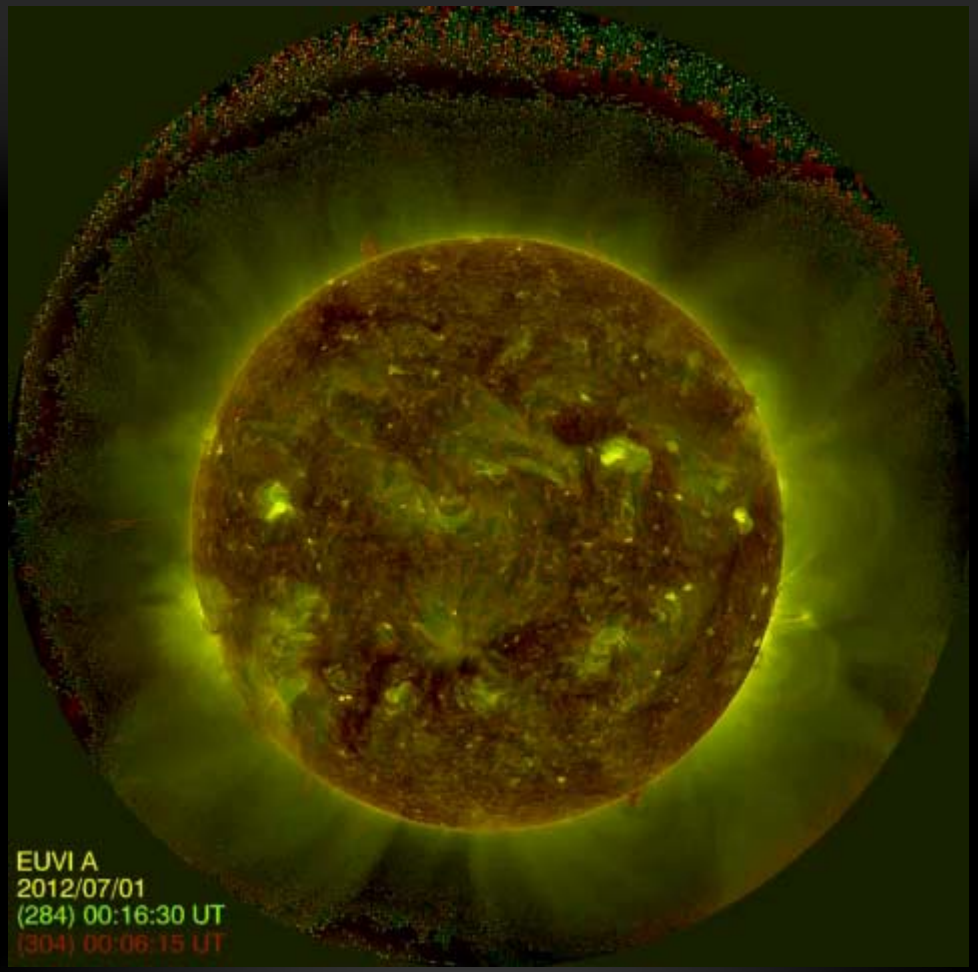
EUV MINIMUM CORONA (EXCEPTIONALLY QUIET)

284Å 1.8 MK
304Å 0.08 MK



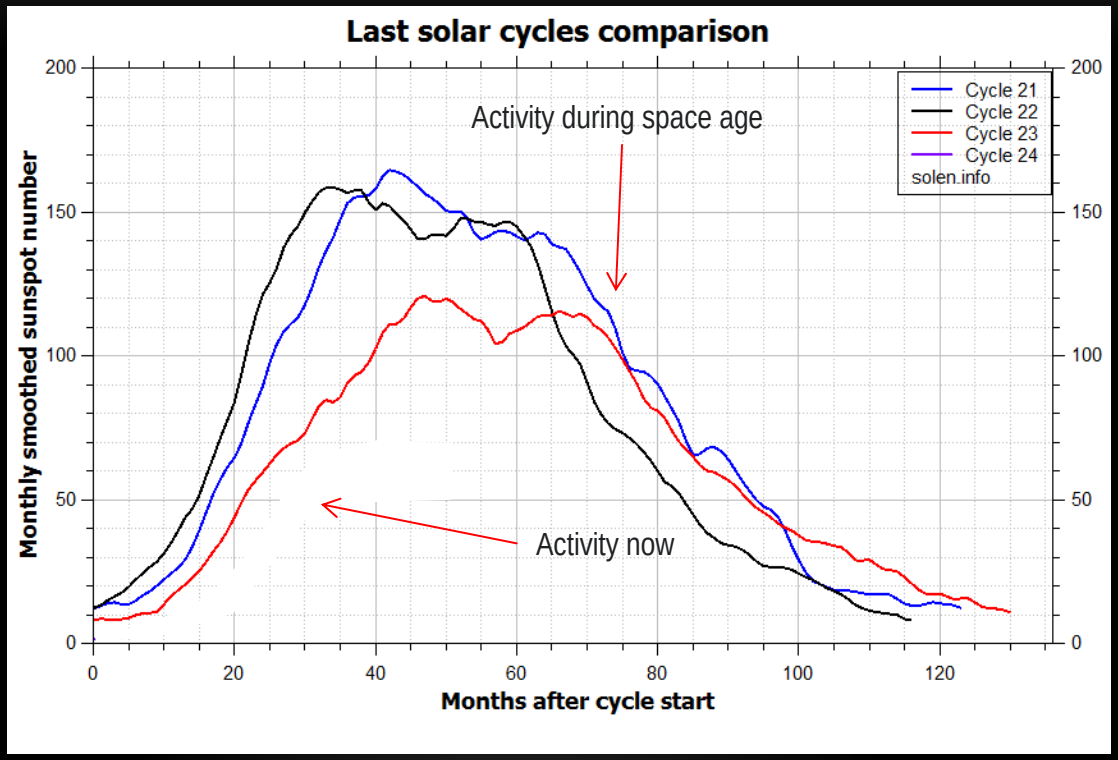
EUV MAXIMUM CORONA IN (WEAK?) CYCLE 24

284Å 1.8 MK
304Å 0.08 MK



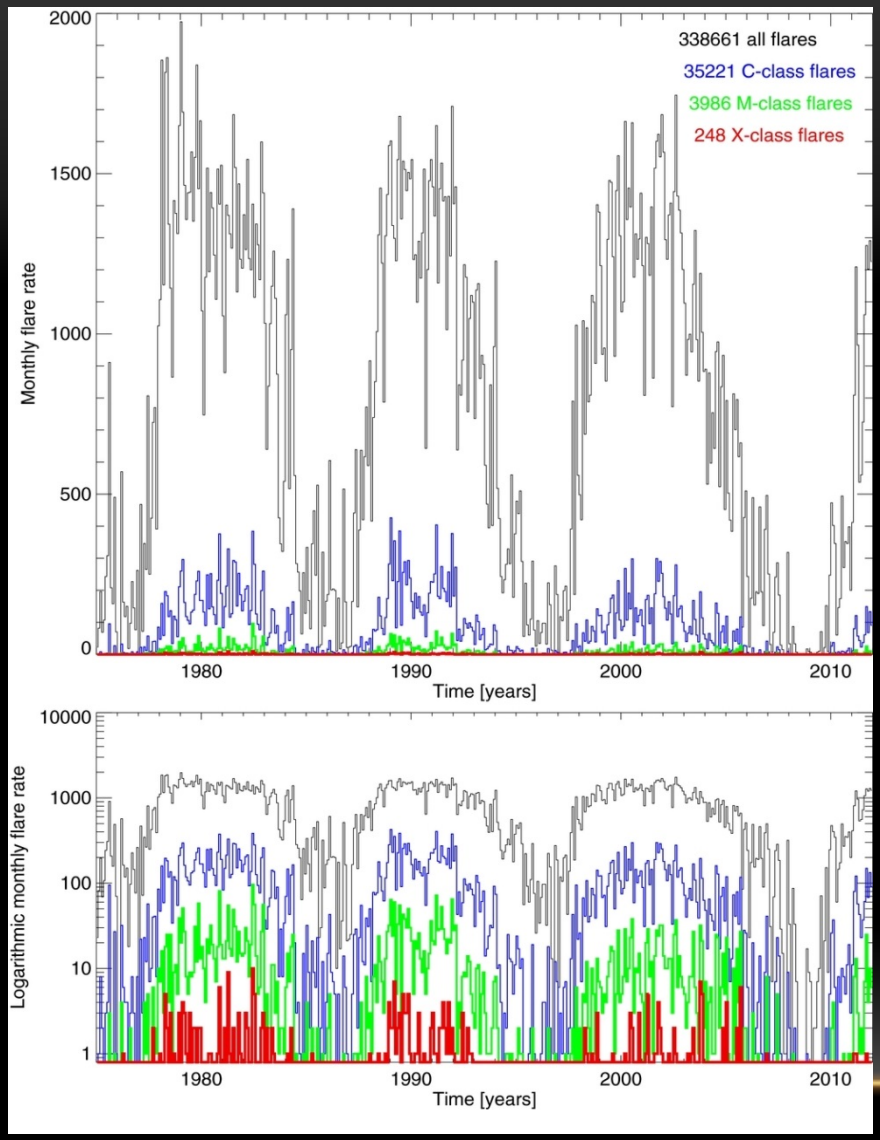
“HURRICANE” SEASON…REALLY?

- Cycle 24 is the most unusual solar cycle since Space Age began.
- Extended minimum --- Low maximum



From www.solen.info/solar/

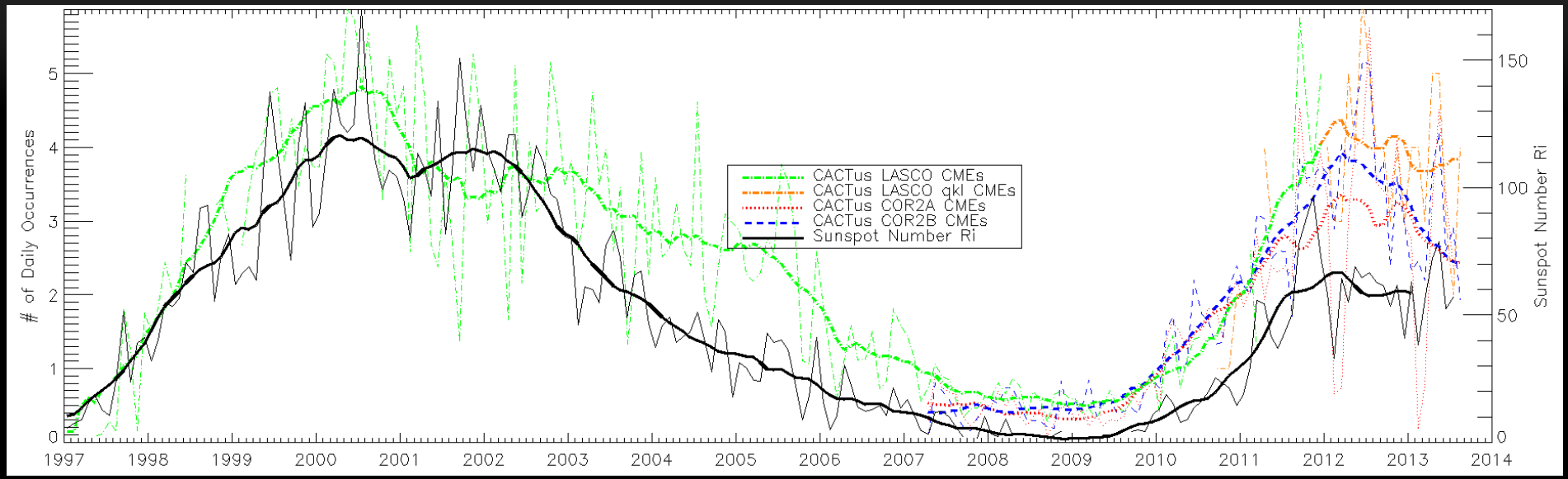
FLARES ARE GENERALLY WEAKER



Monthly flare rate during 1975-2011 on a linear scale (top panel) and on a logarithmic scale (bottom panel). The rates of C- (blue), M- (green), and X-class flares (red) are shown in colors. Note the proportionality of detected flares in different magnitudes.

Aschwanden and Freeland (2012)

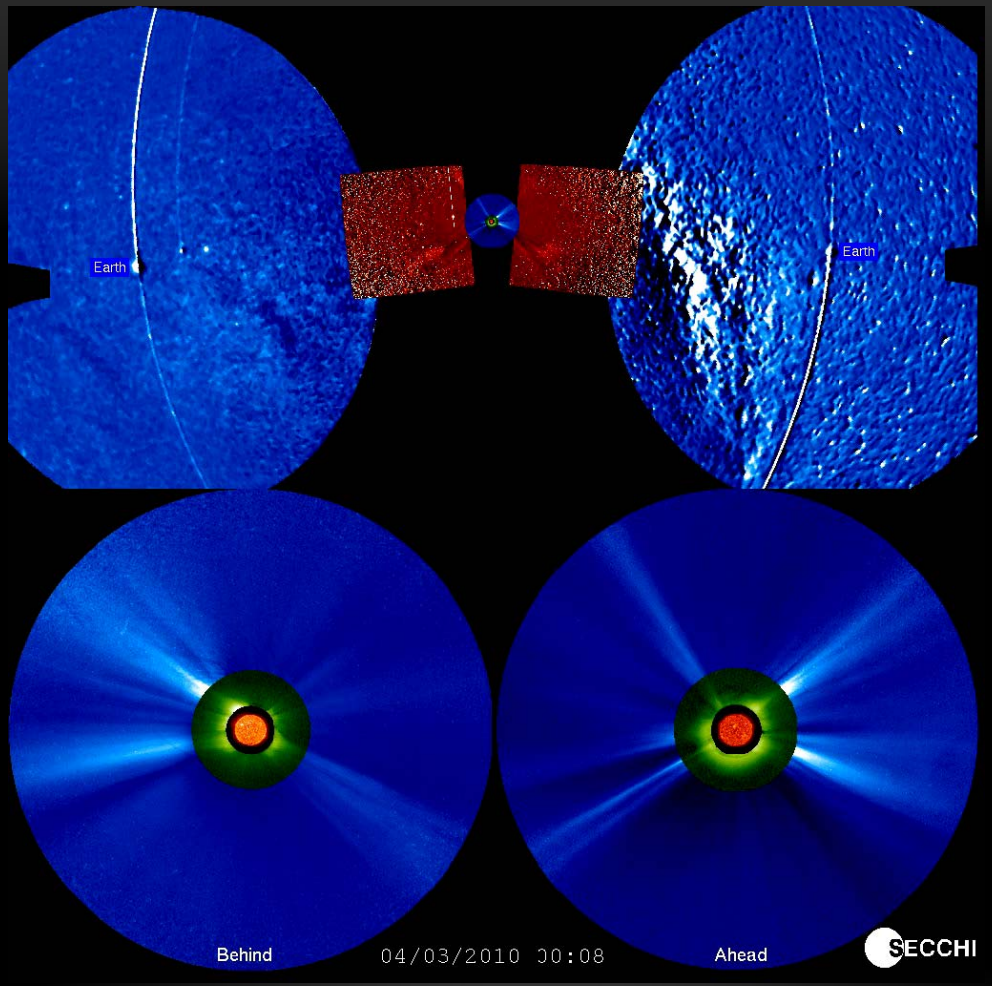
“HURRICANE” SEASON IS ON, HOWEVER



From www.sidc.oma.be

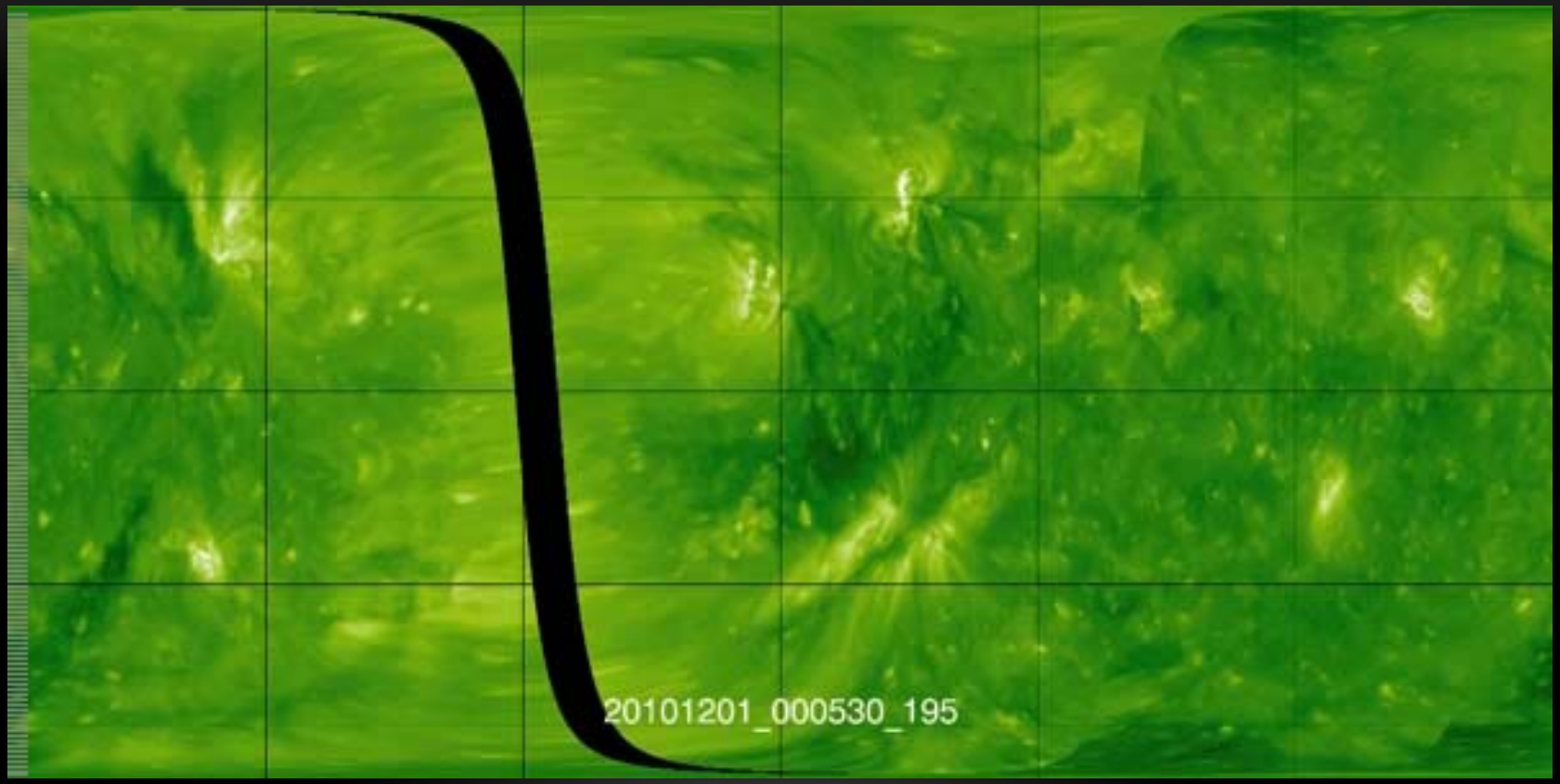
- Coronal Mass Ejection (CME) rate are very similar to past Cycle.
- CME rates DO NOT trace Sunspot Rates well during minimum.

WHEN THE SUN WOKE UP (FEB - APR 2010)

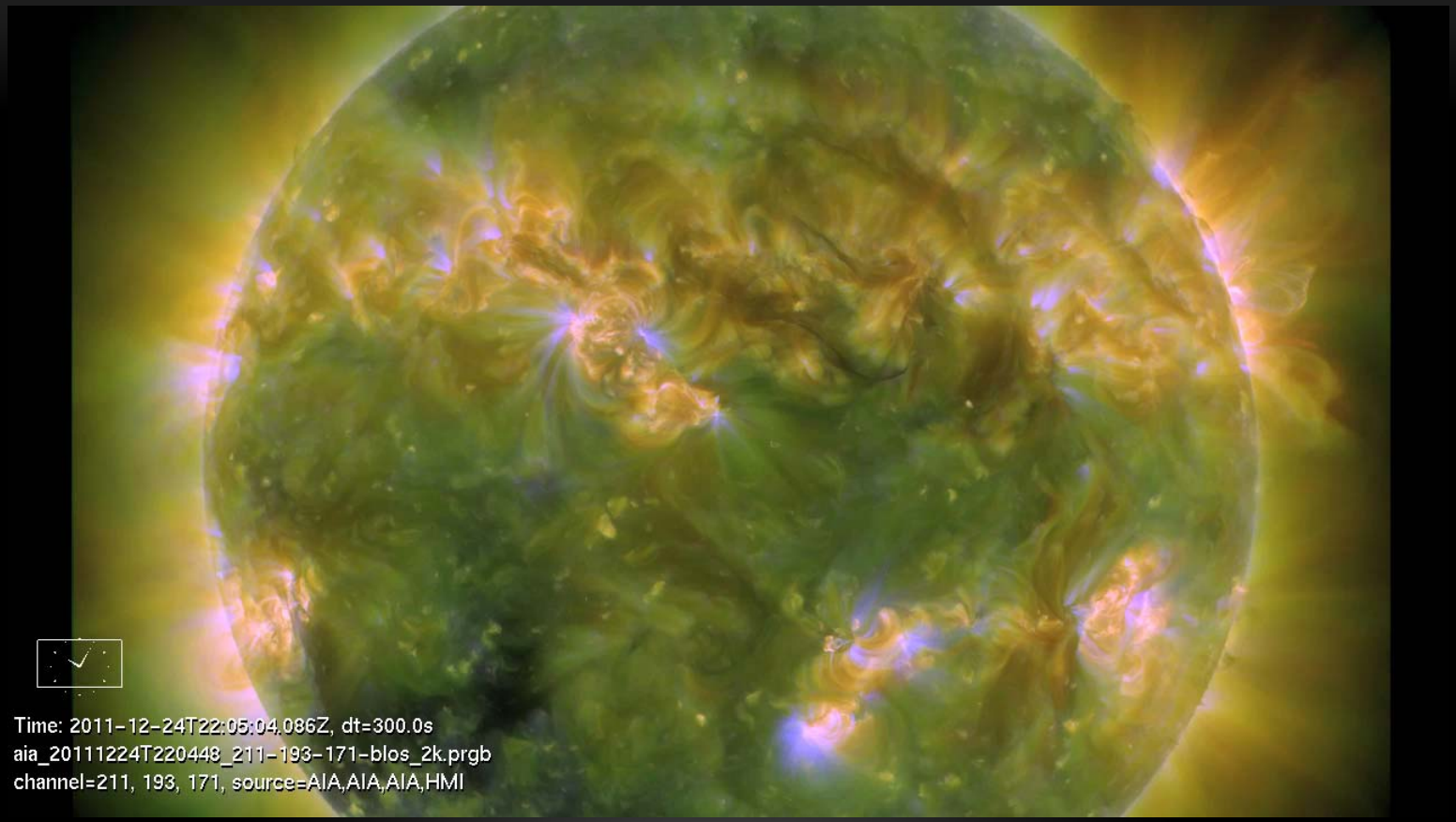


STEREO ACHIEVES THE COMPLETE IMAGING OF A STELLAR ATMOSPHERE

The Sun finally wakes up…the northern hemisphere, at least!

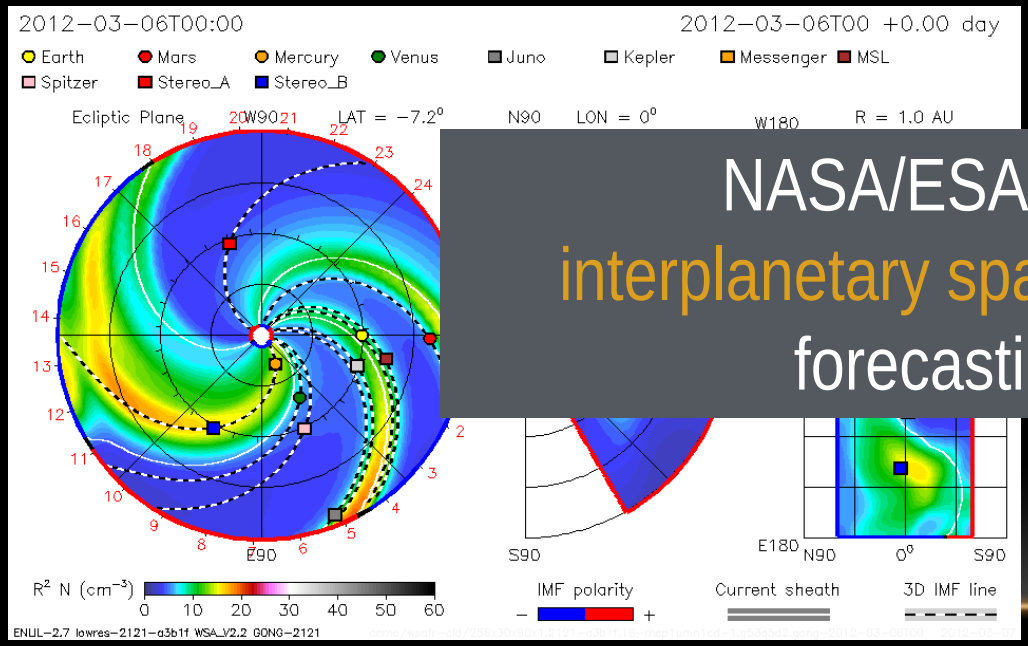


DO CMES TALK TO EACH OTHER?
ARE LONG-RANGE INTERACTIONS POSSIBLE?



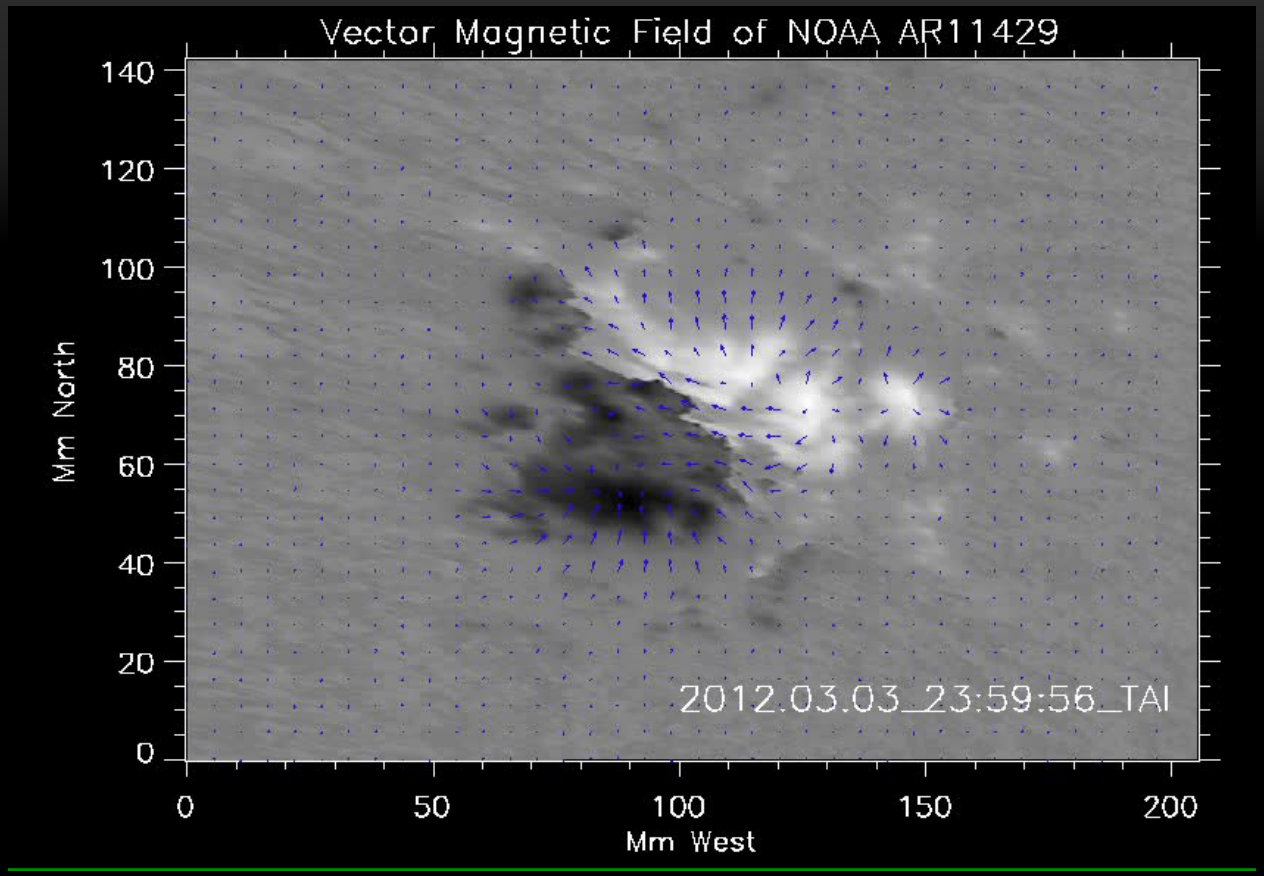
‘HURRICANE’ SEASON : MARCH 2012

- Low sunspot numbers DO NOT imply weak activity.
- An intense episode of solar activity began on 2 March 2012 with the emergence of sunspot AR1429.
- In 2 weeks, AR1429 fired off more than 50 flares, (3 of them X - class, the most powerful type).
- By the time it decayed, it had done a 360 - degree pirouette in heliographic longitude, hitting every spacecraft and planet in the solar system at least once with either a coronal mass ejection or a burst of radiation. This extraordinary series of solar storms, referred to as the “St. Patrick’s Day storms” caused reboots and data outages on as many as 15 NASA spacecraft.



NASA/ESA need interplanetary space weather forecasting.

THE UNUSUAL CASE OF AR 11429:
IT EMERGES IN THE WRONG HEMISPHERE & WREAKS HAVOC



Chintzoglou, Patsourakos, & Vourlidas (2014).

Bad news for space weather:
•'wrong' polarity: it should had emerge in the south.

•High separation speeds lead to creation of strong shear.

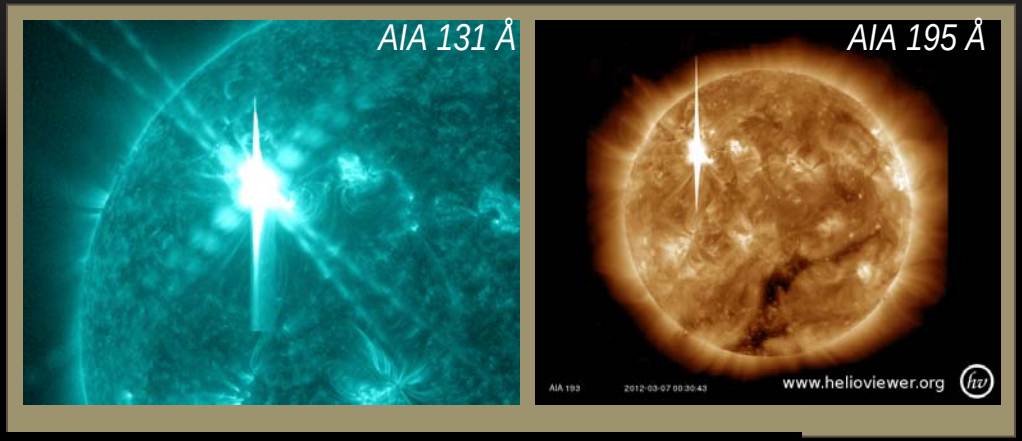
•Rotating sunspot.

THE UNUSUAL CASE OF AR 11429:
THE TWIN EJECTIONS ON MARCH 7, 2012

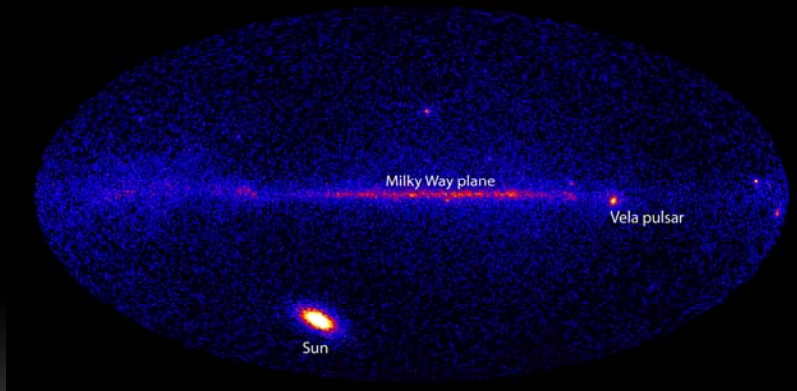
See talk by S. Patsourakos for details

Event Stats

- AR 1429 – Incredible Active Region
- X5.4, then X1.3 class flares within 1 hour
- Largest SEP since 2003



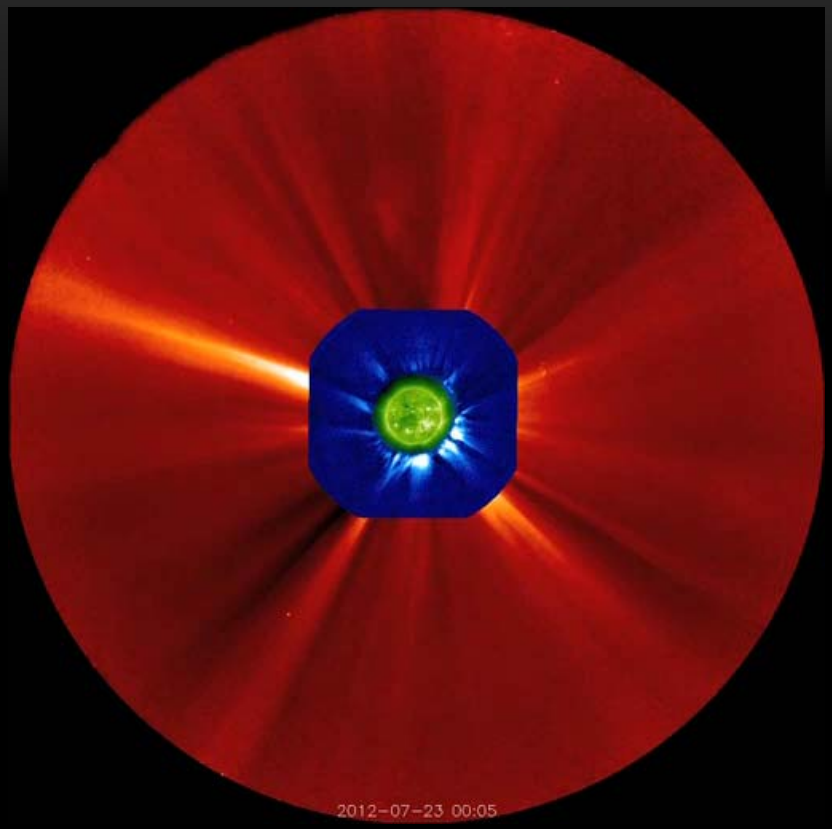
Fermi's Large Area Telescope (LAT) measuring gamma rays with energies beyond 100 Me) saw the Sun as 1,000 times brighter than the Vela pulsar!

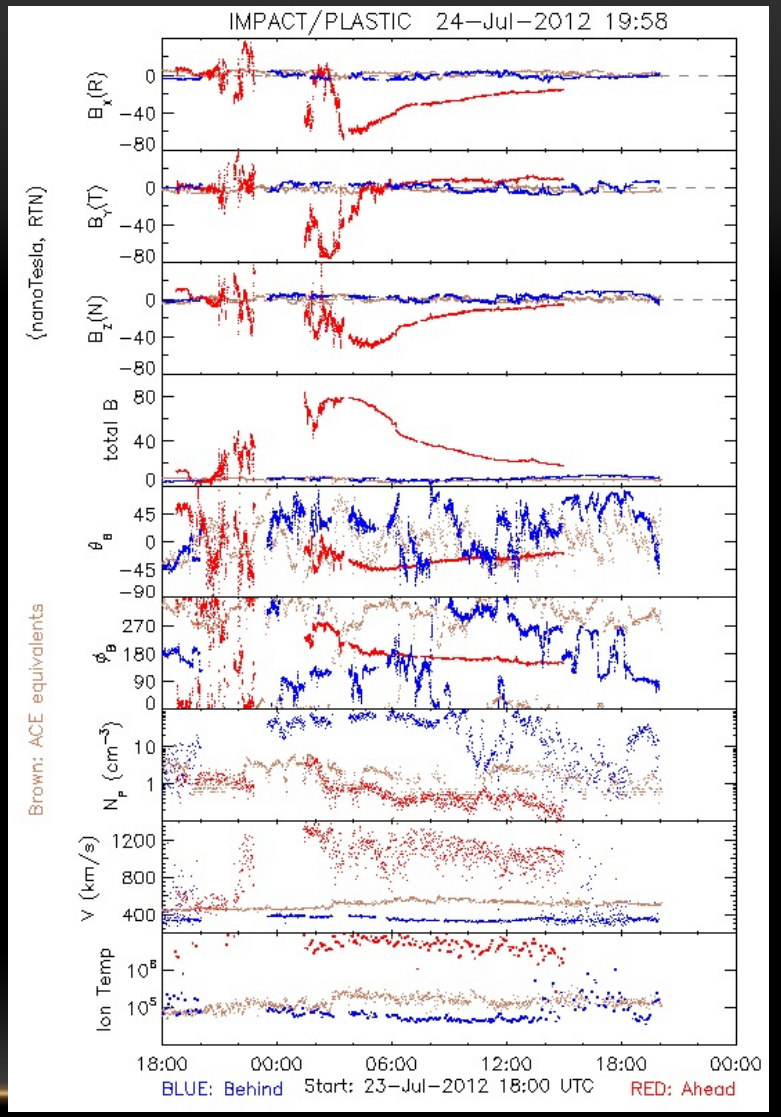


Slide courtesy R. Evans

‘HURRICANE’ SEASON: JULY 2012

17 hour travel time to 1AU (at STEREO-A)!





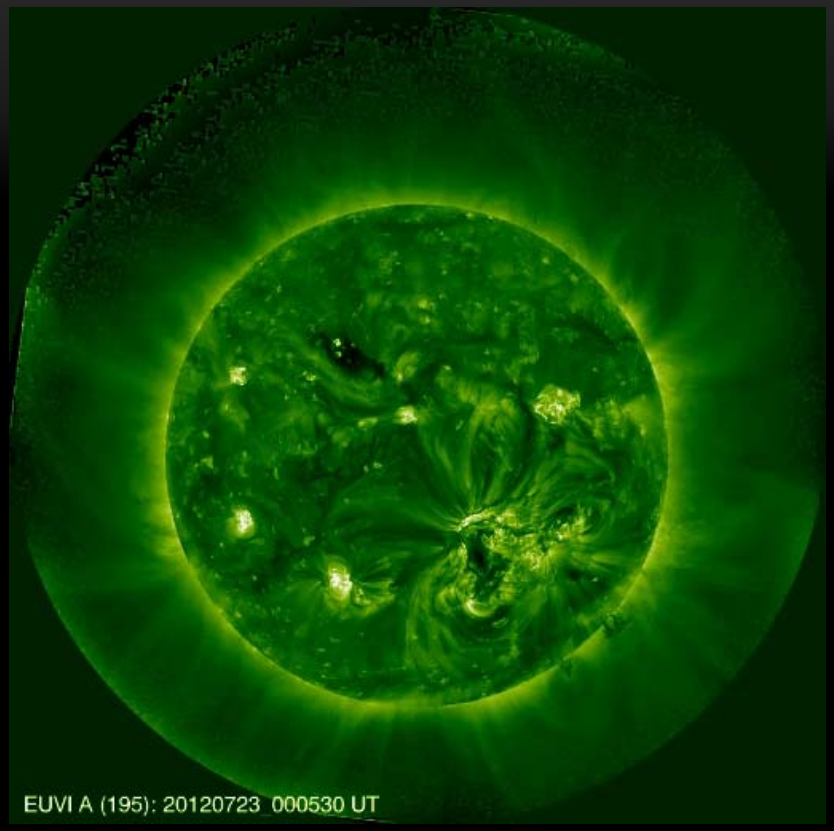
Extremely fast CME ~2400 km/s

Super strong flux rope: |B|~80 nT, with -40 nT Bz for several hours

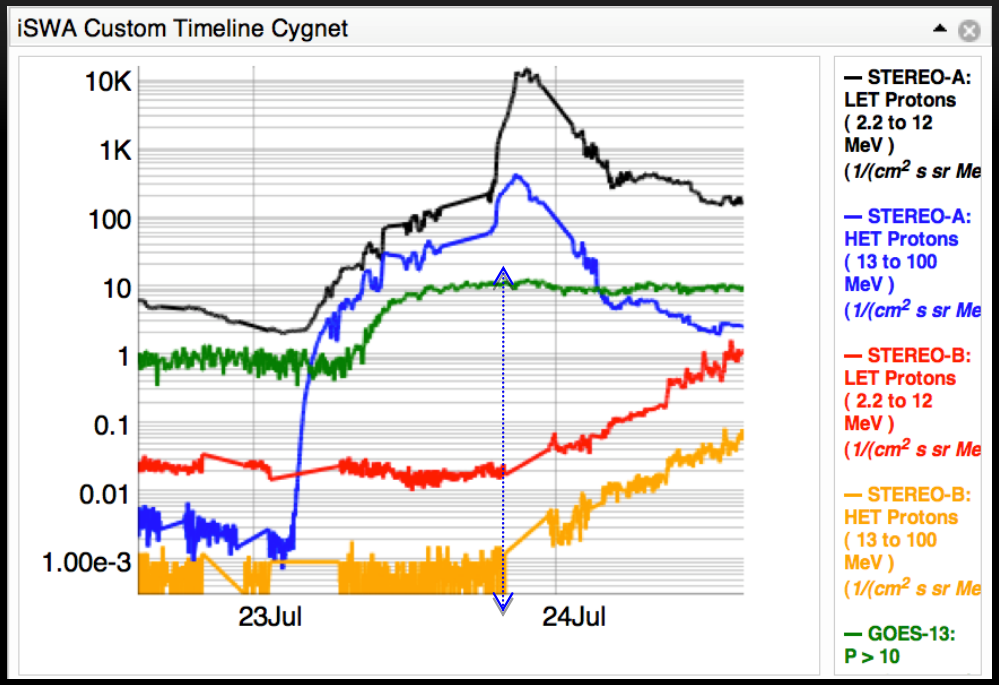
If it had hit Earth, Dst ~1600 nT. (Largest ever)

Slide courtesy R. Evans

JULY 23, 2012



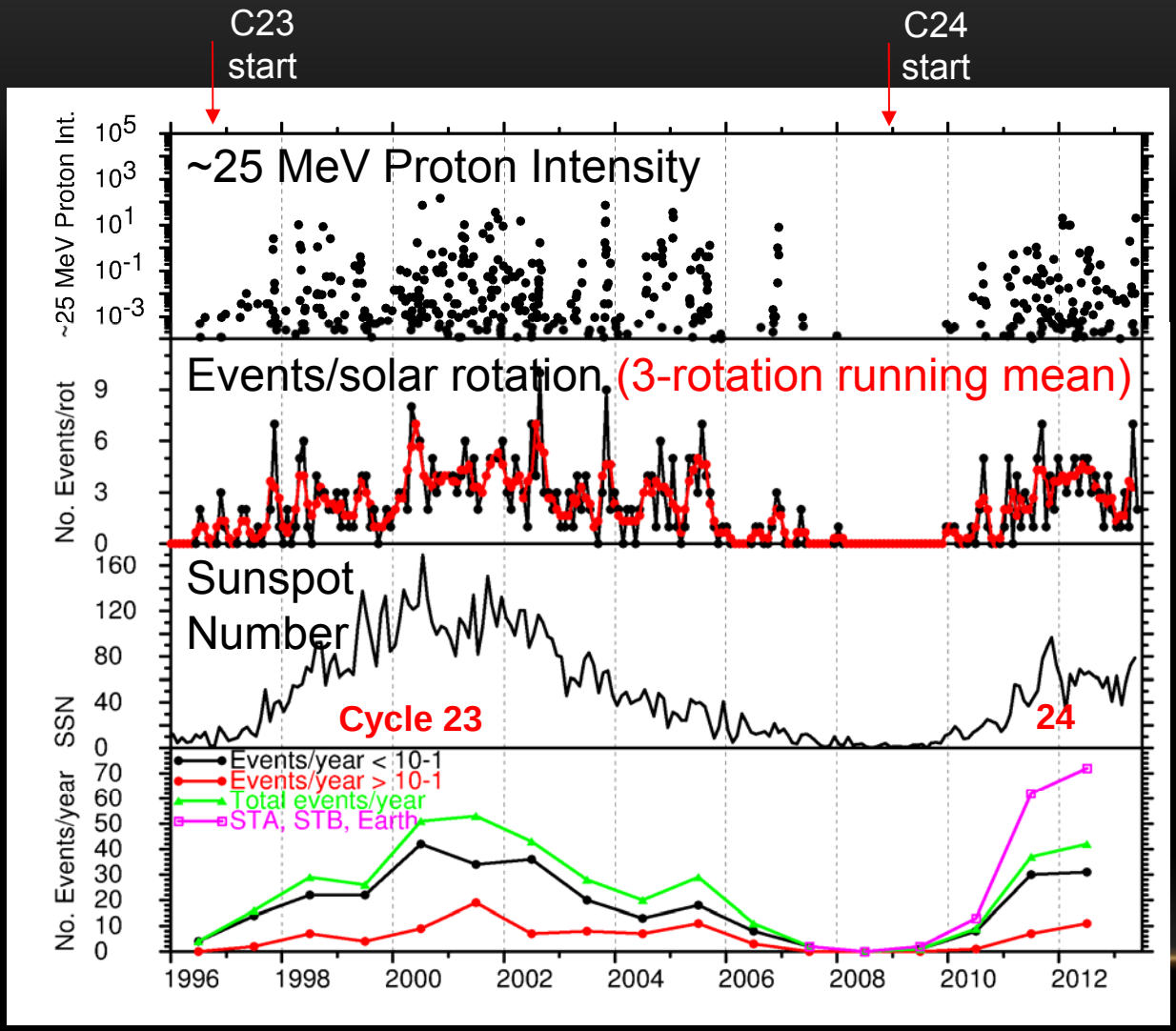
July 23 flare as seen in STEREO-A EUVI 195



Increase of more than 5 orders of magnitude at STEREO A SEP event also detected by GOES, and later enhancement seen at STEREO B.

Slide courtesy R. Evans

OVERVIEW OF >25 MEV PROTON EVENTS AT EARTH IN 1996-MAY 2013



In cycle 23, the first proton event occurred ~2 months after the start of the cycle (smoothed SSN minimum).

The delay was ~a year in cycle 24.

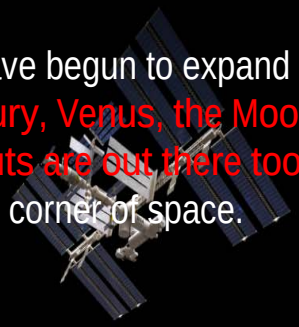
The yearly SEP rates at Earth so far in C24 are just 20% lower than in C23.

Comparing the purple and green graphs suggests that ~40% of the events detected by at least one s/c were not detected at Earth.

Recent months show a decline in the event rate, despite being near solar maximum.

Slide courtesy I. Richardson

Interplanetary Space Weather & Climate: A New Paradigm



- NASA and other space agencies have begun to expand their research into the solar system. Probes are now orbiting or en route to Mercury, Venus, the Moon, Mars, Ceres, Saturn, and Pluto—and it is only a matter of time before astronauts are out there too. Each mission has a unique need to know when a solar storm will pass through its corner of space.

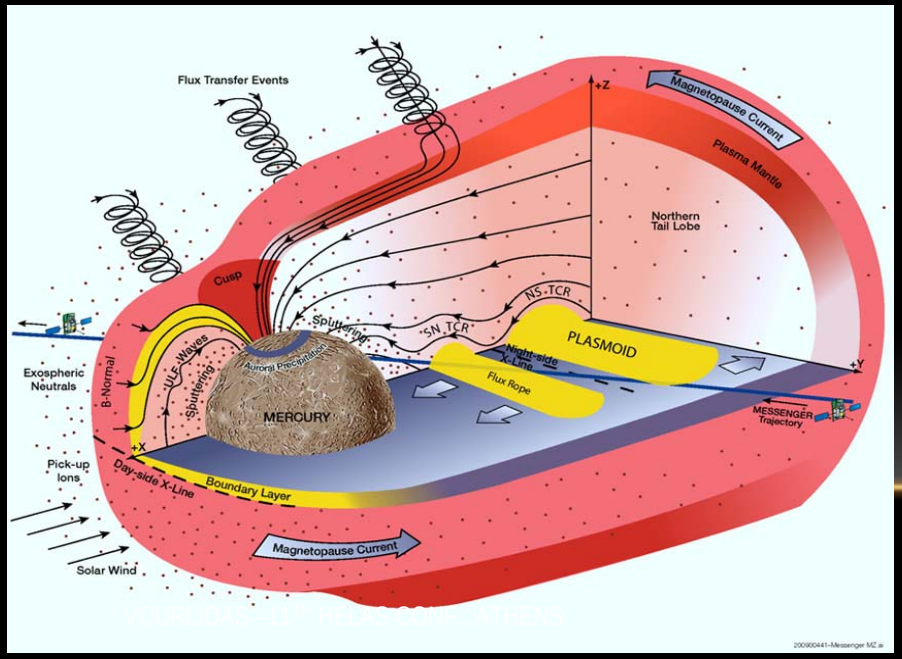
HUMANS & THEIR ROBOTS ARE MOVING INTO THE SOLAR SYSTEM.
THE REALM OF SPACE WEATHER FORECASTING
IS RAPIDLY EXPANDING.

Madhulika Guhathakurta
NASA HQ
Science Mission Directorate
Heliophysics Division

SWEF, June 4, 2013

Space Weather on Mercury

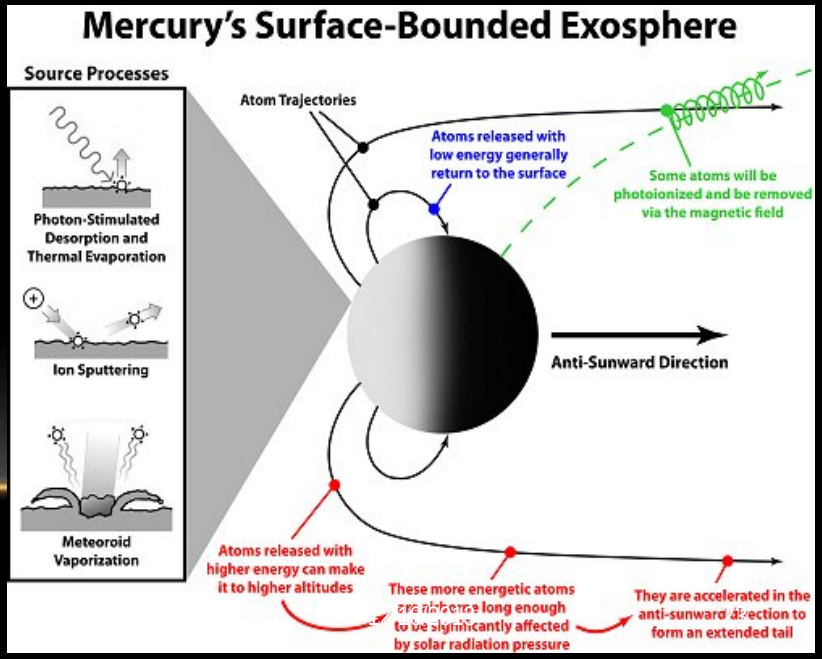
The most ferocious space weather in the solar system is felt on Mercury, the closest planet to the Sun. MESSENGER has observed a highly dynamic magnetosphere with magnetic reconnection events taking place at a rate 10 times greater than what is observed at Earth during its most active intervals.



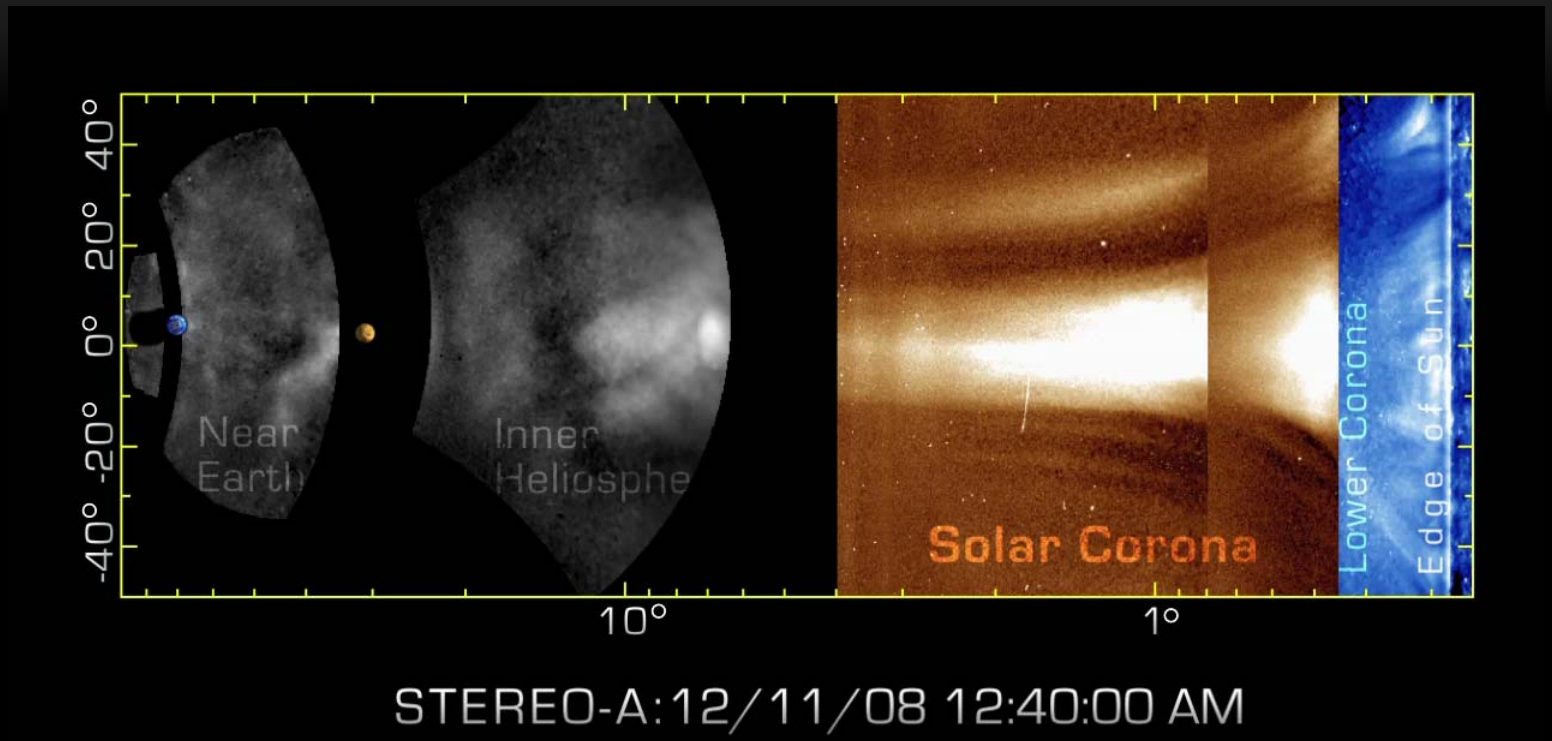
A CME IMPACT ON MERCURY

EXACTLY WHAT WE WOULD SEE IS NOT KNOWN. EVEN GARDEN - VARIETY CMES MAY BE STRONG ENOUGH TO OVERWHELM MERCURY'S WEAK MAGNETIC FIELD AND STRIP ATOMS RIGHT OFF THE PLANET'S SURFACE. MERCURY'S COMET - LIKE TAIL OF SULFUR IS LIKELY POPULATED BY THIS PROCESS.

IF OPERATORS KNOW WHEN A CME IS COMING, SPECIAL PREPARATIONS CAN BE MADE, E.G., INSTRUCTING THEIR SENSORS TO COLLECT DATA AT THE HIGHEST RATES

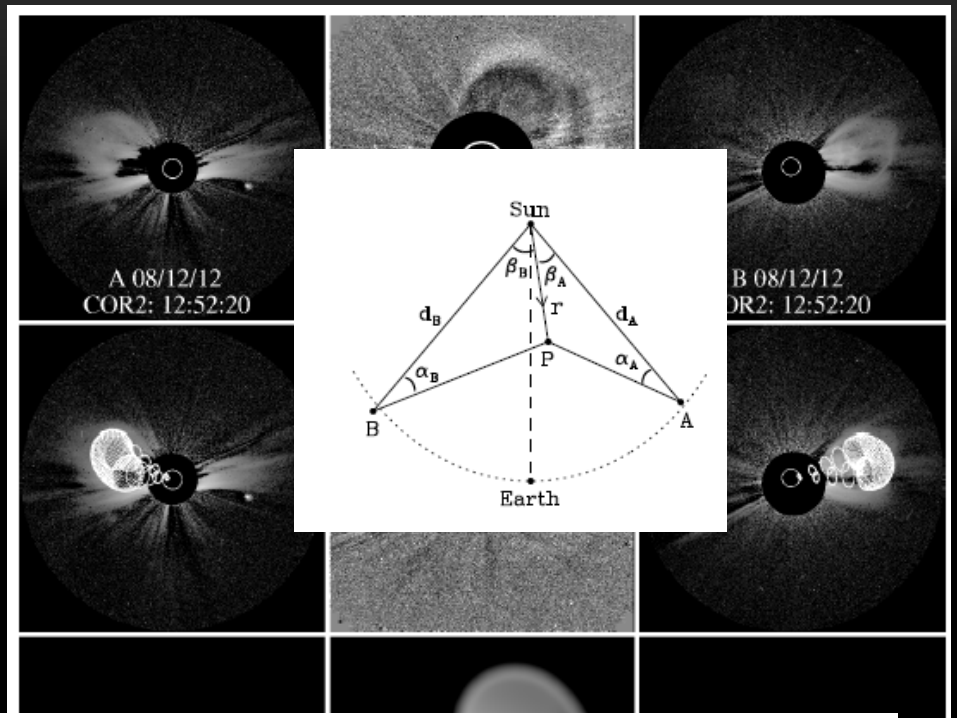


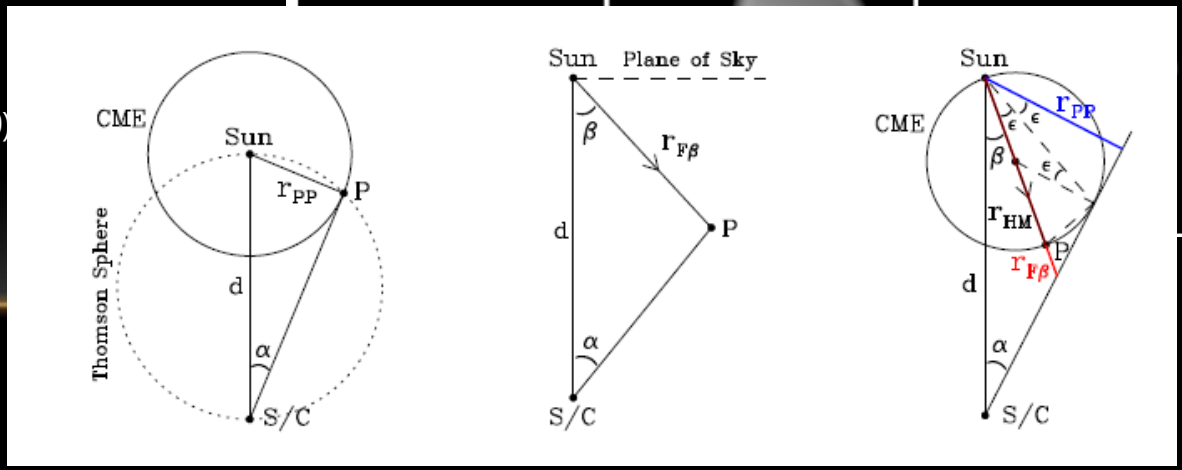
CME TRACKING FOR EFFECTIVE IP SPACE WEATHER RESEARCH



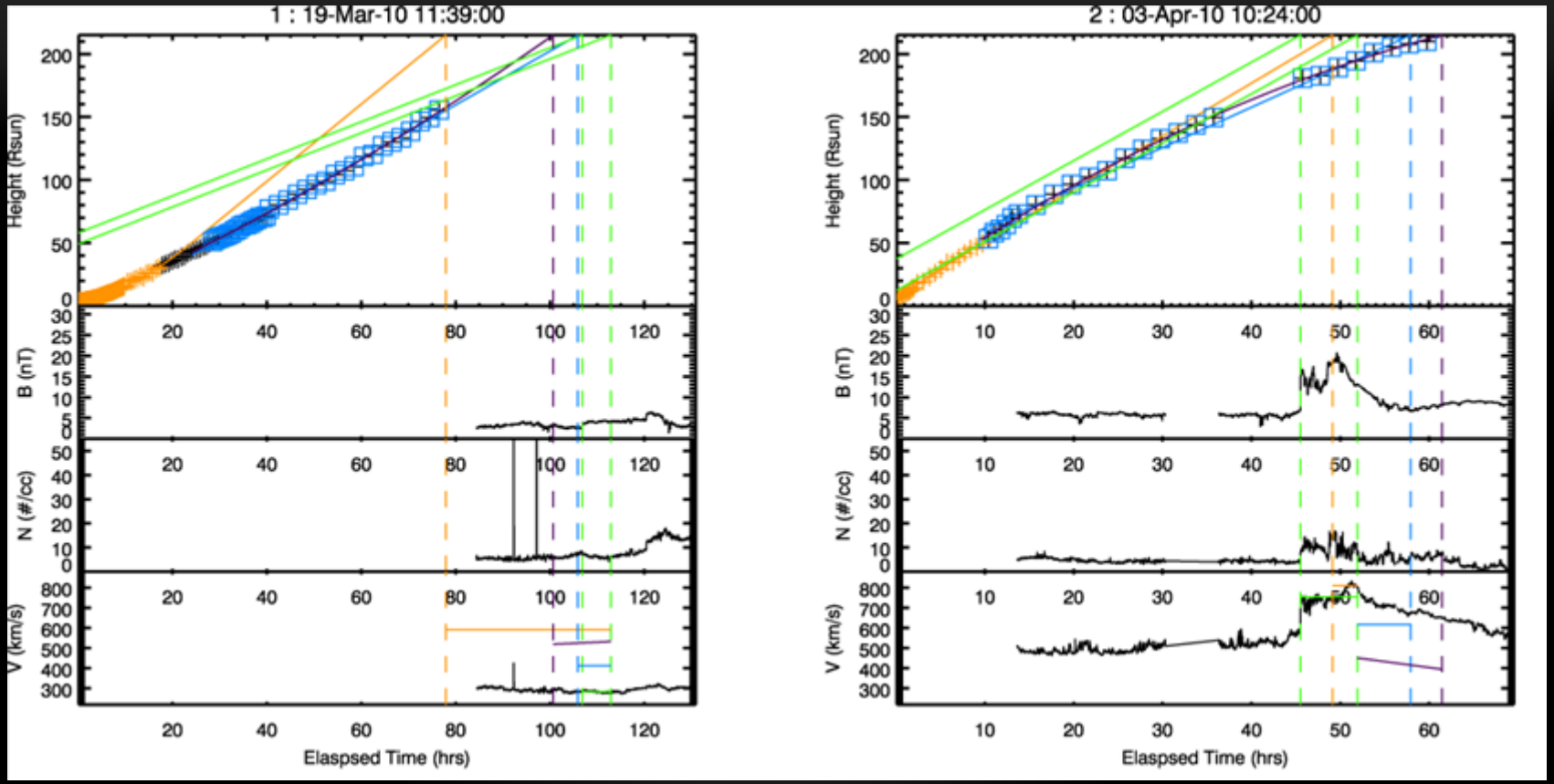
MANY METHODS FOR MEASURING CMES IN 3D!

- Direct Reconstruction
  - Forward Modeling (Thernisien et al, Wood et al)
    - No use of Heliospheric info.
- Geometric techniques
  - Triangulation
    - Using images (H-t)
    - Using J-maps (ε- t)
  - Point-P
  - Point-φ
  - Harmonic mean (Lugaz et al `09)
- *Comparison with in-situ*





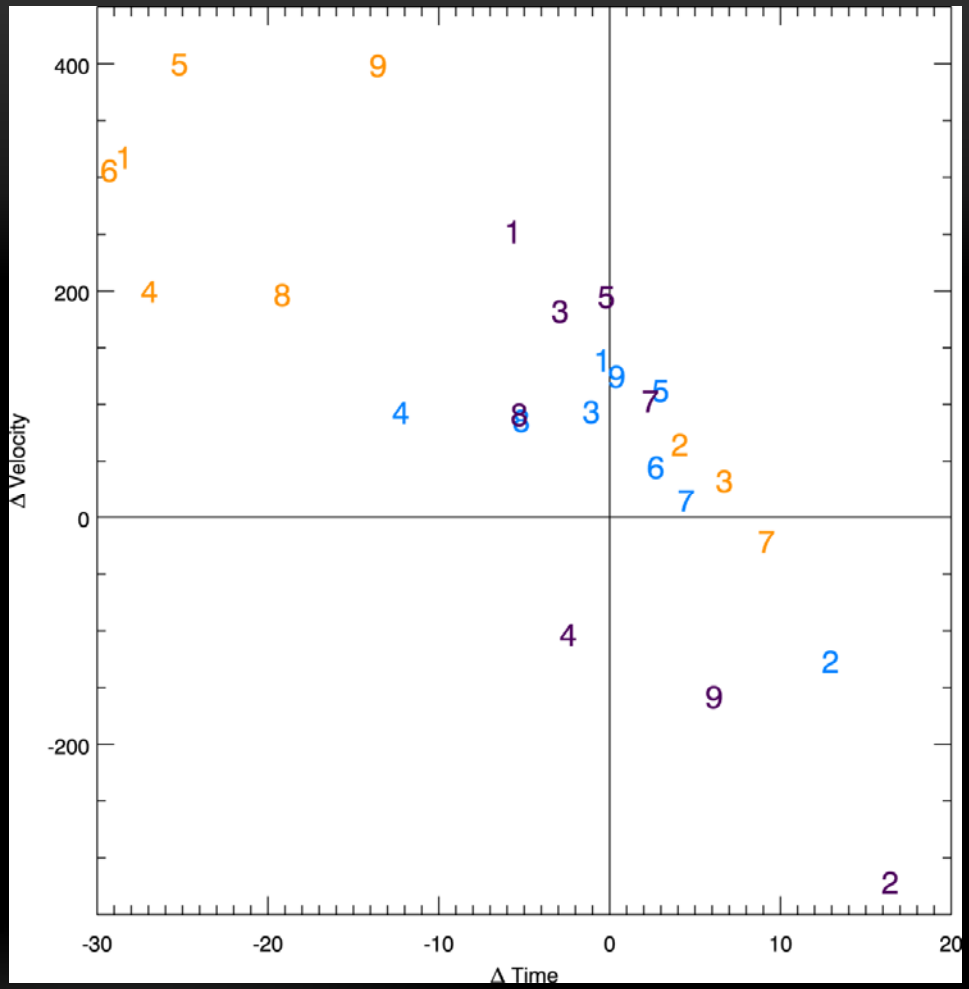
KINEMATICS ARE DIFFICULT TO FIT



Colaninno, Vourlidas, Wu (2013)

TIME-OF-ARRIVAL ACCURACY ~6 -7 HOURS

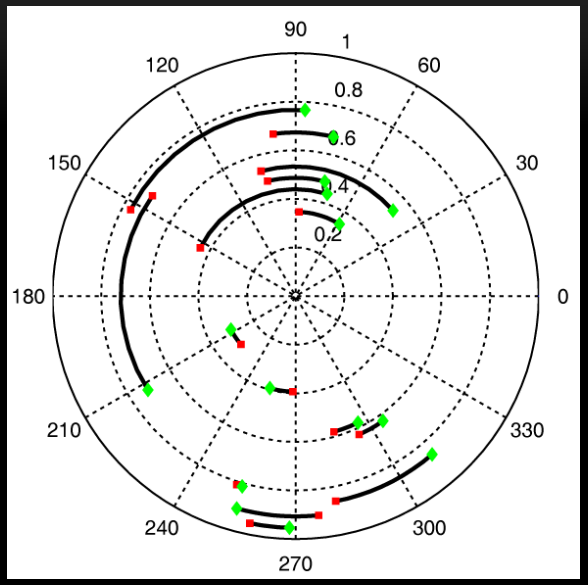
- Orange: fit in COR2 (15 R)
- Purple: 2nd order fit (all)
- Blue: 1st order fit (all)



Colaninno, Vourlidas, Wu (2013)

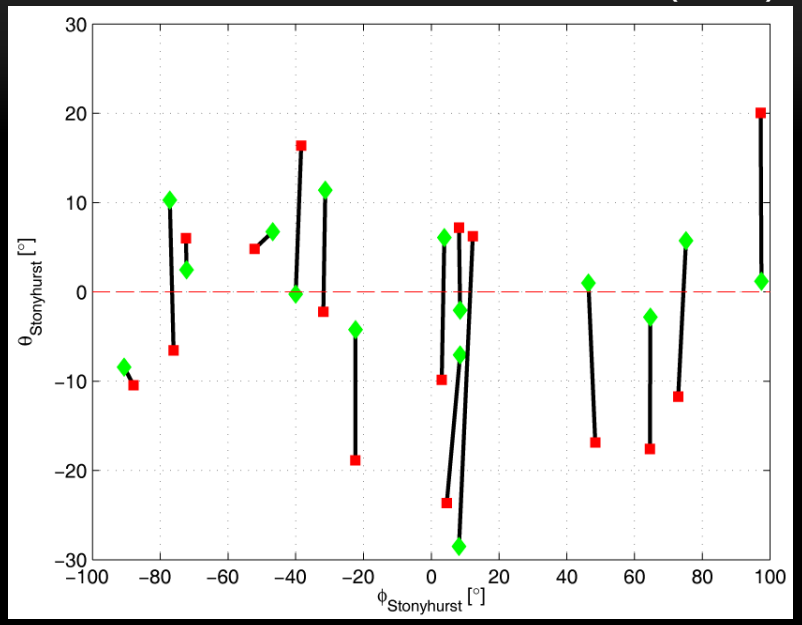
COMPARING IMAGING TO IN-SITU: ICME ROTATIONS AND DEFLECTIONS

- In-situ
- Imaging



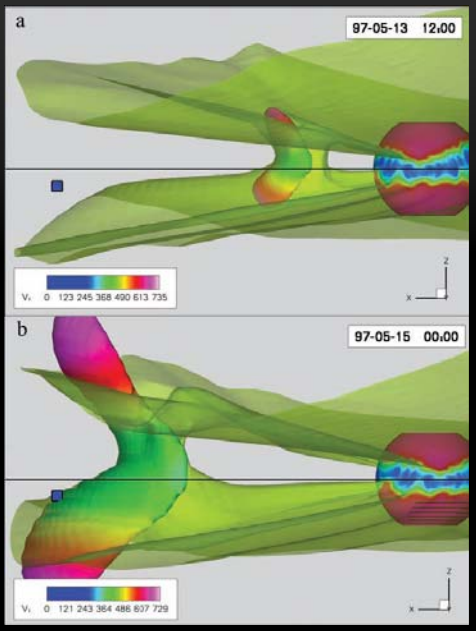
CME rotate CW in the inner heliosphere

Isavnin et al (2012)



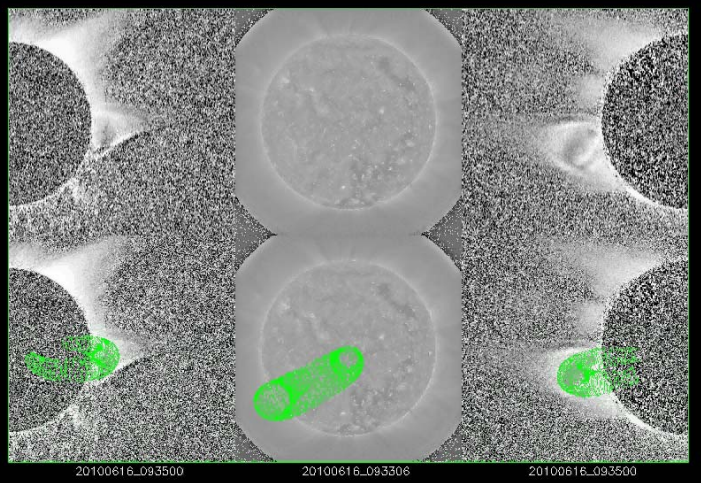
CME deflect towards equator in the inner heliosphere

CME EVOLUTION IN THE HELIOSPHERE?

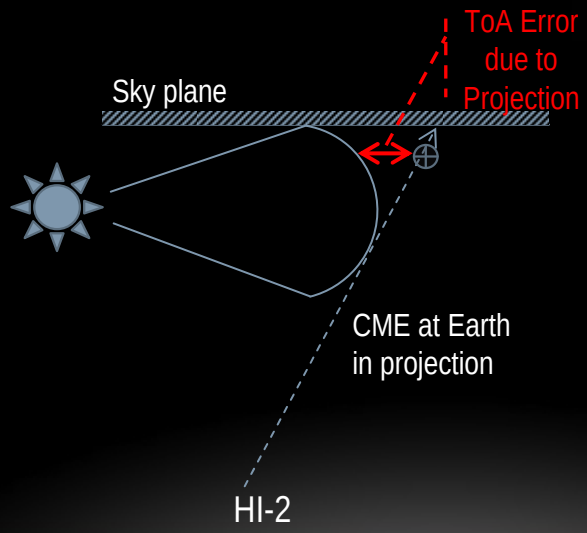


Models: CMEs over-expand out of the ecliptic and compress radially.

Observations: Rotating CMEs…but why?



Vourlidas et al (2011)

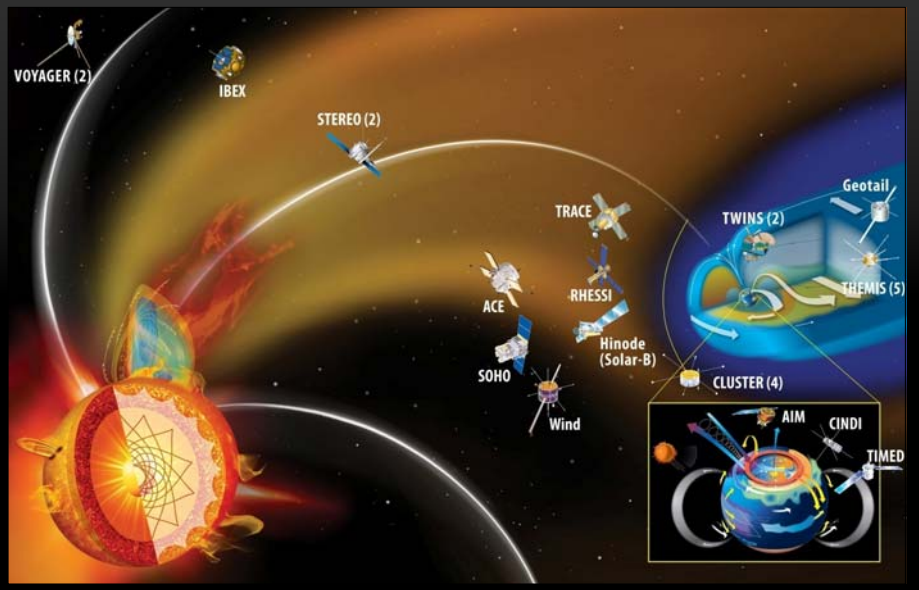


OPEN ISSUES:

- Fitting method/function for Height-time curves?
- Geometry of CME front and LOS?
- Interaction with ambient solar wind.
  - Rotations, deflections, etc

Odstrcil et al (2003)

THE SPACE WEATHER PROBLEM REQUIRES A TEAM APPROACH



- The *Hellenic National Space Weather Research Network* is Greece's research community answer to this problem.
  - Six research institutions (Univ. of Athens, Thes/niki, Ioannina, Xanthi; Academy of Athens, National Observatory).
  - 17 researchers (PI: Dr. L. Vlahos)
  - Many students, postdocs.
  - Several talks on the team's work over the next 2 days.
  - Check it out: *http://proteus.space.noa.gr/~hnswrn/index.html*

RECAP

- The low sunspot cycle DOES NOT MEAN low activity.
  - It only takes one Active Region to produce Space Weather.
  - Strongest magnetic field in CME detected.
  - Long-range interactions are a new variable in understanding solar variability.
  - There are always ejections even when nothing else is seen in the corona.
- CME propagation in the heliosphere is still challenging.
  - Still difficult to compare remote sensing and in situ data.
  - Still difficult to disentangle propagation effects (rotation, flattening, interaction).
  - We don't really know what we are imaging (in the heliosphere).
- Space Weather is now a concern for the full Solar System.
  - Interplanetary SpW is a new paradigm in Heliophysics.
  - New missions: Solar Orbiter (2017), Solar Probe Plus (2018), *L5 Sentinel (2022?)*
- Success can come only from a systems approach.

AS THE SOLAR CYCLE UNFOLDS IN AN UNEXPECTED WAY, IT IS IMPORTANT TO REMEMBER THAT

THE SUN IS NEVER BORING

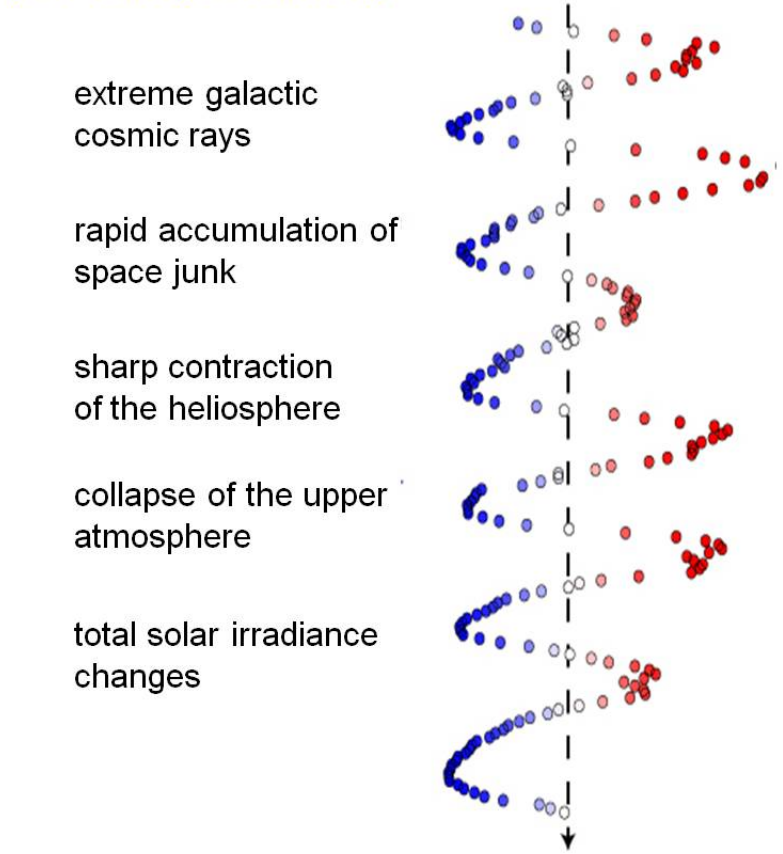


Illustration shows smoothed monthly sunspot counts from the past six solar cycles plotted horizontally instead of vertically. High sunspot numbers are in red and on the right, low sunspot numbers are in blue and on the left. Associated with each high and low sunspot numbers are different space weather impacts experienced at Earth (doi: 10.1002/swe.20039).

Slide courtesy M. Guhathakurta