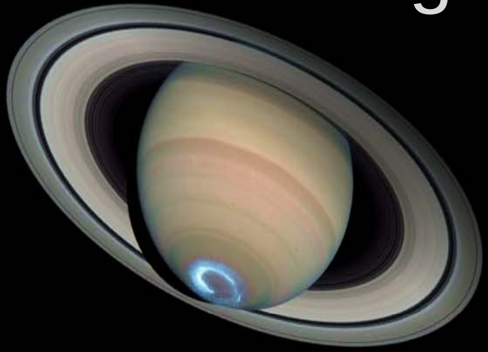
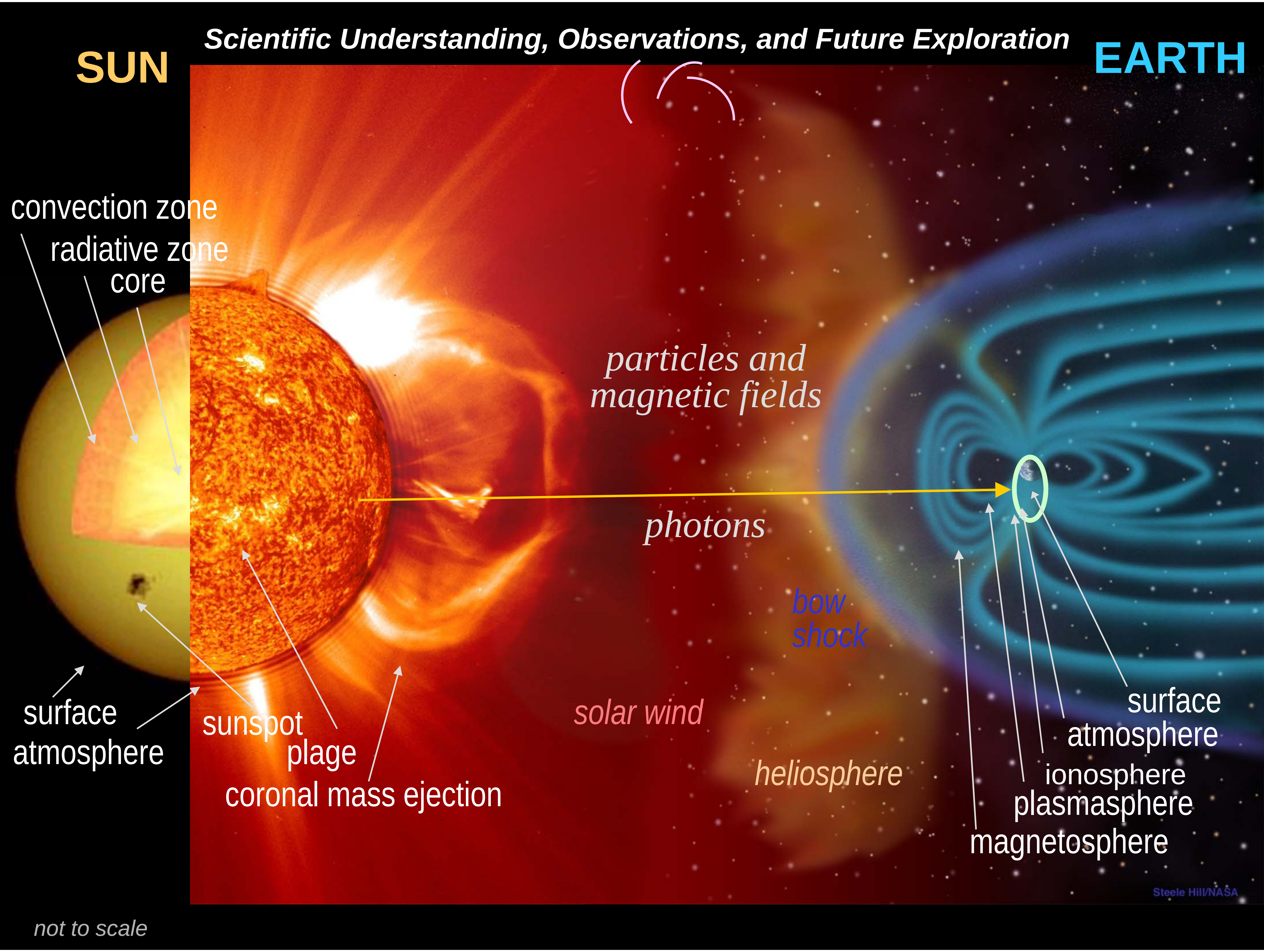
Interplanetary Space Weather & Climate: A New Paradigm



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

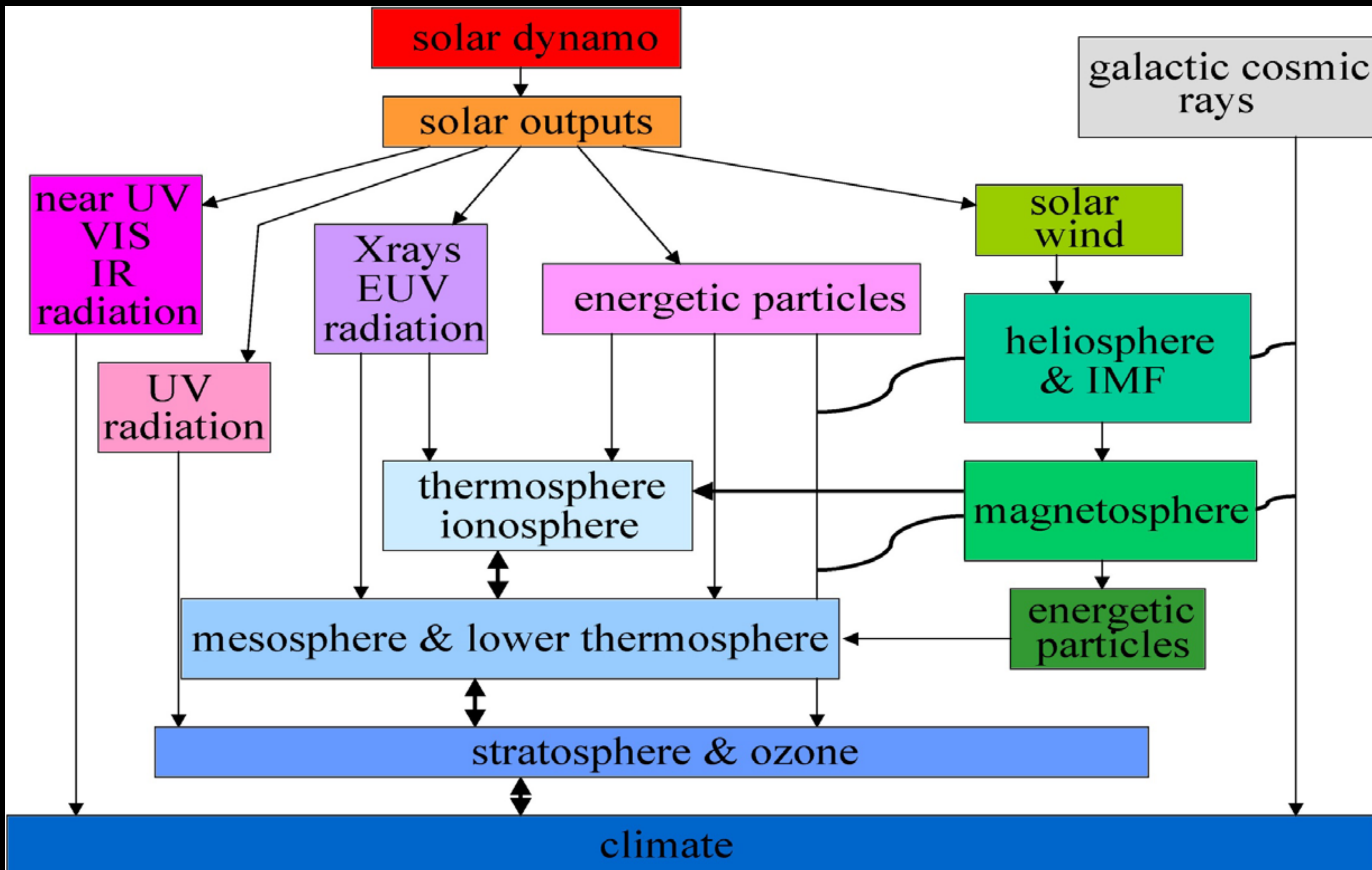
SWEF, June 4, 2013



Scientific Understanding, Observations, and Future Exploration
SUN
EARTH
convection zone
radiative zone
core
surface
atmosphere
sunspot
plage
coronal mass ejection
particles and
magnetic fields
photons
bow
shock
solar wind
heliosphere
surface
atmosphere
ionosphere
plasmasphere
magnetosphere
Steele Hill/NASA
not to scale

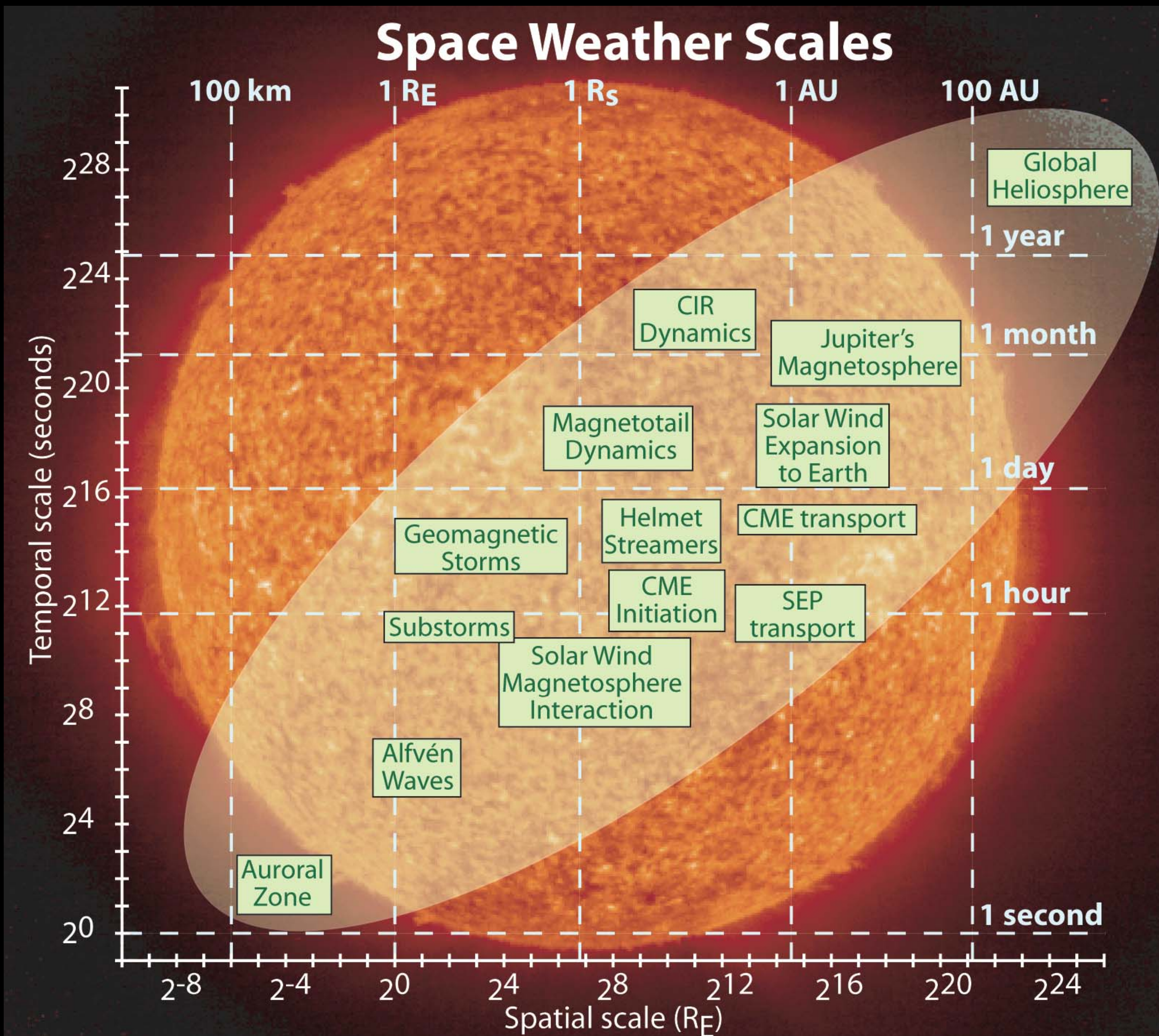
LWS is a Systems Approach

LWS focuses not on any one region of space, but rather on our Sun Earth Region as one system.



A very important part is the study of the connection between the regions and how one drives a response in another.

This is a complex system with many different temporal and spatial scales
System is Multi-Scale & 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

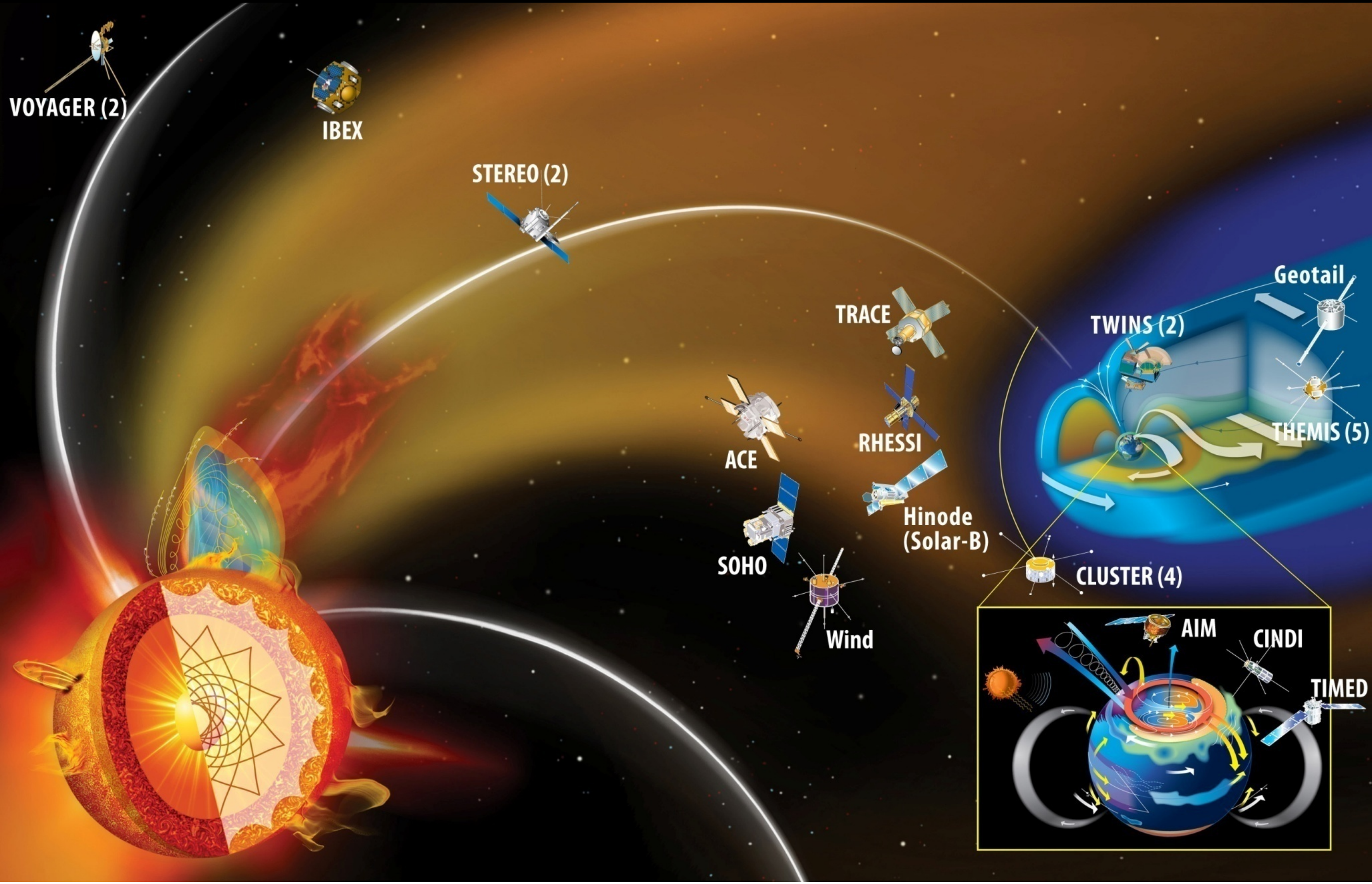
Multi-constituent plasmas and complex photochemistry

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

Heliophysics System Observatory for Heliophysics Research



Birth of Interplanetary Space Weather(How new is it?) February 6, 2011

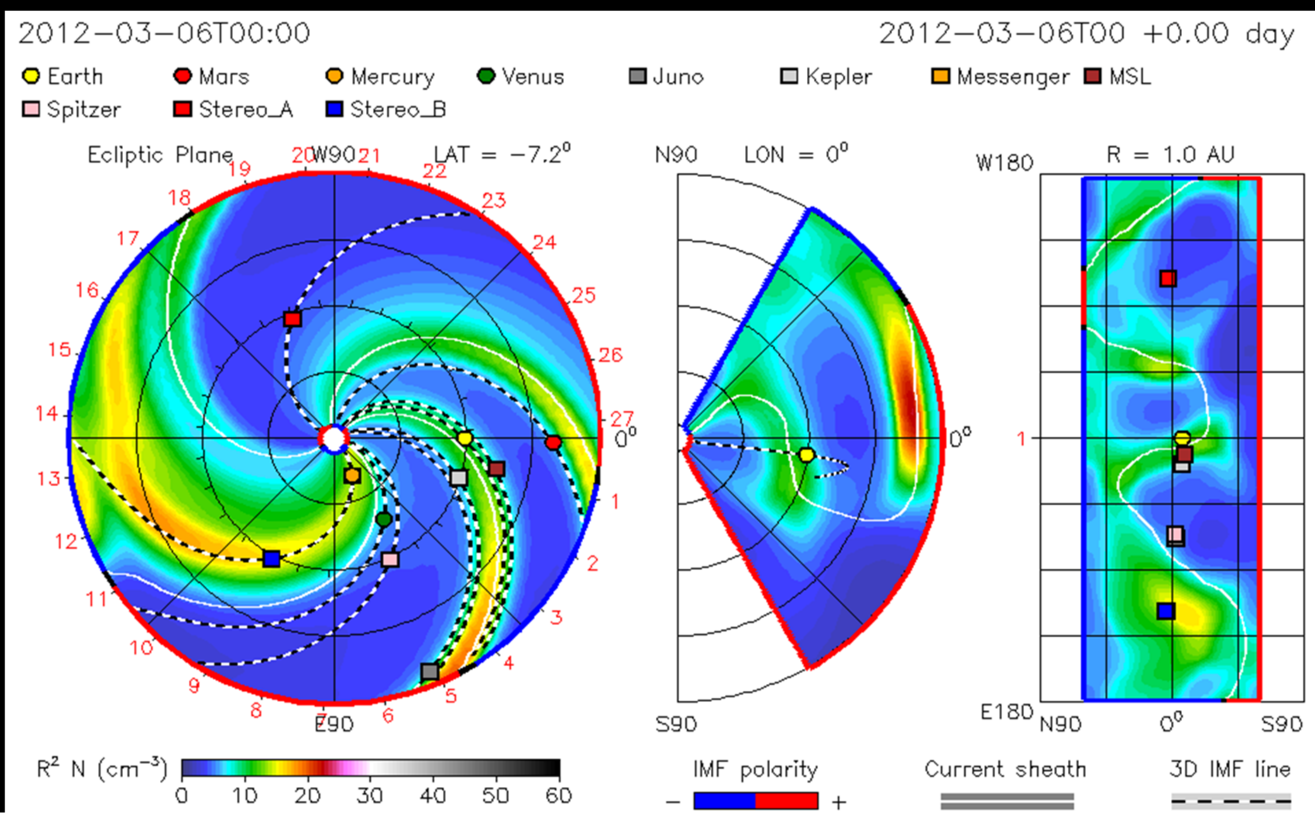
Until recently, forecasters could scarcely predict space weather in the limited vicinity of Earth. Interplanetary forecasting was even more challenging. This began to change in 2006 with the launch of the twin STEREO probes followed almost four years later by the Solar Dynamics Observatory. Together with SOHO, these spacecraft now surround the sun, monitoring active regions, flares, and coronal mass ejections around the full circumference of the star. No matter which way a solar storm travels, the STEREO-SDO-SOHO fleet can track it.

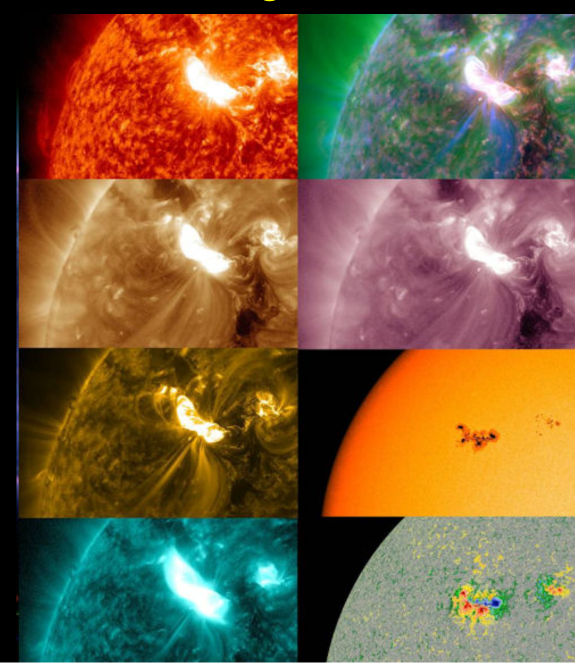
Interplanetary Space Weather & Climate: A New Paradigm

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.

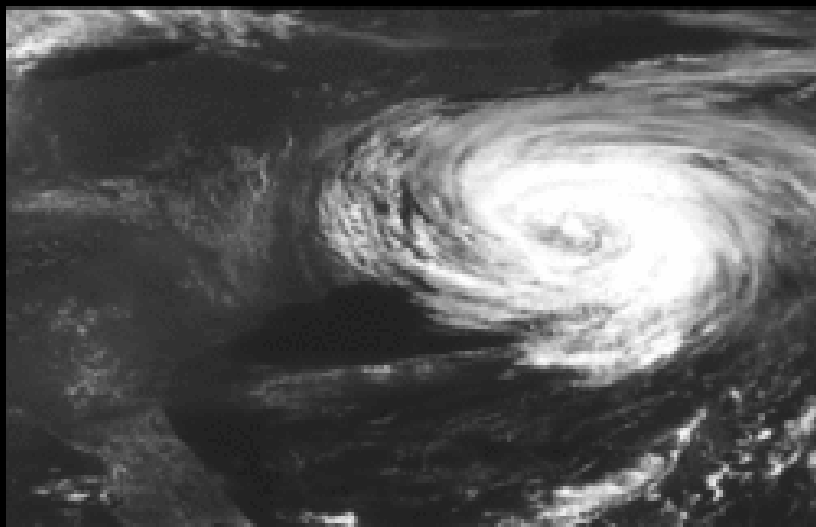
An intense episode of solar activity **in March 2012 drove this point home. It began on 2 March with the emergence of sunspot AR1429. For the next 2 weeks, this active region rotated across the solar disk and fired off more than 50 flares, 3 of which were X-class flares, the most powerful type of flare.** By the time the sunspot finally decayed in April 2012, 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.**

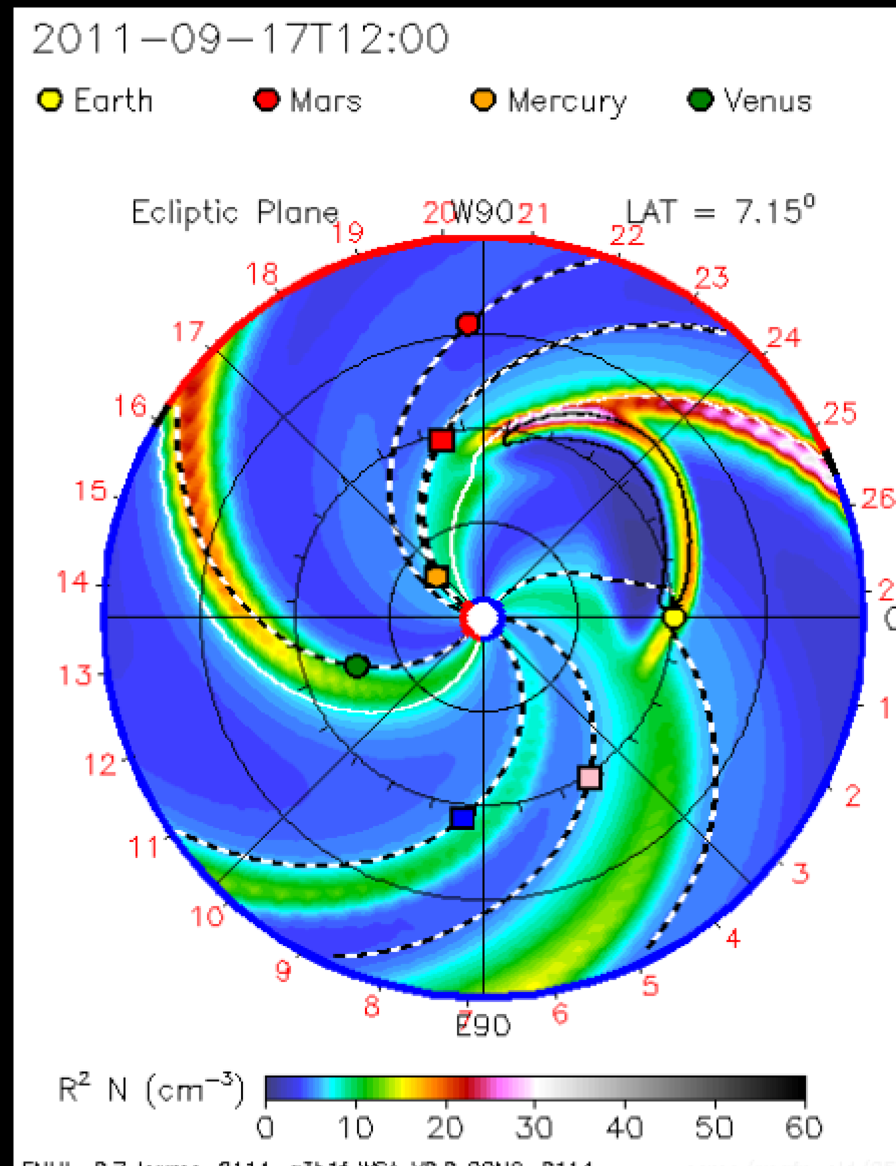
This highlights NASA's need for interplanetary space weather forecasting.





This development is akin to the first satellite images of hurricanes on Earth





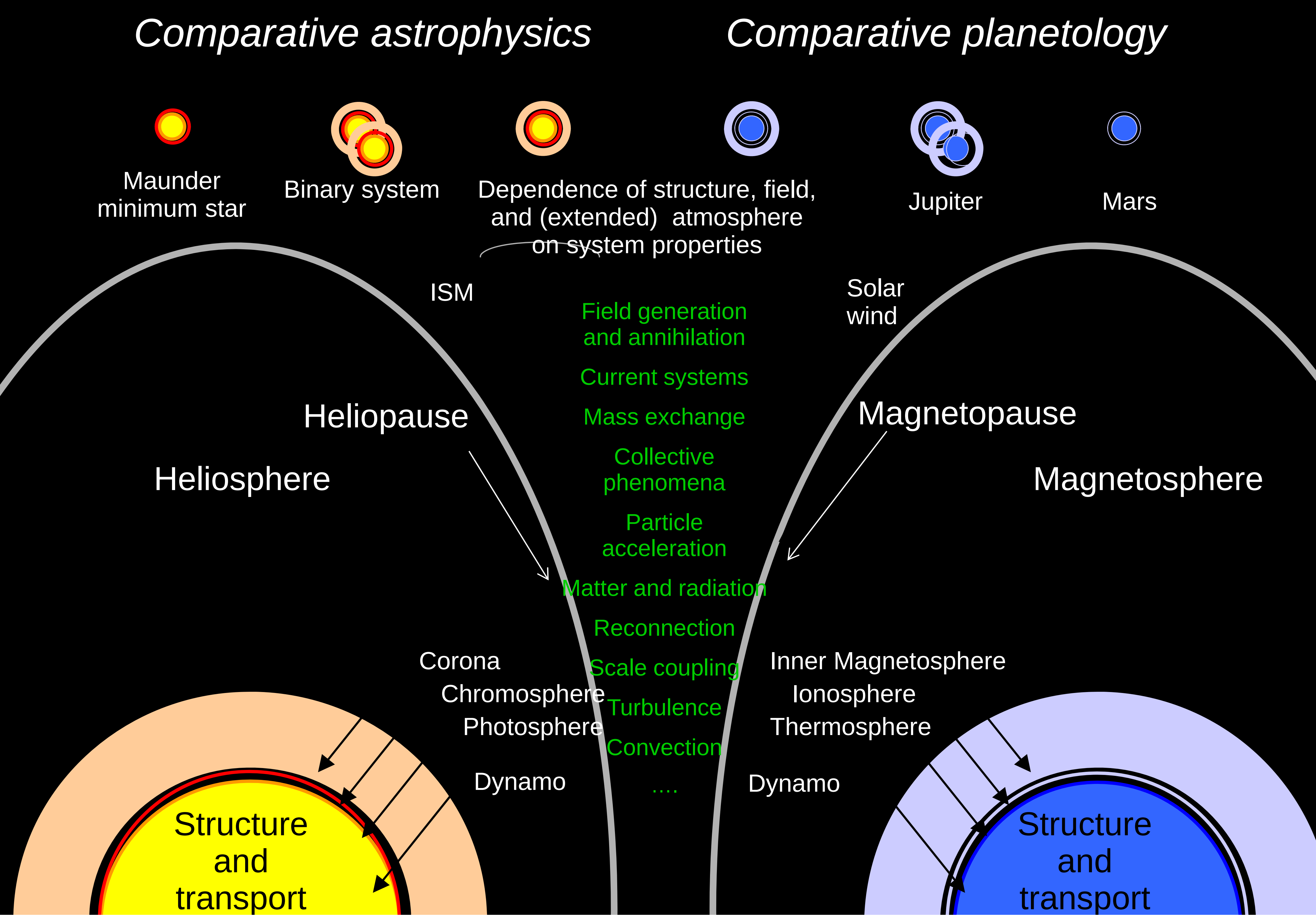
Reasons for developing this predictive capability may be divided into three pressing areas:

Human safety is of paramount concern. At the moment, humans are confined to low-Earth orbit where the planetary magnetic field and the body of Earth itself provide substantial protection against solar storms. Eventually, though, astronauts will travel to the Moon, Mars and beyond where natural shielding is considerably less.

Spacecraft operations are also key. Energetic particles accelerated by solar storms can cause onboard computers to reboot, introduce confusing noise in cameras and other digital sensors, or simply accumulate on the surface of a spacecraft until a discharge causes serious problems.

Scientific research could be the greatest beneficiary of interplanetary space weather forecasting. What happens to asteroids, comets, planetary rings and planets themselves when they are hit by solar storms? Finding out often requires looking at precisely the right moment.

Exploiting natural parallels: Helio, Astro, Planetary & Earth



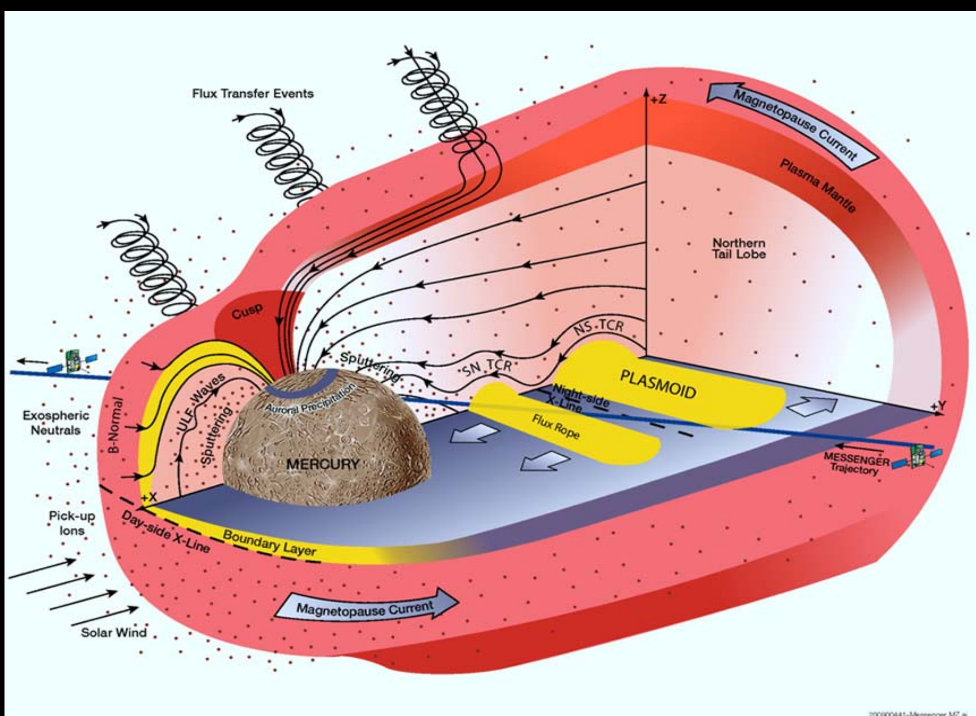
Space Weather on Mercury

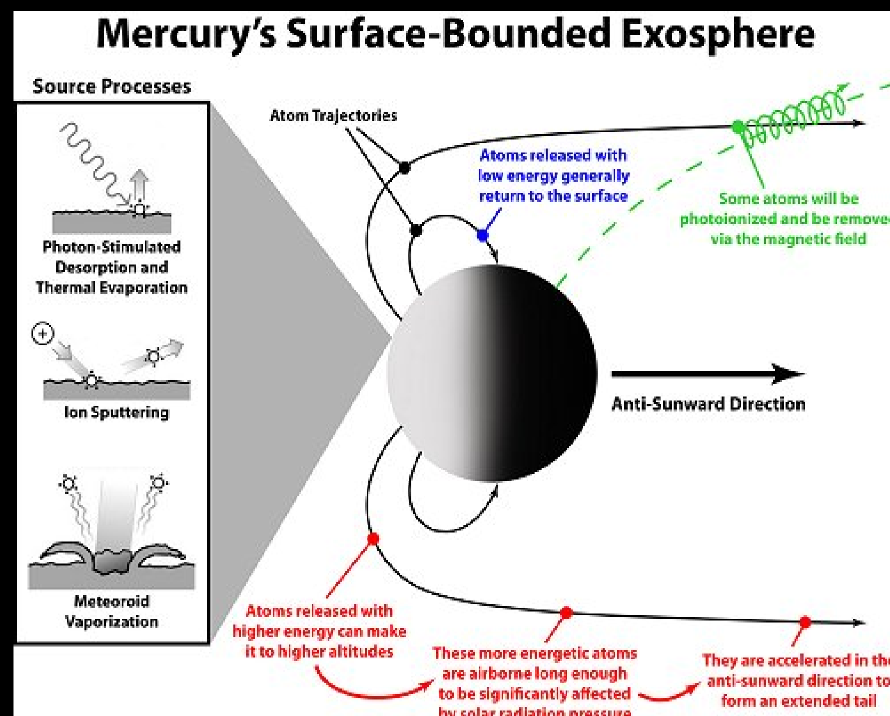
The most ferocious space weather in the solar system is felt on Mercury, the closest planet to the Sun. MESSENGER has observed a highly dynamic magnetosphere with magnetic reconnection events taking place at a rate 10 times greater than what is observed at Earth during its most active intervals.

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 during CME passages.

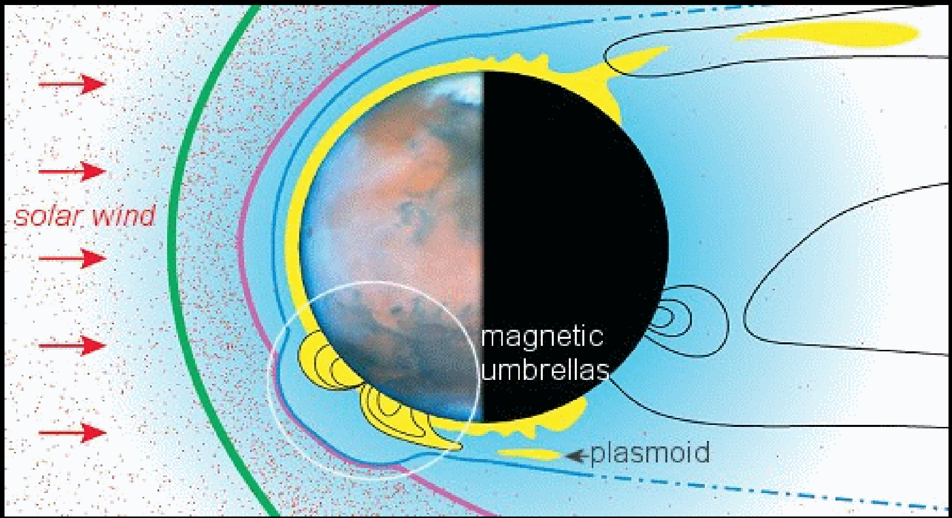




In Support of Mars Missions

In 1998, MGS discovered that Mars has a very strange magnetic field. Instead of a global bubble, like Earth's, the Martian field is in the form of magnetic umbrellas that sprout out of the ground and reach beyond the top of Mars' atmosphere. These umbrellas number in the dozens and they cover about 40% of the planet's surfce, mainly in the southern hemisphere.

When Mars gets hit by a CME, the resulting magnetic storms take place not at the planet's poles but rather in the umbrellas.



Timely interplanetary alerts would allow scientists to make specialized observations.

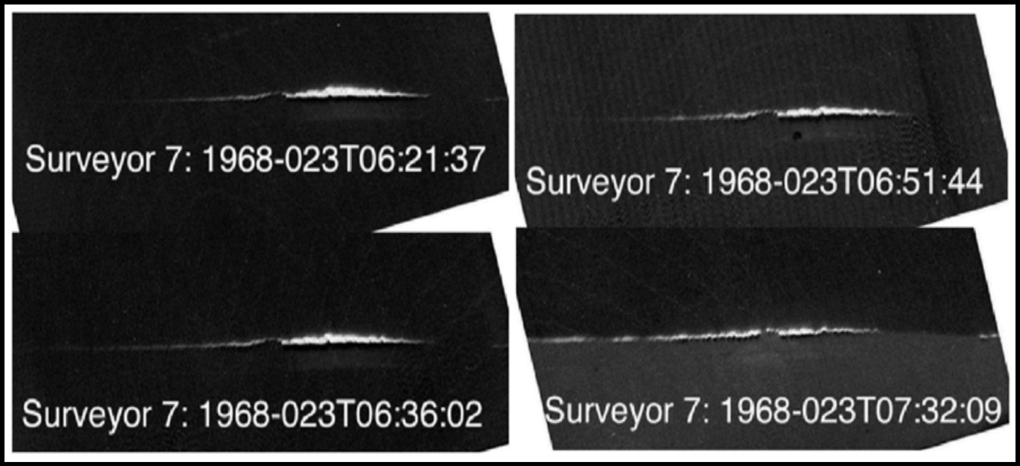
For example, orbiting sensors could make more frequent (higher time resolution) observations of escaping atmospheric particles, and monitor the density and temperature of the upper atmosphere during solar storms. **Spacecraft (MAVEN) or surface rovers (MSL) could look for Martian auroras during solar storm periods**.

MAVEN (Mars Atmosphere and Volatile Evolution) (launch in Nov. 2013)

One important focus of MAVEN is to determine how CMEs and solar energetic particles alter the upper atmosphere and escape rates. Space weather alerts would certainly advance the goals of this mission.

Lunar Space Weather (it's visible to the human eye)

In 1968, on many occasions, NASA's Surveyor 7 moon lander photographed a strange "horizon glow" after dark. Researchers now believe the glow is sunlight scattered from electrically-charged moondust floating just above the lunar surface.



What is going on?

Moondust becomes charged by point-blank exposure to the solar wind and irradiation by solar EUV. Like charges repel ==> charged moondust floats

In Support of Lunar Missions

NASA already has one mission (ARTEMIS) in orbit to measure the plasma environment of the Moon and another (LADEE, Lunar Atmosphere and Dust Environment Explorer) in the works to monitor the lunar exosphere. Both would benefit from accurate storm forecasting.

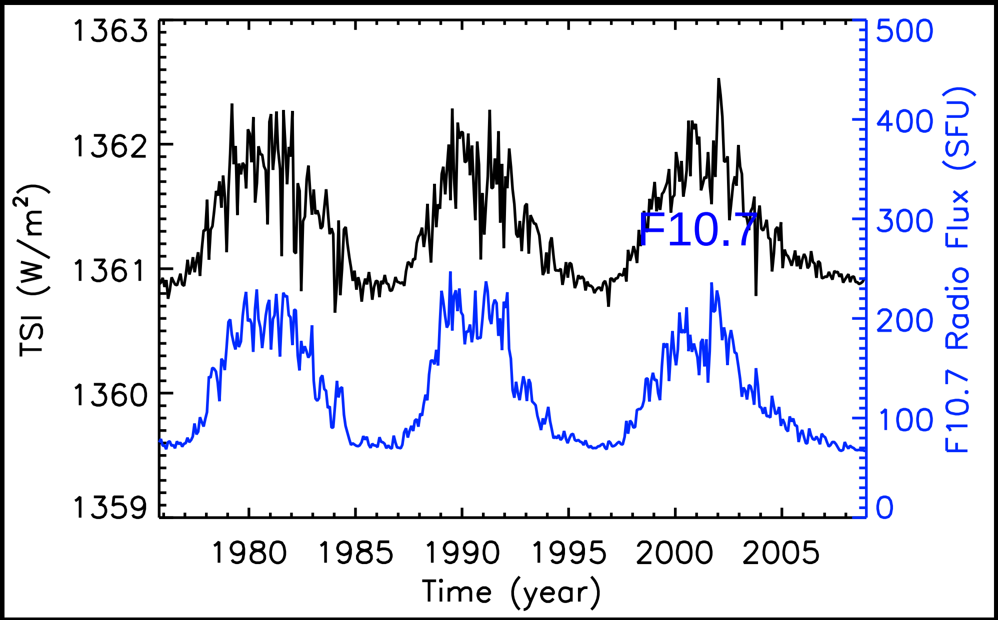
If scientists could be forewarned of a space weather event at the Moon, then they could better prepare their experiments to observe its impact. This could involve making sure that a space plasma observing mission (e.g., ARTEMIS) is set to 'burst mode' in order to collect the highest time resolution data it can when the CME reaches the Moon. Meanwhile, missions that have specific look directions, such as LADEE, could adjust their viewing geometry to make sure they're looking where something interesting is expected to happen.

Sun Climate Connection

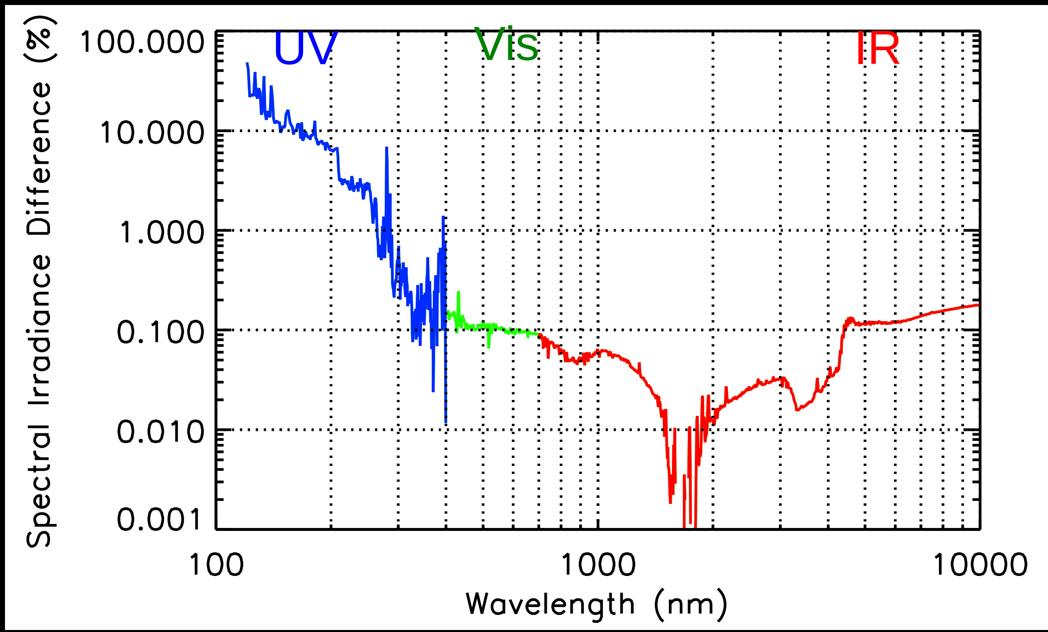
As the scope of space weather forecasting expands to other planets, it is also expanding in directions traditionally connected to climate research. Climate refers to changes in planetary atmospheres and surfaces that unfold much more slowly than individual storms. There is no question that solar activity is pertinent to climate time scales.

The radiative output of the Sun, the size and polarity of the Sun's magnetic field, the number of sunspots, and the shielding power of the Sun's magnetosphere against cosmic rays all change over decades, centuries, and millennia.

Total Solar Irradiance (TSI)

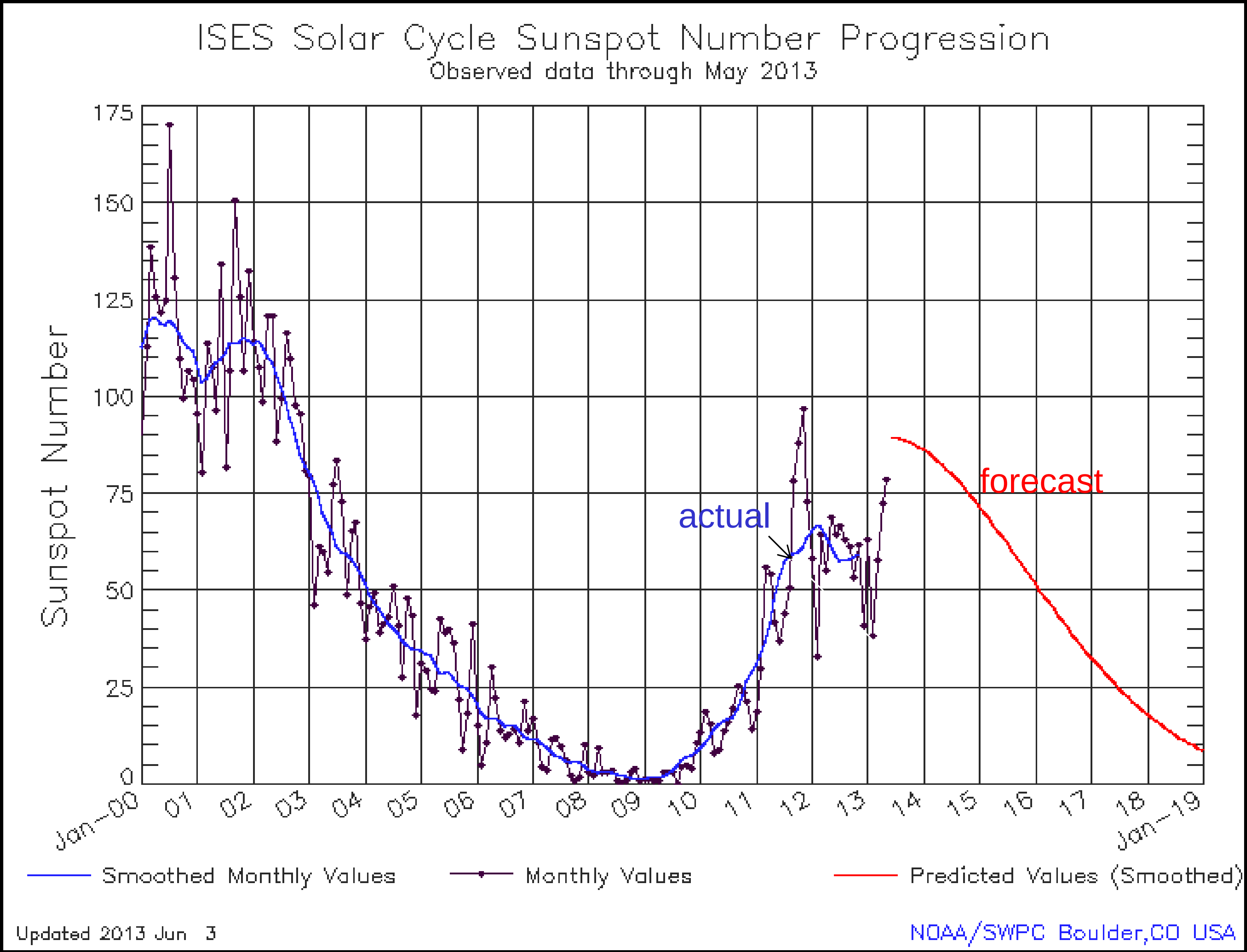


Spectral Solar Irradiance (SSI): SMax vs. SMin



Small variations in the visible (0.1%), but big changes in the UV.

Just When You Thought it was Safe to Predict the Solar Cycle….



If we might be entering into a period of extended low activity, does this mean that we may not have to worry about the sun?

ABSOLUTELY NOT

Heliophysics just got interesting

As the solar cycle unfolds in an unexpected way, it is important to remember that

The Sun is never boring

To see this, we simply turn the solar cycle sideways

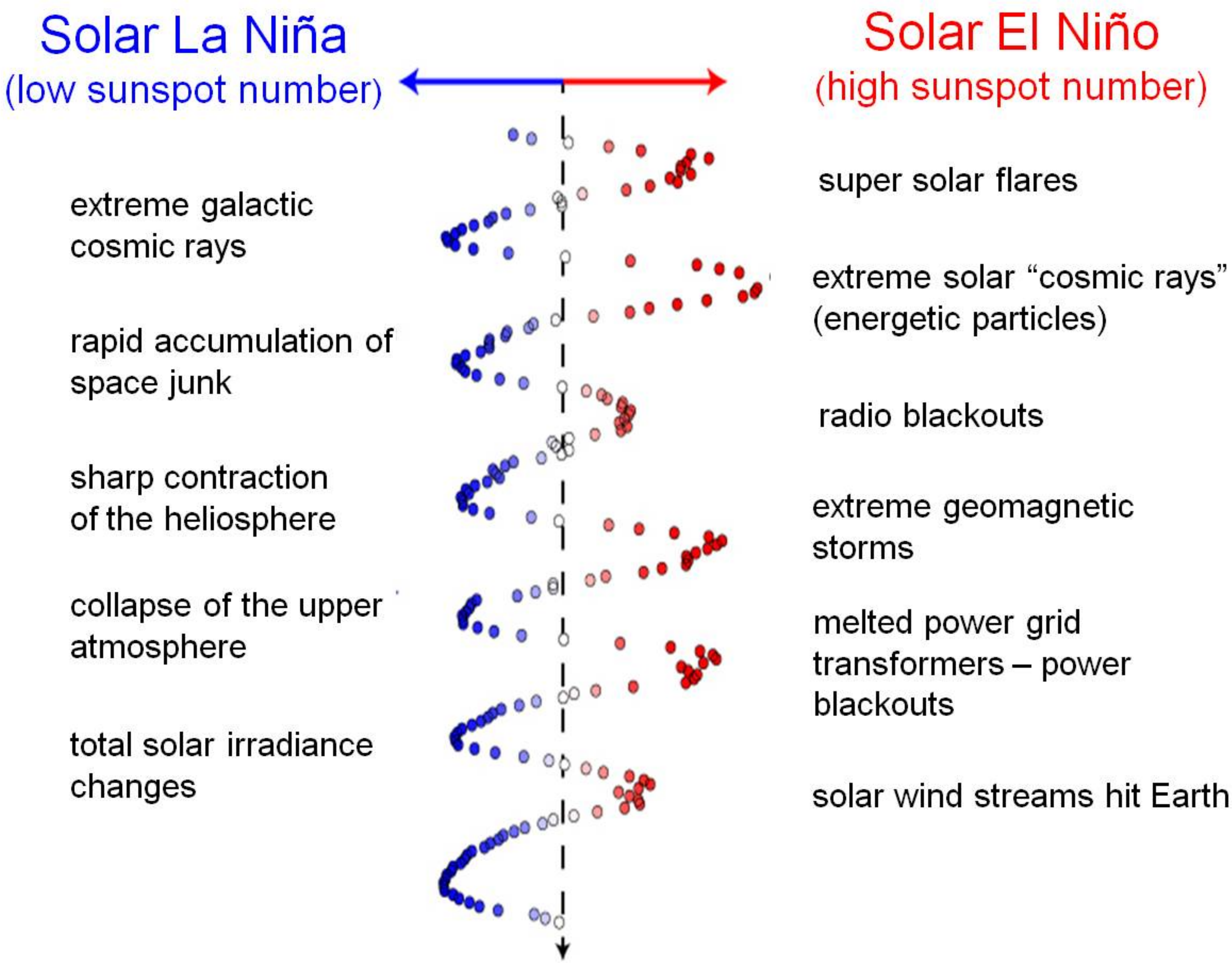
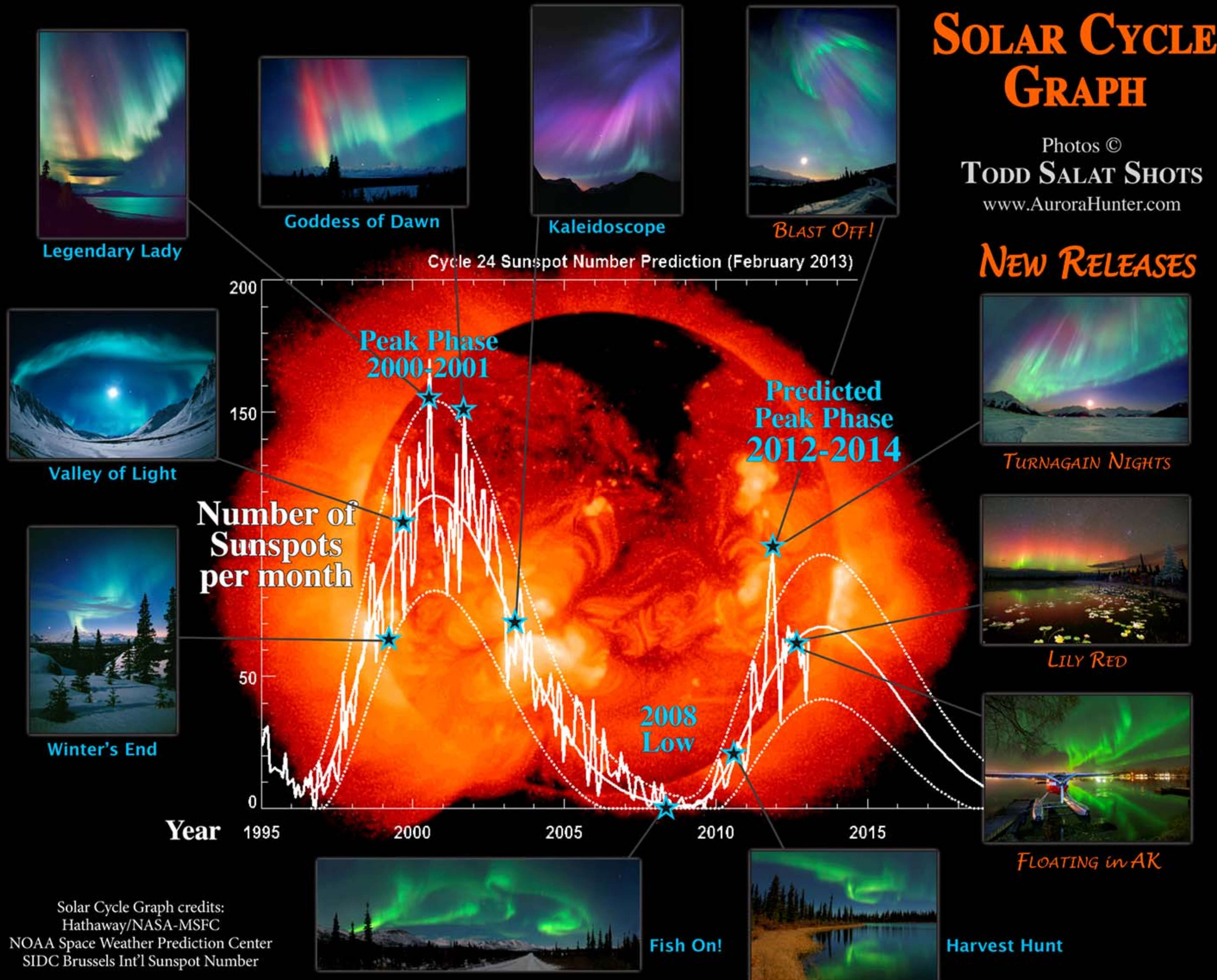


Illustration shows smoothed monthly sunspot counts from the past six solar cycles plotted horizontally instead of vertically. High sunspot numbers are in red and on the right, low sunspot numbers are in blue and on the left. Associated with each high and low sunspot numbers are different space weather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

"Space Weather Impacts: They Happen All the Time"



The END

Future Vision

Think of a virtual interdisciplinary consortium of experts scattered across many universities and agencies.

If a probe is sent to Titan, other experts would come to the fore---e.g., a planetary scientist at Brown University who predicts tropospheric weather on Titan; a CME modeler at Goddard/CCMC who predicts the onset of geomagnetic storms at Saturn; an EUV expert at the University of Colorado who estimates the solar ultraviolet flux impinging on the giant satellite. An approaching Titan probe could get a genuine weather forecast for its target body. Whether the forecast is for Earth or Titan or some other body, what is needed is an interdisciplinary consortium.