Comparative Heliophysics:
Initiation of Interplanetary Space Weather

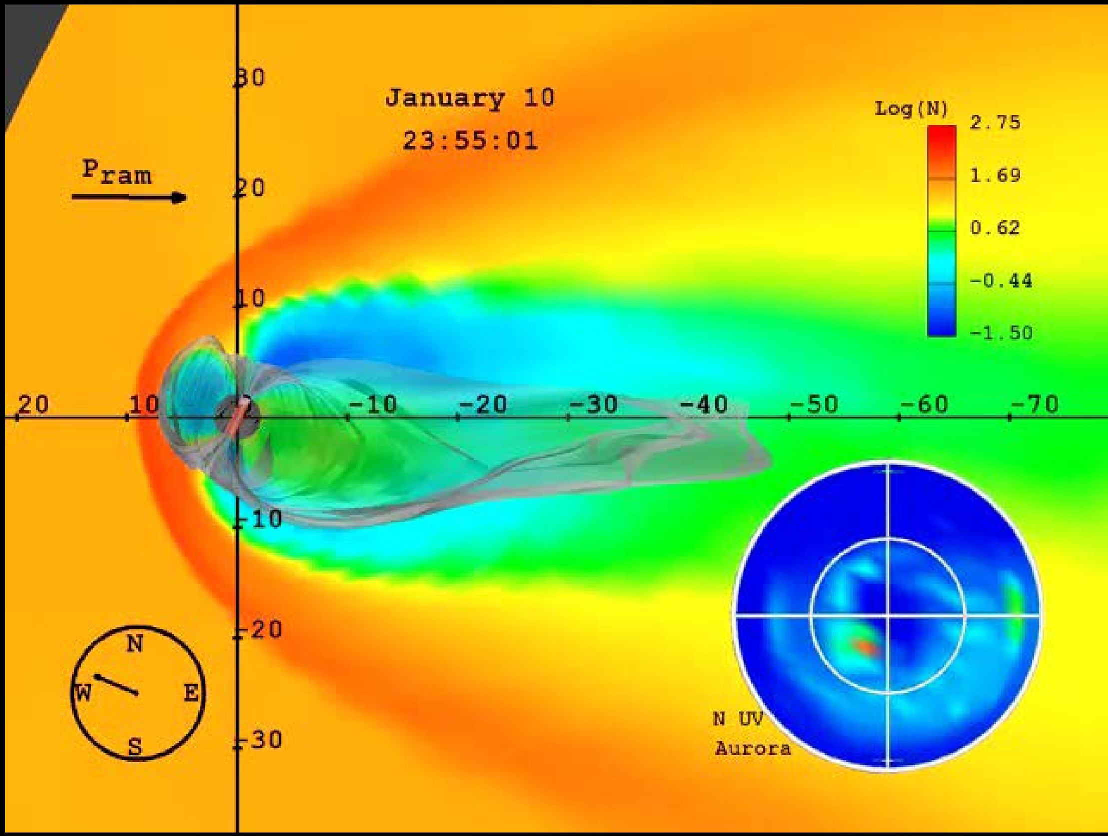
HUMANS & THEIR ROBOTS ARE MOVING INTO THE SOLAR SYSTEM.
THE REALM OF SPACE WEATHER FORECASTING
IS RAPIDLY EXPANDING.

Madhulika (Lika) Guhathakurta
NASA HQ
July 28th, 2016

"Space weather" refers to magnetic disturbances and high radiation levels that result from solar activity. Auroras, power outages and radio blackouts are some of the manifestations we experience on Earth.

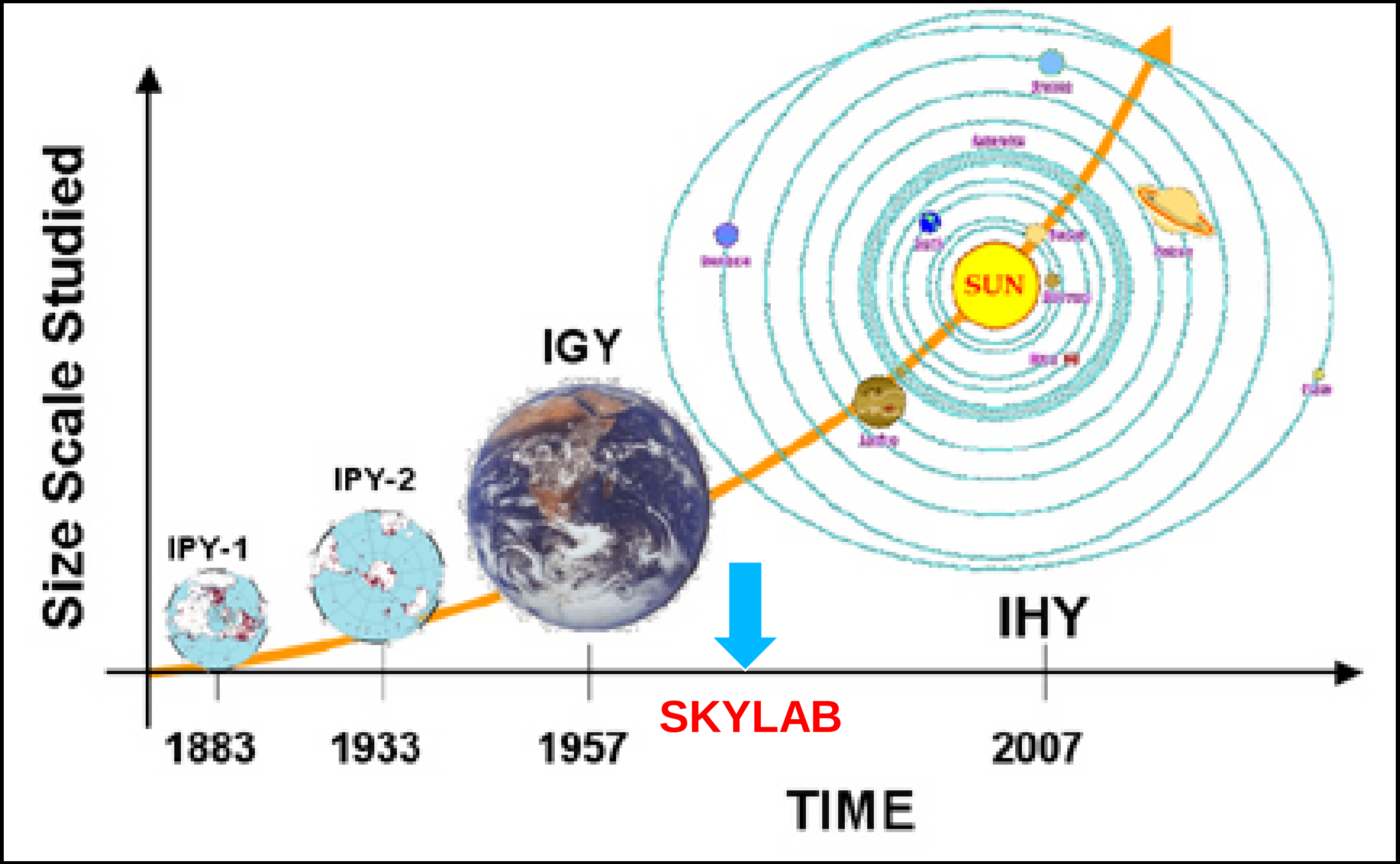
Anyone who has ever seen a picture of Earth taken from deep space can be forgiven for thinking of these two words: "splendid isolation." Surrounded by millions of miles of uninterrupted black, the fragile blue globe seems profoundly alone, disconnected from anything else.

Space Weather's Terrestrial Influence
(an example)



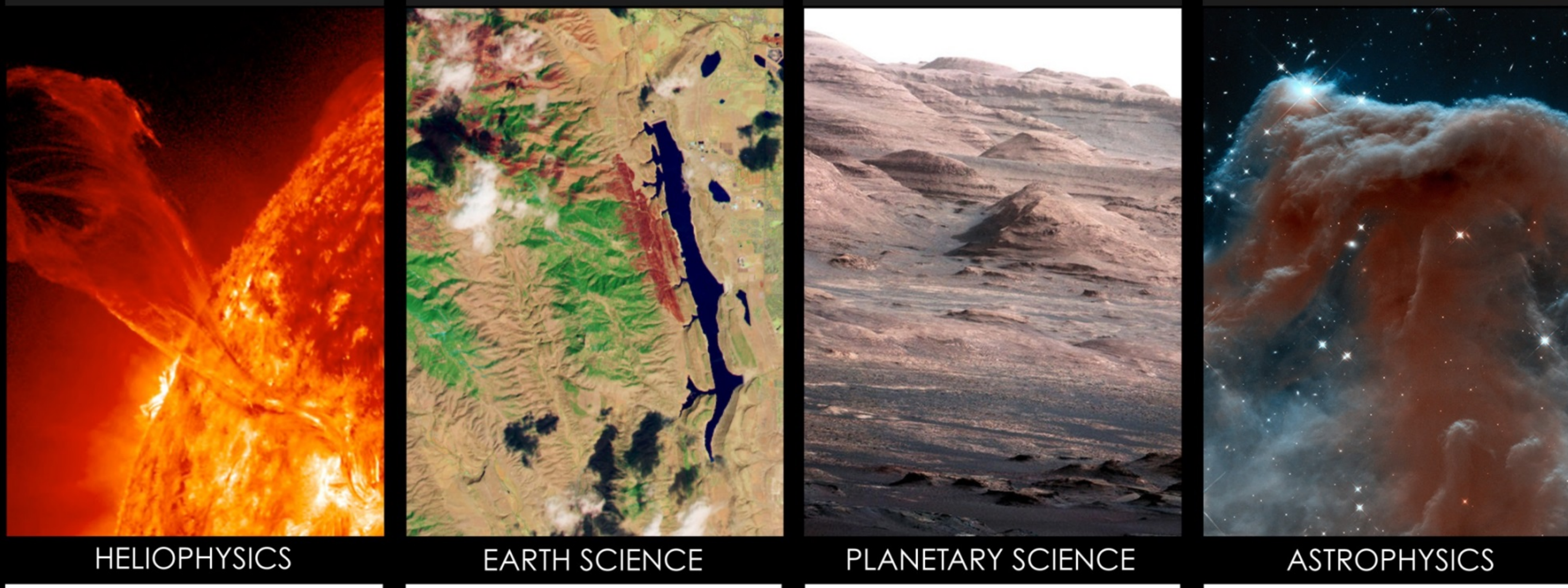
Nothing could be further from the truth: Earth is profoundly connected to our star. The bright blue disk is just the most obvious evidence.

Evolution of System Studies



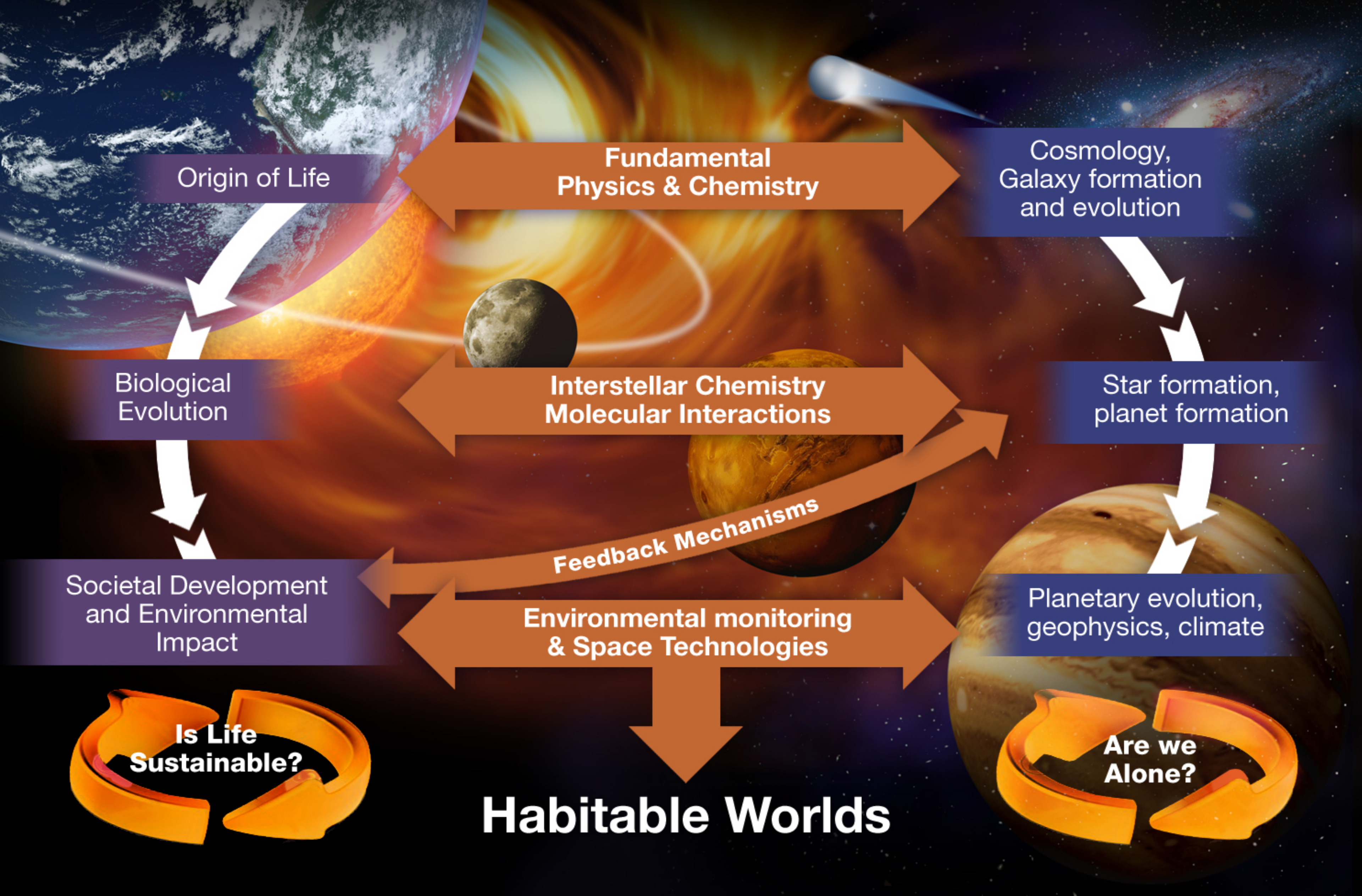
Heliophysical: A broadening of the concept "geophysical," extending the connections from the Earth to the Sun & interplanetary space.

Science Mission Directorate



An Integrated Program of Science

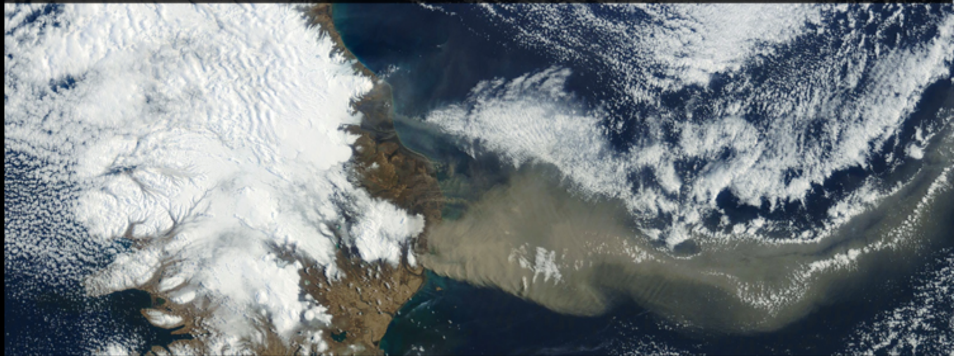
NASA Science is Interconnected



Astrophysics

Answer the question:
“Are we alone?”

Earth Science

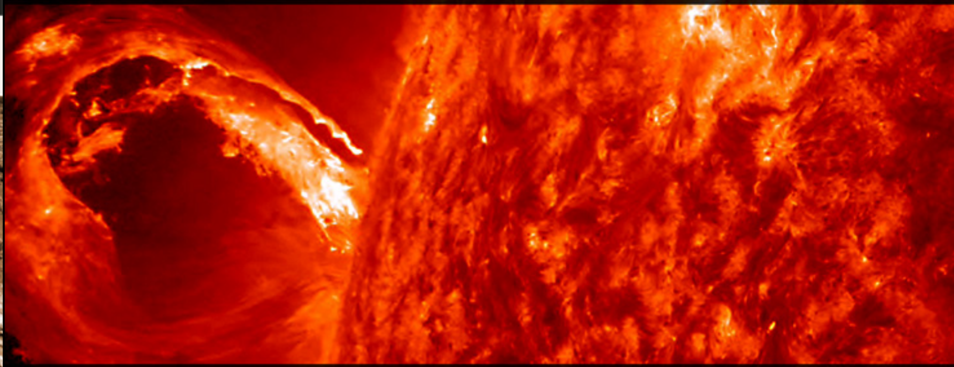


Enable more accurate and useful environmental predictions, including weather, climate, natural and human induced events

Planetary Science

Explore habitable environments across the solar system with human and robotic explorers

Heliophysics



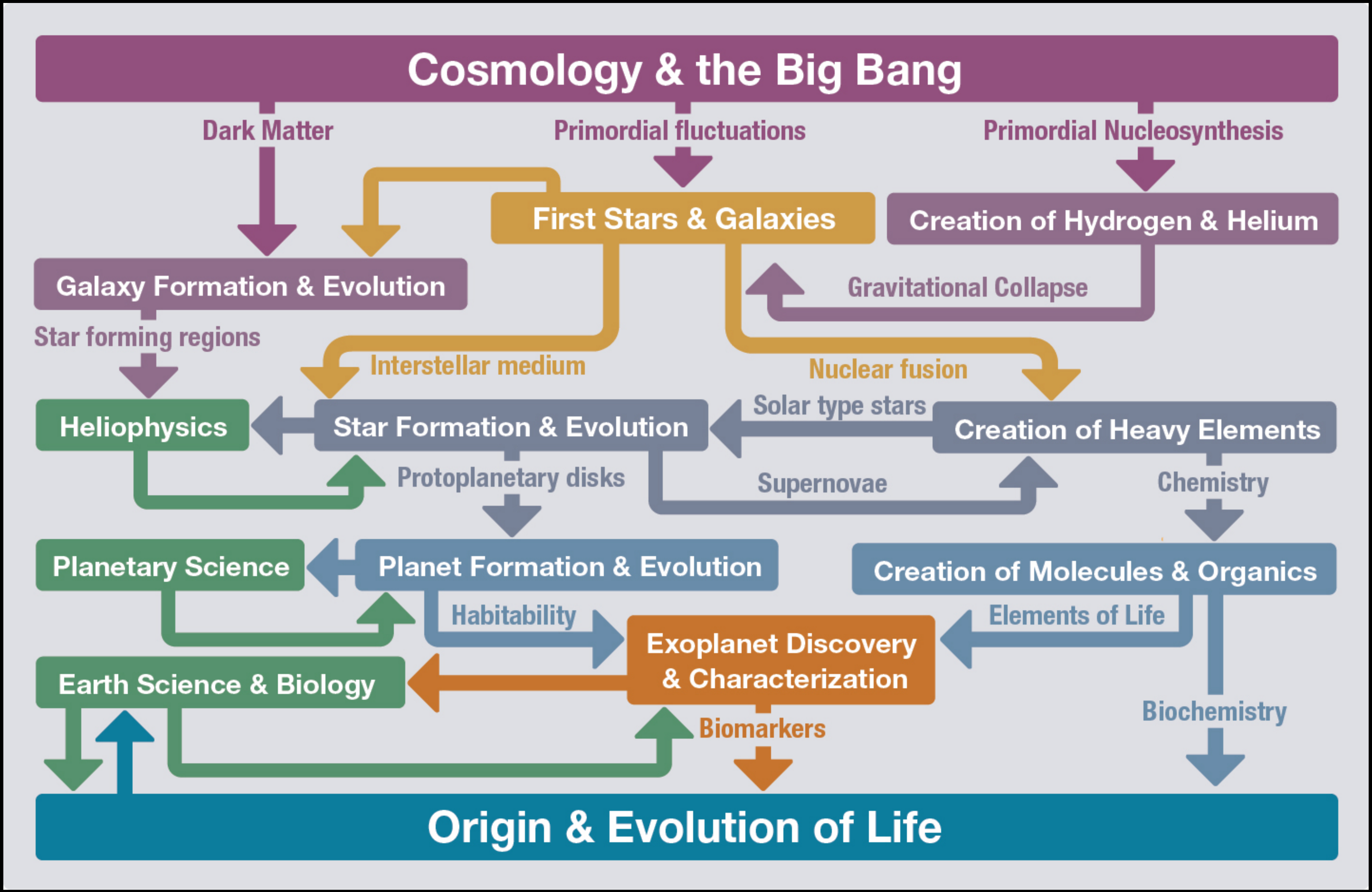
Make possible accurate predictions of solar phenomena throughout the solar system and its impact on earth, planets and interplanetary medium

Science @ NASA executes over:

- 97 missions
- 122 spacecraft
- 9 Balloon launches
- 21 Sounding rockets
- 3,300+ Airborne hours

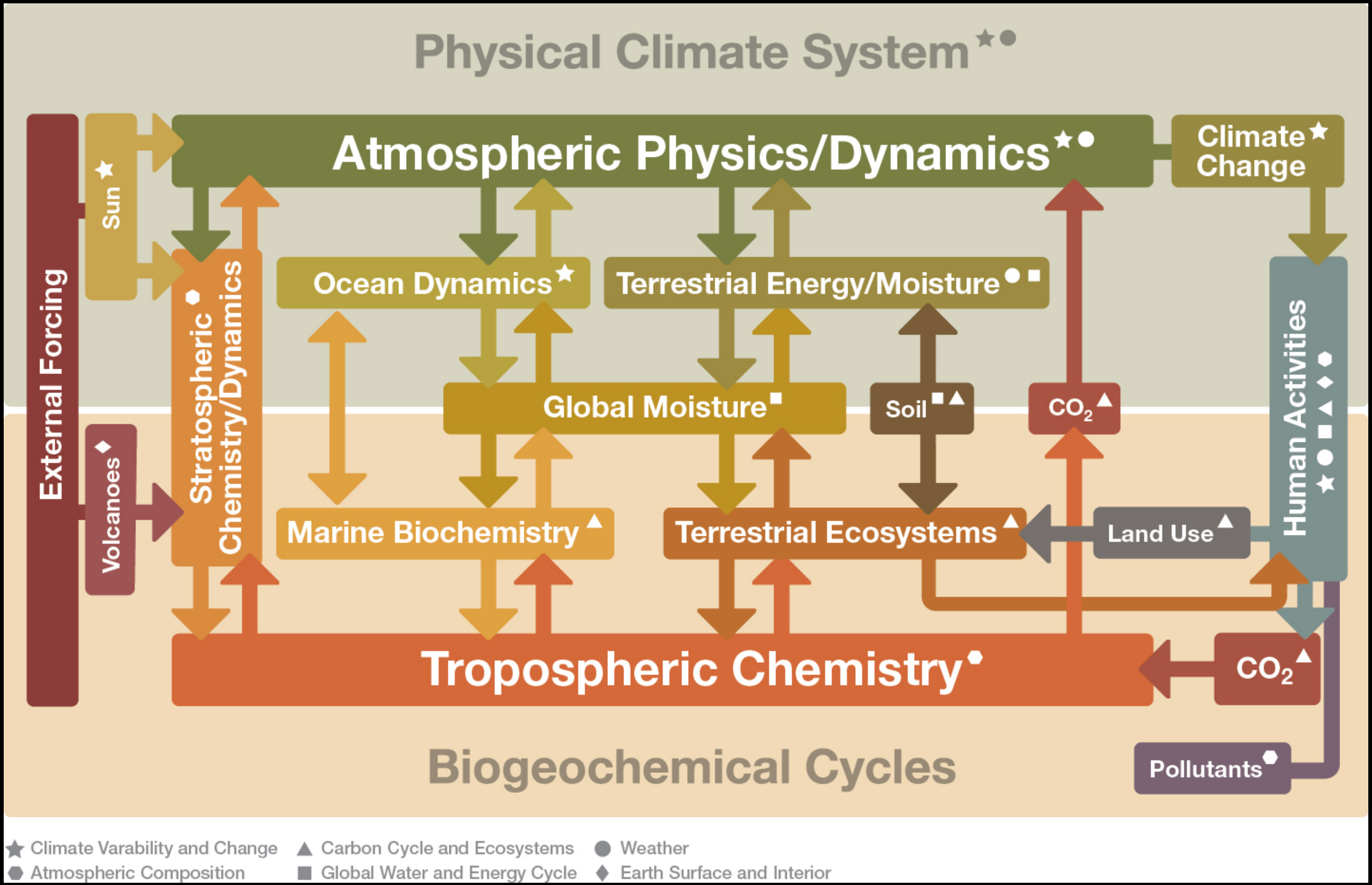
Understanding the Universe

Understanding The Astrophysics



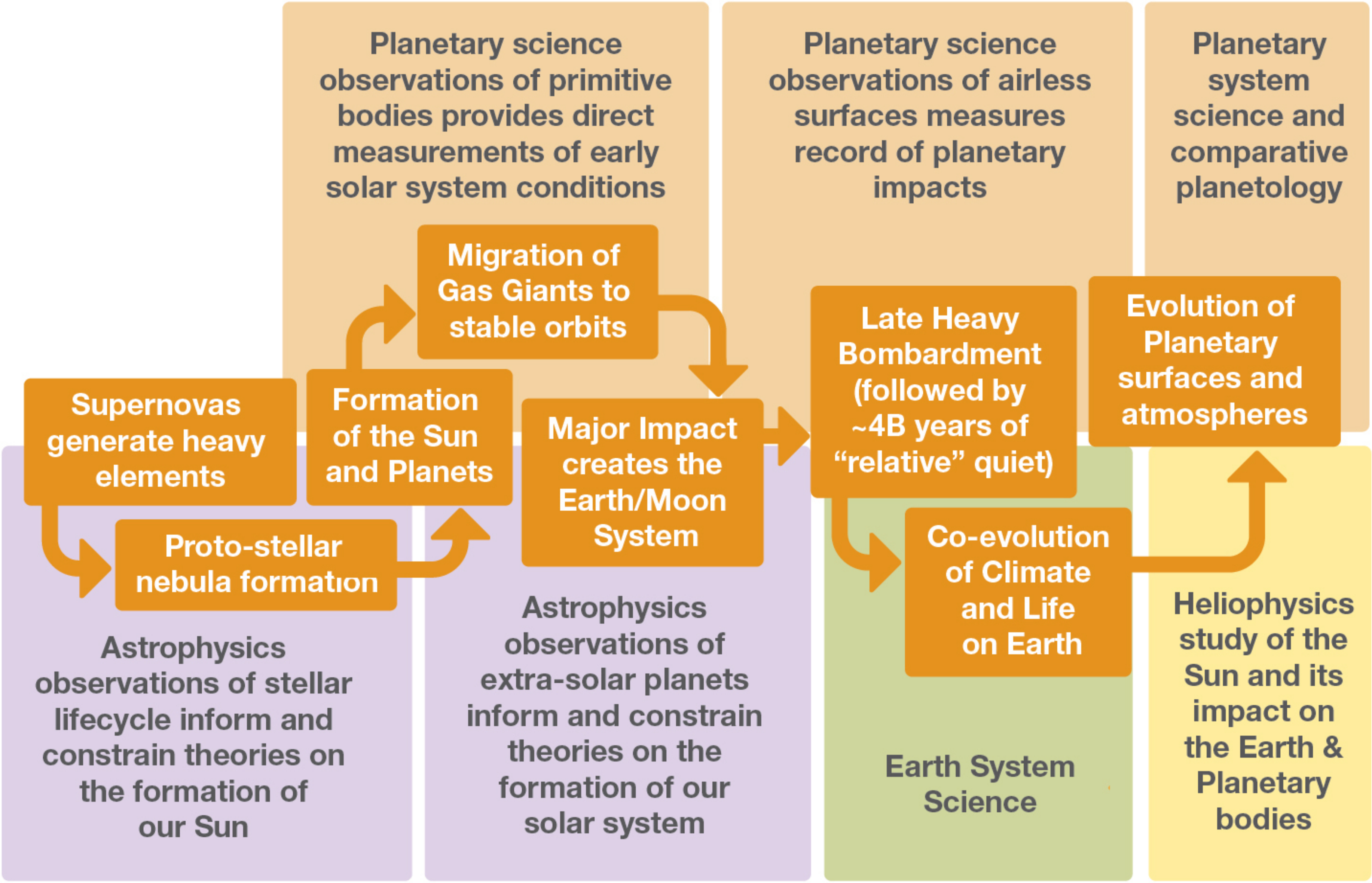
Understanding the Earth as a System

Understanding the Earth System

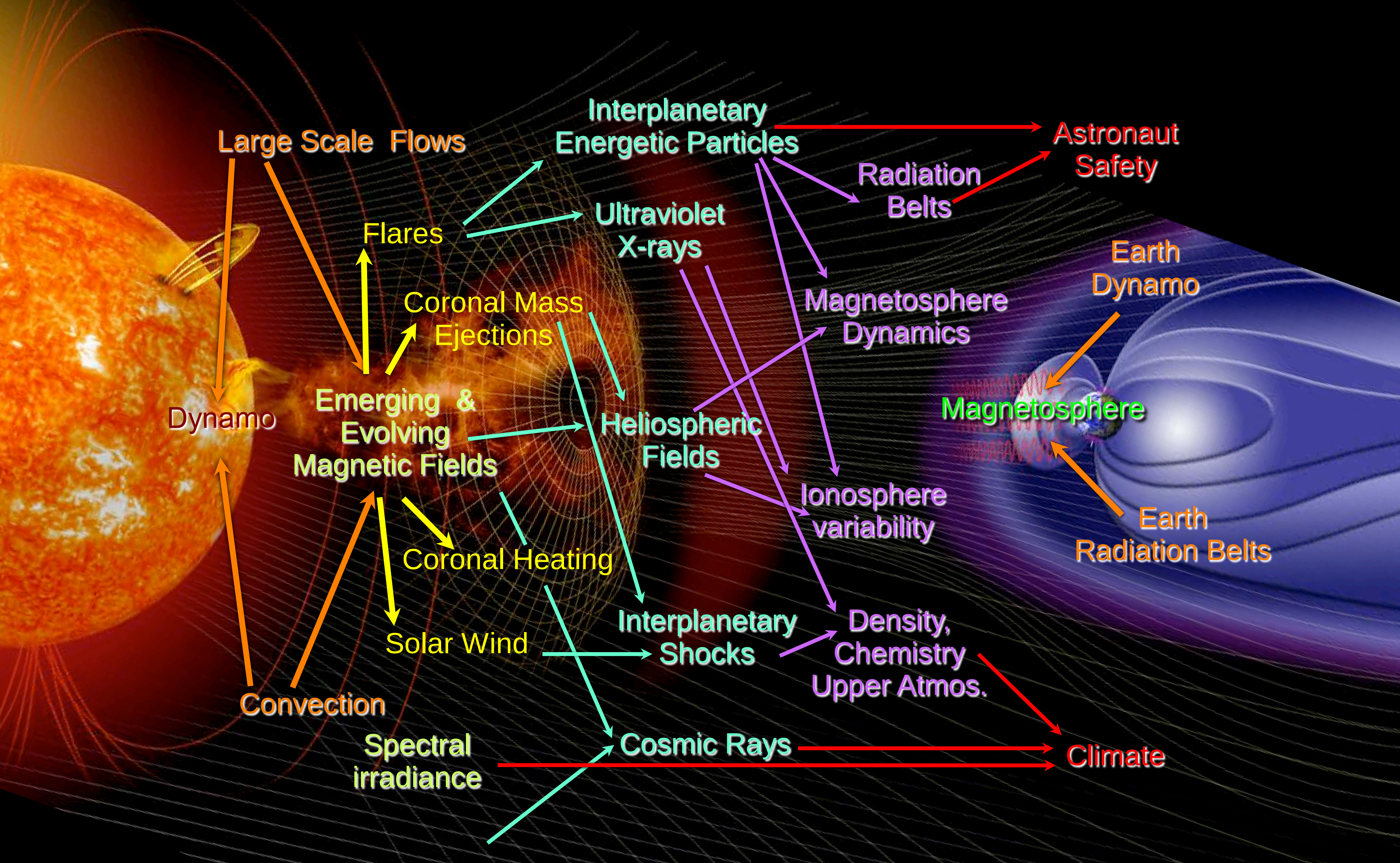


Understanding our Solar System

Understanding the Planetary System

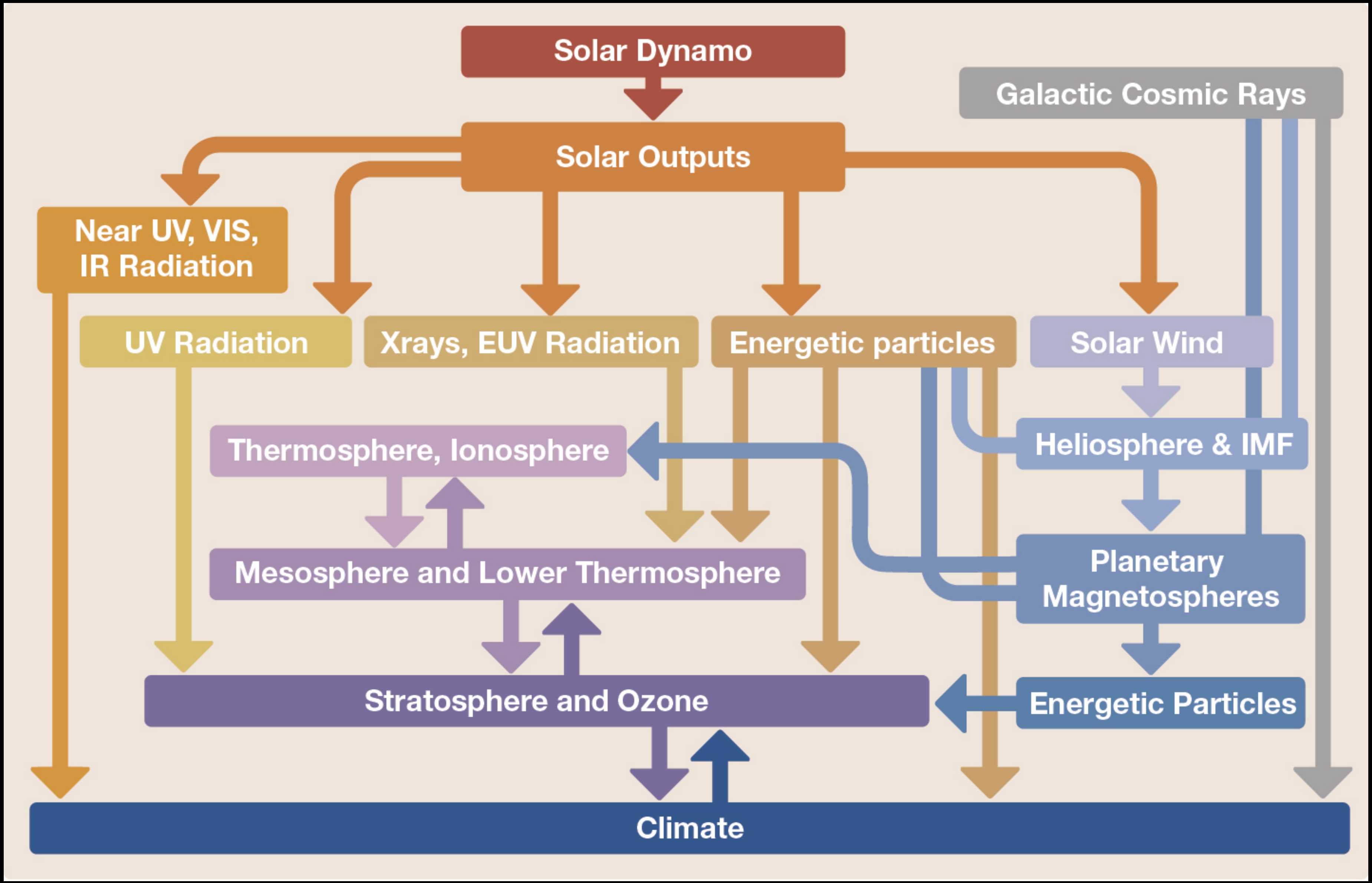


Sun-Earth connections: a complex system of coupled processes and phenomena



artist's impression

Understanding the Sun's System



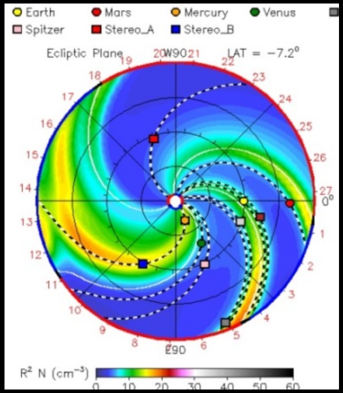
What is Heliophysics

Heliophysics is an environmental science:

a unique hybrid between meteorology and astrophysics

It has an applied branch

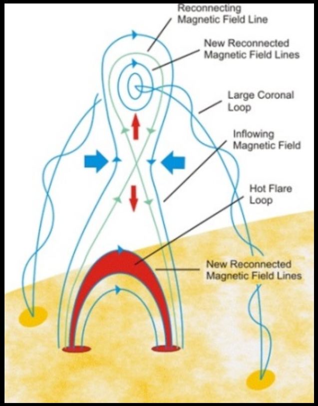
space weather



Propagation models of solar disturbances out to 2 AU

And a pure branch

fundamental physical process



Magnetic reconnection

In the US National Space Weather Program 1995 — Applications directed science coordinated by NSF community

Living With a Star 2000, ILWS 2003 — Applications directed science coordinated by NASA & international community

International Heliosphysical Year 2007 — Add comparative heliospheric studies

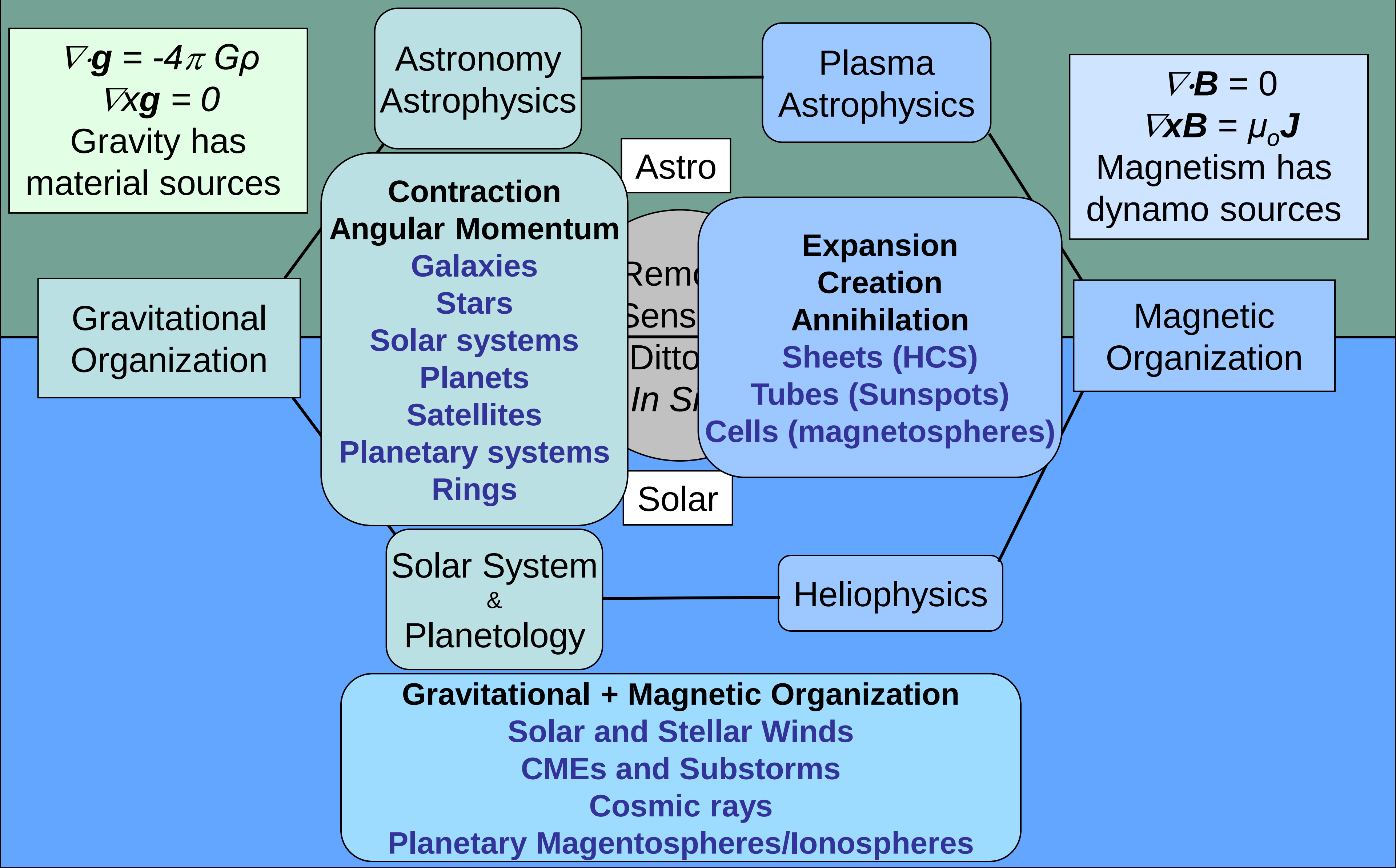
Heliophysics as a Scientific Discipline

NASA's Earliest scientific successes Explorer 1 in 1958 Radiation Belts) and Mariner 3 in 1963 (Solar Wind), and SkyLab (1973 discovered previously undetected processes and conditions, that directly modulate the Earth. These efforts set the stage for the discovery of the connected system of systems in the solar system that comprise the focus of heliophysics research (past).

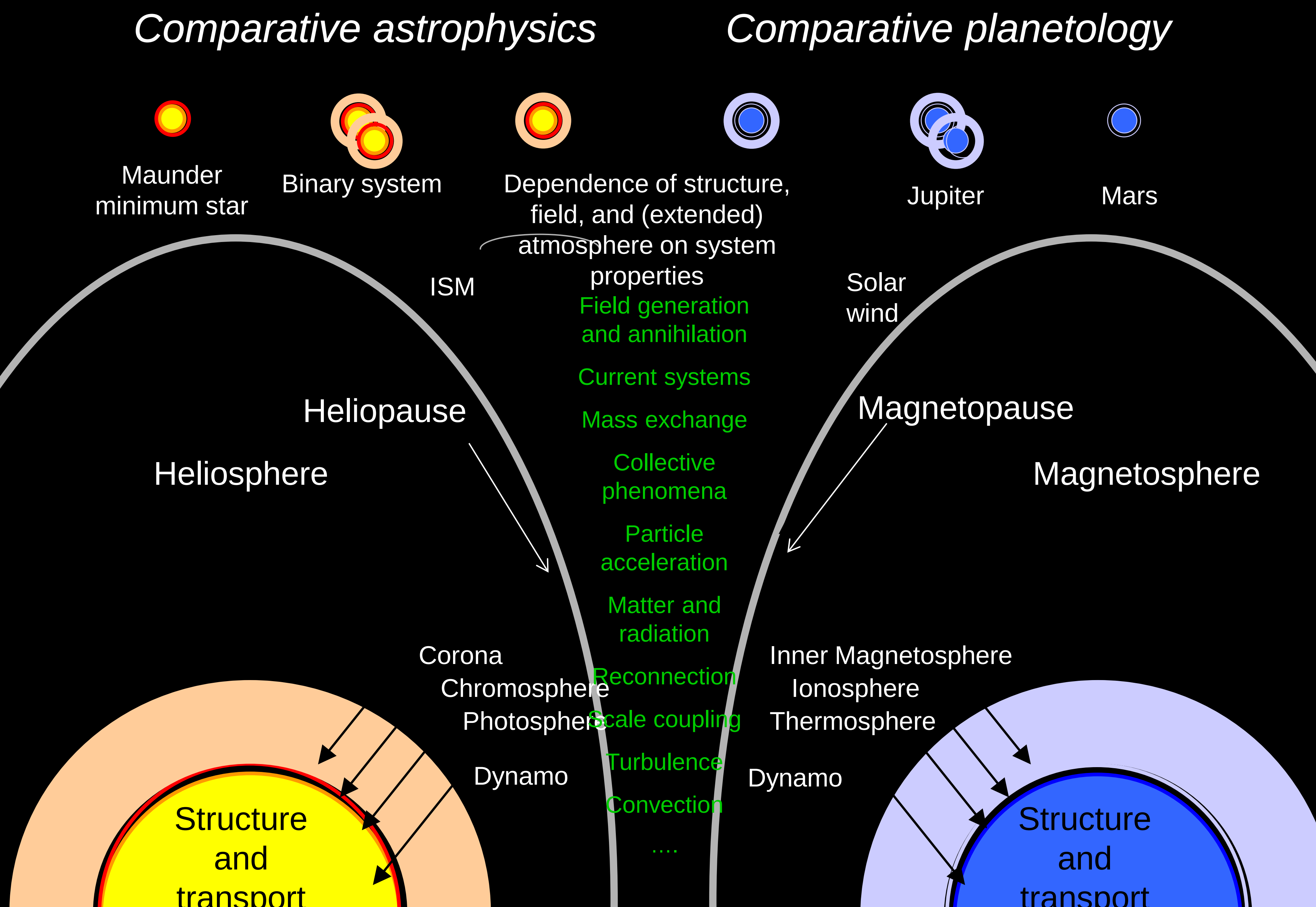
The system of systems is driven by the interaction of three forces, pressure, gravity and magnetism; for which the universal physical processes governing order and disorder have not yet been fully uncovered.

The results of research to date have yielded not only new cultural and intellectual knowledge, but have provided benefits with utility, both, political and economic, to the nation and the world.

Organization of the Universe by Long-Range Forces

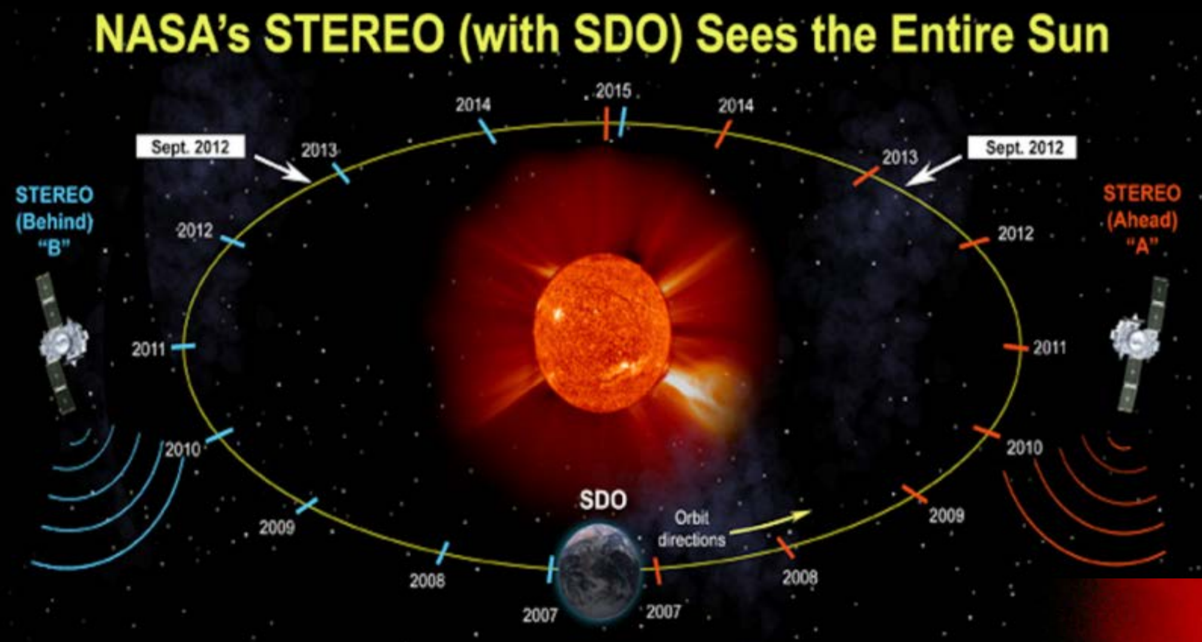


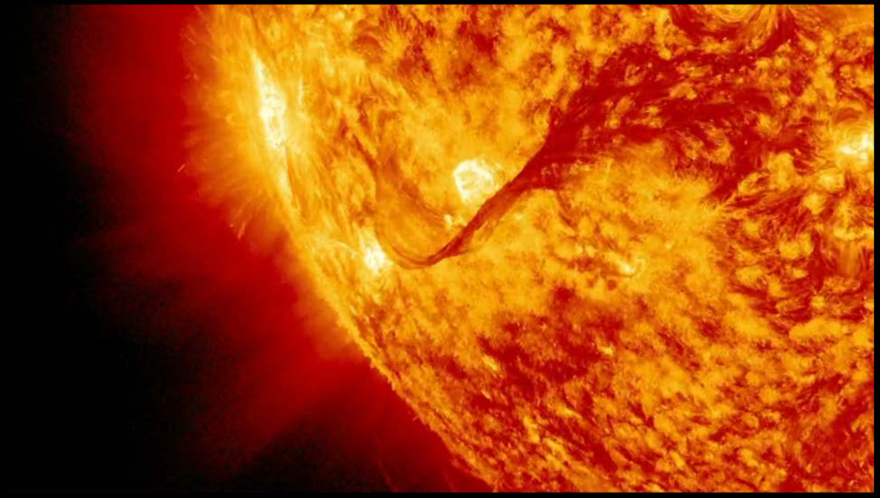
Exploiting natural parallels: Helio, Astro, Planetary & Earth



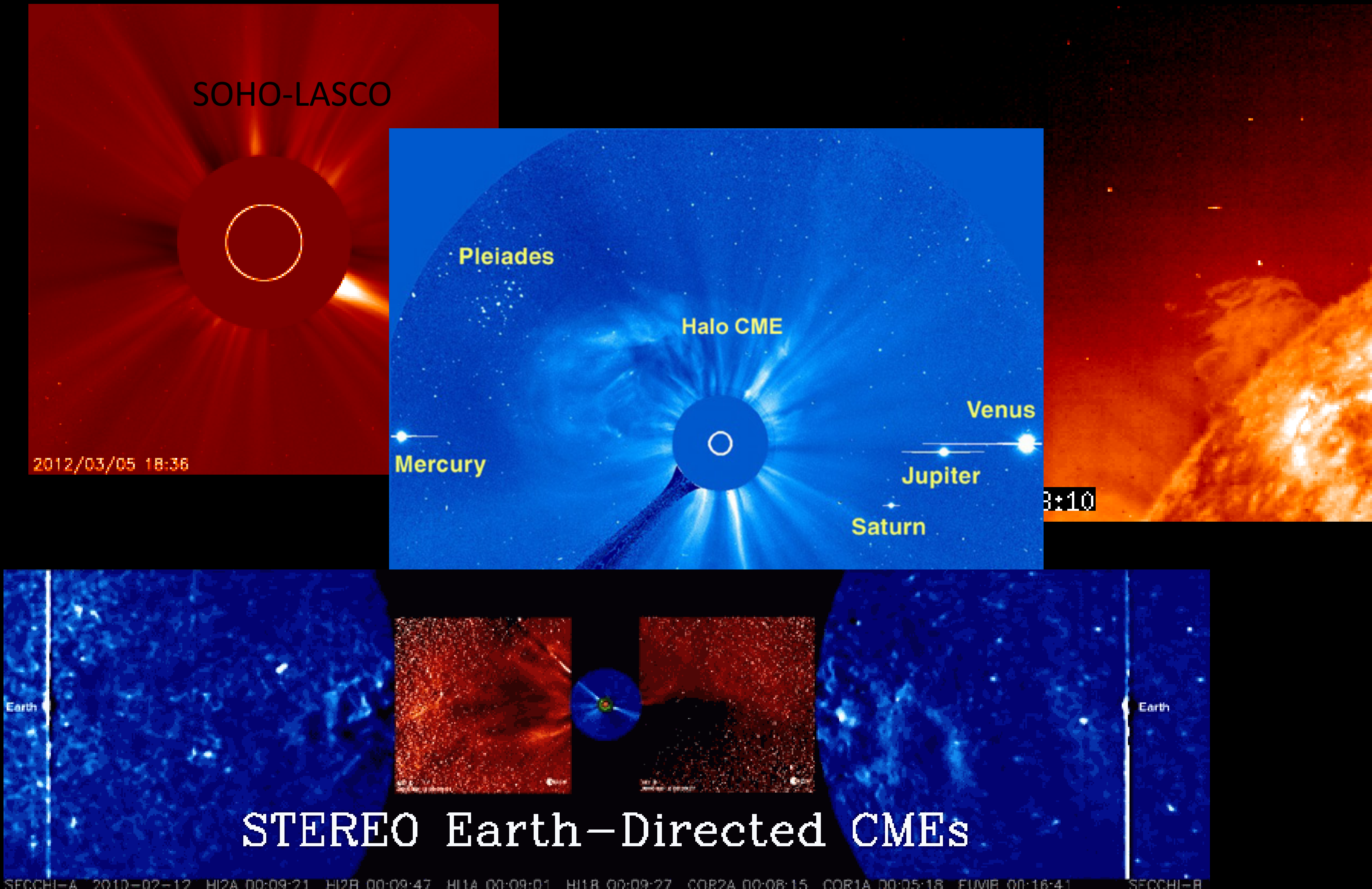
We have entered a new era of Interplanetary Space Weather

This is possible because we've got the Sun surrounded.





Not only Earth, but the entire solar system ‘Lives with its Star’

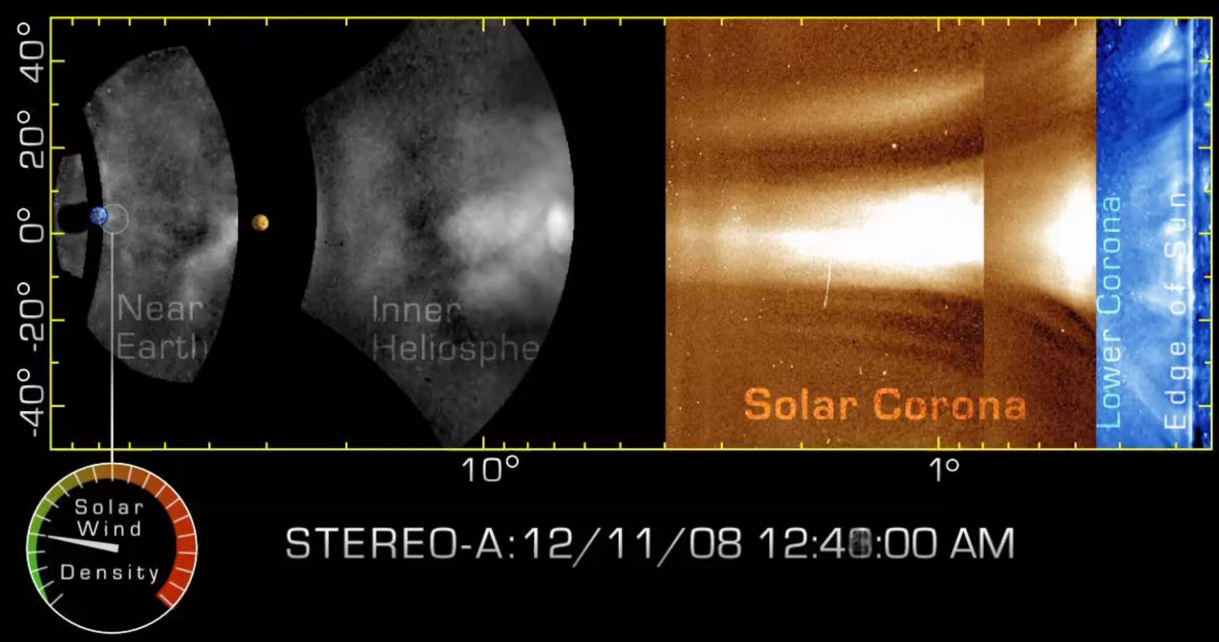


SOHO LASCO images and STEREO SECCHI images of coronal outflows and eruptions. (from SOHO website and Ying Liu, SSL (STEREO panorama))

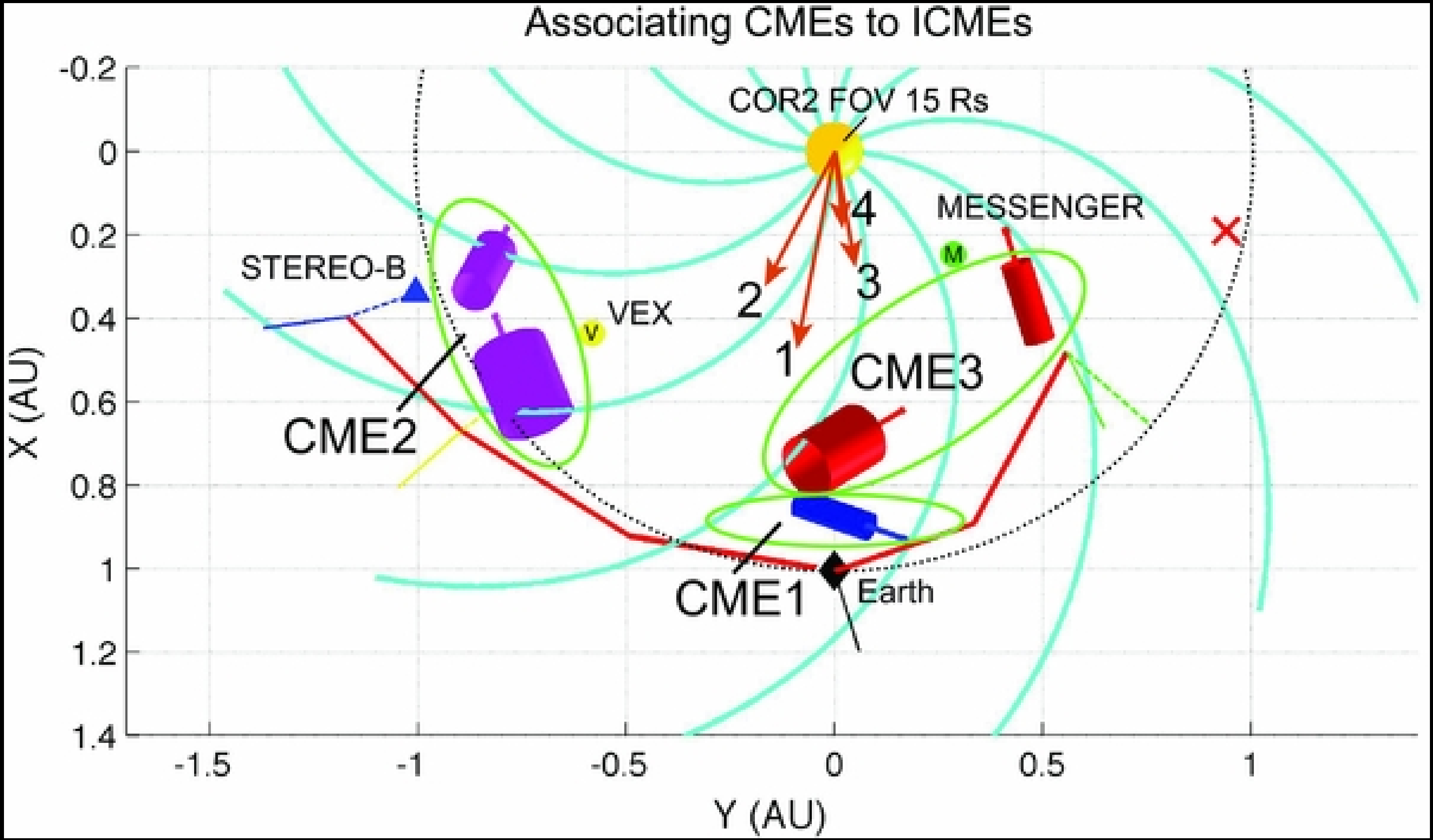
The next frontier in space weather (terrestrial and interplanetary) forecasting involves the uninterrupted tracking of storm clouds from the sun to the planets.

NASA's STEREO spacecraft and new data processing techniques have succeeded in tracking space weather events from their origin in the Sun's ultra hot corona to impact with the Earth’s magnetosphere

STEREO includes 5 telescopes that monitor the sky at large angles from the Sun



Combined with in-situ instruments on planetary missions, (MESSENGER, or ESA's Venus and Mars Express-VEX and MEX), 'reconstructions' of solar system-wide space weather conditions are now possible

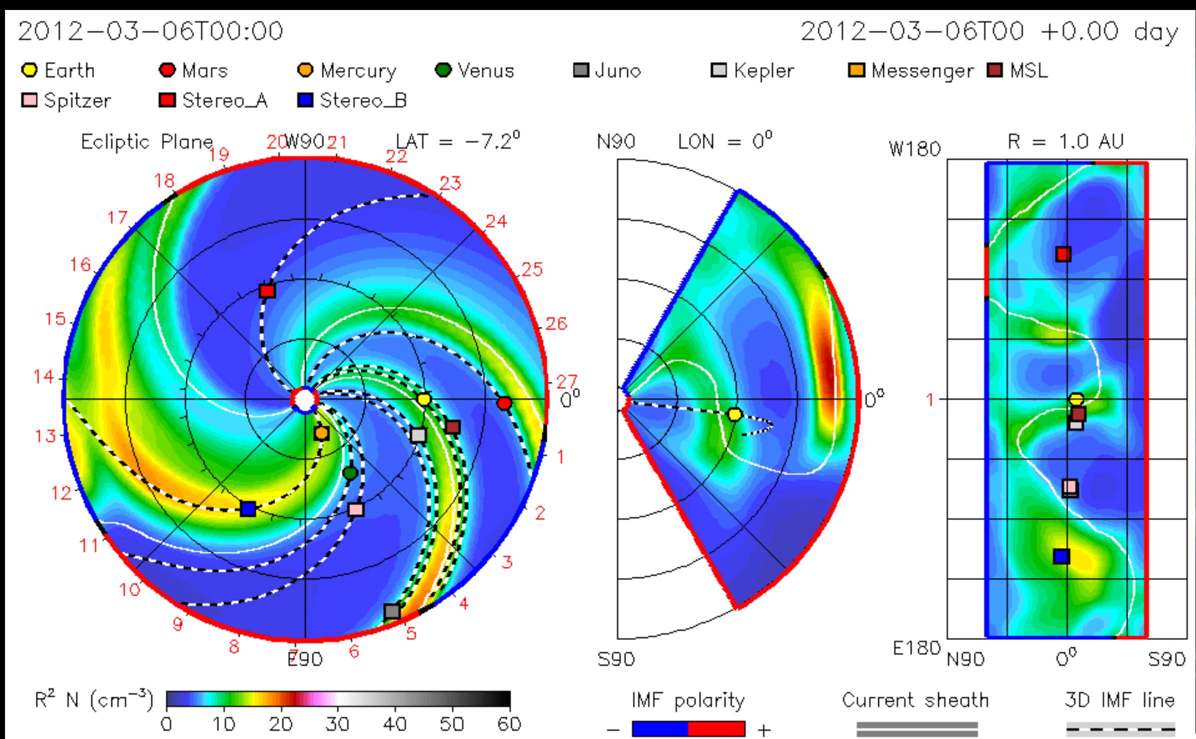


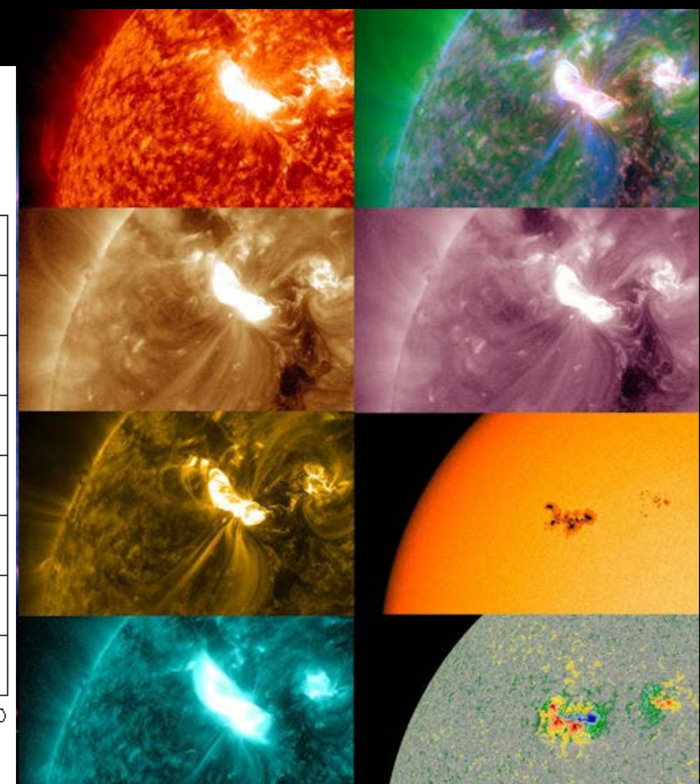
Moestl et al., ApJ 2012

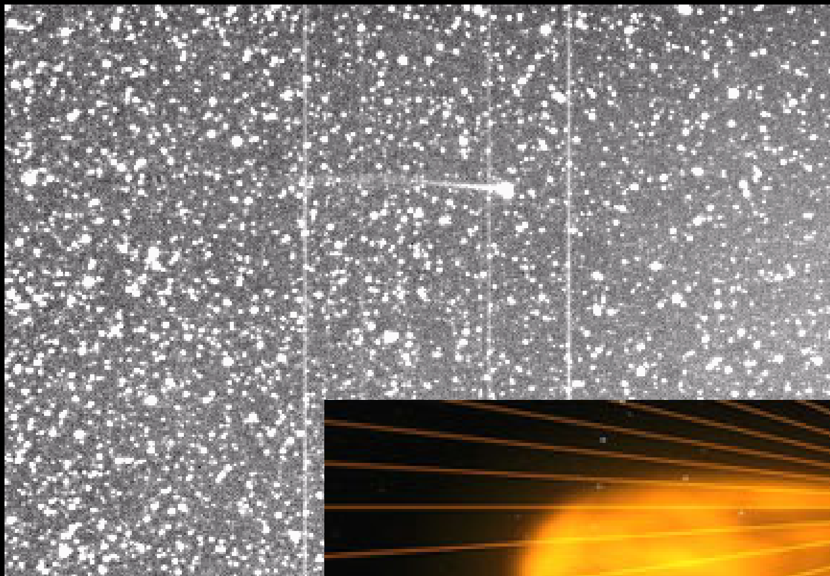
Interplanetary Space Weather: A New Paradigm

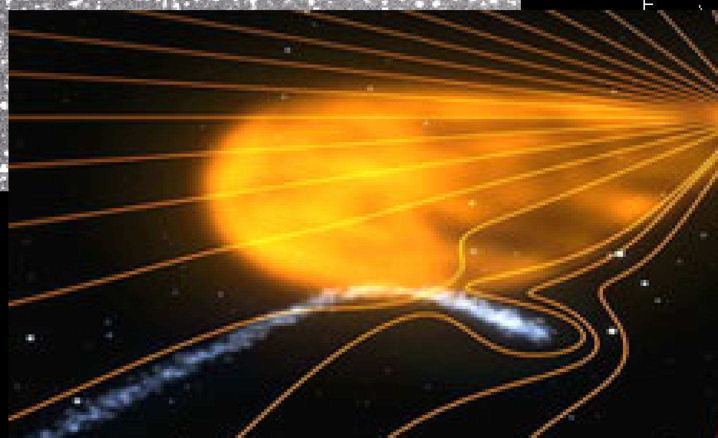
NASA and other space agencies have begun to expand their research into the solar system. **Probes are now orbiting or en route to Mercury, Venus, the Moon, Mars, Ceres, Saturn, and Pluto—and it is only a matter of time before astronauts are out there too**. Each mission has a unique need to know when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



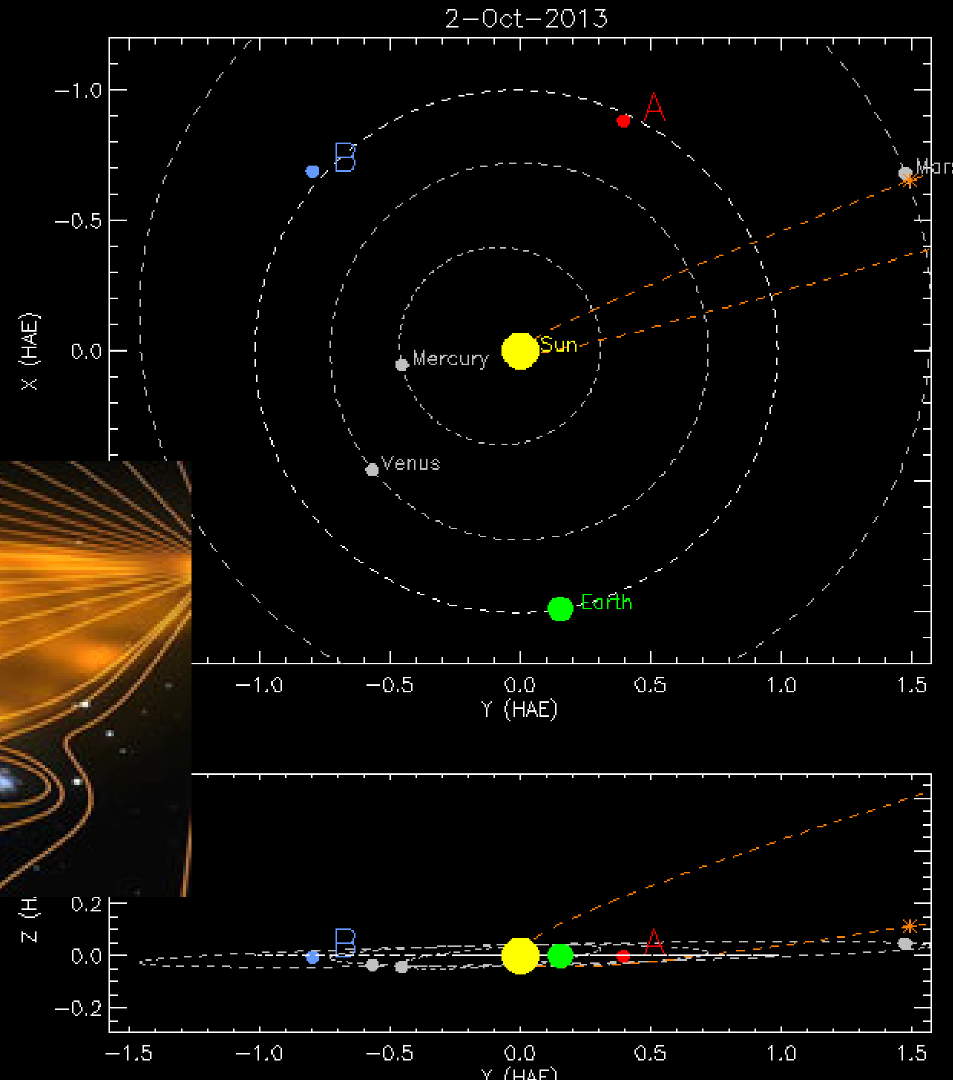






Images of a Cometary tail ‘disconnection’ following a CME encounter, and Artist’s conception

NASA website images from comet Enke passage



Support observations
for other comets. Also, provided info
to the Rosetta mission.

Reasons for developing this interplanetary space weather 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.

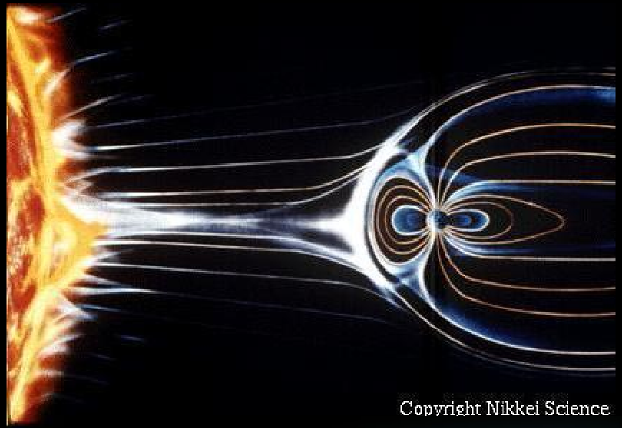
Scientific research could be the greatest beneficiary of interplanetary space weather forecasting. What happens to asteroids, comets, planetary rings and planets themselves when they are hit by solar storms? Finding out often requires looking at precisely the right moment.

Both our terrestrial planet neighbors may have once had oceans and more temperate surface conditions

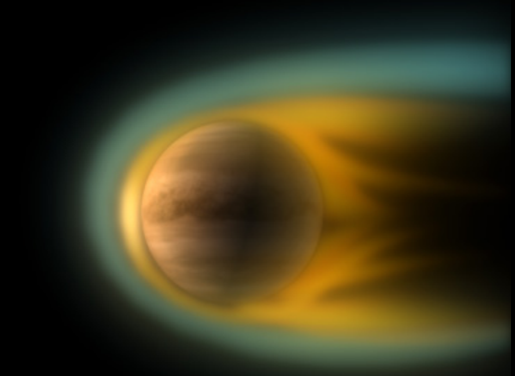
Do Magnetospheres shield planetary atmospheres from significant Solar Wind erosion?

Do solar activity and the related space environment determine their fates?

What are the possible implications for Earth and solar system history if so?



Both also have weak planetary magnetic fields

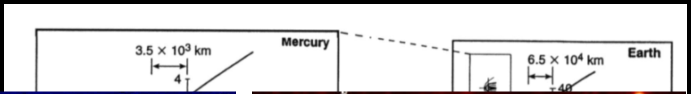


(image: ESA website)

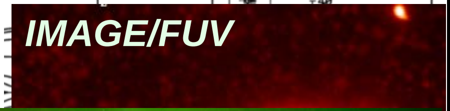
Sun-Earth System Science:
Growth from a “consuming” science to a “producing” science for the benefit of humankind

Space Weather is no longer the domain of Earth only!

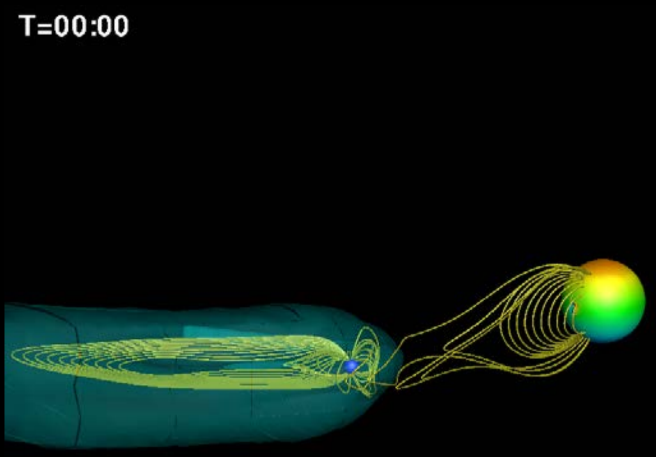
Space Weather is now also Interplanetary!!



Space Weather just became Exopla



Extreme Space
Ex



Heliophysics Volume IV: Active stars, their astrospheres, and impacts on planetary environments

Published by Cambridge in 2016

Years ago, the study of the Sun-Earth connection was edgy stuff. Now Big Thinkers hold the planet and the star to be a system, and new ideas emerged from the synthesis and a new discipline “Heliophysics”.

Now we know that they weren’t thinking big enough. Like Earth, every world in the solar system is connected to its star. From the surface chemistry of Mercury, to the tattered atmosphere of Mars, to the flowing ices of Pluto, the fingerprints of solar activity may be found in all corners of the heliosphere.

The connectedness of things is the subject of this book: “Active Stars, th eir Astropheres, and Impacts on Planetary Environments”. In 13 gradua te-level chapters, experts lay out new ideas about how stars carve out a place in the galaxy to shape their own solar systems. The chapters touc h on subjects ranging from magnetic reconnection and magnetohydrody namics to climate and aeronomy.   It may be one of the most interdiscipli nary textbooks ever written — at least in the physical sciences.

Comparative Heliophysics: The Next Frontier

The 4th volume of the Heliophysics series implicitly makes the case for a new research discipline: comparative heliophysics. As humans and their robots spread throughout the solar system, we will need this kind of interdisciplinary brain trust to understand the places we visit and to anticipate the dangers. What is the weather like on Titan today? How will a solar storm affect the ices of Europe? Is it safe to land on that comet? These questions cannot be answered in “splendid isolation.” Indeed, there really is no such thing … under the Sun.