Monitoring Space Weather from SOHO/PROBA-2 to the future

J. Zender

ESLAB Symposium 2018, ESA/ESTEC

… before we start … some definitions

- Weather: the state of the atmosphere at a particular place and time as regards heat, cloudiness, dryness, sunshine, wind, rain, etc. (wikipedia.com)

- Space Weather: Conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. (US National Space Weather Plan)

- Space Weather: the physical and phenomenological state of natural space environments. The associated discipline aims, through observations, monitoring, analysis and modeling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems. (Lilensten and Belehaki, 2011)

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Working Definition

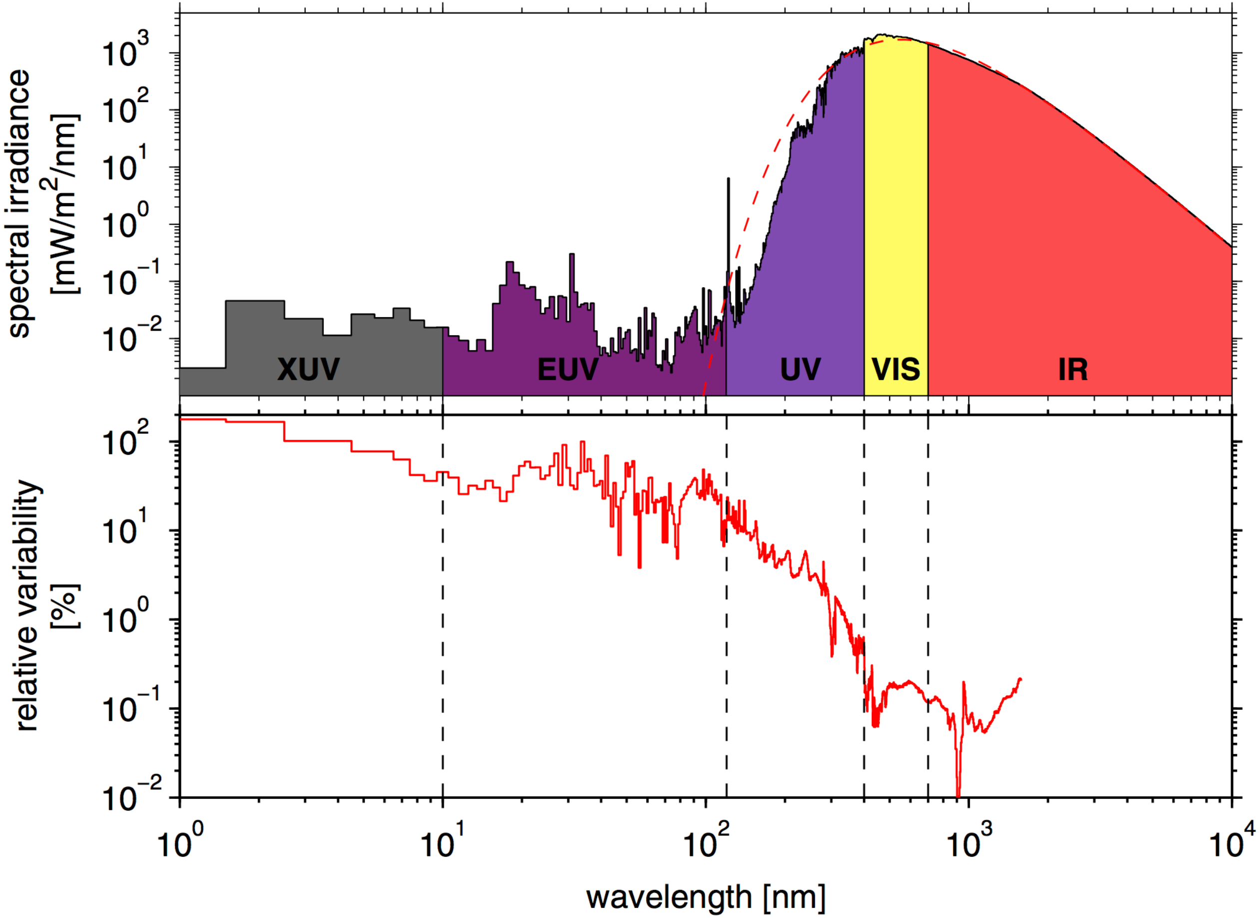







Space weather: the impact of a star on its environment, including the Interplanetary field and the planets, and all effects that have an impact on the life, either for its well-being, its health, or its economy (or whatever holds its ‘society’ together).

Icons are copied from shutterstock.com

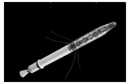


From Lilensten et al., "What characterizes planetary space weather?

Outline

- History of Space Weather (just a trace of it)
- Current Status
- Challenges and Technology Needs
- Future
- Final Remarks

History of Space Weather



Explorer 1

Explorer 3

Explorer IV

Sputnik

Transmit 4b

Ariel-1

Traac

Telstar 1

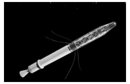
Starfish

1958 1959 1960 1961 1962 1963

CNSA | CSA | ESA | JAXA | NASA | USA (Other) | RFSA | S. America

History of Space Weather

Explorer 1



Explorer 3

Explorer IV

Sputnik

Transmit 4b

Ariel-1

Traac

Telstar 1

Starfish

1962

1963

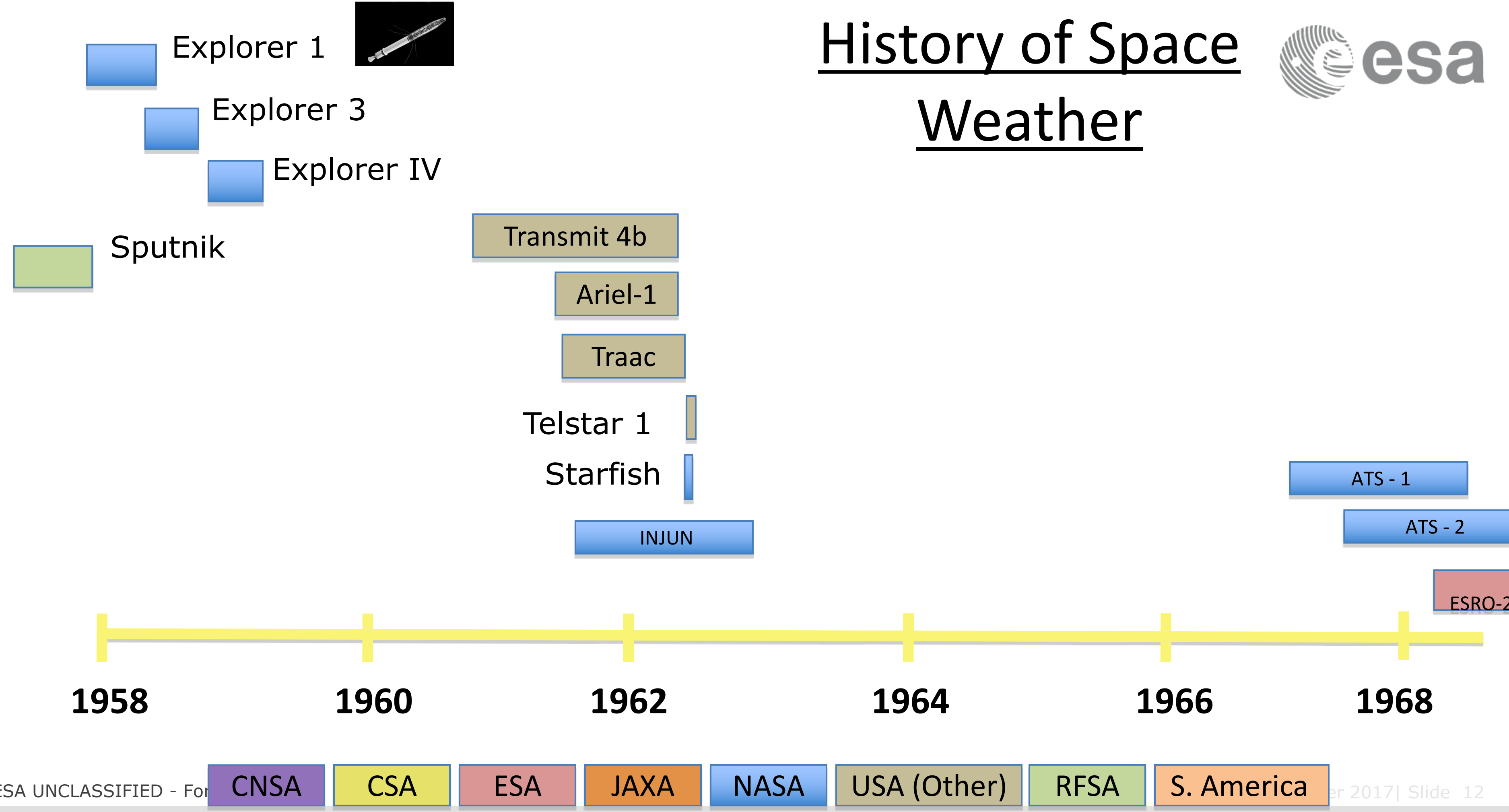
from N.C. Christofilos, The Argus Experiment, J. Geophys. Res., 64, 869-875, 1959

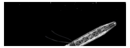
List of the main high-altitude nuclear tests with measured space radiation effects

Explosion	Location	Date	Yield	Altitude
Argus I (USA)	South Atlantic	27 August 1958	1.7 kt	200 km
Argus I (USA)	South Atlantic	30 August 1958	1.7 kt	240 km
Argus I (USA)	South Atlantic	6 September 1958	1.7 kt	540 km
Starfish (prime) (USA)	Johnson Island (Pacific Ocean)	9 July 1962	1.4 Mt	400 km
USSR	Siberia	22 October 1962	300 kt	290 km
USSR	Siberia	28 October 1962	300 kt	150 km
USSR	Siberia	1 November 1962	300 kt	59 km

CNSA | CSA | ESA | JAXA | NASA | USA (Other) | RFSA | S. America

History of Space Weather

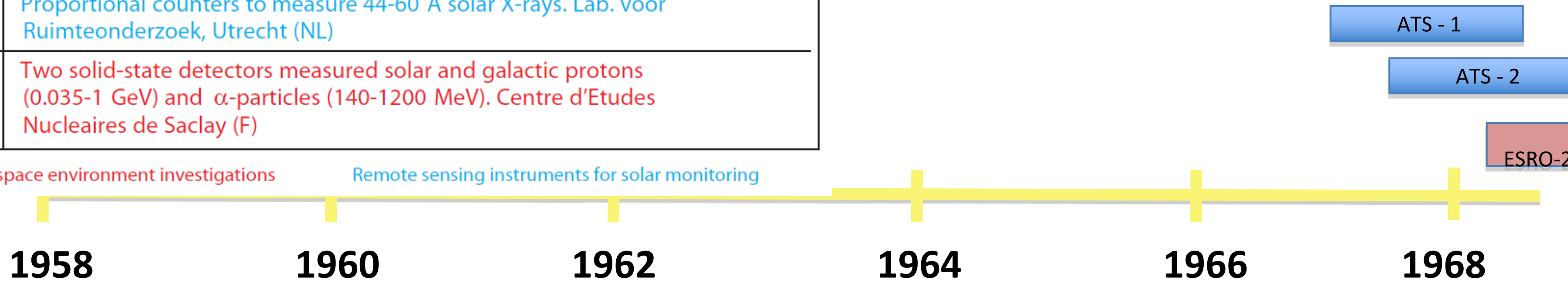




History of Space Weather

ESRO-2 Scientific Instruments	
S25	Two Geiger-Müller counters measured time variations in Van Allen belt population. Imperial College London (UK)
S27	Four solid-state detectors measured solar and Van Allen belt protons (1-100 MeV) and α -particles. Imperial College London (UK)
S28	Scintillator, proportional counters and Cerenkov detectors measuring 0.4-0.8 GeV solar protons/ α -particles. Imperial College London (UK)
S29	Scintillator/Cerenkov detector for flux/energy spectrum of 1-13 GeV electrons. Univ of Leeds (UK)
S36	Proportional counters to measure 1-20 Å solar X-rays. University College London/Leicester Univ (UK)
S37	Proportional counters to measure 44-60 Å solar X-rays. Lab. voor Ruimteonderzoek, Utrecht (NL)
S72	Two solid-state detectors measured solar and galactic protons (0.035-1 GeV) and α-particles (140-1200 MeV). Centre d'Etudes Nucleaires de Saclay (F)

In situ space environment investigations   Remote sensing instruments for solar monitoring



CNSA | CSA | ESA | JAXA | NASA | USA (Other) | RFSA | S. America

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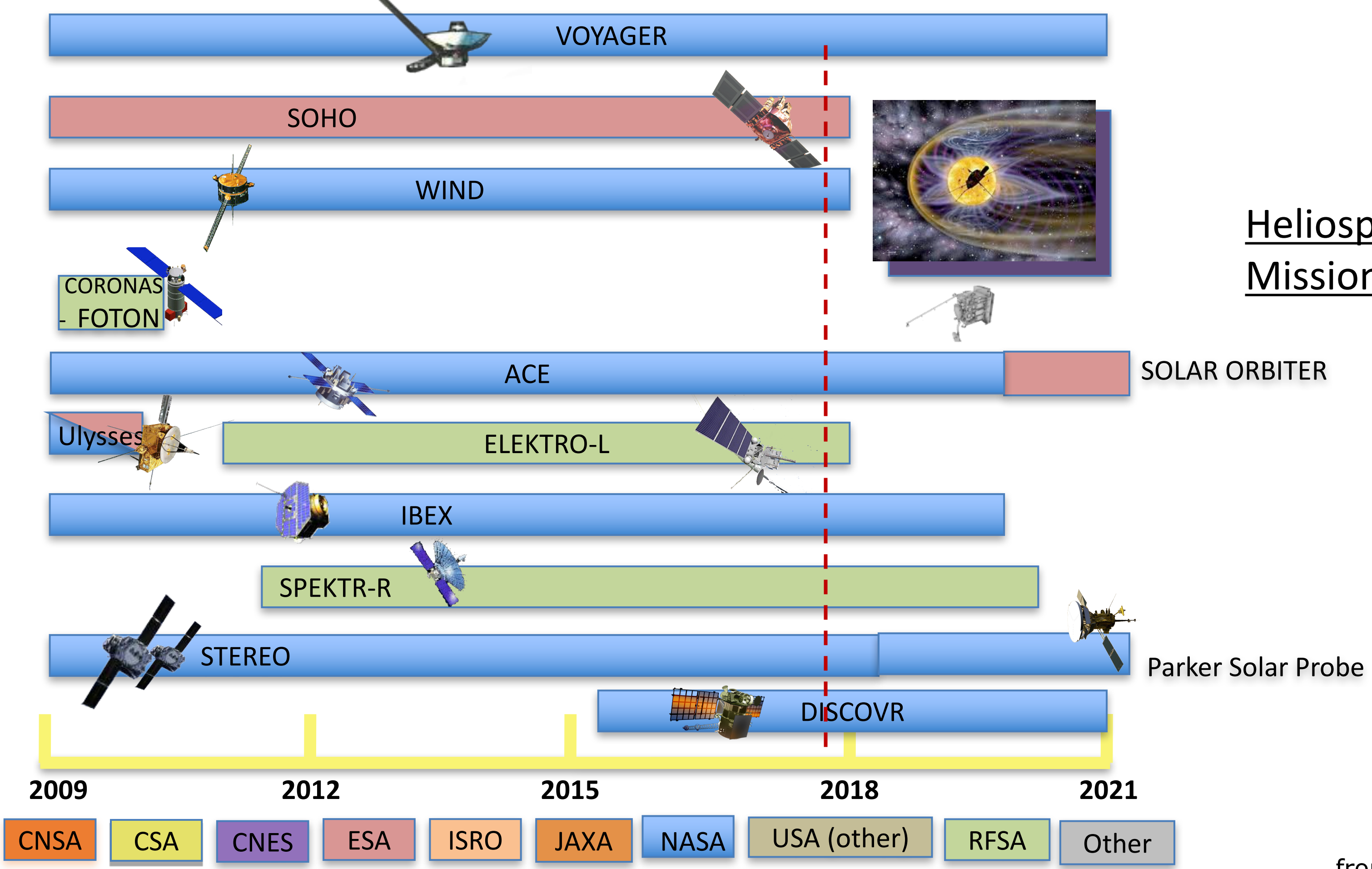
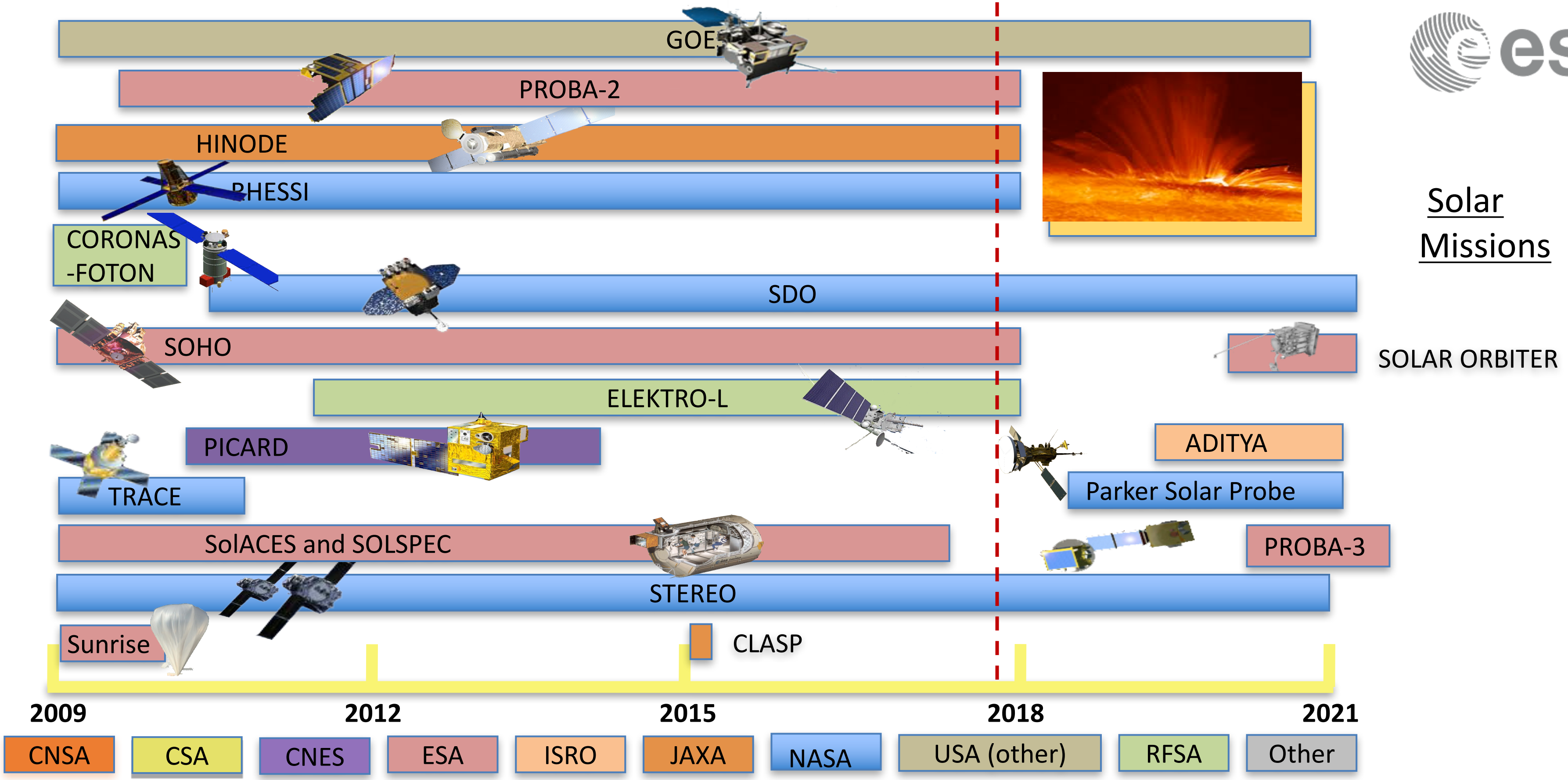
Heliospheric Missions



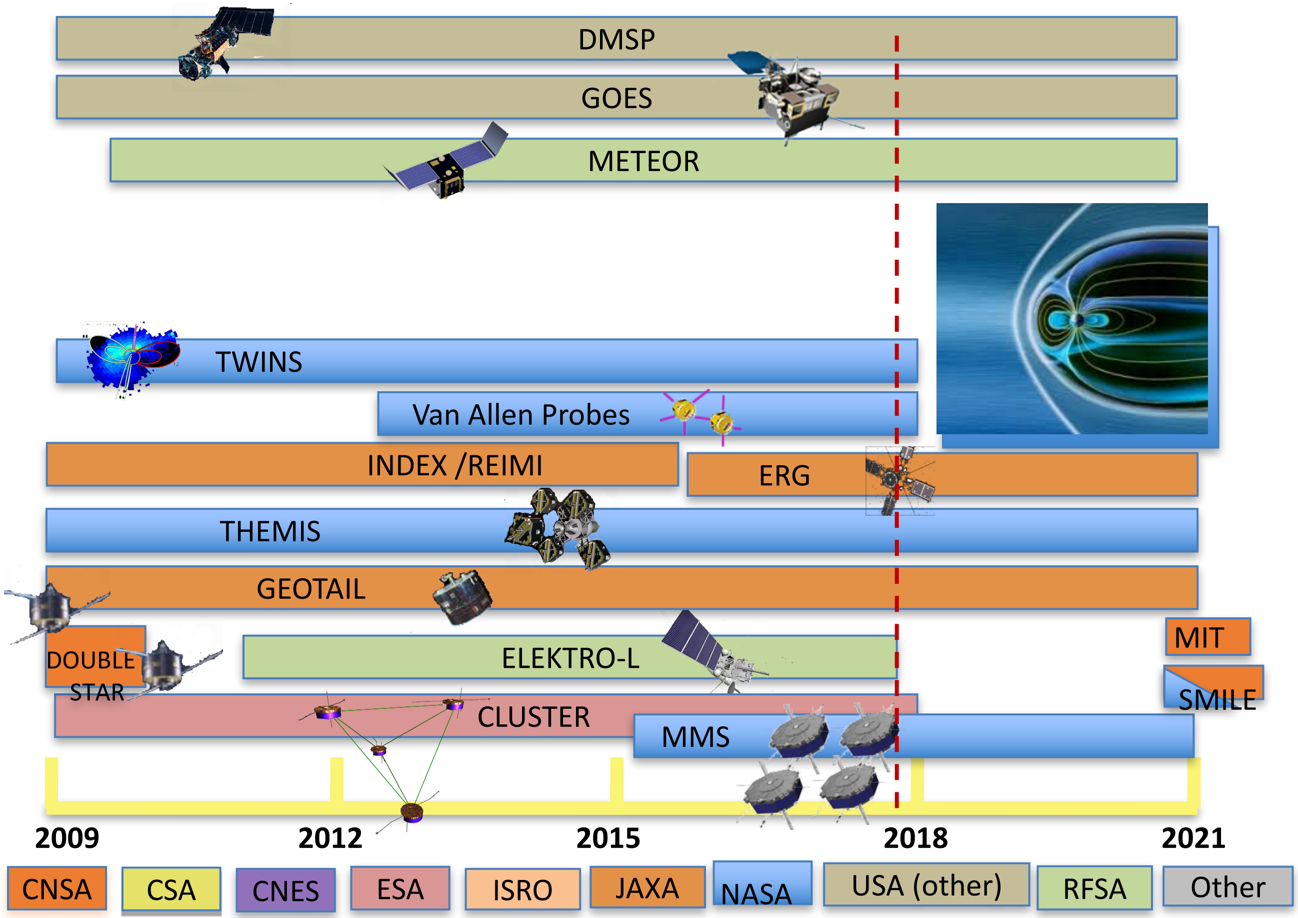
from ILWS

Solar Missions

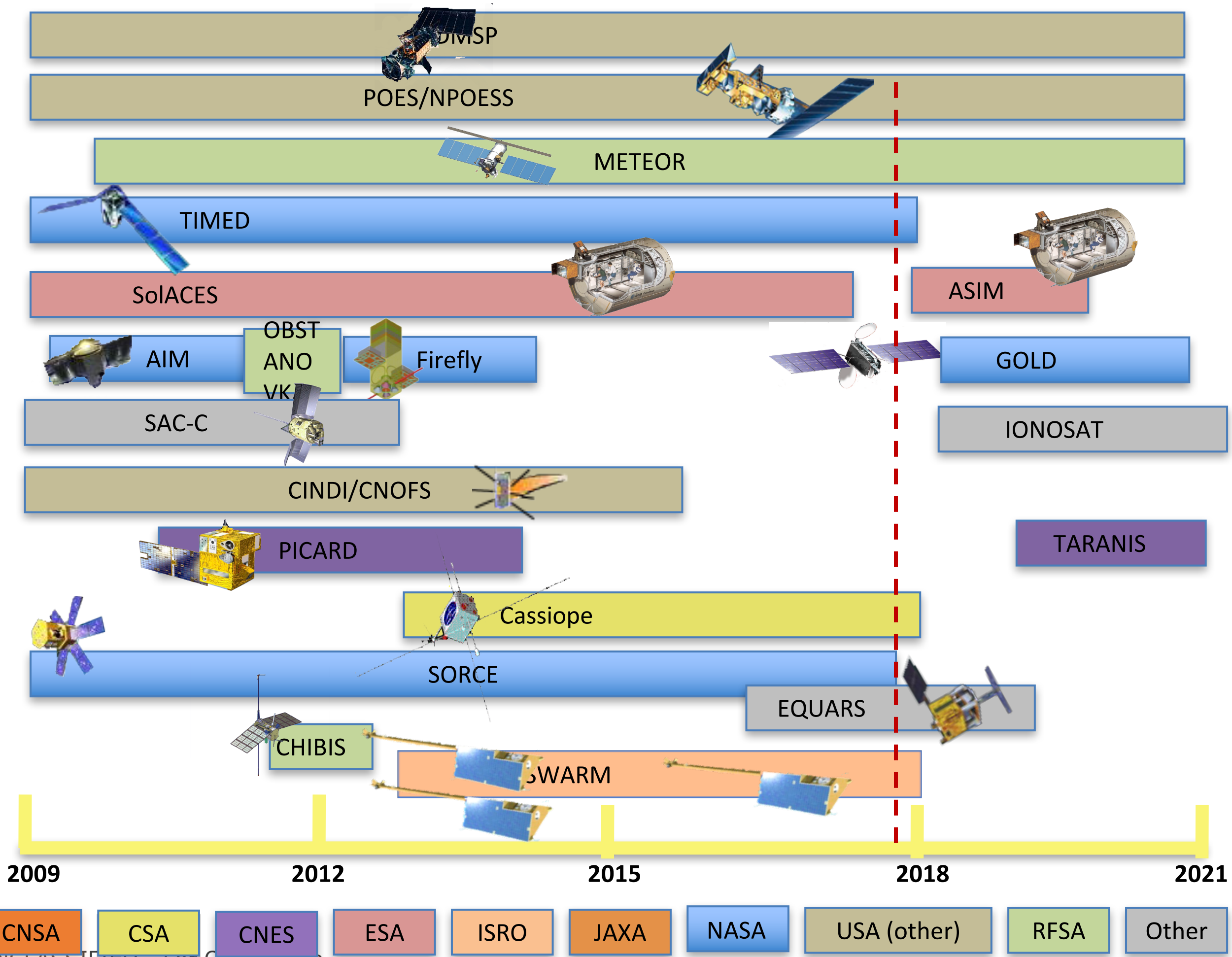


From ILWS

Magnetospheric Missions



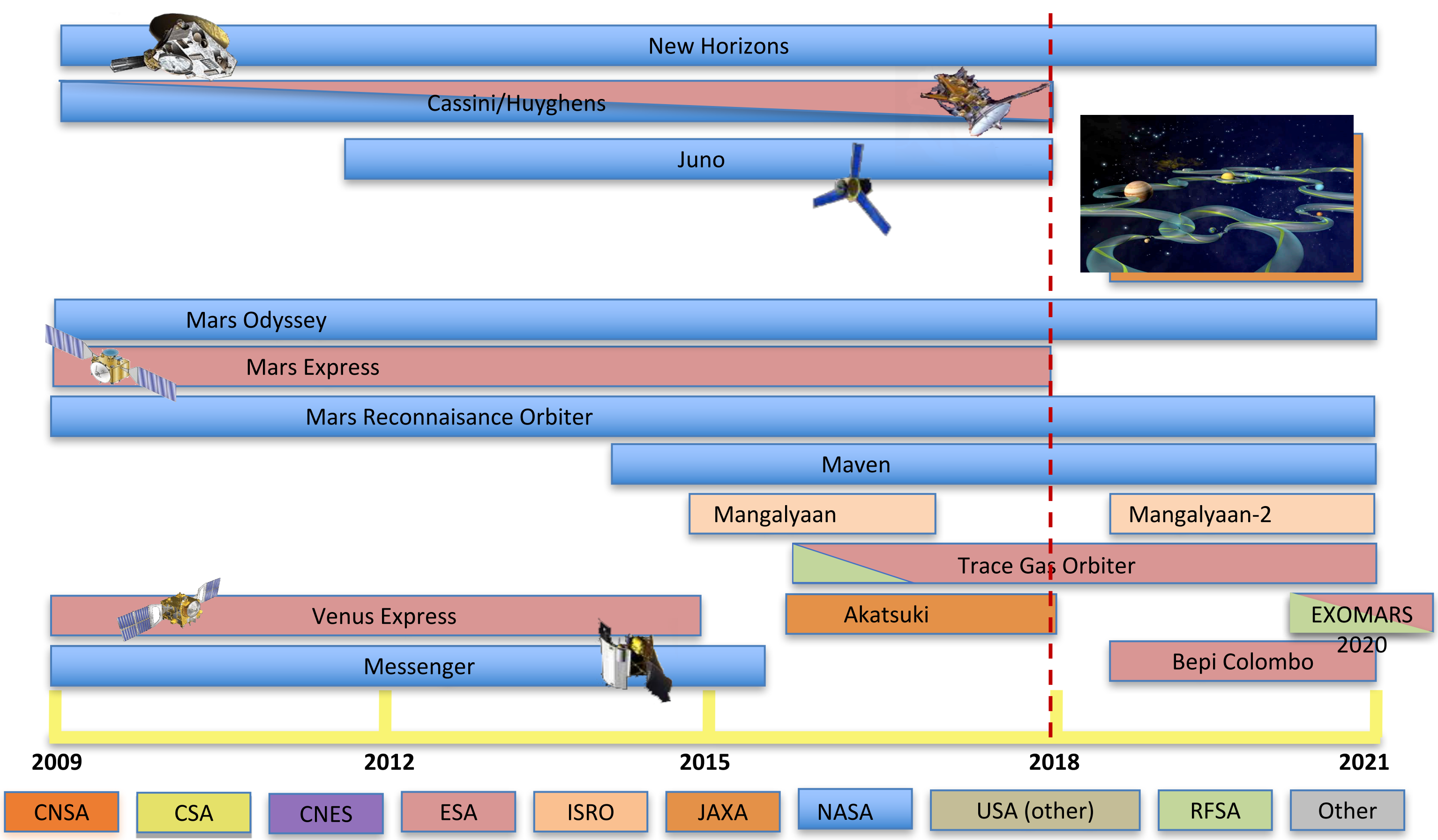
From ILWS



Ionospheric Missions

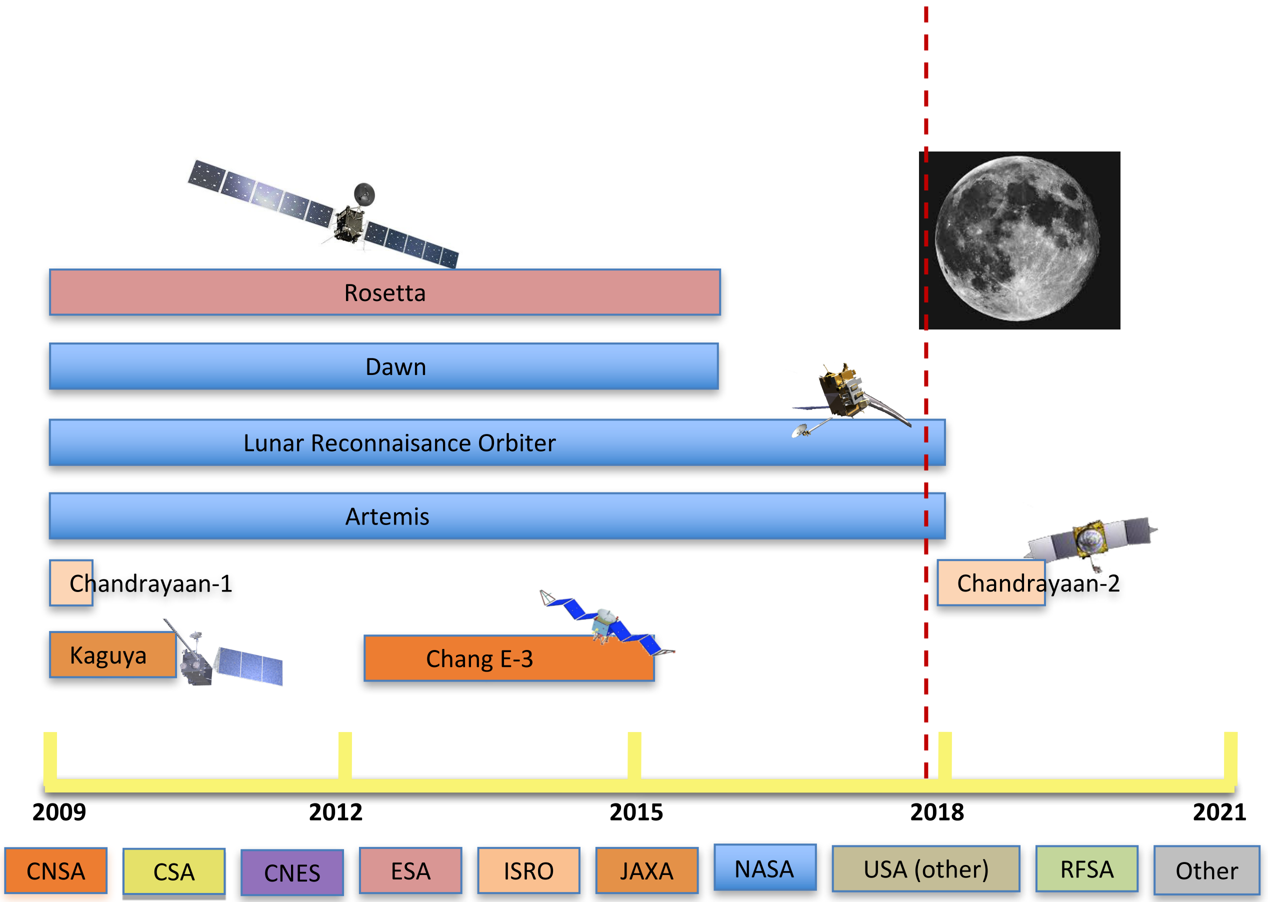
From ILWS

Planetary Missions



From ILWS

Lunar and small bodies Missions



From ILWS

What do we know about the Sun?

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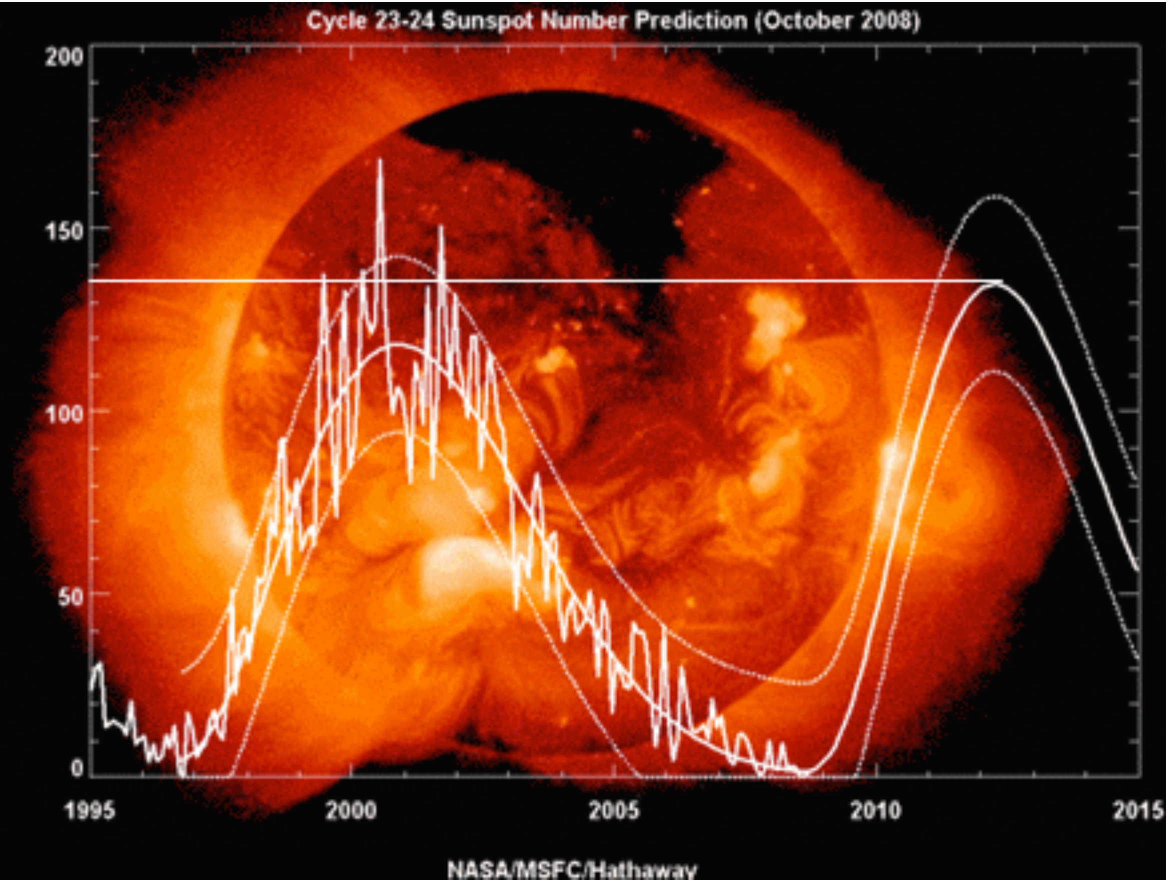
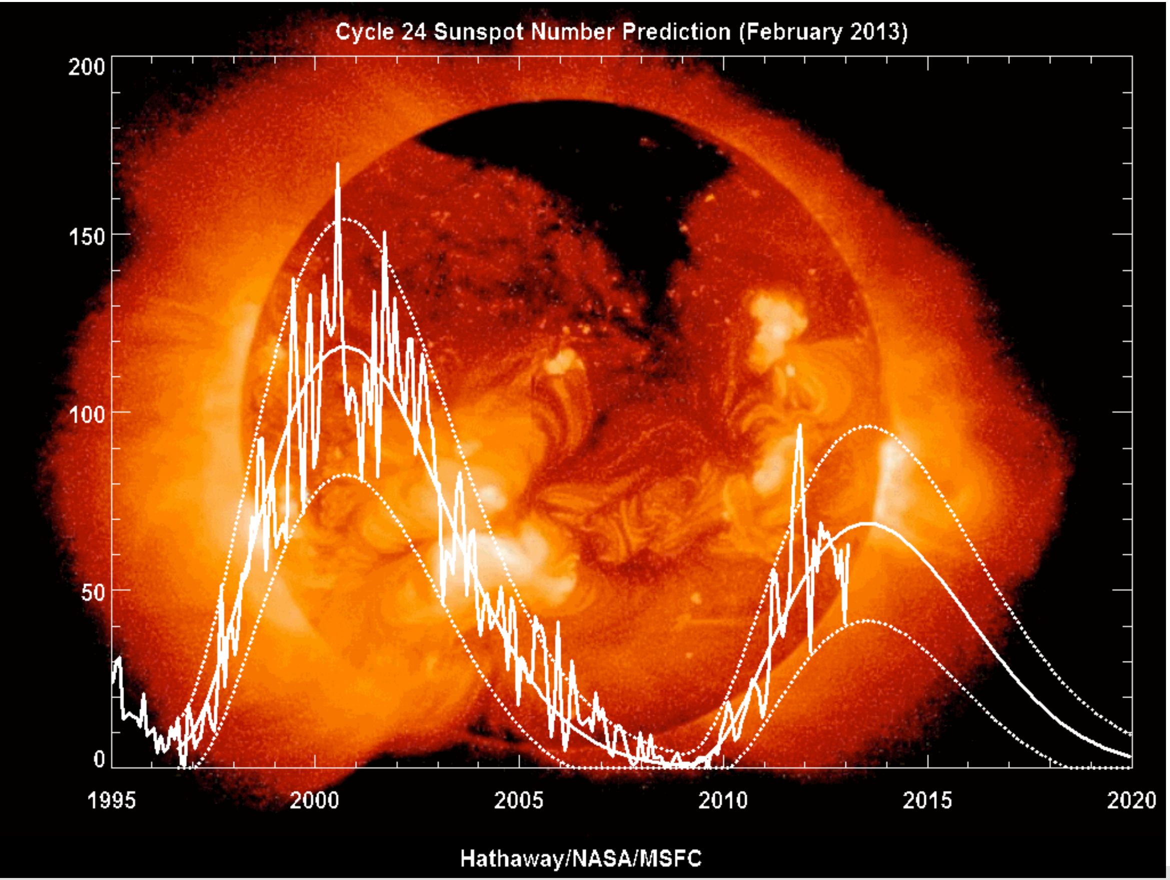


Prediction of cycle 24

In Oct 2008:

- Max: early 2012
- Max: 135

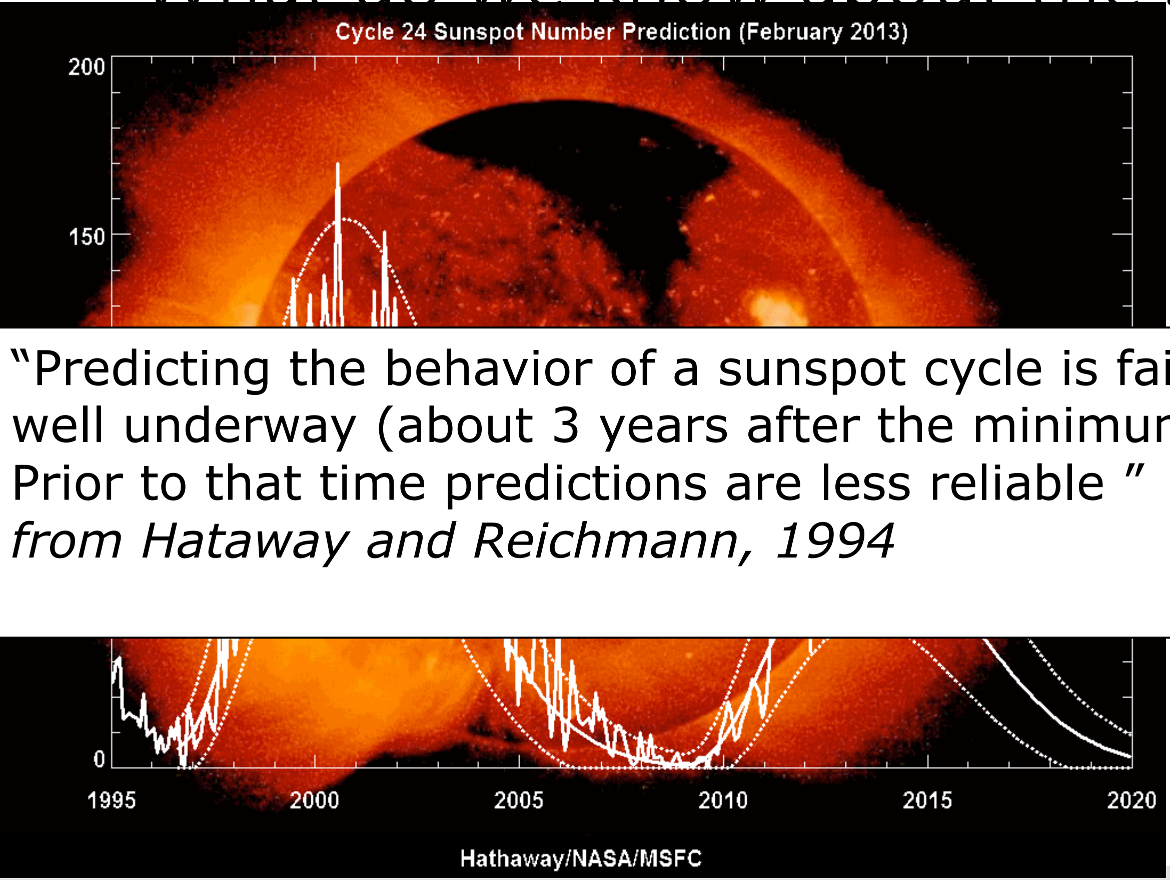
What do we know about the Sun?



Prediction of cycle 24

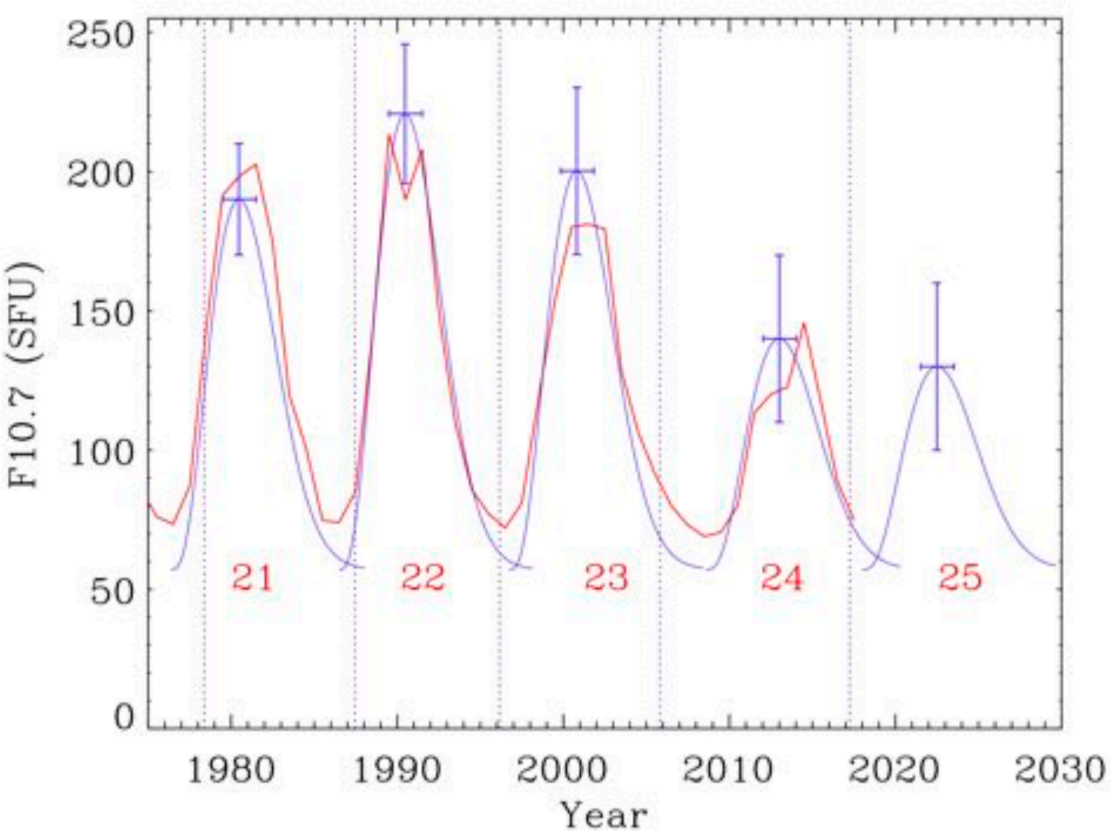
In Feb 2013:
- Max: Mid 2013
- Max: 70

What do we know about the Sun?



“Predicting the behavior of a sunspot cycle is fairly reliable once the cycle is well underway (about 3 years after the minimum in sunspot number occurs). Prior to that time predictions are less reliable ”
from Hataway and Reichmann, 1994

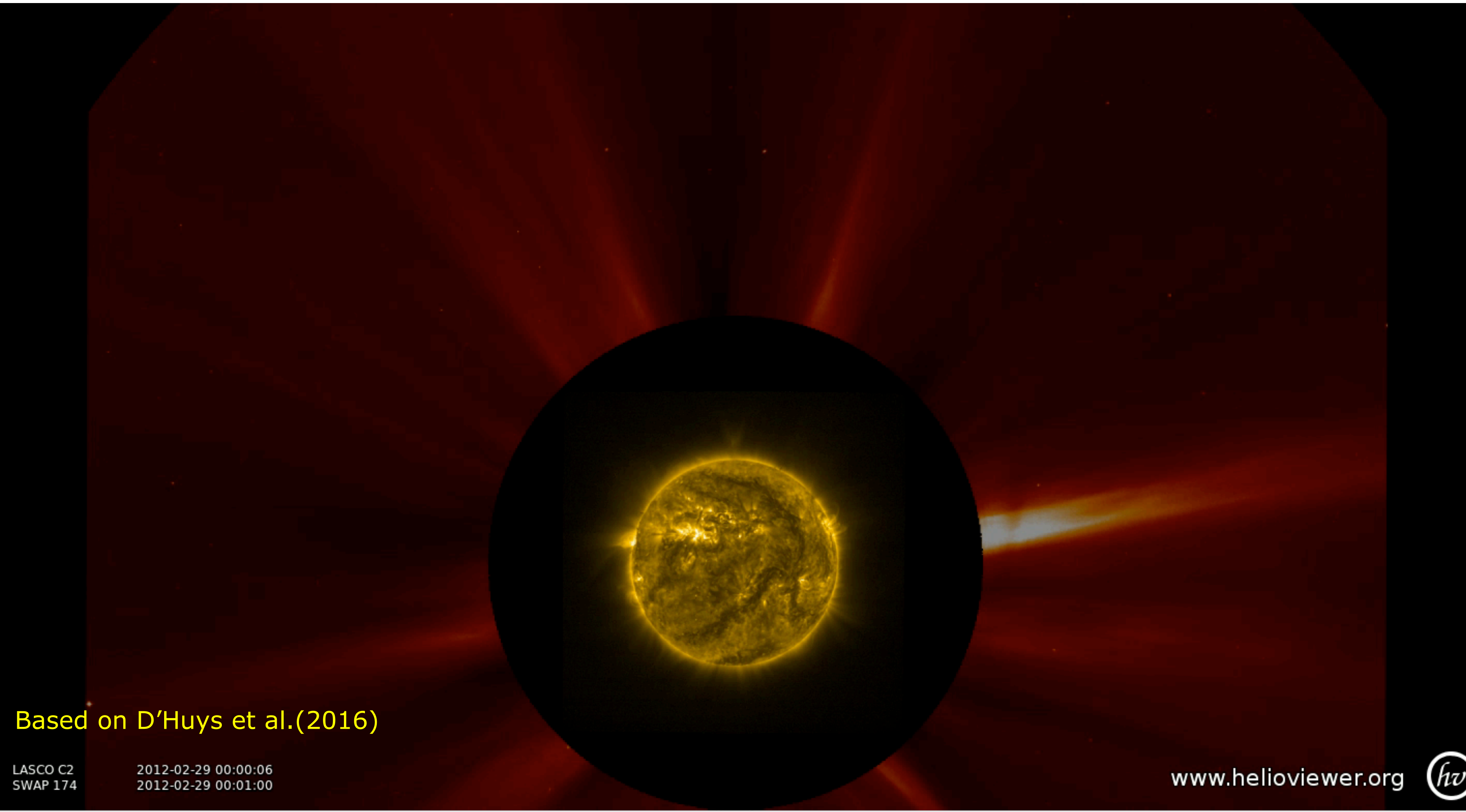
- Max: 70



Solar activity predictions by Schatten *et al.*, have used the polar magnetic field to predict 4 cycles and predict a low Cycle 25.

From D. Pesnell, https://ccmc.gsfc.nasa.gov/RoR_WWW/SWREDI/2017/pesnell_SC_Pred_GSFC_SWx_Jun_2017.pdf

Blue: prediction
Red: measurements
Dashed line: date of prediction



Based on D’Huys et al.(2016)

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The Problem, the Challenges and the Technology Needs

Body	Bimf (nT)	Bimf angle (°)	Solar wind density (cm^{-3})	Solar wind arrival (days)
Mercury	35.78	21.1	46.739	1.7
Venus	11.79	35.8	13.391	3.1
Earth	7.06	44.9	7.000	4.3
Mars	3.91	56.7	3.014	6.6
Jupiter	0.97	79.1	0.259	22.6
Saturn	0.52	84.0	0.077	41.4
Uranus	0.26	87.0	0.019	83.3
Neptune	0.17	88.1	0.008	130.5
Pluto	0.13	88.5	0.005	171.2
Moon	7.06	44.9	7.000	4.3

The time in column 4 is in Earth days assuming a solar wind speed of 400 km s^{-1}

From Lilensten et al, 2014: "What characterizes planetary space weather?"

The Problem

- ➢we cannot at present use observations of the Sun to successfully model the magnetic field in coronal mass ejections (CMEs) en route to Earth, and thus
- ➢we cannot forecast the strength of the perturbation of the magnetospheric field that will occur.
- ➢we understand too little of magnetic instabilities to forecast the timing and energy release in large solar flares or in intense (sub) storms in geospace.

From Schrijver et al, 2015, "Understanding space weather to shield society: A global road map for 2015–2025 commissioned by COSPAR and ILWS"

The Challenges

To predict CME arrivals and predict the impact on the Earth environment **with a 12 hour warning time**, we would need either

- To fully/better understand the CME creation mechanism and its evolution, or
- Measure the magnetic field at the solar surface and solar corona, or
- Obtain 3D remote sensing measurements of the magnetic field, or
- Measure the CME in-situ at the Sun-Earth line at < 0.7 AU

From Schrijver et al, 2015, "Understanding space weather to shield society: A global road map for 2015–2025 commissioned by COSPAR and ILWS"

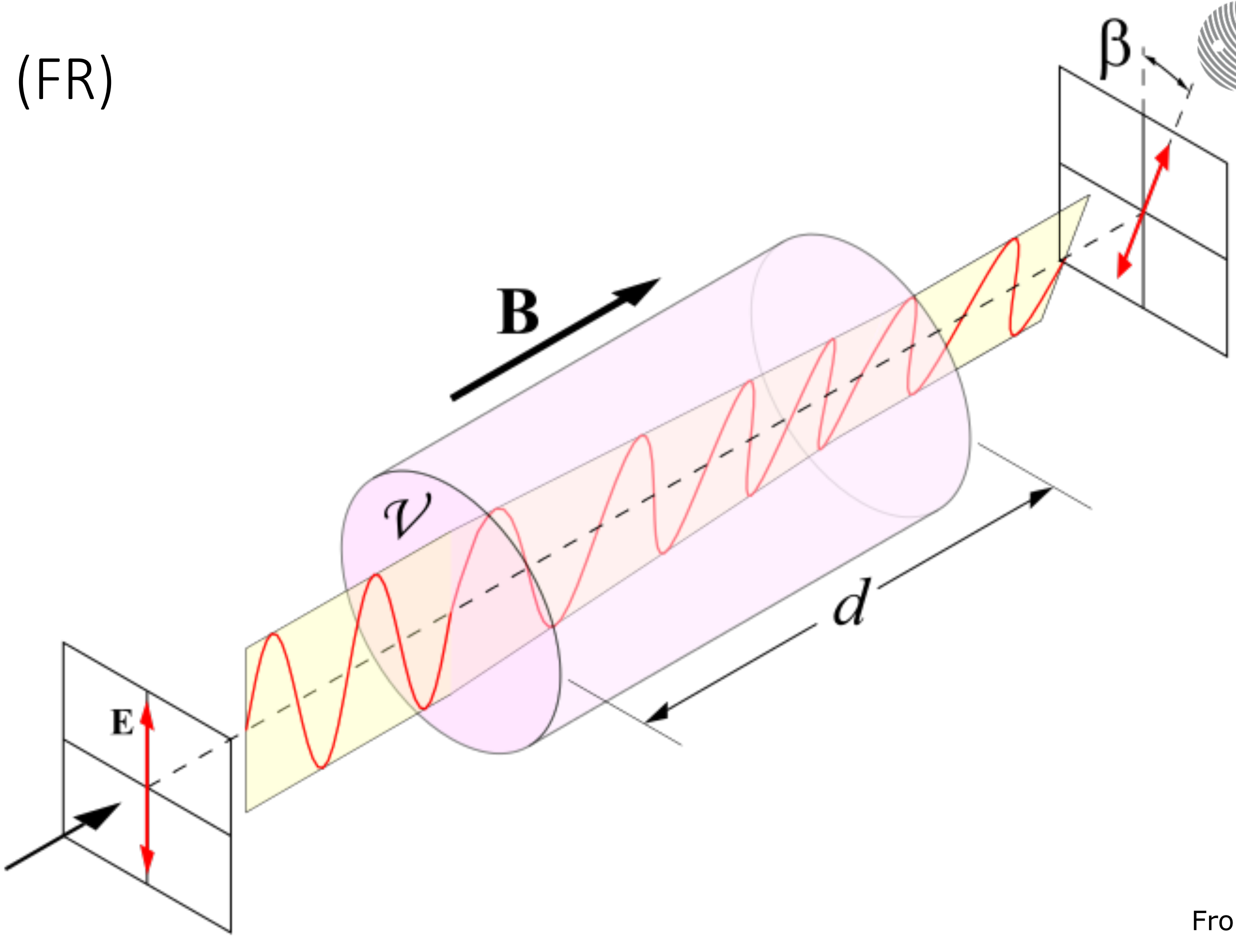
Technology Needs to fully/better understand the CME creation mechanism and its evolution

- Solar Orbiter
- Parker Probe Plus
- Proba-3
- Aditya
- DKIST
- ….

Technology Needs
to measure the magnetic field at the solar surface and solar corona

- Faraday rotation (FR)
- Hanle effect

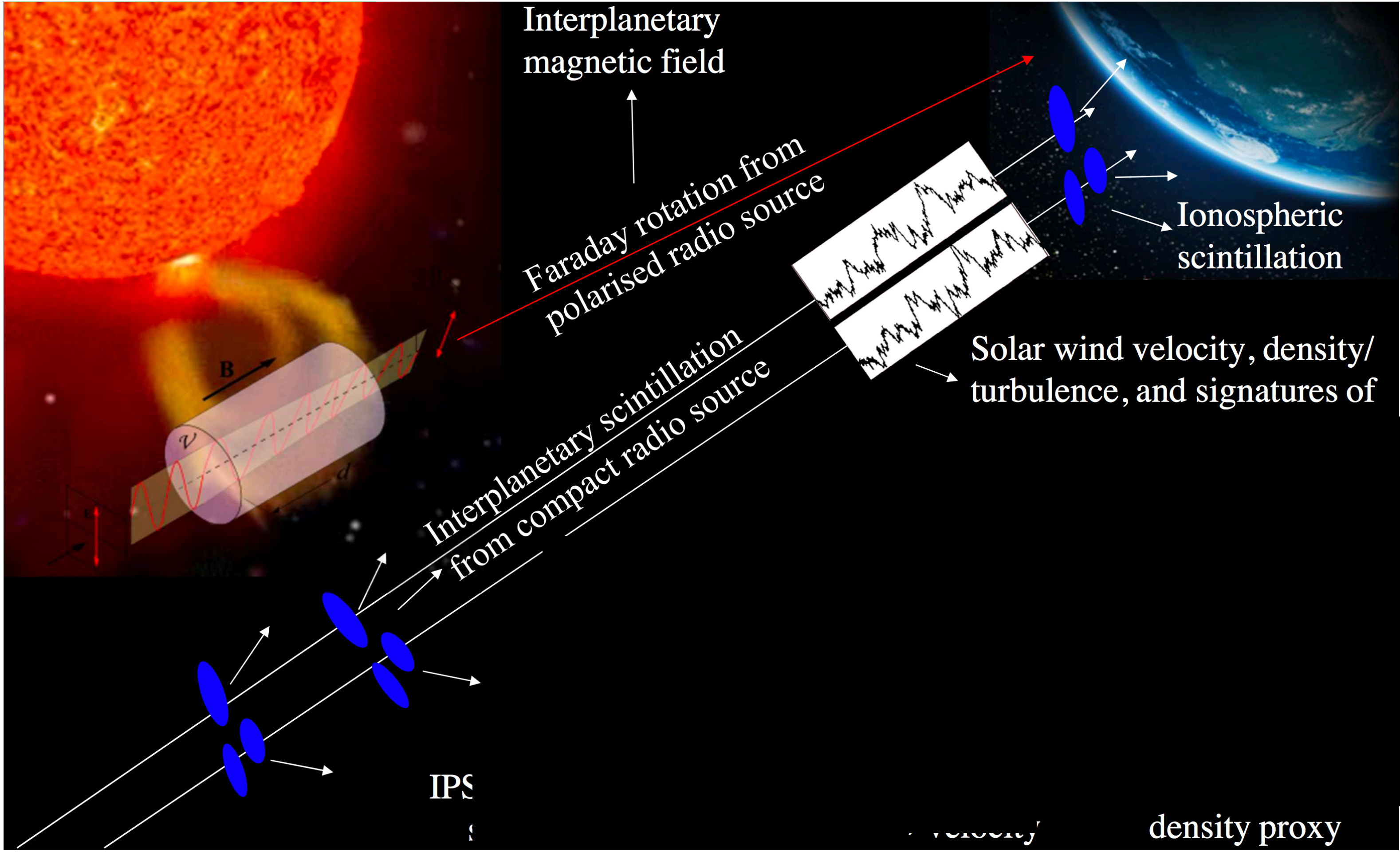
Faraday rotation (FR)



From wikipedia.com

Faraday rotation

Proposal to build The Worldwide Interplanetary Scintillation (IPS) Stations (WIPSS)



Hanle effect

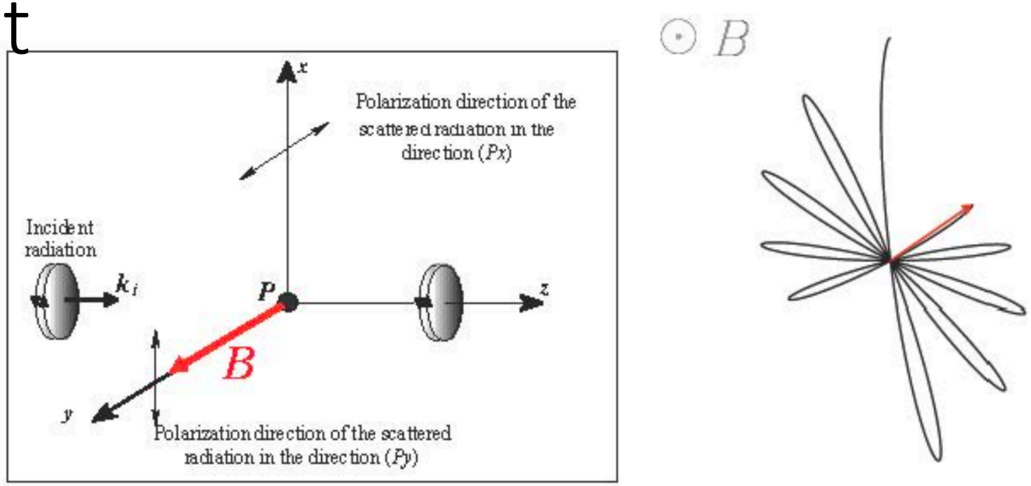
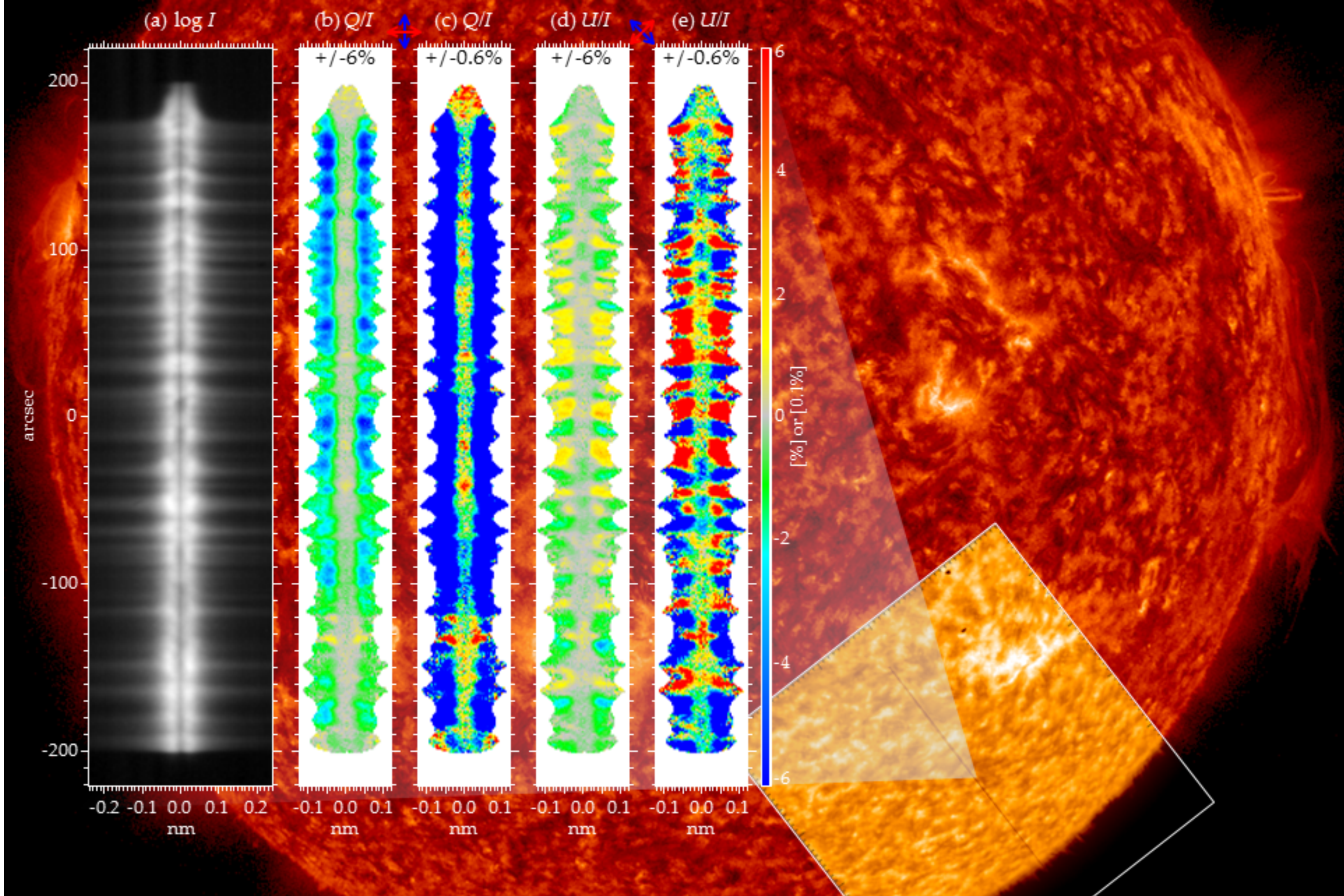


Figure 1. Illustration of the Hanle effect due to a magnetic field aligned with the line of sight (Py). In the absence of a magnetic field, the direction of the linear polarization of the scattered light is parallel to the (Px) axis (left panel). In the presence of a magnetic field, the combination of the precession around the magnetic field and the damping of the atomic dipole results in a modification of linear polarization that depends on both the strength and direction of the field vector (right panel).

From Raouafi et al., 2016, "Diagnostics of Coronal Magnetic Fields Through the Hanle Effect in UV and IR Lines

Hanle effect

- ➢CLASP experiment rocket flight in September 2015



From Kano et al., 2017, "Discovery of Scattering Polarization in the Hydrogen Lyman-α Line of the Solar Disk Radiation"

Technology Needs
to obtain 3D remote sensing measurements of the magnetic field

- Coronagraphs are needed to observe the solar corona. Be aware that the currently used coronagraphs are ‘old’. What are the alternatives?
- Interplanetary Scintillations
- loss-cone anisotropy of ground-based muon observations

From Schrijver et al, 2015, “Understanding space weather to shield society: A global road map for 2015–2025 commissioned by COSPAR and ILWS”

Technology Needs
to measure the CME in-situ at the Sun-Earth line at < 0.7 AU

- Fly constellation at < 0.7 AU such that one spacecraft is always within the Sun-Earth line
- Fly solar sail spacecraft at Sun-Earth line at 0.7 AU

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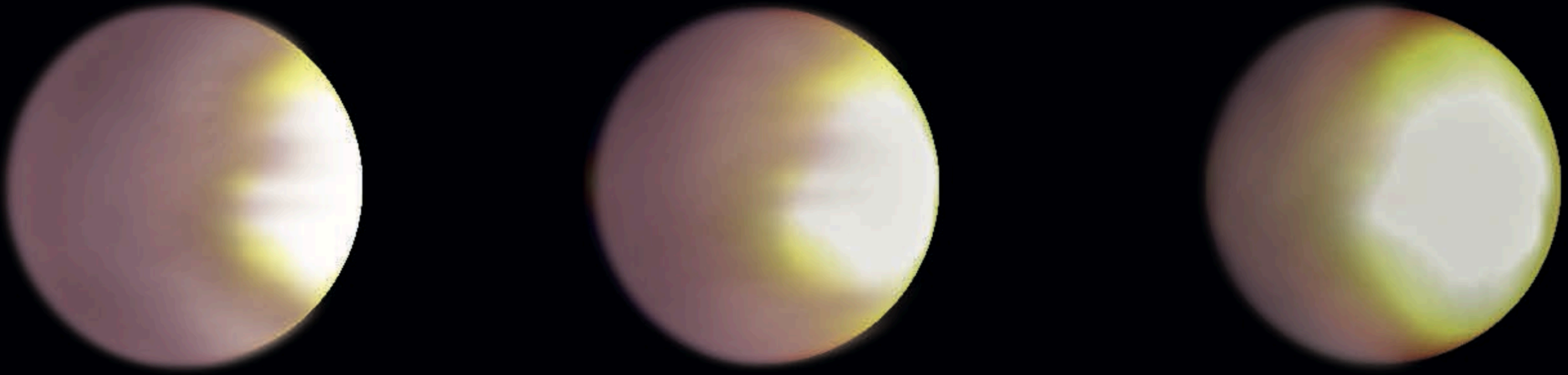
Outlook: Exo-planet Space Weather

Weather forecast for a hot Jupiter

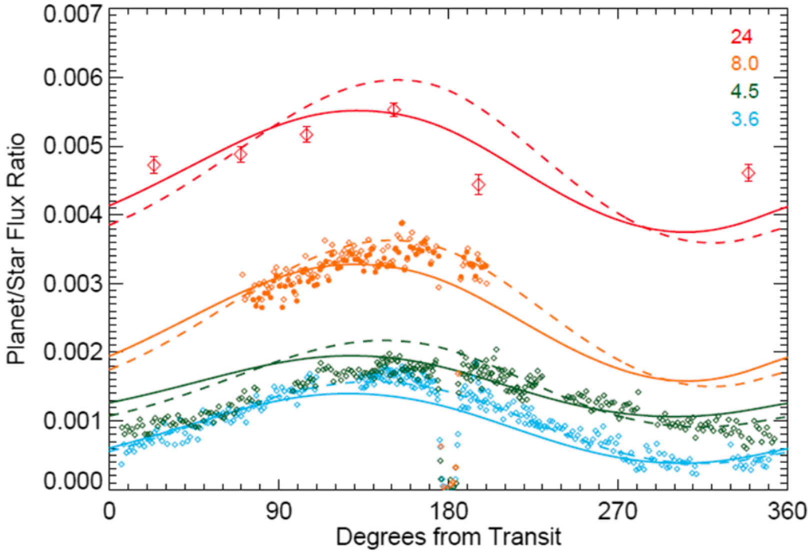
Atmospheres within the Solar System are known to exhibit seasonal changes. Observations with the Kepler spacecraft hint at analogous periodic weather variations in an exoplanet atmosphere.

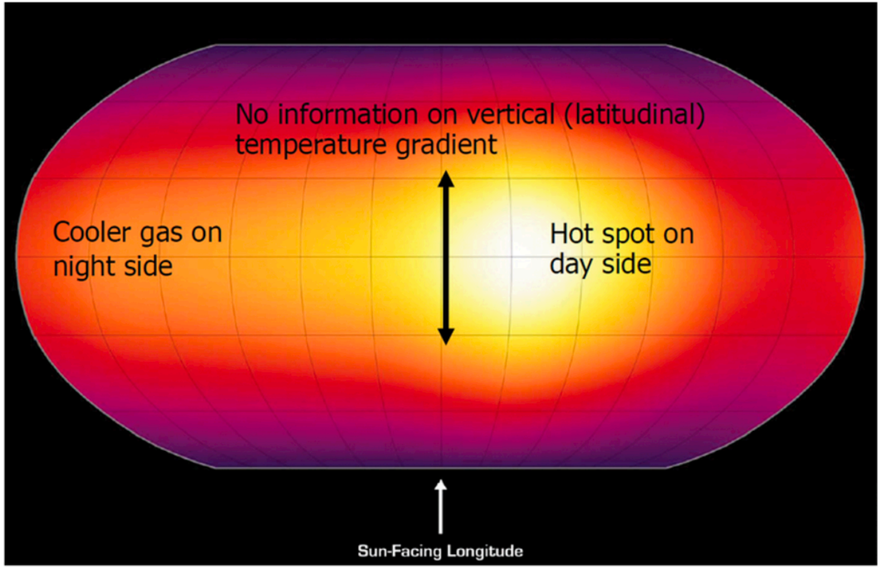
By Nikole Lewis, in PUBLISHED: 04 JANUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0013



Armstrong, D. J. et al. Nat. Astron. 1, 0004 (2016).

Spitzer Observations of HD 189733b





From Knutsen et al., 2012, and Beichmann et al., 2014

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Final Remarks

- The in-situ instrumentation technology is in good shape, only incremental steps needed for technology improvements
- The remote sensing technology is not adequate yet to support space weather, a major technology development is needed
- Our understanding of both the physics in the sun, its surface, and the corona, as well as the phenomena/physics in planetary atmospheres needs a boost
- The subject of space weather is a moving target that goes along the activities of mankind