Osservatorio Astrofisico di Catania

metis

solar orbiter

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EUV SPECTROSCOPY IN VIEW OF THE SOLAR ORBITER AND SOLAR PROBE PLUS SPACE MISSIONS

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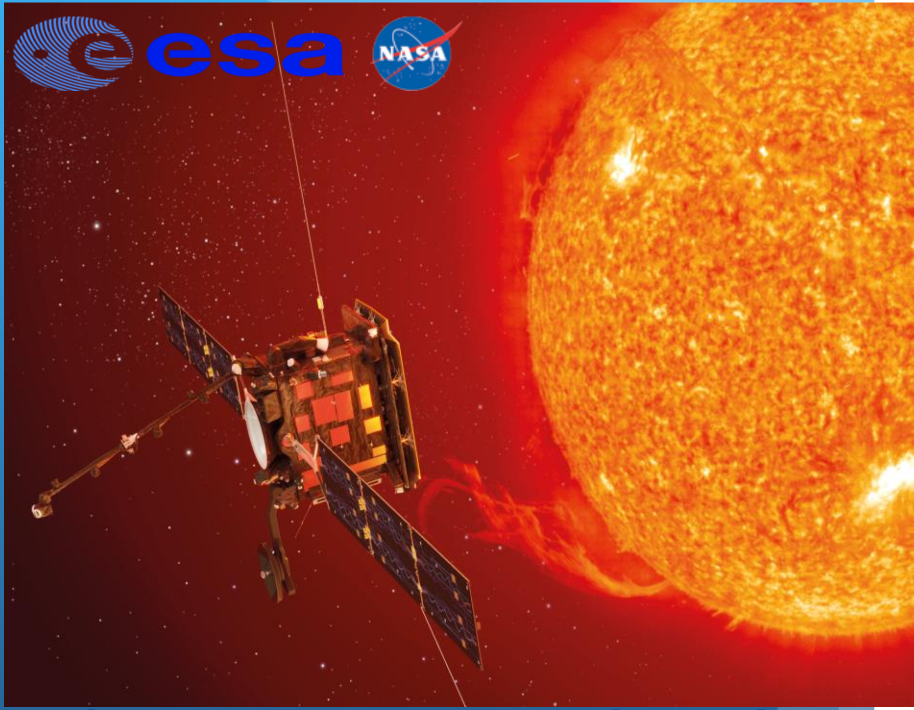
Catania, Italy

Solar Orbiter – Selected as the first medium (M) - class mission of ESA’s Cosmic Vision 2015-2025 programme.

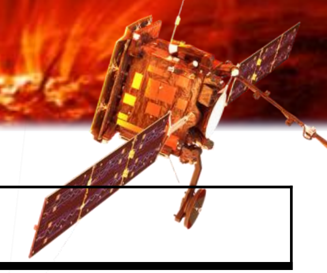


Launch: October 2018

Purpose of the mission:

exploring the Sun-Heliosphere connection by an innovative suite of compact in-situ and remote-sensing instruments, and a new orbital approach

SOLAR ORBITER

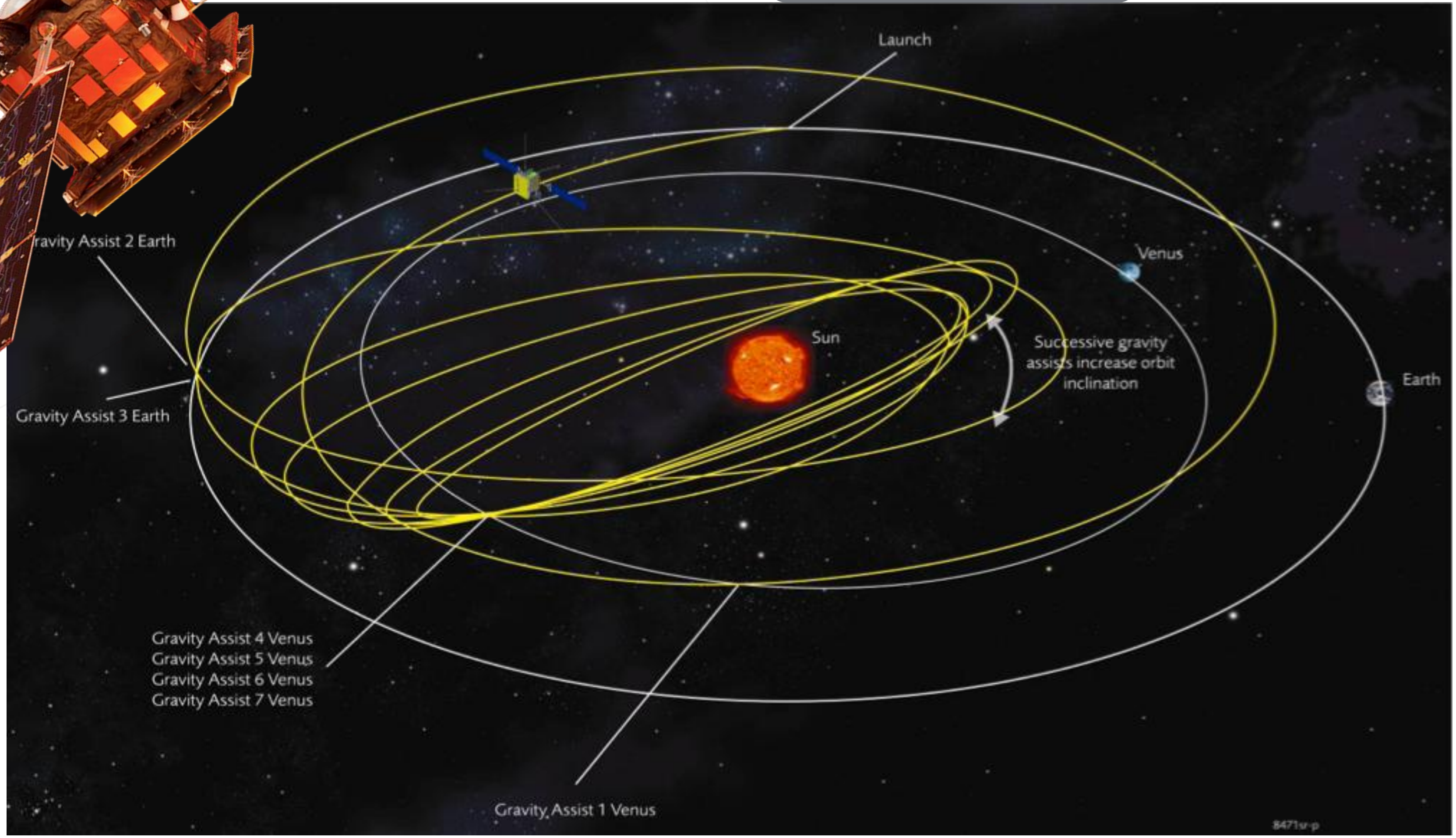


Payload

In-Situ Instruments			
EPD	Energetic Particle Detector	J. Rodríguez- Pach	Composition, timing and distribution functions of energetic particles
MAG	Magnetometer	T. Horbury	High-precision measurements of the heliospheric magnetic field
RPW	Radio & Plasma Waves	M. Maksimovic	Electromagnetic and electrostatic waves, magnetic and electric fields at high time resolution
SWA	Solar Wind Analyser	C. Owen	Sampling protons, electrons and heavy ions in the solar wind
Remote-Sensing Instruments			
EUI	Extreme Ultraviolet Imager	P. Rochus	High-resolution and full-disk EUV imaging of the on-disk corona
METIS	Coronagraph	E. Antonucci	Visible and (E)UV Imaging of the off-disk corona
PHI	Polarimetric & Helioseismic Imager	S. Solanki	High-resolution vector magnetic field, line-of-sight velocity in photosphere, visible imaging
SoloHI	Heliospheric Imager	R. Howard	Wide-field visible imaging of the solar off-disk corona
SPICE	Spectral Imaging of the Coronal Environment	European-led facility instrument	EUV spectroscopy of the solar disk and near-Sun corona
STIX	Spectrometer/Telescope for Imaging X-rays	S. Krucker	Imaging spectroscopy of solar X-ray emission

Solar Orbiter
Exploring the Sun-Heliosphere Connection

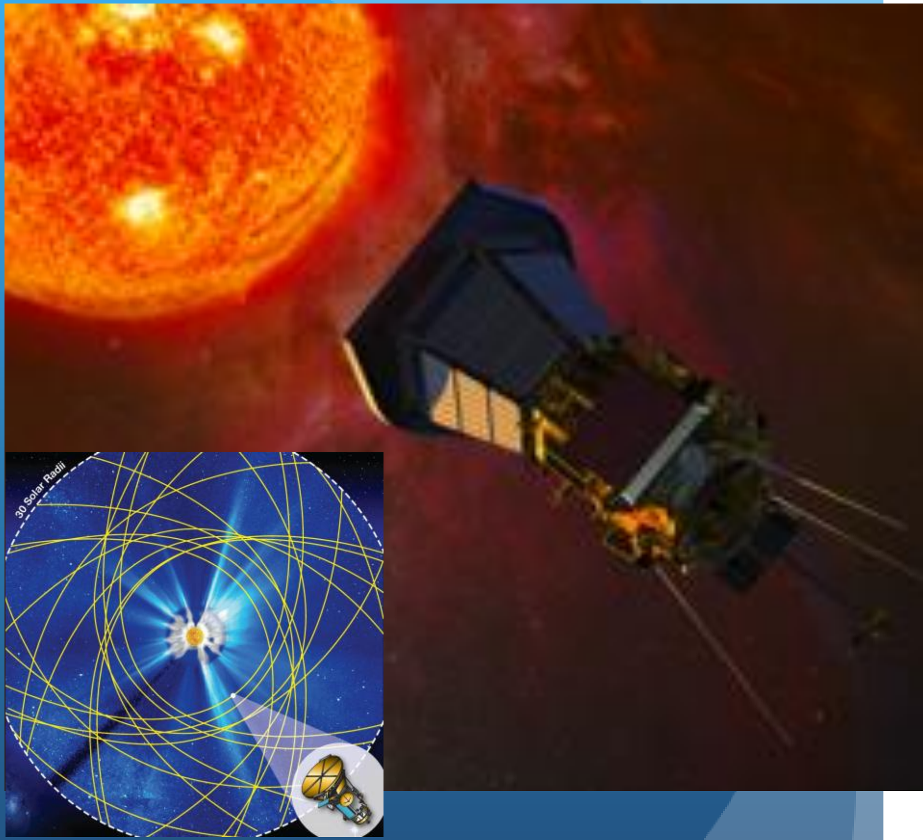
Mission Profile



Solar Probe Plus
A NASA Mission to Touch the Sun

Launch: 2018

By flying into the Sun's outer atmosphere called the corona — Solar Probe Plus will gather data on the processes that heat the corona and accelerate the solar wind, solving two fundamental mysteries that have been top-priority science goals for many decades.



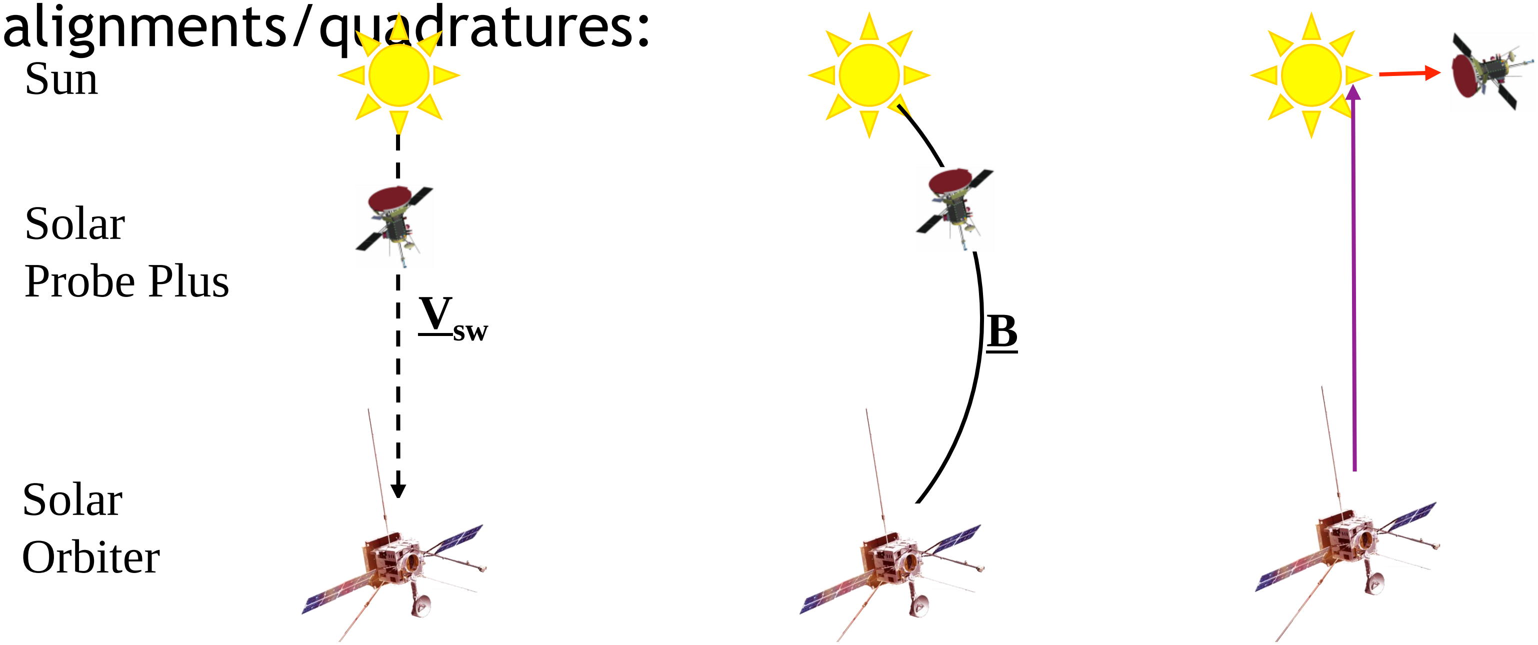
<u>Measuring in place the origins of the Heliosphere:</u>

Solar Probe Plus will fly to within 9 solar radii of the Sun's "surface; it will study the streams of charged particles the Sun hurls into space from a vantage point where the processes that produce the solar wind actually occur

Science payload
3 in-situ instrument +
1 heliospheric imager

Joint Observations Solar Orbiter - Solar Probe Plus

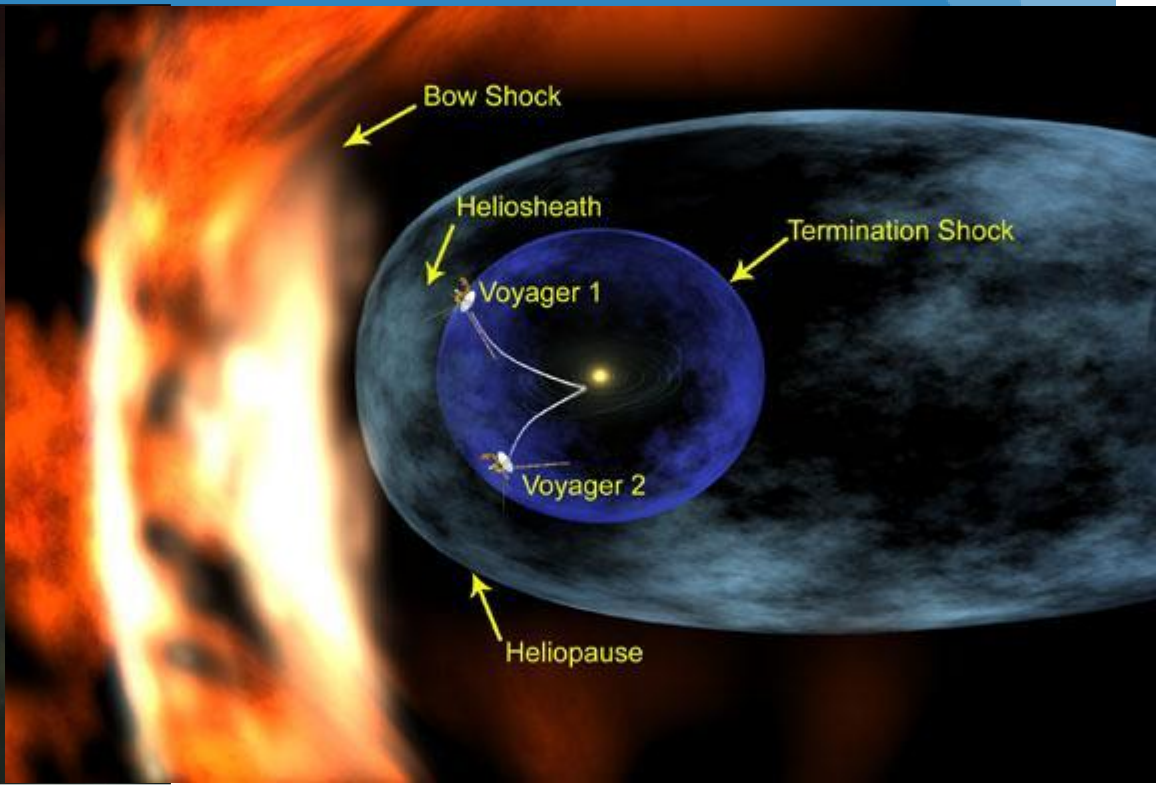
Example of alignments/quadratures:



Radial alignments:	IMF alignments:	Quadratures:
SO and SPP observe the same SW plasma	SO and SPP connect to the same IMF footpoint	SO remote-sensing and SPP in-situ @ ≥9.5 Rs

Why studying the Sun–Heliosphere connection?

To address the central question: how does the Sun create and control the Heliosphere?



Why studying the Sun-Heliosphere connection?

To answer ***How does the solar system work?*** ESA‘s Cosmic Vision Q2.

Sun‘s magnetized atmosphere and wind ***define planetary space environments*** (CV Q1)

It is the site of universal phenomena which can be studied and understood in detail (CV Q3): ***magnetic reconnection, collisionless shocks, turbulence and collective nonlinear effects and energetic particle acceleration***

How does the Sun create and control the Heliosphere ?

(see: Solar Orbiter Definition Study Report & Müller et al. 2013, Solar Physics, **285**, 2

Q1) What drives the solar wind and where does the coronal magnetic field originate from?

Q2) How do solar transients drive heliospheric variability?

Q3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?

Q4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?

These questions represent fundamental challenges in solar and heliospheric physics today.

By addressing them, we expect to make major breakthroughs in our understanding of how the inner solar system works and is driven by solar activity.

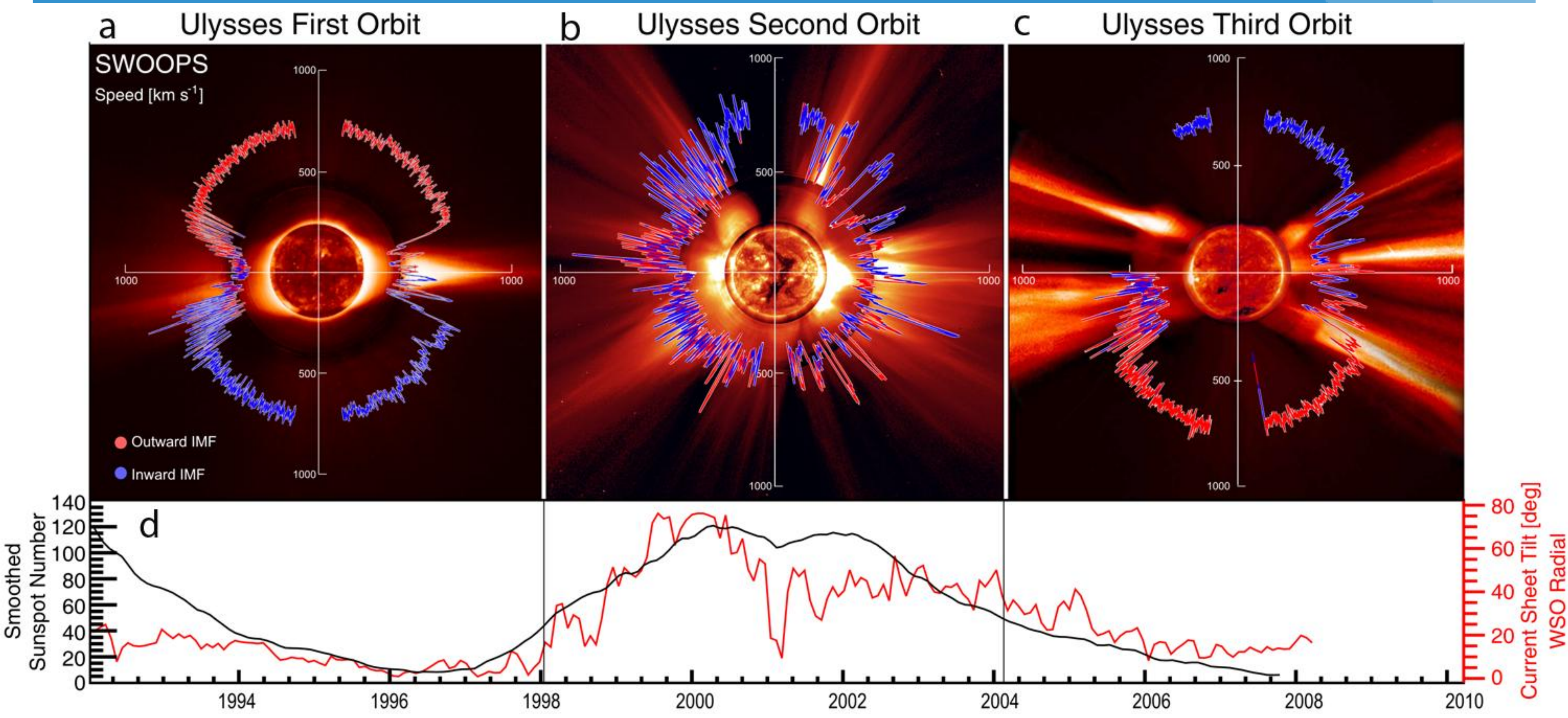
The critical new advances will be achieved by flying spacecraft combining remote and in-situ observations into the inner solar system.

In-situ measurements of the solar wind plasma, fields, waves, and energetic particles close enough to the Sun are essential.

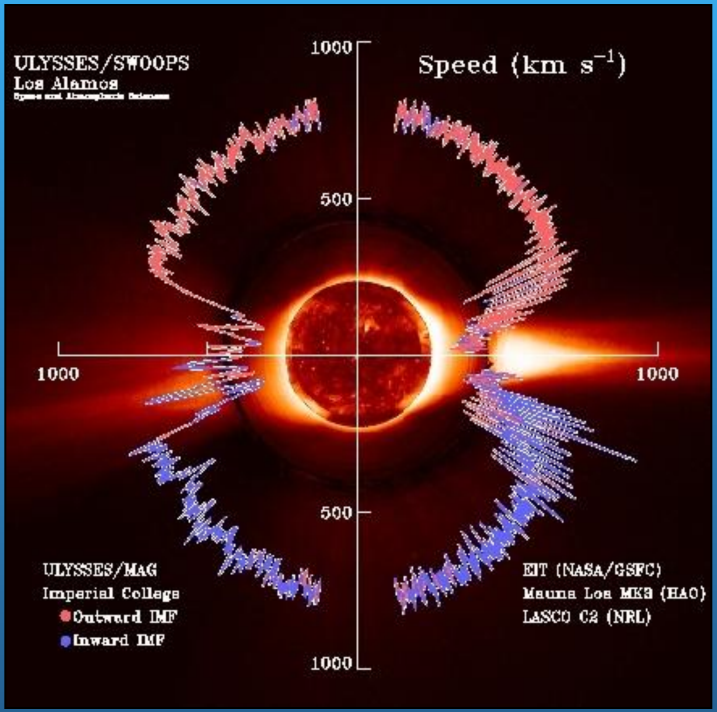
Properties not modified by subsequent transport and propagation processes yet.

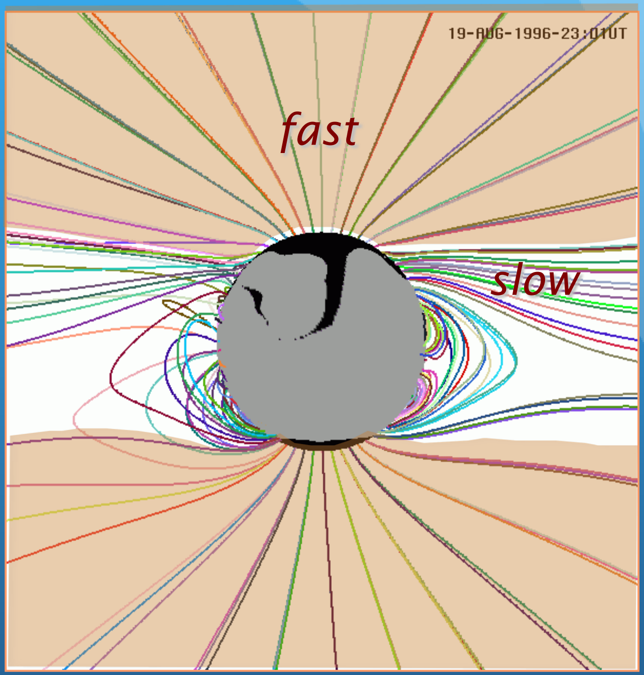
General structure of the solar wind: the scenario appearing from Ulysses over one and a half solar activity cycle

McComas et al. 2003



Rough identification of the solar wind sources at minimum magnetic activity (large scales)





- **Fast wind: polar coronal holes**

- **Slow wind: (less clear picture) boundaries of polar coronal holes, top of helmet streamers (also blobs), edges of active regions, …**

Question:

- **How source region properties are reflected in the solar wind properties through the formation process of the solar wind?**
- **Problem:** **missing link of solar wind structures back to their source regions at the Sun**
- **It is the goal of Solar Orbiter and Solar Probe Plus: thanks to the powerful combination of in-situ and remote-sensing instruments and the unique inner-heliospheric mission design**
- **Capabilities and specific contribution of remote-sensing instruments**

- What do we need to get a firmer identification and characterization of the coronal source regions of the fast and slow solar wind streams?
- Detailed information on:

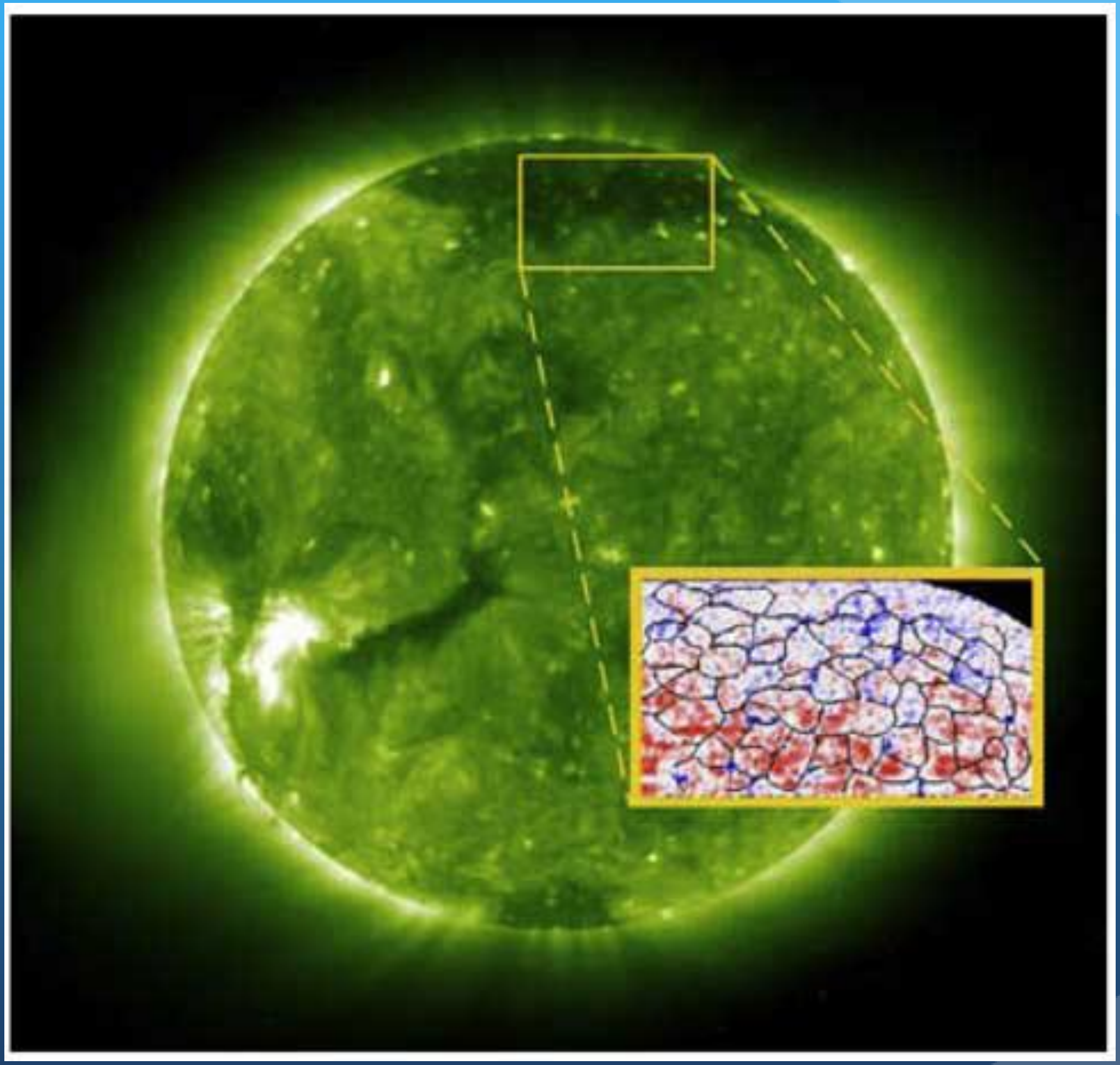
1. Magnetic field intensity and configuration
2. Presence of outflows (velocities?)
3. Chemical composition
4. Energy content and dissipation processes
5. Time variations of the above properties

In solar regions observed on disk and close to the limb

(great help from VL, UV and EUV imagers – morphology)

Spectroscopic studies on the presence of outflows:

EIT, MDI, SUMER on SOHO



Hassler et al. 1999

- **Solar spectroscopic observations, both on-disk and off-limb, provide rich information not only about flows, but also about the electron/ion temperature, density and abundance, in various structures at the Sun from the chromosphere to the corona.**

3. **Chemical composition (*in particular*):**

evidence of different levels of ion fractionation (FIP effect) in various coronal regions (CH, QS, AR)

- **e.g., Feldman & Widing 1990, 1993; Raymond et al. 2001, Feldman et al. 2005, …**

- **FIP bias:** **the factor by which the coronal abundance of an element differs from its abundance in the photosphere**

$= (N_{el}/N_H)_{corona}/(N_{el}/N_H)_{photosphere}$

EUV lines of C, O, Ne, Mg, Si, S, Ar, Fe are very important

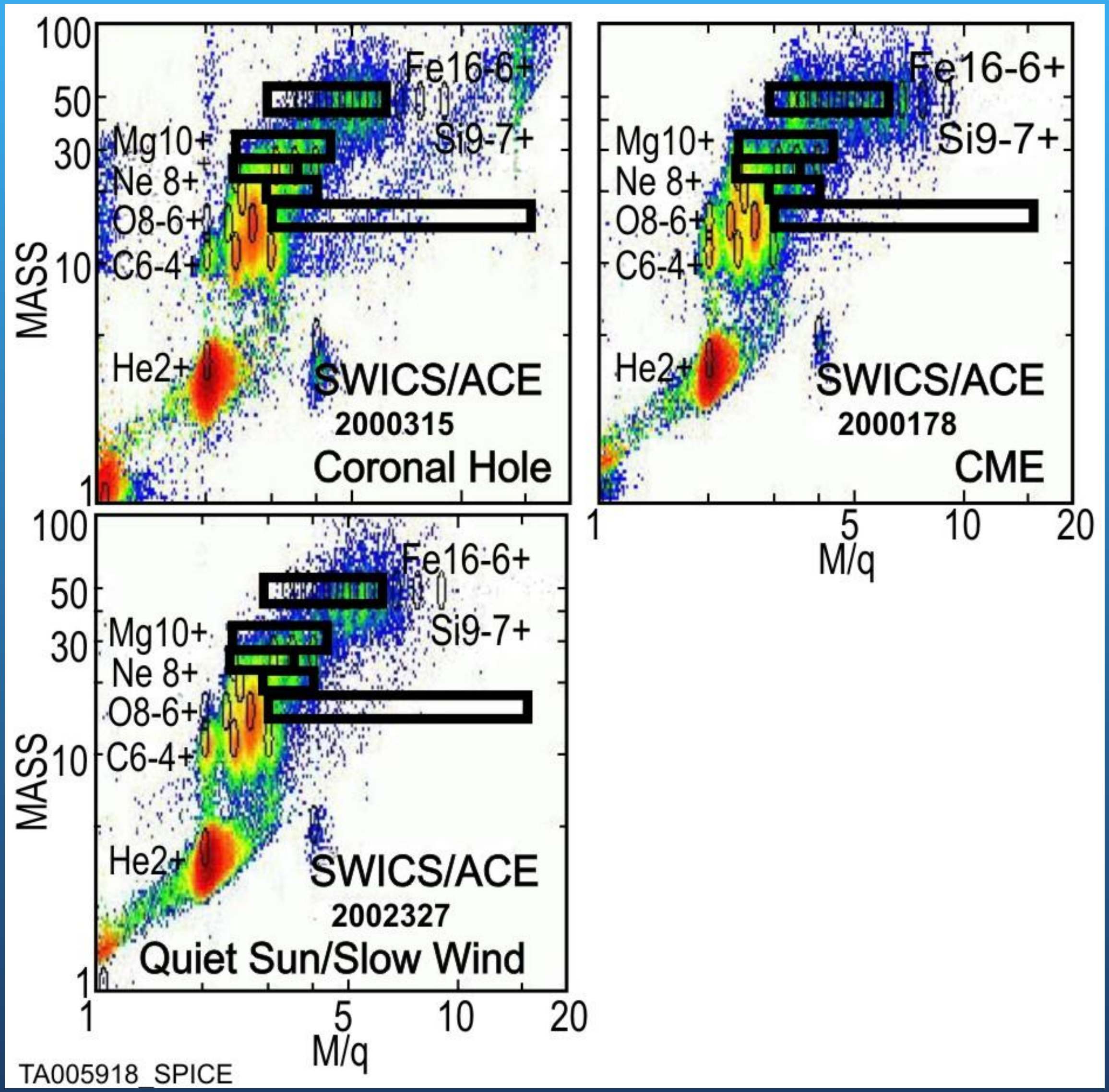
- ***Related to the magnetic field configuration:***

open –> lower FIP bias | **closed –> higher FIP bias**

Coronal holes | **Active regions, Quiet Sun**

- **SPICE on Solar Orbiter will provide detailed composition diagnostic capability of high and low FIP ion species as well as ions with different mass to charge (M/q) ratios**

Remote sensing-in-situ composition correlation is fundamental to help to understanding the origin of solar wind formation:



- fast solar wind:
lower FIP bias

- slow solar wind:
higher FIP bias

e.g.,
Von Steiger et al. 2000,
Zurbuchen et al. 2002,
Ko et al. 2006, 2010
Brooks et al. 2015

magnetic connectivity must be taken into account!

- **Electron temperature in coronal regions is another important parameter – deduced by, e.g., line ratios from three ionisation stages of Fe (X, XII, XIII)** (Ko et al. 2006)

SPICE will measure plasma temperature, in the 0.01-10 MK range

- **Comparison with the freezing-in temperatures deduced by in-situ measurements of the solar wind**

- **See ion ratios: C^{+6}/C^{+5}, O^{+7}/O^{+6}, …**

  (Feldman et al. 2005, Ko et al. 2006)

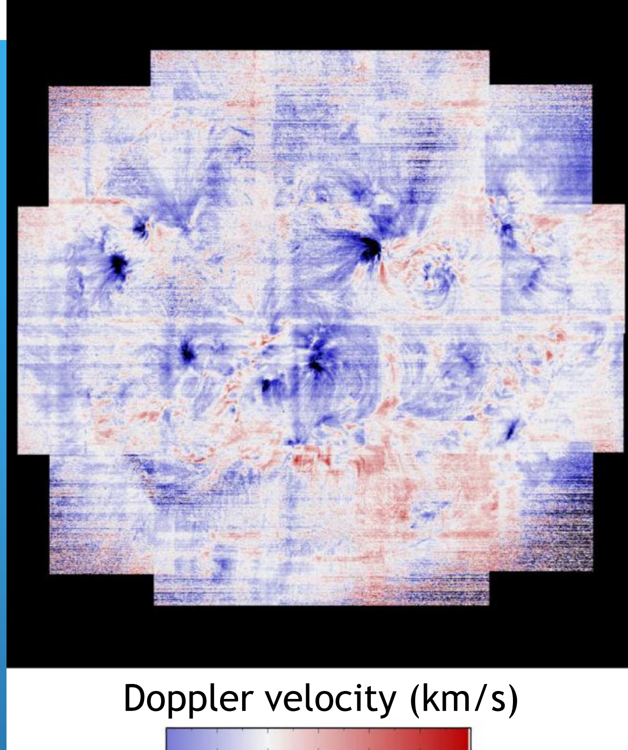
- **Elemental abundances and freeze-in temperatures can be used as tracers for locating the sources from which the slow and fast solar wind emerge** (Feldman et al. 2005)

- **A new paradigm …** (Antiochos 2015)

Full-Sun observations for identifying the source of the slow solar wind (Brooks et al. 2015, Nat. Comm.)

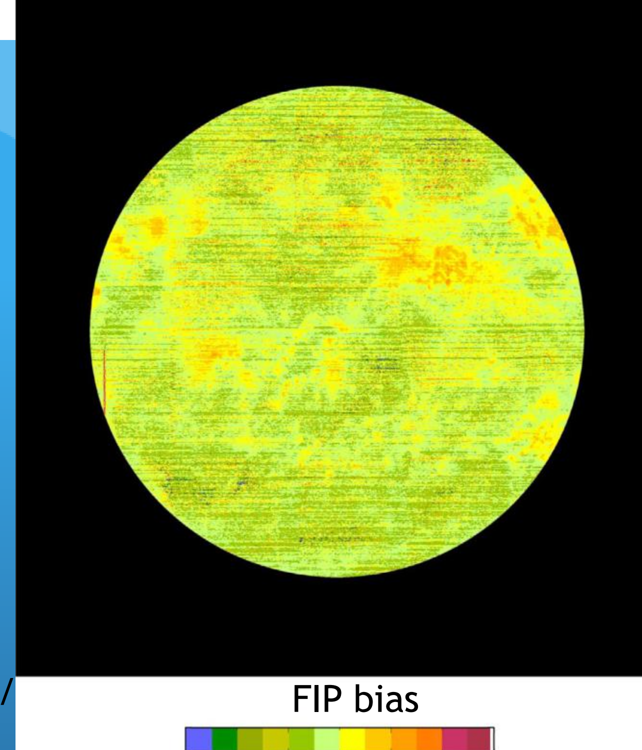
- Specially designed full-disk observations from EIS/Hinode and a magnetic field model
- a series of Fe lines (Fe VIII-XVI) used to measure density and EM (the ratio of the Fe XIII lines at 202.044 and 203.826 Å is sensitive to electron density)
- plus Si X 258.37 Å and S X 264.22 Å to make abundance measurements (their ratio is sensitive to the degree of fractionation of the plasma when convolved with the EM)
- Combining three key ingredients for identifying the sources: velocity, plasma composition and magnetic topology
- <u>Slow solar wind source map of the entire Sun:</u> shows solar wind composition plasma outflowing on open magnetic field lines
  - comparison with ACE/SWICS measurements of the solar wind

Fe XIII
202.044 Å



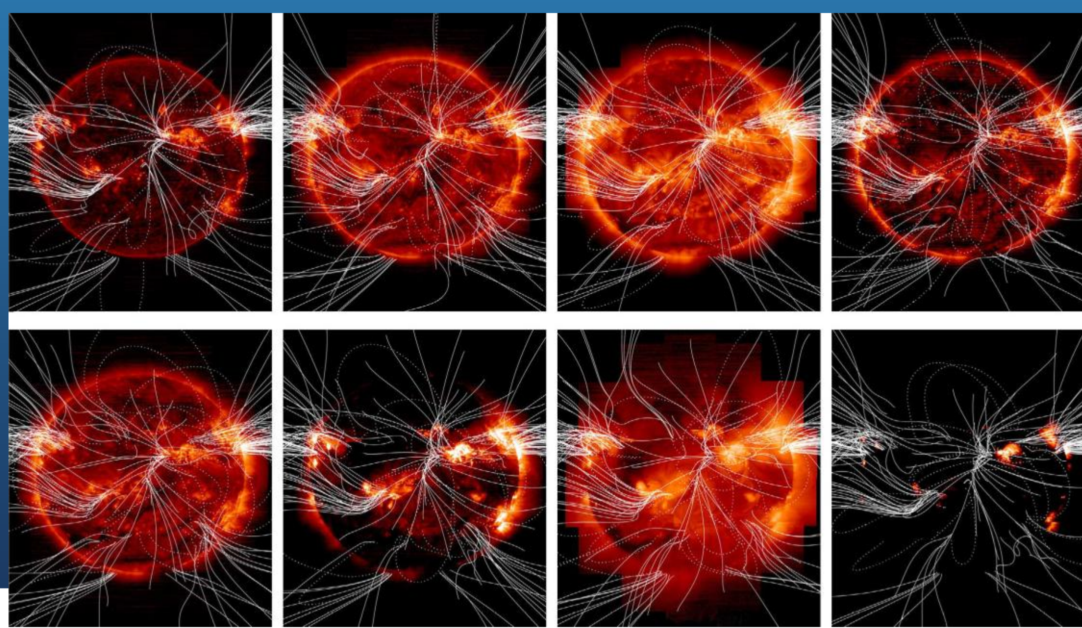
-15 -10 -5 0 5 10 15

Si X 258.37 Å/
S X 264.22 Å



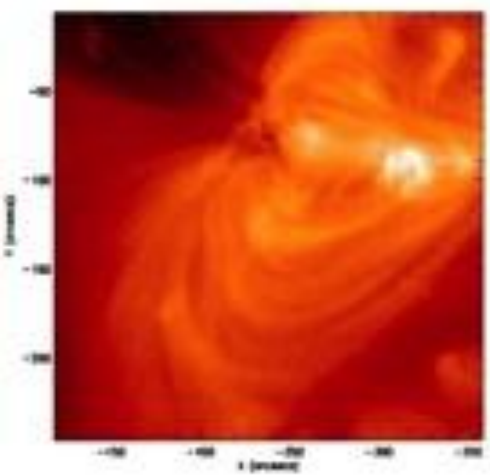
1 2 3 4

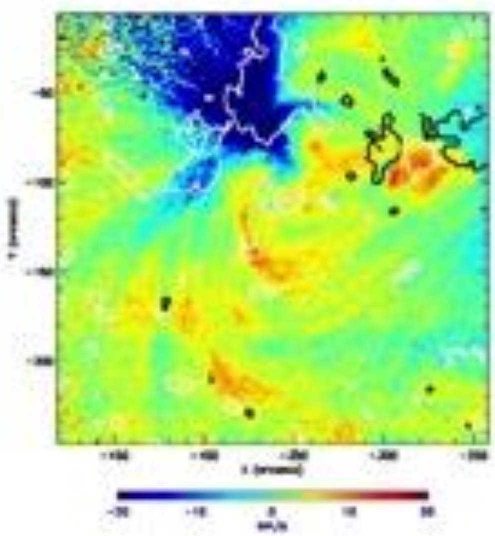
Temperature coverage: from 0.45 MK

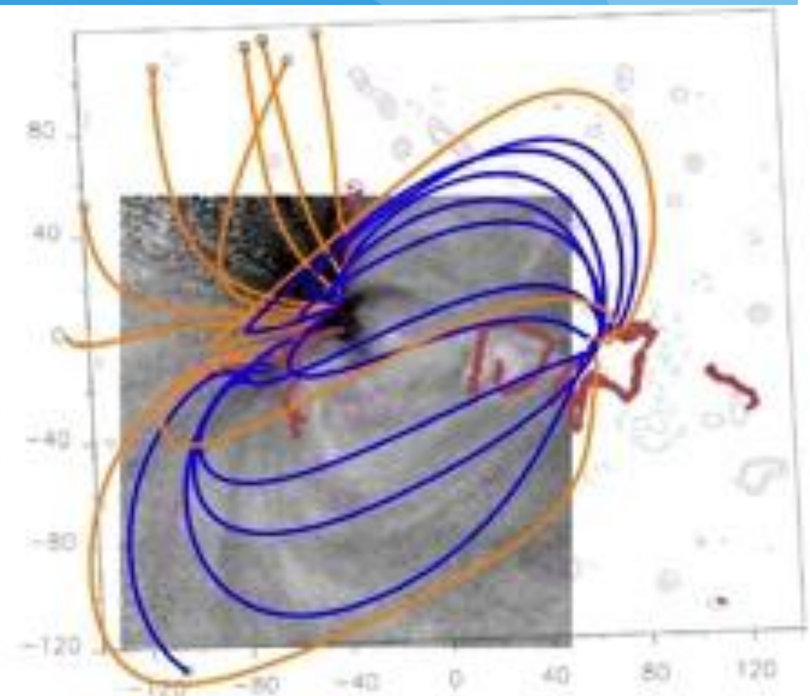


to 2.8 MK

Open field regions in AR edges: potential sources of slow solar wind







Plasma first fractionated to FIP bias levels measured *in-situ* in the slow solar wind and then expelled on open magnetic field lines.

The possibility of deviations from ionisation equilibrium

- due to flows across temperature and density gradients and/or to transient events (e.g., impulsive heating)

Taking this possibility into account is: **- GCR theory -**

- very important in the analysis of line ratios for coronal temperature and density diagnostics
- very important for emission measure determinations
- crucial in abundance and FIP bias evaluations

Freeze-in temperature interpretation (modelling of coronal plasma outflows) should also take into account non-equilibrium ionisation effects…

- Remote sensing instruments (in particular, EUV spectrometers) can give a significant contribution to the investigation on the coronal sources of the solar wind streams
- Combination with measurements by in-situ instruments are crucial to link solar wind structures back to their sources at the Sun,
- so exploring the Sun-heliosphere connection
- Detailed treatment of magnetic connectivity, implying a significant theoretical effort, is fundamental in such exploration.
- Good luck with Solar Orbiter and Solar Probe Plus!

Thank you for your attention!