Planetary magnetospheres

1. The Sun

1.1. 2-D heliosphere
1.2. 3-D structure
1.3. Transient processes – Solar flares and CMEs

2. Solar wind interaction with planets

2.1. Types of interaction
2.2. No atmosphere – No magnetic field
2.3. Role of the atmosphere
2.4. Role of the intrinsic magnetic field

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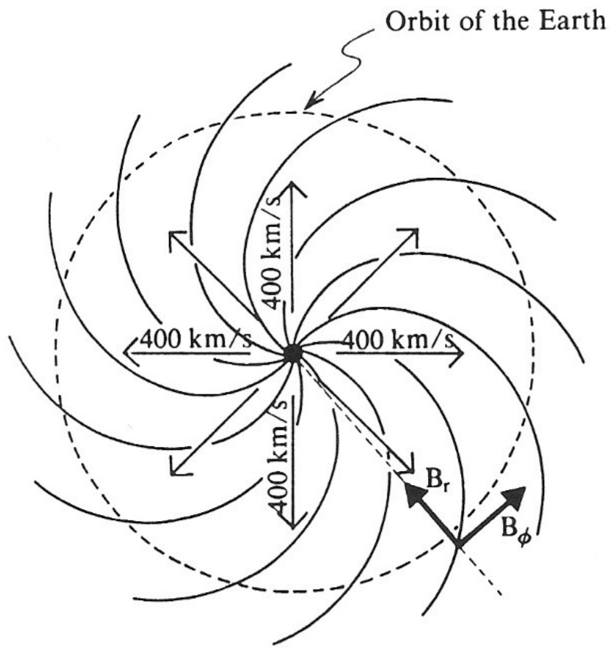
1. The Sun

1.1. 2-D heliosphere

Observations from the ecliptic plane → 2-D structure

Magnetic lines of force leaving the Sun form giant magnetosphere: heliosphere.
Entrained by Sun rotation - Studied with MHD (Magneto-Hydro-Dynamics)



Encrenaz & Bibring, 2002

Magnetic pressure

$$p = \frac{B^2}{2\,\mu_0}$$

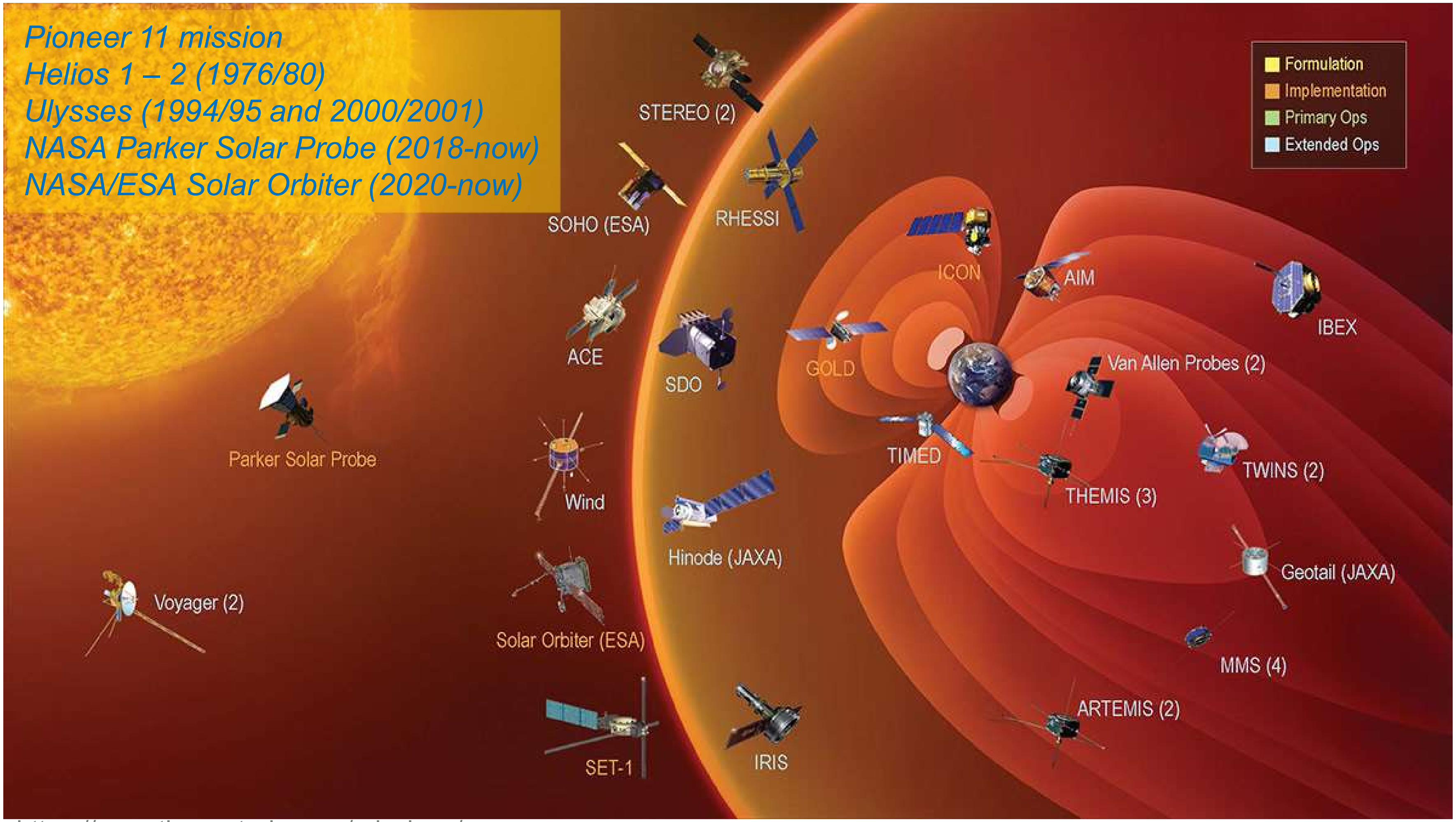
Interplanetary field: average 4 nT

Solar wind: 99% H^+ and He^{++} ions (3.5-4.5%)

Some particles reach velocities of up to 700 km/s

1.2. 3-D structure

We need to measure away from the ecliptic plane:



https://www.thesuntoday.org/missions/

Interplanetary magnetic field organised into sectors of opposite magnetic polarity:
“solar ballerina” model of Alfven (1977)

1 The Solar Atmosphere and Space Weather 11

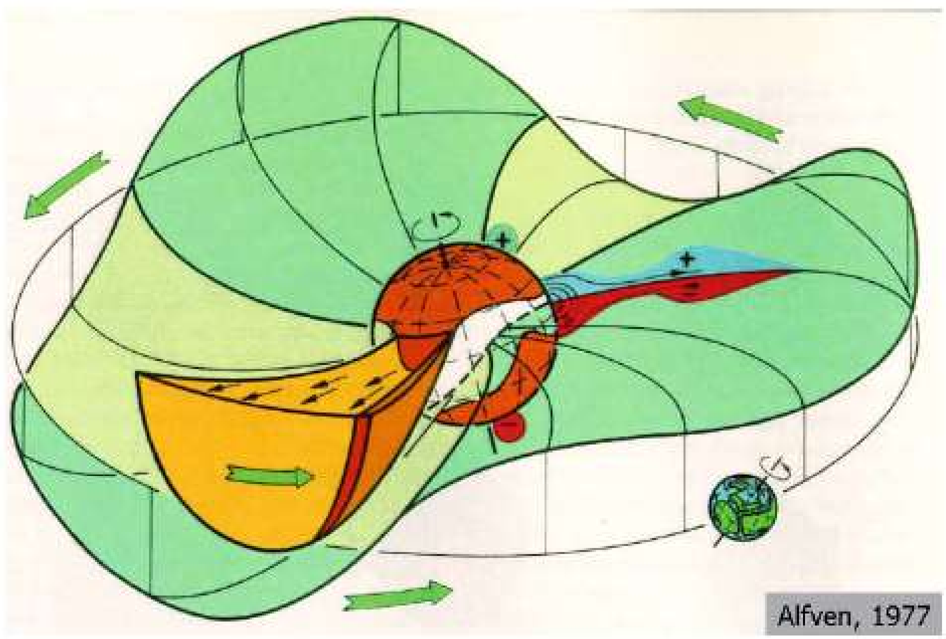


Fig. 1.7. The solar ballerina proposed by H. Alfvén (1977) – schematic picture of the structure of the inner heliosphere near solar minimum. The Sun’s poles are covered with large coronal holes of opposite magnetic field polarity. Co-rotating solar wind streams of opposite magnetic polarity with a heliospheric current sheet (HCS) in between them dominate the flow pattern. The situation shown here is typical for odd cycles.

Blondel & Mason, 2006

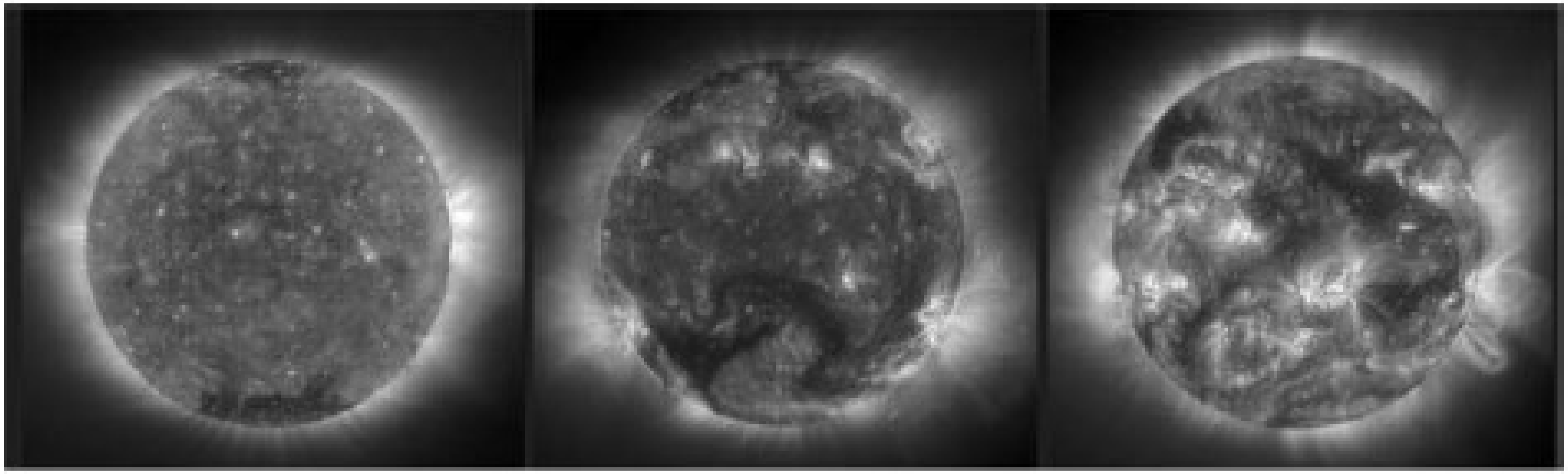
Two states of solar wind:

- low-speed wind (~ 400 km/s), combining jets of different velocities, close to ecliptic;

- high-speed wind (700-750 km/s), homogeneous, at high (solar) latitudes;

Separated by sharp boundary

1.3. Transient processes – Solar flares and CMEs



Blondel & Mason, 2006

Fig. 1.10. Three EUV-images of the solar corona taken by SoHO/EIT at 195 Å in 1996, 1998 and 1999. Solar maximum was in 2000. Note the strong change in coronal structure, the increase of the number of bright shining coronal regions with stronger underlying photospheric magnetic fields and the appearances of dark coronal regions with underlying open magnetic field structure at lower latitudes. Courtesy: SOHO/EIT consortium.

Solar flares

Sudden flash of light on the Sun – Can disrupt radio signals

Analogy: muzzle flash

Coronal Mass Ejections (CMEs)

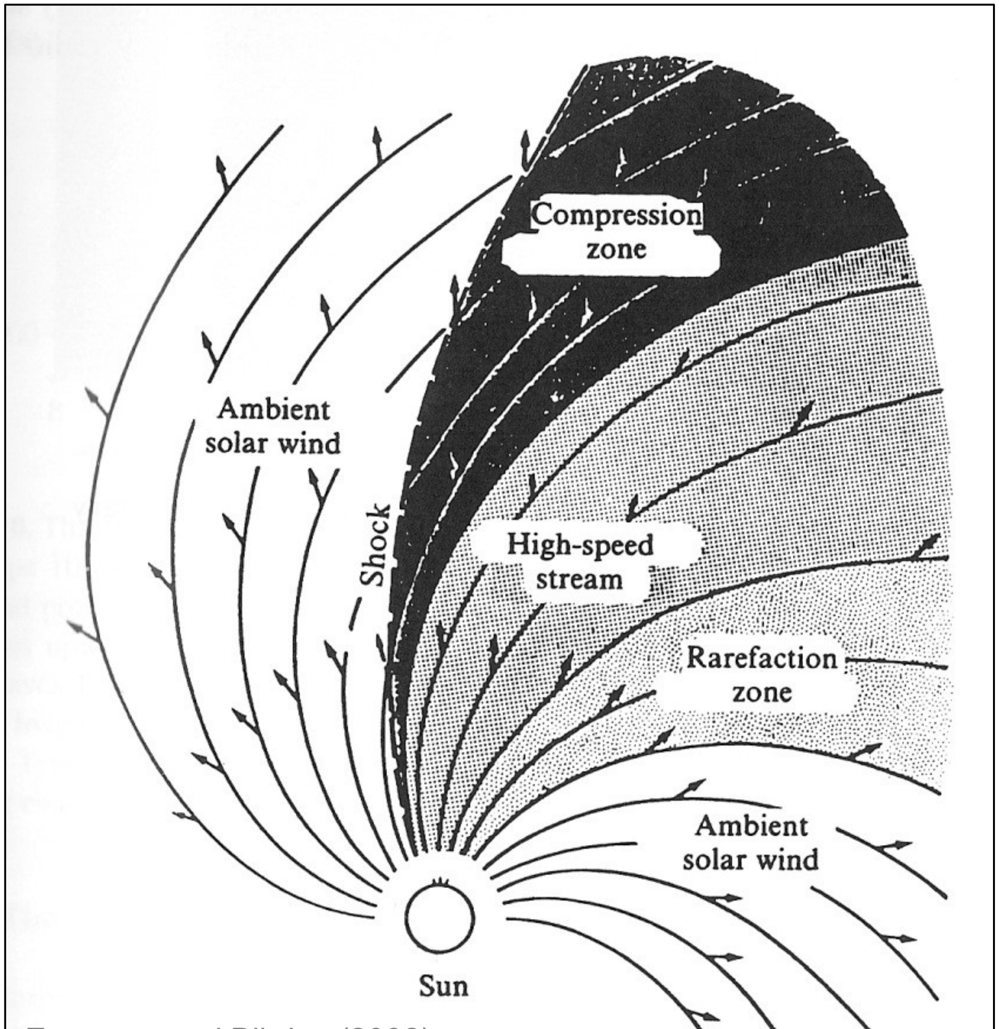
Occur at active regions – New material (particles) preceded by shock wave

Analogy: cannonball

1.3. Transient processes - CMEs

High-speed jets interact with slower ambient solar wind.

Creates compression/rarefaction zones as well as shock waves.



Encrenaz and Bibring (2002)

LATEST RESULTS

<u>NASA Parker Solar Probe (Astrophys. J., Feb. 2020)</u> > 0.25 AU from Sun

Unanticipated “switchbacks” in the solar wind

the Sun's magnetic field abruptly doubles-back on itself

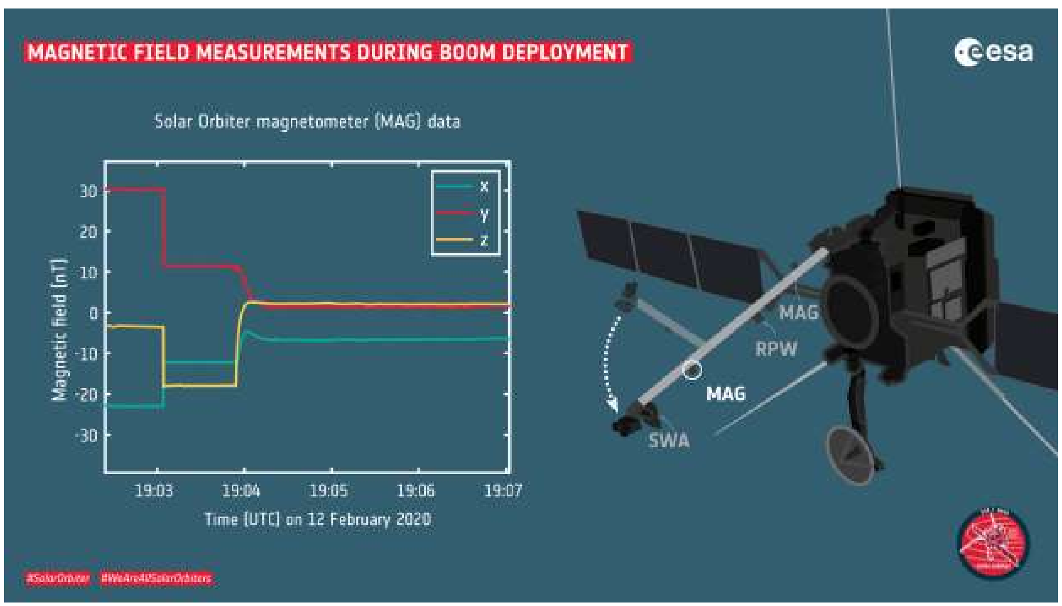
Evidence for a “dust-free zone” — first hypothesized in 1929, but never successfully detected — beginning an estimated 3.5 million miles from the Sun,

The first measurement of rotation in the solar wind — before it begins to flow radially, or straight out from the Sun, as it does near Earth,

Detections of never-before-seen particle events

so small that all trace of them is wiped out before they reach Earth.

<u>ESA/NASA Solar Orbiter (17 Feb. 2020):</u> > 0.28 AU from Sun



Deployment of magnetic boom:

$< 10^{-3}\ B_{earth}$

First mission to image Sun’s poles (in 2025–2029)

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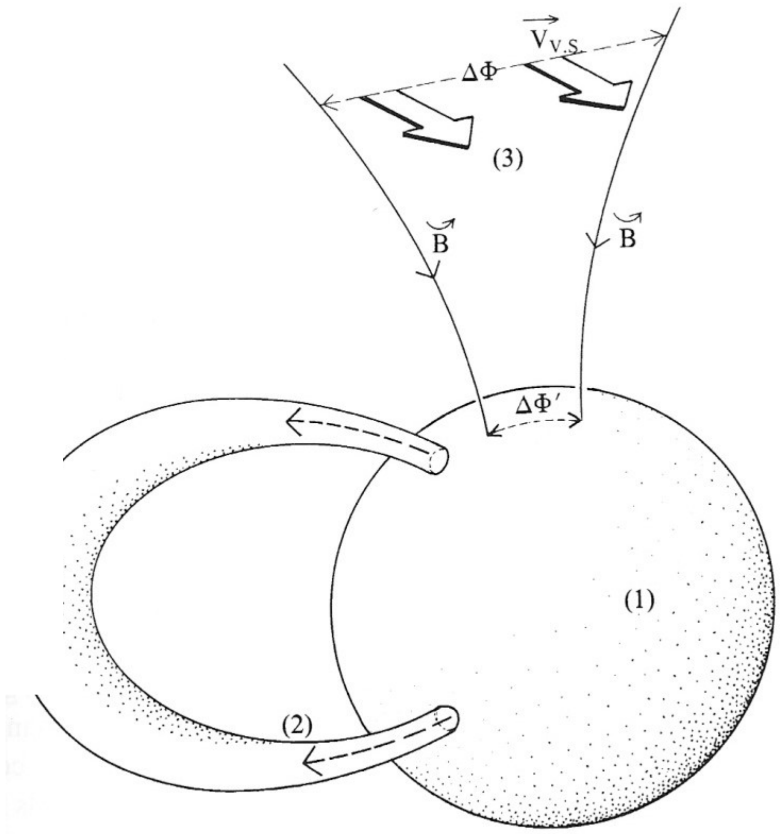
2.1. Types of interaction

Electromagnetic (mostly UV and X) radiation from Sun and corpuscular radiation from energetic particles → ionisation of outermost external envelopes of atmosphere (if any)



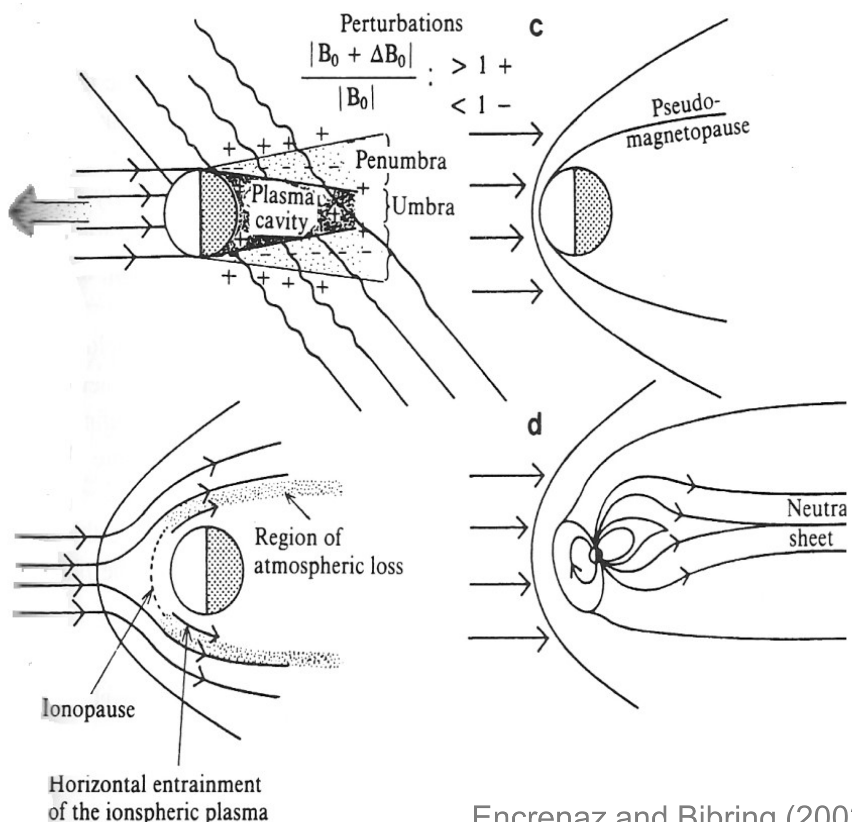
Encrenaz and Bibring (2002)

(1) Ionosphere layers form conducting shell, surrounding the planet;

(2) If planet has a magnetosphere, plasma from ionisation of upper atmosphere diffuses into magnetic tubes, filling them with fairly cool plasma (0.1–1 eV);

(3) Diffused, cold electrons cause lines of force to be highly conductive, connecting the ionospheric conductor to the dynamos set up by the relative motion of the magnetised solar wind and the planet;

Interaction of solar wind with planet depends on its properties



Encrenaz and Bibring (2002)

solar wind directly arrives on planetary body

left: encounters atmosphere
right: encounters external magnetic field

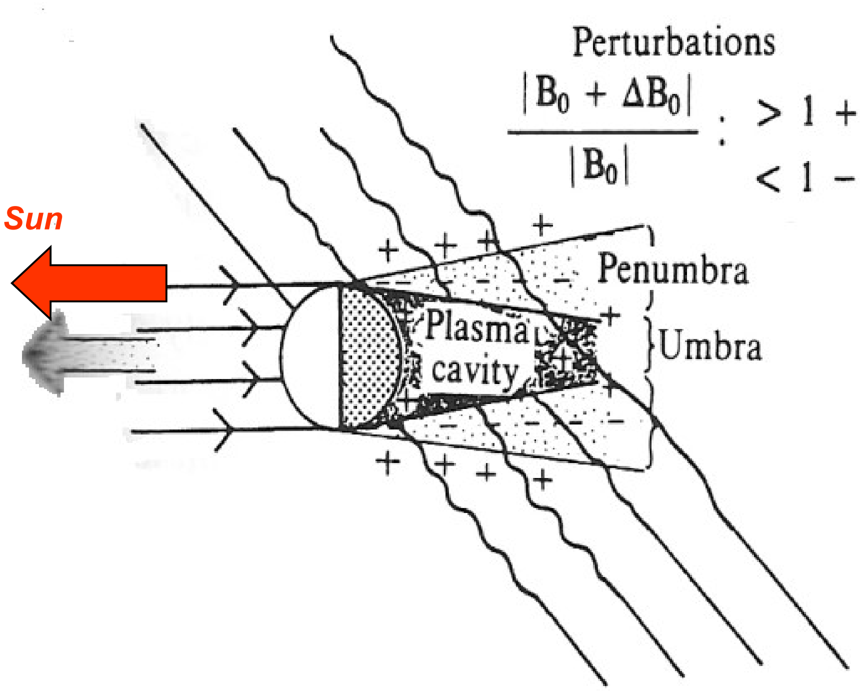
Distance at which planetary field can stand off solar wind pressure: *Chapman-Ferraro distance*

$$R = R_{\text{planet}} \left(\frac{2\, B_{\text{surface}}^{\;2}}{\mu_0\, m_p\, \rho\, v_{\text{solar\_wind}}^2} \right)^{\frac{1}{6}}$$

density of solar wind components

2.2. No atmosphere – No magnetic field

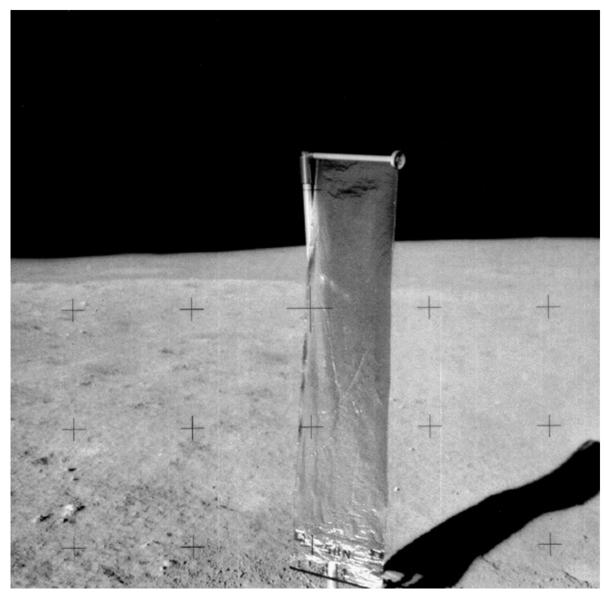
First case: insulator, absorbing ions of the solar wind. Example: the Moon.



Encrenaz and Bibring (2002)

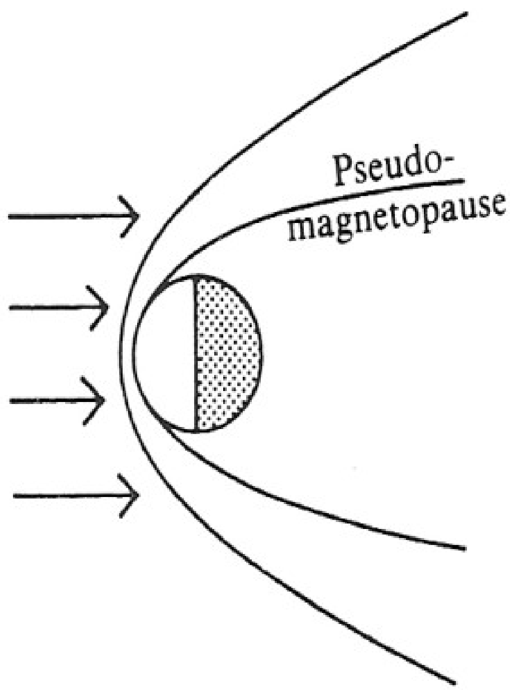
Downstream: plasma-free cavity

Progressively filled by ion/e$^-$ diffusion, further down



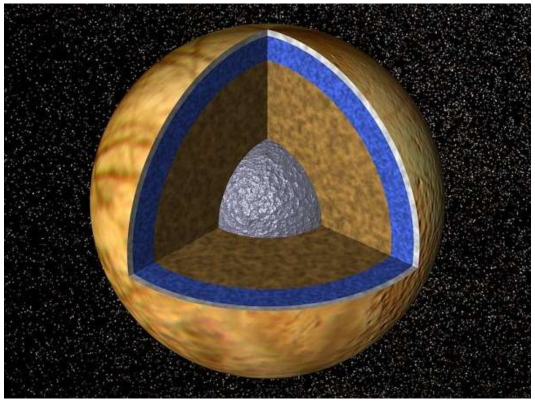
Solar wind experiments (Apollo 11, 12, 14, 15, 16)

Second case: central body is good conductor. Magnetic lines bent/stretched over it.



Encrenaz and Bibring (2002)

Example: Europa and Callisto (Galileo measurements)
Presence of liquid conducting layer (ocean?)

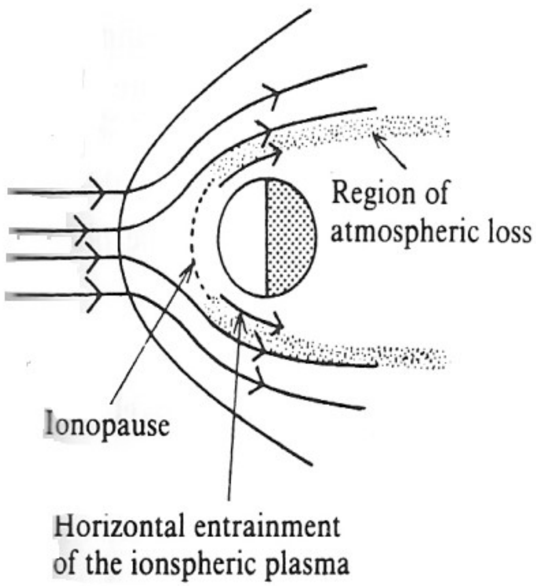


Europa

Callisto

Moment of inertia confirm possible liquid ocean

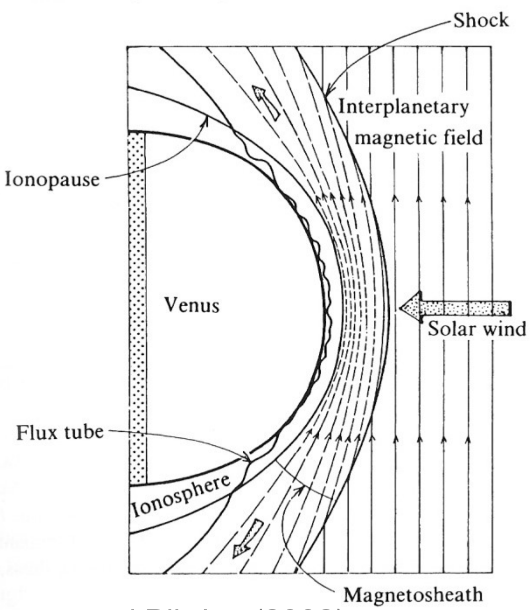
2.3. Role of the atmosphere



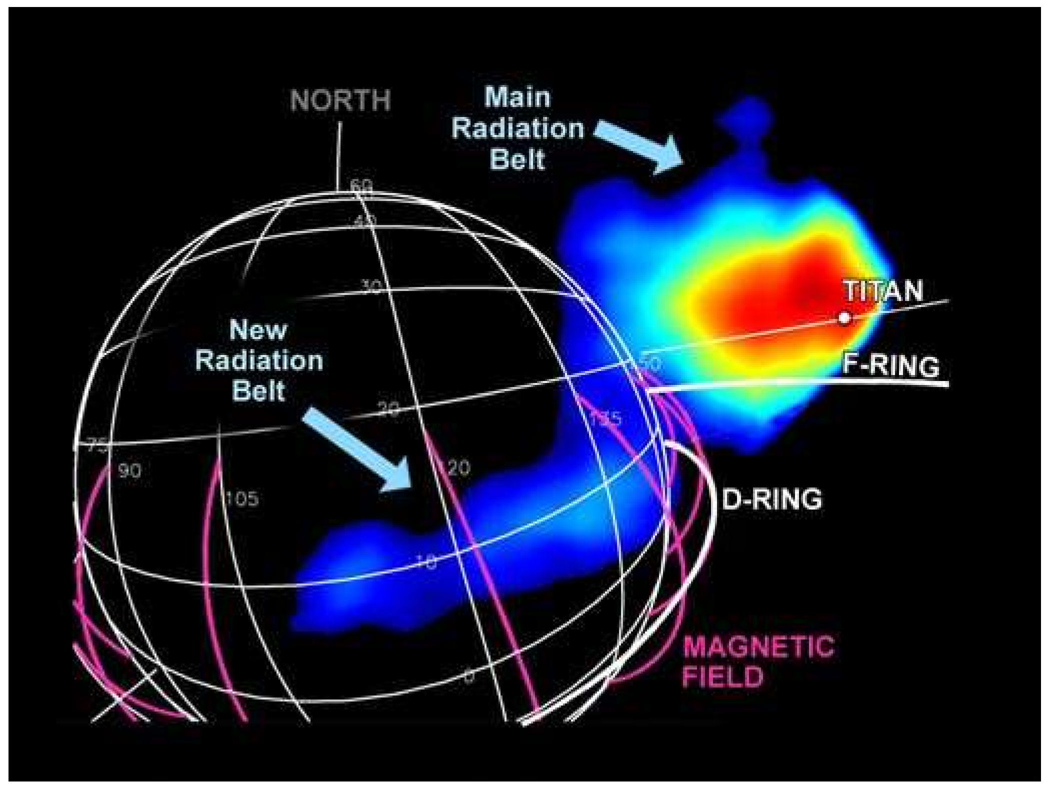
Dense atmosphere – No magnetic field

Solar wind interacts directly with atmosphere.
Examples: Venus, Mars, comets

Also:
Titan (+ interaction with Saturn's magnetic field)
Io (+ interaction with Jupiter's magnetosphere)



Encrenaz and Bibring (2002)



Widely different characteristics of oxygen and hydrogen ion escape from Venus

R. Jarvinen,[1] E. Kallio,[1] S. Dyadechkin,[1] P. Janhunen,[1] and I. Sillanpää[2]

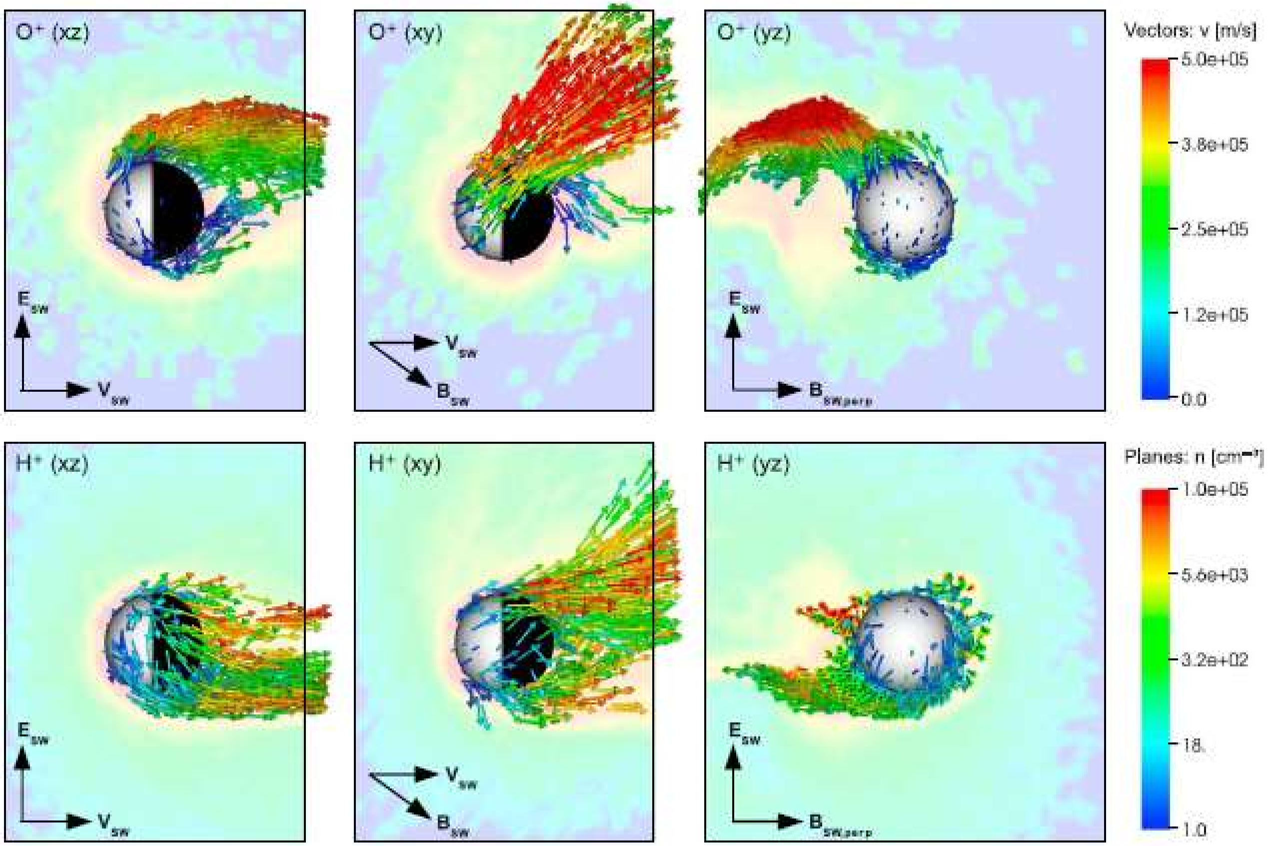
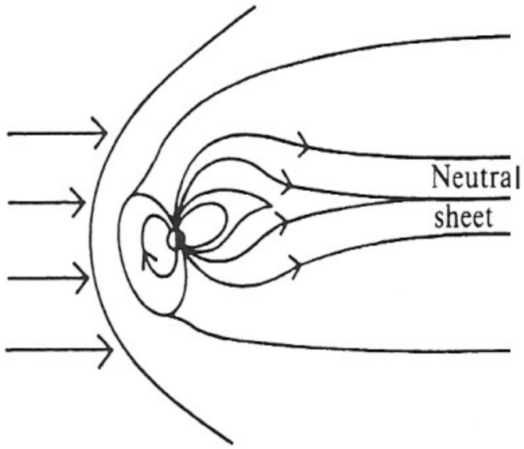


Figure 1. Flow vectors of the planetary (top) O^+ and (bottom) H^+ ions in the regions where their bulk fluxes are high ($n_i v_i > 10^{10}$ s^{-1} m^{-2}). Three different projections onto the (listed from the left) xz, xy and yz planes are shown. Vectors are normalized and their orientation and coloring illustrate the velocity. The background coloring shows the densities at the $y = 0$, $z = 0$ and $x = -2R_V$ planes. The arrows in the lower left corners show the orientation of the velocity (V_{SW}), electric field (E_{SW}) and magnetic field (B_{SW}) of the solar wind.

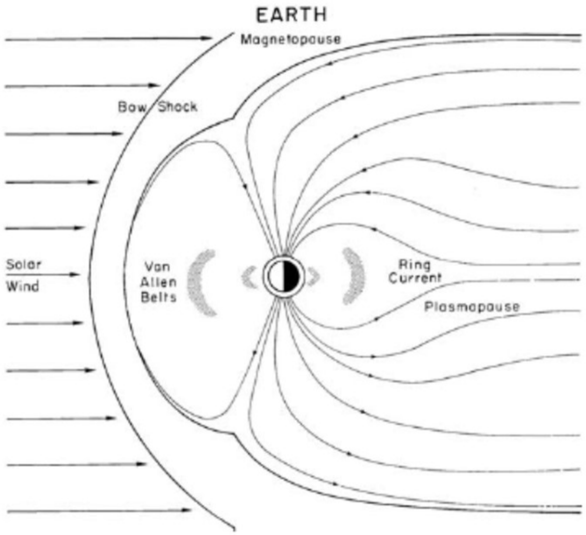
0094-8276/10/2010GL044062

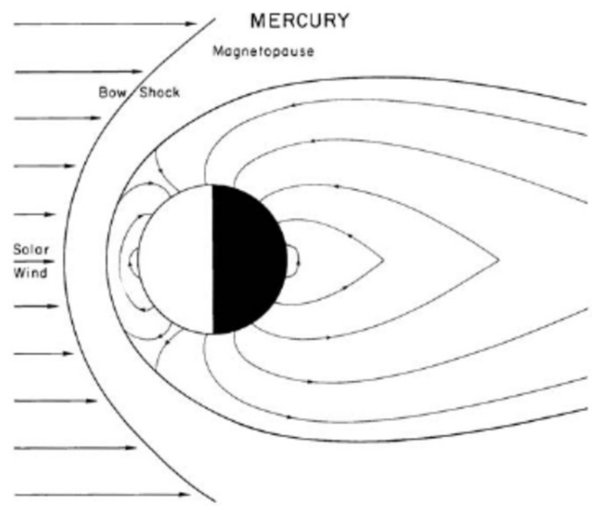
2.4. Role of intrinsic magnetic field

Magnetic field + atmosphere. Magnetic field creates “cavity” in solar wind.

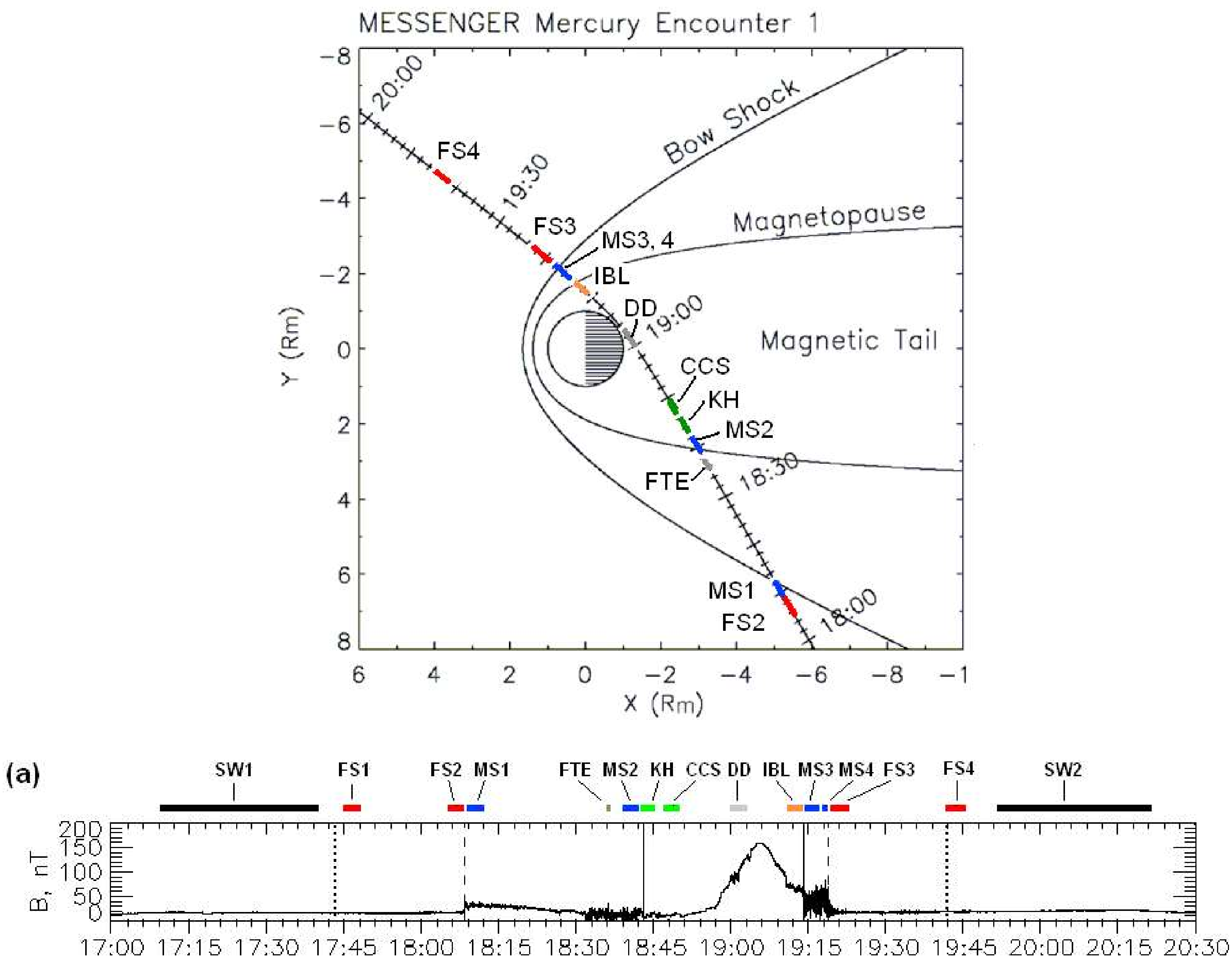


Examples: Mercury, Earth, Jupiter, Saturn, Uranus, Neptune

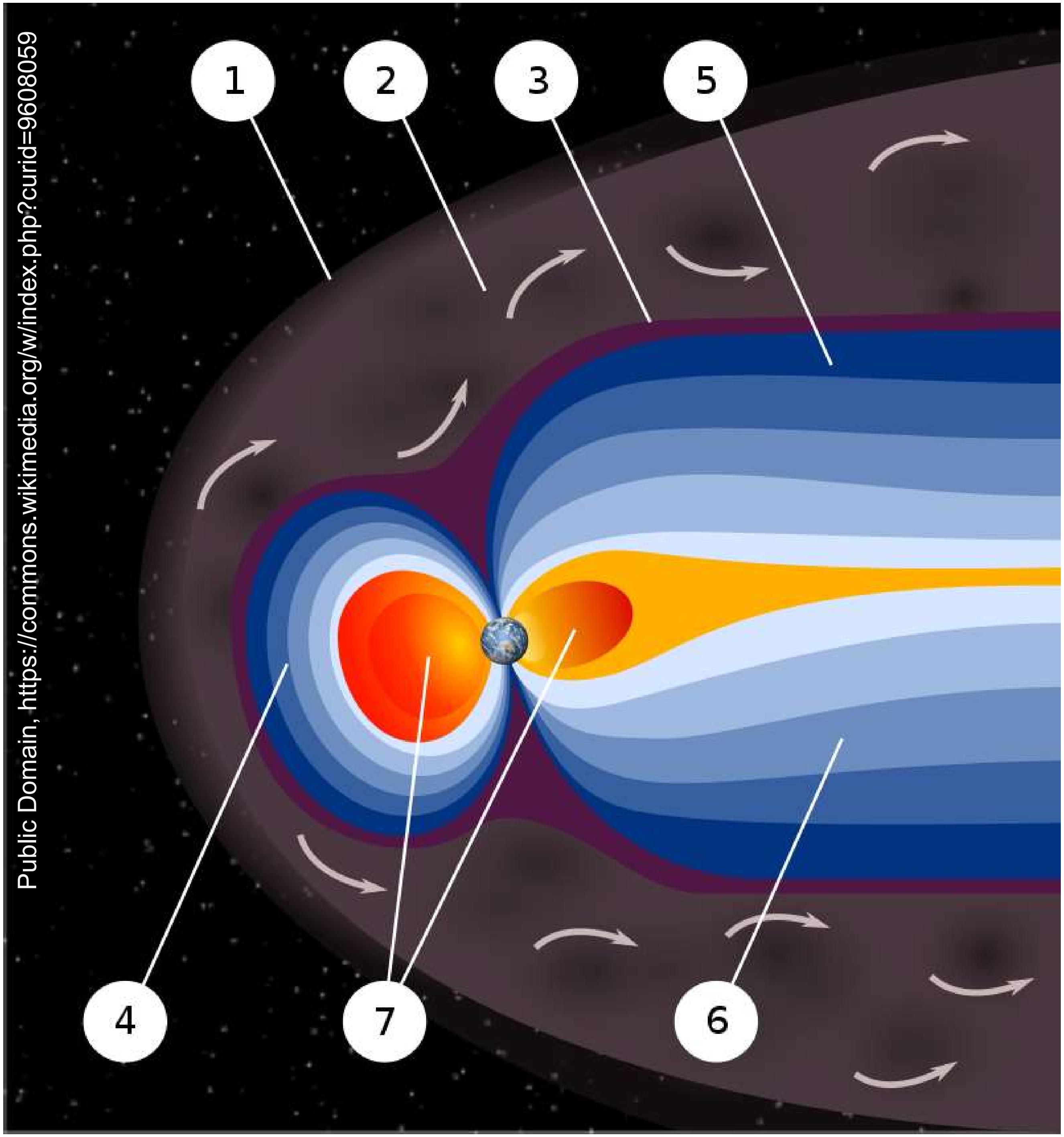




Encrenaz and Bibring (2002)



Citation: Uritsky, V. M., J. A. Slavin, G. V. Khazanov, E. F. Donovan, S. A. Boardsen, B. J. Anderson, and H. Korth (2011), Kinetic-scale magnetic turbulence and finite Larmor radius effects at Mercury, *J. Geophys. Res., 116*, A09236, doi:10.1029/2011JA016744.



1) Bow shock

2) Magnetosheath

3) Magnetopause

4) Magnetosphere

5) Northern tail lobe

6) Southern tail lobe

7) Plasmasphere

<u>Asymmetric:</u>

10 R_{Earth} sunward

> 200 R_{Earth} downstream

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