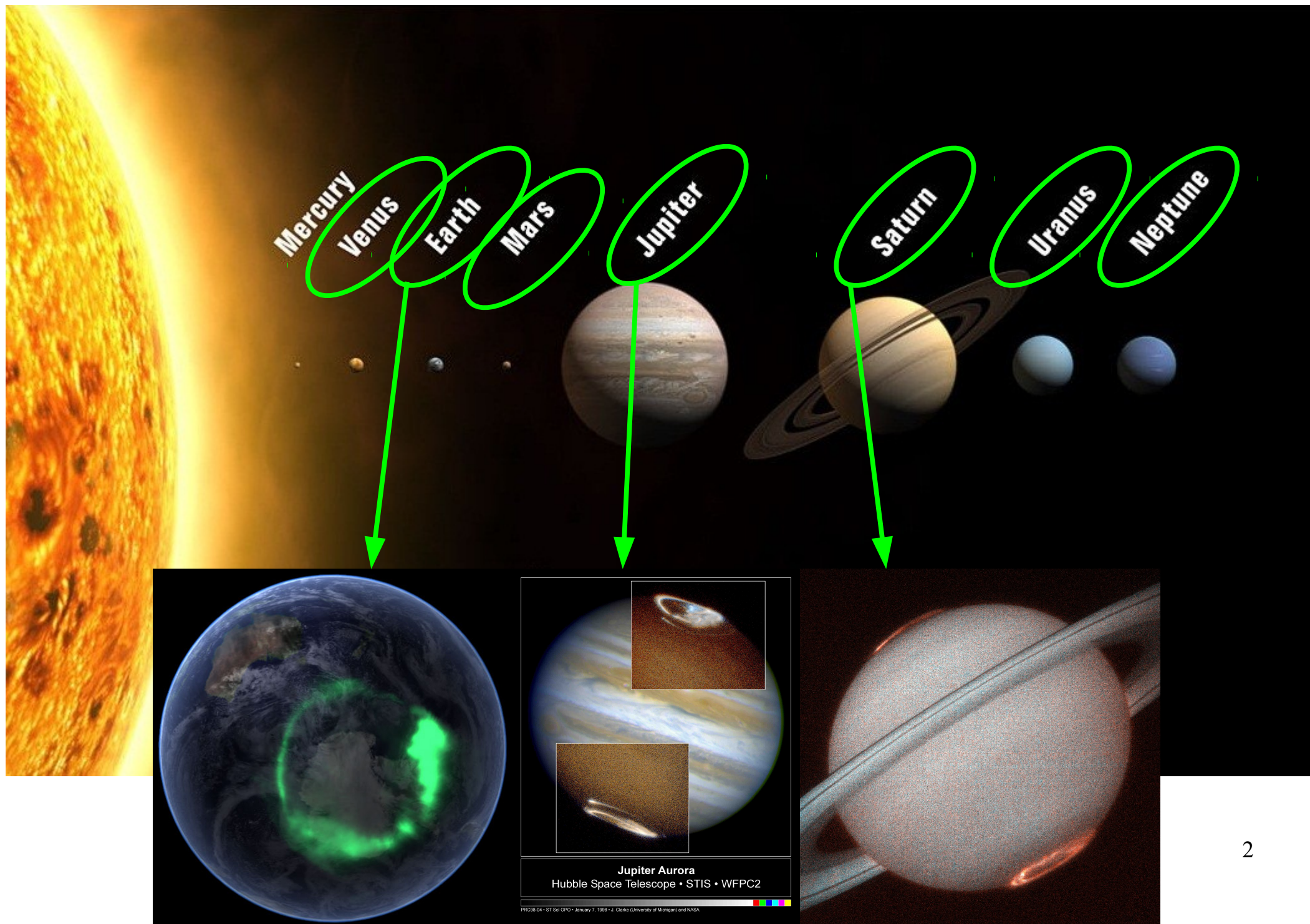


Chapter 9

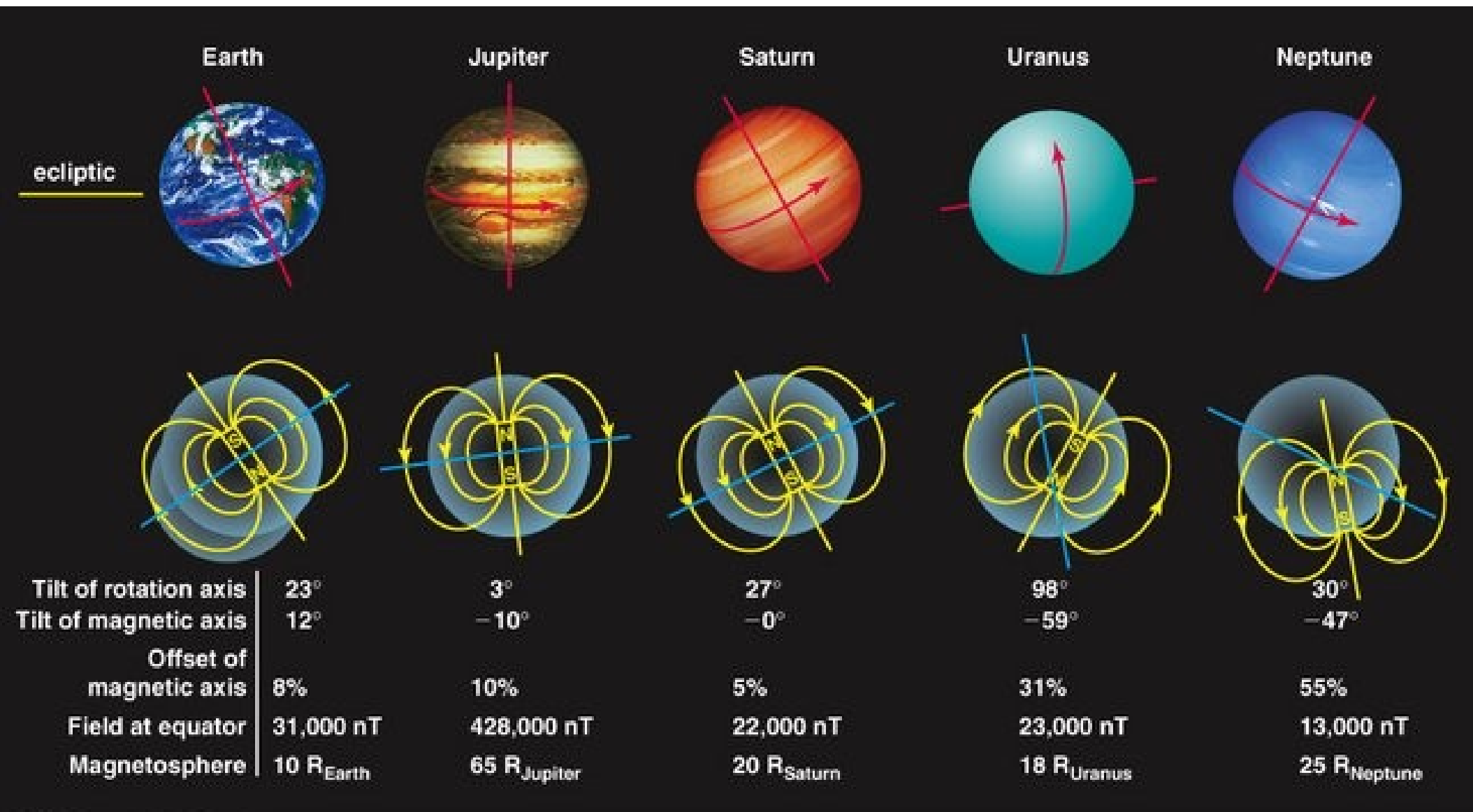
On the magnetic fields of planets



Content

- Outer planets
- Mercury
- Venus
- Mars
- Moon

Magnetic fields of the outer planets

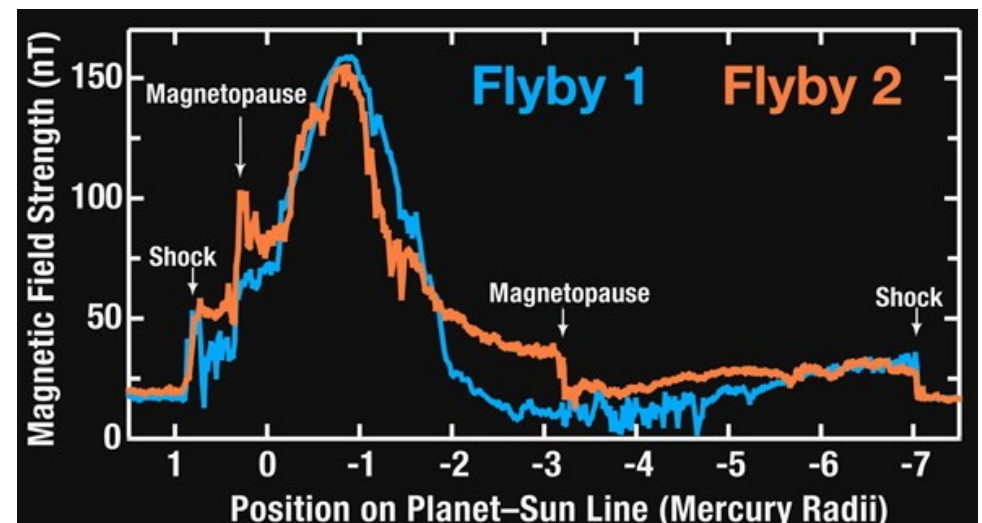
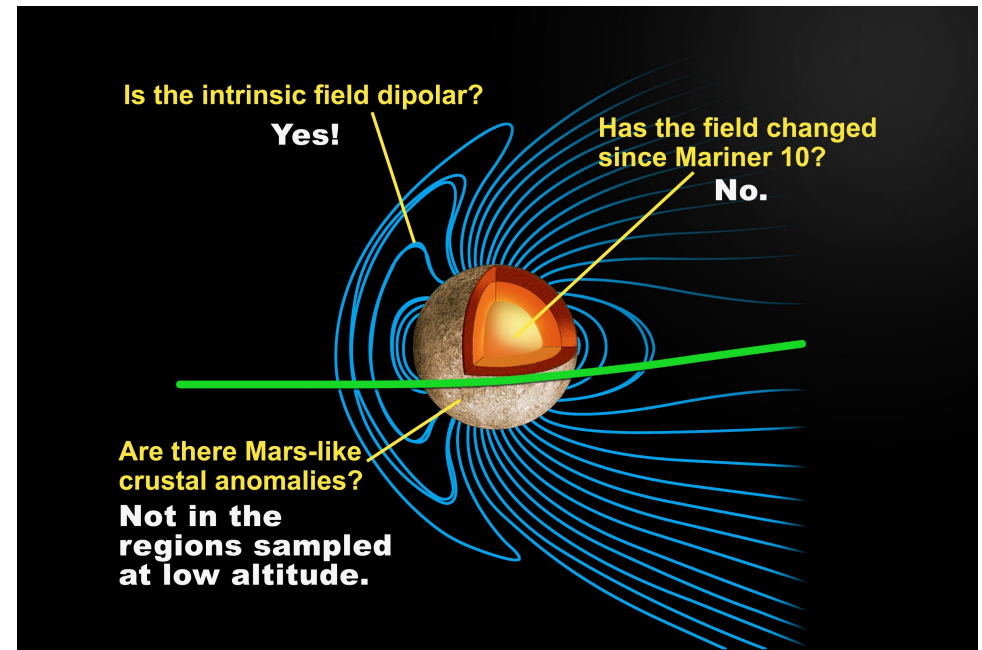


Conditions for an intrinsic magnetic field

- To have a magnetic field, it is believed, a planet must fulfill these conditions:
 - There must be a region within the planet that is liquid;
 - The region must also be electrically conducting;
 - There must be an energy source that sets the region in motion and then keeps it moving.

Mercury

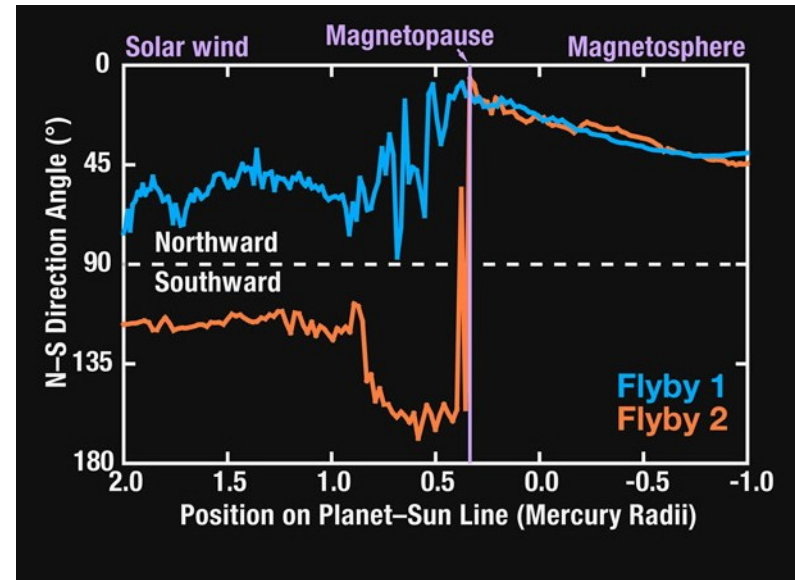
- MESSENGER saw an internal magnetic field that is well described by the field from a dipole nearly aligned with the planet's spin axis (dipole tilt $\sim 10^\circ$).
- This geometry is similar to that observed by Mariner 10 (more than 30 year ago) during its first flyby.
- The dipolar field is consistent with an active electrical dynamo in which the magnetic field is produced by electrical currents flowing in an outer core of molten metal.
- The observations do not yet allow to identify whether a small secular variation may have occurred, determine higher order structure in the field, or assess whether crustal magnetic signatures may be present at other longitudes.



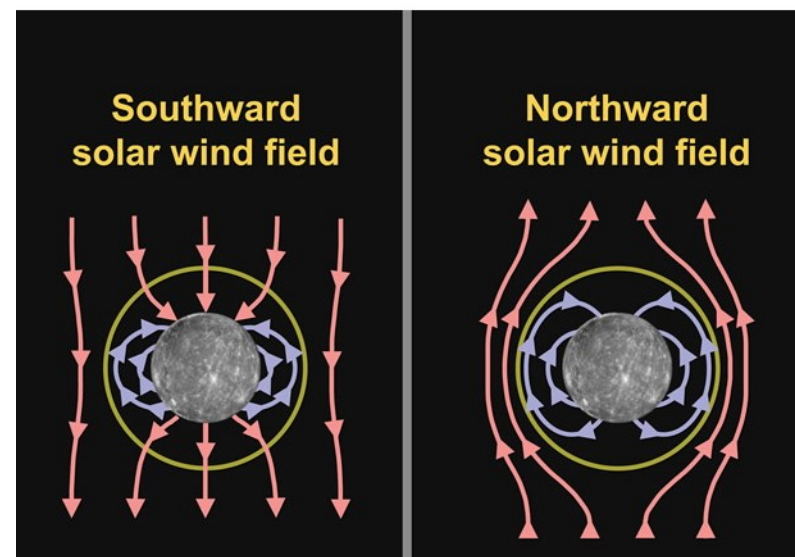
From: <http://messenger.jhuapl.edu>

Interaction of Mercury's magnetic field with the IMF

- For southward IMF, the solar wind and planetary magnetic fields are connected over the poles and Mercury's magnetosphere is tightly coupled and strongly driven by the solar wind.
- For northward IMF, the magnetosphere is “closed” and there is minimal inter-connection between the solar wind and planetary magnetic fields.



Dawn-dusk meridian plane viewed from the Sun.



Venus

- Practically no intrinsic magnetic field.
- Theories of the dynamos operating in the liquid cores of the newly accreted terrestrial planets suggest that there was a magnetic moment of Venus of the same order as Earth's for about the first billion years of Venus' life. During that time, thermal convection from the heat left over from accretion drove the dynamo. However, after that energy source diminished, there was apparently no source to replace it.
- Contrary to popular belief, dynamo theory does not credit the smallness of the magnetic moment to the slow rotation of Venus (a Venus day of ~ 243 Earth days is almost equal to the length of its year of ~ 224 days, and its sense of rotation is retrograde).
- Venus would not have maintained any remnant crustal magnetic fields from its proposed early period of dynamo activity because the temperatures in the crust are expected to be above the Curie point (below which such fields could persist in rocky materials).

The magnetosphere of Venus

- The magnetosphere of Venus that has been detected by spacecraft is known to be an example of an “induced” magnetosphere.

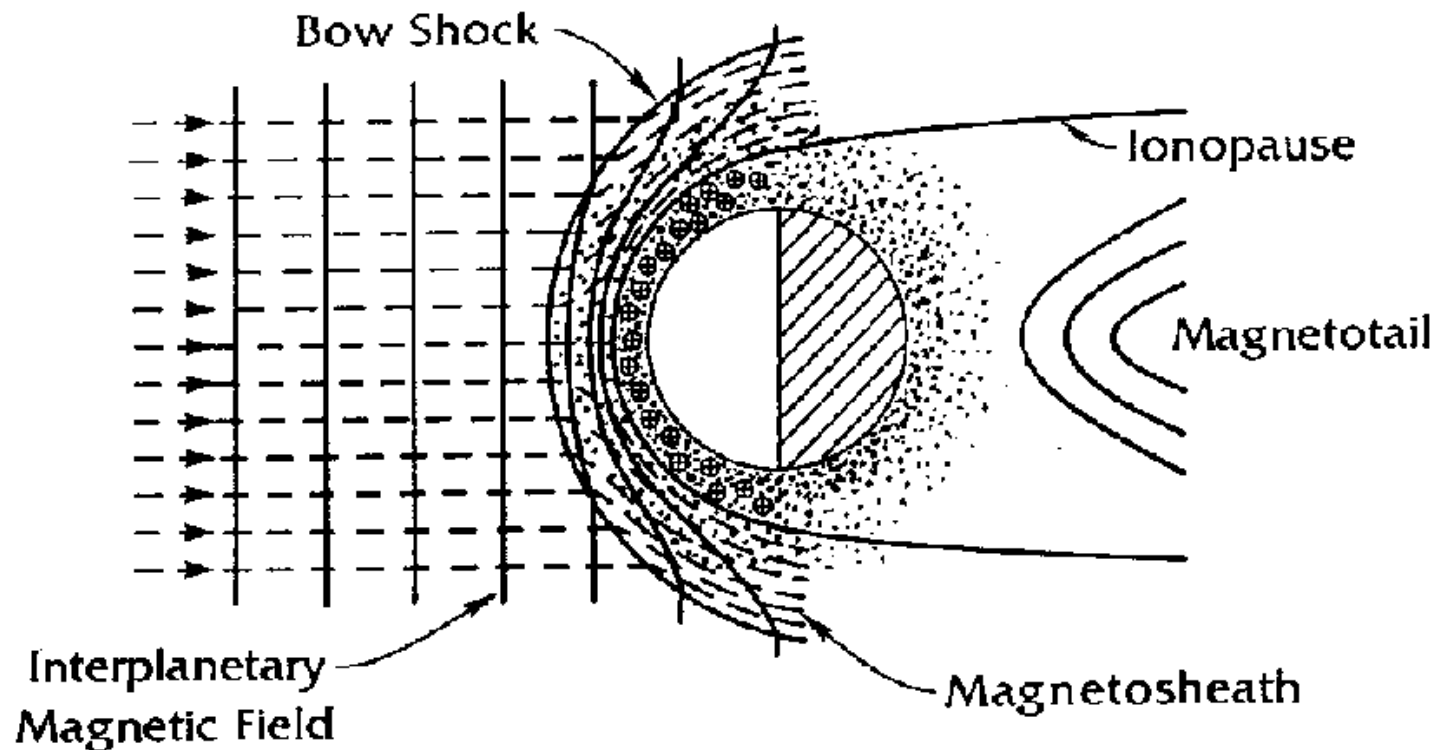


Illustration of the major features of the solar wind interaction with the ionosphere of Venus. The solid dots represent the neutral atmosphere, while the circled plus symbols represent ionized atmosphere. The ionized atmosphere above the ionopause is removed by the solar wind.

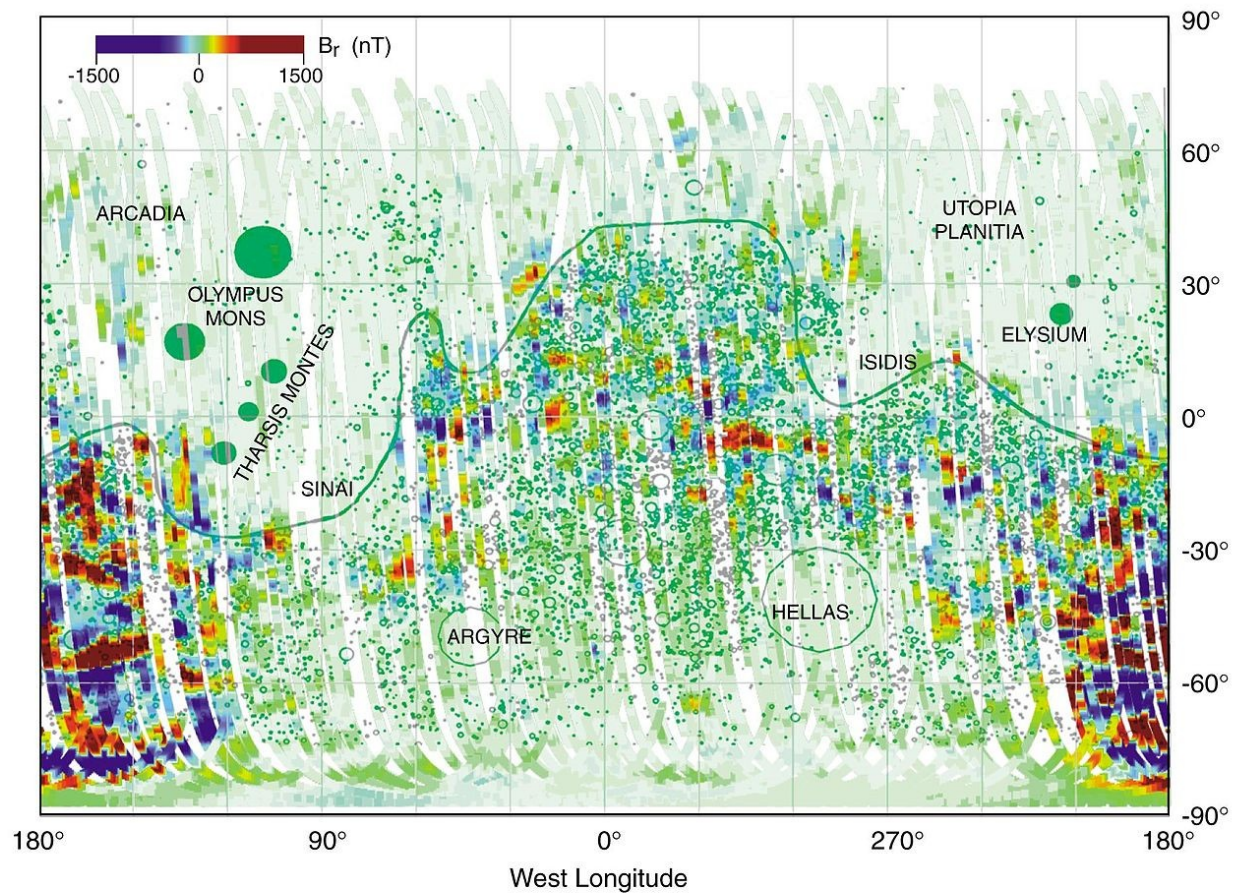
Induced magnetosphere

- In an induced magnetosphere, the solar wind interacts directly with the planetary ionosphere.
- The fields and plasmas that are observed are generally of solar wind or ionospheric origin.
- There are no belts of trapped radiation such as Earth's Van Allen belts, and there is no magnetotail composed of fields of planetary origin.
- The basic features of an induced magnetosphere are:
 - The ionospheric obstacle to the solar wind is defined by a surface called the ionopause. At the ionopause, pressure balance exists between the solar wind dynamic pressure on the outside and the thermal pressure of the ionospheric ions and electrons on the inside.
 - Outside of the ionopause the solar wind interaction has all of the features characteristic to a planetary magnetosphere. A bow shock forms upstream of the obstacle.
 - Inside of the bow shock the solar wind plasma is deflected around the obstacle in a magnetosheath region, which is sometimes referred to as an ionosheath since the obstacle is an ionosphere. The embedded interplanetary magnetic field is compressed and draped around the obstacle in the magnetosheath region in the usual way.
 - Inside of the ionopause the plasma changes from solar wind-dominated to ionospheric in origin.

- The high-altitude wake of Venus is permeated with structured magnetic fields that generally point sunward or antisunward and often exhibit a 'double-lobed' structure like an intrinsic planetary magnetotail.
- However, examination of the polarities of the fields in the lobes shows them to be coupled closely to the interplanetary field and resulting draped magnetosheath field orientations.
- This 'induced' magnetotail can be pictured as an extension of the magnetosheath, with the draped interplanetary fields sinking into the ionospheric obstacles' wake.
- Because of the lack of an intrinsic magnetic field, Venus' ionosphere and upper atmosphere are constantly being scavenged by the passing solar wind.

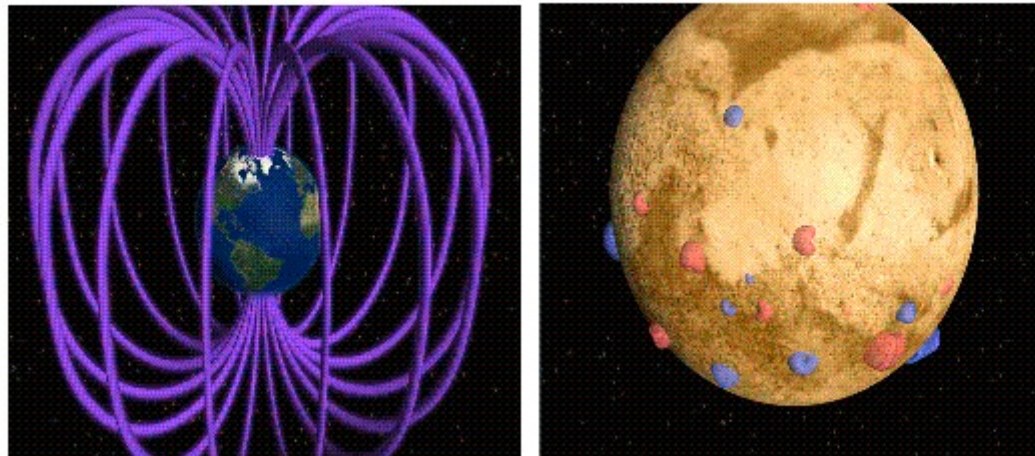
Mars

- Mars' magnetic field is not globally generated in the planet's core, but is localized in small, particular areas of the crust.



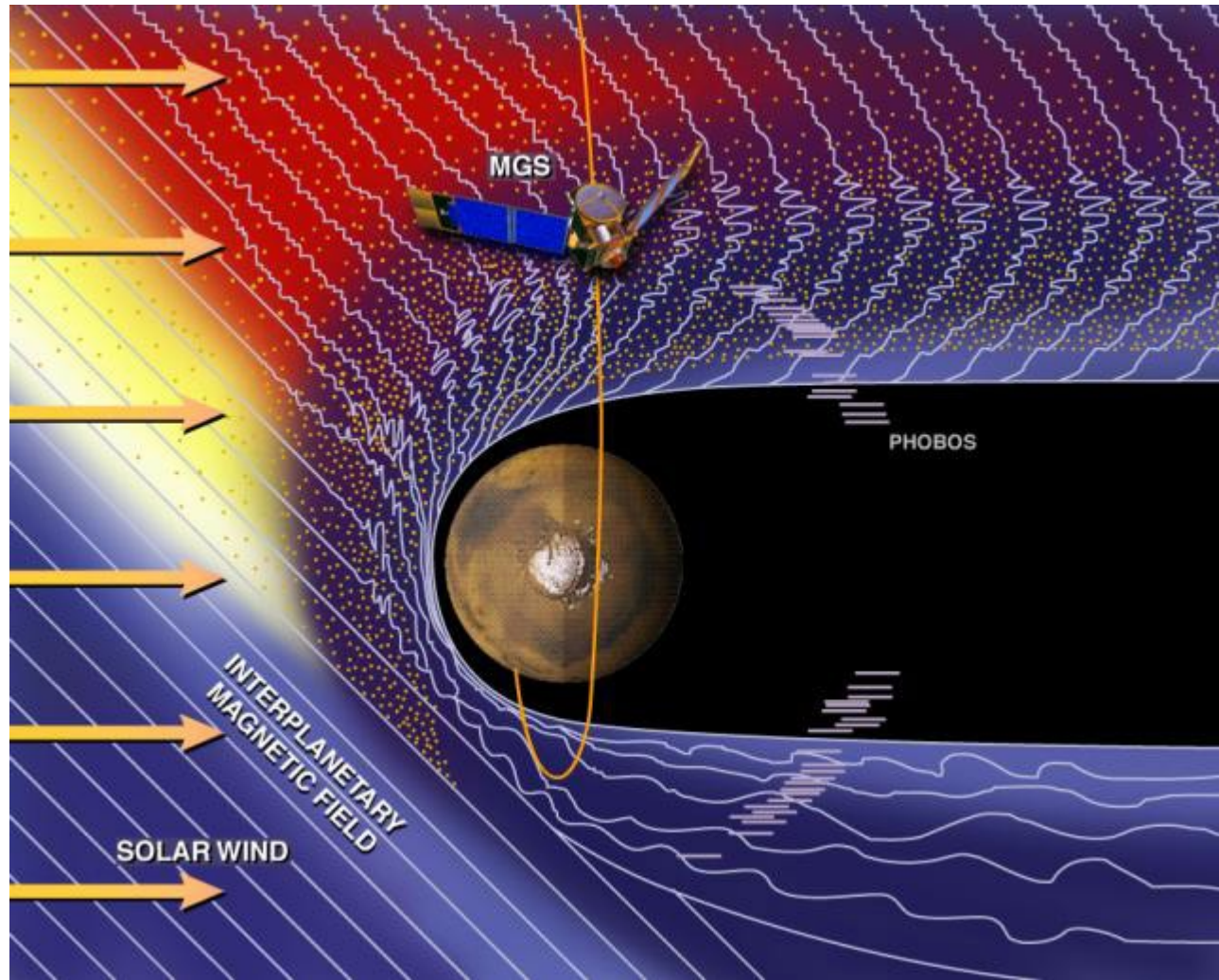
Satellite measurements of the radial magnetic field on Mars.

- Mars is also believed to have once harbored a global magnetic field generated by a dynamo in its core. Like Venus, its formation produced considerable internal heat energy as clumps of material and large asteroids bombarded the forming planet.
- Since Mars is smaller than Earth, it should have released its heat-of-formation, and cooled much faster than Earth.
- If this is correct, Mars' core is likely to have fully solidified leaving no liquid metallic outer core to generate a field.
- Fossil evidence of a past global field can still be seen in the form of surface magnetic field records measured. These magnetic regions act like protective domes for the atmosphere, carrying magnetic fields similar in strength to Earth's crustal magnetic field, about 1/10 the strength of Earth's main magnetic field. Outside these local magnetic domes, the Martian magnetic field is 100 to 1000 times weaker.



An artist's concept comparing the present day magnetic fields on Earth and Mars.

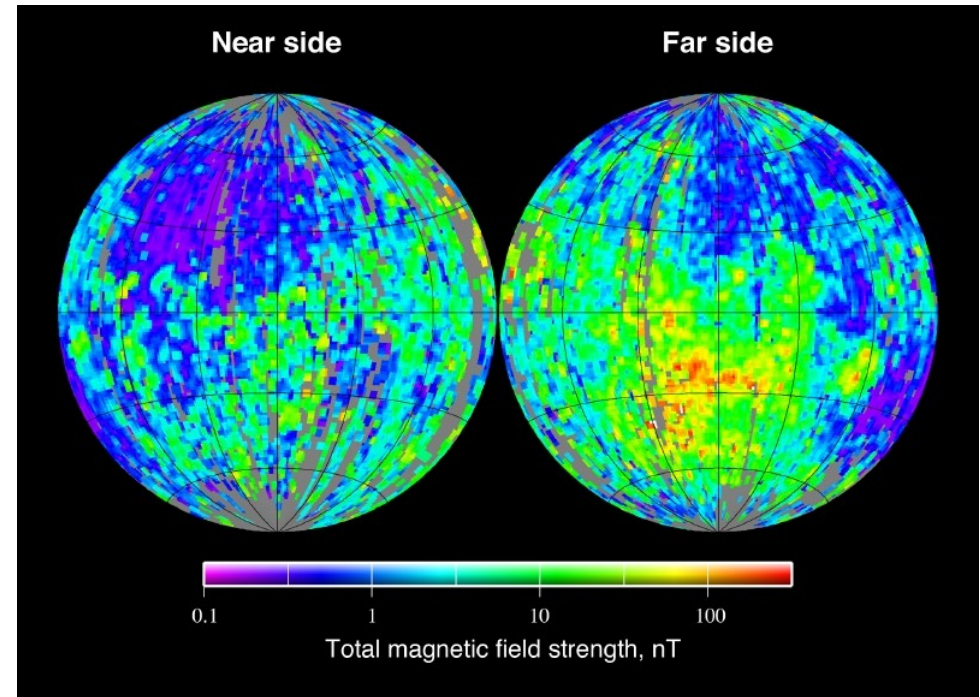
The induced magnetosphere of Mars



The thin martian atmosphere coupled with the lack of a global magnetic field allow the solar wind to penetrate deep into the martian troposphere. It is believed that the direct interaction between the solar wind and the martian atmosphere is partially responsible for the loss of water on the planet.

Moon

- Although the Moon today does not have a global magnetic field, the discovery of remnant magnetization in lunar rocks and in the lunar crust demonstrated that there was a substantial lunar surface field billions of years ago.
- A dynamo magnetic field likely existed on the Moon from at least 4.5 billion to 3.56 billion years ago, with an intensity similar to that at the surface of the Earth today. The field then declined by at least an order of magnitude by 3.3 billion years ago.
- This dynamo may have been driven by convection, possibly powered by crystallization of the core and/or mechanical stirring from mantle precession. The magnetic field was recorded as magnetization by rocks on the lunar surface.



Total magnetic field strength at the surface of the Moon as derived from the Lunar Prospector electron reflectometer experiment.

