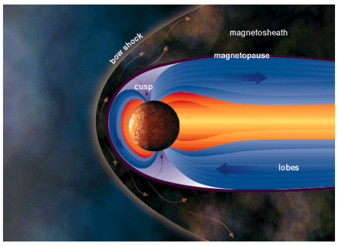
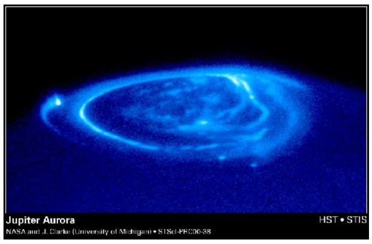
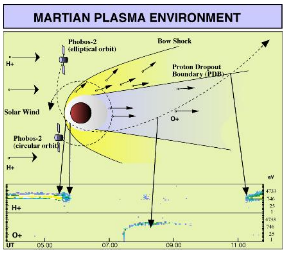
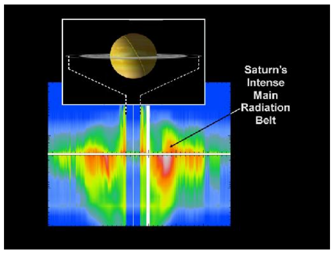




Planetary magnetospheres

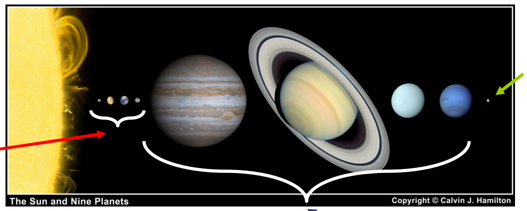


Text-book chapter 19



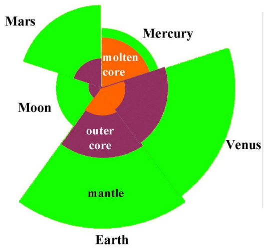
Solar system planets

Terrestrial planets:
Mercury
Venus
Earth
Mars



Pluto is no more a planet!

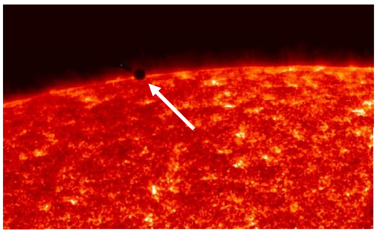
Interiors of terrestrial planets are different → very different magnetic fields



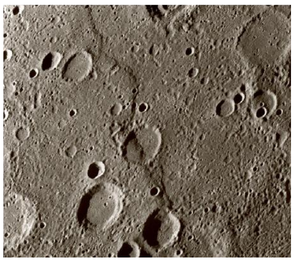
Gas giants:
Jupiter
Saturn
Uranus
Neptune

Gas giants are fast rotators (10 – 17 h) → strong magnetic fields

Mercury



Mercury transit as seen by EIT on SOHO



Rough “moon-like” surface

Surface has undergone most processing of all planets

Facts about Mercury

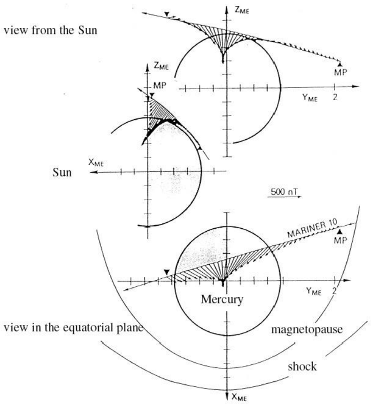
- distance from the Sun: 0.31 – 0.47 AU
- radius: 2440 km
- large average density: 5.4 g/cm^3
  - large iron core
- slow rotation rate: 59 Earth days
  - 2/3 of the orbital period (88 days)
- no atmosphere
  - T_{surf}: day 575 – 630 K ; night 95 – 130 K
  - exosphere begins almost from the surface
  - no collisional ionosphere

Mercury was not expected to posses an internal magnetic field untill two of three Mariner-10 fly-bys in 1974 and 1975 proved otherwise!

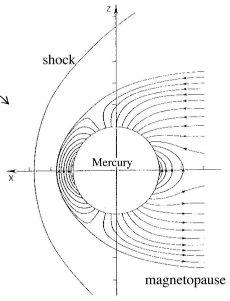
It is not fully understood, why Mercury’s core is not frozen

Mariner 10 observations of the Hermean magnetosphere

Note: Mercury's ↔ Hermean



modeling



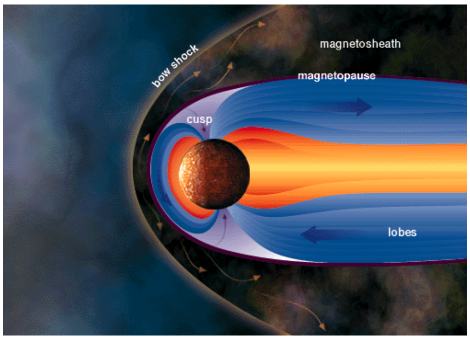
Third encounter in 1975

Model of the Hermean magnetosphere

Dipole field on equatorial surface: 300 nT

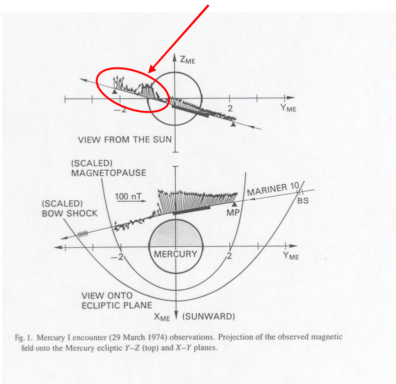
Solar wind dynamic pressure about 10-fold as compared to 1 AU
→ the planet fills most of its magnetosphere
→ existence of a ring current questionable

Slow rotation
→ no corotating plasmasphere

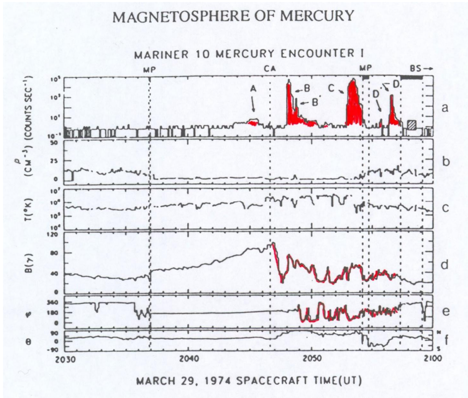


Hermean substorms?

During the 1st encounter the magnetic field became strongly perturbed



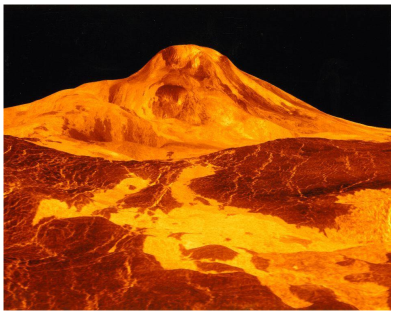
At the same time several injections of energetic particles were observed



Were substorms observed at Mercury?
• was there a current wedge
• where did it close (surface?)

Venus

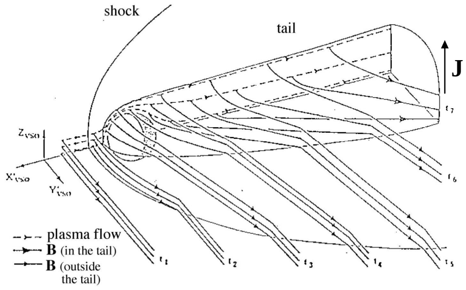
Thick hot atmosphere
Extreme case of the
greenhouse effect



Magellan radar observations
of the Venusian surface

Venus rotates around its axis once per revolution around the Sun (243 d).
It does not possess an intrinsic magnetic field, but it has
a dense ionosphere that interacts with the solar wind.

An induced magnetosphere

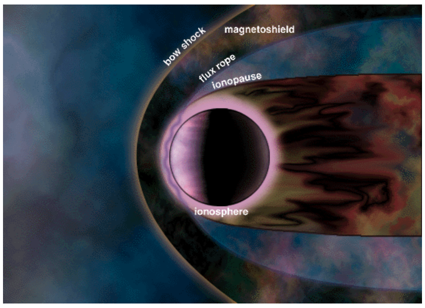


Note that the tail current is a result of the draping of the field lines. Thus it is always $\perp \mathbf{B}_{SW}$

The ionospheric plasma forces the solar wind to flow around the planet

Parts of the neutral atmosphere of Venus reach to the solar wind
→ particles are ionized (EUV, charge-exchange)
→ they feel $E = -V \times B$
→ solar wind "picks-up" these newly born ions (pick-up ions)
→ the mass of solar wind increases (mass-loading)
→ the flow slows down locally

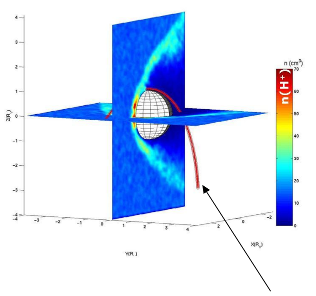
Magnetosphere of Venus



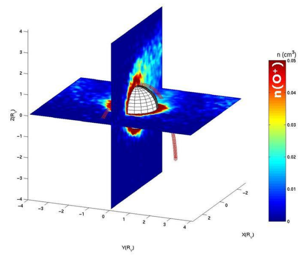
Currently ESA's Venus Express is making observations of Venus' atmosphere and its interaction with the solar wind. One of its instruments is ASPERA-4, parts of which have been built in Finland

Fresh plasma simulations at Venus

Simulation: H^+ density - 3d view

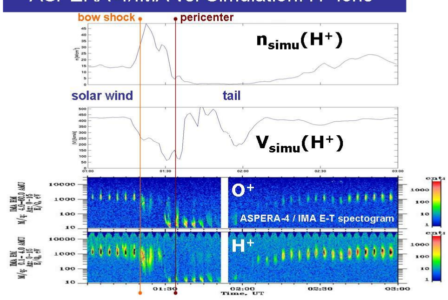


Simulation: O^+ density – 3d view

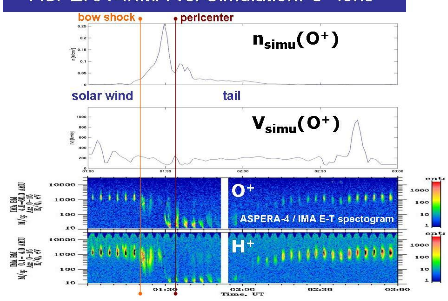


Simulations compared with Venus Express / ASPERA-4 data

ASPERA-4/IMA vs. Simulation: H^+ ions



ASPERA-4/IMA vs. Simulation: O^+ ions

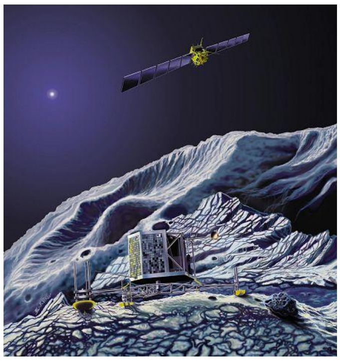


Fresh results;
to be presented at the American Geophysical Union
Fall Meeting in San Francisco, December, 11-15, 2006

Comets

Cometary plasma environments resemble those of Venus

There is much more gas and dust escape
→ mass-loading is much more efficient



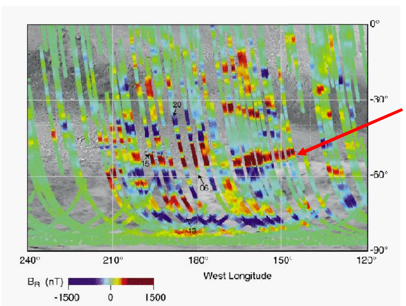
ESA's Rosetta will approach comet Churymov-Gerasimenko in 2014 and deliver a lander (Philae) on its surface in November 2014

Mars

The most Earth-like planet, but smaller $R_M = 3400$ km and lighter $\rho = 3.9$ g/cm^3

Thin atmosphere → ionosphere

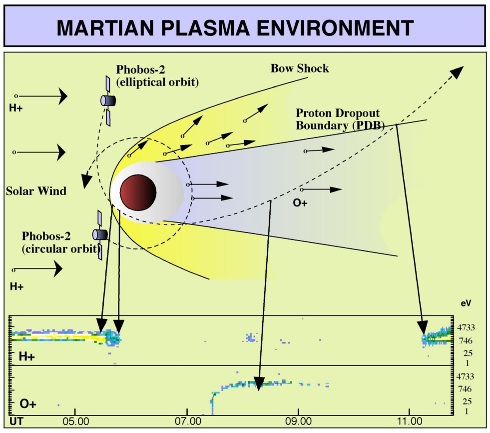
Rotation period 24 h 37 min
but not enough magnetofluid in the core to sustain a dynamo



Remanent magnetism found by NASA's Mars Global Surveyor

Solar wind interacts mostly with the ionosphere

Martian magnetosphere

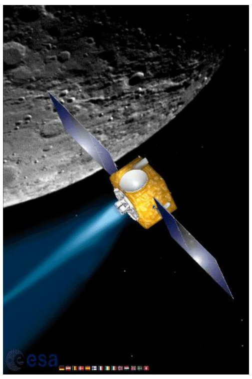


Phobos-2 observations of solar wind – Mars interaction in 1989

The instrument was Swedish-Finnish-Soviet ASPERA

Presently ASPERA-3 is making observations onboard ESA's MarsExpress.

Moon and asteroids



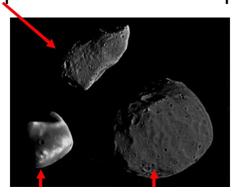
ESA's SMART-1 went to a Moon orbit using novel ion propulsion technique

The Moon is an non-magnetic, atmosphereless body that spends a part of its orbit in the Earth's magnetotail.

Nothing tells the upstream solar wind that it will hit the Moon → the Moon collects solar wind particles (ion implantation).

Downstream a weak wake is formed.

Most asteroids are expected to be non-magnetic. Gaspra is a notable exception

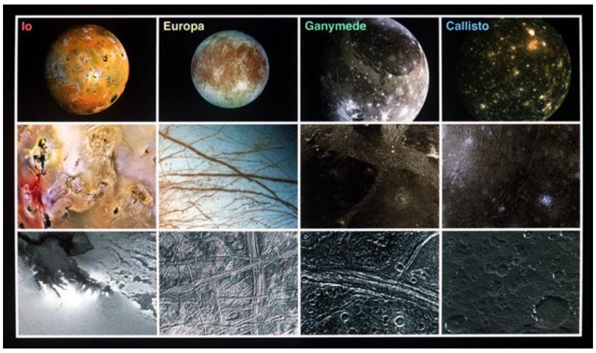


Gaspra's perturbation in the solar wind resembles that of a magnetized small body

Deimos and Phobos (moons of Mars, maybe captured asteroids, non-magnetic)

Jupiter

The largest planet, radius 71400 km,
mass: 1.9×10^{27} kg ($2.5 \times$ the mass of all other planets)
Fast rotation: 9 h 55 min (slightly differential)
Strong magnetic field:
dipole moment about 20000 x Earth's dipole
field at equator 430 μT

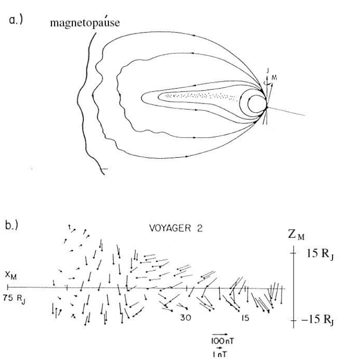


Galileo found 4 moons about 1610
- Io
- Europa
- Ganymede
- Callisto

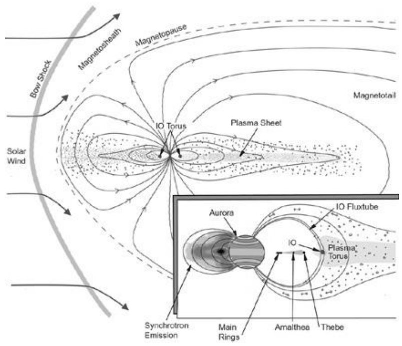
Today more than 60 Jovian moons have been identified.

Many of them are captured asteroids

Jovian magnetosphere



Early dayside observations
(explain how a single spacecraft fly-by can produce such a large cone of observations!)

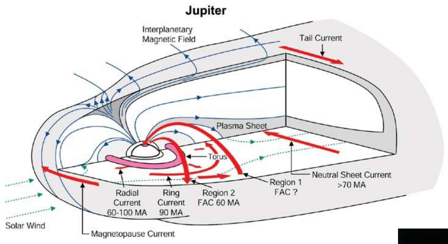


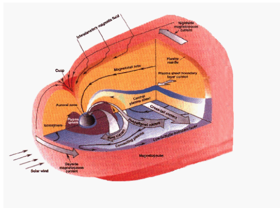
The present view:

The magnetosphere is filled with gas and dust from the moons (especially from the volcanic Io)

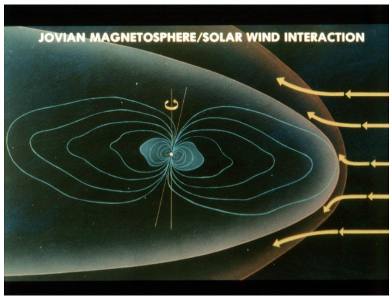
The most complex magnetosphere in the solar system

Comparison with the terrestrial magnetosphere

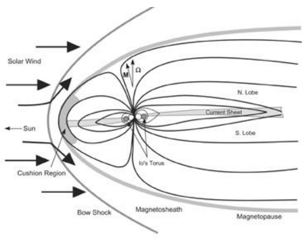


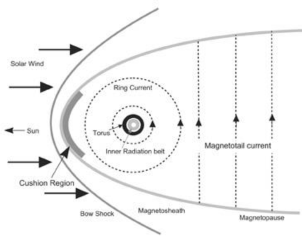


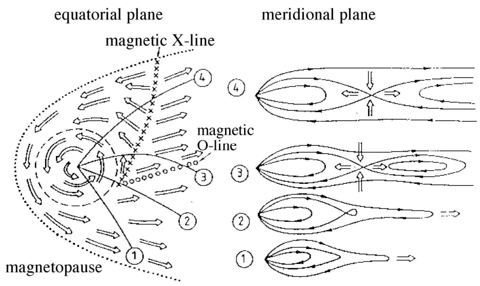
- current directions reversed (dipole upward)
- stronger currents
- radial current in the co-rotating region
- flatter in the north-south direction



Corotation-dominated circulation



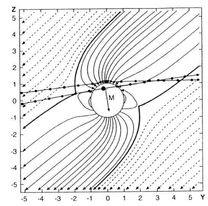




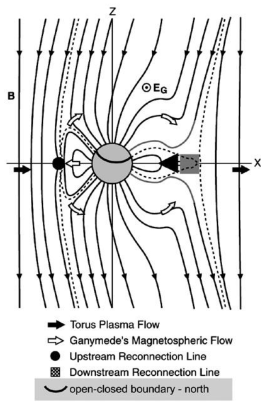
The magnetosphere is asymmetric:
X-line in the dawn sector
SW interaction:
dawn: large velocity shear
dusk: small velocity shear

Ganymede's magnetic field

A magnetosphere embedded in another magnetosphere

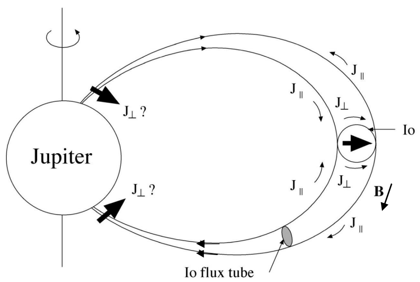


Magnetic field model based on observations with the Galileo spacecraft



Model for plasma circulation

Interaction with Io



Io moves with respect to the co-rotating magnetosphere with a relative speed 57 km/s

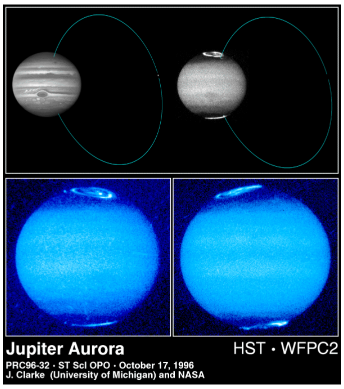
This induces an electric field $\mathbf{E} = -\mathbf{V} \times \mathbf{B}$ (B = 2000 nT)

$\rightarrow$ 500 kV potential across Io

This drives current that couples to FACs that close through the Jovian ionosphere

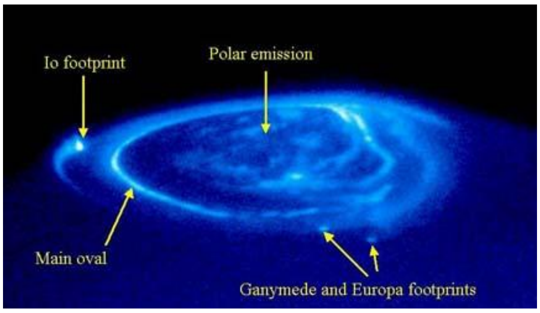
Should the upward FACs be associated with auroral precipitation as in the case of the Earth?

Jovian auroras

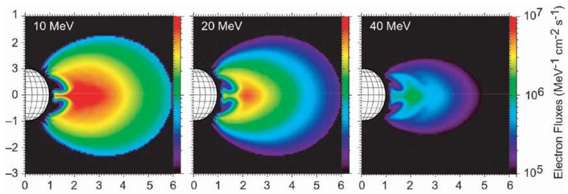


Note that there is much more auroral activity in the polar cap than on the Earth.

The Jovian tail lobes are not as empty as the terrestrial lobes

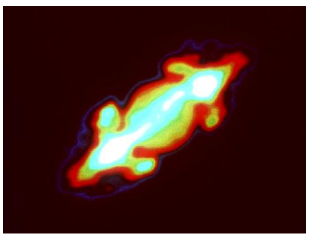


Radiation belts and radiowave emissions

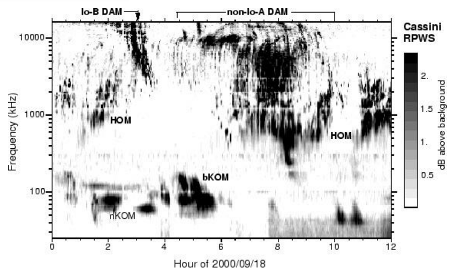


The Jovian magnetosphere is filled with energetic particles.

Very harsh radiation environment

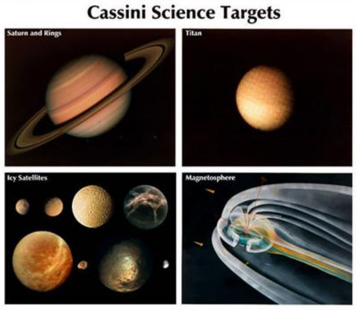


Jupiter seen in radiowaves



A large variety of wave emissions

Saturn



A fast rotating gas giant
- mass: 5.7×10^{26} kg
- radius: 60300 km
- rot. per: 10 h 39 min

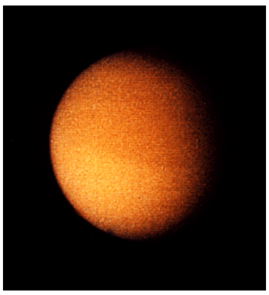
dipole axis almost along rotation axis (incl. 27º)

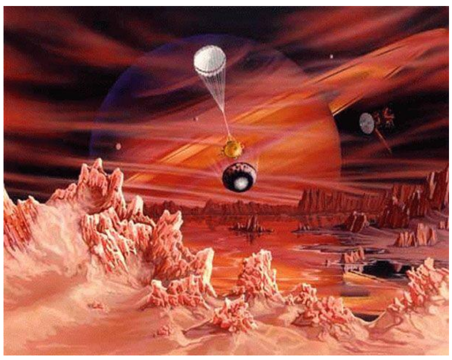
magnetic field at equator: 21 μT

New moons being found:
status on August 2004: 33

NASA/ESA Cassini/Huygens came to Saturn in 2004.
Huygens landed on Titan on Jan 14, 2005
Cassini continues observations of the Saturnian system.

Titan

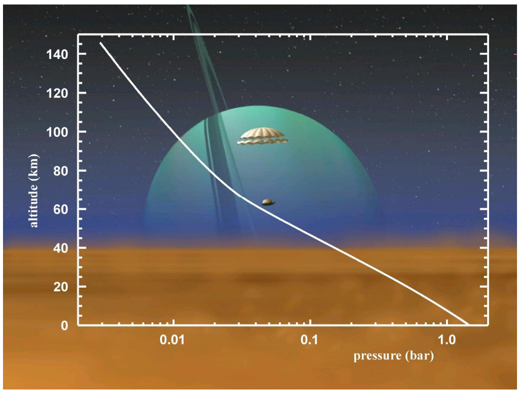




A big moon
- radius 2570 km
- (larger than Mercury)
- nitrogen atmosphere
- at surface p =1.5 atm

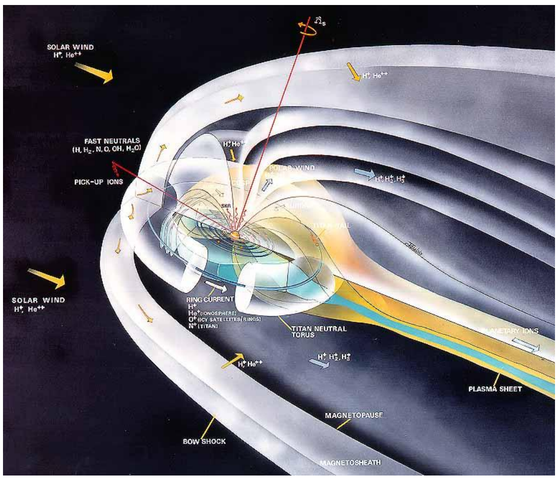
Titan does not have a magnetic field
It has an ionosphere that moves subsonically through the magnetic field of Saturn
(a unique space plasma feature!)

Titan’s atmospheric pressure



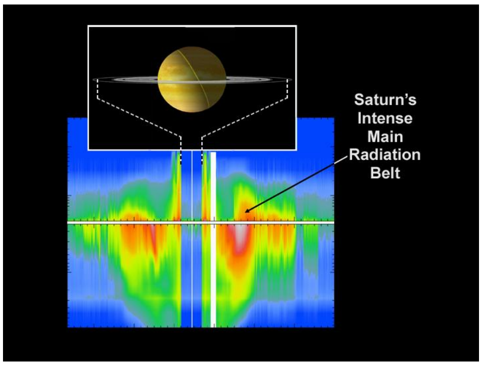
Measured on Janurary 14, 2005 with a Finnish pressure instrument!

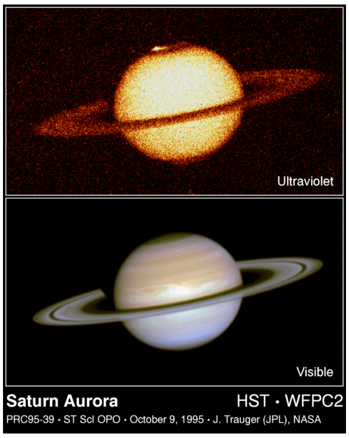
Kronian magnetosphere



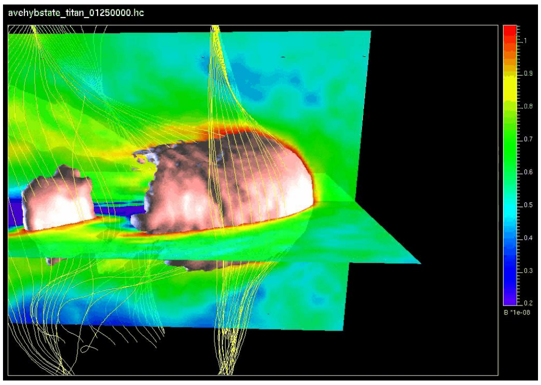
Saturn’s ↔ Kronian

Kronian radiation belts and auroras





Titan in the Kronian magnetosphere



A subsonic induced magnetosphere:

Interaction between Titan's atmosphere
and Saturn's magnetospheric field and plasma

Uranus and Neptune

Uranus	
• Rot. period	17 h 14 min
• Radius	23800 km
• Mass	8.7×10^{25} kg
• Rot. axis	97.9º
• Dipole axis from rotation axis	59º
• B at equator	23 μT

Neptune	
• Rot. period	16 h 06 min
• Radius	22200 km
• Mass	1.0×10^{26} kg
• Rot. axis	28.8º
• Dipole axis from rotation axis	47º
• B at equator	14 μT

Complicated dynamics

Note the dependence on the phase of the orbit around the Sun:

During the period of 83.7 years the rotation axis is Sun-aligned twice and perpendicular to the sun-Uranus axis twice

Splitting and rejoining of the plasma sheet in 8 hours (half day)

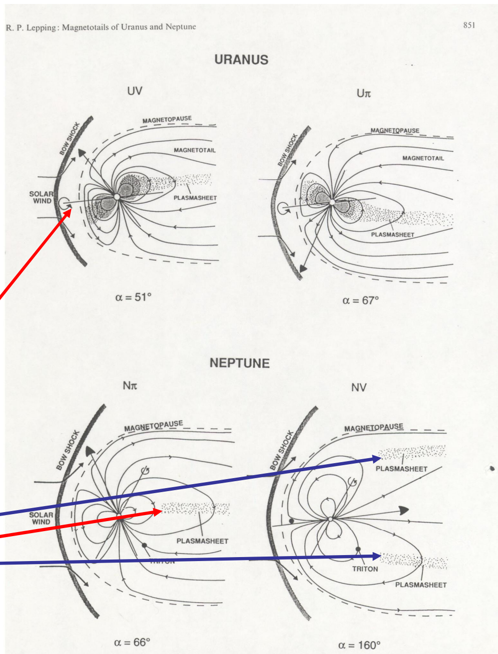


Fig. 3. Qualitatively derived configurations, in a meridian plane view, of the magnetospheric field-lines for Uranus (top) and Neptune (bottom), applicable to the times around the *Voyager* 2 encounters. The heavy arrows represent the magnetic dipole moments of the planets and the symbols above the sketches are explained in the text (Bagenal, 1992)