Chap. 4 Mercury

Magnetized, non-atmospheric body.

Surface magnetic field $\sim$ 200 nT
(Mariner 10, Messenger)
cf. 30000 nT at Earth surface

Magnetopause distance

$$\frac{1}{2}\rho v^2 = \frac{B^2}{2\mu_0}$$ (pressure balance)

$$B \propto \frac{1}{r^3}$$ (dipole field)

$B_0 = 200\,(nT)$ (surface)

$\rho = m_p \times 20\,(cm^{-3})$ (solar wind mass density)

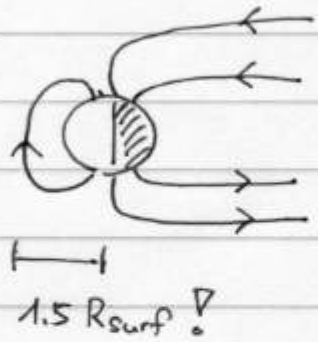
$V = 300\,(km/s)$ (solar wind speed)

$$\Rightarrow R_{mp} \simeq 1.5\, R_{surf}$$!
(from planet center)

surface - magnetopause distance

$0.5\, R_{surf} = 1200$ km

Magnetosphere



weak magnetic field
↓
small magnetosphere

- No radiation belt (or ring current)
  ... planet occupies a lot of volume

- Sodium (Na) sputtering
  → sodium-rich plasma

- "Hybrid" scale ... magnetosphere size of the order of ion gyro-radius

- → currents are carried by electrons? (mpause, plasma sheet)

- Fast reaction, rapid reconfiguration

  length dayside-tail $\ell \sim 10\ R_{surf}$ (24000 km)
  solar wind speed $V \sim 300$ km/s
  ↘
  reaction time $\tau = \ell / V \sim 80$ s
  (cf. 40 min. at Earth)

- reconnection ? substorm ?

Dynamo problem

Theoretical estimate of surface magnetic field

$$\text{Elsässer number } \Lambda = \frac{|\text{Lorentz force}|}{|\text{Coriolis force}|}$$

$$= \frac{|\sigma(\vec{v}\times\vec{B})\times\vec{B}|}{|2\rho\vec{\Omega}\times\vec{v}|}$$

$$\sim \frac{\sigma B^2}{2\rho\Omega}$$

Assume $\Lambda \sim 1$ $\Rightarrow$ $B \propto \sqrt{\Omega}$.

Scale Earth magnetic field into Mercury.

$B(\text{earth}) = 30000$ nT

$\Omega(\text{earth}) = 2\pi/1$ (rad/day)

$\Omega(\text{merc}) = 2\pi/58$ (rad/day)

$\Rightarrow$ $B(\text{merc}) = 4000$ nT.

Mercury field is weaker than Earth-scaled field.

Chap. 5 Venus and Mars

Lost dynamo

Venus and Mars have atmosphere but no global magnetic field.
(dipole)

Estimate of dipole moment (upper limit!)

Venus 10^{-5} × (Earth dipole)
↘ 0.1 nT at surface PVO

Mars 10^{-5} × (Earth dipole)
↘ ~~1~~ 0.5 nT at surface MGS

Mars have magnetized crust
e.g. 200 nT at 400 km altitude

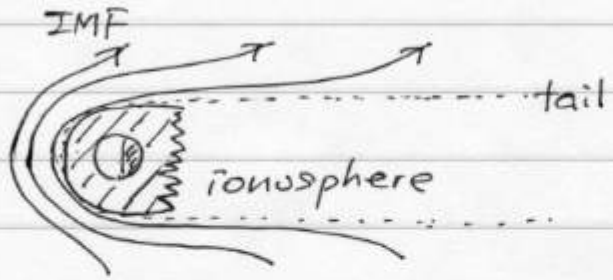
→ Dynamo operating in early time?

Why is dynamo missing?

Venus ... slow rotation (243 days)?

Mars ... core in solid state?
(Liquid core became solid.)
Small planet size

Magnetosphere



Pressure balance

(1) magnetic boundary

$$\frac{1}{2}\rho v^2 = \frac{B^2}{2\mu_0}$$

solar wind dynamic pressure

solar wind magnetic pressure

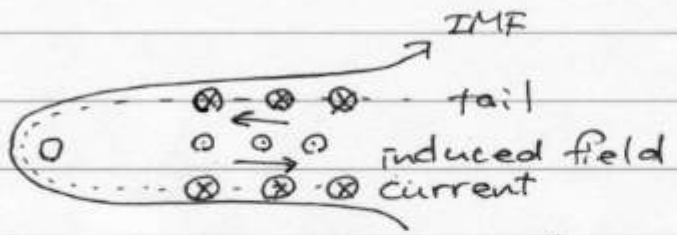
↑ field compression on dayside

(2) ionopause

$$\frac{1}{2}\rho v^2 = nkT$$

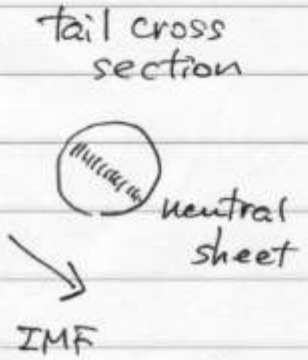
ionosphere gas pressure

Induced magnetic field



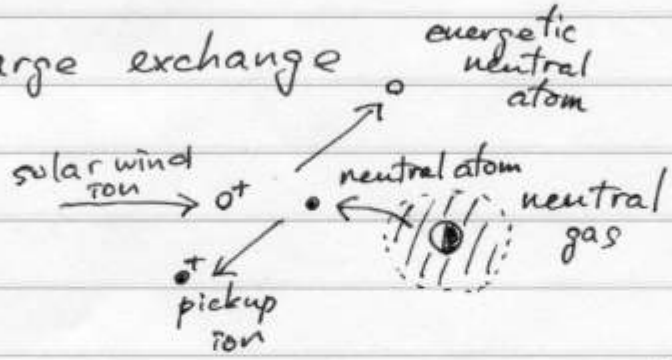
↘ "induced magnetosphere"

sensitive to IMF direction



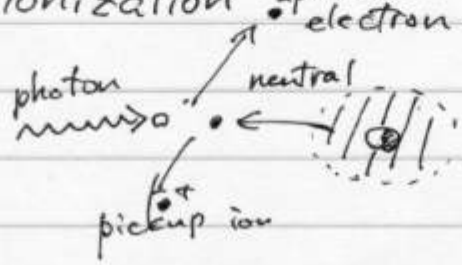
Pickup process

(1) charge exchange



plasma gains additional mass

(2) photoionization



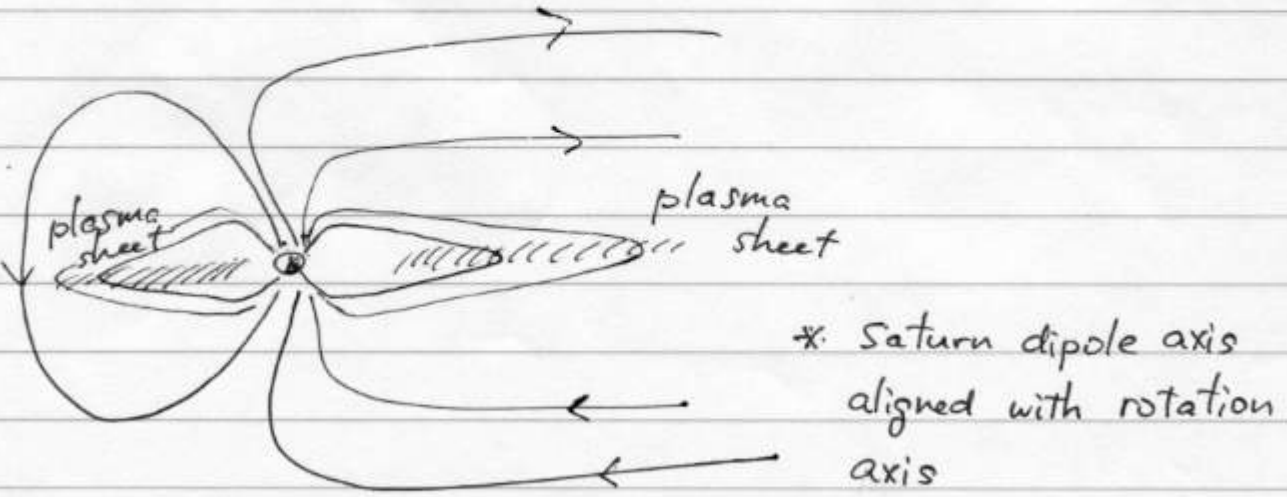
Giant magnetosphere

surface magnetic field
400 000 nT (Jupiter)
20 000nT (Saturn)
metalic hydrogen core ?

magnetopause distance
50 - 100 R_{surf} (Jupite) ca. 5 R_{sun} !
20 R_{surf} (Saturn) ca. 2 R_{sun}

rotation - dominant
10 hours (Jup.), 10.5 hours (Sat.)
→ large centrifugal force

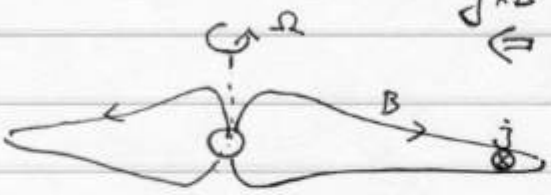
aurora ... magnetosphere - ionosphere coupling.
radio emission source



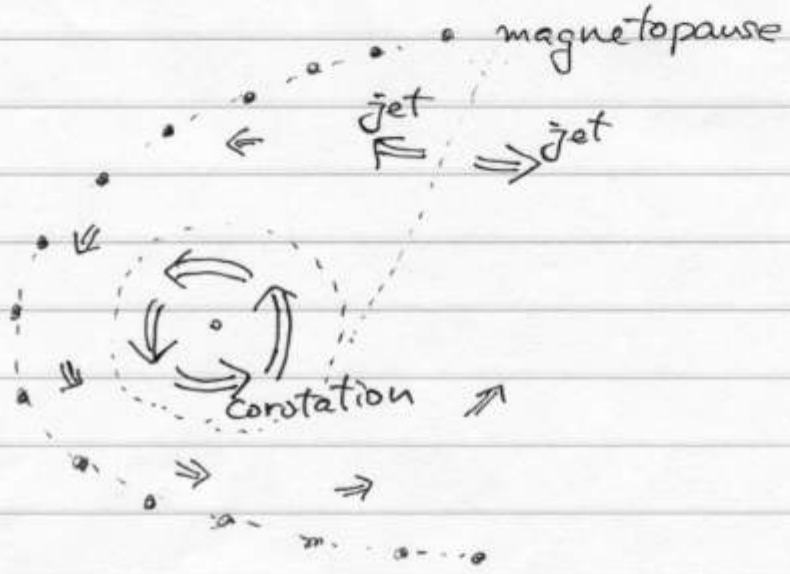
Force balance

$\vec{j} \times \vec{B}$ $\quad -\rho \vec{\Omega} \times (\vec{\Omega} \times \vec{R})$

$\Leftarrow \quad \Rightarrow$ centrifugal



View from rotation axis (Jupiter)



periodic jet → substorm ? reconnection ?
on morningside
↓
internally driven substorm ?

Plasma source from satellites

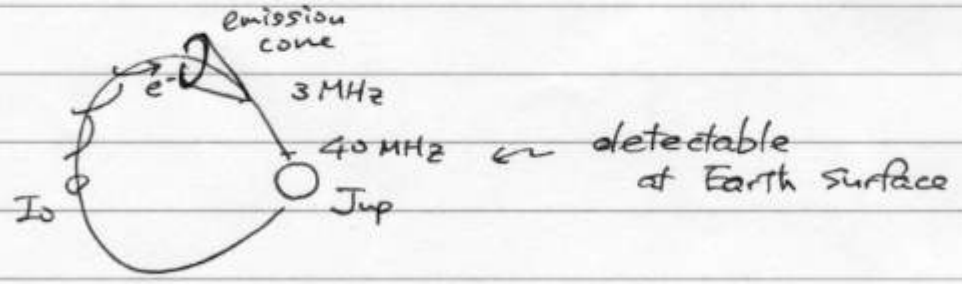
Io (Jup.) ... volcanism, sulfur-rich plasma torus

Enceladus (Sat.) ... water ice, water-ion products

Radio emission

- Auroral emission (cyclotron maser)
- radiation belt (synchrotron)

Jupiter aurora emission



Uranus and Neptune

Magnetized, gas planets

Surface mag. field 23 000 nT (U), 14 000 nT (N)

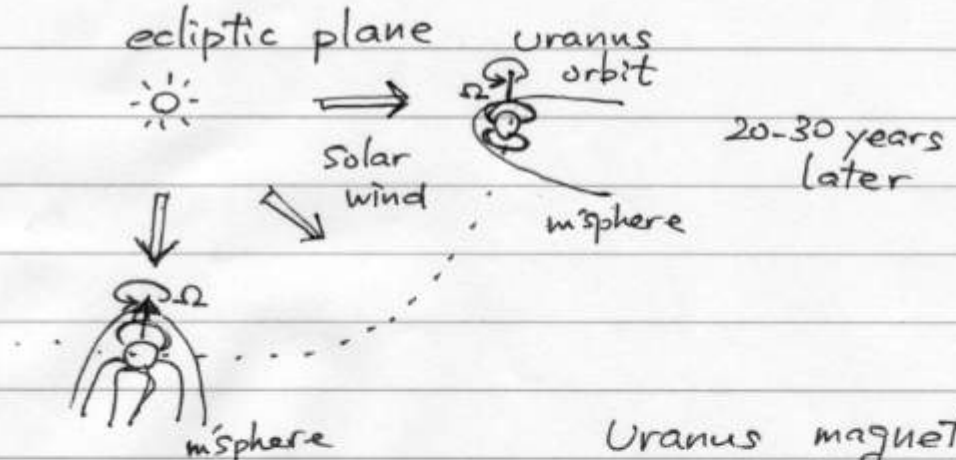
magnetopause distance 25 R_{surf} (U) 26 R_{surf} (N)

Large tilt angle (rotation axis - dipole axis)

59° (U), 47° (N)

Uranus

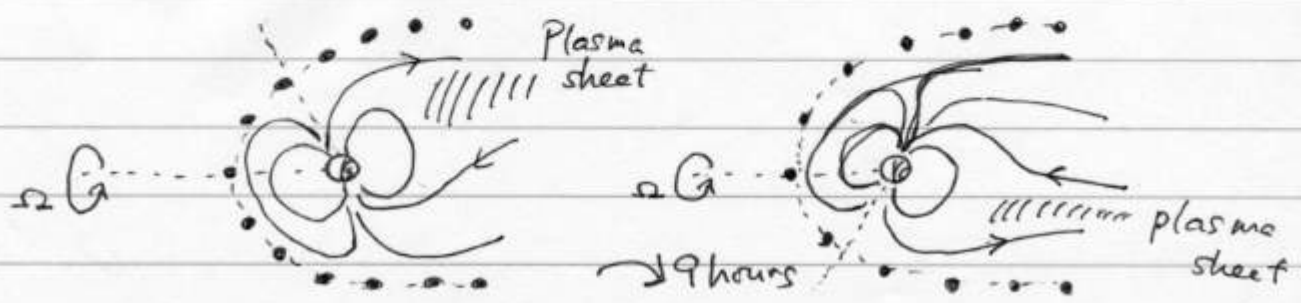
Rotation axis almost in the orbital plane



Voyager encounter 1986

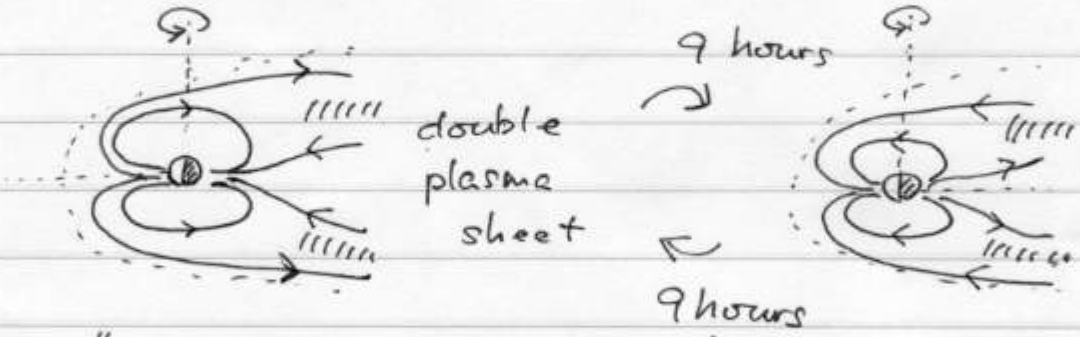
Uranus magnetosphere (1)

(Voyager encounter 1986)



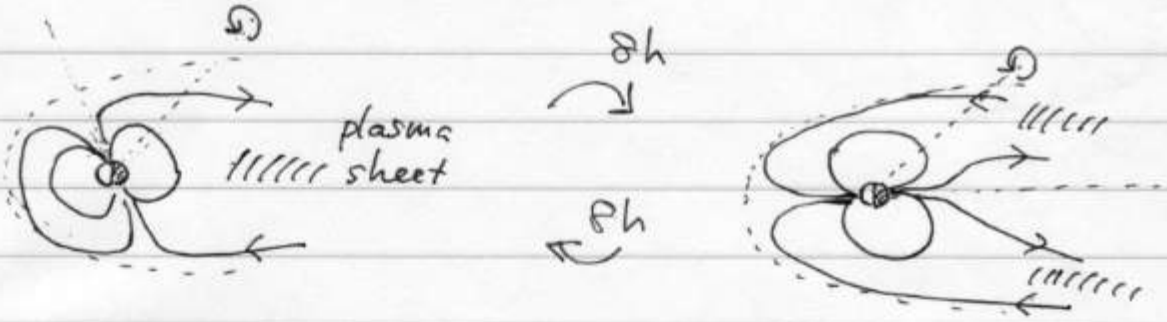
Uranus magnetosphere (2)

20-30 years later



"pole-on magnetosphere"

Neptune



pole-off

pole-on