

Magnetized, non-atmospheric body.

Surface magnetic field  $\sim 200 \text{ nT}$

(Mariner 10, Messenger)

cf.  $30000 \text{ nT}$  at Earth surface

Magnetopause distance

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

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

$$B_0 = 200 \text{ (nT)} \quad (\text{surface})$$

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

$$v = 300 \text{ (km/s)} \quad (\text{solar wind speed})$$

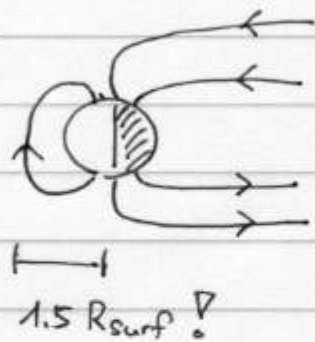
$$\rightarrow R_{mp} \approx 1.5 R_{surf} \quad !$$

(from planet center)

surface - magnetopause distance

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

## Magnetosphere



weak magnetic field



small magnetosphere

- No radiation belt (or ring current)
  - ... planet <sup>occupies</sup> ~~is occupying~~ 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  $l \sim 10 R_{\text{surf}}$  (24000 km)

solar wind speed  $v \sim 300$  km/s

↘

reaction time  $\tau = l/v \sim 80$  s

(cf. 40 min. at Earth)

- reconnection? substorm?

Dynamo problem

Theoretical estimate of surface magnetic field

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

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

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

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

Scale Earth magnetic field into Mercury,

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

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

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

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

Mercury field is weaker than Earth-scaled field.

## Lost dynamo

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

Estimate of dipole moment (upper limit!)

Venus  $10^5 \times$  (Earth dipole)  
 $\rightarrow$  0.1 nT at surface pvo

Mars  $10^{25} \times$  (Earth dipole)  
 $\rightarrow$  ~~100~~ 0.5 nT at surface MGS

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

$\rightarrow$  Dynamo operating in early time?

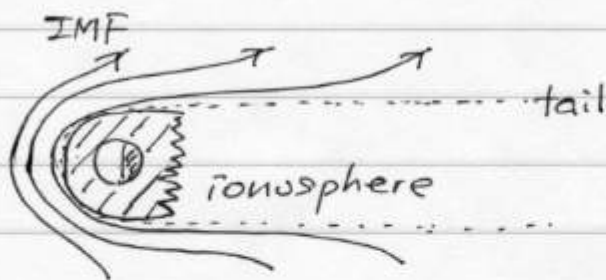
Why is dynamo missing?

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

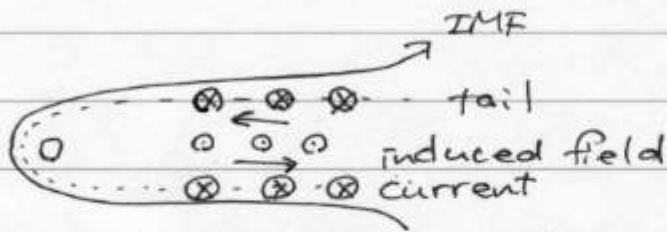
↕  
field compression  
on dayside

(2) ionopause

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

ionosphere  
gas pressure

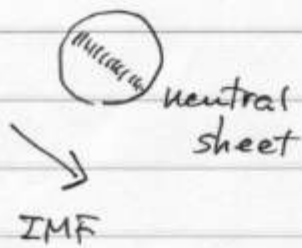
# Induced magnetic field



↳ "induced magnetosphere"

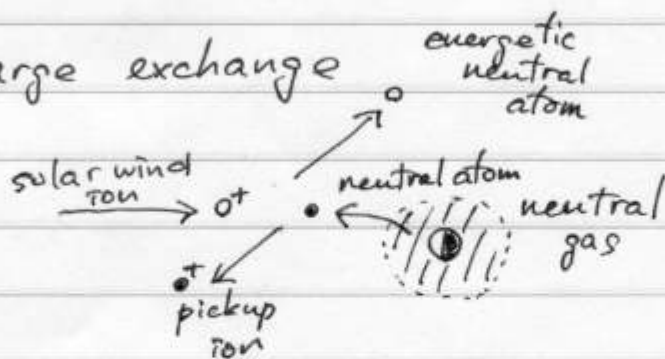
sensitive to IMF direction

tail cross section

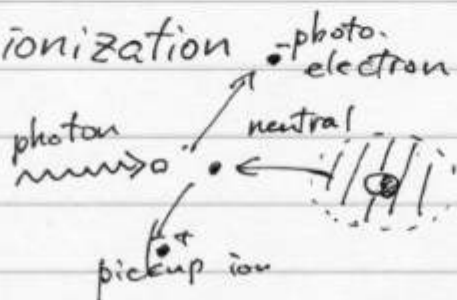


## Pickup process

(1) charge exchange



(2) photoionization



plasma gains additional mass

Giant magnetosphere

surface magnetic field

400 000 nT (Jupiter)

20 000 nT (Saturn)

metallic hydrogen core?

magnetopause distance

50 - 100  $R_{surf}$  (Jupiter) ca. 5  $R_{sun}$ !

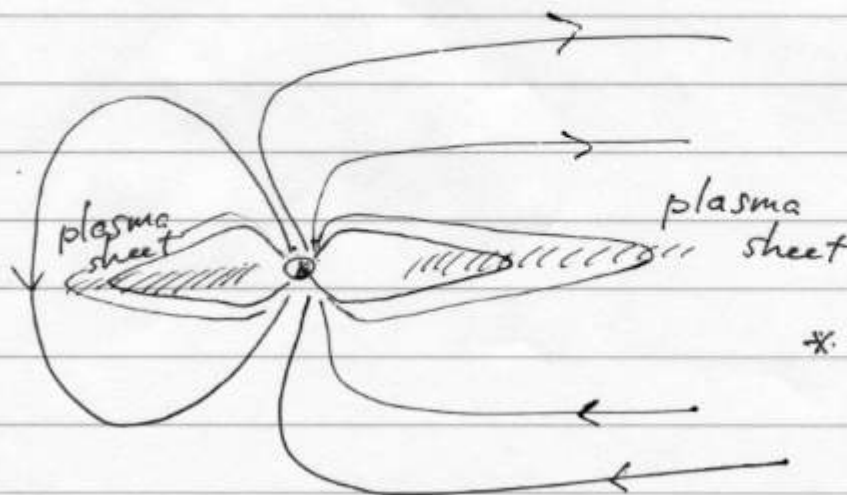
20  $R_{surf}$  (Saturn) ca. 2  $R_{sun}$

rotation - dominant

10 hours (Jup.), 10.5 hours (Sat.)

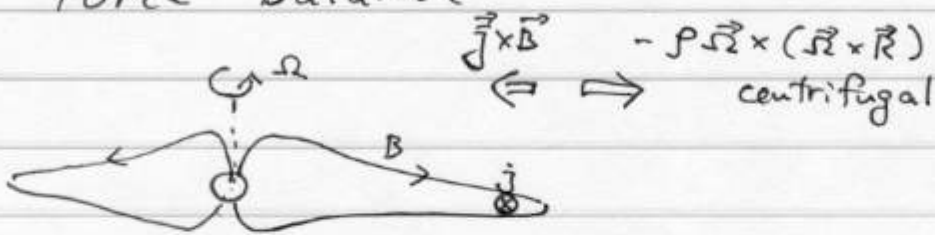
→ large centrifugal force

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

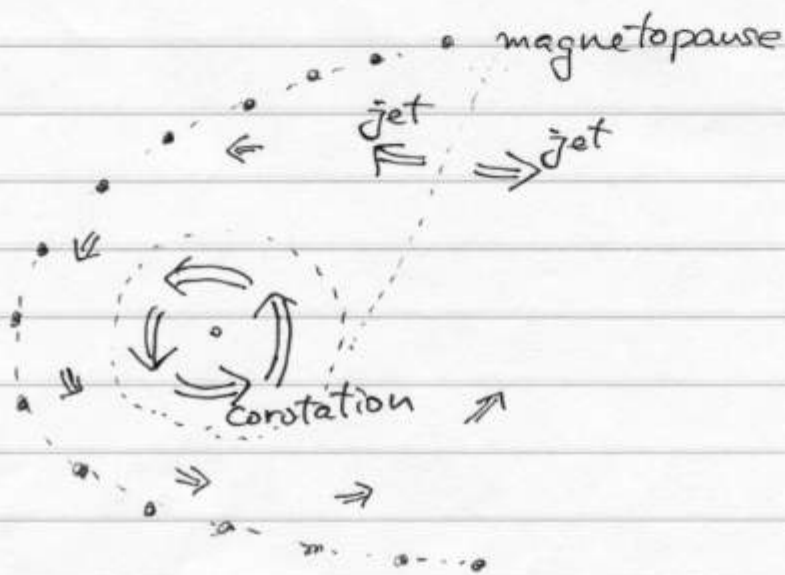


\* Saturn dipole axis aligned with rotation axis

## Force balance



## View from rotation axis (Jupiter)



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

## Plasma source from satellites

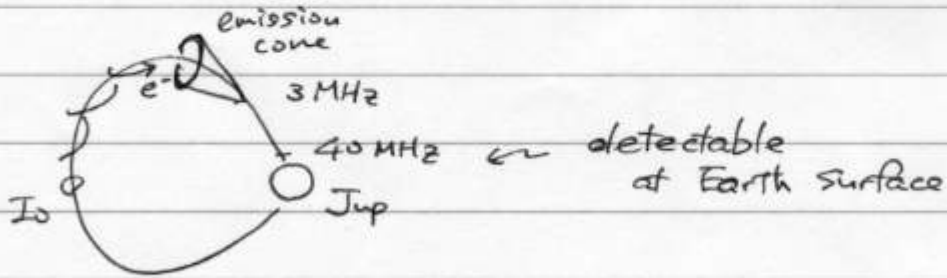
Io (Jup.) ... volcanism, sulfur-rich plasma  
 torus

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)

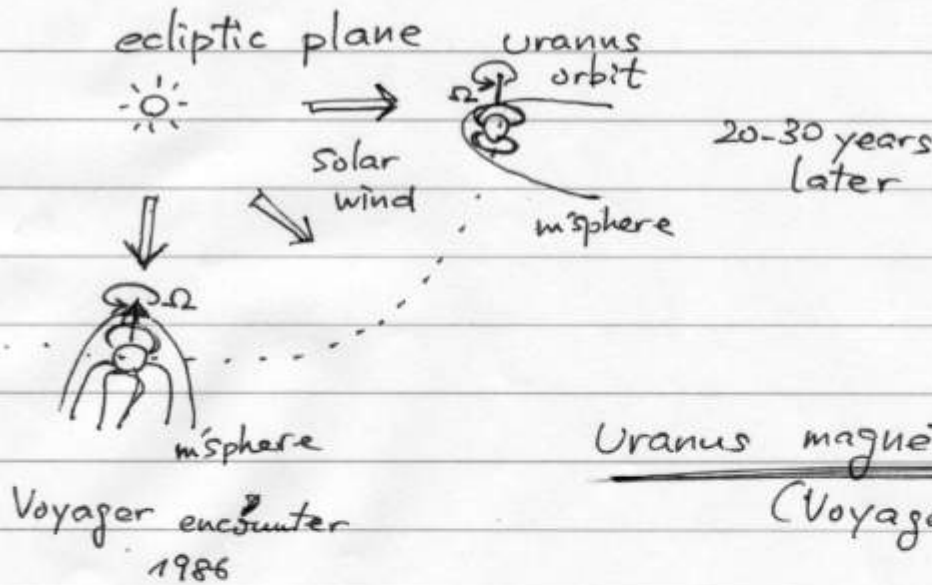
magnetopause distance 25  $R_{surf}$  (U) 26  $R_{surf}$  (N)

Large tilt angle (rotation axis - dipole axis)

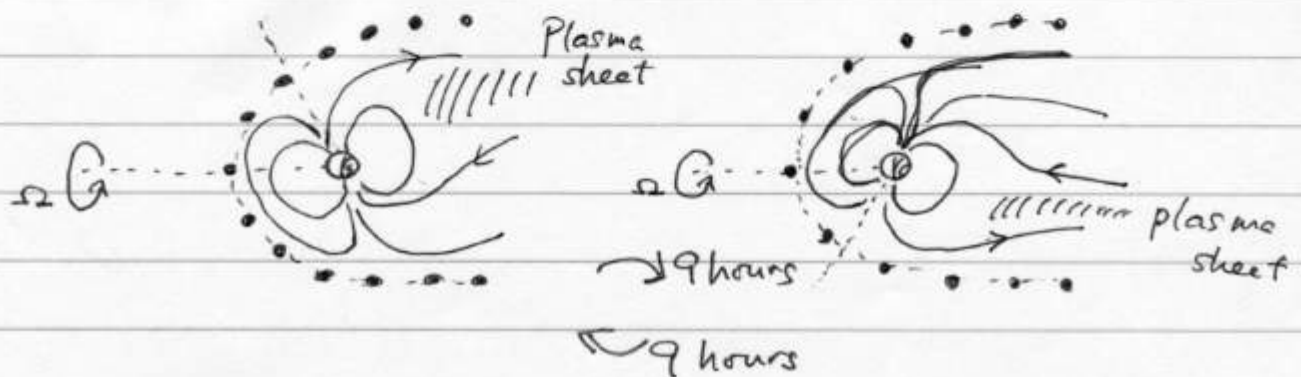
59° (U), 47° (N)

Uranus

Rotation axis almost in the orbital plane

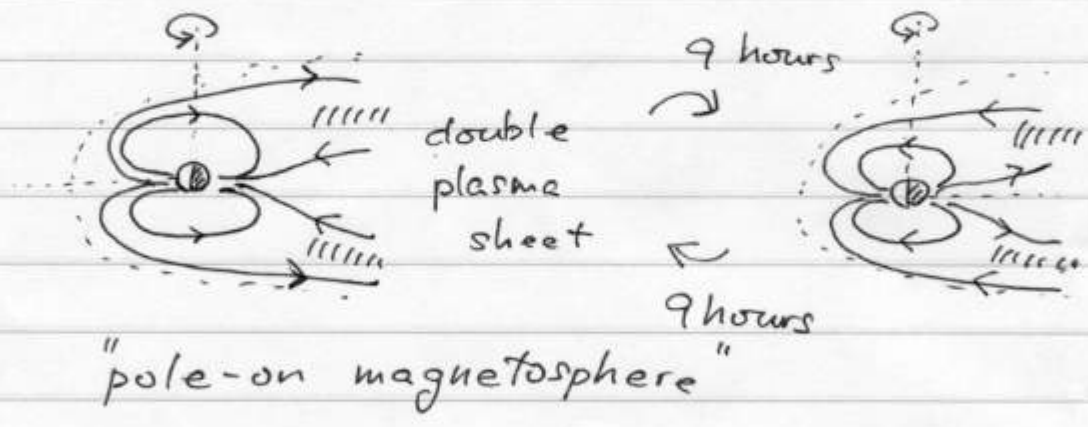


Uranus magnetosphere (1)  
(Voyager encounter 1986)



Uranus magnetosphere (2)

20-30 years later



Neptune

