Planetary magnetospheres

- Overview:
  - The planets,
  - Topology of the magnetospheres,
  - Planets without a magnetic field,
  - Comparison of magnetospheres
    - sizes,
    - Upstream waves,
    - Plasma sources,
    - Radiation belts.

- Pre-requisite:
  - Terrestrial magnetosphere.

Overview planets

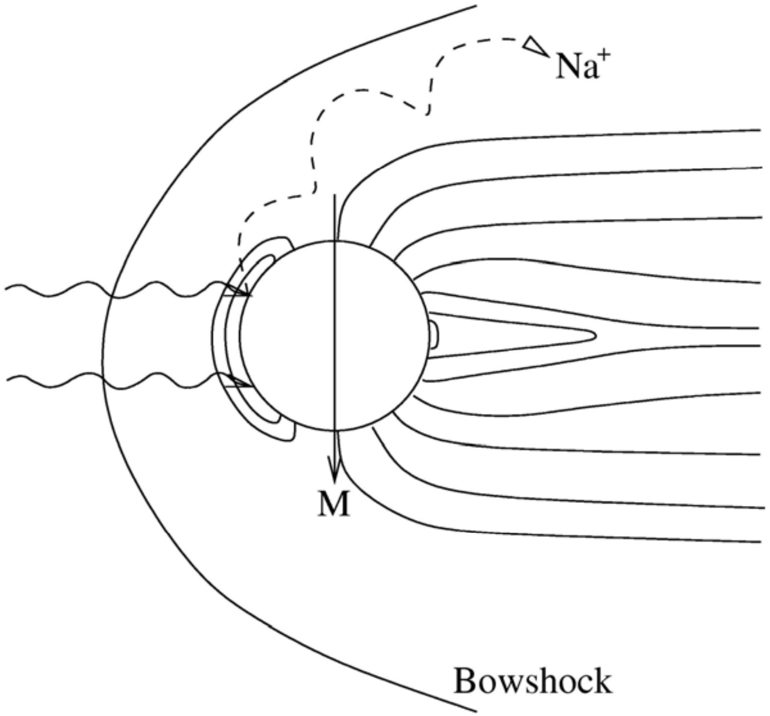
	Solar distance (AU)	Sidereal period	Spin period (days)	Average density (gm/cm^3)	Surface gravity (N/kg)
Mercury	0.39	88 d	56.8	5.4	3.6
Venus	0.72	225 d	243	5.1	8.7
Earth	1.00	365 d	1	5.5	9.8
Mars	1.52	1 yr 322 d	1.03	4.0	3.7
Jupiter	5.20	11 yr 315 d	0.41	1.3	26.0
Saturn	9.55	29 yr 167 d	0.44	0.7	11.2
Uranus	19.22	84 yr 7 d	0.72	1.18	9.4
Neptune	30.11	164 yr 280 d	0.67	1.56	15.0

Earth-like planets:
solid planet, only few moons, small

Outer planets:
gaseous giants, liquid metallic cores (?), ring systems, many moons, fast rotating

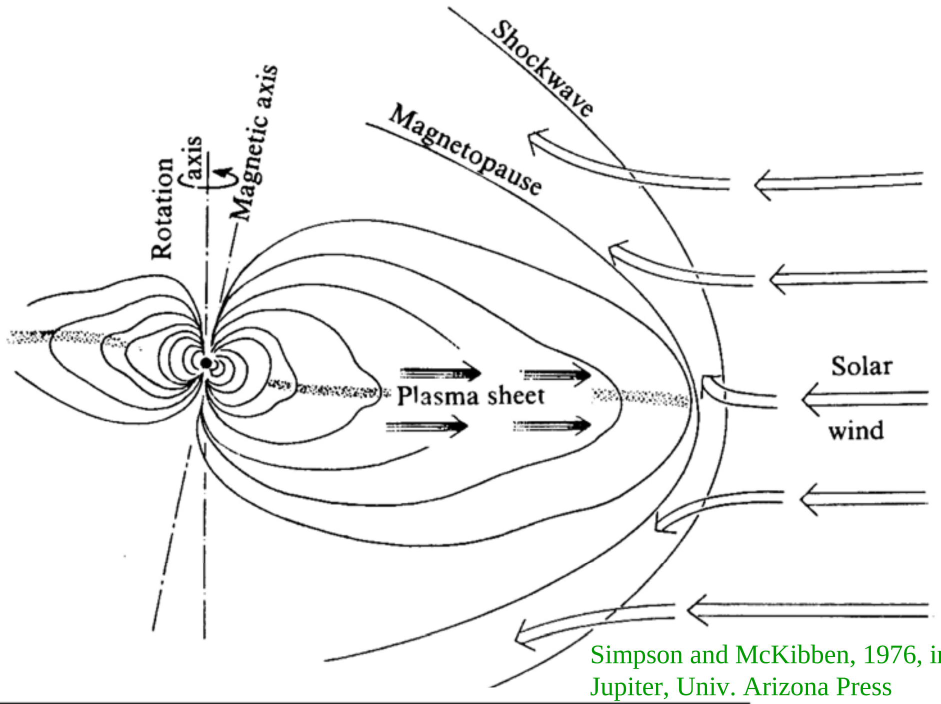
Mercury

- Small magnetosphere:
  - Magnetic moment only small (slow rotation),
  - High solar wind pressure,
  - Substorm phenomena inside the tail.
- Magnetopause can be pushed inside the planet body,
  - No stable radiation belt,
  - Interaction of the solar wind with the planet's surface.
- Plasma populations (H, He, O, Na, K) due to interaction with hard electromagnetic radiation and solar wind.



Jupiter

- Largest object in the solar system:
  - Large magnetic moment,
  - Strong centrifugal force (fast rotation),
  - Radial plasma flow,
  - Flat magnetosphere,
  - Within 15Rj dipole-like.

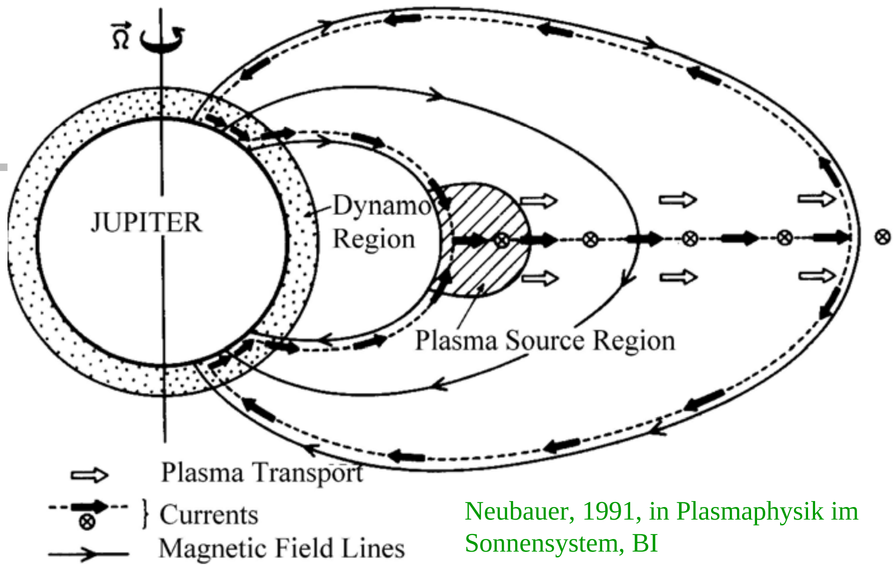


Simpson and McKibben, 1976, in Jupiter, Univ. Arizona Press

	Jupiter	Saturn	Uranus	Neptune
Sources	Io ionosphere	ionosphere, icy moons, solar wind, Titan	ionosphere, H-corona	ionosphere, solar wind, Triton
Composition	H, Na, O, K, S, O, H_2O, N	H, OH, H_2, O,	H	H, N
Source strength	$\sim 3 \times 10^{28}$ i/s	10^{26} i/s	10^{25} i/s	3×10^{25} i/s
Life time	months, years	months	days	weeks

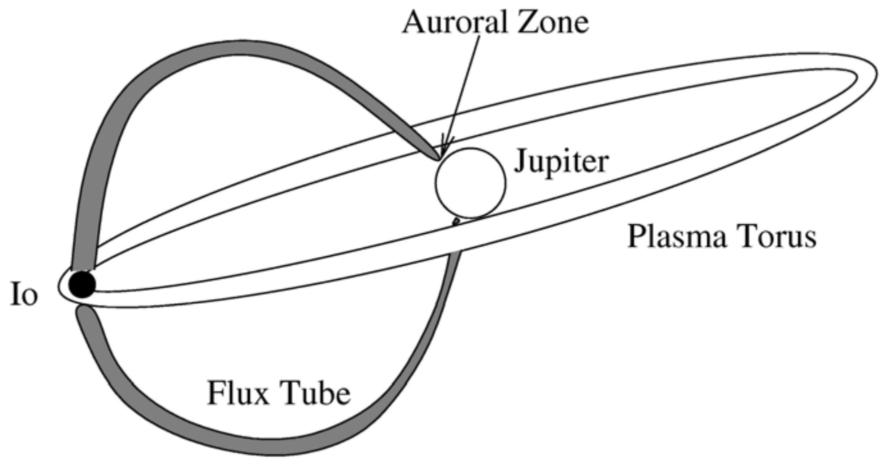
Jupiter: Plasma

- Plasma flow:
  - Radially outwards in the equatorial plane,
  - Allows for corotation of the plasma,
  - Current system closed in the dynamo region.



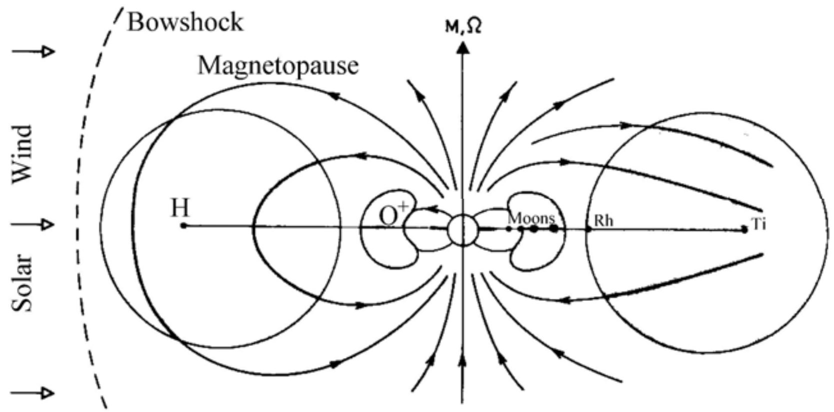
Neubauer, 1991, in Plasmaphysik im Sonnensystem, BI

- Seismic activity on Io as plasma source
  - Io torus,
  - Field parallel plasma flows lead to auroral activity.



Saturn

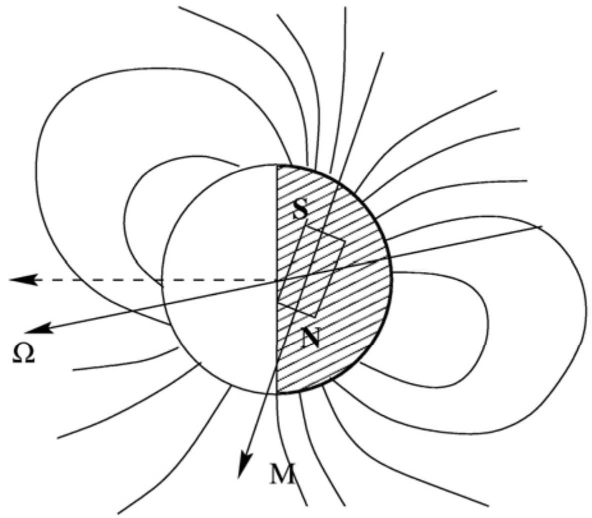
- Symmetric magnetosphere because dipole axis parallel to axis of rotation.
- Corotating outer magnetosphere.
- Rudimentary radiation belts, intensities reduced due to absorption at moons and rings.
- Plasma and dust (rings).



Bryant, 1993, in Plasma Physics, Cambridge Univ. Press

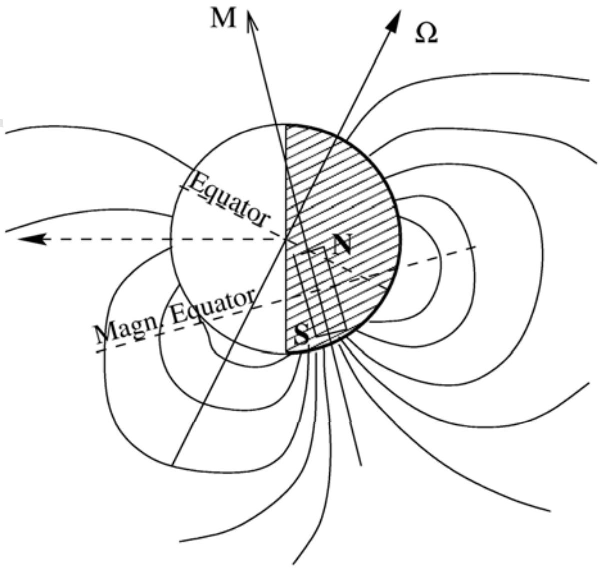
Uranus

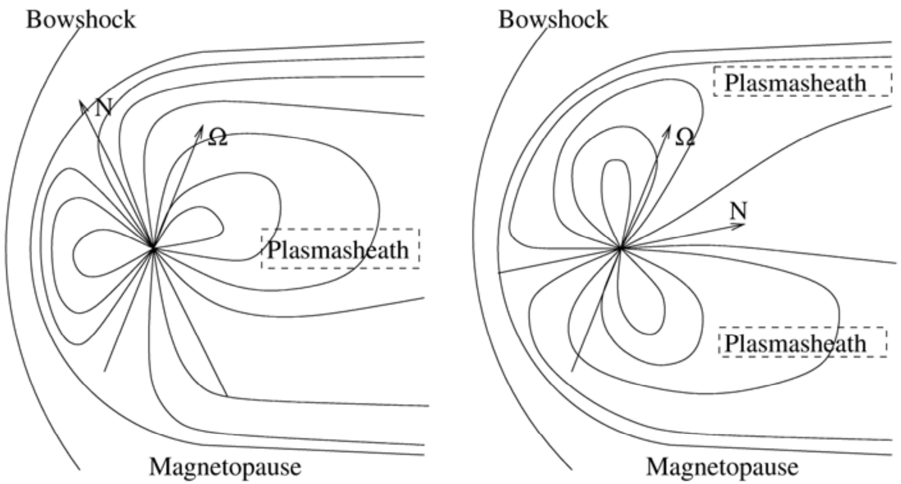
- Axis of rotation almost inside the plane of ecliptic.
- Dipole axis almost perpendicular to the plane of ecliptic:
  - Polarity reversal?
  - Unusual position of the dynamo region inside the planet?
- Radiation belts:
  - Low energies only,
  - Intensities reduced due to absorption at moons.

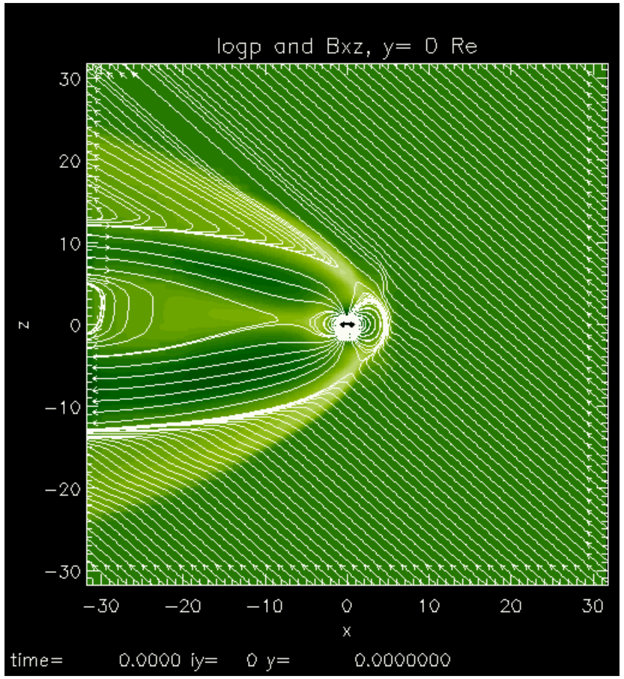


Neptun

- Dynamo region offset from axis of rotation.
- Transition between earth-like and pole-on magnetosphere.
- Radiation belt within the Triton orbit.
- Almost no activity.

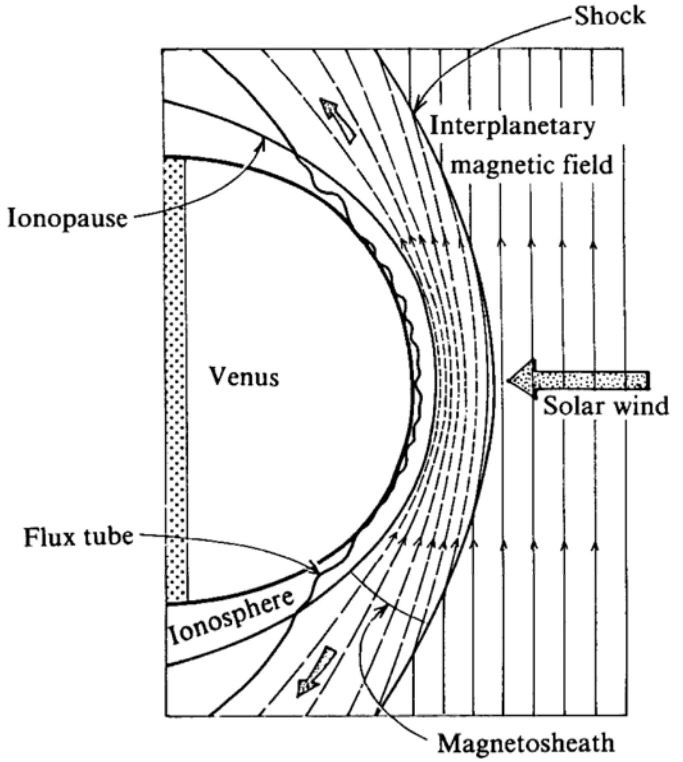






Venus

- No planetary magnetic field.
- Interplanetary magnetic field frozen-out of the ionosphere:
  - Magnetopause
  - Magnetosheath
  - Bowshock.
- Current system similar to that in the tail of the terrestrial magnetosphere.
- Almost no magnetic activity.



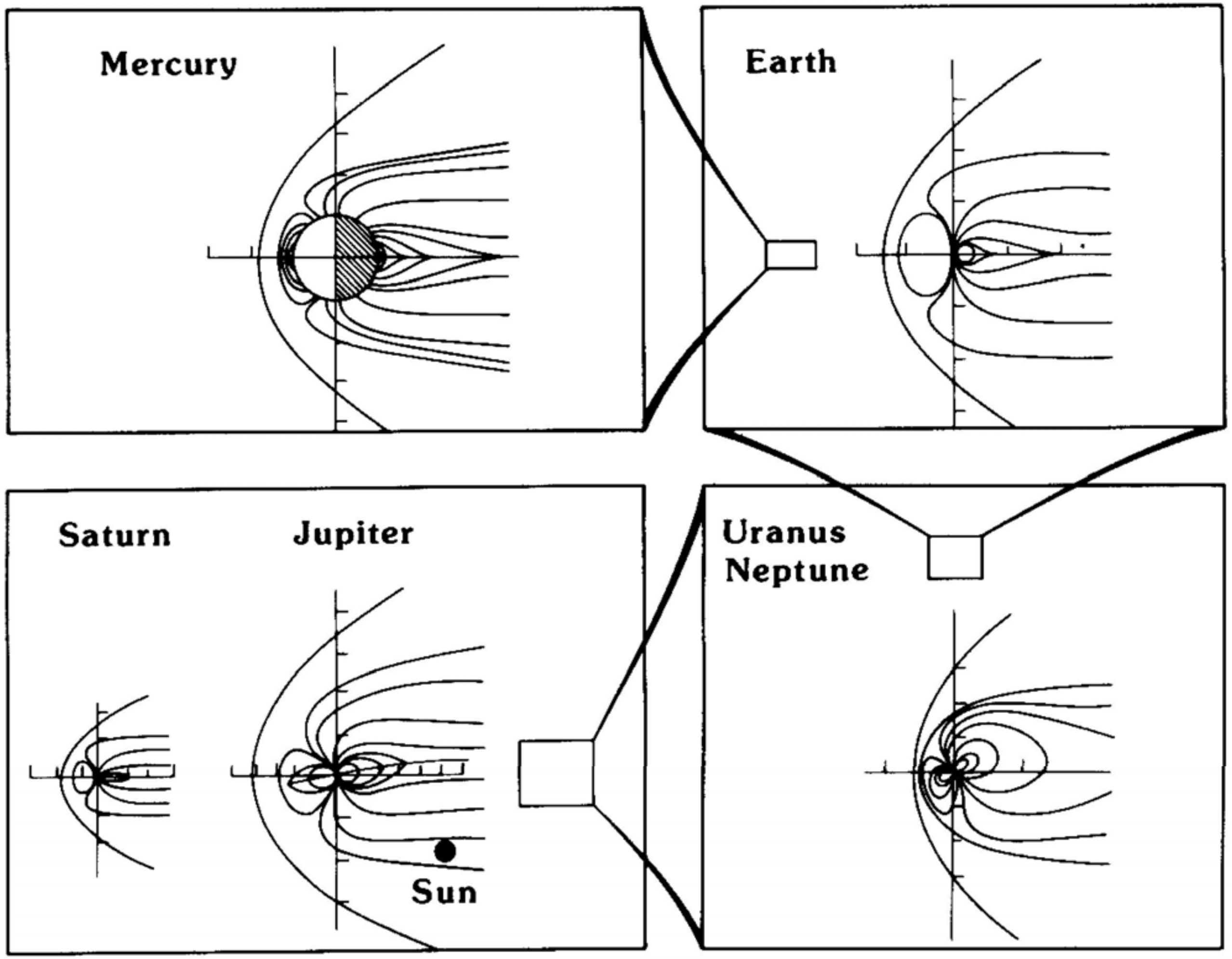
Encrenaz and Bibring, 1990, The solar system, Springer

Planetary magnetic fields

	Equatorial field (gauss)	Dipole moment (gauss cm^3)	Angle between axes	Typical stand-off distance (r_p)	Calculated stand-off distance	Plasma sources
Mercury	0.002	3×10^{22}	$< 10°$	1.45	1.74	W
Venus	<0.0003	$< 10^{21}$	?	1.1	?	W,A
Earth	0.305	7.9×10^{25}	11.5°	10.7	10.7	W,A
Mars	0.0004?	1.4×10^{22}	?	?	?	?
Jupiter	4.2	1.5×10^{30}	9.5°	47–97	45	W,A,S
Saturn	0.2	4.3×10^{28}	$< 1°$	17–24	20	W,A,S
Uranus	0.23	3.8×10^{27}	58.6°	18–25	26	A
Neptune	0.06–1.2	2×10^{27}	46.8°	23–26.5	25	W,A,S

- Dipole moment correlates with speed of rotation (except Mars and Uranus),
- Earth has second largest equatorial magnetic field,
- Modeled standoff distances in good agreement with observed ones.

Relative sizes

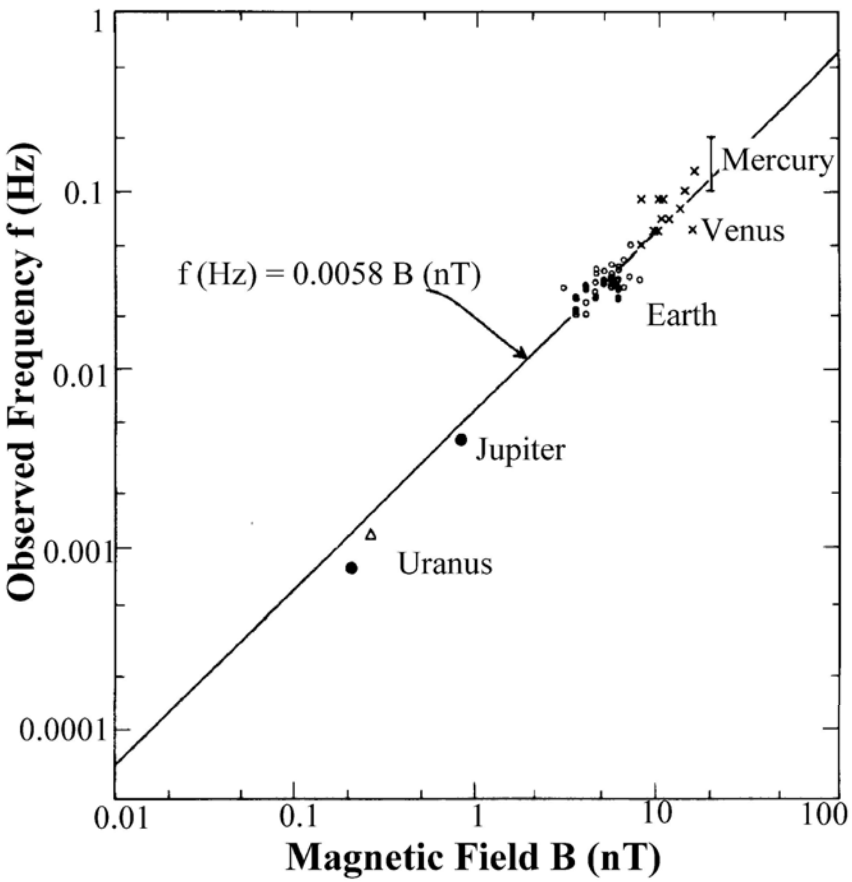


Russell and Walker, 1995, in Introduction to Space Physics, Cambridge Univ. Press

Upstream waves

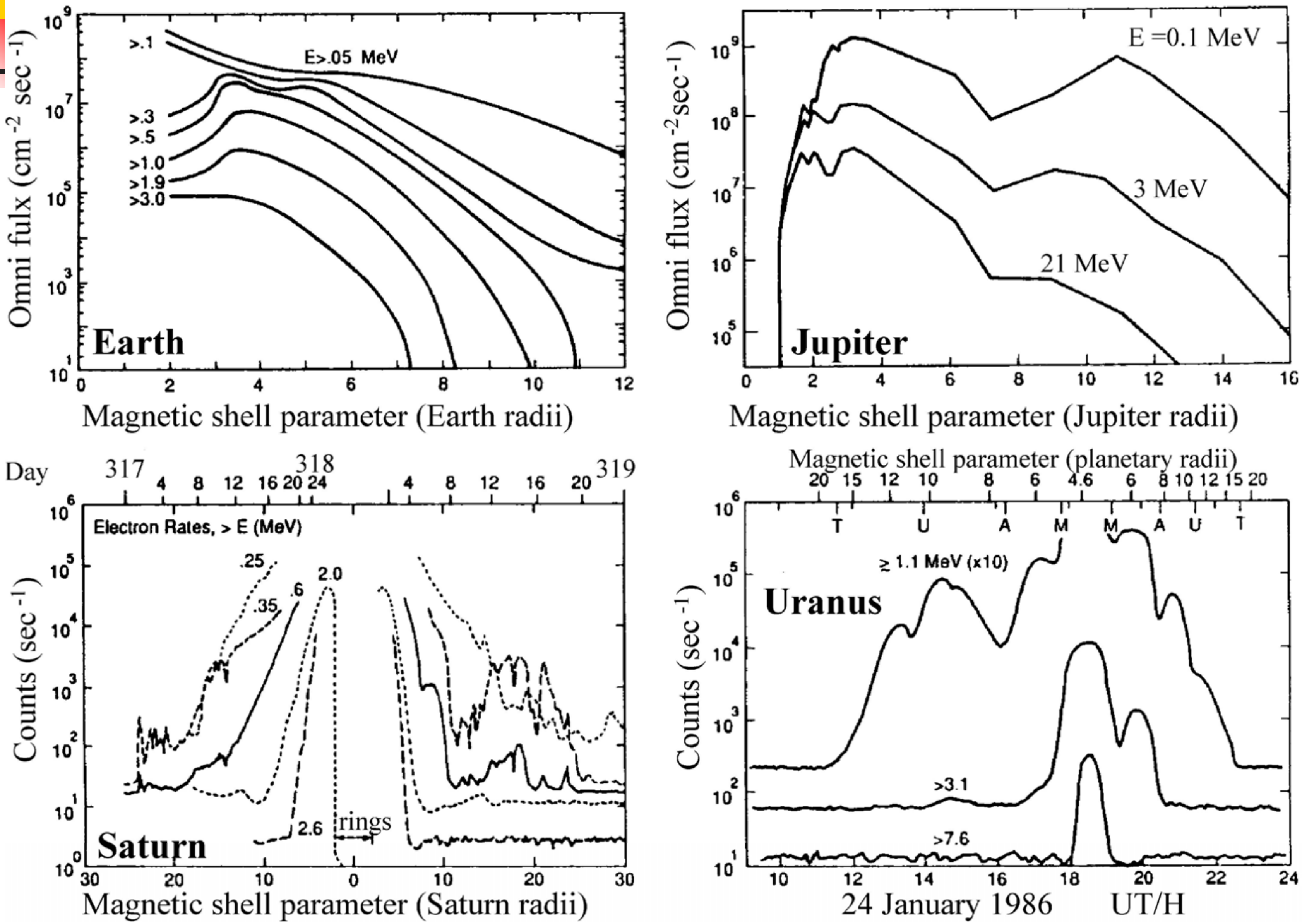
- All planets have foreshocks; their details depend on the angle between interplanetary magnetic field, solar wind flow and planetary magnetic field.

- Frequency of the self-generated waves correlates with magnetic field strength (as expected from theory).



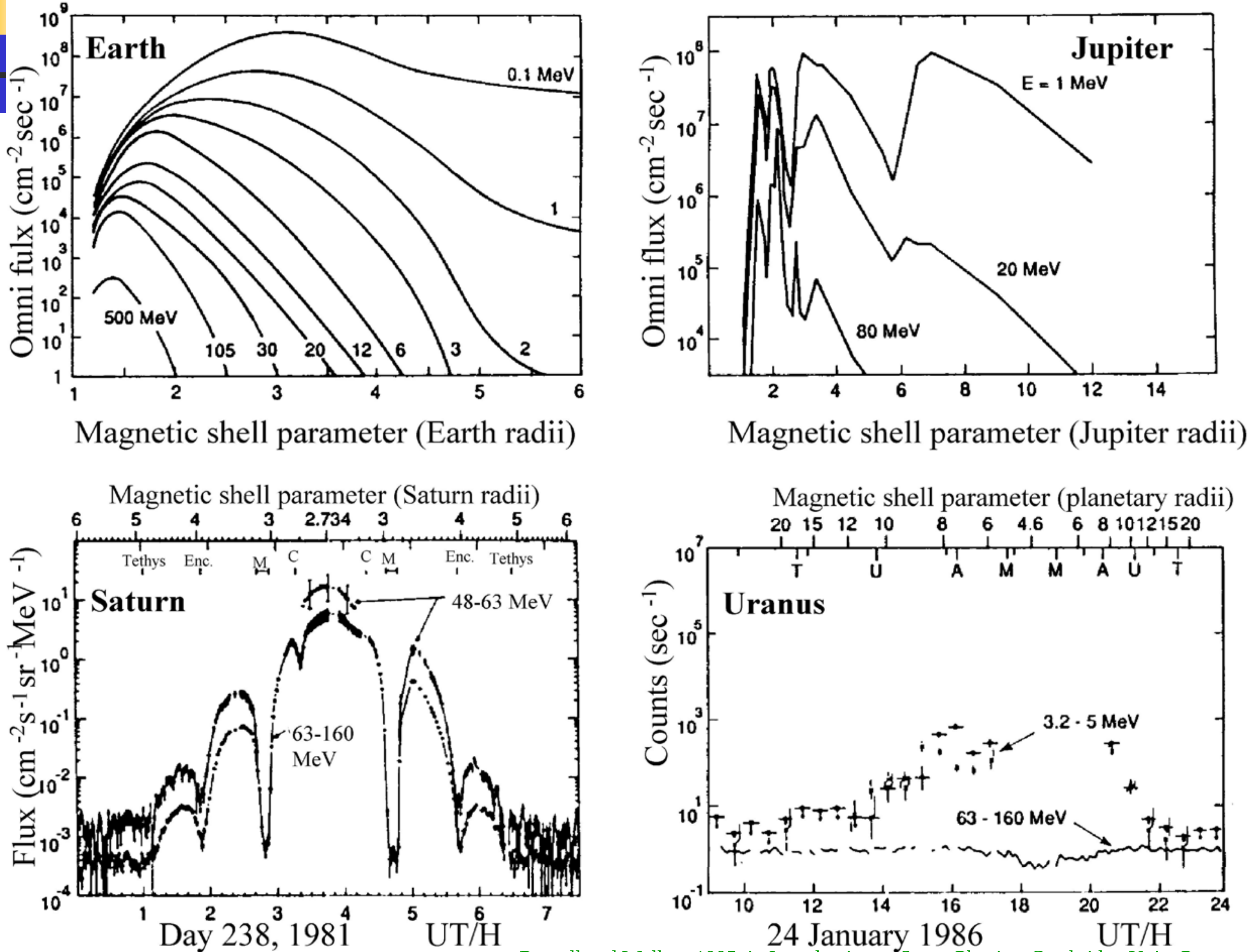
Russell et al., 1990, J. Geophys. Res. 95, 2273

Radiation belts (protons)



Russell and Walker, 1995, in Introduction to Space Physics, Cambridge Univ. Press

Radiation belts (electrons)



Russell and Walker, 1995, in Introduction to Space Physics, Cambridge Univ. Press