Atmosfere planetov

Table 3.1 Distances, visual albedos, effective temperatures, and mean temperatures of the planets[a]

Planet	Average distance, D_P (AU)	Visual geometric albedo, A	Effective temperature, T_{eff} (kelvin)	Mean temperature[b] (kelvin)
Mercury	0.387	0.106	436	440
Venus	0.723	0.65	252	730
Earth	1.000	0.367	249	281
Mars	1.524	0.150	217	210
Jupiter	5.203	0.52	102	165
Saturn	9.537	0.47	77.1	134
Uranus	19.19	0.51	53.3	76
Neptune	30.07	0.41	44.6	73

[a] Distances and mean temperatures are from http://www.jpl.nasa.gov/solar_system/planets. Effective temperatures are calculated from the visual geometric albedos, which are from http://ssd.jpl.nasa.gov.

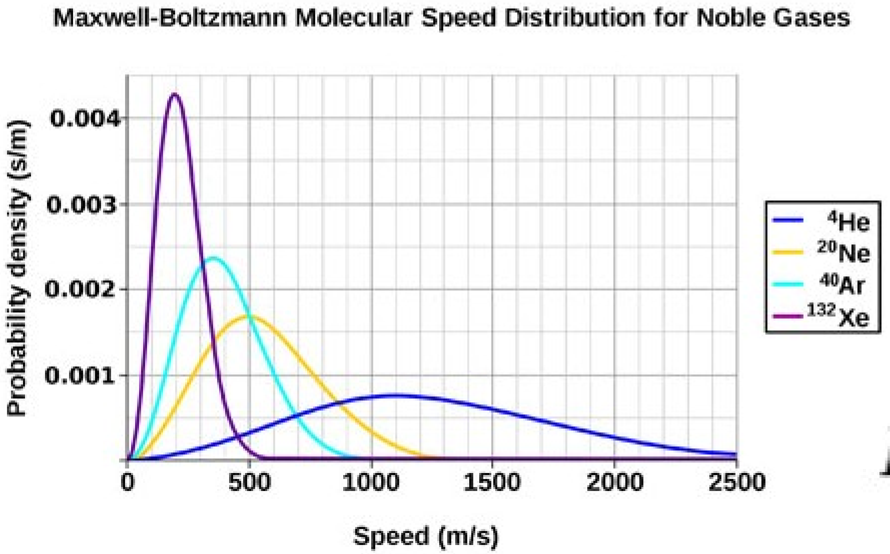
[b] There are the mean surface temperatures for the terrestrial planets and the mean cloud-top temperatures for the giant planets.

Maxwellova porazdelitev hitrosti

- Verjetnost, da ima delec v plinu hitrost med v_x in $v_x + dv_x$ je sorazmerna z $\exp(-mv_x^2/2kT)$. [Tim. Boltzmannov faktor.]
- Nas pa ne zanima v_x ampak velikost hitrosti v. To lahko zapišemo kot $v^2 = v_x^2 + v_y^2 + v_z^2$. Torej je treba upoštevati, da število kombinacij (v_x, v_y, v_z), ki dajo isti v^2 raste kot površina krogle z radijem v, torej kot $4\pi v^2$.
- Po normalizaciji dobimo verjetnost *D*, da je hitrost med v in v+dv:

$$D(v)\,dv = \left(\frac{m}{2\pi kT}\right)^{3/2} 4\pi v^2 e^{-mv^2/(2kT)}\,dv.$$

Maxwellova porazdelitev hitrosti



$$D(v)\,dv = \left(\frac{m}{2\pi kT}\right)^{3/2} 4\pi v^2 e^{-mv^2/(2kT)}\,dv.$$

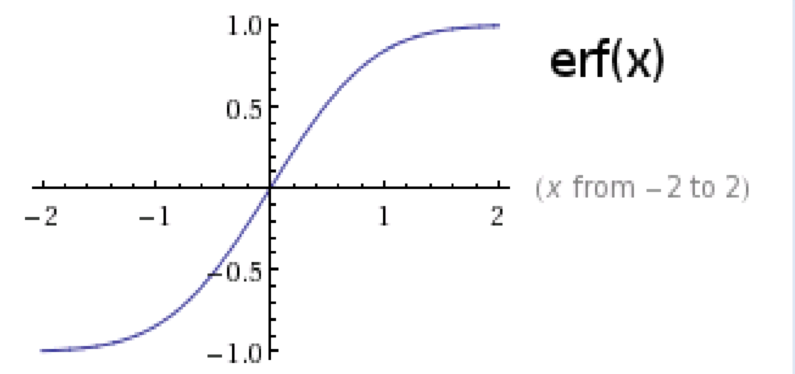
Fig. 3.1 . The Maxwellian probability distribution of speed density (*left axis*) at different speeds, v (*bottom axis*) for a temperature of T = 218.85 kelvin and four noble gases, helium (*blue*), neon (*yellow*), argon (*turquoise*) and xenon (*purple*). The peak of each curve occurs at the most probable speed, vP = (2kT/m)^1/2, where Boltzmann's constant k = 1.38 x 10^-23 Joule per kelvin, T is the temperature, and m is the element's mass. This distribution was derived by teh Scottish scientist James Clerk Maxwell (1831-1879) in 1873. As indicated in this plot, the peak shifts to higher speeds at lower mass provided the temperature is unchanged, for less massive elements tend to move at faster speeds. A similar change occurs at higher temperatures for a given mass.

Ubežna hitrost?

$$D(v)\,dv = \left(\frac{m}{2\pi kT}\right)^{3/2} 4\pi v^2 e^{-mv^2/(2kT)}\,dv.$$

$$\int x^2 e^{-x^2}\,dx =$$

$$\frac{1}{4}\sqrt{\pi}\,\mathrm{erf}(x) - \frac{1}{2}e^{-x^2}x$$



Series expansion at x=∞:

$$e^{-x^2}\left(-\frac{1}{\sqrt{\pi}\,x} + \frac{1}{2\sqrt{\pi}\,x^3} - \frac{3}{4\sqrt{\pi}\,x^5} + \frac{15}{8\sqrt{\pi}\,x^7} - \frac{105}{16\sqrt{\pi}\,x^9} + O\left(\left(\frac{1}{x}\right)^{10}\right)\right) + 1$$

Ubežna hitrost?

$$D(v)\,dv = \left(\frac{m}{2\pi kT}\right)^{3/2} 4\pi v^2 e^{-mv^2/(2kT)}\,dv. \quad = (4/\sqrt{\pi})\, x^2\, e^{-x^2}\, dx$$

$$\int_x^\infty D(v)\,dv \approx (2/\sqrt{\pi})\, x\, e^{-x^2}$$

$m = A\, m_p$
$T = 250$ K
$v = v_{ubežna}$ (R=7000 km)
↓
$x = 5.434\sqrt{A}$

Element	A	$\int_x^\infty D(v)\,dv$	čas, če t(1 poskus)=100s
H	1	$9.2\ 10^{-13}$	10^{14} s = $3\ 10^{6}$ let
He	4	$6.2\ 10^{-51}$	∞

(če pa bi bila v eksosferi T=1000 K, bi bil helij kot vodik pri 250 K).

Sestava atmosfere notranjih planetov

Table 3.2 Percentage composition, surface pressures and surface temperatures of the atmospheres of Venus, Mars and Earth

	Venus	Mars	Earth
Carbon dioxide, CO_2 (%)	96.5	95	0.035
Nitrogen, N_2 (%)	3.5	2.7	77
Argon, Ar (%)	0.007	1.6	0.93
Water vapor, H_2O (%)	0.010	0.03 (variable)	1 (variable)
Oxygen, O_2 (%)	0.003	0.13	21
Surface pressure (bars)	92	0.007 to 0.010	1.0 (at sea level)
Surface temperature (kelvin)	735	183 to 268	288 to 293

Sestava atmosfere zunanjih planetov

Table 3.3 Percentage composition of the Sun and the outer atmospheres of the giant planets[a]

Molecule or atom	Sun	Jupiter	Saturn	Uranus	Neptune
Hydrogen, H_2 (molecule)	84	86.4	97	83	79
Helium, He (atom)	16	13.6	3	15	18
Water, H_2O (molecule)	0.15	(0.1)	–	–	–
Methane, CH_4 (molecule)	0.07	0.21	0.2	2	3
Ammonia, NH_3 (molecule)	0.02	0.07	0.03	–	–

[a] The percentage abundance by number of molecules for the Sun, cooled to planetary temperatures so that the elements combine to form the compounds listed, and for the outer atmospheres of the giant planets below the clouds. Dashes indicate unobserved compounds. Courtesy of Andrew P. Ingersoll.

Vetrovi v atmosferah zunanjih planetov

Jupiter's counter-flowing winds

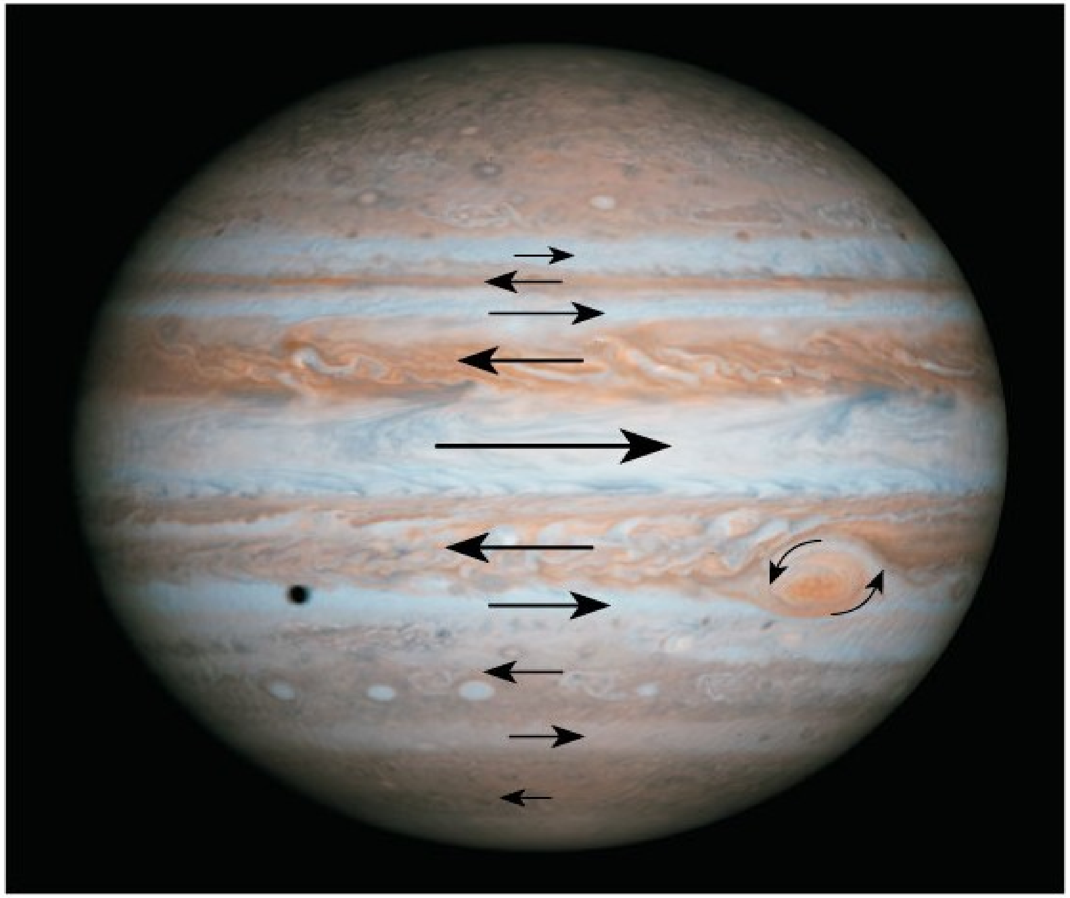


Fig. 3.6 . The rapid rotation of Jupiter has pulled its winds into bands that flow east to west and west to east, shown in this image taken from the *Cassini* spacecraft on 7 December 2001. The windswept clouds move in alternating light-colored, high-pressure zones and dark-colored, low-pressure belts. The arrows point in the direction of wind flow, and their length corresponds to the wind velocity, which can reach 180 meters per second in the equatorial regions (see Figure 3.7). The Great Red Spot swirls in the counter-clockwise direction (*curved arrows*), like a high-pressure anticyclone in the Earth's southern hemisphere, but it has lasted for more than 300 years, much longer than terrestrial storms. Jupiter's moon Europa casts a shadow on the planet. (Courtesy of NASA/JPL.)

Vetrovi v atmosferah zunanjih planetov

Winds on the giant planets

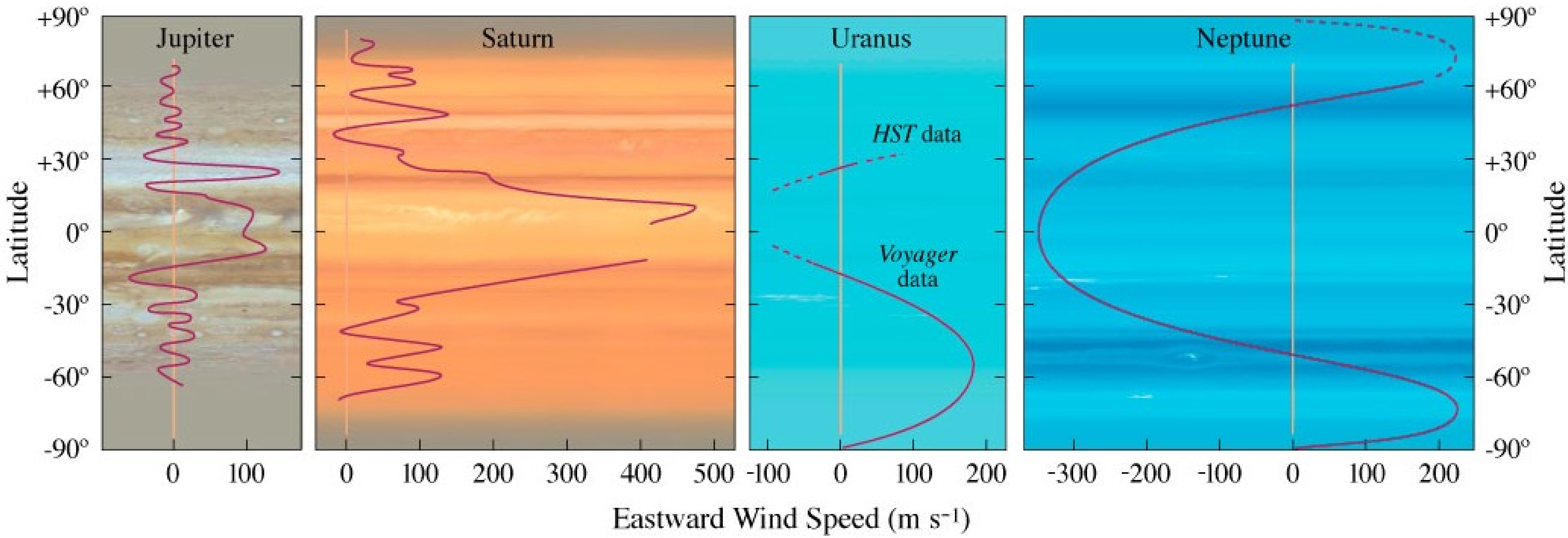


Fig. 3.7 . Variation of wind speed and direction as a function of latitude. Since the giant planets have no solid surfaces, the winds are measured relative to the internal rotation speeds; the rotation period is determined from observations of the planet's periodic radio emission. Positive velocities correspond to winds blowing in the same direction but faster than the internal rotation; negative velocities are winds moving more slowly than the rotation. The winds are faster on Saturn than any other planet. (Courtesy of Andrew P. Ingersoll.)

Atmosfera Saturnove lune Titan

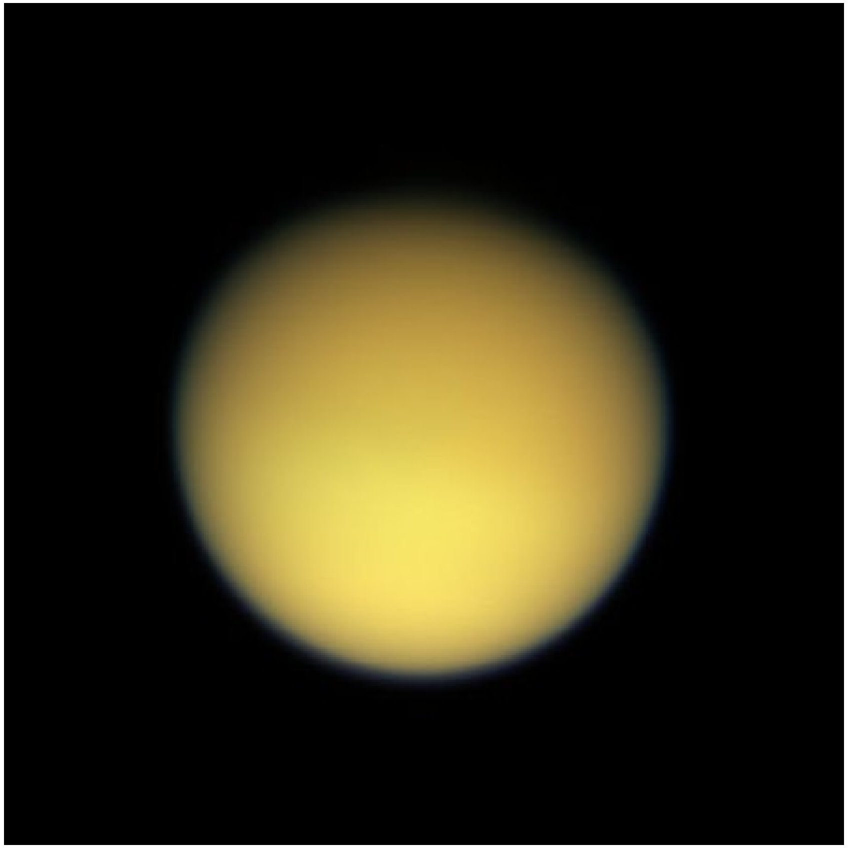


Fig. 3.8a . The surface of Saturn's moon Titan is hidden from view by a hazy layer of smog, giving it a fuzzy, tennis-ball appearance in a *Cassini* natural-color view taken on 15 February 2005. (Courtesy of NASA/JPL/U. Arizona/DLR.)

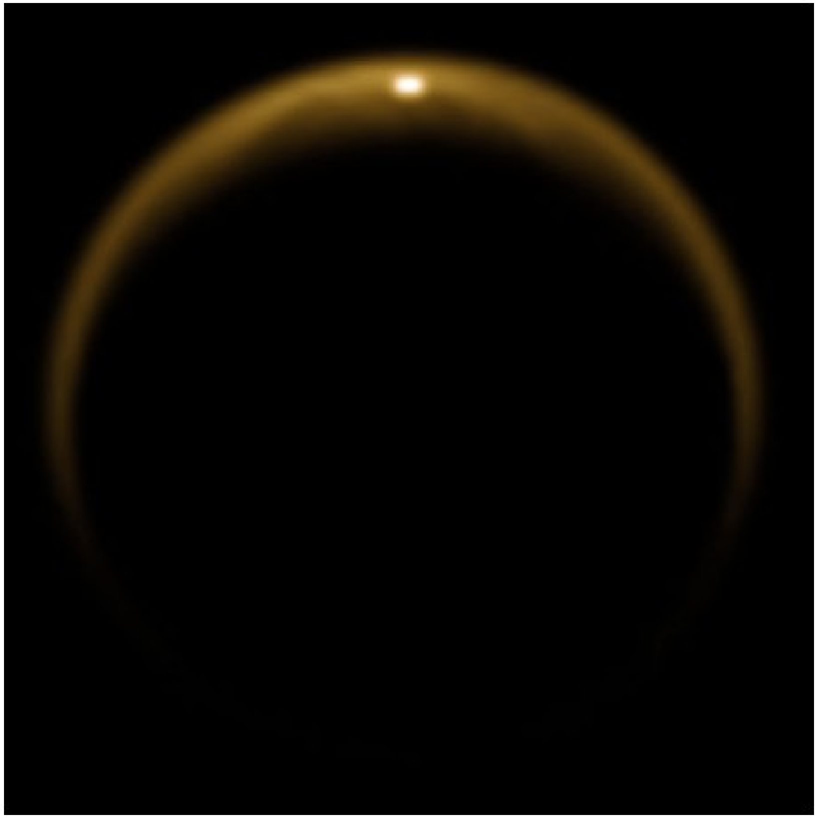


Fig. 3.8b . By observing radiation at infrared wavelengths, on 8 July 2009, a *Cassini* instrument was able to penetrate through the moon's atmosphere and catch the glint of sunlight reflected off a huge lake in the northern hemisphere of Titan; the lake is probably filled with liquid methane and ethane. (Courtesy of NASA/JPL/SSI and NASA/JPL/U. Arizona/DLR.)

Atmosfera Saturnove lune Titan

Tlak na površju: 1.5 bara
Temperature na površju: 94 K

Sestava:
≤ 94% dušik N_2
1-6% metan CH_4

Sončevo UV sevanje tega deloma razbije in se nato rekombinira v etan (C_2H_6), acetilen (C_2H_2), propan (C_2H_8) in cianovodikovo kislino (HCN).

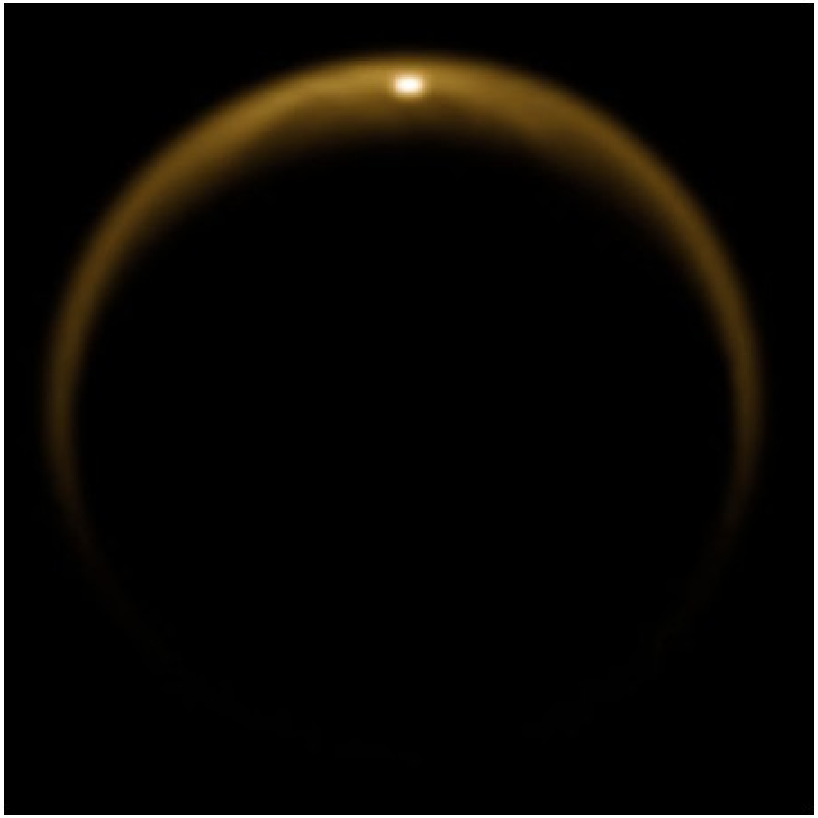


Fig. 3.8b . By observing radiation at infrared wavelengths, on 8 July 2009, a *Cassini* instrument was able to penetrate through the moon's atmosphere and catch the glint of sunlight reflected off a huge lake in the northern hemisphere of Titan; the lake is probably filled with liquid methane and ethane. (Courtesy of NASA/JPL/SSI and NASA/JPL/U. Arizona/DLR.)

Prisotnost plinov okrog Io(ne) in Evrope

Ob mimoletu Jupitrovih lun Io in Evropa so pri prvi opazili sledi SO_2, pri drugi pa kisika O_2.

Pri prvi je to posledica vulkanizma, pri drugi pa (ob površinskem tlaku 10^{-7} bara) bombardiranja vodnega ledu na površju s hitrimi nabitimi delci ali notranjih izbruhov.

Podobna eksosfera obdaja tudi Merkur.

Sončev veter

Masni tok s Sonca je ~10^9 kg/s.
To ustreza1.6 10^{-14} M_{Sonce}/leto.

Fig. 3.9 . The million-degree solar atmosphere, known as the corona, is seen around the black disk of the Earth's Moon, photographed in white light, or all the colors combined, from atop Mauna Kea, Hawaii during the solar eclipse on 11 July 1991. The electrically charged gas is concentrated in numerous fine rays as well as larger helmet streamers. (Courtesy of the HAO/NCAR.)

Sončev veter

Table 3.4 Mean values of solar-wind parameters at the Earth's orbit[a]

Parameter	Mean Value
Particle density, N	$N \approx 10$ million particles per cubic meter (5 million electrons and 5 million protons)
Velocity, V	$V \approx 400$ kilometers per second and $V \approx 800$ kilometers per second
Flux, F	$F \approx 10^{12}$ to 10^{13} particles per square meter per second
Temperature, T	$T \approx 120\,000$ kelvin (protons) to $140\,000$ kelvin (electrons)
Particle thermal energy, kT	$kT \approx 2 \times 10^{-18}$ joule ≈ 12 eV
Proton kinetic energy	$0.5\, m_p V^2 \approx 10^{-16}$ joule ≈ 1000 eV $= 1$ keV
Particle thermal energy density	$NkT \approx 10^{-11}$ joule m^{-3}
Proton kinetic energy density	$0.25\, N\, m_p\, V^2 \approx 10^{-9}$ joule m^{-3}
Magnetic field strength, H	$H \approx 6 \times 10^{-9}$ tesla $= 6$ nanotesla $= 6 \times 10^{-5}$ gauss

[a] These solar-wind parameters are at the mean distance of the Earth from the Sun, or at one astronomical unit, 1 AU, where 1 AU $= 1.496 \times 10^{11}$ meters. Boltzmann's constant $k = 1.38 \times 10^{-23}$ joule per kelvin relates temperature and thermal energy. The proton mass m_p is 1.67×10^{-27} kilograms.

Torej nadzvočen.

Odkritje Sončevega vetra: obstoj hitrega ionskega repa kometov

Fig. 3.10 . Telescopic photograph of Comet Mrkos taken in August 1957, showing the straight, well-defined ion tail and the more diffuse, slightly curved dust tail. Both comet tails point away from the Sun. The electrified solar wind deflects the charged ions and accelerates them to high velocities, creating the relatively straight ion tails. The radiation pressure of sunlight suffices to blow away the unionized comet dust particles, forming a broad arc that can resemble a scimitar. (Courtesy of Lick Observatory.)

Obstoj hitrega ionskega repa kometov

Color image of comet Hale-Bopp, taken on 1997 Mar. 13 (2h42-3h02UT) with

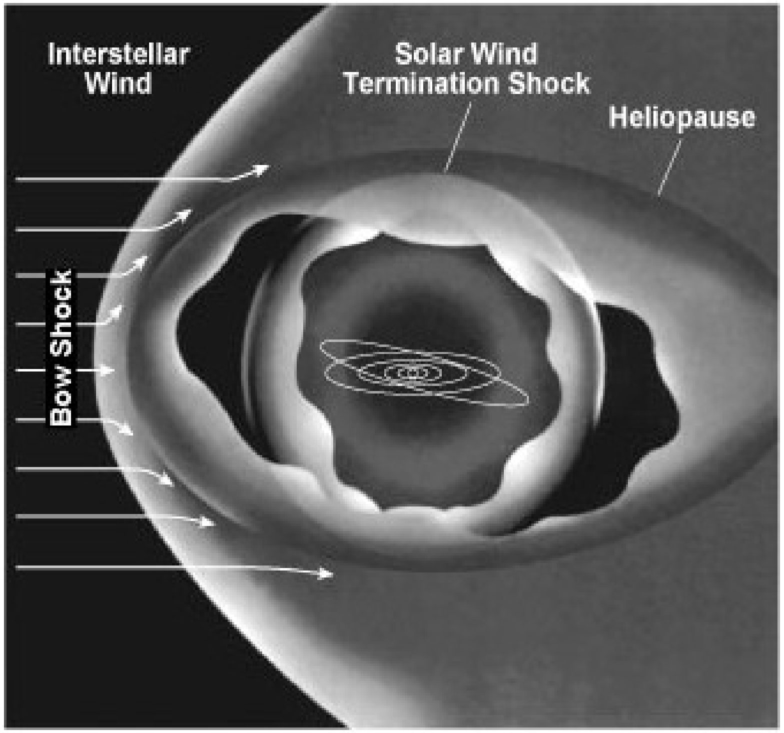
300mm, f/4 Asahi Pentax (6x7) camera lens and Kodak Vericolor 400 film.

The field of view is ~11x13 deg. Copyright © 1997 by A. Flajs & H. Mikuz.

Wide-field color image of comet Hale-Bopp, taken on 1997 Mar. 13 (3h13-3h33UT) with 3.5/65mm (6x6) camera lens and Kodak Vericolor 400 film. The field of view is ~40x40 deg. Copyright © 1997 by A. Flajs & H. Mikuz.

Heliosfera

Heliosphere



$R_{heliosfera} \sim 100$ a.e.

Fig. 3.11 . With its solar wind going out in all directions, the Sun blows a huge bubble in space called the heliosphere. The heliopause is the name for the boundary between the heliosphere and the interstellar gas outside the solar system. Interstellar winds mold the heliosphere into a non-spherical shape, creating a bow shock where they first encounter it. The orbits of the planets are shown near the center of the drawing.

Zemljino magnetno polje

Južni magnetni pol je na geografski širini $78{,}3^{o}$.

Na Zemljinem magnetnem ekvatorju imamo polje $3\ 10^{-5}$ Tesla, ob polih pribl. $6\ 10^{-5}$ Tesla.

Magnetno polje generirajo električni tokovi v rotirajočem tekočem zunanjem jedru.

Polje je obrnilo smer v povprečju na 2 milijona let v zadnjih 200 milijonih let. Intervali so od 10^{4} do 10^{7} let.

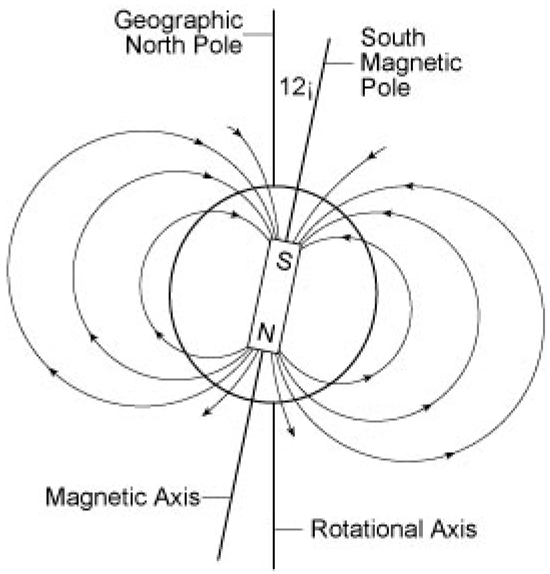
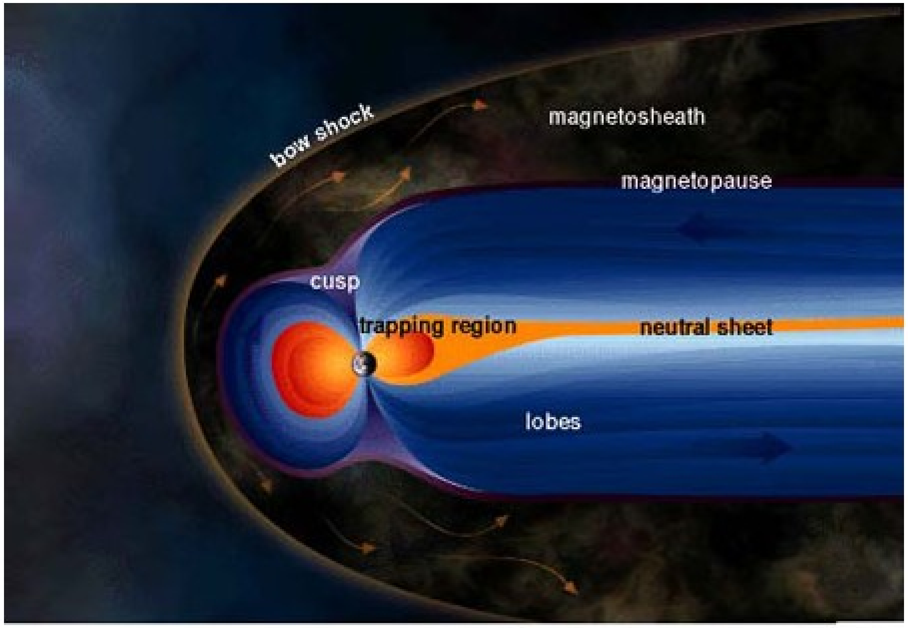


Fig. 3.12 . The Earth’s magnetic field looks like that which would be produced by a bar magnet at the center of the Earth, with the North Magnetic Pole corresponding to the South Geographic Pole and *vice versa*. The Earth's magnetic dipole originates in swirling currents of molten iron deep in the Earth’s liquid outer core, and extends more than 10 Earth radii, or 63.7 thousand kilometers out into space on the side facing the Sun, and all the way to the Moon's orbit, at 384.4 thousand kilometers on the opposite side. Magnetic field lines loop out of the South Geographic Pole and into the North Geographic Pole. The lines are close together near the magnetic poles where the magnetic force is strong, and spread out where it is relatively weak. The magnetic axis is tilted at an angle of 11.7 degrees with respect to the Earth’s rotational axis. This dipolar (two poles) configuration applies near the surface of the Earth, but further out the magnetic field is distorted by the solar wind.

Zemljina magnetosfera

Asymmetric magnetosphere

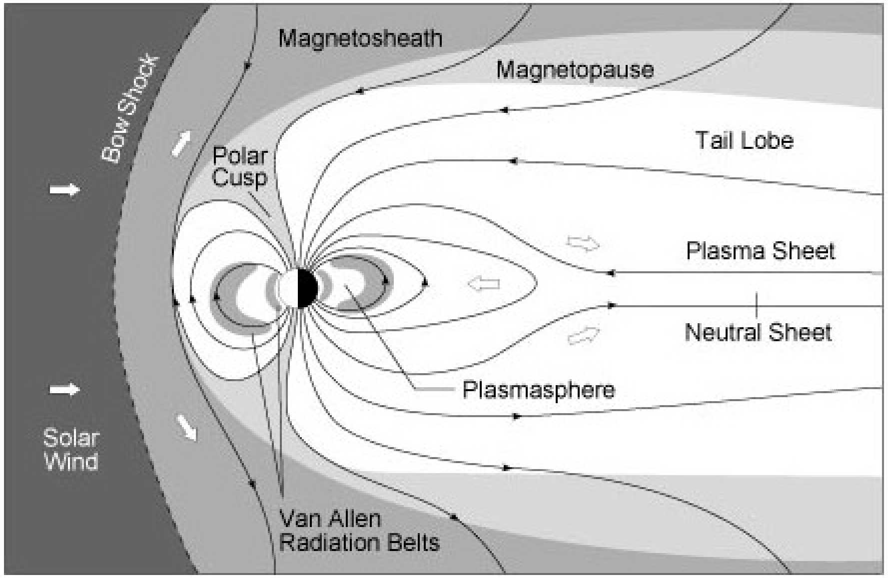


Sončni veter ima nadzvočno hitrost, torej pride do udarnega vala. Sončni veter tako obteka magnetopavzo.

Fig. 3.13 . The Earth's magnetic field carves out a hollow in the solar wind, creating a protective cavity called the magnetosphere (*blue*). It is sculpted into an asymmetric shape by the solar wind, with a bow shock that forms at about ten Earth radii on the sunlit, day-side facing the Sun (*left*). The location of the bow shock is highly variable since it is pushed in and out by the gusty solar wind. The magnetopause marks the outer boundary of the magnetosphere, at the place where the solar wind takes control of the motions of charged particles. The solar wind is deflected around the Earth, pulling the terrestrial magnetic field into a long magnetotail on the night side (*right*). The red regions in the inner magnetosphere contain the plasmasphere, the ring current and the outer Van Allen belt, where electrons, protons and other ions are trapped in closed paths. (Courtesy of ESA.)

Zemljina magnetosfera

Earth's magnetosphere

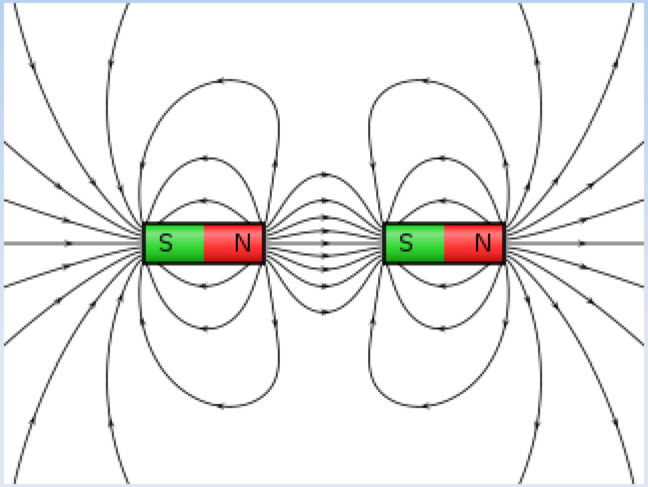


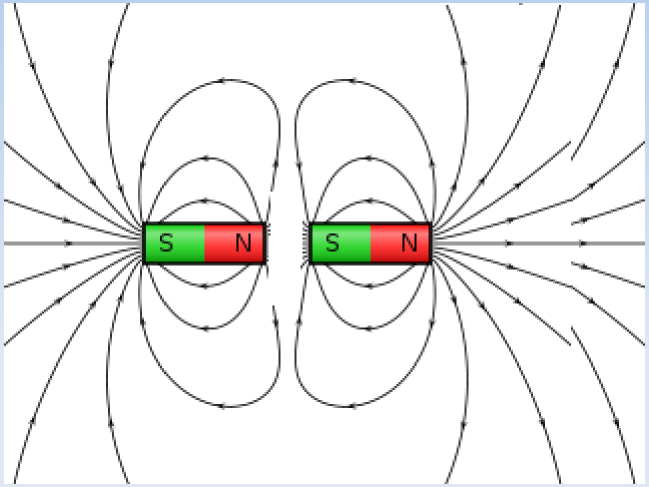
Razdalji Van Allenovih pasov sta ~1.5 in ~4.5 R_{Zemlje} od njenega središča.

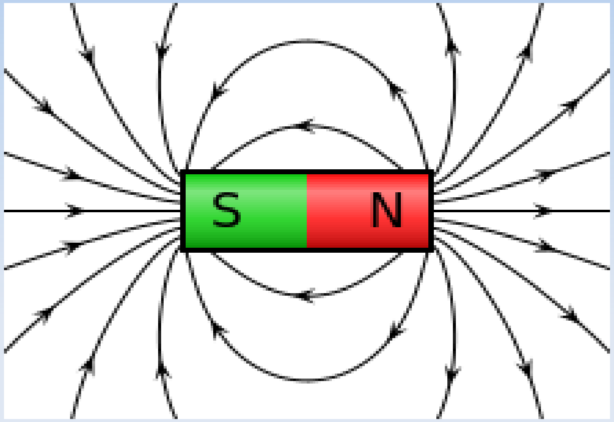
V zunanjem pasu so le elektroni,
V notranjem pa protoni in elektroni.

Fig. 3.14 . The Earth's magnetic field carves out a hollow in the solar wind, creating a protective cavity called the magnetosphere. The Earth, its auroras, atmosphere and ionosphere, and the two Van Allen radiation belts all lie within this magnetic cocoon. Similar magnetospheres are found around other magnetized planets. Electrons and protons in the solar wind are deflected at the bow shock (*left*), and flow along the magnetopause into the magnetic tail (*right*). Electrified particles can be injected back toward the Earth and Sun within the plasma sheet (*center*).

Magnetno prevezovanje (reconnection)







Približevanje nasprotno usmerjenih magnetov

Magnetna steklenica

Magnetic trap

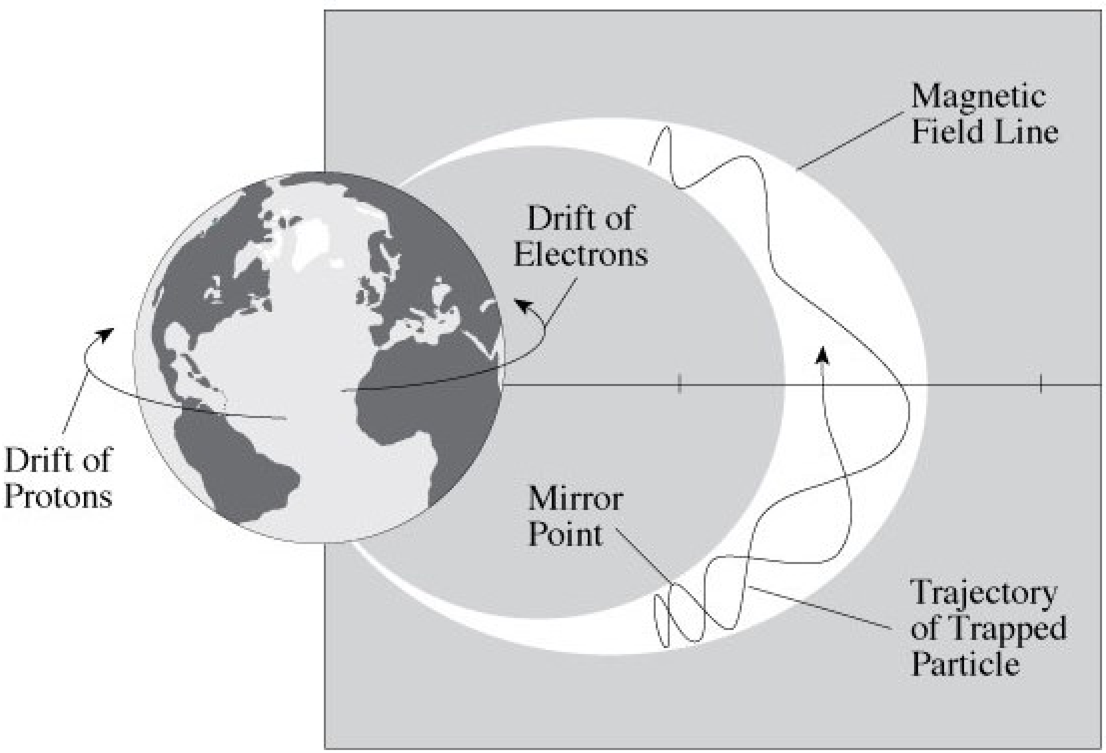


Fig. 3.15 . Charged particles can be trapped by Earth's magnetic field. They bounce back and forth between polar mirror points in either hemisphere at intervals of seconds to minutes, or they also drift around the planet on time scales of hours. As shown by the Norwegian scientist Carl Størmer (1874-1957) in 1907, with the trajectories shown here, the motion is turned around by the stronger magnetic fields near the Earth's magnetic poles. Because of their positive and negative charge, the protons and electrons drift in opposite directions.

Če je magnetno polje s Sonca, ki ga s sabo nosi nabiti Sončev veter nasprotno usmerjeno od Zemljinega magnetnega polja, se polji združita (kot privlak nasprotnih polov 2 magnetov) in nastane "odprtina", skozi katero nabiti delci Sončevega vetra lahko vstopijo v Zemljino magnetno polje in se v njem ujamejo.

Ob hitrosti 400 km/s delec za eno Oscilacijo S-J porabi ~30000/400 s = 75 s.

Radij tira: $evB=mv^2/r$, kar pri v = 400km/s In $B=10^{-5}$ Tesla da r = 23 cm.

Magnetna polja planetov

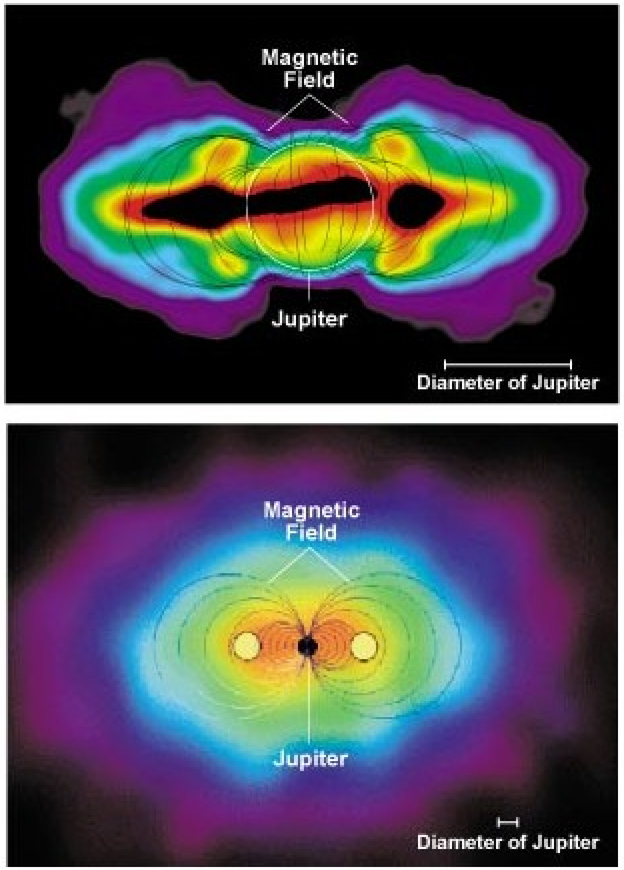
Table 3.5 Planetary magnetic fields[a]

Planet	Magnetic dipole moment (Earth = 1)	Magnetic field at the equator, B_o (Earth = 1)	Tilt of magnetic axis center (degrees)	Offset from planet R_{MP}	Bow shock stance, (R_P)	Planet equatorial radius, R_P (km)
Mercury	0.0007	0.0033	+14	0.05 R_M	1.5 R_M	$R_M = 2439$
Earth	1	0.305	+11.7	0.07 R_E	10 R_E	$R_E = 6378$
Jupiter	20,000	4.28	−9.6	0.14 R_J	42 R_J	$R_J = 71\,492$
Saturn	600	0.22	<1.0	0.04 R_S	19 R_S	$R_S = 60\,268$
Uranus	50	0.23	−58.6	0.3 R_U	25 R_U	$R_U = 25\,559$
Neptune	25	0.14	−47.0	0.55 R_N	24 R_N	$R_N = 24\,764$

[a] The magnetic field strengths are given at the surface of Mercury and the Earth and at the cloud tops for the giant planets. Venus and Mars have no detected global, dipolar magnetic field, with respective upper limits of 2×10^{-9} and 10^{-8} tesla. Here the magnetic dipole moment, $D_P = B_o R_P^3$, is given in units of the Earth's magnetic dipole moment of 7.91×10^{15} T m^3. The tilt is the angle between the magnetic axis and the rotation axis. Here we use the SI unit for magnetic field strength, the tesla (T). The c.g.s. unit of magnetic field strength, the gauss (G), can be computed from 1 T 10^4 G. The nanotesla (nT) is also used, with 1 nT = 10^{-9} T, and the nanotesla has historically also been called the gamma. A dipole moment of 1 T m^3 equals 10^{10} G cm^3, where m and cm respectively denote meter and centimeter. The equivalent unit of 1 G cm^3 = 10^{-3} A m^2 is also used, where the current is in units of amperes (A). The equatorial radius of the planets is given in kilometers (km).

Jupitrova magnetosfera

Jupiter's magnetosphere



Hitra rotacija Jupitra pomeni, da je magnetosfera bolj sploščena.

Fig. 3.17 . High-speed electrons that are trapped in Jupiter's magnetosphere emit steady radio radiation (*top*) by the synchrotron process; it is detected by ground-based radio telescopes such as the Very Large Array. An instrument aboard the *Cassini* spacecraft measured energetic atoms (*bottom*) created when fast-moving ions within the magnetosphere picked up electrons to become neutral atoms. The two open circles denote Io's orbital position on each side of the planet; the central black disk denotes Jupiter. [Courtesy of Imke de Pater, U. C. Berkeley (*top*) and NASA/JPL /JHUAPL (*bottom*).]

Jupitrova magnetosfera

Satellites within Jupiter's magnetic field

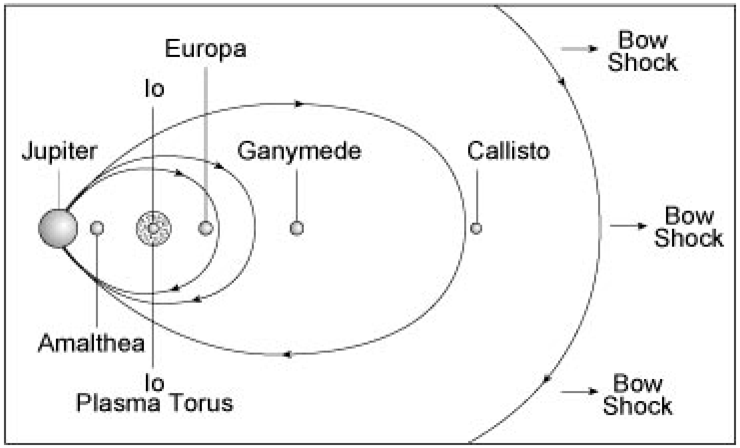


Fig. 3.18 . This cross section shows that the four Galilean satellites, Io, Europa, Ganymede and Callisto, are all embedded within Jupiter's magnetosphere. Small satellites orbit Jupiter within the orbit of Io, the innermost Galilean satellite. The outermost Galilean satellite, Callisto, orbits Jupiter near its bow shock. All of these satellites are being continuously bombarded with energetic charged particles that are trapped within Jupiter's magnetosphere. The distance from Jupiter to Callisto is 1.88 million (1.88 x 106) kilometers, while the radius of the Sun is 0.6955 billion meters, so Jupiter's bow shock is bigger than the Sun.

Magnetni polji Urana in Neptuna

Tilted magnetic fields

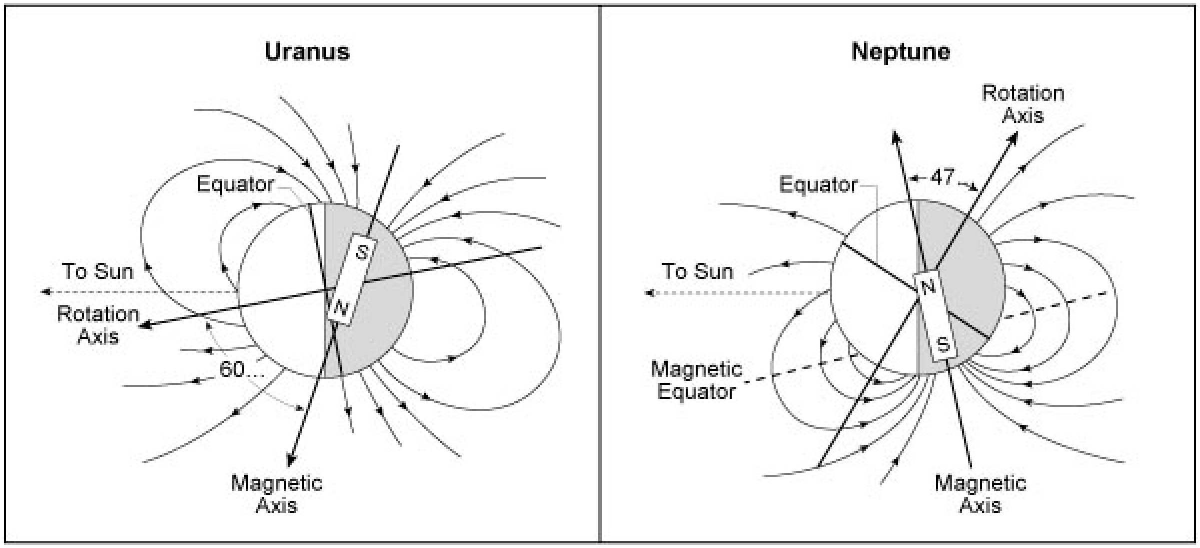


Fig. 3.19 . The magnetic fields of Uranus and Neptune can be represented by a simple bar magnet, or dipole, embedded in the planet, but with a magnetic axis that is tilted with respect to the rotation axis. For Uranus the tilt is about 60 degrees; Neptune has a tilt of 47 degrees. In contrast, the magnetic axes of Jupiter, Saturn and Earth are much more nearly aligned with their rotation axes. The arrow of the rotation axis points from the geographic south towards geographic north, and the magnetic axis similarly points from magnetic south to magnetic north. On Uranus and Neptune a terrestrial compass would point toward the southern hemisphere of the planet, while on Earth it points toward the geographic north pole. In addition to the dipole part of their magnetic field, Uranus and Neptune have a large additional component known as the quadrupole one. A method of visualizing this is to imagine that the dipole has a magnetic center that is offset from the center of the planet. As shown here, the equivalent offset for Uranus is almost a third of the planet's radius, and there is a larger offset for Neptune of nearly half its radius. But such off-center dipoles are only useful as a picture of what the external field looks like and do not help in understanding how it is produced deep down.

Severni sij

Northern lights

Fig. 3.20 . Spectacular green curtains of light dance and shimmer across the northern sky. High-energy electrons are funneled down the Earth's polar magnetic field lines into the atmosphere, where they excite oxygen atoms that fluoresce green light, like a cosmic neon sign. The color is usually green, but the aurora can also have red bottoms, arising from excited nitrogen molecules. This photograph of the fluorescent Northern Lights, or Aurora Borealis, was taken over Fairbanks, Alaska. (Courtesy of Jan Curtis.)

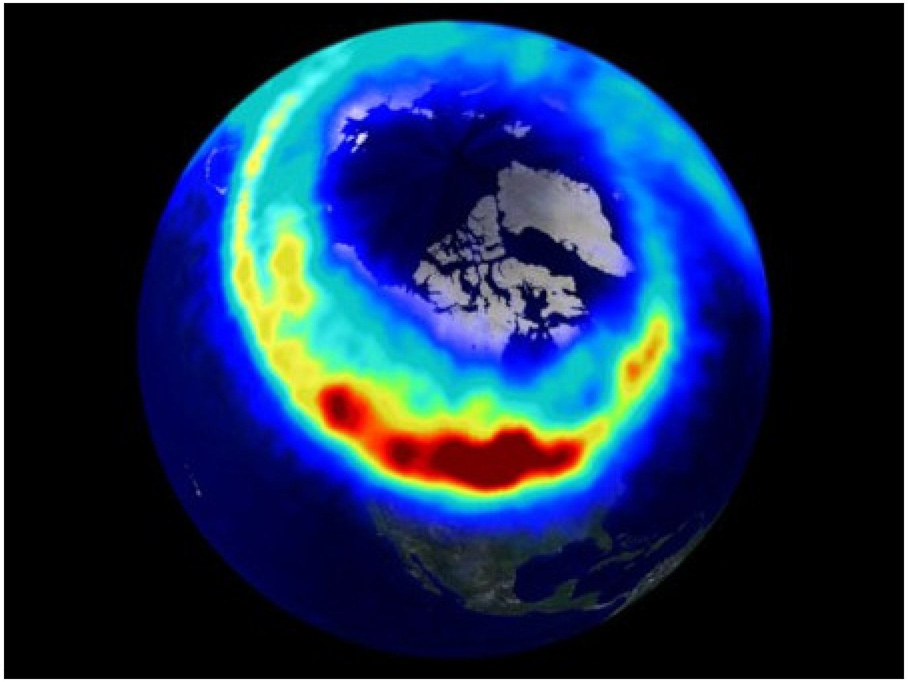
Južni sij

Aurora australis

Fig. 3.22 . The eerie, beautiful glow of auroras can be detected from space, as shown in this image of the Aurora Australis, or Southern Lights, taken from the *Space Shuttle Discovery*. The colored emission of atomic oxygen extends upward to between 200 and 300 kilometers above the Earth's surface. (Courtesy of NASA.)

Oval polarnega sija

The aurora oval



www.spaceweather.com

Fig. 3.23 . The *POLAR* spacecraft looks down on an aurora from high above the Earth's north polar region in February 2000, showing the northern lights in their entirety. The glowing oval is 4.5 thousand kilometers across. The most intense aurora activity appears in bright red or yellow. (Courtesy of NASA/U. Iowa.)

Jupitrov polarni sij

Jupiter's aurora

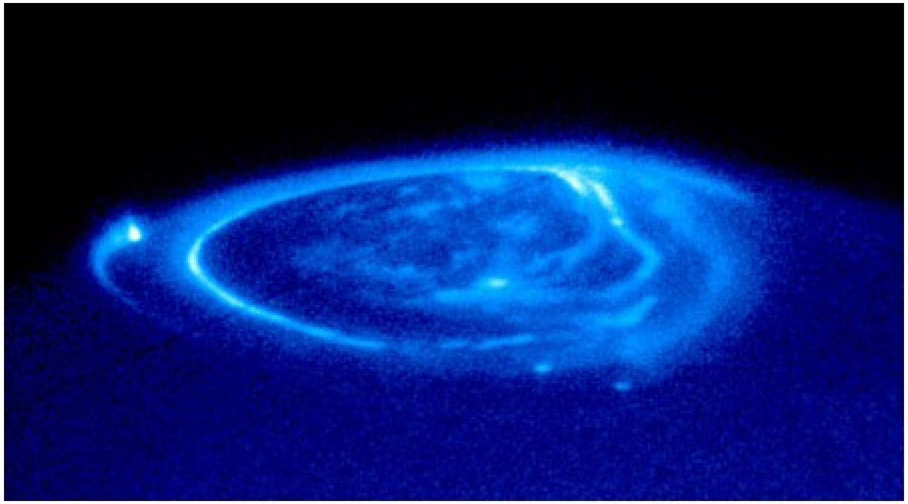


Fig. 3.24 . The aurora oval or ring over the north polar region of Jupiter, as imaged from the *Hubble Space Telescope* in ultraviolet light in September 1997. High-energy electrons and ions cascade into Jupiter's upper atmosphere and create the bright ultraviolet aurora. Several of the bright spots are believed to mark the magnetic "footpoints" of three of Jupiter's largest moons. The footpoints are locations where powerful streams of electrons follow the magnetic fields of Jupiter's magnetosphere from the moons down into Jupiter's atmosphere. (Courtesy of NASA/STScI/U. Michigan.)

Saturnov polarni sij

Aurora on Saturn

Fig. 3.25 . High-energy electrons and ions are captured from the solar wind and funneled down into Saturn's upper atmosphere, creating aurora ovals at its northern (*upper left*) and southern (*lower right*) magnetic poles. This ultraviolet image was recorded from the *Hubble Space Telescope* in October 1997. The bright red aurora features are dominated by emission from atomic hydrogen, while the white regions within them are emitted by molecular hydrogen. (Courtesy of NASA/STScI /JPL.)