JOVIAN MAGNETOSPHERE

MAGNETOSPHERIC MAGNETIC FIELD AT EUROPA ORBIT AND USING MAGNETOMETER DATA TO STUDY OF THE EUROPA INTERIOR

I. I. Alexeev, E. S. Belenkaya

Institute of Nuclear Physics,

Lomonosov Moscow State University,

Leninskie Gory, 119992, Moscow, Russia

alexeev@dec1.sinp.msu.ru

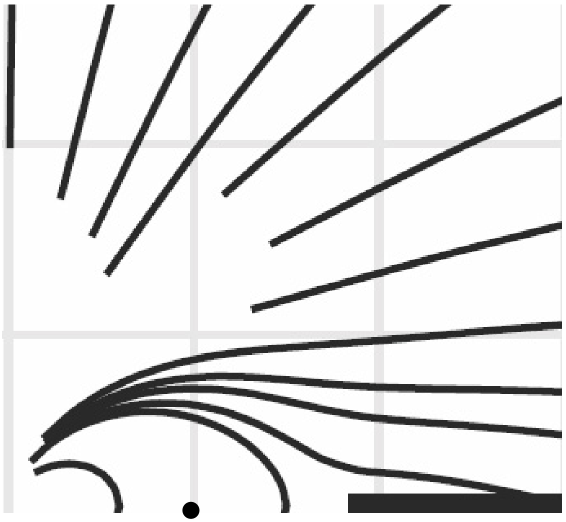
Paraboloid model of the Jovian magnetosphere

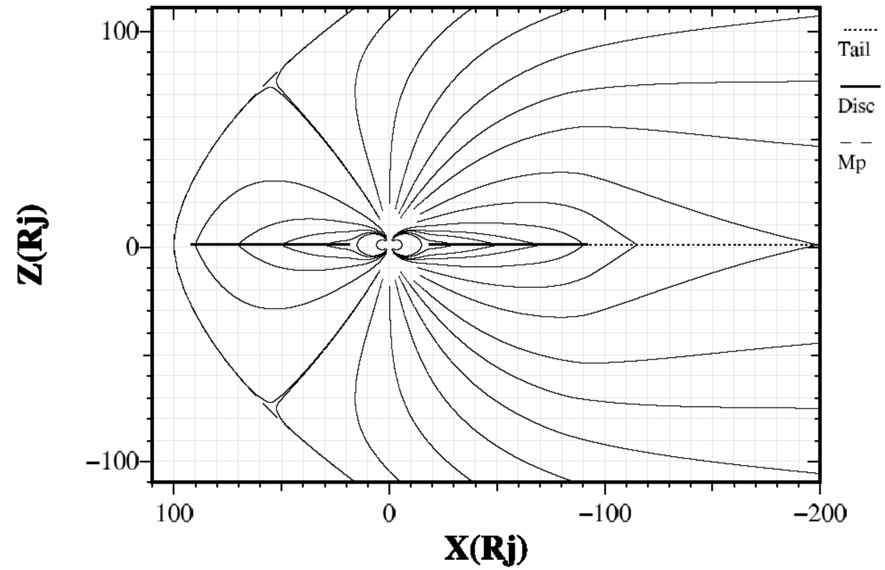
Model components

In a Jovian solar-magnetospheric coordinate system: $\mathbf{B}_m(t)$ =
$\mathbf{B}_d(\Psi)$ - *planetary field vector*
+ $\mathbf{B}_{MD}(\Psi, B_{Dc}, R_{D1}, R_{D2})$ - *field from equatorial current disc*
+ $\mathbf{B}_{sd}(\Psi, R_1)$ - *from currents shielding planetary field*
+ $\mathbf{B}_{MD}(\Psi, B_{Dc}, R_1, R_{D1}, R_{D2})$ - *field from currents shielding current disc field*
+ $\mathbf{B}_{TS}(\Psi,, R_2, B_t)$ - *from cross-tail + closure MP currents*
+ $\mathbf{b}(k_J, \mathbf{B}_{IMF})$ - *fraction of the IMF penetrating into the magnetosphere*

Time-dependent model parameters

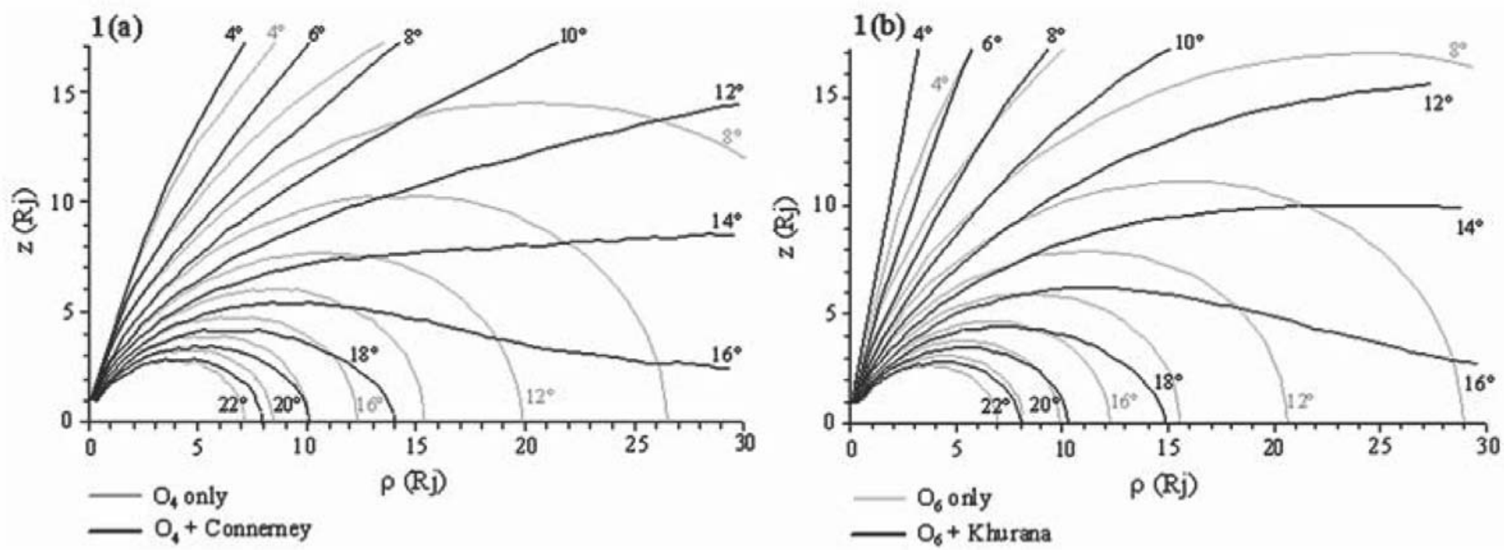
Ψ *magnetic dipole tilt angle*
$\mathbf{R_1}$ *subsolar MP distance*
$\mathbf{R_{D1}}$ and $\mathbf{R_{D1}}$ *radial distances of the inner and outer edges of the current disc*
$\mathbf{R_2}$ *radial distance of the inner edge of the tail current sheet*
$\mathbf{B_t}/(1+2 R_2/R_1)^{1/2}$ *tail field strength at the inner edge of the tail current sheet*
$\mathbf{B_{DC}}$ *current disc field strength at the outer edge of the current disc*
$\mathbf{B_{IMF}}$ *IMF vector*
$\mathbf{k_J}$ *coefficient of IMF penetration*



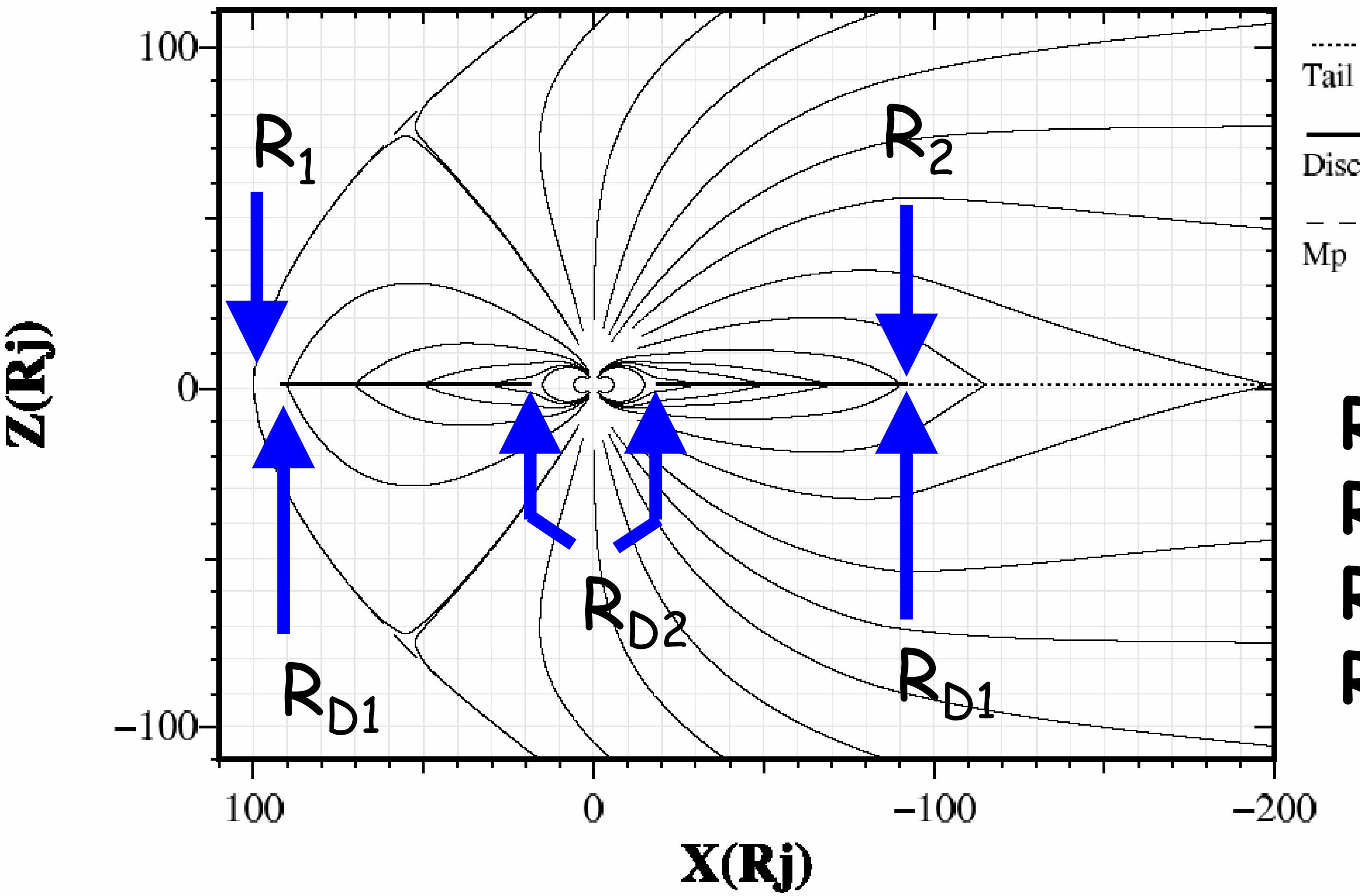


Near Europa magnetosphere

Paraboloid model full size



The Jupiter magnetosphere model
Space and current systems parameters



Ψ =0

B_t=3 nT

B_{DC}=3 nT

R_1 =92.8 R_J

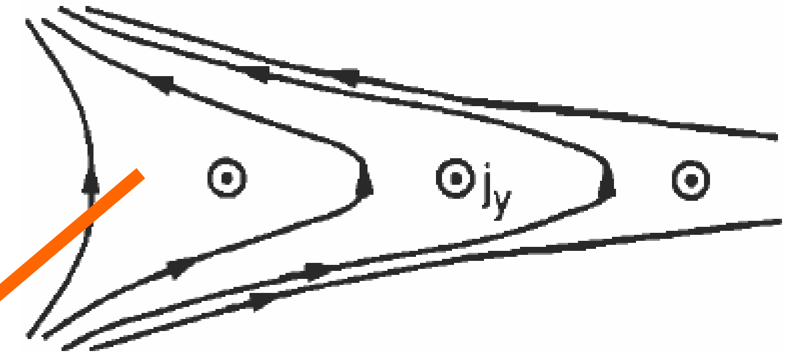
R_2 =85.4 R_J

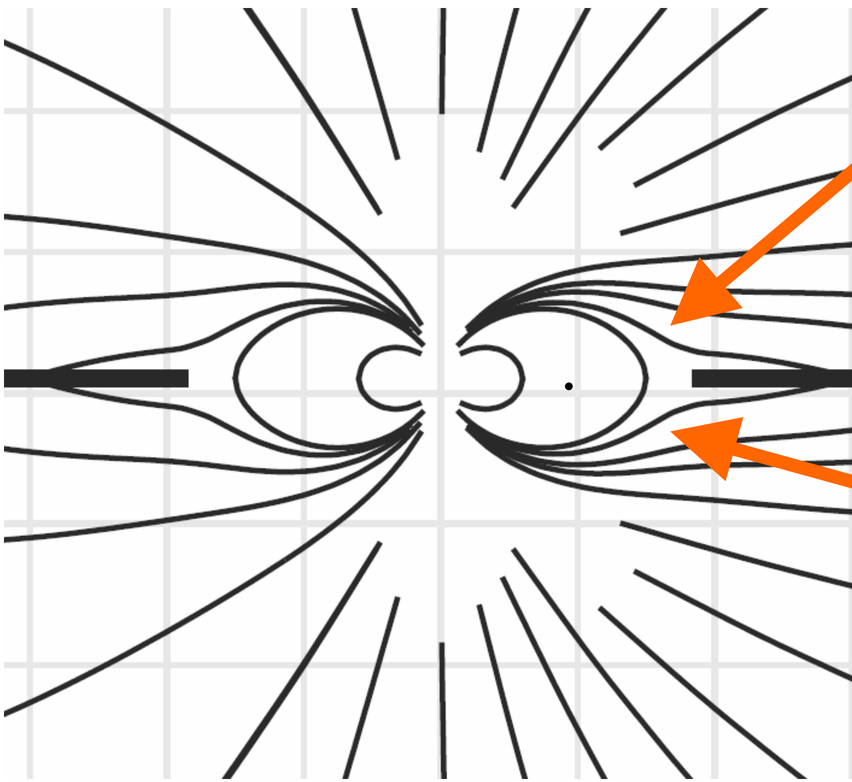
R_{D1} =84.4 R_J

R_{D2} =16.4 R_J

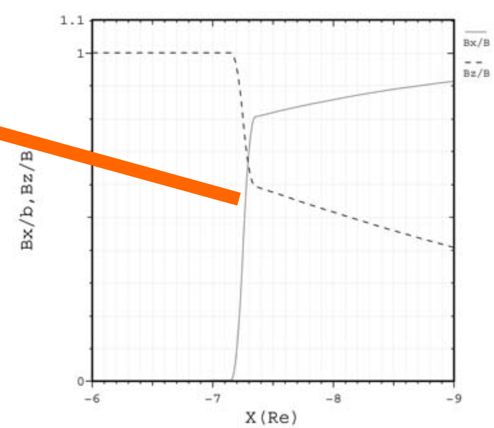
The transition from dipole like to stretched tail-like field lines

Nearest Earth tail edge (e.g. *Lui et al.*, 1992). The carton is based on data by AMPTE CCE Magnetic Field Experiment





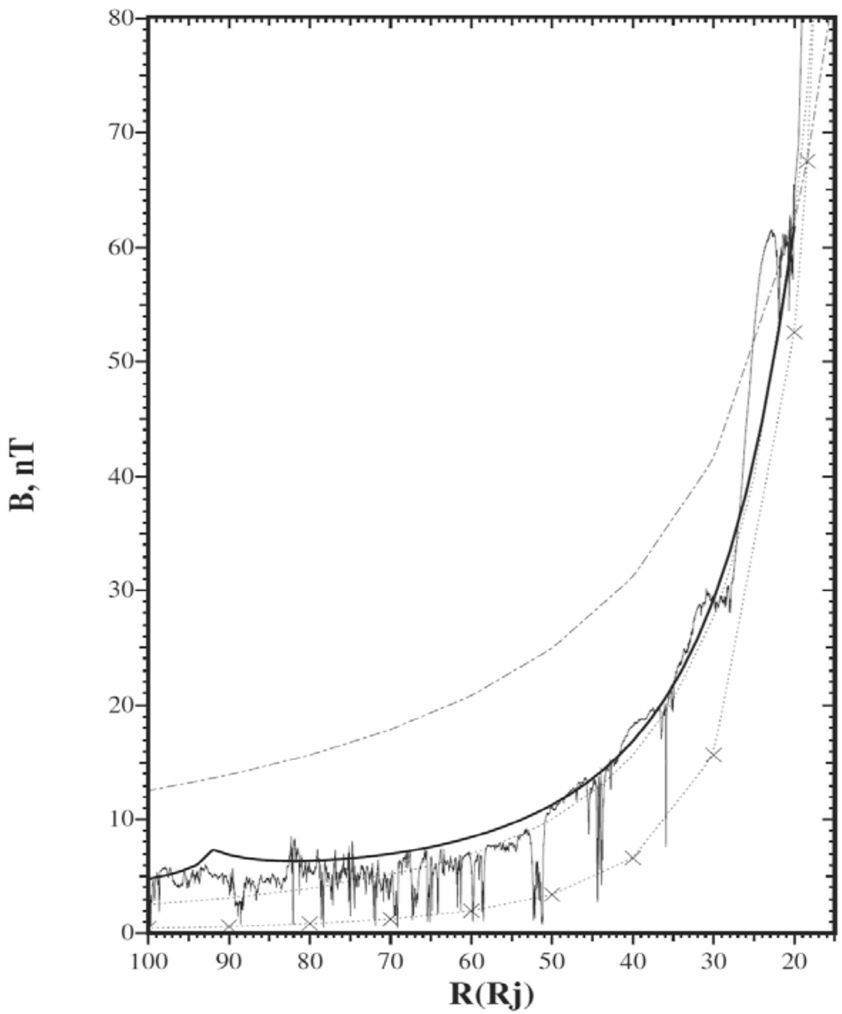
$B_z >> B_x$



The dependences of the ratios B_z and B_x to module magnetic field as functions of the distance are shown. The sharp (~1000 km) transition layer is shown.

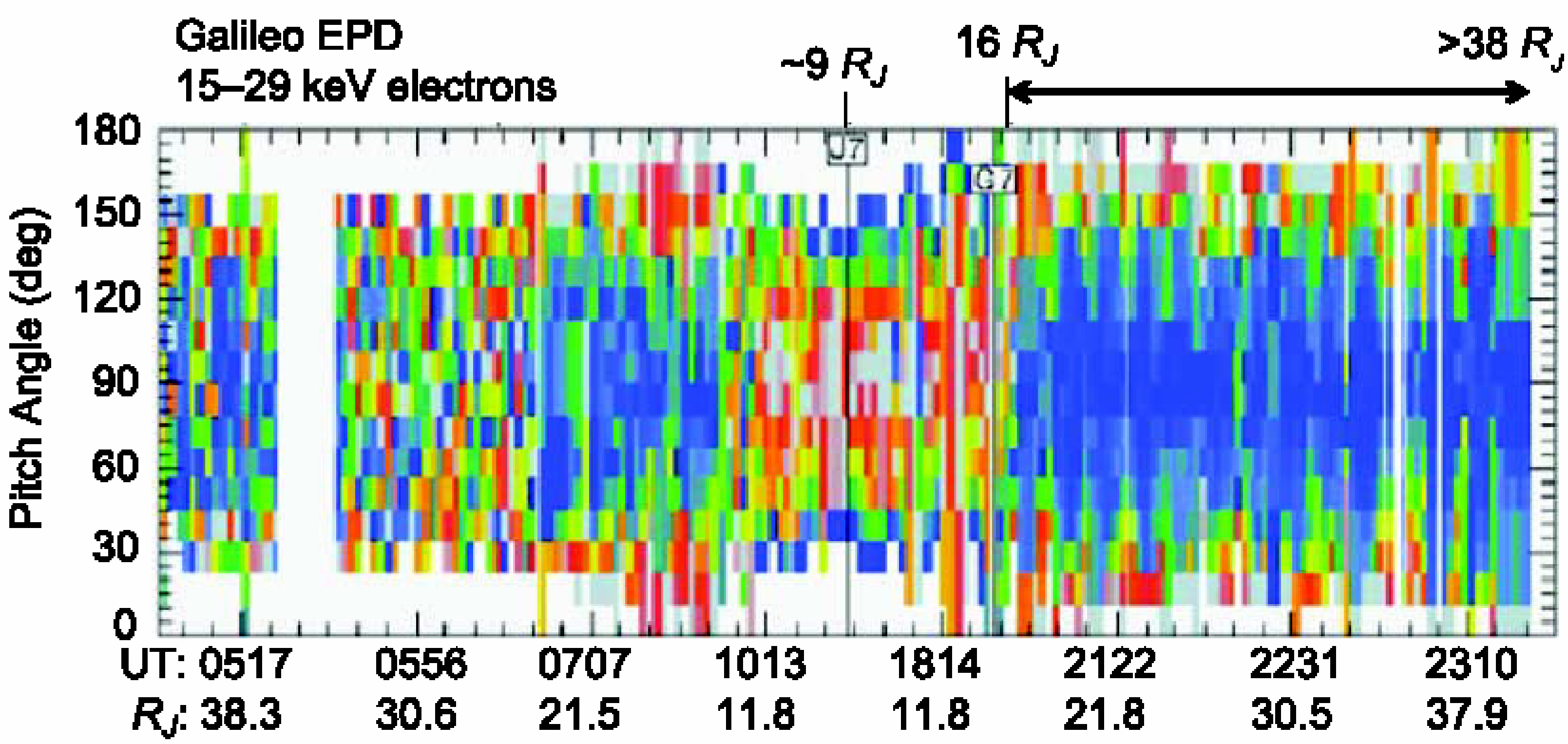
$B_x >> B_z$

Ulysses the magnetospheric magnetic field

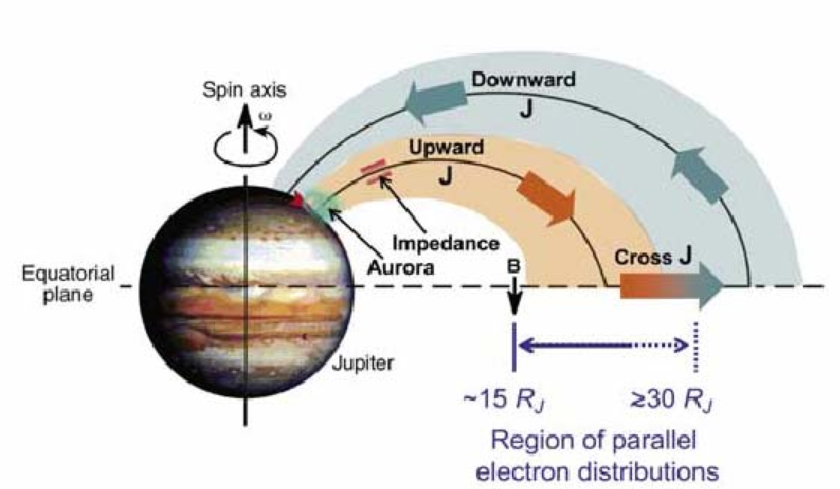


Measured by Ulysses the jovian magnetic field dependent on the radial distance r (Cowley et al., 1996) is marked by solid curve. For comparison there are also shown magnetic field strength calculated by present model (heavy curve). Dotted curve marked by crosses is shown the dipole field. Dashed-dotted curve is 1/r dependence of the plasma disk currents (Khurana, Connerney).

Relative intensity versus pitch angle versus time and position for 15- to 29-keV electron data as generated and reported by Toma´s et al. [2004a, 2004b] using data from the Galileo EPD instrument



Unipolar jovian generator



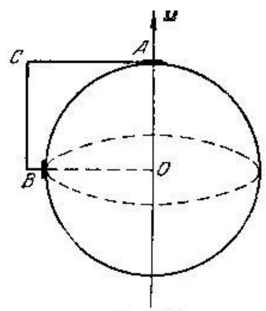


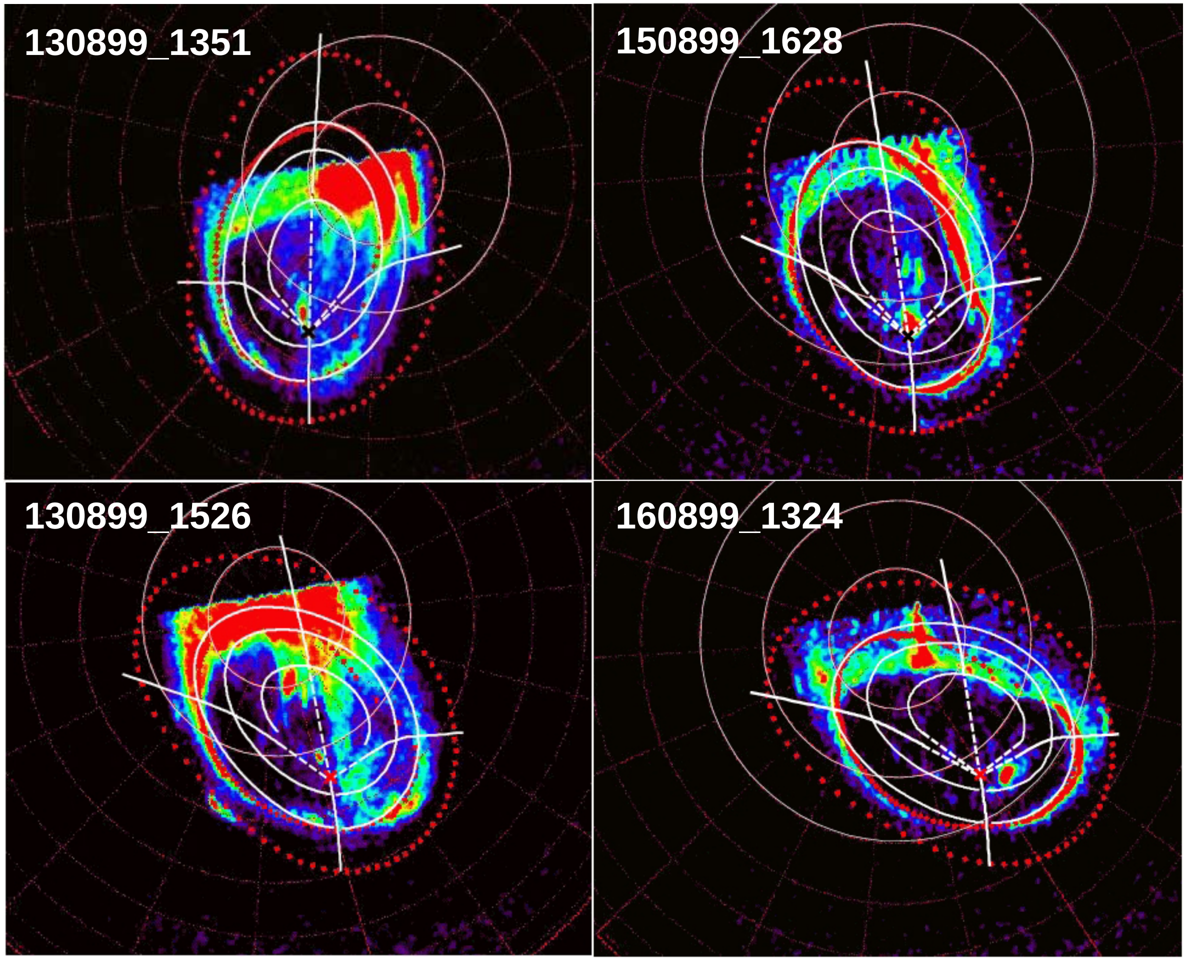
Рис. 27.

sliding contacts

Landay and Lifshitz, 1959

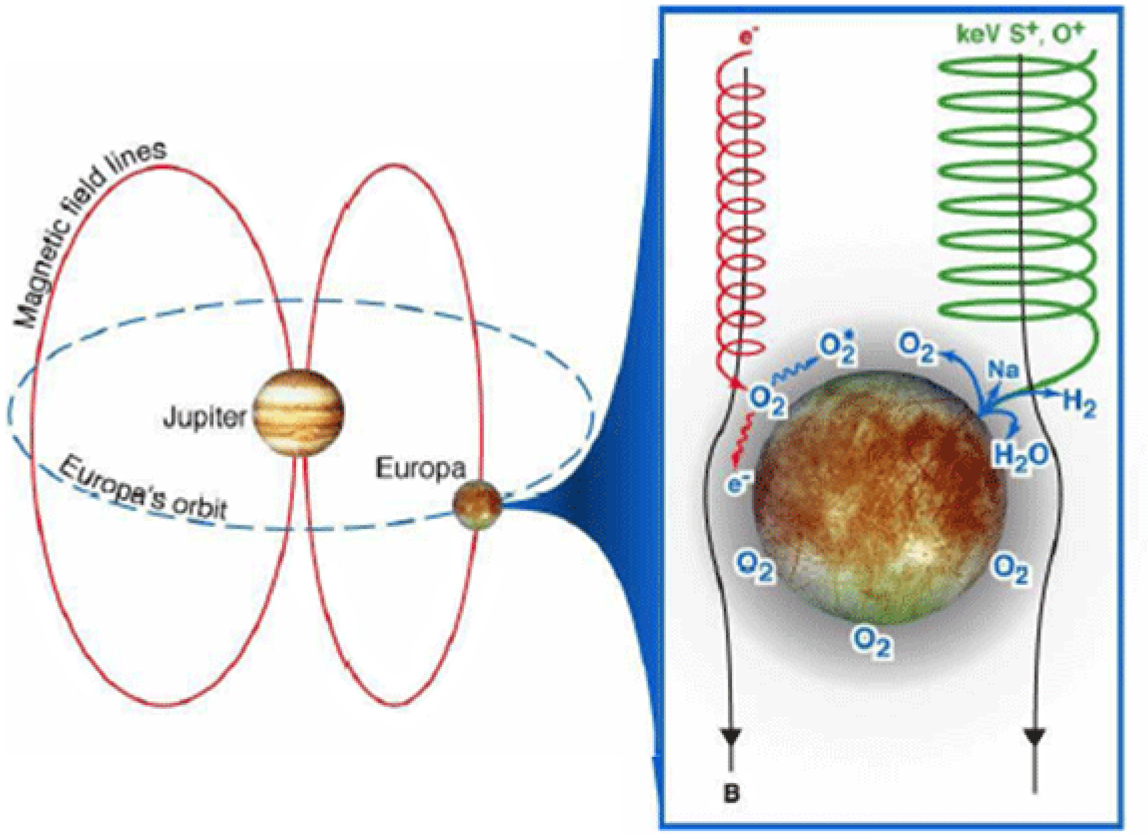
Schematic of the relationship between observed equatorial electron field-aligned enhancements reported by Toma´s et al. [2004a, 2004b] and the circuit of electric currents that connects Jupiter's middle magnetosphere to the auroral ionosphere. The auroral circuit figure is based on concepts of Hill [1979] and Vasyliunas [1983] as replotted by Mauk et al. [2002]. It is understood that the shape of the field lines in the actual Jovian system are substantially stretched away from the dipolar configuration.

Comparison of paraboloid model ovals with HST auroral images: the polar cusp

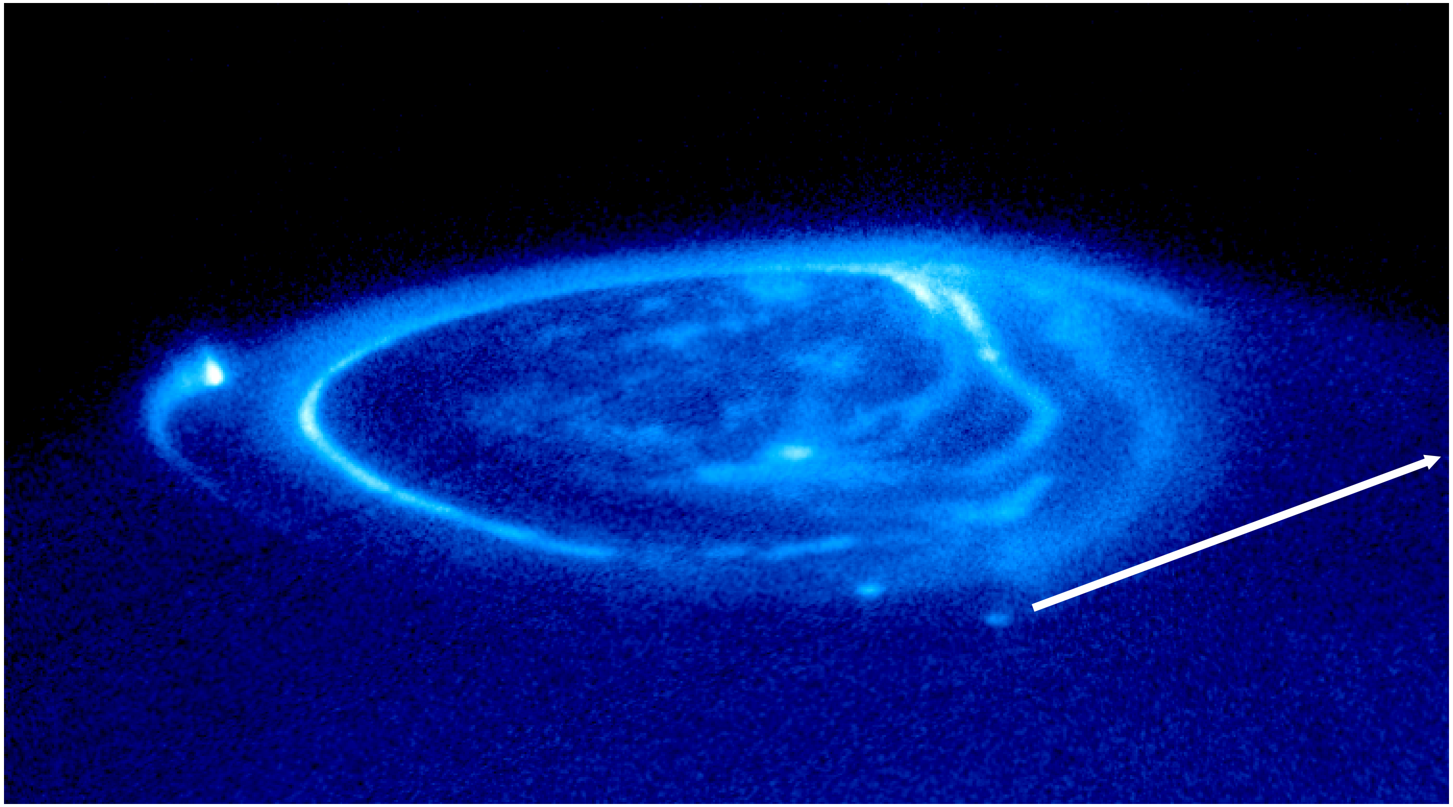


FUV polar cusp observed within a few degrees in latitude and less than 1 hour of the approximated model cusp.

Prangé and Pallier LESIA, Observatoire de Paris, Meudon, France. AGU Fall meeting 2007, USA


Magnetic field lines
Jupiter
Europa
Europa's orbit
e⁻
keV S⁺, O⁺
O_2^*
O_2
Na
H_2
H_2O
e⁻
O_2
O_2
O_2
O_2
B

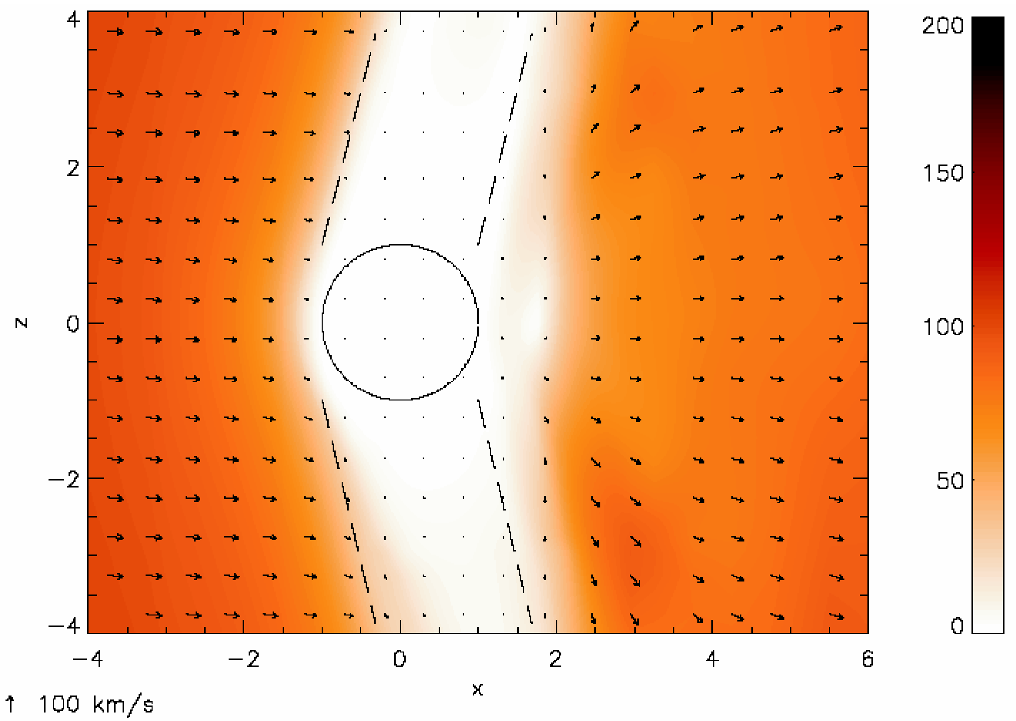
Satellite Footprints Seen in Jupiter Aurora



Io along the left hand limb, Ganymede near the center, and Europa just below and to the right of Ganymede's auroral footprint.

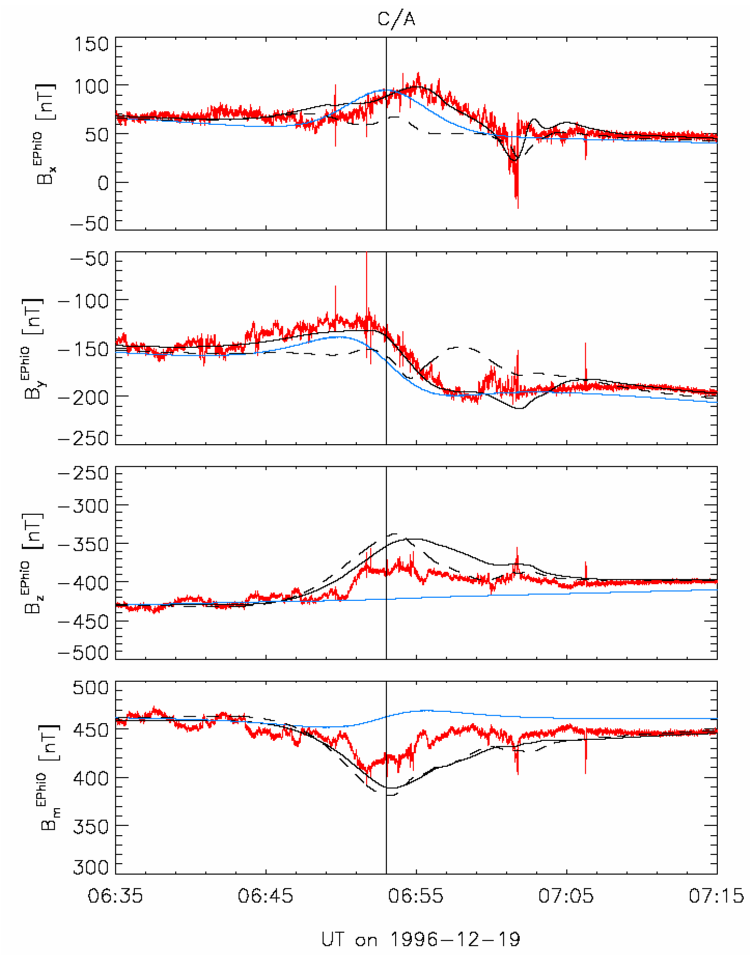
This ultraviolet image of Jupiter was taken with the Hubble Space Telescope Imaging Spectrograph (STIS) on November 26, 1998. John Clarke, BU, USA.

Schilling, N., F. M. Neubauer, and J. Saur (2008), JGR, A03203, doi:10.1029/2007JA012842



Plasma bulk velocity in the xz plane. The Alfven characteristics are shown as black dashed lines. The color scale determines the velocity magnitude.

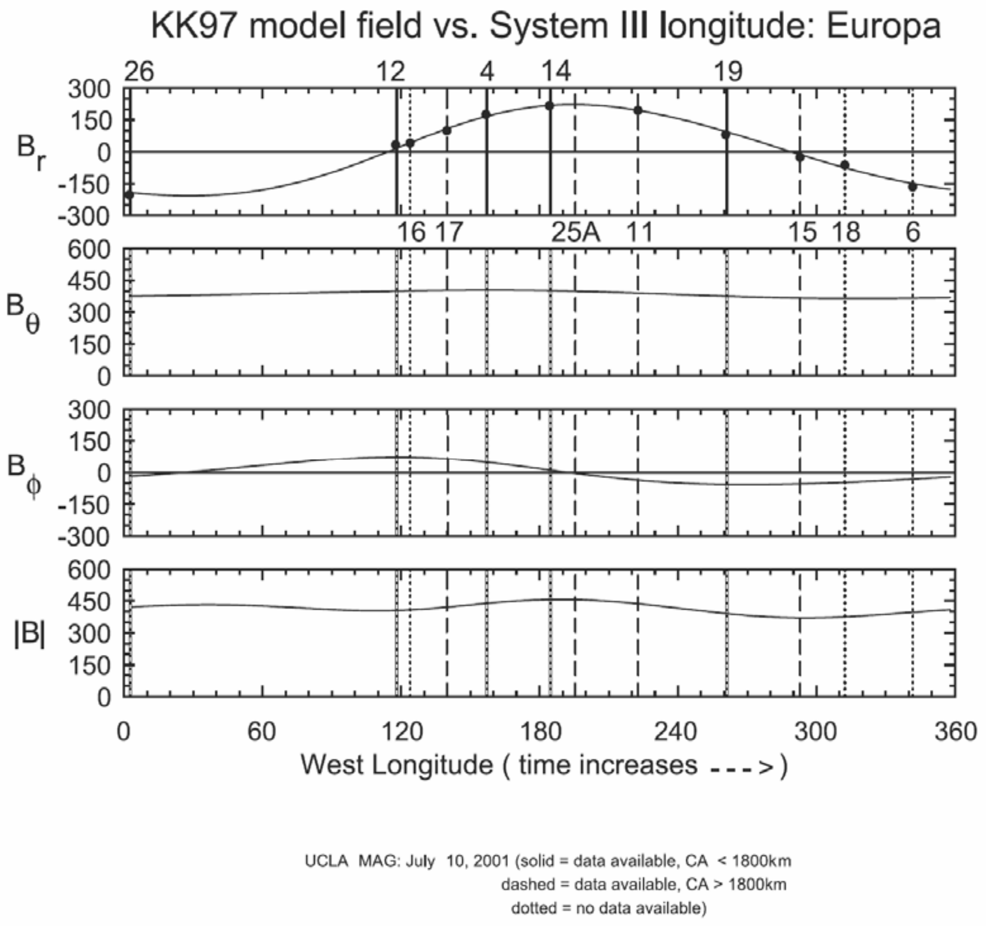
Future spacecraft missions to Europa would allow not only for a more detailed investigation of the 3-D conductivity distribution inside the moon but also for the plasma environment and the atmosphere of Europa.



Observed and modeled magnetic field for the E4 flyby in the EPHIO coordinate system. The red curve shows the measured field [Kivelson et al., 1997]. The dashed black curve shows the predicted field when no induction is included in our model. The predicted field by including induction is shown by the solid black curve for an ocean conductivity soc = 5 S/m. The theoretical case of induction in a perfectly conducting ocean and no plasma interaction is shown by the blue curve. The assumed thickness of the crust is 25 km, and the assumed thickness of the ocean is 100 km

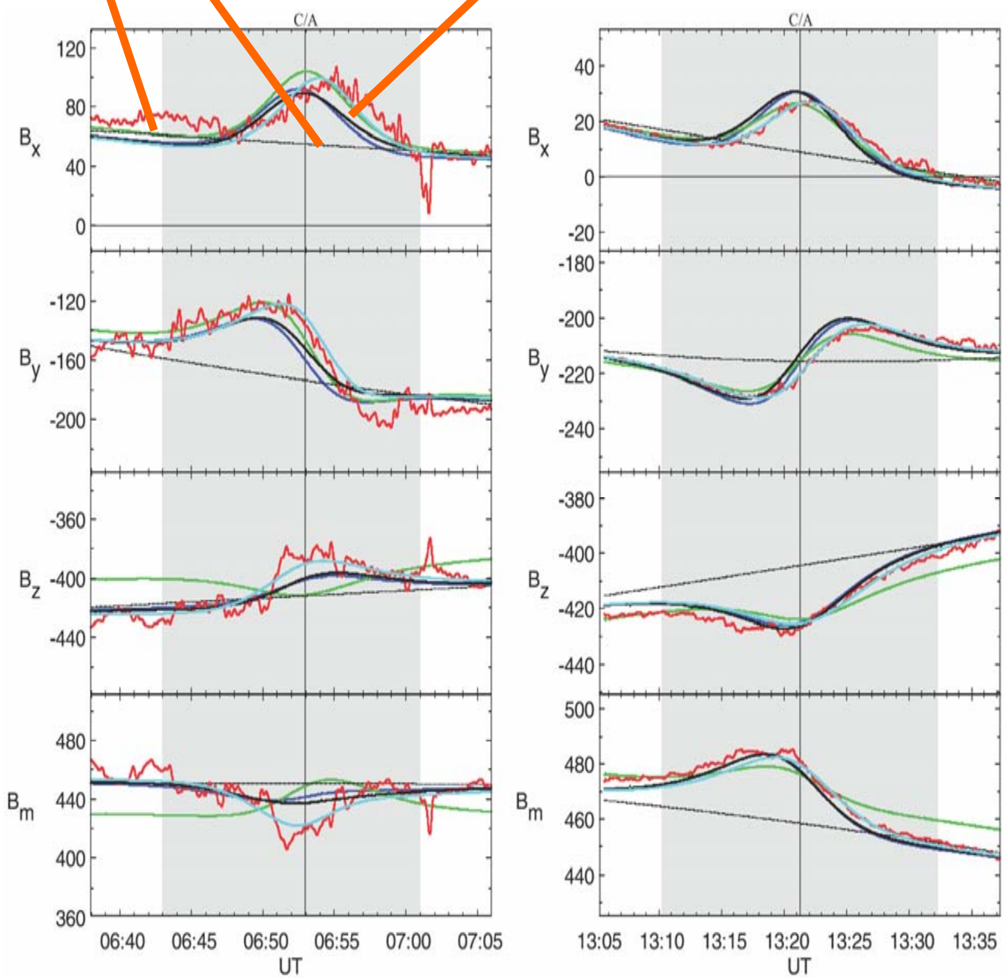
Schilling, Neubauer, and Saur (2008),

Schilling, Khurana, Kivelson (2004), Limits on an intrinsic dipole moment in Europa, JGR,109, E05006, doi:10.1029/2003JE002166

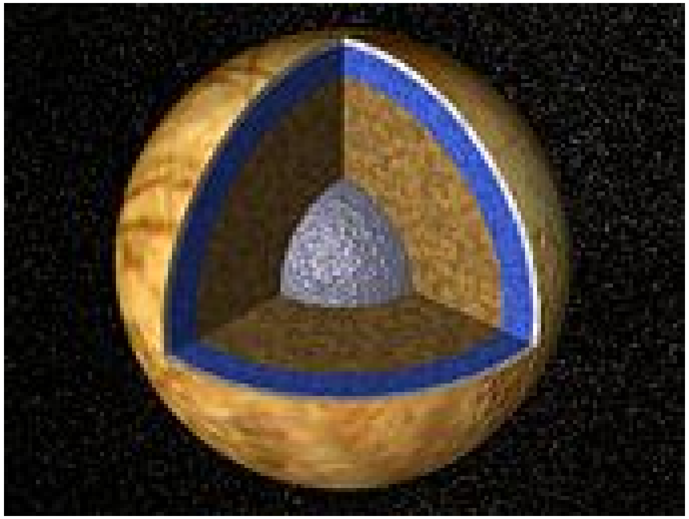


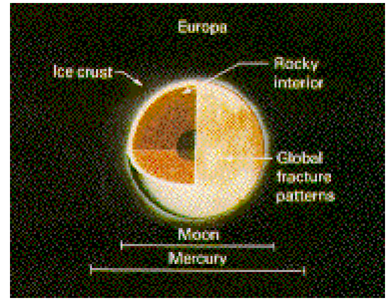
KK97 field model [Khurana, 1997], representing the radial, polar, and azimuthal components of the magnetic field at the position of Europa as a function of its west longitude relative to the origin of System III. Labels are given on top for passes below 1800 km with data and are placed above the second row for passes that had no magnetometer data (dotted) or had data but were above 1800 km (dashed). Vertical markers show where the passes occur relative to west longitude. The dots on Br represent the value inferred from the data taken near CA on the relevant passes.

Europa's induction dipole field (solid black)
Alven wing field (green)
Jupiter field (thin black)



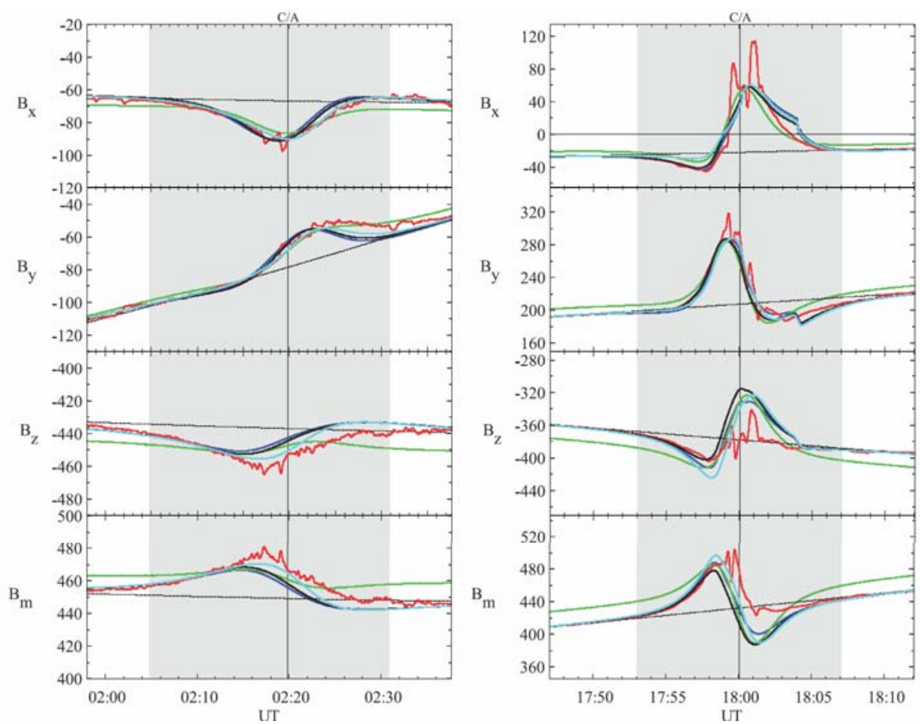
Observed and modeled field for the Europa flyby E4 (left) and E14 (right) in the EPhiO coordinate system. The red curve shows the filtered measured field. The thin black curve shows the background field. The solid green curve shows the predicted field for the internal permanent dipole plus induction by using the UMF for the external field. The predicted field by using the Alfve´n wing model to describe the external local currents is shown for the internal sources: induction only (solid blue), induction plus dipole (solid black), and induction plus dipole plus quadrupole (cyan curve).
Schilling, Khurana, Kivelson (2004)

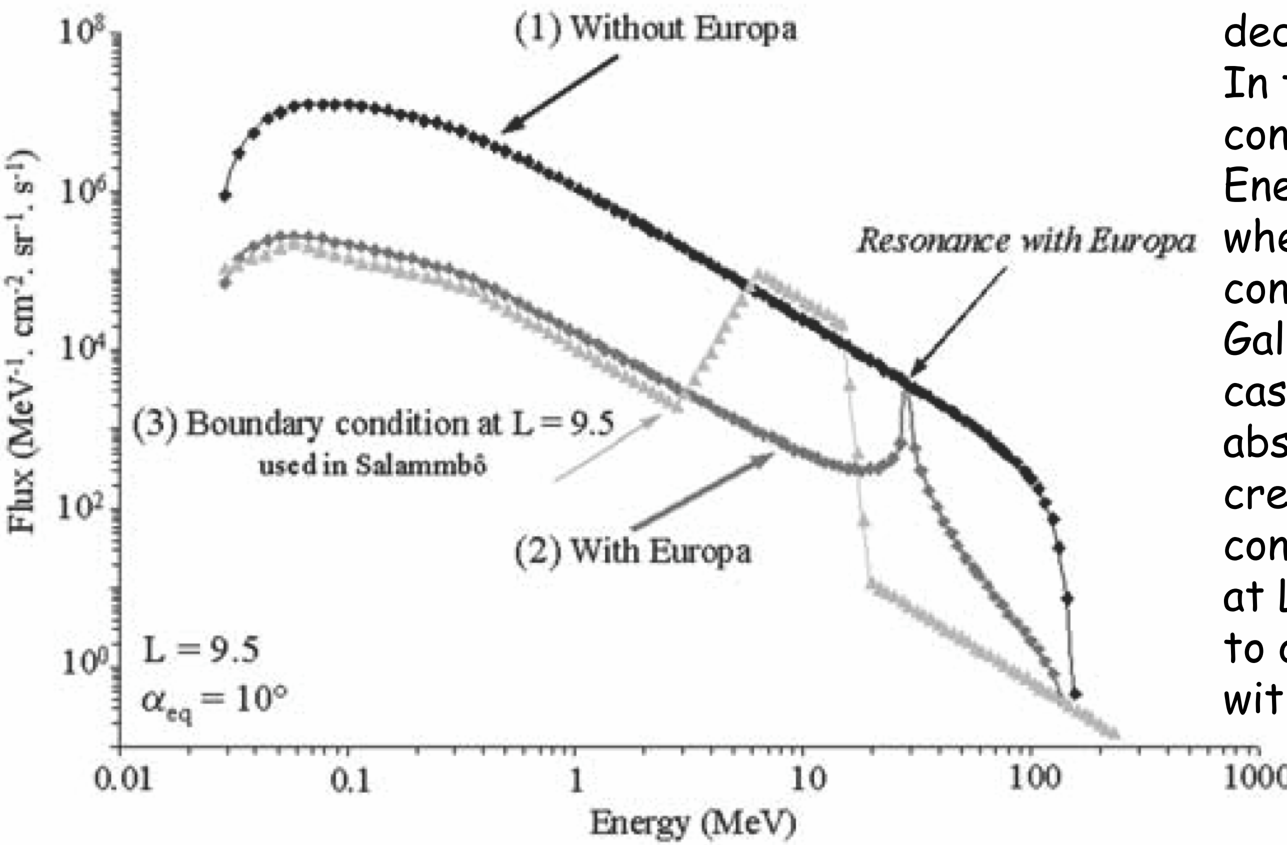




Europa ocean's conductivity comparable to or higher than terrestrial sea water the calculations would be consistent with burial of the conducting layer at a depth of 20 km below the surface.

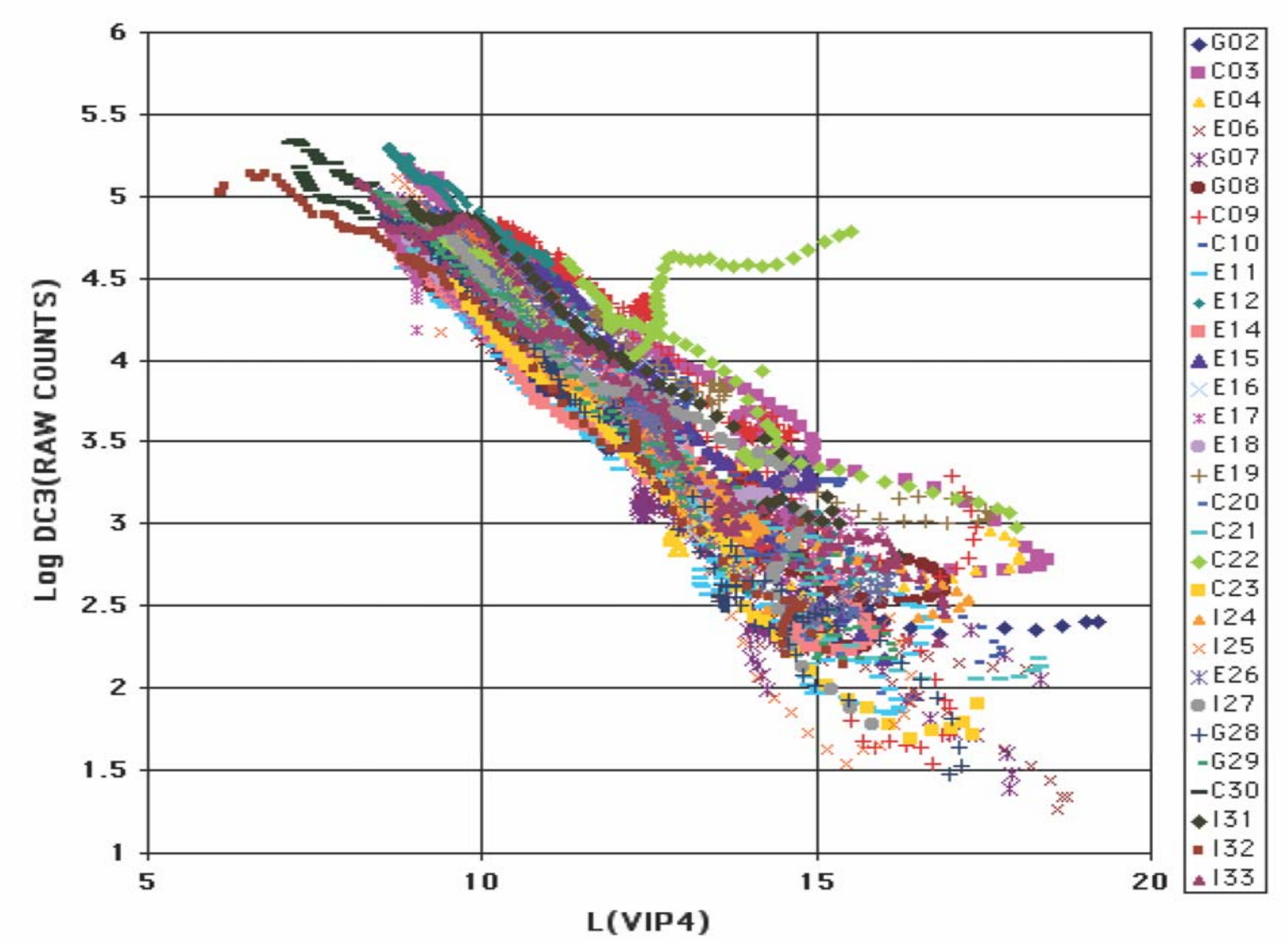
Schilling, Khurana, and Kivelson (2004)



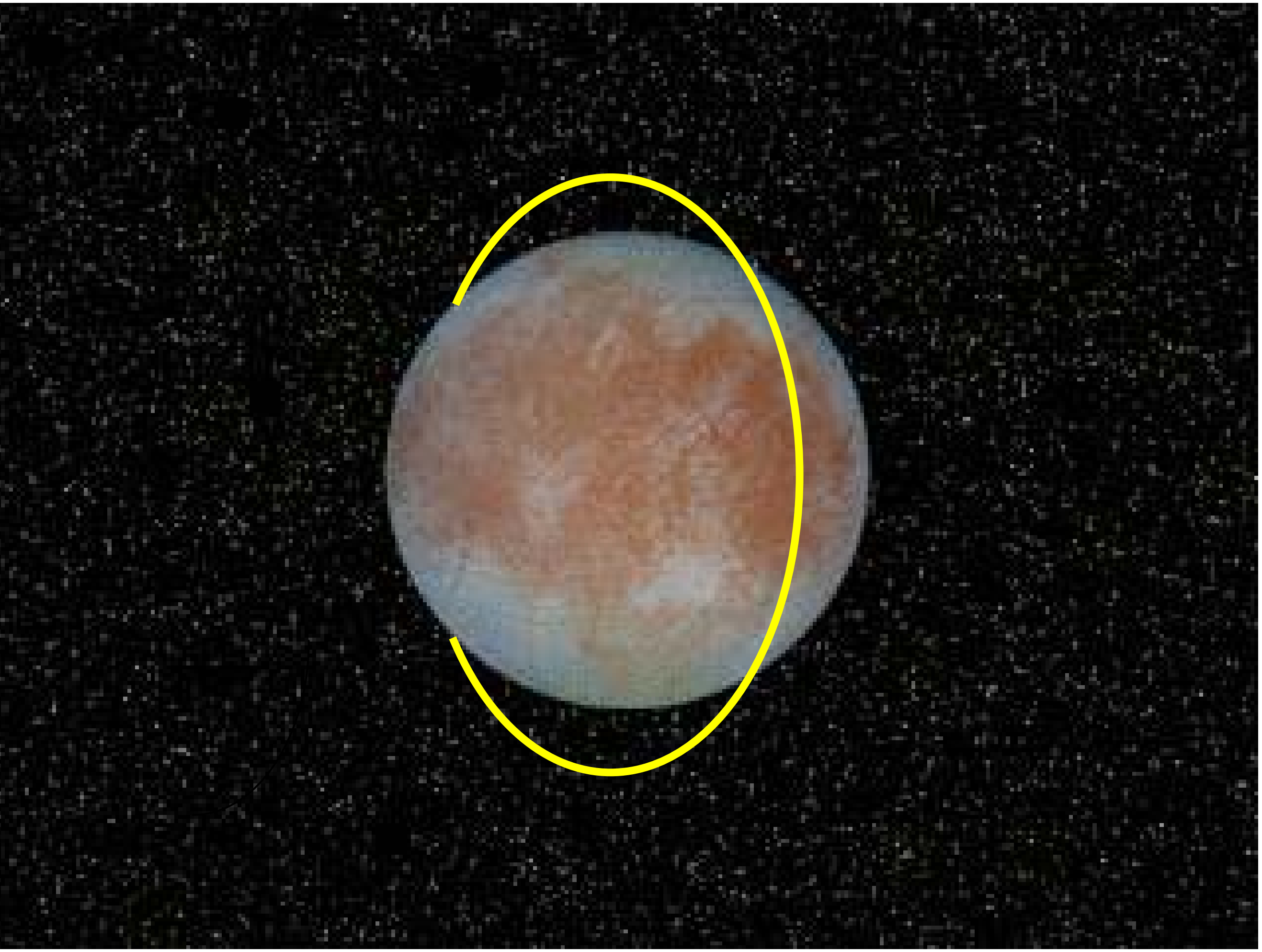


Energy spectra at L = 9.5 for electrons with an equatorial pitch angle of 10° in three different cases: (1) Energy spectrum at L = 9.5 where the boundary condition at L = 15 is deduced from Galileo EPD data. In this case Europa is not considered in the domain. (2) Energy spectrum at L = 9.5 where the same boundary condition at L = 15, deduced from Galileo EPD data, is used. In this case Europa is modeled as an absorber of particles and creates losses. (3) Boundary condition calculated empirically at L = 9.5 and used in Salammbo to obtain very good comparisons with observations

DC3 counts versus L-shell for Galileo orbits G02 to I33



Dual magnetometers (1)
(orbiter/lander) experiments



H_{orbit}=100 km

T_{orbit}=2.1 hours

$M_{ind}=100nT \cdot R^3{}_e$

$M_{Ev}<25nT \cdot R^3{}_e$

Three Goals:

1. Induc. Dipole
2. Own Dipole
3. Europa's conductivity

Dual magnetometers (2) (orbiter/lander) experiments

Dynamics interval:

600 nT- 0.1 nT

Expected weights:

2kg

Power:

several Watts

H_{orbit}=100 km

T_{orbit}=2.1 h

$M_{in}=100nT \cdot R^3_e$

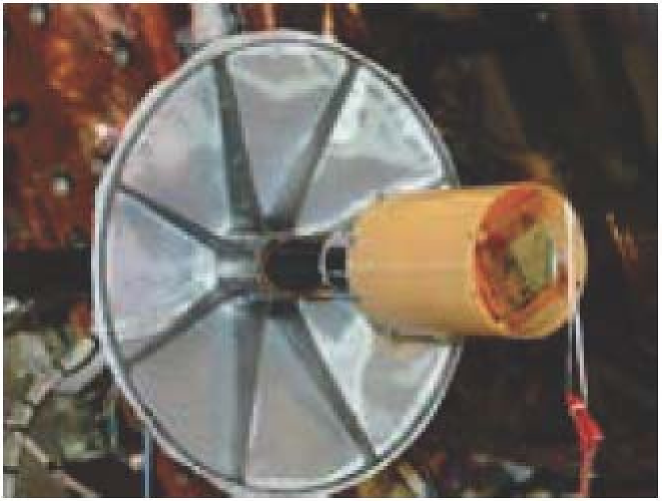
$M_{ev}<25nT \cdot R^3_e$

Three Goals:

1. Induc. Dipole
2. Own Dipole
3. Europa's conductivity

Example of a magnetometer

MESSENGER's three-axis, ring-core fluxgate detector



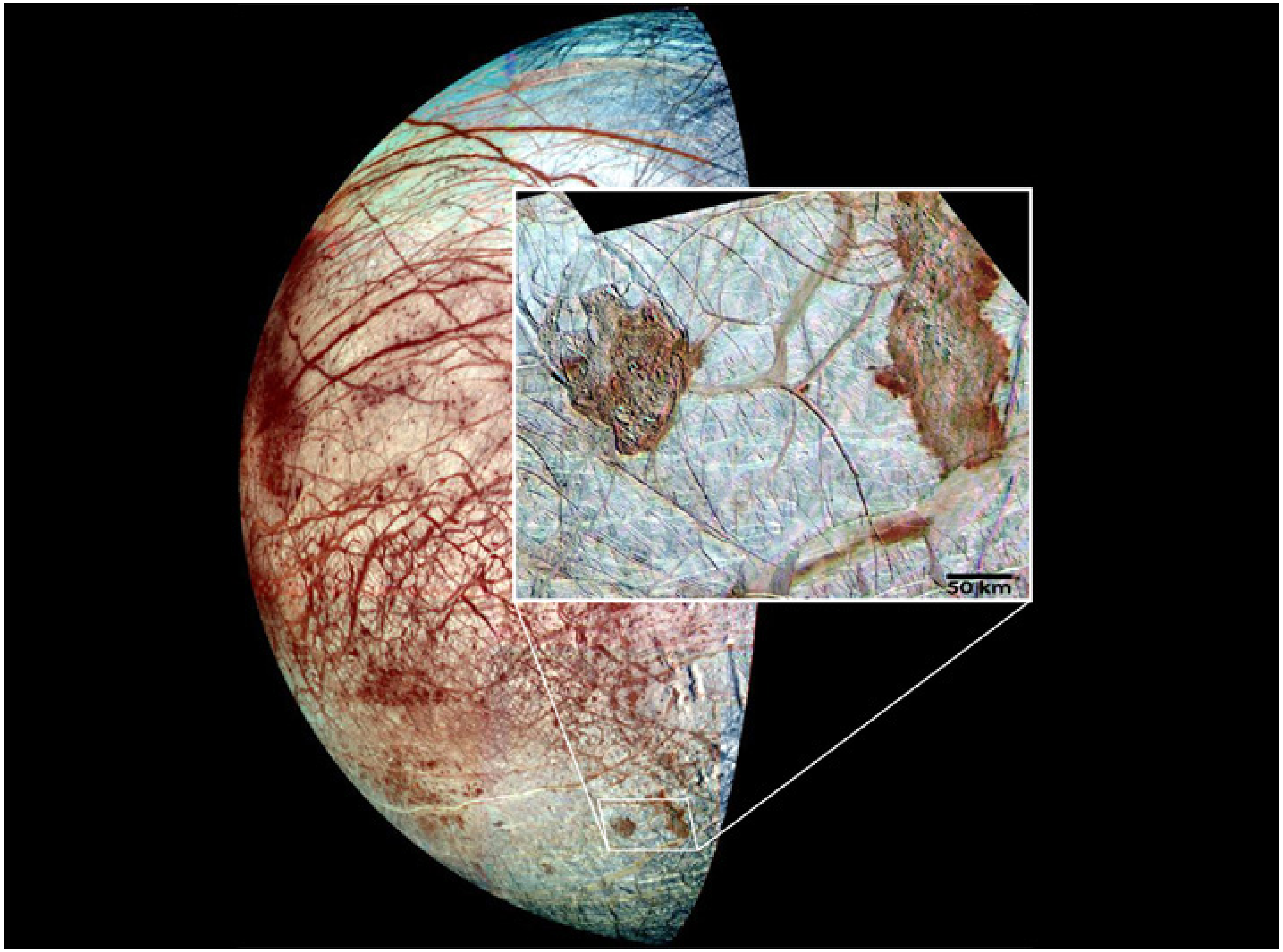
Mass (including boom): 4.4 kgs

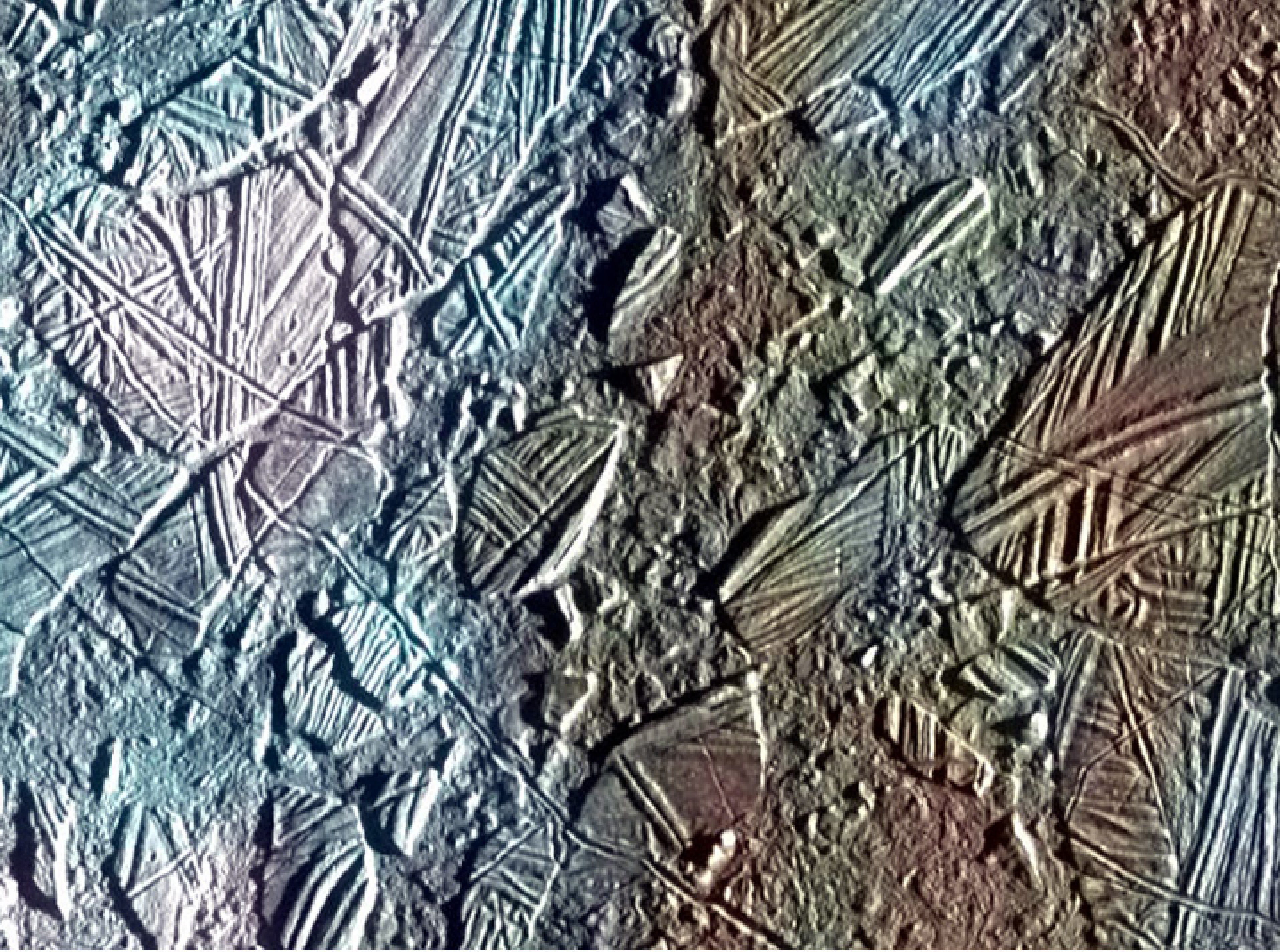
Power: 4.2 watts

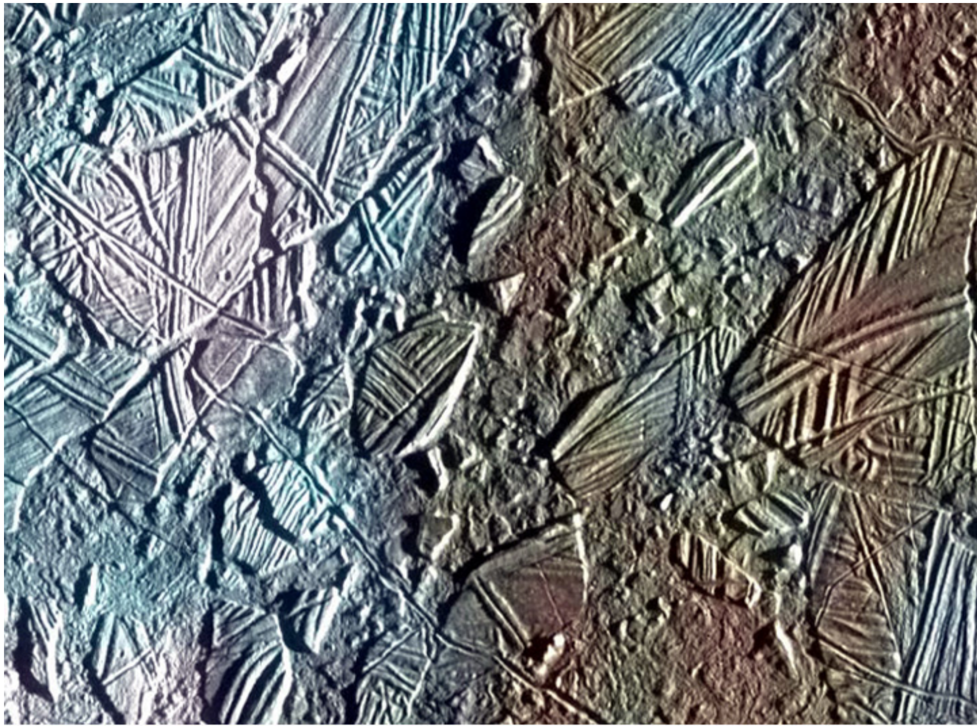
Development: NASA and APL JHU. The MAG sensor is mounted on a 3.6-meter and it will collect magnetic field samples at 50-millisecond to one-second intervals.

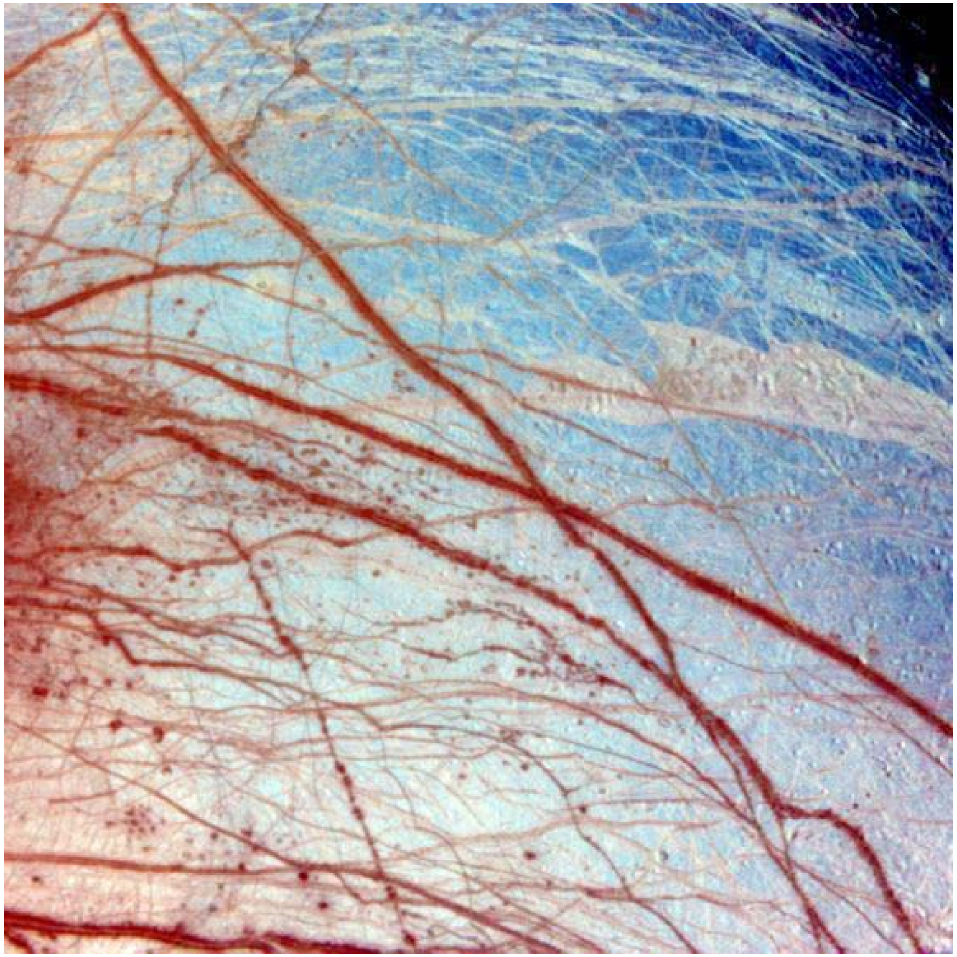
Galileo Europa Animation

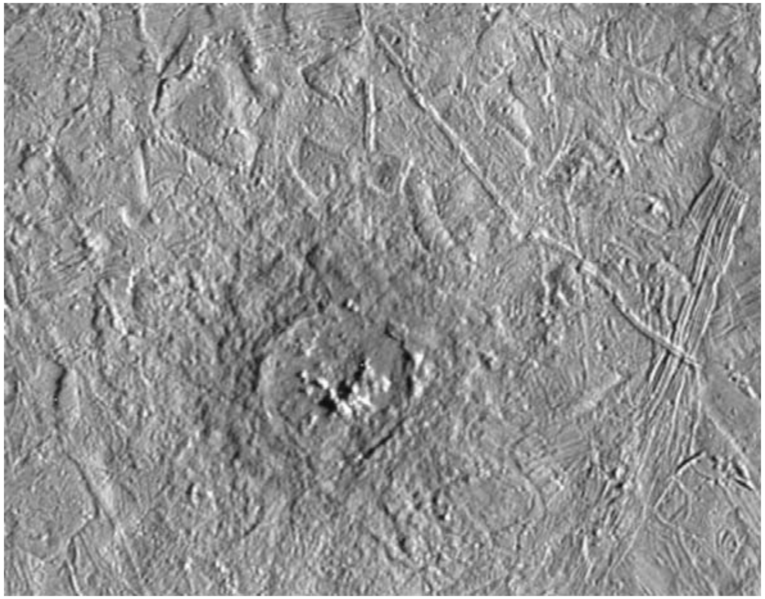
Galileo images are used to create a colored global view of Europa. We zoom into two regions. The first is centered on the crater Pwyll located at 26 deg S latitude, 271 deg W longitude. The second is centered at 9.4 deg N latitude, 274 deg W l ongitude. E6 orbit

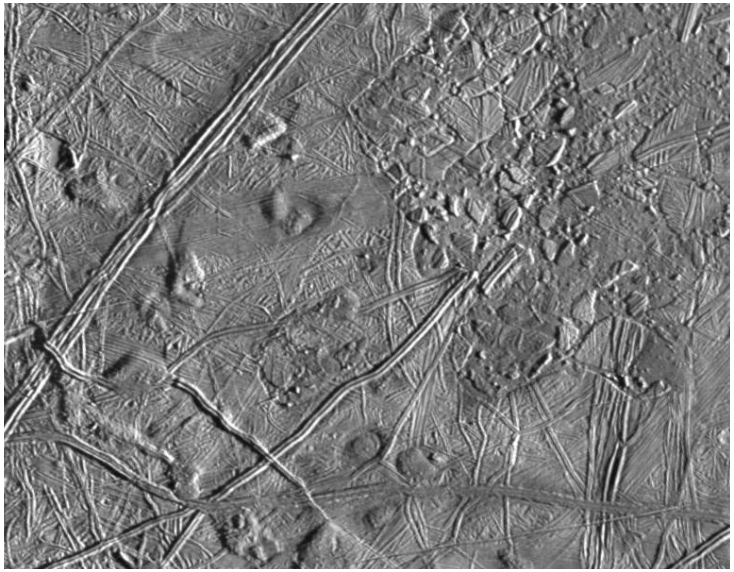

50 km









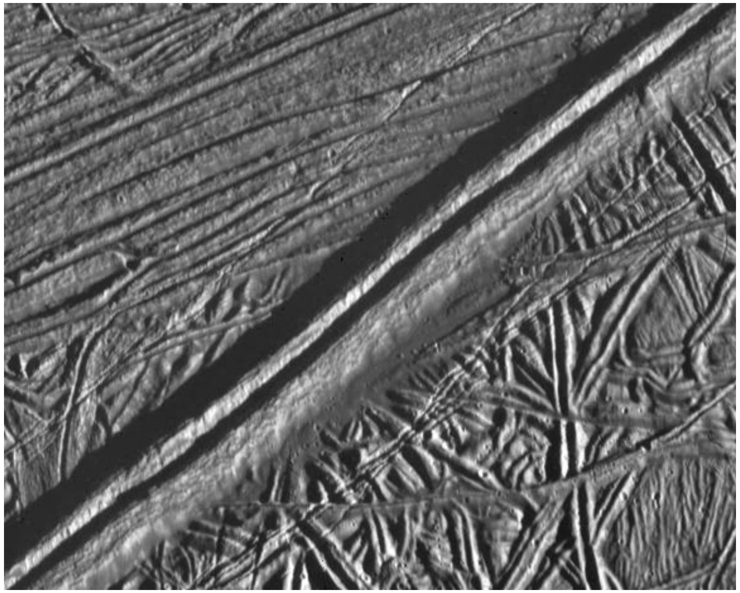
Pwyll Crater on Europa

Pwyll crater on Jupiter's moon, Europa, was photographed by the Solid State Imaging system on the Galileo spacecraft during its sixth orbit around Jupiter. This impact crater is located at 26 degrees south latitude, 271 degrees west longitude, and is about 26 kilometers (16 miles) in diameter. Lower resolution pictures of Pwyll Crater taken earlier in the mission show that material ejected by the impact can be traced for hundreds of miles across the icy surface of Europa. The dark zone seen here in and around the crater is material excavated from several kilometers (a few miles) below the surface. Also visible in this picture are complex ridges. The two images comprising this mosaic were taken on February 20, 1997 from a distance of 12,000 kilometers (7,500 miles) by the Galileo spacecraft. The area shown is about 120 kilometers by 100 kilometers (75 miles by 60 miles).

Close-up of Europa's Trailing Hemisphere

This complex terrain on Jupiter's moon, Europa, shows an area centered at 12 degrees north latitude, 274 degrees west longitude, in the trailing hemisphere. As Europa moves in its orbit around Jupiter, the trailing hemisphere is the portion which is always on the moon's backside opposite to its direction of motion. The area shown is about 100 kilometers by 140 kilometers (62 miles by 87 miles). The complex ridge crossing the picture in the upper left corner is part of a feature that can be traced hundreds of miles across the surface of Europa, extending beyond the edge of the picture. The upper right part of the picture shows terrain that has been disrupted by an unknown process, superficially resembling blocks of sea ice during a springtime thaw. Also visible are semicircular mounds surrounded by shallow depressions. These might represent the intrusion of material punching through the surface from below and partial melting of Europa's icy crust. The resolution of this image is about 180 meters (200 yards); this means that the smallest visible object is about a quarter of a mile across.

E6 orbit



- This picture of Europa was taken by Galileo's Solid State Imaging system from a distance of 17,900 kilometers (11,100 miles) on the spacecraft's sixth orbit around Jupiter, on February 20, 1997.
  This view of the icy surface of Jupiter's moon, Europa, is a mosaic of two pictures taken by the Solid State Imaging system on board the Galileo spacecraft during a close flyby of Europa on February 20, 1997. The pictures were taken from a distance of 2,000 kilometers (1,240 miles). The area shown is about 14 kilometers by 17 kilometers (8.7 miles by 10.6 miles), and has a resolution of 20 meters (22 yards) per pixel. Illumination is from the right (east). The picture is centered at about 14.8 north latitude, 273.8 west longitude, in Europa's trailing hemisphere.

- One of the youngest features seen in this area is the double ridge cutting across the picture from the lower left to the upper right. This double ridge is about 2.6 kilometers (1.6 miles) wide and stands some 300 meters (330 yards) high. Small craters are most easily seen in the smooth deposits along the south margin of the prominent double ridge, and in the rugged ridged terrain farther south. The complexly ridged terrain seen here shows that parts of the icy crust of Europa have been modified by intense faulting and disruption, driven by energy from the planet's interior.

- E6 orbit

Thank you!