Tutorial 6

Space physics EF2240, 2014

Examination,
Space Physics EF2240

2010-10-21, 08.00-13.00

ALLOWED ON THE EXAM:

- All material handed out on the lectures (including Fälthammar and Lyons)
- All material from the home page (including lecture notes)
- Your own notes
- Standard physics and mathematics formula collections or primers
- Calculator and writing equipment
- Dictionary

NOTE

There is a maximum of 100 p on this exam. The maximum points for each subproblem is indicated. To your results will be added your bonus points earned during the course. The grades will then be given by the following intervals:

Grade:	A:	111-125
	B:	96-110
	C:	81-95
	D:	66-80
	E:	50-65

Motivate your answers carefully, and be careful about units!

1.

On the day of May 11, 1999 (known as 'the day the solar wind disappeared') the solar wind velocity and density decreased to very low values. Figure 1, on the next page, shows solar wind data from the ACE spacecraft from three days, where day number 131 corresponds to May 11, published in a paper by Smith *et al.* [2001]. The solar wind velocity is given in the panel denoted by V_R (in kms^{-1}), and the proton number density in the panel denoted by N_P (in cm^{-3}).

a) Estimate the maximum standoff distance of the Earth magnetosphere for this time, and compare it to the standoff distance at the beginning of day 130. *(10 p)*

b) What is the minimum and maximum Parker spiral angle during the times shown in Figure 1? *(10 p)*

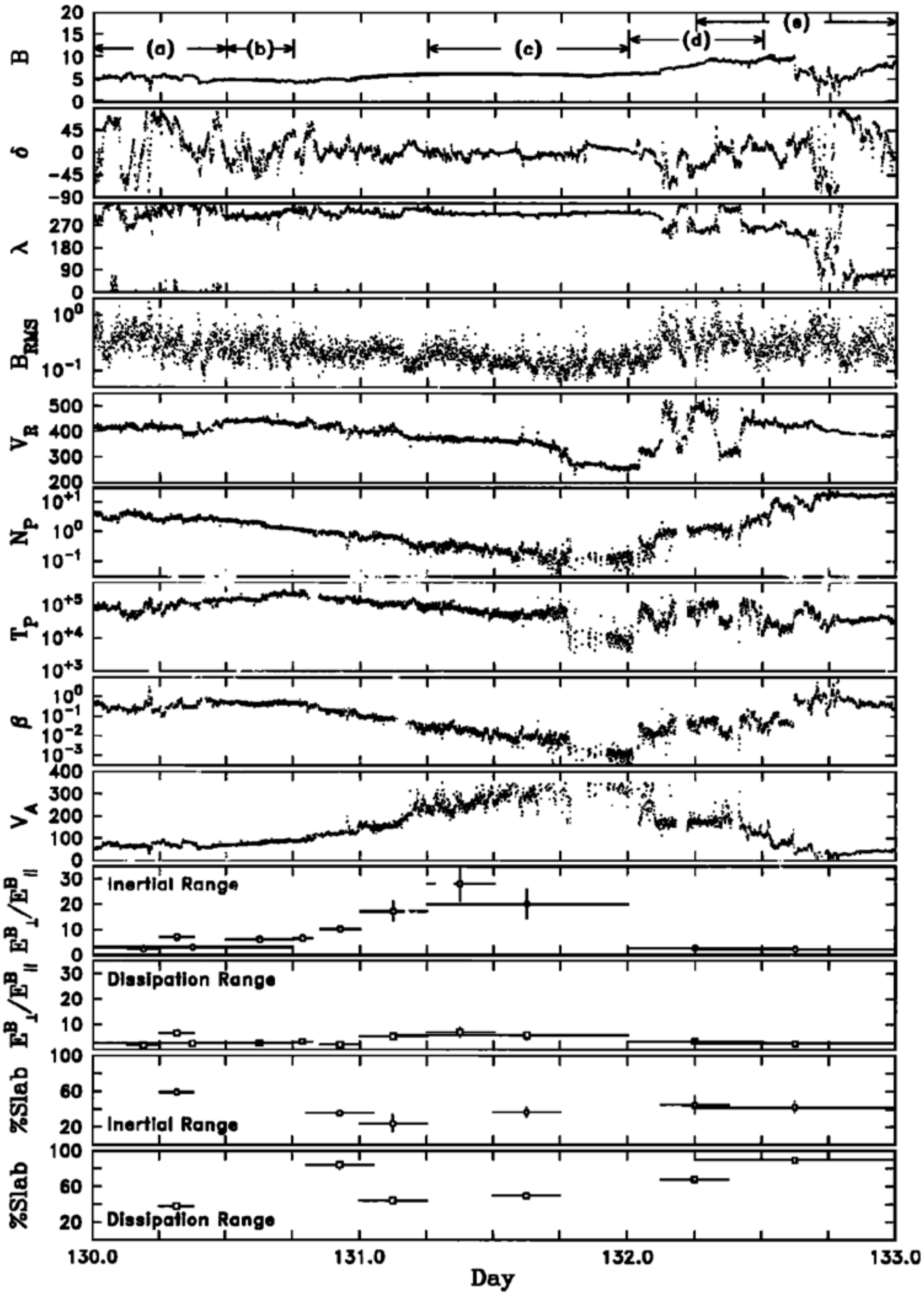

Figure 1. Days 130 through 132, 1999, when the solar wind density is observed to drop to 0.1 p cm^{-3}. IMF intensity B (nanoTeslas), IMF longitude δ (degrees), and IMF latitude λ (degrees), as well as RMS level of the IMF fluctuations B_{RMS} (nanoTeslas) are provided by the MAG instrument. The radial component of the wind speed V_R (km s^{-1}), proton density N_P (cm^{-3}) and proton temperature T_P (Kelvin) are provided by the SWEPAM instrument. The proton β and Alfvén speed V_A (km s^{-1}) are computed from data supplied by both instruments. The anisotropy of the IMF fluctuation spectra $E_\perp^B/E_\parallel^B$ in the inertial range and dissipation ranges are shown along with the anisotropy of the wave vector (expressed in terms of percent slab component in the inertial and dissipation ranges).

2.

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3.

An electron with an energy of 1 keV is positioned at point 1 on a particular field line of the geomagnetic field (see Figure 3), where the magnetic field strength is B_1 = 4000 nT. At that point, the electron has a pitch angle of $\alpha_1 = 20°$. As the particle gyrates around the field line, it also moves along it down towards the atmosphere. If it will reach point 2, it will collide with the neutral particles of the atmosphere. The magnetic field strength increases monotonically along the field line and at point 2 it is B_2 = 50 000 nT. Particles that will make it down to point 2 before they mirror are said to be in the (atmospheric) loss cone.

a) Determine the loss cone angle for particles at point 1. *(6 p)*

b) The electron is not originally in the loss cone. How much would you need to increase the parallel velocity of the electron for it to be in the loss cone, if you keep the perpendicular velocity constant? *(7 p)*

c) This increase in parallel velocity for auroral particles is believed to be obtained by an electric field parallel to the geomagnetic field. How big would the electric potential drop need to be? (You can assume that the acceleration takes place in a small region at point 1.) *(7 p)*

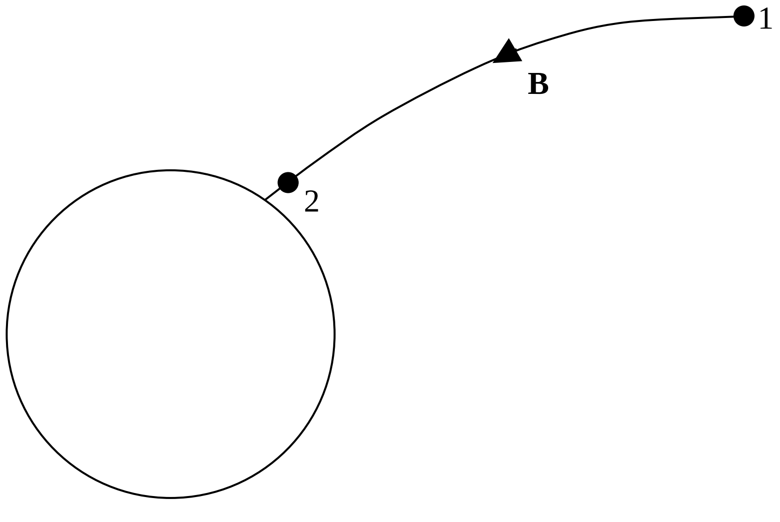

Figure 3.

4.

a) If you consider your own body to be a black-body radiator, what is the wavelength at which the highest intensity of electromagnetic waves is emitted. What kind of an electromagnetic wave is this? (*Hint:* 0 K = -273 C). *(5 p)*

b) We usually think of sunspots as black, since they appear so when observed close to the intense emissions from the undisturbed solar surface. But what colour are they really, if we assume that they have a temperature of 4200 K? *(5 p)*

c) The emitted power per unit area *P*, from a black-body radiator is

$$P = \sigma_{SB} T^4$$

where σ_{SB} is the Stefan-Bolzmann constant. Calculate the decrease (in percent) of total emitted power from the Sun due to a large, circular sunspot with a radius of 100 000 km. *(5 p)*

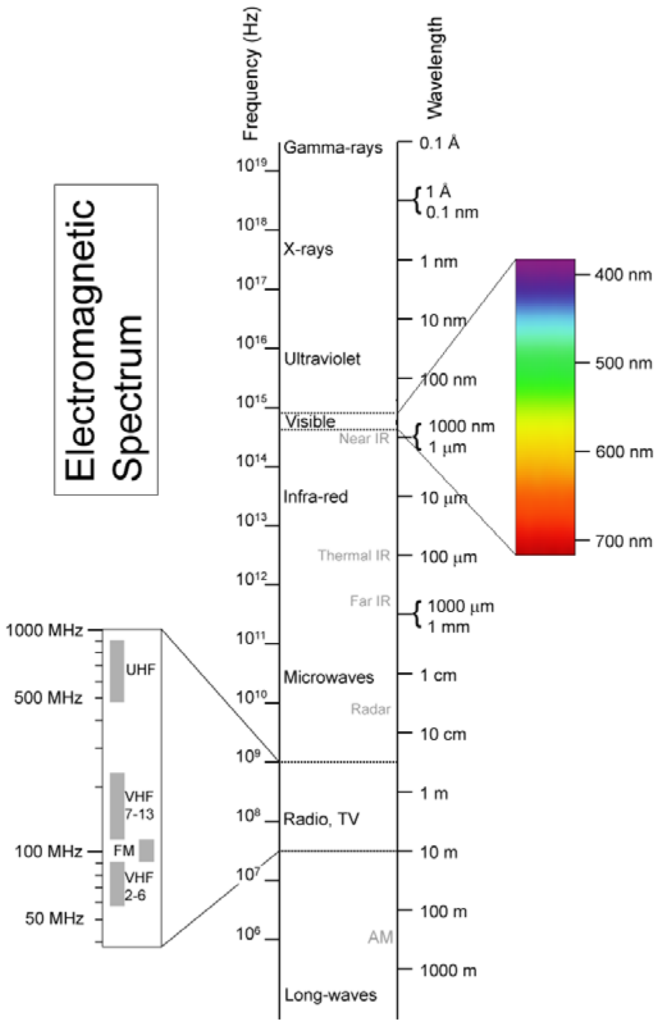

Figure 4. The electromagnetic spectrum.

5.

The ionograms in Figure 5 show recent measurements of the plasma frequency f_{pe} (black solid curve) as a function of altitude in km, performed at Pruhonice, Czech Republic. The first measurement (top part of the figure) is taken at a local time of 18.30, just before sunset, and the second measurement (bottom part of figure) is performed at 20.30, local time.

a) Calculate the maximum electron density for both times. This maximum corresponds to the F2-layer. *(5 p)*

b) The time variation of the electron density at a certain ionospheric altitude is different, depending on if the ions are molecular or atomic. In the first case we talk about a *Chapman layer*, where the time variation (in the absence of ionospheric winds) is given by

$$\frac{dn_e}{dt} = q - \alpha n_e^2$$

whereas in the second case we talk about a Bradbury layer, where the time variation is given by

$$\frac{dn_e}{dt} = q - \beta n_e$$

Use the measured densities at the altitude corresponding to the dayside F2-layer to determine if the layer is best modelled by a Chapman layer, where the ions are molecular oxygen O_2^+, or a Bradbury layer consisting of atomic oxygen ions O^+. Use the following values for the recombination coefficient α, and attachment coefficient β:

$\alpha = 3\cdot10^{-14}$ m^{3}s^{-1}
$\beta = 1\cdot10^{-4}$ s^{-1}

(20 p)

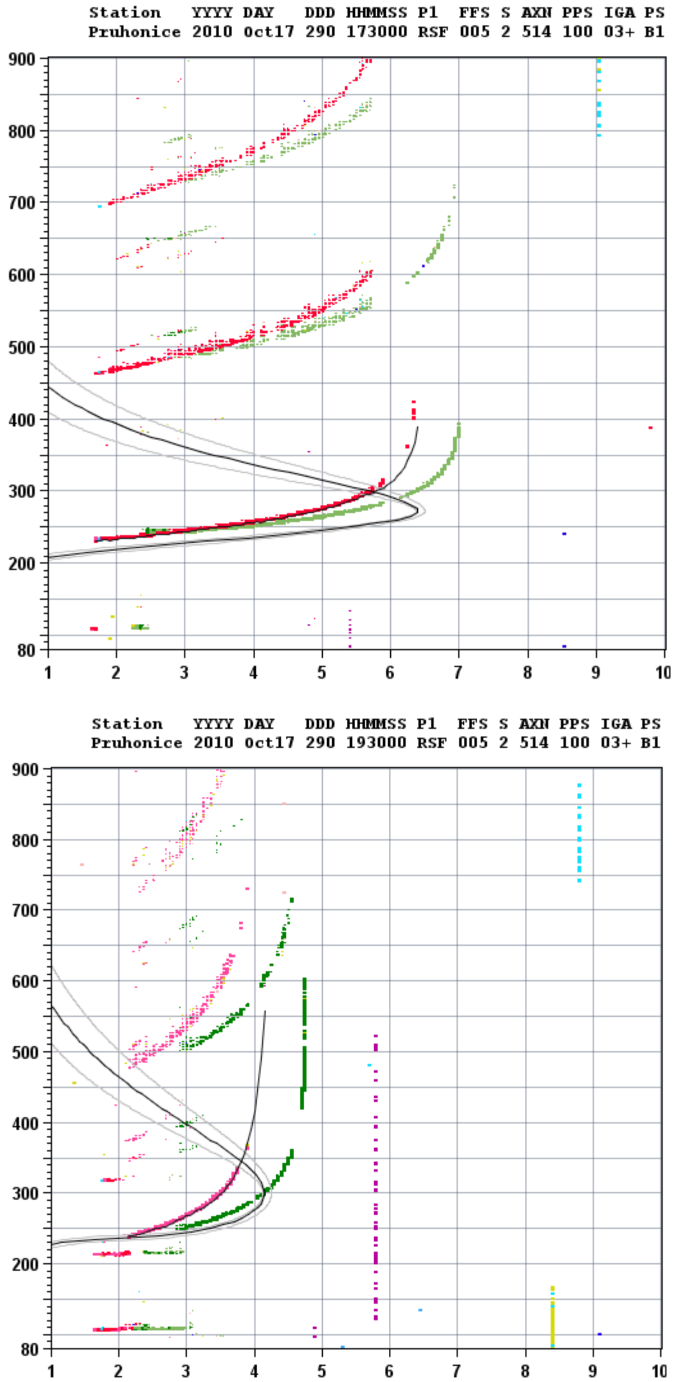

Figure 5. The black curve indicates the plasma frequency (given on the horizontal axis in units of MHz), as a function of altitude (given on the vertical axis in units of km).

Examination,
Space Physics EF2240

2011-10-18, 14.00-19.00

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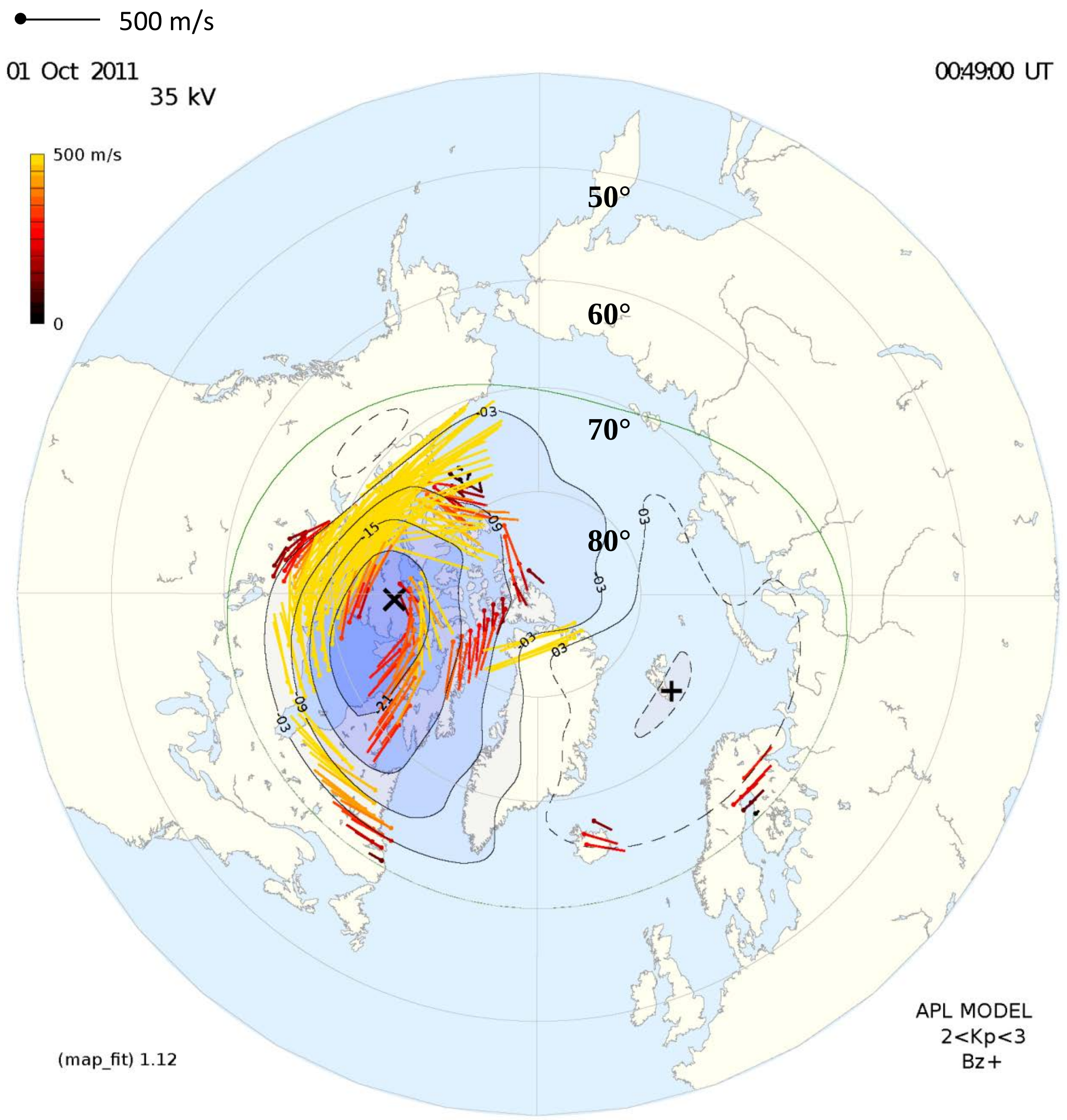
1.

The figure below shows recent radar measurements of ionospheric **E**×**B** plasma drift velocities. For each measurement point (indicated by a dot) the direction and size of the velocity is indicated by a vector starting from that point. The scale is given by a vector at the top left. The geomagnetic latitude is indicated by the grey rings.



a) These measurements are taken from the F-region, at an altitude of 300 km. Using a velocity measurement from the figure, calculate the ionospheric electric field strength at this altitude over Iceland (where it is night at the time of the plot) for one of the points in the plot. *(10 p)*

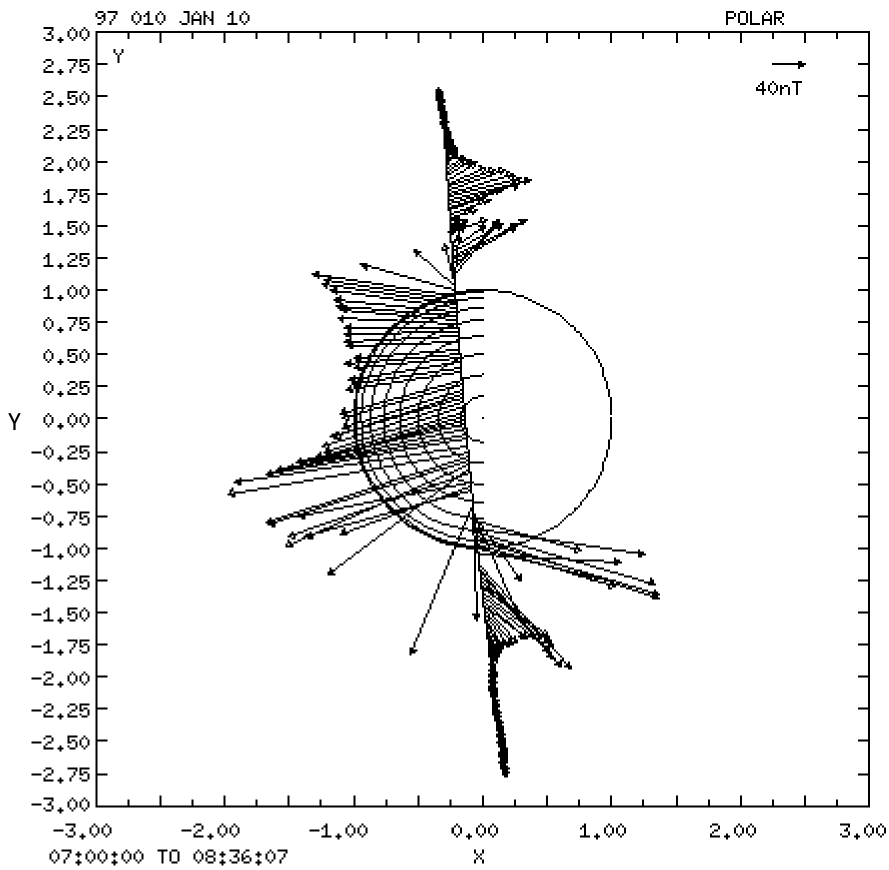
b) Assuming that the electric field is the same in the E-region, estimate the current densities of the Pedersen and Hall currents driven by the electric field of from Exercise 1a). Sketch a figure of the directions of the electric field, and the current. *(10 p)*

2.

The figure below shows magnetic field vectors measured by the Polar satellite above Earth's northern hemisphere. The scale for the magnetic field measurements is given by the arrow at the top right corner. *x* and *y* are measured in Earth radii. (The *z* direction is the direction along the northern magnetic pole.) The Earth is indicated by the circle (the 'shadowing' indicates the night side).

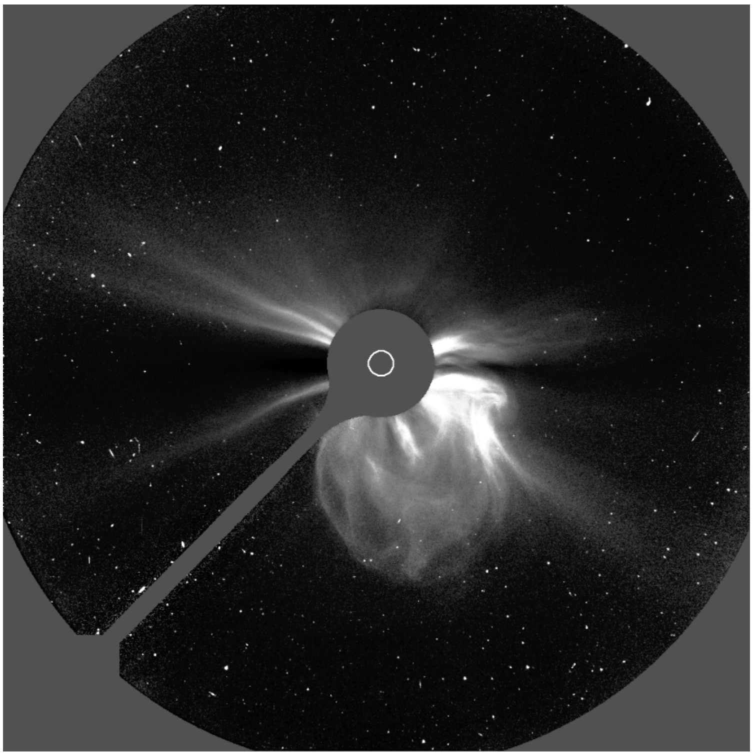
a) Mark in the figure (or draw your own figure) one region where a large current flows down towards Earth, and one region where a large current flows up from Earth. *(5 p)*

b) Use the infinite current sheet approximation to estimate the current density of one of these regions. *(10 p)*



3.

The coronal mass ejection (CME) shown in the image below (taken from the Solar and Heliopsheric Observatory spacecraft) can be considered to consist of a plasma with a uniform number density. In the image the sun is blocked by a disc, with the solar position indicated by the white circle. The CME later passed a satellite close to the Earth magnetosphere. Measurements from this satellite showed that the electron gyro frequency f_{ce} was 1.7 kHz, the electron plasma frequency f_{pe} was 0.12 MHz, the temperature T was $2 \cdot 10^6$ K, and that the CME moved with a velocity of 1200 km/s.



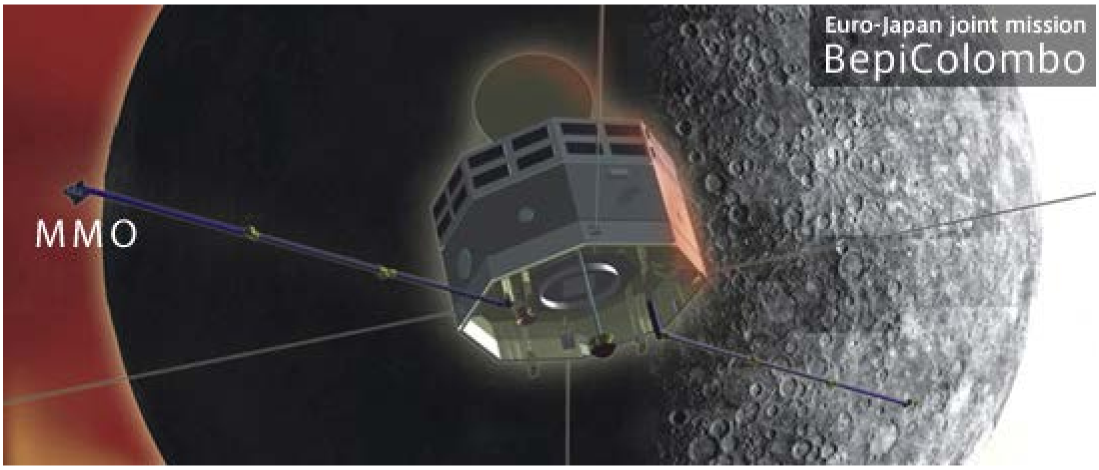
a) Estimate the total kinetic energy of the CME. Assume that the CME did not expand after it left the sun. *(5 p)*

b) Verify that the magnetic field inside the CME fulfills the frozen-in approximation. The conductivity of the plasma in the CME can be calculated by the expression $\sigma = 1.9 \cdot 10^3 T^{\frac{3}{2}}$ S/m, where T_e is the electron temperature given in eV. *(5 p)*

c) Is the internal dynamics of the CME dominated by the magnetic field or by the plasma pressure? *(5 p)*

4.

In 2013 the European Space Agency (ESA) will send the spacecraft Bepi-Colombo to orbit Mercury, to study the Mercury magnetosphere.



The Bepi-Colombo spacecraft.

a) One of the phenomena expected to be studied is periods when the solar wind pressure is high enough to push the Mercury magnetosphere so far back that the solar wind will penetrate all the way to the planetary surface. Suppose that the solar wind plasma number density at Mercury orbit is n_e = 40 cm^{-3}. Estimate the minimum solar wind velocity for this to occur! The planetary radius R_M is 2440 km and Mercury's magnetic dipole moment is 3.0×10^{19} Am^2. *(10 p)*

b) Can a similar phenomenon happen at Earth? Motivate your answer with numbers. *(10 p)*

c) *Deleted*

d) Estimate the highest energy of a cosmic ray proton that can penetrate down to the planetary surface, if it enters in the dayside equatorial plane, during the same solar wind conditions as in **c)**. Ignore relativistic effects, and give the answer in eV. *(10 p)*

5.

The temperature of the central star of an HII emission nebula is known to be 8 000 K, and the density of the surrounding plasma is 85 cm^{-3}. From theoretical arguments, it is believed that the flux of ultraviolet photons (able to ionize neutral hydrogen) per unit surface of the star is 10^{31} $s^{-1}m^{-2}$. The radius of the nebula is 7 light years. What is the radius of the central star? *(Hint: use the following expression for the recombination coefficient:* $\alpha_H(T_e) = 2 \cdot 10^{-16} T_e^{-3/4}$ m^3s^{-1}*, with the electron temperature given in K.)* *(10 p)*

Examination,
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2012-10-16, 14.00-19.00

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1.

Figure 1 shows typical solar wind parameters (from Fälthammar p 124).

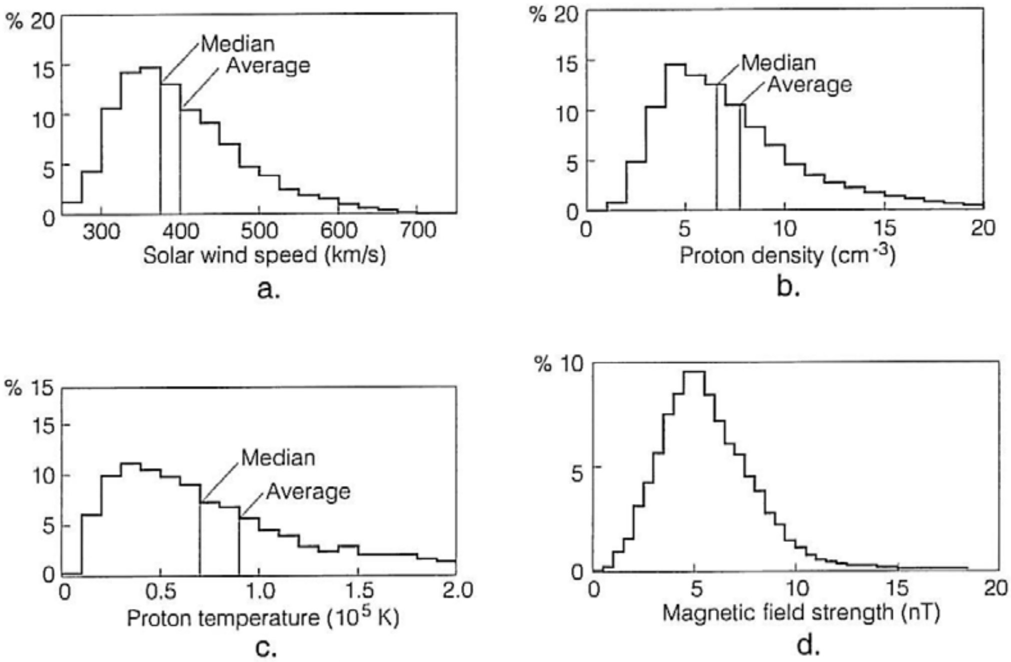

Fig. 1

a) The Parker spiral angle is important in some theories of how the interplanetary field interacts with the geomagnetic field. How much does the angle change between the minimum and maximum solar wind speed values given in Figure 1? *(5 p)*

b) Calculate a typical ratio of the kinetic energy density of the solar wind to its magnetic field energy density, using the typical values in Figure 1. *(5 p)*

2.

a) At an altitude of 200 km in Earth's dayside high-latitude ionosphere (where the magnetic field is directed approximately vertically to the planetary surface), an electric field is pointing towards East, and has a strength of 8 mV/m. In what direction will the resulting current flow? (Express your answer in deviation from the Eastward direction in degrees.) What will the absolute value of the current density be? *(15 p)*

b) At what approximate altitude will the deviation angle be 45° ? *(5 p)*

3.

Shown in the figure is the induced magnetotail of Venus. Estimate the total cross-tail current (the current in the y-direction) between x = -4 R_V and -12 R_V, where R_V = 6052 km is the radius of Venus, if the typical magnetic field strength in the magnetotail is 15 nT. *(15 p)*

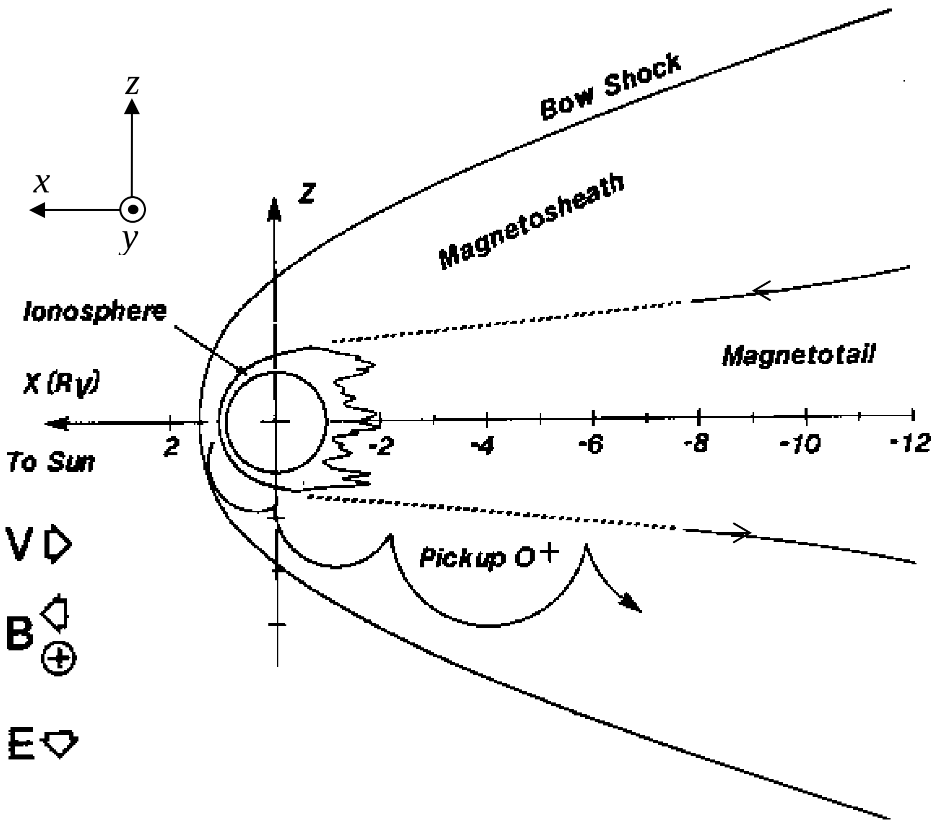

Fig. 3

4.

The region in space where the solar wind can reach before it is braked down to the velocity of the surrounding interstellar medium is called the heliosphere, and corresponds to the pink region in Figure 4 below. The heliosphere contains the interplanetary magnetic field, the average values of which varies with the solar cycle. This magnetic field shields part of the cosmic radiation and prevents it from reaching the solar system.

Assuming that the average heliospheric magnetic field is 0.01 nT, what is the minimum energy required for a cosmic ray proton travelling in the *x* direction to reach the solar system (marked by the blue circle)? Assume that the magnetic field is directed along the *y* axis. The scale of the picture is given by the arrow. *(15 p)*

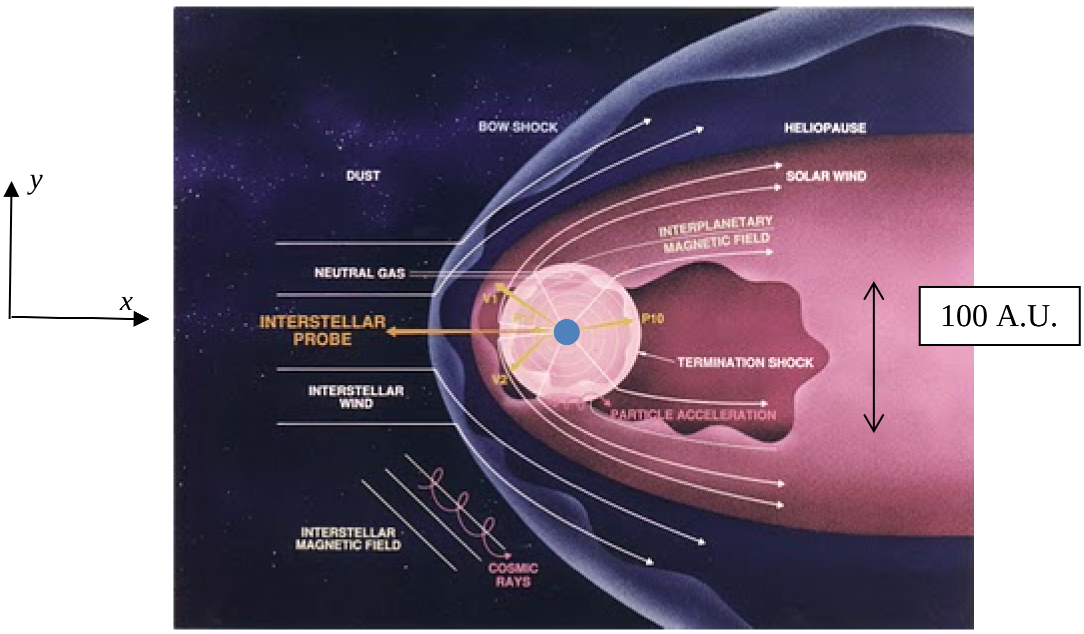

Fig. 4

5.

a) Consider a magnetic field line in the inner part of Mercury's magnetosphere (which we assume can be modeled by a dipole field). The magnetic field strength at position p_a is 11 nT. An electron at position p_a has a pitch angle of 10°, which will make this particle mirror right at the planetary surface. At what angle θ to the dipole axis will this happen? The magnetic moment of Mercury is 3.0×10^{19} Am^2, and its radius is 2440 km. *(Hint:* $\cos^2\theta+\sin^2\theta=1$*) (20 p)*

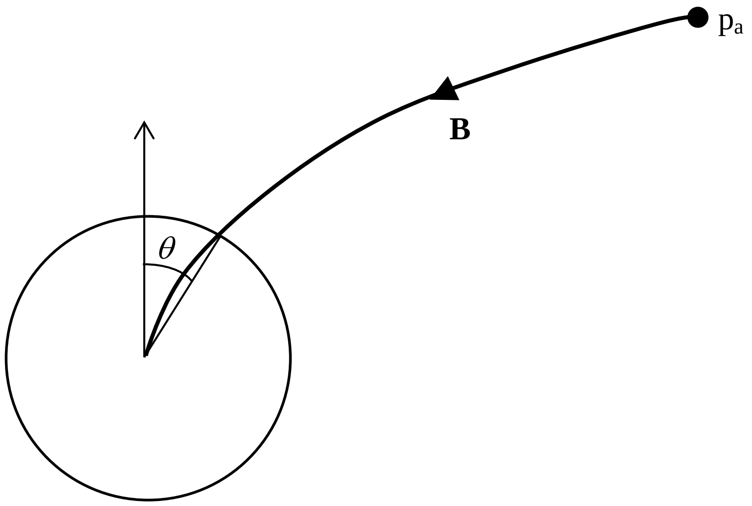

Fig. 5a

b) Figure 5b represents the equatorial plane in Mercury's magnetosphere viewed from "above", with Mercury marked as $\oplus$. If the cross-tail electric field **E** has a magnitude of 0.5 mV/m, calculate the ratio of the ExB drift and the gradient B drift velocities of a particle with a perpendicular energy of 1 keV at point p_b, which is at a distance of 4 Mercury radii from the centre of the planet. Assume that the Mercury magnetic field can be modeled by a dipole field. (*Hint: the gradient of a function A in polar coordinates is* $\nabla A=\frac{\partial A}{\partial r}\hat{\mathbf{r}}+\frac{1}{r}\frac{\partial A}{\partial\theta}\hat{\boldsymbol{\theta}}+\frac{1}{r\sin\theta}\frac{\partial A}{\partial\varphi}\hat{\boldsymbol{\varphi}}$.) (*20 p)*

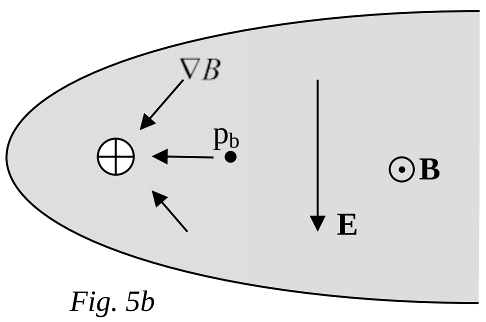

Fig. 5b