Tutorial 6

Space physics EF2240, 2015

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)*

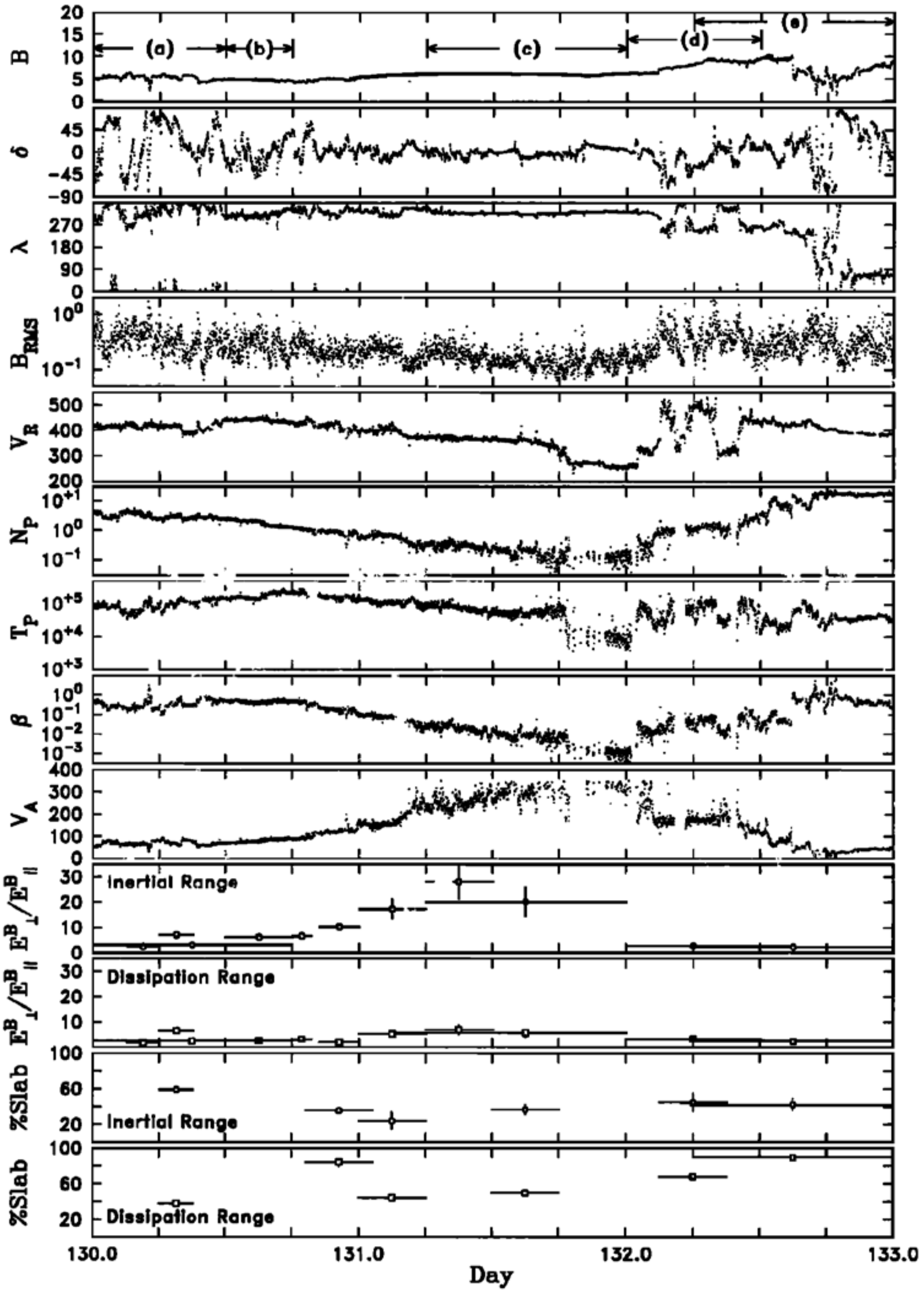

Figure 1. Days 130 through 132, 1999, when the solar wind density is observed to drop to 0.1 p cm^{-3}. IMF intensity B (nanoTeslas), IMF longitude δ (degrees), and IMF latitude λ (degrees), as well as RMS level of the IMF fluctuations B_{RMS} (nanoTeslas) are provided by the MAG instrument. The radial 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 $E^B_\perp/E^B_\parallel$ 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 α_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)*

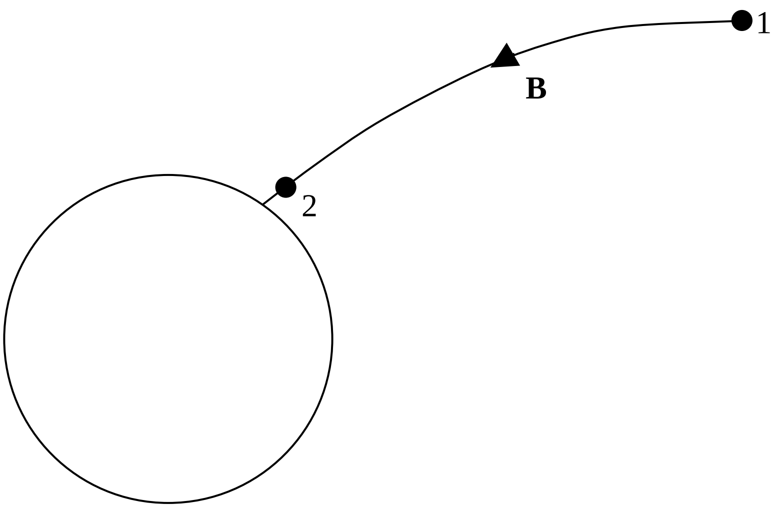

Figure 3.

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)*

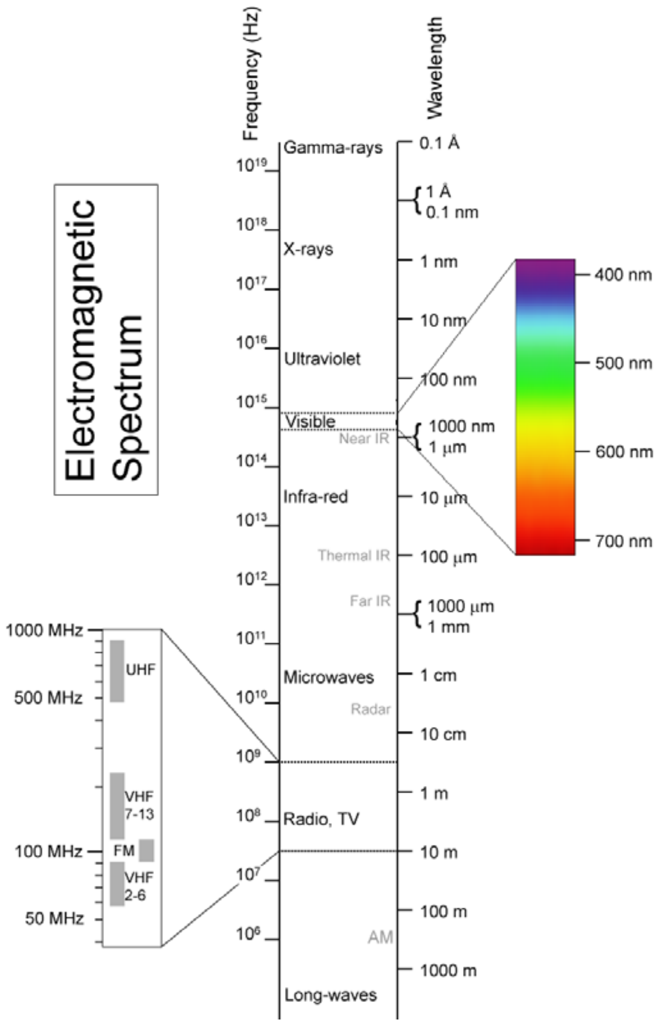

Figure 4. The electromagnetic spectrum.

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:

$\alpha = 3 \cdot 10^{-14}$ m^{3}s^{-1}
$\beta = 1 \cdot 10^{-4}$ s^{-1}

(20 p)

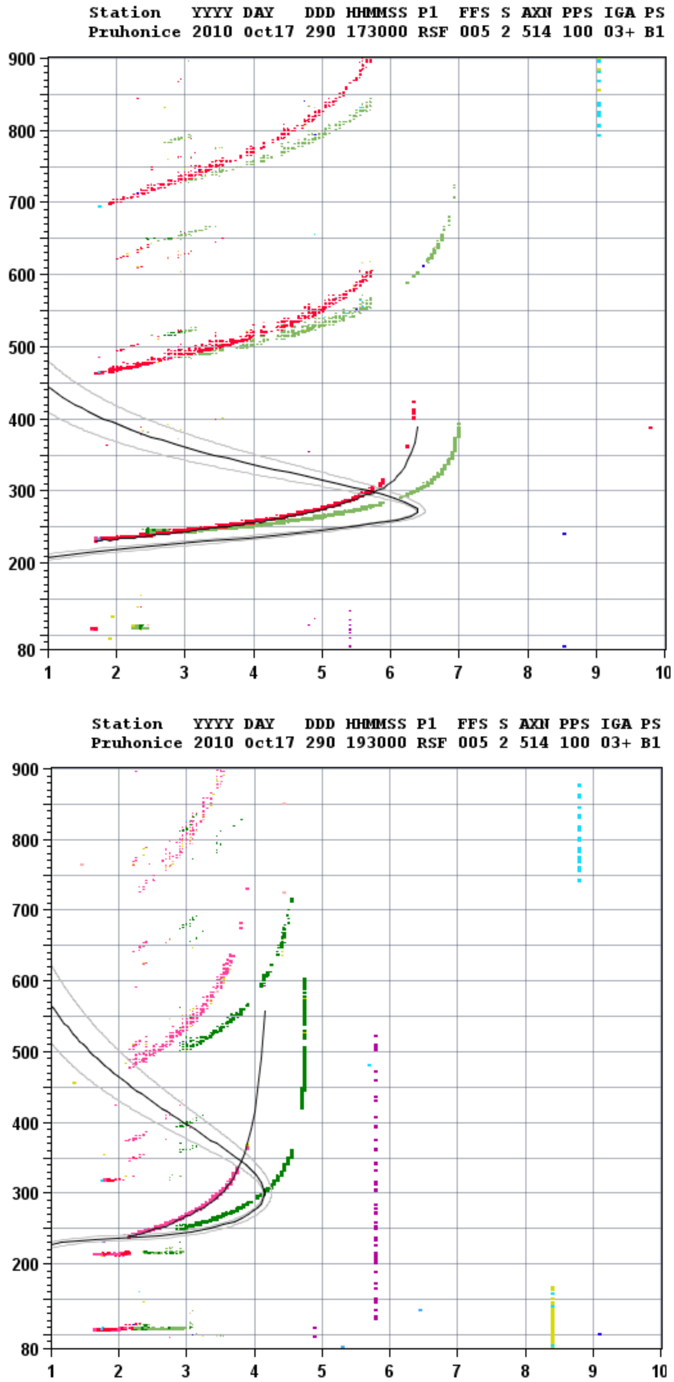

Figure 5. The black curve indicates the plasma frequency (given on the horizontal axis in units of MHz), as a function of altitude (given on the vertical axis in units of km).

Examination,
Space Physics EF2240

2011-10-18, 14.00-19.00

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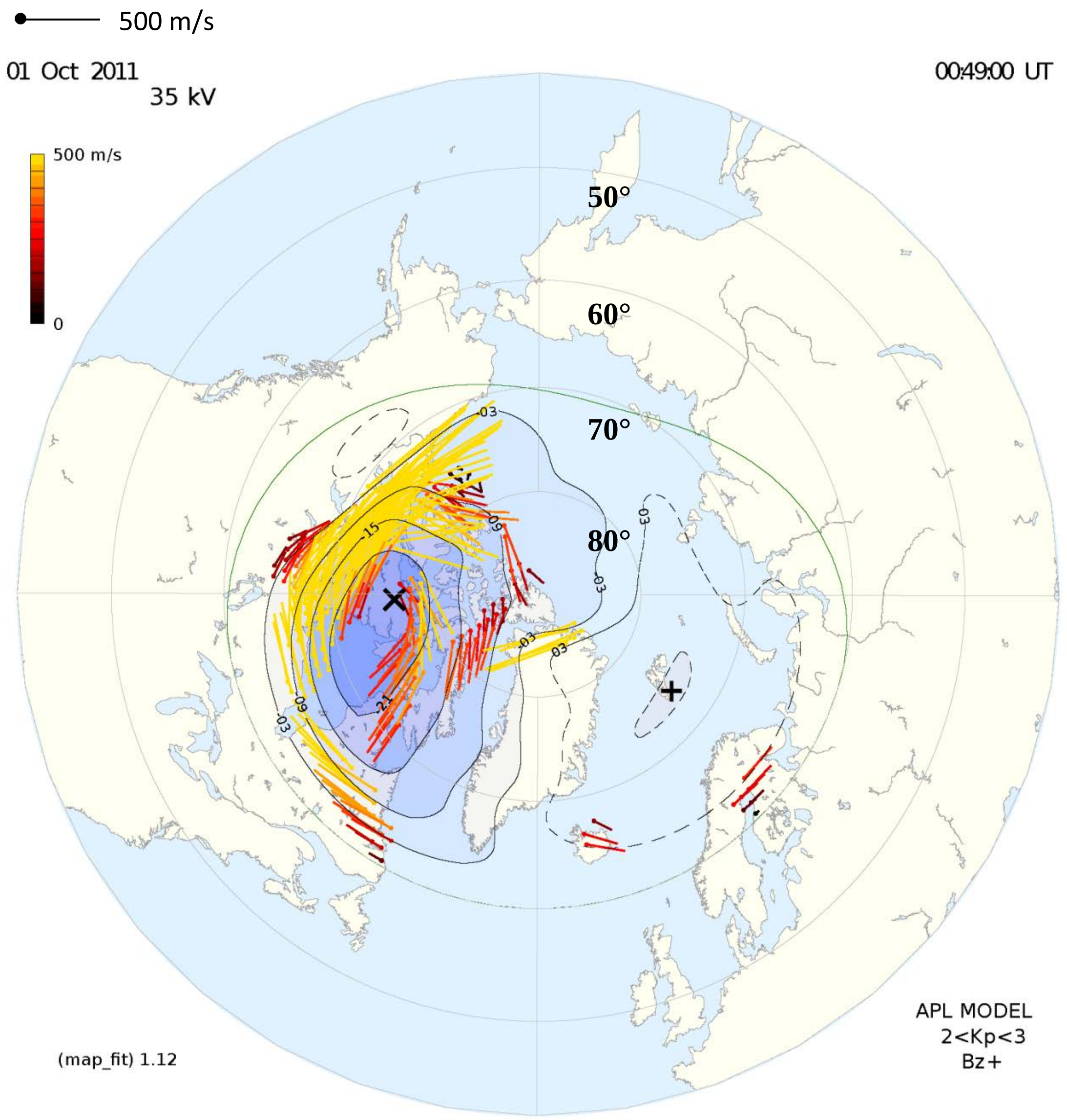
Motivate your answers carefully, and be careful about units!

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)*

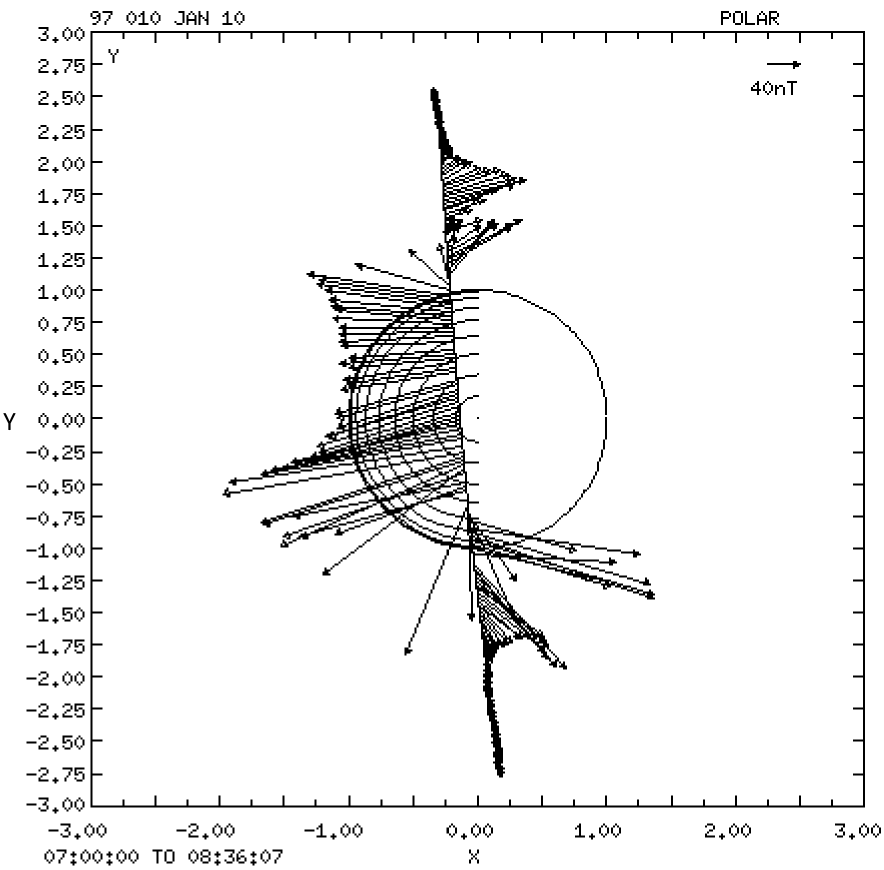
b) Assuming that the electric field is the same in the E-region, estimate the current densities of the Pedersen and Hall currents driven by the electric field of from Exercise 1a). Sketch a figure of the directions of the electric field, and the current. *(10 p)*

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).

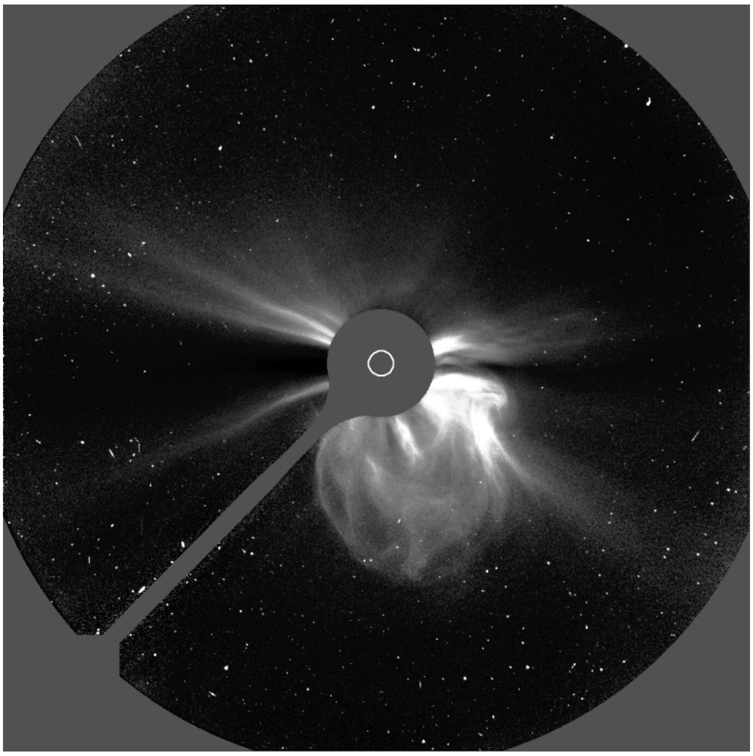
a) Mark in the figure (or draw your own figure) one region where a large current flows down towards Earth, and one region where a large current flows up from Earth. *(5 p)*

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 $2\cdot10^6$ K, and that the CME moved with a velocity of 1200 km/s.



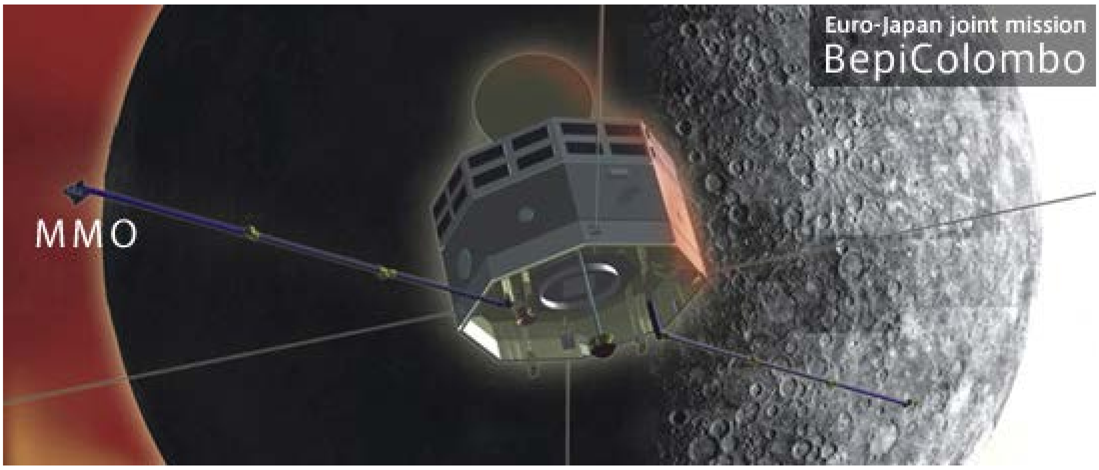
a) Estimate the total kinetic energy of the CME. Assume that the CME did not expand after it left the sun. *(5 p)*

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 $\sigma = 1.9\cdot10^3 T^{\frac{3}{2}}$ 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,
Space Physics EF2240

2013-10-30, 14.00-19.00

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1.

a) Figure 1.1 shows a blackbody curve obtained by a computer simulation of a solar flare (Allred et al., 2006). What temperature does the blackbody curve correspond to? *(Hint: 1 Å = 0.1 nm)* (*5 p*)

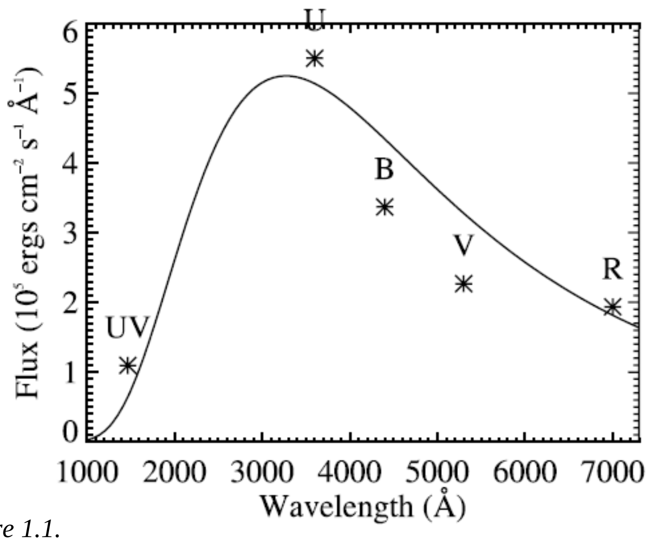

Figure 1.1.

b) Figure 1.2 shows a coronal loop associated with a large solar flare (Earth's size indicated in the figure). If a typical electron gyro frequency of the plasma that fills the magnetic field loop is 4 GHz, and the plasma frequency is 900 GHz, estimate the total magnetic energy of the loop as well as the total thermal energy of the plasma in the loop (assuming the plasma is evenly distributed in the loop). *(Hint: use the result from 1a))* (*15 p*)

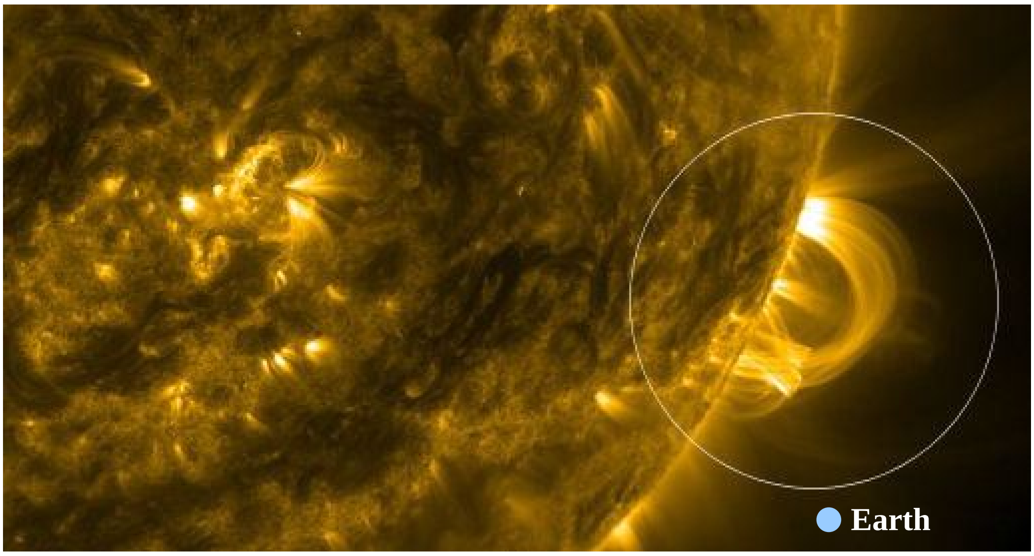

Figure 1.2.

2.

Figure 2 shows 48 h of solar wind data measured by the ACE spacecraft from June 7 and 8, 2000. The top panel shows the proton density in particles/cm^3, the bottom panel shows the solar wind speed in km/s. Between around 09:30 and 16:00 on June 8, a small Coronal Mass Ejection (CME) passes the spacecraft. Estimate how much the standoff distance of Earth's magnetosphere changes as it is hit by the highest density part of the CME, compared to what it was at the beginning of June 7. Give your answer in Earth radii (R_E). (*15 p*)

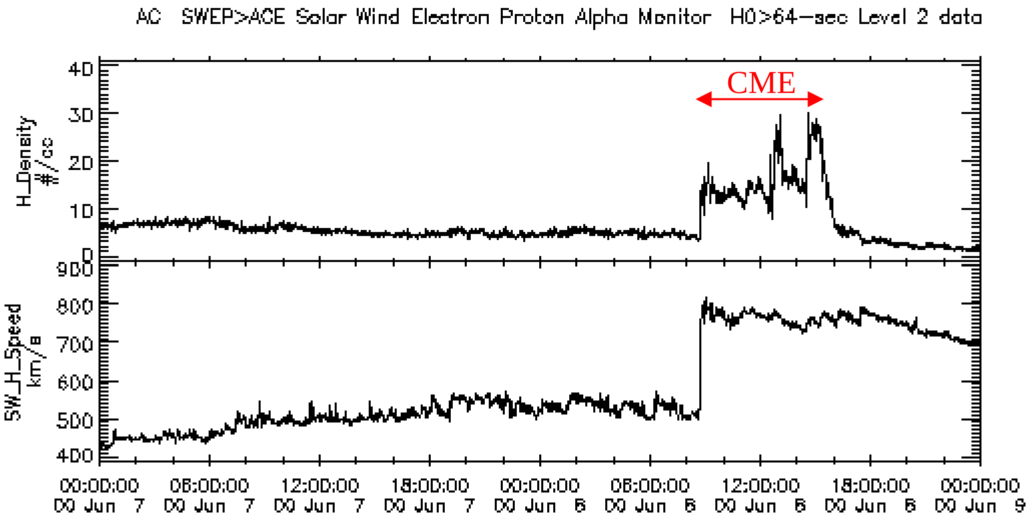

Figure 2.

3.

Figure 3a shows measurements by the Cassini spacecraft from the Saturn magnetosphere. The fourth panel shows the Eastward component of the magnetic field (B_E). Indicated at the bottom of the plot is magnetic local time (LT), co-latitude (which is the angle θ to the magnetic axis, see Figure 3b), and the radial distance of the spacecraft to the centre of Saturn.

Ignoring the other magnetic field components, use the Eastward component of the magnetic field to estimate the absolute value of the current density of the downward field aligned current in the sheet indicated by the red arrow. For simplicity, assume that the altitude of the spacecraft is constant during the passage of the current sheet. *(Hint: Saturn's radius, R_S, is 60 268 km.)* (*20 p*)

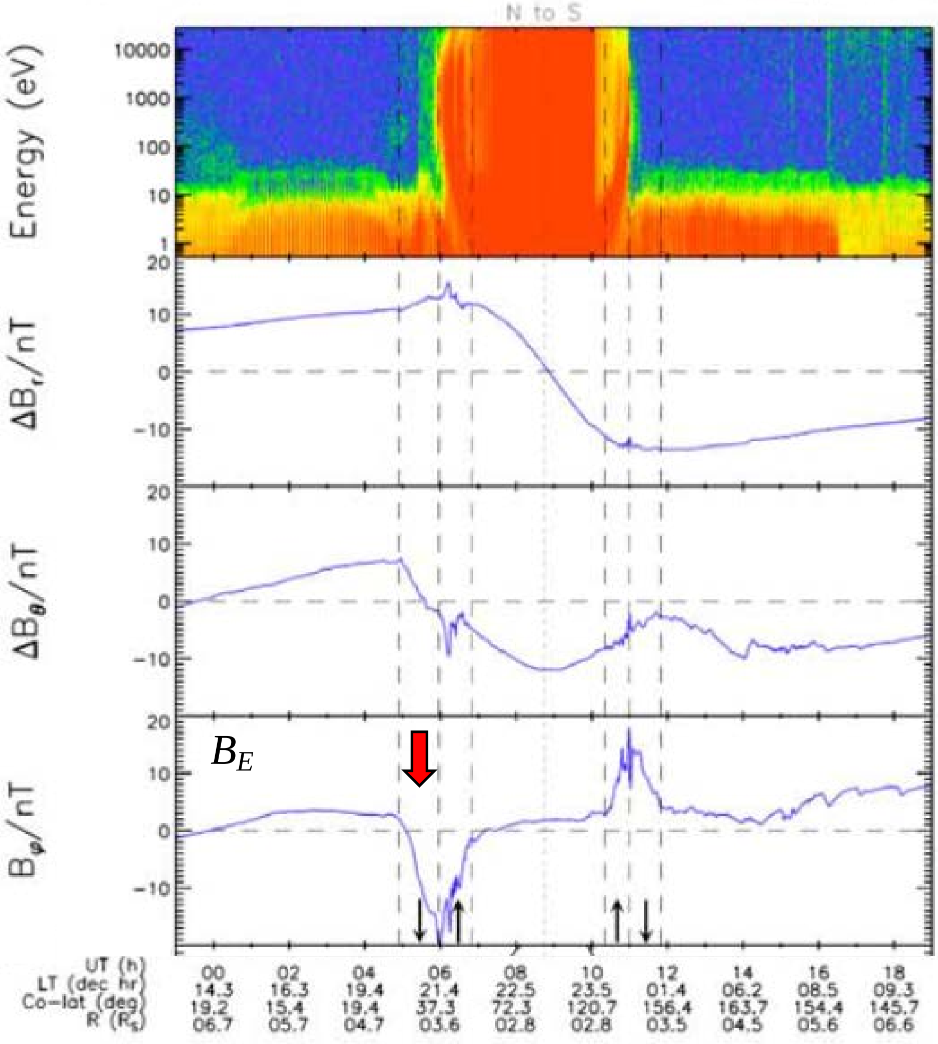

Figure 3a (Talboys et al, 2009).

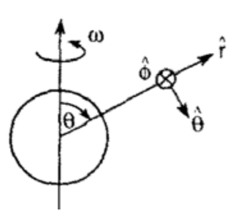

Figure 3b.

4.

a) What is the electron gyro (angular) frequency and gyro radius just inside the subsolar point of Mercury's magnetosphere (Figure 4), where the plasma can be assumed to have a temperature of 0.5 keV? Assume that the solar wind speed is 250 kms^{-1}, and the solar wind electron density is 27 cm^{-3}. *(10 p)*

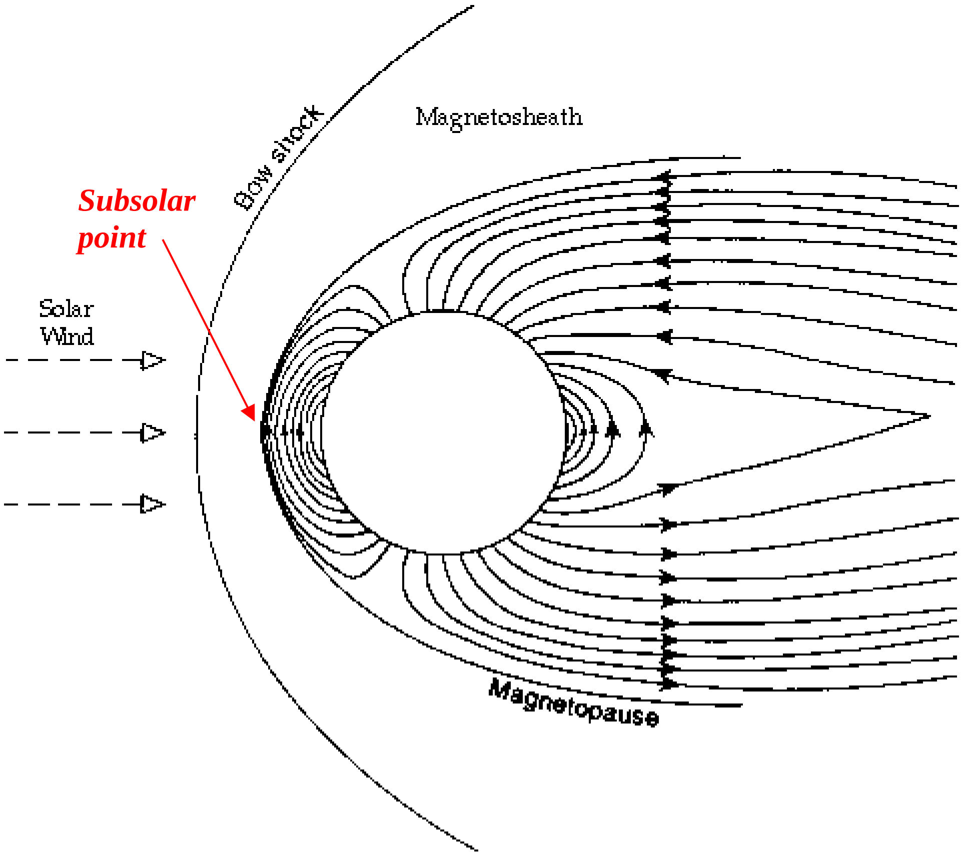

Figure 4.

b. If the stand-off distance is measured to be 1.4 Mercury radii (R_M) at the time, estimate the magnetic dipole moment of Mercury. (*Hint: R_M = 2440 km*) (*5 p*)

c. If a cosmic radiation particle (assume it is a proton) travelling in the equatorial plane enters the magnetosphere at the subsolar point, estimate the minimum energy it needs to have, to be able to reach the surface of Mercury. Give the answer in eV. Note that this energy is so small that we need not use relativistic expressions, but can use the ordinary classical expressions for kinetic energy etc. (*10 p*)

5.

Figure 5 shows rocket measurements of two electric field components (Eastward and Northward) above an auroral arc (indicated by the grey area), at an altitude of around 200 km. Shown are also the current densities in the same direction. You can assume that both the Eastward and Northward components are perpendicular to the geomagnetic field.

Conductivities in regions of auroral activity is greater than that of the quiet ionosphere, due to additional ionizations casued by the auroral electrons. Estimate the Hall and Pedersen conductivities from the measurements above the auroral arc! (*20 p*)

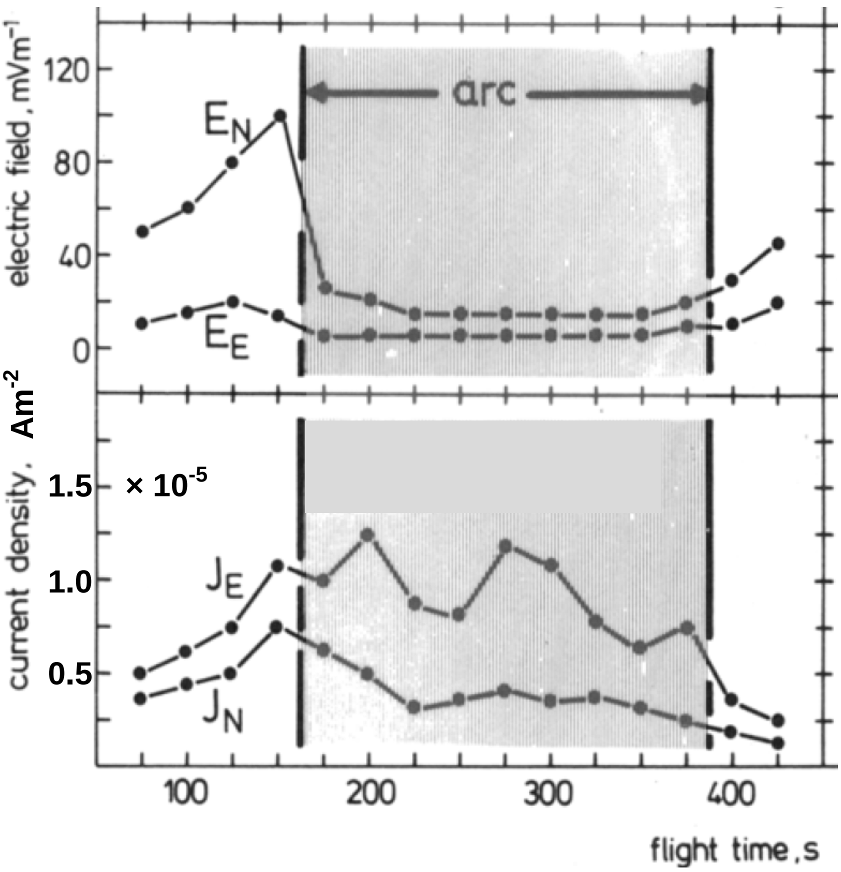

Figure 5 (Marklund et al., 1982).