

Our Invisible Environment:

Electromagnetism in the Solar System

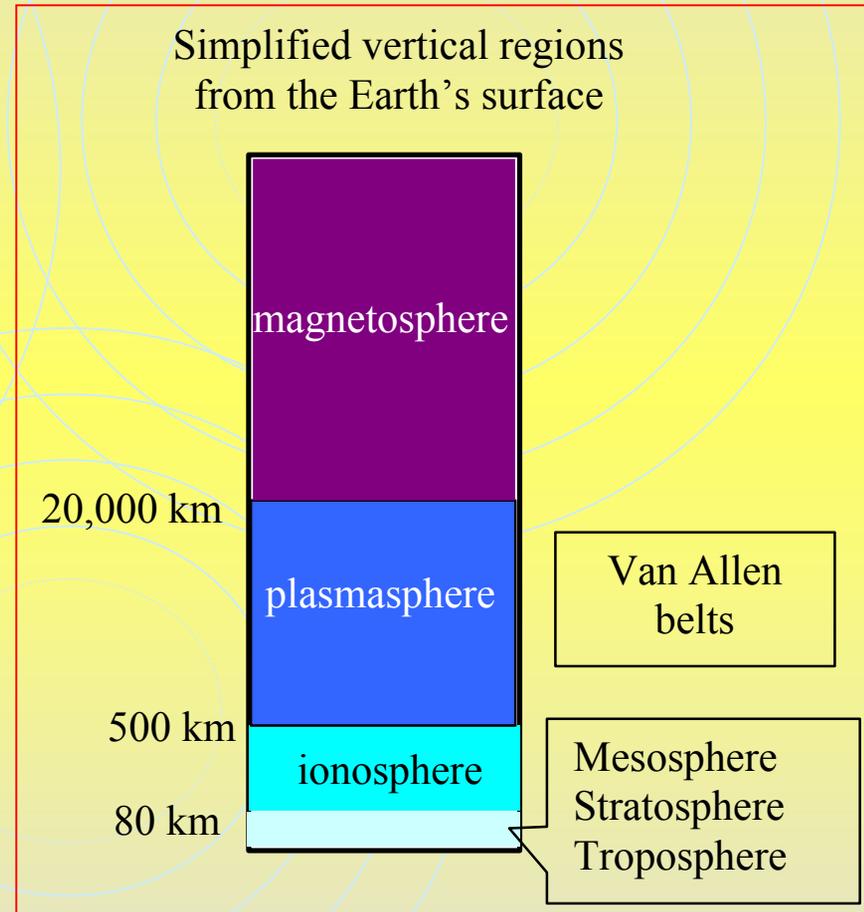
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Above the Earth

- The Earth's atmosphere influences behaviour below ~100 km altitude
- Above that, electrical behaviour dominates
- The electromagnetic properties affect many aspects of everyday life
 - ions and electrons are the important material content

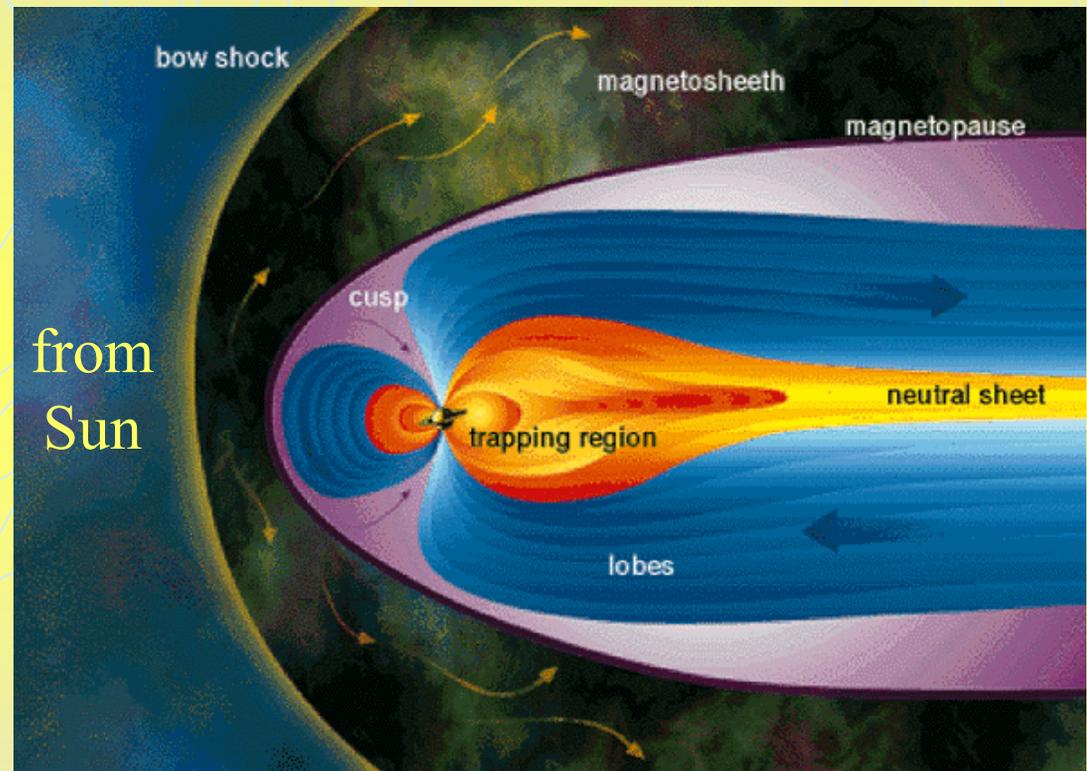


Space is different.....

- Different from the matter around us
 - different in the way that charges move compared with what we're used to in wires
 - different in the sizes of the constants, fields, etc.
- Illustrations relevant to
 - cosmic rays
 - aurora
 - Van Allen belts

The bigger picture

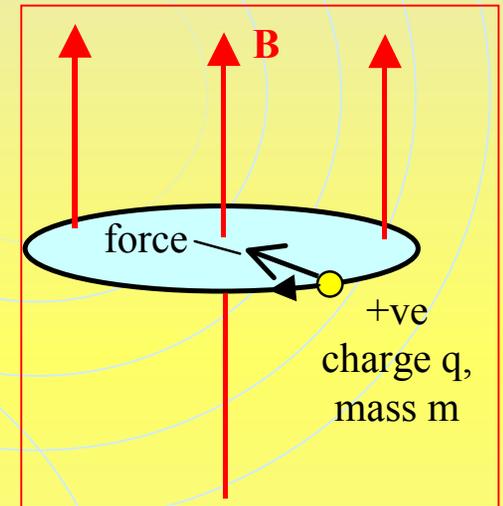
The electromagnetic environment of the Earth extends beyond the Moon and ties into the magnetic field from the Sun transported with the solar wind



Courtesy: NASA

Charged particles and a uniform magnetic field - 1

- Charged particles circulate around magnetic field lines, **B**
- The magnetic force on them is at right angles to their velocity and to **B**
 - this force maintains their motion in a circle
 - this force doesn't change the energy of the particle
 - gyration frequency f is $f = \frac{qB}{2\pi m}$
 - for electrons with **B** = 10^{-5} T, $f = 2.8 \times 10^5$ Hz
 - circle radius = (perpendicular speed)/ $2\pi f$

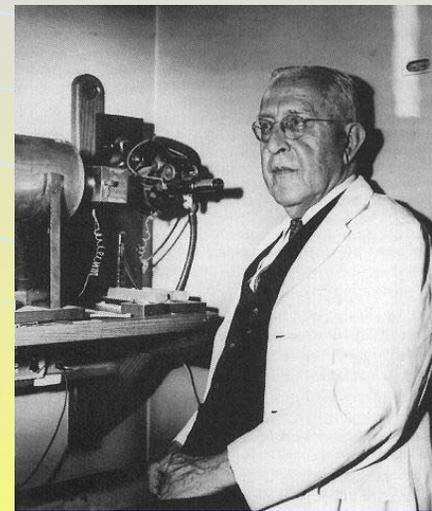


Application to cosmic rays

- Cosmic rays are generated outside the solar system
 - they consist of energetic charged particles of H^+ and many other ionic species
 - do they come straight to us or are they deviated by the interplanetary magnetic field?

Victor F. Hess (1883 – 1964)

<http://www.th.physik.uni-frankfurt.de/~jr/physlist.html>



Periodic Table of Elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar										
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac*	104 Rf	105 Ha	106	107	108	109	110								

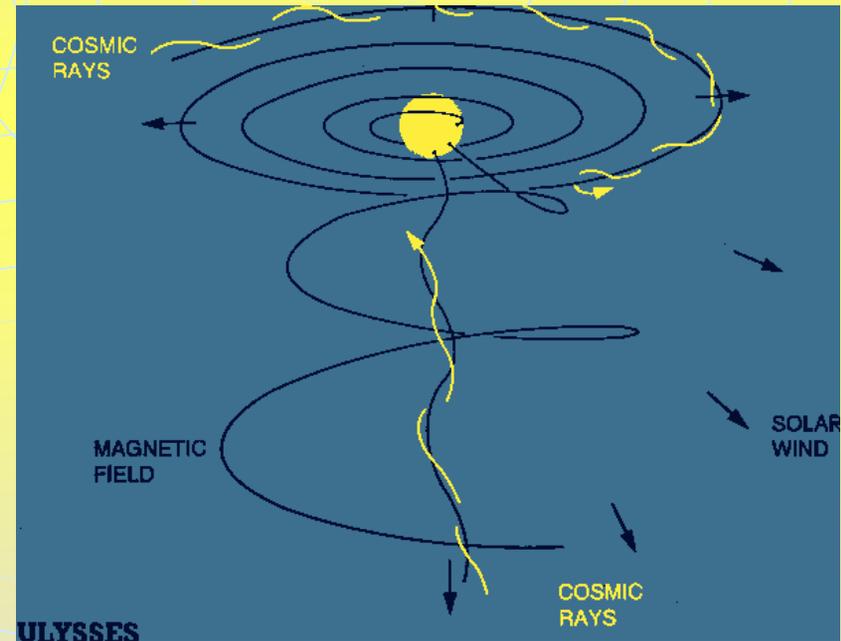
*Lanthinide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	Lu
*Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	Lr

- Cosmic rays spiral around the interplanetary magnetic field lines originating from the Sun

$$f = \frac{qB}{2\pi m}$$

- consider an Fe^{26+} nucleus travelling near the speed of light, c .
- for this particle: $q = 4.165 \times 10^{-18}$ C; $B = 10$ nT (say); $m = 9.37 \times 10^{-26}$ kg
- these figures give $f = 7 \times 10^{-2}$ Hz
- radius r of the circle is such that $2\pi r f = c$
- hence $r = 6.8 \times 10^5$ km, about the diameter of the Moon's orbit
- Therefore there is destruction of information about direction of the source
 - protection of Earth from some irradiation

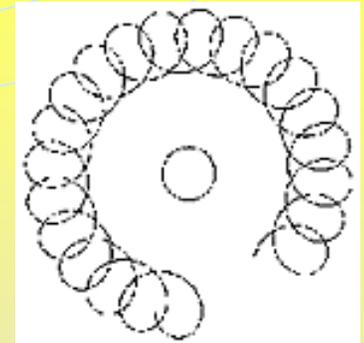
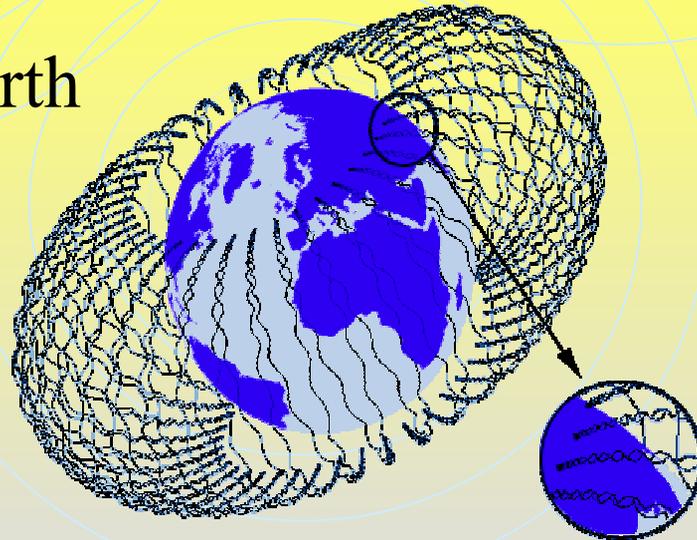
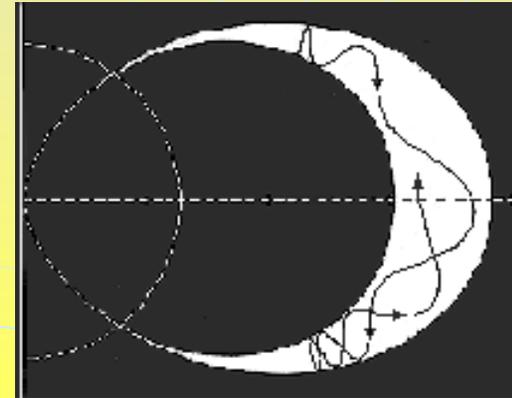
Deviation of cosmic rays



<http://ulysses.jpl.nasa.gov/science/images/fig7magspiral.gif>

The physics of motion in magnetic and electric fields

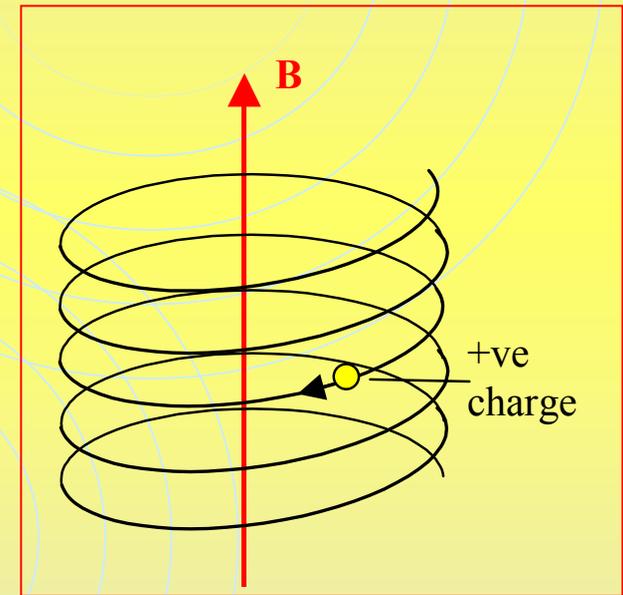
- Charged particles have 3 motions
 - gyration
 - takes \ll ms
 - motion along magnetic field lines
 - takes ~ 0.1 s
 - drift around the Earth
 - takes minutes



Courtesy: NASA

Charged particles and a uniform magnetic field - 2

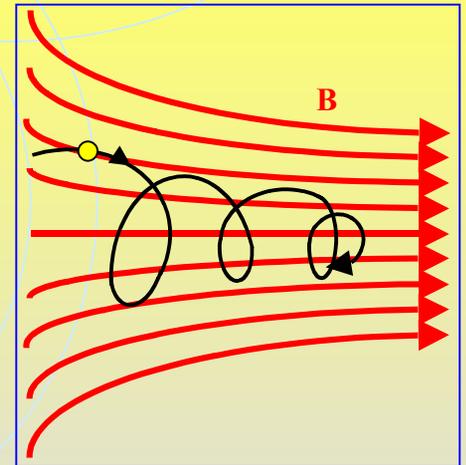
- If the particles also have a motion parallel to the magnetic field lines, they spiral up or down the field lines
 - the motion parallel to the line is unaffected by **B**
 - again, there is no change in the energy of the particle



+ve charge spiralling down a field line

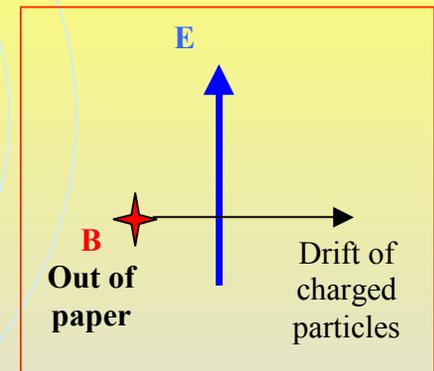
Charged particles spiralling down converging field lines

- The lines of the Earth's field converge at the magnetic poles
- Particles spiralling polewards do so in faster, tighter circles
- Their progress towards the poles becomes slower (because their kinetic energy is conserved)
- They are eventually reflected back up the field line
- The magnetic poles create **magnetic mirrors** for charged particles



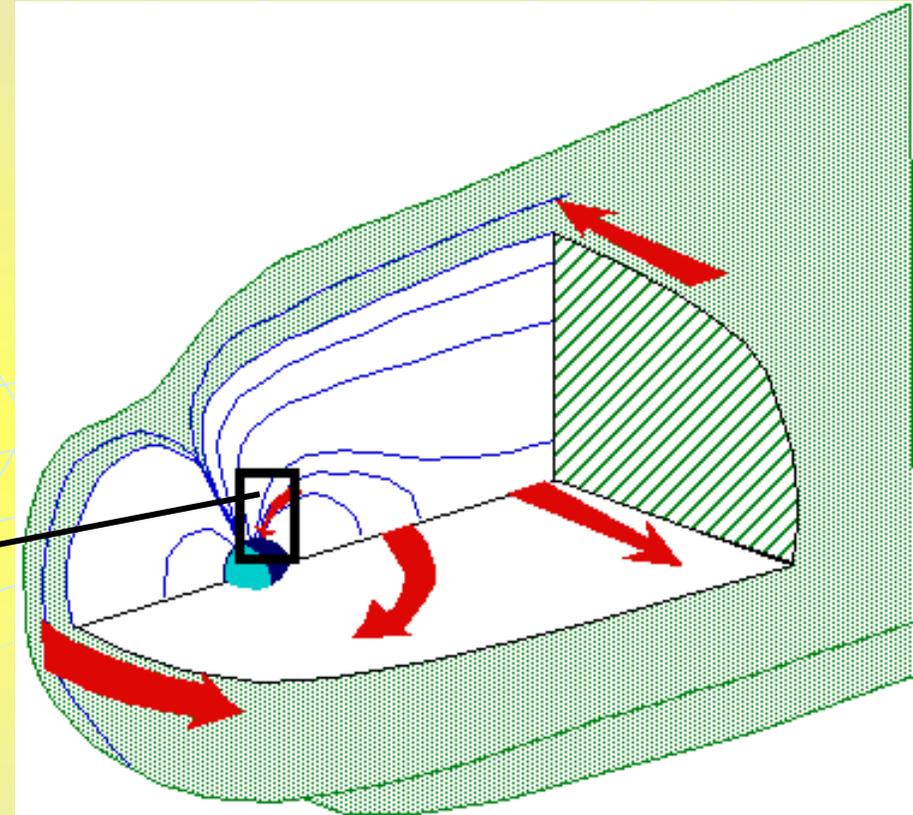
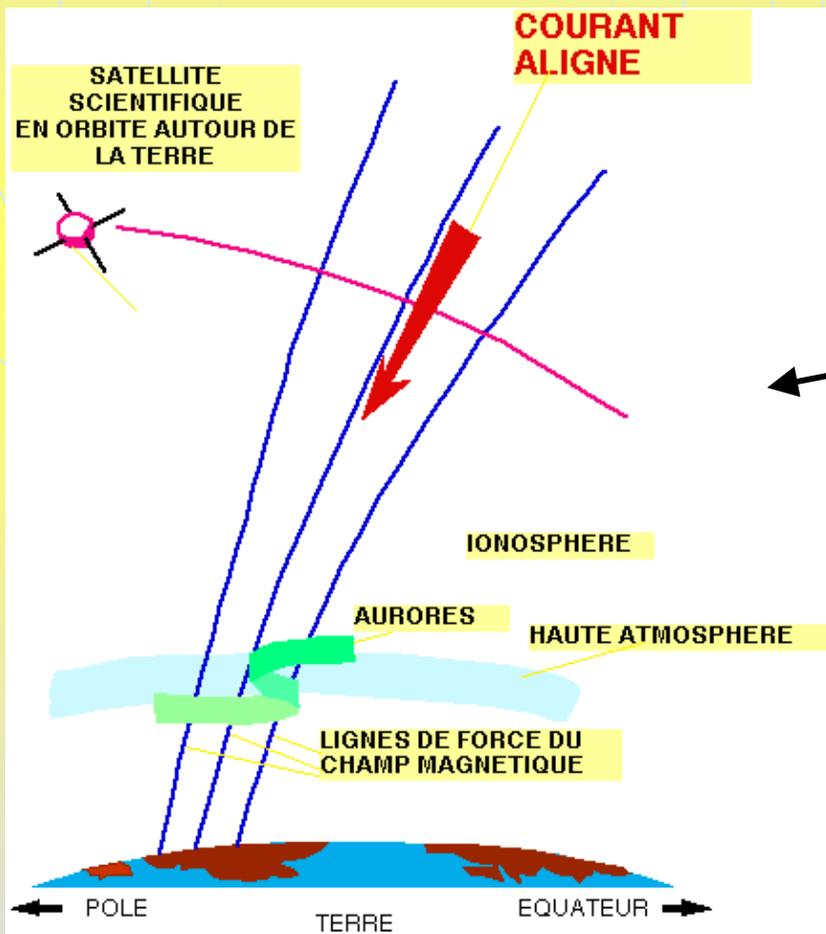
Add an electric field **E** perpendicular to the magnetic field **B**

- Charged particles drift at right angles to both fields
 - drift doesn't depend on particle charge or mass
 - +ve and negative particles drift in the same direction
 - speed of drift is E/B
- This drift causes a ring current around the Earth



Motion of electrons in the magnetosphere

- strong electric currents

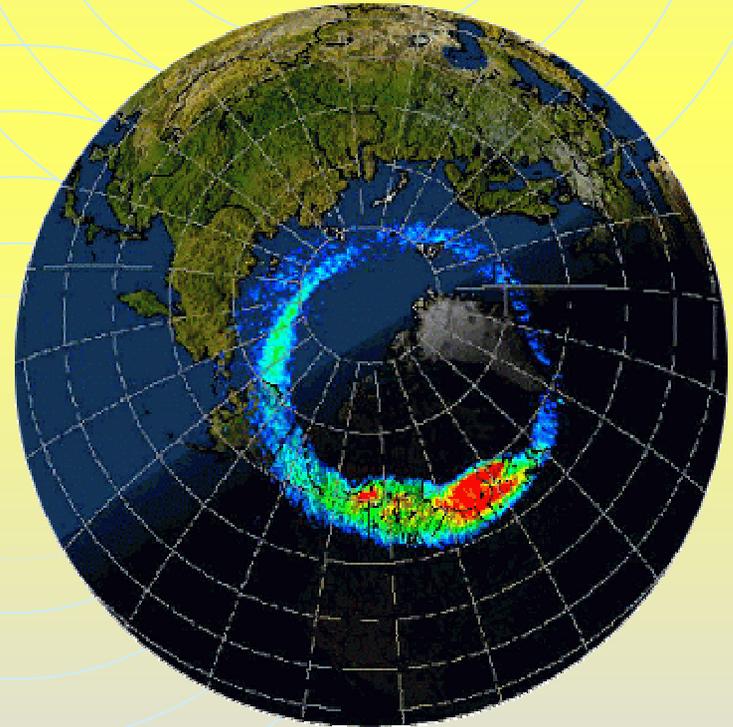
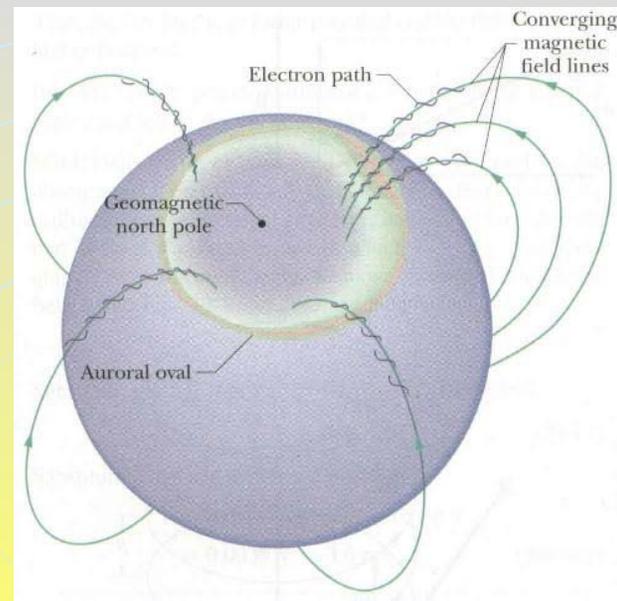


Nous remercions:

<http://www.cetp.ipsl.fr/~rezeau/BclDir/Francais/ObjScientifiques.html>

Permanent auroral oval around both poles

- Electrons spiral down field lines towards poles to height of 300 – 80 km
 - incident energy ~ 6 KV
 - aurora is emission from excited upper- atmosphere molecules



HST image

<http://tide.gsfc.nasa.gov/studies/GILES/bridgman/Auroral%20Oval/>

Auroral colours

- Emission lines from N_2 and O
- Lowest emission < 100 km
 - blue & red from N_2 and N_2^+
- Medium height $100 - 200$ km
 - Green (557.7 nm) from O
- High > 200 km
 - red (630 nm) from O
- Colour mixing of blue, green and red can produce a huge range of colours



http://lasp.colorado.edu/tour/science_research/atmospheric/images/aurora-lasp.gif

Example Auroras

- Notice how the colours correspond to the details on the previous slide



Courtesy Alistair Skene, Orkney 29th Oct. 2003



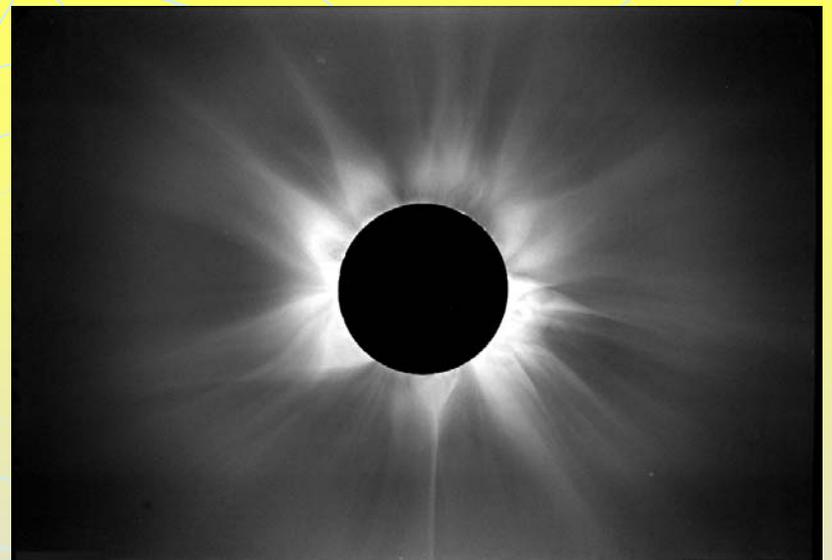
Courtesy: Phil Hart (ADAS)

November 2003: Phil Marston (Aberdeen)



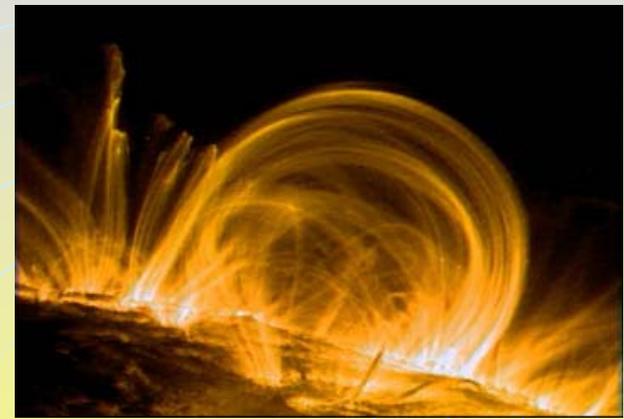
Solar wind and space weather is crucial to the origin of the aurora

- Solar wind originates outside the visible Sun
 - it represents a streaming away of coronal material



The Sun's corona seen during the total eclipses of 1991 and 1980 courtesy *High Altitude Observatory/ National Center for Atmospheric Research* & http://umbra.nascom.nasa.gov/ssu/magnetic_carpet.html

Magnetic fields and plasma



<http://www.gsfc.nasa.gov/gsfsc/spacesci/sunearth/tracecl.htm>

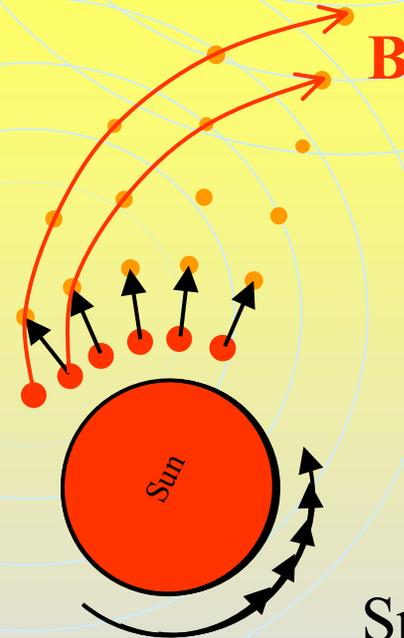
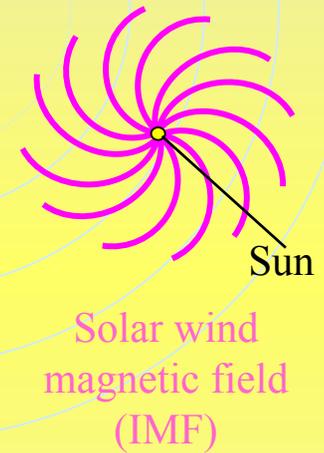
- Close to the Sun, the strong magnetic field controls the motion of the plasma
 - as the field lines loop round, so the plasma in the inner corona follows the field lines
- Far from the main body of the Sun, the magnetic field is comparatively weak and is controlled by the plasma
 - this is the case in the solar wind

'Frozen' or 'trapped' magnetic field

- In a plasma like the solar wind there is virtually no electrical resistance to the motion of charge
- Maxwell's and related equations:
 - "E = IR" \Rightarrow E = 0 if R = 0
 - E = 0 \Rightarrow $\frac{\partial \Phi}{\partial t} = 0$ and hence **B** remains constant
 - the magnetic field in such a plasma is trapped and carried along unchanged by the plasma in motion
- Hence magnetic field generated on the Sun reaches the Earth

The Sun's spiral magnetic field

- As the hot solar wind is ejected, it drags out its accompanying magnetic field
- The resulting field lines spiral out from the Sun
 - try building up diagram

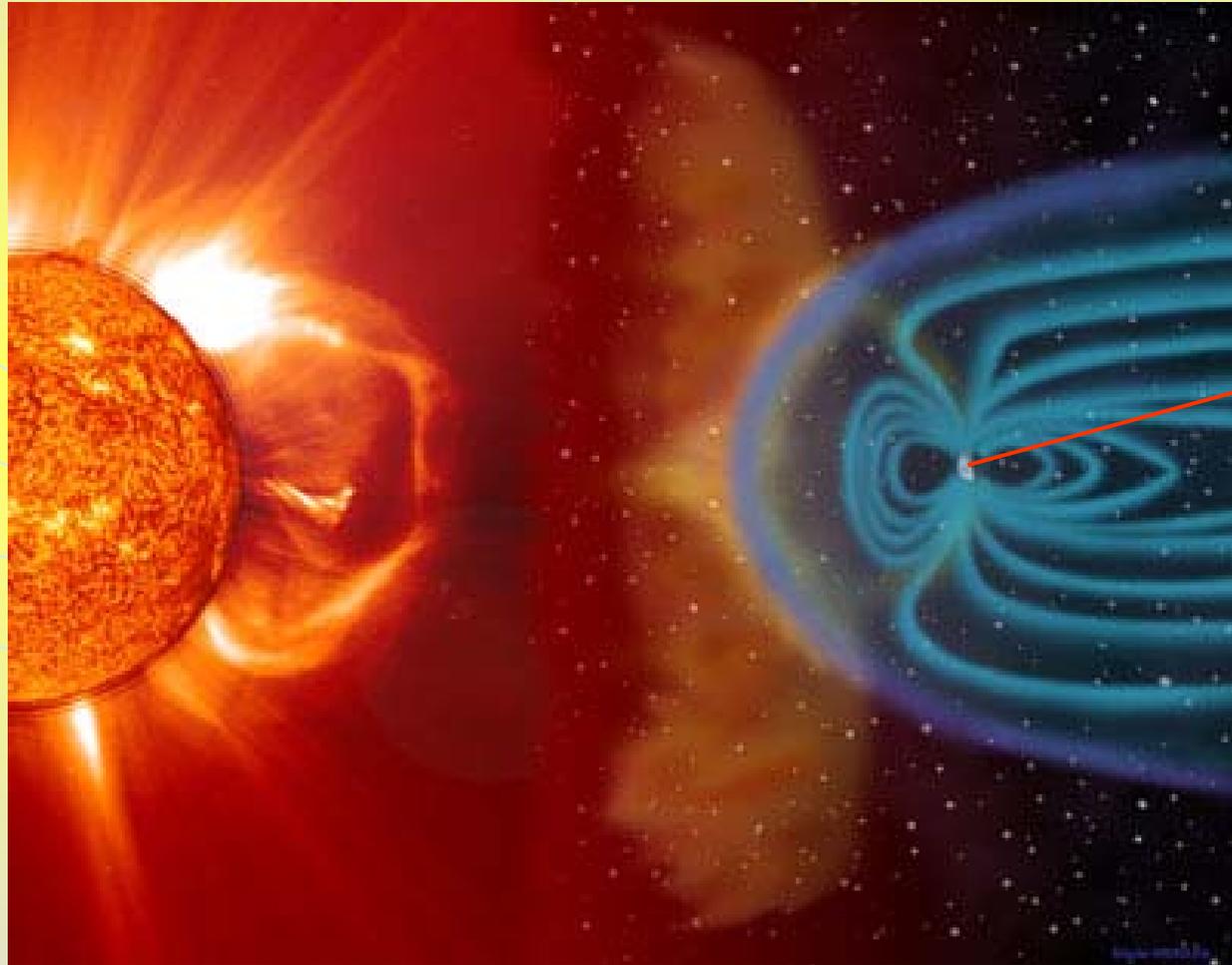


Spiral field lines



When fields collide

- The Earth's field acts like an umbrella



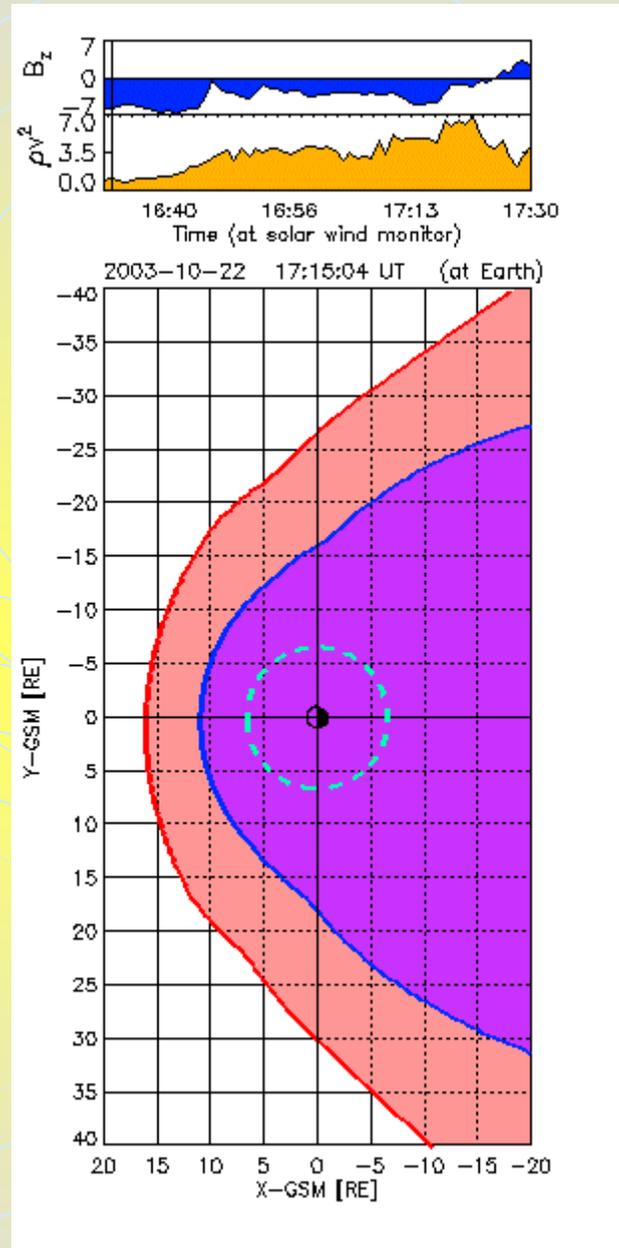
Earth

Courtesy: SOHO/LASCO/EIT (ESA & NASA)

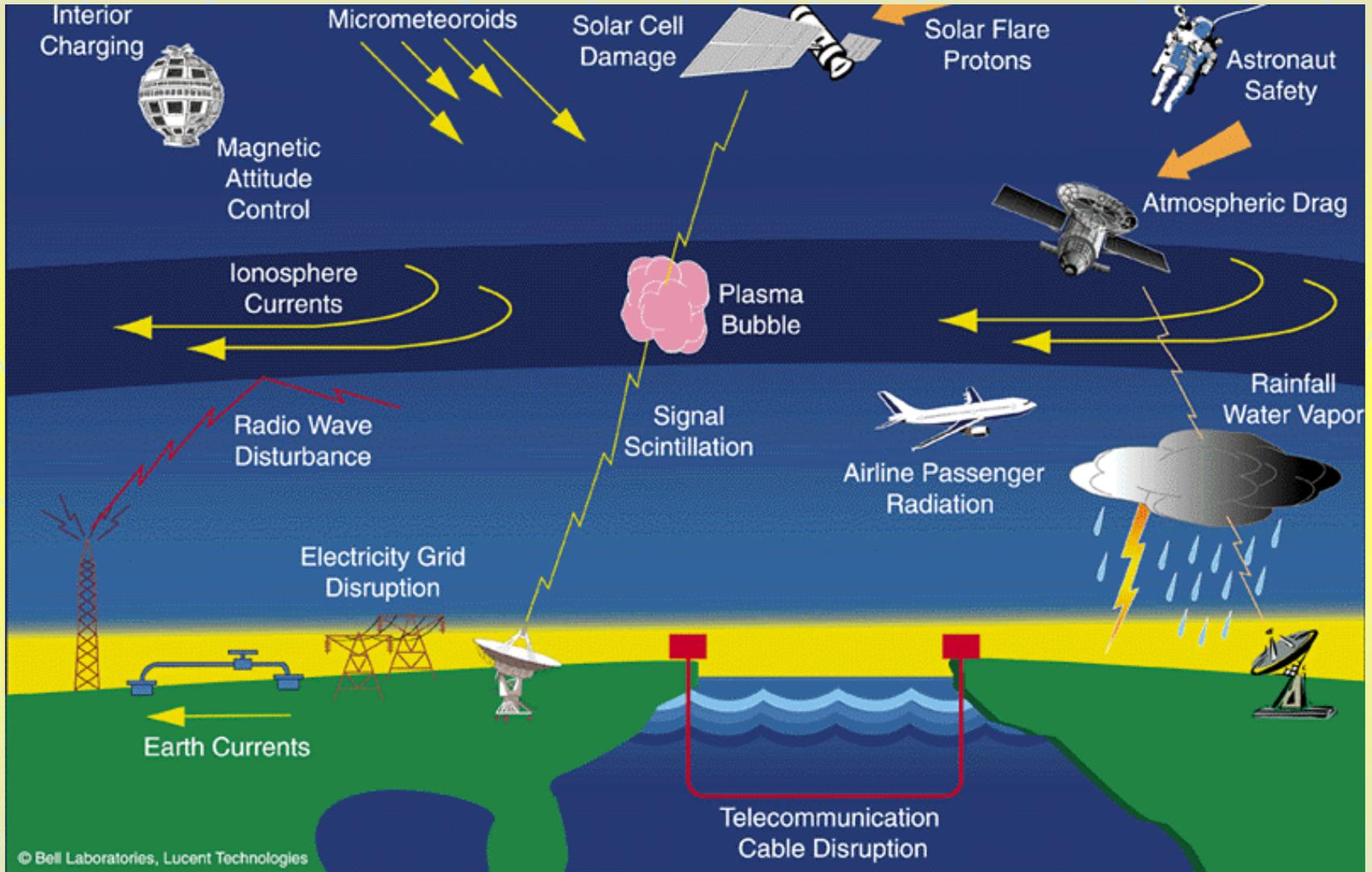
The fluctuating magnetosphere

- The web-page quoted here evaluates the magnetopause from ACE data on a minute by minute basis
 - the gif shows one hour of data
 - note how variable it is

Animated gif



Magnetic storm effects



The effects of magnetic storms - what scientists call space weather - extend from the ground to geostationary orbit and beyond. <http://pwg.gsfc.nasa.gov/istp/outreach/theretohere.html>