Space Physics

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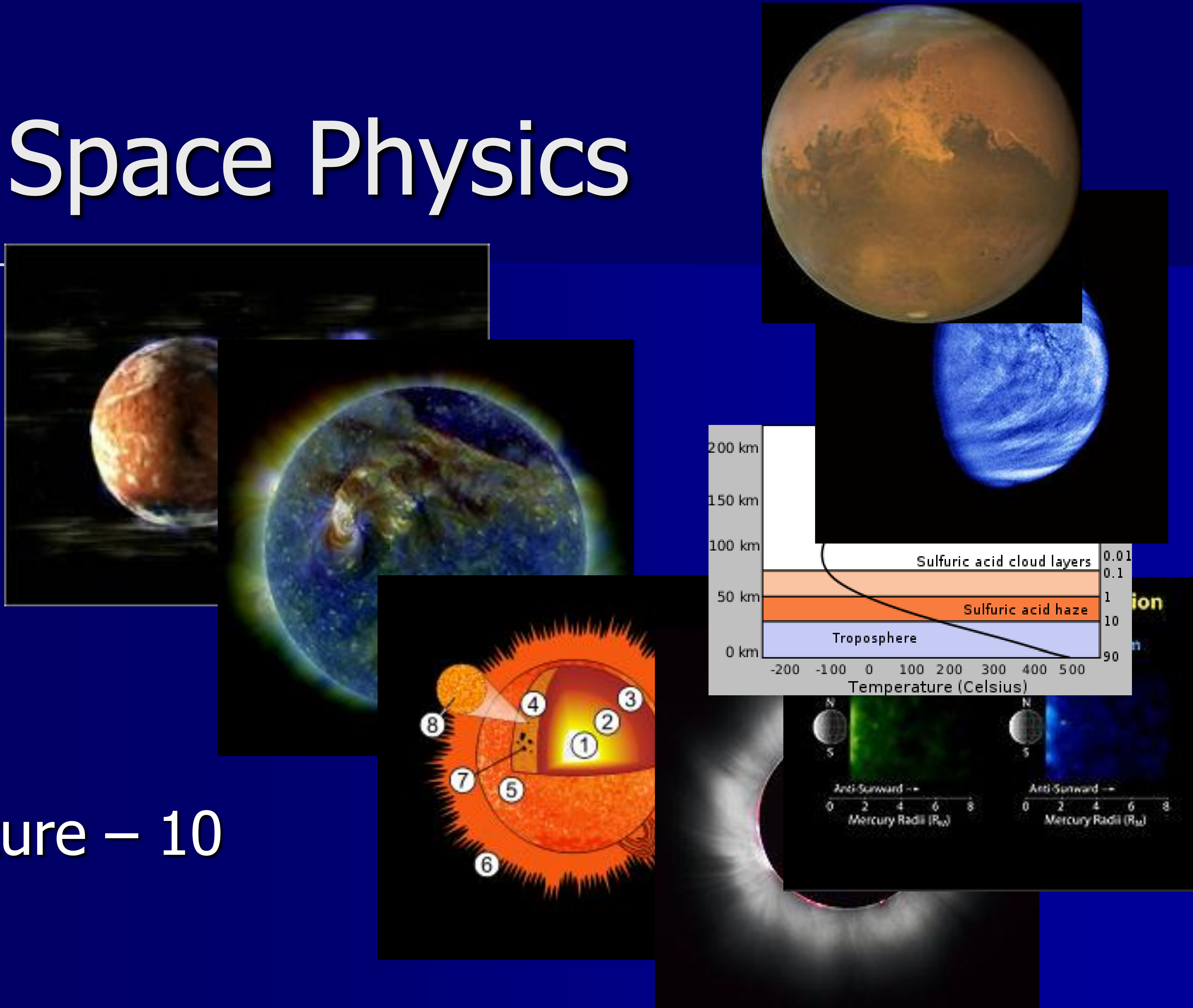
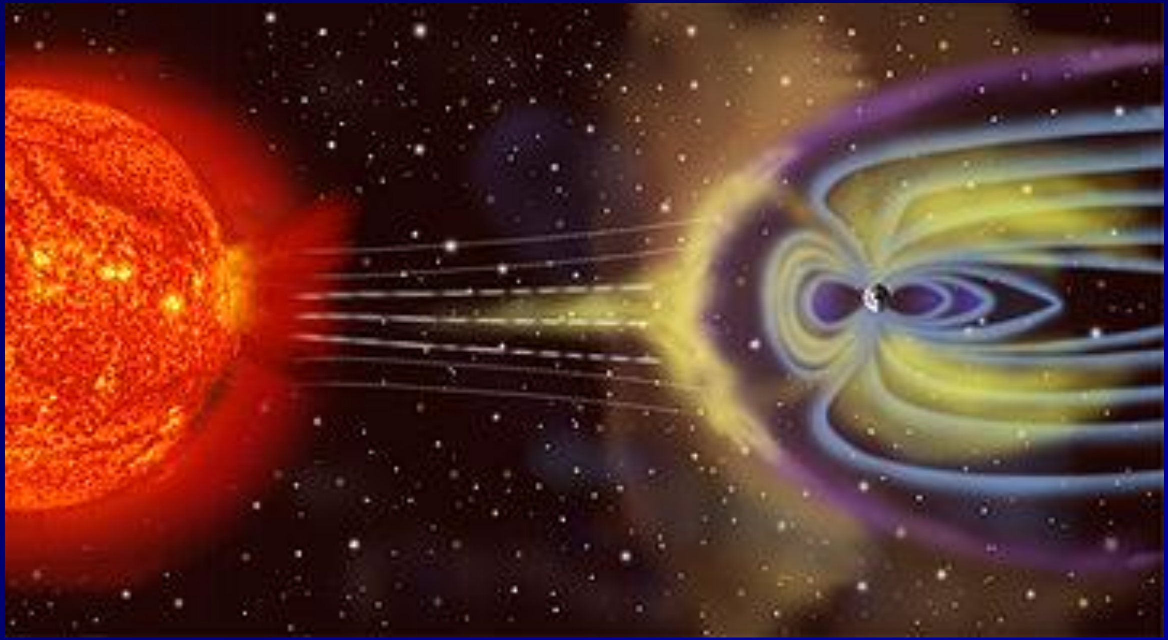


Lecture – 10

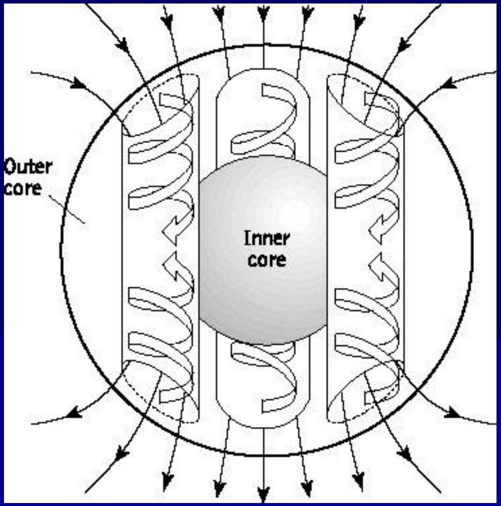
The Magnetosphere



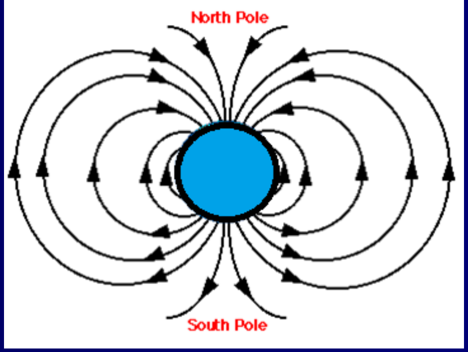
The Earth's Magnetic Fields
The Dipole Magnetic Field
Motion of charged particles in a Dipole Magnetic Field
The Radiation Belts
The boundary and the tail of the Magnetosphere

The Earth's Magnetic Field

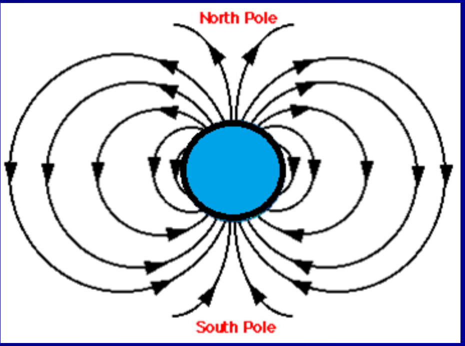
Present theories believe that the Earth's magnetic field arises (appears) from electric currents flowing in the molten metallic core of the planet, which has a radius approximately one-half the radius of the Earth



The currents are attributed to a dynamo mechanism operating inside the core. Recent discoveries suggest that the strength and orientation of the terrestrial magnetic field have changed considerably over geological periods. There is also strong evidence that the Earth's magnetic field has reversed its direction several time during the life time of our planet.



Million of years

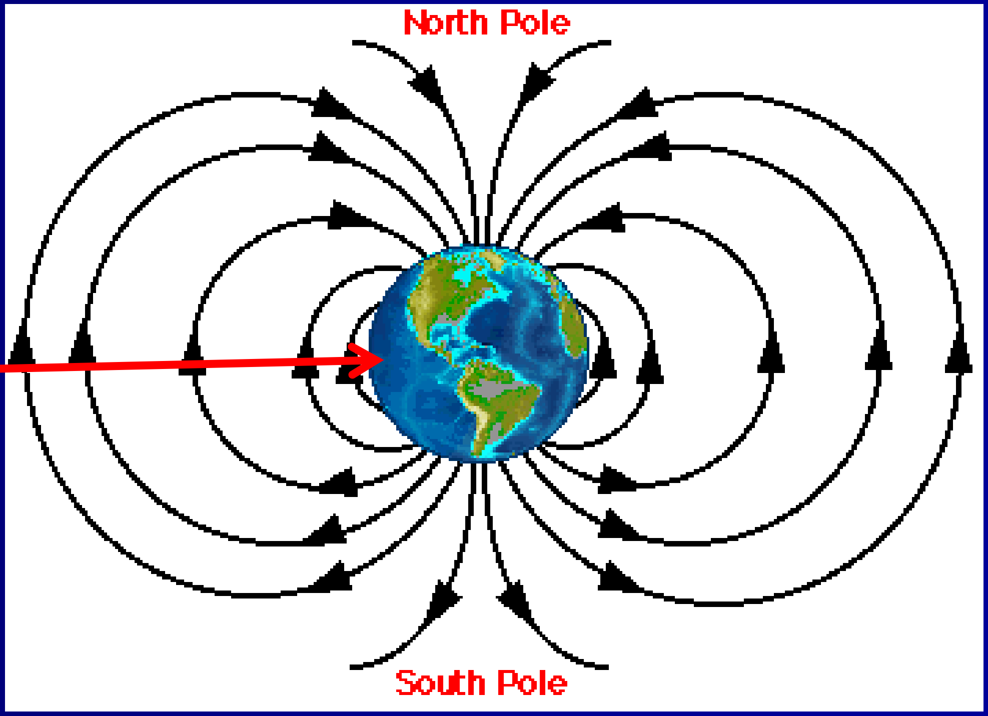


The Earth's Magnetic Field

The magnetic field of the Earth can be represented to a good approximation, by a **dipole-field** with a magnetic moment $M = 8.05 \pm 0.02 \times 10^{25}$ Gauss cm^3. The intensity of the field at the equator is ~0.3 Gauss and at poles ~0.6 Gauss.

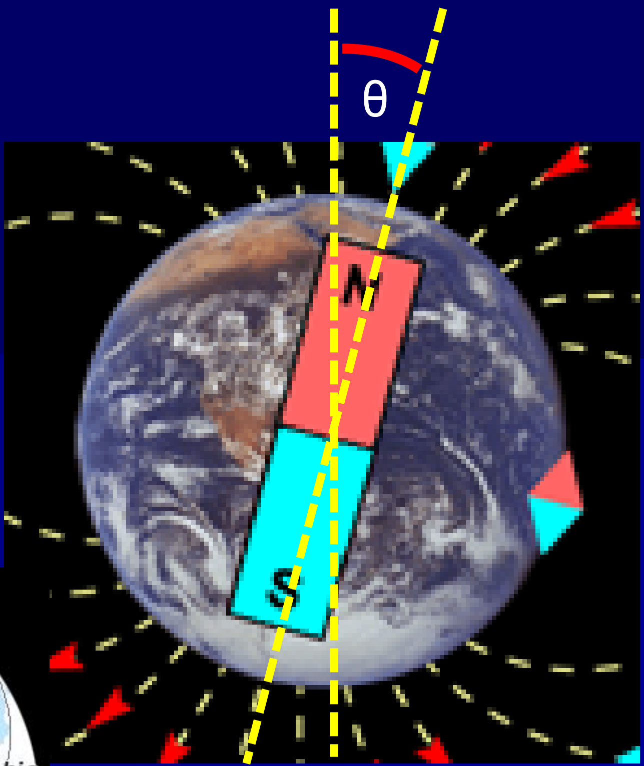
$$1 \text{ Gauss (G)} = \sim 1 \times 10^{-4} \text{ Tesla (T)}$$

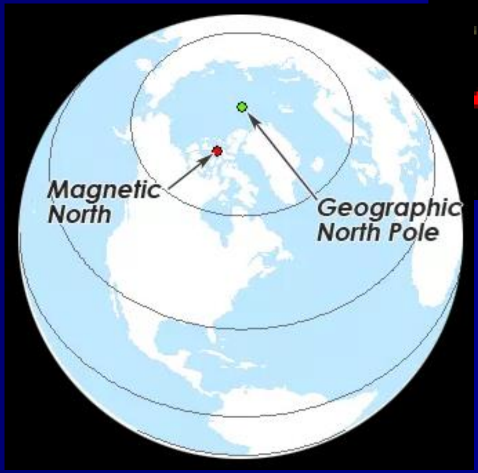
The Earth magnetic field intensity at the equator ~40,000 nT.



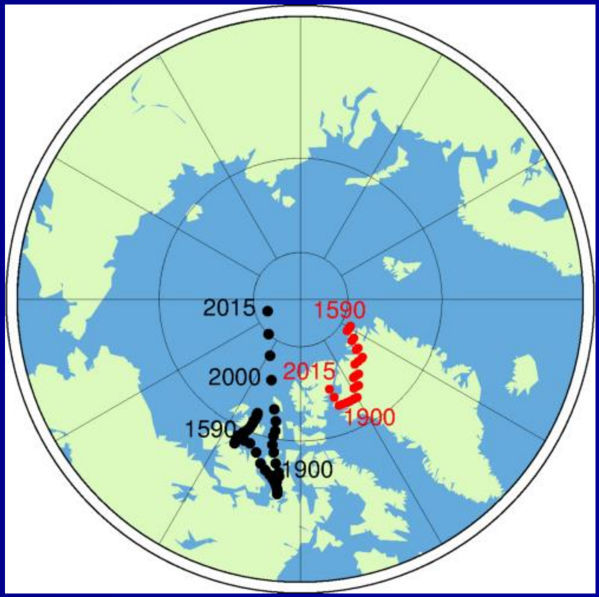
The Earth’s Magnetic Field

The centered dipole (its axis passes through the center of the Earth) which fits best the Earth's magnetic field has its axis directed along the line (79°N, 290°E) to (79°S, 110°E). These are referred to respectively as the **north geomagnetic pole** and the **south geomagnetic pole**.



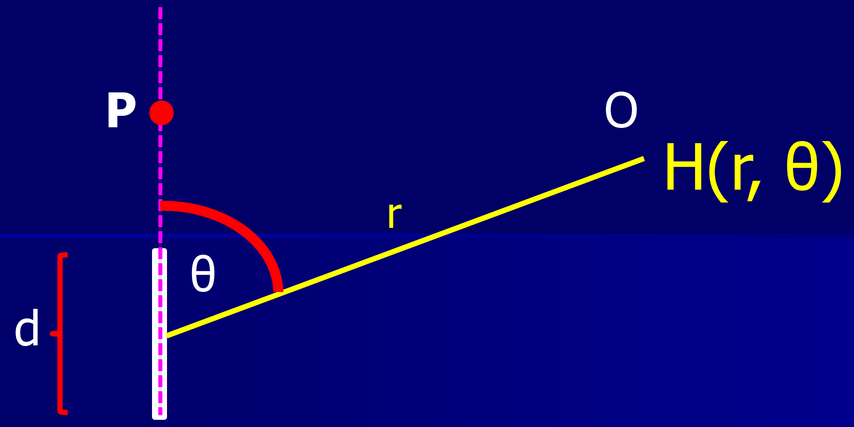


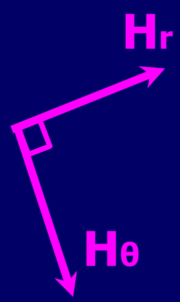
The **actual magnetic poles** are asymmetrically (unsymmetrically) located at (73°N, 262°E) to (68°S, 145°E).



The **Earth magnetic poles** are changing with time !

The Dipole Magnetic Field





$$H_r = \frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3} \cos\theta$$

$$H_\theta = \frac{\mu_o}{4\pi} \cdot \frac{M}{r^3} \sin\theta$$

The line connecting the two poles of the dipole defines the axis of the north and south magnetic poles. Therefore, the angle θ represents the **geomagnetic co-latitude**. At the poles, where **θ=0**, the magnetic field **H_P** is all in the **radial direction** and is given by the expression,

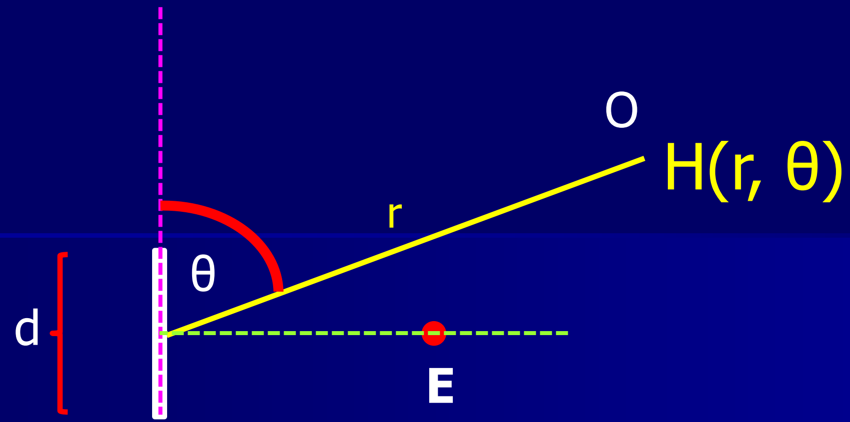
$$H_P = H_r \big|_{\theta=0}$$

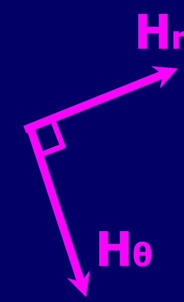
Because,

$$H_\theta \big|_{\theta=0} \to 0$$

$$\therefore \quad H_P = \frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3}$$

The Dipole Magnetic Field





$$H_r = \frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3} \cos\theta$$

$$H_\theta = \frac{\mu_o}{4\pi} \cdot \frac{M}{r^3} \sin\theta$$

While at the equator, where **θ=90°,** the magnetic field **H_E** is entirely in the **tangential direction** and is given by the expression,

$$H_E = H_\theta \Big|_{\theta=90^o}$$ Because, $$H_r \Big|_{\theta=90^o} \rightarrow 0$$

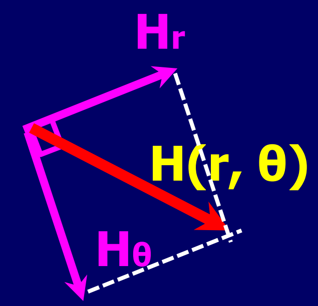
$$\therefore \quad H_E = \frac{\mu_o}{4\pi} \cdot \frac{M}{r^3}$$

Thus the magnetic field at the poles has twice the intensity of the magnetic field at the equator !

i.e.; **$H_P = 2\, H_E$**

The Dipole Magnetic Field

Total Magnetic Field



$$H_r = \frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3} \cos\theta$$

$$H_\theta = \frac{\mu_o}{4\pi} \cdot \frac{M}{r^3} \sin\theta$$

Now we can compute the intensity of the total magnetic field at any **geomagnetic co-latitude, θ** from radial and the tangential components we have already obtained,

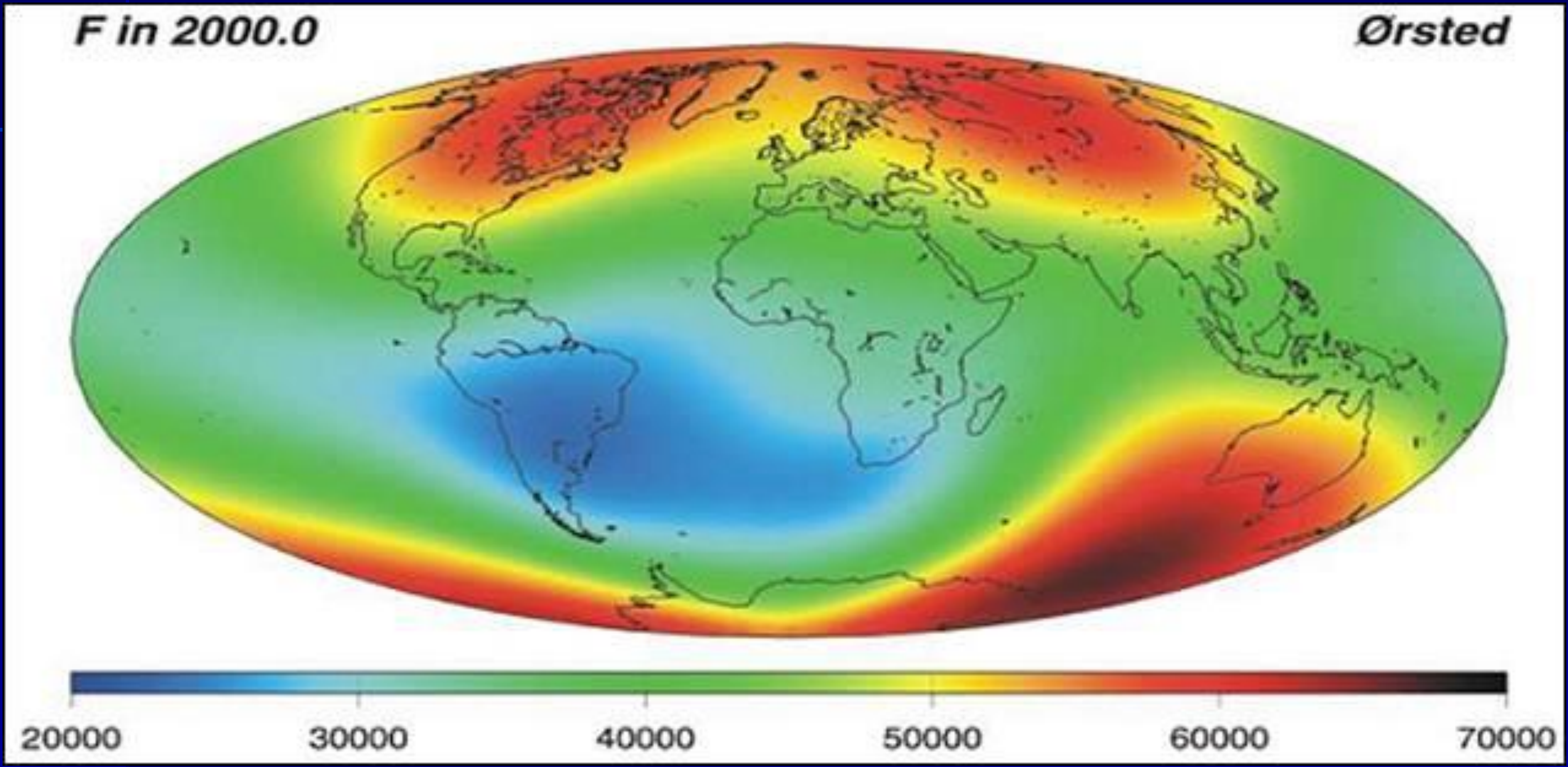
$$H = \left[H_r^2 + H_\theta^2\right]^{1/2}$$

$$H = \left[\left(\frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3} \cos\theta\right)^2 + \left(\frac{\mu_o}{4\pi} \cdot \frac{M}{r^3} \sin\theta\right)^2\right]^{1/2}$$

. . . .

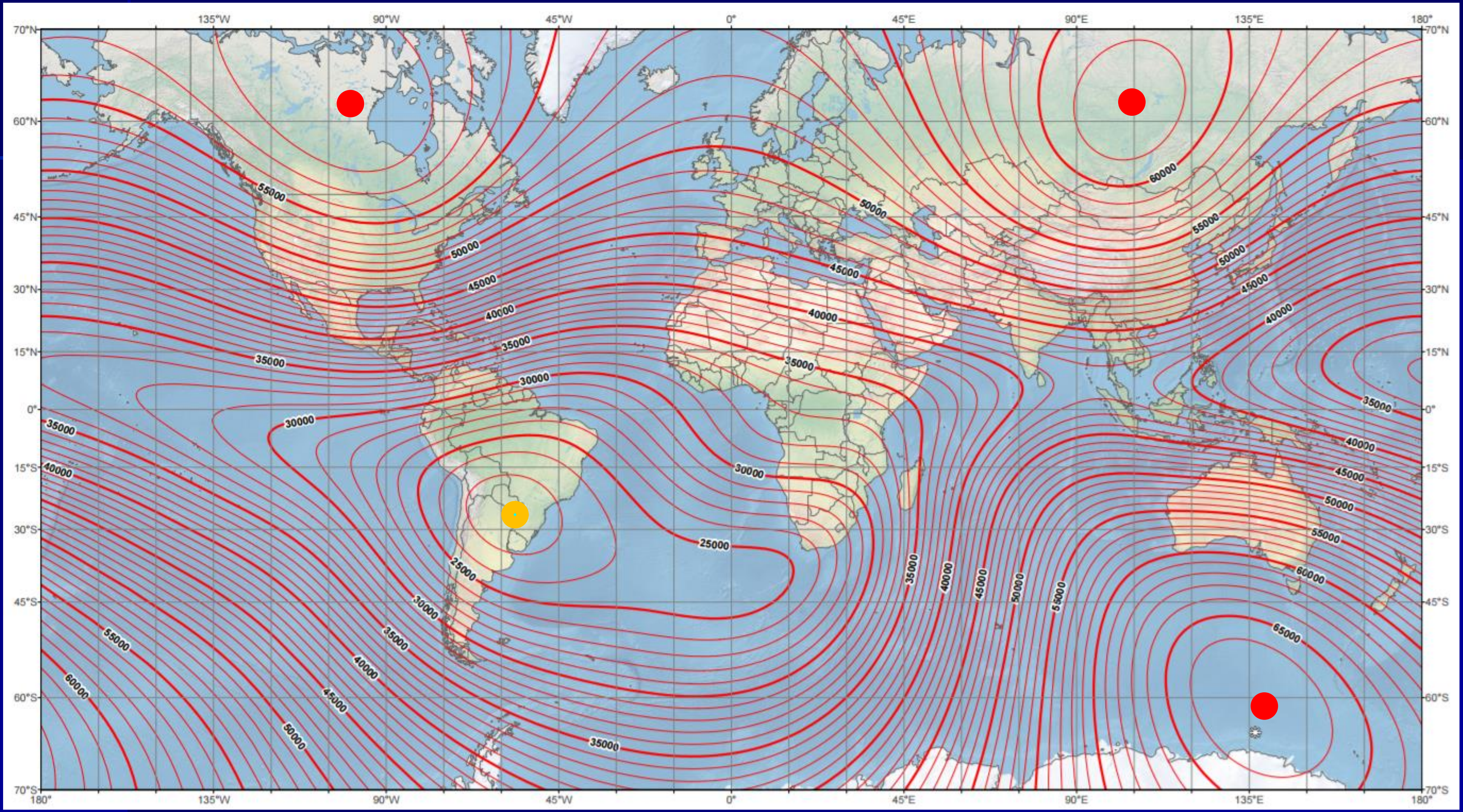
$$H(r,\theta) = \frac{\mu_o}{4\pi} \frac{M}{r^3} \left[1 + 3\cos^2\theta\right]^{1/2}$$

The Earth Magnetic Field



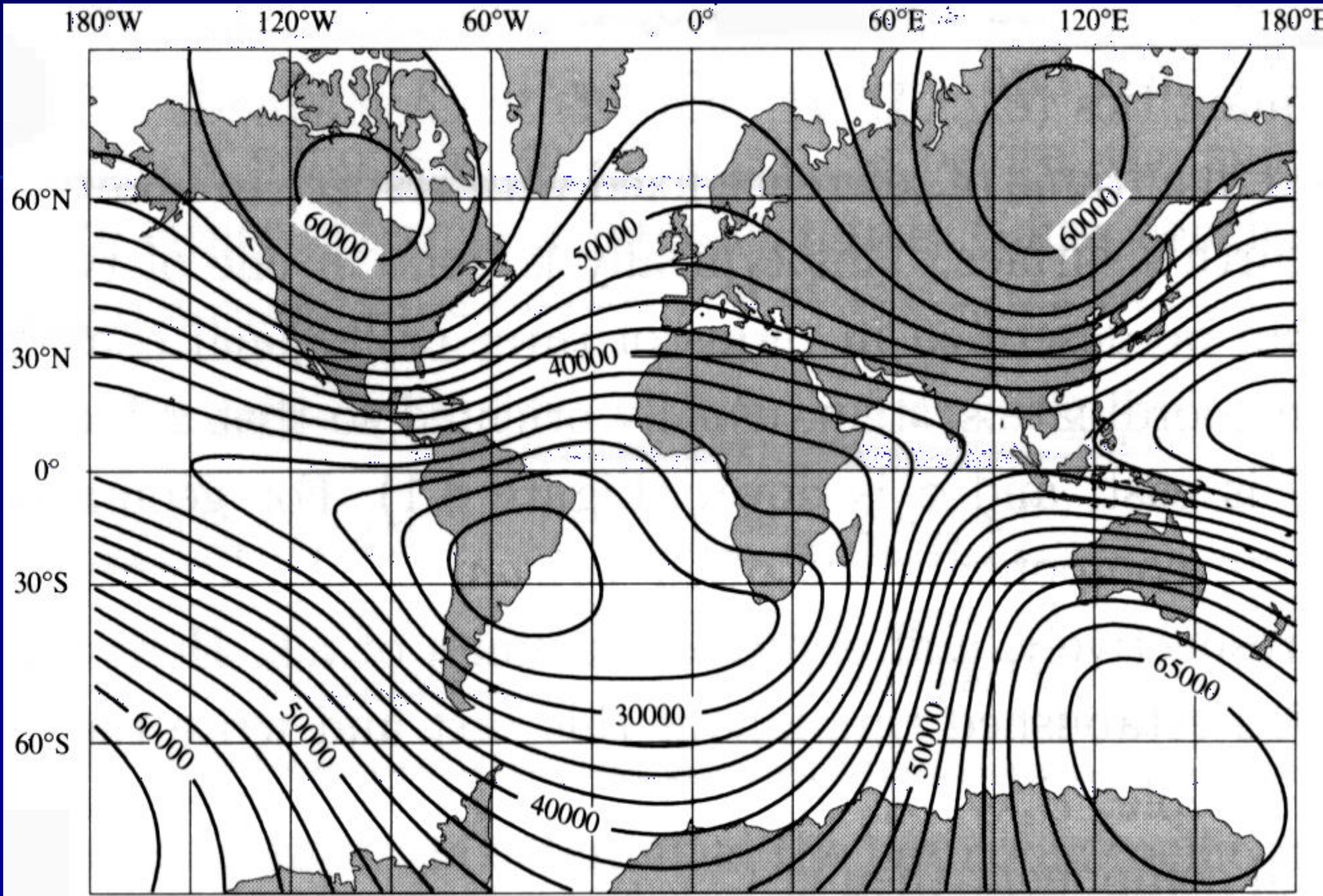
The Earth's magnetic field ranges between approximately ~25,000 nT and ~65,000 nT (0.25–0.65 G).

The Earth Magnetic Field



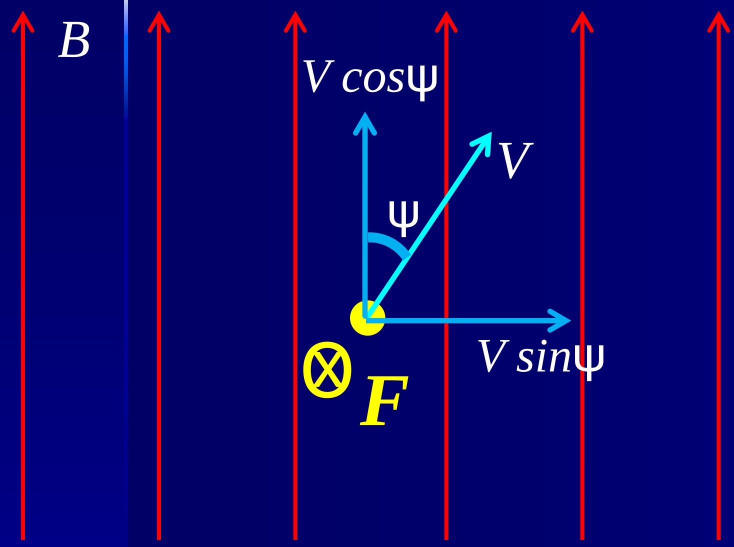
Min -
Max

Earth magnetic Field



Motion of Charged Particle in a Dipole Magnetic field

A charged particle moving with velocity *V* at an angle *ψ*, called **patch angle**, to a magnetic field will experience the **Lorentz Force** *F*.



Magnetic Force, F

$$F = q\, V \times B$$

$$F = q\, V \times \frac{H}{c}$$

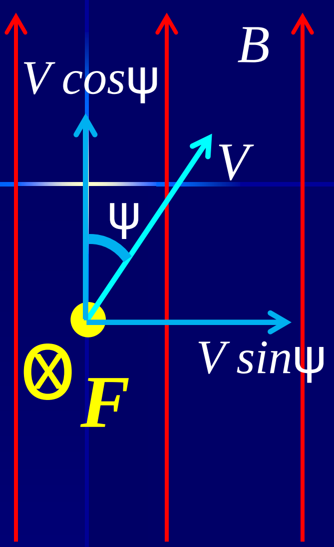
$$F = e\,(V \sin\psi)\frac{H}{c} \quad \otimes$$

Using Fleming's Left hand Law

$$F = \frac{e}{c} VH \sin\psi$$

Which will set the particle in a **helical** (spiral) **motion** around a line of force of the magnetic field.

Motion of Charged Particle in a Dipole Magnetic field



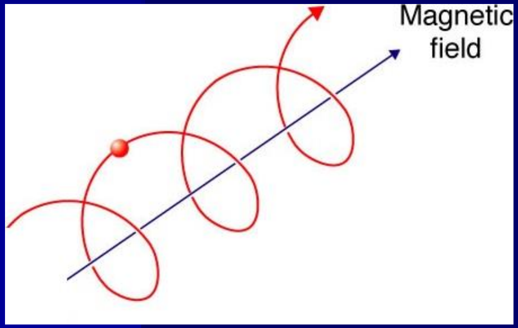
The Lorentz Force is balanced by the centrifugal force produced by the component $V_n = V \sin\psi$ of the particle's velocity which is normal to the magnetic field, i.e.;

$$\frac{e}{c} VH \sin\psi = \frac{mv_n^2}{r}$$

$$\Rightarrow \frac{e}{c} VH \sin\psi = \frac{m(V\sin\psi)^2}{R_H}$$

Gyro-radius

Where R_H is the **radius of gyration** around the field line which is called the **Gyro-Radius** of the **Cyclotron Path**.



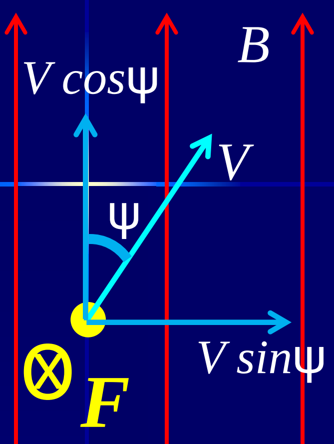
. . . .

$$\Rightarrow R_H = \frac{mcV\sin\psi}{eH}$$

or

$$R_H = \frac{m\,c\,v_n}{eH}$$

Motion of Charged Particle in a Dipole Magnetic field



$$R_H = \frac{mcV \sin\psi}{eH} \quad \text{or} \quad R_H = \frac{m\ c\ v_n}{eH}$$

The above equation defined also the angular cyclotron frequency, ω_H which is given by the relation,

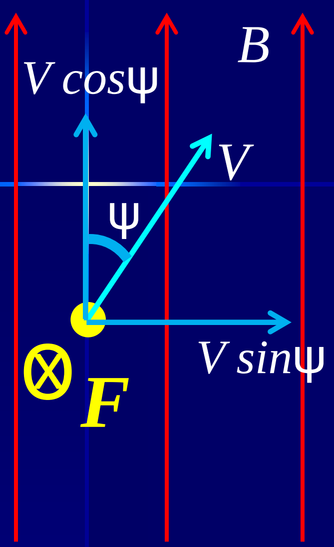
$$\omega_H = \frac{v_n}{R_H} \quad \text{because,} \quad V = r\ \omega$$

$$\Rightarrow \omega_H = \frac{e\ H}{m\ c} \quad \text{because,} \quad \frac{v_n}{R_H} = \frac{e\ H}{m\ c}$$

From which we obtain also the expression for the **Gyro- frequency** or **cyclotron frequency**, f_H,

$$f_H = \frac{\omega_H}{2\pi} \Rightarrow f_H = \frac{e\ H}{2\pi\ m\ c} \Rightarrow f_H = \frac{e}{2\pi\ m\ c} H$$

Motion of Charged Particle in a Dipole Magnetic field



Gyro-frequency → $f_H = \dfrac{e}{2\pi\ m\ c} H$ or $f_H \ \alpha\ H$

The value of $\dfrac{e}{2\pi\ m\ c} = \dfrac{1.6\times10^{-19}C}{2\pi\ 9.1\times10^{-31}kg\ 3\times10^{8}ms^{-1}}$

$= 93.28$

$\therefore\ f_H = 93.28\ H$ or $f_H = 93.28\ Bc$

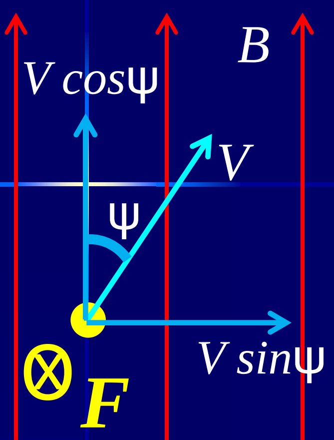
or $f_H = 2.8\times10^{10}B$

An example : When the strength of the Earth Magnetic Field is 60,000 nT at a certain point, then find the **electron gyro-frequency** at that point.

$f_H = 2.8\times10^{10}B$ → $f_H = \left(2.8\times10^{10}\right)\times(60000\ \times10^{-9})$ → $f_H = 1.68\times10^{6}Hz$

or $f_H = 1.68MHz$

Motion of Charged Particle in a Dipole Magnetic field



$$f_{H\,ion} = \frac{m}{M} f_{H\,e^n}$$

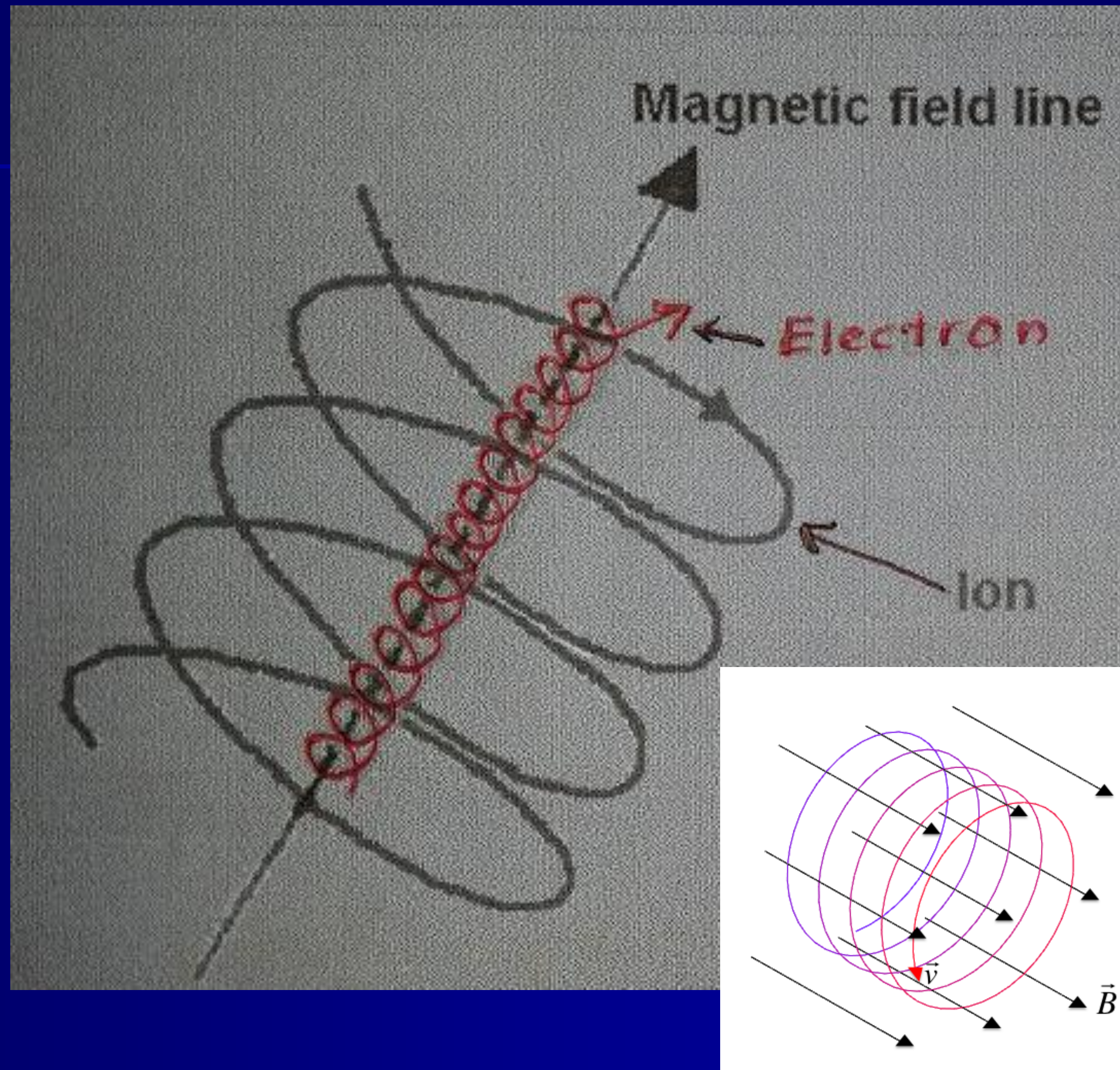
For e^ns

$$f_H = 1.68 MHz$$

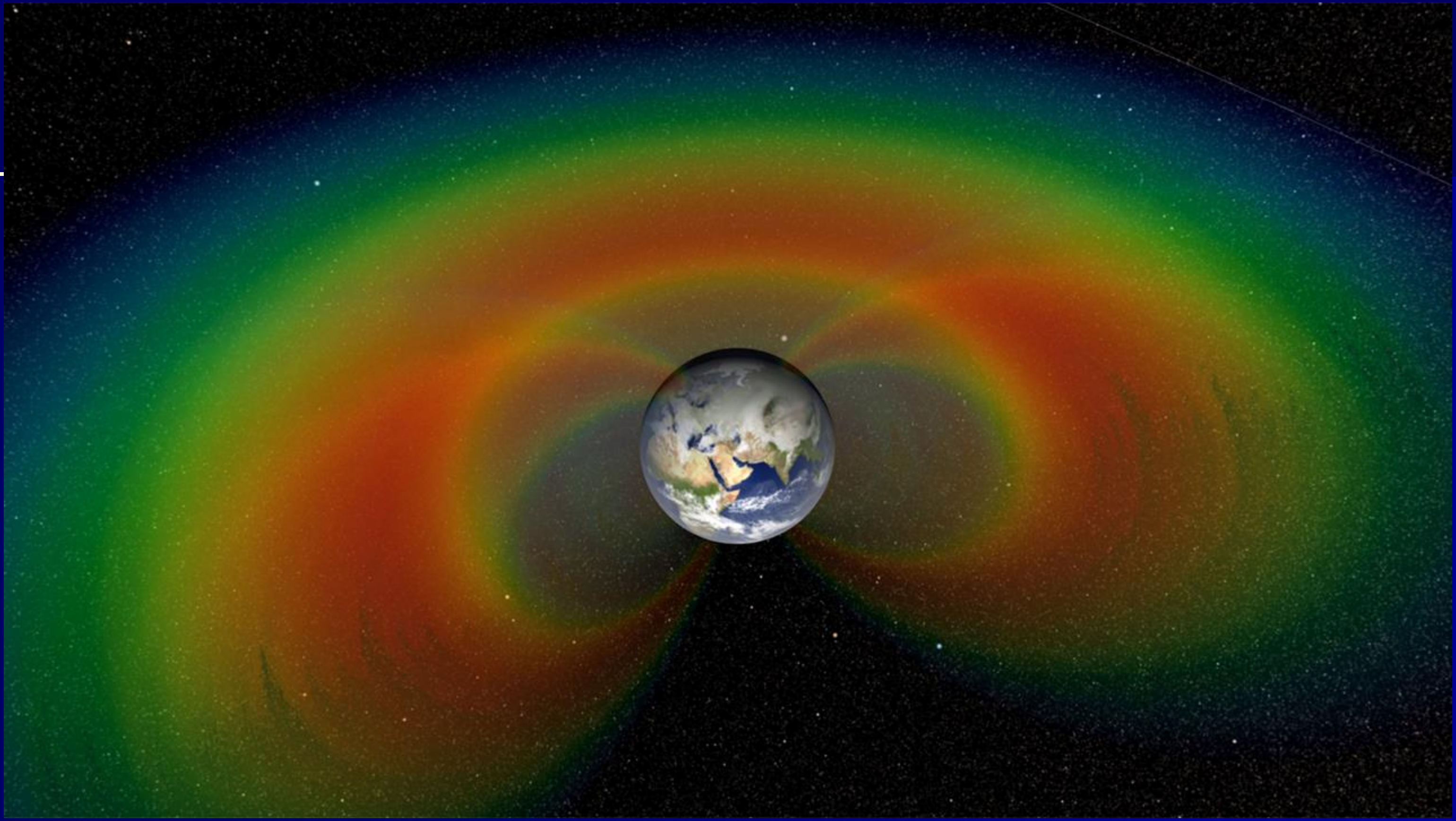
For O+ ions

$$f_H = 48 Hz$$

Because, $M >> m$



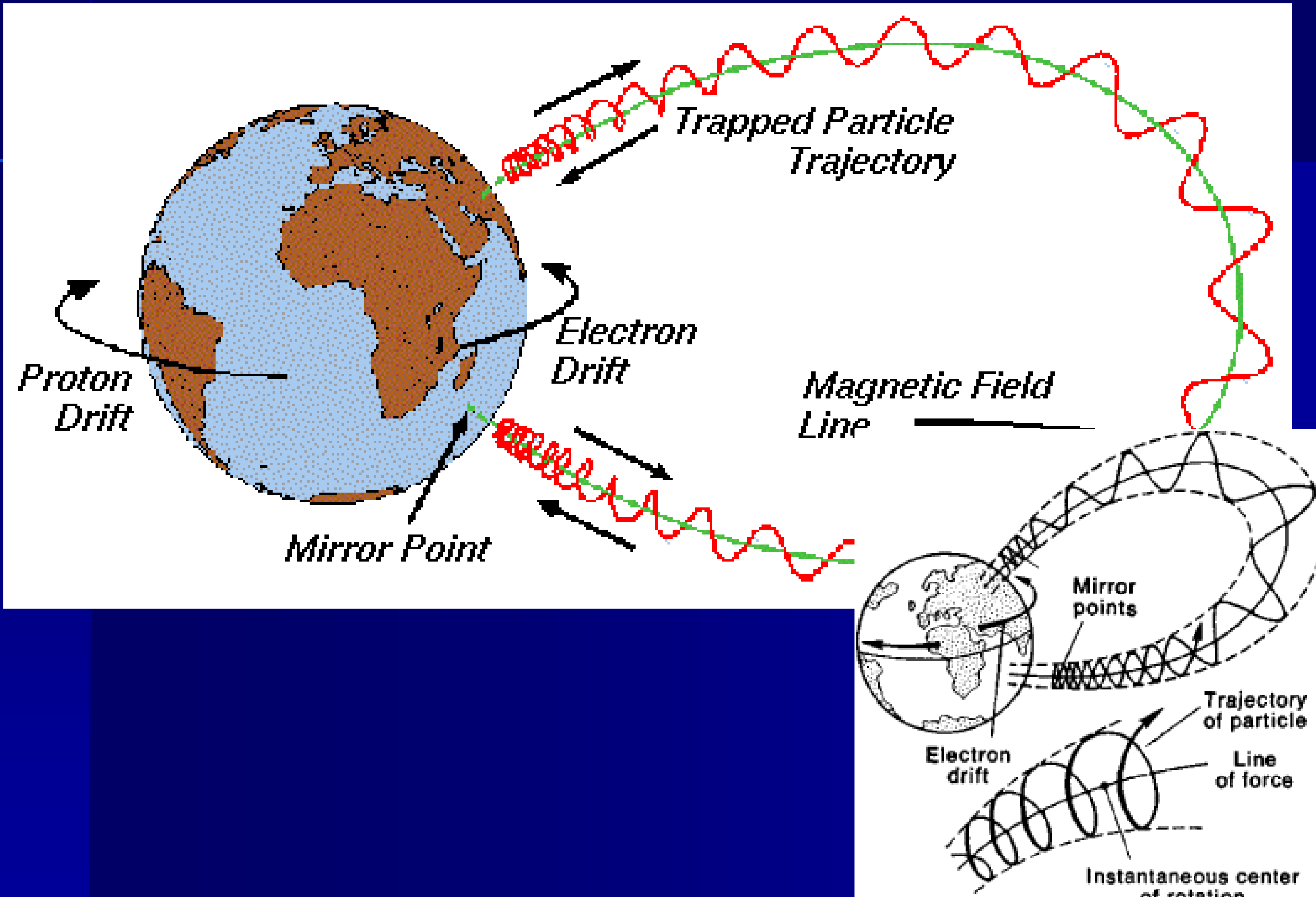
The Radiation Belts



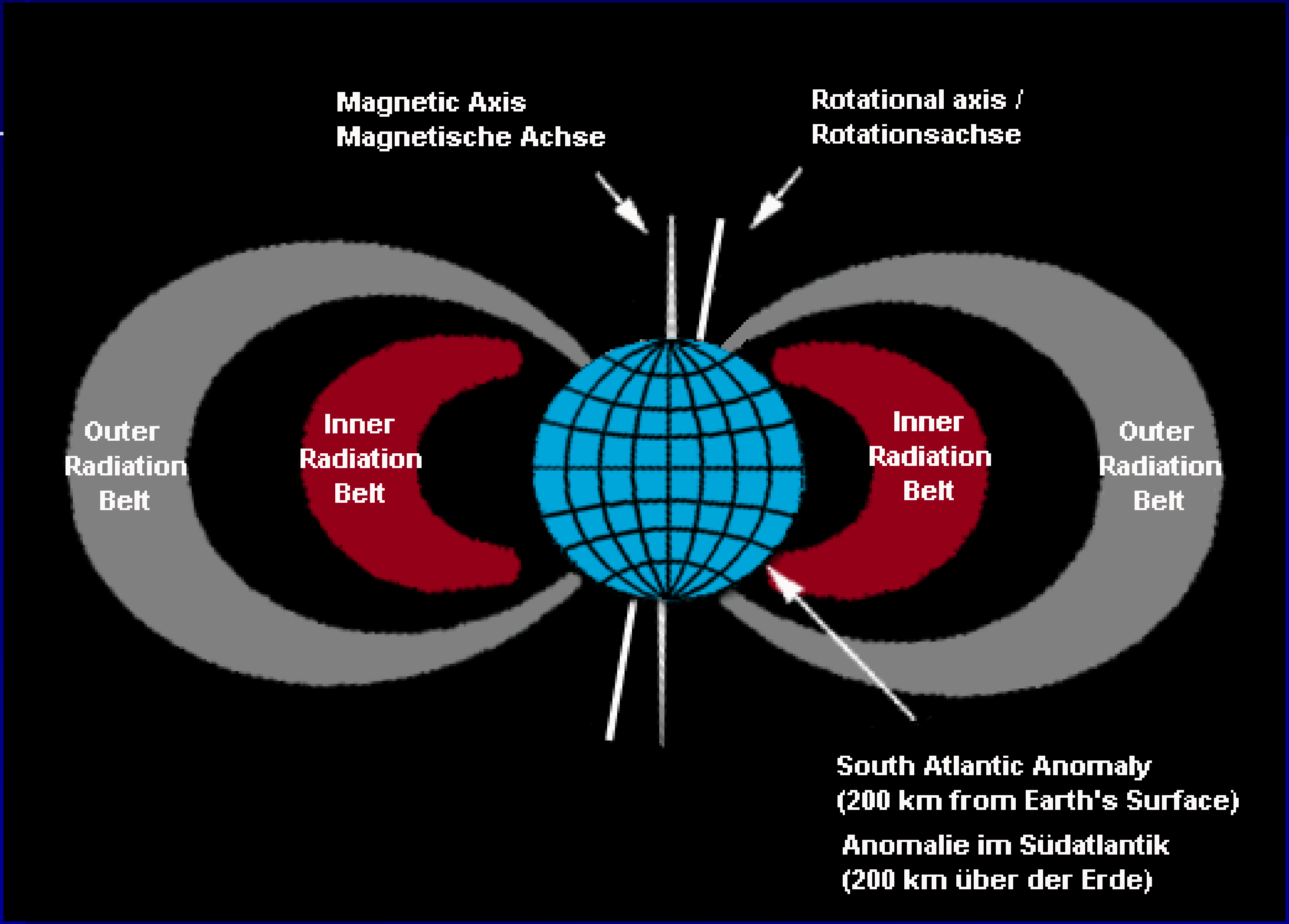
The belts or zones of trapped radiation were the first major discovery of the space age. The first American satellite, **Explore-I**, was launched on **January 31,1958**, carrying among other instruments a **Geiger counter** provided by **Van Allen's group** of the university of Iowa.

The Magnetosphere

The Radiation Belts



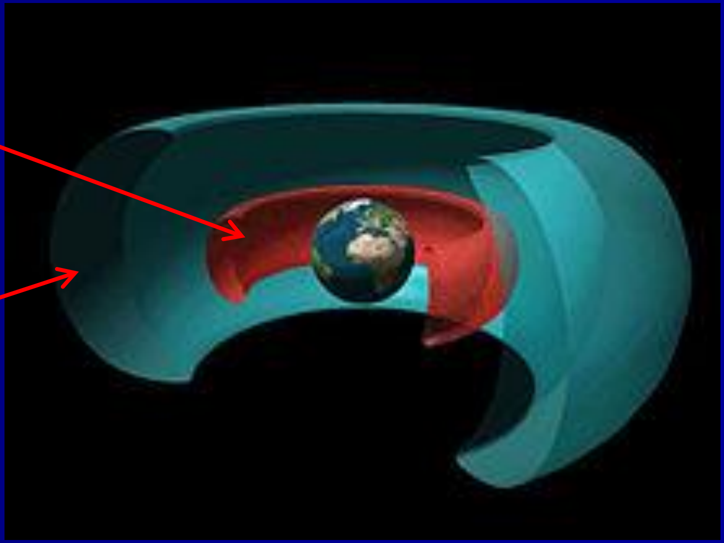
The Radiation Belt



The Radiation Belts

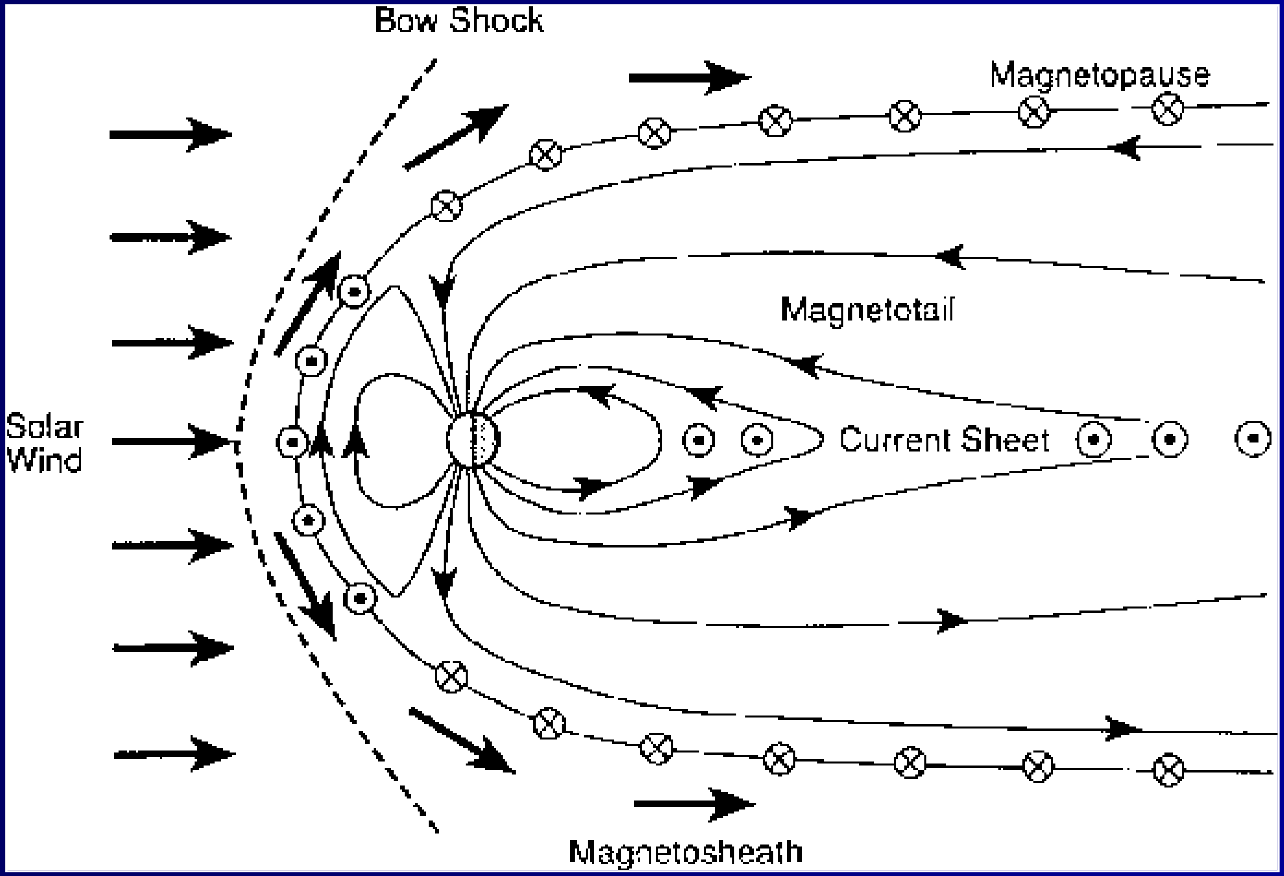
Two radiation belts which were named the inner and outer Von Allen belts.

- The first counters could not differentiate between energetic protons and energetic electrons.
- Today we know that the high counting rates of the **inner belt are produced by energetic protons** with energies in the 10 to 100 MeV range, while the high counting rates of the **outer belt are produced by high energetic electrons** with energies in the 1 MeV range and above.



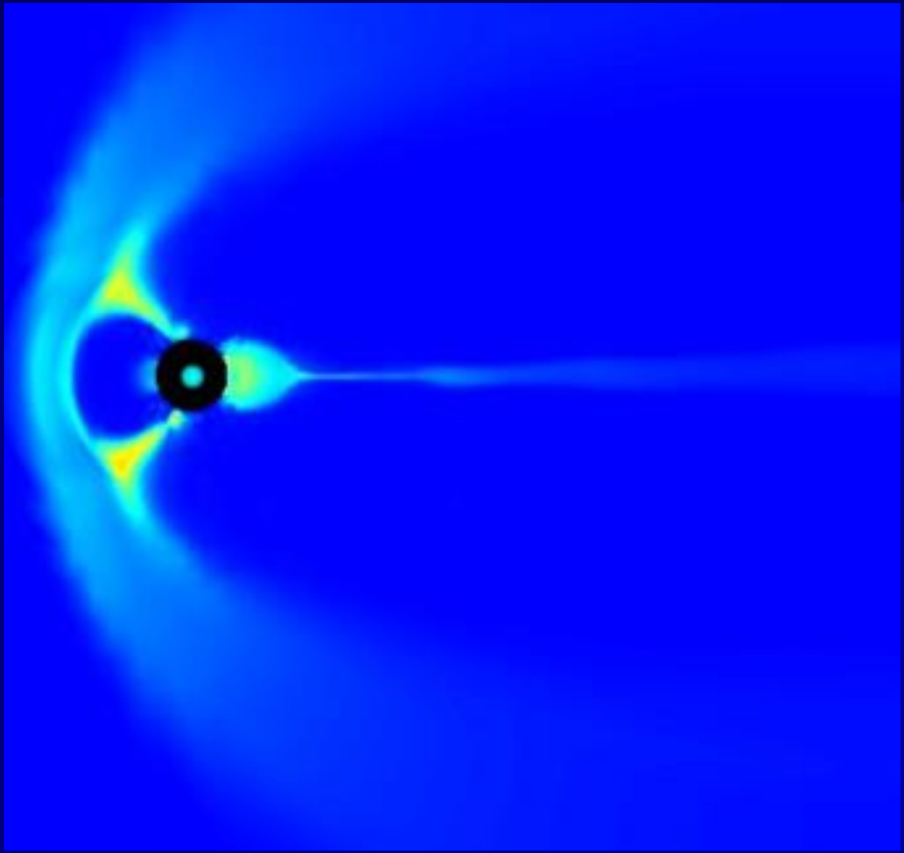
The Boundary and the Tail of the Magnetosphere

The magnetosphere is **the region where the motion of the charged particles is primarily governed by the Earth's magnetic field**. Originally it was thought that the terrestrial magnetic field extends way out into the interplanetary space, becoming weaker with distance and gradually merging into the emptiness of free space.



The Boundary and the Tail of the Magnetosphere

The magnetic field of the Earth under the sweeping action of the solar wind forms a **magnetic tail** in the anti-solar direction. Thus behind the Earth the magnetopause becomes a **cylindrical surface**. The radius of the magnetic tail **R_t** is approximately **22 R_o** and remains the same for at least **100 R_o**.



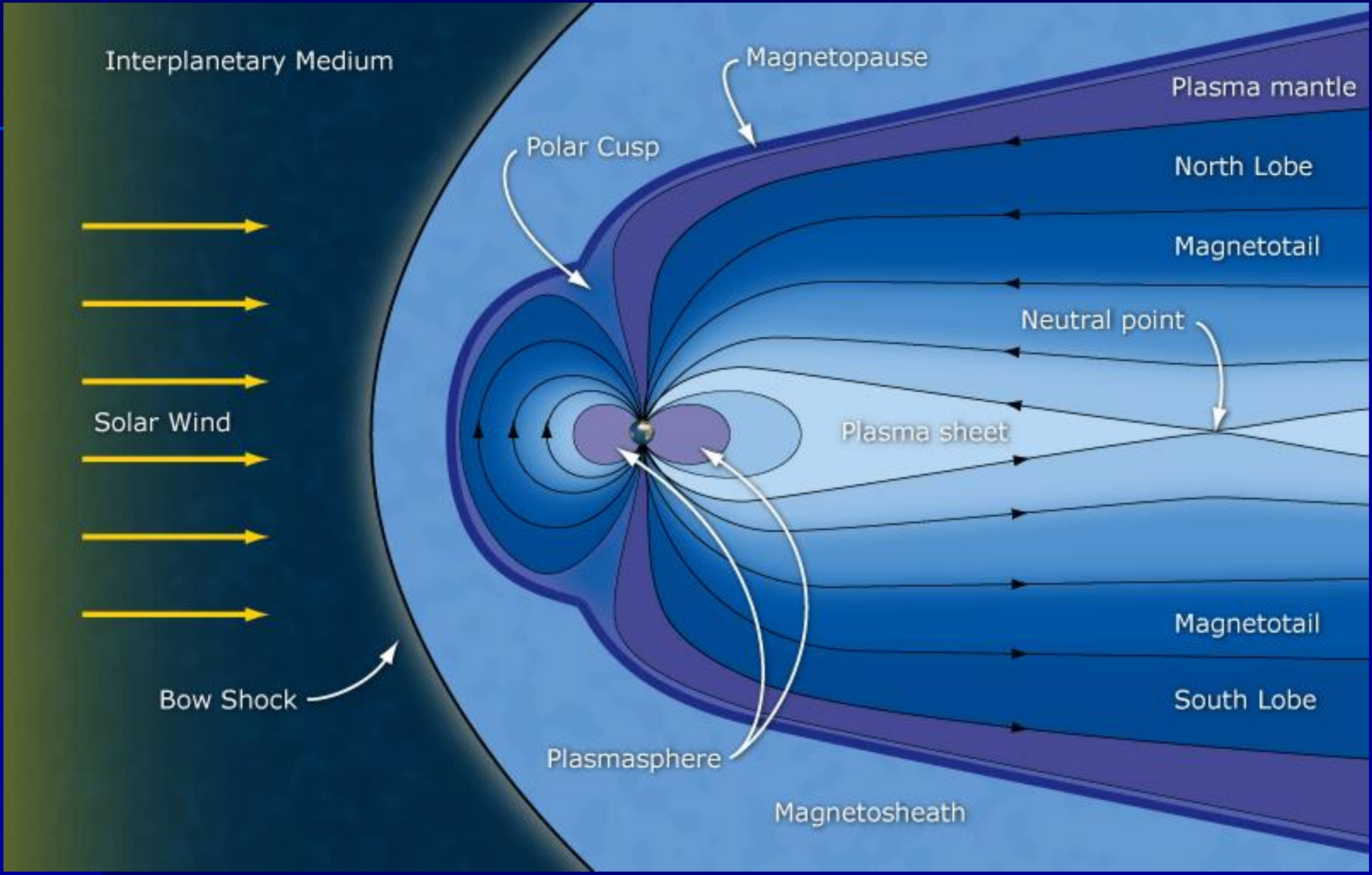
As seen from the above figure, the magnetic field of the tail is actually the magnetic field of the polar caps which has been swept back by the solar wind.

The Boundary and the Tail of the Magnetosphere

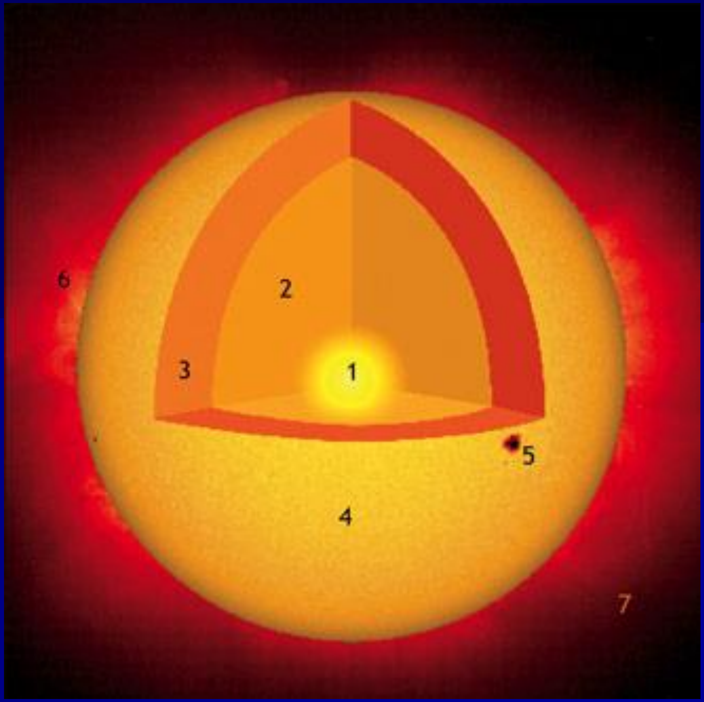
The **magnetic tail** of the Earth's magnetosphere has been detected with certainty by satellites orbiting the moon so that it definitely extends beyond **half a million kilometers**. Mariner-4 has found no evidence of the tail at **3,300 R_o**, whereas observations with Pioneer-7 near **1000 R_o** were rather ambiguous.

magnetic tail

The Boundary and the Tail of the Magnetosphere



The Active Sun



The Sun and Stars
Introduction of the Active Sun
The Photosphere
The Chromosphere and the Corona
Sunspots and the Solar Cycle
Faculae, Flares and Prominences
Radio and X-ray Bursts from the Sun
The Development of an Active Region on the Sun
Effect of the Solar Cycle
Life Cycle of the Sun

The Active Sun

Introduction

The sun is a star of mass M = 1.99×10^{30} kg, radius R=6.96×10^{8} m and effective temperature T=5750K. The total energy radiated by the Sun per second, i.e. its luminosity L is ,

$$L = 4\pi R^2 . \sigma . T^4$$

$$\Rightarrow L = 4\pi (6.96 \times 10^{8})^2 . (5.67 \times 10^{-8}) . (5750)^4$$

$$\Rightarrow L = 3.77 \times 10^{26} Js^{-1} (W)$$

Using Stephan's Law

$$E = \sigma T^4$$

Energy density per second

$$\Rightarrow E = A \sigma T^4$$

Total Energy per second

The Sun is a main sequence **G2 star** (A star is between super giant and bright giant), approximately **5 billion years old**. In many ways it is a very representative star and it is estimated that it will remain essentially in its present state for at least another 5 billion years.

Thank You !