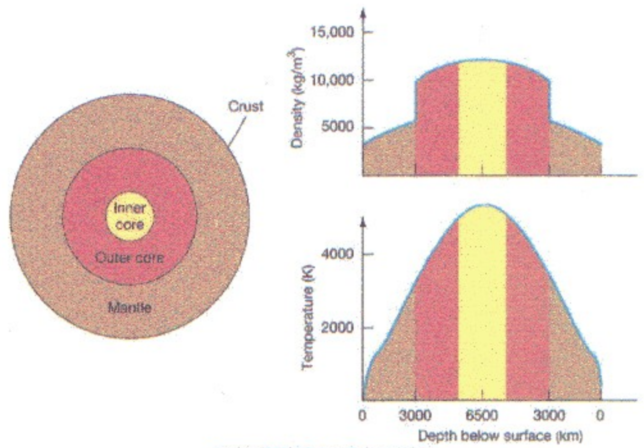
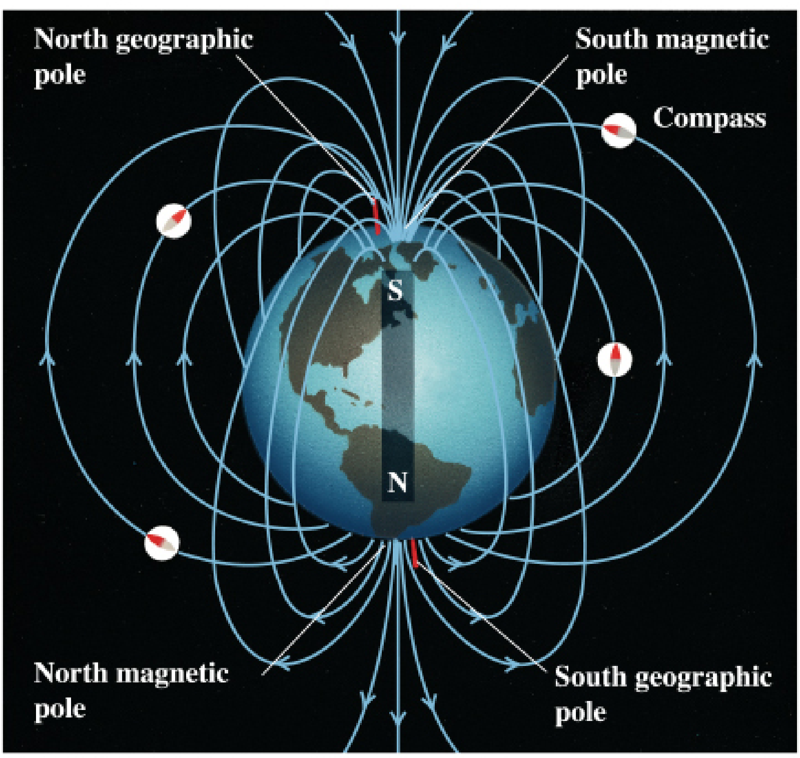
# CHAPTER 1

- Earth magnetic field.
- Planet rotation and core at the origin of the magnetic field.
- Charged particles motion in the magnetic field of the planets.
- Van Allen belts and plasma torus of Jupiter due to Io.
- Magnetosphere of a planet.

# Earth magnetic field



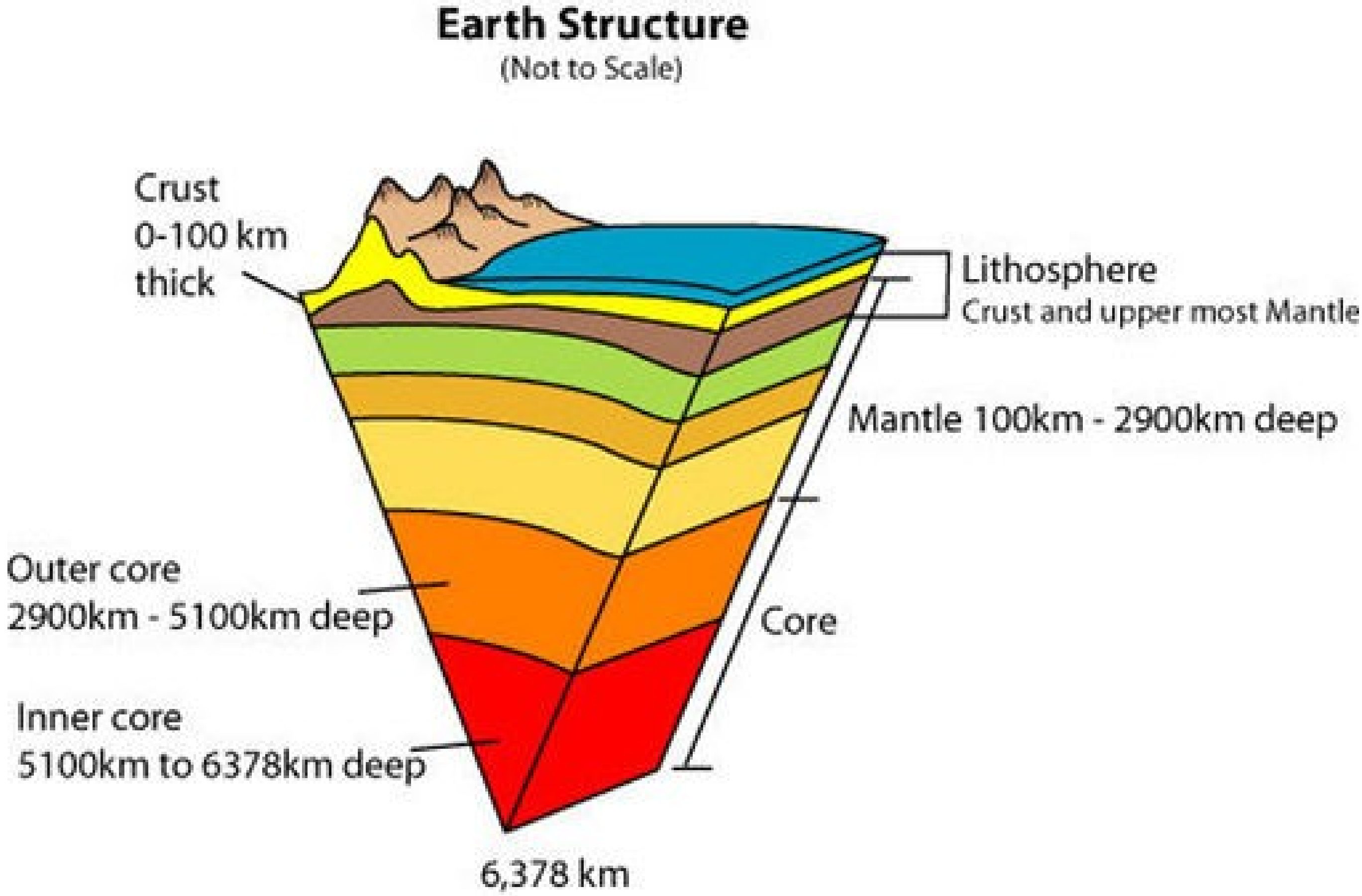

**Origin: Origine: convective currents in the outer fluid core coupled to the planet rotation.**



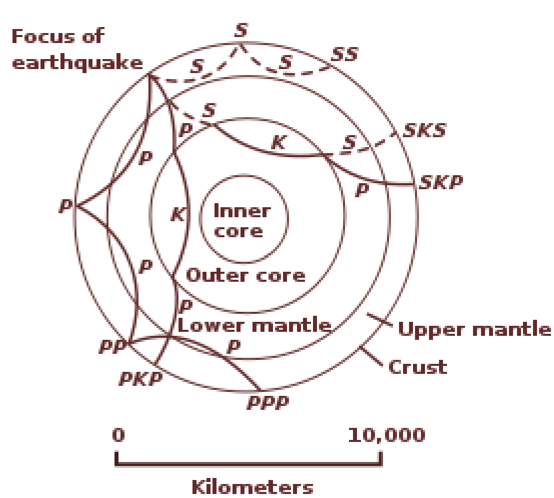


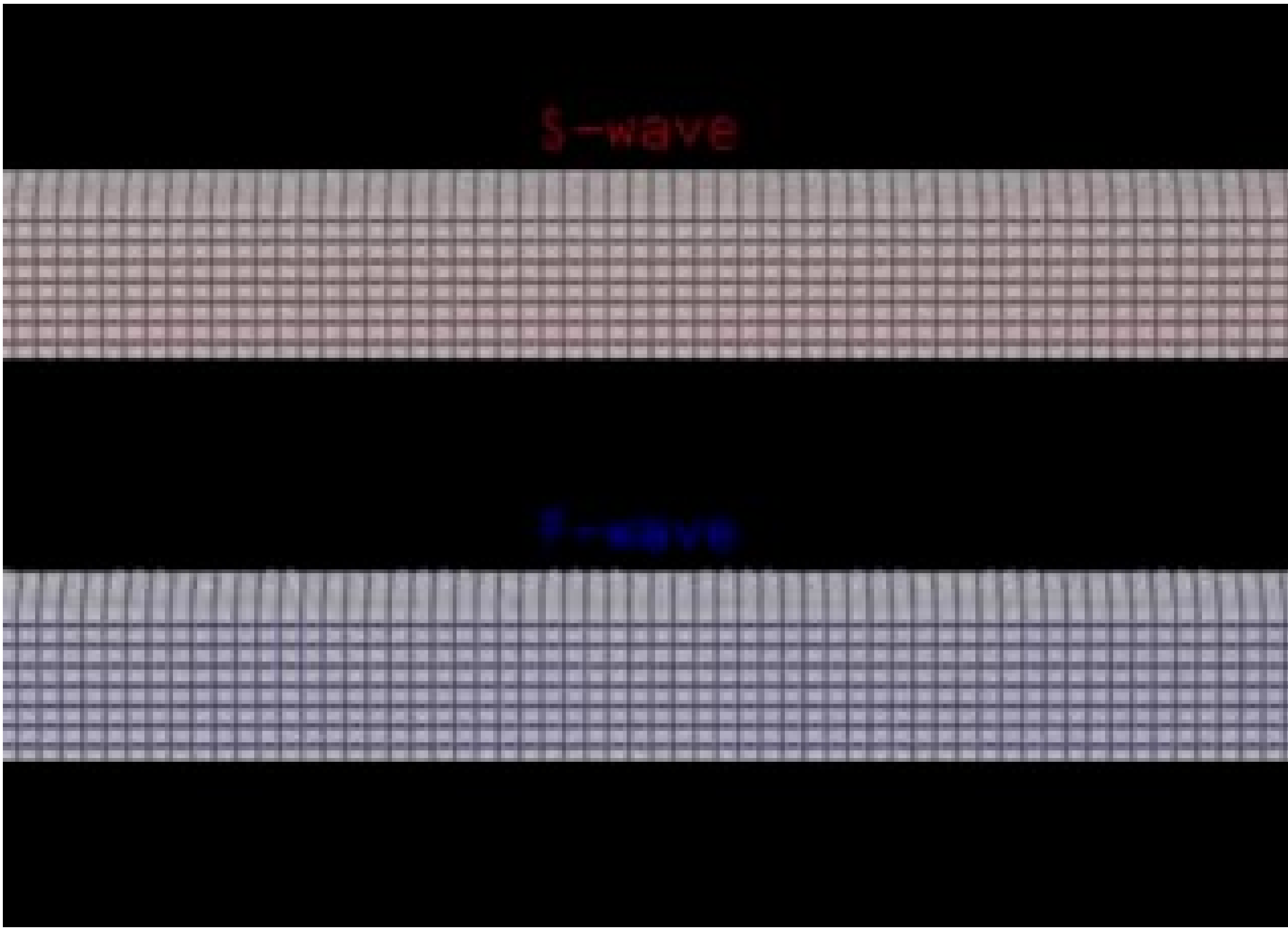

**Dipole field: 90% of the total field.**

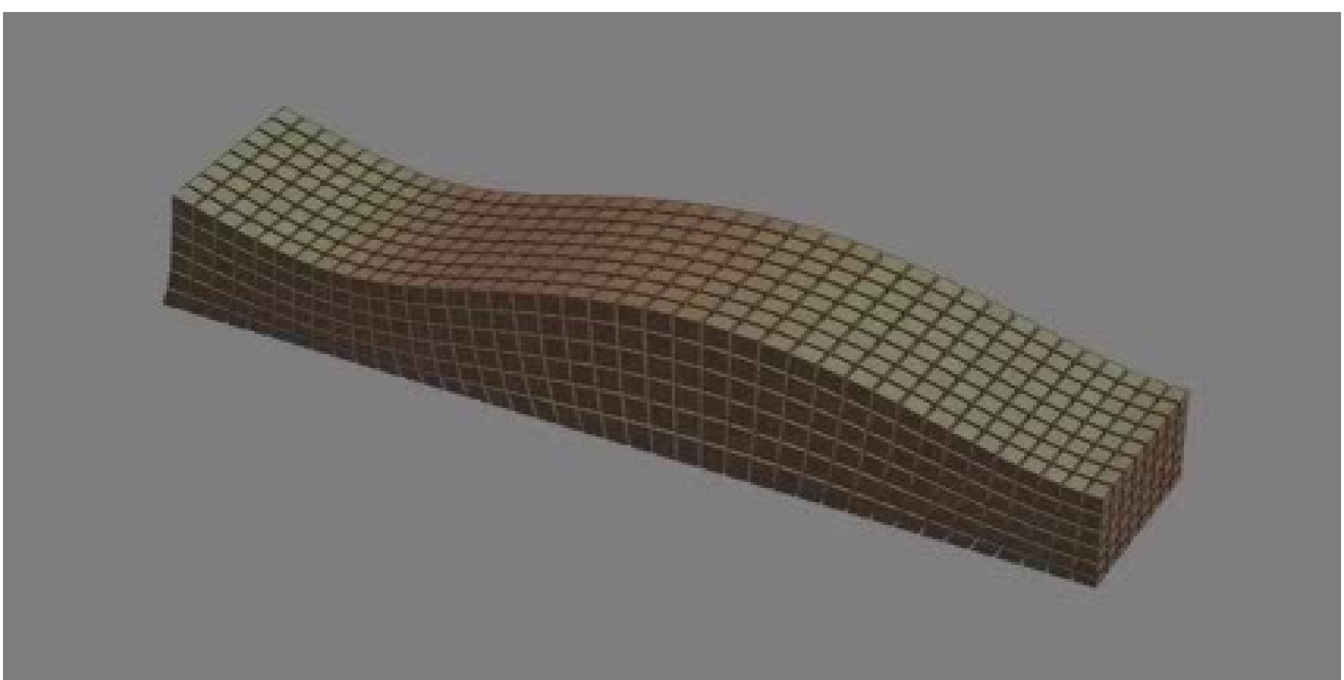
- 97-99% Campo principale dovuto a correnti nel nucleo
- 1-2% Campo dovuto a rocce magnetizzate nella crosta
- 1-2% Campo esterno prodotto da correnti attorno alla Terra

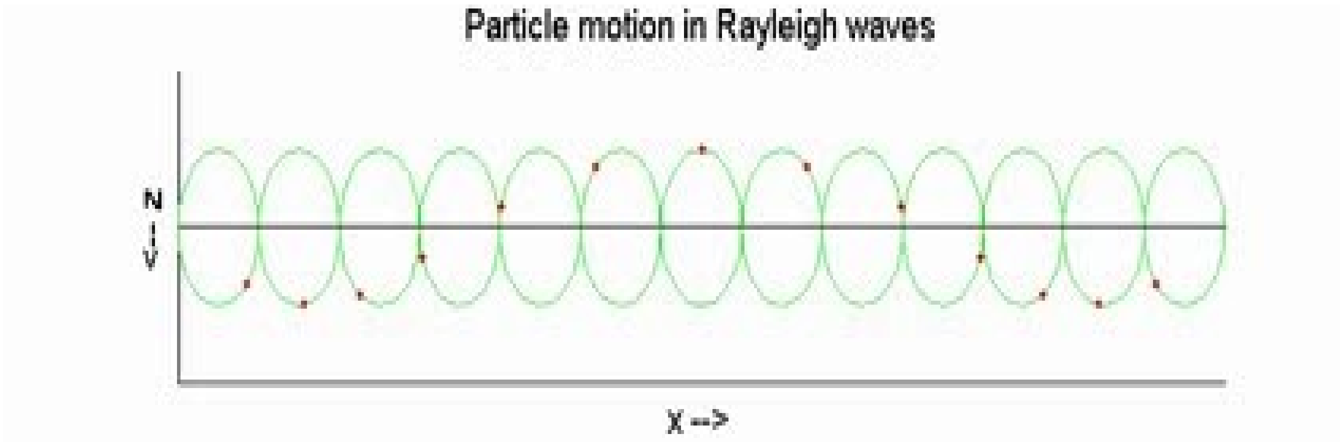



## Tomography based on sismic waves

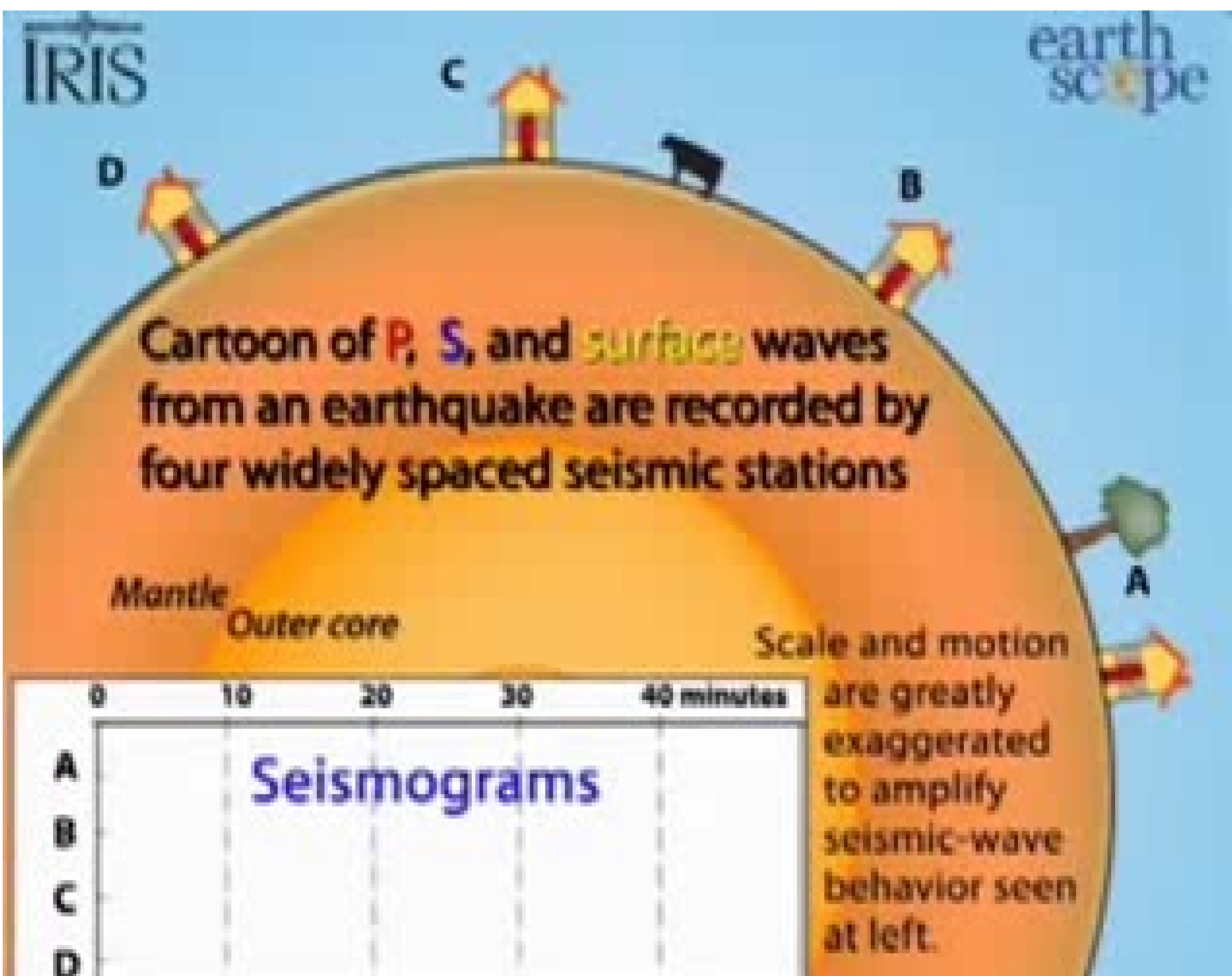


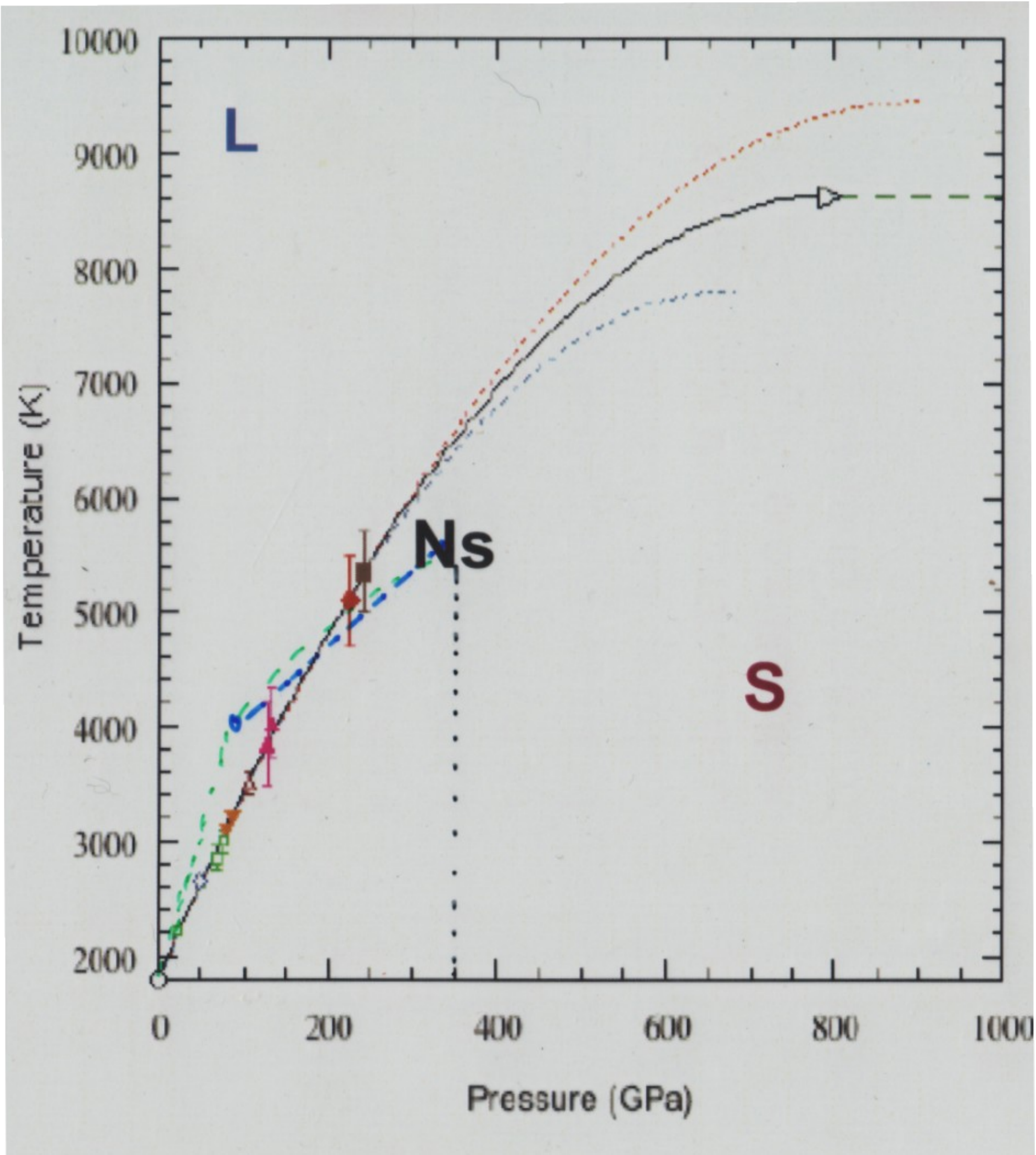

S-wave






**Con le onde sismiche è possibile eseguire una 'tomografia' della Terra.**

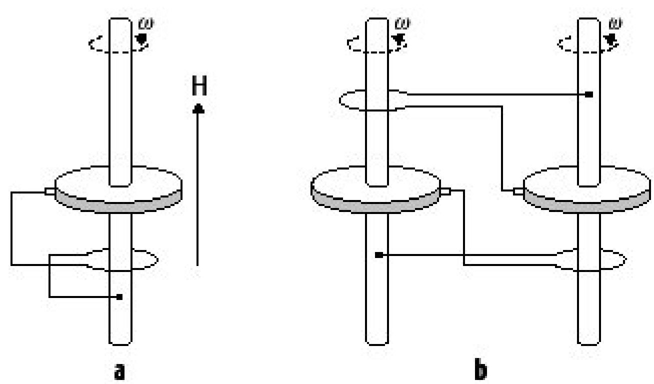





**The Earth nucleus is partly liquid (outer core) and partly solid (inner core) because the temperature growth is slower than the pressure increase and the line of the fusion temperature is crossed. In the inner core P~ 350 Gpa and T ~ 5700 K.**

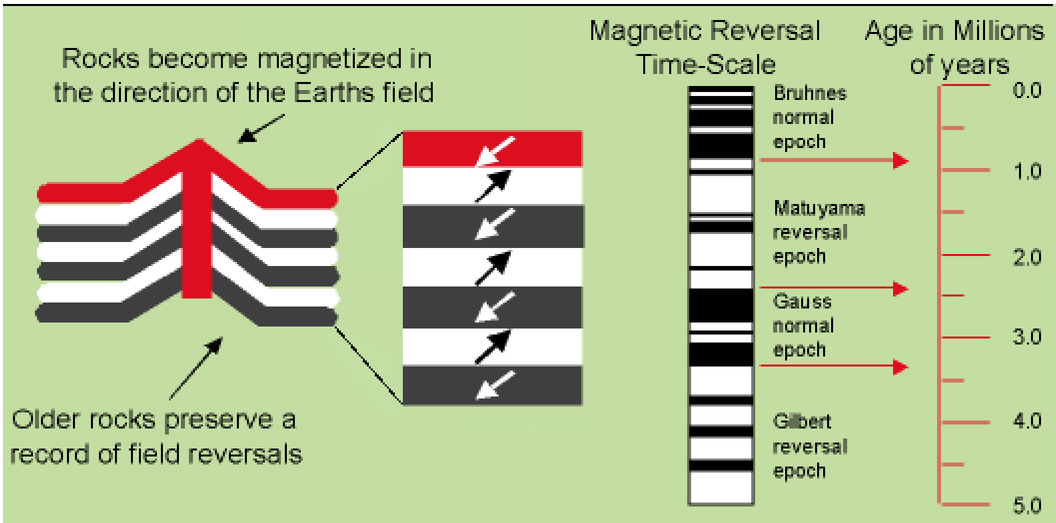
$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) + \frac{1}{\mu \sigma} \nabla^2 \boldsymbol{B} .$$

Equation for the magnetifield B in a plasma (sigma is the conductivity). Is there a solution to this equation where the plasma velocity generates a self-sustaining B ?

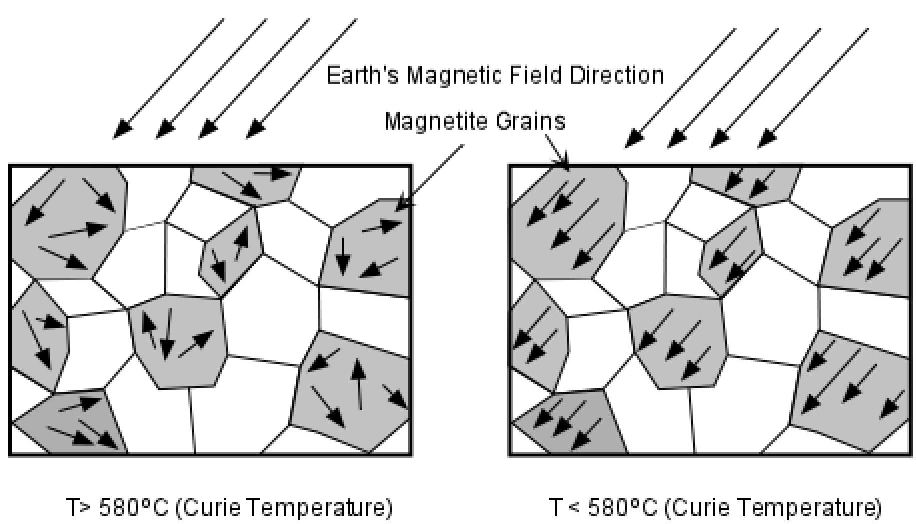



Classical example: the presence of an initial magnetic field B and the rotation motion generates a current which, passing through the bottom coil, generates a new magnetic field. Once the cycle is started, B is self-sustained.

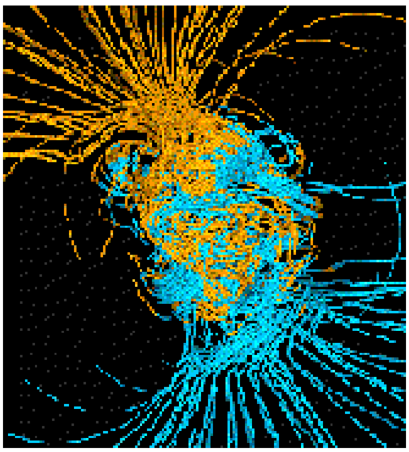
# The Earth magnetic filed flips about every 250000 years. (On average it is almost random…). How do we know of the flip? Sediments!!

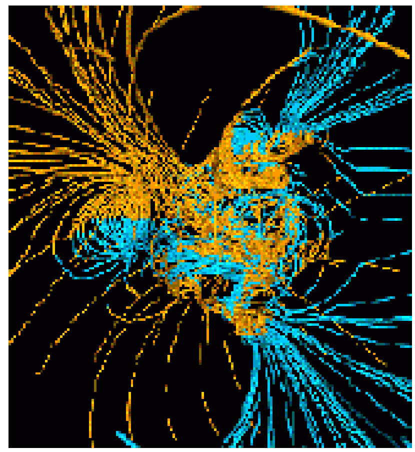


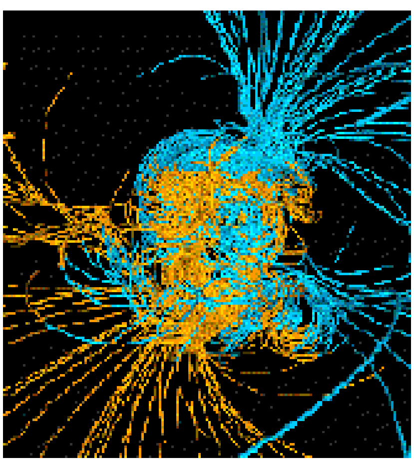

**Magma flows out of the crust with T > T di Curie and it is not magnetized. When it cools down, it becomes magnetic and the orientation is that of the Earth B.**



# Numerical model simulating the evolution of the magnetic field of the Earth. The MHD equations are solved.

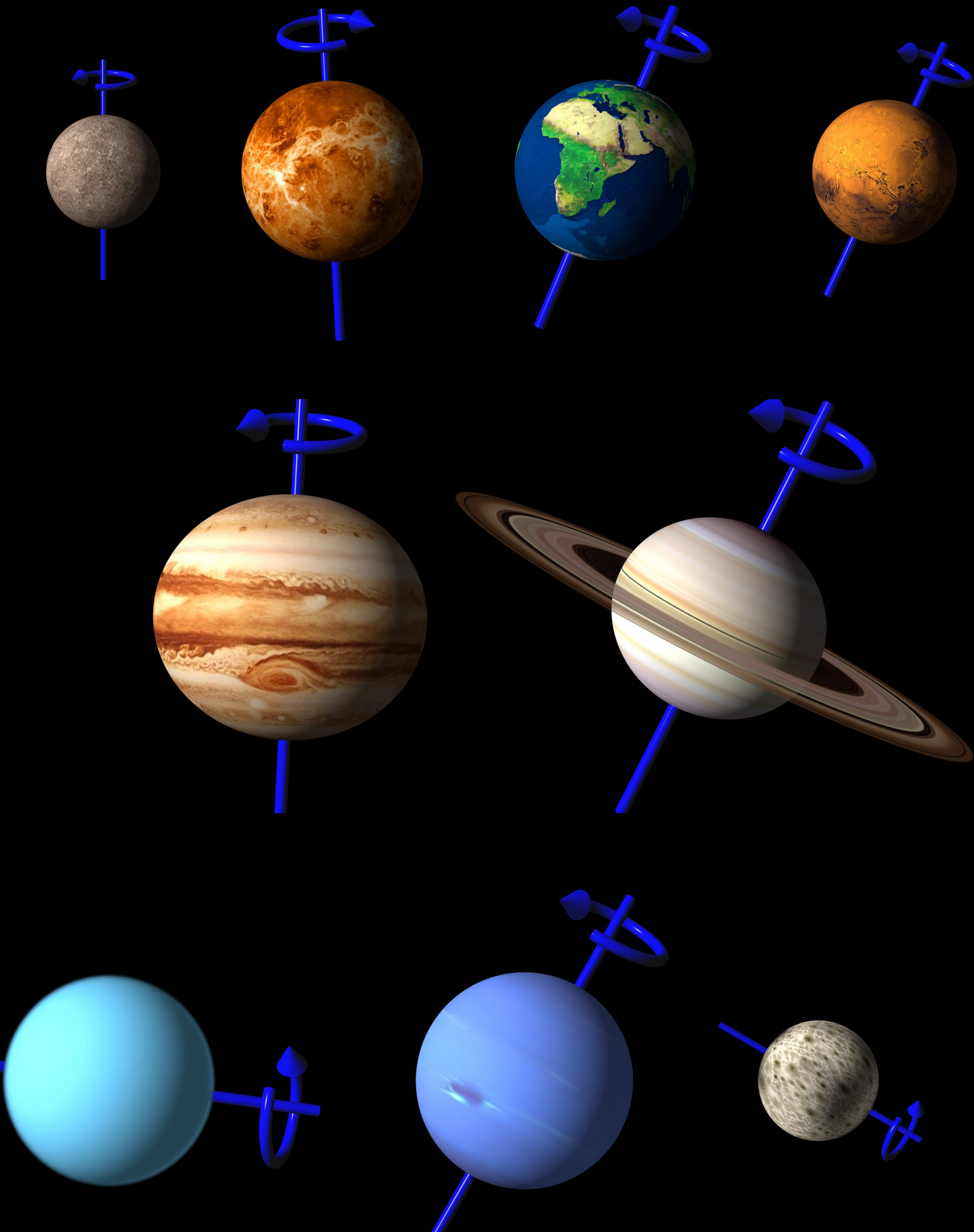




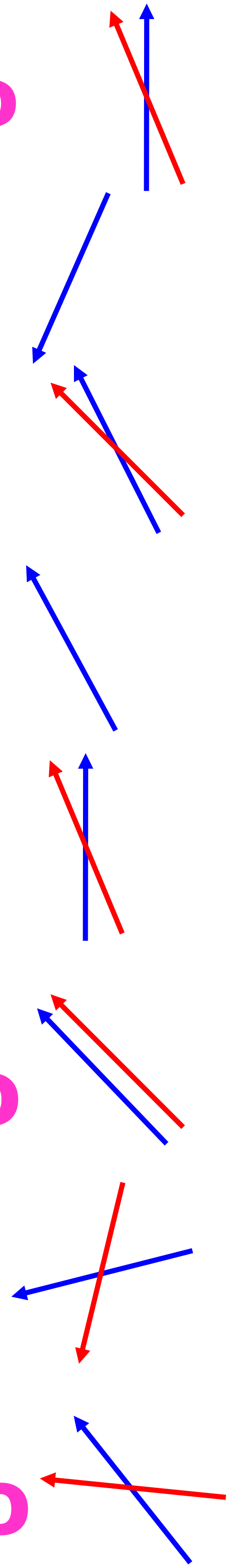


**Hydro-simulations of Glatzmaier-Roberts: the convective motions in the outer core are modeled. The reversal of B lasts only a few thousands yrs.**

[redacted]



ε = obliquity  α = angle between the B dipole and rot axes



| | | | | |
|---|---|---|---|---|
| Mercurio | α=10° | $M_B = 4\ 10^{-4}$ | ε=0° | P ~ 58.6 d |
| Venere | α=0° | $M_B = 0$ | ε=177° | P ~ -243 d |
| Terra | α=10.8° | $M_B = 1$ | ε=23.5° | P ~ 1 d |
| Marte | α=0° | $M_B = 0$ | ε=25.9° | P ~ 1 d |
| Giove | α=9.6 ° | $M_B = 20000$ | ε=3.12° | P ~ 9.9 d |
| Saturno | α <1° | $M_B = 600$ | ε=26.75° | P ~ 10.7 d |
| Urano | α =60° | $M_B = 50$ | ε=97.86° | P ~ -17.2 d |
| Nettuno | α =47° | $M_B = 25$ | ε=29.56 ° | P ~ 16.1 d |

$M_B = 7.906\ 10^{25}$ Gauss $cm^{-3}$  Earth magnetic moment

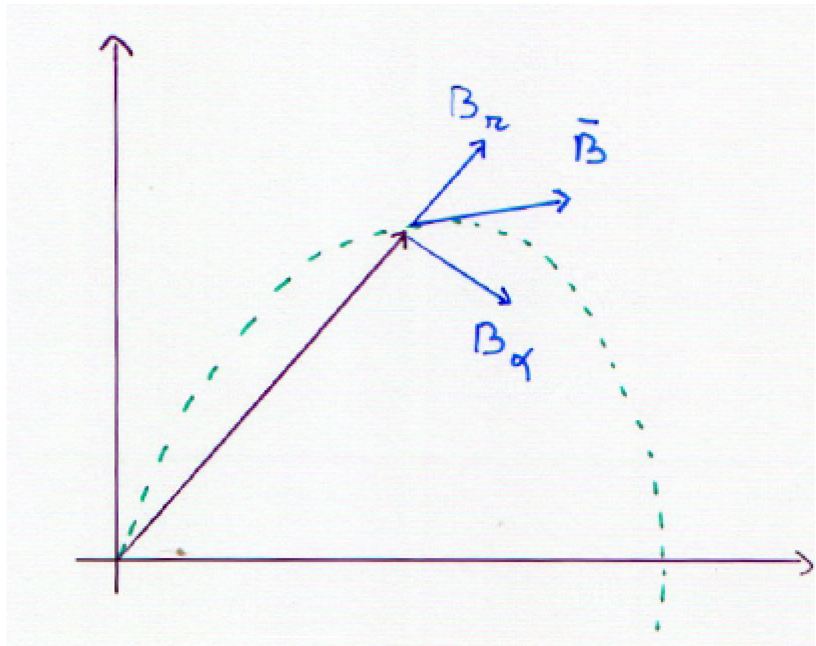
# Classical dipolar field:

$$B_r = \frac{2\mu_0 m}{4\pi r^3}\cos\alpha$$

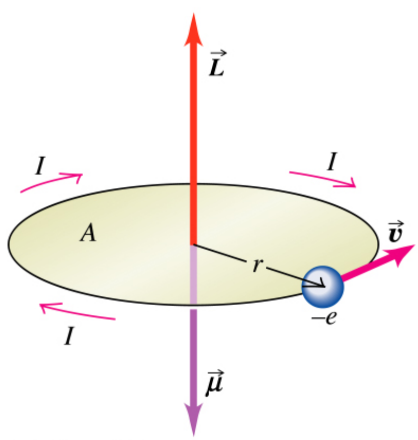
$$B_r = \frac{\mu_0 m}{4\pi r^3}\sin\alpha$$

$$B_\phi = 0$$

M= magnetic moment



Magnetic moment of a coil:






$$\vec{m} = -As \cdot I\,\hat{z}$$

Units: Tesla 1 T = 1 N s/ (C m)

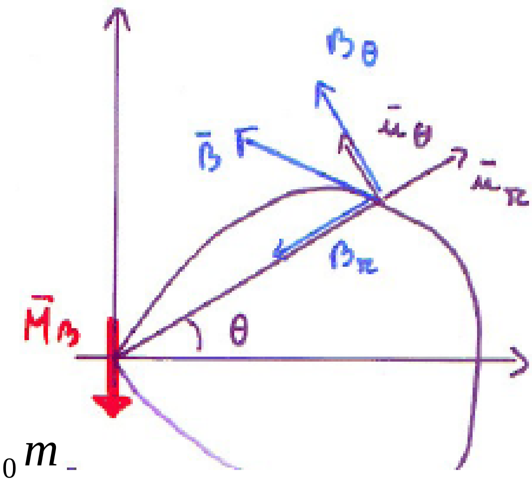
1 T = 10000 Gauss

# Earth magnetic field: dipolar approximation

$$B_r = -\frac{2 M_B}{r^3} \cos\alpha$$

$$B_r = \frac{M_b}{r^3} \sin\alpha$$

$$B_\phi = 0$$




$$M_B = 7.906 \times 10^{25}\ Gauss/cm^3 = \frac{\mu_0 m}{4\pi}$$

$$r(\theta) = r_e \cos^2(\theta)$$

**Field line**

$$\vec{v} = \dot{r}\,\vec{u}_r + r\,\dot{\theta}\,\vec{u}_\theta + r\sin\theta\,\dot{\phi}\,\vec{u}_\phi$$

$$\vec{v}_c = -2 r_e \cos\theta \sin\theta\,\dot{\theta}\,\vec{u}_r + r_e \cos^2\theta\,\dot{\theta}\,\vec{u}_\theta$$

$$\vec{v}_c = r_e \cos\theta\,\dot{\theta}\left(-2\sin\theta\,\vec{u}_r + \cos\theta\,\vec{u}_\theta\right)$$

**Field line tangent vector**

$$\vec{v}_c \parallel \vec{B}$$

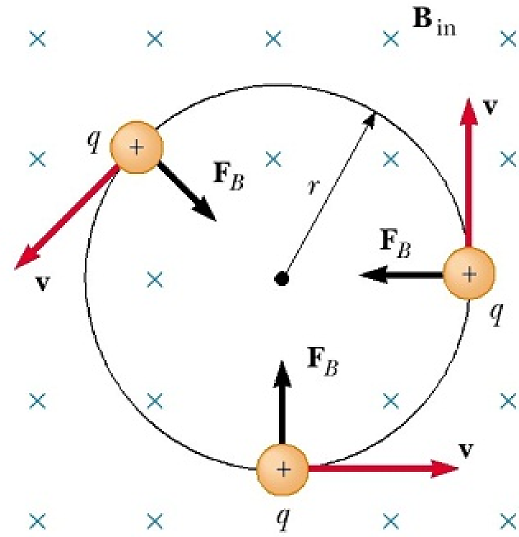
**Magnetic field along field lines.**

$$|\vec{B}| = \frac{M_b}{r_e^3 \cos^6\theta}\left[4\sin^2\theta + \cos^2\theta\right]^{1/2} = \frac{M_b}{r_e^3}\frac{\left[4 - 3\cos^2\theta\right]^{1/2}}{\cos^6\theta} =$$

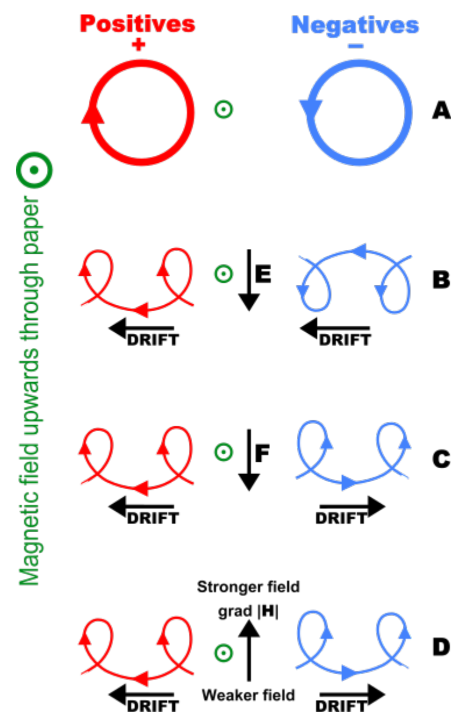
$$= B_e \frac{\sqrt{4 - 3\cos^2\theta}}{\cos^6}\theta$$

$$B_e = \frac{M_B}{r_e^3}$$

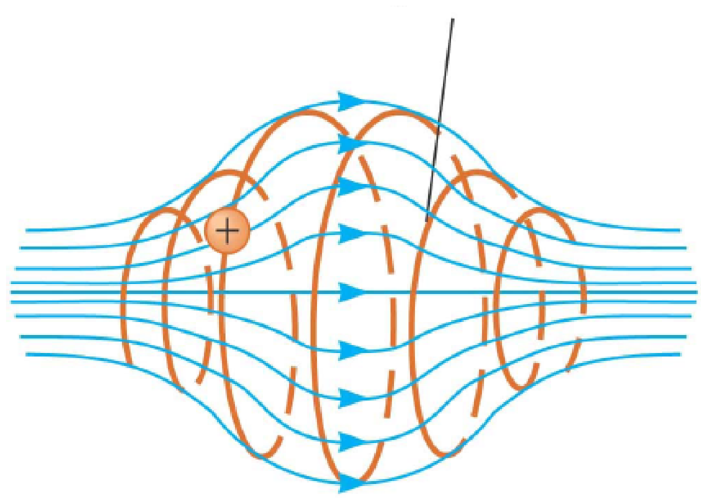
# Moto dominante: giromagnetico




# Moto di drift 1: gradiente e curvatura del campo B e forze esterne.




# Moto di drfit 2: componente della velocità iniziale lungo la linea di campo



# MOTO delle CARICHE nel CAMPO MAGNETICO TERRESTRE.

## 1) MOTO GIROMAGNETICO

$$\bar{B} = (0, 0, B) \qquad \bar{v} = (v_x, v_y, 0)$$

$$\begin{cases} m \dot{v}_x = q v_y B \\ m \dot{v}_y = -q v_x B \end{cases} \qquad \begin{cases} \dddot{x} = \frac{qB}{m} \ddot{y} = -\left(\frac{qB}{m}\right)^2 \dot{x} \\ \dddot{y} = \frac{qB}{m} \ddot{x} = -\left(\frac{qB}{m}\right)^2 \dot{y} \end{cases}$$

$$\ddot{x} = -\Omega_c^2 x \qquad \ddot{y} = -\Omega_c^2 y$$

$$\bar{a} = -\Omega_c^2 \bar{r}$$

MOTO CIRCOLARE UNIFORME

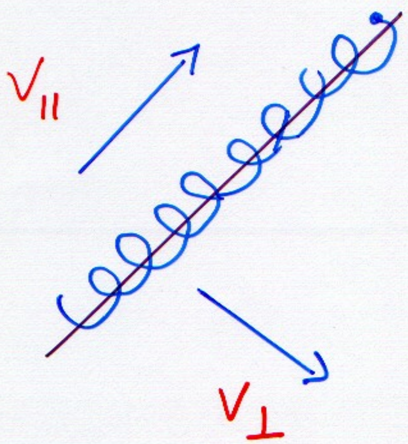
$$\boxed{\Omega_c = \frac{qB}{m}}$$

FREQUENZA di CICLOTRONE.

$$|a| = \Omega_c^2 |r| = \frac{v^2}{r}$$

$$r = \frac{v}{\Omega_c} = \frac{v_\perp m}{qB}$$

RAGGIO di CICLOTRONE (o LARMOR)



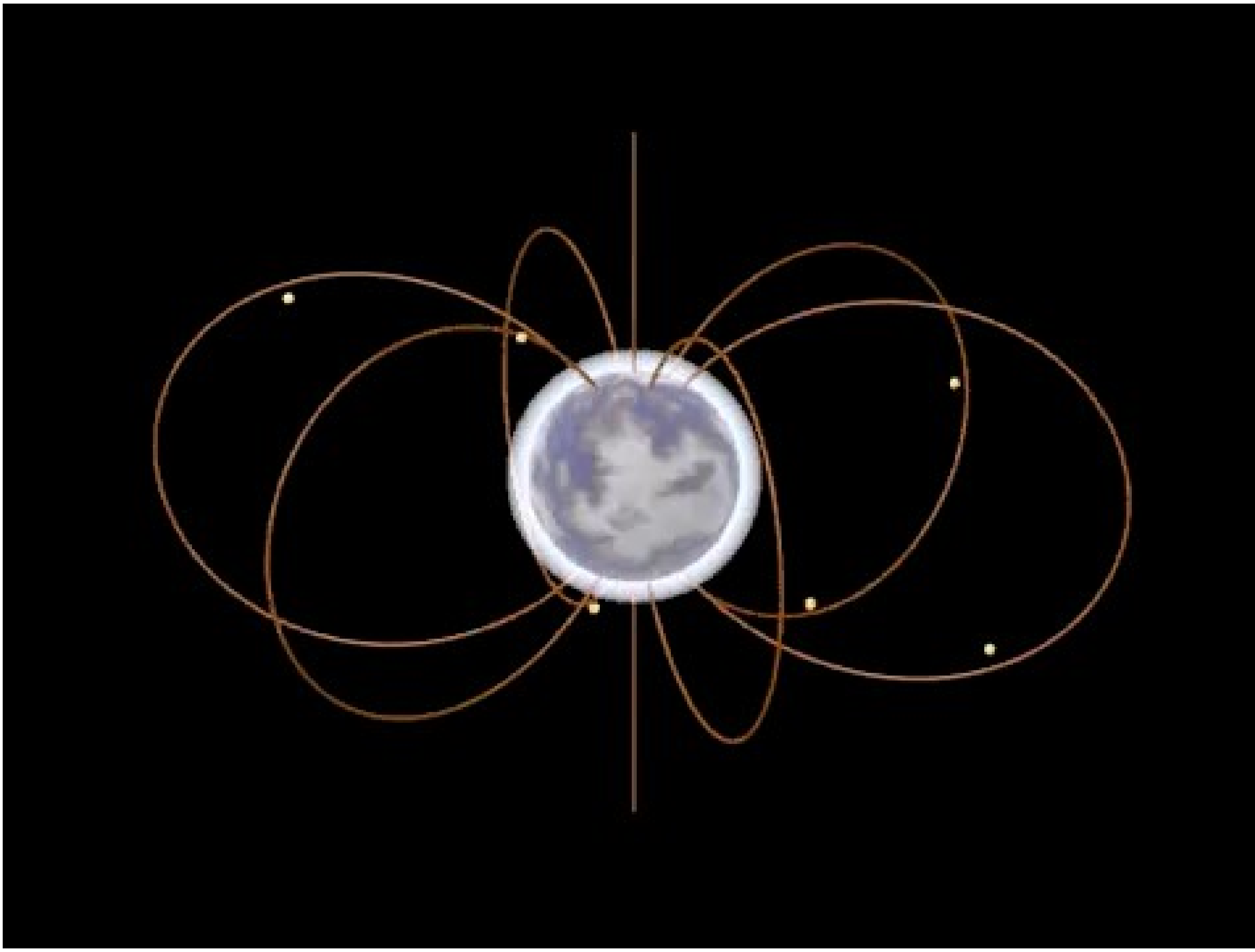

per la Terra

$e^-$ di 100 keV $\Rightarrow$

$r \sim 100$ m

$P \sim \mu s$

$v \sim 10^6$ km/s

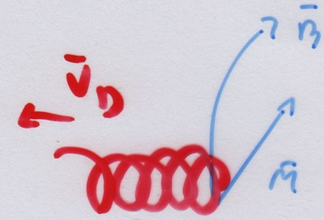


$$v_D = m v_p^2 \frac{\vec{B} \times \vec{n}}{R_c q B^2}$$

# 2) Moto di DRIFT

1) Dovuto alla curvatura delle linee di campo.

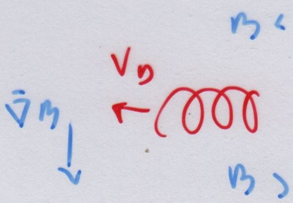
$$\bar{V}_D^{\parallel} = m v_{\parallel}^2 \frac{\bar{B} \times \bar{n}}{R_c q B^2}$$




$R_c$ = raggio di curvatura $= \frac{B}{\nabla_{\perp} B}$

2) Dovuto al gradiente del campo

$$\bar{V}_D^{\perp} = \frac{1}{2} m v_{\perp}^2 \frac{\bar{B} \times \bar{\nabla} B}{q B^3}$$





Protoni e elettroni hanno moto di drift opposto

3) Dovuto ai campi $\bar{E}$ e $\bar{G}$

$$\bar{V}_D^{E} = \frac{\bar{E} \times \bar{B}}{B^2} \qquad \bar{V}_D^{G} = m \frac{\bar{G} \times \bar{B}}{q B^2}$$

Termine dominante $V_D^{\perp}$ perché proporzionale a $V_{\perp} >> V_{\parallel}$

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"Introduction to Plasma Physics

•) $\bar{E} \times \bar{B}$ drift.

$\bar{B} = B \cdot \hat{z}$ introduciamo campo $\bar{E}$ uniforme e costante.

$$m \dot{\bar{v}} = q \left( \bar{E} + \bar{v} \times \bar{B} \right)$$

Sia $\bar{u} = \bar{v} - \frac{(\bar{E} \times \bar{B})}{B^2}$

velocità della particella in un SdR con $V_{SdR} = \frac{\bar{E} \times \bar{B}}{B^2}$

$$\dot{\bar{u}} = \dot{\bar{v}} \qquad \text{( per la costanza di } \bar{E}, \bar{B} \text{)}$$

$$m \dot{\bar{u}} = q \left( \bar{E} + \bar{v} \times \bar{B} \right) = q \left( \bar{E} + \bar{u} \times \bar{B} + \frac{(\bar{E} \times \bar{B}) \times \bar{B}}{B^2} \right)$$

$$= q \left( \bar{E} + \bar{u} \times \bar{B} + \frac{(\bar{E} \cdot \bar{B}) \bar{B}}{B^2} - \bar{E} \right) =$$

$$= q \left( \hat{b} \, (\bar{E} \cdot \hat{b}) + \bar{u} \times \bar{B} \right) \qquad \text{con } \hat{b} = \frac{\bar{B}}{B}$$

$* \ (A \times B) \times C = (A \cdot C) B - (B \cdot C) A$

Consideriamo ora $u_{\parallel} = \bar{u} \cdot \hat{b}$

$u_{\perp} = \| \bar{u} - u_{\parallel} \hat{b} \|$

$$m \dot{\bar{u}} \cdot \hat{b} = m \dot{u}_{\parallel} = q \left( \hat{b} \cdot \hat{b} \, (\bar{E} \cdot \hat{b}) + \underbrace{(\bar{u} \times \bar{B}) \cdot \hat{b}}_{=0} \right) =$$

$$= q E_{\parallel}$$

ma $u_{\parallel} = v_{\parallel}$ perché

$$\bar{u} \cdot \hat{b} = \bar{v} \cdot \hat{b} - \underbrace{\left( \frac{\bar{E} \times \bar{B}}{B^2} \right) \cdot \hat{b}}_{=0}$$

quindi

$$\boxed{v_{\parallel} = \frac{q}{m} E_{\parallel} t + v_{\parallel 0}}$$

Ora: per ottenere $u_{\perp}$ si sottrae a $\dot{\bar{u}}$ $\dot{u}_{\parallel}$ lungo $\hat{b}$ =>

$$m \dot{\bar{u}} - m \dot{u}_{\parallel} \hat{b} = q \left( \hat{b} \, (\bar{E} \cdot \hat{b}) + \bar{u} \times \bar{B} - q E_{\parallel} \hat{b} \right) =$$

$$= q (\bar{u} \times \bar{B}) = q \, \bar{u}_{\perp} \times \bar{B}$$

$$m \dot{\bar{u}}_{\perp} = q \, \bar{u}_{\perp} \times \bar{B}$$

Nel Sd.R in moto con $\bar{v}_{d} = \frac{\bar{E} \times \bar{B}}{\ldots}$ la

3) il guiding center si muove lungo le linee di campo con $V_{\parallel}$ ($\parallel$ a $\bar{B}$)

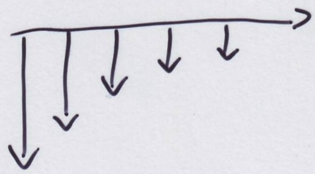
ALLORA, nel SdR originale il guiding center si muove con velocità

$$\bar{v}_{gc} = V_{\parallel} \hat{b} + \frac{\bar{E} \times \bar{B}}{B^2}$$

$$\boxed{V_E = \frac{\bar{E} \times \bar{B}}{B^2}}$$

VELOCITÀ di DRIFT

## •) Drift dovuto a $\bar{\nabla} B$



Campo NON omogeneo

(Si assume che $R_L$ << scala di variazione di $\bar{B}$)

$$\frac{r_L}{B} |\bar{\nabla} B| \ll 1$$

Si sviluppa la $\bar{v}$ della particella come una serie

$$\bar{v} = \bar{v}_0 + \bar{v}_1 + \bar{v}_2 \dots$$ Termini via via più piccoli.

dove il termine 0 corrisponde al moto giromagnetico. Si assume anche che:

$$\bar{B} = B_{gc} \hat{z} + (y - y_{gc}) \frac{dB}{dy} \cdot \hat{z}$$

dove $y_{gc}$ è il guiding center della particella all'inizio $(t=0)$

5) Le eq. del moto sono: $(m\dot{\bar{v}} = q\bar{v} \times \bar{B})$

$$m\dot{v}_x = q v_y \left[ B_{gc} + (y - y_{gc}) \frac{dB}{dy} \right]$$

$$m\dot{v}_y = -q v_x \left[ B_{gc} + (y - y_{gc}) \frac{dB}{dy} \right]$$

Introduciamo nelle equazioni lo sviluppo in serie fino al I° ORDINE (si trascura il II°)

$$m\dot{v}_{x0} + m\dot{v}_{x1} = q(v_{y0} + v_{y1}) \left[ B_{gc} + (y_0 + y_1 - y_{gc}) \frac{dB}{dy} \right]$$

$$m\dot{v}_{y0} + m\dot{v}_{y1} = -q(v_{x0} + v_{x1}) \left[ B_{gc} + (y_0 + y_1 - y_{gc}) \frac{dB}{dy} \right]$$

- Assumiamo che $v_{x0}$ e $v_{y0}$ e $y_0$ corrispondano al moto giromagnetico
- si trascura $y_1 \cdot \frac{dB}{dy}$ perché di II° ordine (piccoli rispetto al moto giromagnetico)

SOLUZIONE 0 (ORD.) => moto giromagnetico

SOLUZIONE 1 => moto di drift

↓

$$m \dot{v}_{x1} = q v_{y1} B_{gc} + q v_{y0} (y_0 - y_{gc}) \frac{dB}{dy}$$

$$m \dot{v}_{y1} = - q v_{x1} B_{gc} - q v_{x0} (y_0 - y_{gc}) \frac{dB}{dy}$$

(si trascura $q v_{y1} (y_0 - y_{gc}) \frac{dB}{dy}$ perché II' ordine, le stesso per $q v_{x1} (y_0 - y_{gc}) \frac{dB}{dy}$).

→ Si esegue media delle quantità nelle equazioni su molti periodi di moto giromagnetico.

Ora $m \langle v_{x1} \rangle$ e $m \langle v_{y1} \rangle$ sono quantità piccole (I° ord) e la media $m \langle \dot{v}_{x1} \rangle$ ad esempio rappresenta la piccola variazione di una quantità piccola (II° ord).

In altre parole, la variazione di $\langle v_x \rangle$ rispetto al periodo giromagnetico è piccola.

7) Allora:

$$q \langle v_{y1} \rangle B_{gc} + q \langle v_{y0} (y_0 - y_{gc}) \rangle \frac{dB}{dy} = 0$$

$$-q \langle v_{x1} \rangle B_{gc} - q \langle v_{x0} (y_0 - y_{gc}) \rangle \frac{dB}{dy} = 0$$

Ora la media di $v_{y0} (y_0 - y_{gc})$ è nulla perché

$$v_{y0} = \pm i v_\perp e^{i(\omega_c t + \delta)} \quad \leftarrow \text{PARTE REALE}$$

$$y_0 - y_{gc} = \pm \frac{v_\perp}{\omega_c} e^{i(\omega_c t + \delta)}$$

I due termini sono sfasati di 90°, sono oscillanti e quindi la media è 0. $\Rightarrow \langle v_{y1} \rangle = 0$

$$\langle v_{x1} \rangle = - \langle v_{x0} (y_0 - y_{gc}) \rangle \frac{dB}{dy}$$

dove $\langle v_{x0} (y_c - y_{gc}) \rangle = \frac{v_\perp^2}{\omega} \langle e^{2i(\omega_c t + \delta)} \rangle =$

$$= \frac{v_\perp^2}{2\omega_c}$$

*

- $\left\langle \mathrm{Re}\left(i V_\perp e^{i(\omega_c t + \delta)}\right) \cdot \mathrm{Re}\left(\frac{V_\perp}{\omega_c} e^{i(\omega_c t + \delta)}\right) \right\rangle =$

$$= \frac{V_\perp^2}{\omega_c} \langle - \sin\varphi \cos\varphi \rangle = -\frac{V_\perp^2}{\omega_c} \frac{1}{2\pi} \int_0^{2\pi} \sin\varphi \cos\varphi \, d\varphi = 0$$

- $\langle V_{x0} \cdot (Y_c - Y_{gc}) \rangle = \frac{V_\perp^2}{\omega_c} \left\langle \mathrm{Re}\left(e^{i(\omega_c t + \delta)}\right) \cdot \mathrm{Re}\left(e^{i(\omega_c t + \delta)}\right) \right\rangle =$

$$= \frac{V_\perp^2}{\omega_c} \frac{1}{2\pi} \int_0^{2\pi} \cos^2\varphi \, d\varphi = \frac{V_\perp^2}{\omega_c} \frac{\pi}{2\pi} = \frac{V_\perp^2}{2\omega_c}$$

8)

$$\langle v_{x_1} \rangle = \frac{v_\perp^2}{2\omega_c} \frac{1}{B_{gc;i}} \frac{dB}{dy}$$

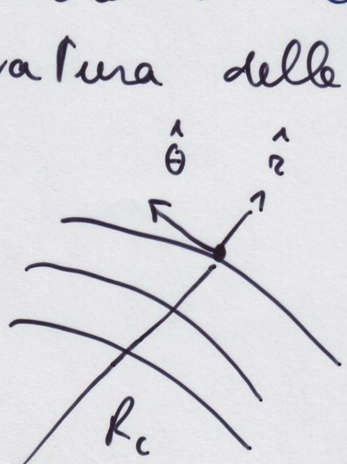
La particella quindi 'drifta in una direzione ⊥ a y e z quindi dove B è costante e quindi $B_{gc;i} = B_{gc}$

La forma generale è:

$$\bar{V}_{grad} = \frac{v_\perp^2}{2\omega_c} \frac{\bar{B} \times \bar{\nabla} B}{B^2} = \frac{v_\perp^2 m}{2q} \frac{\bar{B} \times \bar{\nabla} B}{B^3}$$

•) DRIFT dovuto alla CURVATURA del CAMPO.

Introduciamo un sistema di coordinate cilindriche che localmente approssimano la curvatura delle linee di campo B



9)

Ad ordine 0, le particelle si muovono lungo le linee di campo (direzione $\hat{\theta}$) con velocità $v_{\parallel}\hat{b}$ e $v_{\perp}$. Ci si pone in un sistema di Rif. che si muove solidalmente con le linee di campo.

$$\bar{F}_{cf} = \frac{m v_{\parallel}^2}{R_c}\hat{r} = m v_{\parallel}^2 \frac{\bar{R}_c}{R_c^2}$$

con $R_c$ raggio di curvatura. In presenza di una forza si utilizza:

$$\bar{v}_{curv} = \frac{(\bar{F} \times \bar{B})}{q B^2} = \frac{m v_{\parallel}^2}{q B^2} \frac{\bar{R}_c \times \bar{B}}{R_c^2} = m v_{\parallel}^2 \frac{\bar{B} \times \bar{n}}{R_c q B^2}$$

$$\bar{n} = \frac{\bar{R}_c}{R_c}$$

Ora $\dfrac{\bar{R}_c}{R_c^2} = (\hat{b} \cdot \bar{\nabla})\hat{b}$

$$\bar{v}_{curv} = \frac{m v_{\parallel}^2}{q B^2} \bar{B} \times [(\hat{b} \cdot \bar{\nabla})\hat{b}]$$

# INVARIANTE ADIABATICO $\mu$

Una particella che ruota (moto giromagnetico) è analoga a una corrente → si può definire momento magnetico $\bar{\mu} = I \cdot A_s \cdot \bar{n}$

$$r_c = \frac{V_\perp}{\Omega_c} \qquad I = \frac{dq}{dt} = q\frac{\Omega_c}{2\pi} \qquad (\Omega_c \cdot T = 2\pi)$$

$$\bar{\mu} = I \pi r_c^2 \cdot \bar{n} = \frac{e\,\Omega_c}{2\pi}\,\pi\,\frac{V_\perp^2}{\Omega_c^2} = \frac{1}{2}\,m\frac{V_\perp^2}{B}\cdot\bar{n}$$

$\mu$ si conserva se $B$ VARIA LENTAMENTE RISPETTO AL PERIODO del MOTO GIROMAGNETICO

Legge di Faraday: Se $\varepsilon_T = \frac{1}{2} m V_\perp^2$ (En. moto rotat.)

$$\Delta \varepsilon_\perp = q \oint \bar{E} \cdot d\bar{l} = -q \int_\Sigma \frac{\partial \bar{B}}{\partial t} \cdot d\bar{s}$$

Su un periodo di rotazione $P = \frac{2\pi}{\Omega_c}$

$$\Delta \varepsilon_\perp = q \frac{\partial \Phi_B}{\partial t} = q \pi \rho_c^2 \cdot \frac{\partial \bar{B}}{\partial t} =$$

(il segno + perché nel moto giromagnetico convenzione invertita)

$$= q \frac{V_\perp^2 m^2}{q^2 B^2} \cdot \pi \frac{\partial \bar{B}}{\partial t} = \frac{\varepsilon_\perp}{B} \cdot T \cdot \frac{\partial \bar{B}}{\partial t} =$$

Se si assume che $B$ sia costante su $P_c$

$$= \frac{\varepsilon_\perp}{B} \cdot \Delta B \quad \text{con} \left(\Delta B = T \cdot \frac{\partial B}{\partial t}\right)$$

$$\Delta\left(\frac{\varepsilon_\perp}{B}\right) = 0 = \Delta \mu$$

$$\Delta\left(\frac{y}{x}\right) = \frac{\partial\left(\frac{y}{x}\right)}{\partial x}\cdot \Delta x + \frac{\partial\left(\frac{y}{x}\right)}{\partial y}\cdot \Delta y$$

$$= -\frac{y}{x^2}\cdot\Delta x + \frac{\Delta y}{x} = -\frac{y}{x^2}\Delta x + \frac{y}{x^2}\cdot\Delta x = 0$$

# 3) INVARIANTE ADIABATICO e MOTO A SPECCHIO

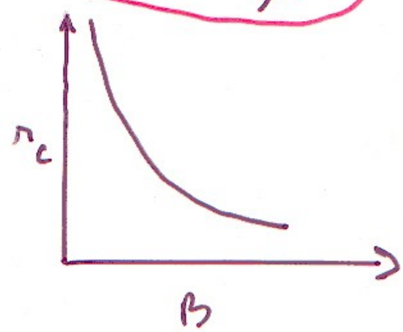
$$\mu = \frac{1}{2}\frac{m v_\perp^2}{B}$$ costante se $B$ varia lentamente.

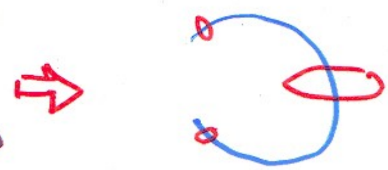
$$B = \frac{1}{2}\frac{m v_\perp^2}{\mu}$$

- $r_c = \dfrac{v_\perp m}{q B}$

$$r_c = \frac{2\mu}{q v_\perp}$$

$r_c \propto \dfrac{1}{B}$

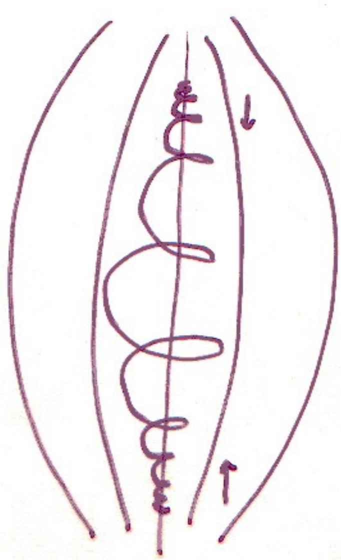


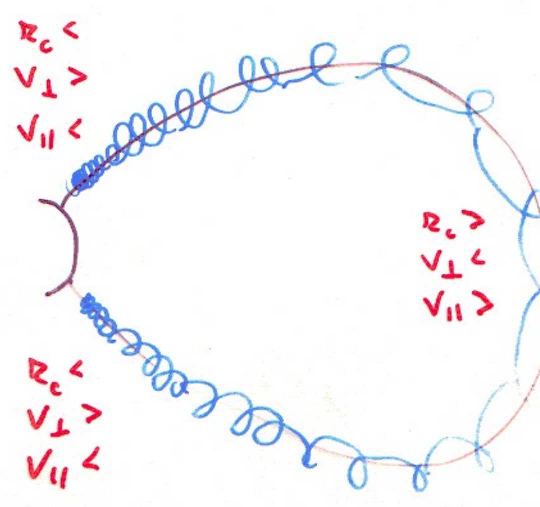



- $\frac{1}{2}\left(v_\perp^2 + v_\parallel^2\right) m$ = costante (CAMPO B NON FA LAVORO)

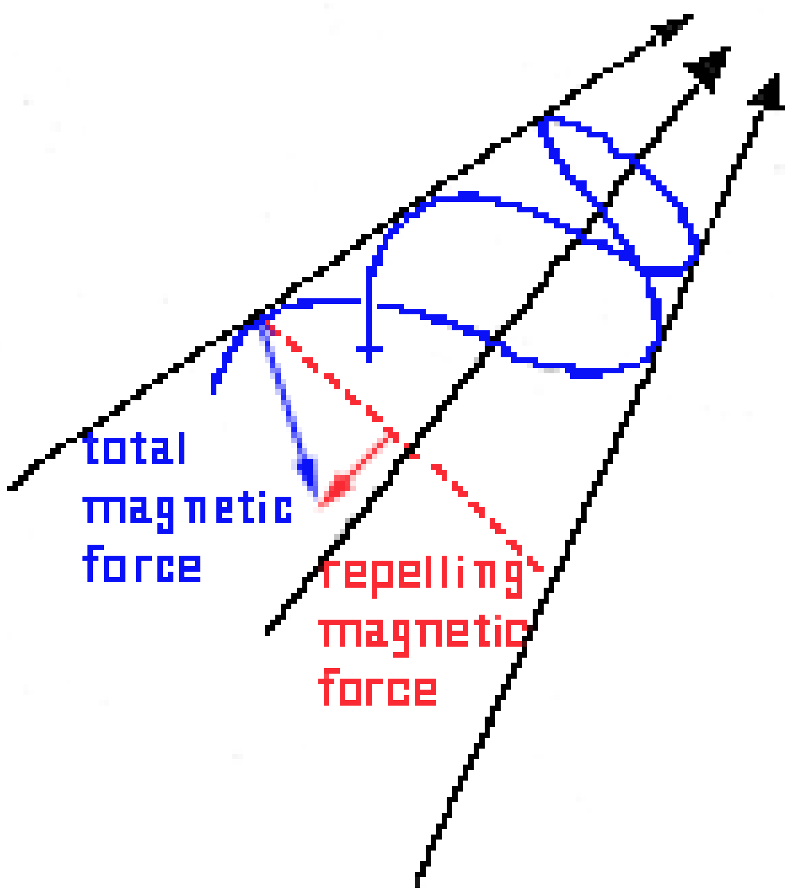
Se $B > \dfrac{1}{2}\dfrac{m v^2}{\mu}$ $\qquad v^2 = v_\perp^2 + v_\parallel^2$

PARTICELLA VIENE RIFLESSA!



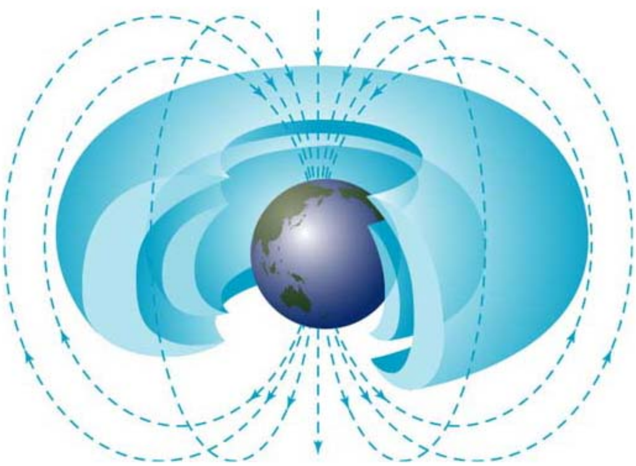


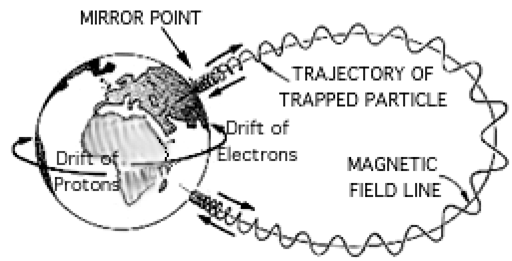
**Quando il campo magnetico è inclinato, appare una forza repulsiva (si vede scomponendo le componenti di B). La forza è infatti perpendicolare alle linee di campo.**

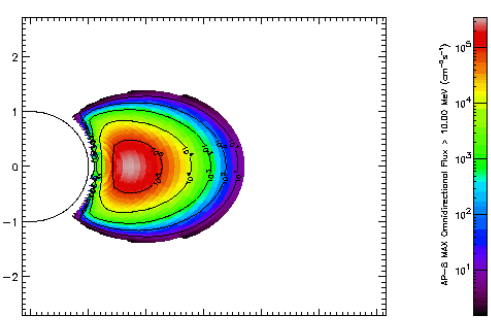


# Fasce di Van Allen

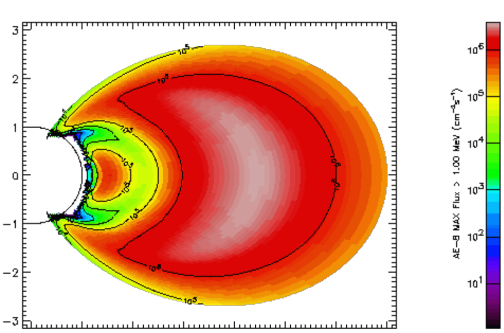
- INTERNA: R~ 1-3 $R_E$ (max. 2 $R_E$)  Composizione: $p^+$ (10-50 Mev)  $e^-$,$p^+$,$O^+$ (1-100 Kev) $N^+$,$He^+$, $C^+$ (~50 Mev)
- ESTERNA: R ~ 3-9 $R_E$ (max. 4 $R_E$)   Composizione: $e^-$ (10 Mev)





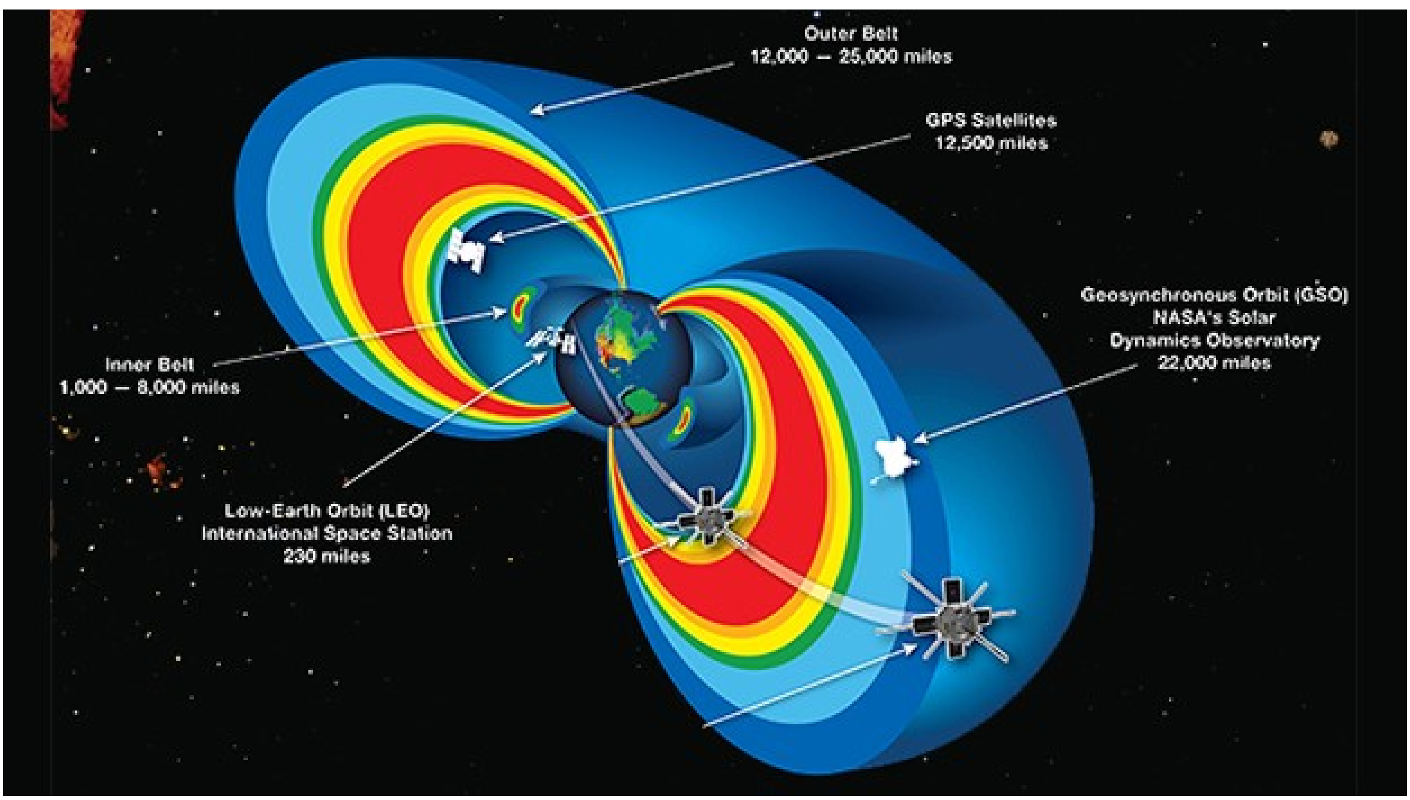



Inner proton belt

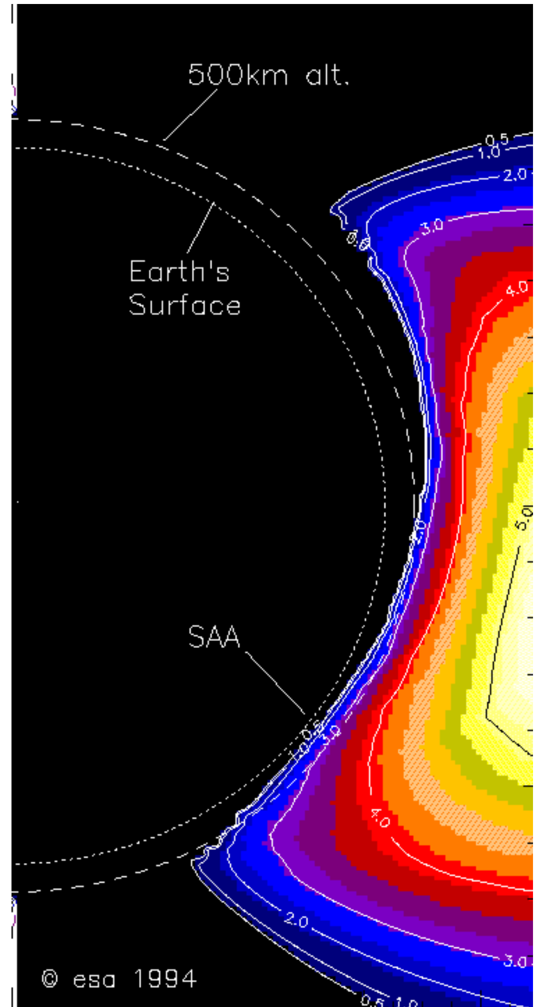


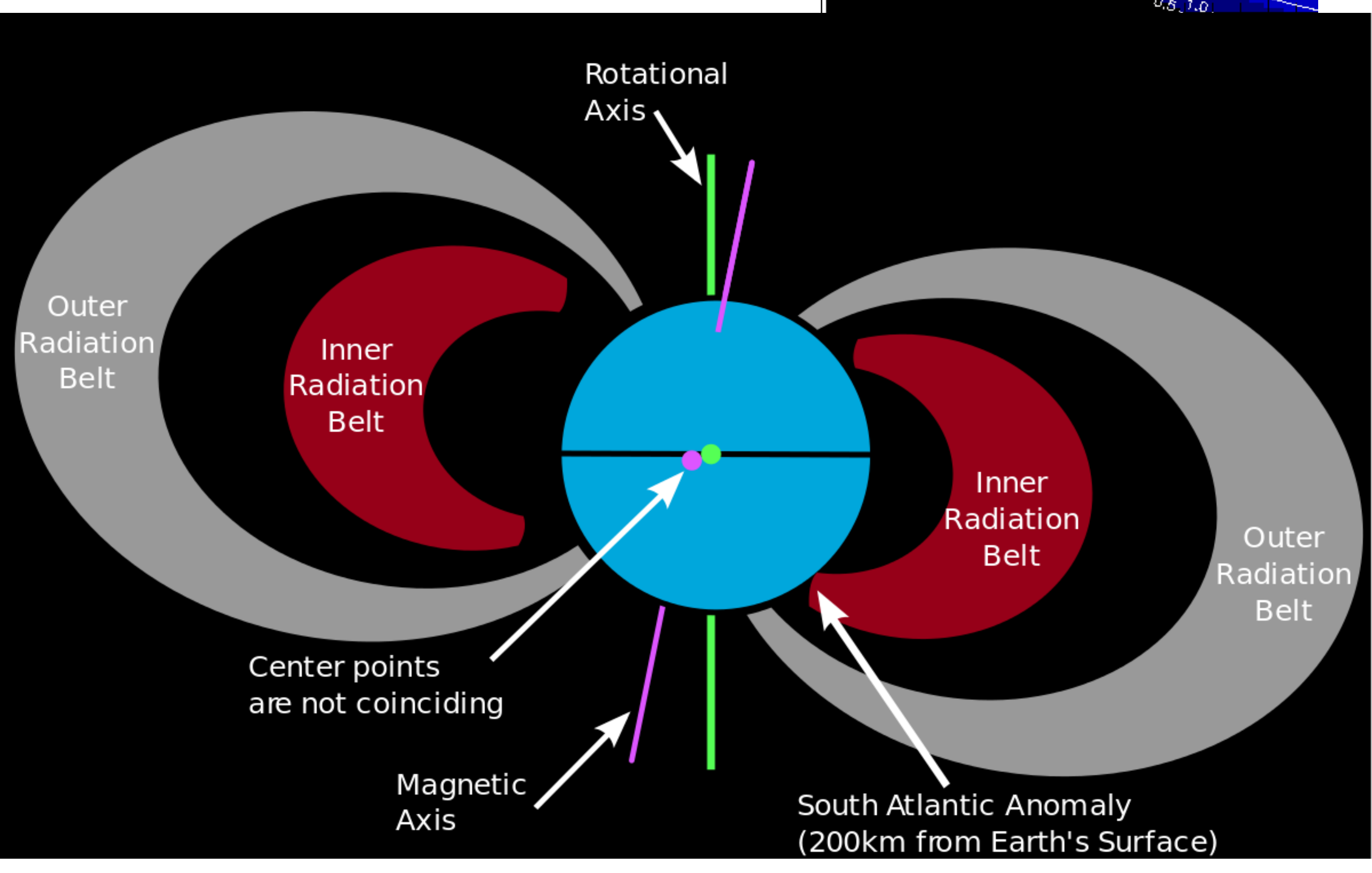
Outer electron belt

I satelliti devono orbitare fuori dalle Belts altrimenti ci sono problemi con gli strumenti elettronici.

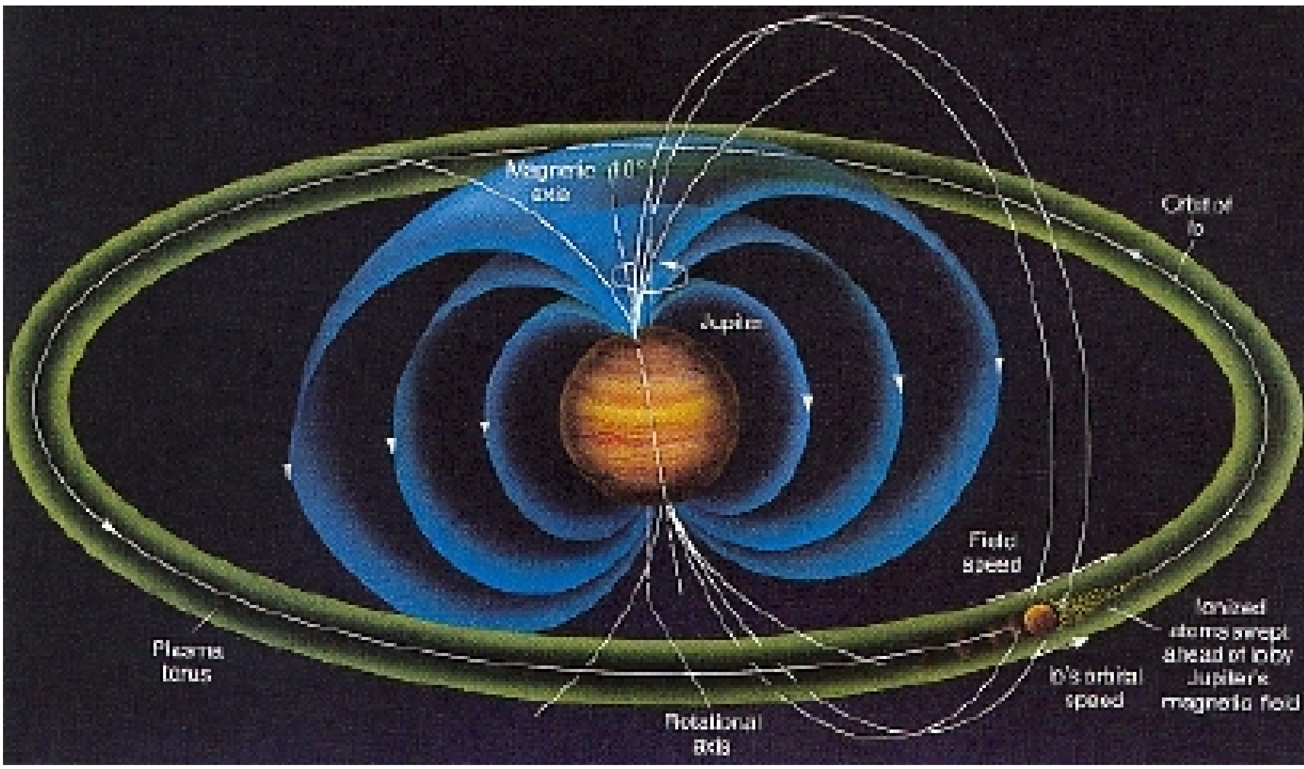


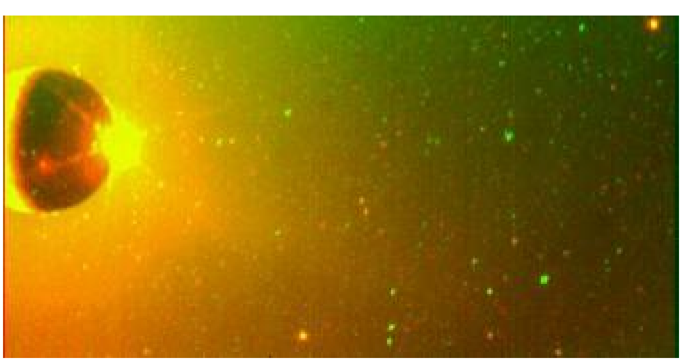
Anomalia del sud Atlantico: la fascia di Van Allen interna è allineata con il campo magnetico che è inclinato rispetto all'asse terrestre e leggermente spostato rispetto al centro della Terra. Di conseguenza al Sud la fascia di Van Allen si avvicina di più alla Terra e genera l'anomalia.  Radiazioni più intense e campo magnetico indotto dalle cariche maggiore.



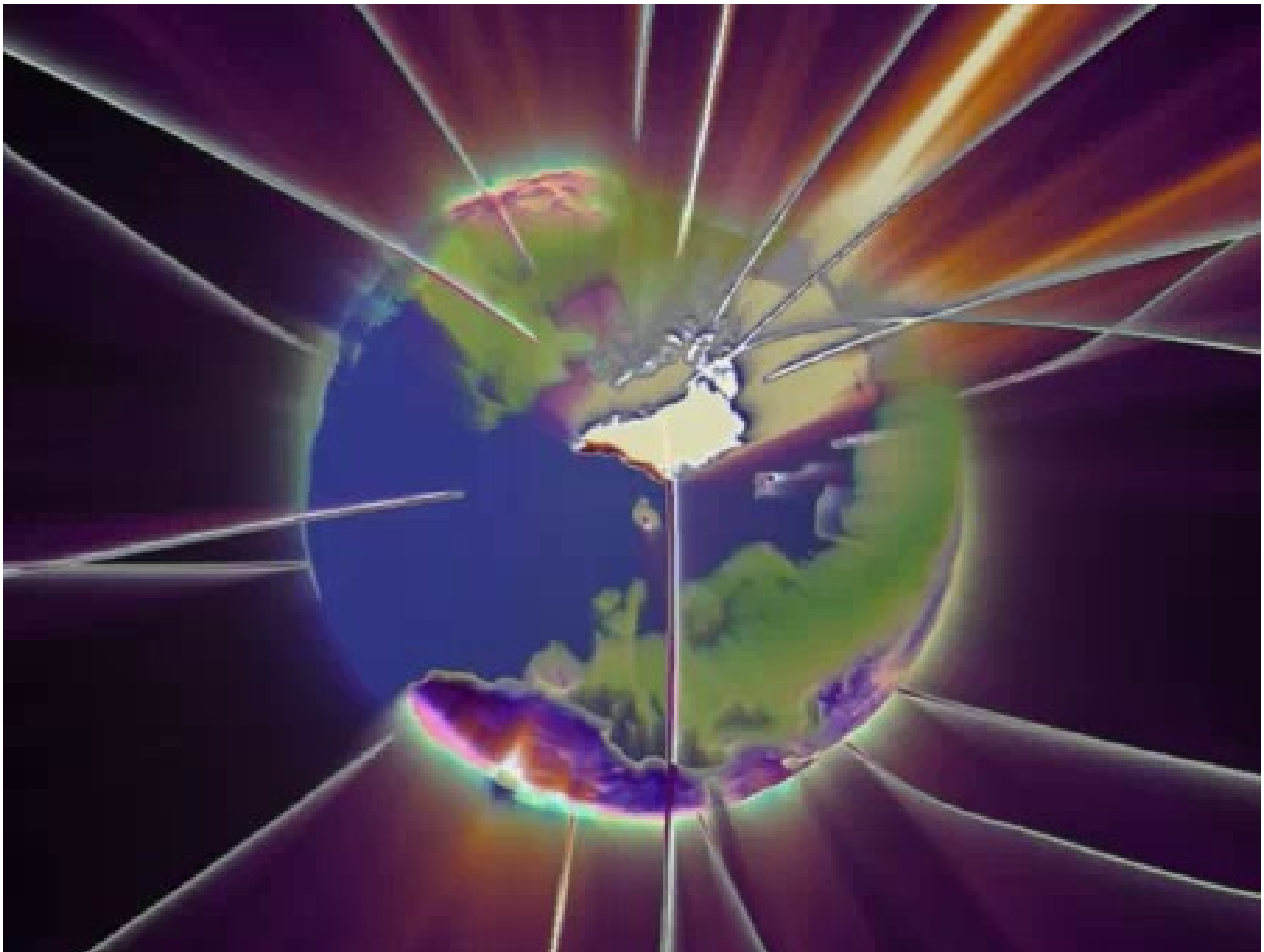
**GIOVE**: Fasce di Van Allen + Toro di plasma che circonda orbita di satellite Io (5.3-8 $R_J$, con $R_J$~71500 km)

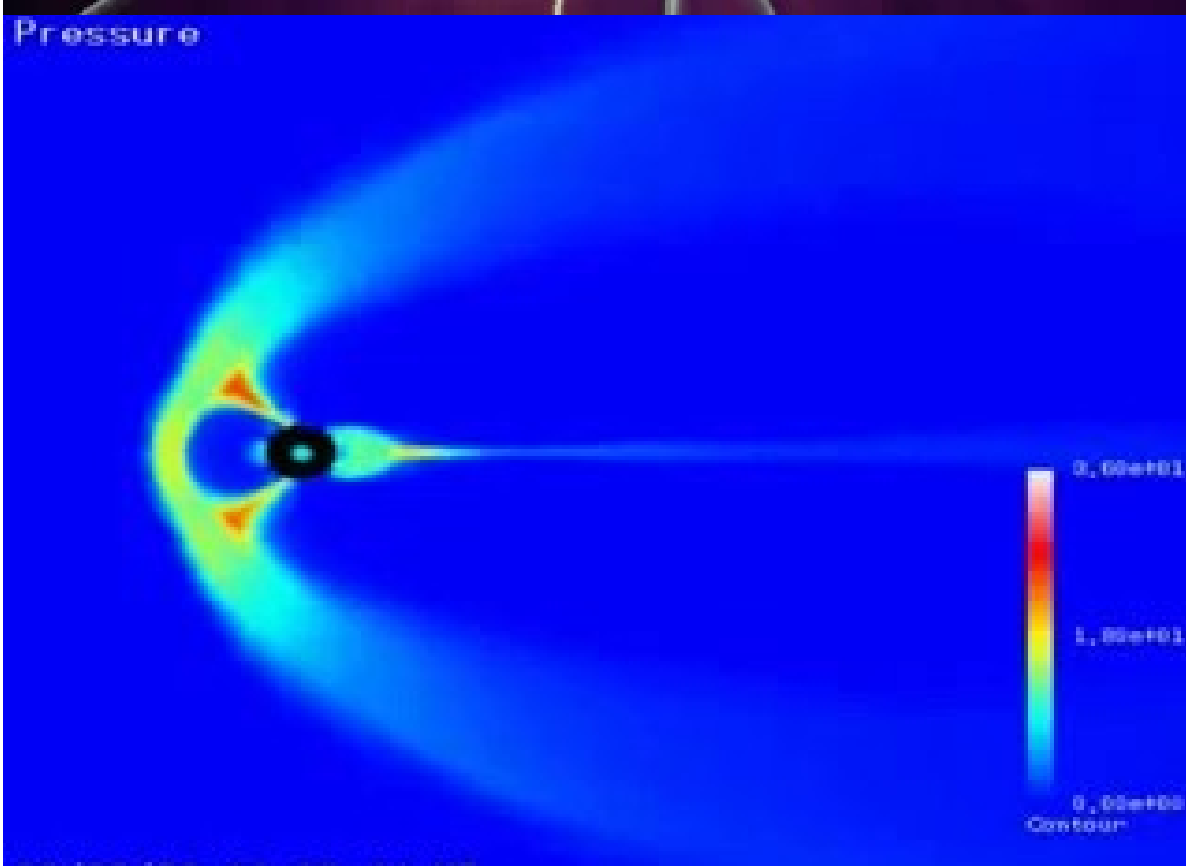


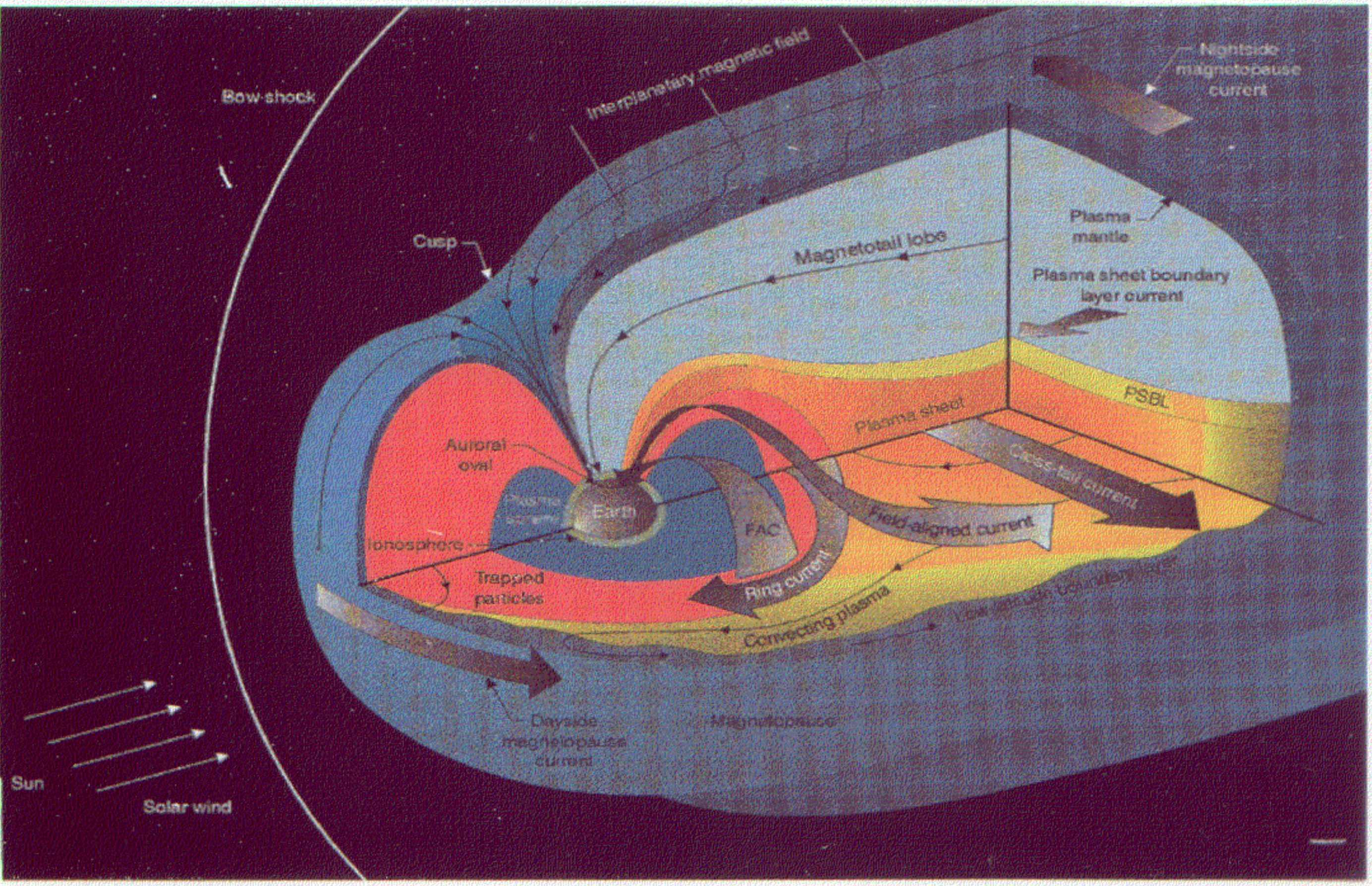
**Il toro è prodotto dall'emissione di particelle da parte di Io (attivita' vulcanica)**

# MAGNETOSFERA





# MAGNETOSFERA: derivazione delle dimensioni




Bilanciamento tra $P_{sw}$ (pressione vento solare) E pressione magnetica dovuta a campo $\bar{B}$

$m$ = massa $p^+$

$V$ = vel. del vento solare

$$\Delta p = -mV$$

$$\Delta p_{tot} = -NmV \qquad F = \frac{\Delta p_{tot}}{dt}$$


$dx = Vdt$

$$F = \frac{\Delta p_{tot}}{dt} = Nm\frac{V^2}{dx} \qquad P = \frac{F}{A}$$

$$P = \frac{NmV^2}{A \cdot dx} = \frac{N}{V} mV^2 = \rho V^2$$

$$P_{sw} \simeq \rho V^2$$

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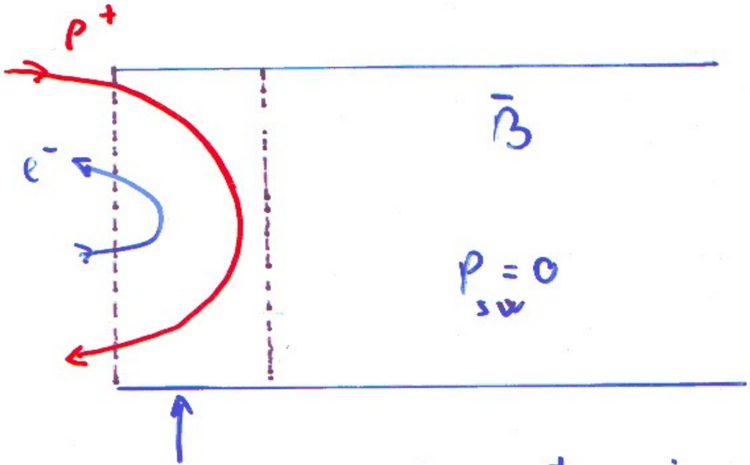


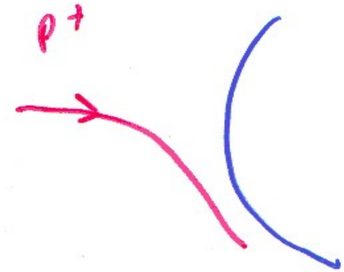


CORRENTI ⇒ $e^-$ e $p^+$ si spostano.

$$P_M = \frac{B^2}{2\mu_0} \quad \text{(da MHD)}$$

$$\rho v^2 = \frac{B^2}{2\mu_0}$$

All'equatore $B(r) = \frac{M_B}{r^3} = \frac{7.9 \times 10^{25}}{r^3}$ Gauss

$$\rho v^2 \simeq \frac{M_B^2}{2\mu_0 r^6} \Rightarrow$$

$$\boxed{r_M \simeq \left(\frac{M_B^2}{2\mu_0 \rho v^2}\right)^{\frac{1}{6}}}$$

per $\rho \simeq 5\ p^+ / cm^3$

$v \simeq 300$ Km/s

$r_M \simeq 10\ R_E$