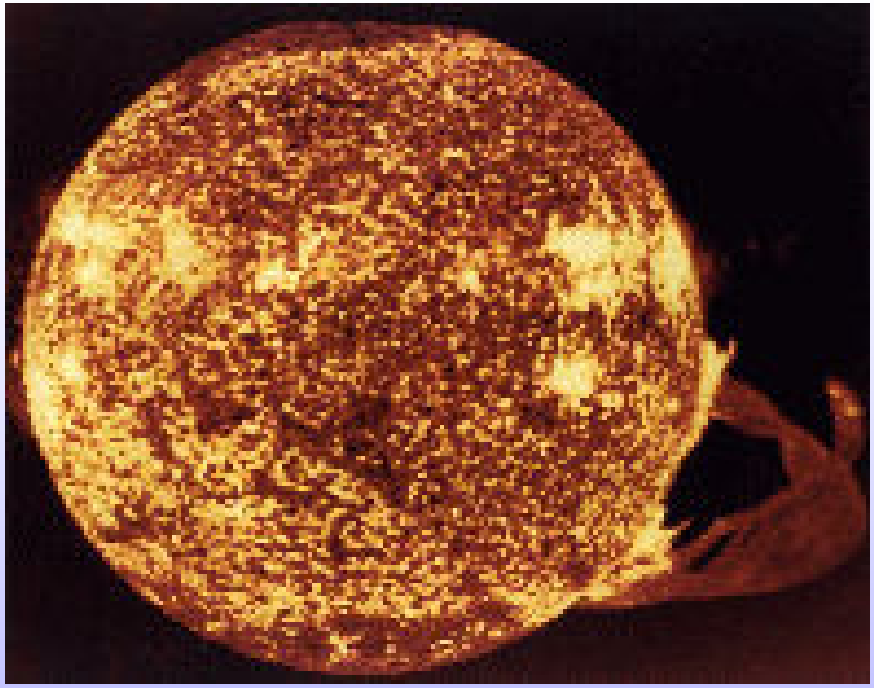
IL SOLE E L'AMBIENTE CIRCOSTANTE LA TERRA

- Il Sole
- L'atmosfera neutra
- La Ionosfera
- La Magnetosfera
- Le fasce di Van Allen

SOLE 1/6: dati



G2 V

Magnitudine = 4.8

$M_{\odot} = 2 \times 10^{30}$ kg

$R_{\odot} = 6.96 \times 10^{8}$ m *

Età = 4.5×10^{9} anni

Energia Totale = 4×10^{33} erg/s

Composizione = H *90%* - He *10%* - C,N,O *0.1%* *

$T_{core} = 1.6 \times 10^{7}$ K (se gravitazionale 2×10^{7} anni !) *

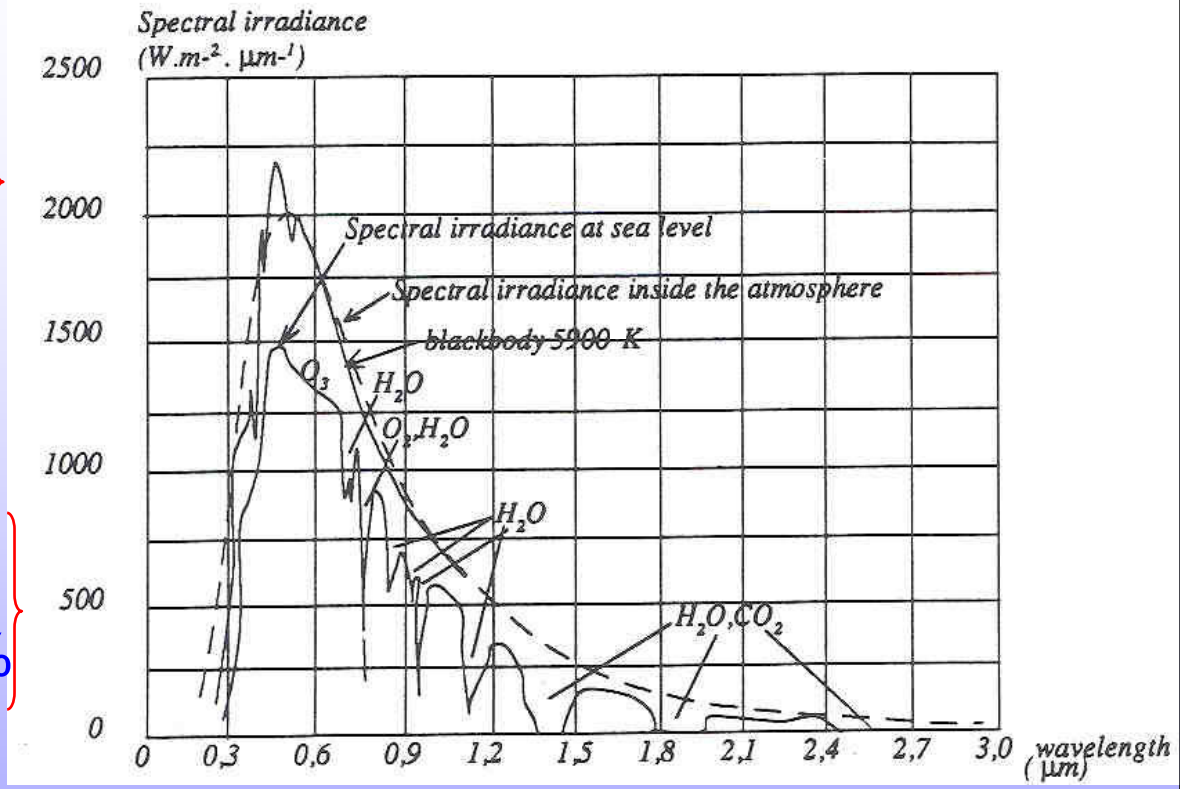
Spettro Corpo Nero T = 4600 K ("*quiet Sun*") *

Distanza Terra/Sole =1.5×10^{11} m = 1 A.U. *

SOLE 2/6: spettro

Spettro: *

InfraRosso	52 %
Visibile	41%
NUV	<7%
EUV	0.1%
Radio	0.1%
X	<0.1%



Energia sulla Terra (Costante Solare) = 1370 W/m^2 *

variazioni 1%, 1326÷1418 W/m^2 $\Rightarrow$ Δ T ~ 1 %

Δ /anno ~ – 0.018 %

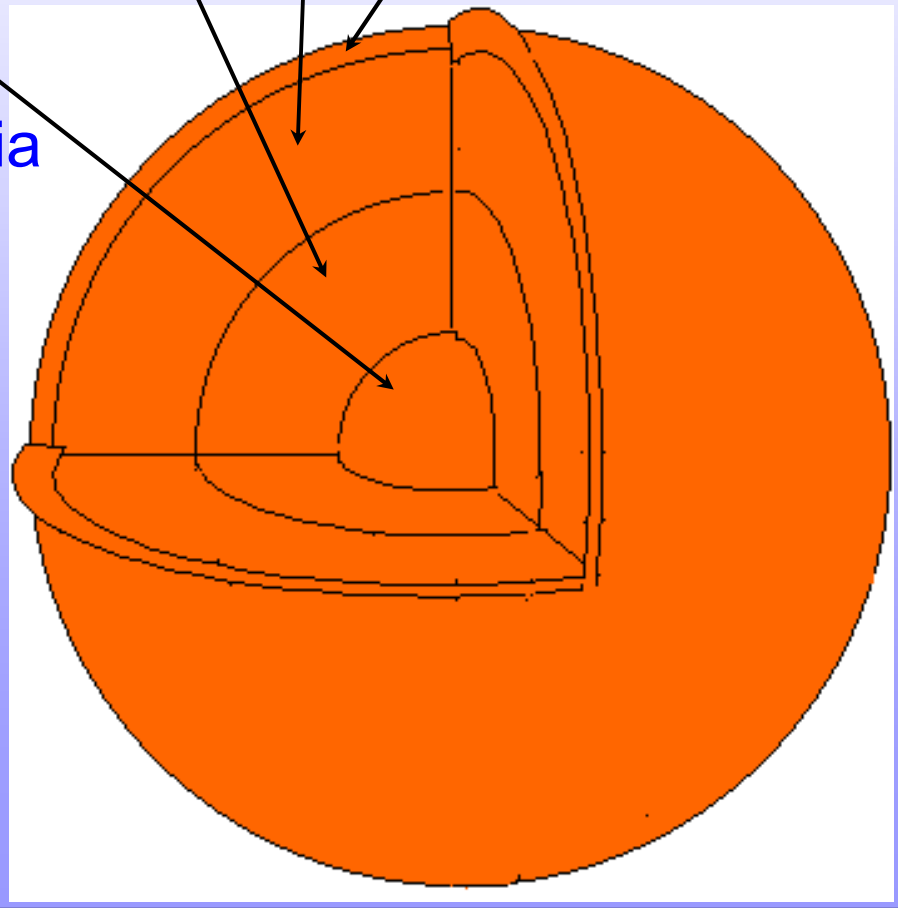
SOLE 3/6: struttura

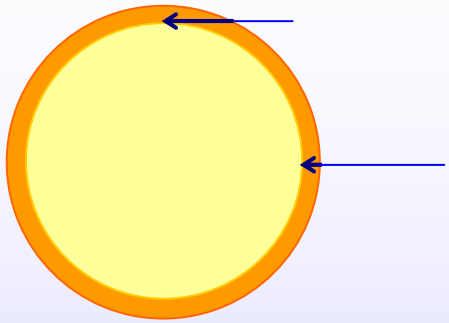
zona convettiva **
6×10^3 K, $R_\odot$

zona radiativa *
5×10^5 K, 0.86 $R_\odot$

fotosfera **
4×10^3 K

core *
1×10^7 K, $R_\odot/4$,
$M_\odot/2$, 99% energia





cromosfera *
T >>, 10 $R_\odot$,
$n\sim10^{10}$ p/cm^3

coronosfera *
T >> / T<<,
2×10^6 K,
sistema solare
$n\sim10^5$ p/cm^3

SOLE 4/6: attività solare

w_{eq} ~ 2.9 $\times 10^{-6}$ rad/s * (T ~ 24.9 giorni)
w_{poli} ~ 2.0 $\times 10^{-6}$ rad/s * (T ~ 31.5 giorni)

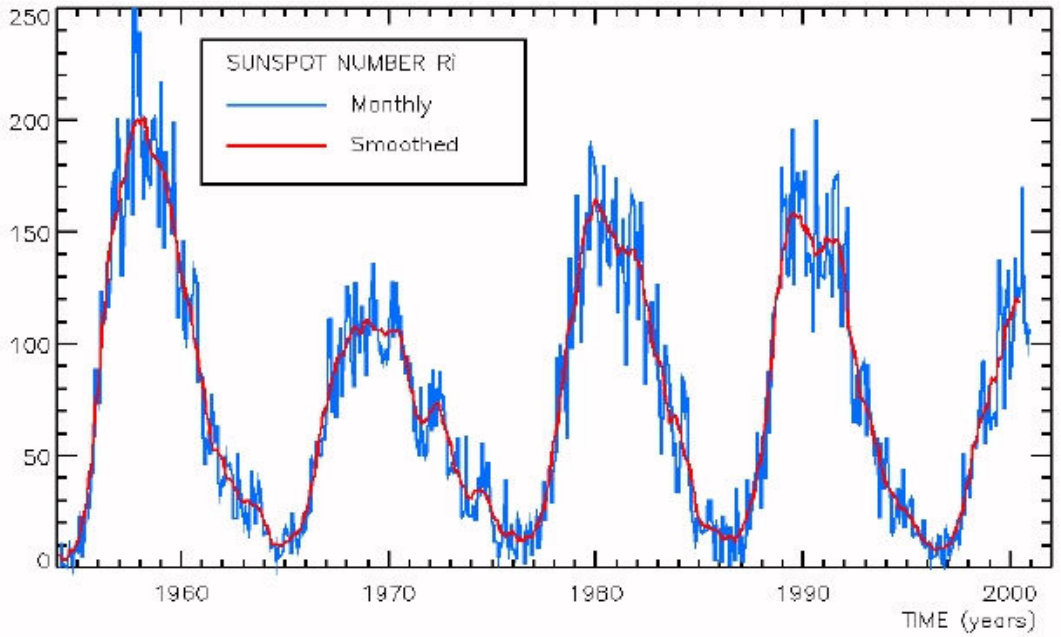
Campo Magnetico (superficie) ~ 1÷3 G ... 1000 G

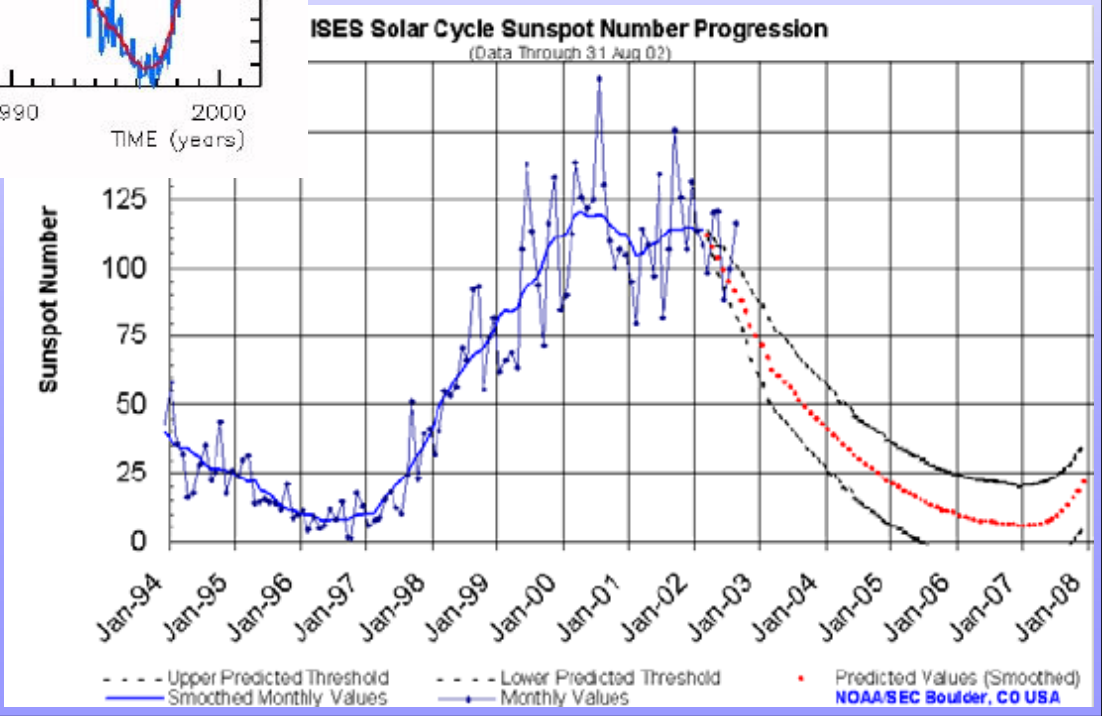
$\Rightarrow$ ATTIVITA' SOLARE 7÷13 anni

Granuli ∅ ~ 1000 km, h ~ 0 km, τ ~ 8 min
Mesogranuli ∅ ~ 7000 km
Supergranuli ∅ ~ 30000 km, h ~ 15000 km, τ ~ 1 ora
Granuli giganti ∅ ~ 200000 km
Macchie solari ∅ ~ 300÷2500 km (1000 G)
Plages, Facula, Spicules, Prominences, Flares *

SOLE 5/6: attività solare

http://science.nasa.gov/ssl/pad/solar/default.htm





Trieste, 14-15 Maggio 2006

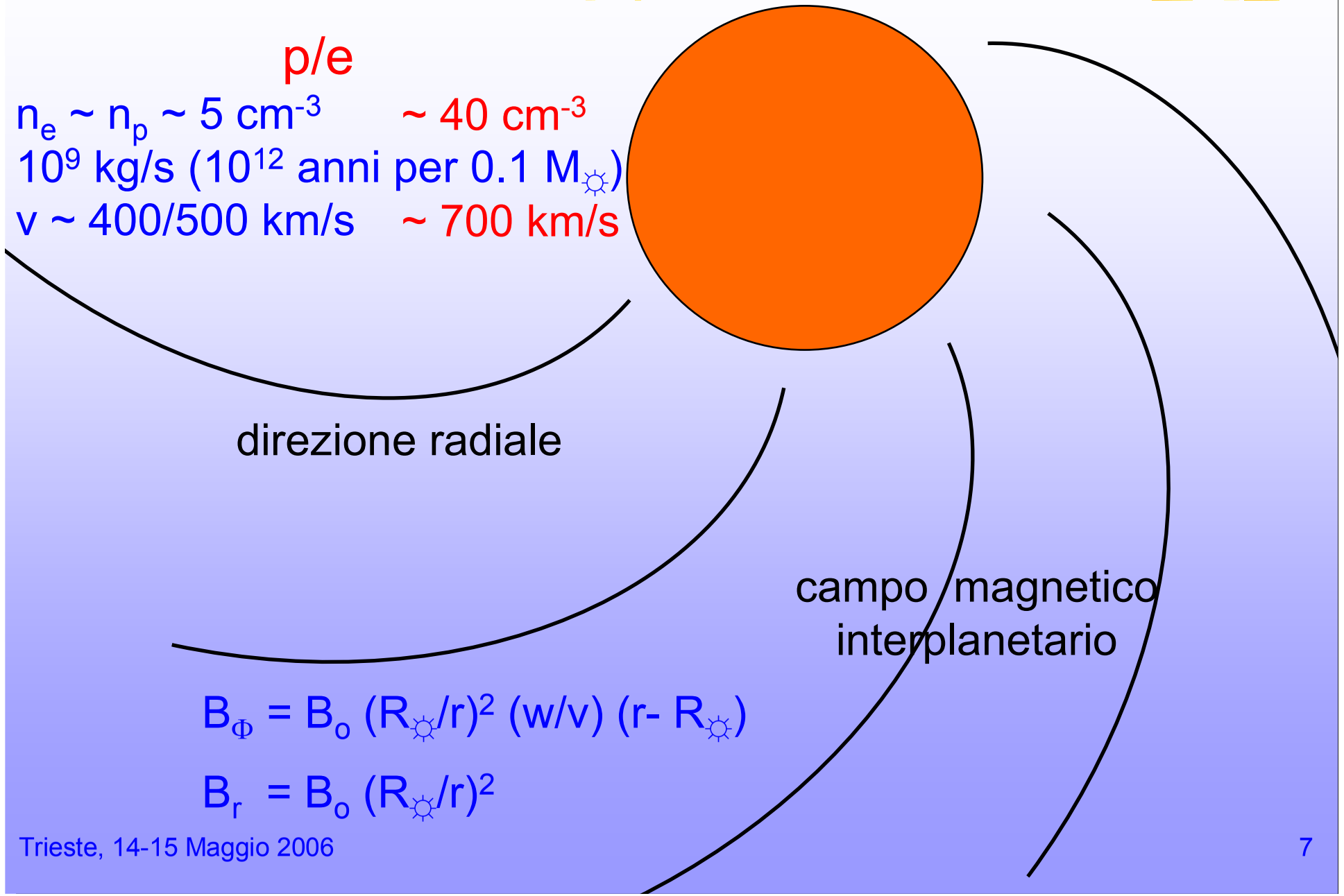
SOLE 6/6: vento solare

p/e

$n_e \sim n_p \sim 5\ cm^{-3}$ $\sim 40\ cm^{-3}$

10^9 kg/s (10^{12} anni per 0.1 $M_\odot$)

v ~ 400/500 km/s ~ 700 km/s



direzione radiale

campo magnetico interplanetario

$$B_\Phi = B_o (R_\odot/r)^2 (w/v) (r- R_\odot)$$

$$B_r = B_o (R_\odot/r)^2$$

Atmosfera Neutra 1/3

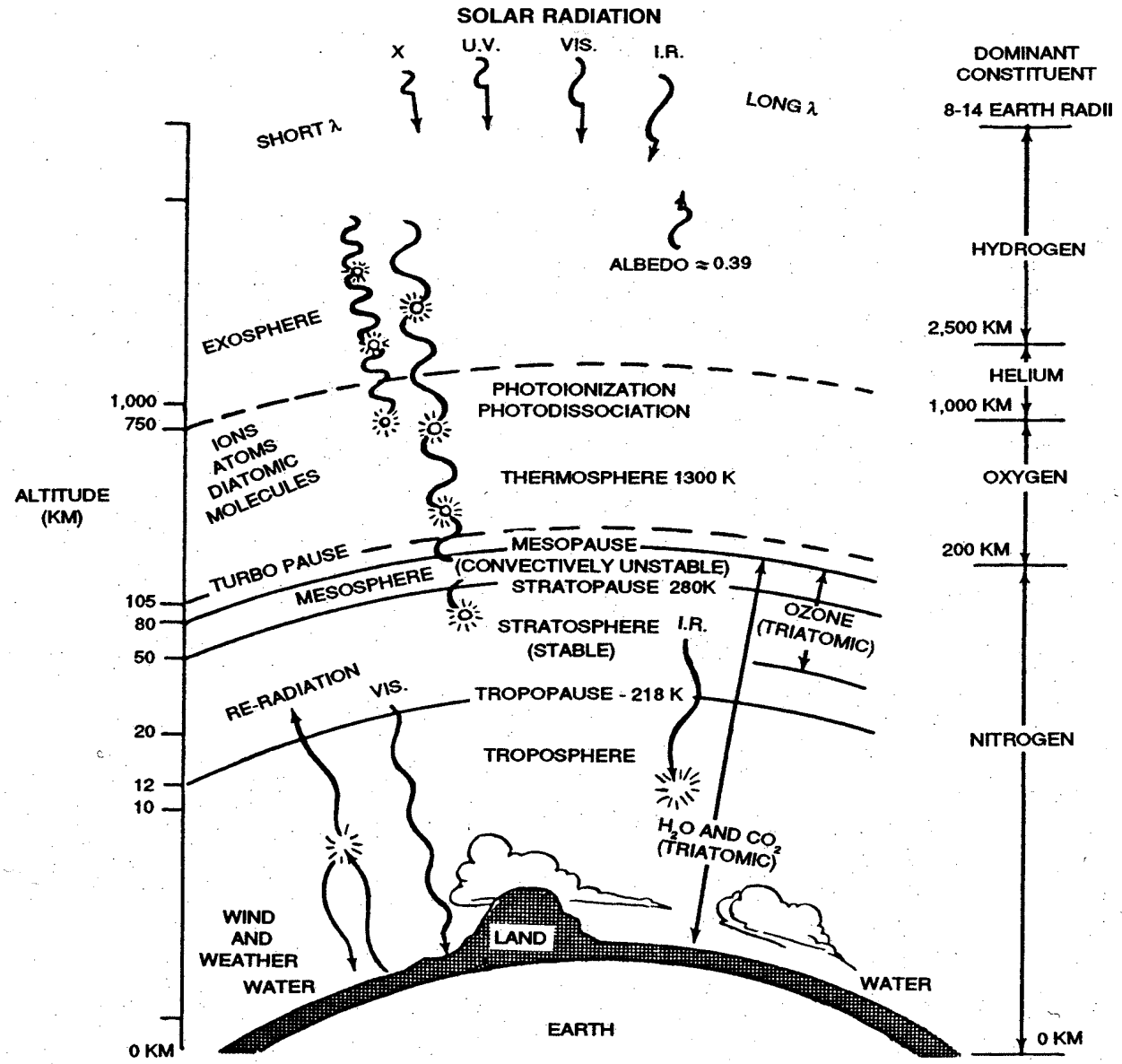


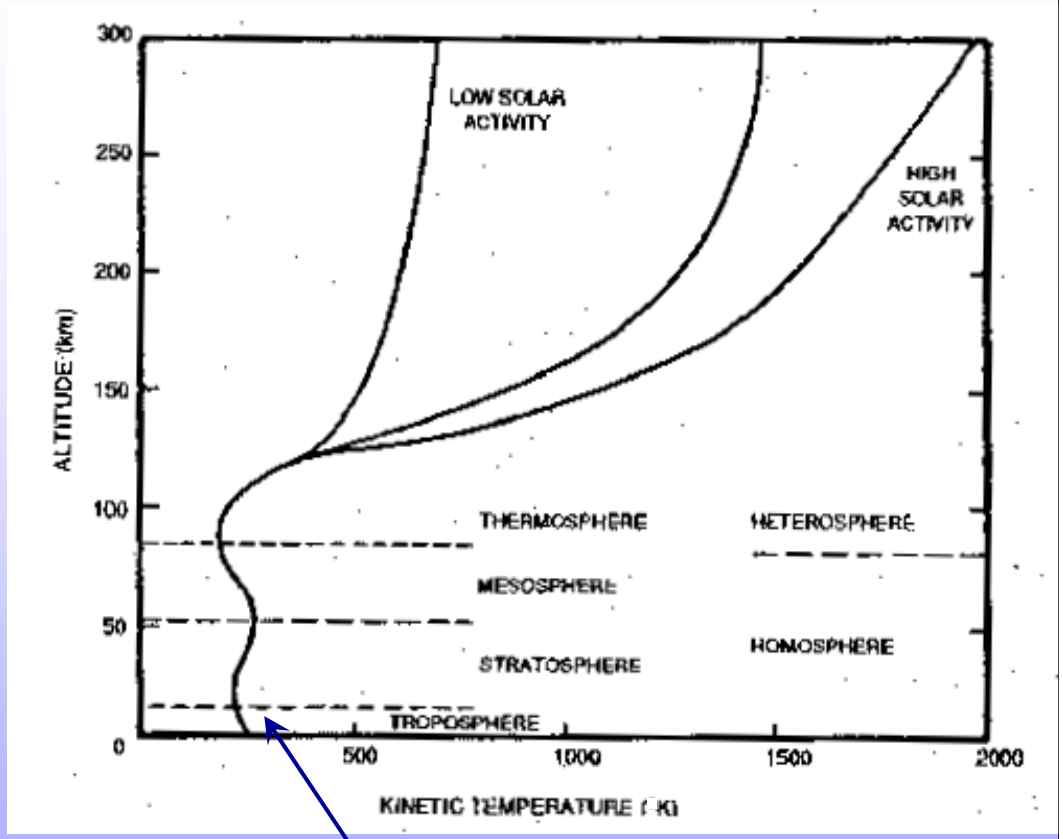
Figure 6.2 Atmospheric chemical regimes *(after Carpenter et al., 1978)*.

Atmosfera Neutra 2/3

Suddivisione per

- temperatura *cinetica**:
  - Troposfera
  - Stratosfera
  - Mesosfera
  - Termosfera

- composizione:
  - Omosfera
  - Eterosfera

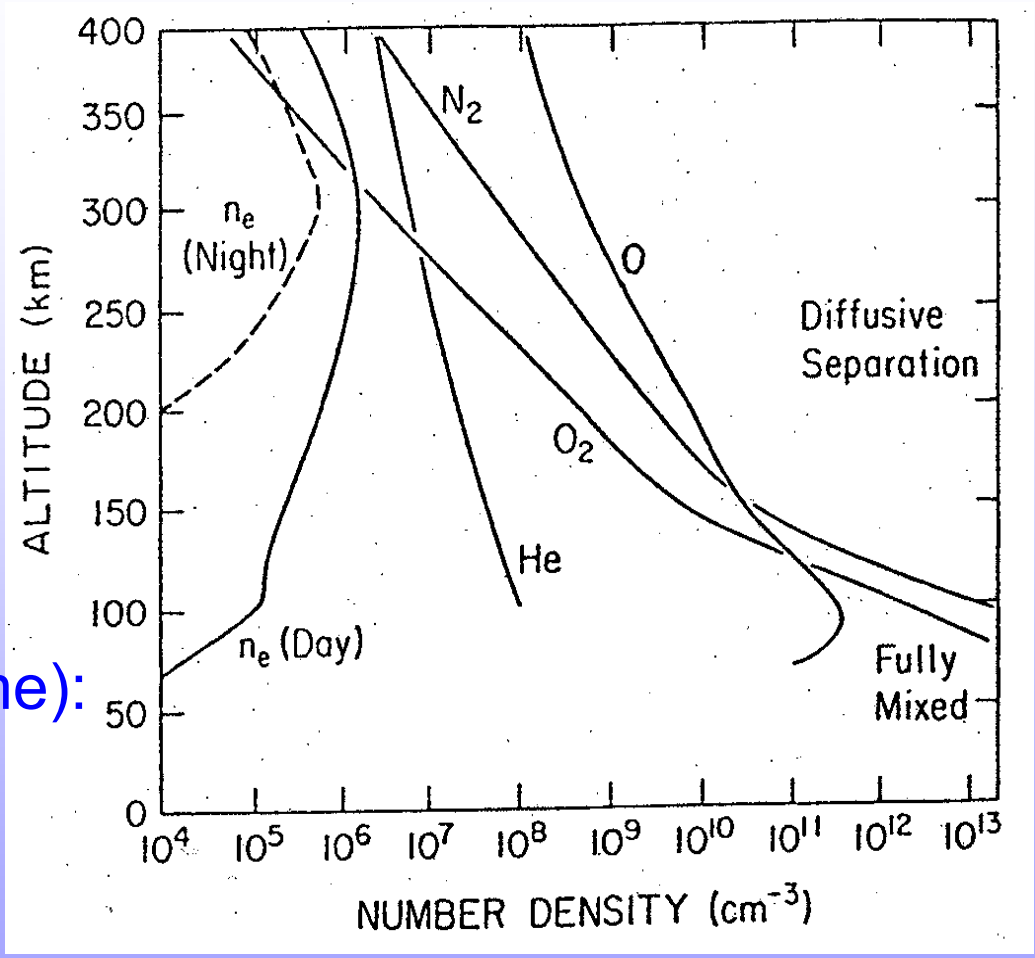


$\Delta T \sim 6.5^{o}$ C/km

Atmosfera Neutra 3/3

Composizione chimica:

- Azoto N_2
- Ossigeno O_2, O
- He
- n_e

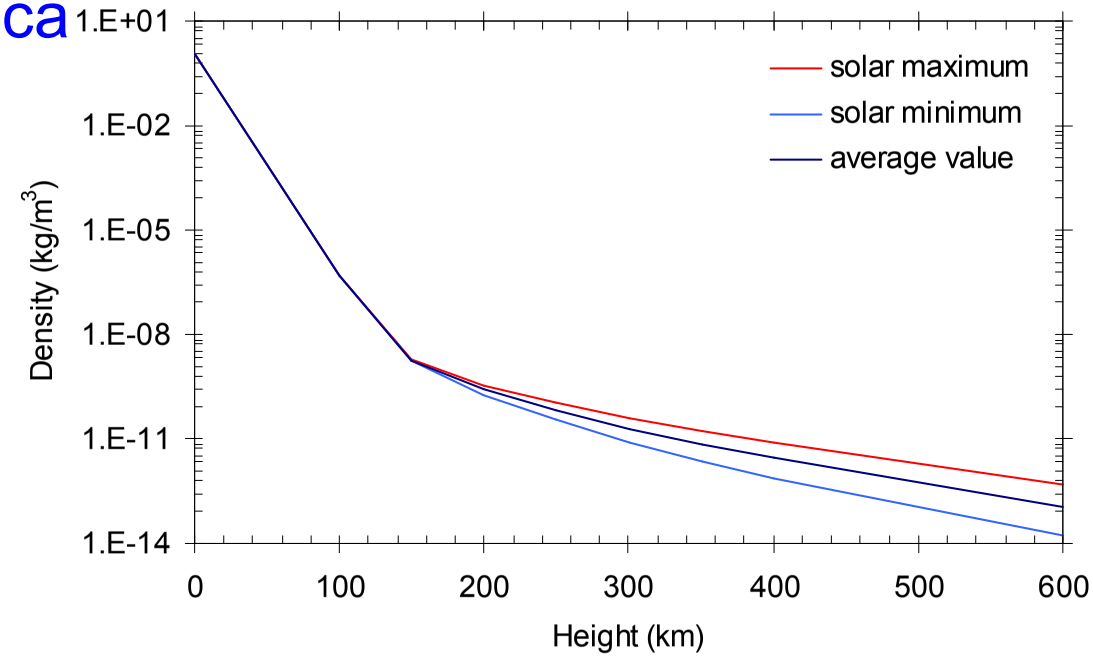


Fino a ~100 km (volume):

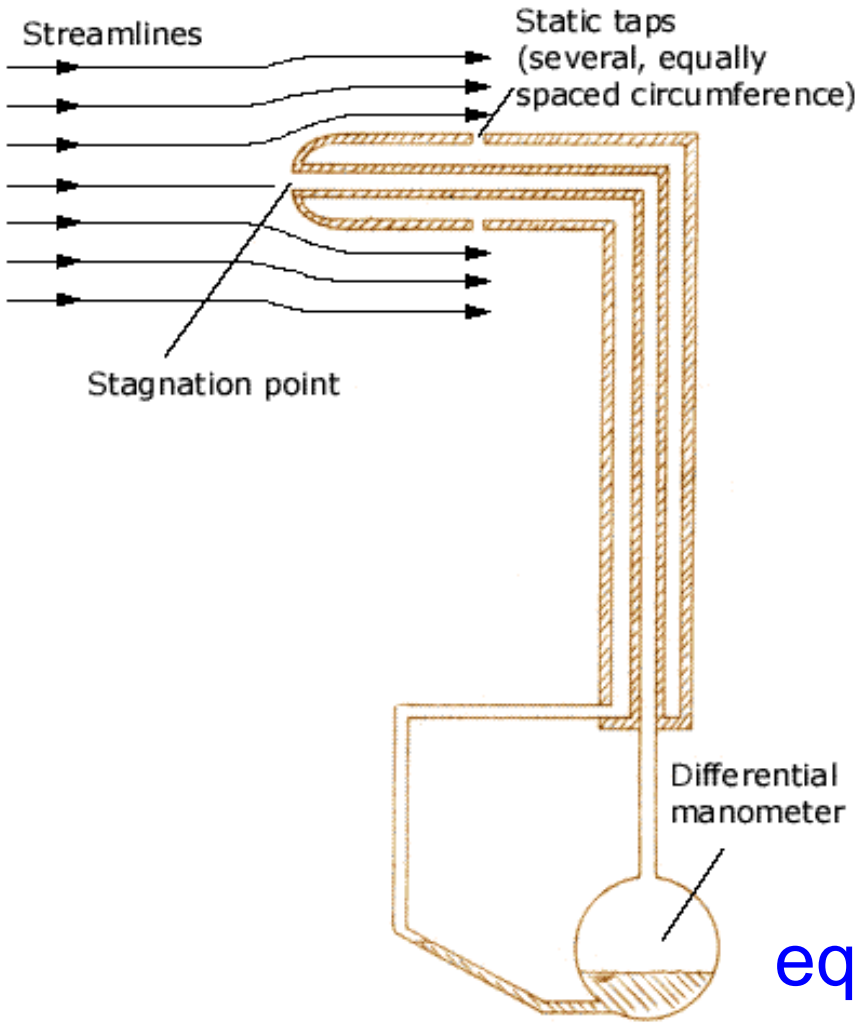
78.08%	N_2
20.95%	O_2
0.93%	Ar

Misure atmosferiche: ρ, v, T

- Pallone (30÷35 km)
- Razzi Sonda
  - Esplosioni
  - Rilascio di Traccianti (Na)
  - Tubi di Pitot
  - Equazione Barometrica
- Satellite
  - Misure orbitali
  - Strumenti



Tubo di Pitot



$$\Delta p = \rho_{Hg}\, g\, \Delta h$$

$$p_1 = p + \rho\, v^2 / 2 \Rightarrow$$

$$\Delta p = \rho\, v^2 / 2$$

$$\Downarrow$$

v, ρ

eq. Bernoulli

$$p_A + \rho g z_A + \rho v_A^2/2 = p_B + \rho g z_B + \rho v_B^2/2 = \text{cost.}$$

Equazione Barometrica

$$F_g = \mu g' = G M\mu / R^2 = G M\mu /(R_T+h)^2 =$$

$$= GM/R_T^2 \; \mu R_T^2 / (R_T+h)^2 = \mu g R_T^2/(R_T+h)^2 =$$

$$\Rightarrow g' = g R_T^2 / (R_T+h)^2$$

Stratosfera:

D ~ 7 km, h ~ h'

$$E = \mu g' h = \mu h g R_T^2/(R_T+h)^2 = \mu g h'$$

$$\Rightarrow h' = h R_T^2 / (R_T+h)^2 = \text{altezza geopotenziale}$$

$dN = N\rho(E)dE = e^{-E/kT}dE = e^{-\mu g h'/kT}$ (statistica di Boltzmann)

$\rho(E) \sim e^{-E/kT} = e^{-\mu g(h_1'-h_2')/kT}$ (statistica di Boltzmann)

$n_1/n_2 = e^{-\mu g(h_1'-h_2')/kT}$

~ 29, h<100 km

$\Rightarrow \log(n_1/n_2) = -\mu g(h_1'-h_2')/kT = -d/D$ eq. Barometrica

μ ~ 16, h<1000 km

$D = kT/\mu g$ = altezza di scala, $d = h_1'-h_2'$

~ 4, h>1000 km

OZONO 1/2

Strato fra (30÷50) km

$$O + O_2 + M \rightarrow O_3 + M'$$

$\rho \sim 0.001\%$ (volume)

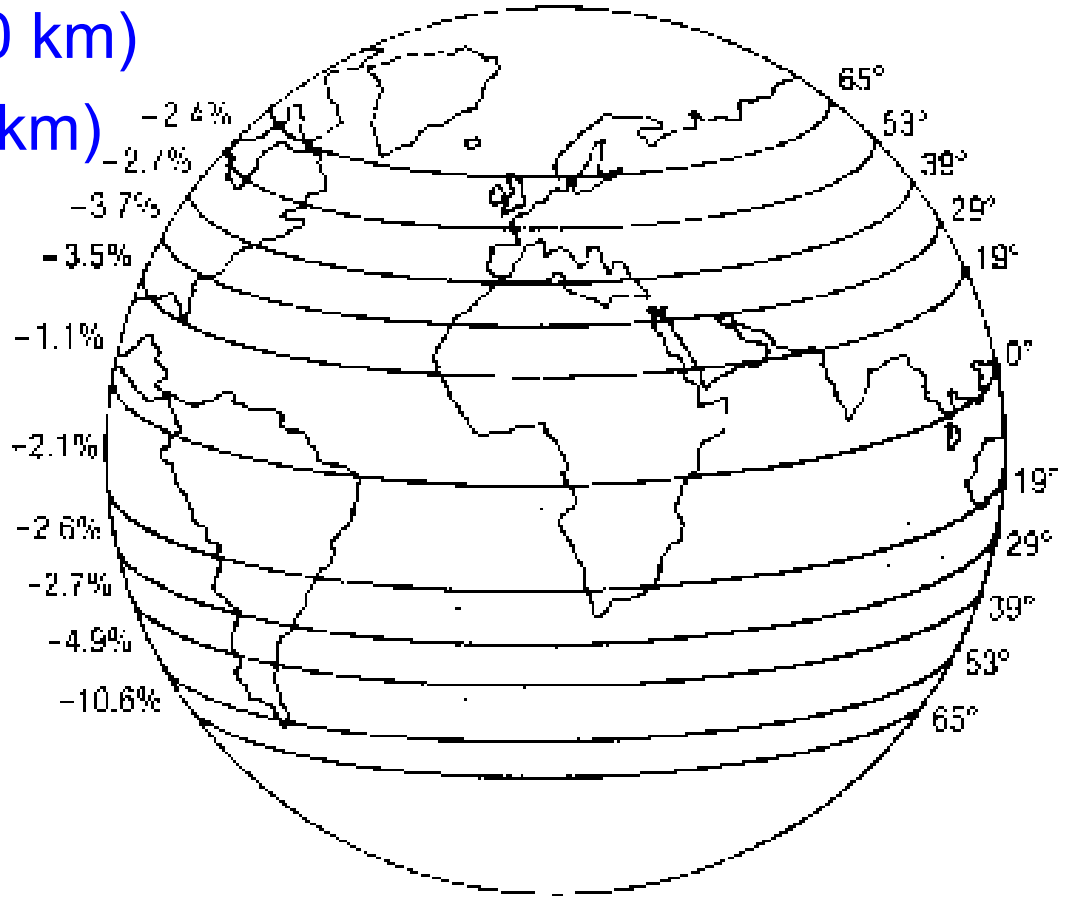
$\lambda < 1760$ Å (h ~ 100 km)

$\lambda < 2420$ Å (h ~ 40 km)

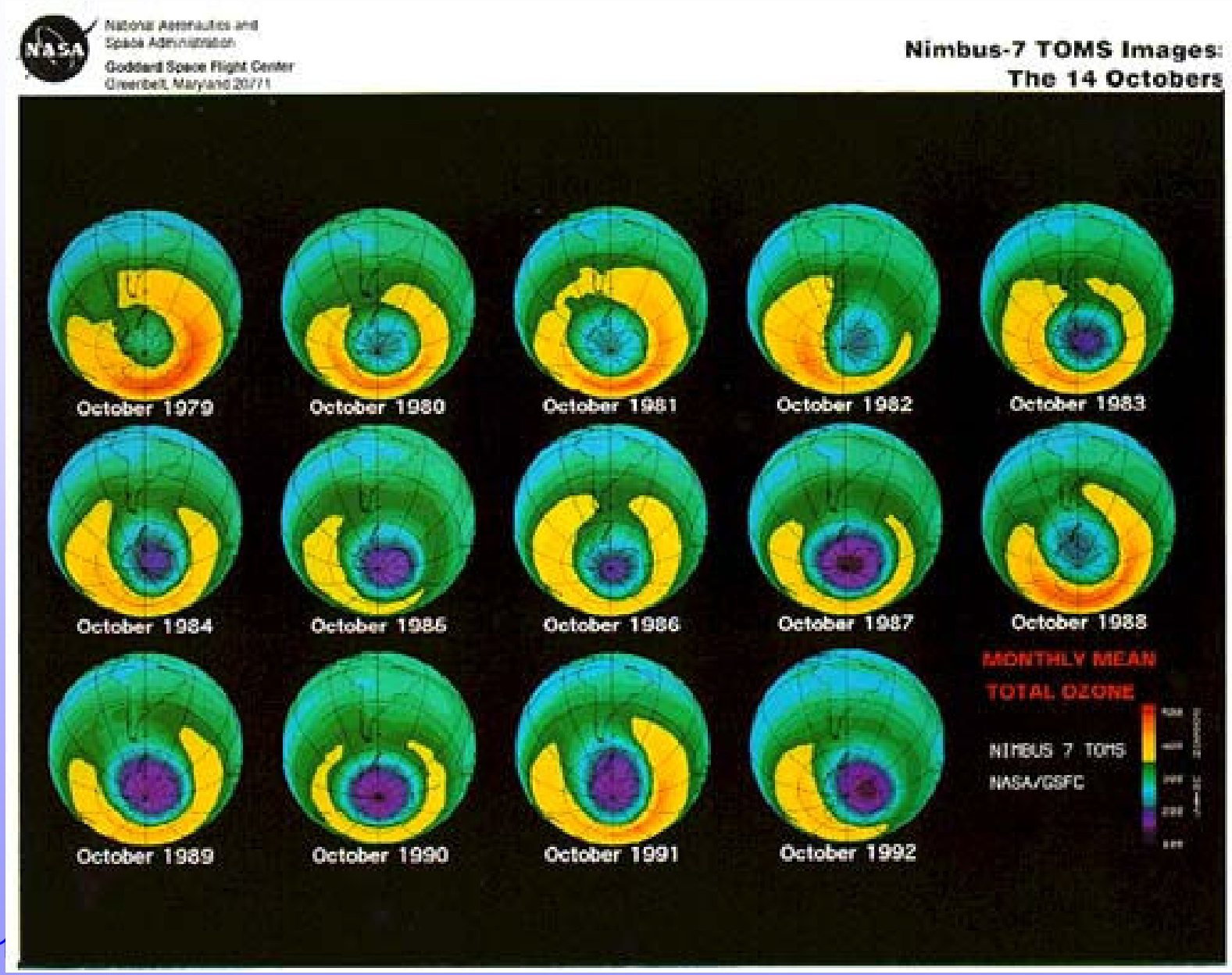
SAGE
(Stratospheric Aerosol and Gas Experiment)

TOMS
(Total Ozone Mapping Spectrometer)

1979:
Antartide



OZONO 2/2


National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
Nimbus-7 TOMS Images:
The 14 Octobers
October 1979
October 1980
October 1981
October 1982
October 1983
October 1984
October 1985
October 1986
October 1987
October 1988
MONTHLY MEAN
TOTAL OZONE
NIMBUS 7 TOMS
NASA/GSFC
October 1989
October 1990
October 1991
October 1992

Airglow

luminescenza atmosferica prodotta dall'ossigeno* (100÷160) km:

$O + O + M \rightarrow O_2' + M'$

$O_2' + O \rightarrow O_2 + O'$

λ = 5577 Å
(aurorale, verde,
h ~ 100 km)

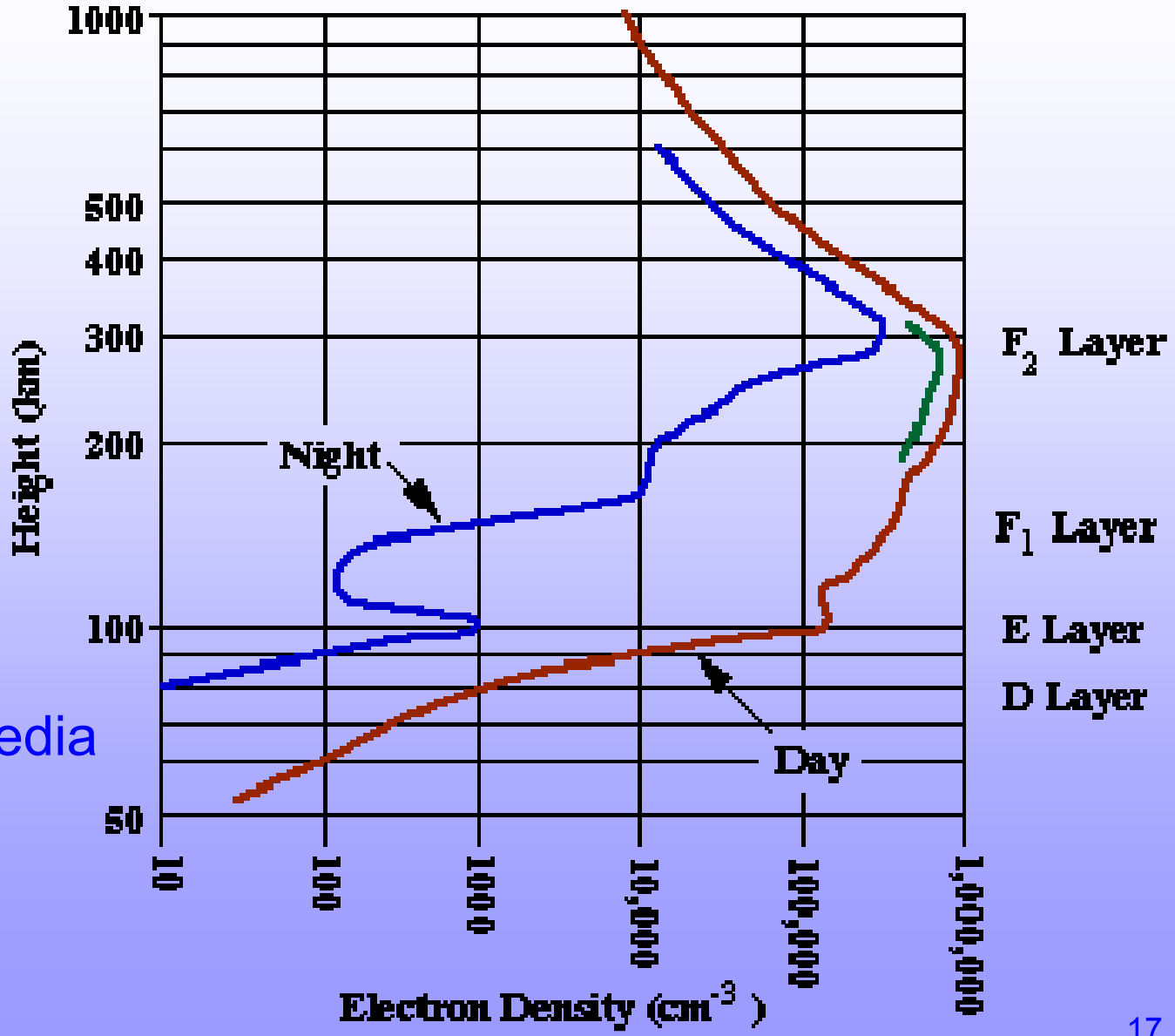
λ = 6300, 6364, 6391 Å (nebulari,
tripletto rosso, h ~160 km)

Ionosfera 1/4

Strato conduttivo

1901: Marconi

- estate
- latitudine intermedia
- massimo solare



Ionosfera 2/4: Disturbi

- Maree e Venti Atmosferici
  - Strato D, E
- SID (Sudden Ionospheric Disturbances)
  - Strato D (onde corte)
- Tempeste Ionosferiche
  - Strato D (alta frequenza)
- Tempesta Aurorale

Ionosfera 3/4

Processi di produzione e rimozione e^-

- Produzione
  - $A + \gamma \rightarrow A^+ + e^-$ (fotoionizzazione)

D (NO): Ly-α (1216 Å)* + raggi cosmici + SID

E (O_2, NO, O): X molli (10-100 Å) + EUV (<912 Å)

F (O): EUV (100-912 Å)

- Ricombinazione: $n_{ione} \sim n_e \Rightarrow$ prob. $\sim n_e^2$
  - $A^+ + e^- \rightarrow A' + \gamma$ (r. associativa)
  - $BC^+ + e^- \rightarrow B' + C'$ (r. dissociativa)
  - $D + e^- \rightarrow D^-$ (r. associativa)*
  - $O^+ + O_2 \rightarrow O + O_2^+$; $O_2^+ + e^- \rightarrow O' + O'$ (scambio di carica)

D

F*

Ionosfera 4/4: Densità Elettroniche

$\log(n_{i,1}/n_{i,2}) = -\mu_i g(h_1'-h_2') / k(T_i+T_e) = -d/D$

$h>1000$ km

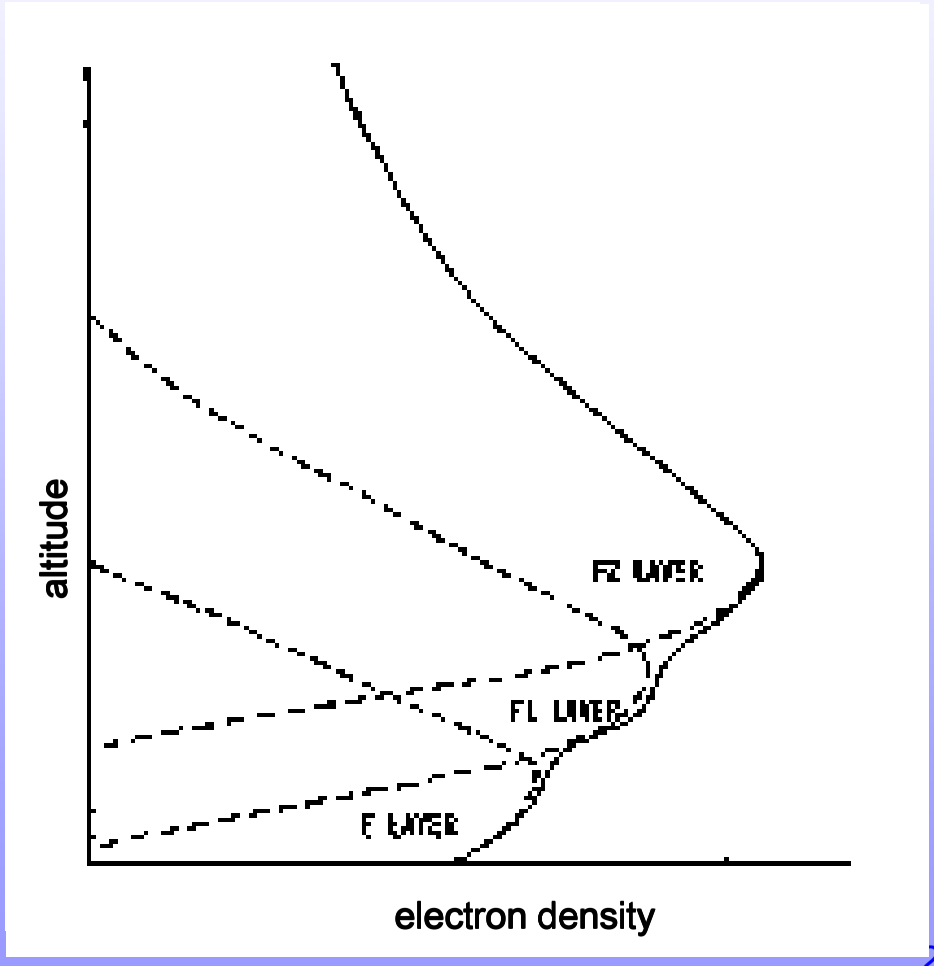
$D=k(T_i+T_e)/\mu_i g$

$\text{Log } n_e = -\text{Log}(e)\ d/D$

$d = -D\ \text{Log } n_e/\text{Log}(e) =$

$d = -2.3\ D\ \text{Log } n_e$

O^+ / He^+



Onde Radio VS Ionosfera 1/2

Assorbimento energia / Rifrazione dell'onda

$$u = \frac{c}{\sqrt{1 - e^2 n_e / \pi m_e \nu^2}}$$

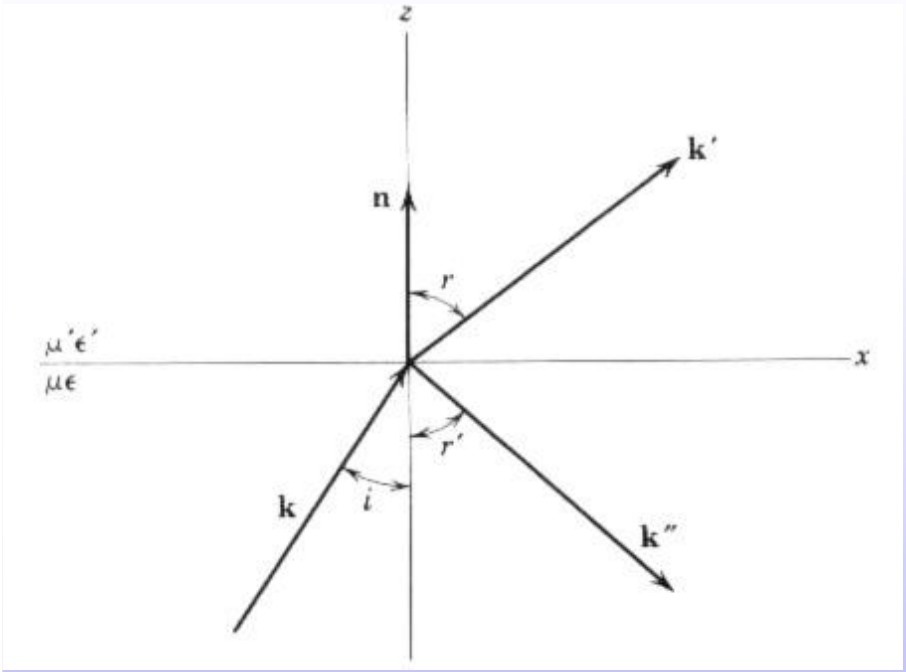
$$n = c/u = \sqrt{1 - 8.06\times10^{-5}\, n_e / \nu^2}$$

n_e in cm^{-3}, ν in MHz

$$n_e^c = 1.24\times10^4\, \nu^2 \cdot \cos^2 i$$

$$\nu^c = 8.98\times10^{-3} \sqrt{n_e} / \cos i$$

Ottica 1/2



$$n = (\mu\varepsilon)^{1/2}$$

$$\sin i / \sin r = n' / n$$

$$\mu = \text{cost}$$

$$\varepsilon = E_{\text{vacuum}} / E_{\text{iono}}$$

Ionosfera: plasma di elettroni, tenue, intrappolato in un forte campo magnetico B_o, statico ed uniforme

$$m\, d^2x/dt^2 + e/c\, B_o x\, dx/dt = -e\, E\, e^{-i\omega t}$$

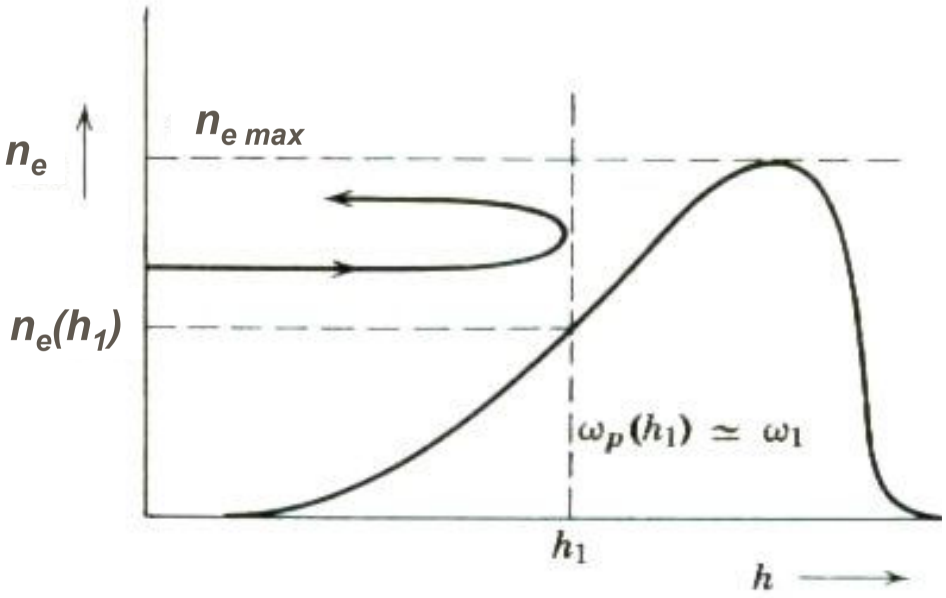
Ottica 2/2

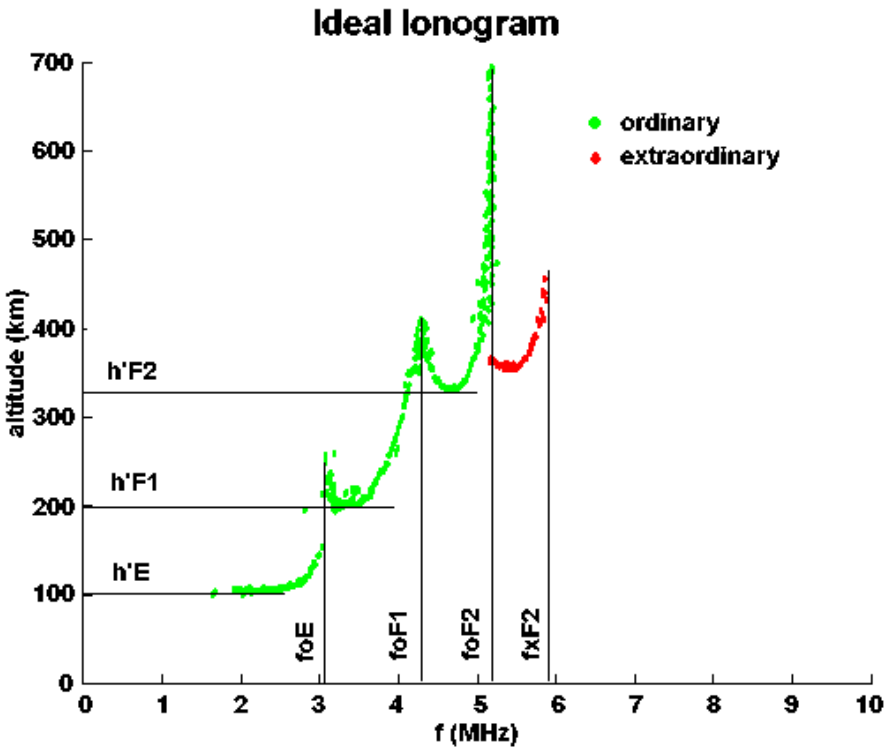
$\varepsilon_{\pm} = 1 - \omega_p^2 / \omega(\omega \pm \omega_B)$ (+/- pol. circolare dx/sx)

$\omega_B = eB_0 / mc \sim 6\times10^6\ s^{-1}$

$\omega_p^2 = 4\pi\, NZ\, e^2 / m \sim 6\times10^6 \div 6\times10^7\ s^{-1}$

n_e





Onde Radio VS Ionosfera 2/2

Description	Frequency	Wavelength
High frequency	3 - 30MHz	100 - 10m
VHF	50 - 100MHz	6 - 3m
UHF	400 -1000MHz	75 - 30cm
Microwaves	3×10^9 - 10^{11}Hz	10cm - 3mm
Millimetre waves	$10^{11} - 10^{12}$Hz	3mm - 0.3mm
Infrared	$10^{12} - 6 \times 10^{14}$Hz	0.3mm - 0.5μm
Light	$6 \times 10^{14} - 8 \times 10^{14}$Hz	0.5 μm - 0.4μm
Ultra-violet	$8 \times 10^{14} - 10^{17}$Hz	0.4μm - 10^{-9}m
X-rays	$10^{17} - 10^{19}$Hz	10^{-9}m - 10^{-13}m
Gamma rays	$> 10^{19}$Hz	$< 10^{-13}$m

valutare

n_e^c

valutare

ν^c

Layer / n_e (cm^{-3})	Night	Day
D	1.E+02	1.E+03
E	1.E+03	1.E+05
F1	1.E+04	3.E+05
F2	2.E+05	1.E+06

Esercizio

Assumete (per $|z-z_0| \leq D$)

$$n_e(z) = a\left[1 - \left(\frac{z - z_0}{D}\right)^2\right]$$

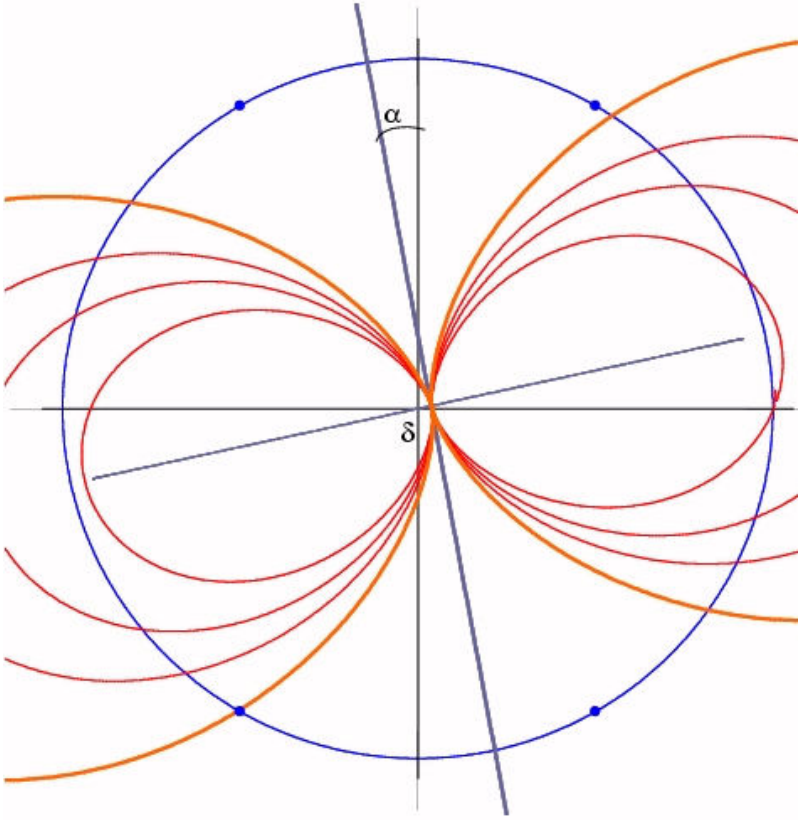
con:

$a = 10^{12}\ m^{-3}$
$z_0 = 300$ km
$D = 200$ km

1. valutare la densita' di distribuzione degli elettroni (grf: n_e vs h, h vs n_e, – n_e Log scale)
2. calcolate analiticamente l'altezza di riflessione per onde radio che si propagano verticalmente verso l'alto

Magnetosfera 1/3: dipolo magnetico

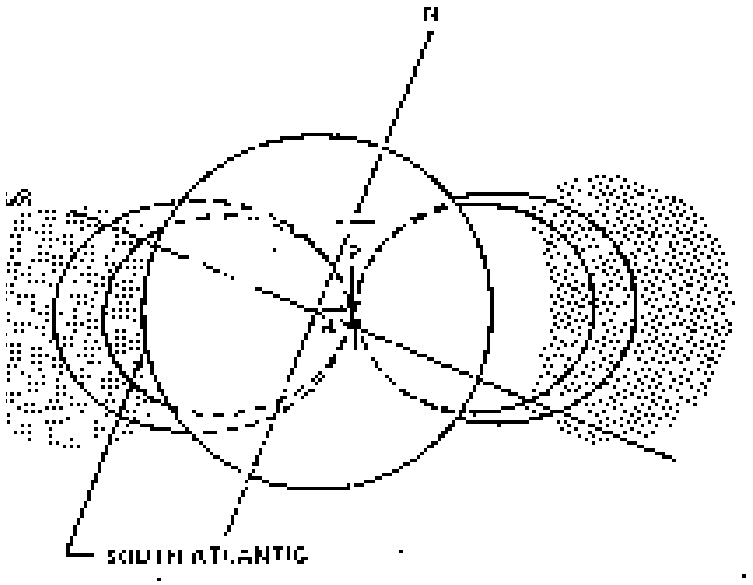
- $B_{poli} \sim (0.65 \div 0.70)$ G
- $B_{eq} \sim (0.30 \div 0.35)$ G
- $B(r,\lambda) = B_o \sqrt{1 + \sin^2 \lambda} / r^3$ *



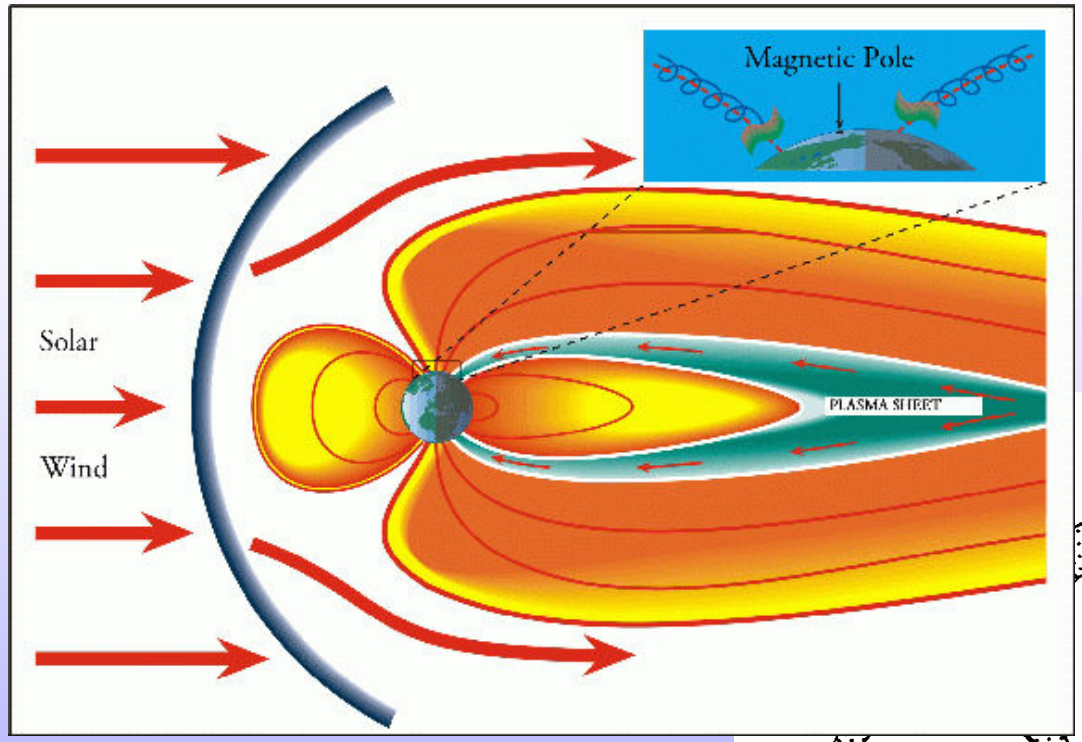
Variazioni:

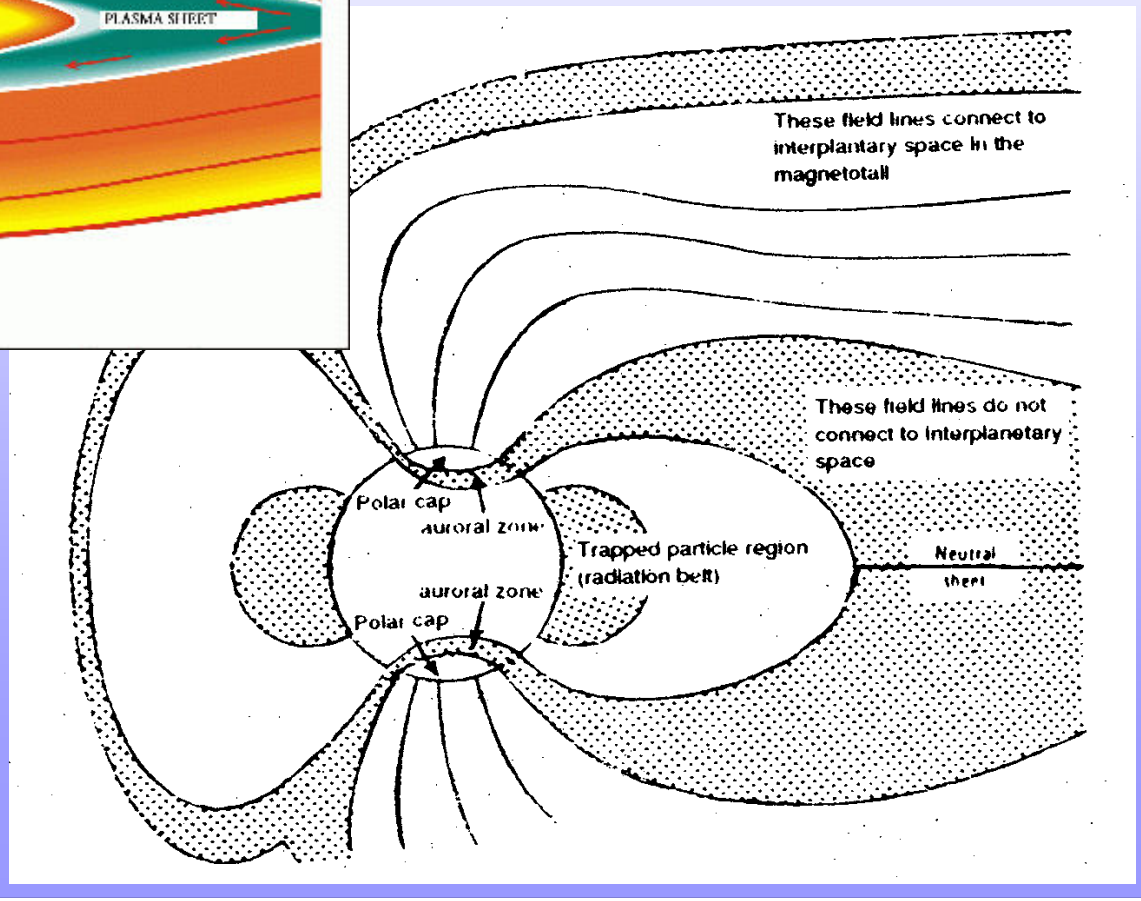
Scalari

Transienti

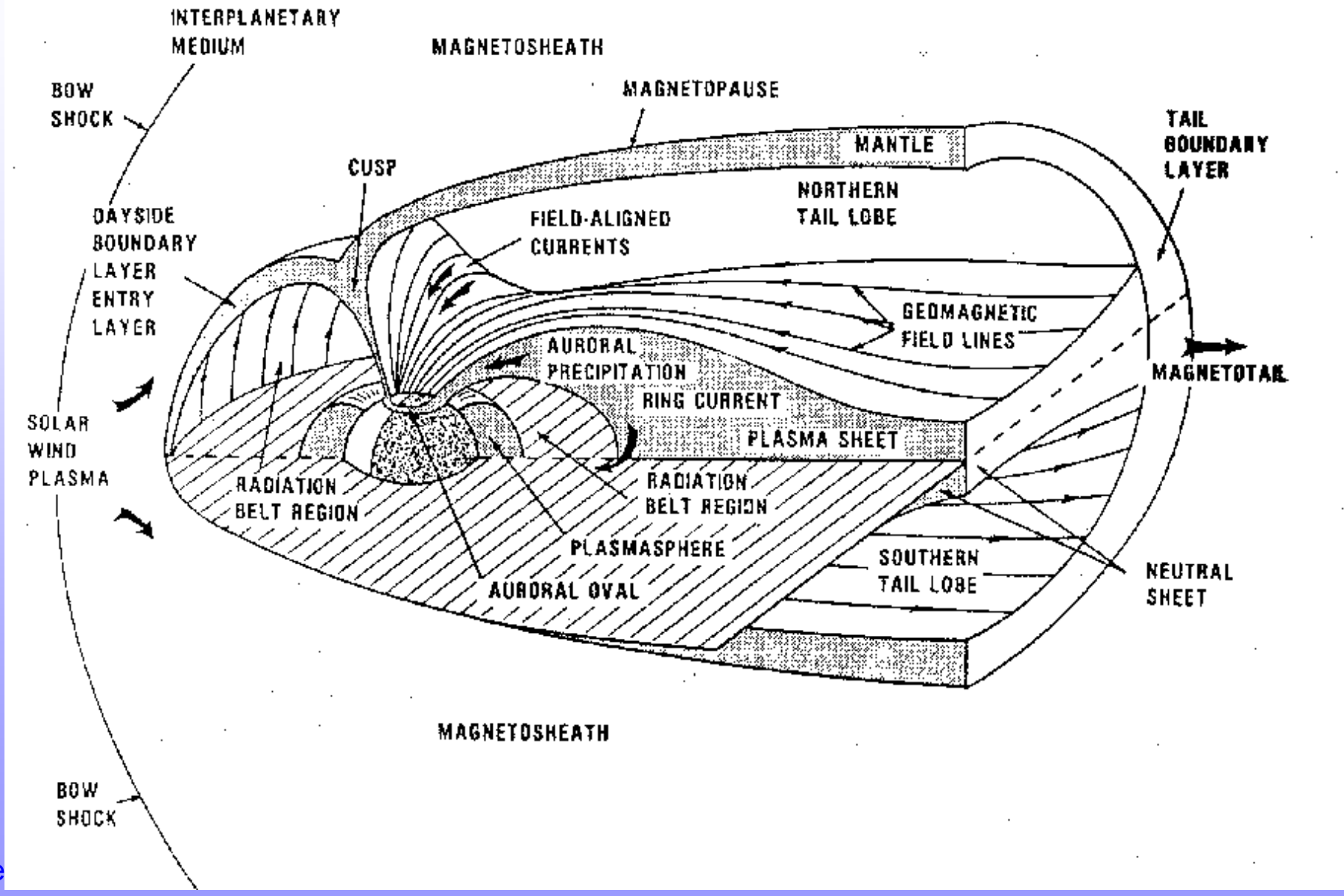


Magnetosfera 2/3



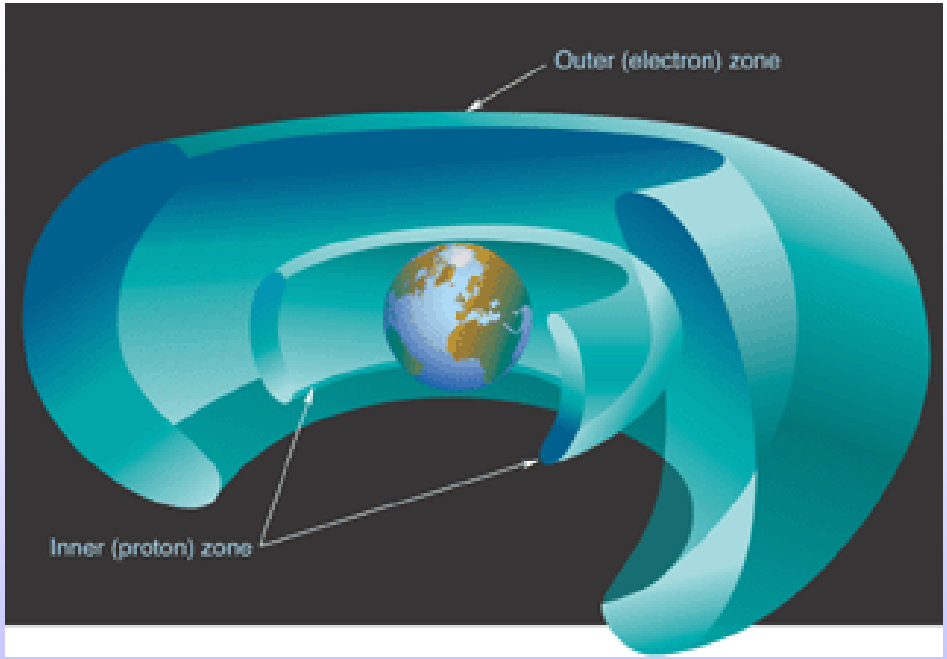


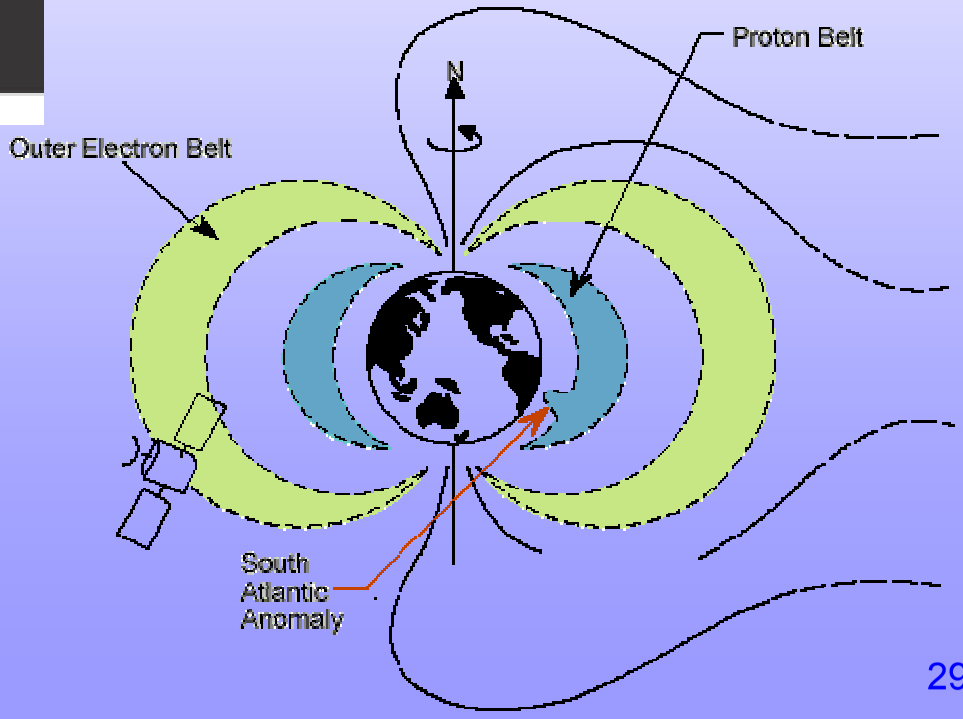
Magnetosfera 3/3



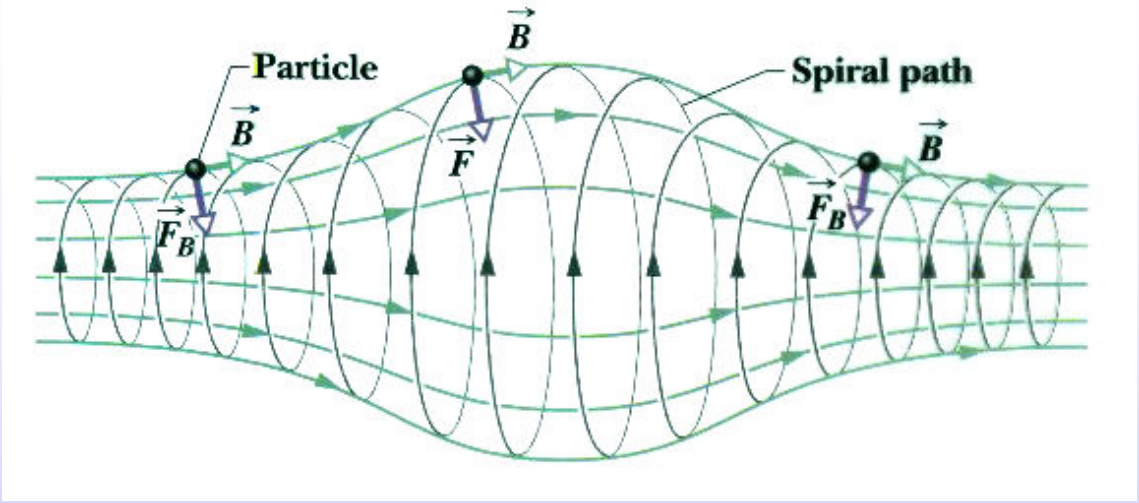
Trie

Cinture di Radiazione 1/3



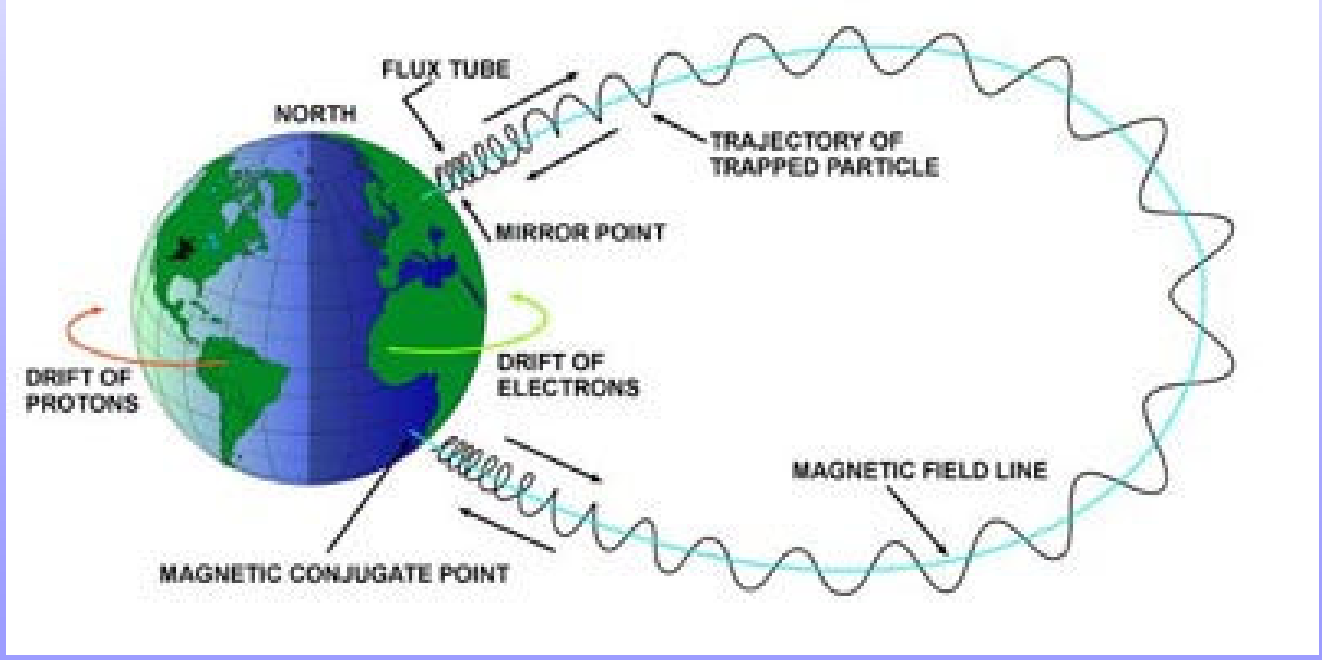


Cinture di Radiazione 2/3



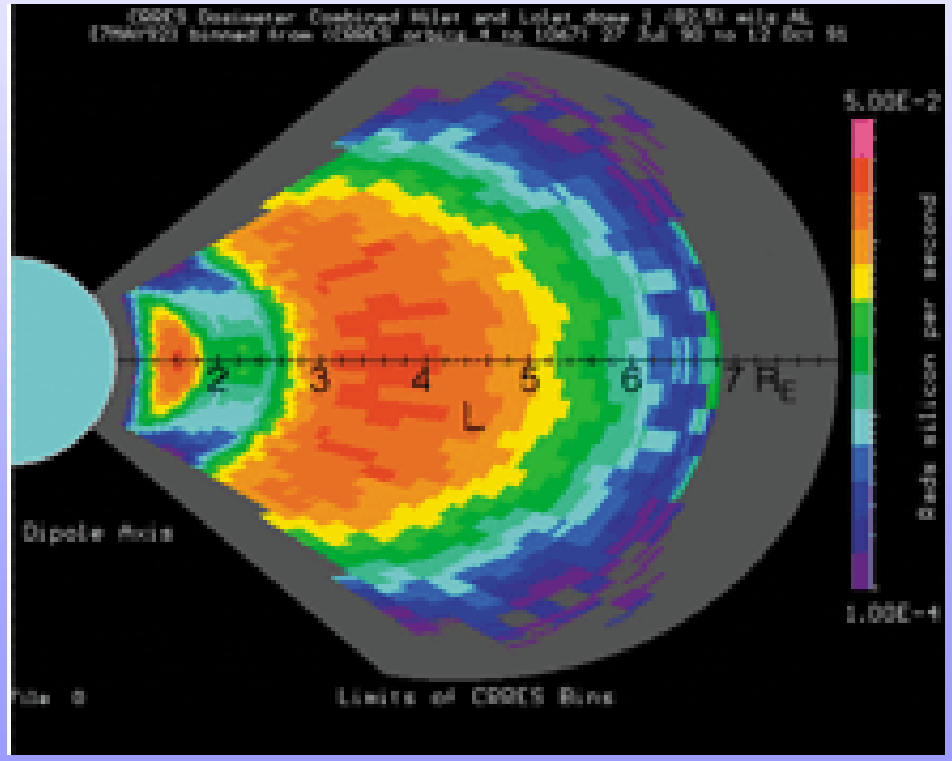
$r = m_{part}\, v_{ort}\, c / eB$

$B_{mirror} = B_1 / \sin^2\theta_1$

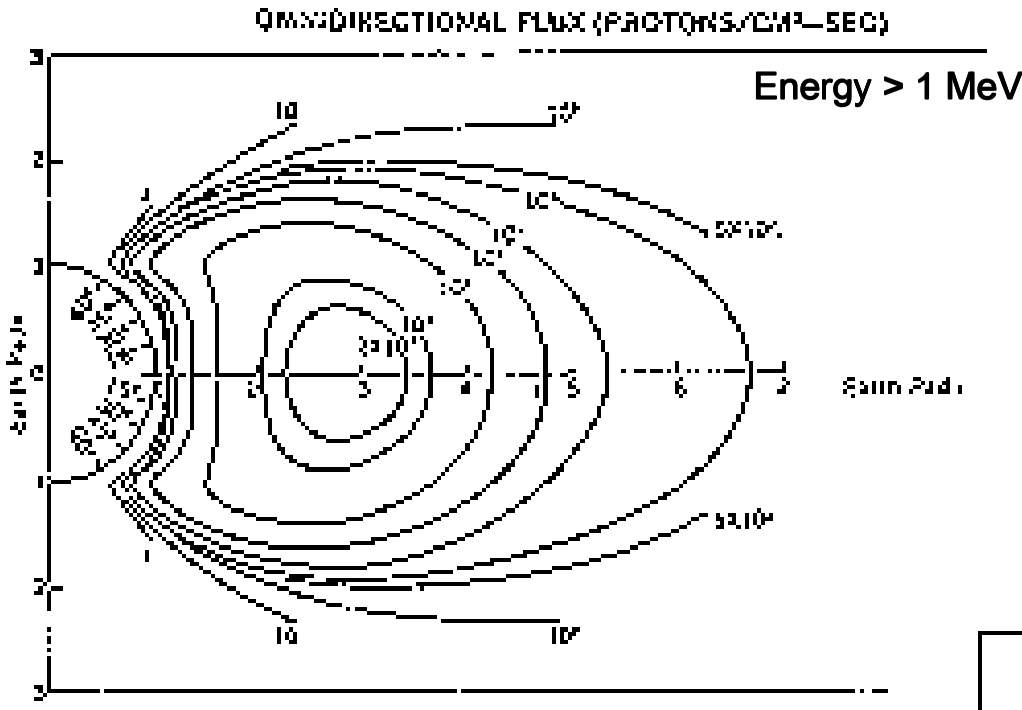


Cinture di Radiazione 3/3

Inner Zone (< 2.5R_E)	Outer Zone (> 2.5R_E)
Proton flux dominates	About 10 times higher electron flux in outer zone than inner zone
Electron energies < 5 MeV	Electron energies around 7 MeV
Electron and proton fluxes peak at 1.5R_E to 2.0R_E	Electron flux peaks at about 5R_E

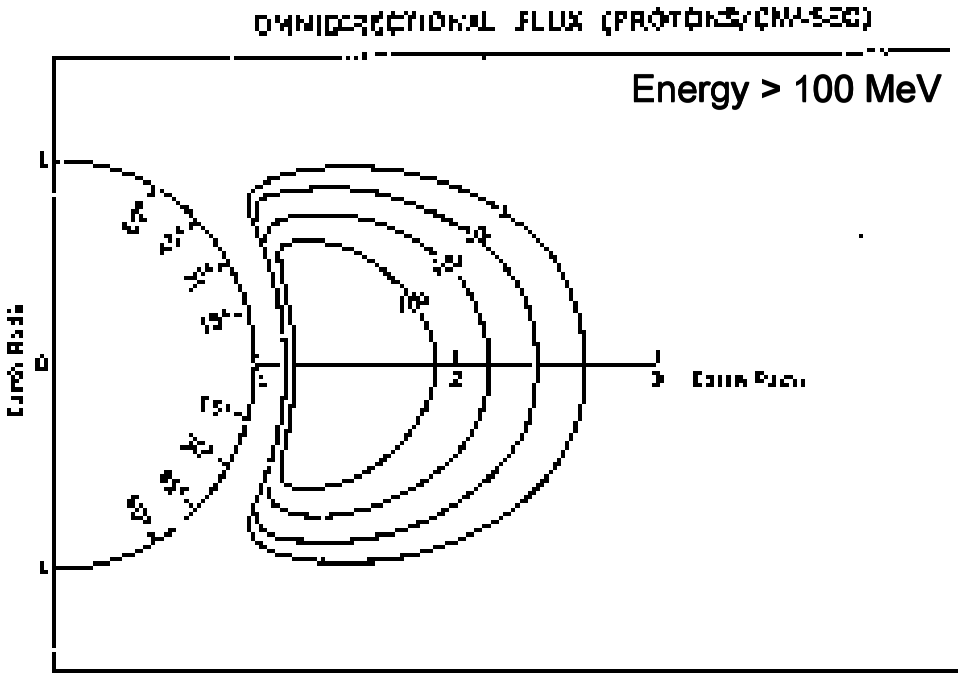


Cinture di Radiazione: protoni

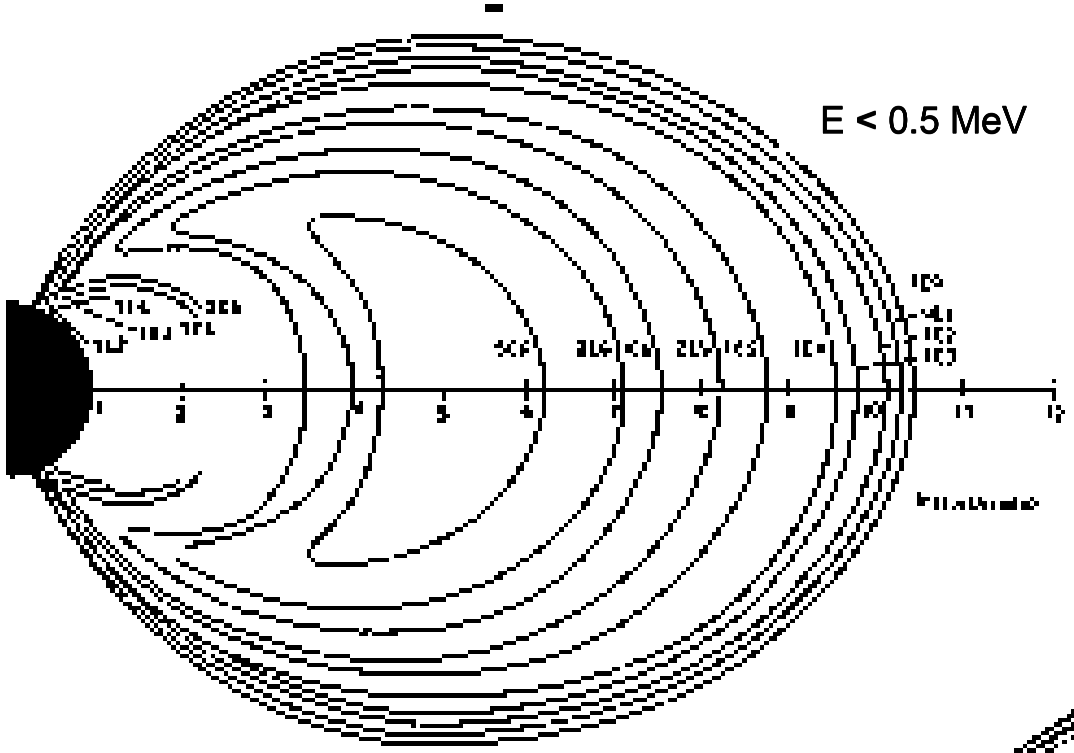


$$r = m_p \, v_{ort} \, c \, / \, eB$$

$$B_{mirror} = B_1 \, / \, \sin^2\theta_1$$

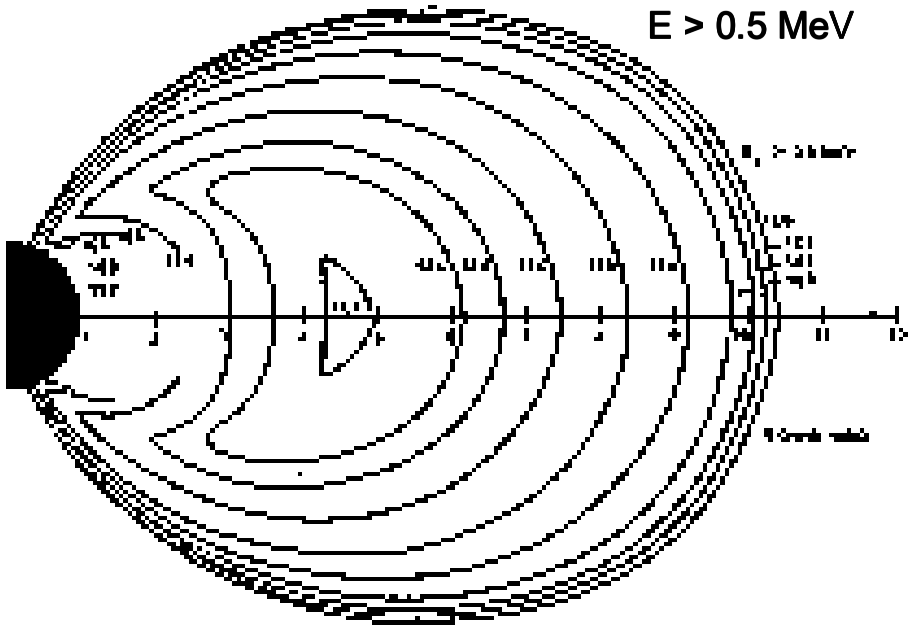


Cinture di Radiazione: elettroni

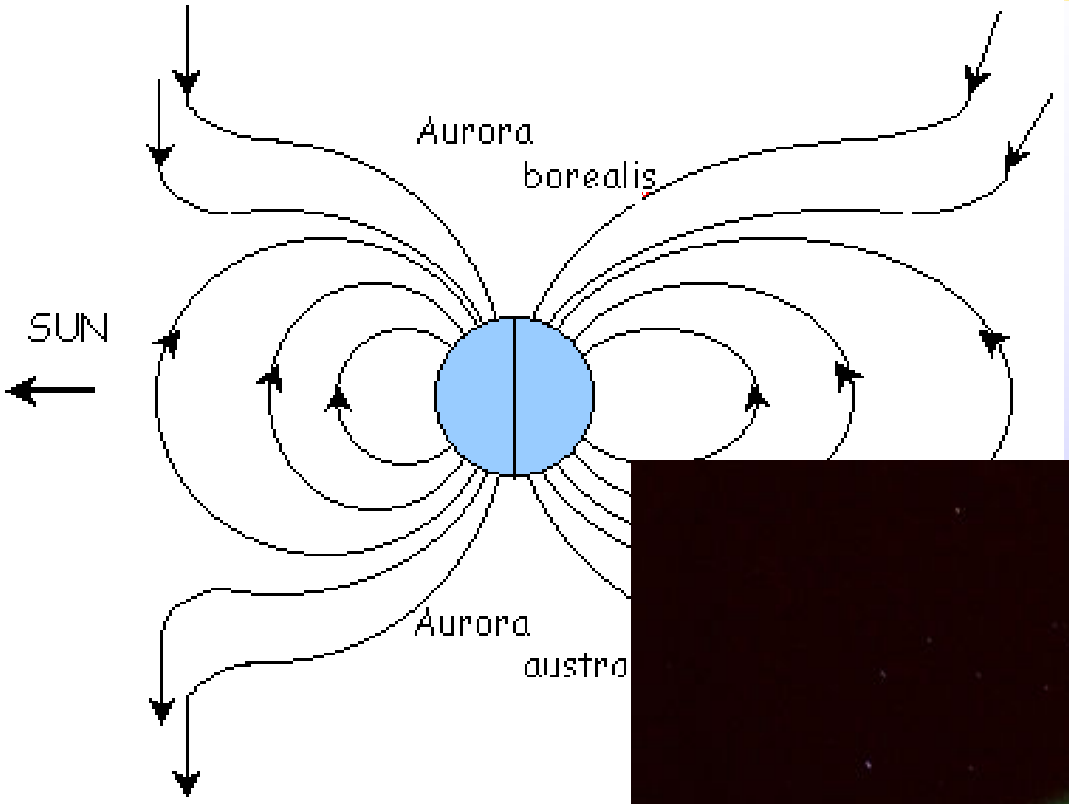


$$r = m_e \, v_{ort} \, c \, / \, eB$$

$$B_{mirror} = B_1 \, / \, \sin^2\theta_1$$



Aurora



Onde Radio VS Ionosfera 2/2

valutare n_e^c

	f_{min} MHz	f_{max} MHz	f MHz	$N_e^c{}_{min}$ cm^{-3}	$N_e^c{}_{max}$ cm^{-3}	N_e^c cm^{-3}
HF	3.E+00	3.E+01	2.E+01	1.12.E+05	1.12.E+07	3.38.E+06
VHF	5.E+01	1.E+02	8.E+01	3.10.E+07	1.24.E+08	6.98.E+07
UHF	4.E+02	1.E+03	7.E+02	1.99.E+09	1.24.E+10	6.08.E+09
μ w	3.E+03	1.E+05	5.E+04	1.12.E+11	1.24.E+14	3.29.E+13
mm w	1.E+05	1.E+06	6.E+05	1.24.E+14	1.24.E+16	3.75.E+15
IR	1.E+06	6.E+08	3.E+08	1.24.E+16	4.47.E+21	1.12.E+21
LIGHT	6.E+08	8.E+08	7.E+08	4.47.E+21	7.94.E+21	6.08.E+21
UV	8.E+08	1.E+11	5.E+10	7.94.E+21	1.24.E+26	3.15.E+25
X RAYS	1.E+11	1.E+13	5.E+12	1.24.E+26	1.24.E+30	3.16.E+29
γ RAYS	1.E+13	1.E+13	1.E+13	1.24.E+30	1.24.E+30	1.24.E+30

valutare n^c

Layer / n_e cm^{-3}	Night	Day	f_C Night MHz	f_C Day MHz
D	1.E+02	1.E+03	8.98.E-02	2.84.E-01
E	1.E+03	1.E+05	2.84.E-01	2.84.E+00
F1	1.E+04	3.E+05	8.98.E-01	4.92.E+00
F2	2.E+05	1.E+06	4.01.E+00	8.98.E+00