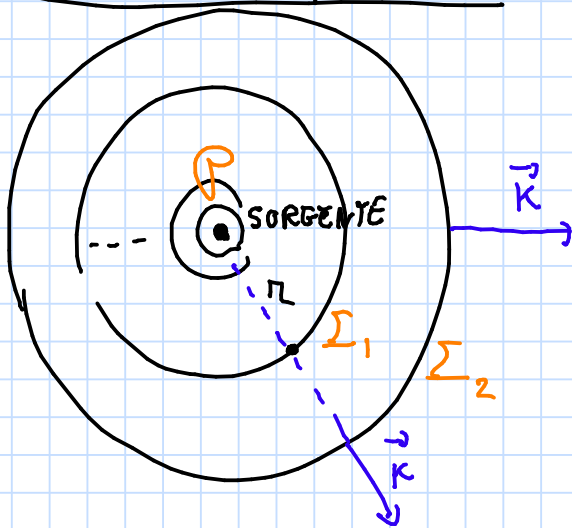


Onde sferiche



$$\zeta(r, t) = A(r) \sin(kr - \omega t)$$

(isotropica, non dip.
da angoli)

P , potenza

senza assorbimento, P è la
stessa su tutte le sup. sferiche

$$P_{\Sigma_1} = P_{\Sigma_2} = P$$

$$I \sim \zeta^2 \sim A(r)^2$$

$$I_{\Sigma_1} \Sigma_1 = I_{\Sigma_2} \Sigma_2 = P$$

$$\Sigma \sim r^2$$

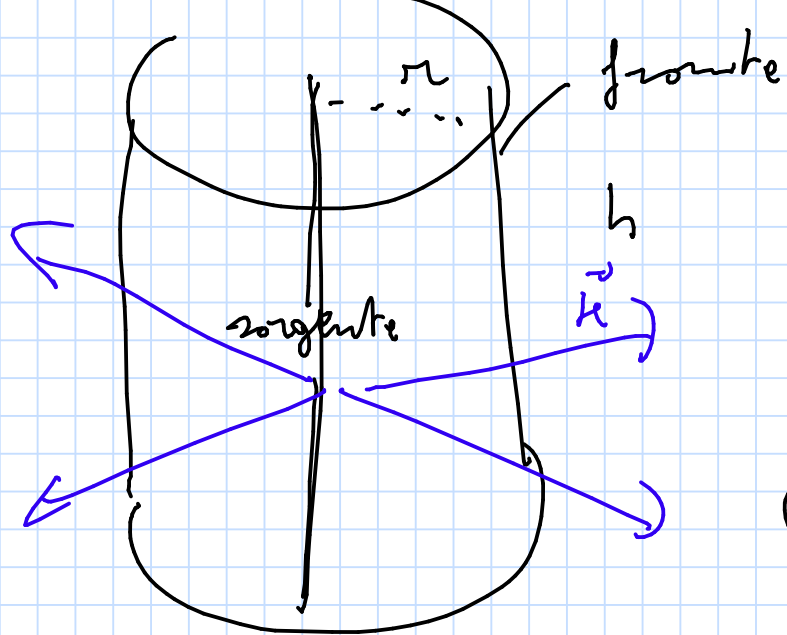
$$\Rightarrow I(r) \sim \frac{1}{r^2}$$

$$\Rightarrow A(r) \sim \frac{1}{r}$$

$$A(r) = \frac{\zeta_0}{r}$$

$$\zeta(r, t) = \frac{\zeta_0}{r} \sin(kr - \omega t)$$

onda sferica
isotropica



Onda cilindrica

$$P = I(r) \Sigma(r) = \text{constante}$$

$$= C A(r)^2 \cdot 2\pi r h$$

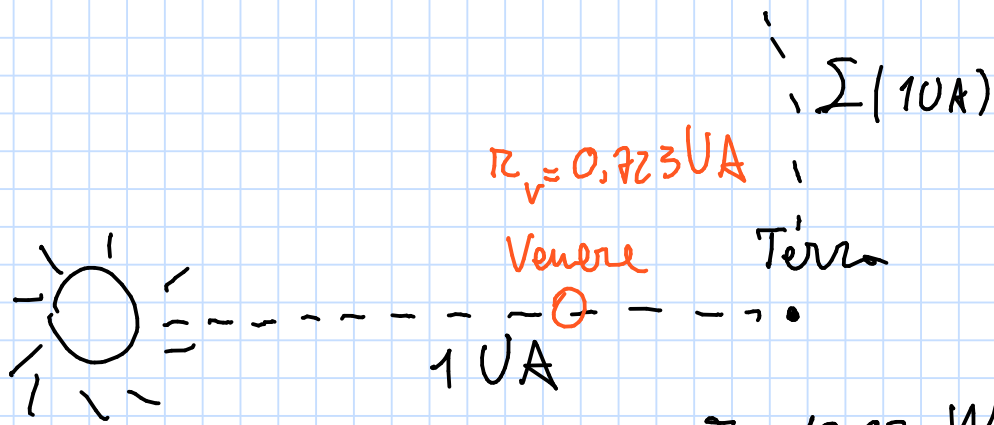
$$P \text{ constante} \Rightarrow A(r) \sim \frac{1}{\sqrt{r}}$$

$$\text{amp. onda } A(r) \sim \frac{1}{\sqrt{r}}$$

$$I \sim A^2$$

$$I \sim \frac{1}{\sqrt{r}}$$

$$h_1 = \frac{h_0}{\sqrt{r}} \sin(kx - \omega t)$$



$$I_T = 1367 \frac{\text{W}}{\text{m}^2}$$

↓

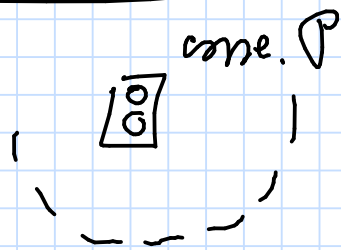
$$P_{\text{sole}} = 1367 \Sigma(1 \text{ UA})^2$$

$$= I_T \cdot 4\pi (1 \text{ UA})^2$$

$$I_{ve} = \frac{P_{\text{sole}}}{\Sigma_{\text{Venus}}} = \frac{4\pi (1 \text{ UA})^2}{4\pi (0,723)^2} I_T = 2615 \frac{\text{W}}{\text{m}^2}$$

$$\text{Plutone}, \quad r_{pe} = 39,53 \text{ UA} \quad \Rightarrow \quad I_{pe} = 0,88 \frac{\text{W}}{\text{m}^2}$$

Esercizio in dB



$$r_1 = 5 \text{ m}$$

$$B_1 = 126 \text{ dB}$$

1) P

2) B_2 a $r_2 = 80 \text{ m}$

assumiamo onde sferiche isotrope

$$B = 10 \log \frac{I}{I_0}$$

$$I_0 = 10^{-12} \frac{\text{W}}{\text{m}^2}$$

→ data sensibilità

$$I_1 = 10^{B_1/10} \cdot I_0$$

$$= 10^{126/10} 10^{-12} \frac{\text{W}}{\text{m}^2} = 10^{0.6} \frac{\text{W}}{\text{m}^2} = 4 \frac{\text{W}}{\text{m}^2}$$

$$I_1 = 4 \pi r_1^2 = 314 \text{ m}^2$$

$$P = I_1 I_1 = 1250 \text{ W}$$

P costante nell'aria

$$I_1 I_1 = I_2 I_2$$

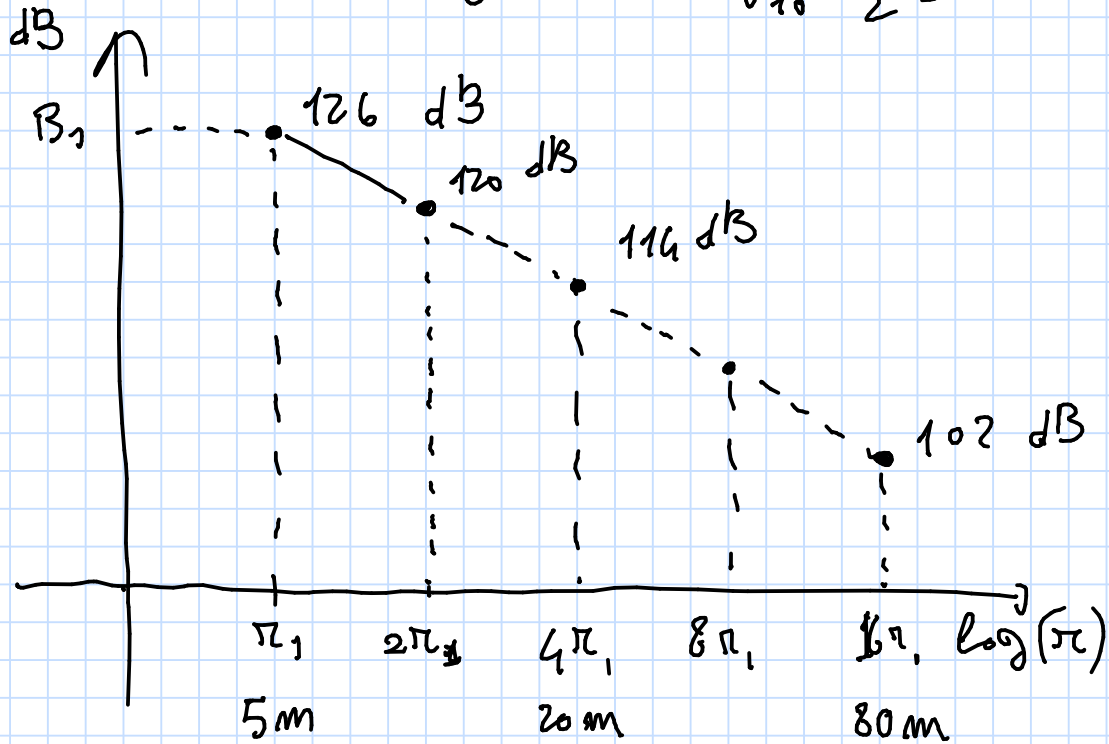
$$\frac{I_2}{I_0} \frac{I_1}{I_0} = \frac{I_1}{I_0} \left(\frac{r_1}{r_2} \right)^2$$

$$\downarrow \log \frac{I}{I_0}$$

$$\downarrow B_2 =$$

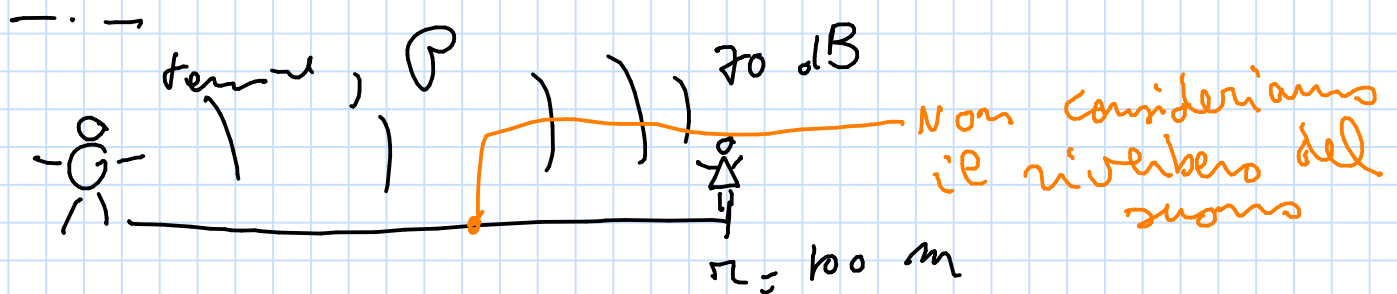
$$B_1 + 10 \log_{10} \left(\frac{r_1}{r_2} \right)^2 = B_1 + 20 \log_{10} \frac{r_1}{r_2}$$

$$20 \log_{10} \frac{1}{2} = -6 \text{ dB}$$



direttamente $B_2 = B_1 + 20 \log_{10} \frac{r_1}{r_2}$

$$= 126 + 20 \log_{10} \frac{1}{16} = 102 \text{ dB}$$



$$I = 10^{B/10} I_0 = 10^7 \cdot 10^{-12} \frac{W}{m^2} = 10^{-5} \quad \left. \vphantom{I = 10^{B/10} I_0} \right\} P = I \Sigma$$

$$\Sigma (r=100m) = 12.6 \cdot 10^4 m^2$$

$$P = 12.6 \cdot 10^{-1} W = 1.26 W$$

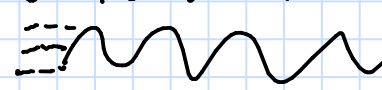
con assorbimento: pre fattore $e^{-\alpha x} \sim I$

onda piana: $\psi = \psi_0 e^{-\alpha x/2} \sin(kx - \omega t)$

" sferica $\psi = \frac{\psi_0}{r} e^{-\alpha x/2} \sin(\quad)$

cilindrica: $\psi = \frac{\psi_0}{\sqrt{r}} e^{-\alpha x/2} \sin(\quad)$

⚠ unità di ψ_0 dipendono dal tipo

$\pm E_0$ intensità di onde e.m., varie forme
 $-E_0$ 

$$I = \frac{1}{2} u_{em} v = \frac{1}{2} \epsilon v E_0^2$$

in mezzo
senza
cariche
e correnti

materiale $v = \frac{1}{\sqrt{\mu \epsilon}} = \frac{1}{\sqrt{\mu_0 \epsilon_0} \sqrt{k_e k_m}}$

$$= \frac{c}{\sqrt{k_e k_m}} = \frac{c}{\sqrt{k_e}} \quad \text{per def. di indice di rifrazione } n$$

$\nearrow \text{se } k_m = 1$

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \Rightarrow \epsilon_0 c = \sqrt{\frac{\epsilon_0}{\mu_0}}$$

impedenza del vuoto

$$Z_0 \equiv \sqrt{\frac{\mu_0}{\epsilon_0}} \approx 377$$

$$\Rightarrow \boxed{n = \sqrt{k_e}}$$

$n > 1$
nei materiali

$$I = \frac{\epsilon v}{2} B_0^2 = \frac{1}{2} \epsilon_0 k_e \frac{c}{\sqrt{k_e k_m}} B_0^2$$

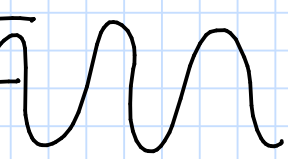
$$= \frac{1}{2} \epsilon_0 c \sqrt{\frac{k_e}{k_m}} B_0^2$$

$$= \frac{1}{2} \sqrt{\frac{\epsilon_0}{\mu_0}} \frac{\sqrt{k_e}}{\sqrt{k_m}} B_0^2$$

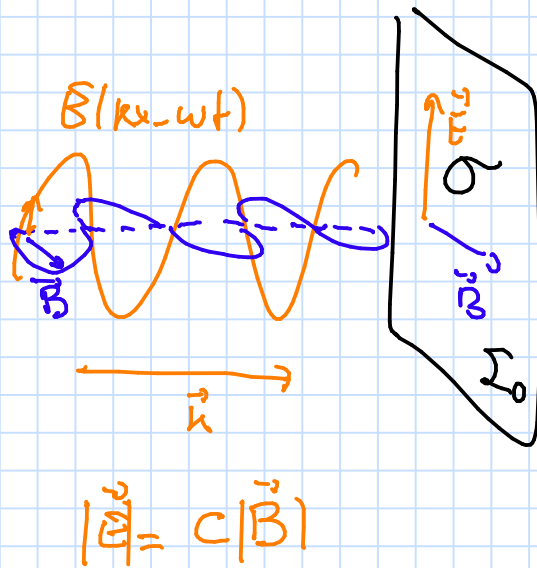
materiali
non
magnetici
 $k_m = 1$

$$\boxed{I = \frac{1}{2} \frac{1}{Z_0} n B_0^2}$$

$$\sqrt{k_e} = n$$

$B_0 \uparrow \downarrow A$ 
nel mezzo

Pressione di radiazione



onde e.m. trasportano
quantità di moto
 Σ_0 unitaria
per unità di tempo

$$P = \frac{I}{c} = \frac{1}{2} \epsilon_0 E_0^2$$

$$\Rightarrow \text{sup. assorbente: } P_{\text{rad}} = \frac{I}{c}$$

$$\text{sup. riflettente } P_{\text{rad}} = 2 \frac{I}{c}$$



$$\vec{\sigma}_0 \parallel \vec{E}_0$$

per unità Σ_0

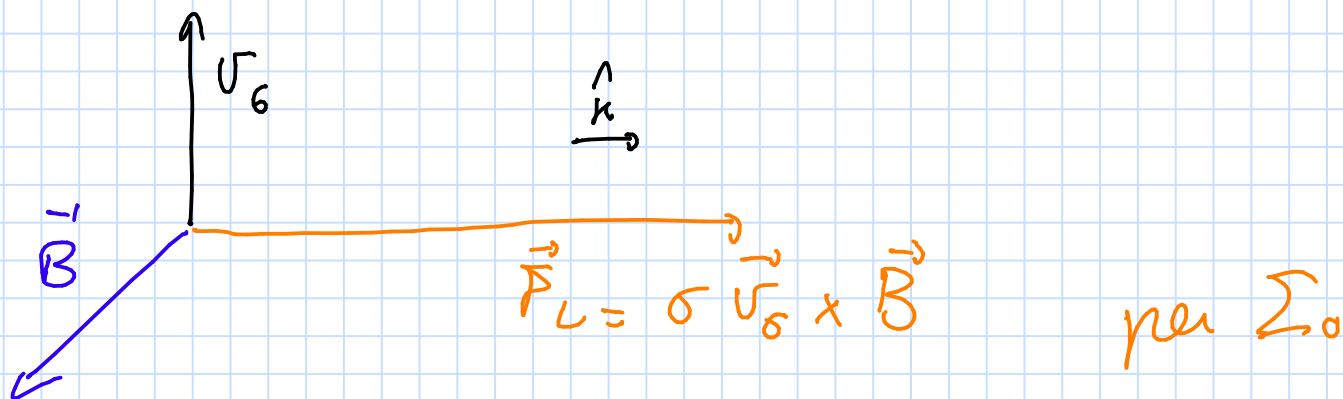
$$\text{potenza per unità di superficie} \quad \frac{P_{\text{rad}}}{\Sigma_0} = P_\sigma = \vec{E}_0 \cdot \vec{\sigma}_0 = \sigma E_0 \sigma_0$$

energia ceduta per unità di tempo e per Σ_0
deve essere $= I$ (in media)

$$\sigma \langle E \sigma_0 \rangle = I$$

mediante

non produce effetti meccanici (o nella dir.
della radiazione), solo oscillazioni $\vec{E}_0 \parallel \vec{\sigma}_0$



$$\langle \vec{F}_L \rangle = \sigma \langle \vec{v}_6 \times \vec{B} \rangle = \sigma \langle v_6 \frac{\vec{B}}{c} \rangle \cdot \hat{k}$$

$$= \frac{I}{c} \left(\frac{N}{m^2} \right)$$

forza media non nulla $\parallel \vec{k}$
 per unità di sup

$$\Rightarrow \text{pressione di radiazione } P_{\text{rad}} = \frac{I}{c}$$

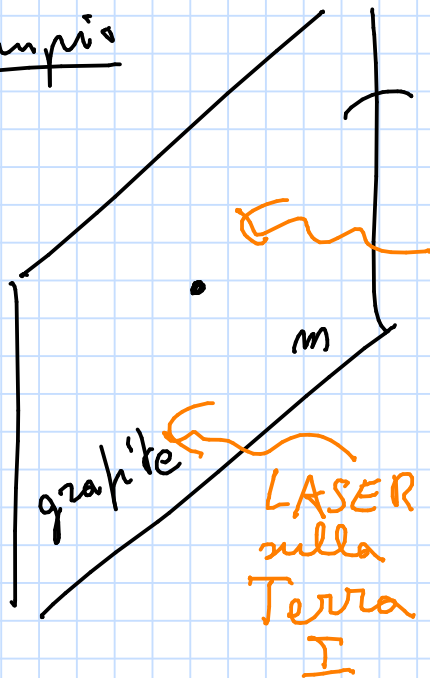
c'è anche interpretazione con quantità di
 moto dei fotoni, spiega $2 \frac{I}{c}$

i.g. se $1-\eta$ di luce assorbita
 e $+\eta$ riflessa

η = riflettività del materiale $\eta \in [0, 1]$

$$P_{\text{rad}} = (1+\eta) \frac{I}{c}$$

esempi



$$\Sigma = 6 \text{ m}^2$$

$$m = 10 \text{ g}$$

$$I_{\text{max}} = ?$$

$$I = \frac{I_{\text{max}}}{10}$$

$$\Rightarrow a? \text{ accel.}$$

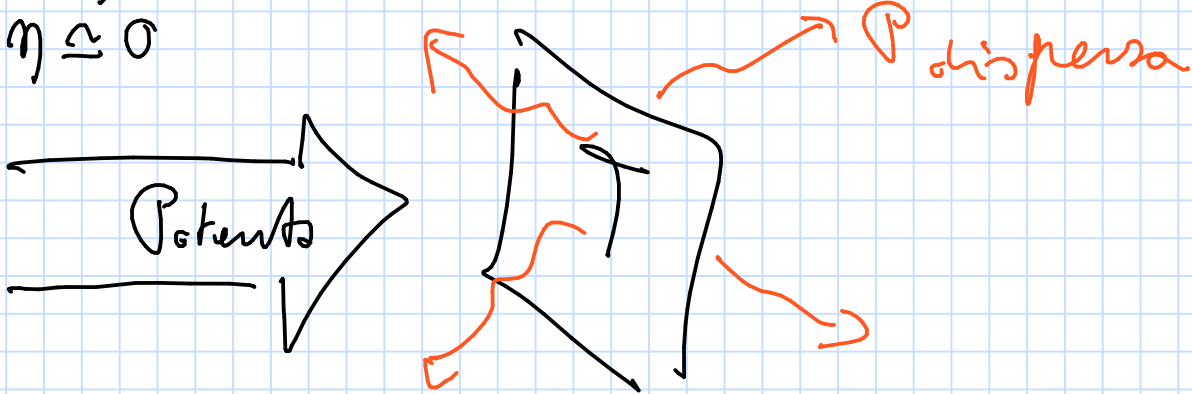
"Breakthrough Starshot"

sonde spinte in sistemi solari vicini

$$m a = (\eta + 1) P_{\text{rad}} \Sigma$$

$$= (\eta + 1) \frac{I}{c} \Sigma$$

grafite perché ha T di fusione alta $\approx 3000^\circ\text{K}$
 $\eta \approx 0$



$$P_{\text{dispersa}} = \alpha P_{\text{assorbita}} = 2 \Sigma \epsilon \kappa_{\text{SB}} T^4 = I \Sigma$$

$$\alpha = 1 - \eta \approx 1$$

$$\epsilon \approx 0.75 \text{ per grafite (emissività)}$$

$$\kappa_{\text{SB}} = 5.67 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$$

cost. Stefan Boltzmann

$$T \approx 3000^\circ\text{K} \Rightarrow I_{\text{max}}$$

$$I_{\max} \stackrel{?}{=} 2 \cdot \frac{3}{4} \cdot 6 \cdot 10^{-8} \cdot 10^{14} \stackrel{?}{=} 10^7 \frac{\text{W}}{\text{m}^2}$$

↑
(3000) 4

$$I = \frac{1}{10} I_{\max} = 10^6 \frac{\text{W}}{\text{m}^2}$$

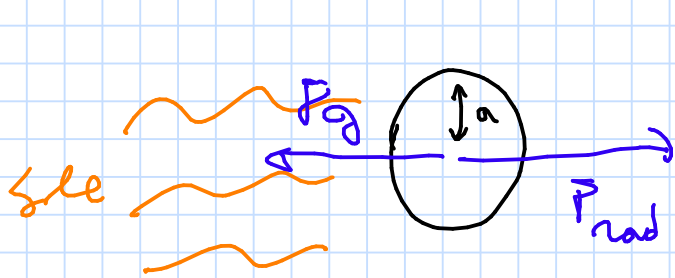
$$a = \frac{dv}{dt} = \frac{1}{m} \frac{F}{c} \sum$$

$$= \frac{1}{10^{-2} \text{ kg}} \frac{10^6 \text{ W/m}^2}{3 \cdot 10^8 \text{ m/s}} \cdot 6 \text{ m}^2$$

$$= 2 \text{ m/s}^2$$

esercizio

pressione di radiazione su polvere
cosmica



quando P_{rad} vince risp.
forza gravitaz.

cioè, per quali raggi a ?

$$P_{rad} = \frac{I}{c} \cdot \pi a^2 = \frac{P_{sole}}{c 4\pi r^2}$$

r distanza
dal Sole

$$P_g = \gamma \frac{m M_{sole}}{r^2} = \frac{\gamma M_{sole}}{r^2} \rho \left(\frac{4}{3} \pi a^3 \right) \quad \rho = \text{densità}$$

$$F_{rad} > F_g \quad \Leftrightarrow \quad \frac{P_{sole}}{4c} a^2 \geq \gamma M_{sole} \left(\frac{4}{3} \pi a^3 \right) \rho$$

⚠ $\frac{1}{r^2}$ è sparito

$$\text{se } a \leq a_0 = \frac{3}{16} \frac{P_{sole}}{\pi \gamma c \rho M_{sole}} = 0.22 \mu\text{m}$$

particelle sotto 0.2 micron di raggio spazzate
via dal sistema solare

$\Rightarrow$ rimane solo polveri più grandi