

Strokovno izobraževanje

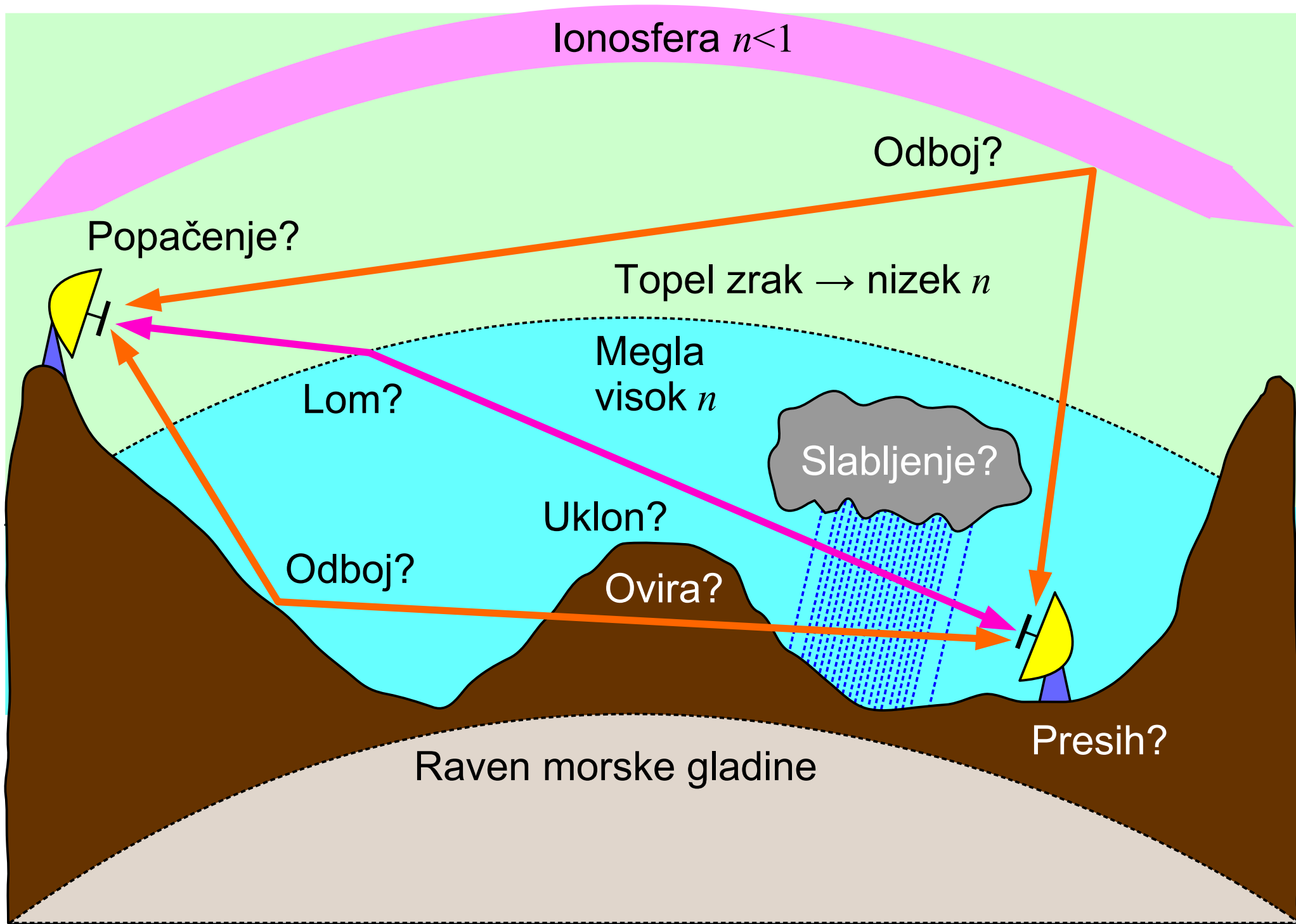
RAZŠIRJANJE RADIJSKIH VALOV

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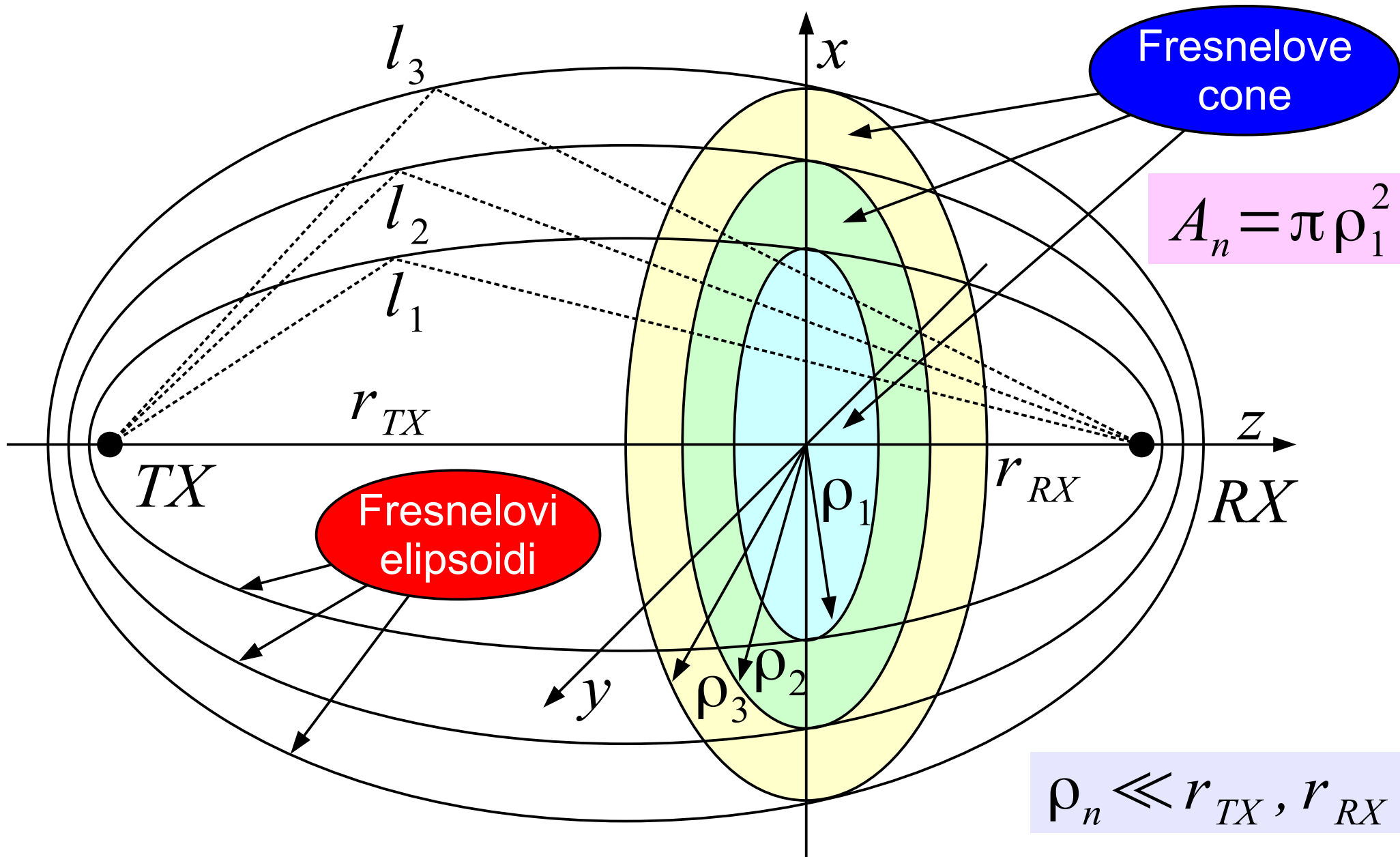
AKOS, Ljubljana, 12.6.2015

Seznam prosojnic predavanja: RAZŠIRJANJE RADIJSKIH VALOV

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1 - Pojavi pri razširjanju radijskih valov

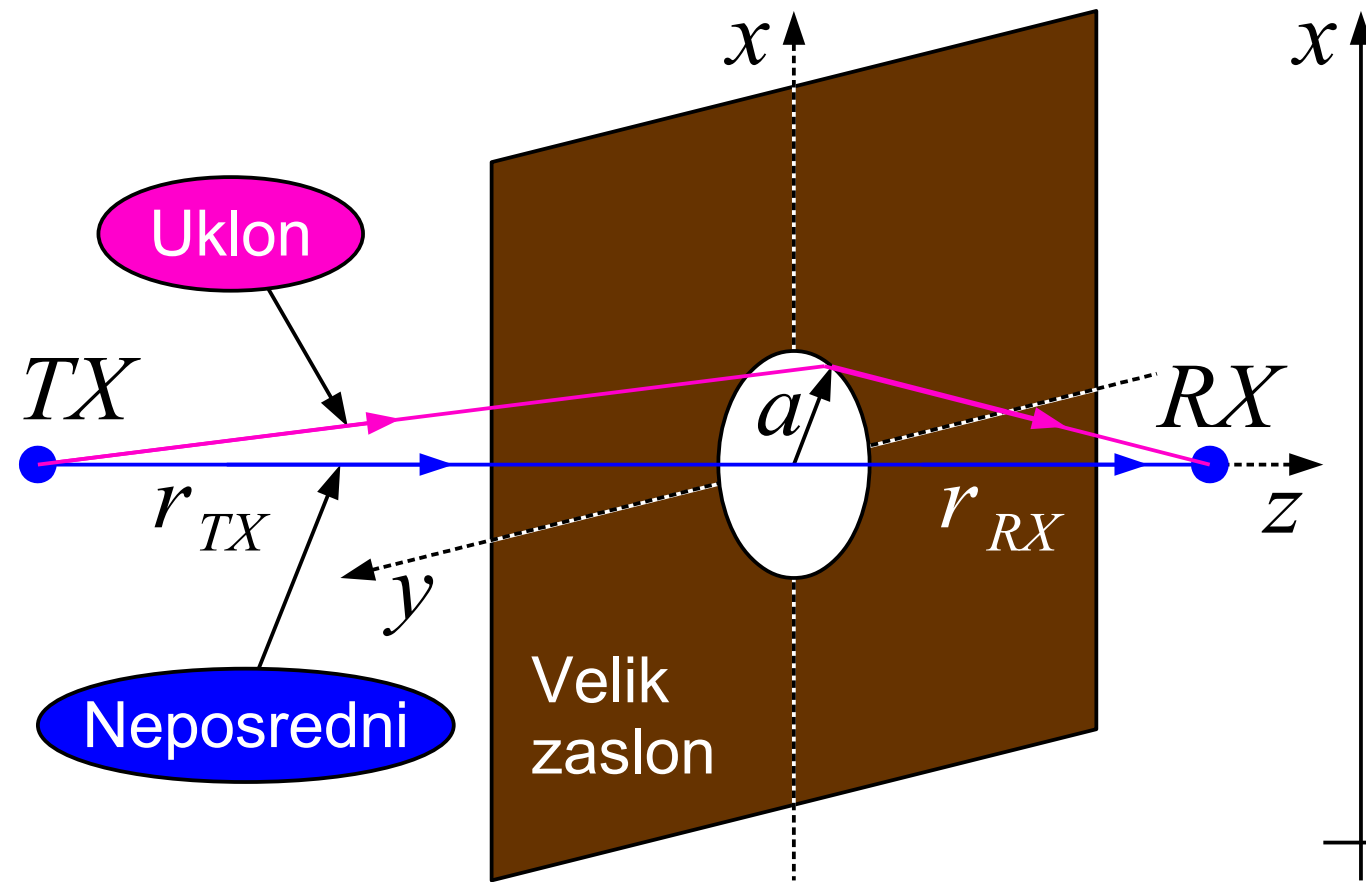
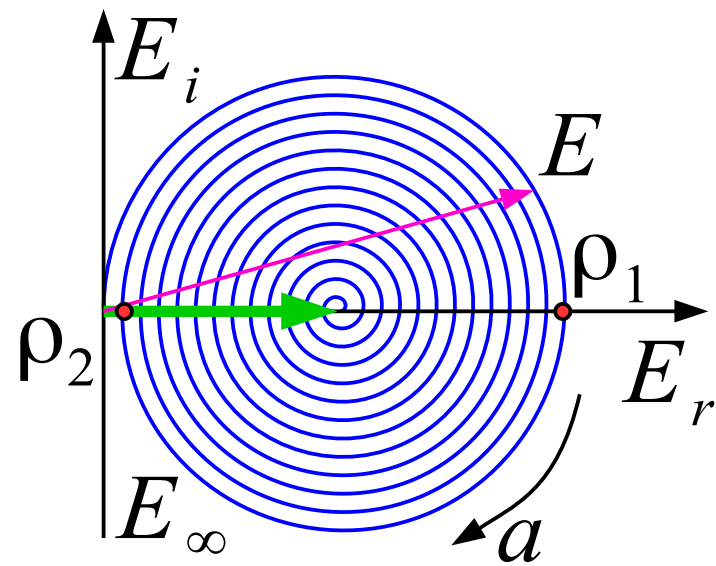


$$l_n = r_{TX} + r_{RX} + n\lambda/2$$

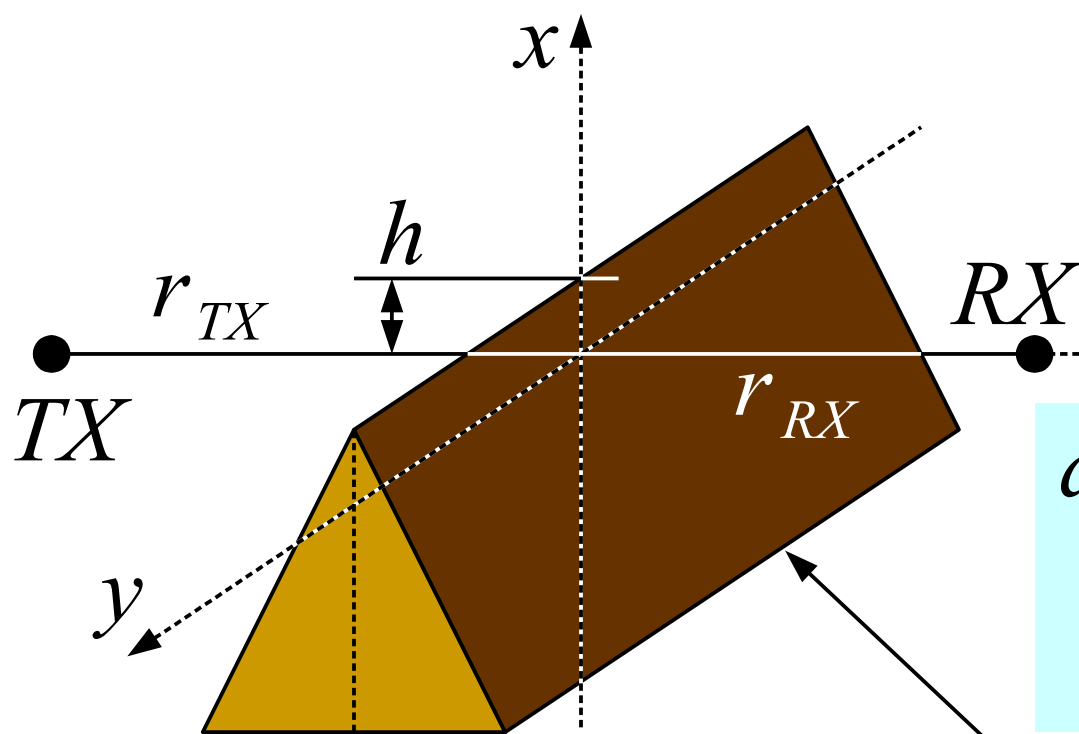
$$\rho_n \approx \sqrt{n\lambda \frac{r_{TX} r_{RX}}{r_{TX} + r_{RX}}}$$

2 - Fresnelovi elipsoidi in Fresnelove cone

$r_{TX} = 20\text{km}$ $r_{RX} = 10\text{km}$	f	λ	ρ_1	A_1
Radio	100MHz	3m	141m	62831m^2
Mikrovalovi	10GHz	3cm	14.1m	628m^2
Svetloba	600THz	$0.5\mu\text{m}$	5.8cm	0.0105m^2



3 - Uklon na krožni odprtini v velikem zaslonu



$$E = \frac{E_\infty \sqrt{\frac{2}{\pi}}}{1-j} \int_{h \frac{\sqrt{\pi}}{\rho_1}}^{\infty} e^{-ju^2} du$$

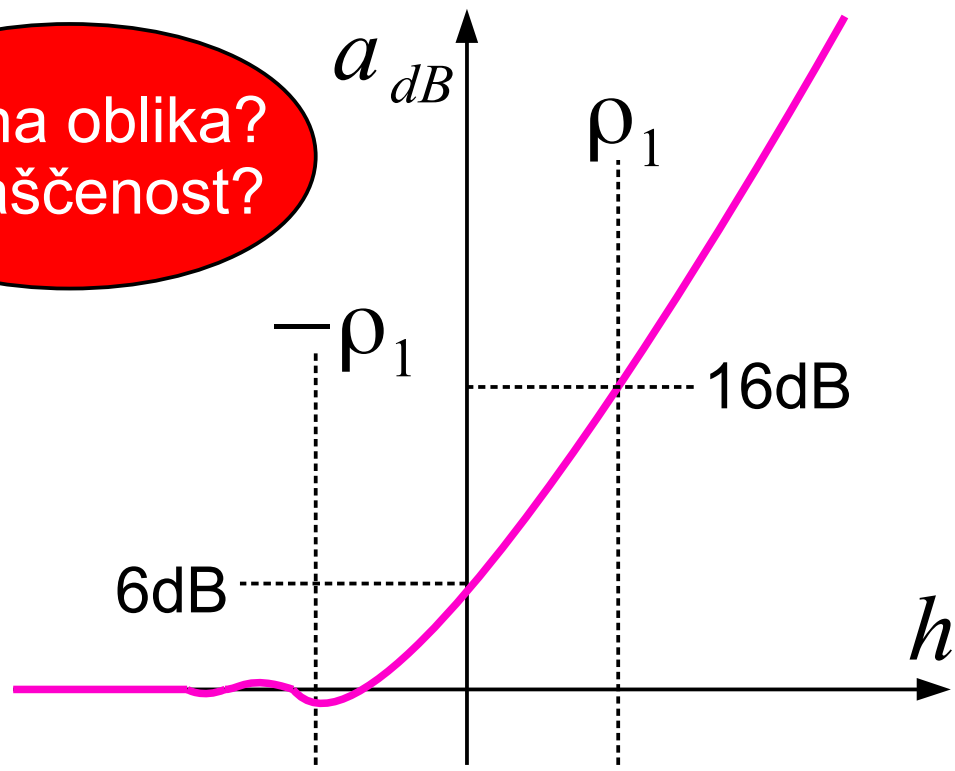
$$a_{dB} = 20 \log_{10} \left[\frac{\sqrt{\pi}}{\int_{h \frac{\sqrt{\pi}}{\rho_1}}^{\infty} e^{-ju^2} du} \right]$$

$$h \leq -\rho_1 \rightarrow a_{dB} \approx 0 \text{ dB}$$

$$h = 0 \rightarrow a_{dB} = 6 \text{ dB}$$

$$h \geq \rho_1 \rightarrow a_{dB} \approx 16 \text{ dB} + 20 \text{ dB} \log_{10} \frac{h}{\rho_1}$$

Točna oblika?
Poraščenosť?

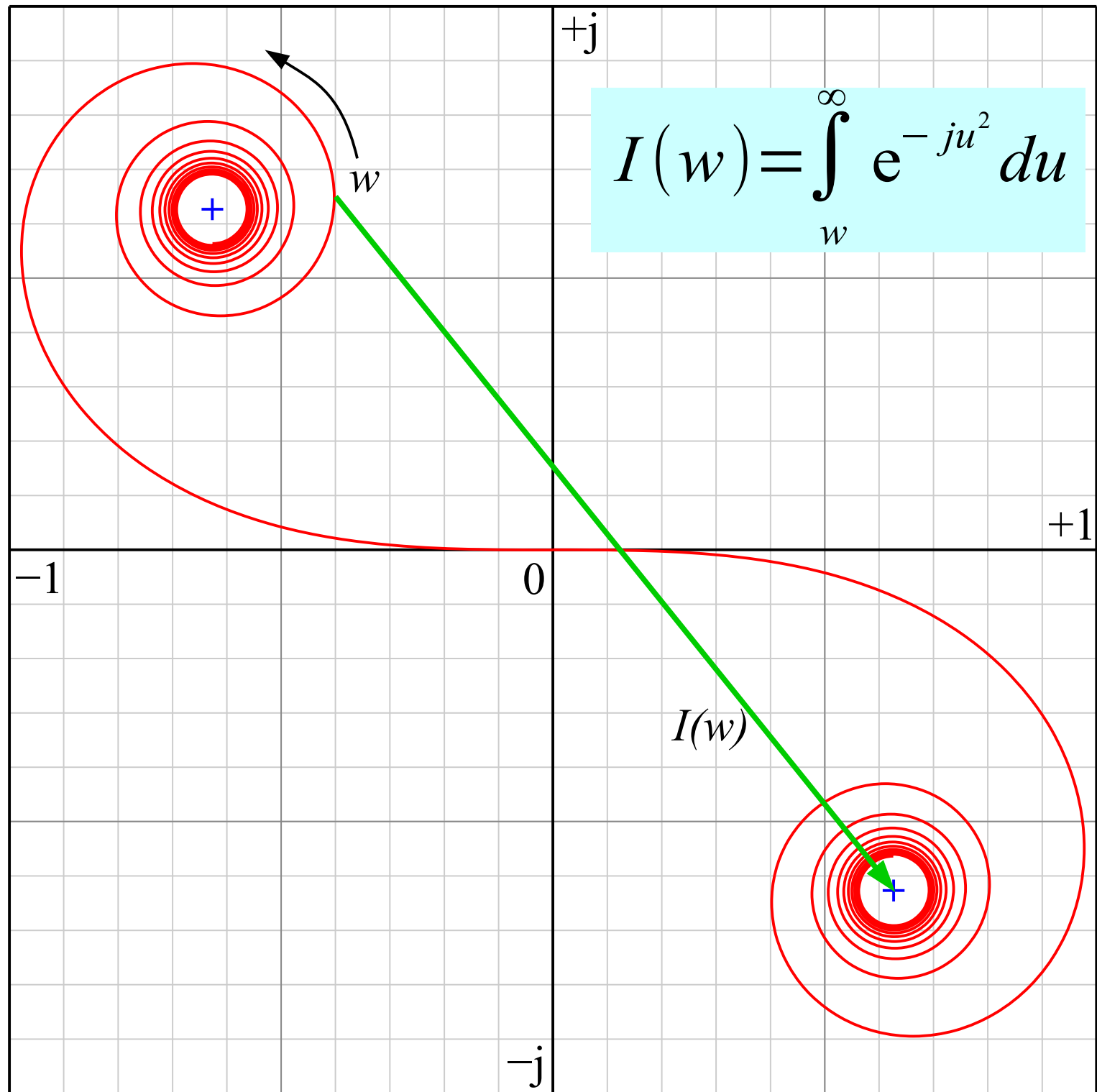


Eulerjeva ali Cornujeva spirala

$$\int_{-\infty}^{\infty} e^{-ju^2} du = (1-j) \sqrt{\frac{\pi}{2}}$$

$$\int_{-\infty}^0 e^{-ju^2} du = \int_0^{\infty} e^{-ju^2} du = (1-j) \sqrt{\frac{\pi}{8}}$$

5 - Klotoida



$$I(w) = \int_w^{\infty} e^{-ju^2} du$$

$$P_{RX} = P_{TX} G_{TX} G_{RX} \left[\frac{\lambda}{4\pi(r_{TX} + r_{RX})} \right]^2 \left(\frac{A \cos \Theta}{A_1/\pi} \right)^2$$

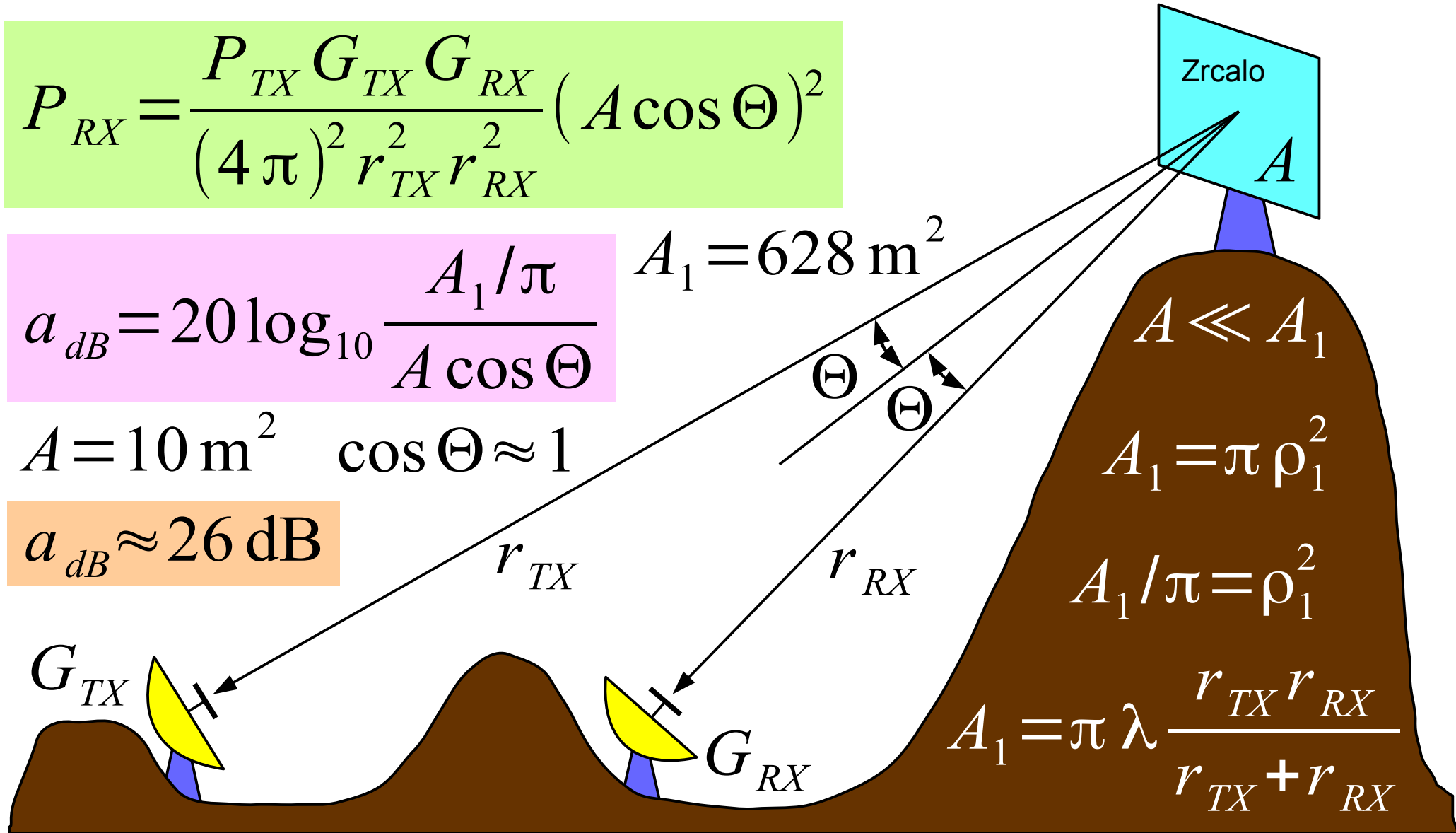
$$P_{RX} = \frac{P_{TX} G_{TX} G_{RX}}{(4\pi)^2 r_{TX}^2 r_{RX}^2} (A \cos \Theta)^2$$

$$a_{dB} = 20 \log_{10} \frac{A_1/\pi}{A \cos \Theta}$$

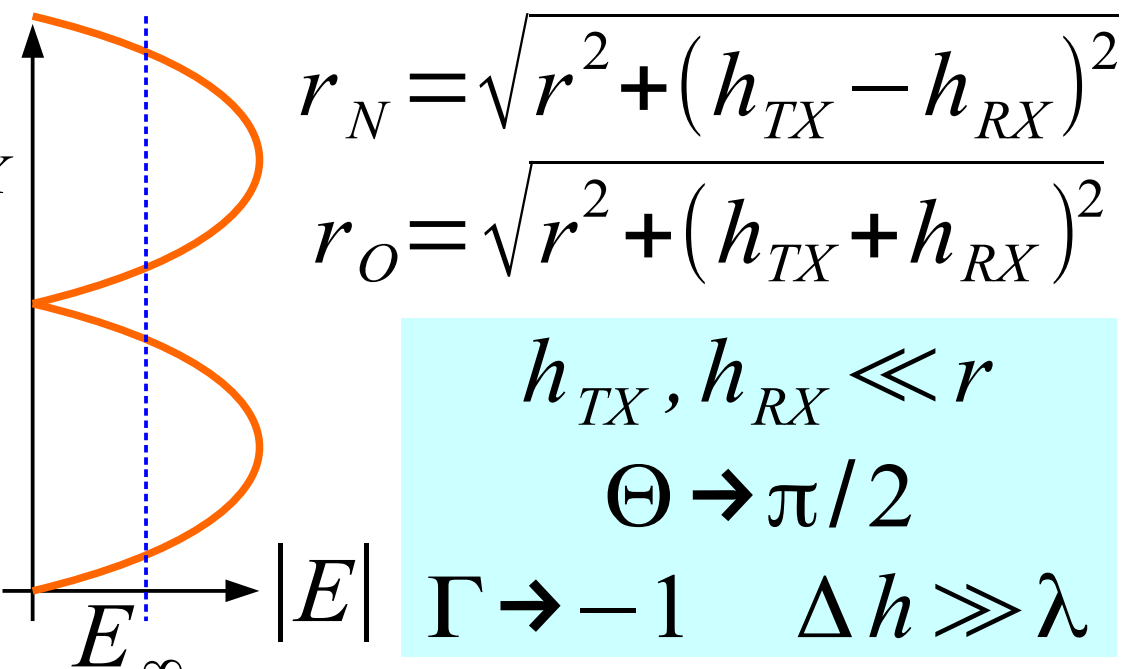
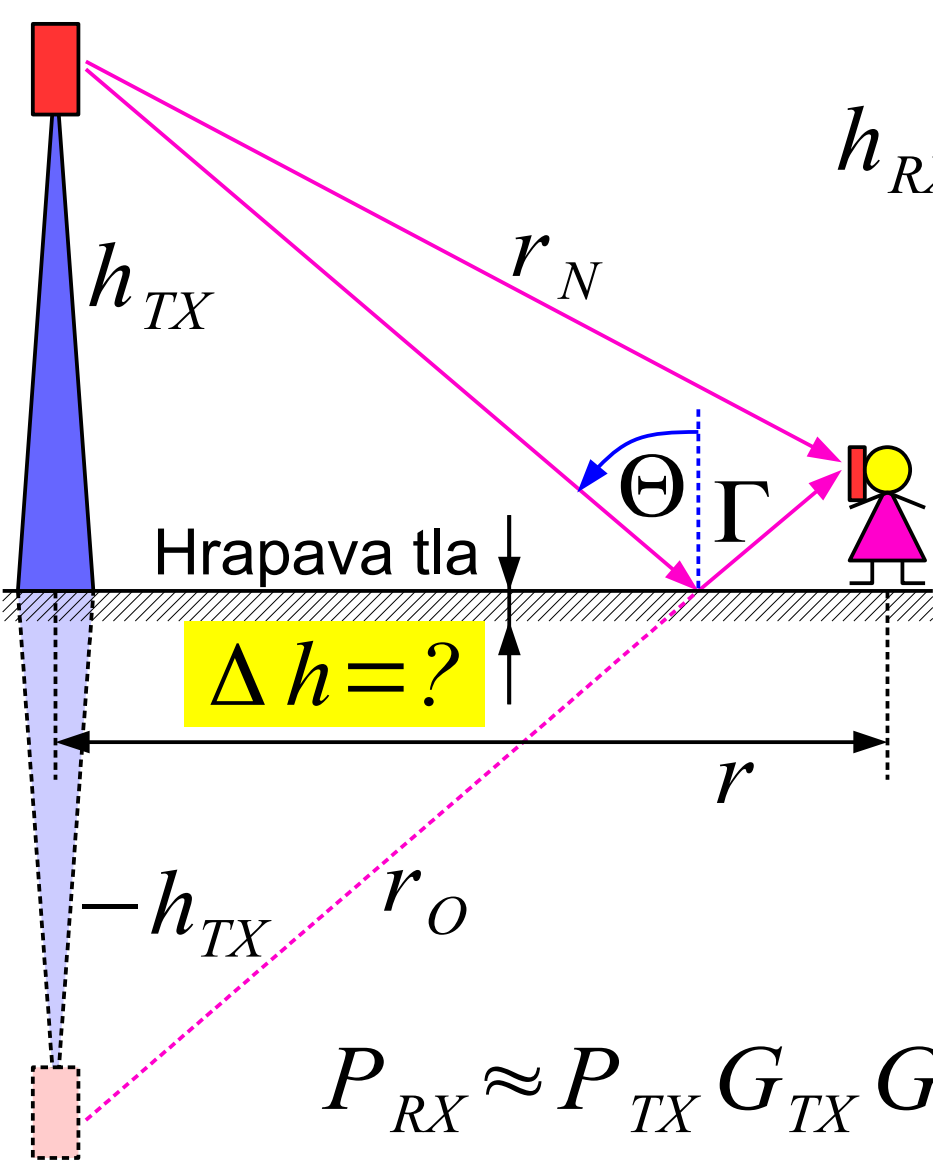
$$A_1 = 628 \text{ m}^2$$

$$A = 10 \text{ m}^2 \quad \cos \Theta \approx 1$$

$$a_{dB} \approx 26 \text{ dB}$$



6 - Radijska zveza preko majhnega zrcala



$|E| \approx \left| 2 E_\infty \sin \left(\frac{2\pi}{r\lambda} h_{TX} h_{RX} \right) \right|$

$$P_{RX} \approx P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi r} \right)^2 4 \sin^2 \left(\frac{2\pi}{r\lambda} h_{TX} h_{RX} \right)$$

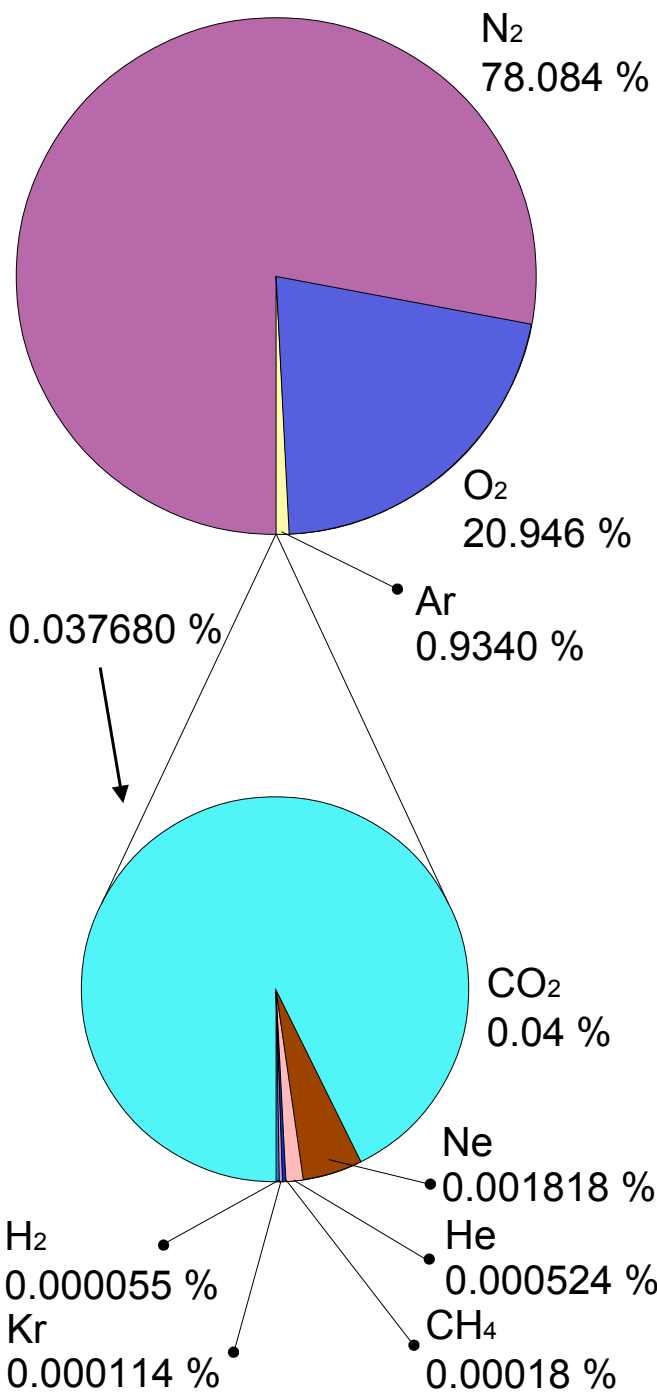
Rayleigh Γ -1dB

$$\Delta h \leq \frac{\lambda}{8 \cos \Theta}$$

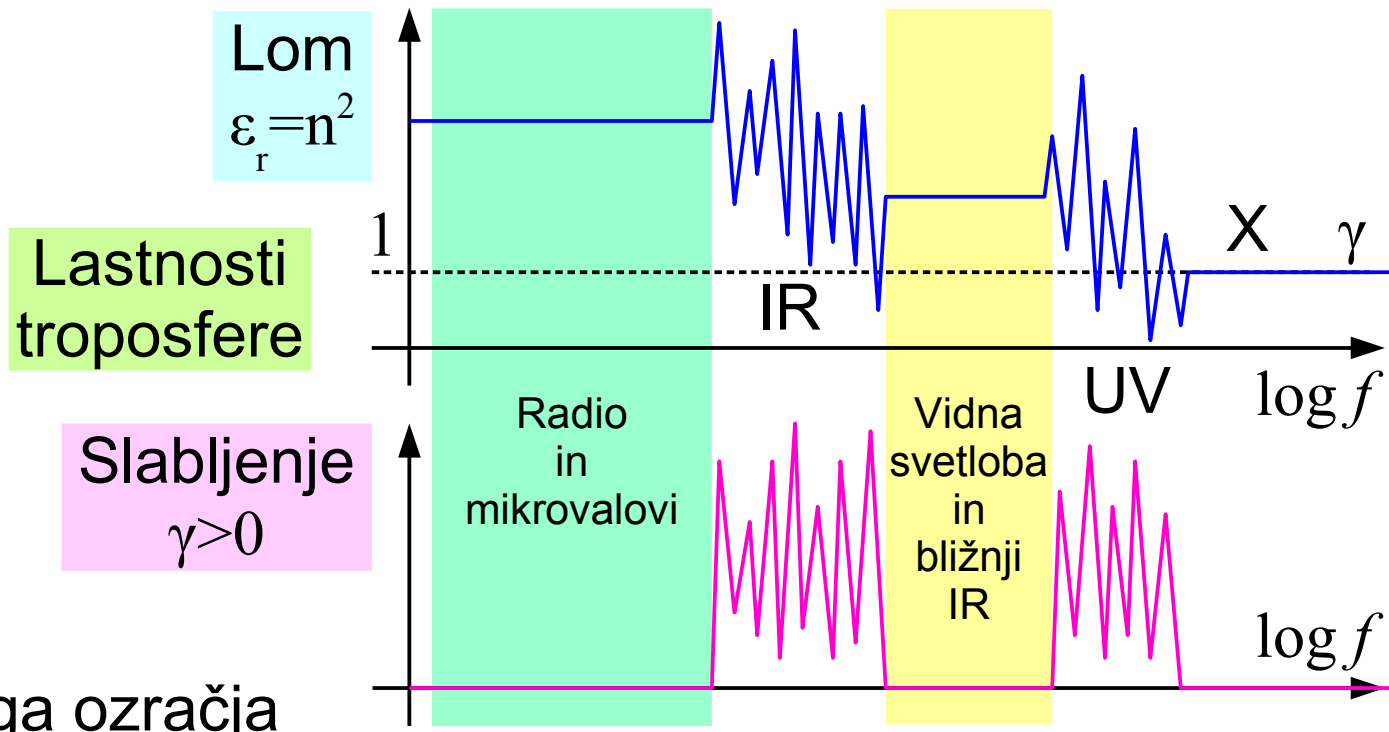
$h_{TX} h_{RX} \ll r \lambda$

$$P_{RX} \approx P_{TX} G_{TX} G_{RX} \frac{h_{TX}^2 h_{RX}^2}{r^4}$$

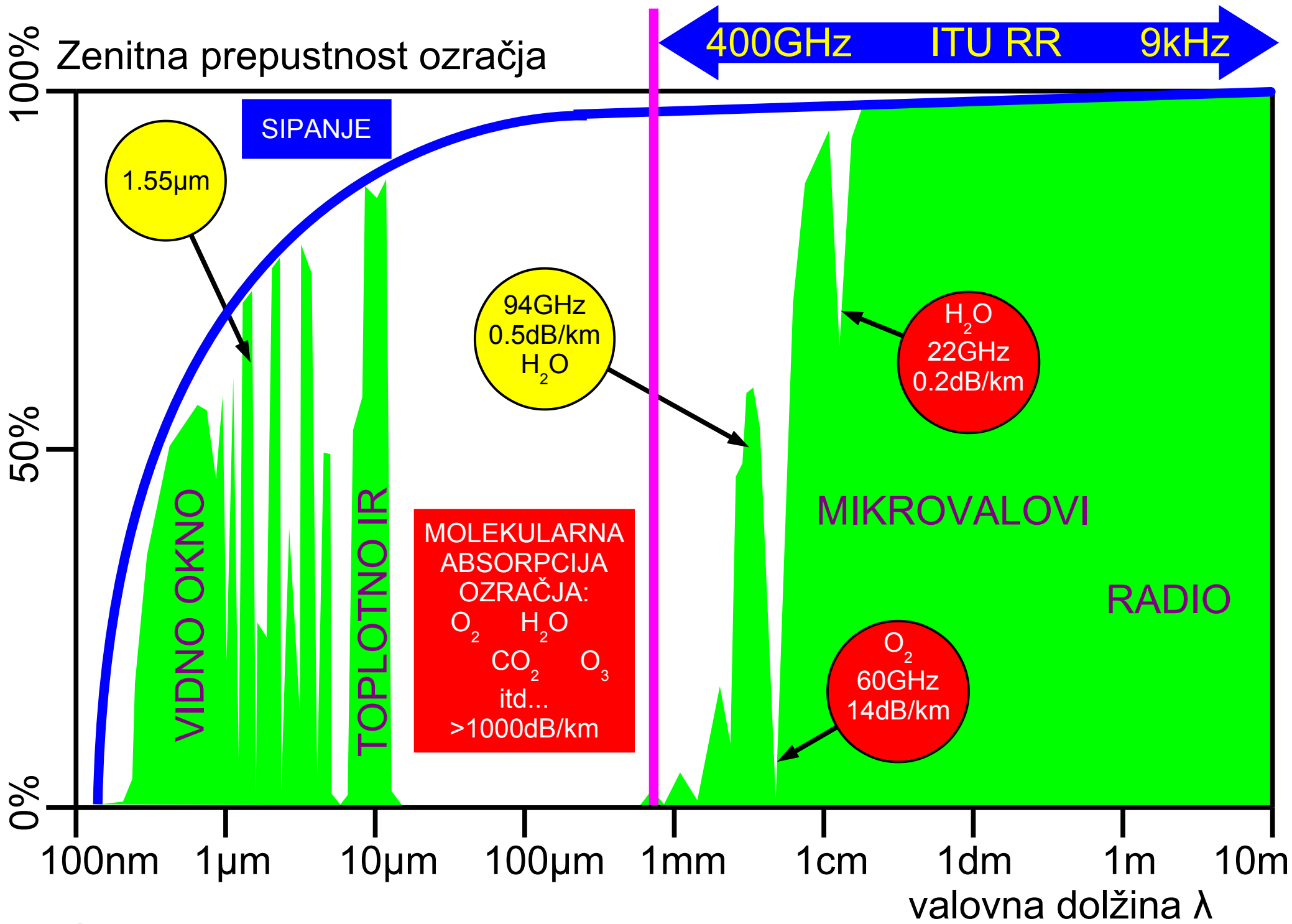
7 - Odboj od tal



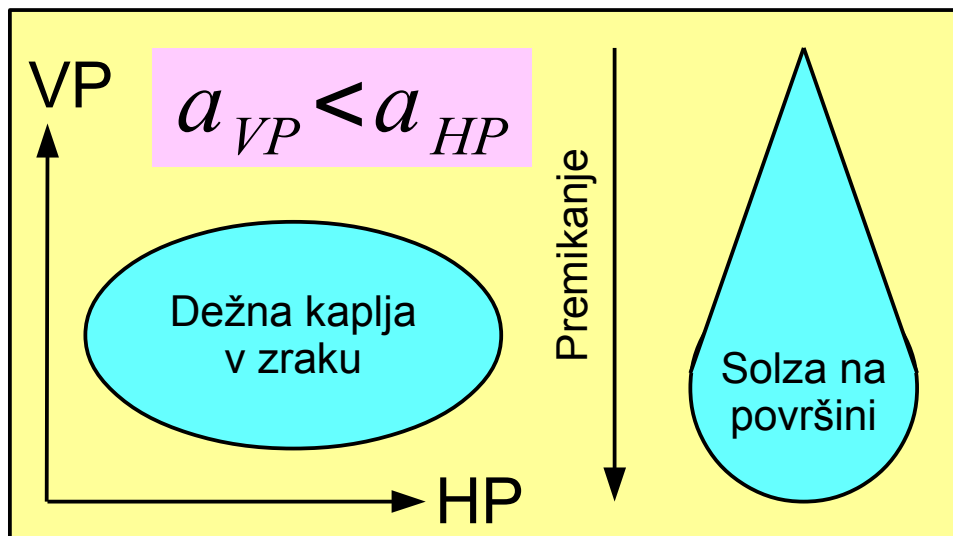
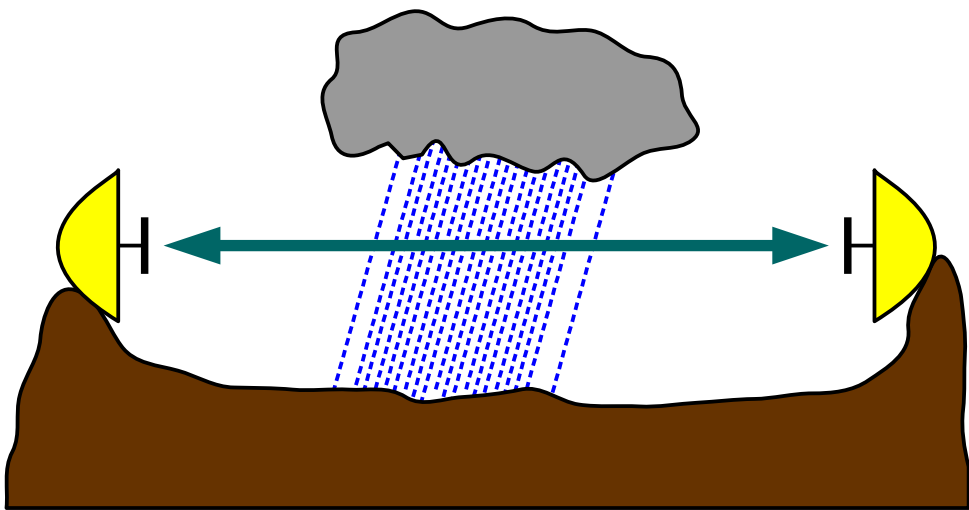
Plast ozračja	Višina h	EM učinek
Eksosfera	>700km	Praznina vesolja
Termosfera	80km-700km	Ionosfera elektroni $\epsilon_r(\omega) < 1$ $\gamma(\omega) > 0$
Mezosfera	50km-80km	Brez večjega učinka (O ₃)
Stratosfera	12km-50km	
Troposfera	0-12km	Nevtralni plini $\epsilon_r(\omega) > 1$ $\gamma(\omega) > 0$



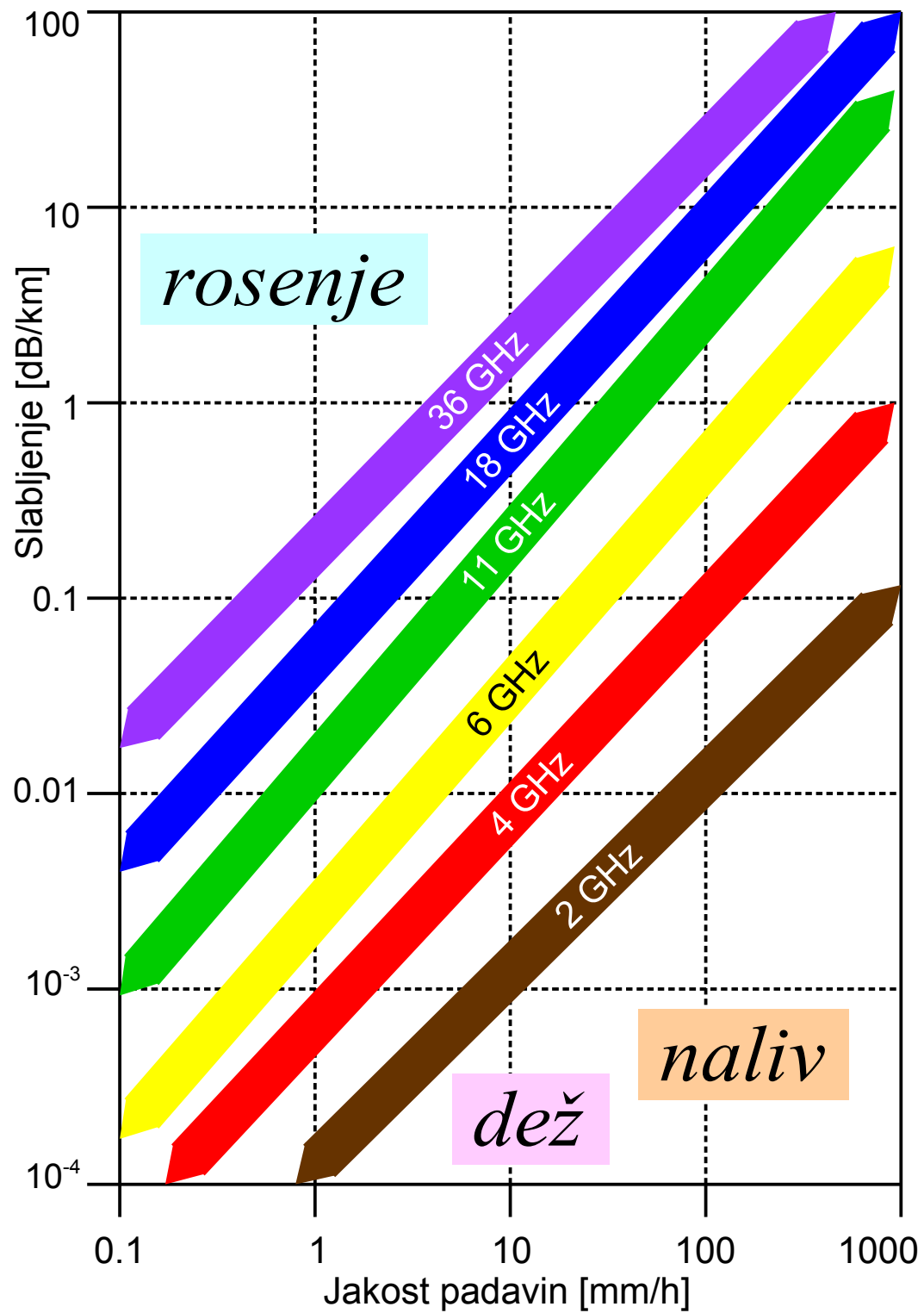
8 - Sestava zemeljskega ozračja



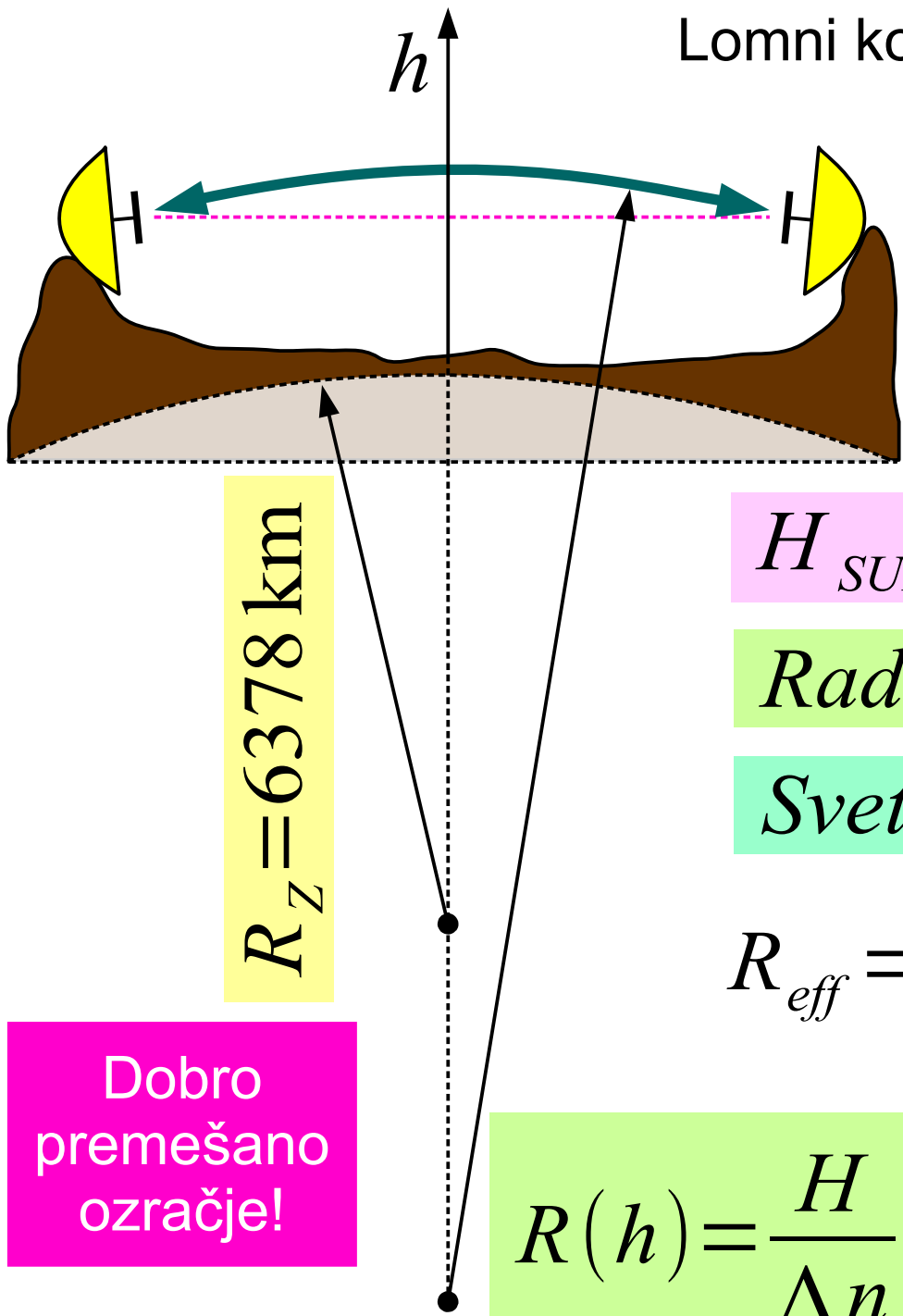
9 - Slabljenje zemeljskega ozračja



Sneg? Žled? Solze vode na površini anten?



Lomni količnik troposfere



$$n(h) = 1 + \Delta n e^{-\frac{h}{H}}$$

Radio: $\Delta n \approx 0.0003$

Svetloba: $\Delta n \approx 0.00015$

$H_{SUHI} \approx 8.5 \text{ km}$

$H_{H2O} \approx 1.5 \text{ km}$

$R_z = 6378 \text{ km}$

Radio: $R(h=0) \approx 25000 \text{ km}$

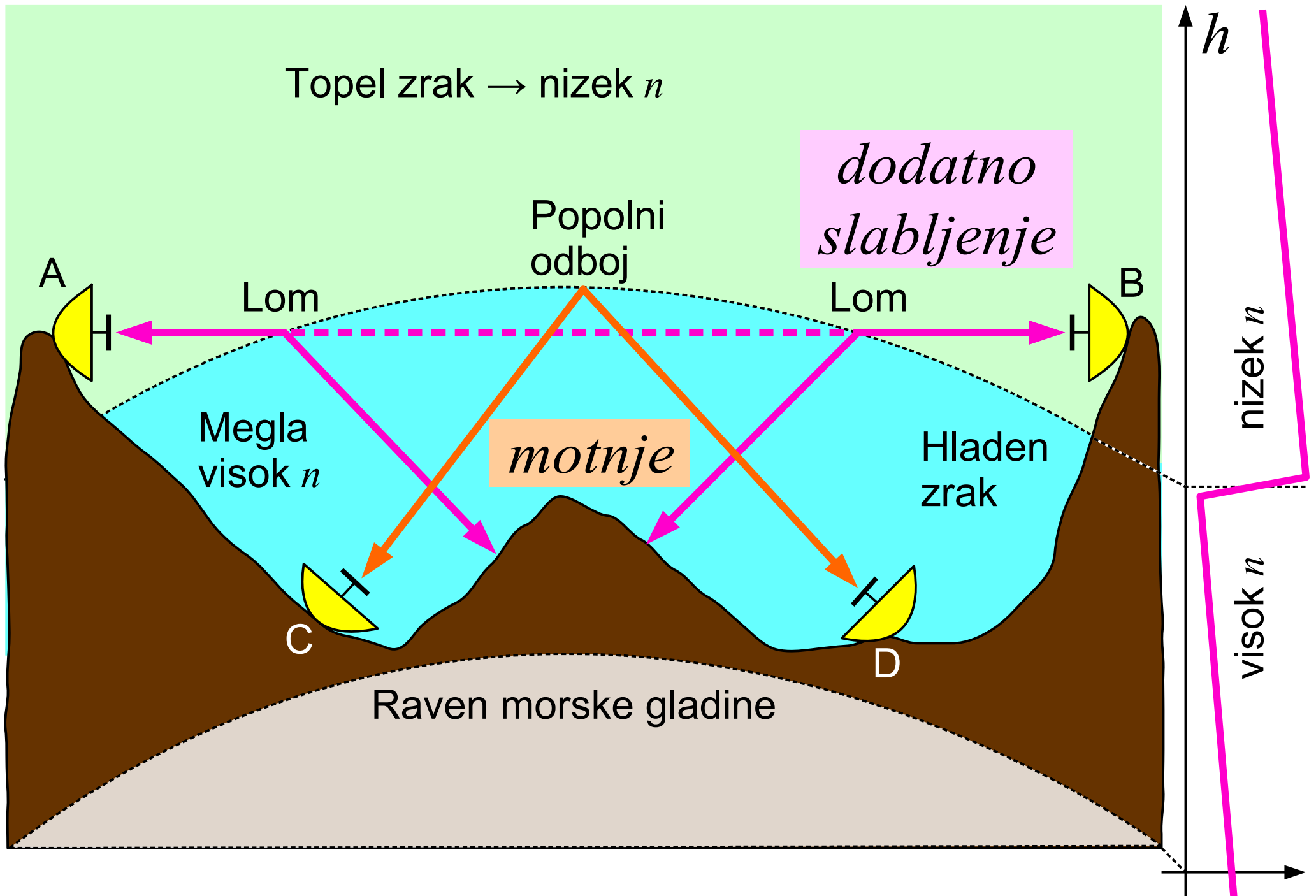
Svetloba: $R(h=0) \approx 50000 \text{ km}$

$$R_{eff} = \frac{1}{1/R_z - 1/R} \approx \frac{4}{3} R_z \text{ (radio)}$$

Dobro premešano ozračje!

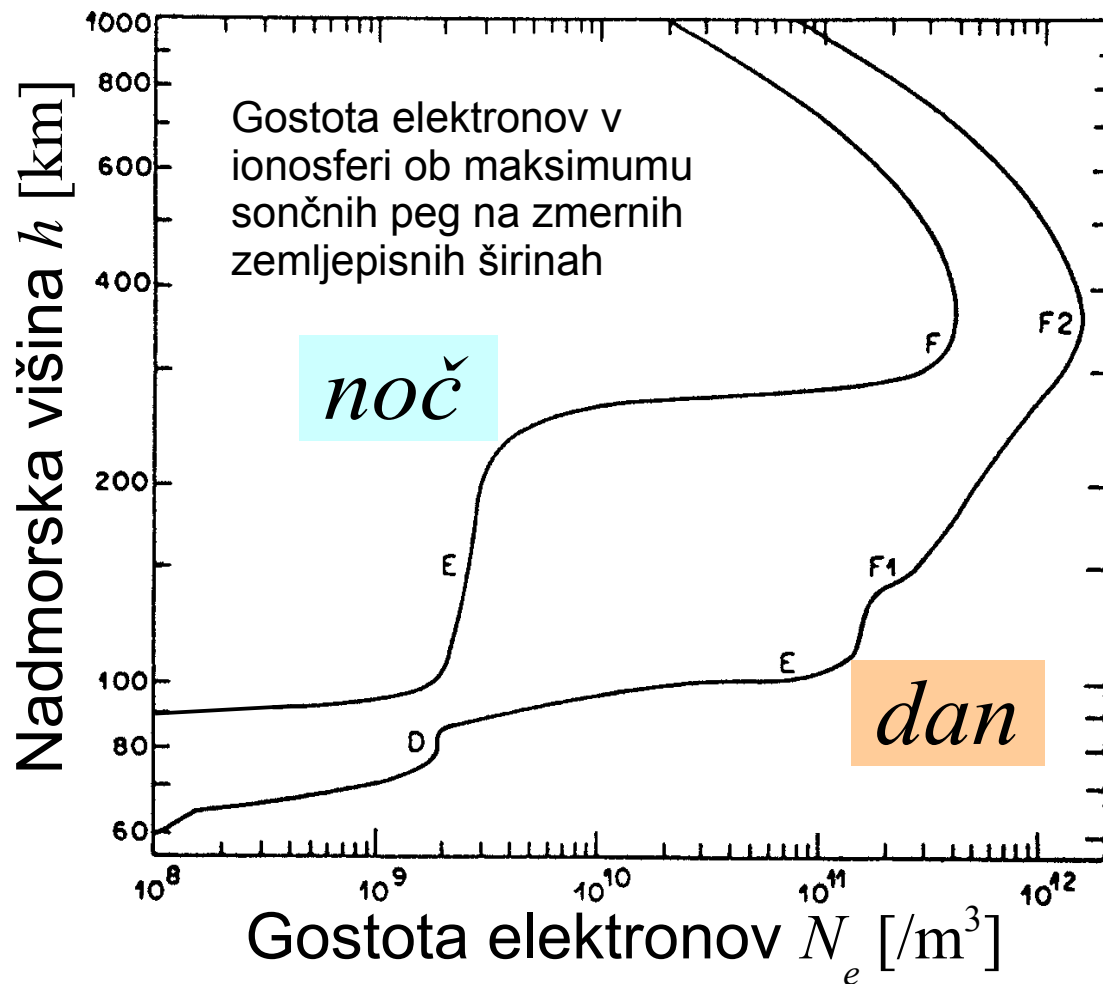
$$R(h) = \frac{H}{\Delta n} e^{\frac{h}{H}}$$

Vidljivost s hriba $d = \sqrt{2Rh}$
 $d_{radijski} = d_{geometrijski} + 16\%$
 $d_{optični} = d_{geometrijski} + 7\%$



12 - Temperaturna inverzija

$$f_p = \frac{1}{2\pi} \sqrt{\frac{N_e Q_e^2}{\epsilon_0 m_e}} = \sqrt{80.6 \frac{\text{m}^3}{\text{s}^2} N_e} \approx \left\{ \begin{array}{l} 11 \text{ MHz } \textit{dan} \\ 5 \text{ MHz } \textit{noč} \end{array} \right\}$$



$f < f_p \rightarrow$ prevodnik

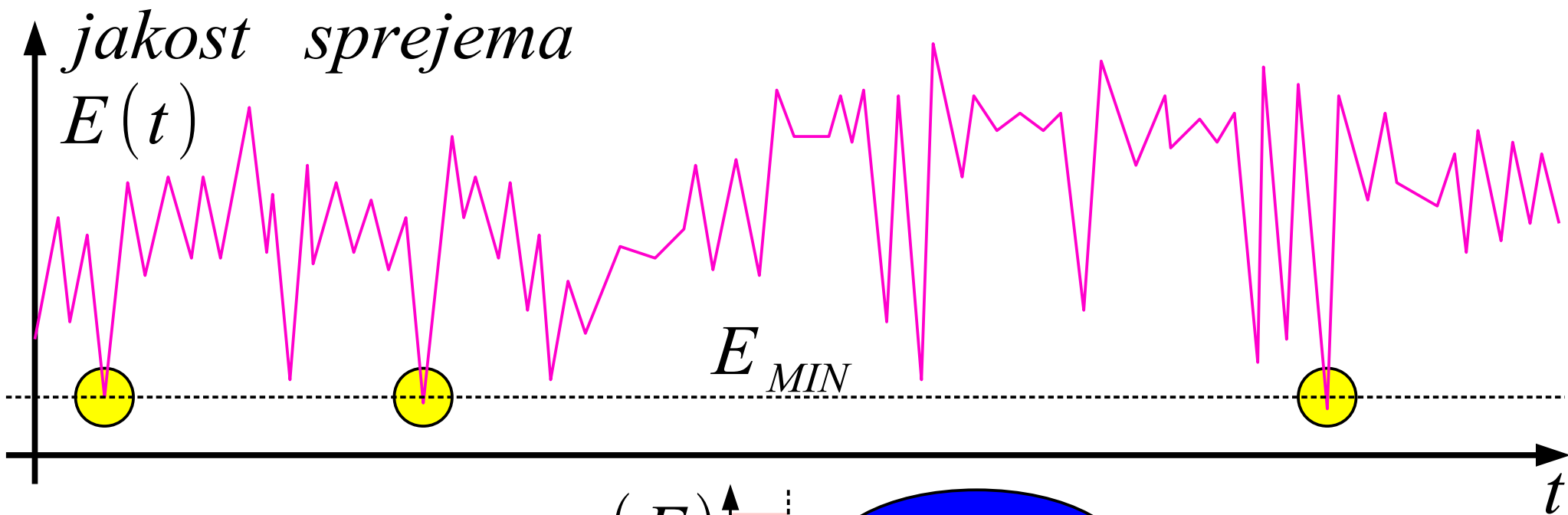
$f > f_p \rightarrow$ dielektrik

$$n = \sqrt{1 - \left(\frac{f_p}{f}\right)^2} < 1$$

Meja popolnega odboja za zvezo preko ionosfere

$$MUF \approx f_p \sqrt{\frac{R_Z}{2h}} \approx 3 f_p$$

Trki v slojih D, E \rightarrow slabljenje, *LUF!*

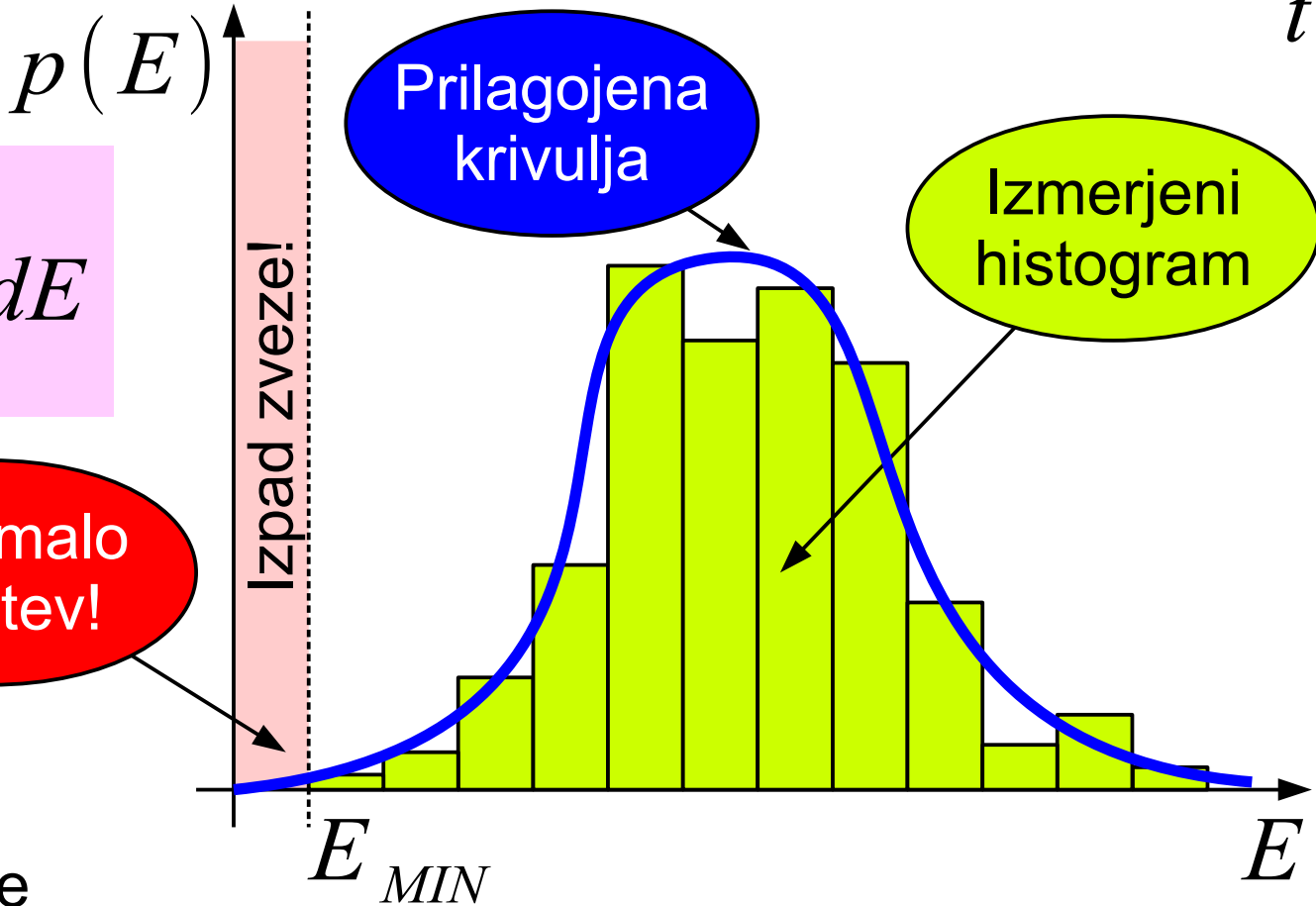


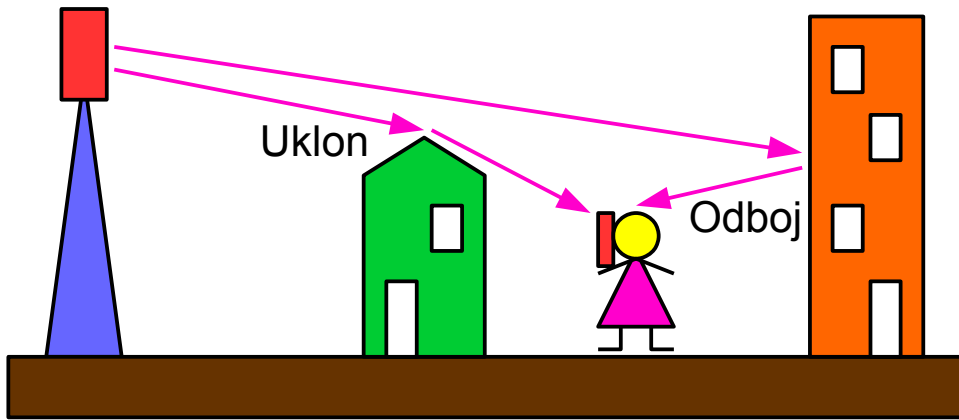
Pogostnost izpada:

$$P_{izpada} = \int_0^{E_{MIN}} p(E) dE$$

Prilagajanje krivulje zahteva fizikalno utemeljitev!

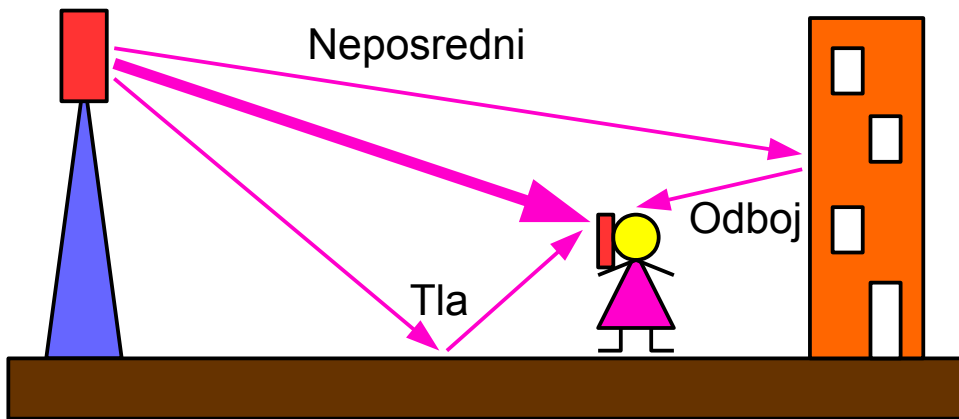
Zelo malo meritev!





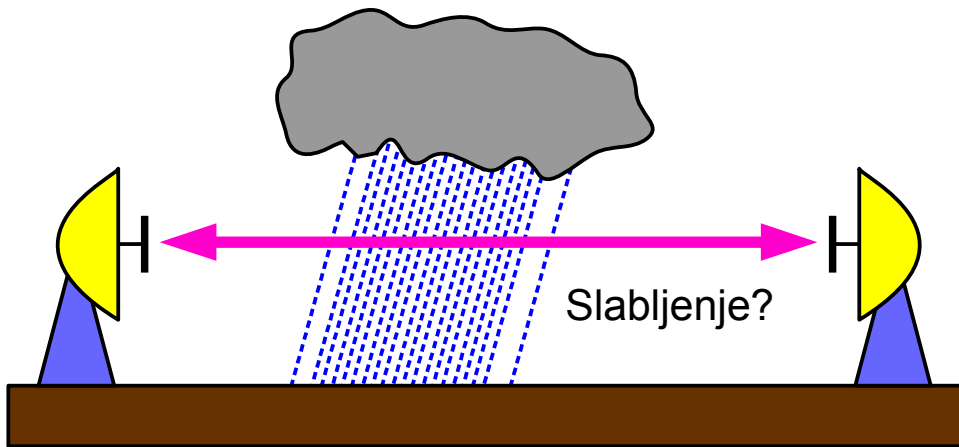
Večpotje brez vidljivosti: Rayleigh ($\langle E \rangle$)
naključna vsota malih kazalcev

$$p(E) = \frac{2E}{\langle E^2 \rangle} e^{-\frac{E^2}{\langle E^2 \rangle}}$$



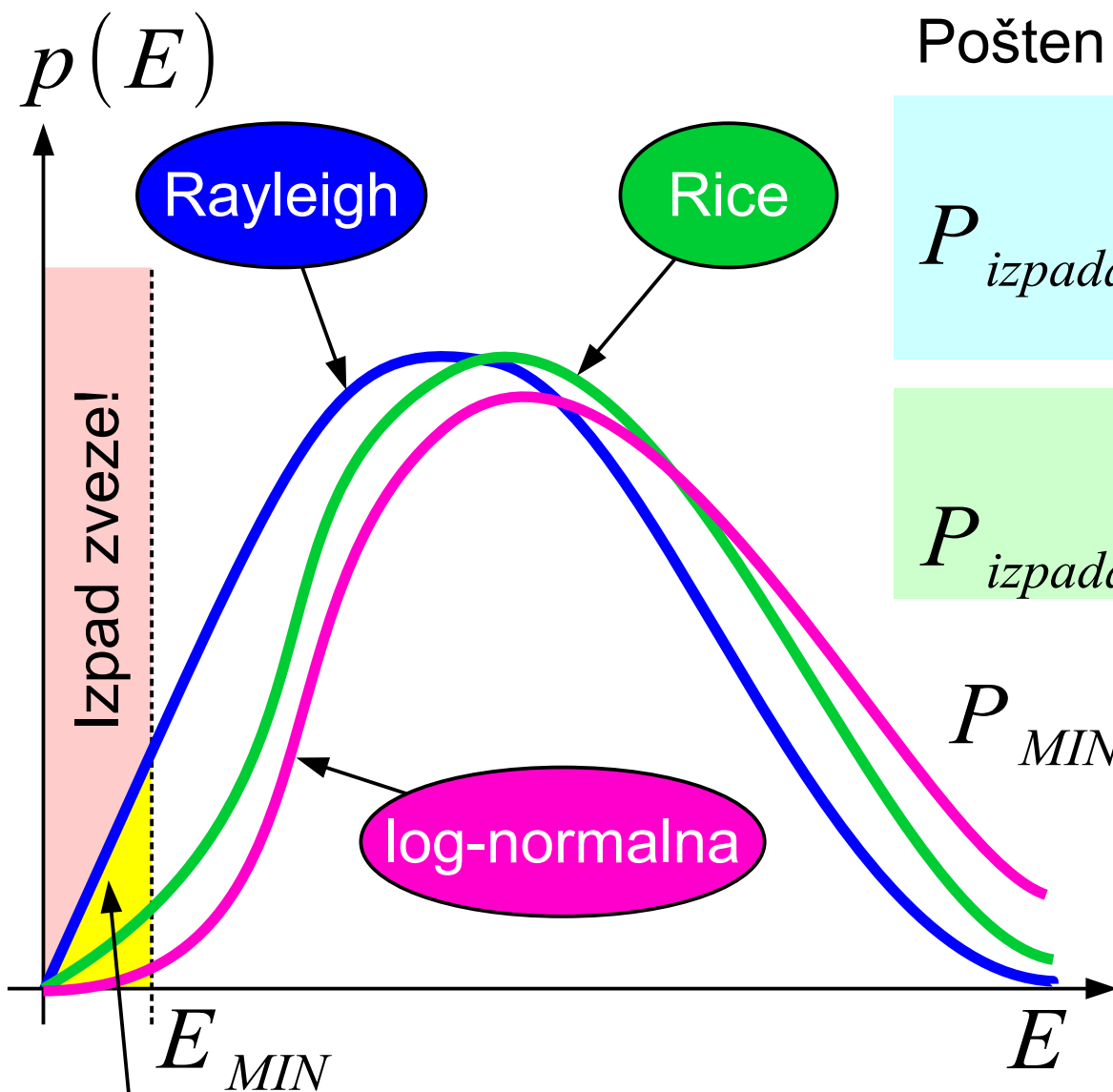
Večpotje z neposrednim žarkom: Rice (E_0, σ)
en velik in mnogo naključnih malih kazalcev

$$p(E) = \frac{E}{\sigma^2} e^{-\frac{E^2 + E_0^2}{2\sigma^2}} I_0\left(\frac{E_0 E}{\sigma^2}\right)$$



Neznane razmere: log-normalna ($\langle E_{dB} \rangle, \sigma_{dB}$)
Fizikalno neutemeljeno!

$$p(E_{dB}) = \frac{1}{\sigma_{dB} \sqrt{2\pi}} e^{-\frac{(E_{dB} - \langle E_{dB} \rangle)^2}{2\sigma_{dB}^2}}$$



Pošten Murphyjev račun: Rayleigh

$$P_{izpada} = \int_0^{E_{MIN}} \frac{2E}{\langle E^2 \rangle} e^{-\frac{E^2}{\langle E^2 \rangle}} dE$$

$$P_{izpada} = 1 - e^{-\frac{E_{MIN}^2}{\langle E^2 \rangle}} = 1 - e^{-\frac{P_{MIN}}{\langle P \rangle}}$$

$$P_{MIN} \ll \langle P \rangle \rightarrow P_{izpada} \approx \frac{P_{MIN}}{\langle P \rangle}$$

Mestno okolje brez vidljivosti:

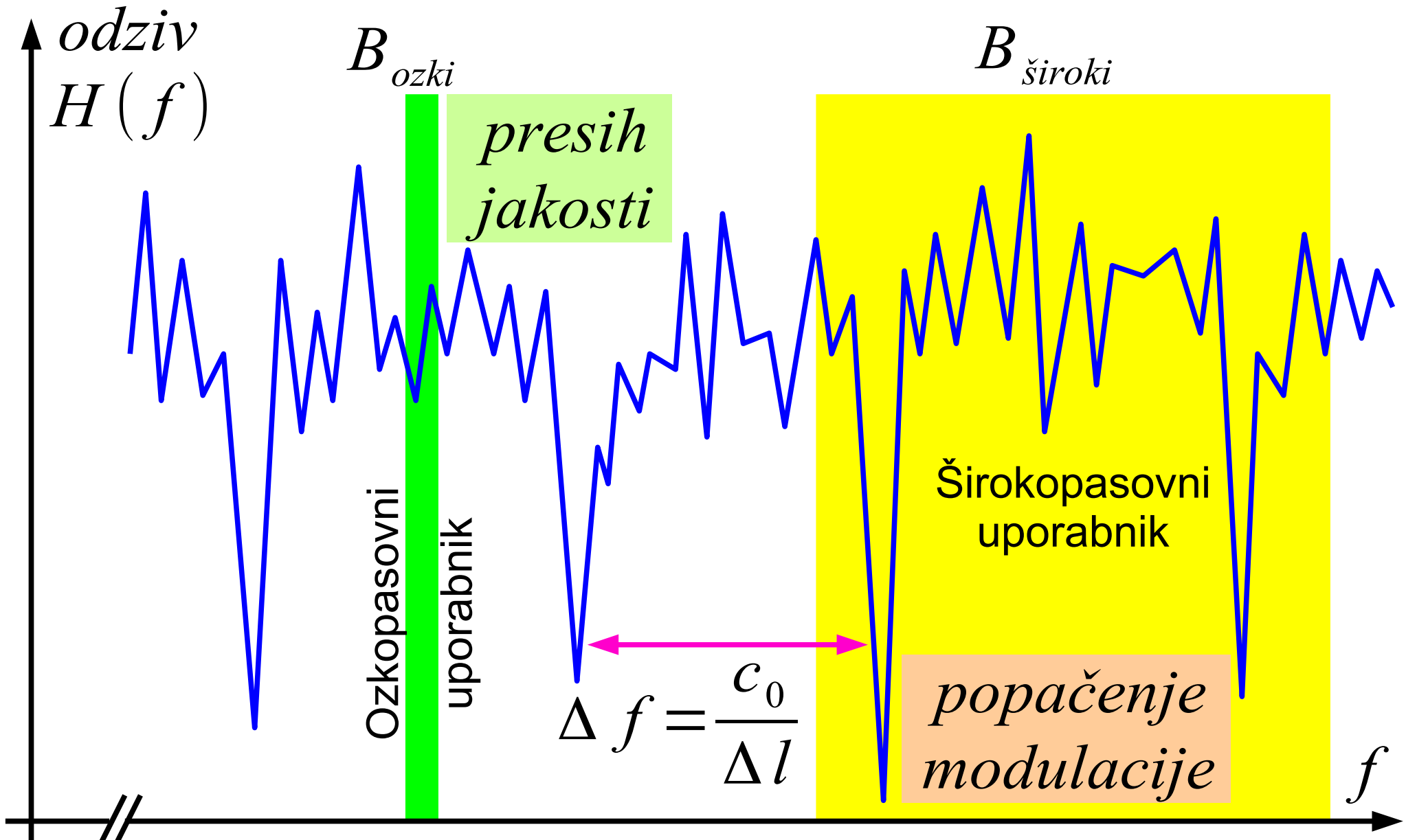
$$\langle P \rangle = \alpha P_{TX} r^{-N} \quad N = 3 \dots 5$$

Zgled: mobilni telefon

$$\langle P \rangle = -90 \text{ dBm} = 1 \text{ pW}$$

$$P_{MIN} = -105 \text{ dBm} = 0.032 \text{ pW}$$

$$P_{izpada} \approx 0.032 \approx 3\%$$



$$B_{ozki} \ll \Delta f \ll B_{široki}$$

Mestno okolje $f_0 \approx 450\text{MHz}$
 $\Delta l = 200\text{m} \dots 1.5\text{km}$
 $\Delta f = 1.5\text{MHz} \dots 200\text{kHz}$