Strokovno izobraževanje

SATELITI, RADARJI IN NAVIGACIJA

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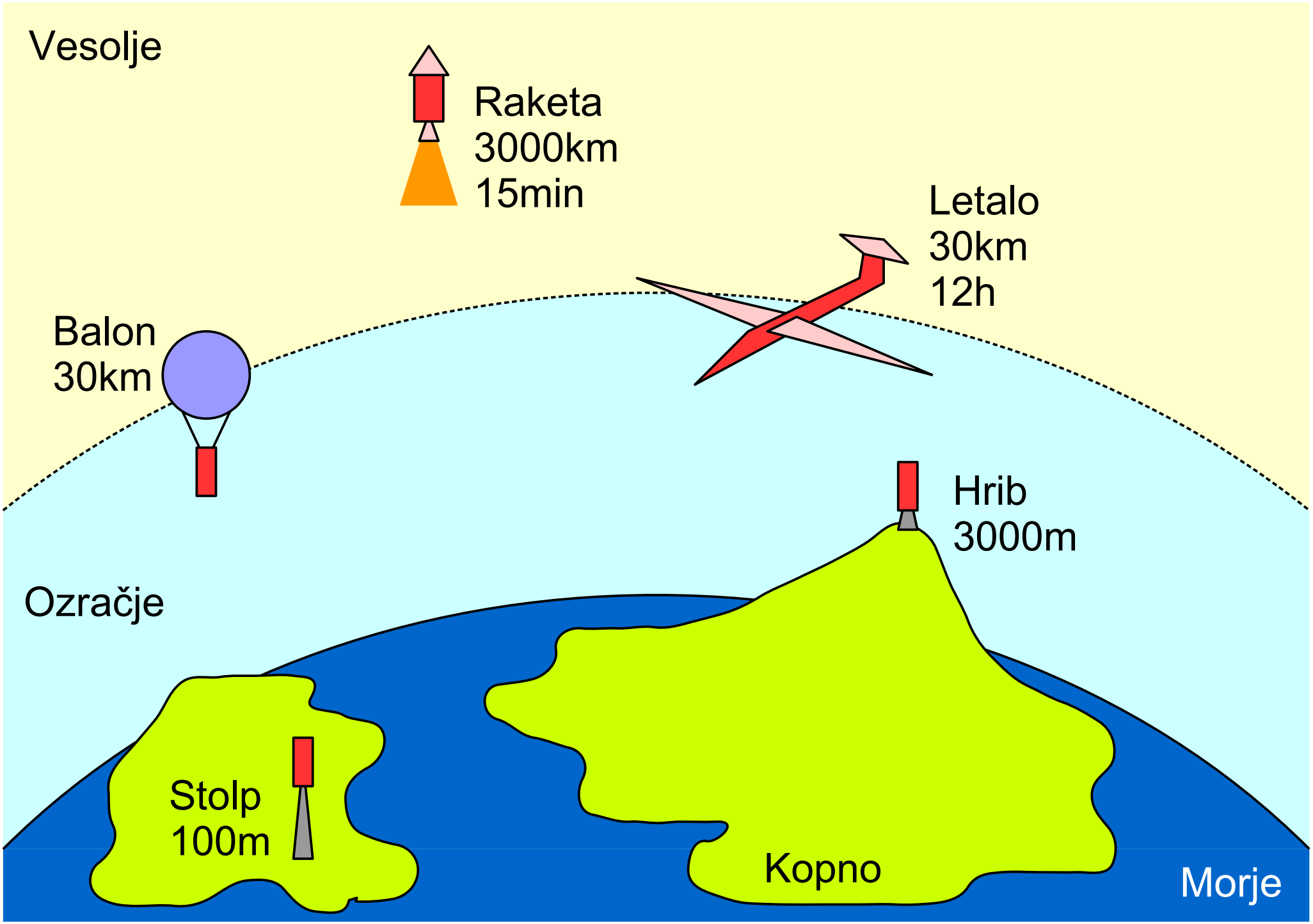
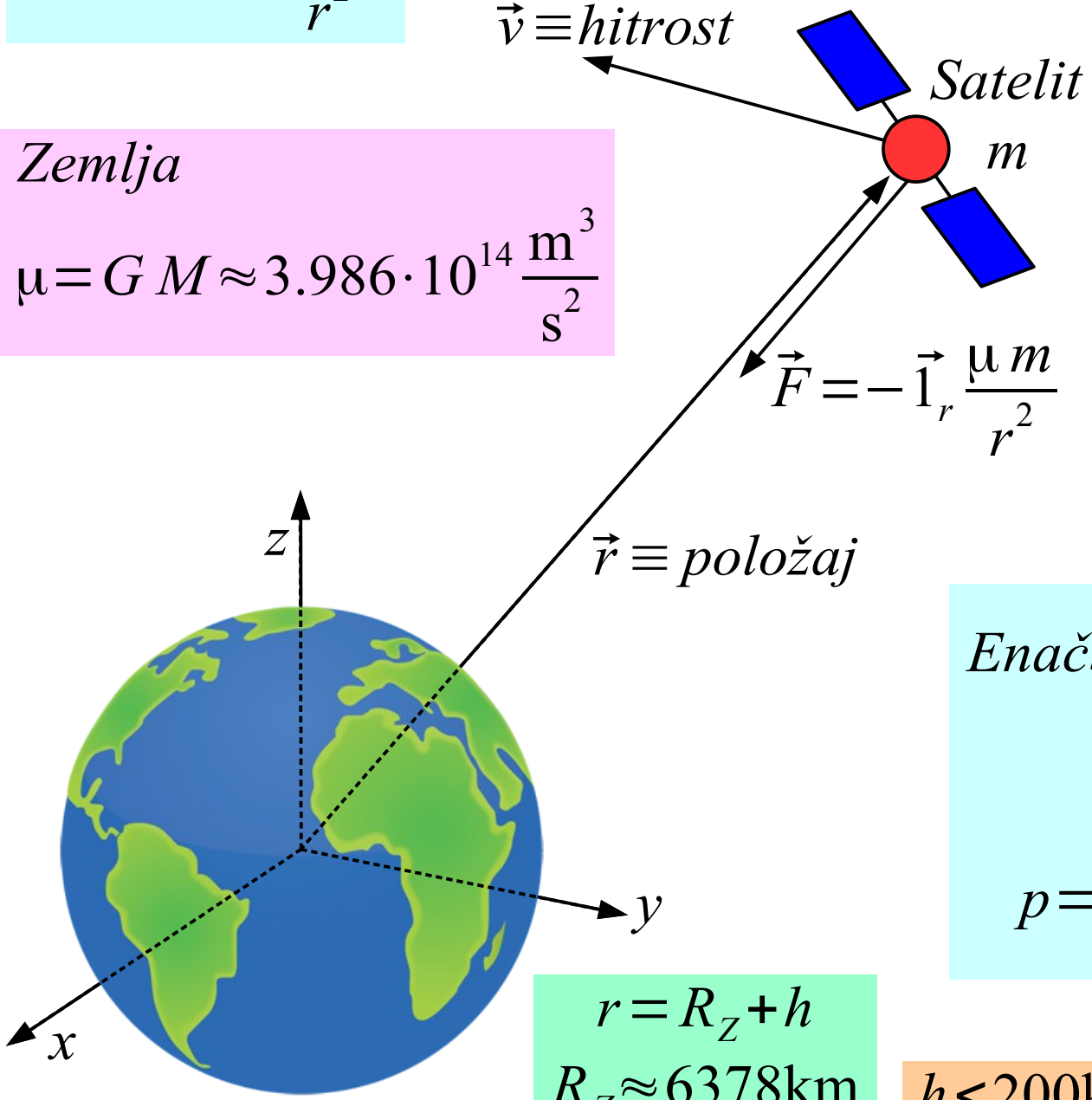


1 - Visoka radijska postaja

$$\vec{F} = -\vec{1}_r \, G \frac{M\,m}{r^2}$$



Zemlja

$$\mu = G\,M \approx 3.986 \cdot 10^{14} \frac{\mathrm{m}^3}{\mathrm{s}^2}$$

Energija

$$W = \frac{1}{2} m v^2 - \frac{\mu\,m}{r} = konst.$$

Vrtilna količina

$$\vec{l} = \vec{r} \times m\vec{v} = \overrightarrow{konst.}$$

Enačba gibanja

$$\vec{a} = \frac{d^2\vec{r}}{dt^2} = \frac{\vec{F}}{m} = -\vec{1}_r \frac{\mu\,m}{r^2}$$

Enačba stožnice $\quad r = \dfrac{p}{1 + e\cos\varphi}$

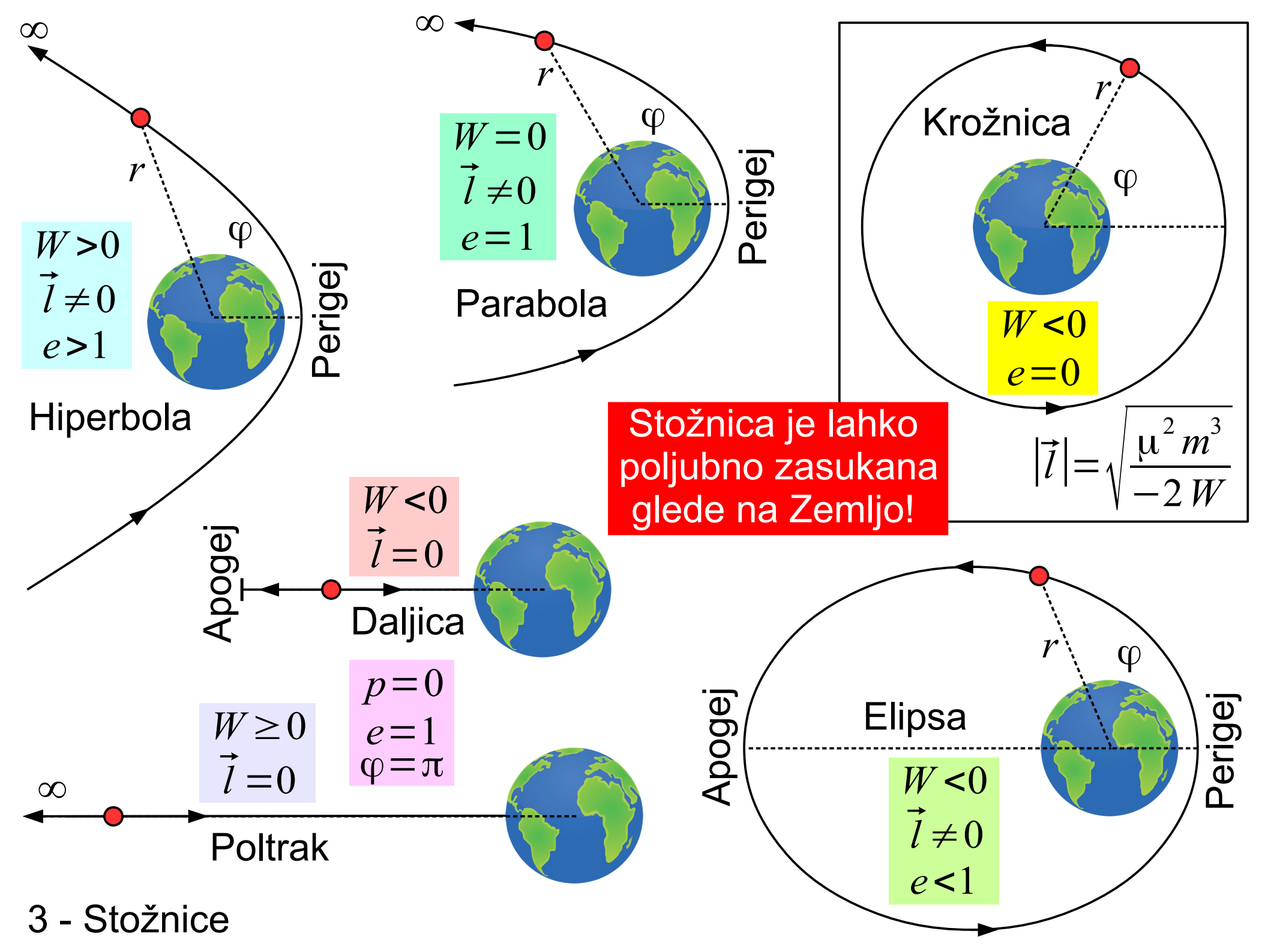
$$p = \frac{|\vec{l}|^2}{\mu\,m^2} \qquad e = \sqrt{1 + \frac{2\,W\,|\vec{l}|^2}{\mu^2 m^3}}$$

$$r = R_Z + h$$

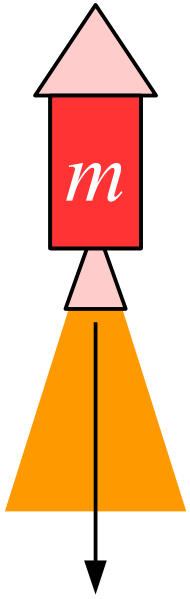
$$R_Z \approx 6378\mathrm{km}$$

$h < 200\mathrm{km}$ → *trenje z ozračjem!*

$h > 50000\mathrm{km}$ → *težnost Sonca, Lune!*


∞
r
φ
$W>0$
$\vec{l}\neq 0$
$e>1$
Perigej
Hiperbola
∞
r
φ
$W=0$
$\vec{l}\neq 0$
$e=1$
Perigej
Parabola
r
φ
Krožnica
$W<0$
$e=0$
$|\vec{l}|=\sqrt{\frac{\mu^2 m^3}{-2W}}$
Stožnica je lahko poljubno zasukana glede na Zemljo!
Apogej
$W<0$
$\vec{l}=0$
Daljica
$p=0$
$e=1$
$\varphi=\pi$
$W\geq 0$
$\vec{l}=0$
∞
Poltrak
r
φ
Elipsa
Apogej
Perigej
$W<0$
$\vec{l}\neq 0$
$e<1$

3 - Stožnice



$$\sum \vec{F} = 0 = \frac{-d\,m}{d\,t}\vec{v}_i + \vec{a}\,m \quad \rightarrow \quad \vec{a} = \frac{\vec{v}_i}{m}\cdot\frac{d\,m}{d\,t}$$

$$\Delta\vec{v} = \int_{t_1}^{t_2}\vec{a}\,d\,t = \int_{m_1}^{m_2}\frac{\vec{v}_i}{m}\,d\,m = -\vec{v}_i\frac{m_1}{m_2} = -\vec{v}_i\ln\left(1+\frac{m_g}{m_t}\right)$$

$m_g \equiv masa\quad goriva \qquad m_t \equiv masa\quad tovora$

$\vec{v}_i \equiv hitrost\quad izpuha$

$\Delta\vec{v} \equiv sprememba\quad hitrosti$

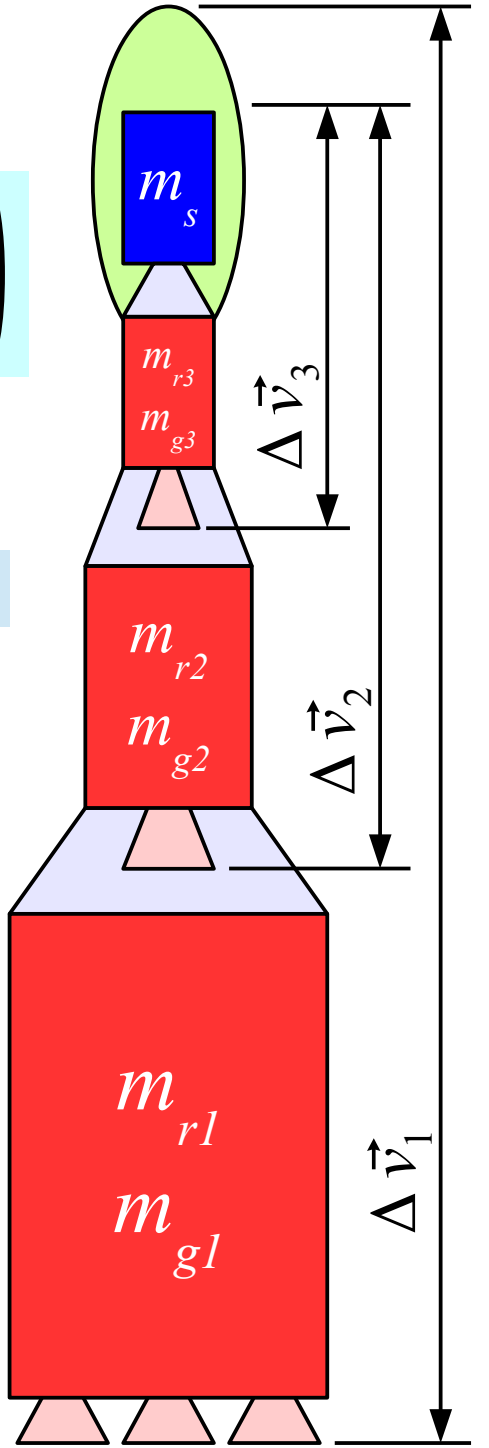
Gorivo	v_i	Δv $m_g = 9m_t$
Hladen N_2	0.3km/s	0.7km/s
H_2O_2	1.5km/s	3.5km/s
N_2H_4	2.2km/s	5.1km/s
$Al+NH_4ClO_4$	2.7km/s	6.2km/s
$N_2H_2(CH_3)_2+N_2O_4$	3.0km/s	6.9km/s
Tekoča H_2+O_2	4.5km/s	10.4km/s

Potrebno:

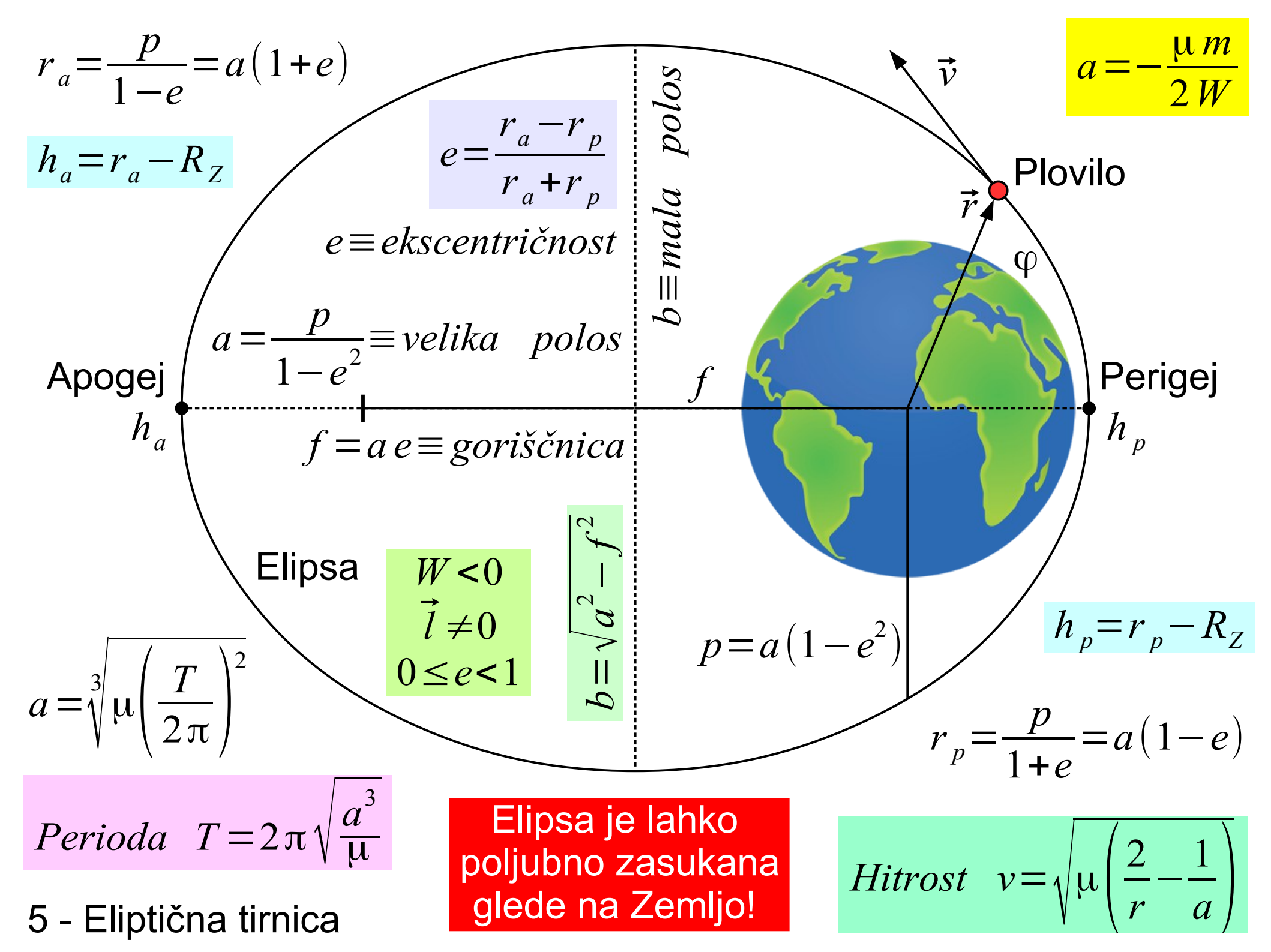
$$\sum \Delta v = 8\ldots12\,\mathrm{km/s}$$

Večstopenjska raketa!

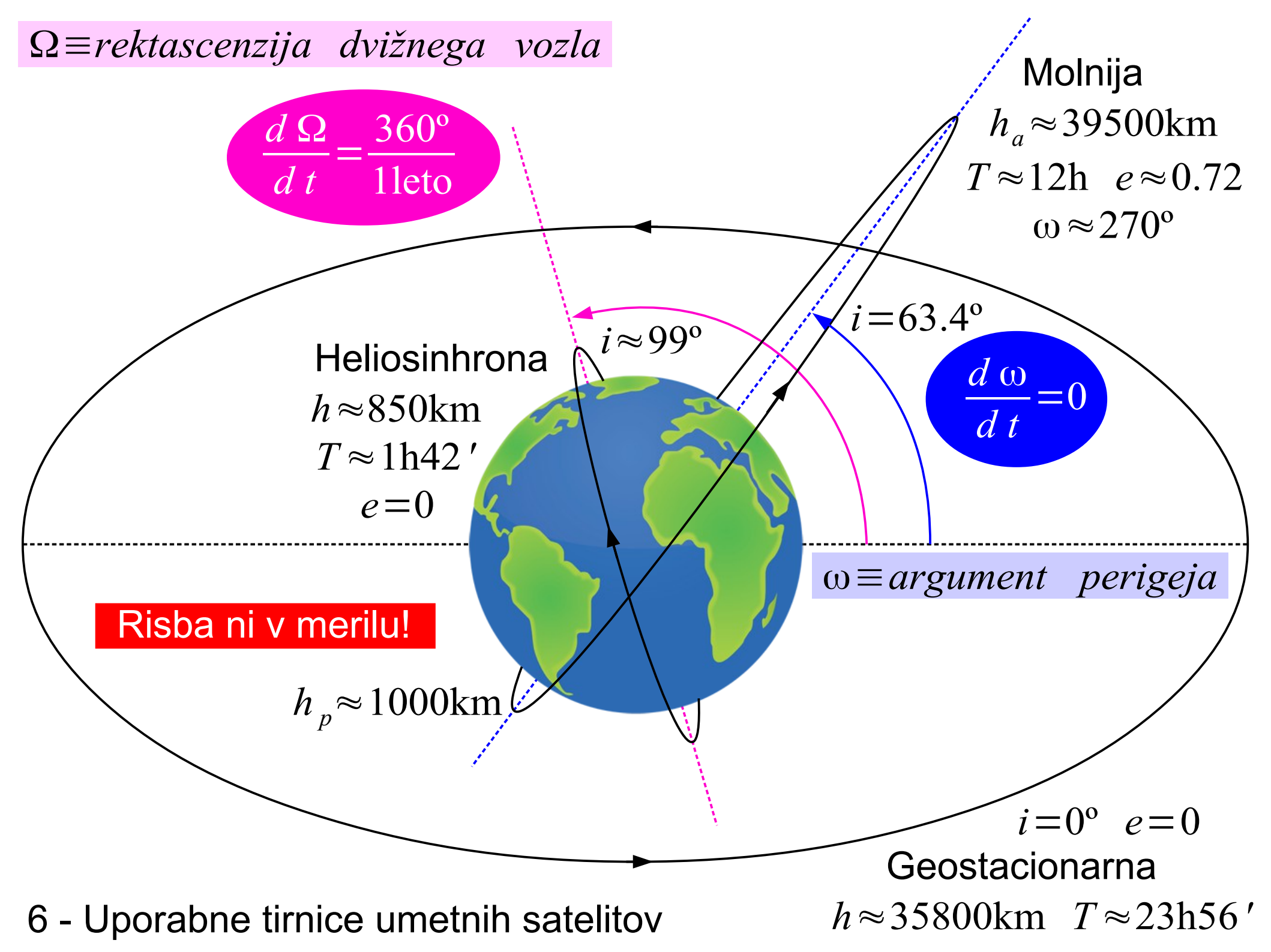
$$m_g = m_t\left(e^{\frac{\Delta v}{v_i}} - 1\right)$$

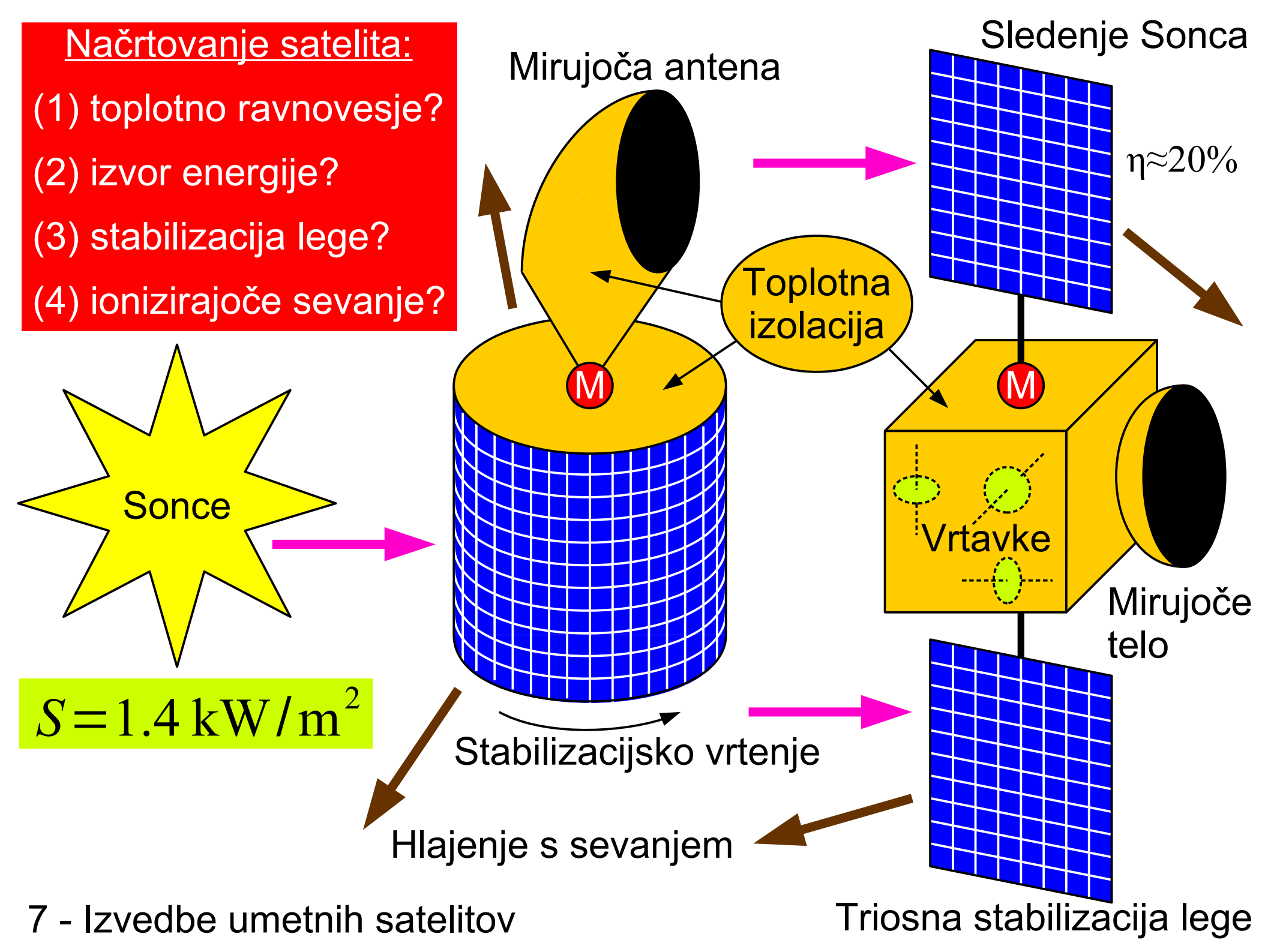


4 - Enačba gibanja rakete



5 - Eliptična tirnica

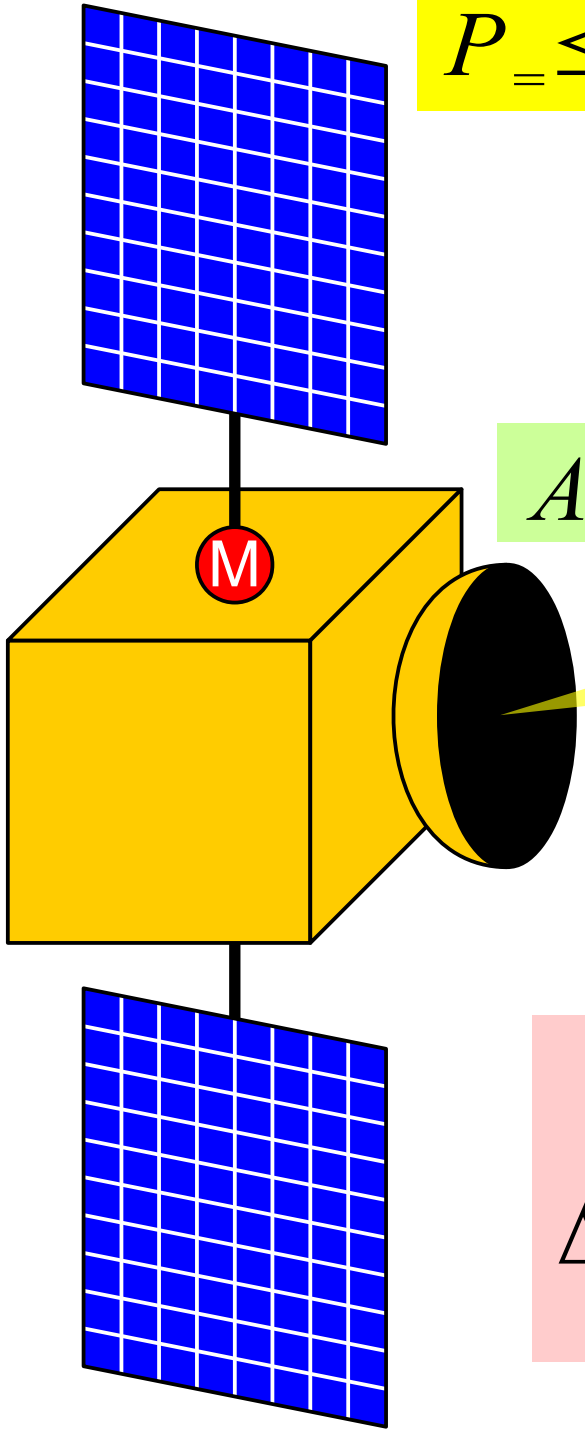

Ω ≡ rektascenzija dvižnega vozla
$\frac{d\Omega}{dt} = \frac{360^\circ}{1\text{leto}}$
Molnija
$h_a \approx 39500\text{km}$
$T \approx 12\text{h}$ $e \approx 0.72$
$\omega \approx 270^\circ$
$i = 63.4^\circ$
$i \approx 99^\circ$
Heliosinhrona
$h \approx 850\text{km}$
$T \approx 1\text{h}42'$
$e = 0$
$\frac{d\omega}{dt} = 0$
ω ≡ argument perigeja
Risba ni v merilu!
$h_p \approx 1000\text{km}$
$i = 0^\circ$ $e = 0$
Geostacionarna
$h \approx 35800\text{km}$ $T \approx 23\text{h}56'$


Načrtovanje satelita:
(1) toplotno ravnovesje?
(2) izvor energije?
(3) stabilizacija lege?
(4) ionizirajoče sevanje?
Mirujoča antena
Sledenje Sonca
η≈20%
Toplotna izolacija
M
M
Sonce
Vrtavke
Mirujoče telo
$S = 1.4\,\mathrm{kW/m^2}$
Stabilizacijsko vrtenje
Hlajenje s sevanjem
Triosna stabilizacija lege

$P_{=} \leq 10\text{kW}$

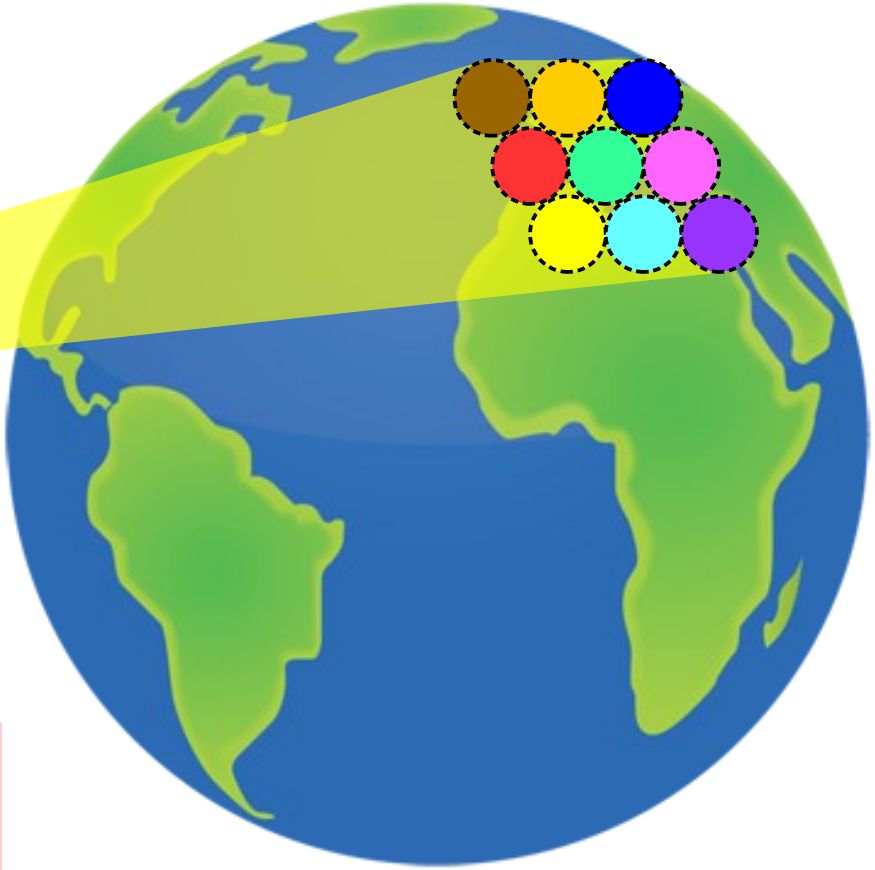
Prepustnost ozračja

$100\text{MHz} \leq f \leq 50\text{GHz}$



$A \leq 10\text{m}^2$

$r \approx 38000\text{km}$



Zakasnitev

$$\Delta t = \frac{2r}{c_0} \approx 0.25\text{s}$$

Omejena zmogljivost:
(1) radiodifuzija
(2) radionavigacija
(3) opazovanje Zemlje

$$P_{RX} \approx \frac{P_{TX} G^2 \lambda^2}{(4\pi)^3 r^4} \sigma$$

$$\lambda = 0.1\text{m}$$

$$t_p \approx 1\,\mu\text{s}$$
$$T \approx 3\text{ms}$$

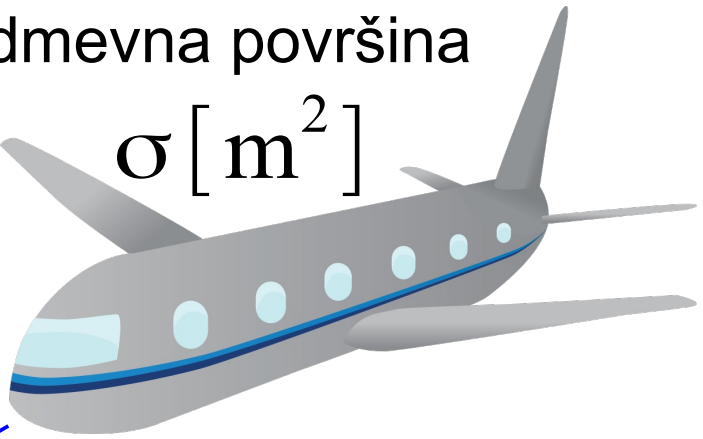
$$P_{TX} = +90\text{dBm} = 1\text{MW}$$

$$P_{RX} = -90\text{dBm} = 1\text{pW}$$

$$G = 40\text{dBi} = 10^4$$

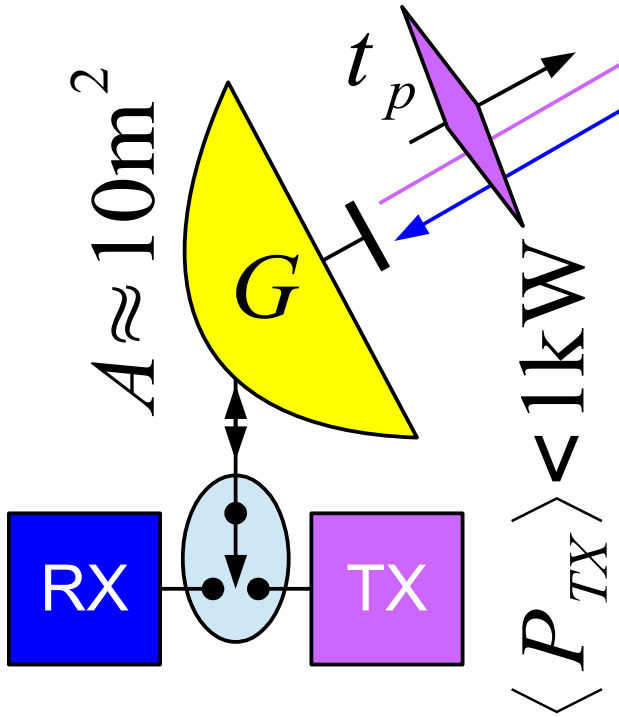
Odmevna površina

$$\sigma\,[\text{m}^2]$$

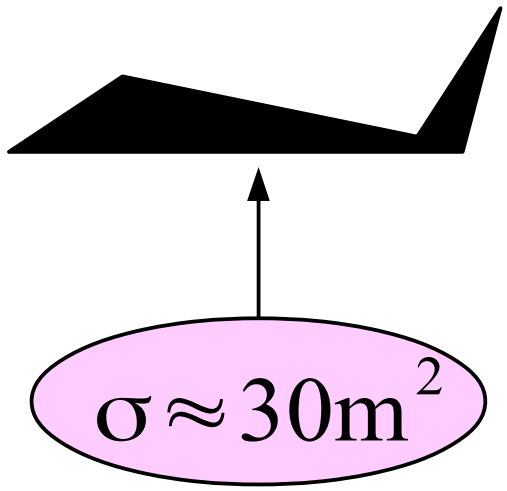


$$r = \sqrt[4]{\frac{P_{TX} G^2 \lambda^2}{P_{RX} (4\pi)^3} \sigma}$$

$$r = c_0 2\,\Delta t$$



$$\sigma \approx 0.01\text{m}^2$$



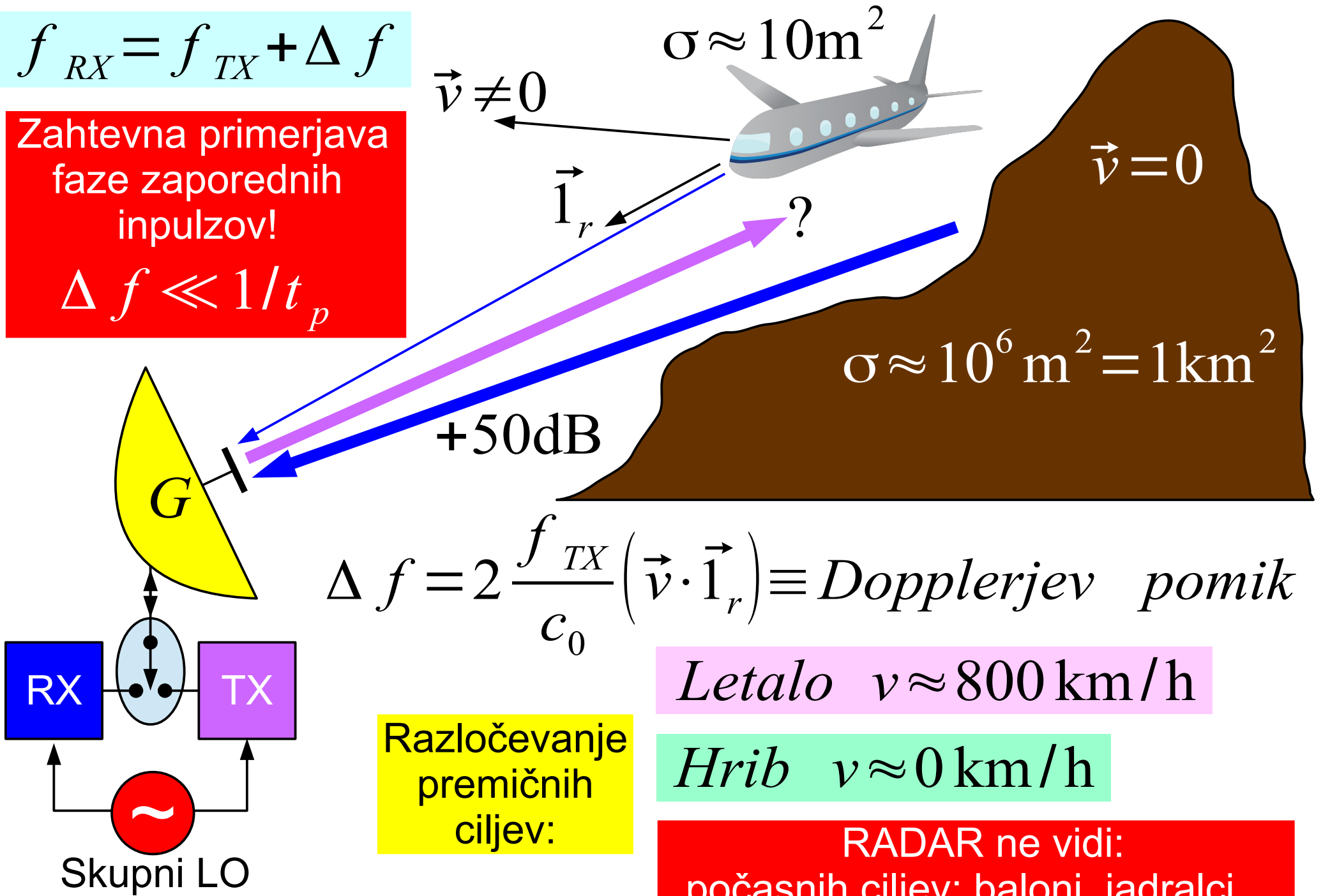
$$\sigma \approx 30\text{m}^2$$

Letalo	σ	r
Cessna C172	~1m^2	~150km
Airbus A320	~10m^2	~266km
Lockheed F117	~0.01m^2	~47km

$$f_{RX} = f_{TX} + \Delta f$$

Zahtevna primerjava faze zaporednih inpulzov!

$$\Delta f \ll 1/t_p$$



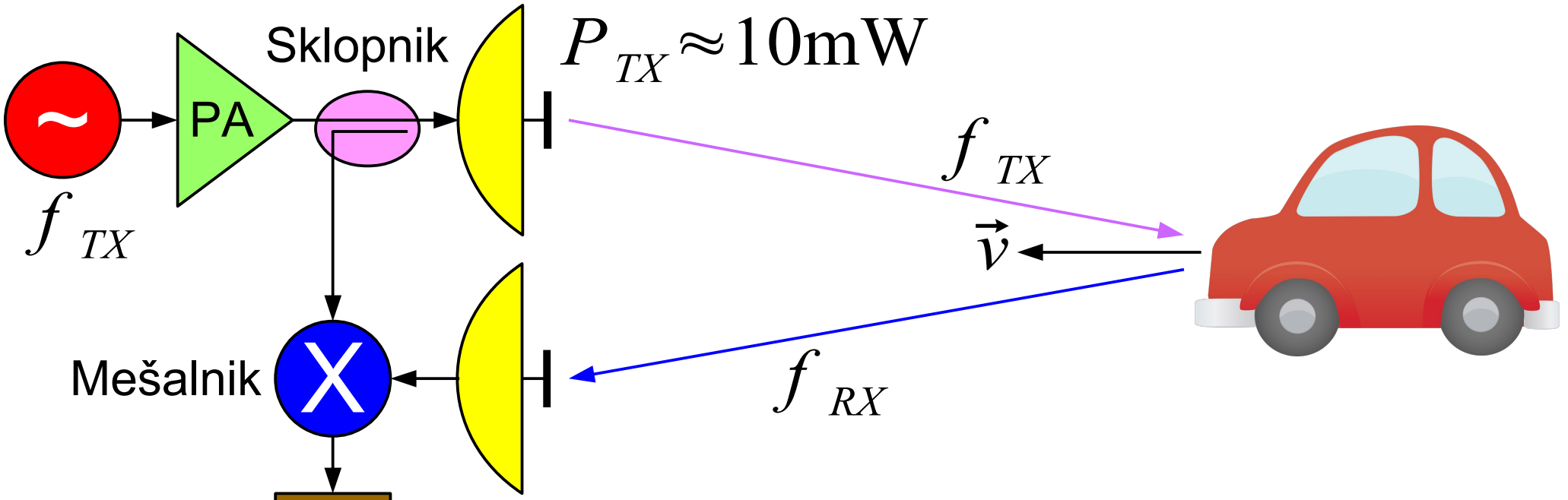
$$\Delta f = 2\frac{f_{TX}}{c_0}\left(\vec{v}\cdot\vec{1}_r\right) \equiv Dopplerjev \quad pomik$$

$$Letalo \quad v \approx 800\,\mathrm{km/h}$$

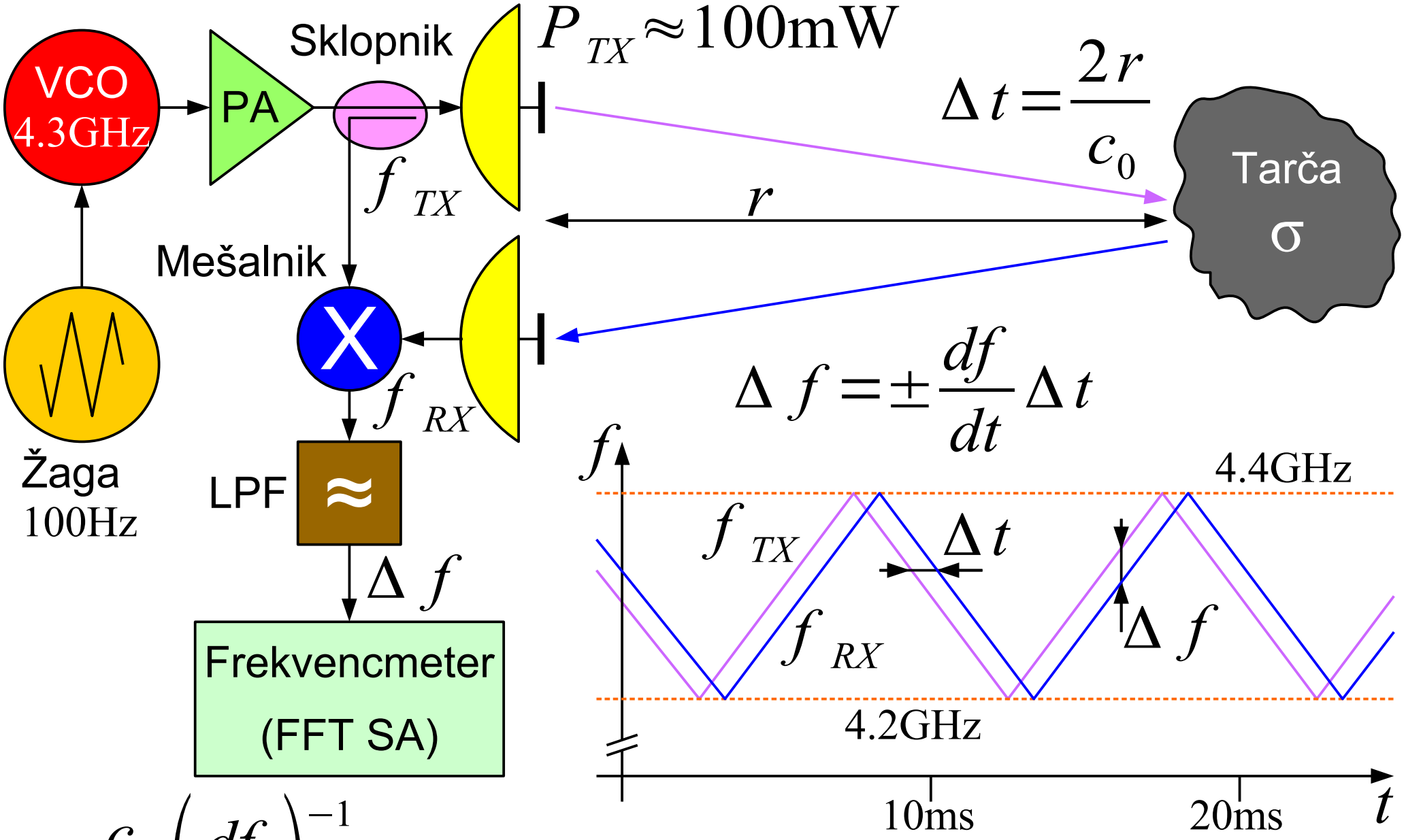
$$Hrib \quad v \approx 0\,\mathrm{km/h}$$

Razločevanje premičnih ciljev:

RADAR ne vidi:
počasnih ciljev: baloni, jadralci...
tangencialnih ciljev: $\vec{v} \perp \vec{1}_r$

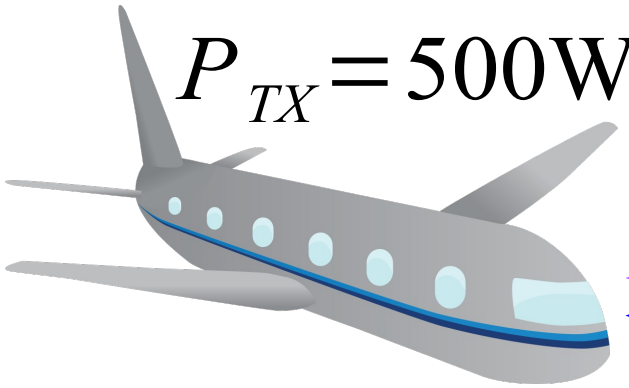


Frekvenčni pasovi	
9.375GHz	Ni več v uporabi
10.525GHz	Region 2
24GHz	ISM
34GHz	Licenciran



$$r = \frac{c_0}{2} \left(\frac{df}{dt} \right)^{-1} \Delta f$$

Letalski višinomer	4.3GHz±100MHz
Avtomobilski RADAR	77GHz±1GHz

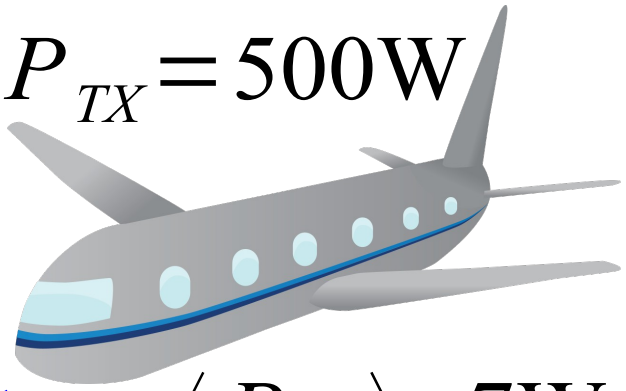


$P_{TX}=500\mathrm{W}$

TCAS

1030MHz

1090MHz



$P_{TX}=500\mathrm{W}$

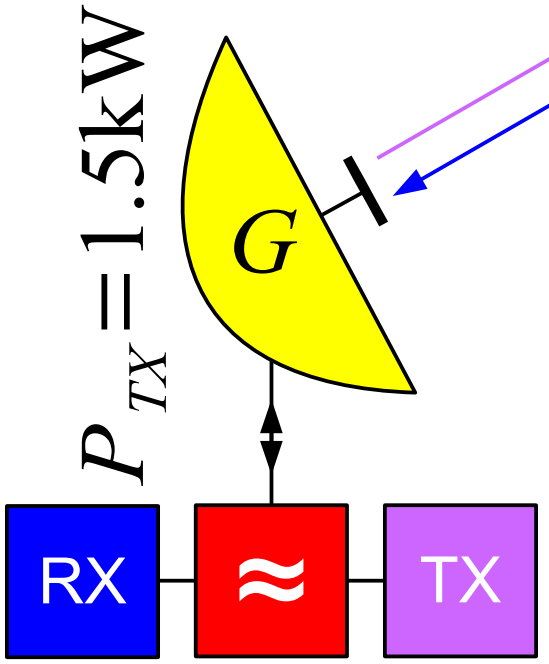
$\langle P_{TX}\rangle<7\mathrm{W}$

Vprašanja 1030MHz:
Mode „A“ 2 pulza 8µs
Mode „C“ 2 pulza 21µs
Mode „S“ 56bit/112bit
4Mbps BPSK

1030MHz

1090MHz

TCAS ≡ Traffic-alert Collision Avoidance System
TCAS-1: Traffic Advisory C/S
TCAS-2: Resolution Advisory S



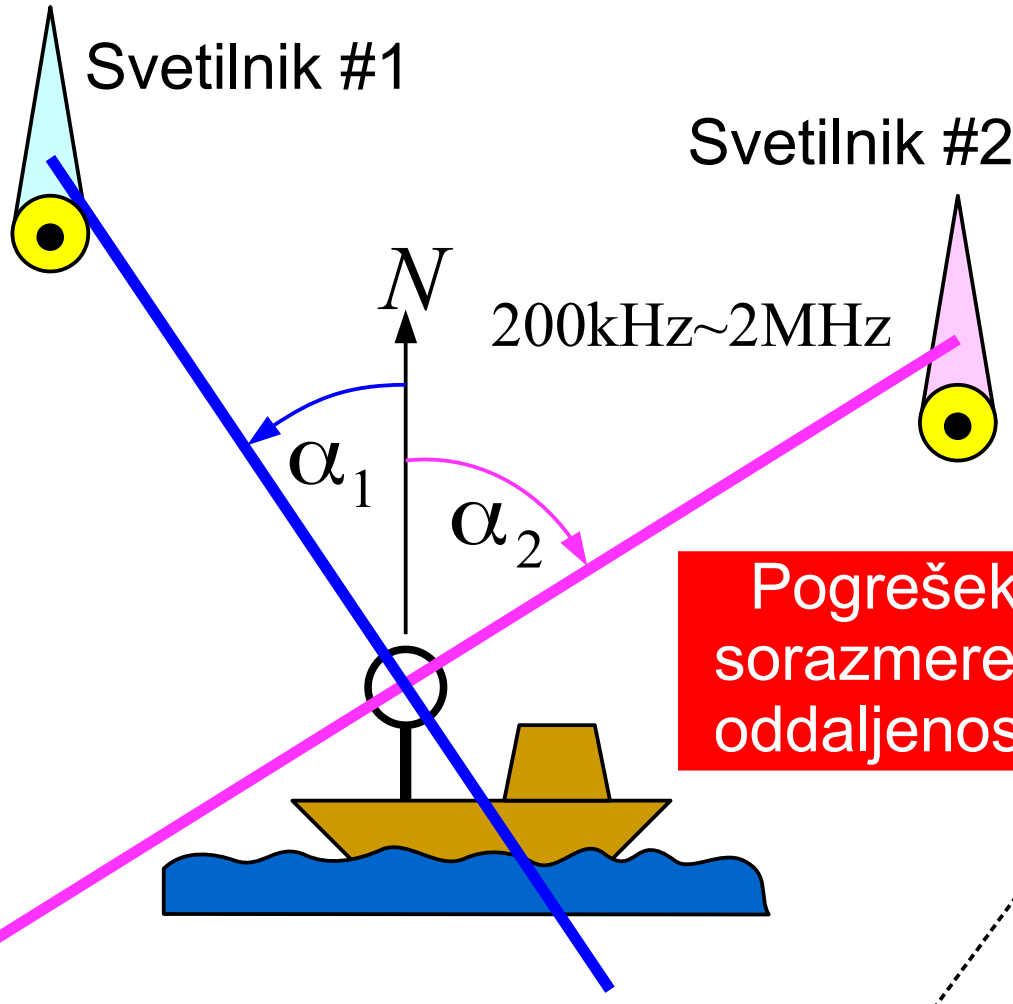
$\langle P_{TX}\rangle<5\mathrm{W}$

Odgovori 1090MHz:
Mode „A“ koda letala 15bit
Mode „C“ višina letala 13bit
Mode „S“ 56bit/112bit
1Mbps Manchester/ASK

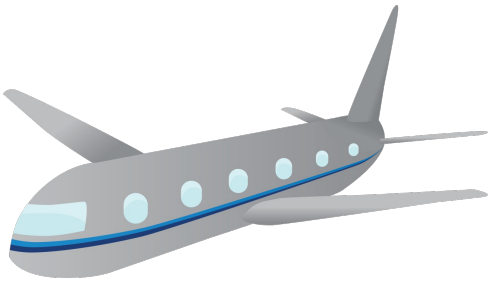
TCAS nima avtentikacije

TCAS nima kriptozaščite

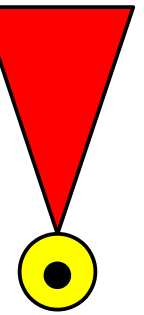
Protokol TCAS je javno dosegljiv



Pogrešek sorazmeren oddaljenosti

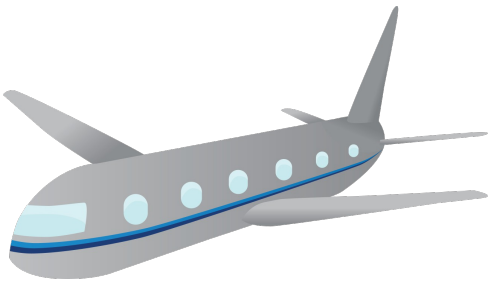


Zelo groba navigacija

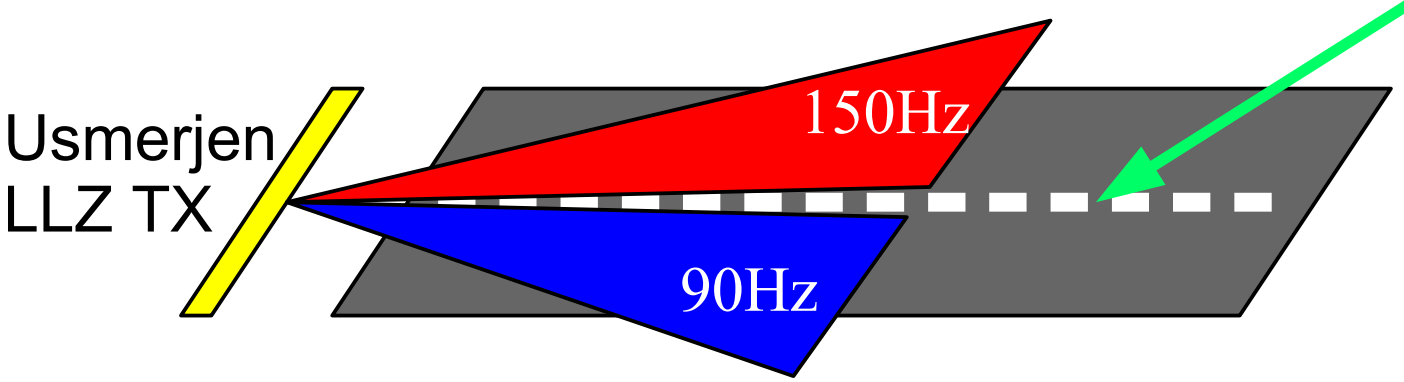


Usmerjen marker TX

Marker 75MHz	
OM	400Hz
MM	1300Hz
IM	3000Hz



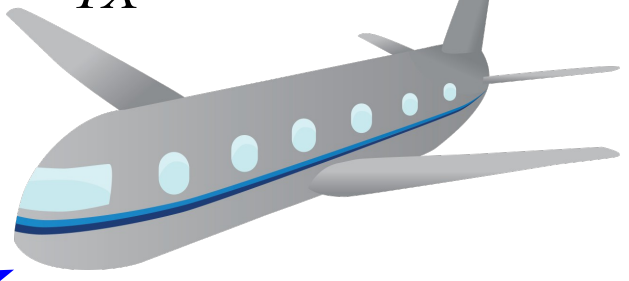
Navigacija na točko



Frekvence ILS	
LLZ	108.1MHz~ ~111.95MHz
GS	328.6MHz~ ~335.4MHz

DME/P uporablja 2 pulza 18μs ali 24μs

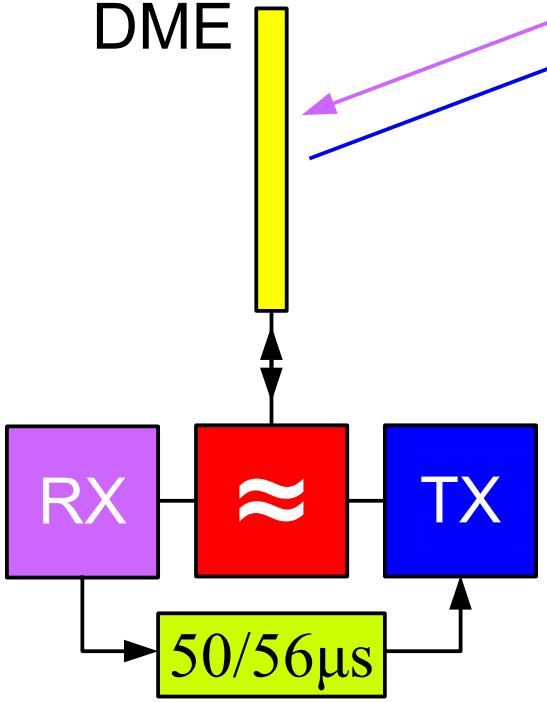
$P_{TX} \approx 150\mathrm{W}$



DME vprašanja:
126 kanalov „X“ 2 pulza 12μs
126 kanalov „Y“ 2 pulza 30μs
f=1025MHz~1150MHz

Omejeno število aktivnih uporabnikov N<100 / en odzivnik

Odzivnik DME



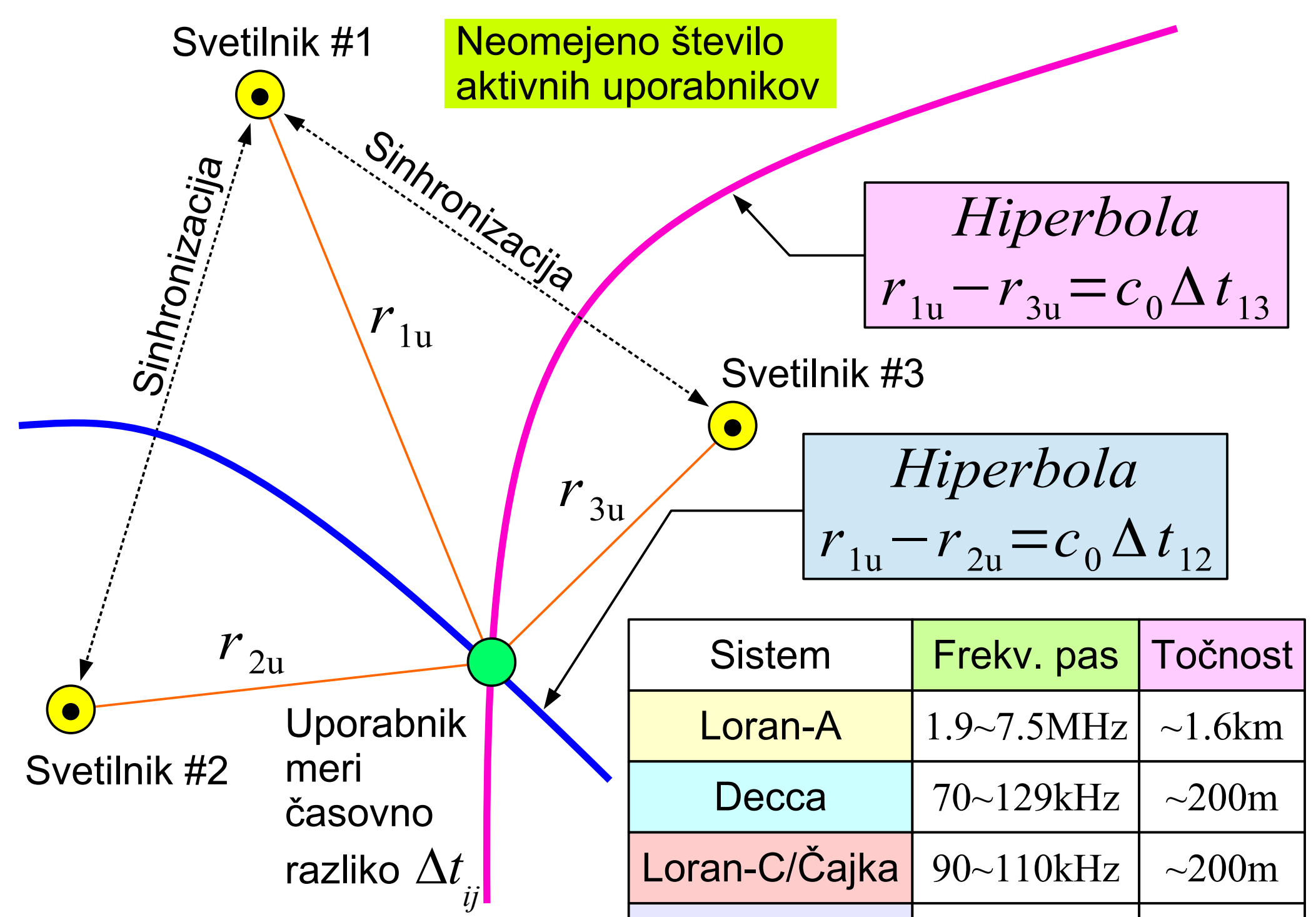
$P_{TX} \approx 1.5\mathrm{kW}$

DME odgovori:
126 kanalov „X“ 2 pulza 12μs
f_X=962MHz~1024MHz in 1151MHz~1213MHz
126 kanalov „Y“ 2 pulza 36μs
f_Y=1025MHz~1150MHz

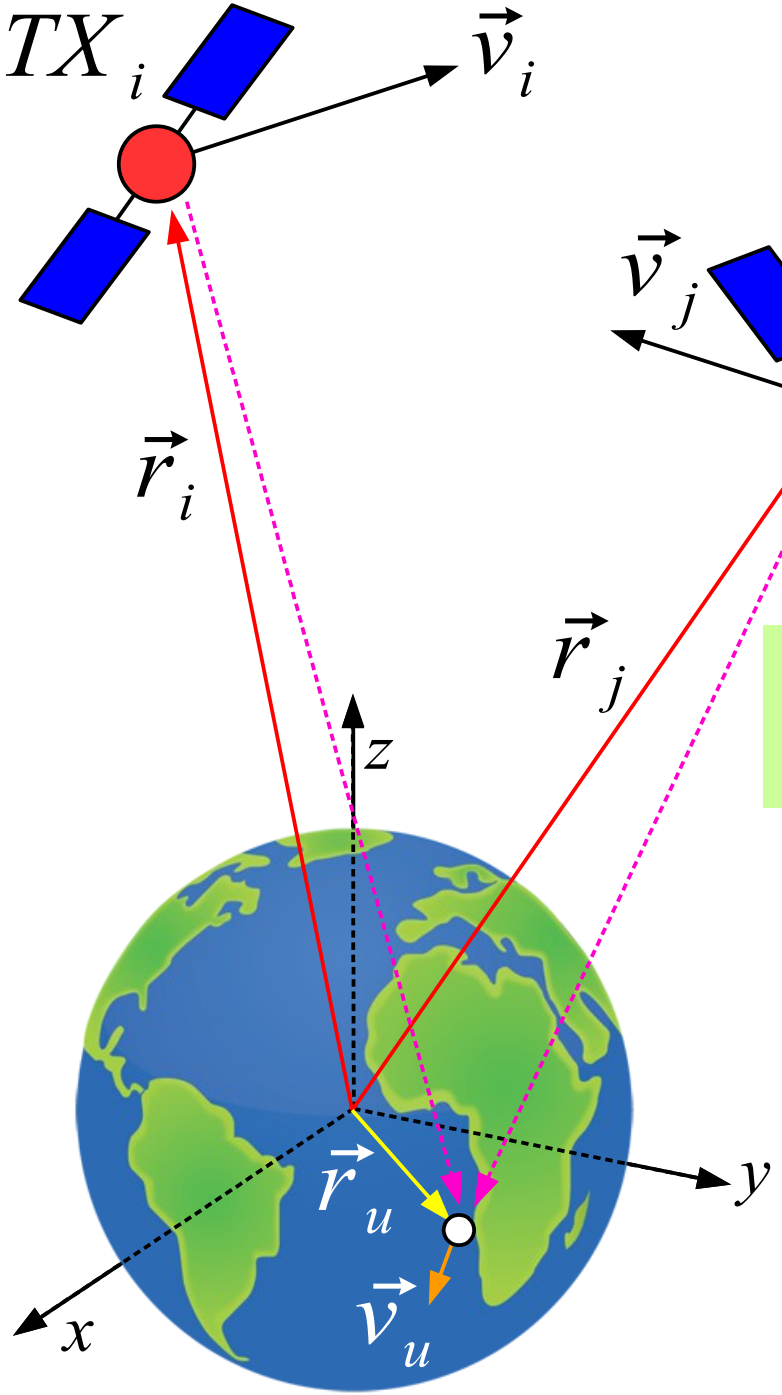
$$f_{odgovor} = f_{vprašanje} \pm 63\mathrm{MHz}$$

Točnost ~0.1nm=185m neodvisna od razdalje

2/3 odzivniki omogočajo 2D/3D navigacijo



Sistem	Frekv. pas	Točnost
Loran-A	1.9~7.5MHz	~1.6km
Decca	70~129kHz	~200m
Loran-C/Čajka	90~110kHz	~200m
Omega/Alpha	9~14KHz	~2.2km



Zakasnitev modulacije:

$$|\vec{r}_i - \vec{r}_u| - |\vec{r}_j - \vec{r}_u| = c_0 \Delta t_{ij}$$

$$Neznanke: \vec{r}_u, \vec{v}_u, t_u, f_u$$

$$Potreben\ nabor\ enačb?$$

Doppler nosilca:

$$(\vec{v}_i - \vec{v}_u) \cdot \frac{(\vec{r}_i - \vec{r}_u)}{|\vec{r}_i - \vec{r}_u|} - (\vec{v}_j - \vec{v}_u) \cdot \frac{(\vec{r}_j - \vec{r}_u)}{|\vec{r}_j - \vec{r}_u|} = \frac{c_0}{f_0} \Delta f_{ij}$$

Sistem	Tirnica	Frekvence
Transit	1100km/90°	399.968MHz 149.988MHz
Cikada	970km/83°	~400MHz ~150MHz
GPS	20200km/55°	1575.42MHz 1227.6MHz
GLONASS	19100km/65°	~1600MHz ~1250MHz
BeiDou	21500km/55°	1561.098MHz 1207.140MHz