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Meteor Brightness Due to Standard Ablation
(and some improvements)

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Meteor physics

- The main advantage of meteor physics is to describe the meteor phenomena in terms of interaction processes with atmosphere and to predict the change of mass, velocity, brightness and ionization along its path.

- To solve these problems, we use so-called **physical theories of meteors**.
- The most simple theory is **sinle body theory**, which describes the change of meteor parameters only in terms of momentum and kinetic energy conservation laws, and without any microscopic processes of meteoroid matter interaction with atmosphere constituents.

Single body theory

- Basic system of differential equations:

$$\frac{dv}{dt} = -\Gamma \mathrm{A} m^{-1/3} \rho_m^{-2/3} \rho_a v^2$$

$$\frac{dm}{dt} = -\frac{\Lambda \mathrm{A}}{2Z} m^{2/3} \rho_m^{-2/3} \rho_a v^3$$

$$+ \qquad \frac{dh}{dt} = -v \cos z_r$$

- Meteor luminous equation:

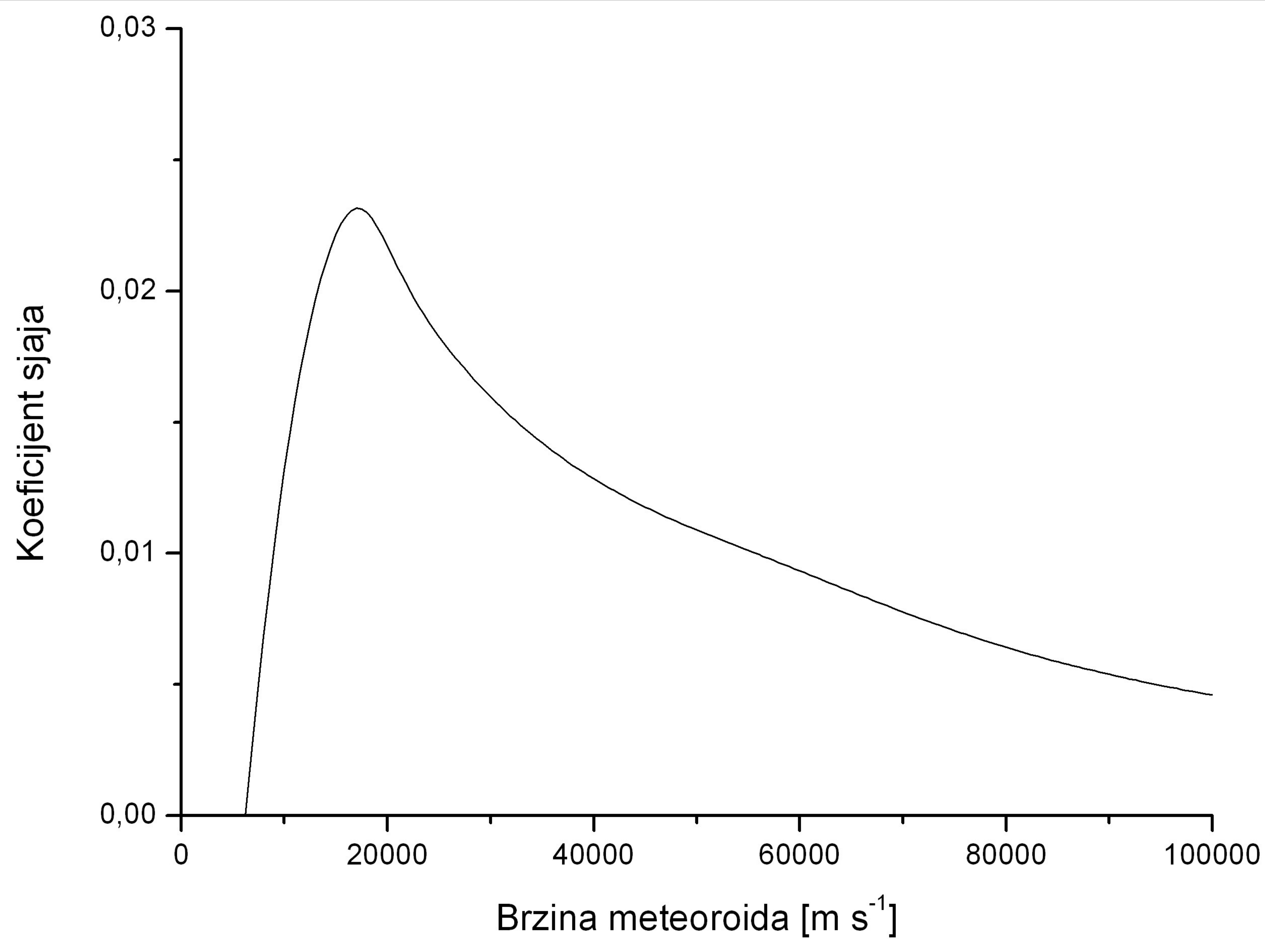
$$I = \tau \frac{1}{2} v^2 \frac{dm}{dt}$$

$$I = -\frac{\Lambda \mathrm{A} \tau}{2Z} m^{2/3} \rho_m^{-2/3} \rho_a v^5$$

Luminous efficiency

- Luminous efficiency factor, τ, shows which amount of kinetic energy goes to meteor radiation.
- In general, it depends on velocity, mass and the meteoroid composition, but we supposed that the most significant dependance is on velocity, and that it is power function.
- We used the definition of luminous efficiency by universal excitation coefficient and the data from Hill *et al.* (2005) to fit 6th order rational polynomial function:

$$\frac{1}{2}\tau\mu v^2=\varepsilon\zeta \quad \Rightarrow \quad \tau = 2\left(\frac{\varepsilon}{\mu}\right)\frac{\zeta}{v^2} = 2\left(\frac{\varepsilon}{\mu}\right)\frac{\sum_{i=1}^{6} a_i v^i}{\sum_{i=1}^{6} b_i v^i}$$

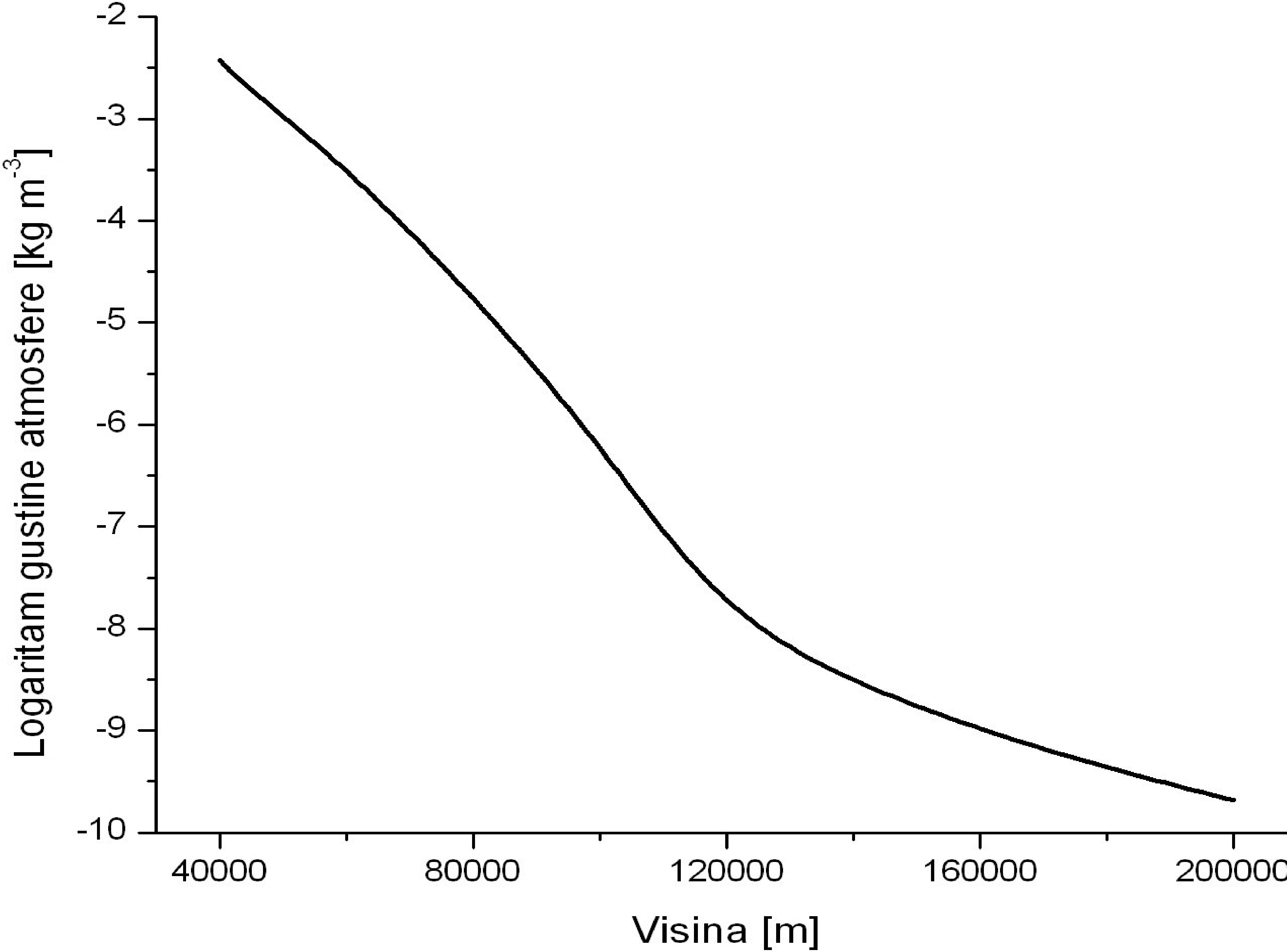

Koeficijent sjaja
0,03
0,02
0,01
0,00
0
20000
40000
60000
80000
100000
Brzina meteoroida [m s-1]

Model of the atmosphere

- For single body theory, the most important parameter of atmosphere is its mass density.
- We were using real atmosphere data (MSIS-E-90 database) and 6th order rational polynomial function to fit the logarithm of mass density for one set of conditions:

$$\ln\rho = \frac{\sum_{i=1}^{6} c_i h^i}{\sum_{i=1}^{6} d_i h^i}$$

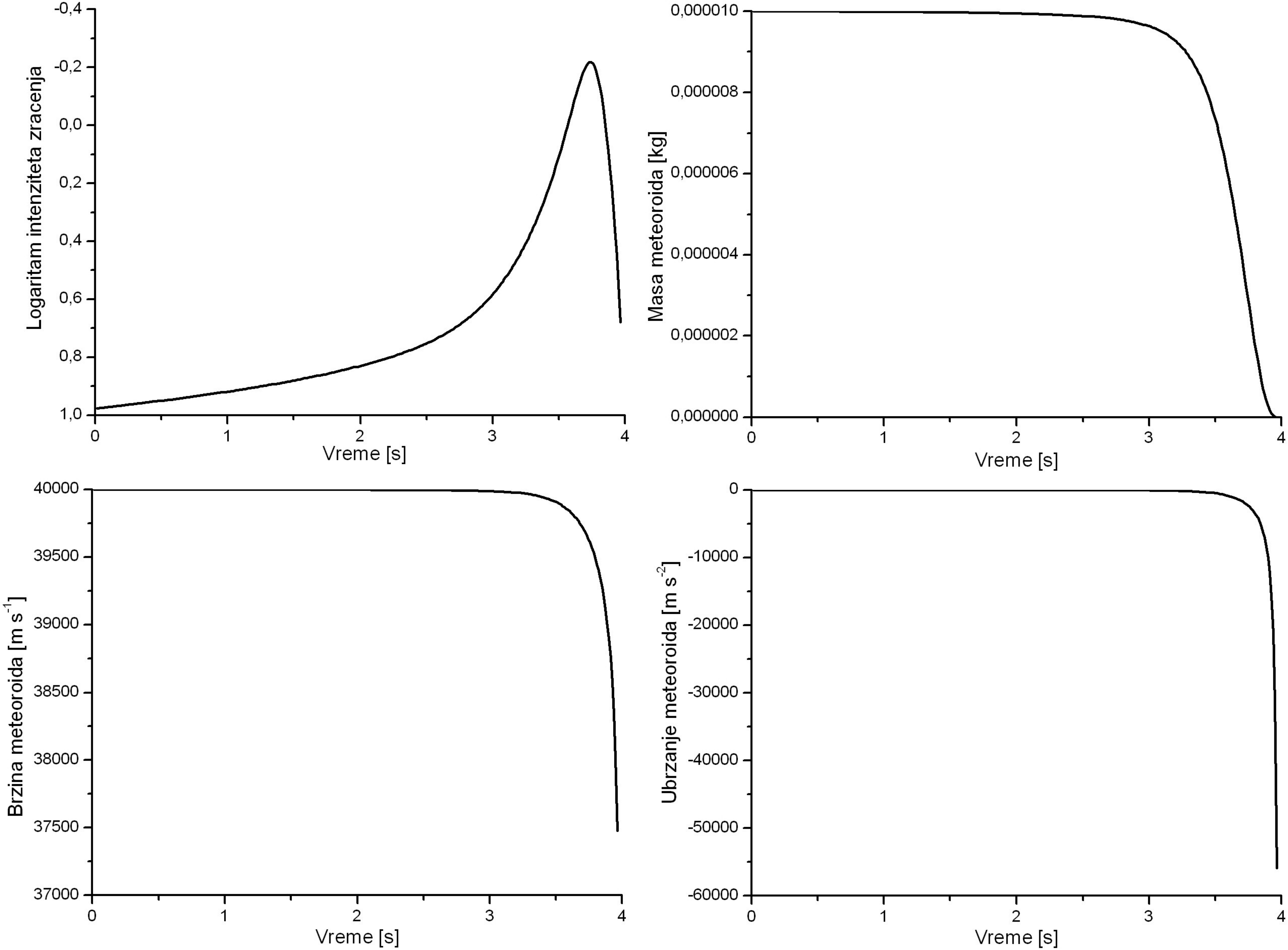
- The geometry of the atmosphere used in single body theory equation is plan-parallel, so we can not discuss meteors with high values of zenithal radiant distance.



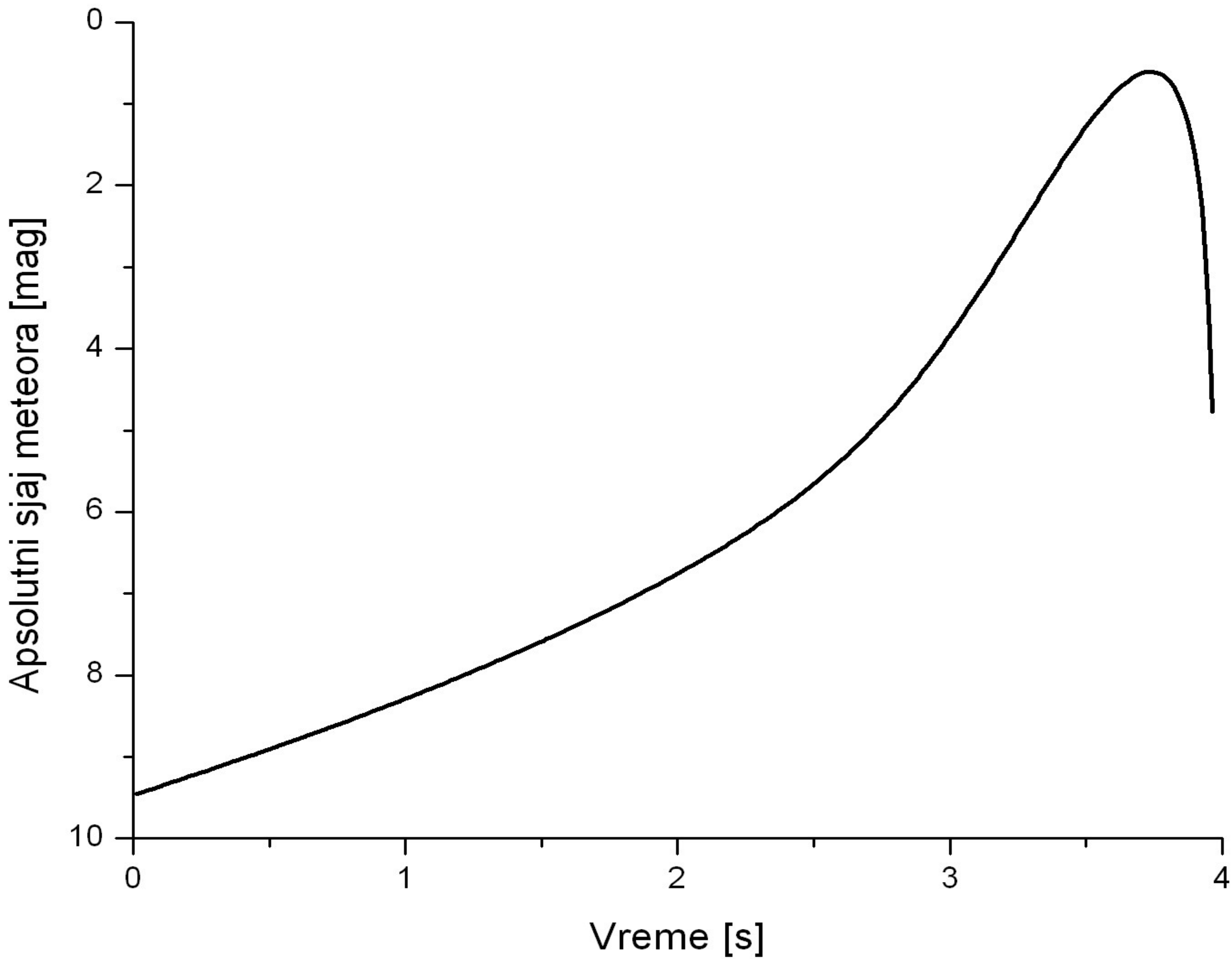
Logaritam gustine atmosfere [kg m^{-3}]
-2
-3
-4
-5
-6
-7
-8
-9
-10
40000
80000
120000
160000
200000
Visina [m]

Numerical simulation

- The equations of single body theory were solved numericaly by 4^{th} order Runge-Kutta method with constant step-size, for some initial values of meteoroid parameters.
- The final result of the simulation are:
  - Values of meteoroid mass along the meteor path
  - Values of meteoroid velocity along the meteor path
  - Values of meteoroid acceleration along the meteor path
  - Values of meteoroid luminosity along the meteor path (**light curve**)



Logaritam intenziteta zracenja
-0,4
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
0
1
2
3
4
Vreme [s]
Masa meteoroida [kg]
0,000010
0,000008
0,000006
0,000004
0,000002
0,000000
0
1
2
3
4
Vreme [s]
Brzina meteoroida [m s^-1]
40000
39500
39000
38500
38000
37500
37000
0
1
2
3
4
Vreme [s]
Ubrzanje meteoroida [m s^-2]
0
-10000
-20000
-30000
-40000
-50000
-60000
0
1
2
3
4
Vreme [s]



0
2
4
6
8
10
Apsolutni sjaj meteora [mag]
0
1
2
3
4
Vreme [s]

Applications

- Integration of a meteors in a wide range of initial parameters
- Obtaining the function that represents maximum brightness dependace on initial parameters
- Obtaining the function that represents meteor height at the point of the maximum brightness in dependance of initial parameters
- Application of the functions to the observed data to obtain the densities of a shower meteors

Application I

- Range of initial parameters that is used in simulation:

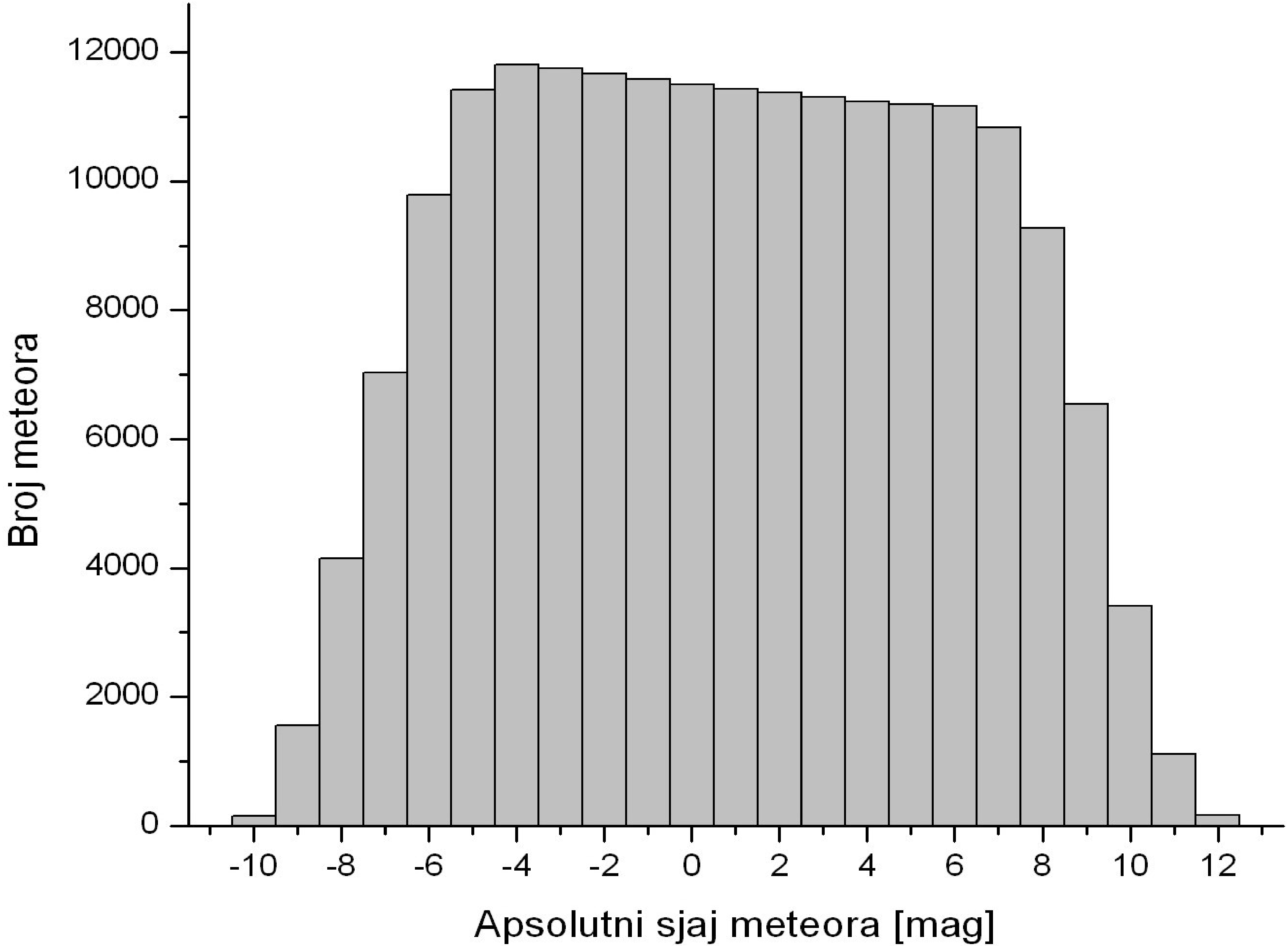
$$10^{-8}\,kg \le m \le 10^{-1.5}\,kg$$

$$11.2\,km/s \le v \le 72.8\,km/s$$

$$0^\circ \le Z_r \le 80^\circ$$

$$300\,kg/m^3 \le \rho_m \le 3000\,kg/m^3$$

- This range and proper incrementation (the magnitude difference of two neighbour meteors is approximately 0.2 mag) gains 234520 meteors, from which 191527 comes successfully to the end of the simulation.


12000
10000
8000
6000
4000
2000
0
Broj meteora
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
Apsolutni sjaj meteora [mag]

Application II

- Maximum luminosity as function on initial meteor parameters:

$$I_{\max} = Kv^{k_1} m^{k_2} \cos^{k_3} Z_r \rho_m^{k_4}$$

$$\log I_{\max} = \log K + k_1 \log v + k_2 \log m + k_3 \log\cos Z_r + k_4 \log \rho_m$$

Application III

- Meteor height at the point of the maximum luminosity as a function of initial parameters:

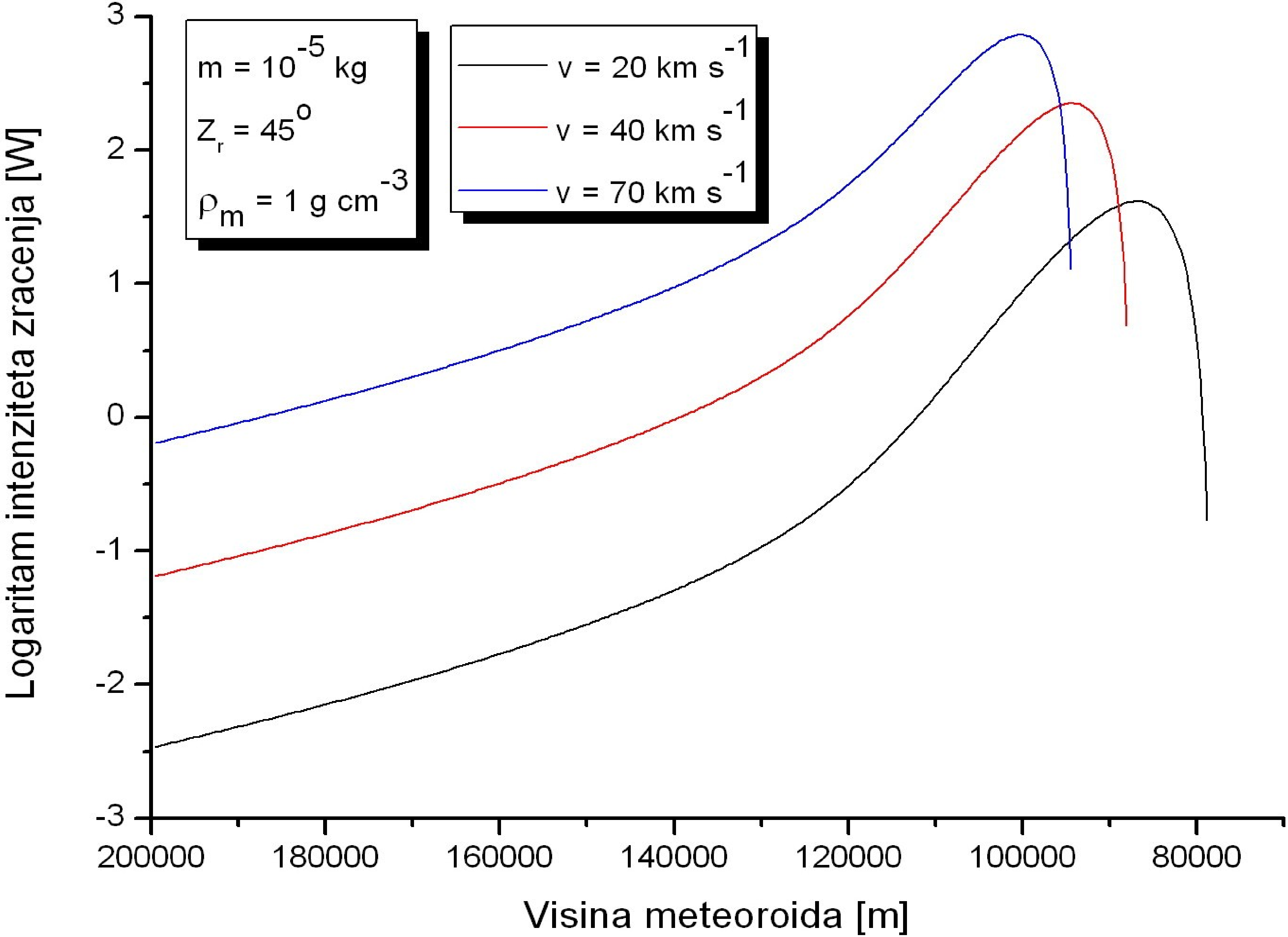
$$H_{\max} = \log J + j_1 \log v + j_2 \log m + j_3 \log\cos Z_r + j_4 \log \rho_m$$

Obtaining unknown coefficients

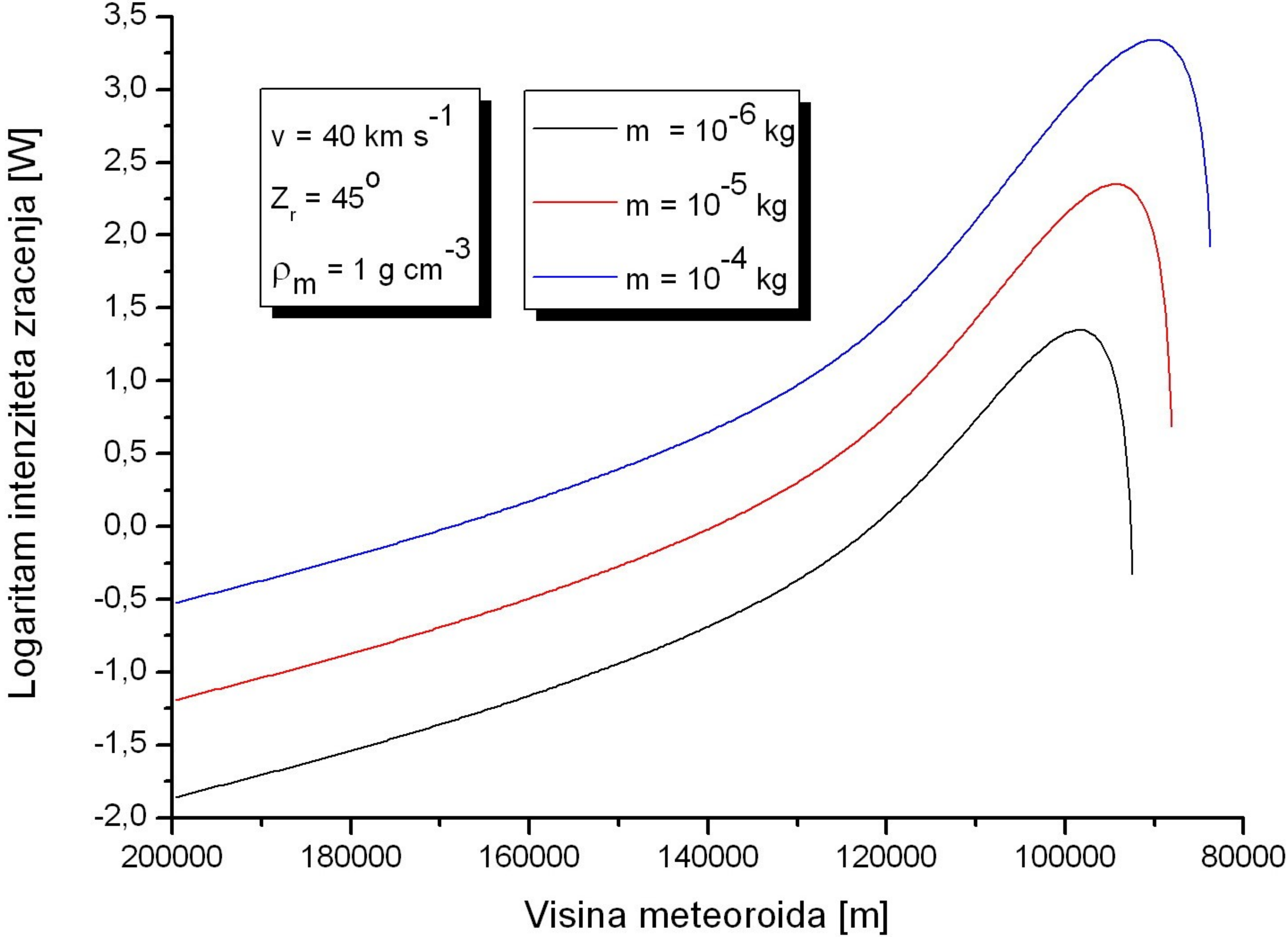
- Range of an apsolute brightness from 6.5^{mag} to -6.5^{mag}, gains totally 147221 meteors.
- Range of an apparent brightness from 6.5^{mag} to -6.5^{mag} gains totally 134833 meteors.

	Value	Error
$\log K$	-3.319	0.003
k_1	2.3392	0.0007
k_2	1.00405	0.00009
k_3	1.0134	0.0006
k_4	0.0122	0.0004

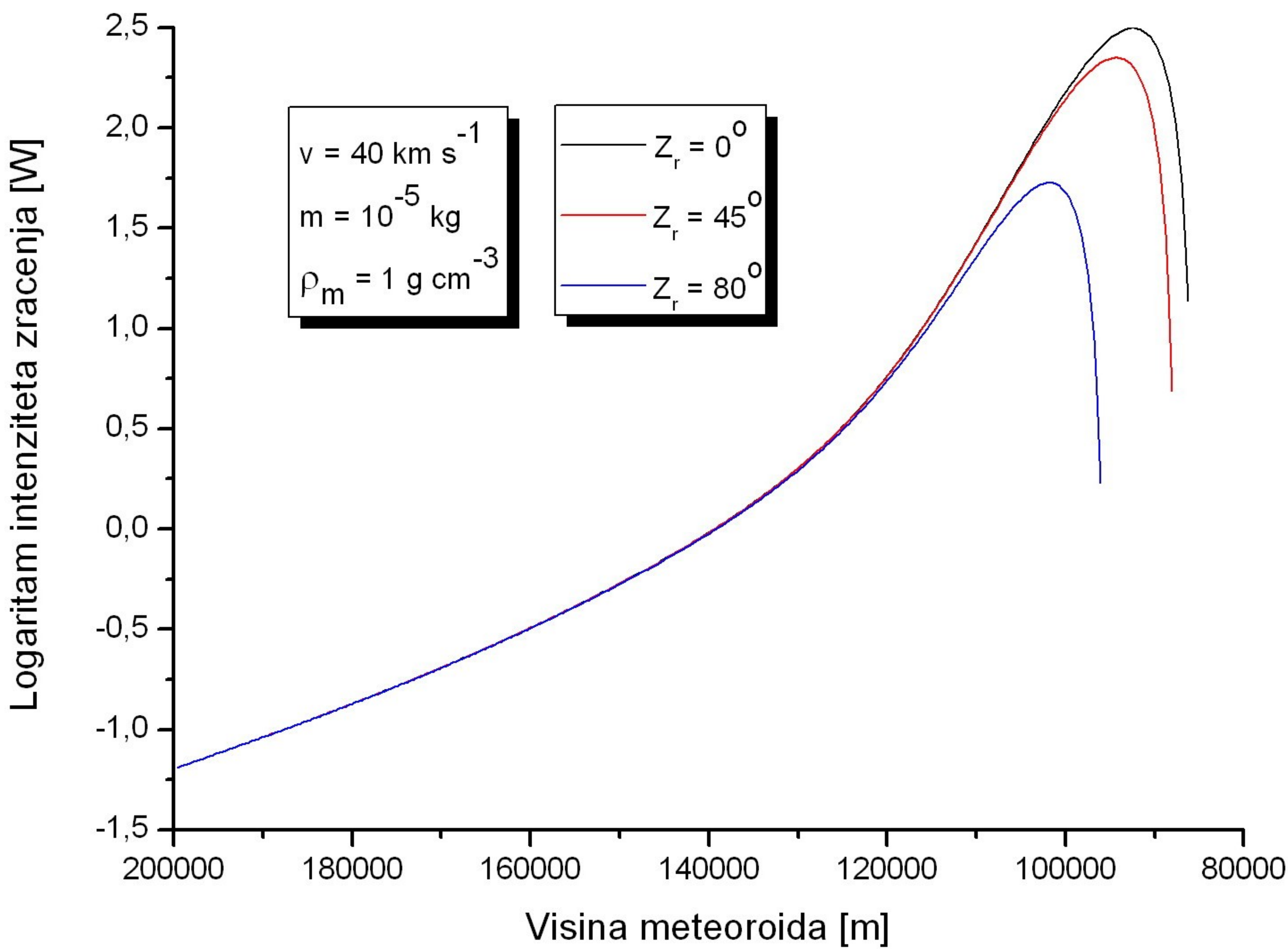
	Value	Error
$\log J$	-19070	30
j_1	25180	6
j_2	-4382.9	0.7
j_3	-13274	5
j_4	-8849	3



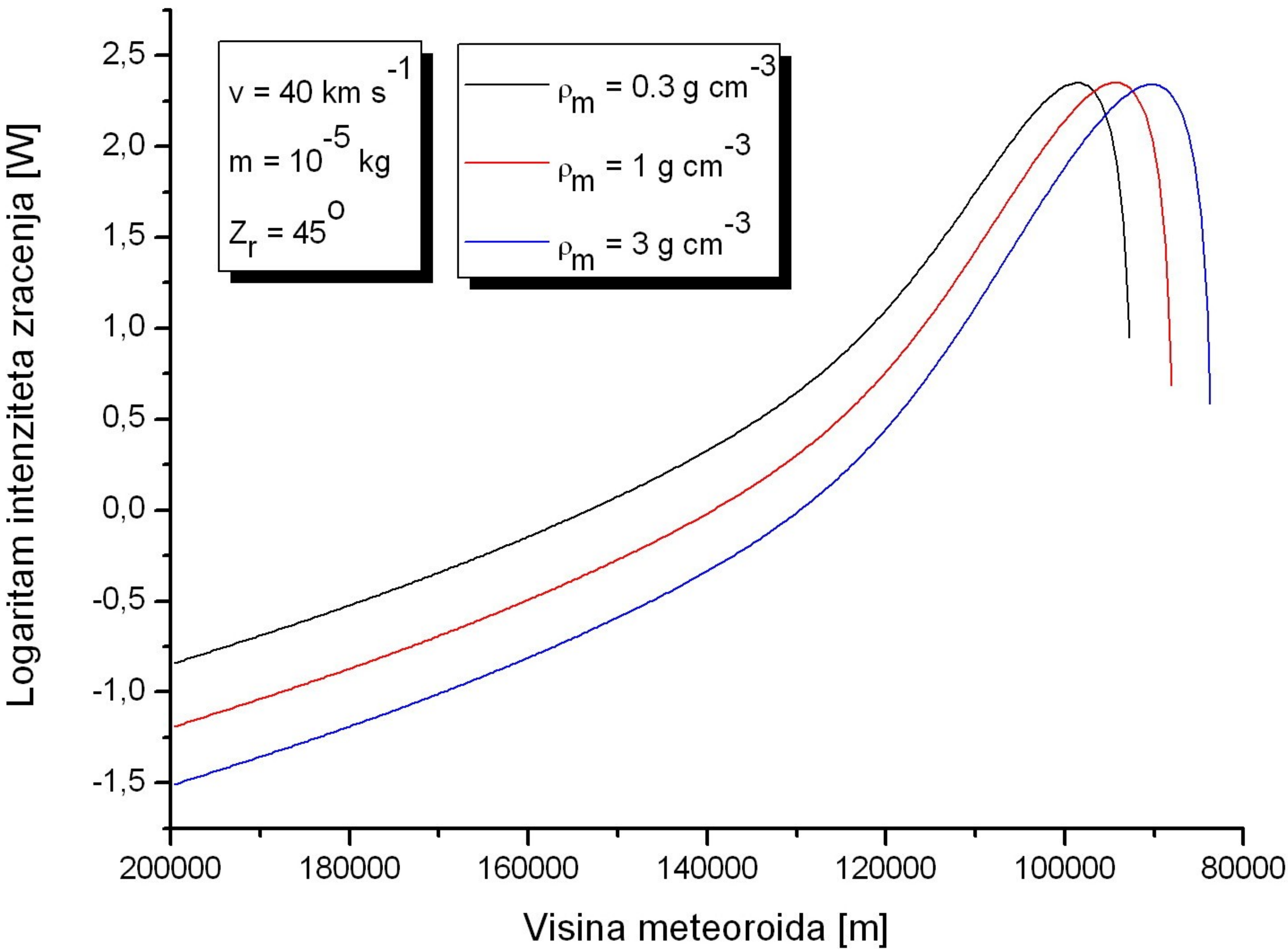
$m = 10^{-5}$ kg
$Z_r = 45^{o}$
$\rho_m = 1$ g cm^{-3}
v = 20 km s^{-1}
v = 40 km s^{-1}
v = 70 km s^{-1}
3
2
1
0
-1
-2
-3
200000
180000
160000
140000
120000
100000
80000
Logaritam intenziteta zracenja [W]
Visina meteoroida [m]



3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
-2,0
200000
180000
160000
140000
120000
100000
80000
Logaritam intenziteta zracenja [W]
Visina meteoroida [m]
$v = 40$ km s^{-1}
$Z_r = 45^o$
$\rho_m = 1$ g cm^{-3}
$m = 10^{-6}$ kg
$m = 10^{-5}$ kg
$m = 10^{-4}$ kg



Logaritam intenziteta zracenja [W]
Visina meteoroida [m]
v = 40 km s-1
m = 10-5 kg
ρm = 1 g cm-3
Zr = 0o
Zr = 45o
Zr = 80o
2,5
2,0
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
200000
180000
160000
140000
120000
100000
80000



v = 40 km s-1
m = 10-5 kg
Zr = 45O
ρm = 0.3 g cm-3
ρm = 1 g cm-3
ρm = 3 g cm-3
Logaritam intenziteta zracenja [W]
Visina meteoroida [m]
2,5
2,0
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
200000
180000
160000
140000
120000
100000
80000

Another function of meteor height

- Instead of mass, we can use the apparent magnitude of meteors, and that gives us another function:

$$H_{\max} = \log L + l_1 \log v + l_2 \log\cos Z_r + l_3 \log\rho_m + l_4 M_{app}$$

	Value	Error
$logL$	-40500	30
l_1	34004	5
l_2	-8483	4
l_3	-8433	3
l_4	1679,6	0,3

Application IV

- Obtaining densities of a shower meteors
- By application of previous function to the observational data (Koten *et al.* 2004) we can obtain values of mass density of meteoroids from observed showers.

Shower	$H_{\max}[km]$	$v[km/s]$	$Z_r[°]$	$\rho_m[kg/m^3]$
Leonids	106.9	70.7	44.2	416.51
Orionids	106.7	66.4	42.7	333.13
Perseids	104.4	59.6	42.7	403.79
Taurids	92.7	28.0	37.3	432.53
Geminids	91.7	34.4	32.2	1224.88

Up-to-date model improvements

- Single body theory with variable coefficients
- Thermal ablation model
- New model of luminous efficiency
- New model of the atmosphere (number density, mass density, temperature and mean molecular mass dependances on height)

Future improvements:

- Atmosphere with spherical geometry
- Meteoroid fragmentation model
- Sputtering processes at high altitudes

Thank you for your attention!

Questions? Suggestions?