The effect of the solar wind on the evolution of dust grains trapped in the mean motion orbital resonance with Jupiter

Jozef Klačka, **Roman Nagy**, Milan Jurči

Comenius University in Bratislava

Outline

- A brief introduction
- The equation of motion
- Equilibrium points and numerical simulations
- Summary

Introduction

- An evolution of interplanetary dust particles is influenced by:
  - Gravitational force of the Sun and planets:
    - **the restricted planar circular three-body problem**
  - Non-gravitational effects:
    - **solar wind**
    - **electromagnetic radiation of the Sun (Poynting-Robertson effect)**

- The size of investigated particles: 1-100 μm (i.e. Zodiac cloud)
- The shape of investigated particles: spherical

Non-gravitational effects

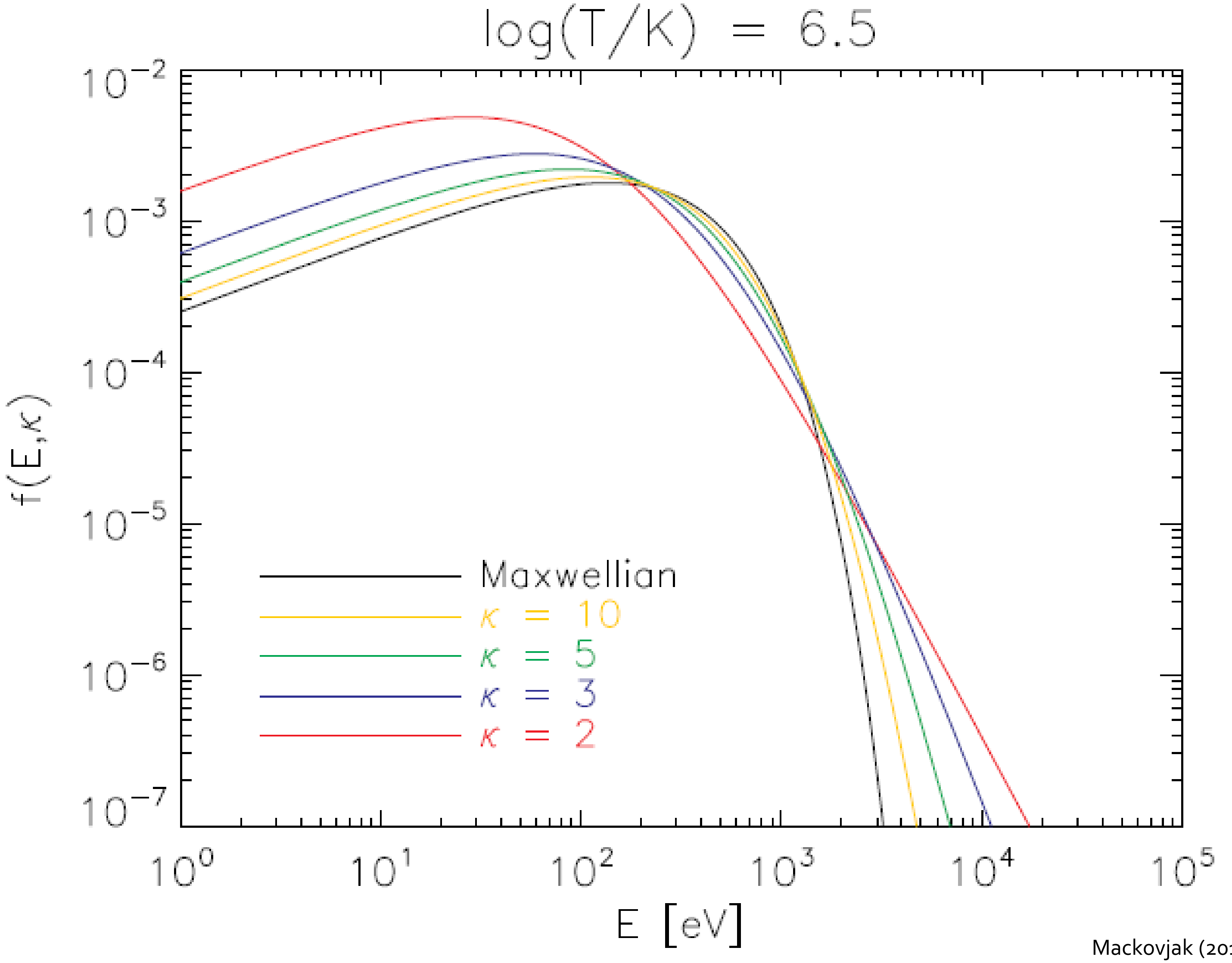
- Poynting-Robertson effect (PR):
  - Absorption and re-emission of the electromagnetic radiation
- Solar wind (SW):
  - Corpuscular radiation of the Sun
  - Considering Maxwell-Boltzmann distribution – PR is approx. 3 times more important than SW
  - Considering *Kappa* distribution – SW becomes more important than PR

Kappa distribution

$$f(v,\kappa) = \frac{1}{2\pi(\kappa\, v_\kappa^2)^{\frac{3}{2}}} \times$$

$$\times \frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)\Gamma(3/2)}\left(1+\frac{v^2}{\kappa v_\kappa^2}\right)^{-(\kappa+1)}$$

- $\kappa \rightarrow \infty$ - Maxwell distribution



Mackovjak (2014)

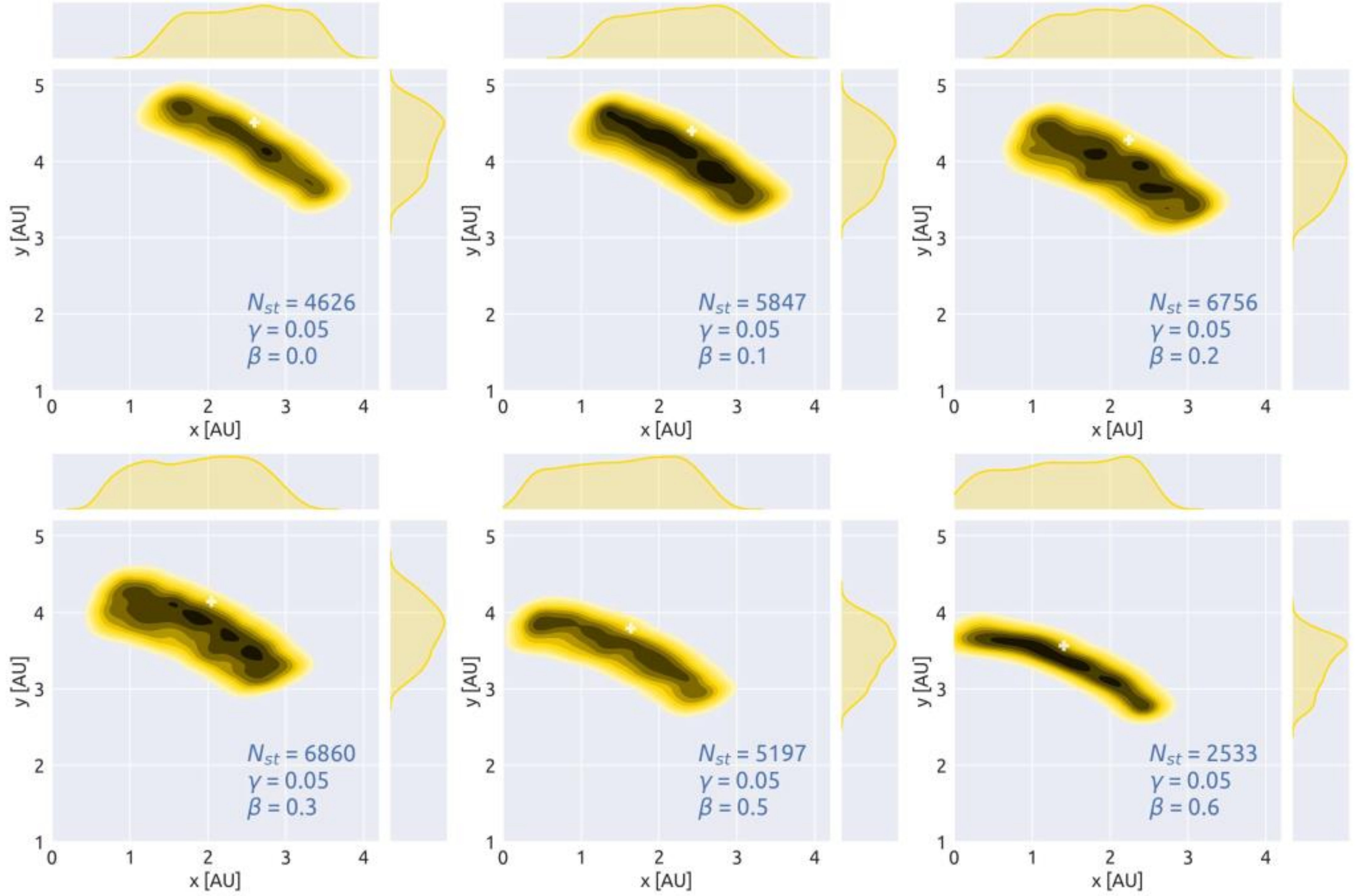
The equation of motion (neglecting non-radial component of solar wind)

$$\frac{d\vec{v}}{dt} = -\frac{G\,M_\odot\,(1-\beta)}{r^2}\,\vec{e}_R - \beta\,\frac{G\,M_\odot}{r^2}\left(1 + \frac{\eta_1}{\overline{Q}\,'_{pr}}\right)\frac{\vec{v}\cdot\vec{e}_R}{c}\,\vec{e}_R - \beta\,\frac{G\,M_\odot}{r^2}\left(1 + \frac{\eta_2}{\overline{Q}\,'_{pr}}\right)\frac{\vec{v}}{c} - G\,m_P\left(\frac{\vec{r}-\vec{r}_P}{|\vec{r}-\vec{r}_P|^3} + \frac{\vec{r}_P}{|\vec{r}_P|^3}\right)$$

- $\beta = f(R,\rho) = \dfrac{F_{ng}}{F_g}$
- Parameters:
  - Maxwell distribution:
    $$\eta_1 = \eta_2 = 2/3$$
  - *Kappa* distribution:
    $$\eta_1 = 1.1$$
    $$\eta_2 = 1.4$$

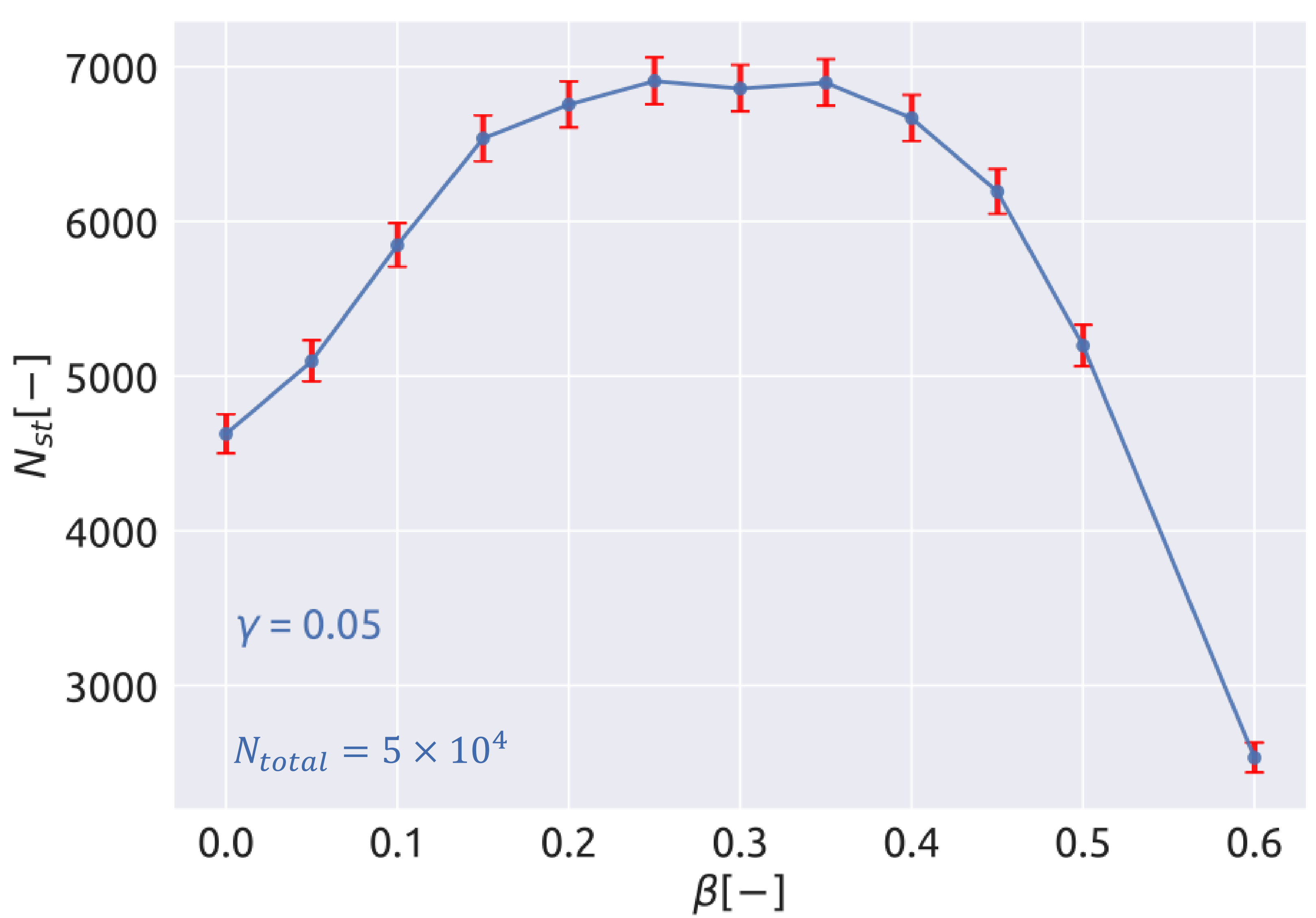
Simulations – Jupiter's L_4 equilibrium point

- 5×10^4 test particles randomly distributed near L_4:
  - distance from $L_4 < 1.5\ AU$
  - $\boldsymbol{v}_t = \langle -8, +8 \rangle\ km/s$ in the co-rotating frame
- Integration time = 1×10^4 years
- 2D density plot of an initial position of test particles staying in stable orbits during the integration time



$N_{st} = 4626$
$\gamma = 0.05$
$\beta = 0.0$
$N_{st} = 5847$
$\gamma = 0.05$
$\beta = 0.1$
$N_{st} = 6756$
$\gamma = 0.05$
$\beta = 0.2$
$N_{st} = 6860$
$\gamma = 0.05$
$\beta = 0.3$
$N_{st} = 5197$
$\gamma = 0.05$
$\beta = 0.5$
$N_{st} = 2533$
$\gamma = 0.05$
$\beta = 0.6$
x [AU]
y [AU]

Number of stable orbits



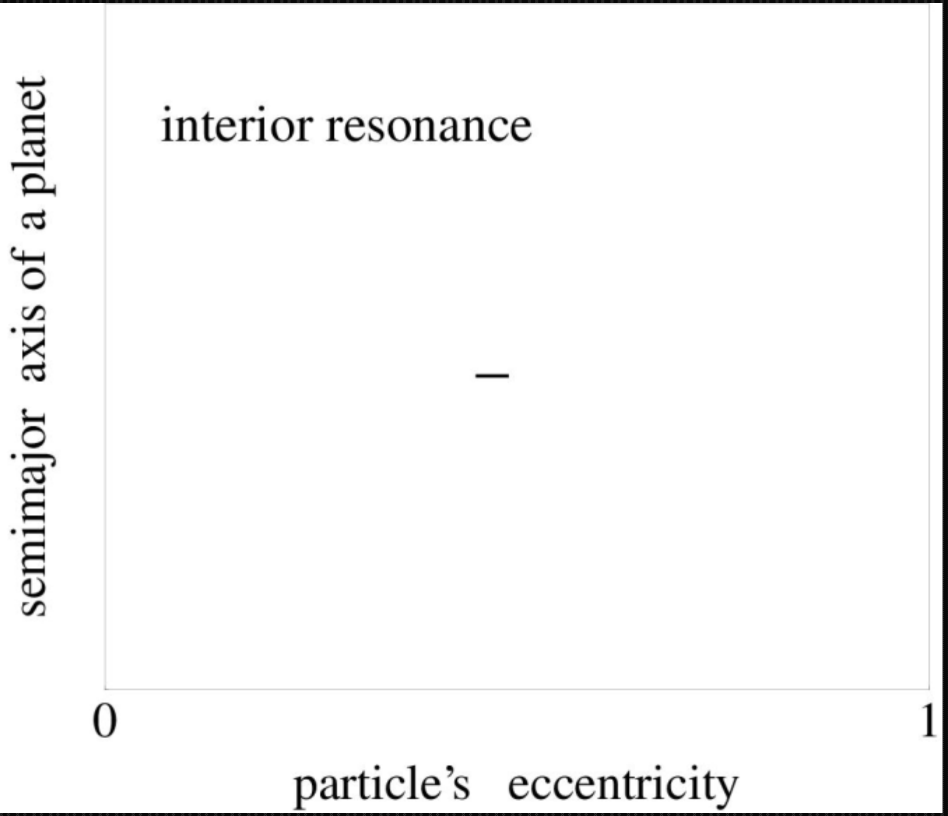
Summary

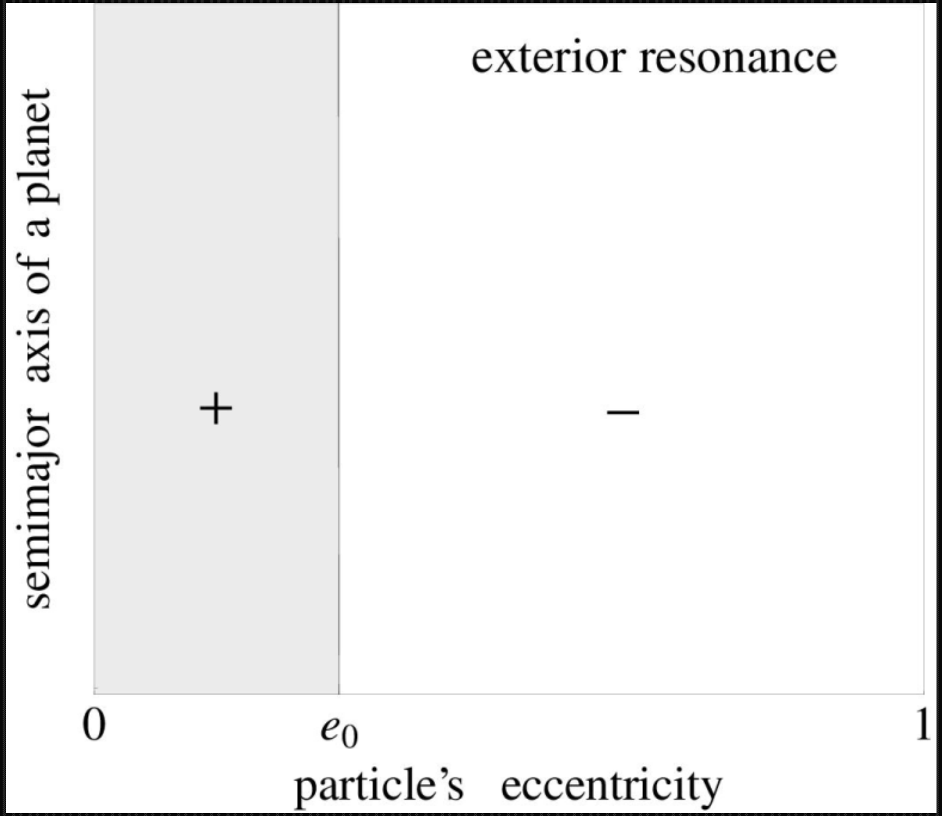
- We studied the effect of non-gravitational effects on the orbital evolution of dust grains in the Solar System:
  - We found the equilibrium points in the restricted three-body problem
  - The simulations showed, that the non-gravitational effects increased number of stable orbits for $\beta < 0.5$
  - $\beta > 0.7$ none of the test particles remained in the stable orbit

Thank you for your attention

Secular evolution of the particle eccentricity

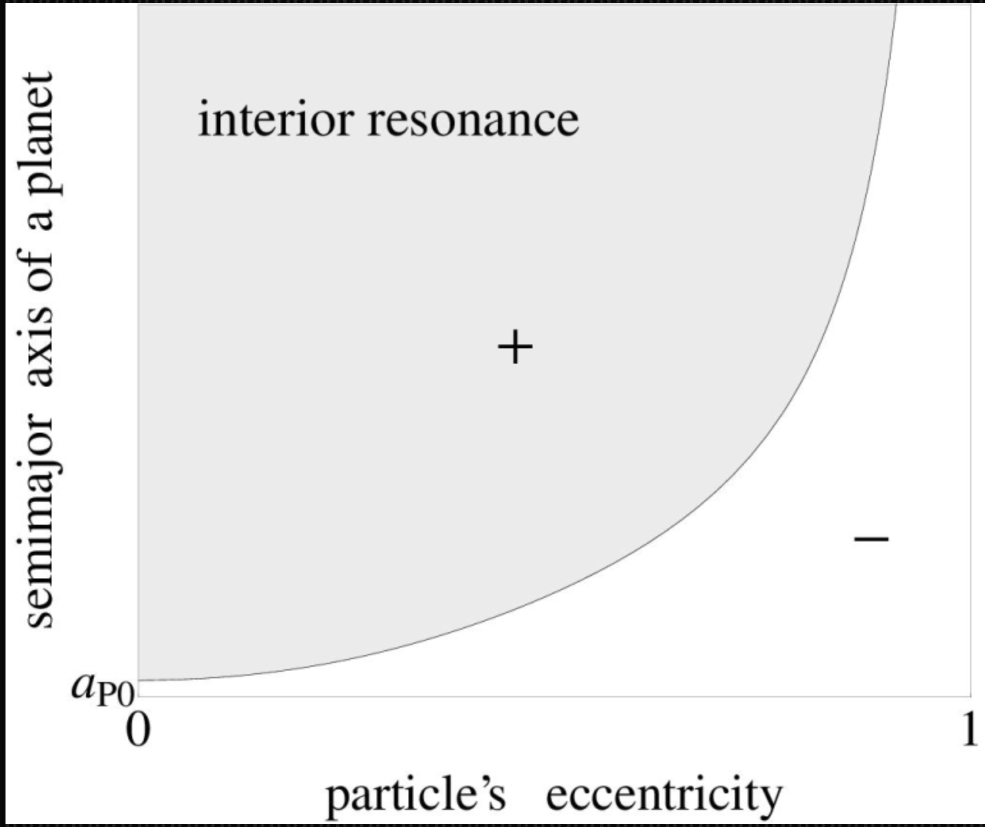
- Neglecting non-radial solar wind ($\gamma_T = 0$)

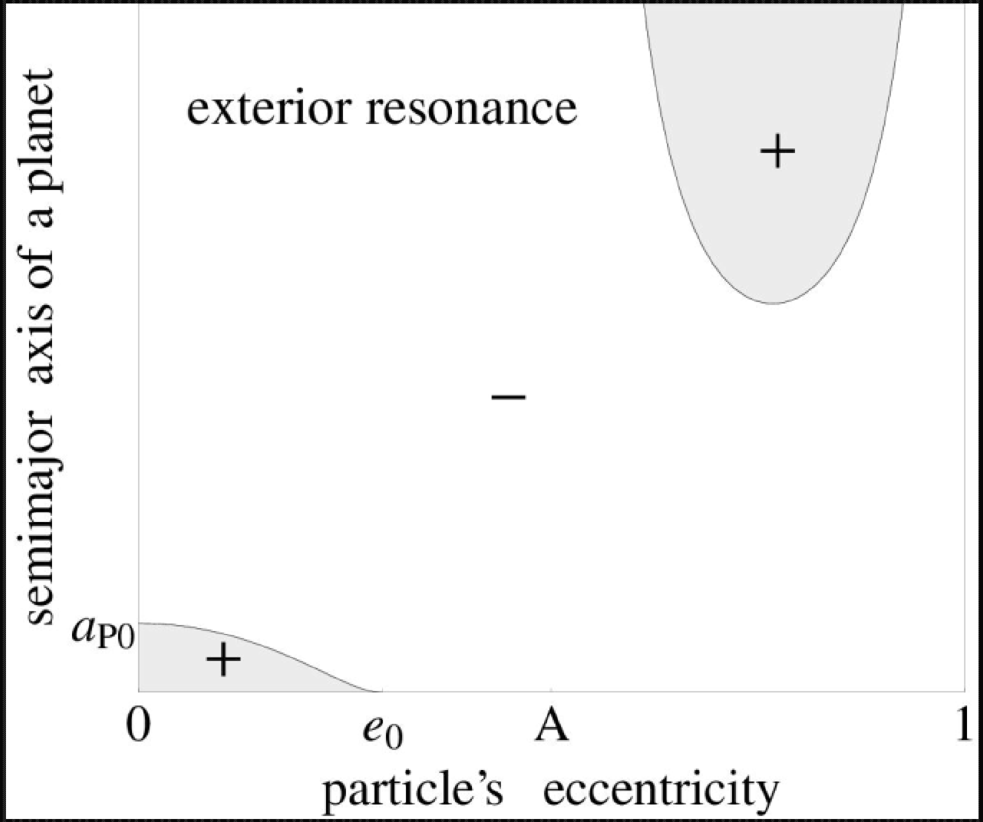




Secular evolution of the particle eccentricity

- Considering non-radial solar wind ($\gamma_T \neq 0$)





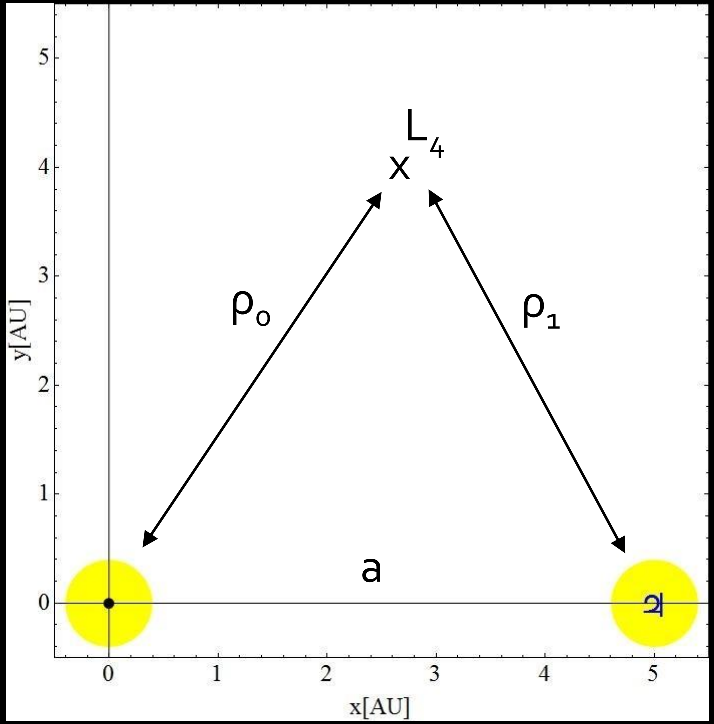
Stable solution – L_4 and L_5 in the co-rotating frame

- The equilibrium points:

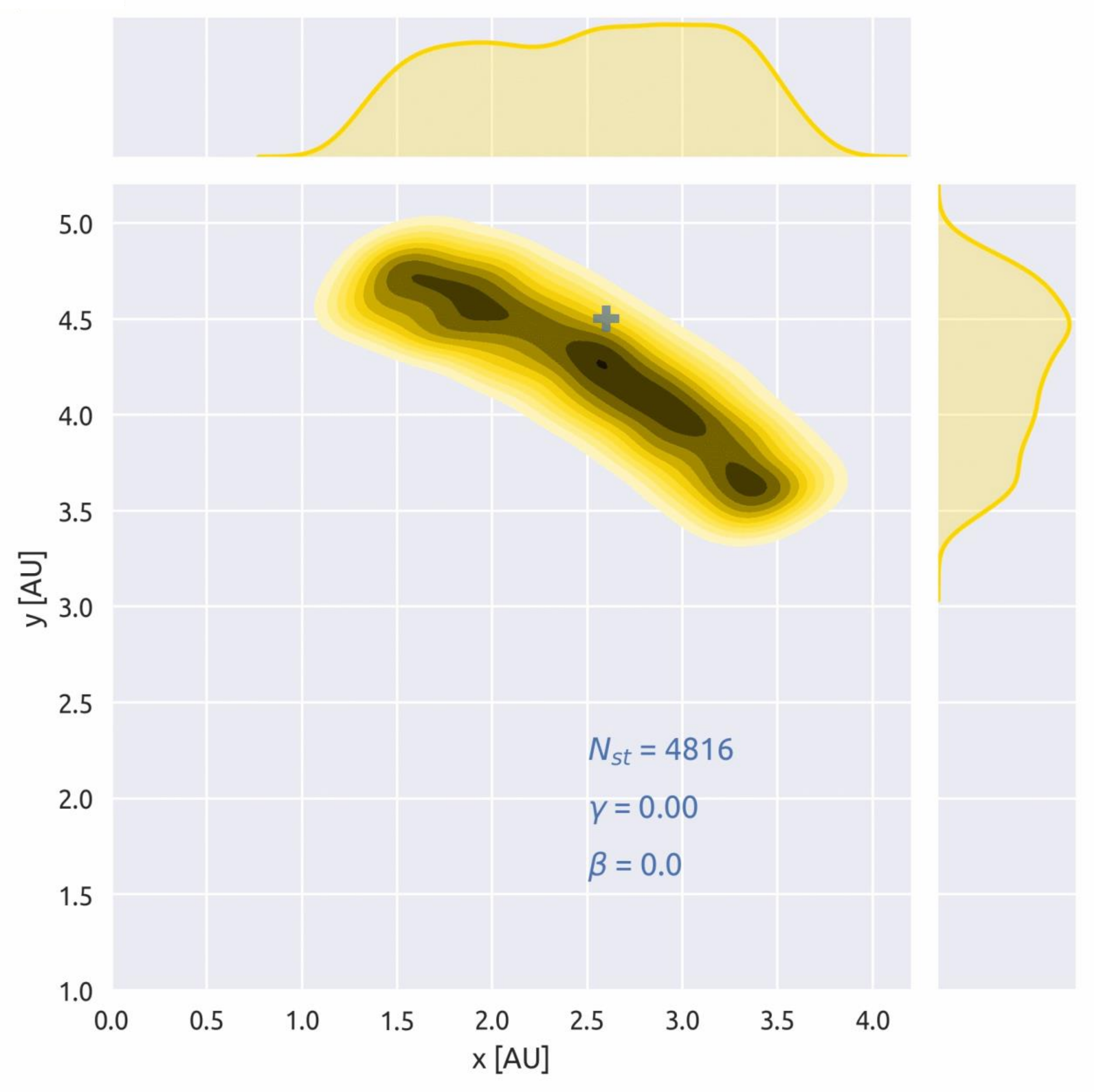
$$\begin{aligned} \varrho_0 &= \left\{1 - \beta\left[1 + \eta_2 u / \left(c\, \overline{Q}\,'_{pr}\right)\right]\right\}^{1/3} a \\ \varrho_1 &= a \end{aligned}$$

- If the condition is satisfied:

$$\begin{aligned} \frac{m_p}{M_\star + m_p} &< \frac{1}{2} - \frac{1}{2}\sqrt{1 - \frac{4}{9\,(4 - G)}} \\ G &\equiv \left\{1 - \beta\left[1 + \eta_2 u / \left(c\, \overline{Q}\,'_{pr}\right)\right]\right\}^{2/3} \end{aligned}$$



Simulations for various values of β



β parameter

$$\beta = 5.760 \times 10^2 \frac{\overline{Q}\,'_{pr}}{R[\mu m]\ \rho[kg\ m^{-3}]}$$

$$\eta_1 = \eta_2 = 0.2 - 0.3$$