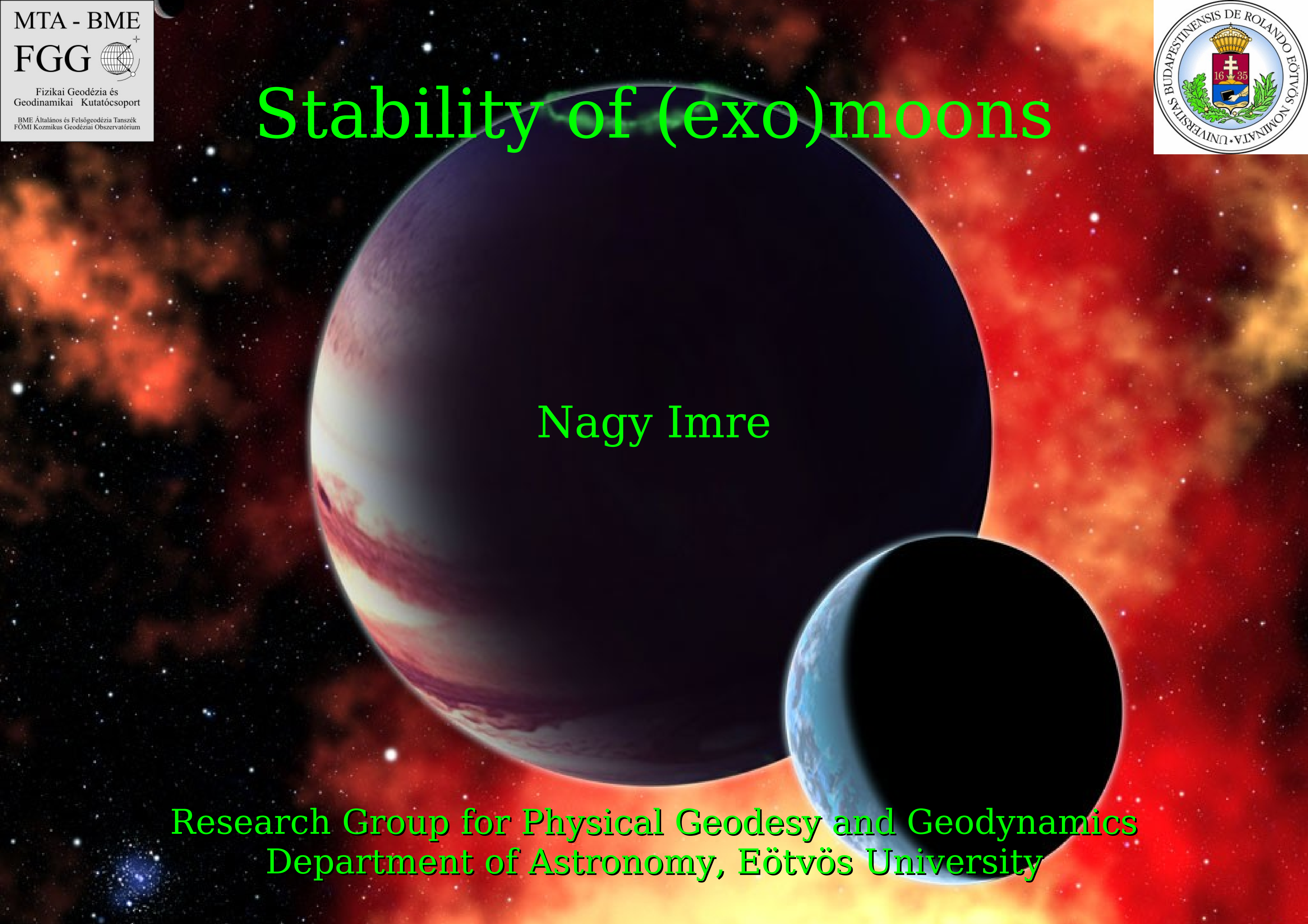
MTA - BME
FGG
Fizikai Geodézia és
Geodinamikai Kutatócsoport
BME Általános és Felsőgeodézia Tanszék
FÖMI Kozmikus Geodéziai Obszervatórium



Stability of (exo)moons

Nagy Imre

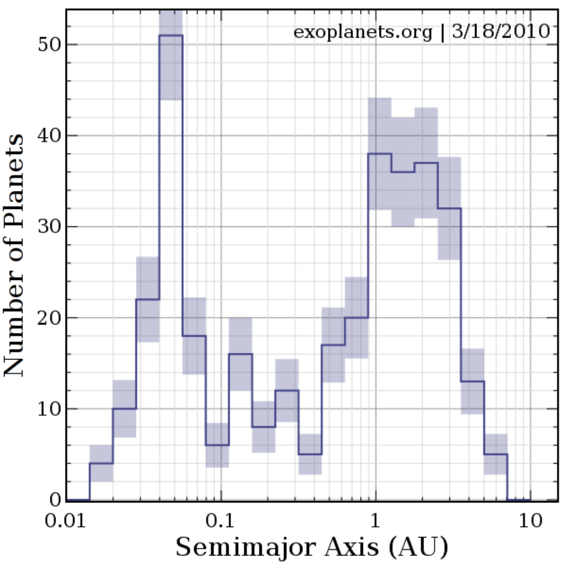
Research Group for Physical Geodesy and Geodynamics
Department of Astronomy, Eötvös University

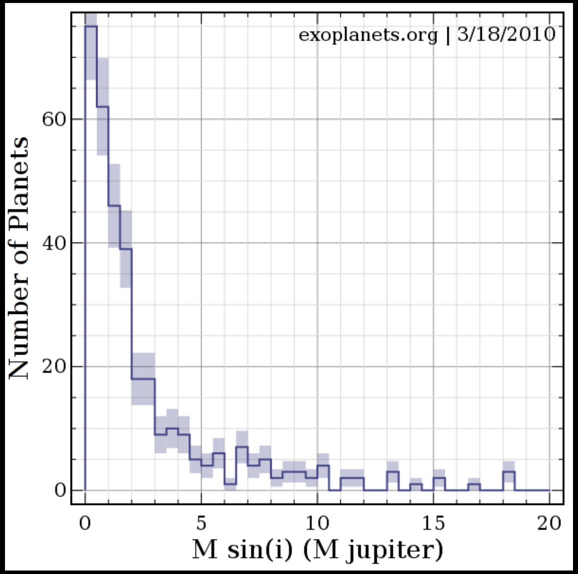
Contents

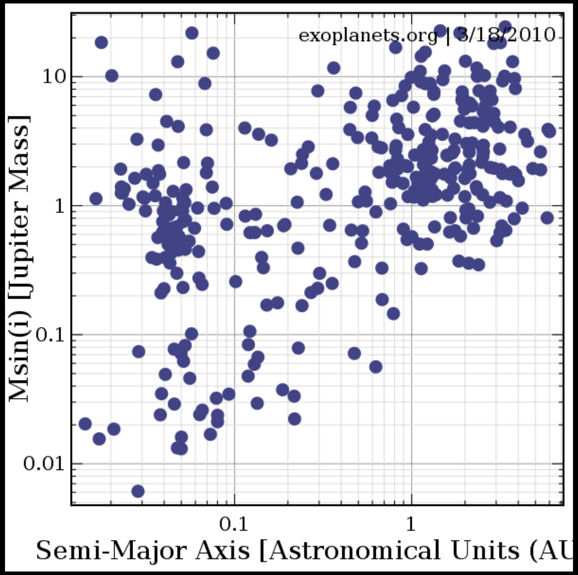
- Exoplanets
- Detectability of exomoons and transit timing effects
- Where can we find exomoons?
  - Hill sphere and Roche limit
  - The limit of existence of the exomoons
- Layout of the model for stability investigations
- Preliminary results
  - Stability of exomoons
  - Permissible range
- Further works

Exoplanets

- The first exoplanet (HD 114762 b) was discovered in 1989.
- Up to date 432 exoplanets are known in 365 systems (45 multiple planet systems).

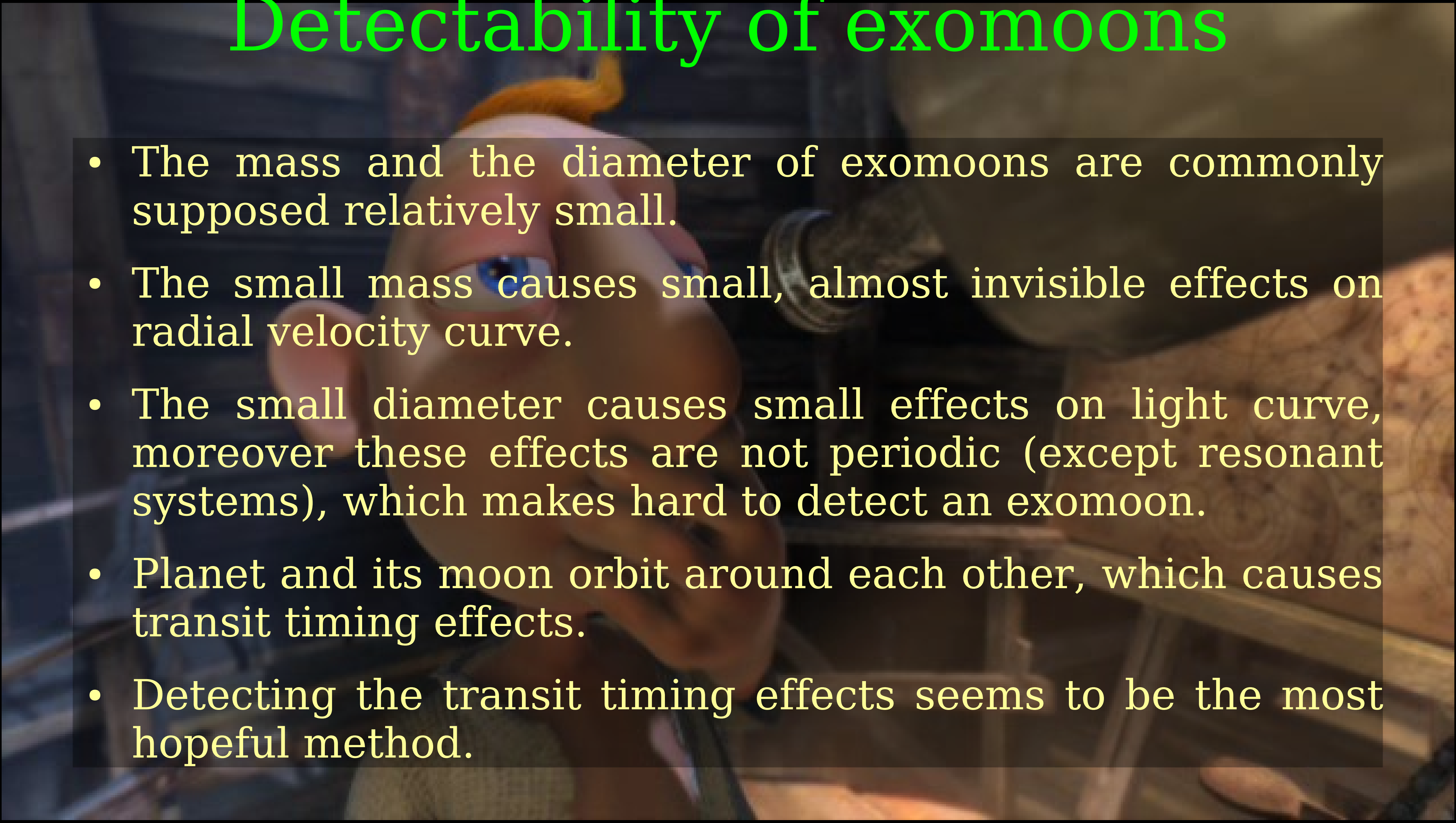






- One can see, that many exoplanets are giant planet close to the host star, and some of them are Neptune size object.

Detectability of exomoons

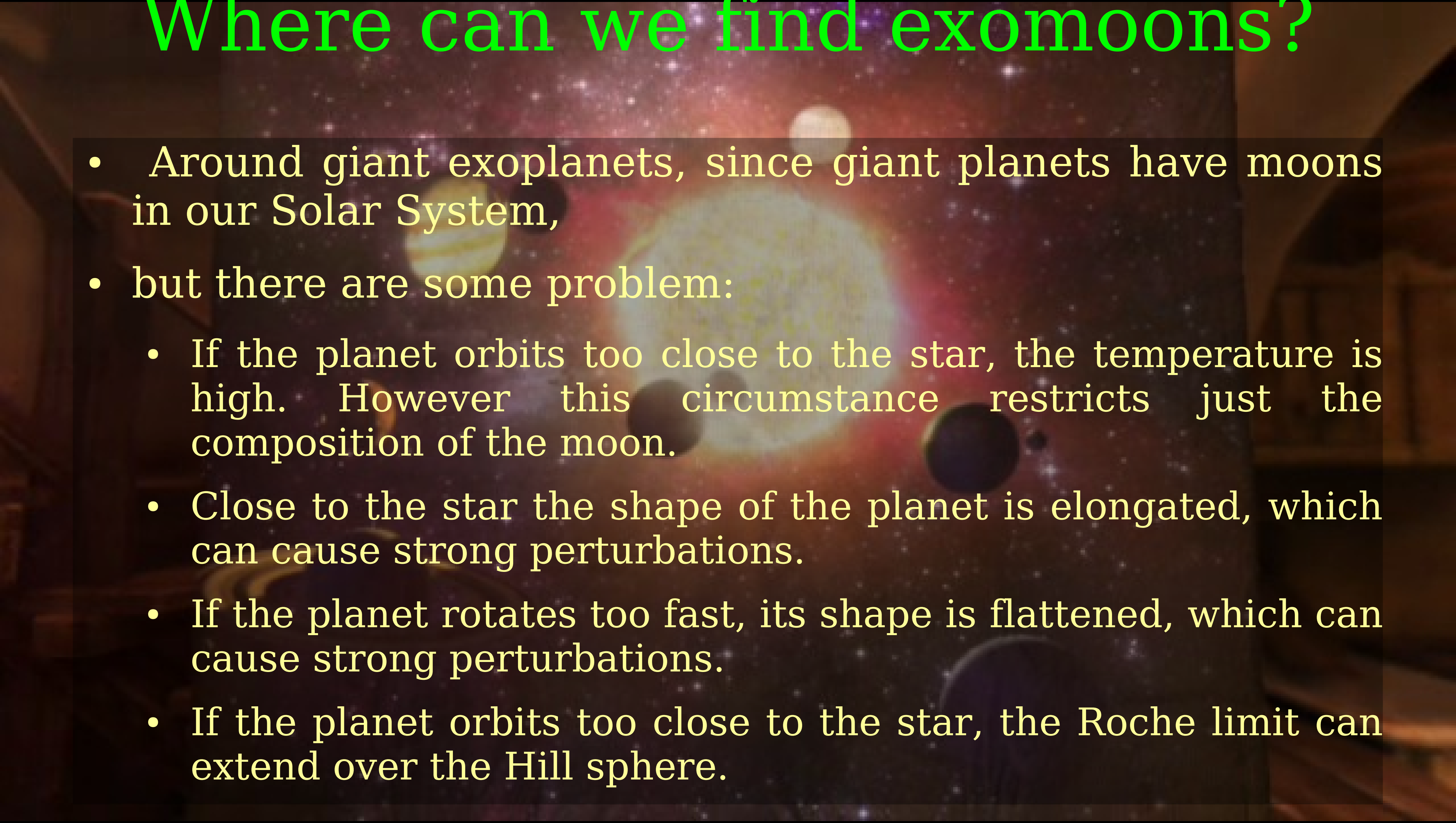


- The mass and the diameter of exomoons are commonly supposed relatively small.
- The small mass causes small, almost invisible effects on radial velocity curve.
- The small diameter causes small effects on light curve, moreover these effects are not periodic (except resonant systems), which makes hard to detect an exomoon.
- Planet and its moon orbit around each other, which causes transit timing effects.
- Detecting the transit timing effects seems to be the most hopeful method.

Transit timing effects

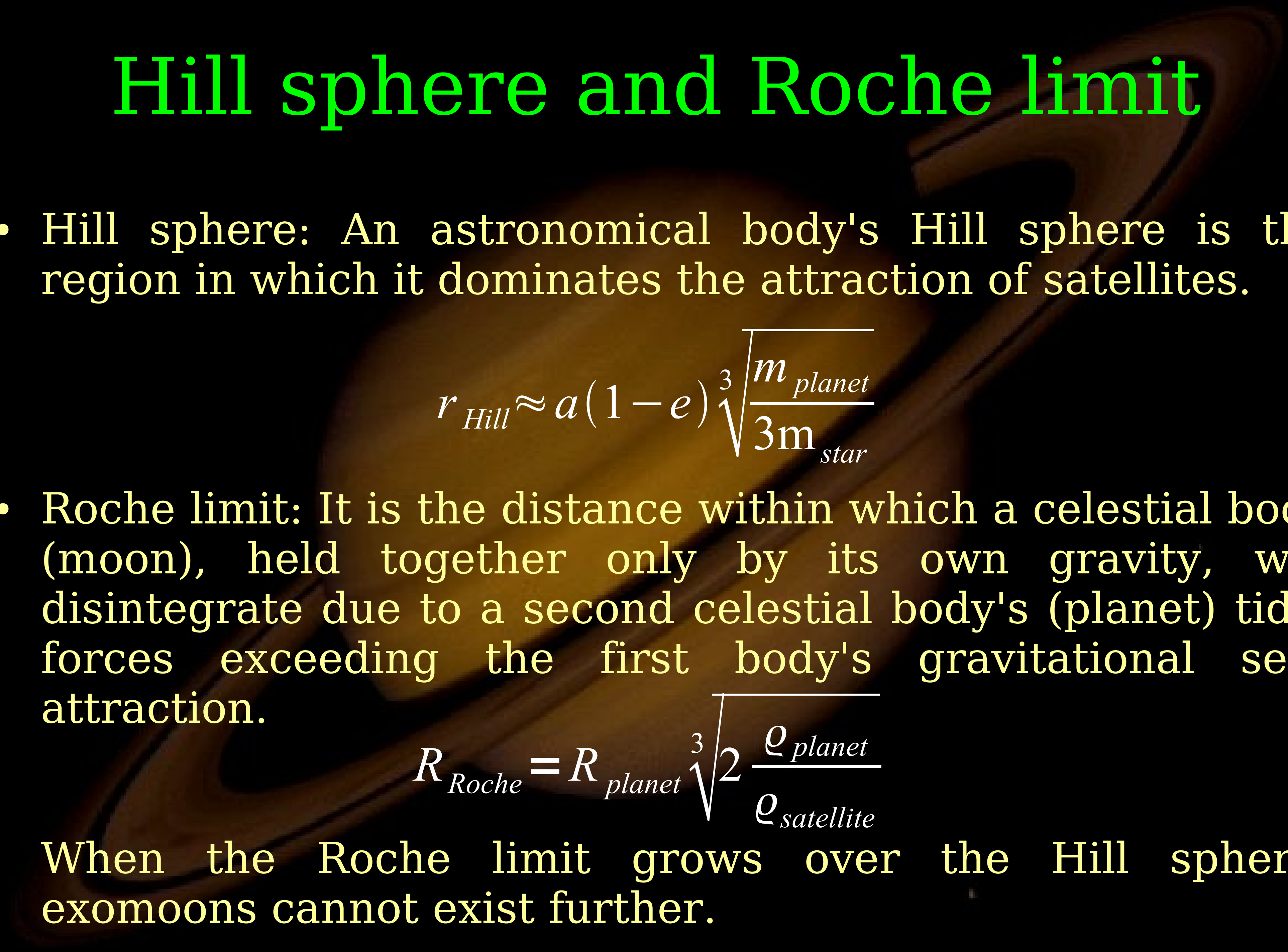
- Planets and its moon orbit around their barycentre, which causes variations in the transit of the planet.
- Transit Time Variation (TTV):
  - Amplitude is proportional to $m_{moon}a_{moon}$
- Transit Duration Variation (TDV):
  - Amplitude is proportional to $m_{moon}(a_{moon})^{-1/2}$
- Detecting the TTV and TDV moon's mass and semi-major axis can be separately determined.
- Current ground-based telescopes could detect a $1M_{\oplus}$ exomoon in the habitable zone around a Neptune-like exoplanet.

Where can we find exomoons?



- Around giant exoplanets, since giant planets have moons in our Solar System,
- but there are some problem:
  - If the planet orbits too close to the star, the temperature is high. However this circumstance restricts just the composition of the moon.
  - Close to the star the shape of the planet is elongated, which can cause strong perturbations.
  - If the planet rotates too fast, its shape is flattened, which can cause strong perturbations.
  - If the planet orbits too close to the star, the Roche limit can extend over the Hill sphere.

Hill sphere and Roche limit



- Hill sphere: An astronomical body's Hill sphere is the region in which it dominates the attraction of satellites.

$$r_{Hill} \approx a(1-e)\sqrt[3]{\frac{m_{planet}}{3\mathrm{m}_{star}}}$$

- Roche limit: It is the distance within which a celestial body (moon), held together only by its own gravity, will disintegrate due to a second celestial body's (planet) tidal forces exceeding the first body's gravitational self-attraction.

$$R_{Roche} = R_{planet}\sqrt[3]{2\frac{\varrho_{planet}}{\varrho_{satellite}}}$$

When the Roche limit grows over the Hill sphere, exomoons cannot exist further.

The limit of existence of the exomoons

- When the Roche limit grows over the Hill sphere, exomoons cannot exist further.

$$R_{R-H} \approx R_{moon} \frac{1}{1-e_{planet}} \sqrt[3]{48 \frac{M_{star}}{m_{moon}}}$$

$$R_{R-H} \approx \sqrt[3]{\frac{36}{\pi} \frac{1}{\left(1-e_{planet}\right)^3} \frac{M_{star}}{\varrho_{moon}}}$$

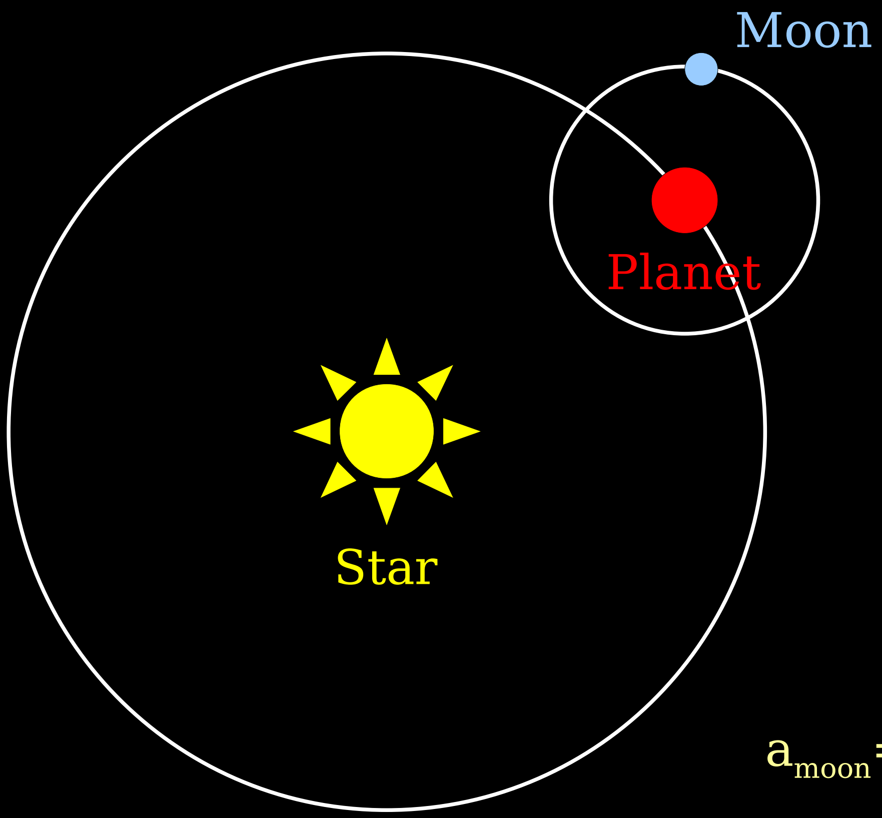
For example Gliese 581:

$M = 0.3\ M_{Sun}$

$\rho_{moon} := \rho_{Earth} \approx 6\ \mathrm{g/cm^3}$

$R_{R\text{-}H} \approx 0.007\ \mathrm{AU} < a_{Gl581e} = 0.0285\ \mathrm{AU}$

Layout of the model



$m_{moon} = e_{planet} = e_{moon} = 0$

$a_{moon} = 1$

$a_{planet} = 1 – 400\ a_{moon}$

$m_{Star} = 66.6 – 10^5\ m_{planet}$

$m_{planet} = 1$

$a_{moon} = 1$

$a_{planet} = 1 – 400\ a_{moon}$

$m_{Star} = 1$

$m_{planet} = 0 – 0.015\ m_{Star}$

$a_{moon} = 0.0025 – 1\ a_{planet}$

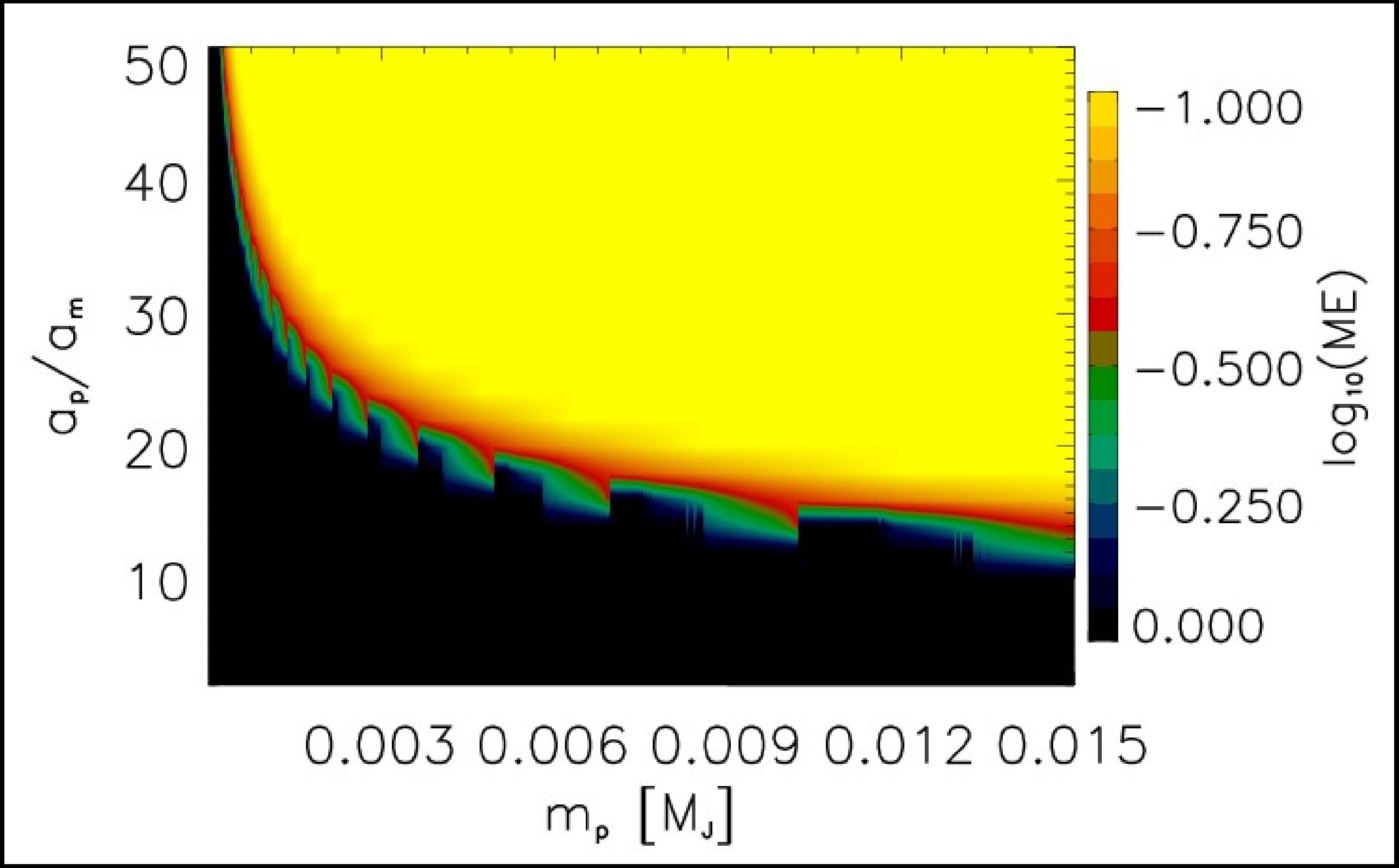
$a_{planet} = 1$

$m_{Star} = 1$

$m_{planet} = 0 – 0.015\ m_{Star}$

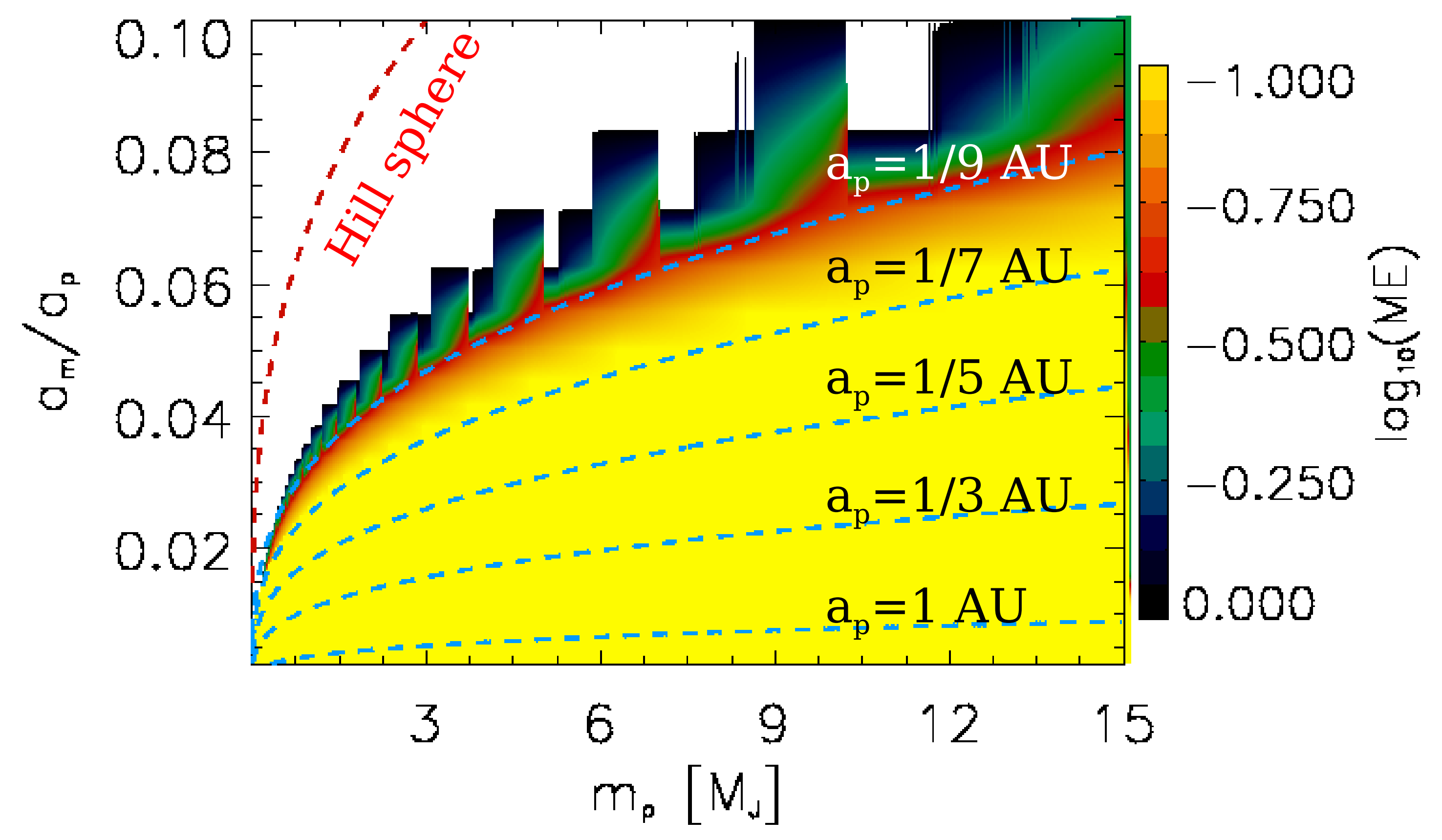
Stability of exomoons

(Preliminary results)



Permissible range

(Preliminary results)



Conclusions

- We can conclude that, ...

Further works

- We would like to calculate
  - perturbations from the shape of the planet, which are caused by:
    - fast rotation of the planet (J_2);
    - vicinity of the star (C_{22}, S_{22});
  - stability of inclined moon orbits;
  - more precisely the radius of the Hill sphere.
- We would like to use Pickard iteration calculating the effect of spherical perturbations. It is a Taylor-series method, similar to Lie integration, but more flexible, however very slow. (Renáta's task)

Thank you for you attention!