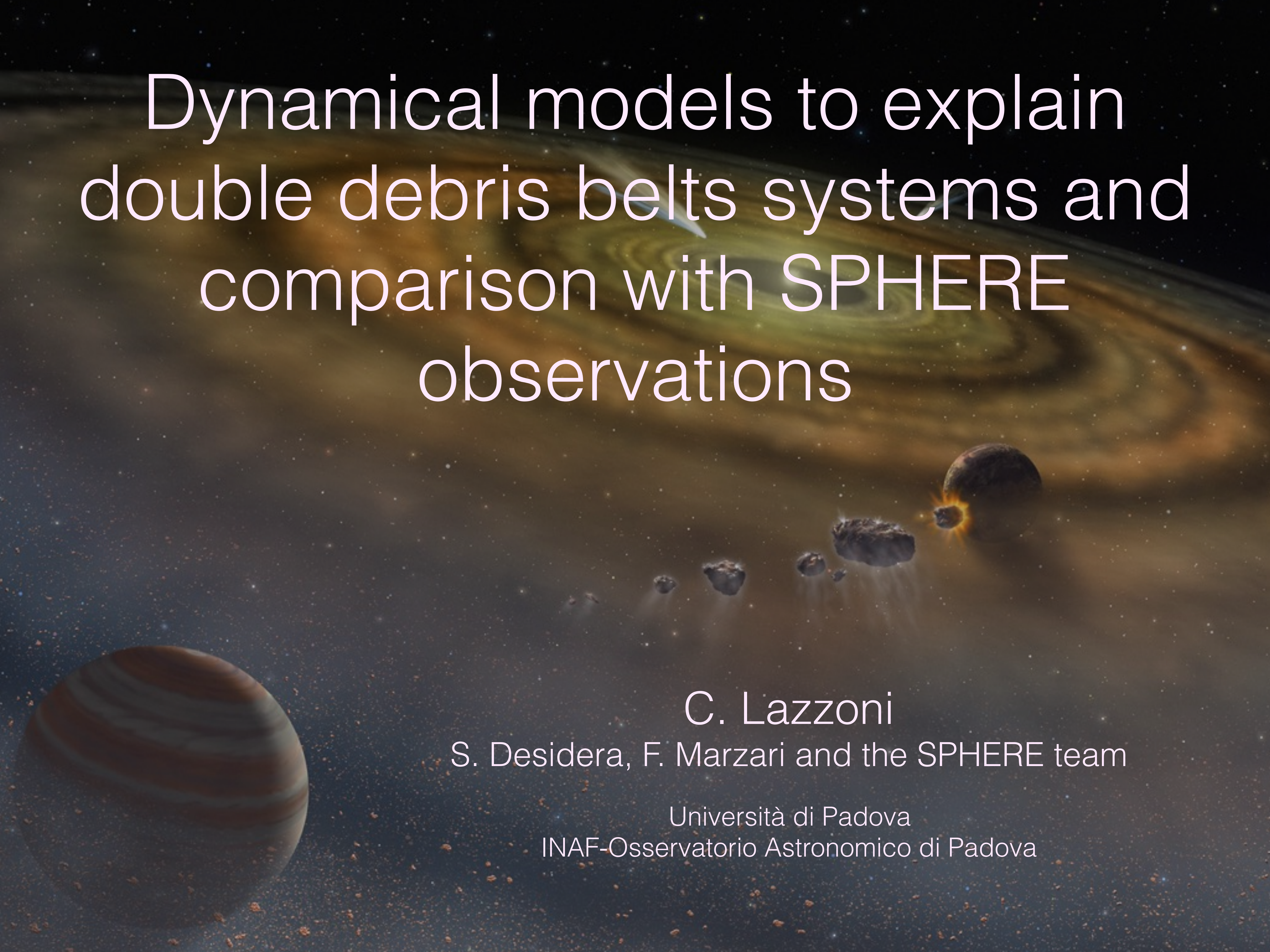

Dynamical models to explain double debris belts systems and comparison with SPHERE observations

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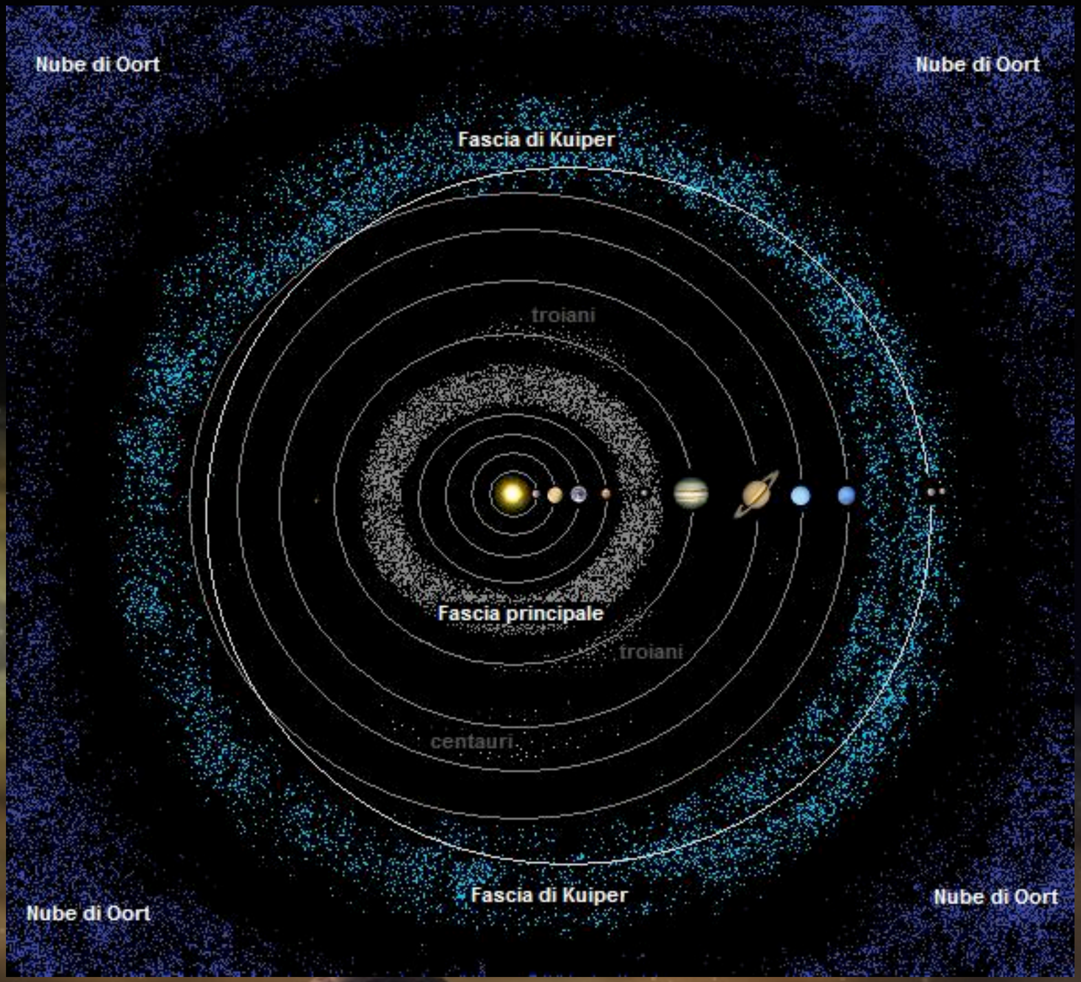
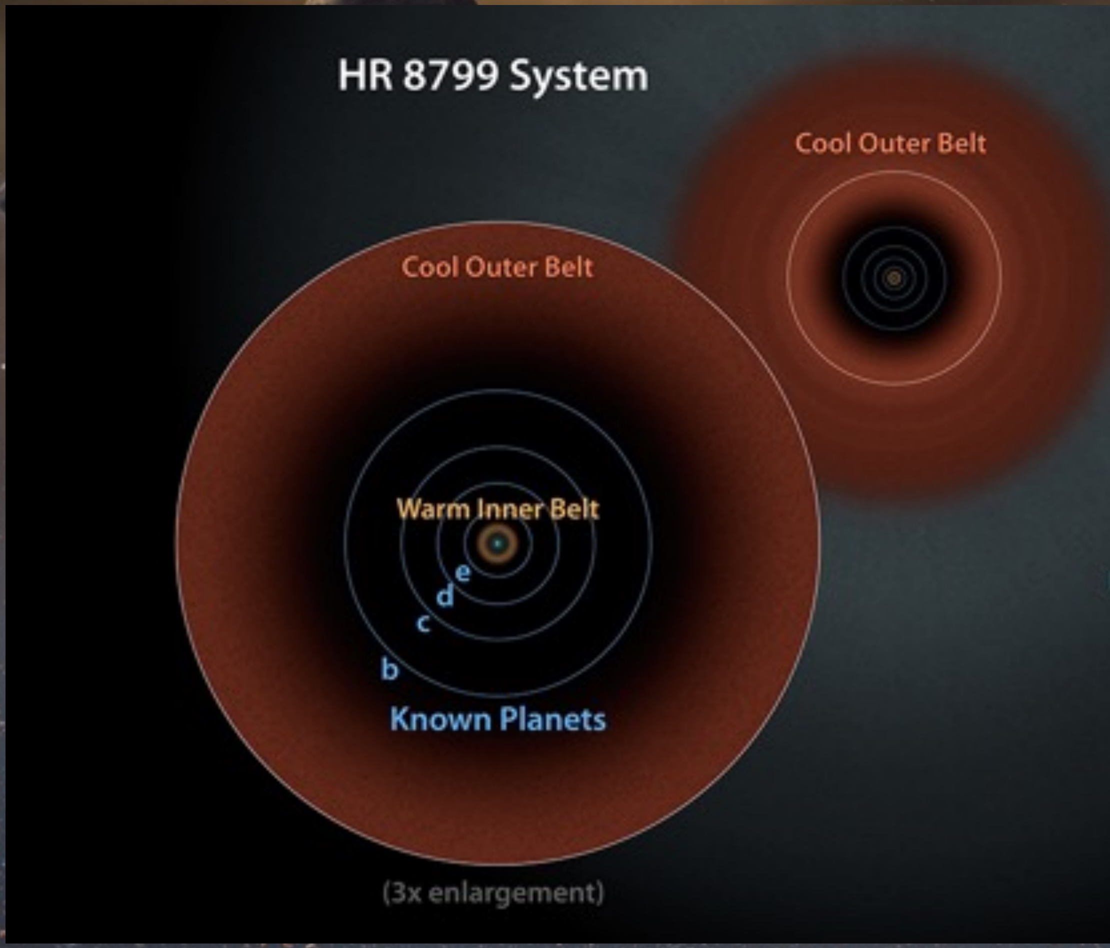
Introduction

- Many systems with a double debris belts architecture similar to the Solar System have been found.
- Most intuitive way to explain the double belts structures is to introduce planets inside the region between the two.
- Apart from the Solar System, clear examples of double belts + planets in between are HR8799 and HD95086 (see A. Zurlo talk).





Introduction

- Analytical tools to estimate the masses, semi-major axes and eccentricities of putative planets (one, two or three) responsible for gaps in debris disks.

- Method applied to 35 systems with double belts structure, as obtained by SED analysis of the IR excesses or from images of the disk, and observed with SPHERE

- With the exception of HR8799, PZ Tel, HD95086 and HD206893, SPHERE, within SHINE/GTO survey, found no companion around the stars in the sample

- We want to compare dynamical properties of the putative planets with SPHERE detection limits in order to derive possible architectures that are compatible with the observations.

Lazzoni et al. 2017

Presentation of the method

- Debris disks are second generation disk almost completely depleted from gas

- Planets inside disks leave footprints of their passage (**gaps**, warps, luminosity asymmetries, etc.)

- Gaps result from scattering of dust particles due to the presence of the planet —> **Chaotic Zone**

$$\Delta \propto \left(\frac{M_P}{M_*}\right)^{\alpha} a_p e_p^{\beta}$$

- When analyzing multi-planetary architectures, also dynamical stability of the systems must be taken into account —> **Max Packing** condition in order to avoid degeneracies

Single planet: circular

- Wisdom (1980) firstly derived an analytical equation for the CZ for the planar circular-restricted three-body problem from estimation of the stability of dynamical systems for a non-linear Hamiltonian with two degrees of freedom

$$\Delta a = 1.3\mu^{2/7} a_p$$

- Then, Mustill and Wyatt (2012) derived a similar expression from numerical N-body simulations considering also the eccentricities of the dust particles in the disk

$$\Delta a = 1.8(\mu e)^{1/5} a_p$$

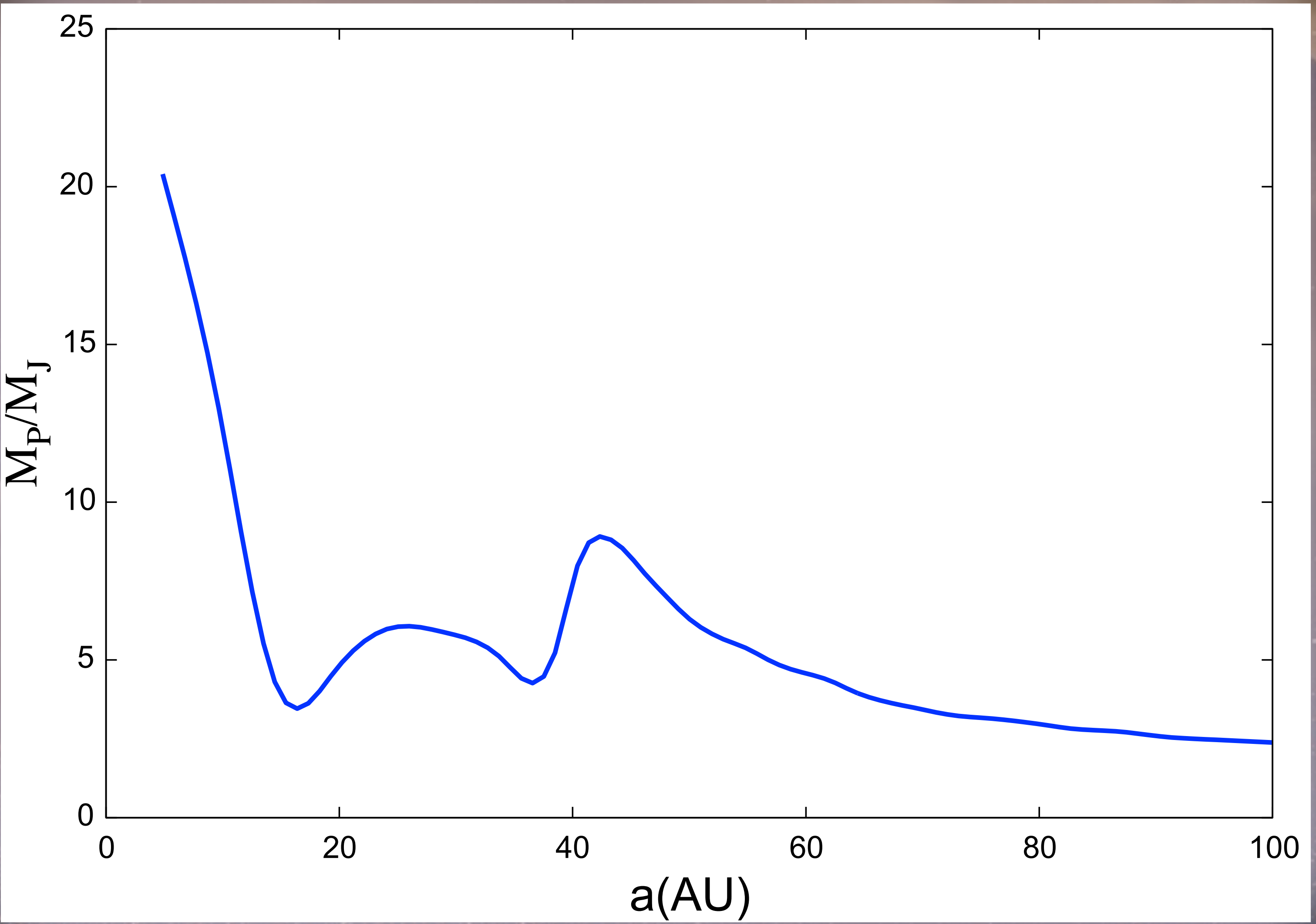
- △a represents the semi-amplitude of the chaotic zone

$$\Delta a_{ex} = d_2 - a_p \qquad \Delta a_{in} = a_p - d_1$$

and we know that △a_ex +△a_in must equal the gap width

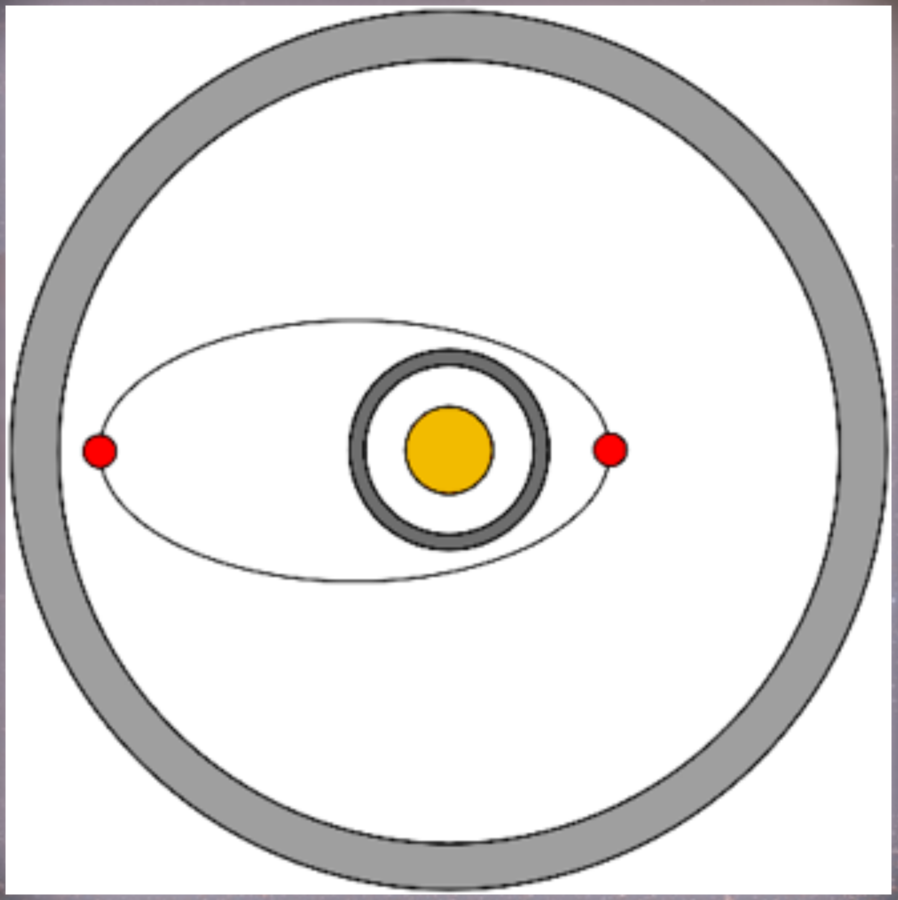
Single planet: circular —> HD 181327

- $M_\star$=1.3 $M_\odot$, d1=15.3 AU, d2=70 AU (Δ=54.7 AU)
- Single planet: Mp=120 MJ, ap=40AU



Single planet: eccentric

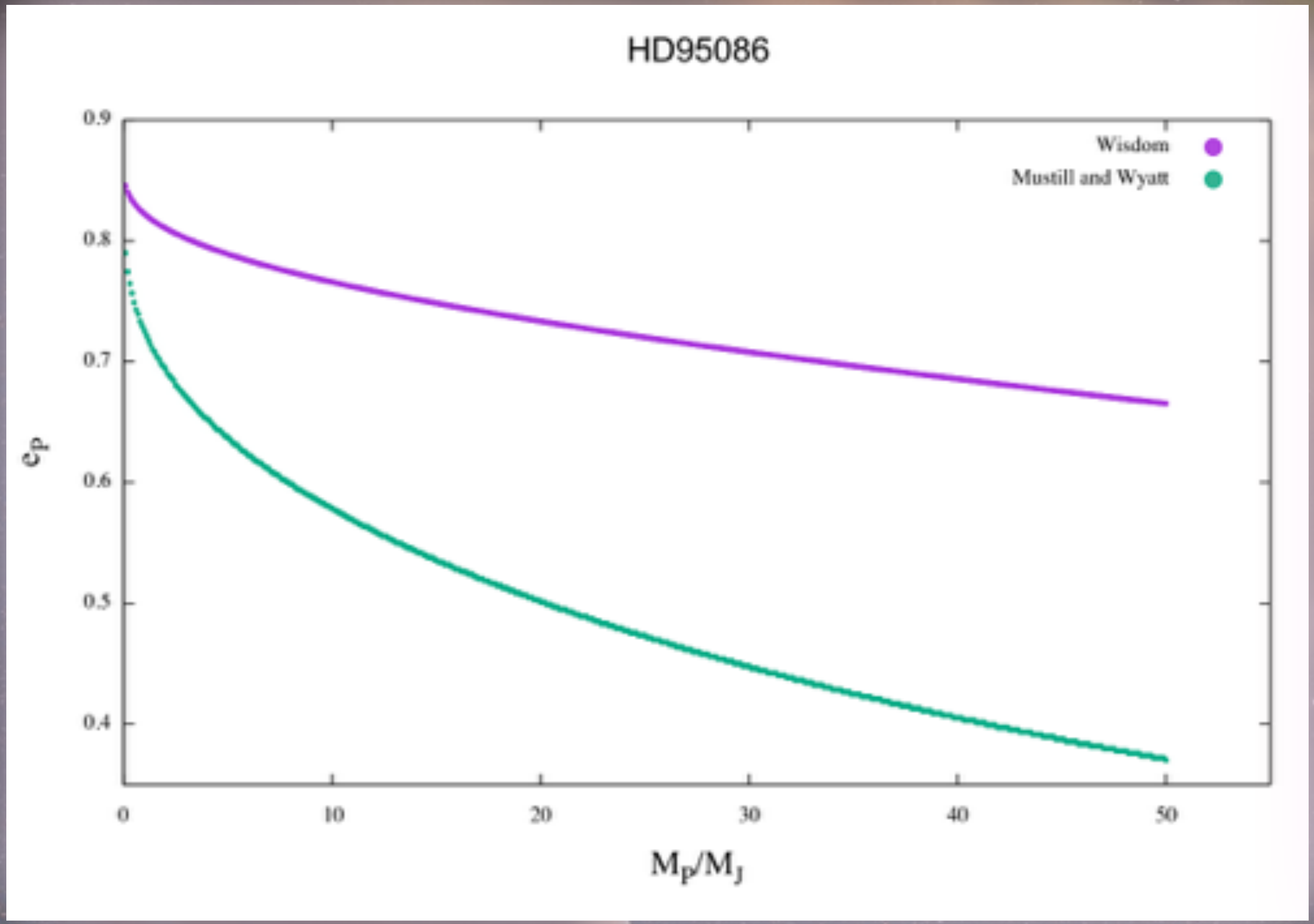
- Formalisms presented are valid only for circular orbits
- Eccentricity is a common feature of planets beyond the Solar System
- Guess on the equations that rule the disk-planet interaction in the eccentric case, tested with N-body numerical simulations

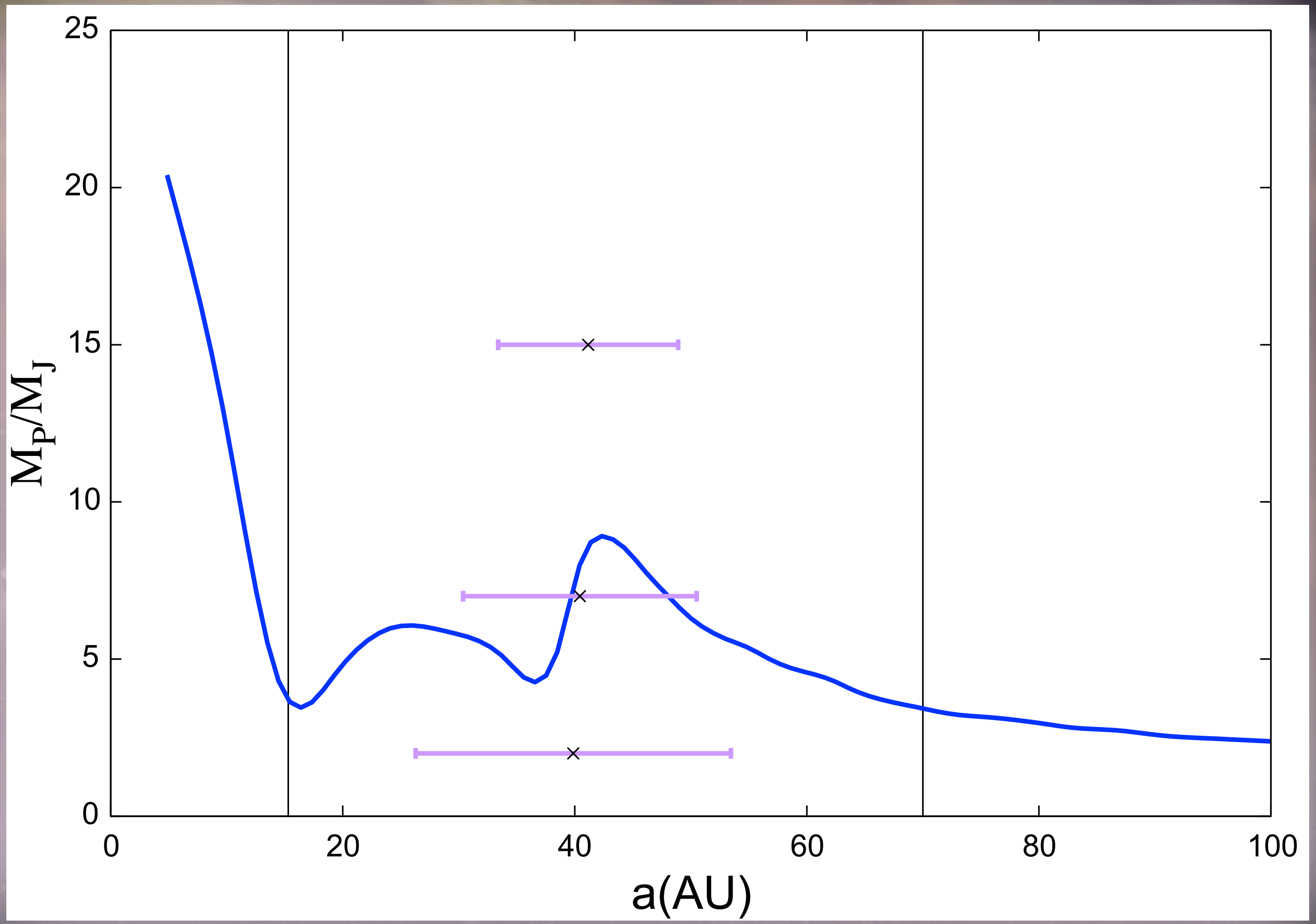


$$(\Delta a)_{ex} = 1.8(\mu e_p)^{1/5} apo$$
$$(\Delta a)_{in} = 1.8(\mu e_p)^{1/5} peri$$

$$(\Delta a)_{ex} = 1.3\mu^{2/7} apo$$
$$(\Delta a)_{in} = 1.3\mu^{2/7} peri$$

Single planet: eccentric —> HD 181327





Two planets: circular

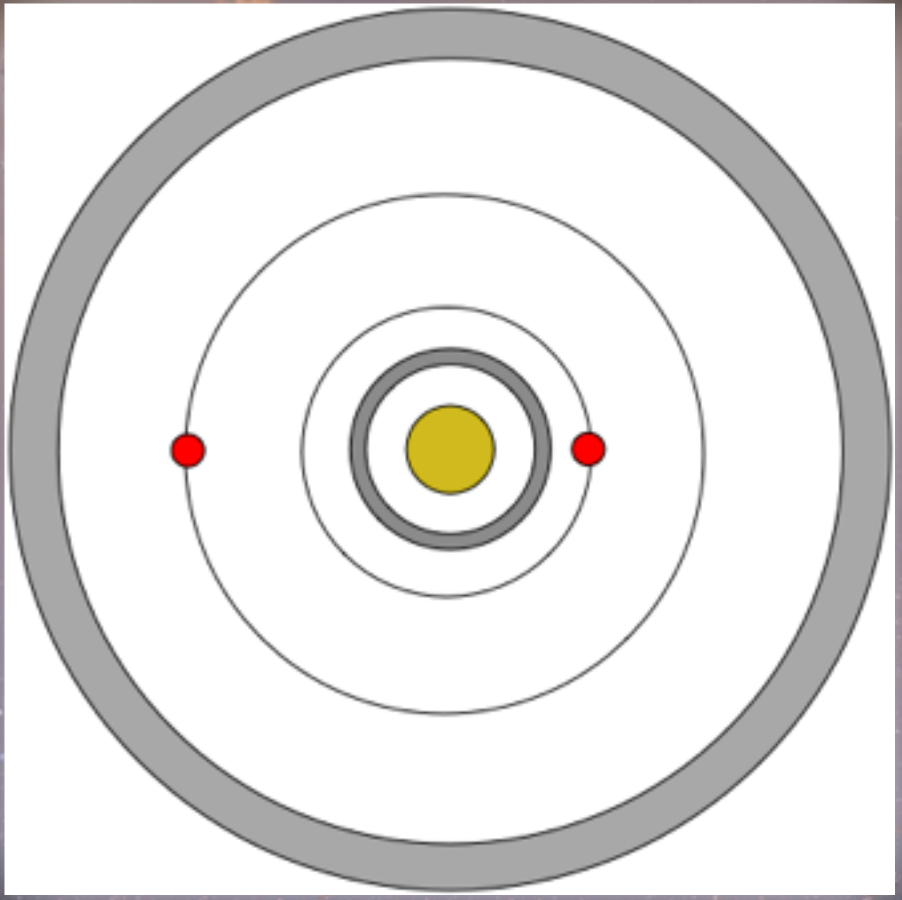
- In multi-planetary systems, we have also to consider interactions between the planets. If two planets are present, depending on their minimum approach distance the system may be stable, marginally stable or unstable as follows

$$\frac{1}{(\mu_1+\mu_2)^3}\left(\mu_1+\frac{\mu_2 a_1}{a_2}\right)\left(\mu_1\sqrt{1-e_1^2}+\mu_2\sqrt{1-e_2^2}\sqrt{\frac{a_2}{a_1}}\right)^2 \geq 1+3^{4/3}\frac{\mu_1\mu_2}{(\mu_1+\mu_2)^{4/3}}$$

- Choosing "=" implies consider the system at its stability limit, thus the two planets get as near as possible in order to have a yet stable system —> **Max Packing Condition**

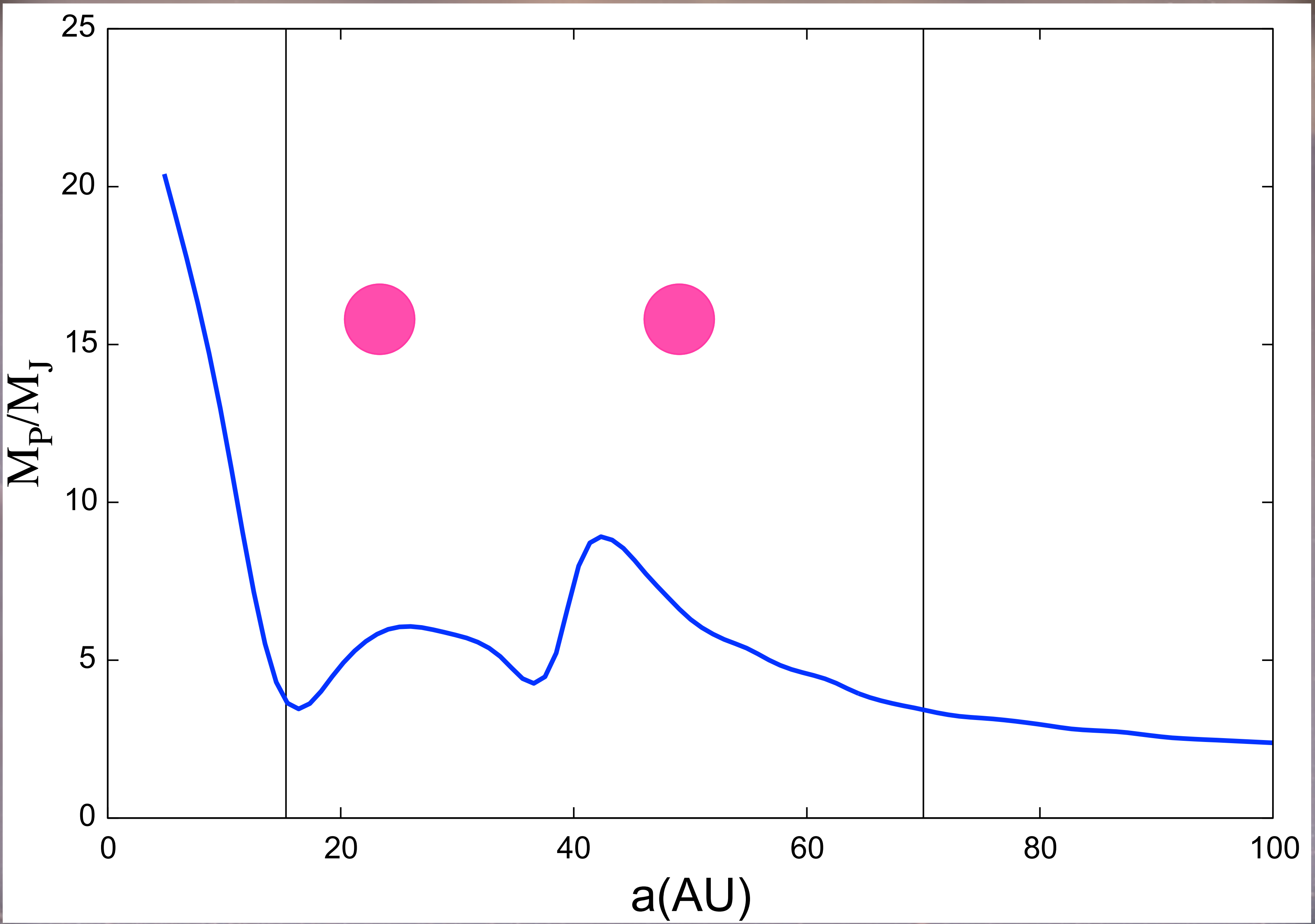
- In case the two planets are on circular orbits and in max packing condition, the previous equation can be approximated with

$$a_2-a_1 \sim 2\sqrt{3}\left(\frac{M_1+M_2}{3M_*}\right)^{1/3}\frac{a_1+a_2}{2}$$



Two planets: circular —> HD181327

- Assuming two equal-mass planets —> M1=M2=15.8MJ, a1=23AU and a2=49AU



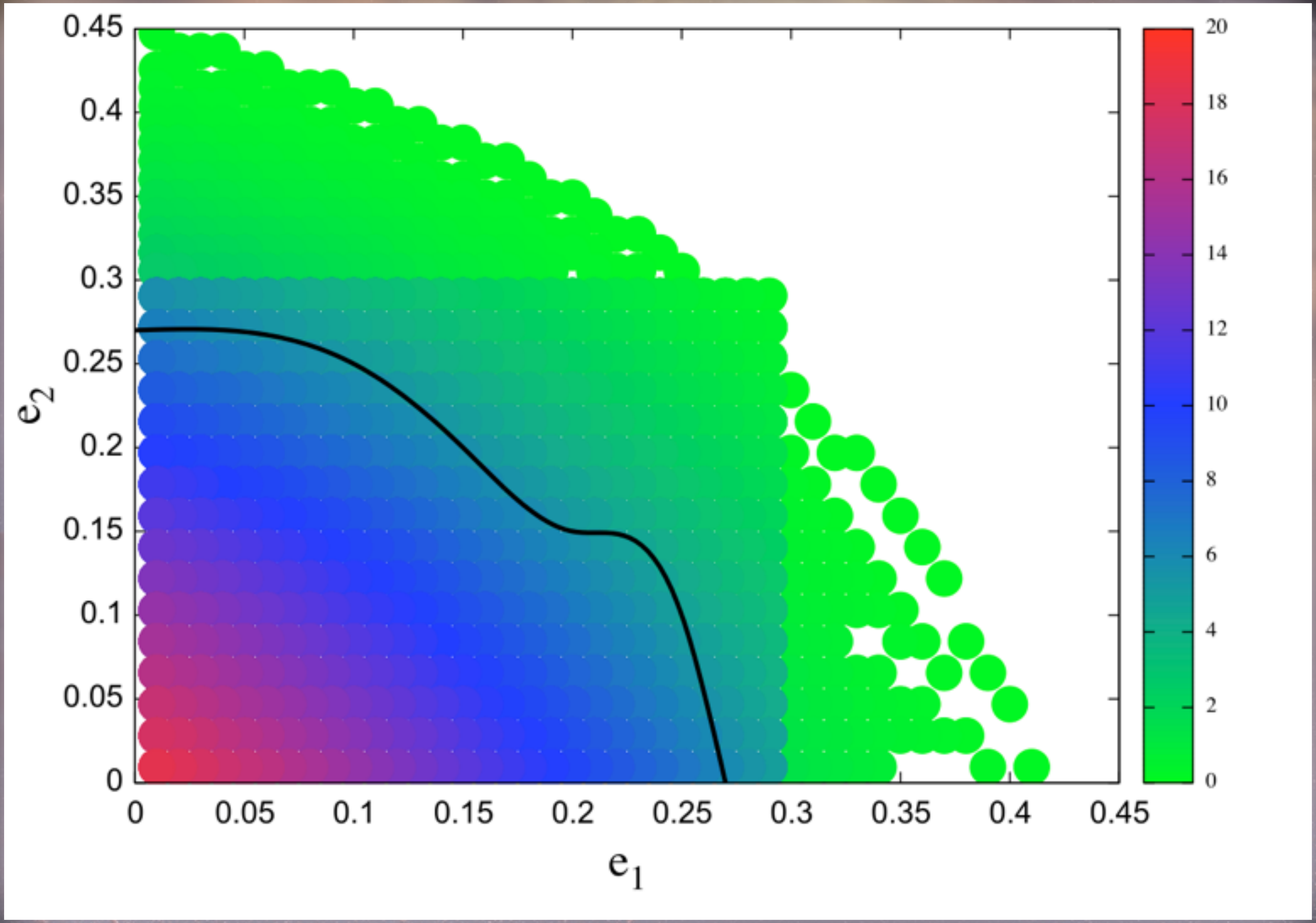
Two planets: eccentric

- Assuming two equal-mass planets on eccentric orbits in max packing condition

$$\frac{1}{8}\left(1+\frac{a_{p,1}}{a_{p,2}}\right)\left(\sqrt{1-e_{p,1}^2}+\sqrt{1-e_{p,2}^2}\sqrt{\frac{a_{p,2}}{a_{p,1}}}\right)^2-1-\left(\frac{3}{2}\right)^{4/3}\mu^{2/3}=0.$$

- Strong dependence on the eccentricity and low dependence on the mass of the planet.

Two planets: eccentric —> HD181327



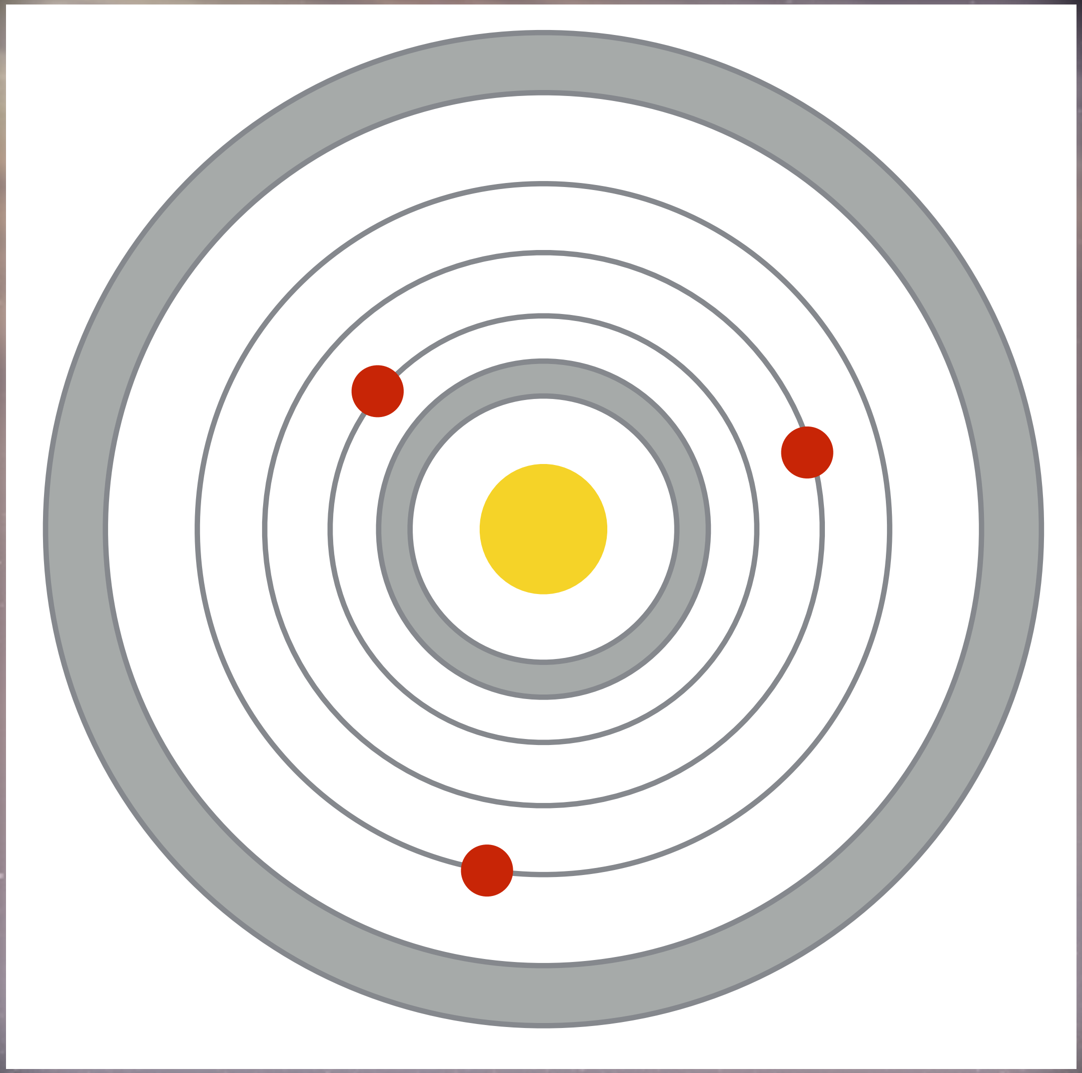
Three planets: circular

- For three equal-mass planets on circular orbit in max packing condition, the semi-major axes of the planets are linked by

$$a_{p,i+1} = a_{p,i} + KR_{Hi,i+1},$$

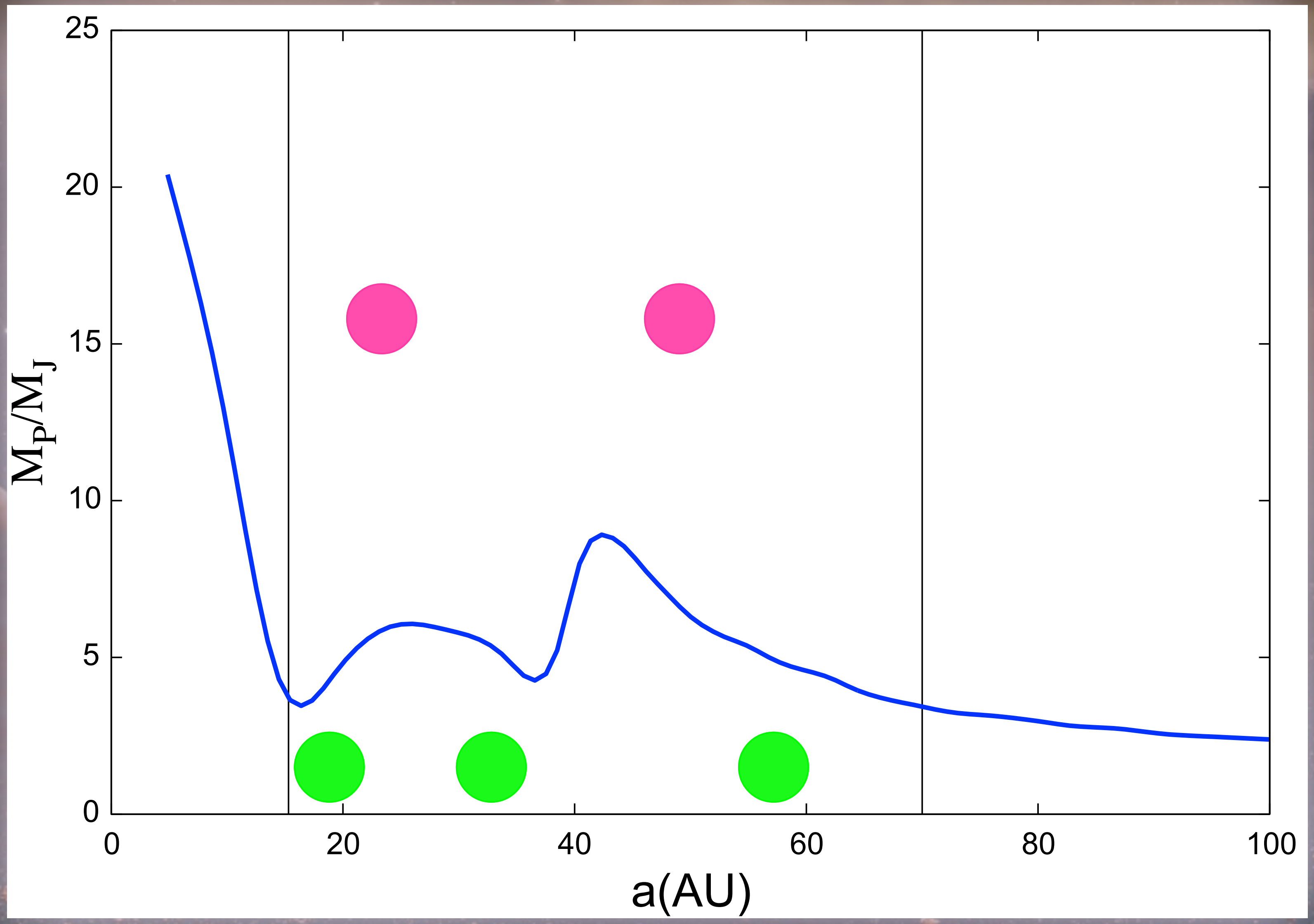
with i=1,2.

- The constant K assumes different values depending on the mass of the planet. We used
K = 8 for Neptune-size planets;
K = 7 for Saturn-size planets;
K = 6 for Jupiter-size planets .



Three planets: circular —> HD181327

- Assuming three equal-mass planets —> M1=M2=M3=1.5 MJ, a1=18.8AU, a2=32.8AU and a3=57AU



Sample

- The sample was obtained combined the targets observed with SPHERE up to May 2016 and the systems classified as double-belts in Chen et al 2014

- 35 systems:

  Spectral types [B8,G9]
  Ages [11,600] Myr
  Masses [0.9,3] M
  Distance from the Sun <150 pc.

- Positions of the two belts —> from blackbody temperatures as given by Chen et al. (2014) we can derive the position of the belts, assuming a thin ring between r-dr and r+dr

$$R_{i,BB} = \left(\frac{278K}{T_{i,BB}}\right)^2 \left(\frac{L_*}{L_\odot}\right)^{0.5} AU$$

- For the cold components, comparison with images of resolved disks shows that the estimation of the blackbody radius underestimates the real position of the ring. Thus we apply a correction to the blackbody radii,

$$\Gamma = A(L/L_\odot)^B$$

with A=6 and B=-0.4 (Pawellek et al. 2014).

Results

Applying the formalism to the 35 systems in the sample we

- one planet on circular orbit —> no good result, all detectable objects
- one planet on eccentric orbit —> in most cases, too high values of eccentricities to have objects beneath detection limits
- two planets on circular orbits —> no good result, all detectable objects
- two planets on eccentric orbits —> most systems could have low mass companions (undetectable) with low values of eccentricities
- three planets on circular orbits —> more than half of the systems could harbor three undetectable planets

Summary, conclusions and future perspective

- Analytical tools to estimate a first guess on the possible architectures of planetary systems between debris belts
- Adding more than one planet and/or considering higher values of eccentricity give planets, responsible for the gap, under (actual) detectability
- SPHERE will observe more than 80 double debris belts systems —> future statistical analysis
- Many others parameters to take into account: time needed to dig the gap, projection effects, resonances, and more… STAY TUNED!

Thank you for your attention!

SPHERE

Spectro-Polarimetric
High-contrast
Exoplanet REsearch