Eccentricity Formation and Habitable Planets of OGLE-06-109L System

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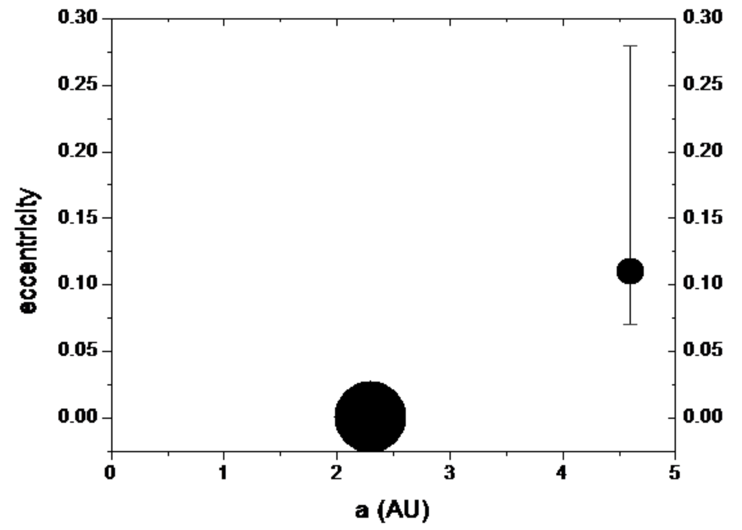
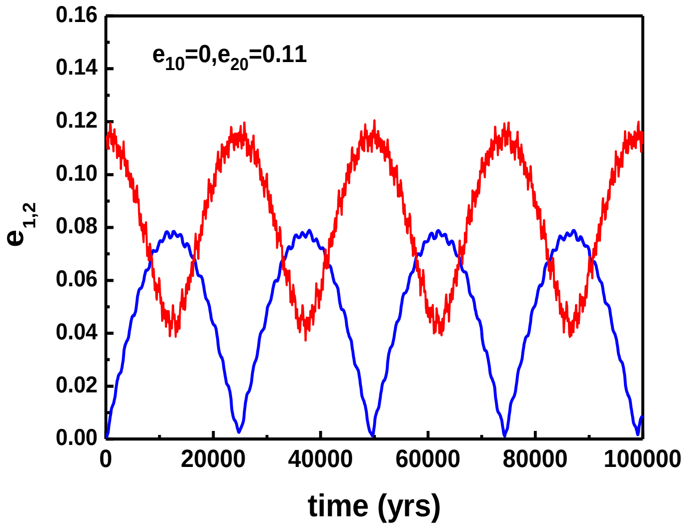
The OGLE-06-109L System



The configuration of the system



The secular motion of the system

Name	OGLE-06-109L b	OGLE-06-109L c
Mass	0.71 (± 0.08) M_J	0.27 (± 0.03) MJ
Planet Dist.	2.3 (± 0.2) AU	4.6 (± 0.5) AU
Orbital period	1825 (± 365) days	5100 (± 730) days
Eccentricity	-	0.11 (−0.04+0.17)
Inclination	-	59 (± 6) deg.

Properties of the system:

The system is an analogy of our Solar system.

http://exoplanet.eu.

Outline

- Eccentricity formation (three models and results)
  - Smooth and convergent migration
  - Planetary scattering
  - Divergent migration in the presence of planetesimal disk

- Habitable planets

Mainly focus on the influence of the speed of type I migration.

Eccentricity Formation (model)

N-body simulations (gravitational interaction between them)

Interaction with the disk: gas drag ,type II migration:

$$\frac{d}{dt}V_i = -\frac{G\,(M_* + m_i)}{r_i^2}\left(\frac{\vec{r}_i}{r_i}\right) + \sum_{j\neq i}^{N} G m_j \left[\frac{(\vec{r}_j - \vec{r}_i)}{\left|\vec{r}_i - \vec{r}_j\right|^3} - \frac{\vec{r}_j}{r_j^3}\right] + F_{edamp}(+F_{migII})$$

$$\vec{F}_{damp} = -2\frac{(\vec{V}\bullet\vec{r})\vec{r}}{r^2\tau_{damp}}\exp\left(-\frac{t}{tdep}\right)$$

Cresswell & Nelson 2006

$$\tau_{damp} = \frac{Q_e}{0.78}\left(\frac{M_*}{m}\right)\left(\frac{M_*}{a^2\Sigma_g}\right)\left(\frac{h}{r}\right)^4\Omega^{-1}\left[1+\frac{1}{4}\left(e\frac{r}{h}\right)^3\right]$$

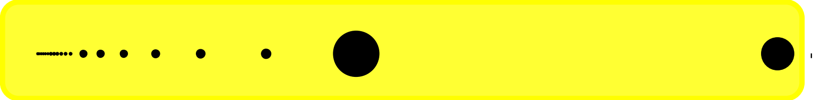
$$\vec{F}_{migII} = -\frac{\vec{V}}{2\tau_{migII}}\exp\left(-\frac{t}{tdep}\right)$$

Ida & Lin 2004

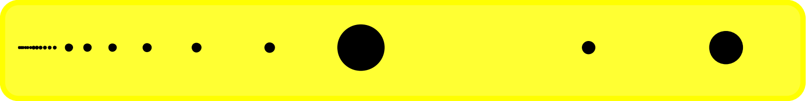
$$\tau_{typeII} = 0.8\times10^6 f_g^{-1}\left(\frac{m_p}{M_{Jup}}\right)\left(\frac{M_*}{M_{sun}}\right)^{-1/2}\left(\frac{\alpha}{10^{-4}}\right)^{-1}\left(\frac{a}{1AU}\right)^{1/2}$$

Initial configurations:

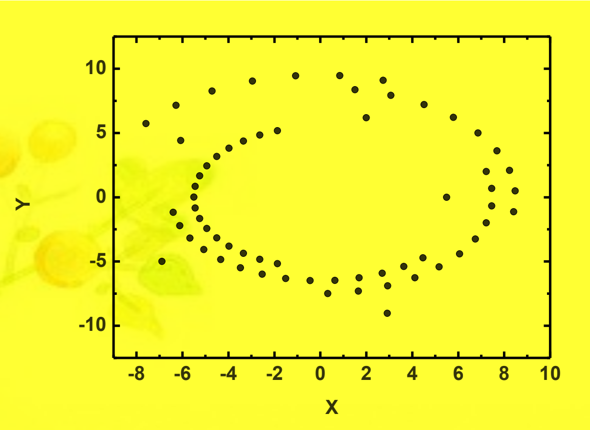
Model 1: 2 giants + 18 embryos



Model 2: 2 giants + 19 embryos

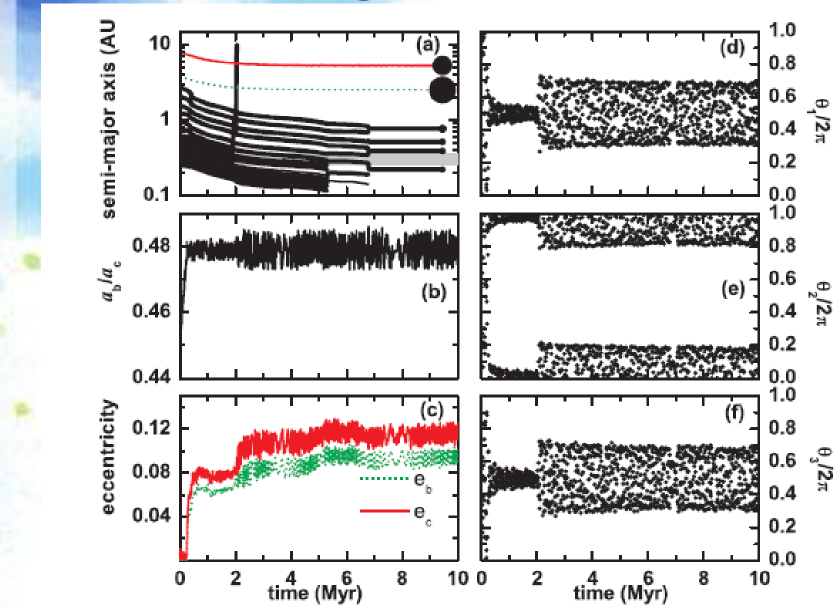


Model 3: 2 giants + planetesimals

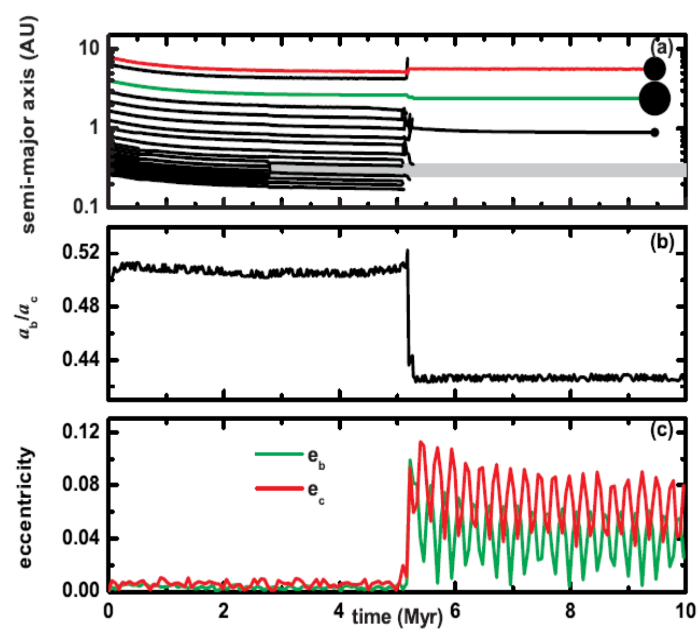


Smooth and convergent migration

Planetary scattering



The results of model 1



The results of model 2

Two giants are in 3:1 MMR at about 1Myr.

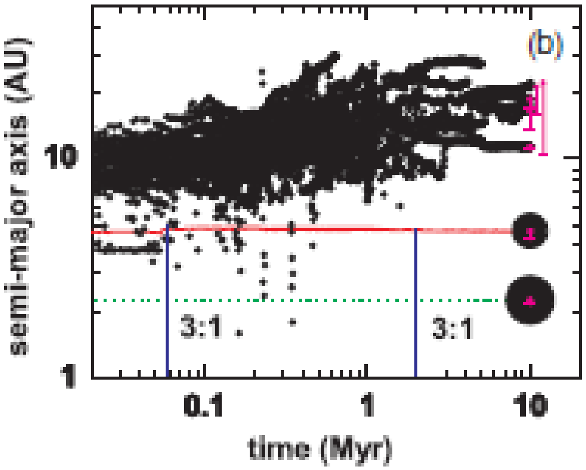
Eccentricities are both excited to about 0.1.

Four planets left in the system at the end. The inner two are in the edge of the HZ (0.25-0.36 AU).

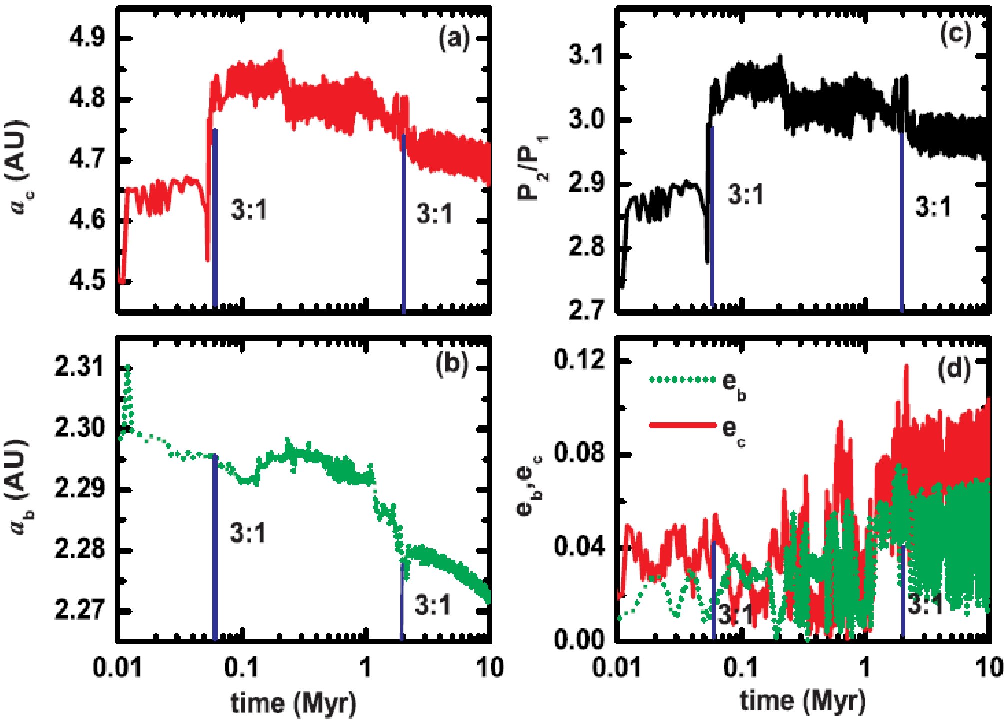
Close encounter happened at about 5.2 Myr.

The eccentricities are in the same configuration to the secular motion of the nominal system .

Divergent migration



The orbit evolution of all the planets and planetesimals



The evolution of the two giants

- The two giants cross 3:1 MMR during the divergent migration at 0.06Myr and 2Myr.

- The eccentricities of the two giants are excited to [0.01-0.07] and [0.03-0.1] respectively.

In our simulations, the probability of 3:1 MMR crossing is about 33%.

Summary

When gas disk is present

I. Initial configuration is loose, $a_b/a_c < 0.48$, model 1 (smooth migration) may be the reason leading to the eccentricity of the two giants. This scenario is less likely because of the low probability for the two giant planets in 3:1 MMR (3%).

II. Initial configuration is compact, $a_b/a_c > 0.48$, model 2 (planetary scattering) can result in the eccentricity in near-separatrix motion agree with the secular motion of the nominal system.

After the gas disk is almost depleted

The 3:1 MMR crossing model will excite the eccentricities up to the nominal value of the two giants.

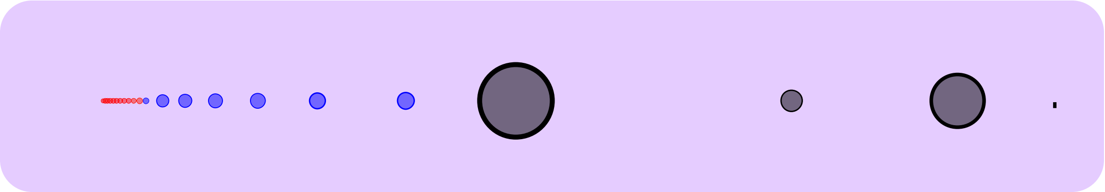
This work has been published in ApJ 706, 772-784

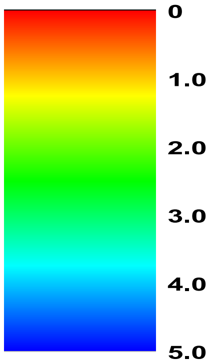
Habitable planets in the system

Model: the same scenario with model 2 (planetary scattering model) Additionally, the embryos whose mass is less than 10 Earth-mass suffer from type I migration. f_1 [0.001,1] is an efficient factor of the speed of type I migration.

$$F_{mig} = -\frac{\vec{v}}{2\tau_{mig}}$$

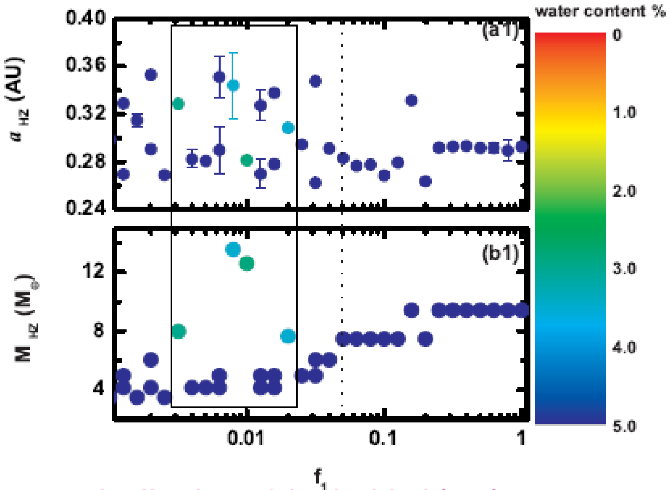
$$\tau_{mig} = \frac{1.3}{f_1(2.7+1.1\beta)}\left(\frac{m_p}{M_{sun}}\right)^{-1}\left(\frac{M_*}{M_{sun}}\right)^{3/2}\left(\frac{a}{1AU}\right)^{3/2}\left[\frac{1+\left(\frac{er}{1.3h}\right)^5}{1-\left(\frac{er}{1.1h}\right)^4}\right]$$



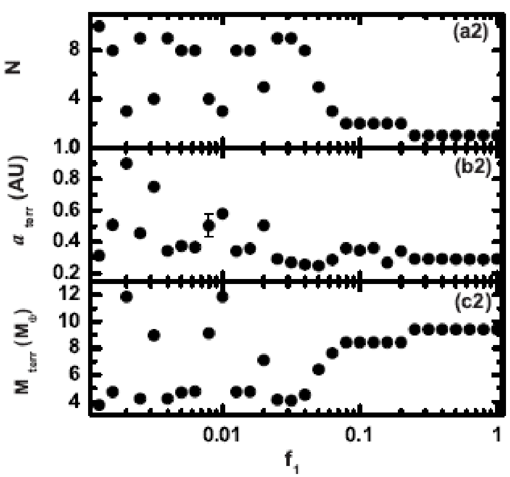


Semi-major axis (AU)	Water content (by mass)
> 0.625	5%
0.5 - 0.625	0.1%
< 0.5	0.001%

Distribution of the habitable planets in the system



Distribution of the habitable planets



Distribution of the terrestrial planets

Results

I. There are always planets survival in the habitable zone when f_1 is in the range of [0.001,1]

II. If the mass of the habitable planet in the system is larger than 7 Earth- mass, f_1 is larger than 0.05 is proper for the system or the planet underwent merge process with type I migration slower than 0.05.

III. With slow type I migration, there are always low mass (lower than 7 Earth-mass) habitable planets left in the system.

IV. In this case, the water content of the habitable planets are always high, about 5% by mass.

V. If f_1 is larger than 0.2, there is only one terrestrial planet left in the system.

The End

Thank you!