Planet formation around M-type stars

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Introduction

- There are over 3000 planets since 1995.
- The number of planets around M-type stars is about 50.
- IRD surveys are carrying out for detecting planets around M-type stars.

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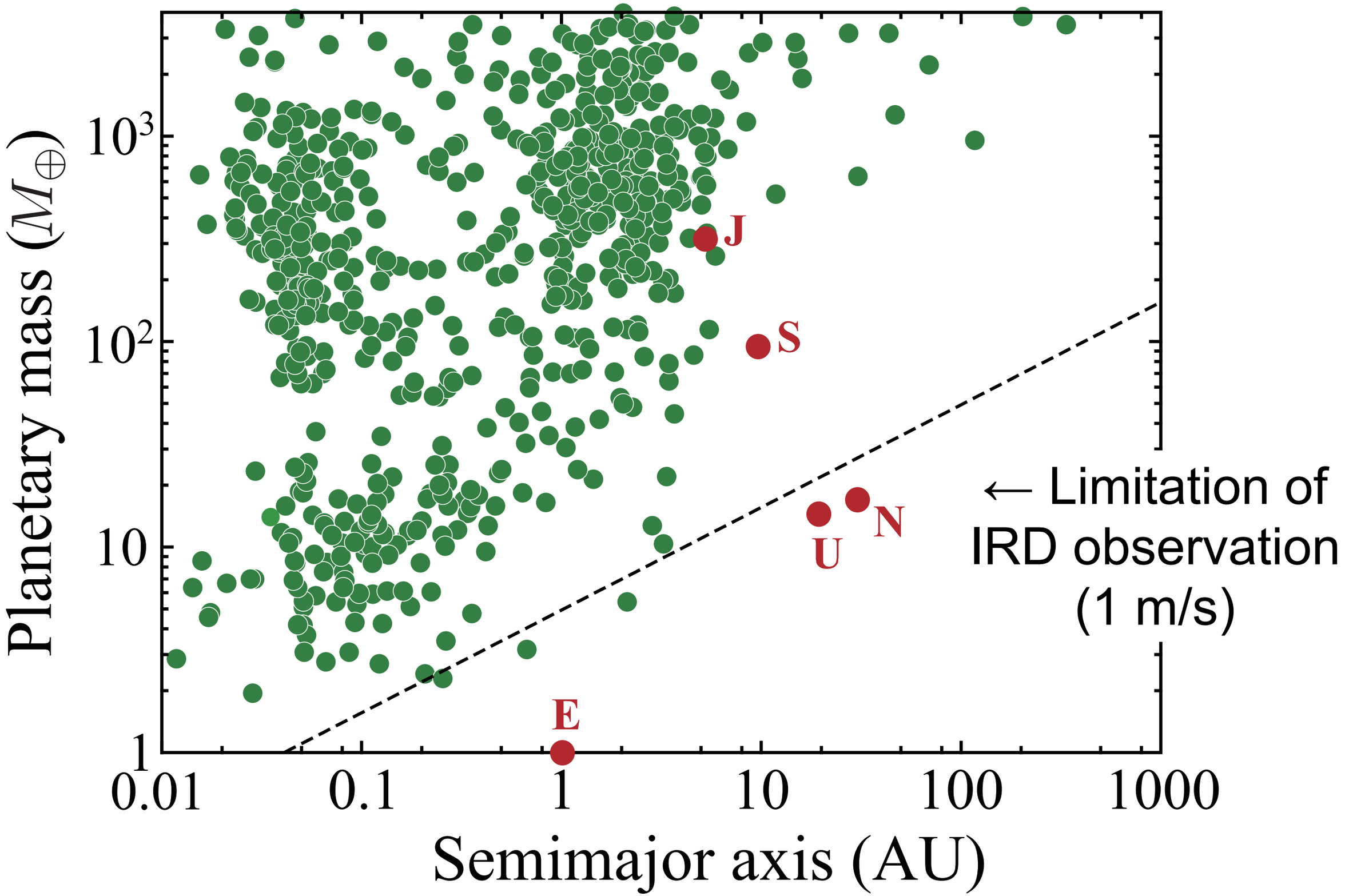
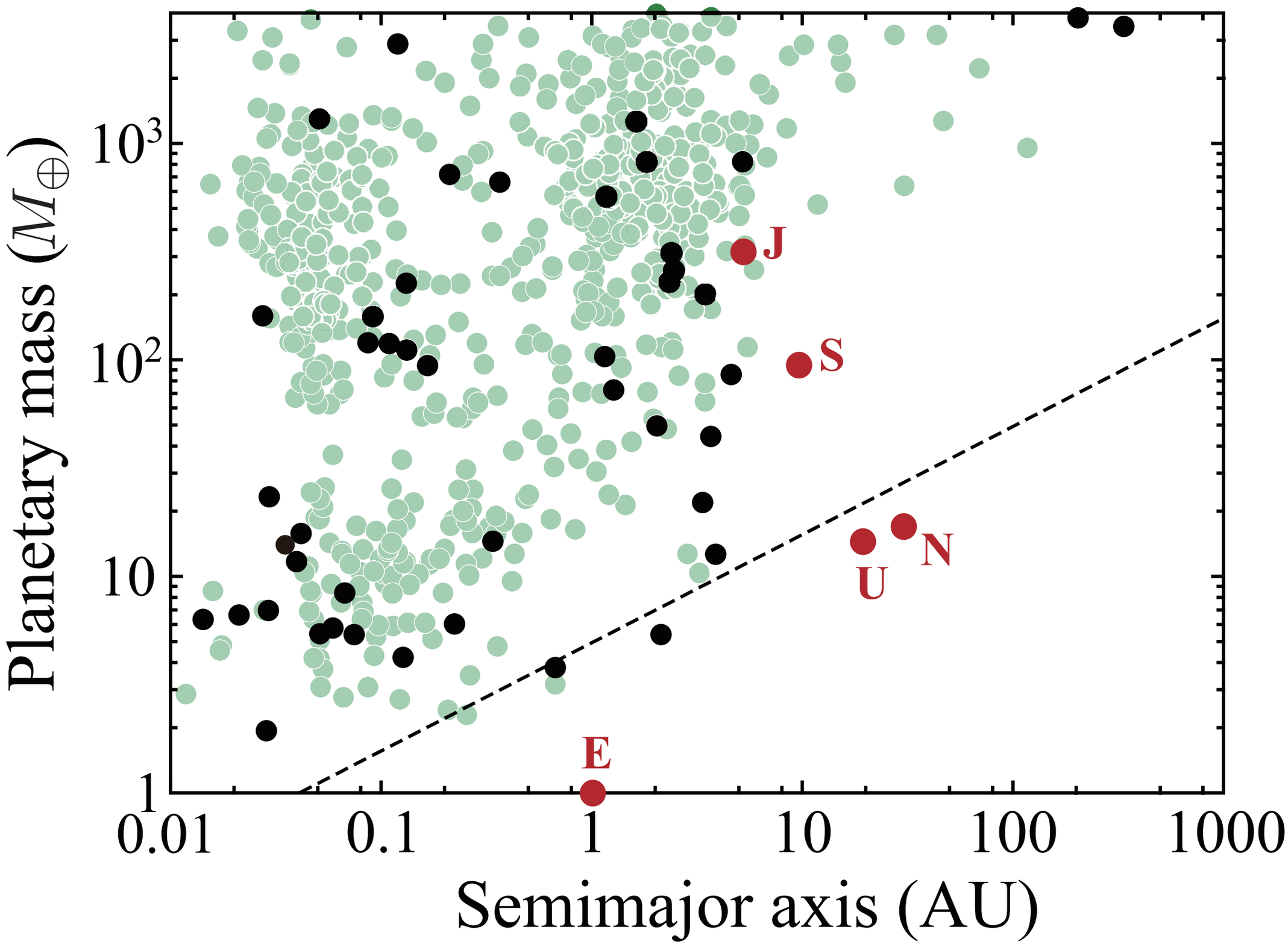
    - Subaru/IRD
    - MEarth (Nutzman & Charbonneau 2008)
    - GAIA (Lattanzi & Sozzetti 2010)

Observation of planets around M-type stars



Observation of planets around M-type stars



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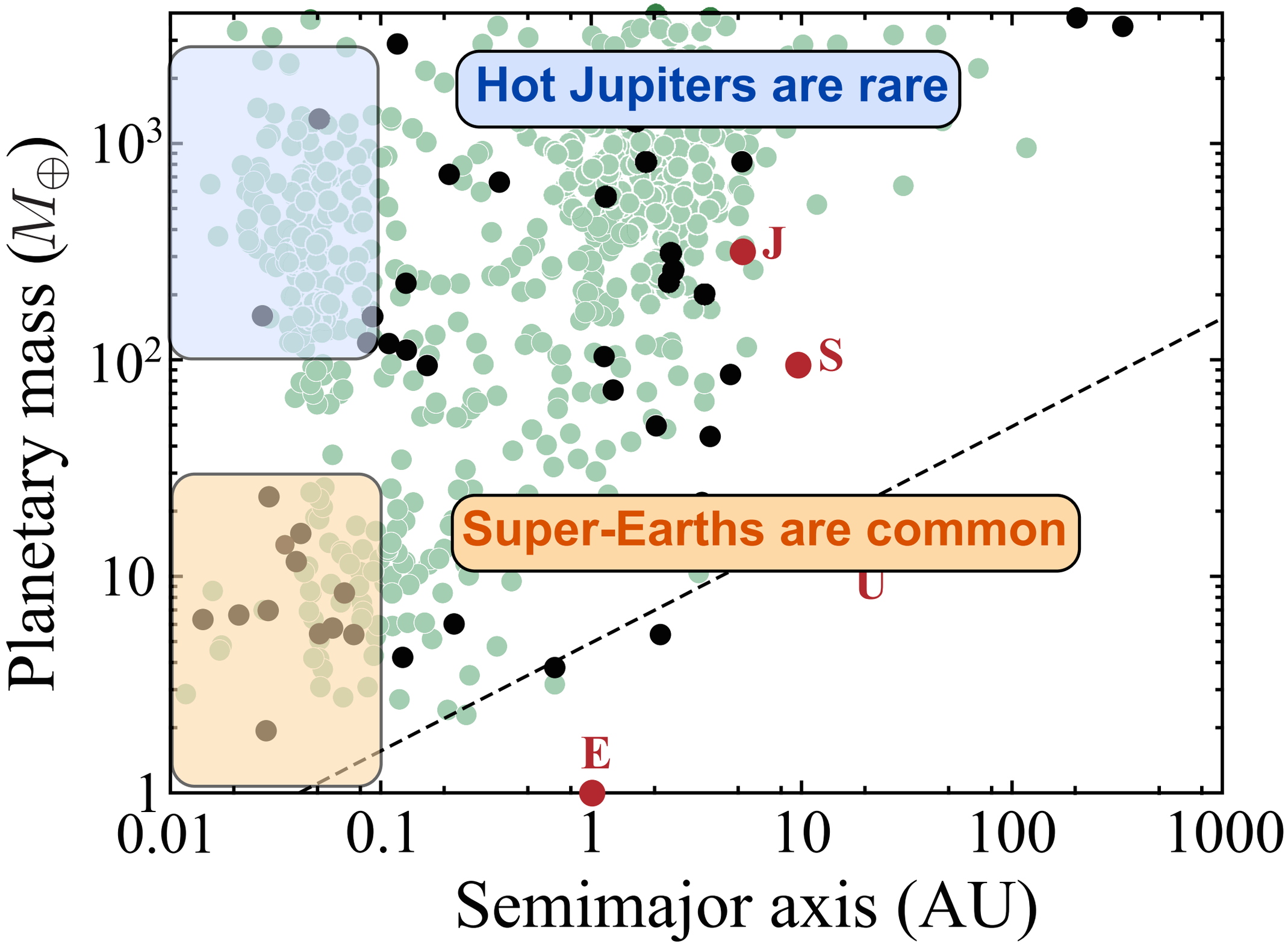
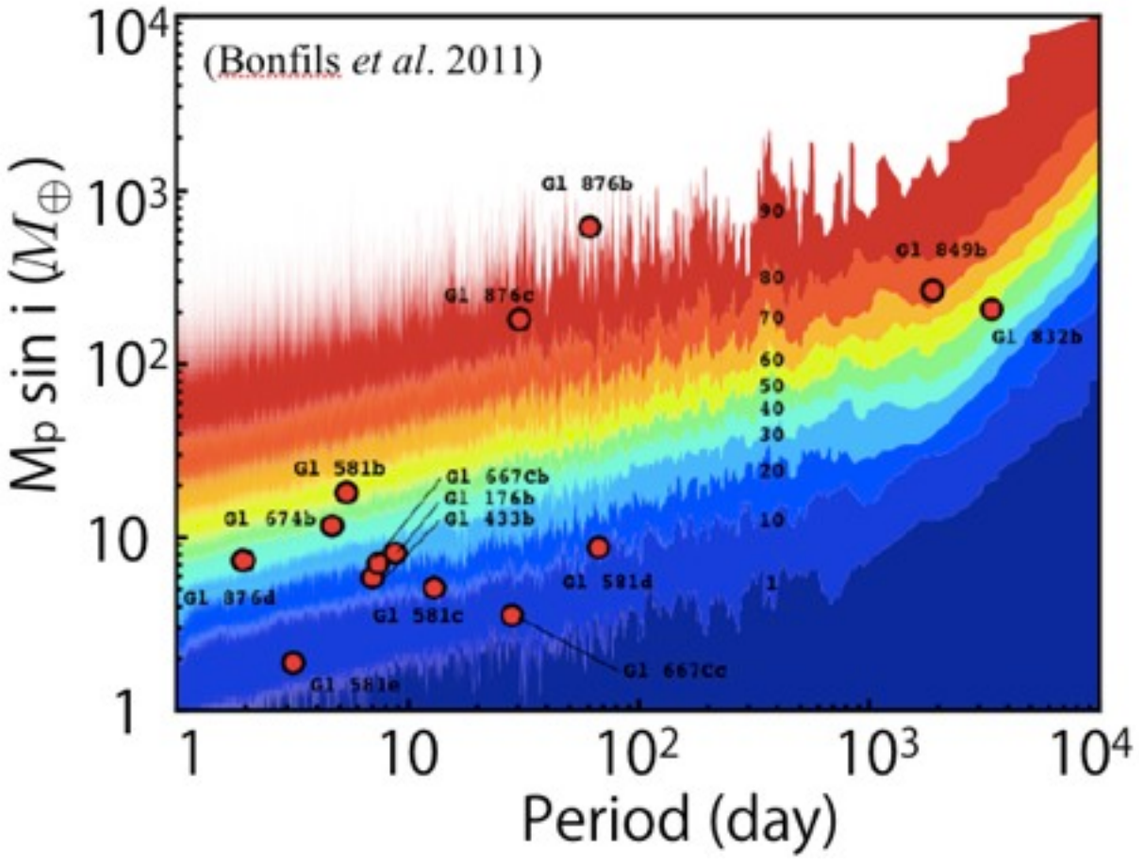


Planetary Occurrence of M-type stars



✦**HARPS** (RV survey)

- 102 bright M-type stars

→ **90%** planet < **20 $M_\oplus$**

	Super-Earth	Gas giant
1<P<10day	36^{+25}_{-10}%	<1%
10<P<100day	35^{+45}_{-11}%	2^{+3}_{-1}%

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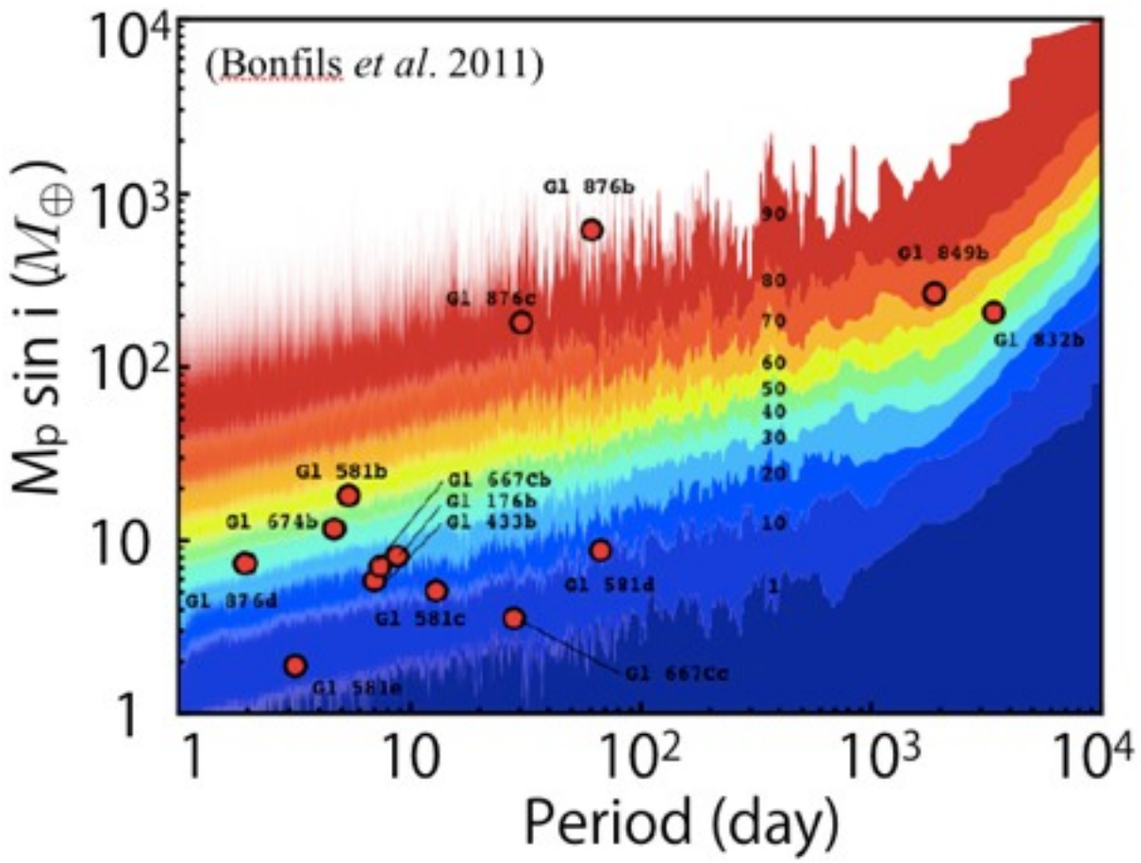

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■ **MEarth** (transit survey) : **2000** mid-late M-type stars

→ discovered **GJ1214b**

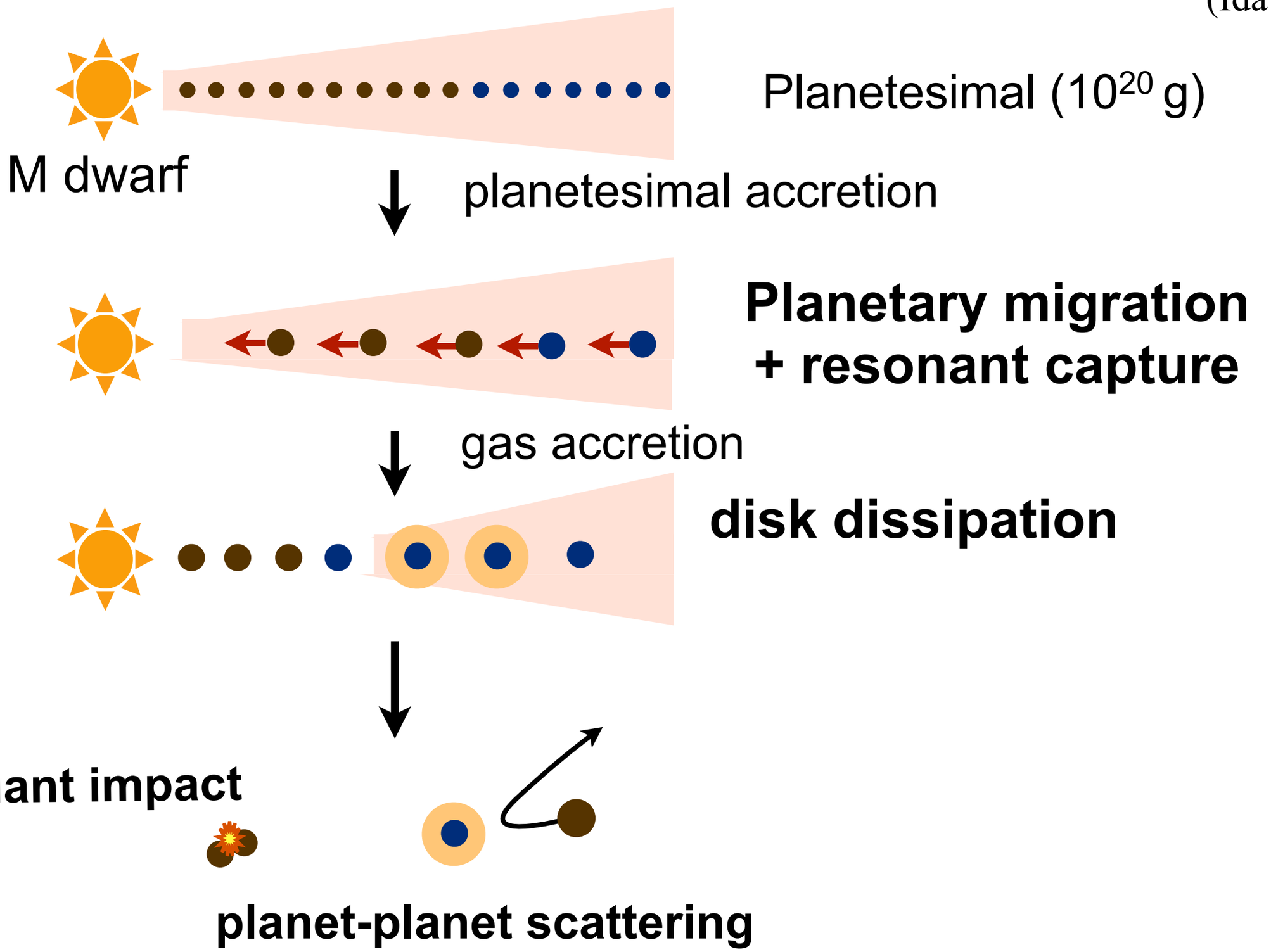
2-4 $R_\oplus$ (Super-Earth) : 38^{+36}_{-22} %

4-8 $R_\oplus$ (Gas giant?) : < 8%

(P<10 day)

Population Synthesis of Planets around M-type stars

(Ida & Lin, 2010)



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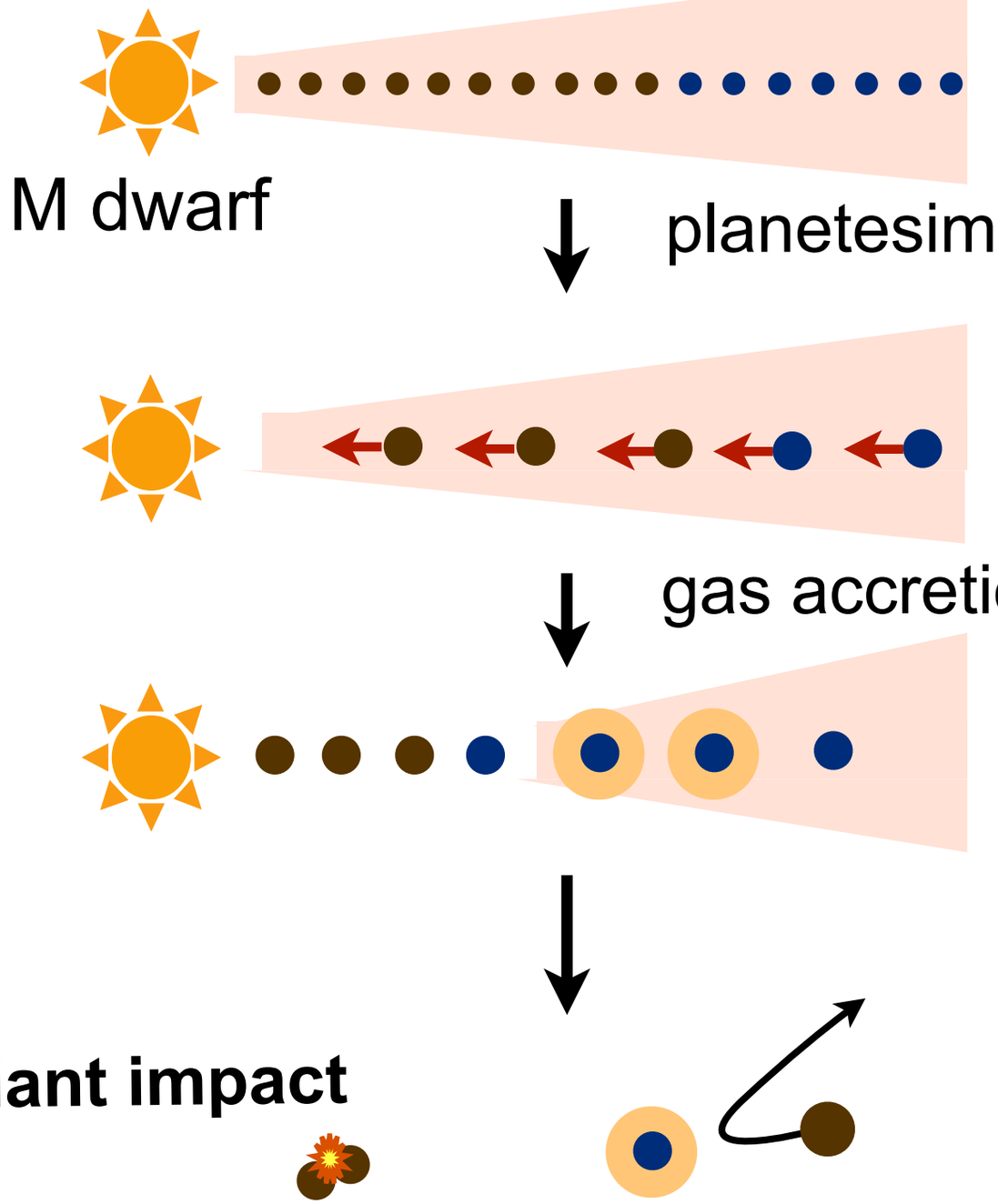


stellar mass

disk model (mass, Σ)

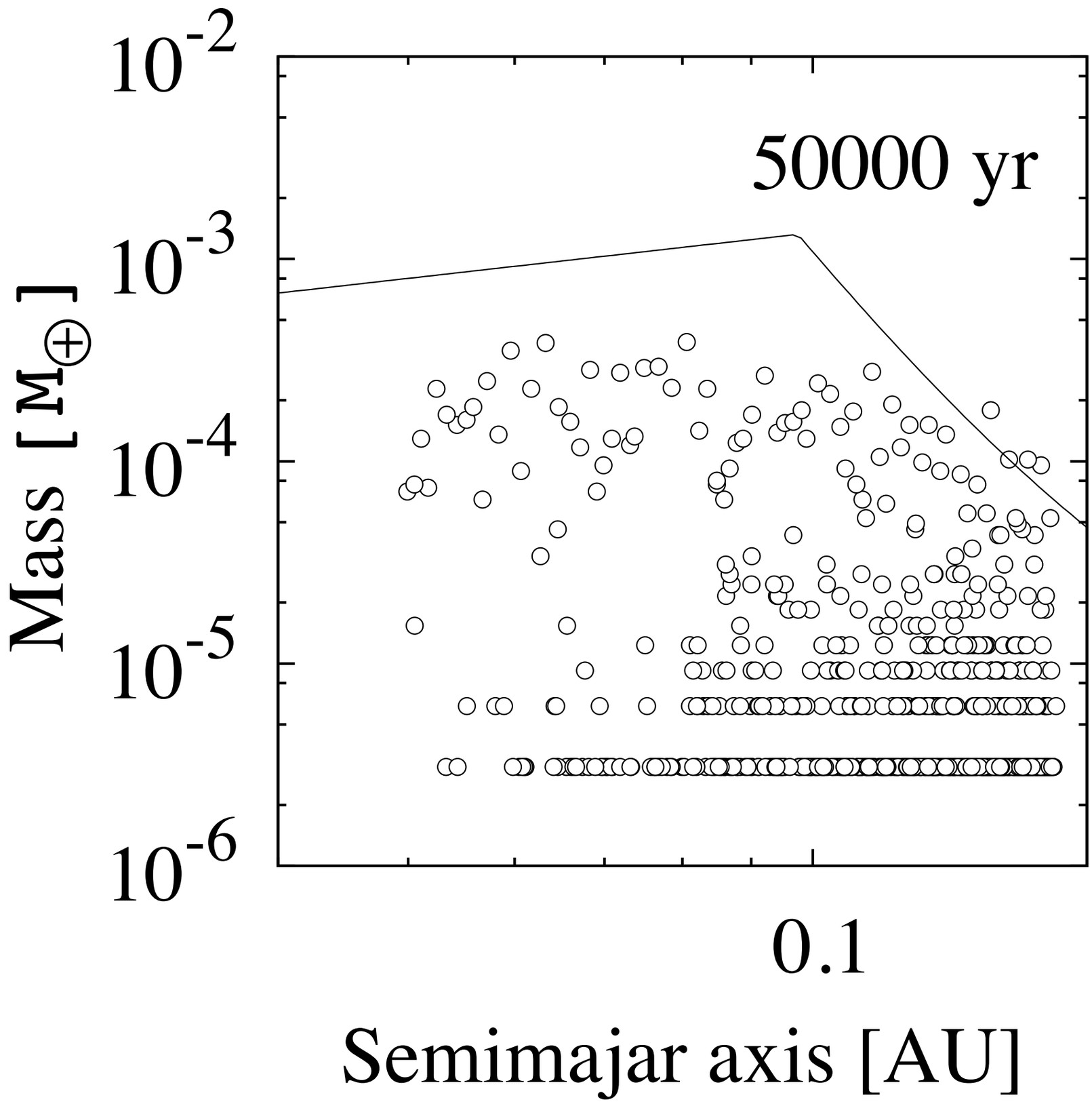
$M_d \propto M_\star$ (Machida+2010)

disk lifetimes (0.1-10Myr) (e.g., Ercolano+11)

photoevaporation/disk wind (Hollenbach+04;Suzuki+10)

migration rate

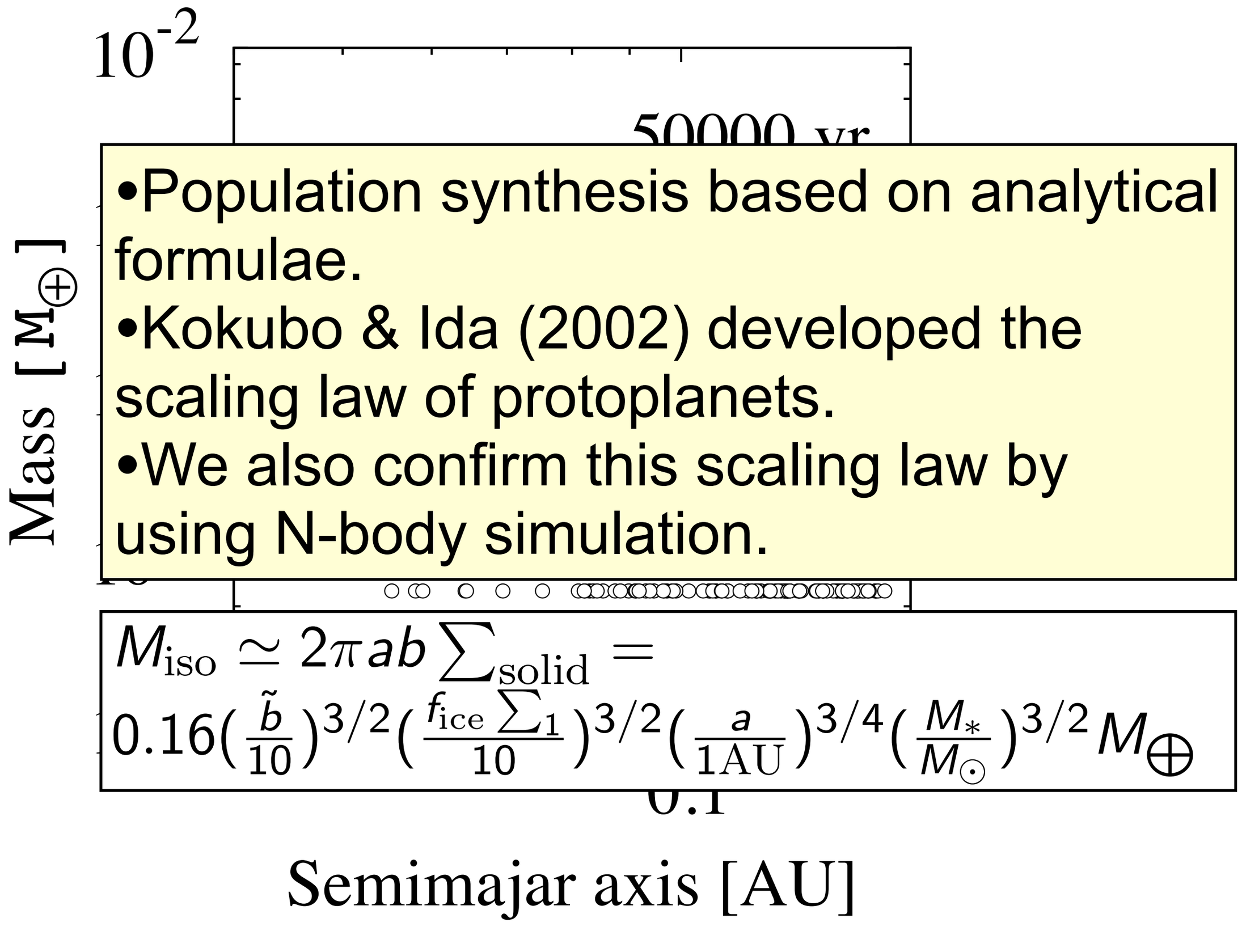
Population Synthesis of Planets around M-type stars



- N-body simulation
- MMSN model

(Kokubo & Ida 2002)

Population Synthesis of Planets around M-type stars



- Population synthesis based on analytical formulae.
- Kokubo & Ida (2002) developed the scaling law of protoplanets.
- We also confirm this scaling law by using N-body simulation.

$$M_{\rm iso} \simeq 2\pi ab\Sigma_{\rm solid} = 0.16\left(\frac{\tilde{b}}{10}\right)^{3/2}\left(\frac{f_{\rm ice}\Sigma_1}{10}\right)^{3/2}\left(\frac{a}{1{\rm AU}}\right)^{3/4}\left(\frac{M_*}{M_\odot}\right)^{3/2}M_\oplus$$

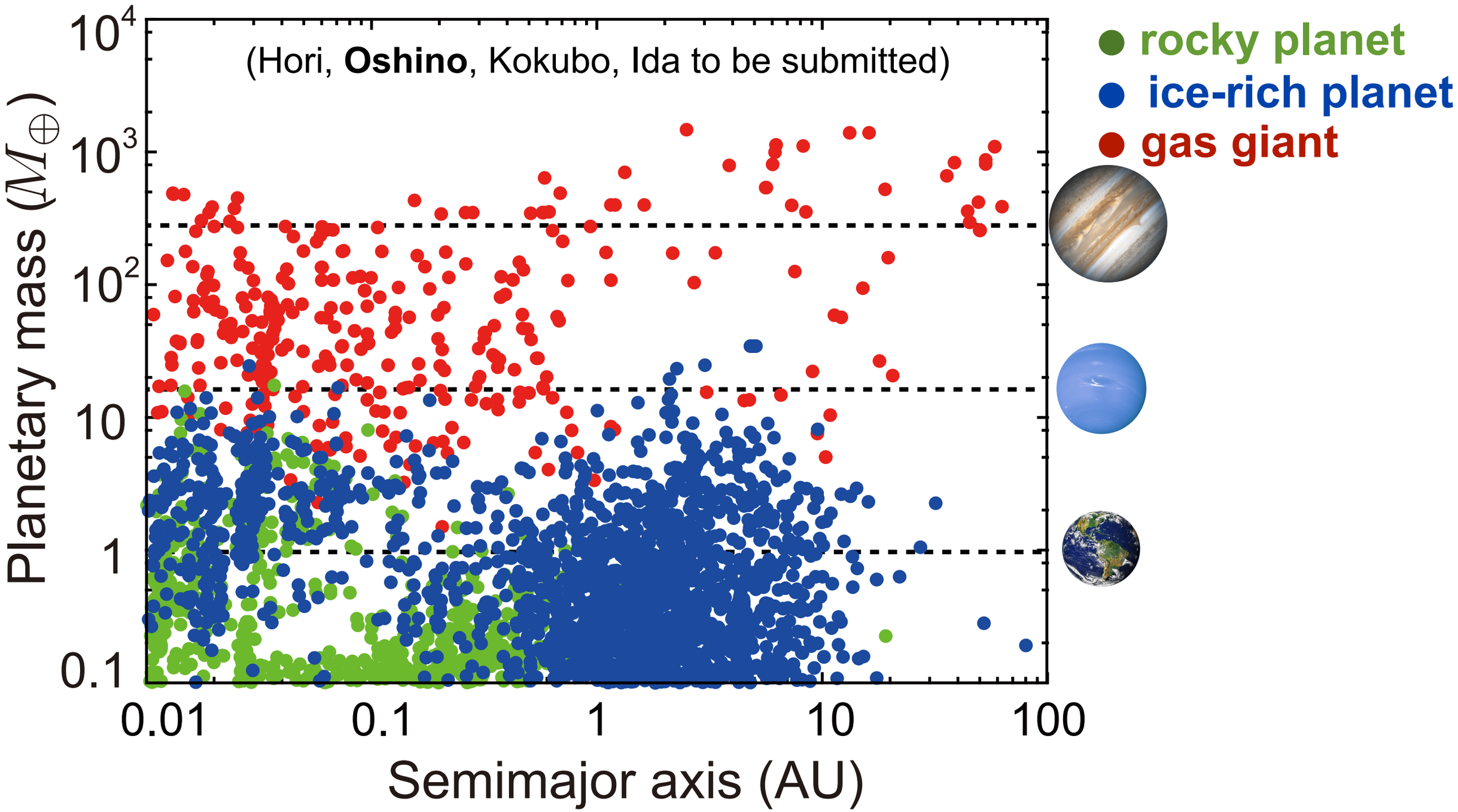
Population Synthesis of Planets around M-type stars

- Monte Carlo simulations of planet formation around M-Type stars. (Laughlin+ 2004, Ida & Lin 2005)
- Kennedy+ (2007) investigated the effect stellar evolution on planet formation (moving snow line).
- Alibert+ (2011) showed that week Type-I migration is consistent with observation for M-Type stars.
- Previous (and our) works show that formation of gas giants around M-Type stars is suppressed.
- The advantage of this work is to develop formation of multiple planets around M-type stars.

Population Synthesis of Planets around M-type stars

$M_{\rm p}$-$a_{\rm p}$ distr. is not incompatible with observations

(from the viewpoint of Kolmogorov-Smirnov test)



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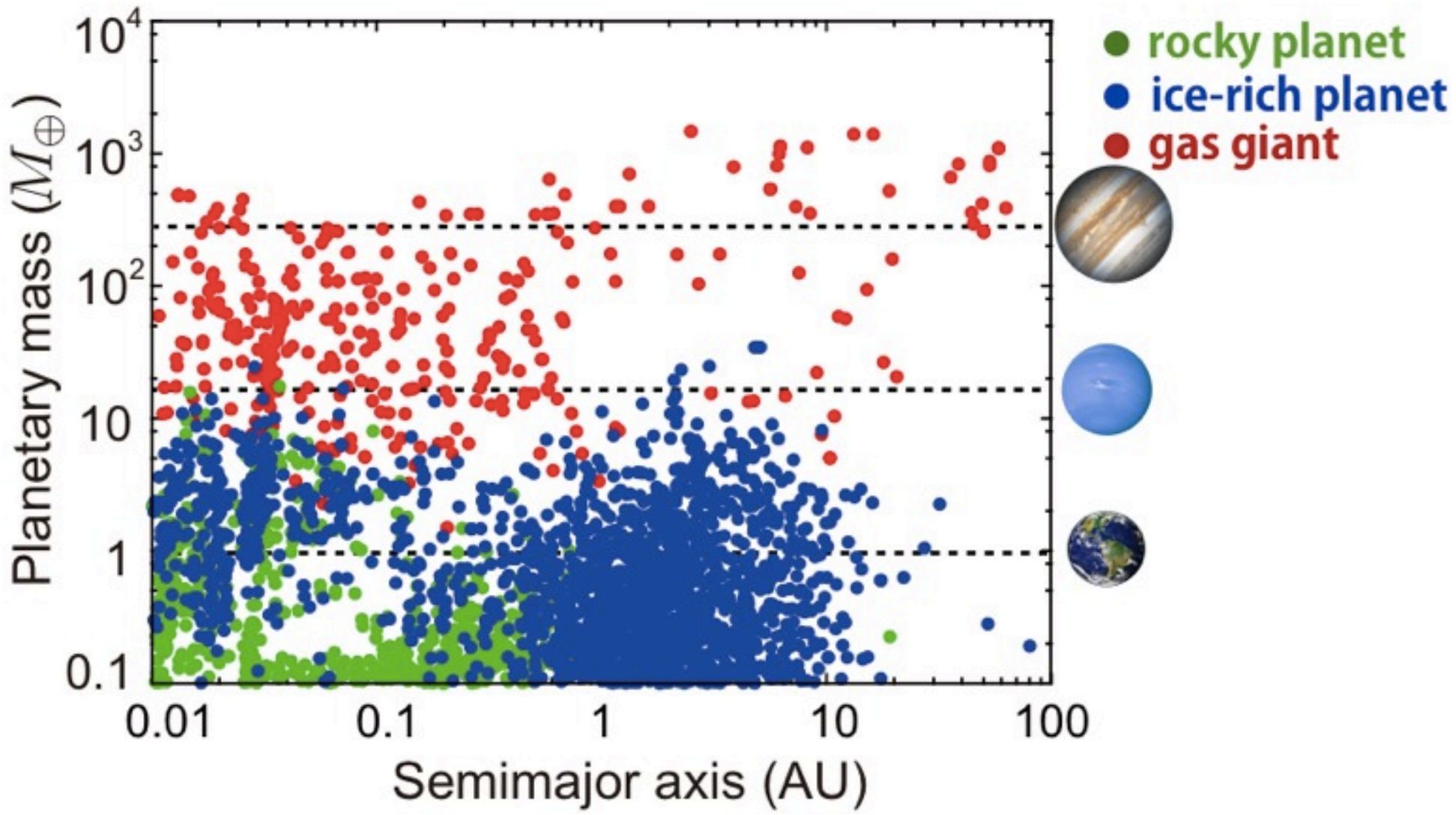

	Simulation			Obs.
super-Earth	**50%** (<0.1AU : **33% ice-rich**)			35-40%
	27% (0.1-1AU : 25% ice-rich)			
hot Jupiter	**4%** --- **too high** (<0.1AU)			<1% (<0.1AU)
multiplicity	**34%** (only SEs)	10% (SE-GG)	2% (only GGs)	20%

Summary

- The number of giant planets around M-type stars is less than that of super-Earths because of lower amount of mass of protoplanetary disk.
- Formation of multiple planets around M-type stars (~50%) may be lower than G-type stars (~70%).
- Our result also shows that ice-rich planets are abundant in inner regions (<1 AU) around M-type stars.
- In the “near” future, IRD survey (e.g. multiplicity) allows us to verify and improve theoretical model of planet formation around M-type stars.