Orbital Evolution of Planets around Evolving Low- and Intermediate-Mass Stars

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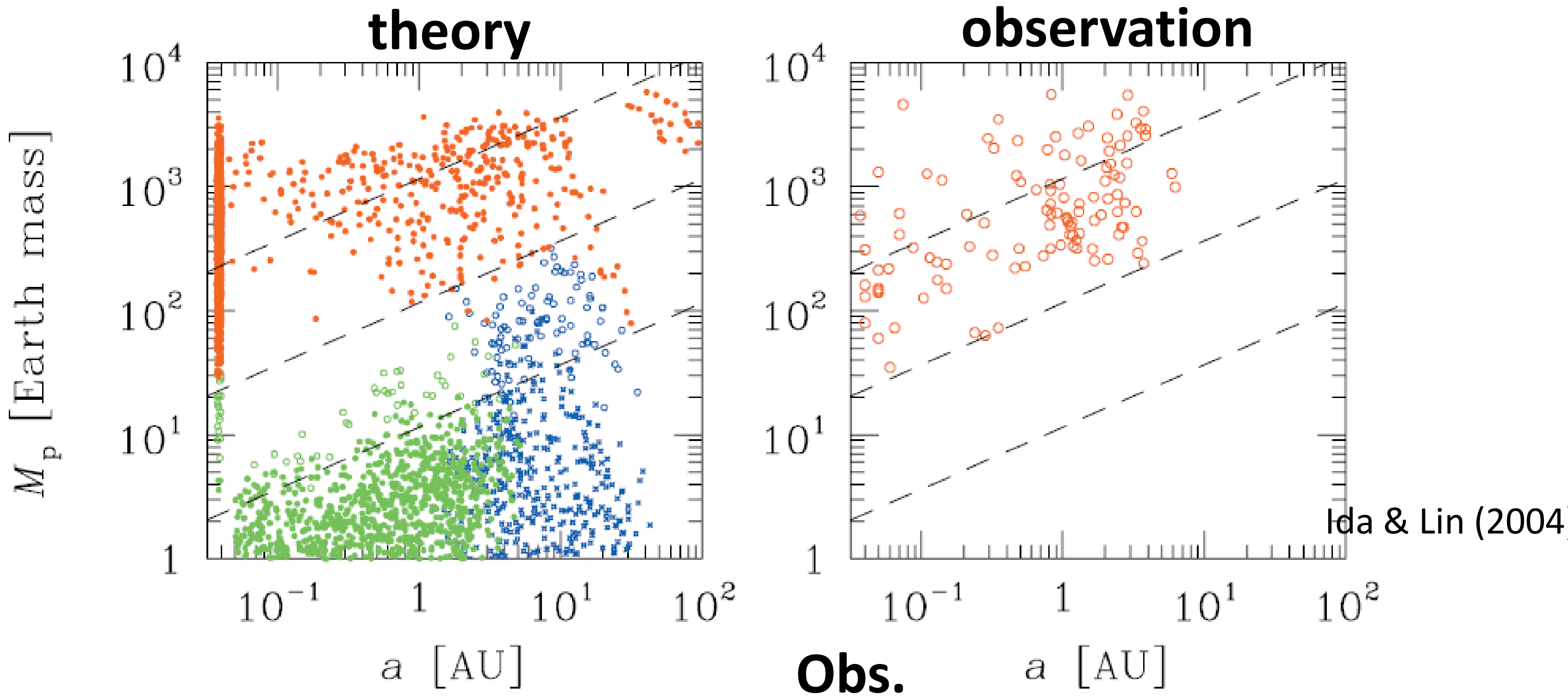
INTRODUCTION

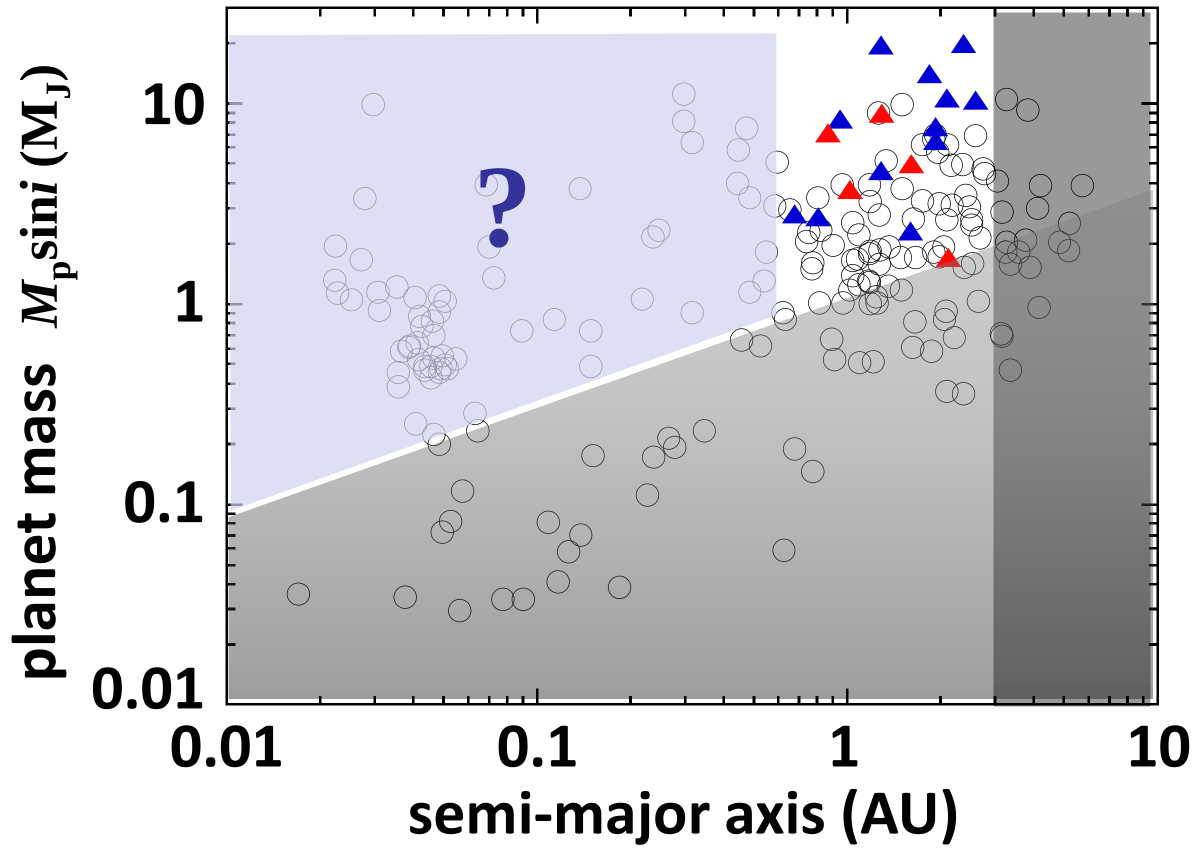
Planet Formation around Solar-Type Stars



Obs.

$1M_{Sun}$ star:	Disks	$\xrightarrow[\text{<pre-MS>}]{\text{theory}}$	Planets			Obs.
$2\text{-}3M_{Sun}$ star:	Disks	$\longrightarrow$	Planets	$\xrightarrow[\text{<post-MS>}]{\text{theory}}$	Planets	

Orbits of Planets around Evolved Stars



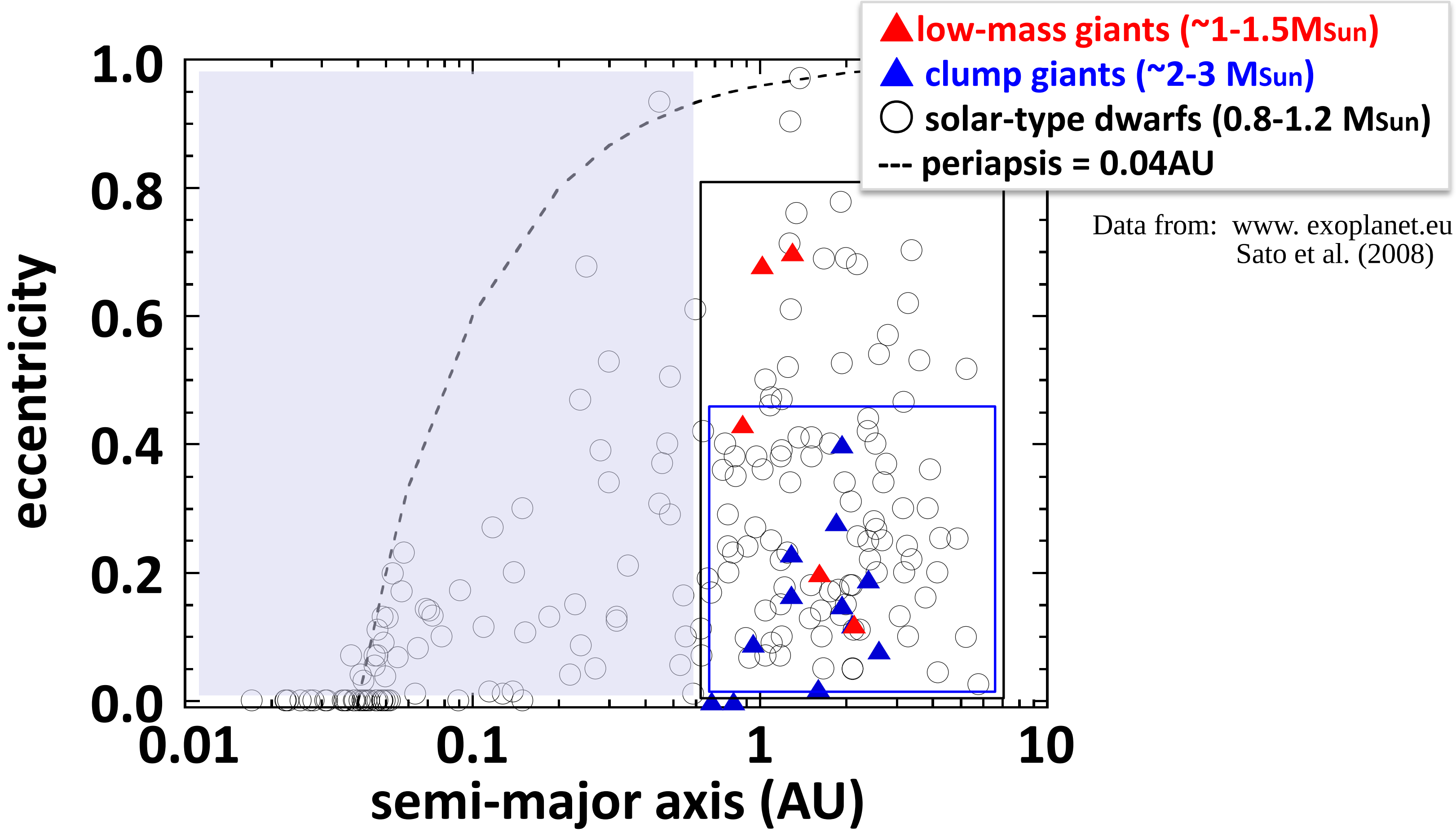
Detection Limit (Radial Velocity) ~10-20 m/s

Detection Limit (Time) ~3 AU

No planet inside ~ 0.6AU around giants.

Data from: www. exoplanet.eu
Sato et al. (2008)

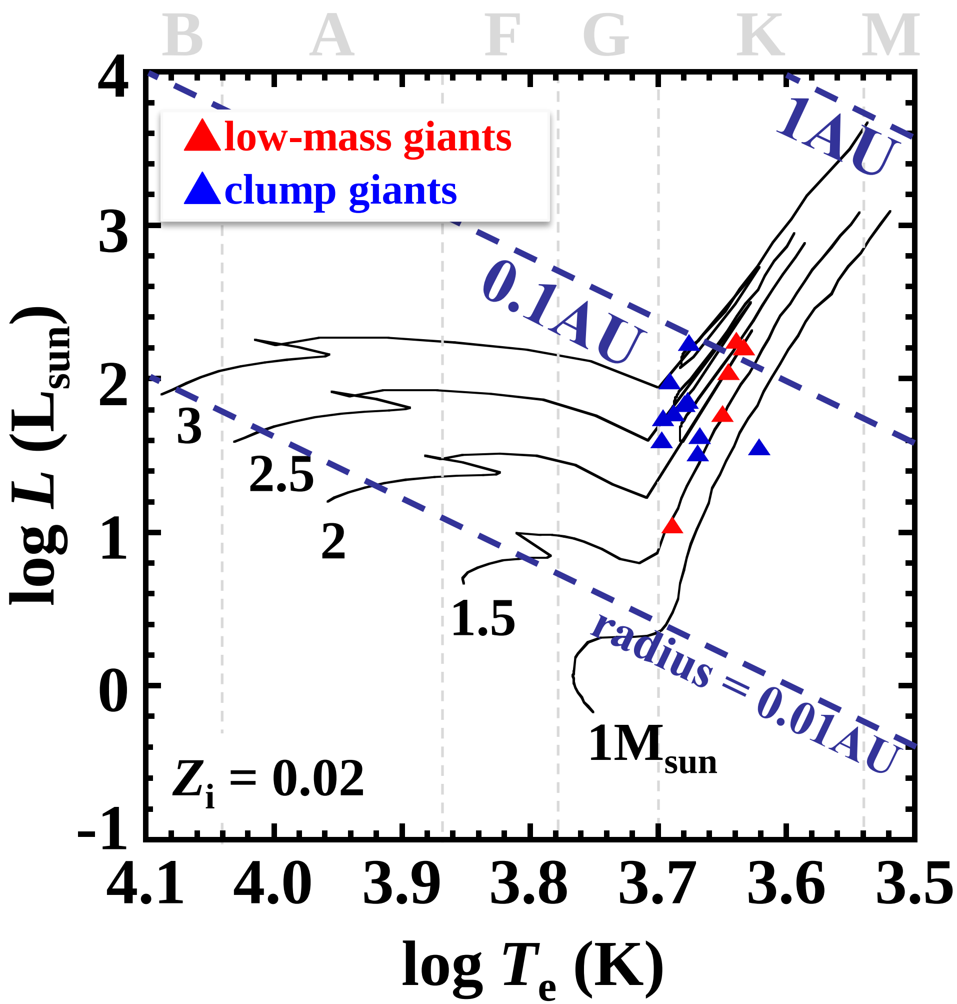
Orbits of Planets around Evolved Stars



Data from: www. exoplanet.eu
Sato et al. (2008)

Eccentricities of the planets around **clump giants** are **small** relative to those around solar-type dwarfs.

Post-Main-Sequence Evolution



(Stellar Data from *Lejeune & Schaerer* 2001)

Do such properties result from the evolution of their parent stars?

Evolution = Expansion

INFLATED PARENT STAR

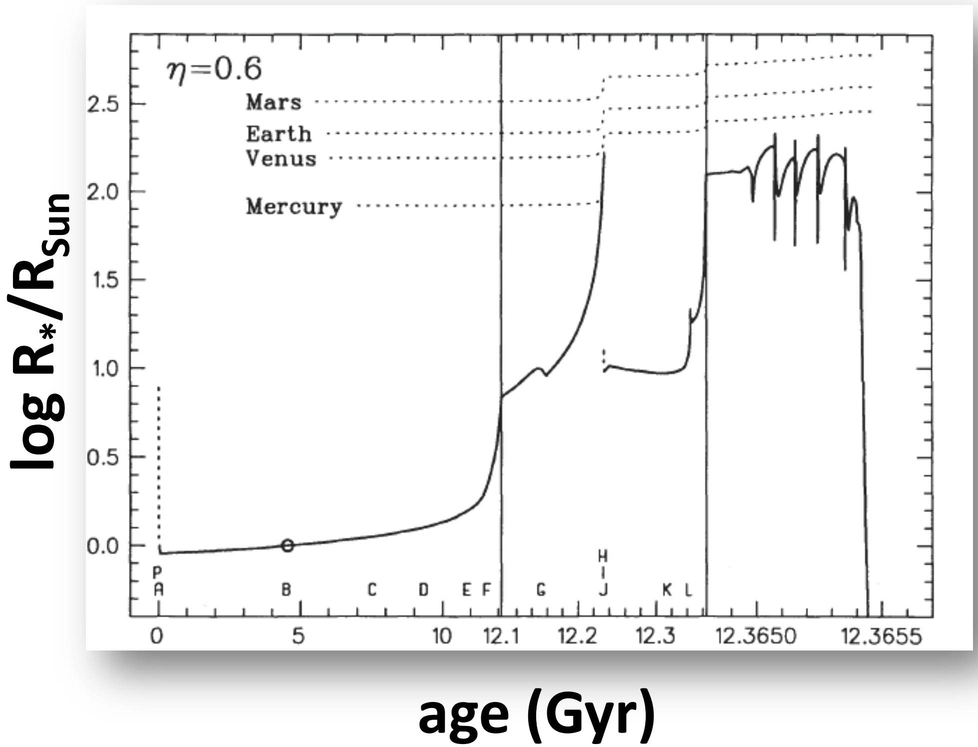
(1) **engulf** planets

(2) exert a **tidal force** on planets

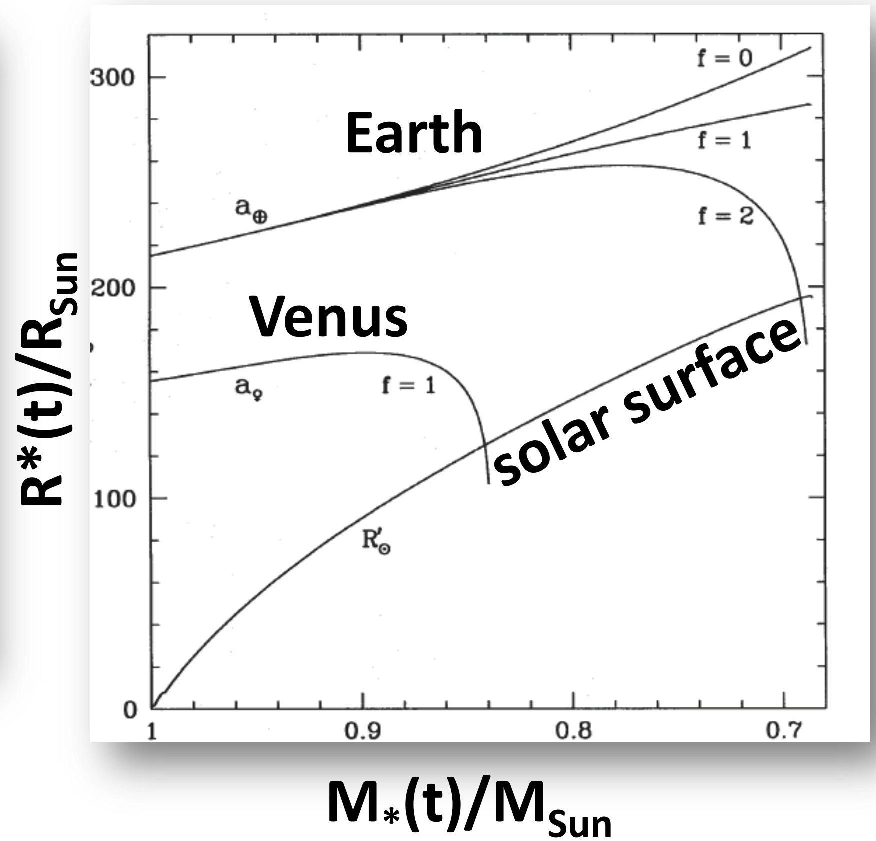
(3) **lose its mass**, which results pushing planets outward

INTRODUCTION

Fate of the Solar System (Previous Studies)



(Sackmann et al. 1993)



(Rasio et al. 1996)

Orbital Evolution of Planets = Tide vs. Mass Loss

SIMULATION OF PLANETARY ORBIT EVOLUTION

Assumptions, Equations, etc.

MAJOR Assumptions:

- equilibrium tide
- fully convective envelope
- stellar rotation << planetary revolution

EQUATIONS:

$$\frac{1}{a}\frac{da}{dt} = -6\frac{k}{t_f}\frac{m_p}{M_s}\left(1+\frac{m_p}{M_s}\right)\left(\frac{R_s}{a_p}\right)^8 \frac{f_1(e^2)}{(1-e^2)^{15/2}} + \frac{\dot{M}_s}{M_s}$$

mass loss

$$\frac{de}{dt} = -27\frac{k}{t_f}\frac{m_p}{M_s}\left(1+\frac{m_p}{M_s}\right)\left(\frac{R_s}{a_p}\right)^8 \frac{e f_3(e^2)}{(1-e^2)^{13/2}}$$

t_f : convective friction time; k : apsidal constant

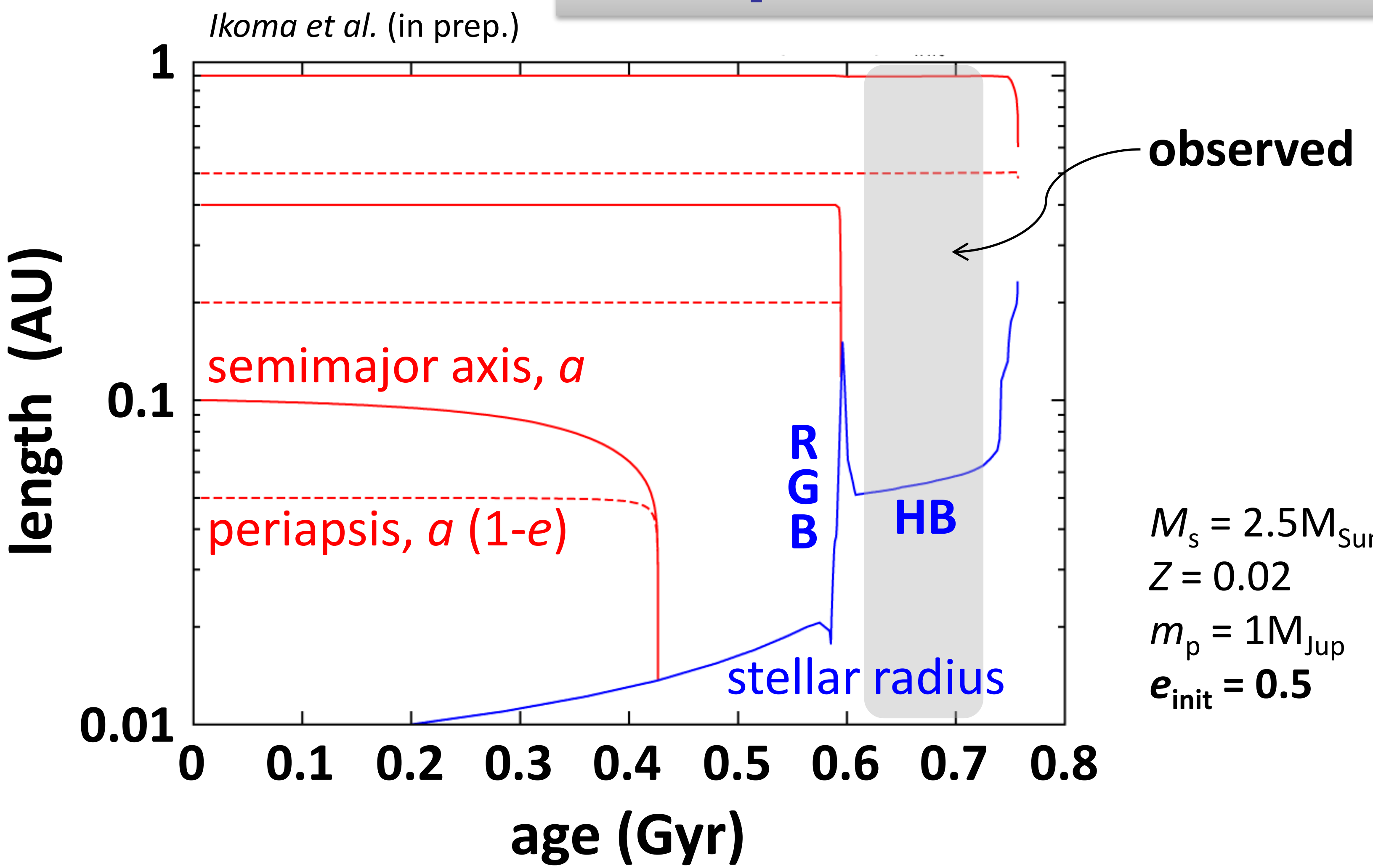
STELLAR MODELS: Lejeune & Schaerer (2001)

PARAMETERS:

- Stellar mass, M_s = 1.0, 1.5, 2.0, 2.5, 3.0 M_{Sun}
- Metalicity, Z = 0.02
- Planetary mass, m_p = 1, 10 M_{Jup}
- Initial orbit, a = 0.1-2AU & e = 0.01-0.9

SIMULATION OF PLANETARY ORBIT EVOLUTION

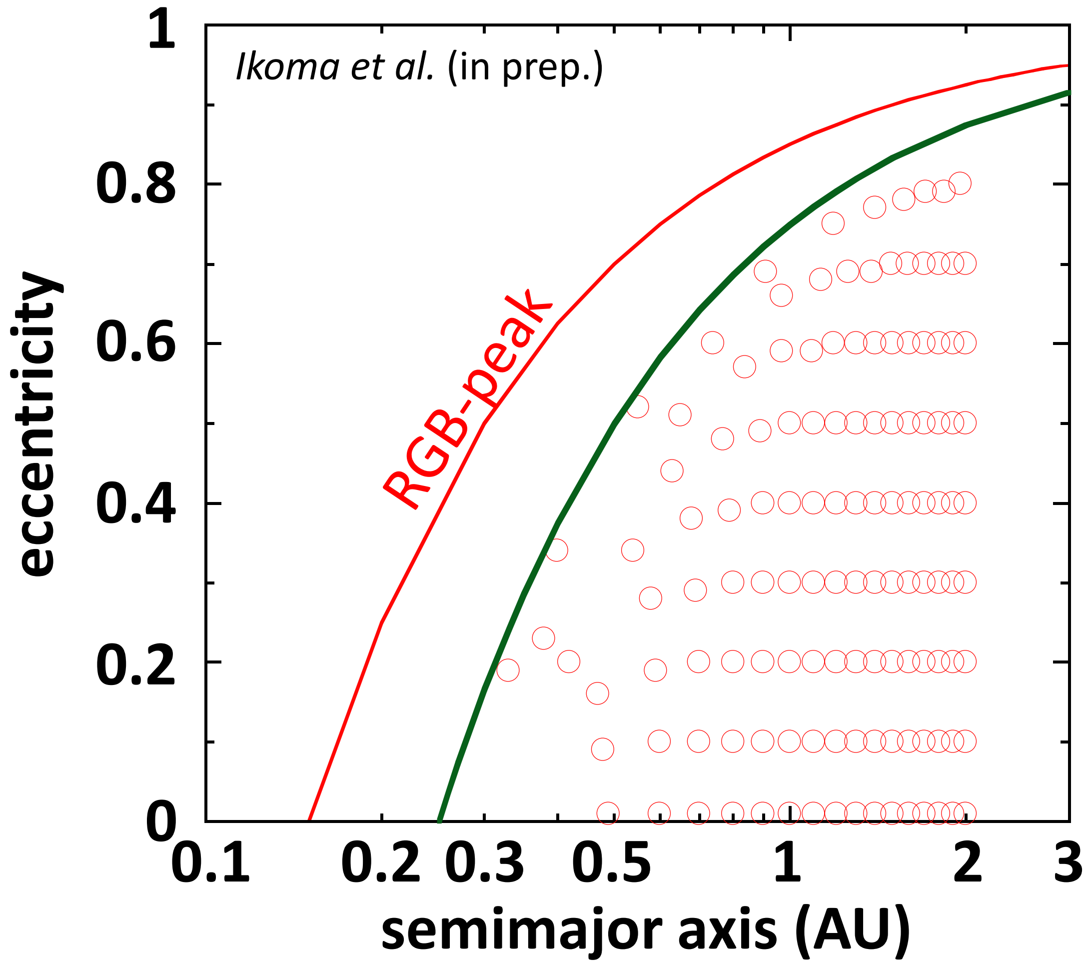
Examples of Orbital Evolution



- **Both *a* and *e* decrease in such a way that periapsis is kept constant.**
- **Stellar mass loss makes a negligible contribution.**

SIMULATION OF PLANETARY ORBIT EVOLUTION

a & *e* in HB ($2.5M_{Sun}$ Star)

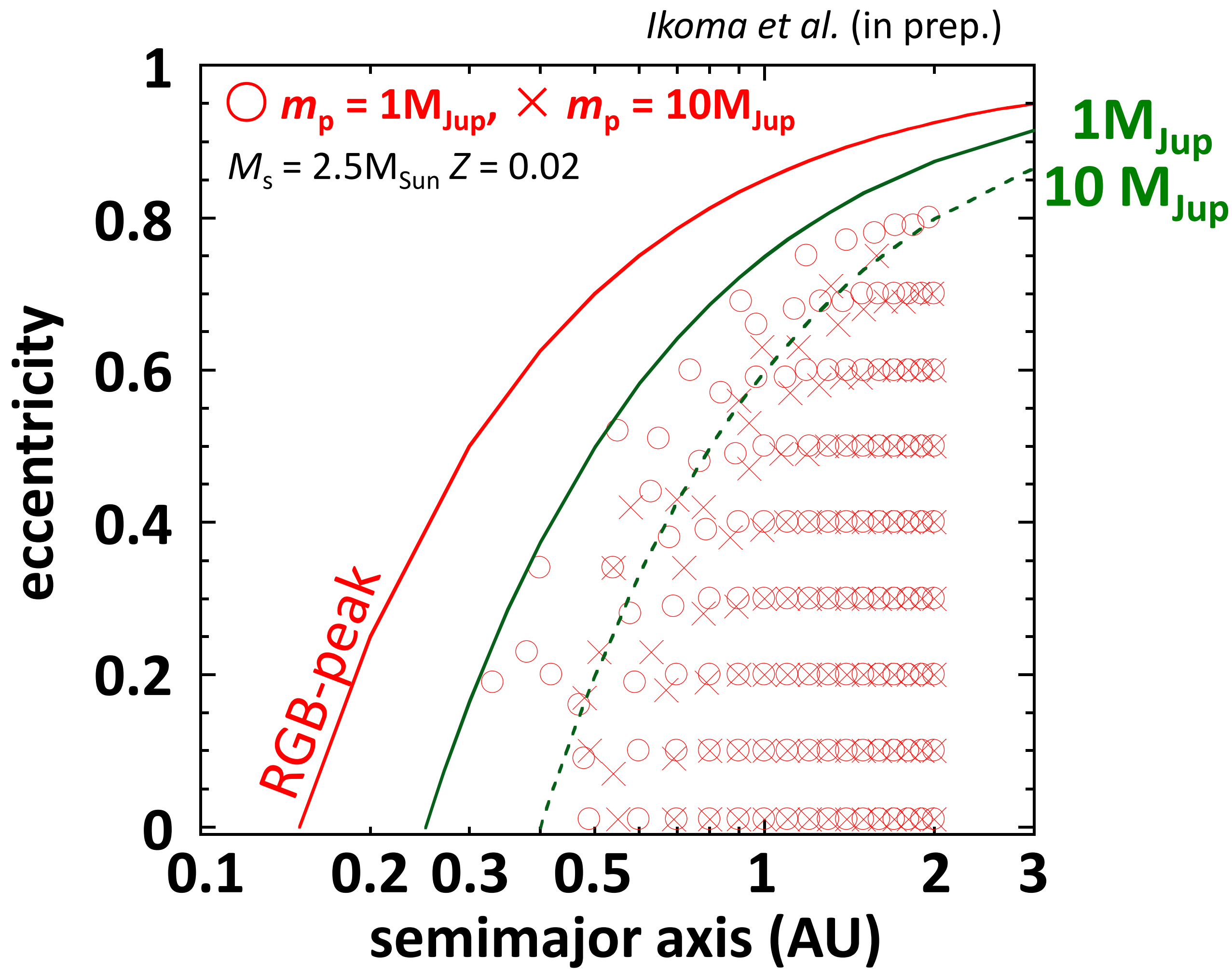


$M_s = 2.5M_{Sun}$
$Z = 0.02$
$m_p = 1M_{Jup}$

- Planets at $a(1\text{-}e) > \sim 2x\ R_{peak}$ survive RGB phase.
- Eccentricity ranges between 0 and 0.8 for a < 2 AU.

SIMULATION OF PLANETARY ORBIT EVOLUTION

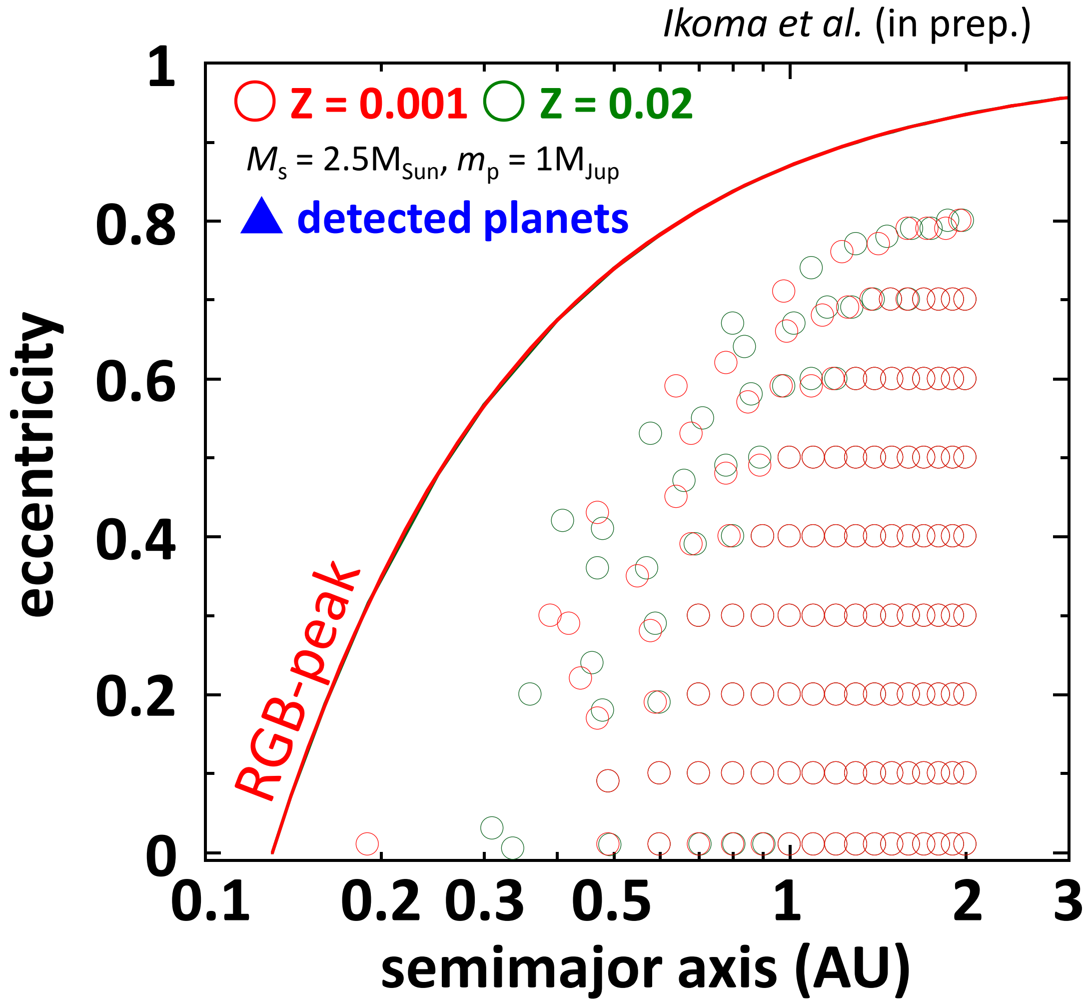
a & *e* in HB: Sensitivity to Planet Mass



Effect of stellar tide is somewhat stronger for more massive planets.

SIMULATION OF PLANETARY ORBIT EVOLUTION

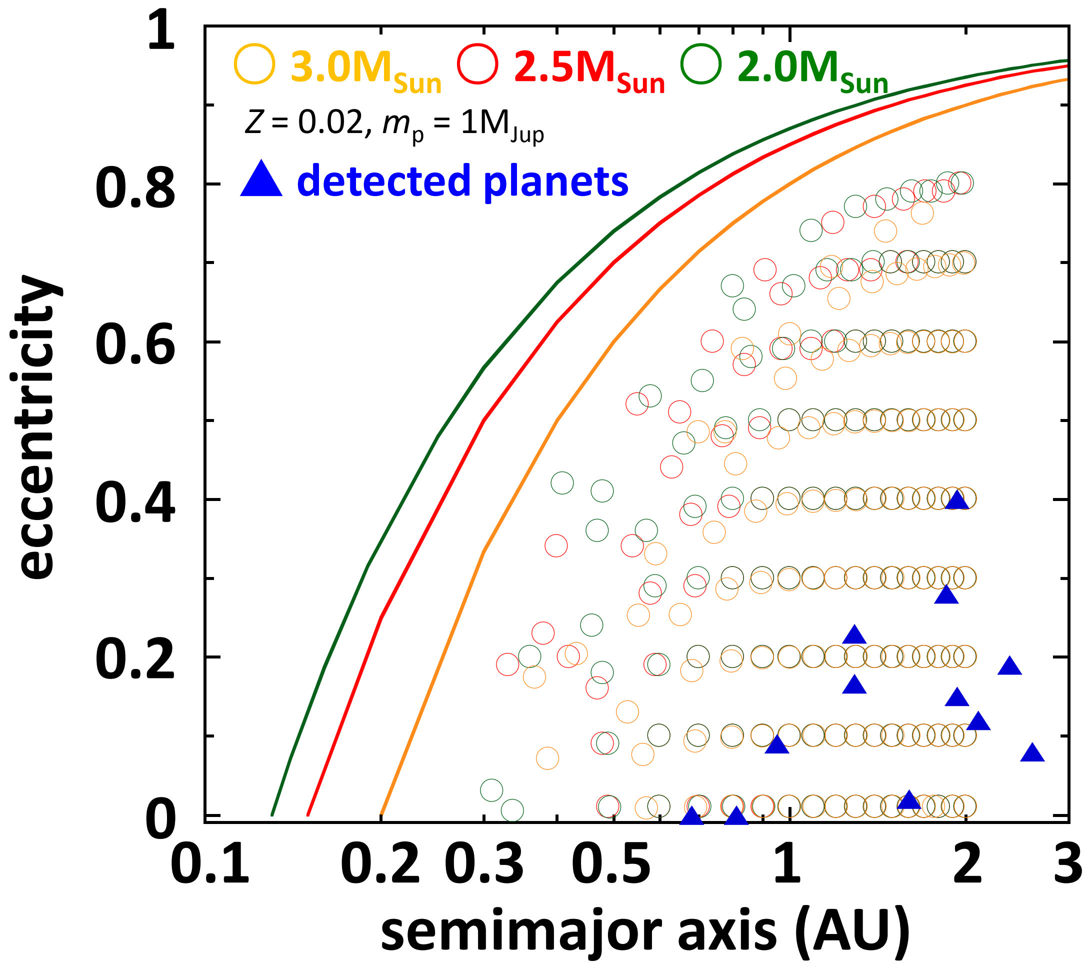
a & *e* in HB: Sensitivity to Stellar Metalicity



Effects of different stellar metalicity seem to be small.

SIMULATION OF PLANETARY ORBIT EVOLUTION

a & *e* in HB: Sensitivity to Stellar Mass

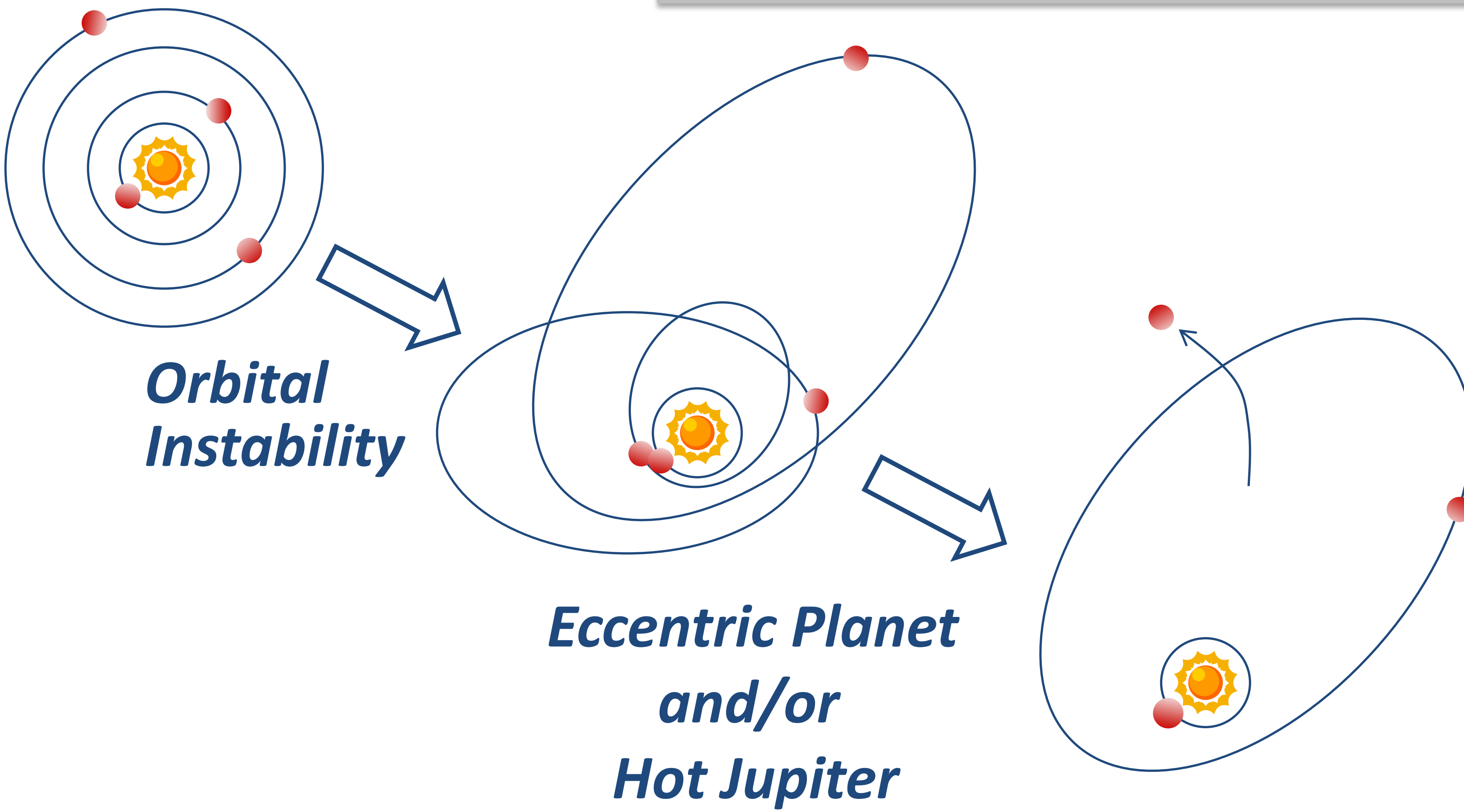


Ikoma et al. (in prep.)

- Eccentricities of detected clump giants are low. → initially low?
- Measured semimajor axes are somewhat larger. → initially distant?

ORIGIN OF LOW ECCENTRICITIES AROUND CLUMP GIANTS

Widespread Idea for the origin of eccentric planets around solar-type stars



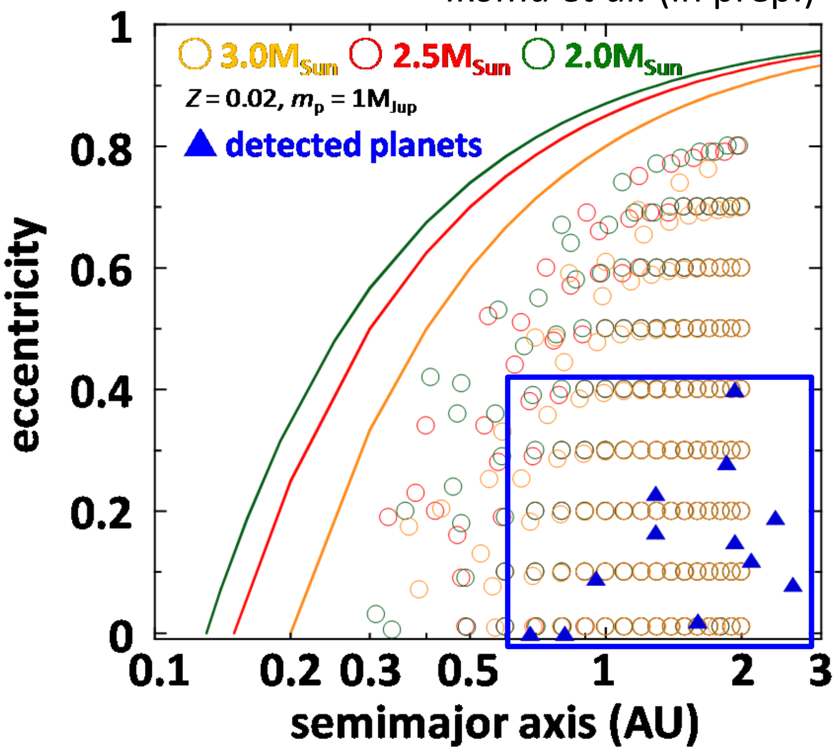
e.g., *Weidenschiling et al.*

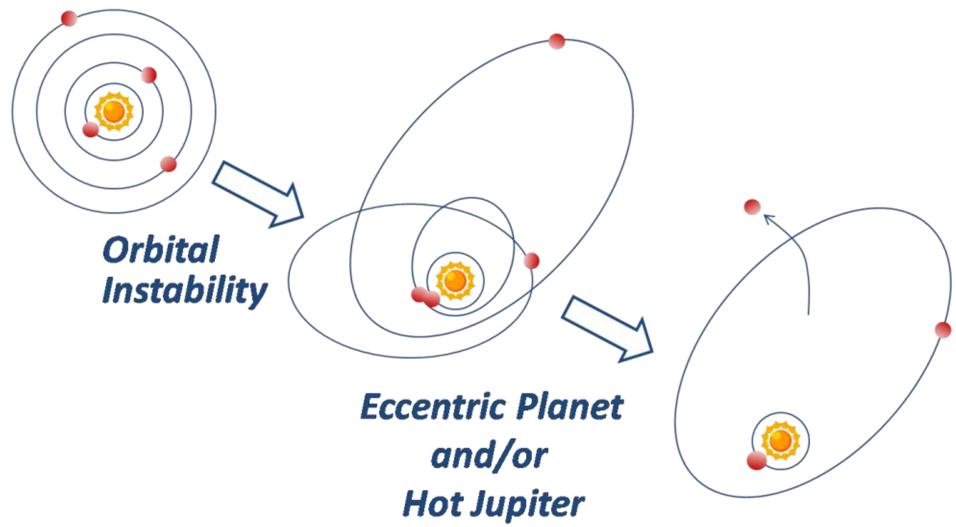
ORIGIN OF LOW ECCENTRICITIES AROUND CLUMP GIANTS

How can we explain it?

- **Formation of gas-giant planets is less frequent around intermediate-mass stars than around solar-type stars.**
- **Multi-planet systems are rare, so that orbital instability rarely happens around intermediate-mass stars.**

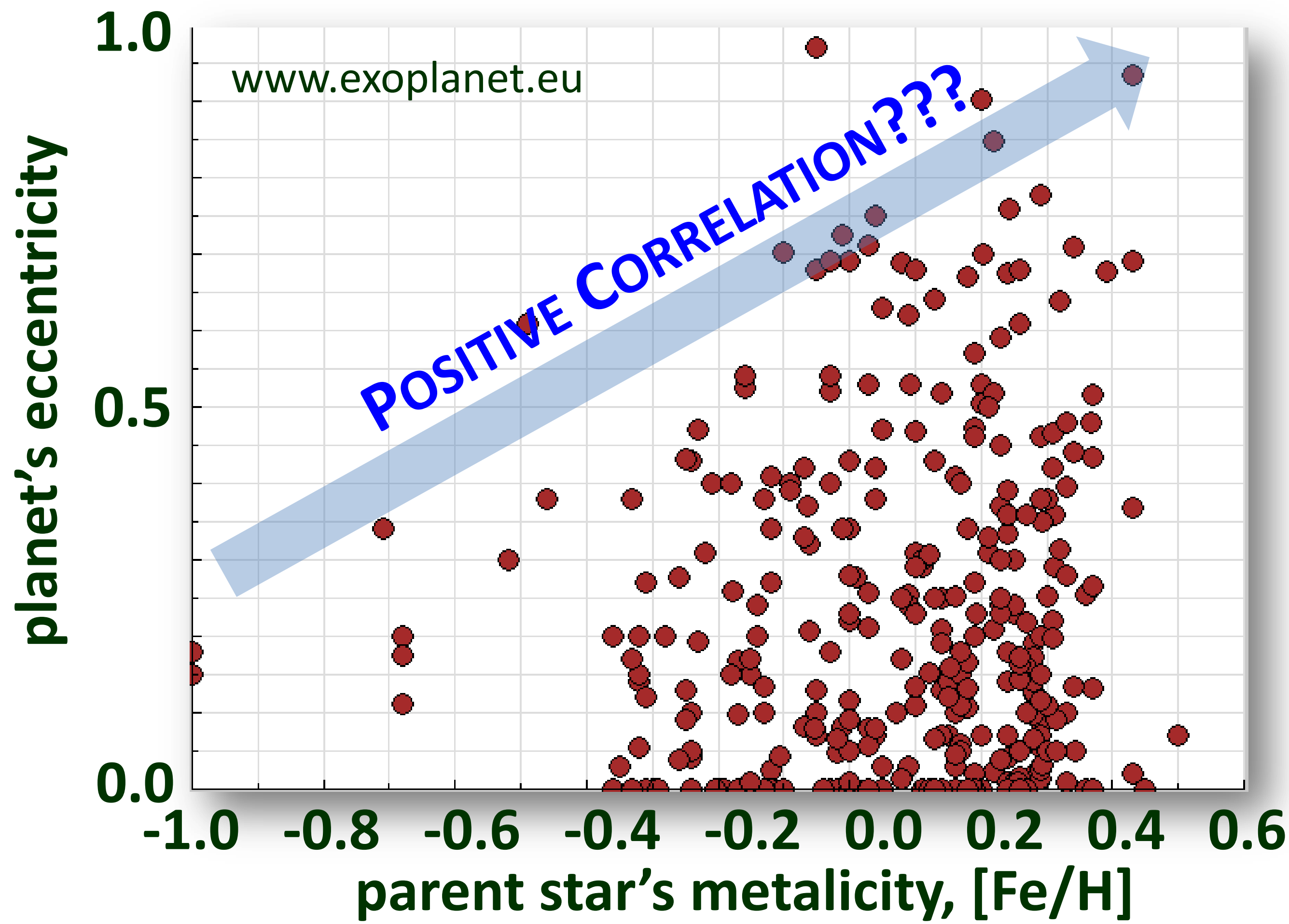
Ikoma et al. (in prep.)





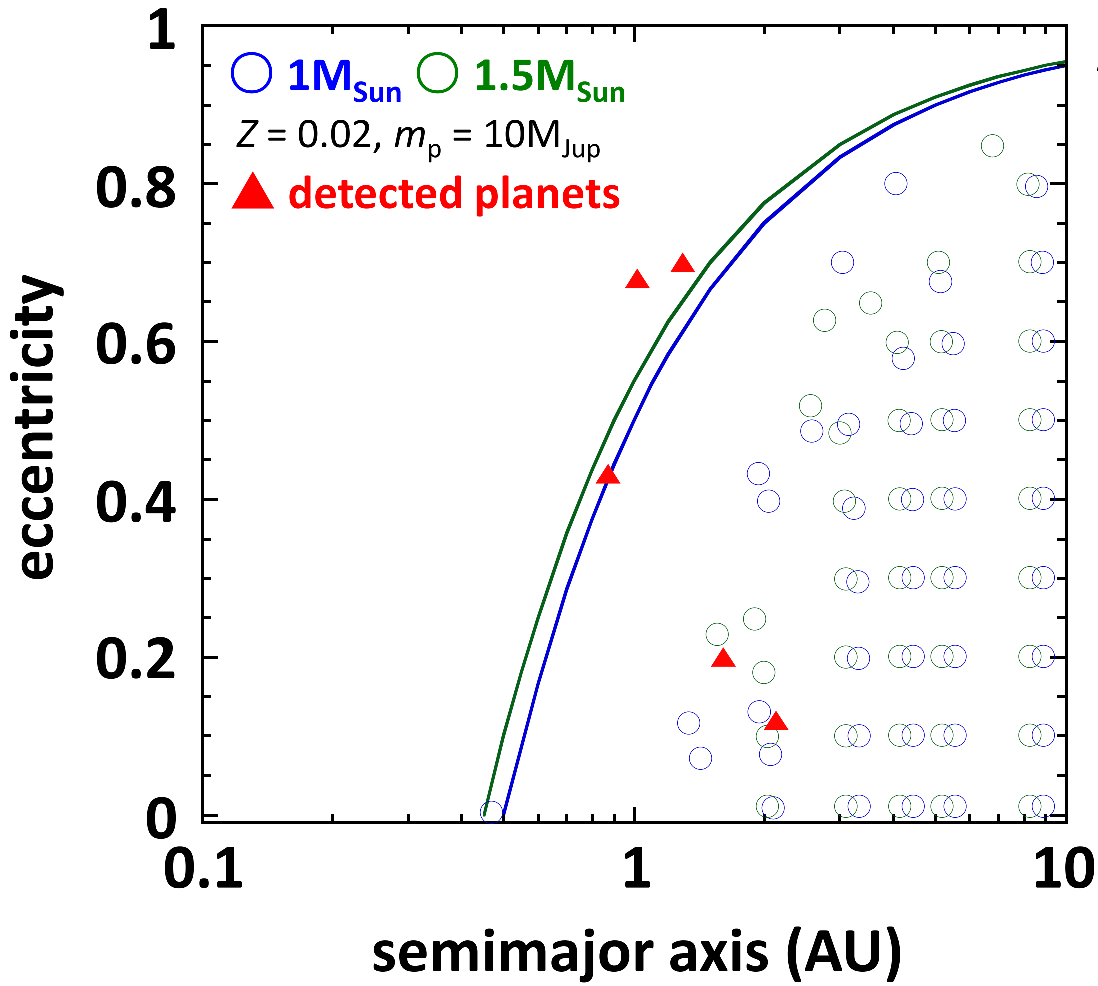
Discussion: Origin of Low-Eccentricities

Correlation between Stellar Metalicity and Planetary Eccentricity in the case of Solar-Type Stars



SIMULATION OF PLANETARY ORBIT EVOLUTION

Low-Mass Giants



Ikoma et al. (in prep.)

- Two of them are consistent with our results
- The other three seem not to have undergone RGB phases.

Summary and Conclusions

- I have simulated orbital evolution of planets around evolving low- and intermediate-mass stars.
- Clump giants
  - Planets of a < 0.5AU are likely to have been engulfed by their parent stars, which is, however, not fully consistent with observational results.
  - Our theoretical model that assumes the planets' eccentricities in the MS phase range uniformly from 0 to ~1 does not account for low eccentricities of the detected planets, which may means their eccentricities were originally low.
- Low-mass giants
  - Some of them seem not to have yet undergone the RGB phase of their parent stars.

Need more samples!