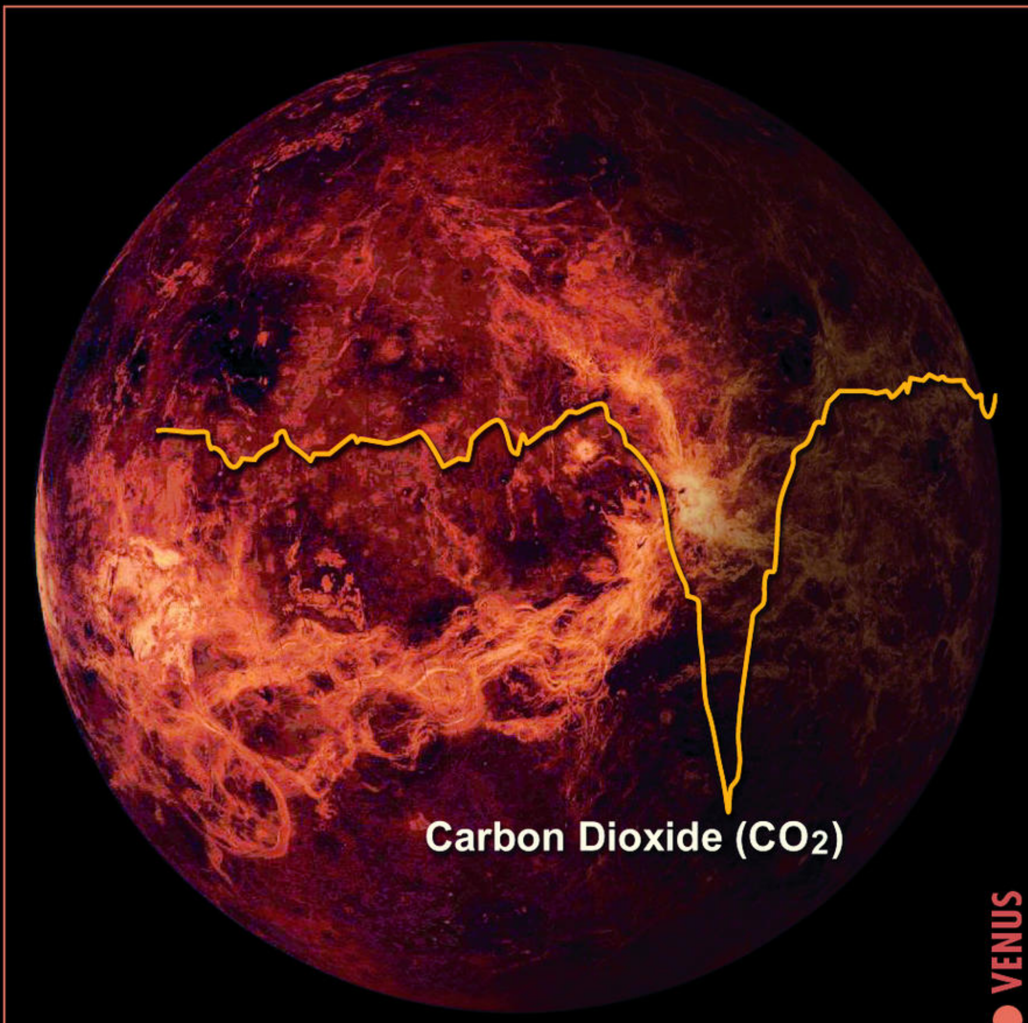
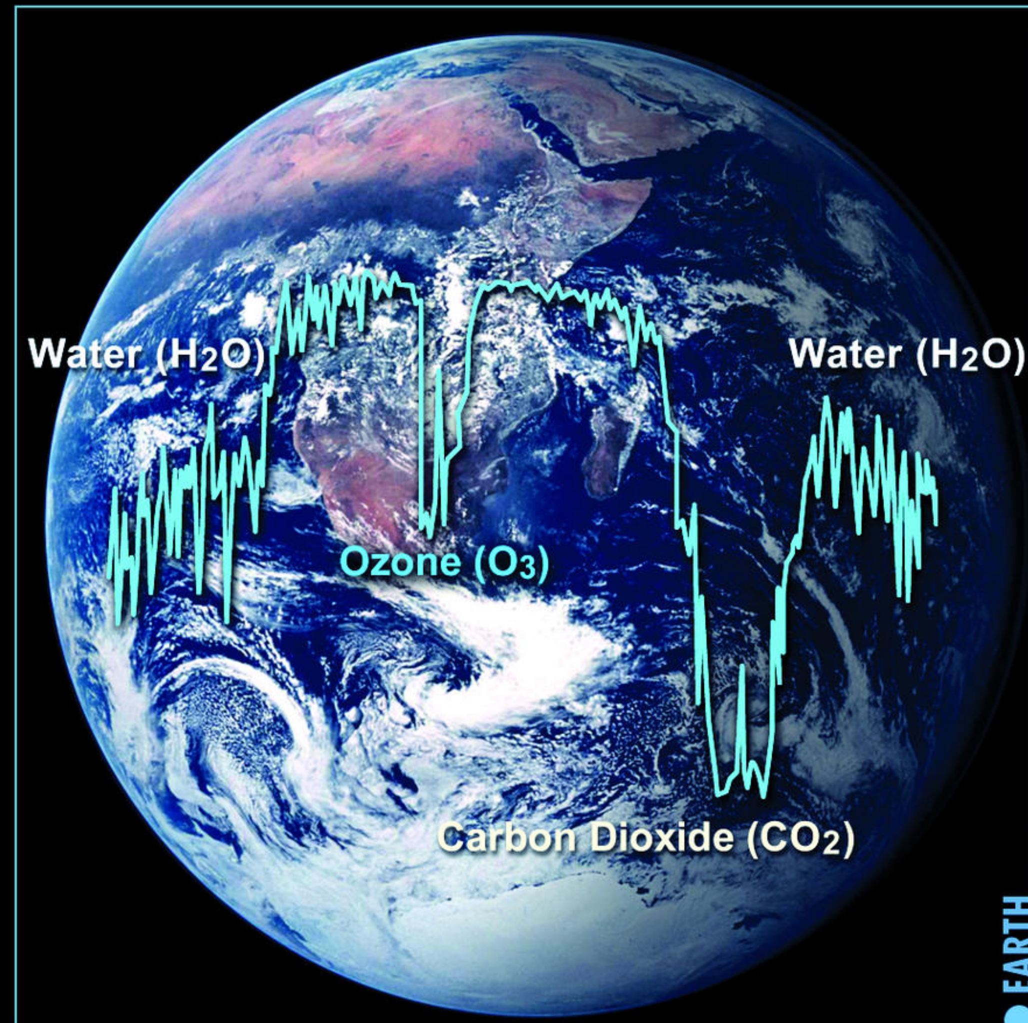
Planetary Habitability





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Topics

- Lecture 1 – Introduction
- Lecture 2 – Habitability Factors
- Lecture 3 - Stars
- Lecture 4 – Planetary Atmospheres
- Lecture 5 – Planetary Interiors
- Lecture 6 – Planetary Energy Balance
- Lecture 7 – Habitable Zone I
- Lecture 8 – Habitable Zone II
- Lecture 9 – Earth as a Living Planet
- Lecture 10 – Mars
- Lecture 11 – Icy Moons
- Lecture 12 – Venus
- Lecture 13 – Mercury & the Moon
- Lecture 14 – The Role of Giant Planets
- Lecture 15 – Stellar Influences
- Lecture 16 – Magnetic Fields
- Lecture 17 – Milankovitch Cycles
- Lecture 18 – Geological Cycles
- Lecture 19 – The Next Steps
- Lecture 20 – Summary/Discussion

The Role of Giant Planets

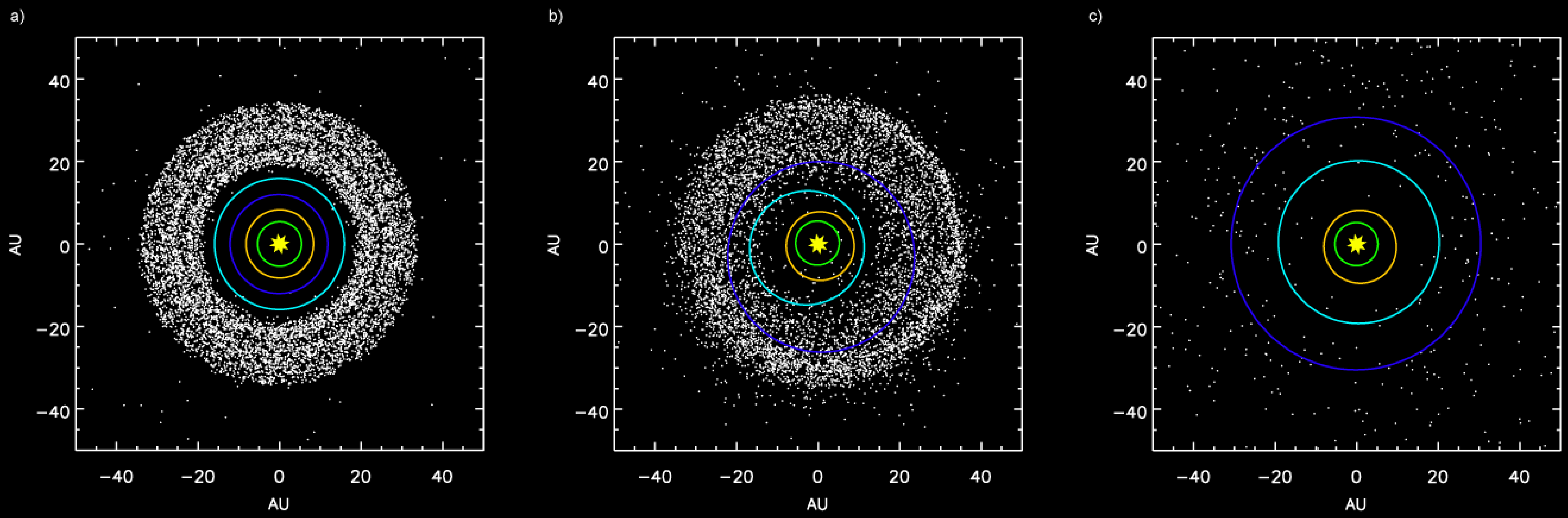
- **Formation/Migration of giant planets**
- **Occurrence rates of giant planets**
- **Jupiter: Friend or foe?**

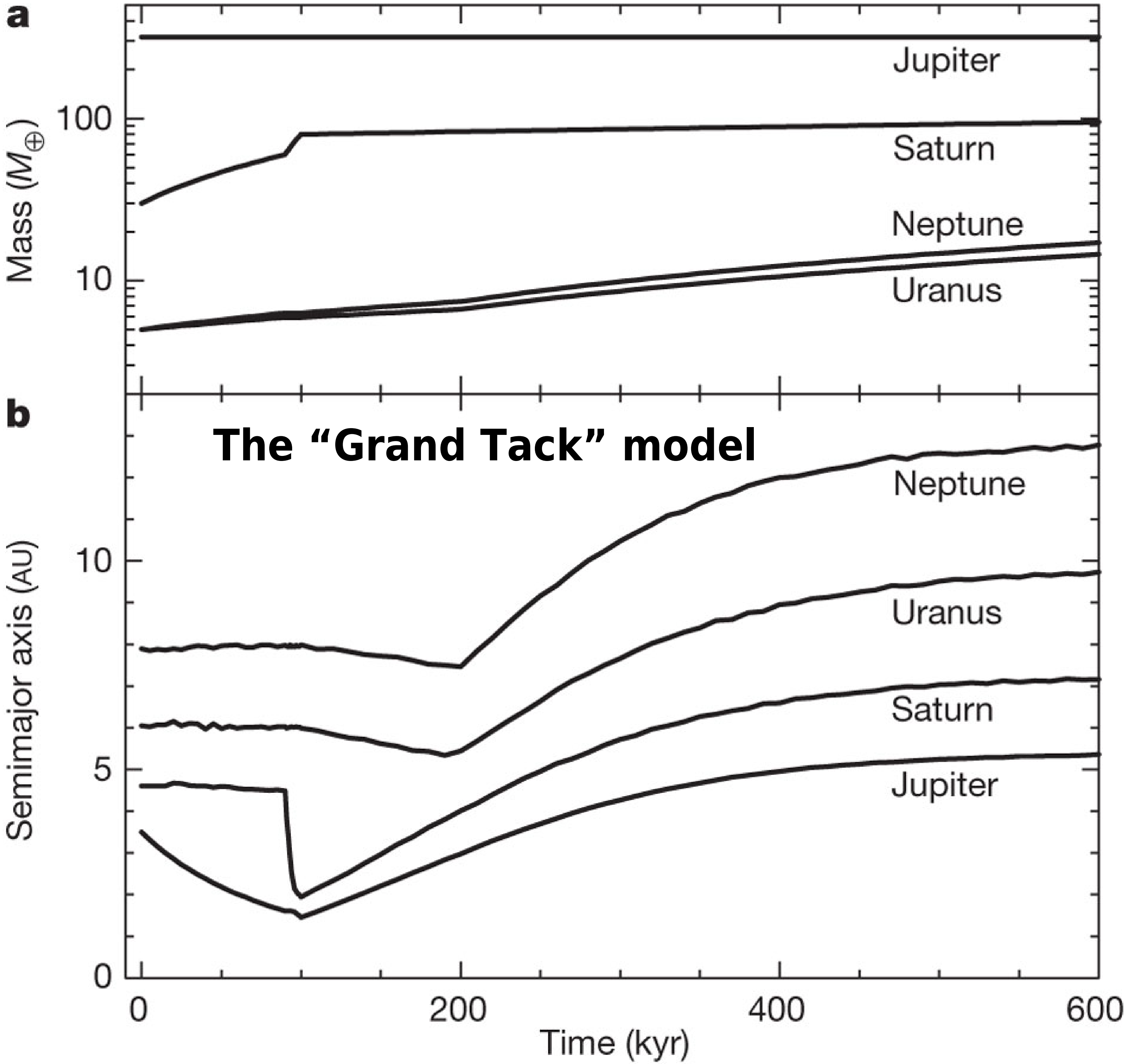
The Nice Model

• Originally developed in 2005 and revised in 2009.

• A theory of the outer Solar System evolution can explain the clustering of lunar age dates near 3.9 Gya.

• In the Nice model, Saturn starts closer in, and its orbital period is less than twice that of Jupiter.




a
Mass ($M_\oplus$)
100
10
Jupiter
Saturn
Neptune
Uranus
b
The “Grand Tack” model
Semimajor axis (AU)
10
5
0
Neptune
Uranus
Saturn
Jupiter
0
200
400
600
Time (kyr)

The Nice Model and Grand Tack Model

These models address the formation of terrestrial planets via two main considerations:

- **The processes whereby giant planets redistribute material and angular momentum throughout the system.**

- **The truncation of the material within the inner protoplanetary disk, thus limiting the size of the terrestrial planets.**

Occurrence rate of giant planets

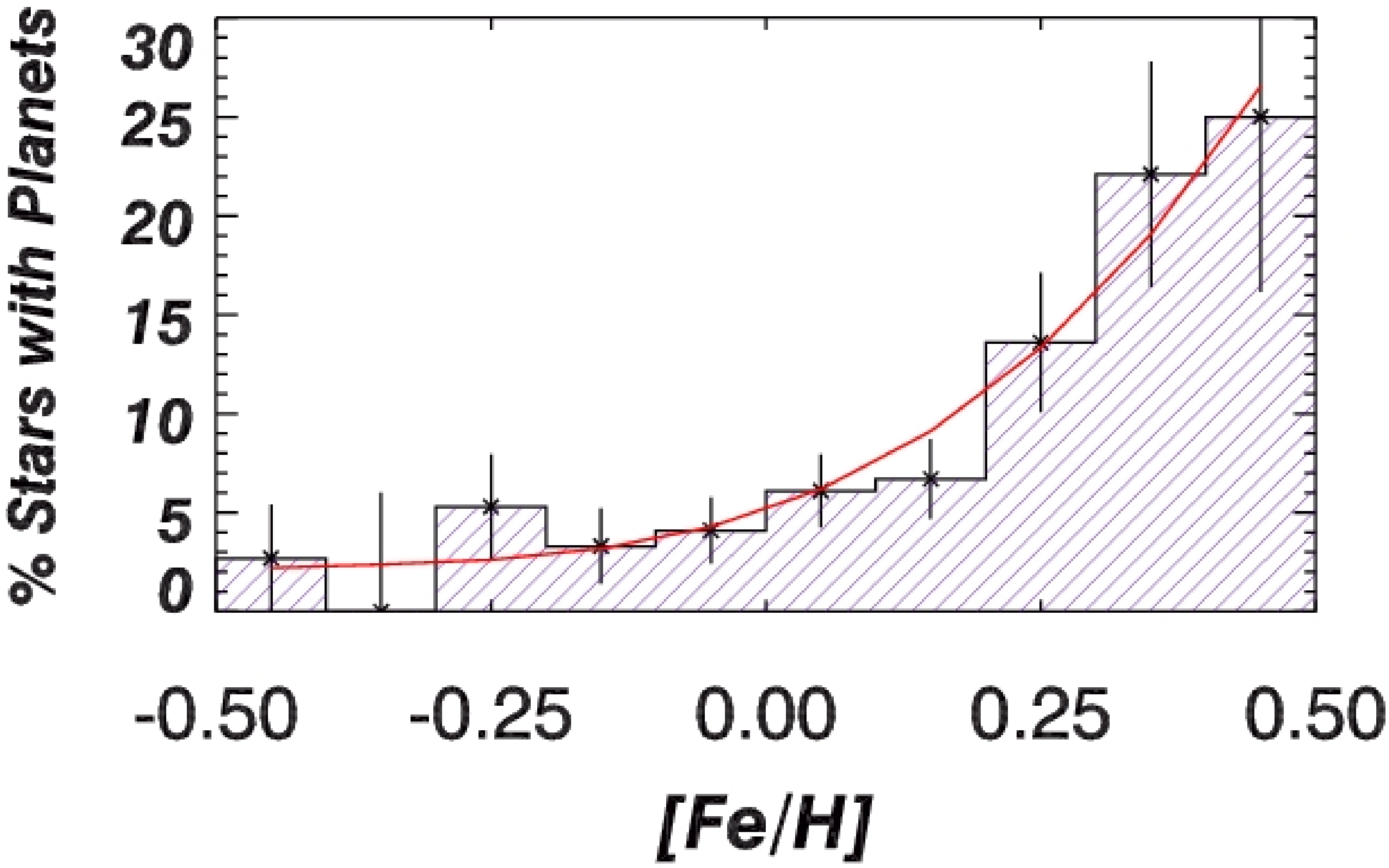
- Giant planet formation depends on host star properties and stellar environment.

- Giant planets drive major interactions and instabilities in a system.

- Observational biases are gradually being overcome.

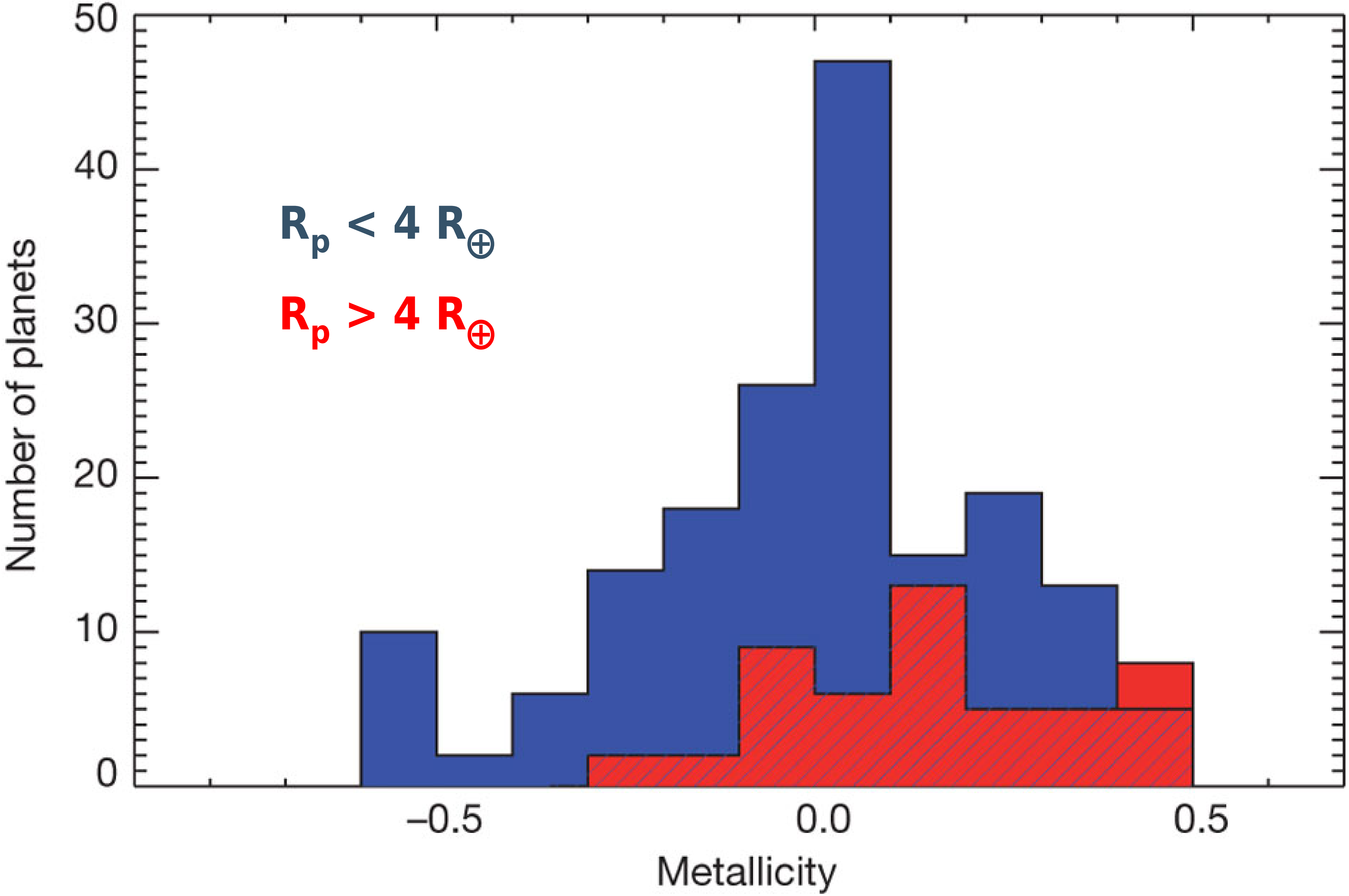
Stellar Metallicity

Fischer & Valenti, 2005, ApJ, 622, 1102



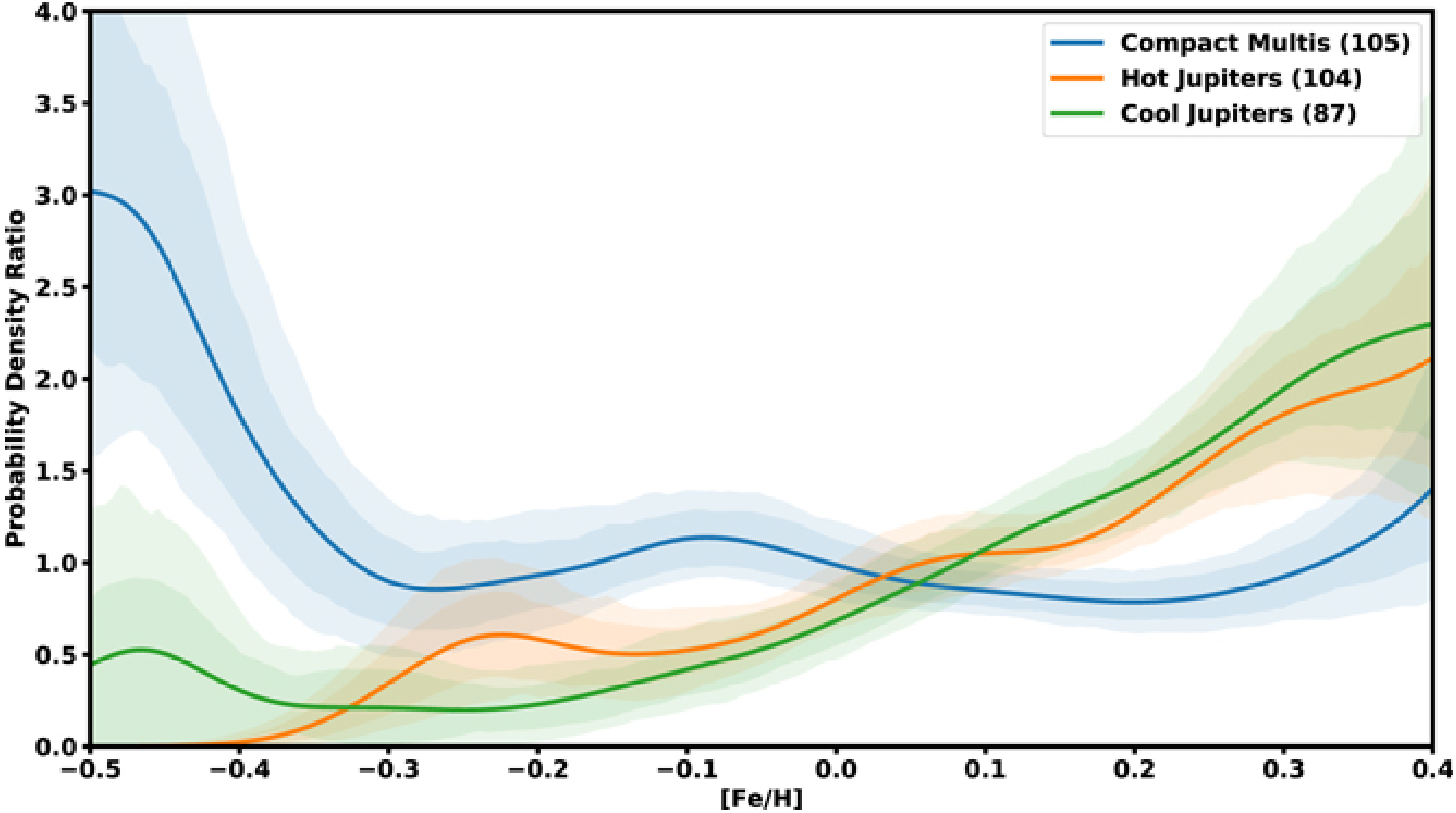
Stellar Metallicity

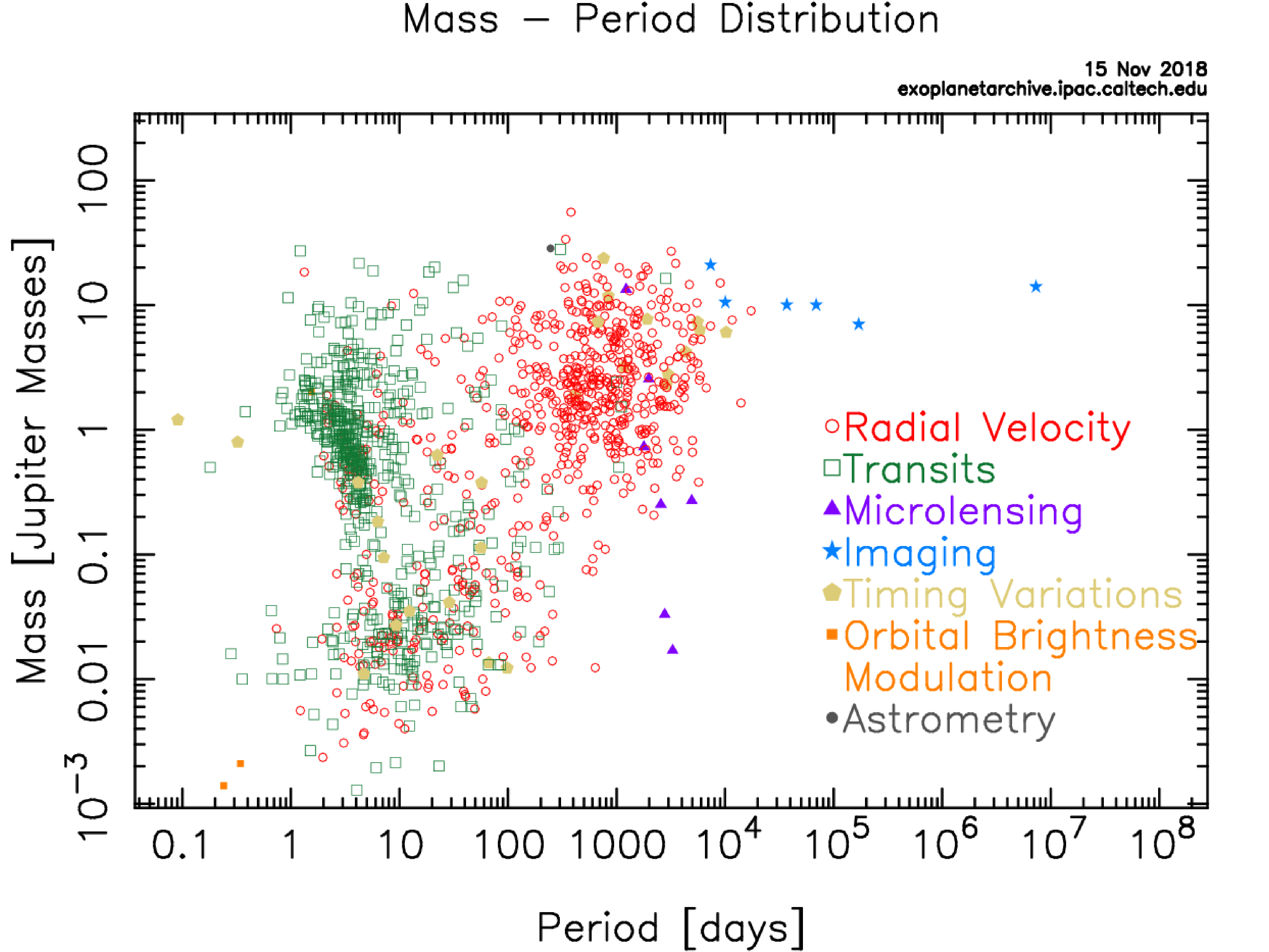
Buchhave et al. 2012, Nature, 486, 375

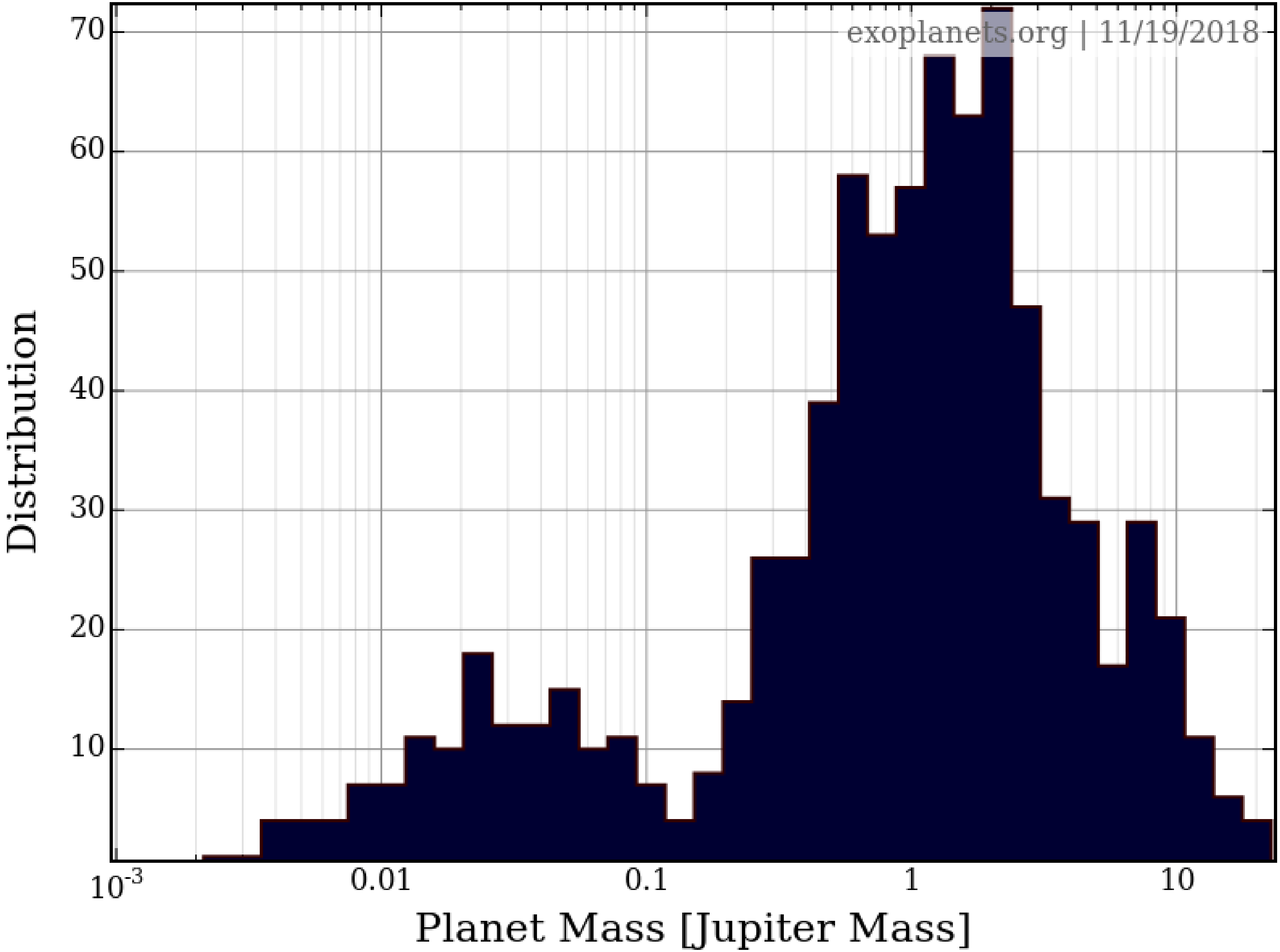


Stellar Metallicity

Brewer et al. 2018, ApJ, 867, L3




Mass – Period Distribution
15 Nov 2018
exoplanetarchive.ipac.caltech.edu
Mass [Jupiter Masses]
Period [days]
100
10
1
0.1
0.01
10^-3
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation
Astrometry


exoplanets.org | 11/19/2018
Distribution
70
60
50
40
30
20
10
10^{-3}
0.01
0.1
1
10
Planet Mass [Jupiter Mass]

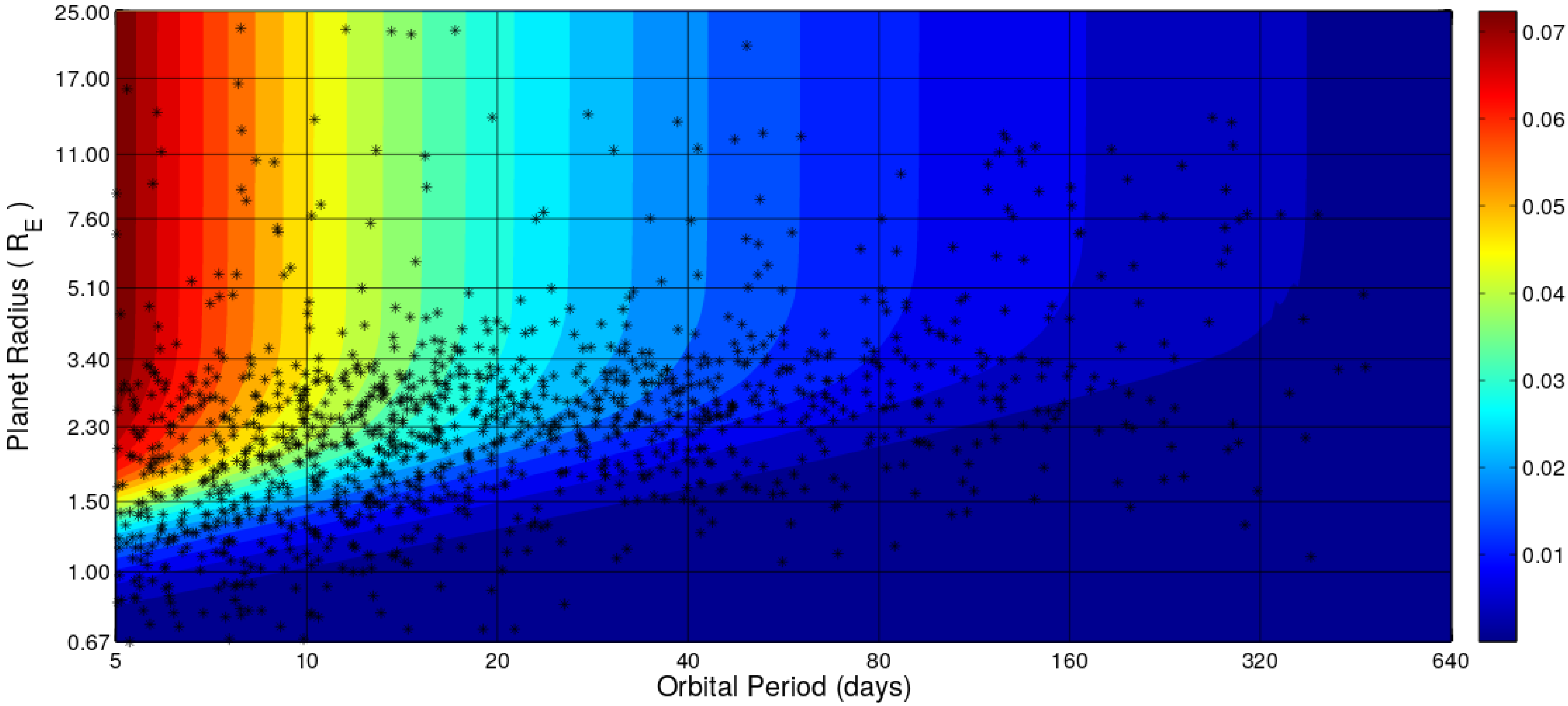


Figure 1. Average detection probability for G stars as a function of planet radius and orbital period. The star symbols represent the 1,819 *Kepler* candidates detected for these stars. Note the color bar to the right indicates the detection probability of the planets with greatest probability of detection corresponding with the top of the scale. Planets found on the top left corner of the graph will have a greater probability of detection.

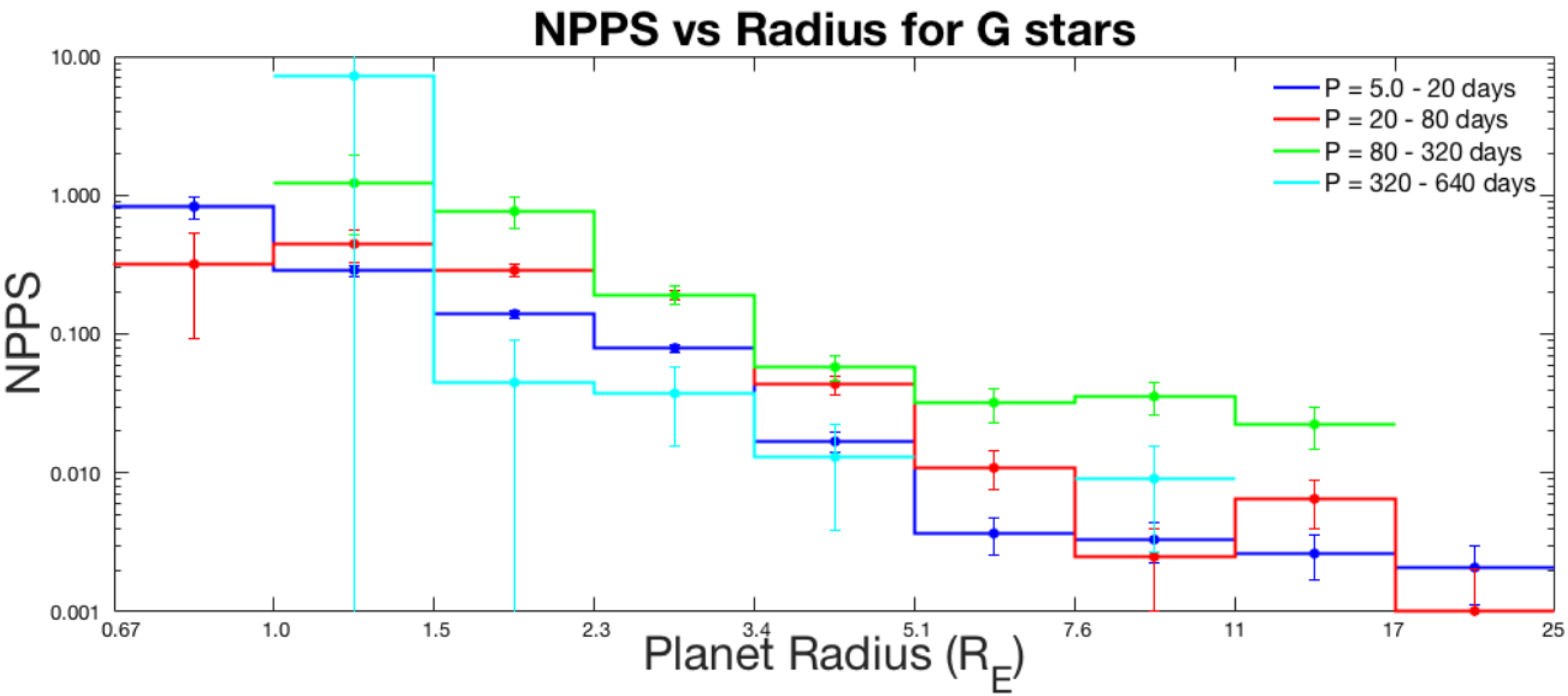


Figure 5. Number of Planets Per Star (NPPS) vs radius for G stars. Each line color represents a set range of periods. The data indicates that, for G stars, planets with radii greater than 1.5 $R_\oplus$ are most commonly found with orbital periods between 80–320 days. Also the occurrence rate of planets with orbits between 320–640 days shows a large spike for planets with radii between 1.0–1.5 $R_\oplus$.

Jupiter: Friend or Foe?

- Giant planets “stir up” the population of asteroids, KBOs, and Oort cloud objects.

- Some of these disturbed orbits result in the objects colliding with the giant planet or being ejected from the system.

- Other objects are placed on new orbits that send them towards the inner Solar System.

- Volatile deliver (mass fraction of water) may be highly dependent on the presence, or lack, of giant planets.

- Dynamical effects of giant planets may influence climate stability of terrestrial planets.

The Astronomical Journal, 146:16 (11pp), 2013 July doi:10.1088/0004-6256/146/1/16

THE INFLUENCE OF OUTER SOLAR SYSTEM ARCHITECTURE ON THE STRUCTURE AND EVOLUTION OF THE OORT CLOUD

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ABSTRACT

We study the influence of outer solar system architecture on the structural evolution of the Oort Cloud (OC) and the flux of Earth-crossing comets. In particular, we seek to quantify the role of the giant planets as "planetary protectors." To do so, we have run simulations in each of four different planetary mass configurations to understand the significance of each of the giant planets. Because the outer planets modify the structure of the OC throughout its formation, we integrate each simulation over the full age of the solar system. Over this time, we follow the evolution of cometary orbits from their starting point in the protoplanetary disk to their injection into the OC to their possible re-entry into the inner planetary region. We find that the overall structure of the OC, including the location of boundaries and the relative number of comets in the inner and outer parts, does not change significantly between configurations; however, as planetary mass decreases, the trapping efficiency (TE) of comets into the OC and the flux of comets into the observable region increases. We determine that those comets that evolve onto Earth-crossing orbits come primarily from the inner OC but show no preference for initial protoplanetary disk location. We also find that systems that have at least a Saturn-mass object are effective at deflecting possible Earth-crossing comets but the difference in flux between systems with and without such a planet is less than an order of magnitude. We conclude by discussing the individual roles of the planets and the implications of incorporating more realistic planetary accretion and migration scenarios into simulations, particularly on existing discrepancies between low TE and the mass of the protoplanetary disk and on determining the structural boundaries of the OC.

Key words: comets: general – Oort Cloud

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Jupiter: Cosmic Jekyll and Hyde

Kevin R. Grazier

Abstract

It has been widely reported that Jupiter has a profound role in shielding the terrestrial planets from comet impacts in the Solar System, and that a jovian planet is a requirement for the evolution of life on Earth. To evaluate whether jovians, in fact, shield habitable planets from impacts (a phenomenon often referred to as the ''Jupiter as shield'' concept), this study simulated the evolution of 10,000 particles in each of the jovian inter-planet gaps for the cases of full-mass and embryo planets for up to 100 My. The results of these simulations predict a number of phenomena that not only discount the ''Jupiter as shield'' concept, they also predict that in a Solar System like ours, large gas giants like Saturn and Jupiter had a different, and potentially even more important, role in the evolution of life on our planet by delivering the volatile-laden material required for the formation of life.

The simulations illustrate that, although all particles occupied ''non-life threatening'' orbits at their onset of the simulations, a significant fraction of the 30,000 particles evolved into Earth-crossing orbits. A comparison of multiple runs with different planetary configurations revealed that Jupiter was responsible for the vast majority of the encounters that ''kicked'' outer planet material into the terrestrial planet region, and that Saturn assisted in the process far more than has previously been acknowledged. Jupiter also tends to ''fix'' the aphelion of planetesimals at its orbit irrespective of their initial starting zones, which has the effect of slowing their passages through the inner Solar System, and thus potentially improving the odds of accretion of cometary material by terrestrial planets. As expected, the simulations indicate that the full-mass planets perturb many objects into the deep outer Solar System, or eject them entirely; however, planetary embryos also did this with surprising efficiency. Finally, the simulations predict that Jupiter's capacity to shield or intercept Earth-bound comets originating in the outer Solar System is poor, and that the importance of jovian planets on the formation of life is not that they act as shields, but rather that they deliver life-enabling volatiles to the terrestrial planets. Key Words: Asteroid—Comets—Interstellar meteorites—Extrasolar terrestrial planets—Simulation. Astrobiology 16, 23–38.

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Eccentricity Distribution beyond the Snow Line and Implications for Planetary Habitability

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Abstract

A fundamental question in the study of planetary system demographics is: how common is the solar system architecture? The primary importance of this question lies in the potential of planetary systems to create habitable environments, and dissecting the various components of solar system evolution that contributed to a sustainable temperate surface for Earth. One important factor in that respect is volatile delivery to the inner system and the dependence on giant planets beyond the snow line as scattering agents, particularly as such cold giant planets are relatively rare. Here, we provide an investigation of the eccentricity distribution for giant planet populations both interior and exterior to their system snow lines. We show that the median eccentricity for cold giants is 0.23, compared with a far more circular orbital regime for inner planets. We further present the results of a dynamical simulation that explores the particle scattering potential for a Jupiter analog in comparison with a Jupiter whose eccentricity matches that of the median cold giant eccentricity. These simulations demonstrate that the capacity for such an eccentric cold giant system to scatter volatiles interior to the snow line is significantly increased compared with the Jupiter analog case, resulting in a far greater volume of Earth-crossing volatiles. Thus, many of the known systems with cold giant planets may harbor water worlds interior to the snow line.

Unified Astronomy Thesaurus concepts: Habitable zone (696); Exoplanets (498); Exoplanet systems (484); Exoplanet dynamics (490); Exoplanet evolution (491); Orbits (1184); Orbital evolution (1178); Solar system (1528); Solar system gas giant planets (1191); Solar system evolution (2293)

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Planetesimal Scattering Efficiency of Cold Giant Planet Architectures

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Abstract

The discovery of many exoplanets has revealed an incredible diversity of orbital architectures. These orbital configurations are intrinsically linked to the potential for habitable environments within the system, since the gravitational influence of the planets governs the angular momentum distribution within the system. This angular momentum distribution in turn alters the planetary orbits and rotational obliquities. In the case of giant planets, their gravitational influence can also produce significant redistribution of volatiles, particularly those that lie beyond the snow line. Here, we present the results of dynamical simulations that investigate the role of cold giant planets in scattering material to inner terrestrial planets. We highlight 10 exoplanetary systems with two or more known giant planets beyond the snow line, and adopt a solar system analog template that investigates the scattering of material within the range 3–8 au. We show that increasing the eccentricity of a Jupiter analog from its present, near-circular value to a moderate range (0.2–0.3) results in an order of magnitude increase in scattered material to the inner part of the system. The inclusion of a Saturn analog to the dynamical model produces a similar increase, highlighting the importance of multiple giant planets beyond the snow line. However, the addition of analogs to Uranus and Neptune can have a minor negative effect on scattering efficiency through the transfer of angular momentum from the inner giant planets.

Unified Astronomy Thesaurus concepts: Habitable planets (695); Habitable zone (696); Exoplanets (498); Exoplanet systems (484); Exoplanet dynamics (490); Exoplanet evolution (491); Orbits (1184); Orbital evolution (1178); Solar system (1528); Solar system gas giant planets (1191); Solar system terrestrial planets (797); Solar system evolution (2293)