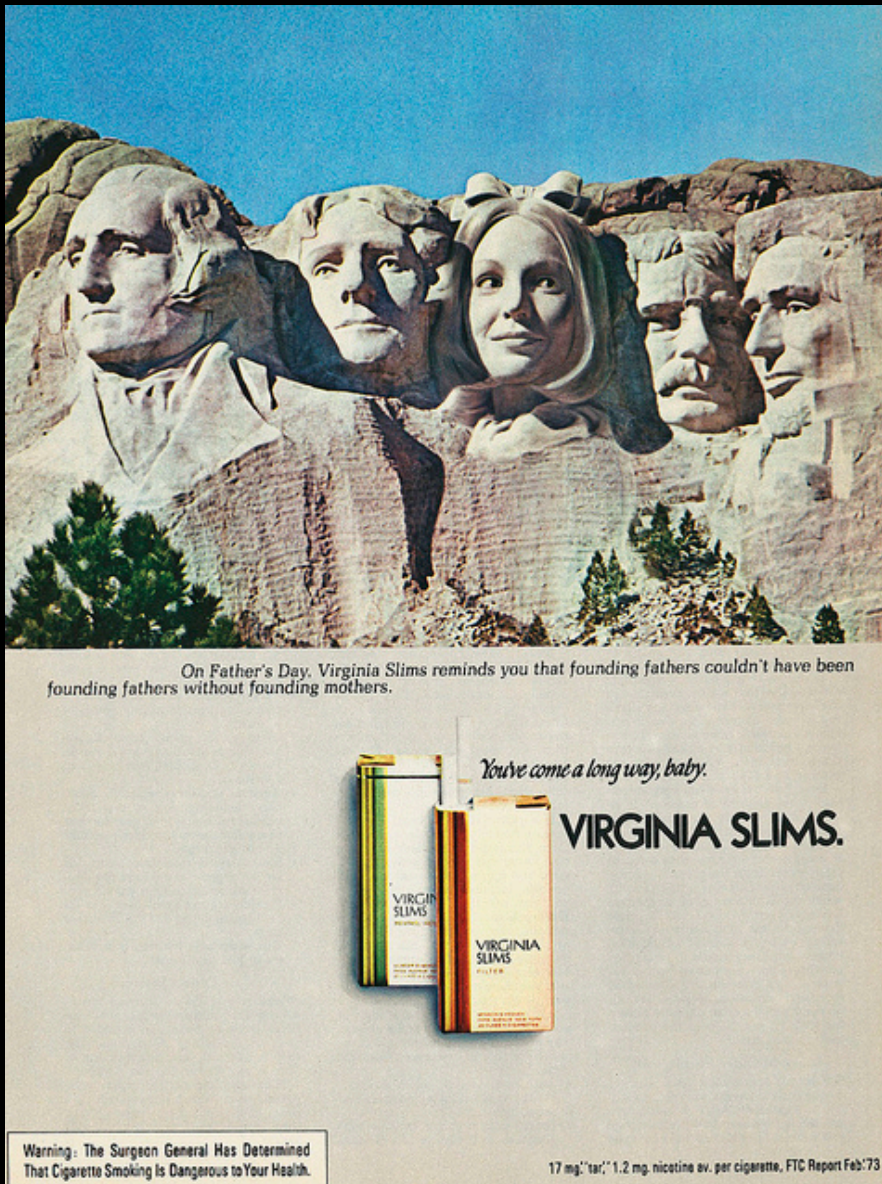
New Worlds, Baby!

Debra Fischer



1973

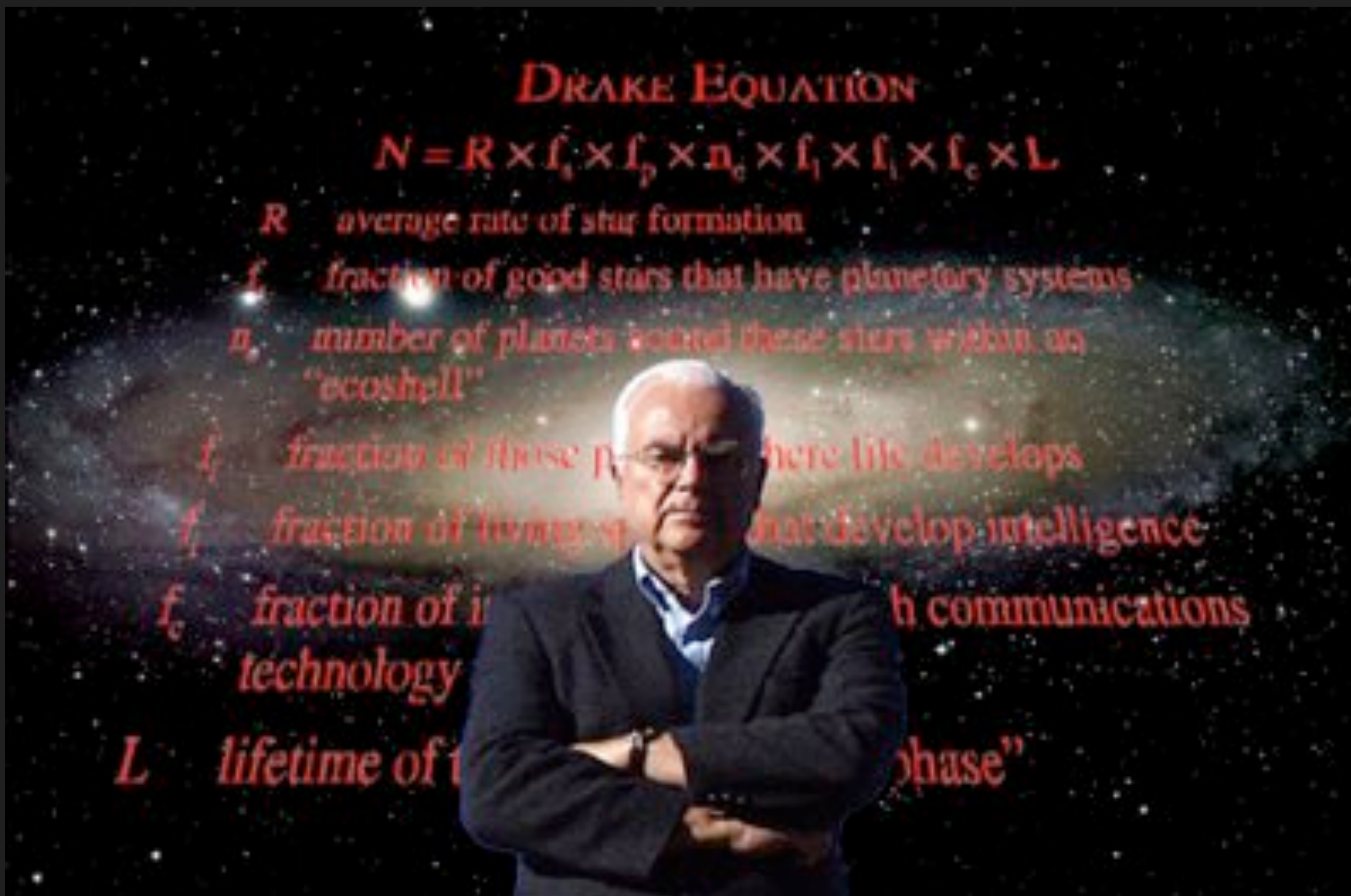
You've come a long way, Baby!

You can smoke like a man.
You can act like a man.
You can think like a man.

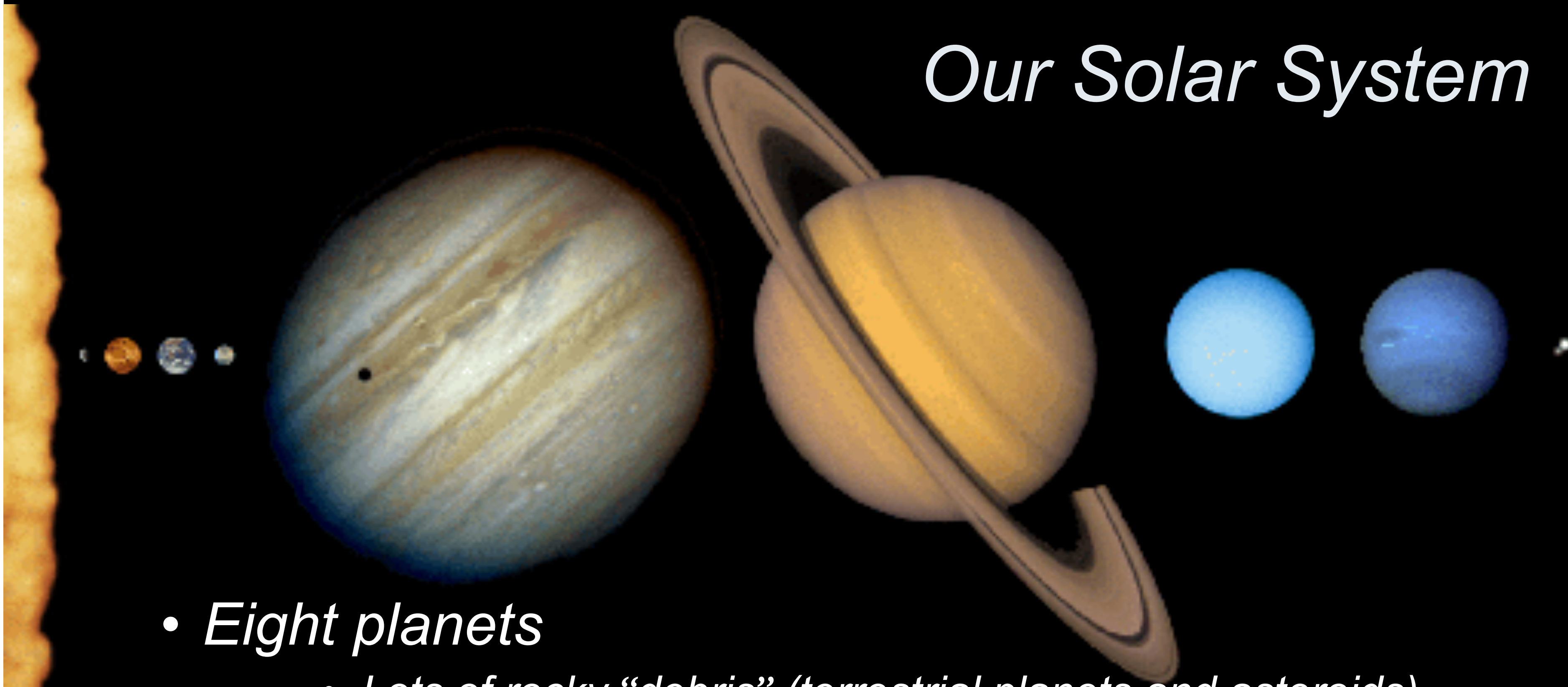
Is that really the best we can be?

1995

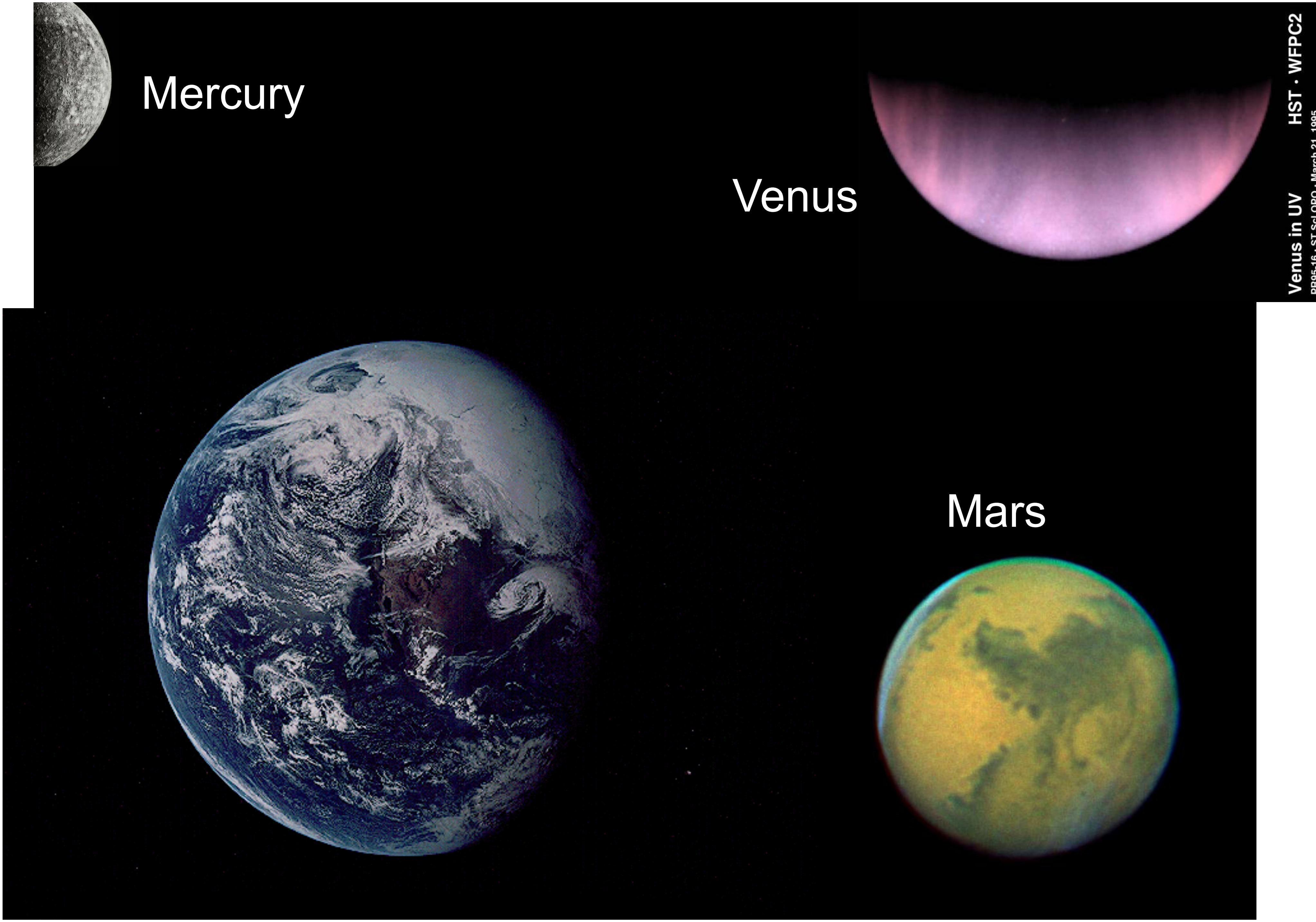
first planet detected


DRAKE EQUATION
N = R × f_s × f_p × n_e × f_l × f_i × f_c × L
R average rate of star formation
f_s fraction of good stars that have planetary systems
n_e number of planets bound these stars within an "ecoshell"
f_l fraction of those p
here life develops
f_i fraction of living sp
hat develop intelligence
f_c fraction of i
h communications
technology
L lifetime of t
phase"

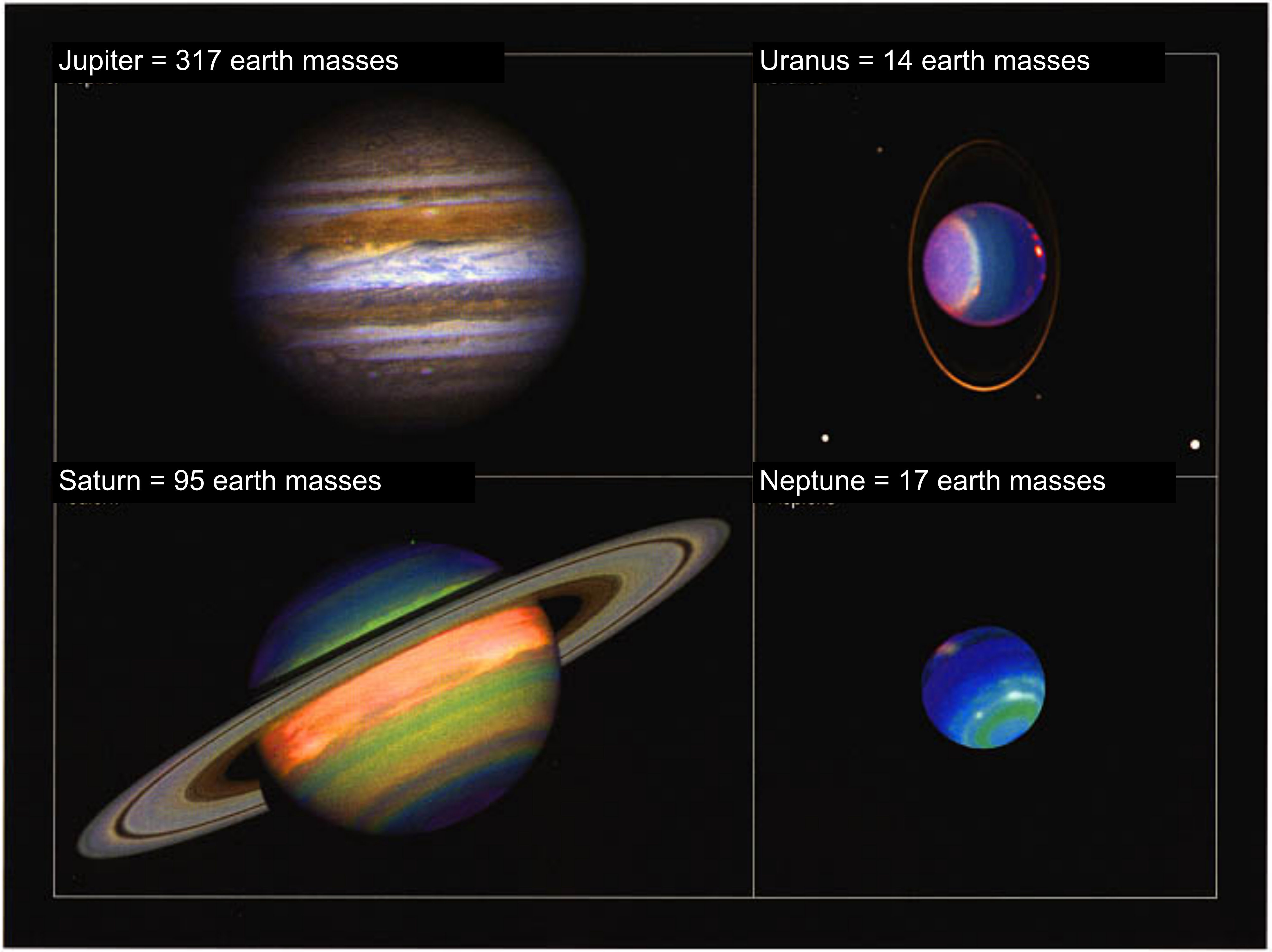
Our Solar System

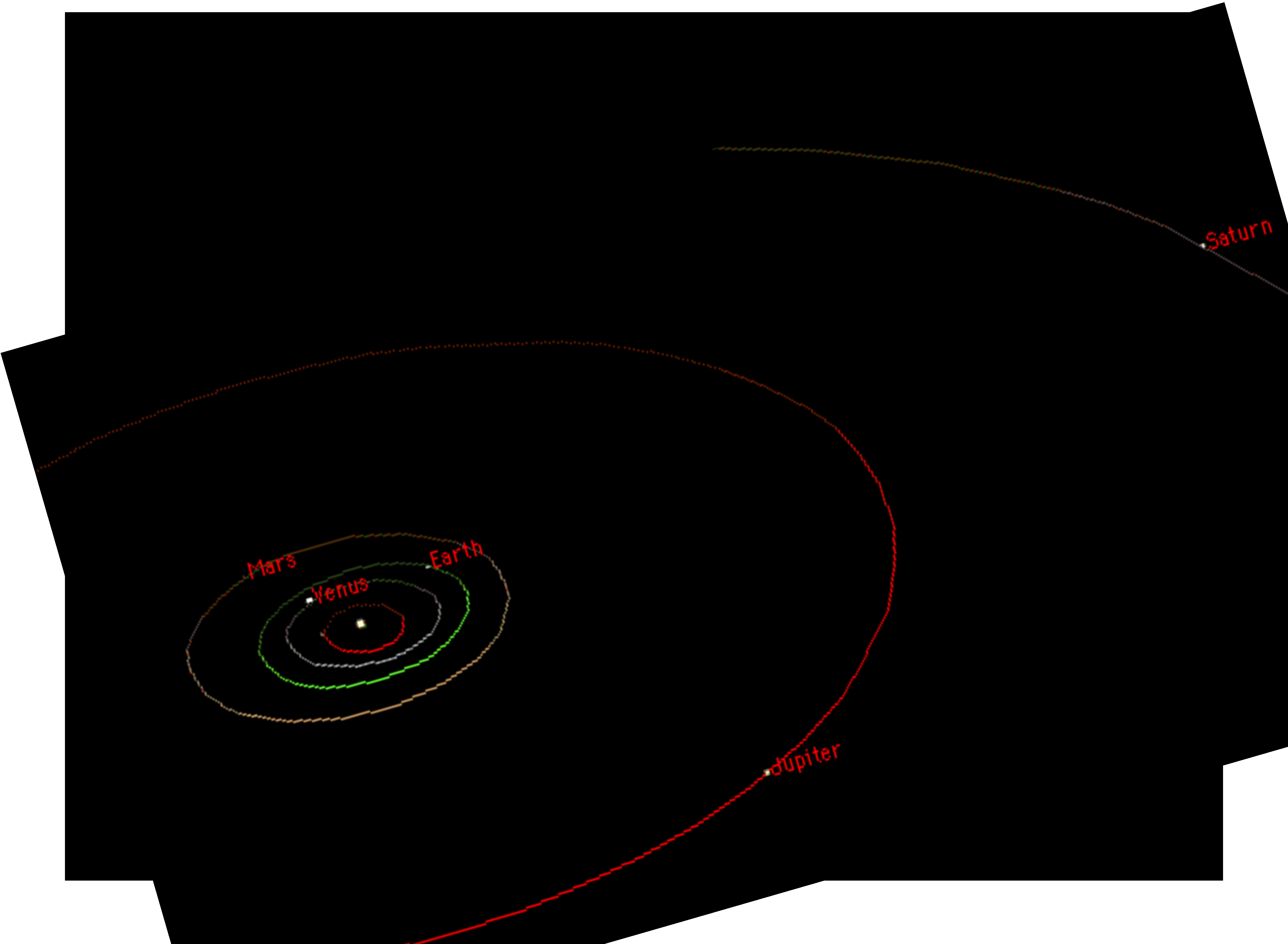


- Eight planets
  - Lots of rocky "debris" (terrestrial planets and asteroids)
  - Most planets have moons
  -
- Nearly circular orbits
- Only one inhabited planet

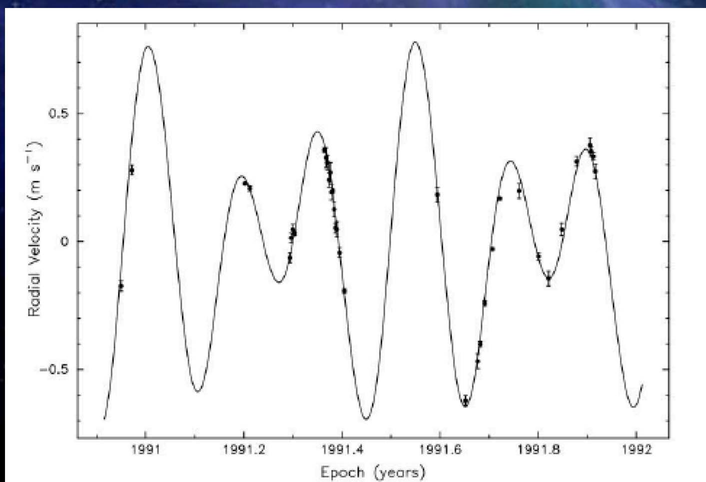

Mercury
Venus
Venus in UV
HST · WFPC2
PR95-16 · ST ScI OPO · March 21, 1995
Mars

Jovian Planets

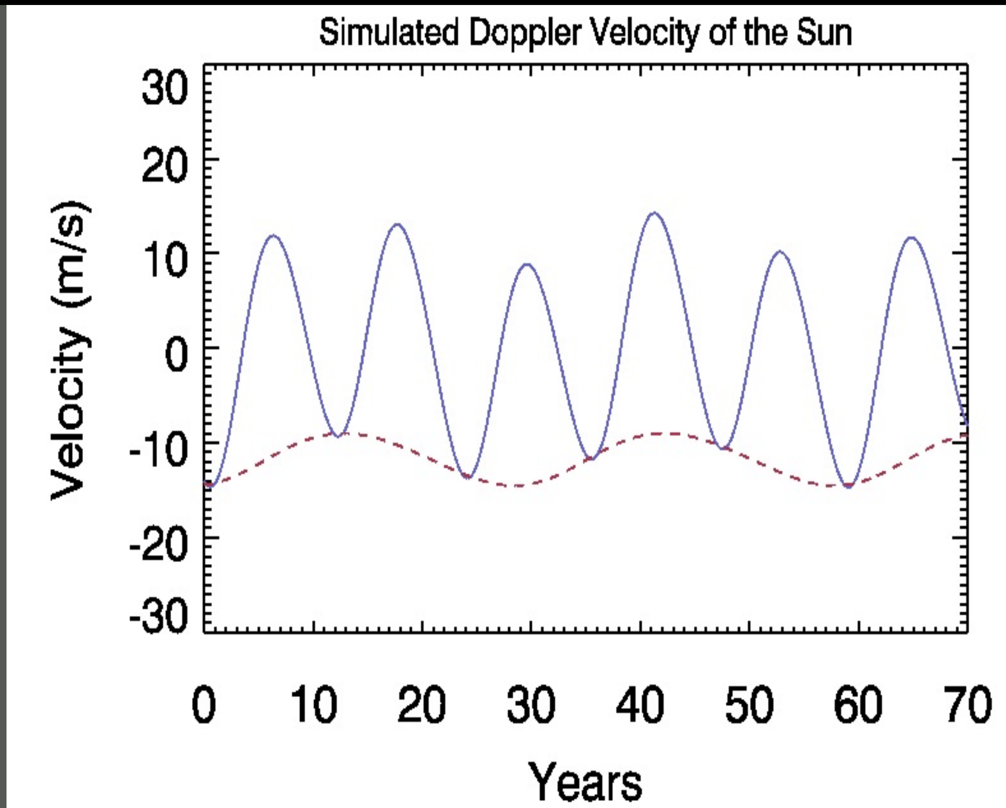



Saturn
Mars
Earth
Venus
Jupiter

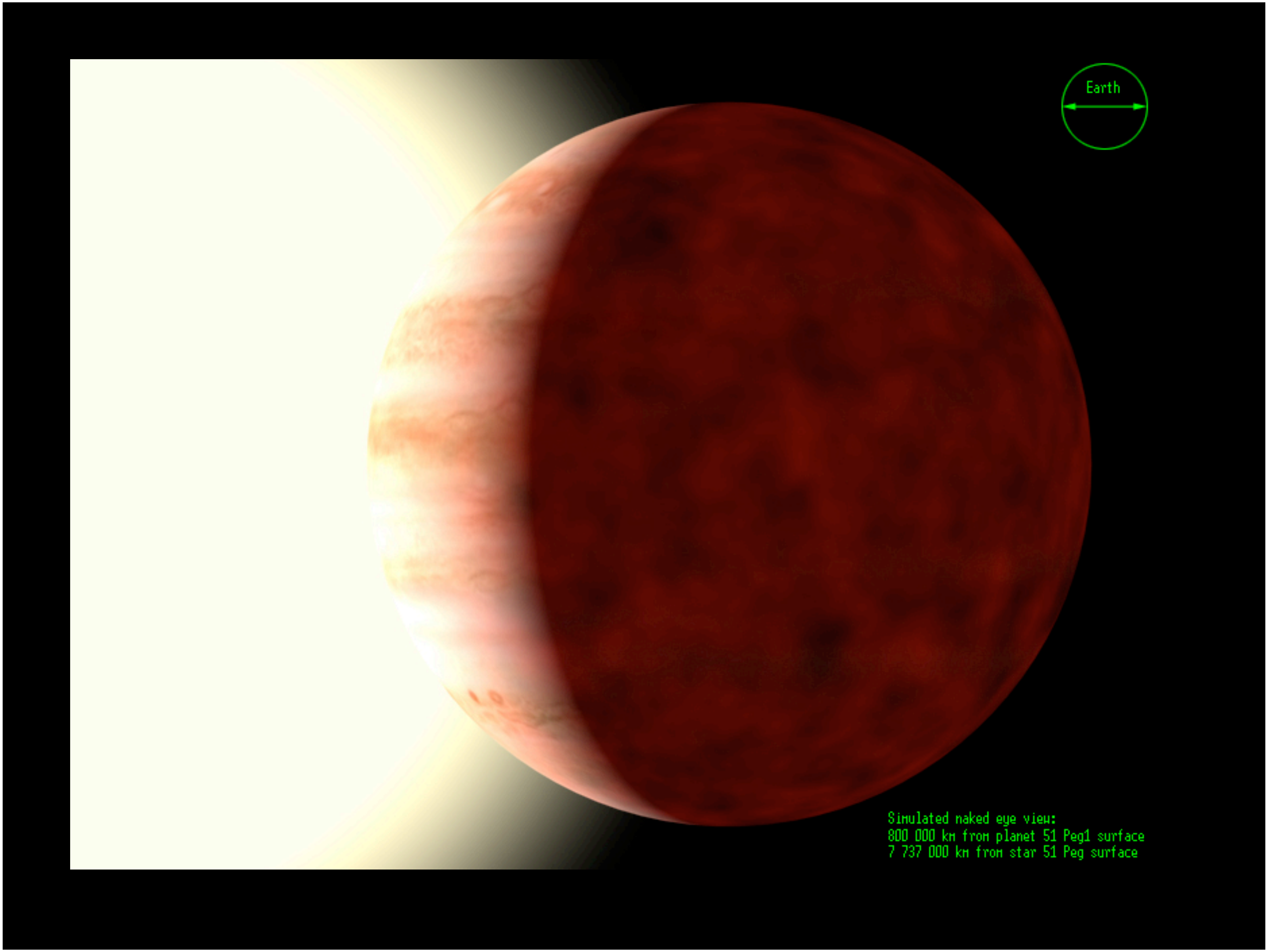
Pulsar timing: *uses the Doppler effect, need to collect data over the entire obit to model.*

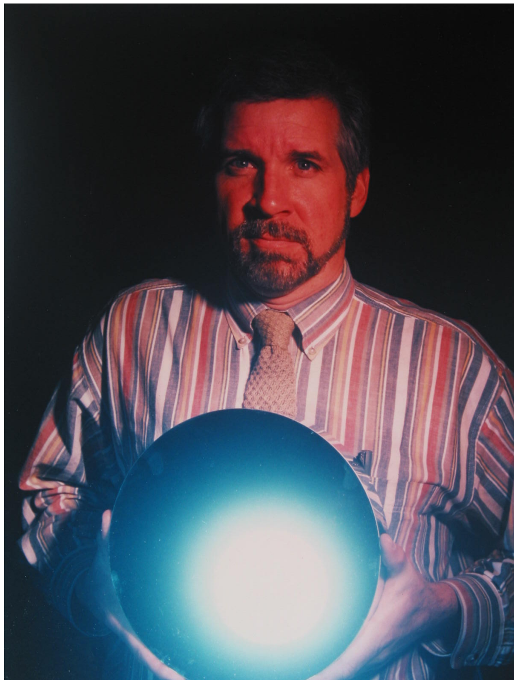


Radial Velocity technique: *uses the Doppler effect - need one full orbit*



1995


Earth
Simulated naked eye view:
800 000 km from planet 51 Peg1 surface
7 737 000 km from star 51 Peg surface



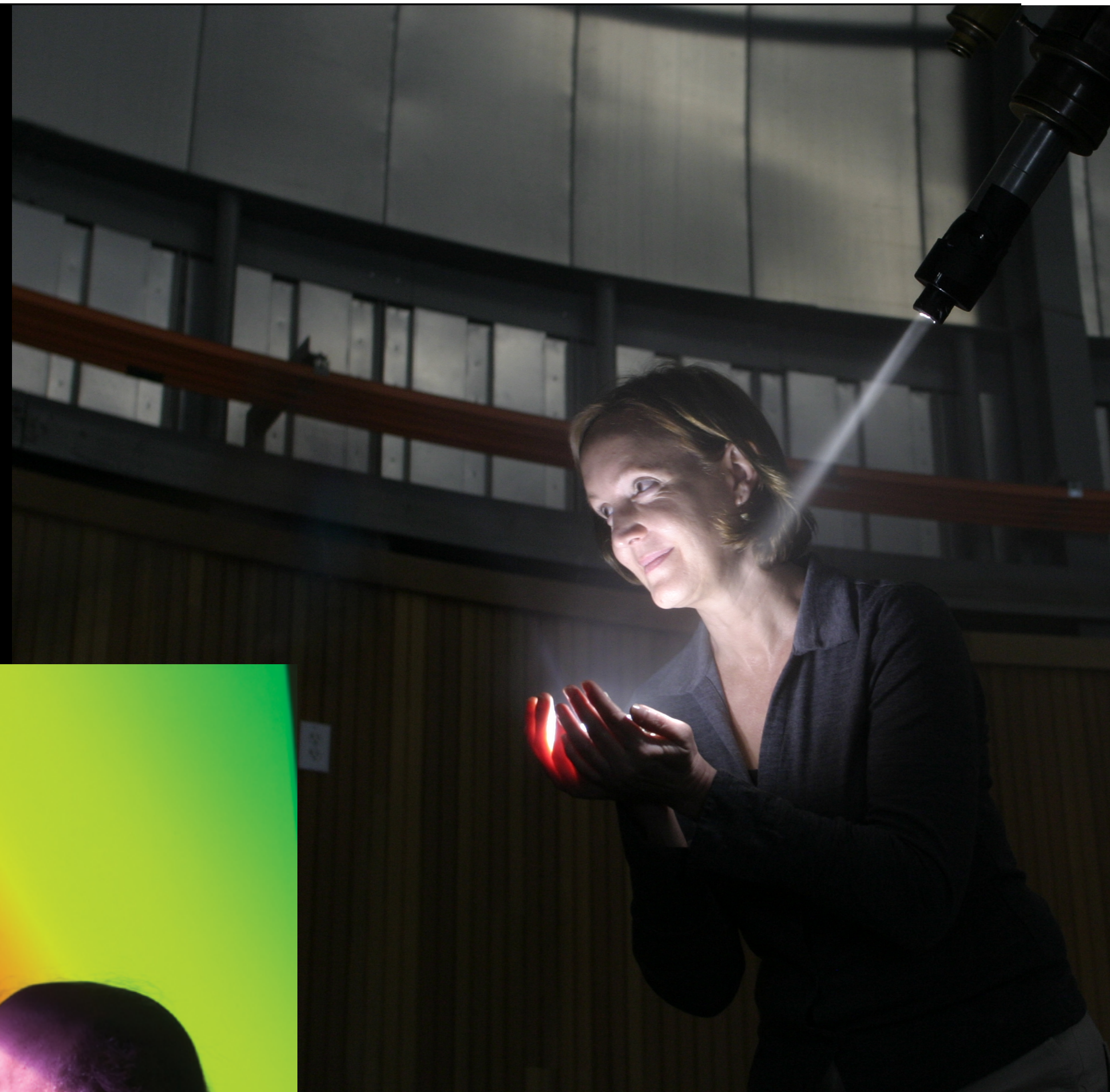
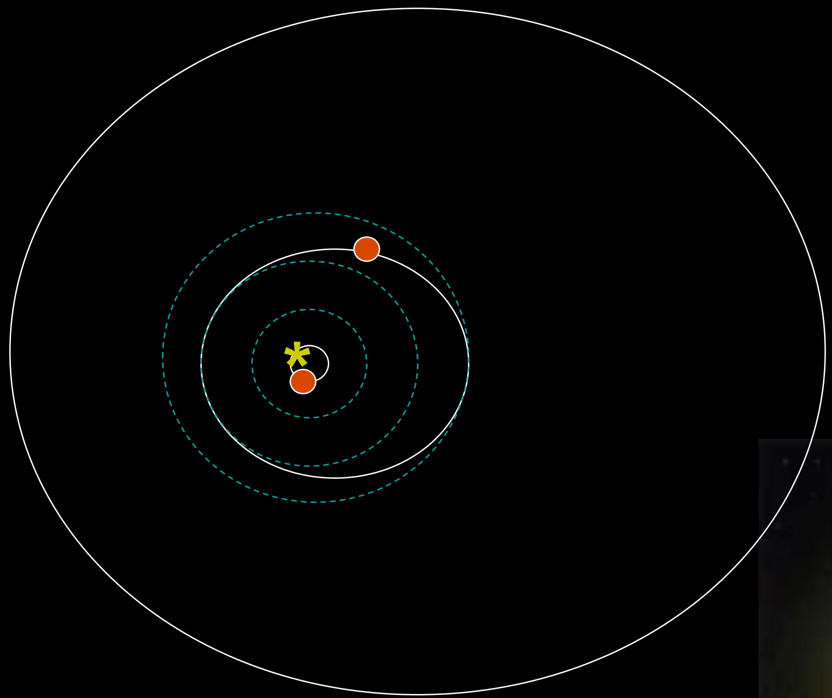


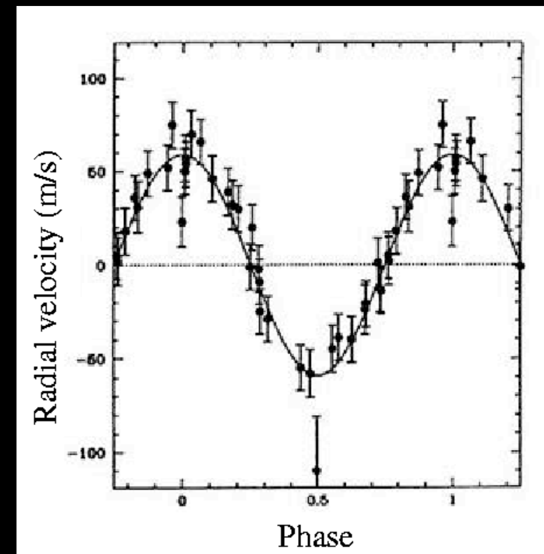
Photo credit: National Geographic



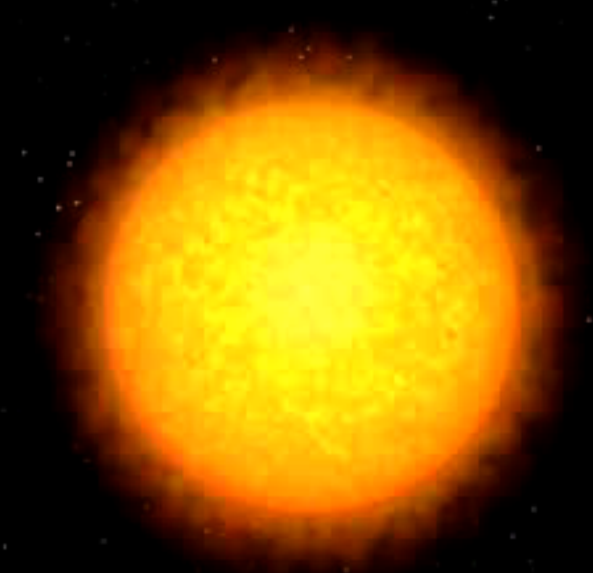
Artist: Lynette Cook

1999

2012



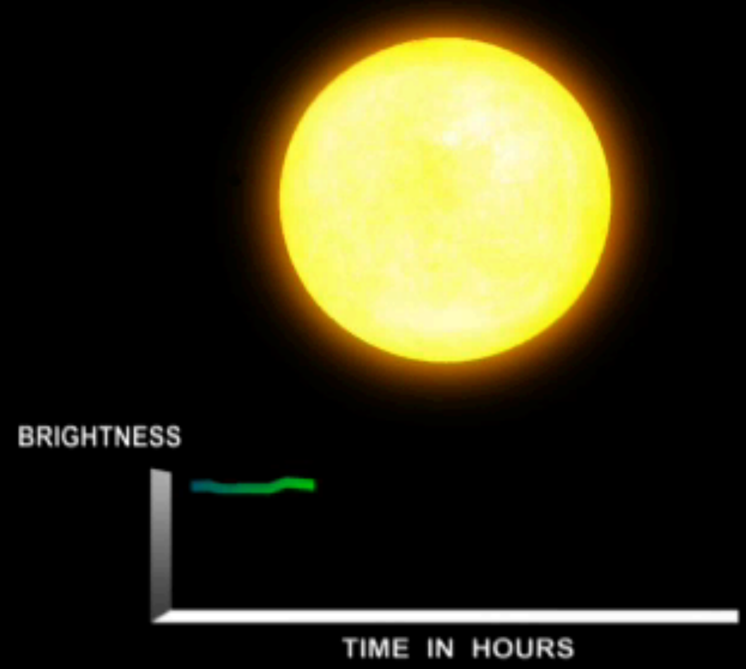
RV Planet count: 515

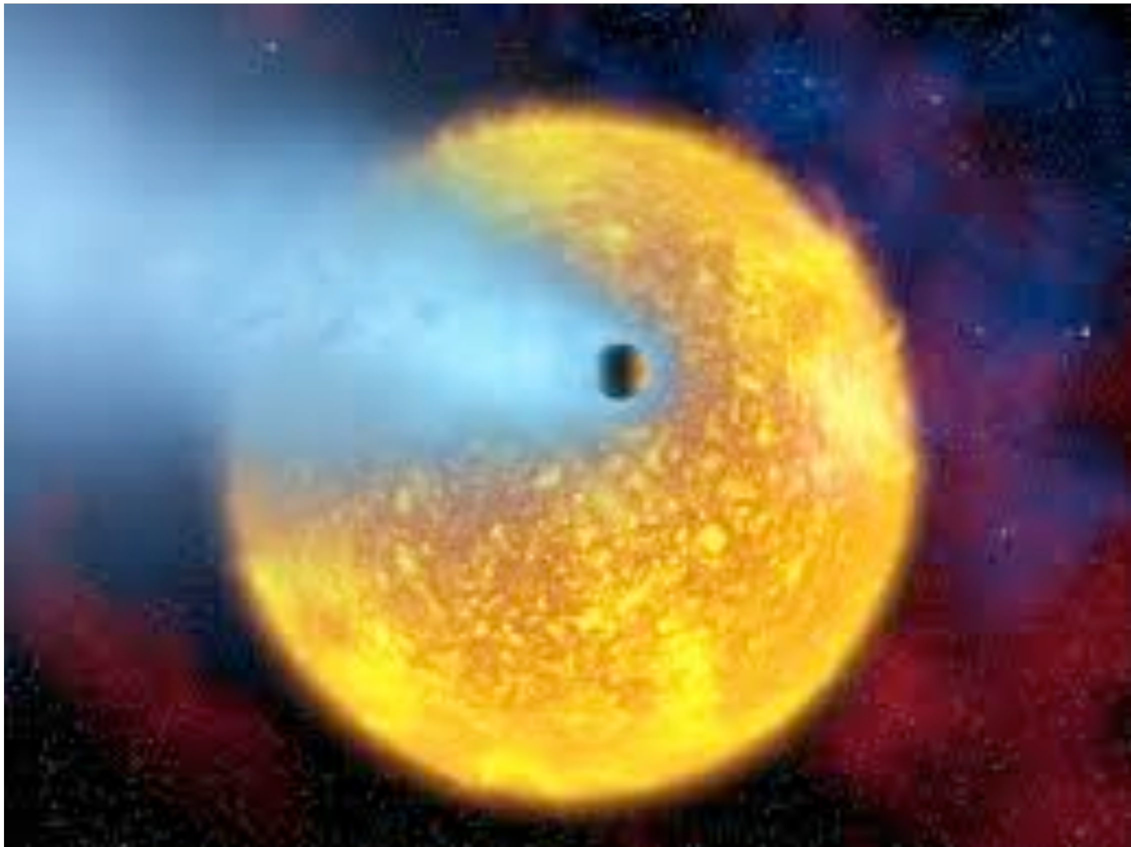


Many scientists were skeptical about the interpretation of the RV data. However, we knew that the orbit of some of these planets should be oriented so that the planet would transit in front of it's host star.

Transit Technique: the planet passes in front of the star, dimming the starlight for a few hours. The bigger the planet, the greater the light decrement.

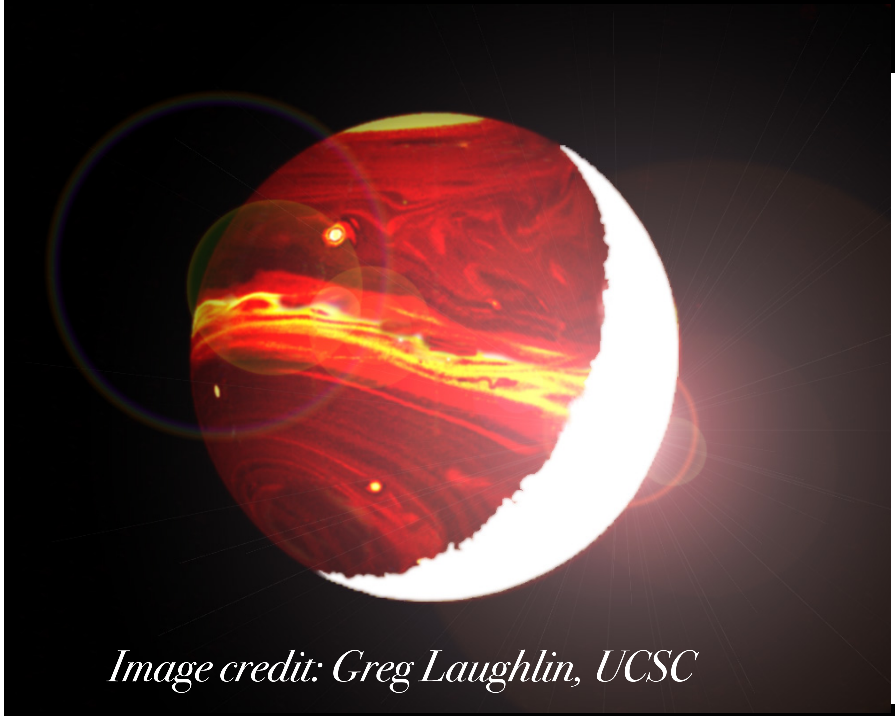
Artistic license: star and planet are not resolved!

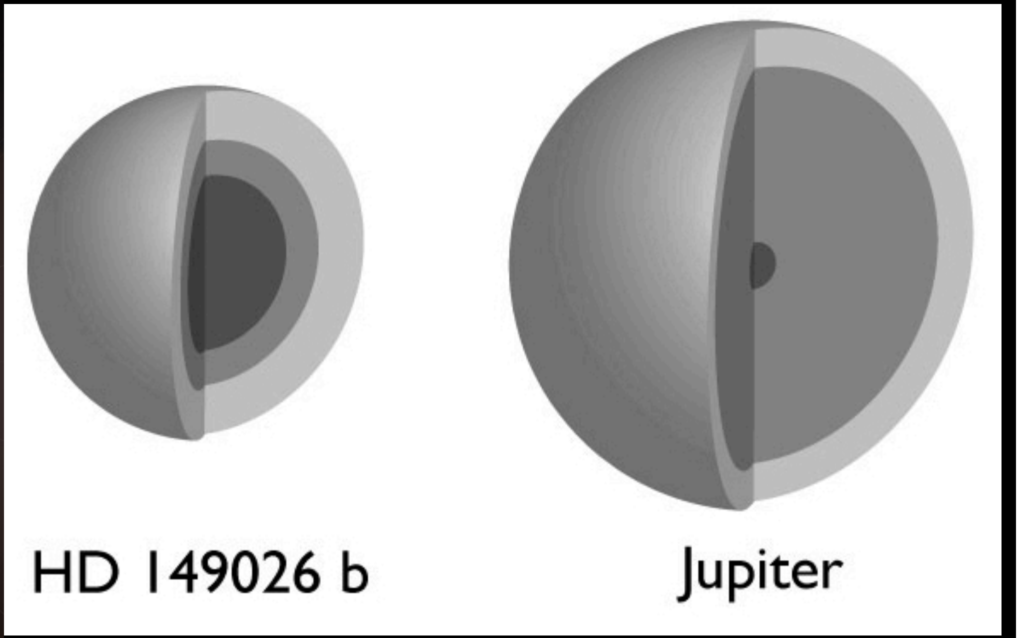




1999

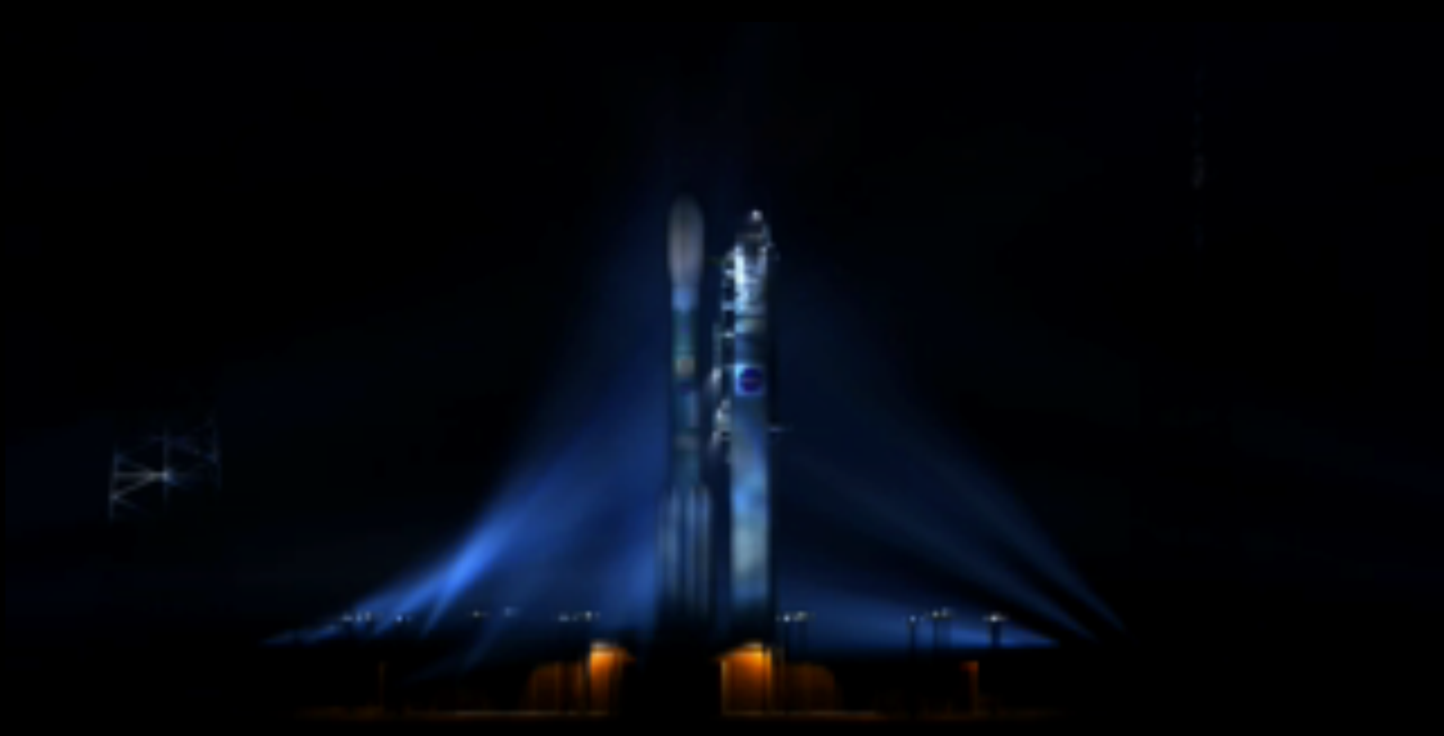
Transiting planets: models allow us to determine interior structure of planets orbiting stars hundreds of light years away



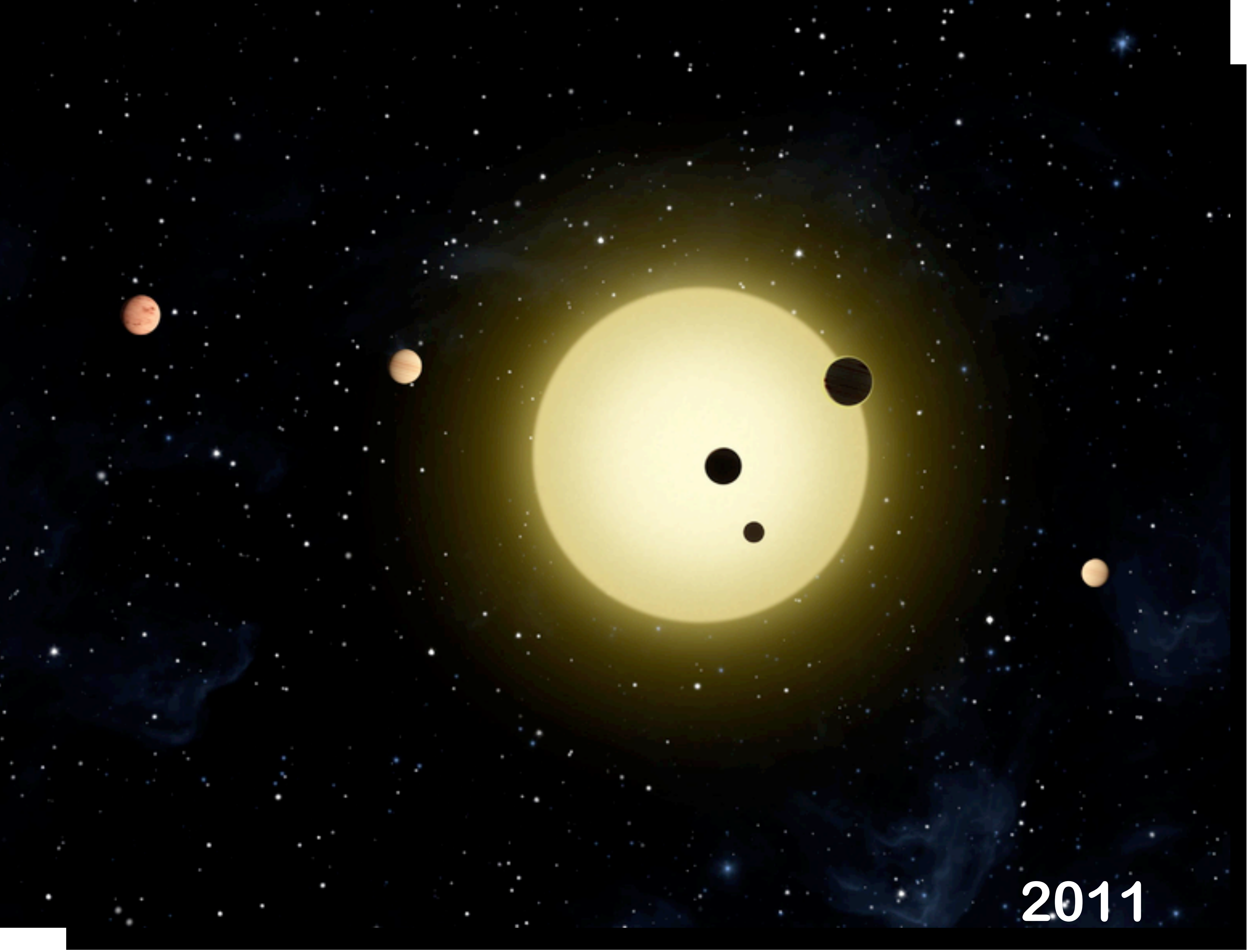


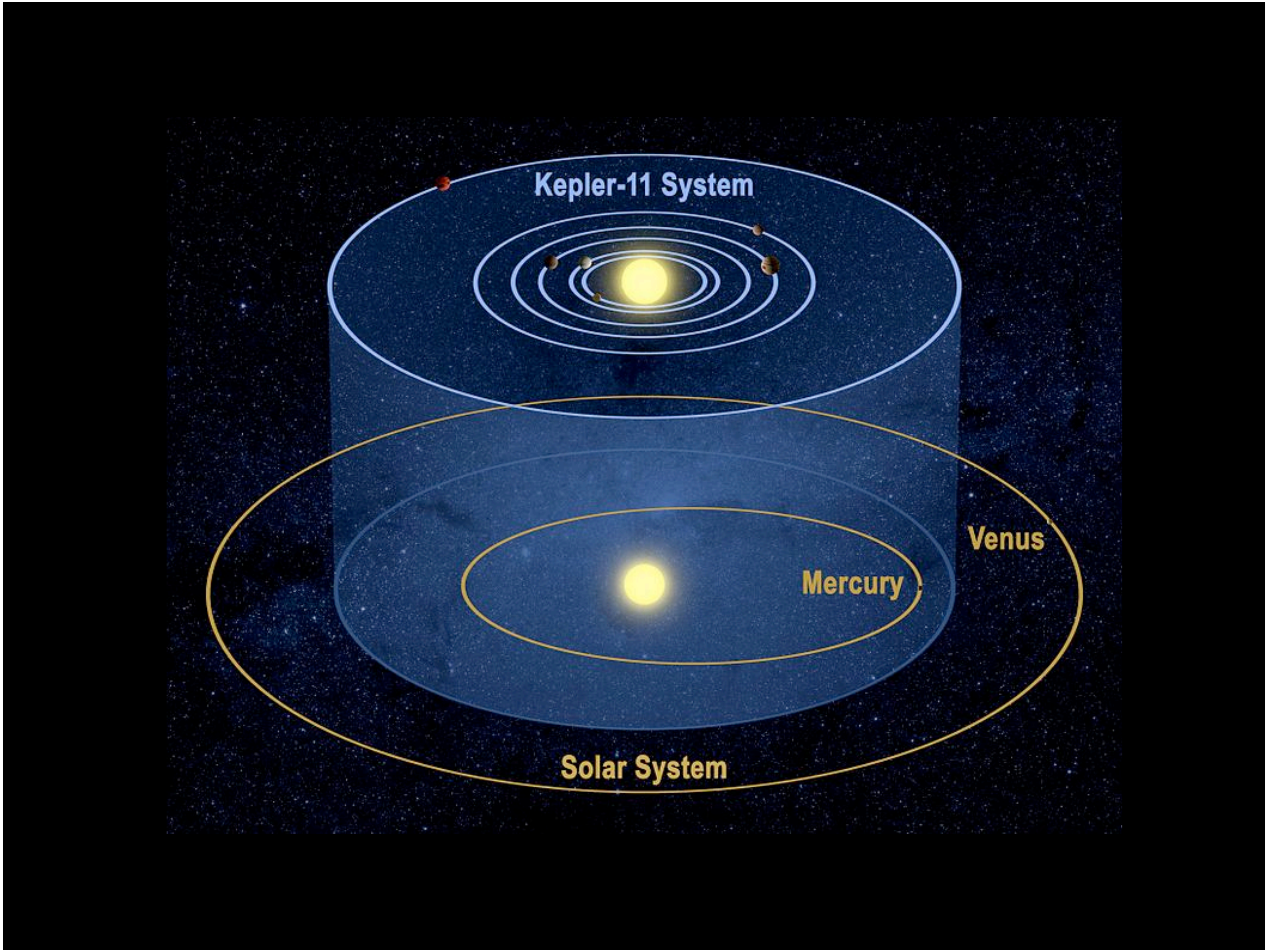
Planet count: 308

Kepler Mission: transits from space

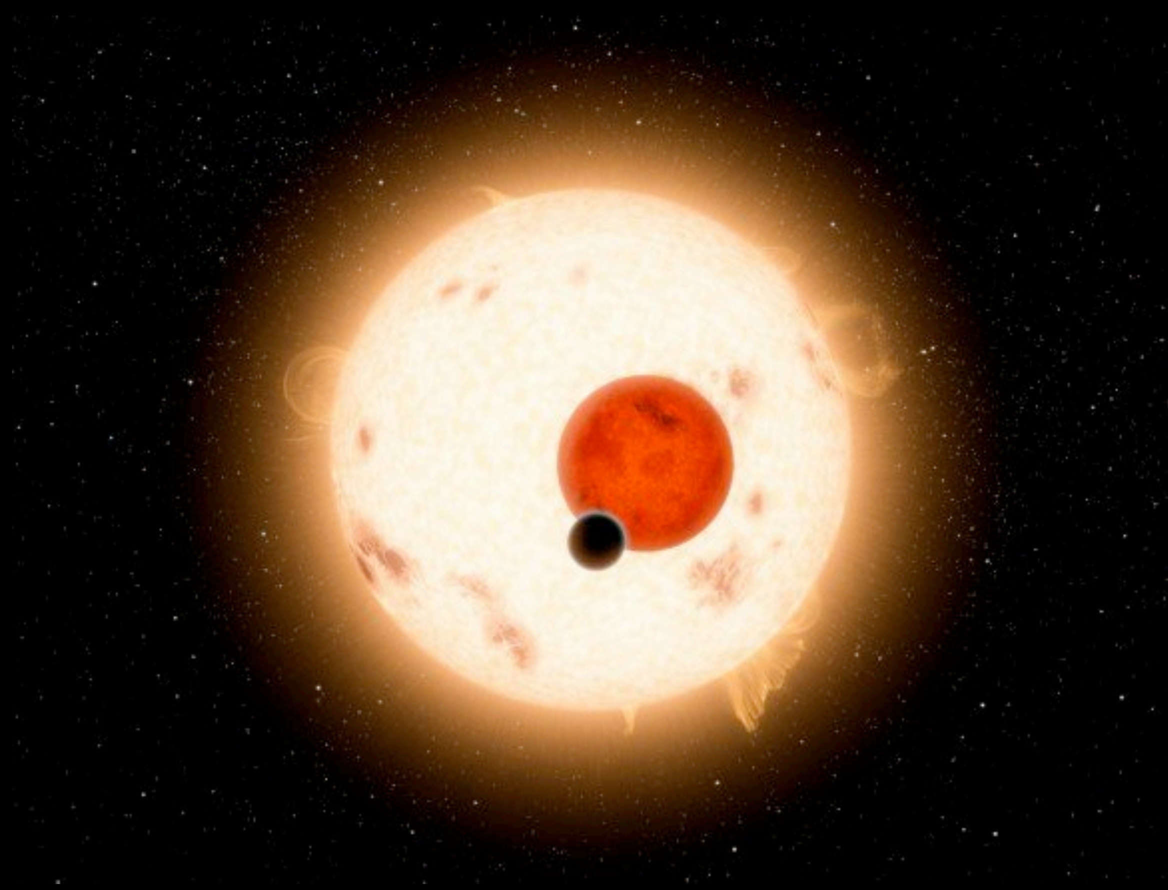


2009


2011


Kepler-11 System
Venus
Mercury
Solar System

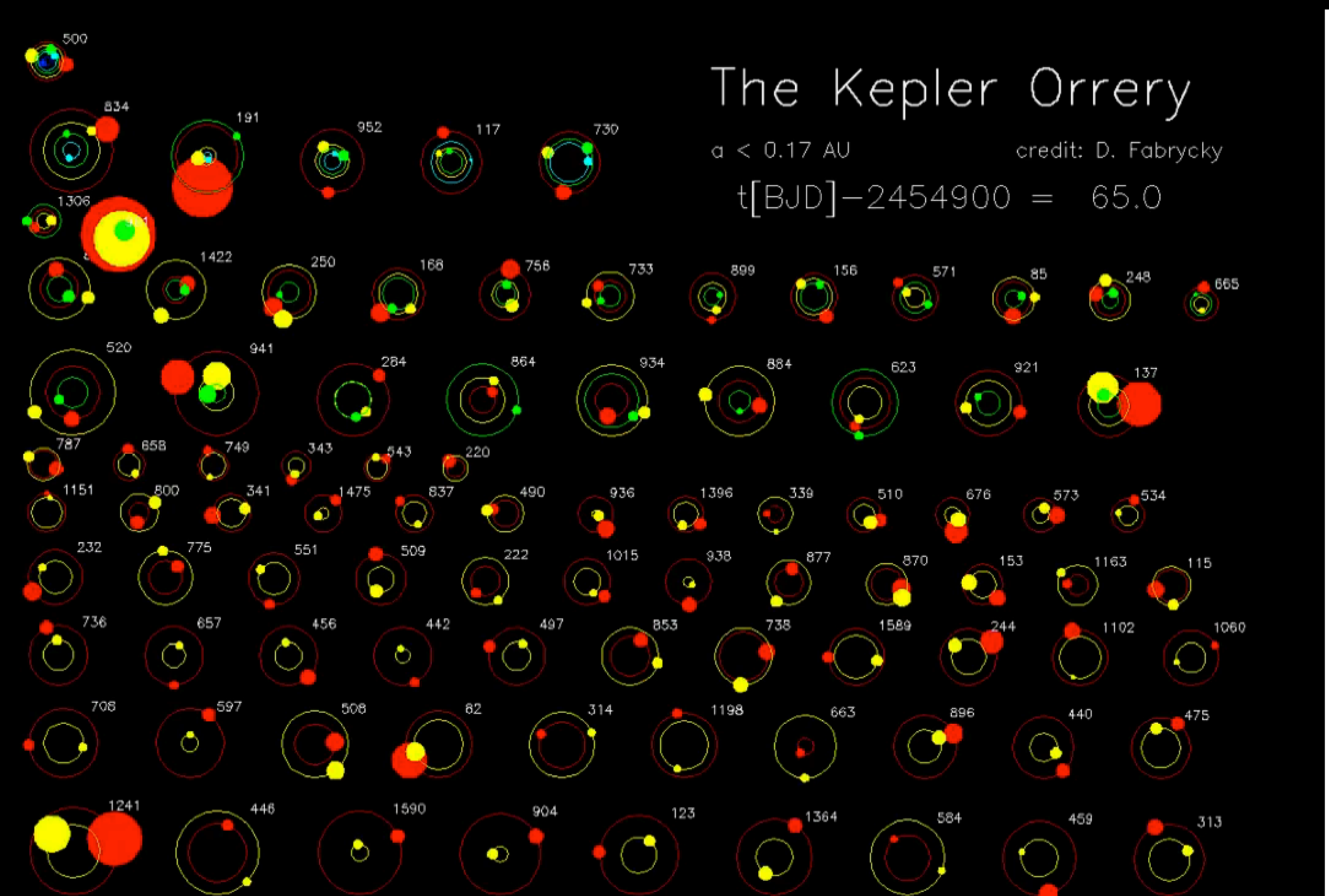
Tatooine



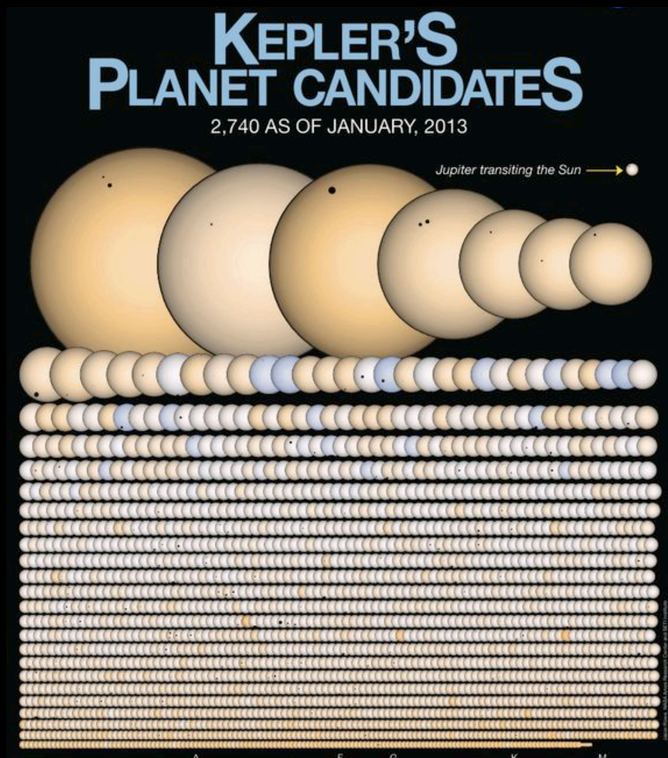
A Saturn mass planet orbiting a double star system!

2011

Kepler Transit Candidates: many are multi-systems



Dan Fabrycky, U Chicago

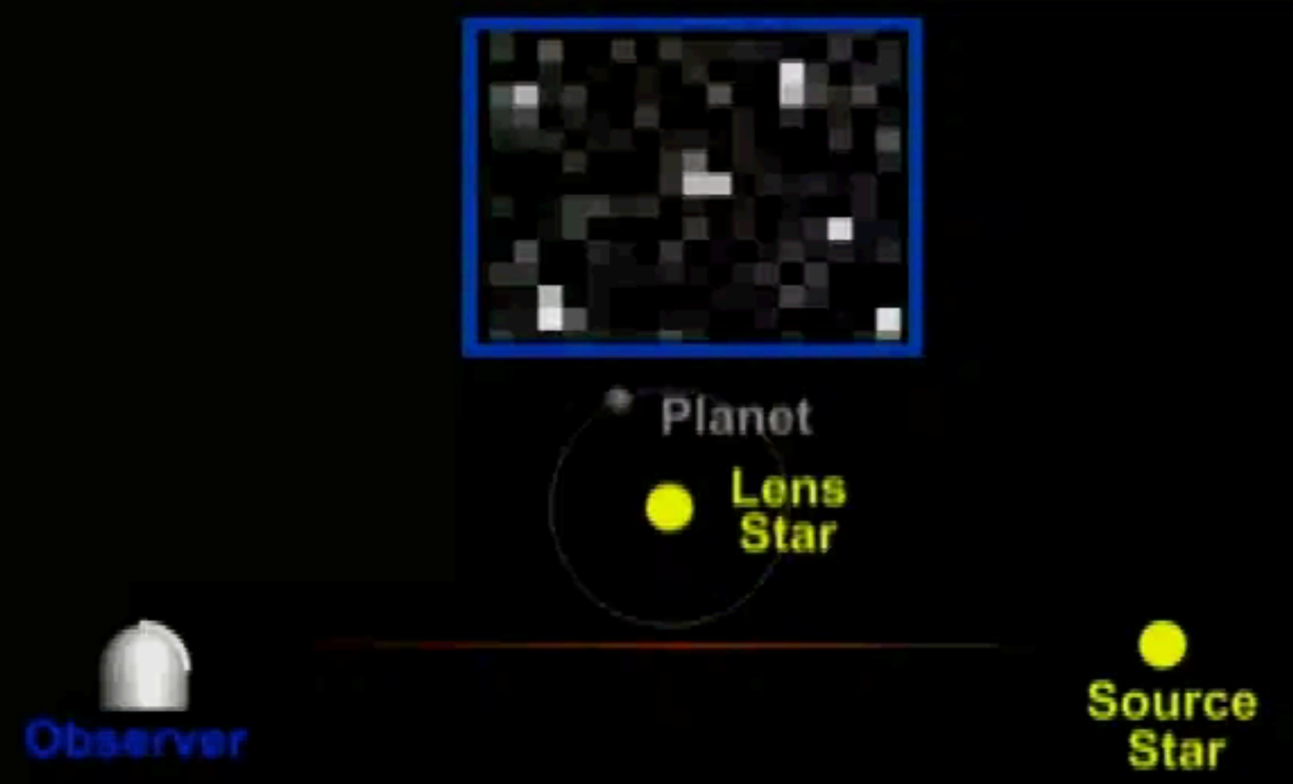


"Practically all Sun-like stars have planets"

- ~17% have planets 0.8 - 1.25 with P < 85 days
- ~50% have planets 1.25 - 4 times the mass of the Earth
- 10% have larger (up to Neptune-size) planets with P < 400d

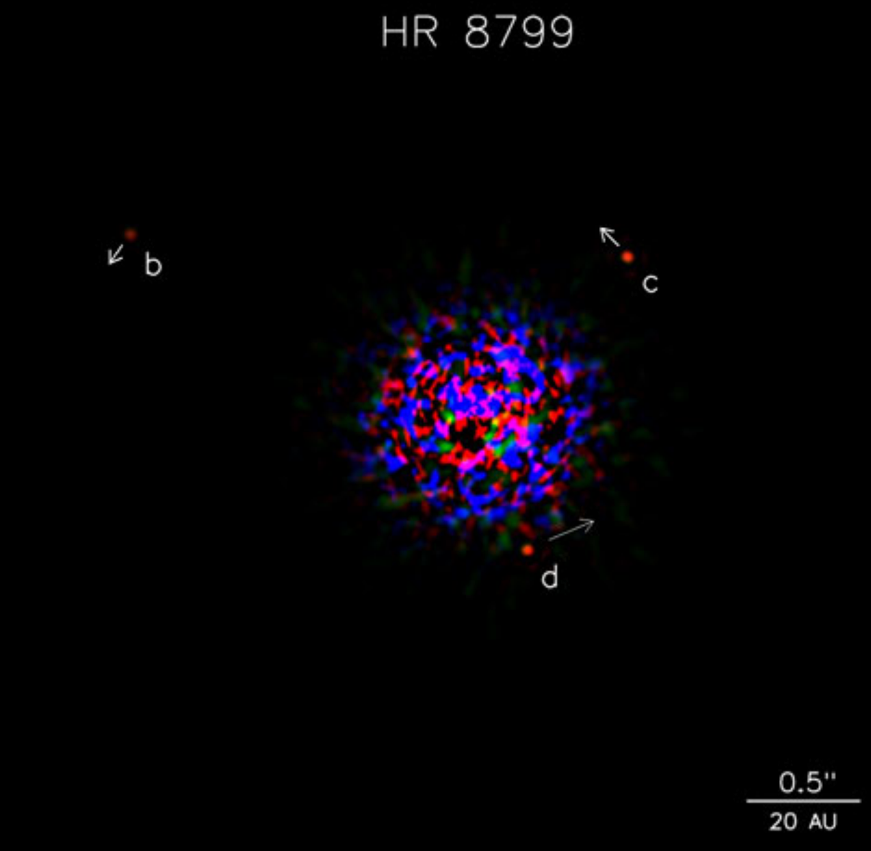
CANDIDATE COUNT: 2740

Microlensing: the star with a planet passes in front of a distant and gravitationally distorts space so that the source light is lensed, and brightens (for a few hours or days).



PLANET COUNT: 21

Direct Imaging: *challenging and exciting work on the horizon with Keck Adaptive Optics Imaging.*



PLANET COUNT: 31

Of the various observational techniques, how many will find “Earths”?

Microlensing (21)?

Transits with Kepler (2740)?

Transits with ground-based telescopes (308)?

Doppler observations (515)?

Imaging (31)

How will we find ***many*** “Earths”?

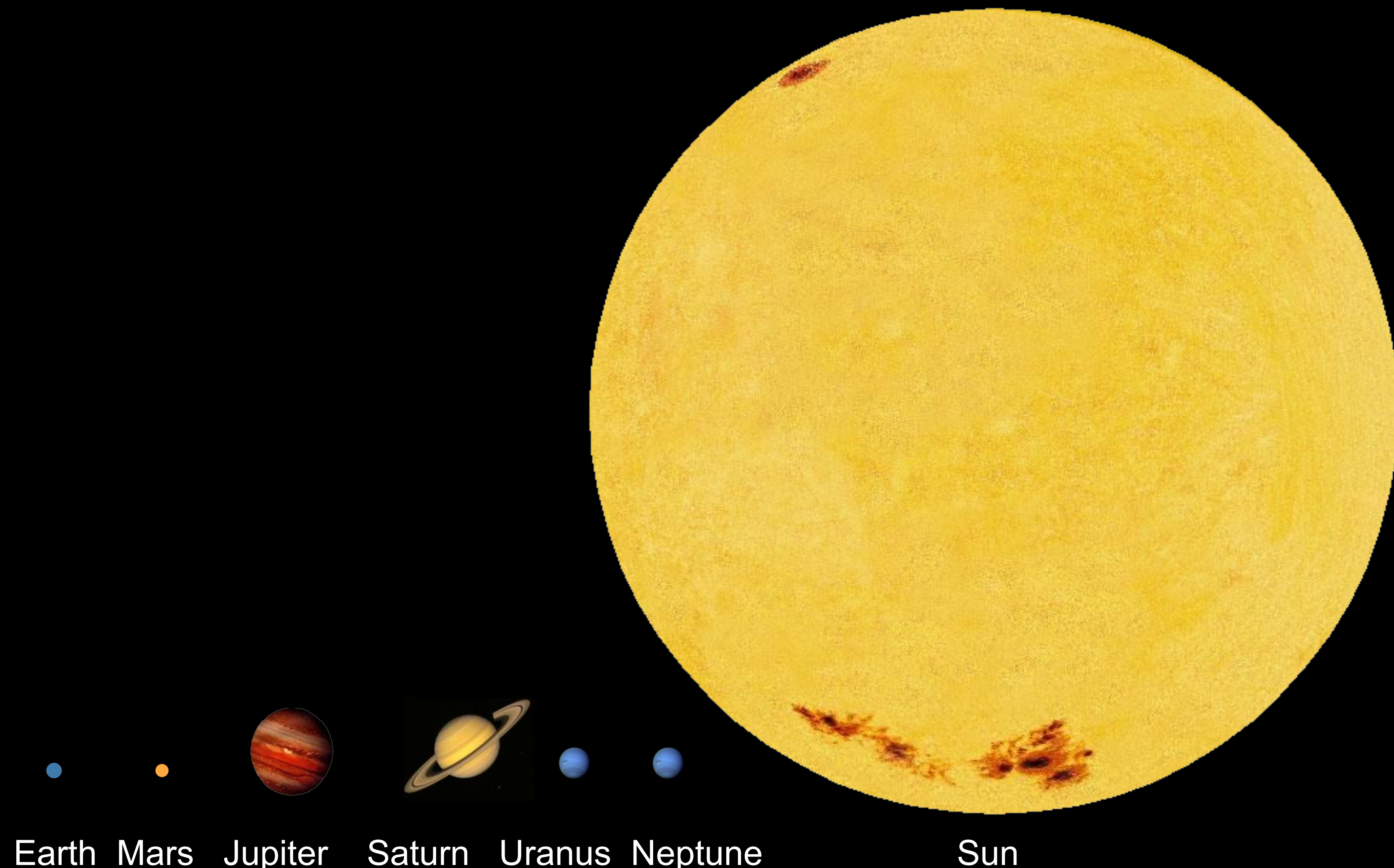
Why Earths?

Best chance of detecting life we can recognize.

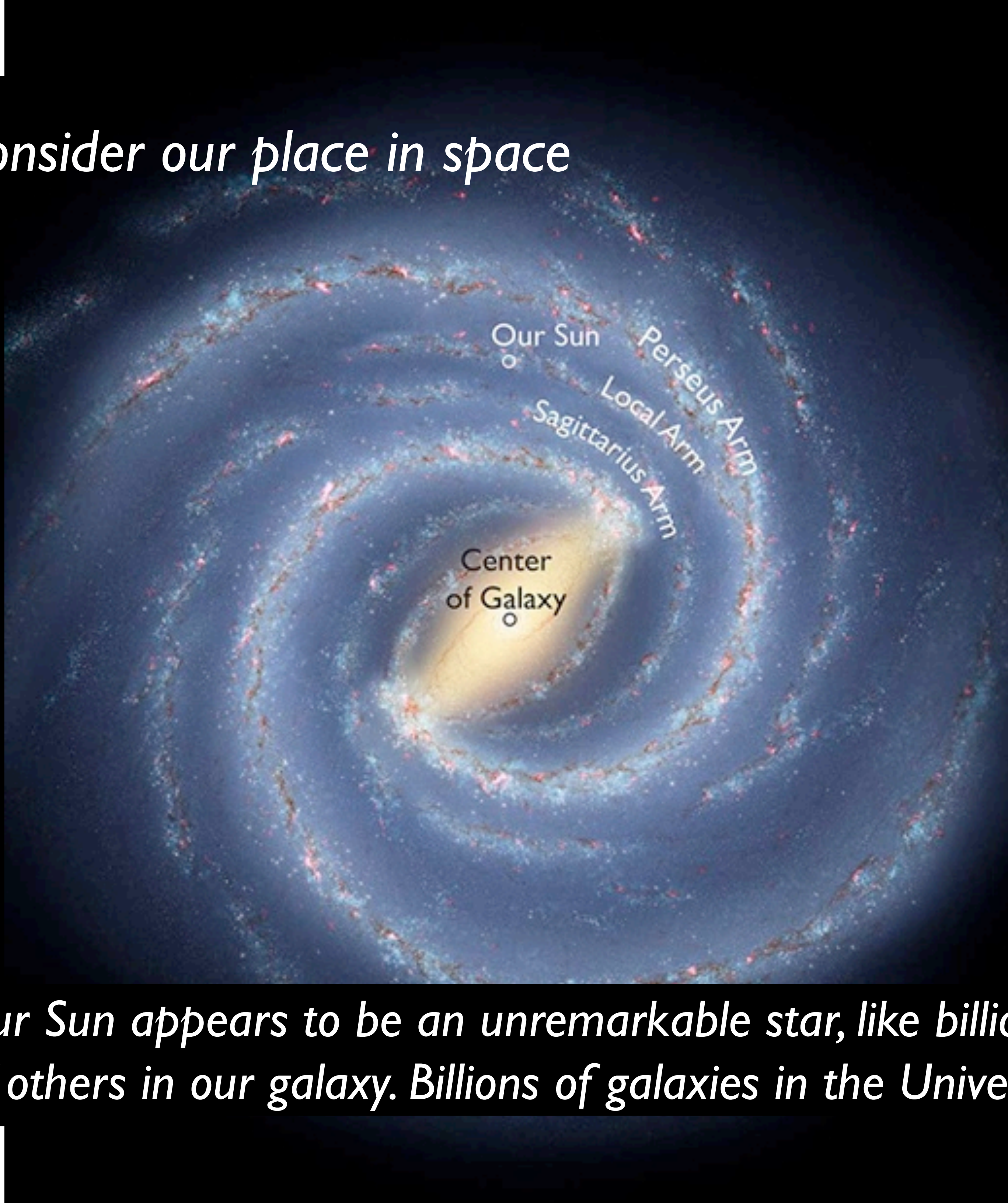
Why look?

What are the practical applications?

1. Consider our place in space



1. Consider our place in space

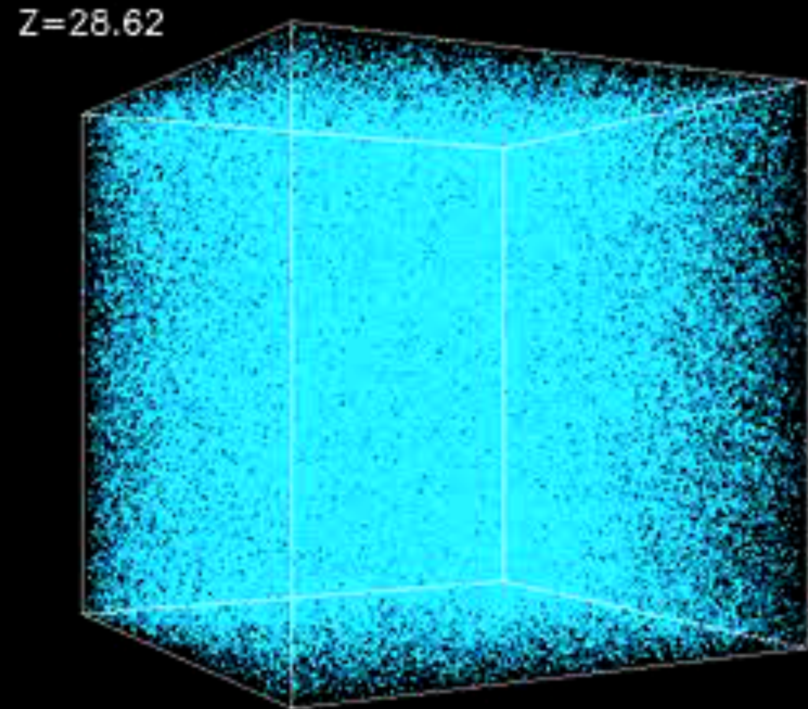


Our Sun appears to be an unremarkable star, like billions of others in our galaxy. Billions of galaxies in the Universe.

1. Consider our place in space

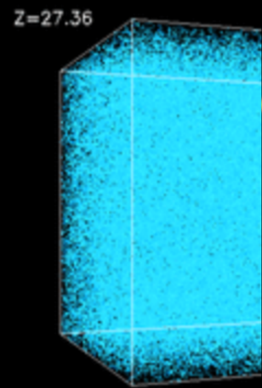
The Universe Contains Billions of Galaxies

2. Consider the rareness of our composition

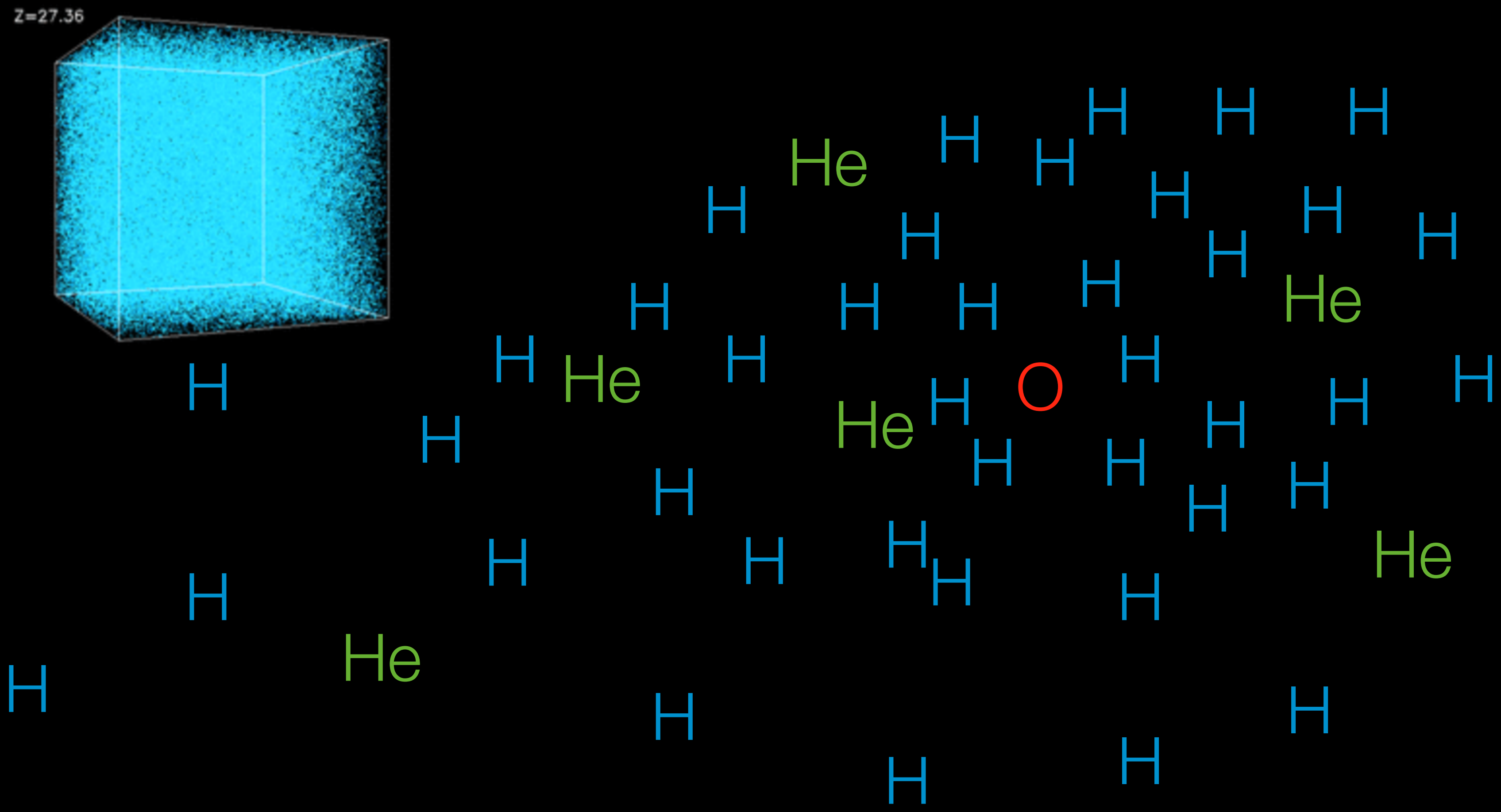


Fair sample of the Universe: a representative volume, large enough to show the average structure.

2. Consider the rareness of our composition



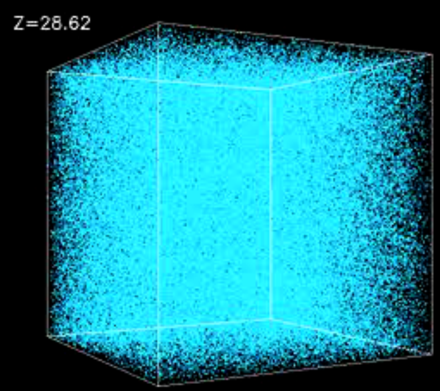
2. Consider the rareness of our composition



2. Consider the rareness of our composition

Neutrinos

2. Consider the rareness of our composition

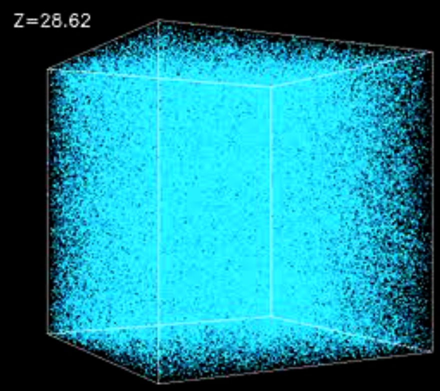


Something else in this Fair Sample that we can barely sense. It does not reflect or absorb light. The only sign of it's presence is the gravitational pull of its mass.

........Dark Matter.

Drifts through solid matter but moves slowly and outweighs normal matter by a factor of 5.

2. Consider the rareness of our composition

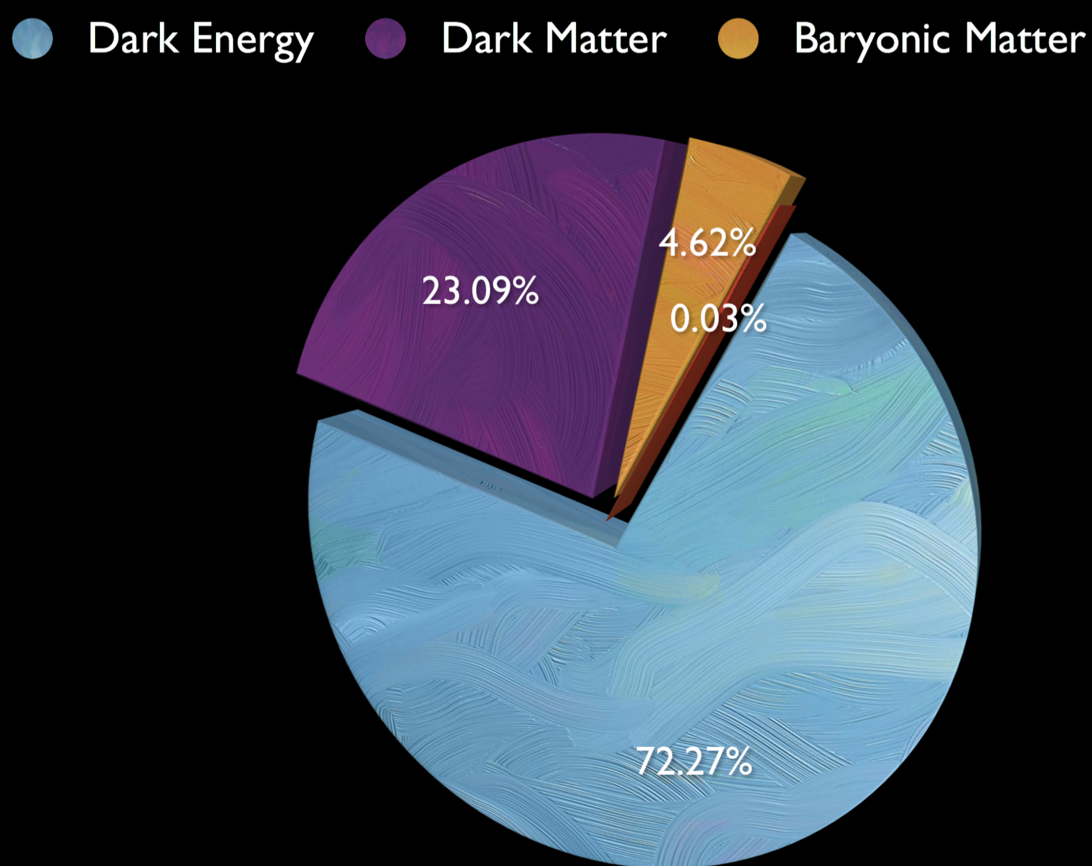


In 1995, we learned that there was something else in this Fair Sample.

........Dark Energy.

We can compare energy and mass: $E=mc^2$ and as far as we can tell, dark energy makes up ~75% of the stuff in our Fair Sample.

2. Consider the rareness of our composition

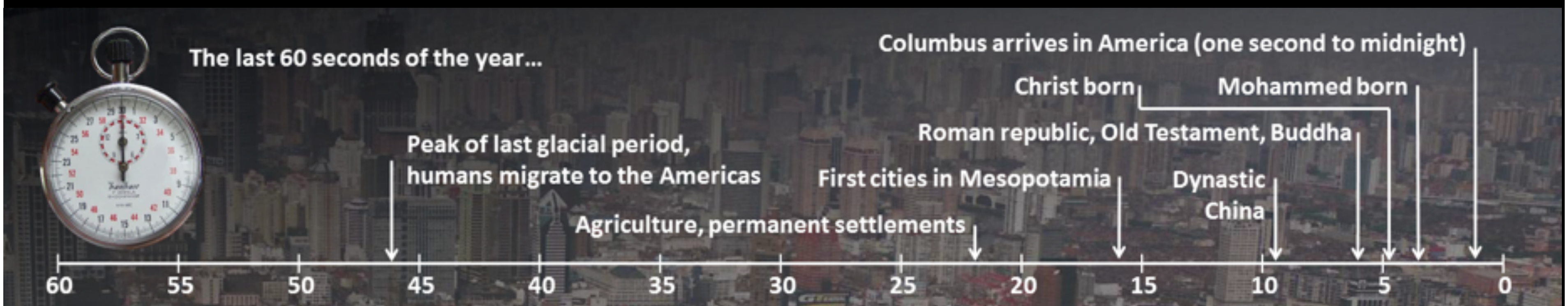


3. Consider our place in time

3. Consider our place in time

December						
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17 Animal fossils	18 Trilobites	19	20 Land plants	21 Insects
22 Amphibians	23	24 Reptiles	25 Dinosaurs	26 Mammals	27 Pangaea splits	28 Birds, flowers
29 Dinosaurs at top of food chain 	30 Dinosaurs go extinct, mammals diversify and return to the sea					

3. Consider our place in time



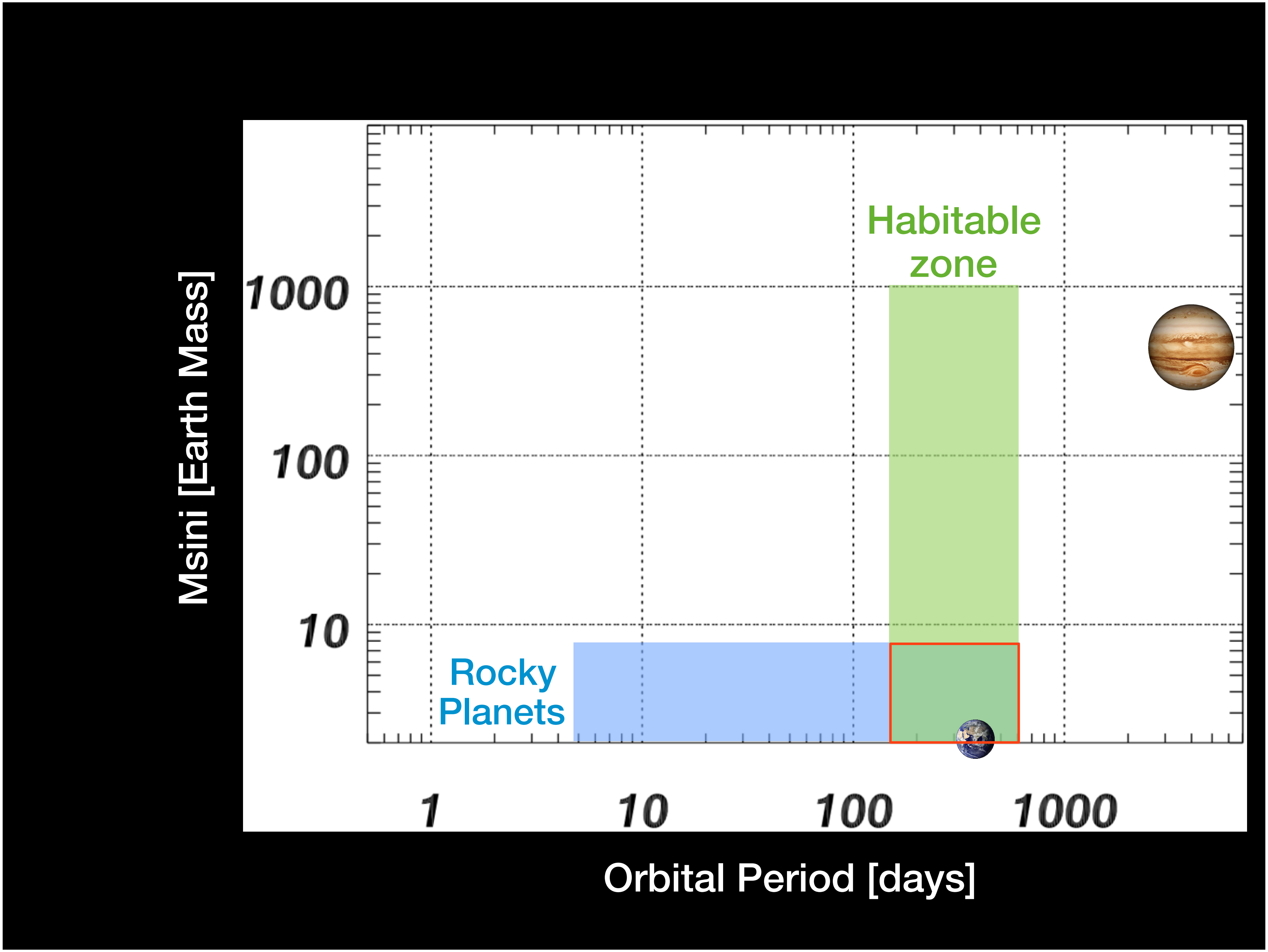
3. Consider our place in time

We do not dominate the Universe in any sense - our place in space is small.

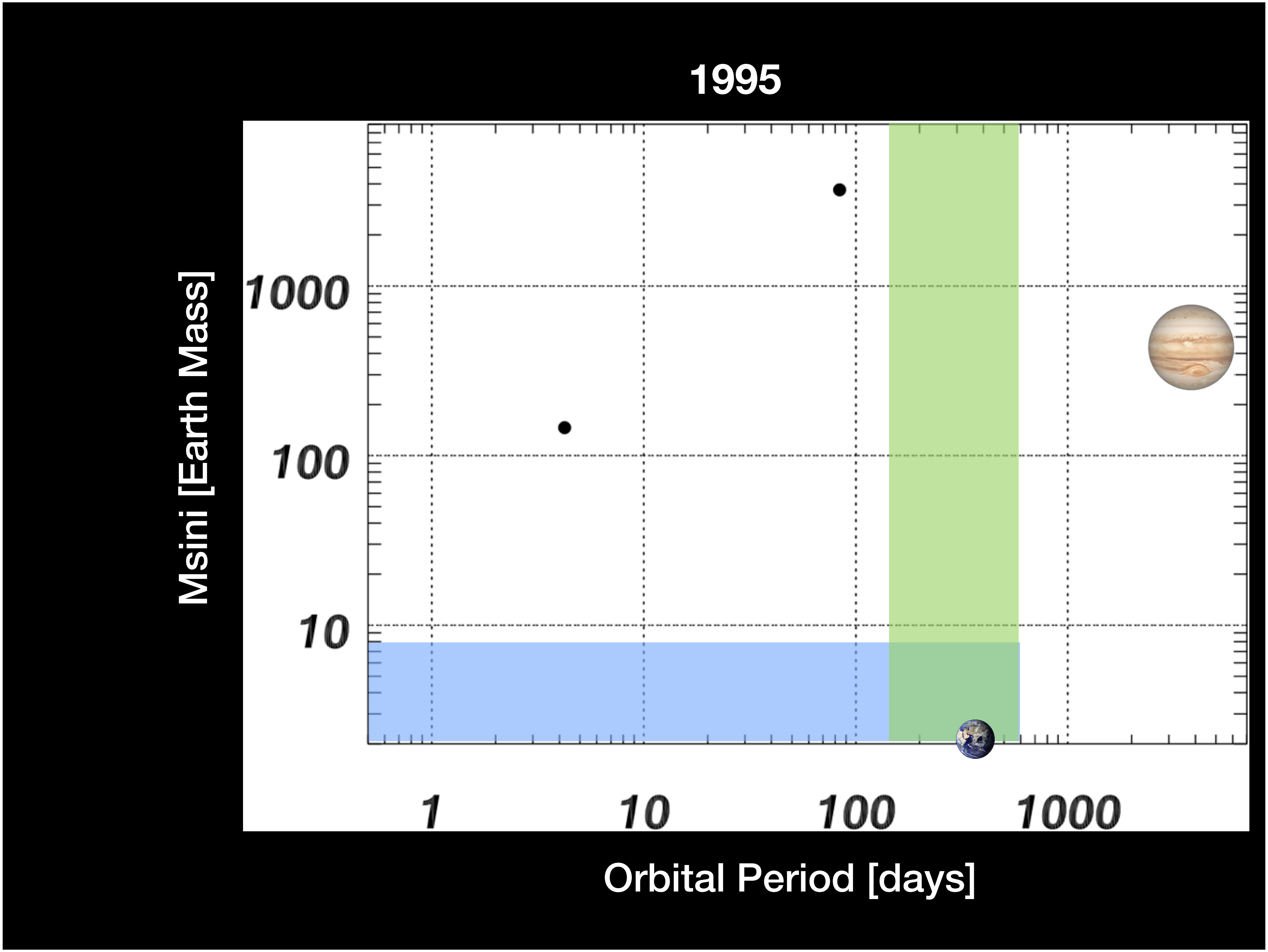
We are rare stuff in the Periodic Table

We are newcomers to this planet.

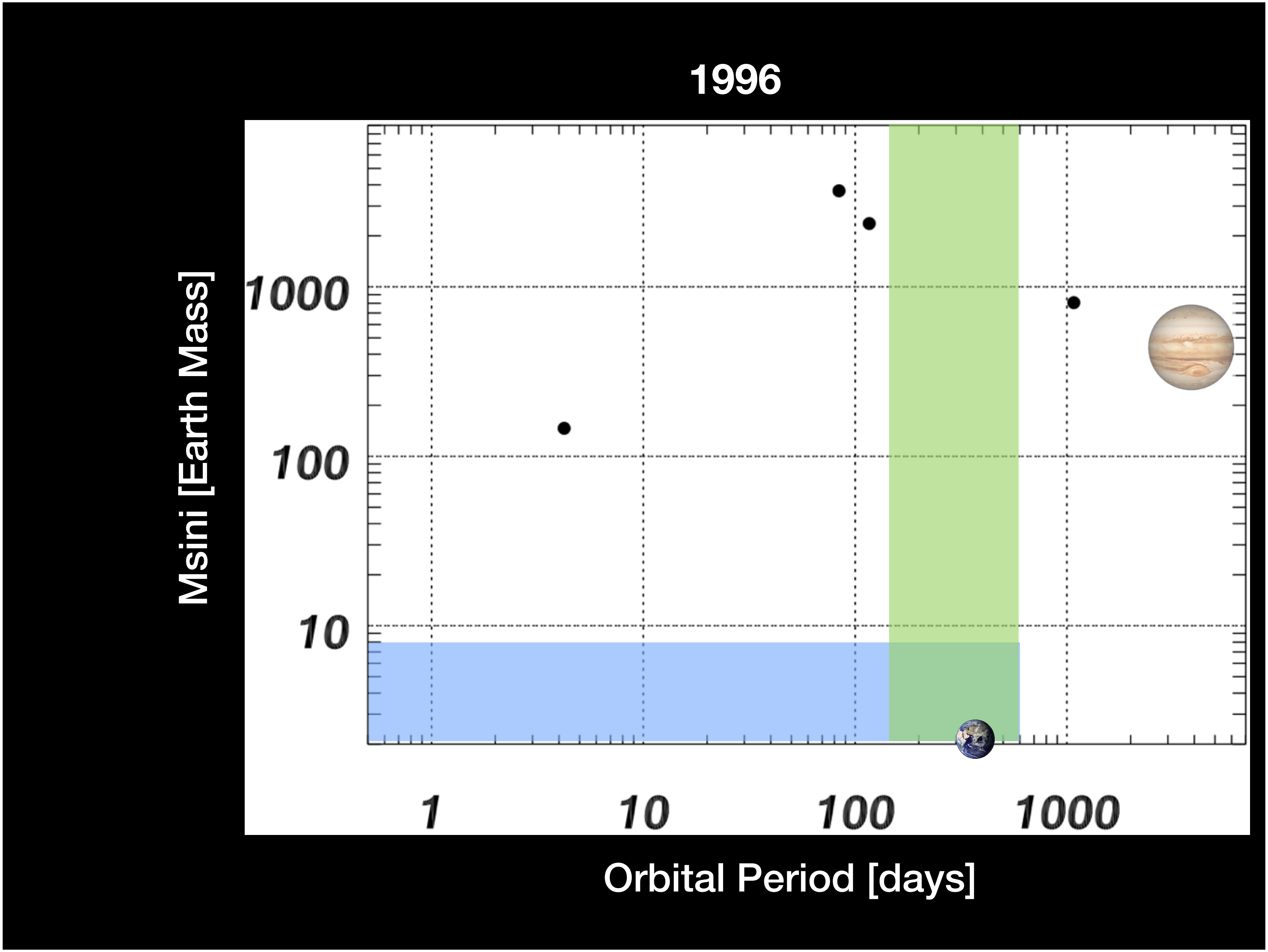
http://www.youtube.com/watch?v=MrqqD_Tsy4Q

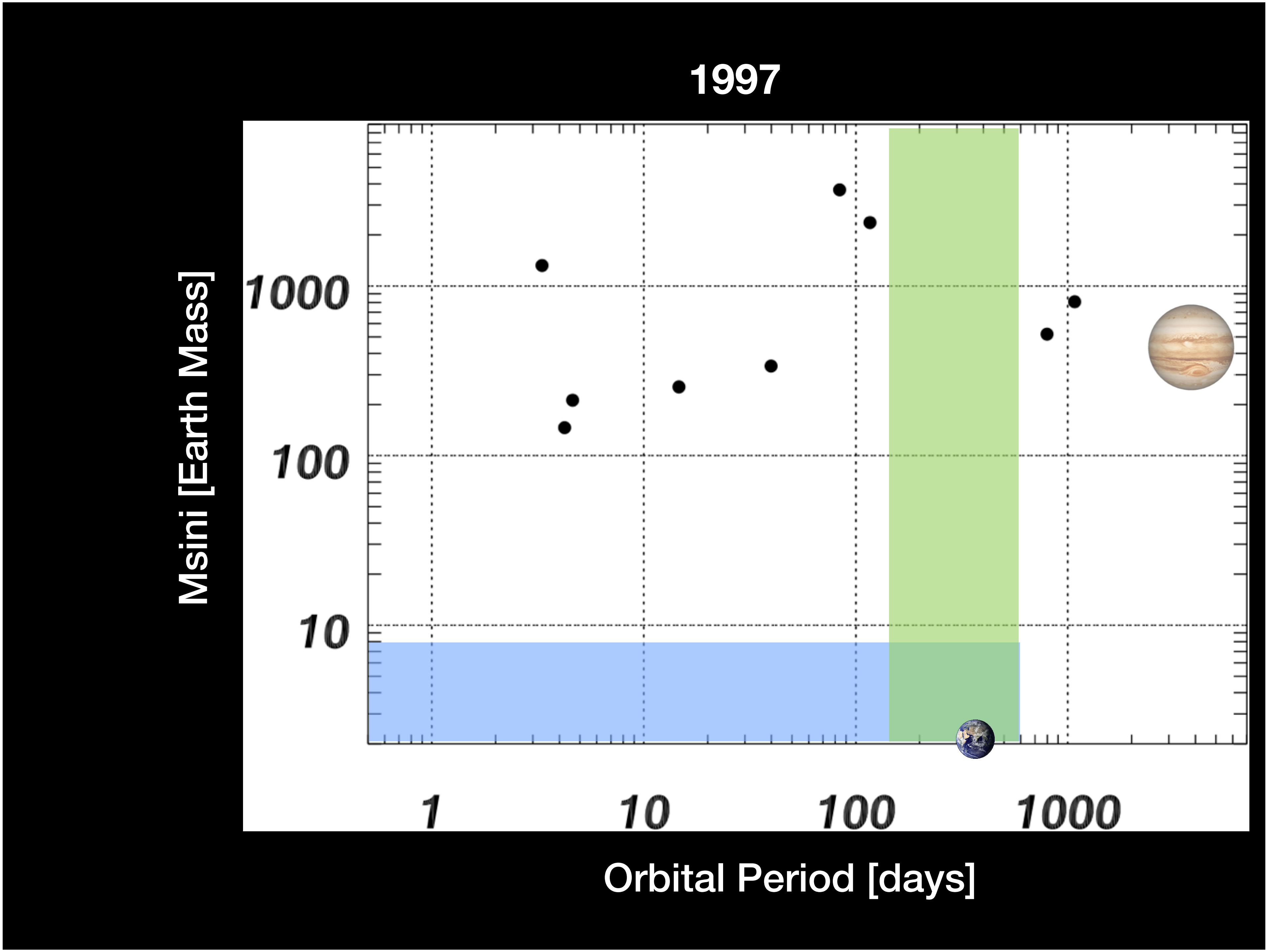


Habitable
zone
Rocky
Planets
1000
100
10
1
10
100
1000
Msini [Earth Mass]
Orbital Period [days]

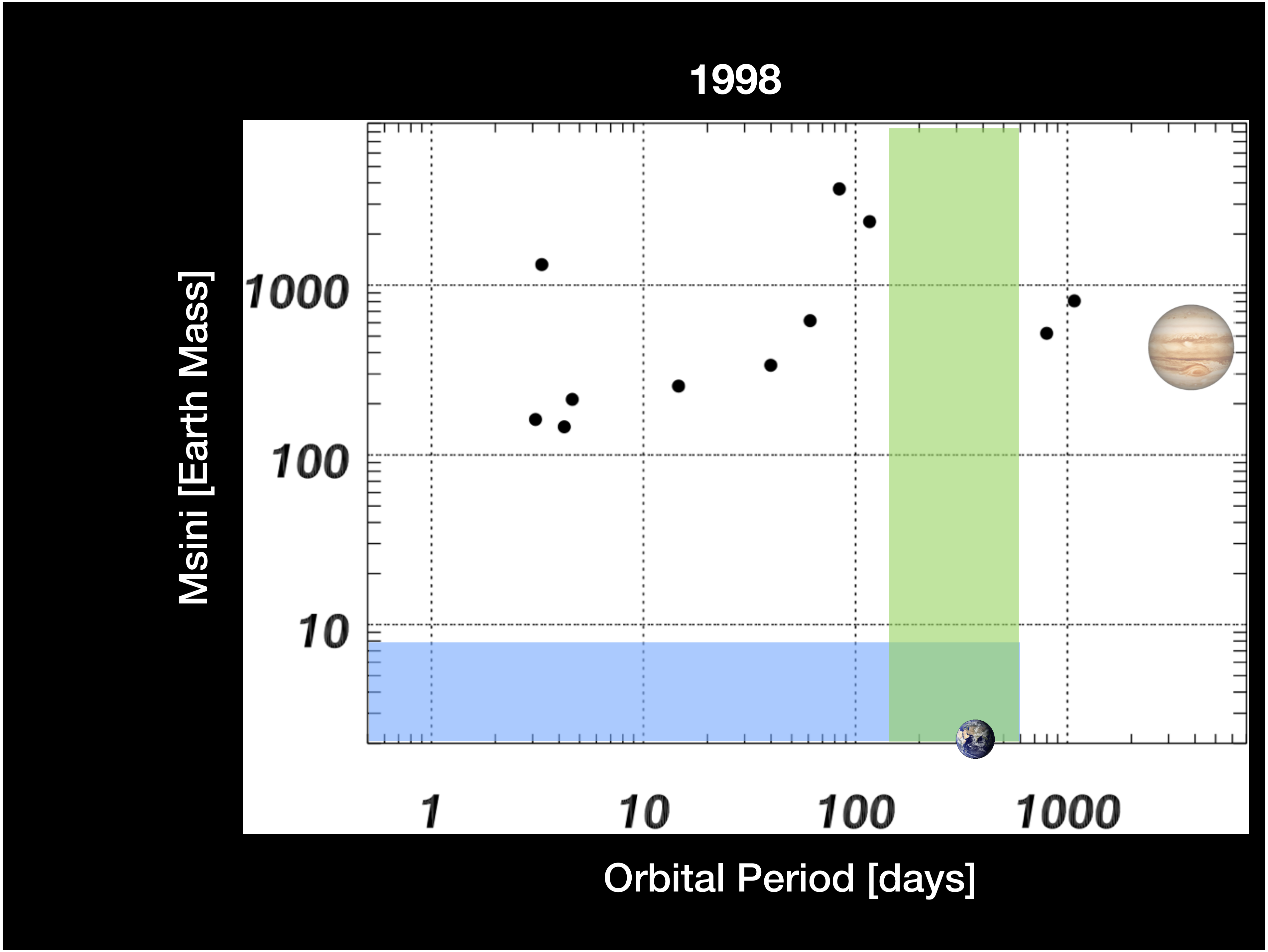


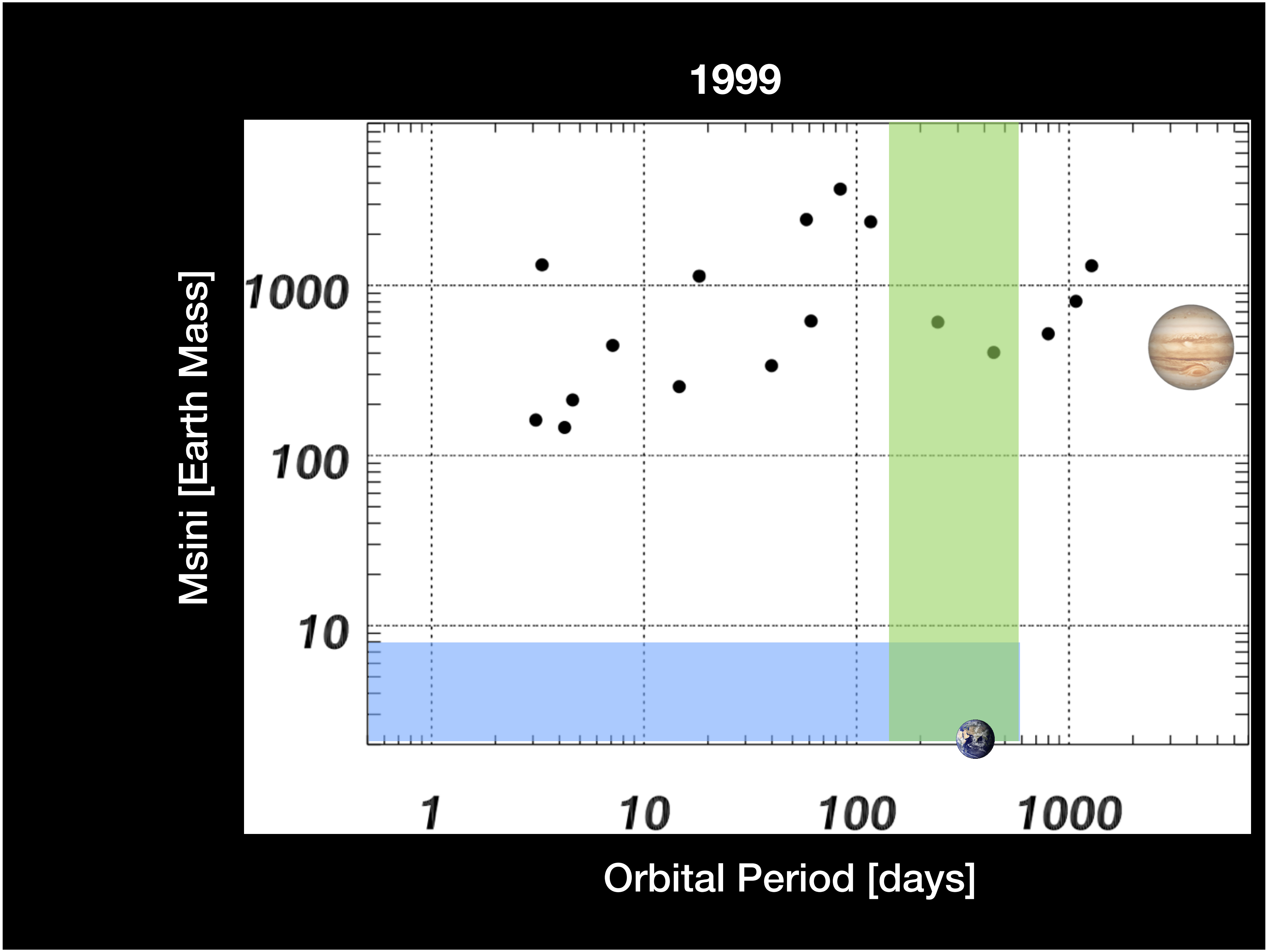
1995
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

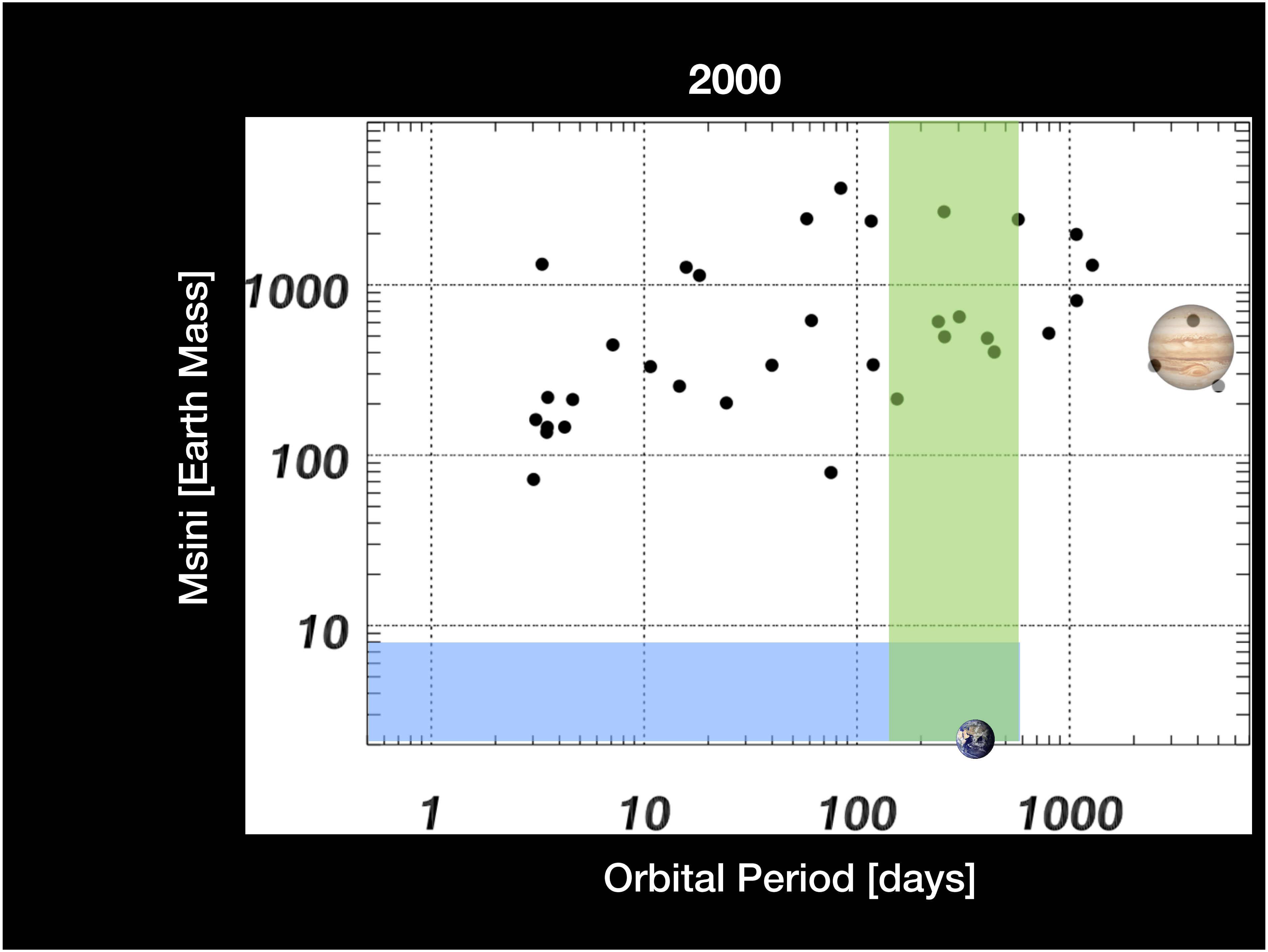

1996
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]



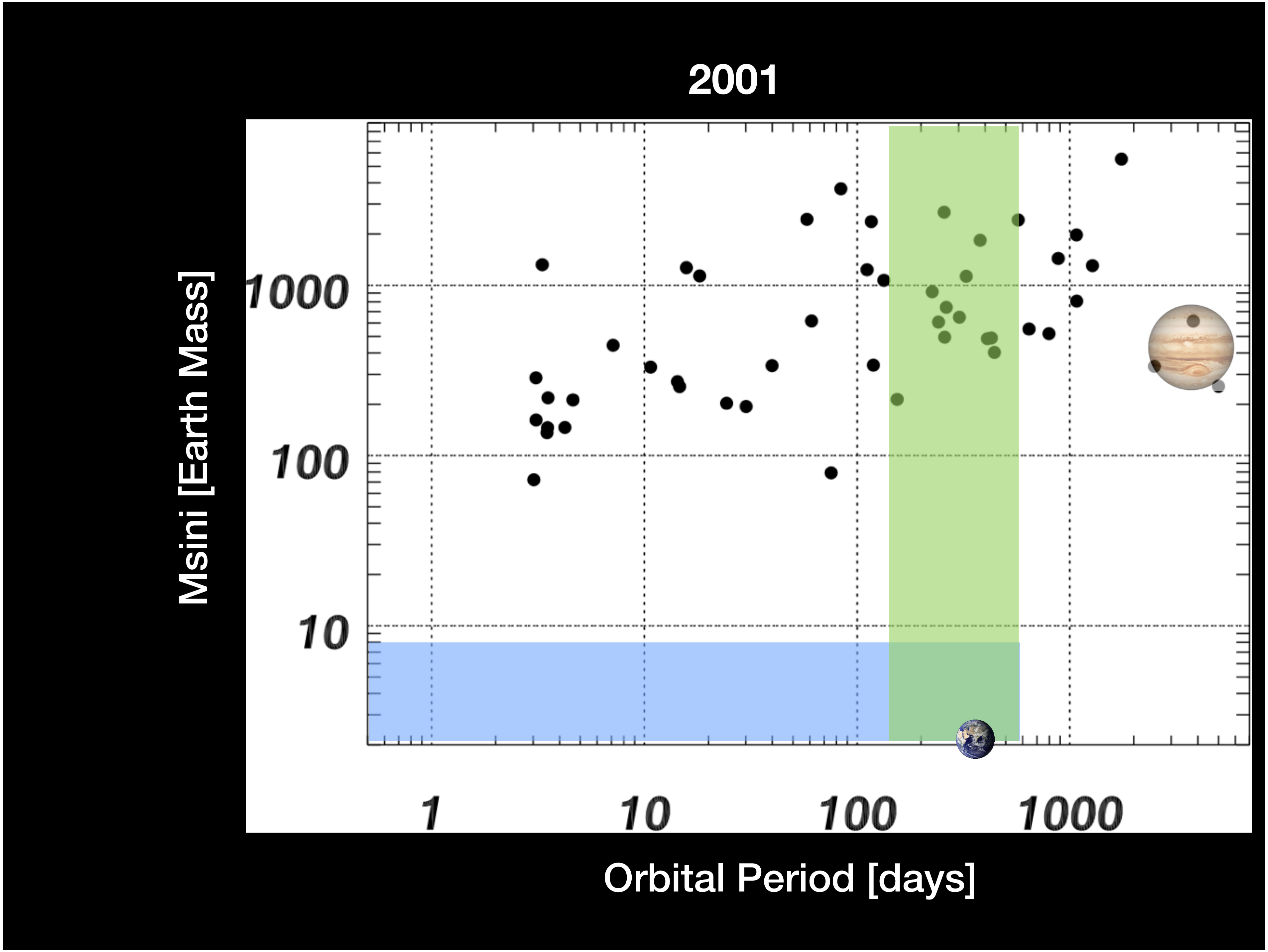
1997
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

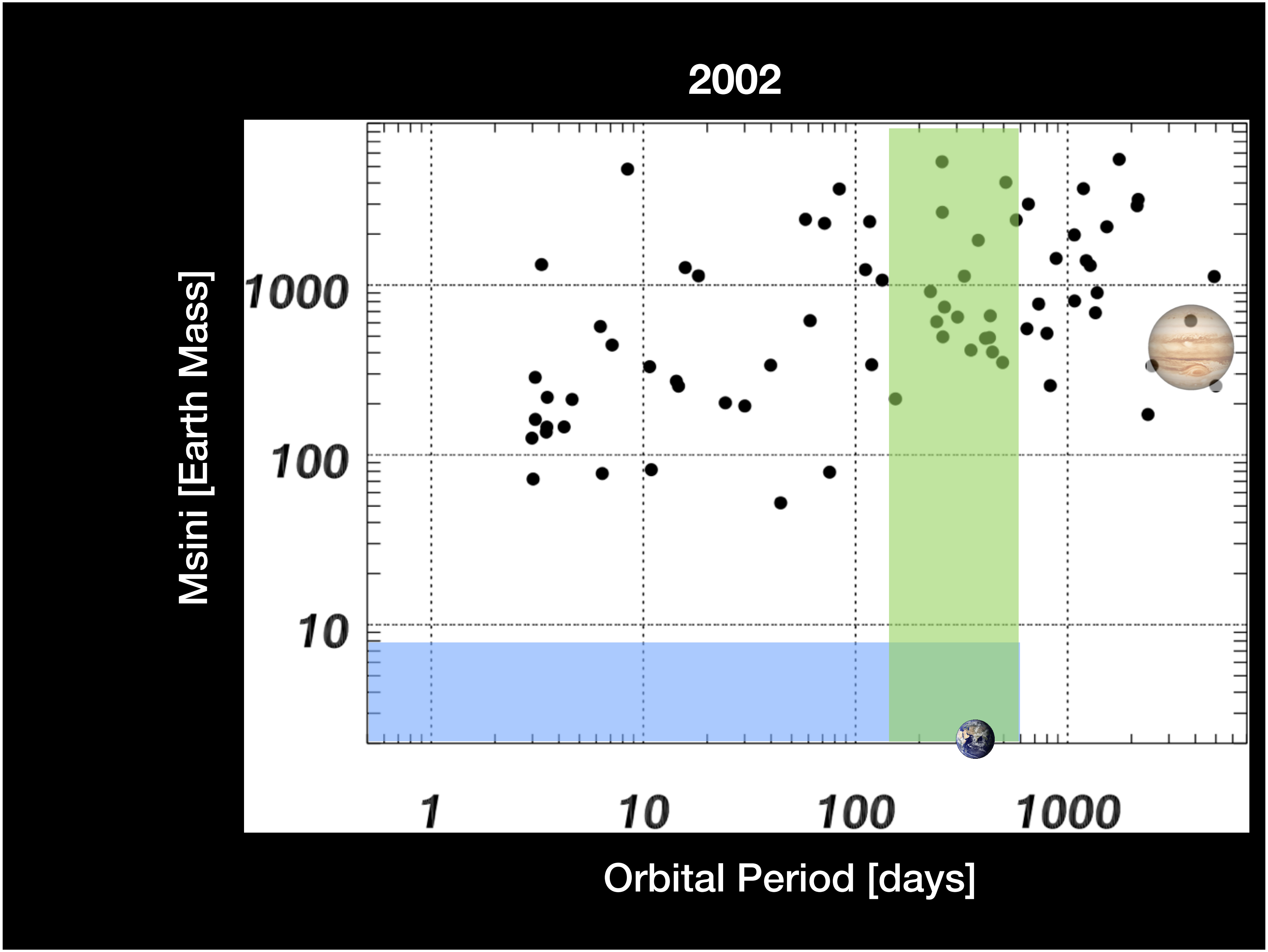

1998
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]


1999
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

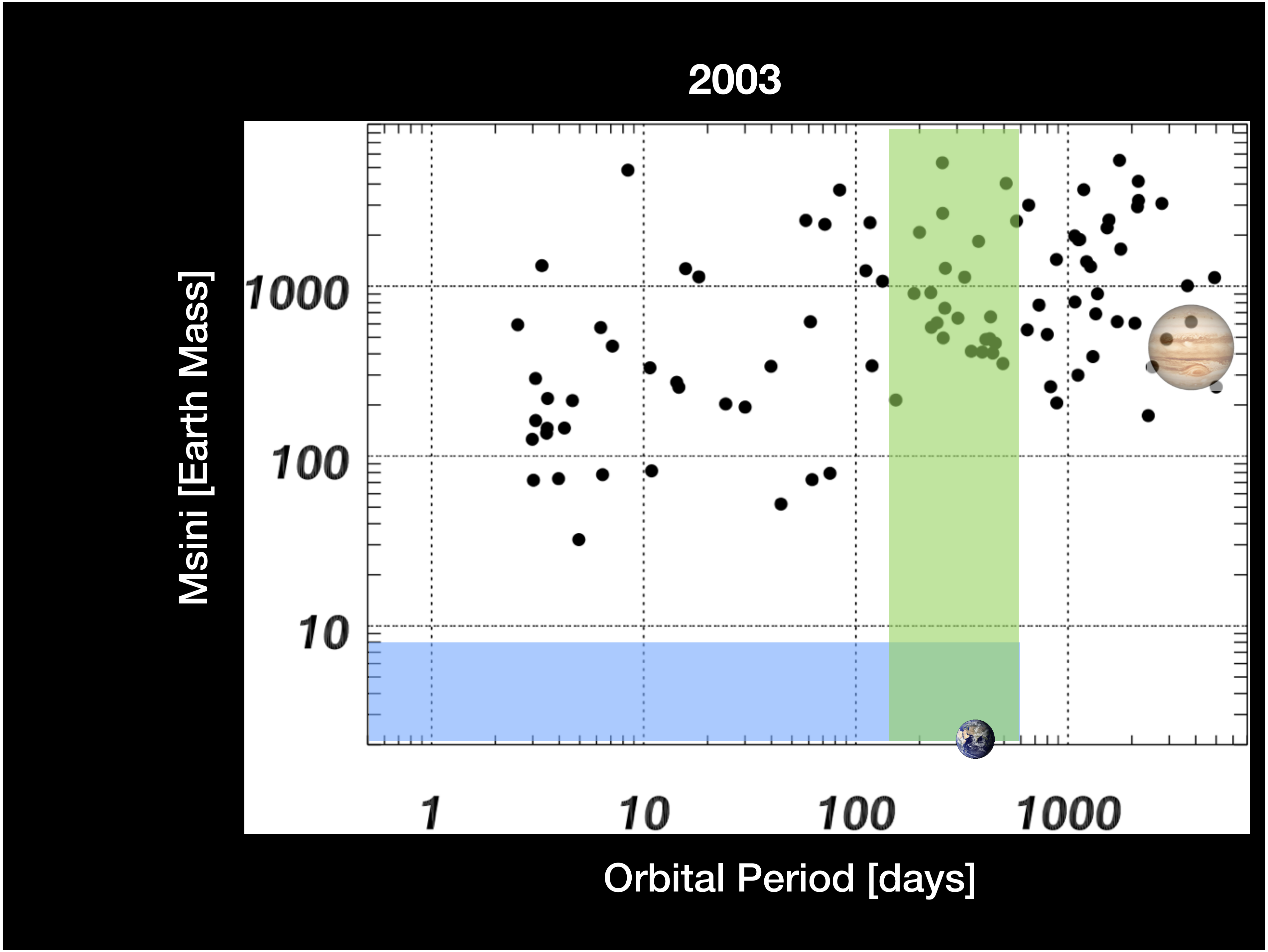


2000
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

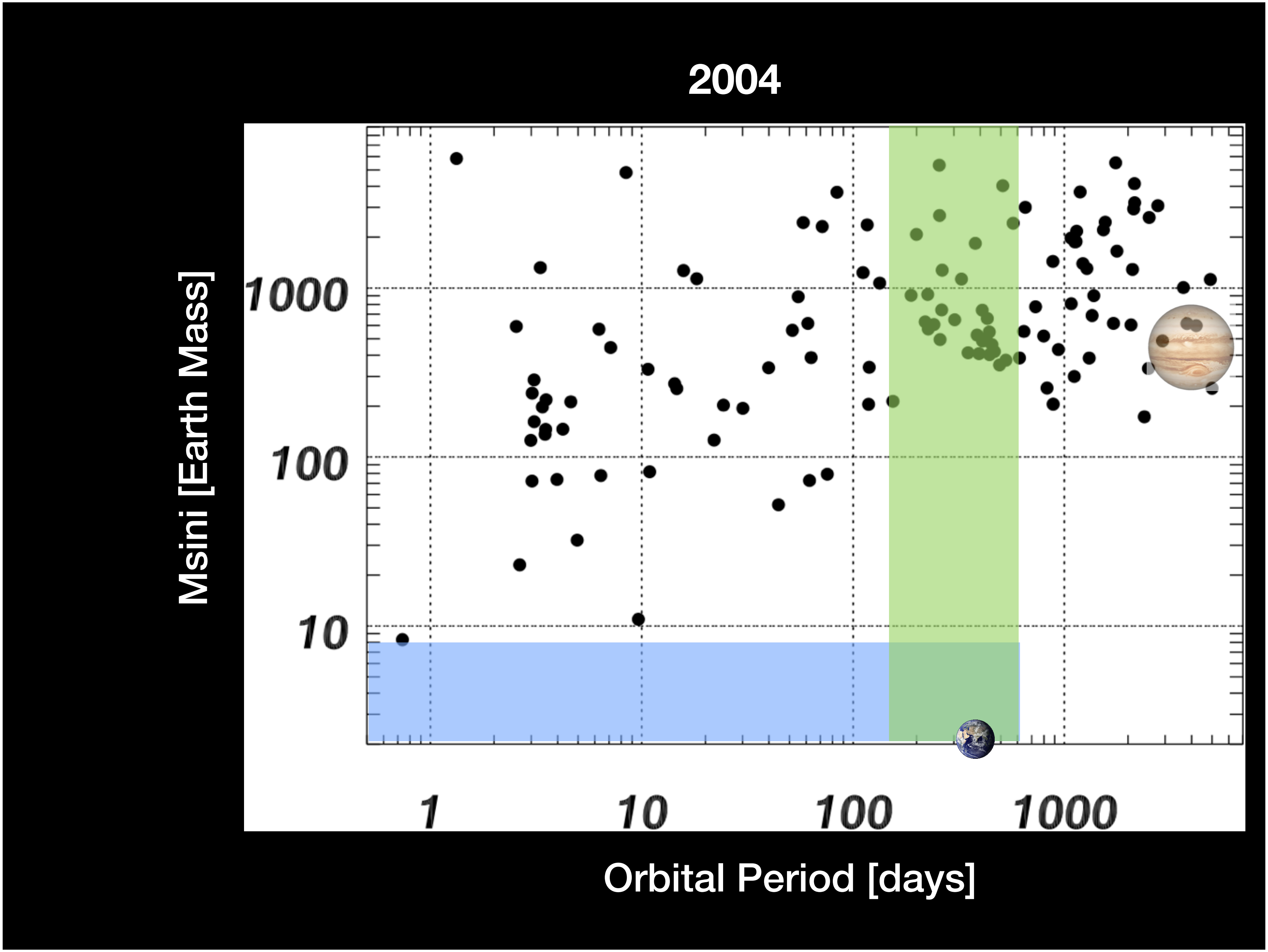

2001
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]



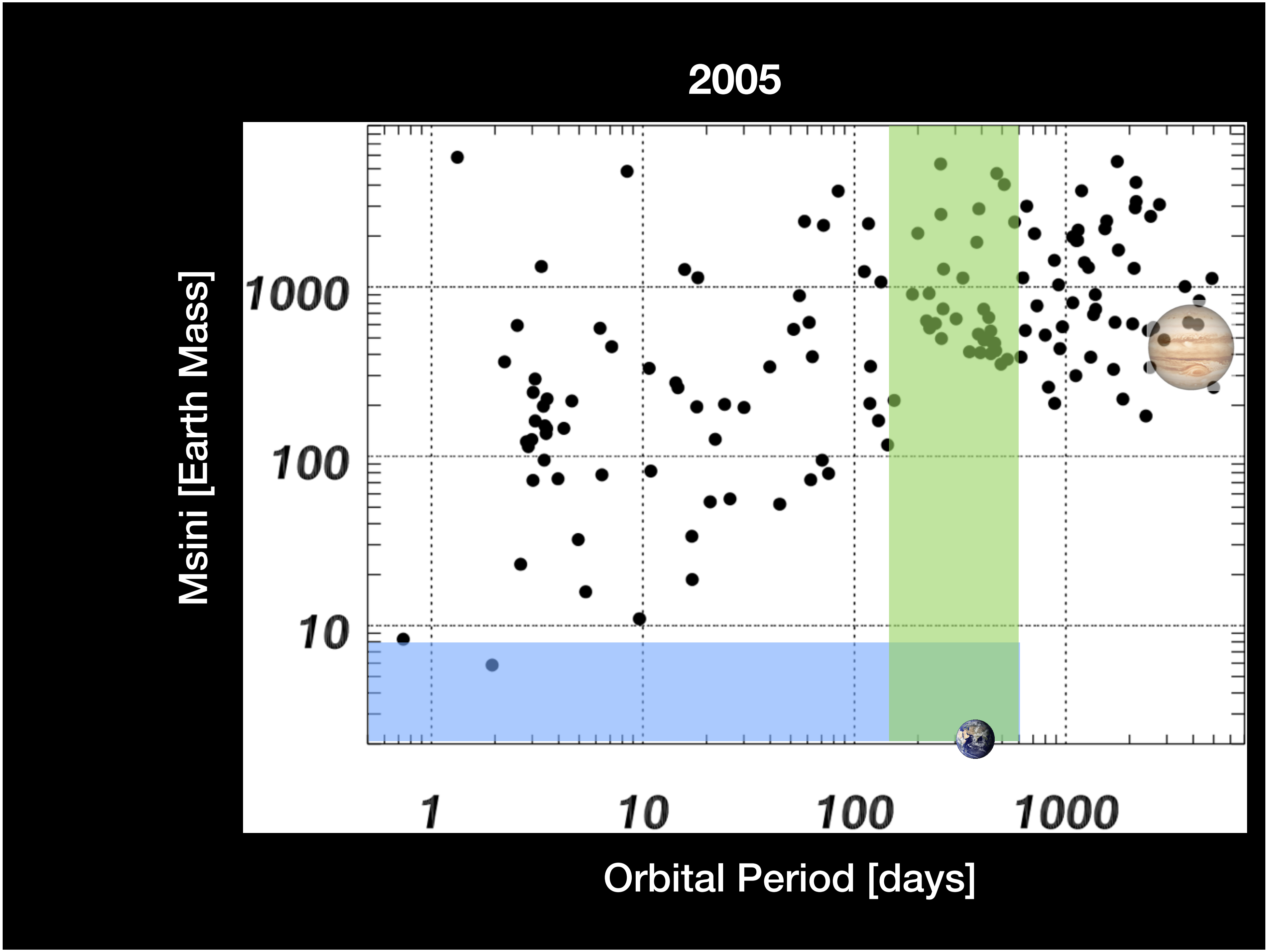
2002
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

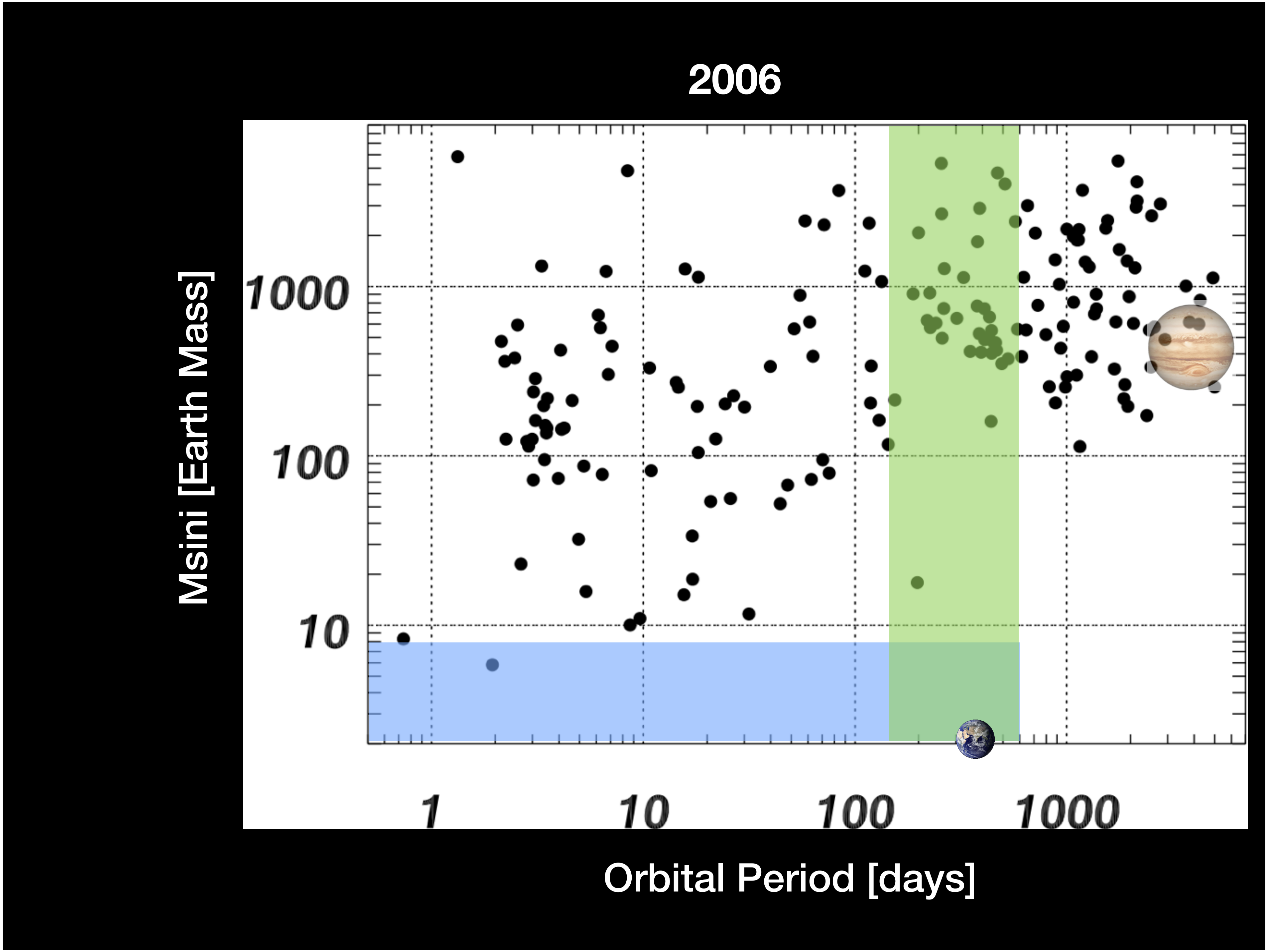


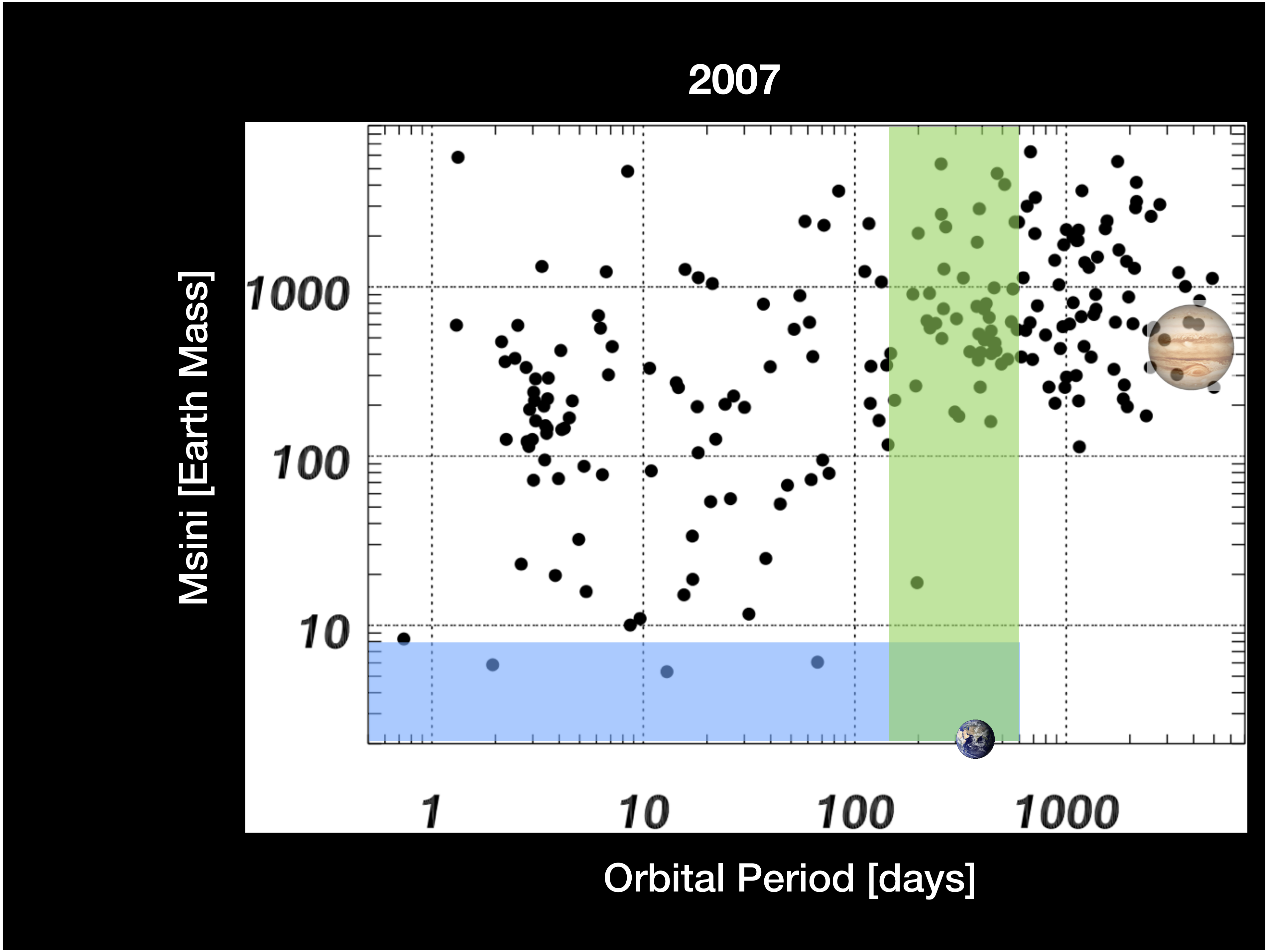
2003
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]



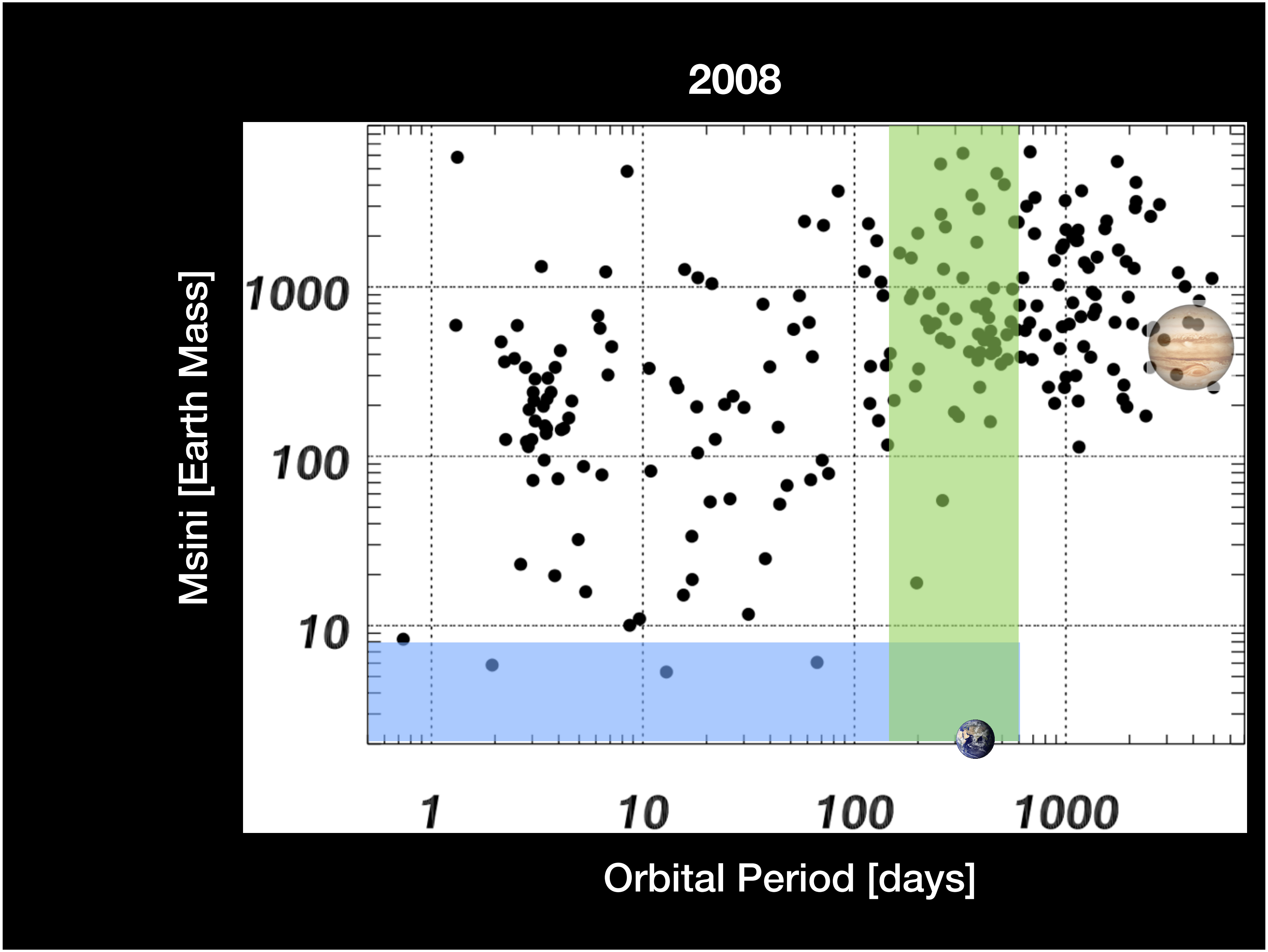
2004
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]


2005
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

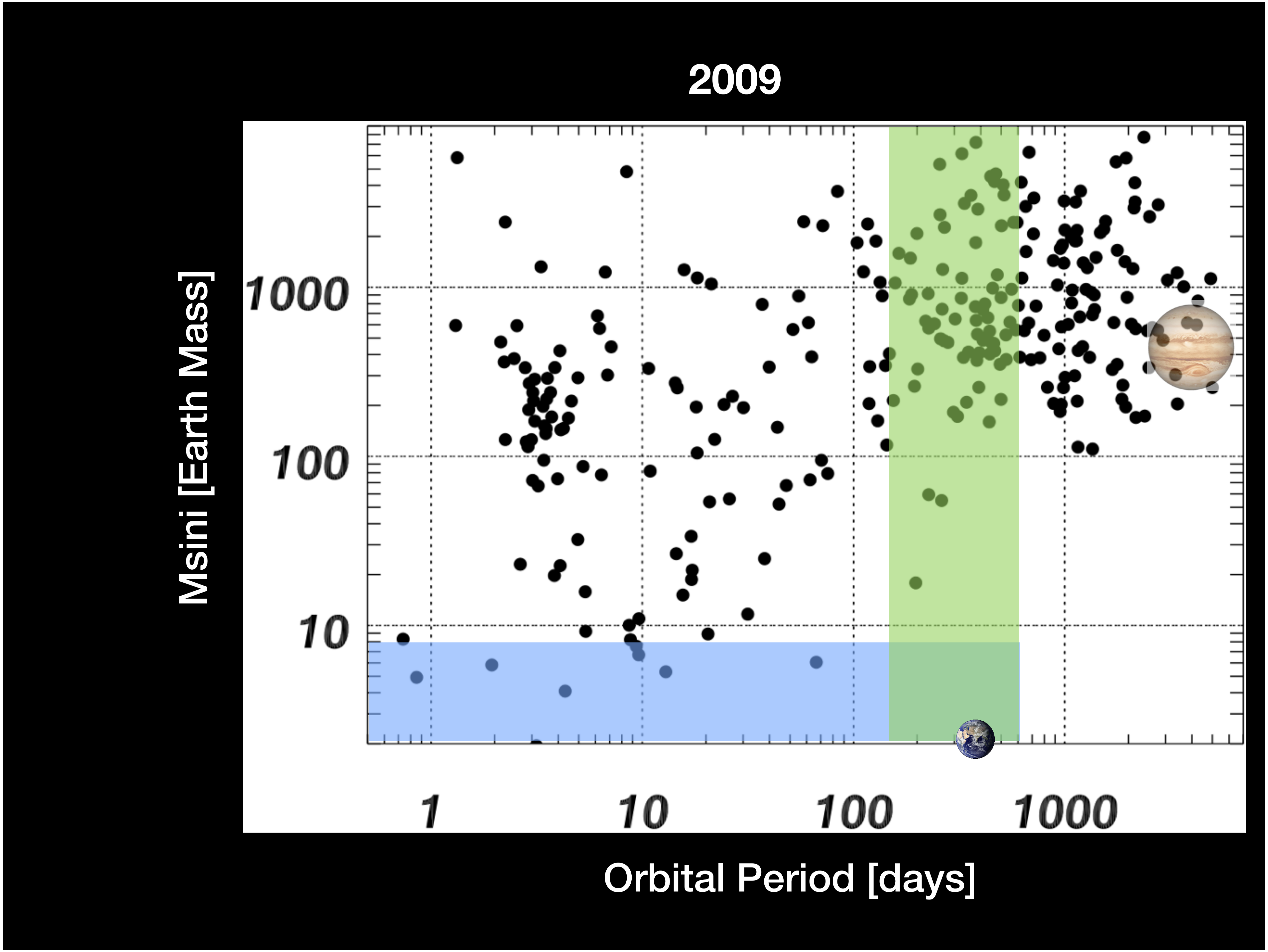

2006
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

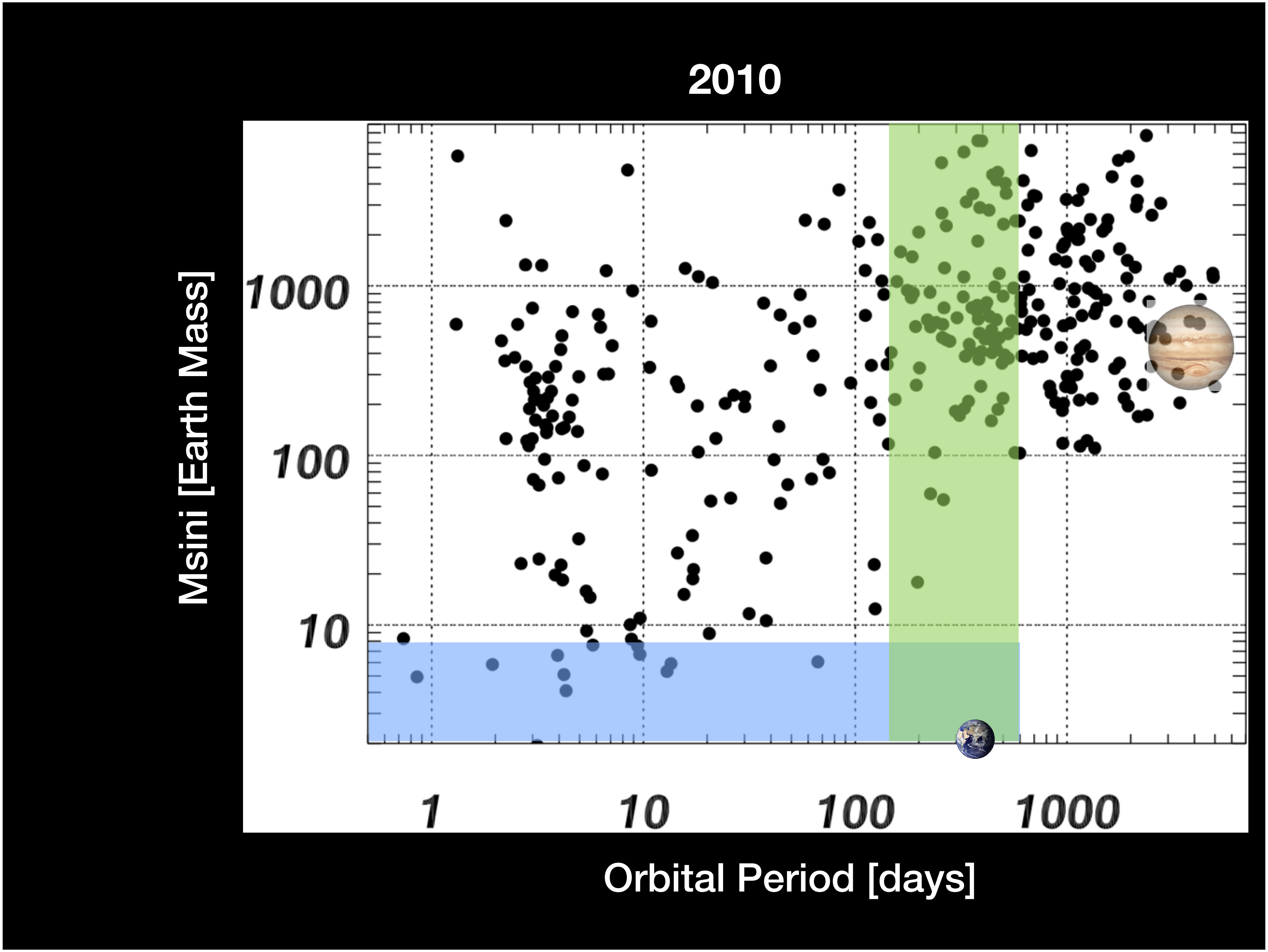


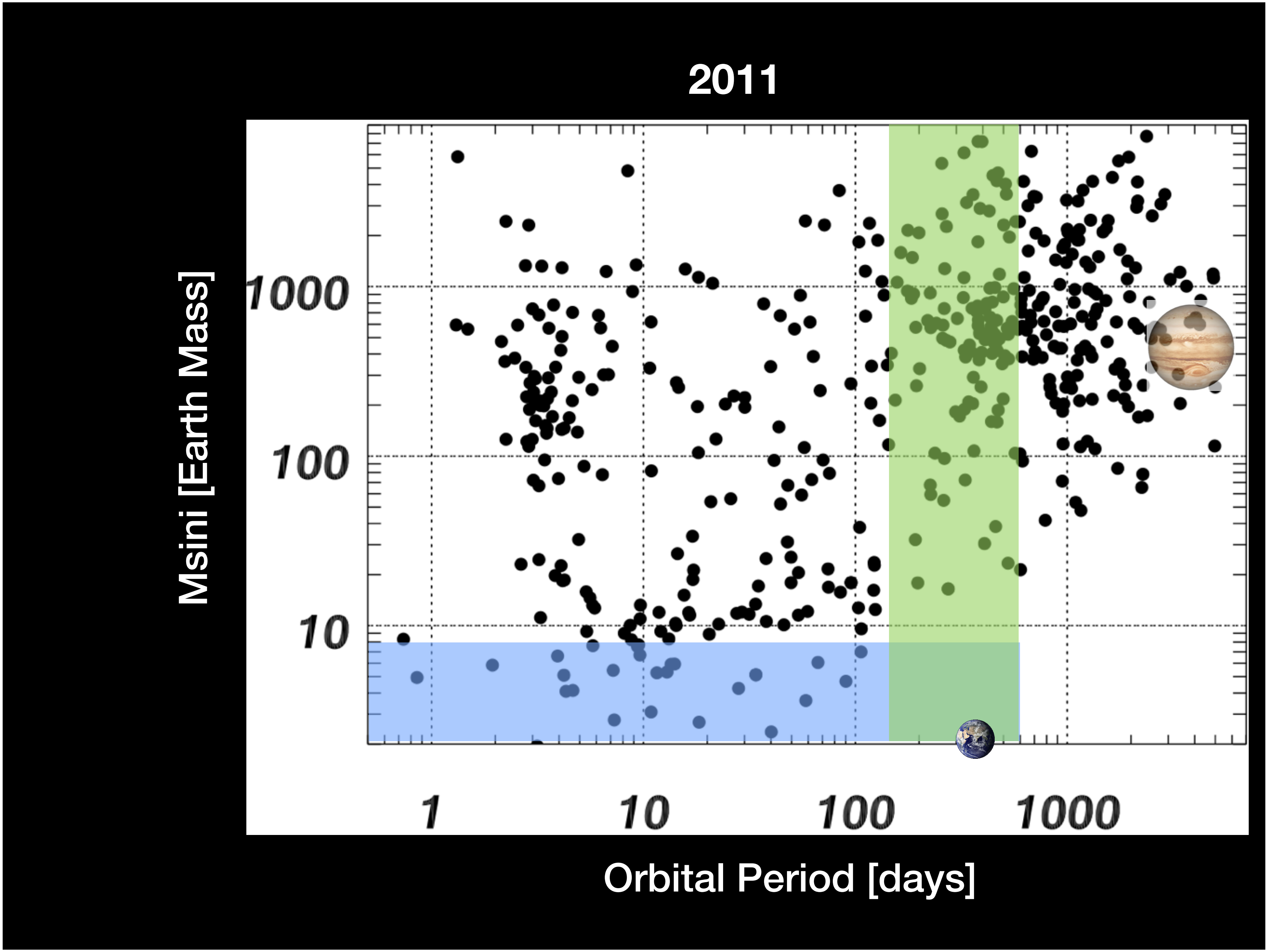
2007
1000
100
10
Msini [Earth Mass]
1
10
100
1000
Orbital Period [days]

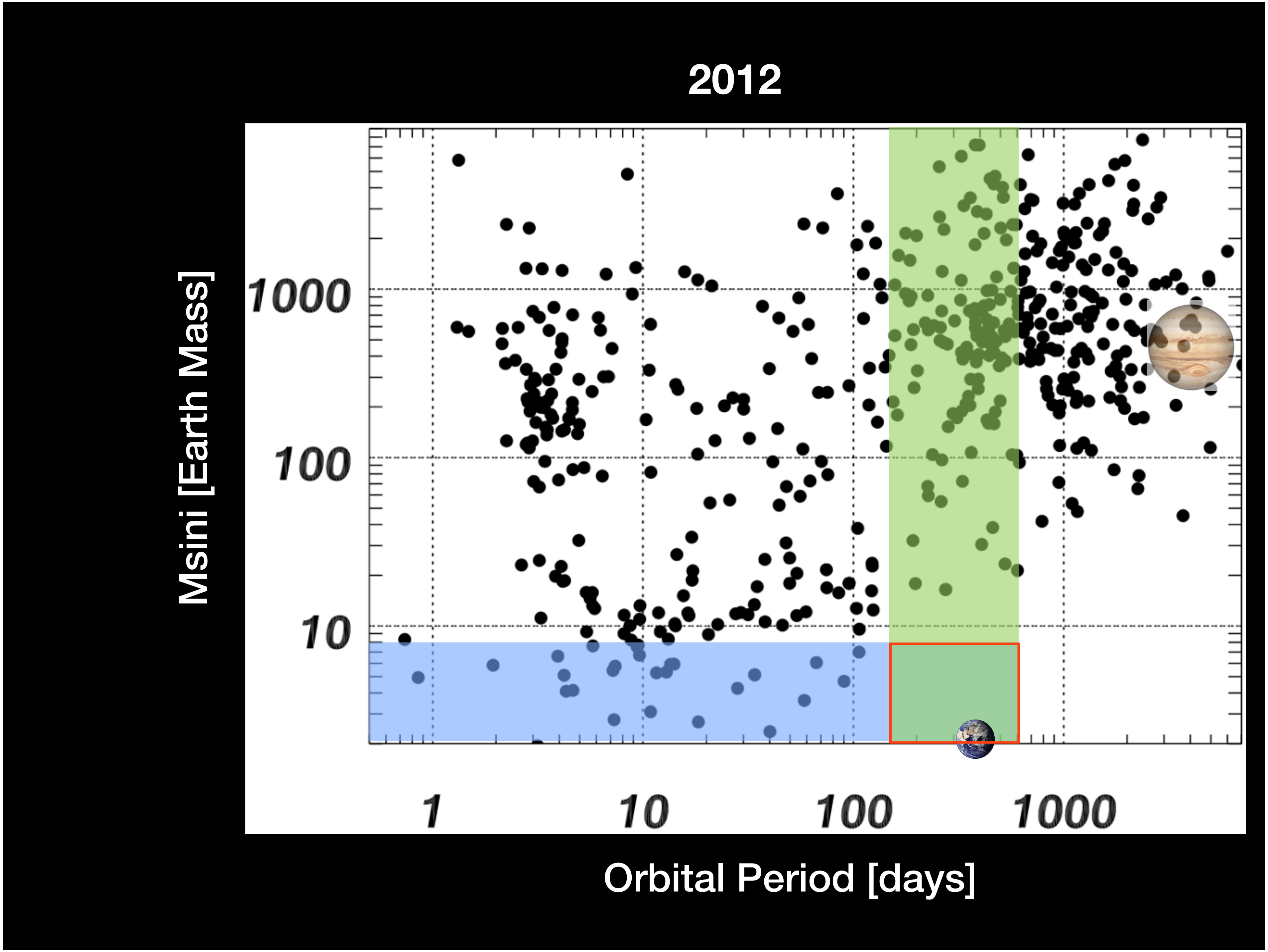


2008
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]

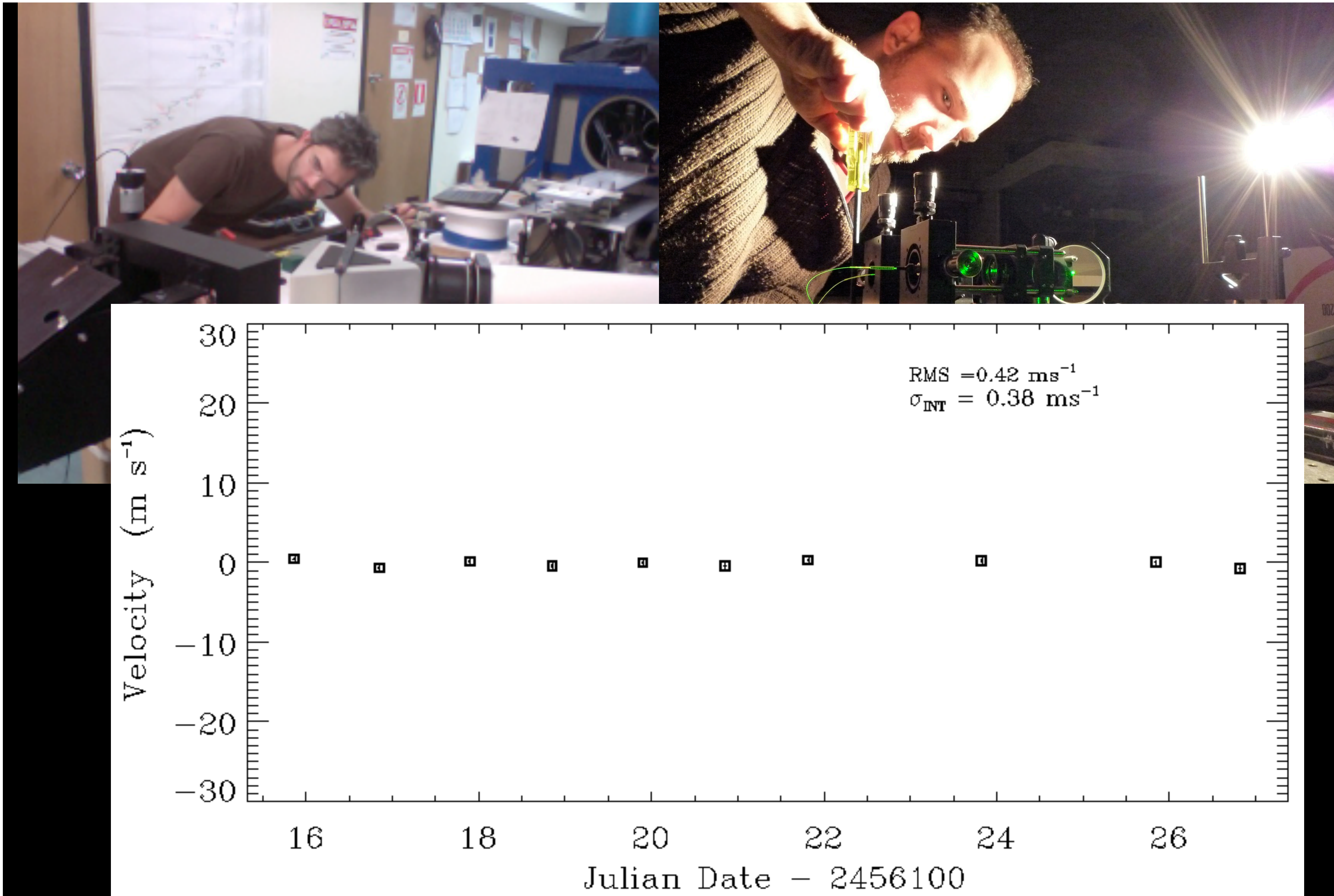

2009
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]


2010
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]


2011
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]



2012
Msini [Earth Mass]
1000
100
10
1
10
100
1000
Orbital Period [days]


RMS =0.42 ms^{-1}
σ_{INT} = 0.38 ms^{-1}
Velocity (m s^{-1})
30
20
10
0
−10
−20
−30
16
18
20
22
24
26
Julian Date − 2456100