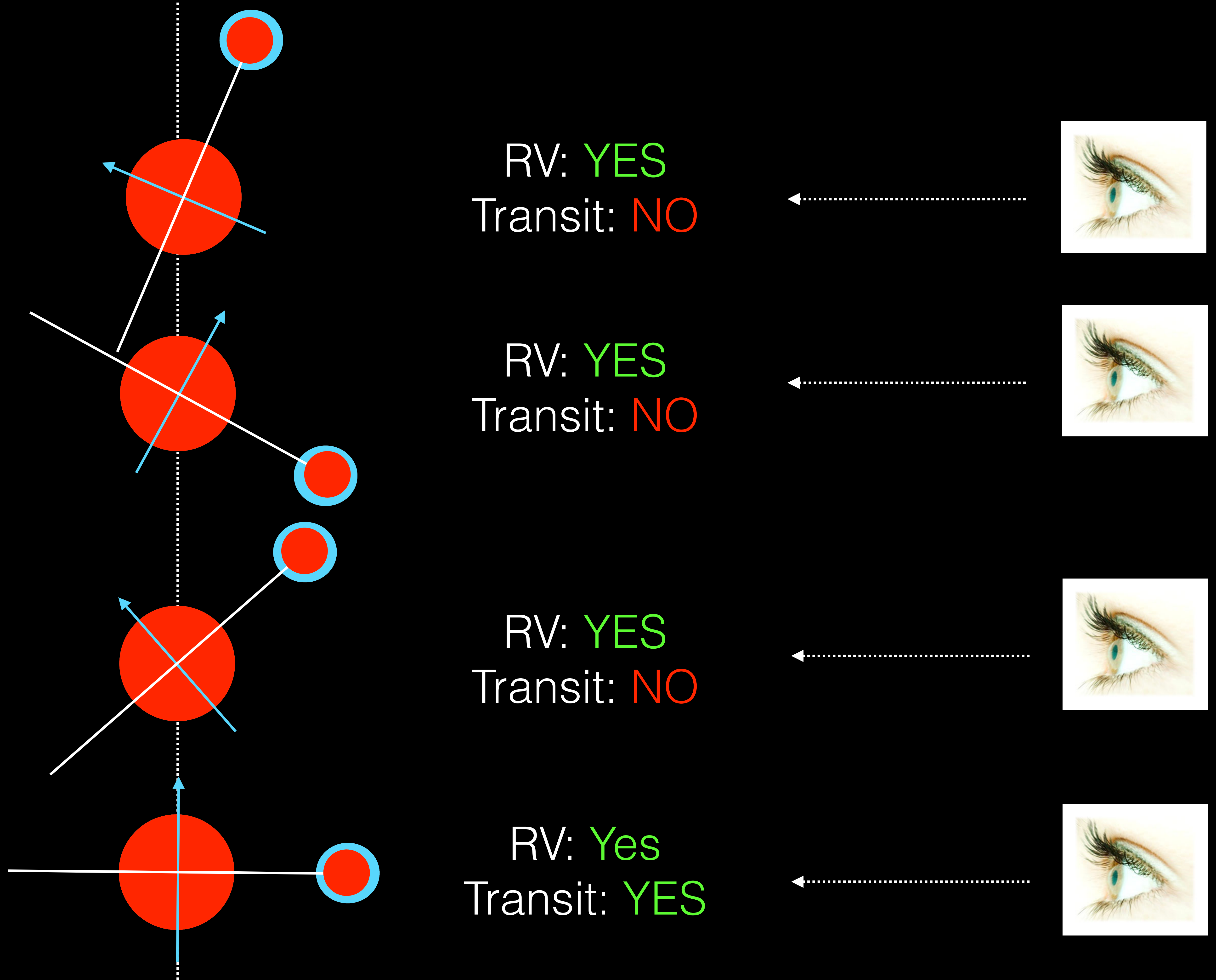
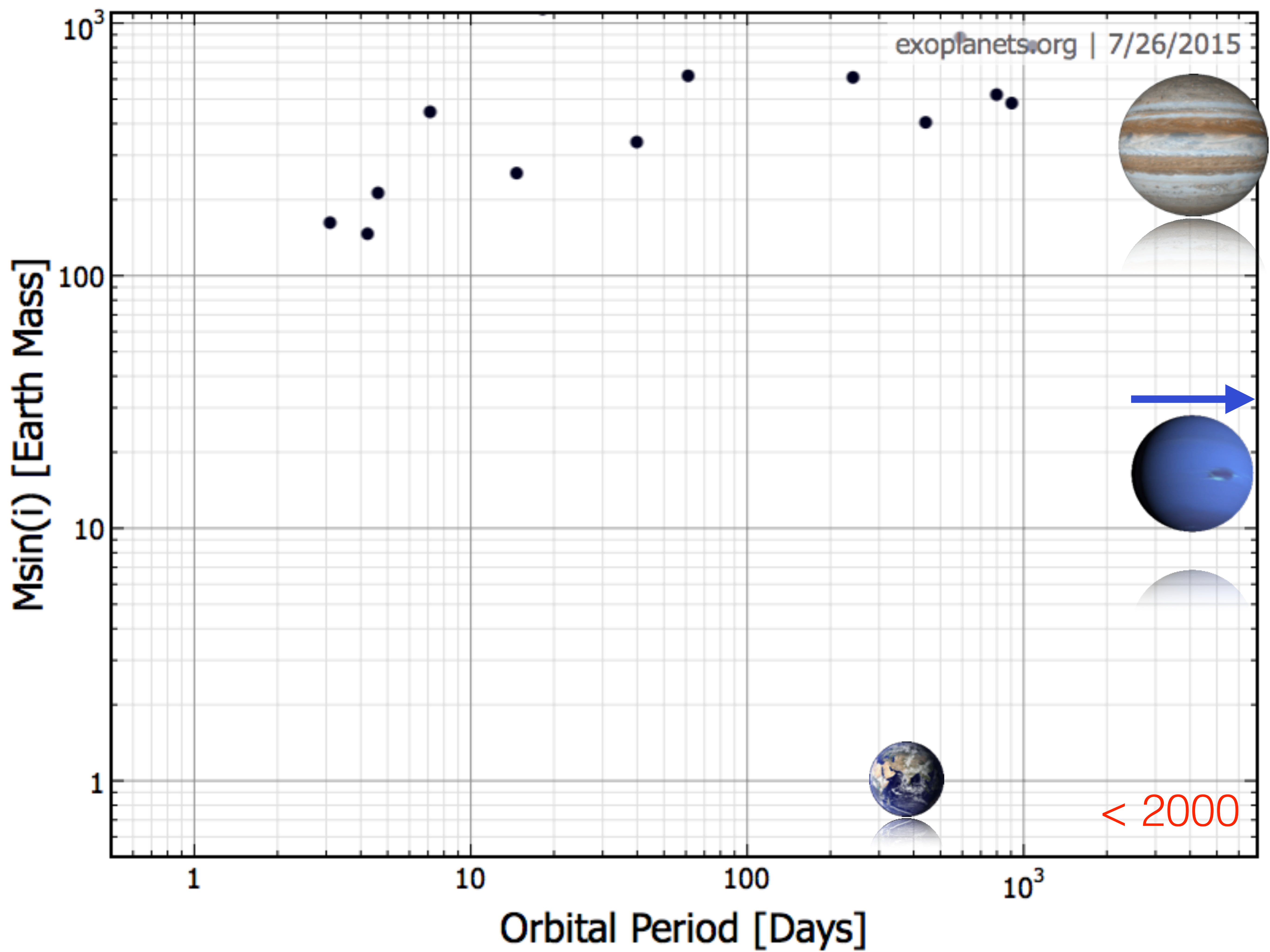
Xavier Dumusque

Radial velocity surveys

Planet frequency rates and selection effects


RV: YES
Transit: NO
RV: YES
Transit: NO
RV: YES
Transit: NO
RV: Yes
Transit: YES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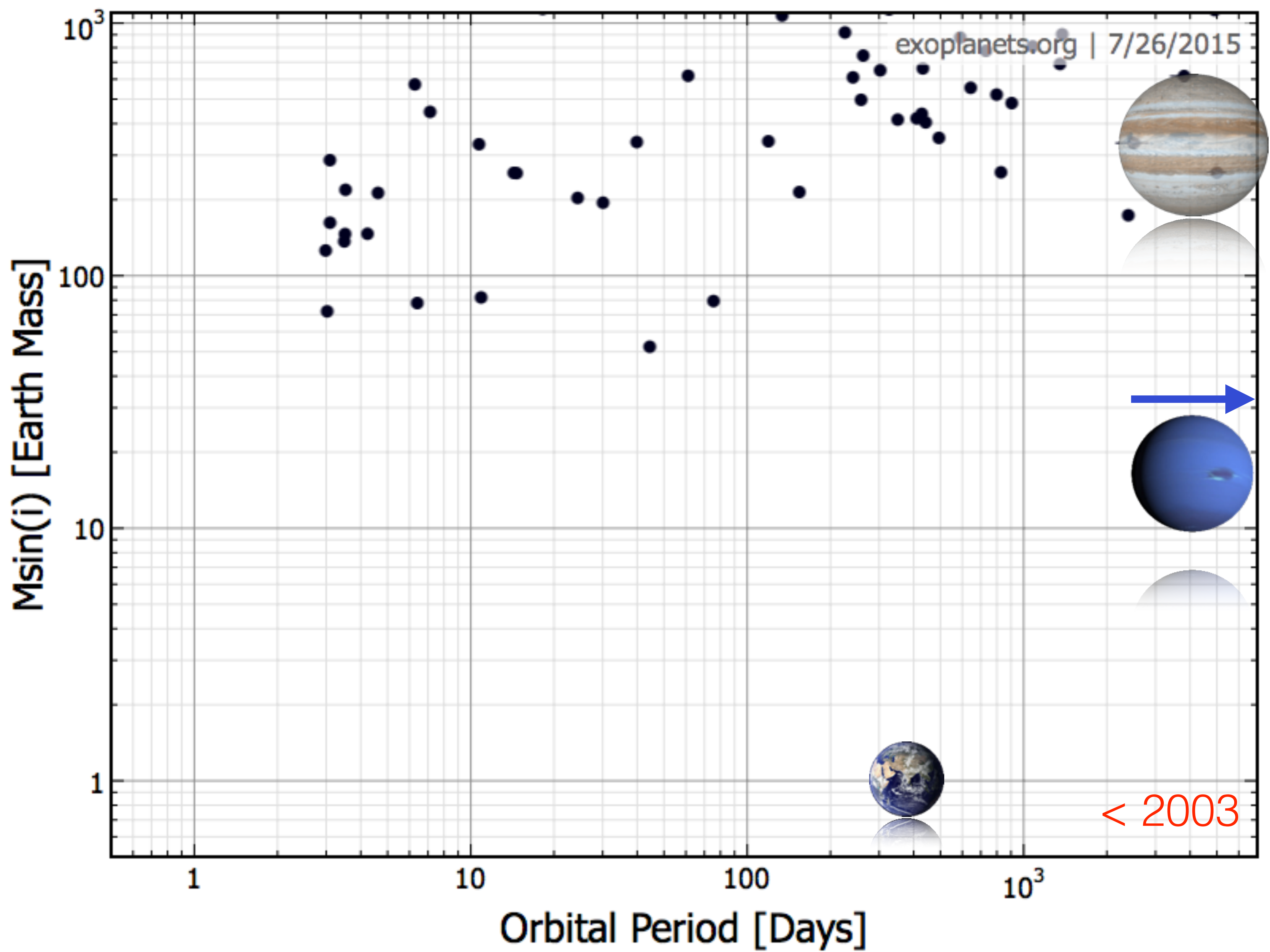
Msin(i) [Earth Mass]
Orbital Period [Days]
10^3
100
10
1
1
10
100
10^3
< 2000



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10^3
100
10
1
Orbital Period [Days]
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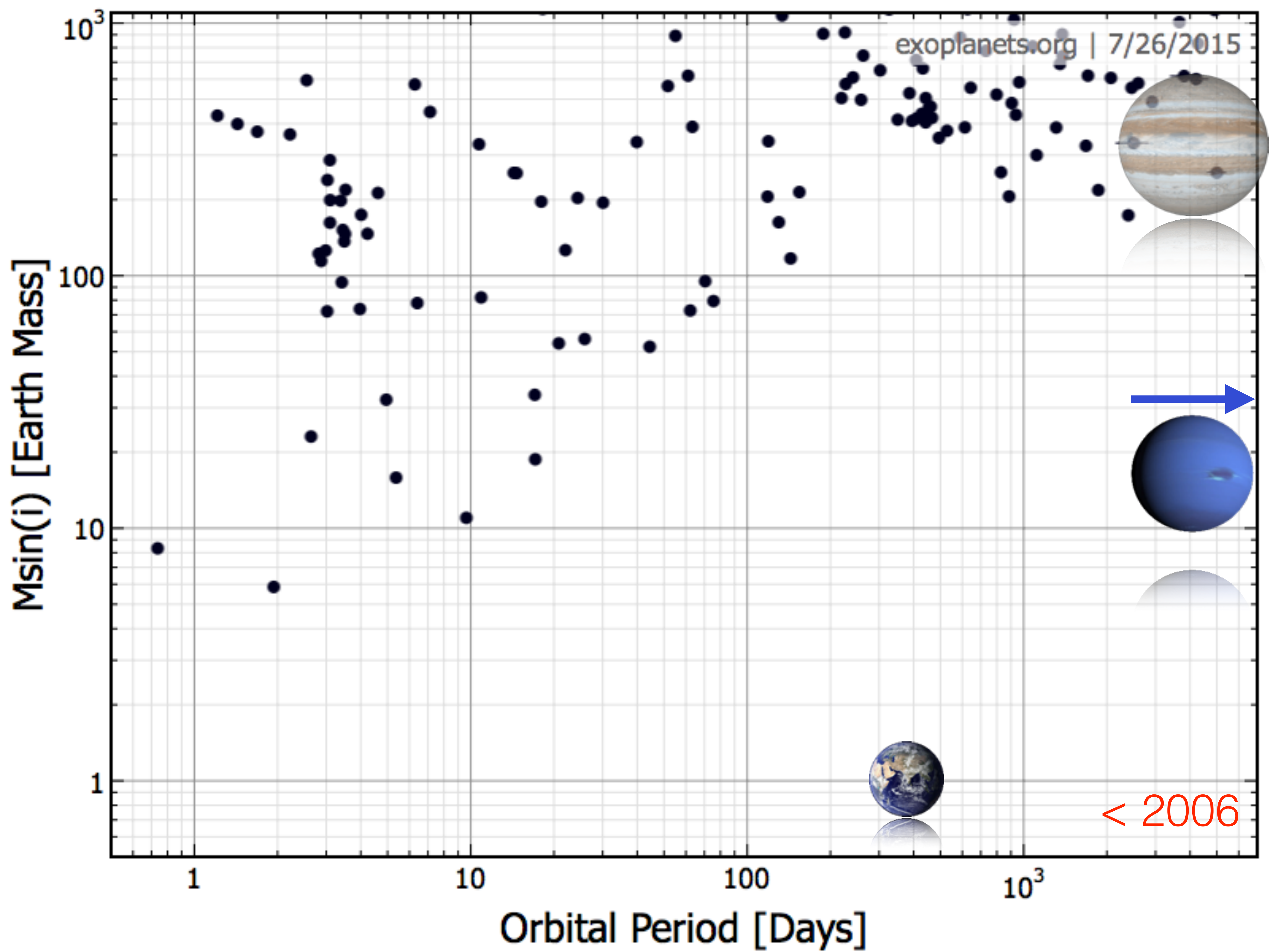
10
100
10^3
< 2003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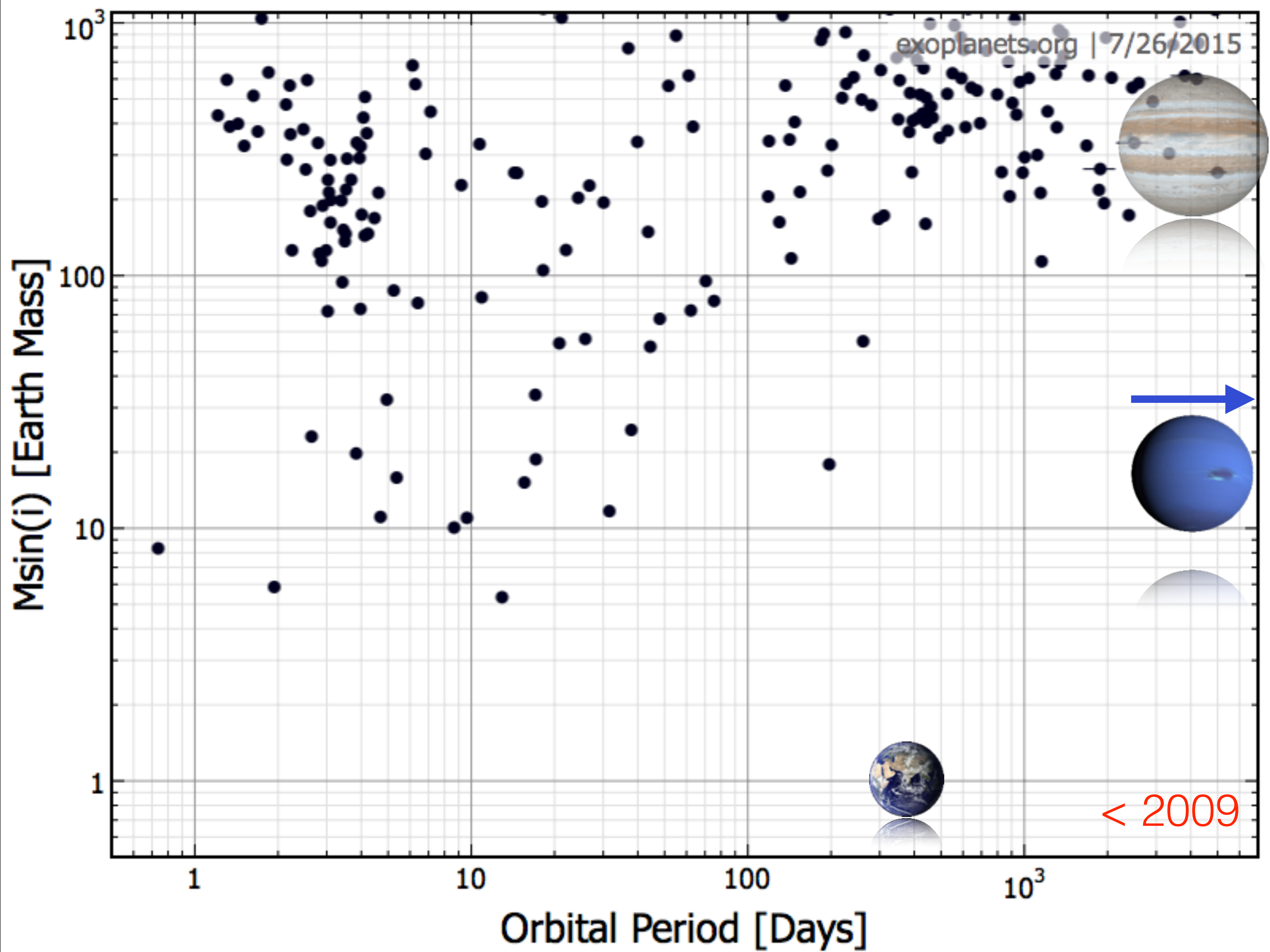
Orbital Period [Days]
10^3
100
10
1
1
10
100
10^3
< 2006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Msin(i) [Earth Mass]
10^3
100
10
1
Orbital Period [Days]
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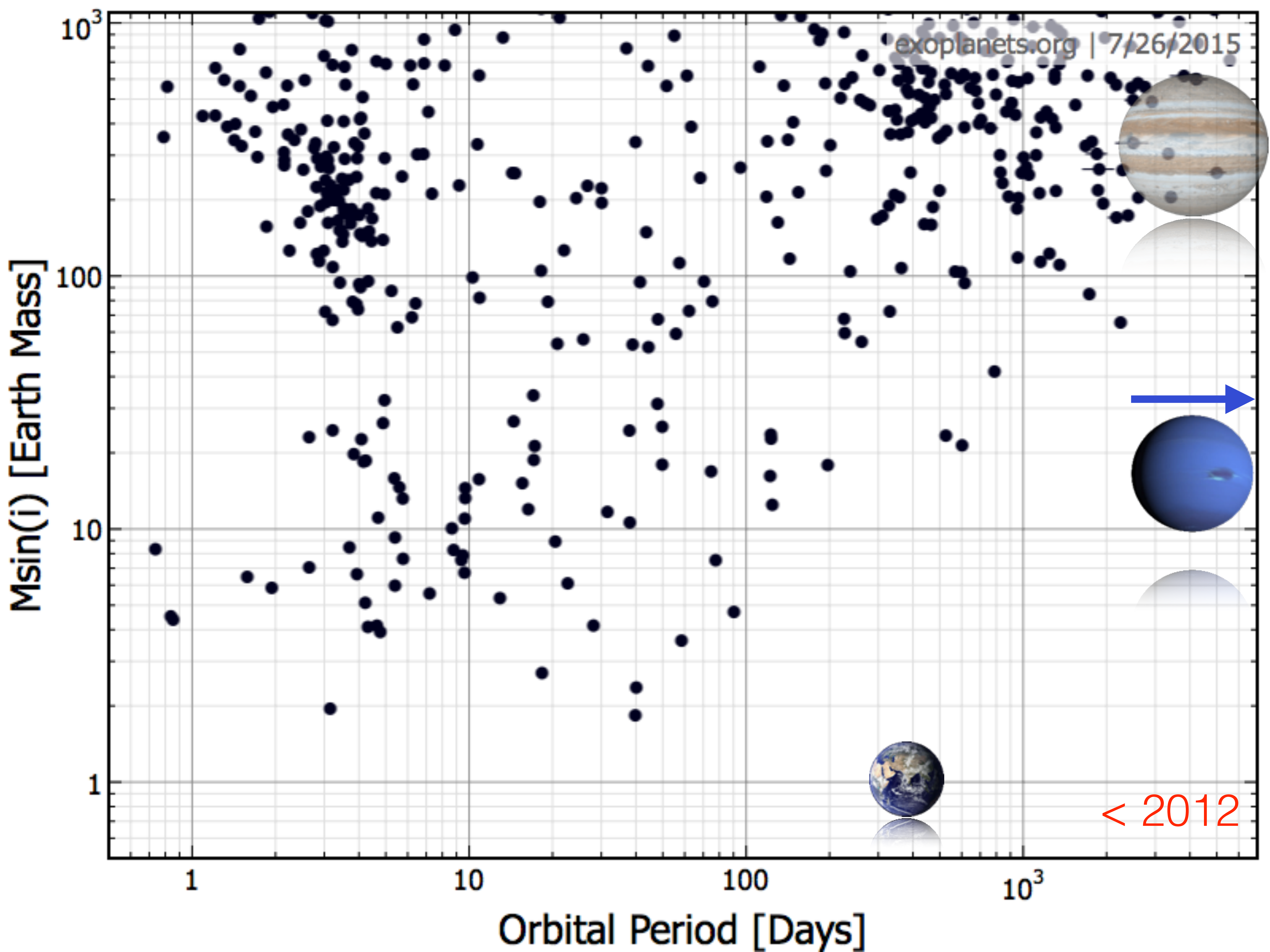
100
10^3
< 2009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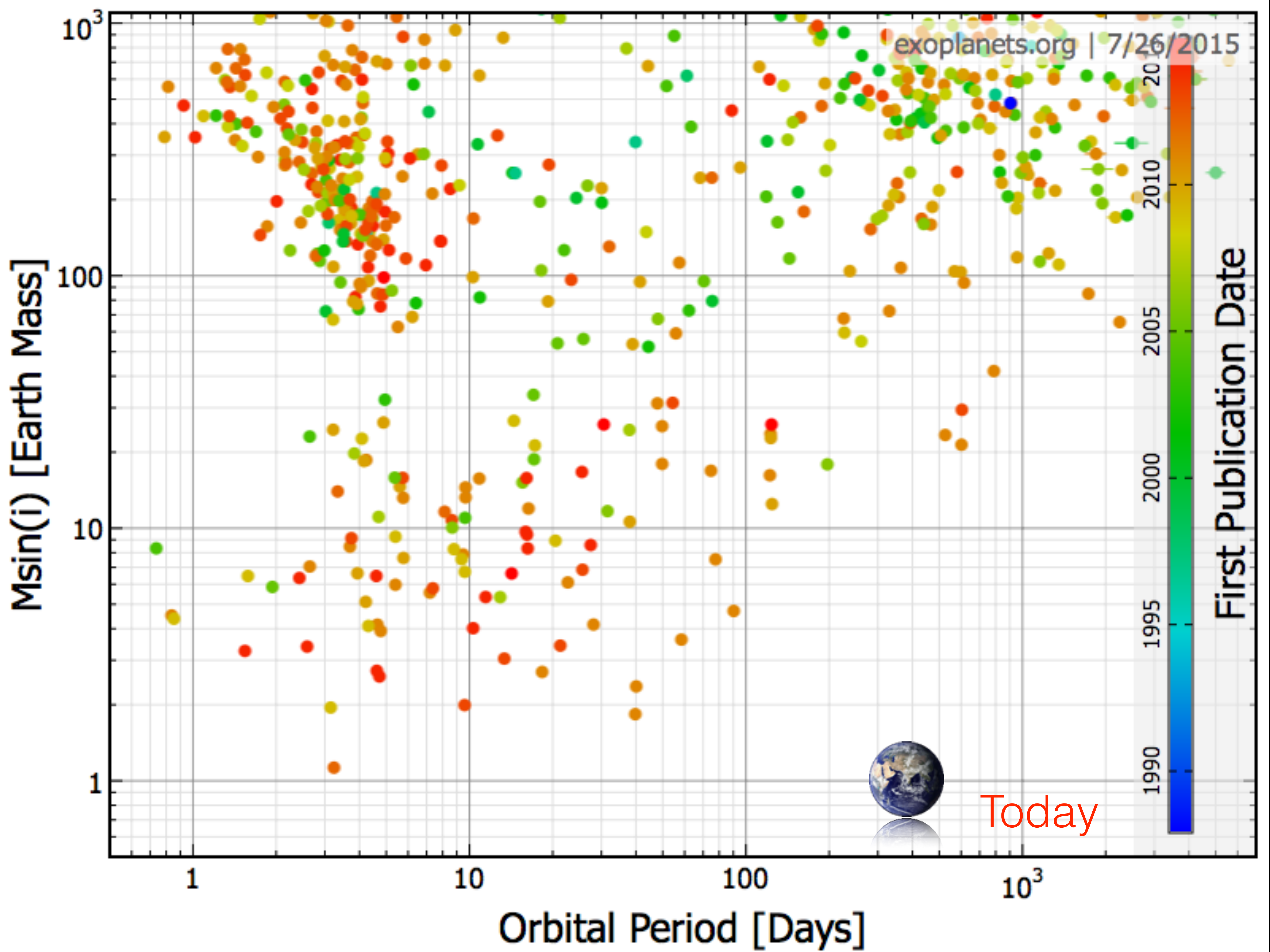
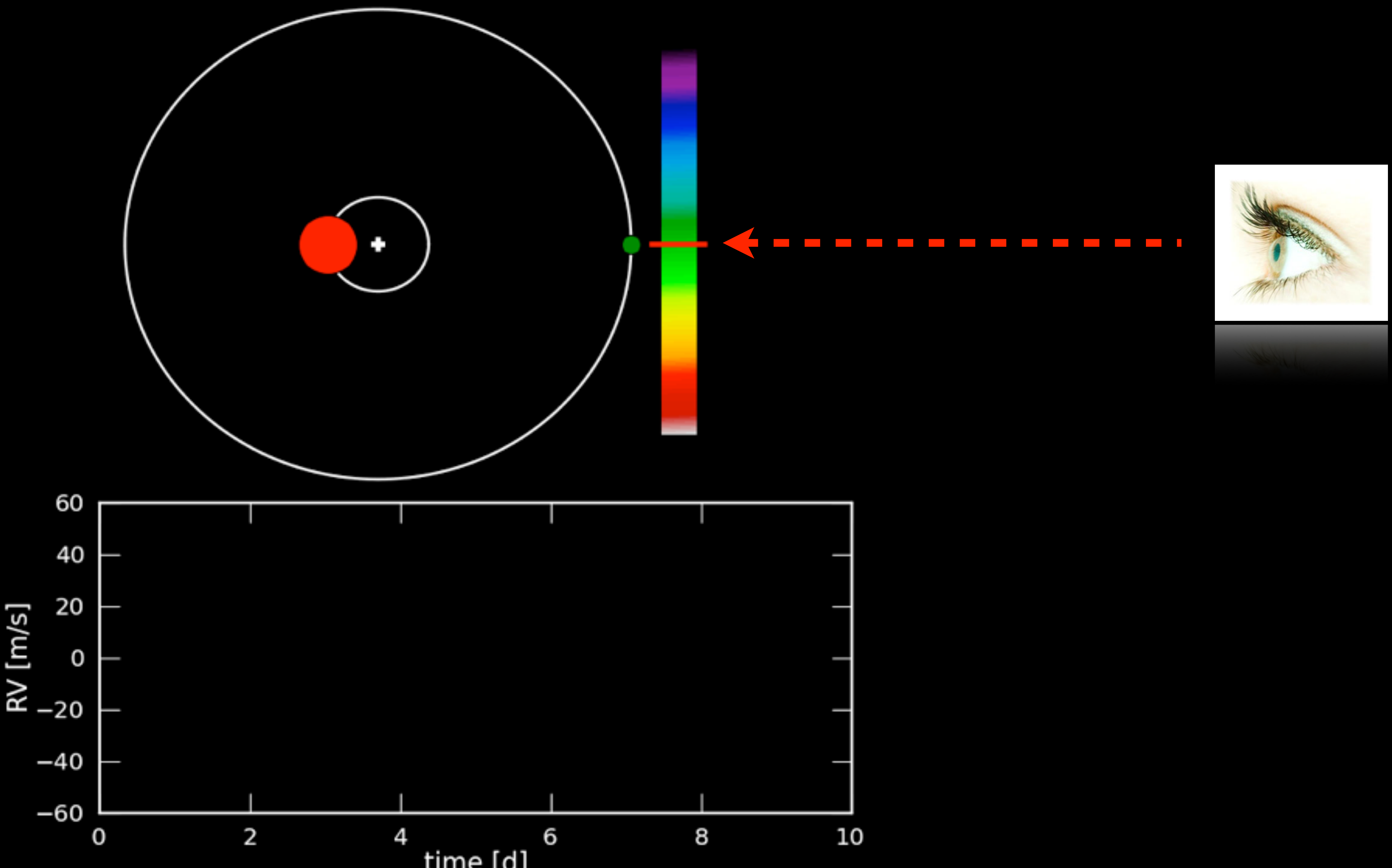
Orbital Period [Days]
10^3
100
10
1
1
10
100
10^3
< 2012



exoplanets.org | 7/26/2015
Msin(i) [Earth Mass]
10^3
100
10
1
Orbital Period [Days]
1
10
100
10^3
First Publication Date
1990
1995
2000
2005
2010
Today

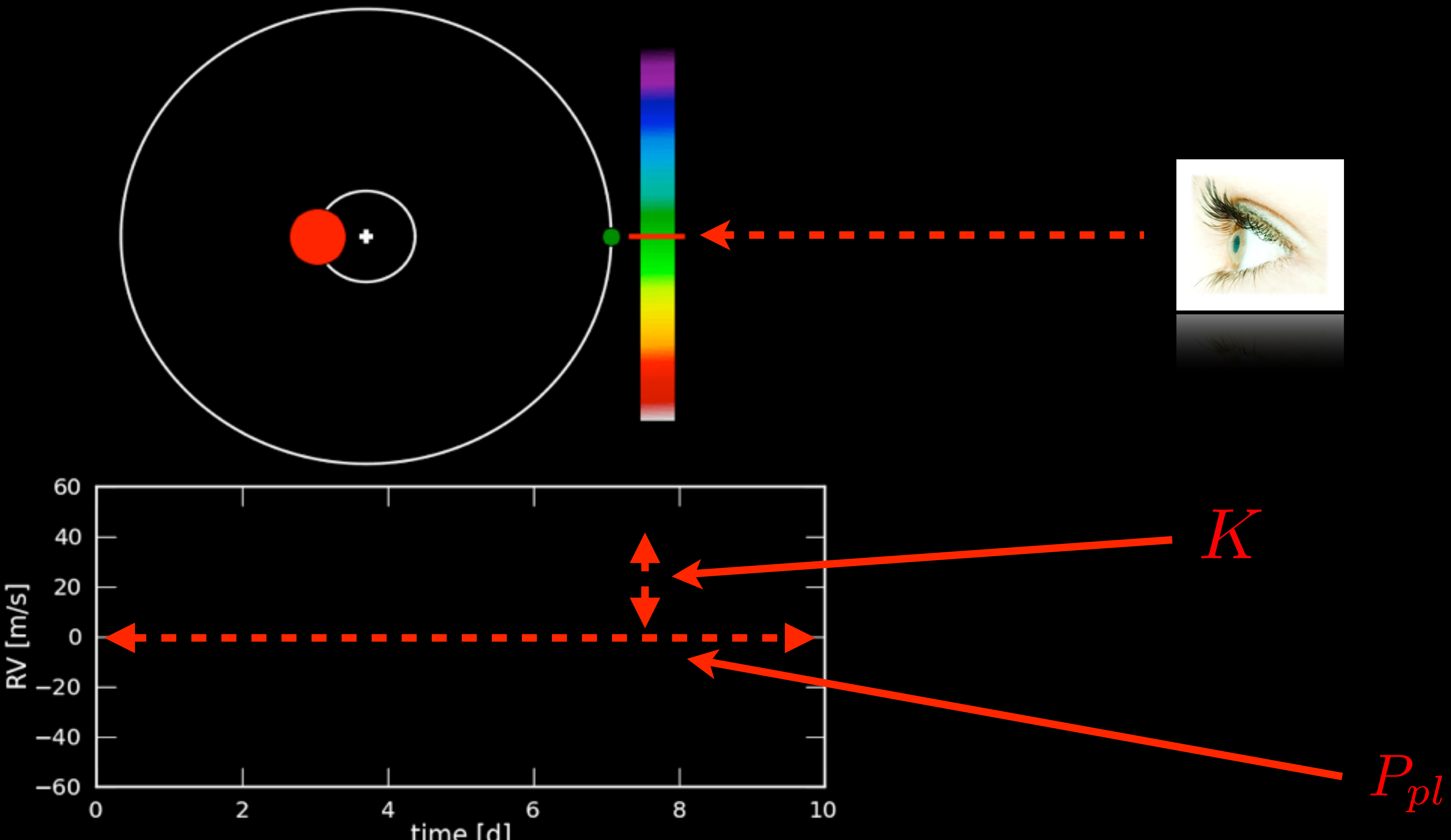
The RV technique

The RV technique



The RV technique

The RV technique



Improvement towards smaller masses

Improvement towards smaller masses

$$K = \frac{28.4}{\sqrt{1-e^2}} \frac{M_{\text{planet}}\, sin\, i}{M_{\text{jupiter}}} \left(\frac{M_{\text{star}}}{M_{\text{sun}}}\right)^{-\frac{2}{3}} \left(\frac{P}{1\text{year}}\right)^{-\frac{1}{3}} \quad [m.s^{-1}]$$

Improvement towards smaller masses

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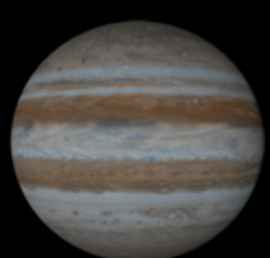
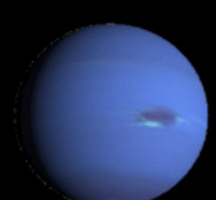
$e = 0$ $\qquad$ $M_{star} = M_{sun}$

Improvement towards smaller masses

Improvement towards smaller masses

$$K = \frac{28.4}{\sqrt{1 - e^2}} \frac{M_{\mathrm{planet}}\, sin\, i}{M_{\mathrm{jupiter}}} \left(\frac{M_{\mathrm{star}}}{M_{\mathrm{sun}}}\right)^{-\frac{2}{3}} \left(\frac{P}{1\mathrm{year}}\right)^{-\frac{1}{3}} \quad [m.s^{-1}]$$

$e = 0$ $\quad$ $M_{star} = M_{sun}$

	P = 3.5 d	P = 1 yr	P = 12 yr
	133	28	12
	7	1.5	0.7
	0.4	0.1	0.04

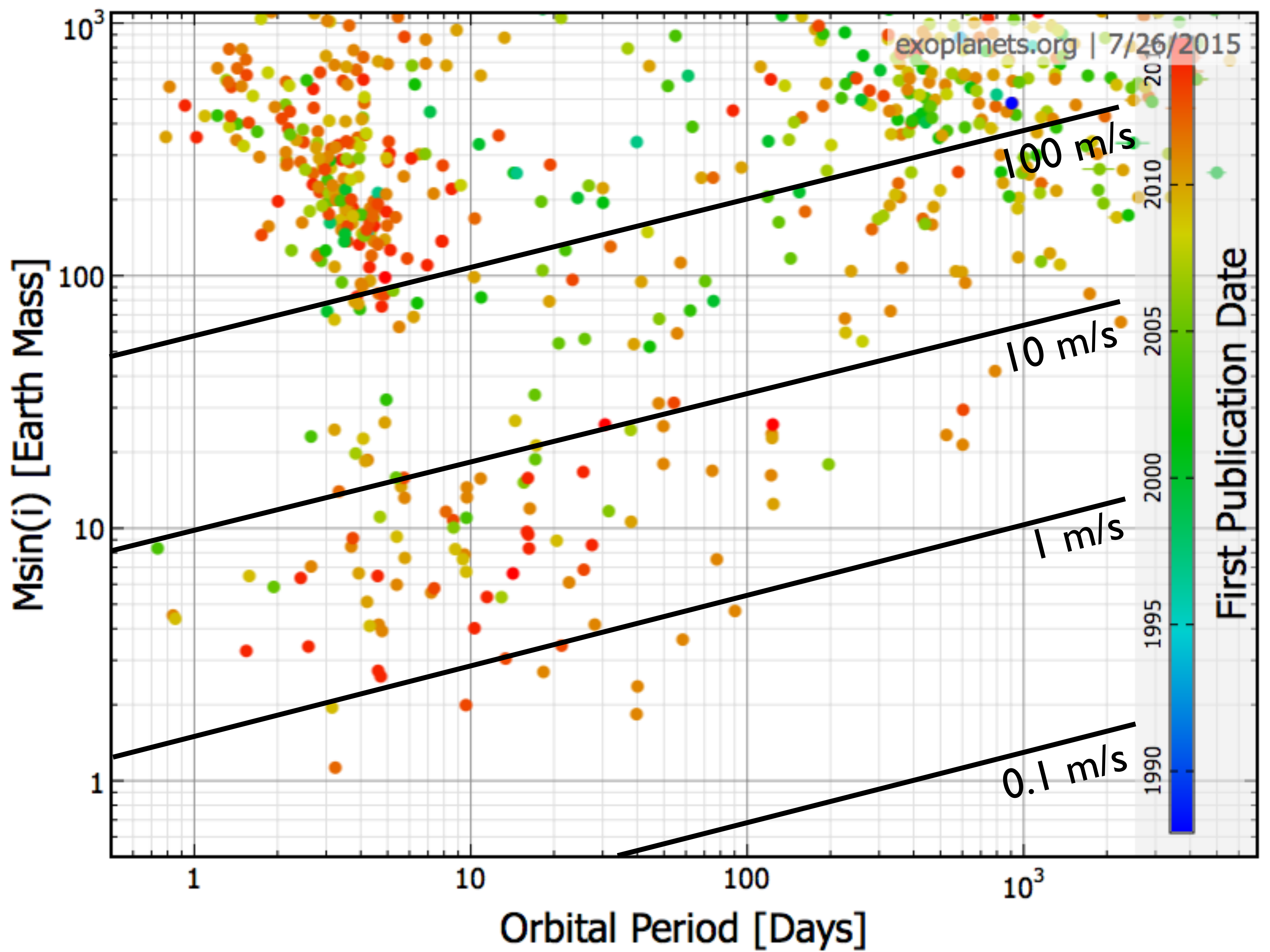
Improvement towards smaller masses

Improvement towards smaller masses

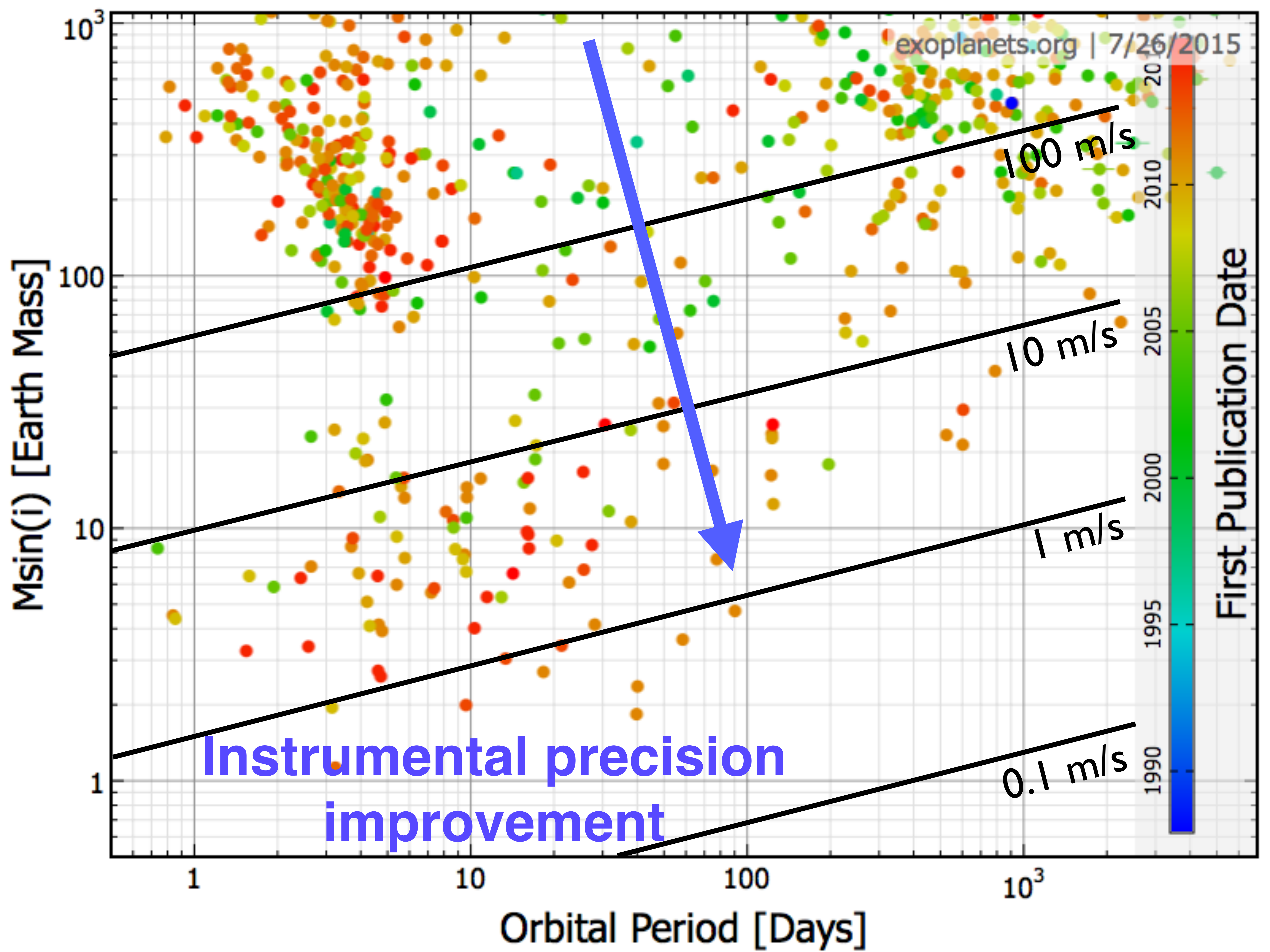
$$K = \frac{28.4}{\sqrt{1-e^2}} \frac{M_{\text{planet}}\, sin\, i}{M_{\text{jupiter}}} \left(\frac{M_{\text{star}}}{M_{\text{sun}}}\right)^{-\frac{2}{3}} \left(\frac{P}{1\text{year}}\right)^{-\frac{1}{3}} \quad [m.s^{-1}]$$

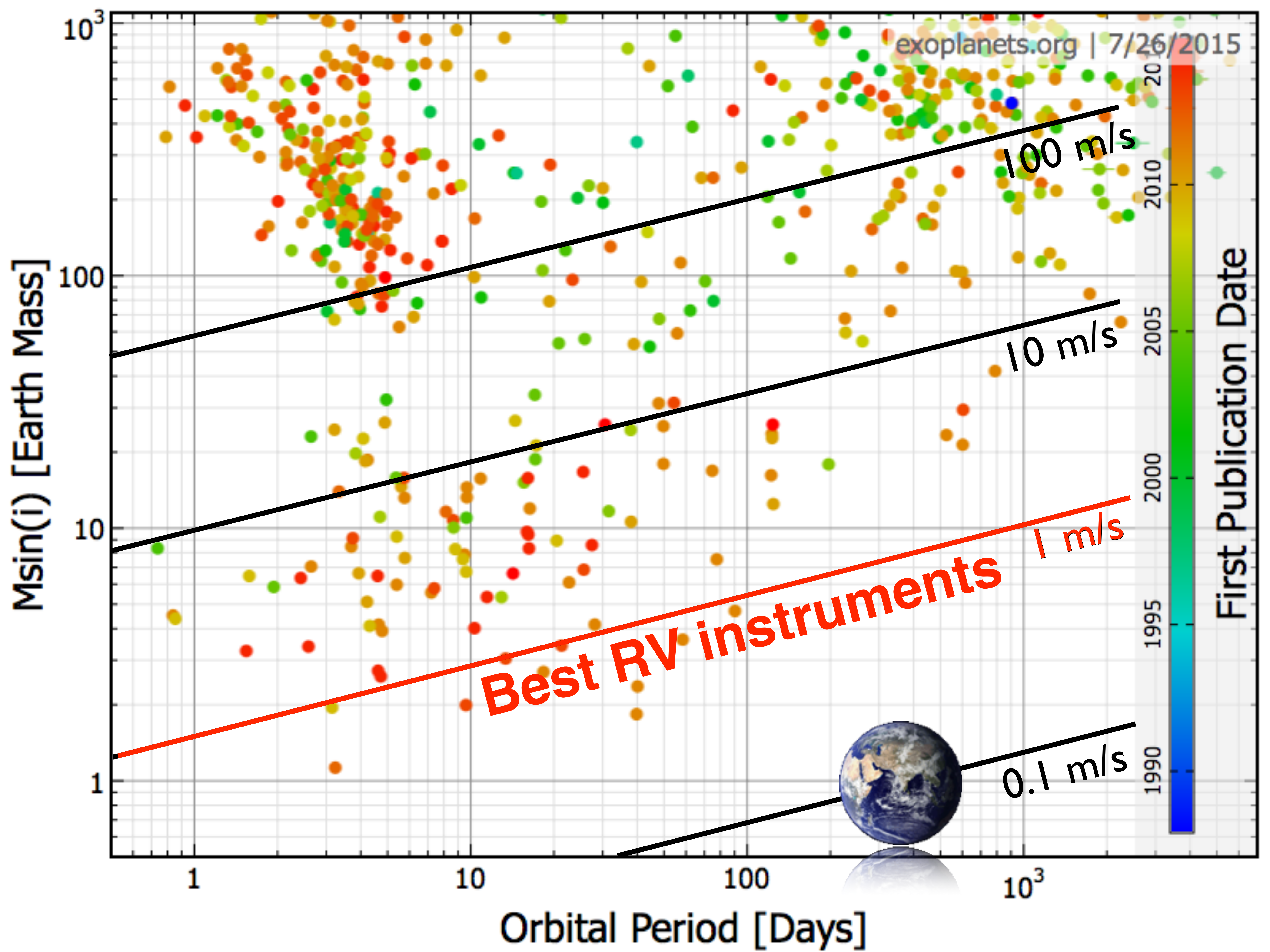
$e = 0$ $\quad$ $M_{star} = M_{sun}$

$$\boxed{Log(M_{\text{planet}}\, sin\, i) \propto Log(K) + \frac{1}{3} Log(P)}$$

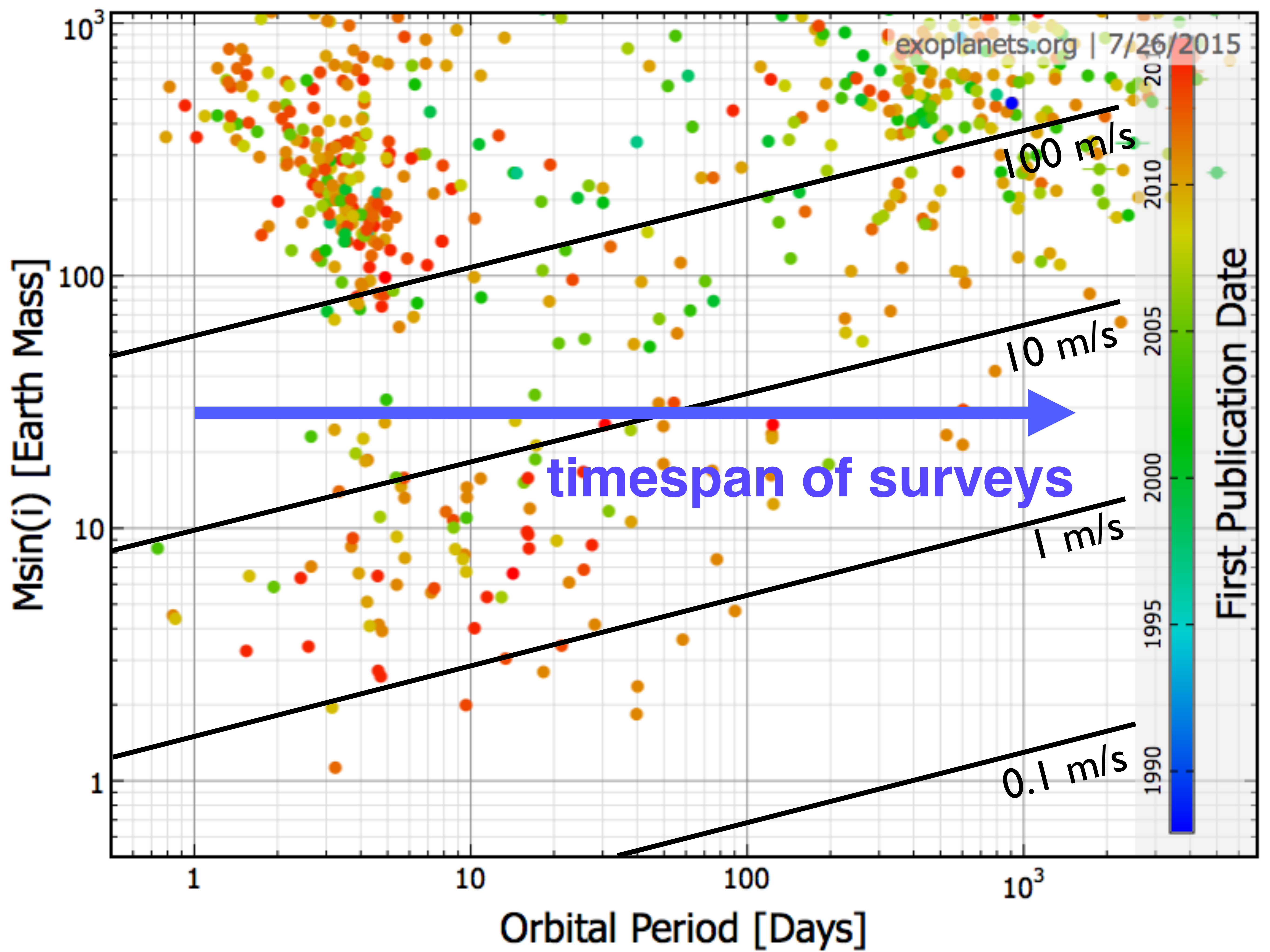


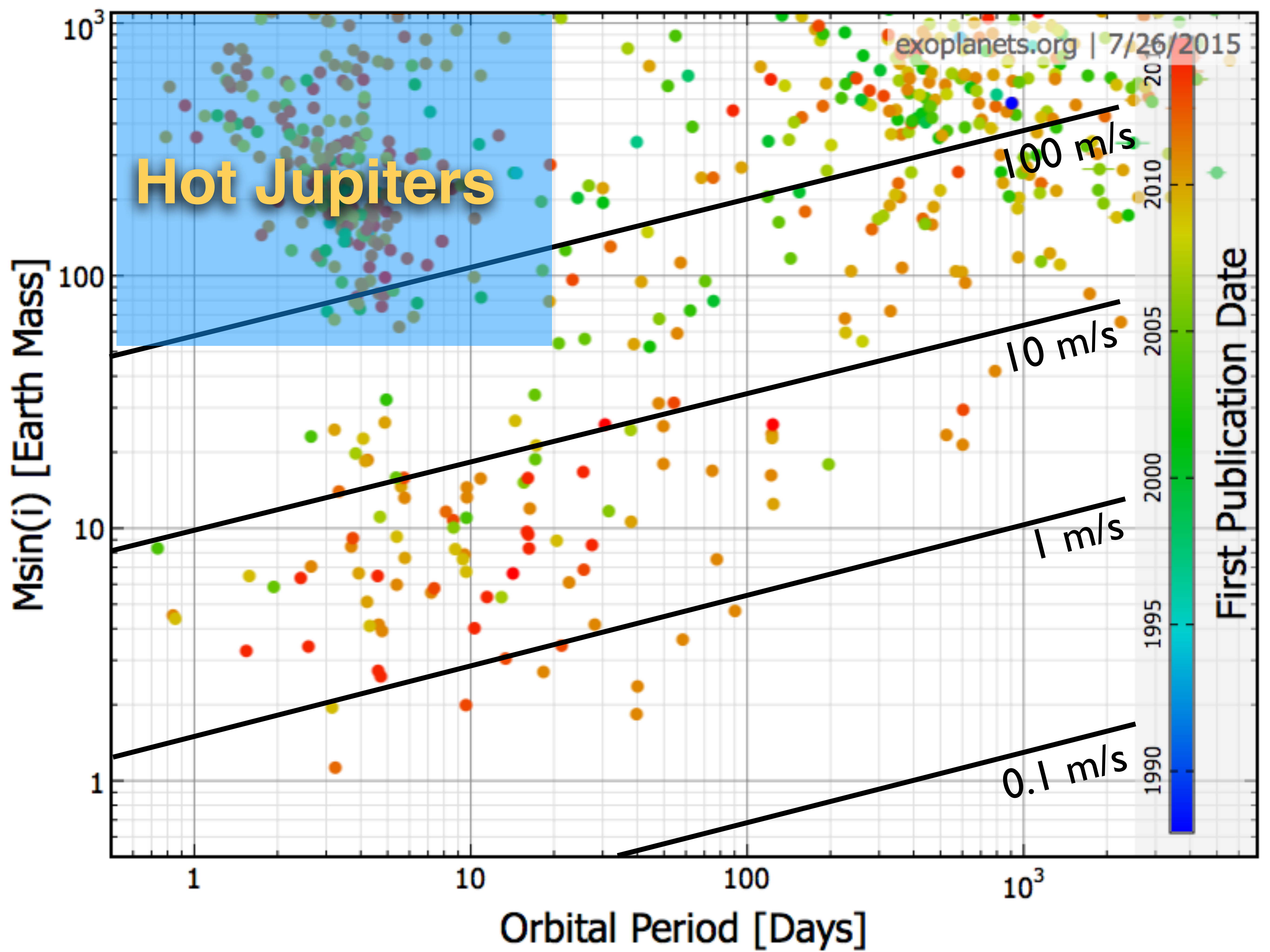
exoplanets.org | 7/26/2015
100 m/s
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
1
10
100
10^3


exoplanets.org | 7/26/2015
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
100 m/s
10 m/s
1 m/s
0.1 m/s
Instrumental precision improvement
10^3
100
10
1
1
10
100
10^3
1990
1995
2000
2005
2010



exoplanets.org | 7/26/2015
100 m/s
10 m/s
1 m/s
0.1 m/s
Best RV instruments
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010


exoplanets.org | 7/26/2015
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
100 m/s
10 m/s
1 m/s
0.1 m/s
timespan of surveys
10^3
100
10
1
1990
1995
2000
2005
2010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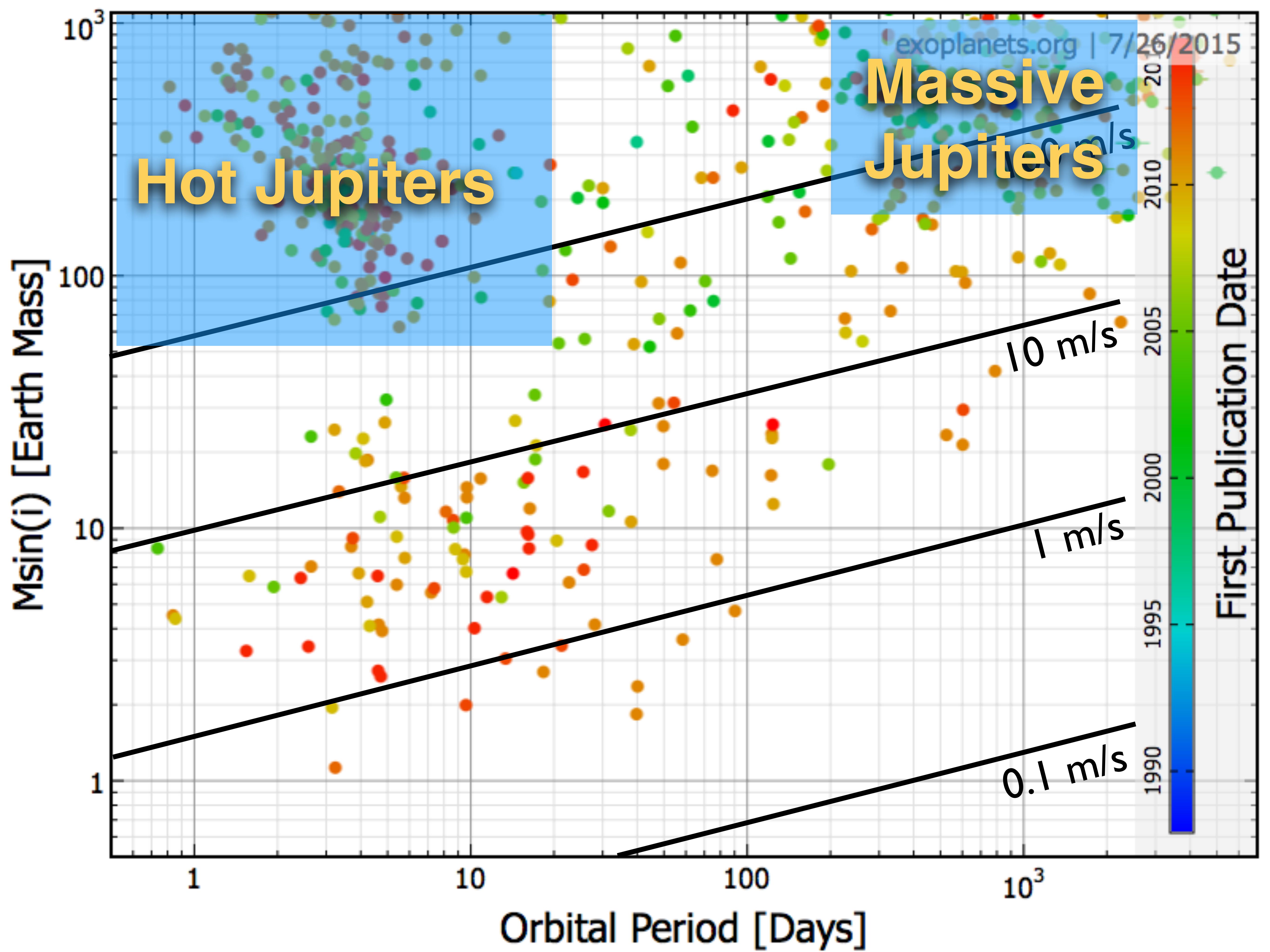
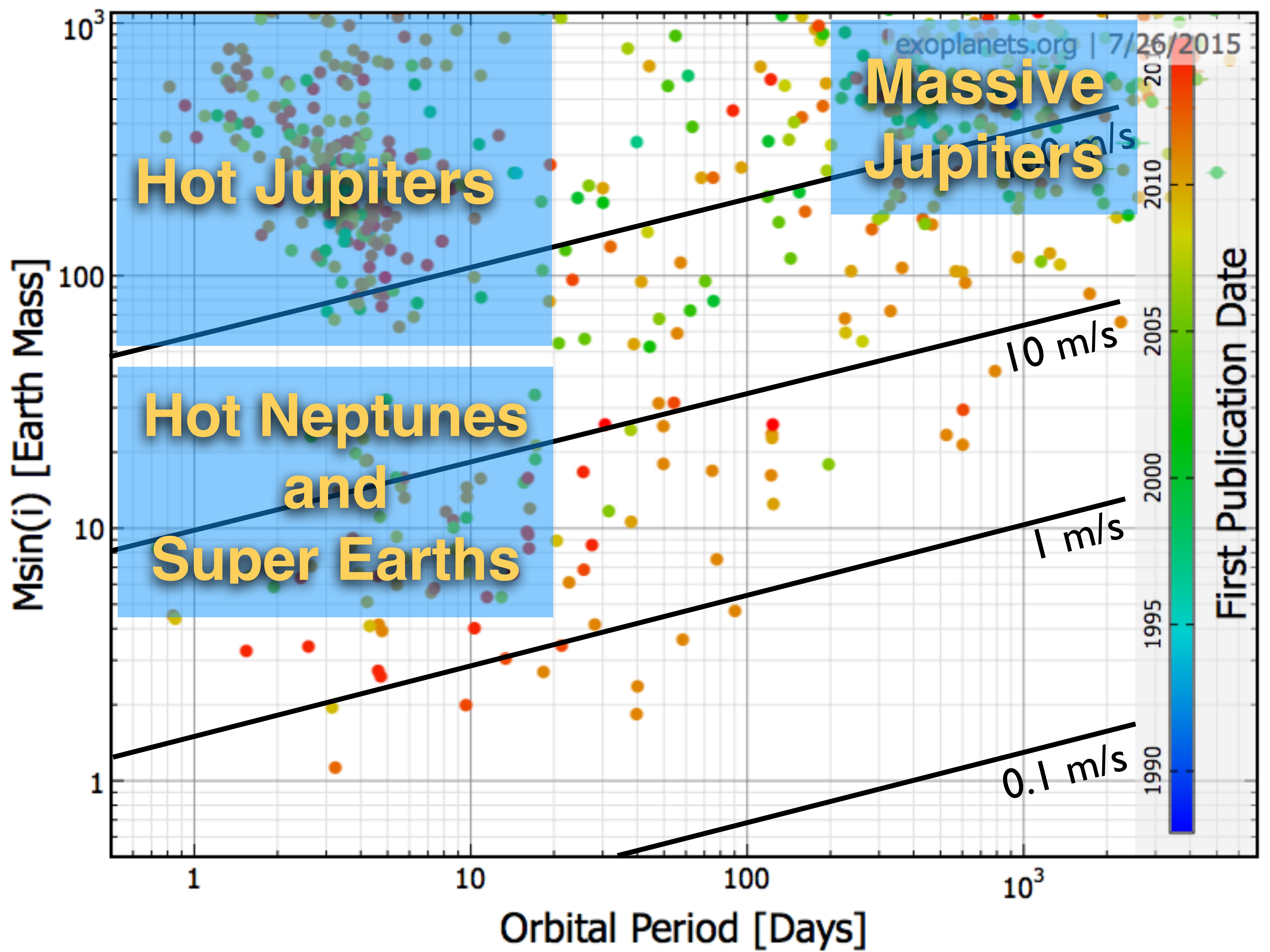
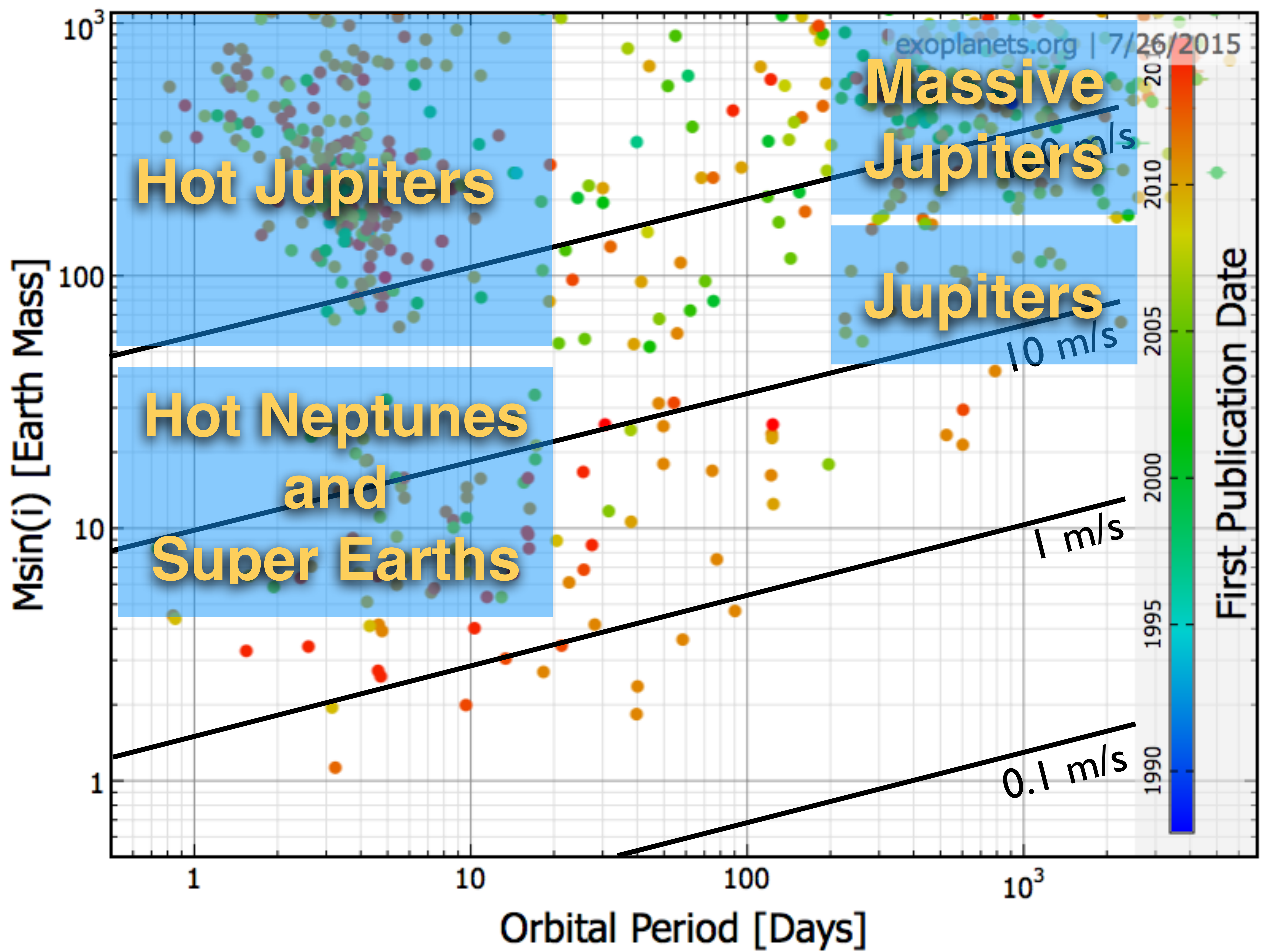
Hot Jupiters
100 m/s
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1
10
100
10^3
1990
1995
2000
2005
2010

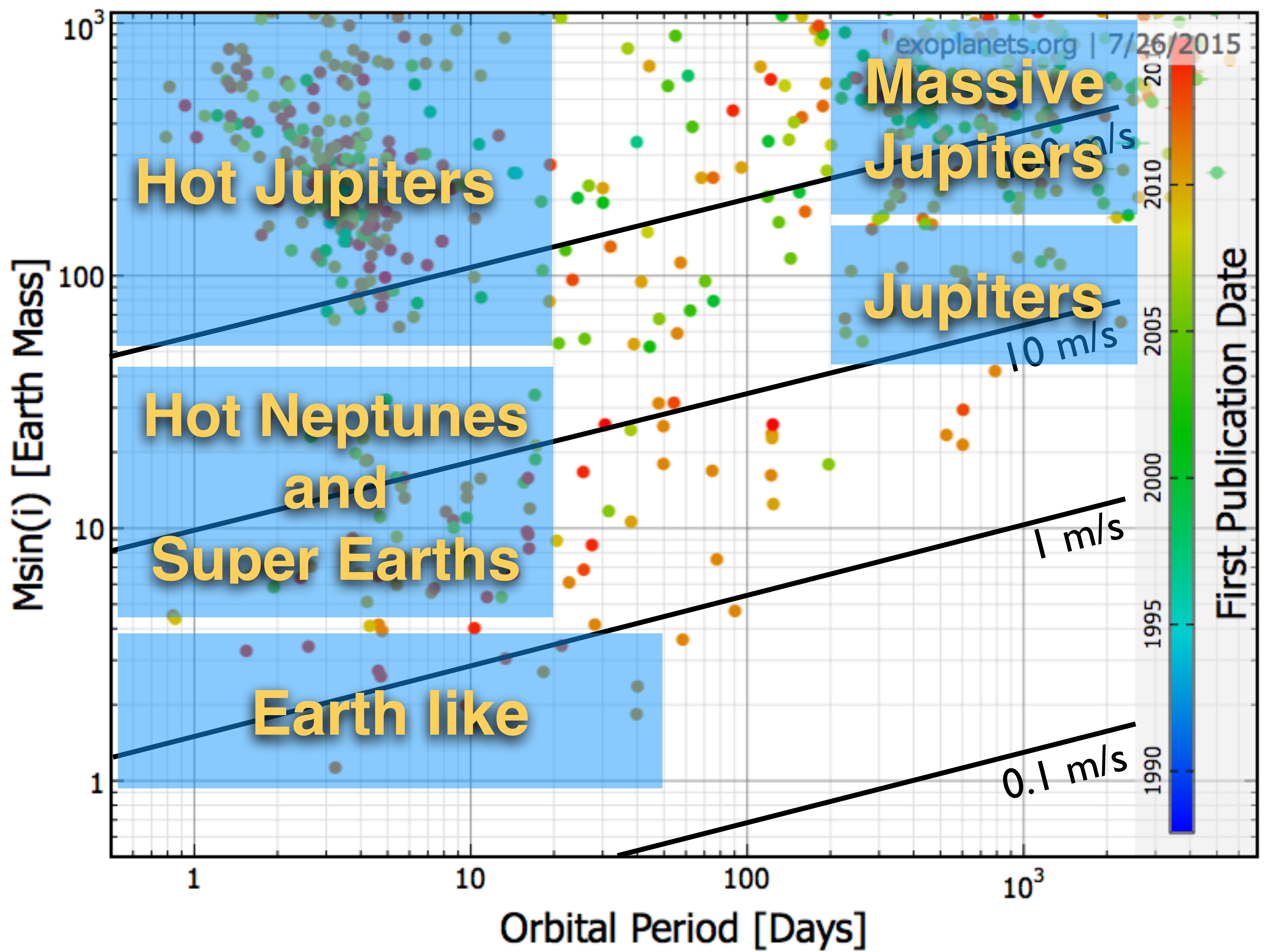


exoplanets.org | 7/26/2015
Hot Jupiters
Massive Jupiters
100 m/s
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
1
10
100
10^3



exoplanets.org | 7/26/2015
Hot Jupiters
Massive Jupiters
Hot Neptunes and Super Earths
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
1
10
100
10^3


exoplanets.org | 7/26/2015
Massive Jupiters
10 m/s
Hot Jupiters
Jupiters
10 m/s
Hot Neptunes and Super Earths
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
10^3
100
10
1
1
10
100
10^3
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010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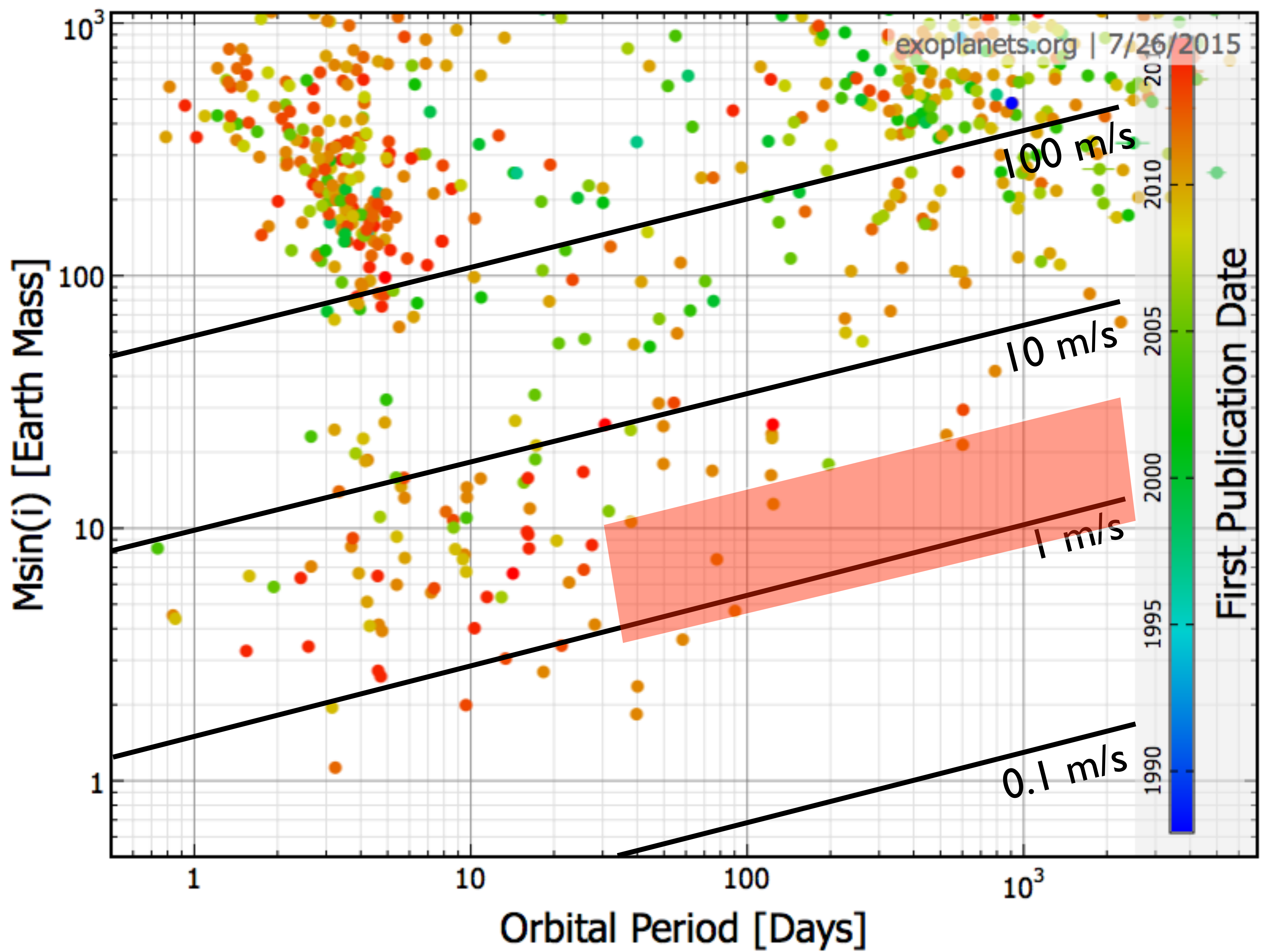
Hot Jupiters
Massive Jupiters
Jupiters
10 m/s
Hot Neptunes and Super Earths
1 m/s
Earth like
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010

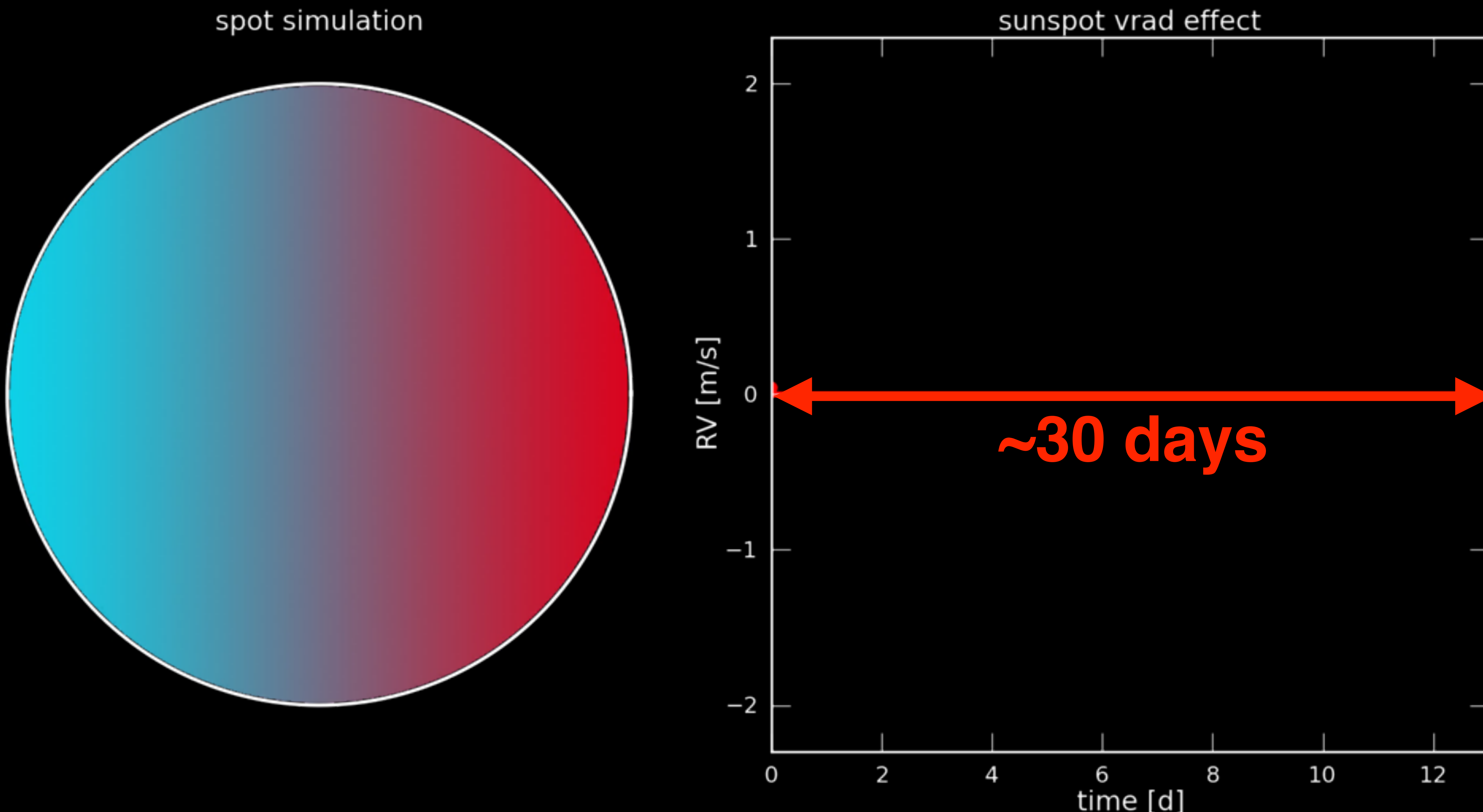


exoplanets.org | 7/26/2015
100 m/s
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
20
10^3
100
10
1
10^3

Active regions

ACTIVE REGIONS

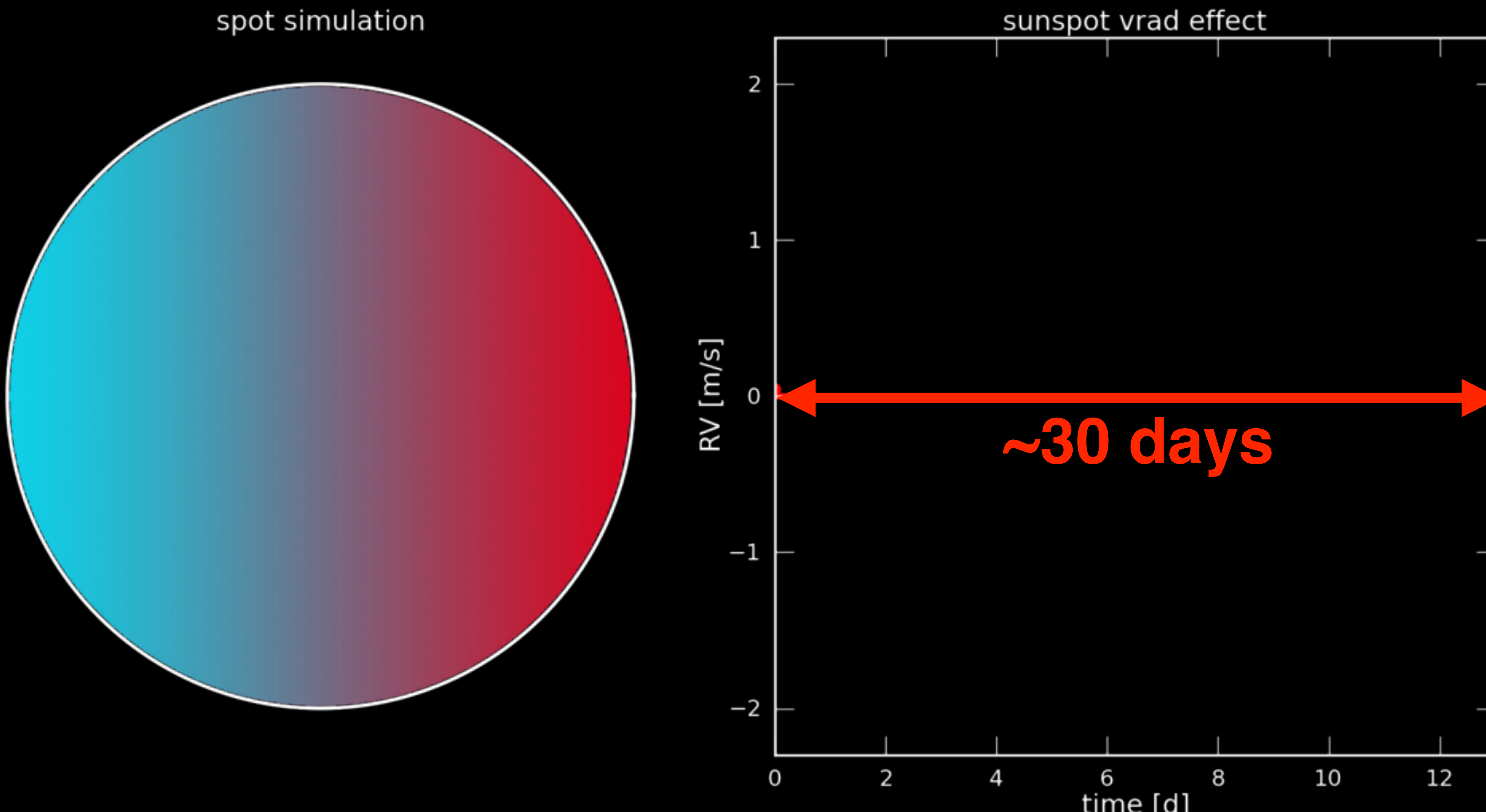
a few m/s (Meunier+ 10)



Dumusque+14

Active regions

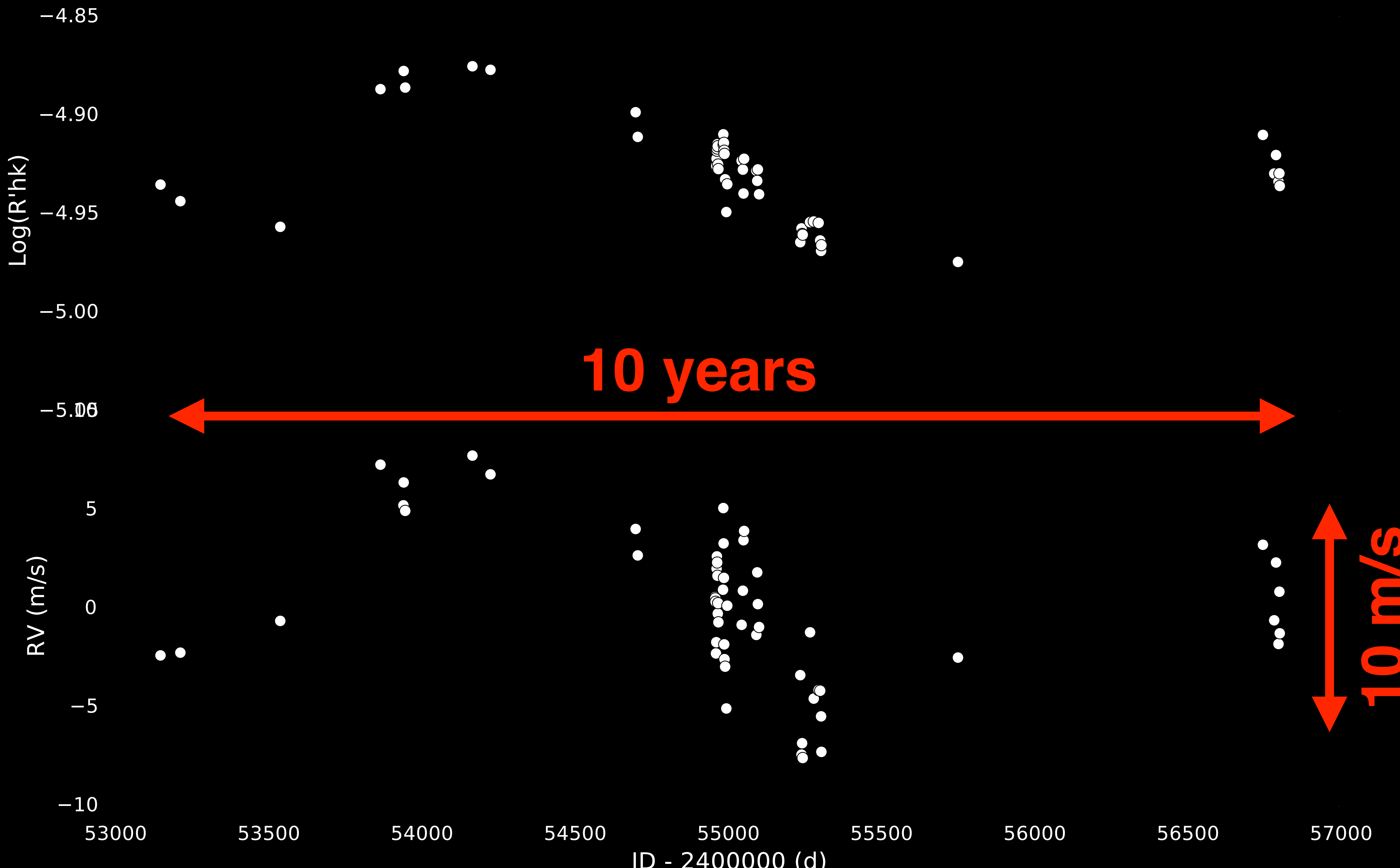
a few m/s (Meunier+ 10)



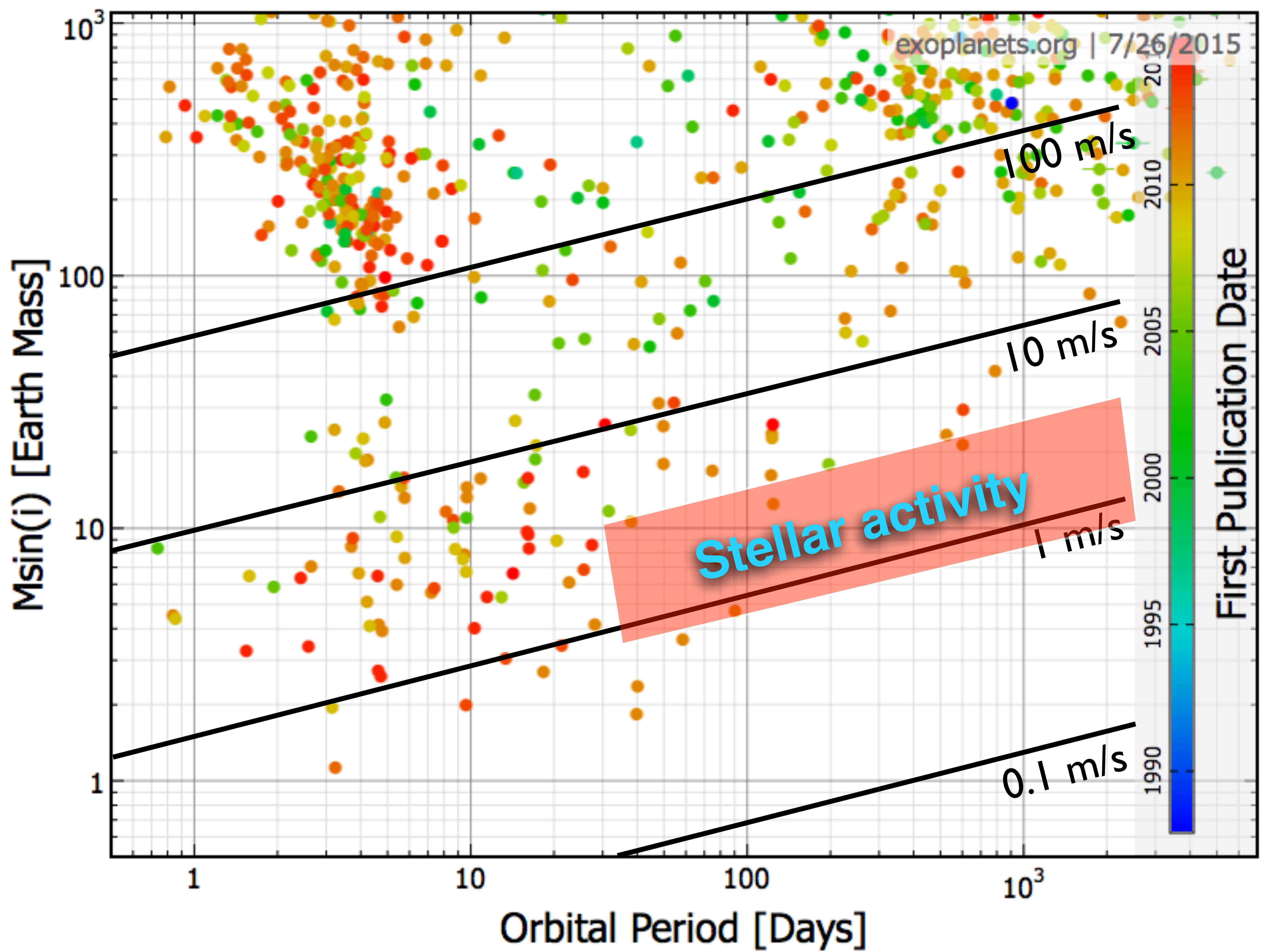
Dumusque+14

Magnetic Cycles

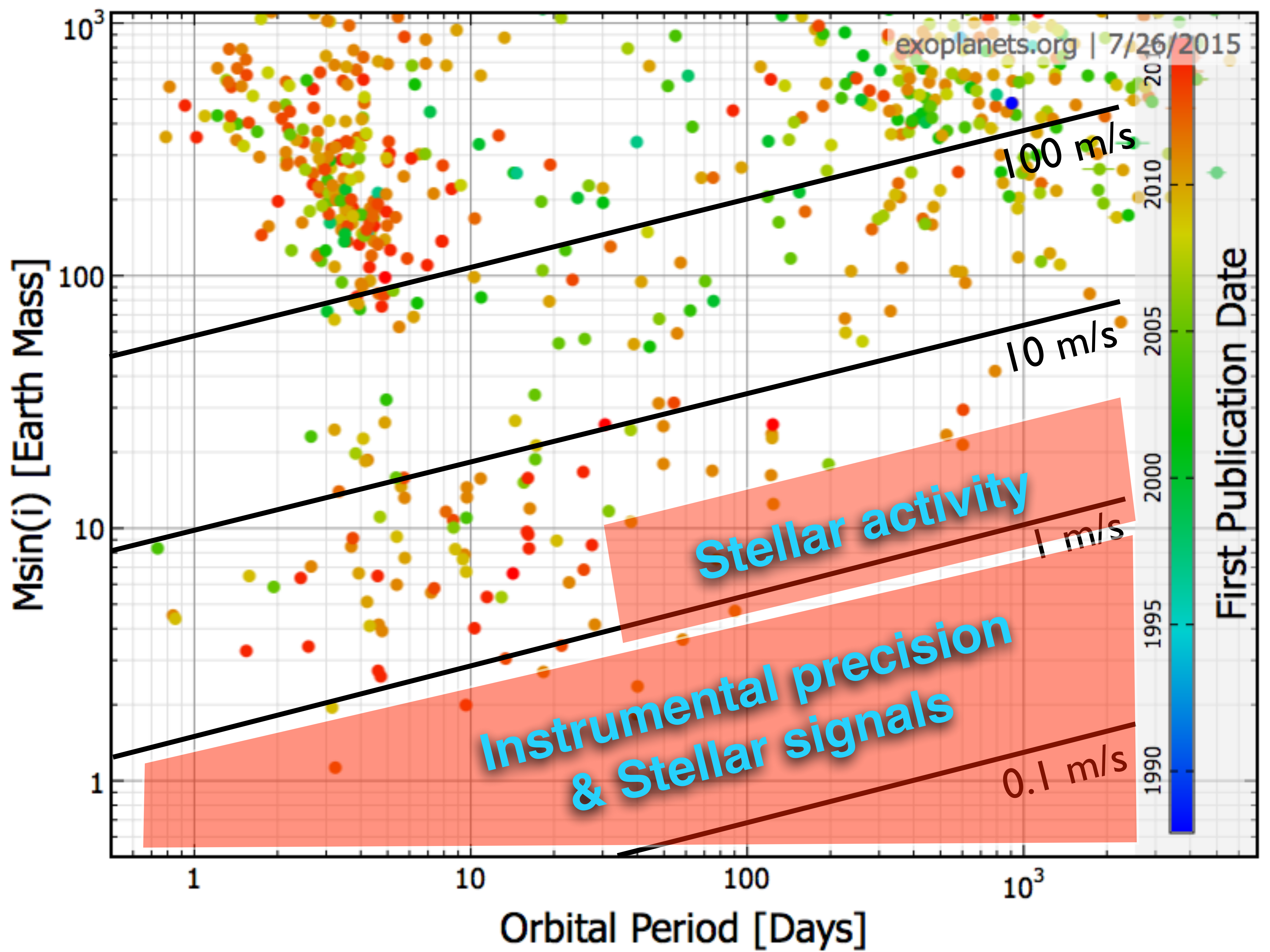
Magnetic Cycles



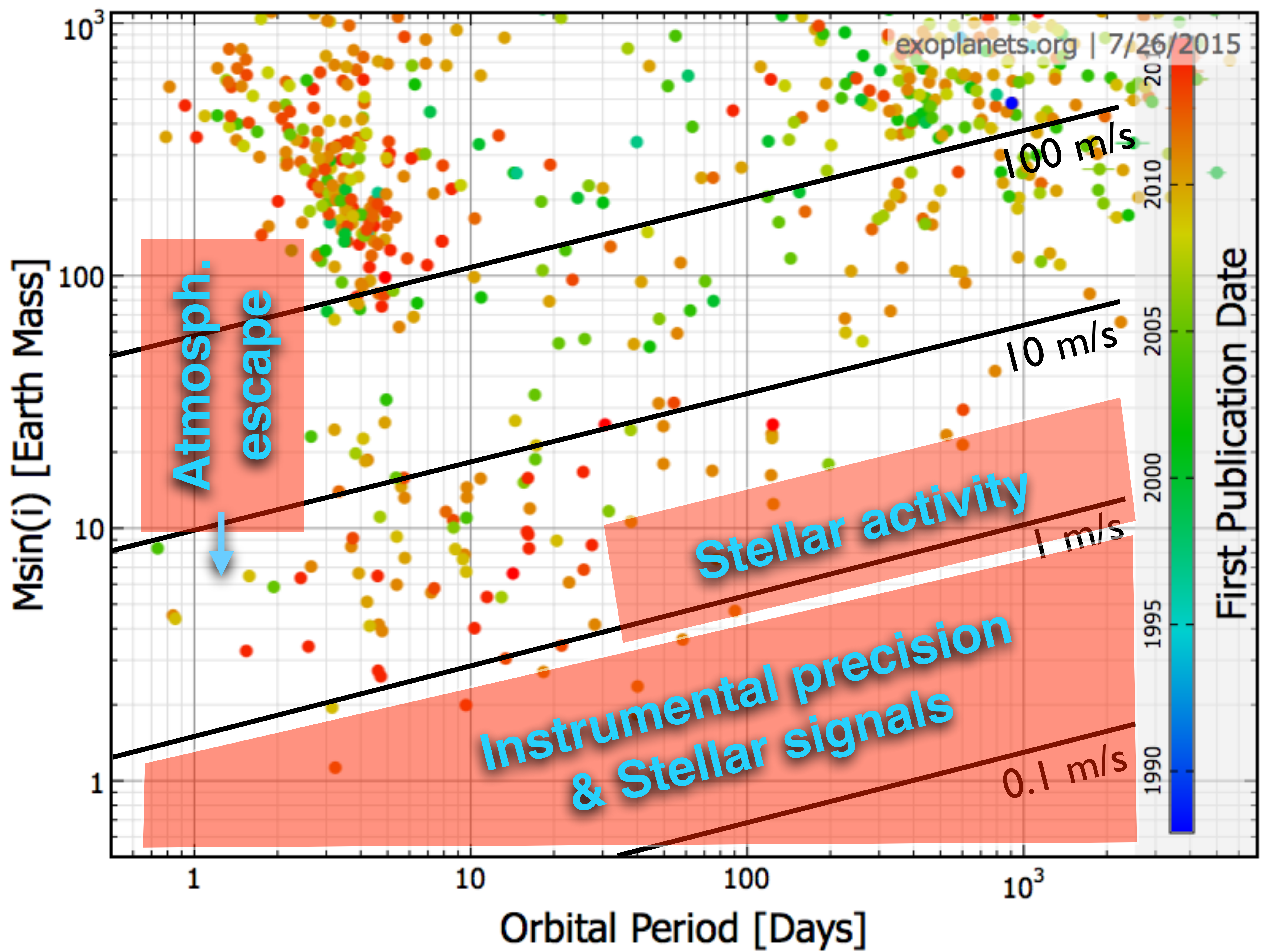
HARPS data



exoplanets.org | 7/26/2015
100 m/s
10 m/s
1 m/s
0.1 m/s
Stellar activity
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
10^3
100
10
1
10^3



exoplanets.org | 7/26/2015
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
100 m/s
10 m/s
1 m/s
0.1 m/s
Stellar activity
Instrumental precision
& Stellar signals
1
10
100
10³
1990
1995
2000
2005
2010



exoplanets.org | 7/26/2015
Atmosph. escape
Stellar activity
Instrumental precision & Stellar signals
100 m/s
10 m/s
1 m/s
0.1 m/s
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010

SELECTION BIAS

SELECTION BIAS

BRIGHT STARS m/s precison
for $V < 7$

less affected by
stellar activity **QUIET STARS**

SAMPLING detection extremely
sensitive to sampling

Correct for bias

Correct for bias

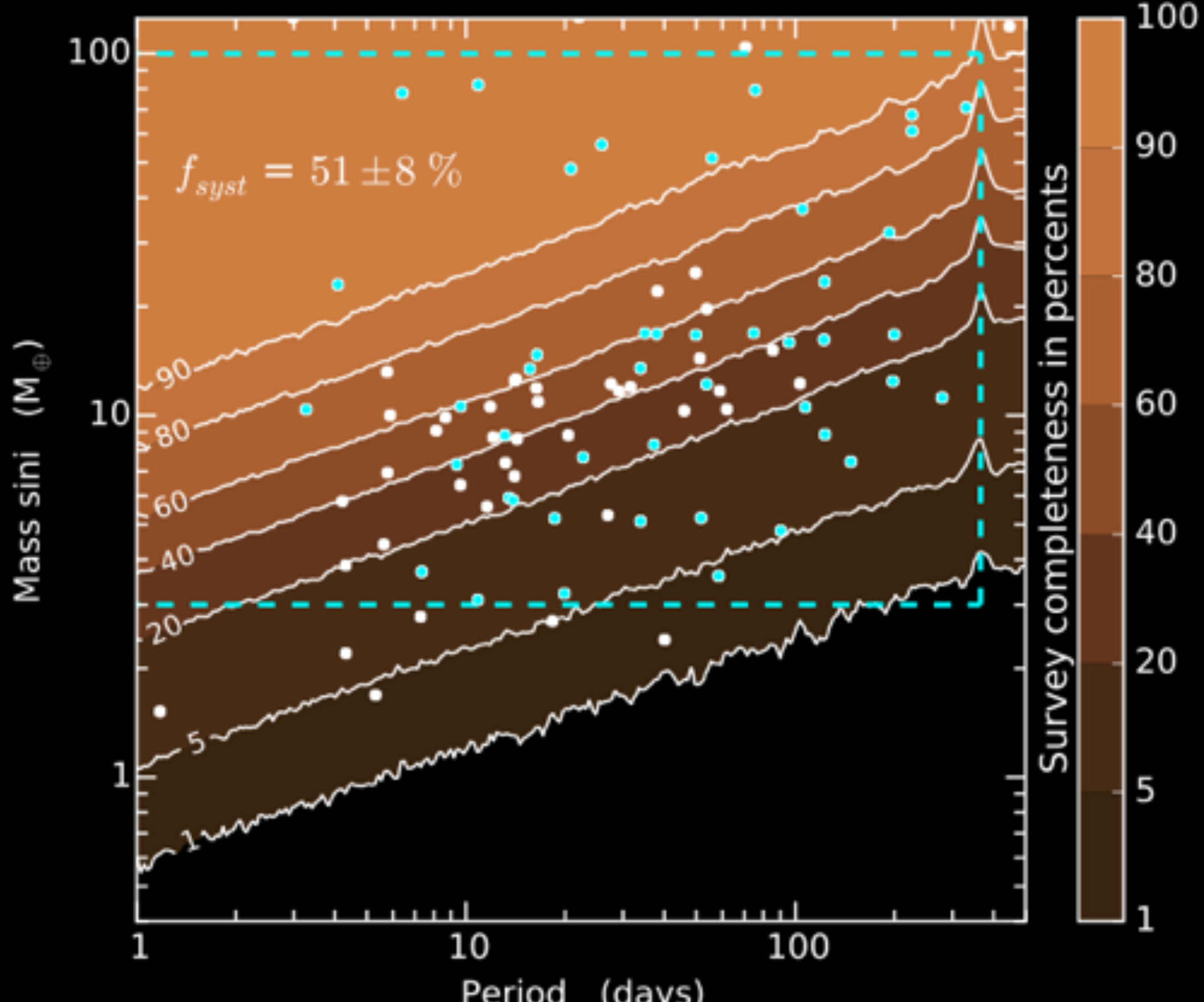
- Remove all the detected planets from the RV measurements of a star

- Inject a fake planet at a given period in the RV measurement, and increase its mass until the signal is significant in a periodogram analysis

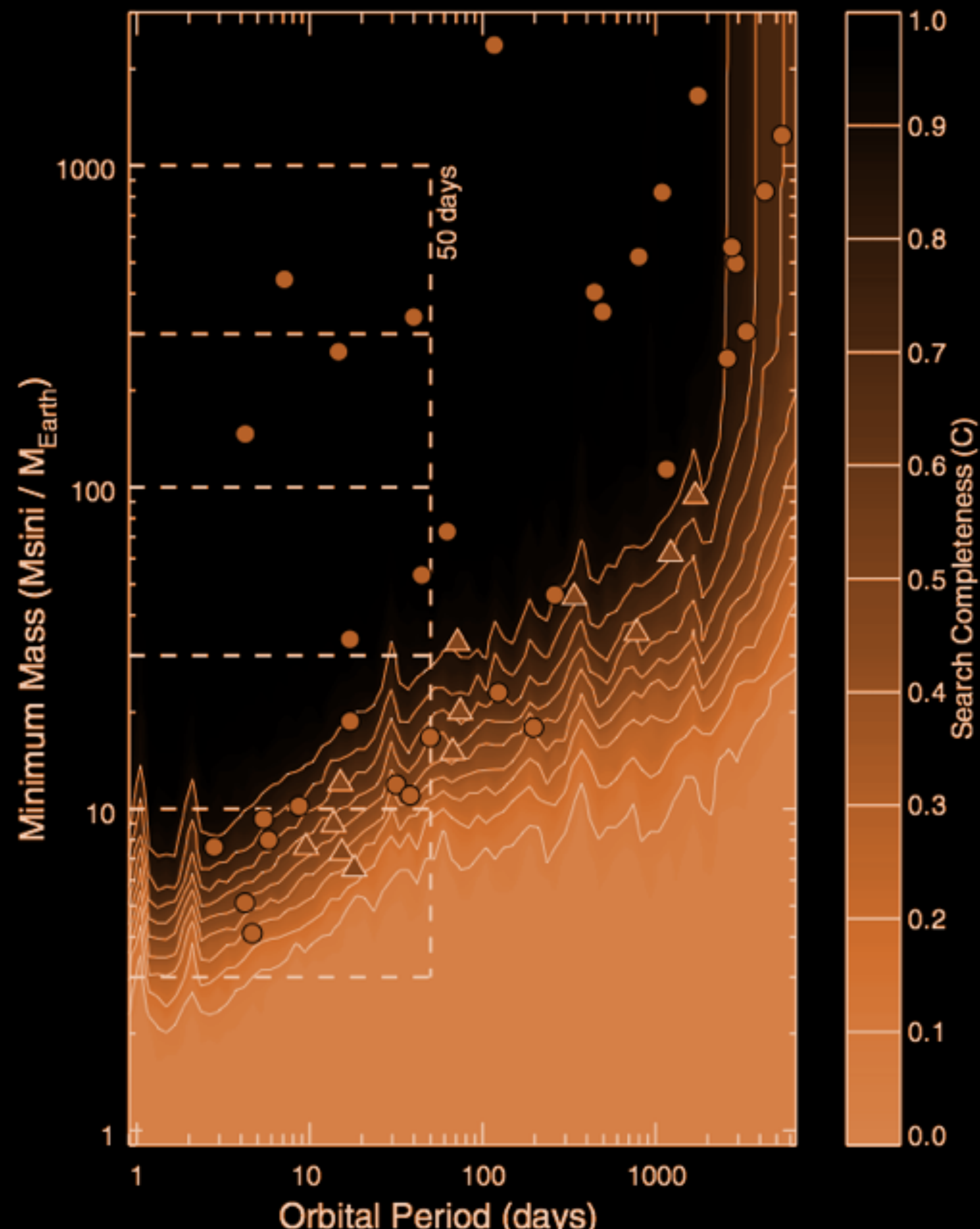
  → Detection limits for the RV measurement of a star at given period

- Perform this analysis for all periods, for all the stars in the survey

HARPS survey
376 stars



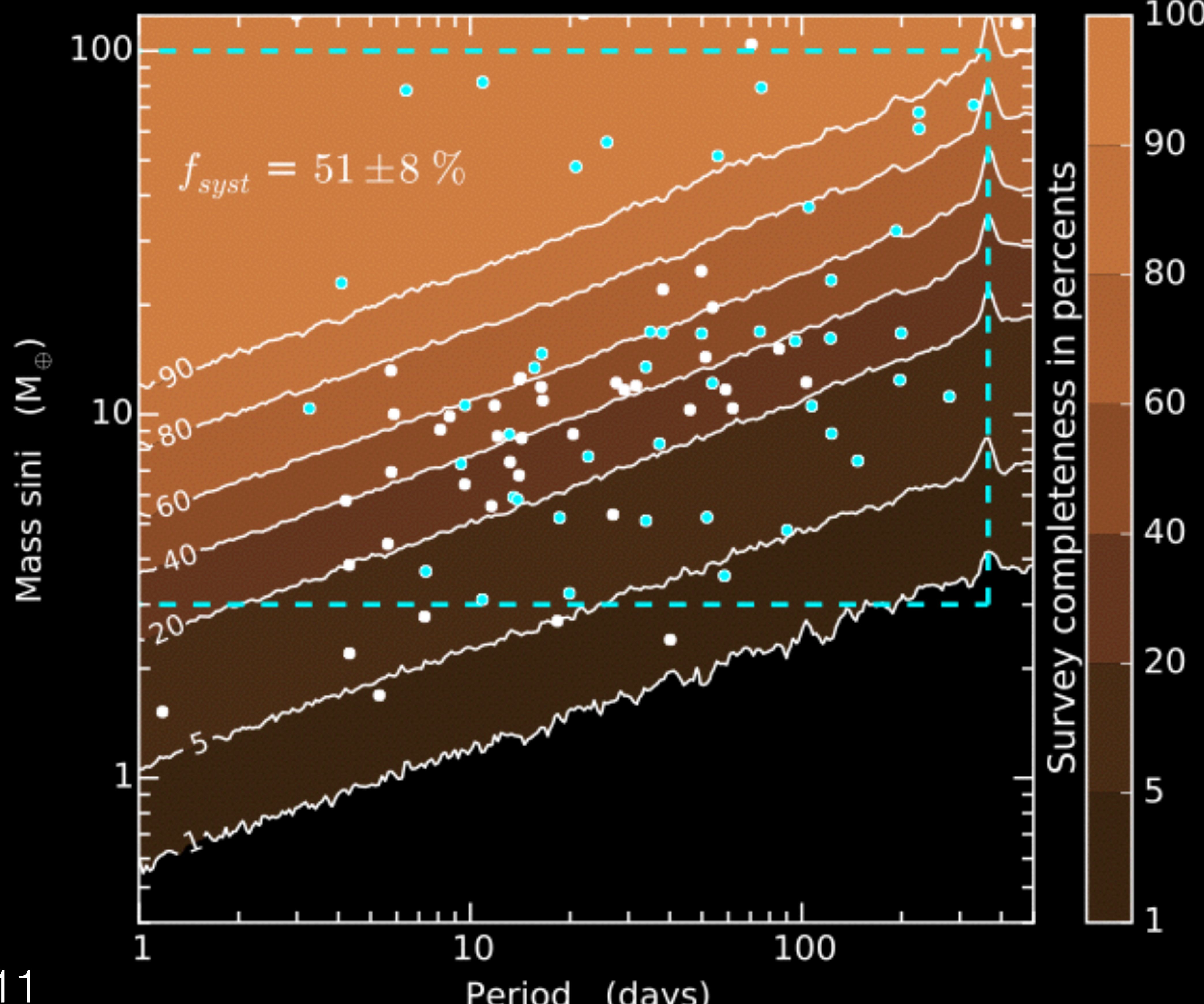
KECK survey
166 Stars



Mayor+11

Howard+10

HARPS survey
376 stars



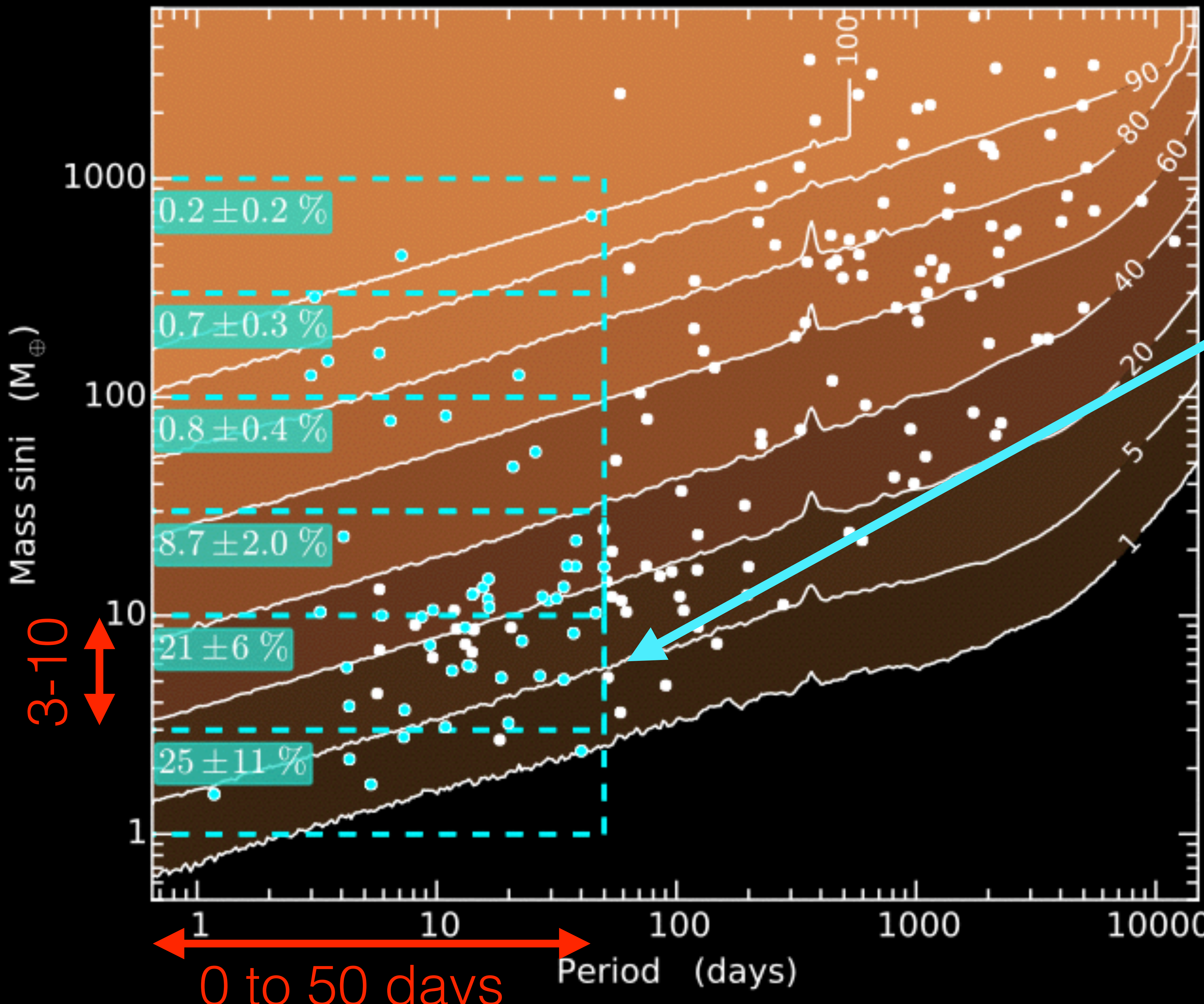
Mayor+11

Occurrence rates around G-K dwarfs

Occurrence rates around G-K dwarfs

- For only 10% of the stars, the RV measurements are good enough to detect planets with masses between 1 and 5 M_{Earth} and periods between 1 and 10 days
- If 10 planets have been detected in this region of the parameter space
- The unbiased occurrence rates if 100 planets, and not 10.

HARPS survey
376 stars



3 - 10 M_E
0 and 50 d
16 detections
20% complete

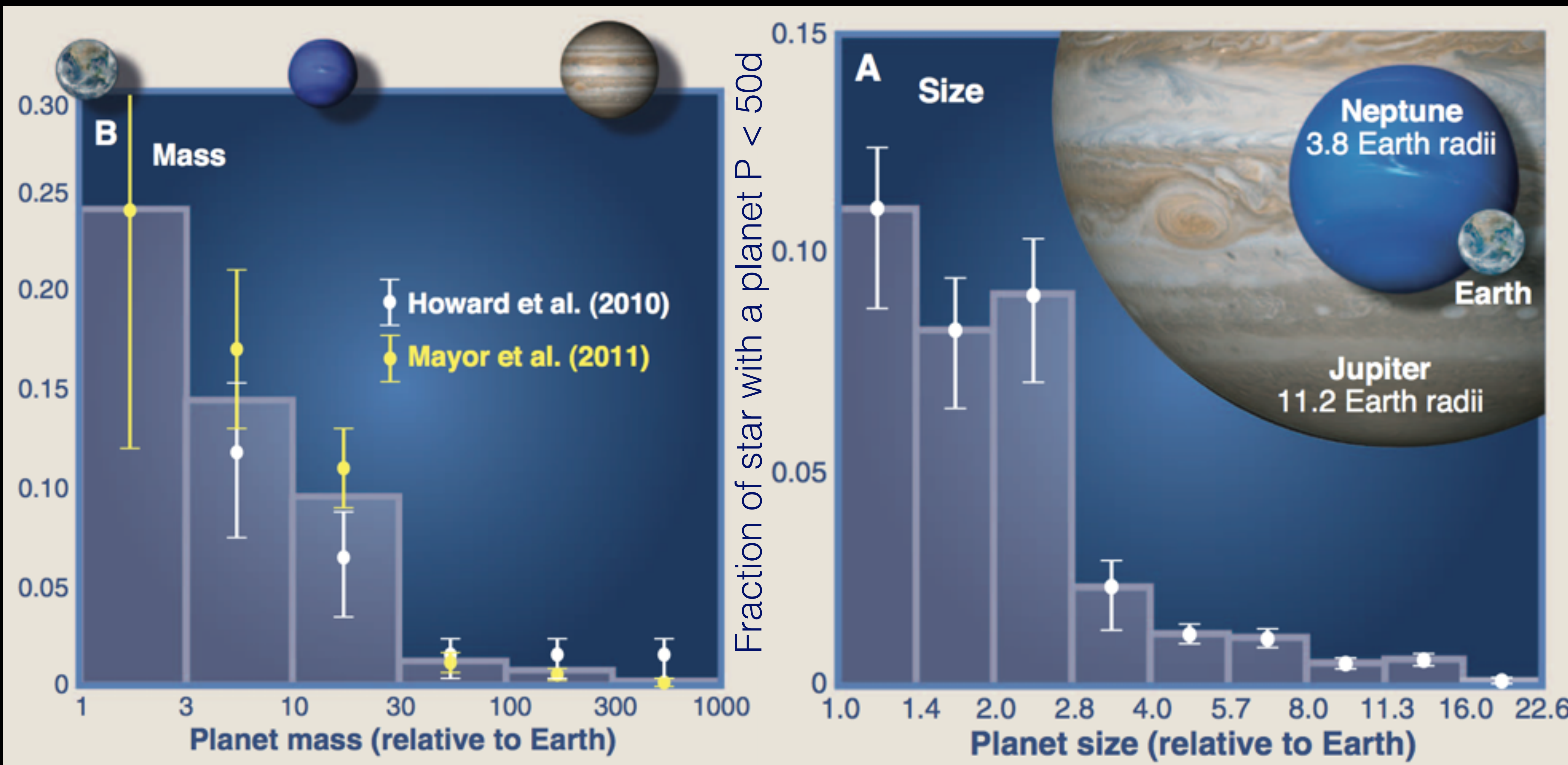
80 pl. after correction -> 21%

Mayor+11

Occurrence rates around G-K dwarfs

Occurrence rates around G-K dwarfs

Earth-mass planets are common within 50 days



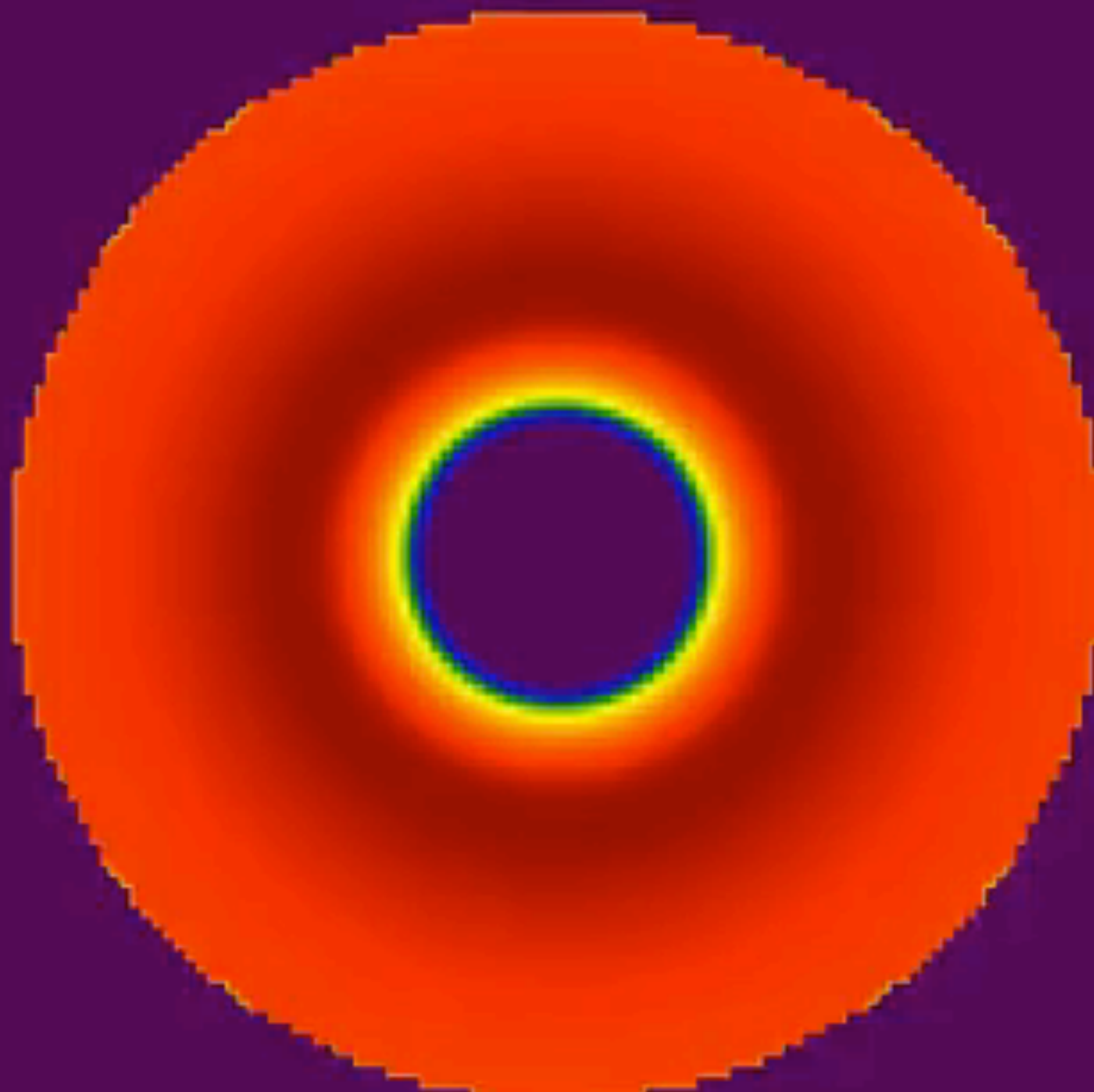
Howard+12

Core accretion

Core accretion

Gravitational instability

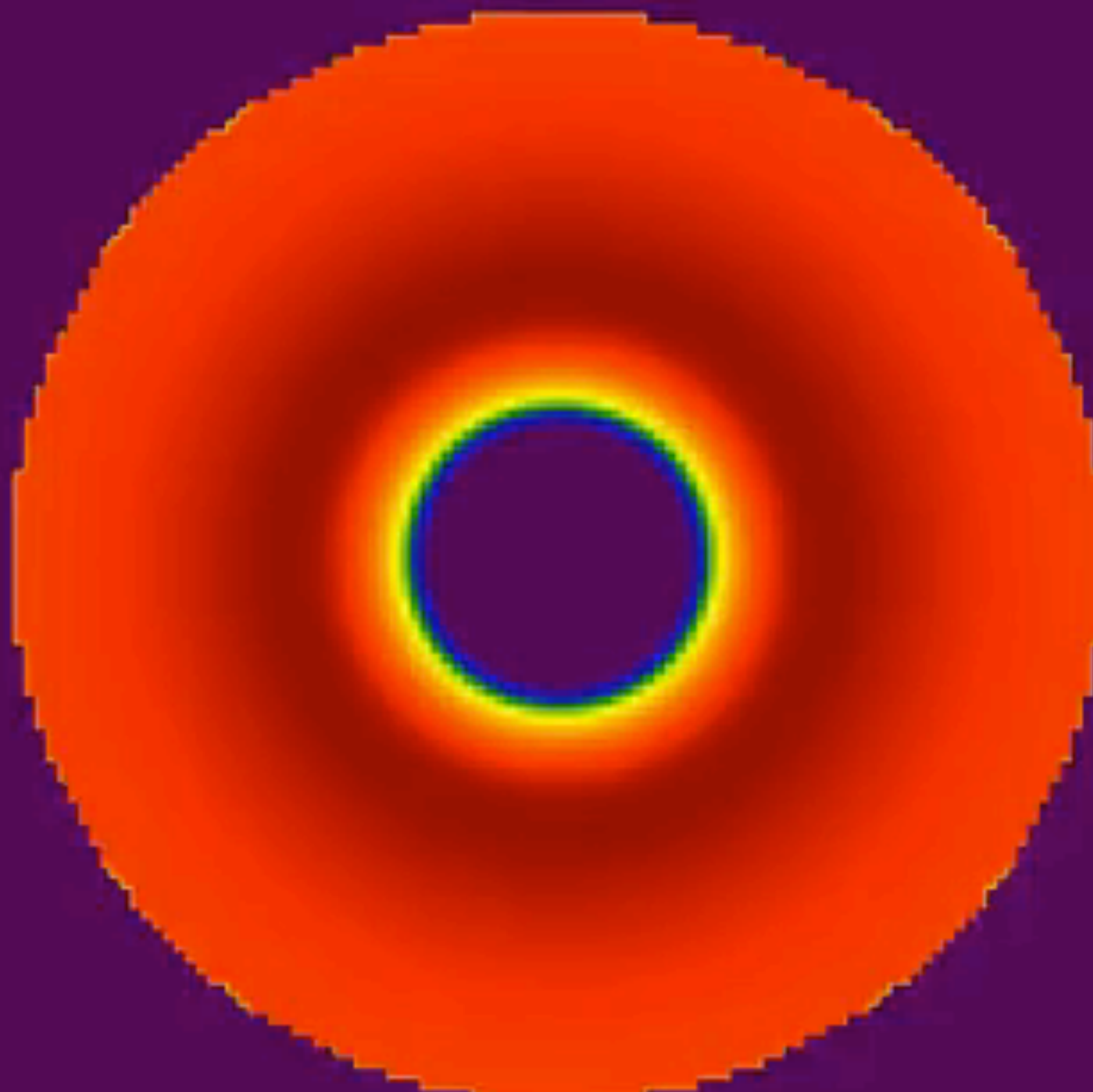
Gravitational instability



Lichtenberg+15

Gravitational instability

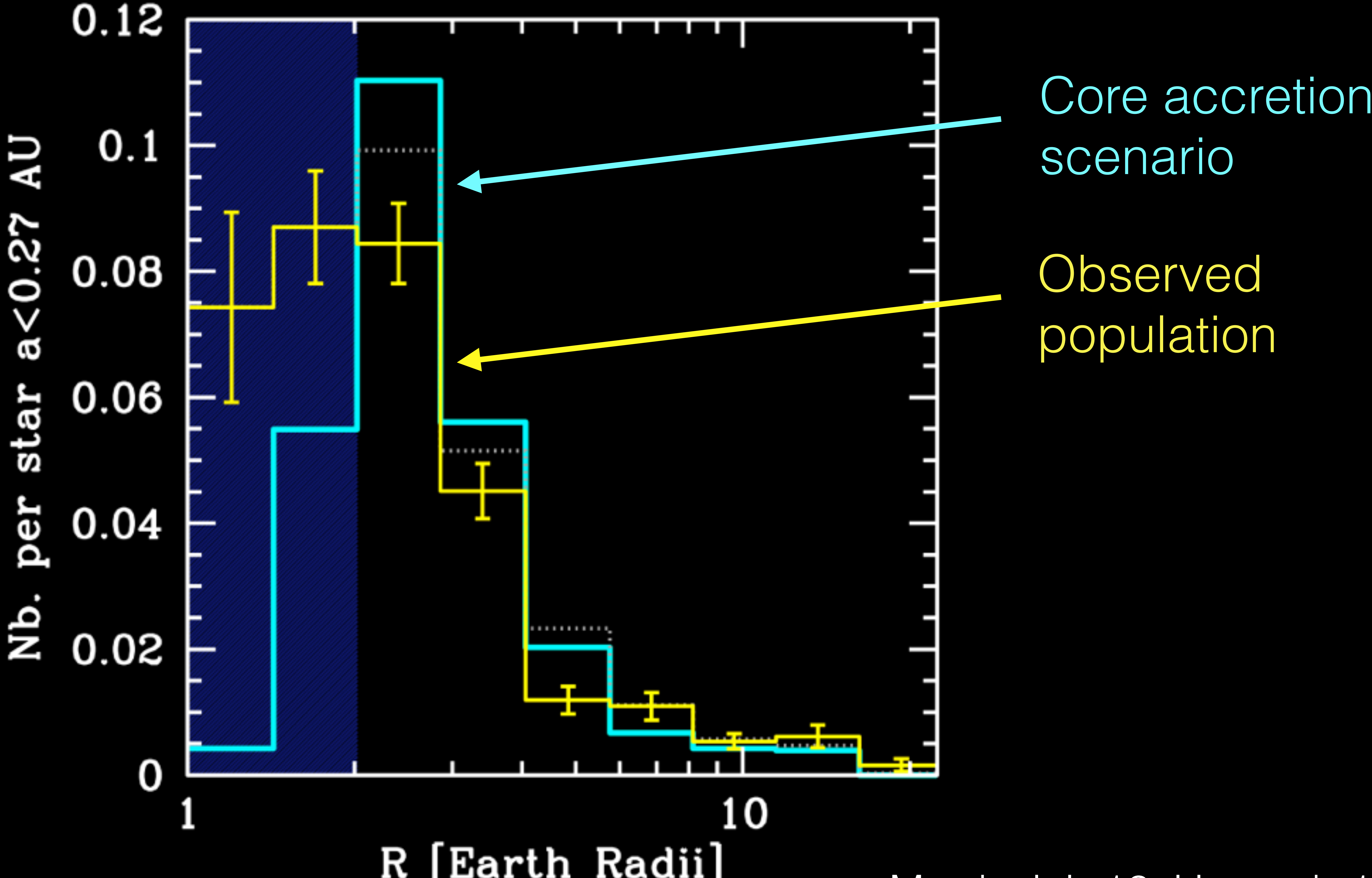
Gravitational instability



Lichtenberg+15

CONSTRAIN FORMATION SCENARIOS

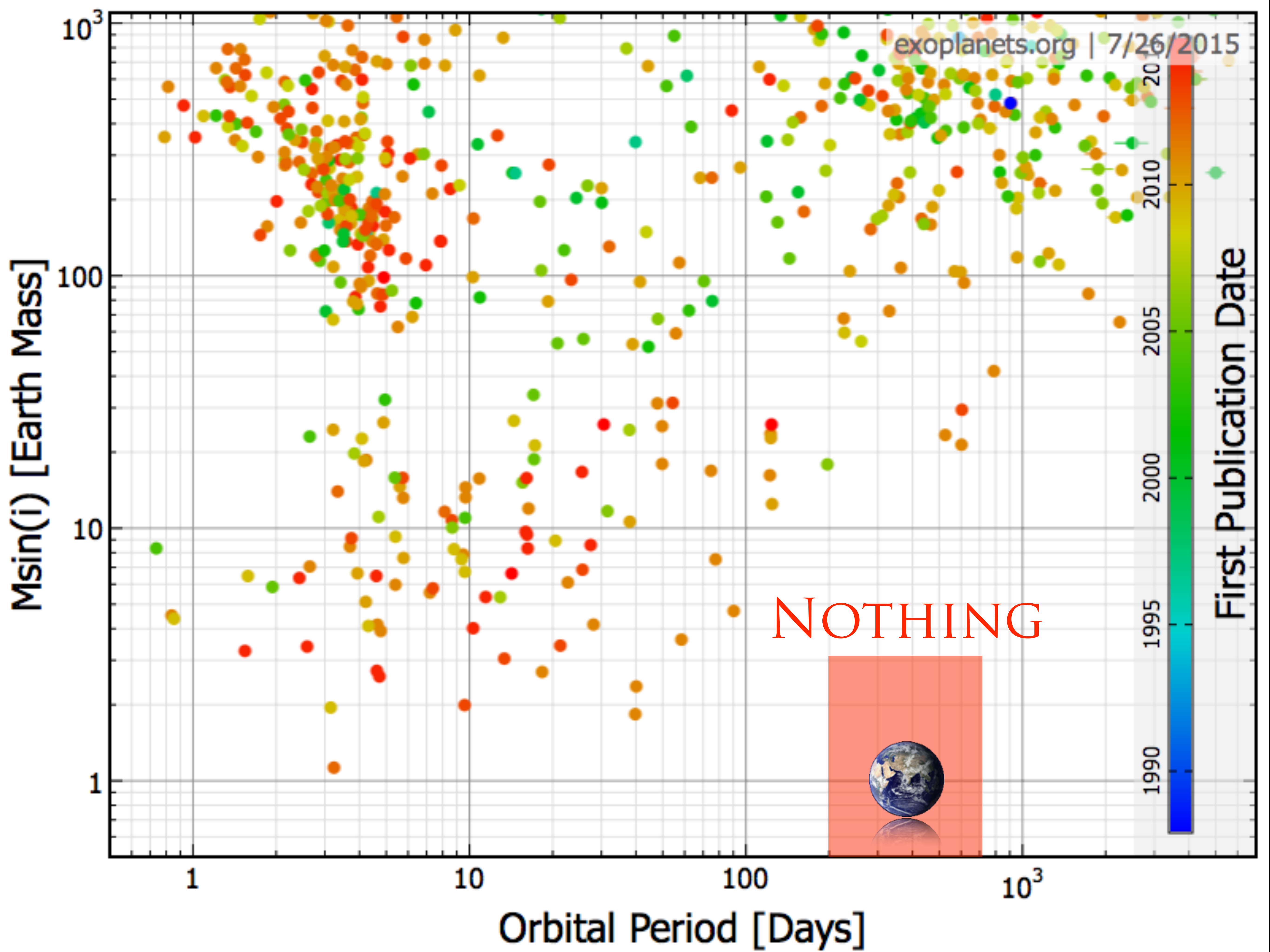
CONSTRAIN FORMATION SCENARIOS

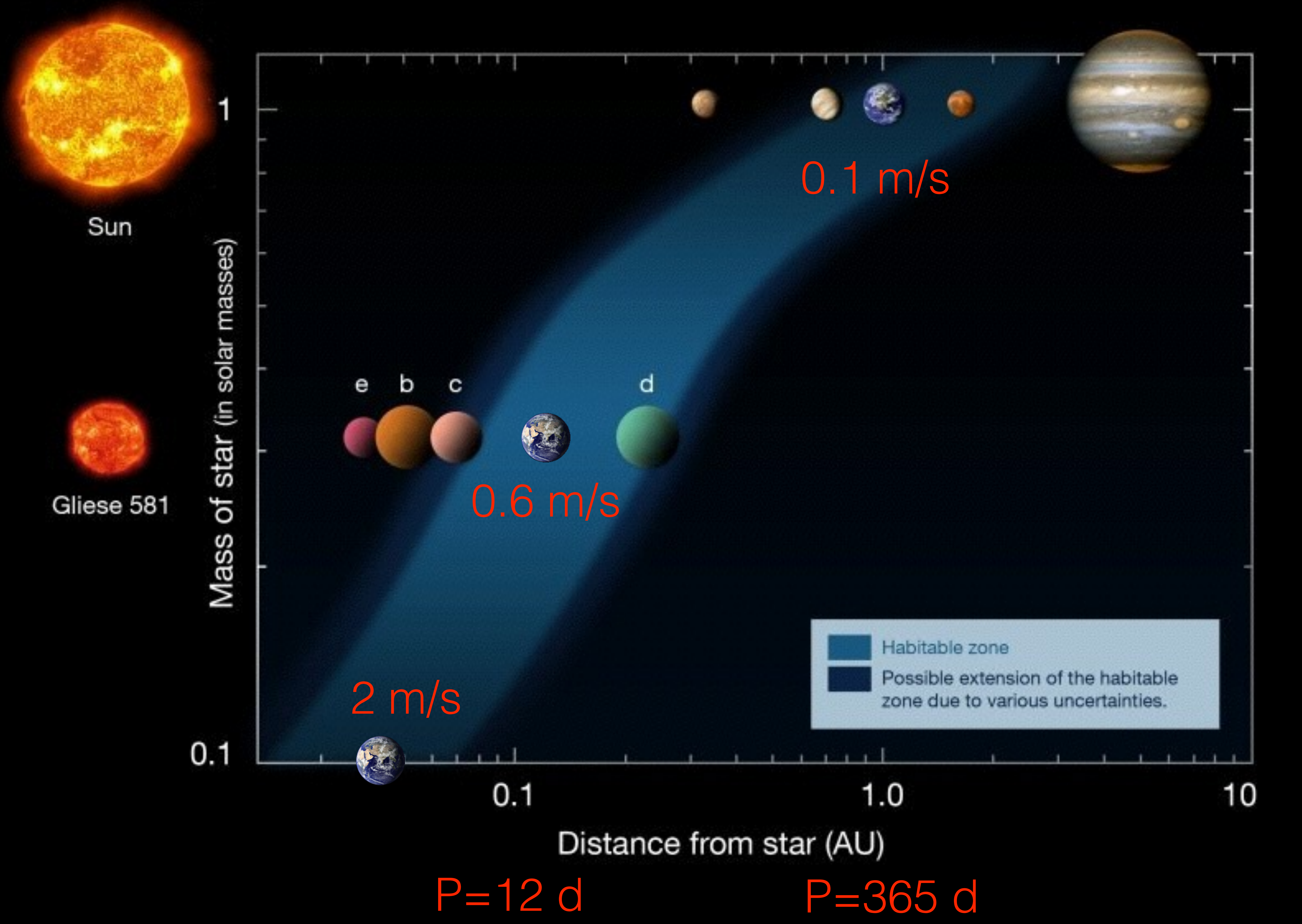


Mordasini+12, Howard+12

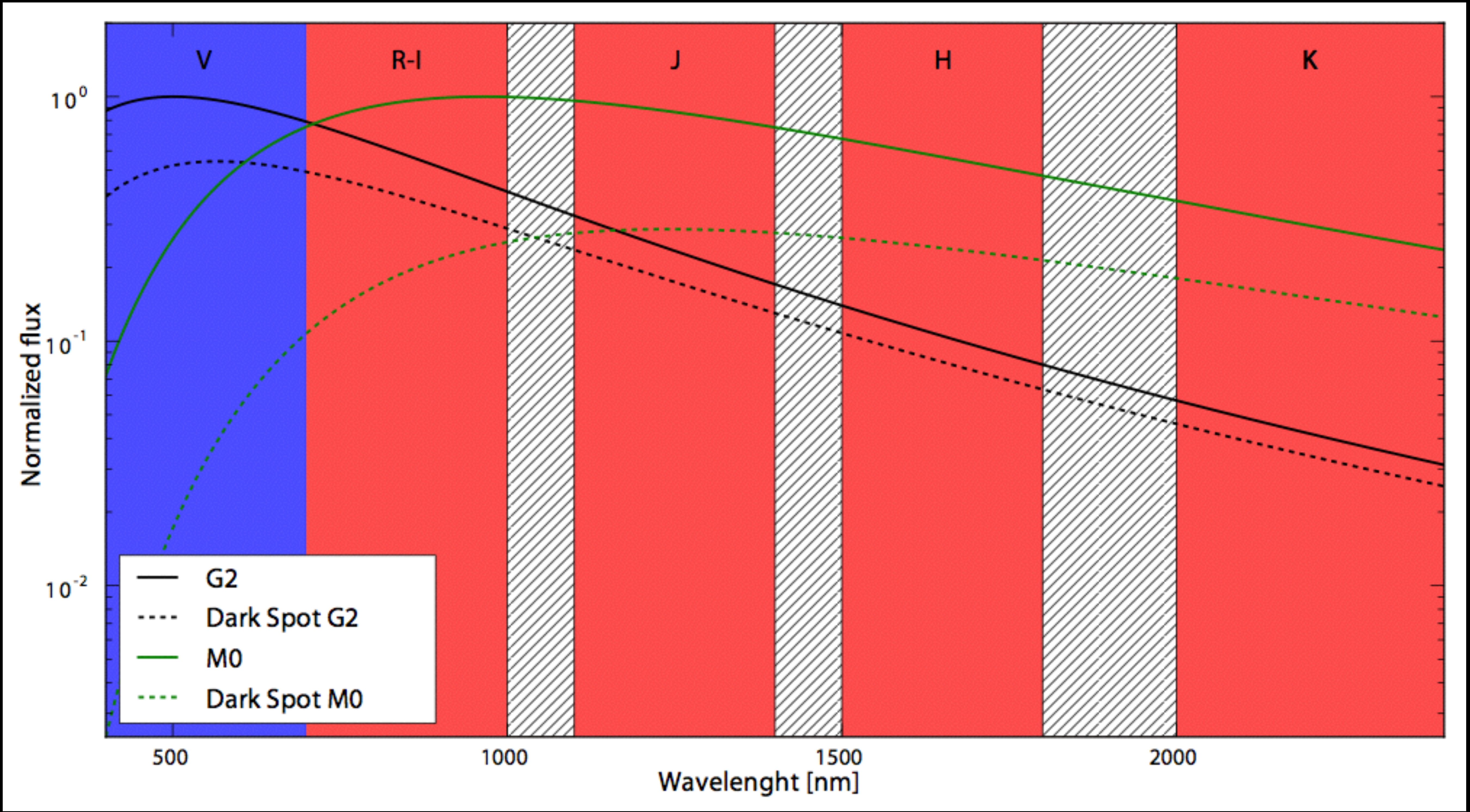
Earth-mass planets are common within 50 days

What about Earth-mass planet in the Habitable Zone ?


exoplanets.org | 7/26/2015
Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
1990
1995
2000
2005
2010
Nothing
1
10
100
10^3



Sun
Gliese 581
Mass of star (in solar masses)
1
0.1
e
b
c
d
0.1 m/s
0.6 m/s
2 m/s
Habitable zone
Possible extension of the habitable zone due to various uncertainties.
0.1
1.0
10
Distance from star (AU)
P=12 d
P=365 d



V
R-I
J
H
K
10^0
10^{-1}
10^{-2}
Normalized flux
500
1000
1500
2000
Wavelenght [nm]
G2
Dark Spot G2
M0
Dark Spot M0

Habitable zone planets around M dwarfs

Habitable zone planets around M dwarfs

RV

- $3 < M\sin i < 10\ M_{Earth}$: 0.2 HZ pl / star (Tuomi+14)
- $1 < M\sin i < 10\ M_{Earth}$: 0.4 HZ pl / star (Bonfils+13)

Transit

- $0.5 < R_{pl} < 1.4\ R_{Earth}$: 0.5 HZ pl / star (Kopparapu +13, Dressing+13)

Characterizing planet composition

RV

Mass

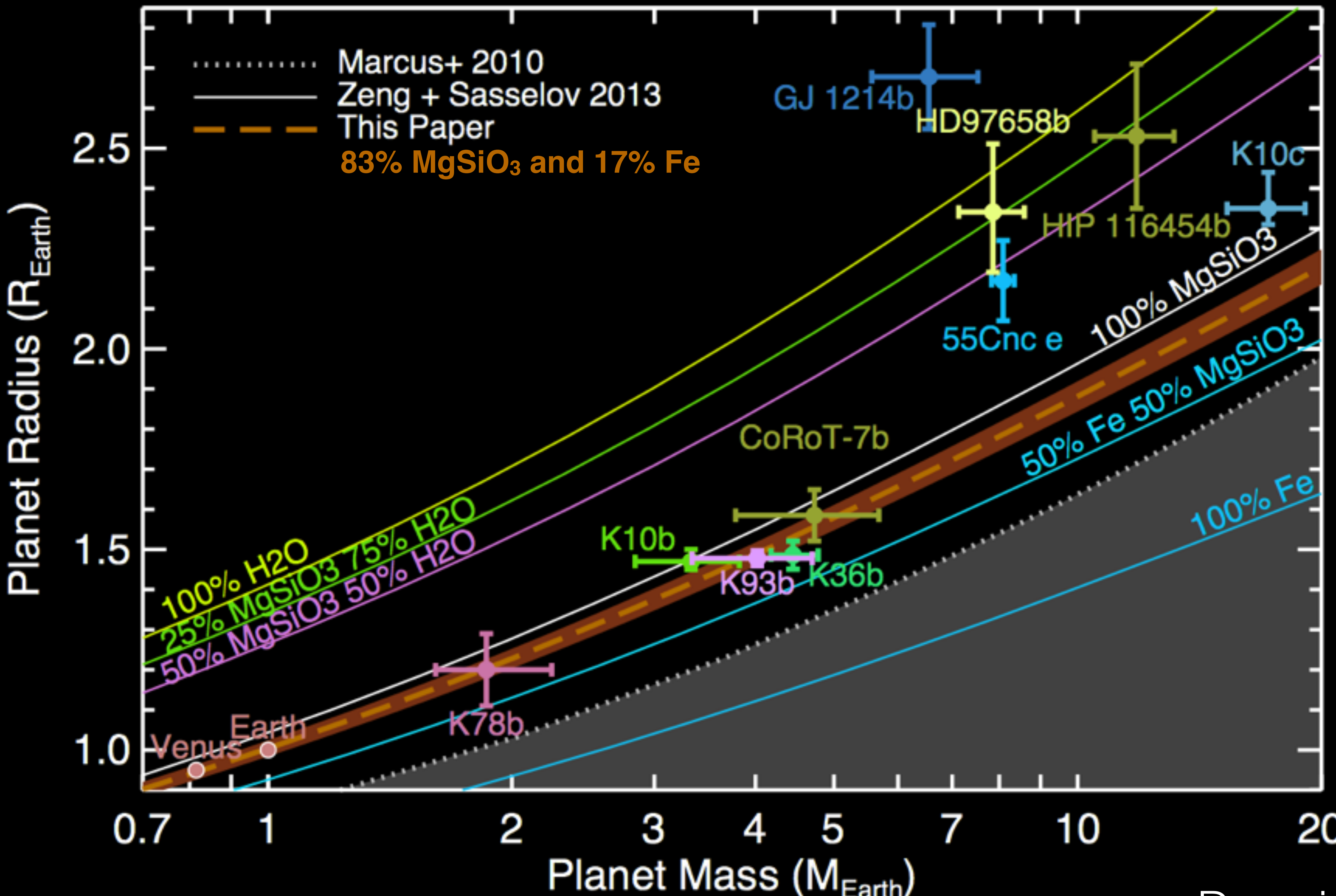
Transit

Radius

Density

Composition of terrestrial planets

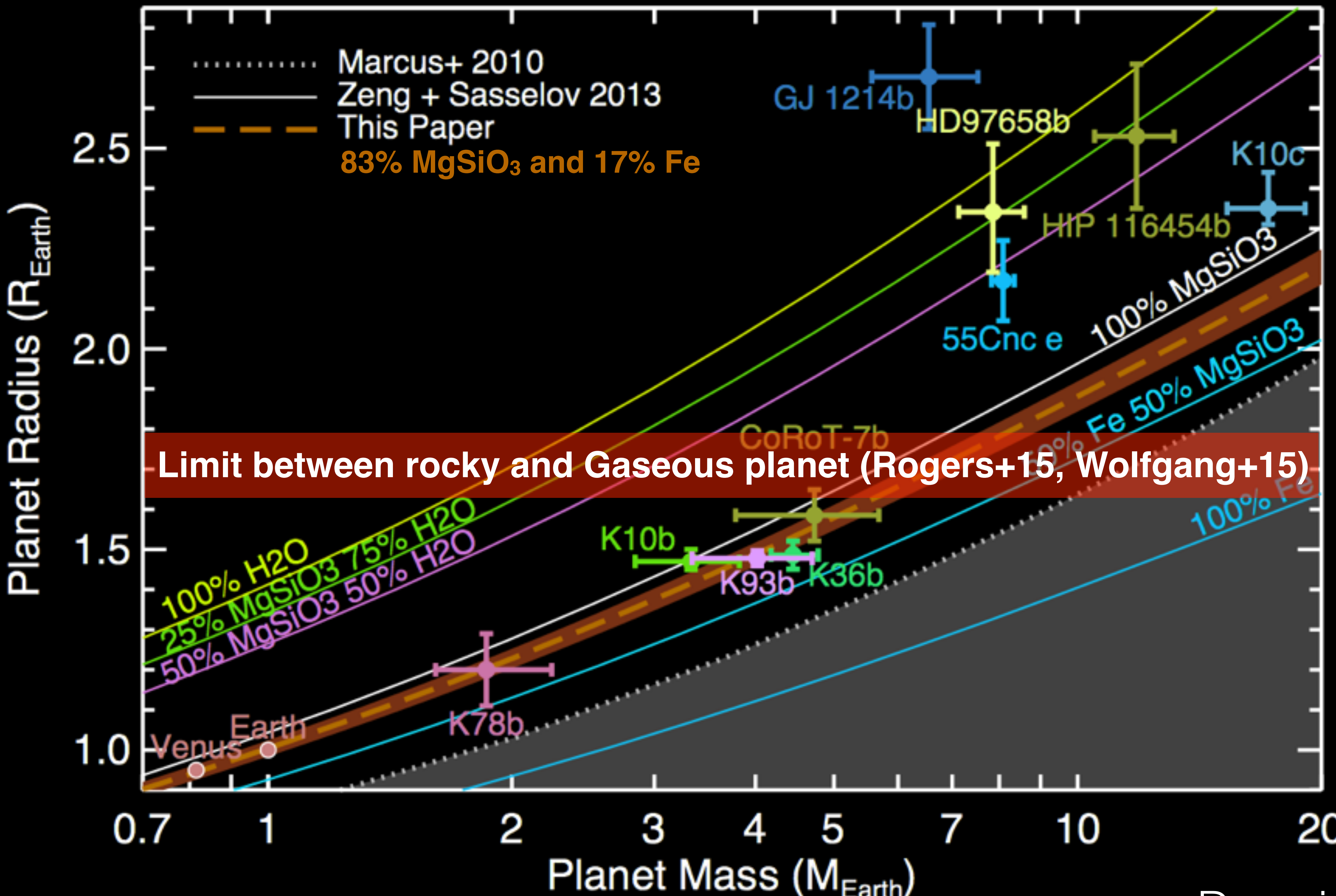
Composition of terrestrial planets



Dressing+15

Composition of terrestrial planets

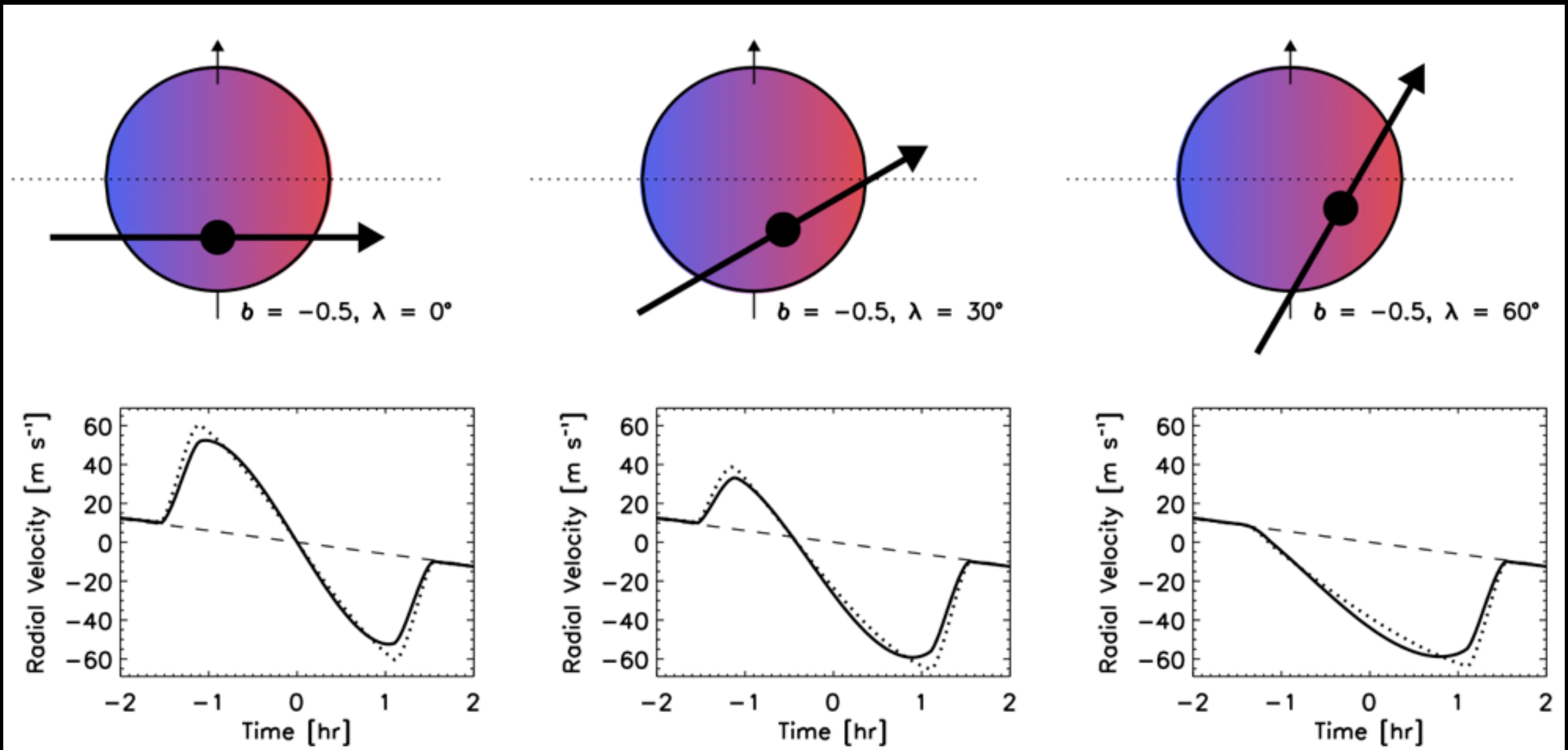
Composition of terrestrial planets

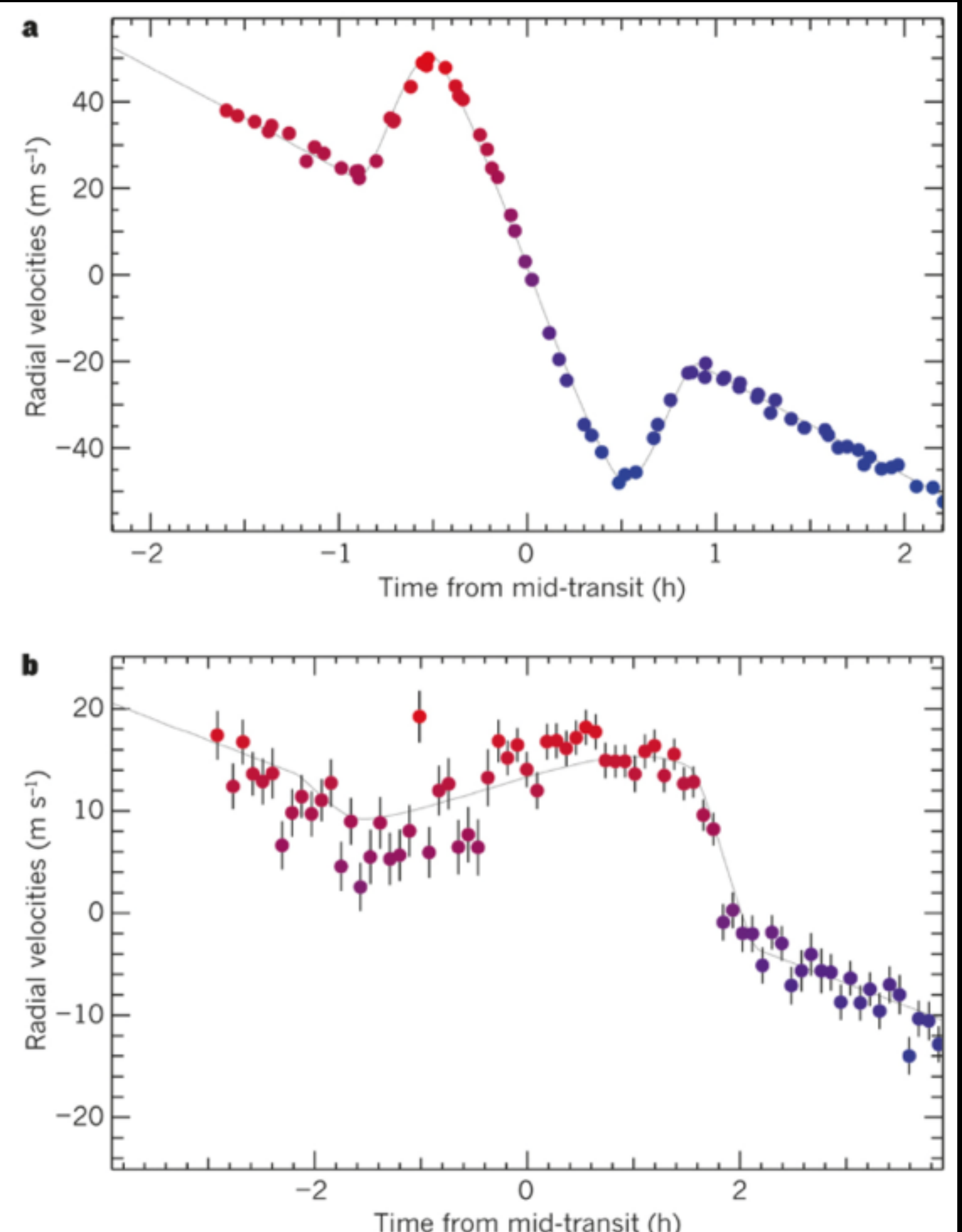


Dressing+15

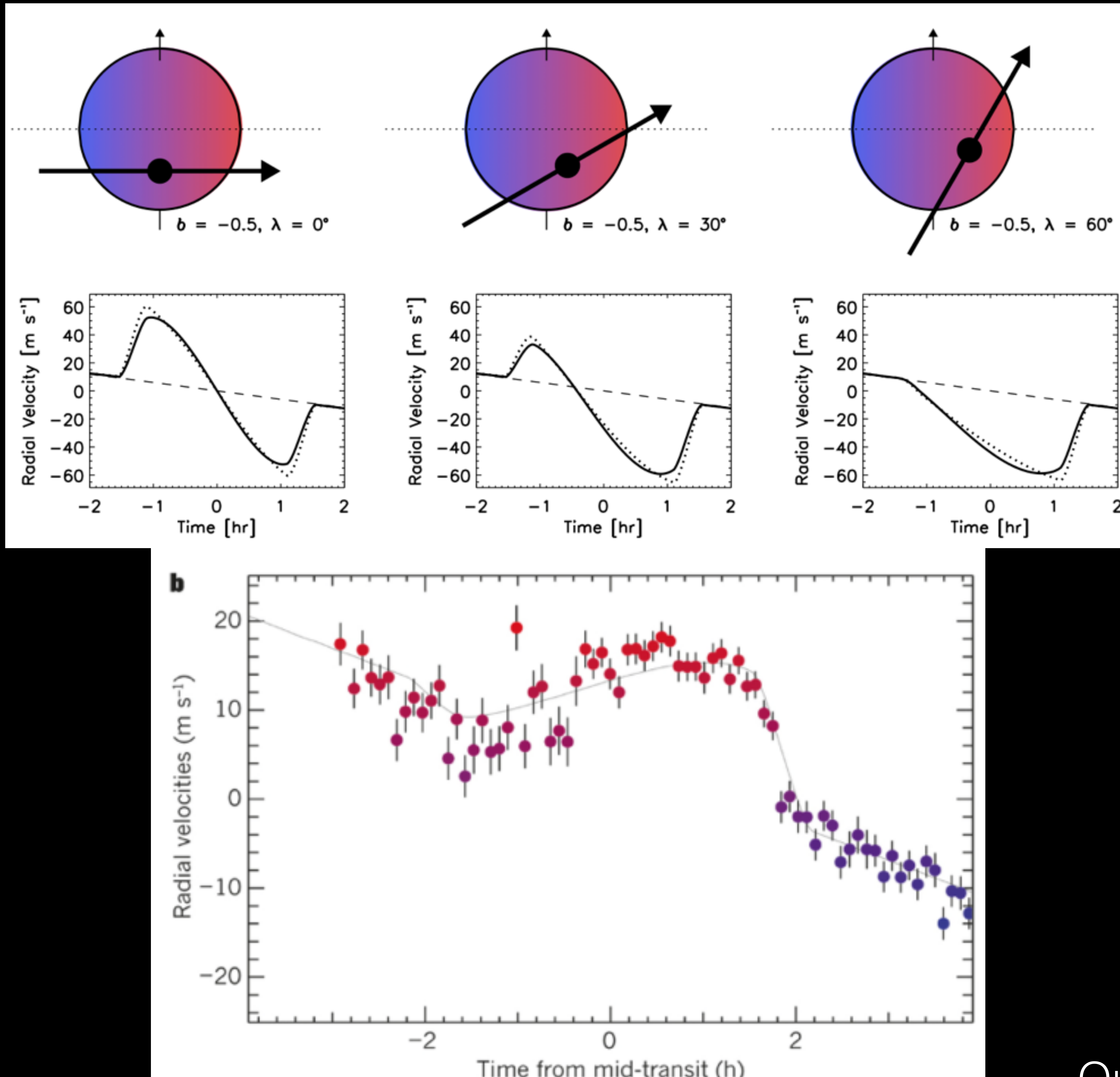
Rossiter McLaughlin Effect

Rossiter McLaughlin Effect



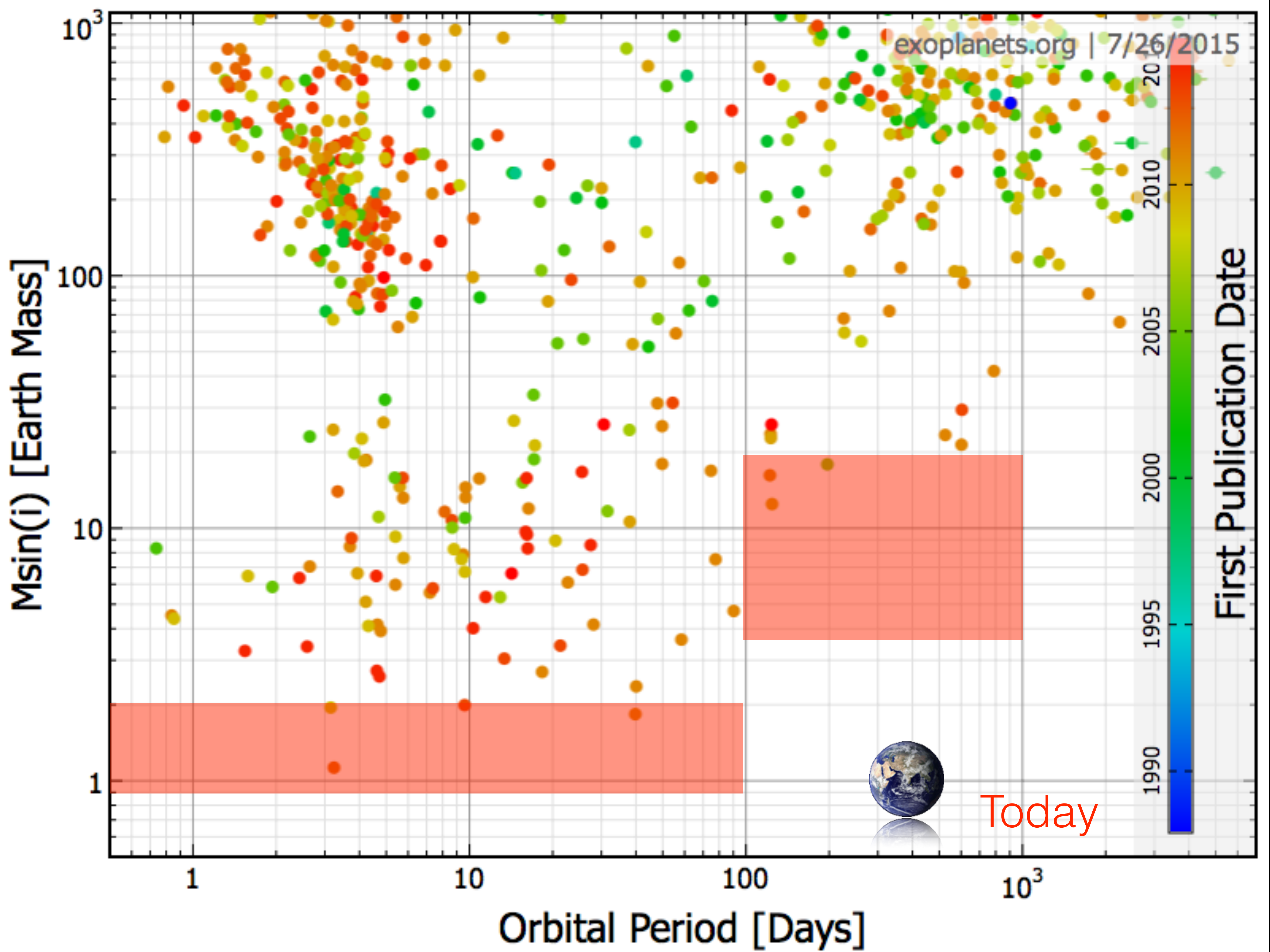

a
Radial velocities (m s⁻¹)
40
20
0
−20
−40
−2
−1
0
1
2
Time from mid-transit (h)
b
Radial velocities (m s⁻¹)
20
10
0
−10
−20
−2
0
2
Time from mid-transit (h)

Queloz+10



b = −0.5, λ = 0°
b = −0.5, λ = 30°
b = −0.5, λ = 60°
Radial Velocity [m s⁻¹]
Time [hr]
b
Radial velocities (m s⁻¹)
Time from mid-transit (h)

Queloz+10



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Msin(i) [Earth Mass]
Orbital Period [Days]
First Publication Date
Today