The planets at the extremes of WFIRST's microlensing sensitivity

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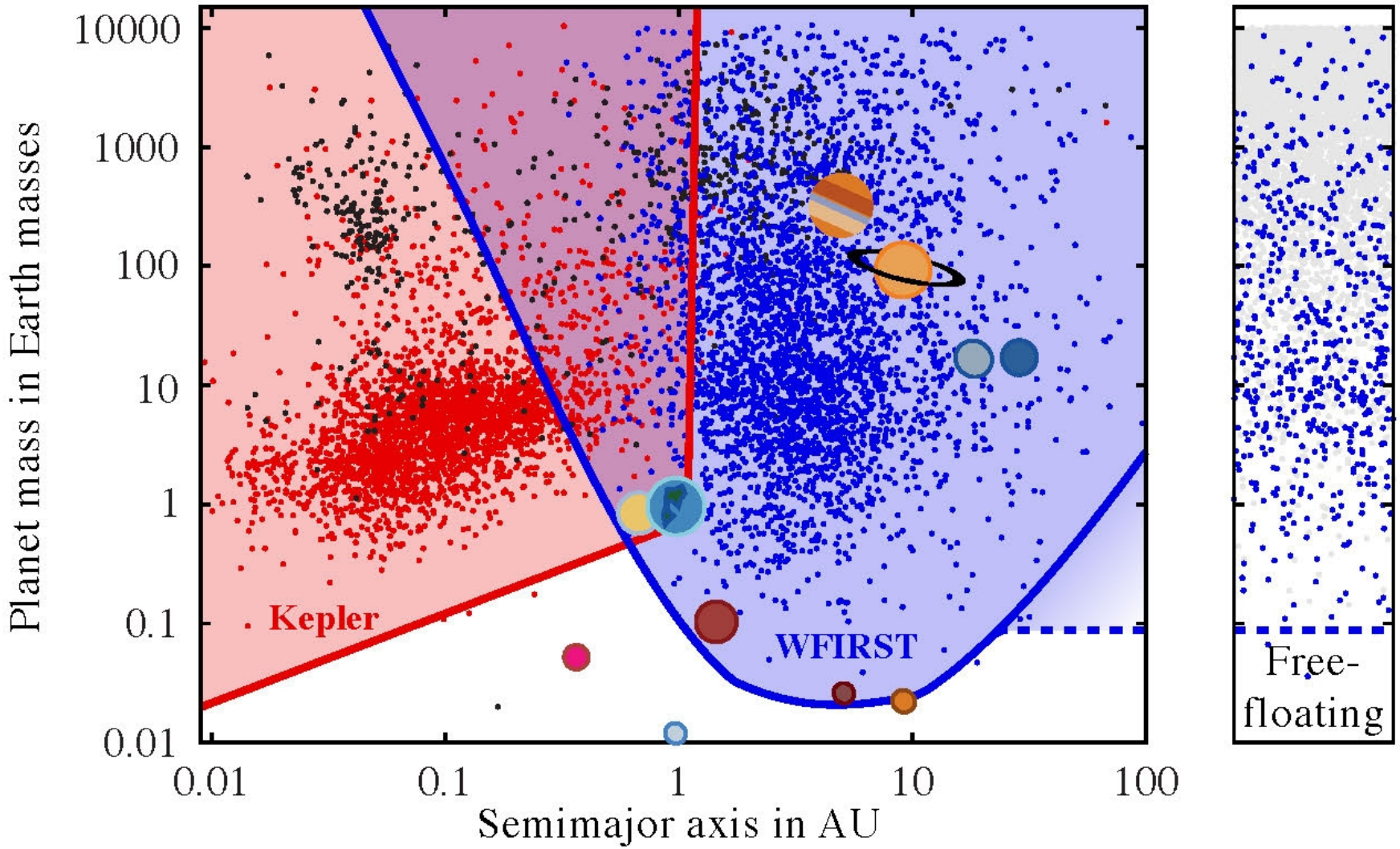
Contributions from Scott Gaudi, Sean Raymond, Andrew Mann

The WFIRST microlensing survey



The WFIRST microlensing survey: What do we learn?

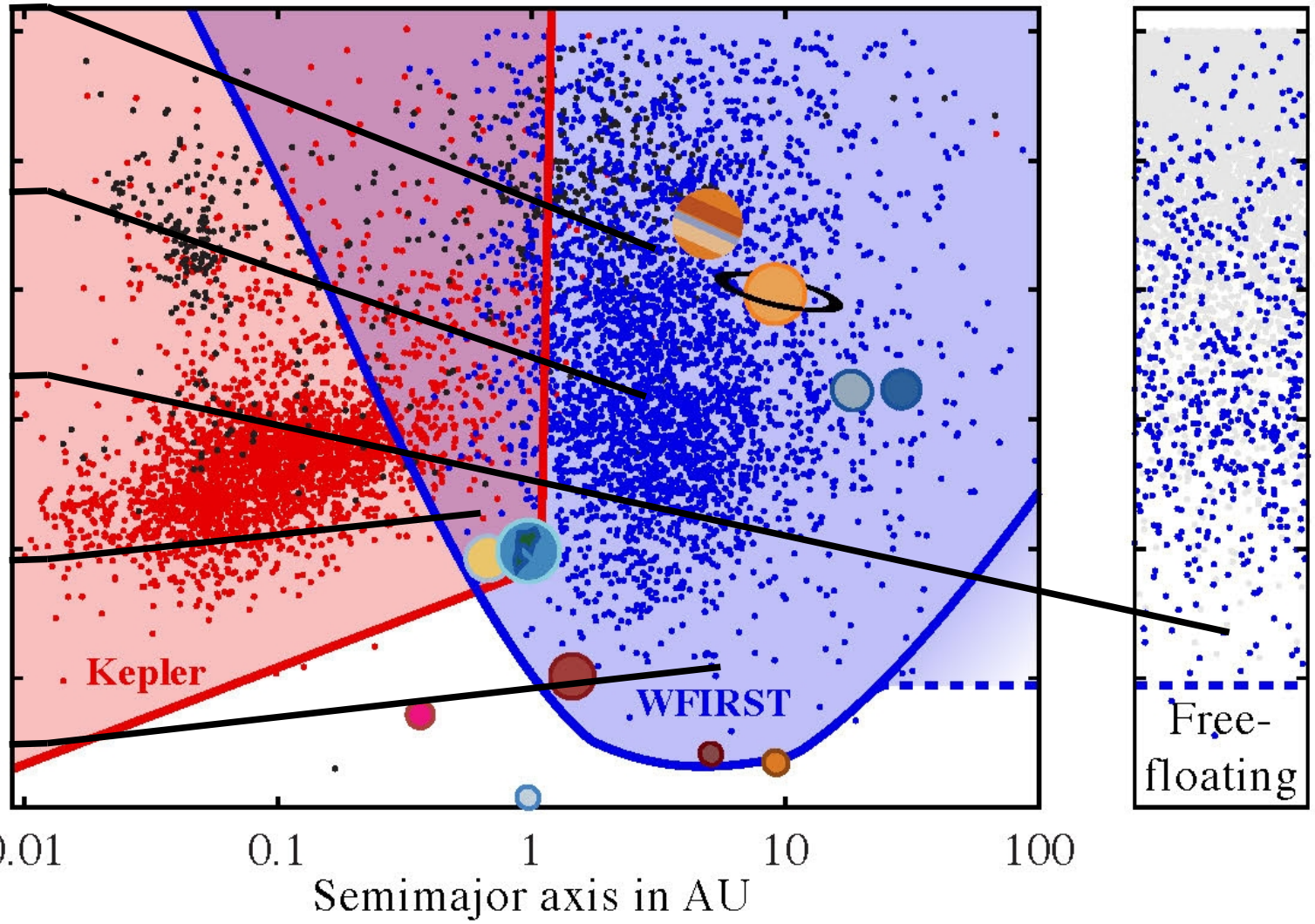
~3000 cold bound planets

Mass + distance of most

Free-floating planets down to Mars-mass

Outer HZ + Kepler overlap

Abundance of cold sub-Earths



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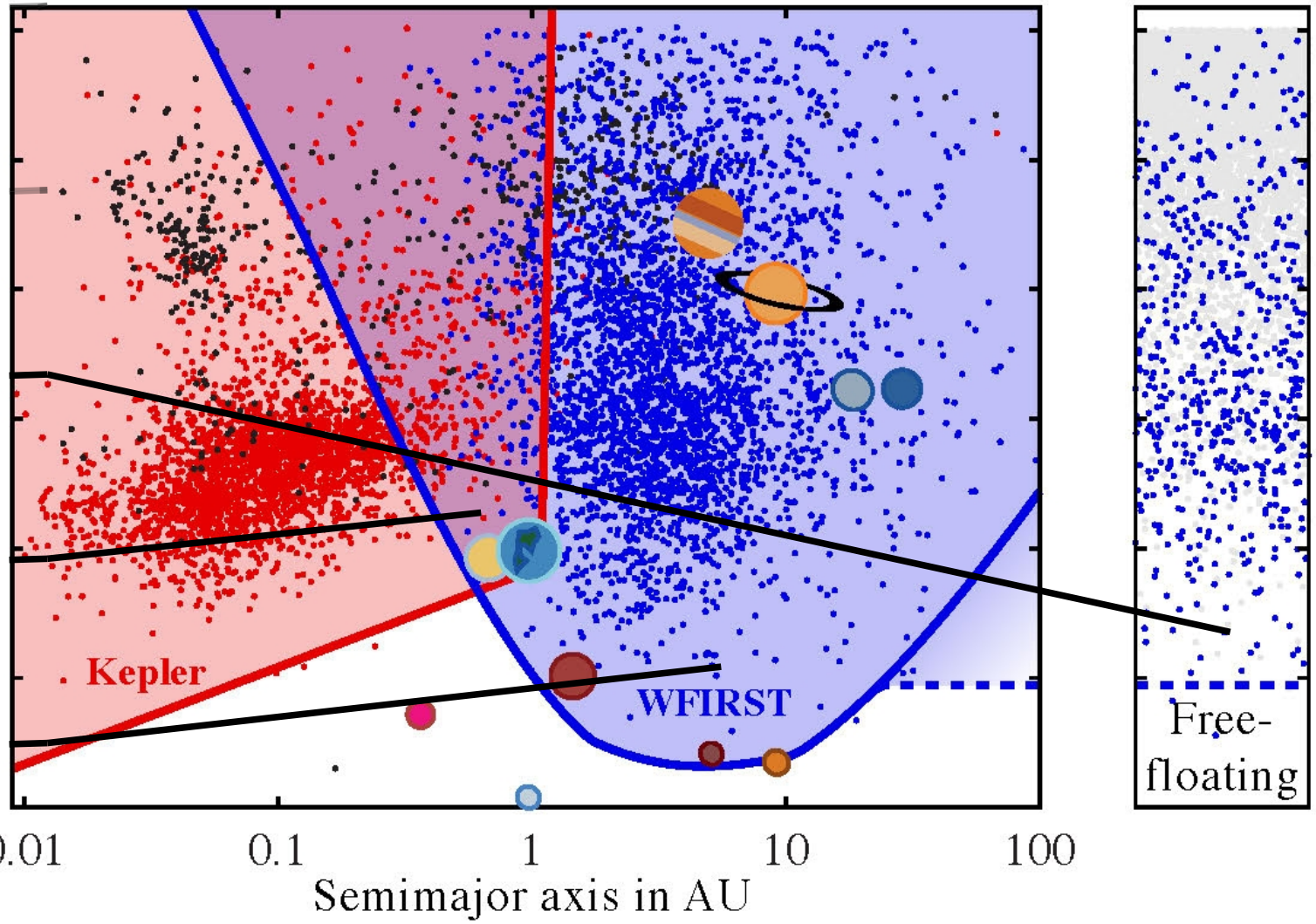
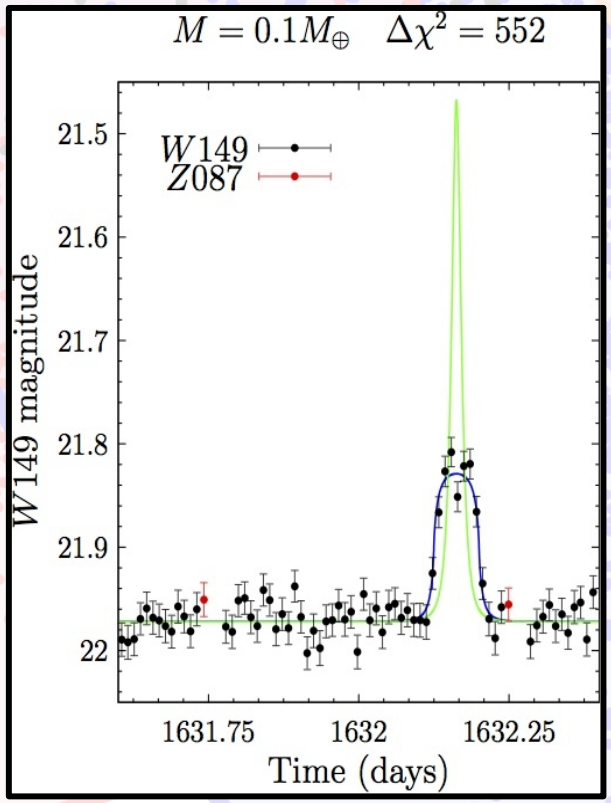


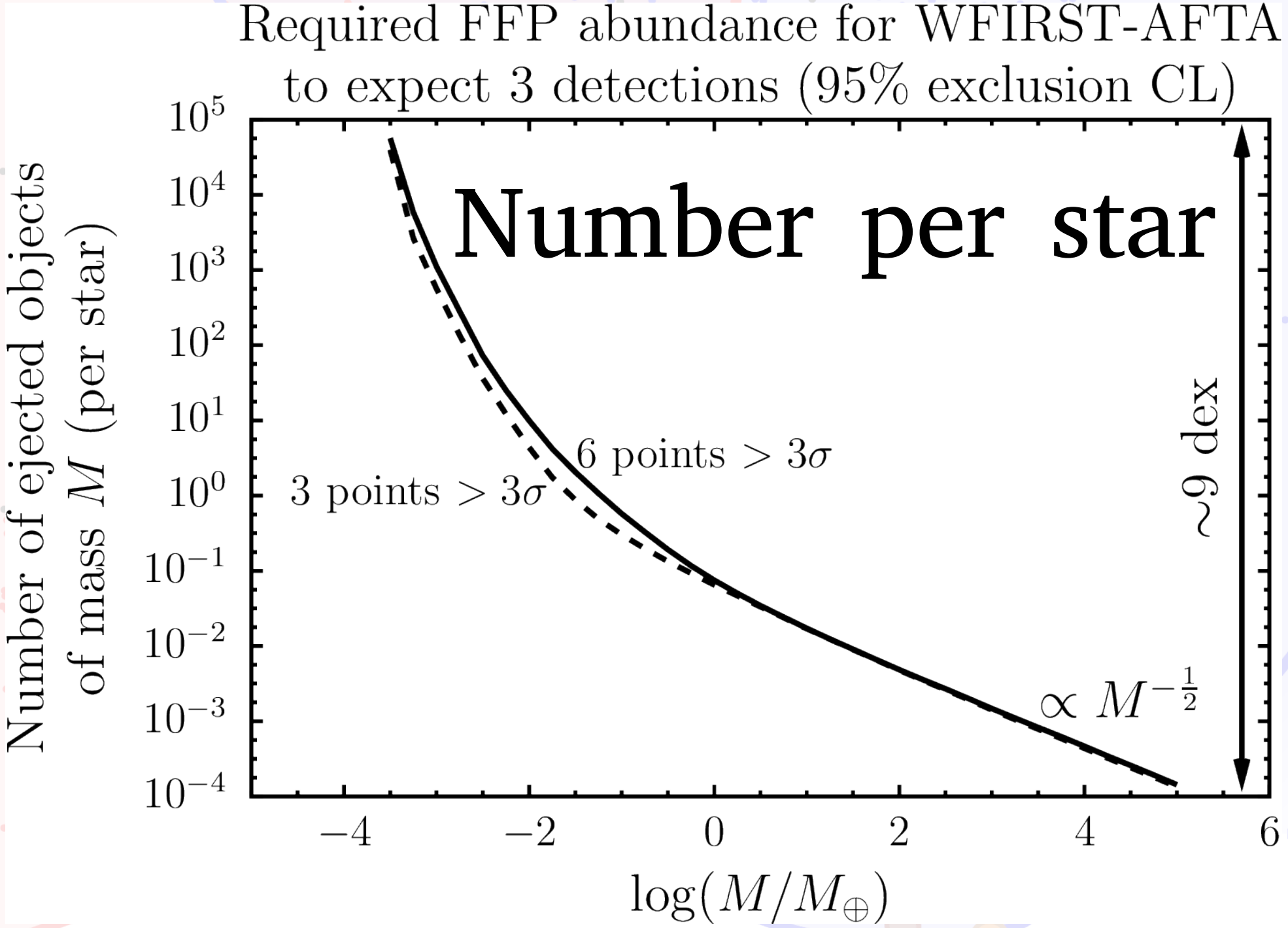
Free-floating planets

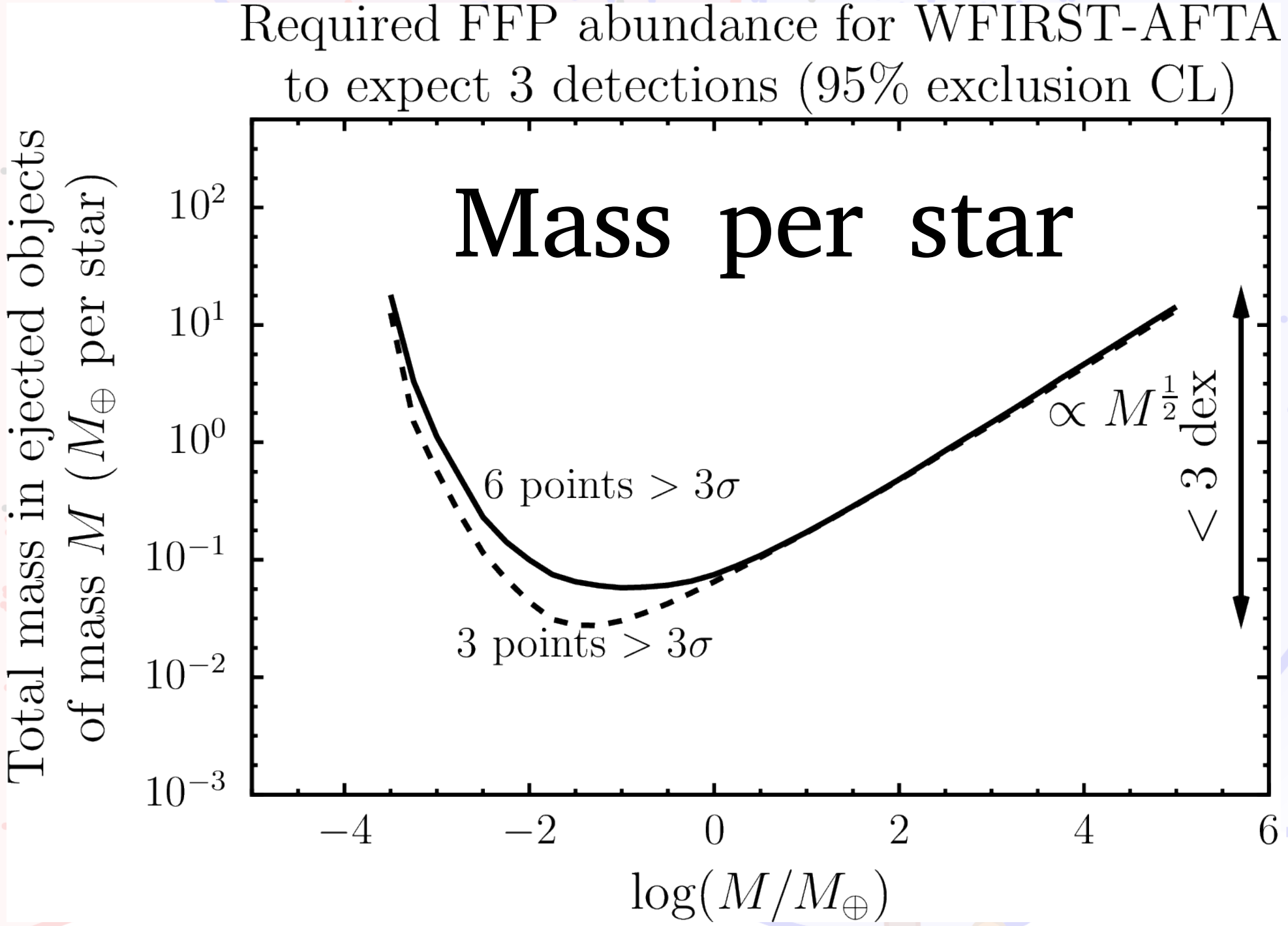


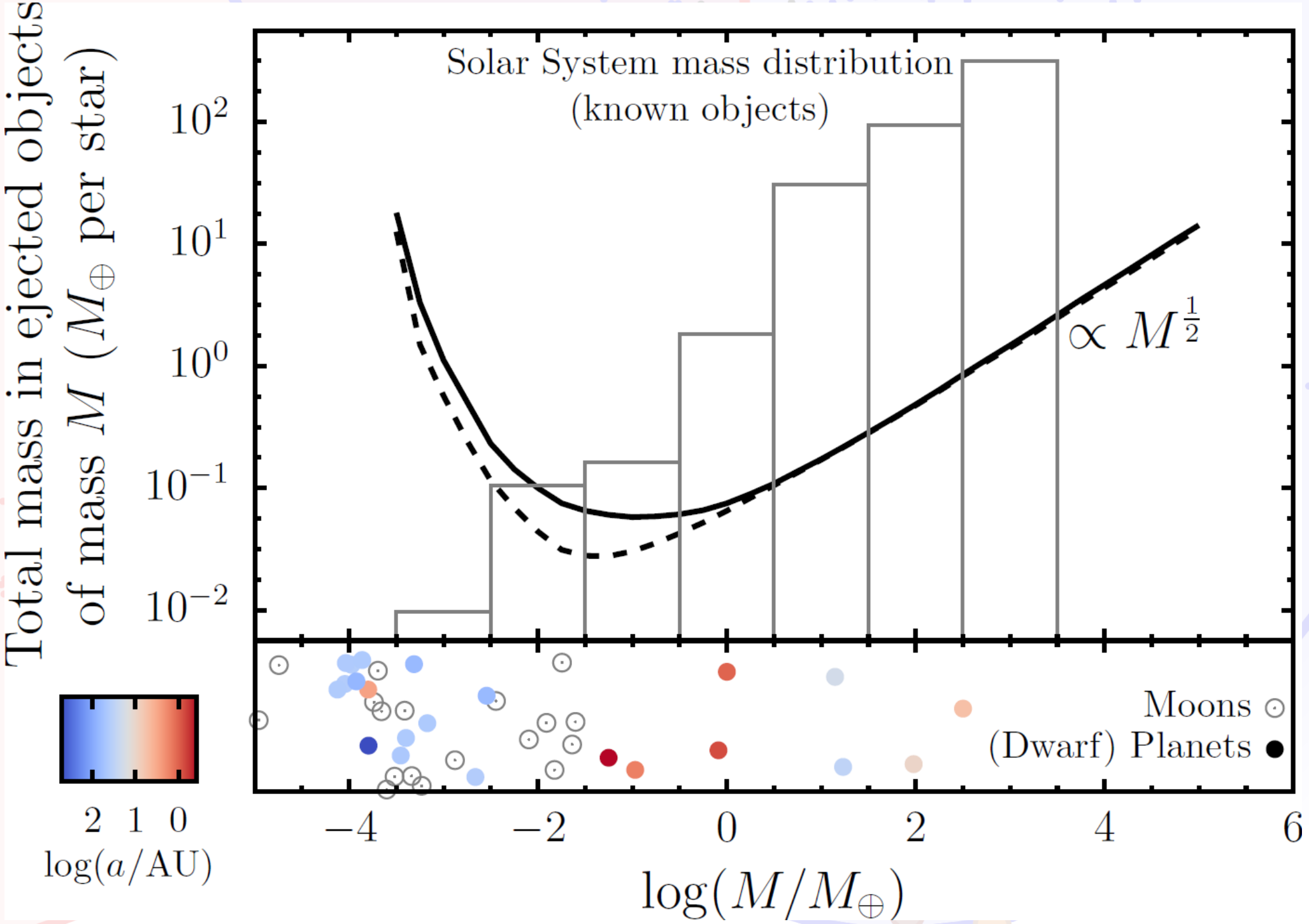
Free floating Mars
(~23 sigma)

- Free-floating planets may be more common than stars in the Galaxy.
- WFIRST-AFTA can detect free-floating planets down the mass of Mars.
- Expect to detect hundreds of free-floating planets.
- Sensitive to moons of free-floating planets.

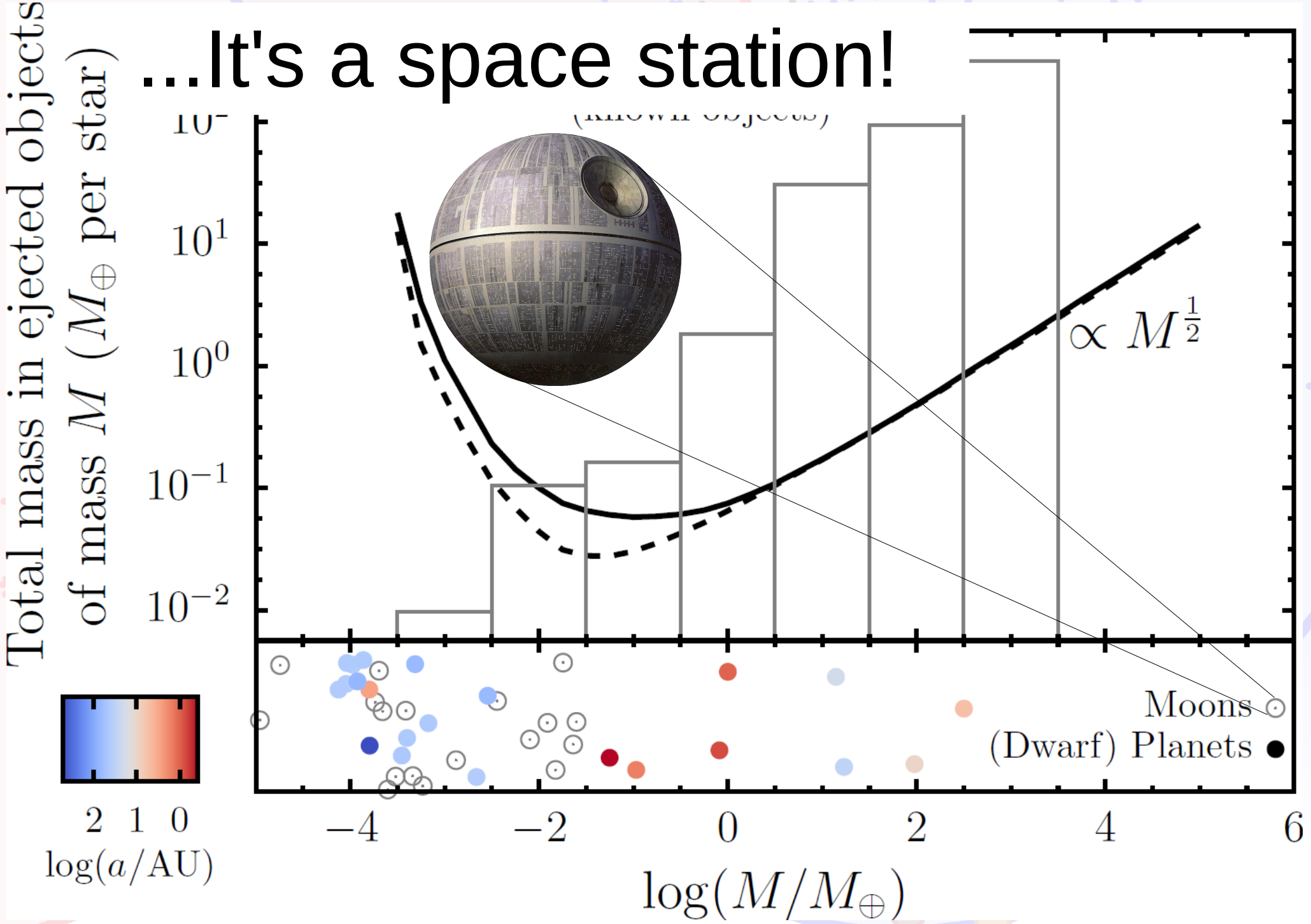
From AFTA SDT interim report


Required FFP abundance for WFIRST-AFTA
to expect 3 detections (95% exclusion CL)
Number per star
Number of ejected objects
of mass M (per star)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
6 points $> 3\sigma$
3 points $> 3\sigma$
$\sim$9 dex
$\propto M^{-\frac{1}{2}}$
-4
-2
0
2
4
6
$\log(M/M_\oplus)$

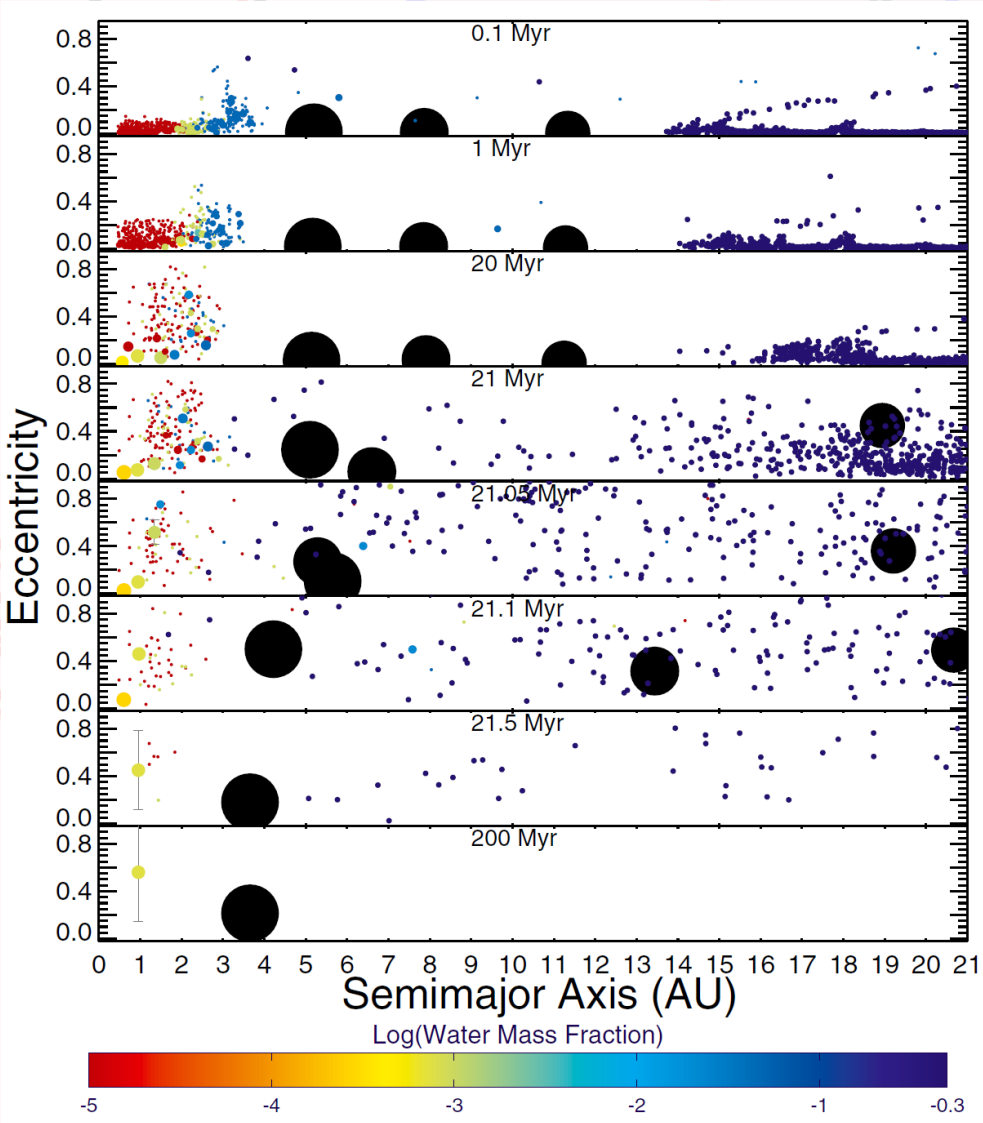

Required FFP abundance for WFIRST-AFTA
to expect 3 detections (95% exclusion CL)
Mass per star
Total mass in ejected objects
of mass M ($M_\oplus$ per star)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
6 points $> 3\sigma$
3 points $> 3\sigma$
$\propto M^{\frac{1}{2}}$
$\vee$ 3 dex
−4
−2
0
2
4
6
$\log(M/M_\oplus)$

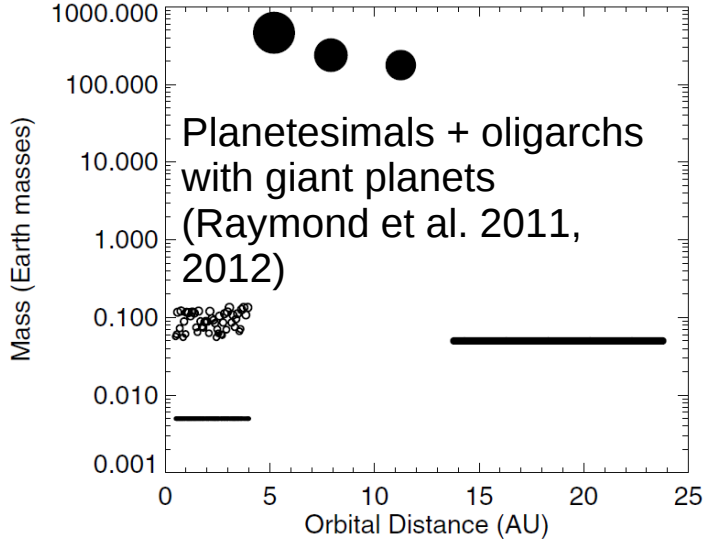

Solar System mass distribution
(known objects)
Total mass in ejected objects
of mass M ($M_\oplus$ per star)
10^2
10^1
10^0
10^{-1}
10^{-2}
$\propto M^{\frac{1}{2}}$
Moons
(Dwarf) Planets
2 1 0
$\log(a/\mathrm{AU})$
−4
−2
0
2
4
6
$\log(M/M_\oplus)$

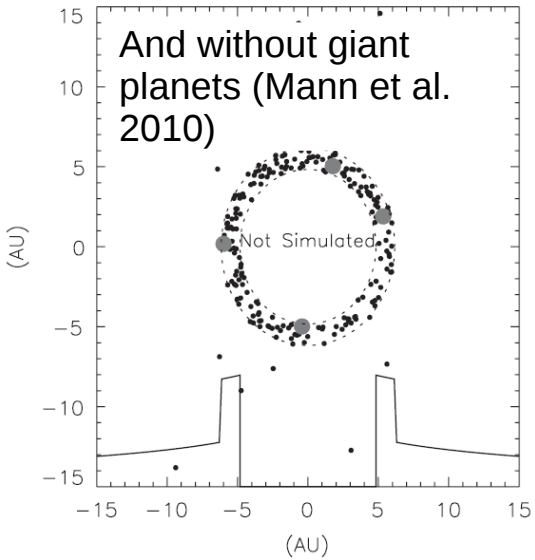
...It's a space station!

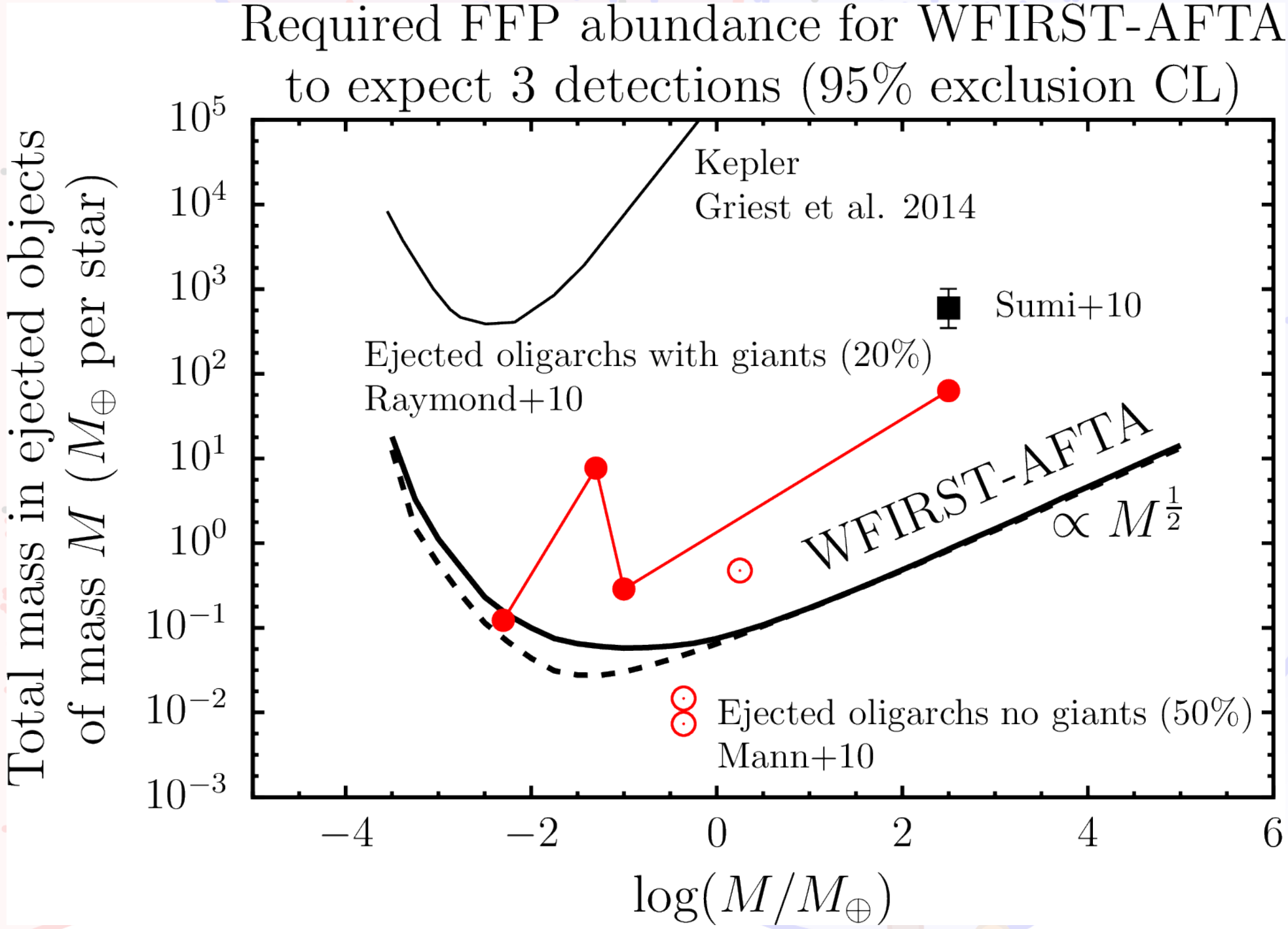


Simulations of Ejected Oligarchs





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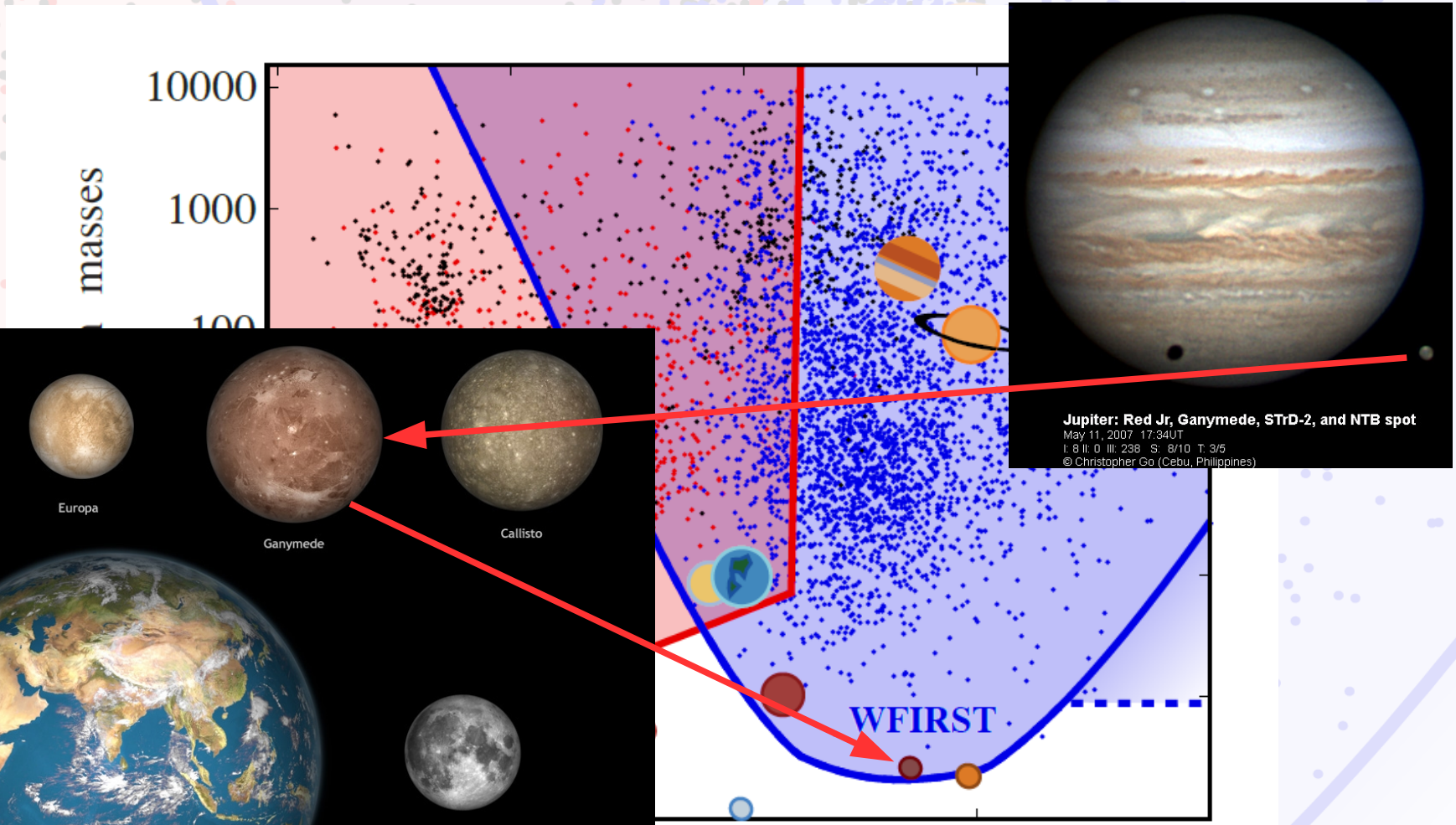
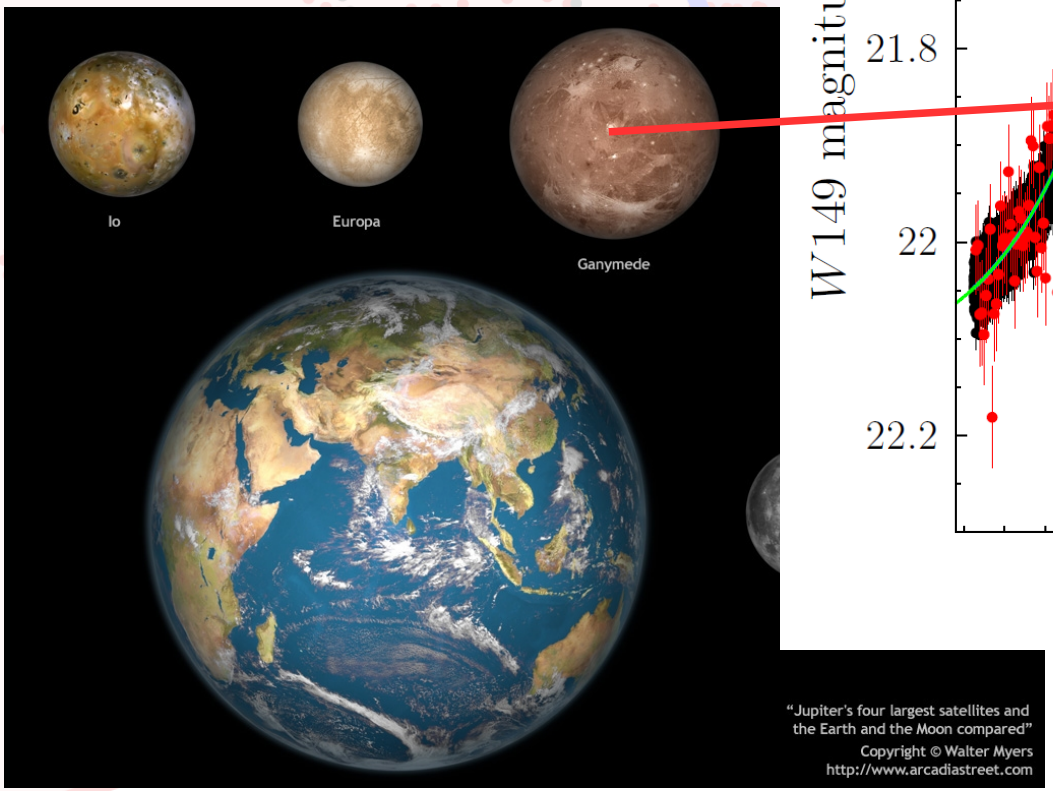
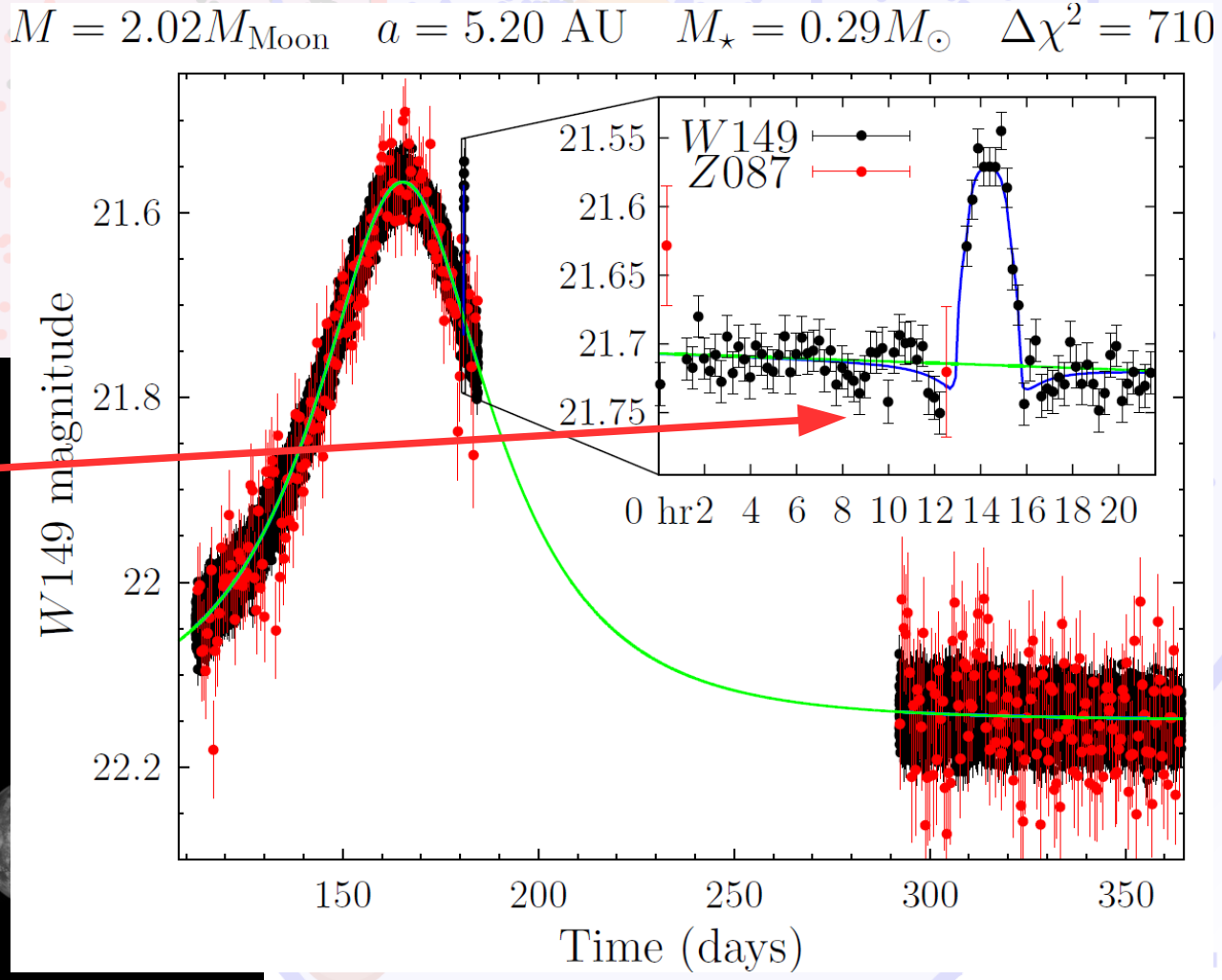
Total mass in ejected objects
of mass M ($M_\oplus$ per star)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
Kepler
Griest et al. 2014
Sumi+10
Ejected oligarchs with giants (20%)
Raymond+10
WFIRST-AFTA
$\propto M^{\frac{1}{2}}$
Ejected oligarchs no giants (50%)
Mann+10
−4
−2
0
2
4
6
$\log(M/M_\oplus)$

Really low-mass planets

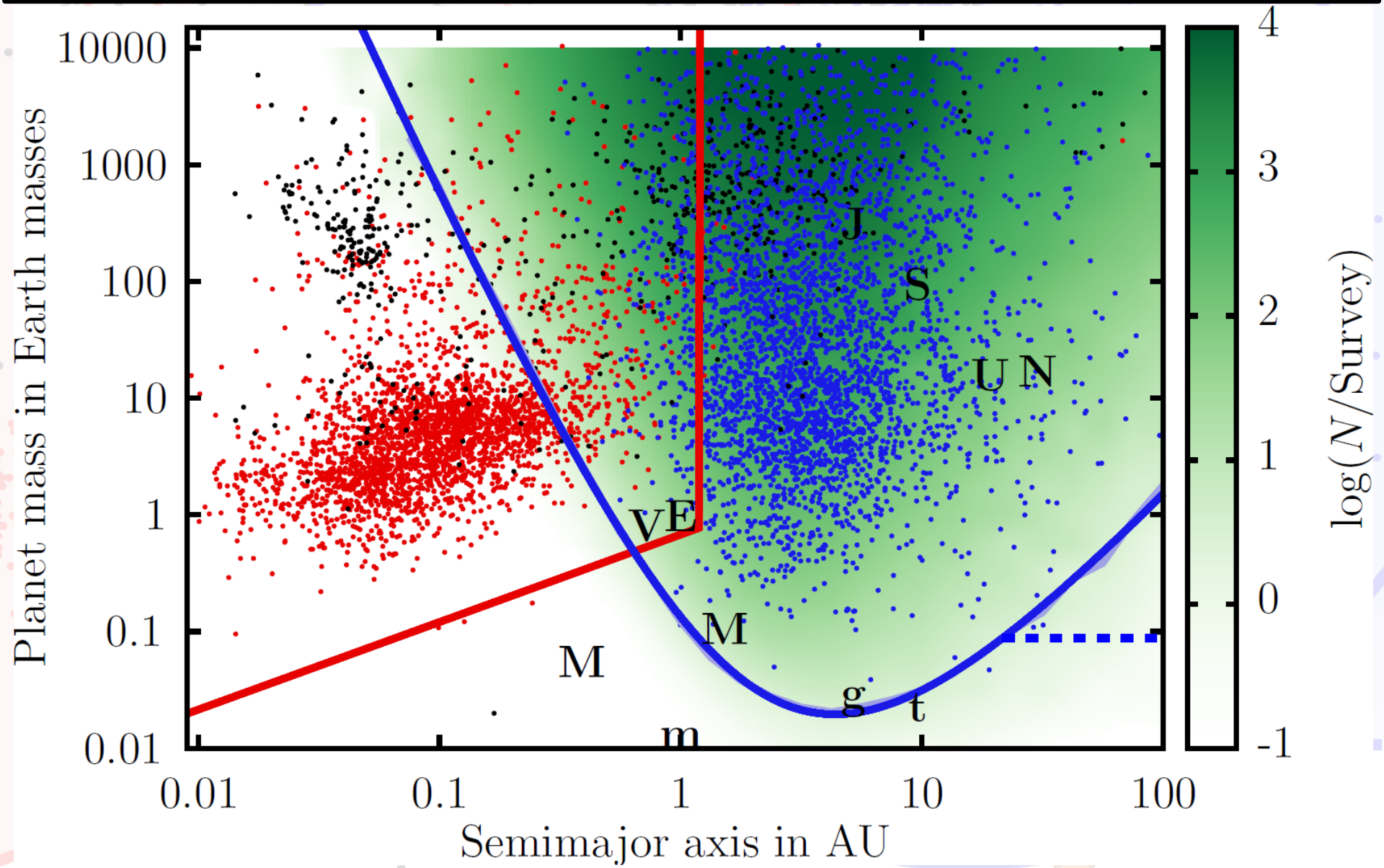


Really low-mass planets

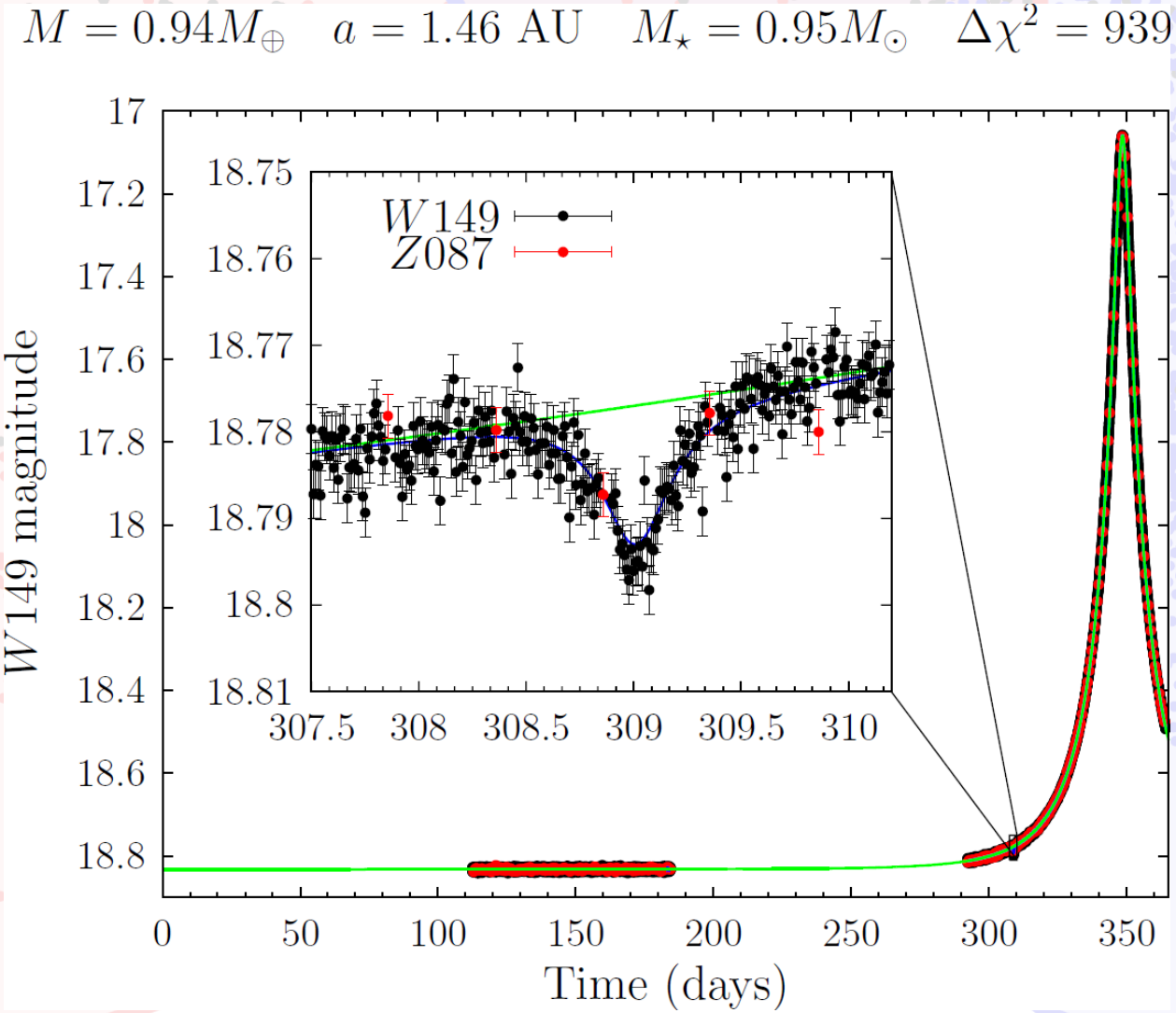


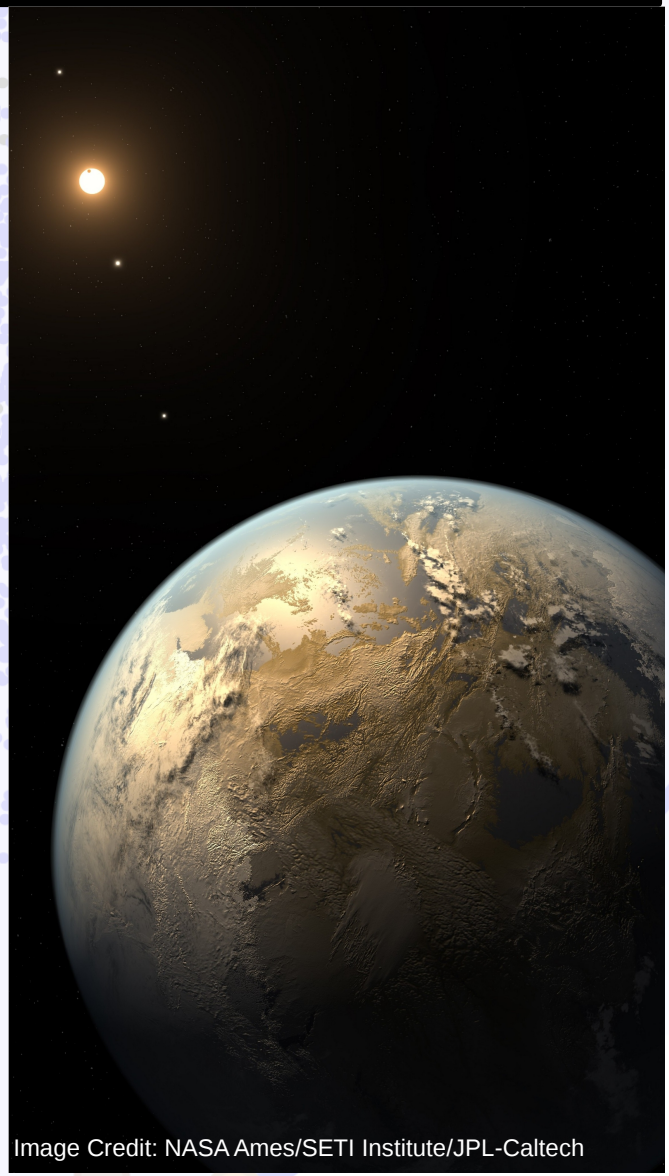


Carefully vetted low-mass detections



Habitable Zone planets

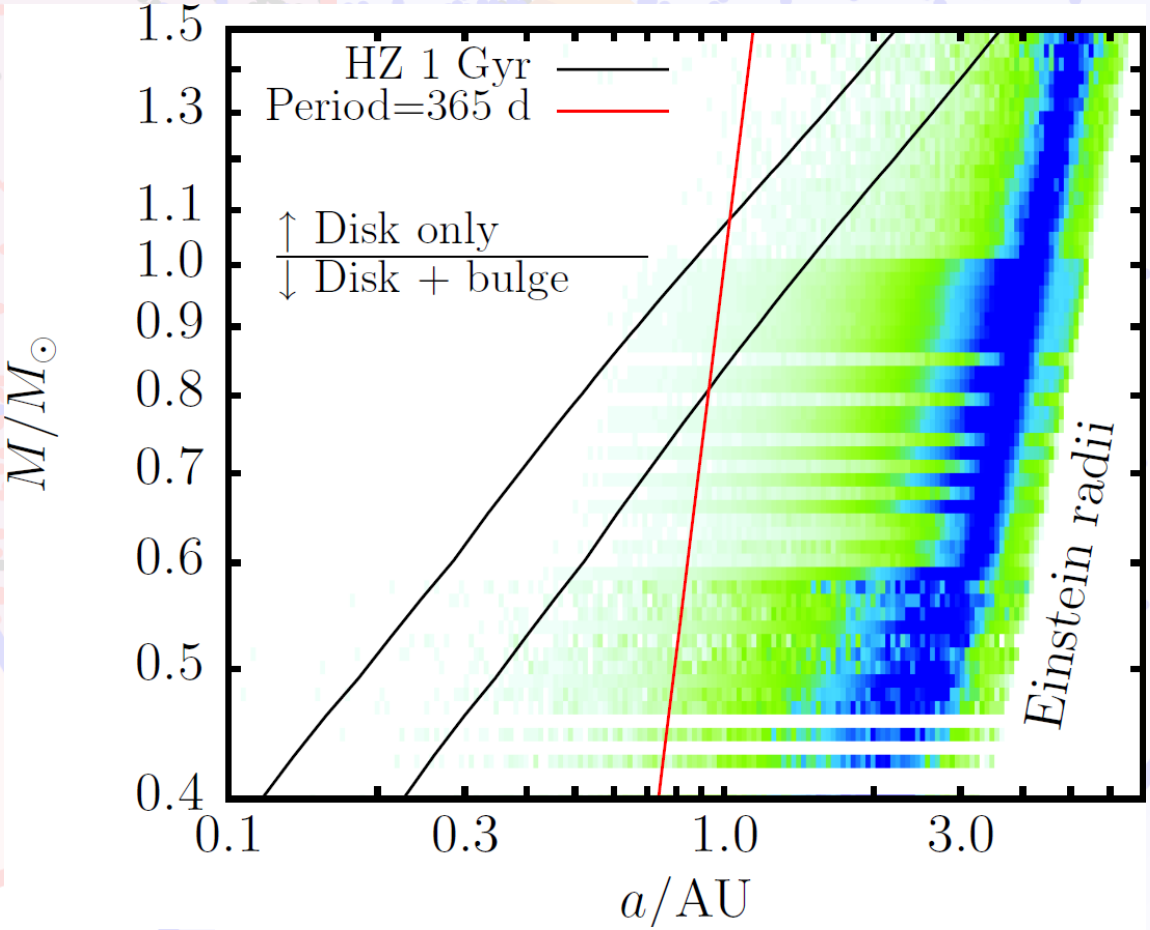




Microlensing in the Habitable Zone

- Transits most sensitive to HZ of low-mass hosts
- Microlensing most sensitive to HZ of high-mass hosts

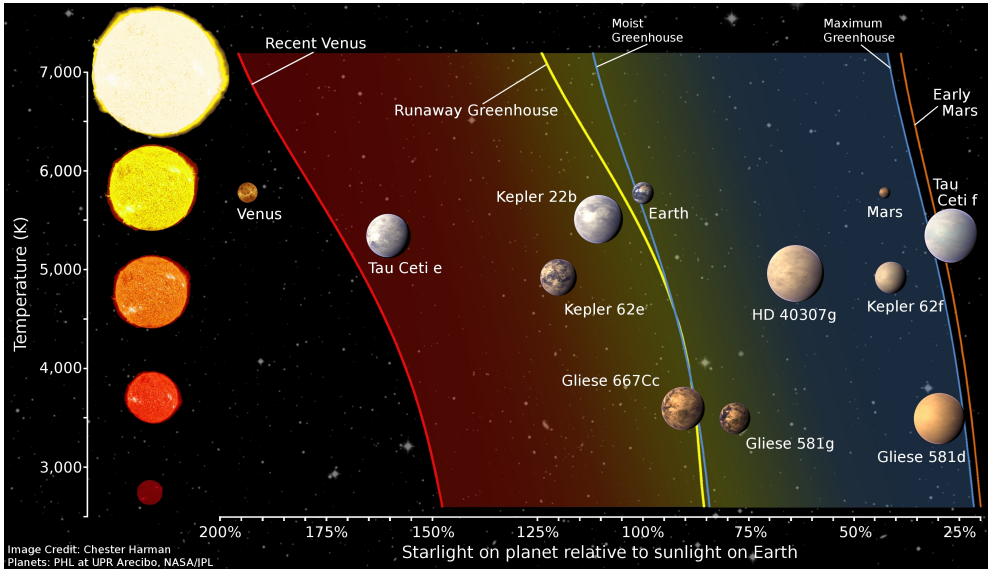
  -but how sensitive?



$$\frac{a_{\rm HZ}}{r_{\rm E}} \simeq 0.3 \begin{cases} M^{1.5} & M \lesssim 1 M_\odot \\ M^{1.75} & M \gtrsim 1 M_\odot \end{cases}$$

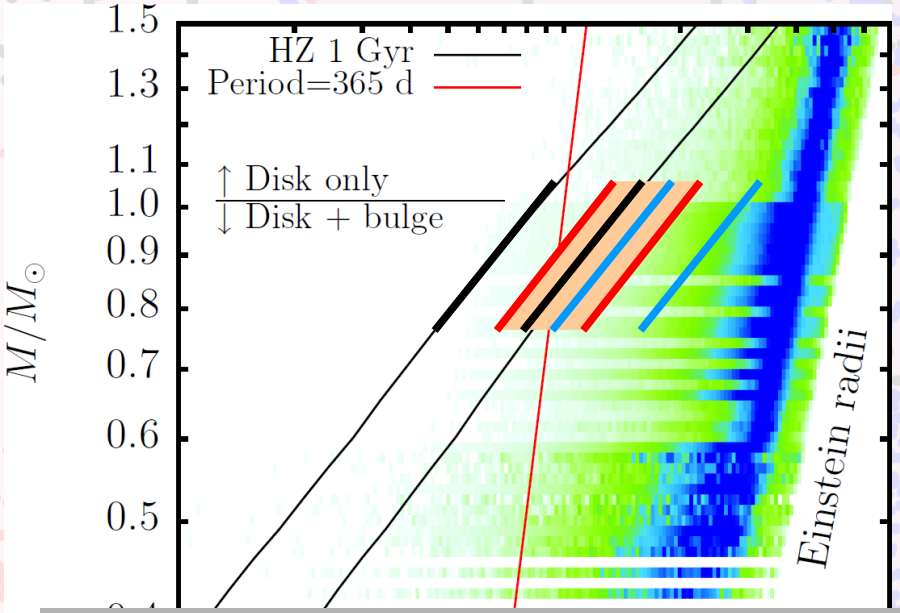
AFTA in the Habitable Zone

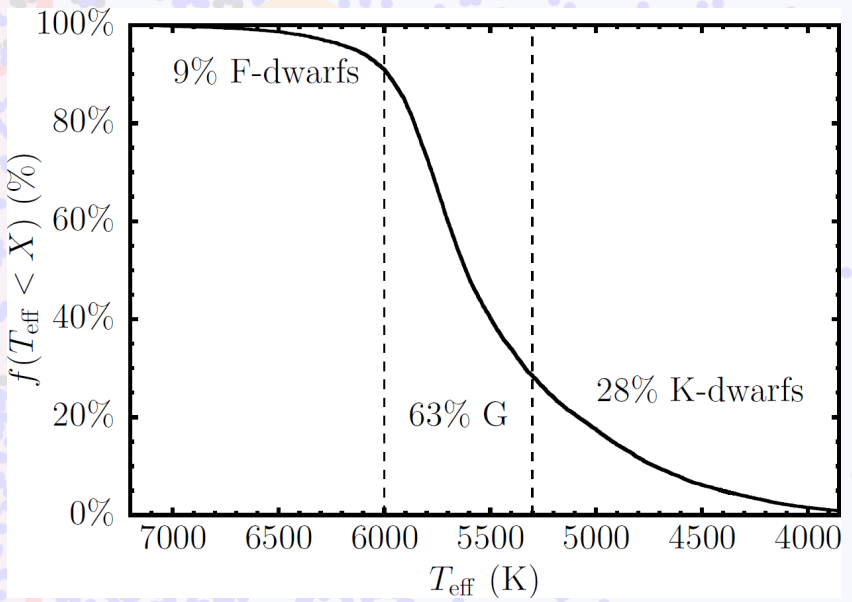
- Using the recent Kopparapu et al HZ definition



- Take the WFIRST simulations and throw out everything but FGK dwarfs (no hope for M)
- Put an Earth mass planet in the HZ of each star

Spying on the Neighbors





AFTA-WFIRST yields if 1 planet per star in shifted HZ around FGK dwarfs

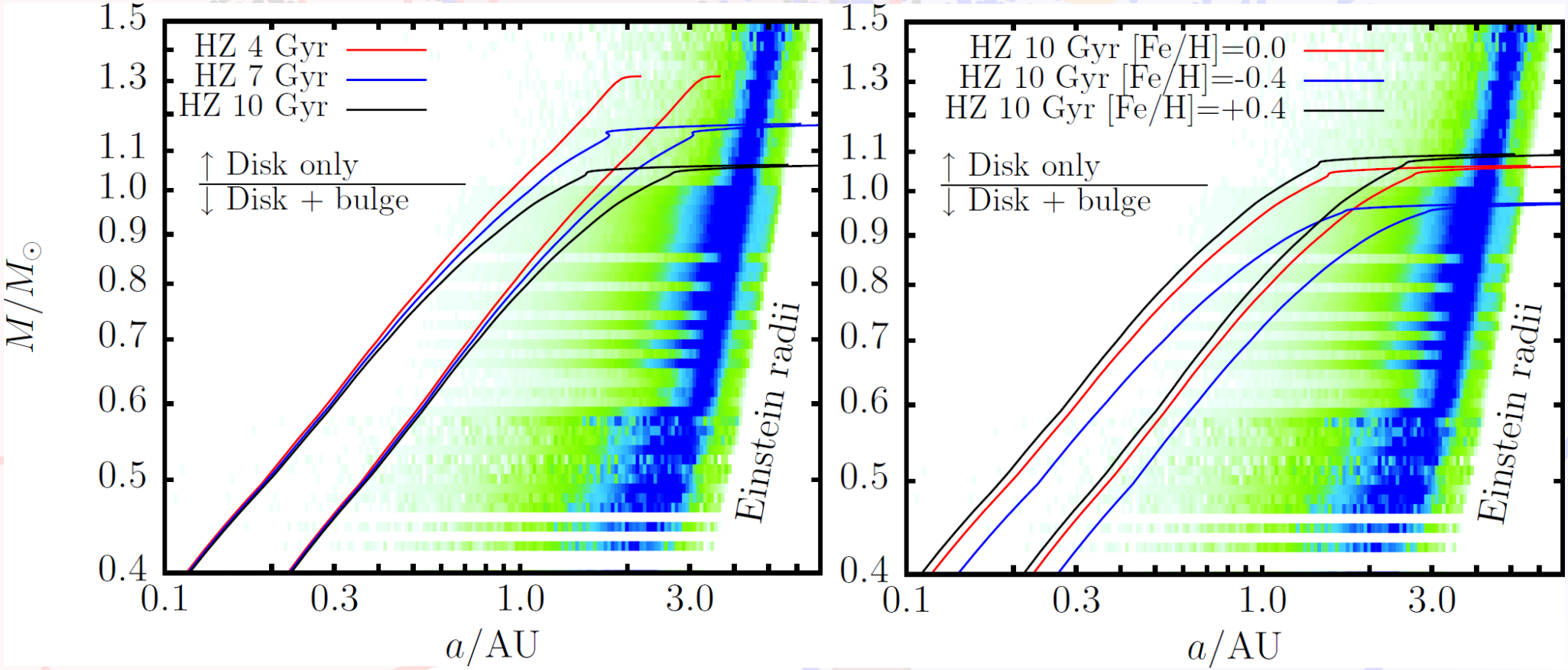
Mass/HZ	**HZ x 1.0 0.99–1.68 AU**	**HZ x 1.5 1.49–2.52 AU**	**HZ x 2.0 1.98–3.36 AU**
10 Mearth	8	25	53
3.2 Mearth	3	11	24
1 Mearth	1	5	10

1.0 dex

0.3 dex

Changing

Age [Fe/H]



Conclusions

Bound

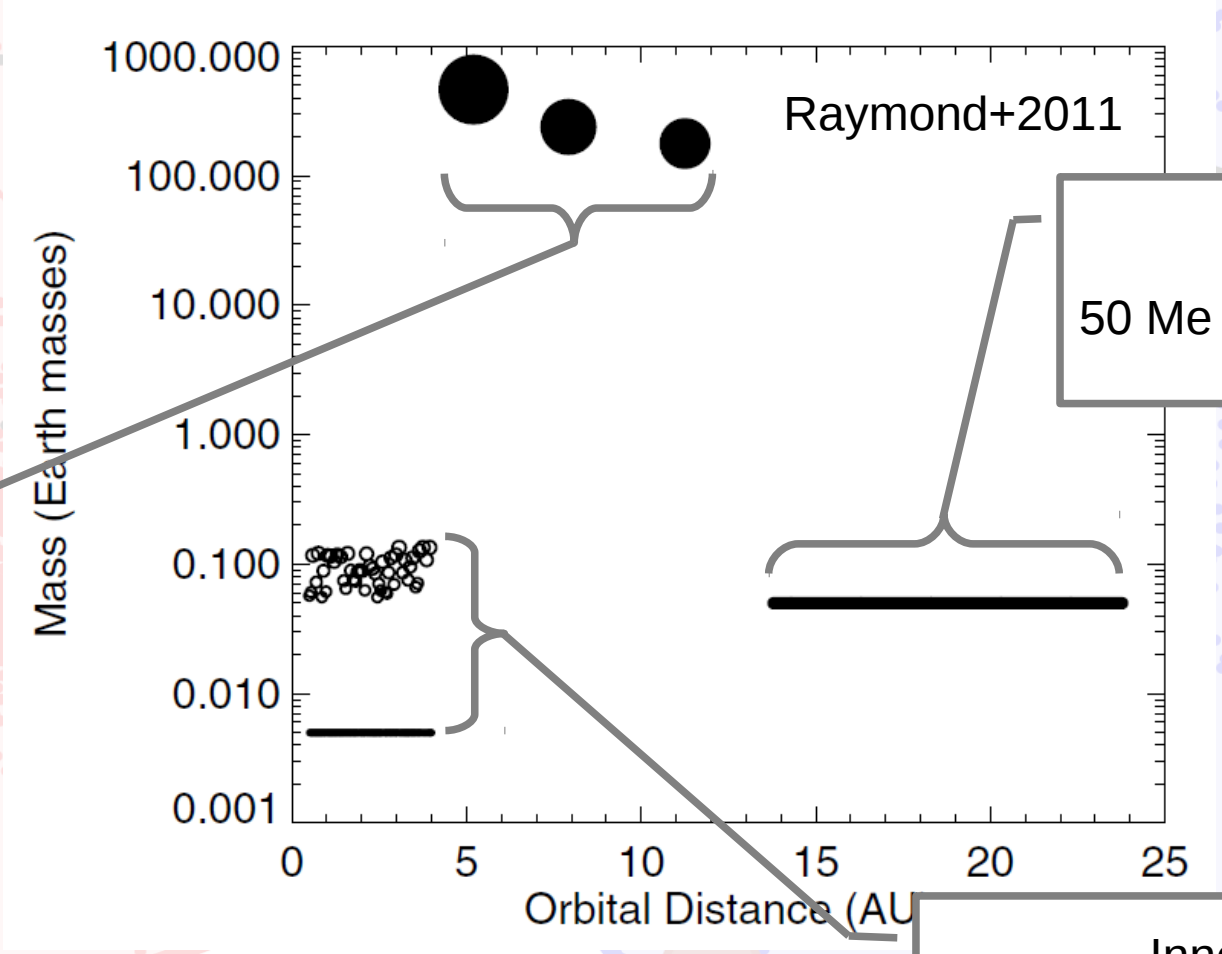
- WFIRST-AFTA will do for cold planets what Kepler has done for hot planets
- Will measure abundance of cold bound planets down to mass of solar system moons
- Has sensitivity in the habitable zone, but Earth-masses there are a stretch

Free-floating

- WFIRST-AFTA will find hundreds of FFPs
- Sensitive to planetesimals pushed beyond ~10 AU or ejected
- Will measure “total loosely- or un-bound mass in objects of mass M per star” for Plutos to Jupiters if it is above 1 Mearth/star

Backup Slides

Starting conditions



3 Giant planets:
>90% unstable
<10% stable

Outer disk:
50 Me of 0.05 Me objects

Inner disk:
2.5 Me of 0.005 Me objects
2.5 Me of ~0.1 Me Embryos