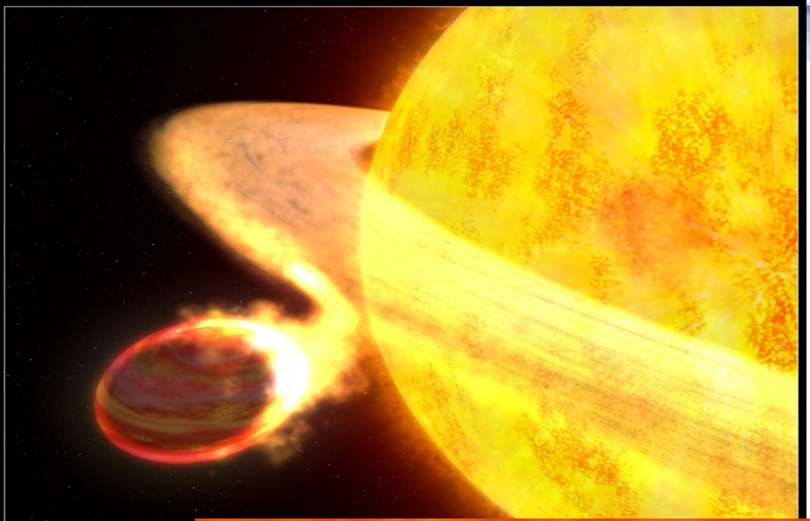
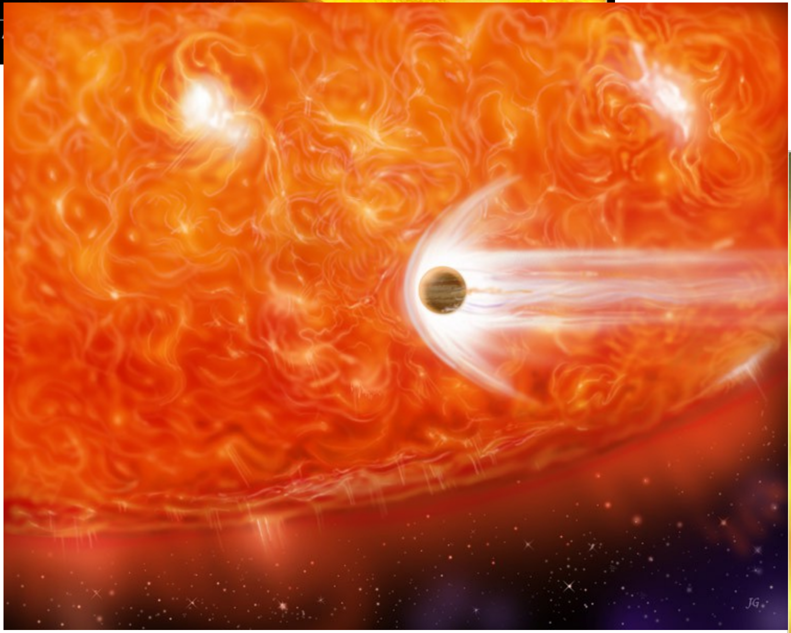
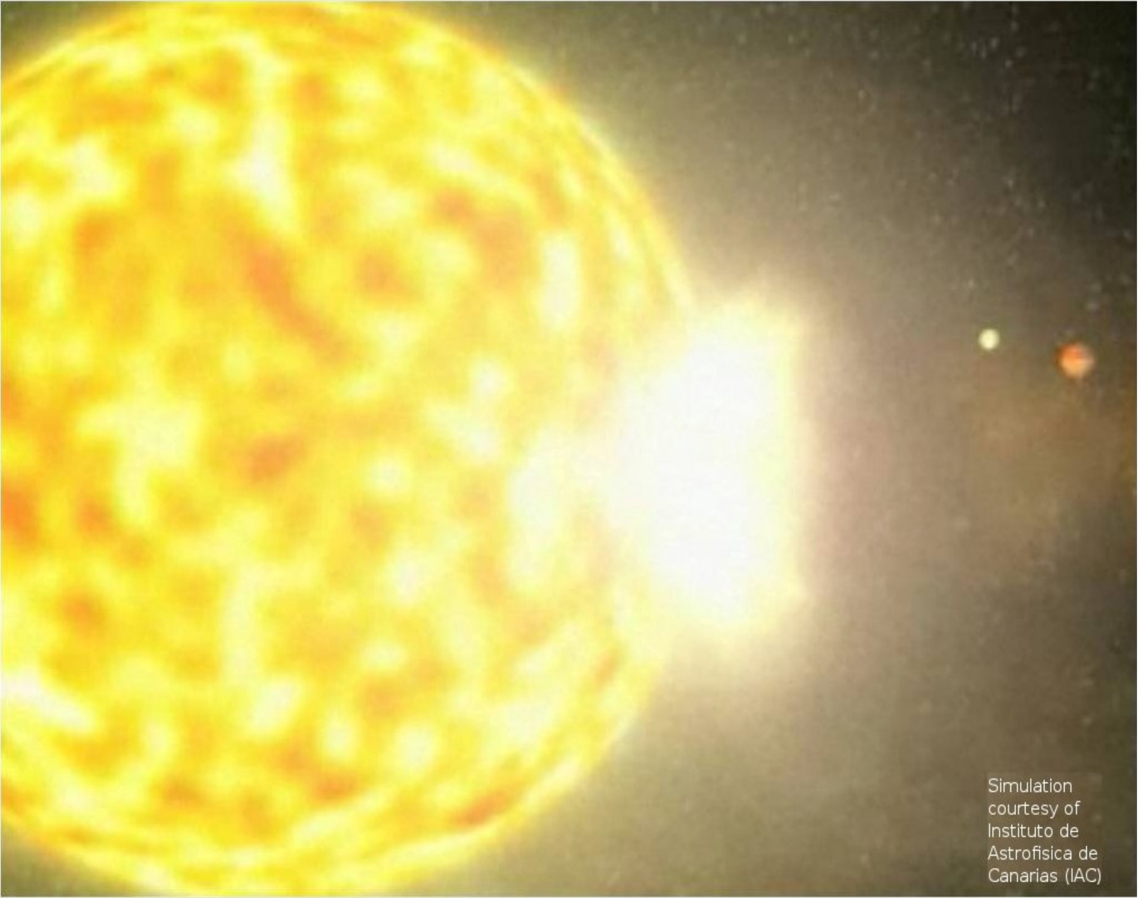
Planet Flow, Not Weak Tidal Evolution, Produces Excess of Short-Period Planets







Simulation
courtesy of
Instituto de
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Canarias (IAC)

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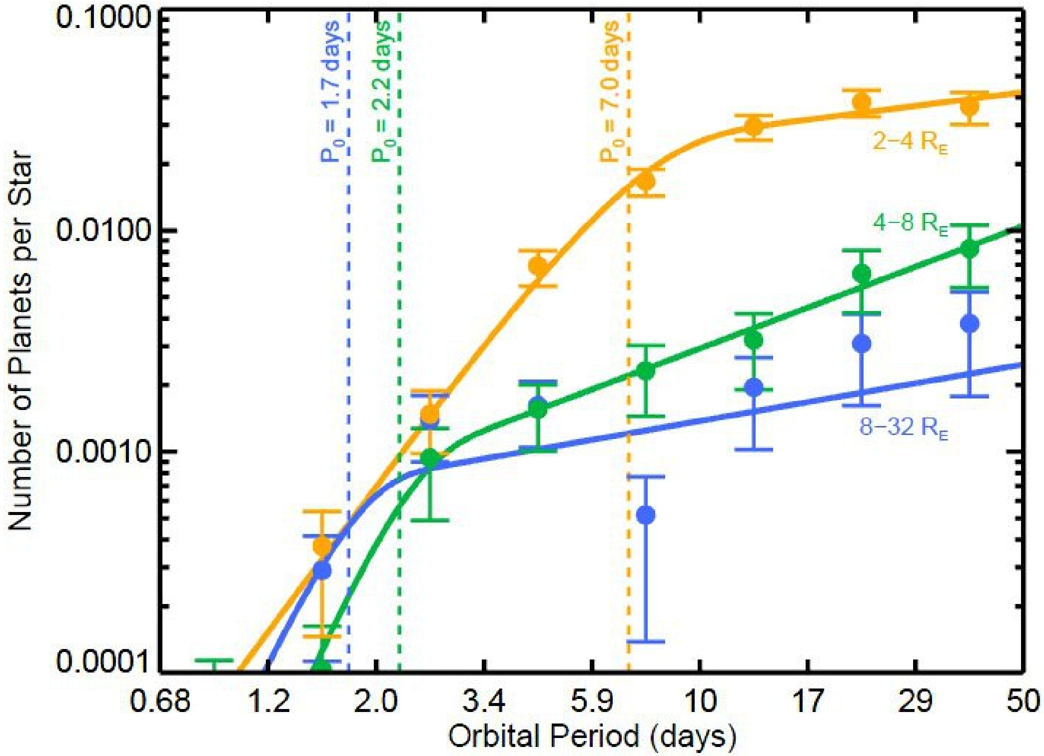
Planet occurrence of giant and medium planets show an inner fall off that has a power index close to that produced by tidal migration for eccentricity of zero.

(“Planets” includes “planet candidates”, throughout)



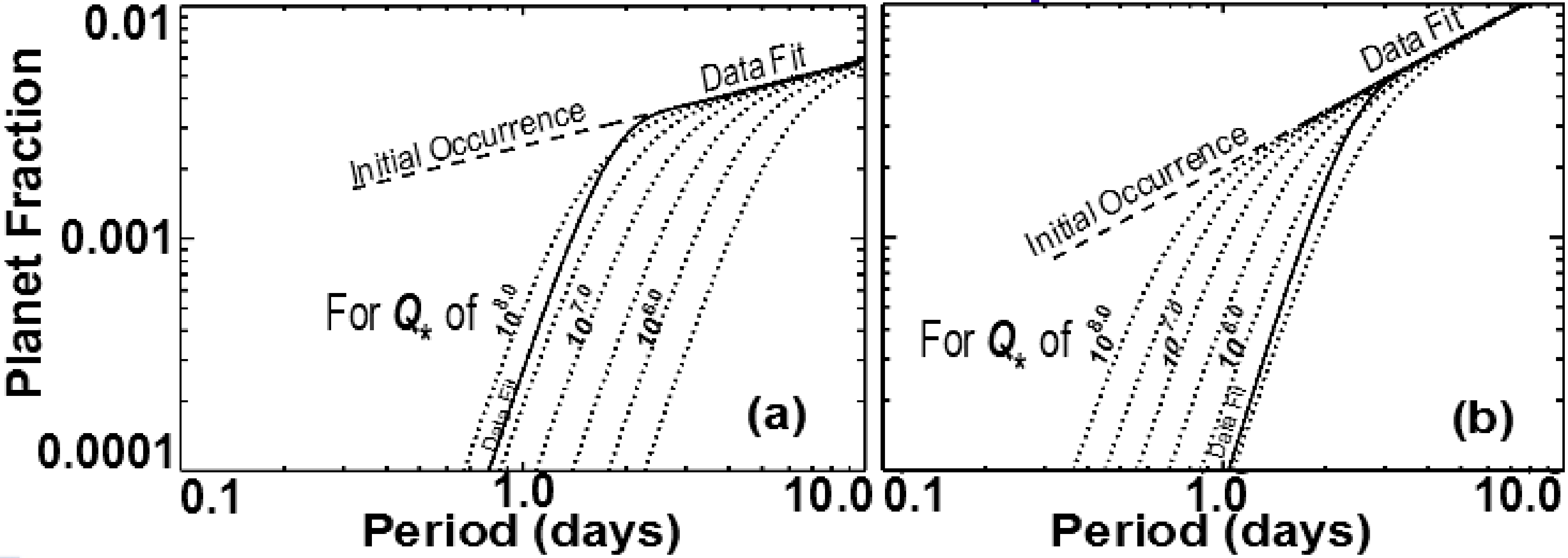
Above: Distribution of Kepler candidates with fit by Howard et al. (2011; H12). The slope gives the power law index (PLI).

Largest planets (Jupiters: 8-32 R_{earth}): Inner PLI matches expected distribution for planets undergoing tidal migration, 13/3.

Medium planets (Neptunes: 4-8 R_{earth}): Inner PLI matches expected distribution for planets in range,13/3. However, the turnover point is further out.

Small(er) planets (Super earths: 2-4 R_{earth}): Inner PLI lower than 13/3. Fall off is likely too far out, so distribution may be primordial.

Occurrence distribution power index



Giant planets, summed for 8 to 32 $R_\oplus$ **Medium** planets, summed 4 to 8 $R_\oplus$

Data compared to model fall off for sum of giant planets of 100 to 2000 $M_\oplus$ and 10 to 100 $M_\oplus$ at representative age of 4.5 Gigayears.

- Consistent with fall in for giant and medium planets (above).
- but too low for sub-Neptune planets.
  - The difference could be a flow of giant planets. –

The values: Tidal migration

Tidal migration rate from Jackson et al. (2009) gives a P dependence on t to the power of of $P^{-13/3}$, after converting to period $P \propto a^{3/2}$

$$\frac{1}{a}\frac{\mathrm{d}a}{\mathrm{d}t} = -\left(\frac{63}{2}(GM_*^3)^{1/2}\frac{R_p^5}{Q'_p M_p}e^2 + \frac{9}{2}(G/M_*)^{1/2}\frac{R_*^5 M_p}{Q'_*}\left(1+\frac{57}{4}e^2\right)\right)a^{-13/2}$$

Plotting the planet distribution d log $f(P)$/d log P gives a power law index of 13/3 due to its dependence on dt/da .

Power index of 13/3: Tidal migration due to tides on the star (“stellar TM”) for circular orbits.

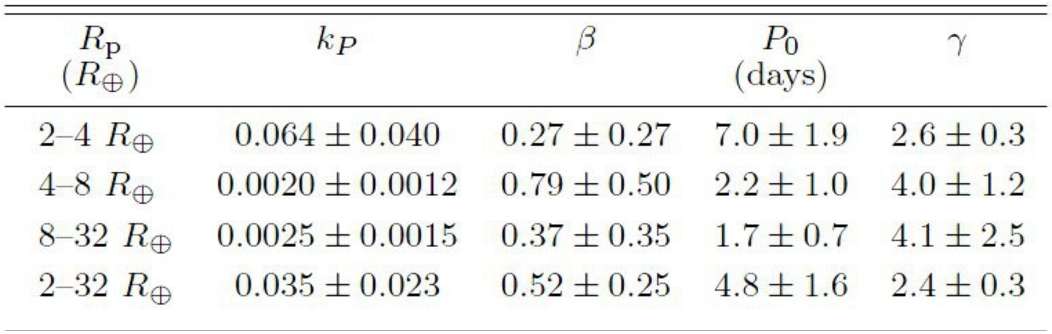
Lower power index would result for eccentricity increasing as a function of semi-major axis.

The values: Kepler planet distribution

H12 find values of a little over 4 for the PLI (the slope of the log-log distribution) of the closest Kepler candidates, where they fit to

$$\frac{\mathrm{d}f(P)}{\mathrm{d}\log P} = k_P P^{\beta}\left(1 - e^{-(P/P_0)^{\gamma}}\right)$$

and obtain these best fits:



R_p ($R_\oplus$)	k_P	β	P_0 (days)	γ
2–4 $R_\oplus$	0.064 ± 0.040	0.27 ± 0.27	7.0 ± 1.9	2.6 ± 0.3
4–8 $R_\oplus$	0.0020 ± 0.0012	0.79 ± 0.50	2.2 ± 1.0	4.0 ± 1.2
8–32 $R_\oplus$	0.0025 ± 0.0015	0.37 ± 0.35	1.7 ± 0.7	4.1 ± 2.5
2–32 $R_\oplus$	0.035 ± 0.023	0.52 ± 0.25	4.8 ± 1.6	2.4 ± 0.3

As $P \longrightarrow 0$, this equation goes towards P having a power law of $\beta+\gamma$:

$$\mathrm{d}\log f(P)/\mathrm{d}\log P \longrightarrow k_P\, P^{\beta+\gamma}$$

The power law values $\beta+\gamma$ for the three planet radii ranges (in R_{earth}) are:

8-32 R_{earth} $\beta+\gamma$ = 4.5 ± 2.5

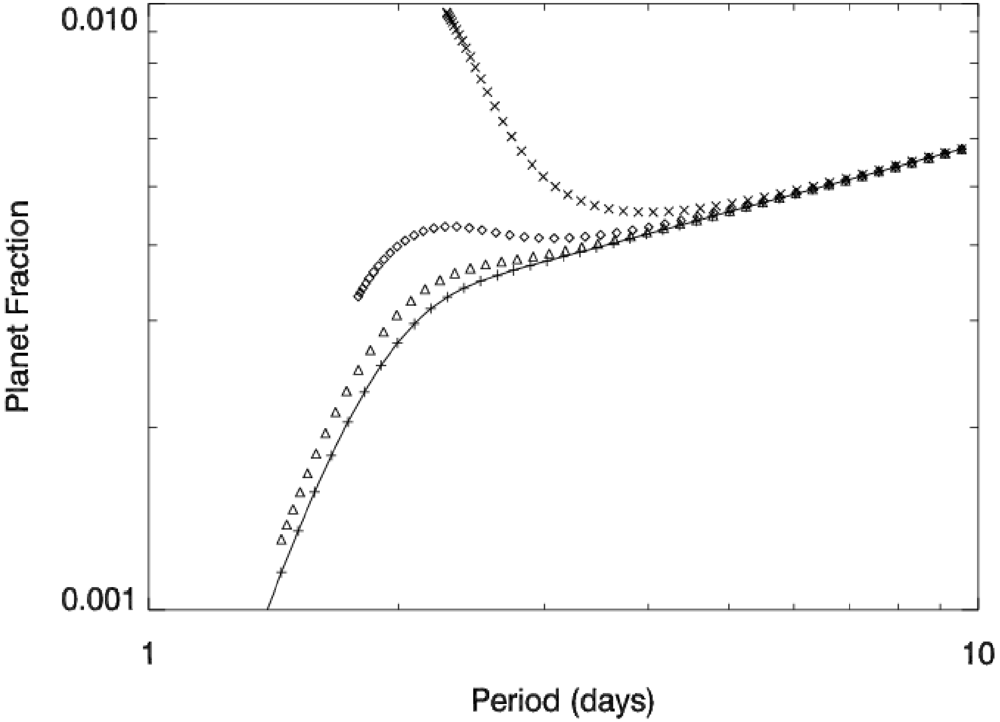
4-8 R_{earth} $\beta+\gamma$ = 4.8 ± 1.3

2-4 R_{earth} $\beta+\gamma$ = 2.9 ± 0.4

Pileup can be produced by flow

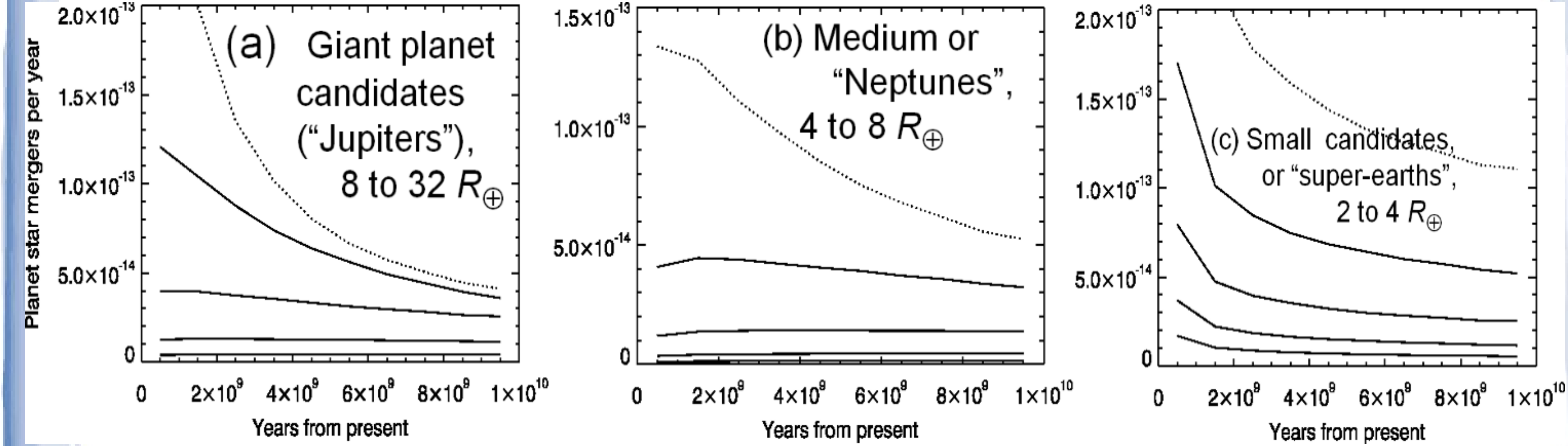
Taking an initial distribution without a pileup (bottom curve) backwards in time gives a pileup. Modeling backwards for three tidal dissipation strengths gives limit on Q'_{star}.

Top (crosses) shows $Q'_{star}=10^{6.5}$ would be too strong.
Middle two curves (triangles and diamonds) show that $Q'_{star}=10^{7.0}$ and $Q'_{star}=10^{7.5}$ would be reasonable.



Future infall: Modeling Fit Distribution

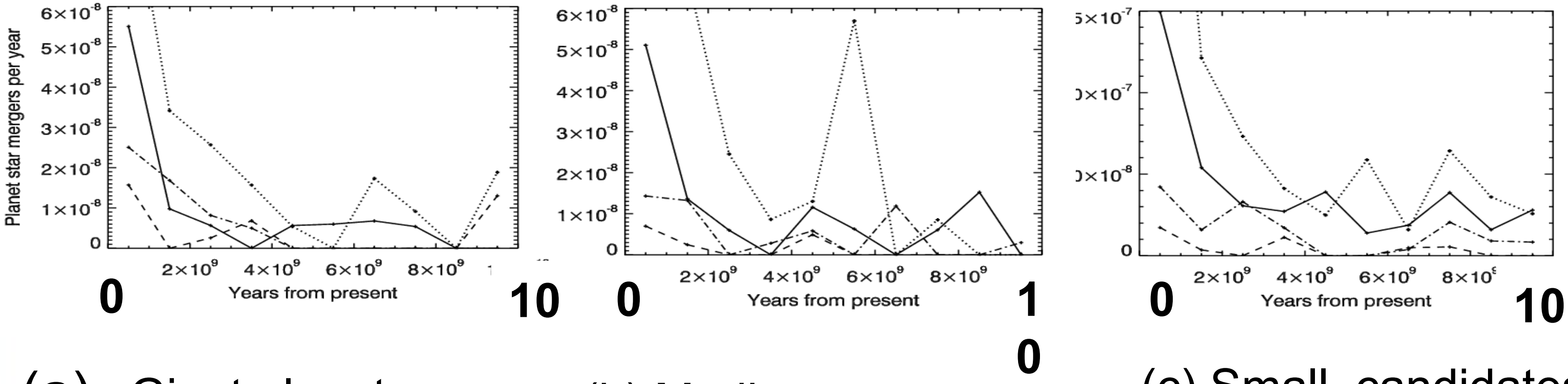
Rate of calculated future infall for giant, medium, and (relatively) small planets. Rate given for Q'_{star} values of $10^{6.5}$ (top line, dotted) to $10^{8.5}$ in increments of $10^{0.5}$.



Planet infall should remain constant, other than the stars in this population will age, so reject for Q'_{star} values that make "now" different from future.

- Not consistent with same tidal dissipation strength
- The difference could be made up by an increasing flow new giant planets

Future infall: Modeling Data



(a) Giant planet candidates ("Jupiters"), 8 to 32 $R_\oplus$

(b) Medium or "Neptunes", 4 to 8 $R_\oplus$

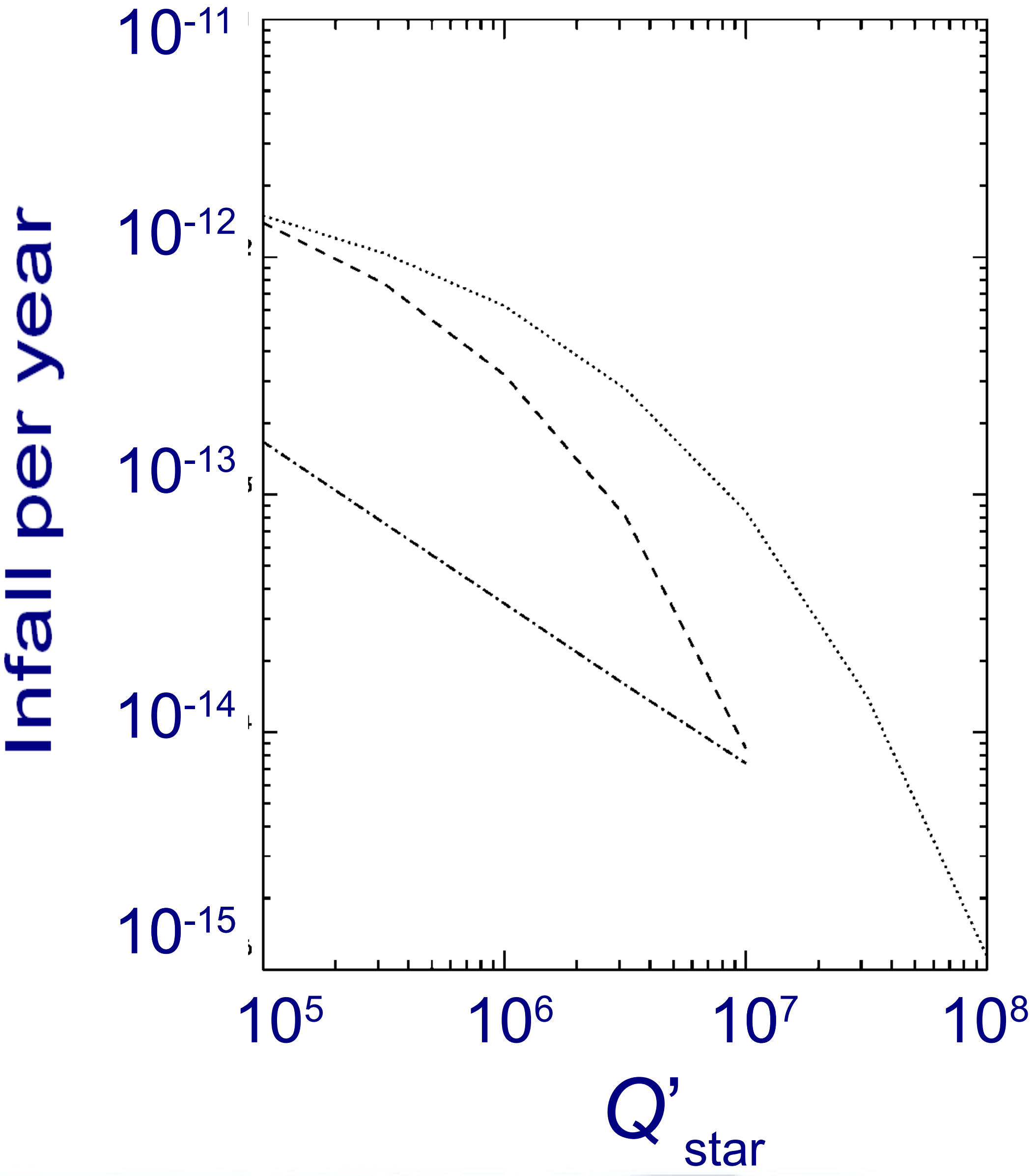
(c) Small candidates, or "super-earths", 2 to 4 $R_\oplus$

Consistent with results from fit, but noisier.

Rate of infall

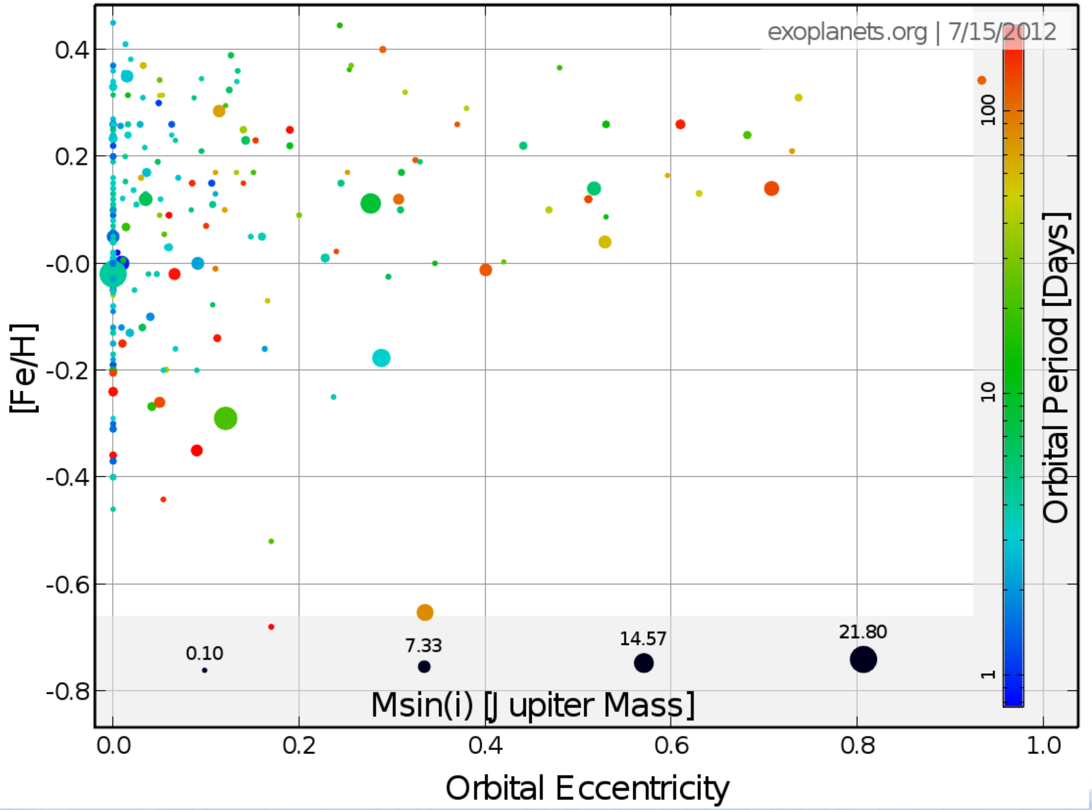
Rate as function of tidal dissipation strength *Q*'$_{star}$., shown for giant, medium, small planets

- Does not require too many planets: order of 1/1000 stars or less per gigayear



Correlation of higher Fe/H with higher eccentricity

- Few hot Jupiters in multiplanet systems, more hot Neptunes in multiplanet systems (Fabrycky et al. 2012; Latham et al. 2012)
- Others rule out pollution looking at other element ratios of short period planets



Future work:

- Watch for period decreases – However, for Q'_{star} of $10^{7.0}$, the period of WASP-18b will decrease by only 1.3 milliseconds per year.
- Compare the numbers of planets required for infall with eccentric planets and the rates of inward scattering.
- Migration of non-zero eccentricity, including higher order terms.
- Model whether moderate eccentricity could create pileup, and extreme eccentricity could send planets right through pileup.
- Better statistics needed: Follow whether these results hold.
- Fit pile up of giant planets
- Model pollution in stars, first to estimate time of convection to mix away from stellar surface.

Conclusions

- Excess of shortest period giant planets would require a different tidal dissipation strength than medium planets if no new planet supply.
- Flow of planets could also explain pile up of giant planets:
    - Possible that more giant planets migrate in
    - Possible that smaller planets migrate more quickly
- Is migration of one planet correlated with planet/star mergers of other planets?
- Posting on astro-ph appeared today.