The Mass Function, Multiplicity, and Origins of Directly Imaged Planets and Brown Dwarfs

Introduction / Overview

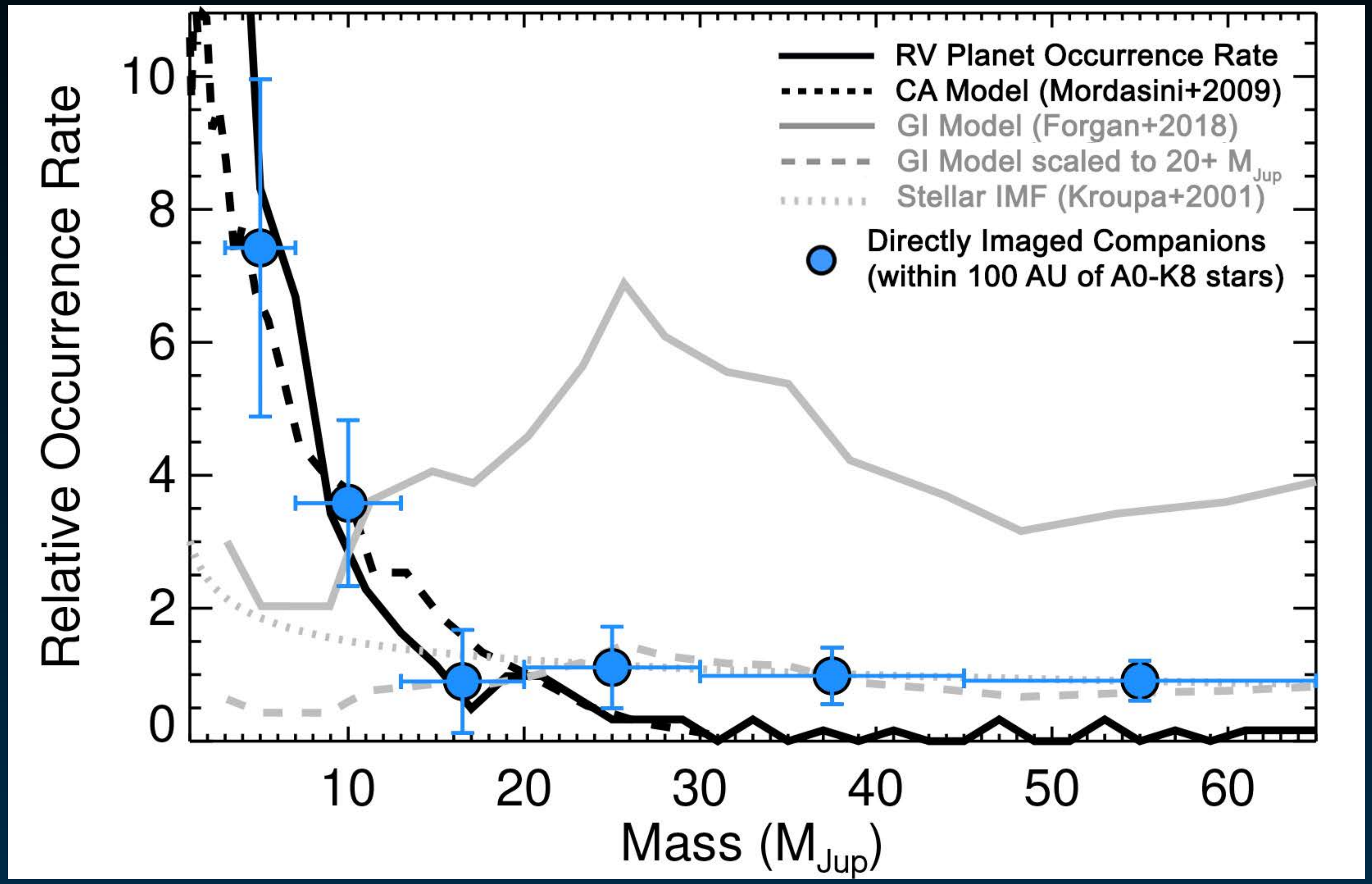
The mass function is a fundamental outcome and diagnostic of a population's formation mechanism(s). Bottom-up processes such as core accretion (e.g., Pollack+1996, Mordasini+2009) result in a majority of low-mass companions, whereas top-down processes involving gravitational instabilities result in a majority of higher mass companions–typically brown dwarfs and low-mass stars (e.g., Kratter+2010, Forgan+2018). An empirical measurement of the substellar companion mass function will enable the relative contributions of each process to be determined. Furthermore, **knowledge of the substellar companion mass function, combined with existing detection limits, will enable estimations of additional (unseen) companions, and better exoplanet yield estimates for future surveys**.

Sample and Methodology

We compiled **all known systems with substellar companions** (N=67), recomputed masses and mass detection limits from initial photometric measurements, and assembled these observations **into a survival analysis framework** (Feigelson+Nelson 1985) to compute the cumulative mass function–the derivative of which gives **the relative substellar companion mass function**.

See Wagner, Apai, & Kratter (2019) for more details: https://arxiv.org/abs/1904.06438

The Substellar Companion Mass Function



The substellar companion mass function (blue points) **is rising steeply toward smaller values, in broad agreement at low masses with the core accretion model and distribution of RV planets**. The flat shape of the distribution beyond ~10-20 M_{Jup} indicates the contribution from companions formed via gravitational instabilities (possibly in the disk stage or earlier). This enables a crude estimate of a companion's likely formation mechanism based on its mass, and enables an assessment of the undetected multi-planet systems. ***This paints an optimistic picture for the future of exoplanet imaging, as improvements in capabilities will enabling imaging lower-mass planets that are more numerous than currently imaged super-Jupiters.***

Multiplicity of Known Systems

TABLE 1
MULTIPLICITY PROBABILITIES

System	P(Double) %	P(Triple) %	P(Quad) %
51Erib	34.1	11.6	3.97
GJ504b	77.9	60.7	47.3
GJ758b	85.6	73.3	62.7
HD1160B	79.1	62.6	49.5
HD19467b	94.1	88.5	83.3
HD206893b	84.2	70.9	59.7
HD4113C	89.3	79.7	71.2
HD95086b	40.9	16.7	6.84
HD984b	76.2	58.1	44.2
HIP65426b	53.3	28.4	15.1
HIP73990b	100.	79.6	63.4
HIP74865b	74.3	55.2	41.0
HR2562b	68.3	46.6	31.9
HR3549b	60.8	37.0	22.5
HR8799b	100.	100.	100.
PDS70b	65.7	43.2	28.4
PZTelb	48.4	23.4	11.3
BetaPicb	22.5	5.06	1.14
KappaAndb	40.8	16.6	6.79
Mean	68.2%	50.4%	39.5%

NOTE. — Note: this table also serves to identify the companions that were considered as part of our primary analysis (those within 100 AU of A0-K8 stars), and is a subset of the objects whose properties are described Table 2.

The mass function's behavior of rising toward low-masses, combined with existing detection limits, suggests that **many systems with at least one known planet could actually be part of a multi-planet system**. In line with these predictions, *both PDS 70 and Beta Pictoris have since been confirmed as multi-planet systems* (Haffert+2019, Lagrange+2019).

Kevin Wagner | U. Arizona, NASA Sagan Fellow | Exoplanet Demographics 2020 | kevinwagner@arizona.edu | @AstroWagner