



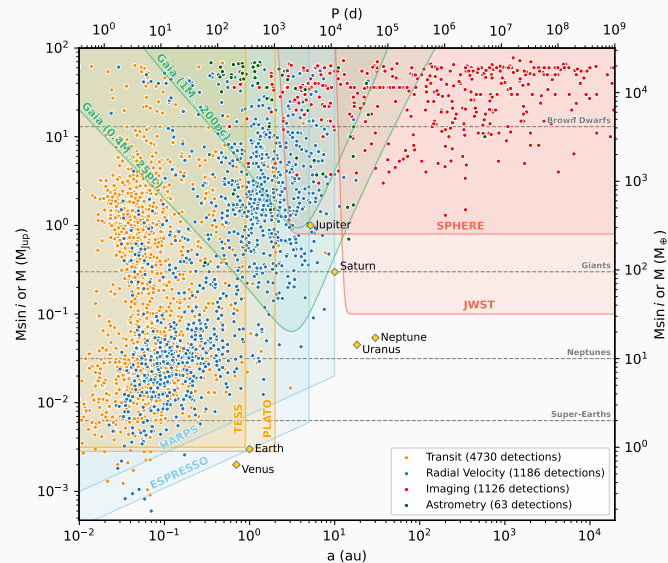
BRIDGING DISCOVERY SPACES

A MULTI-TECHNIQUE VIEW
ON INNER AND OUTER WORLDS



Domenico Barbato
INAF - Osservatorio Astronomico di Padova

THE EXOPLANETARY PUZZLE



Origin of the observed features?

How do planets form and migrate?

Is the Solar System unique?

Frequency of different architectures?

Role of stellar type in formation?

What favors the origin of life?

Impact of detection biases on observed population?

How to reconcile single-technique demographics?

Technique synergies are the way forward!

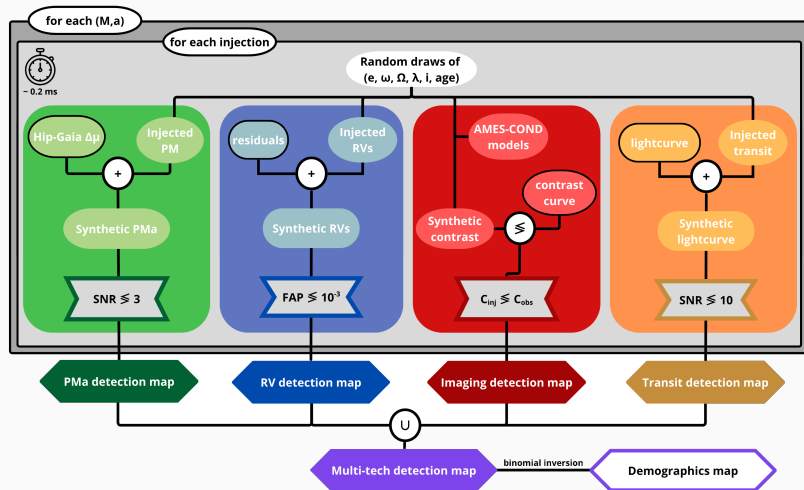
RENARD: A MULTI-TECHNIQUE CODE FOR COMPLETENESS AND DEMOGRAPHICS



RENARD

Retrieval of Exoplanets for the
multi-technique Assessment
of Rates and Detection

Two-year INAF grant
for code development



Forthcoming updates: epoch astrometry, multi-epoch imaging...

Long-term goal:

multi-technique analysis
of the full Kervella+2022 catalog
(116 017 stars)

Current focus:

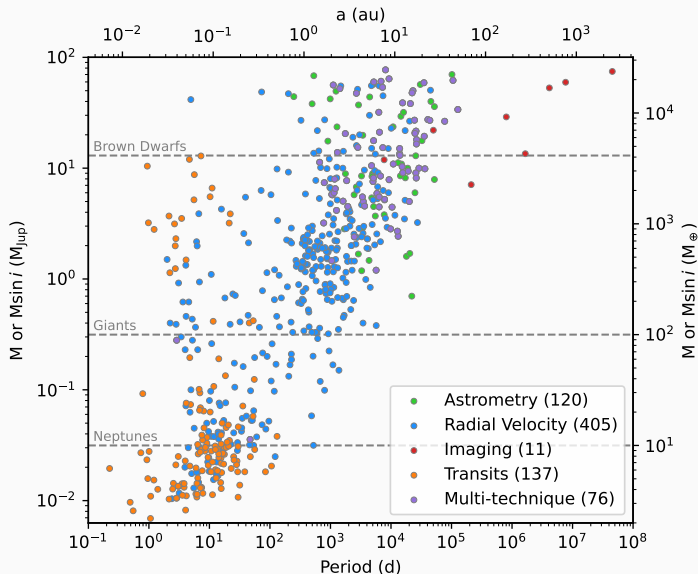
solar-mass ($0.5\text{--}2M_{\odot}$) subsample
(58 223 stars)

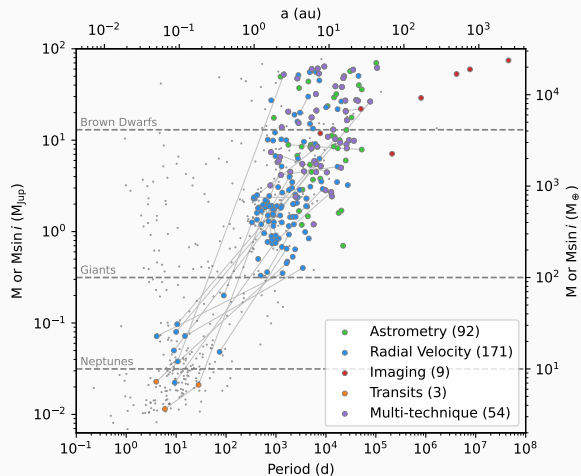
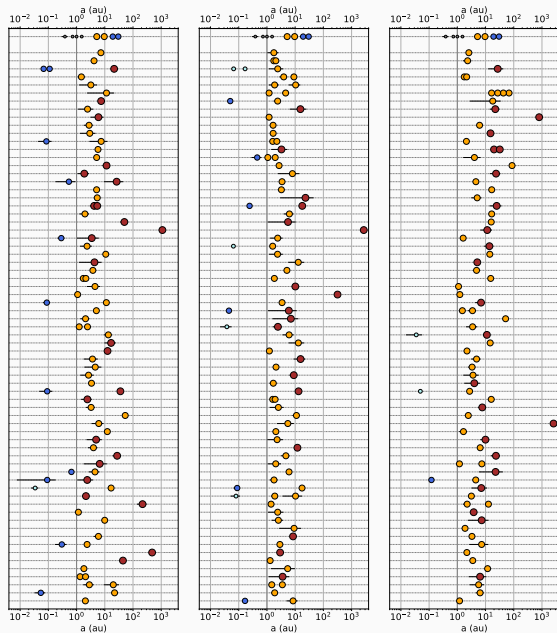
**Public data retrieved:**

52 906 lightcurves
2 321 RV timeseries
279 contrast curves

Preliminary results, long-term analysis

First case of interest:
the frequency of ordered systems





207 stars with massive companion >1 au

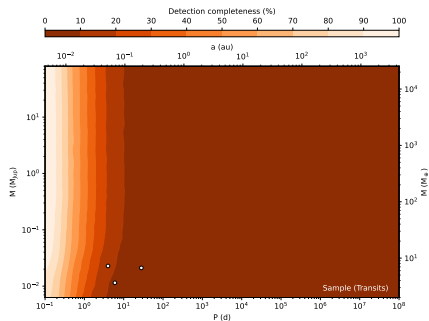
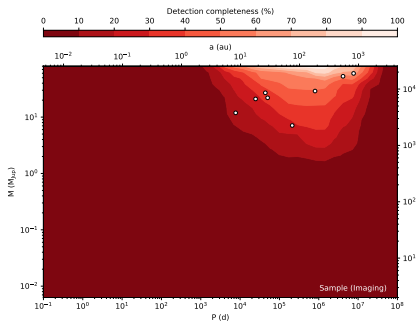
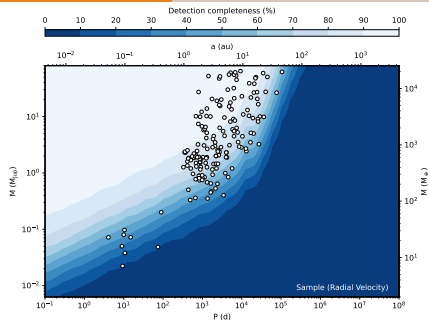
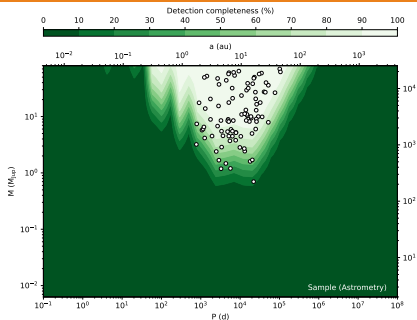
142 with outer giant ($<13 M_{\text{J}}$)

15 with inner companions

65 with outer BD ($>13 M_{\text{J}}$)

9 with inner companions

FULL-SAMPLE COMPLETENESS

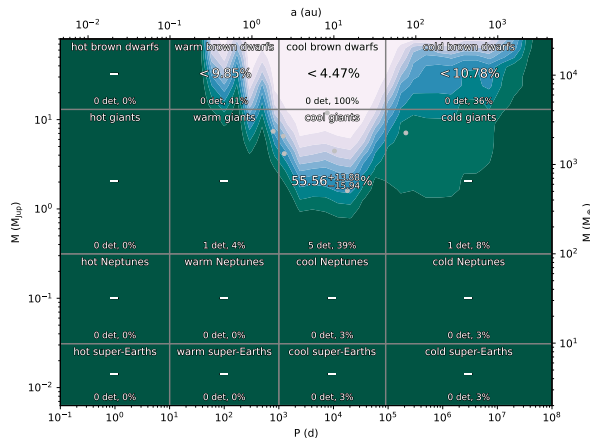


207 stars sample
40 M $\times$ 40 P $\times$ 100 inj $\rightarrow$ $\sim$ 1h50m

197 with photometry
157 with radial velocities
33 with imaging
22 with all data

Single-star maps can guide
follow-up observations!

23 systems with outer giants



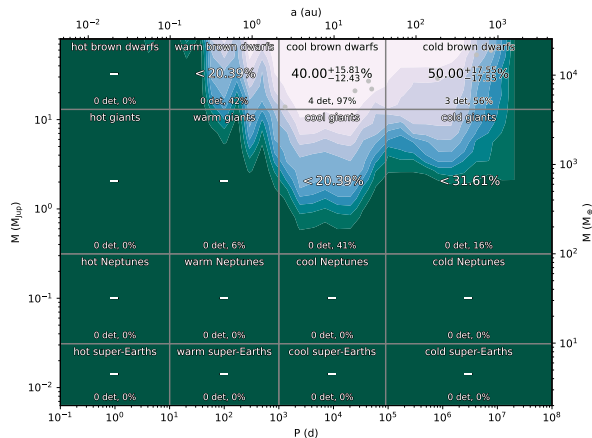
$$C_{cBD} = 100\% \quad f = < 4.47\%$$

$$C_{fBD} = 36\% \quad f = < 10.78\%$$

$$C_{cG} = 39\% \quad f = 55^{+14}_{-16}\%$$

$$C_{fG} = 8\% \quad f = \text{N.D.}\%$$

10 systems with outer brown dwarfs



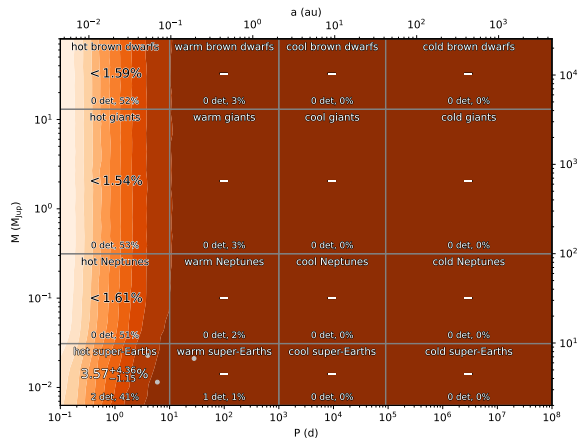
$$C_{cBD} = 97\% \quad f = 40^{+16}_{-12}\%$$

$$C_{fBD} = 56\% \quad f = 50 \pm 17\%$$

$$C_{cG} = 41\% \quad f = < 20\%$$

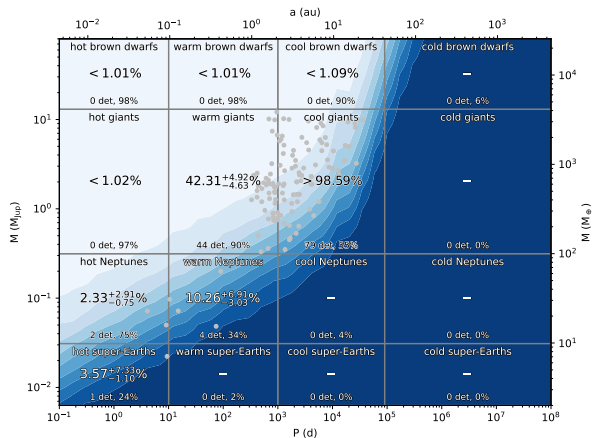
$$C_{fG} = 16\% \quad f = < 31\%$$

137 systems with outer giants



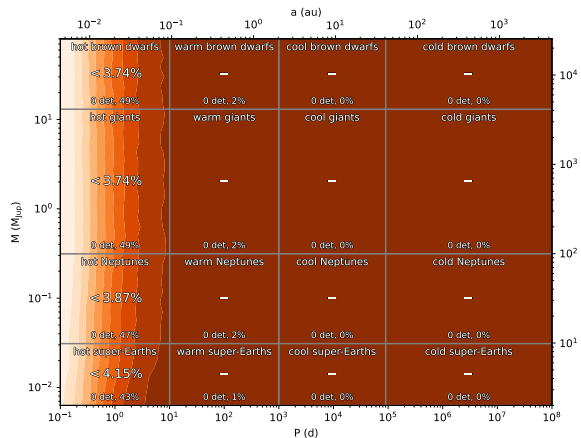
Low completeness for warm companions

115 systems with outer giants



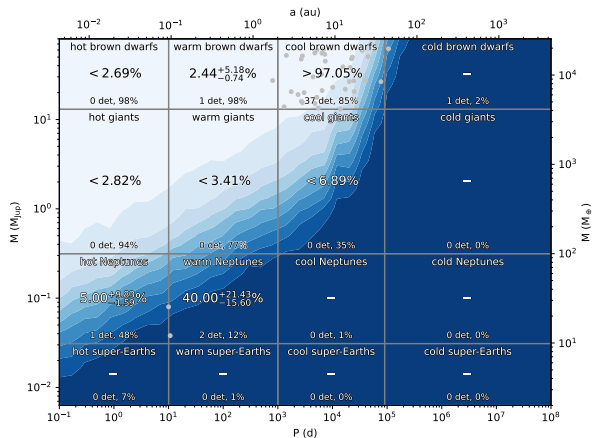
Low completeness for super-Earths

60 systems with outer giants



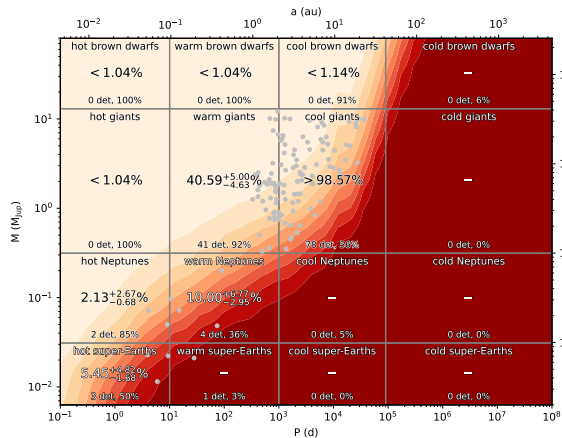
Low completeness for warm companions

42 systems with outer giants



Low completeness for super-Earths

110 systems with outer giants



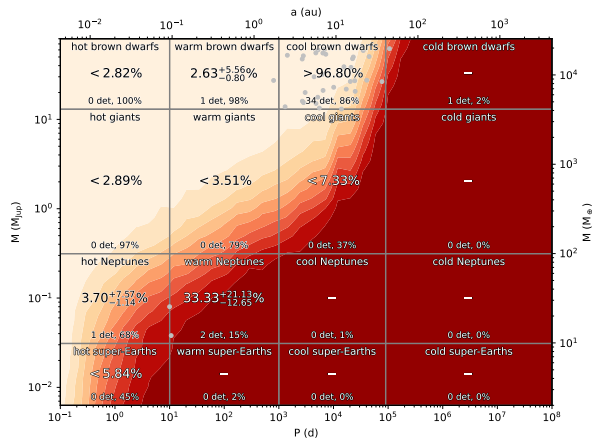
$$C_{\text{hN}} = 85\% \quad f = 2.1^{+2.7}_{-0.7}\%$$

$$C_{\text{wN}} = 36\% \quad f = 10.0^{+6.7}_{-2.9}\%$$

$$C_{\text{hSE}} = 50\% \quad f = 5.4^{+4.8}_{-1.7}\%$$

$$C_{\text{wSE}} = 3\% \quad f = \text{N.D.}\%$$

39 systems with outer brown dwarfs



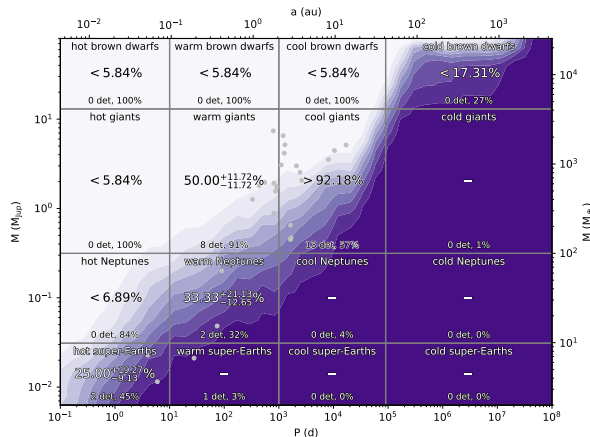
$$C_{\text{hN}} = 68\% \quad f = 3.7^{+7.6}_{-1.1}\%$$

$$C_{\text{wN}} = 15\% \quad f = 33.3^{+21.1}_{-12.6}\%$$

$$C_{\text{hSE}} = 45\% \quad f = < 5.84\%$$

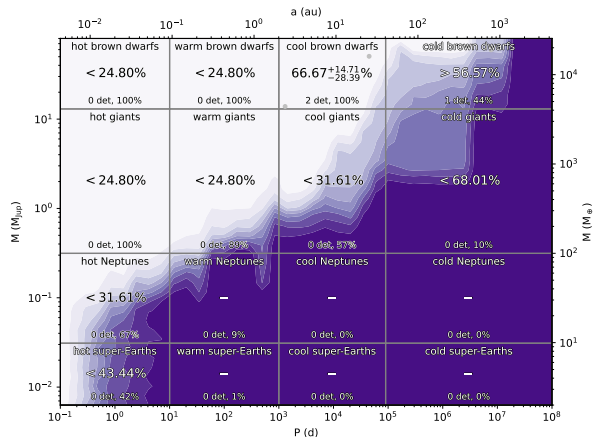
$$C_{\text{wSE}} = 2\% \quad f = \text{N.D.}\%$$

18 systems with outer giants



Large uncertainties due to sample size

only 3 systems with outer brown dwarfs



Too small a sample for statistics

Omnitechnique assessment hindered by small sample size – more data is needed!

FUTURE RENARD UPDATES:

Astrometric orbit injection
Multi-epoch imaging
Refracted light

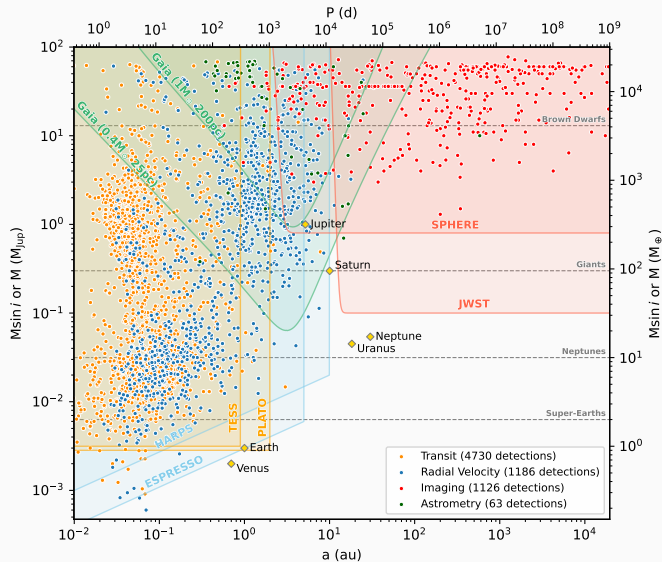
SAMPLE EXPLORATION:

Additional data search
Further signal search
Additional subsamples analysis



Comments, suggestions?
Interested in collaborating?
Have a favourite subsample?

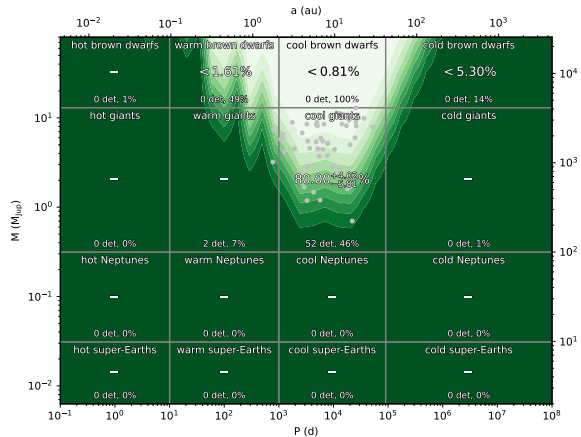
✉ domenico.barbato@inaf.it



A surreal landscape featuring a bright, glowing sun partially obscured by large, white, fluffy clouds. The sky is a mix of blue and orange, suggesting a sunset or sunrise. Numerous planets of various sizes and colors (including Jupiter-like planets with stripes, Earth-like planets with green and blue, and smaller red and blue spheres) are floating in the sky. Some planets are partially obscured by the clouds. The foreground is a rolling green field with small, dark, bushy plants. The word "APPENDICES" is written in a bold, black, sans-serif font in the center of the image.

APPENDICES

142 systems with outer giants



PMA+Imaging results:

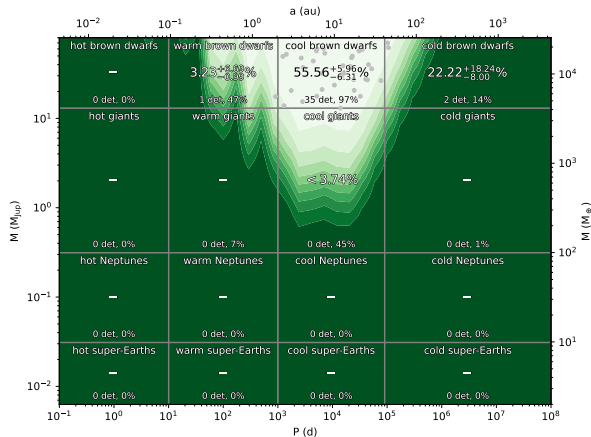
$$C_{cBD} = 100\% \quad f = < 4.47\%$$

$$C_{fBD} = 36\% \quad f = < 10.78\%$$

$$C_{cG} = 39\% \quad f = 55^{+14}_{-16}\%$$

$$C_{fG} = 8\% \quad f = \text{N.D.}\%$$

65 systems with outer brown dwarfs



PMA+Imaging results:

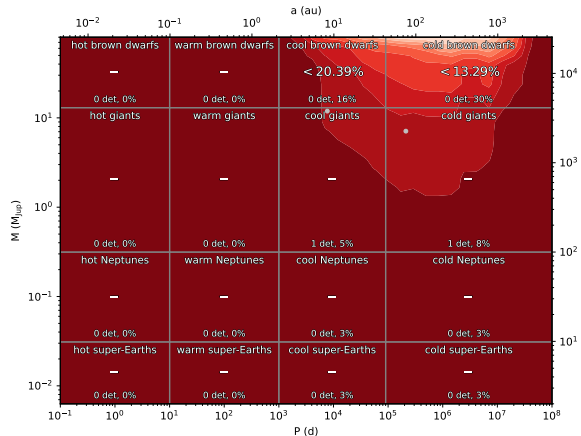
$$C_{cBD} = 97\% \quad f = 40^{+16}_{-12}\%$$

$$C_{fBD} = 56\% \quad f = 50 \pm 17\%$$

$$C_{cG} = 41\% \quad f = < 20\%$$

$$C_{fG} = 16\% \quad f = < 31\%$$

23 systems with outer giants



PMA+Imaging results:

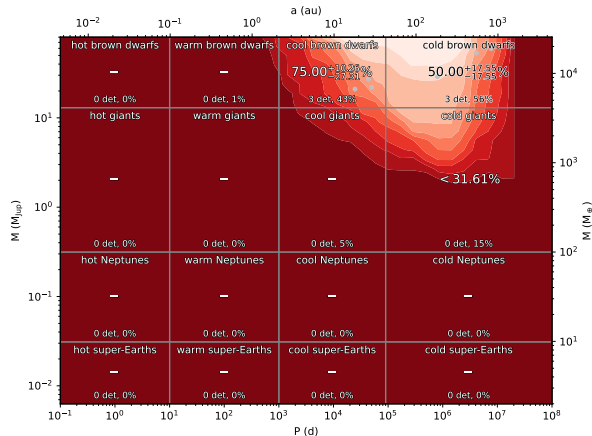
$$C_{\text{cBD}} = 100\% \quad f = < 4.47\%$$

$$C_{\text{fBD}} = 36\% \quad f = < 10.78\%$$

$$C_{\text{cG}} = 39\% \quad f = 55^{+14}_{-16}\%$$

$$C_{\text{fG}} = 8\% \quad f = \text{N.D.}\%$$

10 systems with outer brown dwarfs



PMA+Imaging results:

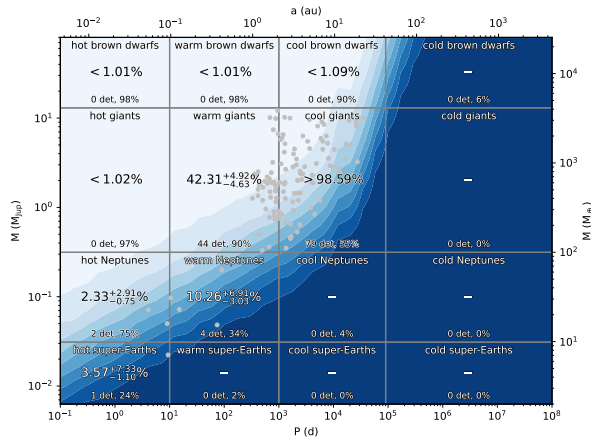
$$C_{\text{cBD}} = 97\% \quad f = 40^{+16}_{-12}\%$$

$$C_{\text{fBD}} = 56\% \quad f = 50 \pm 17\%$$

$$C_{\text{cG}} = 41\% \quad f = < 20\%$$

$$C_{\text{fG}} = 16\% \quad f = < 31\%$$

115 systems with outer giants



RV+photometry results:

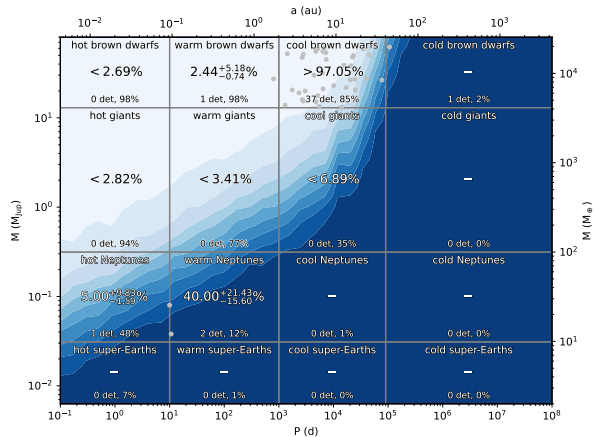
$$C_{\text{hN}} = 85\% \quad f = 2.1^{+2.7}_{-0.7}\%$$

$$C_{\text{wN}} = 36\% \quad f = 10.0^{+6.7}_{-2.9}\%$$

$$C_{\text{hSE}} = 50\% \quad f = 5.4^{+4.8}_{-1.7}\%$$

$$C_{\text{wSE}} = 3\% \quad f = \text{N.D.}\%$$

42 systems with outer brown dwarfs



RV+photometry results:

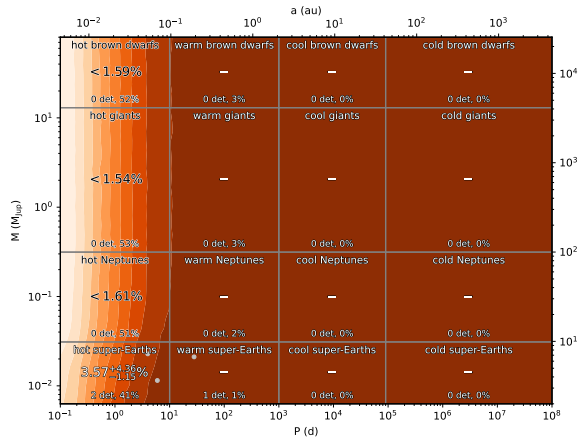
$$C_{\text{hN}} = 68\% \quad f = 3.7^{+7.6}_{-1.1}\%$$

$$C_{\text{wN}} = 15\% \quad f = 33.3^{+21.1}_{-12.6}\%$$

$$C_{\text{hSE}} = 45\% \quad f = < 5.84\%$$

$$C_{\text{wSE}} = 2\% \quad f = \text{N.D.}\%$$

137 systems with outer giants



RV+photometry results:

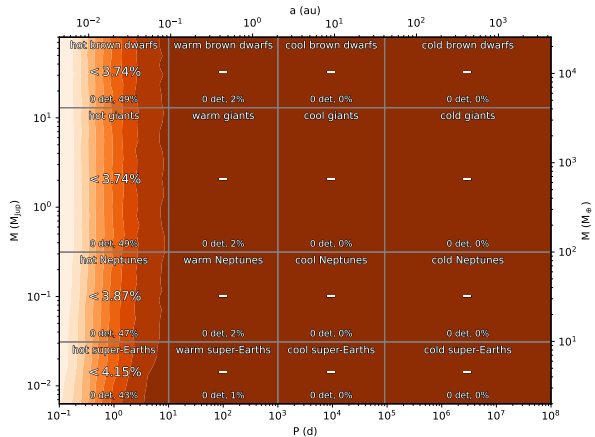
$$C_{\text{hN}} = 85\% \quad f = 2.1^{+2.7}_{-0.7}\%$$

$$C_{\text{wN}} = 36\% \quad f = 10.0^{+6.7}_{-2.9}\%$$

$$C_{\text{hSE}} = 50\% \quad f = 5.4^{+4.8}_{-1.7}\%$$

$$C_{\text{wSE}} = 3\% \quad f = \text{N.D.}\%$$

60 systems with outer brown dwarfs



RV+photometry results:

$$C_{\text{hN}} = 68\% \quad f = 3.7^{+7.6}_{-1.1}\%$$

$$C_{\text{wN}} = 15\% \quad f = 33.3^{+21.1}_{-12.6}\%$$

$$C_{\text{hSE}} = 45\% \quad f = < 5.84\%$$

$$C_{\text{wSE}} = 2\% \quad f = \text{N.D.}\%$$