

Occurrence rates of small close-in planets in the presence of cold Jupiters

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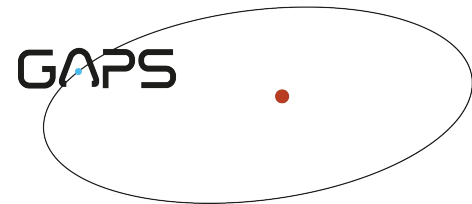
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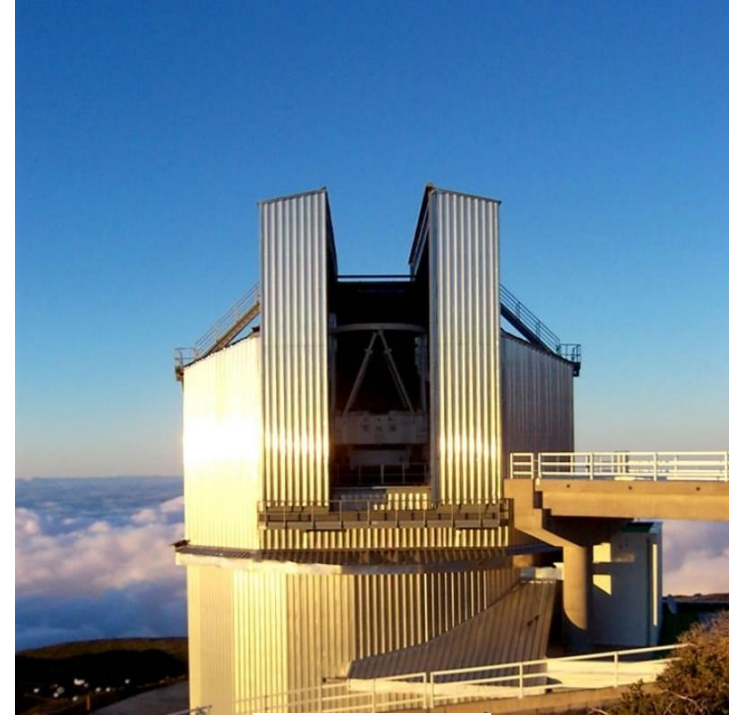


Introduction

Aim: connection between CJs and inner SPs

Expansion of a previous project by GAPS

Sample selected for detectability



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Sample selection

NASA exoplanet archive: RVs only

$V < 10$: bright to see small planets

$M_* > 0.6 M_{\text{sun}}$

External giant: $m_{\text{Jup}} > 0.1$ e periastron > 1 au

Unevolved stars: $\log g > 3.5$ (Gaia DR3)

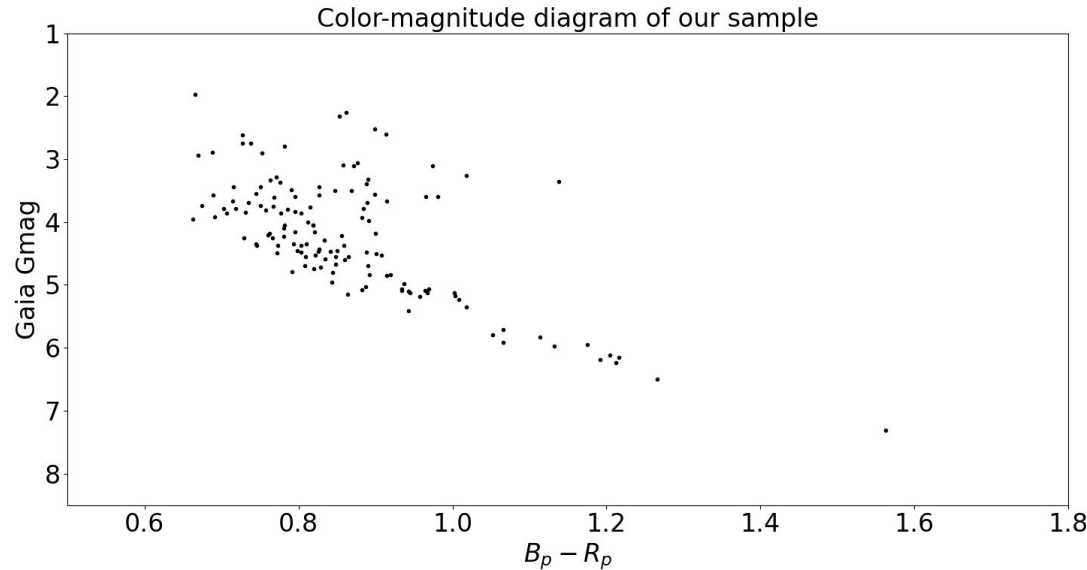
$\log R_{\text{hk}} < -4.8$ (Boro Saikia+2018)

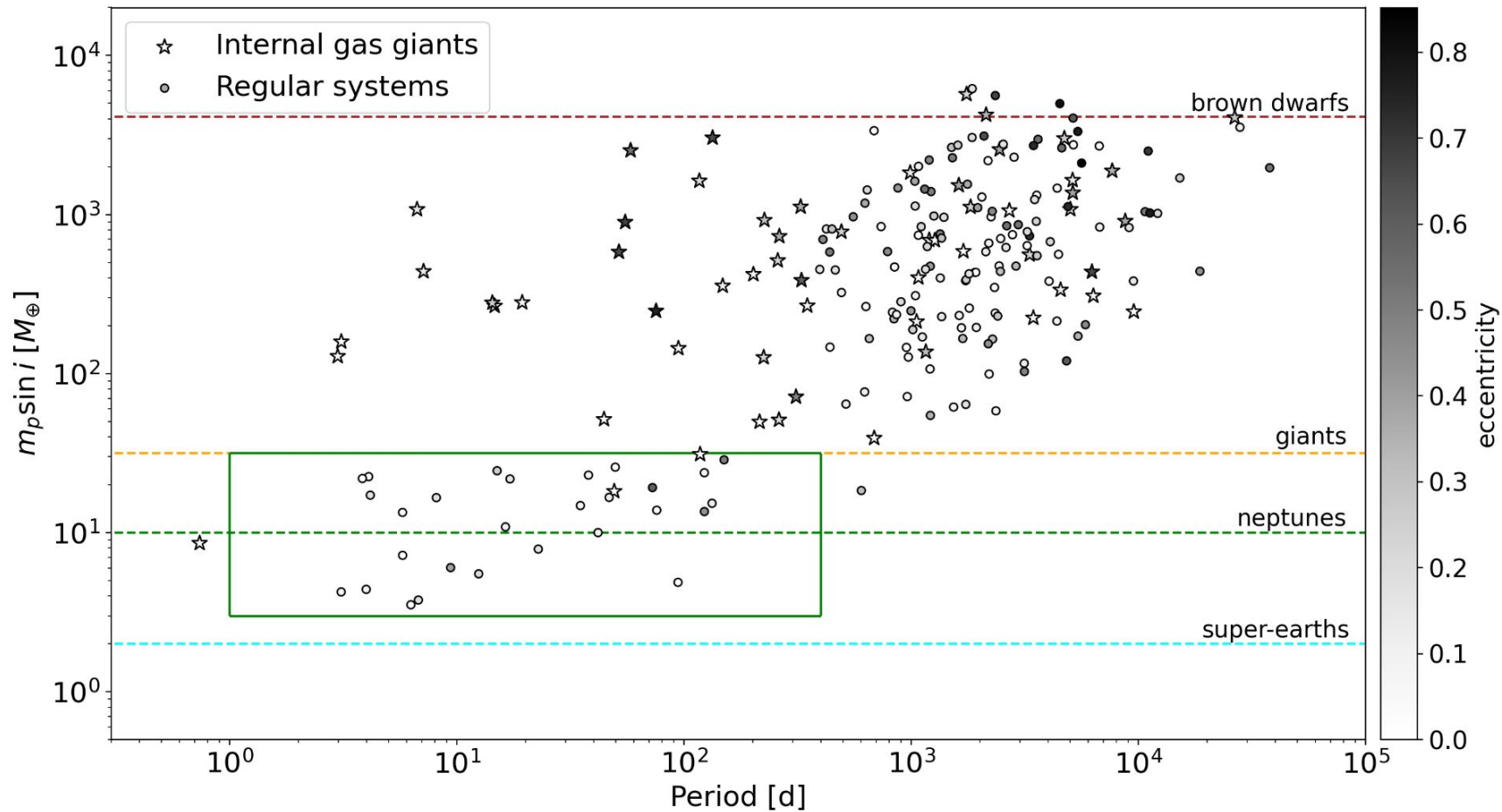
Binaries with separation > 5 arcsec (contamination)

Removed some other giants

Other removed for various reasons (HD 220773, bet Pic, ecc.)

We have 161 planets in 114 systems, 83 single
23 more systems (58 planets) with inner giants





Data gathering and analysis

Gathering of all available data (not easy task!)

Fit of all systems (PyORBIT, Malavolta+2016, 2018)

Found **a few robust candidates**, a new **activity cycle** and **two revised orbits**

Occurrence rates for inner SPs (n. of planets per star)

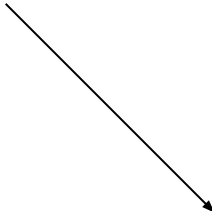
Statistical analysis

Double analysis: codes by M. Pinamonti and D. Barbato to double-check

Injection and retrieval scheme to assess detectability

100 x 100 grid, $3 < m \sin i < 31.7 M_{\oplus}$, $1 < P < 400$ d

Comparison with previous works



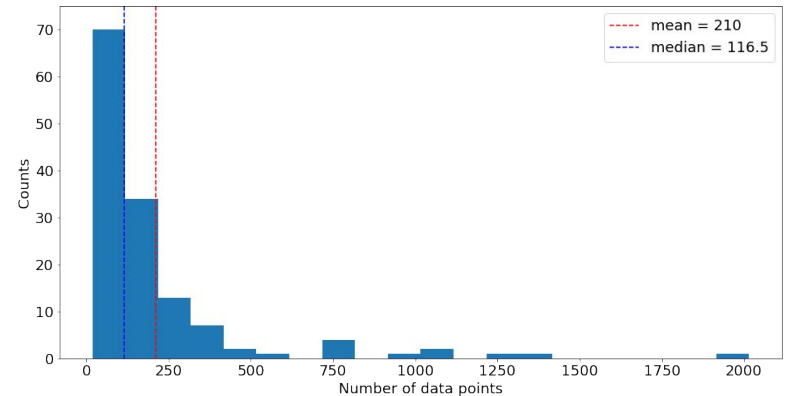
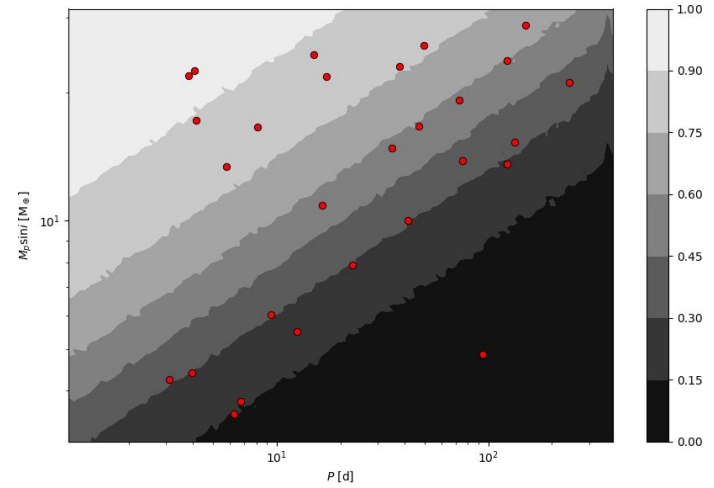
See Domenico's talk in a couple of hours!

Detection map

20 Neptunians, 9 SEs

Systems with SEs: very well studied with a lot of data

Not representative, some systems only have 20-30 sparse data points



Base case

Test without our new candidates: results compatible

Removed systems with < 50 RV measures: still compatible

$m_p \sin i [M_\oplus]$	hot	warm	cool
[1, 10]			
[10, 100]			
[100, 400]			
[10, 31.7]	$4.9^{+3.4}_{-1.3}$	$13.7^{+5.8}_{-3.1}$	$10.1^{+8.0}_{-2.8}$
	$n = 5$	$n = 10$	$n = 5$
	$C = 88.7\%$	$C = 64.2\%$	$C = 34.7\%$
[3, 10]	$11.5^{+6.9}_{-2.9}$	* $16.5^{+16.0}_{-4.9}$	-
	$n = 6$	$n = 3$	$n = 0$
	$C = 45.7\%$	$C = 15.9\%$	$C = 4.80\%$

Neptunes

Super-Earths

n is the number of detections, C is the average completeness

Influence of the outer giant

Sub-samples based on outer giant parameters

No difference for hot planets

eccentricity: 8/10 WNs and 3/3 WSEs when the CJ has $e < 0.3$

msini: 9/10 WNs and 3/3 WSEs when the CJ has $msini < 4 M_{\text{jup}}$

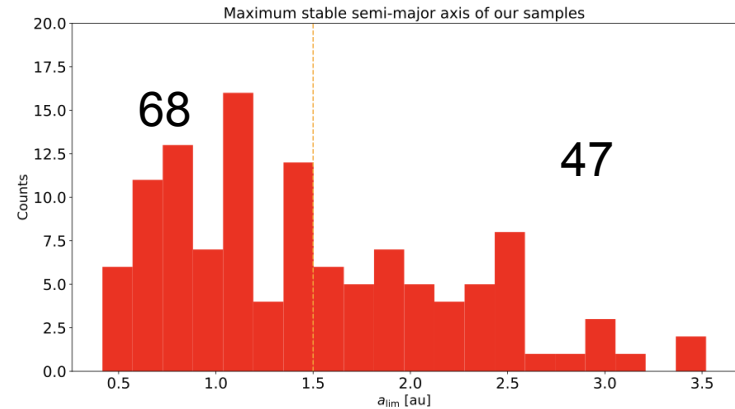
Influence of the outer giant

Hill criterion: $a_2 < a_1(1 - e_1) - 2\sqrt{3}R_H$

Warm objects only for $a_2 > 1.5$ au

1.5 σ significance for SE but 3.7 σ for Neptunes

Qualitatively similar to Rosenthal+2022: CJs favour inner planets except when $0.3 < a_1 < 3$ au



Comparison with Barbato+2018

msini = [10,30] M_{\oplus} , $P = < 150$ d ($n = 19$, $C = 73\%$)

They all belong to this larger sample

They derived occurrence $< 9.8\%$

We find $22.9 - 4.1 + 6.5\%$ so 2.1σ significance

Probably just a statistical effect

Comparison with Rosenthal+2022

msini = [3,30] M_{\oplus} , $P = [1.2, 365]$ d (n = 29, C = 44%)

Blind survey: compare with $P(\text{Inner}|\text{Outer}) = 69 \pm 19\%$

We find $55.6 - 8.6 + 12.5\%$, agreement at $< 1\sigma$

Comparison with Bonomo+2023,2025

msini = [3,20] M_{\oplus} , $P < 100$ d ($n = 11$, $C = 45\%$)

N. of stars with planets \neq n. of planets per star

Bonomo+2025: $P(\text{SP}|\text{CJ}) = 32 \pm 11\%$

We find $P(\text{SP}|\text{CJ}) = 24.1 - 5.1 + 7.3\%$

Agreement at $<1\sigma$

$$P(\text{SP}) \times P(\text{CJ}|\text{SP}) = P(\text{CJ}) \times P(\text{SP}|\text{CJ})$$

$$P(\text{CJ}) = 10 \pm 1\% \text{ (Bonomo+2025)}$$

$$P(\text{SP}) = 28 \pm 6\% \text{ (Rosenthal+2022)}$$

$$\text{Bonomo+2023: } 6.4 - 2.1 + 7.4\%$$

$$\text{We derive } P(\text{CJ}|\text{SP}) = 9.1 \pm 3.6\% \text{ (< } 1\sigma)}$$

Adjusted for differences
in CJ definition



Results for HJs

Howard+2010

$msini = [0.3, 3] M_J$, $P < 12$ d
($n = 3$, $C = 93\%$)

They found $1.2 \pm 0.2\%$

We find $2.3 - 0.6 + 2.4\%$

Wittenmyer+2020

$msini = [0.3, 13] M_J$, $P = [1, 10]$ d
($n = 4$, $C = 96\%$)

They found $0.84 - 0.20 + 0.70\%$

We find $3.0 - 0.8 + 2.5$

$\sim 2\sigma$ significance, hint of more HJs?

Results for WJs

Occurrence rate of WJs poorly studied

Su+2024 (definition with snow line): WJs \sim 10% for Solar-like

$m_{\text{J}} = [0.1, 13] M_{\text{J}}$, $P = [10, 100] \text{ d}$ ($n = 9$, $C = 70\%$)

We find $9.5 - 2.2 + 4.3\%$ so perfectly compatible

No significant difference in subsamples ($< 1.5\sigma$)

Sum up

Large and homogeneous sample,
self-consistent analysis

The external giant DOES MATTER!

Agreement with Rosenthal+2022-2024 and
Bonomo+2023,2025

Disagreement with Bryan+2019 and Zhu
and Wu 2018

HJs possibly abundant with CJs, not WJs

	Barbato et al. (2018b) $m \sin i \in [10, 30] M_{\oplus}, P < 150 \text{ d}$	Bonomo et al. (2025) $m \sin i \in [3, 20] M_{\oplus}, P < 100 \text{ d}$	Rosenthal et al. (2022) $m \sin i \in [3, 30] M_{\oplus}, P \in [1.2, 365.25] \text{ d}$
This work	$22.9^{+6.5}_{-4.1}\%$ $n = 19, C = 73\%$	$24.1^{+7.3}_{-5.1}\%$ $n = 11, C = 45\%$	$55.6^{+12.5}_{-8.6}\%$ $n = 29, C = 44\%$
Literature	$< 9.84\%$	$32 \pm 11\%$	$69 \pm 19\%$

	Howard et al. (2010) $m \sin i \in [0.3, 3] M_J, P < 12 \text{ d}$	Wittenmyer et al. (2020) $m \sin i \in [0.3, 13] M_J, P \in [1, 10] \text{ d}$	Su et al. (2024) $m \sin i \in [0.1, 13] M_J, P \in [10, 100] \text{ d}$
This work	$2.4^{+2.3}_{-0.7}\%$ $n = 3, C = 92.6\%$	$3.0^{+2.5}_{-0.8}\%$ $n = 4, C = 95.8\%$	$9.5^{+4.3}_{-2.2}\%$ $n = 9, C = 69.5\%$
Literature	$1.2 \pm 0.2\%$	$0.84^{+0.70}_{-0.20}\%$	$\sim 10\%$

Ruggieri et al. to be resubmitted very soon!



THANK YOU!

Introduction

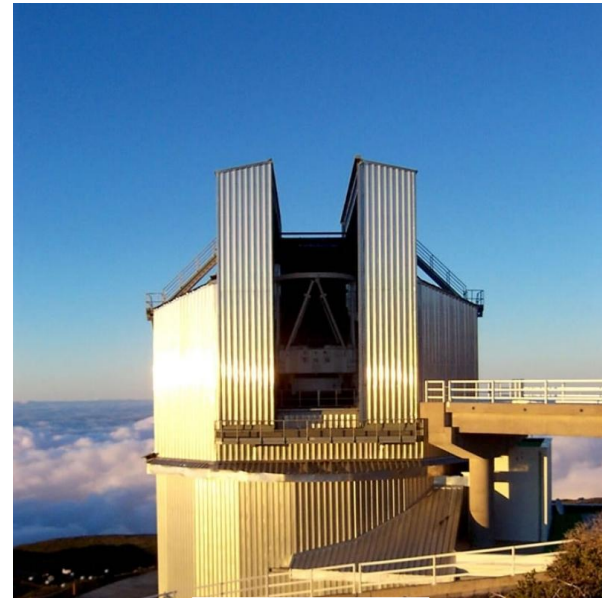
Aim: connection between CJs and inner SPs

GAPS1 - Known Planets (KP): 16 stars (2012)

Search for SP where a CJ was already known

Sample selected for detectability + room for improvement

Barbato+2018: same but with HARPS (20 stars)



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Introduction

Problems of KP: too few stars and chosen ad hoc

Discovery of a few planets (Benatti+2020, Ruggieri+2024,2025)

Dedicated analysis in preparation (Pinamonti et al.)

New analysis with more rigorous criteria and larger sample

The GAPS programme at TNG

XXIII. HD 164922 d: close-in super-Earth discovered with HARPS-N in a system with a long-period Saturn mass companion***

S. Benatti¹, M. Damasso², S. Desidera³, F. Marzari⁴, K. Biazzo⁵, R. Claudi³, M. P. Di Mauro⁶, A. F. Lanza⁷, M. Pinamonti², D. Barbato^{2,8}, L. Malavolta⁴, E. Poretti⁹, A. Sozzetti³, L. Afferl¹, A. Bignamini¹⁰, A. S. Bonomo², F. Borsari¹¹, M. Brogi^{12,2,13}, G. Bruno¹, I. Carleo¹⁴, R. Cosentino⁹, E. Covino¹⁵, G. Frustagli^{11,16}, P. Giacobbe², M. Gonzalez², R. Gratton³, A. Harutyunyan⁹, C. Knäuper¹⁰, G. Leto¹, M. Lodi⁹, A. Maggio¹, J. Maldonado¹, L. Mancini^{17,18,2}, A. Martinez Fiorenzano⁹, G. Micela¹, E. Molinari¹⁹, M. Molinaro¹⁰, D. Nardiello^{20,3}, V. Nascimben³, I. Pagano⁷, M. Pedani⁹, G. Piotto³, M. Rainer²¹, and G. Scandariato²

The GAPS Programme at TNG

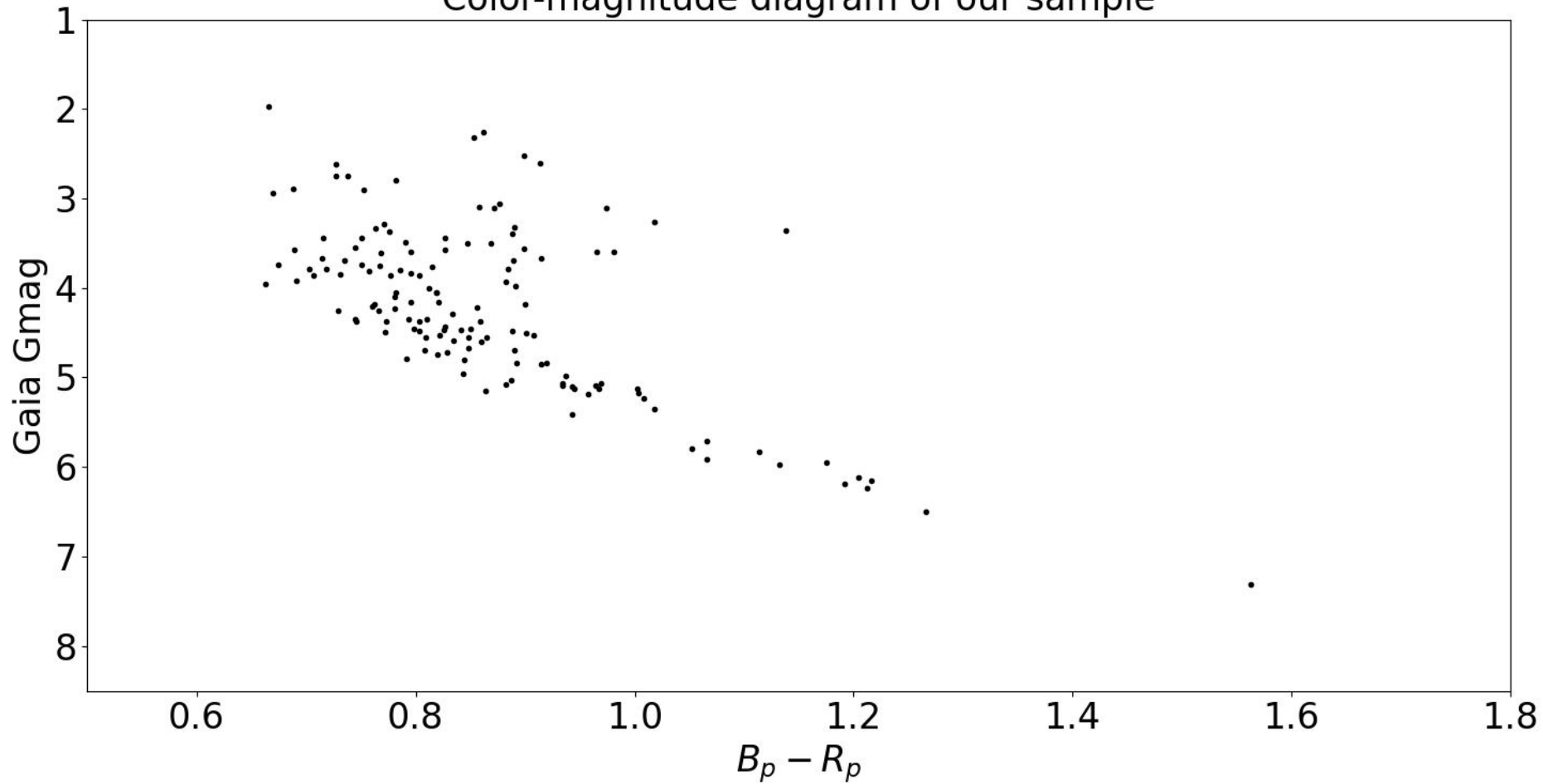
LVIII. Two multi-planet systems with long-period substellar companions around metal-rich stars*

A. Ruggieri^{1,2,***}, S. Desidera², A. Sozzetti³, F. Marzari^{4,2}, M. Pinamonti³, R. Gratton², K. Biazzo⁵, V. D'Orazi^{9,2}, L. Malavolta^{1,2}, D. Mesa², R. Claudi², S. Benatti¹, A. Bignamini¹⁰, L. Cabona², G. Chauvin¹⁰, J. Hagelberg¹⁰, L. Mancini^{3,11}, G. Mantovan^{1,2}, M. Molinaro⁸, D. Nardiello^{1,2}, G. Scandariato², A. Vigan¹³, and T. Zingales¹

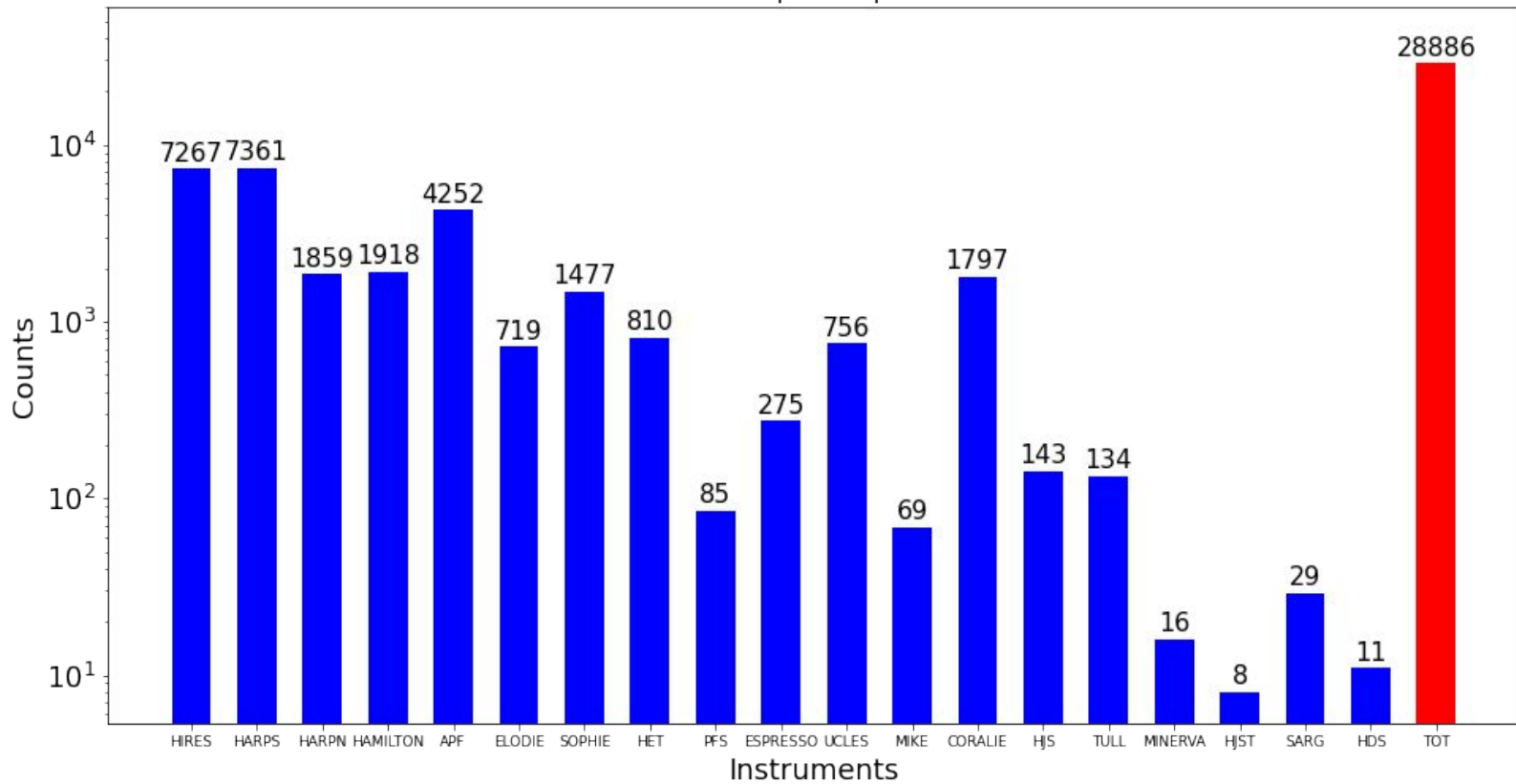
The GAPS programme at TNG LXVIII. Characterization of the outer substellar companion around HD 72659 with a multitechnique approach*

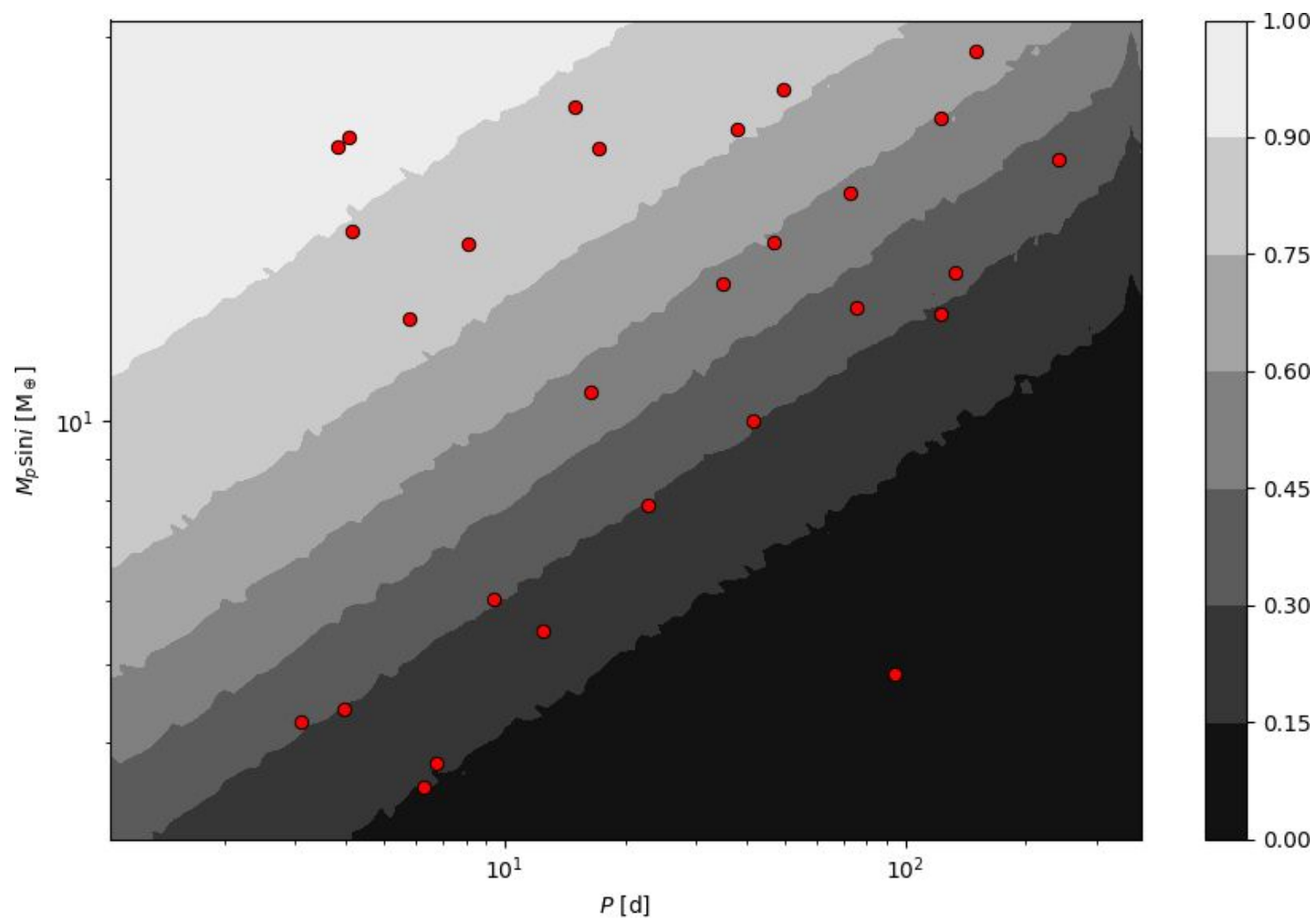
A. Ruggieri^{1,2,*}, A. Sozzetti³, S. Desidera², D. Mesa², R. Gratton², F. Marzari^{2,4}, M. Bonavita⁵, K. Biazzo⁶, V. D'Orazi^{2,7}, C. Ginski^{8,9,10}, M. Meyer¹¹, L. Malavolta^{2,12}, M. Pinamonti¹⁰, D. Barbato², C. Lazzoni², A. F. Lanza¹, L. Mancini³, L. Naponiello³, D. Nardiello^{2,12}, T. Zingales^{2,12}, M. Rainer¹³, G. Scandariato¹, P. Giacobbe³, R. Cosentino¹⁴, A. Fiorenzano¹⁴, and R. Claudi^{2,15}

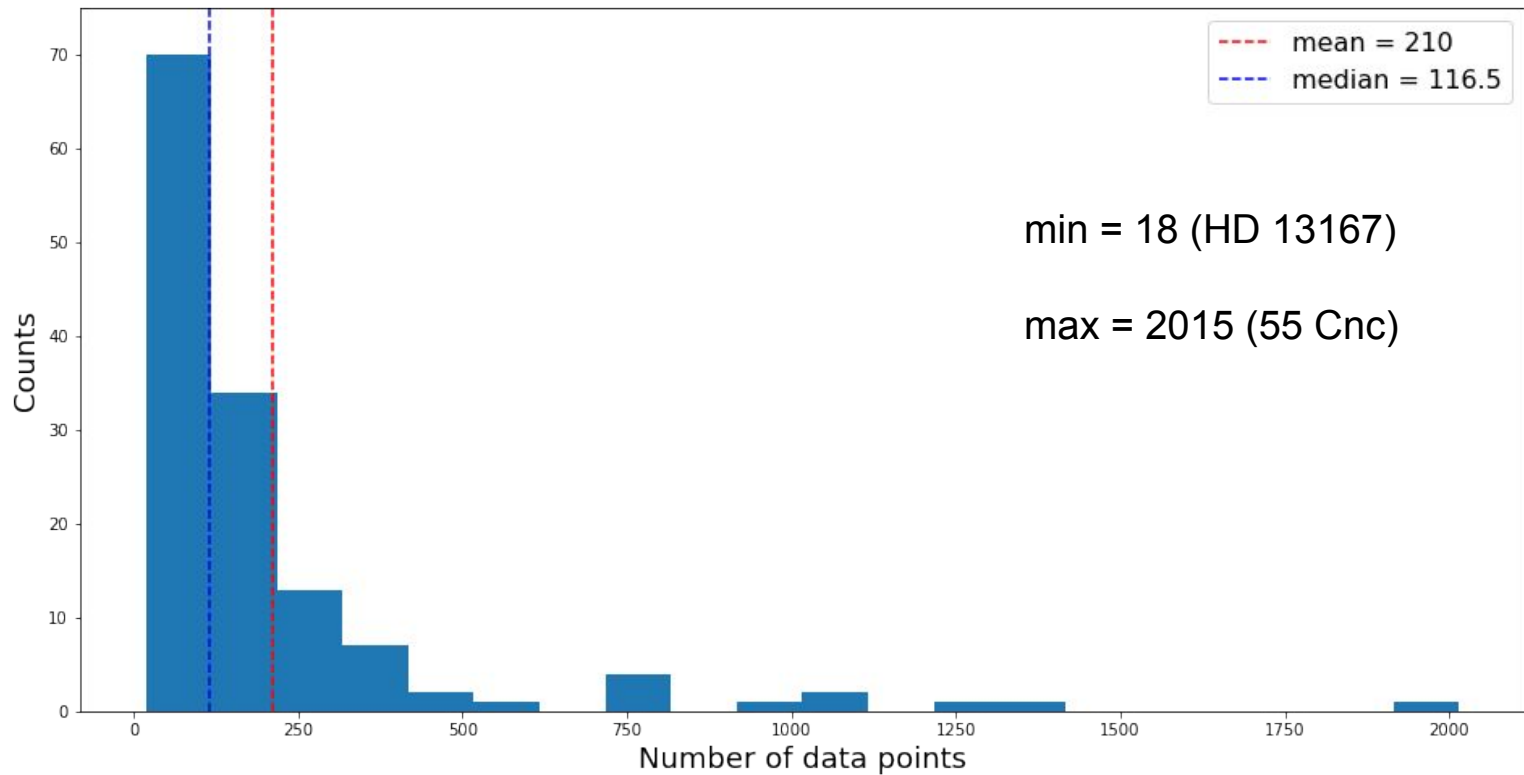
Color-magnitude diagram of our sample



Number of data points per instrument







Candidates validation (thanks to Luca N. and Mario D.!!)

HD 3765: new planet with $P = 130$ d, $m \sin i = 15.3 \pm 2.0 M_{\oplus}$, almost circular orbit; short- or long-term activity? Stellar P_{rot} around 46 d?

HD 204941: signal at 28 d but only in the last season due to better sampling but also lower exposure times. Requires more investigation.

HD 30669: new planet with $P = 150$ d and $m \sin i = 28.7 \pm 3.5 M_{\oplus}$. Also $e \sim 0.5$ and planet b has $e = 0.33$, dynamic interaction?

HD 170469: signal at 8 d but only 45 points over 19 yr. Candidate found in a region with completeness $< 10\%$. Requires more investigation.

Candidates validation (thanks to Luca N. and Mario D.!!)

HD 103891: textbook case of “eccentric impostor”, two planets in 2:1 MMR on circular orbits give rise to an eccentric signal. New planet with $P = 951 \pm 5$ d and $m \sin i = 0.46 \pm 0.034$ M_{Jup}.

HD 13908: new planet with $P = 7700 \pm 1500$ d, $m \sin i = 5.9 \pm 0.8$ M_{Jup}, and $e = 0.35 \pm 0.10$. Adding a third planet reduces instrumental jitter from 33 to 7 m/s.

HD 10697: new planet with $P = 8.1127 \pm 0.0006$ d, $m \sin i = 16.6 \pm 2.6$ M_⊕, and $e = 0.18 - 0.12 + 0.15$

HD 136925: activity cycle from literature is dubious. New planet with $P = 311 \pm 0.6$ d, $m \sin i = 71 \pm 9$ M_⊕, and $e = 0.48 - 0.15 + 0.13$

New activity cycle and revised orbits

HD 7199: RVs correlated with BIS ($r = 0.68$, $p = 7 \times 10^{-19}$). RV residuals, BIS, S-index, CCF contrast all same peak in GLS. We find $P_{\text{cycle}} = 7.4 \pm 0.15$ yr, $K_{\text{cycle}} = 7.8 \pm 0.5$ m/s ($\Delta\text{BIC} = 117$).

HD 156098: CJ + Neptunian planet at 21 d. But K_b compatible with zero and 1-planet model is favored ($\Delta\text{BIC} = 13$). So planet b is dubious for us (not included in the statistical analysis).

HD 47186: CJ with $P = 3.7$ yr, $m \sin i = 0.35$ Mjup, $e = 0.25$; we find $P = 16 \pm 0.5$ yr, $m \sin i = 0.64$ Mjup, $e = 0.47$, why? Bouchy+2009 used 66 HARPS data, now we have 170 HARPS + 67 HIRES spectra. The new solution has lower jitters, lower residuals and $\Delta\text{BIC} = 581$.