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

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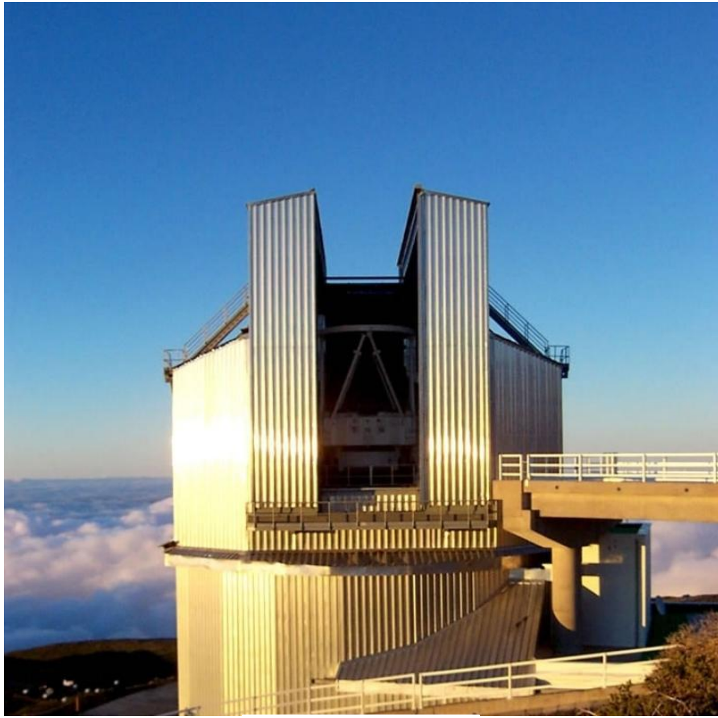
GAPS

Introduction

<u>Aim: connection between CJs and inner SPs</u>

Expansion of a previous project by GAPS

<u>Sample selected for detectability</u>



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Sample selection

NASA exoplanet archive: RVs only

V < 10: bright to see small planets

$M_* > 0.6$ Msun

External giant: msini > 0.1 M_{jup} e periastron > 1 au

Unevolved stars: logg > 3.5 (Gaia DR3)

Some missing (e.g. too bright)
Selected based on HR diagram position

logRhk < -4.8 (Boro Saikia+2018)

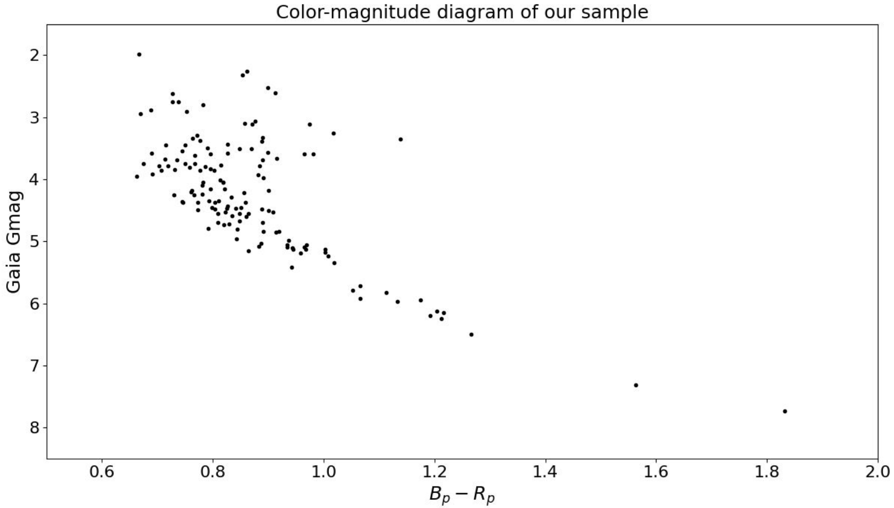
Binaries with separation > 5 arcsec (contamination)

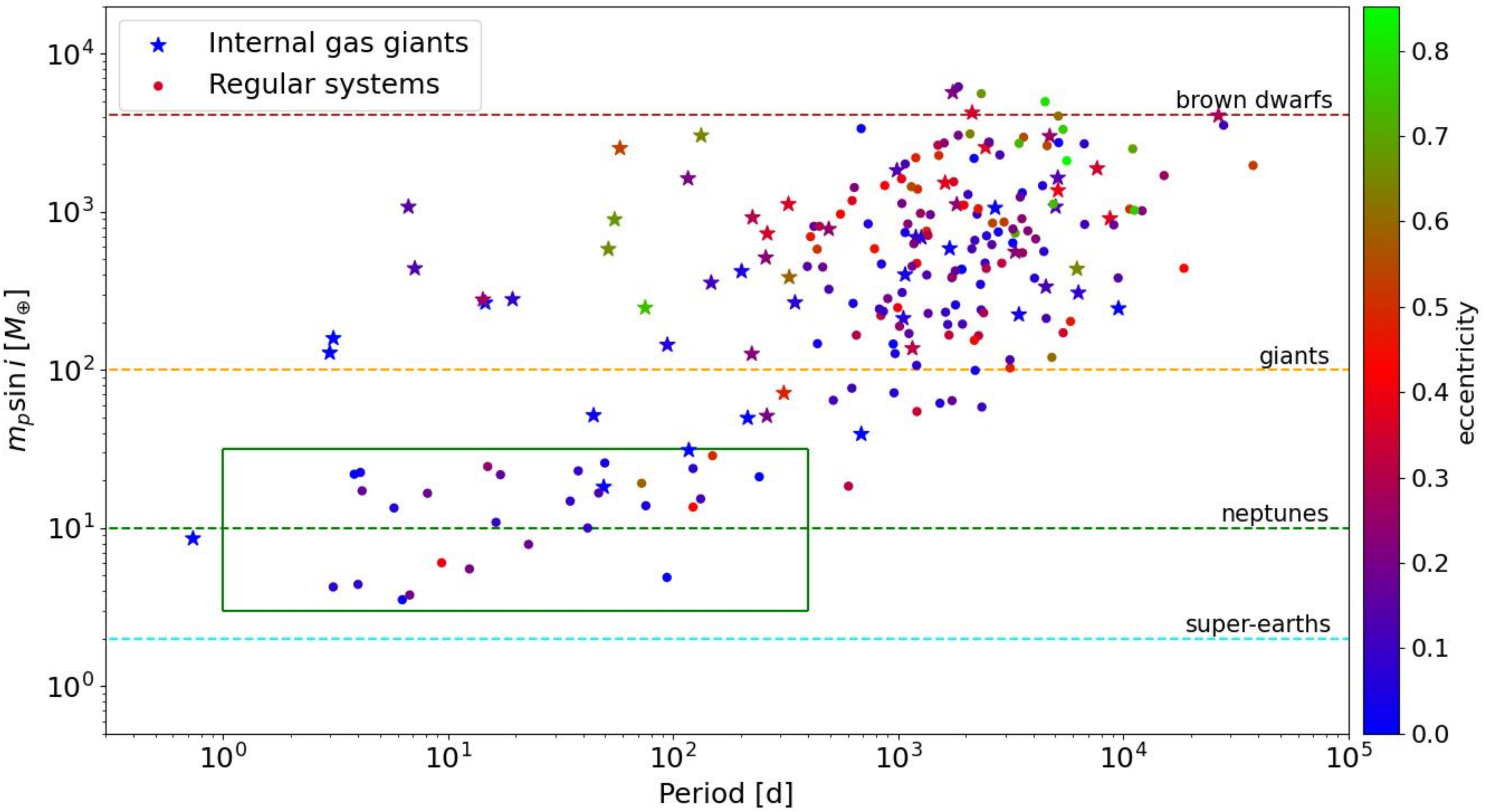
Removed some other giants

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

We have 162 planets in 115 systems, 83 single

23 more systems (58 planets) with inner giants





Internal gas giants
Regular systems
brown dwarfs
giants
neptunes
super-earths
$m_p \sin i\ [M_\oplus]$
Period [d]
eccentricity

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 one revised orbit

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 asses detectability

10 x 10 grid, $3 < m\sin i < 31.7\ M_{\oplus}$, $1 < P < 400$ d

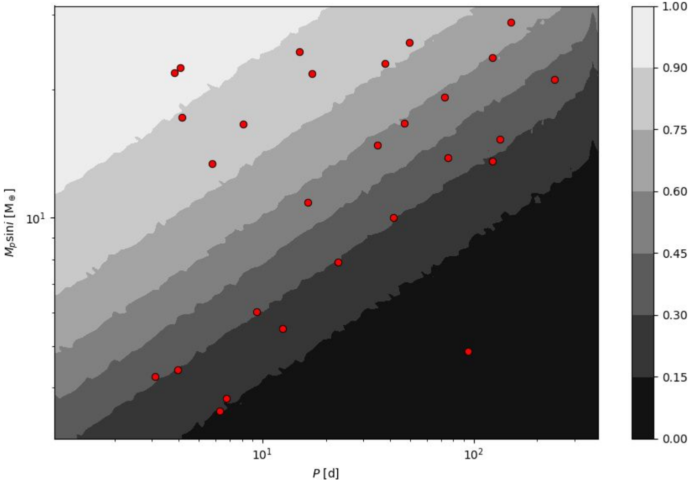
Comparison with previous works

Detection map

20 Neptunians, 8 SEs

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

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



hot warm cool

	Period [d]		
$m_p \sin i$ [$M_\oplus$]	[1, 10]	[10, 100]	[100, 400]
[10, 31.7]	$4.1^{+2.7}_{-1.1}$	$11.2^{+4.8}_{-2.5}$	$10.3^{+6.9}_{-2.8}$
	$n = 5$	$n = 10$	$n = 5$
Neptunes	$C = 89.21\%$	$C = 64.84\%$	$C = 35.31\%$
[3, 10]	$7.8^{+5.3}_{-2.1}$	$13.8^{+13.4}_{-4.1}$	-
	$n = 5$	$n = 3$	$n = 0$
Super-Earths	$C = 46.45\%$	$C = 15.76\%$	$C = 4.33\%$

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

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

<u>msini: 9/10 WNs and 3/3 WSEs when the CJ has msini < 4 Mjup</u>

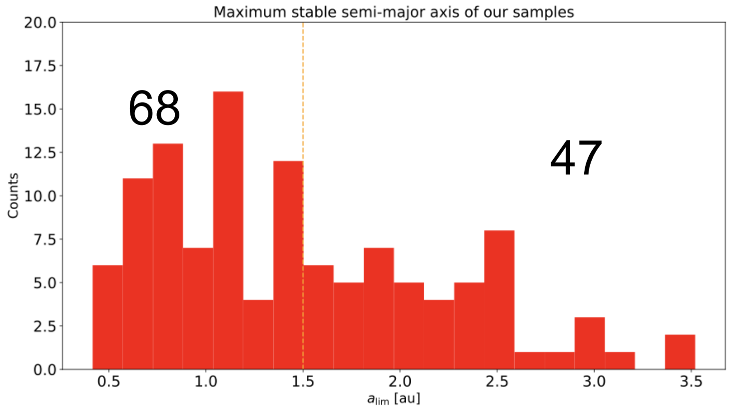
Influence of the outer giant

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

<u>Warm objects only for $a_2 > 1.5$ au</u>

1.5σ significance for SE but <u>3.7σ for Neptunes</u>

<u>Qualitatively similar to Rosenthal+2022</u>: 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 22.6 - 4.0 + 6.5% so 2.1σ significance

<u>Probably just a statistical effect</u>

Comparison with Rosenthal+2022

msini = [3,30] $M_{\oplus}$, P = [1.2, 365] d (n = 28, C = 44%)

Blind survey: compare with P(Inner|Outer) = 69 ± 19%

We find 54.9 - 8.4 + 12.5%, <u>agreement at < 1σ</u>

Comparison with Bonomo+2023,2025

msini = [3,20] $M_\oplus$, P < 100 d (n = 17, C = 45%)

N. of stars with planets =/= n. of planets per star

Bonomo+2025: P(SP|CJ) = 32 ± 11%

We find P(SP|CJ) = 19.4 - 4.3 + 6.6%

<u>Agreement at 1σ</u>

Much lower than P(SP|CJ)~100% found by Bryan+2019 or Zhu and Wu 2018

P(SP) x P(CJ|SP) = P(CJ) x P(SP|CJ)

P(CJ) = 10 ± 1% (Bonomo+2025)

P(SP) = 28 ± 6% (Rosenthal+2022)

Bonomo+2023: 9.3 - 2.7 + 7.7%

We derive P(CJ|SP) = 6.9 ± 3.0% <u>(< 1σ)</u>

Results for HJs

Howard+2010

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

They found 1.2 ± 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

~ 2σ significance, hint of more HJs?

Results for WJs

Occurrence rate of WJs poorly studied

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

msini = [0.1,13] M_J, P = [10,100] d (n = 9, C = 70%)

We find 9.4 - 2.2 + 4.3% so perfectly compatible

No significant difference in subsamples (< 1.5σ)

Sum up

Large and homogeneous sample, self-consistent analysis

The external giant <u>DOES MATTER</u>!

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

Disagreement with Bryan+2019 and Zhu and Wu 2018

HJs possibly abundant with CJs, WJs no

Barbato et al. (2018b)		Bonomo et al. (2023)		Rosenthal et al. (2022)	
	P < 150 d		P < 100 d		$P \in [1.2, 365.25]$ d
$[10, 30]\ M_\oplus$	$22.6^{+6.5}_{-4.0}$	$[3, 20]\ M_\oplus$	$19.4^{+6.6}_{-4.3}$	$[3, 30]\ M_\oplus$	$54.9^{+12.5}_{-8.4}$
	$n = 19$		$n = 17$		$n = 28$
	$C = 73\%$		$C = 45\%$		$C = 44\%$

Howard et al. (2010)		Wittenmyer et al. (2020)		Su et al. (2024)	
	P < 12 d		$P \in [1, 10]$ d		$P \in [10, 100]$ d
$[0.3, 3]\ M_J$	$2.3^{+2.4}_{-0.6}$	$[0.3, 13]\ M_J$	$3.0^{+2.5}_{-0.8}$	$[0.1, 13]\ M_J$	$9.4^{+4.3}_{-2.2}$
	$n = 3$		$n = 4$		$n = 9$
	$C = 92.6\%$		$C = 95.8\%$		$C = 69.5\%$

Ruggieri et al. to be submitted very soon!


THANK YOU!

Introduction

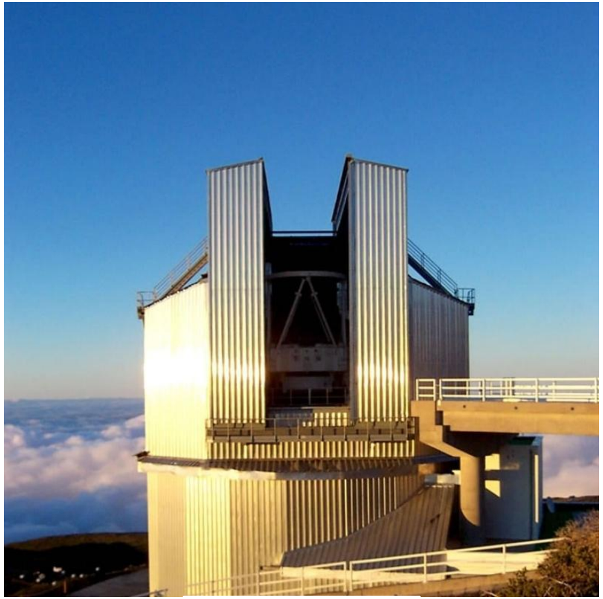
Aim: connection between CJs and inner SPs

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.)

<u>New analysis with more rigorous criteria and larger sample</u>

A&A 639, A50 (2020)
https://doi.org/10.1051/0004-6361/202037939

Astronomy & Astrophysics

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. Benatti[1], M. Damasso[2], S. Desidera[3], F. Marzari[4], K. Biazzo[5], R. Claudi[3], M. P. Di Mauro[6], A. F. Lanza[7], M. Pinamonti[2], D. Barbato[2,8], L. Malavolta[4], E. Poretti[9], A. Sozzetti[2], L. Affer[1], A. Bignamini[10], A. S. Bonomo[2], F. Borsa[11], M. Brogi[12,2,13], G. Bruno[7], I. Carleo[14], R. Cosentino[9], E. Covino[15], G. Frustagli[11,16], P. Giacobbe[2], M. Gonzalez[9], R. Gratton[3], A. Harutyunyan[9], C. Knapic[10], G. Leto[7], M. Lodi[9], A. Maggio[1], J. Maldonado[1], L. Mancini[17,18,2], A. Martinez Fiorenzano[9], G. Micela[1], E. Molinari[19], M. Molinaro[10], D. Nardiello[20,3], V. Nascimbeni[3], I. Pagano[7], M. Pedani[9], G. Piotto[4], M. Rainer[21], and G. Scandariato[7]

A&A, 689, A235 (2024)
https://doi.org/10.1051/0004-6361/202449456

Astronomy & Astrophysics

The GAPS Programme at TNG

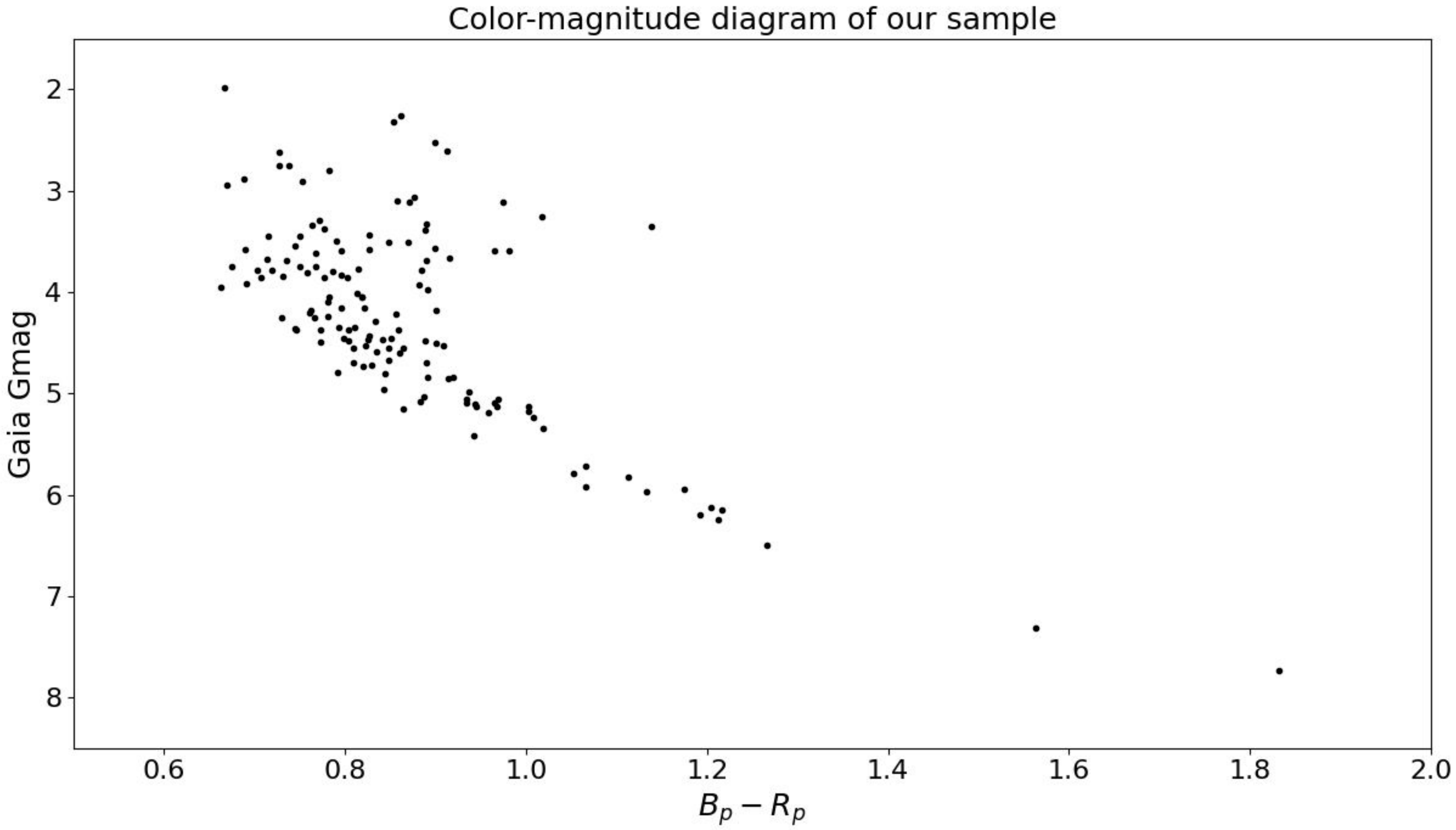
LVIII. Two multi-planet systems with long-period substellar companions around metal-rich stars★

A. Ruggieri[1,2,★★], S. Desidera[2], A. Sozzetti[3], F. Marzari[4,2], M. Pinamonti[3], R. Gratton[2], K. Biazzo[5], V. D'Orazi[6,2], L. Malavolta[1,2], D. Mesa[2], R. Claudi[2], S. Benatti[7], A. Bignamini[8], L. Cabona[2], G. Chauvin[9], J. Hagelberg[10], L. Mancini[3,11], G. Mantovan[1,2], M. Molinaro[8], D. Nardiello[1,2], G. Scandariato[12], A. Vigan[13], and T. Zingales[1]

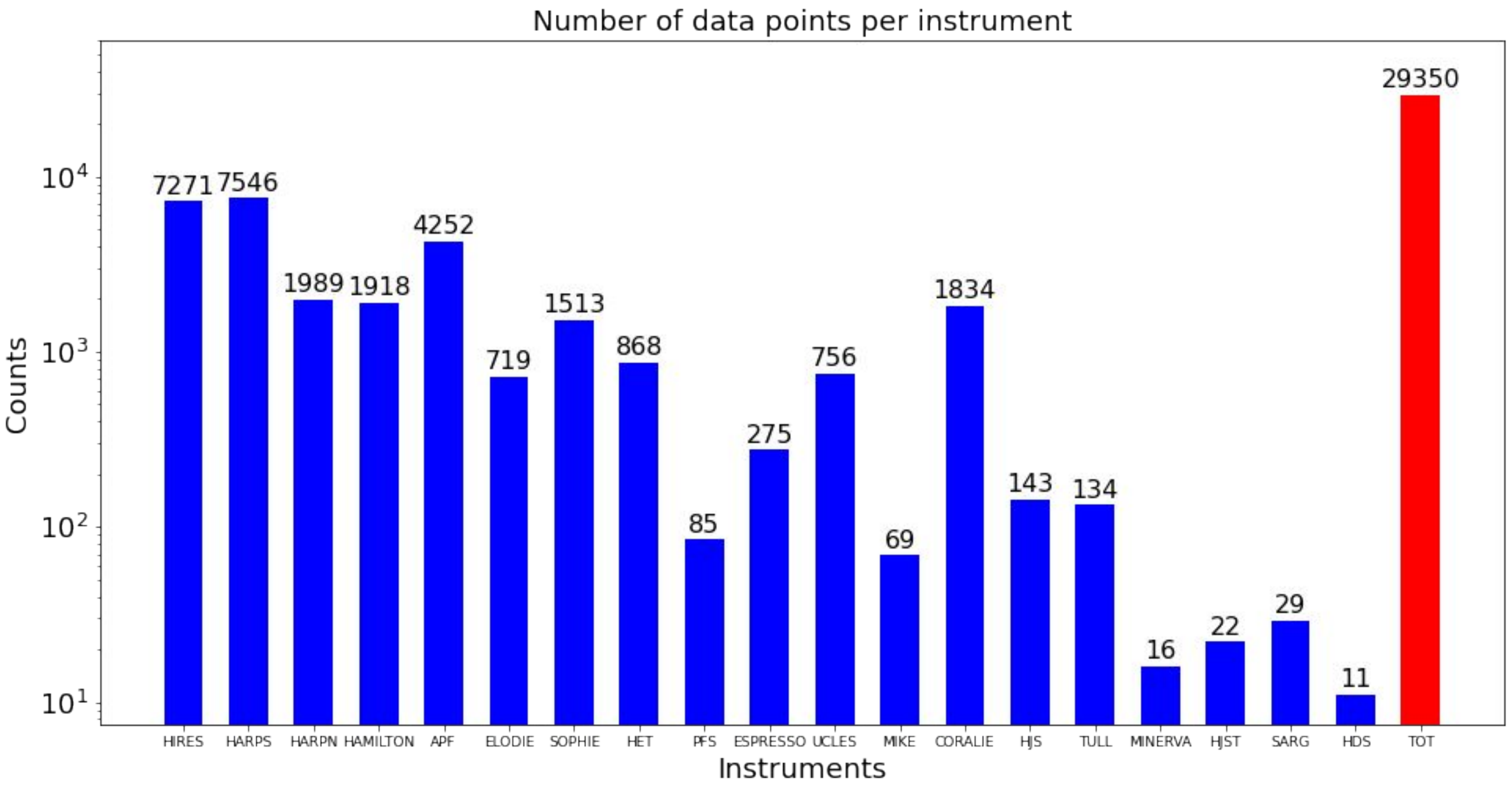
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **542,** 1233–1247 (2025) https://doi.org/10.1093/mnras/staf1251
Advance Access publication 2025 July 30

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

A. Ruggieri ,[1,2★] A. Sozzetti ,[3] S. Desidera,[2] D. Mesa,[2] R. Gratton,[2] F. Marzari,[2,4] M. Bonavita ,[5] K. Biazzo ,[6] V. D'Orazi ,[2,7] C. Ginski,[8,9,10] M. Meyer,[11] L. Malavolta ,[2,12] M. Pinamonti ,[3] D. Barbato,[2] C. Lazzoni,[2] A. F. Lanza ,[1] L. Mancini,[3] L. Naponiello,[3] D. Nardiello ,[2,12] T. Zingales ,[2,12] M. Rainer ,[13] G. Scandariato,[1] P. Giacobbe,[3] R. Cosentino,[14] A. Fiorenzano[14] and R. Claudi[2,15]



Color-magnitude diagram of our sample
Gaia Gmag
2
3
4
5
6
7
8
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$B_p - R_p$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Counts
Instruments
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10^2
10^3
10^4
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1918
4252
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756
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134
16
22
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11
29350
HIRES
HARPS
HARPN
HAMILTON
APF
ELODIE
SOPHIE
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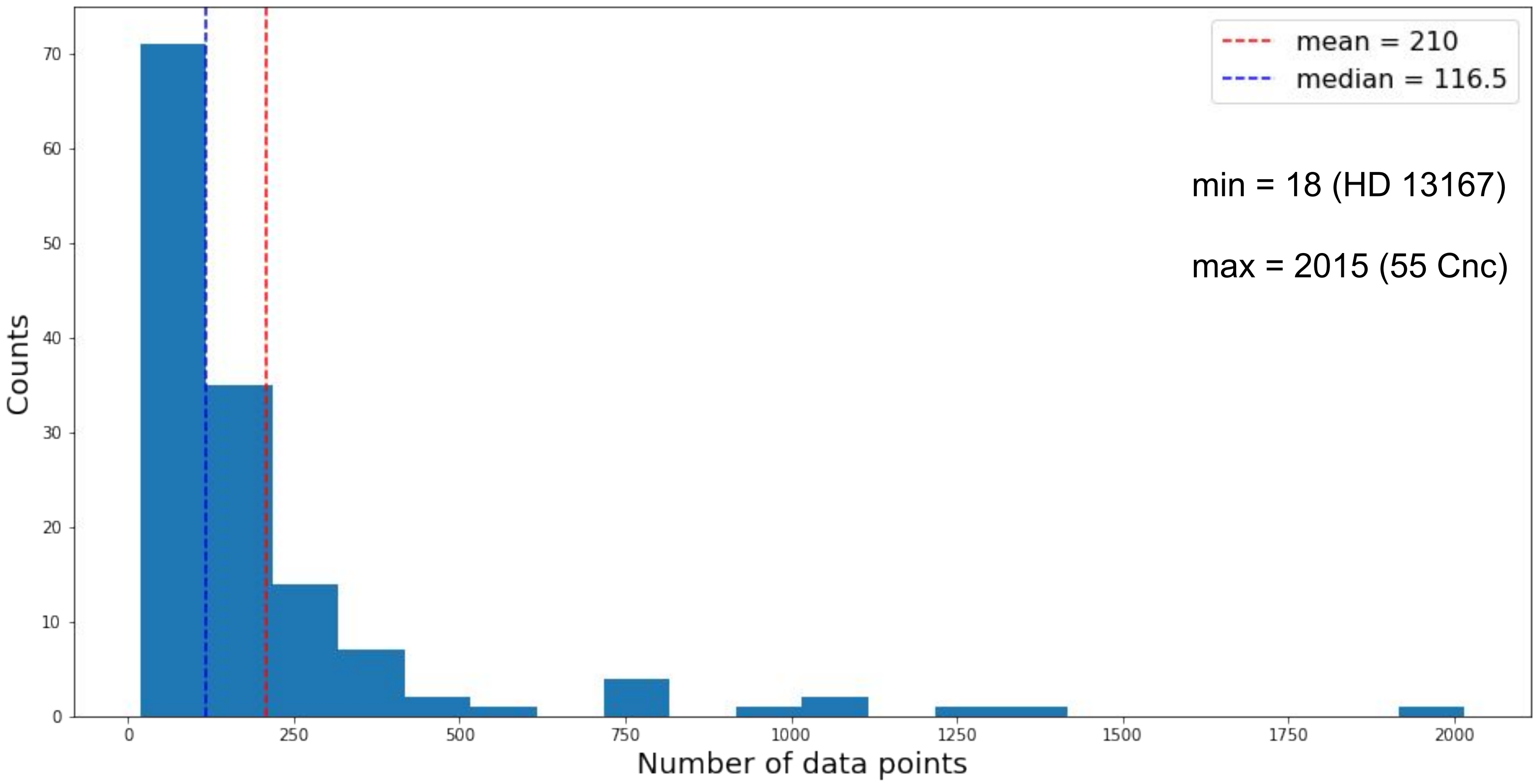
ESPRESSO
UCLES
MIKE
CORALIE
HJS
TULL
MINERVA
HJST
SARG
HDS
TOT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median = 116.5
min = 18 (HD 13167)
max = 2015 (55 Cnc)
Counts
Number of data points
0
10
20
30
40
50
60
70
0
250
500
750
1000
1250
1500
1750
2000

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

HD 3765: new planet with P = 130 d, msini = 15.3 ± 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 msini = 28.7 ± 3.5 $M_{\oplus}$. Also e ~ 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 ± 5 d and msini = 0.46 ± 0.034 Mjup.

HD 13908: new planet with P = 7700 ± 1500 d, msini = 5.9 ± 0.8 Mjup, and e = 0.35 ± 0.10. Adding a third planet reduces instrumental jitter from 33 to 7 m/s.

HD 10697: new planet with P = 8.1127 ± 0.0006 d, msini = 16.6 ± 2.6 $M_{\oplus}$, and e = 0.18 - 0.12 + 0.15

HD 136925: activity cycle from literature is dubious. New planet with P = 311 ± 0.6 d, msini = 71 ± 9 $M_{\oplus}$, and e = 0.48 - 0.15 + 0.13