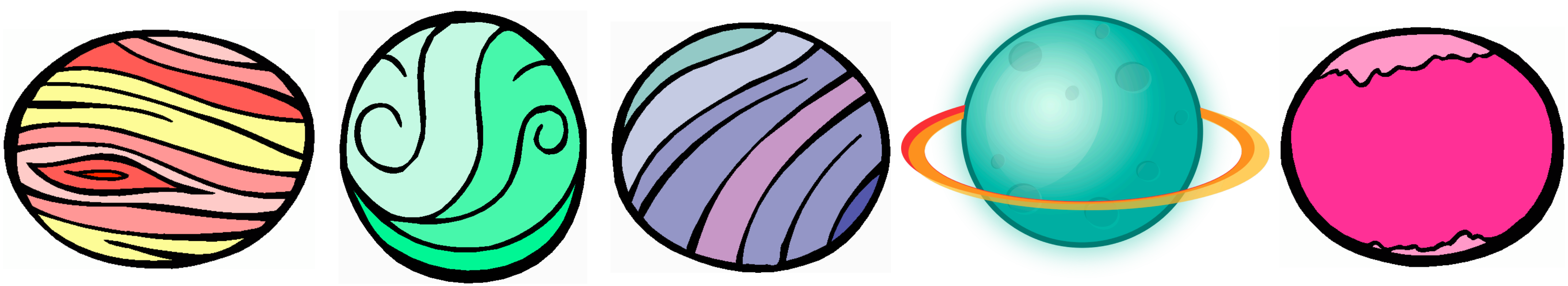
~~TOI-2257b: A hightly eccentric, long period sub-Neptune confirmed by SAINT-EX~~

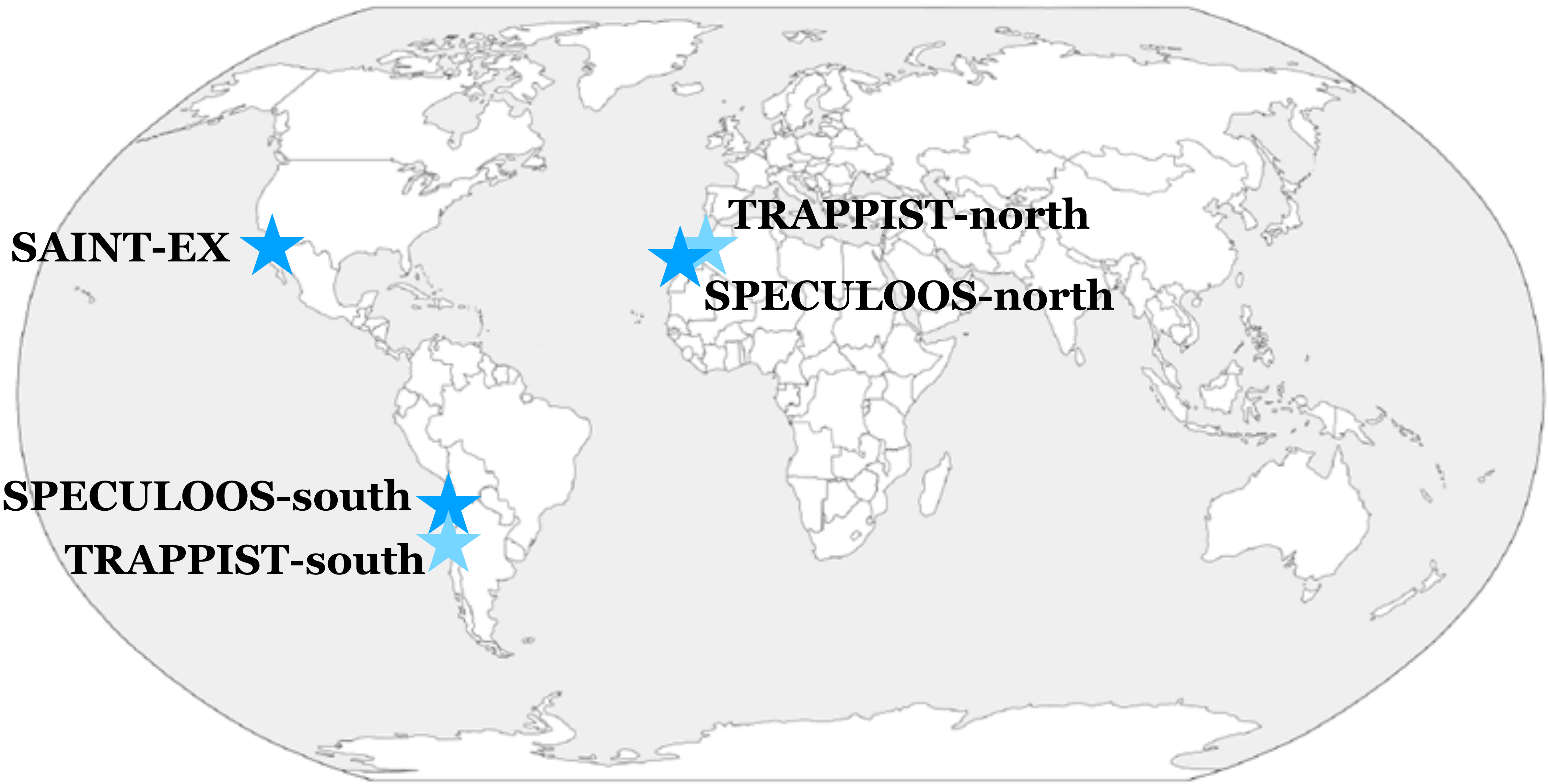
The Diverse Discoveries of SAINT-EX

Nicole Schanche, CSH (Bern)
PlanetS GA,
~~25 Jan, 2022~~
26 April, 2022



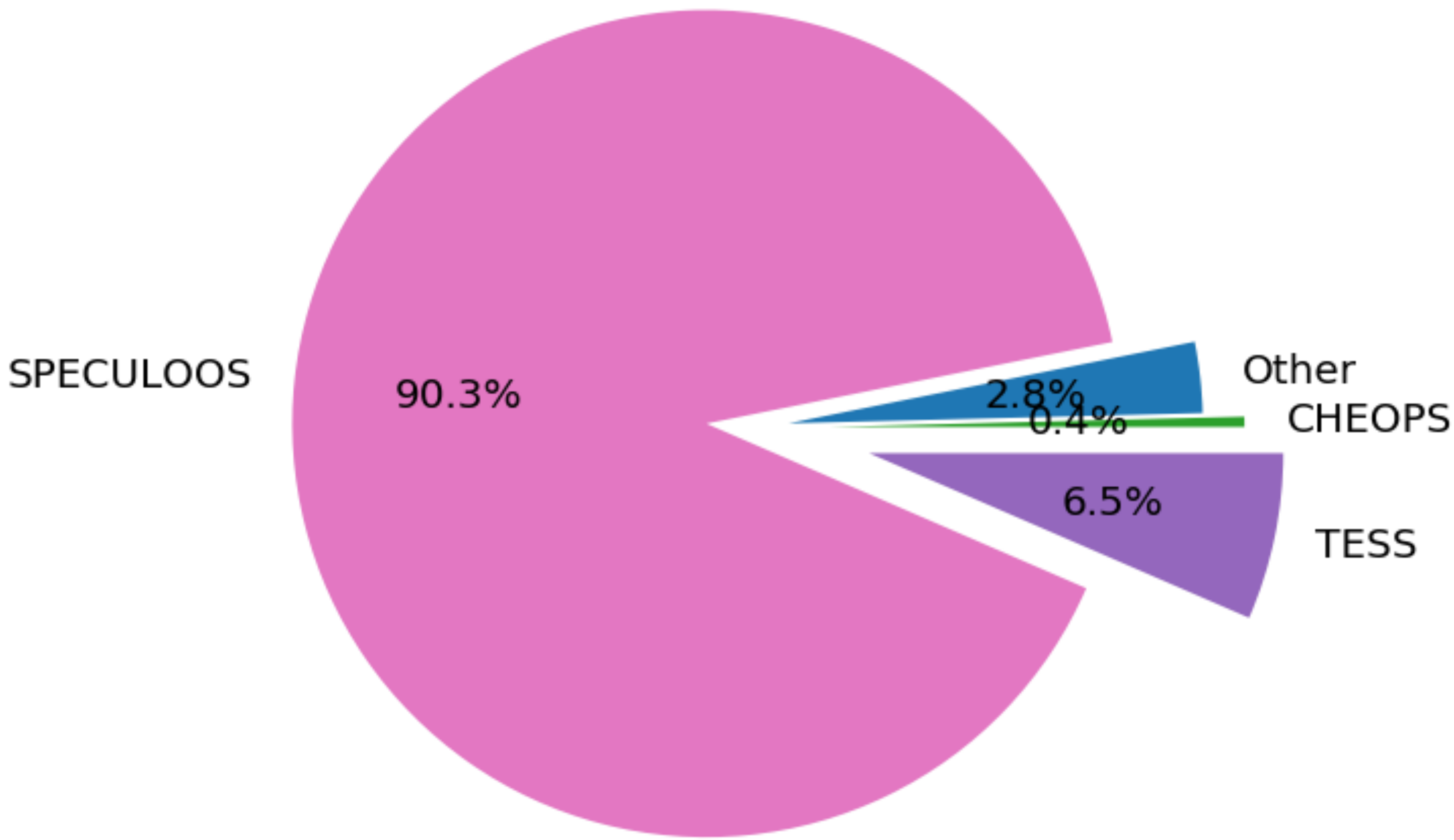
SPECULOOS Group

conducting an exoplanet transit survey targeting a volume-limited (40 pc) sample of ultracool dwarf stars (spectral type M7 and later)

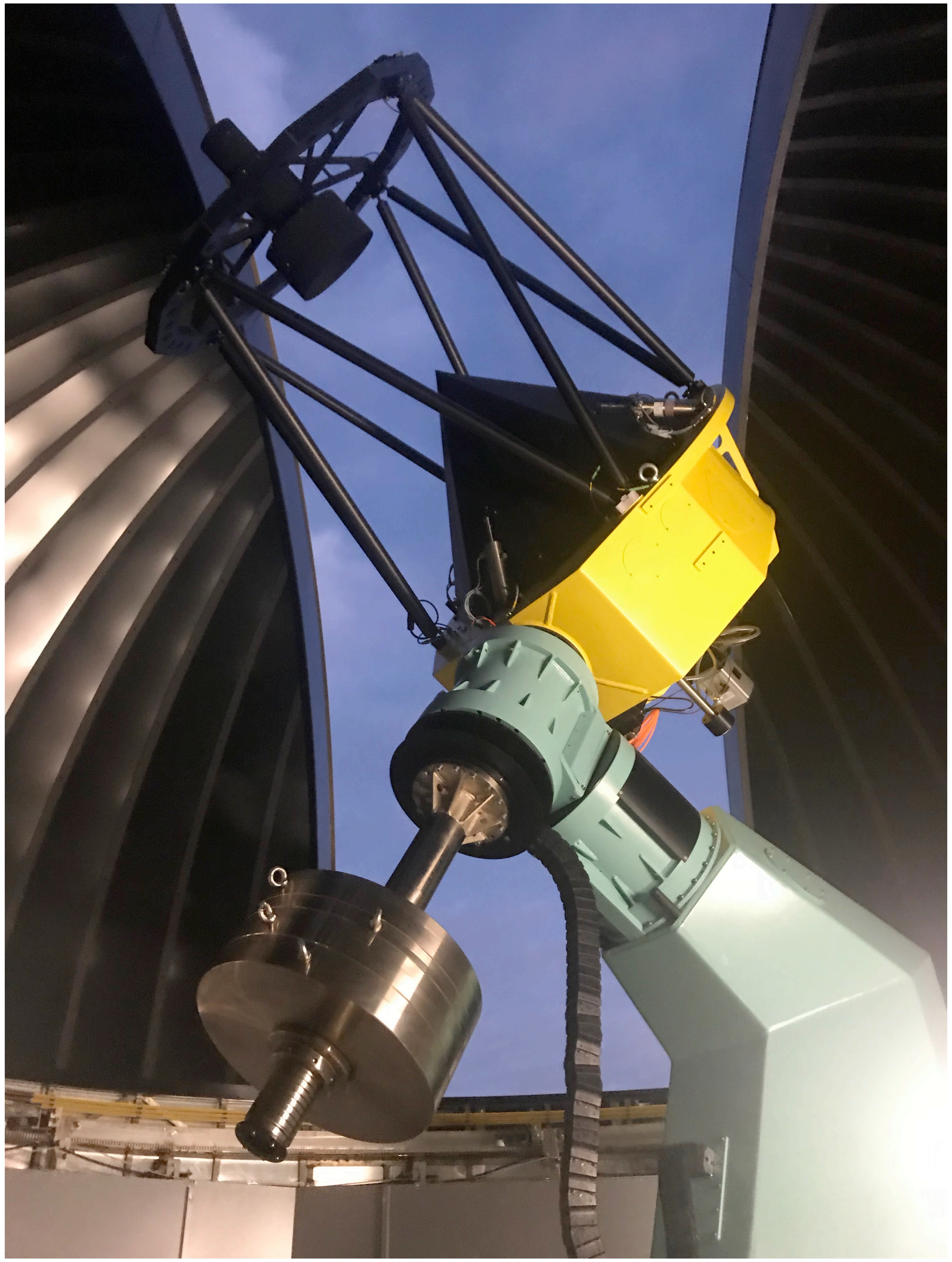


Search And characterIsatioN of Transiting-EXoplanets

First light in January 2019
(Closed for 8 months in 2020 (COVID-19))
~5,000 total hours of observations



SAINT-EX



5 accepted, 7 in prep

A&A 642, A49 (2020)
https://doi.org/10.1051/0004-6361/202038616

Astronomy & Astrophysics

A super-Earth and a sub-Neptune orbiting the bright, quiet M3 dwarf TOI-1266

B.-O. Demory[1], F. J. Pozuelos[2,3], Y. Gómez Maqueo Chew[4], L. Sabin[5], R. Petrucci[4,6,7], U. Schroffenegger[1], S. L. Grimm[1], M. Sestovic[1], M. Gillon[3], J. McCormac[8,9], K. Barkaoui[3,10], W. Benz[1], A. Bieryla[11], F. Bouchy[12], A. Burdanov[13,14], K. A. Collins[11], J. de Wit[13], C. D. Dressing[15], L. J. Garcia[3], S. Giacalone[15], P. Guerra[16], J. Haldemann[1], K. Heng[1,8], E. Jehin[2], E. Jofré[4,6,7], S. R. Kane[17], J. Lillo-Box[18], V. Maigné[1], C. Mordasini[19], B. M. Morris[1], P. Niraula[13], D. Queloz[20], B. V. Rackham[13,21], A. B. Savel[15,22], A. Soubkiou[10], G. Srdoc[23], K. G. Stassun[24], A. H. M. J. Triaud[25], R. Zambelli[26], G. Ricker[21], D. W. Latham[11], S. Seager[13,21,27], J. N. Winn[28], J. M. Jenkins[29], T. Calvario-Velásquez[5], J. A. Franco Herrera[5], E. Colorado[5], E. O. Cadena Zepeda[5], L. Figueroa[5], A. M. Watson[4], E. E. Lugo-Ibarra[5], L. Carigi[4], G. Guisa[5], J. Herrera[5], G. Sierra Díaz[5], J. C. Suárez[30,31], D. Barrado[18], N. M. Batalha[32], Z. Benkhaldoun[10], A. Chontos[33], F. Dai[34], Z. Essack[13,21], M. Ghachoui[10], C. X. Huang[21], D. Huber[33], H. Isaacson[15,35], J. J. Lissauer[29], M. Morales-Calderón[18], P. Robertson[36], A. Roy[34], J. D. Twicken[29,37], A. Vanderburg[38], and L. M. Weiss[33]

A&A 653, A97 (2021)
https://doi.org/10.1051/0004-6361/202141277

Astronomy & Astrophysics

A large sub-Neptune transiting the thick-disk M4 V TOI-2406

R. D. Wells[1], B. V. Rackham[2,3,⋆], N. Schanche[1], R. Petrucci[4,5], Y. Gómez Maqueo Chew[6], B.-O. Demory[1], A. J. Burgasser[7], R. Burn[8], F. J. Pozuelos[9,10], M. N. Günther[3,11,⋆⋆], L. Sabin[12], U. Schroffenegger[1], M. A. Gómez-Muñoz[12], K. G. Stassun[13], V. Van Grootel[10], S. B. Howell[14], D. Sebastian[15], A. H. M. J. Triaud[15], D. Apai[16,17,⋆⋆⋆], I. Plauchu-Frayn[12], C. A. Guerrero[12], P. F. Guillén[12], A. Landa[12], G. Melgoza[12], F. Montalvo[12], H. Serrano[12], H. Riesgo[12], K. Barkaoui[9,18], A. Bixel[16], A. Burdanov[2], W. P. Chen[19], P. Chinchilla[9,20], K. A. Collins[21], T. Daylan[3,11,⋆⋆⋆⋆], J. de Wit[2], L. Delrez[9,10], M. Dévora-Pajares[22], J. Dietrich[16], G. Dransfield[15], E. Ducrot[9], M. Fausnaugh[3,11], E. Furlan[23], P. Gabor[24], T. Gan[25], L. Garcia[9], M. Ghachoui[18], S. Giacalone[26], A. B. Gibbs[27], M. Gillon[9], C. Gnilka[14], R. Gore[26], N. Guerrero[3,11], T. Henning[8], K. Hesse[3,11], E. Jehin[10], J. M. Jenkins[14], D. W. Latham[21], K. Lester[14], J. McCormac[28], C. A. Murray[29], P. Niraula[2], P. P. Pedersen[29], D. Queloz[29], G. Ricker[3,11], D. R. Rodriguez[30], A. Schroeder[26], R. P. Schwarz[31], N. Scott[14], S. Seager[2,3,11,32], C. A. Theissen[7,⋆⋆⋆⋆⋆], S. Thompson[29], M. Timmermans[9], J. D. Twicken[33,14], and J. N. Winn[34]

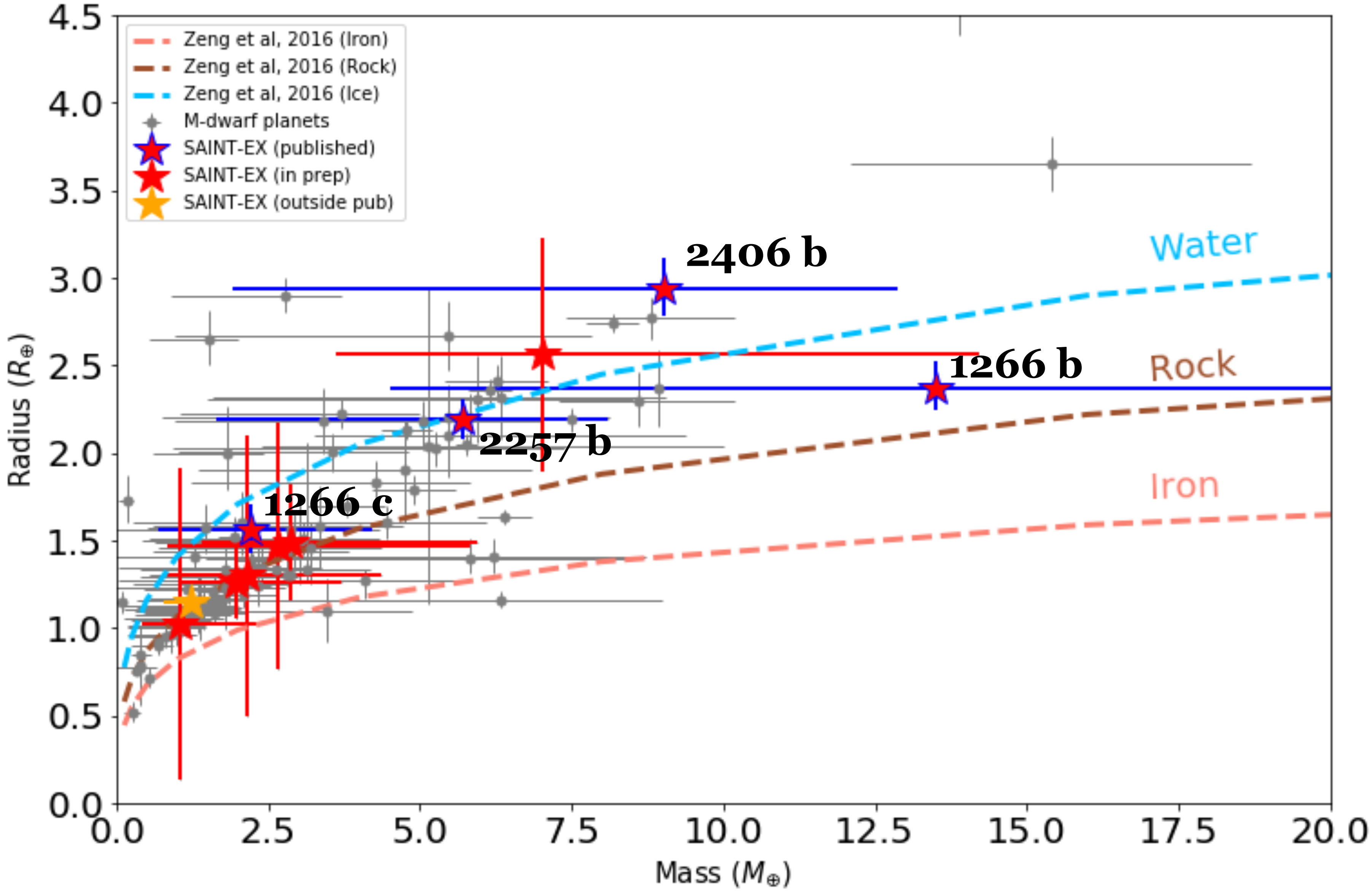
A&A 657, A45 (2022)
https://doi.org/10.1051/0004-6361/202142280

Astronomy & Astrophysics

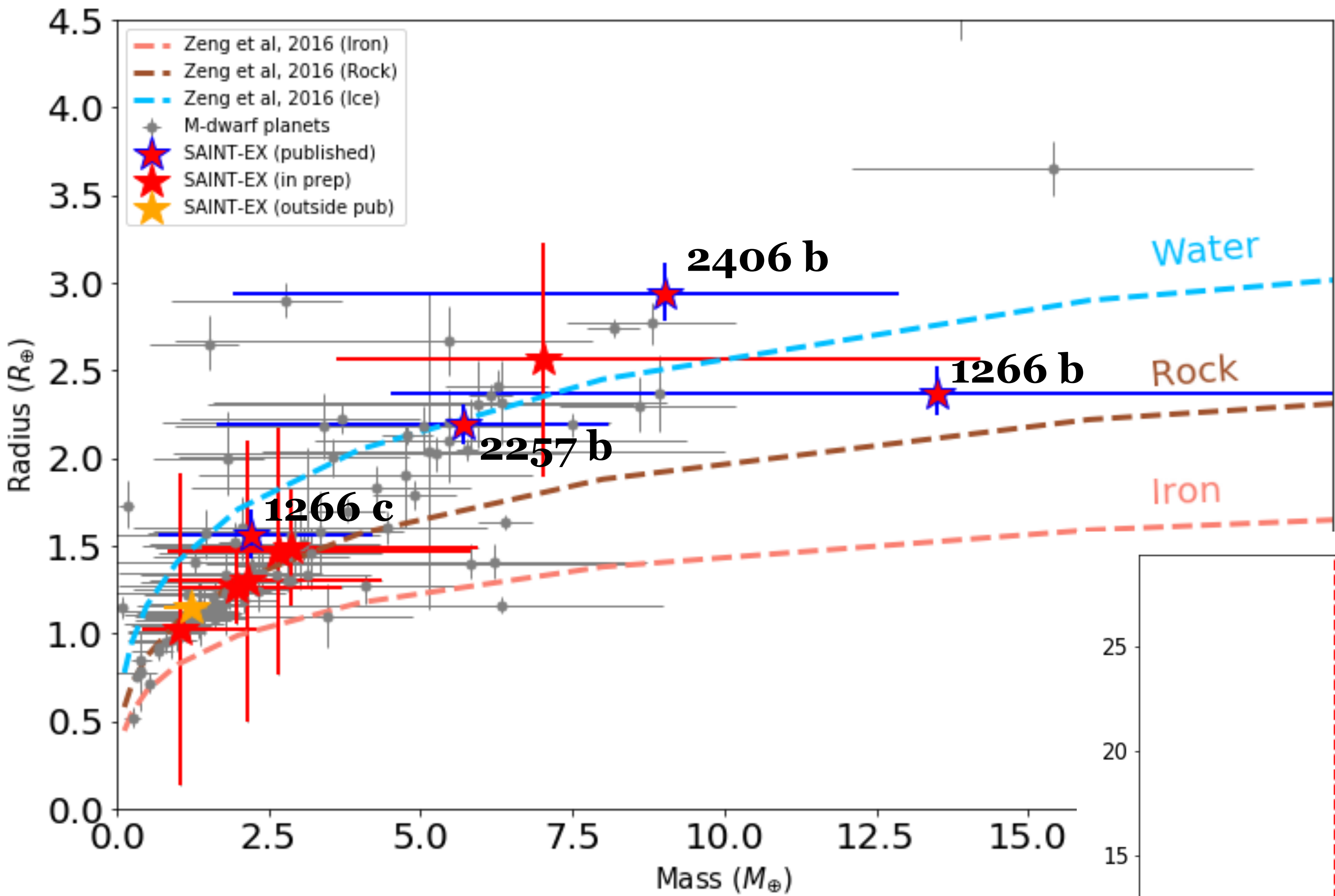
TOI-2257 b: A highly eccentric long-period sub-Neptune transiting a nearby M dwarf

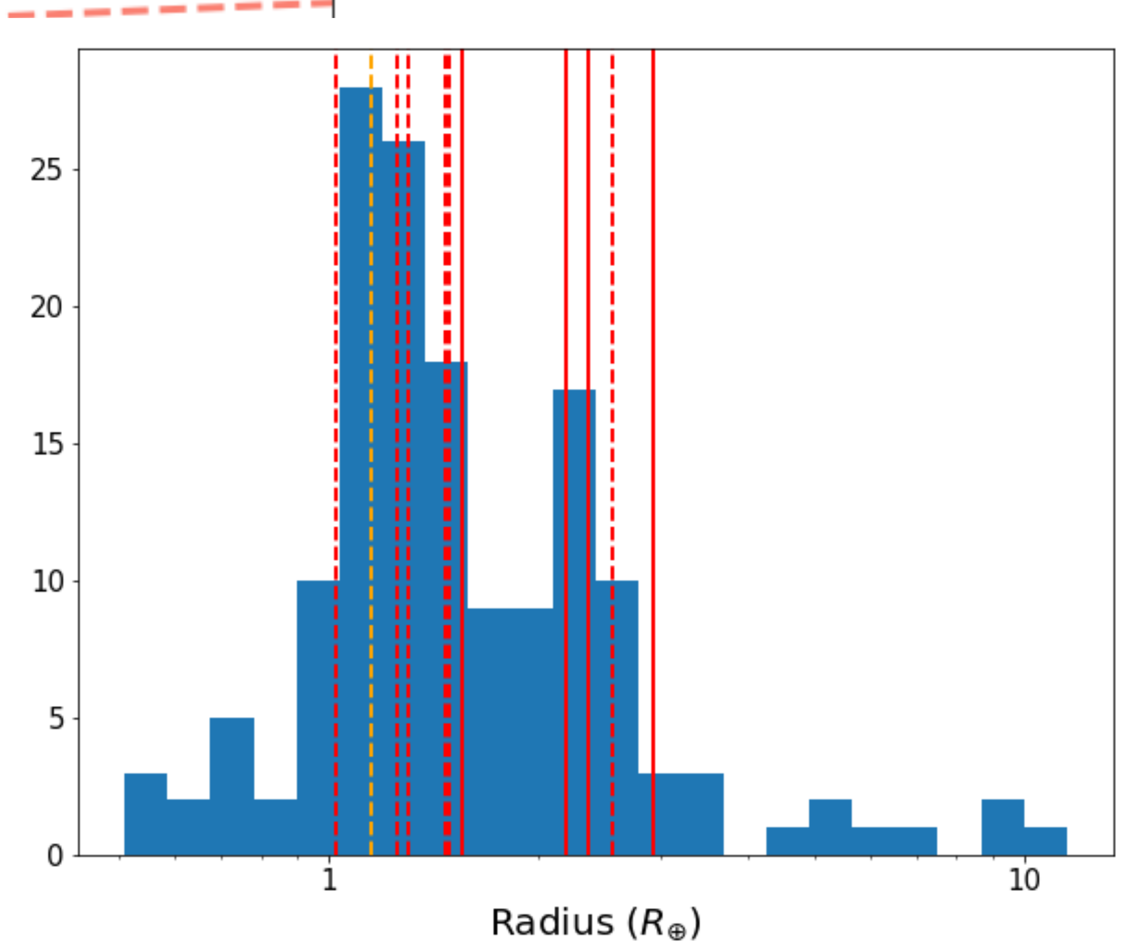
N. Schanche[1], F. J. Pozuelos[2,3], M. N. Günther[4,5,⋆,⋆⋆], R. D. Wells[1], A. J. Burgasser[6], P. Chinchilla[2,7], L. Delrez[2,3], E. Ducrot[2], L. J. Garcia[2], Y. Gómez Maqueo Chew[8], E. Jofré[8,9,10], B. V. Rackham[11,4,⋆⋆⋆], D. Sebastian[12], K. G. Stassun[13], D. Stern[14], M. Timmermans[2], K. Barkaoui[2,15], A. Belinski[16], Z. Benkhaldoun[15], W. Benz[1,17], A. Bieryla[18], F. Bouchy[19], A. Burdanov[11], D. Charbonneau[18], J. L. Christiansen[20], K. A. Collins[18], B.-O. Demory[1], M. Dévora-Pajares[21], J. de Wit[11], D. Dragomir[22], G. Dransfield[12], E. Furlan[23], M. Ghachoui[2,15], M. Gillon[2], C. Gnilka[24], M. A. Gómez-Muñoz[25], N. Guerrero[26,4], M. Harris[22], K. Heng[1,27], C. E. Henze[24], K. Hesse[4], S. B. Howell[24], E. Jehin[3], J. Jenkins[24], E. L. N. Jensen[28], M. Kunimoto[4], D. W. Latham[18], K. Lester[24], K. K. McLeod[29], I. Mireles[22], C. A. Murray[30], P. Niraula[11], P. P. Pedersen[30], D. Queloz[30], E. V. Quintana[31], G. Ricker[4], A. Rudat[4], L. Sabin[25], B. Safonov[16], U. Schroffenegger[1], N. Scott[24], S. Seager[4,11,32], I. Strakhov[16], A. H. M. J. Triaud[12], R. Vanderspek[4], M. Vezie[4], and J. Winn[33]

Straddling the radius gap

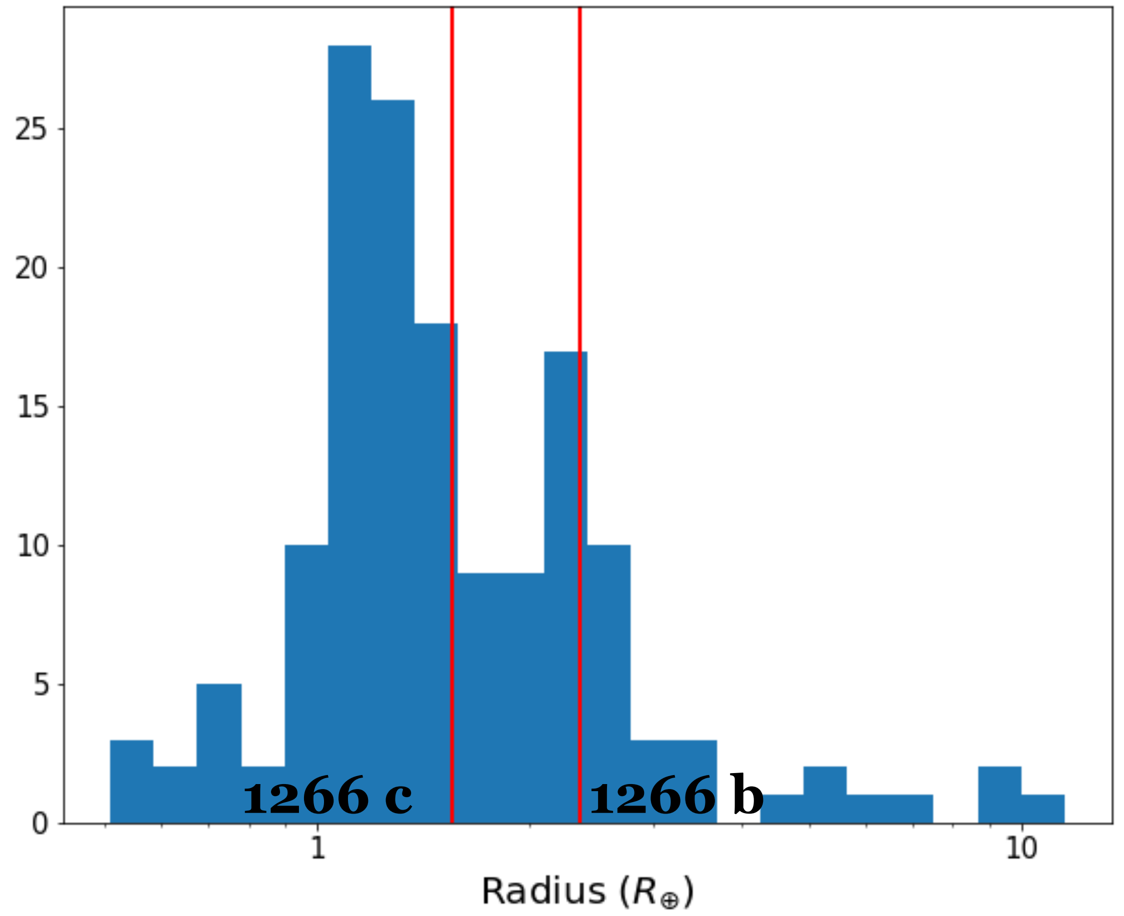


Straddling the radius gap

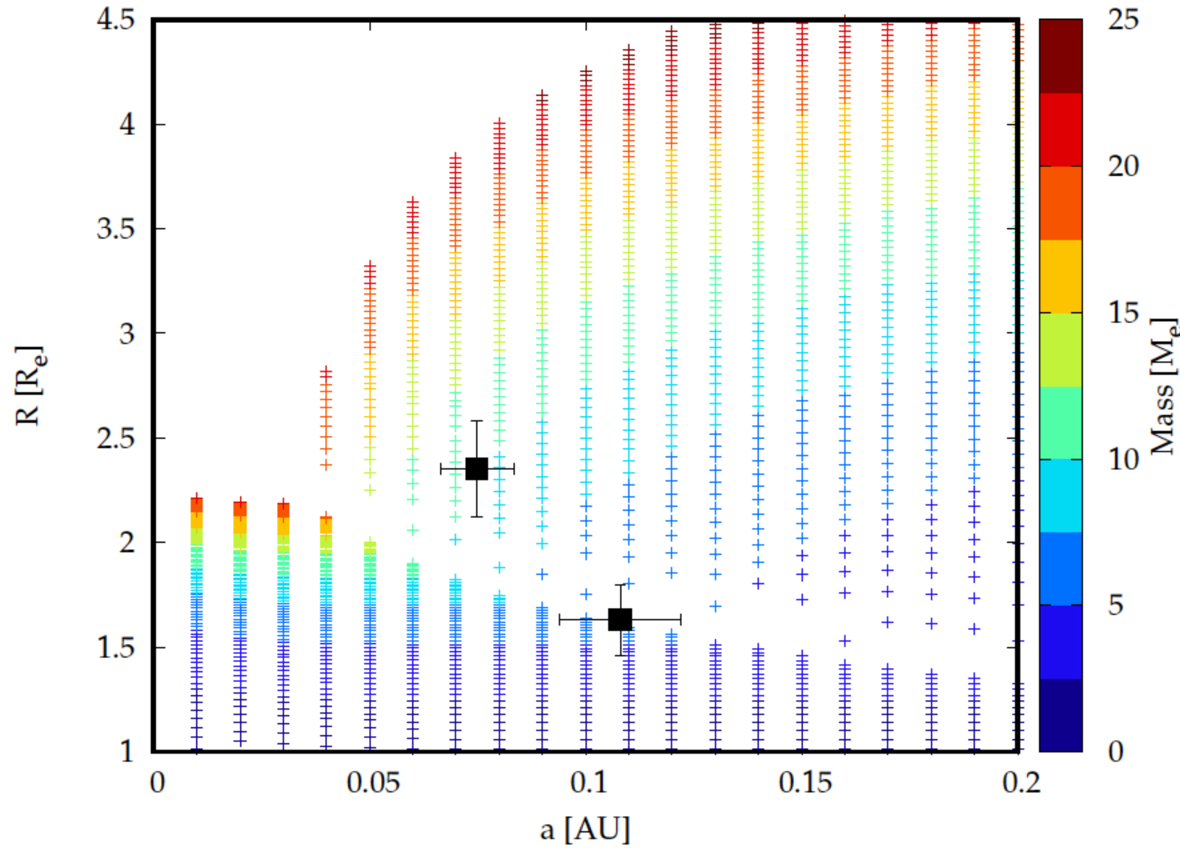




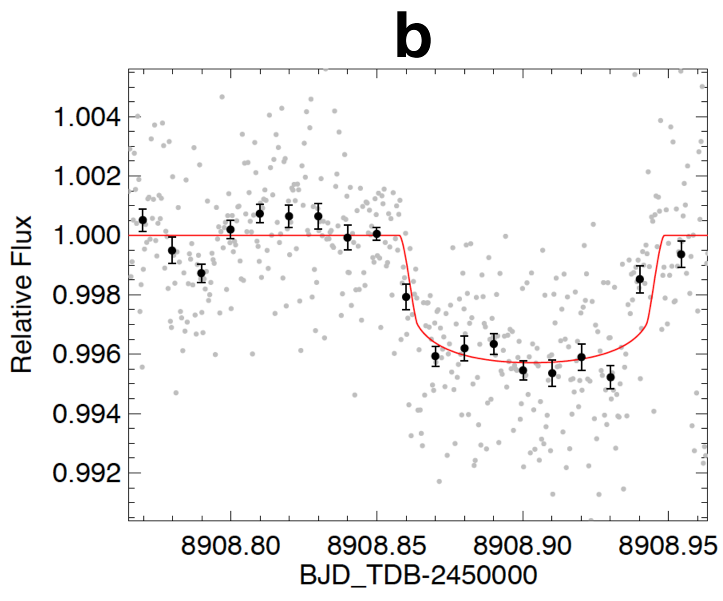
TOI-1266



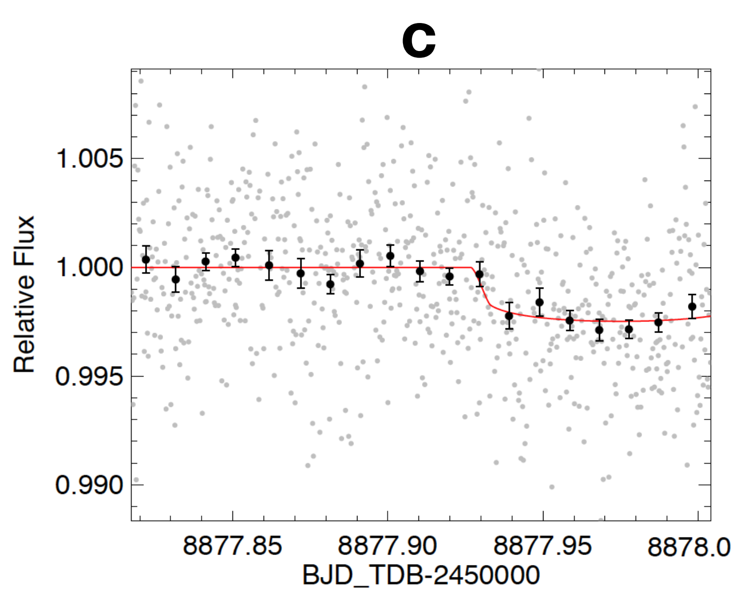
1266 c
1266 b
Radius ($R_\oplus$)



R [R$_e$]
a [AU]
Mass [M$_e$]

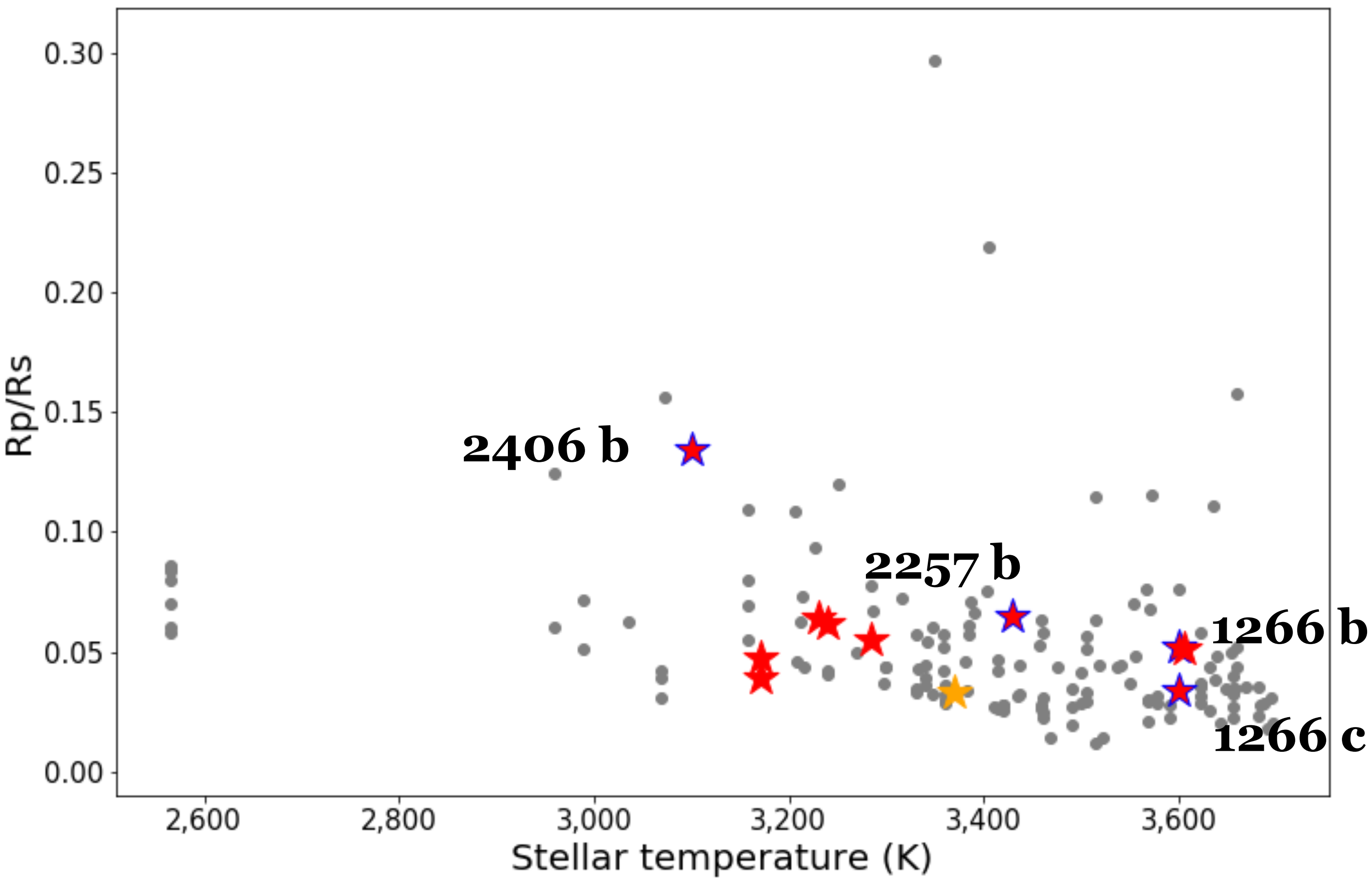


b
Relative Flux
BJD_TDB-2450000

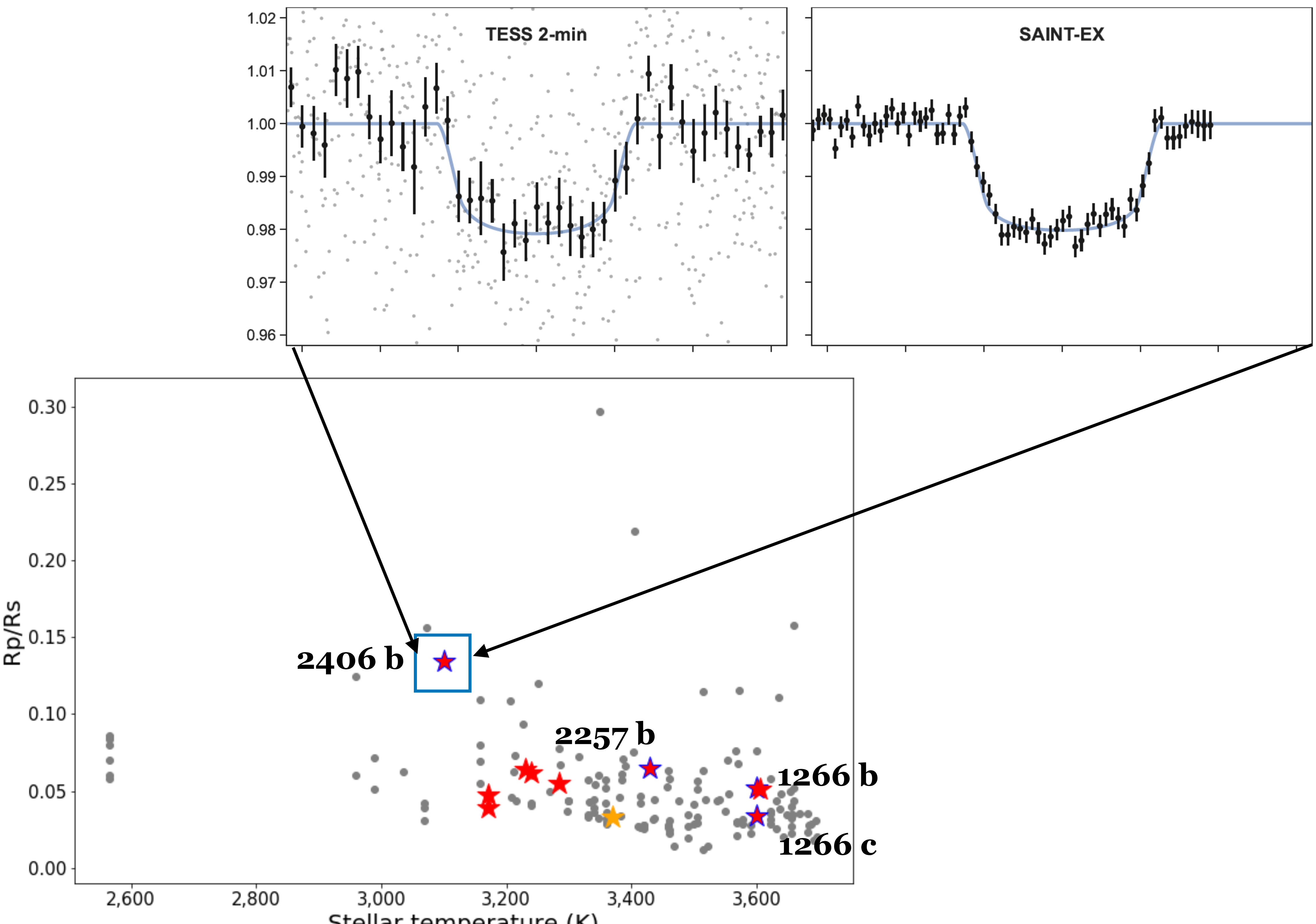


c
Relative Flux
BJD_TDB-2450000

TOI-2406

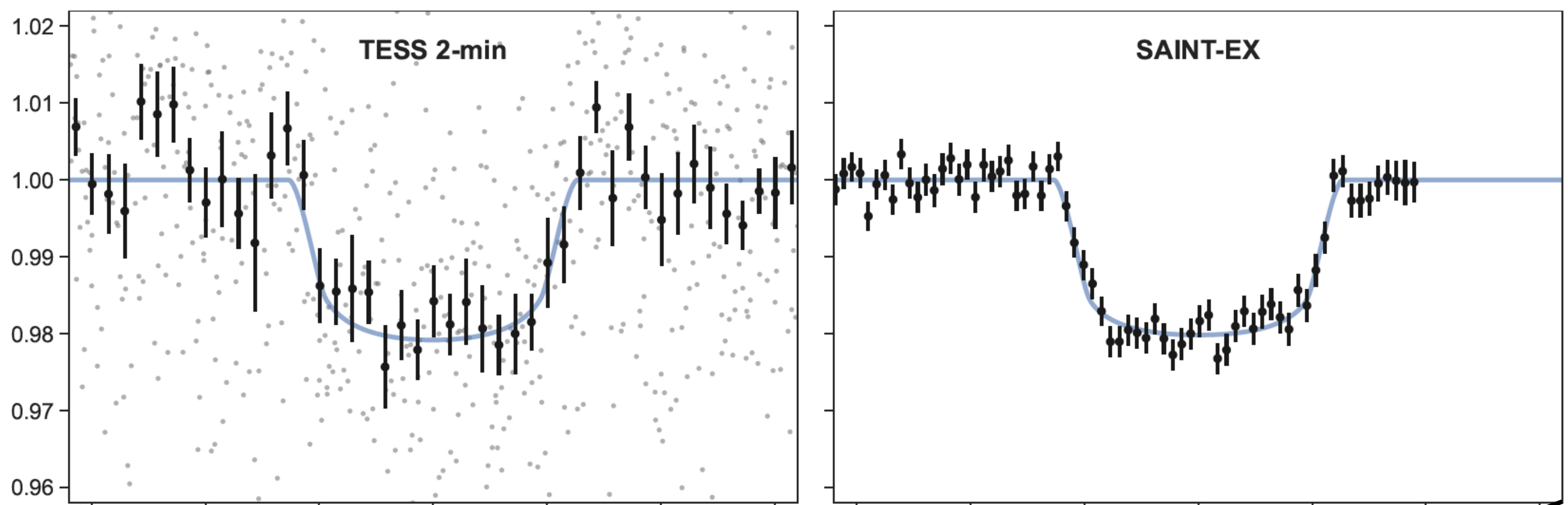

0.30
0.25
0.20
0.15
0.10
0.05
0.00
Rp/Rs
2,600
2,800
3,000
3,200
3,400
3,600
Stellar temperature (K)
2406 b
2257 b
1266 b
1266 c

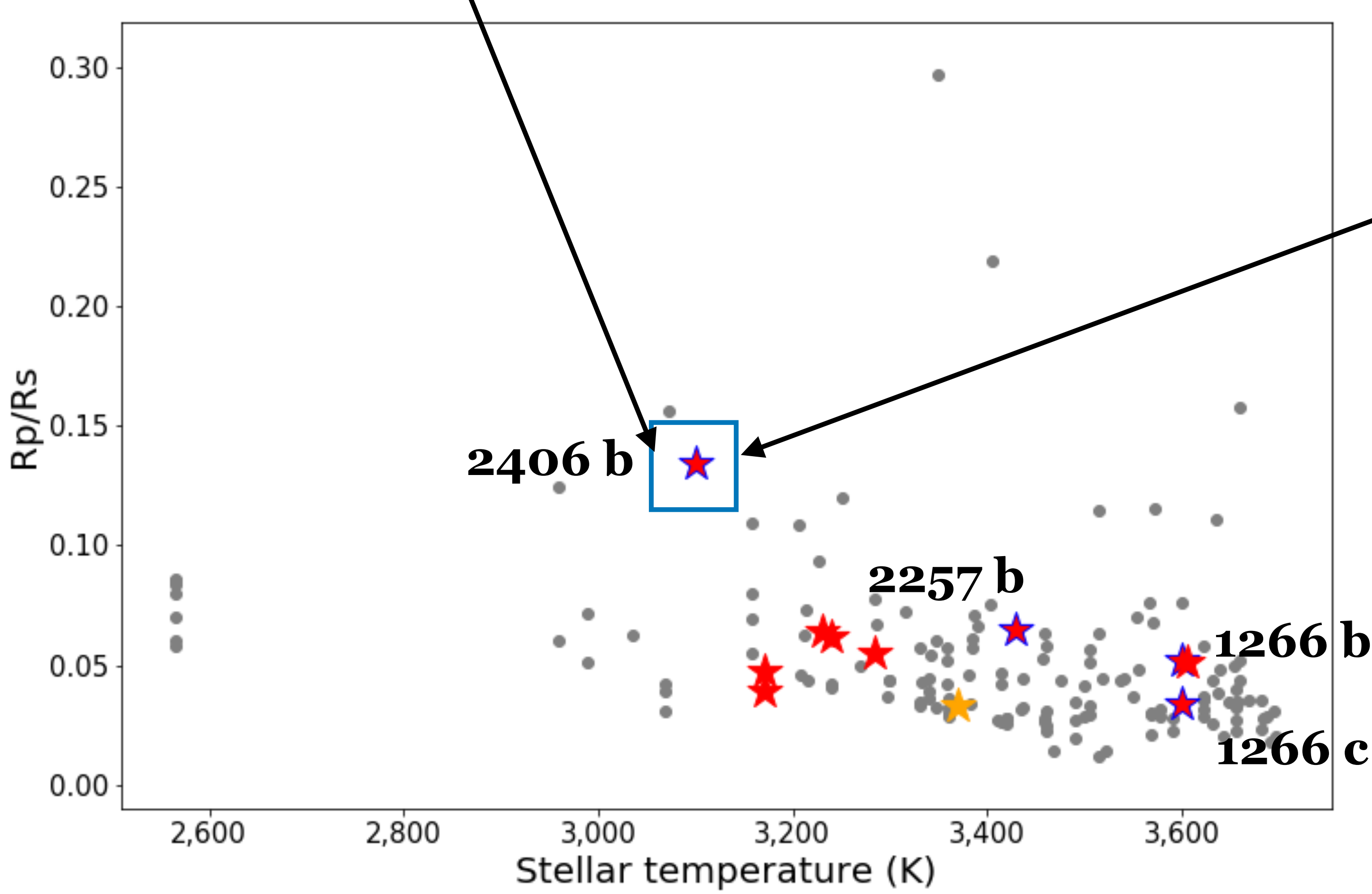
TOI-2406



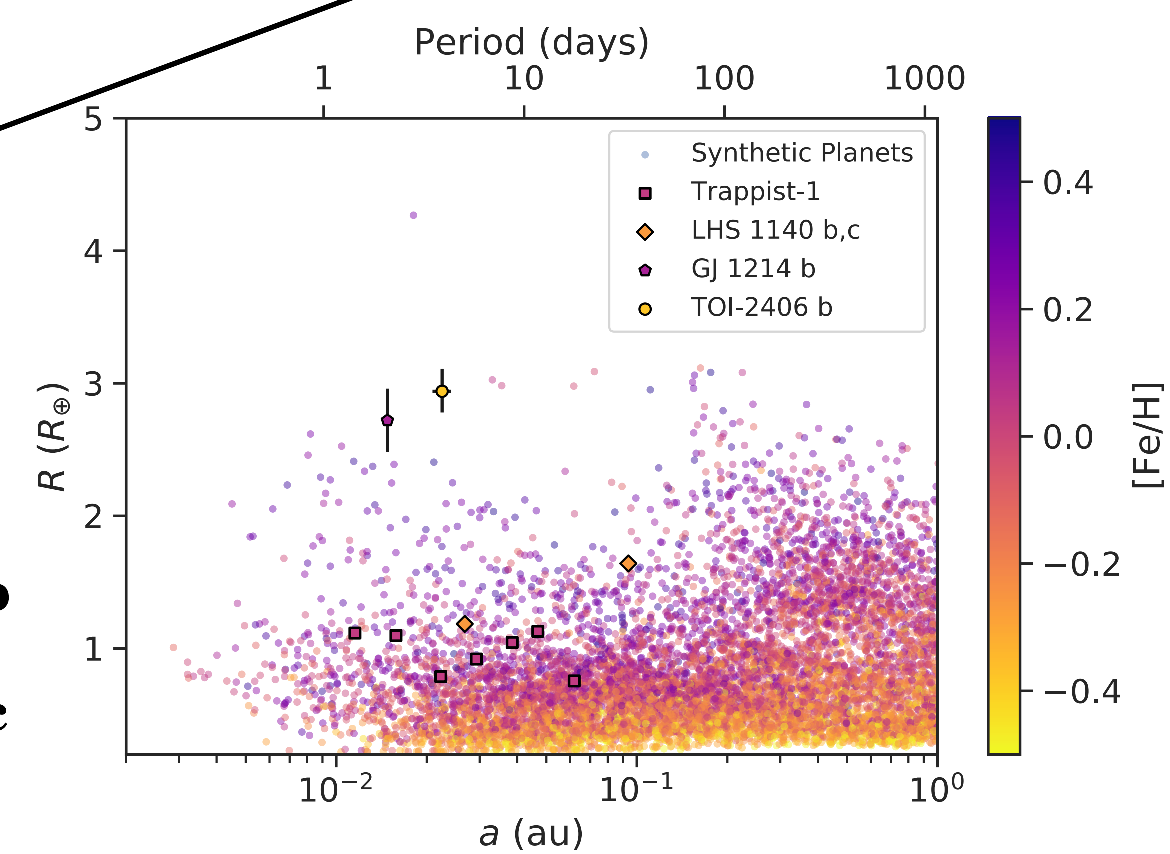
TESS 2-min
SAINT-EX
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Rp/Rs
2406 b
2257 b
1266 b
1266 c
2,600
2,800
3,000
3,200
3,400
3,600
Stellar temperature (K)

TOI-2406

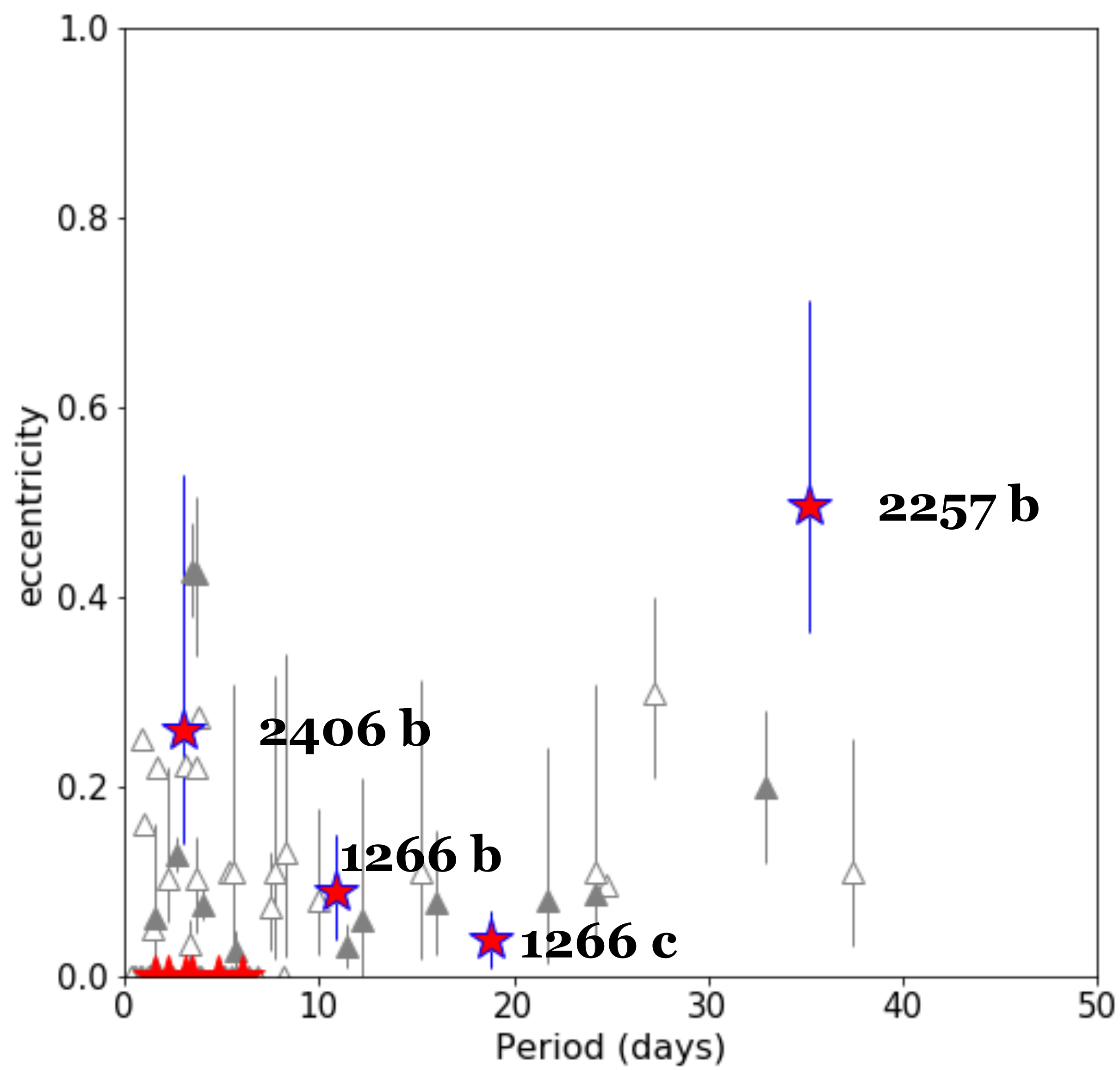




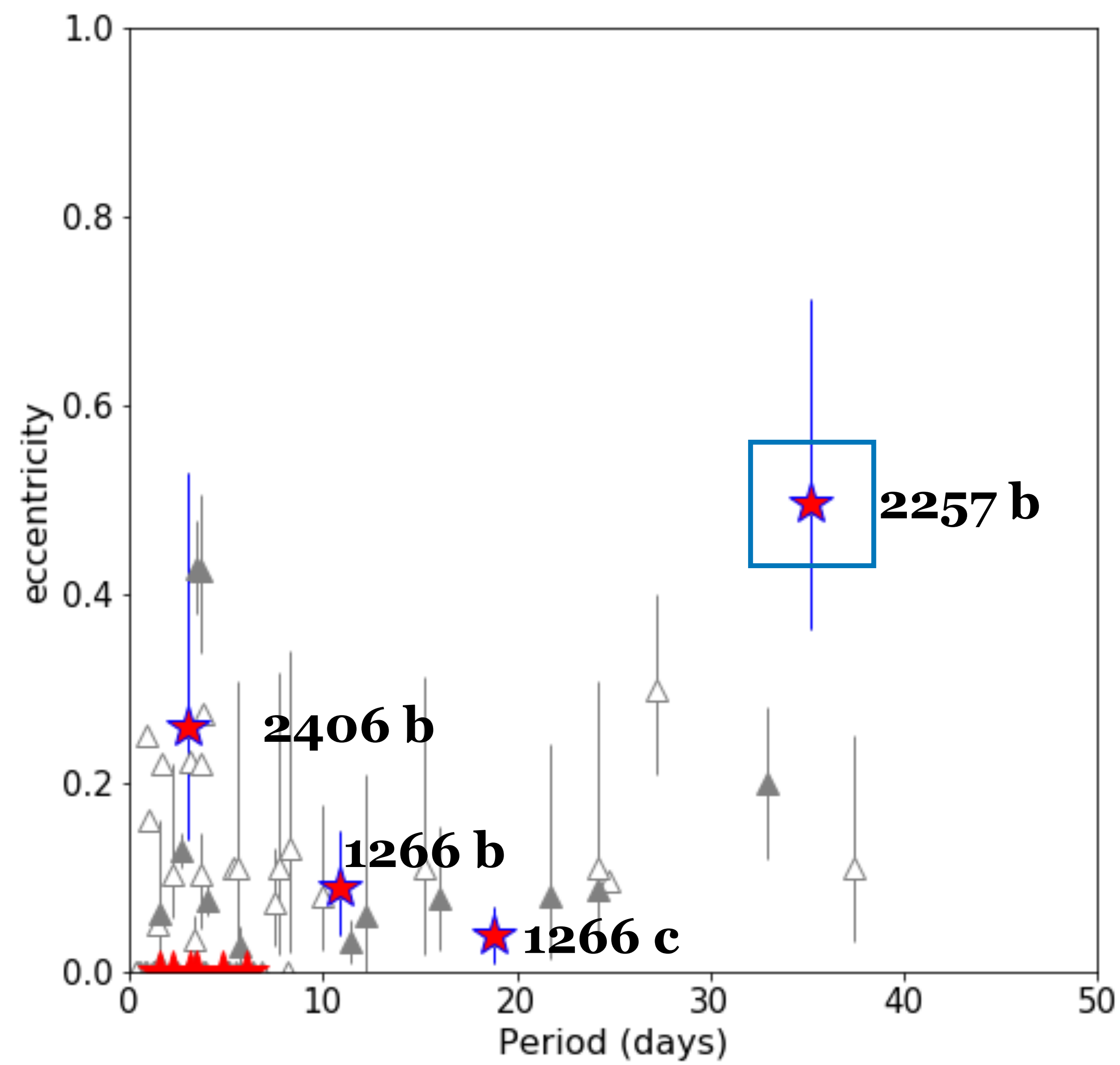
At odds with core accretion?

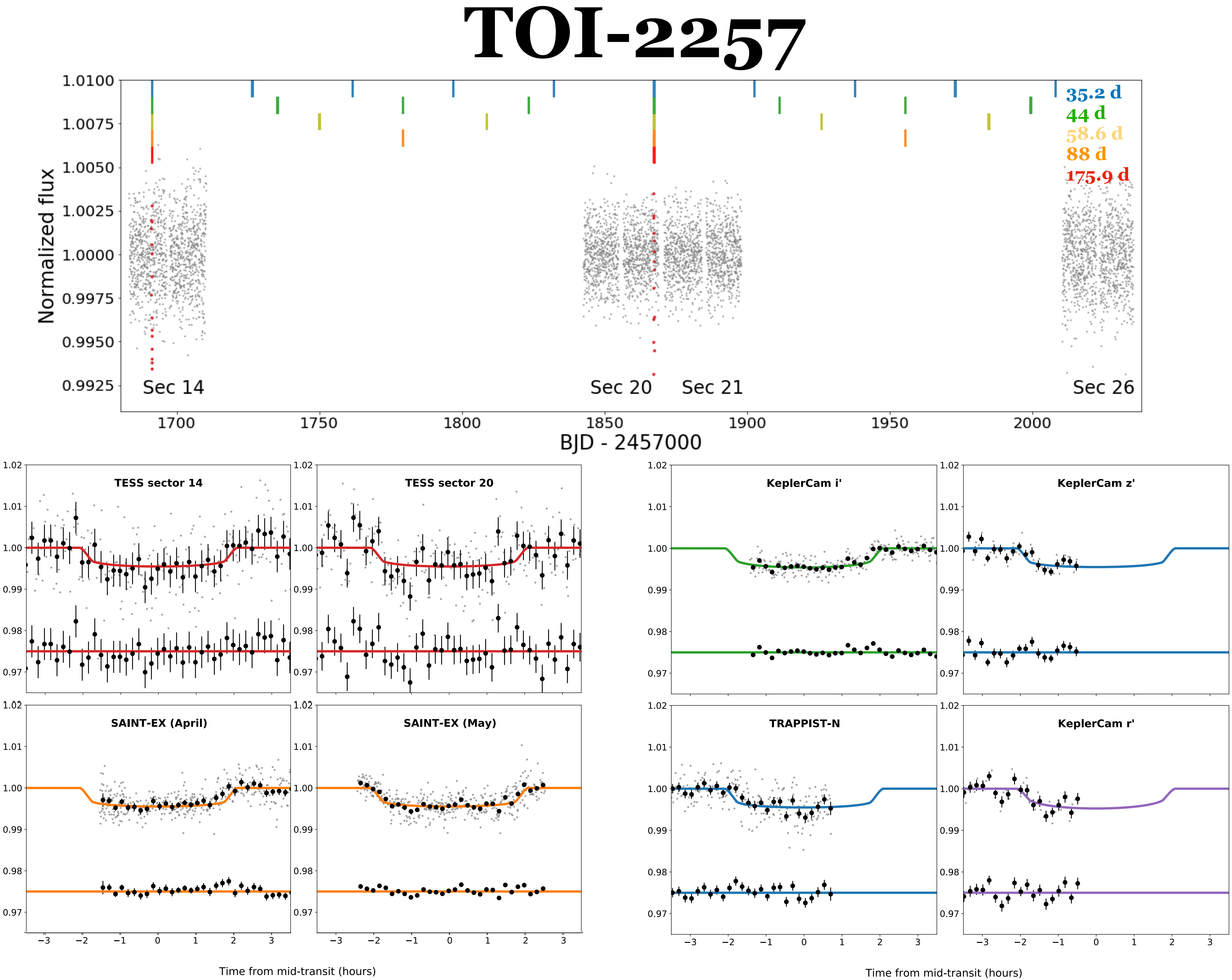


Eccentric mini-Neptunes

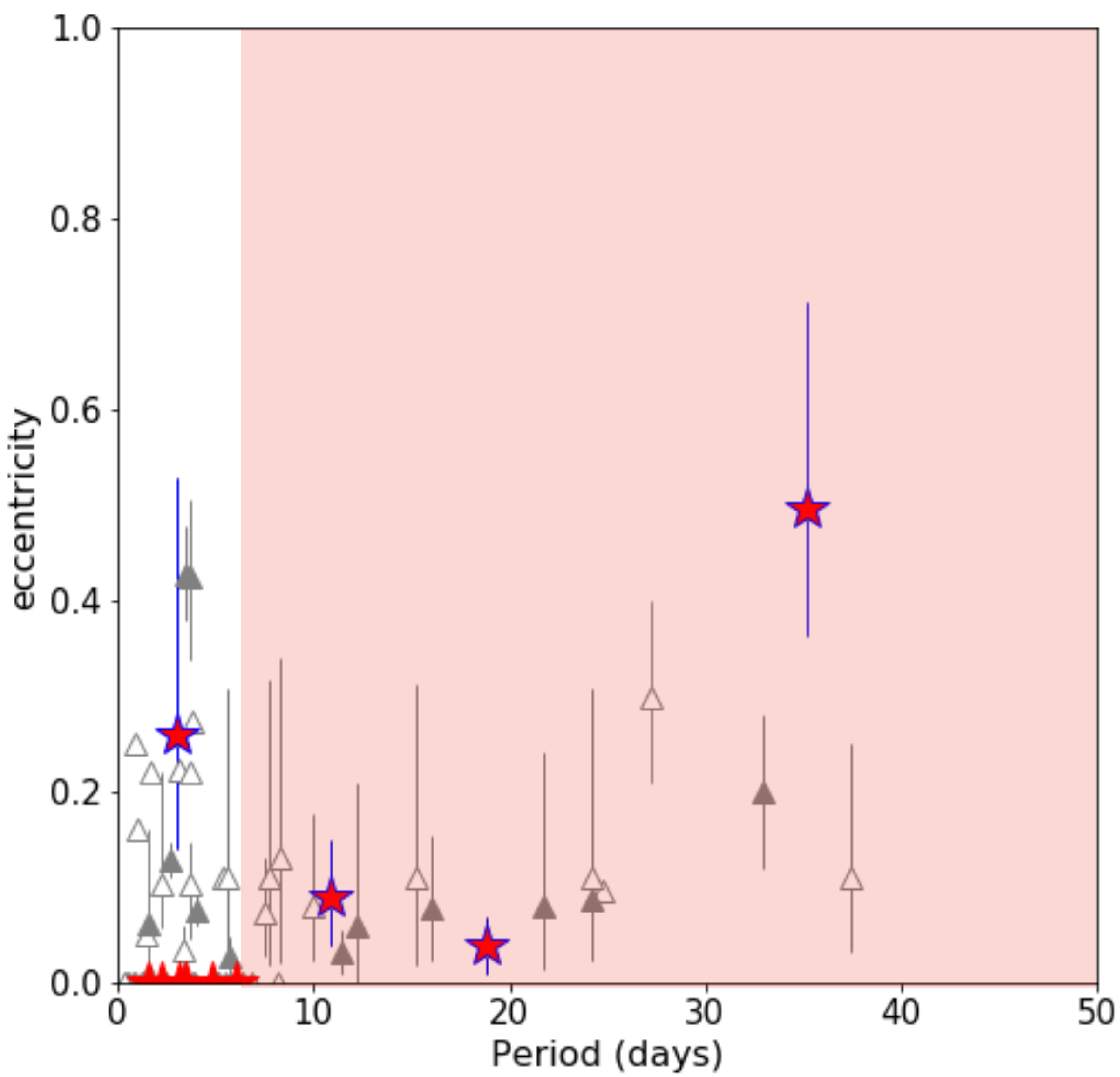


Eccentric mini-Neptunes



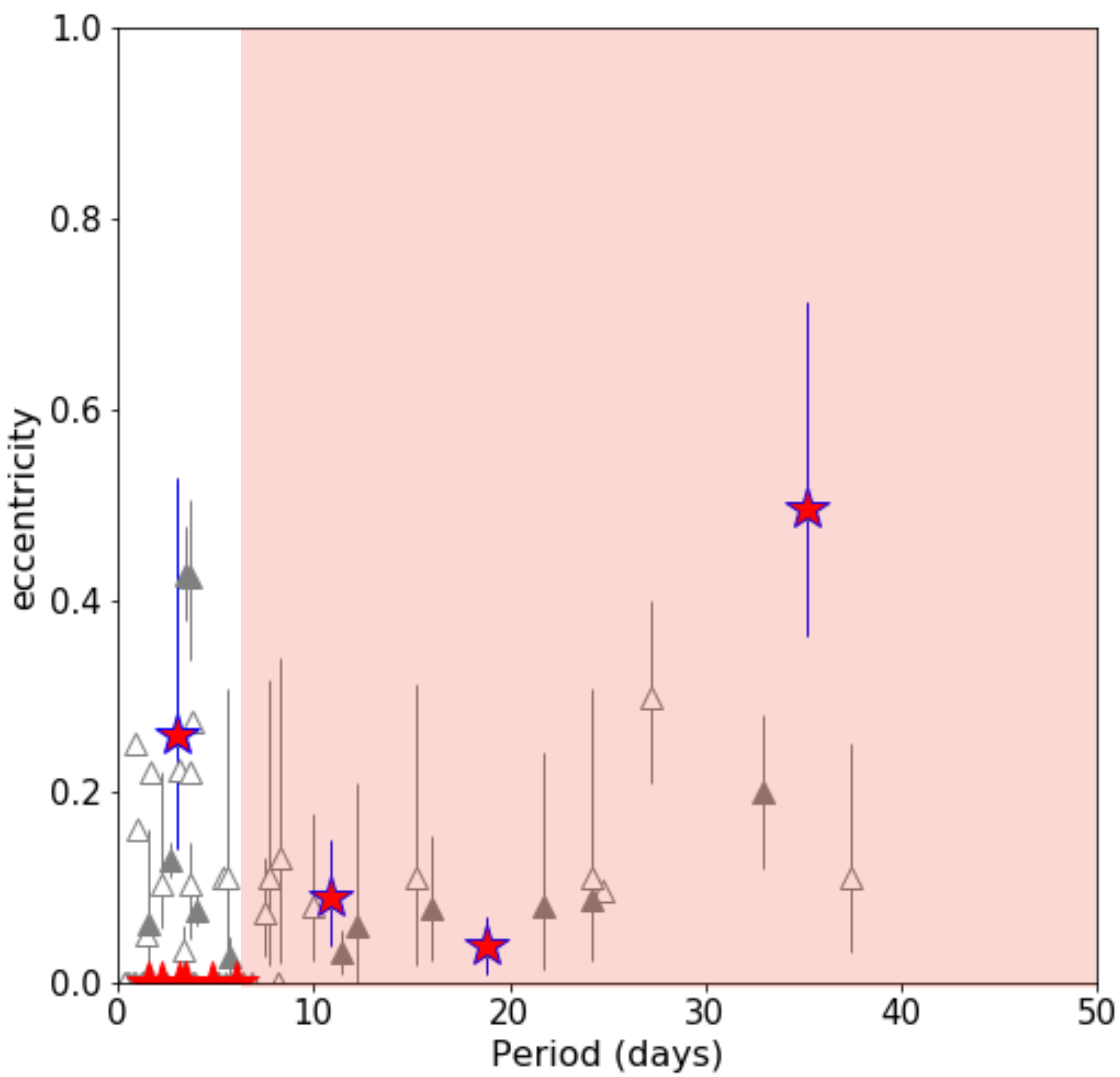

TOI-2257
Normalized flux
BJD - 2457000
35.2 d
44 d
58.6 d
88 d
175.9 d
Sec 14
Sec 20
Sec 21
Sec 26
TESS sector 14
TESS sector 20
KeplerCam i'
KeplerCam z'
SAINT-EX (April)
SAINT-EX (May)
TRAPPIST-N
KeplerCam r'
Time from mid-transit (hours)
Time from mid-transit (hours)

Eccentric mini-Neptunes



Eccentric mini-Neptunes

- Giant planets reduce multiplicity of inner super-Earths
  - Surviving population has larger eccentricities and inclinations (Huang et al, 2017)



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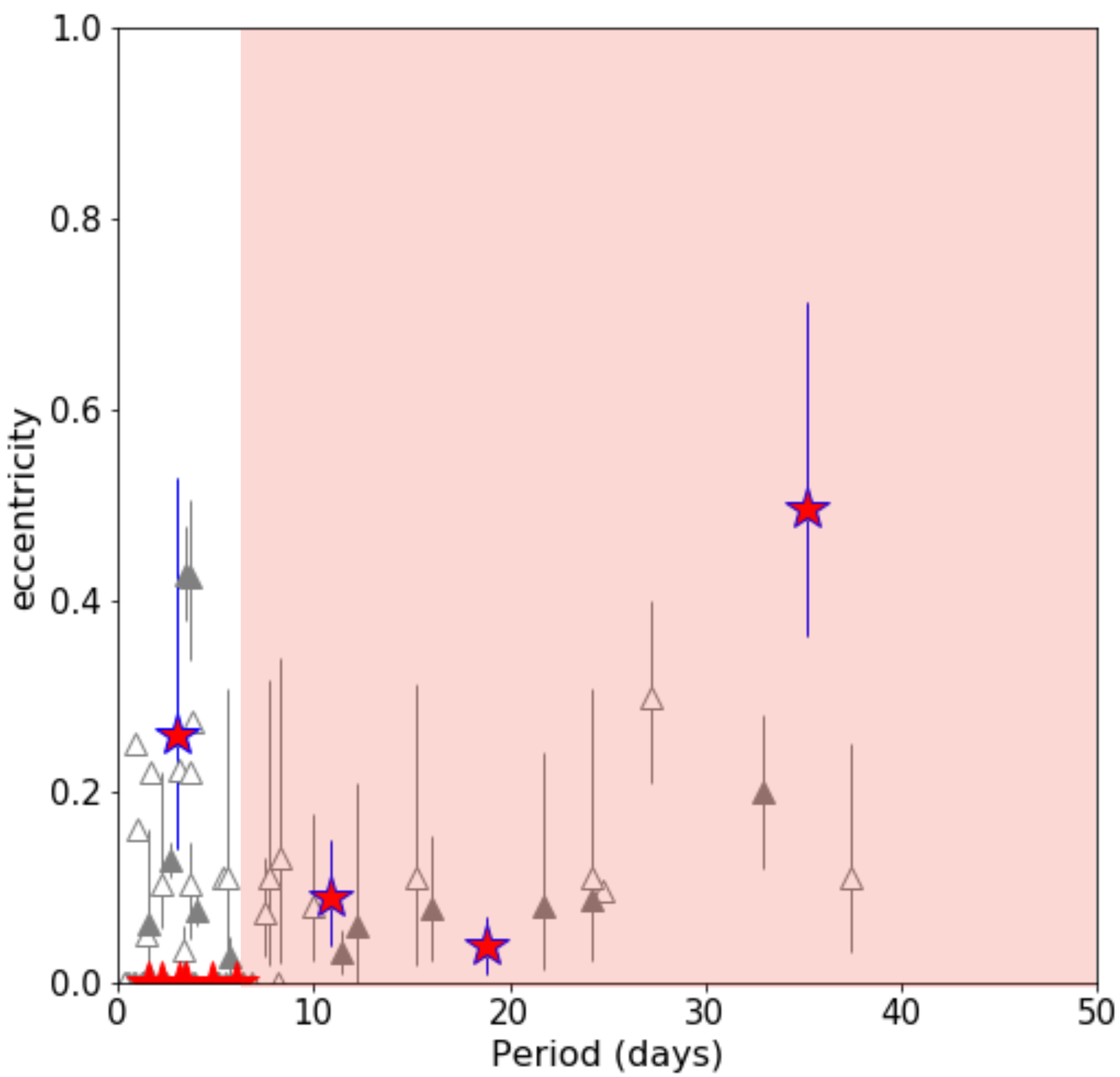
  - does not seem to be related to metallicity (Van Eylen et al, 2019)



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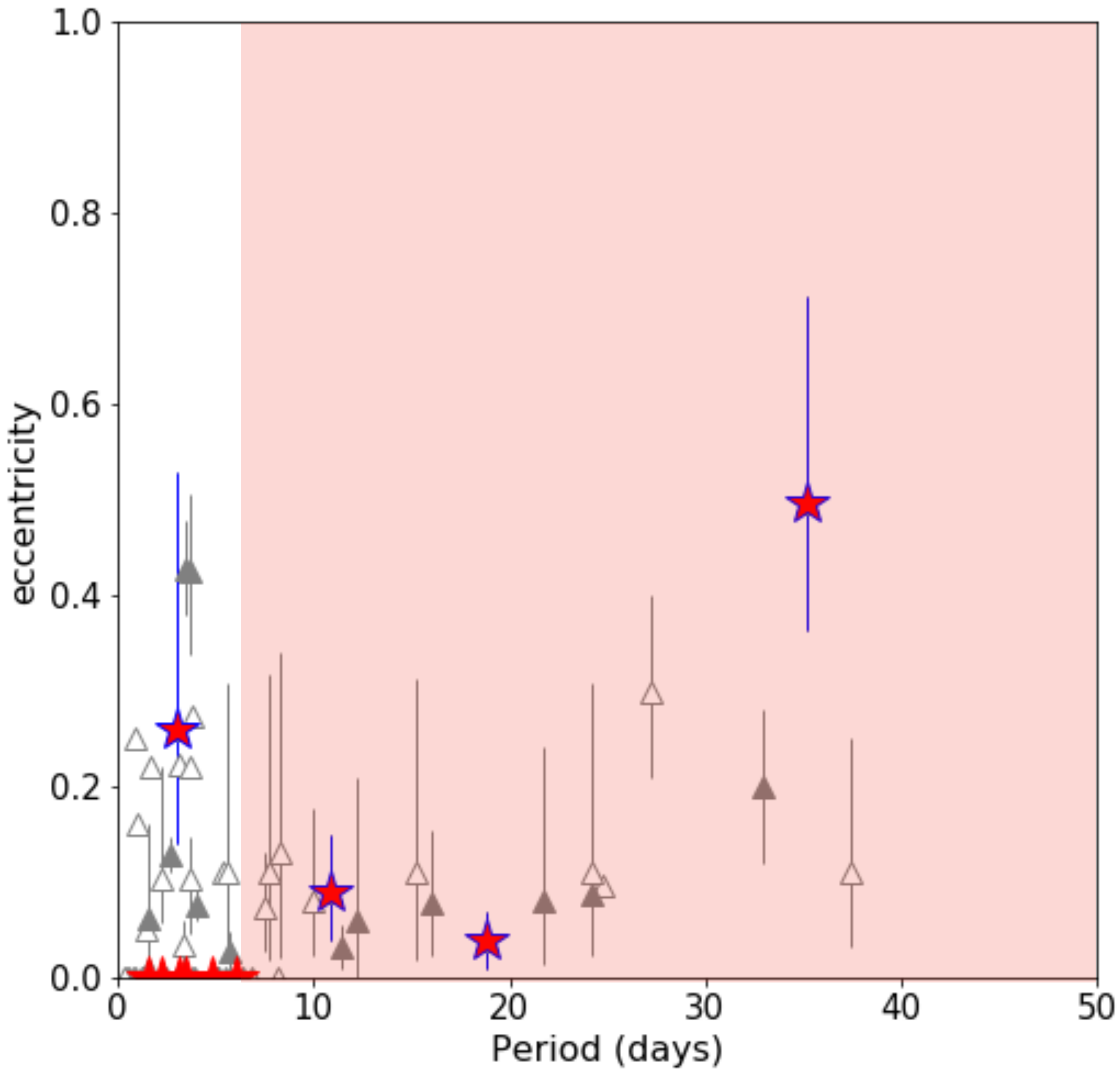
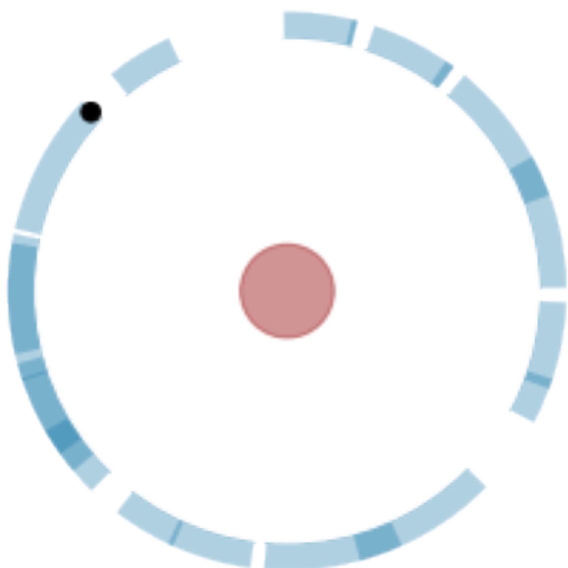
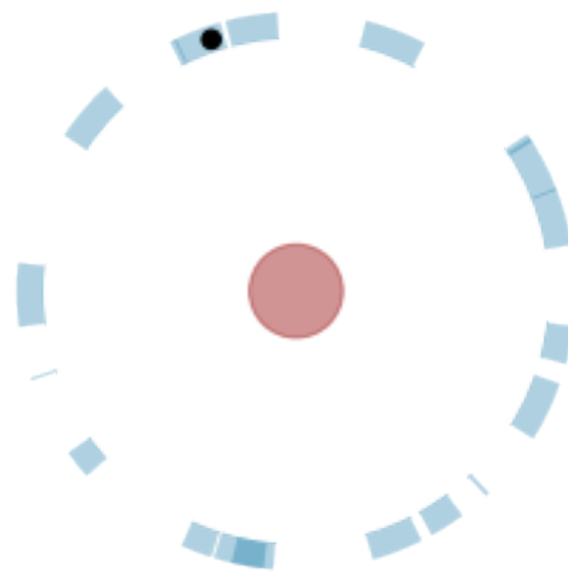
- Single transiting systems are observed to have higher eccentricities
  - does not seem to be related to metallicity (Van Eylen et al, 2019)
- Cold Jupiters tend to be co-planar with inner super-Earths
  - co-planarity is anti-correlated with planet multiplicity (Xie et al, 2016; Masuda et al, 2020)



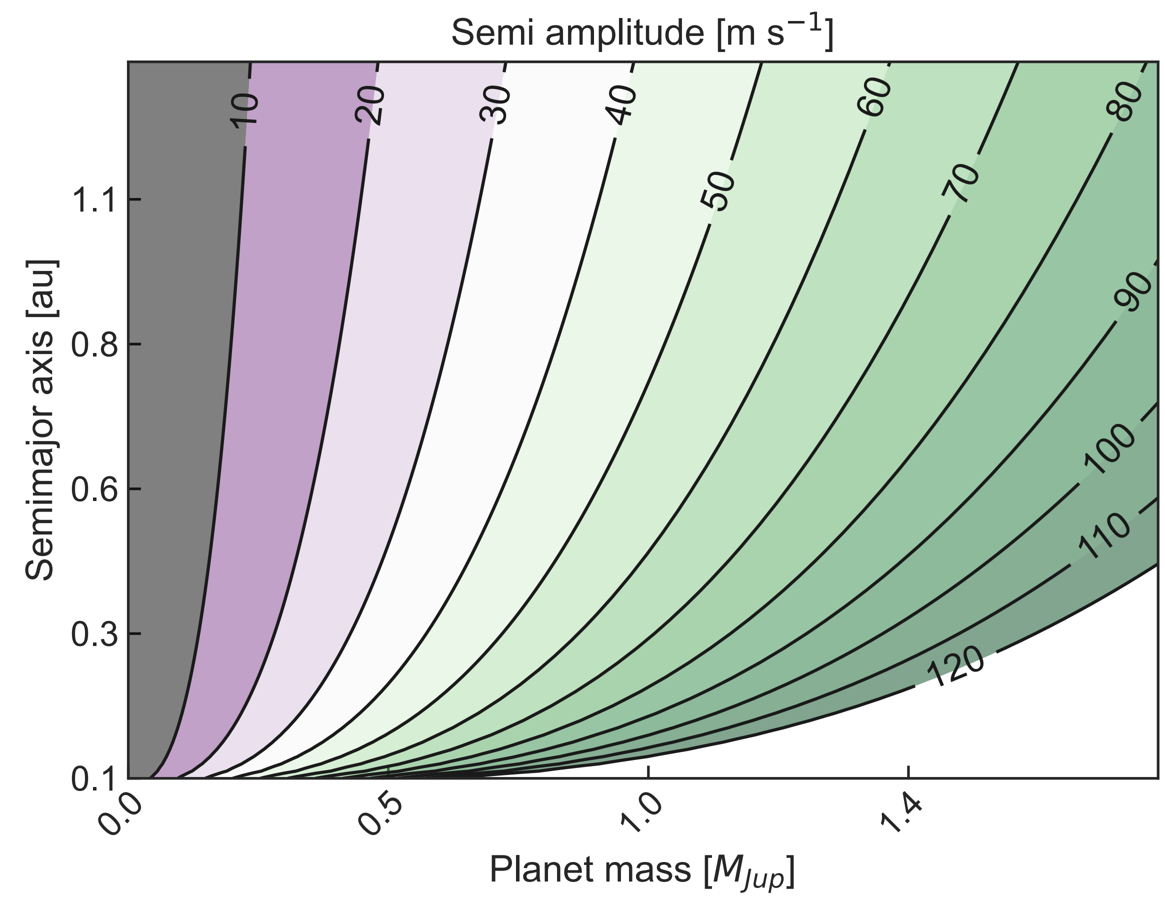
Is there an outer companion?

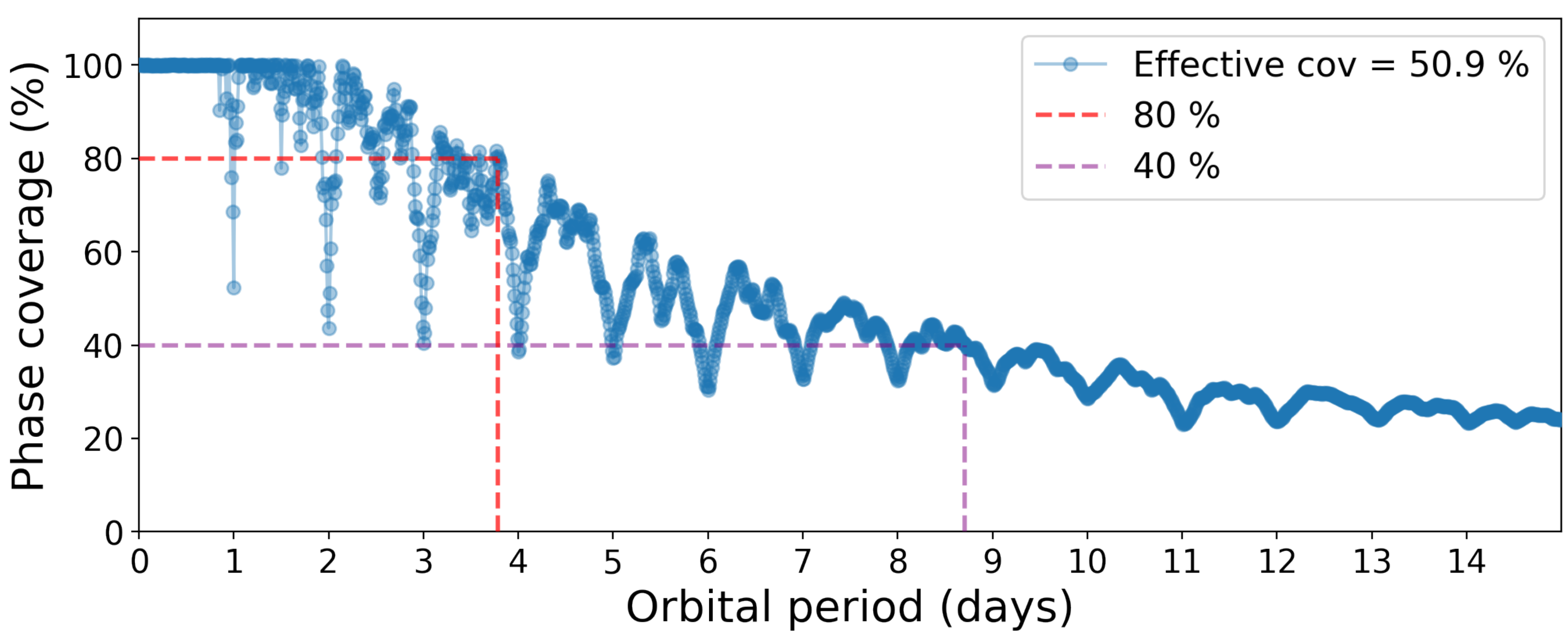


For period 3.78 days
coverage is 82.1%



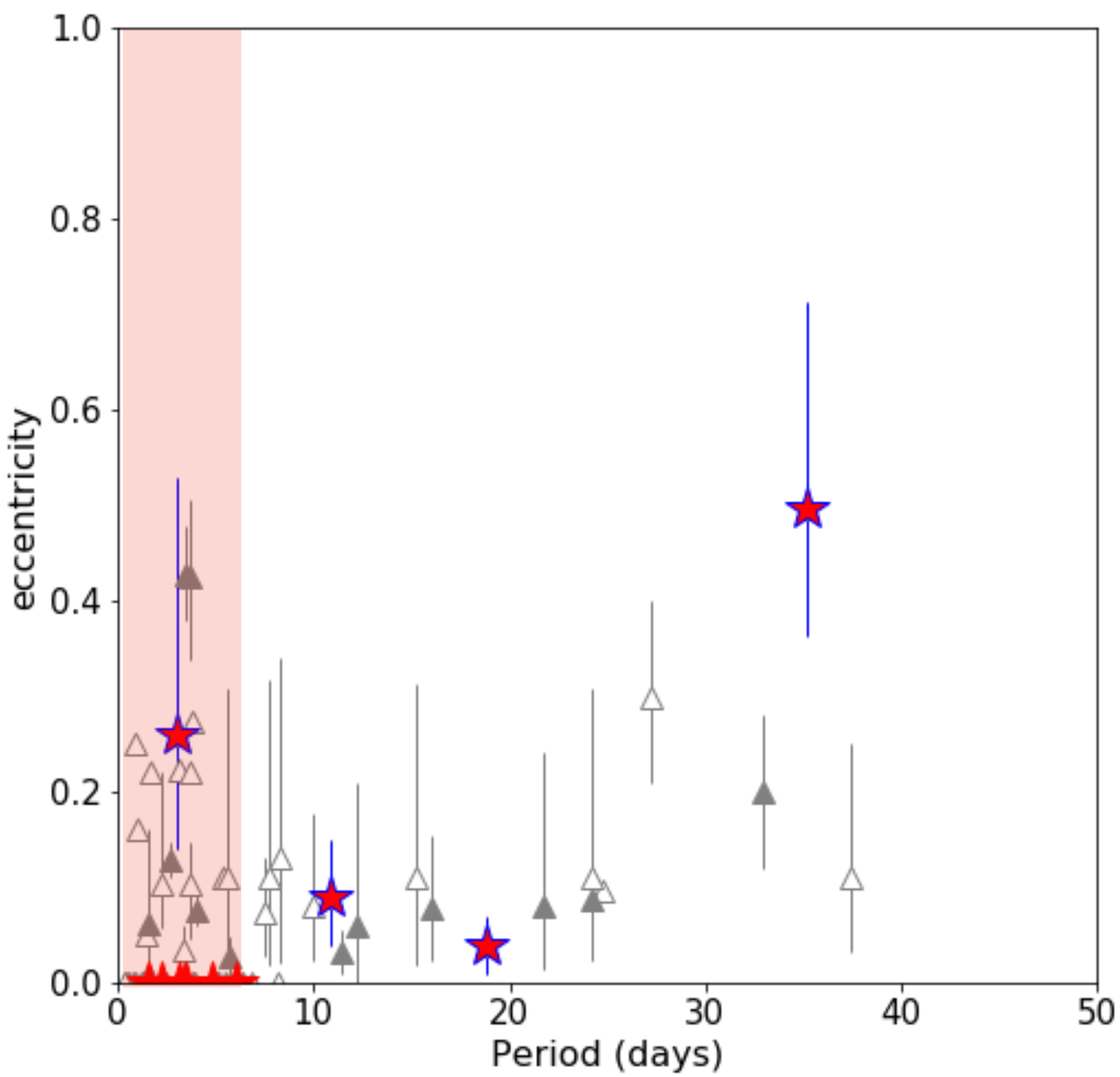
For period 8.71 days
coverage is 41.6%





What’s up with the eccentric warm mini Neptunes?

Correia et al, 2020



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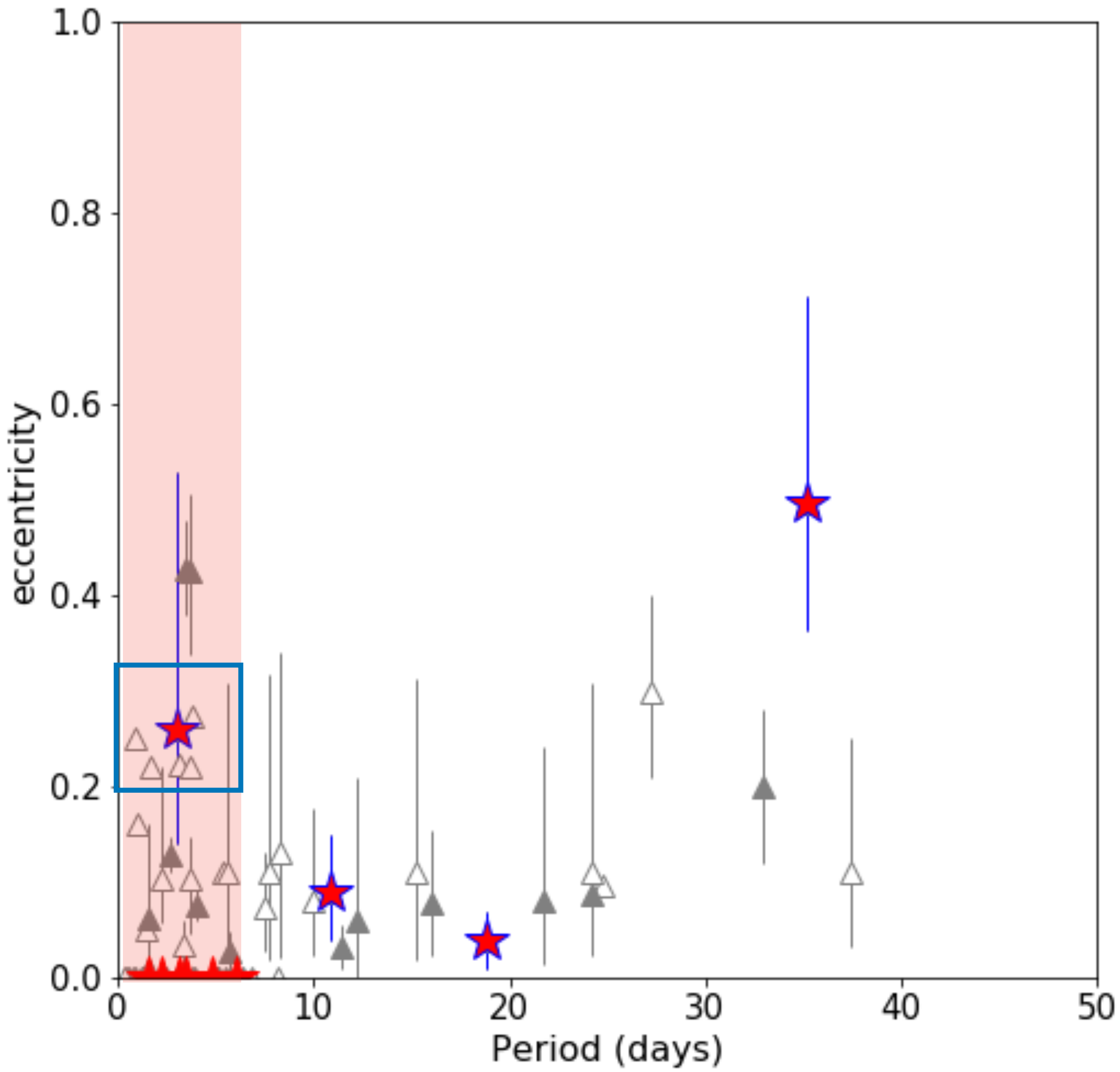

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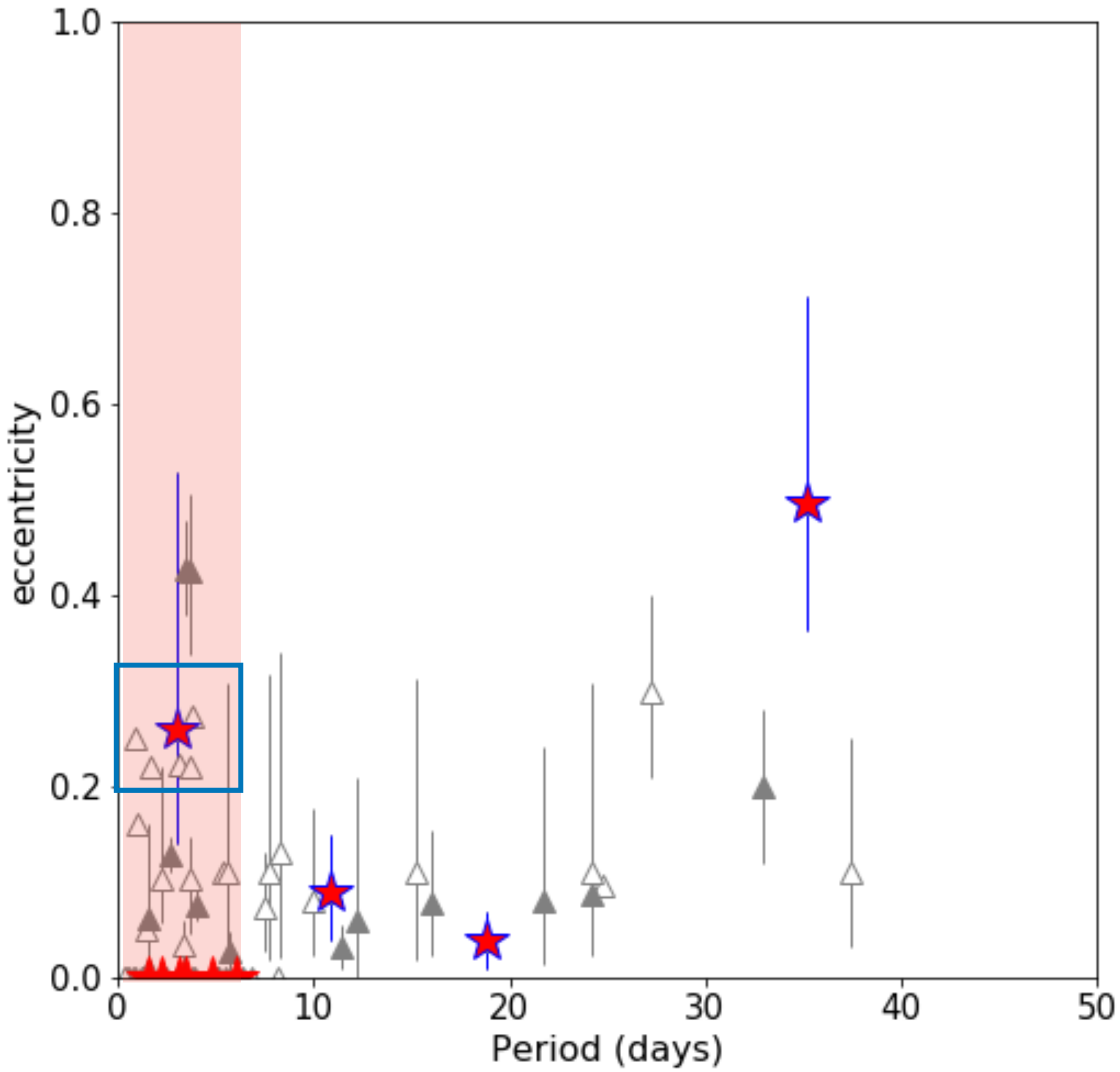
High initial eccentricity

- requires the observations to be at a special time in their evolution



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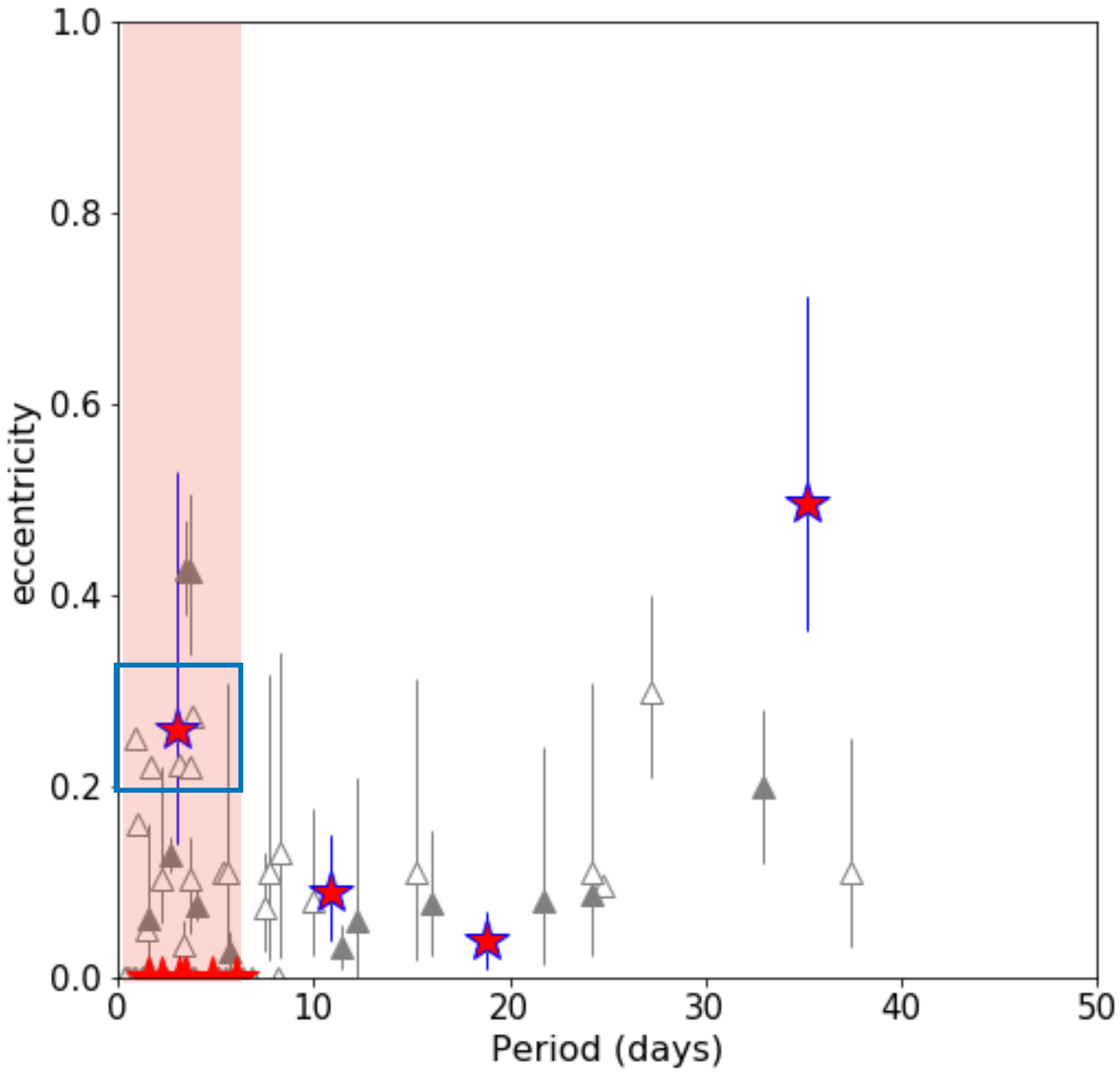

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Thermal atmospheric tides

- some scenarios allow this, but need to understand more about the atmospheres to see if it is plausible

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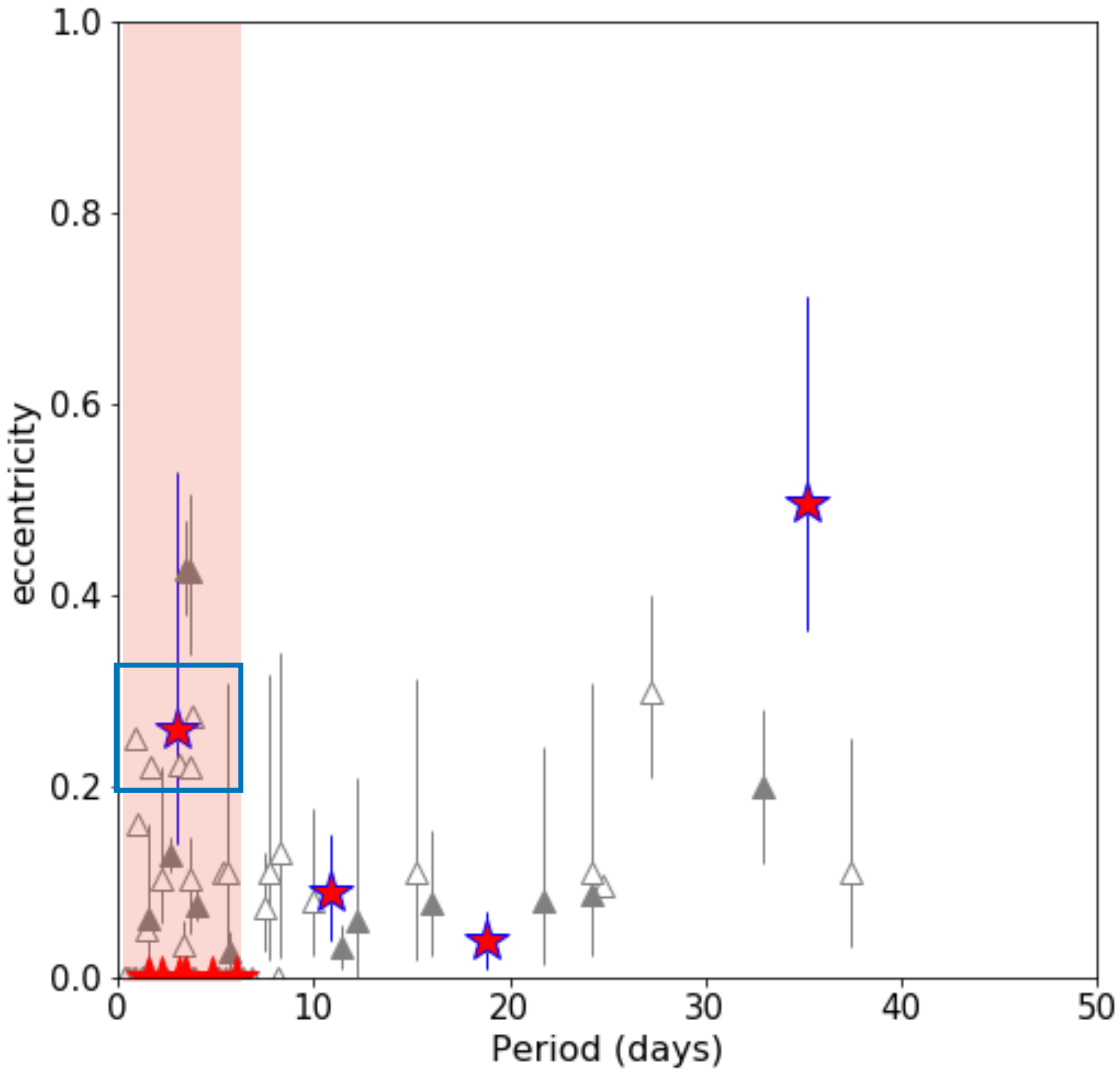
Correia et al, 2020



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Evaporation of the atmosphere

- planets would have to lose 1/2 their mass every 100Myr(!)

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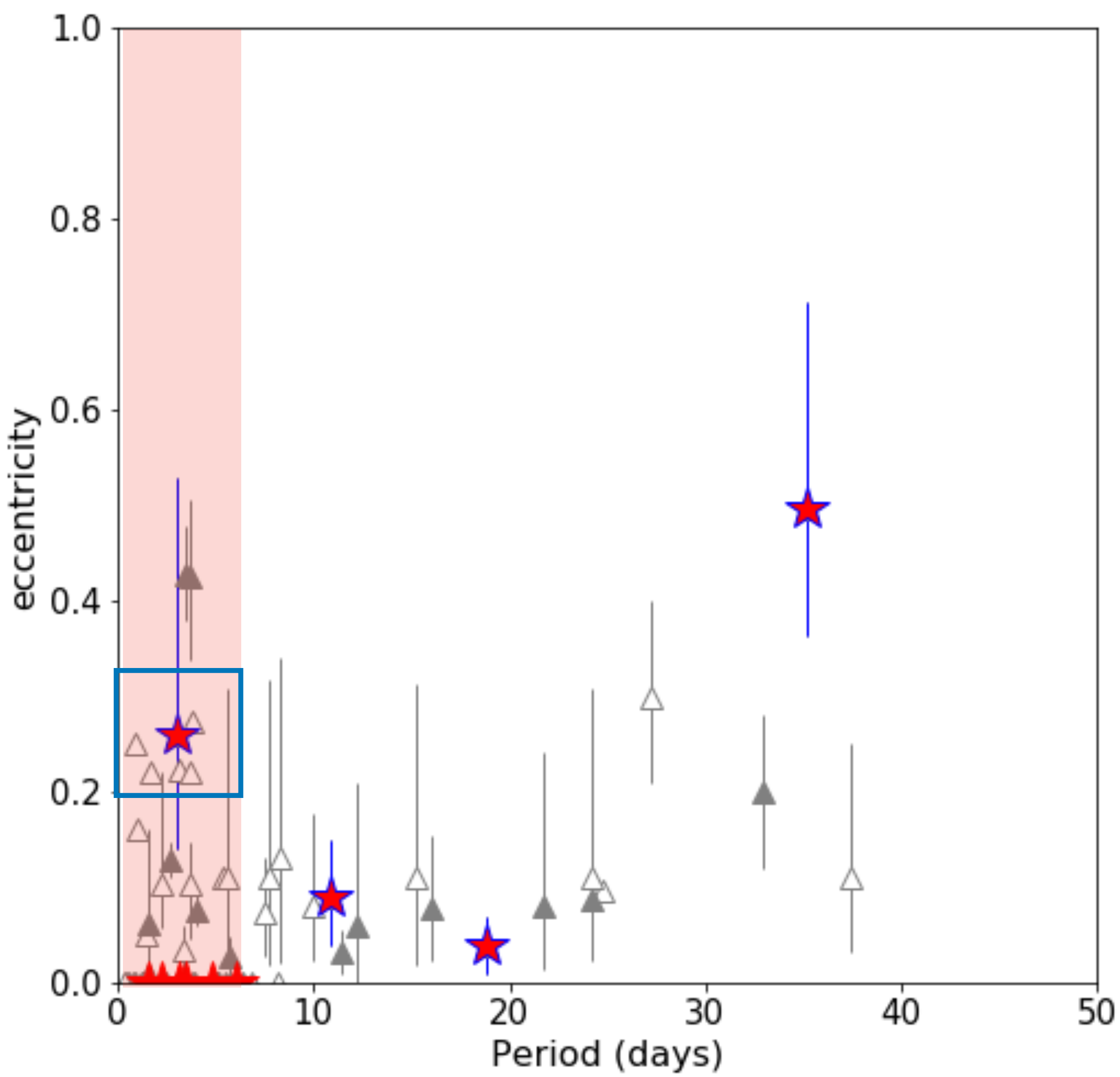
Correia et al, 2020



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Exitation from a faraway compaion
- Can’t rule out an inclined planet

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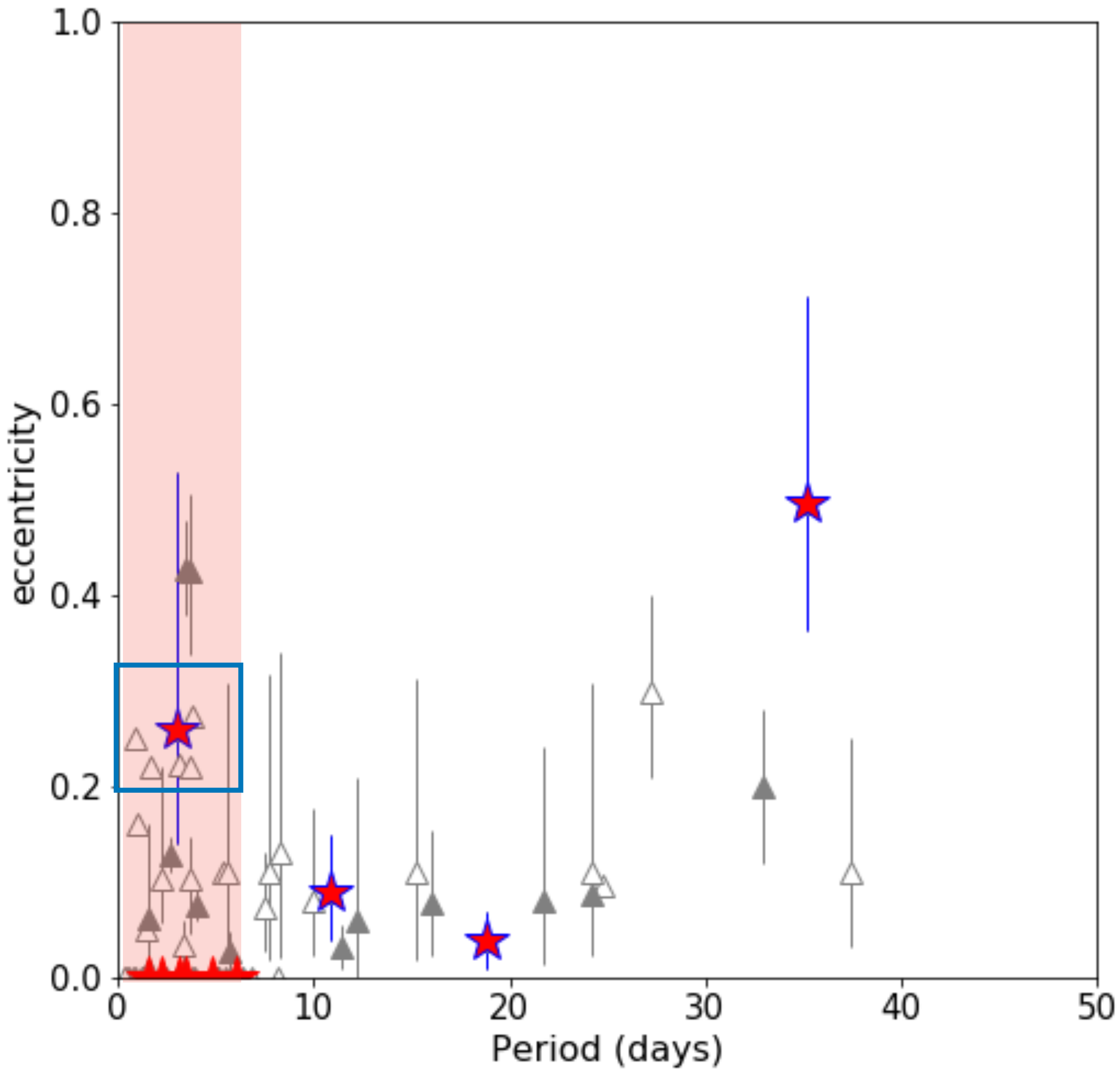

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- high-eccentricity migration+evaporation? (Bourrier et al 2018)

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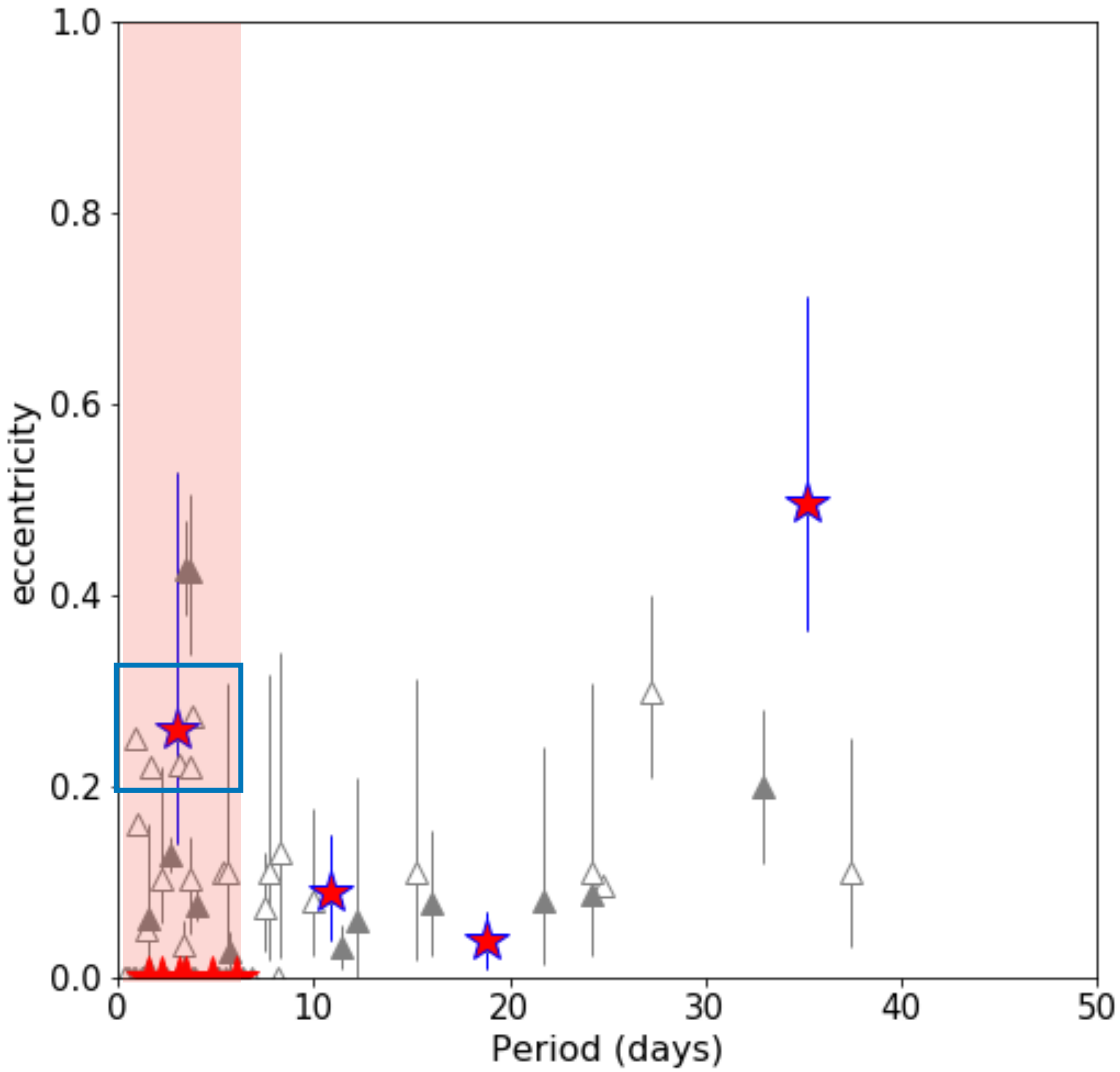

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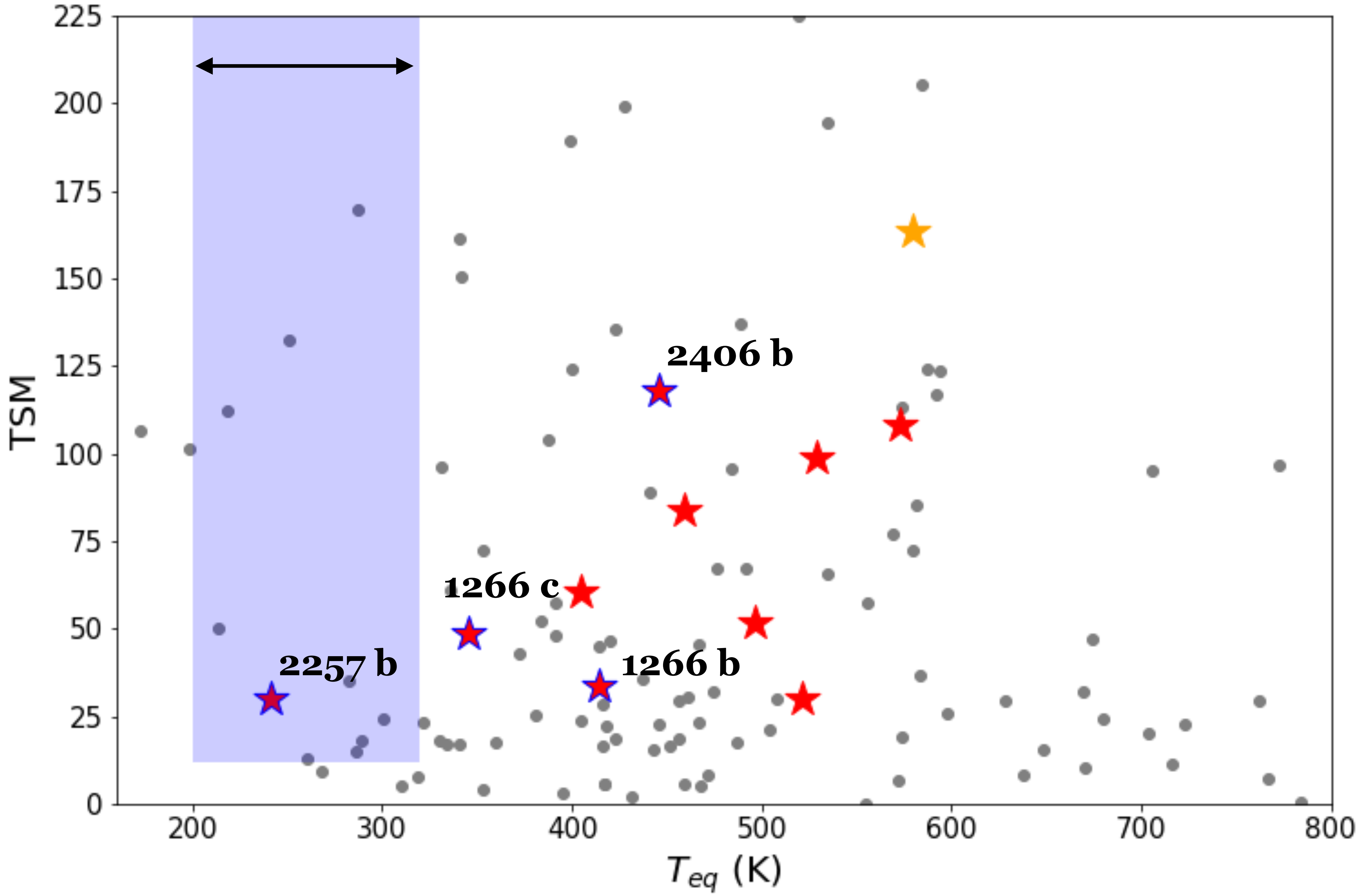
And What about JWST?

Life in the clouds is possible (Seager et al. 2021)



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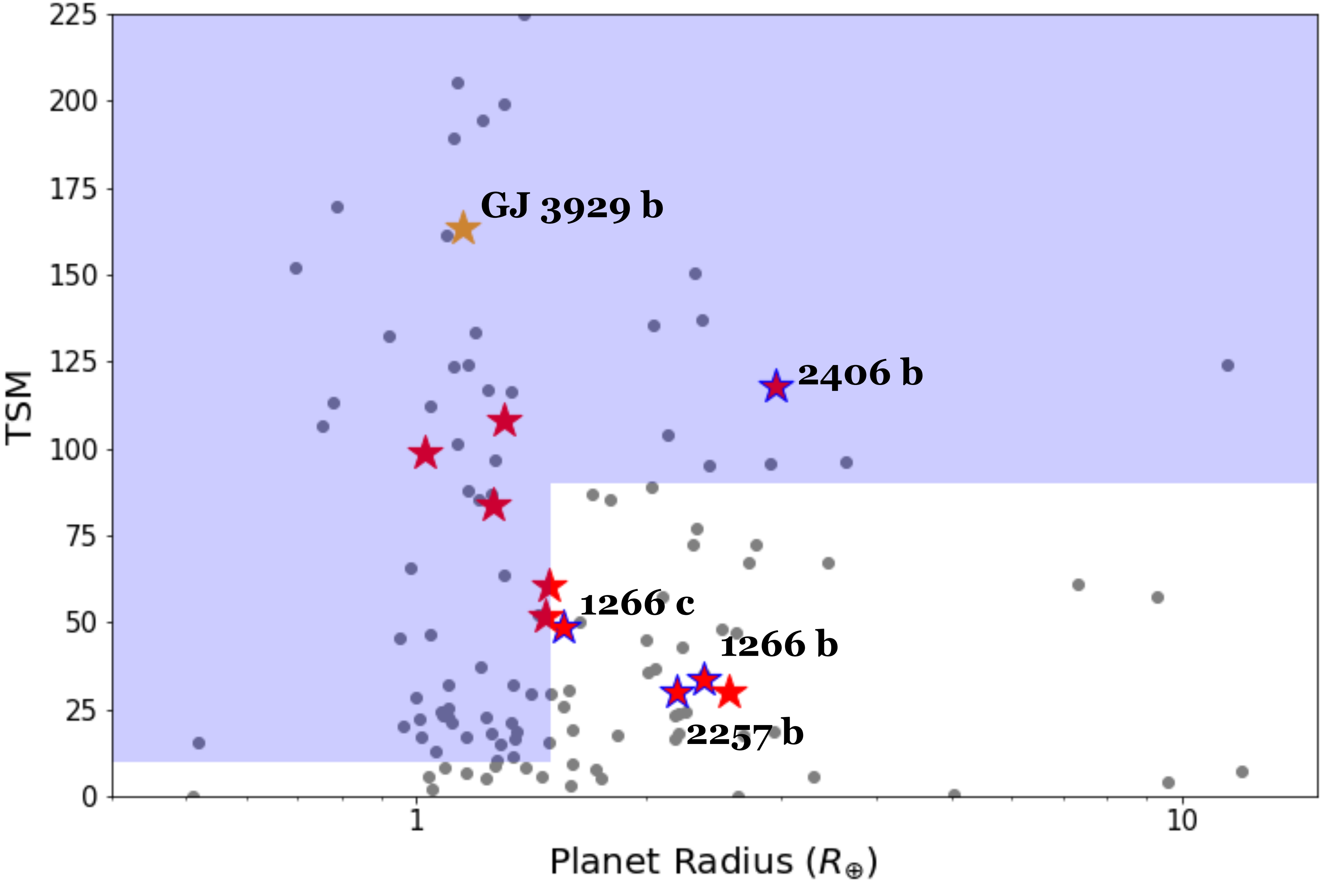

Conclusions

- ★ the SAINT-EX team has led the publication of 3 new systems orbiting M-dwarf stars, with many more in the works
- ★ TOI-1266 b&c straddle the 'radius gap'
- ★ TOI-2406 b is unusually large relative to its star, challenging formation scenarios
- ★ TOI-2257 b & TOI-2406 b both have notably high eccentricities which could be explained by massive outer companions (both have proposals for RVs that can test this scenario)

Thank you!

Property	Value
Fitted parameters:	
T_0 (BJD−2 450 000)	9115.97547 ± 0.00027
P (d)	$3.0766896 \pm 6.5 \times 10^{-6}$
R_p/R_*	0.1322 ± 0.0020
b (R_*)	$0.16^{+0.15}_{-0.11}$
$\sqrt{e}\cos\omega$	$0.06^{+0.45}_{-0.55}$
$\sqrt{e}\sin\omega$	$-0.358^{+0.111}_{-0.095}$
R_* ($R_\odot$)	0.204 ± 0.011
M_* ($M_\odot$)	0.162 ± 0.008
Limb-darkening:	
u_1 TESS	0.313 ± 0.059
u_2 TESS	0.39 ± 0.11
u_1 z'	0.240 ± 0.045
u_2 z'	0.354 ± 0.088
u_1 i'	0.337 ± 0.066
u_2 i'	0.37 ± 0.11
u_1 V	0.56 ± 0.13
u_2 V	0.21 ± 0.17
u_1 Exo	0.268 ± 0.064
u_2 Exo	0.25 ± 0.12
Derived parameters:	
R_p ($R_\oplus$)	$2.94^{+0.17}_{-0.16}$
ρ_*	$26.9^{+4.9}_{-4.4}$
a/R_*	$24.0^{+1.0}_{-1.1}$
a (AU)	0.0228 ± 0.0016
i (°)	$89.63^{+0.27}_{-0.35}$
e	$0.26^{+0.27}_{-0.12}$
ω (°)	279^{+47}_{-63}
S_p ($S_\oplus$)	$6.55^{+0.94}_{-0.80}$
T_{eq} (†) (K)	447 ± 15

Parameter	TOI-1266 b	TOI-1266 c
Transit fitted parameters		
Transit depth, $(R_p/R_\star)^2$	$0.00276^{+0.00010}_{-0.00011}$	0.00120 ± 0.00017
Transit duration, T_{14} (days)	$0.0887^{+0.0013}_{-0.0012}$	$0.0911^{+0.0055}_{-0.0056}$
Impact parameter, b	0.38 ± 0.12	$0.61^{+0.08}_{-0.09}$
Mid-transit time, T_0 (BJD_{TDB})	$2458821.74439^{+0.00054}_{-0.00055}$	$2458821.5706^{+0.0034}_{-0.0029}$
Orbital period, P (days)	$10.894843^{+0.000067}_{-0.000066}$	$18.80151^{+0.00067}_{-0.00069}$
Tr. depth diff., $\delta_{TESS-SAINT-EX,z'}$	$0.00106^{+0.00069}_{-0.00067}$	0.00089 ± 0.00063
Tr. depth diff., $\delta_{TESS-TRAPPIST-N,z'}$	$0.00079^{+0.00071}_{-0.00075}$	
Tr. depth diff., $\delta_{TESS-TRAPPIST-N,V}$	$0.00067^{+0.00045}_{-0.00046}$	
Tr. depth diff., $\delta_{TESS-ARTEMIS,r'}$	0.00049 ± 0.00120	
Tr. depth diff., $\delta_{TESS-OAA,Ic}$	$-0.00039^{+0.0016}_{-0.0013}$	
Tr. depth diff., $\delta_{TESS-ZRO,clear}$	$0.0035^{+0.0026}_{-0.0019}$	
Tr. depth diff., $\delta_{TESS-Kotizarovci,TESSband}$	$0.00192^{+0.00094}_{-0.00098}$	
Physical and orbital parameters		
Planet radius, R_p ($R_\oplus$)	$2.37^{+0.16}_{-0.12}$	$1.56^{+0.15}_{-0.13}$
Semi-major axis, a_p (au)	$0.0736^{+0.0016}_{-0.0017}$	$0.1058^{+0.0023}_{-0.0024}$
Orbital inclination, i_p (deg)	$89.5^{+0.2}_{-0.2}$	$89.3^{+0.1}_{-0.1}$
Irradiation, S_p ($S_\oplus$)	$4.9^{+1.0}_{-0.8}$	$2.3^{+0.5}_{-0.4}$
Equilibrium temperature, T_{eq} (K)	413 ± 20	344 ± 16
Planet mass (TTV), M_p ($M_\oplus$)	$13.5^{+11.0}_{-9.0}$ (<36.8 at 2-σ)	$2.2^{+2.0}_{-1.5}$ (<5.7 at 2-σ)
Orbital eccentricity (TTV), e	$0.09^{+0.06}_{-0.05}$ (<0.21 at 2-σ)	0.04 ± 0.03 (<0.10 at 2-σ)

Table 3. Fit and derived parameters for the TOI-2257 b system.

Parameter	Unit	Value	Prior
Fitted Parameters			
Orbital period P	days	35.189346(90)	$\mathcal{N}(35.189295, 1e-4)$
Mid-transit time T_0	BJD-2450000	$9007.97949^{+0.00108}_{-0.00105}$	$\mathcal{N}(9007.978906, 0.1)$
(R_p/R_*)		$0.06423^{+0.00142}_{-0.00133}$	$\mathcal{U}(0.001, 0.4)$
Impact parameter b		$0.374^{+0.098}_{-0.137}$	$\mathcal{U}(0, 1)$
$\sqrt{e}sin\omega$		$-0.615^{+0.083}_{-0.073}$	$\mathcal{U}(-1, 1)$
$\sqrt{e}cos\omega$		$-0.126^{+0.484}_{-0.387}$	$\mathcal{U}(-1, 1)$
Stellar Mass M_*	$M_\odot$	$0.328^{+0.021}_{-0.019}$	$\mathcal{N}(0.33, 0.02)$
Stellar Radius R_*	$R_\odot$	0.313 ± 0.015	$\mathcal{N}(0.311, 0.015)$
Physical and Orbital Parameters			
Planet Radius R_p	$R_\oplus$	$2.194^{+0.113}_{-0.111}$	
Orbital Eccentricity e		$0.496^{+0.216}_{-0.133}$	
Argument of Periastron ω	°	$-101.674^{+42.453}_{-26.881}$	
Semimajor axis a	au	0.145 ± 0.003	
Inclination i	°	$89.786^{+0.078}_{-0.062}$	
Equilibrium Temperature $T_{eq}{}^*$	K	256^{+61}_{-17}	
Depth δ		$0.00413^{+0.00018}_{-0.00017}$	
Transit duration	hrs	$3.846^{+0.057}_{-0.051}$	
Predicted Parameters			
Planet Mass M_p	$M_\oplus$	$5.712^{+4.288}_{-2.311}$	
RV Semi-amplitude K	$m\,s^{-1}$	$3.521^{+2.901}_{-1.507}$	
TSM		$32.708^{+24.08}_{-14.362}$	