

The changing face of AU Mic: transit timing variations, stellar spots, spin-orbit commensurability

location of AU Mic

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CHEOPS Workshop VI., 2022

20 AU

2017

AU Mic with HST

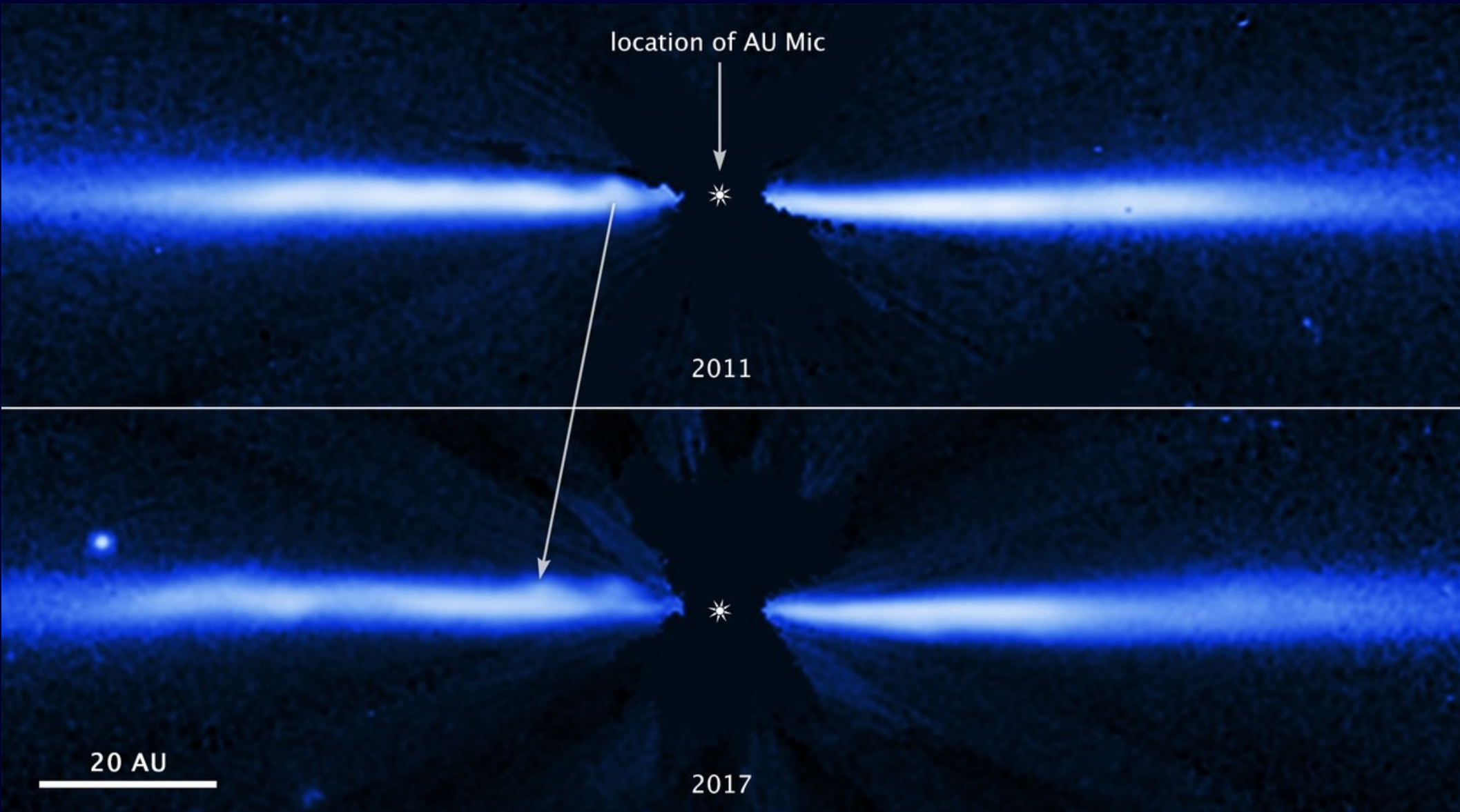


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The host star: AU Mic

SpT=M1 Ve

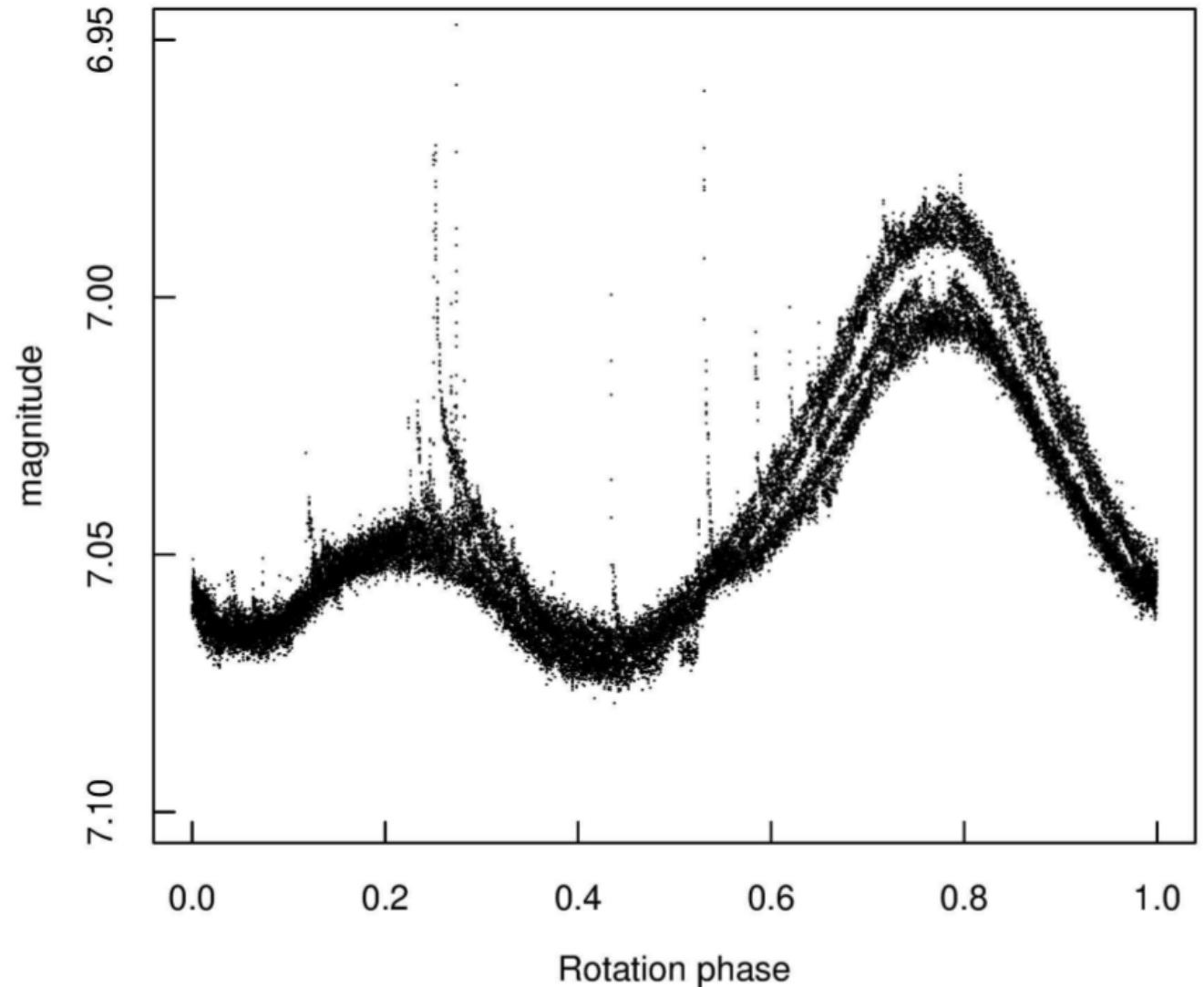
$0.5 M_{\text{Sun}}, 0.75 R_{\text{Sun}}$

Age ~ 22 Myr

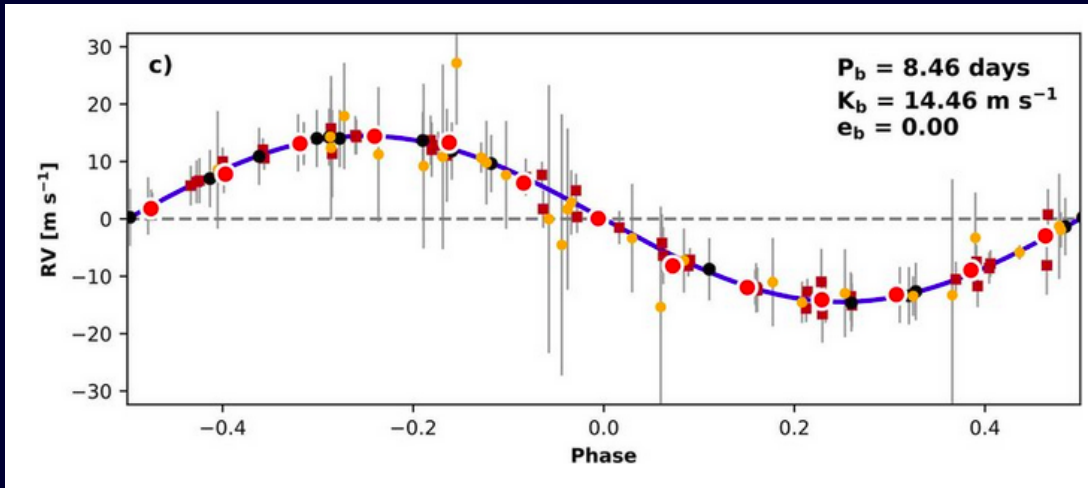
One of the most active
planet-hosting stars
known today

$P_{\text{rot}} \sim 4.83$ d

$7 \times P_{\text{rot}} = 4 \times P_{\text{orb,b}}$



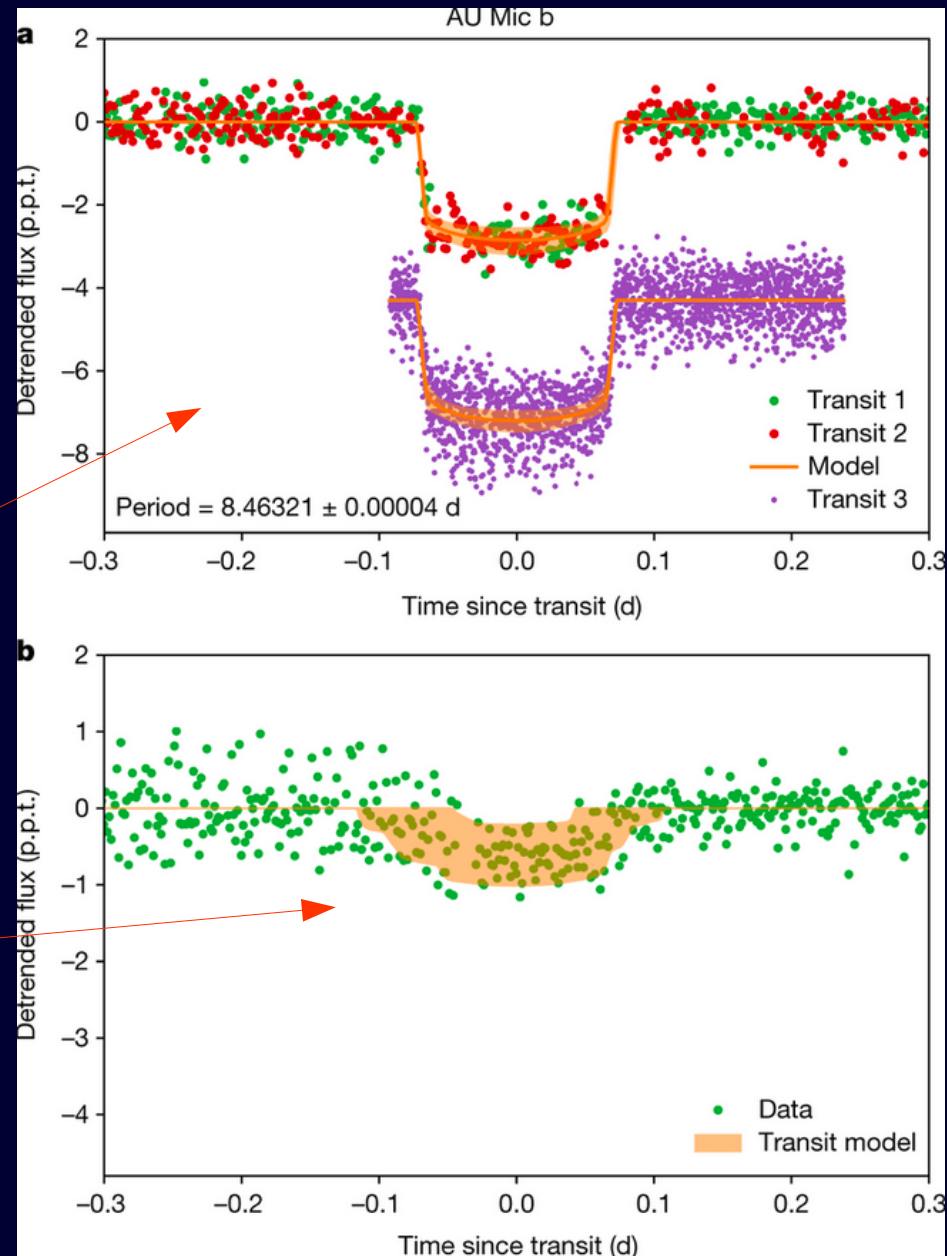
The AU Mic planetary system



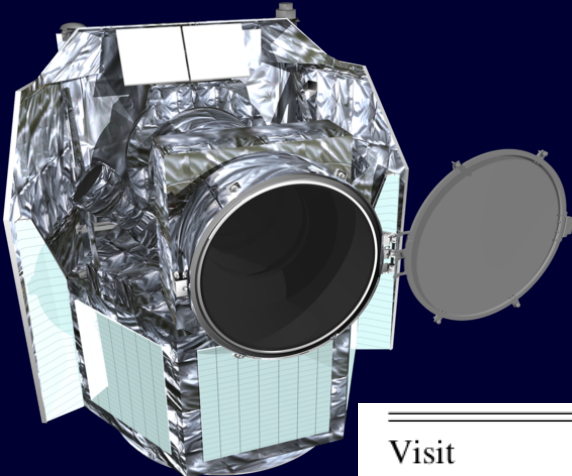
Plavchan et al. 2020

Planet	Mass (M_{Jup})	Radius (R_{Jup})	Period (day)	a (AU)
AU Mic b	0.053	0.3908	8.462991	0.0645
AU Mic c	0.0463	0.3131	18.858991	0.1101

exoplanet.eu



Plavchan et al. 2020

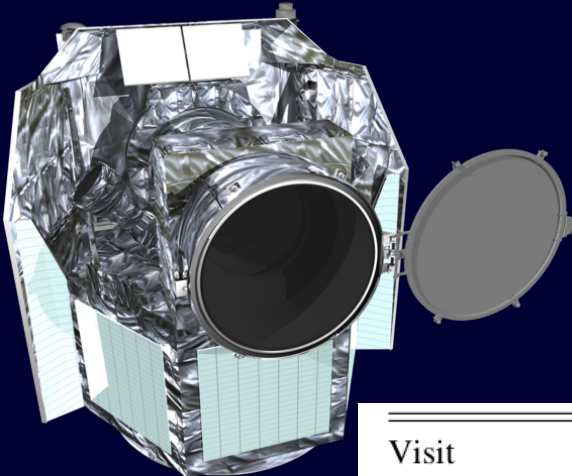


2020-2021 CHEOPS observations

Visit #	Start date	End date	File key	CHEOPS product	Integ. time (s)	Co-added exposures	Num. of frames
1	2020-07-10 09:07:24	2020-07-11 00:45:29	PR100010_TG001701	Subarray	30	15 s × 2	3597
				<i>Imagettes</i>	15	—	7194
2	2020-08-21 19:07:06	2020-08-22 06:05:26	PR100010_TG001702	Subarray	30	15 s × 2	4422
				<i>Imagettes</i>	15	—	8844
3	2020-09-24 16:29:54	2020-09-25 10:16:00	PR100010_TG001801	Subarray	42	3 s × 14	873
				<i>Imagettes</i>	3	—	12 222

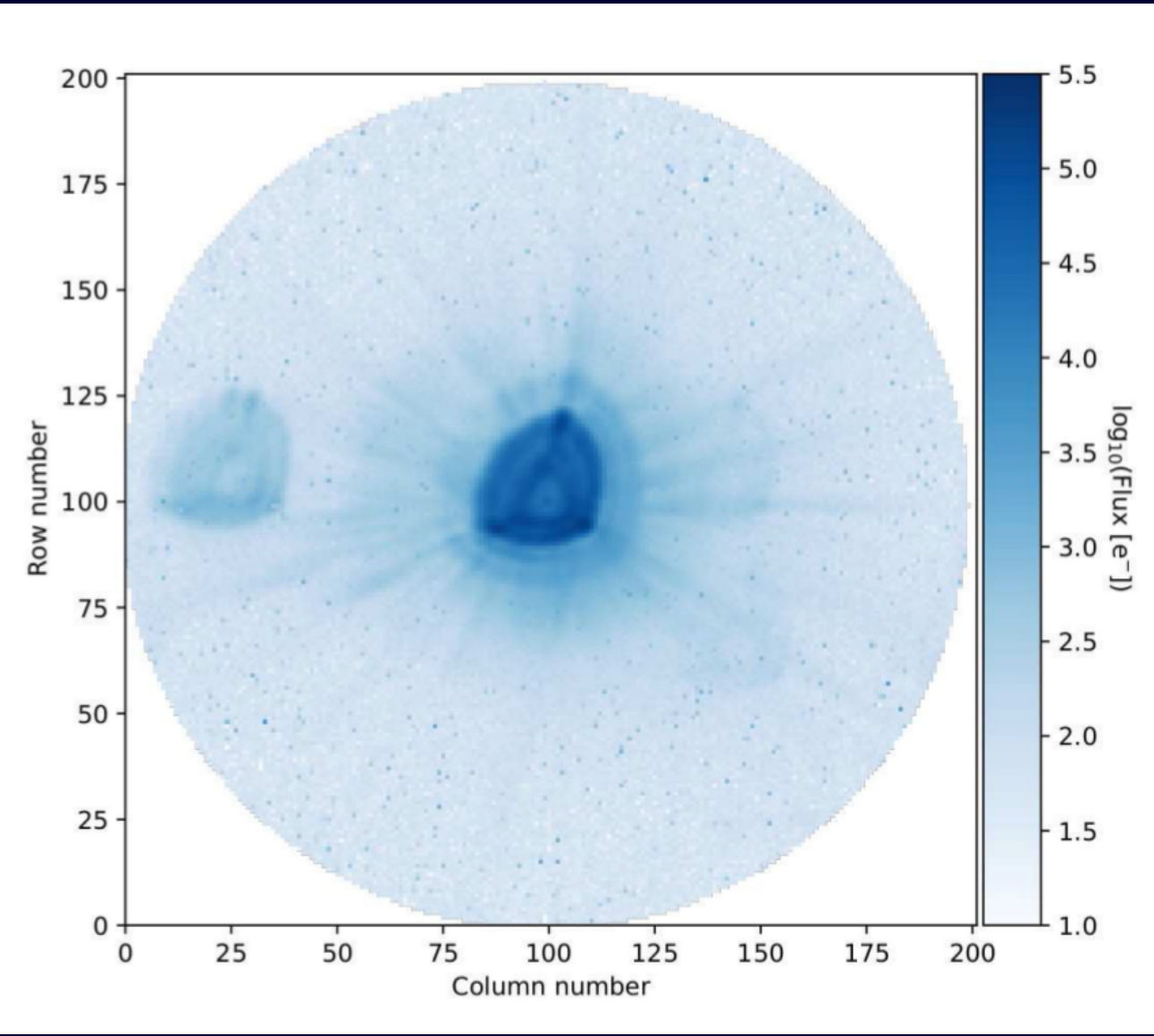
Visit ID	Start Date (2021)	End Date (2021)	File Key	CHEOPS product	Integ. time (s)	Co-added exposures	Num. of frames
AU Mic b 21-07-26	07-26 11:27:13	07-26 22:34:04	PR100010_TG003001	Subarray	42	3 s × 14	669
				<i>Imagettes</i>	3	—	9366
AU Mic c 21-08-09	08-09 04:59:15	08-09 19:37:47	PR100010_TG003401	Subarray	42	3 s × 14	1029
				<i>Imagettes</i>	3	—	14 406
AU Mic b 21-08-12	08-12 08:25:41	08-12 19:53:00	PR100010_TG003601	Subarray	42	3 s × 14	839
				<i>Imagettes</i>	3	—	11 746
AU Mic c 21-08-28	08-28 02:09:13	08-28 16:35:03	PR100010_TG003402	Subarray	42	3 s × 14	907
				<i>Imagettes</i>	3	—	12 698
AU Mic b 21-08-29	08-29 05:17:41	08-29 16:44:59	PR100010_TG003701	Subarray	42	3 s × 14	667
				<i>Imagettes</i>	3	—	9338
AU Mic b 21-09-06	09-06 17:38:41	09-07 05:05:59	PR100010_TG003101	Subarray	42	3 s × 14	643
				<i>Imagettes</i>	3	—	9002

2020-2021 CHEOPS observations



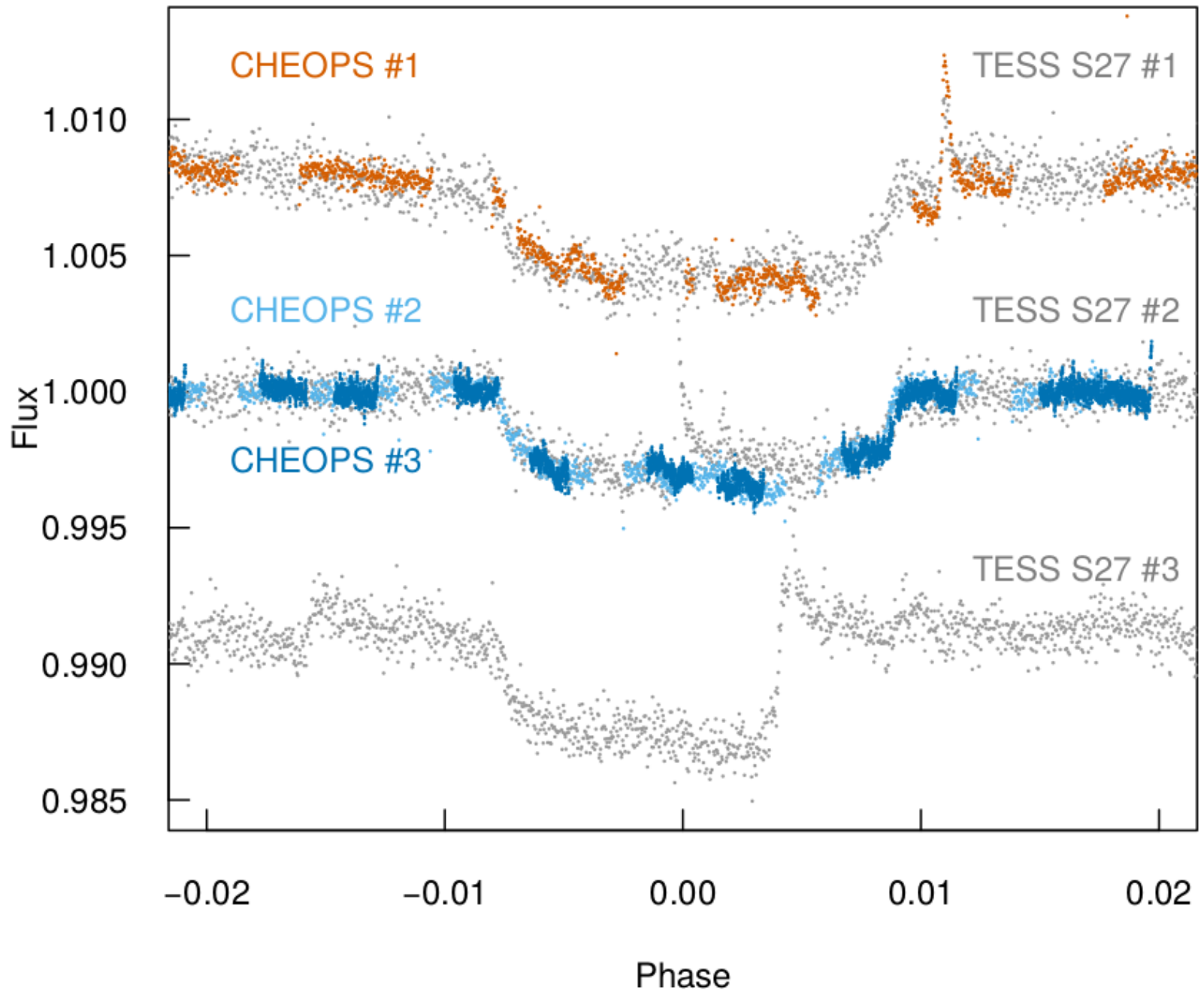
Visit #	Start
1	2020-07
2	2020-08
3	2020-09

Visit ID
AU Mic b 21-0
AU Mic c 21-0
AU Mic b 21-0
AU Mic c 21-0
AU Mic b 21-0
AU Mic b 21-0

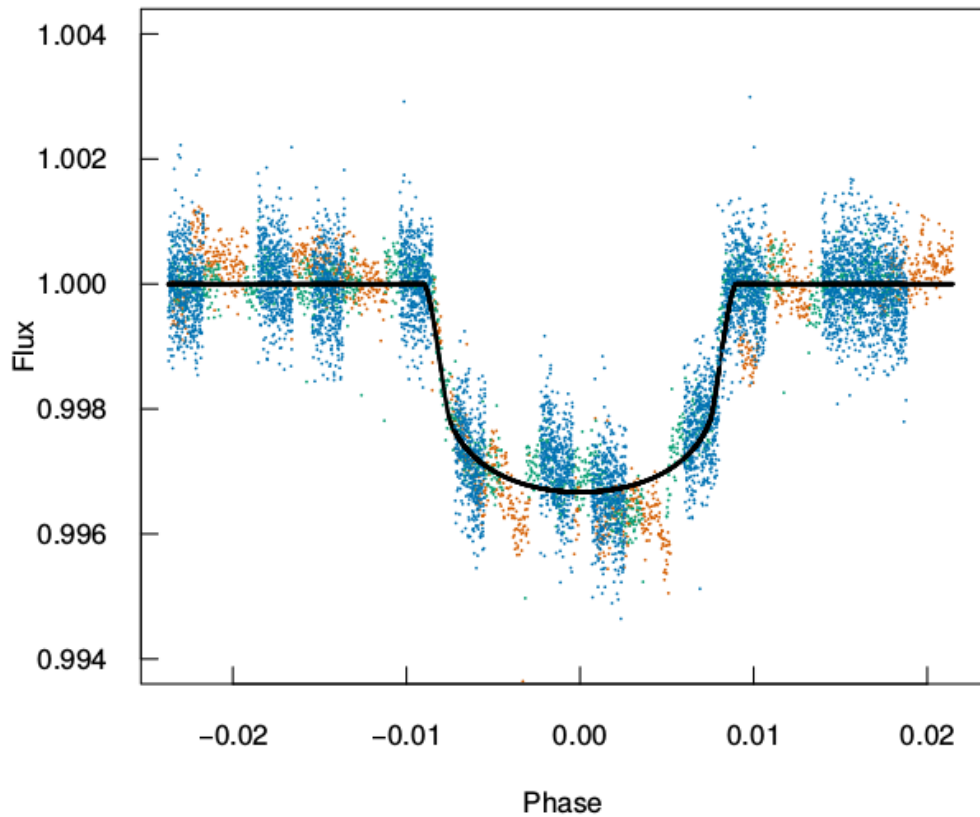


Star	Num. of frames
1	3597
2	7194
3	4422
4	8844
5	873
6	12 222

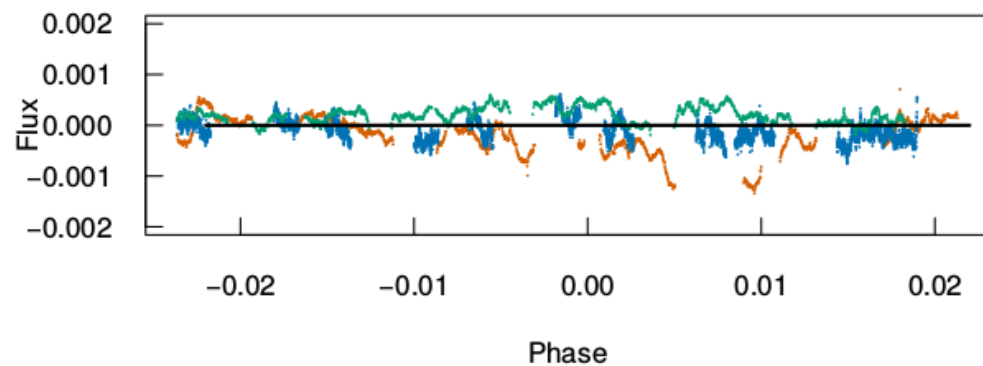
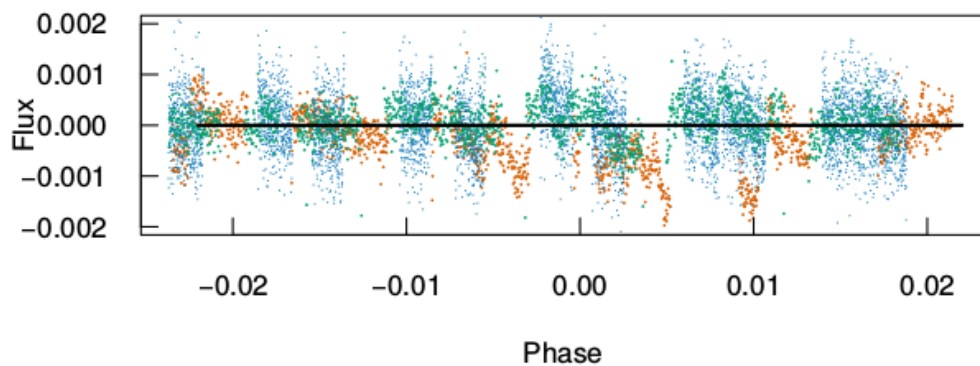
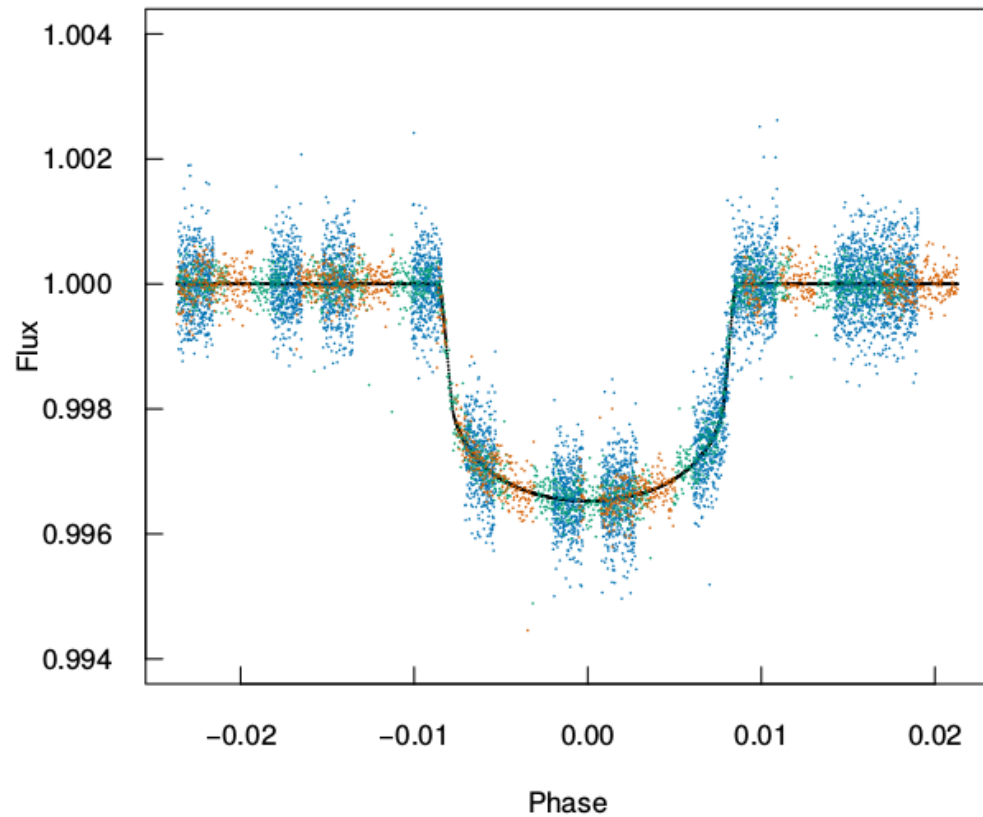
Star	Num. of frames
7	669
8	9366
9	1029
10	14 406
11	839
12	11 746
13	907
14	12 698
15	667
16	9338
17	643
18	9002



PyCheops (GP-based)



TLCM (Wavelet-based)



A bias in the planet parameters due to stellar activity

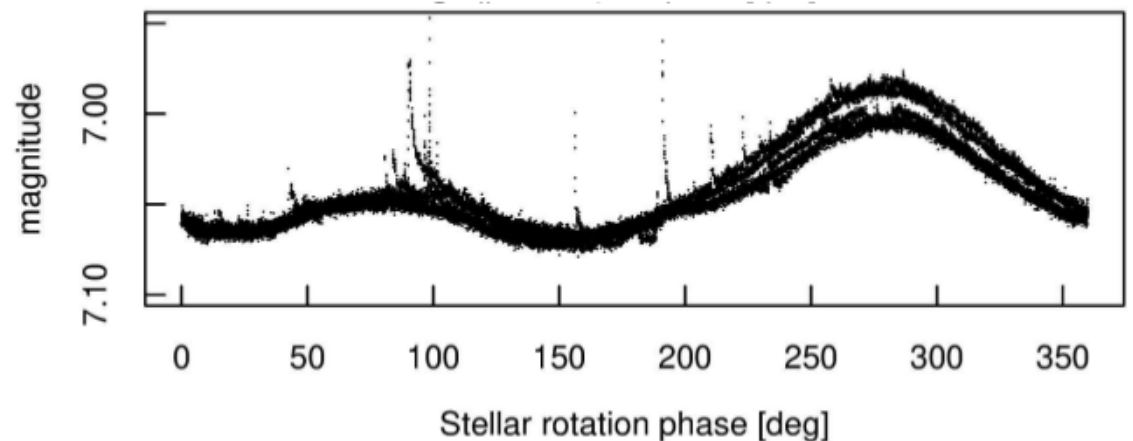
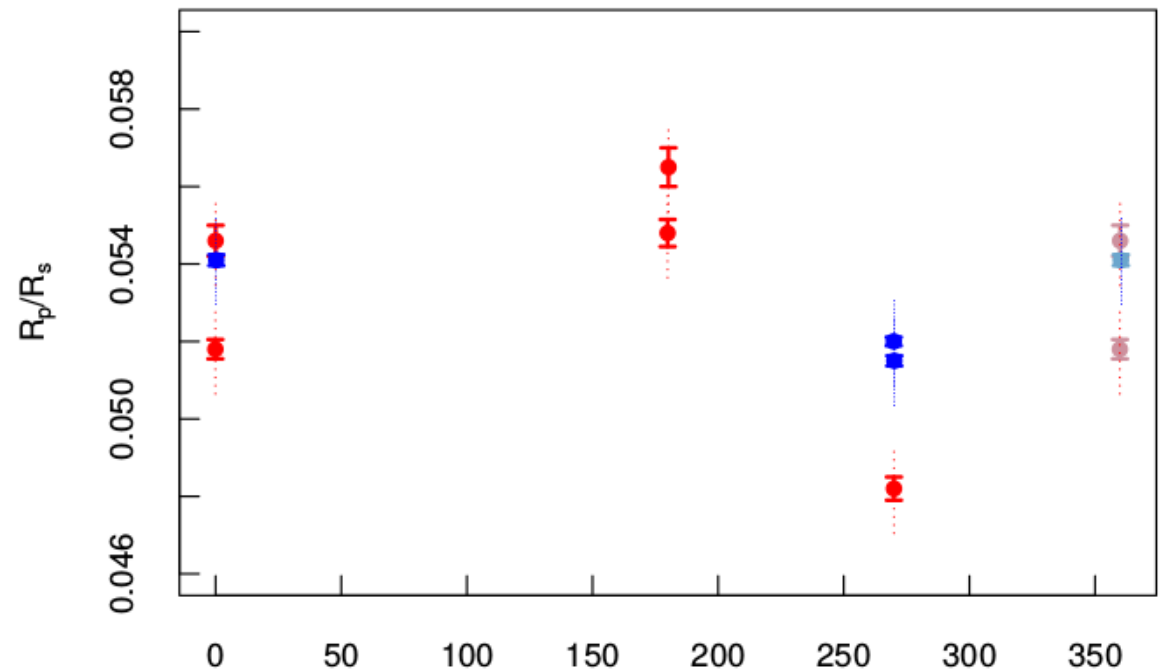
Systematic biases
in planet radius
Observed both in
CHEOPS and TESS data

Depends on stellar longitude

Transit timing
Accurate to ~3 minutes

Is there any TTV?...

Times of mid-transit sharing
the same sub-stellar
longitude can be reliably
compared



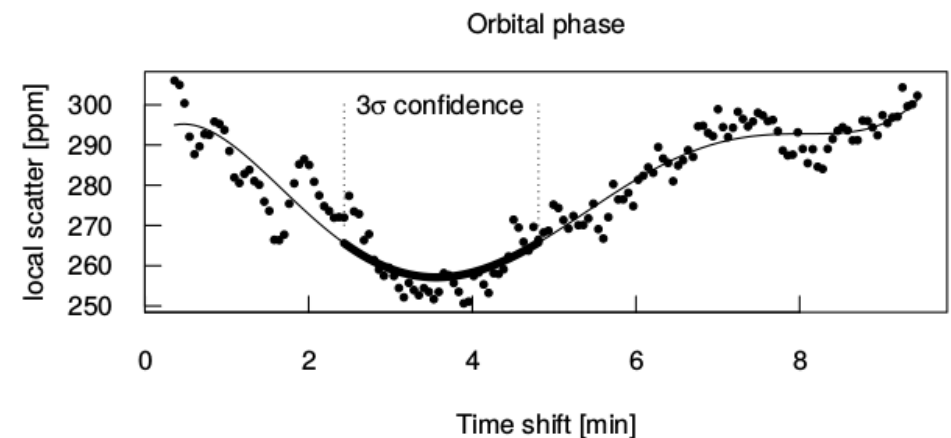
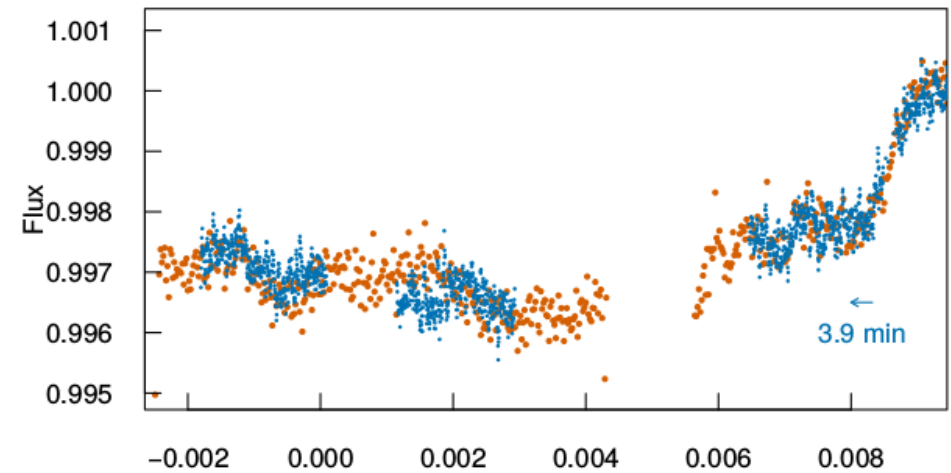
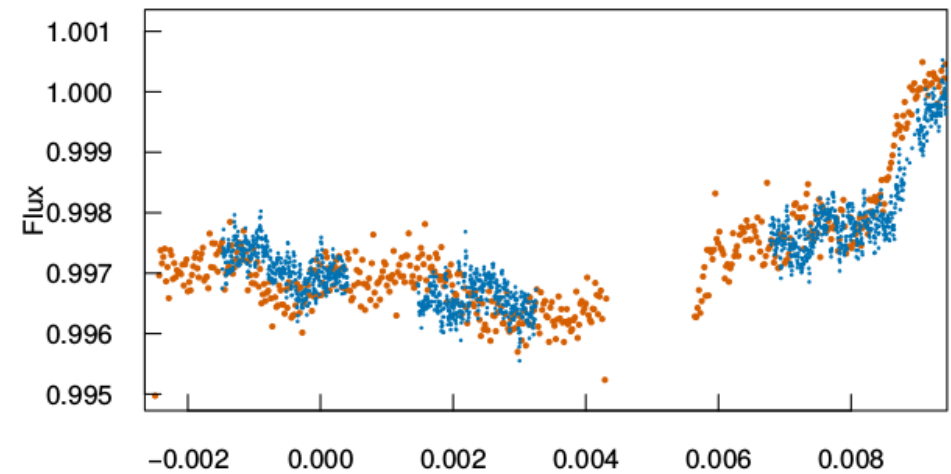
Systematical biases
in planet radius
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Transit times
Accurate to ~3 minutes

Is there TTV?...

Transit times belonging only
to the same longitude can be
reliably compared



The TTV as we saw it before the CHEOPS observations in 2021 summer

Don't take too seriously
It has been updated...

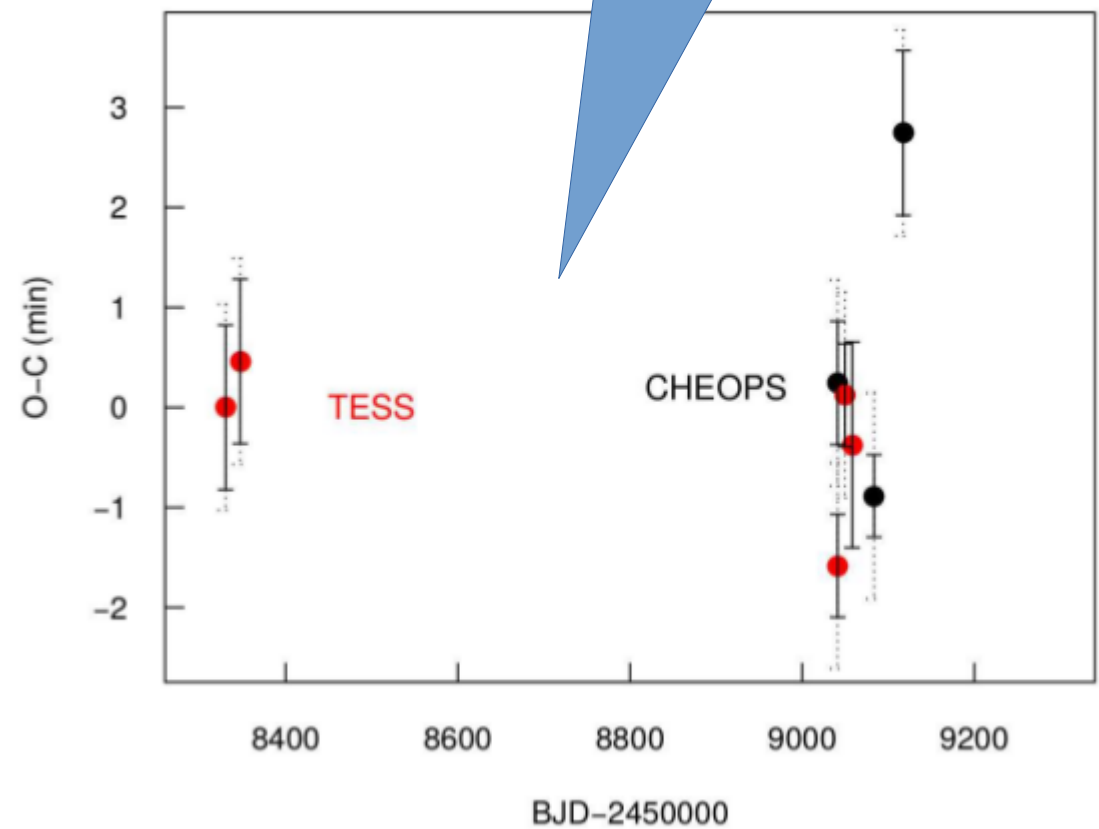
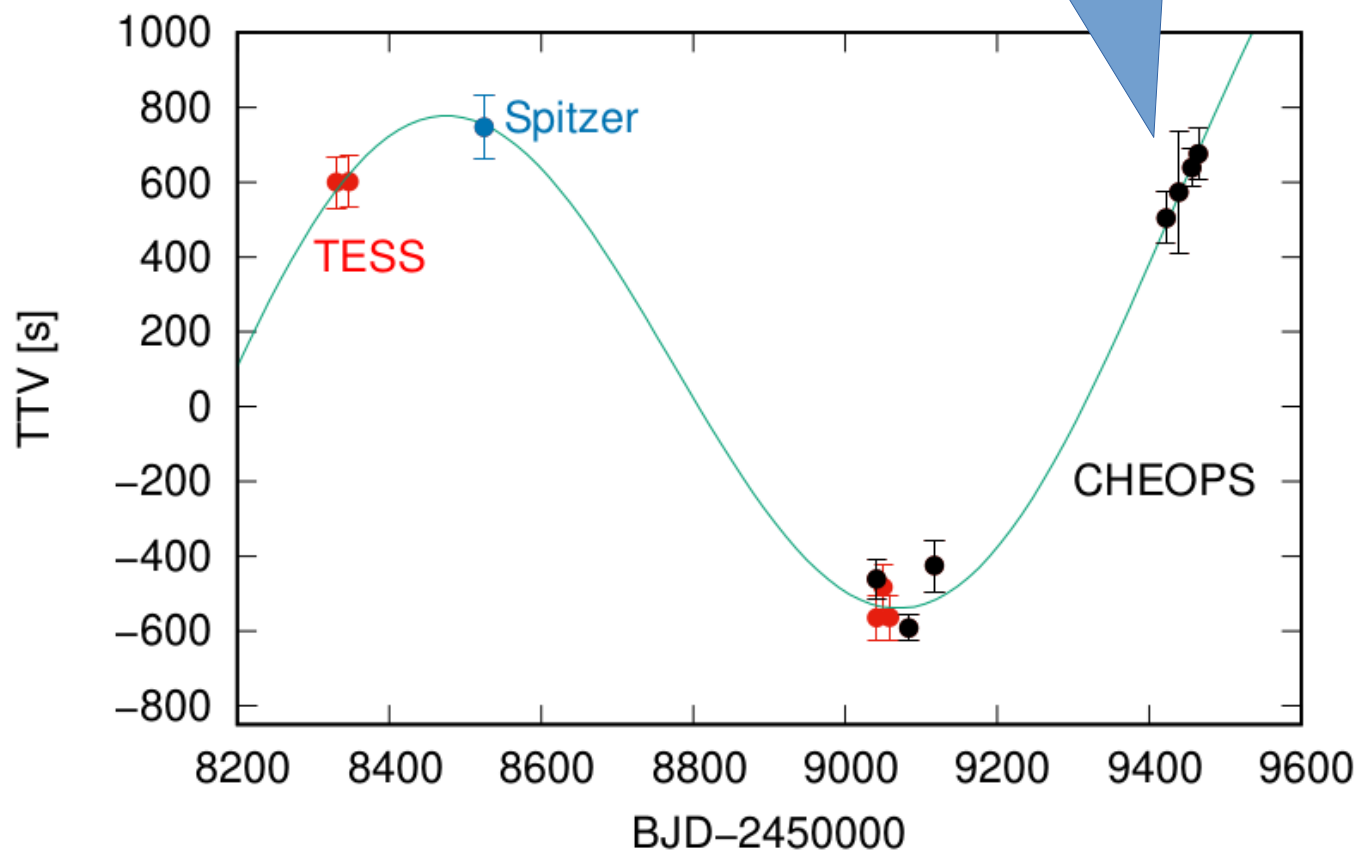


Table A.2. Observed mid-transit times and $O - C$ values of AU Mic b based on *TESS*, *Spitzer* and *CHEOPS* observations analysed in the present work, with $T_c = 2\,458\,330.38416$ d and $P_{\text{mean}} = 8.4631427$ d. References to transit times are: *a*: Szabó et al. (2021), *b*: Plavchan et al. (2020), *c*: This Letter.

Designation	Transit Time [BJD-2 450 000]	$O - C$ [s]	Err [s]
<i>TESS</i> S1#1 ^a	8330.3911±0.0009	603	80
<i>TESS</i> S1#2 ^a	8347.3174±0.0009	604	80
<i>Spitzer</i> #1 ^b	8525.04509±0.0010	750	86
<i>TESS</i> S27#1 ^a	9041.2816±0.0008	-458	70
<i>TESS</i> S27#2 ^a	9049.7457±0.0008	-589	70
<i>TESS</i> S27#3 ^a	9058.2080±0.0008	-422	70
<i>CHEOPS</i> 20-07-10 ^a	9041.2828±0.0006	-562	52
<i>CHEOPS</i> 20-08-21 ^a	9083.5970±0.0004	-479	35
<i>CHEOPS</i> 20-09-24 ^a	9117.4515±0.0008	-560	70
<i>CHEOPS</i> 21-07-26 ^c	9422.1342±0.0010		
<i>CHEOPS</i> 21-08-12 ^c	9439.0636±0.0021		
<i>CHEOPS</i> 21-08-29 ^c	9455.9895±0.0007		
<i>CHEOPS</i> 21-09-06 ^c	9464.4531±0.0009		

Transits in 2021
LARGE amplitude TTV!



The TTV as we see it
Right now

AU Mic b and c
with CHEOPS in 2021

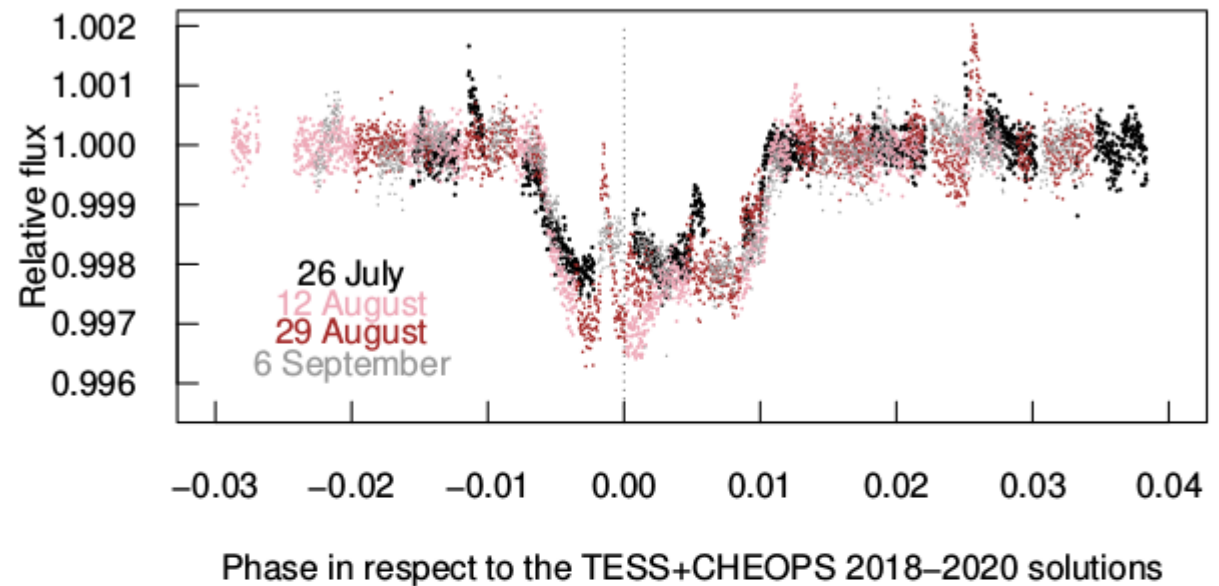
Times of midtransit shifted

Activity keeps increasing

Planet radius parameter
decreased (3.5 sigma)

First CHEOPS
Observations of planet c

AU Mic b



AU Mic c

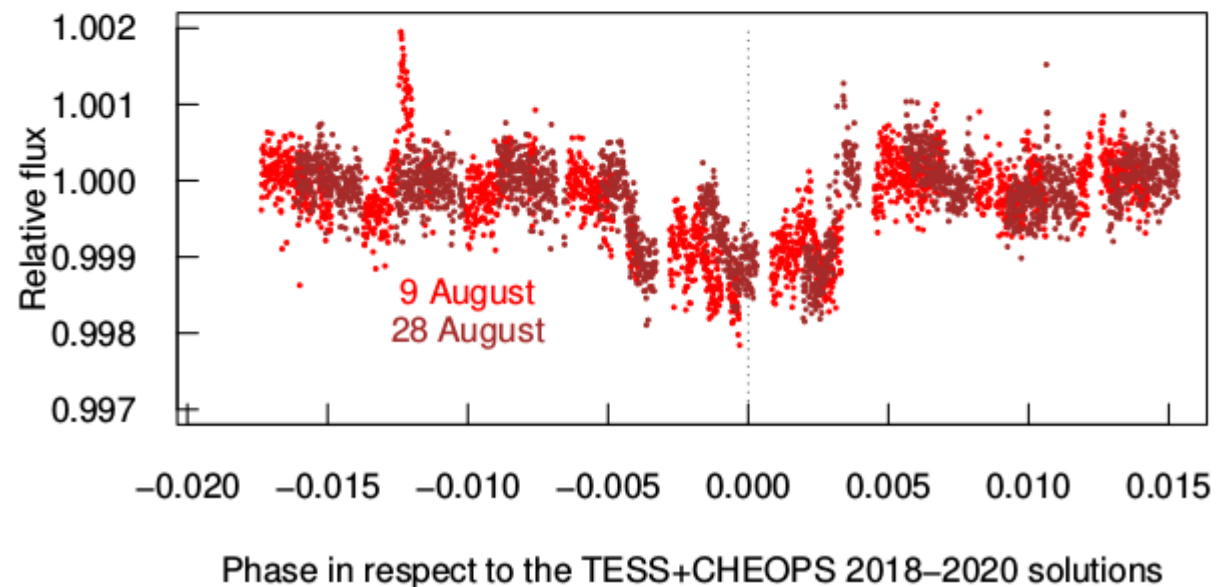


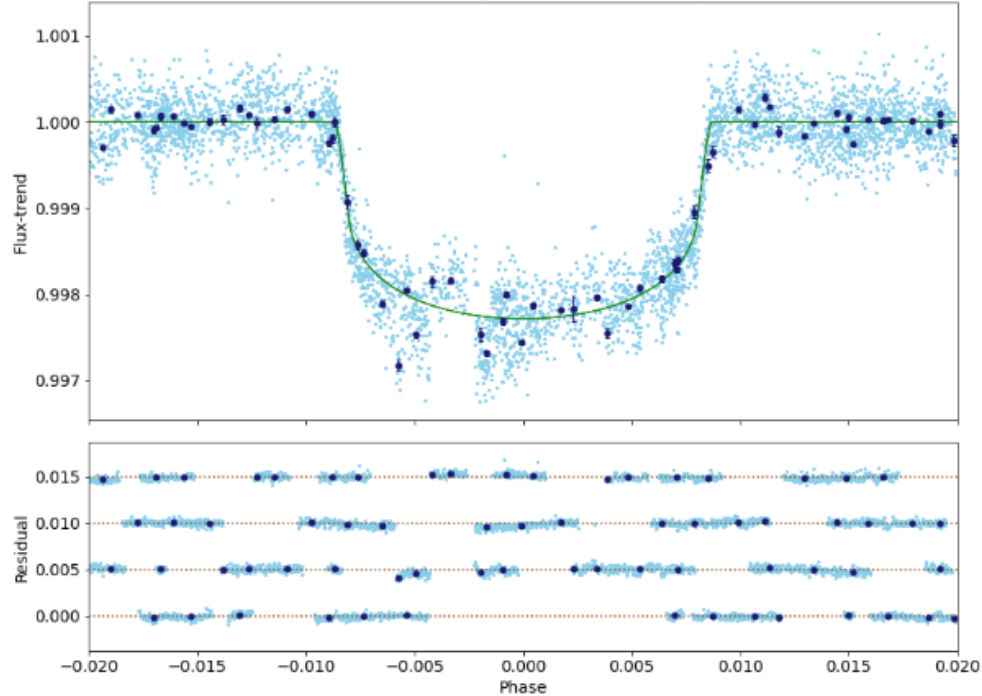
Table 2. Best-fitting parameters of AU Mic b. The parameters are compared to the results of [Plavchan et al. \(2020, P2020\)](#), [Martioli et al. \(2021, M2021\)](#), [Szabó et al. \(2021, Sz2021\)](#), and [Gilbert et al. \(2021, G2021\)](#).

	Szabó+ 2022	P2020	M2021	Sz2021	G2021
R_p/R_\star	0.0433 ± 0.0017	0.0514 ± 0.0013	$0.0526^{+0.0003}_{-0.0002}$	0.0531 ± 0.0023	0.0512 ± 0.0020
a/R_\star	18.95 ± 0.35	$19.1^{+1.8}_{-1.6}$	$19.1^{+0.2}_{-0.4}$	19.24 ± 0.37	19.07
W [h]	3.51 ± 0.03	$3.50^{+0.63}_{-0.59}$	3.50 ± 0.08	3.48 ± 0.19	$3.56^{+0.60}_{-0.46}$
R_p [R_\oplus]	3.55 ± 0.13	4.29 ± 0.20	4.07 ± 0.17	4.36 ± 0.18	4.27 ± 0.17
a [AU]	0.0654 ± 0.0012	$0.066^{+0.007}_{-0.006}$	0.0645 ± 0.0013	0.0678 ± 0.0013	$0.0644^{+0.0056}_{-0.0054}$
b	0.17 ± 0.11	$0.16^{+0.14}_{-0.11}$	0.18 ± 0.11	0.09 ± 0.05	$0.26^{+0.13}_{-0.17}$

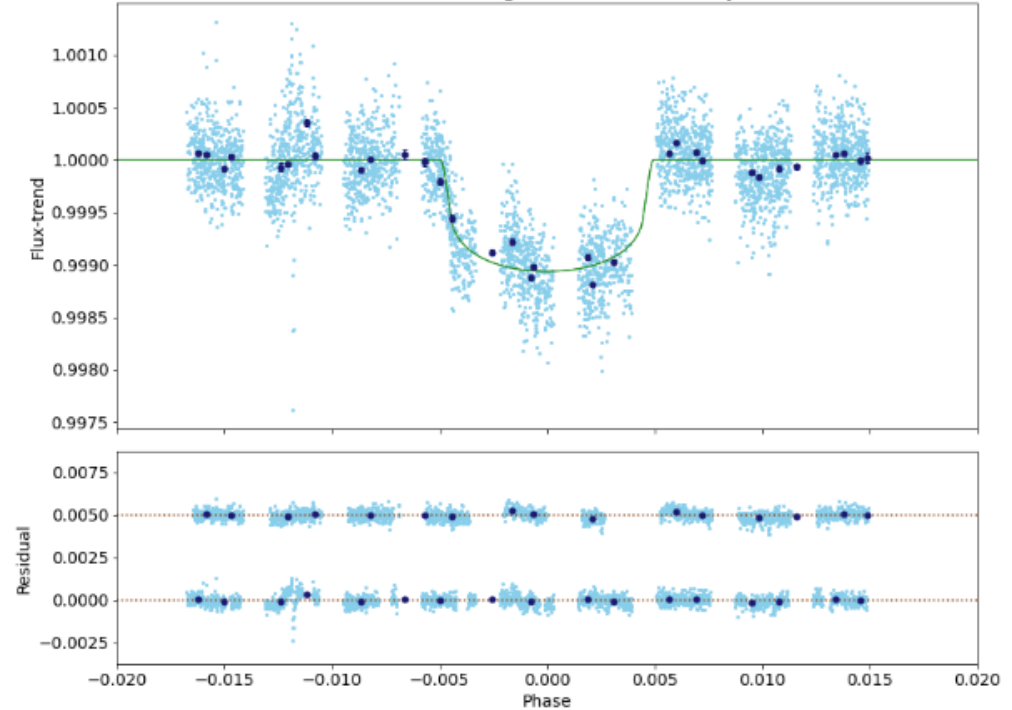
Table 3. Best-fitting parameters of AU Mic c. The parameters are compared to the results of M2021 and G2021.

	Szabó+ 2022	M2021	G2021
R_p/R_\star	0.0313 ± 0.0015	0.0395 ± 0.0011	$0.0340^{+0.0033}_{-0.0034}$
a/R_\star	28.8 ± 2.4	29 ± 3.0	$31.7^{+2.7}_{-2.6}$
W [h]	4.29 ± 0.30	4.50 ± 0.80	$4.20^{+0.92}_{-0.67}$
R_p [R_\oplus]	2.56 ± 0.12	3.24 ± 0.16	$2.79^{+0.31}_{-0.30}$
a [AU]	0.0993 ± 0.0085	0.1101 ± 0.0022	$0.110^{+0.010}_{-0.010}$
b	0.58 ± 0.13	0.51 ± 0.21	$0.30^{+0.21}_{-0.20}$

AU Mic b fitted transit light curves observed by CHEOPS

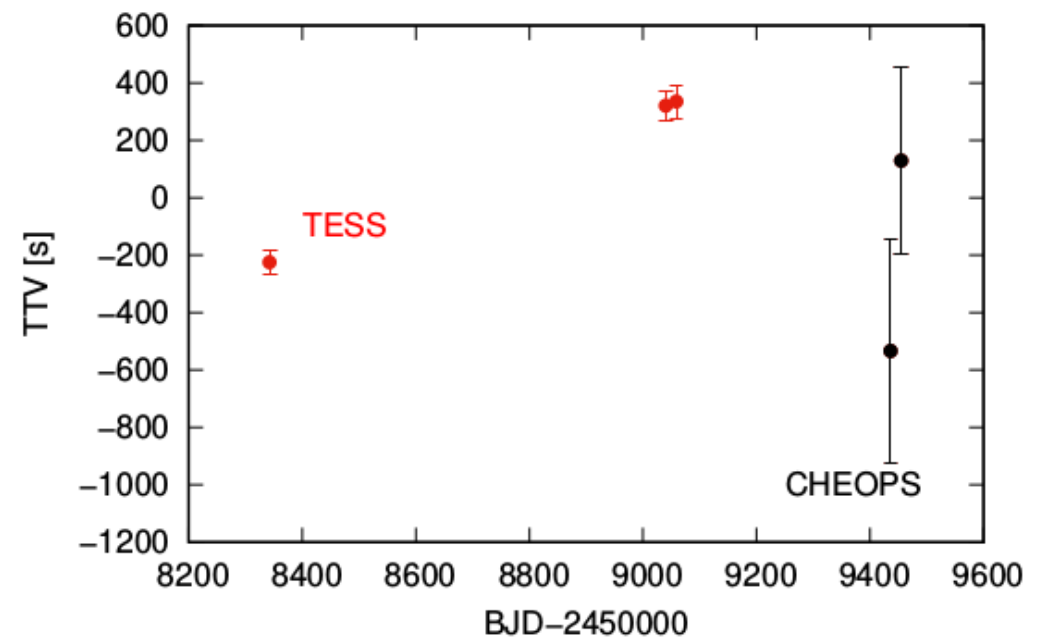
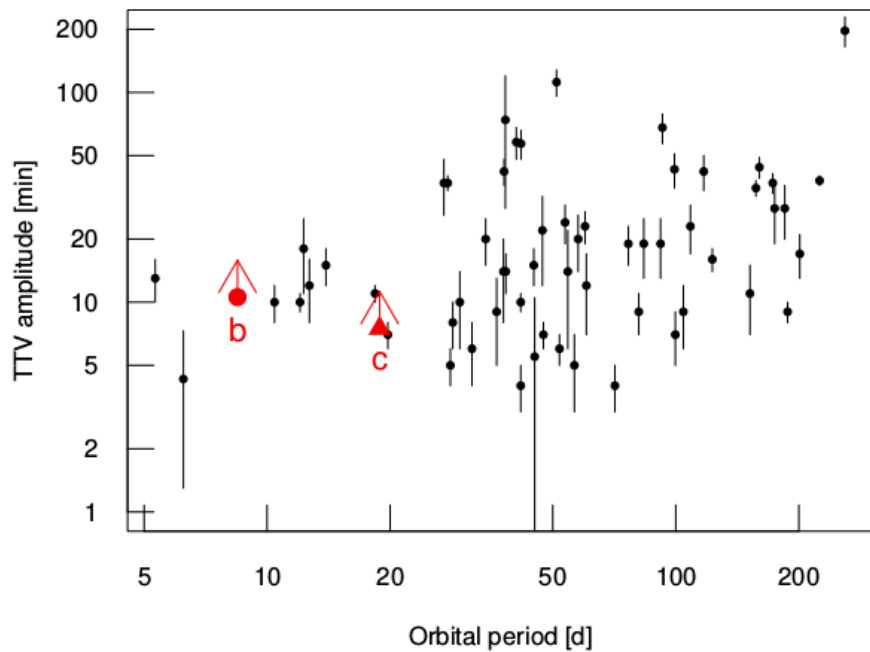
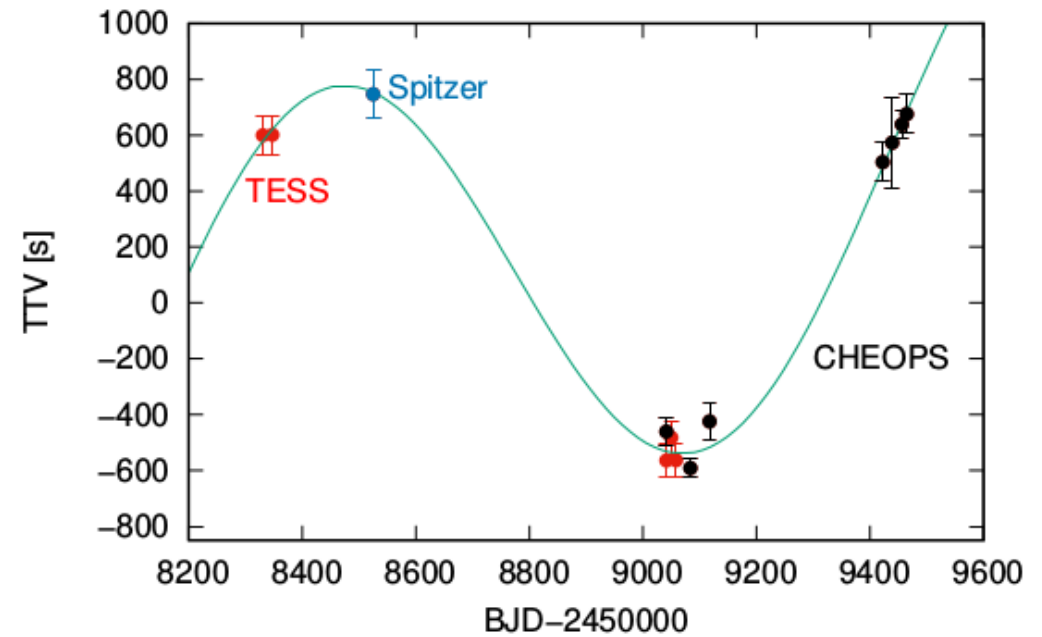


AU Mic c fitted transit light curves observed by CHEOPS



TTV as we see it now

AU Mic b and c are among the short-period planets with the largest TTVs known today



Be CAREFUL when planning 2022 observations

