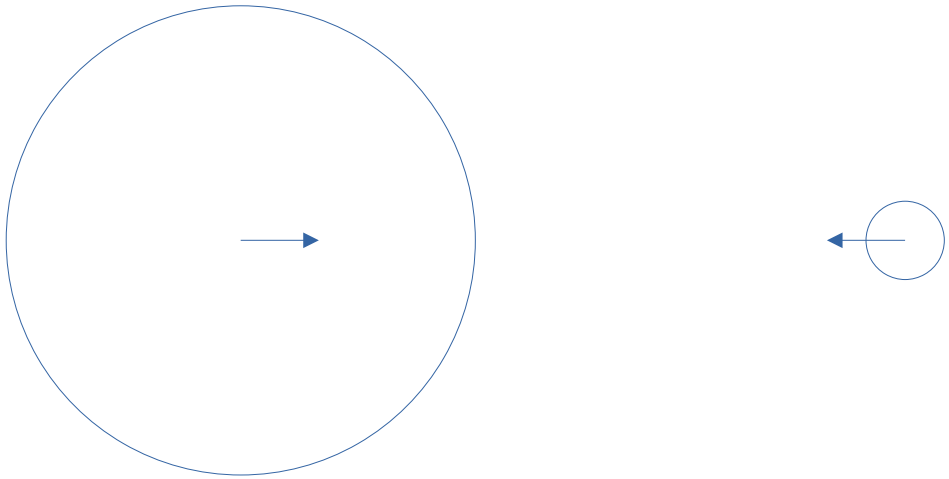
Probing planet-star tidal interactions with precise transit timing of hot Jupiters. Preliminary results from 2022/2023.

Jan Golonka
Supervisor: dr hab. Gracjan Maciejewski, prof. UMK

12.09.2023

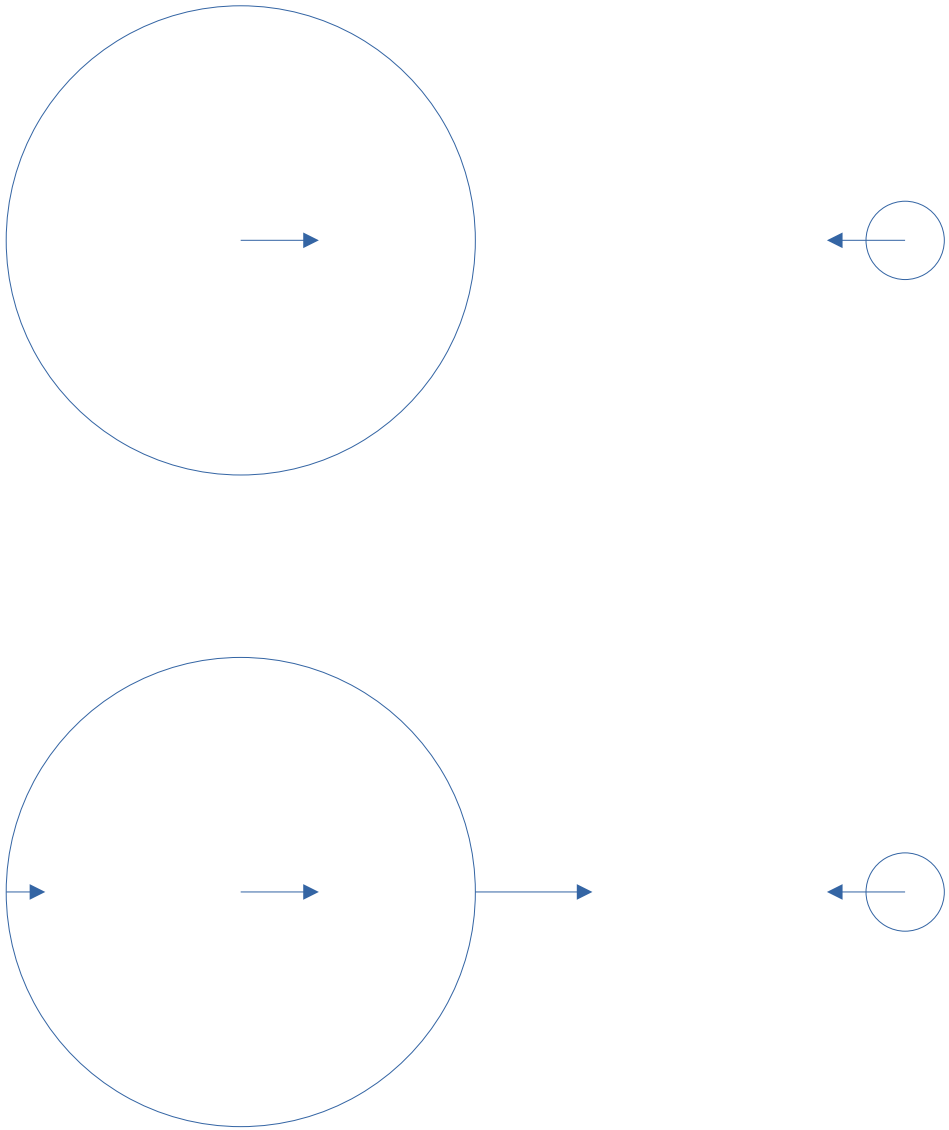
Tidal interactions



Force

$$G\frac{m_1 m_2}{R^2}$$

Tidal interactions



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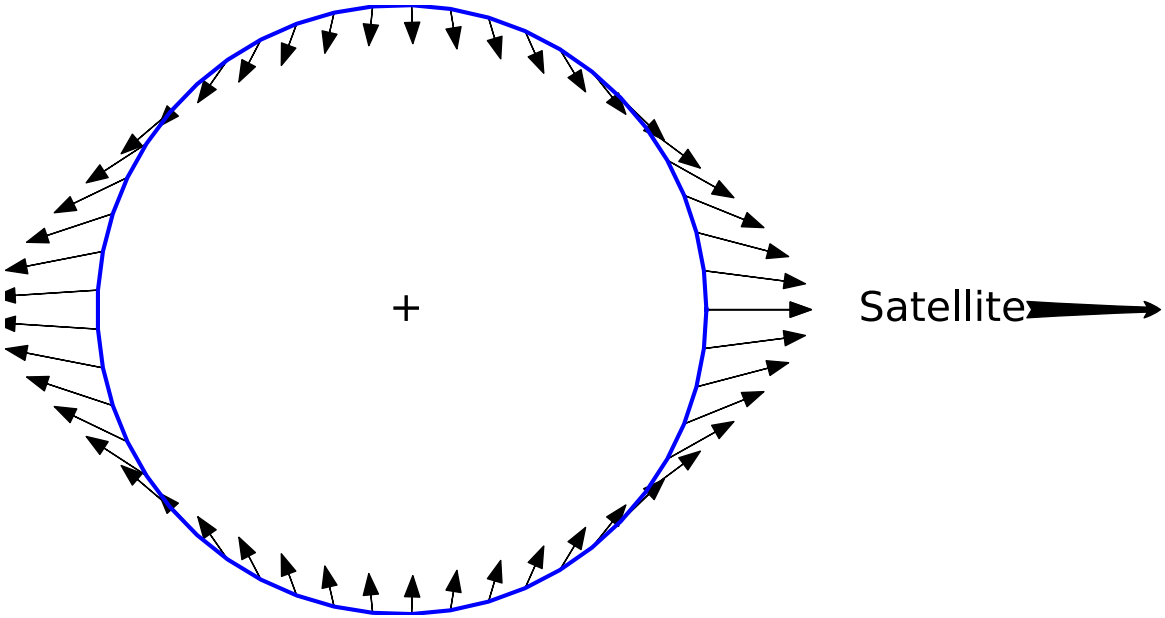
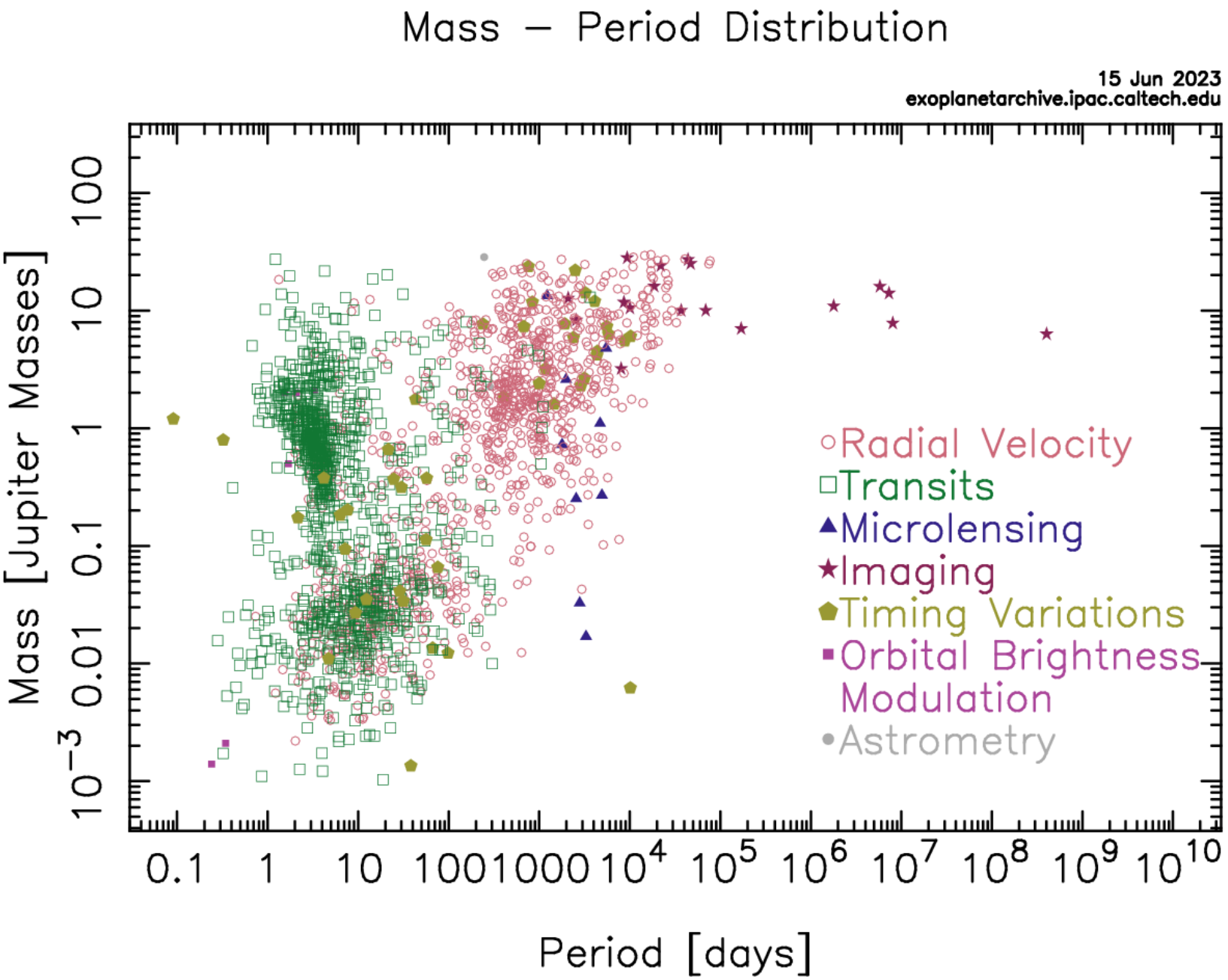
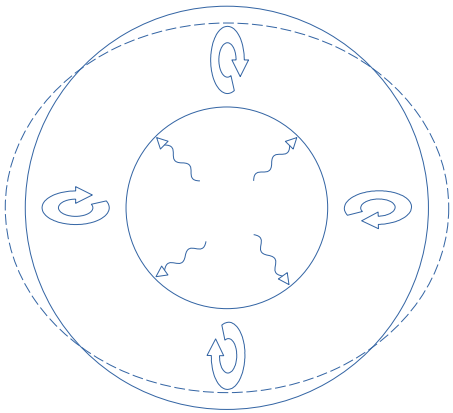


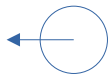
Wikipedia, Krishnavedala

Hot Jupiters



Models of tidal interactions





- Inertial waves

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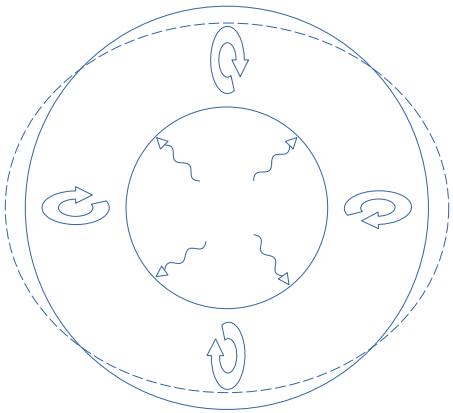

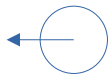

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- Expected to be strong in evolved stars

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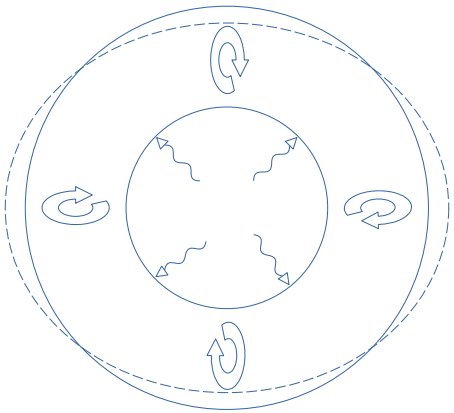

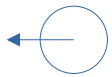

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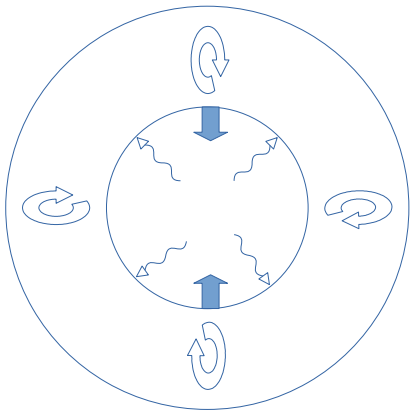

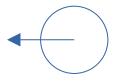

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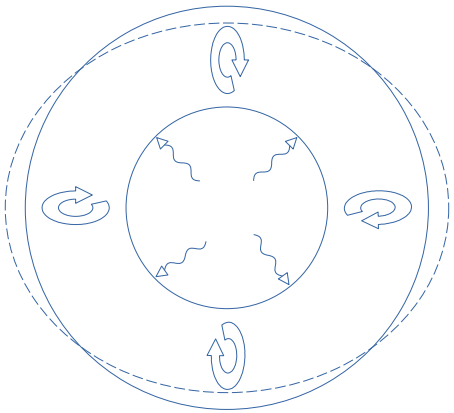

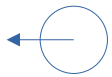

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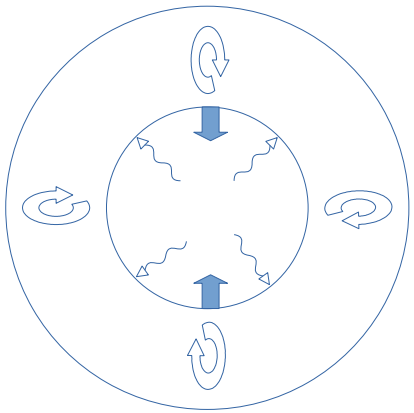

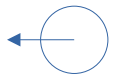

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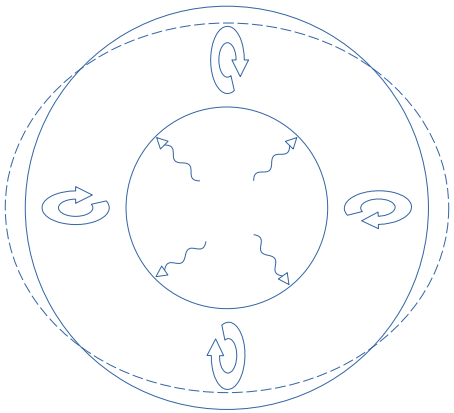

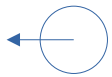

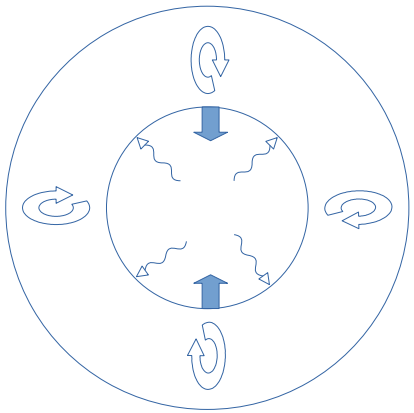

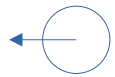

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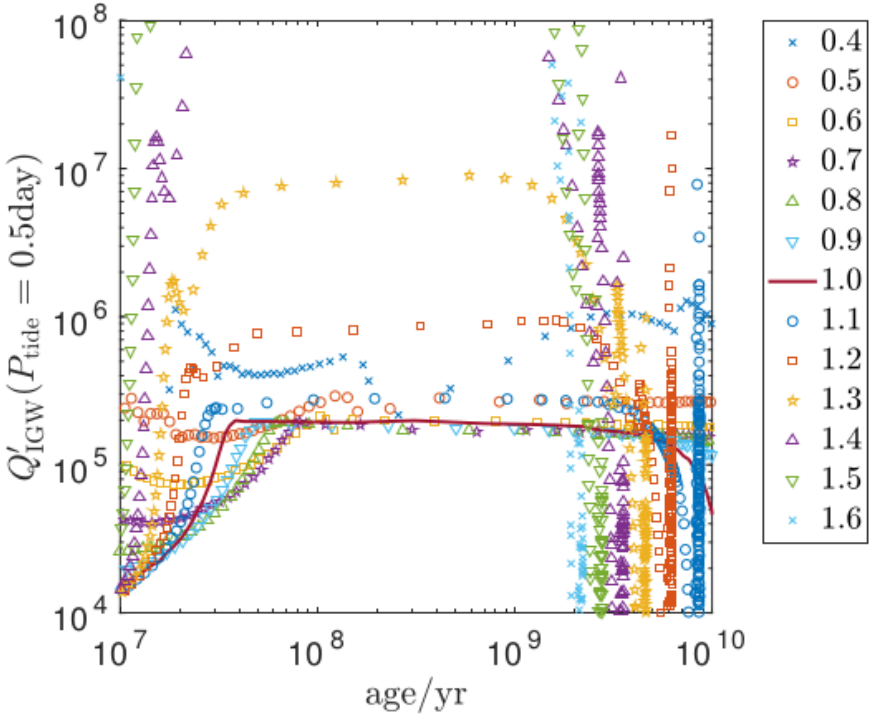
Quantified with Q - tidal quality factor

Gravity waves



Barker, 2020

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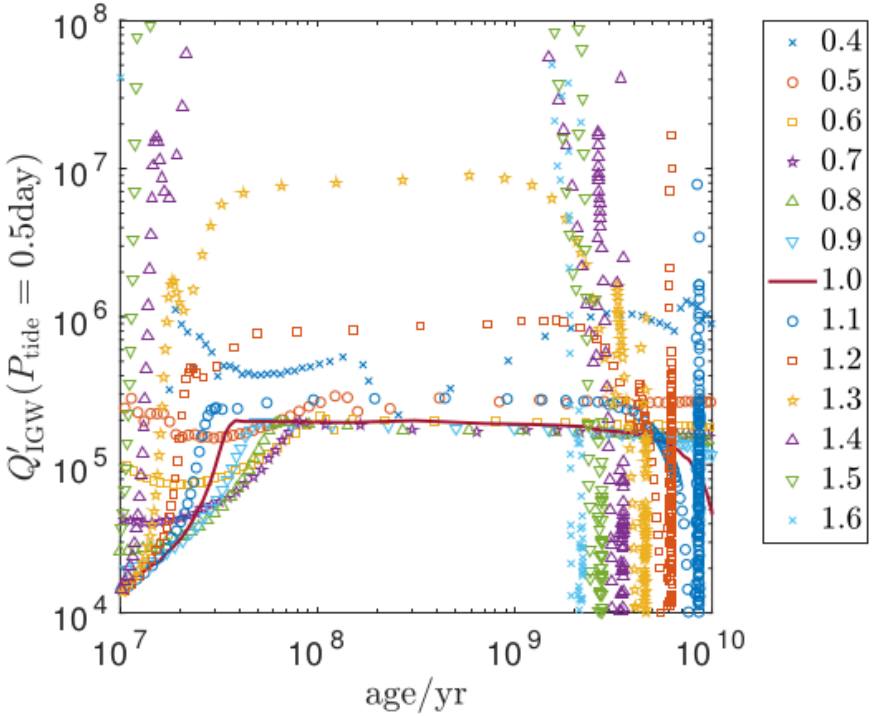

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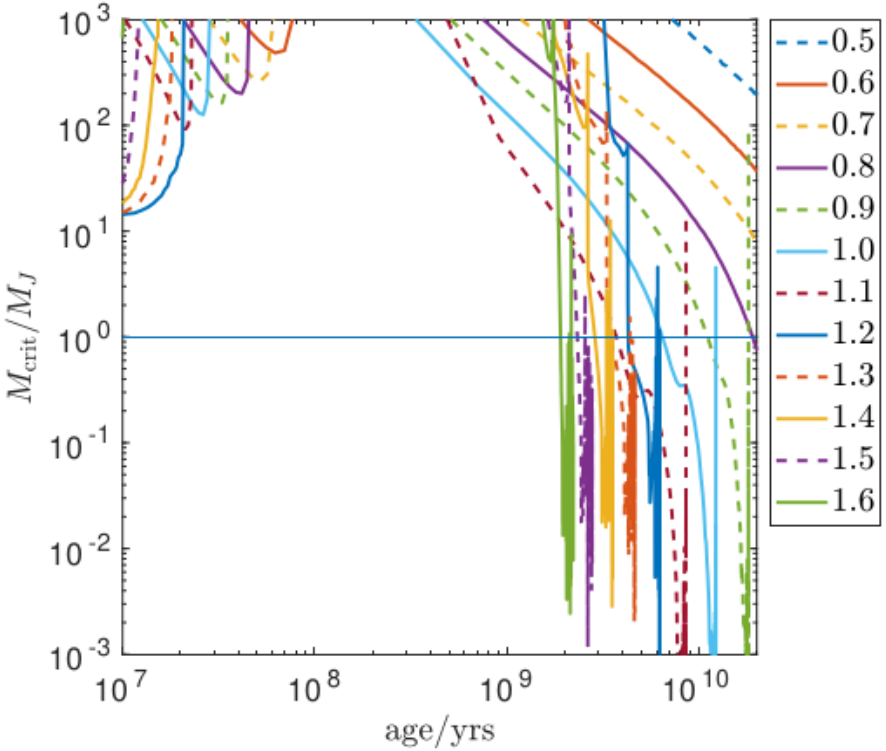

Barker, 2020

Testing theoretical models

Theory

Predicted values of Q for individual systems.

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Observations

Transit timing variations.

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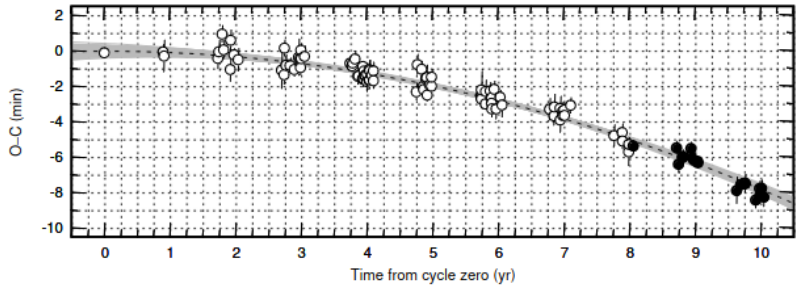

Maciejewski, 2018

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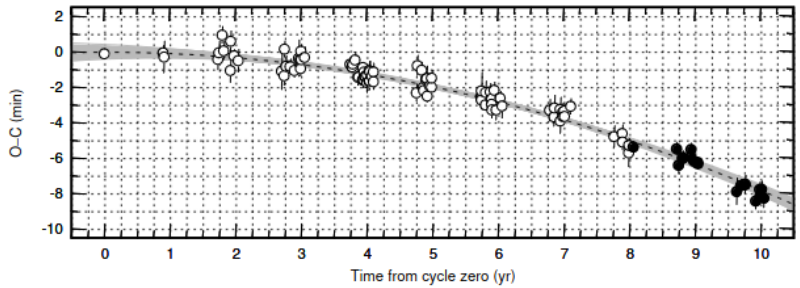
$$T_{shift} = \frac{-27\pi}{4} Q^{-1} \frac{M_p}{M} \left(\frac{R}{a}\right)^5 T_{dur}^2$$



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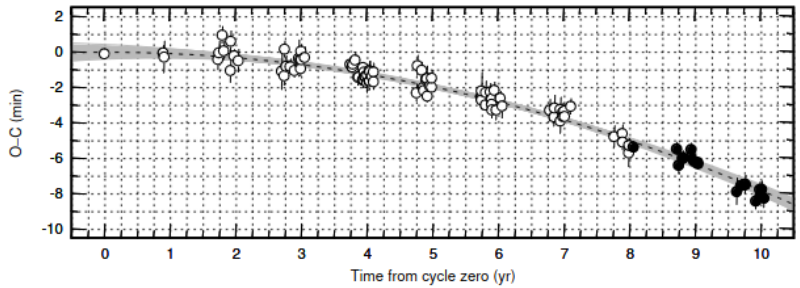

Maciejewski, 2018

Detection

Direct comparison with theory:

$$Q = -\frac{27}{2}\pi \left(\frac{M_p}{M_{star}}\right) \left(\frac{a}{R_{star}}\right)^{-5} \left(\frac{dP_{orb}}{dE}\right)^{-1} P_{orb}$$

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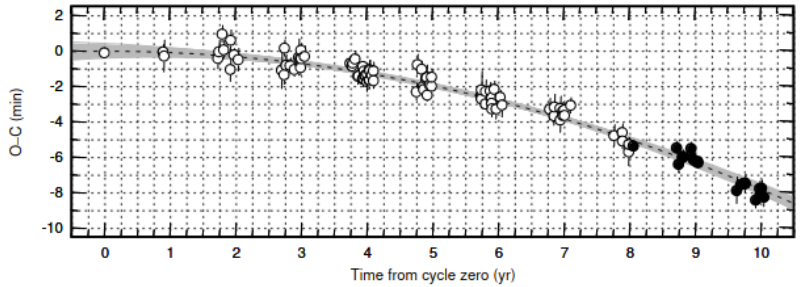

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Lack of detection

Lower limits on Q.

System sample

System	M_* [Msol]	First obs	Q_{IGW}	Tshift [s]	Mcrit
HAT-P-7	1.51	2008	8E+4	-260	yes
WASP-74	1.48	2012	8E+4	-43	no
XO-3	1.41	2004	2E+5	-74	no
KELT-1	1.34	2011	5E+6	-151	no
KELT-16	1.21	2015	4E+5	-207	no
HAT-P-53	1.09	2011	6E+5	-6	yes
HAT-P-36	1.02	2010	2E+5	-96	no
WASP-135	0.98	2014*	5E+5	-9	no
TrES-3	0.93	2007	4E+5	-28	no
Qatar 4	0.90	2015	1E+6	-2	no
TrES-5	0.89	2009	6E+5	-11	no
Qatar 2	0.74	2011	4E+5	-22	no

Data sources

Literature

- Taking available lightcurves, not Tc values
- Only full lightcurves, with points before and after transit
- PNR < 2.0 ppth/min

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Ground telescopes

- Piwnice, mainly TC60 but also TSC90 recently
- Observatory Sierra Nevada, Spain, 90cm and 150 cm telescopes
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- And other

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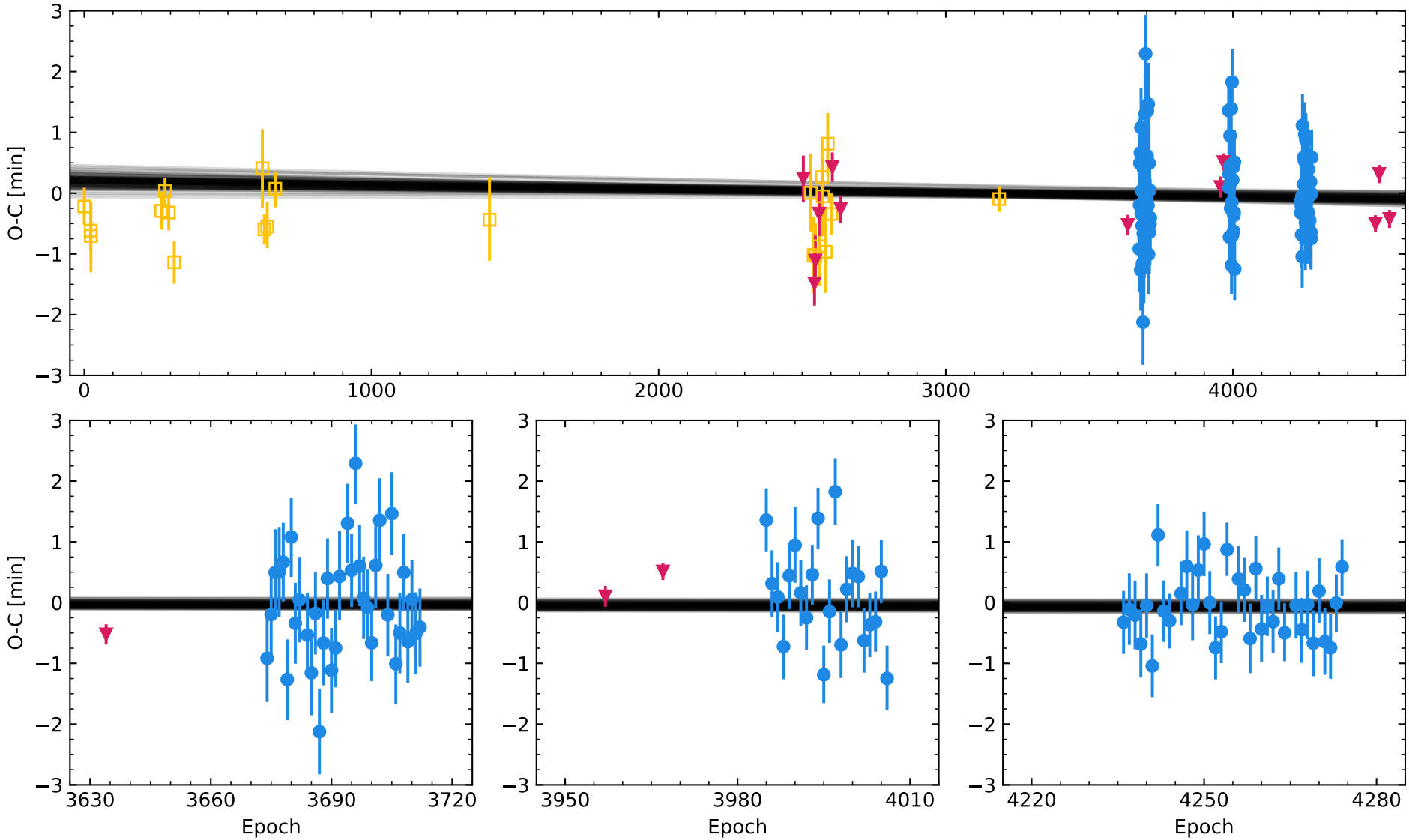
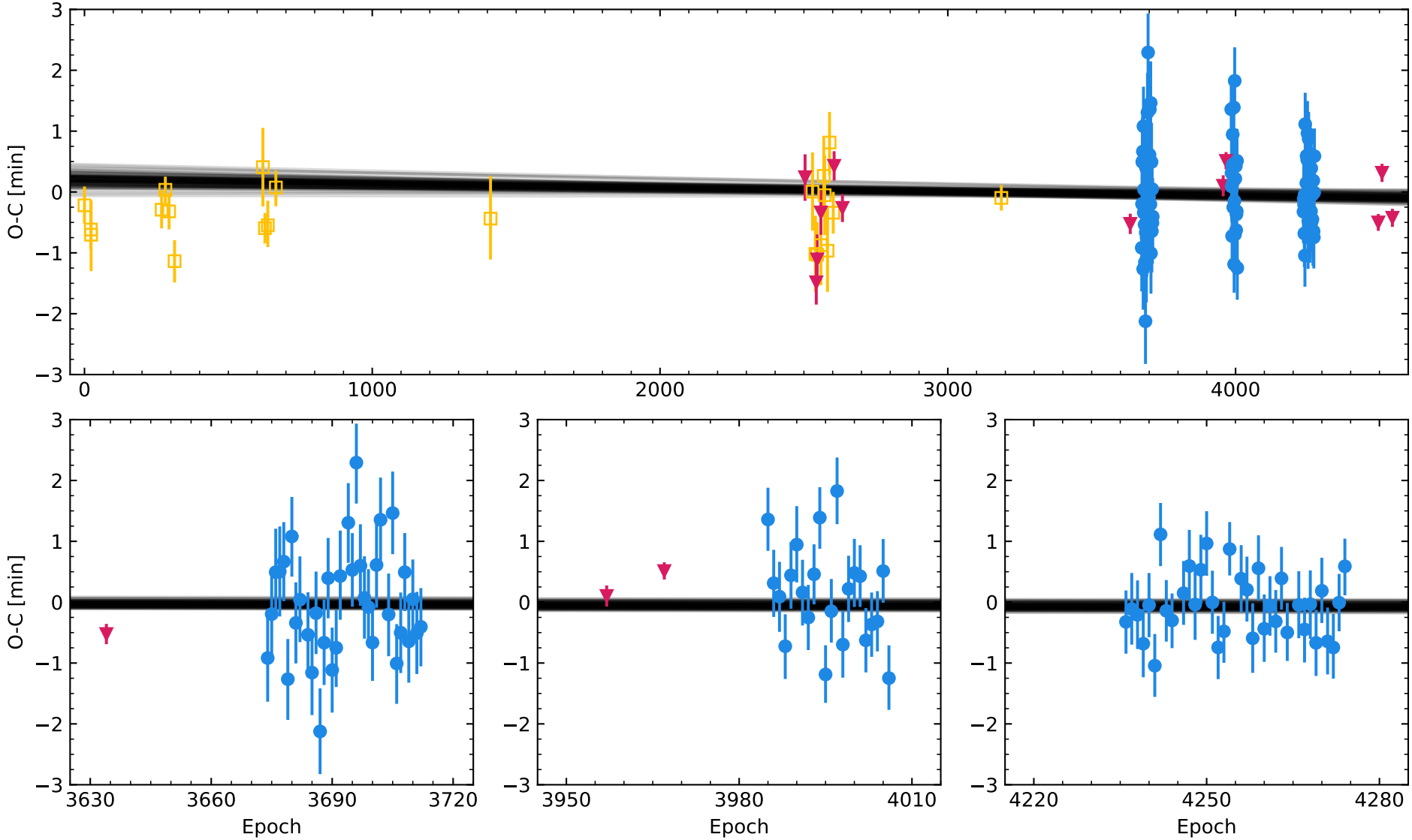
TESS

- Manual photometry
- All selected systems observed in TESS
- Up to 20 transits per sector

TrES-3

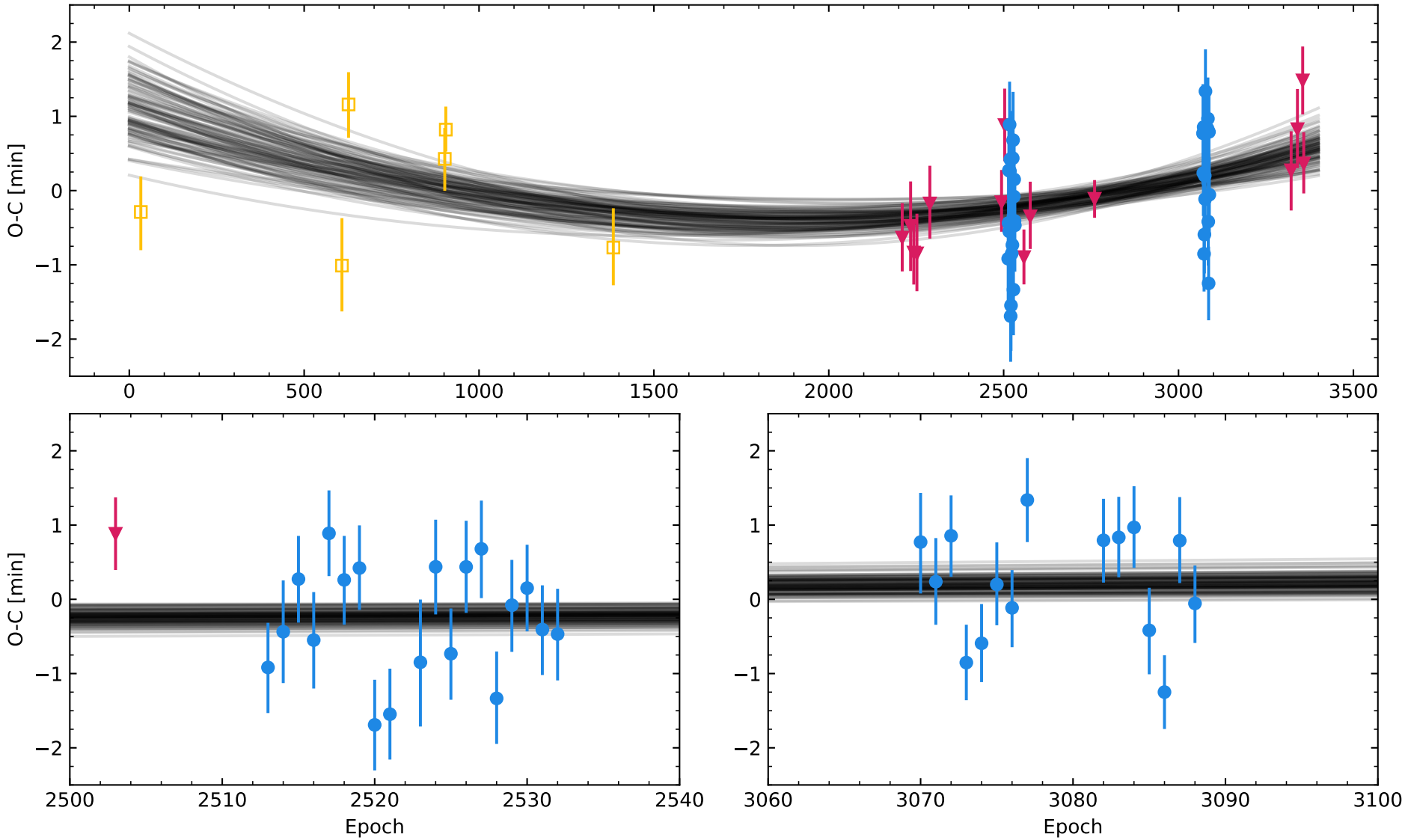

O-C [min]
Epoch
3
2
1
0
−1
−2
−3
0
1000
2000
3000
4000
3630
3660
3690
3720
3950
3980
4010
4220
4250
4280

TrES-3

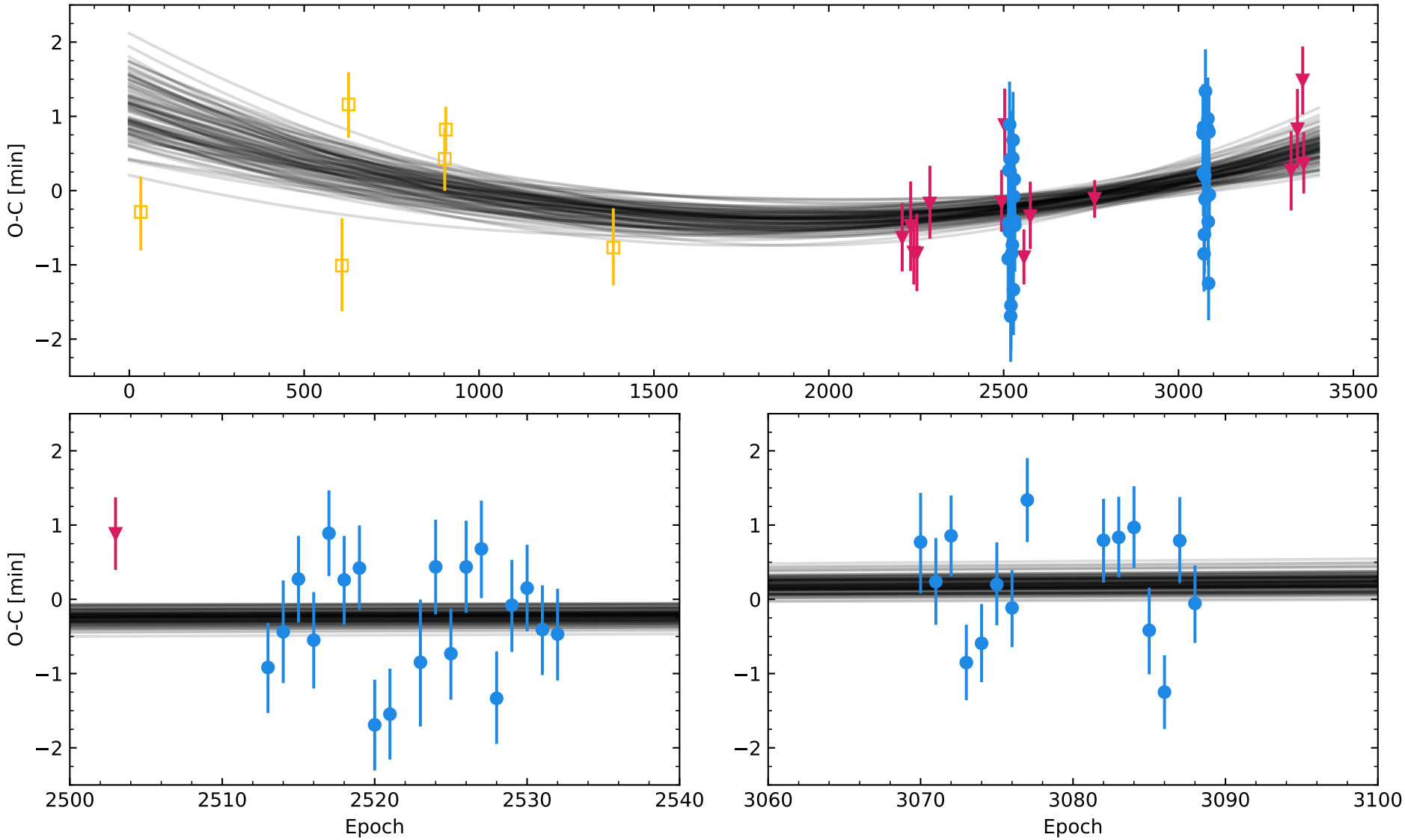


Linear over quadratic, $Q > 2\text{E}{+}5$ with 95%, $Q = 4\text{E}{+}5$ from theory

HAT-P-36

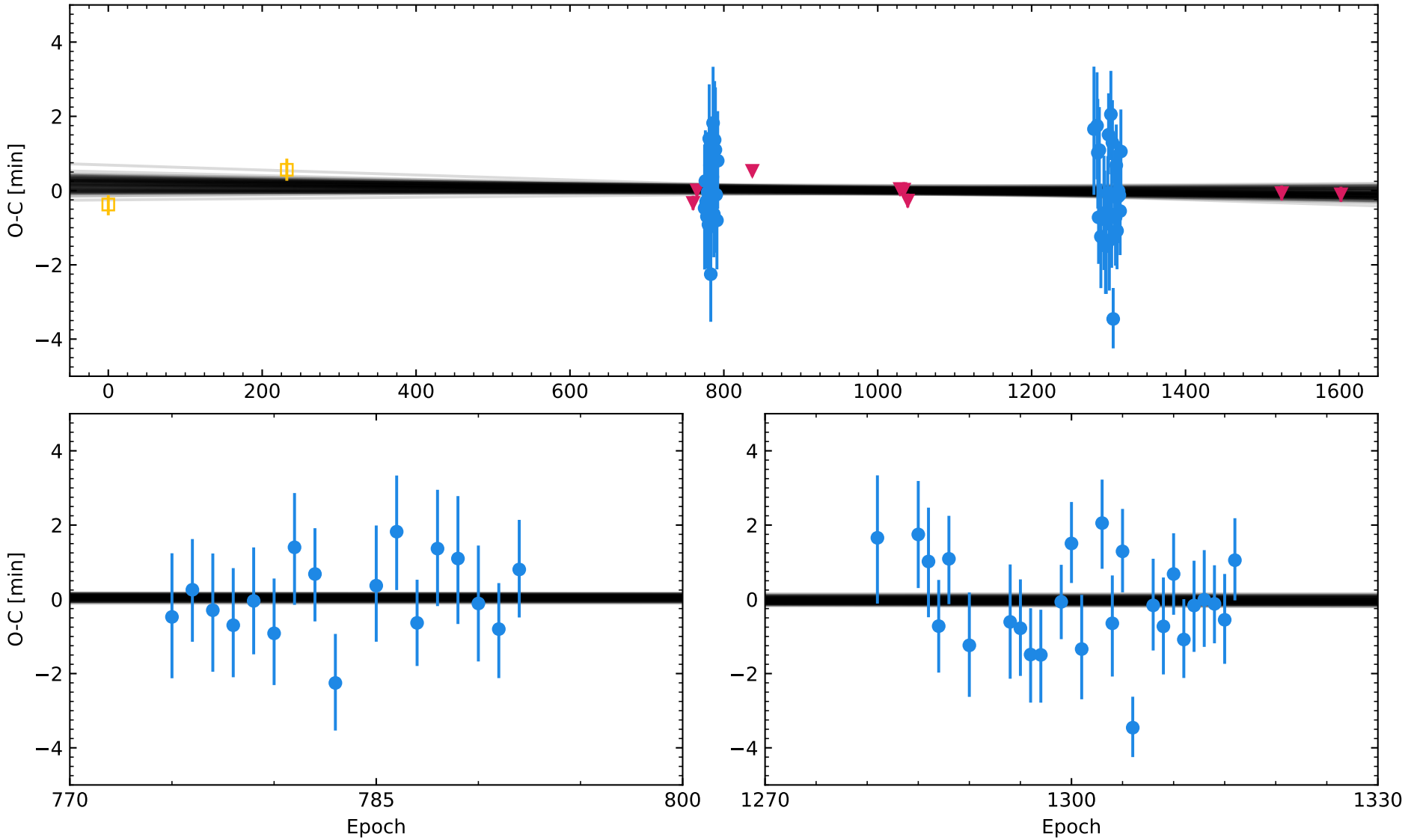

O-C [min]
Epoch
2500
2510
2520
2530
2540
3060
3070
3080
3090
3100

HAT-P-36

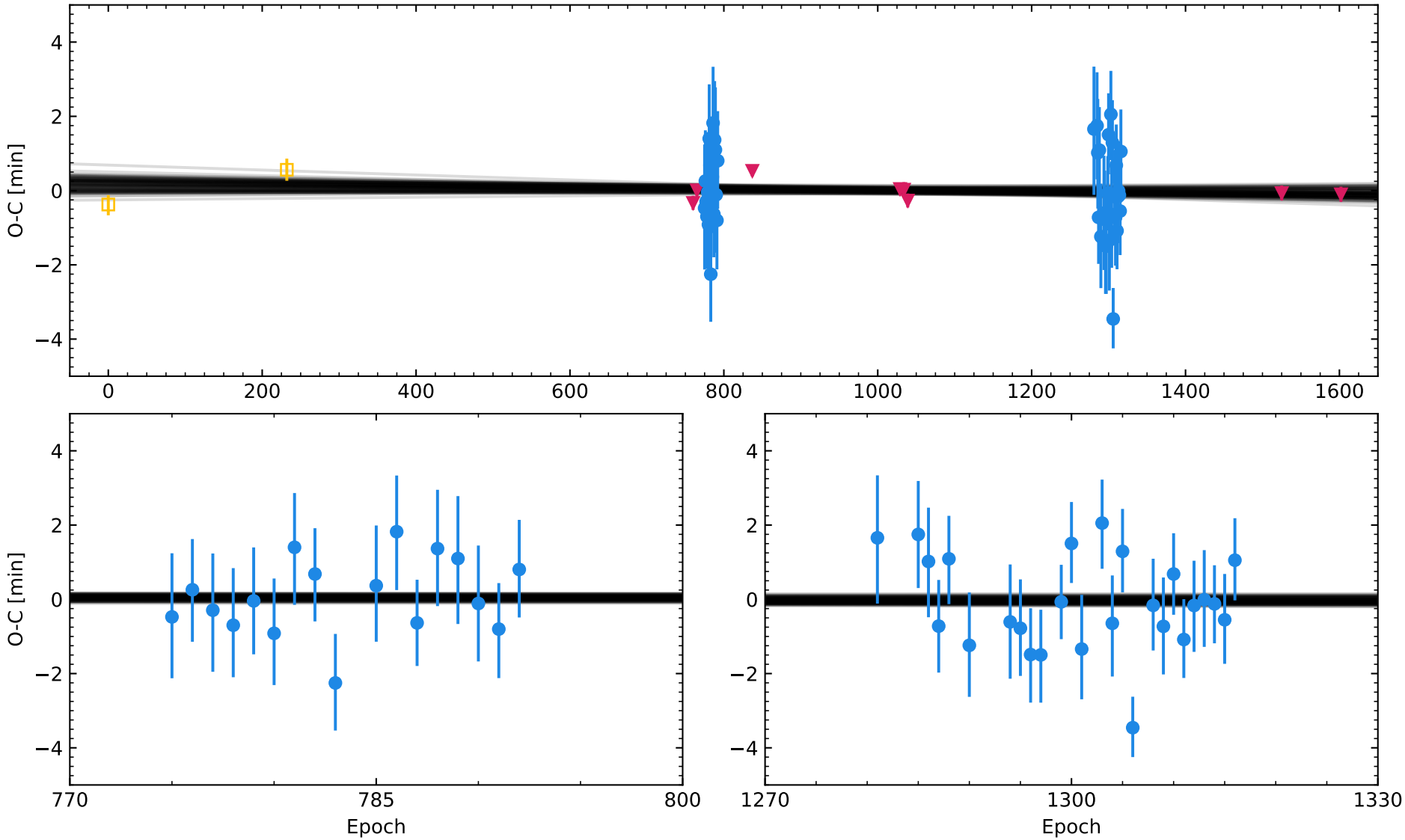


Quadratic over linear, dPer= 5.7E-10±1.4E-10, 4 sigma detection

WASP-135


O-C [min]
4
2
0
−2
−4
0
200
400
600
800
1000
1200
1400
1600
O-C [min]
770
785
800
Epoch
1270
1300
1330
Epoch

WASP-135



Linear over quadratic*, $Q > 1.6\text{E}{+4}$ with 95%, $Q = 5\text{E}{+5}$ from theory

Conclusions

1. Testing tidal interactions with Transit Timing Variations of hot Jupiters.
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