RFO Exoplanet Transits Follow-up

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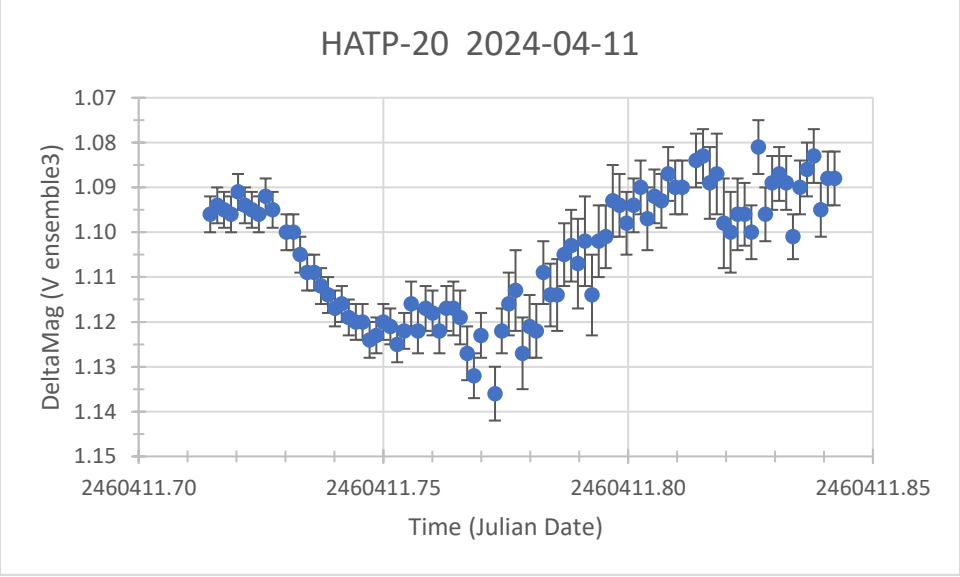
Error Bars

Using AIP4WIN to determine target brightness in magnitudes will automatically compute formal measurement errors. The transit curves reported here were obtained by requesting differential photometry with respect to an ensemble of comparison stars. The results are given in terms of instrumental magnitudes. However, if standard magnitudes are available for the comparison stars used for the ensemble, it should be possible to adjust the results for the ensemble and obtain standard magnitude values.

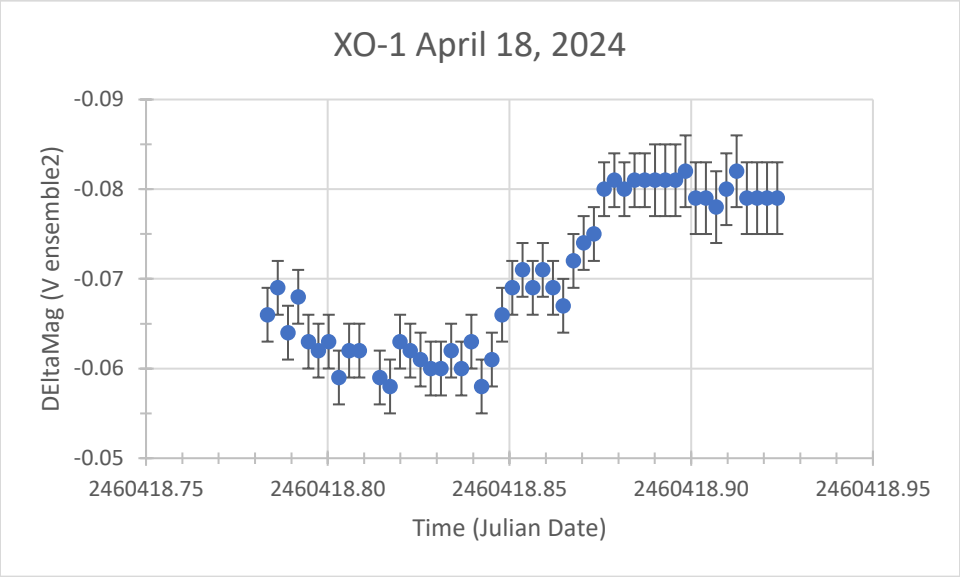
Formal errors are available for each image and data point, but they have not been plotted for simplicity. As examples, several transit curves showing error bars are included here.

HATP-20 2024-04-11

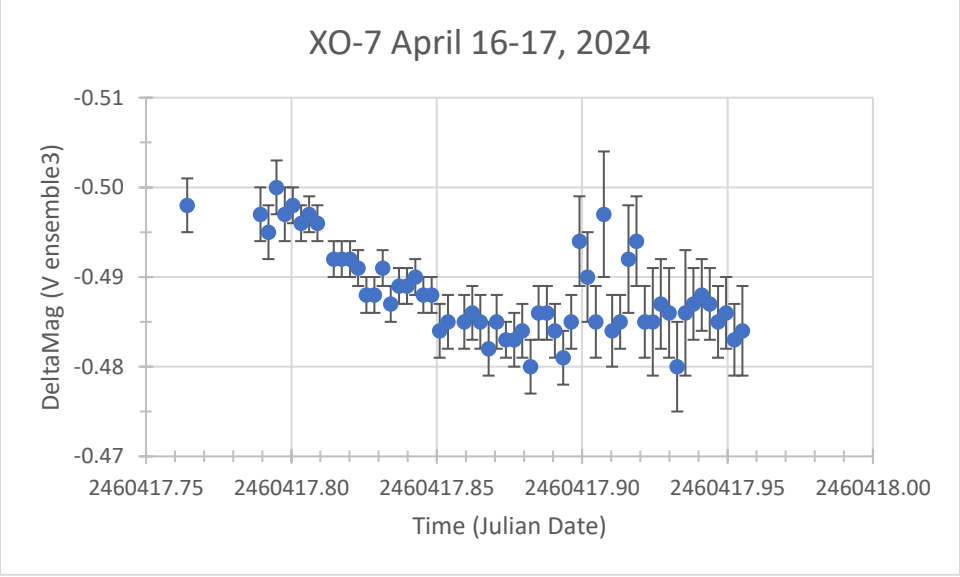


It can be seen how the presence of high scattered clouds has decreased the precision of the results. Larger errors are present during the second half of the observing run.

XO-1 2024-04-18



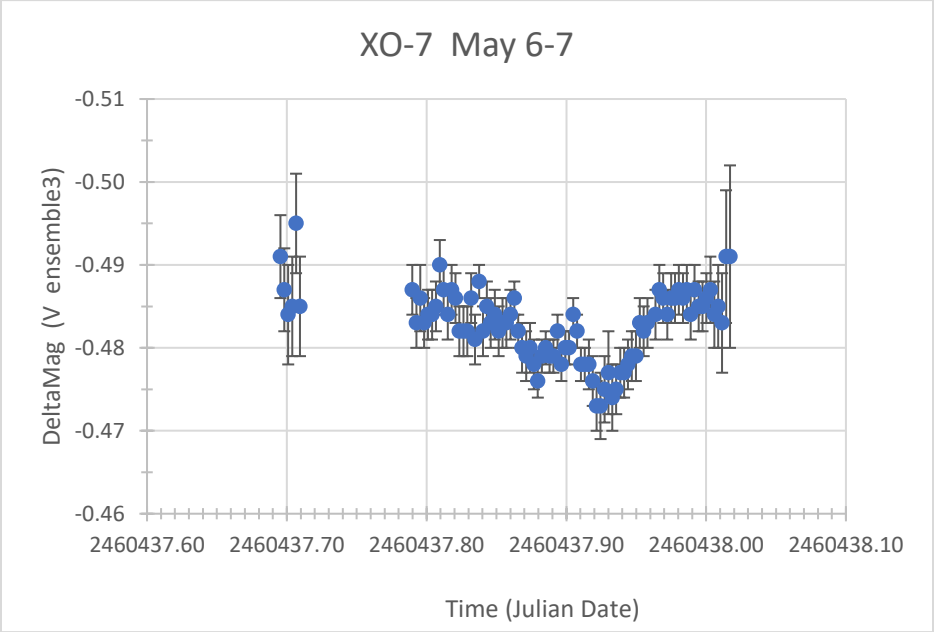
XO-7 2024-04-17



The error bars clearly indicate that the suppression of brightness after the supposed end of transit is real. What was causing the star to stay faint? The flickering around the supposed

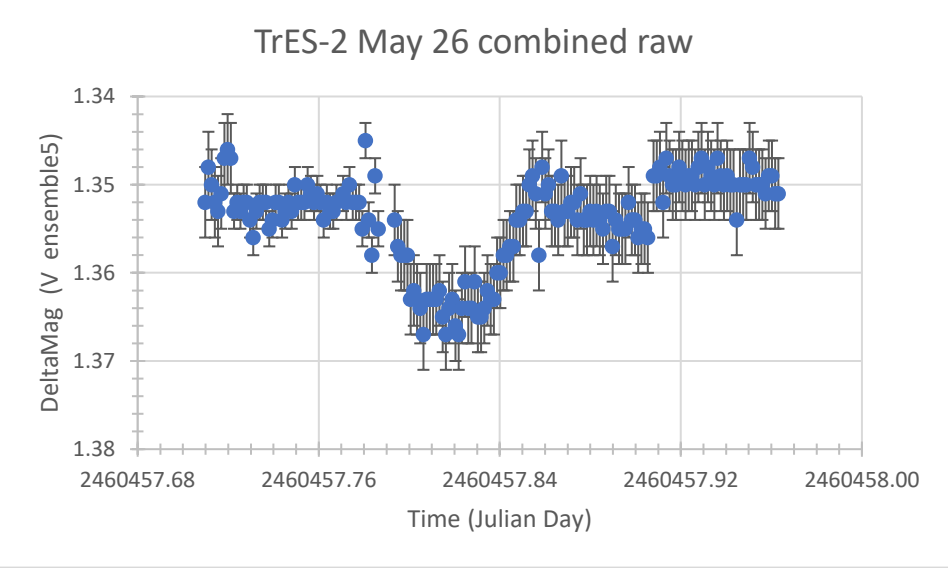
time of transit egress is also real. The mean error bar for this set of measurements is a little larger than 0.003 magnitude.

XO-7 2024-05-07



The error bars show that the "flickering" observed prior to the start of the transit may not be real, and may have been the result of dissipating high clouds. Also, the two points at the end of the run may also have been caused by something in the atmosphere.

TrES-2 2024-05-26

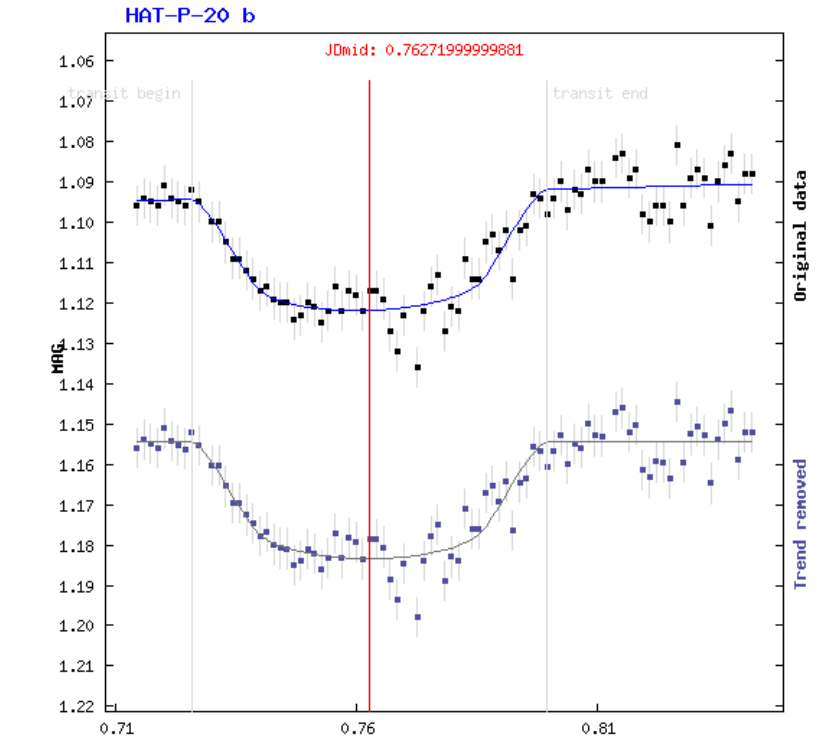


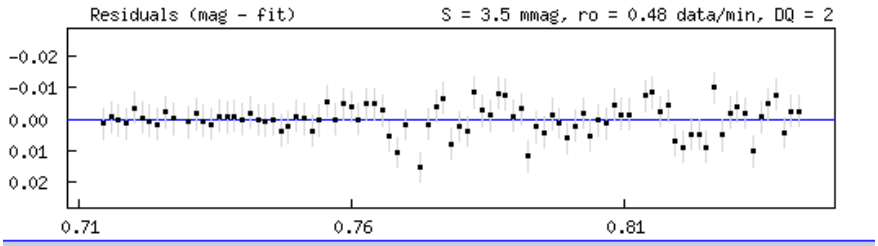
The error bars for this data sequence average about 3 mmag. The dip and brightness shift after the end of the transit seems to be real.

Transit Model Fits

The transit data was fit to a simple transit model provided by the **Exoplanet Transit Database (ETD).** http://var2.astro.cz/ETD/protocol.php This model will determine the time of mid-transit, the duration of the transit, and the depth of the transit curve for confirmed exoplanets with transits. The results obtained were always consistent with the expected parameters for the exoplanet. Sort of…

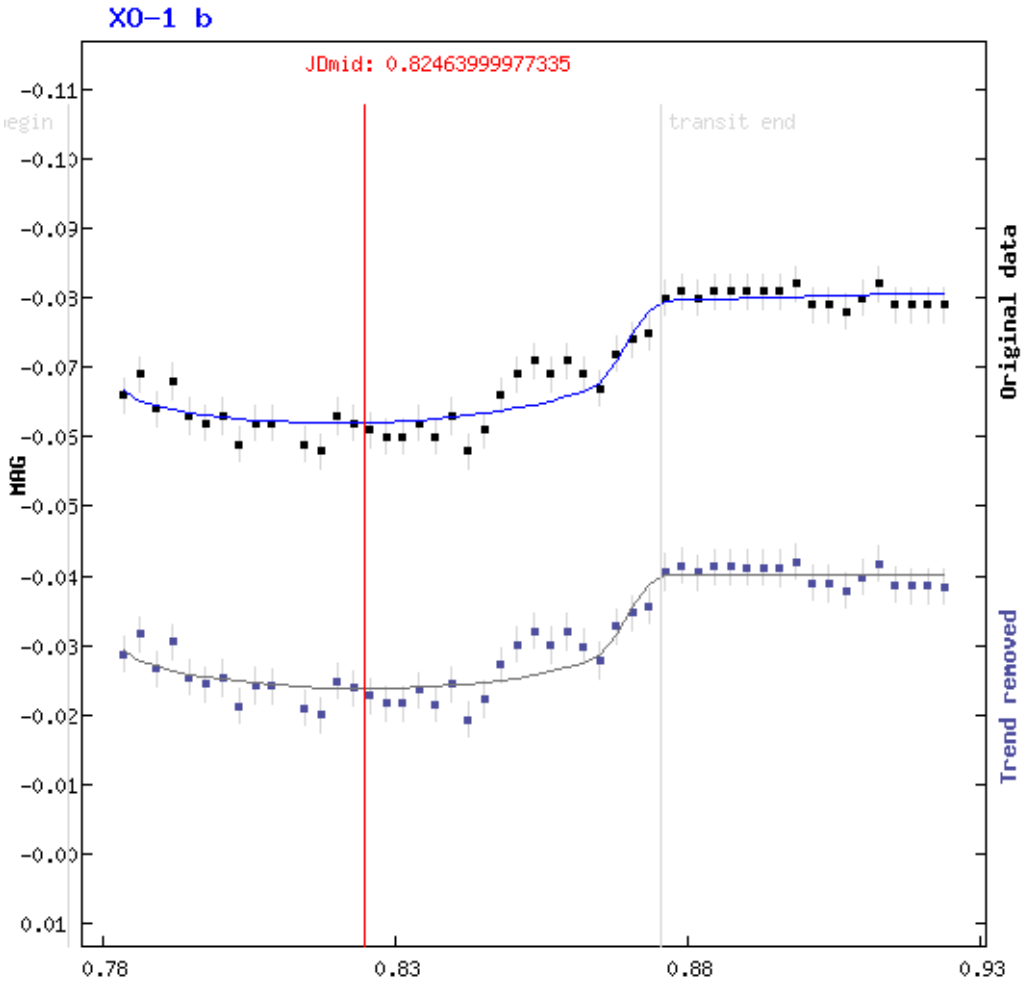
HATP-20 2024-04-11

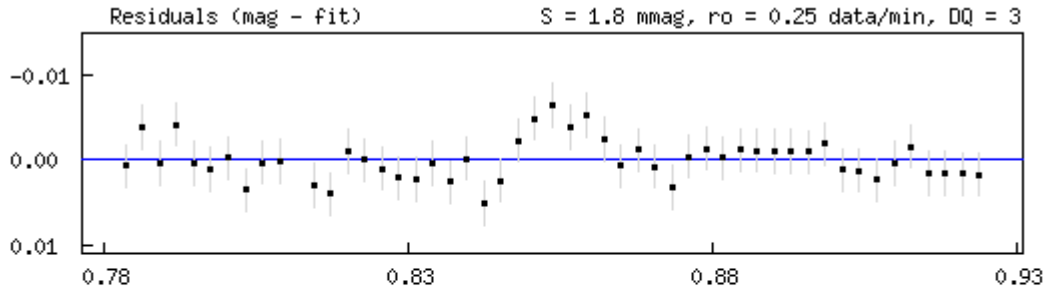




JD mid:	2460411.76272 +/- 0.00071	
HJD mid:	2460411.76251 +/- 0.00071	(helcor = **-0.00021**)
Duration:	105.9 +/- 2.9	minutes
Depth:	0.0288 +/- 0.0014	mag

XO-1 2024-04-18





JD mid:	2460418.82464 +/- 0.00176	
HJD mid:	2460418.82829 +/- 0.00176	(helcor = **0.00365**)
Duration:	145.8 +/- 5.8	minutes
Depth:	0.0164 +/- 0.0019	mag

Note that for this XO-1 data for 2024-04-18, an acceptable model fit was possible even though the start of the transit was not observed. The residuals for this fit amounted to 1.8 mmag.

Note also that the residuals confirm the presence of a blip in brightness during the rising branch of the transit.

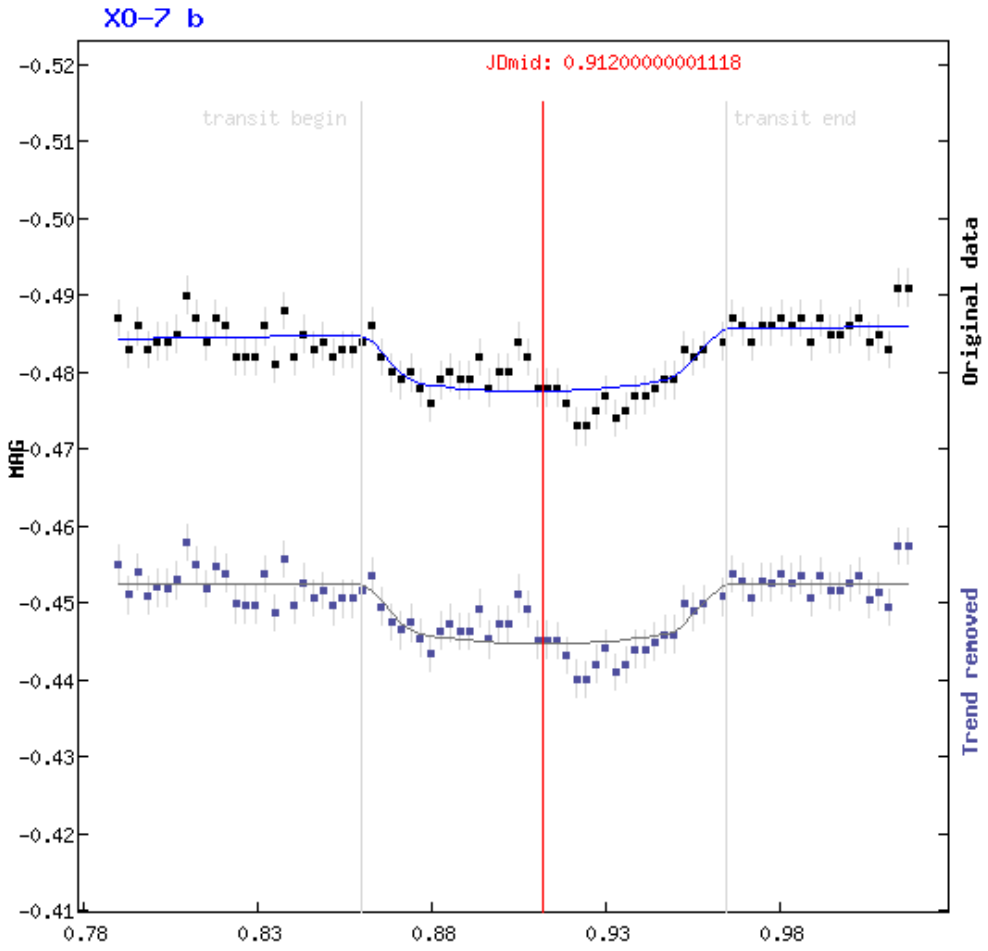
How about XO-7?

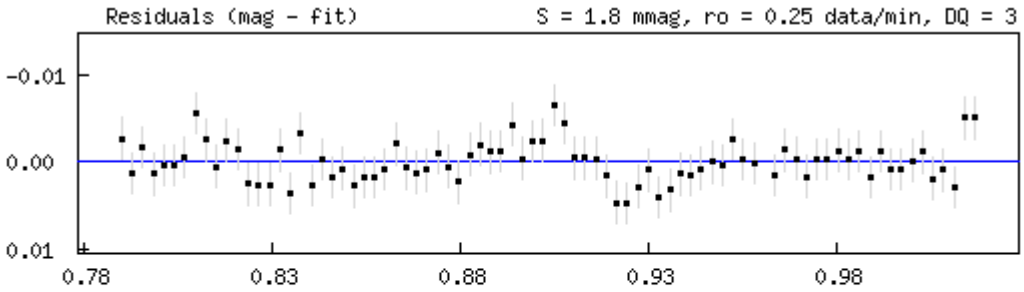
A model fit was **not possible** for the XO-7 data set obtained on 2024-04-17. The brightness did decrease about the time a predicted transit was supposed to occur. However, the brightness did not return to pre-transit levels after the transit was supposedly over.

We have now obtained data for several additional transits for XO-7. For one transit, the data obtained did not have the appearance of a simple, normal transit. However, several successful transit curves were obtained.

A successful transit was observed for XO-7 on the night of May 6. Even though the appearance of the transit was quite unusual, a model fit to the data was possible. The transit curve is noticeably asymmetric with the second half of the transit becoming fainter than usual for this object while the first half of the transit remains brighter than usual. During the first half of the transit brightness levels nearly return to pre-transit levels. The over-all depth of the transit is less than expected.

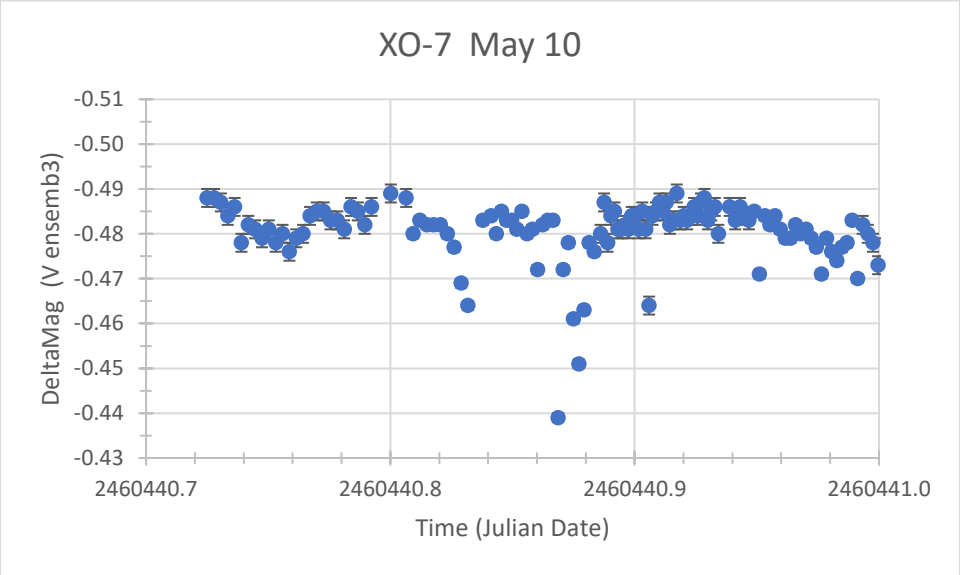
XO-7 2024-05-07





JD mid:	2460437.91200 +/- 0.00182	
HJD mid:	2460437.91058 +/- 0.00182	(helcor = **-0.00142**)
Duration:	151.1 +/- 6.6	minutes
Depth:	0.0077 +/- 0.0006	mag

Additional observations for XO-7 were obtained on the night of May 9. Observations began on the night of May 9 and were continued until dawn on May 10. A normal recognizable transit was not present in the data. The beginnings of a normal transit may have been recorded, but near the time of mid-transit irregular variations began and continued throughout the observing run during the morning of May 10. It is true that on the night of May 10 unusual bright aurora were observed throughout Sonoma County. No visible aurora were detected at the observatory during the morning of May 10.

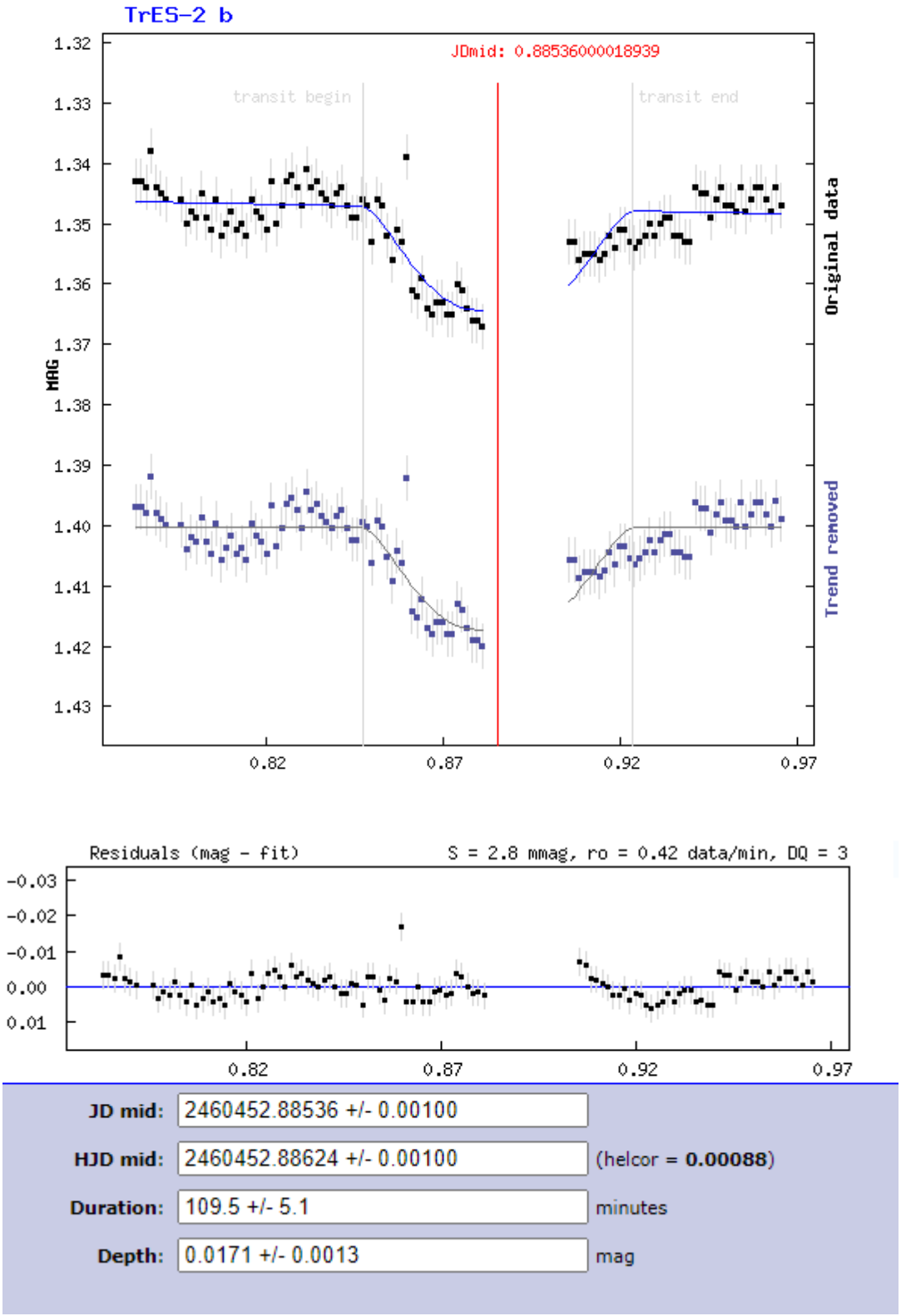


Mid-transit was predicted to occur at JD 2460440.78 and the transit should have ended by JD 2460440.84.

After observing the unusual and variable features of the transit curves for XO-7, it was decided to observe an additional object that would hopefully have a more stable and reproduceable transit curve. The object TrES-2 was selected for this exploration. Three successful transits were observed for this target.

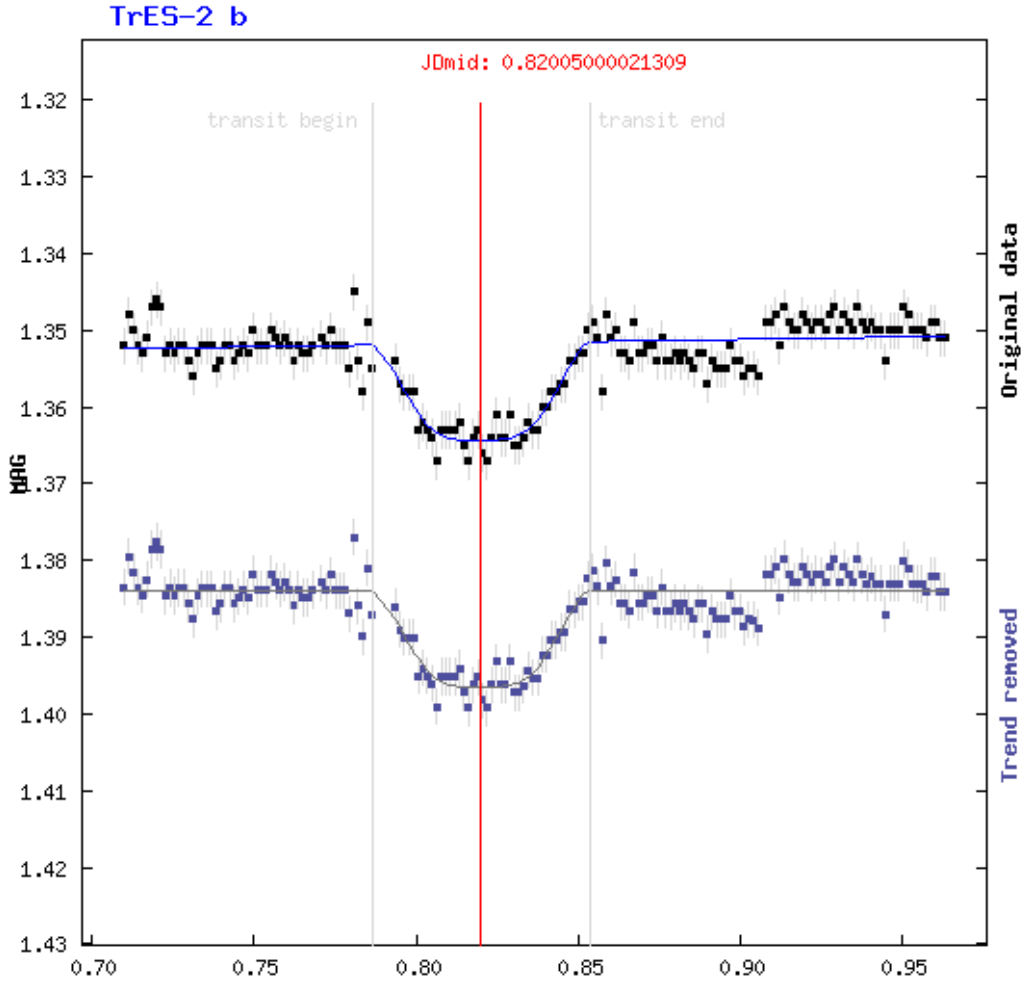
TrES-2 was first observed at RFO on May 21. This target had a well defined transit curve, but did have a prominent dip which preceded the transit. Something was causing the brightness of the star to decrease slightly just before the start of the transit. There is also a small feature at the end of the transit that delays the return to full brightness for about 30 minutes after the end of the transit. Something was preventing the return to full brightness after the planet moved off from the edge of the star. A model was readily fit to the data with a mean residual of 2.8 mmag.

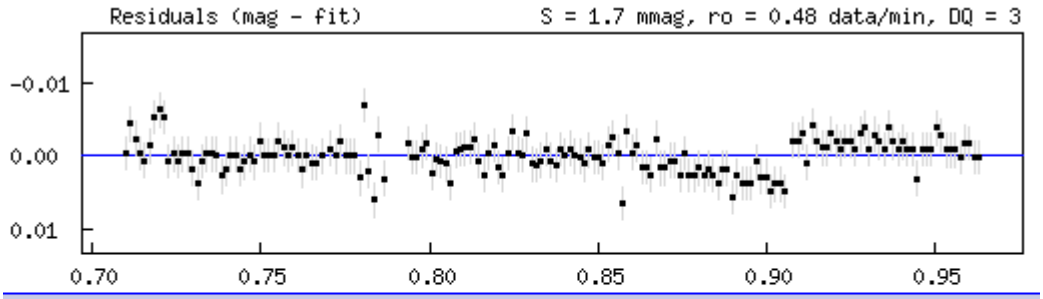
TrES-2 2024-05-21



JD mid:	2460452.88536 +/- 0.00100	
HJD mid:	2460452.88624 +/- 0.00100	(helcor = **0.00088**)
Duration:	109.5 +/- 5.1	minutes
Depth:	0.0171 +/- 0.0013	mag

TrES-2 2024-05-26





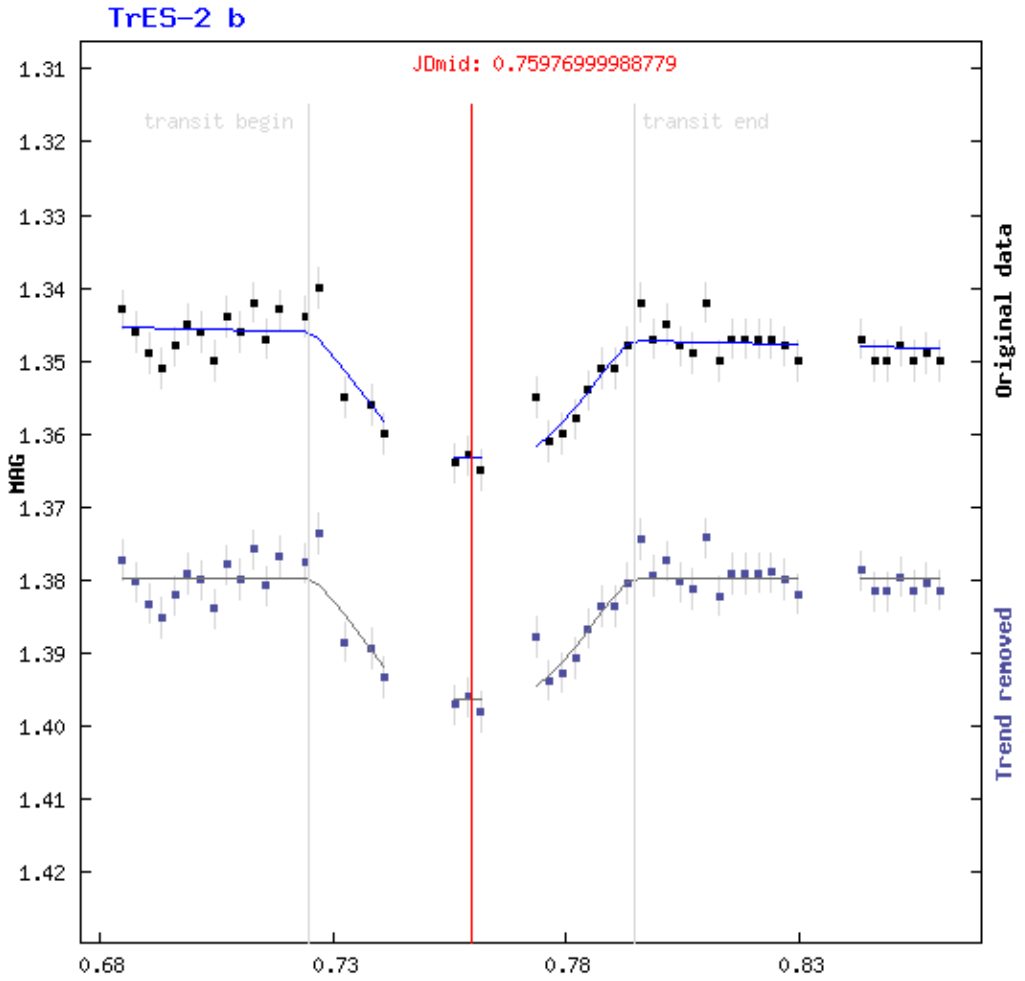
JD mid:	2460457.82005 +/- 0.00078	
HJD mid:	2460457.82107 +/- 0.00078	(helcor = **0.00102**)
Duration:	96.1 +/- 3.7	minutes
Depth:	0.0127 +/- 0.0006	mag

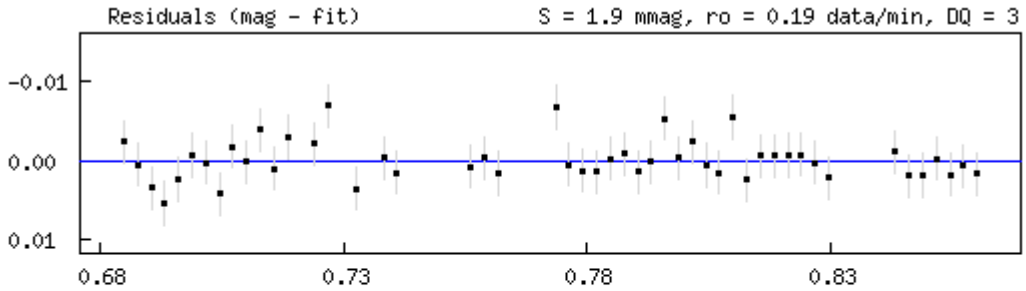
Unlike the May 21 transit with a dip prior to the start of the transit, the May 26 transit has a prominent dip after the end of the transit. There is no preceding dip for the May 26 transit data. A model was readily fit to the May 26 data with a mean residual of 1.7 mmag.

The final transit observed for TrES-2 was on June 1. For this data a dip is again observed prior to the beginning of the transit. The model fit to this data has a mean residual of 1.7 mmag.

The expectation that an additional exoplanet would exhibit a stable and well-defined and traditional transit curve was not realized. It seems that the hot Jupiter exoplanets observed at RFO all exhibit irregularities and instabilities. Each transit observed for an object seems a little different. Transits do not repeat exactly. There may be material preceding or following in their orbit. Perhaps this is the nature of the orbital plane for planets orbiting this close to their star.

TrES-2 2024-06-01

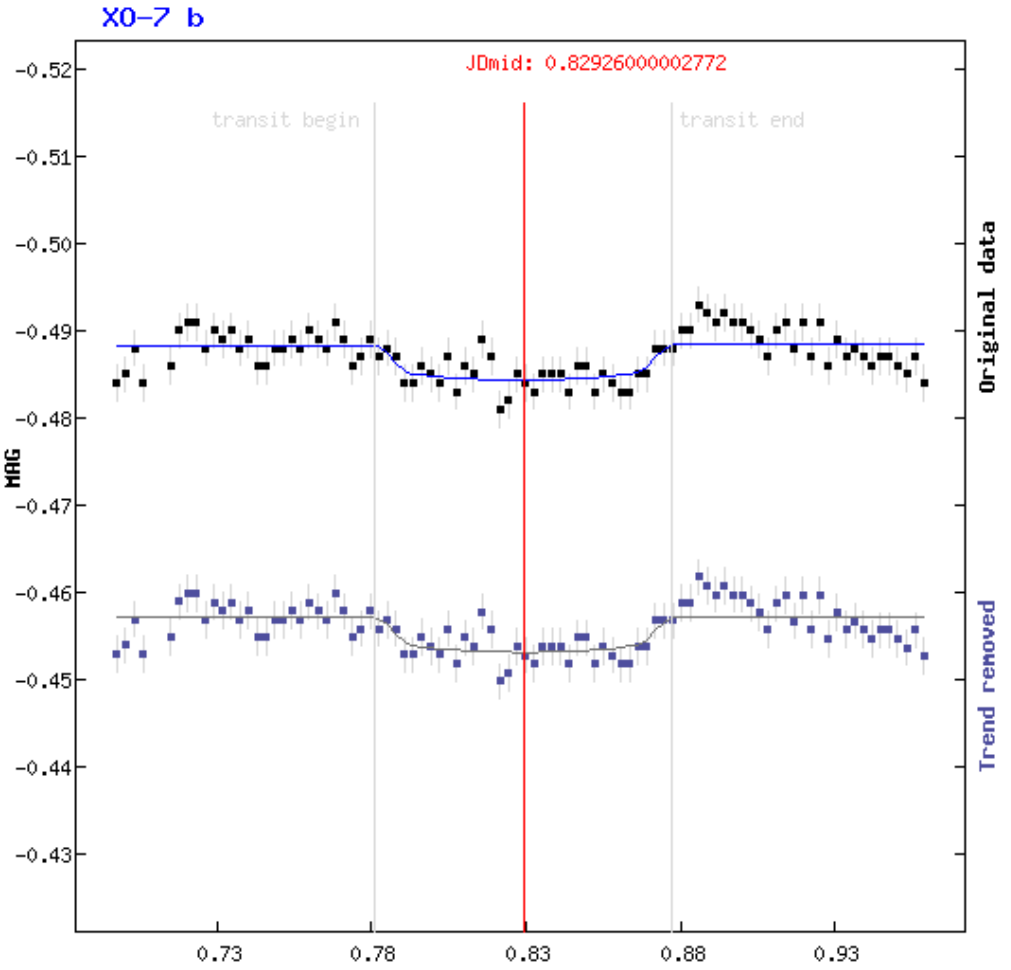




JD mid:	2460462.75977 +/- 0.00115	
HJD mid:	2460462.76092 +/- 0.00115	(helcor = **0.00115**)
Duration:	101.0 +/- 5.7	minutes
Depth:	0.0167 +/- 0.0014	mag

But how about XO-7? The odd-ball? Two additional XO-7 transits were observed.

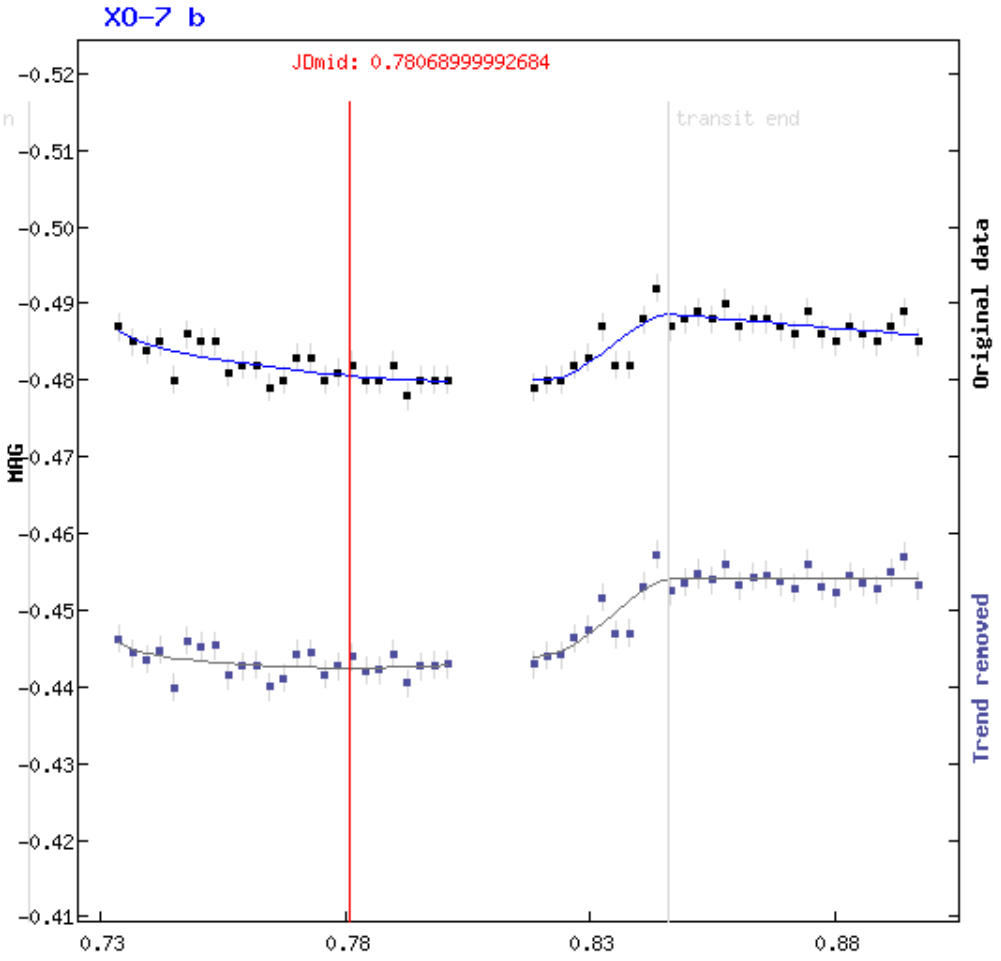
XO-7 2024-05-29

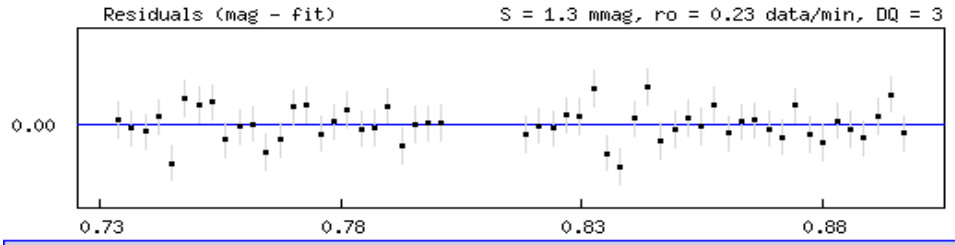


JD mid:	2460460.82926 +/- 0.00237	
HJD mid:	2460460.82748 +/- 0.00237	(helcor = **-0.00178**)
Duration:	138.5 +/- 8.1	minutes
Depth:	0.0041 +/- 0.0005	mag

A transit was definitely detected. But this transit was significantly shallower than expected. And this transit did not have the irregularities seen in the bottom of the May 7 transit.

XO-7 2024-07-11





JD mid:	2460503.78069 +/- 0.00289	
HJD mid:	2460503.77895 +/- 0.00289	(helcor = **-0.00174**)
Duration:	187.9 +/- 10.1	minutes
Depth:	0.0116 +/- 0.0016	mag

Observations for the July 11 transit did not begin until the approximate time the transit was predicted to begin.

Transit observations were obtained for a total of five predicted transits. Model fits were not always possible. All three successful model fits for XO-7 look quite similar (May 6, May 29, and July 11). They are slightly asymmetric with a slow decline and a rapid egress at the end of the transit. However, there were two transits for which data was obtained (April 16 and May 9), but for which model fits were **not** possible. The XO-7 system was brightest for the first transit observed on April 16 at the start of the transit. For this observation sequence the system stayed at the low-level brightness within the transit. No egress from transit was observed. Indeed, throughout the extensive observations of XO-7 from April through July the system never returned to the brightness observed at the start of the transit on April 16.

Comparison with Predictions

This table summarizes the differences between the observed model parameters and predicted, or computed, or assumed properties for the exoplanets observed at RFO. The table shows the values for O-C (Observed minus Computed).

			O-C -->	...	...
Object	Date	Epoch	Tmid (days)	Duration (minutes)	Depth (mag)
HATP-20	2024-04-11	1289	-0.00263	-4.98	0.0084
XO-1	2024-04-18	1277	0.00297	-33.7	-0.0007
XO-7	2024-04-17				
	2024-05-07	463	-0.00253	-15.9	-0.0021
	2024-05-10				
	2024-05-29	471	0.00164	-28.5	-0.0057
	2024-07-11	486	-0.00896	20.9	0.0018
TrES-2	2024-05-21	2629	0.00740	19.5	0.0002
	2024-05-26	2631	0.00087	6.1	-0.0042
	2024-06-01	2633	-0.00064	11.0	-0.0002

Our observations are basically consistent with the expectations for these objects. Changes in the planetary orbits do not seem to be indicated by our data. Specifically, changes in the time of mid-transit (Tmid) can indicate a change of the period which could indicate the presence of additional planets in the system.

The Epoch is the approximate number of cycles, or orbits around the star, since the discovery and confirmation of the exoplanet. XO-7 is the most recently discovered exoplanet on this list. It turns out that XO-7 is also the youngest star and planetary system on this list. XO-7 has an age of approximately 1 billion years. (What is the age of the sun and the earth?)