Issue 12 – Dec 1, 2020

ExoClock Newsletter

Dear ExoClock participants,

we hope that you are all doing well! It is exactly one year since our first newsletter and we are very happy to have both older members and newcomers. November was a really productive month with more than 110 observations. Many thanks to everyone!

For this newsletter, these are the main updates we are discussing:

- ExoClock virtual meeting – November 2020
- Outreach activities
- ExoClock logo campaign
- Highlighted observations
- ALERTS
- Educational series: The O-C diagram

ExoClock virtual meeting – November 2020

The meeting and all the previous ones are accessible from:
www.exoclock.space/users/material

During our recent meeting we discussed several topics and here we share some of the highlights:

- Ariel adoption

On the 12th of November, we had the announcement that the Ariel mission has been adopted by ESA and has entered the final phase of implementation. Practically this means that the Ariel team will start building the spacecraft while continuing the scientific planning. We are very glad to work for the mission and very excited to have all you in our team with the scope of increasing the mission efficiency! The table below will give you some historical information on the path of Ariel towards adoption.

Proposed	Sort-listed	Phase A study	Selected	Phase B study	Adopted
Ariel was proposed together with other 26 missions	Ariel was selected together with THOR and XIPE for further studies	The three missions were further designed	Ariel was selected for further studies	Ariel “blue-prints” were created	Ariel was adopted to be built
Aug 2014	Jun 2015	2015-2017	Mar 2018	2018-2020	Nov 2020

You can also find the press release here:
http://www.esa.int/Science_Exploration/Space_Science/Ariel_moves_from_blueprint_to_reality

- <u>Coordinated observations</u>

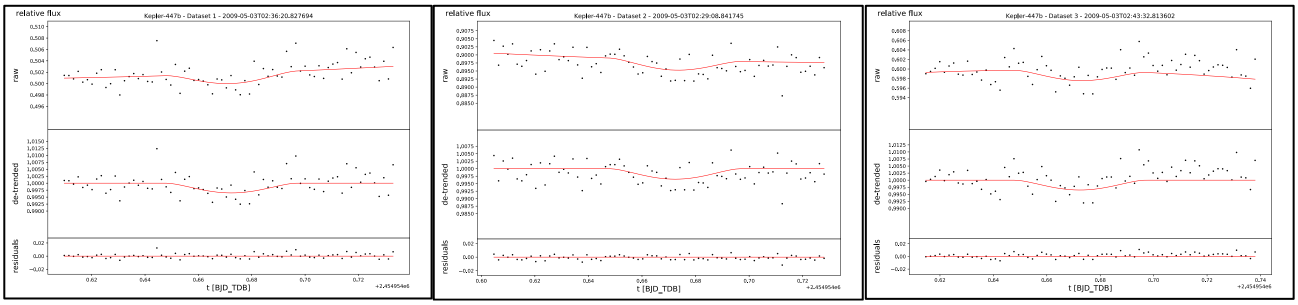
We discussed the potential of coordinated observations and how we can start organising them through ExoClock. To efficiently arrange this type pf observations, it is necessary to examine the possibilities of each instrument and start developing protocols to be widely used. The topic of simultaneous observations is still unexplored, and it is significant to investigate it thoroughly before we standardise the implementation.

Multiple parallel observations can be used to observe the transits of fainter stars. By combining these observations, we can detect a transit from a system (telescope & camera) with lower capabilities. Essentially, we can increase the capacity of instruments and improve the S/N ratio.

To understand how the S/N is improved, you can have a look on the following example. Kepler-447b is a 12.5 V mag star with a transit of 3 mmag depth. Due to an error in the initial catalogue it was assigned with a transit depth of 20 mmag so some observers took the chance to go after it. However, it was not detected easily. Here we use an example an observation from Martin Crow on the 6th of May:

https://www.exoclock.space/database/observations/Kepler-447b_martin.crow_Burnham_Observatory_Celestron_C9.25_2020-05-06/

We simulated three observations with the same scatter (9.25 inch telescope), starting one hour before the transit and ending one hour after the transit, as in our usual observations. With only one observation the uncertainty in the final O-C measurement is 40 min. This means that, in practice, the transit has not been detected. However, if we analyse all three observations, then the uncertainty decreases to 5.7 min. As you can see from the diagrams below, the S/N is very low in each independent observation, but the model has managed to capture the transit.



We have created a dedicated Slack channel for this, and we will start sending further details very soon on how to proceed. If you are interested to join this effort, please send us an email or a message on Slack and we will include you in the sub-group (if you have done so but you have not been invited to the Slack channel yet, please contact us again, we may have missed your message).

- <u>Multicolour observations</u>

At the same time, we have initiated a working group for multi-colour observations. Observations with different filters can be used to identify differences in the Rp/Rs which indicates the presence of an atmosphere. However, this process requires at least a 16’’ telescope since the SNR for each filter will be lower than expected. If you are interested to join the investigation of this idea, again send us a message and we will include you in the sub-group.

Note that the activities of these working groups are done in parallel to the ExoClock usual observations and they are independent (at the moment). This is because we need to further explore these topics through a number of test/experimental observations and calibrations. The scope is to create the framework for such activities and then include them in ExoClock in a standardised way. Your participation will be really important to create these frameworks and we will be very happy to explore these and other ideas together!

Outreach activities

The ExoClock community is growing up and includes people from various backgrounds and countries. To facilitate the communication within and between communities and widen the participation, it is important to organise outreach events and share our common, collaborative, efforts! We strongly encourage you to connect with your local astronomical societies and arrange such activities (even online at the moment) and we are always here to support you if you need help in preparing some material. Also, if you have organised or participated in an outreach even with your community recently, please send us your updates to be share them with everyone.

Recently, ExoClock was presented in:

- the 52nd Conference on Variable Stars Research

The *Conference on Variable Stars Research* is organised by the Czech Astronomical Society and took place between the 6th and 7th November. The ExoClock team was kindly invited to talk about the project, and our collaboration with ETD, to the Czech community and discuss the importance of collaborations between professional and amateur astronomers. We thank Filip Walter, our contact for the Czech Republic, for this invitation and we will be very happy to be part of such meetings and other fruitful discussions within your other communities in the future.

- the Annual Conference of the Federation of Amateur Astronomers of Québec

Francois Regembal, an ExoClock participant and our contact for Canada, presented the ExoClock project at the annual conference organised by the Federation of Amateur Astronomers of Québec. The presentation was followed by 160 attendees, with some of them already joining the project. Francois has kindly provided his presentation (in French) for anyone who is interested:
www.exoclock.space/users/material/document/presentation_Francois_FAAQ_2020

Many thanks Francois and congratulations for your effort!

ExoClock logo campaign

As you may remember, we are looking for a new ExoClock logo, and if you have an idea you can still send it to us! The campaign is open to everyone and of course there are no requirements (such as having a telescope) to participate. You can encourage others to participate, too - not only ExoClock participants! More information can be found here:
www.exoclock.space/logo_campaign

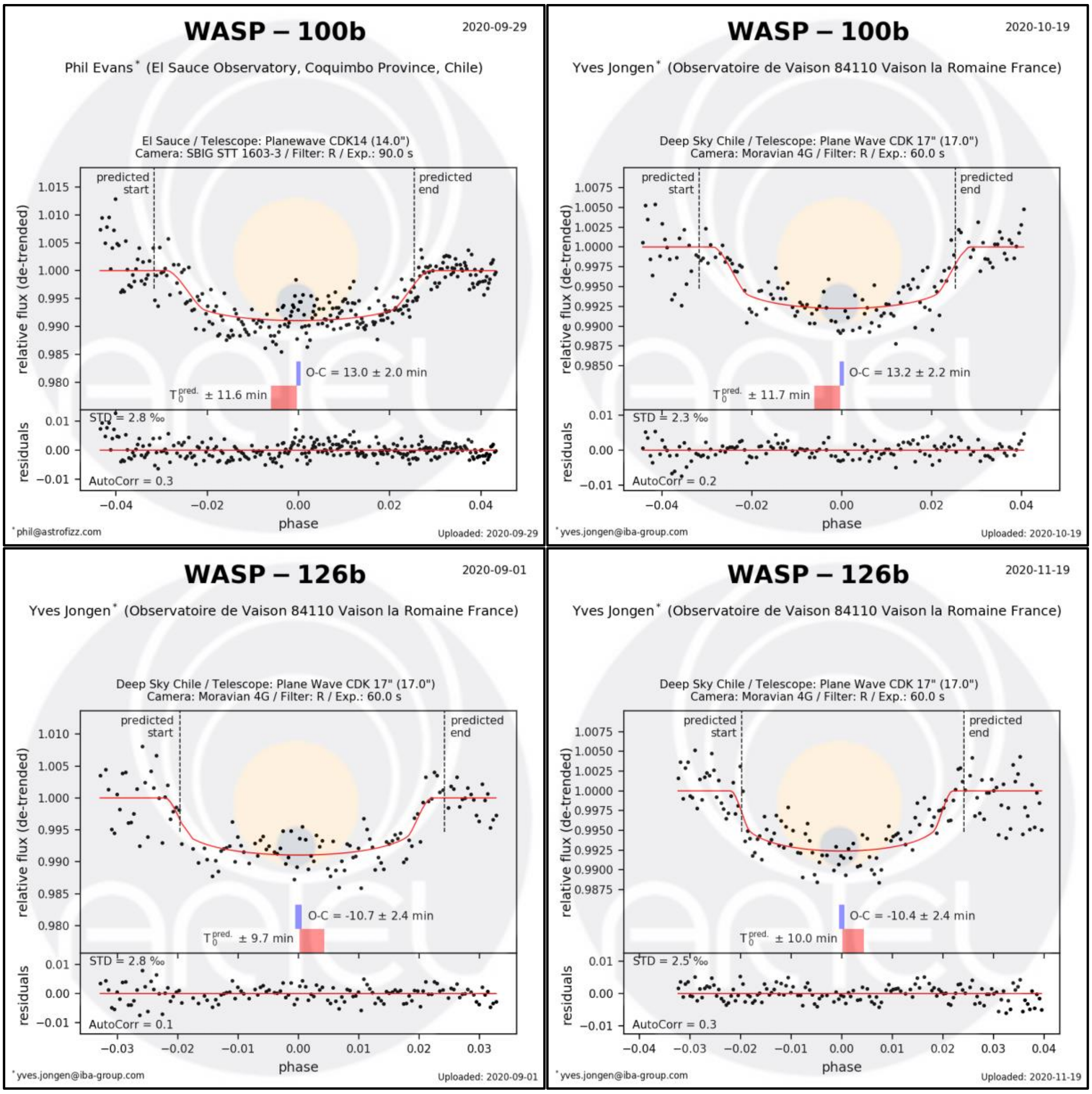
The prize for the winner is free observing time with the telescopes of Telescope Live in collaboration with Marco Rocchetto who is also a member of the ExoClock coordinating team.

Many thanks to those of you who have already sent us our ideas, there are some really inspired!

Highlighted observations

Many thanks to everyone who observed some of the **ALERT targets** during last month!

The alert system is really helping us confirm unexpected shifts which were not detected previously. The detection and the confirmation of these shifts would have not been possible without your excellent collaboration. **WASP-100b** and **WASP-126b** were two of the recent alert targets. A shift of 13 minutes was identified initially by Phil Evans during September and Yves Jongen confirmed this with two recent observations. Additionally, Yves observed WASP-126b for four nights and detected a shift of around 10 minutes. Congratulations everyone for your efforts!



ALERTS

WASP-62b remains an alert target. Additionally, the following targets are in the current **alert system**:

- HAT-P-33b
- HAT-P-50b
- K2-260b

Please check your personalised alert schedule at:

www.exoclock.space/schedule/alerts

and if you get a clear sky, and a long night, observe them!

We remind you also that even if a target is not in the alert list, it can become an alert because an unexpected shift was identified by ExoClock participants – you! This highlights the importance of observing targets that are also of low and medium priorities since so far, several targets of low priority had unexpected time shifts.

We remind you also to send us at exoclockproject@gmail.com (or through the Slack Channel):

- Request to join the Slack channel
- Your feedback on the website
- Suggestions for new features
- Questions on the observations or the analysis
- Ideas for topics you would like to see in the newsletters

Stay well and healthy!

Clear Skies,
the ExoClock team

The O-C diagram

what does it mean and how do we calculate it?

The term O-C stands for "Observed – Calculated" and it is used in many fields of research. As far as the ephemerides of transiting exoplanets are concerned, we use the term O-C to present the difference between the observed transit mid-time and the expected transit mid-time (this is the "calculated" part).

The ephemeris

For every transiting planet we have an ephemeris – an equation that is determined by current observations and connects the mid-times of different transit events in the past and in the future. This equation looks like this:

$$T = T_0 + N \times P$$

where:
T_0 is the zero-epoch transit mid-time –
the mid-time of a transit that we use as reference (it is up to us to choose which transit this will be)
P is the period –
the difference in time between two transit mid-times
T is the transit mid-time –
refers to the mid-time a transit
N is the transit epoch –
the number of periods that have elapsed since the reference transit

From the above parameters, T_0 and P are determined from existing transit observations. For example, the current ephemeris of WASP-10b is:

$$T = 2454664.038040(6) + N \times 3.0927295(3)\ BJD_{TDB}$$

This means that one transit – the one that we take as reference – happened at 2454664.03804 BJD_{TDB}, corresponding to the 16^{th} of July 2008, 12:51:14.4 UTC, and other transits happen every 3.0927295 days.

Note: BJD_{TDB} is the Julian Date of the transit mid-time, corrected for the leap seconds, as if we were observing form the barycentre of the Solar System. This correction is important because as the Earth orbits around the Sun, the distance between us and the exoplanet-hosting system is changing, causing variations in the light travel-time. We will in more detail what BJD_{TDB} means and how we do the conversion from Julian Date in a future newsletter.

The "Calculated" part of O-C

Let's assume that we observed one transit of WASP-10b on the 10^{th} of July 2016. At the UTC noon of that day, the BJD_{TDB} time was equal to 2457580.002037649. If we divide the difference between this time and T0, we can find how many cycles have elapsed since the T_0:

$$\frac{t - T_0}{P} = \frac{2457580.002037649 - 2454664.038040}{3.0927295} = 942.8448228818683$$

The transit we observed happened during the night, so a bit later. The next integer cycle is 943, which is the epoch, N, of the observed transit.

Hence, the predicted transit mid-time is:

$$T_{calc} = 2454664.038040 + 943 \times 3.0927295 = 2457580.4819585\ BJD_{TDB}$$

The uncertainty in the transit mid-time prediction can be calculated from the uncertainties on the T_0 and P parameters as follows:

$$\sigma_{T_{calc}} = \sqrt{\sigma_{T_0}^2 + N^2\sigma_P^2} = \sqrt{0.000006^2 + 943^2 \times 0.0000003^2} = 0.00029\ days = 0.4\ minutes$$

The "Observed" part of the O-C

This part comes from the transit model fitting on our data. On the ExoClock website, the data you upload are converted from any time format that you provide to BJD_{TDB}, and then your light curve is fitted using a transit model and an MCMC algorithm. Suppose that the result of this analysis is:

$$T_{obs} = 2457580.4802(8)\ BJD_{TDB}$$

The final O-C diagram

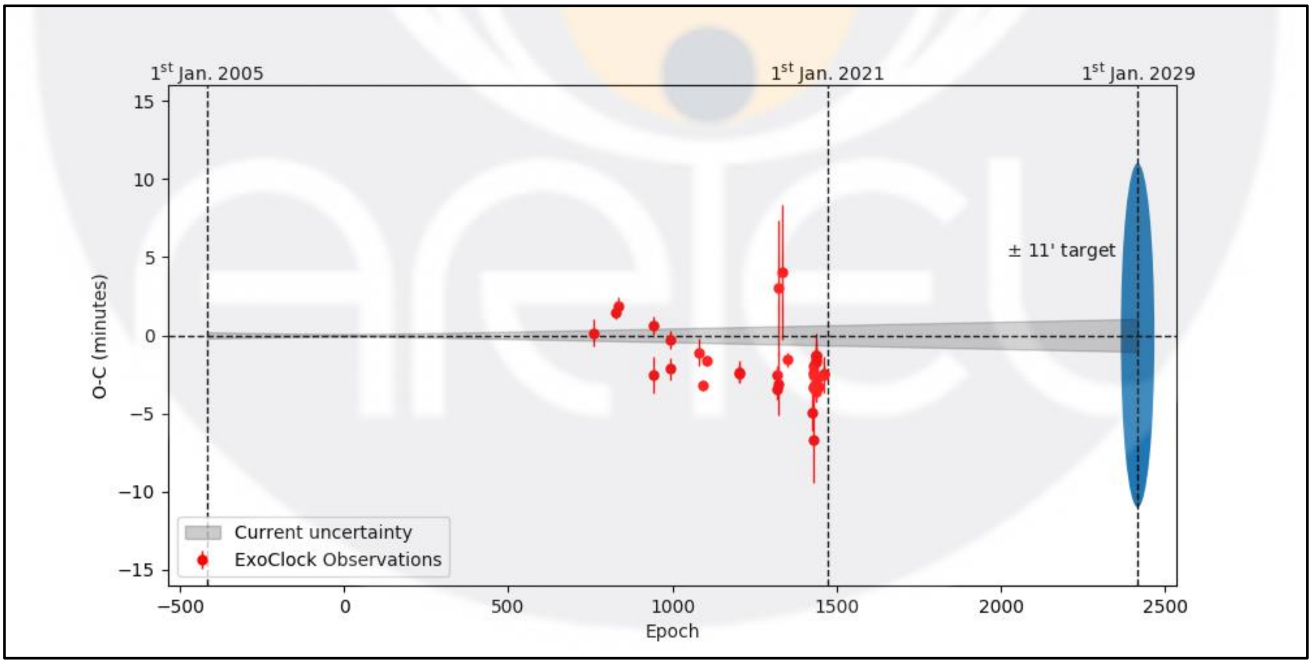
From the above values, the O-C is simply the difference between the T_{calc} and T_{obs}:

$$O - C = T_{obs} - T_{calc} = 2457580.4802 - 2457580.4819585 = -0.00176(8)\ days$$

or

$$O - C = -2.5 \pm 1.2\ minutes$$

By repeating the process for all the observations that we have, we can construct the final O-C diagram that will tell us if we see any deviations from the current ephemeris – i.e. if the transits happen when expected, earlier or later. If the observations disagree with the predictions (large O-C values) this indicates that an ephemeris update is necessary. On the ExoClock website, you will find the following diagram for every planet (this is for WASP-10b):



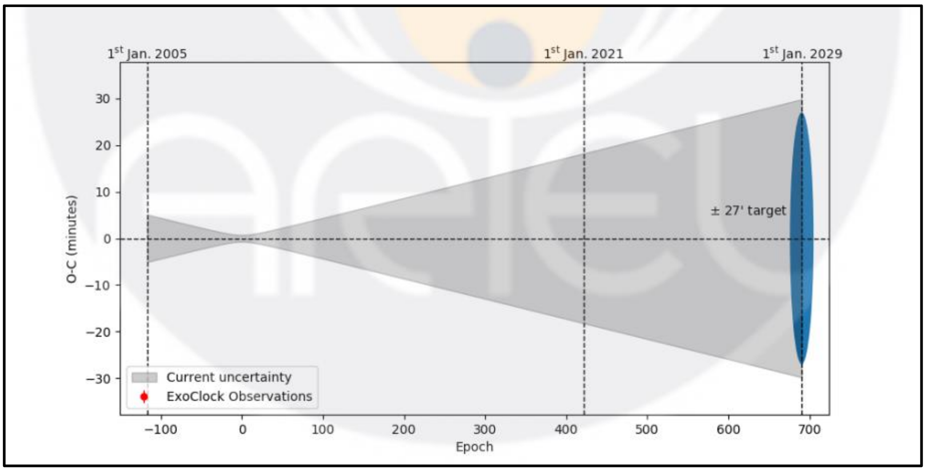
The horizontal axis represents the epochs (N) of all the transits that between the 1st of January 2005 and the 1st of January 2029, calculated in the same way as for the example transit on the 10th of July 2016. The vertical axis represents the O-C in minutes. Moreover:

- with red, we can see all the observations submitted to ExoClock and their respective uncertainties.
- with gay, we can see the uncertainty in the transit mid-time prediction (using the current ephemeris) for all the transits, calculated in the same way as for the example transit on the 10th of July 2016
- with blue, we can see the target uncertainty in the transit mid-time prediction that we have set for the ExoClock project – this is equal to the 1/12th of the transit duration (in this case 11 minutes) for transits that will happen at the end of 2028 / beginning of 2029.

We can see that for WASP-10b, using the current ephemeris, the uncertainty in the transit mid-time prediction for transits that will happen at the end of 2028 / beginning of 2029 is much lower than the target of 11 minutes. This is why the planet has a LOW priority. However, we can also see that the is a small deviation for the transit mid-time predictions of about -2.5 minutes, implying that we may need to update the ephemeris, although this is not crucial at the moment.

Note: The target uncertainty for the ExoClock project has been set to be equal to the 1/12th of the transit duration for transits that will happen at the end of 2028 / beginning of 2029. If this goal is achieved, we will be 99% sure that when Ariel observes, any O-C will be smaller than 1/4th of the transit duration (3 sigma).

HIGH priority planets usually have ephemerides that give predictions with uncertainties higher than the target uncertainty. For example, HAT-P-15 (the grey area is larger than the blue on the 1st of January 2029):



ALERT planets may have ephemerides that give predictions with uncertainties lower than the target uncertainty, however, there are observations with unexpectedly large O-C values. For example, XO-4b (the grey area is smaller than the blue on the 1st of January 2029, but the red points have O-C values of -20 minutes):