Breakthrough Listen is managed by the Breakthrough Initiatives, sponsored by the Breakthrough Prize Foundation. This material is based upon work supported by the National Science Foundation under Grant No. 1950897

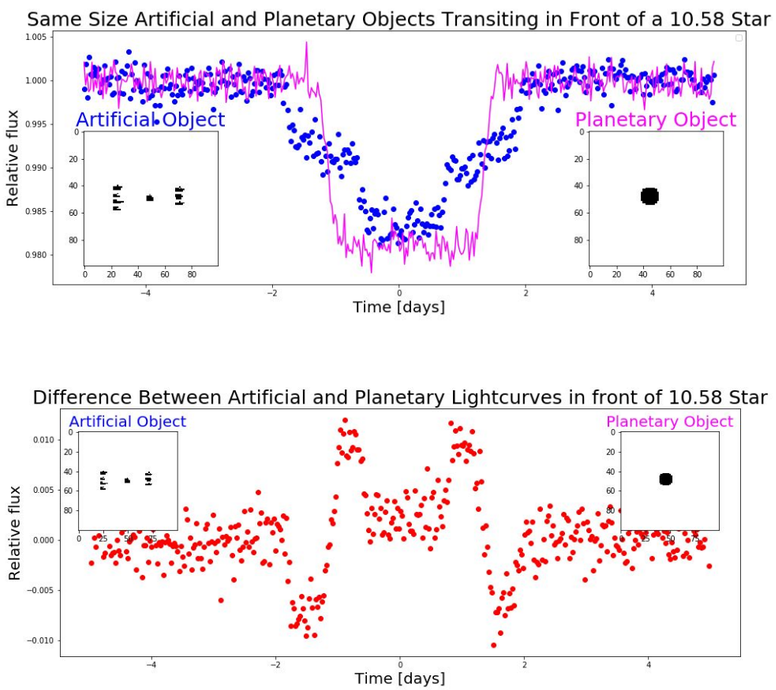
Is it Possible to Observe Megastructures with TESS?

An Analysis of Megastructure Observability and Presence in TESS Light Curves

Piper Stacey[1, 3], Howard Isaacson[1], Steve Croft[1, 2], Ann Marie Cody[2], Doug Caldwell[2], Marvin Morgan[2, 4], Brian Powell[2]

[1] University of California, Berkeley; [2] SETI Institute; [3] Dartmouth College; [4] University of Pennsylvania

We present the quantifiable limits of observation of artificial megastructures within TESS data. We characterize observability using a ratio of the in-transit RMS residuals and the out-of-transit RMS residuals. We measure a percent difference in circularity (a non-circularity index) by summing the artificial object's pixels that do not fall within the pixel area of the planet. We have determined an observability threshold using our observability index to be O = 3. At this threshold, given simulated standard TESS noise (gaussian with a zero mean and standard deviation dependent upon the individual star's TESS magnitude), we quantity the non-circularity of an artificial object in order to be observable.

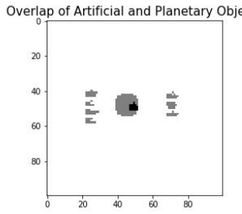


Using EightBitTransit, a modeling code developed by Sandford and Kipping, 2018, we model the transit of an artificial object and a same size (same number of pixels) planet. We add standard TESS observational noise. The artificial object shown to the left is the first three digits of pi expressed through individual ETI ships.

To determine observability, we then subtract the planetary transit from the artificial transit to visualize the residuals between the two light curves. Using our observability characterization, these pi ships have an observability index of 3.15 meaning the RMS of the residuals in-transit is 3.15 times the RMS of the residuals out-of-transit.

(See equations to the top right)

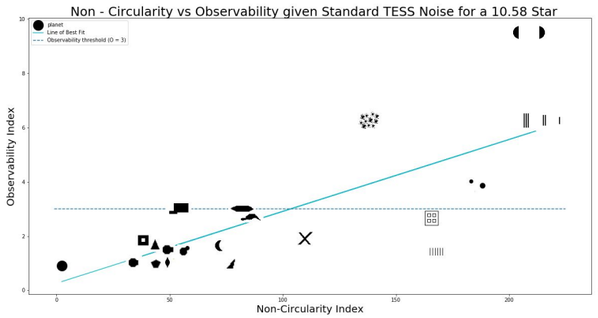
Index Equations:



$$\text{Non-Circularity} = \frac{[\textit{The difference in shape between the artificial and the planetary objects}]}{[\textit{The total area of the planet}]}$$

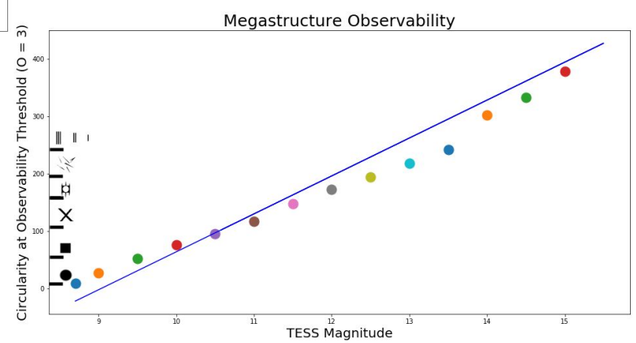
The difference in shape between the artificial object and the planetary object is calculated by summing the number of pixels in the artificial object that do not overlap with the area of the planet.

$$\text{Observability} = \frac{[\textit{RMS of Residuals of In-Transit Points}]}{[\textit{RMS of Residuals of Out-of-Transit Points}]}$$



With a quantifiable observability index, the threshold at which artificial objects are observable using TESS could be decided. We decided upon an observability index of three, O = 3. At O = 3, the RMS of the residuals of the two light curves (artificial - planetary) while in-transit is three times the RMS of the out-of-transit data. Effectively O = 3 parallels σ = 3.

Given any TESS magnitude, we propose a model to determine how non-circular an artificial object has to be in order to be observable by TESS. Due to the increased TESS noise in dimmer stars and the threshold of O = 3, we propose that megastructures are only feasibly observable as objects different than planets in front of stars with magnitudes brighter than 13. This is because circularities greater than ~250 are mostly indistinguishable from dust.



Using these relationships between non-circularity and observability within TESS light curves, we can more effectively create a statistical approach to search for feasibly observable artificial megastructures within TESS data. Our next step is to characterize other parameters that might differentiate artificial objects from natural ones and employ them alongside our knowledge of non-circularity and transit shape to search for artificial objects hidden in TESS data.

References: Sandford and Kipping, 2018; Arnold 2005; Rappaport et al. 2019; Wright et al. 2015.