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PHYS305 Observation Project

WASP-10b

Questions for the Final Report

1.) The photometric data points you analyzed have uncertainties σ associated with them. How could you estimate the per-point uncertainty? Using your method, what is that uncertainty? How would you expect anomalously outlying data points to affect your estimate? What are some techniques you could use to mitigate the effects of outliers on your estimate?

$$\chi^2 = \sum_{i=0}^{N-1} \left(\frac{y_i - y(x_i)}{\sigma_i} \right)^2$$

YOU COULD TREAT σ_i AS ONE OF YOUR MODEL PARAMETERS AND ADJUST IT TO ESTIMATE THE PER POINT UNCERTAINTY.

YOU COULD ALSO USE

$$MAD(y_i) = \text{MEDIAN}\left(\left| y_i - \text{MEDIAN}(y_i) \right| \right)$$

* TAKE THE MEDIAN OF ALL DATA POINTS
* SUBTRACT FROM EACH DATA POINT $ TAKE ABS VALUE
* TAKE THE MEDIAN OF THOSE

ONCE YOU FOUND $MAD(y_i)$...

$$\text{std. } \sigma = 1.4826 \times MAD$$

- I WOULD EXPECT ANOMALOUSLY OUTLYING DATA POINTS TO HAVE LITTLE EFFECT ON THIS ESTIMATE BECAUSE OF THE AMOUNT OF DATA POINTS COLLECTED. I'D EXPECT THOSE DATA POINTS TO BE RARELY CLOSE TO EACH OTHER, SO TO MITIGATE THE EFFECTS OF THE OUTLIERS ON THE ESTIMATE, WE CAN LOOK AT THE DATASET AS A GAUSSIAN DISTRIBUTION, AND THEN FIGURE OUT WHICH POINTS IN THE DATASET DEVIATE FROM GAUSSIAN.

2.) Imagine you switched planets to observe a star that was 2.5 magnitudes brighter than your first target. Assuming Poisson uncertainties, how would you expect σ to change and by how much?

$$m = -2.5 \log_{10}\left(\frac{F}{F_\phi}\right)$$

$$m' = m - 2.5$$

$$m - m' = 2.5$$

$$= -2.5 \log_{10}\left(\frac{F}{F_\phi}\right) - (-2.5)\log_{10}\left(\frac{F'}{F_\phi}\right)$$

$$m - m' = -2.5 \log_{10}\left(\frac{F}{F'}\right) = 2.5$$

$$\frac{F'}{F} = 10$$

NUMBER OF PHOTONS, $N = F \cdot A \cdot \tau$

NUMBER OF PHOTON FOR OTHER STAR, $N' = F' \cdot A \cdot \tau$

$$\frac{N'}{N} = \frac{F'}{F} = 10$$

$$\sigma = \sqrt{N}$$

$$\frac{\sigma'}{\sigma} = \frac{\sqrt{N'}}{\sqrt{N}} = \sqrt{\frac{N'}{N}} = \sqrt{10} \approx 3$$

$$SNR = \frac{N}{\sigma}$$

THE SNR WOULD GO DOWN BY A FACTOR OF 3.

3.) Of course, the photometric uncertainty σ will impact your results, specifically the results you get for the estimate of each transit time, *tc*. The uncertainty on *tc* depends on the system parameters according to the following equation:

$$\sigma_{t_c} = \sqrt{\frac{\tau}{2\Gamma}} \cdot \frac{\sigma}{\delta}$$

where τ is related to the ingress or egress duration, Γ is the sampling rate for your data (probably once every 2 minutes), σ is the per-point photometric uncertainty, and δ is the transit depth (how big the planet is compared to the star).

How would your uncertainty on the transit time change if you doubled the photometric uncertainty? How would it change if you doubled the transit depth (made the planet bigger compared to the star)? You can, of course, use the equation to make these estimates, but also explain qualitatively *why* you would expect that behavior? In words, why does the transit timing uncertainty go up or down as you change the photometric uncertainty and the transit depth?

- DOUBLED PHOTOMETRIC UNCERTAINTY (σ)
  - IF PHOTOMETRIC UNCERTAINTY (σ) DOUBLES, THEN TRANSIT TIME UNCERTAINTY (σ_{t_c}) DOUBLES AS WELL.
  - TRANSIT TIME UNCERTAINTY GOES UP BECAUSE IF YOU ARE MORE UNSURE ABOUT EACH PHOTOMETRIC DATA POINT, THEN IT WOULD MAKE SENSE THAT YOU WOULD BE MORE UNSURE ABOUT YOUR TRANSIT TIME.
- DOUBLED TRANSIT DEPTH (δ)
  - IF TRANSIT DEPTH (δ) DOUBLES, THEN TRANSIT TIME UNCERTAINTY (σ_{t_c}) IS HALVED.
  - TRANSIT TIME UNCERTAINTY WOULD GO DOWN. THIS MAKES SENSE BECAUSE IF THE PLANET THAT IS TRANSITING IS LARGER, THEN YOU WOULD GET A LARGER, MORE DISTINGUISHABLE DIP IN MEASURED FLUX, WHICH WOULD IN TURN MAKE YOU MORE CERTAIN ABOUT YOUR MEASURED TRANSIT TIME.

4.) Now look at the period value reported on the Exoplanet Archive. We want to know whether your result is consistent (to within uncertainties) with their value. Look at your period value ***Pyours*** and their period value ***Ptheirs***, along with the corresponding uncertainties (***σyours*** and ***σtheirs***, respectively). We want to consider the function ***f = Pyours - Ptheirs***, calculate the corresponding uncertainty for that function, and figure out whether the function might be equal to zero to within uncertainties. Consult Chapter 2 in Chromey to refresh your memory about how to propagate uncertainties.

If your result does not agree with the Archive's, what are some possible reasons? Look at your transit model and compare it to the data. Does it look like a good fit to all the transits?

P_{YOURS}, P_{THEIRS}

$P_{YOURS} = 3.09276 \pm 3.61204e{-}06$ DAYS

$P_{THEIRS} = 3.09276 \pm 11.2\ e{-}06$ DAYS

$$f = P_y - P_t$$

$$\sigma_f^2 = \sum \left(\frac{\partial f}{\partial P}\right)^2 \sigma_P^2$$

$$\sigma_f = \sqrt{\sigma_y^2 + \sigma_t^2}$$ - UNCERTAINTIES IN QUADRATURE

$$\frac{|f|}{\sigma_f} \leq 3 \text{ SIGMA}$$

$$f = 0$$

$$\sigma_f \approx \sqrt{(3.6e{-}06)^2 + (11.2\ e{-}06)^2}$$

$$\sigma_f \approx 1.2\ e{-}05$$

- THIS LOOKS LIKE A GOOD FIT TO ALL THE TRANSITS.

5.) Using your period *P* and *T*0 value (called "ephemeris_fit_params[1]" in your python notebook), you will estimate the next time that your planet could be observed in transit.

First, you'll need to figure when your planet will next be visible. One way to check this is to use Stellarium (https://stellarium-web.org/). Most of your targets are in the web version, but a few (WASP-10, HAT-P-19, and Qatar-1) seem not to be. For those, you'll have to download and install Stellarium.

In Stellarium, run time forward from today and check when your object will next be visible at night. Record that date and convert it to Julian date using this online calculator - https://www.aavso.org/jd-calculator. Don't worry about getting the exact instant the planet is visible at night; just get close.

Next, you'll need to calculate the times in the future when your object will transit. You can calculate the transit time *tc* for the *E*th orbit using this equation: *tc* = *T*0 + *P E*. The first thing you'll need to do is to convert your *T*0 value from your fit into Julian date. The fit value you get is in Julian date - 2457000, so start by adding 2457000 to your *T*0. Then determine the number of orbits you'll have to wait until *tc* is greater than the date you estimated from Stellarium. That should give you the minimum orbit number *E* for when your object is both visible and transiting. Record the next date when your object could be observed transiting and include all your arithmetic (neatly written) as part of your answer to this question.

NEXT VISIBLE DATE TO VIEW WASP-10 AT NIGHT:

2024 - 10 - 16 @ 23:00:00 MT

MDT $\longrightarrow$ UTC

2024/10/16 23:00:00 MDT = 2024/10/17 05:00:00 UTC

UTC $\longrightarrow$ JULIAN DATE

2024/10/17 05:00:00 UTC = 2460600.70833

TRANSIT TIME FOR ETH ORBIT:

$$t_c = T0 + PE$$

$$T0 = 1.0545 + 2457000$$
$$= 2457001.0545$$

$$P = 3.09276$$

$$t_c = (2457001.0545) + (3.09276)E$$

E	t_c
1162	2460594.84162
1163	2460597.93438
1164	2460601.02714

$$t_c = (2457001.0545) + (3.09276)(1164)$$
$$= 2460601.02714$$

JULIAN $\longrightarrow$ UTC

2460601.02714 = 2024/10/17 12:39:00 UTC

UTC $\longrightarrow$ MDT

2024/10/17 12:39:00 UTC = 2024/10/17 06:39:00 MDT

NEXT TRANSIT TIME:

2024/10/17 06:39:00 MDT