Rotational modulation of Luhman 16: new analysis with TESS data sector 36 and 37

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and others

1. TESS Data

- Data cleaning: remove points with **sigma_SKY>140, *DQUALITY # 0***
- Photometric error: 4.5%
- Used PSF-extracted light-curve
- **Figure 1:** image cutout (25 pixel) obtained with ***lightkurve***
- **Figure 2:** PSF & 1-3 pixel – extracted light-curve

Question: can we check light curve of possible contaminating-sources?

(Sector 36, 37 TESS extraction not found in *PATHOS from astroquery.mast*)

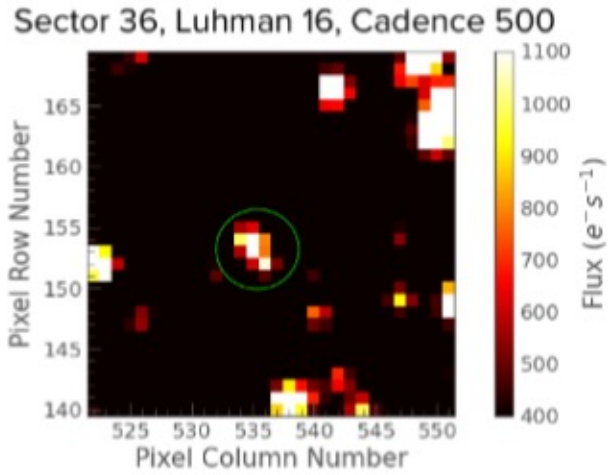


Figure 1. TESS image cut-outs in sector 36, showing full frame images of the object at two different epoch, with a pixel scale of 21 arc-seconds per pixel. Each frame in a cadence is taken every 2 minutes apart.

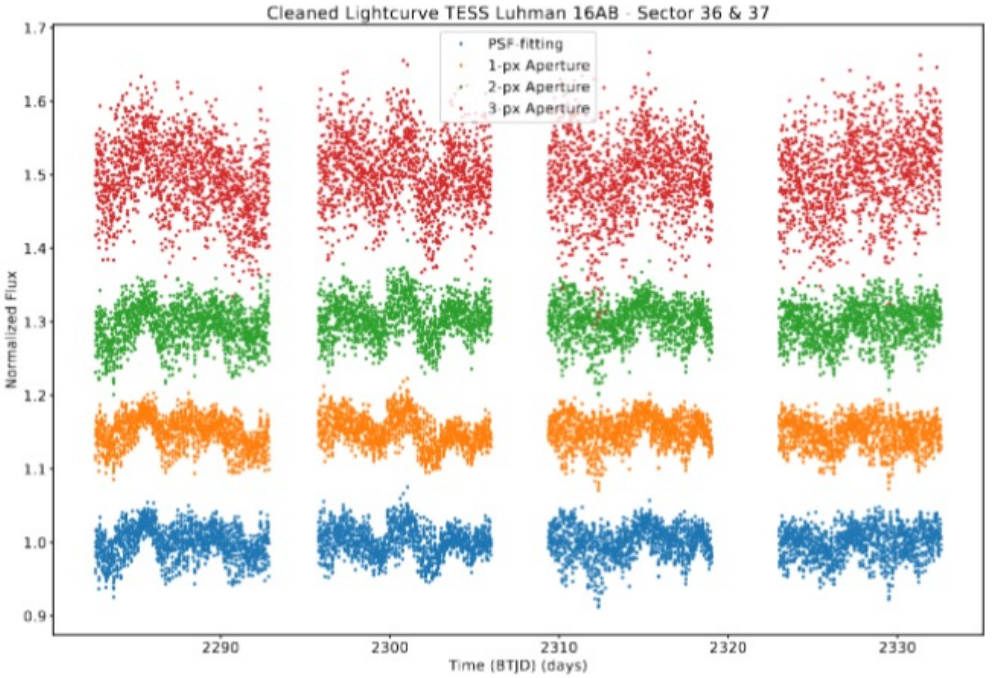


Figure 2. TESS 50-day baseline light curves of Luhman 16AB in sector 36 and 37. Gaps are data downlinks. 1-3 pixels and PSF-extracted intensity. Scattered lights and background sources are filtered out.

2. Periodograms

- **LS Periodograms**: confirmed previous result, found multiple peaks. **Figure 3, 4.**
- **Short-period < 20 hours**: no contamination from window function, found k=2 wave, signs of atmospheric rotational modulation
- **Long period < 140 hours**: strong contamination from window function and spacecraft jitter.
    - Some specific period peaks (i.e 70, 90 hours) coincide with minima in window function/jitters periodograms -> recoverable?

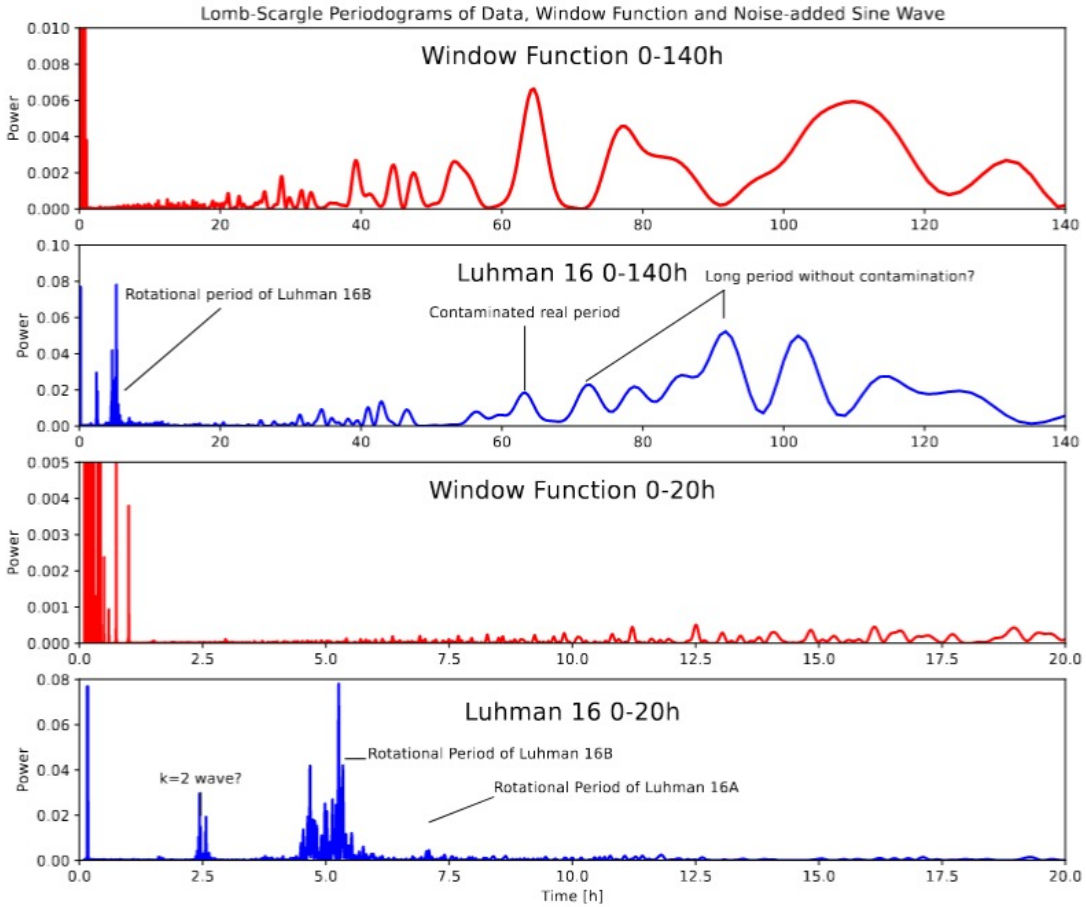
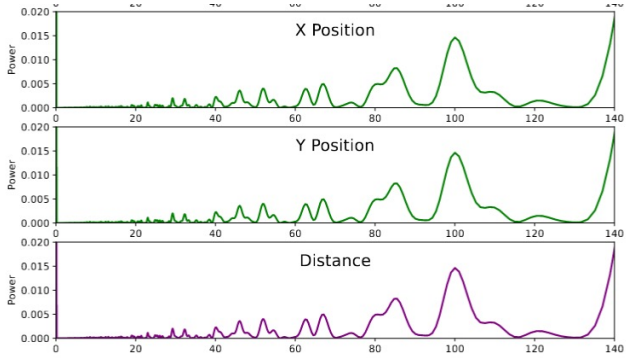


Figure 3. LS Periodogram - Window function - Data - cutout 0-120 hours and 0-20 hours



2. Periodograms fit

- Periodogram sine fits: fit 1, 3 and 6 sine waves models
- Multi-sine waves model *could explain* observation → planetary scale wave works well

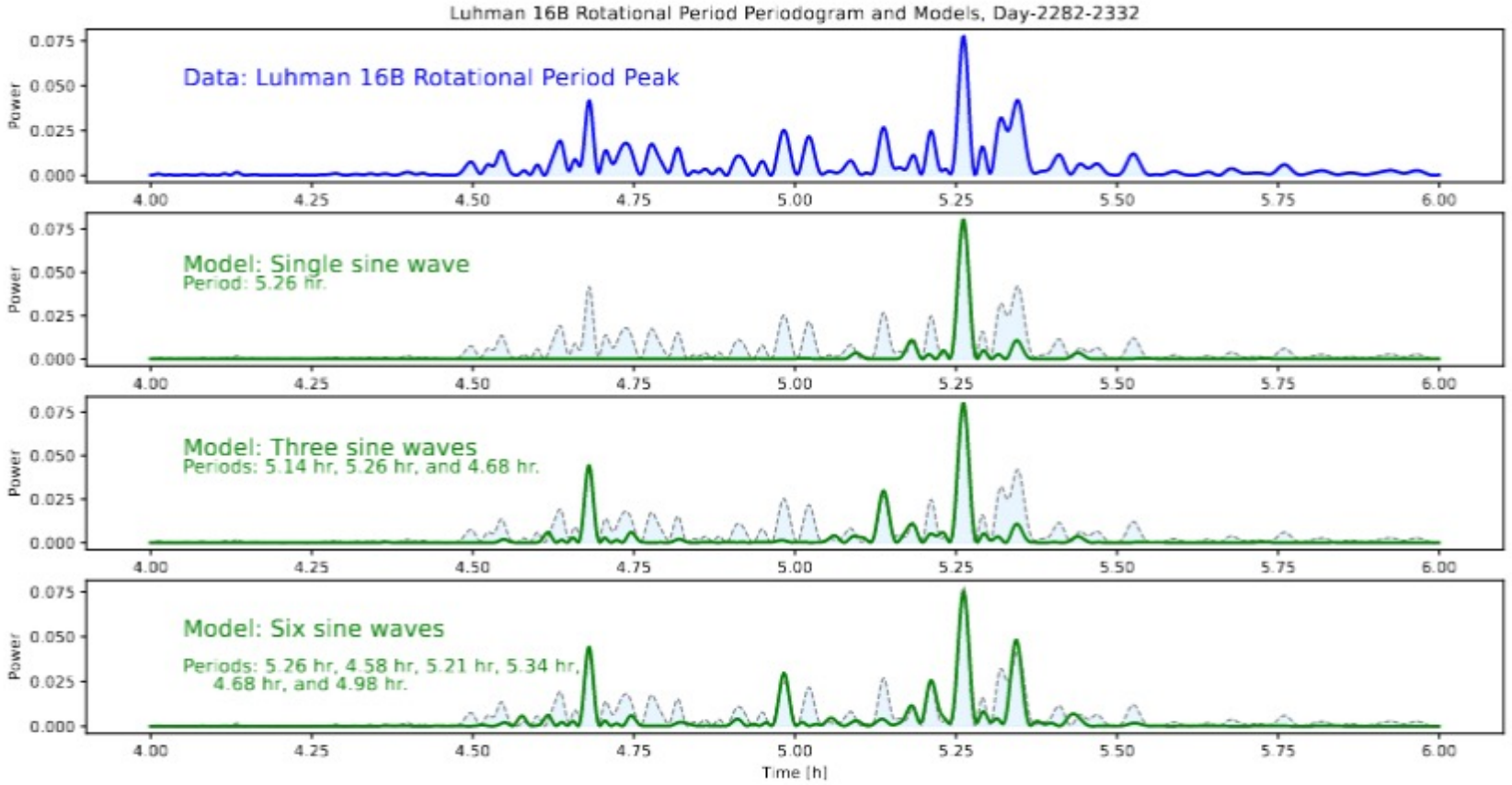
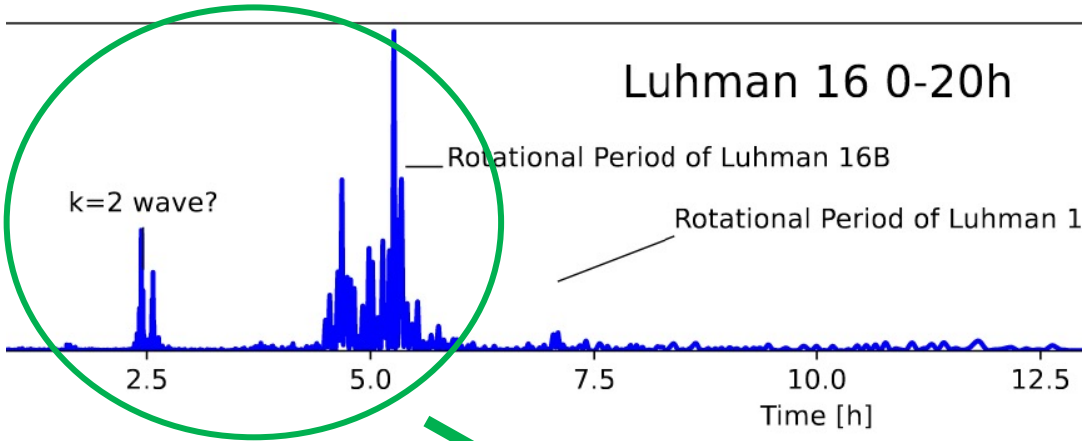


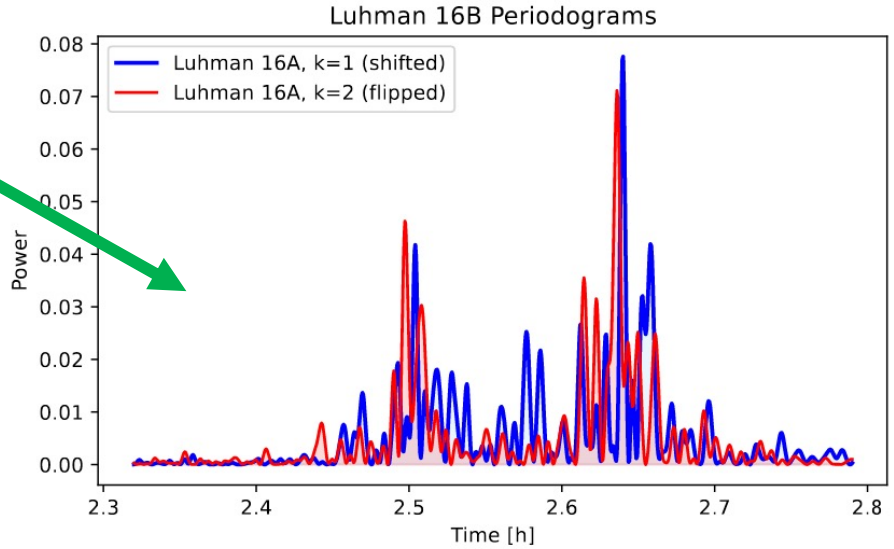
Figure 5. Zoom in - LS periodogram + Sine fit of 4-6 hours - 1-3-6 sines fit

2. Periodograms: k=2 wavenumber

- K=2 wave: waves in zonal circulation matching half rotation rates



Shift and flip



- K=2 wavenumber: scale and match exceedingly well with k=1 main period peaks of Luhman 16B !

- New data has 4 times better cadence -> confirm k=2 existence better than previous result

Figure 6. LS Periodogram k=2 wave

3. Light curve fit: short-period

- Fit light curve with: ***3-SINE WAVES*** model, 9 params

$$1 + \Sigma_i^3 a_i * \sin(\omega_i t + \phi_i)$$

- **MCMC** routine: results matches well, contrains:
  - Two periods in k=1 regime around Period = 5 hours
  - One period in k=2 regime around Period = 2.5 hours

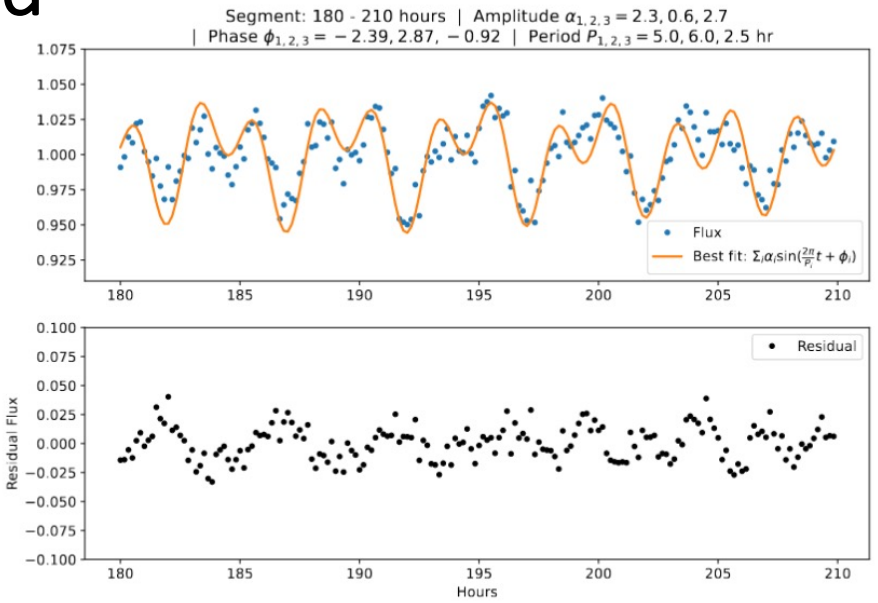


Figure 10. 180-210 hours light curve fit

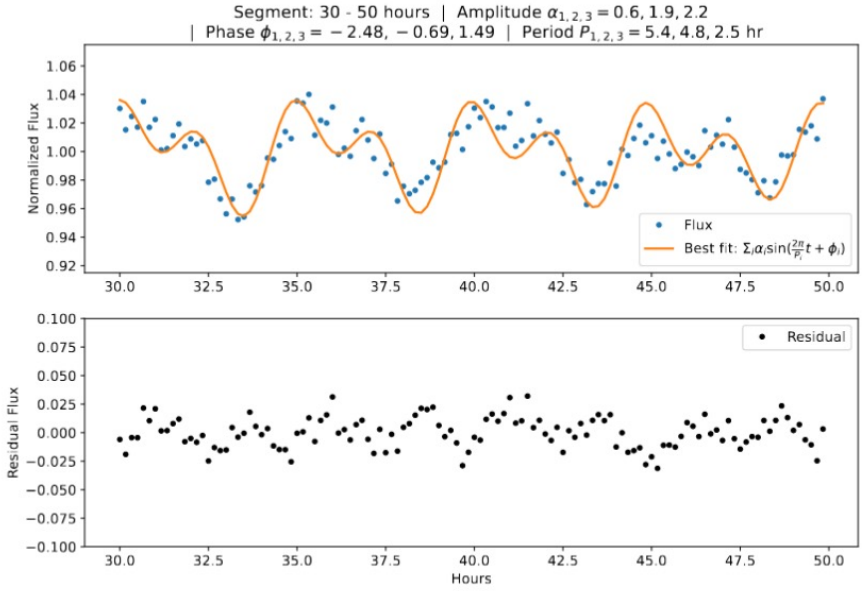


Figure 7. 30-50 hours light curve fit

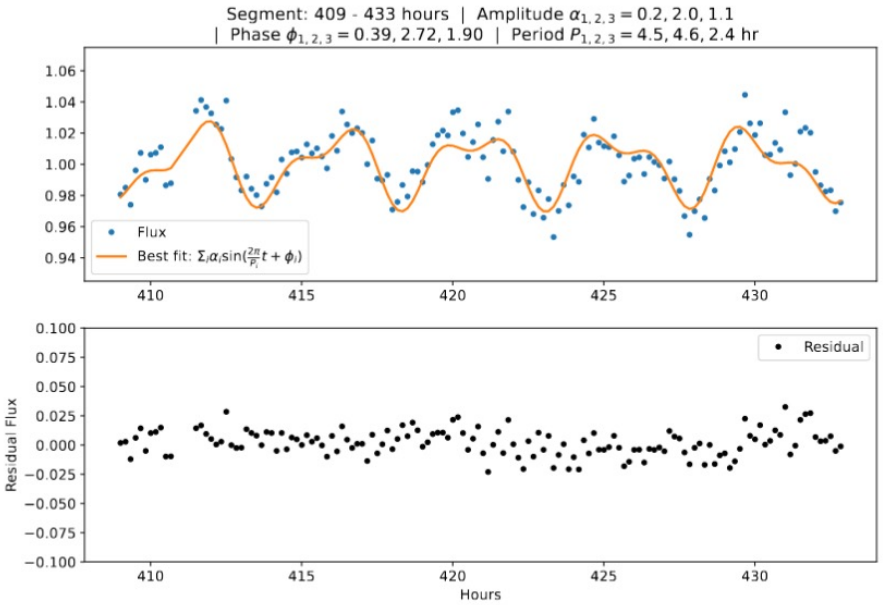
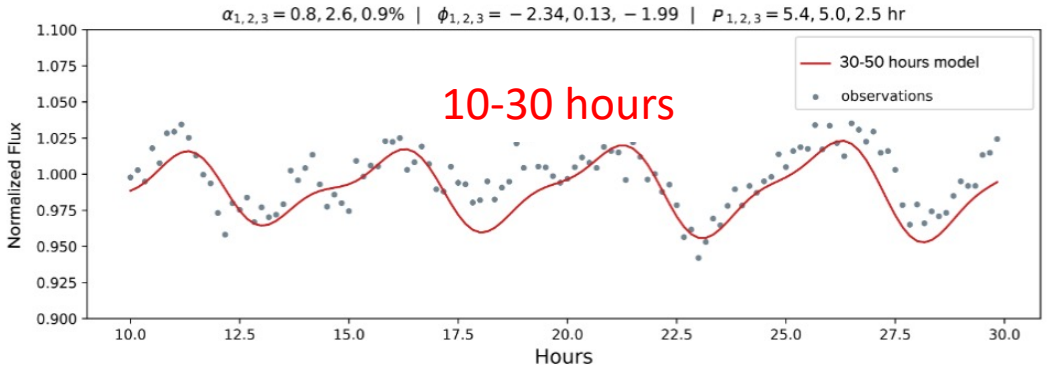
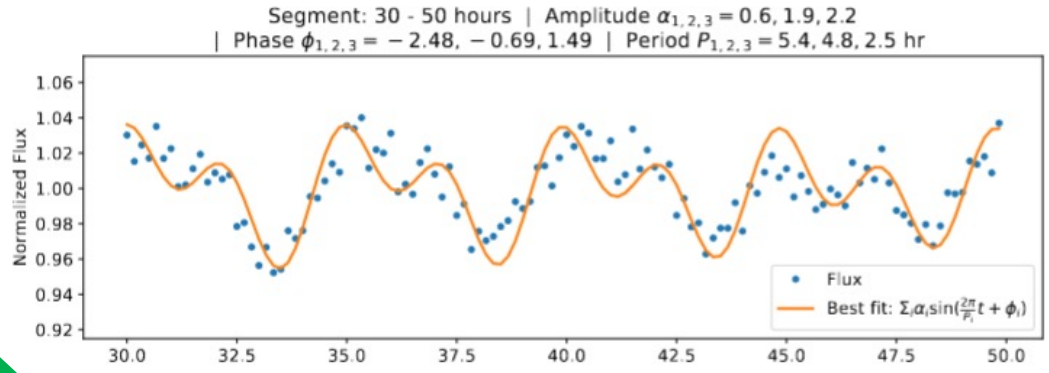


Figure 11. 409-433 hours light curve fit

3. Light curve fit: evolution

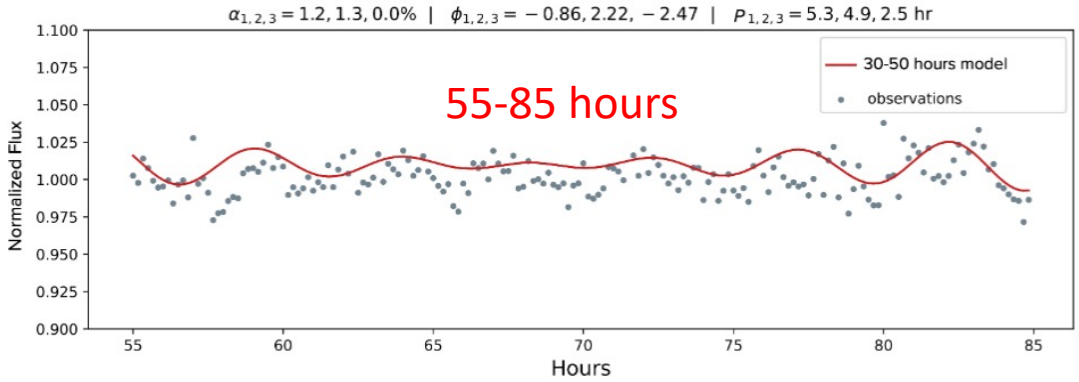
- **Light curve shows variable evolution:** Period peaks dissolve and evolve into other
- Proof:
  1. used previously fitted segment,
  2. keep the periods relatively constant, allow fluctuation in amplitude & phase;
  3. fit subsequent segment -> see changes in amplitude





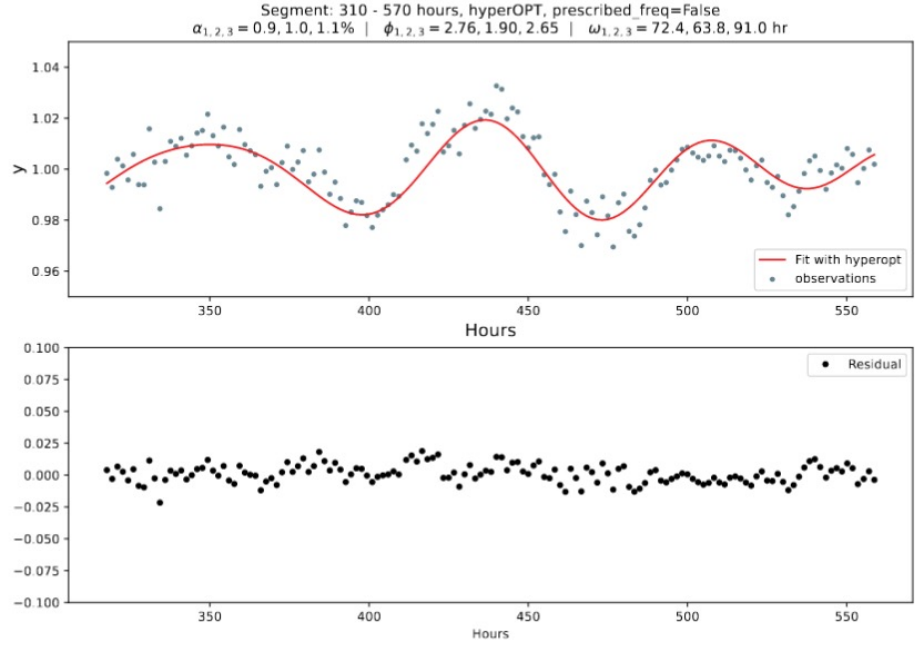
30-50 hours

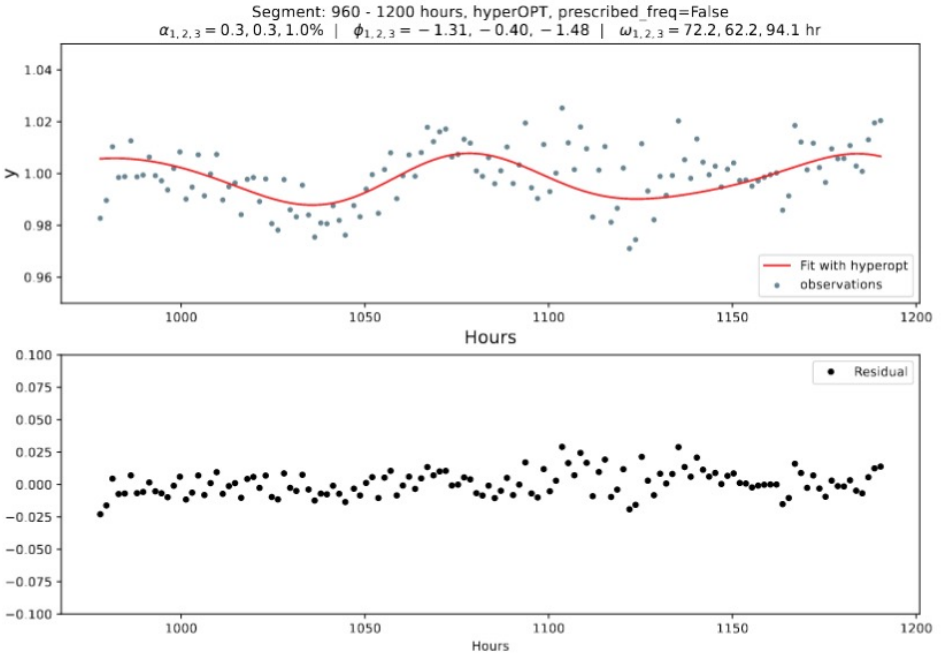
Evolution of periods peaks with time



3. Light curve fit: long-period

- **Use similar 3-sine wave routine** to fit long-period light-curve
- Smoothing: box-car average periods larger than 20 hours to examine only the long-periods
- Result: *COULD* fit long-periods with planetary scale wave model
- Disclaimer: needs extra treatment, strong contamination in long-period, unknown credibility.





To be continued…

Overleaf draft: https://www.overleaf.com/project/63163d81cd30f854609620e4