Variability in V4046 Sagittarii

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Introduction to the project

- V4046 Sagittarii (Sgr) is a close, circular binary system consisting of two T-Tauri stars.
  - Orbital period of 2.42 +/- .000004 days
- T-Tauri stars are pre-main sequence stars and therefore their luminosities are dependent on the material accreting from their circumstellar disk.
  - Well understood in the case of one star.
- In binary case this accretion is significantly more complicated.
  - Higher eccentricity orbits leads to “sharper”, more periodic accretion events.
  - Circular orbit is more dependent on the physics of the circumbinary disk evolution and accretion
- Primary goal of research was to examine V4046 Sgr and understand its variability.
- Then use this understanding to provide insight into how the circumbinary disk interacts with the binary and even the disk’s evolution.

	Temperature (K)	Mass (Solar Mass)	Radius (Solar Radii)	Orbital Radius (Solar Radii)
Primary Star	4370 +/- 50	.86	1.2	4.32
Secondary Star	4100 +/- 50	.69	1.12	4.58

http://adsabs.harvard.edu/abs/2000IAUS..200P..28Q

Data and Methods

- Data taken with Las Cumbres Observatory (LCO) network
  - Used nine 1-meter telescopes from all around the world.
- Simultaneously took data in U, B, V, R, and I bands
  - R band not utilized due to not being useful for science being done
- In total more than 2500 CCD images were taken from June 10, 2014 to August 30, 2014.
  - About 40 gigabytes of data.
- Exposures were taken in sets of 3 where I then aligned and combined each set of images together.
  - Improves signal to noise (S/N) by $\sqrt{3}$.
- Then fit a world coordinate system to the resultant images to derive Right Ascension (Ra) and Declination (Dec) coordinates for each pixel.

Data and Methods Cont.

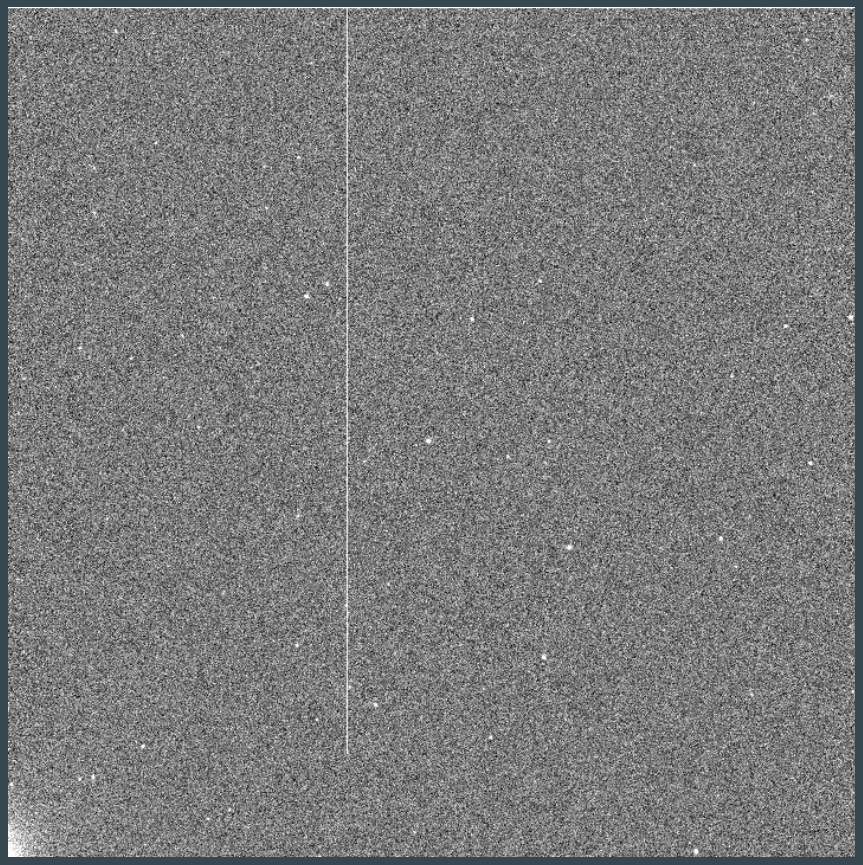


Image before combining

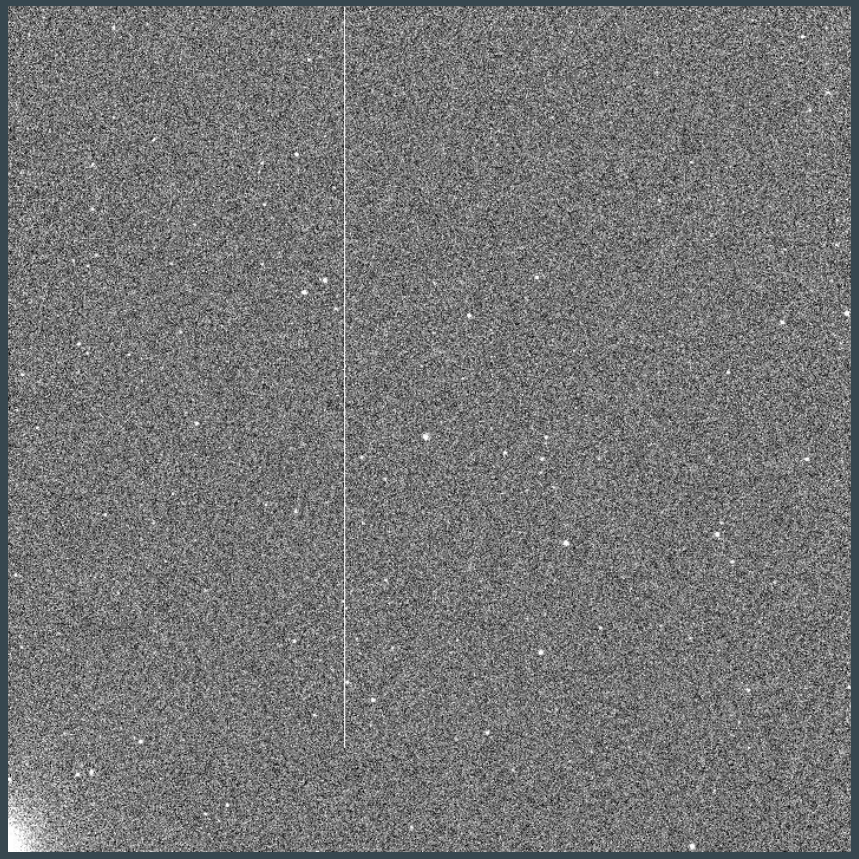
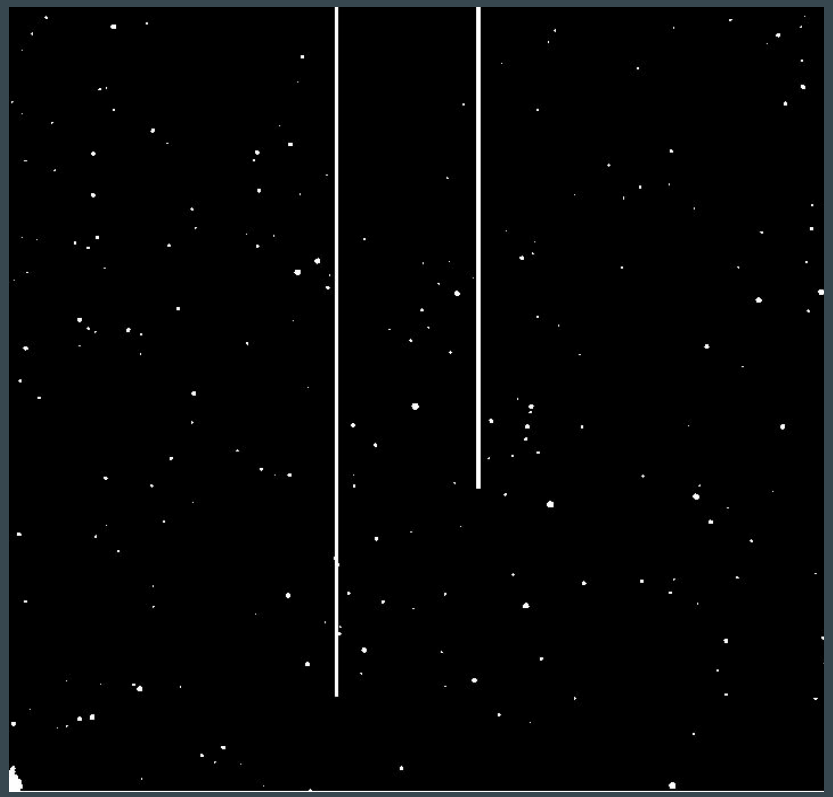


Image after combining

Data and Methods Cont.

- Then did photometry using source extractor (Bertin, 1996) a script that catalogs the brightness of every source in each image.
    - Will then use the catalog to do differential photometry (i.e. measure the change in brightness of the target relative to the other stars in the field)



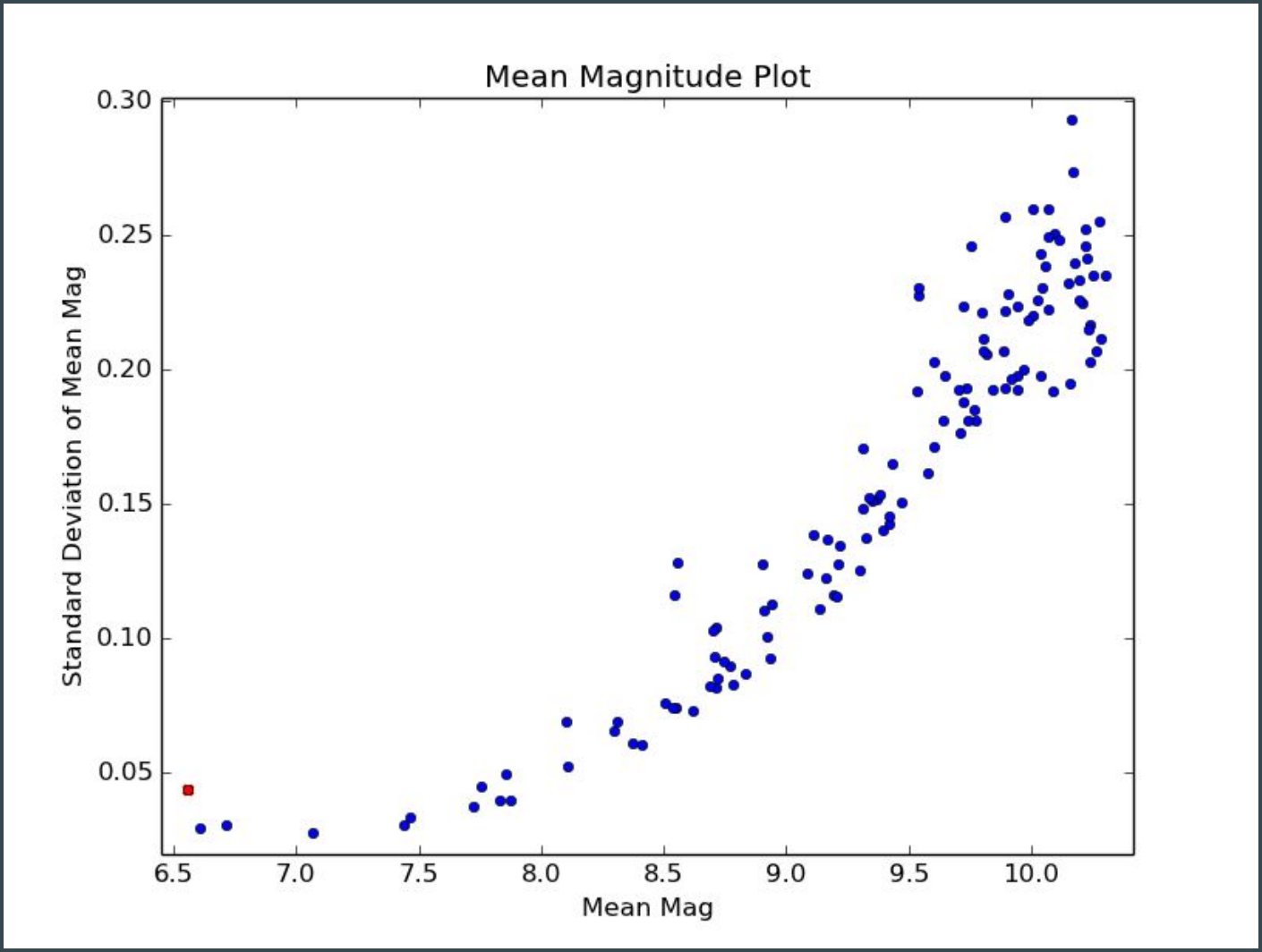
The “mask” source extractor creates.

Combined Image

Analysis

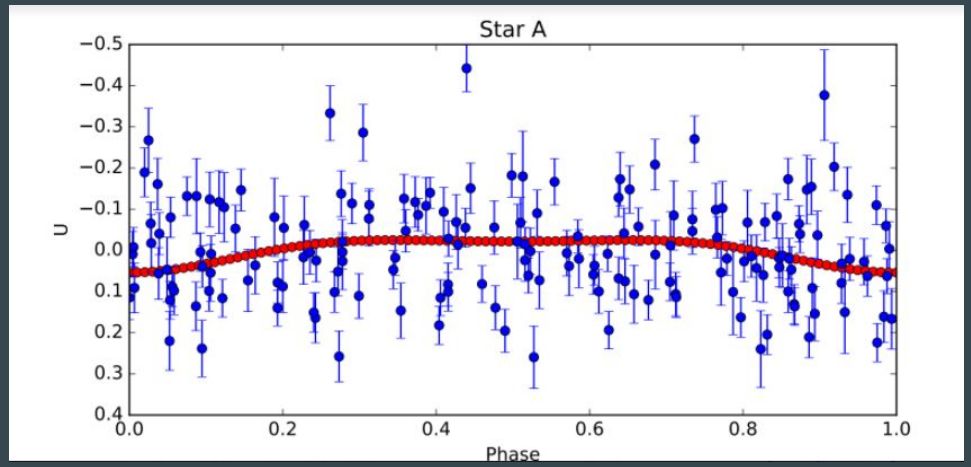
- Using the catalog, created an ensemble of light curves for all sources in the field were made.
- Average magnitude and standard deviation of the variability of the star were then calculated.
  - When plotted against each other, variable stars will “jump” out of the baseline curve, making it easy to identify variable stars. Call this plot a Mean Magnitude Diagram.
- Stars which appeared to be variable were examined by hand.
  - Bad data points in their light curve due to cosmic rays, or clouds were removed or if the star itself was variable, the whole star was removed from the ensemble.
- When only constant field stars remained in the ensemble, they were used as “comparison stars” to measure the brightness of the target, V4046 Sgr, relative to these constant stars.
  - Improves the S/N by $\sqrt{n}$ where n is the number of comparison stars.
- End result is a light curve of the target, relative to the field.

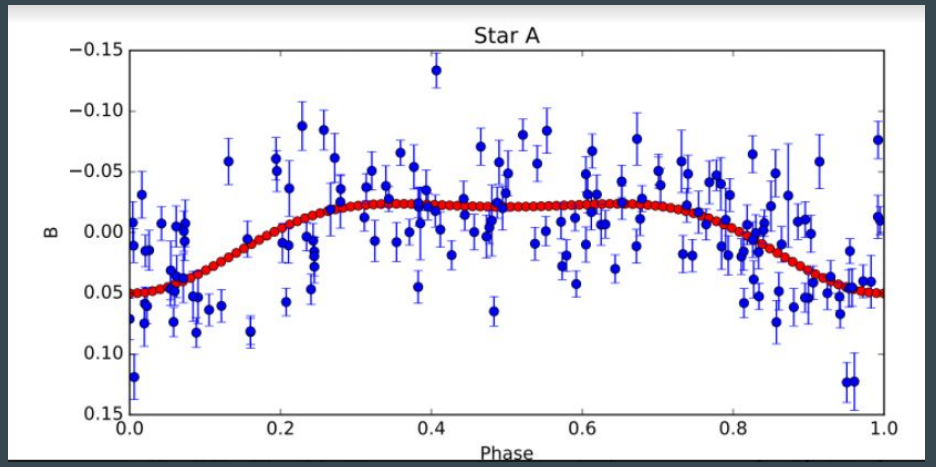
Analysis Cont.

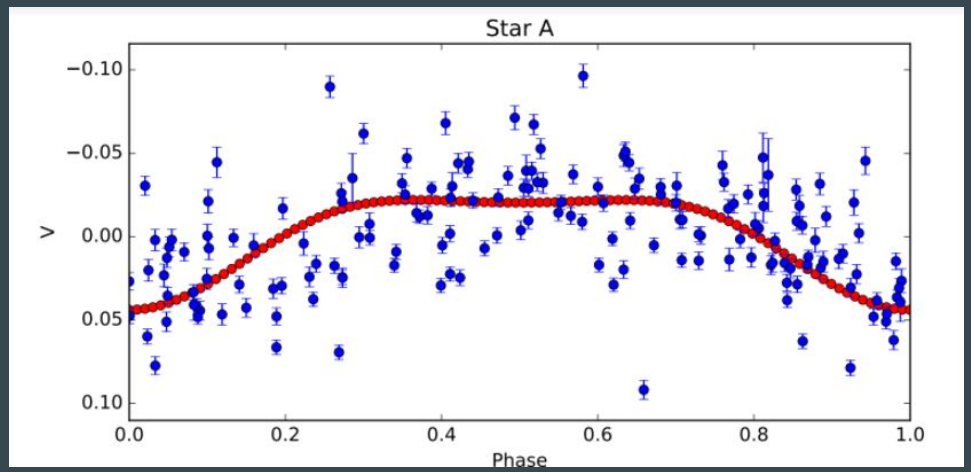


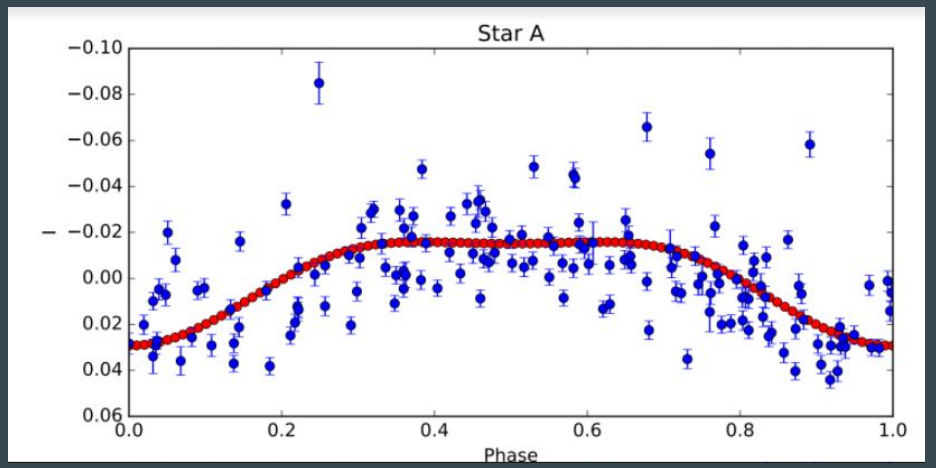
Mean Magnitude plot of the B band

Analysis Cont.





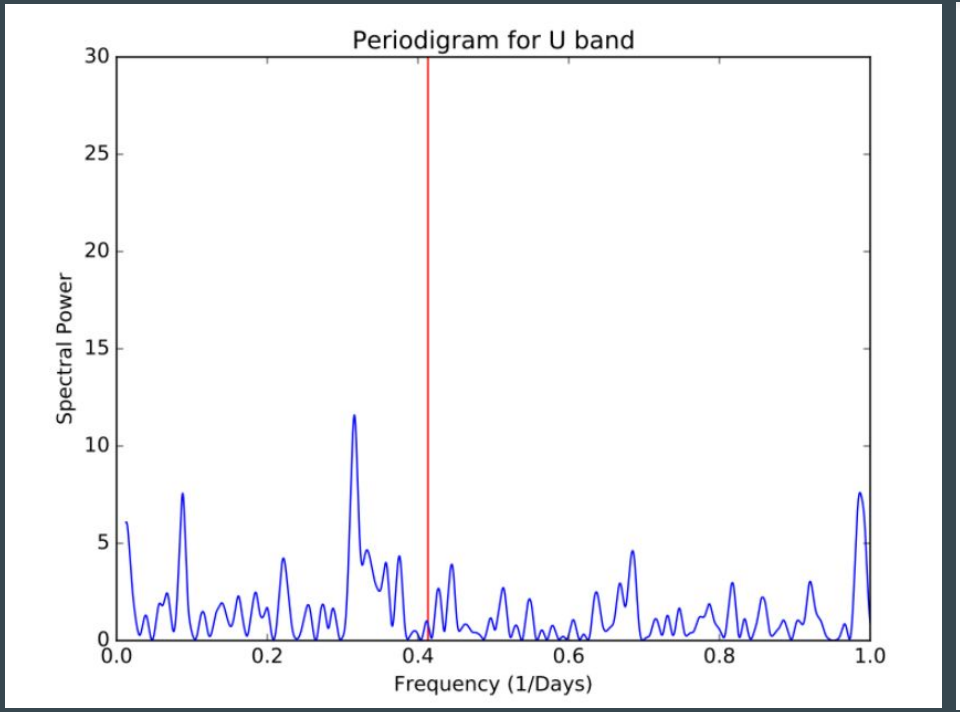


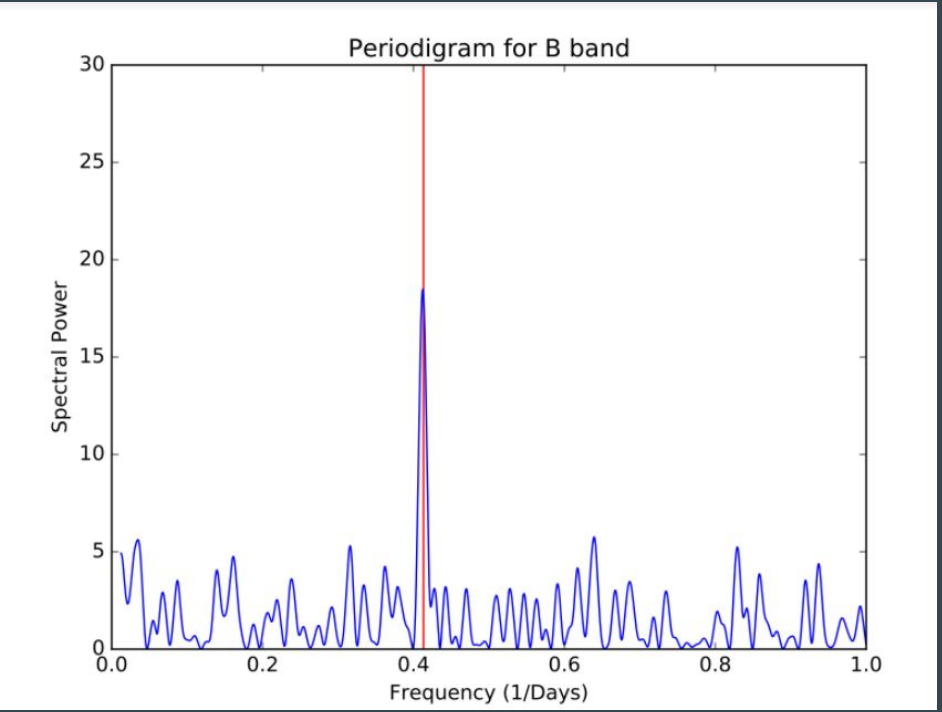


Light curves plotted versus phase for each of the four bands used. Note the range of magnitude variability.

Analysis Cont.

- Performed a Fourier analysis on the light curves in each band.
  - Strong periodic variability in the B, V and I bands however this periodicity disappears in the U band
  - Note I still need to calculate the false alarm probability for these plots.



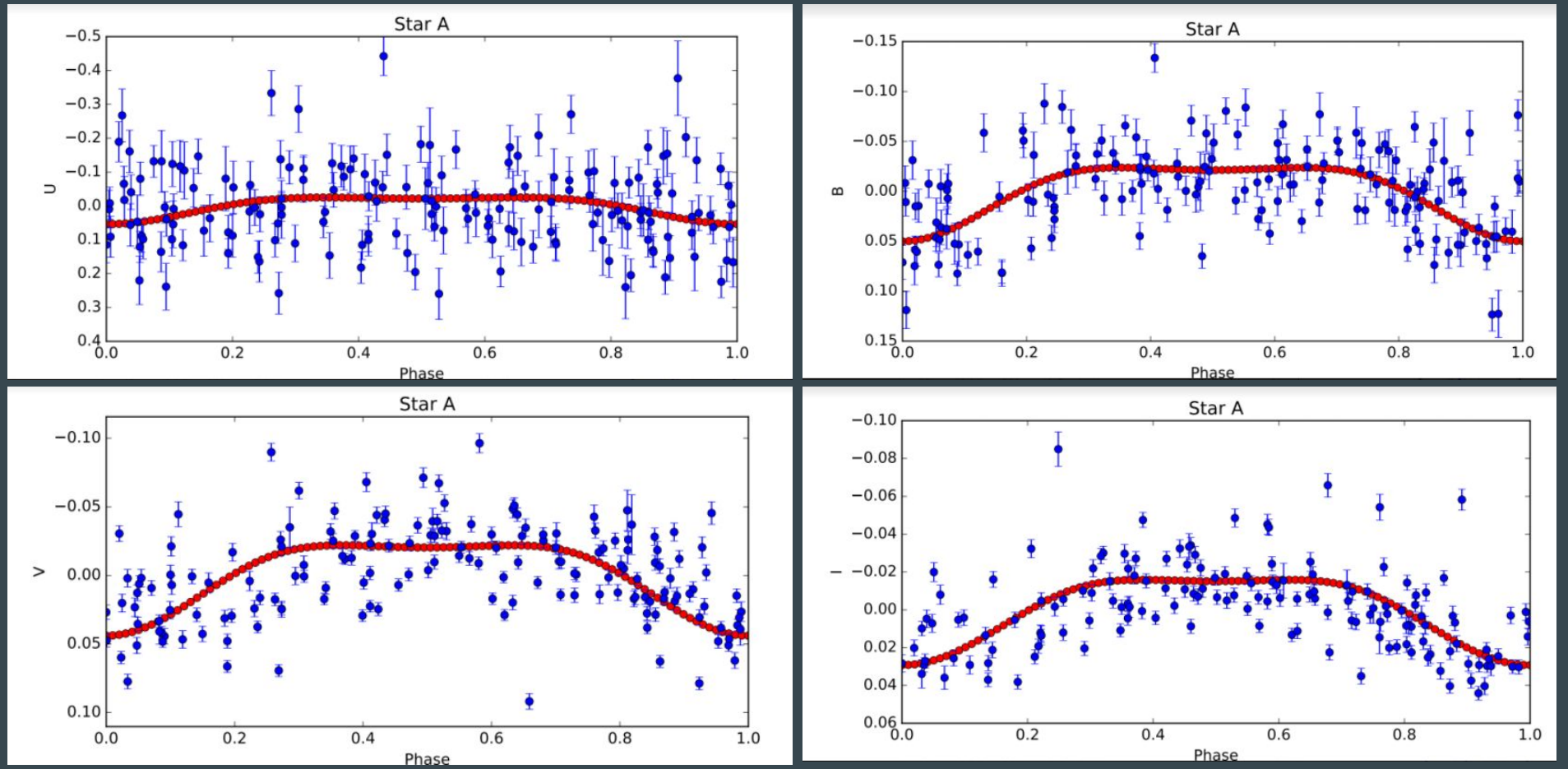


Red line here is the period of the orbit

Analysis Cont.

- To explain this periodic variability I used PHOEBE, a spot modeling software, to create model light curves for V4046 Sgr if it had one star spot on its primary star.
- The two stars are old enough (10 million years) such that their rotation period has been tidally synchronized with the orbital period.
- First I did a crude, by hand calculation of the spot size assuming a temperature of the spot to be 65% of the normal temperature of the primary.
    - 65% is a common estimate within the field of star spots.
- I then used this as a starting point for my actual model and fit the B, V, and I band light curves simultaneously.

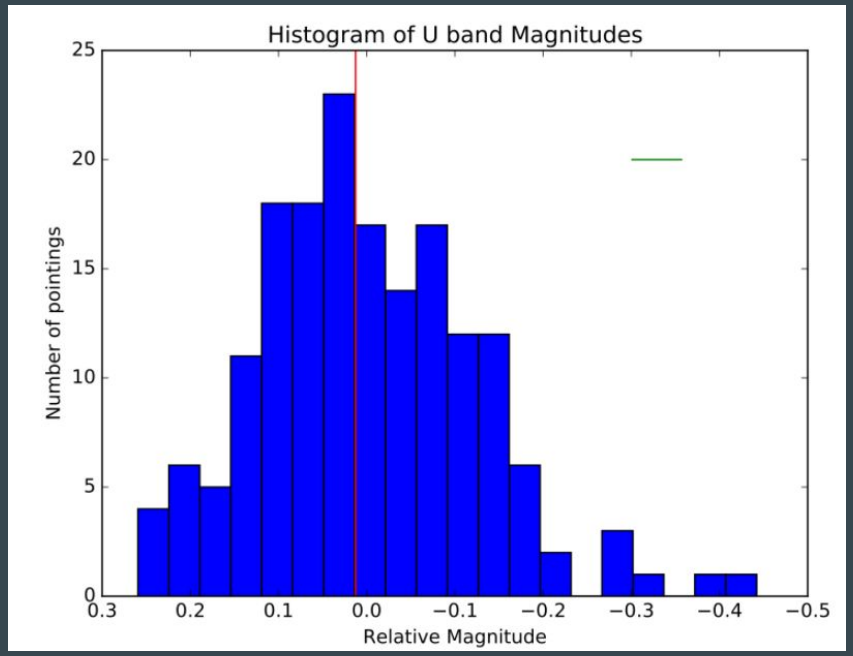
Analysis Cont.



Light curves plotted versus phase for each of the four bands used. The red points are the spot models light curve.

Analysis Cont.

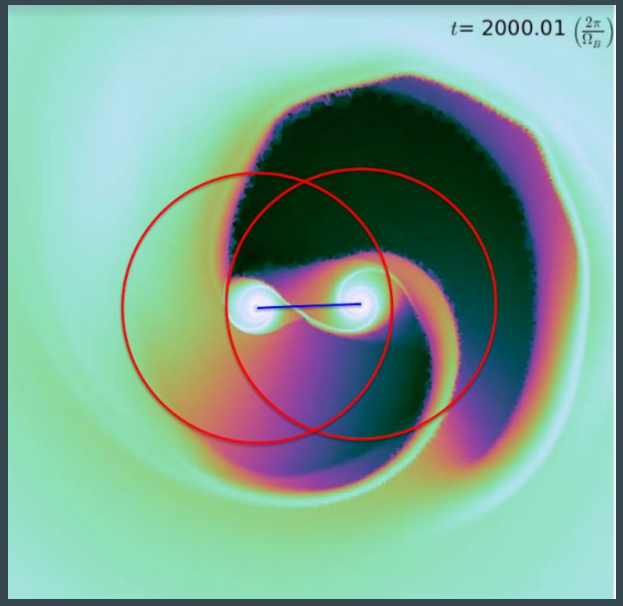
- Based on the poorness of the fit in the ultraviolet, and the scatter around the model, the remaining variability is attributed to accretion from the circumbinary disk.
  - Accretion produces excesses in the ultraviolet



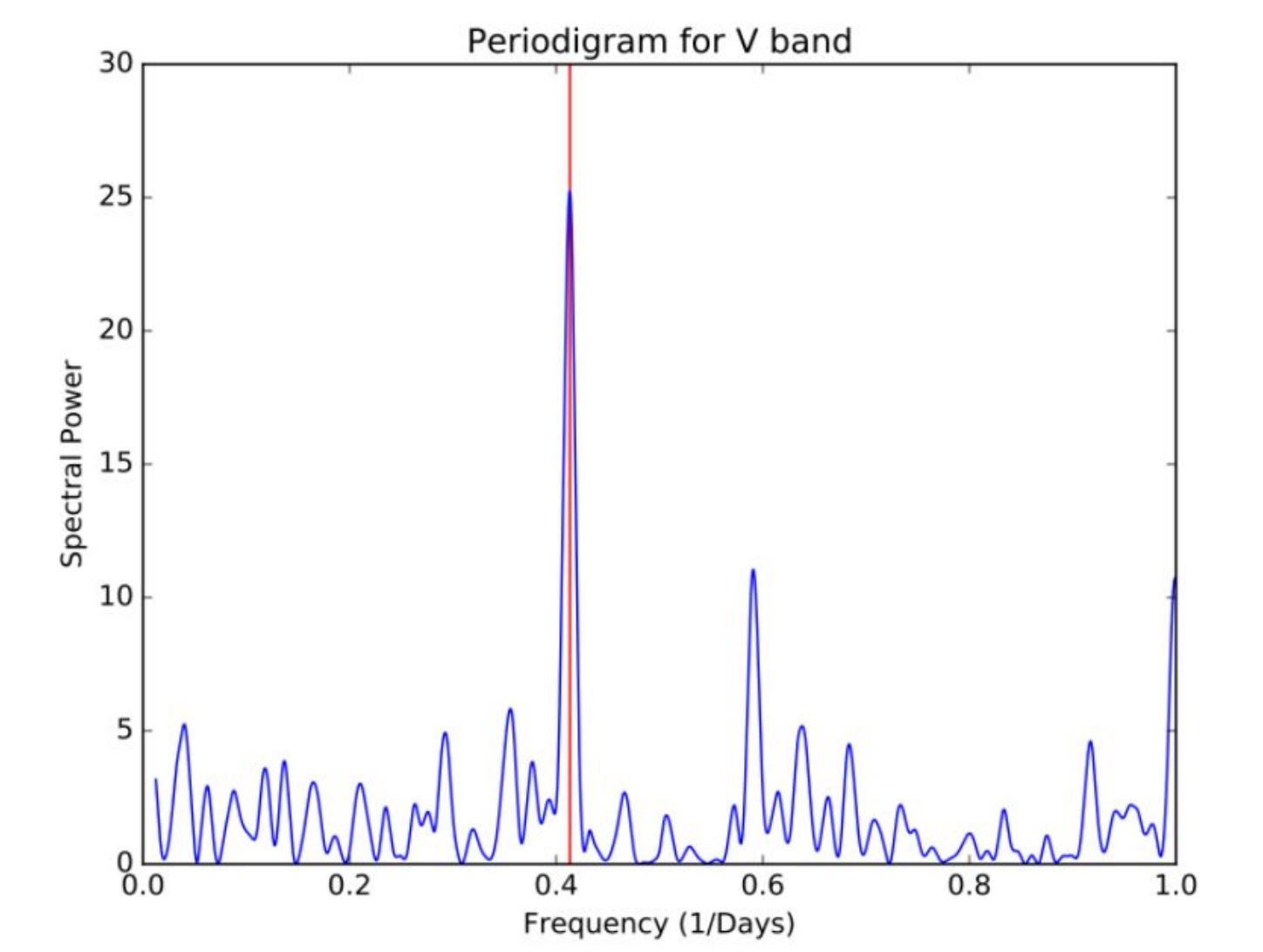
Red vertical line is the median magnitude while the green is the mean error on all points in the ultraviolet

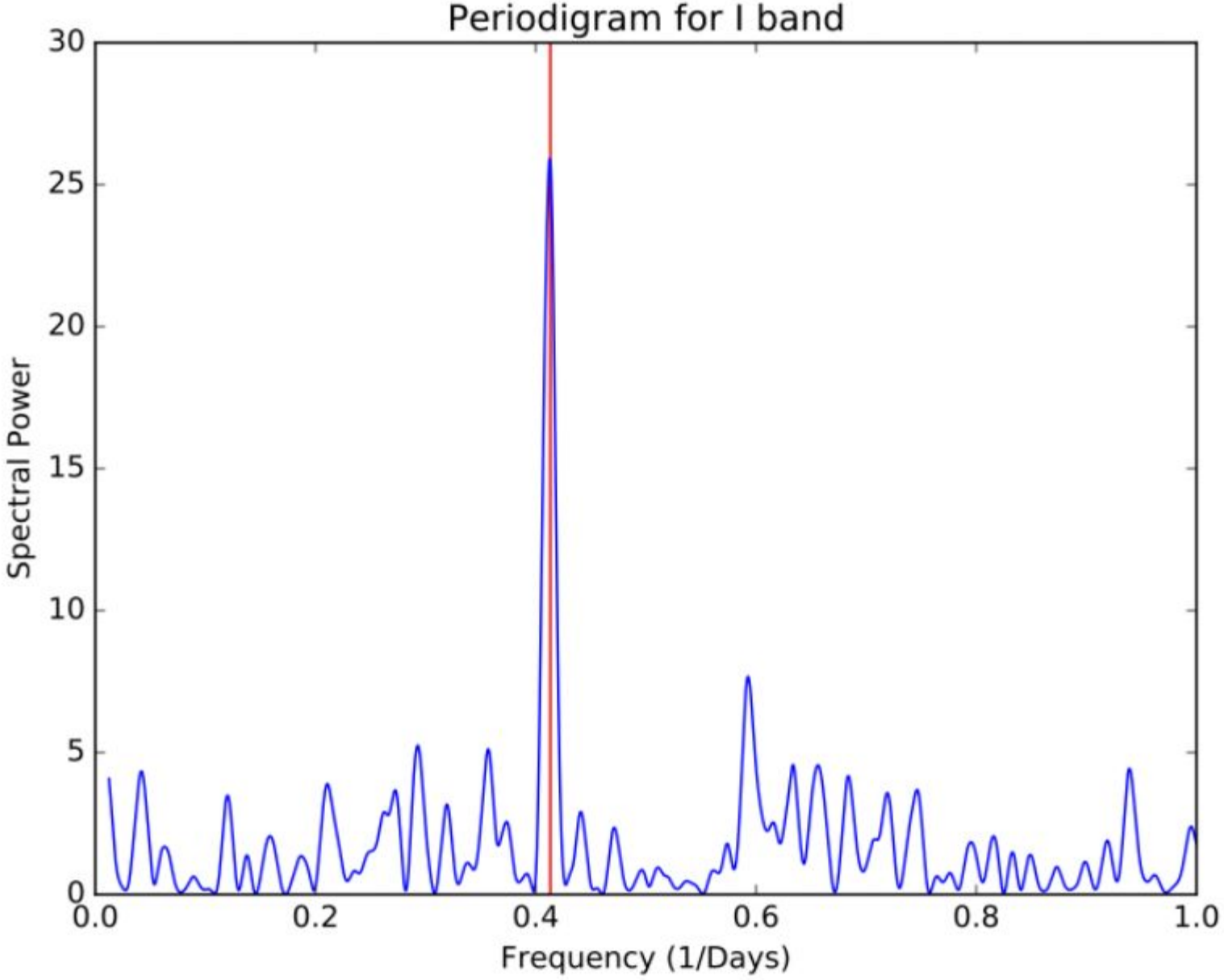
Analysis Cont.

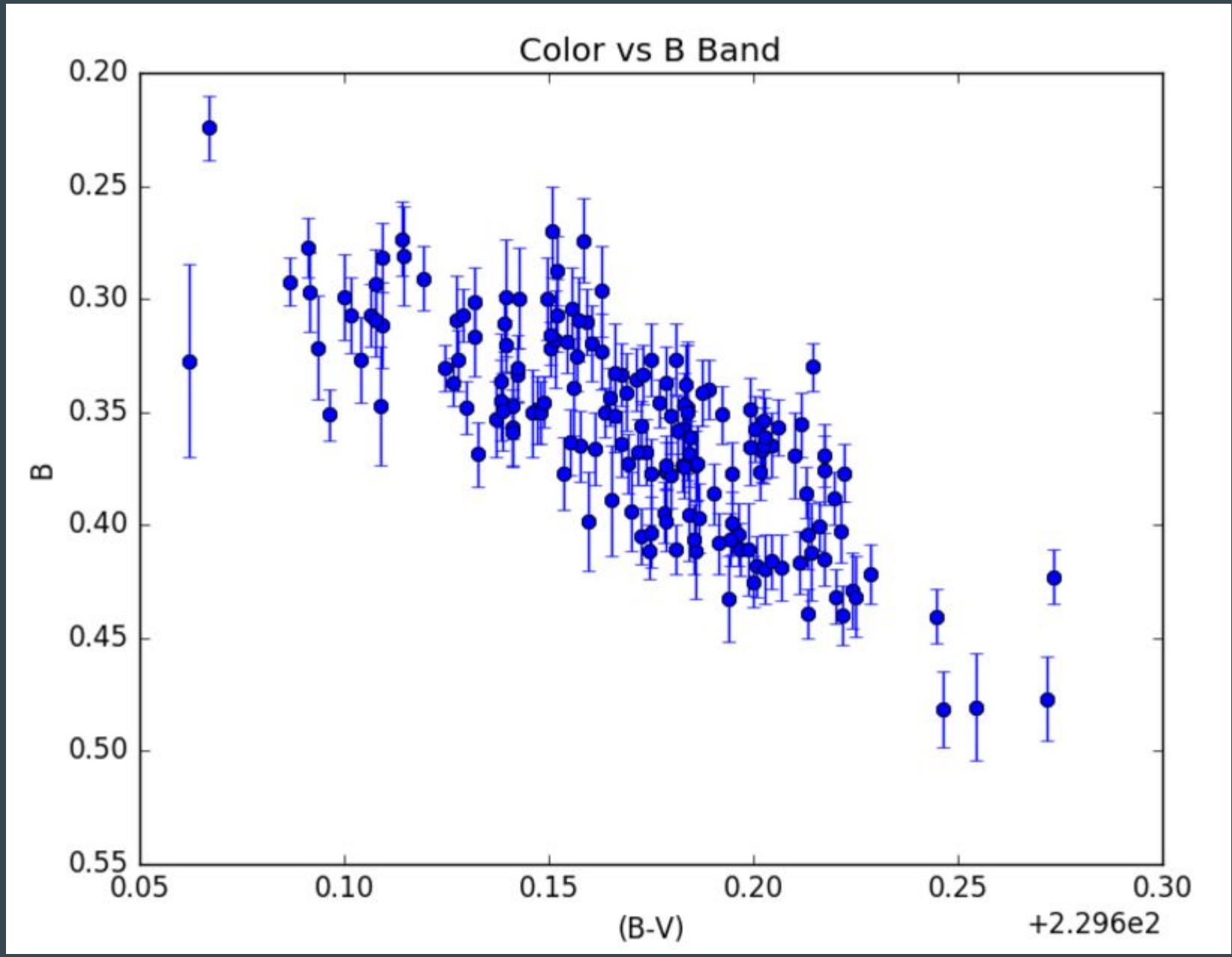
- Due to the closeness of the binary, the magnetic fields of each star are directly interacting.
- Below is a screenshot scale free simulation of how a circular binary and its circumbinary disk interact without taking magnetic fields into effect (Munoz, 2012).
    - By using the parameters of V4046 Sgr, according to this model the magnetic fields (denoted by the red circle) of each star would be directly interacting with the circumbinary disk.

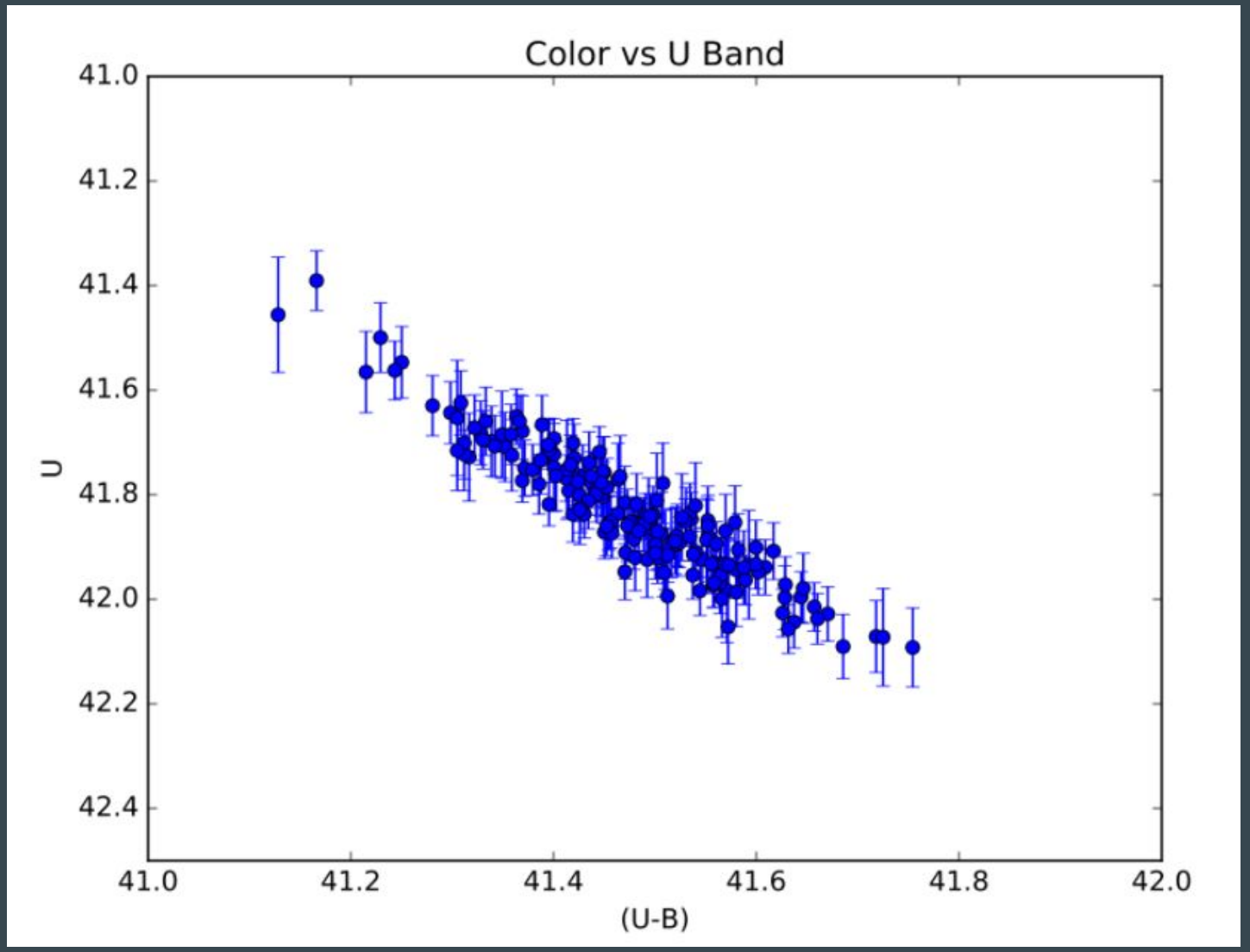


Backups


Periodigram for V band
Spectral Power
Frequency (1/Days)
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0


Periodigram for I band
Spectral Power
Frequency (1/Days)
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0


Color vs B Band
B
(B-V)
+2.296e2
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.05
0.10
0.15
0.20
0.25
0.30


Color vs U Band
41.0
41.2
41.4
41.6
41.8
42.0
42.2
42.4
U
41.0
41.2
41.4
41.6
41.8
42.0
(U-B)