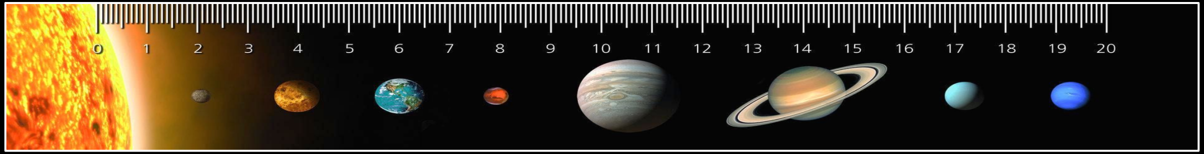

Light as a Ruler:

The Accuracy of Delta Scuti Variables as a Distance Metric

Big Drippers:
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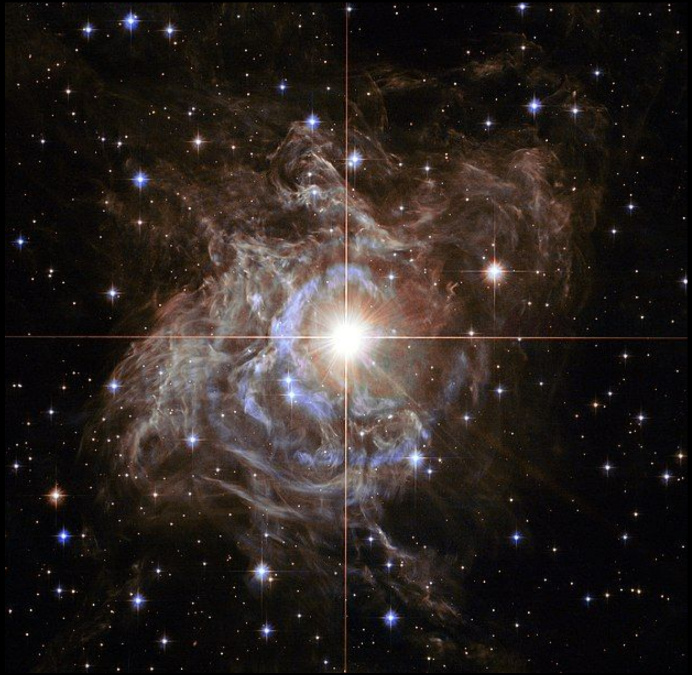
Department of Physics, Stanford University

Abstract:

We estimated the distance to Delta Scuti variable star SZ LYN using a period-luminosity relation and commented on the accuracy of this method by comparing our results to archival parallax data.

Outline:

- Introduction to Variable Stars
- Methods
- Analysis
- Conclusion



RS Puppis, one of the brightest known Cepheid variable stars in the Milky Way galaxy (Hubble Space Telescope)

What are Pulsating Variable Stars?

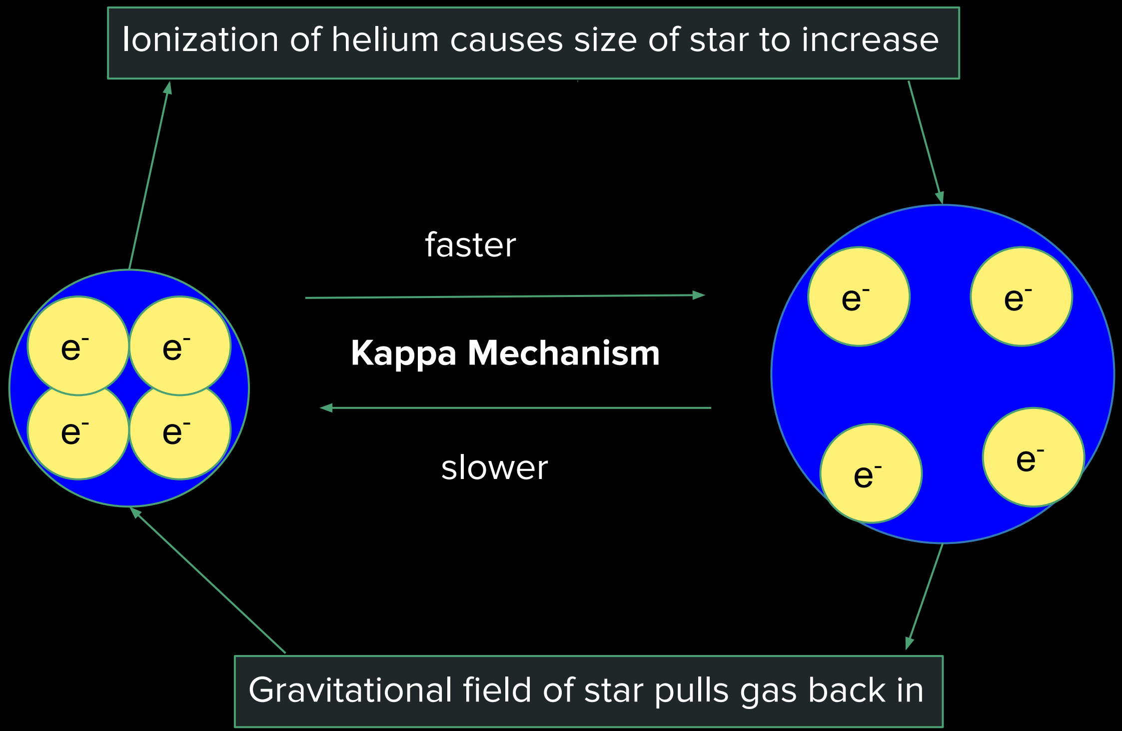
Pulsating Variable Stars

- Stars that fluctuate periodically in temperature and size due to K-mechanism
    - P-modes: pressure causing the star to inflate
    - G-modes: gravity causing the star to collapse and restart the cycle

- Subclasses of Variable Stars
    - Cepheid Variables
    - RR Lyrae Variables
    - Beta Cephei (β Cep), SPB stars, gamma Doradus (γ Dor), delta Scuti (δ Scuti)

Kappa Mechanism

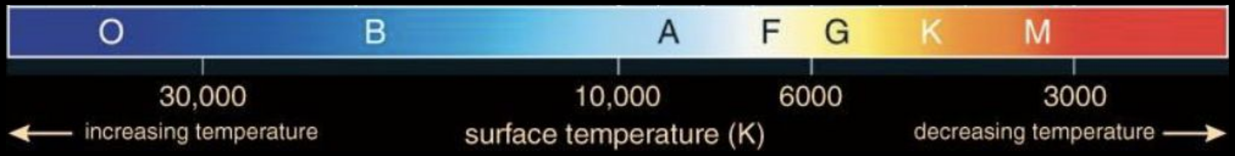
- Small
- Hot
- Opaque



- Large
- Cool
- Transparent

Delta Scuti Stars

- Spectral range A2 to F0
- corresponding to temperatures of 7000–9300K



- Mass ranges between 0.5–20 $M_\odot$

Delta Scuti Stars

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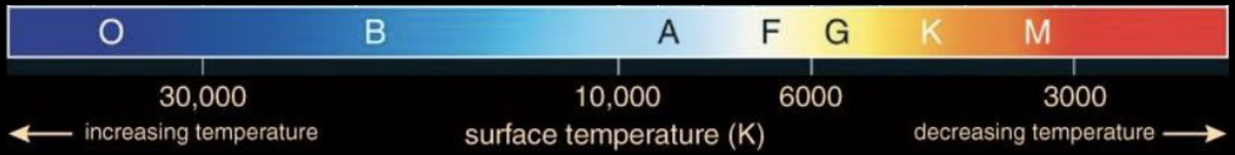
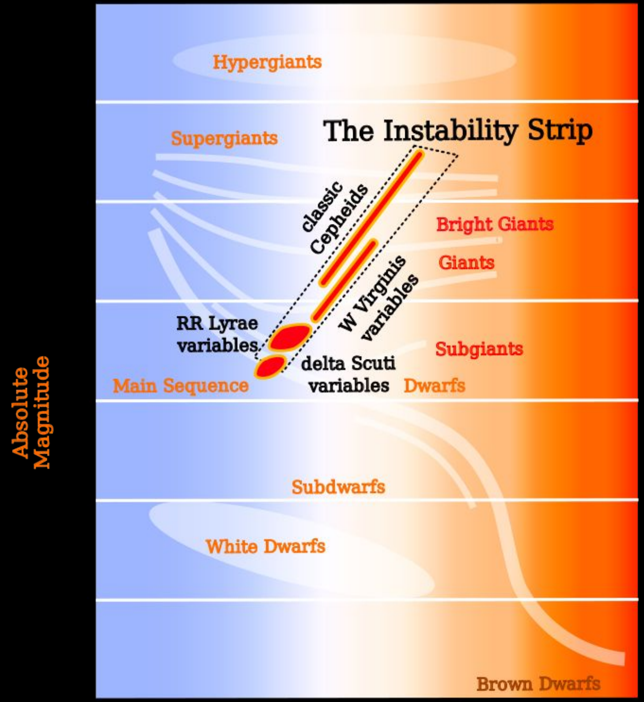


- Mass ranges between 0.5–20 $M_\odot$

What makes them special for measuring distances?

Why Delta Scuti Variables?

- Shorter periods (15min to 5hr) make for more straightforward observations
- Class of pulsating variable stars commonly found in Milky Way – we chose *SZ Lyncis*
- Measuring the period of a delta scuti variable accurately will allow us to estimate its luminosity using a Period-Luminosity relationship (PLR)



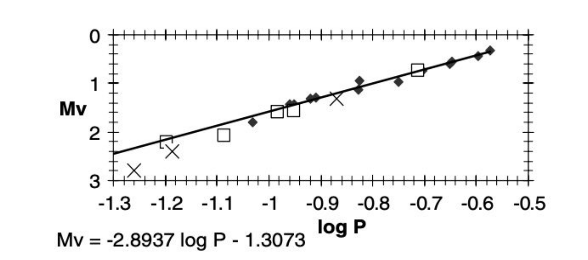
Source: AAVSO

Period-Luminosity Relationships

- Direct proportionality law discovered by Henrietta Leavitt in 1908 for type I Cepheids
- Delta Scuti Variables also follow strict Period-Luminosity relationships
- *RR Lyrae Variables do not follow a strict period-luminosity relationship at visual wavelengths, although they do in the infrared band
- More luminous variables pulse slower

Table 1
M_V Values of Metal-strong Variables

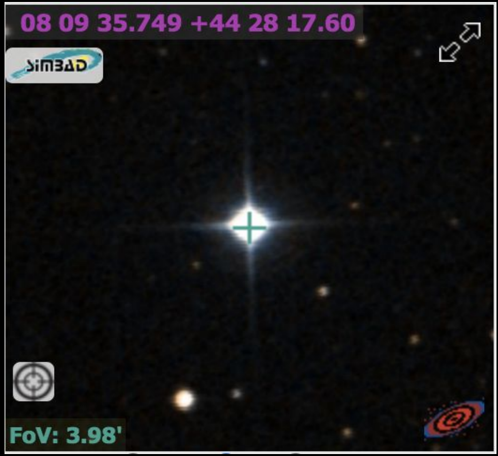
Object	log *P*	M_V	(M_V)old	[Fe/H]
RV Ari	−1.031	1.79	1.83	0
BP Peg	−0.96	1.42	1.42	−0.02
AI Vel	−0.952	1.44	1.51	−0.15
SZ Lyn	−0.919	1.32	1.35	−0.13
AD C Mi	−0.91	1.29	1.3	0.1
DY Her	−0.828	1.12	1.15	0
V567 Oph	−0.825	0.94	0.93	−0.15
VZ Cnc	−0.749	0.96	0.88	0.15
BS Aqr	−0.704	0.74	0.62	0.2
VX Hya	−0.651	0.6	0.52	0.05
RY Lep	−0.647	0.56	0.47	−0.05
DE Lac	−0.596	0.43	0.38	0.18
V1719Cyg	−0.573	0.33	0.15	0.3



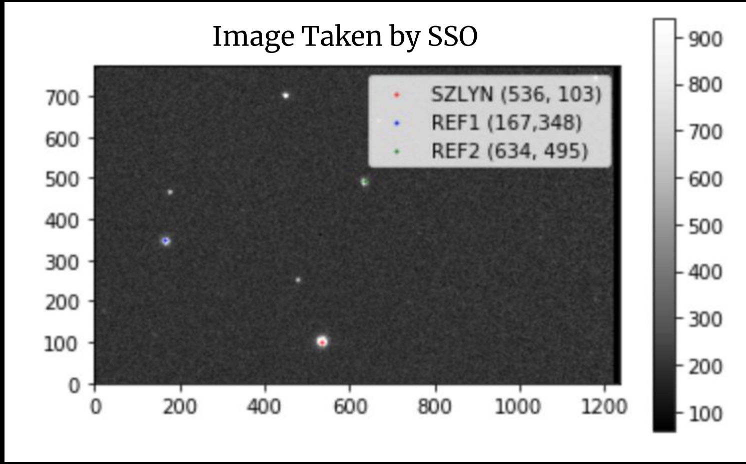
McNamara 2011

SZ Lyncis - HD 67390 - HIP 39960

- High amplitude Delta Scuti star – 9.06 to 9.72 V, $\Delta m = 0.64$
- Period of 0.12 days, or 2.89 hours (AAVSO)
- High altitude—good for observing the entire period before setting
- Spectral type A9



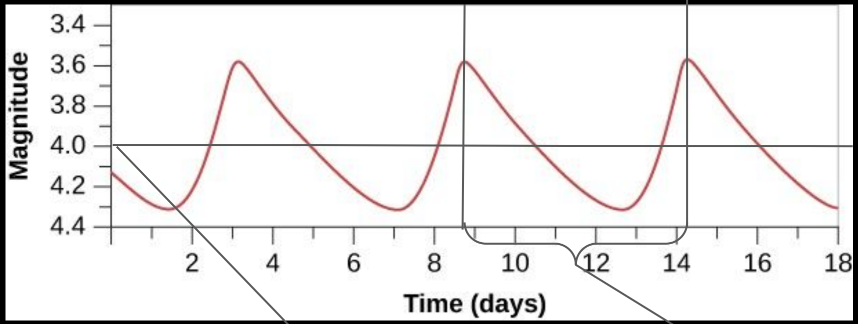
Source: SIMBAD



Method for Estimating Distance

1. Measure the star's period
2. Use a period-luminosity relationship to estimate the absolute magnitude
3. Use observed data to calculate apparent magnitude
4. Use distance modulus to compute distance

Example Light Curve



$$M_v = a + b * log(P)$$

$$D = 10^{0.2(M_{av} - M_v + 5)}$$

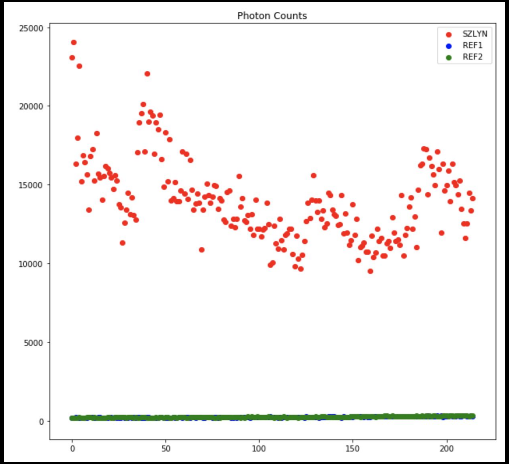
Observation

- One three hour observing session at Stanford Student Observatory.
- R band yielded highest photon count.
- Took images at 20 second exposure each, 20 seconds apart.
- Refocused intermittently and moved dome in middle - break in curves.

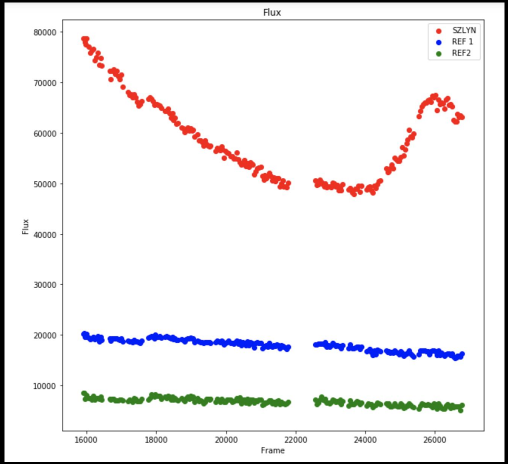
Stanford Student Observatory, Linda Cicero

Photometry

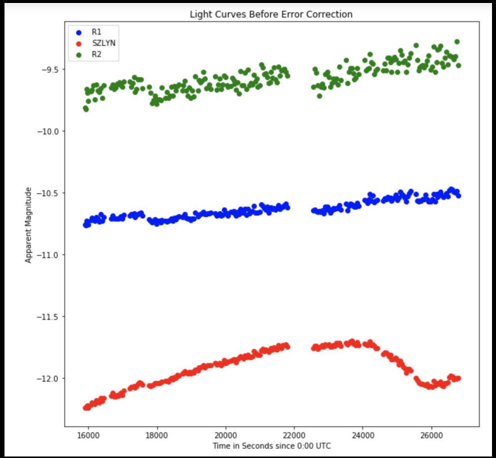
Photon Counts



Flux (Photons/s)



Instrumental Magnitude

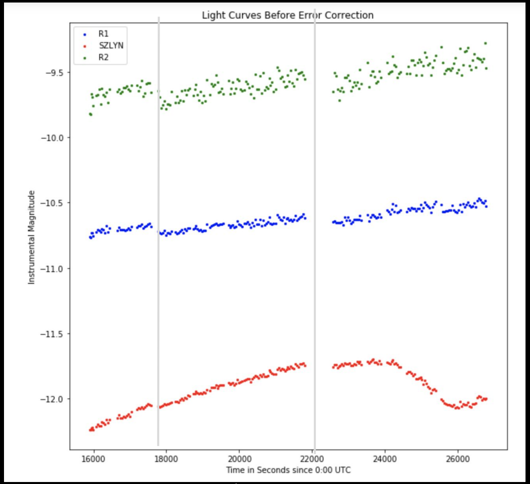


$$f = \frac{(\sum_{i,insource} p_i) - p_{bkgmed} n_{source}}{t_{exp}}$$

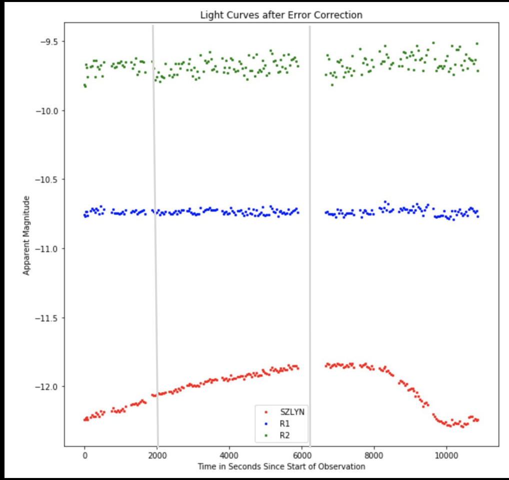
$$M = -2.5 log(f)$$

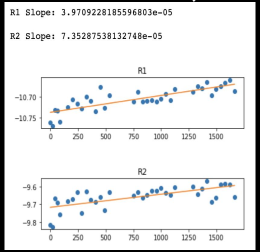
Air mass and Refocusing Corrections

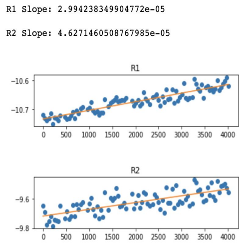
Before

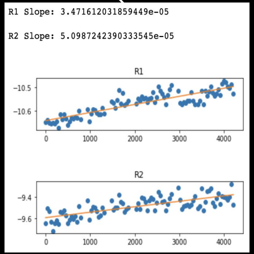


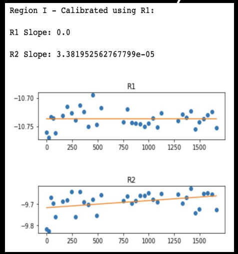
After

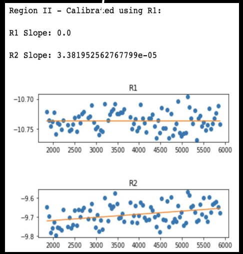


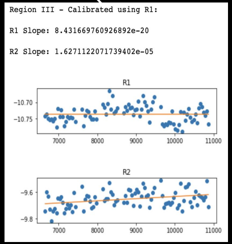






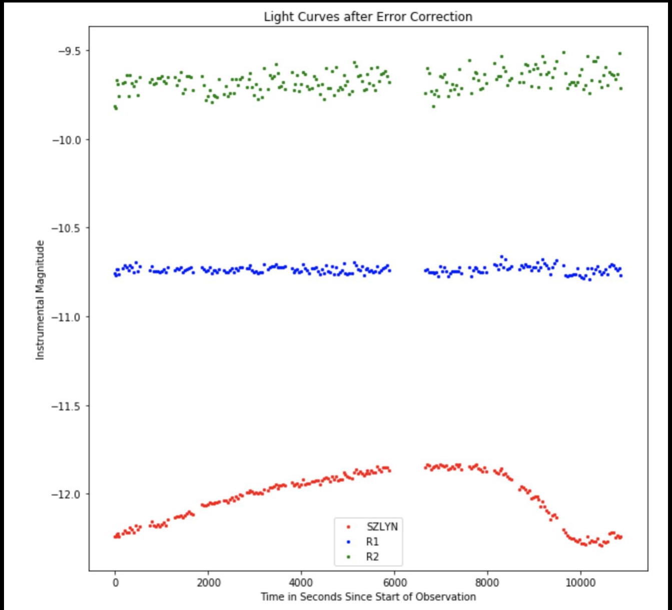




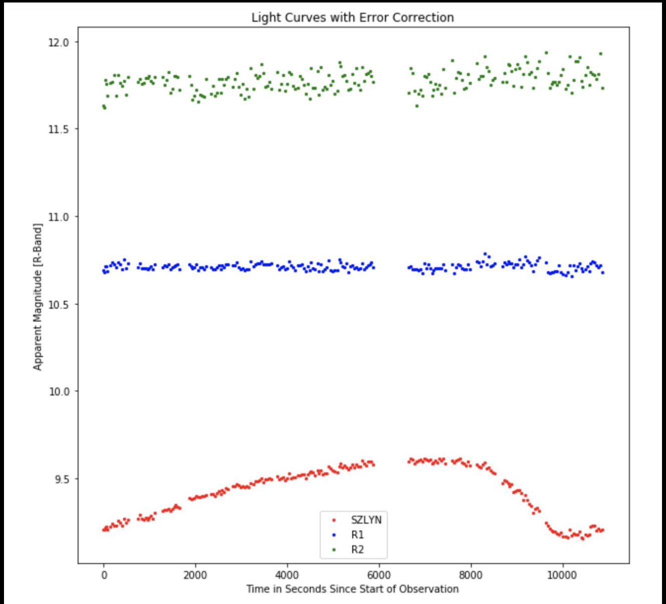


Zero-Point Correction

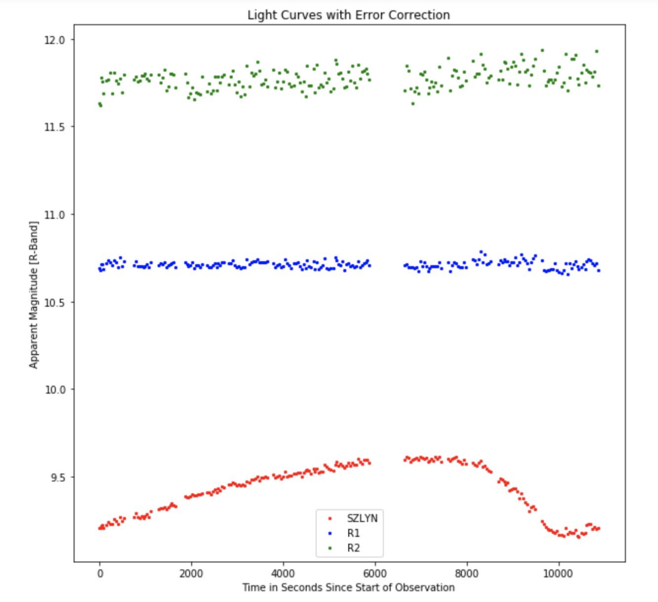
Instrumental Magnitude

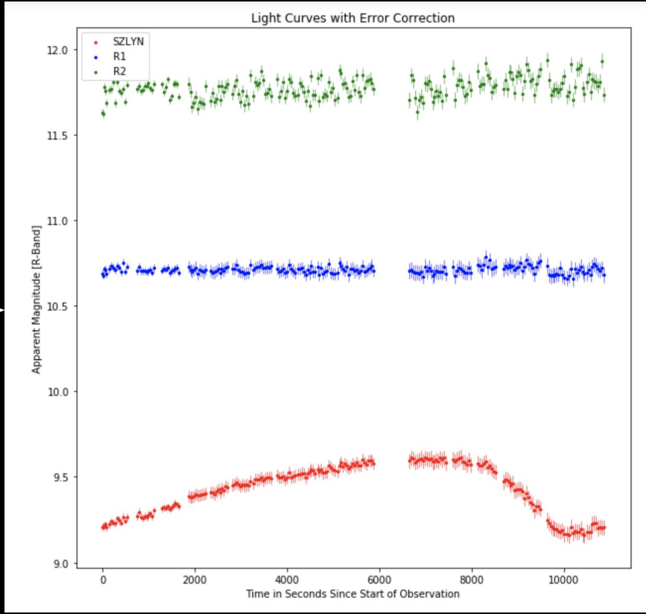


Apparent Magnitude [R-Band]



Error Propagation





Extracting Period using Fourier Analysis

We fit data points to curve of form:

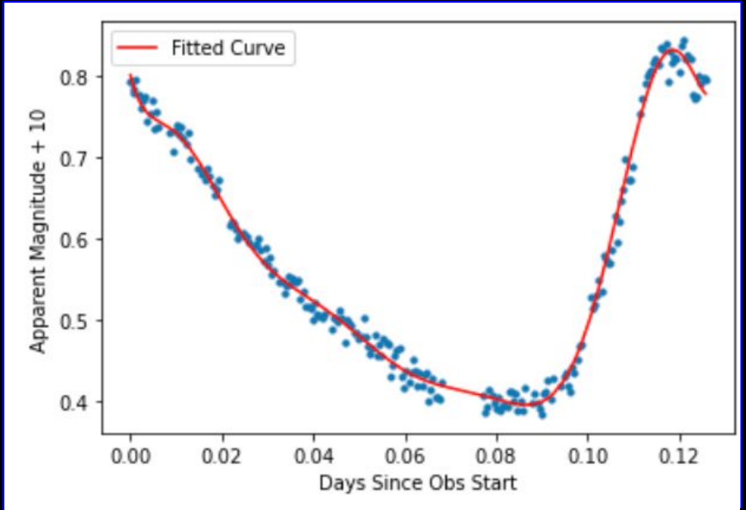
$$\boxed{M(t) = a_0 + \sum_{n=1}^{17} a_n cos(nwt) + b_n sin(nwt)}$$

Using SciPy, we extract the parameters:

$$argmax_n(a_n, b_n) = 13$$
$$w = 4.018255$$

Thus, our primary period is

$$P = \frac{2\pi}{13 * 4.018255} = 0.1202816 days = 2.886757 hours$$




```
Goodness of fit qualifiers:
chi_squared                0.035393778749932804
objective_value            0.017696889374966402
r_squared                  0.9920925722011632
```

Distance Calculations with PLR

$$M_v = a + b * log(P)$$

$$\underbrace{a = -1.31 \pm 0.1, b = -2.89 \pm 0.13}_{\text{Parameters for delta scuti variables}}$$

$$M_v = 1.348 \pm 0.0745$$

$$D = 10^{0.2(M_{av} - M_v + 5)}$$

Average of apparent light curve

$$\boxed{D = 412.571 \pm 1.704pc}$$

Conclusions

- We report a 412.571 ± 1.704pc distance with the period-luminosity relation
- Parallax data from GAIA 2020 survey reports a 1.9104 [0.1127] mas angle, corresponding to 523.451 ± 30.8799pc
- Curiously, GAIA 2018 data reports a 400.9462 ± 11.2048pc
- A 21.1% error in our accuracy from 2020, 2.91% from 2018
- AAVSO lists period as 2.892hr, we report 2.886hr (0.2% error)
- As expected, parallax methods are highly accurate for "nearby" stars, but less so for measuring distances to other galaxies
- Luminous Cepheids are far more useful for distance measurements in these cases, as discussed before

References

1. Photoelectric observations of SZ Lyncis (Soliman et al. 1986)
2. Estimating Distance from Parallaxes (Bailer-Jones et al. 2018)
3. Pulsational mode identification from multi-colour photometry (Handler 2008)
4. An Overview of Stellar Pulsation Theory (Saio 1993)
5. Asteroseismology of SZ Lyn using very high time resolution photometry in BVR bands (Adassuriya et al. 2018)
6. Light curve analysis of variable stars using Fourier decomposition and principal component analysis (S. Deb and H. P. Singh)
7. Delta Scuti and RR Lyrae Stars in Galaxies and Globular Clusters (D. H. McNamara 2011)

Acknowledgements

Of course, a very special thank you to our teaching team for assisting and teaching us throughout the entire 5-hour observation session, being available throughout the whole quarter for questions and guidance, and working with us to fully flesh out our science. Thank you!

🤝

Questions?