Probing the Pulsation Modes in High Resolution Spectroscopy: A Case Study of SZ Lyn

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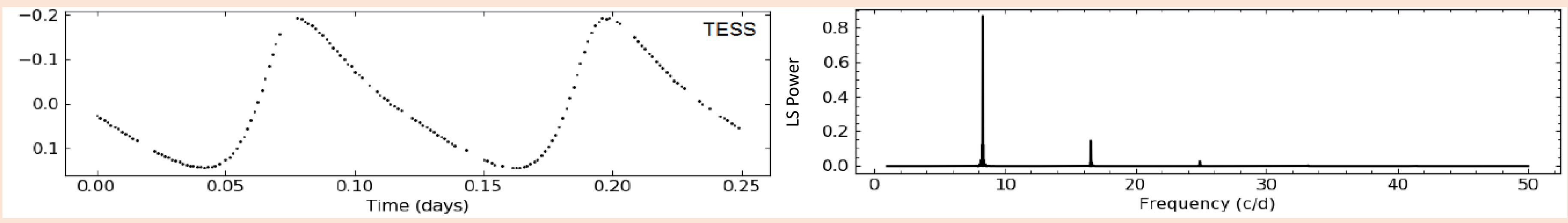
Abstract

A high-resolution spectroscopic study of the δ Scuti type pulsating star SZ Lyn (HD 67390) was conducted to investigate its radial and non-radial pulsation modes. A total of 15 high-resolution spectra obtained by HERMES spectrograph in 2023 were analyzed using a combination of data reduction steps, including binary and phase calculation, spectral normalization, and heliocentric velocity correction. Three unblended metallic absorption lines, Ti (II) 4501.28 Å, Fe (I) 4957.59 Å, and Fe (II) 4508.29 Å, were examined using the FAMIAS. Frequencies were extracted using the Pixel-by-Pixel Fourier analysis method, and pulsation modes were identified through both the Fourier Parameter Fit (FPF) method and the moment method. The Ti (II) 4501.28 Å line revealed a frequency of 8.827 d^{-1}, consistent with the photometric radial mode frequency of 8.296 d^{-1}. The FPF method consistently identified the dominant pulsation mode of SZ Lyn as radial, with spherical degree l=0, and azimuthal order m=0. These results confirm that the primary pulsation of SZ Lyn is radial in nature. Radial velocity curves and radius variations over the pulsation phase further illustrate the star's behavior. This study demonstrates the possibility of high-resolution spectroscopy in probing stellar interiors and emphasizes the need for additional high-quality spectra and metallic lines, particularly those of heavier elements, to refine pulsation models and better constrain stellar parameters.

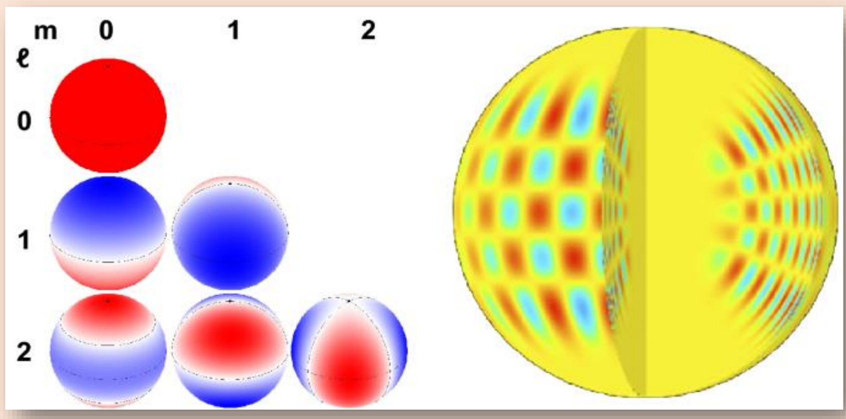
1. Introduction

SZ Lyn is a short period Delta Scuti type pulsating star in a binary system. The star pulsates in both radial and non-radial modes, of which the dominant one is radial.



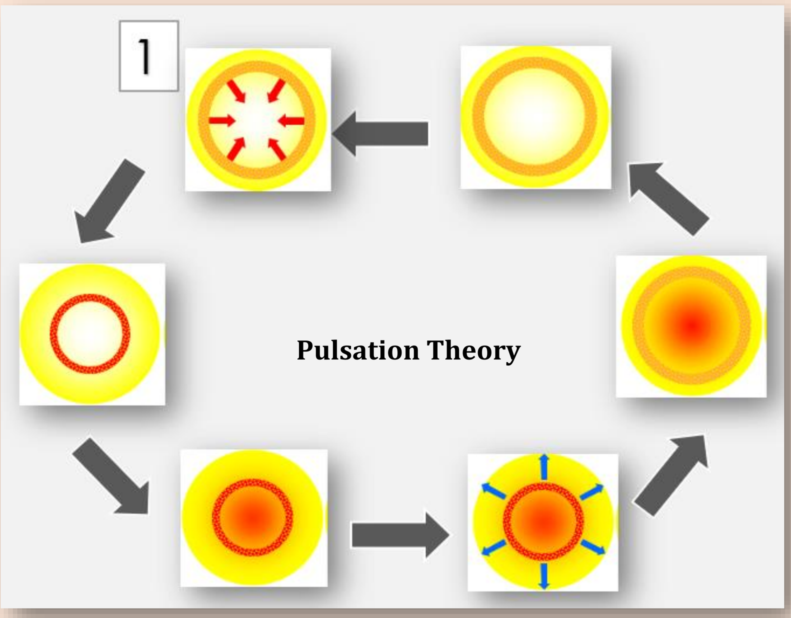
Adassuriya et al.(2021)

Parameter of SZ Lyn	Value	Remarks
Pulsation Period	0.1205263 days	J. Adassuriya et al. (2021) (Photometric Observation)
Temperature	7500 – 7800 K	
Orbital Period	1187 days	J. Adassuriya et al. (2018) (Photometric Observation)
Eccentricity (e)	0.18	
Inclination (i)	39 degrees	Sheng-Bang et al. (2013)
Mass function	0.095 M_{sun}	Gazeas (2004)
Mass	M_p=1.90 M_{sun} M_s=1.65 M_{sun} or 0.88 M_{sun}	M_s are the real solutions of binary mass function
Main Radial mode frequency	F1 = 8.296 c/d	Adassuriya et al.(2020)



Garcia, R. A., & Ballot, J. (2019). *Asteroseismology of solar-type stars. Living Rev. Sol. Phys.*, 16, 4.

(l,m) = (0,0) → Rdial
When l > 0 and m = 0 → Non-radial

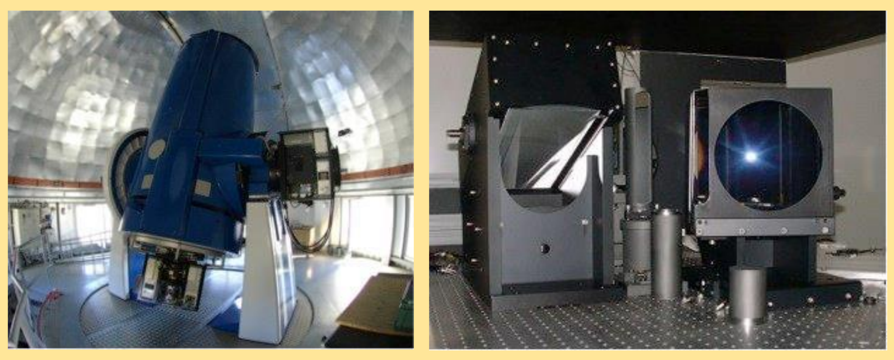


Credit: HET611-M17A01: Pulsating Stars: Stars that Breathe, Swinburne University of Technology, 2010

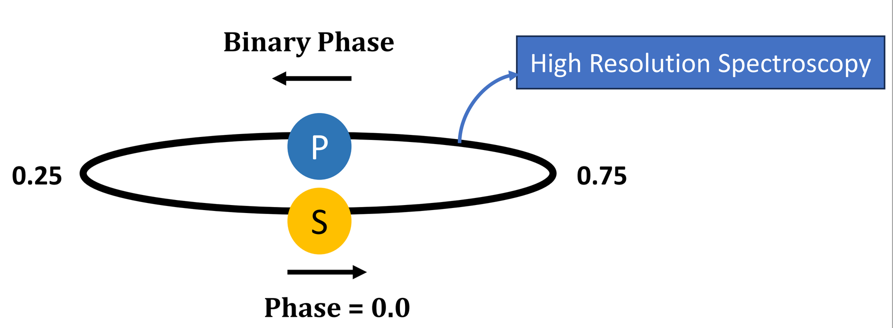
2. Spectroscopic Observations

Spectrum No.	SNR50	BJD Value	Binary Phase	Pulsation Phase
Spectrum 1	32.65	2460092.37198390	0.6466571	0.92
Spectrum 2	31.79	2460092.37834910	0.6466624	0.97
Spectrum 3	30.53	2460092.38471430	0.6466678	0.02
Spectrum 4	29.52	2460092.39108060	0.6466732	0.07
Spectrum 5	30.45	2460092.39744610	0.6466786	0.13
Spectrum 6	32.81	2460092.40381180	0.6466840	0.18
Spectrum 7	34.61	2460092.41017750	0.6466894	0.23
Spectrum 8	33.98	2460092.41654300	0.6466948	0.29
Spectrum 9	32.05	2460092.42290950	0.6467002	0.34
Spectrum 10	29.24	2460092.42927540	0.6467056	0.39
Spectrum 11	50.71	2460094.36873260	0.6483478	0.48
Spectrum 12	50.09	2460094.37509800	0.6483532	0.54
Spectrum 13	47.90	2460094.38146330	0.6483586	0.59
Spectrum 14	46.08	2460094.38782970	0.6483640	0.64
Spectrum 15	45.91	2460094.39419530	0.6483693	0.69

High Resolution R = 85000
No. of spectra = 15
27^{th}(10) and 29^{th}(5) May. 2023



The 1.2-m Mercator Telescope(left) with HERMES Fibre-fed echelle spectrograph(right), Roque de los Muchachos Observatory, La Palma, Spain.



Pulsation Phase = Fractional part of $\left[\frac{\text{BJD} - \text{EPOCH of pulsation}}{\text{Pulsation period}_{SZLyn}}\right]$

For the Spectrum 1,
BJD = 2459109.7431252
EPOCH of pulsation = 2456664.2611
Pulsation period of SZ Lyn = 0.120526 days

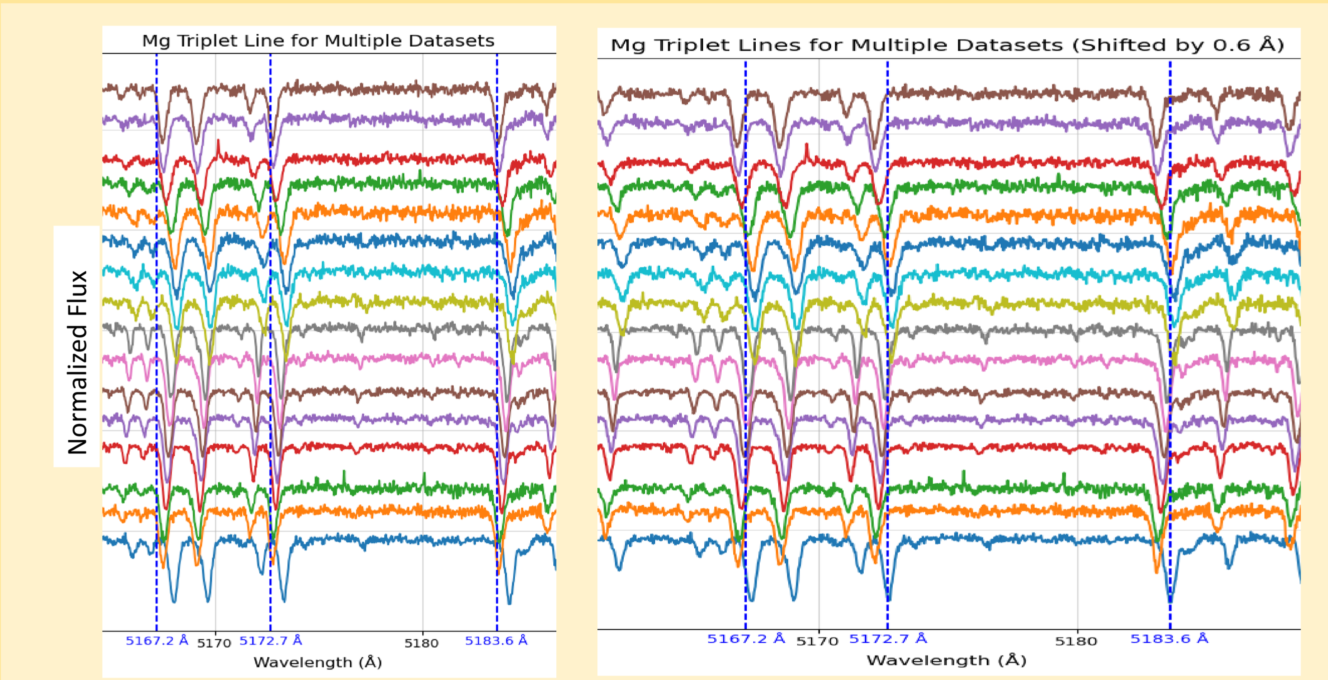
Phase ≈ 0.08

Binary Phase = Fractional part of $\left[\frac{\text{BJD} - \text{EPOCH of primary}}{\text{Binary period}}\right]$

For the Spectrum 1,
BJD = 2459109.7431252
EPOCH of primary = 2445156.6
Binary period = 1182 days

Phase ≈ 0.8(red shift) ⟶ v = 35 Km s^{-1}

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \longrightarrow \frac{\Delta\lambda}{5183.6} = \frac{35}{299729} \longrightarrow \Delta\lambda = 0.6A^0$$

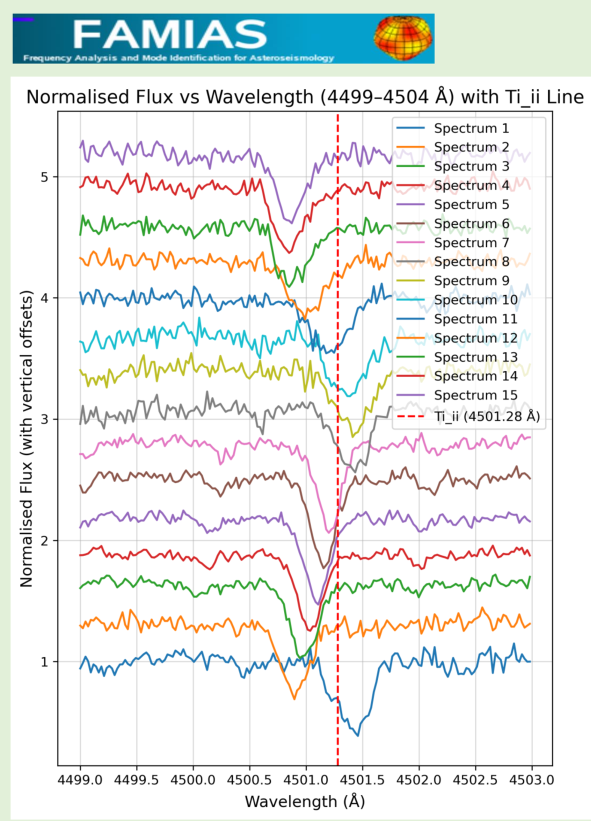


3. Using FAMIAS software for Mode Identification

For mode identification using FAMIAS, Ti_II(4501.28 Å) absorption line was chosen. Photometric F1 = 8.296 c/d, identified as a radial mode(J Adassuriya et al.,2020) and Spectroscopic F1= 8.826925 c/d(Other lines showed larger deviations)

Best l,m-combinations:

chi-sq.	l0	m0	Vel. Amp. [km/s]	P [2Pi]
29.8968	1	0	20	0.433071
30.6143	2	1	20	0.944882
31.1057	0	0	20	0.433071
31.5399	3	2	20	0.448819



4. Findings and Conclusions

We performed a spectroscopic mode identification with FAMIAS for the pulsation frequency F1 = 8.826925 c/d. Several factors support its radial nature:

- In photometry, the pulsation frequency F1 = 8.296 c/d is identified as a radial mode (Adassuriya et al. (2021).
- The (l,m) = (0, 0) solution is the best (l,m) combination found with the FPF method (see table Best l,m-combinations).
- Only 15 HERMES spectra are available with SNR < 50. In general, a confident mode identification requires a collection of spectra with a good pulsation phase coverage and with SNR > 150.

✓ The identification of F1 = 8.826925 c/d as a radial mode, consistent with previous photometric findings

✓ Among the tested spectral lines, the Ti II (4501.28 Å) line was found to be the most suitable for determining the main radial pulsation mode of SZ Lyn.