Interpreting Frequency and Period Spacings for Variable Stars in the NGC 6819 Field Observed by the NASA *Kepler* Spacecraft

Los Alamos NATIONAL LABORATORY

LA-UR-23-21476

J. A. Guzik[1], A. Baran[2], S. Sanjayan[2], P. Nemeth[3], A. Hedlund[1,4], J. Jackiewicz[4] and L. Dauelsberg[1]

[1]Los Alamos National Laboratory (joy@lanl.gov), [2]Ardastella Research Group, [3]Astroserver.org, Malomsok, Hungary, [4]New Mexico State University

Introduction

From 2009 to 2013, the NASA *Kepler* spacecraft obtained 30-minute cadence high-precision photometric data on stars in a 200 x 200 pixel (4 arcsec/pixel) 'superstamp' field centered on the 2.4 billion-year-old star cluster NGC 6819. We analyzed the photometric data to identify δ Scuti and γ Doradus pulsating variables.

We identified 5 confirmed cluster members and 8 non-members for analysis. Four cluster members are 'blue stragglers', i.e., they are still on the main sequence above the cluster turnoff but should have already left the main sequence to become red giants.

We find 6 γ Dor, one δ Sct, and 6 γ Dor/δ Sct hybrid candidates. For nine stars, we found many (20 to over 200) significant frequencies.

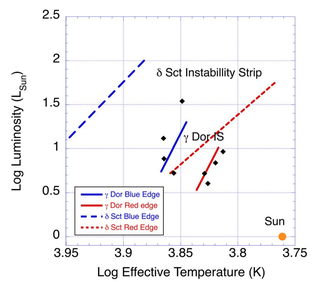
The average frequency separations of δ Scuti stars can be used to determine their mean densities and to derive their masses. The slopes of period-spacing sequences for γ Doradus variables can be used to determine their near-core rotation rates.

δ Scuti and γ Doradus main-sequence pulsating variables

Radial and nonradial modes

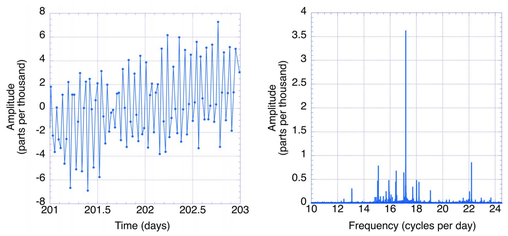
δ Sct: ~1.7-2 M_{sun}
Pressure modes
Periods 2 hours

γ Dor: ~1.5 M_{sun}
Gravity modes and Rossby modes
Periods 1-3 days



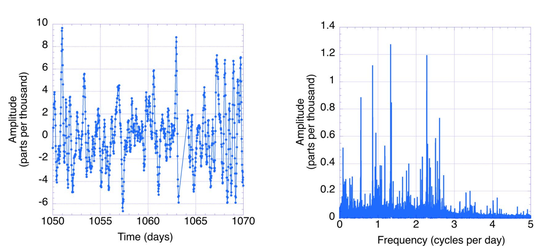
Location in H-R diagram of instability strips [1, 2] and NGC 6819 variables with available luminosity estimates [3]

KIC 5113357–δ Sct star



Light curve excerpt and amplitude spectrum for KIC 5113357, a blue straggler δ Sct star with 124 significant frequencies.

KIC 5024455–γ Dor star

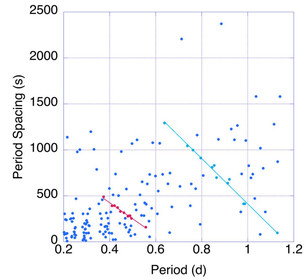


Light curve excerpt and amplitude spectrum for KIC 5024455, a blue straggler γ Dor star. Pre-whitening analysis revealed 210 low frequencies.

A histogram of frequency spacings vs. frequency (left) and a K-S test [4] for frequency spacings (right) reveals a commonly occurring spacing Δν around 5.5 cycles/day for KIC 5113357. This frequency spacing can be used in conjunction with a δ Sct Δν – mean density relation [5] to estimate the mass and radius of the star.

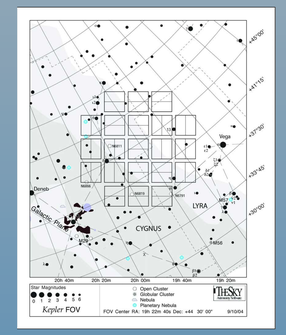
$$\frac{\bar{\rho}}{\bar{\rho}_\odot} = (1.55^{+1.07}_{-0.68})\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{2.035\pm0.095}$$

δ Sct Δν – mean density relation

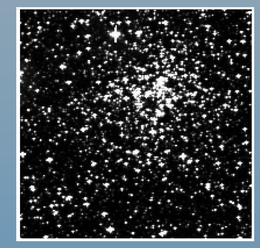


Period spacing vs. period for γ Dor star KIC 5024455. The location and slopes of period spacing sequences can be used to identify gravity modes and Rossby modes, and to estimate the near-core rotation rate [6].

While we do not claim to have found definitive sequences, the hypothetical sequence in red and cyan, respectively, could be ℓ=2 and ℓ=1 gravity modes. Their slopes and mean spacing imply a near-core rotation period of 1.7 days.



Kepler field of view showing NGC 6819 location in lower center CCD module.



200 x 200 pixel 'superstamp' centered around NGC 6819 [7].

Results

Using frequency separations and scaling relations to derive mean density, and adopting an observed T_{eff}, we adjust observed log g and luminosity within uncertainties to derive a self-consistent mass and radius. The results for two blue straggler δ Sct stars are given in the table below.

KIC	5024468	5113357
$\Delta\nu$ (c/d)	2.3	5.5
ν_{max} (μHz)	147.05	198.93
Mean Density ($\bar{\rho}_\odot$)	0.0571	0.3367
$T_{\rm eff}$ (K)	7412	7565
Adjusted log g	3.71	4.19
Mass ($M_\odot$)	2..15	1.59
Radius ($R_\odot$)	3.35	1.68
Luminosity ($L_\odot$)	30.4	8.28

Further information

Guzik, J.A. et al., *Variable Blue Stragglers in Open Cluster NGC6819 Observed in the Kepler 'Superstamp' Field*, AJ, submitted (2023)

Guzik, J.A. et al., SAS Proc. 41st Annual Symposium on Telescope Science, June 2022, p. 83, https://socastrosci.org/publications/

Literature cited

1. Breger, M. and Pamyatnykh, A.A., A&A 352, 938 (1998)
2. Warner, P.B., et al., MNRAS 498, 4272 (2020)
3. Stassun, K.G., et al., AJ **158**, 131 (2019)
4. Kawaler, S.D., IAUS 123, 329 (1998)
5. Garcia-Hernandez, A., et al., ApJL 811, L29 (2015)
6. Li, G., et al., MNRAS 491, 3586 (2020)
7. Kuehn, C., et al., EPJWC Vol. 101 (2015)

Acknowledgments

We are grateful for data from the NASA Kepler mission. J.G. and A.H. acknowledge a LANL Center for Space and Earth Sciences grant XX8P and support from LANL, managed by Triad National Security, LLC for the U.S. DOE's NNSA. Funding from the NSC Poland No. UMO-2017/26/E/ST9/00703 and UMO-207/25/B/ST9/02218 is acknowledged. This work made use of the SIMBAD database and the Mikulski Archive for Space Telescopes.