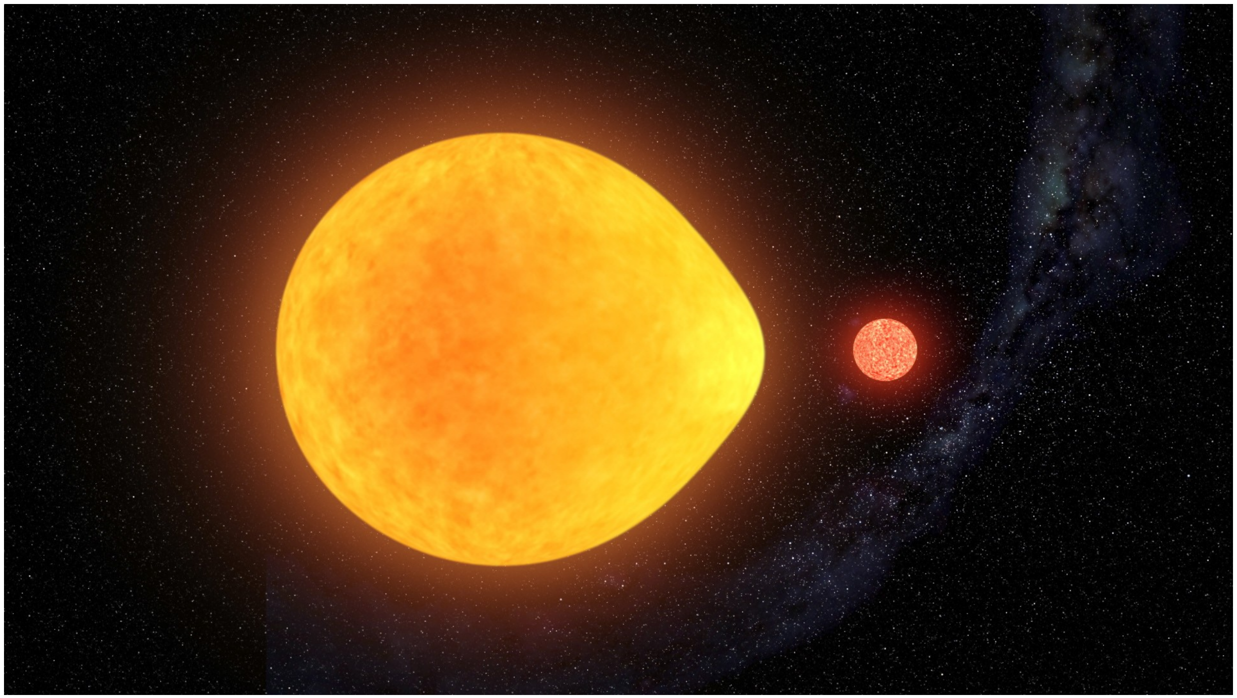
Tidally tilted pulsators and their potential for astrophysics

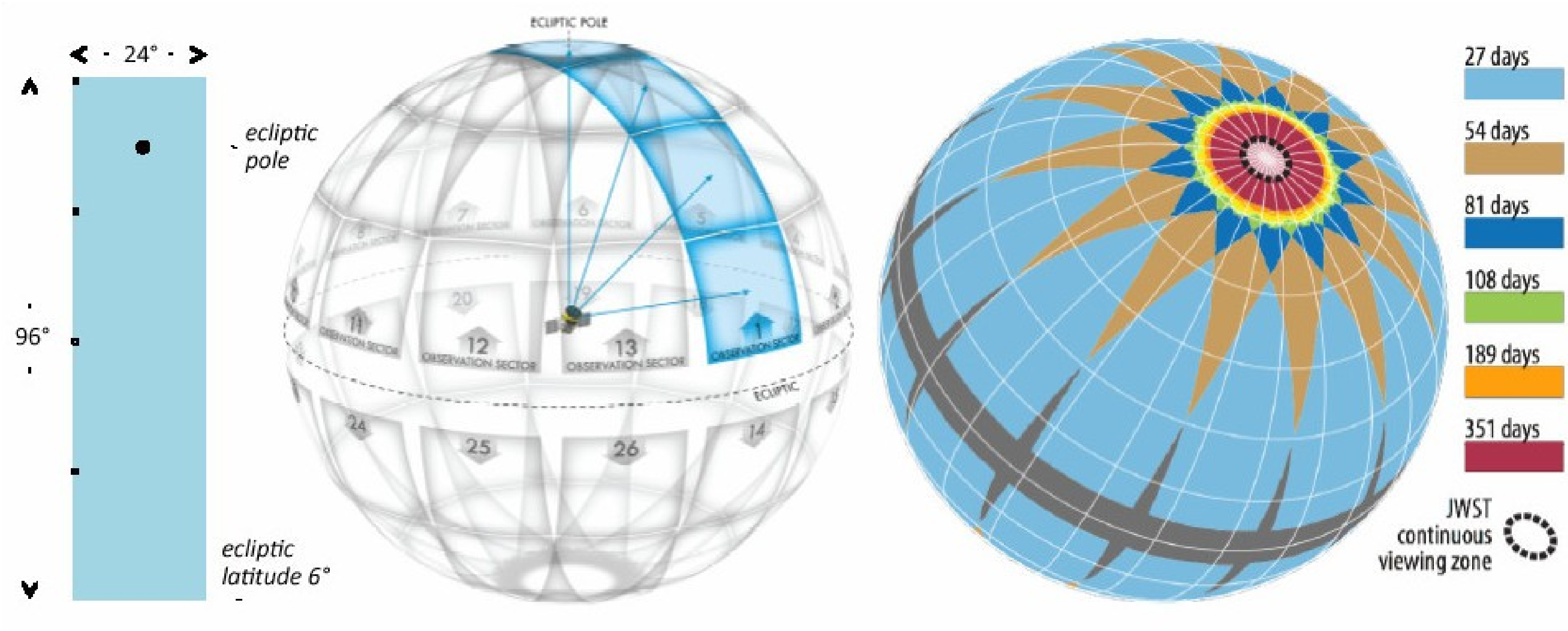


Gerald Handler
Nicolaus Copernicus Astronomical Center
Warszawa

Starring...

TESS

Starring...



TESS

Fwd: strange LC 355151781

From Saul A Rappaport
To Gerald Handler, Olah Katalin
Date 11-05-2019 19:25
Priority Highest

Hi Katalin and Gerald:

Here is a nifty light curve sent to me by one of the amateurs. There is a 1.58-day (likely) rotational modulation with a set of 4 closely spaced pulsations near 3 hours superimposed.

If the 1.58 day modulations are rotational I have no idea what produces them in such a hot star.

I have even less of an idea of whether this is astrophysically interesting or not.

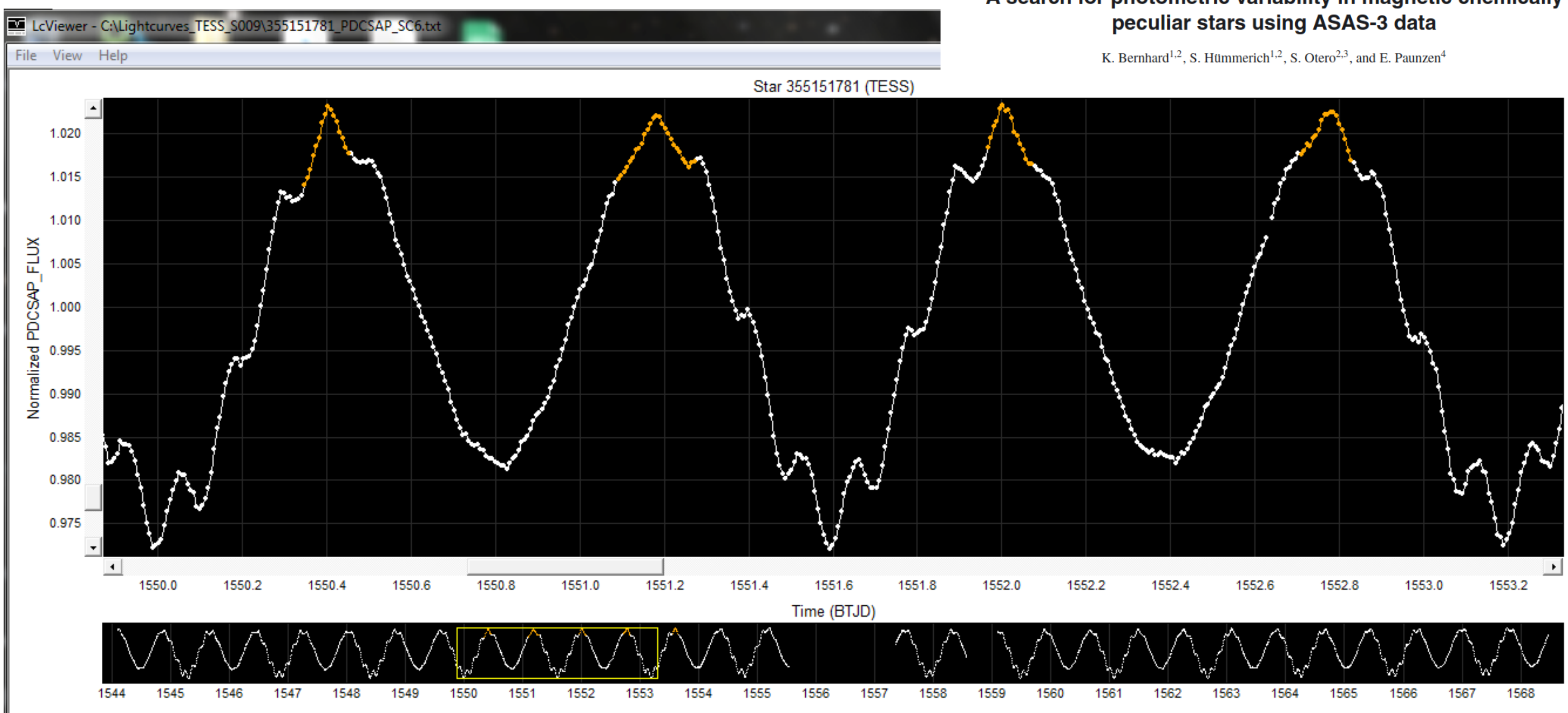
Saul

A&A 581, A138 (2015)
DOI: 10.1051/0004-6361/201526424

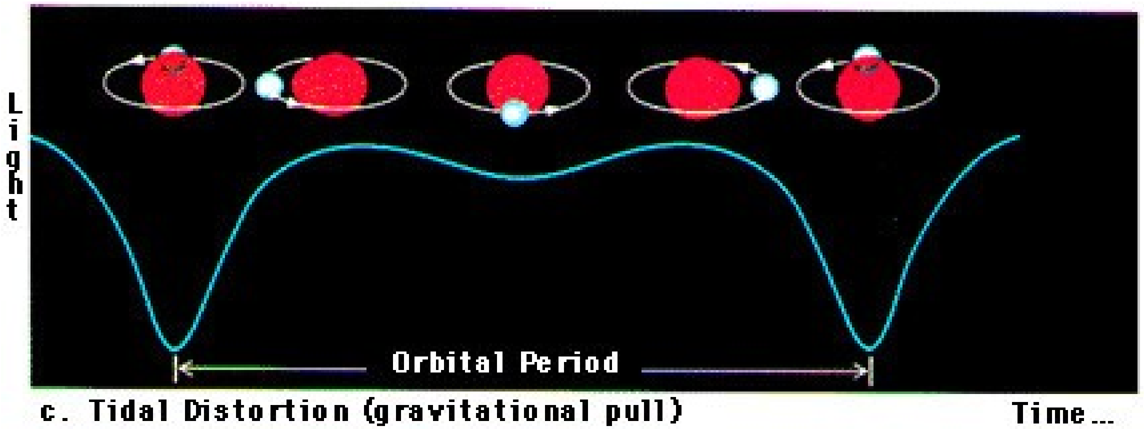
Astronomy & Astrophysics

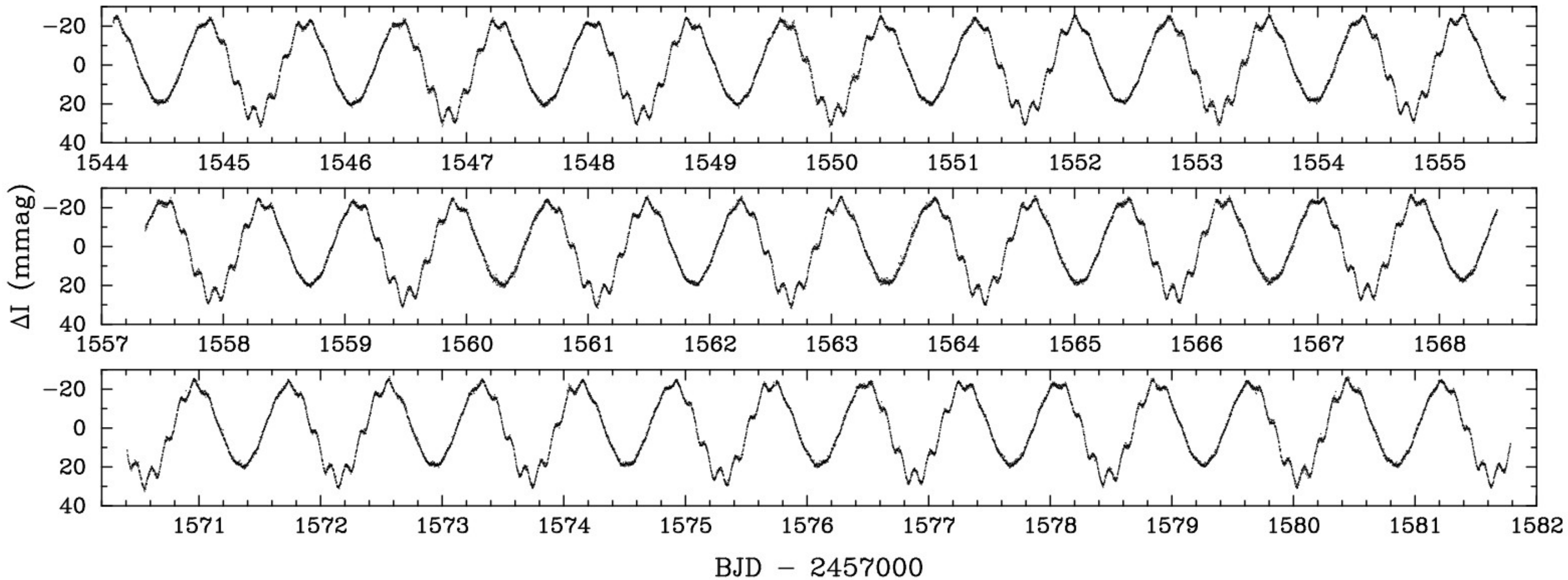
A search for photometric variability in magnetic chemically peculiar stars using ASAS-3 data

K. Bernhard[1,2], S. Hümmerich[1,2], S. Otero[2,3], and E. Paunzen[4]

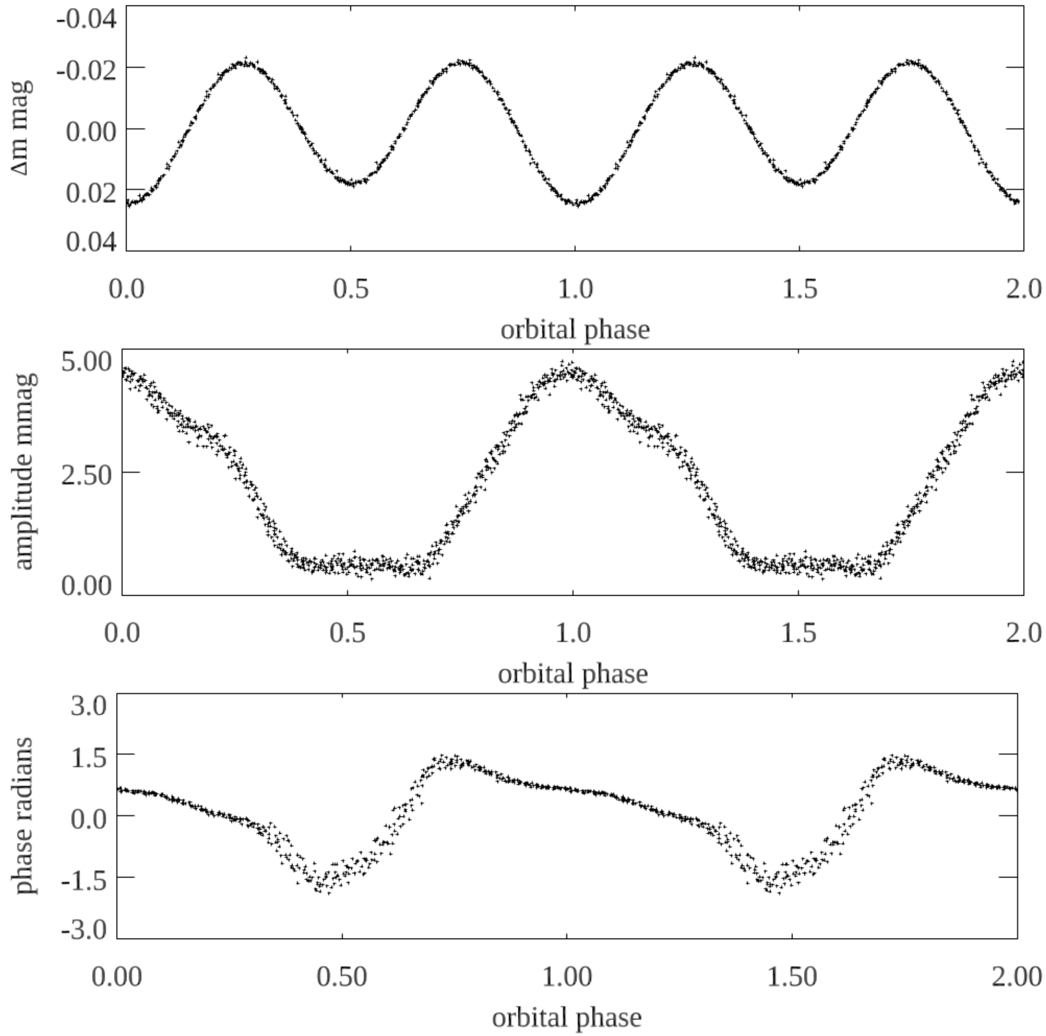


A pulsating ellipsoidal variable





The pulsation is stronger during the deeper ellipsoidal light minima



Analogy with rapidly oscillating Ap (roAp) stars

Pulsation modes occur in frequency multiplets interpreted as caused by aspect variations of the oscillation – The Oblique Pulsator Model (Kurtz 1982)

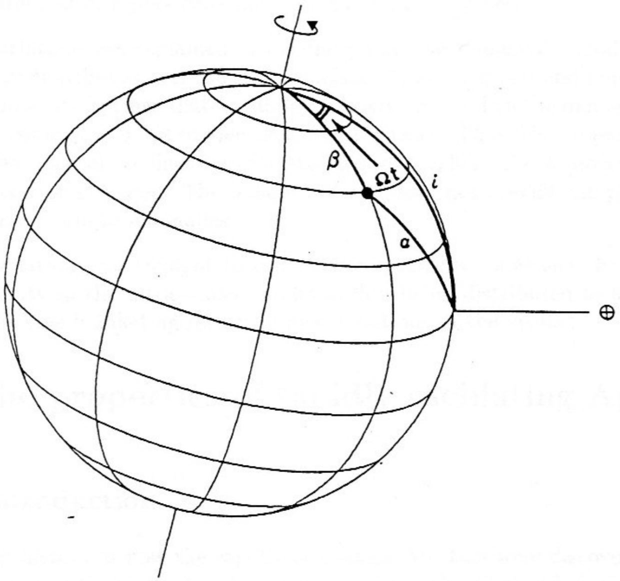
$$\frac{\Delta L}{L} \propto A_0 \cos(\omega t + \phi) + A_1 \cos[(\omega - \Omega)t + \phi] + A_1 \cos[(\omega + \Omega)t + \phi]$$

where

$$A_0 = \cos i \cos\beta$$

and

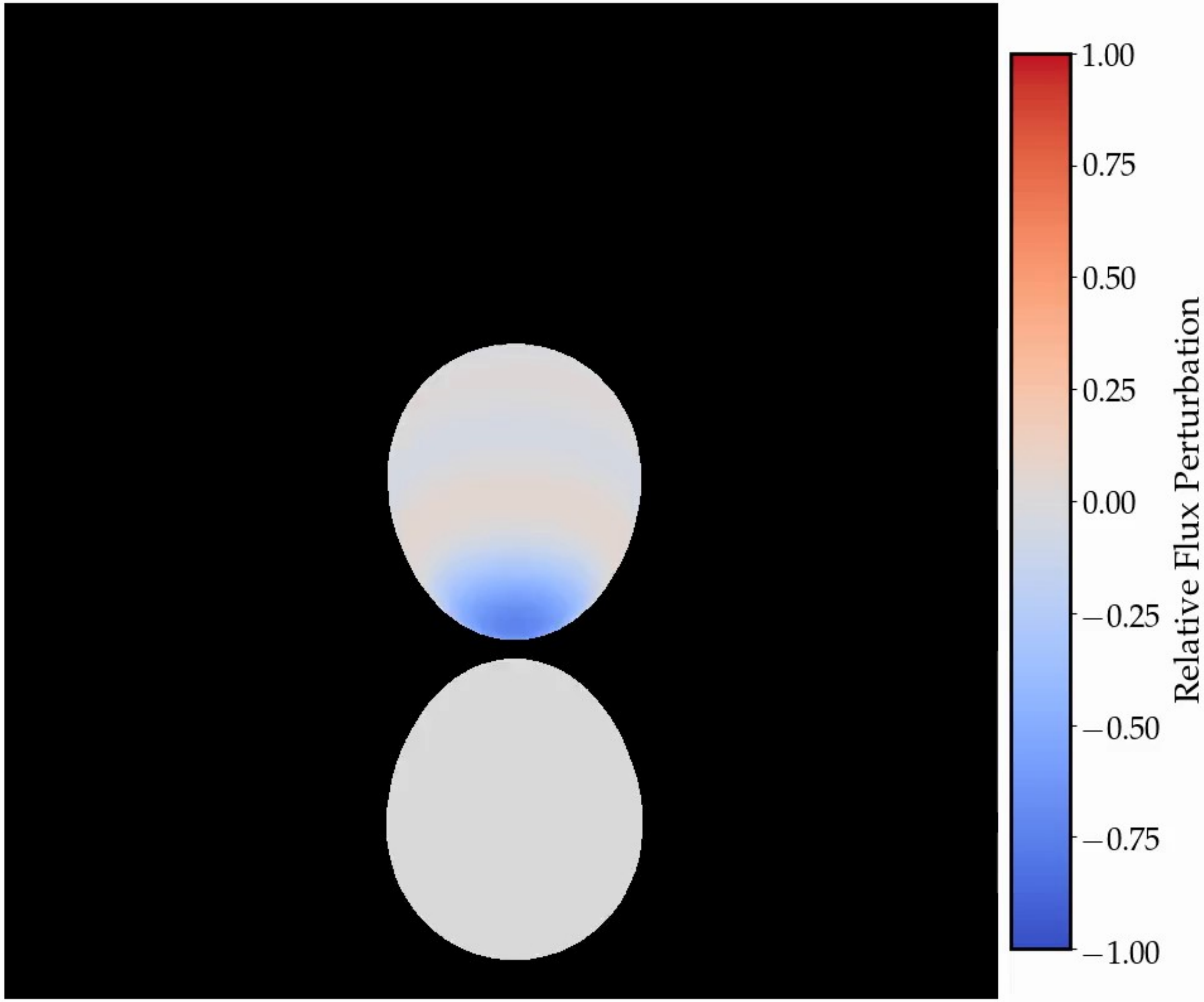
$$A_1 = \tfrac{1}{2} \sin i \sin\beta.$$



Rotational and pulsational axis are not aligned (oblique)

The oscillations of a tidally tilted pulsator can be mathematically described the same way as roAp pulsations, with β close to 90^o.

Schematic of the HD 74423 system



Fuller et al. 2020, MNRAS 498, 5730

nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-020-1035-1

Check for updates

Tidally trapped pulsations in a close binary star system discovered by TESS

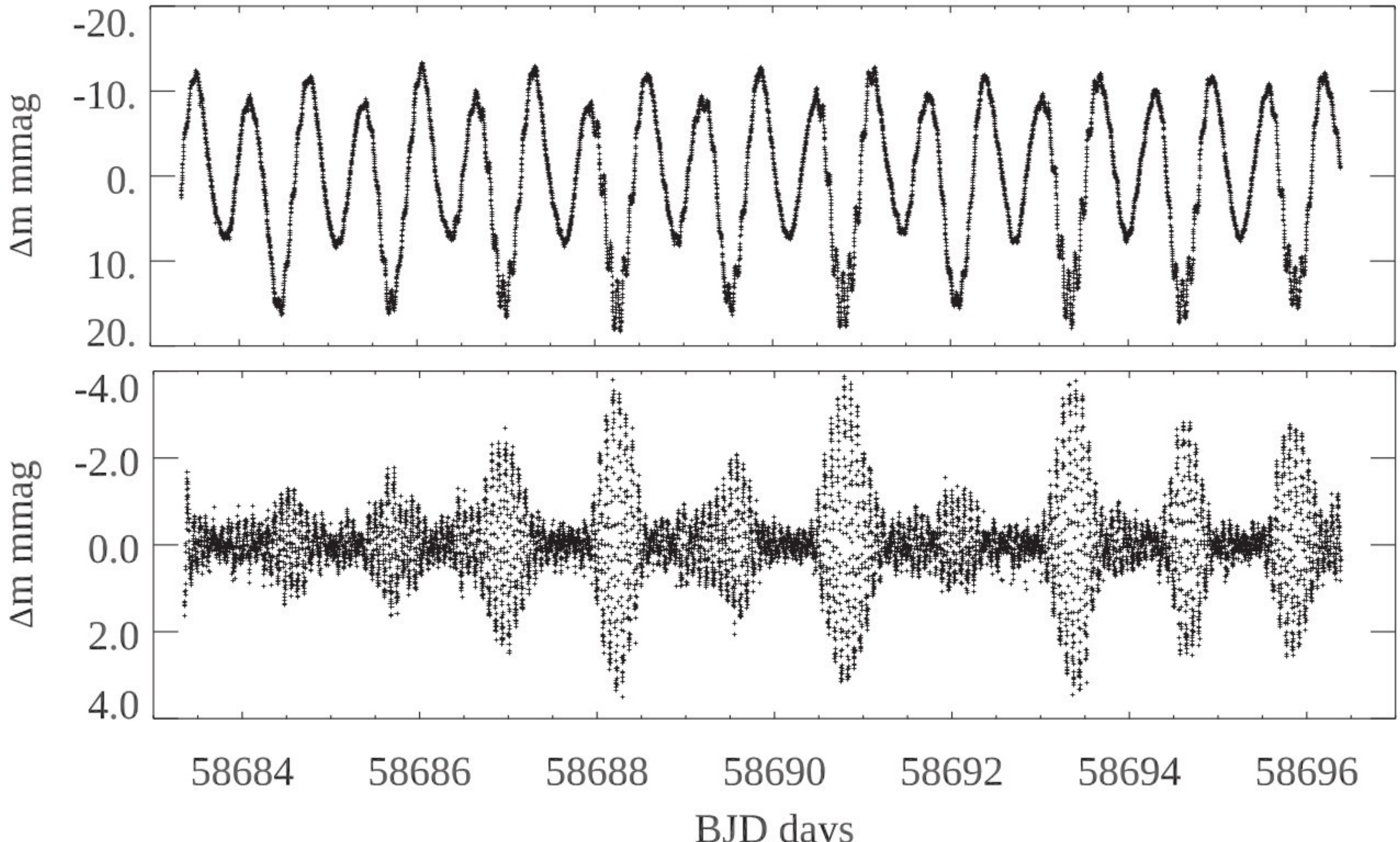
G. Handler[1] ✉, D. W. Kurtz[2], S. A. Rappaport[3], H. Saio[4], J. Fuller[5], D. Jones[6,7], Z. Guo[8], S. Chowdhury[1], P. Sowicka[1], F. Kahraman Aliçavuş[1,9], M. Streamer[10], S. J. Murphy[11], R. Gagliano[12], T. L. Jacobs[13] and A. Vanderburg[14]

It has long been suspected that tidal forces in close binary stars could modify the orientation of the pulsation axis of the constituent stars. Such stars have been searched for, but until now never detected. Here we report the discovery of tidally trapped pulsations in the ellipsoidal variable HD 74423 in Transiting Exoplanet Survey Satellite (TESS) space photometry data. The system contains a δ Scuti pulsator in a 1.6 d orbit, whose pulsation mode amplitude is strongly modulated at the orbital frequency, which can be explained if the pulsations have a much larger amplitude in one hemisphere of the star. We interpret this as an obliquely pulsating distorted dipole oscillation with a pulsation axis aligned with the tidal axis. This is the first time that oblique pulsation along a tidal axis has been recognized. It is unclear whether the pulsations are trapped in the hemisphere directed towards the companion or in the side facing away from it, but future spectral measurements can provide the solution. In the meantime, the single-sided pulsator HD 74423 stands out as the prototype of a new class of obliquely pulsating stars in which the interactions of stellar pulsations and tidal distortion can be studied.

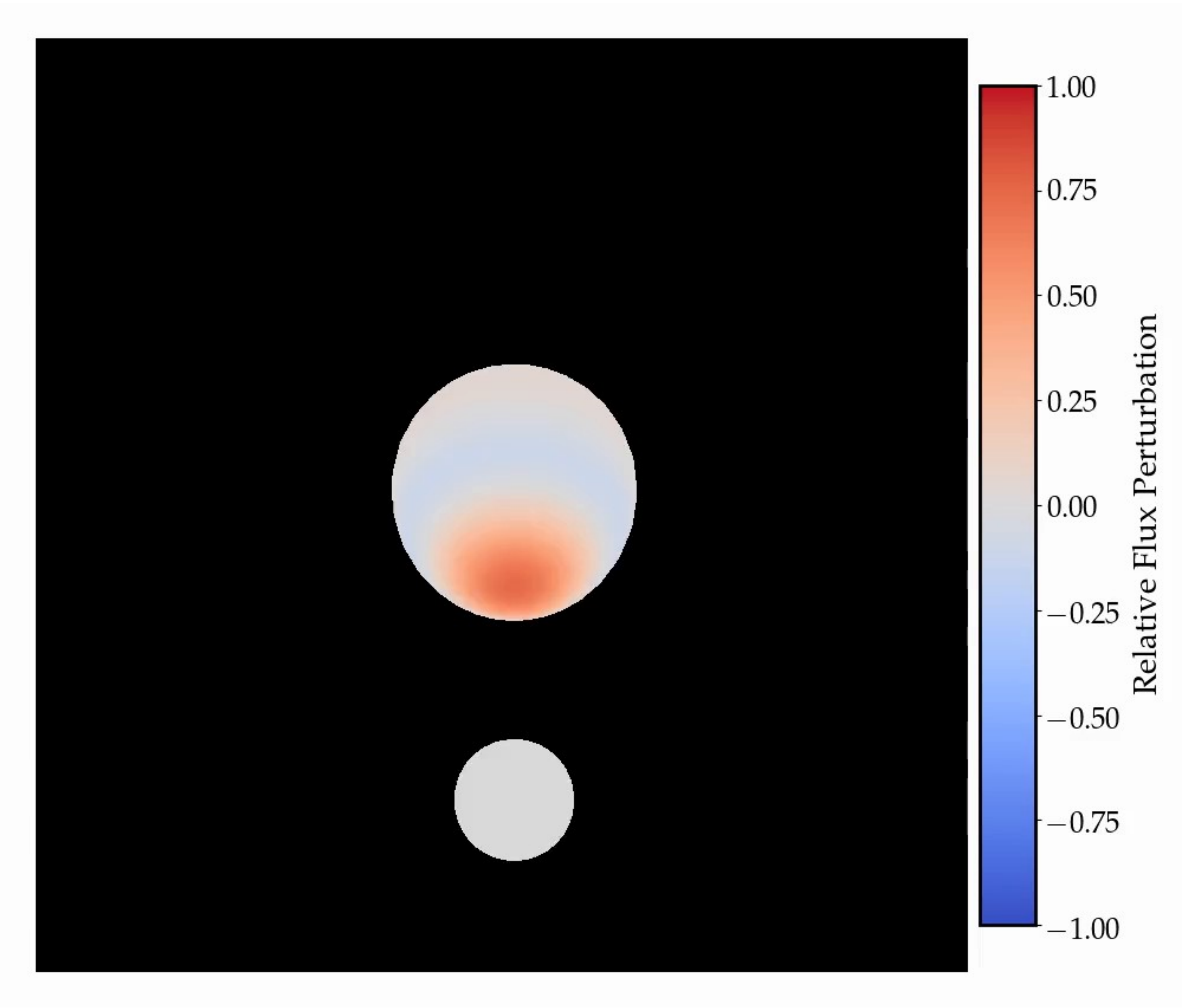
Mon. Not. R. Astron. Soc. **000**, 1–?? (2019) Printed 6 April 2020 (MN LaTeX style file v2.2)

The single-sided pulsator CO Camelopardalis

D. W. Kurtz[1,2⋆], G. Handler[3], S. A. Rappaport[4], H. Saio[5], J. Fuller[6], T. Jacobs[7], A. Schmitt[8], D. Jones[9,10], A. Vanderburg[11], D. LaCourse[12], L. Nelson[13], F. Kahraman Aliçavuş[3,14] and M. Giarrusso[15]



Schematic of the CO Cam system

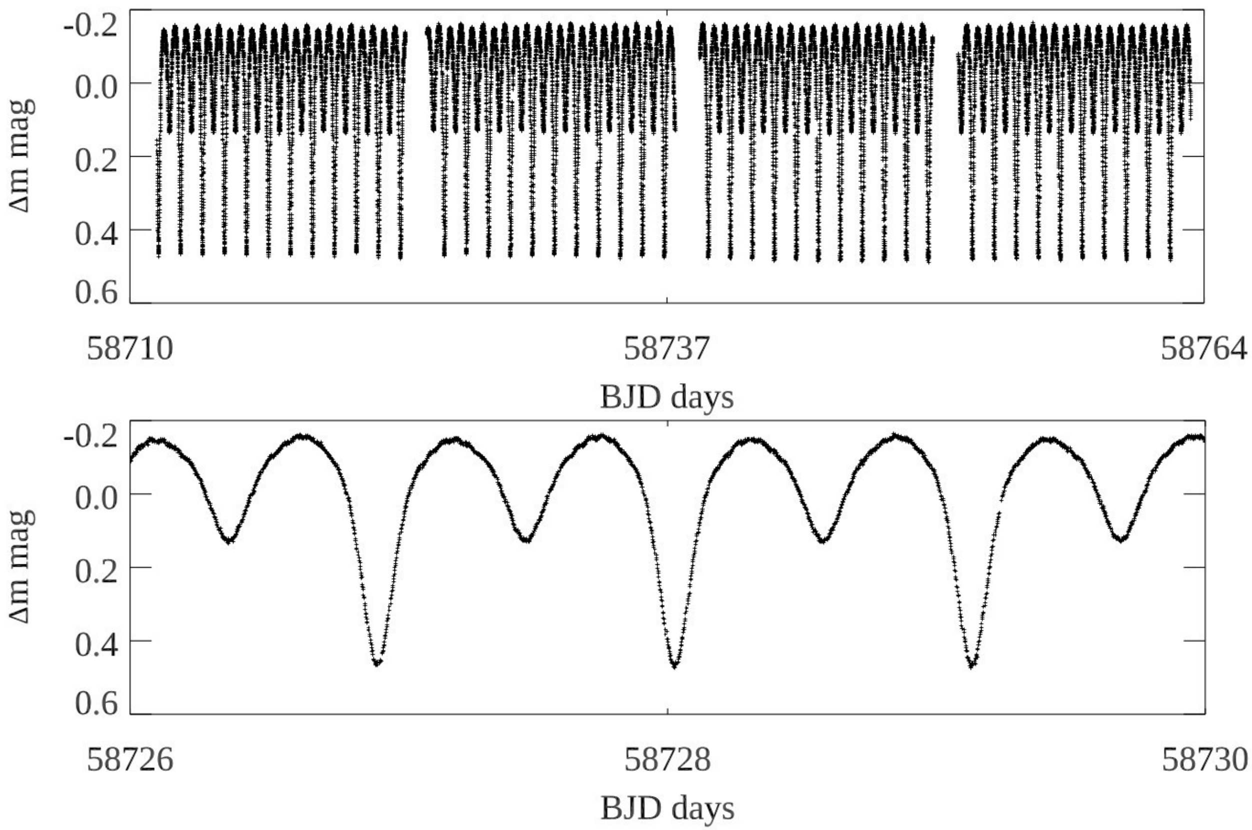


Fuller et al. 2020, MNRAS 498, 5730

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **503,** 254–269 (2021)
Advance Access publication 2021 February 9
doi:10.1093/mnras/stab336

A tidally tilted sectoral dipole pulsation mode in the eclipsing binary TIC 63328020

S. A. Rappaport,[1★] D. W. Kurtz,[2,3★] G. Handler,[4★] D. Jones,[5,6] L. A. Nelson,[7] H. Saio,[8] J. Fuller,[9] D. L. Holdsworth,[3] A. Vanderburg,[10] J. Žák,[11,12,5] M. Skarka,[11,13] J. Aiken,[7] P. F. L. Maxted,[14] D. J. Stevens,[15] D. L. Feliz[16,17] and F. Kahraman Aliçavuş[18,19]



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A tidally tilted sectoral dipole pulsation mode in the eclipsing binary TIC 63328020

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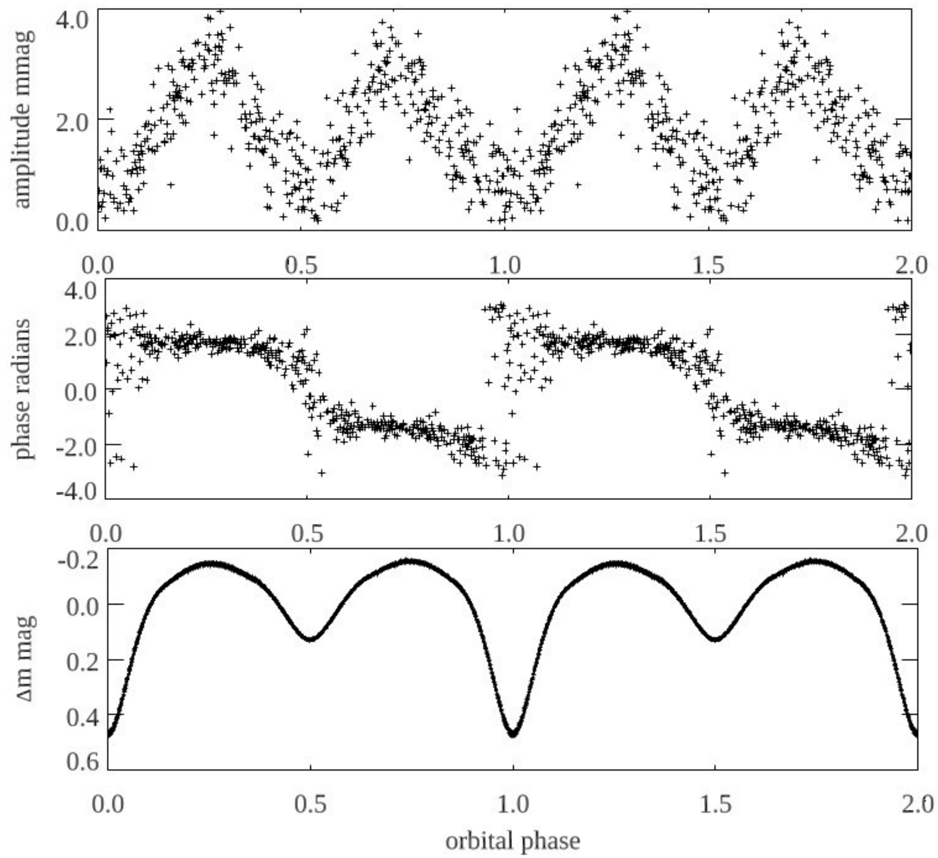
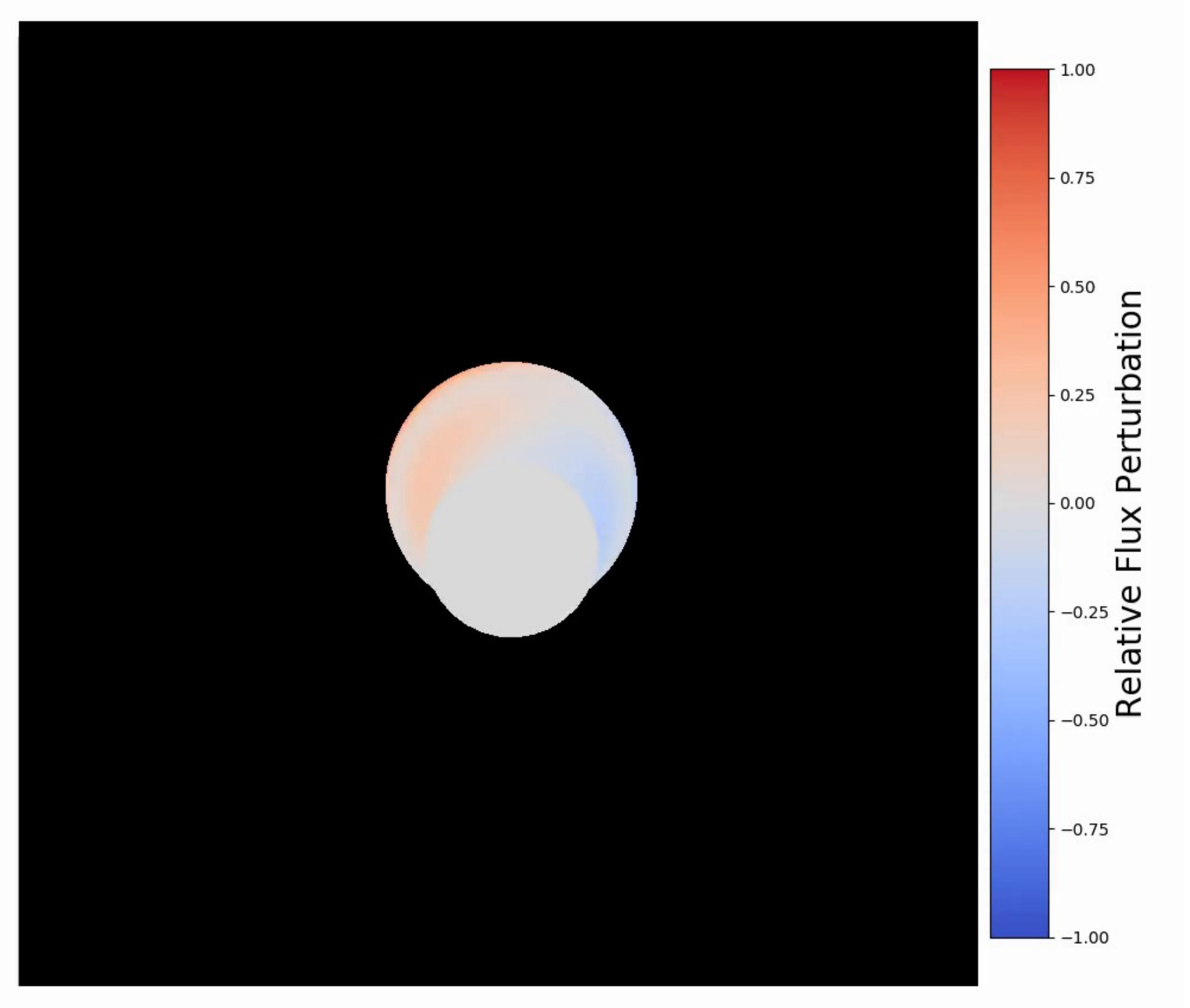


Schematic of the TIC 63328020 system

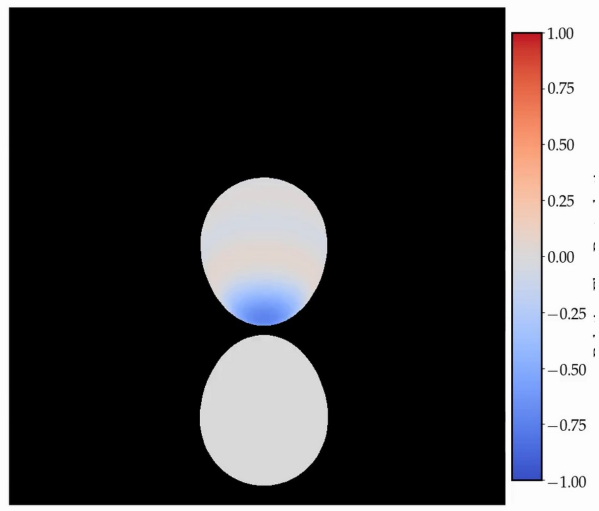


Fuller et al. 2020, MNRAS 498, 5730

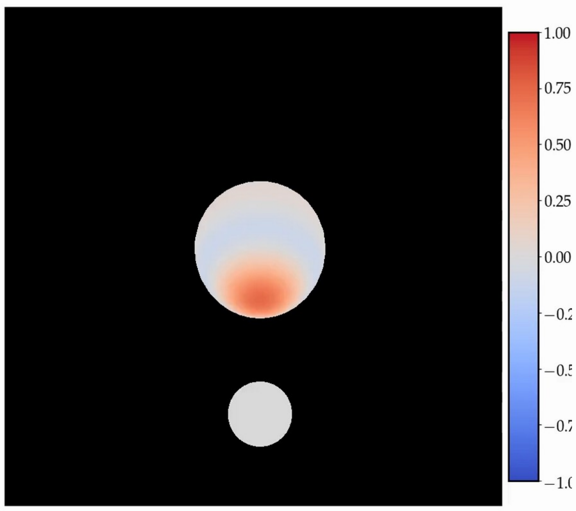
Geometrical configurations of the three TTPs discovered first:

δ Sct pulsators with main sequence companions

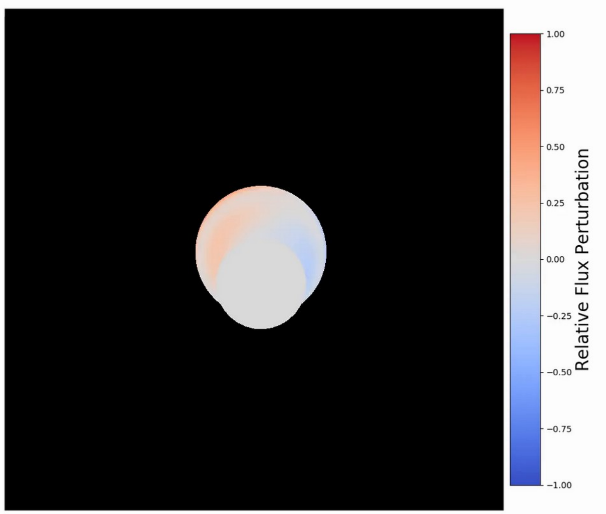
HD 74423



CO Cam



TIC 63328020



Fuller et al. 2020, MNRAS 498, 5730

Basic properties of these three TTPs

	HD 74423	CO Cam	TIC 63328020
P (d)	1.580723	1.27099	1.105769
$M_1(\mathrm{M}_\odot)$	2.1 ± 0.1	$1.48^{+0.02}_{-0.01}$	2.5 ± 0.2
$M_2(\mathrm{M}_\odot)$	2.0 ± 0.1	0.86 ± 0.02	1.07 ± 0.06
$R_1(\mathrm{R}_\odot)$	3.3 ± 0.1	1.83 ± 0.01	3.1 ± 0.1
$R_2(\mathrm{R}_\odot)$	3.2 ± 0.1	0.84 ± 0.02	2.06 ± 0.06
T_1 (K)	7900 ± 150	7080 ± 80	8200 ± 450
T_2 (K)	7600 ± 200	5050 ± 150	5600 ± 250
i (deg)	33 ± 2	48.9 ± 1.0	79.1 ± 0.6
R_1/R_L	> 0.95	0.65 ± 0.02	> 0.95
R_1/a	0.36 ± 0.02	0.28 ± 0.01	0.45 ± 0.03
$f_{\max}$ (d^{-1})	8.76	13.38	21.10
$n_{\max}$	2	1	5
$\Delta R_{\mathrm{tide}}/\Delta R_{\mathrm{cen}}$	1.5 ± 0.1	1.10 ± 0.02	0.9 ± 0.1

Fuller et al. 2020, MNRAS 498, 5730


And now for something completely different

ARTICLES
https://doi.org/10.1038/s41550-021-01413-0

nature astronomy

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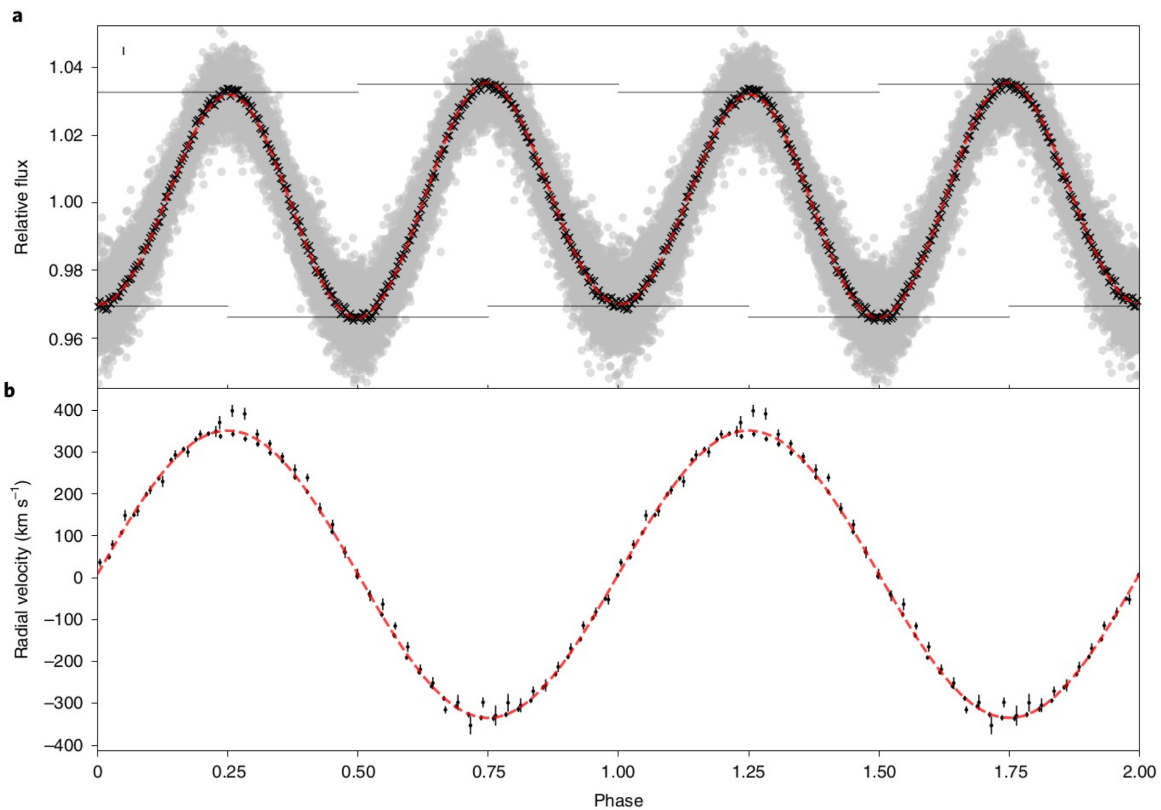
A hot subdwarf–white dwarf super-Chandrasekhar candidate supernova Ia progenitor

Ingrid Pelisoli[1,2], P. Neunteufel[3], S. Geier[1], T. Kupfer[4,5], U. Heber[6], A. Irrgang[6], D. Schneider[6], A. Bastian[1], J. van Roestel[7], V. Schaffenroth[1] and B. N. Barlow[8]



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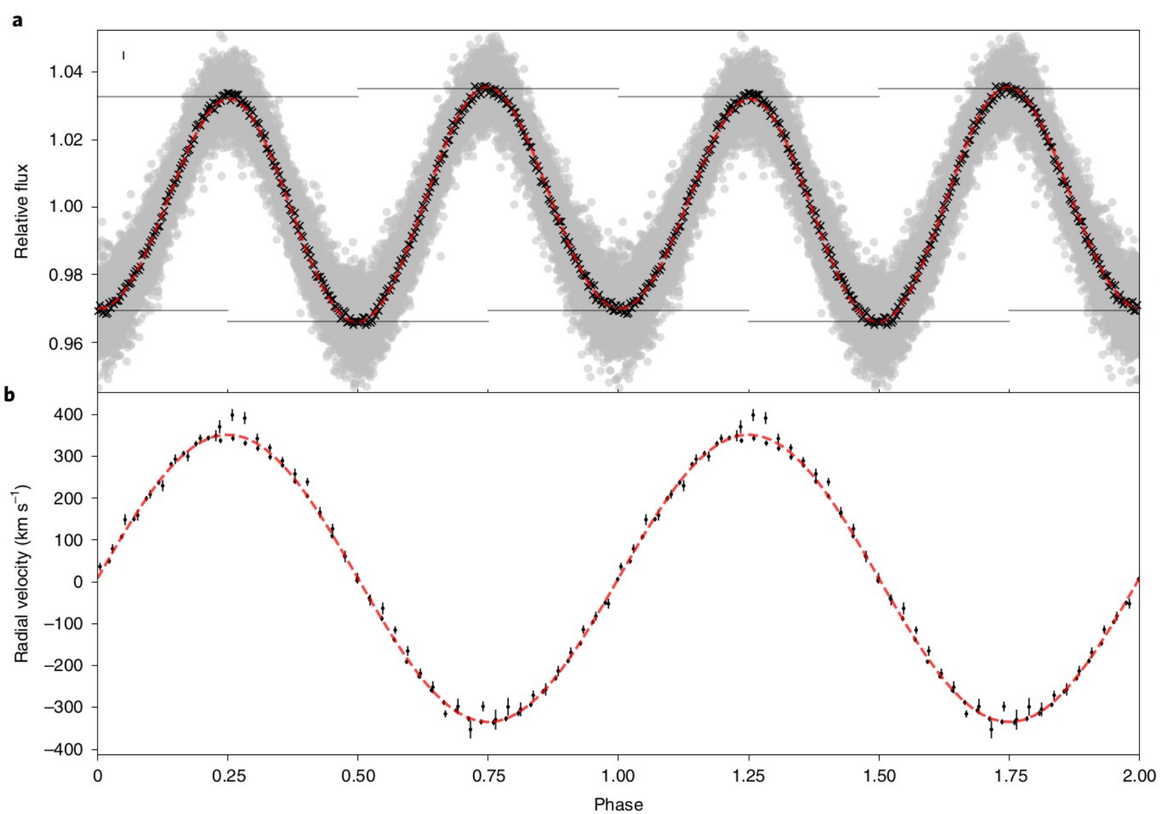
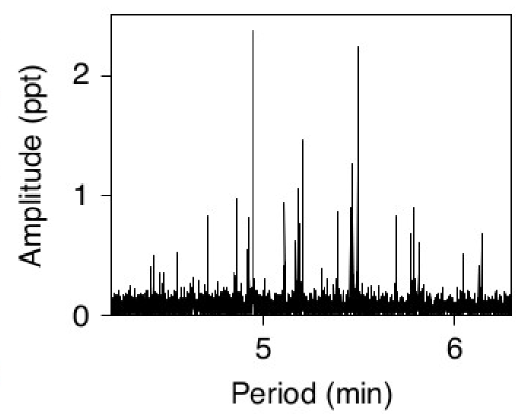
https://doi.org/10.1038/s41550-021-01413-0
nature astronomy

A hot subdwarf–white dwarf super-Chandrasekhar candidate supernova Ia progenitor

Ingrid Pelisoli[1,2] ✉, P. Neunteufel[3], S. Geier[1], T. Kupfer[4,5], U. Heber[6], A. Irrgang[6], D. Schneider[6], A. Bastian[1], J. van Roestel[7], V. Schaffenroth[1] and B. N. Barlow[8]





The Astrophysical Journal Letters, 928:L14 (12pp), 2022 April 1 https://doi.org/10.3847/2041-8213/ac5c59

Tidally Tilted Pulsations in HD 265435, a Subdwarf B Star with a Close White Dwarf Companion

Rahul Jayaraman[1], Gerald Handler[2], Saul A. Rappaport[1], Jim Fuller[3], Donald W. Kurtz[4,5], Stéphane Charpinet[6], and George R. Ricker[1]

[1] MIT Department of Physics and MIT Kavli Institute for Astrophysics and Space Research, Cambridge, MA 02139, USA; rjayaram@mit.edu
[2] Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland
[3] TAPIR, Walter Burke Institute for Theoretical Physics, Mailcode 350-17, Caltech, Pasadena, CA 91125, USA
[4] Centre for Space Research, Physics Department, North West University, Mahikeng 2735, South Africa
[5] Jeremiah Horrocks Institute, University of Central Lancashire, Preston PR1 2HE, UK
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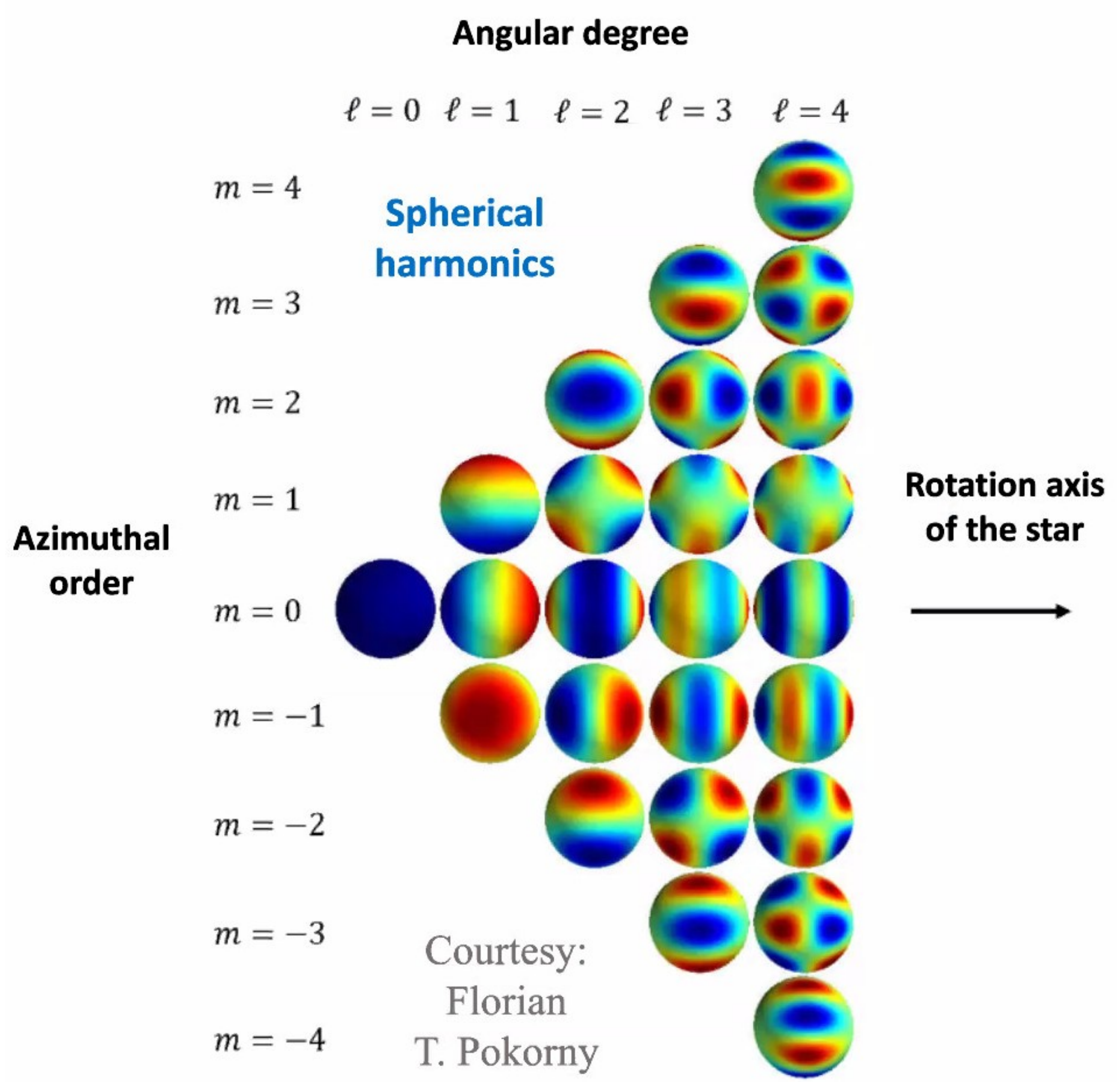
Received 2022 February 9; revised 2022 March 9; accepted 2022 March 9; published 2022 March 30

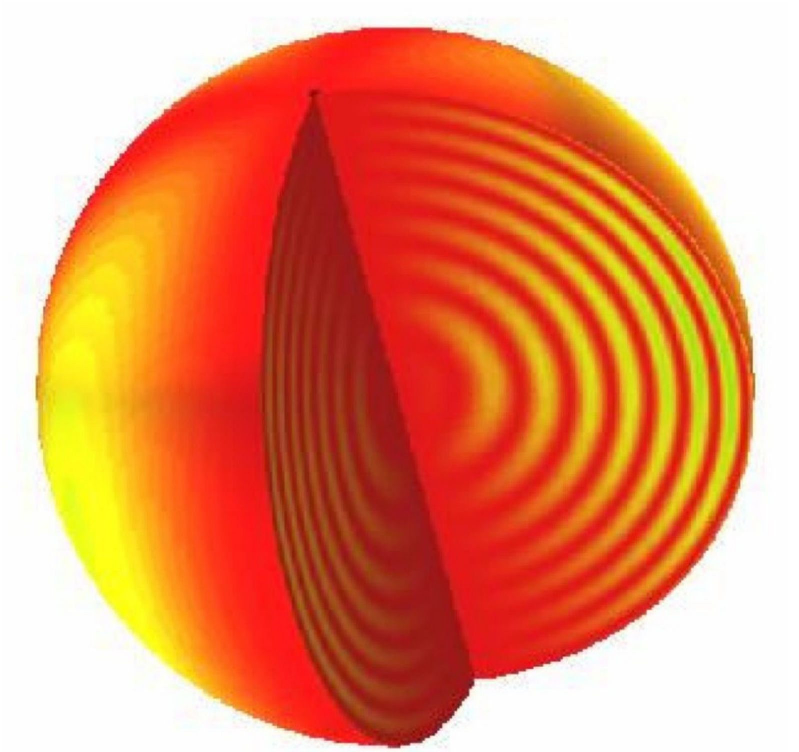
Abstract

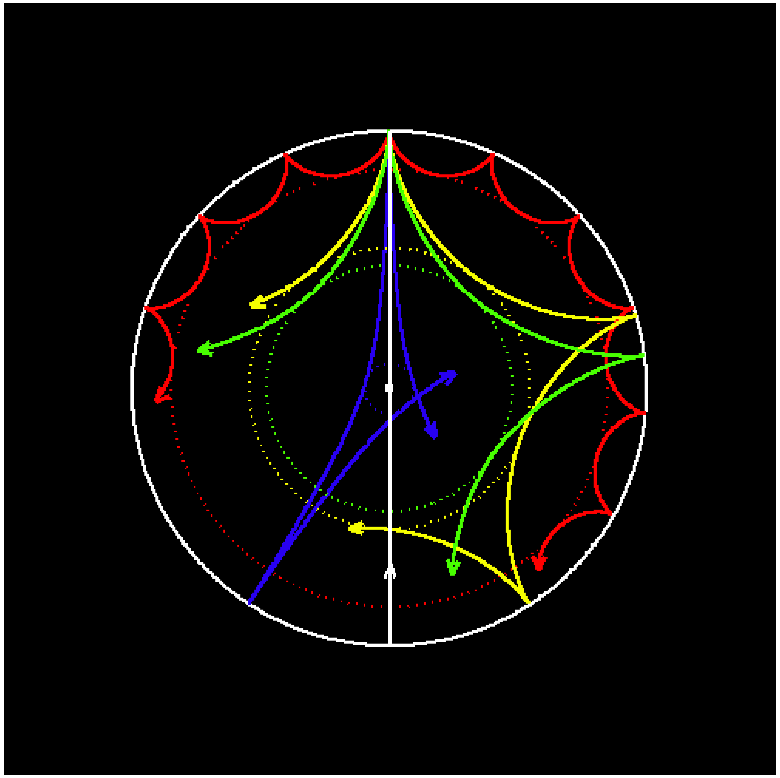
Tidally tilted pulsators (TTPs) are an intriguing new class of oscillating stars in binary systems; in such stars, the pulsation axis coincides with the line of apsides, or tidal axis, of the binary. All three TTPs discovered so far have been δ Scuti stars. In this Letter, we report the first conclusive discovery of tidally tilted pulsations in a subdwarf B (sdB) star. HD 265435 is an sdB–white dwarf binary with a 1.65 hr period that has been identified and characterized as the nearest potential Type Ia supernova progenitor. Using TESS 20 s cadence data from Sectors 44 and 45, we show that the pulsation axis of the sdB star has been tidally tilted into the orbital plane and aligned with the tidal axis of the binary. We identify 31 independent pulsation frequencies, 27 of which have between 1 and 7 sidebands separated by the orbital frequency ($\nu_{\rm orb}$) or multiples thereof. Using the observed amplitude and phase variability due to tidal tilting, we assign ℓ and m values to most of the observed oscillation modes and use these mode identifications to generate preliminary asteroseismic constraints. Our work significantly expands our understanding of TTPs, as we now know that (i) they can be found in stars other than δ Scuti pulsators, especially highly evolved stars that have lost their H-rich envelopes, and (ii) tidally tilted pulsations can be used to probe the interiors of stars in very tight binaries.

Scientific curiosity or astrophysically useful?



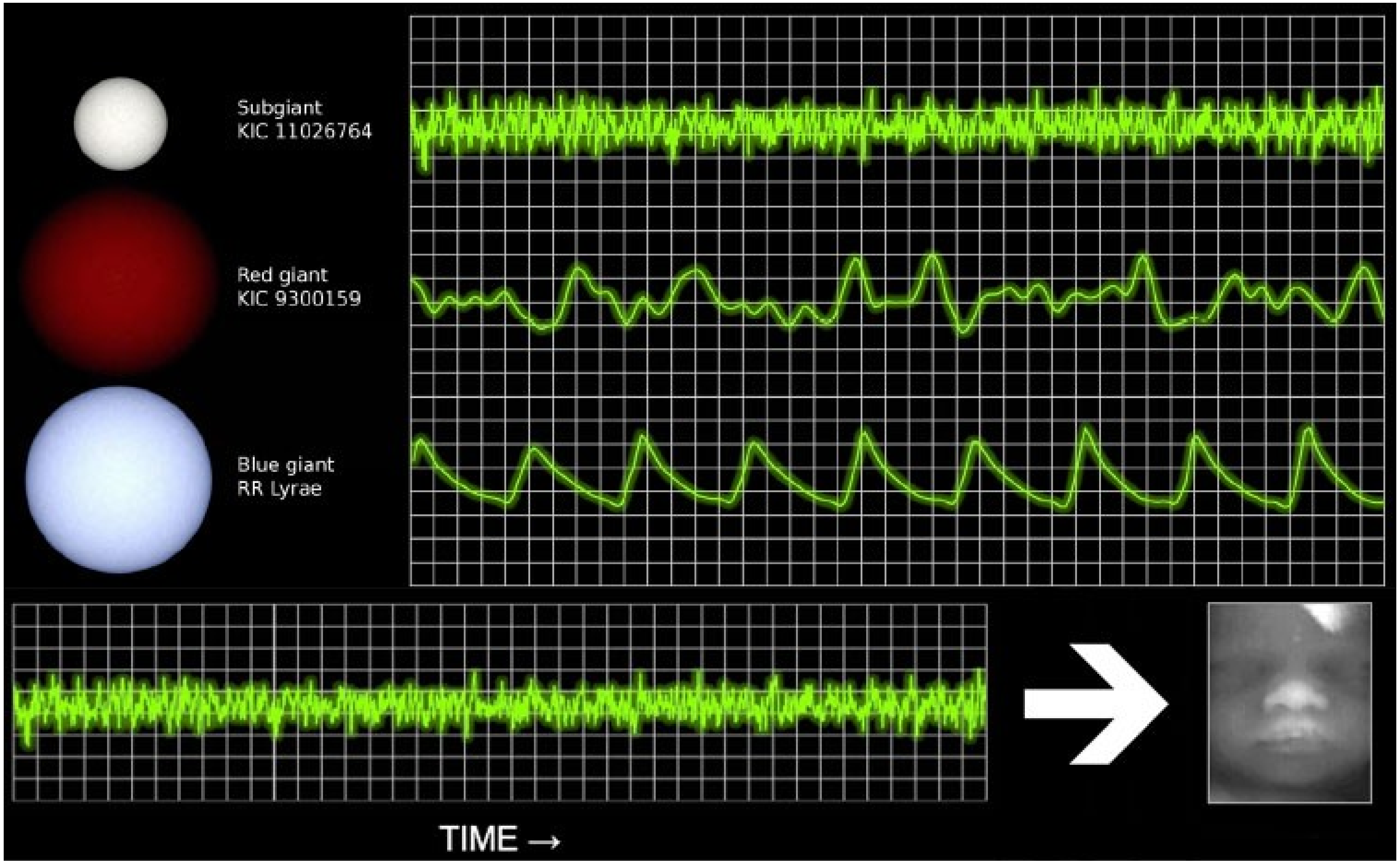
Scientific curiosity or astrophysically useful?



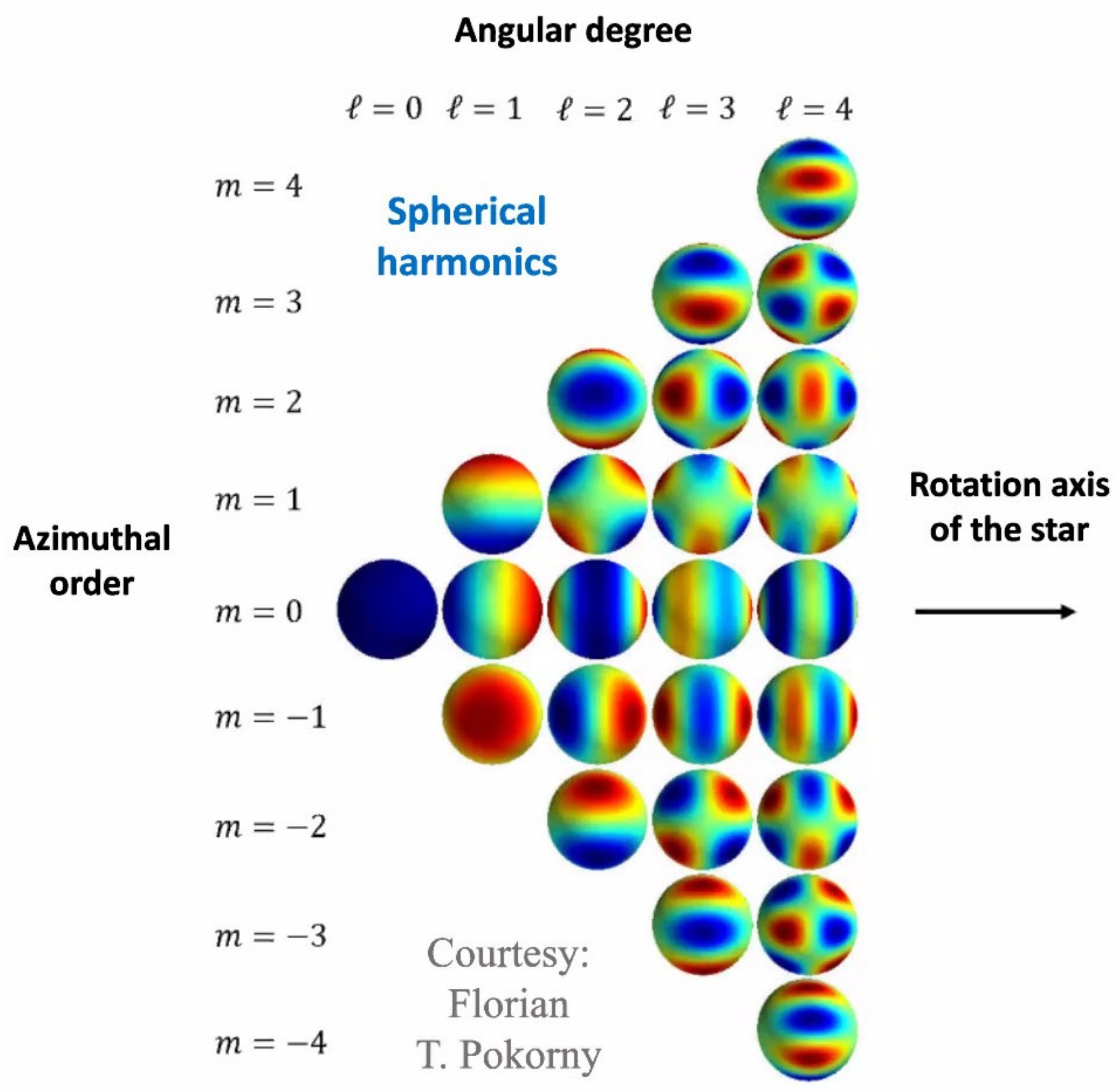


Each individual stellar oscillation samples a different interior cavity; its frequency is governed by the physical conditions in this cavity

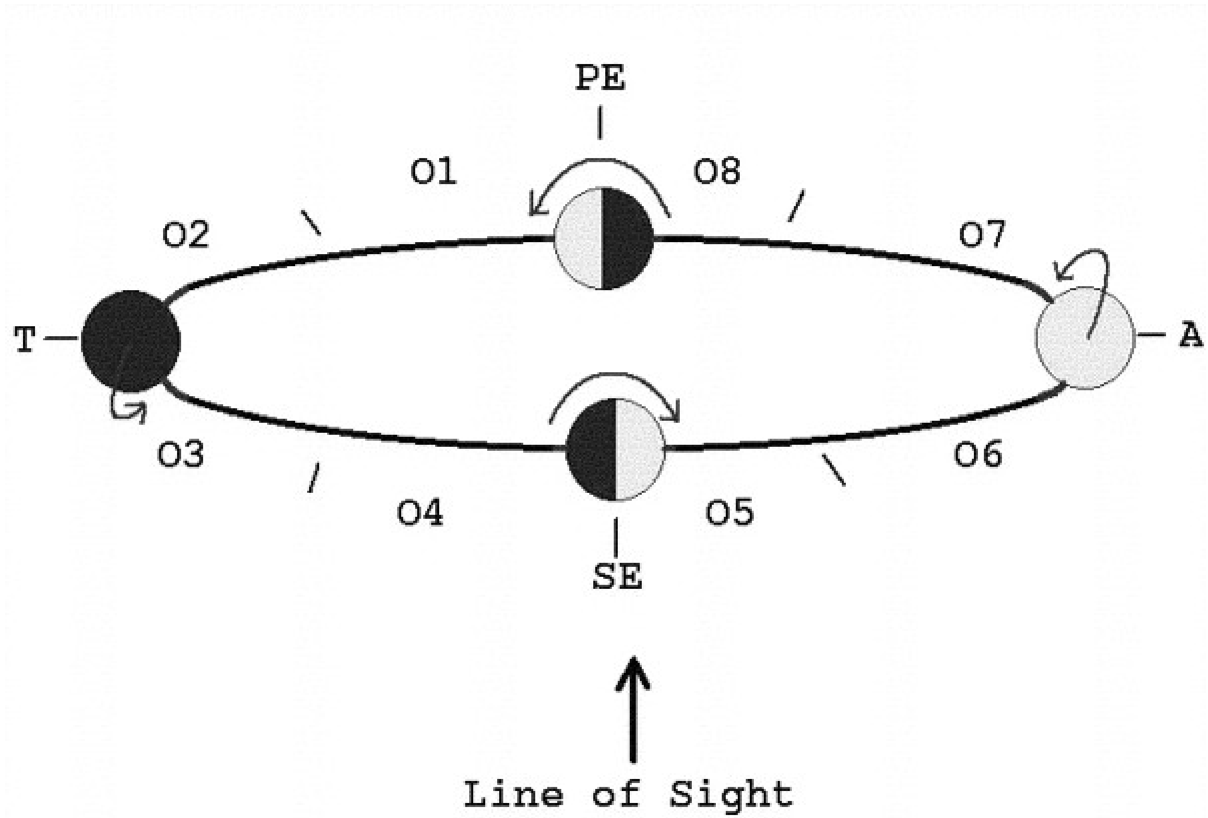
How can we look inside stars?



How do we know what kind of pulsation we deal with?

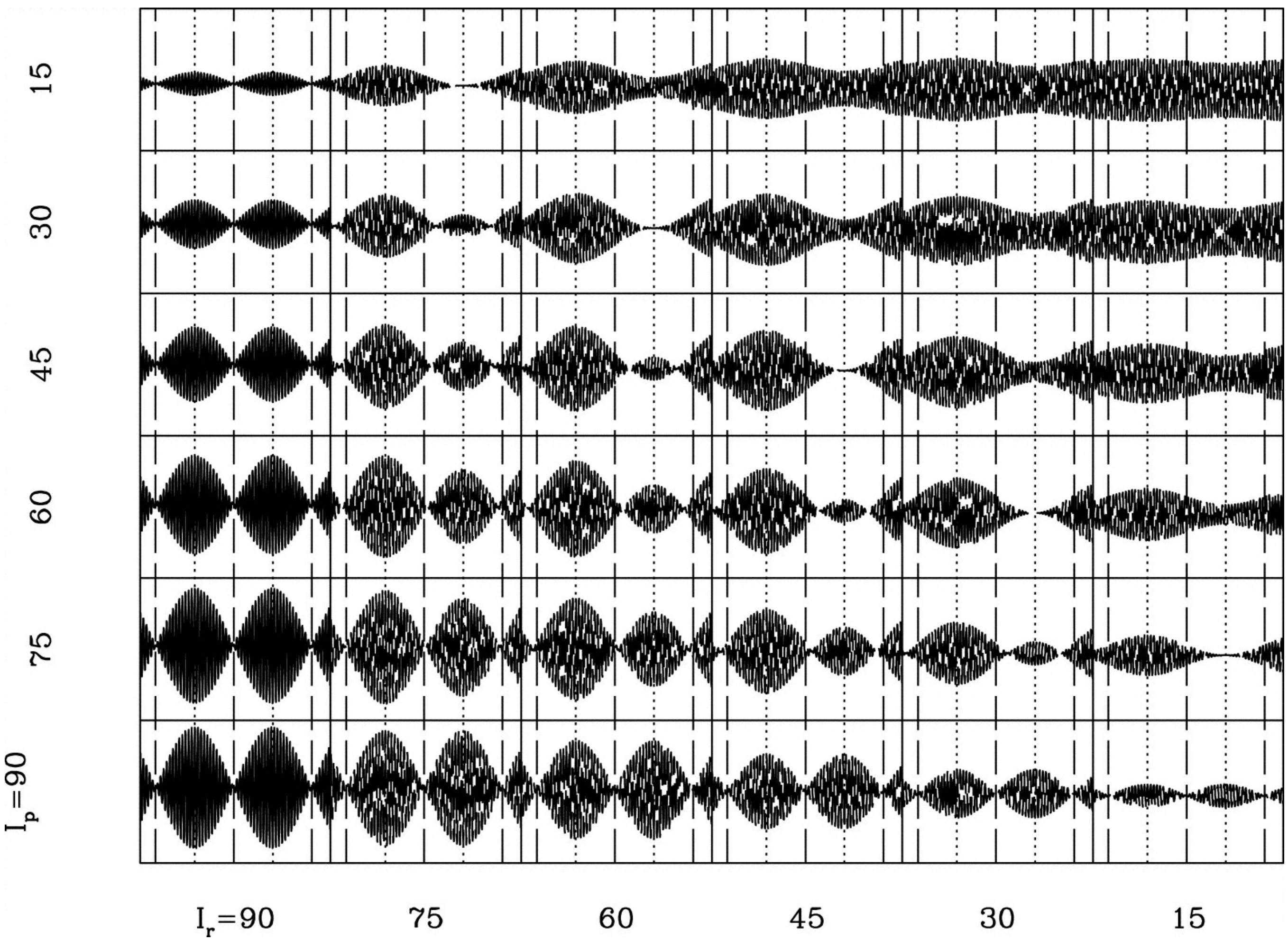


Tidally tilted pulsation axis



Reed, Brondel & Kawaler 2005,
ApJ 634, 602

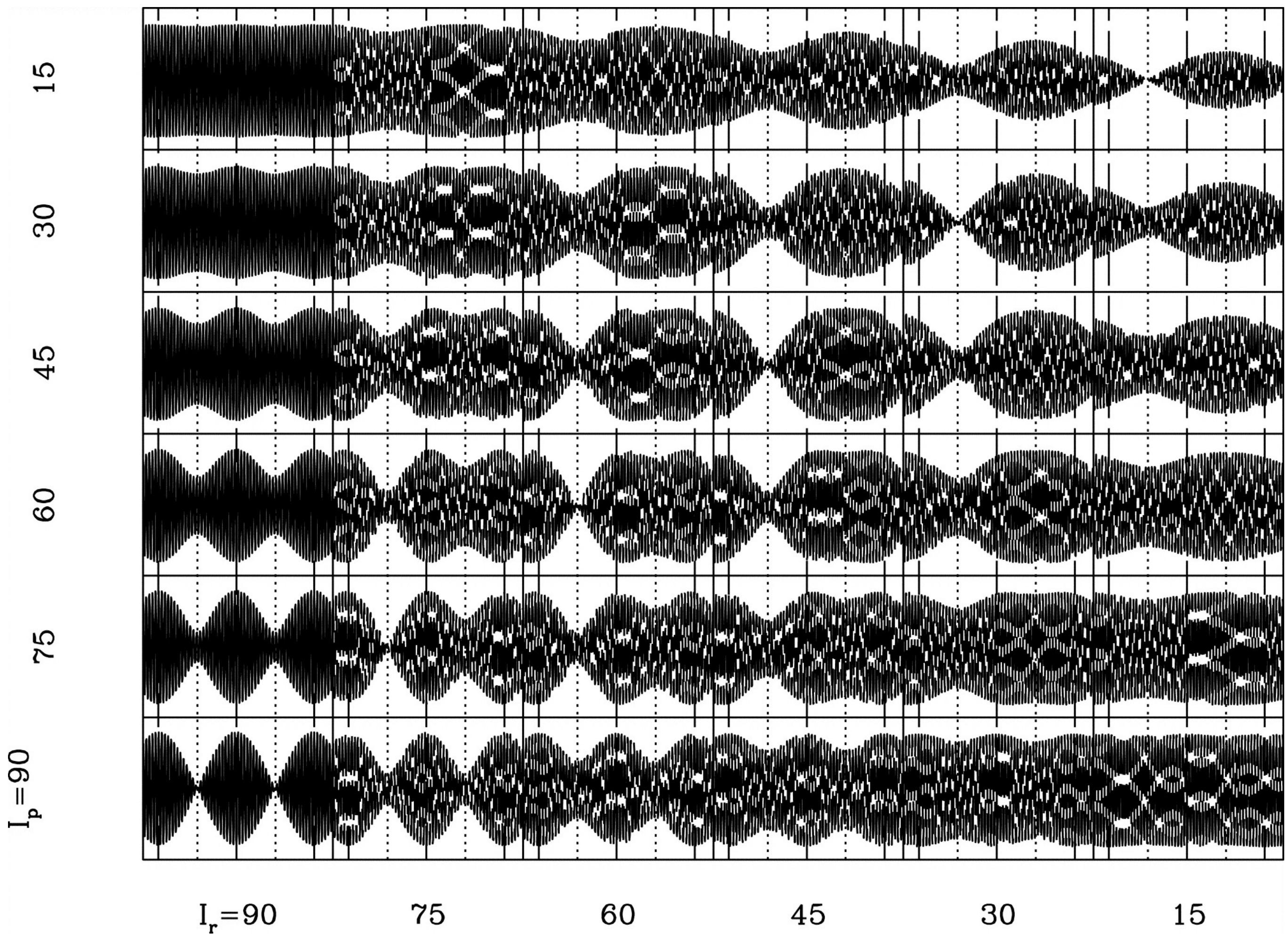
Tidally tilted pulsation axis



Reed, Brondel & Kawaler 2005,
ApJ 634, 602

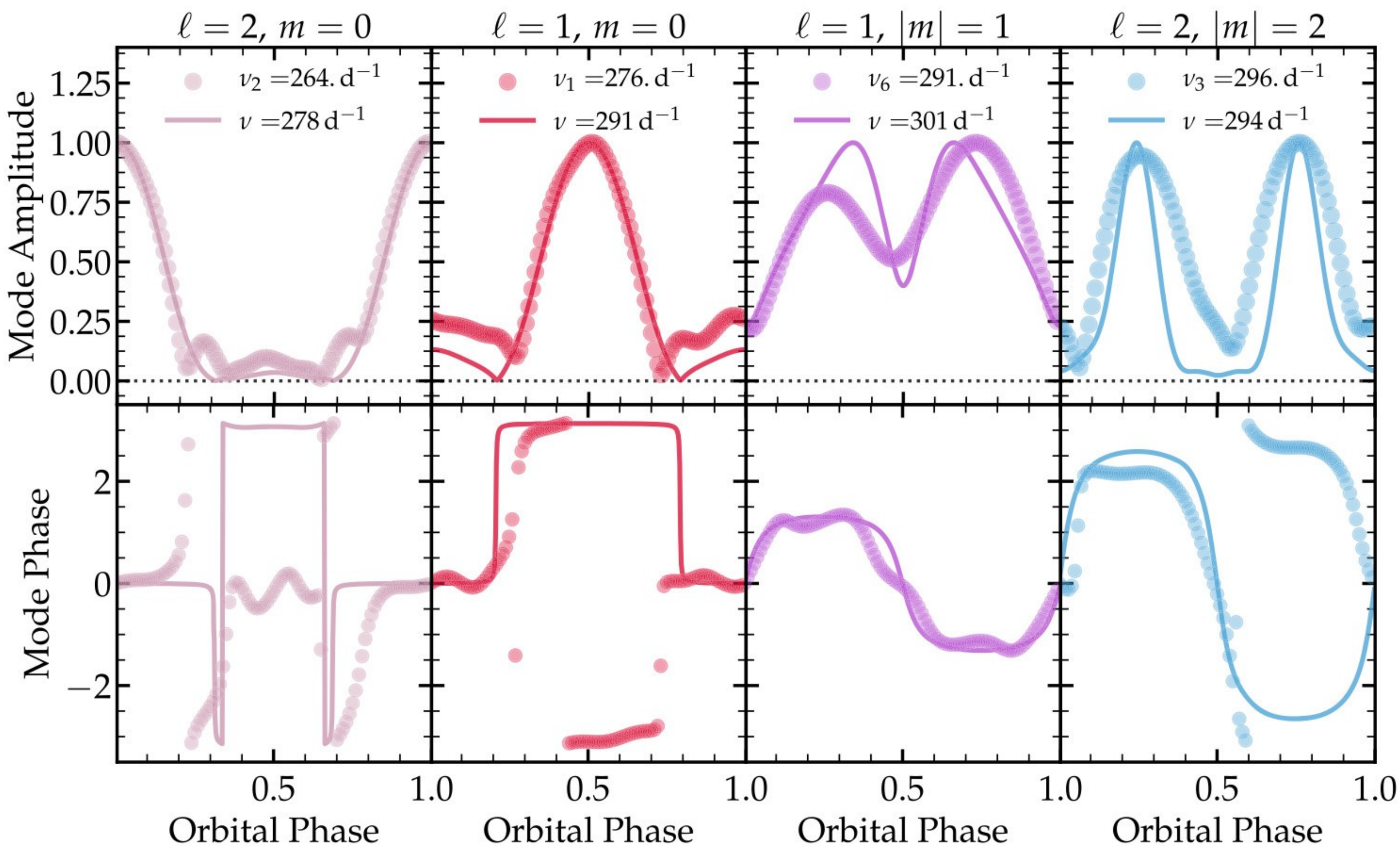
l=1, m=0

Tidally tilted pulsation axis



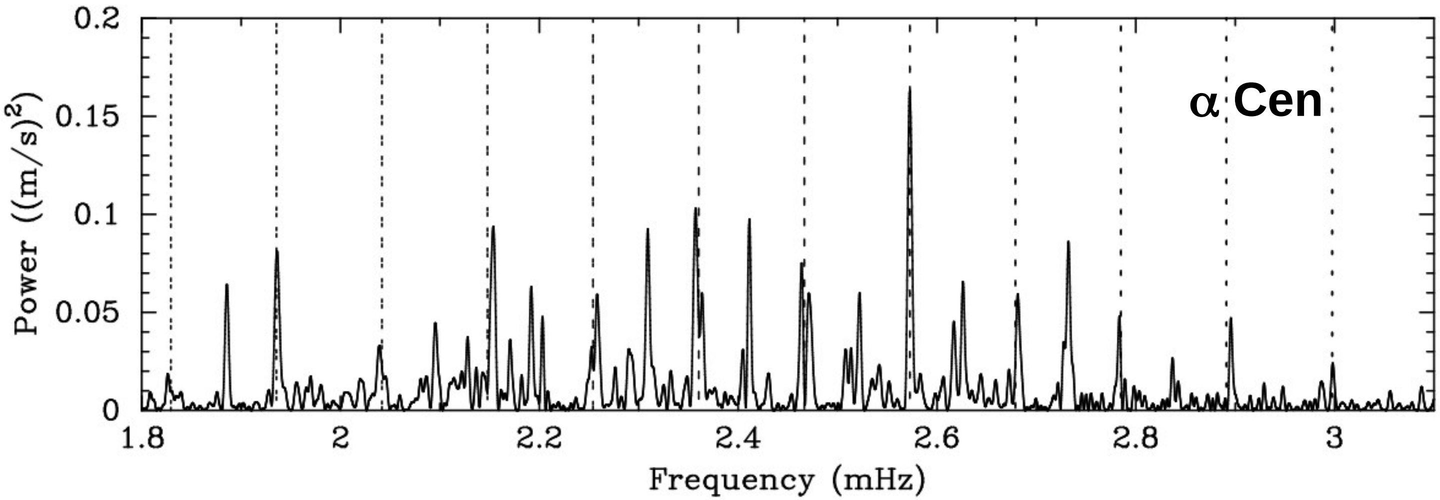
Reed, Brondel & Kawaler 2005,
ApJ 634, 602

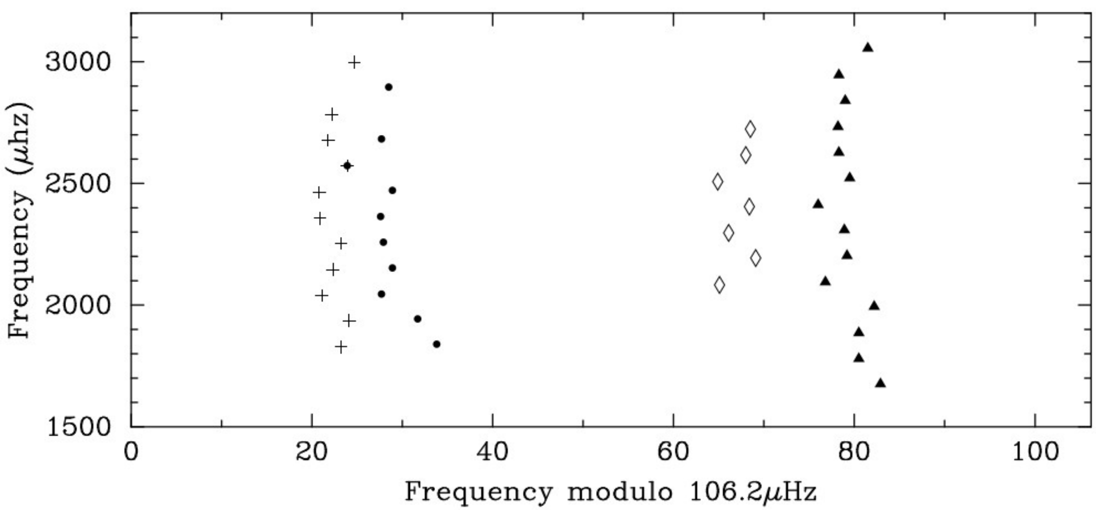
l=1, m=1



$\ell = 2, m = 0$
$\ell = 1, m = 0$
$\ell = 1, |m| = 1$
$\ell = 2, |m| = 2$
$\nu_2 = 264.\,\mathrm{d}^{-1}$
$\nu = 278\,\mathrm{d}^{-1}$
$\nu_1 = 276.\,\mathrm{d}^{-1}$
$\nu = 291\,\mathrm{d}^{-1}$
$\nu_6 = 291.\,\mathrm{d}^{-1}$
$\nu = 301\,\mathrm{d}^{-1}$
$\nu_3 = 296.\,\mathrm{d}^{-1}$
$\nu = 294\,\mathrm{d}^{-1}$
Mode Amplitude
Mode Phase
Orbital Phase

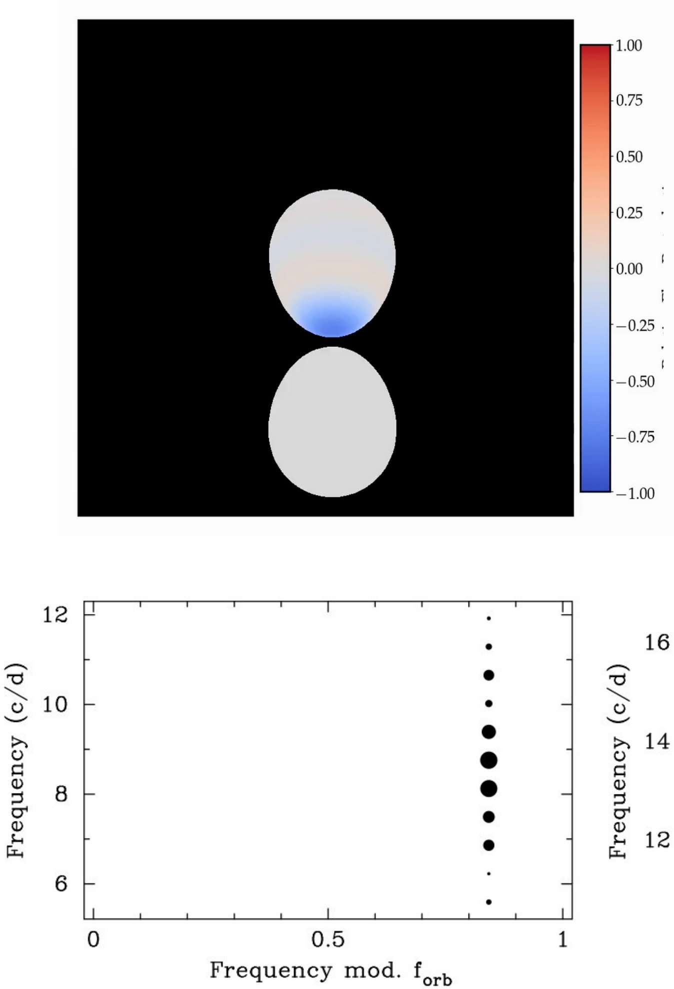
The use of Echelle Diagrams



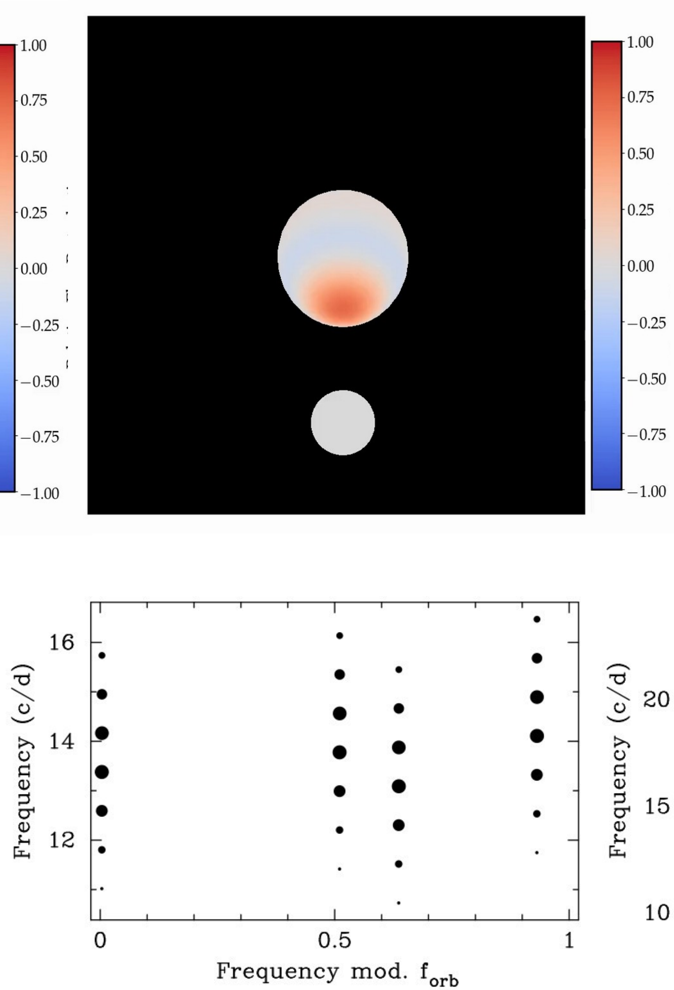


The use of Echelle diagrams

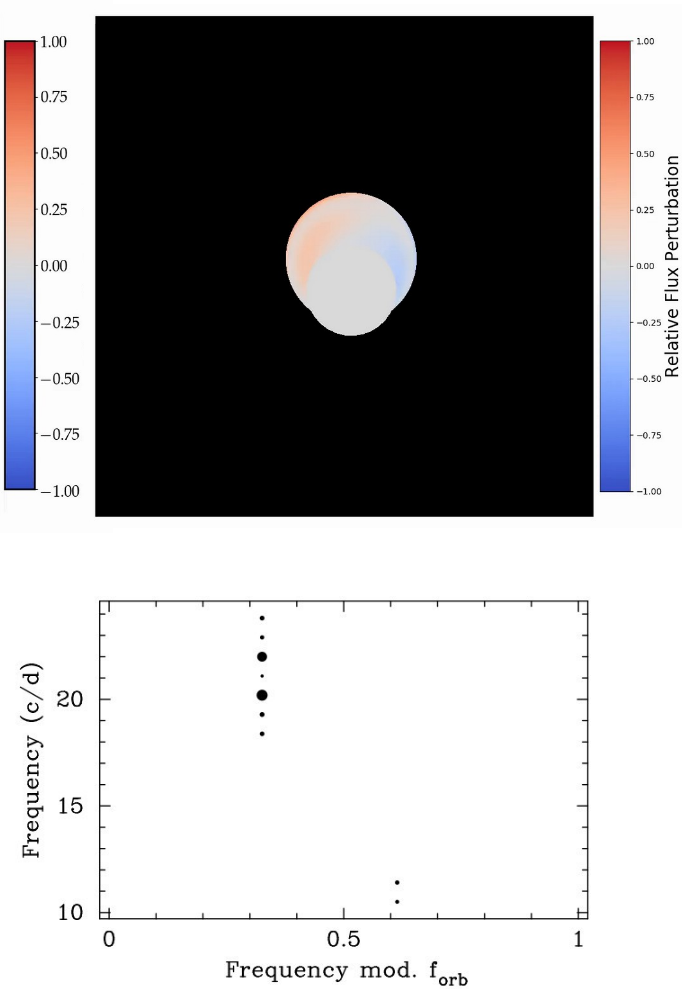
HD 74423



CO Cam



TIC 63328020



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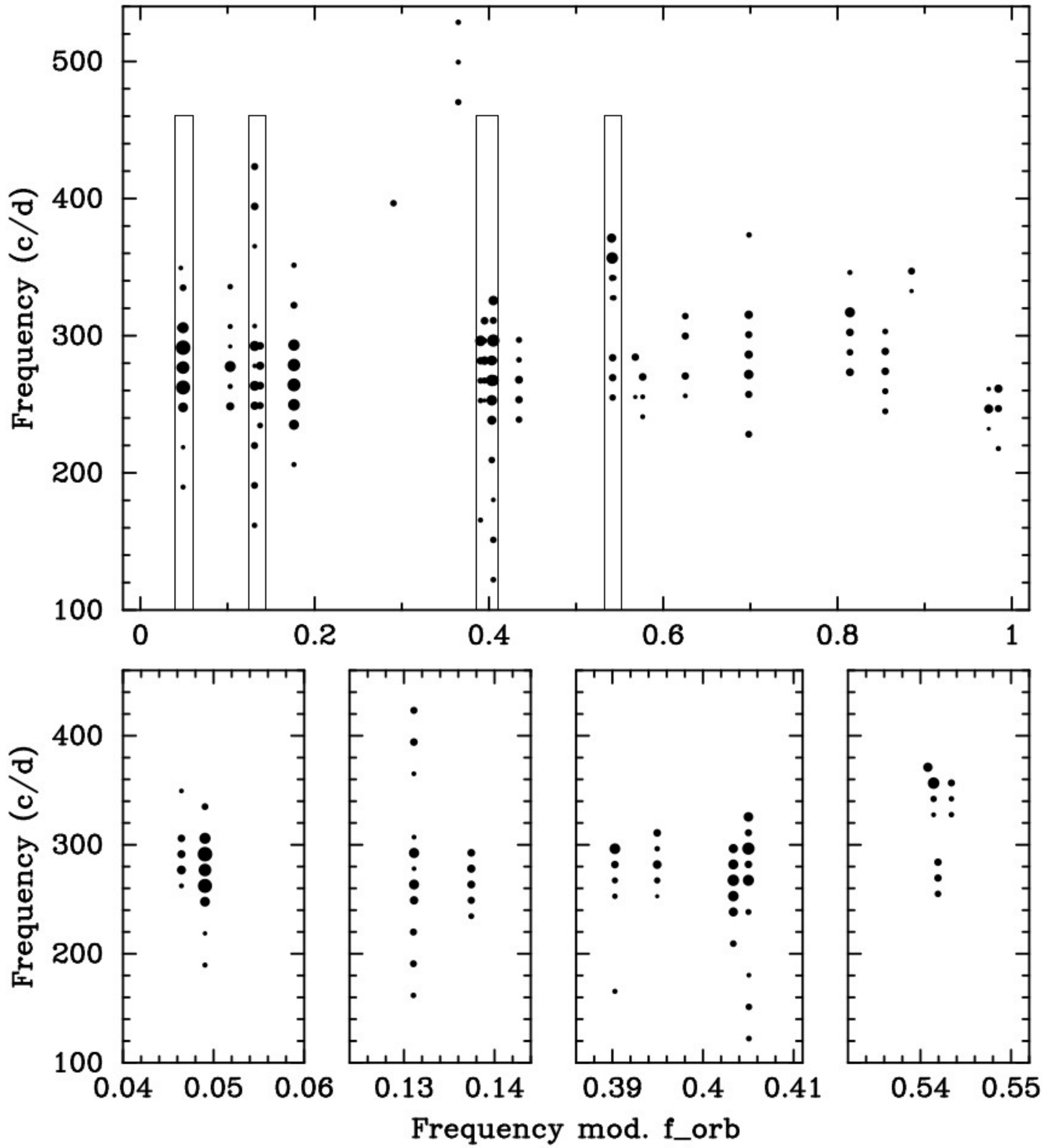
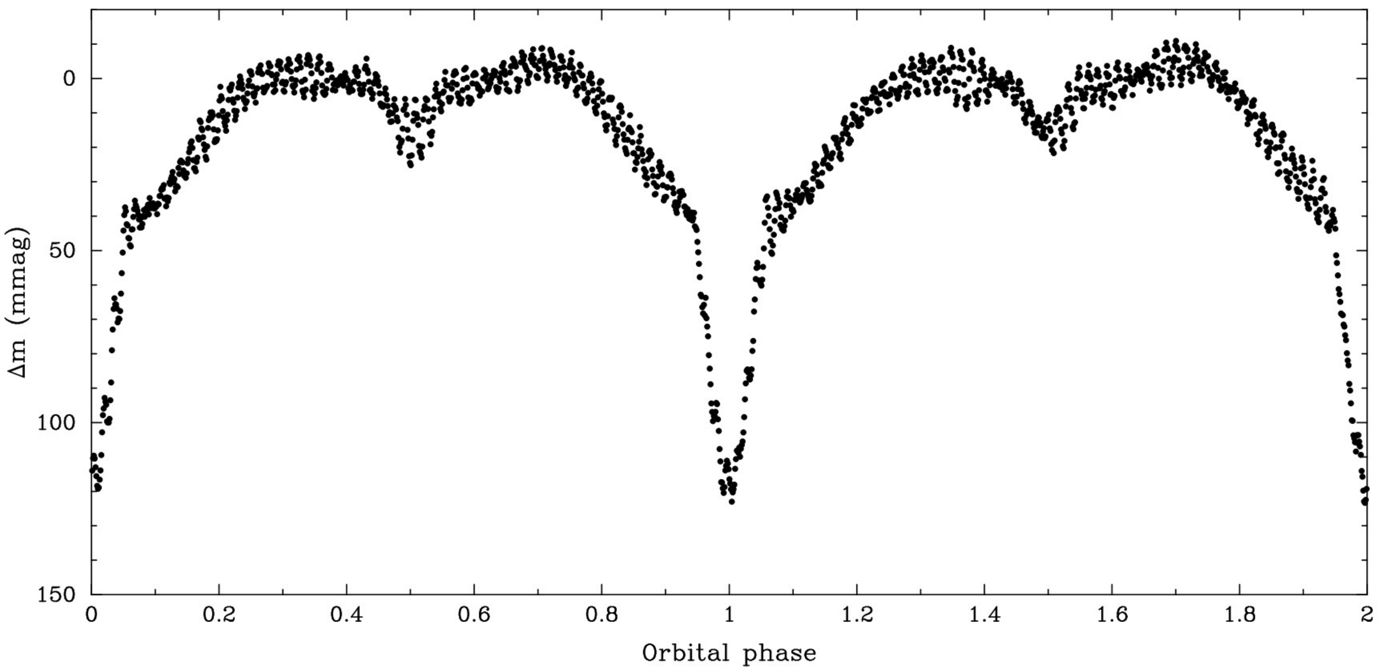
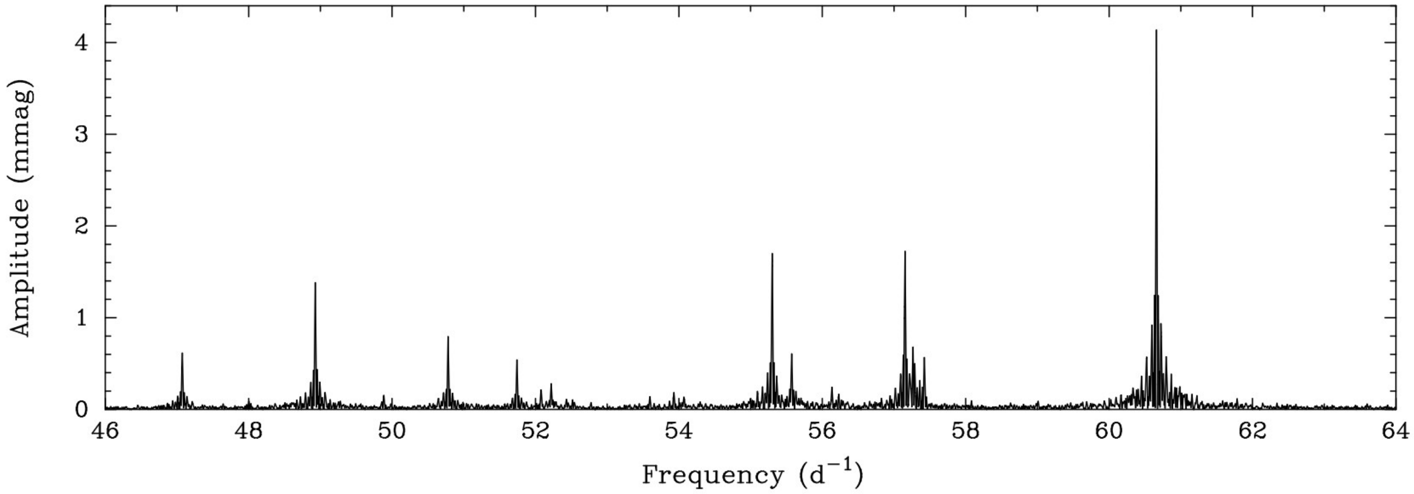


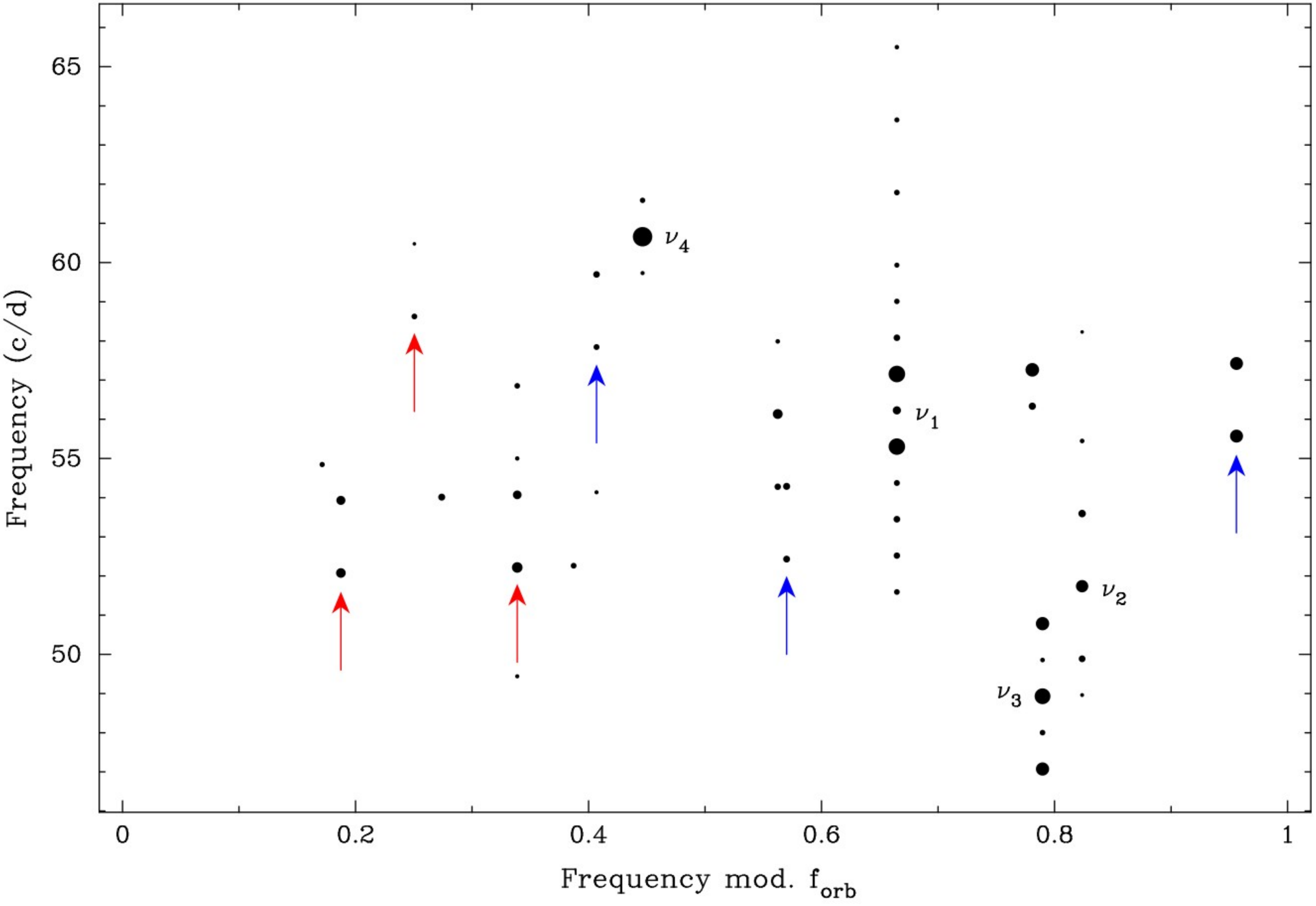
HD 265435

Opening our treasure trove

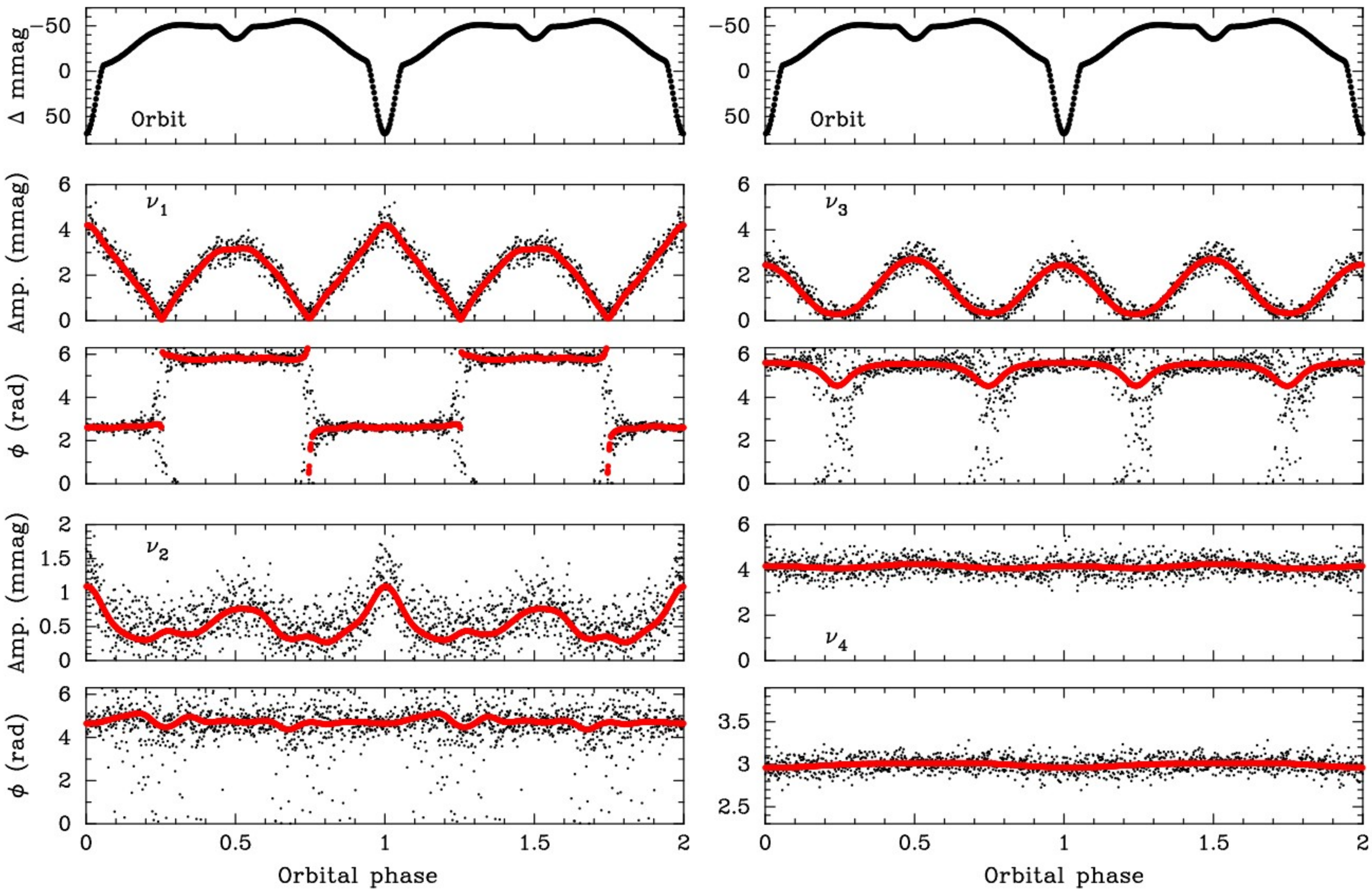




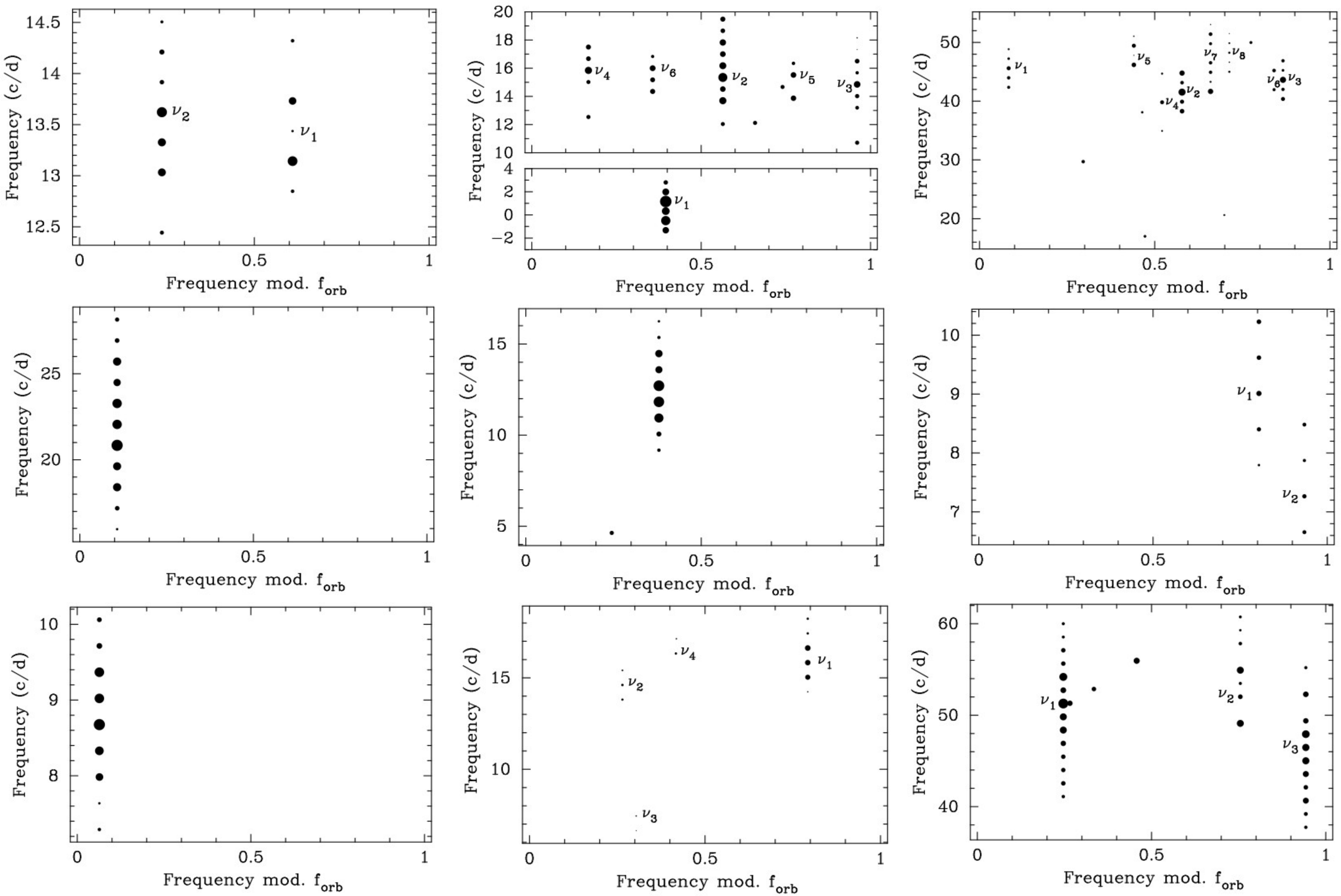
Opening our treasure trove



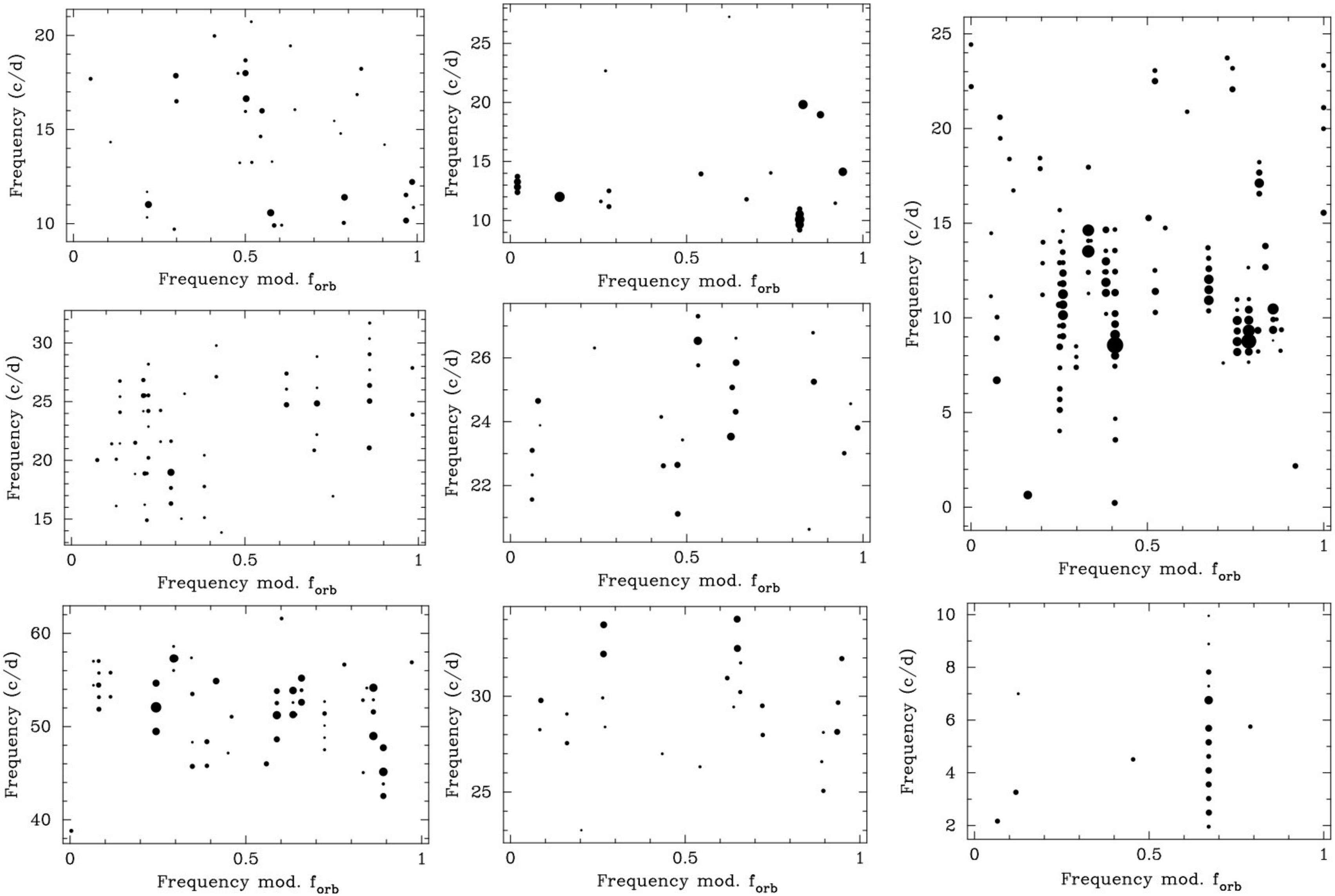
Opening our treasure trove



Opening our treasure trove



...and Pandora's Box



Take-away points

A **tidally tilted pulsator** (TTP) has its pulsation axis pulled into the orbital plane by a close binary companion

A **single sided pulsator** additionally has the pulsation modes distorted by the gravitational pull of the companion

TTPs offer new insights into stellar astrophysics: they are a new type of pulsators in binary systems, and they are oblique pulsators → mode identification

This should enable some of these systems to be studied asteroseismically; accurate stellar parameters from binarity provide tight constraints and vice versa

The TTPs known so far share little except that they are TTPs: different amount of tidal distortion, different chemical composition, different pulsational behaviour, different evolutionary history, different type of star

A systematic study of these stars, and discovery of more representatives are needed. There is a multitude of objects that can be examined – for instance almost a million stars with TESS data