Stars and their variability observed from space
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LONG-TERM *BRITE* AND *SMEI* SPACE PHOTOMETRY OF γ CAS (B0.5 IVe)

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Abstract. For years, the first Be star discovered, γ Cas, had only one short period known. Because that period falls into the range of possible rotation periods, it was assumed that it was really the rotation period. Space photometry has now found multiperiodicity that is best understood as multi-mode nonradial pulsation, thereby leaving the rotational hypothesis (and other assumptions built around it) less well founded.

Keywords: Stars: emission-line, Be, oscillations, individual: γ Cas

1 Introduction

Classical Be stars rotate typically at ∼80% of the critical velocity (Rivinius et al. 2013), eject material when multiple nonradial pulsation (NRP) modes interact (Baade et al. 2018), form Keplerian decretion disks from the ejecta in a viscous process (Lee et al. 1991), and exhibit no large-scale magnetic fields (0/97 detections by Wade et al. 2016). γ Cas was the first emission-line star discovered (Secchi 1866); it possesses an unseen $\sim 1\,M_\odot$ companion in a circular 203.5-d orbit (Nemravová et al. 2012), is the prototype of a ∼1% sub-population of Be stars with peculiar hard X-ray emission and spectral types B0.5–B1.5 (Smith et al. 2016), and has for years exhibited optical mmag variability with a frequency of 0.82 c/d (Henry & Smith 2012). Smith et al. (2016) have suggested that 0.82 c/d is the frequency of (critical) rotation. They went on to assume the existence of two magnetic fields, one due to a subsurface convection zone in the star and the other produced by magneto-rotational instability (MRI) in the circumstellar disk. In the picture painted by Smith et al. (2016), X-rays are produced when particles hit the star after the two magnetic fields have reconnected after a temporary rupture, and thereby accelerate matter. The stellar property that is thought to be modulated by rotation and giving rise to the 0.82 c/d photometric variability is left unidentified, and the spatial scales of the two magnetic fields are stated to be too small to be detectable. It is therefore, by design, impossible to design an observational experiment that can verify or falsify the proposed rotation-based and magnetic description of γ Cas.

Most Be stars pulsate in multiple NRP modes (Rivinius et al. 2003). The range in amplitude is large, and amplitudes can vary on time-scales of weeks to years so non-detections may only be a matter of insufficient sensitivity and/or time coverage. In many of these stars, the observed NRP frequencies straddle the range into which global stellar parameters would place the rotation frequency (e.g., Baade et al. 2017; Semaan et al. 2018); however, in no case has it been possible to prove that a frequency is actually rotational. Therefore, if it can be shown that γ Cas, also exhibits multiple frequencies, NRP would be the most likely common interpretation, and it would be less justified to assign a completely different nature to one of them. In any event, if stellar frequencies differ by a large factor, not all of them can be due to (differential) rotation. For the detection of multiple low-amplitude variabilities, the method of choice is photometry from space.

2 Observations and analysis

Observations by the Automated Photometric Telescope (APT) (∼7,800 and ∼7,900 measurements in the *B* and *V* passbands, respectively), which were obtained between 1997 and 2011 and analyzed by Henry & Smith (2012), were downloaded through VizieR (Ochsenbein et al. 2000). Even without a comprehensive and very complex preprocessing similar to that applied by Henry & Smith (2012), the 0.82 c/d frequency (referred to

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below as f_1) was easily recovered. However, there were no other significant peaks in the APT power spectrum thus calculated. In addition, archival observations with SMEI (Jackson et al. 2004), which extending from 2004 to 2011 (and therefore fully overlapping the APT data) were also studied. The SMEI database, kindly made available (to D.B.)by B. Jackson, permits the observations to be investigated separately for the three cameras. The Camera 3 data were discarded because the noise was too high. In the 38,500 or so measurements with the other two cameras, f_1 was clearly detected, and the strong decline in amplitude reported by Henry & Smith (2012) was confirmed. Furthermore, another frequency appeared in the analysis at $f_2 \sim 1.25\,\mathrm{c/d}$ with Camera 2 but only marginally in Camera 1. More periodic variabilities may exist but do not stand out strongly above the presumed noise.

New observations were obtained with *BRITE*-Constellation (Weiss et al. 2014). All five *BRITE* satellites (up to three in parallel) observed γ Cas in four seasons from 2015–2018/19 and accumulated a total of ~4,500 orbit-averaged data points. Frequency f_1 had not returned at the time of these observations, but there were hints of f_2. By far the strongest signal persisted at $f_3 = 2.48\,\mathrm{c/d}$. Because the data strings are long, the frequency determinations are precise enough to establish the following numerical inequalities: $f_3 \neq 3 \times f_1$ and $f_3 \neq 2 \times f_2$. That is, there are no harmonic relations between these three frequencies.

3 Discussion and conclusions

Although the individual datasets used in this study do not have ideal noise properties (most notably for SMEI), the detection of all frequencies with completely independent equipment leaves little room for doubts as to their reality. Their values are consistent with NRP frequencies found in other early-type Be stars (e.g., Baade et al. 2017; Semaan et al. 2018). The simultaneous presence of frequencies differing by a large factor demonstrates that at least two of them are, in fact, due to nonradial pulsations. Since rotational modulation is not an established property of Be stars, the rotational-modulation hypothesis for γ Cas is not convincing. In that regard, γ Cas therefore no longer differs from the large majority of Be stars. Accordingly, γ Cas might once more be considered prototypical of Be stars; the explanation of the peculiar X-ray properties may be found in its binary evolution (Langer et al. 2019). High-cadence spectroscopy is the most promising method for determining the nature of f_1 unambiguously.

A full account of this work, which also includes the recovery of the orbital 203.5-d period from a time-series analysis of 300+ archival Hα profiles, has been submitted to *Astronomy & Astrophysics*.

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