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# DISCOVERY AND CATALOGING OF A NEW DELTA SCUTI STAR IN PERSEUS

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**Abstract:** In this work, we present the discovery and cataloguing of a new variable star in Perseus. After its photometric study, it was concluded that we were facing a new δ Scuti type variable star which, although it was included in the ZTF catalogue of periodic variables as suspected, was not adequately characterised. For our study, we used data from other sources, such as the aforementioned ZTF or ASAS-SN, and our own data. Finally, it was included in the AAVSO's The International Variable Star Index with the name GSC 03319-01926.

## 1 Introduction.

Through this paper, we announce the discovery of a new variable star in the constellation Perseus. This detection was made in the context of monitoring the variable star V526 Per, organised by the ASPIRE Group (Asteroid and Stellar Photometric Research Group)[1] as part of the BY Dra Project.

After photometrically reviewing all the stars in the field, we detected the possible variability of a star that, although listed as a suspected variable in the ZTF Catalog of Periodic Variable Stars (Chen *et al.*, 2020), had not been adequately characterized. Several intensive observation sessions were conducted to obtain sufficient data for its characterisation. The results of this work indicate that we are dealing with a δ Scuti-type variable star with very low amplitude, as we will discuss further below. This star's coordinates (J2000.0) are = 03 20 00.06 +49 47 43.8.

The δ Scuti stars are a type of pulsating variable star with spectral types ranging from A to F. They are located where the classical instability strip intersects with the main sequence on the Hertzsprung-Russell (HR) diagram. These variable stars exhibit pulsation periods between approximately 18 minutes and 8 hours, corresponding to radial and non-radial pulsations and mixed modes of low radial order. δ Scuti stars include various subtypes and display diverse behaviours, making it valuable to describe these differences to navigate the complexities of the δ Scuti category (Handler, 2009).

## 2 Observers and types of equipment

In addition to data obtained from sky surveys, we supplemented this with data collected by the authors at their private observatories in Southern Europe (specifically Spain and Malta). Each observatory involved in this research has its own Minor Planet Center code (Table 1) and extensive experience in observing variable stars, as well as in astrometry and photometry.

[1] https://www.aspireastro.net/

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Table 1: Location and main characteristics of the observatories.

| Observer | Observatory | MPC Code | Telescope | CCD chip (FOV) | Plate scale | Filter |
|---|---|---|---|---|---|---|
| Juan-Luis González Carballo | Cerro del Viento (Badajoz, Spain) | I84 | 0.20-m | KAF-8300 (46’x31’) | 1.36”/px | *V* Johnson |
| Stephen Brincat | Flarestar (Malta) | 171 | 0.25-m | KAF-1603ME (26’x17’) | 0.99”/px | *V* Johnson |
| Rafael Benavides Palencia | Posadas (Córdoba, Spain) | J53 | 0.28-m | KAF-8300 (49’x36’) | 1.75”/px | *V* Johnson |

## 3 Observations and data reduction.

As mentioned above, the discovery occurred within the BY Dra Project of the ASPIRE Group. One of the stars under study, V526 Per, was observed by various collaborators of the Group over several nights in the fall of 2023. All observations were made using a *Johnson V* filter with 60 to 100-second exposures. Additionally, all images were calibrated with their corresponding dark, flat, and bias frames through *MaxImDL 6* (Diffraction Limited, 2012) and *MPO Canopus/Photored* software (Warner, 2021).

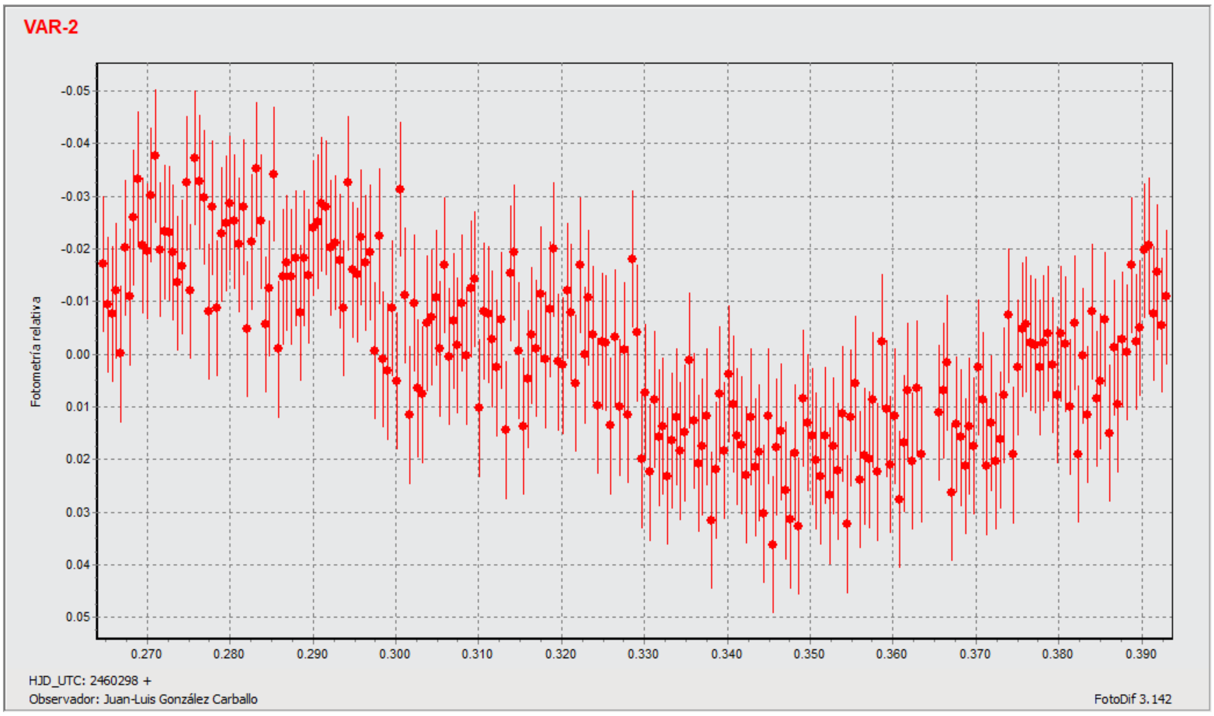


Figure 1: Data from the first night of observation conducted by González Carballo, during which the possible variability of GSC 03319-01926 was detected. The light curve represents 4 hours of observation on the night of November 21, 2023.

González Carballo checked all the stars in the field within their CCD images to detect possible brightness variations of other nearby stars, a common practice among observers of variable stars. The *FotoDif 3.95* software (Castellano, 2002) was used to carry out this process. On the first night, a weak signal of possible variability was detected from a relatively bright star (*V mag* = ~13) that appeared to have a periodic oscillation of a few hours (Figure 1). At that time, a check was performed to verify that this star was not listed in the AAVSO's International Variable Star Index (VSX) (Watson *et al.*, 2006), and it was found that it was not included.

After informing the other members of the ASPIRE Group, Brincat decided to perform photometric reduction on his previously recorded images of V526 Per to analyse the data for the potential new variable star. Subsequently, another observer, outside the ASPIRE Group but an experienced observer of variable stars (Benavides Palencia), dedicated part of his observational time to gathering data on the target star. Ultimately, we collected data over five nights in November 2023 (Table 2).

Table 2: Observation nights dedicated to studying the target star

| Date [HJD] | Observatory | Time-span [h] | Images |
|---|---|---|---|
| 2460291 | Flarestar | ~4 | 111 |
| 2460295 | Cerro del Viento | ~4 | 242 |
| 2460298 | Cerro del Viento | ~3 | 234 |
| 2460301 | Cerro del Viento | ~1 | 99 |
| 2460301 | Posadas | ~2 | 335 |

To photometrically reduce our images, we used three nearby comparison stars and one check star (Table 3). All were selected using the *SeqPlot 4.1* software from the AAVSO, with particular attention given to their B-V values (Figure 2, next page).

Table 3: Reference and Check stars used for the photometry reduction.

| Star | Coordinates | V Mag[1] | B-V[1] |
|---|---|---|---|
| Comp1 | 031902.27 +495218.0 | 12.000 | 0.611 |
| Comp2 | 031927.73 +495203.9 | 12.425 | 0.776 |
| Comp3 | 032023.23 +495735.1 | 12.568 | 0.657 |
| Check | 032000.61 +494540.0 | 12.778 | 0.739 |

*References*
[1]APASS Catalog (Henden *et al.*, 2016)

Once the variability of the target star was identified, we began to study its amplitude and period characteristics. At that point, Brincat searched other professional catalogues via VizieR (Zacharias *et al.*, 2012) to locate additional relevant data about this star. It was then discovered that the star (ZTF J032000.06+494743.8) was listed in the ZTF Catalog of Periodic Variable Stars as suspected (Masci *et al.*, 2019). We consulted Sebastián Otero, an External Consultant for AAVSO and administrator of the AAVSO International Database (VSX) (Watson *et al.*,2006), to determine if submitting the potential new variable star to VSX was appropriate. Our submission was endorsed, as suspected variables in the VSX catalogue that were not adequately characterised could be included in the VSX.

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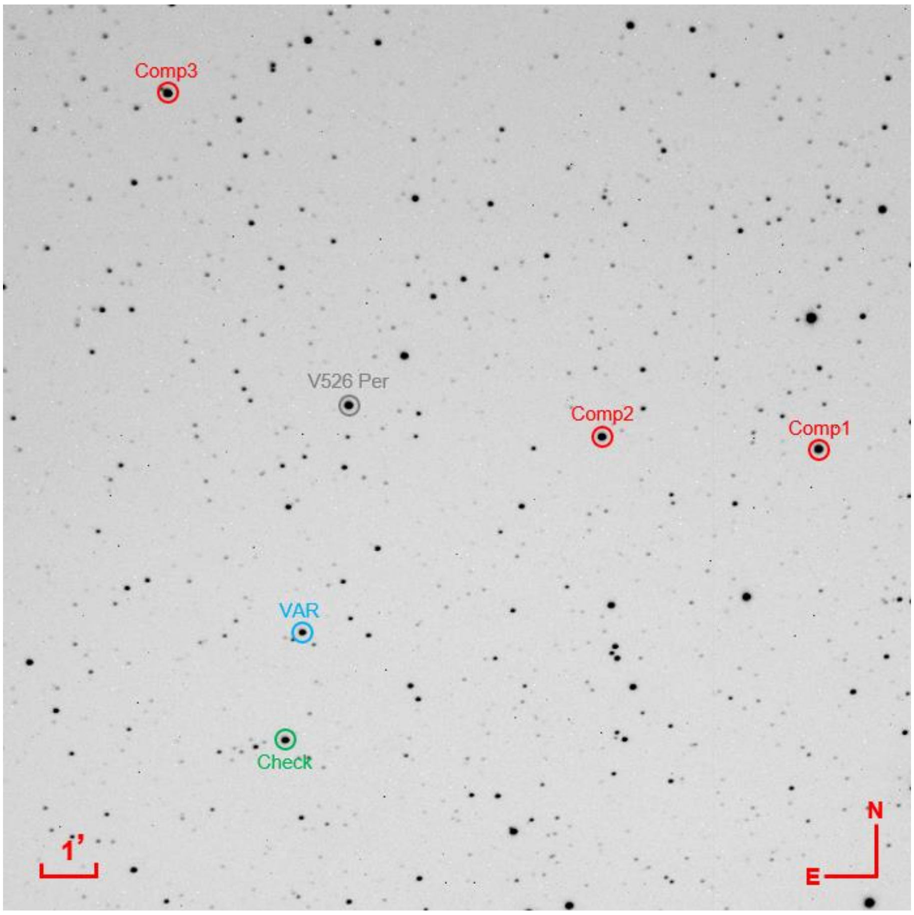

Figure 2: Star field with the target star, along with the comparison and check stars used.

To achieve a comprehensive photometric analysis of the new variable star, we used data from two professional surveys that provided extensive coverage with long time series: ASAS-SN (Kochanek *et al.*, 2017) and ZTF (Masci *et al.*, 2019) (Table 3). To accomplish this, it was necessary to adjust the *zero point*. This adjustment involved using the ASAS-SN *V* band measurements as reference points, aligning the maximum and minimum phases of the light curve with the data from the other source. Specifically, this required calibrating the ZTF *g*-band measurements by —0.49 magnitudes. The same adjustment was applied to the measurements provided by the three authors. The mean uncertainty of these measurements was 0.012 *V* mags. The final light curve can be seen in Figure 3 (next page).

Table 4: Data used from surveys.

| Survey | Band | HJD start | HJD end | Number of measurements |
|---|---|---|---|---|
| ASAS-SN | *V* | 2457007 | 2458831 | 143 |
| ZTF | *g* | 2458304 | 2458831 | 514 |

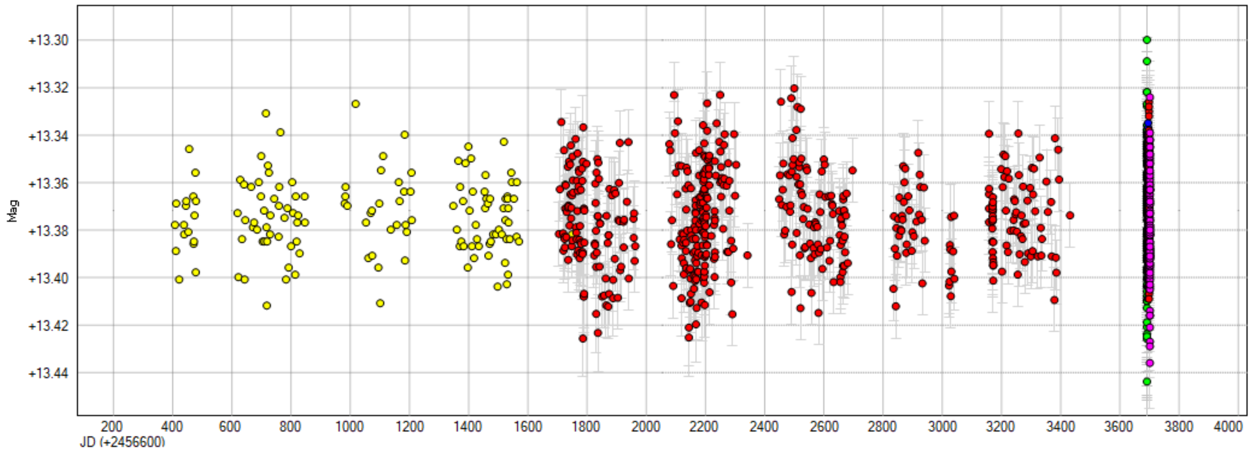


Figure 3: Light curve of the star under study with all data incorporated and appropriately corrected to *zero point*. The yellow circles correspond to ASAS-SN, the red ones to ZTF and the rest to the authors of this work.

For the photometric analysis of its light curve, we used *Peranso 3.0.4.3* software (Paunzen & Vanmunster, 2016), applying the PDM (Stellingwerf, 1978) and Lomb-Scargle (Lomb, 1976; Scargle, 1982) algorithms, and obtained nearly identical results with both. Initially, the periodogram displayed a strong signal for a period of around 0.12 days, which was ultimately refined to its final period of 0.126840 days (Figure 4). This value is slightly higher than that provided by the ZTF catalogue (0.11643 days). The final result is a phase diagram showing the typical profile of a δ Scuti type variable star (Figure 5, next page). The resulting parameters that characterise this variable, as included in the VSX, are listed in Table 4 (next page).

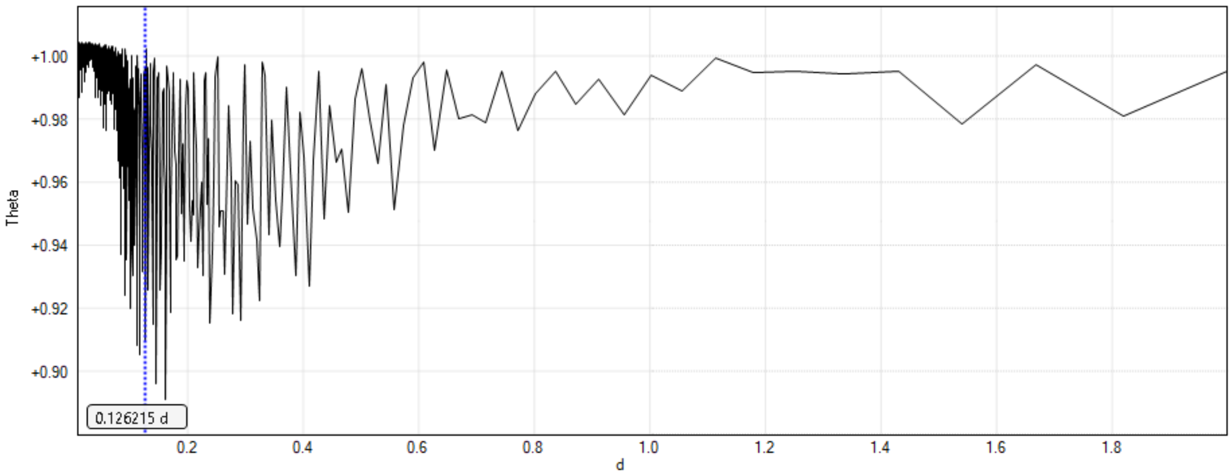


Figure 4: Periodogram obtained for the star under study.

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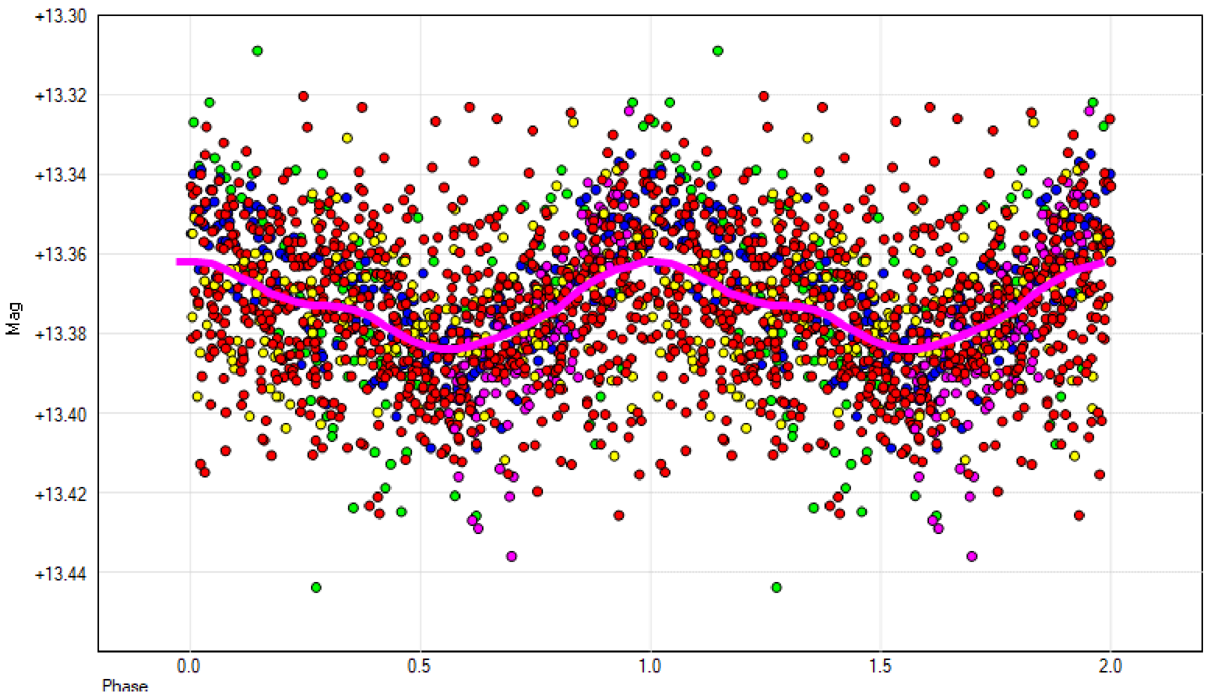


Figure 5: Phase plot of GSC 03319-01926.

Table 5: Data included in the VSX for the new variable star.

| | |
|---|---|
| Name | GSC 03319-01926 |
| AAVSO UID | 000-BPT-705 |
| Coordinates J2000.0 | 03 20 00.06 +49 47 43.8 |
| Other names | UCAC4 699-023369, ZTF J032000.06+494743.7 |
| Max. Mag. (*V*) | 13.35 |
| Min. Mag. (*V*) | 13.39 |
| Amplitude | 0.04 |
| Period | 0.126798 d (3.0432 h) |
| Spectral type | F0 |
| Variability type | δ Scuti (DSCT) |

As can be observed, we also incorporated, at the suggestion of the aforementioned S. Otero, the spectral class of this star obtained from the LAMOST DR7 catalogue (Luo *et al.*, 2019). Its classification reinforced the idea that we were dealing with a δ Scuti variable, as these stars are found precisely between types A0 and F5 with temperatures between approximately 6000 and 7500K.

## 4 Data analysis and characterisation within the HR Diagram.

Although identifying this star as a δ Scuti variable is unequivocal, we aimed to obtain additional data regarding its physical characteristics to position it within the HR Diagram. We followed the work of Conzo *et al.* (2022) for this process.

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For this purpose, obtaining parameters such as its absolute magnitude and distance is essential. To achieve this, we used both published data from the professional literature and our values calculated. Regarding its distance, we utilised the stellar parallax data provided for this source in Gaia EDR3 (Gaia Collaboration, 2020): *plx* = (0.7616 ± 0.0144) mas *d* = (1313.025 ± 24.8) pc.

From this distance data and its photometric magnitude (which we determined as the mean value of its amplitude, i.e., magnitude *V* = 13.37 ± 0.012), it is possible to calculate its absolute magnitude using the well-known distance-magnitude relationship. For this, we first corrected the V magnitude of the star with its interstellar extinction (*Av* = 1.8361 mag) obtained from the NASA/IPAC Infrared Science Archive[2].

$$M_v = m - 5\,log(d) + 5 - Av = (0.94 \pm 0.04)\,mag \quad (1)$$

From this information, it is possible to calculate its luminosity using the brightness-magnitude relation (Unsöld, 2013):

$$L = 10^{\frac{Mv - M_{\odot}}{-2.5}} = (35.9 \pm 1.4)\,L_{\odot} \quad (2)$$

Thanks to these data, it is possible to approximately calculate the stellar radius (*R*), for which we need to know its temperature $T_{eff}$ = (6871.92 ± 105.20) K obtained from Luo *et al.* (2019). For this, it is also necessary to use the Stefan-Boltzmann law (Narimanov & Smolyaninov, 2011), resulting in:

$$R = \sqrt{\frac{L \cdot L_{\odot}}{4\pi\sigma {T_{\mathrm{eff}}}^4}} = (4.23 \pm 0.25)\,R_{\odot} \quad (3)$$

Finally, its mass (*M*) is calculated. To do this, we use the previously computed luminosity and temperature using the mass-luminosity relation (Cox, 2017):

$$\frac{L}{L_{\odot}} \approx \left(\frac{M}{M_{\odot}}\right)^{3.5} = (2.20 \pm 0.17)\,M_{\odot} \quad (4)$$

We summarise all the parameters calculated or extracted from the literature in Table 6.

Table 6: Fundamental parameters of GSC 03319-01926

| | |
|---|---|
| Apparent magnitude (*m*) | 13.37 ± 0.012 |
| Absolute Magnitude (*Mv*) | 0.94 ± 0.04 |
| Parallax (*plx*) | 0.7616 ± 0.0144 *mas* |
| Distance (*d*) | 1313.03 ± 24.8 *pc* |
| Temperature (*T*) | 6872 ± 105 K |
| Luminosity ($L_{\odot}$) | 35. 9 ± 1.4 |
| Radius ($R_{\odot}$) | 4.23 ± 0.25 |
| Mass ($M_{\odot}$) | 2.20 ± 0.17 |
| *log L/L*$_{\odot}$ | 1.56 ± 0.02 |
| *log Teff* | 3.8 ± 0.01 |

[2] https://irsa.ipac.caltech.edu/applications/DUST/

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All these values help confirm that we are dealing with a δ Scuti type variable star, as the generally established parameters for this type of star are (North *et al.*, 1997): absolute magnitudes between +0.5 and +2.5 (0.94 for the star under study), effective temperatures between 6000 and 7500 K (6872 K), spectral types between A0 and F5 (F0), and masses between 1.4 and 2.23 $M_{\odot}$ (2.20). The only value that is slightly higher than the typically indicated range for these variables is the radius. However, it is not uncommon to find some δ Scuti stars with larger radii (Poro *et al.*, 2021) depending on their stellar evolution and different pulsation states (the star that names this type of variable, Delta Scuti, has a radius of 4.78 ± 0.8 $R_{\odot}$).

However, we have been able to compare the results we calculated for the present work with those published in some recent publications. Anders *et al.* (2022) collected data from GAIA EDR3 on 363 million stars, for which they calculated some parameters of stars brighter than G = 18.5, among which is the new variable under study. We have paid particular attention to the parameter published in this work referring to the stellar mass (1.93 $M_{\odot}$ in the 84th percentile), which is only 0.27 $M_{\odot}$ lower than the one we calculated (-13.90%).

Finally, GSC 03319-01926 fits perfectly within the narrow range at the centre of the instability strip analogous to Cepheids (Figure 6), characteristic of δ Scuti stars (Handler, 2009).

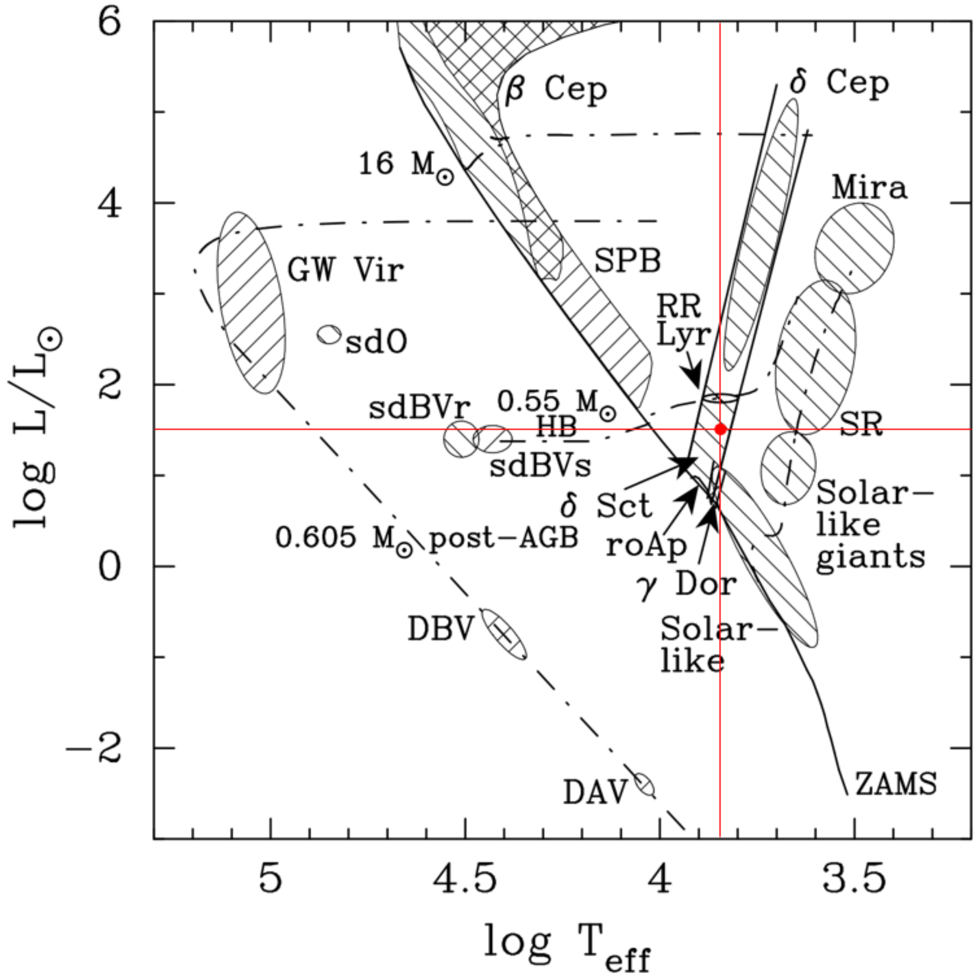


Figure 6: GSC 03319-01926 (red dot) in the HR Diagram (adapted from Handler, 2009).

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