SF2A 2024
M. Béthermin, K. Baillié, N. Lagarde, J. Malzac, R.-M. Ouazzani, J. Richard, O. Venot, A. Siebert (eds)

EXPLORING MAGNETISM IN δ SCUTI STARS AND ITS DIVERSITY

K. Thomson-Paressant[1], C. Neiner[1] and J. Labadie-Bartz[1]

Abstract. δ Scuti stars are intermediate-mass stars exhibiting high-frequency p-mode pulsations. The first examples of magnetic δ Scuti stars have only been discovered in the last decade. However, recent spectropolarimetric observations have resulted in an increasing number of known magnetic δ Sct stars and in the full-field characterisation of a few of them. Several of these magnetic δ Sct stars have relatively weak fields (1-250 G), while on the other hand, examples of strong fields have also been recently discovered, with field strengths up to several tens of kG. This suggests the existence of a broader distribution of magnetic field strengths in this family of stars compared to other OBA-type stars. We try to understand this diversity and the specificity of the magnetism of δ Sct stars by studying the relationships between magnetism and various other factors (pulsations, convection, age, etc.). I present the sample of magnetic δ Sct stars, its diversity and our statistical results on this group of stars.

Keywords: spectropolarimeter, stellar magnetism, δ Scuti stars

1 Introduction

Significant progress has been made in recent years in the field of stellar magnetism, thanks to the development of reliable techniques for identifying candidate magnetic stars, that have come about as a result of the ever-growing list of known magnetic stars. In the case of δ Scuti (δ Sct) stars, the first spectropolarimetrically confirmed magnetic δ Sct was discovered barely a decade ago (HD 188774, Lampens et al. 2013), with a few more being found in the following years (ρ Pup, Neiner et al. (2017); β Cas, Zwintz et al. (2020); HD 41641, Thomson-Paressant et al. (2020)). Efforts have been made to expand this list through broader surveys, with varying degrees of success (Thomson-Paressant et al. 2023, 2024), which has resulted in the gradual growth of the database over time as well as an improvement on the effectiveness of our detection techniques.

Amongst the handful of previously confirmed magnetic targets, there appears to be a large disparity in the characterisations and strengths of their respective magnetic fields. With such few examples it is difficult to hypothesise as to the origin of this diversity and what mechanisms might come into play to generate such a diversity. It is therefore essential to expand the list of confirmed, well-studied, magnetic δ Sct, such that we might better understand the representation of magnetism in these and other pulsating variable stars.

We present here our latest efforts in this regard, having expanded the list to 13 spectropolarimetrically confirmed magnetic δ Sct, which we have identified and characterised to verify their nature, and constitutes the first comprehensive study of magnetism in δ Sct stars.

2 Magnetic δ Sct stars

The targets in our sample have been collated from a combination of our team's studies and sources in the literature. Aside from the targets alluded to in the previous section established from individual studies (HD 188774, β Cas, ρ Pup, and HD 414641), we have discovered 3 new magnetic δ Sct stars from a broad survey of mCP stars (HD 36955, HD 49198, and HD 63843; Thomson-Paressant et al. (2024)) to which we include HD 73857, which was previously identified as a δ Sct in the literature (Bessell 1969) and for which we show also presents a magnetic signature, and five targets were already known to be magnetic (HD 8441 and HD 68351, Babcock

[1] LESIA, Paris Observatory, PSL University, CNRS, Sorbonne University, Université Paris Cité, 5 place Jules Janssen, 92195 Meudon, France

(1958); HD 10783, Preston & Stepien (1968); HD 81009, Preston (1971); HD 213918, Cramer & Maeder (1980)), for which we have identified δ Sct pulsations in their Fourier spectra (Thomson-Paressant et al., in prep.).

To ensure that the targets in our sample are genuine magnetic δ Sct stars, we have imposed the following criteria: i) that they have at least a single sector of *TESS* photometric data to check for the presence of δ Sct pulsations, and ii) that there exists spectropolarimetric data (archival or acquired by us) that we can analyse in order to characterise the magnetic field of the star ourselves.

A number of young Herbig-type stars have also been shown to present both features (e.g. HD 35929 and HD 72106), but for the purposes of our analysis we have elected to focus on targets that have at least evolved to the main sequence or beyond.

To identify the δ Sct pulsation modes of the stars in our sample, we utilise photometry from the Transiting Exoplanet Survey Satellite (TESS, Ricker et al. 2015), which can be retrieved from the Mikulski Archive for Space Telescopes (MAST) at the Space Telescope Science Institute*. The procedure for analysing the *TESS* photometric data is identical to the one described in Labadie-Bartz et al. (2023).

A couple of additional benefits from this analysis, is that we can take advantage of the FFI in order to verify there is no blending of the signal from nearby stars, and utilise high cadence datasets to eliminate Nyquist reflections of higher frequency signals (e.g. roAp pulsations) that could be misconstrued as δ Sct frequencies.

Datasets for our sample come from a variety of spectropolarimetric instruments, including MuSiCoS (Donati et al. 1999), Narval (Aurière 2003), and ESPaDOnS (Donati et al. 2006). Despite this, all the targets in the sample underwent very similar processing, such as utilising and personalising template line masks for each target before performing the Least Squares Deconvolution (LSD; Donati et al. 1997) method, the standard technique for performing magnetic analysis. This procedure is described in detail in Thomson-Paressant et al. (2023).

3 Statistical results

Having access to a hitherto unprecedented number of confirmed magnetic δ Sct stars, we investigate how the stars in our sample are distributed in the parameter space, and attempt to draw possible conclusions with respect to their magnetic field strengths and characterisations (where possible). With this in mind we have retrieved a maximum of stellar parameters from the literature and, where none are available, we have made estimations using data from the *Gaia* DR3 archive. In particular, we have made use of the values from the Extended Parameter Space for Hot Stars (ESP-HS) (Gaia Collaboration et al. 2023), which provides corrections to the stellar parameters determined for *Gaia* targets with effective temperatures $\gtrsim 7,500$ K (covering the majority of our sample), which have been shown to be less reliable when determined using the standard procedures.

From these parameters, we generated the Hertzsprung-Russell diagram shown in Fig. 1, where we have used evolutionary tracks generated with the BaSTI code (which assume no differential rotation and no magnetic field; Hidalgo et al. 2018) for the range of masses observed in our sample, as well as a sample of reference stars from Murphy et al. (2019) that the authors classified as δ Sct. This same article defines the blue and red edges of the δ Sct instability strip that are also represented in the aforementioned figure by blue and red dashed lines respectively.

As can be seen, our sample probes a large area of the H-R diagram, covering a wide variety of stellar regimes, which in turn assists in our attempts to study the global picture of magnetism within the family of δ Sct stars.

Our sample extends well beyond the blue-edge of the δ Sct instability strip defined by Murphy et al. (2019). Indeed, our sample includes numerous early-A types, as well as a B6 (HD 213918), all of which are hotter than the typical temperatures observed in δ Sct stars. We also see an apparent dearth of magnetic candidates with luminosities lower than $L \sim 1.3\ L_{\odot}$, which contrasts with the δ Sct stars from Murphy et al. (2019).

The results could suggest that δ Sct stars with strong ($\gtrsim 1$ kG) magnetic fields are mostly located at the extremities of the δ Sct instability strip. That is to say, that they are amongst the most massive and most luminous stars in the typical A-F spectral range. Our sample is observationally biased towards hotter stars, however, as they are most likely to present strong (likely fossil) magnetic fields that are the easiest to detect with spectropolarimetry.

We also observe that a significant population of our sample seem to be more evolved stars, located at or just beyond the TAMS (defined by the dashed green line), but we remind the reader that magnetism and differential rotation are not taken into account for the BaSTI models. Due to conservation of magnetic flux, we expect more evolved stars hosting fossil fields to present weaker fields on average than those on the main sequence:

*https://archive.stsci.edu/missions-and-data/tess

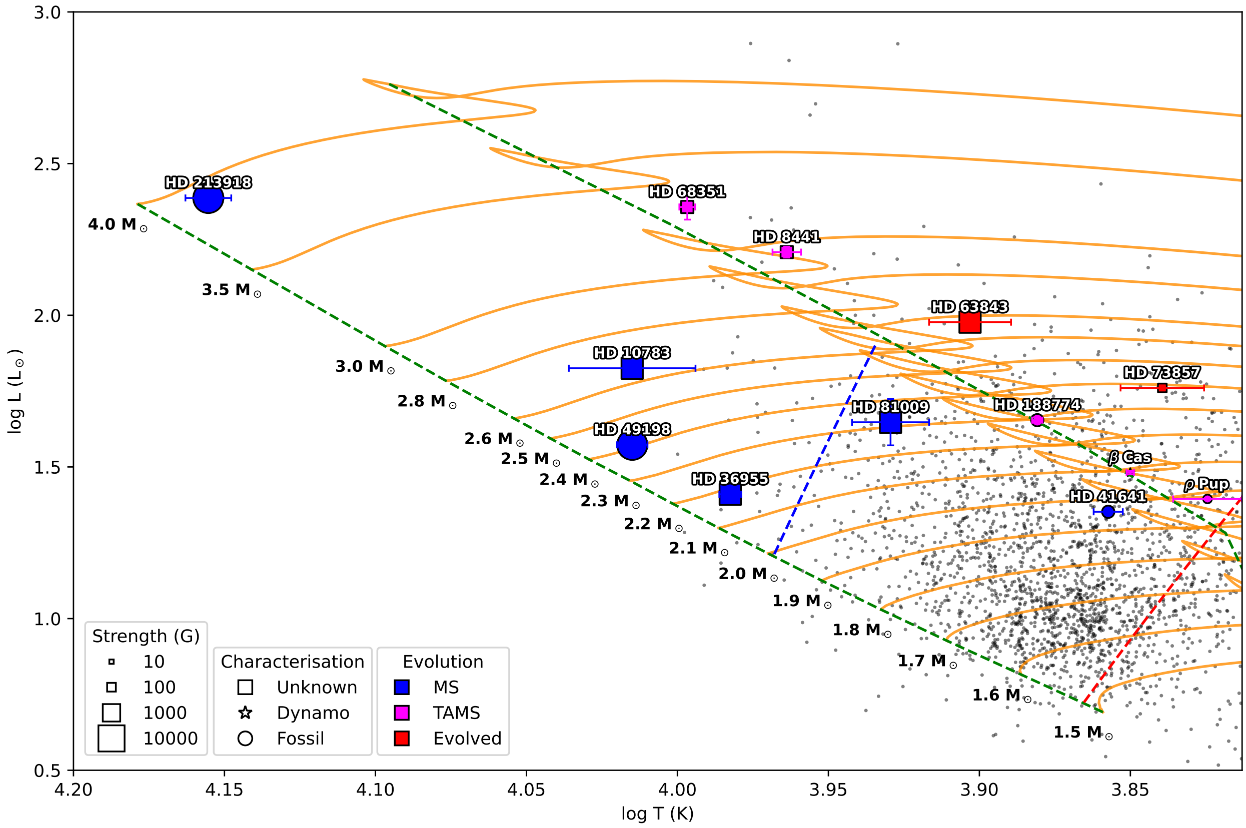

Fig. 1. Representation of the 13 confirmed magnetic δ Sct stars known to date. Orange lines correspond to BaSTI evolutionary tracks (Hidalgo et al. 2018), with reference δ Sct stars as well as observationally constrained red- and blue-edges of the δ Sct instability region from Murphy et al. (2019).

while the magnetic field remains the same, the envelope cools and expands, and as such the strength of the magnetic field we detect at the surface decreases significantly. This is mostly true for our sample.

Additionally we compared the polar magnetic field strength $B_{\rm pol}$ with several stellar parameters including mass, age, temperature, and rotational velocity. The goal is to see if any correlations appear between the magnetic field strengths and the fundamental parameters of the stars in our sample, such as the existence of two or more regimes of magnetism.

Our comparisons do not reveal anything out of the ordinary, in that there appears to be a higher-mass/hotter star regime with strong, well-organised fields, and a lower-mass/cooler regime that have weak and more variable fields. While we also see a general decrease of field strength with $v \sin i$, it should be noted that we are biased here as well, as lower rotational velocities require less exposure time for spectropolarimetric observations.

In a similar vein, we also investigated whether any correlation was visible between the strength of the magnetic field and the location of the δ Sct frequency peaks in Fourier space. The resulting periodograms were pre-whitened using a two-term fit to the lower frequency domain, removing signals typically relating to rotation. While some low-frequency variability can remain in a few cases, they do not hinder the identification of the δ Sct pulsations.

Despite being predicted by theory, we do not see a clear correlation between surface magnetic field strength and the location of δ Sct peaks in Fourier space. This suggests that stellar magnetism is not the sole ingredient for the differences in position and spacing of δ Sct frequencies. In particular, we could not disentangle the effect of rotation and magnetism.

The full details of this comparative analysis will appear in an upcoming article (Thomson-Paressant et al., in prep.).

4 Conclusions

We present a curated list of 13 magnetic δ Sct stars, assembled from a variety of sources, including our own observations and analysis, and confirm both their identification as δ Sct as well as the presence of a magnetic field. This constitutes the most comprehensive list of these objects to date, one that the authors and members of the community will hopefully continue to contribute to as they pursue studies in this field.

We present what may be the first observational signature of the impact of a magnetic field on the excitation zone of δ Sct pulsations, i.e. on stellar structure, resulting from the position of our sample on the H-R diagram.

While the list of magnetic δ Sct stars presented here remains relatively small, it is the first study of its kind for δ Sct stars, and will hopefully pave the way for subsequent studies into the interplay between stellar magnetism and pulsating variable stars across the H-R diagram.

We thank Yves Frémat for his insight into working with Gaia data, and Rupam Jash for providing copies of the BaSTI evolutionary tracks presented herein.

References

Aurière, M. 2003, EAS Publications Series, 9

Babcock, H. W. 1958, ApJS, 3, 141

Bessell, M. S. 1969, ApJS, 18, 195

Cramer, N. & Maeder, A. 1980, A&AS, 41, 111

Donati, J. F., Catala, C., Landstreet, J. D., & Petit, P. 2006, in Astronomical Society of the Pacific Conference Series, Vol. 358, Solar Polarization 4, ASP Conference Series, Vol. 358, Proceedings of the conference held 19-23 September, 2005, in Boulder, Colorado, USA. Edited by R. Casini and B. W. Lites, p.362, 362

Donati, J. F., Catala, C., Wade, G. A., et al. 1999, A&AS, 134, 149

Donati, J. F., Semel, M., Carter, B. D., Rees, D. E., & Collier Cameron, A. 1997, MNRAS, 291, 658

Gaia Collaboration, Creevey, O. L., Sarro, L. M., et al. 2023, A&A, 674, A39

Hidalgo, S. L., Pietrinferni, A., Cassisi, S., et al. 2018, ApJ, 856, 125

Labadie-Bartz, J., Hümmerich, S., Bernhard, K., Paunzen, E., & Shultz, M. E. 2023, A&A, 676, A55

Lampens, P., Tkachenko, A., Lehmann, H., et al. 2013, A&A, 549, A104

Murphy, S. J., Hey, D., Van Reeth, T., & Bedding, T. R. 2019, MNRAS, 485, 2380

Neiner, C., Wade, G., & Sikora, J. 2017, MNRAS

Preston, G. W. 1971, ApJ, 164, 309

Preston, G. W. & Stepien, K. 1968, ApJ, 154, 971

Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2015, J. Astron. Telesc. Instrum. Syst., 1, 014003

Thomson-Paressant, K., Neiner, C., & Labadie-Bartz, J. 2024, A&A, 689, A208

Thomson-Paressant, K., Neiner, C., Lampens, P., et al. 2023, MNRAS, 526, 1728

Thomson-Paressant, K., Neiner, C., Zwintz, K., & Escorza, A. 2020, MNRAS, 500, 1992

Zwintz, K., Neiner, C., Kochukhov, O., et al. 2020, A&A, 643, A110