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Magnetic OB[A] Stars with TESS: probing their Evolutionary and Rotational properties (MOBSTER) – I. First-light observations of known magnetic B and A stars


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ABSTRACT
In this paper we introduce the MOBSTER collaboration and lay out its scientific goals. We present first results based on the analysis of 19 previously known magnetic O, B, and A stars observed in 2-min cadence in sectors 1 and 2 of the Transiting Exoplanet Survey Satellite (TESS) mission. We derive precise rotational periods from the newly obtained light curves and compare them to previously published values. We also discuss the overall photometric phenomenology of the known magnetic massive and intermediate-mass stars and propose an observational strategy to augment this population by taking advantage of the high-quality observations produced by TESS.

Key words: techniques: photometric – stars: early-type – stars: magnetic field – stars: rotation.

1 INTRODUCTION
Unlike their lower mass counterparts (e.g. Böhm-Vitense 2007), massive and intermediate-mass stars are not known to host magnetic fields generated by contemporaneous dynamos at their surfaces. Instead, there exists a distinct population of magnetic O-, B-, and A-type stars whose fields appear to be of fossil origin (Borra, Landstreet & Mestel 1982; Neiner et al. 2015; Alecian et al. 2017).

Magnetic OBA stars host strong surface fields that typically have large-scale, mostly dipolar topologies that are stable over decades (for a broader review, see e.g. Donati & Landstreet 2009). Despite the fact that this spectral type range covers a large variety of stellar parameters (masses, radii, luminosities), the incidence rate of detectable magnetic fields in these stars seems to be uniformly small, \( \sim 10 \) per cent, and the field properties show no systematic change with, e.g. mass or luminosity (Wade et al. 2014; Morel et al. 2015; Grunhut et al. 2017; Sikora et al. 2019).

These stars exhibit a range of phenomenologies that can be understood in terms of the interaction between their magnetic...
fields and their photospheres or atmospheres. In particular, since the magnetic field is not generally aligned with the rotational axis, many observable quantities across the electromagnetic spectrum are found to be rotationally modulated, in a manner that is understood in the context of the Oblique Rotator Model (Stibbs 1950).

In earlier-type (OB) magnetic massive stars, the interaction between the magnetic field and the strong, supersonic line-driven stellar winds leads to the formation of an observable magnetosphere (ud-Doula & Owocki 2002), the global characteristics of which are determined by the stellar rotation rate, wind parameters and magnetic field strength (Townsend & Owocki 2005; ud-Doula, Owocki & Townsend 2009; Petit et al. 2013). More specifically, dynamical magnetospheres (DMs) are formed around slow rotators and consist of outflowing ionized material channelled by the closed magnetic field lines creating strong shocks near the magnetic equator. The shocked gas cools radiatively and falls back on to the stellar surface in complex dynamic flows. Fast rotators additionally form a centrifugal magnetosphere (CM): centrifugal support of plasma above the co-rotation radius prevents material from falling back on to the star, leading to the formation of dense clouds, which co-rotate with the stellar surface.

The presence of a magnetosphere around these massive stars is inferred from observations at many different wavelengths. In the optical, periodic variations in $H\alpha$ are detected (e.g. Howarth et al. 2007; Bohlender & Monin 2011; Grunhut et al. 2012; Rivinius et al. 2013), as well as line profile variations in wind-sensitive resonance lines (primarily in the ultraviolet; e.g. Stahl et al. 1996; Marcelino et al. 2012), variable emission in the X-rays (Sanz-Ferrada, Franciosini & Pallavicini 2004; Gagné et al. 2005) and in the infrared (Oksala et al. 2015b), and, in some cases, emission in the radio is also observed (e.g. Chandra et al. 2015; Kurapat et al. 2017; Leto et al. 2018). Some of these observations can be understood using magnetohydrodynamic (MHD) simulations (e.g. Marcelino et al. 2013; ud-Doula et al. 2013; Nazé et al. 2014), as well as through simplified analytic prescriptions such as the ‘Analytic Dynamical Magnetosphere’ model for DMs (ADM; Owocki et al. 2016) and the ‘Rigidly Rotating Magnetosphere’ model for CMs (RRM; Townsend & Owocki 2005).

In intermediate-mass stars (late B-type and A-type stars), the effect of magnetism is somewhat different, as they do not possess the same fast, dense winds as higher mass stars. Instead, fossil fields are known to affect diffusive processes in their radiative envelope (Michaud 1970; Alecian & Stift 2007), often leading to chemical abundance patches on their surface and, as a result, rotational modulation of spectral lines of various chemical elements in their spectra (e.g. Kuchukhov et al. 2015; Yakunin et al. 2015; Silvester et al. 2017). The energy distributions associated with magnetic intermediate-mass stars are also known to exhibit abnormal flux depressions in the ultraviolet (Kodaia 1969; Adelman 1975; Maizten 1976b). This is understood to be a direct consequence of the presence of strong surface magnetic fields (Kochukhov, Khan & Shulyak 2005).

The Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2015) is the latest high-precision photometric space mission. During its 2-yr nominal mission time, it will observe 85 per cent of the full sky, in overlapping sectors of 96 $\times$ 24 deg, for a total of roughly 470 million point sources observed in full-frame images. The targets will be observed with various temporal baselines, from 27.4 d to almost 1 y, depending on their position on the sky. Designed to search for exoplanets transiting in front of their host star, TESS was launched on 2018 April 18 and started delivering public data of the first two observed 27.4-d sectors of the sky in 2018 December. Given their high quality, these data can be used for a wide range of astronomical investigations in addition to exoplanet detections, including detailed astroseismology and, in our case, studies of rotational modulation associated with stellar magnetism in early-type stars.

Of particular relevance to TESS, both massive and intermediate-mass stars with surface magnetic fields are known to exhibit periodic photometric variations associated with rotational modulation. In the case of earlier-type stars (earlier than about B1), these variations are due to a changing column density as the viewing angle through the magnetosphere varies with phase. This phenomenon is observed for instance in the light curve of HD 191612 (Wade et al. 2011). For later-type magnetic stars (later than about B5), photometric variations are associated with chemical inhomogeneities on their surface manifesting as brightness spots due to flux redistribution (e.g. Peterson 1970). In fact, two classes of variable stars, as defined by the General Catalog of Variable Stars (GCVS; Samus’ et al. 2017), correspond tochemically peculiar B- and A-type stars understood to host strong magnetic fields, the SX Arietis and $\alpha^2$ Canum Venaticorum ($\alpha^2$ CVn) variables, respectively. Finally, for stars with an intermediate spectral type (roughly between B1 and B5), their photometric variability can be caused by either one of the two aforementioned effects, although it is often dominated by photospheric inhomogeneities. Indeed, even when magnetospheric eclipses are seen (as is the case with $\sigma$ Ori E; Townsend 2008; Townsend et al. 2013), there can still be a signature associated with chemical spots (as shown for that same star: Oksala et al. 2015a).

Furthermore, pulsations also contribute to photometric variability in a subset of magnetic OBA stars, notably slowly pulsating B stars (SPB; Waelkens & Rufener 1985), $\beta$ Cephei variables (e.g. Struve 1952), $\delta$ Sct pulsators (e.g. Fath 1937), and rapidly oscillating Ap (roAp) stars (Kurtz 1982).

Therefore, optical time-series photometry can be a powerful means of characterizing known magnetic OBA stars and identifying promising magnetic candidates. Moreover, in some cases additional phenomena that are associated with photometric signatures, such as binarity and pulsations, can be modelled to provide valuable constraints on the physical parameters of these stars. With the rise of high-precision space-based photometric missions over the last decade (e.g. MOST, CoRoT, Kepler, K2, BRITE-Constellation) and given the comparatively limited availability and time-sampling of high-resolution spectropolarimetry, we can leverage the observations acquired by these missions to further our understanding of phenomena associated with stellar magnetism in the upper Hertzsprung–Russell Diagram (HRD). This approach has been employed to infer the characteristics of putative magnetic fields in extra-Galactic Of?p stars (Nazé et al. 2015; Munoz et al. 2018), a spectral class known to be associated with magnetism in the Milky Way (Grunhut et al. 2017).

1.1 The MOBSTER collaboration

The MOBSTER collaboration (Magnetic OB[A] Stars with TESS: probing their Evolutionary and Rotational properties) aims to leverage TESS observations to gain further insight and understanding into the nature of magnetic massive and intermediate-mass stars. In particular, this project focuses on three types of targets:

(i) Known magnetic OBA stars with rotational periods shorter than $\sim 27$ d: these targets will be observed for at least one full rotational cycle during the TESS mission and their photometric variations can be used to test and calibrate models by comparing them to synthetic light curves;

(ii) Known magnetic OBA stars with rotational periods greater
than ∼27 d; these targets will likely be observed for only part
of their rotational cycle; therefore shorter-term, potentially
stochastic processes (e.g. dynamic flows in a DM) as well as other
phenomena (such as pulsations) can be investigated; and
(iii) Magnetic OBA candidates: we can identify magnetic can-
didates directly from their light curves and flag them for spectropolar-
metric follow-up; such an observational strategy has proven highly
successful for K2 data (Buysschaert et al. 2018a). Such efforts are
led in parallel with similar studies classifying variability types in
OBA stars observed by TESS (e.g. Balona et al. 2019; Pedersen
et al. 2019; Sikora et al., submitted; for a complementary study of
Ap stars using TESS data, see Cunha et al., submitted).

High-quality light curves from TESS will allow us to pursue
various science goals, such as the asteroseismic characterization of
magnetic massive stars (which can teach us about the internal effects
of surface magnetic fields; e.g. Briquet et al. 2012; Buysschaert
et al. 2018b) and precise determinations of their rotational periods.
In this first paper of a series, we focus on the latter objective as we
present newly determined rotational periods for 19 known magnetic
B and A1 stars that were observed in TESS sectors 1 and 22 and
compare them to previously published values. By ‘known magnetic
stars’, we mean stars whose surface magnetic fields have been
directly diagnosed using the Zeeman effect, in either spectroscopic
or spectropolarimetric observations (and sometimes both). The
relevant references for each star’s magnetic detection can be found
in Section 3.2. Seven more B- and A-type stars that were observed
in sectors 1 and 2 (HD 10840, HD 19400, HD 58448, HD 65950,
HD 221507, HD 203932, and HD 221760) yielded spurious or
marginal detections in spectropolarimetric observations, and were
not included in this sample.

In Section 2, we present the observations. In Section 3, we report
results for known magnetic B and A stars, and discuss each star
individually. Finally, we present our conclusions and consider future
work in Section 4.

2 TESS OBSERVATIONS

The TESS data included and analyzed here are the 2-min light
curves provided by the TESS Science Team and which are publicly
available via the Mikulski Archive for Space Telescopes (MAST).3

A description of the data processing pipeline of these light curves is
provided by Jenkins et al. (2016). Full-frame images with 30-min
cadence are not considered within the scope of this paper. Sector 1
was observed from 2018 July 25 to August 22, while sector 2 was
observed from 2018 August 23 to September 20.

To select our sample, we cross-matched the list of observed stars
in sectors 1 and 2 with the SIMBAD database (Wenger et al. 2000)
and considered all the stars with known spectral types of A and
earlier. The orbital period of TESS is 13.7 d and a gap is present
in the data with this period (i.e. in the middle of each 27.4-d light

1We include in this sample a well-known star exhibiting the classic Ap
phenomenology, HD 213637, but which is classified as F1. Given the
nature of its peculiarities and the typical uncertainty on the spectral type
of chemically peculiar stars, we chose to include it in our sample and consider
it for all intents and purposes as an A-type star.

2While our sample comprises magnetic targets that were observed in sectors
1 and 2, a few of these stars (namely HD 53921, HD 24188, and HD 54118)
were also observed in sector 3, so we included these data in our analysis.

3https://archive.stsci.edu/missions-and-data/transiting-exoplanet-survey-
satellite-tess
Table 1. List of known magnetic B- and A-type stars observed by TESS in sectors 1 and 2. For each star, we provide the TIC number, a more common identifier (mostly the HD number), the spectral type, the TESS instrumental magnitude, as well as three periods that are measured for the star (and that are long enough to potentially be associated with rotation, although in some cases they may be related to other phenomena such as pulsations): published periods based, respectively, on photometry and on other measurements, and our new refined periods derived from the TESS data. For these periods, the number appearing between parentheses corresponds to the uncertainty on the final digit of the reported period; the absence of such a number denotes an unreported uncertainty.

We report the largest measured longitudinal magnetic field for each star (and its uncertainty) and the total number of spectropolarimetric observations for each target. The instrumental uncertainties in the light curves of the stars for which a low-frequency signal was detected are well within the typical range associated with $\alpha^2$ CVn variables, with HD 65712 showing the greatest amplitude (nearly 60 mmag). We further detail our findings for individual stars in the following subsection. The light curves of the stars for which a low-frequency peak potentially associated with rotation is recovered are phase folded using our measured rotational periods and presented in the Appendix (Fig. A1).

### 3.2 Notes on individual stars

Most of the following stars have multiple period determinations in the literature, therefore we report the most recent one prior to our own study in Table 1. For a number of our targets, an independent period analysis was carried out using the TESS data by Cunha et al. (submitted); we report their periods for comparison purposes whenever possible (only in Table 1 for concision, except in the case of HD 218495 since theirs is the only prior rotational period determination available in the literature).

### TIC 89545031 (= HD 223640, $B9pSiSrCr_v$, $v = 5.18$)

A photometric period of 3.73 $\pm$ 0.3 d was derived for HD 223640 (Morrison & Wolff 1971), a period that was also confirmed spectroscopically (Mégevand 1974, 1975), with infrared photometry (Catalano, Kroll & Leone 1991; Catalano, Leone & Kroll 1998b), and with variations of He I $\lambda$5876 (that was however observed to be out of phase with the other reported variability; Catanzaro, Leone & Catalano 1999). The photometric period has been refined a number of times since (Kodaira 1973; North & Burnet 1991), and more recently to 3.735 197 3 0.000 024 d using photometry and magnetic measurements (North et al. 1992). Changes in the shape of the light curve over time have been proposed to be indicative of precession of the magnetic axis (Adelman & Knox 1994; Adelman 1997, 1999). This star was also observed with Hipparcos, and an automated period search yielded a value of 3.7342 d (Dubath et al. 2011). We measure a period of 3.7349 $\pm$ 0.0005 d in the TESS data, consistent with the previous determination; however, we cannot evaluate the precession hypothesis given the different bandpasses involved.

HD 223640 was first found to be magnetic by Babcock (1958), although its field was not detected in a more recent FORS1 spectropolarimetric observation (Hubrig et al. 2006; Baglino et al. 2015). This is not surprising as the observation was taken at the rotational phase corresponding to a magnetic null in the field curve of North et al. (1992).
Figure 1. Light curves (top of each panel) and Lomb Scargle periodograms (bottom of each panel) for each of the four known magnetic B stars observed by TESS in its sectors 1 and 2. The inferred rotational frequency for each star is highlighted in light grey and labelled, and the first harmonic is also labelled (when applicable). An inset is included to show the window function around the frequency peak with the largest amplitude.
Figure 2. Same as Fig. 1, but for the A stars. For some periodograms, there is no convincing signature of rotational modulation; in those cases, we did not include any window function.
Figure 2 – continued.
Out of the 19 known magnetic stars discussed in this study, HD 53921 is the only one that is not known to exhibit chemical peculiarities in its spectrum. The Hipparcos photometry reveals a 1.65-d period that was attributed to a gravity mode pulsation, implying that HD 53921 is an SPB star (Waelkens et al. 1998). This period determination was refined to 1.6520 d using the same data set, but applying an automatic period search (Dubath et al. 2011). Its radial velocity is also found to vary with the same period (1.6518 d; Aerts et al. 1999). In addition, lower frequencies were detected in the radial velocity measurements, possibly indicating long-period orbital variations (De Cat et al. 2000; consistent with a visual double with separation > 1 arcsec, e.g. Horch et al. 2001). This scenario was confirmed by De Cat & Aerts (2002), who found HD 53921 to be an eccentric SB1 with a period of ~340 d. The components have an ~1 magnitude difference in the V band, with the brightest having a spectral type of B9III, and the fainter one B8V (Corbally 1984). It should be noted that both components lie in the same TESS pixel.

The photometric variations are difficult to reconcile with non-radial pulsations (Townsend 2002) and mode identification has proven to be arduous (De Cat et al. 2005). The detected frequency lies within the (large) range of possible rotational frequencies based on its projected rotational velocity and inferred radius (Szewczuk & Daszyńska-Daszkiewicz 2015), and could therefore rather be the rotational period.

Although a first spectropolarimetric observation of HD 53921 yielded only a marginal detection (Hubrig et al. 2006), it was confirmed to be magnetic by Bagnulo et al. (2012). Bagnulo et al. (2015) later identified the B9III primary as the magnetic star. The published frequency is recovered in the TESS data (1.65183 ± 0.00002 d) with a harmonic pattern typical of rotational modulation. We thus propose that this frequency does not correspond to pulsations, but rather to rotation. Further magnetic characterization would help confirm the nature of this frequency.

**Figure 2 – continued.**

**TIC 279511712 (= HD 53921, B9III + B8V, V = 5.64)**

**CPD-60 944B** is a member of an ~10 arcsec visual pair within the open cluster NGC 2516 (Snowden 1975). Its visual companion, CPD-60 944A, might itself be a binary (González & Lapasset 2000), a hypothesis that has also been supported by González, Veramendi & Cowley (2014), who propose an orbital period of 121.6 d or 182.5 d (they also propose CPD-60 944B to be a HgMn star, a claim that is not supported by other studies). There has historically been some degree of confusion between both of these stars, and the membership of CPD-60 944B in NGC 2516 has been questioned (e.g. Frinchaboy & Majewski 2008).

Bernhard et al. (2015) measured a photometric period of 3.7367 ± 0.0003 d and attributed it to component A, although both visual components were within the aperture of ASAS-3. We report this period in Table 1, since we find a similar period in the TESS observations (3.759 ± 0.002 d). However both visual components also fall within the TESS aperture. A marginal magnetic field detection was reported by Bagnulo et al. (2006), and later confirmed by Bagnulo et al. (2015).
HD 65987 was proposed to be an eclipsing binary system (Snowden 1975), and has often been classified as an eclipsing Algol variable (e.g. Avvakumova, Malkov & Kniazev 2013). Based on radial velocity measurements, Abt & Levy (1972) find a possible periodicity of ~9 d that could be associated with binarity. Avvakumova & Malkov (2014) evaluate this system to be a detached main-sequence binary, based on its well-established membership in the NGC 2615 cluster (e.g. Landstreet et al. 2007). Low-level photometric variability was first detected with a putative 1.41-d period (North, Rufener & Bartholdi 1982), which was later refined to 1.44962 ± 0.00018 d by North (1984). If this value is assumed to be related to rotation, the implied small value of $\sin i$ (Hensberge, van Rensbergen & Blomme 1991) would indicate that the inclination of the rotational axis is likely small. The TESS period (1.4561 ± 0.0001 d) is similar to that of North (1984), and the data are of much better quality than the phased photometry presented by Heck, Mathys & Manfroid (1987). While we ascribe this period to rotation, a binary origin of the light curve variations is not conclusively ruled out. Interestingly, a weak peak appears in the periodogram of the non-detrended light curve at a period of about 9 d, corroborating the idea that that period might be linked to binarity.

HD 65987 was found to be magnetic by Bagnulo et al. (2006), and that detection was later confirmed by Bagnulo et al. (2015). However, new magnetic measurements with improved phase coverage do not seem to vary according to the photometric period (Landstreet et al., in preparation), making this system harder to interpret. More work will be required to confirm the origin of HD 65987’s photometric variability.

**TIC 32035258 (≈ HD 24188, A0pSi, V = 6.26)**

HD 24188 was found to exhibit non-linear proper motion, making it an astrometric binary candidate (Makarov & Kaplan 2005; Frankowski, Jancart & Forisson 2007) even though it is not observed to be a spectroscopic binary (Grenier et al. 1999). *Hipparcos* photometry revealed a clear periodicity (2.230 d; Paunzen & Maitzen 1998; Dubath et al. 2011), which was associated with rotation. We confirm and refine this period with the TESS light curve (2.23024 ± 0.00004 d).

Based on a single spectropolarimetric observation, HD 24188 was found to be magnetic by Kochukhov & Bagnulo (2006), a conclusion that was since supported through the reanalysis of the same observation (Hubrig et al. 2006; Bagnulo et al. 2015).

**TIC 69855370 (≈ HD 213637, F1pEuSr, V = 9.58)**

HD 213637 is a roAp star with an 11-min pulsation period (Martinez, Meintjes & Ratcliff 1997). It has two known frequencies, which vary in amplitude over time (Martinez et al. 1998), possibly due to rotation, although no rotational period has been reported in the literature. It is one of the coolest known roAp stars and is likely evolved, and it exhibits magnetically split lines (Kochukhov 2003). We do not find any convincing signature of rotational variation in the TESS light curve.

This star’s magnetic field was further diagnosed using FORS1 observations (Hubrig et al. 2004b; Bagnulo et al. 2015). There is no indication of multiplicity (Schöller et al. 2012), and based on magnetic field modulus measurements, the rotational period is likely longer than 115 d (Mathys 2017).

**TIC 32035258 (≈ HD 24188, A0pSi, V = 6.26)**

HD 24188 was found to be magnetic by Kochukhov & Bagnulo (2006), and that detection was later confirmed by Bagnulo et al. (2015). However, new magnetic measurements with improved phase coverage do not seem to vary according to the photometric period (Landstreet et al., in preparation), making this system harder to interpret. More work will be required to confirm the origin of HD 65987’s photometric variability.

**TIC 312913684 (≈ HD 65987, B9pSiSr, V = 7.59)**

HD 217522 is a well-studied roAp star (13.72-min pulsational period; Kurtz 1983). It is one of the few roAp stars for which mode switching has been observed (Kreidl et al. 1991). However, no sign of rotational modulation of the pulsational amplitudes has been found by van Heerdan, Martinez & Kilkenny (2012), who conclude that either the stellar surface is not very spotted or the rotational axis is nearly aligned with our line of sight, not allowing us to see rotational modulation, a hypothesis further supported by the very low measured value of $\sin i$ (3 km s$^{-1}$; Medupe et al. 2015). Additionally, the magnetic axis could be aligned with the rotational axis. While the amplitude modulation occurs on short time-scales (~1 d), it appears to be stochastic, similar to solar-type oscillations. This also appears to be qualitatively consistent with the fact that we do not find a significant low-frequency series of harmonics in the TESS observations of HD 217522, and in particular, no sign of rotation. Analysis of the high-frequency variability using TESS observations was performed by Cunha et al. (submitted).

A marginal detection of a magnetic field was reported by Mathys & Hubrig (1997), and has since then been confirmed (Hubrig et al. 2004b; Bagnulo et al. 2015). The field strength is not found to vary on the pulsational time-scale (Hubrig et al. 2004a; they acquired 91 short observations within <0.25 d, a time span insufficient to detect rotational modulation).

**TIC 159834975 (≈ HD 203006, A2pCrEuSr, V = 4.82)**

HD 203006 is a visual double with a close faint companion (2 mag fainter in the *Hipparcos* bandpass, separation of 0.1 arcsec; Lindegren et al. 1997). A number of rotational periods have been published for HD 203006. Morrison & Wolff (1971) first reported probable photometric periods of 0.941 d and 1.062 d, then the latter was refined to 1.0609 d by Maitzen (1973). The rotation period was found to be in fact about twice as long as previously thought (2.129 d, based on photometric and spectroscopic data; Maitzen et al. 1974), which was then refined to 2.1215 ± 0.0001 d (Deul & van Genderen 1983), although an automated period search using *Hipparcos* data yielded a period half as long (1.0610 d; Dubath et al. 2011). We find a similar longer period in the TESS data (2.122 ± 0.004 d); it should be noted that it is not the strongest peak in the periodogram, as the first harmonic dominates the spectrum, hence the earlier confusion. HD 203006 has also been observed to vary in the ultraviolet, although there were not enough observations to establish a period (van Dijk et al. 1978). Low-level variability was also observed in the near-infrared with a period of 2.1224 d (Catalano, Leone & Kroll 1998a). It was first observed to be magnetic by Babcock (1958). Later undetected by Borra & Landstreet (1980), its field was eventually confirmed by Bohlender & Landstreet (1990).

**TIC 235007556 (≈ HD 221006, A0pSi, V = 5.68)**

HD 221006 was found to vary photometrically with a period of 2.32 ± 0.03 d (Renson 1978), which was later refined to 2.3148 ± 0.0004 d (Manfroid & Mathys 1985). Spectroscopic variations also phase coherently with this period, as well as photometric variability in many filters, including in the infrared (Leone et al. 1995). This star was also observed with *Hipparcos*, and an automated period search yielded a period of 2.3147 d. The TESS photometry of HD 221006 shows a similar period of...
A double-lined spectroscopic binary with magnetically split lines
2.3119 ± 0.0001 d. This star was detected to be magnetic by Bohlender et al. (1993).

\[ \text{TIC 237336864 (HD 218495, A2pEuSr, V = 9.38)} \]

HD 218495 was found to host high-frequency pulsations \((P = 7.44 \text{ min; Martinez \\& Kurtz 1990; Martinez, Kurtz \\& Kauffmann 1991})\). No other variability period is reported in the literature for this roAp star prior to the TESS observations.

Although the periodogram is clearly dominated by the first harmonic (see Fig. 2, the amplitude of the signal is clearly modulated on a period that is twice as long as the one that we would derive from the dominant peak), we determine a rotational period of 4.183 ± 0.006 d. This is similar to the value given by Cunha et al. (submitted), which offer the first determination of this star’s rotational period \((4.2006 ± 0.0001 \text{ d})\).

A first attempt to observe HD 218495’s magnetic field did not yield a significant detection (Mathys \\& Hubrig 1997), but it has since been found to be magnetic (Hubrig et al. 2004b), a detection that was confirmed by Bagnulo et al. (2015).

\[ \text{TIC 262956098 (HD 3988, A0pCrEuSr, V = 8.35)} \]

A double-lined spectroscopic binary with magnetically split lines \(B_d \sim 2.7 \text{ kG; Elkin, Kurtz \\& Nitschelm 2012})\), HD 3988 does not show evidence of a companion in speckle interferometry (White et al. 1991). It also does not vary with any known rotational or pulsational period (Martinez \\& Kurtz 1994b), similarly, no evidence of rotational modulation is found in the TESS light curve.

\[ \text{TIC 277688819 (HD 208217, A0pSrEuCr, V = 7.19)} \]

HD 208217 is an astrometric binary candidate based on proper motion measurements (Frankowski et al. 2007). HD 208217 was found to vary photometrically with a period of 8.35 ± 0.10 d (Manfroid \\& Renson 1983). Its period was refined to 8.4447 ± 0.0011 d (Manfroid \\& Mathys 1997) using both photometry and magnetic field modulus measurements derived from resolved line splitting (for the latter, see also Mathys et al. 1997; they mention this is a spectroscopic binary with a potentially long period, on the order of 2 yr). We recover a slightly shorter period based on its TESS light curve \((8.317 ± 0.001 \text{ d})\). HD 208217’s magnetic field was detected and measured to provide a phase-resolved longitudinal field curve by Landstreet \\& Mathys (2000), with additional measurements published by Mathys (2017).

\[ \text{TIC 278804454 (HD 212385, A3pSrEuCr, V = 6.84)} \]

HD 212385 exhibits non-linear proper motion that makes it an astrometric binary candidate (Makarov \\& Kaplan 2005; Frankowski et al. 2007). A period of 2.48 ± 0.04 d was found in photometry (Renson 1978), and then refined to 2.5265 ± 0.0015 d (Manfroid \\& Mathys 1985). We find a slightly shorter period in the TESS data \((2.5062 ± 0.0002 \text{ d})\). HD 212385 was discovered to be magnetic by Hubrig et al. (2006), a detection confirmed by Kochukhov \\& Bagnulo (2006) and Bagnulo et al. (2015).

\[ \text{TIC 279573219 (HD 54118, A0pSr, V = 5.17)} \]

Identified as an astrometric binary candidate due to non-linear proper motion (Makarov \\& Kaplan 2005; Frankowski et al. 2007), HD 54118 was later found to be a spectroscopic binary by Ammler-von Eiff \\& Reiners (2012), though its companion is not well characterized. Its optical light curve was found to vary on a period of 3.275 ± 0.015 d (Manfroid \\& Renson 1981), a period that was refined a few times using ground-based photometry (Manfroid \\& Mathys 1985; Catalano \\& Leone 1993), most recently to 3.2753 ± 0.0010 d (Manfroid \\& Renson 1994). This star was also observed with Hipparcos, and an automated period search yielded a rotational period of 3.2749 d (Dubath et al. 2011).

Found to be magnetic with \(P_{\text{rot}} = 3.2 ± 0.1 \text{ d} \) (Borra \\& Landstreet 1975), its field detection was confirmed by Bohlender et al. (1993) using phase resolved observations; they also refined the period to 3.2753 ± 0.0002 d, which is consistent with the photometric period. There was also a further follow-up spectroscopic observation by Donati et al. (1997). The TESS light curve reveals a period of 3.2759 ± 0.0002 d, consistent with the previous results.

\[ \text{TIC 280051011 (HD 18610, A2pCrEuSr, V = 8.14)} \]

Zeeman splitting in the spectra of HD 18610 led to discovery of a magnetic field with a modulus of about 5.7 kG (Stütz, Ryabchikova \\& Weiss 2003). This star has no rotational or pulsational periods reported in the literature (Martinez \\& Kurtz 1994b), and no signature of rotation is detected in the TESS data.

\[ \text{TIC 281668790 (HD 3980, A7pSrEuCr, V = 5.70)} \]

HD 3980 is a known visual double (Kopal 1955; De Rosa et al. 2014; its companion is 2.89 mag fainter in the K band and separated by ∼13 arcsec). The first photometric period determined for HD 3980 was 0.4 d (Maitzen 1976a). Since then, different photometric periods have been reported: 2.13d or 0.68 d (Renson 1979), and later 3.9516 ± 0.0003 d (Maitzen et al. 1980). The latter study also took into account magnetic measurements based on Zeeman line broadening/splitting. Photometric variability in the infrared \((J, H, K)\) bands is also found to phase coherently with the longer optical period (Catalano et al. 1991, 1998a). Hipparcos data reveal, as a result of an automated search, a potential 1.1628 d period (Dubath et al. 2011), but this value does not agree with any other study.

We find a period in the TESS light curve that is similar to the values obtained from earlier ground-based observations \((3.951 ± 0.003 \text{ d})\); it should be noted that it is not the strongest peak in the periodogram, as the first harmonic dominates the spectrum. The detection of a magnetic field at the surface of HD 3980 has been reported by Hubrig et al. (2006) and Bagnulo et al. (2015), supporting the earlier Zeeman line broadening measurements.

\[ \text{TIC 348717688 (HD 19918, A5pSrEuCr, V = 9.35)} \]

HD 19918 is a well-known roAp star discovered in the Cape survey (Martinez \\& Kurtz 1991, 1994a; Martinez et al. 1995; see also Cunha et al. submitted) with no visual companion (Schöller et al. 2012). A marginal field detection (Mathys \\& Hubrig 1997) was later confirmed by Kochukhov \\& Bagnulo (2006) (see also Hubrig et al. 2006; Bagnulo et al. 2015), and investigated through line broadening as well (Ryabchikova et al. 2007). The TESS light curve does not yield any frequency peak compatible with rotational modulation.
HD 65712 is a member of NGC 2516 (Snowden 1975, despite being identified as a possible high-velocity star by Jaschek et al. (1983). Its membership in the cluster was confirmed by Landstreet et al. (2007).

HD 65712 was found to have a $1.943 \pm 0.001\text{d}$ photometric rotation period by Warhurst (2004), although a shorter period of $1.88\text{d}$ was found by Paunzen et al. (2011). We find a period in the TESS photometry of this star ($1.9460 \pm 0.0002\text{d}$) that appears to be more consistent with the earlier determination of Warhurst (2004); hence, we choose to report that value in Table 1. A magnetic field was detected by Bagnulo et al. (2006) (and confirmed by Bagnulo et al. 2015).

**TIC 358467700 (= HD 65712, A0pSiCr, $V = 9.35$)**

**TIC 410451752 (= HD 66318, A0pEuCrSr, $V = 9.56$)**

HD 66318 is a probable member of NGC 2516 (Cox 1955; Frinchaboy & Majewski 2008). No previous study of this star has discovered photometric variability (North et al. 1982; North 1987; Dachs & Kabus 1989). A strong magnetic field was detected by Bagnulo et al. (2003) and later confirmed by Bagnulo et al. (2006) and Bagnulo et al. (2015), with a significant discrepancy observed between the field strengths measured from hydrogen and metal lines (Landstreet, Bagnulo & Fossati 2014). These authors do not find spectral variability, suggesting a very long rotation period (potentially on the order of years). This is also consistent with their finding that the projected rotational velocity is very low as determined from high-resolution UVES spectra, contradicting previous findings that $v\sin i = 30\text{ km s}^{-1}$ (Dachs 1972; Wolff 1981); this indicates that the viewing angle might simply not allow us to detect significant rotational modulation.

Similarly, we do not detect a convincing rotational period in the TESS photometry; as such, we reiterate the conclusion of Mathys (2017) that more observations are required to characterize the long-term variability of this star. However, there appears to be a weak potential rotational peak at $1.3\text{ d}^{-1}$ (and its first harmonic); given that the pixels from which this star’s signal is measured are highly contaminated (contamination ratio of 0.815 according to the TIC), it is plausible that the flux of nearby stars is within the light curves of HD 66318. A similar conclusion is reached by Cunha et al. (submitted), who report a period of $0.7768 \pm 0.0005\text{d}$.

**4 DISCUSSION AND CONCLUSIONS**

This paper introduces the MOBSTER collaboration, a group consisting of both observers and theorists with the aim of using TESS data to further the study and characterization of magnetic OBA stars and to discover new magnetic stars out of a photometrically pre-selected sample of targets. Upcoming studies will include the characterization of specific magnetic objects of interest via spectropolarimetry and will confront analytic models with observations.

12 out of the 19 known magnetic B and A stars observed in the first two sectors of TESS show periodograms displaying a main frequency peak and at least one harmonic – this is a characteristic signature of rotational modulation (e.g. Bowman et al. 2018), understood to be due to the presence of an oblique dipole magnetic field – with an additional star exhibiting only a fundamental peak, but whose light curve still appears to be rotationally modulated. Other targets showing this behaviour in the periodogram of their TESS light-curves should be considered as promising magnetic candidates. Such candidates have been identified for OB stars in sectors 1 and 2 by Pedersen et al. (2019) and for A stars in sectors 1 to 4 by Sikora et al. (submitted). They are prime targets for future spectropolarimetric observations. This identification is a crucial first step to increase the sample size of magnetic OBA stars (especially for the earliest spectral types) since spectropolarimetry is an expensive observational technique. Large spectropolarimetric surveys have uncovered a number of such stars, but the efficiency limit of these (essentially magnitude limited) surveys has been reached. Therefore, photometrically pre-selecting strong candidates among a fainter sample of stars with a high expected detection rate (e.g. Buysschaert et al. 2018a) constitutes our best possible strategy moving forward, and this is uniquely enabled by the high-quality light curves obtained with TESS.

We have refined the period determinations for 13 targets, and in some cases, compared to published values based both on photometric studies and other types of observations. We also present phase folded light curves for these 13 stars in the Appendix (Fig. A1); these show a wide variety of morphologies and nicely illustrate the exquisite quality of the TESS observations. We find our results to be consistent with the literature values overall, and in particular, unsurprisingly, with the values derived by Cunha et al. (submitted) using the same data set. In a few cases (especially in the case of HD 223640), there is an apparently significant departure between our values and the latter; this is likely due to the different methodologies employed to calculate the rotational periods. These results also illustrate the immense potential of TESS, compared to other large space-based surveys, as we detect rotational modulation and derive the rotational period in three stars (HD 65987, HD 208217, and HD 212385) that were observed by Hipparcos, but for which no period was recovered.

As for the six stars that did not show significant low-frequency peaks in their periodograms (HD 213637, HD 217522, HD 3988, HD 18610, HD 19918, and HD 66318), we are not able to conclude anything about their rotational periods. Half of them (HD 213637, HD 217522, and HD 19918) are known to exhibit rapid oscillations, identifying them as roAp stars, while the last one is likely too heavily contaminated for its rotational modulation to be significantly detected (although a weak signal with a period of about 0.8 d might be present). The most useful constraint to evaluate these stars’ rotational periods would be to obtain phase-resolved magnetic measurements, although it is possible that the lack of apparent rotational modulation is due to an unfavourable alignment of the rotational and magnetic axes with respect to the line of sight.

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APPENDIX: PHASED LIGHT CURVES

In this section, we present phase folded light curves for each star showing rotational modulation (with overlaid binned light curves using 20 phase bins over the full rotational cycle).
**Figure A1.** Phase folded light curves (with phase 0 corresponding approximately to minimum light; the time of minimum light used to phase the light curve is indicated on the x-axis of each plot for reference) for the 13 stars showing potential rotational modulation. The light grey points correspond to individual measurements, and the larger black points connected by a line correspond to binned data (with bins of 0.05 in phase). For some stars, we see streaks of outliers; these are due to artefacts that could not be completely detrended. We find that the light curves have diverse morphologies, with at least 9 out of the 13 showing signs of double-wave variations, and all of them having an asymmetric profile.