

Magnetosphere around high mass star revealed by polarimetry

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Abstract. Approximately 10% of massive stars possess a significant magnetic field. Magnetohydrodynamic simulations demonstrate that, when combined with the high rotation of these stars, these strong magnetic fields can result in a co-rotating magnetosphere. The Rigidly Rotating Magnetosphere (RRM) model by Townsend & Owocki (2005) was initially capable of reproducing the spectroscopic, photometric, and magnetic modulation of σ Ori E, but failed when applied to polarization. A new model, called Dumbbell plus Disk (D+D), was proposed by Carciofi et. al (2013) and succeeded in reproducing the polarization observed in σ Ori E and 4 other stars known to possess a magnetosphere (Oliveira 2022). In this contribution, using the Perkin-Elmer telescope with the Ixon instrument and, more recently, the SPARC4 polarimeter, made at the Pico dos Dias Observatory. Preliminary results showed that the D+D is capable of modeling the temporal variation of polarization and providing reliable magnetosphere parameters, such as its density. These results are part of a long-term observational campaign that aims to obtain polarimetric data for a total of 18 magnetic stars.

Resumo. Aproximadamente 10% das estrelas massivas possuem um campo magnético significativo. Simulações magnetohidrodinâmicas demonstram que, combinados com a alta rotação dessas estrelas, estes fortes campos magnéticos podem resultar em uma magnetosfera em corotação. O modelo RRM (Rigidly Rotating Magnetosphere) de Townsend & Owocki (2005) foi, inicialmente, capaz de reproduzir a modulação espectroscópica, fotométrica e magnética de σ Ori E, mas falhou quando aplicado à polarização. Um novo modelo, chamado Dumbbell plus Disk (D+D), foi proposto por Carciofi et. al (2013) e obteve sucesso ao reproduzir a polarização observada em σ Ori E e outras 4 estrelas conhecidas por possuírem uma magnetosfera (Oliveira 2022). Nesta contribuição, utilizando o telescópio Perkin-Elmer com o instrumento Ixon e, mais recentemente, o polarímetro SPARC4, feitas no Observatório do Pico dos Dias. Resultados preliminares mostraram que o D+D é capaz de modelar a variação temporal da polarização e fornecer parâmetros confiáveis da magnetosfera, tais como sua densidade. Estes resultados fazem parte de uma campanha observacional de longo prazo que visa obter dados polarimétricos de um total de 18 estrelas magnéticas.

Keywords. Magnetohydrodynamics (MHD) – Polarization – Stars: magnetic field

1. Introduction

Massive stars, defined as stars with masses exceeding 8 solar masses, exhibit high temperatures and luminosities. As a result, they generate stellar winds driven by radiation pressure, leading to substantial mass loss (Castor, Abbott & Klein 1975). These winds interact with the interstellar medium, producing various phenomena such as bow shocks and ionization fronts. Magnetohydrodynamical simulations (ud-Doula & Owocki 2002) suggest that the outflow can be confined within closed loops of magnetic field lines.

Townsend & Owocki (2005) developed a model, dubbed RRM (Rigidly Rotating Magnetosphere Model). The authors first used the RRM model to study the magnetosphere of σ Ori E. The model predicts the existence of two corotating clouds at the intersection between the magnetic and rotational equators, providing a quantitative description of the circumstellar environment. The first modeling attempt of Townsend & Owocki (2005) qualitatively showed that the model can reproduce the photometric, spectroscopic and magnetic variation of the star along its 1.19d rotation period.

Later, Carciofi et. al (2013) observed the linear polarization of σ Ori E with great precision. The authors tried to reproduce the observed polarization modulation of σ Ori E by feeding the predicted density distribution of the RRM model to the HDUST radiative transfer code. They could not find a model that simultaneously reproduces both photometry and polarimetry. To solve this problem, they made a simplified, parametric model to study σ Ori E's magnetosphere, which was called the Dumbbell plus Disk model (hereafter D+D). This single-scattering model con-

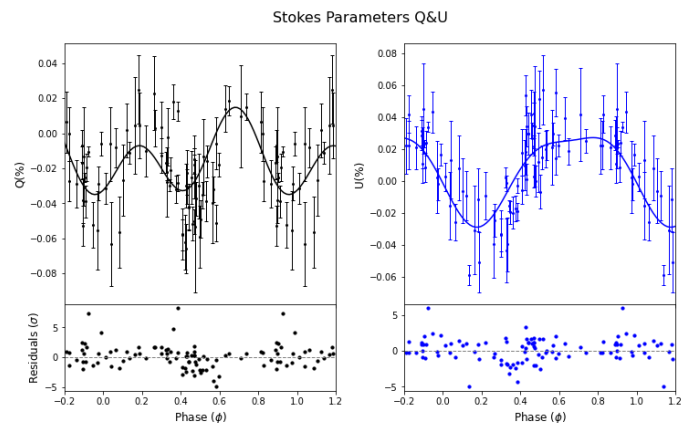


FIGURE 1. D+D Modulation for HR7355.

sists of a thin uniform disk tilted by an angle from the rotational equator and a pair of spherical blobs situated at the intersection between the equatorial plane and the magnetic equator. Oliveira (2022), in his MSc dissertation, greatly expanded on these results. He developed a more robust version of the D+D incorporating Bayesian statistics for parameter inference, providing much more reliable results.

Furthermore, more observations were carried out that resulted in the positive detection of the magnetosphere of four more stars (HD 35502, HD 142990, HR 7355, and HR 5907), for which D+D was also developed.

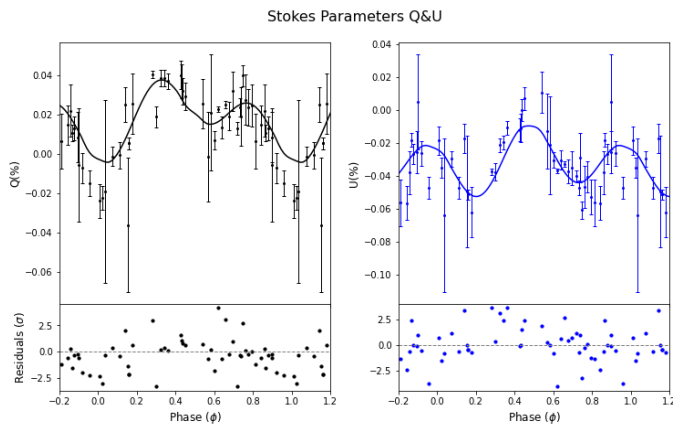


FIGURE 2. D+D Modulation for σ Ori E.

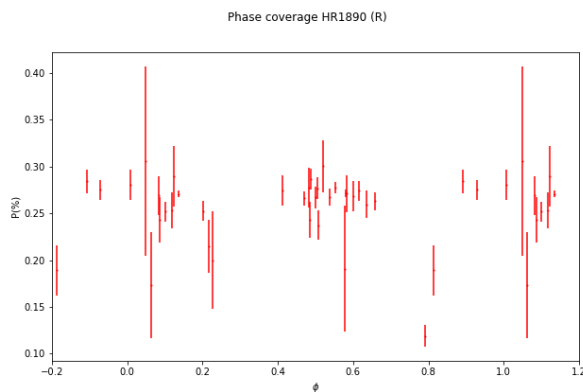


FIGURE 3. Rotational phase coverage of HR 1890

2. New simulations using D+D

Recently, we have been carrying out new simulations using the D+D model for the stars studied in Oliveira (2022). We also propose to perform simulations for additional magnetic stars, such as HR 1890 and τ Sco. We are conducting a more detailed analysis of these stars with the ultimate goal of publishing a paper reporting the results presented in Oliveira (2022) alongside the two new magnetic stars. So far, we have completed simulations for σ Ori E and HR 7355, the results of which are shown in Figures 2 and 1. Once the analysis for HR 7355 is finalized, we plan to carry out simulations for the three remaining stars from Oliveira (2022), as well as the two new targets (HR1890 and τ Sco). Once these simulations are complete, we will be able to finalize and publish the paper.

3. Observational efforts

A reliable simulation using the D+D model strongly depends on a substantial amount of observational data. We are conducting an observational survey with the goal of observing in linear polarimetry the 18 magnetic stars reported so far. Since a good rotational phase coverage is required for a reliable simulation, some stars are not yet suitable for D+D modeling. We propose to increase the volume of polarimetric data using the new polarimeter, named SPARC4, available at the Pico dos Dias Observatory, with the ultimate goal of studying their magnetospheric parameters.

4. Future Prospects

In the future, we plan to run new D+D simulations for additional magnetic stars as soon as sufficient phase coverage is achieved. The polarimeter, SPARC4, has proven to be an effective instrument for our project, increasing the number of stars observed each night with high precision. Since the D+D is a simplified model, we expect to find limitations in its capability to describe the magnetospheres of certain stars. Once these limitations are identified, we propose to upgrade the model and explore other potential systems.

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