Planets or Magnetic Activity?

Evolution of the Stellar Gravitational Quadrupole Moment from Magnetic Activity

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In Short

- *Motivation.* Observations of quasi-periodic variations of the eclipsing times in certain binary stars hint at the presence of planets or magnetic activity.
- *Goals.* We study the role of magnetic activity in the modulation of eclipsing time variation and whether we can exploit this to study stellar magnetic fields.
- *Methods.* We combine magnetohydrodynamical simulations with N-body simulations. Furthermore, we rely on analytic studies to connect the gap between numerical studies and observations.

Approximately 50% of all stars come in pairs that orbit each other, known as binary stars. These astrophysical objects are very important as they allow us to study, for example, theory of stellar evolution. A fration of them are *eclipsing binaries*, meaning that the two orbiting stars lie in our line of sight, thus eclipsing each other as they orbit.

Eclipsing binaries are divided into more specific categories. One of them are the *post common envelope binaries* (PCEBs). Their evolution is quite spectacular and was first proposed by [1]. Initially, the stars are separated by a distance of roughly equal to the distance between the Sun and the Earth. The two have different masses, and the more massive one evolves faster because it consumes its nuclear fuel supply at a faster pace. As this happens, it evolves to a red giant and the secondary star is trapped inside its inflated atmosphere. Because of friction, the secondary star looses orbital energy and heats the envelope of the red giant and starts to spiral inwards. At the end, the envelope of the red giant is expelled and its core, a white dwarf, is exposed. The secondary star normally has a mass between 10% to 50% and up to 100% of the Sun and is typically an M dwarf. Now the system has evolved into a PCEB with an orbital period of a few hours and a binary separation of less than the solar radius.

Because of their small separation, the stars eclipse each other several times a day. Observations of the eclipsing times often differ from what is expected if the presence of just the two bodies is assumed. Approximately 90% of all PCEBs show such behavior [2]. This problem can be alleviated if there were one or more extra bodies orbiting the binary, like giant planets or brown dwarfs. In this scenario a sufficiently massive third body can exert a force on the stars that alters the orbital motion, thus also affecting the eclipsing times.

Detection of planets around PCEBs and in binary stars in general would be an important step in our understanding of planet formation. This is because explaining their formation is not an easy task considering the evolutionary path of PCEBs. However, a recent study reported no detection of such a third body around V471 Tau, a PCEB with a White Dwarf and a solar mass star [3].

Another equally intriguing explanation connects the eclipsing time variations to magnetic activity in the secondary star in PCEBs. This is know as the Applegate mechanism [4] and, more recently, the Applegate-Lanza mechanism [5]. In this picture the magnetic activity alters the density distribution within the star. A non-perfect spherical distribution of density gives rise to a non-zero gravitational quadrupole moment (Q), that is, Q measures the deviation from a perfect sphere. When Q increases, the orbital separation decreases and thus the orbital period decreases and vice versa. As the variations in density and Q are related to the magnetic fields and to cyclic magnetic activity, periodic eclipsing time variations can be understood as being due to magnetic activity.

Magnetic activity is driven by combined action of *convection and rotation*. Low-mass stars like the Sun have convective envelopes that are heated from below and cooled by radiation at the surface. In these convection zones (CZ) energy is transported by motions of the gas due to the material being opaque to radiation at these temperatures and densities. In the case of the Sun, the CZ covers the outer 30% of its radius, below which radiation is again effective in transporting the energy emanating from nuclear fusion in the core. The convection zones of less massive stars are deeper than that of the Sun. For stellar masses less than about a third of the solar mass the whole star is convective.

Convection plus rotation results in the creation, destruction, and evolution of magnetic activity, which in general is referred to as a *dynamo*. Stellar magnetic activity is not confined into their convection zones but is manifested also in regions closer to the surface, where flares and winds are observed. The magnetic phenomena of our Sun produce Auroras (borealis and australis) near the magnetic poles of the Earth. Magnetism can also determine if exoplanets are able to sustain life as we know it because a highly magnetically active star can hit its planets

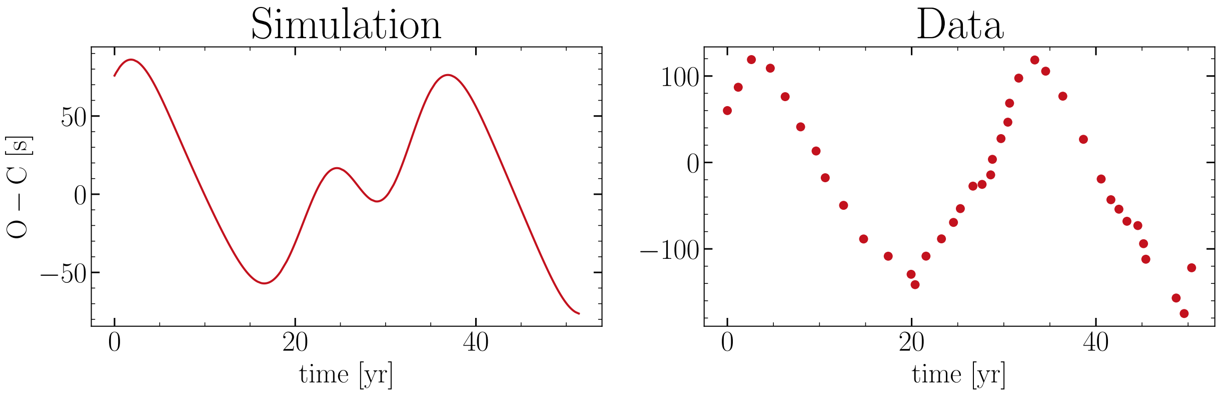

Figure 1: *Simulation data (left) compared to observed data (right) for a given binary system.*

with waves of charged particles, which may provide unfavorable conditions for life.

The study of magnetic activity of distant stars is a challenging task. This is due to the fact that we need very precise instruments to detect stellar surface phenomena. They can also be misinterpreted as a planet eclipsing the star, because starspots of magnetic origin decrease the amount of light that reaches us the same way a planet would do. In the context of the Applegate mechanism and PCEBs, the study of magnetic activity through variations of the eclipsing times can provide us with a new tool to study magnetic activity of stars other than the Sun.

In this project, we aim at connecting magnetic activity with eclipsing time variations by using computer simulations. Furthermore, we rely on theoretical studies to further bridge this gap. We have already explored the origin of the density and quadrupole moment variations in magnetohydrodynamical simulations of stellar magnetic fields [6,7]. We now aim at connecting our numerical results to observations by using N-body simulations. This simulations are run with Rebound, an N-body integrator. Early results show that we are able to reproduce the observed data, as seen in Figure 1. This aspects will be carefully studied during the current computing period.

WWW

`https://www.physik.uni-hamburg.de/en/hs.html`

More Information

[1] B. Paczynski, *IAU Simposium*, 1976 **73**, 75 `https://ui.adsabs.harvard.edu/abs/1976IAUS...73...75P`

[2] M. Zorotovic & M.R. Schreiber, 2013, *Astronomy & Astrophysics*, **549**, A95 `doi:10.1051/0004-6361/201220321`

[3] A. Hardy, M. R. Schreiber, S. G. Parsons et al., *Astrophysical Journal Letters*, 2015, **800**, L24 `doi:10.1088/2041-8205/800/2/L24`

[4] James H. Applegate, *The Atrophysical Journal*, 1992, **385**, 621A `doi:10.1086/170967`

[5] A.F. Lanza, *Monthly Notices of the Royal Astronomical Society*, 2020, **491**, 1820-1831 `doi:10.1093/mnras/stz3135`

[6] Felipe H. Navarrete, Petri J. Käpylä, Dominik R.G. Schleicher, et al., *Astronomy & Astrophysics*, 2022, **663**, A90 `doi:10.1051/0004-6361/202243252`

[7] Felipe H. Navarrete, Dominik R.G. Schleicher, Petri J. Käpylä, et al., *Astronomy & Astrophysics*, 2022, **667**, A164 `doi:10.1051/0004-6361/202243917`

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