Magnetic Field Reversal of Tau Boötis

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Abstract

Magnetic field reversal is not a unique property of the Sun. Tau Boötis A, a star located 51 light-years from Earth, with one exoplanet, has been undergoing magnetic field reversals that have been observed since 2008. Many solar-type stars outside our solar system have shown indirect signs of magnetic activity, suggesting possible reversals. While a few of them have been directly observed, their magnetic field changes include shifting magnetic poles. The magnetic field reversal of Tau Boötis A is interpreted to be driven by the interaction with its exoplanet, Tau Boötis Ab, similar to the interaction between the Sun, Jupiter, and Saturn. For solar-type stars with empirical data, the correlation of star's magnetic activity cycle to its rotation period is compared with another possible correlation of magnetic activity cycle to the rotation period, radius, and B-field intensity of the star–together.

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Tau Boötis A

There are numerous stars out there in space, although their size, age, composition, and general properties are not the same as the Sun; the Sun is a yellow dwarf star hosting planets in the solar system and undergoes magnetic field reversals approximately every 11 years. It's known that many solar-type stars[2] outside our solar system have reversing magnetic fields, but Tau Boötis A was the first star, besides the Sun, whose magnetic field reversal was directly observed in 2008. Since then, its magnetic reversals have been observed multiple times (J.-F. Donati & et al., 2008; S. Boro Saikia & et al., 2016; S. V. Jeffers & et al., 2018; S. Bellotti & et al., 2025).

Tau Boötis A is a primary F-type star in a wide binary system with Tau Boötis B, located in the constellation of Tau Boötes. The system, approximately 51 light-years from Earth, is known to host one planet and undergoes magnetic reversals almost annually or about 120 days, as reported in 2017 and 2018 (M. Mittag & et al., 2017; S. V. Jeffers & et al., 2018; Wikipedia contributors, 2025). The planet, Tau Boötis Ab (NASA, 2024), has 5.6 times the mass of Jupiter and orbits Tau Boötis A once every 3.3 days at a distance of about 0.049 AU. Meanwhile, its companion star, Tau Boötis B, moves around the primary at an average distance of 245 AU and takes about 2,000 years to complete one revolution (Sol Company, 2012).

Mechanism of Magnetic Field Reversal

According to the PVN charge dynamo mechanism for generating magnetic fields in stars, planets, and other celestial objects with global magnetic fields (Kim, 2008; Kim, 2017), the magnetic field reversals in these bodies are directly related to their internal electric charge distribution. This implies that changes in the internal electric charge distributions can lead to variations or even reversals of their global magnetic fields. Such changes are believed to be caused only by external sources or through interactions with other celestial objects (Kim, 2020; Kim, 2025).

The Sun, composed of super-heated, electrically charged gas known as plasma, flips its magnetic poles approximately every 11 years. In contrast, Earth–with its solid crust–has undergone numerous magnetic field reversals throughout its geological history (Wikipedia contributors, 2025).

Now, let's review the magnetic field reversals in Tau Boötis A, which hosts one planet, Tau Boötis Ab. Compared to the Sun, Tau Boötis A has a mass of approximately 1.3 $M_\odot$ and a radius of about 1.5 $R_\odot$ This gives it an average density roughly 0.385 times that of the Sun. Its

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[2] solar-type stars are main-sequence stars that share structural and physical characteristics with the Sun.

luminosity is approximately 3.425 L⊙, its surface temperature is about 1.11 T⊙, and its surface magnetic field intensity is a few Gauss–about 2–3 times higher than the Sun's. Considering the star's differential rotation—where the rotation period is 3.0 days at the equator and 3.9 days at the pole—and the host planet's orbital period of 3.3 days, the relative rotational period of the star with respect to the planet is approximately 33 days at the equator (in the forward direction) and 21.5 days at the pole (in the reverse direction). At a latitude of 40 degrees, the star's differential rotation is synchronized with the planet's orbit. The gravitational (tidal) force exerted by the planet on the star's surface is stronger than the gravitational influence of Jupiter on the Sun.

Now, let's explore the mechanism behind the magnetic field reversals of Tau Boötis A—one that may be considered speculative, yet remains feasible and, more importantly, consistent with the PVN charge dynamo mechanism for generating magnetic fields in stellar objects.

In the outer layer, or convective zone, of the star, the gravitational pull from its host planet, Tau Boötis Ab, is stronger on the side facing the planet than on the opposite side, due to the difference in distance. Since the PVN charge interaction is proportional to the strength of gravity—similar to tidal interactions with the exoplanet—positive charges are drawn toward the side of the star facing the planet.

The viscosity of the charged plasma within the star delays the kinetic motion of positive charges. As the star rotates, these positive charges gradually migrate toward the outer layer, while negative charges move inward to replace them. The density of positive charges in the outer layer eventually reaches a point where the repulsive interactions among them become stronger than the magnetic force. However, the positive charges continue their inertial motion, which eventually stops, causing them to move backward due to the repulsive forces.

Now, in the outer layer, positive charge density decreases, and this inertial motion of positive charges continues, leading to the appearance of negative polarity at the equator of the outer layer. Due to the magnetic field generated by these negative charges and the star's rotation, more negative charges accumulate and move toward higher latitudes in the outer layer. This process ultimately results in a magnetic polarity reversal for the star.

These alternating distributions of positive and negative charge polarities in the outer layer are driven by the PVN charge interaction with the host planet, Tau Boötis Ab. Plasma viscosity and inertial movement are crucial factors influencing this variation in charge distribution. These processes are expected to depend on the rotation period of Tau Boötis A, the orbital period of Tau Boötis Ab, the gravitational strength—or simply tidal interaction—between the star and its exoplanet, the star's magnetic field intensity, and internal properties such as the viscosity of the charged plasma (characterized by the Reynolds number with inertia), temperature, mass density within the star.

Since Tau Boötis A has one single host planet Tau Boötis Ab, which revolves around it in an almost circular orbit, the planet's revolution period is not directly related to the star's magnetic field reversal. Instead, the relative rotational periods—33 day at the equator in the forward direction and 21.5 days at the poles in the reverse direction, relative to the planet's rotation—are

more relevant for understanding the PVN charge interaction with the host planet. This interaction is much stronger than that between the Sun and Jupiter.

It can be expected that the magnetic poles of Tau Boötis A can shift more easily and faster than the Sun's magnetic poles. However, it is unclear how regularly it occurs, whereas the Sun follows a roughly 11-year magnetic activity cycle. In fact, this behavior depends on the Reynolds number in the star's convection layer, which relates the viscosity of the ionized hot plasma and inertia, as well as the magnetic force acting on moving charges.

If the Reynolds number in Tau Boötis A is similar to that of the Sun—since Tau Boötis A is a solar-type star—its magnetic cycle can be estimated as $4(6) \times 10^{-2}$ times solar magnetic cycle, which is approximately 160 (240) days. This is because the magnetic force in Tau Boötis A is about 16 (24) times stronger than in the Sun due to its 2-3 times higher magnetic field strength and a rotational rate about 8 times faster than that of the Sun.

Here, we need to point out an interesting correlation between the relative rotational periods of the star—33 days at the equator and 21.5 days at the poles—because 231 days ($3 \times 7 \times 11$) or 66 days ($2 \times 3 \times 11$) can makes one cycle for both periods. This is similar to the correlation between solar magnetic activity cycle and the time interval between Jupiter and Saturn's opposition or conjunction, which occurs approximately every 20 years.

Correlation between Rotation Rate and Magnetic Cycle in Solar-Type Stars

Many solar-type stars, including Tau Boötis, have shown observed magnetic field reversals or indirect signs indicating such reversals. However, while some stars exhibit periodic magnetic behavior, others do not. An additional point of interest is the correlation between a star's magnetic activity cycle and its rotation rate. According to the mainstream magnetic dynamo theory, a faster stellar rotation rate is expected to correspond to a shorter magnetic cycle, considering the Rossby number (Ro), which is defined as the ratio of inertia to the Coriolis force. In contrast, an alternative model proposes the opposite: more slowly rotating stars were expected to have magnetic cycles that repeat more quickly (Harvard-Smithsonian Center for Astrophysics, 2017).

However, empirical data show that the relationship between a star's rotation rate and its magnetic cycle does not exhibit a strong correlation, as illustrated by the red circles in Figure 1, which represent the correlation between the rotation periods and magnetic activity cycles of the stars listed in Table 1.

Star	Rotation	Magnetic	Sources
	(days)	Cycle (years)	
Sun	26	22	Solar standard; Hale cycle ~22 yr
Tau Bootis	3.31	2	Fares et al. 2009, MNRAS
61 Cyg A	35	14.6	Boro Saikia et al. 2016, A&A
HD 9986	21.03	5.5	Bellotti et al. 2025, A&A (BCool)
HD 56124	20.7	2.5	Bellotti et al. 2025, A&A (BCool)
HD 76151	17.5	2.5	Bellotti et al. 2025, A&A (BCool)
Kappa1 Ceti	9.2	10	Boro Saikia et al. 2022 summarized in Bellotti et al. 2025, A&A (BCool)

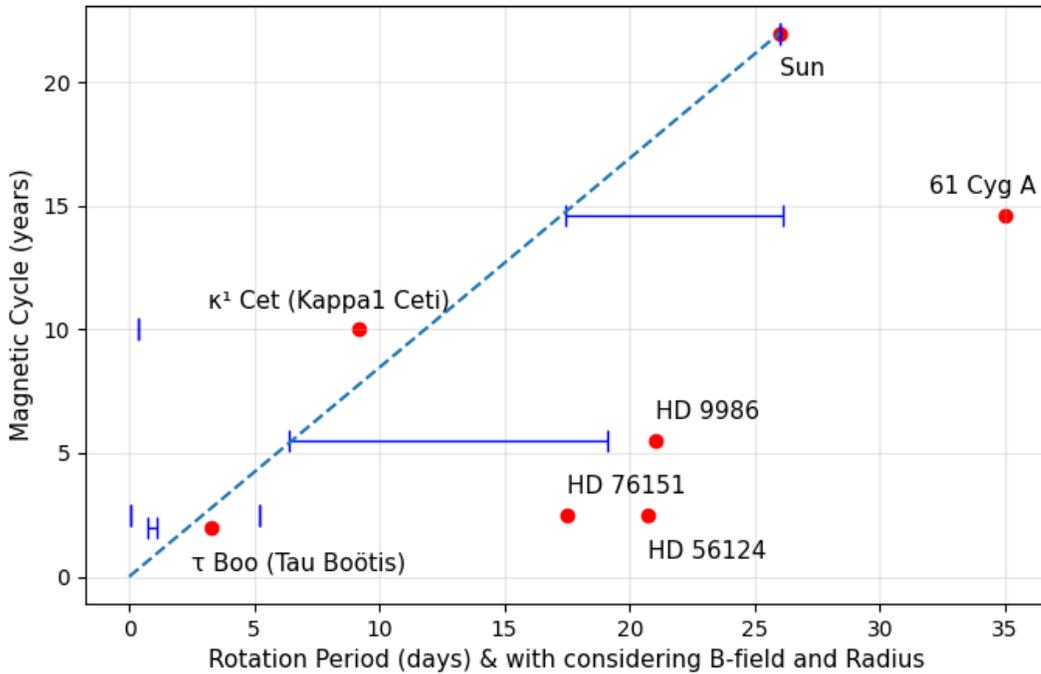**Table 1:** solar-type stars observed magnetic polarity reversals

Figure 1: correlations of magnetic cycle to magnetic force

However, in the PVN charge dynamo mechanism, the magnetic activity cycle is expected to depend on magnetic force acting on hot ionized plasma within the star. Therefore, it is influenced not only by the star's rotation rate but also by its magnetic field intensity and radius.

Alternatively, in the correlation between the magnetic cycle and the rotation period T, as shown in the figure, the rotation period T can be modified as $T/(r \cdot b)$, where T is rotation period (day), $r = R/R_\odot$ that is ratio of star's radius to that of the Sun, $b = B/B_\odot$ that is the ratio of star's magnetic field to the Sun's. For example, consider the star HD 9986 in Table 2, where $r \cdot b = 1.1(3.3)$, its Rotation period, 21.03 days,

Table 2: Radius and B-field

Star	Radius (ratio)	B-field (ratio)
Sun	1	1
Tau Bootis	1.5	2-3
61 Cyg A	0.67	2-3
HD 9986	1.1	1-3
HD 56124	1.5	220
HD 76151	1.125	3
Kappa1 Ceti	0.95	24

can be adjusted to 21.03/1.1 and 21.03/3.3 as shown by the blue horizontal line, which moves closer the straight dotted line connecting the origin to the data point representing the Sun. Except Kappa1 Ceti–which is known young and more active than the Sun–the other stars also move close to the line. This suggests that the correlations among these solar-type stars are consistent with the relationship between the magnetic cycle and the magnetic force within the star.

Discussion

According to the PVN charge dynamo mechanism for generating magnetic fields in stellar objects, the magnetic polarity reversal of Tau Boötis A is driven by PVN charge interactions with its host planet, Tau Boötis Ab. Unlike the Sun's magnetic activity cycle, which is somewhat interlocked with Jupiter and Saturn, Tau Boötis A's cycle can vary depending on the star's internal state. Compared to the Sun's cycle, Tau Boötis A's magnetic activity cycle could be as short as few hundred days.

The correlation between a star's magnetic cycle and its rotation period, as expected in mainstream magnetic dynamo theory, was reviewed using empirical data. Alternatively, the correlation of the magnetic cycle with the rotation period, radius, and magnetic field intensity of the star was investigated, since the star's magnetic field reversal is thought to be driven by the PVN charge dynamo mechanism and magnetic forces acting on the hot ionized plasma inside the star.

Let's compare the process of magnetic polarity reversal in astronomy with a simple example from hydrodynamics that we can observe in daily life. Imagine watching a tree branch moving outside a window. First, we can confirm that the wind is causing the branch to move. Then, we might notice that the branch's movement appears somewhat regular, irregular, or even chaotic, depending on the wind's strength and consistency. Since both the intensity and stability of the wind fluctuate over time—and the branch itself has internal tension that responds to external forces—its movement may result in a gentle, periodic swaying during a light breeze, or a wild, erratic motion during a storm.

This brings us to a broader question: in nature, what kind of cyclic phenomenon can truly occur on its own, without any interaction from external sources? Without even bringing the concept of entropy in physics into the discussion, we must ask—what, in the natural world, can exist or function entirely in isolation, without interaction with anything else?

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