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# A star's surface revealed: 16-year study shows chaotic dynamo

**The STELLA observatory in Tenerife has studied a star's surface for 16 years using robotic spectroscopy and Doppler imaging. Unlike the cyclic spots on our Sun, this star exhibited chaotic, non-periodic star spot behavior, revealing a fundamentally different dynamo mechanism. The groundbreaking study has now been published in Nature Communications and presents a unique movie of the evolution of the star's surface, which is otherwise only an unresolvable dot of light in the sky.**

It is known that our sun develops spots on its surface that change systematically over time and tell us about its cyclical internal dynamo and structure. For other stars, astronomers have only occasionally the chance to obtain a view of their star spots, usually never enough to follow the timely changes. Now, one of the most spotted stars in the sky, with the name XX Trianguli, was observed every clear night since the inauguration of AIP's robotic observatory STELLA in Tenerife in 2006, enabling a comparable data set like for sunspots. An research team from the Leibniz Institute for Astrophysics in Potsdam (AIP) in Germany and the HUN-REN Research Centre for Astronomy and Earth Sciences, Hungary, applied a tomographic inversion technique called Doppler imaging, resolving the stellar surface and monitoring the appearance and decay, motion, and morphology of star spots for 16 years that revealed a pronounced non-solar chaotic dynamo without a cycle.

Sunspots are the most well-known manifestations of solar magnetic fields and exhibit a range of phenomena related to the interior dynamo. Star spots are the direct analogs of sunspots on other stars but with the big observational restriction that one usually cannot resolve other star's surfaces. In the present study an indirect surface imaging technique called Doppler imaging was applied and presented 99 independent reconstructed surface images of the spotted star XX Trianguli. The star was selected because it had shown a gigantic star spot in a previous study and was thus well suited for a long-term monitoring effort.

Dark spots on the star's surface caused shifts in its photocenter—essentially the point that represents the "center of light" of the star—by up to 24 micro arc seconds, equivalent to about 10% of the star's visible disk radius. These shifts occur because dark spots reduce the brightness in certain areas of the star, causing the perceived center of light to move slightly. However, unlike the Sun's predictable activity cycle, these photocenter displacements did not follow a periodic pattern, suggesting a mostly chaotic and likely non-periodic dynamo very different to the Sun's. This phenomenon also highlights a challenge for detecting exoplanets, as these spot-induced variations in the photocenter can mimic or obscure the tiny motions caused by orbiting planets, adding an intrinsic limitation for such astrometric exoplanet catches.

Creating a decade-long homogeneous data set was only possible due to the continuous operation of the Stellar Activity (STELLA) robotic observatory on Tenerife and its high-resolution STELLA Echelle Spectrograph (SES). "STELLA is our home-made observatory: designed, constructed, built, and operated remotely from Potsdam", says Professor Klaus G. Strassmeier, first author of the present study and Principal Investigator of STELLA. Spectral line profiles were recorded with SES between 11 and 28 times over the length of a stellar rotation (24 days), depending on the local weather and target visibility on the sky. It thus enabled a large number of viewing angles (phases) of the rotating stellar surface because each line profile is a one-dimensional representation of the visible surface in velocity space. These views were mathematically inverted into a two-dimensional Doppler surface image approximately once per stellar rotation. It enabled the reconstruction of a total of 99 independent surface images over the course of the 16 years, which were stacked into a three-minute movie of the star's surface.

XX Tri (HD 12545) is a bright giant star in a stellar binary system with a most probable mass just 10% more massive than the Sun, a radius of about 10 solar radii, an effective temperature of 4630 Kelvin, and a rotation period of 24 days synchronized to the orbital period of the binary. The star was previously found to have a gigantic star spot with physical dimensions about 10,000 times the area of the largest spot group ever seen on the Sun, equivalent to 10 times the projected solar disk.

"XX Tri's maximum photocenter shift with the stellar rotation period is certainly a large value for spotted stars but comparable to the expected astrometric displacement for a star with a Saturn-mass planet in a one year orbit around it at about 300 lightyears distance", emphasizes Prof. Strassmeier. It is even many times higher than similar displacements expected for shorter-period exoplanets. Early planet-catch simulations for the ESA mission Gaia had demonstrated that short-period planetary systems (periods less than 40 days) have expected astrometric signatures of typically below 1 micro arc second, thus much less than what was observed on XX Tri due to spots. The original Gaia simulation predicted a planet catch of tens of thousands of systems for the nominal mission lifetime. Given the now quantified spot-induced photocenter offsets for XX Tri it appears very challenging to impossible to separate these two effects, rotationally modulated spots and exoplanets, in particular if of similar periodicity. In any case, our values for XX Tri are the first ever such measures of a stellar photocenter.

More about STELLA https://stella.aip.de

The STELLA (short for STELLar Activity) Observatory is located at the Izana ridge of the Teide Observatory on the Canary Island Tenerife at an altitude of 2390m above sea level. No personnel is on site. STELLA is a fully robotic observatory and consists of two independent 1.2m robotic telescopes, each of them serving a single dedicated instrument to avoid instrument changes. Both telescopes were manufactured by Halfmann Telescopes in Augsburg, Germany and are modern az-alt telescopes with a high slewing speed. The inauguration of the observatory took place in May 2006. Science observations were started soon thereafter, including the target in this paper. The instrument applied was the STELLA Echelle Spectrograph (SES). SES is a fiber-fed fixed-format echelle spectrograph. Its white-pupil design provides a resolving power of 55,000 over a wavelength range of 390–880 nm with a sampling of three pixels per resolution element. At a wavelength of 600 nm this corresponds to an effective resolution of 5.5 km/s or 110 milli-Angstroem.

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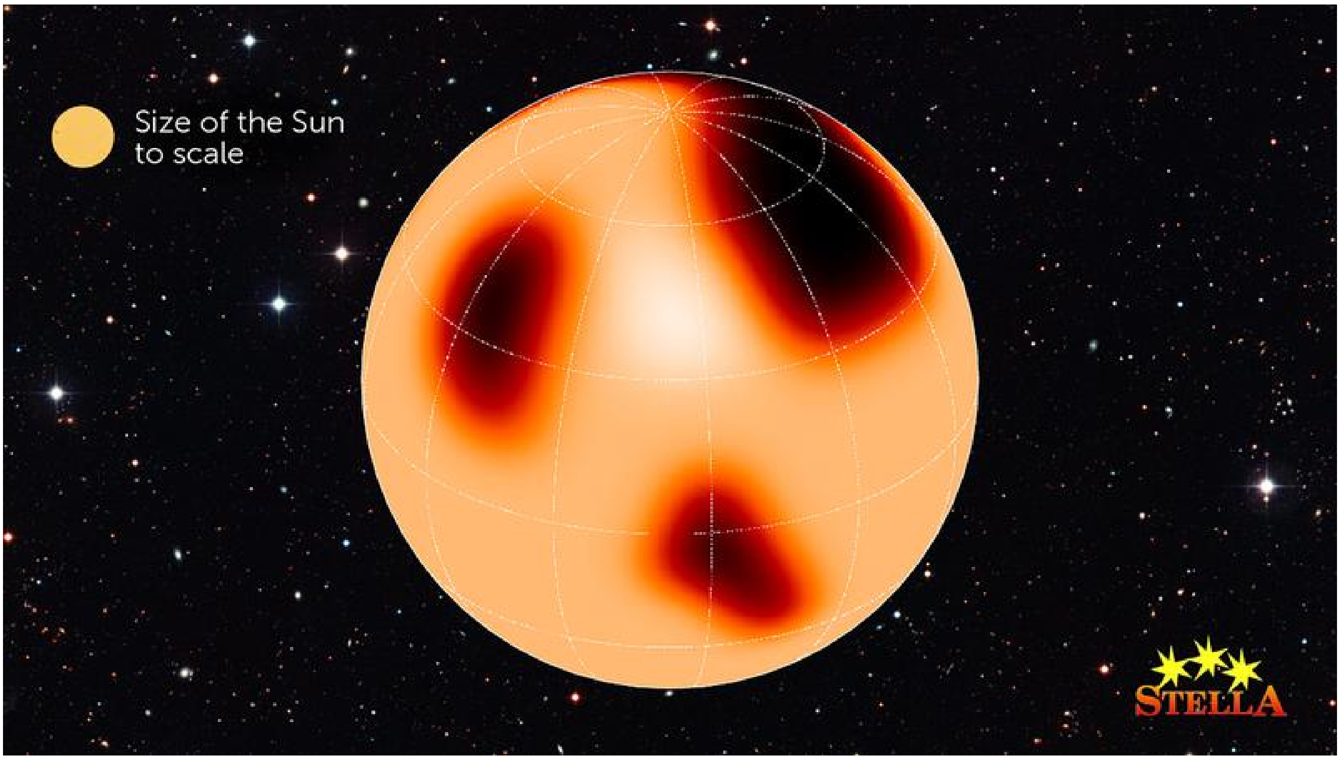
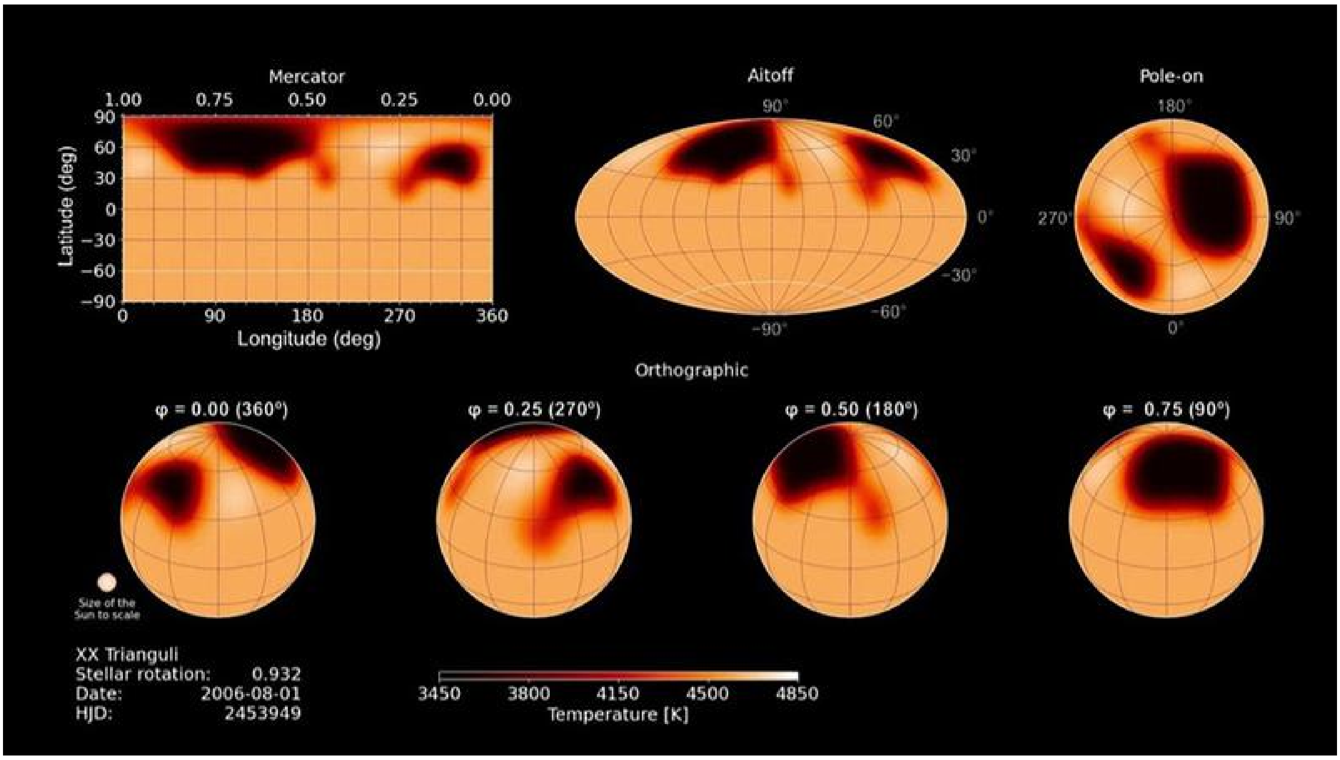



Snapshot image of the surface of the K-giant XX Trianguli. The size of the sun is shown for comparison.
HUN-REN RCAES/Zs. Kővári, MOME/Á. Radványi, AIP/K. Strassmeier



Surface of the star XX Trianguli in four projections
HUN-REN RCAES/Zs. Kővári, MOME/Á. Radványi, AIP/K. Strassmeier