Detection of a complex magnetic field on the surface of the intermediate-mass star Vega

A decade of ultra-deep observations at Pic du Midi and the Haute-Provence Observatory

Vega, the prototype of intermediate-mass stars, has revealed after more than a decade of observations a double magnetic identity: a stable large-scale fossil field coexists with a variable small-scale field, likely generated by a dynamo mechanism. This discovery provides unprecedented constraints for modeling the evolution of stars that contribute to the chemical enrichment of our Universe.

For over 150 years, Vega in the constellation Lyra has served astronomers as a reference of stability. Yet, this bright northern-hemisphere star has continually surprised them in recent decades.

Vega is an intermediate-mass star (twice the mass of the Sun, spectral type A), rotating very rapidly with an equatorial velocity of nearly 200 km/s. In 2009, the discovery of an extremely weak magnetic field at its surface surprised the scientific community. According to stellar evolution models, this type of star should not generate a magnetic field in the absence of a convective envelope near the surface, unlike cooler stars that possess a deep outer convection zone. Since then, other stars of the same category have been found to host similar magnetic fields, but their origin remains mysterious: are they fossil fields, created in an earlier stage of the star's life, or the result of an active dynamo mechanism? Constraining the origin of magnetic fields in intermediate-mass stars would represent a major breakthrough, as magnetism is both essential and poorly understood in their evolution.

In 2015, detailed analysis of a very large number of high-resolution spectra revealed the presence of bright and/or dark spots co-rotating with Vega, generally attributed to a dynamo mechanism generating magnetic fields. The short-term variability of these spots was suspected as early as 2017. To shed light on this mystery, an unprecedented large-scale observing campaign was launched.

An international team led by CNRS *Terre & Univers* researchers (see inset) studied more than 13,000 high-resolution spectra collected over more than a decade. These observations were obtained with the highly stabilized SOPHIE spectrograph at the Haute-Provence Observatory and through spectropolarimetry (a technique that measures magnetic properties from polarized light) using the Narval and then Neo-Narval instruments on the Bernard Lyot Telescope at the Pic du Midi Observatory.

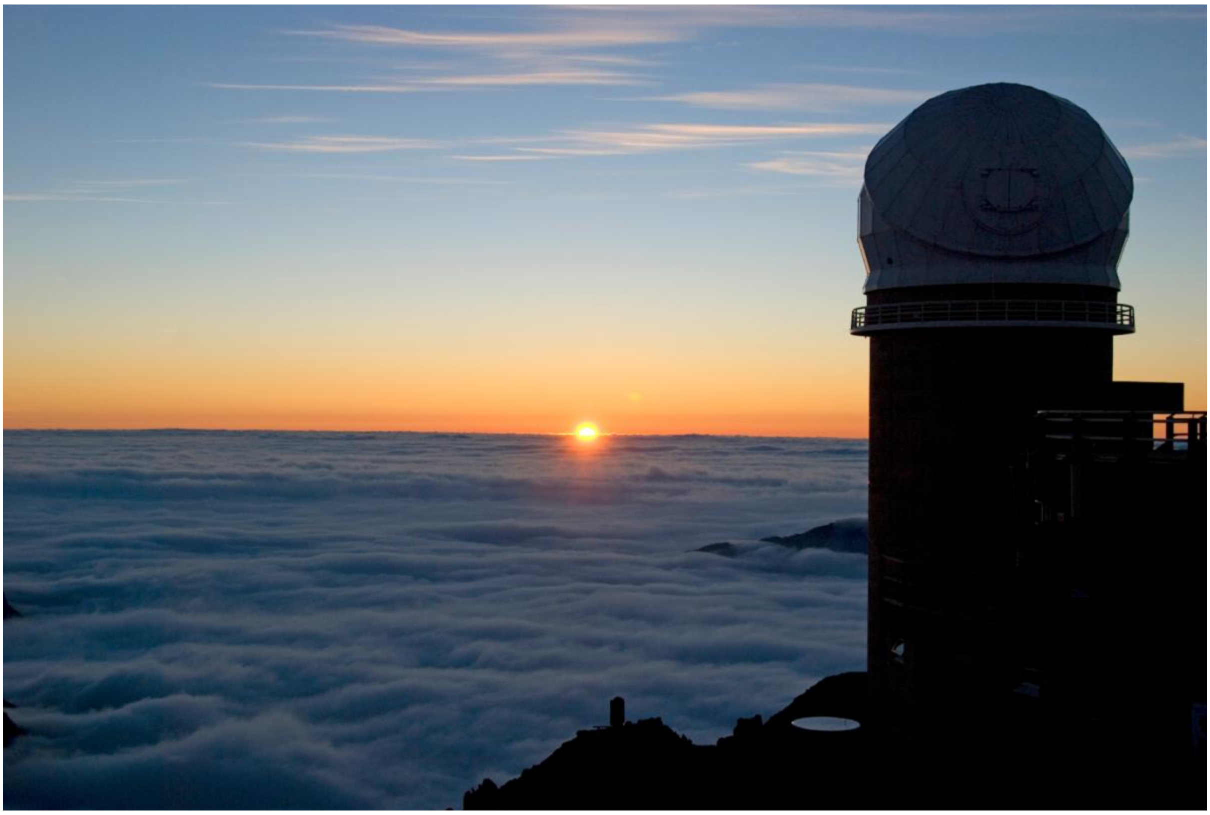

Figure: Bernard Lyot Telescope, Midi-Pyrénées Observatory. This telescope hosts the Neo-Narval spectropolarimeter. (Credits: Sébastien Chastanet – OMP/UT).

The exceptional quality of the data (very high signal-to-noise ratio), combined with ultra-precise reduction using the NEXTRA data reduction pipeline, revealed unexpected complexity in the observed magnetic field. For the first time, a prototype intermediate-mass star reveals the coexistence of a fossil magnetic field in the form of an inclined dipole, where the magnetic poles are not aligned with the rotation axis (detected in 2022) and a variable small-scale magnetic field, likely generated by a dynamo effect.

This large-scale work, based on the reconstruction of magnetic maps using Zeeman-Doppler imaging and intensity maps via an innovative Doppler imaging technique, will, if extended to other similar stars, have a major impact on our understanding of the stars driving the chemical evolution of our Universe.

First theoretical approaches exist to explain such weak dynamos in this category of stars, whose envelopes were historically considered purely radiative. A whole new field of research now opens.

CNRS laboratories involved
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Reference
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