# The surface magnetic field topologies of both M-dwarf components from the double-line spectroscopic binary FK Aqr

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## Introduction

Stellar magnetic fields play a crucial role in the stellar evolution since they impact on inner plasma flows, mass-loss processes, rotation and planet habitability. Knowing more about their strengths and topologies (on the stellar surfaces and magnetospheres) and how this is linked to the properties of their host stars, brings an important knowledge to stellar astrophysics.

M-dwarfs are the most frequent type of stars. They are main-sequence stars with masses between ≈0.08 M_sun and ≈0.55 M_sun. One of their interesting features is the change of their internal structure – the transition from a structure similar to that of the solar-like stars (with a convective envelope) to a fully convective star happens around spectral type M3/M4 (≈0.35 M_sun). This fact makes M-dwarfs objects of particular interest to dynamo theory according to which the tachocline is the place where the large-scale toroidal fields are stored and amplified. Another challenge of understanding the nature of magnetic fields is to study them in binary/multiple systems.

GJ 867 system is one of only four quadruple systems within 10 pc of the Sun and the only one among these systems with all four M-dwarf components. GJ 867 A is the primary component of a widely separated visual binary. Its visual component is GJ 867 B and they are separated by 24".5 (Two Micron All Sky Survey). In the current study we present the system GJ 867 AC (FK Aqr). It is a double-lined spectroscopic binary consisting of two dM1-dwarfs with similar masses (0.55 M_sun and 0.45 M_sun of the primary and secondary, respectively). The orbital period of the system is 4.08322 d (Herbig & Moorhead 1965). FK Aqr has already shown periods with strong flare activity and presence of spots noticed in the light curves and more quiet periods (Cutispoto 1995, Cutispoto & Leto 1997, Cutispoto et al. 2003, Sanz-Forcada et al. 2003). The system exhibits also X-ray activity (Pollock et al. 1991, Dempsey et al. 1997).

## Observations

- Observations were obtained under the project BinaMIcS which aims to understand the interaction between binarity and magnetism in different type of stars.
- 26 spectra obtained in September 2014 with the spectropolarimeter Espadons@CFHT
- spectral resolution ≈65 000
- spectrum coverage from 370 nm to 1030 nm in a single exposure
- The Stokes I (unpolarized light) and Stokes V (circular polarization) parameters are simultaneously measured using a sequence of four sub-exposures.

## Data reduction

- Least-squares deconvolution technique (LSD) is used to extract the mean Stokes I and V profiles and to compute the longitudinal magnetic field $B_l$ using the first-order moment method (Rees & Semel 1979, Donati et al. 1997, Wade et al. 2000).
- Zeeman Doppler imaging (ZDI) inversion method is employed to reconstruct the topology of the surface large-scale magnetic field of both components (Donati et al. 2006). We use the implementation of ZDI adapted to binary stars by Colin Folsom (Folsom et al. 2018).
- Phoebe software is employed to refine the orbital parameters of the system (Prša & Zwitter 2005, Prša et al. 2016 ) (http://phoebe-project.org/).

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## Results

In all presented figures the data is phased according to the following ephemeris (Herbig & Moorhead 1965) : T = 2437144.123 + 4.08322φ

LSD multiline technique is employed to average about 5100 spectral lines in the case of FK Aqr and to receive mean Stokes I and V line profiles. Clear Stokes V signatures are detected from all observations of both components. Then, Bl is computed for both components separately (fig. 1) with an integration window of 56 km/s around the line center of LSD profiles.

Both components of FK Aqr exhibit the strongest unsigned magnetic fields Bl compared to other single early-type M-dwarfs (M0-M2.5, Donati et al. 2008), which values for |Bl| reach up to 100 G.

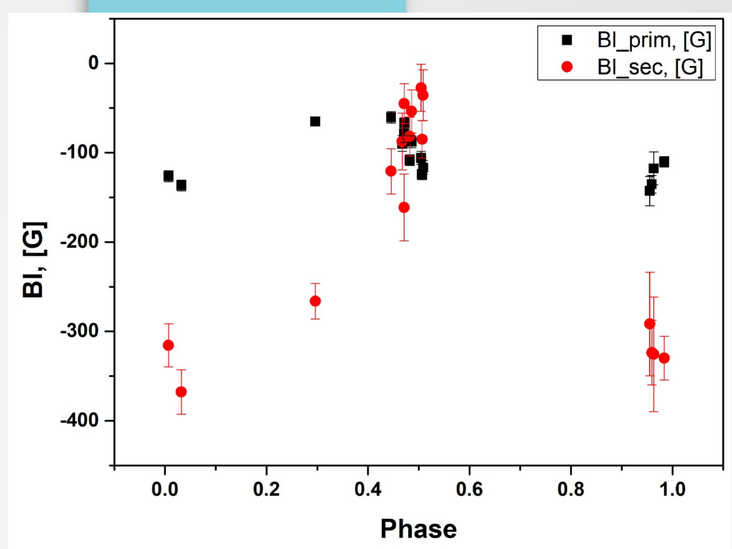



Fig.1: Variability of the longitudinal magnetic field $B_l$ – black squares stand for the primary and red dots stand for the secondary.

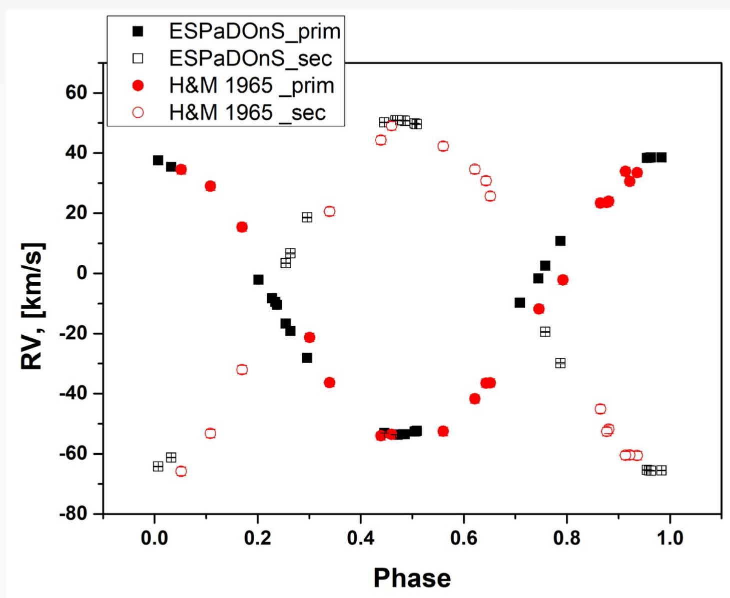



Fig.2: Variability of the radial velocities (RV) of both components of FK Aqr. In this figure we plot data from ESPaDOnS observations from 2014 (black symbols) and the measurements taken from the paper of Herbig & Moorhead (1965) (red symbols). Filled symbols stand for the primary, opened symbols stand for the secondary. RVs of both components are measured from the mean Stokes I profiles.

Fig.3: Stokes I (left) and Stokes V (right) profiles of both components of FK Aqr. Observed profiles are colored in black. Synthetic profiles are colored in red. Both components show simple shaped Stokes V profiles with negative blue lobs and positive red lobs.

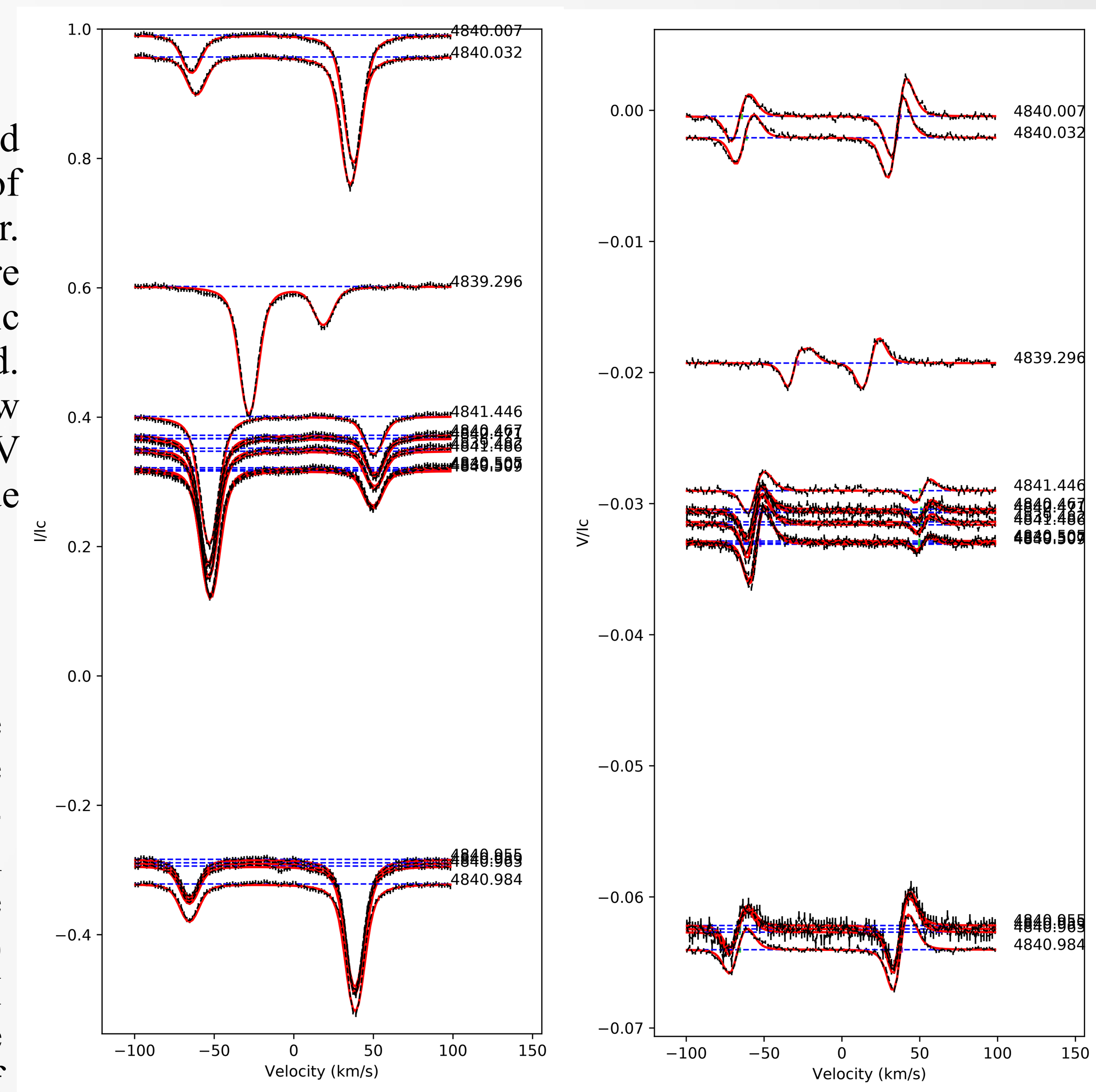
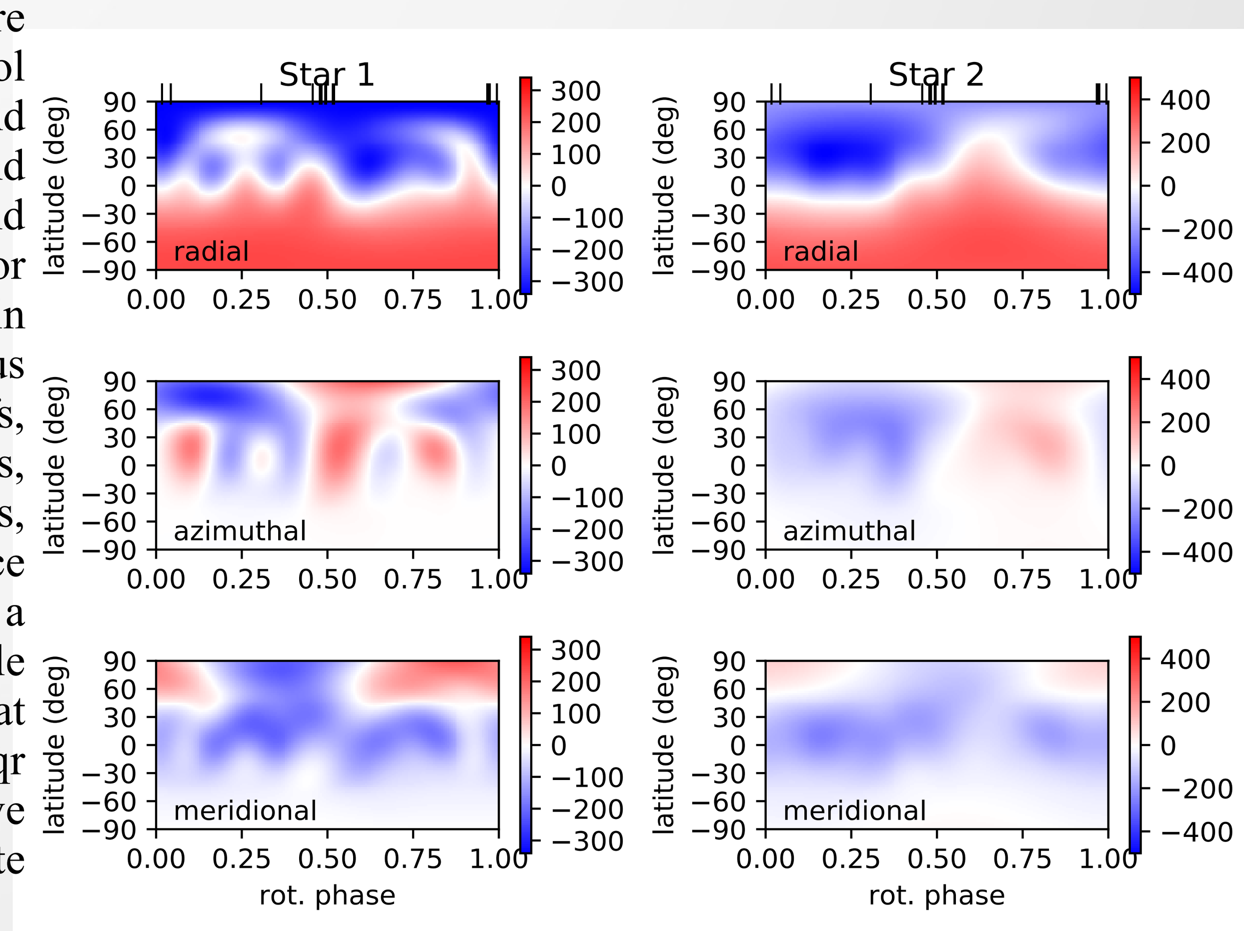



Fig.4: The first maps of the system FK Aqr, showing the topology of the surface large-scale magnetic field of both components (primary on the left, secondary on the right) reconstructed with the ZDI method with a $\chi^2$ = 1.3. The large-scale magnetic fields of both M-dwarfs are dominated by the dipol component ( ≈80% and ≈90% for the primary and secondary, respectively) and are axisymmetric ( ≈70% for both components). This is in agreement with previous studies of single M-dwarfs, showing that M-dwarf stars, even in close binary pairs, can generate surface magnetic fields displaying a strong axisymmetric dipole component. We also note that the components of FK Aqr are among the most massive M-dwarfs known to generate this type of magnetic field.




Both stars are very close to the boundary of 0.5 M_sun, which divides the preferable large-scale topologies of M-dwarfs (Donati et al. 2008, Morin et al. 2010, Morin 2012). Both of the dwarfs fit very well on the well-known plot for M-dwarfs of the properties of the large-scale magnetic field as a function of rotation period and mass (Morin et al. 2010, Morin 2012).