# Magnetic activity in selected evolved stars

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Non-degenerated magnetically active stars are spread throughout the entire Hertzsprung-Russell diagram ($HRD$) – pre-main sequence stars, Solar-type stars, upper-main sequence stars, $M$ dwarfs, RS CVn- and FK Com-type systems, single $G$, $K$ and $M$ giants. Their magnetic fields range from a few gauss up to several thousands gauss. These magnetic fields feature large-scale topologies varying from simple nearly-axisymmetric dipoles to complex non-axisymmetric structures, and from mainly poloidal to mainly toroidal topology (reviews by Berdyugina 2005, Donati & Landstreet 2009, Reiners 2012).

Single giants of spectral class $G$ and $K$ are another group of stars, which show magnetic activity. They possess large convective zones, potentially allowing the operation of a dynamo. First detections of surface magnetic fields for these single giants were reported by Konstantinova-Antova et al. (2008 a, b, 2009), Aurière et al. (2009 a, b). A sample of about 50 $G$ and $K$ giants, with rotational periods between 5 and 200 days, is studied by Konstantinova-Antova et al. (2013) and Aurière et al. (2014, accepted). The measured magnetic fields $B_l$ are in the order of 0.25 G to about 100 G. This study shows that probably the magnetic activity of these giants is due to dynamo action. Only for four of them the authors conclude that they possess fossil fields.

The main hypotheses for the magnetic activity of red giants are two – their magnetic fields are generated by a dynamo action or they possess fossil fields, which originate in the interstellar cloud from which the star forms. The classical $\alpha - \omega$ dynamo operates as follows: the $\omega$-effect generates a toroidal field from a poloidal field by the radial differential rotation inside the tachocline. Then the $\alpha$-effect converts a poloidal field from a toroidal field (but also a toroidal field from a poloidal field) at the base of the convective zone, but above the tachocline. The tachocline (Parker 1993) is a rotational shear layer, uncovered by helioseismology, which is beneath the Sun's convective envelope, providing smooth transition between the latitudinal differential rotation of the envelope and the rigidly rotating radiative core.

It is supposed that the magnetic fields in magnetic chemically peculiar stars (hereafter $Ap$ stars) have a fossil field origin. These $Ap$ stars appear similar to normal $A$ and late $B$ main sequence stars, but: (1) have peculiar chemical abundance – show spectral lines of abnormal strength or weakness of various elements; (2) have lower values for $v \sin i$; (3) possess magnetic fields. Nowadays, $Ap$ stars are known to be about 5–10 % of the $A$ and $B$ type main sequence stars (Wolff 1968, Moss 2001, Power et al. 2008). Such fields are expected to be relatively simple in structure and have simple large-scale topologies (Landstreet 1992, Donati & Landstreet 2009). Usually, the variations with time of the longitudinal magnetic field $B_l$ are sinusoidal (Aurière et al. 2007, Wade et al. 2000 a, b, Kochukhov & Wade 2010, Silvester et al. 2012).

Three single late-type giants are choosen ($\beta$ Ceti, EK Eri, V390 Aur), in order to study the properties of their magnetic activity and surface magnetic geometry, and to test the different hypotheses about the origin of their magnetic fields. The observational data were obtained with two twin fiber-fed échelle spectropolarimeters – *Narval* (Aurière 2003), which operates at the 2-$m$ Télescope Bernard Lyot (TBL) at Pic du Midi Observatory, France, and *ESPaDOnS* (Donati et al. 2006 a), which operates at the 3.6-$m$ Canada-France-Hawaii Telescope ($CFHT$) at Hawaii. In polarimetric mode, both have a spectral resolution of about 65 000 and a nearly continuous spectrum coverage from the near-ultraviolet (at about 370 nm) to the near-infrared domain (at 1050 nm) in a single exposure, with 40 orders aligned on the CCD frame by two cross-disperser prisms. Stokes I (unpolarized light) and Stokes V (circular polarization) parameters are simultaneously obtained by four subexposures between which the retarders – Fresnel rhombs – are rotated in order to exchange the beams in the instrument and to reduce spurious polarization signatures (Semel et al. 1993).

The least squares deconvolution ($LSD$) multiline technique (Donati et al. 1997) was applied to detect and measure the longitudinal magnetic field $B_l$. This widely used cross-correlation technique enables averaging of several thousand absorption atomic lines recorded throughout the échelle spectrum, generating a single Stokes $I$ and $V$ line profile. In this way, the signal-to-noise ratio (S/N) is increased to the point where weak polarized Zeeman signatures can be detected. A line mask, created from Kurucz (1993) atmospheric models, was used. The stellar parameters, which were needed to create such a mask, are $T_{eff}$, $\log g$ and a microturbulence.

The magnetic topology of the stellar surface was reconstructed using the Zeeman Doppler Imaging tomographic method ($ZDI$; Semel 1989, Donati & Brown 1997, Donati et al. 2006 b). We used a recent implementation of this algorithm where the surface vectorial magnetic field is projected onto a spherical harmonics frame, allowing us to easily distinguish between the poloidal and toroidal components of the surface magnetic geometry (Donati et al. 2006 b). This method performs iterative adjustment of the observed time series of $LSD$ polarized profiles by a simulated set of Stokes $V$ profiles computed for an identical sequence of rotational phases. The synthetic Stokes profiles are calculated from an artificial star whose surface is divided into a grid of 2 000 rectangular pixels of roughly similar area. Each surface pixel is associated with a local Stokes $I$ and $V$ profile.

The line activity indicators $H\alpha$, the CaII infrared triplet component at 854.2 nm, the core emission of the CaII K line through the intensity ratio between the line core and the continuum intensity at 395 nm, radial velocity were also measured. The abundances of $^{12}C/^{13}C$ ratios and evolutionary tracks on the $HRD$ were modeled.

The results of the current thesis for the three giants ($\beta$ Ceti, EK Eri, V390 Aur) are presented in Chapter 3 and 4.

The properties of the magnetic field of the giants EK Eri (G8 III-IV; $M = 2\ M\odot$; $v \sin i = 0.5\ km/s$) and $\beta$ Ceti (K0 III; $M = 3.5\ M\odot$; $v \sin i =$

3.5 $km/s$), are studied by means of $ZDI$ and by analysis of the variations of the activity indicators. The magnetic model is almost purely dipolar. These two stars are at different evolutionary stages – EK Eri is at the first dredge-up and $\beta$ Ceti is at the core He-burning phase, and both of them are suspected of being descendants of $Ap$ stars during the main sequence. The study indicates that the magnetic fields in $Ap$ stars survive till advanced evolutionary stages, like core He-burning is. In this way for the first time the question what is the fate of an $Ap$ star after the main sequence is answered.

Another star of similar mass, studied in the same way, and being at the first dredge-up phase is the fast rotator V390 Aur (G8 III; $M = 2.25\ M\odot$; $v \sin i = 29\ km/s$). It is rather likely that the magnetic activity of the star is due to dynamo action. The surface magnetic field shows a complex structure and an azimuthal field belt is presented, which indicates a toroidal field close to the surface and a dynamo operation within the convective envelope. A vertical gradient of rotation in the atmosphere is observed for the first time, in agreement with the predictions of the theoretical works by Palacios et al. (2006) and Brun & Palacios (2009).

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