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STELLAR DYNAMO IN CONTEXT OF STELLAR ACTIVITY DATA

D. Sokoloff ^{a*}, ***N. Ismayilov*** ^{b**}

[a] *Moscow State University and IZMIRAN, Moscow, Russia*

[b] *Shamakhy Astrophysical Observatory named after N.Tusi,*
Azerbaijan National Academy of Sciences, Shamakhy region, Azerbaijan

Investigations in cyclic stellar activity naturally departs to some extent from solar cyclic activity studies and are expected to provide a valuable material for understanding of solar activity. Solar instrumental observations are however much more detailed rather the stellar ones and covers much longer temporal interval. This creates various problems in comparison between observational and theoretical concepts for stellar activity with that ones for solar activity. We discuss the problems to arrive to conclude that the key issue to develop solar-stellar activity comparison is organizing of long-term monitoring of cyclic activity of several more or less solar like stars.

Keywords: Stellar activity – Stellar dynamos

1. INTRODUCTION

Solar activity cycle can be considered as a basic phenomenon of various manifestations of solar magnetic activity like solar flares. Solar dynamo based on joint action of differential rotation and mirror-asymmetric magnetic convection in solar interior is believed to be a physical mechanism responsible for solar magnetic field formation which underlines various physical processes known by solar surface data. The point however is that solar dynamo operates somewhere in solar interior and we are unable to observe this action directly and have to learn about it using indirect surface activity data which have to be considered as tracers for dynamo action. In particular, the very solar cycle was isolated in XIX century basing on temperature data and its magnetic nature becomes clear in XX century only. Such indexes of solar activity as sunspot number and sunspot

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[*] E-mail: sokoloff.dd@gmail.com

[**] E-mail: ismailovnshao@gmail.com

area being temperature data which are connected with magnetic field indirectly remain important until now.

Common sense tells us that solar type magnetic activity hardly can be a peculiar property for the Sun only. Stellar observations for last several decade confirm this natural expectation and provide information concerning magnetic cycles in several dozens late type stars (e.g. [1]). Stellar activity cycle data are interesting not by themselves only however can provide better understanding of slar activity and leads even to practically important results. To be specific, resent observations (see for review [2]) tell that stars quite closed to the Sun by physical properties can demonstrate flares with so huge energy which would be dangerous for modern civilization provided they happens at the Sun. It is an obvious duty for stellar and solar activity experts to decide to what extend this fact isolates a new hazard for our civilization.

Obviously, solar activity data are more rich and detailed rather the stellar activity ones however a rapid progress in observational abilities for stellar activity observations is obvious as well. In particular, an important development from photometric observations to spectral photometry and then to inverse Doppler imaging and Zeeman-Doppler imaging is a fundamental achievement in this area. Importance of this line of development is obvious and do not need particular advertising. Another direction of research is development of long-term monitoring of a sample reasonably chosen stars to reveal how reach is the variety of magnetic stellar activity. Here we argue the importance of the second line of development.

2. STELLAR CYCLES AND OSCILLATIONS OF STELLAR ACTIVITY

Duration of solar activity cycle is about 22 years (nominal 11-year Schwabe cycle represents a half of the whole cycle only). It immediately means that a project for stellar cycle observations have to be presumed for several decades. Contemporary astronomical community appears to be able for such long-term project. The most well-known example here is the well-known HK-project initiated by O.Wilson [3] (see for review [1]). Historically, the Schwabe cycle was isolated in sunspot data just by naked eye consideration. A natural more deep tool for isolation of (quasy)periodic components in time series is Fourier analysis in this contemporary form known as wavelet analysis (e.g. [4]). The point however is that apart from 11-year peak the solar as well as stellar activity data may contain several additional peaks, in particular Gleissberg cycle with a length of about century (e.g. [4]). Instrumental observations of solar activity are available for 4 centuries what allows to argue that the additional peaks are unstable and should be considered as physically different phenomenons rather Schwabe cycle (e.g. [5]). From the viewpoint of dynamo theory, Schwabe cycle corresponds to an eigenfrequency of mean-field dynamo equations while additional peaks is more naturally to consider as various time scales of magnetic convection in solar interior.

Available data of stellar activity monitoring provide the stars for which wavelet spectra of activity tracers demonstrate at least two peaks of different frequencies (e.g. [1]). Corresponding interpretation sounds sometimes as two periods of substantially variable frequency and shape. It looks attractive to think that we deal here with two scales in magnetic convection rather with two eigenfrequencies of stellar dynamo (e.g. [6]) however simultaneous excitation of two dynamo eigensolutions is possible in principle and may be useful for understanding of solar activity data as well (e.g. [7]). Of course, the final decision in such cases can be obtained after centuries of corresponding observations and can be achieved in remote future only however a more critical interpretation of available data is very desirable at this stage already.

3. VARIOUS SHAPES OF STELLAR CYCLES

A more accessible aim of stellar activity monitoring is clarification of the variety of the shapes of stellar activity and understanding of the point how general are more or less sinusoidal shape of solar activity known from solar observations. Experts in numerical models of spherical dynamos recognized as early as in 1980th that the same mechanism of cyclic activity based on differential rotation and mirror asymmetric convection can result in several very specific shapes of cyclic activity (e.g. [8]). Of course, including in the model additional physical processes as meridional circulation or interaction in binary systems dynamo modellists obtain even more reach variety of cycle shapes.

First of all, stellar dynamo can produce magnetic configurations symmetric to the stellar equator (e.g. [9]) rather the antisymmetric solar configuration. Even if the configuration is antisymmetric, activity wave can propagate to the stellar poles rather to the equator.

Speaking about temporal shapes of activity cycle only, we obtain several possible shapes of the cycles. In course of the cycle, dipole magnetic moment can avoid reversal and demonstrate periodic variations with nonvanishing mean level (such behaviour is known as vacillations rather oscillations). A magnetic cycle with a shape very remote from a sinusoidal one, with a rapid increase of magnetic moment just before reversal (so called dynamo bursts) is also possible. A regime with long epochs of quasy-stationary magnetic moments and further sharp reversals is possible as well. By the way, the last option is typical (according to paleomagnetic data) for the geomagnetic field. All these regimes was obtained experimentally in course of laboratory dynamo experiments (see for review [10]).

Various basically nonaxisymmetric magnetic configurations can be excited by stellar dynamo action as well (e.g. [11]).

Magnetic energy produced by spherical dynamo action can differs quite substantially from one type of cyclic activity to another one while a difference in amplitudes in shapes of dynamo drivers responsible for two different activity shapes may be reasonably moderate (e.g. [12]). In is far to be clear in advance which of the above mentioned shapes of activity cycle can be a result of arbitrary play with the shape of dynamo drivers and which could be physically relevant. In particular, clarification of this point could be important to clarify whether superflares can occur on the Sun (e.g. [2]).

Some of the above mentioned activity cycle shapes can be in principle identified basing on photometric data, another need technique of inverse Doppler imaging. Of course, Zeenam-Doppler imaging is the most preferable however difficult in realization option. The point however is that each option needs a monitoring on the time scales of decades comparable with famous HK-project.

4. METHODS FOR STELLAR ACTIVITY OBSERVATIONS

Magnetic activity can be observed in various time scales staring from the exposition times (minutes and hours) up to decades. Minimal time scale for stellar activity seems to be the flare time scale provided aflares are considered as a kind of stellar activity. Flares lead to larger temperature what results in enhancement of coronal spectral lines as well as larger X-ray fluxes. What about solar-type magnetic activity, long-term projects of photometric, spectral and polarimetric monitoring are required.

4.1. Photometric observations

Cool star monitoring in wide band photometric system in UBVRI bands with accuracy 0.01- 0.005 mag look as a relevant for the problem. Indeed, for a typical cool star with KOV spectrum ($T_e = 5000$ K) with a spot (temperature $T_s = 4000$ K and area of about 2% - 10% of the whole stellar disc) the light variations are expected to be of about 0.01 – 0.3 mag what looks accessible for contemporary observations. Contemporary photometric CCD observations with small telescopes like Zeiss 600 (60 cm at Shemakhy observatory) or AZT 8 (70 cm, at Crimean observatory) provided observations with accuracy up to 0.01 mag (e.g. [13, 14]).

Classical T Tauri stars are known to be magnetoactive stars at early stage of stellar evolution (e.g. [15] – [17]) and observations of this activity is a very attractive goal. Observation of angular momentum losses for such stars before they reach the Main Sequence, magnetic fields up to 0.5 – 2 kGs, anomalous high emission in UF and optical ranges definitely require its long term monitoring. Starting from the middle of XX century a huge bulk of corresponding observations for young stars in young open starfburst clusters is accumulated. The most rich archive of photometric data for T Tauri and Ae/Be Herbig is [18, 19]. The arcive accumulates the light estimates for more than 1000 nights in various filters over 30 – 50 years. Some stars from the database demonstrate the light variations similar to the solar ones [20]. Among 28 investigated stars, 13 stars (e.g. DR Tau, sp K7V, Fig. 1) do not demonstrate any pronounced yearly averaged light variations, while variations inside an observational season can be as large as 0.5 mag (refrred as type II, [20]). We see from Fig. 1 that the light variations for DR Tau from a peak to peak in V-band in some seasons can rich 0.5 – 1.5 mag and two times in 30 years was in an active state with $\Delta V \approx 1.5$ mag (JD 2448000-2450000 and JD 2453000-2455000) and at least one time (JD2450000 - 2453000) was in a low activity state ($\Delta V \approx 0.5$ mag).

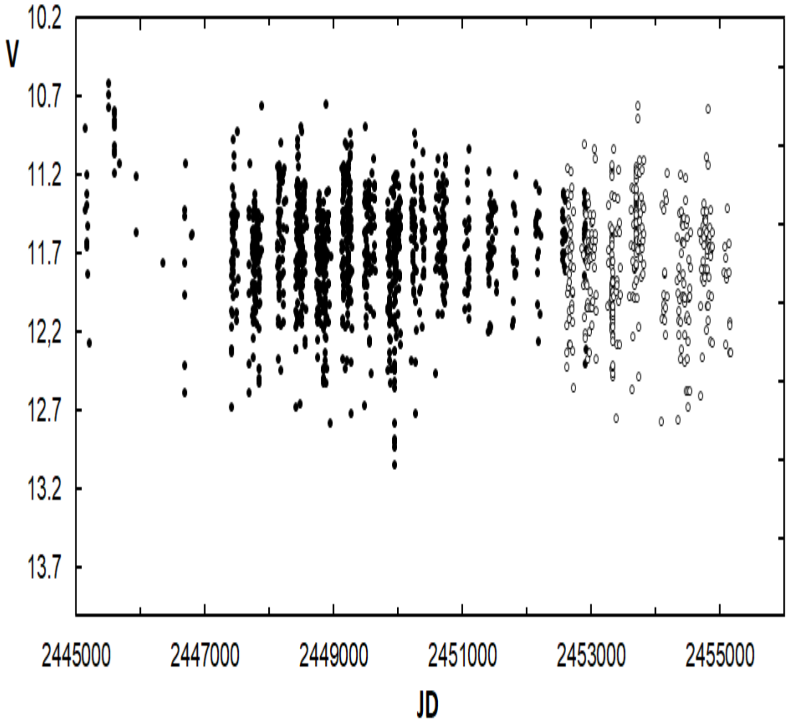

Fig. 1. Light curve for a classical T Tauri star, DR Tau obtained after POTOR data ([18, 19], black circles) and archive ASAS [21] data, open circles. Each vertical strip of points corresponds to a particular observational season.

One more T Tauri star, AA Tau (sp K7V) also demonstrate a similar light curve (Fig. 2). Again, a yearly average light is stable, while particular seasons demonstrate various light variabilities.

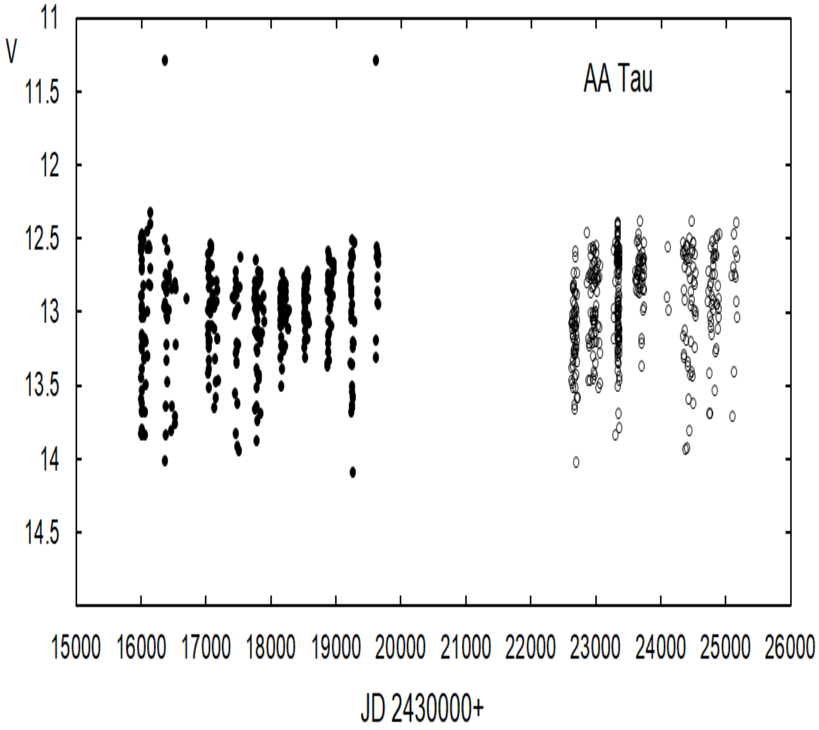

Fig. 2. Light curve for AA Tau, notetions as in Fig. 1.

A consistent photometric monitoring programm should include Main Sequence stars of various ages what would allow to learn magnetic activity evolution for solar type stars.

4.2. Spectral monitoring

The light of many solar type stars in young open clusters is quite weak so its long-term spectral monitoring requires telescopes with aperture at least 2 m. The desired observation are expected to show variations in selected spectral lines, temperature, gravity, rotation rates, radial velocities basing on spectra with high spectral resolution. Lines H, K CaI II or S-index which shows this lines variability in respect to the continuum in V and R bands are known to be the most reliable tracer of magnetic activity [22]. Again, monitoring of solar type stars with various ages including various young stars is desirable. There are e.g. a subgroup of T

Tauri (WTTS and NITS) which losses in course of its evolution their accretion discs so main emission comes from their chromosphere.

Spectral monitoring of young stars in difficult because many T Tauri are of 10 mag and weaker so observations at 2 m telescope of Shemakhy observatory with 1 hour exposition allows to observe stars up to 16 mag using 2×2 prism spectrograph Canberra or diffraction spectrograph UAGS with $R = 2000 - 3000$. Observation of fine dynamical spectral variations which correspond to velovities of about 2 – 5 km/sec [23] are problematic for this spectral resolution. For the signal-to-noise ratio $S/N = 100$ the continuum level can be measured with accuracy of about 1-2% while radial velocities can be measured with accuracy up to ±15 km/sec. Equivalent width of spectral absorption lines (EW) in intervals 0.10 – 0.15 Åcan be measured with accuracy 15-20% while EW of more intensive chromospheric emission lines (H and K Ca II lines) can be measured with accuracy up to 4 – 5 %.

What about more brighter late type stars from the Main Sequence, spectral observations with resolution $R = 28000$ and $R = 56000$ can be performed with eshelle spectrograph ShAFES with CCD matrix $4K \times 4K$ cooled by liquid nitrogen [24]. One hour exposition allows to get spectra with resolution 28000 for $S/N = 100$ and star up to 8 mag. Accuracy for radial velocities is ±1 km/sec and EW accuracy is about 4 – 5 % while accessible spectral range is 3700-8000 Åwhat allows to observe H and K CaII, H_α and another chromosperic lines simultaneously. Similar telescopes are available at Terscol (Zeiss 2 m) [25] and in Crimea (2.6 m) [26]. The telescopes allow late type stare monitoring with $V \approx 5 - 8$ mag.

4.3. Magnetic field measurements

Observations in chromospheric lines as well as Faraday dispersion and linear polarisation gives indirect information conserning magnetic activity while Zeeman effect gives a direct information concerning stellar magnetic fields. Observations of Zeeman splitting requires however large telescopes with high spectral resolution (see for review [27, 28]). There are several realisations of the idea and the most developed now is believed to be the Least-Square Deconvolution [29] which allows to measure magnetic field with accuracy of about 30-40 G [30].

It attidion to the mean field stellar observation, mapping of stellar surface is possible. Inverse Doppler imaging gives possibility to obtain temperature maps of stellar surface [30, 31] while Zeeman Doppler Imaging [33] gives surface magnetic field distribution. Both methods provides very high requirements to the signal-to-noise ratio and direct long term accumulation of photons is not applicable because individual expositions have to be short enough to get sufficient spatial resolution.

Both methods are very attractive however it looks convincing that the monitoring have to be started with less sophisticated methods.

5. CONCLUSIONS

We can conclude now that stellar activity monitoring is the key issue for understanding of the nature and properties of stellar magnetic activity. This monitoring is however a very complicated and difficult undertaking. In our opinion, this is a challenge for several forthcoming generations of stellar astronomer. A natural way to resolve the problem is to use gradually more and more sophisticated observational approaches.

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