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ON A POSSIBLE CYCLIC ACTIVITY OF THE PLEIADES FLARE STAR II TAU

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Abstract. We present preliminary results of a possible cyclic activity of the flare star II TAU based on flare activity observed during long monitoring campaign of the Pleiades region performed in 60-80-ies of the last century. Bayesian statistical analysis (Gregory-Loredo method for periodic signal detection of unknown shape in time-series with Poissonian and Gaussian errors) of the registered flare times and released energies during the maximum of the flares indicates on a 3-3.5 year activity period.

1. INTRODUCTION

Even historical observations of the Sun show increase and decrease sunspots numbers roughly in 11 year period. Because the sunspots are magnetic in nature, it is natural, that the cyclic activity is a result of a variation in a surface magnetism. Moreover, the solar cyclic activity in the form of flares and related phenomena has long been known, the discovery that such activity occurs on most stars, and that it frequently appears in more violent forms on stars other than the Sun, prompted a further reassessment of the nature of stars.

In particular, the flare activity of the red dwarf stars in stellar associations and star clusters, as well as in the solar vicinity can be considered as another important property common for them at some evolutionary stage.

However, in contrast, the cyclic activity of the flare stars is not enough investigated yet. In particular, as suggested by Mirzoyan & Oganyan (1977), according to the flare statistics, only half of the probable members of the Pleiades open cluster, having low luminosity ,exhibited flare activity during the period of all observations. To explain this discrepancy with ideas about the evolutionary significance of the flare phase of stars, through which all dwarfs pass, two suggestions are made: that the flare activity is cyclic and that there is a large dispersion in the duration of the flare activity phase for stars of the same luminosity. Some evidence for the first possibility is put forward, i.e the flare activity of the stars is cyclic, like the Sun: periods of maximal flare activity are followed by periods of comparative quiescence. Possible cases and other arguments in favor of this kind of variability are given elsewhere (Gurzadian 1985, Pettersen 1989, Parasamian and Andrews 1996, Akopian 1999, 2001, 2008, Akopian and Sargsyan 2002).

Here, we present preliminary analysis of possible cyclic activity of the flare star II TAU or HII 2411; T55; HCG 377; A11; A12; A41; A51; R9 based on the flare activity observed during long monitoring campaign of the Pleiades region performed in 60-80-ies of the last century. We used a Bayesian statistical analysis developed by Gregory & Loredo (Gregory and Loredo 1992, Gregory 1999) (henceforth GL method) for periodic signal detection of unknown shape in time-series with Poissonian/Gaussian errors, i.e an application to the registered flare times and released energies during the maximum of the flares of II TAU.

2. DATA ANALYSIS AND RESULTS

The flare star II TAU for observational period spanning over $\sim$ 20 years is known as a most frequently flaring one in the Pleiades region (Haro et al. 1996). Having at disposal the Flare Stars Database (Tsvetkova et al. 1995, 1996) we took the data for all flares registered in the observational period, in total 132, of II TAU, in different photometric bands, mostly in U or photographic (Pg). The flare amplitudes were converted from Pg to U photometric band taking into account synchronous or parallel observations of some flares. Unfortunately, the exact times of registered flares of II TAU are not given in the published papers, and we adopted such with uncertainty of 6 hours. Since the characteristic time scales considered in this study are much longer than this uncertainty this assumption can not have crucial influence upon our results. The data set of flares of II TAU is shown in Fig. 1.

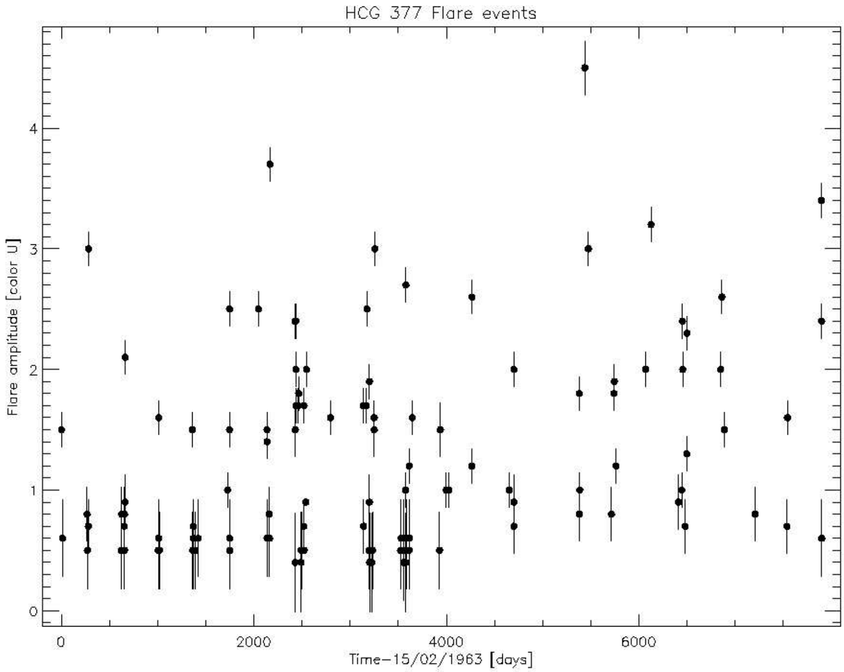

Figure 1. Long-term flare activity of II TAU, flare amplitude in U photometric band vs flare registered time, is shown spanning ≈ 8000 days. Error bars of the flare amplitudes are adopted according to the accuracy of the photographic photometry at the maximum of the flare. The GL method, a Bayesian approach for periodic signal detection of unknown shape with Gaussian noise is applied to this data set (for details, see text).

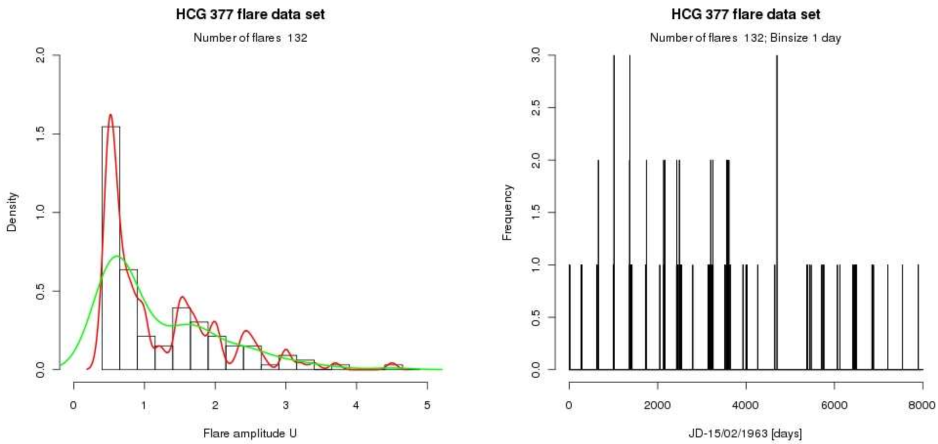

Figure 2. Distributions of ΔU amplitudes of flares (left panel) and registered times of flares (right panel) of the most frequently flaring star II TAU in the Pleiades region.

In order to detect cyclic activity of II TAU we first applied the GL method developed by Gregory & Loredo (1992) to the above described data set, assuming that the flare amplitudes in U photometric band at the flare maximum are in the case of Gaussian errors (Gregory 1999, 2005).

The method is using a Bayesian approach to the problem of detection and characterization of a periodic signal in a time series when we have no specific prior knowledge of the existence of such a signal or of its characteristics, including shape.

In the current approach, we are dealing with stellar magnitude measurements i.e. analyzing a sampled time series with Gaussian noise (Gregory 1999). This analysis does not assume uniform sampling; the approach allows us to draw optimal inferences about the nature of the signal for whatever data is available.

Thus, for the II TAU flare data sets, for which long term observations are available, we can represent the measurements of the flare amplitudes in $U-band$ and corresponding errors spanning more than 20 years, by the equation:

$$\Delta U_i^O = \Delta U_i^M + \epsilon_i + s$$

where ΔU_i^O is the measured flare amplitude at time t_i, ΔU_i^M the periodic model or constant model prediction at time t_i, ϵ_i the component of ΔU_i^O, which arises from measurement errors, and s is any additional unknown measurement errors plus any real signal in the data that cannot be explained by the model prediction ΔU_i^M.

Under the proposition that the quantity $\Delta U^O - \Delta U^M$ obeys to the Gaussian distribution, for the Bayesian posterior probability of the angular frequency ($\omega = \frac{2\pi}{P}$) of a periodic signal we may write (Gregory 1999, 2005):

$$Prb(\omega|\Delta U^O, M_m) = \frac{C}{\omega}\int_{s_{lo}}^{s_{hi}} \frac{ds}{s}\int_0^{2\pi} \exp(-\frac{1}{2}\sum_{j=1}^{m}\chi^2_{W_j})$$

$$\prod_{j=1}^{m} W_j^{\frac{1}{2}}[erfc(y_{jmin}) - erfc(y_{jmax})]d\phi,$$

where $C = \left[\int_{\omega_{lo}}^{\omega_{hi}} \frac{d\omega}{\omega} Prb(\omega|\Delta U_i^O, M_m)\right]^{-1}$, $\chi^2_{W_j} = \sum_{i=1}^{n_j} \frac{(\Delta U_i - <\Delta U_{W_j}>)^2}{(s^2+\epsilon_i^2)}$,
$W_j = \sum_{i=1}^{n_j} \frac{1}{s^2+\epsilon_i^2}$, $<\Delta U_{W_j}> = \frac{\sum_{i=1}^{n_j} \Delta U_i/(s^2+\epsilon_i^2)}{W_j}$,
and $erfc(y) = \frac{2}{\sqrt{\pi}}\int_y^\infty \exp(u^2)du$, $y_{min,max} = \sqrt{\frac{W_j}{2}}(\Delta U_{min,max} - <\Delta U_{W_j}>)$.

The GL method is intended to compute the ratio of the probabilities (odds ratio) of two models, i.e. periodic and constant. The periodic model is a family of models capable of describing a background plus a periodic signal of arbitrary shape.

A priori, we assume that the constant and periodic models have equal probability. Each member of the family of the periodic models is a histogram with m bins, with m ranging from 2 to some upper limit, typically 12. The unknown parameters are P (period), ϕ (phase offset of start of data and beginning of first bin), m (number of bins), and s (extra Gaussian noise parameter).

The long-term period search was performed in the range of 250 to 2500 days. As a result, we obtained a most likely periodicity of 1220 days with a 68 % credibility range of 1100 to 1300 days of activity cycle length.

Next, we applied the GL method in the case of Poissonian errors to the registered times of the flares of II TAU. Again we compared hypothesis constant vs periodic, i.e. flare arrival times are consistent with purely constant rate Poissonian process or there is an evidence of cyclic activity. Despite of the spare data set, we obtained result again supporting our idea on a possible periodicity of 3.0-3.5 years (see above) with analysis of the amplitudes of the flares of II TAU.

In addition, we have simulated large number of random data sets with a similar number of data points (e.g. 100 to 150), with a certain cycle length (e.g. 3-5 years), and also measurement errors ($\pm 0.1 - 0.3$ mag) to check, how precise we can then determine the cycle length with our method. It shows that for overwhelming majority cases our approach with Bayesian statistics has detected the periodic signal, i.e. possible cyclic activity of II TAU. Unfortunately, this powerful approach, certainly extracting more information from the available data than other methods, can be applied only in a few cases, when statistically significant number of flares have been registered. Nevertheless, an approach for a synthetic flare star could be applicable, assuming that the flare stars of the similar luminosities observed in the Pleiades region possess approximately the same flaring activity (Ambartsumyan 1978).

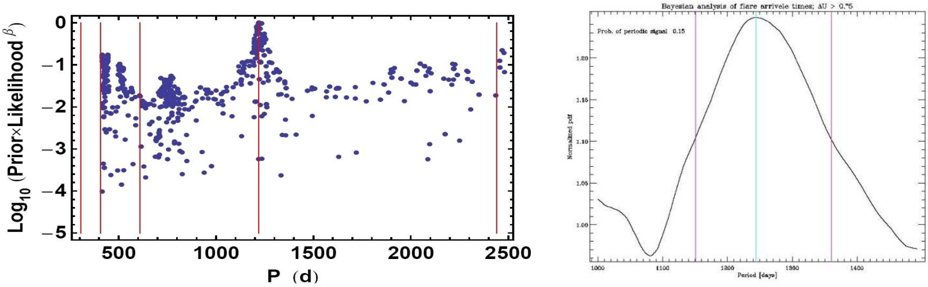

Figure 3. Log of Bayesian posterior probability of density function of period of amplitudes (ΔU left panel) and registered times of flares (right panel) of HCG 377 is shown. The application of the GL method in the case of Gaussian and Poissonian noise revealed a significant period of ~ 1220 days (higher harmonics also are indicated by vertical lines). A Bayesian odds ratio of periodic vs constant model is equal ≈ 100 (for details, see text).

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