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RT VIR – A SEMIREGULAR STAR WITH MASER EMISSION: MATHEMATICAL MODELLING OF OPTICAL VARIABILITY

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ABSTRACT. The historical light curve of the semi-regular pulsating star RT Vir (SRb, Sp M8III) with a maser emission is analyzed based on the AAVSO database. The star is extensively studied in the IR, radio and the optical ranges. The value of the period from the CCVS (155^d) conflicts with some observational data. Signs of a systematic variability were also detected in the radio frequency range with a period that was close to 200 days. Studies of the period showed that the period of this star varies with time and the latest value was found to be roughly 136 days. Period analysis result of the visual data from 1904 May to 2016 August provided by AAVSO for RT Vir. Published databases of "virtual observatories" - AAVSOnet, Hipparcos, ASAS-SN, KWS were used. Periodogram analysis revealed that the star still has several periods (320, 280, 169 and 153 days). In fact, the variations are not truly periodic, there are large shifts in time, changes in amplitude, and these smaller periods occur as smaller-amplitude peaks in-between the main ones with 320 period. Two-color diagrams of gloss in I and color index (V-I) from V were constructed. Approximation of “Running parabola” was carried out, average values <V>=8.457, <I>=3.658, <B-V>=+1.8 were determined.

Keywords: Stars: Pulsating: SR; Periodogram analysis

АНОТАЦІЯ. На основі бази даних AAVSO проаналізовано історичну криву блиску напіврегулярної пульсуючої зорі RT Vir (SRb, Sp M8III) з мазерним випромінюванням. Ця зоря широко досліджується в ІЧ-, радіо- та оптичному діапазонах. Значення періоду з GCVS (155^d) суперечить деяким даним спостережень. Ознаки систематичної змінності також були виявлені в радіочастотному діапазоні з періодом, який був близьким до 200 днів. Дослідження періоду показали, що період цієї зорі змінюється з часом, і було встановлено, що останнє значення становить приблизно 136 днів. Результат аналізу періоду візуальних даних з травня 1904 року по серпень 2016 року, наданий AAVSO для RT Vir. Використовувалися опубліковані бази даних «віртуальних обсерваторій» - AAVSOnet, Hipparcos, ASAS-SN, KWS. Аналіз періодограми показав, що зоря все ще має кілька періодів (320, 280, 169 і 153 дні). Фактично варіації не є справді періодичними, є великі зсуви в часі, зміни амплітуди, і ці менші періоди виникають як піки меншої амплітуди між основними з періодом 320. Були побудовані двоколірні діаграми блиску в I та показника кольору (V-I) від V. Проведено апроксимацію «Running parabola», визначено середні значення <V>=8,457, <I>=3,658, <B-V>=+1,8.

1. Introduction

The star RT Vir = BD+05°2708= HD113285= IRC+10262 = SAO119734 = ASASSN-V J130238.04+051108.2 = HIP 63642=RAFGL 1594 is known as a semi-regular variable (SRb) with brightness limits 7.41 – 9.0 V, spectral type is M8III (GCVS).

The Oxygen-Rich Asymptotic Giant-Branch (AGB) star RT Vir is surrounded by gas and dust as it loses its atmosphere to space. Several mass-loss estimates are given, lying between 1.1×10^{-7} $M_\odot$yr^{-1} and 5×10^{-7} $M_\odot$yr^{-1} (Paladini et al., 2017).

RT Vir is known as a maser source. The 22-GHz emission is located in approximately spherical, thick, unevenly filled shells. The outflow velocity increases two fold or more between the inner and outer shell limits. (Richards et al., 2012). The H_2O masers are located between 2.4 and 18.0 AU from RT Vir. Linear polarization was observed in 9 features around RT Vir. Circular polarization was found in 3 features around RT Vir. It is concluded that in the H2O maser region, the magnetic energy density dominates the thermal and kinematic energy density (Leal-Ferreira et al., 2013).

There are indications that the rate of mass loss correlates with pulsation period (McDonald et al., 2018). In connection with this, the question arises of the most accurate determination of the period (or periods, if the star is multiperiodic). The value of the period from the CCVS (155^d) conflicts with some observational data. For example, Wenzel (1977) obtained a value of about 200 days for the period from the light curve. Signs of a systematic variability were also detected in the radio frequency range with a period that was also close to 200 days. Studies of the period (Andronov et al., 1988) showed that the period of this star varies with time and the latest value was found on that moment to be roughly 136 days. Detailed information about the period values obtained by different authors for RT Vir is collected in the review by Kudashkina (2019).

2. Data and analysis

For periodogram analysis, the observations from the databases of AFOEV (ftp://cdsarc.u-strasbg.fr/pub/afoev), AAVSO (http://aavso.org), ASAS-SN (https://asas-sn.osu.edu/variables), ASAS-SN SKY PATROL (https://asas-sn.osu.edu/), KWS (Kamogata/Kiso/Kyoto Wide-field Survey http://kws.cetus-net.org/~maehara/VSdata.py) were used. A description of working with the data-bases can be found, for example, in the articles by Andronov and Marsakova (2006), Marsakova and Andronov (2006, 2007) and Vavilova et al. (2012). The methods for determination of the characteristics of individual extrema are reviewed by Andronov (2005), Andrych and Andronov (2019) and Andrych et al. (2020). The most recent review on various methods is presented by Andronov (2020), Andronov et al. (2020) and in this volume (Andronov and Chinarova 2020).

The least squares method is used for periodogram analysis. The method is described by Andronov (1994, 2003). The method allows the use of a trigonometric polynomial fit of the statistically optimal degree s:

$$m(t) = a_0 - \sum_{k=1}^{s} r_k \cos\left(2\pi k \cdot (t - T_{0k})/P\right)$$

where r_k are semi-amplitudes and T_{0k} are initial epochs for the brightness maximum (minimum magnitude) of the wave with a period $P_k=P/k$.

The preliminary value of the period (from the General Catalogue of Variable Stars, (Samus et al. 2007-2015) was corrected using the method of differential corrections for each order s of the trigonometric polynomial.

Figure 1 shows the periodogram obtained from AAVSO data. A pulsating period of 372 days is found for RT Vir. The periodogram shown on the fig. 2 has several peaks *V* and *Ic* filters (KWS data), there is no peak at 370^d. There are peaks corresponding to 320, 280, 169 and 153 days. Figure 3 shows 3-period approximation (320, 156, 169 days) of Japanese (KWS) *V* data.

The method of "running parabolae" for smoothing signals with both equidistantly and not equidistantly distributed in time signals was proposed by Andronov (1990, 1996) and was applied to light curves of stars of different types. Figure 4 shows dependence of the Running Parabola approximations with a statistically optimal ratio Signal/Noise (Δt=53 days) from the Japanese (KWS) database for the *B*, *V*, *Ic* filters and the color indexes *B-V* (too few) and *V-Ic*.

Mean values <*V*>=8.457, <*I*>=3.658, <*B-V*>=+1.8 were determined.

Figure 5 shows dependence of the brightness in I and the color (*V-I*) index on *V*, for the Running parabola approximations. If the filters were the same, the expected theoretical slope is 1 for the upper curve, and 0 for the lower one. Deviation of the slope shows a photometrical gradient of dI/dV=0.624±0.007.

3. Conclusions

An analysis of photometric observations of the semi-regular pulsating star RT Vir, whose envelope is the source of maser radiation, was carried out. Such objects are at active stages of evolution (Kudashkina and Rudnitskij, 1988, 1994; Kudashkina, 2003, 2019). Our previous study (Andronov and Kudashkina, 1987) was based on photovisual observations obtained at the Astronomical Observatory of Odesa National University. I.I. Mechnikova. The periodogram showed the presence of several peaks that satisfactorily describe the average light curve. In addition, it turned out that the period increases with time. Its last value at that time was equal to 136^d. Periodogram analysis revealed that the star still has several periods (320, 280, 169 and 153 days). In fact, the variations are not truly periodic, there are large shifts in time, changes in amplitude, and these smaller periods occur as smaller-amplitude peaks in-between the main ones with 320 period.

Two-color diagrams of gloss in *I* and color index (*V-I*) from *V* were constructed.

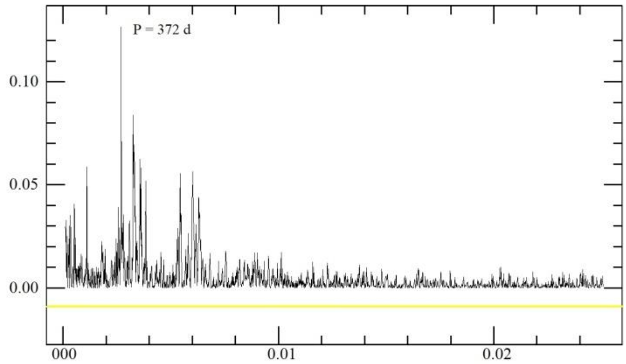

Figure 1: The periodogram obtained from AAVSO data. A pulsating period of 372 days is found.

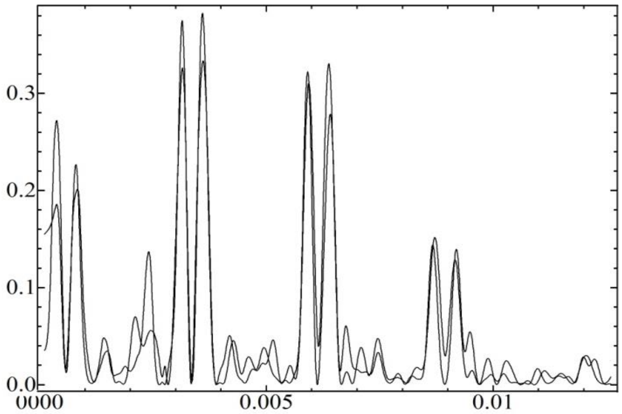

Figure 2: The periodogram has several peaks *V* and *Ic* filters, there is no peak at 370^d. There are peaks corresponding to 320, 280, 169 and 153 days. However, these are not strict periods, as the multi-period approximation shows. Large deviations, amplitude changes, phase shifts are present.

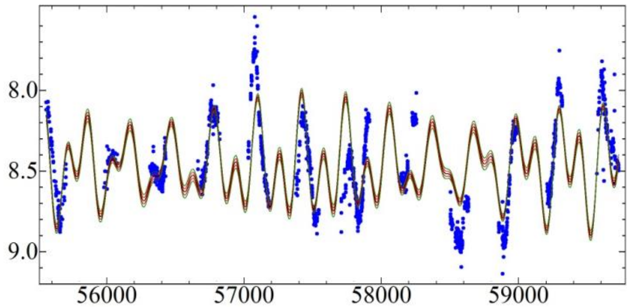

Figure 3: 3 shows 3-period approximation (320, 156, 169 days) of Japanese (KWS) V data.

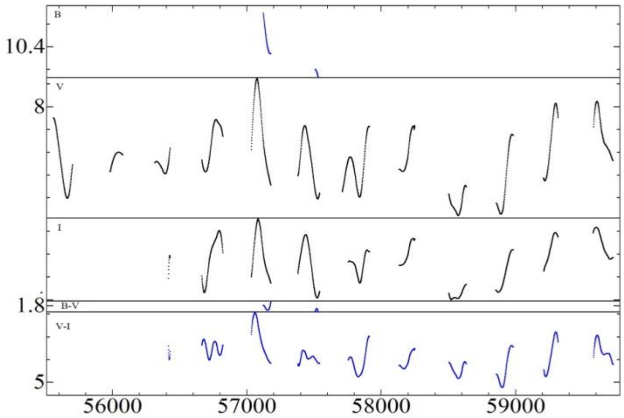

Figure 4: Dependence of the Running Parabola approximations with a statistically optimal ratio Signal/Noise (Δt=53 days) from the Japanese (KWS) database for the *B*, *V*, *Ic* filters and the color indexes *B-V* (too few) and *V-Ic*.

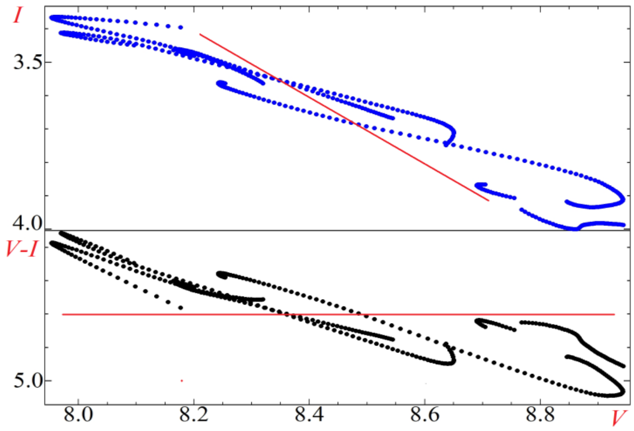

Figure 5: Dependence of the brightness in I and the color (*V-I*) index on *V*, for the Running parabola approximations.

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