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THE FIRST RESULTS OF OBSERVATIONS OF THE JOINT RUSSIAN-CUBAN

LOS PRIMEROS RESULTADOS DE LAS OBSERVACIONES DEL OBSERVATORIO CONJUNTO DE RUSIA Y CUBA

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In this paper we present the first research results of the optical station at the Russian-Cuban observatory. The observatory includes two stations – optical and geodynamical, created by The Institute of Geophysics and Astronomy of Cuba in collaboration with The Institute of Astronomy of The Russian Academy of Sciences and the Institute of Applied Mathematics of The Russian Academy of Sciences. The main instrument of the optical station is a 20-cm wide-field robotic telescope with a CCD camera equipped with the wheel of photometric filters. We present the first photometric researches of active stars V410 Tau, FR Cnc and FK Com obtained in the late 2021 and early 2022.

En este artículo presentamos información sobre los primeros resultados de las investigaciones sobre la estación óptica del observatorio Ruso-Cubano. El observatorio consta de dos estaciones, óptica y geodinámica, creadas por el Instituto de Geofísica y Astronomía de Cuba en colaboración con el Instituto de Astronomía de la Academia de Ciencias de Rusia y el Instituto de Matemáticas Aplicadas de la Academia de Ciencias de Rusia. El instrumento principal de la estacíen óptica es un telescopio robótico de campo ancho de 20 cm con cámara CCD y una rueda de filtros fotométricos. A finales de 2021 y principios de 2022 se realizaron las primeras investigaciones fotométricas de las estrellas activas V410 Tau, FR Cnc y FK Com.

PACS: Telescopes (telescopios), 95.55.-n; Optical instruments (instrumentos ópticos), 07.60.j; Astronomical observations (observaciones astronómicas),95.98.-e.

I. INTRODUCTION

The beginning of 2022 was marked by a significant event in the history of Russian-Cuban scientific collaboration. The international Russian-Cuban astronomical observatory (RCO) was launched on the site of Institute of Geophysics and Astronomy of the Republic of Cuba in Havana. This observatory is the first collaborative result of three scientific institutions from Russia and Cuba in the area of Astronomy: the In-stitute of Astronomy of the Russian Academy of Sciences (INASAN), the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) and the Institute of Geophysics and Astronomy (IGA) in Havana, Cuba. It was built within the framework of inter-governmental agreements on scientific and tech-nical cooperation between Russia and Cuba.

The first joint scientific and technical work on space research started in Cuba nearly sixty years ago. In 1964, Cuban astronomers in cooperation with Soviet specialists started systematic observations of artificial satellites, thus initiating an extensive program of space exploration from the Cuban territory. In 1966, a station for receiving radio signals from artificial satellites started operating at IGA, making possible to obtain the necessary data for studying the upper atmosphere. Simultaneously, stations for tracking artificial satellites equipped with the most advanced instruments [1] were put in operation in Havana and Santiago de Cuba. Since the middle of the 1960s, the Astronomical Council of the Academy of Sciences of the USSR (currently Institute of Astronomy of the Russian Academy of Sciences) has been actively involved in the creation of observation sites for space research. Staff members of the Institute of Astronomy installed in Santiago de Cuba a satellite photometric camera AFU-75 and a laser rangefinder, and organized their time service. In 1969, the astronomers of The Main (Pulkovo) Astronomical Observatory and Special Astrophysical Observatory (SAO) together with Cuban colleagues started studying solar activity from the Cuban territory using a RT-3 radio telescope and a 25-cm refractor telescope [2]. Further, scientific cooperation was expanded within the framework of the ”Intercosmos” program implemented by the USSR. The ”Intercosmos” program included different experiments in space medicine and biology, launching of artificial satellites, and space flights piloted by international crews [3]. The Cuban scientists participated in processing the data from space satellites and studied the interaction between the magnetosphere and the ionosphere in cooperation with scientists from other countries. For many years, as part as international teams, Cuban specialists have performed optical observations of artificial Earth satellites using special photographic and laser systems. On the Cuban territory, the united telemetric system was built, which allowed receiving scientific information directly from board of “Interkosmos” satellites. Within that program, Cuban scientists participated in the projects ”Atmosphere”, ”Big chord” and others for the observation of artificial satellites. Joint scientific work within the program ”Intercosmos” between USSR and Cuba lasted until late 1991, and was suspended due to the collapse of the Soviet Union.

A new stage of Russian-Cuban cooperation began in 2017. The ”Russian-Cuban scientific, technical and environment working group” was made up of government’s members and ministries representatives of the two countries. The working group approved strategic priority areas for scientific cooperation – medicine, biotechnological areas, nano-technologies, astronomy and applied mathematics. The first projects for joint implementation led to the foundation of the Russian-Cuban Observatory for astronomical researches, the Russian-Cuban Geodynamical Station, the Russian-Cuban Station of Climatic Tests for materials and construction elements in tropical conditions of the Cuban region, as well as the joint Russian-Cuban paleontological expedition for all-side study of evolutionary history of biodiversity of Cuba based on paleontological data.

The first activities on the joint Russian-Cuban Observatory started in autumn 2017 [4]. The Russian side was represented by INASAN and IAA RAS, while Cuba was represented by IGA. The first stage included the study of areas for observatory location with primary evaluation of the astroclimate and watching conditions, and the development of the architectural concept of the building. At the second stage that started in 2019, INASAN and IAA RAS finalized the list of technical and scientific equipment for the future observatory and purchased missing items. Restrictions caused by the pandemic corrected the initial plans and project schedule. The restriction delayed equipment shipment from Russia for almost one year. Due to the lockdown of 2020 – 2021, Russian specialists could not arrive in Havana to start the observatory construction. Still, in spite of many obstacles, the project was successfully implemented by the late 2021.

The observatory is located on the territory of the Institute of Geophysics and Astronomy (Havana, Cuba), which provided the entire infrastructure, including the building on which the astronomical dome was placed, and its connection to electrical and information networks. In October-November 2021, IGA, INASAN and IAA scientists jointly completed the construction of the first optical-geodetic station of the Russian-Cuban Observatory. The description of this optical station can be found in [5–7]. Figs. 1 and 2 show pictures of the station.

The main instrument of the observatory is an optical complex consisting of the 20-cm telescope Officina Stellare Veloce RH-200 equipped with FLI Proline 16803 CCD camera on the 10 Micron GM1000 HPS automated mount. The Veloce RH-200 telescope is a wide-field telescope with a 600 mm focal distance, f/3 focal ratio and 220-mm aperture. The telescope is equipped with a set of UBVRI photometric filters implemented as a filter wheel. The telescope is placed into a Scopedome 3M dome with a diameter of 3 m. Astronomical devices are controlled through a control computer using standard software supplied along with the instrumentation.

Figure 1. General View of Russian-Cuban observatory.

Observations can be carried out remotely in two modes, automatic and manual. In the manual mode, the telescope operator points the telescope at the object under study using special software, and sets the duration and number of exposures of the CCD camera. In the automated mode, no operator is required to perform the observational operations. An automatic observation session is controlled by a software developed at INASAN.

Figure 2. Overview of the space inside the dome.

Despite the fact that the observatory is located in Havana, where light pollution is strong, we are able to observe objects up to 13m in the V filter. During observation sessions from the territory of the IGA, all internal illumination of the site is turned off. To reduce scattered light in the telescope, the telescope tube was equipped with a 20 cm long hood. Observations of selected objects begin only when they rise higher than 35 degrees above the horizon and only after 22 hours, local time. Such conditions make it possible to conduct observations and obtain high-quality results.

II. THE FIRST SCIENTIFIC RESULTS OF THE OBSERVATORY

The Russian-Cuban Observatory began receiving the first scientific data by the end of 2021. From December 2021 to April 2022, 52 observation sessions were carried out. The first objects of study were the 3 stars - V410 Tau, FR Cnc and FK Com. These stars belong to rapidly rotating, chromospherically active stars. They exhibit rotational light modulation due to the presence of cold spots on their surfaces. For each star, the light curves were obtained with several photometric filters. Based on the photometric variability in the V filter, maps of surface temperature inhomogeneities were constructed for each star. The method for restoring the map of surface temperature inhomogeneities is described in detail in [8]. The light curves of the stars were analyzed using the iPH program [8]. The program allows solving the inverse problem of reconstructing the temperature inhomogeneities of a star from the light curve in a two-temperature approximation, in which the temperatures of the unperturbed photosphere and sunspots are specified. The description and tests of the program were presented in [9]. The data obtained from the stars V410 Tau, FR Cnc, and FK Com allowed estimating the area of spots on the surface of the star.

II.1. Observation and study of V410 TAU

V410 Tau is a young, fully convective T Tauri star (WTTS), about 1 million years old, with magnetic field of complex structure [10, 11]. The star was the subject of numerous studies [12]. The distance to the star is 129.4±0.4 pc. V410 Tau belongs to one of the young star-forming regions C2-L1495 in the Taurus complex. The age of the star was recently estimated using GAIA data as 1.34±0.19 Myr [13]. The effective temperature of the star is 4500 K, log(g) is 3.8. The mass and radius of the star (in solar units) are 1.42±0.15$M_\odot$ and 3.40±0.5 $R_\odot$, respectively [11]. Paper [14] reports the study of spots evolution on the star's surface over a period of 46 years with the method of reconstructing the surface temperature inhomogeneities from photometric measurements. In addition, the star's surface has been recently mapped many times by the method of Zeeman-Doppler mapping [12]. New photometric observations of V410 Tau were carried out from December 7, 2021 to January 25, 2022. All the observations were carried out automatically according to a predetermined observational plan with no operator on duty. To achieve the optimal signal-to-noise ratio, the exposure time was chosen for each filter individually: in the B filter - 120 s, in the V, R, I filters - 90 s. A total of 400 brightness estimates were obtained in the B, V, and R photometric filters in the epoch interval HJD 2459555.738 – HJD 2459604.750.

The observational data were reduced using standard photometric calibration procedures using the Maxim DL software. The original images were subjected to the bias frame and dark frame subtraction procedure. To eliminate the effects of illumination and dust shadows on the telescope optics, the image calibration procedure included flat field correction. The star's brightness was estimated by differential photometry. This method implies the target brightness to be estimated relatively to a comparison star that is well photometrically examined.

Following [12], we picked the comparison star to be V1023 Tau (B=14.179^m, V=12.641^m, R=11.573^m). The accuracy of a single measurement was RMS 0.02^m-0.05^m in three filters. The data of the star's photometric variability in the V filter were used to construct a map of surface temperature inhomogeneities. After plotting the phase diagram, the measurement data were averaged over intervals of 0.05 phase periods, see Fig. 3.

In Fig. 3, our measurements are compared with the results published in [12] (photometric observations were made at the CrAO RAS in 2019). The observations presented are two years apart. Noteworthy are the differences in the shape of the curves at the phases between 0.0 – 0.45 (the position of the second active region on the stellar surface, see below). At the phases of 0.5 – 0.85, the curves are in a good agreement. The light curve we obtained (averaged for 20 equally spaced phases) was analyzed using the iPH program.

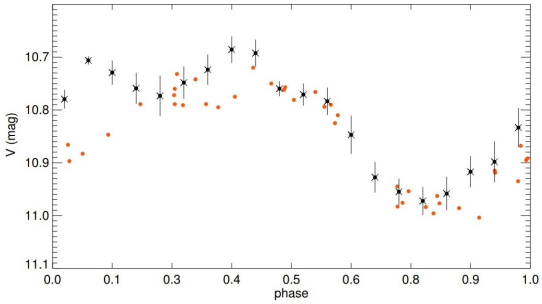

Figure 3. Phase variation of light V410 Tau in a V filter. Dark symbols with error bars – our measurements, light dots are the data reported in [12].

To construct a map of surface temperature inhomogeneities, we assumed that the effective temperature is 4500 K, and the temperature of the spots is 3750 K. The grid data of Kurucz models were used for calculations. During the simulation, the surface of the star was divided into elementary areas of the size of 6°x6°, for which the filling factors f were determined, which are unknown quantities of our analysis. Fig. 4 shows the results of reconstruction of temperature inhomogeneities on the surface of V410 Tau for the ob-servation period HJD 2459555.738 – HJD 2459604.750.

Based on the constructed maps, we determined the longitudes corresponding to the maximum values of f (darker areas on the maps in Fig. 4). Note that there are sunspot concentrations at two longitudes (at 290° it is pronounced, but at 80°, it is determined with a larger uncertainty). The more active region has a complex structure; it may be more elongated towards the smaller region. The position of the more active region with the longitude of 290° coincides with the position obtained in [12] for the cold spot, phases 0.7-0.8.

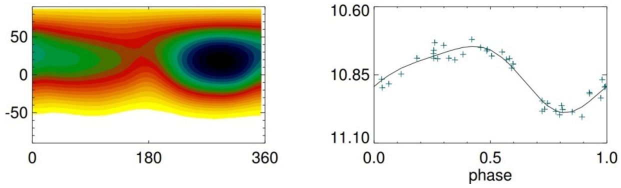

Figure 4. Results of the reconstruction of temperature irregularities on the surface of V410. Left panel: Surface maps are represented in one and the same scale, dark spots correspond to higher filling factor f values. The X and Y axes of the left-most panel are longitude and latitude axes, respectively. Right pane: Light curves (crests) and theoretical light curves developed on the basis of reconstruction simulation (solid line).

As noted above, the photometric measurements spanning the period of 46 years allowed I. Savanov [14] to restore the maps of surface temperature inhomogeneities of V410 Tau and to study the evolution of spots along with changes in the position of the dominant active region. In some cases, a second active region (longitude) located close to the counter-phase of the dominant region was detected. In [14], it is also shown that within the interval of 4800 days (13 years), lasting up to the end of 2002, the brightness minimum remained at the same phase, implying the stationary location of the active region. In late 2002, the active regions started moving across the star's surface. In our research we detected the active regions at the phases of 0.22 and 0.80, which is in agreement with the results of previous studies. According to [14], the average spotted fraction of the surface of V410 Tau (spottedness parameter S) is 32 %, varying from 27 % to 40 % within the specified observation period. In our study, we determined the value of S as 34 % (see the corresponding surface map in Fig. 4), which practically coincides with the previously determined average value.

II.2. *Observations and study of FR Cnc*

FR Cnc (BD + 161753 = MCC 527 + 1RXS J083230.9 + 154940) is a single young, fast-rotating star of the K7V spectral type. Its brightness is V=10.41m. Photometric and spectroscopic studies of FR Cnc [15, 16] gave an estimate of the rotation period of 0.8267±0.0004 days. The light curves of the star significantly vary both in phase and in amplitude, which may indicate the evolution of spots on the star's surface. FR Cnc spectra demonstrate strong lines of hydrogen and ionized calcium, which prompts high stellar activity. Works [17, 18] report stellar eruptive activities.

In [19] the authors report detailed simultaneous X-ray and optical observations of FR Cnc. They found that the X-ray spectrum can be explained by a dual-temperature plasma model with the temperatures of cold and hot components of 0.34 keV and 1.1 keV, respectively. The X-ray light curve within 0.5 – 2.0 keV is rotation-modulated with the amplitude of modulation of 17 %. This light curve also demonstrates anti-correlation with optical light and color curves, the maximum of X-ray radiation corresponds to the minimum of optical emission and colder spots on the surface of FR Cnc. The X-ray brightness of FR Cnc has remained almost constant for the last 30 years with the average total flux of $4.85{\cdot}10^{29}$ erg/sec within 0.5 – 2.0 keV energy range.

New photometric observations of FR Cnc were carried out from December 17, 2021 to January 3, 2022, during the second half of the night, at optimal visibility conditions. This study continues a long-term monitoring of FR Cnc initiated by a team of scientists in 2019 [18].

The observations were carried out in the automatic mode following a preset program with no opera-tor involvement. Exposure times were individually selected for each filter: B – 90 sec, V and R filters – 60 sec. In total, each filter provided 200 estimates of the brightness. Observation data were processed under the standard photometric calibration procedure. To measure brightness variations we used the method of differential photometry. The comparison star was BD+16 1751 (B=10.22^m, V=9.51^m, R= 8.72^m). The RMS of a single measurement was 0.01^m-0.012^m in the three filters. No flares were registered during the observations.

The measured photometric variability in the V filter was used to construct a map of surface temper-ature inhomogeneities. Following the computation of the phase diagram, the data were averaged over phase intervals of 0.05 (see Fig. 5). When comparing with the results of our previous observations in [18], we can conclude that the shape of the light curve has changed – the light minimum corresponding to phase 0.65 has almost disappeared.

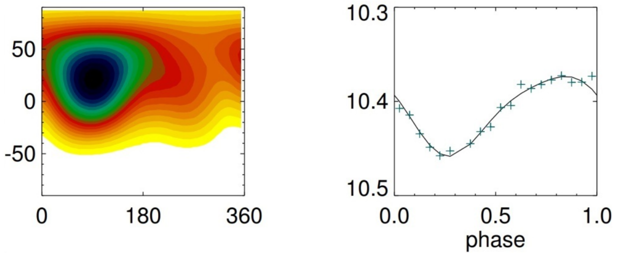

Figure 5. Results of reconstruction of temperature inhomogeneities on the surface of FR Cnc. Left panel: Surface maps are presented on a single scale, darker areas correspond to higher values of the fill factors f. On the abscissa and ordinate axis we have longitude and latitude in degrees, respectively. Right panel: observed light curves (crosses) and the restored light curve (solid line).

The map of surface temperature inhomogeneities was reconstructed using the technique described in detail above. Similar to [20], we assumed that the effective temperature of FR Cnc is Teff = 4250 K, and the spots' temperature is 3000 K. The brightness of the star in the V filter, given the absence of spots on its surface, was taken equal to 10.3m. According to [20], the inclination angle of the star's rotation axis to the line of sight is 55°. Fig. 5 shows the resulting reconstructed map of temperature inhomogeneities on the FR Cnc surface for the observations by the end of 2021. As noted earlier in [18, 20] FR Cnc spots concentrate near two longitudes (one of them is more pronounced) possibly connected by a bridge, which is very visible on Doppler maps built from spectral observations of 2004. In the map based on observations of 2021 the smaller spot is quite weak; it almost disappears. According to [18], the spotted fraction of the star's surface in the beginning of 2019 was about 12 %. In 2021, the fraction decreased down to 8 %.

To compare, in 2004 according to [20] (based on the results of Doppler mapping) the spotted fraction was only 6 % of the total surface of FR Cnc.

II.3. *Observations and study of FK Com*

The star FK Com (FK Comae Berenices, HD117555) is a very-fast rotating yellow giant. It is commonly believed that this single star was formed by merging components of a binary star. Its chromo-spheric activity is accompanied by intense ultraviolet and X-ray radiation, as well as flares [21]. FK Com is actively studied by ground-based photometry and spectroscopy, as well as by space telescopes in the UV and gamma wavelength ranges. The brightness of the object is V=8.245m, spectral class is G5III. The pho-tometric rotation period of FK Com is estimated as 2.4 days. Its photometric variability is related to the rotational modulation of emission from spotted star surface. Photometric studies of FK Com led to discov-ery of a phenomenon of changing active longitudes (flip-flop phenomenon) [22].

New photometric studies of FC Com had been carried out at the RCO from March 5, 2022 to April 3, 2022. This observational work on the FK Com is a continuation of the series of works carried out by the team of authors since 2013. The observations were carried out automatically. The star was imaged only in the V filter. The exposure time was 15 seconds. During the observational period, 1570 brightness estimates were obtained. The observational data were processed using standard photometric reduction procedures. For differential photometry of the star FK Com, the star HD117567 (F2, V= 7.62^m) was used as a refer-ence. The RMS of a single measurement was 0.02^m. No flares were recorded during the observations.

The photometric variability in the V filter was used to construct a map of surface temperature in-homogeneities. Following the computation of the phase diagram, the data were averaged over phase inter-vals of 0.05 (see Fig. 6). After analysing the new data, we can conclude that the shape of the light curve has changed in comparison with our previous observations [23]. The light modulation is weak, and the light curve itself has two weakly expressed minima corresponding to phases 0.25 and 0.55. The spotted fraction of the surface is 14 %, which is slightly lower than the average spottedness (parameter S = 0.18) [20]. Note that a “flat” light curve of FK Com, similar in shape, was recorded previously in 1998 – early 1999 [22].

From March 5 to April 3 2022, FK Com was also available for observations from the European part of Russia. Therefore, joint observations of FK Com were carried out at two observatories - at the Zvenigorod Observatory of INASAN and at the Russian-Cuban observatory in Havana. On the night of March 30 to March 31, an experiment was carried out on continuous observations of the star. We obtained a continuous series of observations of a single object 9.7 hours long. The Zvenigorod observations were made before dawn, the duration of observations was 2.5 hours. 15 minutes after the end of observations in Zvenigorod, the Russian-Cuban observatory in Havana continued the run. The results of joint observations showed that a distributed observational network can be successfully implemented on the basis of two observatories.

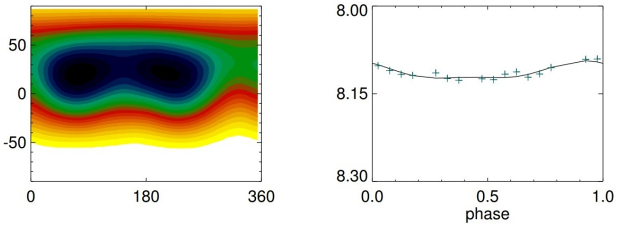

Figure 6. Results of the reconstruction of temperature inhomogeneities on the surface of FK Com. Left panel: Surface maps are presented on a single scale, darker areas correspond to higher values of the fill factors f. On the abscissa and ordinate axis we have longitude and latitude in degrees, respectively. Right panel: Observed light curves (crosses) and the theoretical light curves constructed from the reconstructed model (solid line).

III. CONCLUSIONS

In the course of joint work carried out by the Institute of Geophysics and Astronomy of Cuba and the Institute of Astronomy of the Russian Academy of Sciences and with the active support of the Ministry of Science, Technology and Environment of the Republic of Cuba and the Ministry of Science and Higher Education of the Russian Federation, a joint Russian-Cuban astronomical observatory was built.

The observatory carried out optical observations of the chromospherically active stars V410 Tau, FR Cnc and FK Com. The first observations within the period December 2021 - April 2022, resulted in obtaining light curves of the mentioned objects with photometric filters B, V, R. It should be noted that within the specified period, INASAN observatories could not observe these objects due to poor weather conditions, so the observations of the Russian-Cuban Observatory perfectly filled this gap. The measured light curves of V410 Tau, FR Cnc and FK Com allowed us to construct the maps of surface temperature inhomogeneities of these objects. According to our estimate, the spotted fractions of the total surface area are 32 %, 8 %, and 14 % for V410 Tau, FR Cnc, and FK Com, respectively. The results of the joint observations of FK Com from the territories of Russia and Cuba have shown the capabilities of a distributed observational network.

The creation of an RCO is a new stage in the scientific cooperation between Russia and Cuba. In the future, the observatory will become a new center for education and professional training of Cuban astronomers and technical specialists.

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