STERNBERG ASTRONOMICAL INSTITUTE
MOSCOW STATE UNIVERSITY

INSTITUTE OF ASTRONOMY
RUSSIAN ACADEMY OF SCIENCES

ASTRONOMY AT THE EPOCH OF MULTIMESSENGER STUDIES

Proceedings of the VAK-2021 conference, Aug 23–28, 2021

Edited by A.M. Cherepashchuk et al.

Moscow
Janus-K
2022

UDK 52
BBK 22.6

Astronomy at the epoch of multimessenger studies. Proceedings of the VAK-2021 conference, Aug 23–28, 2021 — Moscow, Janus-K, 2022 (486 pp.)

ISBN 978-5-8037-0848-3

Edited by

Cherepashchuk A.M., Emelyanov N.V., Fedorova A.A., Gayazov I.S., Ipatov A.V., Ivanchik A.V., Malkov O.Yu., Obridko V.N., Rastorguev A.S., Samus N.N., Shematovich V.I., Shustov B.M., Silchenko O.K., Zasov A.V.

This volume contains papers based on talks presented at the Russian Astronomical Conference VAK-2021 and comprises a wide range of astronomical and astrophysical subjects.

Change of the structure and physical properties of optical pulsations from transitional millisecond pulsar J1023+0038

A. Tanashkin[1], G. Beskin[2,3], S. Karpov[2,3,4], V. Plokhotnichenko[2], Yu. Shibanov[1], D. Zyuzin[1]
artyom.tanashkin@gmail.com

[1] *Ioffe Institute, Saint Petersburg 194021, Russia*
[2] *Special Astrophysical Observatory, Nizhniy Arkhyz, Russia*
[3] *Kazan Federal University, Kazan, Russia*
[4] *Institute of Physics, Prague, Czech Republic*

In this paper we present some results of high temporal resolution multichannel optical observations of a transitional millisecond pulsar J1023+0038 with the panoramic photometer-polarimeter mounted on the 6-meter BTA telescope of Special Astrophysical Observatory. Besides the double-peaked optical pulsations with the neutron star rotation period, similar to those reported by other authors, during one of the nights we observed dramatic state change of the system. For about 230 seconds instead of typical double-peaked structure single peak with strongly increased amplitude was seen. Simultaneous observations in two channels also allowed us to detect energy redistribution in the spectrum of the system in this event. We also note chaotic orbital phase changes of the signal with maximum amplitude of about 25 seconds, corresponding to the linear shifts of about 3000 kilometers.

Keywords: stars: neutron; pulsars: individual (PSR J1023 + 0038); accretion, accretion disks

DOI: 10.51194/VAK2021.2022.1.1.115

1. Introduction

Transitional pulsars constitute a subclass of millisecond pulsars in close binary systems which demonstrate switches between two distinctive regimes of interaction of a neutron star with its companion: episodes of intense accretion, during which the system is seen as a low mass X-ray binary, are followed by quiescent states observed as millisecond radio pulsars. The archetypal member of this class, J1023+0038, shows extremely rich variety of observational properties. One of the most intriguing is millisecond optical pulsations, first found by [1] and confirmed by a number of subsequent studies [2, 3]. The pulsing optical emission is characterized by double-peaked structure with variable amplitudes of the peaks, reaching about 1% in maximum. Simultaneous optical and X-ray observations revealed strong connection between optical pulsations and behaviour of the system in X-rays [3].

2. Observations

We observed PSR J1023+0038 during seven nights between Feb 17 2017 and Jan 5 2020 with the 6-m telescope BTA of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS). The observations were carried out using the panoramic photometer-polarimeter operating in the dual-channel regime [4]. This provides the advantage of collecting photons simultaneously with the two MCP-based panoramic photon counters, the "red" one with the GaAs photocathode sensitive at the 5640 Å effective wavelength, and the "blue" one with the multi-alcali photocathode sensitive at the 4170 Å effective wavelength. All the photons in a $10'' \times 10''$ diaphragm around the object were detected and registered with an effective temporal resolution 1 μs. The overall length of the collected data is about 10 hours.

The times of arrival of every photon were converted to the Solar system barycenter. In order to search for the periodic signal one also should account for the orbital motion of the neutron star in the binary system. It was shown in previous studies that the system exhibits rather complex orbital behaviour, so we performed standard analysis (see, e.g., [5]) to find the best orbital phase of the emitting area for each data segment (see the next section).

3. Results and discussion

In the majority of our data we see double-peaked pulsations with variable amplitudes, similar to those reported in previous studies (see Fig. 1). However, during the Nov 15 2017 night we observed very strange behaviour of the object. For about 230

Table 1: Summary of the BTA observations.

Night	Date	Start, UT	Duration, s	Orbital phases
1	17.02.2017	19:19:16	3800	0.31–0.54
2	14.11.2017	02:00:21	3200	0.64–0.83
3	15.11.2017	00:54:19	6700	0.46–0.91
4	07.04.2018	21:33:51	3800	0.68–0.89
5	31.01.2019	23:55:27	6000	0.54–0.89
6	04.01.2020	00:22:25	8700	0.83–0.33
7	05.01.2020	02:28:36	3300	0.32–0.38

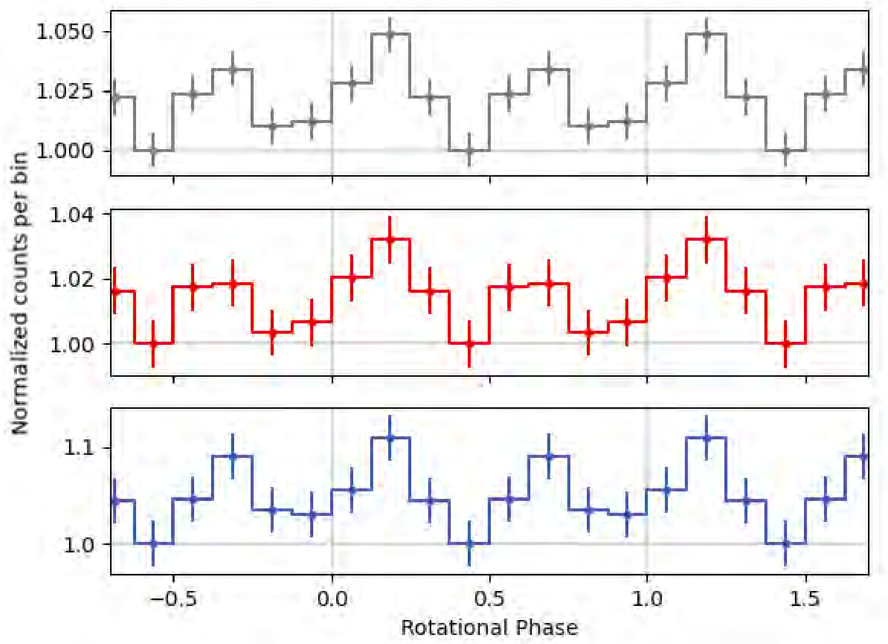

Figure 1: Typical double-peaked pulse profile observed in the major part of our data. Top, middle and bottom panels show both channels joined, only red, and only blue channels, respectively.

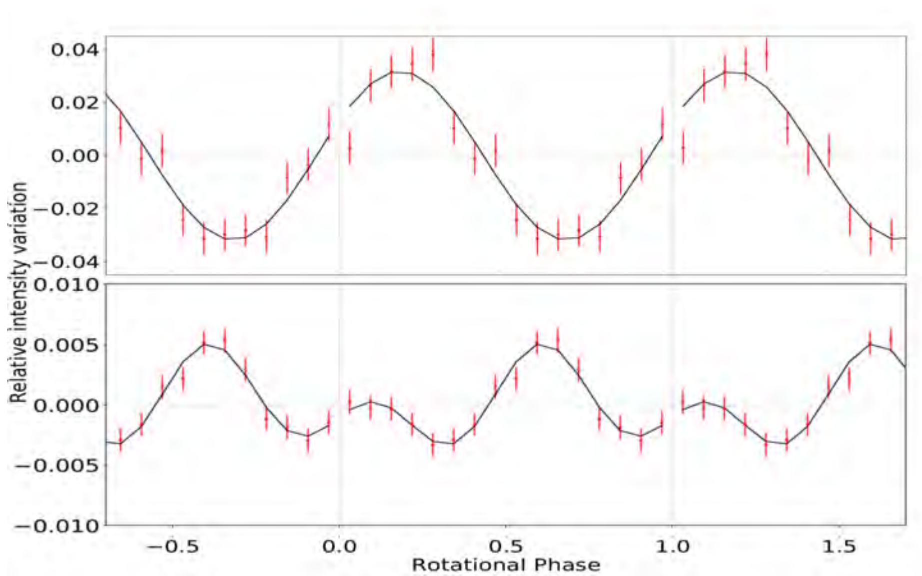

Figure 2: Pulse profiles in the "red" channel during the 230-s long event (upper panel) and the rest of the night (lower panel).

seconds the "standard" double-peaked pulsations (Fig. 2, lower panel) were replaced by much stronger single-peaked ones (Fig. 2, upper panel). The profile became nearly sinusoidal and the distribution of energy in the spectrum of the pulsing component became softer. Significant flaring activity was also seen on the light curve during the event.

Another interesting feature seen in our data is the chaotic orbital phase changes of the area responsible for the pulsing emission. This peculiarity was noted in previous studies, but the characteristic timescales were thought to be much longer than a few days. In contrast to this, we observe such changes on timescales of one day and in some cases even a few hours. Maximum orbital shifts of about 25 seconds correspond to linear displacements up to 3000 kilometers. This fact indicates that the emission area can not be bound to the neutron star; in particular, it can not be located near the light cylinder of the neutron star, as proposed by some models. More probable scenario seems to be the one in which various clouds of matter are scattered along the orbit and spontaneously generate physical conditions favorable for the pulsar wind energy to be re-emitted in the optical band.