Historical light curve of the black hole binary V4641 Sgr based on the Moscow and Sonneberg plate archives

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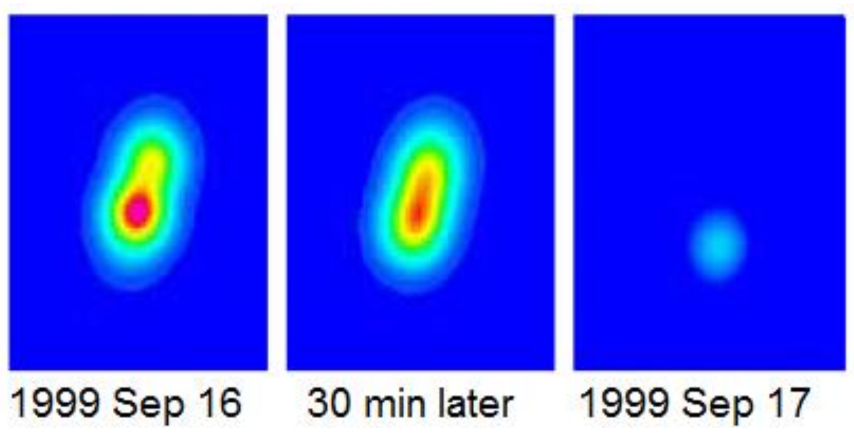

Fig.1 VLA interferometry by R.Hjellming, 1999

Introduction

V4641 Sgr is a system containing B9–A0 III star with the mass of 2.9 ± 0.4 $M_\odot$ and black hole of 6.2 ± 0.7 $M_\odot$. The orbital period of the system is P = 2.817 day. Its distance is 6.2 ±0.7 kpc. The star was discovered by Goranskij during the 1978 outburst but at first it was misidentified with Luyten's variable GM Sgr, a Mira type star (fig.2). In early 1999 V4641 Sgr was detected in X-rays as SAX 1819.3–2525, and later, in 1999 September it experienced a large outburst in all ranges of electromagnetic wavelengths and reached magnitude of $8^m.9$ in V band. In this event, relativistic jets were detected with the VLA radio interferometer (fig.1). The orbital period was determined by using spectroscopy and photometry. Photometric observations show active states and outbursts, short-time flaring in the scale of seconds, temporal appearance of reflection effect, rapid changes in the profiles of Balmer lines and other manifestation of the black hole activity.

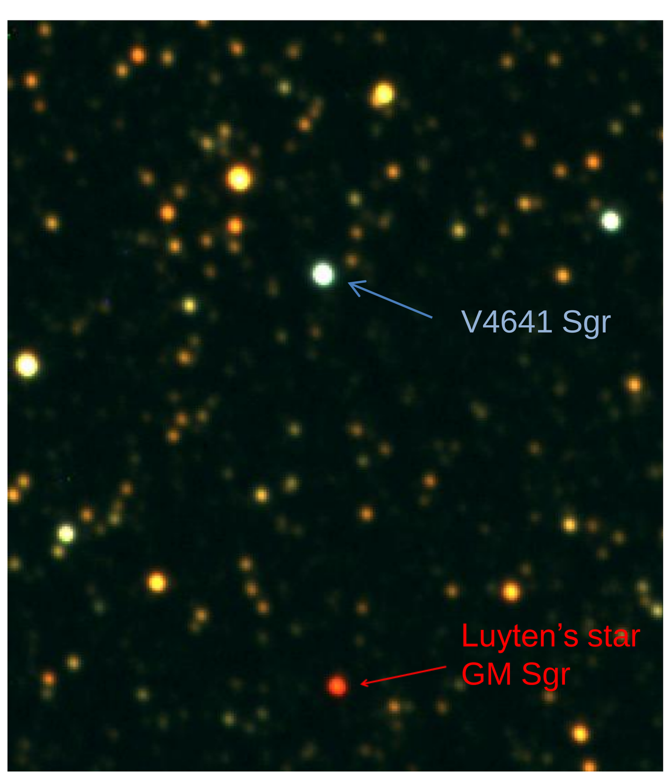

Fig.2 Sky area around V4641 Sgr.

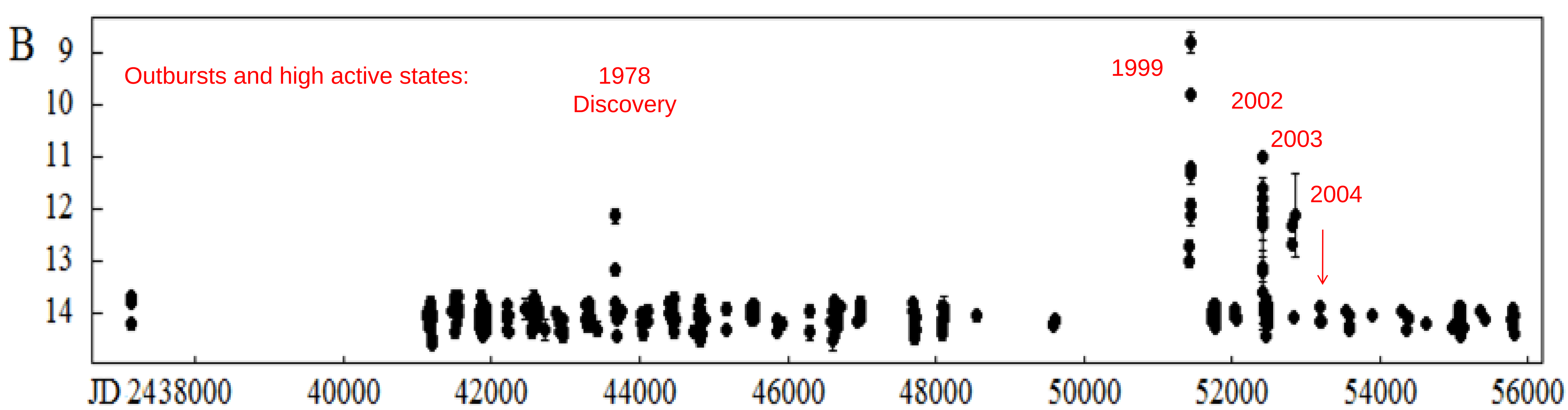

Fig.3 Historical half-century light curve of V4641 Sgr

Results

We found 266 plates of V4641 Sgr in the Moscow SAI collection taken with 40 cm astrograph of SAI Crimean Station which are dated between 1960 and 1992. Additionally, 11 plates were found in Sonneberg collection. Plates were taken between 1984 and 1988 with the similar astrograph. The total light curve of V4641 Sgr in the B band is presented in Fig.1. In the period between 1972 and 1992, only single 1978 outburst was detected, this is the outburst which led to discovery of the star. In this period, the object was not detected in X-rays. In the peak of 1978 outburst, the star reached $12^m.12$ B, and subsequent decay continued about 2 days. After the strong 1999 outburst, the optical outbursts became frequent. They were repeated in 2002, 2003, and 2004. Object appeared in X-rays also in 2008, 2010, and in 2014. Frequency analysis with the phase-dispersion minimization method gives the best period $2^d.81728 \pm 0^d.00004$ and the double-wave light curve with unequal minima depths. The deepest minimum coincides with the black hole inferior conjunction. The date of conjunction is JD Hel. 2451764.337 ±0.005. The light curve plotted versus phase of this period is given in Fig. 4. We used 17 comparison stars, and characteristic curves was fitted with the one or two order polynomial. The accuracy of the fit varies between $0^m.03$ and $0^m.20$, mean $0^m.08$. An amplitude of the averaged orbital light curve is $0^m.45$, and a depth of a secondary minimum is $0^m.28$. Such low-amplitude effects as X-ray irradiation and rapid flaring in optical bands are lost due to errors of photographic observations and long exposures.

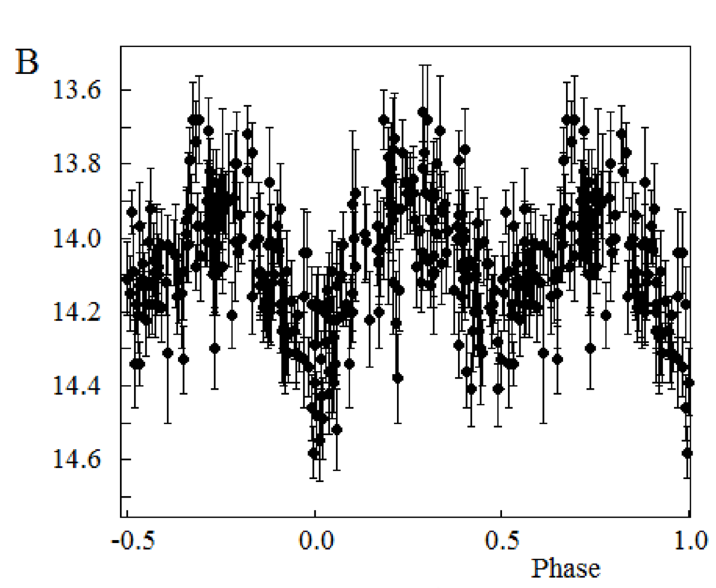

Fig.4 Photographic photometry. The light curve has a double-wave shape with two minima of unequal depth, the deepest minimum coincides with the inferior conjunction of the black hole at the epoch of T_0 = JDhel.2451764.337.

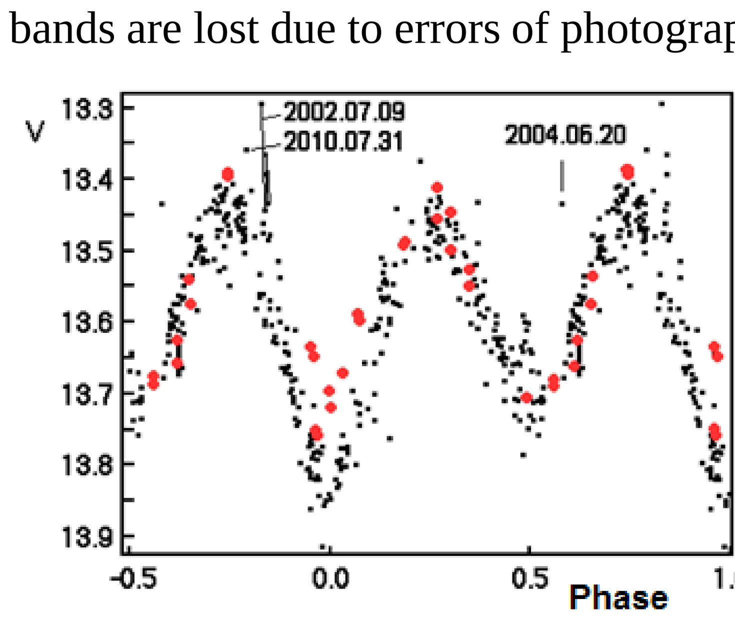

Fig.6 Appearance of reflection effect in May 2007 (red circles) in V band. SWIFT detected a weak and variable X-ray radiation.

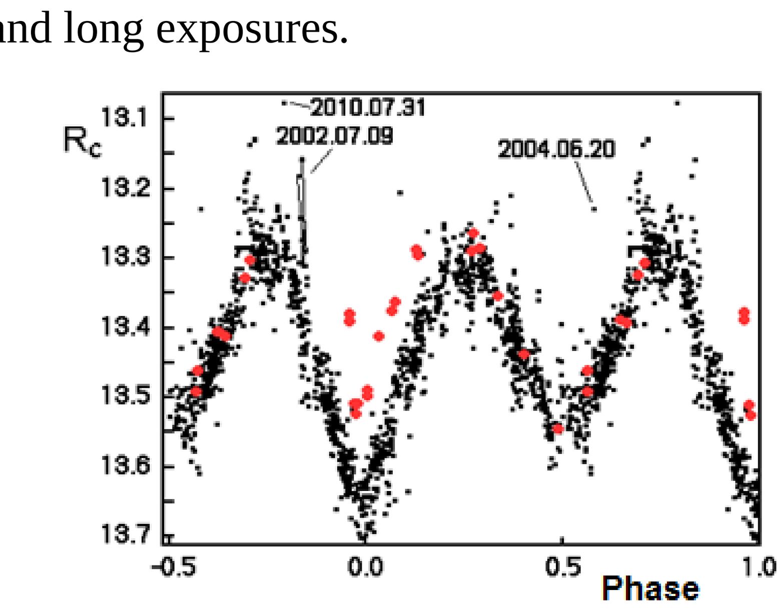

Fig.7 CCD photometry in R band in May 2007 (red circles). Short solid lines mark splashes of an optical radiation off.

We performed accurate CCD V and R_C photometry in 16 nights between June 5 and 25 using 60-cm telescope of Sternberg Institute's Crimean Station and SAO 1-m telescope (Fig.6 and Fig.7). These observations show essential light excess over the quiet light level seen only in the orbital phases between -0.25 and +0.25 with the maximum value of 0.15 mag in the V band at the black hole inferior conjunction. The excess is absent in other orbital phases. This phenomenon has not been observed previously. We treat it as an irradiation of the area of A0 star facing to the black hole. The area re-emits faint X-ray radiation of the black hole in optical bands.

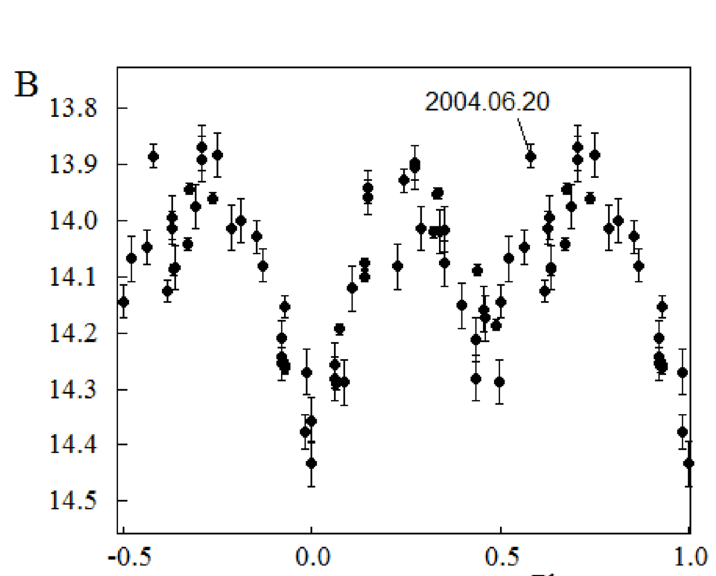

Fig.5 CCD photometry in the B band. Accurate orbital period found from archive photometry + CCD $2^d.817278 \pm 0^d.000044$

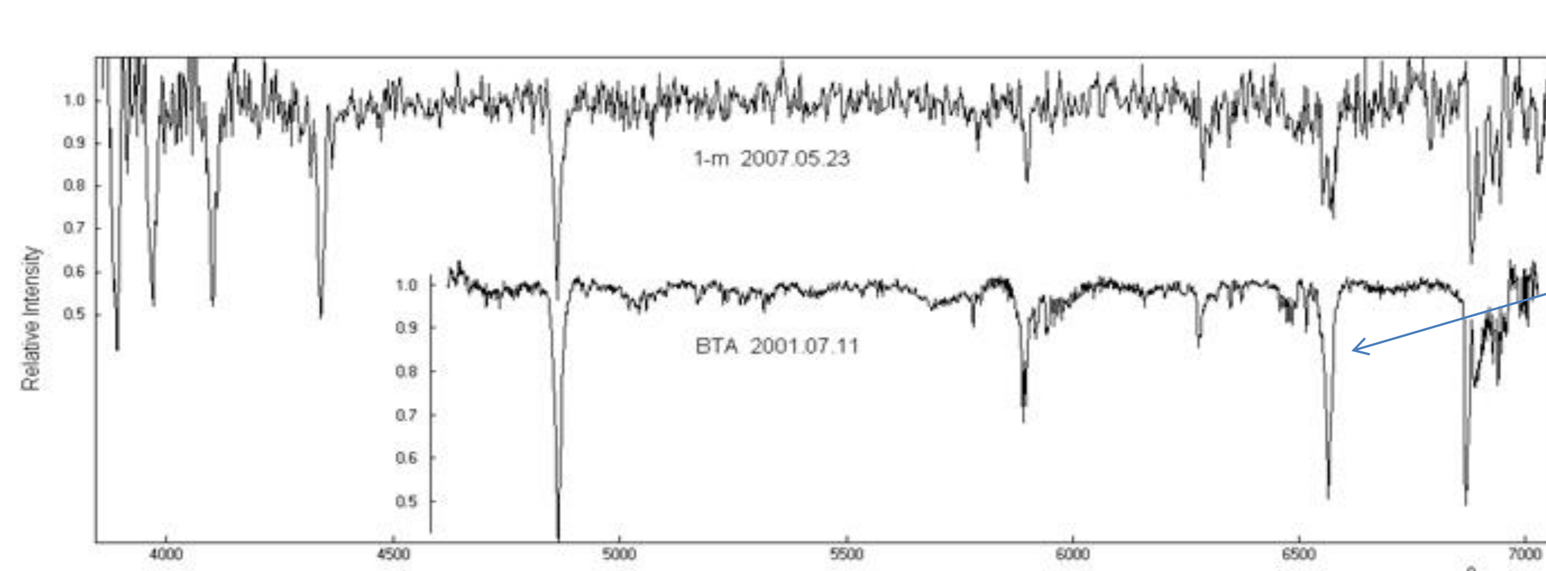

Fig.8 Top spectrum was taken with ZEISS-1000/UAGS in the active state during the reflection effect. The absorption line of H_alpha is filled up with an emission. Lower spectrum was taken with BTA/UAGS in the inactive state during the inferior conjunction of the black hole. The absorption of a gaseous flow near the black hole is seen.

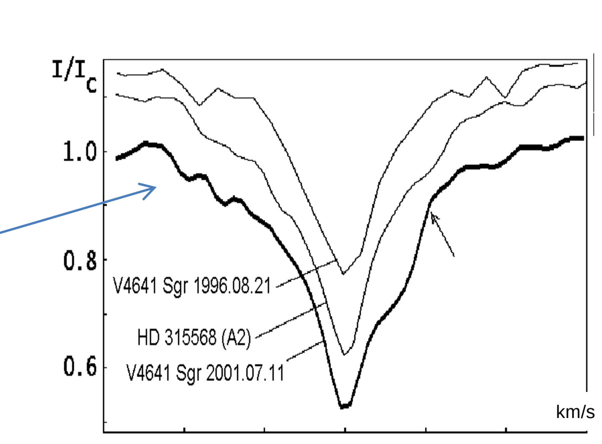

Fig.9 Profiles of H_alpha emission in a quiescent state in an elongation (head profile, thin line), the profile of the check star (in the middle), the profile in the inferior conjunction of the black hole (lower profile, bold line). The black hole mass was confirmed with a maximum gas flow velocity.