Monitoring of the peculiar X-ray binary pulsar SAX J0635.2+0533

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The X-ray binary pulsar SAX J0635.2+0533

Discovered with *BeppoSAX* in 1997 (Kaaret et al. 1999):
- f(2-10 keV) = 1.2x10^{-11} erg cm^{-2} s^{-1} ⇒ L_X = 3.4x10^{34} erg s^{-1}
- hard power-law spectrum (Γ = 1.5), extending up to 40 keV
- positionally coincident with a Be star (V = 12.8) ⇒ HMXRBs
- X-ray pulsations with P_{spin} = 33.8 ms (Cusumano et al. 2000)

⇓

B ~ 10^9 G for accretion onto the NS surface

⇓

quite a peculiar object

Pulse frequencies measured with *RXTE* in September 1999 (Kaaret et al. 2000):
- discovery of a possible orbital modulation with P_{orb} = 11.2 days
- lower limit ($\dot{P}_{spin}$ > 3.8x10^{-13} s s^{-1}) on its long-term spin down

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possible large rotational energy loss ($\dot{E}_{rot}$ > 4x10^{38} erg s^{-1} >> L_x)

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possibility of a rotation-powered pulsar:
the X-ray emission is due to the shocks between
the relativistic wind of the pulsar and that of the companion star

In-depth timing and spectral analysis of SAX J0635.2+0533

1) We intestigated the long-term variability of SAX J0635.2+0533 through:
- a systematic reanalysis of all the *RXTE* observations performed between 1999 and 2001 (epochs A, B, and C)
- a systematic reanalysis of all the *XMM-Newton* observations performed between 2003 and 2004 (epochs D and E)
- a new long-term source monitoring performed with *Swift*/XRT between 2015 and 2016 (epochs F and G)

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- SAX J0635.2+0533 was clearly detected in most of the observations, although at very different flux levels (Fig. 1 and 2).
- The source is very variabile, with a dynamic range of more than two orders of magnitude
- The source variability is rather fast: the source flux can increase/decrease of more than one order of magnitude over a timescale of a few days
- In most observations the source was detected with f_X ~ 10^{-13} - 10^{-12} erg cm^{-2} s^{-1} ⇒ L_X ~ 10^{32} - 10^{33} erg s^{-1} (assuming d = 5 kpc)

2) We searched for the presence of pulsations in the data of epochs B and C, that were not analyzed by Kaaret et al. (2000): we took into account a possible spin-up or spin-down of the pulsar since the time of the previous period measurement (P = 33.9 ms in epoch A), but we could not confirm the pulsed emission

3) We investigated the possible spectral dependence on the source flux: we considered two separate spectra (with similar count statistics) for, respectively, the high and low flux states observed with *Swift*/XRT, but the simultaneous fit of the two spectra provided no evidence of spectral variability

4) We searched for long-term periodicities in the *Swift*/XRT data by applying the Lomb-Scargle method (Scargle 1982), but we could not confirm the proposed orbital period of 11.2 days (Kaaret et al. 2000)

⇒ See La Palombara & Mereghetti 2017, A&A 602, A114

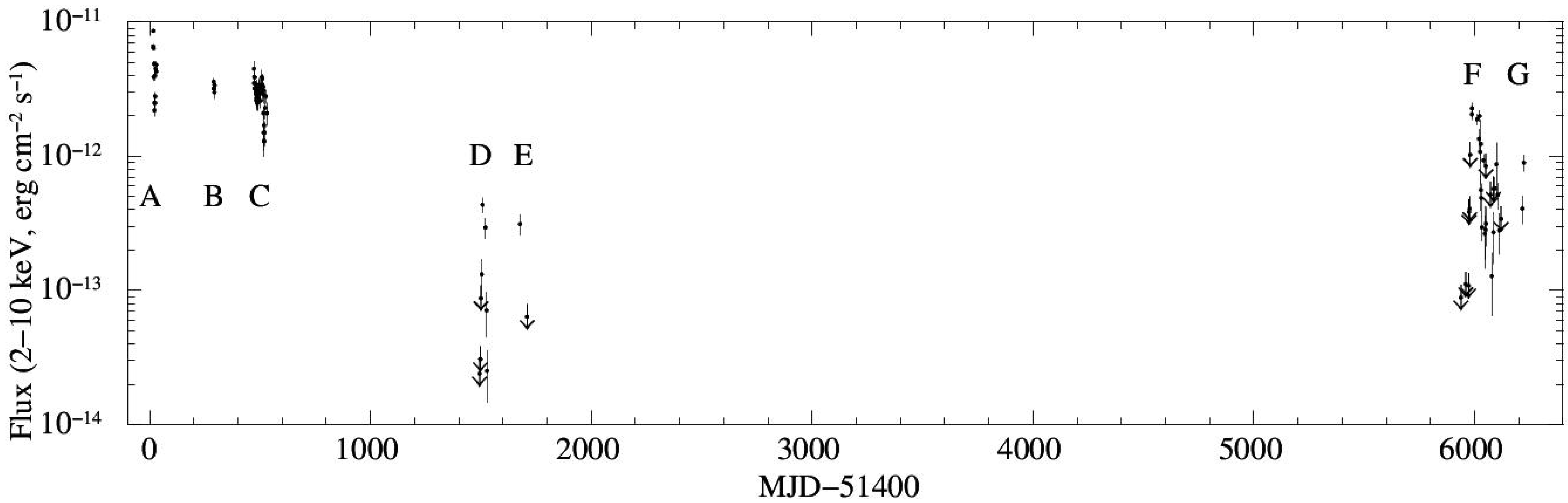

Fig. 1: long-term light curve of SAX J0635.2+0533 since MJD = 51400 (10 August 1999), with all the flux measurements (with different telescopes) obtained after the source discovery in 1997

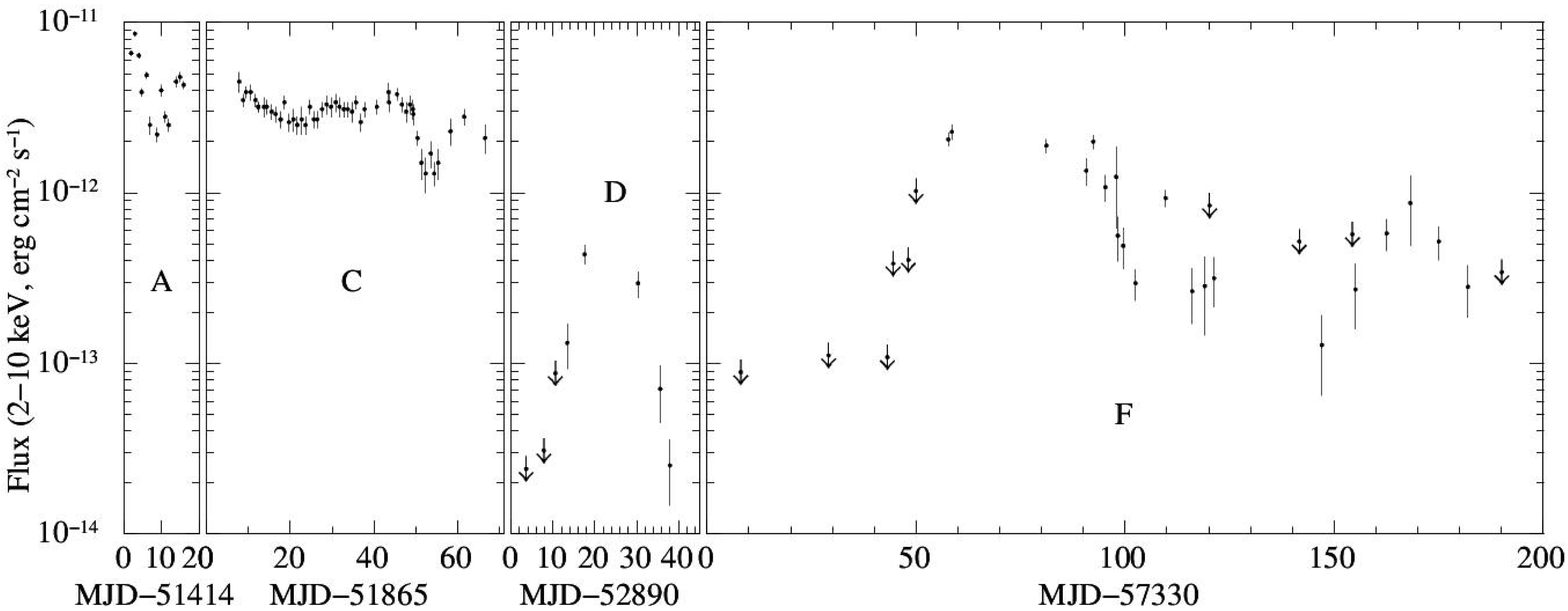

Fig. 2: zoom into the observations of epochs A, C, D, and F, respectively; for a better comparison of the flux variability among the different epochs, the same scale for the time and flux axes is used

The X-ray emission of SAX J0635.2+0533

In the latest years similar quiescent luminosities have been observed in several Be X-ray binaries, and various emission mechanisms have been proposed to explain them (see e.g. Tsygankov et al. 2017a). In the case of SAX J0635.2+0533, the high and fast variability implies that the emission is due neither to the companion Be star nor to the cooling of the NS crust

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the source emission is most likely due to matter accretion

Very short pulse period P_{spin} = 33.8 ms ⇒ several constraints on the accretion regime:
- no possibility of accretion from a cold recombined disc, regardless of the magnetic field (Tsygankov et al. 2017b)
- very unlikely the subsonic accretion, even in the case of plasma radiative cooling (Shakura et al. 2013)

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For a typical neutron-star magnetic field (B = 10^{12} G)
the low source luminosity can be explained only with a propeller regime,
where the accreting matter is stopped by the centrifugal barrier at the magnetosphere

Comparison with other BeXRBs

In Fig. 3 we report the L_{max}/L_{min} ratio as a function of L_{max}, for several known BeXRBs:
- open circles (○) = transient MW sources (Tsygankov et al. 2017a)
- crosses (x) = SMC sources (Haberl & Sturm 2016)
- filled circles (●) = persistent, long-spin-period and low-luminosity BeXRBs (see e.g. La Palombara et al. 2012)
- star (☆) = short-period (P_{spin} = 69 ms) binary pulsar A0538-66 in the LMC (Skinner et al. 1982; Kretschmar et al. 2004)

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- in both the MW and the MCs the source dynamic range increases with L_{max}, while the low-luminosity sources are also less variable
- lack of persistent high-luminosity sources (lower-right corner of the figure), due to the transient nature of the BeXRBs
- SAX J0635.2+0533 is clearly an outlier: it shows the largest dynamic range ($L_{max}/L_{min} \simeq$ 400) among the less luminous sources

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SAX J0635.2+0533 has rather peculiar properties, at variance with those of the typical accretion-powered BeXRBs

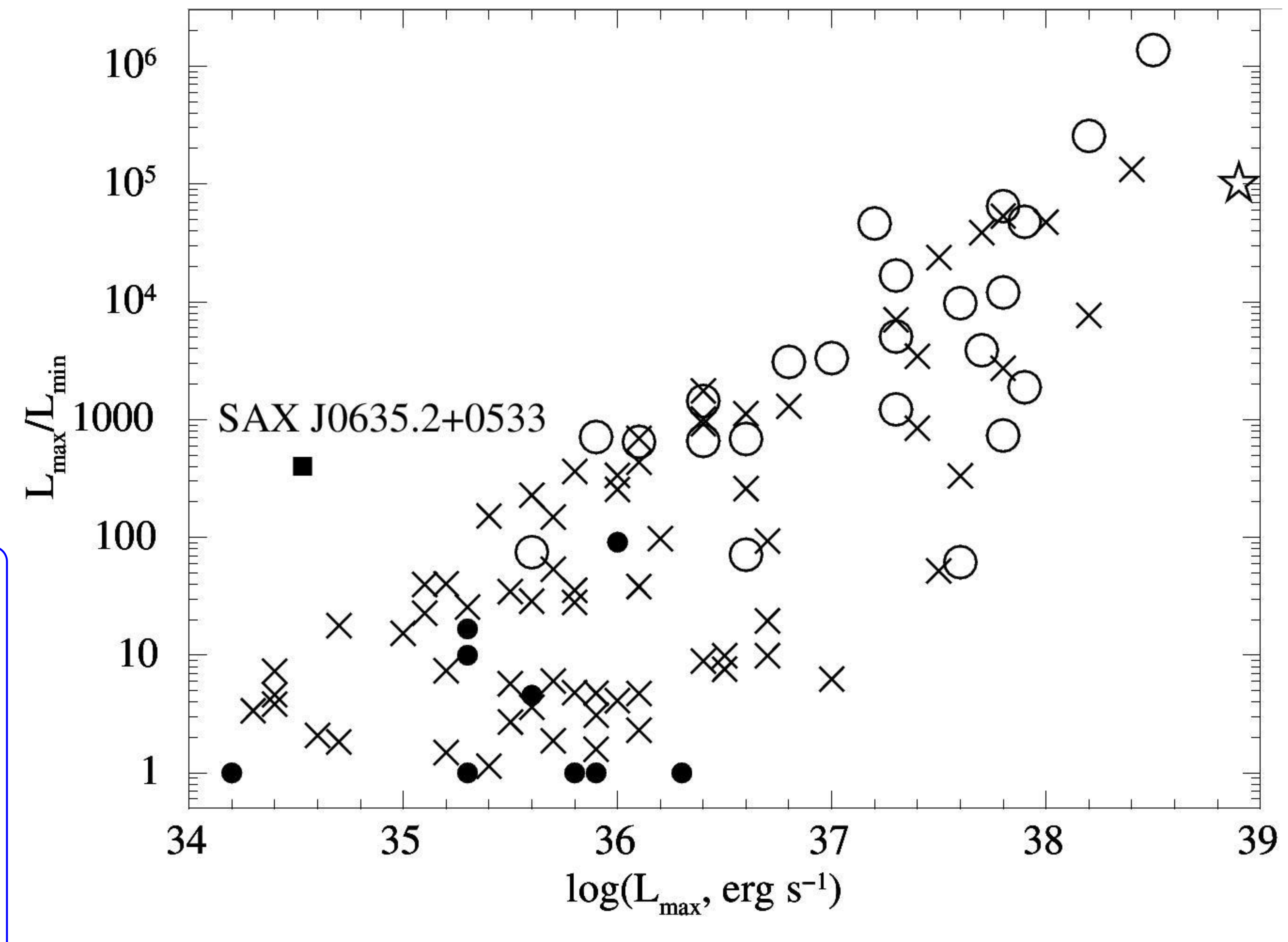

Fig. 3: X-ray luminosity ratio L_{max}/L_{min} as a function of L_{max}

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