南京大學 天文与空间科学学院 School of Astronomy & Space Science

”No magnaters in ULXs” and comments

Ref: arXiv: 1903.03624 & 1903.06343

Reporter: Kun Xu

April 12, 2019

Outlines

- No magnaters in ULXs (King & Lasota)
- Comments from Tong (1903.06343)
- My comments
- Magnetic field evolution

No magnaters in ULXs – KL

No magnetars in ULXs

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Abstract:

Pulsing ultraluminous X-ray sources (PULXs) with $B \sim 10^{11} - 10^{13}$ G is collimated ("beamed") by the outflow from an accretion disk supplied with mas at a super-Eddington rate.

All proposed pictures of magnetar formation suggest that they are unlikely to be members of binary systems (all confirmed magnetars are single).

Intro - ULXs

Ultraluminous X-ray sources (ULXs) are defined by apparent (assumed isotropic) luminosities $L_{\mathrm{X}} > 10^{39}\ \mathrm{erg\ s^{-1}}$, above the usual Eddington value for stellar-mass objects, but which do not contain supermassive BH.

But when seen in a narrow range of viewing angle, they are not isotropic but collimated ("beamed") by some factor $b < 1$

$$L_{\mathrm{sph}} = \frac{1}{b} L$$

Intro - beaming

The reason for the beaming is that mass transfer rates in ULX binaries are highly super–Eddington (defining the unusual evolutionary state) but mass accretion is effectively only Eddington.

The excess is ejected in a quasi-spherical outflow whose collimating structure is the cause of the anisotropic luminosity (Shakura & Sunyaev 1973). This outflow leaves only narrow channels around the rotational axis of the accretion disc for the accretion luminosity to escape, giving an effective beaming factor $b < 1$ (King 2009).

Intro - M82 X-2, a magnetar ?

If M82 X-2 is a magnetar, the accretion disk would be disrupted very far from the NS. This would imply a huge accretion lever-arm and a spinup far larger than observed. Using the observed rate, Kluzniak & Lasota (2015) instead postlated a magnetic fieldstrength typical of a millisecond pulsar ($B \lesssim 10^9$ G, $B \simeq 10^{11}$ G in this paper, ?).

From King (2009),

$$b \simeq \frac{73}{\dot{m}}$$

$b \sim 0.06 - 0.6$

Xu & Li (2017) shows $B \sim 10^{13}$ G.

Intro - KLK17

King, Lasota & Kluzniak (2017) showed all three systems (M82 X-2, NGC 7793 P13 and NGC 5907 ULX-1) had magnetospheric radii R_{M} very close to the spherization radii R_{sph} where radiation pressure becomes important and drives mass loss from the accertion disk.

KLK17 argued that the condition

$$R_{\mathrm{M}} \sim R_{\mathrm{sph}} \tag{1}$$

is very probably neccessary for pulsing

R_{sph} is only defined at all if it is larger than R_{M}, but if $R_{\mathrm{sph}} >> R_{\mathrm{M}}$ the pulse fraction must be small, so the system would probably appear as an unpulsed ULX.

Intro - NSULXs I

There are now 9 identified neutron -star ULXs (NSULXs) (M51 ULX8), four of them (M82 ULX2, NGC7793 P13, NGC5907 ULX1 and M51 ULX8) are ’standard’ ULXs, where the mass transfer rate seems to be fairly stably super-Eddington.

The five other PULXs are transient (?) and probably Be-X-ray binaries. The system becomes a ULX only in these bright putburst phases.

and 2014 Mar 06 as part of a follow-up campaign of the supernova SN2014J. The galaxy’s disk contains several ULXs, the most luminous being M82X-1[12], which can reach L_X (0.3-10 keV) $\sim 10^{41}$ erg s^{-1}, and the second brightest being a transient, M82X-2 (also referred to as X42.3+59[13]), which has been observed to reach[4,14] L_X (0.3 -10 keV) $\approx 1.8 \times 10^{40}$ erg s^{-1}. The two sources are separated by 5″, and so can

Intro - NSULXs II

Name	$L_X\,(\max)$ [erg s^{-1}]	P_s [s]	$\dot{\nu}$ [s^{-2}]	$P_{\rm orb}$ [d]	M_2 [M$_\odot$]
M82 ULX2[1]	2.0×10^{40}	1.37	10^{-10}	2.51 (?)	$\gtrsim 5.2$
NGC7793 P13[2]	5×10^{39}	0.42	2×10^{-10}	63.9	18–23 (B9I)
NGC5907 ULX1[3]	$\sim 10^{41}$	1.13	3.8×10^{-9}	5.3(?)	
NGC300 ULX1[4]	4.7×10^{39}	~31.5	5.6×10^{-10}	> 8	40 (Be ?)
SMC X-3[5,6]	2.5×10^{39}	~ 7.7	6.9×10^{-11}	45.04	> 3.7(Be ?)
NGC 2403 ULX[7]	1.2×10^{39}	~ 18	3.4×10^{-10}	60 – 100 (?)	(Be ?)
Swift J0243.6+6124[8]	$\gtrsim 1.5 \times 10^{39}$ (?)	9.86	$2.2. \times 10^{-10}$	28.3	(Be ?)
NGC 1313 PULX[9]	1.6×10^{39}	~ 765.6			(Be ?)
M51 ULX8[1]0	2×10^{39}	NO	NO	8 – 400 (?)	40 (?)

Intro - NSULXs III

Name	$\dot{m}_0$	$\boldsymbol{\mu} q^{7/4} m_1{}^{1/2} I_{45}{}^{3/2}$ [Gcm^3]	$\boldsymbol{R}_{\rm sph} m_1{}^{1}$ [cm]	$\boldsymbol{R}_M m_1{}^{1/3} I_{45}{}^{2/3}$ [cm]	$\boldsymbol{R}_{\rm co} m_1{}^{1/3}$[cm]	$\boldsymbol{P}_{\rm eq} q^{7/6} m_1^{1/3}$ [s]	$\boldsymbol{t}_{\rm eq}$ [yr]^1
M82 ULX2	36	9.0×10^{28}	3.6×10^7	1.0×10^7	1.9×10^8	0.02	15600
NGC 7793 P13	20	2.5×10^{29}	2.1×10^7	1.6×10^7	8.4×10^8	0.09	1386
NGC5907 ULX1	91	2.1×10^{31}	9.1×10^7	1.1×10^8	1.6×10^8	1.86	0
NGC300 ULX1	20	$1.2 \times 10^{30\#}$	2.1×10^7	3.2×10^7	1.5×10^9	0.19	297
SMC X-3	18	2.3×10^{28}	1.8×10^7	7.1×10^6	5.9×10^8	0.006	76621
NGC 2403 ULX	11	5.6×10^{29}	1.1×10^7	2.3×10^7	1.1×10^9	0.16	578
Swift J0243.6+6124	14	1.6×10^{29}	1.4×10^7	1.7×10^7	6.9×10^8	0.07	2047
NGC 1313 ULX	14		2.8×10^7		8.8×10^{13}		
M51 ULX8	16	$\sim 3 \times 10^{29\$}$	1.6×10^7	$2.7 \times 10^{7\%}$	?	?	

All confirmed magnetars are single

No optical/near-infrared counterpart of the magnetar has been identified.

Ref:

Olausen & Kaspi 2014

http://www.physics.mcgill.ca/∼pulsar/magnetar/TabO3.html

McGill Online Magnetar Catalog

Table 3: Optical/near-IR counterparts

Magnetar detections and upper limits made at optical/IR wavelengths are listed here.

- Magnitudes are uncorrected, ie. they are absorbed/reddened.
- Where reported, levels at which the upper limits were measured are given in parentheses (2s = 2 sigma, 3s = 3 sigma, 5s = 5 sigma).
- This table is available in ASCII and CSV format.
- Back to main catalog.

Name	A_V{a}	A_{Ks}{b}	Ks	H	J	I	R	V	B	U	Obs. Date	Refs.{c}
CXOU J010043.1−721134†	0.3 [dv05b]	0.03	…	…	…	F814W>24.5(3s)	…	F606W=24.19(15)	…	F300W>21.7(3s)	2001-03-03	[dv05b]
			…	…	…	F814W>25.9(3s)	…	F606W>26.2(3s)	F439W>25.6(3s)	F336W>24.2(3s)	2007-05-09	[dv08]
4U 0142+61	3.5(4) [dv06c]	0.4	…	…	…	23.84(6)	24.99(7)	25.62(8)	…	…	1994-10-31	[hvk00]
			K=19.68(5)	…	…	…	…	…	…	…	1999-02-08	[hvk04]
			…	…	…	23.84(4)	24.89(5)	25.62(8)	>27.4(3s)	…	2000-12-29	[hvk04]
			…	…	…	…	…	…	28.1(5)	…	2000-12-29	[hvk04]
			20.15(8)	…	…	…	…	…	…	…	2001-10-31	[hvk04]
			K′=19.76(5)	20.52(11)	21.96(12)	…	…	…	…	…	2002-08-18	[dv06d]
			…	…	…	i′=23.7(1)	…	…	g′=27.2(2)	u′>25.8	2002-09-12	[dmh+05]
			19.85(4)	…	…	…	…	…	…	…	2002-12-18	[hvk04]
			…	…	…	23.77(11)	25.29(19)	26.10(18)	…	…	2003-01-02	[dv06d]
			…	…	…	23.973(93)	25.556(177)	25.316(134)	>27.2(3s)	…	2003-09-04	[mkk+05]
			K′=20.18(8)	…	…	…	…	…	…	…	2003-09-08	[dv06d]
			K′=20.78(8)	20.90(8)	22.18(9)	…	…	…	…	…	2003-09-09	[dv06d]
			19.85(4)	…	…	…	…	…	…	…	2003-09-14	[dv06d]
			19.83(3)	…	…	…	…	…	…	…	2003-10-29	[dv06d]
			…	…	…	23.44(18)	25.34(12)	…	…	…	2003-12-21	[dv06d]
			K′=19.73(9)	…	…	…	…	…	…	…	2004-07-31	[mkk+09]
			19.96(7)	20.69(12)	21.97(16)	…	…	…	…	…	2004-11-02	[dv06d]
			…	…	…	…	r′=25.42(6)	…	…	…	2005-07-13	[dv06d]
			19.96(10)	…	…	…	…	…	…	…	2005-07-26	[dv06d]

No magnetars in binary systems

There is strong evidence that magnetars are (or even must be) formed in binary systems, but that the formation process usually leads to the destruction of the binary (Popov 2016).

In principle, a small fraction of binaries could survive the catastrophe: for example the very slow (pulse period $\sim$ 2.6 h) X-ray pulsar in the high-mass X-ray binary 4U 0114+65 could have a magnetar–strength magnetic field (Sanjurjo-Ferrrin + 2017, and references therein).

The problem with this channel as a model for PULX formation is that strong neutron–star fields $\sim 10^{15}$ G decay quickly ($\lesssim$ a few Myr) by several orders of magnitude (Mereghetti, Pons, & Melatos 2015).

Comments from Tong - I

Ref: 1903.06343

Abstract:

The magnetic dipole field of ultraluminous X-ray pulsars may not be very high. However, it is too early to say that they are not magnetars. The existence of low magnetic field magnetars should be taken into consideration.

Comments from Tong - II

- ULX pulsars can be accreting low magnetic field magnetar.
  The super-Eddington luminosity of ULX pulsar may be due to the presence of magnetar strength magnetic field ($\sim 10^{14}$ G) in the vicinity of the neutron star (Paczynski 1992; Mushtukov + 2015). The large scale magnetic dipole field of ULX pulsars may be of normal value (Tong 2015; Dall'Osso + 2015; Israel + 2017b).
- Near sinusoidal pulse profiles.
  For the four ULX pulsars (M82 X-2, NGC 7793 P13, NGC 5907 ULX, NGC 300 ULX1), they all have near sinusoidal pulse profiles. This means that they do not have a strong beaming.

Comments from Tong - III

Magnetar is not simply a neutron star with high magnetic dipole field.

However, this definition of magnetars are often taken as granted in the accreting neutron star and gamma-ray burst studies.

Therefore, seeing a strong magnetic dipole field in slow pulsation X-ray pulsars does not grant their magnetar nature (Sanjurjo-Ferrrin + 2017). Similarly, a low magnetic dipole field in ULX pulsars can not rule out the presence of magnetars. At present, they are all “accreting magnetar candidates”, which are often shortened as “accreting magnetars”.

My comments

- Why M82 X-2 is a beamed X-ray source as the pulsation profile is near-sinusoidal?
  so small beaing factor (b) means s very small angle and low probability to be seen.
- The defination of ’magnetar’?
- There is not much new idea in KLK17 model (probably, I haven’t understood the model).

Reply from King (?)

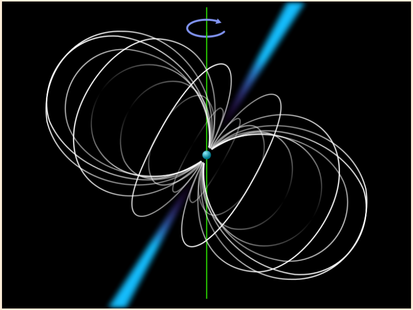
Hi Kun,

I think to get the result that `sinusoidal pulsing means there is no beaming’ you must be implicitly assuming
that the NS spin axis is precisely aligned to the collimation axis (= accretion disc axis). Then indeed it would be
like viewing a radio pulsar along its spin axis: you would see no pulsing because of complete axisymmetry.

But in general the NS spin axis is misaligned from the disc axis. This is obvious (and even directly observed) in Be - NS binaries, and must be true to some extent in the usual ULX binaries. The NS spin is misaligned wrt to the binary rotatation at birth, because SNe are not symmetrical. Afterwards the timescale for alignment is longer
than the lifetime of the ULX phase. Then seeing a pulsing NS with beaming is like looking at a pulsar along a tube:
you can still see the pulses.

So there is no problem seeing pulses and having beaming.

Andrew



Low magnetic field magnetar

magnetar evolution

ref: arXiv: 1903.06718 & 1904.05768

Formation Rates and Evolution Histories of Magnetars

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19 March 2019

ABSTRACT
We constrain the formation rate of Galactic magnetars directly from observations. Combining spin-down rates, magnetic activity, and association with supernova remnants, we put a 2σ limit on their Galactic formation rate at $2.3-20\mathrm{kyr}^{-1}$. This leads to a fraction $0.4^{+0.6}_{-0.28}$ of neutron stars being born as magnetars. We study evolutionary channels that can account for this rate as well as for the periods, period derivatives and luminosities of the observed population. We find that their typical magnetic fields at birth are $3\times10^{14}-10^{15}$ G, and that those decay on a time-scale of $\sim 10^4$ years, implying a maximal magnetar period of $P_{\max}\approx 13$ s. A sizable fraction of the magnetars' energy is released in outbursts. Giant Flares with $E\geq 10^{46}$ erg are expected to occur in the Galaxy at a rate of $\sim 5\mathrm{kyr}^{-1}$. Outside our Galaxy, such flares remain observable by *Swift* up to a distance of ~ 100 Mpc, implying a detection rate of $\sim 5\ \mathrm{yr}^{-1}$. The specific form of magnetic energy decay is shown to be strongly tied to the total number of observable magnetars in the Galaxy. A systematic survey searching for magnetars could determine the former and inform physical models of magnetic field decay.

Key words: stars: magnetars – magnetic fields – stars: evolution

Generation of strong magnetic fields in old neutron stars driven by the chiral magnetic effect

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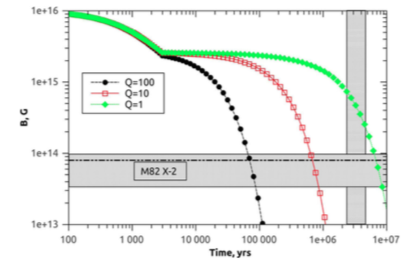
Abstract
We suggest the generalization of the Anomalous Magneto-Hydro-Dynamics (AMHD) in the chiral plasma of a neutron star (NS) accounting for the mean spin in the ultrarelativistic degenerate electron gas within the magnetized NS core as a continuing source of the chiral magnetic effect. Using the Parker dynamo model generalized in AMHD, one can obtain the growth of a seed magnetic field up to $10^{18}\,\mathrm{G}$ for an old non-superfluid NS at its neutrino cooling era $t<10^6\,\mathrm{yr}$, while neglecting any matter turbulence within its core and assuming the rigid NS rotation. The application of the suggested approach to the evolution of magnetic fields observed in magnetars, $B\sim10^{15}\,\mathrm{G}$, should be self-consistent with all approximations used in the suggested laminar dynamo, at least, up to the jumps of growing fields.

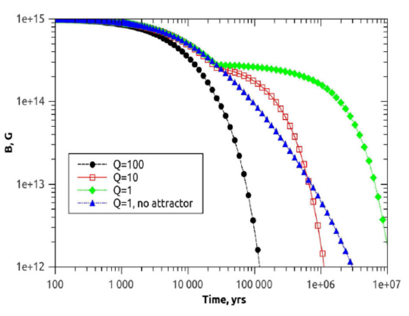
Magnetic field evolution - I

Ref:

Igoshev & Popov, 2018, MNRAS, 473, 3204.

Aguilera, Pons & Miralles, 2008.





Magnetic field evolution - II

Ref:

Igoshev & Popov, 2018, MNRAS, 473, 3204.

Aguilera, Pons & Miralles, 2008.

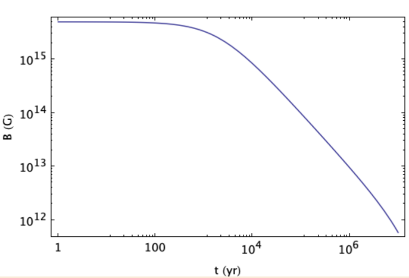
$$B(t) = \frac{B_0 \times exp(-t/\tau_{\rm Ohm})}{1 + (\tau_{\rm Ohm}/\tau_{\rm Hall})[1 - exp(-t/\tau_{\rm Ohm})]} \tag{2}$$

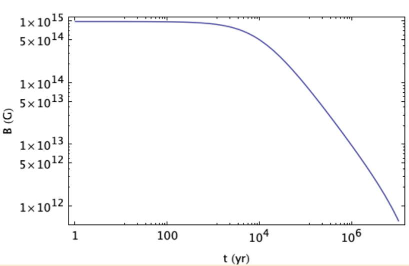
where $\tau_{\rm Ohm}$ is the Ohmic decay (resistivity in the crust) timescale and $\tau_{\rm Hall}$ is the Hall cascade timescale.

Magnetic field evolution of 4U0114

The detection of a cyclotron resonance scattering fearture at $E \approx 22$ keV (Bonning & Falanga 2005) indicate $B \sim 2 \times 10^{12}$ G.

Parameters:
$B_0 = 5 \times 10^{15}/10^{15}$ G, $\tau_{\rm Ohm} = 10^7$ yr, $\tau_{\rm Hall} = 10^4/B_{0,15}$ yr,
we get B@2.4 Myr $= 3.7 \times 10^{12}$ G; B@5 Myr $= 1.5 \times 10^{12}$ G.



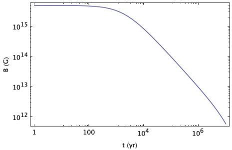


Appendix I: Tool - mathematica

```
Clear["`*"]
yr = 365.*24*3600;
B0 = 5*10^15;
B015 = B0 / 10^15;
tauHall = 10^4 / B015;(*units: yr*)
tauOhm = 10^7;(*units: yr*)
Bt = B0 * E^(-t/tauOhm) / (1 + (tauOhm / tauHall) * (1 - E^(-t/tauOhm)));
Bt /. t → 2.4*10^6
Bt /. t → 5.*10^6
LogLogPlot[Bt, {t, 1, 10^7}, Frame → True, FrameLabel → {"t (yr)", "B (G)"}]
```

3.6832×10^{12}

1.54071×10^{12}



$$\left(\frac{\left(\frac{\text{mdot0}^{19/21}}{\text{Rf8}^{19/21}}\right)\text{Rf8}\left(\frac{\left(\frac{\text{mdot0}^{17/21}}{\text{Rf8}^{17/21}}\right)\left(\left(\frac{\text{mdot0}^{19/21}}{\text{Rf8}^{19/21}}\right)\text{Rf8}\right)^{16/21}}{\text{mdot0}}\right)^{63/340}}{\left(\frac{\text{mu30}^{4*1/7}}{\text{mdotin}^{2*1/7}}\right)\text{xi}}\right)^{14/19} \text{ // FullSimplify}$$

$$\left(\frac{\text{mdot0}^{19/21}\,\text{mdotin}^{2/7}\left(\frac{\text{mdot0}^{5/7}}{\left(\text{mdot0}^{19/21}\,\text{Rf8}^{2/21}\right)^{5/21}\text{Rf8}^{5/7}}\right)^{63/340}\text{Rf8}^{2/21}}{\text{mu30}^{4/7}\,\text{xi}}\right)^{14/19}$$

$$\left(\frac{\text{mdot0}^{19/21}\,\text{mdotin}^{2/7}\left(\frac{\text{mdot0}^{5/7}}{\left(\text{mdot0}^{19/21*5/21}\,\text{Rf8}^{2/21*5/21}\right)\text{Rf8}^{5/7}}\right)^{63/340}\text{Rf8}^{2/21}}{\text{mu30}^{4/7}\,\text{xi}}\right)^{14/19} \text{ // FullSimplify}$$

$$\left(\frac{\text{mdot0}^{19/21}\,\text{mdotin}^{2/7}\left(\frac{\text{mdot0}^{220/441}}{\text{Rf8}^{325/441}}\right)^{63/340}\text{Rf8}^{2/21}}{\text{mu30}^{4/7}\,\text{xi}}\right)^{14/19}$$

$$\left(\frac{\text{mdot0}^{19/21}\,\text{mdotin}^{2/7}\left(\frac{\text{mdot0}^{220/441*63/340}}{\text{Rf8}^{325/441*63/340}}\right)\text{Rf8}^{2/21}}{\text{mu30}^{4/7}\,\text{xi}}\right)^{14/19} \text{ // FullSimplify}$$

$$\left(\frac{\text{mdot0}^{356/357}\,\text{mdotin}^{2/7}}{\text{mu30}^{4/7}\,\text{Rf8}^{59/1428}\,\text{xi}}\right)^{14/19}$$

$$\left(\frac{\text{mdot0}^{356/357*14/19}\,\text{mdotin}^{2/7*14/19}}{\text{mu30}^{4/7*14/19}\,\text{Rf8}^{59/1428*14/19}\,\text{xi}^{14/19}}\right) \text{ // FullSimplify}$$

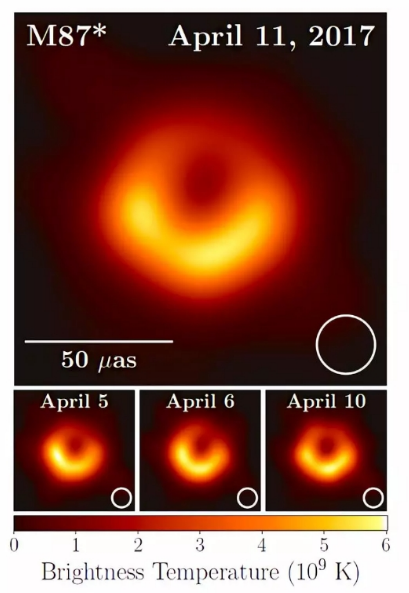
$$\frac{\text{mdot0}^{712/969}\,\text{mdotin}^{4/19}}{\text{mu30}^{8/19}\,\text{Rf8}^{59/1938}\,\text{xi}^{14/19}}$$

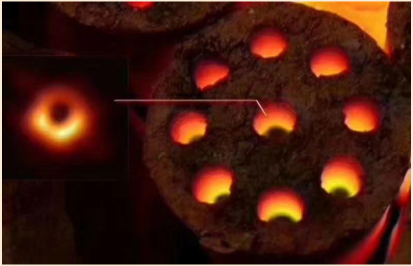
Appendix II: New observations of 1E 1613

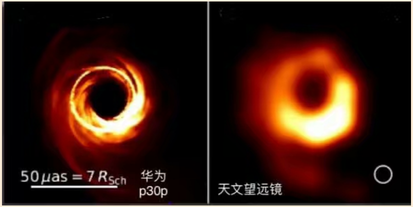
Ref: arXiv: 1904.05424

ABSTRACT

We observed the slowly revolving pulsar 1E 161348–5055 (1E 1613, spin period of 6.67 h) in the supernova remnant RCW 103 two times with *XMM–Newton* and one with the Very Large Telescope (VLT). The VLT observation was performed on 2016 June 30, about a week after the detection of a large outburst from 1E 1613. We found at the position of 1E 1613 a near infrared (IR) source with $K_S = 20.68 \pm 0.12$ mag that was not detected ($K_S > 21.2$ mag) in data collected with the same instruments in 2006, during X-ray quiescence. Its position and behaviour are consistent with a counterpart in literature that was discovered with *HST* in the following weeks in adjacent near-IR bands. The *XMM–Newton* pointings were carried out on 2016 August 19 and on 2018 February 14. While the spectra collected are similar in shape between each other and to what is observed in quiescence (a blackbody with $kT \sim 0.5$ keV plus a second, harder component—either another, hotter blackbody with $kT \sim 1.2$ keV or a power law with photon index $\Gamma \sim 3$), the two pointings caught 1E 1613 at different luminosity along its decay pattern: about 4.8×10^{34} erg s^{-1} in 2016 and 1.2×10^{34} erg s^{-1} in 2018 (0.5–10 keV, for the double-blackbody model and for 3.3 kpc), still almost ≈10 times brighter than the quiescent level. The pulse profile displayed dramatic changes, apparently evolving from the complex, multi-peak morphology observed in high-luminosity states to the more sinusoidal form characteristic of latency. The inspection of the X-ray light curves revealed in the 2016 observation two flares with unusual properties: they are long (~1 ks to be compared with 0.1–1 s of typical magnetar bursts) and faint (≈10^{34} erg s^{-1}, with respect to 10^{38} erg s^{-1} or more in magnetars). Their spectra are comparatively soft and resemble the hotter thermal component of the persistent emission. If the flares and the latter component have a common origin, this may be a spot on the star surface heated by back-flowing currents induced by a magnetospheric twist. In this hypothesis, since the increase in the luminosity of 1E 1613 during the flare is only by ~20%, an irregular variation of the same order in the twist angle could account for it.


M87*
April 11, 2017
50 μas
April 5
April 6
April 10
0 1 2 3 4 5 6
Brightness Temperature (10^9 K)




50 μas = 7 R_{Sch}
华为
p30p
天文望远镜

Thanks