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The puzzling source SWIFT J195509+261406

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(on behalf of a larger collaboration)

We present multiwavelength observations of the optically flaring source SWFIT J195509+261406, and discuss its nature considering several possibilities, amongst them a microquasar origin. Finally we suggest a likely magnetar nature implying a missing link to the dim isolated neutron stars.

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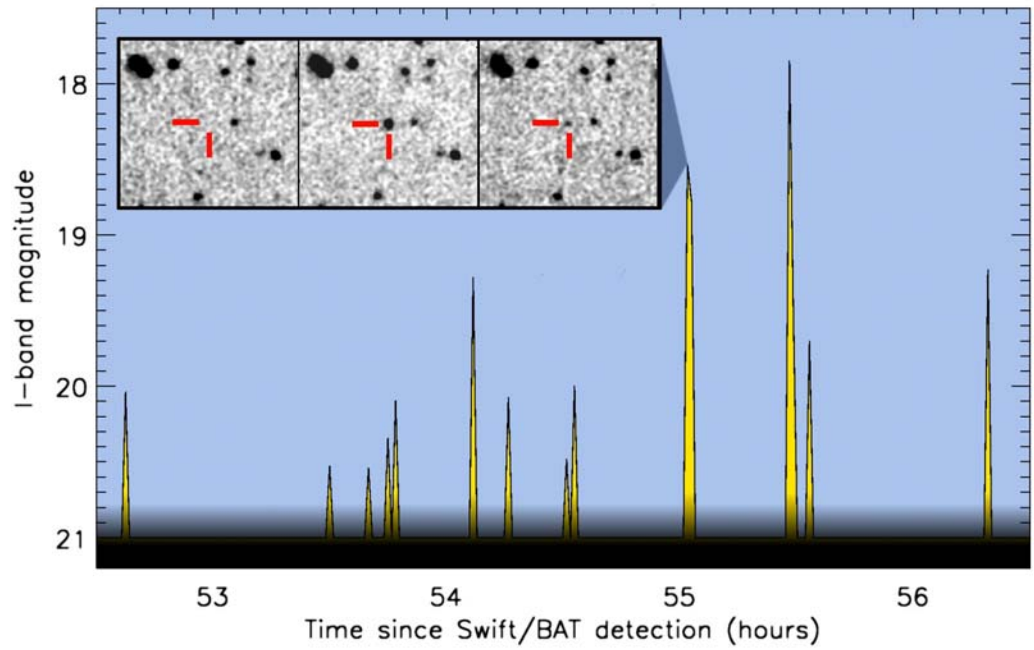

Fig. 1. Optical flaring activity in the SWIFT source Flaring activity of SWIFT J185509+261406 as seen on a 4 hr of ground-based data obtained with the 1.2m Mercator telescope on June 13 (I-band filter). The observation started at 04:20:38 UT, with an exposure time of 3 x 42s.The flare reaches I = 17.8.

1.Introduction

The majority of bright gamma-ray transients in the sky are gamma-ray bursts (GRBs), events marking the gravitational collapse of massive stars or the merger of compact objects in a binary systems in distant galaxies and thought to be the birth cries of stellar black holes [1,2]. However, another type of gamma-ray transients intermittently show up in the high-energy sky: these are the so called soft gamma-ray repeaters which contain magnetars [1]. These are young neutron stars (NS) with very strong magnetic fields of the order of $10^{14\text{-}15}$ G. They are detected in our Galaxy either as soft gamma-ray repeaters (SGRs) or anomalous X-ray pulsars (AXPs). SGRs are a rare type of gamma-ray transient sources that are occasionally detected as bursters in the high-energy sky [2-4]. No optical counterpart to the gamma-ray flares or the quiescent source has been identified. Here we show multi-wavelength observations of a puzzling source, for which we detected more than 40 flaring episodes in the optical band over a time span of 3 days, and a faint infrared flare 11 days later, after which it returned to quiescence.

On 10 June 2007, 20:52:26 UT *Swift*/BAT detected GRB 070610 / SWIFT J195509+261406, as a burst with a single "FRED"-like (fast rise phase and exponential decay) profile, lasting about 4.6s total. The spectrum was consistent with a power law with photon index of 1.76 +/- 0.25 and a total fluence of 2.4 +/- 0.4 x 10^{-7} erg/cm^2 [5].

The source became observable by *Swift*/XRT about 3100s after the discovery, and an X-ray counterpart was reported soon afterward [6]. Unlike the prompt gamma-ray emission, it was soon realized that this counterpart behaved differently from the "classical" GRB afterglows observed so far; i.e, the X-ray light curve showed evidence of rapid variability, with intense flaring activity. For the first 8000s, the X-ray spectrum, modelled with an absorbed power law, gives a photon index of 1.8 +/- 0.3 with the total column density consistent with the Galactic value of 1 x 10^{22} cm^{-2}. The absorbed (unabsorbed) 0.3-10.0 keV average flux was 2.4 x 10^{-12} (3.9 x 10^{-12}) ergs cm^{-2} s^{-1} [5-8].

Following the detection of GRB 070610 and its bizarre X-ray counterpart, we mounted a multi-wavelength observing campaign.

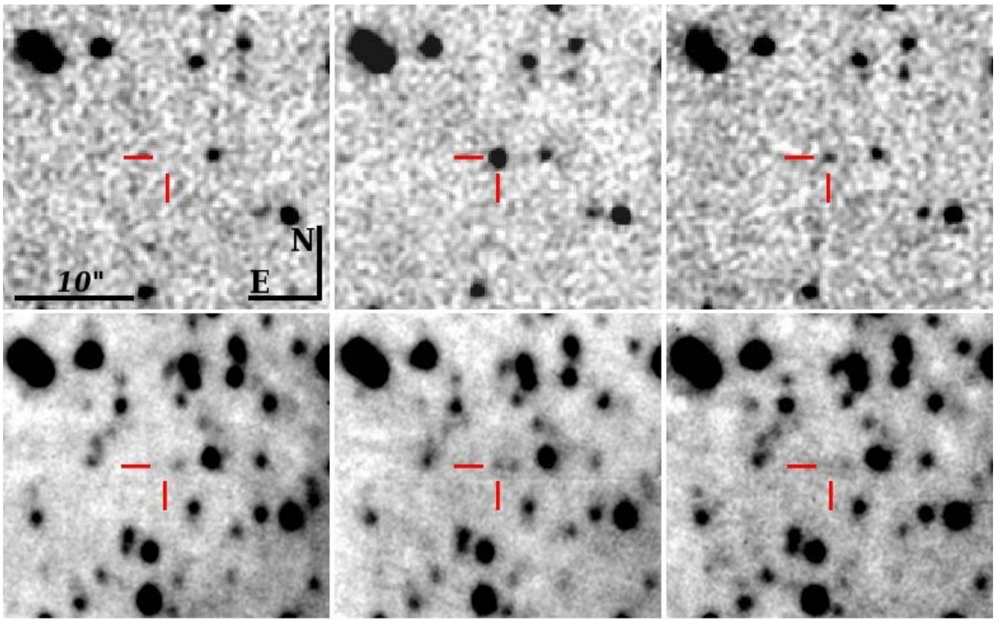

Fig. 2. Shots of the SWIFT source obtained at different epochs: a) Upper three: Optical images obtained on June 11 with the 1.5m telescope at Observatorio de Sierra Nevada showing the flaring source increasing its brightness by a factor of about 100 in a few seconds; b) Lower three: near-IR images obtained with the 8.2m VLT telescope in Chile on June 22 showing a near-IR flare.

2.Observations

We triggered a multi-wavelength observing campaign including radio observations at RATAN-600, millimeter observations at Plateau de Bure, optical photometry at several ground-based observatories, near-infrared (NIR) adaptive optics imaging at the ESO Very Large 8.2m Telescope, optical spectroscopy at the Russian 6.0m telescope and late time X-ray observations with *XMM-Newton*. We also carried out CO (J = 1-0) millimeter observations at Pico Veleta in order to search for molecular clouds towards the line of sight. This campaign was supplemented by 21 cm radio observations at Effelsberg and available *Swift*/XRT data. Our data were collected starting 1 min after the burst trigger time. In the first three nights of our observations, the source displayed strong optical flaring activity [7-9]. See Figure 1. This, together with the location of the source in the Galactic plane, supported the view that the source is hosted by the Milky Way [10] as we give strong evidence for in this work. By adding several optical frames, we derive the following position (+/- 0.5”): R.A. (J2000) = 19h 55m 09.63s, Dec.: +26º 14’ 05”.

The flares from SWIFT J195509+261406 had durations in the range of tens of seconds to a few minutes and flux amplitudes of up to 10^2 with respect to the ``outburst" baseline flux (or > 10^4 times the quiescent state). After 13 June, the activity decayed abruptly (Fig. 1) and no further flares were seen until 22 June, when a late-time, lower-brightness flare was detected in the near-infrared (NIR) using the 8.2m VLT (+NACO). See Figure 2.

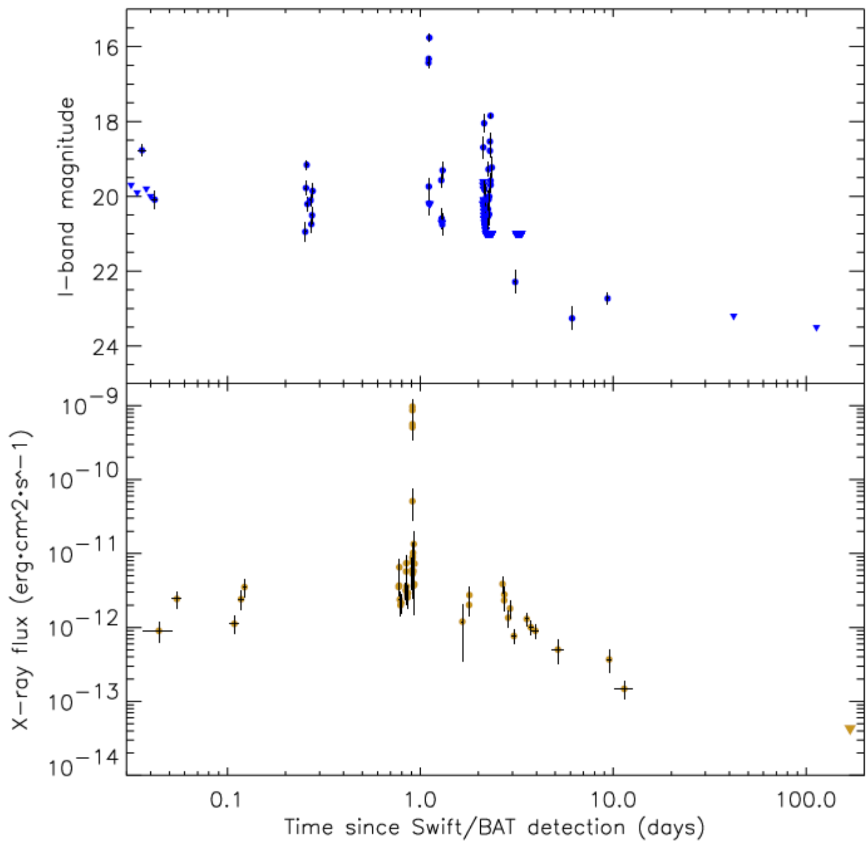

Fig. 3. Optical and X-ray light curves of SWIFT J195509+261406 (June-November 2007)}. a) Optical detections (Ic-band magnitudes, filled circles, with 1σ error bars) are shown together with 3σ upper limits (downward pointing triangles). b) *Swift* X-ray data (0.2-10 keV, filled circles, with 1σ error bars) together with the late time 3σ limit obtained with *XMM-Newton*. Both light curves show strong activity during the first three days, reaching the maximum around two days after the gamma-ray burst and gradually decaying after the third day until the source became undetectable. The X-ray observations performed by *Swift* do not overlap with the times of any of the optical flares we have recorded.

The X-ray data after the giant flare one day after the event (excluding minor flaring-like activity) can be fitted by a power-law decay $F = t^{\alpha}$ with $\alpha = -0.75 \pm 0.25$, consistent with the values seen in the decline phase of the anomalous X-ray pulsar [22] XTE J1810-197 and the transient magnetar [23] SGR 1627-41. The baseline X-ray luminosity of SWIFT J195509+261406 during the first 8,000 s that followed the initial gamma-ray spike was ~1.2×10^{34} (D/5 kpc)^2 erg s^{-1} whereas the quiescent X-ray luminosity was < 9.0×10^{31} (D/5 kpc)^2 erg s^{-1} at the time of our late-time X-ray observation after 173 days. This is in any case significantly smaller that the values of 4×10^{33} erg s^{-1} and ~1.3×10^{35} erg s^{-1} derived for SGR 1627-41 and some AXPs respectively.

A late-time observation by *XMM-Newton* 173 days after the burst failed to detect the source, imposing an upper limit (3σ) to any underlying X-ray flux of < 3.1×10^{-14} erg cm^{-2} s^{-1} (0.2-10 keV). Figure 3 shows that observations in both X-ray and optical agree that the strongest flaring activity is found around one day after the gamma-ray event. A short (~30s) powerful X-ray flare, for which the flux increased by a factor of $\Delta f/f$ ~100 on a timescale of $\Delta t/t \sim 10^{-4}$, was followed by several optical flares of similar amplitude.

3.Discussion

3.1. The distance

Our ^{12}CO (J = 1 - 0) spectrum towards the SWIFT J195509+261406 source reveals a molecular cloud in the range +25 km s^{-1} and +30 km s^{-1}, and we infer a lower limit to the kinematic distance to the SWIFT source of 3.7 kpc. This is based on the fact that the measured CO velocities are consistent with the location of the MC in the "tangent point", i.e. the point where the line-of-sight (l.o.s.) is tangent to the galactocentric circle and therefore the observed radial velocity V_{LSR} reaches its maximum value (+29.3 km/s at a distance of 3.7 kpc using the Galactic rotation law of Clemens for R_0 = 8 kpc and θ_0 = 220 km s^{-1}). Following similar studies and considering the X-factor to be $N(H_2) = 2.3 \times 10^{20} \times W_{CO}$, we can conclude that the MC at the tangent point location (3.7 kpc) is contributing with $N(H_2) = (2.38 \pm 0.09) \times 10^{21}$ cm^{-2}. This implies a 50% contribution to the total column density N(H) derived by *Swift*/XRT. From the 21cm observations, we can also derive the equivalent H density, considering $N(H\,I) = 1.822 \times 10^{18} \int_{-400}^{+400} T_B\, dv$ and assuming optical thin emission, we obtain $N(H\,I) = (8.1 \pm 1.2) \times 10^{21}$ cm^{-2}. In fact, the overall Galactic column density along the line of sight towards (l^{II},b^{II}) = (63.5^o, -1.0^o) is $N(H) = N(H\,I) + 2N(H_2) = (14.1 \pm 2.0) \times 10^{21}$ cm^{-2} which should be compared with the X-ray absorption column derived from the *Swift*/XRT data: 10 (+4, -3) x 10^{21} cm^{-2} from this work, or 7.2 (+3,-2) x 10^{21} cm^{-2} (from [7], all quoted errors here being 3σ). Therefore we conclude that SWIFT J195509+261406 is located in the Galaxy and beyond this particular molecular cloud at a kinematic distance of 3.7 kpc from the Sun. This value is consistent with 4 kpc derived from the ``red clump" method, a quite independent method by constructing the function of extinction versus distance based on field red giant stars [24,25]. Hereafter, we consider a reference distance of 5 kpc.

3.2. The nature of the source

In order to discern the nature of the source, we explored several possibilities: i) a bursting pulsar, ii) a microquasar; iii) an ultracompact low-mass X-ray binary and iv) a magnetar.

3.2.1. Another bursting pulsar?

The source could be mimicking the ``bursting pulsar" GRO J1744-28 [11-12] which, after displaying 20 hard X-ray bursts per hour following its discovery, entered a regime of hourly bursting lasting for nearly 4 months, with the burst rate decreasing dramatically after that time. In spite of more than 5800 bursts being detected by *CGRO*/BATSE, no burst episodes were reported at other wavelengths for this pulsar, due to the high Galactic extinction along the line of sight.. However, *Swift*/BAT has not recorded any other gamma-ray burst from SWIFT J195509+261406 after the initial one.

3.2.2. A Galactic microquasar?

A second scenario will be based on the proposed similarity to the black hole (BH) candidate V4641 Sgr [13-14]. This BH, orbiting an intermediate mass companion (a B9 subgiant), was suggested as the first member of the ``fast X-ray novae" group [15] and it has been proposed SWIFT J195509+261406 to be a member of this class [7]. However, several lines of evidence point against this association. First, the lack of further detections of the baseline (non-flaring) flux during the outburst phase at gamma-ray (by *Swift*/BAT), millimeter (during the outburst, < 0.6 mJy, 3σ) and centimetre wavelengths [7] (during the decline phase, < 0.09 mJy, 3σ) implies a different physical mechanism, because considerable gamma-ray and radio emission (the latter arising from a collimated jet) was recorded at the time of the V4641 Sgr outbursts [16]. Moreover, the lack of H-alpha emission (< 9.0 x 10^{-16} erg s^{-1} cm^{-2} within a 2” aperture) in our spectra and in our narrow-band images obtained at the 6.0m BTA makes it unlikely that it is an accreting black hole candidate in a binary system (a microquasar pointing to us; i.e. a microblazar).

3.2.3. An ultracompact low-mass X-ray binary?

Deep H-band image obtained on 30 Sep 2007 with the 8.2m VLT (+ NACO) using laser guide star adaptive optics. The image we obtained showed that the source was beyond the reach of ground-base telescopes. The NIR limit imposed on the quiescent counterpart of SWIFT J195509+261406 (H > 23; i.e. M_H > 8.1 assuming D = 5 kpc and E(B-V) = 1.9 +/- 0.6 towards the source) constrains the spectral type of any companion to a main sequence star with spectral type later than [17] M5V (i.e. < 0.12 solar masses) unless the donor would be a hydrogen-poor (semi-) degenerate star in an ultra-compact X-ray binary [18] (with < 1 hr orbital period). In fact, an ultra-compact low-mass X-ray binary with blobs of homogeneous synchrotron-emitting plasma of size 10^7 cm and magnetic fields of strength 10^5 G can explain both the observed baseline flux and the flaring episodes in X-ray and optical wavelengths. This third scenario will allow such blobs to be found in a magnetized corona [19] (an extended region of low-density, X-ray irradiated material above and below the accretion disk) or a wind, rather than in the outer regions of a collimated jet. Thus, SWIFT J195509+261406 would be part of such a system.

3.2.4. A magnetar?

On the other hand, we point to the last possibility that it is an isolated compact object, i.e. a new magnetar in our Galaxy, displaying soft gamma-ray repeater like activity in the optical; and from which only one hard burst was recorded in gamma-rays, near the onset of its bursting activity. If this is the case, SWIFT J195509+261406 becomes the first SGR detected at optical wavelengths. This would be supported by the burst durations (Fig. 3 of ref [26]). The optical flares fluxes are lognormally distributed as seen in the high-energy flares of SGR 1806-20 and SGR 1900+14 [27,28], supporting the claim that SWIFT J195509+261406 is a new SGR, although this is not conclusive. In addition to this, we also want to point out that intermediate duration (~1-30 s) bursts have been recorded in SGR 1627-41 and SGR 1900+14 [29]. In particular, two events arising from the latter source (at ~7 kpc) and lasting about ~1 s displayed unusual hard power-law spectra similar and comparable in energy, (6.5-11) x 10^{39} erg, to GRB 070610, the burst of gamma-rays associated with SWIFT J195509+261406 (1.9 x 10^{39} (D/ 5 kpc)^2 erg). Thus, both the gamma-ray burst duration and the lognormal distribution of the optical flares strengthen the association of the SWIFT source with a magnetar, although the lack of persistent X-ray pulses (i.e. which allow us to determine the spin period derivative $\delta P/\delta t$ in order to yield the magnetic field value) prevents us, for the time being, to prove the existence of extreme magnetic fields typical of magnetars (including both SGRs and anomalous X-ray pulsars, AXPs). In any case, we searched for GRBs detected in the BATSE Current Burst Catalog that are consistent (within errors) with the SWIFT J195509+261406 position, and found six events. To determine whether this could represent an excess with respect to the expected number of event in this direction of the sky, we performed 1000 MonteCarlo simulations taking into account the BATSE exposure map and found out that the probability of having six overlapping error boxes is ~15%.

How can the optical flares be produced in SWIFT J195509+261406? One possibility is, according to magnetar corona models [20], due to coherent plasma bunches, and its luminosity depends on the unknown bunching factor, leading easily to 10^{35} (D/ 5 kpc)^2 erg s^{-1}, as observed at optical frequencies [8]. In contrast to SGR 0526-66, SGR 1806-20 and SGR 1900+14, which all show "persistent" X-ray emission in the range 10^{-11} to 10^{-12} erg cm^{-2} s^{-1}, SWIFT J195509+261406 strongly resembles the ``transient" behaviour of SGR 1627-41 and another magnetar [21], XTE J1810-197. The former source experienced an activity period for 6 weeks in 1998 [22] and its underlying X-ray flux was then observed to decrease by a factor of 50 over a time span of 1,000 days, flattening off at 3 x 10^{-13} erg cm^{-2} s^{-1}, implying a quiescent X-ray luminosity [23] 4 x 10^{33} erg s^{-1}, which is still significantly higher than < 9.0 x 10^{31} (D/5 kpc)^2 erg s^{-1} derived for the SWIFT source from our late-time X-ray observation after 173 days. Therefore we suggest that SWIFT J195509+261406 could be the first magnetar (either persistent or transient) that shows strong and protracted optical flaring activity in our Galaxy. This result is also independently supported by other team [8].

4.Conclusions

We have suggested that SWIFT J195509+261406 could be the first magnetar (either persistent or transient) that shows strong and protracted optical flaring activity in our Galaxy and for which the long-term X-ray emission is short-lived. A deeper X-ray observation together with a detailed study of future activity periods of SWIFT J195509+261406, including simultaneous X-ray/optical monitoring, can shed light onto its nature and discern whether the source is an ultra-compact low-mass X-ray binary or a NS displaying a new manifestation of magnetar activity. In this latter case, it would constitute the link between ``persistent'' SGRs/AXPs (with L_X = (2-4) x 10^{35} erg s^{-1} and (0.2-5) x 10^{35} erg s^{-1} respectively) and dim isolated NS [30] (with L_X = (2-20) x 10^{30} erg s^{-1}), being one of a few hundred Galactic magnetars becoming active [31] in the last 10^4 yr.

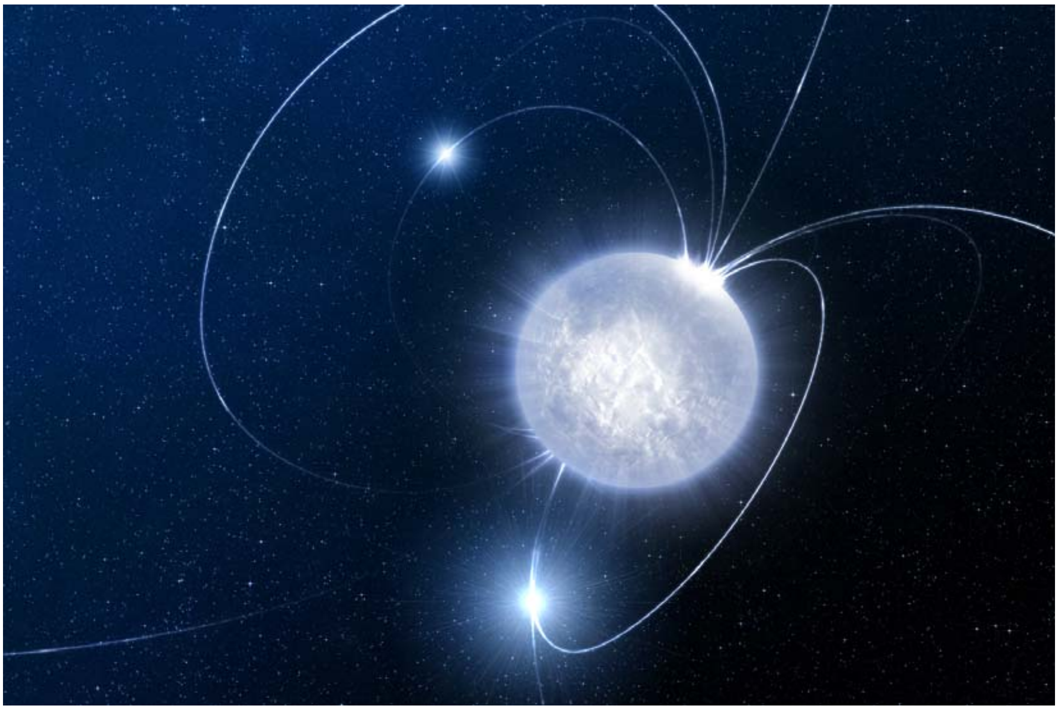

Fig. 4. An artist's view of the SWIFT source. The twisting of magnetic field lines in magnetars, giving rise to crustquakes which will eventually led to an intense soft gamma-ray burst. In the case of the SWIFT source, the optical flares that reached the Earth were probably due to ions ripped out from the surface of the magnetar and gyrating around the field lines. As ions are much heavier than electrons, they gyrate slower and emit radiation at much lower frequencies. Courtesy L. Calcada (ESO).

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