The Twin Magnetars: SGR 1627–41 and 1E 1547–5408

S. Mereghetti*, A. Tiengo*, P. Esposito*,†, G. Vianello*, A. De Luca*,**, D. Götz‡, G. Weidenspointner§,¶, A. von Kienlin§, G.L. Israel∥, L. Stella∥, N. Rea††, R. Turolla‡‡ and S. Zane§§

*INAF-IASF Milano, v. E.Bassini 15, 20133 Milano, Italy
†INFN-Pavia, via A. Bassi 6, 27100 Pavia, Italy
∗∗IUSS - Istituto Universitario di Studi Superiori, viale Lungo Ticino Sforza 56, 27100 Pavia, Italy
‡CEA Saclay, DSM/Irfu/Service d’Astrophysique, Orme des Merisiers, Bât. 709, 91191 Gif sur Yvette, France
§MPI für extraterrestrische Physik, Giessenbachstrasse, Postfach 1312, D-85741 Garching, Germany
¶MPI Halbleiterlabor, Otto-Hahn-Ring 6, 81739 Muenchen, Germany
∥Astronomical Institute “Anton Pannekoek”, University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands
‡‡Dipartimento di Fisica, Università degli Studi di Padova, via F. Marzolo 8, 35131 Padova, Italy
§§MSSL, University College London, Holmbury St. Mary, Dorking, Surrey RH5 6NT, UK

Abstract. We report on recent results obtained thanks to Target of Opportunity observations of the two galactic sources SGR 1627–41 and 1E 1547–5408. These two transient sources present several similarities which support the interpretation of Anomalous X–ray Pulsars and Soft Gamma-ray Repeaters as a single class of strongly magnetized neutron stars.

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INTRODUCTION

During the last decade, mounting evidence has been found supporting the idea that Soft Gamma-ray Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are isolated neutron stars with peculiar properties resulting from the presence of an ultra strong magnetic field, $B \sim 10^{14} – 10^{15}$ G. The magnetar model [25, 26], initially developed to explain the SGRs, has been quite successfully applied to both classes of sources, which indeed show many commonalities. Actually, the distinction between SGRs and AXPs might well be only a semantic heritage linked to the way these objects were first observed: the SGRs, discovered as sources of short (< 1 s) repeating bursts of hard X-rays [13] have persistent counterparts practically indistinguishable from the AXPs, while several AXPs, discovered as spinning down X-ray pulsars without evidence of companions stars [16], have been observed to emit short bursts very similar to those of the SGRs. For a recent review on AXPs and SGRs see [18].

Here we report on new X–ray observations of two sources, SGR 1627–41 and 1E 1547.0–5408, obtained as Target of Opportunity requests to study their recent outbursts. The results give further evidence for the similarities between AXPs and SGRs. Among the small group of known magnetars (about 15 sources) the two objects discussed here stand out for having the shortest spin periods: 2.6 s for SGR 1627–41 and 2.1 s for 1E 1547.0–5408. Both sources are transients and lie in supernova remnants. Curiously, they are also located almost in the same direction of the Galactic plane, hence their "twins" nickname.

SGR 1627–41

SGR 1627–41 was discovered in 1998, during a bursting state that lasted about six weeks [52]. Its X-ray counterpart, identified at the time of the outburst, had a luminosity of $\sim 10^{35}$ erg s$^{-1}$ (for $d=11$ kpc). In the following years its X-ray luminosity monotonically decreased [17], until the lowest flux was observed in Febru-ary 2008 with XMM-Newton (see Fig. 1). This flux corresponds to a luminosity of only $\sim 10^{33}$ erg s$^{-1}$, the lowest ever observed for a SGR [4]. The long-term flux decay can be interpreted as the cooling of the neutron star, assuming that the star was significantly heated during the outburst. The modelling of the long term light curve can provide information on the mechanism for (and location of) the heating, as well as on the neutron star structure [11]. However, this is complicated by the fact that the measurements carried out over several years were obtained with different satellites. This introduces some un-
FIGURE 1. X-ray light curve of SGR 1627–41 spanning ten years of observations with different satellites (observed flux in the 2-10 keV energy range). The vertical lines indicate the two periods of bursting activity seen from this source (June 1998 and May 2008).

FIGURE 2. Comparison of the long term flux decays following outbursts of SGRs and AXPs. For SGR 1627–41 both the 1998 and 2008 events are plotted. The lines are power laws with time decay index ranging from –0.2 (SGR 1627–41 in 2008) to –0.6 (SGR 1627–41 in 1998).
The brightest part of the outburst could not be observed with observe SGR 1627–41 until September 2008, thus the contribution to the initial steep phase (see below). The initial bright burst, delayed by interstellar dust scattering, is also possible that X-rays emitted during the initial might play in Fig. 4: the burst is composed of a very bright, rapid decrease, later followed by a shallower phase consistent with a power law of index $\sim -0.2$. In Fig. 4, the light curve of the 2008 outburst is compared with that of the previous outburst from this source, and with the behavior seen after the outbursts of a few other AXPs/SGRs. This figure shows that, whenever early data are available, they indicate that a single power law decay cannot reproduce the source fading. This is due to the presence of a steeper initial phase in the first days after the outburst and suggests the presence of two different mechanisms at play. One possibility is that the steep phase be due to magnetospheric currents dissipation while the later phase reflect the effect of crustal cooling. It is also possible that X-rays emitted during the initial bright burst, delayed by interstellar dust scattering, contribute to the initial steep phase (see below).

Due to visibility constraints, XMM-Newton could not observe SGR 1627–41 until September 2008, thus the brightest part of the outburst could not be observed with this satellite. A Target of Opportunity observation was performed on 2008 September 27-28, and despite the low source flux $\sim 3 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, the large effective area of the EPIC instrument allowed us to collect enough counts to perform a meaningful timing analysis. This led to the discovery of the long-sought pulsations. The spin period is 2.6 s, one of the shortest among magnetar candidates. The X-ray pulse profile, characterized by two peaks of different intensity, is shown in Fig. 3.

The deep XMM-Newton observation also showed, for the first time, diffuse X-ray emission from the vicinity of SGR 1627–41(Fig. 4). This consists of two spectrally distinct components with different spatial extent. The harder emission is a spatially resolved source located about 1.5 arcmin south of the SGR. Its high absorption and evidence for a redshifted Fe line suggest that it might be a cluster of galaxies. The softer emission is more extended and most likely related to the supernova remnant / HII region complex CTB 33.

1E 1547.0–5408

The transient X-ray source 1E 1547.0–5408 was discovered with the Einstein Observatory almost 30 years ago in the supernova remnant G 327.24–0.13. It attracted little interest until new X-ray and optical studies ruled out more standard interpretations and led to propose it as an AXP candidate. This suggestion was confirmed by the subsequent discovery of radio pulsations with $P = 2.1$ s and period derivative $\dot{P} = 2.3 \times 10^{-11}$ s$^{-1}$. In October 2008 1E 1547.0–5408 started an outburst with the emission of several short bursts and a significant increase in its X-ray flux.

The bursting activity from 1E 1547.0–5408 culminated on 2009 January 22, when more than 200 bursts were detected in a few hours. Some of these bursts were particularly bright, reaching a peak flux above $2 \times 10^{-4}$ erg cm$^{-2}$ s$^{-1}$ at E$>25$ keV. While most of the bursts had durations of few hundreds milliseconds, as typical SGR bursts, two bright events lasted several seconds and showed a clear modulation at the neutron star spin period. The light curve of the most interesting one is displayed in Fig. 5: the burst is composed of a very bright, short ($\sim 0.3$ s) initial spike, followed by a $\sim 8$ s long pulsating tail. These features are typical of giant flares from SGRs. However, the analysis of INTEGRAL data obtained with the SPI Anticoincidence Shield indicates that the energy released in this event was only of the order of a few times $10^{46}$ erg (for an assumed distance of 10 kpc), which is smaller than that of the three historical giant flares. The energetics of the strongest bursts and flares from SGRs/AXPs are compared in Fig. 6.
FIGURE 4. XMM-Newton EPIC X-ray image of the region of SGR 1627–41 with overlaid contours from the 1375 MHz radio map of Sarma et al. (1997). The colors indicate the photon energy (1.7–3.1 keV in red, 3.1–5 keV in green, and 5–8 keV in blue). The bright source in white is SGR 1627–41. The bluish diffuse source is most likely a cluster of galaxies. The soft X-ray (in red) diffuse emission can be associated to the SNR G337.0–0.1.

FIGURE 5. Bursts from 1E 1547.0–5408 observed at E>80 keV with the Anti-Coincidence System of the SPI instrument on board INTEGRAL on January 22, 2009. The initial spike of the longest burst had a duration of ~0.3 s and reached a peak flux greater than 2 x 10^{-4} erg cm^{-2} s^{-1} (25 keV - 2 MeV). A modulation at 2.1 s, reflecting the neutron star rotation period, is clearly visible in the burst tail.
FIGURE 6. Energetics of flares and peculiar bursts from SGRs and AXPs. The different sources are distinguished by the symbols color. The ordinate gives the energy in the pulsating tails that often follow the brightest bursts, while the abscissa reports the energy in the initial spikes (data from Mereghetti et al. (2009) and references therein). The vertical/horizontal lines refer to events in which only one of these components has been observed. The three historical giant flares from SGRs are in the upper right corner. Note that in some cases only lower limits to the total energy could be derived due to instrument saturation. The two points for SGR 1806–20 are for the generally assumed distance of 15 kpc and for the more recent estimate d=8.7 kpc. The energetics of the burst from 1E 1547.0–5408 for an assumed distance of 10 kpc, is in the range of the so called “intermediate flares”.

characterized by an initial spike followed by a pulsating tail; the plot axis refer to these two features. Note that in some cases only lower limits to the emitted energy could be derived due to instrument saturation. The two points for SGR 1806–20 are for the generally assumed distance of 15 kpc and for the more recent estimate d=8.7 kpc [2]. The values reported in Fig. 6 clearly indicate that there is a rather continuous distribution of intensities, from the typical short bursts up to the brightest giant flares. It is also noteworthy that extended pulsating tails have been detected not only for the three giant flares, but also after less intense bursts [3,14,33]. Conversely, also a few examples of pulsating tails apparently without a bright initial hard spike have been observed [7,19]. This is possibly an indication that the spike emission is non-isotropic, a fact that adds a some uncertainty to proper estimates of the involved energy.

Immediately after the discovery of the strong bursting activity of January 22, several follow-up pointings of 1E 1547.0–5408 were carried out with the Swift satellite. During the first Swift/XRT observations, the imaging mode could not be used because the source was too bright. The first data providing full imaging (Fig. 7) were obtained on January 23 at ~15:30 UT and showed the presence of remarkable dust scattering rings around the source position [28]. Further observations carried out with Swift, XMM-Newton and Chandra clearly showed that the angular size of the three rings increased with time. Dust scattering X-ray halos around bright galactic sources were predicted well before their observations with the first X-ray imaging instruments [21]. Their study gives information on the properties and spatial distribution of the interstellar dust. When the scattered radiation is a short burst/flare and the dust is concentrated in a relatively narrow cloud, an expanding ring (instead of a steady diffuse halo) appears, due to the difference in path-lengths at different scattering angles. X-ray expanding rings due to dust scattering have been observed in a few gamma-ray bursts, and through their study accurate distances of the scattering dust clouds in our galaxy could be determined [30,27,31].

The dust scattering rings around 1E 1547.0–5408 are
FIGURE 7. X-ray rings produced by dust scattering around 1E 1547.0–5408. In this image, obtained with the Swift/XRT instrument on January 23, the innermost and brightest ring has a radius of $\sim 1$ arcmin. Two outer rings, produced by closer dust layers are also visible. The ring dimensions were seen to increase in later observations, as expected for scattering by narrow dust layers of the X-ray flux emitted during the strong bursting activity that took place around 6:48 UT of January 22.

the brightest ever observed and the first ones for an AXP/SGR. By fitting their expansion law it is possible to determine the burst emission time, which is found to coincide with the interval of highest activity including the bright event of $\sim$6:48 UT shown in Fig. 5. A comprehensive spectral analysis of all the available X-ray data of the expanding rings around 1E 1547.0–5408 will allow us to determine the distances of the source and of the three dust layers.

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