RECENT RESULTS ON MAGNETARS

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Several observations obtained in the last few years indicate that Soft Gamma-ray Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) are basically a single class of isolated neutron stars. Their properties are well explained by the magnetar model, based on neutron stars powered by magnetic fields as high as \(10^{14}-10^{15}\) G. Here I report some recent results obtained for the transient Soft Gamma-ray Repeater SGR 1627–41, that started a new outburst after about 10 years from the previous one, and for the Anomalous X–ray Pulsar 1E 1547.0–5408. The latter source recently showed a remarkable bursting activity, that reinforces the similarity between AXPs and SGRs.

1 Anomalous X-ray Pulsars and Soft Gamma-Ray Repeaters

Two small classes of peculiar high-energy sources, the Anomalous X-ray Pulsars (AXPs) and the Soft Gamma-Ray Repeaters (SGRs), have attracted increasing attention in the last decade. Their classification in two distinct groups reflects the different manifestations that led to their discovery, but there is mounting evidence that they are probably a single class of objects. Namely, observations performed in the last few years showed many similarities between AXPs and SGRs.

AXPs were first detected as persistently bright pulsars in the soft X-ray range (<10 keV) and thought to belong to the population of galactic accreting binaries. When more X-ray data accumulated, and deeper optical/IR searches excluded the presence of bright companion stars, their peculiar properties started to emerge and led to classify them as a separate class of pulsars. Their common properties are periods of a few seconds, secular spin-down in the range \(10^{-13} - 10^{-10}\) s s\(^{-1}\), relatively soft spectra below 10 keV, and, in some cases, associations with supernova remnants.

SGRs were discovered through the detection of short bursts in the hard X-ray/soft gamma-ray range and initially considered as a subclass of gamma-ray bursts. During sporadic periods of activity, lasting from days to months, they emit short bursts (<1 s) of hard X-rays/soft \(\gamma\)-rays reaching \(L\sim10^{41}\) erg s\(^{-1}\). Occasionally, SGRs emit much more energetic “giant flares” with luminosity up to \(10^{47}\) erg s\(^{-1}\). Only three of these rare events have been observed, each one from a different source. When good positions for the SGRs bursts could be obtained it became possible to identify their X-ray counterparts, finding that they are pulsating sources very similar to the AXPs.

It is generally believed that both SGRs and AXPs are Magnetars: neutron stars with extremely high magnetic fields, B\(\sim10^{14}-10^{15}\) G, i.e. 100-1000 times stronger than those of the typical neutron stars observed as radio pulsars powered by rotational energy or as X–ray pulsars powered by accretion from their binary companions. In this interpretation, the magnetic field
is the ultimate energy source of all the persistent and bursting emission observed in AXPs and SGRs.

Here I present some results on two sources that entered new periods of strong activity in the last months: the SGR 1627–41 and the AXP 1E 1547.0–5408. These results further support the similarity between these two classes of sources.

### 2 The 2008 reactivation of SGR 1627–41

SGR 1627–41 was the first SGR to show a transient behavior. It was discovered in 1998, during a bursting state that lasted about six weeks. At the time of the outburst its X-ray counterpart had a luminosity of \( \sim 10^{35} \) erg s\(^{-1} \), but in the following years its X-ray luminosity gradually decreased, as shown in Fig. 1. This long-term decay was interpreted as the cooling of the neutron star after the heating that occurred during the outburst. In principle, the modelling of the long term light curve could provide information on the mechanism for (and location of) the heating and on the neutron star structure. However, uncertainties in the relative cross calibrations of the different instruments as well as the limited spectral information make it difficult to obtain reliable results.

An XMM-Newton observation carried out in February 2008 revealed SGR 1627–41 at only \( \sim 10^{33} \) erg s\(^{-1} \) (for d=11 kpc), the lowest luminosity observed for a SGR. In May 2008 SGR 1627–41 started a new outburst, during which several short bursts were detected and a peak luminosity higher than that observed in 1998 was attained (Fig. 1). The subsequent evolution could be monitored by a series of Swift observations that showed an initial rapid decrease followed by a shallower phase. The 2008 light curve is compared in Fig. 2 with that of the previous outburst and with the behavior seen in a few other AXPs/SGRs. When early data are available, they show that a single power law decay cannot reproduce the source fading, owing to the presence of a steeper initial phase in the first days after the outburst. This suggest
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, the brightest part of the SGR 1627–41 outburst could not be observed by XMM-Newton, but we requested a Target of Opportunity observation to be performed as soon as possible, in order to take advantage of the source brightness to measure its still unknown spin period. The observation was done 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 and to discover 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 led also to the discovery of diffuse X-ray emission from the vicinity of SGR 1627–41, as shown in Fig. 4. Spectral and spatial analysis shows that the resolved source about 1.5 arcmin south of the SGR is most likely due to a cluster of galaxies, while the more extended and softer emission is related to the supernova remnant / HII region complex CTB 33.

3 The January 2009 outburst of 1E 1547.0–5408

The transient X-ray source 1E 1547.0–5408 was discovered almost 30 years ago in the supernova remnant G 327.24–0.13, but it attracted little interest until it was proposed as a possible AXP on the basis of new X-ray and optical studies ruling out more standard interpretations. Radio pulsations with $P = 2.1$ s and period derivative $\dot{P} = 2.3 \times 10^{-11}$ s$^{-1}$ were subsequently discovered confirming its AXP nature. 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.
Figure 3: X-ray light curve of SGR 1627–41 folded at the spin period of 2.59 s discovered by Esposito et al. (2009). The data have been obtained with the XMM-Newton EPIC pn camera in the 2-12 keV energy range.

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 galaxy in the background, as indicated by its high absorption and redshifted Fe line. The soft X-ray (in red) diffuse emission can be associated to the SNR G337.0–0.1.
Figure 5: Bursts from 1E1547.0–5408 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 \( \sim 0.3 \) s and reached a peak flux greater than \( 2 \times 10^{-4} \) 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 1E1547.0–5408 for an assumed distance of 10 kpc, is in the range of the so called “intermediate flares”.
More recently, a new period of strong activity culminated on 2009 January 22, when more than 200 bursts were detected in a few hours. Some of these bursts were particularly bright, and two had durations sufficiently long to show a clear modulation at the neutron star spin period. Of particular interest is the burst shown in Fig. 5 that started with a very bright and short initial spike ($\sim$0.3 s) followed by a $\sim$8 s long pulsating tail. Although these features are typical of giant flares from SGRs, the energy released in this event was not as large as that of the three historical giant flares. This is shown in Fig. 6, where the energetics of the strongest bursts and flares from SGRs/AXPs are compared. Although the plotted data are affected by some uncertainties, especially for the brightest events that caused instrument saturation, it is clear that there is a rather continuum distributions of intensities, from the normal 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. Conversely, also a few examples of pulsating tails apparently without a bright initial hard spike have been observed. This is possibly an indication that the spike emission is non-isotropic, a fact that adds a further 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 Swift. During the first 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 $\sim$15:30 UT and showed the presence of remarkable dust scattering rings around the source position. Dust scattering X-ray halos around bright galactic sources were predicted well before their observations with the first X-ray imaging instruments. Their study allows to get 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 than a steady diffuse halo) appears, due to the difference in path-lengths at different scattering angles. Halos in the form of expanding rings have been observed in a few gamma-ray bursts, and their study allowed to determine accurate distances for the scattering dust clouds in our galaxy.

The dust scattering rings around 1E 1547.0–5408 are the brightest ever observed and the first ones for an AXP/SGR. Further observations carried out with Swift, XMM-Newton and Chandra clearly show that their angular size is increasing with time. 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 to determine the distances of the source and of the three dust layers.

4 Conclusions

The two sources described here have many similarities. Their spin periods (2.1 and 2.6 s) are the shortest of all the AXPs/SGRs, both are located in supernova remnants (and are in the same region of the galactic plane), both are transient sources and emitted short bursts when in the high state. If 1E 1547.0–5408 had not been previously known as a weak X-ray source, but discovered through its bursts it would have been baptized SGR, as it recently happened for the new source SGR 0501+4516. This underlines once more that the distinction between AXPs and SGRs does not reflect a real difference in the two classes of sources, that can be well explained by the same physical model.

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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.

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