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Abstract

Magnetars are very exotic objects that are related to neutron stars and pulsars. A neutron star is formed when a massive star undergoes a supernova explosion. The super-dense core that is left after such an explosion is a neutron star. It is approximately 10 miles in diameter, yet weighs more than our Sun. We can observe some of those neutron stars as pulsars. Pulsars are highly magnetic, fast spinning neutron stars that emit beams of radio waves from their magnetic poles. Their high magnetic field and spin period are due to the conservation of magnetic flux and momentum during formation. Pulsar spin periods range from 1ms-8s and tend to slow down rapidly. That is another indication of a strong magnetic field, as magnetic braking causes the pulsar to spin-down rapidly. Magnetars are a type of a neutron star with extremely high magnetic fields of 1015-1014 G, which makes these stars the most magnetic objects known. These fields are thought to be generated by a dynamo action during the magnetar's formation (Duncan and Thompson 1992). This is known as a magnetar model. The decay of the magnetic field creates powerful X-ray or gamma-ray emission. However, this magnetic field decays rather fast which makes the magnetar's detectable lifespan short. Some of the known magnetars have poorly understood radio emission. Our group was motivated to better study the correlation between X-ray and radio activity of magnetars via a radio monitoring project. We are regularly observing eight magnetar sources that are visible with the 100-m Green Bank Telescope (GBT) located in Green Bank, WV. Our program is the first major effort to monitor these sources on a regular basis and complements other existing observing programs of southern objects at the Parkes radio telescope (Burgay et al. 2009; Camilo et al. 2009) as well as the high-energy monitoring projects with the Swift gamma-ray observatory and XMM X-ray observatory.

Scientific Background

The magnetar model is used to describe anomalous X-ray pulsars (AXPs) and soft-gamma repeaters (SGRs). AXPs are slowly rotating neutron stars with bright quiescent X-ray radiation and bursts. SGRs are characterized by high-luminosity bursts of soft gamma-ray emission. Currently, four SGRs and nine AXPs are known (for a recent review, see Woods and Thompson (2006)). The rotation periods of magnetars are in the range 2–12s. With the exception of 1E1547.0– 5408 where a periodicity was found in the radio, the periods are known through observation of pulsed X-ray and/or gamma-ray emission. Of particular interest is the magnetar XTE J1810–197. It was revealed in 2003 as the first AXP with transient emission when its luminosity increased 100-fold from the quiescent level (Ibrahim et al. 2004). Radio emission was subsequently detected using the Parkes telescope with period P = 5.54s (Camilo et al. 2006). This was in agreement with the X-ray period and indicated that magnetars are related to radio pulsars. Follow-up observations show this pulsar to be extremely luminous and have a virtually flat radio spectrum detectable up to frequencies of 144 GHz (Camilo et al. 2007a). The second radio emitting magnetar is 1E1547.0–5408, a variable X-ray source (Gelfand and Gaensler 2007) located in the center of supernova remnant G327.24–0.13. Although no X-ray pulsations were detected from this object, Parkes observations revealed a periodicity at P = 2.069s (Camilo et al. 2007b). The same position was previously observed during a Parkes multibeam Galactic plane survey in 1998, and no pulsations were found in the data. This suggests that in 1998 1E1547.0–5408 was fainter than in 2007. As for XTE J1810–197, it is not clear what the cause is for such changes in the electromagnetic activity of this object. This source has recently undergone an X-ray outburst in which pulsations were seen consistent with the radio ephemeris (Dib et al. 2008). While radio pulsations were not initially found (Camilo et al. 2009), more recent observations have shown that the radio emission has now returned (Burgay et al. 2009).

GBT Observations

As it is unclear what the relationship is between radio and high-energy activity in these sources, we became motivated to begin a monitoring program of all magnetars visible from the GBT. We were awarded time to observe AXPs and SGRs that are listed in Table 1 over the course of 8 epochs. The table lists all of our sources, their positions, periods determined from the X-ray pulsations, distance in kiloparsecs (1 parsec = 3.26 light years), and dispersion measure. The value of dispersion measure (DM) is very useful to us. It is related to the slowing down of lower frequency radio waves as they travel though the interstellar medium, much like the effect you get where visible light travels through a prism. With an electron density model of the galaxy and the DM of the sources, we can figure out the distance to our sources, which is what was done in this case. The list of sources includes the original radio magnetar XTE1810−197 as a test source. An example observation is shown in Figure 1.

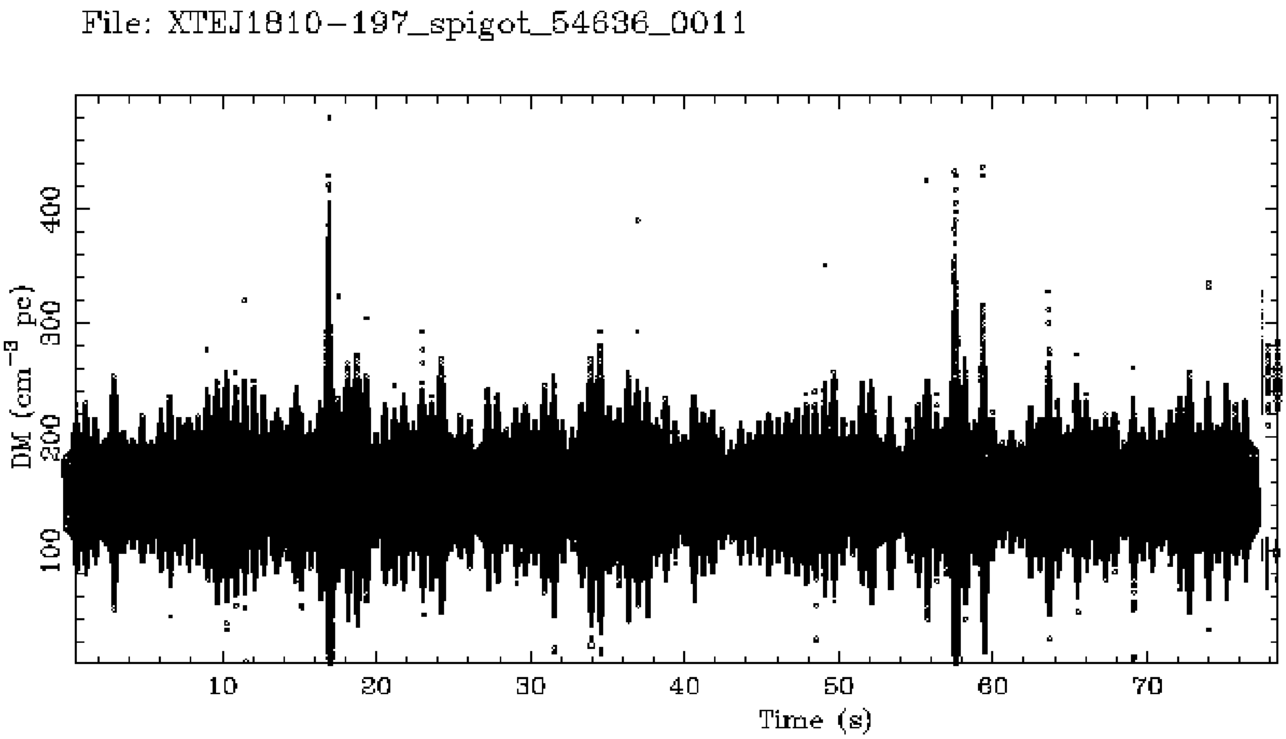

Figure 1: Single pulse plot for XTE1810-197 showing a bright detection of the magnetar at a DM of 177 pc/cm-3.

18:09:51.08

Source name	Right Ascension (J2000)	Declination (J2000)	P (s)	D (kpc)	DM (cm-3 pc)
4U 0142+61	01:46:22.4	+61:45:03.3	8.7	>2.5	70
1RXS J170849.0-400910	17:08:46.9	−40:08:52.4	11.0	8	700
SGR 1806-20	18:08:39.3	−20:24:39.9	7.6	14-17	1200
1E 1841-045	18:41:19.3	−04:56:11.2	11.8	6-8	530
AXP J1845-0258	18:44:54.7	−02:56:53.1	7.0	<20	1300
SGR 1900+14	19:07:14.3	+09:19:20.1	5.2	12-15	700
1E 2259+586	23:01:08.3	+58:52:44.5	7.0	3	90
SGR 0501+4516	05:01:6.78	+45:16:34.0	5.8	?	?
XTE J1810-197	18:09:51.08	-19:43:51.7	5.5	5	180

Table 1, above: Target list of magnetars plus the candidate AXP J1845–0258. Dispersion measures (DM) are estimates based on the distance constraints using the Cordes and Lazio (2001) electron density model.

So far, 6 epochs have been observed. SGR 0501+4516 is a newly discovered SGR observed with Swift and XMM-Newton in August 2008 (Israel et al. 2008). We were granted permission from the GBT scheduling committee to add this new source to our monitoring list in September and have so far obtained four epochs on this source. The first five epochs utilized the GBT setup with the S-band receiver centered at 2.1 GHz using the spigot backend in 800 MHz bandwidth with 1024 frequency channels and 16-bit recording mode. For the sixth epoch we have used a new backend, the Green Bank Ultimate Pulsar Instrument (GUPPI) in 800 MHz bandwidth with 512 frequency channels and 8-bit recording mode. The GUPPI data represent a substantial improvement over the original SPIGOT observations both in immunity to radio frequency interference and in size.

Results

All data collected thus far have now been processed using single pulse and periodicity searches. Single pulse searches are sensitive to any sporadic emission. They search for individual events that deviate from the mean. Periodicity searches make use of the Fast Folding Algorithm (Staelin

1969) to detect any coherent pulsations that might be present. While XTE1810-197 is routinely visible in these searches (Fig.1), all other sources in our list remain radio quiet or at least below the flux density thresholds of our searches. For periodic sources, assuming the pulse width is 10% of the pulse period, we reach a limiting S-band flux density of 30 μJy in each 30 minute observation, which is well below any expected radio emission from a magnetar. For individual bursts of width 10 ms, the threshold for a 10 σ detection is 40 mJy and is well within our sensitivity range.

Future of the Project

The project will likely run until the end of 2009. During this time, we will employ more sophisticated radio frequency interference (RFI) removal techniques and new algorithms for pulsar detection. This will allow us to provide better limits on the emission from the magnetar. At the end of this period, we will submit the complete results of this project to a refereed journal.

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