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JCMT observations of Soft Gamma-Ray Repeaters*

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Abstract. The spectra of the quiescent counterparts to the Soft Gamma-Ray Repeaters SGR 1900+14 and SGR 1806–20 peak in the infrared. Their infrared spectra appear to contain several components: the photospheric emission from star(s) dominates at shorter wavelengths, a bright point source dominates at 25 μm, while an extended source dominates at 60 μm. However, we show here that these counterparts were not detected by the James Clerk Maxwell Telescope at 450 μm or 800 μm. These observations are consistent with other millimeter studies, and are consistent with the detection of a point-like "core" to the radio nebula of SGR 1806–20. We show that monoenergetic synchrotron radiation and black body spectra are too broad to be consistent with both the infrared and submillimeter observations. However, simple dust models can explain the combined observations.

Key words: gamma rays: bursts – radio continuum: stars – infrared: stars – supernovae: general – stars: neutron

1. Introduction

The Soft Gamma-Ray Repeaters (SGR) are sources of brief intense outbursts of low energy gamma rays. The discovery of quiescent counterparts to all three SGR has been a significant breakthrough: see Hurley (1996) for a review. While a possible counterpart to SGR 0525–66 has only been detected in X-rays, SGR 1900+14 and SGR 1806–20 both appear to be associated with unusual sources whose spectra peak in the infrared. We have embarked on a program of multi-wavelength observations of these quiescent counterparts, in the hope this will lead to an understanding of the source of the bursts of gamma rays. In this paper we report our observations of SGR 1900+14 and SGR 1806–20 at 450 μm and 800 μm using the James Clerk Maxwell Telescope (JCMT).

The current status of the millimeter through near infrared observations of the quiescent counterparts to SGR 1806–20 and SGR 1900+14 are shown in Figs. 1 and 2 (see also Smith et al. 1996a,b; Smith, Chernin, & Hurley 1996): we briefly review these multi-wavelength observations in the next subsections. In Sect. 2, we detail our JCMT observations, and in Sect. 3 we use several different models to compare the results with the far infrared detections. Finally, in Sect. 4 we outline our planned future observations.

1.1. Previous observations

Soft X-ray observations of SGR 1806–20 have shown that this source may be associated with the galactic supernova remnant G 10.0–0.3 (Kouveliotou et al. 1994; Murakami et al. 1994; Kulkarni et al. 1994). SGR 1900+14 has been shown to have a position near the galactic supernova remnant G 42.8+0.6 (Hurley et al. 1994a), and a ROSAT soft X-ray source has been found at this location (Vasisht et al. 1994; Hurley et al. 1996a,b). Kulkarni et al. (1994) suggested that the counterparts are plerions, i.e. powered by synchrotron radiation from young pulsars. However, the SGRs are quite rare compared to plerionic supernova remnants (Hurley et al. 1994b; Kouveliotou et al. 1994), and it appears that they may be completely new manifestations of neutron stars. Possible stellar counterparts have been found for both SGR, but the multi-wavelength observations indicate that several emission processes are active. Multi-wavelength observations of the quiescent counterparts have therefore become important to try to untangle these components.

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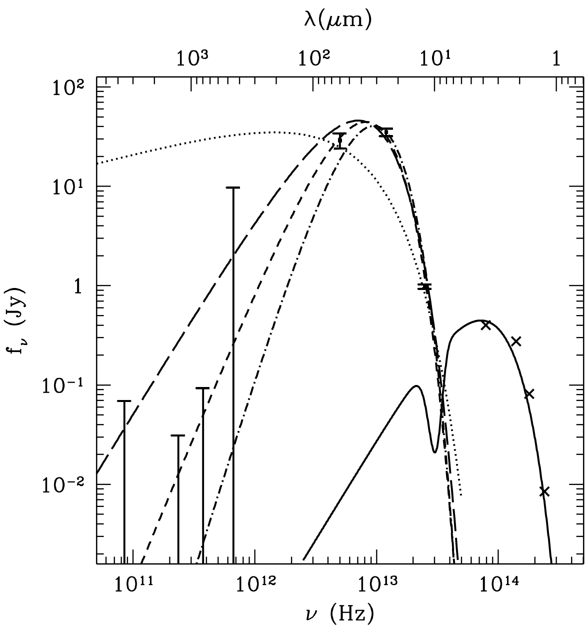

Fig. 1. SGR1806–20. 3σ point source upper limit at 85 GHz (3.5 mm) from the Berkeley-Illinois-Maryland Array (Smith, Chernin, & Hurley 1996). 3σ upper limit at 235 GHz (1.3 mm) from the Swedish-ESO Submillimeter Telescope (Wallyn et al. 1995; Durouchoux et al. 1996a). 3σ upper limits at 800 μm and 450 μm from the JCMT (this paper). IRAS flux densities are shown with 1σ error bars; the source is point-like at 12 μm and 25 μm, and extended at 60 μm (Van Paradijs et al. 1996). Crosses: L′, K, H, and J-band flux densities for star A in Kulkarni et al. (1995). Dotted line is a monoenergetic synchrotron spectrum with $\nu_c = 5 \times 10^{12}$ Hz. Long dashed line is a 120 K black body spectrum. Short dashed line is a Population I dust model with T_{gr} = 100 K (Dwek & Werner 1981). Short dashed-dotted line is a Population II dust model with T_{gr} = 92 K (Dwek & Werner 1981). Solid curve is a 30,000 K black body attenuated by the interstellar extinction law of Rieke & Lebofsky (1985) with A_V = 30 (Van Kerkwijk et al. 1995).

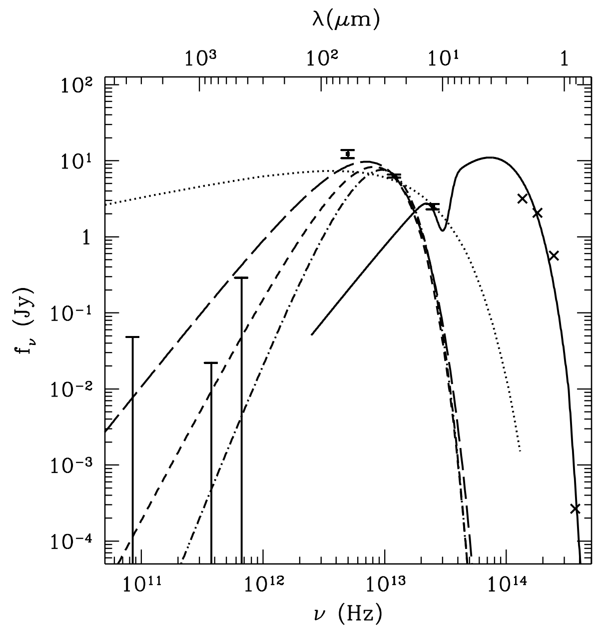

Fig. 2. SGR1900+14. 3σ point source upper limit at 85 GHz (3.5 mm) from the Berkeley-Illinois-Maryland Array (Smith, Chernin, & Hurley 1996). 3σ upper limits at 800 μm and 450 μm from the JCMT (this paper). IRAS flux densities are shown with 1σ error bars; the source is point-like at 12 μm and 25 μm, and extended at 60 μm (Van Paradijs et al. 1996). Crosses: K, H, J, and I_C-band flux densities for stars A plus B seen by the USNO (Vrba et al. 1996). Dotted line is a monoenergetic synchrotron spectrum with $\nu_c = 1.3 \times 10^{13}$ Hz. Long dashed line is a 120 K black body spectrum. Short dashed line is a Population I dust model with T_{gr} = 100 K (Dwek & Werner 1981). Short dashed-dotted line is a Population II dust model with T_{gr} = 92 K (Dwek & Werner 1981). Solid curve is a 2900 K black body attenuated by the interstellar extinction law of Rieke & Lebofsky (1985) with A_V = 19.2 (Vrba et al. 1996).

1.2. Near infrared observations

The near infrared and optical observations of SGR 1806–20 are discussed in Kulkarni et al. (1995) and Van Kerkwijk et al. (1995). They found a heavily reddened star, that is consistent with being a rare Luminous Blue Variable. The solid curve in Fig. 1 shows an approximate fit to the near infrared data: it is a 30,000 K black body attenuated by the interstellar extinction law of Rieke & Lebofsky (1985) with A_V = 30. Since the errors in the observations are small, this simple model does not give a perfect fit to the data, though it does account for the general shape and the sharp drop in the optical emission. The dip near 10 μm from interstellar silicate absorption may be overly deep (Draine & Lee 1984), and may be partially filled in by silicate emission from a dusty stellar wind, although this is not important here.

Near infrared and optical observations of the possible counterpart to SGR 1900+14 have found a pair of heavily reddened stars (Vrba et al. 1995, 1996; Hartmann et al. 1996). These stars appear to be variable M5 supergiants at a distance of $\sim 12 - 15$ kpc. The spectra of the two stars are remarkably similar, although they are slightly different (Vrba et al. 1996; Smith et al. 1996b; Hartmann et al. 1996). The solid curve in Fig. 2 shows an approximate fit to the near infrared data (the sum of the two stars): it is a 2900 K black body attenuated by the interstellar extinction law of Rieke & Lebofsky (1985) with A_V = 19.2 (Vrba et al. 1996). As for SGR 1806–20, this model accounts for the sharp drop in the optical.

1.3. Far infrared observations

An image of SGR 1900+14 at 10 μm was made using the Thermal Imaging Multi-Mode Instrument (TIMMI) on the 3.6-m telescope at ESO: the emission is still dominated by the well-resolved stars, with a faint extended component (Van Paradijs et al. 1996). Van Paradijs et al. also performed a detailed study of the IRAS observations of the SGR, and found that the emission appears to consist of multiple components. For SGR 1900+14, the 25 μm IRAS emission is consistent with a point source. Fig. 2 shows that the 25 μm flux density is well in excess of that expected from the stellar photospheric emission. SGR 1900+14 has an even higher flux density at 60 μm, though the IRAS source is larger than predicted for a point source: the figures should be interpreted with care, because they mix both point-like and extended components.

For SGR 1806–20, the IRAS source is point-like at 12 and 25 μm, but extended at 60 μm (Van Paradijs et al. 1996). Fig. 1 shows that the stellar photospheric emission is too faint to explain the IRAS observations. The IRAS colors resemble those of some other Luminous Blue Variables with dust shells, although the fact that the emission is extended at 60 μm while point-like at 12 and 25 μm does not fit naturally into this scenario.

1.4. Millimeter and radio observations

Observations of SGR 1900+14 and SGR 1806–20 were made at 85.0 GHz (3.5 mm) using the Berkeley-Illinois-Maryland Array (BIMA) located in Hat Creek, California (Smith, Chernin, & Hurley 1996). No significant signals were detected for either SGR 1806–20 or SGR 1900+14, with r.m.s. noise values of 23 and 16 mJy/beam respectively (and synthesized beam widths $18'' \times 13''$ and $13'' \times 10''$ respectively).

SGR 1806–20 was observed with the Swedish-ESO Submillimeter Telescope (SEST) using a bolometer at 235 GHz (1.3 mm) (Wallyn et al. 1995; Durouchoux et al. 1996a). No source was detected with a 3σ upper limit of 31 mJy (the beam size was $23''$): a more stringent limit will be given in Durouchoux et al. (1996b).

Radio emission has been detected for SGR 1806–20 (Kulkarni et al. 1994), but only upper limits are found for SGR 1900+14 (G. Vasisht and D. Frail, private communications; Hurley et al. 1996b). The central ‘core’ to SGR 1806–20 has a flux density of 4.8 mJy at 3.6 cm (Vasisht, Frail, & Kulkarni 1995).

2. JCMT observations

The observations were performed September 23, 24, and 25, 1995 (UT) using the UKT14 photometer on the JCMT at Mauna Kea: see Duncan et al. (1990) for the instrument details. The observations reported here used two filters: the 450 μm filter with a 65 mm aperture (half power beam width of $17.5''$), and the 800 μm filter with a 65 mm aperture (half power beam width of $16.0''$). Chopping was done at 7.8 Hz, with a throw of $60''$. The pointing and focusing were tested several times each night, with no problems encountered: the absolute positional accuracy was $\lesssim 2''$.

The observations were coadded, despiked, and extinction corrected using the standard JCMT reduction procedures (Stevens & Robson 1994). The secondary submillimeter calibrators G45.1 (which is very close to SGR 1900+14), and G10.62 (which is very close to SGR 1806–20) were observed several times each night. These sources plus Jupiter and the secondary submillimeter calibrator NGC 6334I were used to determine the flux densities of the SGRs; the resulting errors in the flux densities are $\lesssim 10\%$ (Sandell 1994).

SGR 1900+14 was observed at 450 μm on UT September 23, 1995 when reasonable weather conditions gave low atmospheric optical depths and good seeing (observations at the shorter submillimeter wavelengths are sensitive to the observing conditions). The observations were centered on the location of the infrared source, RA(J2000) = 19:07:15.23, DEC(J2000) = +09:19:21.35. We did not detect SGR 1900+14, with a 3σ upper limit of 290 mJy.

Table 1. JCMT limits for map around SGR 1900+14 at 800 μm

RA(J2000) -19:07:00 ($''$)	DEC(J2000) -09:19:00 ($''$)	3σ upper limit (mJy)
14.42	15.32	140
14.83	15.35	170
15.23	15.35	170
15.64	15.35	160
14.01	21.35	670
14.42	21.35	120
14.83	21.35	230
15.23	21.35	22
15.64	21.35	210
14.83	27.35	1750
15.23	27.35	240
15.64	27.35	160

The location of the infrared counterpart to SGR 1900+14 was observed at 800 μm on UT September 23, 1995. We did not detect SGR 1900+14, with a 3σ upper limit of 22 mJy. The ROSAT X-ray counterpart to SGR 1900+14 is offset $\sim 15''$ from the infrared counterpart (Hurley et al. 1996a,b). Since it is not certain that the two counterparts are the same source, we mapped the region at 800 μm on UT September 24 and 25, 1995. No significant signals were detected. In Table 1, we list the locations observed, and the 3σ upper limits.

SGR 1806–20 was observed at 450 μm on UT September 25, 1995 when changing cloudiness made the optical depth larger and variable. Therefore, we only observed the source for 10 minutes at this wavelength. The observations were centered on the location of the radio source, RA(B1950) = 18:05:41.675, DEC(B1950) = -20:25:12.5. We did not detect SGR 1806–20, with a 3σ upper limit of 9.7 Jy.

SGR 1806–20 was observed at 800 μm on UT September 24 and 25, 1995 at the location of the radio source. On the first night, it appeared we were seeing a weak signal, with a flux density of 88 ± 30 mJy. However, we could not duplicate this on the second night at approximately the same noise level, giving a 3σ upper limit of 93 mJy. Large changes in the radio flux have not been detected (Vasisht et al. 1995); however, more sensitive observations and further monitoring of this source are strongly recommended.

In Figs. 1 and 2, we include the JCMT flux density limits at the locations of the stars. The JCMT results agree with the lack of detection of SGR 1900+14 and SGR 1806–20 at other millimeter wavelengths. The JCMT upper limits are consistent with the ‘core’ radio point source in SGR 1806–20, provided the submillimeter emission from this source is $\lesssim 30$ mJy. The

JCMT observations are also consistent with the observations of the extended radio nebula in SGR 1806–20 (Kulkarni et al. 1994), which is much larger than the JCMT beam size.

3. Model fitting

In addition to the photospheric emission from the stars, there needs to be at least one more component to explain the bright far infrared emission of both SGR. There is not enough information in the current far infrared spectra to make a complete comparison between the JCMT and infrared observations. However, we show that useful information can still be obtained using very simple models; a more thorough examination will be performed after we have spectra from the Infrared Space Observatory.

3.1. Monoenergetic synchrotron radiation

The possibility that the SGR are plerions suggests that synchrotron radiation may be responsible for the far infrared excess. To produce the most narrowly peaked synchrotron spectrum that is possible, we assume the radiating particles are monoenergetic and the magnetic field is uniform: in reality, spreads in the particle energies and magnetic field strengths will broaden the emitted spectra. The dotted curves in Figs. 1 and 2 show typical monoenergetic synchrotron spectra (Ginzburg & Syrovatskii 1965): for SGR 1806–20, the critical frequency was $\nu_c = 5 \times 10^{12}$ Hz, while for SGR 1900+14, $\nu_c = 1.3 \times 10^{13}$ Hz. It can be seen that these spectra are too broad, and are well above the JCMT upper limits; this is similar to the results of Strom and Greidanus (1992), who found that this mechanism could not explain the IRAS excesses in the Crab.

3.2. Black body radiation

The long dashed curves in Figs. 1 and 2 show representative single temperature black body curves at 120 K that were chosen to go through the 25 μm IRAS points. As was already discussed in Smith, Chernin, & Hurley (1996), these curves are too broad to be consistent with the submillimeter observations, indicating that a model with a steeper drop into the millimeter is needed for both sources.

3.3. Dust models

The extended far infrared components to the SGR suggest that the stars have shed massive shells, leading to dust emission at different temperatures (Van Paradijs et al. 1996). It is possible that part of the point source infrared excess might come from an opaque dusty accretion disk around a compact object in the system that is responsible for the gamma-ray bursts (Smith et al. 1996a,b). These scenarios, plus the fact that a steeper spectrum than a black body is needed, suggest that dust models should be used.

Since we only have a limited amount of observational data at this time, we use the very simple dust models of Dwek & Werner (1981); these are representative of the range of more detailed models. In the Dwek & Werner models, two types of dust grain are considered: Population I grains, whose grain radiation absorption/emission efficiency at frequency ν, $Q_\nu \propto \nu$, and Population II grains whose $Q_\nu \propto \nu^2$. In the future, when we have stricter submillimeter limits or detections, and spectra from the Infrared Space Observatory, we will meaningfully be able to use more realistic multi-component dust models, for example, Draine & Lee (1984).

In Figs. 1 and 2, the short dashed lines show representative Population I dust models, while the dotted-short dash lines show Population II dust models. We did not include any ISM reddening of the dust spectra.

For SGR 1806–20, we assume the source is at a distance of 14.5 kpc (Corbel et al. 1996). The Population I model in Fig. 1 used a grain temperature $T_{\rm gr}$ = 100 K, and a total mass of condensates locked up in the dust grains $M_{\rm d} = 2 \times 10^{-2} {\rm M}_\odot$. This curve goes through all three IRAS data points, and predicts a 50 mJy signal at 800 μm. However, since the 60 μm IRAS source is believed to be extended, while the 25 and 12 μm sources are point-like, this Population I model is probably not correct: it could easily be ruled out by more sensitive JCMT observations of SGR 1806–20. The Population II dust model in Fig. 1 used $T_{\rm gr}$ = 92 K, and $(M_{\rm d}/{\rm M}_\odot)(a/\mu{\rm m}) = 0.45$, where a is the radius of the grain. This model explains the 12 and 25 μm IRAS data, and is easily consistent with the JCMT upper limits. If the 60 μm source really is extended, it is harder to compare with the JCMT observations, since only a fraction of the flux may be falling inside the JCMT beam.

For SGR 1900+14, we assume the source is at a distance of 13 kpc (Vrba et al. 1996). The Population I model in Fig. 2 used $T_{\rm gr}$ = 100 K and $M_{\rm d} = 3 \times 10^{-3} {\rm M}_\odot$. This curve goes through the 25 μm IRAS data point, and is just consistent with the JCMT limits: this model could be ruled out by more sensitive JCMT observations of SGR 1900+14. The Population II dust model in Fig. 2 used $T_{\rm gr}$ = 92 K, and $(M_{\rm d}/{\rm M}_\odot)(a/\mu{\rm m}) = 0.067$; it is easily consistent with the JCMT upper limits. Both dust models produce only a small contribution at 12 μm, where the flux density is believed to be dominated by the stellar photospheric emission. Neither model comes close to explaining the 60 μm emission. This may be coming from a separate, cooler, extended dust component, which would be consistent with the JCMT limits if only a fraction of the flux is falling inside the JCMT beam.

4. Future observations

The results shown here highlight the need for continued multiwavelength observations and long-term monitoring of the quiescent sources. For both SGR, a factor of $\sim$ 10 improvement in the submillimeter sensitivity beyond the current observations would tightly constrain the allowed dust emission models. This will be feasible with the recently installed SCUBA on the JCMT. Our program of scheduled observations also includes using the Infrared Space Observatory, ground-based near and mid-infrared observatories, and the Swedish-ESO Submillimeter Telescope.

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