MAGNETIC FIELD LIMIT ON SGR 1900+14

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ABSTRACT

We measured the period and spin-down rate for SGR 1900+14 during the quiescent period two years before the recent interval of renewed burst activity. We have shown that the spin-down age of SGR 1900+14 is consistent with a braking index of \( \sim 1 \) which is appropriate for wind torques and not magnetic dipole radiation. We have shown that a combination of dipole radiation, and wind luminosity, coupled with estimated ages and present spin parameters, imply that the magnetic field for SGR 1900+14 is less than \( 6 \times 10^{13} \) G and that the efficiency for conversion of wind luminosity to x-ray luminosity is <2%.

KEYWORDS: gamma-rays: bursts, pulsars: individual (SGR 1900+14), magnetic fields

1. SPIN-DOWN HISTORY OF SGR 1900+14

The spin-down of SGR 1900+14 from 1966 September to 1999 April (Figure 1) is characterized by three intervals of time for which the spin-down rate was essentially constant within the interval. This characterization of the SGR 1900+14 spin-down is based upon either direct measurements of \( \dot{P} \) as part of the period determination, or upon differences in measured spin periods between two different observations. The first interval begins with the RXTE observation in September of 1996 and ends with the ASCA observation at the beginning of May, 1998. The mean spin-down \( \dot{P} \sim 6 \times 10^{-11} \) s/s (Marsden, Rothschild and Lingenfelter 1999a; Hurley et al. 1999; Woods et al. 1999b). The second interval begins with the onset of bursting on May 26, 1998 and continues until mid-September 1998. The mean spin-down during this time \( \dot{P} \sim 13 \times 10^{-11} \) s/s (Kouveliotou et al. 1999; Marsden, Rothschild and Lingenfelter 1999a; Murakami et al. 1999). The third interval begins in mid-September 1998 and continues at least until March 30, 1999. The mean spin-down at that time \( \dot{P} \sim 6 \times 10^{-11} \) s/s (Woods et al. 1999b).

Woods et al (1999b) have suggested that the data may be consistent with a discontinuous spin-down event during the second interval as a result of the Superburst, as opposed to a doubling of \( \dot{P} \) during the entire second interval (Marsden, Rothschild and Lingenfelter 1999a). This appears to be at odds with the measurement of \( \dot{P}=(11.0\pm1.7) \times 10^{-11} \) s/s in early June, 1998 (Kouveliotou et al. 1999), approxi-
FIGURE 1. The pulse period history for SGR 1900+14 versus time. All of the published values of the pulse period are given along with the three measurements of $\dot{P}$ made as part of the period determination analysis. The mean spin-down in the three time intervals are also given.

approximately 3 months before the Superburst and with the RXTE/ASCA determination of $\dot{P} \sim 10 \times 10^{-11} \, \text{s/s}$ just after the event (Murakami et al. 1999).

2. SPIN-DOWN IN SGR 1900+14 IS DUE TO A RELATIVISTIC WIND

Assuming that the spin-down torque is given by $\dot{\Omega} \propto \Omega^n$, the age of a pulsar with period $P$ and spin-down $\dot{P}$ is given by

$$t_{age} = \frac{P}{[(n - 1)\dot{P}]}$$

where the spin-down braking index, $n = 3$ for pure magnetic dipole radiation and $n \sim 1$ for wind torques. Inverting the age equation yields

$$n = 1 + \frac{(P/\dot{P})(t_{age})^{-1}}{10^{4 \text{yr}}}.$$  

Using parameters appropriate for SGR 1900+14, we find that

$$n = 1 + 0.27/(t_{age}/10^{4 \text{yr}}).$$

This indicates that the braking index for SGR 1900+14 must be $\sim 1$, and that the spin-down of SGR 1900+14 is dominated by torques due to the relativistic wind and not magnetic dipole radiation.
3. SPIN-DOWN TORQUES OF SGRS

In reality, there will be more than one torque spinning down the pulsar at any given time. The torque provided by the emission of a relativistic wind is (Thompson et al. 1999):

\[ I_\ast \dot{\Omega}_w = -\Lambda \left( L_w / c^2 \right) R_A^2 \Omega \]

where \( I_\ast \) is the neutron star moment of inertia, \( L_w \) is the luminosity of the wind, \( \Omega \equiv 2\pi / P \) is the spin frequency, \( \dot{\Omega}_w \) is the spin-down rate due to the wind, and \( R_A \) is the Alfven radius. \( \Lambda \) is a constant equal to 2/3 for a magnetic dipole field aligned with the rotation axis. The Alfven radius is given by:

\[ L_w^2 / 4\pi R^3 \approx B^2(R_A) / 8\pi \]

where \( B_\ast \) is the magnetic field of the neutron star. When the Alfven radius is inside the light cylinder radius (\( R_A < R_{lc} \), where \( R_{lc} = c / \Omega \)),

\[ I_\ast \dot{\Omega}_w = -\Lambda B_\ast R_A^3 \left( \frac{L_w}{c^2} \right)^{1/2} \Omega \]

where \( R_\ast \) is the radius of the neutron star and dipole geometry is assumed. When the Alfven is outside the light cylinder radius, the torque is limited to

\[ I_\ast \dot{\Omega}_w = -\Lambda L_w \Omega^{-1} \]

The transition frequency between these two wind spin-down regimes is
\[ \Omega_{tr} = 8.572 \left( \frac{L_w}{10^{36} \text{ergs/s}} \right)^{1/4} \left( \frac{B_*}{10^{13} \text{G}} \right)^{-1/2} \text{radians/s}. \]

The torque due to a rotating magnetic dipole is (Shapiro & Teukolsky 1983):

\[ I_\Omega \dot{\Omega}_{mdr} = -k B^2 R^6 \Omega^3 \]

where \( k = 1 \) (Harding, Contopoulos, & Kazanas 1999).

Once the total spin-down torque is specified as a function of \( \Omega \), the age of the SGR can found by the integral of \( d\Omega \) over the total torque divided by \( I_* \), where the integration is performed from an initial frequency to the present-day angular frequency.

4. MAGNETIC FIELD AND WIND LUMINOSITY LIMITS

Using the above model we explore a wide range of magnetic fields \( B_* \) and wind luminosity \( L_w \), shown in Fig. 2. We see that the presently observed period of \( P = 5.157 \) s, the spindown rate of \( \dot{P} = 6 \pm 1 \times 10^{-11} \) s/s (dotted lines) of SGR 1900+14, and the 10 to 20 Kyr range of ages (solid lines) of its associated supernova remnant G42.8+0.6 (Vaiht et al. 1994), tightly constrain the allowable magnetic field to \( B_* < 6 \times 10^{13} \) G and wind luminosities \( L_w > 5 \times 10^{36} \) erg/s. Compared to the quiescent 2-10 keV x-ray luminosity of \( \sim 10^{35} \) erg/s (Murakami et al. 1999), this wind luminosity implies a < 2 % conversion efficiency of wind energy to x-rays in that band which is quite consistent with theoretical calculations (Tavani 1994, Harding 1995; Harding, Contopoulos & Kazanas 1999). The magnetic field limits are also quite consistent with the limiting values inferred for radio pulsars, but not with those expected for magnetars. Very similar limits are set by comparable analyses (Harding, Contopoulos, & Kazanas 1999; Marsden, Rothschild & Lingenfelter 1999b) of SGR 1806-20 and its supernova remnant G10.0-0.3.

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