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MAGNETICALLY ACCRETING ISOLATED OLD NEUTRON STARS

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ABSTRACT

Previous work on the emission from isolated old neutron stars (IONSs) accreting from the interstellar medium (ISM) has focused on gravitational capture—i.e., Bondi accretion. We propose a new class of sources that accrete via magnetic interaction with the ISM. While for the Bondi mechanism the accretion rate $\dot{M}_{\rm Bondi}$ decreases with increasing neutron star velocity, in magnetic accretors (MAGACs) $\dot{M}_{\rm MAGAC}$ *increases* with increasing neutron star velocity ($\dot{M}_{\rm Bondi} \propto v^{-3}$ vs. $\dot{M}_{\rm MAGAC} \propto v^{1/3}$). MAGACs will be produced among high-velocity ($\gtrsim$100 km s^{-1}), high magnetic field ($B > 10^{14}$ G) radio pulsars—the "magnetars"—after they have evolved first through magnetic dipole spin-down, followed by a "propeller" phase (during which the object sheds angular momentum on a timescale $\lesssim 10^{10}$ yr). The properties of MAGACs may be summarized thus: dipole magnetic fields of $B \gtrsim 10^{14}$ G; minimum velocities relative to the ISM of 25–100 km s^{-1} or higher, depending on B, well below the median in the observed radio pulsar population; spin periods of greater than days to years; accretion luminosities of 10^{28}–10^{31} ergs s^{-1}; and effective temperatures $kT_{\rm eff} = 0.3$–2.5 keV if they accrete onto the magnetic polar cap. We find no examples of MAGACs among previously observed source classes (anomalous X-ray pulsars, soft gamma-ray repeaters, or known IONs). However, MAGACs may be more prevalent in flux-limited X-ray catalogs than their gravitationally accreting counterparts.

Subject headings: pulsars: general — stars: magnetic fields — stars: neutron — X-rays: stars

1. INTRODUCTION

Accretion onto isolated old neutron stars (IONSs) through the spherical Bondi accretion mode (Bondi & Hoyle 1944; Bondi 1952) has been investigated as a means to produce a population of neutron stars detectable in the *ROSAT* All-Sky Survey (RASS; Treves & Colpi 1991; Blaes & Madau 1993; Madau & Blaes 1994; Zane et al. 1995; Popov et al. 2000). The estimated number of these sources in the RASS was initially high ($\sim 10^3$–10^4). However, as observations of higher mean velocities in the radio pulsar population (Lorimer, Bailes, & Harrison 1997; Hansen & Phinney 1997; Cordes & Chernoff 1998 and references therein) were considered, the predicted number of detectable IONSs accreting from the interstellar medium (ISM) decreased dramatically ($\sim 10^2$–10^3). This is because the Bondi accretion rate is a strong function of the neutron star (NS) velocity through the ISM:[1]

$$\dot{M}_{\rm Bondi} = 4\pi (G M_{\rm NS})^2 \rho v^{-3} , \quad (1)$$

where ρ is the local mass density of the ISM. Bondi-accreting IONSs are expected to have X-ray luminosities $\sim 10^{31}$ ergs s^{-1} and effective temperatures $kT_{\rm eff} \lesssim 200$ eV, both dependent upon the accretion rate.

There will be a different accretion mode, however, when the NS magnetic field dominates over the gravitational field in attracting accretion from the ISM. In this mode, the warm ionized medium (WIM) attaches to the NS magnetic field at the magnetosphere, accreting directly onto the NS surface. These magnetically accreting isolated old neutron stars (MAGACs, pronounceable "magics") contrast with IONSs, which accrete through the Bondi mode, in that the Bondi accretion rate decreases with the NS velocity, while in MAGACs, the accretion rate *increases* with increasing velocity:

$$\dot{M}_{\rm MAGAC} = \pi R_M^2 v \rho , \quad (2)$$

where $R_M = [\mu^2/(4\pi\rho v^2)]^{1/6}$ is the size scale for the magnetosphere of a nonrotating NS with the magnetic energy density from the NS's magnetic moment μ, equal to the ram pressure of the WIM. This yields $\dot{M}_{\rm MAGAC} \propto v^{1/3}$. So, for a given magnetic field strength, Bondi accretion dominates at low velocities, while magnetic accretion dominates at high velocities.

The evolutionary scenario of magnetically accreting NSs has been outlined by Harding & Leventhal (Harding & Leventhal 1992, hereafter HL92). HL92 found that magnetized NSs first spin down via dipole radiation, followed by a longer spin-down period via the propeller effect. They restricted their attention to sources with surface magnetic fields $\lesssim 10^{13}$ G and found that they are unable to accrete onto the compact object, as the propeller spin-down time is longer than the age of the universe. A similar line of argument is followed in the review by Treves et al. (2000) in the context of Bondi-accreting IONSs. This limitation does not apply to NSs with magnetic fields $\gtrsim 10^{14}$ G: an NS with magnetic field $B = 10^{15}$ G and velocity $v = 300$ km s^{-1} spins down in $\sim 4 \times 10^9$ yr.

On the other hand, this same evolutionary scenario has been used to argue for magnetic field decay in the IONSs RX J0720.4−3125 (Wang 1997; Konenkov & Popov 1997) and in NSs in general (see Livio, Xu, & Frank 1998; Colpi et al. 1998). We suggest, instead, that high magnetic field IONSs have not been discovered because strong magnetic field sources accreting from the ISM are spectrally harder (as we find below) than Bondi accretors and have been selected against by observers, or confused with background active galactic nuclei.

[1] Here $v = (V^2 + C_s^2)^{1/2}$, the geometric sum of the spatial velocity of the NS and the sound speed in the accreted medium. The sound speed of the ISM is low ($\sim$10 km s^{-1}) compared with spatial velocities relevant to the present work ($v \gtrsim 100$ km s^{-1}), so we assume $v \gg C_s$ throughout.

Moreover, since HL92's work, observations have revealed NSs with considerably stronger magnetic fields than considered by HL92, in the range of 10^{15} G—the magnetars. Pulse timing of soft gamma-ray repeaters (Kouveliotou et al. 1998, 1999) confirms their existence as proposed in earlier theoretical work (Thompson & Duncan 1993; Duncan & Thompson 1992). Circumstantial evidence suggests that anomalous X-ray pulsars have similarly strong B-fields (Thompson & Duncan 1996; Vasisht & Gotthelf 1997; Heyl & Hernquist 1997), and precision pulsar-timing evidence also implies magnetic fields in excess of 10^{14} G (Kaspi, Chakrabarty, & Steinberger 1999), confirming less precise, multiepoch timing solutions that nonetheless led to a magnetar interpretation (Gotthelf, Vasisht, & Dotani 1999). Static solutions for NSs have been proposed for surface fields up to $\sim 10^{18}$ G (Bocquet et al. 1995; Cardall, Prakash, & Lattimer 2001), although no objects with magnetic fields as high as this have yet been observed. Thus, with theoretical and observational motivation, we reconsider the scenario of HL92, but with particular attention paid to NSs with magnetic fields above 10^{13} G.

In § 2, we describe the model for this population, following the scenario of HL92. In § 3, we summarize the properties of MAGACs, discuss observational ramifications, and conclude.

2. MODEL

2.1. *Evolutionary Model*

We assume that the neutron star is born with a velocity $v = v_7\, 10^7$ cm s^{-1} relative to the ISM and a magnetic moment $\mu = \mu_{33}\, 10^{33}$ G cm^3, which corresponds to a dipole field strength at the NS surface (10 km) of 10^{15} G (appropriate for magnetars; Thompson & Duncan 1993; Duncan & Thompson 1992). The spin period is initially short ($P \ll 10$ s). We assume that the magnetic field does not decay. We assume a compact object mass $M = M_{\rm NS}\, 1.4\, M_\odot$ and radius $R = R_{\rm NS}\, 10^6$ cm. We assume the NS travels through a spatially uniform proton density $n_p = 0.1 n_{-1}$ cm^{-3} in the WIM (Boulares & Cox 1990; Ferriere 1998a, 1998b). A more detailed examination of the properties of this population, which would include a distribution of NS kick velocities, orbits about a realistic Galactic potential, and the Galactic gas density and ionization state—such as that performed for Bondi accretors and cooling NSs (Popov et al. 2000; Popov 2001)—will be the subject of forthcoming work.

First, HL92 argue that magnetic accretion dominates over Bondi accretion when the magnetospheric radius $R_M = 4.2 \times 10^{12} \mu_{33}^{1/3} v_7^{-1/3} n_{-1}^{-1/6}$ cm is larger than the Bondi accretion radius $R_{\rm Bondi} = 2GM_{\rm NS}/v^2$. This inequality results in a velocity limitation for a MAGAC of

$$v_{\rm lim} > 94 \mu_{33}^{-1/5} n_{-1}^{1/10} M_{\rm NS}^{3/5} \ {\rm km\ s^{-1}}\ . \quad (3)$$

Electromagnetic dipole radiation pressure inhibits accretion from the ISM until the light cylinder is external to the magnetospheric radius ($R_{\rm LC} > R_M$), which occurs at a spin period of

$$P_{\rm LC} = 880 \mu_{33}^{1/3} v_7^{-1/3} n_{-1}^{-1/6} \ {\rm s}\ . \quad (4)$$

The timescale to reach this period through dipole radiation is

$$\tau_{\rm LC} = 2.3 \times 10^7 I_{45} \mu_{33}^{-4/3} v_7^{-2/3} n_{-1}^{-1/3} \ {\rm yr}\ , \quad (5)$$

where I_{45} is the moment of inertia in units of 10^{45} g cm^2. This is a short timescale, compared with the life of the NS. After reaching this period, the light cylinder is at R_M; however, the NS still cannot accrete (or accretes inefficiently) as a result of the "propeller effect" (Illarionov & Sunyaev 1975), in which matter is spun away by the magnetosphere, which is outside the Keplerian orbit in corotation with the neutron star (the corotation radius). This matter is ejected from the system, carrying angular momentum with it and spinning down the NS until the corotation radius reaches R_M, at which point the NS will have a spin period of

$$P_P = 3.9 \times 10^6 \mu_{33}^{1/2} v_7^{-1/2} n_{-1}^{-1/4} M_{\rm NS}^{-1/2} \ {\rm s}\ . \quad (6)$$

This spin period is substantially longer (by 3 orders of magnitude) than any spin period yet observed from an NS. The propeller spin-down timescale, when the accretion rate is dominated by magnetospheric accretion, is

$$\tau_P = 2.3 \times 10^{10} I_{45} \mu_{33}^{-4/3} v_7^{-5/3} n_{-1}^{-1/3} \ {\rm yr} \quad (7)$$

(Illarionov & Sunyaev 1975; Davies, Fabian, & Pringle 1979). The τ_P timescale dominates the evolutionary time between NS birth and emergence of the NS as a magnetic accretor. It is comparable to the age of the Galaxy ($\lesssim 10^{10}$ yr) for velocities already observed among the NS population, but only for high magnetic field sources ($\gtrsim 10^{15}$ G). This makes magnetic accretors with the right combination of magnetic field and velocity observable.

Following spin-down via the propeller, matter is accreted onto the polar cap of the NS. The maximum accretion rate onto the compact object is

$$\dot{M}_{\rm MAGAC} = \pi R_M^2 v \rho = 9.6 \times 10^7 \mu_{33}^{2/3} v_7^{1/3} n_{-1}^{2/3} \ {\rm g\ s^{-1}}\ . \quad (8)$$

(HL92). This is an upper limit to the mass accretion rate onto the NS surface and could be potentially much lower (see § 2.2). Moreover, the Bondi and MAGAC accretion rates are simply related to the magnetospheric and Bondi radius:

$$\frac{\dot{M}_{\rm MAGAC}}{\dot{M}_{\rm Bondi}} = \left(\frac{R_M}{R_{\rm Bondi}}\right)^2 . \quad (9)$$

If we assume free-fall accretion onto the NS surface, this provides an accretion luminosity of

$$L_{\rm MAGAC} = 1.8 \times 10^{28} \mu_{33}^{2/3} v_7^{1/3} n_{-1}^{2/3} M_{\rm NS} R_{\rm NS}^{-1} \ {\rm ergs\ s^{-1}}\ . \quad (10)$$

To estimate the effective temperature, we take the size of the polar cap to be $R_{\rm cap} = R_{\rm NS}(R_{\rm NS}/R_M)^{1/2}$. This might seem unusually small—approximately 50 m for $B = 10^{15}$ G. Nonetheless, the effective temperature $T_{\rm eff}$ of this emission is

$$kT_{\rm eff} = 0.39 \mu_{33}^{1/4} n_{-1}^{1/8} M_{\rm NS}^{1/4} R_{\rm NS}^{-1} \ {\rm keV}\ . \quad (11)$$

Note that $kT_{\rm eff}$ is independent of the NS velocity. The accretion luminosity will remain below the local Eddington luminosity if

$$\frac{\sigma_{\rm es}}{m_{\rm H}} \frac{L_{\rm MAGAC}}{c\pi R_{\rm cap}^2} \left(\frac{R_{\rm NS}}{r}\right)^2 < \frac{GM_{\rm NS}}{r^2}\ , \quad (12)$$

where $m_{\rm H}$ is the proton mass. The electron scattering cross section in a strong magnetic field, $\sigma_{\rm es}$, is suppressed from the Thomson rate $\sigma_{\rm T}$ by $\sigma_{\rm es}/\sigma_{\rm T} = 4 \times 10^{-6}[E/$

$(1\ \mathrm{keV})]^2(B_{\rm QED}/B)^2$, with $B_{\rm QED} = 4.4 \times 10^{14}$ G and photon energy E (Herold 1979). This result yields the constraint $\mu_{33}^{-1}\, n_{-1}^{1/2} < 3 \times 10^9$. This will not be violated for NSs with $B > 10^{13}$ G unless the ISM is unphysically overdense ($n_{-1} \gtrsim 10^6$). Thus, the accretion rate will be locally sub-Eddington.

Finally, the ratio of $\dot{M}_{\rm MAGAC}$ to $\dot{M}_{\rm Bondi}$ is

$$\frac{\dot{M}_{\rm MAGAC}}{\dot{M}_{\rm Bondi}} = 1.8 \mu_{33}^{2/3}\, v_7^{10/3}\, n_{-1}^{-1/3}\, M_{\rm NS}^{-2} \ . \quad (13)$$

Thus, for the same velocity distribution, MAGACs will be more luminous than Bondi accretors. We discuss the observational ramifications of this in § 3.

2.2. *Comments on the Accretion Luminosity*

We have two comments on the accretion luminosity. The first regards the accretion at magnetopause, and the second regards the need for the ISM to be ionized in order to be accreted.

Arons & Lea (1976) have performed a detailed analytic description of mass transfer across magnetopause in a 10^{12} G neutron star system fed by a $\approx$600 km s^{-1} wind from its companion, but with a substantially higher accretion rate at magnetopause (6×10^{19} g s^{-1}) than we consider here. Even at this lower magnetic field strength and higher mass accretion rate, they found that a cusp forms with a standoff shock, causing an interchange instability that mediates accretion onto the compact object. While inflow at the cusp increases with increasing density, the interchange instability operates more efficiently and prevents very high densities from arising at magnetopause. Three-dimensional MHD simulations find similar results (Toropin et al. 1999).

If the interchange instability of Arons & Lea (1976) permits accretion across the entire NS surface (rather than just at the magnetic poles), then the luminosity will remain the same, while dramatically decreasing the effective temperature to

$$kT_{\rm eff} = 0.0076 \mu_{33}^{1/3}\, v_7^{1/12}\, n_{-1}^{1/6}\, M_{\rm NS}^{1/4}\, R_{\rm NS}^{-3/4}\ \mathrm{keV} \ . \quad (14)$$

Further analysis of accretion onto a magnetic dipole with strength 10^{13}–10^{18} G is necessary to estimate the magnitude of the effect on the luminosity and spectrum. For now, we adopt $\dot{M}_{\rm MAGAC}$ as an upper limit.

Second, to accrete material via magnetic interaction, the material must be ionized. Throughout, we have therefore assumed that MAGACs accrete from the (ionized) WIM, and not from the neutral ISM. However, one might wonder whether a MAGAC's luminosity would be sufficient to ionize the ISM by the time it reached the magnetosphere (assuming that accretion was already taking place). Ionization of the ISM by an accreting IONS has been examined previously (Shvartsman 1971; Blaes, Warren, & Madau 1995). These investigations found that a Bondi accretion luminosity was capable of ionizing the ISM well beyond the Bondi accretion radius. However, we have applied a similar approach to MAGACs accreting onto the magnetic polar cap and find the fraction of a neutral ISM that would be ionized by the MAGAC at R_M to be $\ll 1$, for a broad range of velocities ($0.1 < v_7 < 10$) and densities ($0.1 < n_{-1} < 100$) for the magnetic field strengths considered here. Therefore, MAGACs must accrete from the WIM, which has a typical density of $\sim$0.13 cm^{-3} for a filling factor of 20% in the plane and a scale height of 1 kpc (Ferriere 1998b). This justifies our assumption that MAGACs must accrete from the WIM, and not from the neutral ISM.

2.3. *Limits on the Observability of MAGACs*

Here we list those effects that will limit the observability of MAGACs and which determine the luminosity, spectral hardness, velocity, magnetic field, and pulse-period parameter space in which they may be observable. In Figure 1, we divide the NS *B*-field dipole strength and velocity parameter space on the basis of the following limits:

1. $\dot{M}_{\rm MAGAC} > \dot{M}_{\rm Bondi}$.—As we find above, this results in a velocity limit (eq. [3]) above which the NS is a MAGAC, and below which the NS is a Bondi accretor (*dashed line*).
2. *The propeller phase must be shorter than the age of the Galaxy.*—We use as a limit (eq. [7]) that $\tau_p < 1 \times 10^{10}$ yr (*dotted line*), and also include the line for $\tau_p < 1 \times 10^9$ yr. This age limit also effectively sets a magnetic field strength limit: NSs with $B < 10^{14}$ G will not spin down in a Hubble time. Thus, if magnetic fields in NSs decay to below 10^{14} G in less than a Hubble time, they will not be observed as MAGACs.
3. *The pulsar must not escape the Galaxy.*—We adopt an escape speed limit of 700 km s^{-1} (cf. Miyamoto & Nagai 1975; Paczyński 1990), although the exact value depends on where in the Galaxy the NS is formed. This limit is indicated by the hatched area at $v > 700$ km s^{-1}.
4. *The NS magnetic field should not exceed the stability limit.*—We assume a surface dipole field of $B < 10^{18}$ G (Bocquet et al. 1995; Cardall et al. 2001; *dash-dotted line*).

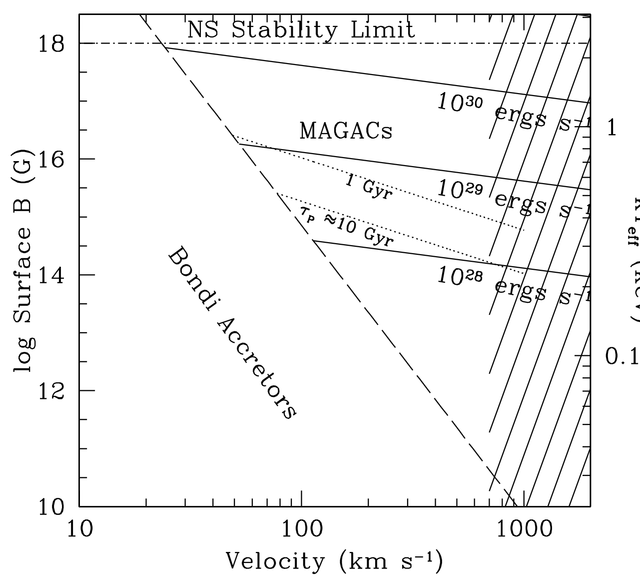

FIG. 1.—Magnetic field strength (*B*) vs. velocity for pulsars, showing regions where MAGAC IONSs can be observed and their accretion luminosities. The observability of MAGACs are limited at low velocities (left; *dashed line*) by a large magnetosphere (these then accrete always via Bondi); at high velocities (right; *hashed area*) by the likelihood they will escape the Galaxy's gravitational field; at low *B* (below; *dotted line*) from the fact that the NSs will not spin down via the propeller mechanism in less than 10 Gyr (we also include a line for $\tau_p = 1$ Gyr); and at high *B* (above; *dash-dotted line*) by the instability of high-*B* neutron stars. Note also that a moderate, magnetic-field NS (10^{12} G) with an average velocity of 500 km s^{-1} will not accrete gravitationally due to the propeller mechanism. We include lines of the maximum-accretion luminosity for the MAGACs after being spun down via the propeller. The right axis shows the effective temperature for accretion onto the magnetic cap, which is independent of velocity and only weakly dependent on density ($\propto n^{1/8}$).

We see in Figure 1 that acceptable magnetic fields are above 10^{14} G, and acceptable velocities range from ~ 25 km s^{-1} to the escape speed from the Galaxy. We include lines of constant L_{MAGAC} (for density = 0.1 protons cm^{-3}; eq. [10]); the luminosities of MAGACs are between 10^{28} and 10^{31} ergs s^{-1} (again, assuming free-fall accretion from the magnetosphere onto the NS). On the right axis of the figure, we mark kT_{eff}, which is independent of velocity and only weakly dependent upon the density of the ISM ($\propto n^{1/8}$). MAGACs have $kT_{eff} = 0.3$–2.5 keV. These are harder than observed from any of the identified IONSs to date (Treves et al. 2000), perhaps as a result of an observational bias.

Finally, we note that for values of $B = 10^{12}$ G and $v = 400$ km s^{-1}, which are not unusual in pulsars, such an object will not accrete via the Bondi mode from the ISM, as the magnetic field is in the propeller range. In addition, the source will not spin down in a $< 10^{10}$ yr timescale; so it will wander the Galaxy as a dipole, spun-down, propelling NS.

3. DISCUSSION AND CONCLUSIONS

Strong magnetic field ($B > 10^{14}$ G) NSs go through three stages of evolution: (1) dipole emission, (2) propeller slowdown, and finally, the MAGAC stage, (3) magnetic accretion onto the NS surface. MAGACs have the following properties: surface magnetic fields between 10^{14} G up through the NS stability limit ($\sim 10^{18}$ G); spin periods between 10^6 and 10^8 s; X-ray luminosities 10^{28}–10^{31} ergs s^{-1} for a WIM density of 0.1 protons cm^{-3}; and effective temperatures $kT_{eff} = 0.3$–2.5 keV. The low X-ray luminosities of these sources make it unlikely that the very long spin periods will be detected as pulsations with present X-ray instrumentation, as prohibitively long integrations with frequent monitoring would be required.

At the median velocity for radio pulsars, MAGACs will be ~ 130 times more luminous than Bondi accretors (for $v_7 = 3$, a typical median velocity for pulsars; Lorimer et al. 1997; Hansen & Phinney 1997; Cordes & Chernoff 1998). Although the birthrate of magnetars has been estimated to be $\sim 10\%$ of isolated pulsars (Kouveliotou et al. 1994; Kouveliotou et al. 1998), they can be observed to ≈ 10 times the distance and ≈ 130 times the volume of the Galactic disk of Bondi accretors at the radio pulsar median velocity. Magnetic accretors, therefore, may be more prevalent in flux-limited X-ray catalogs, such as the *ROSAT* All-Sky Survey/Bright Source Catalog (RASS/BSC; Voges et al. 1999), than the lower-magnetic field Bondi accretors. Note, however, that Popov et al. (2000) found that the detected RASS/BSC isolated neutron stars are more naturally interpreted as soft, young, nearby cooling neutron stars, rather than Bondi accretors; in this interpretation, no NSs accreting from the ISM have yet been discovered. The relative number of detectable MAGACs versus Bondi accretors will ultimately depend upon the particulars of the distribution of magnetic fields at birth in NSs, the kick velocities (and their possible dependence on B), as well as magnetic field decay, which we have neglected herein.

A brief comparison between observations and the predicted properties of this population reveals no strong candidates for MAGACs among known source classes.

Among radio pulsars, there are no known objects with implied B and v that would place them in the MAGAC B, v parameter space. The strongest B-field radio pulsar is 5.5×10^{13} G (Camilo et al. 2000), just below the low-B limit; its velocity is unmeasured. At a velocity of ~ 300 km s^{-1}, this NS will spin down on a timescale of $\tau_P \approx 210^{11}$ yr, much longer than the age of the Galaxy. Thus, there are no observed radio pulsars in which the magnetic field is clearly strong enough to evolve into a MAGAC. This is possibly due to the relatively short timescale during which such objects are dipole emitters ($\tau_{LC} \lesssim 10^6$ yr).

The observed spin periods of magnetars are $P \sim 1$–15 s, which, for the magnetic fields implied (10^{15} G), is still within the range where electromagnetic dipole radiation will inhibit accretion. In addition, their X-ray luminosities are a factor of $\gtrsim 1000$ larger than those we expect for MAGACs. These objects therefore are not presently MAGACs; however, depending on their spatial velocities, they may evolve into MAGACs.

The (model dependent) age of the isolated NS RX J185635$-$3754 (~ 1 Myr; Walter, Wolk, & Neuhauser 1996; Walter 2001) is shorter than τ_P, unless the NS has close to $B \sim 2 \times 10^{18}$ G. With such a high magnetic field, along with the implied velocity (≈ 200 km s^{-1}), the source would be within the MAGAC parameter space. Its X-ray luminosity is $\approx 2 \times 10^{31}$ ergs s^{-1}, which is within a factor of a few of the expected luminosity for a MAGAC with this B and v. However, the effective temperature ($kT_{eff} = 0.057$ keV) is substantially below that expected from a MAGAC with $B \times 10^{18}$ G (2.6 keV; eq. [11]). The spectral hardness seems to rule out this object as a MAGAC for the polar-cap accreting scenario. Since all previously observed INSs have effective temperatures below 200 eV (Treves et al. 2000), it seems similarly unlikely that any known INS is a MAGAC. It is possible, however, that an interchange instability at the magnetosphere permits accretion over a larger fraction of the NS, which results in a softer spectrum, such as that observed here (eq. 14).

Discovering these objects in the RASS/BSC requires a similar approach taken in previous work to identify IONSs—i.e., identifying an X-ray source with no apparent optical counterpart, down to an X-ray to optical flux ratio of $f_X/f_{opt} \gtrsim 1000$, with confirmation coming from an optical detection at an appropriate value. However, MAGACs can be spectrally harder than their Bondi-accreting counterparts ($kT_{eff} \sim 1$–3 keV; cf. Popov 2001), and searches for these objects must take this into account. Also, given their strong magnetic fields, these objects may have a cyclotron emission line, which may aid identification through X-ray spectroscopy (Nelson et al. 1995). Moreover, because we have assumed no magnetic field decay, the absence of MAGACs in the Galaxy, in combination with a population synthesis with high magnetic field soft gamma-ray repeaters and anomalous X-ray pulsars, would support field decay models.

We conclude that MAGACs may present a population that is equally prevalent in flux-limited X-ray catalogs as Bondi-accreting sources. However, no observed examples of this class are yet known.

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