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CONSTRAINTS ON ACCRETING, ISOLATED NEUTRON STARS FROM THE *ROSAT* AND *EUVE* SURVEYS

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ABSTRACT

Nearby old neutron stars can be detected by the radiation released from the accretion of interstellar material. We derive the expected numbers of such sources in current EUV/X-ray surveys, including the effects of dynamical heating on the speed distribution of the stellar population. Assuming blackbody emission and $N_{\rm tot} = 10^8 N_8$ neutron stars in the Galaxy, we estimate that, in the case of isotropic accretion over the entire stellar surface and depending on the importance of dynamical heating, between 70 and $700N_8$ isolated neutron stars might have been detected in the *ROSAT* PSPC all-sky survey, with 4–$50N_8$ of them showing up in the *ROSAT* WFC and *EUVE* surveys. An accretion flow channeled onto 1 km^2 magnetic polar caps produces instead 500–$4000N_8$ detectable X-ray sources in the PSPC survey, and only $\lesssim 4N_8$ EUV sources in the WFC and *EUVE* surveys. Such observations could constrain the accretion flow topology and the long-term evolution of isolated neutron stars, and we discuss potentially observable properties. The combined identification programs of the *EUVE*, WFC, and PSPC all-sky surveys might have already ruled out there being as many as 10^9 dead pulsars in the Galaxy.

Subject headings: accretion, accretion disks — stars: neutron — ultraviolet: stars — X-rays: stars

1. INTRODUCTION

Old ($>10^9$ yr) neutron stars are observed either as millisecond pulsars or low-mass X-ray binaries. In both cases, rapid accretion from the binary companion is known to strongly affect the neutron star's properties and evolution. Isolated neutron stars are detected only as pulsars, and these fade away after $\sim 10^7$ yr. The Galaxy is estimated to contain $N_{\rm tot} \sim 10^8$–10^9 dead pulsars, with a local space density of $\sim 10^{-4}(N_{\rm tot}/10^8)$ pc^{-3}. The nearest such neutron star is therefore expected to be $\lesssim 15$ pc from the Sun. For comparison, the nearest observed active pulsar, PSR 0950+08, is 10 times farther away (Taylor, Manchester, & Lyne 1993). As first suggested by Ostriker, Rees, & Silk (1970), nearby isolated old neutron stars (IONs) might be detectable by the radiation released from the accretion of interstellar material. There are at least 700 IONs which are closer than PSR 0950+08 and might then be observed as UV/soft X-ray sources—this is comparable to the total number of known neutron stars of all types!

In a previous paper (Blaes & Madau 1993, hereafter Paper I) we performed a preliminary investigation of the expected number of detectable IONs in current EUV/X-ray surveys. We predicted that somewhere between several 10–100 would be seen in the *Extreme Ultraviolet Explorer* (*EUVE*) and *ROSAT* Wide Field Camera (WFC) surveys. The *ROSAT* Position-Sensitive Proportional Counter (PSPC) survey would see many more (see also Treves & Colpi 1991). In this paper we expand and extend our analysis of the expected source counts in the *ROSAT* and *EUVE* all-sky surveys and the potentially observable properties of slowly accreting IONs. We believe a fresh, critical reexamination is needed as the first catalogs of sources discovered during the survey phases of the WFC and the *EUVE* mission were recently presented by Pounds et al. (1993) and Malina et al. (1993). These catalogs provide the effective area curves for each of the filters on the telescopes, together with a preliminary analysis of the optical identifications, an excellent resource for statistical studies of the EUV source population.

In § 2 we briefly summarize how the local accretion rate distribution onto IONs can be determined by combining what is known about the geography of the local interstellar medium (ISM) with radio pulsar birth properties. We improve on the analysis of Paper I by including the effects of dynamical heating of the ION population. Expected number counts are computed in § 3. We also suggest simple tell-tale signs for identifying IONs. In § 4 we compare our predictions with the observations and discuss some implications. These are potentially far reaching, as unique information and constraints can be provided on number densities, properties, and long-term evolution of ION (and therefore on the star formation and chemical enrichment histories of the Galaxy), and on the physics of the accretion process.

2. DEAD PULSARS ACCRETING FROM THE ISM

Provided the ambient material is ionized, interstellar accretion onto the surface of an ION occurs at the Bondi rate

$$\dot{M} = 7.3 \times 10^{14} \frac{n}{(v^2 + c_s^2)^{3/2}} \text{ g s}^{-1} , \quad (1)$$

which is very low compared to that observed in X-ray binaries. Here v is the relative speed between the star and the ISM in km s^{-1}, c_s is the ambient sound speed, and n is the baryon density in cm^{-3}. Throughout this paper we assume a representative ION of mass 1.4 $M_\odot$ and radius $R = 10$ km. We choose $c_s = 10$ km s^{-1}, typical for a photoionized gas at 8000 K. The total luminosity radiated is $1.9 \times 10^{30}\ \dot{M}_{10}$ ergs s^{-1}, where

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$\dot{M}_{10}$ is the accretion rate in units of 10^{10} g s^{-1}. The incoming material is channeled to the poles in the case of magnetized IONs. If the accretion columns have a total cross-sectional area $A = A_1$ km^2, the effective temperature of the emitting region is

$$kT_{\rm BB} \simeq 120\dot{M}_{10}^{1/4}A_1^{-1/4}\ {\rm eV}\ . \quad (2)$$

The accretion of interstellar material will therefore maintain the surface of an ION at several hundred thousand degrees. Depending on the star's speed, the gas phase of the ISM, and the accretion geometry, observed bolometric luminosities and effective temperatures are expected to be in the range 10^{28}–10^{33} ergs s^{-1} and 10^5–10^7 K. This implies substantial emission in the extreme ultraviolet and soft X-ray bands.

In Paper I, the distribution of IONs in the Galaxy was obtained by assuming that the kinematic properties of all neutron stars at birth are identical to those of young radio pulsars which are observed today. The birth parameters were taken from the best-fit model of Narayan & Ostriker (1990). A fast, accurate quasi-analytic scheme was developed, which enables us to calculate the equilibrium phase space distribution of IONs. The technique, which we term the "thin disk approximation," uses the fact that the galactic potential in the solar neighborhood varies much more rapidly with height than with radius. This means that the radial and vertical motions associated with orbits which do not stray too far from the Galactic plane are approximately separable, enabling us to identify all the conserved integral of motion (Paper I). The local ION density was derived to be

$$n_{\rm ION} \simeq 7.5 \times 10^{-13} N_{\rm tot}\ {\rm pc}^{-3}\ , \quad (3)$$

with a half-density scale height of 280 pc. The nearby ION population was found to be dynamically much cooler than present-day radio pulsars, as stars which are born with very high space velocities end up in the Galactic halo (see also Paczyński 1990). Figure 1*a* depicts the speed distribution derived in Paper I. This is far from Maxwellian, with excess

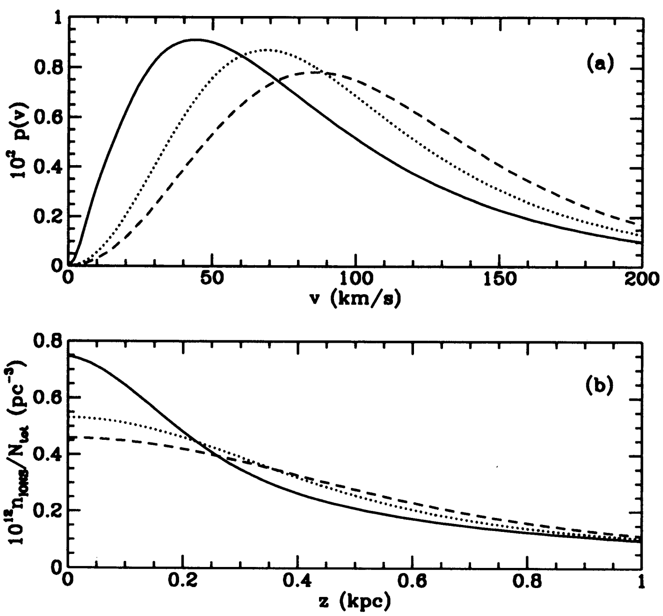

FIG. 1.—(*a*) Differential neutron star speed distributions in the Galactic plane, normalized to unit area, and (*b*) vertical density distribution, both figures referring to the solar circle $R = R_0$. The solid curves correspond to the equilibrium distributions of Paper I. The dot and dashed curves depict the effects of diffusive heating over 5×10^9 yr and 10^{10} yr, respectively.

low-velocity stars for its rms speed of 98 km s^{-1}. This excess arises because low-velocity stars never move far away from the Galactic plane, and so they can contribute much more to the local density.[2]

In Paper I we neglected scattering of IONs by molecular clouds, spiral arms, and whatever else might be responsible for the increase in velocity dispersion with age observed in the local disk population of stars (e.g., Wielen 1977). Dynamical heating would, over the lifetime of the Galaxy, scatter the excess low-velocity stars in the distribution to higher speeds. This could have a major effect on the predicted source counts because these stars have the highest accretion luminosities. There is as yet no generally accepted theory which explains the heating of disk stars. Wielen (1977) has found that reasonable agreement with the observations can be obtained by assuming that the stellar peculiar velocity distribution $f(v, t)$ changes with time t according to a force-free diffusion equation,

$$\frac{\partial f}{\partial t} = \frac{1}{2}\sum_{i=1}^{3} \frac{\partial}{\partial v_i} C_i \frac{\partial f}{\partial v_i}\ . \quad (4)$$

Here the C_i's are constant one-dimensional diffusion coefficients, and $D \equiv (C_1 + C_2 + C_3)/3 = 2.0 \times 10^{-7}$ (km s^{-1})^2 yr^{-1} provides a good empirical fit. We may use this result to make a crude estimate of the effects of heating on the speed distribution of IONs in the following way. Dynamical heating will start to have a significant impact only after several orbital periods, during which time the stars will have phase-mixed and approached the equilibrium speed distribution, $f(v, 0)$, derived in Paper I. If we then neglect the Galactic potential, the anisotropy of the equilibrium velocity distribution (cf. Paper I), and assume $C_i = D$, then equation (4) implies that the speed distribution of IONs (all born at the same time) will evolve according to

$$f(v, t) = v\left(\frac{1}{2\pi Dt}\right)^{1/2} \int_0^\infty dv_0 \frac{f(v_0, 0)}{v_0} \times \left\{\exp\left[-\frac{(v_0 - v)^2}{2Dt}\right] - \exp\left[-\frac{(v_0 + v)^2}{2Dt}\right]\right\}\ . \quad (5)$$

The heated distributions are presented in Figure 1*a* for $t = 5 \times 10^9$ yr, the mean age for a constant birthrate of IONs over the history of the Galaxy, and 10^{10} yr, appropriate if most IONs were born early with the Galactic disk. The rms speeds are 109 and 120 km s^{-1}, respectively, only 10%–20% higher than in $f(v, 0)$. However, the low-velocity stars have been depleted substantially.

Heating will also increase the vertical scale height above the Galactic plane, thus reducing the local density of IONs. Since the radial and vertical motions are approximately separable, we can estimate the effects of heating on the vertical space and velocity distribution $f(z, v_z, t)$ from

$$\frac{\partial f}{\partial t} + v_z \frac{\partial f}{\partial z} - \nu^2 z \frac{\partial f}{\partial v_z} = \frac{D}{2}\frac{\partial^2 f}{\partial v_z^2}\ . \quad (6)$$

Because we are primarily interested in the low-velocity stars, we have adopted a harmonic vertical potential with frequency

[2] As a simple example, consider stars born with an arbitrary distribution of speeds at the origin of a one-dimensional harmonic oscillator potential. In this case the orbital periods are all the same, so the amount of time a given star spends in an infinitesimal distance around the origin is proportional to the reciprocal of its speed through the origin. Hence the time-averaged speed distribution at the origin will be proportional to the birth distribution times v^{-1}, implying an excess of low-velocity stars compared to what one had started with.

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$\nu = 99$ km s^{-1} kpc^{-1}, appropriate for the solar circle. Averaging over the rapid vertical oscillations and integrating over all velocities, we obtain a diffusion equation for the space density which is easily solved to give

$$n_{\rm ION}(z, t) = \frac{\nu}{(\pi D t)^{1/2}} \int_{-\infty}^{\infty} dz_0 \, n_{\rm ION}(z_0, 0) \exp\left[-\frac{\nu^2 (z - z_0)^2}{Dt}\right]. \tag{7}$$

The heated distributions are depicted in Figure 1*b*. We find that the density in the Galactic plane decreases only slightly relative to the unheated value given in equation (3), by a factor 1.4 at $t = 5 \times 10^9$ yr and 1.6 at $t = 10^{10}$ yr.

Interstellar absorption measurements (Paresce 1984; Warwick et al. 1993) suggest that the local interstellar medium consists of neutral hydrogen with density $n_{\rm H\,I} \simeq 0.07$ cm^{-3} within a distance of ~ 100 pc, and $n_{\rm H\,I} \simeq 0.57$ cm^{-3} beyond. Such a description is probably appropriate for many lines of sight through the "local bubble." The density of interstellar material determines both the accretion luminosity and the severity of absorption along the line of sight. As the Sun is in an anomalously low density region, larger volumes can be sampled and we can detect IONs accreting at high rates from H I walls and atomic and molecular clouds located beyond the local bubble. To determine the source counts per unit solid angle, we will consider a representative line of sight in the Galactic plane, which passes through 100 pc of local cavity material with $n \simeq 0.095$ cm^{-3}, and then goes into a surrounding medium with $n \simeq 1$ cm^{-3}. For the total source counts over the sky, we adopt a crude model where the cavity is a sphere of radius 100 pc centered on the Sun and the surrounding medium is a homogeneous slab of half-thickness 100 pc. The filling factor of cavity material is uncertain. However, as accreting IONs in the local bubble generally make only a small contribution to the counts (cf. Fig. 3 below), this uncertainty is not very important. Outside the bubble, $n \simeq 1$ cm^{-3} includes the warm neutral and ionized atomic phases of the ISM, which have large volume filling factors and $n \sim 0.2$ cm^{-3} (e.g., Kulkarni & Heiles 1988), as well as the cold neutral medium and molecular gas, which may however have very small filling factors.

3. SOURCE COUNTS AND EMISSION PROPERTIES

The distribution of accretion rates for the ION population, $f(\dot{M}, r)$, is easily derived from the speed distribution and the ambient interstellar density. The local ION space density is taken to be constant, as the ION scale height is much greater than that of the ISM. The number of IONs along a given line of sight detectable above a count rate C is

$$\frac{dN}{d\Omega}(>C) = n_{\rm ION} \int_0^{\infty} d\dot{M} \int_0^{d(\dot{M})} dr r^2 f(\dot{M}, r), \tag{8}$$

where $d(\dot{M})$ is the maximum source distance, given implicitly by

$$C = \frac{A}{4hd^2(\dot{M})} \int_0^{\infty} B_\nu(\dot{M}) A_{\rm eff}(\nu) e^{-\tau(\nu)} \frac{d\nu}{\nu}. \tag{9}$$

Here B_ν is the Planck function (we have assumed blackbody emission), $A_{\rm eff}$ is the effective area of the relevant filter, and τ is the photoelectric optical depth to the source (Morrison & McCammon 1983).

Cumulative source counts for the *EUVE* and *ROSAT* surveys are presented in Figure 2. The *EUVE* detectors have roughly the same sensitivity as the WFC, but with larger bandpasses and so the source counts are larger. The source counts for both *EUVE* and the WFC are generally smaller for IONs accreting onto a polar cap than for stars which are isotropically accreting over their entire surface. The much harder bandpass of the PSPC generally samples the Wien region of the emitted spectrum, and the contrary is true—more sources are predicted for polar cap accretion, as illustrated in Figure 2. The different surveys therefore complement each other perfectly for the purpose of determining the accretion flow topology, and magnetic field strengths and evolution in IONs.

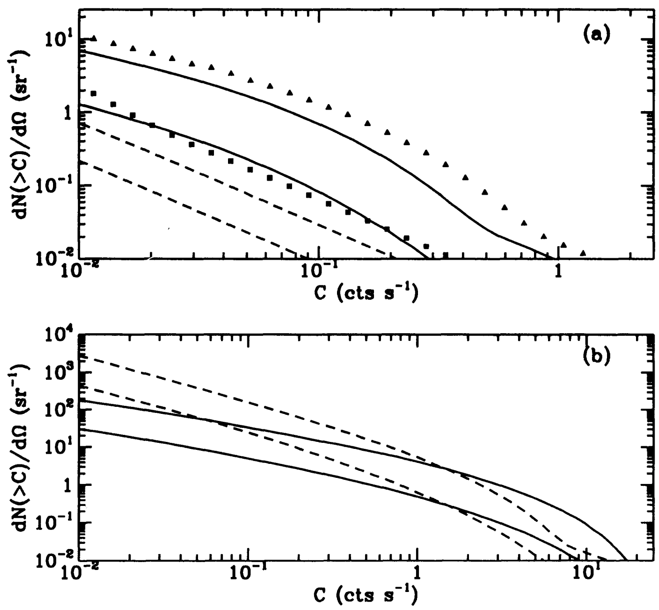

FIG. 2.—Predicted ION source counts for the *EUVE* and *ROSAT* all-sky surveys, assuming $N_{\rm tot} = 10^8$. (*a*) *EUVE* (Lexan-Boron filter, bandpass 50–180 Å) counts for isotropic accretion (*triangular points*) and polar cap accretion with $A_1 = 1$ (*square points*), and *ROSAT* WFC (S1 filter, bandpass 60–140 Å) counts for isotropic accretion (*solid curves*) and polar cap accretion with $A_1 = 1$ (*dashed curves*). The upper curve of each pair in the *ROSAT* results as well as the *EUVE* points assume the equilibrium speed distribution of Paper I is valid, while the lower curve of each assumes the same distribution modified by diffusive heating over 5×10^9 yr. (*b*) Same curves for the *ROSAT* PSPC all-sky survey (bandpass 0.1–2.4 keV).

Figure 3 depicts the relative contributions to the *ROSAT* number counts from different speeds and locations inside and outside the local cavity. The curves shown assume that the stars are moving with the unheated equilibrium speed distribution and the cases chosen are those which give the maximum number of detectable sources. This figure clearly shows that we are most sensitive to the low-velocity tail of the speed distribution, and explains why dynamical heating can have an important effect on the predicted source counts. It also shows that generally most of the counts come from IONs beyond the local bubble. The only exception to this is for polar cap accretion in the *EUVE* and *ROSAT* WFC surveys, where sources are too faint to be seen beyond the cavity (cf. Table 1).

According to the bright source WFC and *EUVE* catalogs (Pounds et al. 1993; Malina et al. 1993), white dwarfs and active late type stars dominate the EUV source population. Cataclysmic variables are the next most common sources. Given that the *EUVE* and *ROSAT* surveys might have detected nearby ION, it is crucial to find ways of identifying them. Some simple tell-tale signs for slowly accreting ION include them being relatively faint for their EUV/soft X-ray emission, lacking optical counterparts, and being correlated

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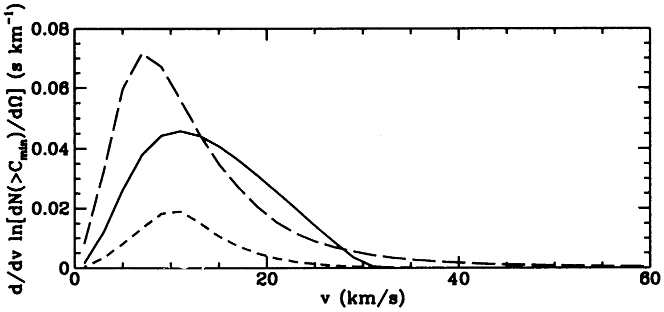

FIG. 3.—Normalized contributions from different neutron star speeds to the *ROSAT* all-sky survey source counts above a minimum photon count rate, C_{min}. The solid curve depicts the case for the WFC S1 filter with $C_{min} = 0.02$ counts s^{-1} and isotropic accretion onto stars which are outside the local cavity. The short dashed curve is the same but for stars inside the local cavity. The long dashed curve depicts the contribution to the PSPC survey ($C_{min} = 0.015$ counts s^{-1}) for polar cap accretion with $A_1 = 1$ onto stars which are outside the local cavity. The contribution from stars inside the local cavity in this case is negligible. The unheated equilibrium speed distribution of Paper I has been assumed in all cases.

with the denser phases of the ISM. For example, an ION accreting isotropically from a medium with density 1 cm^{-3} has an apparent *B* magnitude $\gtrsim 25.6$ at a distance of 100 pc, increasing with the star's speed. Accretion onto a magnetized polar cap typically makes the ION significantly fainter in the blue, by about 5.8 magnitudes. For comparison, a white dwarf with surface temperature 2×10^4 K at the same distance would have a *B* magnitude ~ 16. Optical emission is far into the Rayleigh-Jeans region for detectable IONs, implying extremely blue $U-B$ and $B-V$ colors. Follow-up observations might reveal pulsed emission if the accretion flow is magnetically focused onto the polar cap. Note, however, that a rapidly rotating, magnetized ION may prevent accretion through the "propeller" mechanism unless the rotation period exceeds $\sim 10^3\,(B/10^{12}\ \mathrm{G})^{6/7}$ s.[3]

The EUV/soft X-ray emission spectrum from the star itself (which we assumed to be a blackbody) is highly uncertain and depends on how the flow is decelerated near the star's surface (see, e.g., Paper I). For field strengths above $\sim 10^9$ G, atomic structure is severely modified as the cyclotron energy becomes comparable to the binding energy of hydrogen (Miller 1992). For example, in a 10^{12} G magnetic field, the Lyman absorption edge of hydrogen is at ~ 200 eV, where it could be observed by *EUVE*. A significant fraction of the total luminosity of the star might also be released in cyclotron lines at energies $\sim 120(B/10^{10}\ \mathrm{G})$ eV (Nelson, Salpeter, & Wasserman 1993). Any spectral features will be gravitationally redshifted by approximately 20%.

Because neutron stars typically have large space velocities, proper motions might be detectable over a timescale of order few years. For such proper motions to be large enough to be measured at 100 pc, however, the accretion luminosity ($\propto v^{-3}$) will likely be too small for the star to be observable. Hence this is not a practical method for distinguishing IONs from other EUV sources.

The effect of the star radiation field on its environment is also worth exploring. If the ambient ISM is largely neutral, an ION moving at $v = 40 v_{40}$ km s^{-1} will ionize the surrounding gas far outside the accretion radius $\sim 10^{13} v_{40}^{-2}$ cm, producing an elongated, cometary H II region. In Paper I we made a preliminary analysis of the properties of the cometary nebula using a Strömgren approximation. An ION accreting isotropically over its entire surface will emit $\sim 2 \times 10^{40} n^{3/4} v_{40}^{-9/4}$ ionizing photons s^{-1} for $v_{40} \lesssim n^{1/3}$. The ambient medium will become ionized at a distance $\sim 2 \times 10^{16} n^{-1/8} v_{40}^{-13/8}$ cm ahead of the star and will slowly recombine over a distance $\sim 4 \times 10^{19} v_{40} n^{-1}$ cm behind the star. The maximum transverse width of the H II region will be $\sim 8 \times 10^{16} n^{-1/8} v_{40}^{-13/8}$ cm ($\sim 50''$ at 100 pc with the chosen scalings). The H II region could reprocess $\sim 10^{29}$ ergs s^{-1} of the star energy output into UV, optical, and radio recombination lines as well as free-free radio continuum. Infrared radiation could also be produced by dust and, if the ION is passing through a molecular cloud, by molecular emission lines as H_2 recombines downwind of the star.

4. IMPLICATIONS

Table 1 gives the predicted number of sources detectable by *ROSAT*, assuming that the surveys are complete down to the given photon count rate. If there are 10^8 IONs in the Galaxy, then we estimate that, in the isotropic accretion model, between 70 and 700 IONs might have been detected in the PSPC all-sky survey, depending on the importance of dynamical heating. For polar cap accretion we predict as many as 500–4000 sources.[4] In the WFC survey, we estimate between 4 and 50 isotropically accreting IONs, and $\lesssim 4$ if accretion

[3] If neutron stars are all born as pulsars, i.e., magnetized and spinning rapidly, then the pulsar wind (initially) and the propeller mechanism (later on) can act to prevent accretion from the ISM. We have estimated in Paper I that this effect is not expected to substantially reduce the number of detectable sources (because the same propeller mechanism can spin down a neutron star in less than 10^{10} yr), and slowly moving IONs will in fact be able to accrete. Still it is fair to say that the physics of the propeller mechanism is only poorly understood.

[4] The PSPC survey could also detect magnetized IONs accreting material in dense ($n \sim 100\ cm^{-3}$), nearby giant molecular clouds. In the unheated case, we estimate $N_{PSPC-GMC}^{cap} \sim 100(N_{tot}/10^8)$ and a sampling depth of ~ 5 kpc (Paper I). These additional sources will be tightly concentrated toward the Galactic plane.

TABLE 1

ROSAT SOURCE COUNTS AND MAXIMUM SAMPLING DISTANCES[a]

Accretion Mode	Heating Time (yr)	$dN_{WFC}/d\Omega$ (sr^{-1})	N_{WFC}	$d_{max}^{WFC\,S1}$ (pc)	$dN_{PSPC}/d\Omega$ (deg^{-2})	N_{PSPC}	d_{max}^{PSPC} (pc)
Isotropic	0	4.1	45	170	0.042	670	610
	5×10^9	0.66	7.4	...	0.0069	130	
	10^{10}	0.32	3.6	...	0.0034	66	
Polar Cap	0	0.28	3.5	56	0.52	4000	1700
($A_1 = 1$)	5×10^9	0.084	1.1	...	0.083	950	
	10^{10}	0.048	0.6	...	0.042	530	

[a] $N_{tot} = 10^8$, C_{min}(WFC) = 0.02 counts s^{-1}, C_{min}(PSPC) = 0.015 counts s^{-1}.

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occurs over the magnetic polar caps instead. These number counts should be considered as lower limits, as they are based on there being $N_{tot} = 10^8$ neutron stars born over the lifetime of the Galaxy. This is the number one obtains by assuming that IONs have always been produced at the present radio pulsar birth rate (see, e.g., Narayan & Ostriker 1990). There are plausible reasons to believe that this birth rate could have been higher in the past, and metallicity arguments require N_{tot} to be as high as 10^9 (Arnett, Schramm, & Truran 1989), assuming neutron stars are all born in Type II supernovae. Detecting IONs would give us a measurement of the total number of Type II supernovae in the past, and therefore constrain models of Galactic chemical evolution.

We can already set constraints on N_{tot} from the number of unidentified sources in the *EUVE* and *ROSAT* surveys. There are 23 sources (out of a total of 384 detected objects) in the WFC bright source catalog (Pounds et al. 1993) which as yet do not have plausible optical counterparts, and might be accreting ION candidates. This number is inconsistent with our estimates if N_{tot} is as large as 10^9 and accretion occurs isotropically onto the ION surface, as in this case Table 1 predicts more than 36 IONs. To date, the preliminary *EUVE* bright source catalog contains 341 sources, only 15 of which have no optical identifications (Malina et al. 1993). Again, this appears consistent with our estimates for polar cap accretion and $N_{tot} \simeq 10^9$, but an isotropic accretion model agrees with the observed numbers only if N_{tot} is closer to 10^8. The small number of unidentified sources in the WFC and *EUVE* all-sky surveys is therefore inconsistent with there being 10^9 isotropically accreting ION.

The PSPC survey has $\sim 14{,}000$ sources in the Galactic plane ($|b| < 20°$). With our crude ISM model, $\gtrsim 65$ (72)% of IONs accreting isotropically (over the polar cap) are confined to $|b| < 20°$. To date, the optical follow-up identification program for the PSPC Galactic plane survey has completed analysis of only one 65 square degree field with 60 sources (C. Motch 1992, private communication). Only six sources remain unidentified in this field, corresponding to $\simeq 0.09$ sources deg^{-2}. Table 1 then requires $N_{tot} \lesssim 2 \times 10^8$ if the accretion flow is magnetically channeled onto the ION polar cap. We conclude that the combined identification program of the *EUVE*, WFC, and PSPC surveys might have already ruled out there being as many as 10^9 dead pulsars in the Galaxy.

It is important to stress that our predictions in Table 1 are only weakly sensitive to changes in the geometry of our crude model of the local interstellar medium. We have explored in some detail the WFC isotropic unheated case and found that the predicted source counts per steradian take the values $dN/d\Omega(>0.02 \text{ counts s}^{-1}) \simeq 3.1$, 4.1, 3.8, and 1.3 for cavity radii of 50, 100, 150, and 300 pc, respectively, and $N_{tot} = 10^8$. A substantial decrease in number counts is apparent only when the cavity radius becomes larger than the absorption depth. The photoionization cross section at 100 Å (roughly equal to the effective wavelength of the S1 WFC filter) is 3.2×10^{-20} cm^{-2}, which corresponds to a mean free path of 150 pc for $n_{\text{H I}} = 0.07$ cm^{-3}. On the other hand, if we assume a cavity radius of 300 pc and $n_{\text{H I}} = 0.005$ cm^{-3}, which might be relevant for the absorption free tunnel toward the star βCMa in the third quadrant (e.g., Paresce 1984; Welsh 1991) then the number counts increase again to $dN/d\Omega(>0.02 \text{ counts s}^{-1}) \simeq 4.2$, and all the detected sources lie within a thin shell of high-density material just beyond this empty tunnel. The same trends are found in the case of a heated speed distribution. As the sampling depth in the soft X-ray band is even larger, small variations in the cavity radius will not change the PSPC predictions either. The WFC polar cap case only has detectable sources within the local cavity, so our counts are independent of the cavity radius, although in this case they are sensitive to the filling factor of cavity material.

It is possible that the average ISM density for accretion onto IONs is only 0.2 cm^{-3} outside the local cavity. In the worst possible case where this low-density ISM is combined with 10^{10} yr heating, we predict $\simeq 11$ sources in the WFC survey (isotropic accretion) and $\simeq 0.054$ sources deg^{-2} in the Galactic plane PSPC survey (polar cap accretion), for $N_{tot} = 10^9$. While these numbers are still consistent with the data, very few additional identifications will be required to rule out even this scenario.

We note that IONs might have already been detected in previous X-ray surveys. Because of its lower sensitivity in the 0.2–3.5 keV observing band, the *Einstein* mission was not well suited for detecting a large number of faint IONs. The EMSS serendipitous survey (Gioia et al. 1990) and the *Einstein* All-Sky Slew Survey (Elvis et al. 1992) covered 778 deg^2 and ~ 50% of the sky respectively, with a limiting sensitivity of $\sim 3 \times 10^{-12}$ ergs s^{-1} cm^{-2}. We estimate that between a few and few tens IONs could have been detected if $N_{tot} \sim 10^9$ and accretion occurs onto the magnetic polar cap. Our counts are consistent with the lack of unidentified objects in the EMSS, and the ~ 180 sources in the Slew Survey which still remain unidentified.

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