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OLD ISOLATED ACCRETING NEUTRON STARS: THE DIFFUSE X-RAY EMISSION FROM THE GALACTIC CENTER

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ABSTRACT

The contribution of weakly magnetized ($B \sim 10^9$ G) neutron stars accreting the interstellar medium to the diffuse X-ray emission observed in the Galactic center is investigated. It is shown that, under rather conservative assumptions about the neutron stars and gas distributions, the accretion luminosity can account for a sizable fraction, possibly most, of the detected X-ray flux in the 2.5–7 keV band. In particular, model results are compared with *Granat* data and show a general agreement in both the flux energy and radial distributions.

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

1. INTRODUCTION

It was suggested long ago in a seminal paper by Ostriker, Rees, & Silk (1970) that old isolated neutron stars (ONSs) can be roused from their lethargy by the accretion of the interstellar medium, revealing themselves as weak, soft X-ray sources. About 20 years later it was realized that the capabilities of the *ROSAT* satellite were unprecedented in matching the challenge of observing ONSs (Treves & Colpi 1991; Blaes & Madau 1993; Madau & Blaes 1994; Zane et al. 1996). The basic criteria for discriminating ONSs from other classes of X-ray sources should be their very low luminosity, extreme X-ray–to–optical flux ratio and spectral softness. In accordance with the pioneering suggestion by Shvartsman (1971), giant molecular clouds (GMCs) were recognized as very favorable sites for the detection of accreting ONSs (Blaes & Madau 1993; Colpi, Campana, & Treves 1993).

Despite the increasing efforts, up to now only two X-ray sources have been proposed as ONSs accreting the interstellar medium: MS 0317.7-6647 (Stocke et al. 1995) and RXJ 185635-3754 (Walter, Wolk, & Neuhäuser 1996). In both cases, the arguments in favor of their identification are strong but not completely compelling. Systematic searches on available X-ray data are under way (see, e.g., Danner, Kulkarni, & Hasinger 1994; Belloni, Zampieri, & Campana 1996), but the positive detection of ONSs, which could be as many as 10^9 in the Galaxy, appears still a difficult goal to achieve.

Because of the intrinsic difficulties in detecting single objects and of the expected relative abundance of ONSs in the Galaxy, it is natural to consider their overall emission and more specifically their contribution to the soft X-ray background, as already suggested by Ostriker et al. (1970). Assuming $B \sim 10^9$ G and $N_{ONS} \sim 10^9$, (Zane et al. 1995) have recently shown that ONSs accreting the interstellar gas can account for a nonnegligible fraction of the observed excess in the soft X-ray background that is not extragalactic in origin but could be produced by a Galactic population (Maoz & Grindlay 1995).

Since the diffuse emissivity of accreting ONSs depends on their spatial concentration and on the density of the interstellar medium, it is of particular interest to consider the Galactic center, a site where both the stellar and gas densities exceed by orders of magnitude those of other regions of the Galaxy. At the same time, the Galactic center is a well-known source of diffuse X-ray emission, first detected by *Uhuru* (Kellogg et al. 1971) and then studied by virtually all X-ray missions. The possible association of the Galactic center diffuse X-ray source with accreting ONSs was originally suggested by Maraschi, Treves, & Tarenghi (1973).

In this paper we first review the X-ray observations of the Galactic center (§ 2.1). We then discuss the interstellar medium (§ 2.2), the stellar and the expected neutron star distributions (§ 2.3). The calculation of the emission due to accreting ONSs is presented, and our results are compared with observational data (§ 3). Discussion follows in § 4.

2. THE GALACTIC CENTER

2.1. *The X-Ray Emission*

The Galactic center is one of the more widely explored regions of the sky in the X-rays, and observational efforts appear indeed motivated in the light of the complexity of the source. The inner 100 pc of the Galaxy exhibit, in fact, a region of diffuse emission together with a number of point-like sources. The strong absorption in the direction of the Galactic center makes its appearance substantially dependent on the energy band (soft or medium X-rays) in which the source is observed. Here we briefly outline the current status of X-ray observations of the Galactic center, focusing our attention on the diffuse component.

The presence of a weak, diffuse emission from about ~ 1 deg^2 was already suspected in the *Uhuru* 2–10 keV data (Kellogg et al. 1971) and first confirmed by *Einstein* in the 0.5–4 keV band (Watson et al. 1981). Observations with 10′ resolution in the 2–15 keV range, performed with Spartan 1 (Kawai et al. 1988) and Spacelab 2 (Skinner et al. 1987; Skinner 1989), confirmed the diffuse emission at higher energies. Spectral measurements by *Ginga*, with an angular resolution of $\sim 1°$, have shown the presence of a strong emission line at 6.7 keV, which was identified with the Kα

line of He-like iron (Koyama et al. 1989; Yamauchi et al. 1990). The continuum appears rather flat and is well fitted by a thermal bremsstrahlung. A temperature of 12.7 ± 0.4 keV was calculated on the basis of TTM observations by Nottingham et al. (1993). Such temperature, however, is more than 1 order of magnitude too high for a plasma to be confined in the Galactic center potential well.

The ART-P telescope on board *Granat* observed the Galactic center region with 5′ resolution in the 2.5–30 keV band with rather long exposure times (Sunyaev, Markevitch, & Pavlinsky 1993; Markevitch, Sunyaev, & Pavlinsky 1993). The intensity profiles obtained in four energy bands, after subtracting pointlike sources, show the presence of an elliptical, extended source, as first suggested by Kawai et al. (1988). Spectra from the total 1° × 1°.5 ellipse and from a central region 30′ wide were produced, confirming a flat bremsstrahlung-like continuum; a strong absorption feature at 8–11 keV was also detected. Sunyaev et al. (1993) noted that the structure of the diffuse emission differs substantially below and above ∼8 keV. While the lower energy component is thermal and roughly elliptical, the hard emission comes from an elongated region, parallel to the Galactic plane, which resembles the distribution of giant molecular clouds. This led Sunyaev et al. (1993)to the conclusion that the diffuse emission consists of two components and that the high-energy portion of the spectrum may be due to Thomson scattering of hard photons on the dense material of the clouds. In this picture the bremsstrahlung temperature could be lower than the previous estimate (Markevitch et al. 1993 give $T_{\rm brems} \sim 3$ keV), easing the problem of confining the hot gas to the Galactic center.

The best-resolution X-ray map of the Galactic center was obtained with *ROSAT* in the 0.8–2 keV range (Predehl & Trümper 1994). In order to explain the lack of X-ray sources at the position of Sgr A*, an interstellar absorption higher than 2×10^{23} cm^{-2} was invoked by Predehl & Trümper. Preliminary reports of *ASCA* observations (Koyama et al. 1996) indicate the presence of several metal lines besides iron. In particular, a 6.4 keV fluorescent Kα component appears superposed on the 6.7 keV emission feature.

2.2. *The Gas Distribution*

The structure of the interstellar medium (ISM) in the central 10^2 pc of the Galaxy has been extensively investigated, and a detailed review can be found in Genzel, Hollenbach, & Townes (1994). Information about the dust distribution is obtained from the reradiation of UV and visible photons into the infrared continuum; atomic and ionized components are observed directly in the 21 cm line, while the more abundant molecular gas is sampled by the millimeter, submillimeter, and infrared lines of trace molecules (CO, OH, HCN, etc.). The resulting picture shows that the Galactic center is a region characterized by a strong concentration of dense interstellar material, with an average density of gas and dust 10^2–10^5 times higher than in the rest of the Galaxy. The central 5 pc contain a circumnuclear disk (CND) of orbiting filaments and streamers with its inner edge at ∼1.5 pc from the center. This disk is probably fed by the infalling gas from denser molecular clouds at $r \gtrsim 10$ pc and drops streamers in the central region. The inner regions ($r \lesssim 1.5$ pc—the central cavity and the minispiral) are comparatively devoid of material, and the average gas density is, at least, 1 order of magnitude lower than in the CND. On larger scales, surveys of 2.6 mm CO and far-infrared dust emission with *IRAS* (Dame et al. 1987; Deul & Burton 1988) show that $\sim 10^8\ M_\odot$ of gas (∼10% of the total Galactic ISM) are contained in the inner few hundred parsecs. Using a new CO-to-H_2 conversion factor, Sofue (1995a) estimated a value for the gas mass of $\sim 4.6 \times 10^7\ M_\odot$ within $\varpi \sim 150$ pc, where ϖ is the distance from the center in the plane of the sky. The corresponding average gas density turns out to be ~ 100 cm^{-3}, in agreement with the value reported by Genzel et al. (1994) for the inner 100 pc. The total mass of gas and dust is only 1%–10% of the stellar mass and does not contribute significantly to the Galactic gravitational potential. The dust comprises only about 1% of the ISM mass, which is mainly in the form of molecular, atomic, and ionized gas. A fraction of the interstellar material is organized in dense molecular clouds and macrostructures: within ∼500 pc, the filling factor is ∼10% for clouds with $n \sim 10^3$ cm^{-3} and ∼0.05% for clouds with $n \sim 10^5$ cm^{-3} (see, e.g., Campana & Mereghetti 1993 for a discussion). As recently discussed by Sofue (1995a), the gas distribution in the central ∼1 kpc region is dominated by a rotating ring with $n \approx 10^3$ cm^{-3} located at ∼120 pc while the gas density drops by 1 order of magnitude outside. An expanding, roughly spheroidal, molecular shell is also observed at $r \sim 180$ pc, $|z| \lesssim 50$ pc, with the gas mainly concentrated at intermediate latitudes (Sofue 1995b).

Using *IRAS* observations of the 3° × 2° region around Sgr A, Cox & Laureijs (1989) proposed that the dependence of the gas mass on the projected distance from the Galactic center is

$$m_{\rm gas}(<\varpi) \sim 2 \times 10^3 \varpi^{1.8}\ M_\odot\ . \qquad (1)$$

Such distribution holds approximately up to 300 pc from the center and implies, on such scales, a nearly constant surface density. As discussed by Cox & Laureijs, this result is very sensitive to the assumed dust temperature and the value of the total gas mass is correct to about 30% within 300 pc (50% at larger distances). Clearly, the averaged volume density profile can be derived only by de-projection, and any distribution matching the constraint of constant surface density is a priori acceptable. In particular, if the extension of the gas along the line of sight is roughly constant when ϖ varies, it is not unreasonable to assume a homogeneous gas distribution with an averaged, constant value for n. Within 225 pc, the averaged value of n derived from *IRAS* data is ∼60 cm^{-3}, assuming an elliptical gas distribution with an axial ratio 0.7 and using a value of $3.6 \times 10^7\ M_\odot$ for the total mass (Cox & Laureijs). However, in the inner ∼100 pc, this value is probably an underestimate (see the preceding discussion) and $n = 10^2$ cm^{-3} seems to be closer to observations. In the following sections we will focus our attention on the contribution of accreting ONSs to the diffuse emission from the Galactic center. The accretion rate will be estimated assuming a homogenous distribution of the ISM with

$$n = 100\ {\rm cm}^{-3}\ , \quad \varpi < 100\ {\rm pc}\ . \qquad (2)$$

Outside this region, in order to correct the X-ray emission for interstellar absorption, we need an estimate of the gas density in the Galaxy. This is known to be of order unity and is a parameter in our model, adjusted in such a way to give a total column density, integrated over 8.5 kpc at $z = 0$, always greater that $N_{\rm H} = 2 \times 10^{23}$ cm^{-2}. As discussed by Predehl & Trümper (1994), such a large value of N_H appears compelling if the deficit of X-ray sources observed by *ROSAT* toward Sgr A* has to be accounted for.

2.3. *The Star Distribution*

Both observations and theory (see, e.g., Bailey 1980; Allen, Hyland, & Hillier 1983; Sanders 1989; Morris 1993) provide convincing evidence that in a very large range of Galactocentric distances, from a few arcseconds to a few degrees from the center, the star volume density scales approximately as r^{-2} (r is the Galactocentric spherical radius), in agreement with the prediction of the isothermal cluster model for the region outside the core radius a. The value of the core radius derived from observations ranges between ~ 0.04 and ~ 0.8 pc (see, e.g., Morris 1993; Genzel et al. 1994 and references therein). Within the core radius, data derived from the dynamics of both the stellar and gas components agree quite well in suggesting that an additional dark mass of $\sim 3 \times 10^6\ M_\odot$ is present in the central region. This mass could be in the form of either a single, massive black hole or, if the central density is not in excess of $10^8\ M_\odot$ pc^{-3}, a cluster of many compact remnants (Morris 1993; Genzel et al. 1994). According to this picture, the mass volume density of the stellar component is given by

$$\rho(r) = \rho_c r^{-1.8}\ M_\odot\ \mathrm{pc}^{-3}\ , \qquad (3)$$

where ρ_c is the central density, which can be inferred from the estimated mass inside the core radius; typical values for ρ_c are a few times $10^5\ M_\odot$ pc^{-3} (Sanders 1989; Morris 1993). In the following we assume that this profile adequately describes the stellar distribution in the region beyond 1 pc from the Galactic center and we take $\rho_c = 4 \times 10^5\ M_\odot\ \mathrm{pc}^{-3}$.

The fraction f of the total mass comprised of neutron stars is a free parameter in our model, and we assume that all neutron stars have the same mass, $M_{NS} = 1.4\ M_\odot$. For a Salpeter initial mass function (IMF)

$$N(M) \propto M^{-\alpha} \qquad (4)$$

with $\alpha = 2.35$, and assuming that all stars with initial masses between ~ 10 and $\sim 50\ M_\odot$ have left neutron stars, f turns out to be $\sim 1\%$. With a fixed α, the previous formula can be assumed to describe the IMF of an already formed galaxy for masses in a given range, so possible differences due to the evolution of the bulge in the early Galactic history are ignored. However, as suggested by Morris (1993), the initial mass function for stars formed in the Galactic center may be quite different from that averaged over the disk of the Galaxy, because of the different physical conditions in the star-forming clouds. In particular, throughout most of the central region, strong tidal forces increase the value of the limiting density for a cloud to become self-gravitating and this, in turn, acts toward inhibiting star formation. This implies also that close to the center self-gravitating clouds are increasingly unlikely to be present and that those in which the density is above the tidal limit are presumably supported by the strong magnetic pressure. Large internal velocity dispersions and higher temperatures within the clouds tend to increase the Jeans mass up to an order of magnitude with respect to the typical value in the rest of the Galaxy. In the inner few parsecs, the most effective way of forming stars seems to be external cloud compression due to collisions with other clouds and/or with shock fronts produced by supernova explosions and other forms of nuclear activity. During the compression, the gas temperature and the value of the Jeans mass are increased. Based on these arguments, Loose, Krügel, & Tutukov (1982) argued that the mass spectrum in the Galactic center is probably skewed toward higher masses, with a lower cutoff at $M_{min} \sim 1$–$3\ M_\odot$ ($M_{min} = 0.08\ M_\odot$ is often assumed in the disk). In addition, the value of α itself turns out to be smaller than in the disk, so $f = 0.01$ should be regarded as a lower limit. Corrections due to the effects of dynamical friction over the lifetime of the Galaxy have been considered by Morris (1993), but they have not been included here since they are more relevant for black holes because of their larger masses. Black hole remnants are expected to dominate the central cluster, and their total mass is a large fraction of the dynamically inferred one. On the other hand, since mass segregation is not expected to modify strongly the distribution of neutron star remnants, in the following we will use a number density of neutron stars given, outside the core radius, by

$$n(r) = f \frac{\rho_c}{M_{NS}} r^{-1.8}\ \mathrm{pc}^{-3}\ . \qquad (5)$$

Since the total luminosity emitted in the accretion process depends on both the gas density and the star velocity, the velocity distribution $f(v)$ of neutron stars is needed in order to estimate the cumulative emission associated with the NS population. The velocity distribution of Galactic ONSs can be obtained assuming a suitable distribution of NSs at birth in phase space and following the evolution of a large number of orbits in the Galactic gravitational potential (see, e.g., Blaes & Madau 1993; Zane et al. 1995 and references therein). This kind of approach proved very useful in calculating $f(v)$ on large scales but, because of the particular conditions of the Galactic center, results obtained from a detailed analysis are not necessarily more correct than a simpler estimate. As discussed by Sellgren et al. (1990; see also Genzel et al. 1994), the velocity dispersion σ_v for low-mass stars in the central region is nearly constant between 0.6 and 100 pc, with $\sigma_v \sim 75$ km s^{-1}. At very small r, observational data indicate that σ_v increases up to ~ 125 km s^{-1}. Here we assume that NS remnants were able to reach energy equipartition with the field stars, establishing a Maxwellian distribution

$$f(v) = \frac{x^2}{v_0} \exp\left(\frac{-3x^2}{2}\right), \qquad (6)$$

where $x = v/v_0$, $v_0 = \sigma_v$, and typical values for σ_v are in the range 75–125 km s^{-1}. For a typical mass of $\sim 1\ M_\odot$, it can be easily shown that the relaxation time t_{relax} (see, e.g., Binney & Tremaine 1987) is $\lesssim 10^{10}$ yr in the inner ~ 10 pc. Since t_{relax} is a measure of the time required for deviations from a Maxwellian distribution to be significantly decreased, in the innermost region our hypothesis is justified. Energy equipartition between populations of different mass is reached in about the same time. In addition, the evaporation time turns out to be $\gtrsim 10^{10}$ yr for $r \lesssim 10$ pc, so the irreversible leakage of stars from the system as result of stellar encounters is negligible over the Galaxy lifetime. A similar approach was used by Morris (1993) for the velocity distribution of the central cluster of black hole remnants.

Extending the Maxwellian assumption up to ~ 100 pc is motivated on the basis of observational data. The total mass scales approximately as r here and, as previously discussed, this is just what is expected in an isothermal cluster model. Actually, a lowered Maxwellian distribution is probably more reasonable, but the correction in the high-energy tail (above $\sim v_{\rm esc} \sim 2\,\sigma_v$) is not very important as far as the fraction of accreting ONSs is concerned, and will not be included in our calculations.

3. RESULTS

In this section we estimate the contribution of the neutron star population to the diffuse emission near the Galactic center, using the NS and gas distributions considered in the previous sections. For a general discussion of neutron stars accreting the ISM, we refer to Treves & Colpi (1991) and Blaes & Madau (1993).

The spectral properties of the radiation emitted by accreting ONSs have been recently investigated by Zampieri et al. (1995). They have shown that, even if the atmosphere is in LTE, the emergent spectrum is harder than a blackbody at the neutron star effective temperature and that the hardening ratio, typically ~ 1.5–3, increases with decreasing luminosity. This spectral hardening, produced by the decoupling of different frequencies at different depths, is present independently of the assumed geometry of the accretion flow. If ONSs retain a relic magnetic field that channels accretion onto the polar caps, the spectrum is harder because of the reduced emitting area (see, e.g., Treves & Colpi 1991) and the two effects add together, making the emission of medium X-rays ($\sim$4–5 keV) possible in the dense region of the Galactic center. In the following we assume that the emitted spectrum is that calculated by Zampieri et al. (1995) and that ONSs have a relic magnetic field $B = 10^9$–10^{10} G. Note that in this case the luminosity released in the cyclotron line is negligible (Nelson et al. 1995).

The monochromatic flux emitted by ONSs in a region of volume V centered at $r = 0$ can be calculated from the expression

$$F_\nu = \int_V n(r)\varpi\, d\varpi\, dz\, d\phi \int_0^\infty f(v)\,\frac{\tilde{L}_\nu}{4\pi R^2}\, dv \text{ ergs cm}^{-2}\text{ s}^{-1}\,, \qquad (7)$$

where $\tilde{L}_\nu$ is the monochromatic luminosity at the source corrected for the interstellar absorption. In the previous expression the volume element is expressed in terms of the cylindrical coordinates (ϖ, z, ϕ): z is along the line of sight and ϖ has been defined in § 2. $R_0 = 8.5$ kpc and $R = (R_0^2 + \varpi^2 - 2R_0 z + z^2)^{1/2}$ are the distance of the Galactic center and of the star from the Sun. The integral in equation (7) has been evaluated for $|z| \le z_{\max}$ and for different values of ϖ. *IRAS* data discussed in § 2 show that the dense material extends for a few hundred parsecs around the center, so we assume $z_{\max} = 300$ pc. The unabsorbed monochromatic flux at the source depends on the accretion rate, which, in turn, is a function of v and n. To avoid the direct calculation of the spectrum for each value of the parameters within the multiple integral, we have computed a set of models for different values of $\dot{M}$. The spectral distribution corresponding to any given pair of values of v and n is then obtained by spline interpolation. The total emitted flux and the total flux per square degree in a fixed energy band are calculated integrating equation (7) over frequencies. All multiple integrals have been evaluated numerically, and the cross sections for the interstellar absorption have been taken from Morrison & McCammon (1983).

The region within ~ 1 pc from the center (central cavity), where our assumed star and gas distributions cease to be valid, has been excluded from the integration domain in all models. The X-ray emission from accretion onto collapsed objects in the cavity under hypotheses similar to ours has been recently estimated by Haller et al. (1996) and turns out to be completely negligible.

Results of model calculations are compared with *Granat* ART-P observations. As discussed in § 2.1, the diffuse emission detected by *Granat* in the 2.5–8.5 keV band comes from a roughly elliptical region of ~ 1.18 deg^2 around Sgr A*. The values of the observed total flux reported by Sunyaev et al. (1993) are $(4.8 \pm 1) \times 10^{-10}$ ergs cm^{-2} s^{-1} and $(4.6 \pm 1.3) \times 10^{-10}$ ergs cm^{-2} s^{-1} in the two energy bands

TABLE 1

COMPUTED FLUXES FOR DIFFERENT PARAMETER VALUES

v_0 (km s^{-1})	$N_{\rm H}$ (10^{23} cm^{-2})	B (G)	$F_{(2.5-8.5)}$ (10^{-10} ergs cm^{-2} s^{-1})	$F_{(8.5-22)}$ (10^{-10} ergs cm^{-2} s^{-1})
75	2	10^9	7.11	0.071
75	3	10^9	3.90	0.064
75	4	10^9	2.44	0.057
100......	2	10^9	3.18	0.031
100......	2.5	10^9	2.30	0.030
100......	3	10^9	1.74	0.028
100......	3.5	10^9	1.36	0.027
100......	4	10^9	1.09	0.025
125......	2	10^9	1.68	0.017
125......	3	10^9	0.92	0.015
125......	4	10^9	0.57	0.013
150......	2	10^9	0.99	0.010
100......	2	10^{10}	7.80	0.151
100......	3	10^{10}	4.61	0.135
100......	4	10^{10}	3.03	0.121
200......	2	10^{10}	1.05	0.020
300......	2	10^{10}	0.32	0.006

NOTE.—$f = 10^{-2}$, $a = 1$ pc, $z_{\max} = 300$ pc.

2.5–8.5 keV and 8.5–22 keV, respectively. For the sake of simplicity, we approximate the total ellipse with a circle of the same area, centered at $r = 0$. We then calculate the expected X-ray flux in the two spectral bands, varying B, v_0, and N_H. The fraction f of neutron stars is always taken equal to 0.01; obviously fluxes scale linearly with f. Results are reported in Table 1. As can be seen, the flux emitted above 8.5 keV never exceeds a few percent of the observed one, so accreting ONSs cannot be directly responsible for the detected hard X-ray emission. On the contrary, the contribution of ONSs in the lower energy band can be substantial. For the two values of B we have considered, the expected emission ranges from a minimum of 0.07 up to ~ 1.6 times the *Granat* flux in the 2.5–8.5 keV band. Clearly, this kind of calculation is necessarily influenced by the uncertainties in the assumed ISM and ONS distributions. However, allowing for different values of the mean velocity of the ONSs and of the total column density, computed values are always comparable to observational data. In addition, while it could be not unreasonable to assume higher mean velocities for the NS population (see, e.g., Lyne & Lorimer 1994; Haller et al. 1996), the range of column densities we have explored corresponds to the higher values for the interstellar absorption toward the Galactic center reported in the literature (see, e.g., Thomas et al. 1996). Moreover, the fraction f of neutron stars has been fixed to a rather conservative (low) value. All these considerations suggest that the ONS contribution to the diffuse X-ray emission from the Galactic center can be substantial in the low-energy component.

We note that the integrated luminosity of the ONSs is typically $\gtrsim 10^{38}$ ergs s^{-1} and that most of the radiation is in soft X-rays. This may prove of importance in the discussion of the heating and dynamics of the ISM in the central region of the Galaxy.

The spectrum of the diffuse emission from both the total $1° \times 1°.5$ ellipse and a smaller circle 30′ in diameter has been obtained by Markevitch et al. (1993). For the sake of comparison, we have calculated the monochromatic flux from these two regions using equation (7). Results are presented in Figures 1 and 2 for three sets of parameter values. Crosses in Figures 1 and 2 are the *Granat* data with their error bars. As can be seen, the observed spectral distribution is flatter than the predicted one, but the spectral shape is reasonably reproduced up to 6–7 keV. Other physical processes should be invoked to explain the harder emission.

We have compared the radial distribution of the emitted flux with available observational data. From the central 30′ region we expect approximately 34% of the total flux. This fraction should be compared with the $\sim 25\%$ deduced from *Granat* data. The two values are in rough agreement, although the radial distribution of the diffuse emission predicted by our simplified model appears more concentrated

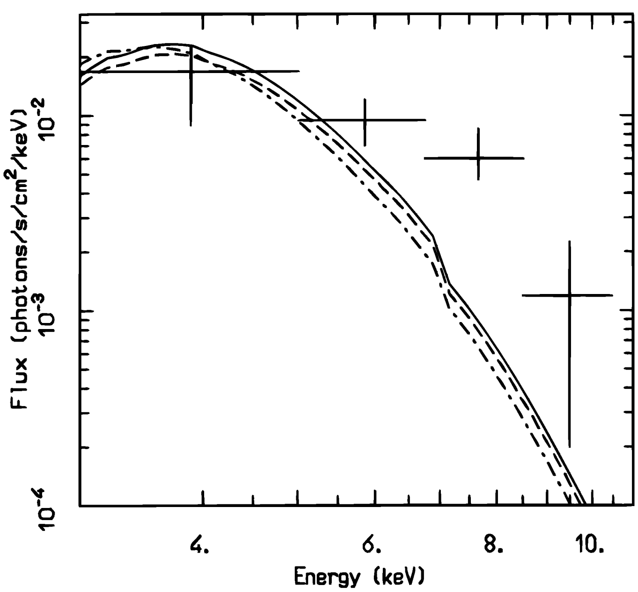

FIG. 1.—*Granat* ART-P data (Markevitch et al. 1993, *crosses*) and calculated X-ray spectra from a region of 1.18 deg² for (*a*) $f = 0.01$, $v_0 = 75$ km s^{-1}, and $N_H = 3 \times 10^{23}$ cm^{-2} (*solid line*); (*b*) $f = 0.02$, $v_0 = 100$ km s^{-1}, and $N_H = 3 \times 10^{23}$ cm^{-2} (*dashed line*); (*c*) $f = 0.015$, $v_0 = 100$ km s^{-1}, and $N_H = 2.5 \times 10^{23}$ cm^{-2} (*dash-dotted line*). For all models $B = 10^9$ G.

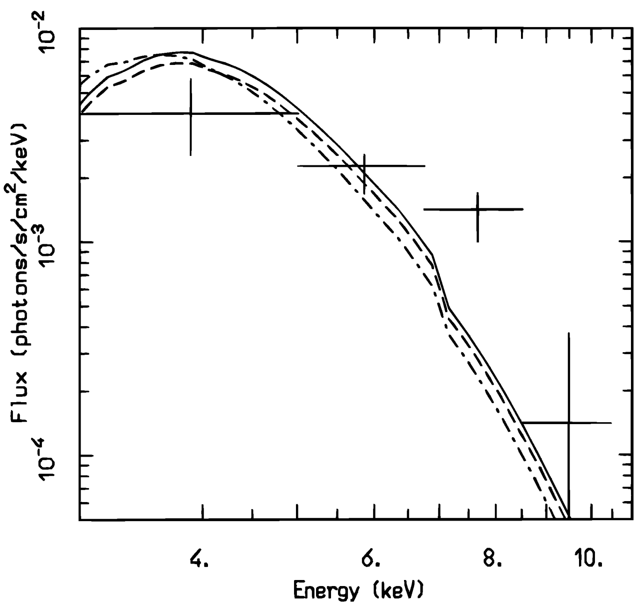

FIG. 2.—Same as in Fig. 1 for the central region 30′ in diameter

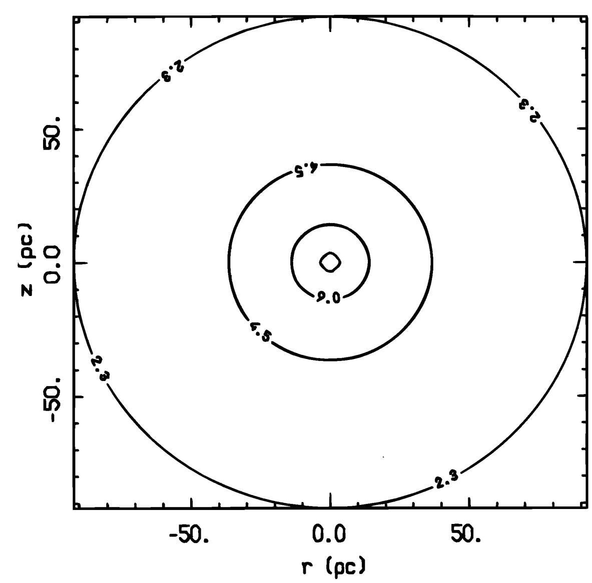

FIG. 3.—Contour levels of the X-ray flux per square degree in the 2.5–5 keV band. Parameter values are $B = 10^9$ G, $f = 0.01$, $v_0 = 75$ km s^{-1}, and $N_H = 3 \times 10^{23}$ cm^{-2}.

toward the center than the observed one. Figure 3 shows the contour levels of the X-ray flux per square degree, normalized to the total, in the 2.5–5 keV band.

As a final point, we note that accretion onto ONSs produces an extremely smooth X-ray source in our model. In fact, the neutron star with the highest accretion rate contributes only to 3×10^{-4} of the total X-ray luminosity.

4. DISCUSSION

In this paper we have considered the possibility that the 2.5–7 keV component of the diffuse X-ray source observed in the direction of the Galactic center is due to the unresolved emission from old neutron stars accreting the interstellar medium near the Galactic center. Because of the large gas and stellar densities, the central region of the Galaxy appears, in fact, a very promising site to detect the overall emission from accreting ONSs. We have shown that a sizable fraction, possibly most, of the 2.5–7 keV emission observed in the Galactic center may be explained in terms of an old neutron star population accreting the dense ISM. Because of the intrinsic uncertainties in our assumptions, mainly in the value of the neutron star relic magnetic field and in the star velocity distribution, it is not possible to assess firmly that ONSs are responsible for the extended X-ray emission in this band. Moreover, accretion itself onto magnetized neutron stars could be questionable. Although the propeller effect is not a serious threat if $B \sim 10^9$ G (see Blaes & Madau 1993; Treves, Colpi, & Lipunov 1993), preheating of the infalling gas due to the emitted radiation may inhibit accretion, as recently pointed out by Blaes, Warren, & Madau (1995). Modulo these caveats, our calculations show that the observed intensity, spectral shape and flux radial dependence are substantially well reproduced for different values of the free parameters of the model. Above $\sim$6–7 keV the integrated spectrum of the ONSs gives only a marginal contribution to the observed flux.

The calculated continuum is rather flat and then drops sharply above $\sim$6 keV, so we do not expect that emission from the ONSs could provide an important photoionization source to ultimately produce iron lines. However, our synthetic spectra were computed considering only pure hydrogen atmospheres around accreting neutron stars. A definite assessment of the presence of Kα lines in the emerging spectrum would require the extension of our model to include line processes and a more realistic chemical composition for the accreting gas. If accretion onto neutron stars with a magnetic field as high as $\sim 10^{12}$ G is possible (which is dubious; see, e.g., Treves et al. 1993), about 10% of the flux is emitted in the cyclotron line at $E_B = 11.6 B_{12}$ keV (Nelson et al. 1995) and the excitation of the Fe lines could be substantial.

Sunyaev et al. (1993) noticed some correlation between the distribution of giant molecular clouds and the X-ray brightness and interpreted it as a signature of the reprocessing of medium-energy photons by the clouds themselves. Such a correlation is naturally explained in our scenario, since GMCs provide regions of very high density, in which the accretion rate can be substantially higher than our present estimate, based on $n = 100$ cm^{-3}. This also implies harder spectra, so that the emission of hard photons, $\sim$10 keV, is possible for ONSs accreting in clouds with $n \sim 10^4$ cm^{-3}. On this regard, see the discussion of Campana & Mereghetti (1993) on the source 1740.7-2942.

The correlation between X-ray emission and the ISM distribution may become the basic probe to test the real relevance of ONS accretion in explaining the diffuse X-ray source in the Galactic center. The *Advanced X-Ray Astrophysics Facility* (*AXAF*) and JET-X will have the required sensitivity and space resolution in medium-energy X-rays to shed light on this important issue.

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