TeV EMISSION FROM THE GALACTIC CENTER BLACK HOLE PLERION

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Received 2004 October 8; accepted 2004 November 11; published 2004 November 19

ABSTRACT

The HESS (High Energy Stereoscopic System) collaboration recently reported highly significant detection of TeV $\gamma$-rays coincident with Sgr A*. In the context of other Galactic center (GC) observations, this points to the following scenario: In the extreme advection-dominated accretion flow (ADAF) regime of the GC black hole (BH), synchrotron radio/submillimeter emission of $\sim 100$ MeV electrons emanates from an inefficiently radiating turbulent magnetized corona within $20R_{\text{GCBH}}$ (Schwarzschild radii) of the GCBH. These electrons are accelerated through second-order Fermi processes by MHD turbulence, as suggested by Liu et al. Closer to the innermost stable orbit of the ADAF, instabilities and shocks within the flow inject power-law electrons through first-order Fermi acceleration to create a black hole–powered "plerion" where the TeV radiation mechanisms: nonthermal acceleration of particles — black hole physics — Galaxy: center — plasmas — radiation mechanisms: nonthermal

1. INTRODUCTION AND OBSERVATIONS

The HESS (High Energy Stereoscopic System) measurements of TeV fluxes from Sgr A* (Aharonian et al. 2004) confirm, with high significance, the earlier reports by the Whipple (Kosack et al. 2004) and CANGAROO (Tsuchiya et al. 2004) collaborations (albeit at higher flux levels than HESS) about TeV emission from the Galactic center (GC). This result adds important new information about the massive ($M_{\text{GC}} \sim 4 \times 10^6 M_\odot$; Ghez et al. 2003) black hole (BH) at the center of the Galaxy. When combined with the wealth of observational data in the radio to X-ray wave bands (for review, see Melia & Falcke 2001), the TeV $\gamma$-ray data point to a scenario involving an inner, inefficiently radiating magnetized corona, i.e., the advection-dominated accretion flow (ADAF), and a subrelativistic outflow of particles and field from the ADAF. As in pulsar plerions such as the Crab Nebula (see Kennel & Coroniti 1984), the MHD wind from the ADAF powers a BH plerion where the quiescent X-ray and TeV emissions are produced.

The VLBI (very long baseline interferometry) size of the radio source at the location of Sgr A* is $110(\pm 60) \mu$as at $\nu = 215$ GHz and $190(\pm 30) \mu$as at $\nu = 87$ GHz (Krichbaum et al. 1998). Using the Very Long Baseline Array, Bower et al. (2004) resolve Sgr A* at 42 GHz to have an angular size of $240(\pm 10) \mu$as, or $R_{\text{rad}} \approx 24R_g$ for $M_{\text{GC}} = 4 \times 10^6 M_\odot$ BH and a GC distance $d = 8$ kpc, and find that the size increases with frequency. The radio emission of Sgr A* is rather stable, with total luminosity $L_{\text{radio}} \approx L_{\text{radio}}/10^{16}$ ergs s$^{-1}$ $\approx 1$ and spectral flux $S_{\nu} \propto \nu^{-0.3}$ that sharply falls off above $\nu \sim 10^{12}$ Hz (Zylka et al. 1995; Falcke et al. 1998).

The near-infrared (NIR) flares show factors of 2 flux variations on timescales of $\sim 20$ minutes and reach powers of $\sim 10^{36}$ ergs s$^{-1}$ (Genzel et al. 2003). The spectra rise in $\nu S_{\nu}$ diagrams and show powers $\approx 10^{35}$ erg s$^{-1}$, similar to the (non-simultaneously) detected X-ray flares (Baganoff et al. 2001; Porquet et al. 2003). The 200 s X-ray variability timescale limits the engine size to $r = R/R_g \lesssim 5$. The unabsorbed quiescent flux detected by the Chandra X-Ray Observatory from Sgr A* is $L_{\text{X, qu}}(2–10 \text{ keV}) \approx 2.4 \times 10^{35}$ ergs s$^{-1}$ and has an angular extent $\theta_{\text{FWHM}} \approx 1'4$ (Baganoff et al. 2003), corresponding to source size $R_{\text{S}} \approx 8.3 \times 10^{16}$ cm.

The TeV spectral fluxes in two HESS campaigns in 2003 June/July and July/August are almost exactly the same, extending with photon index $\approx 2.1$–2.3 from 160 GeV to 10 TeV, with total power $L_{\gamma} \approx 10^{35}$ ergs s$^{-1}$. There is no sign of flux variation within the statistics available in each of these sets (Aharonian et al. 2004). Given the high statistical significance of the signal in both data sets, these results suggest a quiescent or quasistationary TeV source coincident within $\lesssim 1'5$ of Sgr A*.

We propose a model for Sgr A* in which the quasi-stationary radio and flaring X-ray/NIR emissions are synchrotron radiation from the ADAF. The MHD wind from the ADAF powers a BH plerion where the quiescent X-ray and TeV emissions are produced by electrons accelerated at the wind shock. The model explains the existing multiwavelength data and makes predictions that can be checked by various X-ray and $\gamma$-ray detectors.

2. PARAMETERS OF THE ADAF

The dimensionless mass accretion rate $\dot{m} = \eta_{\text{BH}} \dot{M}/L_{\text{Edd}}$, where $\eta_{\text{BH}} \approx 0.1$ is the maximum efficiency of gravitational-to-photon energy conversion by the BH. In the ADAF model (Narayan & Yi 1995; Esin et al. 1998), thermal radiation of the accretion plasma at the level $L_{\gamma} \approx \dot{m}^2 L_{\text{Edd}}/m_*$ is predicted when $\dot{m} \lesssim m_* \approx 0.1$. The rate $\dot{m} = 1.5 \times 10^{-5}$ is obtained if one formally equates $L_{\gamma}$ with the observed $L_{\text{rad}} \approx 10^{36}$ ergs s$^{-1}$.

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The compact radio emission cannot originate from an optically thick accretion disk, which would only be allowed at $R > R_{\text{rad}}$, or from a much hotter ADAF plasma at smaller scales, but it is compatible with a synchrotron origin (Liu et al. 2004). The thermal output of the ADAF would be peaked mostly in the hard X-ray/soft $\gamma$-ray domain, where the quiescent luminosity is at least 2 orders of magnitude smaller than $L_{\text{rad}}$. This results in the accretion rate estimate $m_{\text{ac}} > m/10^{-1} \leq 1$, consistent with the ADAF model and Sgr A* observations. Even for $m$ this small, $\lesssim 10^{38}$ ergs $s^{-1}$ of accretion power either is still advected into the BH or escapes as an outflow.

Adopting a GCBH mass equal to $3 \times 10^{6} M_{\odot}$, the ADAF magnetic field at radii $r = R/R_{G}$ is (Narayan & Yi 1995)

$$B(r) \approx 370 \alpha^{-1/2} \lambda^{1/2} m_{\text{ac}}^{1/2} R^{-5/4} G,$$

where $\lambda = 1 - \beta$ is the ratio of the magnetic to the total pressure in the accreting gas and $\alpha$ is the viscosity parameter. Using $\alpha \sim 0.1$ and $\lambda \sim 0.15$ (Quataert & Narayan 1999), the magnetic field $B \sim 10$ G in the ADAF at $r \sim 20$ is found. For these models, the Lorentz factor of electrons producing synchrotron radiation peaked at $v_{p} \gtrsim 10^{12}$ Hz is $\gamma_{s} \sim 200$, and the ADAF is still transparent to self-absorption for $\gtrsim$GHz radiation.

A stochastic acceleration model for the radio-millimeter emission from Sgr A* (Liu et al. 2004) can be quantified using the second-order Fermi acceleration theory of Dermer et al. (1996). The magnetic field is defined through the relation $B/8 \pi = (3 \eta / 4r_{\text{ac}}) M_{\odot} c^{3} / (4 \pi R^{2} c^{3})$, implying that $B \approx 30 \eta^{1/2} L_{\text{acc}}^{1/2} G$ for a region of size $20 R_{G}$. Equating the acceleration rate of electrons by whistler turbulence with the synchrotron loss rate gives a characteristic electron Lorentz factor $\gamma_{e} \approx 5 (\eta R_{G}^{1/2} L_{\text{acc}}^{1/2} R_{G}^{-1/4})$, assuming a Kolmogorov spectrum for the turbulence. Here $\xi$ is the fractional whistler turbulent energy density compared to $B^{2} / 8 \pi$, and $\tau_{r}$ is the Thomson depth of the ADAF; assumed to be composed of $e$-p plasma. Values of $B \sim 10$ G and $\gamma_{e} \approx 200$ are implied for the ADAF when $\xi \sim 0.1$, $\epsilon_{p} \sim 0.1$, and $\tau_{r} \approx 2 \times 10^{-5}$.

3. BLACK HOLE PLERION

A Compton (i.e., leptonic) origin for nonvariable TeV flux detected with HESS implies that the synchrotron counterpart of that flux is the quiescent component of the X-ray flux. The magnetic-field energy density in the source should then be $u_{B} = B^{2} / 8 \pi < 0.1 u_{\text{rad}}$, where

$$u_{\text{rad}} = \frac{L_{\text{rad}}}{4 \pi c R^{2}} = 2.65 \times 10^{-3} \frac{L_{\text{acc}}}{R_{G}^{3}} \text{ ergs cm}^{-3} \quad (2)$$

is the energy density of the target photons at $R = R_{G} 10^{16}$ cm. Inside the radio sources at $r \sim 20$, the radiation energy density saturates at the level $u_{\text{rad}} \approx L_{\text{rad}} / 2 c R_{\text{rad}}$. Thus, the origin of TeV flux at those small distances would require magnetic fields $B \sim 0.1$ G, far below the ADAF model values.

In the advection-dominated inflow-outflow extension (Blandford & Begelman 1999) of the ADAF model, the outflow may carry a significant fraction of the generated kinetic energy of the plasma from the BH vicinity to large distances. We assume a wind of magnetized accretion plasma with total power $L_{\text{wind}} = L_{\text{wind}} c^{2} 10^{37}$ ergs $s^{-1}$ propagating in a two-sided cone with an opening angle $\Omega$ at speed $v_{w} \lesssim c$; for calculations we use $v_{w} = c/2$. This wind terminates at a subrelativistic shock at $R_{\text{shock}} \sim 30 R_{G}$ from the GCBH. The shock accelerates electrons to energies $E_{\text{max}} = \gamma_{\text{max}} m_{e} c^{2} \gg 10$ TeV to produce the observed TeV $\gamma$-rays by Compton upscattering of submillimeter ($\nu_{c} \sim 10^{2}$ Hz) photons from the ADAF. Another important photon target is the emission from the cold $(\approx 100$ K) dust ring of Sgr A West, with total luminosity $= 5 \times 10^{9} L_{\odot}$ in the central arcm (few parsec) region around Sgr A* (Becklin et al. 1982). This radiation has a spectral peak at $\nu \sim 10^{15}$ Hz and estimated energy density $\approx 2.4 \times 10^{5}$ eV cm$^{-3}$. It becomes the main contributor to the $\leq 100$ GeV Compton flux from the plerion at $R \approx 10^{17}$ cm from Sgr A*. Synchrotron radiation from these same multi-TeV electrons at $R \leq 10^{17}$ cm produces the quiescent X-ray flux detected from Sgr A*.

Chandra observations (Baganoff et al. 2003) reveal diffuse thermal X-rays with luminosity $2.4 \times 10^{34}$ ergs $s^{-1}$ from the central parsec region of Sgr A*, produced by $kT \approx 1.3$ keV plasma with $n_{e} = 26 \eta^{1/2} cm^{-3}$ density, where $\eta = 10^{-4} \epsilon_{e} - 1$ is the volume filling factor. Equating the gas pressure $n_{e} k T$ in that region with the energy density of the wind gives the shock distance

$$R_{\text{shock}} \approx 3.1 \times 10^{16} L_{\text{acc}}^{1/2} R_{G}^{-1/2} \Omega^{-1/2} \eta^{1/4} \text{ cm}.$$  

The TeV luminosity $L_{\gamma} \approx 10^{38}$ ergs $s^{-1}$ implies a total electron acceleration power $L_{e} \gtrsim 10^{36}$ ergs $s^{-1}$. Assuming that the efficiency of electron acceleration $L_{e} / L_{\text{wind}} \lesssim 30\%$, and letting the rest go to thermal plasma and nonthermal protons (unlike in pulsar winds where relativistic electrons dominate), we arrive at $L_{e, 37} \approx 0.3$ . Note that equation (3) predicts that the maximum power of the outflow sustainable at distances $R_{\text{shock}} \leq R_{G}$ is $L_{e, 37} \lesssim 10$. The mean fluid speed $v_{f}$ in the TeV plerion formed downstream of the shock can be derived from $(R_{G} - R_{\text{shock}}) = v_{f} / c(\gamma_{e})$, where

$$v_{f}(\gamma_{e}) \approx 4 \times 10^{6} \frac{R_{G}^{3}}{L_{36}} \left(\frac{\epsilon_{e}}{1 \text{ keV}}\right)^{-1/2} \text{ cm s}^{-1} \quad (4)$$

is the Compton cooling time of electrons producing synchrotron X-rays with energy $\epsilon_{e}$ for the estimated magnetic field $B_{\text{phot}} \sim 100 \mu G$ in the GCBH plerion at scales $R \approx R_{G}$. Taking $R_{G} = 5$ for the median distance of the TeV plerion, we find $v_{f} \approx 500$ km s$^{-1}$ at those distances.

Since relativistic electrons of all energies convect with the fluid at the same speed, the TeV plerion model predicts shrinking of the quiescent X-ray source size at higher energies. Note also that the opening angle of the outflow should be $\Omega \sim 1$ rather than $\Omega \ll 1$, since otherwise $R_{\text{shock}}$ would exceed $R_{G}$. This indicates that the energy outflow is in the form of a wind rather than a well-collimated jet.

4. SPECTRAL MODELING

Figure 1 shows numerical calculations of the quiescent radiation components of Sgr A*. These include synchrotron and synchrotron self-Compton (SSC) emission from the magnetized ADAF within $r_{\text{rad}} \approx 20$ of the GCBH (dashed curves), X-ray and TeV emission from the compact plerion at scales $R \sim (3-10) \times 10^{16}$ cm (solid curves), and the emission from the larger plerion (dot-dashed curves) inflated to parsec scales in the process of convective (and possibly also diffusive) propagation of the accelerated electrons on timescales $\approx 10^{4}$ yr. The magnetic field in the latter, $B_{t} = 140 \mu G$, is assumed higher than $B_{t} = 90 \mu G$ in the TeV plerion. This is in agreement with the expected increase of the magnetic field downstream of the shock in typical pulsar plerions (Kennel & Coroniti 1984) and
is explained by deceleration and compression of the plasma. But it is possible that \( B_t < B_i \) in which case a smaller synchrotron flux from the parsec-scale plerion than shown in Figure 1 is predicted.

The inset in Figure 1 shows the nonthermal electron distributions. Besides synchrotron and Compton losses, calculations also include Coulomb and bremsstrahlung losses in a medium with \( n_{\text{gas}} = 10^4 \) cm\(^{-3} \) characteristic for central parsec regions of Sgr A*. Electrons with a power-law injection index \( \alpha_{\text{inj}} = 2.2 \) and an exponential cutoff above \( E_{\text{max}} = 50 \) TeV are injected into the two-sided nebula with total power \( L_{g} = 6.5 \times 10^{36} \) ergs s\(^{-1} \). These electrons radiatively cool downstream of the shock and propagate to distances \( \gtrsim 10^{17} \) cm on the timescale \( t_{\text{esc}} = 50 \) yr, during which most of the injected energy of the multi-TeV electrons (producing TeV and X-ray flares) has been already lost.

The radio emission is produced at \( r \approx 20 \) in the \( B \approx 10 \) G field by a relativistic Maxwellian electron distribution proportional to \( \gamma^3 e^{-\gamma/\gamma_{0}} \) with \( \gamma_{0} = 200 \) resulting from a balance between second-order energy gains and synchrotron losses (Schlickeiser 1985). The stochastic acceleration power of radio electrons is therefore about equal to the observed radio luminosity \( L_{\text{radio}} \).

The SSC emission component of these electrons, shown in Figure 1 by the dashed curve, falls in the sub-KeV region below the level of the quiescent X-ray flux. However, if magnetic fields \( \lesssim 5 \) G are assumed, this SSC contribution would rise and also move to 1 keV, and it could contribute to radiation at that energy. It cannot, however, explain the entire quiescent flux extending to 10 keV.

The powerful X-ray and NIR flares observed from Sgr A* are explained in our model by the onset of instabilities of the accretion flow at distances of only a few \( R_{\text{G}} \). They result in strong shocks in the accretion flow and effective acceleration of particles advected with the flow. The accelerated particles are then easily taken out of this region in the wind/jet outflow.

Synchrotron emission of electrons accelerated to \( \gamma > 10^{6} \) explains the X-ray flares with very small variability scales. Furthermore, while propagating through the first few tens of \( R_{\text{G}} \), these electrons have sufficient time, \( \sim 10^{6} \) s, to cool in the high \( B \) fields there down to \( \gamma \lesssim 3 \times 10^{3} \) to produce flares in the NIR domain. Self-absorbed flares at \( \approx 100 \) GHz detected on \( \approx 1 \) day timescales after the X-ray flares (Zhao et al. 2004) could be explained by the radiation from these same electrons at later stages/larger distances of the outburst in the “expanding source” scenario.

In Figure 2 we show the flare fluxes expected in this model. After shock-acceleration close to the BH and injection into a limited wind outflow with speed \( c/2 \), electrons propagate through the inner \( r = 10-30 \) region on timescale \( t_{\text{esc}} = 1200 \) s, after which the radiation losses drop because of wind expansion and decline of \( B \). The solid, dashed, and dot-dashed curves show synchrotron and Compton fluxes produced at 100 s, 1200 s, and 1 h after the onset of the flare. The electron injection time profile is \( L_{e,\text{inj}}(t) = L_{e,0}/(1 + t/t_{0})^{5} \), with \( t_{0} = 720 \) s. The mean magnetic field in the ADAF outflow could be enhanced at the flaring state, so we take \( B = 25 \) G. The Compton fluxes shown (thin curves) clearly demonstrate that no detectable TeV flares should be expected during powerful X-ray flares. This is in agreement with the nondetection of TeV flux variations during many days of observation with the HESS telescopes, whereas the X-ray flares occur with a frequency of \( \sim 1 \) per day (Baganoff et al. 2003).

5. SUMMARY AND CONCLUSIONS

A model consisting of magnetized coronal ADAF (synchrotron) radio emission within \( \approx 20 R_{\text{G}} \) of the GCBH and of a BH plerion powered by a wind from the ADAF resolves many puzzling observations of Sgr A*. X-ray flares are synchrotron radiation of electrons accelerated through the first-order Fermi process by shocks within a few \( R_{\text{G}} \) of the GCBH. Electrons

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**Figure 1**—Quasi-stationary/quiescent synchrotron (thick curves) and Compton (thin curves) fluxes expected from Sgr A*. Dashed curves show the fluxes from the magnetized ADAF corona with \( B = 10 \) G and \( R \sim 20 R_{\text{G}} \) due to a relativistic Maxwellian distribution of electrons with mean Lorentz factor \( \gamma_{e} = 200 \). The solid curves show the fluxes from the BH plerion with \( B_{t} = 90 \) \( \mu \)G at a distance \( R_{\text{esc}} \sim 5 \times 10^{16} \) cm; the calculations assume escape of the flow from the TeV plerion to \( R \gtrsim 10^{17} \) cm on a timescale of 50 yr. The dot-dashed curves show the fluxes formed during assumed \( t_{\text{esc}} = 2 \times 10^{7} \) yr propagation time in the plerion at scales \( R < 0.03-3 \) pc. The dotted curve shows the bremsstrahlung from the central few parsecs of Sgr A West with gas density \( n_{\text{gas}} = 10^{4} \) cm\(^{-3} \). The inset shows the electron energy distributions formed in those three spatial scales. The hatched regions in the X-ray domain show the bremsstrahlung from the central few parsecs of Sgr A West with gas density \( n_{\text{gas}} = 10^{4} \) cm\(^{-3} \).

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**Figure 2**—Synchrotron and Compton fluxes (thick and thin curves, respectively) expected during a flare at 200 (solid curves), 1200 (dashed curves), and 3600 s (dot-dashed curves) after the onset of the injection of relativistic electrons with \( \alpha_{\text{inj}} = 2.2 \) and \( \gamma_{\text{max}} = 10^{6} \), initial injection power \( L(0) = 6.3 \times 10^{36} \) ergs s\(^{-1} \), and characteristic decline time \( t_{0} = 720 \) s (see text). Escape of electrons with the conical wind during \( t_{\text{esc}} = 1200 \) s from the central \( R \lesssim 20 R_{\text{G}} \) at 1.8 \( \times 10^{15} \) cm region of the ADAF is supposed. The dotted curve shows the expected bremsstrahlung \( \gamma \)-rays at \( t = 200 \) s, calculated for plasma density of \( 10^{4} \) cm\(^{-3} \) in the ADAF. [See the electronic edition of the Journal for a color version of this figure.]
accelerated to $\gamma \gtrsim 10^8$ at the wind termination shock at $\approx 3 \times 10^{16}$ cm create the GCBH plerion. Its synchrotron X-ray emission has been resolved as an $\sim 1\arcmin$4 source with Chandra (Baganoff et al. 2003). The multi-TeV electrons Compton-scatter the radio photons from Sgr A* and far-infrared photons from the dust ring of Sgr A West to produce the TeV emission. TeV emission from the GCBH plerion is nearly stationary because the cooling (and also the escape) time of TeV electrons is $\sim 100$ yr.

A “jet-ADAF” model for Sgr A* has been proposed by Falcke & Markoff (2000) and Yuan et al. (2002). Our model, although also based on energy outflow from the ADAF, differs greatly. In particular, the quiescent and flaring X-ray components are produced at different sites. The origin of the X-ray and NIR flares are explained as synchrotron emission of electrons accelerated during episodes of instabilities very close to the BH, not as Compton radiation in the SSC scenario of the jet-ADAF model. Importantly, the TeV flux cannot be easily explained if the observed X-ray flares were due to the SSC jet-ADAF model. Importantly, the TeV flux cannot be easily explained if the observed X-ray flares were due to the SSC mechanism in the vicinity of the GCBH, as suggested by Falcke & Markoff (2000).

Propagation of GeV electrons from the plerion on timescales of $\gtrsim 10^4$ yr with speeds $\sim 100$ km s$^{-1}$ to parsec scales could significantly contribute to the radio synchrotron flux of Sgr A West. In particular, it could explain the suggested nonthermal radiation in the direction of Sgr A West (Wright et al. 1987), formed in the outflow direction.

We also predict that quasi-stationary Compton and bremsstrahlung fluxes from the parsec-scale plerion, coincident with the central parts of Sgr A West, will be significantly detected and possibly resolved with GLAST (Gamma-Ray Large Area Space Telescope) at GeV energies. But the expected highly variable Compton counterpart of the synchrotron X-ray flares from the GCBH vicinity is too weak to be detectable with GLAST or HESS. The synchrotron extension of the flare emission in the hard X-ray/soft $\gamma$-ray domain explains the $\sim 40$ minute episode of a profound increase of flux detected by INTEGRAL from the direction of Sgr A* (Béland et al. 2004).

The absence of apparent TeV flux variations may suggest a proton origin for the TeV radiation (Aharonian & Neronov 2004). Indeed, proton and ion acceleration through first- and second-order processes in the ADAF and through first-order acceleration at the wind termination shock could make cosmic rays to produce TeV emission through nuclear $p$-$p$ interactions with $n \sim 10^3$ cm$^{-3}$ dense gas on parsec scales and could form extended TeV emission possibly already detected with HESS (Aharonian et al. 2004). The hadronic origin of the TeV radiation in the ADAF itself in the BH vicinity requires, however, an extremely dense gas target or extremely large proton powers $\gtrsim 10^{39}$ erg s$^{-1}$.

Finally, we note that the unidentified EGRET source 3EG J1746–2851 toward the GC (Mayer-Hasselwander et al. 1998) is significantly displaced (Dingus & Hooper 2002) from the direction of the GCBH and is unlikely to be related to Sgr A*. It is probably emission from a young pulsar, although not with the “mouse” PSR J1747–2958 (McLaughlin & Cordes 2003). A young pulsar with $\gamma$-ray properties like Vela but with apparent $\gamma$-ray power $\approx 10$ times larger could have been missed in pulsar surveys because of the large dispersion measure toward the GC. We suggest a deeper X-ray and higher radio frequency search at the refined location of 3EG J1746–2851.

We thank I. Grenier, S. Markoff, R. Narayan, P. Ray, and R. Romani for discussions. Research of C. D. D. and visits of A. A. to the NRL High Energy Space Environment Branch are supported by GLAST Science Investigation DPR-S-1563-Y. The work of C. D. D. is supported by the Office of Naval Research.

REFERENCES

Aharonian, F., & Neronov, A. 2004, ApJ, submitted (astro-ph/0408303)
Aharonian, F., et al. 2004, A&A, 425, L13
Baganoff, F. K., et al. 2001, Nature, 413, 45
———. 2003, ApJ, 591, 891
Becklin, E. E., Gatley, I., & Werner, M. W. 1982, ApJ, 258, 135
Béland, G., et al. 2004, ApJ, 601, L163
Blandford, R. D., & Begelman, M. C. 1999, MNRAS, 303, L1
Bower, G. C., et al. 2004, Science, 304, 704
Dermer, C. D., Miller, J. A., & Li, H. 1996, ApJ, 456, 106
Dingus, B., & Hooper, D. 2002, preprint (astro-ph/0212509)
Èsín, A. A., Narayan, R., Cui, W., Grove, J. E., & Zhang, S. 1998, ApJ, 505, 854
Falcke, H., Goss, W. M., Matsuo, H., Teuben, P., Zhao, J.-H., & Zylka, R. 1998, ApJ, 499, 731
Falcke, H., & Markoff, S. 2000, A&A, 362, 113
Genzel, R., Schödel, R., Ott, T., Eckart, A., Alexander, T., Lacombe, F., Rouan, D., & Aschenbach, B. 2003, Nature, 425, 934
Ghez, A. M., et al. 2003, ApJ, 586, L127
Kennef, C. F., & Coroniti, F. V. 1984, ApJ, 283, 694
Kosack, K., et al. 2004, ApJ, 608, L97
Krichbaum, T. P., et al. 1998, A&A, 335, L106
Liu, S., Petrosian, V., & Melia, F. 2004, ApJ, 611, L101
Mayer-Hasselwander, H. A., et al. 1998, A&A, 335, 161
McLaughlin, M. A., & Cordes, J. M. 2003, preprint (astro-ph/0310748)
Melia, F., & Falcke, H. 2001, ARAA, 39, 309
Narayan, R., & Yi, I. 1995, ApJ, 452, 710
Porquet, D., Predelh, P., Aschenbach, B., Grosso, N., Goldwurm, A., Goldoni, P., Warwick, R. S., & Decourchelle, A. 2003, A&A, 407, L17
Quataert, E., & Narayan, R. 1999, ApJ, 516, 399
Schlickeiser, R. 1985, A&A, 143, 431
Tsuchiya, K., et al. 2004, ApJ, 606, L115
Wright, M. C. H., Genzel, R., Güsten, R., & Jaffe, D. T. 1987, in AIP Conf. Proc. 155, The Galactic Center, ed. C. H. Townes & D. C. Backer (New York: AIP), 133
Yuan, F., Markoff, S., & Falcke, H. 2002, A&A, 383, 854
Zhao, J., Herrnstein, R. M., Bower, G. C., Goss, W. M., & Liu, S. M. 2004, ApJ, 603, L85
Zylka, R., Mezger, P. G., Ward-Thompson, D., Duschl, W. J., & Lesch, H. 1995, A&A, 297, 83