Astronomy
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Astrophysics

Variable gamma-ray emission from the Be/X-ray transient A0535+26?

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Abstract. We present a study of the unidentified gamma-ray source 3EG J0542+2610. This source is spatially superposed on the supernova remnant G180.0-1.7, but its time variability makes a physical link unlikely. We have searched in the EGRET location error box for compact radio sources that could be the low energy counterpart of the gamma-ray source. Although 29 point-like radio sources were detected and measured, none of them is strong enough to be considered the counterpart of a background gamma-ray emitting AGN. We suggest that the only object within the 95% error box capable of producing the required gamma-ray flux is the X-ray transient A0535+26. We show that this Be/accreting pulsar can produce variable hadronic gamma-ray emission through the mechanism originally proposed by Cheng & Ruderman (1989), where a proton beam accelerated in a magnetospheric electrostatic gap impacts the transient accretion disk.

Key words. X-rays: stars – gamma-rays: theory – radio continuum: observations – stars: individual: A0535+26 – stars: neutron

1. Introduction

The EGRET instrument of the Compton Gamma Ray Observatory detected 271 point-like gamma-ray sources at energies $E > 100$ MeV during its lifetime (Hartman et al. 1999). The majority of these sources still remain unidentified. Excluding 6 possible artifacts, there are 75 sources at low galactic latitudes $|b| < 10°$ still not conclusively identified with objects seen at lower energies (Romero et al. 1999). Several of these low-latitude, presumably galactic sources seem to display significant levels of variability over timescales of months (Tompkins 1999; Torres et al. 2001a, b). A few particular cases of variable gamma-ray sources at low latitudes have been recently studied by Tavani et al. (1997, 1998), Paredes et al. (2000) and Punsly et al. (2000), but there is not yet consensus on their nature. The variety of behaviours displayed by the sources seems to suggest that more than a single class of gamma-ray emitting objects exists in the Galaxy. To establish the nature of these peculiar objects is one of the most urgent problems of high-energy astrophysics.

In this paper we present a study of the gamma-ray source 3EG J0542+2610. We show that the only known object within the 95% confidence location contour of the source capable of generating the observed gamma-ray emission is the Be/X-ray transient A0535+26. We argue that the gamma-rays are produced during the accretion disk formation and loss phases in each orbit, through hadronic interactions between relativistic protons accelerated in an electrostatic gap in the pulsar magnetosphere and the matter in the disk. The structure of the paper is as follows. In the next section we summarize the main characteristics of 3EG J0542+2610 and the results of our analysis of the radio field within the EGRET location error contours. We then present the peculiarities of the system A0535+26. In Sect. 4 we present a model for the gamma-ray production based on the accelerator gap model by Cheng & Ruderman (1989, 1991). The main difference between our treatment and the accreting pulsar gamma-ray model of Cheng et al. (1991) lies in the introduction of time variability through the variation of the matter content of the disk, which is a transient structure according to recent observations.

2. The gamma-ray source 3EG J0542+2610 and the surrounding radio field

The best estimated position of the gamma-ray source 3EG J0542+2610 is at $(l, b) \approx (182.02, -1.99)$. Its 95% confidence location contour overlaps with the shell-type supernova remnant (SNR) G180.0-1.7 (Romero et al. 1999; Torres et al. 2001c). The gamma-ray flux for the combined EGRET viewing periods is $(14.7\pm3.2)\times10^{-8}$ ph cm^{-2} s^{-1}. Since the flux is highly variable on a timescale of months, it originate in a compact object and not in the

extended SNR. In Fig. 1 we show the EGRET light curve. The source switches between periods of clear detections and periods when only upper bounds to the flux can be determined. The variability analysis of Torres et al. (2001b) assigns to 3EG J0542+2610 a variability index $I = 3.16$, which means that the source variability level is 4.32σ above the average (spurious) variability of all known gamma-ray pulsars. Tompkins' (1999) variability index for this source ($\tau = 0.7$) also indicates that the source is variable.

If a pulsar origin is discarded due to the high variability and the steep spectral index ($\Gamma = -2.67 \pm 0.22$), we are left with two main possibilities: 1) the source is a background, unnoticed gamma-ray blazar seen through the galactic plane, or 2) it is a galactic compact object with an energy budget high enough to generate significant gamma-ray emission and, at the same time, does not have the stable properties usually associated with isolated pulsars.

In the standard model for gamma-ray blazars, the high energy photons are produced by ultra-relativistic electrons through inverse Compton interactions with seed lower energy photons that can come from external sources (e.g. the accretion disk) or from the jet itself (see Krolik 1999 and references therein). The model is supported by the fact that all identified gamma-ray AGNs are strong flat-spectrum radio sources (Mattox et al. 1997).

In Fig. 2, lower panel, we show a 1.4-GHz VLA map made with data from the NVSS Sky Survey (Condon et al. 1998), where all point-like radio sources within the 68% confidence contour of 3EG J0542+2610 can be seen. The measured characteristics of these 29 sources are listed in Table 1. Most of them have no entry in any existing point source catalog. In those cases where we were able to find positional counterparts at other frequencies we have estimated the spectral indices, which are also shown in the table. Most of these sources are very weak, at the level of a few mJy. No strong (at Jy level), flat or nonthermal source is within the location error box of the gamma-ray source. The strongest radio source (No. 23 in our table) has a rather steep spectrum and is a factor $\sim$10 below the minimum flux density of firm gamma-ray blazar identifications given by Mattox et al. (1997). The nature of this source is not clear at present; it could be a background weak radio quasar. The fact that it is not seen at X-rays seems to argue against a galactic microquasar or any other kind of accreting source.

At X-ray energies the most significant source within the EGRET error box is the X-ray transient A0535+26, which is discussed in the next section. This source does not present significant radio emission and consequently it cannot be seen in our maps. We have indicated its position with a star symbol in Fig. 2, middle panel. We also show in this figure the direction of the proper motion of the system, as determined by Lee Clark & Dolan (1999). The upper panel shows the entire radio field as determined from radio observations with Effelsberg 100-m single dish telescope at 1.408 GHz (data from

Table 1. Point radio sources within the inner location probability contours of the gamma-ray source 3EG J0542+2610.

Number (on the map)	l (deg)	b (deg)	$S_{1.42\,\text{GHz}}$ (mJy)	Spectral index
1	181.46	−1.56	18.00	
2	181.50	−2.18	13.15	$\alpha^{0.408}_{1.42} = -2.9$
3	181.56	−1.71	62.90	$\alpha^{0.408}_{1.42} = -1.3$
4	181.59	−1.75	78.67	$\alpha^{0.365}_{1.42} = -1.6$
				$\alpha^{1.42}_{4.85} = -0.9$
5	181.61	−2.22	7.65	
6	181.62	−2.09	7.39	
7	181.67	−1.88	22.47	
8	181.68	−2.39	14.61	
9	181.76	−1.88	25.00	
10	181.78	−2.22	35.00	$\alpha^{1.42}_{4.85} = 0.2$
11	181.81	−1.58	27.00	
12	181.84	−1.56	18.22	
13	181.95	−2.35	11.80	
14	182.02	−1.89	20.32	
15	182.05	−1.80	53.40	
16	182.18	−2.01	37.30	
17	182.18	−1.40	33.00	
18	182.27	−2.22	8.70	
19	182.27	−1.73	18.88	
20	182.32	−1.71	9.91	$\alpha^{0.151}_{1.42} = -2.27$
21	182.33	−2.35	10.30	
22	182.35	−2.38	6.00	
23	182.38	−1.72	225.40	$\alpha^{0.365}_{0.151} = -0.86$
				$\alpha^{0.408}_{1.42} = -0.75$
24	182.40	−1.83	18.72	
25	182.41	−2.41	20.67	
26	182.43	−2.44	11.90	
27	182.44	−2.53	22.33	
28	182.50	−2.48	57.80	$\alpha^{0.408}_{1.42} = -1.33$
29	182.58	−1.59	41.86	

Reich et al. 1997). The middle panel present an enhanced image obtained at 2.695 GHz with the same telescope (Fuerst et al. 1990), where the gamma-ray location probability contours have been superinposed (Hartman et al. 1999). We have processed these large-scale images using the background filtering techniques described by Combi et al. (1998).

3. The X-ray transient A0535+26

A0536+26 is a Be/X-ray transient where the compact object is a 104s pulsar in an eccentric orbit around the B0III star HDE 245770 (Giovanelli & Sabau Graziati 1992). Be stars are rapidly rotating objects which eject mass irregularly forming gaseous disks on their equatorial planes. If there is a compact companion in a close orbit, accretion from the star can result in strong X-ray emission.
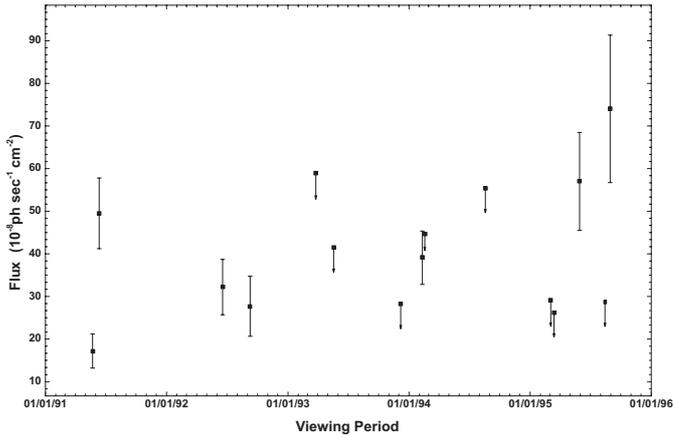
Fig. 1. Flux evolution of 3EG J0542+2610 through single viewing periods.

In the case of A0535+26, strong and recurrent X-ray outbursts are observed with a period of 111 days, which has been identified with the orbital period (Giovanelli & Sabau Graziati 1992). It is generally agreed that these outbursts occur when the accretion onto the neutron star increases at the periastron passage. The average ratio of the X-ray luminosity at the periastron to that of the apoastron is ~100 (Janot-Pacheco et al. 1987). In Table 2 we list the main characteristics of the A0535+26 system.

During a major outburst of A0535+26 in 1994, the BATSE instrument of the Compton Gamma Ray Observatory detected a broad quasi-periodic oscillation (QPO) in the power spectra of the X-ray flux (Finger et al. 1996). The QPO component was detected during 33 days, with a central frequency that was well correlated with both the hard X-ray flux and neutron star spin-up rate inferred from pulse timing. Finger et al.'s (1996) observations are the first clear evidence that an accretion disk is formed during giant outbursts.

Using the simultaneous variations of the spin and the QPO frequencies in the context of the beat frequency model (Alpar & Shaham 1985), Li (1997) has determined the evolution of the ratio ξ of the inner accretion disk radius to the Alfvén radius. He found that during the initial rise of the outbursts, ξ quickly increased from ~0.6 to ~1, indicating a transition of the accretion process from spherical accretion before the outbursts to disk accretion during the high X-ray luminosity phase.

Prior to the direct evidence for a transient accretion disk in A0535+26, Motch et al. (1991) have already suggested, on the basis of an analysis of the long-term X-ray, UV, and optical history of the system, that two different types of interactions exist between the Be star and the pulsar, and accordingly with the dynamical state of the highly variable circumstellar envelope. "Normal" outbursts would occur for high equatorial wind velocities (~200 km s^{-1}), whereas "giant" outburst would result from lower equatorial wind velocities (~20−80 km s^{-1}) which allow the formation of a transient accretion disk.

It is interesting to notice that, during the initial stage of the 1994 outburst, when QPOs were
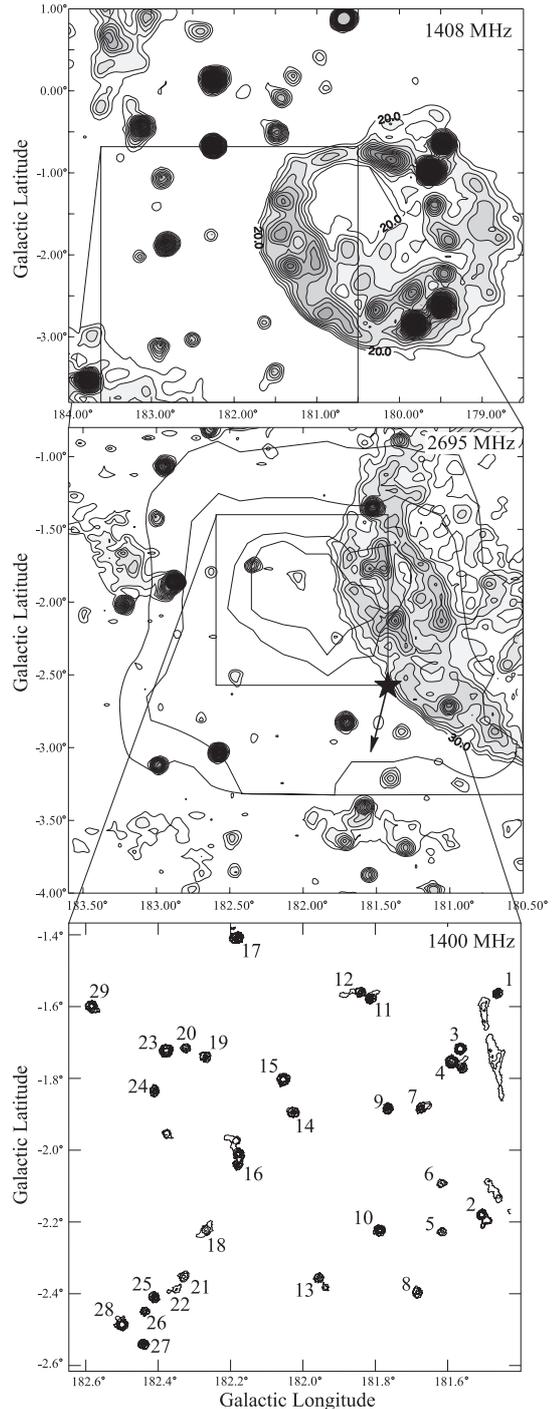
Fig. 2. Radio maps at different resolutions of the field containing the gamma-ray source 3EG J0542+2610. **Upper panel**: 1408-MHz image obtained with Effelsberg 100-m single dish telescope. The shell-type SNR G180.0-1.7 is clearly visible in the map. Contours are shown in steps of 25 mJy beam^{-1}, starting from 20 mJy beam^{-1}. **Middle panel**: 2695-MHz map obtained by the same telescope. Contours in steps of 30 mJy beam^{-1}, starting from 30 mJy beam^{-1}. The position of A0535+26 is marked by a star symbol. The arrow indicates the direction of the proper motion. EGRET confidence location contours are superposed to the radio image. **Lower panel**: VLA image of the inner region at 1.4 GHz. Contours in steps of 1 mJy beam^{-1}, starting from 1 mJy beam^{-1}. The diffuse background emission has been removed from the first two maps.

Table 2. Physical parameters for A0535+26 (from Janot-Pacheco et al. 1987 and Giovanelli & Sabau Graziati 1992).

Primary spectral type	B0III
Primary mass	9–17 $M_\odot$
Secondary mass	<2.7 $M_\odot$
Primary mass loss rate	7.7×10^{-7} $M_\odot$ yr^{-1}
Distance	2.6 ± 0.4 kpc
L_X peak (average)	$7.5 \pm 2.4 \times 10^{36}$ erg s^{-1}
X-ray pulse period	104 s
Orbital period	111 ± 0.5 d
Orbital eccentricity	0.3–0.8
L_X^{max}/L_X^{min}	~ 100

found in A0535+26, the gamma-ray source 3EG J0542+2610 was detected by EGRET with a flux of $(39.1 \pm 12.5) \times 10^{-8}$ ph cm^{-2} s^{-1} (viewing period 321.1: February 8–15, 1994). But when A0535+26 was at the peak of its X-ray luminosity, on February 18, the gamma-ray source was not detected (viewing period 321.5). The gamma-ray emission seems to have been quenched precisely when the accretion disk was well-formed and maximally rotating. In the next section we present a model that can account for the gamma-ray production in A0535+26 necessary to explain the EGRET source 3EG J0542+2610 and that is in agreement with our present knowledge of the Be/X-ray transient source.

4. Model

Our purpose in this section is to show that a plausible mechanism exists that could explain the gamma-ray emission of the source 3EG J0542+2610 as originating in the X-ray transient A0535+26. This mechanism should be capable of predicting the observed gamma-ray flux, the variability in the lightcurve, the fact that no gamma-ray emission was observed on February 18, when A0535+26 was at the peak of the X-ray outburst, but also that it was positively detected the previous days when the X-ray flux was rising, and finally the fact that A0535+26 is not a non-thermal radio source. This latter restriction seems to suggest a hadronic origin for the gamma-rays. Otherwise, relativistic electrons should also produce synchrotron radio emission.

Cheng & Ruderman (1989, 1991) have studied the disturbances produced in the magnetosphere of an accreting pulsar when the Keplerian disk rotates more rapidly than the star. As in the case of equal angular velocities, when $\Omega_* < \Omega_d$, inertial effects of electrons ($-$) and ions ($+$) lead to a complete charge separation around the "null surface" $\boldsymbol{\Omega}_* \cdot \boldsymbol{B} = 0$. However, since now the equatorial plasma between the inner accretion disk radius r_0 and the Alfvén radius r_A co-rotates with the disk, whereas the rest of plasma co-rotates with the star, an electrostatic gap with no charge at all is created around the "null surface" (see Fig. 3). In this gap $\boldsymbol{E} \cdot \boldsymbol{B} \neq 0$ and a strong potential drop is established (see Cheng & Ruderman 1991 for details).
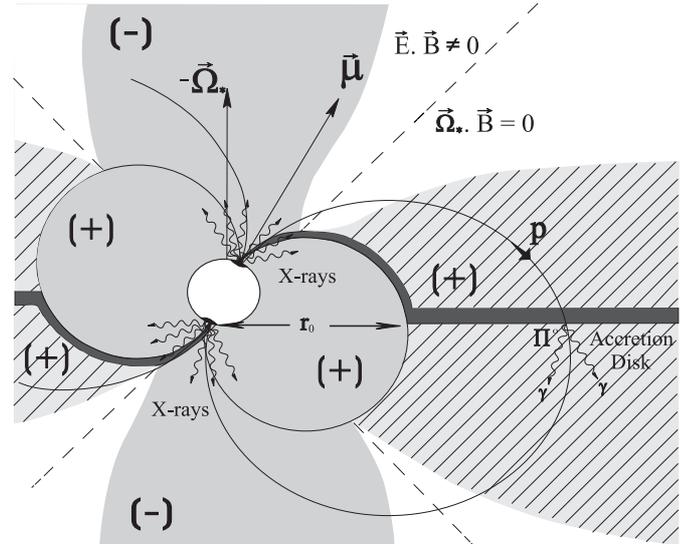
Fig. 3. Sketch of the magnetosphere model for A0535+26 when $\Omega_d > \Omega_*$. The gray region co-rotates with the star, whereas the hatched region co-rotates with the accretion disk. An empty plasma gap where $\boldsymbol{E} \cdot \boldsymbol{B} \neq 0$ exists around $\boldsymbol{\Omega}_* \cdot \boldsymbol{B} = 0$. Protons from the stellar surface are accelerated in this gap and collide with the disk, where they produce π^0-decay gamma-rays. Adapted from Cheng & Ruderman (1991).

Cheng & Ruderman (1989) have shown that the potential drop along the magnetic field lines through the gap is:

$$\Delta V_{max} \sim \frac{B_s R^3 \Omega_d(r_0)}{r_0 c}$$
$$\sim 4\,10^{14} \beta^{-5/2} \left(\frac{M}{M_\odot}\right)^{1/7} R_6^{-4/7} L_{37}^{5/7} B_{12}^{-3/7} \text{ V, (1)}$$

where B_s is the neutron star's surface dipole magnetic field, R is its radius, r_0 is the inner accretion disk radius, M is the compact star mass, and L_{37} is the X-ray luminosity in units of 10^{37} erg s^{-1}. The radius and magnetic field in the second expression are in units of 10^6 cm and 10^{12} Gauss, respectively. The parameter $\beta \equiv 2r_0/r_A$ is twice the ratio of the inner accretion disk radius to the Alfvén radius. For the particular case of A0535+26 we can adopt $\beta \sim 1$, according to the estimates by Li (1997).

Protons entering into the gap are accelerated up to energies above $E_p \sim e\Delta V_{max}$ whereas inverse Compton and curvature losses would limit the energy gain of electrons and positrons to lower values. The maximum current that can flow through the gap can be determined from the requirement that the azimuthal magnetic field induced by the current cannot exceed that of the initial field $\boldsymbol{B}$ (Cheng & Ruderman 1989):

$$J_{max} \sim c B_s R^3 r_0^{-2}$$
$$\sim 1.5\,10^{24} \beta^{-2} \left(\frac{M}{M_\odot}\right)^{-2/7} R_6^{1/7} L_{37}^{4/7} B_{12}^{-1/7} \text{ esu s}^{-1}.$$
$$(2)$$

As can be seen from Fig. 3, the proton current flux is directed from the polar cap of the star, where the accreting material impacts producing strong X-ray emission and abundant ions to be captured by the gap, towards the accretion disk. Electrons move in the opposite sense in order to cancel any net charge current flow, keeping in this way $\boldsymbol{E} \cdot \boldsymbol{B} \neq 0$ in the gap.

The collision of the relativistic proton beam into the disk will produce hadronic interactions with copious π^0 production (Cheng et al. 1990). These π^0 will quickly decay into γ-rays that could escape only if the disk density is sufficiently low. Otherwise, they will be absorbed by the matter and then re-emitted as X-rays. The interaction of relativistic protons with a thin hydrogen layer has been studied by Cheng et al. (1990) in the context of their model for the Crab pulsar. The π^0-decay γ-rays will only escape if the column density of the disk is $\Sigma \leq 100 \text{ g cm}^{-2}$. From Novikov & Thorne (1972), we have:

$$
\Sigma \approx 7 \times 10^2 \beta^{-3/5} \left(\frac{M}{M_\odot} \right)^{-3/35}
$$
$$
\times R_6^{-30/35} L_{37}^{27/35} B_{12}^{-12/35} \text{g cm}^{-2}. \tag{3}
$$

In a system like A0535+26, the column density of the disk will evolve with time following the variations in the X-ray luminosity. All other physical parameters in Eq. (3) remain constant along the orbital period. If at some point near the periastron, when the X-ray luminosity is close to its maximum, the column density exceeds the value $\sim 100 \text{ g cm}^{-2}$, the medium will be no longer transparent to gamma-rays and the gamma-emission will be quenched (we are assuming that the disk is seen from the opposite side to that where the current impacts). This could explain the fact that A0535+26 has not been detected by EGRET at the peak of its X-ray outbursts on February 18, 1994. The detection, instead, was clear a few days before, during the previous viewing period.

The expected hadronic γ-ray flux from A0535+26 on Earth will be:

$$
F(E_\gamma) = \frac{1}{\Delta\Omega D^2} \int_{E_\gamma}^{\infty} \frac{\mathrm{d}^2 N_\mathrm{p}(E_{\pi^0})}{\mathrm{d}t \, \mathrm{d}E_{\pi^0}} \, \mathrm{d}E_\mathrm{p}, \tag{4}
$$

where D is the distance to the source, $\Delta\Omega$ is the beaming solid angle and:

$$
\frac{\mathrm{d}^2 N_\mathrm{p}(E_{\pi^0})}{\mathrm{d}t \, \mathrm{d}E_{\pi^0}} = \frac{2 \, J_{\max}}{e} \frac{\Sigma <m_{\pi^0}>}{m_\mathrm{p}} \frac{\mathrm{d}\sigma(E_\mathrm{p}, E_{\pi^0})}{\mathrm{d}E_{\pi^0}} \tag{5}
$$

is the differential production rate of neutral pions from pp interactions. In this latter expression, $\mathrm{d}\sigma(E_\mathrm{p}, E_{\pi^0})/\mathrm{d}E_{\pi^0}$ is the differential cross-section for the production of π^0-mesons of energy E_{π^0} by a proton of energy E_p in a pp collision, and $<m_{\pi^0}>$ is the mean multiplicity of π^0.

For calculation purposes we shall adopt the cross section given by Dermer (1986a,b) and a beaming factor $\Delta\Omega/4\pi \approx 0.3$ as used by Cheng et al. (1991). We shall evaluate the total gamma-ray luminosity between 100 MeV and 20 GeV of A0535+2610 at an early epoch

t of the disk formation, when the X-ray luminosity ratio is $L_\mathrm{X}^{\max}/L_\mathrm{X}^t \sim 10$. If the absorption feature observed near 110 keV is a cyclotron line, the polar magnetic field of the neutron star results 9.5×10^{12} G (Finger et al. 1996). In our calculations we adopt this value along with $\beta \sim 1$, $R_6 = 1$ and $M = 1.4 \, M_\odot$ (Janot-Pacheco et al. 1987). We then obtain that the column density of the disk is $\sim 42.5 \text{ g cm}^{-2}$ at this stage and, consequently, gamma-rays are not absorbed in the disk material. The potential drop in the electrostatic gap results $\Delta V_{\max} \sim 2.5 \times 10^{13}$ V whereas the proton current deposited into the disk is $N_\mathrm{p} = J_{\max}/e \sim 4.8 \times 10^{32} \text{ s}^{-1}$. Using Eq. (4) for photons in EGRET's energy range we obtain:

$$
F(100 \text{ MeV } < E_\gamma < 20 \text{ GeV})
$$
$$
\approx 5.1 \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}. \tag{6}
$$

This flux is consistent with the lower EGRET detections. As the accretion onto the neutron star increases the gamma-ray flux also increases, reaching a maximum when $\Sigma \approx 100 \text{ g cm}^{-2}$. At this point the flux has grown by a factor ~ 4 (notice the dependence on $J_{\max}$ in addition to Σ) and photon absorption into the disk becomes important in quenching the radiation. The gamma-ray source, then, is not detected when the peak of the X-ray luminosity occurs. The additional gamma-ray flux expected from secondary electrons and positrons radiating in the the strong magnetic fields anchored in the disk can explain even higher EGRET fluxes (Cheng et al. 1991). A more detailed analysis in this sense will be presented elsewhere, including spectral considerations. The observed spectrum depends on the proton injection spectrum at the gap. Strong shocks near the polar gap can accelerate the protons up to a power law which will be preserved through the propagation across the gap and imprinted onto the π^0 gamma-ray spectrum. Additionally, e^+e^- cascades induced in the disk material can result in a relativistic bremsstrahlung contribution. Electromagnetic shower simulations are in progress in order to determine this contribution (Romero et al., in preparation).

5. Discussion

The model outlined here does not imply strict periodicity because of the highly chaotic nature of the Be stellar winds, which can significantly vary on short timescales producing strong changes in the accretion rate. Notwithstanding, the general prediction that the peak of the gamma-ray emission should not be coincident with the maximum X-ray luminosity during a given outburst can be used to test the general scenario proposed here. At present, the poor time resolution of the gamma-ray lightcurve does not allow correlation studies. EGRET data for the best sampled X-ray outburst (in February 1994) consist of only two viewing periods, as it was mentioned, and in one of them the source was not detected. In the future, however, new instruments like GLAST could provide the tools for these kind of investigations.

TeV emission should be produced in the accretion disk according to Eq. (4), although degradation effects during the propagation in the strong magnetic and photon fields around the accretion disk could suppress much of it. The magnetic field at the inner accretion disk radius is (e.g. Cheng et al. 1991):

$$B(r_0) = 3 \times 10^5 \beta^{-3} B_{12}^{-5/7} R_6^{-9/7} L_{37}^{6/7} (M/M_\odot)^{-3/7} \quad \text{G} \quad (7)$$

which for the typical values of A0535+26 yields $B \sim 10^4$ G. TeV gamma-rays can be absorbed in the field through one-photon pair production above the threshold given by (e.g. Bednarek 1993):

$$\chi \equiv \frac{E_\gamma B \sin\theta}{2m_e c^2 B_{\rm cr}} = \frac{1}{15}, \tag{8}$$

where θ is the angle between the photon momentum and the magnetic field and $B_{\rm cr}$ is the critical magnetic field given by $B_{\rm cr} = m^2 c^3/e\hbar \approx 4.4 \times 10^{13}$ G. This process, then, suppress gamma-ray photons with energies higher than $\sim$300 TeV in A0535+26. Since this value is well above the energy of the protons that impact on the disk, we find that absorption in the magnetic field should not occur.

However, TeV photons with lower energies should be absorbed by two-photon pair production in the accretion disk X-ray photosphere. Calculations by Bednarek (1993) show that the optical depth quickly goes to values above 1 for disks with luminosities $L_{37} \sim 1$. The opacity effects can reach even GeV energies leading to a steepening in the spectrum with respect to what is expected from a pure pion-decay mechanism. The fact that the observed spectrum in 3EG J0542+4610 has an index $\Gamma \sim -2.7$ seems to support the idea that important absorption is occurring in the X-ray photosphere of this source. Additional spectral modifications should be produced by the emission of secondary pairs in the magnetic field close to the disk (Cheng et al. 1991; Romero et al., in preparation).

In their original model, Cheng & Ruderman (1989) suggested that if the disk is sufficiently dense then the gamma-rays could be produced only in a moving low-density "window". This window would collimate a pencil beam of gamma-rays aligned with the magnetic axis. Consequently, a pulsed emission could exist with the same period of the X-ray source (104 s in the case of A0235+26). Small changes in the gamma-ray period might be produced by the radial motion of the "window". It would be interesting to test whether these pulses are present in A0235+26. However, since the disk is a transient structure and only would exceed the critical density during a few days per orbit, the number of photon counts in EGRET data are too low to allow a periodicity analysis as in the case of isolated and stable gamma-ray pulsars. Instruments with higher sensitivity like GLAST could sum up data over several viewing periods in order to look for these features.

6. Summary

We have shown that the Be/X-ray transient system A0535+26 also can be a transient gamma-ray source under very reasonable assumptions. The existence of a QPO phenomenon detected by BATSE during the 1994 X-ray outburst provided direct evidence of the formation of a transient accretion disk near the periastron passage. In the beat frequency model for QPO the Keplerian orbital frequency of the material at the inner edge of the accretion disk should exceed the spin frequency of the neutron star. Cheng & Ruderman (1989) have shown that in such a circumstance an electrostatic gap is open in the magnetosphere around the null surface determined by $\mathbf{\Omega_* \cdot B = 0}$. This gap can accelerate protons up to energies of tens of TeV, producing a hadronic current that impacts the accretion disk generating π^0 gamma-rays. The transient character of the disk makes the high-energy gamma radiation highly variable, as was found in the observed gamma-ray flux evolution. A specific prediction of the model is the suppression of gamma-ray emission when the column density of the disk exceeds a critical value, near the peak of the X-ray luminosity. Future GeV and TeV observations of this source with instruments of high temporal resolution, like GLAST or 5@5 (see Aharonian et al. 2001), could be used to test the proposed model and, if it is basically correct, to probe the evolution of the matter content on the accretion disk in this extraordinary X-ray binary.

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