The Milky Way’s *Fermi* bubbles: echoes of the last quasar outburst?

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**ABSTRACT**

*Fermi*-LAT has recently detected two gamma-ray bubbles disposed symmetrically with respect to the Galactic plane. The bubbles have been suggested to be in a quasi-steady state, inflated by ongoing star formation over the age of the Galaxy. Here we propose an alternative picture where the bubbles are the remnants of a large-scale wide-angle outflow from Sgr A*, the supermassive black hole (SMBH) of our Galaxy. Such an outflow would be a natural consequence of a short but bright accretion event on to Sgr A* if it happened concurrently with the well-known star formation event in the inner 0.5 pc of the Milky Way ~6 Myr ago. We find that the hypothesized near-spherical outflow is focused into a pair of symmetrical lobes by the greater gas pressure along the Galactic plane. The outflow shocks against the interstellar gas in the Galaxy bulge. Gamma-ray emission could be powered by cosmic rays created by either Sgr A* directly or accelerated in the shocks with the external medium. The Galaxy disc remains unaffected, agreeing with recent observational evidence that SMBHs do not correlate with galaxy disc properties. We estimate that an accreted mass $\sim 2 \times 10^3 M_\odot$ is needed for the accretion event to power the observed *Fermi*-LAT lobes. Within a factor of a few, this agrees with the mass of the young stars born during the star formation event. This estimate suggests that roughly 50 per cent of the gas was turned into stars, while the rest accreted on to Sgr A*. One interpretation of this is a reduced star formation efficiency inside the Sgr A* accretion disc due to stellar feedback, and the other a peculiar mass deposition geometry that resulted in a significant amount of gas falling directly inside the inner ~0.03 pc of the Galaxy.

**Key words:** accretion, accretion discs – black hole physics – Galaxy: centre – galaxies: evolution – quasars: general.

1 INTRODUCTION

1.1 Sgr A* – the SMBH of the Milky Way

Sgr A* is the supermassive black hole (SMBH) in the nucleus of our Galaxy. Its mass $M_{bh} \approx 4 \times 10^6 M_\odot$ (Schödel et al. 2002; Ghez et al. 2005, 2008) makes it directly comparable with SMBH in other galaxies. The Soltan relation (Soltan 1982) implies that most of the mass of these black holes was gained through luminous accretion. Yet by comparison with active galactic nuclei (AGN), Sgr A* is famously dim. It is spectacularly faint both in X-rays (less than $\sim 10^{-11} L_{\text{Edd}}$, where $L_{\text{Edd}} \sim a \times 10^{44} \text{erg s}^{-1}$ is its Eddington luminosity; Baganoff et al. 2003) and in the near-infrared (Genzel et al. 2003), prompting suggestions of a radiatively inefficient accretion flow (Narayan 2002, and references therein). Currently, Sgr A* appears to be fed by accretion of gas captured (Cuadra et al. 2006) from the winds of the young massive stars populating the inner ~0.5 pc of the Galaxy (Paumard et al. 2006). However, X-ray reflection nebulae suggest that Sgr A* might have been much brighter a few hundred years ago, with luminosity of a few $\times 10^{39} \text{erg s}^{-1}$ (e.g. Revnivtsev et al. 2004; Ponti et al. 2010). This may reflect variations in the wind feeding rate of Sgr A* caused by changes in the stellar orbits of the most important wind-producing massive stars (Cuadra, Nayakshin & Martins 2008), or longer time-scale feeding events from a few pc-scale molecular gas reservoirs (Morris, Ghez & Becklin 1999).

Sgr A* is also famous as the site of a recent (~6 $\times 10^6$ yr ago) star formation event in one and perhaps two stellar discs (Genzel et al. 2003; Levin & Beloborodov 2003, Lu et al. 2009) on scales of ~0.03–0.5 pc from the SMBH. The observed (e.g. Paumard et al. 2006) and theoretically constrained (Nayakshin et al. 2006) mass of the young stars is around a few times $10^3 M_\odot$, perhaps even $10^5 M_\odot$. Significantly, there is currently no trace of even a remnant gaseous disc near Sgr A* (Cuadra, Nayakshin & Sunyaev 2003; Paumard, Maillard & Morris 2004). This led Nayakshin & Cuadra (2005) to question whether Sgr A* failed to become a quasar because this recent star formation event consumed nearly all the available gas in the central pc of the Milky Way. They noted that this could be constrained with future observations: “a past bright AGN phase..."
should also leave a hot buoyant radio bubble in the Milky Way halo.

### 1.2 The Fermi-LAT gamma-ray lobes

The recent Fermi-LAT observations by Su, Slatyer & Finkbeiner (2010) show that the Milky Way has a pair of gamma-ray lobes, symmetrical about its dynamical centre (Sgr A*) and about the Galactic plane. The lobes extend ~5 kpc from the plane, but have a narrow (~100 pc) waist along it. The limbs of the lobes coincide with the extended structure seen in medium-energy X-rays by ROSAT (Snowden et al. 1997). The lobes have gamma-ray luminosity \( L_\gamma \simeq 4 \times 10^{37} \text{ erg s}^{-1} \), and their total energy content is at least \(~\sim 10^{54}–55\) erg.

Su et al. (2010) considered numerous physical processes that could give rise to the bubble structure and provided a constraint that if they are older than a few \( \times 10^9 \) yr, the gamma-ray emission must be powered by ions rather than electrons due to a short cooling time of the latter. Crocker et al. (2011) and Crocker & Aharonian (2011) detailed these arguments further and suggested that the emission is powered by cosmic ray (CR) protons rather than electrons. They further consider a quasi-steady state model in which the CR protons are continuously injected by supernova explosions. CR protons and heavier ions are then trapped inside the bubbles for approximately the age of the Galaxy.

Alternatively, the Fermi-LAT lobes could be a more recent feature. The mechanism of inflating the bubbles is then unlikely to be of star formation origin. One would require \(~\sim 10^5 \) Type II supernovae to provide the energy content of the bubbles, which is far higher than can be realistically expected from the inner \(~\sim 100 \) pc. Cheng et al. (2011) thus argued that the bubbles are inflated by episodic Sgr A* activity caused by tidal disruptions of stars passing too close to Sgr A*. Guo & Mathews (2011) performed hydrodynamical numerical simulations of jets launched by Sgr A* and showed that the Fermi-LAT observations are qualitatively consistent with their simulations if the jets were launched \(~\sim 1–2 \) Myr ago.

### 1.3 Sgr A* feedback: when and how?

In this letter, we shall argue that Sgr A* is a very natural candidate for the source of the energy that inflated the gamma-ray lobes. As noted above, the Galactic Centre underwent a peculiar star formation event localized to the inner 0.03–0.5 pc about 6 Myr ago (Paumard et al. 2006). Thus, a plausible scenario is that not all of the gas deposited into the central pc of the Milky Way went into making the young stars, and a fraction of it was accreted by Sgr A*, as found in realistic simulations of the process (e.g. Bonnell & Rice 2008; Hobs & Nayakshin 2009). Thus Sgr A* is likely to have had a short but very bright quasar phase concurrent with the star formation event \(~\sim 6 \) Myr ago.

We further argue that the observed highly symmetrical lobes are unlikely to have originated from a jet outflow. To obtain the qualitative agreement with the observed shape of the lobes, Guo & Mathews (2011) directed their jets perpendicular to the plane of the Galaxy. We believe this would be unlikely. Radio surveys show that jet directions are completely uncorrelated with the large-scale structure of the host galaxies (Nagar & Wilson, 1999; Kinney et al. 2000). Furthermore, the observed orientations of the stellar discs in the central pc of the Galaxy (see Paumard et al. 2006) are inclined at very large angles to the Galactic plane. The jets are likely to be fed by gas discs oriented similarly to the stellar discs. We would therefore expect that accretion of gas on to Sgr A* \(~\sim 6 \) Myr ago would result in jets directed at very large angles to the symmetry axis of the lobes, contradicting observations.

In contrast, a symmetrical pair of lobes with a narrow waist along the galaxy plane is natural if an isotropic outflow from near the black hole encounters higher gas densities along this plane than perpendicular to it. Near-spherical outflows like this are a direct consequence of super-Eddington disc accretion (Shakura & Sunyaev 1973; King & Pounds 2003) and offer a plausible explanation for the \( M-\sigma \) relation (Silk & Rees 1998; King 2003, 2005).

The Letter is structured as follows. We first discuss the simpler and better understood quasi-spherical AGN outflows in Section 2, and then we consider the more complicated case of the present day Milky Way nucleus in Section 3. The implications of the quasar outburst for the observed gamma-ray lobes are elucidated in Section 4, while Section 5 spells out ramifications for the poorly understood problem of star formation versus gas accretion in the central pc of AGN. We note that our approach here is to try to reproduce the main energetics of the lobes and their morphology rather than to produce detailed spectral models. We assume that Sgr A* outflow either carries with it CR protons created near the black hole or that the CR protons are accelerated on shock fronts where the outflow runs into the interstellar medium (ISM).

## 2 SPHERICAL OUTFLOWS

In regions close to the black hole, the AGN outflows are revealed through blueshifted absorption lines in X-ray emission (Pounds et al. 2003a,b; King 2010a). Tombesi et al. (2010a,b) show that they are present in more than 35 per cent of a sample of over 50 local AGN, and deduce that their solid angles are large (certainly \( > 0.6 \times 2\pi \), and probably greater). The observed absorption columns imply that in many cases the outflows are quite recent (few years), suggesting that outflows are an almost ubiquitous feature of central black hole activity (King 2010b).

Although SMBHs in galaxy centres frequently accrete at the Eddington rate, accretion at significantly higher rates requires extreme conditions (cf. King 2010a). Accordingly, we consider cases where the accretion rate far from the SMBH only mildly exceeds \( \dot{M}_{\text{Edd}} \), and both the central accretion rate and the outflow rate \( \dot{M}_{\text{out}} \) are \( \geq \dot{M}_{\text{Edd}} \). Then the outflow has scattering optical depth \( \sim 1 \), and the photons driving it typically scatter only once before escaping. The front-back symmetry of electron scattering means that the outflow momentum must be of the same order as the original photon momentum, i.e.

\[
\dot{M}_{\text{out}} \nu \simeq \frac{L_{\text{Edd}}}{c}
\]

so that the outflow velocity \( \nu \sim \eta c \), where \( \eta \sim 0.1 \) is the accretion efficiency (e.g. King & Pounds 2003; King 2010a). The wind flows with essentially constant velocity \( \nu \) until it shocks against the interstellar gas of the host galaxy, driving a second shock outwards into this ambient medium and sweeping it up into a shell. A simple representation of the interstellar density is the isothermal distribution:

\[
\rho(R) = \frac{f_g \sigma^2}{2\pi G R^2}
\]

where \( f_g \) is the gas fraction, and \( \sigma \) is the velocity dispersion. The average cosmological value of \( f_g \) is \( f_g \sim 0.16 \).

Within this model, then, in galaxies with large \( \sigma \gtrsim 150 \text{ km s}^{-1} \), Eddington outflows tend to sweep the vicinity of the hole clear of gas of density (2) and prevent further accretion and growth, establishing the \( M-\sigma \) relation for the black hole mass (King 2003; 2005). At
smaller values of $\sigma$, any effect of this kind is outdone by the effects of mass loss from nuclear star clusters. These sweep out the gas (McLaughlin, King & Nayakshin 2006; Nayakshin, Wilkinson & King 2009) and establish an offset $M-\sigma$ relation between the total cluster mass and the bulge velocity dispersion (Ferrarese et al. 2006; fig. 2, middle panel). The Milky Way is probably a member of this star cluster dominated class of galaxies, and indeed its SMBH mass lies significantly below the value predicted from the $M-\sigma$ relation (see e.g. Greene et al. 2010, fig. 9).

The double shock pattern caused by the impact of an Eddington outflow on the host ISM must move radially outwards from the vicinity of the black hole. The nature of this motion depends crucially on whether or not the shocked wind cools within the flow time. If cooling is effective, most of the energy injection rate crucially on whether or not the shocked wind cools within the flow time. If cooling is effective, most of the energy injection rate

$$E = \frac{1}{2} M_{\text{wind}} v^2 = \frac{\eta^2 c^2}{2} M_{\text{wind}} = \frac{\eta}{2} L_{\text{edd}}$$

(3)

is lost to radiation, and only the ram pressure of the outflow is communicated to the host ISM. This is a momentum-driven flow. If instead the flow does not cool, the shocked wind expands adiabatically, doing $PdV$ work against the swept-up ISM. This is an energy-driven flow, which expands faster through the ISM than a momentum-driven one.

### 3 Fermi-LAT Lobes as Quasi-Spherical Outflows

The gamma-ray lobes observed by the Fermi-LAT instrument are very wide features that we shall first consider approximately quasi-spherical. For the present day Milky Way and directions well out of the Galactic plane, we expect $f_{e}$ to be significantly less than $f_{c}$, so we parameterize $f_{g}$ as $f_{g} = 1.6 \times 10^{-3} f_{0.01}$, where $f_{0.01} \sim 1$ is a dimensionless free parameter of the model.

We now ask if the shocked gas cools in conditions appropriate for the outburst. The outflow speed $v \approx 0.1c$ implies a shock temperature $T_{s} = (3m_{p}/16k)\eta c^{2} \approx 1.6 \times 10^{10} K$. This is much higher than the Compton temperature $\approx 10^{7} K$ of the SMBH accretion flow, so when the shock is sufficiently close to the hole, Compton cooling by the central radiation field is very effective and enforces momentum-driven flow. As the shock reaches a critical radius $R_{\text{en}}$ the radiation field becomes too dilute to cool it. Also, the shocked wind has far too low a density to cool effectively by atomic or free–free processes, so the flow becomes energy-driven (King 2003; King, Zubovas & Power 2011). For the parameters of Sgr A* (mass $M_{\text{BH}} \approx 4 \times 10^{6} M_{\odot}$, velocity dispersion $\sigma \approx 100 \text{ km s}^{-1}$), the transition to energy-driven flow occurs at a radius

$$R_{\text{en}} \approx 15 f_{0.01}^{1/2} \text{ pc}$$

(cf. equations 8–10 of King 2003).

Even at the cosmological gas fraction ($f_{0.01} = 100$) the estimate (4) is so small compared with the size of the gamma-ray lobes that we can regard the outflow as essentially always energy-driven in directions away from the Galactic plane. In an energy-driven outflow, the shocked wind density driving the expansion is always much lower than the density of the swept-up ISM outside it. This makes the shock interface inherently Rayleigh–Taylor unstable (cf. King 2010b). The hot shocked gas mixes with cool dense interstellar gas throughout the flow in directions away from the Galactic plane. This mixture is clearly a promising site for gamma-ray emission. Within the Galactic plane, the gas density is far higher, and we expect little expansion (see also Section 4). This kind of outflow thus naturally produces the main qualitative features of the Fermi-LAT gamma-ray map: extensive gamma-ray emitting lobes placed symmetrically on each side of the Galactic plane, with a narrow waist in the plane.

Energy-driven outflows rapidly attain a constant speed

$$v_{e} = \left[ \frac{2\sigma_{c}^{2} c f_{e} M}{3b f_{g} M_{e}} \right]^{1/3} \approx 1640 \sigma_{100}^{2/3} f_{0.01}^{-1/3} \text{ km s}^{-1}$$

(5)

in the bulge of a galaxy (King 2005). Here the factor $b \lesssim 1$ allows for some collimation of the outflow, $M_{e}$ is the predicted value of the SMBH mass in the Milky Way from the $M-\sigma$ relation and $M \approx 2.0 M_{\odot}$ is the mass of Sgr A*

For the rest of this Section, we model the outflow away from the disc plane as a sector of a spherical flow. If the Eddington accretion phase lasts for a time $t_{\text{acc}}$, the shock reaches radius

$$R_{0} \approx v_{e} t_{\text{acc}}$$

(6)

when the quasar phase ends. However, the shocked wind gas is able to drive further expansion, which finally stalls at a radius

$$R_{\text{stall}} \approx \frac{v_{e}}{\sigma} R_{0} \approx \frac{v_{e}}{\sigma} t_{\text{acc}}$$

(7)

after a time

$$t_{\text{stall}} \approx 0.5 \left( \frac{v_{e}}{\sigma} \right)^{2} t_{\text{acc}}$$

(8)

(King et al. 2011) so that

$$t_{\text{stall}} = \frac{R_{\text{stall}}}{2\sigma}$$

(9)

We now apply these considerations to our Galaxy, and in particular the gamma-ray lobes. If the outflow producing the observed lobes had stalled, we would have $R_{\text{stall}} \sim 5 \text{ kpc}$, which from (9) requires $t_{\text{stall}} = 15 \text{ Myr}$. This would mean that the outflow was produced well before the last accretion event in the Galactic Centre, which appears unlikely.

If instead we assume that the gamma-ray lobes were produced in this event, we must conclude that the energy-driven outflow is still proceeding, with a mean velocity $\langle v \rangle \approx 1000 \text{ km s}^{-1}$ over its lifetime. This is lower than the shell velocity during the quasar phase, which might have been as large as $v_{s} \approx 1600 \text{ km s}^{-1}$ (cf. the figures in King et al. 2011). This is compatible with (5) if $f_{0.01} \approx 1$, i.e. if the gas fraction in the lobes is about 1 per cent of the cosmological value. Requiring $t_{\text{stall}} > 6 \text{ Myr}$ in (8) now gives $t_{\text{acc}} \gtrsim 5 \times 10^{4} \text{ yr}$. At the Eddington accretion rate $\approx 8 \times 10^{-2} M_{\odot} \text{ yr}^{-1}$ appropriate for the mass of Sgr A* this gives the total mass accreted by the black hole during the quasar phase as $\Delta M \gtrsim 4 \times 10^{5} M_{\odot}$. This is comparable to the total expected if the hole accreted the disc mass

$$M_{\text{disc}} = \frac{H}{R} M_{\text{BH}} \approx 8000 M_{\odot}$$

(10)

within the self-gravity radius where the ring of young stars formed (cf. equations 7 and 12 of King & Pringle 2007). This estimate is also consistent with the results of Nayakshin & Cuadra (2005).

In this picture the mass of wind expelled from the vicinity of the hole must be $\sim \Delta M$. Almost all of its kinetic energy is retained by the outflow. This energy is of order

$$E_{\text{lobes}} \approx \frac{\eta^{2}}{2} \Delta M c^{2} \gtrsim 4 \times 10^{55} \text{ erg}$$

(11)

somewhat above the minimum required by observation. At the current gamma-ray luminosity the lifetime is $\sim 10^{10} \text{ yr}$, but there may be other losses of course. We conclude that the properties of the
gamma-ray lobes are consistent with their production in a short phase of Eddington accretion about 6 Myr ago.

4 THE NARROW WAIST OF THE GAMMA-RAY LOBES

So far we considered the outflow in a spherical geometry. However, it is well known that the central ∼200 pc of the Galaxy host as much as ∼10 per cent of all molecular gas of the Galaxy in a flattened, presumably disc-like, configuration (Morris & Serabyn 1996). We shall now show that this feature, called the central molecular zone (CMZ), could not have been significantly affected by the hypothesized outflow from Sgr A∗.

The mass of the molecular gas in the zone is \( M_{\text{cmz}} \sim 5 \times 10^7 M_\odot \). Its weight is

\[
W_{\text{cmz}} \sim \frac{GM_{\text{cmz}}(R_{\text{cmz}})M_{\text{cmz}}}{R_{\text{cmz}}^2} = \frac{2M_{\text{cmz}}\sigma^2}{R_{\text{cmz}}} ,
\]

where \( M_{\text{cmz}}(R_{\text{cmz}}) \) is the mass enclosed within radius \( R_{\text{cmz}} \sim 200 \) pc. The outward force (momentum flux of the outflow incident on the CMZ) in the isotropic outflow model is

\[
F_{\text{out}} \sim \frac{H L_{\text{Edd}}}{R} \frac{R}{c} ,
\]

where \( H/R \sim 0.2–0.3 \) is the geometrical aspect ratio of the disc (see fig. 1 in Morris & Serabyn 1996).

Comparing the two for the fiducial parameters accepted above, we have

\[
\frac{F_{\text{out}}}{W_{\text{cmz}}} \sim 0.1 ,
\]

which shows convincingly that the outflow from Sgr A∗, even in its full ‘quasar’ mode, is not strong enough to disperse the CMZ since the latter is simply too massive. This conclusion is reinforced by the fact that there is also atomic and ionized gas in the region of the CMZ disc that would increase \( W_{\text{cmz}} \) further.

Another way to come to the same conclusion is through estimation of the gas density in the mid-plane of the CMZ, for which we infer \( \rho_{\text{cmz}} \sim 5 \times 10^{-22} \) g cm\(^{-3} \) with the parameters mentioned above, whereas the density of gas which could be driven away by an SMBH outflow, for an SMBH obeying the \( M-\sigma \) relation, is given by equation (2), and is \( \sim 10^{-22} \) g cm\(^{-3} \) at \( R = 200 \) pc and \( \sigma = 100 \) km s\(^{-1} \).

We therefore conclude that the outflow along equatorial directions stalls. As argued above, the outflow should then thermalize and expand away from the plane of the symmetry, i.e. the Galactic plane. This would naturally explain the two-lobe structure of the \textit{Fermi}-LAT bubble.

We also note that a relatively geometrically thin distribution of the molecular gas along the Galaxy plane in the CMZ justifies our assumption that gas mass and density in the direction significantly away from the plane is low. Indeed, the density at height \( z \sim R \) away from the mid-plane is \( \sim \exp \left[ - (R/H)^2 \right] \) that in the mid-plane. Even at \( H/R = 0.3 \) this factor is about \( 10^{-3} \). We therefore estimate that the outflow should have an opening angle larger than 45°, and realistically in the range of ∼60–70°.

Thus although outflows ultimately control black hole growth, and materially affect the Galaxy bulge, as shown by the \( M-\sigma \) relation, they cannot disperse the Galaxy disc. This fits very naturally with the recent conclusion by Kormendy, Bender & Cornell (2011) that SMBHs do not correlate observationally with host galaxy discs.

5 ACCRETION VERSUS STAR FORMATION

One of the major puzzles in how SMBHs gain mass is the role of accretion disc self-gravity in the outer \( \sim 0.03–0.1 \) pc regions. Here we expect the disc to be very cold and massive, provoking the conversion of gas into stars (e.g., Paczynski 1978; Kolykhlov & Sunyaev 1980; Goodman 2003). Hydrodynamical simulations of planar accretion discs in the regime appropriate for the Sgr A∗ star formation episode lead to rapid gas depletion through star formation (Nayakshin, Cuadra & Springel 2007), leaving almost no fuel for the SMBH. The \textit{Fermi}-LAT observations suggest that at least in the last star formation episode near Sgr A∗ it managed to gain roughly the same amount of gas as was used to make stars, which appears to be the first observational evidence of this kind.

The interpretation of the physical significance of an amicable ∼50 per cent split of the gas consumption between the stellar disc and Sgr A∗ is model-dependent. On the one hand, it may be an evidence that feedback from stars inside the accretion disc is able to stave off star formation for long enough to channel a sufficient amount of fuel to the SMBH (Thompson, Quataert & Murray 2005). Alternatively, the dynamically hot structure of the young stars in the central pc of the Milky Way is best explained by a non-planar gas deposition event resulting from, e.g. collisions of two massive gas clouds (Hobbs & Nayakshin 2009), collision between a cloud and the circumnuclear disc, or capture of a large, turbulent giant molecular cloud (Bonnell & Rice 2008; Wardle & Yusef-Zadeh 2008). If this is so, a fraction of the gas may have small enough angular momentum to orbit within the innermost non-self–gravitating disc region, avoiding the star formation catastrophe entirely (King & Pringle 2007; Nayakshin & King 2007; Hobbs et al. 2011). In particular, in all of the cases simulated by Hobbs & Nayakshin (2009), the mass of the gas captured inside their inner boundary (a non-self–gravitating part of the disc) was comparable with the mass required to fuel the \textit{Fermi}-LAT lobes.

6 DISCUSSION

We have shown that the shape and energy content of the gamma-ray lobes observed by \textit{Fermi} are consistent with the effects of a near-isotropic outflow driven by the Milky Way’s last Eddington outburst, which we hypothesize to have been coincident with the well-known star formation event in the central 0.5 pc of the Galaxy about 6 Myr ago. The shape follows because such outflows cannot penetrate the galaxy disc, in agreement with the recent conclusion that SMBHs do not correlate observationally with galaxy discs (Kormendy et al. 2011). The accreted mass driving this event is \( \geq 2 \times 10^5 M_\odot \), comparable with the mass of the ring of stars born in the event. This suggests that a significant fraction of gas captured into orbit by the SMBH has low enough angular momentum to accrete rather than being turned into stars. Because the outflow is Rayleigh–Taylor unstable, the gamma-ray producing gas is homogeneously mixed through the lobes.

Our model is similar to that of Crocker & Aharonian (2011) in terms of assuming the CR protons (rather than electrons) produce the observed gamma-ray emission. We differ in the source and the age of the lobes. It is worth noting that if the bubbles are indeed very old quasi-static features as suggested by Crocker & Aharonian (2011), then our estimates on the recent Sgr A∗ activity should be taken as a non-trivial upper limit for that activity.

The picture of the recent Sgr A∗ outburst developed here fits with a general view that all galaxies are active and reach the Eddington limit from time to time. This latter property is seen most obviously...
among galaxies classified on other grounds as active, particularly in the very high fraction of local AGN with high-speed outflows (Tombesi et al. 2010a,b). It seems likely that other ‘normal’ galaxies may produce similar phenomena. However, the comparative dimness ($L_\gamma \sim 10^{37}$ erg s$^{-1}$) of the lobes may make these difficult to detect. A prediction of the present Letter is that the outermost parts of the lobes should still be expanding at $\sim 1000$ km s$^{-1}$.

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Mertsch & Sarkar (2011) argue that the spectral and morphological details of the Fermi bubble emission are incompatible with hadronic radiation, leaving electrons as the main energy source. This provides further support to the argument that the bubbles are a recent phenomenon and might have been inflated by Sgr A$^*$ activity.

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