Sgr A* flares: tidal disruption of asteroids and planets?

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1 INTRODUCTION

Most of the nearby SMBHs are rather dim (e.g., [H₂] 2008), suggesting that little gas is supplied to them at the current epoch. However, rare and temporary exceptions from this "gas drought" are expected to occur when a star passing too close to a SMBH is shredded into streams by the tidal forces of the SMBH [Rees 1988]. The bound streams precess and self-intersect on the return passage past the black hole, resulting in very strong shocks. The result of these shocks should be a small-scale accretion disc around the SMBH, with the maximum possible luminosity of the order 10⁵⁹ erg s⁻¹. Assuming that the asteroid population per parent star in the central parsec of the Milky Way is not too dissimilar from that around stars in the Solar neighborhood, we estimate the asteroid disruption rates, and the distribution of the expected luminosities, finding a reasonable agreement with the observations. We also note that planets may be tidally disrupted by Sgr A* as well, also very infrequently. We speculate that one such disruption may explain the putative increase in Sgr A* luminosity ~ 300 yr ago.

ABSTRACT

It is theoretically expected that a supermassive black hole (SMBH) in the centre of a typical nearby galaxy disrupts a Solar-type star every ~ 10⁷ years, resulting in a bright flare lasting for months. Sgr A*, the resident SMBH of the Milky Way, produces (by comparison) tiny flares that last only hours but occur daily. Here we explore the possibility that these flares could be produced by disruption of smaller bodies – asteroids. We show that asteroids passing within an AU of Sgr A* could be split into smaller fragments which then vaporise by bodily friction with the tenuous quiescent gas accretion flow onto Sgr A*.

The ensuing shocks and plasma instabilities may create a transient population of very hot electrons invoked in several currently popular models for Sgr A* flares, thus producing the required spectra. We estimate that asteroids larger than ~ 10 km in size are needed to power the observed flares, with the maximum possible luminosity of the order 10⁵⁹ erg s⁻¹.

In this paper we test the asteroid disruption hypothesis for Sgr A* flares in a reasonable level of detail. In doing so, we adopt an approach complimentary to most of the existing popular models of Sgr A* flares. As reviewed in [2] below, these usually predict spectra given specific assumptions about emitting particle distributions; it is not always specified how these distributions are energized. In the context of our model, instead, there is far too much physical uncertainty in predicting the particle distributions at this stage, but we are able to constrain the energetics, the duration and the frequency distribution of the tidal disruption events starting from reasonable assumptions about the pop-
ulations of asteroids in the central parsec of Sgr A*. Our model presents a mechanism for producing the transient hot particle populations responsible for the observed flares.

The paper is structured as follows. In Section 2 we overview the astrophysical setting of the problem, and the observational characteristics of the flares. In Section 3 we estimate the minimum size of the asteroids (~10 km) needed to power the observed flares. We then consider what happens to asteroids of different sizes as they pass by Sgr A* on orbits of a given pericentrical distance. We show that large asteroids approaching Sgr A* within R < 1 AU are broken into smaller pieces (at most ~1 km in size). We also point out that asteroids evaporate as they pass through the gas of the tenuous quasi-spherical accretion flow (that is believed to power the quiescent Sgr A* emission Narayan et al. 1995; Yuan et al. 2003) at very high velocities. The combination of tidal "grinding" of large asteroids into smaller fragments and evaporation of the latter may destroy the asteroids efficiently and turn their bulk energy into heat in the shocks between the evaporated material and the background accretion flow.

In Section 4 we calculate the rate at which asteroids are supplied into the vicinity of the SMBH and find values roughly consistent with the frequency of observed flares. In Section 5 we note that planets, too, could be tidally disrupted by Sgr A*, although clearly far less frequently than asteroids. We consider whether one such disruption could account for the suspected Sgr A* brightening to ~10^39 erg s^{-1} ~300 yr ago due to the well-known X-ray echo on Sgr B2 molecular cloud (Sunyaev & Churazov 1996; Revnivtsev et al. 2004), that is now fading (Terrier et al. 2011). Finally, in 6 we suggest how the evaporating asteroids could produce high energy particles needed by the current models of flare emission from Sgr A*. We present a summary discussion and conclusions of the model in Section 7.

2 Sgr A* AND ITS FLARES

Sgr A* is the supermassive black hole (SMBH) in the nucleus of our Galaxy, with the mass M_{bh} ≃ 4 × 10^6 M_⊙ (Schödel et al. 2002; Ghez et al. 2003). By comparison with active galactic nuclei (AGN) Sgr A* is famously dim in all frequencies. Its bolometric luminosity is only L_{bol} ≃ 300 L_⊙ ≃ 10^{39} L_{Edd} (e.g., Melia & Falcke 2001). In X-rays Sgr A’s quiescent luminosity is less than ~10^{31}\text{L}_{\text{Edd}}, where L_{\text{Edd}} ~ a few \times 10^{34} \text{erg s}^{-1} is its Eddington luminosity (Baganoff et al. 2003), and in the near infrared L ~ 10^{35} \text{erg s}^{-1} (Genzel et al. 2003). This extraordinarily low luminosity has been explained in the literature via models of radiatively inefficient inflow and/or outflow (Narayan et al. 1993; Falcke & Markoff 2000; Narayan et al. 2003; Yuan et al. 2003, and references therein).

The quiescent emission from Sgr A* is punctuated several times a day by short flares in the near infrared (Genzel et al. 2003; Ghez et al. 2004; Marrone et al. 2008). Approximately once per day, these flares are accompanied by corresponding rises in the X-ray emission (Baganoff et al. 2001; Eckart et al. 2006a; Hornstein et al. 2007; Marrone et al. 2008; Porquet et al. 2003, 2006). Sub-mm flares have been observed approximately 1 hour later following some of the IR/X-ray flares (Mauerhan et al. 2003; Herrnstein et al. 2004; Kumeria et al. 2010), although the connection between the two has not been firmly established.

Typically, flares last for approximately an hour to a few hours (t_f \lesssim 10^4 s) and have luminosities a factor 3–100 above the quiescent emission level in both X-rays and near infrared (L_{x,nir} ~ 10^{34}–10^{35} \text{erg s}^{-1}) (Baganoff et al. 2001; Genzel et al. 2003). There may also be more frequent weaker flares that get blended in the quiescent emission of Sgr A* (Dodds-Eden et al. 2011). The brightest flare observed so far reached L_{max} ~ 10^{36} \text{erg s}^{-1} in both the NIR and the X-rays (Porquet et al. 2003, 2006). The observed NIR flare luminosity distribution (4.3) seems to follow a L_{NI} \propto L^{0.4} law, with −1 ≤ α ≤ 0 (Dodds-Eden et al. 2011), where N_{I}ΔL is defined as the number of flares with maximum luminosity during the flare between L and L + ΔL. The rise and fall times, as well as short timescale variability, suggest that the flaring region is very compact and located within R ~ 10R_S of Sgr A* where R_S = 2GM_\odot/c^2 ~ 1.2 × 10^{12} cm is the Schwarzschild radius of Sgr A* (Baganoff et al. 2001; Porquet et al. 2003; Shen et al. 2004; Eckart et al. 2006a). Besides the time variability constraints, the location of the emission region is constrained directly by the NIR observations to be within a few milliarcseconds of Sgr A* (which is equivalent to tens of AU or a few hundred R_\odot) (Genzel et al. 2003).

There is currently no universally accepted model for Sgr A* flares. Even the emission mechanism is not completely settled. The suggested models are synchrotron emission by either thermal or power-law distribution of electrons for the NIR flares plus the inverse Compton or self-Compton emission in the X-rays, or power-law synchrotron emission for all the components (e.g., Markoff et al. 2001; Dodds-Eden et al. 2004). In terms of associated physical mechanisms responsible for flares, magnetic reconnection events (Yuan et al. 2003; Dodds-Eden et al. 2010), turbulent shocks (Liu et al. 2004) and jet acceleration (Markoff et al. 2003; Yuan et al. 2002; Maitra et al. 2009) were proposed. Short-timescale magnetic reconnection event models seem to be more promising than transient density variation models (Markoff et al. 2003; Dodds-Eden et al. 2011).

Another class of flare models envisages a transient feature in the accretion flow around Sgr A*. Such a feature may be an accretion instability (e.g., Tagger & Melchior 2006) or an orbiting hot spot (e.g., Broderick & Loeb 2005). Finally, a number of authors have proposed an expanding plasma blob as the source of the flares (van der Laan 1969; Yusef-Zadeh et al. 2006a; Eckart et al. 2006a; Trap et al. 2011; Kusunose & Takahara 2011). A blob of relativistic plasma, threaded by a magnetic field, is assumed to be suddenly created in the accretion flow around Sgr A* and then proceeds to move outwards while simultaneously expanding at a prescribed velocity. This leads to an evolution of the optical depth of the plasma, which in turn causes different parts of the emission spectrum to appear different...
during the flare, leading to time lags between emission maxima and characteristic light curves for the various spectral bands. The orbiting hot spot model is similar to this, except that in the latter, the plasma blob is assumed to circle around Sgr A* for at least several dynamical times. Scott Tremaine noted this point to one of us in about 2004.

\[ E \sim \frac{3M_{\text{BH}}}{4\pi R^3}, \]  

where \( R \) is the distance to the SMBH. For \( \rho_n = 1 \, \text{g cm}^{-3} \), the tidal disruption radius is

\[ R_{\text{td}} \approx 1.5 \times 10^{13} \, \text{cm} \approx 1 \, \text{AU}. \]

3 Tidal disruption of an asteroid

We shall consider large asteroids to have a “rubber-pile” structure, i.e., be a collection of smaller rocks held together by gravity rather than by material strength. This point of view is physically motivated by the fact that large monolithic bodies are expected to collide at high speeds with abundant smaller bodies. Such collisions do not completely obliterate the large bodies but do erode them even in our Solar System (Chapman 1978; Richardson et al. 1999; Korycansky & Asphaug 2006). In the environment we are considering, collisions occur at even higher speeds (\( \xi \approx 3 \)), and therefore the rubber-pile structure is even more relevant.

There are both similarities and differences in the way that asteroids and stars are tidally disrupted near a SMBH. Since the mean density of asteroids, \( \rho_n \), is of the same order as that of main-sequence solar type stars, the tidal disruption radius is very similar for asteroids and stars. An asteroid is tidally disrupted in the vicinity of the SMBH provided that

\[ \rho_n \lesssim \frac{3M_{\text{BH}}}{4\pi R^3}, \]  

where \( R \) is the distance to the SMBH. For \( \rho_n = 1 \, \text{g cm}^{-3} \), the tidal disruption radius is

\[ R_{\text{td}} \approx 1.5 \times 10^{13} \, \text{cm} \approx 1 \, \text{AU}. \]

Unlike a star, a tidally disrupted asteroid breaks up into smaller fragments that are bound by chemical forces rather than gravity. The fragments of the comet Shoemaker-Levy 9 tidally disrupted as it passed by Jupiter are estimated to be around \( \sim 1 \, \text{km} \) in size (see the discussion and references in Asphaug & Benz 1996). Through analytical arguments and numerical simulations, Benz & Asphaug (1999) suggest that objects greater than about \( \sim 1 \, \text{km} \) in diameter must be composed of smaller pieces held together by gravity. We shall thus consider the maximum size of the fragments to be around \( \sim 1 \, \text{km} \), and probably less than \( \sim 100 \, \text{m} \) due to a more extreme environment we study.

One further difference between stellar tidal disruptions and that of asteroids is in the orbits of the disrupted material. Rees (1988) shows that roughly half of the star’s material falls onto orbits bound to the black hole, whereas the other half is ejected into the larger (outside \( \sim 1 \, \text{pc} \)) host galaxy. The semimajor axes of the orbits of disrupted streams of gas can be found from the specific energy of the relevant streams. Before the disruption, the orbit is assumed to be parabolic, thus the specific energy is nearly zero. After the disruption at pericentre distance \( R \), the specific energy of the stream is \( \sim -v_\text{esc}^2/v_\text{a} \), where \( v_\text{esc} \sim 10^{10} \, \text{cm}/\text{s} \) is the parabolic velocity of the object at the pericentre (eq. 3), and \( \Delta v_\text{a} \) is the escape velocity from the object. The semimajor axis of the most bound material is thus

\[ R_{\text{orb}} \approx \frac{G M_{\text{BH}}}{2v_\text{esc}^2} \sim R \frac{v_\text{a}}{\Delta v_\text{a}}. \]

For a Solar-type star, \( \Delta v_\text{a} \sim \text{few} \times 10^7 \, \text{cm} / \text{s} \), and hence the semimajor axis of the most bound orbit is a few hundred times the pericentre passage distance. This implies that the material will fall back to the SMBH vicinity within a month to a year, depending on the SMBH mass. This leads to a...
bright stellar disruption flare (for recent numerical simulations of the process see [Lodato et al. 2009].

However, for an asteroid, \( \Delta v_{\text{a}} \sim 10^7 \tau_{\text{km}} \text{ cm s}^{-1} \), i.e., much smaller than for a star. Therefore, if an asteroid tidal disruption proceeded in exactly the same fashion as that of a star, the change in the orbital energy of the different fragments of the asteroid would be negligible. The disrupted asteroid would thus continue to travel on almost the same orbit as the one it had before the disruption. The fragments would come back to the SMBH after hundreds or thousands of years. As luminosity is energy released per unit time, the luminosity output of such a disruption would be far too small for us to be interested in it. Finally, unlike the disrupted stellar gas streams, that are certain to intersect due to precession of the orbits ([Roes 1988], the returning asteroid fragments are very unlikely to collide with one another. It seems extremely unlikely that any significant flare would be produced in this "dry" disruption scenario.

3.3 Asteroid evaporation

The inner few AU of our Galactic centre, or any other galactic centre, are very likely to be filled with a gaseous accretion flow onto the SMBH, however tenuous that flow might be. The asteroid moves through this gas at almost a relativistic velocity. Aerodynamic friction may cause a significant heating of the asteroid, perhaps leading to its evaporation before it leaves the central region. We shall term this background gas-mediated disruption "wet disruption" in contrast to the dry disruption discussed in [72].

The quiescent luminosity of Sgr A* and its linear polarization measurements suggest an accretion rate \( \dot{M} \gtrsim 10^{-8} \ M_\odot \text{ yr}^{-1} \) in the system [Aitken et al. 2000, Bower et al. 2003, Marrone et al. 2006]. If we assume that the flow is spherically symmetric, and is in a free-fall onto Sgr A*, the gas density can be estimated as

\[
\rho_\text{G} \approx \frac{\dot{M}}{4\pi R^2 v_\text{ff}} = \frac{\dot{M}}{4\pi (GM_{\text{BH}}R^3)^{1/2}},
\]

\( R_8 \equiv R/10 \text{ AU} \), i.e., well outside the tidal disruption radius. Of the two materials, we expect carbon to be more abundant, so we use its parameters in subsequent calculations.

The radius at which temperature \( T_X \) is reached is given by

\[
R_X \approx \left( \frac{T_X}{1.4 \cdot 10^4 \rho_\text{IS}^{1/4}} \right)^{-8/(3+2s)},
\]

where \( T_X \) is one of the sublimation temperatures of interest as above. For the three cases of interest, and \( s = 1.23 \) we find

\[
R_{F,\text{m}} \approx 21 \text{ AU}, \ R_{F,v} \approx 10 \text{ AU}, \ R_{C,v} \approx 7 \text{ AU}.
\]

This shows that asteroids start melting and evaporating at \( R \sim 10 \text{ AU} \), i.e., well outside the tidal disruption radius. Inside the central few AU, the effective temperature of the asteroid is larger than the melting and evaporation temperature of iron \( (T_{F,\text{m}} \approx 1800 \text{ K}, T_{F,v} \approx 3100 \text{ K}) \) and the sublimation temperature of carbon \( (T_{C,v} \approx 3900 \text{ K}; \text{carbon does not have a liquid phase at pressures below a few } \text{MPa}) \). Therefore, the asteroid’s outer layers should indeed be evaporating as it is passing through the inner regions of the accretion flow onto Sgr A*.

In the asteroid’s rest frame, the mechanical energy flux of the background accretion flow material striking the asteroid’s surface is

\[
\Phi_\text{a} \sim \rho_\text{a} R_{\text{a}}^{3/2} \sim 2.4 \cdot 10^{12} \rho_\text{IS} R_{\text{AU}}^{3/2-s} \text{ erg cm}^{-2} \cdot \text{s}^{-1}.
\]

Assuming that a sizeable fraction of this energy flux is reradiated as a thermal blackbody radiation, hence the effective temperature of the asteroid is

\[
T_a \sim \left( \frac{\Phi_\text{a}}{\sigma_{\text{SB}}} \right)^{1/4} \sim 1.4 \cdot 10^4 \rho_\text{IS}^{1/4} R_{\text{AU}}^{-3/8-s/4} \text{ K},
\]

where \( \sigma_{\text{SB}} \) is the Stefan-Boltzmann constant. The radiation itself is, however, too faint to be detected (see Section 6.2).

To calculate the mass loss by the asteroid, we follow the classical meteor ablation considerations [Bronshten 1983, see also §2.3.2 in Alibert et al. 2005], which give

\[
\mathcal{M}_v \sim \frac{\pi r^2 \Phi_\text{a} C_H}{2 Q_{C,v}},
\]

Here, \( \mathcal{M}_v \) is the mass loss rate due to vapourization and \( Q_{C,v} \sim 3.0 \cdot 10^{11} \text{ erg g}^{-1} \) is the energy per unit mass required to raise the asteroid temperature to the vapourisation temperature and evaporate it (the latter process is energetically dominant). \( C_H < 1 \) is an unknown dimensionless coefficient which specifies how much of the bulk mechanical energy inflow into the asteroid goes into the mass loss as opposed to thermal re-radiation of that flux. In the high density environment of Earth and Jupiter atmospheres, \( C_H \) can be very small because the optical depth of the evaporating material can be large and hence the asteroids self-shield themselves efficiently (so-called “vapor shielding”). For example, for asteroids of size \( 1-10 \text{ m} \) in the Earth’s atmosphere, \( C_H \sim 10^{-3} \) [Svetsov et al. 1993], but this value increases with altitude (i.e. with decreasing atmospheric density).

In the very low ambient gas density environment we study, \( C_H \) is likely to be close to unity because the optical depth of the self-shielding material is small for two reasons. Firstly, the evaporating gas may be heated up to temperatures of the order of that of the surrounding medium, which
For convenience, we define the vaporization timescale, $\tau_v \sim \rho_s r = \frac{M_v}{4\pi r v_{ev}}$. Using equation (13) we have, $\Sigma_v \sim \frac{C_H \Phi_{\perp}}{2Q_{\perp} v_{ev}} \approx 0.3 C_H \frac{r}{1 \text{km}} \text{ g cm}^{-2}$. With opacity coefficient not too different from electron scattering, the evaporated material is obviously optically thin. This ratio is important in determining what exactly happens to an asteroid as it swings by the SMBH.

We hence conclude that thermal ablation of asteroid fragments should be very effective with $C_H \sim 1$ for fragment size $r \lesssim 1 \text{ km}$. The evaporation rate is $M_v \sim 1.3 \cdot 10^{13} \rho_{18} R_{\text{AU}}^{3/2-s} r_1^2 C_H \text{ g s}^{-1}$. For convenience, we define the vaporization timescale, $t_v = \frac{M_v}{\dot{M}_v} \sim 3.2 \cdot 10^5 \rho_{18}^{-1} R_{\text{AU}}^{3/2-s} r_1 C_H^{-1} \text{ s}$. (17)

We see that the smaller the asteroid, the faster it vaporises. The material ablated from the asteroid might assume a cometary shape, with a long gaseous tail behind the solid head (cf. [62]).

### 3.4 Total and partial asteroid disruptions

We can now delineate the parameter space for the possible outcomes of an asteroid’s flyby near a SMBH. An asteroid on a parabolic orbit around Sgr A* with pericentre distance $R_p$ spends a time

$$t_{\text{fly}} \simeq \tau_{\text{fly}} = \frac{\sqrt{R_p^3}}{2GM_{\text{BH}}} \simeq 5600 R_{\text{AU}}^{3/2} \text{ s}$$

at radial distance comparable with $R_g$. The ratio between the vaporisation timescale and the flyby time is

$$\frac{t_v}{t_{\text{fly}}} \sim 57 \rho_{18}^{-1} R_{\text{AU}} R_1 C_H^{-1}. \text{ (19)}$$

This ratio is important in determining what exactly happens to an asteroid as it swings by the SMBH.

#### 3.4.1 Orbits outside 1 AU but inside ~ 10 AU

For asteroids on orbits with pericenter distances larger than $R_{\text{tid}} \sim 1 \text{ AU}$ (equation (2)), the asteroid is not tidally disrupted. If the orbit passes within $R_p \sim 10 \text{ AU}$ (eq. (11)), the surface layers of the asteroid are vaporised at the rate given by equation (16). Only a fraction $\sim t_{\text{fly}}/t_{v}$ of the asteroid is ablated during the close passage. Therefore, large asteroids passing Sgr A* farther away than 1 AU remain relatively untouched and leave the SMBH vicinity on their initial parabolic orbits.

The luminosity released by material lost by the asteroid in this regime can be estimated as

$$L_{f,\text{out}} = \xi \dot{M}_v c^2 = 2 \cdot 10^{33} \xi_1 \rho_{18} R_{\text{AU}}^{3/2-s} r_1^2 \text{ erg s}^{-1}. \text{ (20)}$$

For an approach distance of 5 AU, this luminosity becomes observable (i.e. $L_{f,\text{out}} > 10^{34} \text{ erg s}^{-1}$) only if the asteroid radius is $r \gtrsim 190 \text{ km}$. Such large asteroids are rare. Thus asteroids passing Sgr A* at pericenter distances larger than $\sim 1 \text{ AU}$ are unlikely to result in observable flares.

#### 3.4.2 Total destruction of asteroids inside 1 AU

Inside the tidal disruption radius, the asteroid breaks into fragments with sizes smaller than $r_{\text{frag}} \sim 1 \text{ km}$ (cf. [32]). For these smaller asteroid fragments, vaporisation is much more efficient. The incoming remnants heat up, melt and vaporise rapidly. This leads to a decrease in the material tensile strength, allowing further fragmentation due to tidal shear. As a result, most of the asteroid’s mass evaporates during the flyby (cf. equation (19)). We estimate the luminosity as

$$L_{f,\text{in}} = \frac{\xi M_g c^2}{t_{\text{fly}}^2} = 6 \cdot 10^{34} \xi_1 R_{\text{AU}}^{-3/2} r_1^3 \text{ erg s}^{-1}. \text{ (21)}$$

At an approach of 1 AU, this luminosity becomes observable for asteroids of radius $r \gtrsim 10 \text{ km}$. We can also estimate the maximum flare luminosity. If the asteroid mass is larger than the total mass of the gas in the accretion flow inside 1 AU, then efficiency of converting the asteroid’s bulk motion into radiation must be reduced. Even if the massive asteroid is vaporised completely, the mass of the quiescent accretion flow is simply not high enough to stop the evaporated material bodily. The latter would continue on its outward course from the inner 1 AU. A part of the disrupted material comes back to Sgr A* as in the stellar disruption case but with a time delay much longer than the dynamical time in the inner AU. The proper estimate for the luminosity is then much smaller than equation (21) suggests.

This sets an upper limit to the mass of an asteroid that is wholly disrupted and stopped in the inner AU:

$$M_{\text{max}} \lesssim M_g (R < R_{\text{tid}}) \simeq 6.7 \cdot 10^{22} \rho_{18} \text{ g}, \text{ (22)}$$

for $s = 1.23$, yielding radius $r \sim 250 \text{ km}$. The luminosity that an asteroid this massive would produce if it evaporates is

$$L_{f,\text{max}} = \frac{\xi M_g (R < R_{\text{tid}}) c^2}{t_{\text{fly}}} \approx 10^{39} \xi_1 \rho_{18} R_{\text{AU}}^{-3/2} \text{ erg s}^{-1}. \text{ (23)}$$

No flares of this magnitude have been detected so far, but this may be quite reasonable as such large asteroids are expected to be rare.

### 3.5 Summary on asteroid disruption

From the arguments outlined above, we see that any large asteroids passing Sgr A* within $R \sim 1 \text{ AU}$ could be tidally disrupted and efficiently vaporised. If their material is mixed with the background accretion flow, the bulk kinetic energy of their orbital motion around Sgr A* would be deposited into the accretion flow around the SMBH. If the asteroid’s initial radius exceeds $\sim 10 \text{ km}$, this energy deposition might be large enough to produce an observable flare.

Asteroids passing at larger $R$, on the other hand, are not tidally disrupted. Their vaporisation times are longer than the time they spend near the pericenters of their orbits.
Therefore, they lose just a small fraction of their mass. The amounts of mass and energy deposited by such more distant flybys in the inner regions near Sgr A* are small, and thus no bright flares from such passages could be produced.

4 FLARE FREQUENCY AND LUMINOSITY DISTRIBUTION

4.1 The “Super-Oort cloud” of asteroids

(Navakshin et al. 2011) have recently suggested that AGN may be surrounded by several-pc scale clouds of asteroids and planets that have been formed in situ. In this model, star formation episodes take place inside a massive self-gravitating AGN accretion disc (Paczynski 1973; Kolykoval & Syunyaev 1980; Collin & Zahn 1990; Goodman 2003; Paumard et al. 2006; Nayakshin et al. 2007) during gas-rich phases when the super-massive black hole grows rapidly. The AGN disc orientation performs a random walk due to chaotic mass deposition events of individual large gas clouds (as argued by King & Pringle 2002; Nayakshin & King 2003; Hobbs et al. 2011). As a result, a kinematically and geometrically thick cloud of stars surrounds the SMBH over time. The asteroids are then stripped from their parent stars by close passages of perturbers, such as other stars or stellar remnants, or by tidal forces of the SMBH. This creates a geometrically thick torus of asteroids and planets which may be called a “Super-Oort cloud” of SMBH by analogy with the Oort cloud of the Solar System.

To estimate the properties of this cloud as relevant to our goals here, we first consider asteroids at birth of a single star, assuming that their population is not too dissimilar from that found in “debris discs” of nearby stars and the Solar System. Physically, asteroids are remnants of protoplanetary discs and the planet formation process in stellar systems. While the planet formation process is itself not yet understood, we may use observational constraints on the properties of debris discs around nearby stars. Let \( n(r) \) be the differential distribution function of asteroids, so that the number of asteroids with radii between \( r \) and \( r + dr \) is

\[
n(r) dr = n_0 \left( \frac{r}{r_0} \right)^q dr,
\]

where the slope \( q \) can be reasonably expected to vary between \(-3\) and \(-4\), but is probably close to the value \(-3.5\) expected if the asteroid population is the high-mass tail of a collisionally evolved disc (Wyatt 2008). We now calibrate \( n_0 \) by requiring that the total mass of asteroids per star is \( M_{a,t} \):

\[
M_{a,t} = \int_{r_{\text{min}}}^{r_{\text{max}}} M_a(r)n(r)dr \approx \frac{4\pi\rho_a}{3(q+4)} \left(\frac{r_{\text{max}}}{r_0}\right)^{q+4} N_0 \frac{r_0}{r_{\text{max}}}.
\]

where we have assumed that \( q > -4 \), and therefore it is the upper limit of the distribution that is more important. We now find the total number of asteroids with radius \( r > r_X \) per star:

\[
f_a(r > r_X) = \int_{r_X}^{\infty} n(r) dr = \frac{n_0}{r_X^q - q - 1} r_X^{q+1} = \frac{3M_{a,t}}{4\pi\rho_a} \frac{q + 4}{r_X^{q+1}} r_X^{q+1}.
\]

The mass in asteroids/solid bodies per star, \( M_{a,t} \), is not easily constrained at present. First of all, the absolute upper limit for this quantity is the total metal (dust) content of a protostellar disc, which is of the order of \( 10^{-5}M_\odot \) (assuming Solar metallicity and the disc mass of \( \sim 0.1M_\odot \); see also a compilation of dust mass observations in Figure 3 of Wyatt 2008). The minimum mass of the asteroid population, on the other hand, is the mass of dust in debris disc systems. The dust particles in these aged populations are rapidly blown away by the radiation of the parent stars, and must be replenished by a credible source. The collisional cascade that grinds asteroids into the microscopic dust is believed to be such a source. Figure 3 of Wyatt 2008 shows that the dust mass for observed debris disc is of the order \( \sim (10^{-8} - 10^{-7})M_\odot \). The minimum mass of the asteroids in these discs should be at least several orders of magnitude higher.

Given this, we take the total mass of the asteroids per star as a free parameter of the model, setting \( M_{a,t} = 10^{-5}M_\odot \), where \( m_5 \) is a dimensionless parameter which is hopefully not too different from unity. Setting \( r_{\text{max}} = 500 \) km and \( q = -3.5 \) for illustrative purposes, we find

\[
f_a(r > r_X) = 10^3 m_5 \left(\frac{r_X}{500\text{km}}\right)^{q+1} = 2 \cdot 10^7 m_5 r_X^{q+1}. \tag{27}
\]

Thus there are approximately \( 2 \cdot 10^7 \) asteroids per star that may cause observable flares. Assuming the mean stellar mass inside the sphere of influence of Sgr A* is \( \sim 1M_\odot \) gives \( N_\star = 4 \cdot 10^6 \) stars and a grand total of \( N_a \sim 8 \cdot 10^{13}m_5 \) asteroids large enough to cause observable flares with the default parameter values chosen above.

4.2 Event rates

4.2.1 A quick estimate

Before proceeding to more detailed calculations, let us simply assume that the spatial and velocity distribution of asteroids is exactly the same as that of parent stars. As the mean density of a main sequence solar mass star is similar to that of an asteroid, the tidal disruption radius for both is about the same. Given that the expected rate of stellar tidal disruptions in the Galactic Centre is \( N_\star \sim 10^{-5} \text{yr}^{-1} \), the rate for disruption of asteroids is \( \dot{N}_\star \) times the number of asteroids \( (r > 10 \text{ km}) \) per star:

\[
\frac{dN}{dt} \sim \dot{N}_\star f_a \sim 0.6 \text{ day}^{-1} \left(\frac{N_\star m_5}{10^{-5} \text{yr}^{-1}}\right). \tag{28}
\]

We see that we need \( m_5 \gg 1 \) to satisfy the observed flare rates.

We can do an additional sanity check. If the currently observed flaring rate is representative of a long-term quasi-static process, then during the lifetime of the Galaxy, \( t_{\text{Gal}} \sim 10^{10} \text{yr} \), we expect \( N_{\text{tot}} \sim 3 \cdot 10^{12} \) flares to have occurred. This number is smaller than the total number of asteroids \( r > 10 \) km as estimated above, \( N_a \sim 10^{14} \), within the sphere of influence of Sgr A*.

4.2.2 A filled loss cone estimate

In order to make more detailed estimates of the asteroid disruption rates, we need to calculate the evolution of the angular momentum distribution of the asteroid population.
In accordance with our simple model, given that there are $f_a$ “interestingly” large asteroids per star, the number density of asteroids inside Sgr A*’s sphere of influence is

$$n_{ast} = n_* f_a,$$

(29)

where $n_*$ is the number density of stars in the same region.

If the loss cone of the asteroid distribution in angular momentum and energy space is kept full by some process, then the limiting rate of events is given by the estimate of spherical collisionless accretion. Following the derivation in Chapter 14.2 of Shapiro & Teukolsky (1983) (their eqn. 14.2.19), the number accretion rate onto a sphere of radius $R_t = 1$ AU is

$$\frac{dN}{dt} = \frac{2 \pi G M_{\ast} R_t n_{ast}}{\sigma},$$

(30)

where $\sigma \simeq 10^7$ cm s$^{-1}$ is the velocity dispersion in the Galactic bulge. Numerically,

$$n_{ast} \simeq \frac{3 N_*}{4 \pi R_h^3} f_a \simeq 7.6 \cdot 10^{-44} m_5 \ r_1^{q+1} \ \text{cm}^{-3},$$

(31)

where $R_h \simeq 2$ pc is the radius of influence of Sgr A*. The number accretion rate of asteroids onto Sgr A* is then

$$\frac{dN(r > r_*)}{dt} \sim 3.8 \cdot 10^{-4} R_{AU} m_5 \ r_1^{q+1} \ \text{s}^{-1}$$

(32)

$$= 33 R_{AU} m_5 \ r_1^{q+1} \ \text{day}^{-1}. $$

This is a large rate which may not be realistic since it assumes a filled loss cone.

4.2.3 A depleted loss cone rate

If the loss cone is almost empty, then the accretion rate is set by its refilling timescale. The classical loss cone refilling arguments, e.g., Alexander (2005, eqn. 6.11) and references therein, give

$$\frac{dN}{dt} \sim \frac{2 f_a N_*}{\ln(R_h/R_*) t_{coll}(R_h)} \simeq 5 \cdot 10^{-12} f_a \ \text{s}^{-1},$$

(33)

where $t_{coll}(R_h) \approx 4 \cdot 10^9$ yr is the relaxation time at $R_h$. Substituting for $f_a$ from eq. (24) gives

$$\frac{dN(r > r_*)}{dt} \simeq 9.5 \cdot 10^{-5} m_5 \ r_1^{q+1} \ \text{s}^{-1}$$

$$\simeq 8 m_5 \ r_1^{q+1} \ \text{day}^{-1}.$$ 

(34)

This is somewhat smaller than estimate in equation (32).

4.3 Asteroid-asteroid collisions

In the above treatment, we only considered gravitational perturbations of asteroid orbits by stars (asteroids themselves are too small to perturb each other’s orbits gravitationally in the central parsec of the Galaxy). Asteroids do collide bodily with each other, and some of these collisions can lead to what is called a catastrophic collision (e.g., a collision which breaks the asteroid into two or more pieces). Since we are interested in large bodies for which fragmentation conditions depend on self-gravity rather than tensile strength (Wyatt 2008), the size of an impactor that can just shatter an asteroid of radius $r$ is derived from

$$\frac{M_a(r_0) v^2}{2} = G M_a^2(r)/r,$$

(35)

where the subscript ‘i’ stands for ‘impactor’. Expressing mass in terms of asteroid radius gives an expression

$$r_i \sim 1.9 \cdot 10^3 \ r_1^{5/3} v_{100}^{-2/3} \ \text{cm},$$

(36)

where the impactor velocity is parametrised in units of 100 km/s. Now we consider a large asteroid moving with velocity $v_i$ through a stationary cloud of other asteroids. By definition, it sees on average 1 impactor large enough to shatter it in a cylinder of area $\pi r^2$ and length $v t_{coll}$, where $t_{coll}$ is the collision timescale. Since the number density of impactors can be expressed using eq. (24), we have

$$t_{coll} = \left[ f_a(> r_0) n_ s \pi r^2 \ v_i \right]^{-1}$$

$$= 2.1 \cdot 10^9 \ m_5^{-1} \ r_1^{13/6} \ v_{100}^{-8/3} \ \text{yr}.$$ 

(37)

This timescale is longer than the Hubble time for $r > 24$ km. Therefore we see that while some of the smaller asteroids may be destroyed, the largest ones, which also contain the majority of the total mass, are not. Furthermore, the estimate assumes a steady-state collisional fragmentation cascade of the form (24), which may actually turn over at small $r$ if the smaller bodies are removed from the cascade rapidly.

4.4 Flare luminosity distribution

The asteroid number density (eq. 27) may be used to calculate the number of asteroids per star that have mass greater than $M_X$:

$$f_a \left(M_a > M_X \right) = 6 \cdot 10^5 m_5 \left(\frac{M_X}{4 \cdot 10^{15} \text{g}}\right)^{(q+1)/3}. $$

(38)

The observed distribution of flare luminosities follows a $L_{fl} \propto L^\alpha$ law, with $-1 \leq \alpha \leq 0$ (Dodds-Eden et al. 2011), see also (2). Using this, the frequency of flares with luminosity $L_f > L_X$ is

$$N(L_f > L_X) = \int_{L_X}^{\infty} N_L dL \propto LNL \propto L^\alpha.$$ 

(39)

Since the luminosity of a flare from an asteroid of mass $M_X$ is proportional to $M_X$ in our model, we can convert the asteroid mass distribution into flare luminosity distribution:

$$N(L_f > L_X) \propto L_X^{(q+1)/3},$$

(40)

where the value of the exponent varies between $-2/3$ (for $q = -3$) and $-1$ (for $q = -4$). This is within the observationally constrained range of $\alpha$ (Dodds-Eden et al. 2011).

Flares with luminosity $L_{fl,x} = 10^{34} L_{34}$ erg s$^{-1}$ correspond to

$$r \sim 10 \xi_3^{-1/3} R_{AU}^{1/2} L_{34}^{1/3} \text{km}.$$ 

(41)

Using eq. (34), we normalize the flare luminosity distribution, and obtain, for $q = -3.5$ as the likely value,

$$N \sim 8 m_5 L_{34}^{-5/6} \ \text{day}^{-1}.$$ 

(42)

The brightest flare seen so far has $L_X,_{max} \sim 10^{36}$ erg s$^{-1}$ requiring $r \gtrsim 45$ km, which corresponds to $N \sim 0.2$ day$^{-1}$. The total duration of Chandra observations of Sgr A* is $t_{obs} \sim 1.4$ Msec, so we expect it to have seen $N \lesssim 3.5$ flares of this magnitude or brighter, which is not too far off from the one flare per day actually observed.
5 PLANET DISRUPTIONS

Although much less frequent, planet disruptions may also occur near Sgr A∗. Their frequency is probably comparable to that of stellar disruptions, e.g., one per ∼106 yrs (Alexander 2003), if we assume one planet per star on average. Consider now a gas giant planet passing within 1 AU of Sgr A∗. Its disruption is quite analogous to that of a star. The most bound disrupted material is on an orbit with a semimajor axis (cf. eq. 4)

\[ a_p \sim R \frac{v_e}{\nu_{esc,p}} \sim 2 \times 10^3 \text{AU} \sim 0.01 \text{pc}, \]

where \( v_{esc,p} \) is the escape velocity from the planet’s surface (∼60 km/s for a Jupiter mass body). The bound debris returns back to the vicinity of Sgr A∗ after a time

\[ P_{orb} \sim 2\pi \sqrt{\frac{a_p^3}{GM_{BH}}} \sim 30 \text{yr}. \]

The maximum fallback rate is thus \( M_{\text{back}} \sim 10^{-5} M_\odot/(30\text{yr}) = 3 \times 10^{-5} M_\odot \text{yr}^{-1} \). This rate is significantly larger than the estimated current quiescent accretion rate onto Sgr A∗, \( M \sim 10^{-8} M_\odot \text{yr}^{-1} \). Conceivably one could expect Sgr A∗ to brighten by multiple orders of magnitude for ∼tens to a hundred years. The maximum bolometric luminosity is obtained assuming the radiatively efficient conversion of accretion energy into radiation:

\[ L_{\text{back}} \leq 0.1 c^2 M_{\text{back}} \sim 2 \times 10^{41} \text{ergs}^{-1}. \]

The order of magnitude of this luminosity and the flare duration (tens of years) are within that inferred to have occurred some ∼300 yrs ago, when Sgr A∗ was apparently as bright as \( \sim 10^{39} \text{ergs s}^{-1} \) in X-rays (Revnivtsev et al. 2003; Terrier et al. 2010). We speculate that tidal disruption of a rogue gas giant planet could account for that activity episode.

6 EMISSION MECHANISMS

A detailed modeling of the emission from the vaporised material mixed with the background flow is beyond the scope of our paper due to many physical uncertainties (such as the role of magnetic fields along the interface between the vaporised tail and the ambient gas). However, it is possible to rule out several potential emission mechanisms and point out the most promising scenario under which tidal disruption of asteroids could produce the spectra consistent with those observed.

6.1 Asteroid disruptions are not ”accretion rate” flares

The simplest view on emission from asteroids is that they bring in an additional mass to the inner accretion flow onto Sgr A∗. The transient enhancement in the accretion rate onto Sgr A∗ could then make it temporarily brighter. However, in (3.1.2) we pointed out that the mass of the background quiescent accretion flow onto Sgr A∗ inside 1 AU is \( \sim 10^{21} \text{g} \) based on the model of Yuan et al. (2003). This is \( \sim 3 \) orders of magnitude heavier than the typical asteroid mass that we considered here (see 3.1.2). The mass added by an asteroid to the region within 1 AU is simply too small to make an accretion powered flare unless the asteroid’s diameter is about 500 km, which must be a very rare event. Therefore, if asteroid tidal disruptions are to be observable, they are to be accompanied by production of particles emitting differently (more efficiently) than the background radiatively inefficient accretion flow.

This is consistent with observational constraints on the flares. Markoff et al. (2001) have shown that constraints on the absence of significant variability in the radio emission of Sgr A∗ suggest that during the flares it is not the magnetic field but rather the energy distribution of emitting particles that vary. This conclusion rules out accretion-powered flares as the mean magnetic field is expected to be proportional to the flow pressure and thus density. Similarly, Yuan et al. (2004) found that infrared flares from Sgr A∗ are best explained by assuming that a small fraction of electrons in the flow (e.g., a few percent) is accelerated into a non-thermal power-law tail.

6.2 Thermal radiation from the asteroid’s tail

One new population of particles, compared with the very hot \( T \sim 10^{11} \text{K} \) quiescent accretion flow, is in the vaporising asteroid’s ejecta while it is still relatively cold, i.e., \( T \sim T_X \sim 10^4 \text{K} \) (cf. 3.3). The ejecta has initially a much higher density than the ambient medium and must expand into the latter as it heats up. The evaporating coma is probably shaped as a conical tail behind the asteroid. Since the surface area of the tail is much larger than the asteroid itself, the tail should be much brighter than the asteroid’s face, and perhaps observable from Earth. Its emission can be approximated as thermal, since the thermalisation timescale of electrons in the coma is (e.g., Stepney 1983) less than 1 s. The bolometric luminosity of the emission emanating from the tail is

\[ L_{\text{bb}} \simeq A \sigma_{SB} T_{\text{tail}}^4 \frac{\tau}{\tau + 1}, \]

where \( \tau \) is the optical depth in the direction perpendicular to the tail and \( A \) is the surface area of the tail. The optical depth, \( \tau \), is

\[ \tau \sim \kappa \rho_{\text{tail}} r_{\text{tail}}, \]

with \( \kappa \equiv 10 \kappa_1 \) the opacity of the material. Assuming \( A \sim \pi r_{\text{tail}}^2 h_{\text{tail}} \), where \( r_{\text{tail}} \) and \( h_{\text{tail}} \gg r_{\text{tail}} \) are the base radius and height of the cone, we note that

\[ A \tau = \kappa \rho_{\text{tail}} \pi r_{\text{tail}}^2 h_{\text{tail}} \sim \kappa M_{\text{tail}}, \]

where \( M_{\text{tail}} \lesssim M_a \) is the mass of the tail. The maximum thermal luminosity from the evaporating ejecta is achieved if the tail is moderately optically thin, \( \tau \lesssim 1 \), and is

\[ L_{\text{bb,max}} \simeq \kappa M_a \sigma_{SB} T_{\text{tail}}^4 \simeq 2 \times 10^{31} \kappa_1 r_1^3 \left( \frac{T_{\text{tail}}}{10^4 \text{K}} \right)^4 \text{erg s}^{-1}. \]

This value is significantly smaller than the quiescent NIR luminosity of Sgr A∗. Further, the blackbody spectrum for \( T_{\text{tail}} \sim 10^4 \text{K} \) peaks in the UV, where extinction is very large. In the NIR frequencies, where Sgr A∗ line-of-sight is less obscured, the tail emits in the Rayleigh-Jeans regime and hence is far dimmer than the bolometric luminosity estimate above. Summing this up, we conclude that direct thermal
In this paper we considered the fate of asteroids passing Sgr A* in radio and sub-mm wavelengths just before a flare (Yusef-Zadeh et al. 2010).

6.3 A new relativistic population of particles?
The particles in the asteroid’s tail do have a very different velocity distribution compared with that of the background flow. The initial velocities of the ions in the tail are strongly dominated by the bulk motion inherited from the initial asteroid’s orbit around Sgr A*. This velocity is somewhat larger than the ion sound speed of the accretion flow (for a hot quasi-spherical inflow the sound speed is of the order of the local Keplerian speed).

When the vaporised tail particles get mixed with the accretion flow particles, we get a very anisotropic velocity distribution. Therefore we expect a number of plasma instabilities to operate while the ions and electrons of the vaporised material are assimilated into the hot Sgr A* accretion flow. If non-thermal electrons reach equipartition with the shocked ions as in the models of gamma-ray bursts (e.g. Meszaros et al. 1994), their maximum γ-factors could be as large as $(GM_{\ast}/c^2 R)(m_i/m_e) \sim 0.1 m_i/m_e$, where $m_i$ and $m_e$ are the ion and electron mass respectively. Even for $m_i = m_e$, inside the inner AU this factor exceeds 100.

It is thus likely that a disrupted asteroid produces a transient population of high energy electrons along its original trail. This population should cool by radiative emission and mixing with the background. Without going into a model-dependent characterisation of these processes, we only note that a tidal disruption event may plausibly give rise to the hot particle distributions needed in the scenarios of transient plasma blob based flare emission (e.g. Trap et al. 2011). We feel that this scenario of converting asteroid’s bulk energy into radiation is by far the most promising one to produce spectra resembling Sgr A* flares.

7 DISCUSSION AND CONCLUSIONS
In this paper we considered the fate of asteroids passing Sgr A* within a few AU on nearly radial orbits. As noted in the Introduction, we are unable to make detailed spectral predictions at this time, but we do obtain interesting constraints on the energetics, bolometric luminosity and frequency of flares powered by tidal disruption of asteroids. We give a short summary of our results and model predictions here.

The physical picture of an asteroid disruption near Sgr A* has two stages. Firstly, the asteroid is tidally disrupted if it enters the inner ~ 1 AU region, where it is broken into smaller fragments bound by molecular forces rather than gravity. These fragments are probably less than a few hundred meters in radius. The second stage of the disruption is evaporation of these smaller fragments by heat released due to aerodynamic friction of the fragments on the quiescent accretion flow new Sgr A*. The bulk kinetic energy of the asteroid is sufficient to power an observable flare if the asteroid’s radius is greater than about 10 km. We then estimated the asteroid disruption events rate based on the assumption that the number of asteroids per star is reasonably large and is of the order of that inferred from nearby stars.

Our model makes the following predictions:
1. The small size of the flaring region, $R_f \lesssim 10R_3 \sim 1$ AU. This is the tidal disruption radius for a typical asteroid. Bodies passing Sgr A* outside this radius lose some mass by vaporisation of the outer layers, but the amount of such a mass loss is too small to give a detectable flare (cf. 3.5).
2. Frequency of flare occurrence is given by the rate at which asteroids from the "Super-Oort" cloud in the inner parsec (Navakshin et al. 2011) are deflected onto low angular momentum orbits that bring them within the tidal disruption radius. For fiducial numbers, our model yields a reasonable agreement with the observations (eq. 39). This estimate however sensitively depends on the poorly constrained normalisation factor $m_5$ (equation 41).
3. The model naturally predicts a wide range of flare luminosities due to a range in asteroid sizes. Under the assumption that flare luminosity is proportional to the mass of the asteroid disrupted, we also find that the luminosity-frequency relation for flares is within observational constraints (eq. 39).
4. Extending the model to tidal disruption of gas giant planets predicts rare but much brighter flares. One such event may have produced the AGN-like flare of Sgr A* ~ 300 years ago (15).
5. The flare frequency in our model is given by the supply of asteroids rather than by the properties of the hot quiescent flow. Therefore, we would expect no strong correlation between the quiescent properties of Sgr A* spectrum and the occurrence of flares (that is, if Sgr A* quiescent emission were to brighten or dim by a factor of a few in the next few years, we would not expect the rate of flaring to be affected). A weak correlation may be expected if the luminosity–asteroid mass relation is not quite linear as assumed here.
6. We also note that asteroid disruption flares from exceptionally large asteroids may be observable from nearby galactic nuclei. Equation 42 predicts that a flare with $L \sim 10^{39}$ erg s$^{-1}$ would occur every few years at best. However, for a large enough sample of sources such events may be detected in dormant nearby galactic nuclei.
7. The external origin of the flare trigger provides a way to test this model. Markoff (2002) showed that in the flaring state, Sgr A* sits on the Fundamental Plane of radio and X-ray luminosities for black holes (both stellar mass and supermassive). The Fundamental Plane is thought to arise due to accretion physics, so if the flares are caused by accretion instabilities of any kind, flares more luminous than $L_X \sim 10^{36}$ erg s$^{-1}$ should be accompanied by a corresponding increase in radio luminosity, with a possible lag of months to years. On the other hand, asteroid-induced flares should not exhibit this correlation, at least not up to luminosities $L_{f,\text{max}} \sim 10^{39}$ erg s$^{-1}$ (eq. 29), when the asteroid mass becomes comparable to the gas mass in the quiescent flow. Future long-duration observational campaigns of Sgr A* may thus help distinguish between differing flare scenarios.
The least constrained parts of the model have to do with the exact distribution of asteroids and their orbits in the hypothesised "Super-Oort cloud" around Sgr A*, and with conversion of the bulk kinetic energy of the asteroids into electromagnetic radiation. However, there almost certainly are asteroids in the central few pc of the Galaxy and the processes described here must occur. Our paper makes several estimates of the effects that asteroids have on the luminosity of Sgr A* and suggests a method to distinguish between such externally caused flares and accretion-instability caused ones. If future observations reveal that asteroid disruptions are responsible for at least a fraction of the flares, this would be an important step in understanding the accretion processes in Sgr A*. In addition, further investigation may help constrain the size of the asteroid population in the Galactic centre.

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Sgr A* flares: tidal disruption of asteroids and planets?