Nature of the NIR and MIR flares in Sgr A*

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1. Introduction

Sgr A* is a faint but highly variable source. X-ray flares were first detected by Baganoff et al. (2001) using Chandra data. A strong flare, exceeding the quiescent emission by a factor of ~45, lasted for about 3 hours.

First clear detections of variability and flaring activity in the mm/sub-mm band were reported in the early 2000s (e.g. Zhao et al. 2003; Bower et al. 2002–2004). At a similar time, near-IR variability was discovered (2003; Genzel et al.; Ghez et al.).

This variability implies that the emission originates in a compact region close to the black hole, in contrast to the slower radio variability observed at cm wavelengths already in the 1980s. Flares are commonly interpreted as synchrotron emission with a possible synchrotron self-Compton (SSC) component, often associated with expanding plasma blobs.

2. Current state of the observations

Sgr A* flares are now routinely observed across the electromagnetic spectrum, from radio to X-rays, and occasionally even in the mid-infrared. They are characterized by rapid variability, broad luminosity distributions, and multiwavelength correlations. Their properties are summarized in the Table below.

Band	Timescale	Frequency	Amplitude	Energy / Luminosity
X-ray	minutes – few hours (moderate flares)	~1/day	up to ×100–600	~10^{34}–10^{35} erg/s
Near-IR	~1–2 h (substructure ~15 min)	several per day	× few–10	~10^{34}–10^{35} erg/s
mm / sub-mm	hours	delayed by ~1–3 h vs IR/X-ray	tens of %	lower energy output
Radio (cm)	days–years	continuous variability	~10–50%	quiescent-dominated affected by scintillation
Mid-IR (NEW)	~40 min rare detections	—	synchrotron	first detection with JWST

3. Stationary accretion model

We first analyze the case of a stationary flow onto the central black hole, since the emissivity of Sgr A* averaged over days-months remains on a roughly constant level. This implies that the outer boundary condition provide roughly be a constant flow of the material, and only small perturbations of those conditions may grow inwards and lead to observed strong variability.

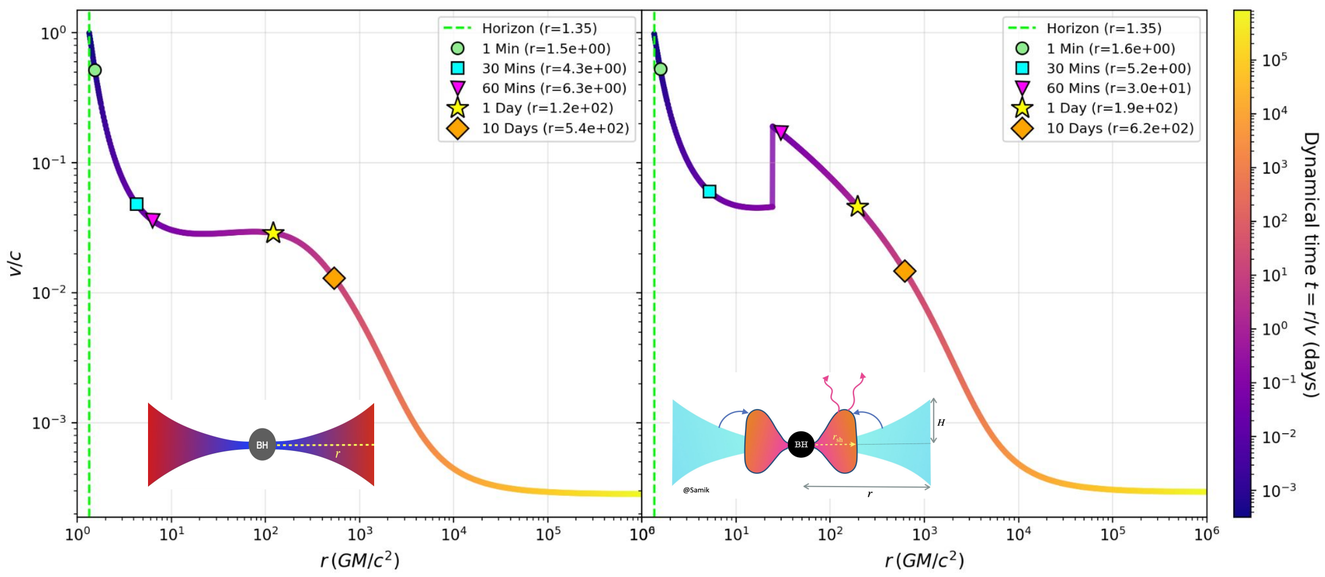
The mysterious accretion of matter around our Galactic centre is believed to happen through the winds coming from the orbiting Wolf-Rayet stars. Hence, the choice of low-angular momentum, quasi-spherical flow is a fairly good approximation (Mitra et al. 2022, 2024). Further, the flow is considered to be steady, axisymmetric, and magnetized. Here, the magnetic fields (radial and toroidal) are considered to be frozen in the plasma, following the ideal MHD condition. To obtain the fluid variables, we solve the conservation equations:

$$\nabla_\mu(\rho u^\mu) = 0; \quad \nabla_\mu T^{\mu\nu} = 0; \quad \nabla_\mu {}^*F^{\mu\nu} = 0.$$

Further, we assume that the motions along the off-equatorial direction is negligible, and the fluid variables become a function of the radial distance (r) only. Also, in our model, we consider a radially varying adiabatic index to mimic the temperature variations within the accretion disk.

4. Timescales in the stationary flow

The stationary flow can lead to evaluation of the local timescales simply from the radio of the local radius divided by the radial velocity. In Figure 1, we show the velocity profile of the flow around a black hole with mass 4.2e6 M⊙ and spin 0.94, with the characteristic timescales from minutes to hours for shock-free (left) and for the shock-induced solution (right).

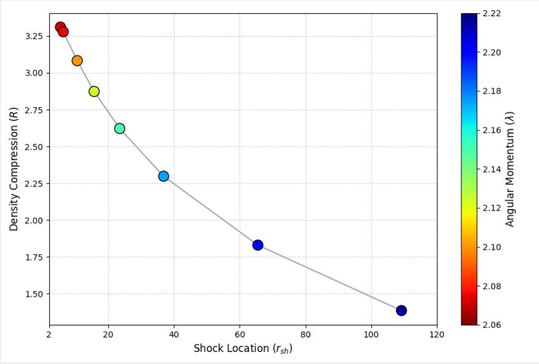


We can interpret near-IR flares as happening at distances about 10 of r_g. Longer timescales (1 day) could be identified with the distance about 100 r_g. However, lack of time delays implies that it is just a perturbation which happens at 100 r_g and propagates inwards, and the emission forms closer in, when strong perturbation there leads to a strong shock. Emission in mm band is basically a delayed/smeared version of near-IR, likely coming from outflowing and expanding medium.

5. Shocks

In our model, we also find the trans-magnetosonic accretion solutions which shows standing shock formation in the inner parts of the disk. This naturally helps in producing hot, puffed up inner disk, like ADAF. Due to the continuous competition between the gravitational and centrifugal forces, the matter slows down near the shock front (the vertical jump at ~24.19 r_g), where density begins to clump, and a hot-electron reach corona forms.

Such shocks can be the source of the X-ray emission, if they are strong enough to accelerate particles. The continuous solution presented above, with the accretion rate $5e^{-8}$ M⊙/year and typically adopted efficiency of 10^{-6}, provides the mean quiescent luminosity of $2e^{33}$ erg/s. Shock formed at 24 r_g can give the locally emitted X-ray flux of $7e^{34}$ erg/s, if the energy related to the velocity drop is converted to non-thermal emission with efficiency of 10^{-4}. Shock formation and disappearance requires very modest change of the angular momentum of about 5%, which is expected from stellar wind powered inflow. Shocks form generally between 5 and 120 r_g (Mitra et al. 2024), closer in they are not expected. Thus, near-IR flares are of different origin, related to the magnetic field, through magnetic field reconnection, temporary formation of the MAD states, or both.



In this figure we show the position of the shock as a function of the radius when the angular momentum of the infalling material changes. Notably, strong shocks (R>3) form closer to the black hole, having higher density compression (R).

We plan to estimate the shock emission as functions of the flow parameters, and to compare it with the observed statistics (e.g. Neilsen et al. 2015).

5. Summary

X-ray emission likely comes from the dynamical shocks in low angular momentum, while near-IR emission is most likely of magnetic origin.

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Take home: X-ray flares are likely driven by shocks in the accretion flow, while near-IR flares originate from magnetic reconnection in the innermost region.