IS SGR A*

UNDERFED, UNDEREFFICIENT, OR UNDERDONE ?

Why the Milky Way Galaxy Is NOT a Seyfert Galaxy ?

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Abstract. We argue that the wind from IRS 16 and He I stars in the central 1 pc of the Galaxy is responsible for the peculiar features of accretion onto a putative black hole at the Galactic center. What makes Sgr A* unique is not that it is just underfed but, in addition, it has a much lower efficiency of accretion and possibly a lower mass, compared to the AGN case.

1. Starvation Paradox of the Galactic Center

The Galactic center used to be considered a scaled-down version of active galactic nuclei (AGN), and Sgr A* – as a template for nuclear 'engines', presumably massive black holes (BHs). A drastic difference with AGN can be seen by evaluating the ratio of the total accretion luminosity of Sgr A* , L_{ac}, to the inferred Eddington luminosity, L_{Edd}:

$$\frac{L_{ac}}{L_{Edd}} \lesssim 4 \cdot 10^{-5} \left(\frac{M_h}{10^6 \ M_\odot} \right)^{-1} \ll 1, \qquad (1)$$

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whereas for AGN this ratio is thought to be much closer to unity. In evaluating Eq. (1), we assume $L_{ac} = L_{obs}$, the total observed luminosity, for which only a rough upper limit of $L_{obs} \lesssim 5 \cdot 10^{39}$ erg/s (Zylka *et al.* 1994) is available so far. The difference between Sgr A* and AGN might similarly be emphasized by evaluating the inferred dimensionless accretion rate

$$\frac{\dot{M}_{ac}}{\dot{M}_{Edd}} \lesssim 4 \cdot 10^{-3} \left(\frac{\epsilon}{0.1}\right)^{-1} \left(\frac{M_h}{10^6 \, \mathrm{M}_\odot}\right)^{-1} \ll 1, \qquad (2)$$

where ϵ is the accretion efficiency. The small value of the l.h.s. in Eqs. (1) or (2) is what is usually meant by the "starvation" of the Galactic-center BH (Falcke & Biermann 1994). However, this is only part of the story! Paradoxically, the inflow rate into the central 10 pc or so is not small at all: $\dot{M}_{inflow} \simeq 10^{-2}$ $\mathrm{M}_\odot$/yr (Blitz *et al.* 1993, Genzel *et al.* 1994). This implies

$$\frac{\dot{M}_{inflow}}{\dot{M}_{ac}} \gtrsim 10^4 \left(\frac{\epsilon}{0.1}\right) \left(\frac{M_h}{10^6 \, \mathrm{M}_\odot}\right) \gg 1, \qquad (3)$$

in a sharp contrast with Eq. (2). Thus the "starvation paradox" can be formulated in this way: why is the Galactic-center BH accretion luminosity so weak although the feeding rate does not seem to be small?

2. Possible Routes to Solve the Problem

Eqs. (1) - (3) include three poorly known quantities – $\dot{M}$, ϵ, and M, *i. e.* accretion rate, accretion efficiency, and black hole mass. Accordingly, three principally different routes are possible to resolve the starvation paradox:

- $\dot{M}_{ac} \ll \dot{M}_{inflow}$ **(a True "Starving Monster")**
- $\frac{\epsilon}{0.1} \ll 1$ **(a Low Efficiency)**
- $M_h \ll 10^6$ $\mathrm{M}_\odot$ **(a Smaller Black Hole Mass)**

The last two options have been widely discussed in literature. A very low efficiency, $\epsilon \ll 0.1$, is known to occur in the conditions of quasi-spherical accretion when the inflow time might become much shorter than the radiation cooling time (Ipser & Price 1982, Chakrabarti 1990, Narayan *et al.* 1994). This results in advection of an appreciable part of the energy released in due course of accretion and therefore in a low output of accretion luminosity. If the feeding of Sgr A* is provided by accretion of the wind from IRS 16 (Ozernoy 1989, Melia 1992, Ozernoy 1993) this proceeds in a quasi-spherical fashion as a Bondi accretion with a very low efficiency. Furthermore, a low BH mass, $M \ll 10^6$ $\mathrm{M}_\odot$, would also weaken inequalities in Eqs. (1) - (3); for a review of this option, see Ozernoy (1994a,b) and refs. therein.

Whichever case – a low ϵ, or a low M, or both – takes place, it seems impossible for Sgr A* to have $\dot{M}_{ac}$ as large as $M_{inflow} \simeq 10^{-2}$ $M_\odot\,\mathrm{yr}^{-1}$, otherwise in order L_{ac} not to exceed $L_{obs} \lesssim 5 \cdot 10^{39}$ erg/s the accretion efficiency should be $\epsilon \lesssim 10^{-6}$, which is unlikely. Therefore, one of the central issues to resolve seems to be the origin of a strong inequality: $\dot{M}_{ac} \ll \dot{M}_{inflow}$.

Two specific mechanisms could, in principle, explain a vast difference between $\dot{M}_{ac}$ and $\dot{M}_{inflow}$: (i) a low transport rate of angular momentum in the CNR and (ii) the wind from IRS 16 + He I stars. The next two sections discuss these mechanisms in detail.

3. Transport of Angular Momentum in the CNR

An issue to be addressed first is whether the above mentioned gas inflow into the central 10 pc with the rate $10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$ can be transferred inward and, if so, with what rate. Between $r \sim 10$ and $r \sim 1.5$ pc the rotating molecular 'circum-nuclear ring' (CNR) is located, which consists of many magnetized clumps. Two basic mechanisms contribute to the transfer of angular momentum: turbulent viscosity and magnetic stresses ("magnetic viscosity"). The net mass inflow rate is given by (Ozernoy & Genzel 1994, Ozernoy, Fridman, & Biermann 1994):

$$\dot{M} = \frac{2\pi r}{v_\varphi}\Sigma\left(\xi v_A^2 + \nu_{\mathrm{eff}}\Omega\right)\left[1 - \left(\frac{R_i}{r}\right)^{1/2}\right]^{-1}, \tag{4}$$

where $v_\varphi \simeq 110$ km s^{-1} is the rotational velocity, $\Sigma \simeq 2\cdot 10^{-2}$ g cm^{-2} is the CNR surface density, $\xi \sim 1$ is the $(-B_r/B_\varphi)$ averaged over z-coordinate, $v_A \simeq h\Omega \simeq 30$ km/s is the Alfven velocity, $\nu_{\mathrm{eff}} \simeq 1\cdot 10^{24}$ cm^{2}s^{-1} is an effective viscosity in the clumpy CNR, and $R_i \simeq 1.5$ pc is the inner radius of the ring. Eq. (4) yields $\dot{M} \simeq 10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$ at a fiducious distance of $r = 2$ pc, *i. e.* the value of the same order of magnitude as the infalling mass rate. Therefore the CNR cannot be responsible for any drastic reduction of the accretion rate compared to the inflow rate entering Eq. (3). Moreover, the inflow rate as high as about $10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$ can be traced down to the distance of 1 pc or so from Sgr A* as it follows from the presence of clumps like the "Tongue" at such distances (Genzel *et al.* 1994). Thus of the two alternative sites, where a substantial reduction in $\dot{M}$, from $\dot{M}_{inflow}$ to $\dot{M}_{ac}$, might occur – the CNR and the central wind – the first one is ruled out. Let us address the second option.

4. Wind from IRS 16 + He I Stars

Considerations of momentum and energy balances in the inflowing gas and in the central wind produced by the IRS 16 and He I stars in the inner 1 pc demonstrate that this wind creates an effective obstacle for the high-rate mass inflow from the CNR (Genzel *et al.* 1994, Ozernoy & Genzel 1994). In respect to the central black hole, the role of the wind is two-fold: On one hand, outflow of momentum and energy with the wind is able to shrink substantially the inflow thereby suppressing a high accretion rate. On the other hand, the wind itself serves as a source of accretion onto the BH as a Bondi accretor, which intercepts a part of the wind at the rate that depends on the BH mass as well as on the density, n_w, and velocity, v_w, of the wind far from the BH:

$$\dot{M}_{ac} \simeq 3 \cdot 10^{-5} A M_6^2 \ \frac{\mathrm{M}_\odot}{\mathrm{yr}}; \ A \equiv \frac{n_w}{10^4 \ \mathrm{cm}^{-3}} \left(\frac{v_w}{700 \ \mathrm{km/s}} \right)^{-3} . \tag{5}$$

Besides the energy-momentum arguments, there is one more, although indirect, evidence that the accreting gas is intercepted by Sgr A* as a BH from a local wind and does not result from an inflow through the CNR: Indeed, if the accreting gas originated in the CNR, it would possess a huge angular momentum and form an extensive disk around Sgr A* , which is not seen. There are serious reasons to believe that the accretion onto Sgr A* proceeds in a quasi-spherical fashion, which could explain the origin of its radio (Melia 1992, Ozernoy 1993) and X-ray emissions (Mastichiadis & Ozernoy 1994).

Meanwhile the orbital velocities of IRS 16 and He I stars are responsible for a non-zero net angular momentum of the wind although, due to the unknown character of those orbits as well as non-homogeneity and velocity gradients in the flow, it would be rather difficult to evaluate how large it is. Moreover, a significant part of the angular momentum might dissipate and be cancelled in the post-bowshock region (Ruffert & Anzer 1994). As a result, it is yet unclear whether the residual angular momentum of the accretion disk formed from a part of the quasi-spherical flow would be Keplerian or sub-Keplerian. Still, it is instructive to compare the expected parameters of a Keplerian disk around Sgr A* in the two cases – with and without the wind at the Galactic center. In the next section, we make this comparison.

5. What if there were no wind available...

Although this section serves mainly for illustrative purposes, its starting point seems to be rather firm: an accretion disk around Sgr A*, both at the present time and at a time when there were no mass-losing massive stars in the Galactic center, is expected to be magnetized. (This assertion hardly needs to be substantiated here, given the well-known facts that the winds from massive stars are known to contain magnetic fields *and* that the CNR possesses a strong magnetic field as well). Therefore the structure of the accretion disk should be dominated by magnetic stresses rather than by viscosity. Using the recent models of magnetized accretion disks (e.g. Field

& Rogers 1993), we estimate below the parameters of the accretion disk around Sgr A* under different conditions (Ozernoy & Genzel 1994).

5.1. SGR A* AT A HYPOTHETICAL SEYFERT PHASE

If there were no wind from IRS 16 and He I stars, it would be a continuous inflow of matter from the CNR down to the accretion disk (AD) around Sgr A* with the rate $\dot{M} \simeq 10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$. A link between the parameters of the CNR and AD could be easily established and the accretion luminosity of the central black hole would be straightforward to evaluate. In particular, the toroidal magnetic field in the disk midplane at the radius $R_{1/2} = 3.6 \cdot 10^{12}\ M_6$ cm, where half of the disk luminosity is produced, is given by $B_0 \simeq 10^5\ \left(\frac{L_{43.7}}{M_6^2}\right)^{2/5}$ G. The total accretion luminosity is expected to be $L \simeq 5 \cdot 10^{43}$ erg/s, which is of the order of a typical Seyfert luminosity.

5.2. SGR A* IN ITS PRESENT STATE

Fortunately we live in a much more quiescent and quiet environment! And this is thanks to the wind in the Galactic center, which prevents the accretion rate onto the central black hole from being as high as the above inflow rate. Although the BH is able to intercept a part of that wind, which results in the accretion rate given by Eq. (5), the accretion disk turns out to be meager. The bulk of accretion luminosity is produced by a quasi-spherical accretion, whose efficiency is very low, which makes the entire situation drastically different from what would happen in the absence of the wind. In particular, the wind-induced accretion rate results in the accretion luminosity $1.5 \cdot 10^{41} \epsilon_{-1} M_6^2$ erg/s, where the efficiency of accretion $\epsilon_{-1} \equiv \epsilon/0.1 \ll 1$. The magnetic field in the corona around the disk is estimated to be $B_c \simeq 2 \cdot 10^2\ \frac{L_{39.7}^{1/2}}{M_6}$ G.

6. Conclusions

If the current paradigm about Sgr A* as an accreting BH is correct, there is an important feature that makes the center of our Galaxy unlike any active galactic nucleus. The feature is *not* that the Galactic center is just a *micro*-quasar (as its total luminosity hardly exceeds 10^{-6} of a Seyfert galaxy's emission). The basic difference with an AGN is that the Sgr A* luminosity is substantially lower than the inferred Eddington luminosity as shown by Eq. (1). We suggest three possible options to explain that difference, *viz.* a low accretion rate $\dot{M}$, a low efficiency ϵ, and a low BH mass M. In other words, is Sgr A* underfed, underefficient, or underdone ?

In this paper, we have explored why an otherwise high inflow rate of $\sim 10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$ into the central 10 pc or so turns out to be much higher than the inferred accretion rate [see Eq. (3)]. The following specific results discussed above are worth mentioning:

- Magnetic + turbulent transport of angular momentum in the circumnuclear ring (CNR) allows $\dot{M} \simeq 10^{-2}\ \frac{M_\odot}{\mathrm{yr}}$ down to $\lesssim 1$ pc.
- Strong wind from IRS 16 + He I stars prevents further accretion with such a high rate onto Sgr A* .
- However, the black hole acting as a Bondi-Hoyle accretor intercepts a part of this wind, which results in the accretion rate $\dot{M}_{ac} \simeq 3 \cdot 10^{-5}\ AM_6^2\ M_\odot\,\mathrm{yr}^{-1}$, depending upon the BH mass $M = 10^6 M_6\ \mathrm{M}_\odot$.
- Along with a quasi-spherical accretion flow, a magnetized accretion disk emerges, which has $B \sim 10^3$ G. The structure, radiation, and evolution of the magnetized disk differ substantially from a standard viscous disk.

Thus Sgr A* is definitely underfed in a sense that, in the absence of central wind, the accretion rate would be the same as the inflow rate from the CNR, $M_{inflow} \sim 10^{-2}\ M_\odot\,\mathrm{yr}^{-1}$, which greatly exceeds the expected feeding rate given above. The wind that is responsible for such a "confinement diet" could provide the total accretion luminosity of Sgr A* to be as high as $1.5 \cdot 10^{41} \epsilon_{-1} M_6^2$ erg/s. Therefore, even if the accretion efficiency and the BH mass were as high as, correspondingly, $\epsilon_{-1} \sim 1$ and $M_6 \sim 1$, then in this wind-fed "starvation" case the Sgr A* luminosity would be comparable with that of some AGN, which is clearly not the case. Therefore the starvation of the BH at the Galactic center seems to not be the entire story: besides being underfed, the BH should also be either underefficient ($\epsilon_{-1} \ll 1$) or underdone ($M_6 \ll 1$), or both. In any case, the small value of the factor $\epsilon_{-1} M_6^2 \ll 1$ is what technically makes Sgr A* underluminous compared to the AGN situation if the accretion rates were the same.

The efficiency issue seems to be straightforward: as discussed in Sec. 4, the wind accretion onto Sgr A* is quasi-spherical and hence its efficiency is very small indeed, as it follows from the accretion models of the Sgr A* radio and X-ray luminosities. Meanwhile in the AGN case, at least for Seyfert galaxies and QSO's, accretion is usually assumed to have a disk character and hence to possess $\epsilon_{-1} \sim 1$.

It remains to be seen whether a very small efficiency is the only cause which makes Sgr A* underluminous or a smaller than $\sim 10^6\ \mathrm{M}_\odot$ mass of this source needs to be incorporated as well. Several methods to evaluate the actual mass of this enigmatic source have been recently reviewed in Genzel *et al.* (1994) and Ozernoy (1994). We would like to emphasize the importance of the direct methods proposed in those papers, such as the measurements of proper motions of stars *and* the radio emitting plasma blobs in the Sgr A* vicinity. Besides, further constraining or detecting the infra red luminosity of Sgr A* would be very helpful for constraining its mass.

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