to appear in “Jets from Stars and Galactic Nuclei”, W. Kundt (ed.)
Springer Lecture Notes

THE MISSING X-RAYS IN SGR A*: EVIDENCE FOR A SUPERMASSIVE BLACK HOLE IN THE GALACTIC CENTER

Heino Falcke [1] [2], Peter L. Biermann [1]

[1]Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[2]Deptartment of Astronomy, University of Maryland, College Park, MD 20742-2421, USA, email: hfalcke@astro.umd.edu

Abstract: We present a simple argument that the missing x-ray flux from the Galactic Center source Sgr A* ist not evidence *against* – as claimed by Goldwurm et al. 1994 – but rather indirect evidence *for* the presence of a supermassive black hole. The radio spectrum provides a strict *lower* limit for the size of Sgr A* ($R > 3 \cdot 10^{11}$cm). A more compact source would be completely synchrotron self-absorbed. This size is 10^6 times larger than a stellar-mass black hole, yet the bolometric radio luminosity is comparable to or even larger than the x-ray luminosity where matter accreting onto a *stellar-mass* black hole would inevitably radiate the *bulk* of its luminosity. Hence, either the bulk of the accretion power is radiated in the UV (where the limits are higher), or the accretion has to stop at the radio-scale to avoid producing x-rays brighter than the radio emission. Both would be a natural consequence of a supermasive black hole with $\sim 10^6 M_\odot$.

1. Introduction

SIGMA/GRANAT observations recently showed (Goldwurm et al. 1994) that Sgr A*, the very center of the Galaxy, does not emit significant hard X-ray radiation ($L(35{-}150\mathrm{keV}) < 3.5{\cdot}10^{35}$ erg/sec) limiting the total X-ray luminosity to $\lesssim 2.5 \cdot 10^{36}$ erg/sec as detected by Art-P at somewhat lower energies. In the same paper this low luminosity was compared with the 10^8 times higher Eddington luminosity of a supermassive black hole (mass $M_\bullet \sim 10^6 M_\odot$) and the hard X-ray spectrum of stellar-mass black holes and concluded that there is "possible evidence against a massive black hole at the Galactic Centre" (title) and that Sgr A* "clearly does not behave like a scaled-down active galactic nucleus".

Since then the situation has become even worse: Koyami (1994) reported ASCA observations of the Galactic Center (GC) where it is found that two sources – a hard and a soft source – exist in the GC separated by 1'. While the soft source coincides with the ROSAT source (Predehl & Trümper 1994) and hence is within 10" of Sgr A*, the 'hard' ASCA source should correspond to the hard GC source detected by Art-P. The hard source therefore might not be Sgr A* but a nearby x-ray binary, thus reducing the x-ray luminosity of Sgr A* even further. This would also relax the need for a high intrinsic absorption in Sgr A* (Predehl & Trümper 1994) as there would be no need to fit the low ROSAT flux to the high Art-P flux anymore. If the 'hard' source is not Sgr A* it can well be behind the Sgr A complex and therefore the soft x-rays are so strongly obscured that the 'hard' source was not detected by ROSAT and hard and soft source were incorrectly identified. The total x-ray luminosity of Sgr A* in the ROSAT band with normal extinction would be not more than $L_{\rm x} \sim 1-2\cdot10^{34}$ erg/sec (Predehl 1995, priv. com.) and if there is more at higher energies it proably would be largely contaminated by the nearby hard x-ray binary (Koyama 1995, priv. comm; Maeda et al. 1996). Even though one probably should await further analysis of the x-ray data, it seems quite likely that the total x-ray luminosity is at best a few hundred $L_\odot$ or less.

Here I want to argue that this extremely low x-ray luminosity contradicts the presence of a low mass back hole at the position of Sgr A*, but that together with the radio spectrum it is consistent with the presence of a supermassive black hole.

2. Size limit from the radio spectrum

Sgr A* was known first as a compact flat-spectrum radio source (Balick & Brown 1974) somewhat similar to those in the nuclei of active galaxies. It is now clear that this radio spectrum extends into the submm regime (maximum flux of $F_{\nu_{\rm max}} \sim 3.5$ Jy at $\nu_{\rm max} \sim 10^{12}$ Hz) with an inverted ($\alpha \simeq +1/3$) spectrum at lower frequencies and a steep cut-off towards the IR. This corresponds to a total radio luminosity of a few 100 $L_\odot$ ($L({\rm radio-submm}) \sim 10^{36}$ erg/sec). An upper limit of $R \leq 2\cdot10^{13}$ cm to the size of Sgr A* at λ3mm is given by VLBI observations (Krichbaum et al. 1995). One can, however, easily derive a strict *lower limit* to the size of Sgr A* from its spectrum.

If we approximate the electron distribution in the source by a quasi monoenergetic electron distribution with energy $\gamma_{\rm e} m_{\rm e} c^2$, as required at least for the submm regime by the inverted spectrum and the sharp cut-off towards the IR, we have the simple condition that the synchrotron self-absorption frequency $\nu_{\rm ssa}$ has to be lower than the characteristic peak frequency $\nu_{\rm max}$ (i.e. $\nu_{\rm ssa} < \nu_{\rm max}$), otherwise the source would not be visible in the radio.

For a spherical blob with radius R this translates into a minimum condition for the size for a given peak flux and peak frequency as observed in Sgr A* (see Falcke 1995 for more details).

$$R_{\rm sync} > 3\cdot 10^{11}{\rm cm}\quad k^{-1/17}\left(\frac{F_{\nu_{\rm max}}}{3.5{\rm Jy}}\right)^{8/17}\left(\frac{\nu_{\rm max}}{10^{12}{\rm Hz}}\right)^{-16/51}\left(\frac{\nu_{\rm ssa}}{10^{12}{\rm Hz}}\right)^{-35/51}$$

This expression is almost independent of the equipartition parameter k and depends only on observable quantities. This limit is also consistent with earlier independent estimates (Gwinn et al. 1991). If Sgr A* were more compact, then the source would be completely self-absorbed and unable to produce the observed radio flux, but of course can $\nu_{\rm ssa}$ be much smaller and hence the size be larger. One should also note that a much smaller, self-absorbed size would lead to substantial synchrotron-self Compton x-ray emission. For comparison it is interesting to note that the gravitational radius of a black hole is $R_{\rm g}=1.5\cdot 10^{11}M_\bullet/10^6M_\odot$ cm and therefore Sgr A* is only slightly larger than a supermassive black hole with $10^6M_\odot$, but 10^6-10^3 times larger than a 1-1000 $M_\odot$ black hole.

3. Why not a low-mass black hole?

The large radio size on its own is not an argument against a low-mass black hole. But if Sgr A* were indeed a low-mass black hole candidate powered by accretion, then even in Bondi-Hoyle accretion some excess angular momentum would lead to the formation of an accretion disk (e.g. Ruffert & Melia 1994), where the bulk of the disk luminosity would be radiated in the x-rays (Shakura & Sunyaev 1973). In the case of Sgr A* *the measured non-thermal radio-submm luminosity would be comparable or even larger than the x-ray accretion disk luminosity* (this is a problem for the Ozernoy 1992 and the Mastichiadis & Ozernoy 1994 model).

Consequently, one would have to argue that for some obscure reasons the gravitational energy in the accretion disk is not dissipated primarily into x-rays but mainly into non-thermal synchrotron radiation, such that the submm regime reflects the true peak in the spectral energy distribution. This, however, implies an important constraint to the size of the emission region. As the bulk of the gravitational energy in the accretion process has to be dissipated within the inner $\sim 10R_{\rm g}$ one would predict

$$R_{\rm sync}\sim 10R_{\rm g}=1.5\cdot 10^8(M_\bullet/10^2M_\odot){\rm cm}$$

and this small size is obviously in contradiction with the lower limits on the Sgr A* radio-submm size, given above, by a margin of at least 3 orders of magnitude. Hence, for a black hole with $M_\bullet \ll 10^6M_\odot$ the x-rays are far too low compared to the radio and the radio size is far too large for being the primary energy channel.

The only alternative way to have a small mass black hole, produce the radio emssion at the large scale and avoid producing the x-rays would be to postulate an almost dissipationless transport of energy within a jet. However, this requires an efficieny of > 99% conversion of gravitational energy into directed jet power which is implausible (see Falcke et al. 1993b; Donea & Biermann 1996)

This problem is more easily resolved if Sgr A* indeed were a supermassive black hole. In this case the accretion disk would radiate mainly in the UV where the limits on the luminosity are much higher (Falcke et al. 1993a, Zylka et al. 1995), with the radio and the X-ray luminosities being secondary emission components representing only a few per cent of $L_{\rm disk}$. Proposed physical models for the radio emisson are synchrotron emission from a jet (Falcke et al. 1993b), magnetic bremsstrahlung in Bondi-Hole accretion (Melia 1994), or synchrotron radiation from an advection-dominated disk (Narayan et al. 1995). However, the latter two models have to cope now with the lowered limit for the x-ray luminosity of Sgr A* and need to be adjusted (see also Falcke & Heinrich 1994 and Falcke 1996a for a longer discussion of some of the models). Considering the radio emission, Fig. 3 in Falcke (1996, this volume) shows that Sgr A* can well be understood as a scaled down AGN.

References

Balick, B., Brown, R.L. 1974, ApJ 194,265

Falcke H. 1996, in: "Unsolved Problems of the Milky Way", IAU Symp. 169, L. Blitz & P. Teuben (ed.), Kluwer, Dordrecht, p. 163

Donea A., Biermann P.L. 1996, A&A subm.

Falcke H., Heinrich O. 1994, A&A 292, 430

Falcke, H., Biermann, P. L., Duschl, W. J., Mezger, P. G. 1993a, A&A 270, 102

Falcke, H., Mannheim, K., Biermann, P. L. 1993b,A&A 278, L1

Goldwurm, B. et al. 1994, Nat 371, 589

Gwinn, C.R., Danen, R.M., Middleditch, J., Ozernoy, L.M., Tran, T.Kh. 1991, ApJ 381, L43

Krichbaum T.P., Schalinski C.J., Witzel A., Standke K., Graham D.A., and Zensus J.A. 1995, in "The Nuclei of Normal Galaxies: Lessons from the Galactic Center", eds. Genzel R. & Harris A.I., Kluwer, Dordrecht

Koyama, K. 1994, in: New Horizon of X-ray Astronomy - first results from ASCA, Universal Academy Press, p. 181

Maeda Y., Koyama K., Sakano M., Takeshima T., Yamauchi S. 1996, to appear in PASJ

Mastichiadis A., Ozernoy L.M. 1994, ApJ 426, 599

Melia F. 1994, ApJ 426, 577

Narayan R., Yi I., Mahadevan R. 1995, Nat 374, 623

Ozernoy L. 1992, in AIP Conf. Proc. 254, Testing the AGN Paradigm, ed. S.S. Holt et al., New York, p. 40,44

Predehl P., Trümper J. 1994, A&A 290, L29

Ruffert M., Melia F. 1995, A&A 288, L29

Shakura N.I., Sunyaev R.A. 1973, A&A 24, 337

Zylka, R., Mezger, P.G., Ward-Thomson, D., Duschl, W., Lesch, H. 1995, A&A 297, 83