THE NUCLEUS OF OUR HOME GALAXY:
A REMNANT OF AN ACTIVE OR A STARBURST GALAXY?

Leonid M. OZERNOY
Institute for Computational Sciences and Informatics
George Mason U., Fairfax, VA 22030-4444, USA
and
Lab. for Astronomy and Solar Physics, NASA/GSFC
Greenbelt, MD 20771, USA
e-mail: ozernoy@hubble.gmu.edu

Abstract. To resolve the above dilemma, two essentially different approaches are undertaken: First, a new, detailed analysis of the entire radiation spectrum of Sgr A*, from radio band up to gamma-rays, is reviewed, which enables us to put substantial constraints on the mass of a putative black hole. The derived upper limit turns out to be too small to allow the black hole to serve as an 'engine' for a Seyfert galaxy. Second, analyses of recent data on the 10 KeV gas in the central 200 pc and on star formation history at the Galactic center both make a star burst the likely episode in a recent past. Taken together, the two approaches seem to indicate that the history of the central part of our Galaxy can be better described as that of a starburst, rather than a Seyfert, galaxy.

Keywords: The Milky Way galaxy; Sgr A*; Sgr A West; IRS 16; starburst galaxies

1. The Problem

Since none of the galactic nuclei is as close to us as the nucleus of the Milky Way galaxy, it is tempting to find out what key element(s) is lacking to result in its pronounced difference from both active galactic nuclei and those of starburst galaxies: unsufficient gas supply, absence of a supermassive black hole, or both?

2. Constraints on the Central Black Hole Mass

Several different methods have been recently implemented to constrain or evaluate the mass of a putative black hole at the Galactic center:

2.1. Dynamics of the Gaseous Rotating Disk in the Innermost, Central Parsec. Provided that the so called 'mini-spiral' (Sgr A West) is a density wave generated by a hydrodynamical instability, the spiral morphology can put interesting constraints to the shape of the gravitational potential assumed to be due to a central point mass plus an extended stellar nucleus [1]. Analytical techniques and numerical simulations both show that the presence of a jump in surface density or/and a kink in rotational velocity of the circum-nuclear disk describe successfully the morphology of the mini-spiral. This enables us to constrain significantly the parameters of the gravitational potential. The observed pattern might be a superposition of the first three spiral modes, and its comparatively large pitch ($|dr/d\varphi| \gtrsim 0.1$ pc/rad in the region $r \sim 1$ pc) indicates that the total enclosed mass within $r \lesssim 0.2$ pc does not exceed $(1.7 - 4.7) \times 10^5 M_\odot$. After subtracting the inferred core mass of the central

T. J.-L. Courvoisier and A. Blecha: Multi-Wavelength Continuum Emission of AGN, 351–354.

stellar cluster found to be 5×10^5 $(10^{\pm 0.3})M_\odot$ (ref. [2]) one concludes that there is no point mass concentration exceeding $10^5 M_\odot$.

2.2. Stellar Collisions in the Core Dominated by a Central Black Hole. Presence of a $\sim 10^6 M_\odot$ BH in the stellar core would enhance considerably star-star collisions, especially in the density spike around the BH. Lower velocity collisions result in building-up massive stars whereas high-velocity collisions are disruptive. Gas released from the latter is largely bound to the BH and is gradually accreted onto the hole. It turns out that the accretion luminosity would exceed the upper limit of the central point source's bolometric luminosity of $\sim 10^{39}$ erg/s unless its mass $M_{bh} \lesssim 10^5 M_\odot$ [3].

2.3. Production of Cosmic Rays and Gamma-rays by a Wind-Accreting Black Hole. An unavoidable source of accretion by the galactic-center BH is the wind from IRS 16, a nearby group of hot, massive stars. Since the density and velocity of the accreting matter are known from observations, the accretion rate is basically a function of the putative BH mass only. Provided the available estimates of the high rate of accretion are correct, one can expect a shock to form around the BH, and efficient particle acceleration will occur. We calculate the expected cosmic-ray flux produced by the BH as a function of its mass, M_{bh}. The inferred contribution to the cosmic ray pool contradicts the existence of a supermassive, 10^6 $M_\odot$ black hole, and may rule out even much less massive ones [4]. The accompanying γ-ray flux produces a similarly stringent limit when compared to the recent *EGRET* measurement of the Galactic center.

2.4. Production of X-rays by a Wind-Accreting Black Hole. The accelerated protons, by colliding with the ambient gas, produce charged pions which, in turn, are responsible for the production of relativistic electrons and positrons. Synchrotron radiation of the latter, in the magnetic field of the accreting wind, results in X-ray emission which expected flux is measurable by available X-ray facilities. This flux turns out to be a function of M_{bh} as well. Comparing these results with recent X-ray observations by *SIGMA/ART-P*, which show Sgr A* to have a relatively low activity level, one can conclude [5] that the putative BH at the Galactic center cannot have a mass greater than about 10^4 $M_\odot$.

2.5. Radiation Spectrum of the Accreting Wind. Approximate analytical expressions are obtained [6] to estimate the BH mass from its spectral luminosity, assumed to result from the Bondi accretion of the IRS 16 wind. To fit the radio spectrum of Sgr A*, $M_{bh} \simeq 5 \times 10^2 M_\odot$ is required. The results of the above calculations are in contradiction with ref. [7] where a similar although numerical aproach have been used resulting in a different value of $M_{bh} \approx 10^6$ $M_\odot$. Such a high value of M would make the temperature of the accretion flow only marginally relativistic for electrons, instead of providing them the Lorentz-factor $\gamma \sim 10^2 - 10^3$ apparently required by the radio data. The bremsstrahlung emission, that would be the dominant in X-ray band, turns out to be at odds with the recent X-ray data which seem to indicate that the X-ray counterpart to Sgr A* has a nonthermal, power law spectrum.

A comparatively low value for the mass of a putative black hole at the Galactic center, constrained/derived above by four different methods, is consistent with the upper limits to Sgr A* mass, which the author [8] found earlier by four other methods – (i) tidal disruption of stars by a BH; (ii) displacement between Sgr A* and IRS 16; (iii) electron-positron pair production by a BH via electromagnetic cascade; and

(iv) wind diagnostics of Sgr A*.

3. The Galactic Center as a Scaled-down Version of Starburst Galaxies

3.1. Ultra Hot Gas at the Galactic Center. Several years ago both continuum [9] and Fe-line emission observations [10] indicated the presence of a high-temperature ($T \sim 10$ KeV) plasma within the central 100 pc of the Galaxy, but there have only been a few attempts so far to duscuss the origin and implications of these results. Some authors [11] objected to this interpretation since that gas would be highly non-stationary; instead, they argued for underlying discrete X-ray sources. However, what at first sight might seem unusual turns out to be just one of the numerous sequences of a recent starburst in the central region of the Galaxy [12]. In particular, that hot, rarefied gas appears to be an interior of the 200-pc expanding molecular ring at the Galactic center.

3.2. Starburst Interpretation. In ref. [12], a *single explosion*, due to either multiple supernovae or a very massive star, was considered. A Sedov-Taylor solution able to fit the observed radius, temperature, and density of the bubble requires $\sim 10^{54}$ erg for the energy release some $(4 - 8) \times 10^3$ yrs ago in a very rarefied environment. Another possibility to form a hot superbubble would be *sequential SN explosions* [13]. In this case, a very low initial gas density required by a single-explosion model, would be naturally produced by a wind from an OB association or/and first SN explosions. In this solution, the derived SN rate is as low as 0.04 yr^{-1}, which is, by a factor of 5, less than in a single-explosion solution, though the total energy release during the characteristic time $R/c_s \sim 10^5$ yr is $\sim 10^{54}$ ergs, *i. e.* about the same. Nevertheless, the sequential SN model results, as a whole, in less restrictive requirements.

3.3. The Galactic Center Hot Bubble As a Scaled-Down Version of Those in Other Starburst Galaxies. It is instructive to compare the parameters of the Galactic center hot bubble with the M 82 and NGC 253 cases. In those objects, the observed features such as a large wind bubble, powerful far-IR, X-ray and other emissions, very young supernova remnants all seem to be formed in consequence of an ongoing starburst. In all three cases, the temperatures of the hot gas are almost the same, and this is a clear and simple signature of the starburst model. Indeed, if the wind flows into a standing shock, the temperature of the wind, during the Sedov-Taylor phase, is given by: $T_s \approx (3/16)(m_H/k)v_w \approx 10^8(E_{SN}/10^{51}\ \mathrm{ergs})(M_{ej}/10\ \mathrm{M}_\odot)^{-1}$ K (e.g. [14]). Evidently, this implies that T_s may vary in a rather limited range until the gas is subject to cool. Meanwhile the other parameters of starbursts differ substantially. As compared to the Galactic center, NGC 253 and M 82 have a much larger mass of gas in their hot superbubbles and, respectively, a much larger total thermal energy as well (by a factor of 10 and 10^3, correspondingly). At a larger SN production rate, both NGC 253 and M 82 have a much larger age ($\sim 10^7$ yrs) of ongoing starburst.

3.4. Isotope Ratios. Observations of various isotopic species toward the starburst nuclei of M 82 and NGC 253 have indicated that $^{12}C/^{13}C$, $^{16}O/^{18}O$, and $^{18}O/^{17}O$ ratios are $\sim$40–50, $\sim$150–200, and $\gtrsim 8$, which significantly differ from the corresponding ratios of 20, 250, and 3.5 in the Galactic center [15]. This seems to be consistent both with a much smaller massive star formation rate at the Galactic center and with a smaller age of the starburst. In the light of all this, a rather small number of young stars in the central parsec [16] should not be a surprise.

4. Conclusions: AGN/Starburst Dilemma

A detailed analysis outlined above indicates that a well-spread belief into a supermassive black hole at the center of the Milky Way galaxy has a rather shaky basis. The current constraints seem to rule out the BH mass as large as $10^6 M_\odot$. Therefore, the main reason why our Galaxy is not a Seyfert one seems to be the lack of a proper 'engine', rather than an unsufficient mass supply. Incidentally, the mass flux onto the central part of the Galaxy is estimated to be $\sim 10^{-2} M_\odot$ /yr [17], which is rather large even on AGN scale. However, a lion fraction of this flux is neither going to 'feed the monster' (otherwise it would result in accretion luminosity much exceeding the available upper limit) nor provide a fresh fuel for continuous star formation (otherwise the total mass of stars within the central parcec would appreciably exceed the observed one). The current mass flux onto the galactic nucleus might be just a transient phenomenon responsible for feeding the starburst.

To sum up, the main conclusions of the present report are the following: (i) The Galactic nucleus does not seem to be a prototype for activity in galactic nuclei; (ii) A recent starburst at the Galactic center has neither resulted from, nor was induced by, a supermassive black hole; and (iii) Rather than being a 'dormant' version of AGN, the Galactic nucleus is a scaled-down version of starburst nuclei.

Acknowledgement. This report was prepared during my visit to École Normale Supérieure, Paris. It is my pleasure to thank the staff of the Laboratoire de Radioastronomie Millimétrique, and especially M. Signore, for their hospitality.

References

[1]. Ozernoy, L., Blitz, L., Fridman, A., Khoruzhii, O., & Lyakhovich, V. 1993, *Bull. AAS* **25,** 891; *Ap. J.* (to be submitted)

[2]. Eckart, A. *et al.* 1993, *Ap. J. (Letters)* **407,** L 77

[3]. Ozernoy, L.M. 1993, In The Nuclei of Normal Galaxies: Lessons From the Galactic Center. R. Genzel & A. Harris, Eds. (in press)

[4]. Johnson, P.A., Ozernoy, L.M., & Protheroe, R.J. 1993, In Proc. 23rd Internat. Cosmic Ray Conf. (in press)

[5]. Mastichiadis, A. & Ozernoy, L. 1993, *Ap. J.* (submitted)

[6]. Ozernoy, L.M. 1993, In Back to the Galaxy. S.S. Holt and F. Verter, Eds. *AIP Conf. Proc.* **278,** 69

[7]. Melia, F. 1992, *Ap. J.* **387,** L25

[8]. Ozernoy, L.M. 1992, In Testing the AGN Paradigm. S.S. Holt et al., Eds. *AIP Conf. Proc.* **254,** 40; Idem, **254,** 44

[9]. Skinner, G.K. *et al.* 1987, *Nature*, **330,** 544

[10]. Koyama, K. *et al.* 1990, *Nature*, **343,** 148

[11]. Markevitch, M., Sunyaev, R., & Pavlinsky, M. 1993, *Nature*, **364,** 40

[12]. Ozernoy, L., Titarchuk, L., & Ramaty, R. 1993, In Back to the Galaxy S.S. Holt and F. Verter, Eds. *AIP Conf. Proc.* **278,** 73

[13]. Ozernoy, L., Titarchuk, L., & Ramaty, R. 1993, *Ap. J.* (to be submitted)

[14]. Chevalier, R.A. & Legg, A.W. 1985, *Nature*, **317,** 44

[15]. Henkel, C. & Mauersberger, R. 1993, *Astr. Astrophys.*, **274,** 730

[16]. Tamblin, P. & Rieke, G.H. 1993, *Ap. J.* (in press)

[17]. Blitz, L., Binney, J., Lo, K.Y., & Ho, P.T.P. 1993, *Nature*, **361,** 417