Acta Polytechnica **53**(Supplement):506–511, 2013
doi:10.14311/AP.2013.53.0506

OUR GALACTIC CENTER – THE NEAREST BURNING DISK

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Abstract. This short presentation will update my more than 25 years long attempts at understanding the actions of the Central Engine at our Galactic Center.

Keywords: galactic center, SgrA*, black holes, burning disk.

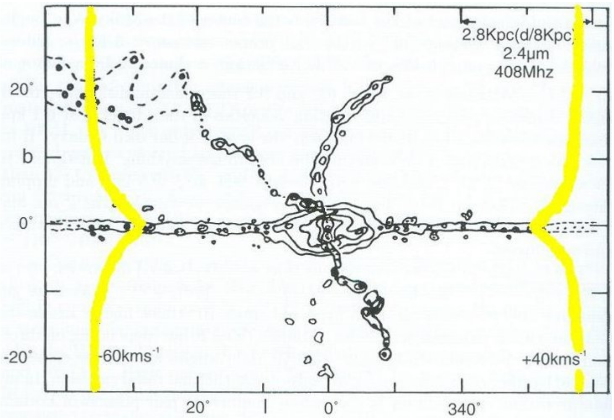

Figure 1. Simplified, joint IR and radio map of our Galaxy seen from Earth, on the 10 kpc scale, with all structures indicated which are likely powered by its Central Engine (CE); after [11]. Further explanations are contained in the text.

1. Introduction

In section 2, I shall present a number of maps of our Galactic center and its range of influence, not all of which are easily found in the standard literature. Section 3 will then explain why they may all require a Burning Disk (BD) as their Central Engine (CE).

2. Activity related to our Galactic Center

Figures 1 to 8 reproduce my knowledge about Galactic phenomena all of which are apparently launched quite near to our Galactic center. The maps start on the (large) ten kpc scale, and home in on the Galactic center by successive focussing factors between 3 and 30. All original figures are in colour except Fig. 7, five of them updated (w.r.t. [10–14], whereby the colours refer to the different overlayed spectral ranges as well as to blue- and redshifts.

Starting with Fig. 1, we look at the Galactic disk at infrared frequencies, plotted in green. We see its central kpc in radius tilted through 22° in projection, with its sense of revolution marked by two arrows. Plotted in blue (−60 km/s) and red (+40 km/s) are 21 cm data on the ribbons of falling hydrogen clouds in the upper and lower Galactic hemispheres respectively, which have a smooth monotonic continuation (in position, radial velocity, and velocity dispersion) into narrow 21 cm emission threads from the Galactic Center (GC). Since [10], I interpret the two hydrogen ribbons in our Galactic halo as glowing channel-wall material from an earlier twin-jet era, whilst a new era has already started, and is mapped (in black) via GHz continuum radiation taken from [20]. The old and the new jets deviate from each other beyond the first {4, 6} degrees in the {upper, lower} hemisphere respectively, where the fresh ones rise more steeply (away from the disk). For a distance of the Center of 8 kpc from us, 5 degrees correspond to (2/3) kpc.

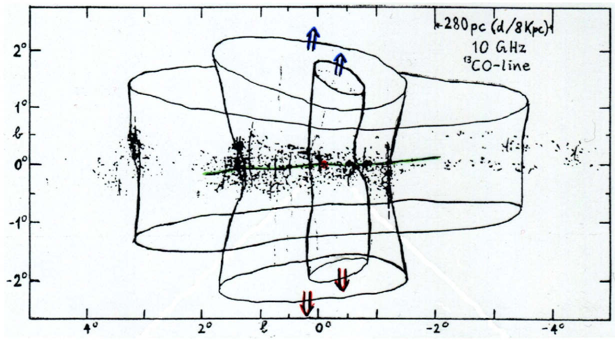

Figure 2. The same view as in Fig. 1, narrowed in and enlarged to the central kpc scale, collected from various maps in the literature in [12].

One more class of observations is indicatd softly in yellow in Fig. 1, at $|l| \gtrsim 25°$, as two antipodal bowl-shaped, or dumbbell-shaped volumes carefully explored and called "*bipolar hypershells*" by [21, 22]. They mapped them both at radio waves and at X-rays, found similar populations in the six neighbouring galaxies M 83, NGC 1808, NGC 253, NGC 4258, M 82, and NGC 3079, and argued convincingly that in the case of our Milky Way, they should not be confused with nearby, 10^4 years old supernova remnants called "spurs", but rather be interpreted as GC based, steady-state outflows, of typical (flaring) ages some 10^7 years. Sofue tentatively considered the hypershells as powered by episodic starbursts near the respective galactic centers, but in view of more recent

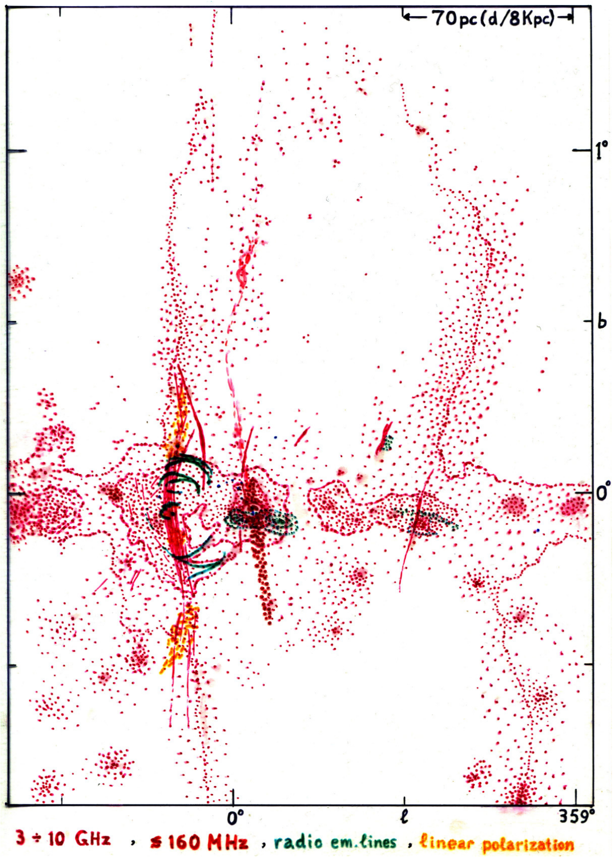

FIGURE 3. Again the same view, this time focussed on the innermost 300 pc with the 'chimney', revealing its central jet structure, from [11].

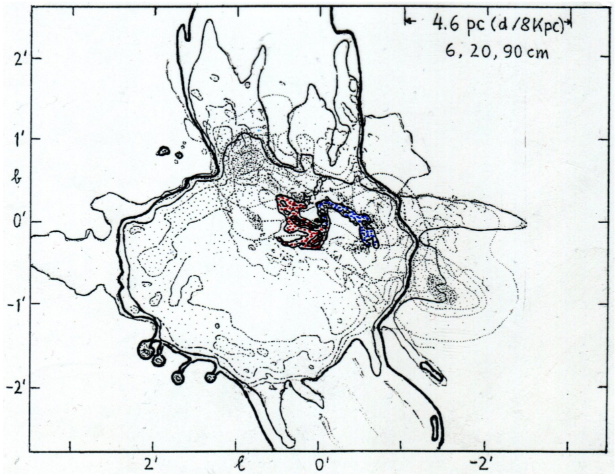

FIGURE 4. This composite map of the innermost few pc is taken from [12]. It shows SgrA*, SgrA West, SgrA East, and their multiple interactions, which are all thought to be powered by the CE.

experiences would probably be contented with a more general explanation by episodic central outbursts, of stellar or diskal nature. Seyfert galaxies have been found to have strongly fluctuating outputs from their centers on various timescales, a behaviour equally observed for our Milky-Way galaxy by the light echo method [18]: 10^2 years ago, our GC was 10^5 times brighter at and around Fe K emission (6.4 keV) than at present. Central Engines tend to be strongly variable. The FERMI mission has yet more recently strengthened this impression by detecting Sofue's dumbbells (even) at γ-rays, between $\gtrsim$ MeV and $\gtrsim$ 10 GeV energies [3], as well as its evaluation upto 10^2 GeV by [23].

Figure 2 is a re-drawing of mainly radio structures on the innermost kpc scale (of our Galaxy) which occurred to me during the 90s by looking at the various published maps, simply by enlarging the original maps (with a copying machine) to a common scale, and by subsequently adding them on transparent foils [12]. Through such overlay mapping I got the impression that the "chimney" shown in Fig. 3 – a hollow cylinder formed from bamboo-like magnetic flux tubes, anchored by hot rising plasma, and wrapped around by layers of molecular gas (mapped via CO-lines) – is not the only one of its kind surrounding the rotation center of the Milky-Way disk, but rather the youngest of its kind, and that earlier outbursts might have produced similar ones which are presently more extended, stacked around each other [13]. It adds a cylindrical substructure on the kpc scale to Sofue's hypershells (on the 10 kpc scale).

Figure 3 enlarges the innermost 100 pc (of our Galaxy), the 'chimney', aleady referred to above – straddling the Galactic rotation center SgrA – along whose axis one sees the Galactic twin jet only slightly blurred, mapped at IR frequencies near its upper end by [16], at various low radio frequencies mainly along its lower-hemispheric half [8, 24], and strictly resolved (of order 1 %) at X-rays only by [2] on the central pc-scale, though not in the printed version, and hardly recognisable on the present scale. Our GC is a bona fide jet source, if only at low power presently.

Figure 4 presents the innermost few pc of our GC at radio and IR frequencies, with its CE SgrA* yet unresolved. On this scale, however, Baganoff's central X-ray jet (2003, internet version) has been clearly mapped, between 0.5 and 1 pc from SgrA*, at right angles to the local Galactic disk, and pointing towards the "SE clump", an X-ray knot at distance 6.1 pc from SgrA*, as well as towards the "NW Clump". Both jet and knots appear to have the typical jet width of 1 % of its length, as in dozens of other resolved jet sources, hence look to me like a standard twin jet (of length $\gtrsim$ 6 pc). In the next section, I shall repeat my earlier conclusion [11] that SgrA West is the central part of our Galactic disk, and that SgrA East is far too energetic and far too small for a SNR, and has a different fine structure at its periphery. Rather, SgrA East looks to me like a spillover bubble for pair plasma from the CE during flaring epochs, which has filled the chimneys in the past, and has filled Sofue's bipolar hypershells.

Figure 5, copied from [11], resolves our CE's Narrow-Line Region (NLR), of size $\lesssim$ lyr, at IR and at radio frequencies, and measures a radial storm of

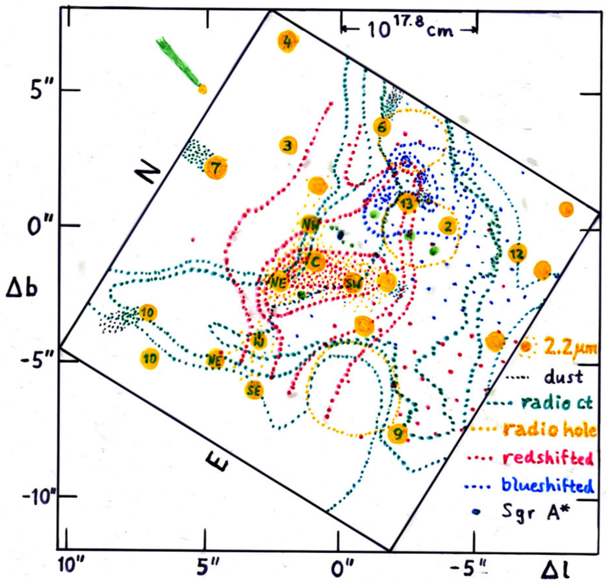

FIGURE 5. Multifrequency view of the CE, on the scale of the innermost lyr, from [11]. Note the central storm field, at right angles to the central disk, and co-aligned with the twin-jet, whose straight shape at X-rays has not been drawn in. It was only found by Baganoff in 2003 [2].

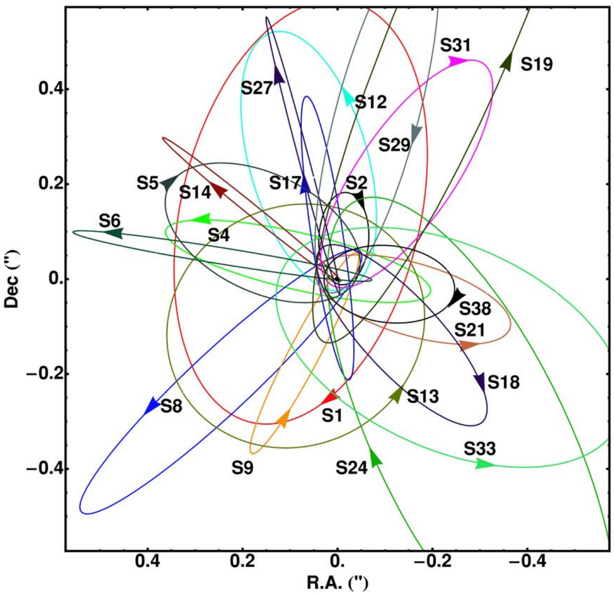

FIGURE 6. The monitored orbits of the innermost 20 bright stars of our Galaxy, on the scale of 0.1 lyr, taken from [5].

speeds $\lesssim 10^3$ km/s, and of an escaping mass rate $10^{-2.5\pm1} M_\odot$/yr, which can be seen to blow off the atmospheres of $\gtrsim 8$ stars radially, out to distances of $\lesssim 1$ lyr. Its velocity structure is traced by the spectral lines Br α, Br γ, He I, and Ne II. The storm emerges from both sides of the central disk; its redshifted half coincides with the luminous star cluster IRS 16. SgrA* is the isolated, slightly elongated point source at the center of this map. There is no hint at a black hole anywhere in this central region of the Milky Way.

Figure 6, copied from [5], shows the monitored orbits of 20 stars within $0.8'' \simeq 0.1$ lyr from the GC, all of them encircling SgrA* as their focal point, in projection, (whereby a projected focal point need not lie on the symmetry axis of its ellipse). Shortest revolution time among them – of 15.8 yr – has the star S2, which passed its last periastron in April 2002, and completed its first monitored orbit in 2008. In his Bonn colloquium on 16. November 2007, Frank Eisenhauer reported that the Kepler ellipse of S2 did not close after one revolution, by some 3°, a statement which is also contained in his Ph.D. thesis, according to Bernd Aschenbach, but is attributed to a non-zero velocity of the CE by [5]. If Eisenhauer is right, the CE cannot be a point mass, its gravitational potential should possess higher multipoles, like a Burning Disk (BD), cf. [12].

Figure 7, copied again from [5], shows a blown-up version of the monitored orbit of S2, whose diameter is of order $0.2'' \simeq 0.02$ lyr. As has already been mentioned, this orbit does not seem to close after one revolution. Two further peculiarities have been that S2 flared by half a magnitude during five successive measurements at periastron passage, and that six of its apparent positions were shifted by $\lesssim 10$ mas towards NE, peculiarities which the authors find "hard to interpret", and "hard to understand". These remarkable deviations from Keplerian behaviour of the orbit of S2 are once more enlarged in Fig. 8.

Figure 8, again copied from [5], on the scale of only $0.05'' \simeq 10^{15.7}$ cm, is to my knowledge the highest-resolution map of our GC achieved so far. It reveals a periastron-passage distance of S2 of only $0.012'' \simeq 10^{15}$ cm (in projection), still ten times larger than my expected BD, and $\gtrsim 10^3$ times larger than a BH horizon (for $10^{6.6} M_\odot$) would be. Both the flaring anomaly, and the shifting anomaly of S2's orbit near the CE can be readily explained by a high enough plasma density n, of order 10^{12} cm^{-3}, for which there is sufficient orbital friction exerted onto its outer atmosphere to cause flaring, and for which even IR rays are bent, like in a fata morgana.

3. IMPLICATIONS FOR THE CENTRAL ENGINE

The name 'Black Hole' (BH) was introduced in 1972 by John Wheeler and Remo Ruffini for the 3-parametric Kerr–Newman class of (possibly charged) spacetimes, to describe the singular outcome of extreme gravitational collapse within Einstein's GR. It was by no means clear in those years whether or not any of them existed in the real world, or if instead, nature had provided a sufficient number of hurdles to prevent their formation in our Universe, both of stellar and of superstellar mass. In particular, supermassive BHs in the centers of galaxies were at some stage believed to be able to power gigantic outbursts, i.e. to help solving the energetics of galactic centers, before it became

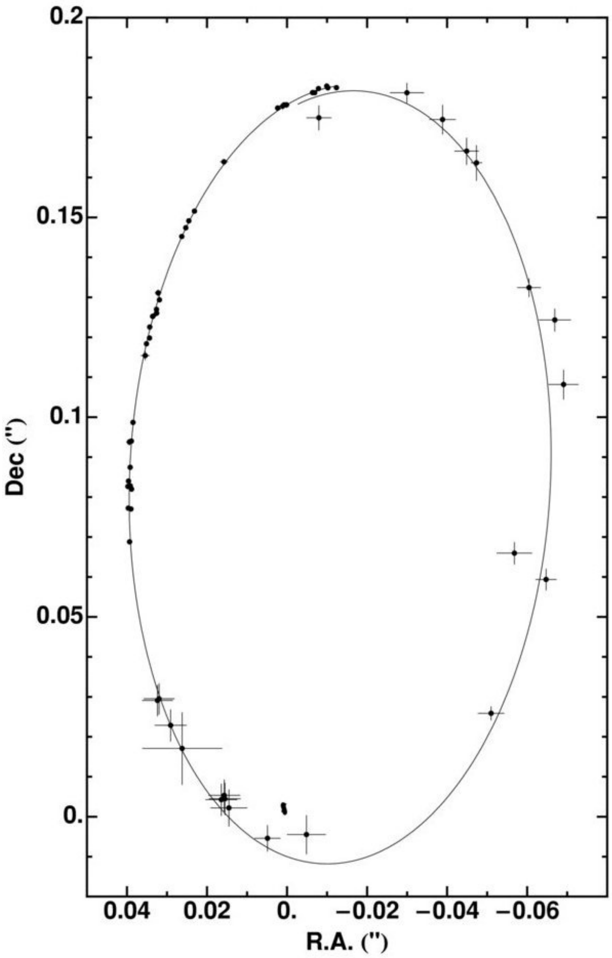

Figure 7. The innermost orbit of star S2, traversed clockwise, of period 15.8 yr, and diameter some $10^{16.3}$ cm, taken again from [5].

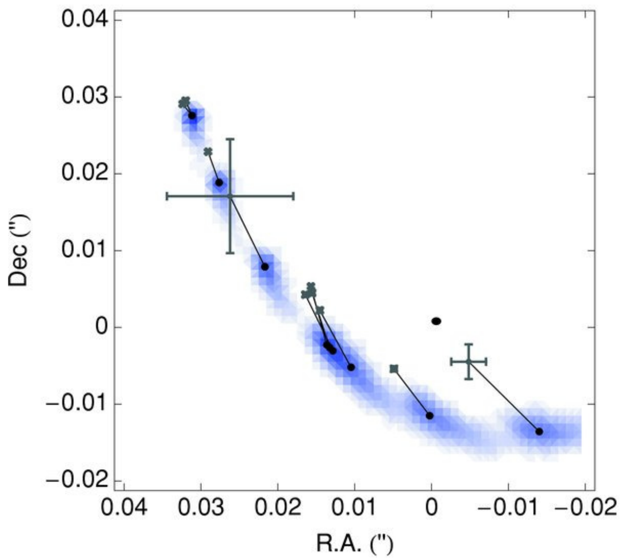

Figure 8. Periastron passage of star S2 (in April 2002), on the enlarged scale of $\lesssim 10^{15.7}$ cm, taken again from [5].

clear to some of us that the Eddington limit restricts such energy conversions drastically, increasingly so with increasing mass of the BH, so that nuclear power of burning hydrogen-rich plasmas easily dominates in efficiency over accretional power of a SMBH. Black holes do not blow, they swallow.

Even worse for the BH paradigm: During the past several years, GR theorists have found that Roger Penrose's conjecture of the principle of "cosmic censorship" fails to hold true, that '*naked singularities*' are expected to form in most collapse situations rather than BHs, the latter forming the rare exception of extreme symmetry rather than the general case in gravitational collapse events [7]. We should not really expect to discover a BH anywhere in our surroundings. And Einstein's cherished GRT would break down wherever extreme collapse phenomena take place, a most uncomfortable situation for a theorist. And moreover, to the best of our knowledge, galactic disks are *gravitationally stable* all the way to their centers, being supported vertically by stellar-type gas pressures, and radially by centrifugal pressures.

All that said, here I want to focus on our knowledge about the CE of our Milky-Way galaxy, and hopefully convince the reader that SgrA* cannot possibly be a BH. All of its observed properties distinctly prefer an interpretation as a '*Burning Disk*' (BD), i.e. as the smooth continuation of the Galactic disk all the way to its center, whereby nuclear burning sets in as soon as stellar densities are reached, at radial distances r below some 10^{14} cm from its center, as already expressed in [12].

A first direct indication of SgrA* to possess a *non-pointlike potential* came during the years 2001 until 2007 when its estimated *mass* M, from orbits of surrounding S stars, rose monotonically from $10^{6.41}\,M_\odot$ to $10^{6.63}\,M_\odot$ during increasing approach, and when correspondingly its estimated *distance* d rose from 8.0 kpc to 8.33 kpc, in marginal conflict with independent estimates which stayed at $\lesssim 8.1$ kpc. Even more telling was Eisenhauer's 2007 message at Bonn that the Kepler ellipse of star S2 *precessed*, by some 3° during its first monitored revolution around SgrA*. This deviation of an orbit from those around point potentials is $10^{2.4}$ times larger than Einstein's periastron advance due to GR, and is expected e.g. for orbits around MacLaurin potentials, as for a central BD.

Already in 1990, I considered the strong *radial storm* mapped in Fig. 5 as an evidence against a central BH [11]. The storm has a mass rate of $10^{-2.5\pm1}\,M_\odot$/yr, at $v \lesssim 10^3$ km/s, hence of kinetic power $L_{\text{storm}} \lesssim 10^{39\pm1}$ erg/s: An even much larger output from SgrA*, of $L_{e\pm} \approx 10^{41}$ erg/s, had been inferred from its steady *synchrotron* radiation, requiring $10^{43}\,s^{-1}$ of relativistic electrons and positrons, at a typical Lorentz factor $\gamma \approx 10^4$, and from episodic (during months) *pair annihilation*, at rates of $\lesssim 10^{43}\,s^{-1}$. BHs cannot blow, they swallow. Recent publications to the contrary try to make a BH blow by considering radiation-pressure driven reflections of part of the infalling material. They violate momentum conservation during individual photon collisions with gas molecules or ions, like in some literature on 'radiation-driven' winds, (instead of centrifugally driven winds). Similar considerations apply to the occasional (erroneous) claim that BHs could expel jets. As argued in [15], *jet engines* are complicated machines, involving rotating magnets. The twin jet shown in Fig. 3 – on scales between 1 pc and 10^2 pc – proves that SgrA* behaves like a BD, like in all the active galactic nuclei.

Two further reasons against SgrA* being a BH have already been mentioned in connection with Fig. 8: Both the observed *deviation* of its orbit from Keplerian near periastron, and the *flaring* of S2 at the same time ask for a high ambient density, of order $10^{12}\,\mathrm{cm}^{-3}$, too high for the terminal accretion flow into a BH, but expected for a BD.

Another, ninth reason against BHship of SgrA* is its large and hard radiated power: $L \gtrsim 10^{38}$ erg/s, which power is more or less logarithmically equi-distributed, $\nu S_\nu \approx$ const, between 10^{12} Hz and at least TeV [1], perhaps even PeV energies. The corresponding BH *hardness*, dictated by sub-Eddington accretion, would be restricted to $kT \lesssim 22\,\mathrm{eV}\,(M_\odot/M_{6.6})^{1/4}$, i.e. would have to be lower by at least 11 orders of magnitude!

Three further, marginal problems with a BH interpretation of SgrA* have come from *high-resolution* mapping at 1.3 cm by Doeleman et al. in *Nature* 455, 78–80 (2008), from a (negative) *tidal stability* analysis of the central B-stars if SgrA* were a point mass, by [17], and from the large amount of *iron ejected* from our Galactic center, seen in absorption via the Fe Kα and Kβ lines [19]: by what nuclear stoves? Extreme nuclear burning is expected near the center of a BD, like for massive stars near the end of their evolution, and so is the explosive ejection of its ashes.

Space is lacking in these proceedings to repeat my earlier conclusions [11, 12] that SgrA East differs from a SNR, rather serves as a steady-state storage bubble for spillover pairplasma from SgrA*, and that fairly well-defined numbers have been obtained from reasonable constraints for the various outflows from SgrA* through the NLR, both non-thermal and thermal: $\gamma_\mathrm{e} = 10^4$, $n_\mathrm{e} = 10^{4.8}\, r_{14}^{-2}$, $\beta_\mathrm{e} = 10^{-1.3\pm0.5}\, r_{14}$, $n_\mathrm{H} = 10^{12.5}\,\mathrm{cm}^{-3}\, r_{14}^{-2}$ with $r_{14} \lesssim 1$, and transverse magnetic field strength $B_\perp = 10^{-2.8\pm0.5}$ G in the core region. These estimates gave me confidence in the BD model, and in Sofue's bipolar hypershells driven by it. Further confidence came from the existence of BH non-believers like Jean-Marie Souriau, Viktor Ambartsumian, and Hoyle et al. [6], to name just a few.

As a final, 14th argument against the BH paradigm, there is the famous Magorrian *mass* relation which asserts strict *proportionality* between the mass of the CE of an active galaxy and that of its central *bulge*, whereas there are no corresponding proportionalities known to any other property of a galaxy [9]. The mass of a BD just scales like that of the bulge part of its disk, whose inner edge it is, but not beyond.

4. SUMMARY

Have I convinced the reader? That a BH – even if such existed in the Universe, or even if it were (rather) a naked singularity – would be largely inferior an engine in influencing its outside world to a BD, with all its free rotational, magnetic, and nuclear power. I hope so.

ACKNOWLEDGEMENTS

My warm thanks go to Ole Marggraf for repeated help during the formation of this talk.

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Discussion

Giora Shaviv — What is the source of attraction which keeps your massive disk? You expect nuclear burning in the disk?

Wolfgang Kundt — A BD is a self-gravitating disk of high enough density to start nuclear burning near its center.

Pieter Meintjes — What type of mechanism can drive jets from a BD? Can a BD drive jets where particles can be accelerated to TeV energies with associated non-thermal emission spanning several decades of energy? What is then the conversion efficiency of thermo-mechanical to non-thermal energy?

Wolfgang Kundt — My BDs are infinitely better on all this than BHs, with efficiencies near 1 %. Please see my homepage.