

## ON THE IONIZING SOURCES IN SPIRAL GALAXIES: II. THE CENTER OF THE MILKY WAY

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### 1. INTRODUCTION

The overall shape of our galaxy, Milky Way, has mainly been revealed – it is classified as a SAB(rs) type galaxy with a bar (Kuijken 1996, and references therein; Gyuk 1996), weak rings and a four arms spiral structure (Valée 1995).

A model for the rotation curves of spiral galaxies by Sofue (Sofue 1996), could be applied to the Milky Way introducing:

- nuclear mass component (scale radius  $r \sim 100 - 150$  pc, mass  $M \sim 3 - 5 \times 10^9 M_\odot$ ),
- central bulge ( $r \sim 0.5 - 1$  kpc,  $M \sim 10^{10} M_\odot$ ),
- disk ( $r \sim 5 - 7$  kpc, thickness  $\sim 0.5$  kpc, and  $M \sim 1 - 2 \times 10^{11} M_\odot$ ),
- massive halo ( $r \sim 15 - 20$  kpc,  $M \sim 2 - 3 \times 10^{11} M_\odot$ ).

The fifth component could be added (Sofue 1996) for the Milky Way – the very nucleus ( $r \sim 30$  pc,  $M \sim 10^7 M_\odot$ ) with a "dark" mass at a dynamical center of the Galaxy ( $r \leq 0.01$  pc,  $M \simeq 2.6 \times 10^6 M_\odot$ ).

The distribution and influence of different ionizing sources throughout the Galaxy (even some local like the great Gum Nebula) could be described by the Taylor-Cordes model (TC93) (Taylor and Cordes 1993), with Galactic center (GC) component added (Lazio and Cordes 1998, hereafter LC98), using a number density of free electrons in the interstellar medium as a parameter of ionization. In this contribution we discuss the fifth (GC) component that becomes dominant from the galactocentric distance of 0.5 kpc towards the GC.

The opened question remains whether the "dark mass" in GC is directly responsible for the high ionization of that region, or only indirectly through the accretion disk, if it is a supermassive black hole (BH).

## 2. THE CENTER OF THE MILKY WAY

The complete activity of the GC region has been studied for almost two decades now, and numerous nonthermal and thermal sources have been revealed. All of them contribute to the total electron density of the last component in the equation that represents the overall estimate of electron density ( $n_e$ ) distribution (TC93, LC98):

$$n_e(x, y, z) = n_1 g_1(r) \operatorname{sech}^2(z/h_1) + n_2 g_2(r) \operatorname{sech}^2(z/h_2) + n_a \operatorname{sech}^2(z/h_a) \sum_{j=1}^4 f_j g_a(r, s_j) + n_{GG} g(u) + n_{GCGC}(r) h_{GC}(z) \quad (1)$$

where  $r$  is the Galactocentric distance projected onto the plane and is equal  $r = (x^2 + y^2)^{1/2}$ , the sum goes over four spiral arms,  $n_i$ ,  $i = 1 \dots 5$  denotes the density in different regions,  $f_i$ ,  $i = 1 \dots 4$  are scale factors,  $g_i$ ,  $i = 1 \dots 5$  are functions of position,  $h_i$ ,  $i = 1 \dots 4$  are scale heights and  $z$  is the height above the galactic plane. The detailed description of each component is given in TC93 and LC98.

The GC component has a following shape:

$$n_{GCGC}(r) h_{GC}(z) = (10 \text{ cm}^{-3}) \times e^{-\left(\frac{r}{0.15}\right)^2} \times e^{-\left(\frac{z}{0.075}\right)^2} \quad (2)$$

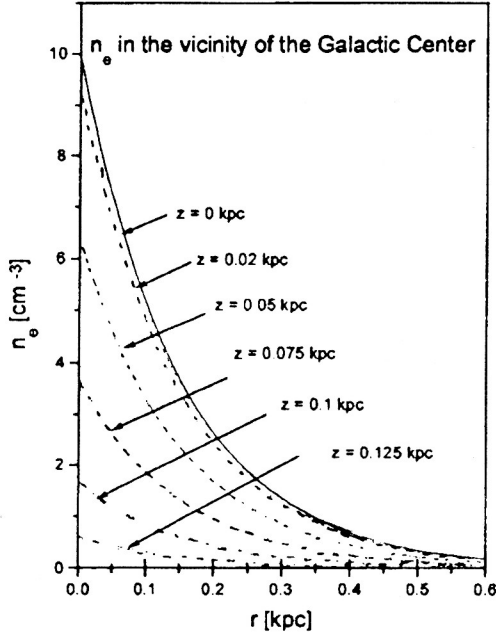


Fig. 1. Dependence of electron density  $n_e$  as a function of Galactocentric radius  $r$  in the vicinity of the GC (up to  $\sim 500$  pc) for different heights above the galactic plane  $-z$ , according to LC98.

The overall contribution of the GC component to the total electron density  $n_e$  of the Galaxy, according to eq. (2), is shown in Fig. 1. The problem of the ionization throughout a spiral galaxy is briefly discussed in Samurović, Čirković, Milošević-Zdjelar and Petrović (1998) (Paper I).

Electron densities as functions of  $r$  are presented in TC93 (in their Fig. 3).

Local contributions from the GC area come from a complex set of sources. At a dynamical center of the Milky Way lies a nonthermal synchrotron radio-source SgrA\*, of yet unrevealed nature, surrounded with thermal orbiting plasma SgrA West (within a Central Cavity,  $r \sim 1$  pc), which is ionized by IRS 16, a cluster of hot HeI/HI (spectral type O) stars in the vicinity of GC ( $r \sim 0.6$  pc) (Zylka *et al.*, 1995). Cavities like this one are usual features around stellar associations which blow out surrounding interstellar matter by stellar winds, leaving hot rarefied gas cavity surrounded with envelope of neutral and ionized gas (Bochkarev and Ryabov 1997). In our case the envelope is a Circum-Nuclear Disc beginning at the outer edge of SgrA West (the Arc) at ( $r \sim 1.7$  pc) and extending as far as 12 pc. SgrA West complex consists of a three arm minispiral and an extended ionized component, and contributes with  $n_e \sim 10^4$  cm $^{-3}$  (minispiral) and  $10^3$  cm $^{-3}$  (extended component) (Beckert *et al.*, 1996).

Some other local features of the smaller scale, like the Bullet (Yusef-Zadeh *et al.* 1998), and the Sickle (Yusef-Zadeh *et al.*, 1997b), contribute the  $n_e \sim 10^4$  cm $^{-3}$  and  $10^2$  cm $^{-3}$ , respectively.

Another contribution of  $n_e \sim 6$  cm $^{-3}$  (Koyama *et al.*, 1996) comes from a probable supernova remnant SgrA East located 30 pc behind the GC. It is heated by a cluster of hot O stars behind SgrA West (Sofue 1993). There have been some attempts to describe its unusual feature, more energetic than supernova, as a Seyfert-like activity like in the nuclei of some other spiral galaxies (LaRosa and Kassim 1985). SgrA East is physically interacting with a "50 km s $^{-1}$  molecular cloud" forming new stars in the areas of collision, and is considered to be the source of the high energy activity of the GC (Yusef-Zadeh 1997a). The GC region ( $r \sim$  few hundred pc) is responsible for 10% of the total star forming rate of the entire Galaxy (Sofue 1993).

The contribution of SgrA complex to the total electron density is  $n_e \sim 6$  cm $^{-3}$ , and it drops outside of that area to 0.3-0.4 cm $^{-3}$ .

One of the largest luminous HII plasma/molecular region in the GC vicinity is SgrB2 at a distance of 100 pc from GC. It consists of several active star forming regions with numerous associated dense HII regions (Gordon *et al.*, 1993). Besides SgrB2, within the Nuclear Disc ( $r \sim 200$  pc, thickness 50 pc), there are several other HII (SgrC, D, and E), and star forming regions.

ASCA observations detected strong  $K\alpha$  lines from highly ionized various elements, and showed presence of high temperature plasma over the GC region (Koyama *et al.*, 1996).

On the large scale, hot plasma is distributed symmetrically along the galactic plane with a strong concentration at the GC. X-ray spectra obtained from ASCA showed high energy (10 keV) spectra of the similar shape over the emission region (Koyama *et al.*, 1996). Their results show that energy generation rate resembles the rates at the active galactic (Seyfert-like) nuclei, having a large mass concentration at the GC.

Weaker thermal emission is detected extending 80 pc along the Galactic plane on both sides of GC. Vertical to the Galactic plane, various thermal arched filaments extending more than 100 pc, are detected along magnetic field, having turbulent motion, preferably towards the GC. Similar vertical structures exist in other galaxies (Sofue 1993).

### 3. THE NATURE OF SgrA\*

Motions of the ionized gas can not reveal characteristics of the central object as the stars can, because the gas is influenced by the magnetic field. Also, high temperature plasma can not be bound by the galactic gravity.

By proper motions of the stars within central 0.01 pc one can draw conclusions about the mass and nature of the central object (Yusef-Zadeh 1998). The most recent research (Eckart and Genzel 1997) finds the value of stellar proper motion greater than  $1000 \text{ km s}^{-1}$  and undoubtedly estimates the central mass:  $2.6 \times 10^6 M_{\odot}$ .

Different models could be applied to the SgrA\* – a central "dark mass". If we consider a black hole model, we have to examine all the problems related to such an object. Radio-emission detected from GC due to cyclo-synchrotron and synchrotron radiation is consistent with a theoretical prediction of an accreting disk around a  $10^6 M_{\odot}$  BH (Bower and Backer 1998). There are few models successfully applicable to it:

- advection dominated accretion (Narayan *et al.*, 1995, Lasota 1998)
- spherical accretion (Melia 1994).

The crucial problem related to the BH model is low X and  $\gamma$ -ray flux detected from SgrA\*. The strongest source in the vicinity of GC is 1E 1740.7-1942, hard X-ray source, and a strong source of annihilation 511 keV line (e.g. Wehrse *et al.*, 1996), but it is not coinciding with SgrA\* (it is situated in a dense molecular cloud 50' away from GC). It shows all the features (similar shape and luminosity) as CygX-1, another BH in a Milky Way.

There have recently been some quite different approaches to the "blackness" of the SgrA\*. We briefly mention here the recent proposal that SgrA\* is a neutrino ball, i.e. there is no BH – instead there is a ball made of self-gravitating, degenerate neutrinos with the same total mass of  $2.5 \times 10^6 M_{\odot}$  (Tsiklauri and[B Viollier 1998a,b). These neutrinos have masses  $m_{\nu} \geq 12 \text{ keV}/c^2$  (for  $g = 2$ ) and  $m_{\nu} \geq 14.3 \text{ keV}/c^2$  (for  $g = 1$ ), where  $g$  is the spin degeneracy factor. These neutrinos are, according to cosmological constraints, decaying thus producing X-ray emission lines. Another way to distinguish the existence of the neutrino ball is to examine in detail the trajectory of stars in the vicinity of the GC. If there is the BH the trajectory will be an ellipse with the BH at the focus, while in the case of the neutrino ball the center of the ellipse will be the center of the ball.

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