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ON THE NATURE OF THE COMPACT OBJECT AT THE GALACTIC CENTRE

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1. Introduction

The great interest roused to the investigation of the central region of our Galaxy (radius $< 1-3$ pc) is stipulated mainly by an hope, that the realizing the nature of "Galactic Centre" can throw light onto one of central problems of today astrophysics-problem of activity of galactic nuclei. Another reason is the unprecedented diversity and complexity observed at this region: point radio and infrared sources, randomly distributed clouds and regular spiral arms, evidence of a compact massive object etc.etc.

In the present paper we shall discuss the nature of the point object assumed to be located at the Galactic Centre. The main attention will be paid to the estimation of the mass of that object - the key parameter for understanding its nature. We shall show that side by side with the available upper limits of the mass, from actually model-independent dynamical considerations, it is possible to obtain a lower mass limit as well. The result allows one to reject previously discussed models of star-mass objects (pulsar, planetary nebulae, binary stars).

First, we briefly review the most interesting observational facts on the dynamical structure of Galactic nucleus necessary for subsequent analysis (Chapter 2). Black hole models are discussed in Chapter 3. In Chapter 4 we obtain the lower mass limit of the compact object.

Further information on observational data and theoretical models one can find in recent reviews by C.H.Townes et al.[1] and N.S.Kardashev [2].

2. Several Observational Facts.

Sgr A West and IRS 16. High resolution radio observations of Sgr A show existence of thermal, non-thermal compo - nents and a point radio source in Sgr A West as well [3]. Variable point radio source Sgr A West with dimensions less than 10^{14}-10^{15} cm (e.g.[4]), within present accuracy of observations ($\sim 1''$) coincides with infrared source IRS 16 [5]. According to 2.2μm data IRS 16 in located probably at the region of maximal stellar concentration in the Galaxy-a compact early-type star cluster with concentration $\gtrsim 10^6 pc^{-3}$ [5]. Observations by differential radioastrometry methods do not show any suf - ficient motion of the point radio source [6].

Compact "[NeII]" clouds. J.H.Lacy et al. [7,8] observing on 12.8μm [NeII] spectral line with $FWHM=3''.5$, discover a system of compact ionized clouds within Sgr A West. Cloud dimensions are 0.1-0.5 pc, internal velocity dispersions 100 km s^{-1}, line-of-sight velocities up to ± 260 km s^{-1}. Clouds are participating both in chaotical and rotational motions with rotation axis perpendicular to that of the Galaxy. The cloud masses are $0.1-1 M_\odot$ and the ages obtained by their expansion rate

are $\sim 10^4$ yr. The analysis of velocities of 14 clouds within inner 1.6pc, gives the virial mass $10^7 M_\odot$ with indication of existance of compact object of a mass $3.10^6 M_\odot$.

Note the following fact: according to spectral study of QSOs and Seyfert galaxies, the regions of formation of broad emission lines $L_\alpha\ \lambda 1216$, $H_\beta\ \lambda 4861$, $MgII\ \lambda 2800$, $CIV\ \lambda 1550$ etc. appear to be ionized clouds with parameters similar to that of Galactic Centre (for detailes see [9]). From this point of view it is of particular interest the observed broad HeI (2.06μm) line ($FWHM = 1500$ km s^{-1}). At the same time the Galactic Centre hydrogen and [NeII] lines have Doppler width almost an order of magnitude smaller those of QSOs. Perhaps the closeness of physical parameters of ionized clouds in QSOs and Galactic nucleus indicates the similarity of cloud formation mechanisms in these objects.

CCD 1 and 2. Photometric observations on 9000 Å using charged coupled device (CCD) detectors showed existence of two red sources (CCD 1 and 2) of $\sim 19^m$ quite near to IRS16 and point source Sgr A West [11]. The situation was intri - guing particularly because of extensive structure clearly seen nearby the sources. However, further broadband observations by Biretta et al. [12] between 7000 - 10000Å show no evidence of expected [SIII] doublet (9069 and 9532 Å). This means that CCD objects are most probably reddened stars a few kilopar - secs from the Galactic Centre and not HII regions or clusters of K5 - MO stars. This conclusion seems to be confirmed by the fact that CCD objects with an accuracy less than $0''.5$ do not coincide with any of known infrared sources [13].

Spiral Structure . In Figure the VLA 1$''$ resolution map of Sgr A West at 6cm, kindly communicated by K.Y.Lo, is presented, where the spiral structure of ionized gas discovered by R.D. Ekers et al (1983, in press) is clearly seen. The velocities of the gas are shown on the map, too. The centre of spiral picture does not coincide with Sgr A West - displacement is $2''.5$. The dynamics of spiral arms are unclear yet - are they leading of trailing, do we observe gas jets (cf. [14]) or on the contrary, accretion process?

3. Upper Limit to Object's Mass.

After D.Lynden-Bell's (1969) outstanding paper [15] the black hole model solidly enters into the repartoire of possible interpretations of galactic nuclei properties. However, because of large number of free parameters on one hand and rather complexity of physical processes in the vicinity of massive black holes on the other hand, the principal question of the existence of a black hole at Galactic Centre up to now remains open. The situation in this sense can be similar to that of Cyg X-1: a decade ago it seemed that the first black hole is discovered at last, however up to date this idea has been neighter confirmed nor refuted.

The most perspective direction from the point of view of objective evaluation of black hole hypothesis appears the estimation of its mass. The mass of the assumed black hole was estimated by several model-dependent methods.

1. Estimation using the inevitable process occuring in the vicinity of massive black hole surrounded by dense stellar sys-

tem - tidal disruption of stars [16,17] . Comparison of calculated tidal luminosity with observed X-ray flux - $L_x = 1.5.10^{35}$ erg.s^{-1} [18] , gives the hole mass of order

$$M \simeq 1\cdot 10^3 M_\odot \left(\frac{\epsilon}{0.1}\frac{m}{M_\odot}\right)^{-0.38} \left(\frac{L_x}{1.5\cdot 10^{35}\,\mathrm{erg\,s^{-1}}}\right)^{0.38} \left(\frac{n}{10^6\,\mathrm{pc^{-3}}}\right)^{-0.53} \left(\frac{v}{200\,\mathrm{km\,s^{-1}}}\right)^{0.53} \quad (1)$$

obtained in [16]* (n,v are the star density and velocity, m is the mean stellar mass, ϵ is the accretion efficiency).

2. The analysis of possible processes (namely, photon-photon interaction with $e^+ e^-$ pair production) in order to explain the observed annihilation line intensity discovered in the direction of Galactic Centre (see [19,20]) by Lingenfelter and Ramaty in certain assumptions led to a maximal dimension of the positron source $\sim 3.10^8$cm [20] . This value corresponds to a mass of a Schwarzscild black hole $500 M_\odot$.

3. Lacy, Townes and Hollenbach [17] trying to interprete theoretically their own observations on [Ne II] , come to following conclusions:

a) The observed density run ($n \sim r^{-4}$) of compact clouds is compatible with the rate of generation of clouds ($2\cdot 10^{-3}$ yr^{-1}) if one assumes that the clouds are formed at stellar disruptive collisions. Existence of massive body ($M \gtrsim 10^6 M_\odot$) should lead to more intensive mechanism of cloud formation - tidal disruption, which is undesirable according, to authors,

* At the time the paper [16] was written only the upper limit $L_x \sim 10^{36}$ erg.s^{-1} was known.

from both predicted cloud velocity and tidal luminosity considerations*.

b) Very difficult it is to explain the radiation flux necessary to support the ionization of Ne by radiation of accretion disk surrounding the massive black hole. The increasing of accretion rate (i.e. the hole mass) should contradict the observed flux on $2\,\mu m$.

These arguments are partly removed if the hole mass does not sufficiently exceed $10^3 M_\odot$.

From presented results on determination of the hole mass, less model - dependent are that from p.1 and 3b; the value (1), moreover, not strongly depends on free parameters.

Special attention should be paid to the question of ionization flux, so far as its parameters may be obtained from already available observation data on [Ar II] [21] , [Ar III] [8] , Brα, Brγ [22] , HeI [10] etc.

Rees [23] has reviewed the arguments against the massive $(M \gtrsim 10^6 M_\odot)$ black hole and claimed that the model of two-temperature ion-pressured torus can remove them (i.e. the difficulties related with disk accretion). In spite of attractiveness of that model, it is difficult to justify the assumed

*Note an additional argument. A massive object will not only open another chanal of cloud formation (tidal), but will distort the observed distribution law (r^{-4}), so far as steller velocity becomes dependent on radius. This fact does not depend whether one neglects by density cusp or not.

complete absence of collective plasma processes, which can quickly equal the electron and ion temperatures and therefore "shut up" the torus into disk.

Besides the model of black holes, the model of pulsar was suggested repeatedly [24 - 26] . It was known, however, that the properties of pulsars raughly can explain the observational data: the needed high rate of positron production [20], the high radio luminosity and the absence of significant space motion of Sgr A West [27] , etc. Model of planetary nebulae was discussed also, whose radiation is apparently unsufficient to support the needed ionization degree [17].

As will shall see below, the result following from dynamical approach presented, completely reject both the pulsar and planetary nebulae models.

4. Lower Limit to Object's Mass.

As one could easily see, all presented above estimations of the black hole mass assumed to be located at the Galactic Centre, in fact concern the upper limit of the mass only. Here we inquire into the possibility of determination of lower limit of this parameter of principal importance.

Assume a massive compact object* is situated at the center of star cluster. As was originally mentioned by Bahcall

* We suppose that objects CCD 1 and 2 are not related with Galactic Centre.

and Wolf [28] a massive black hole of a mass M due to the interaction with stars should oscillate respect the centre of the cluster, with an amplitude

$$r_c \left(\frac{m}{M}\right)^{1/2} , \tag{2}$$

where r_c is the clueter core radius.

For more detailed analysis of this process it is necessary to proceed from stochastic differential equation introducing a δ-correlated source, in the simplest case in Langevin form

$$M \frac{d^2\xi}{dt^2} = F(t) + U , \tag{3}$$

where U is the regular part of the force (resistance force, etc.) and $F(t)$ - the fluctuating. The latter satisfies the conditions

$$\langle F(t) \rangle = 0$$
$$\langle F(t) F(t') \rangle = \alpha \delta (t-t') , \tag{4}$$

where $\langle \rangle$ means, generally, averaging by ansemble. Function $F(t)$ is usually well approximated by Holtsmark distribution.

Acccording to the analysis from [29] if the mass of the object satisfies the inequality

$$M > 1 \cdot 10^2 M_\odot \left(\frac{n}{10^6 pc^{-3}}\right)^{-3} \left(\frac{r_c}{1 pc}\right)^{-6} \tag{5}$$

the object should oscillate with an amplitude given by (2). Otherwise the dynamics of the massive body should be determined by stochastic component of the field and the former should execute a Brownian motion within the cluster core.

So far as point source Sgr A West coincides with IRS 16

within uncertainity $a = 1'' - 2''$, which is assumed to be localized at the mass centre of Galaxy, we conclude that the role of stochastic processes is suppressed, i.e. inequality (5) is fulfilled for the conditions of Galactic Centre. Exqluding from (5) using (2) we find, that the mass of the compact object will satisfy the condition

$$M > 1.34 \cdot 10^2 M_\odot \left(\frac{n}{10^6 pc^{-3}}\right)^{-3/4} \left(\frac{a}{1''}\right)^{-3/2} . \tag{6}$$

Thus, the presented in fact model-independent approach (i.e. without modelling the processes of accretion, formation of annihilation line, etc.) allows us to obtain the lower limit of the mass of compact object. Evidently, the latter can be neighter pulsar and planetary nebulae nor any star-mass object.

To whom of the known sources can be applied this estimation, besides evidently to the point source Sgr A West? Following versions are possible:

1. Point radio source does not coincide with IRS 16 which is the real center of Galaxy (mass center). Then (6) respects to the radio source and a is displacement between it and IRS 16;

2 Radio source and IRS 16 are one and the same object which is not located at the real Galactic Centre. Then a is its displacement from the centre and (6) respects to that object;

3. Radio source does not coincide with IRS 16, which is, not the Centre of Galaxy. Then (6) is applicable to IRS 16 too, where a should be its displacement from the real Centre.

To choose between this possibilities and therefore to do more definite conclusion on the nature of Galactic Centre will allow observations with higher resolution ($< 1''$), particularly by means of IRAS.

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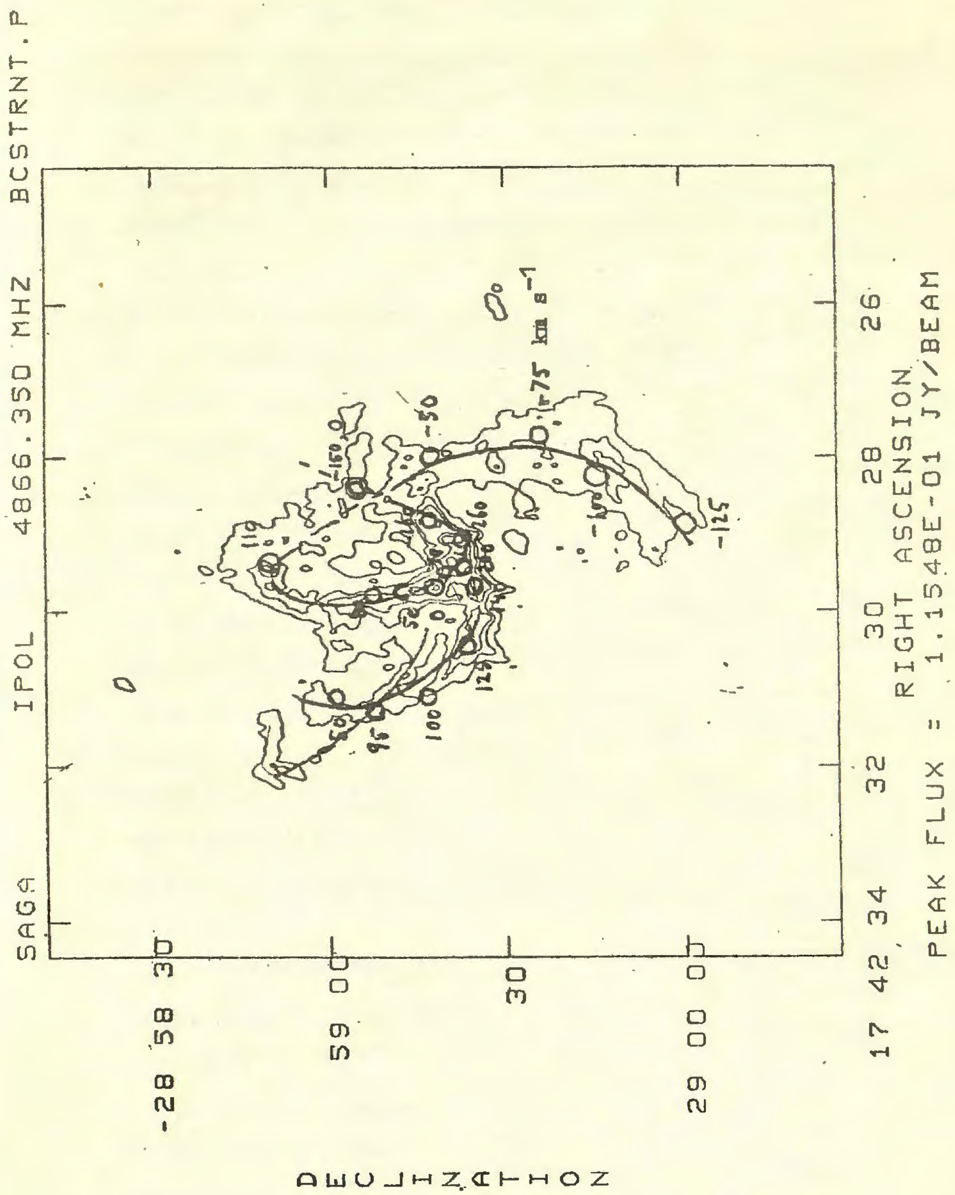

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