astro950 Methods and Project Planning

Short proposal for Master Thesis

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Thesis Title:
Determination of the Mass Distribution in the Galactic Centre from the Stellar Motions

The central parsec of our Galaxy harbours a super-massive black hole (SMBH), associated with a compact radio source Sgr A*. It is surrounded by a spherical cluster of old stars with broken power-law density profile. At radius 1.8 pc of the Sgr A* is a molecular ring, known as the circumnuclear disk (CND).

Recent NIR observations revealed presence of few tens of young OB stars in the central 0.4 pc of the Sgr A*. Further analysis of their positions and velocities suggests that these stars form two structures with coherent rotation patterns. These structures are known as clockwise disk (CWS) and the counter-clockwise disk (CCWS). These disks were investigated using the normalised angular momentum along the line of sight

$$j = \frac{xv_y - yv_x}{\sqrt{(x^2+y^2)(v_x^2+v_y^2)}}. \tag{1}$$

Spatial disk-like structure of the CCWS is less confident and its stars have value of j scattered around ~ -1. The CWS disk is more confident disk-like structure. The inner part of the CWS disk follow the $j \sim +1$, while the part outside the 0.22 pc radius shows a deflection in the mean value of j and is more erroneous.

The main aim of the thesis is to study the perturbing potential through deformation of the CWS disk. The disk will be modelled as a set of testing particles moving under influence of the gravitational potential dominated by the central potential of the SMBH. This central potential is perturbed by the axi-symmetrical potential due to the CND and the spherical potential due to the cluster of old stars. The perturbing potential causes a secular evolution of the orbital elements of testing particles. This long-term evolution leads to the deformation of the initial spatial structure.

The rate of the secular evolution depends on two groups of parameters. The first group characterise the perturbing potentials: $M_{\mathrm{SPHE}}/M_{\bullet}$, profile of the spherical perturbation γ_{SPHE}, $M_{\mathrm{SPHE}}/M_{\mathrm{CND}}$ and a_{CND}/a_*. The second group of parameters characterise initial orbital elements of the testing particles, a_*, e_*, ω_* and so called Kozai constant $c_1 = \sqrt{1-e_*^2}\cos i_*$. The inclination of the orbit i_* with respect to the CND plane is determined by e_* and c_1.

The chosen parameters of the perturbing potential determine the rate of secular evolution of the orbital elements. Hence, if the CWS disk was initially assumed as planar, then, due to the secular evolution of the orbital elements, it changed its spatial structure. Preliminary simulations show different magnitudes of the disk deformation for different potential parameters. The whole parameter space of the modelled system is wide, but the current state of observations and the preliminary simulations indicate possible restrictions on number of scanned parameters. The most important change of all the orbital elements is that of the longitude of the ascending node Ω. This long-term change is mainly due to the axi-symmetrical perturbation. Therefore the evolution of the modelled CWS disk enables us to limit some of the potential parameters, e.g. limit the mass of the CND in the way independent on observed molecular emission.

astro940 Scientific Exploration of the Master Thesis Topic

Essay

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Determination of the Mass Distribution in the Galactic Centre from the Stellar Motions

The central parsec of our Galaxy harbours a super-massive black hole (SMBH), associated with a compact radio source Sgr A*. It is surrounded by a spherical cluster of old stars with broken power-law density profile (Genzel et al. (2003), Schödel et al. (2007)). The break radius $R_{\text{break}} = (6 \pm 1)$" divides inner power-law density profile with power-law index $\gamma_{\text{inner}} = (1.19 \pm 0.05)$ and the outer power-law density profile with index $\gamma_{\text{outer}} = (1.75 \pm 0.10)$. Such power-law density profile is consistent with the theoretical work by Bahcall and Wolf (1977) for a steady-state distribution of two-mass star cluster near a black hole.

Observations show a well-defined molecular ring, known as the circumnuclear disk (CND), at radius of 1.8 pc of the Sgr A*. The estimate of the total mass of CND lies in the range from $\sim 10^4\,M_\odot$ (Genzel et al. (1985)) to $\sim 10^6\,M_\odot$ (Christopher et al. (2005)).

Recent near-infrared (NIR) observations and data analysis of the central 0.4 pc revealed two disk-like structures composed of a few tens of young OB supergiants, giants and main sequence stars (Levin & Beloborodov (2003), Genzel et al. (2003), Paumard et al. (2006)). These disks are usually referred to as the clockwise disk (CWS) and the counter-clockwise disk (CCWS), depending on their direction of rotation with respect to the galactic rotation. The thesis is focused on study of the CWS disk. This disk consists of young stars (6 ± 2) Myr old, orbiting the central SMBH on eccentric orbits with eccentricities $e_{\text{CWS}} \in [0.2; 0.3]$. The disk has a sharp inner edge at 0.04 pc of the Sgr A*. The outer edge is roughly 0.4 pc, but its determination is less confident.

At the first approximation the CWS disk can be considered as a set of testing particles moving on nearly Keplerian orbits in the central potential of the SMBH. The dominating central potential is perturbed by the spherical potential of the cluster of old stars and the axi-symmetrical potential of the CND. The composed perturbing potential causes secular evolution of the stellar orbits. The long-term evolution of orbits due to the axi-symmetrical perturbing potential was described by Kozai (1962). Ivanov et al. (2005) applied a similar method on a dense stellar cluster in the binary black hole system assuming the nearly Keplerian orbits of stars around the primary BH perturbed by the secondary one.

The rate of the secular evolution of the orbital elements of CWS disk stars depends on several parameters characterising of the perturbing potentials and on the initial orbital elements of considered testing particles. This long-term evolution of the orbital elements deforms the initially assumed planar disk. Study of this deformation and its dependence on the parameters of perturbing potentials should set independent limits on mass in the CND and possible limits on mass in the central spherical cluster.

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