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Opponent report on Dr.Jiří Kovář's Habitation Thesis

I take great pleasure in providing a report on Dr.Jiří Kovář's Habitation Thesis. I have known him for several years. We first met at Prague in 2011, and immediately started research collaboration. He worked so hard that our collaboration work was successfully published. Since then we met several times in Japan and in Czech Republic. I have a good opinion of him and his work.

His main research concern is theoretical modeling of electrically charged fluid structures rotating around compact objects, such as black holes or neutron stars. For a neutral particle or fluid, a stable circular orbit is centered on equatorial plane, since central gravity and centrifugal force should be balanced in cylindrically radial direction. By incorporating electro-magnetic interaction, a new feature arises: It is possible that the orbit is centered above or below equatorial plane. That is, levitation of circular orbit. Actually, such an off-equatorial orbit of charged dust grains can be seen in polar region of planetary magnetosphere. Dr.Kovář comprehensively studied the dynamics of charged particle or fluid in the framework of general relativity. That is natural extension to strong gravity regime. The motion is periodic in azimuthal direction, and meridian section is bounded, since there are two integrals, which correspond to generalized energy and angular momentum. The trajectory forms a torus in three-dimensional space. The orbit is not in general closed, and the surface in meridian sector is explored by recurrence map. It represents strength of complexity of the motion. It is very interesting to study the transition from regular to chaotic orbits by changing a certain parameter.

Charged fluid-structures encircling compact objects are studied by two approaches in the work of Dr.Kovář. One is test-particle approximation, in which pressure is ignored in the limit of dilute gas. The motion of a charged particle is studied in various background metrics and electromagnetic fields. By analyzing an effective potential in meridian section, orbits are classified. This pressure-less fluid approach can be considered as a kind of preliminary study of the charged fluid motion, and good survey is provided. Subsequently, the work is extend to more general charged fluid by magneto-hydro-dynamical treatment. Various types of toroidal structures are demonstrated. The pressure, density, temperature and charge profiles are also explored. Formation of an off-equatorial torus is also shown under a certain condition. It is therefore very interesting that the halo orbit is likely to occur in the vicinity of a compact object's polar-region under more realistic circumstances.

In many astrophysical processes coupled with electro-magnetic interaction, the ideal MHD regime has been explored. That is, charged density distribution is completely ignored in the approximation, where the electric field is given by magnetic field and plasma velocity. Large-scale MHD simulations are also popular and have been performed to study dynamical phenomena under the Newton or Einstein gravity, such as solar atmosphere, star formations, accretion disks and outflows/jets. Theoretical approach by Dr.Kovář et al. is complementary. At present, there is no astrophysical observation, to which charged fluid model circling close to a general relativistic object is applied. Nobody knows how a counterpart of charged dust-grains dynamics observed in the planetary magnetosphere is realized in a system containing black hole or neutron star. Astrophysical observation has been rich and mysterious at any period. It is not easy to observe the stationary model itself, but a structural change between equilibrium states may be related to energetic events such as bursts. For example, high energy flares in the vicinity of a black hole or irregular sub-pulse components of pulsars may be associated to the transition of the charged fluid structures. Modeling of charged fluid torus will be potentially useful from a viewpoint of fundamental theory. As a first step, the comprehensive research on existence and properties of halo orbits by Dr.Kovář is unique, and very important. Stability of the structure in relation to dynamical transition would be also valuable as the future work.

Dr.Kovář's habitation thesis vastly exceeds the requirement for approval. Moreover I have recognized during our collaboration in the past that he is a very hard-working excellent researcher. For the above reasons I strongly support his habitation.

Best Wishes

Yasufumi Kojima