論文の内容の要旨

論文題目

Studies of equilibrium states with magnetic field and meridional flow in astrophysics (天体物理学における磁場や子午面流を伴った平衡状態の研究)

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We have considered and calculated equilibrium states with magnetic field and meridional flow in astrophysics under the assumptions of stationary and axisymmetric barotropes. We have obtained many equilibrium states across the widely astrophysical areas in order to understand equilibrium configurations deeply.

In our present formulation, arbitrary functions of the magnetic flux function appear in the expression for the current density in case of magnetic field configurations. By appropriately choosing the functional form for one of the arbitrary functions that corresponds to the distribution of the non force-free toroidal current density, we have obtained magnetized equilibrium states with extremely strong but highly localized poloidal magnetic fields in the second chapter. The absolute values of the central magnetic fields are stronger than those of the surface region by two orders of magnitude. By applying our results to magnetars, the internal magnetic poloidal fields could be 10^{17} G, although the surface magnetic fields are about 10^{15} G in the case of magnetars. For white dwarfs, the internal magnetic poloidal fields could be 10^{12} G, when the surface magnetic fields are 10^{9-10} G. If the star has such extremely strong but localized poloidal magnetic field deep inside, the contributions from higher order magnetic multipole moment to the outer fields around the star cannot be neglected.

We have showed the importance of coexistence of oppositely flowing φ currents for magnetized stars to sustain strong toroidal magnetic fields within the stars by analysing stationary states of

magnetized stars with surface currents which flow in the opposite direction with respect to the bulk currents within the stars in the third chapter. If the stars could have the toroidal surface currents which flow in the opposite directions to the internal toroidal currents, the positively flowing internal toroidal currents can become stronger than the upper limit value of the current for configurations without surface toroidal currents. Thus, the energies for the toroidal magnetic fields can become much larger than those for the magnetized stars without surface toroidal currents.

The physical meaning of the oppositely flowing toroidal current density has been discussed in the fourth chapter. We have showed a sufficient condition for magnetized star with large toroidal magnetic fields in stationary and axisymmetric system. As we have seen in the third chapter, the magnetized star with large toroidal magnetic field has oppositely flowing non force-free toroidal current density, and such oppositely flowing toroidal current density changes the stellar shape prolate. These results mean that the large toroidal magnetic fields result in and result from the prolate stellar deformation and oppositely flowing non force-free toroidal current density. A condition that a star has oppositely flowing non force-free toroidal current density and its shape is prolate is sufficient for large toroidal magnetic fields inside the star.

We have succeeded in obtaining magnetic field configurations with both poloidal and toroidal components throughout magnetized stellar interior and exterior in the fifth chapter. We have divided the magnetized star into a hydromagnetic equilibrium core, a Hall equilibrium crust and a twisted force-free magnetosphere. We have calculated these regions under various boundary conditions simultaneously and systematically using the Green function relaxation method and found four interesting characteristics of numerical results. First, the core toroidal magnetic fields and the twisted magnetosphere make the size of the crustal toroidal magnetic field region large in Hall equilibrium. Second, the current sheet on the core-crust boundary affects both internal and external magnetic field configurations. Especially, the negative and positive current sheets make the core magnetic field energy ratio $\mathcal{M}co/\mathcal{M}$ large and small respectively. Finally, the twisted magnetosphere makes a cross-point of magnetic field lines such as X-point geometry in the magnetosphere. The X-point geometry appears and disappears according to the strength of the twisted field in the magnetosphere or the core-crust boundary conditions. Our results mean that both Hall MHD secular evolution and magnetospheric dynamical evolution would be deeply affected by conditions of another region and core-crust stress of magnetars.

We have obtained the general forms for the current density and the vorticity from the integrability conditions of the basic equations which govern the stationary states of axisymmetric magnetized self-gravitating barotropic objects with meridional flows under the ideal magnetohydrodynamics (MHD) approximation in the sixth chapter. As seen from the stationary condition equations for such bodies, the presence of the meridional flows and that of the poloidal magnetic fields act oppositely on the internal structures. The different actions of these two physical quantities, the meridional flows and the poloidal magnetic fields, could be clearly seen through stationary structures of the toroidal gaseous configurations around central point masses in the framework of Newtonian gravity because the effects of the two physical quantities can be seen in an amplified way for toroidal systems compared to those for spheroidal stars. The meridional flows make the structures more compact, i.e. the widths of toroids thinner, while the poloidal magnetic fields are apt to elongate the density contours in a certain direction depending on the situation. Therefore, the simultaneous presence of the internal flows and the magnetic fields would work as if there were no such different actions within and around the stationary gaseous objects such as axisymmetric magnetized toroids with internal motions around central compact objects under the ideal MHD approximation, although these two quantities might exist in real systems.

We have evaluated the stellar deformation by the meridional flows in the seventh chapter. We have shown analytically that shapes of incompressible stars could be prolate if appropriate meridional flows exist. Although this result is strictly valid only if either the meridional flow or the rotation is absent and the vorticity is associated uniformly with meridional flow, this implies that perpendicular forces against centrifugal and/or magnetic forces might play important roles within stars. A consequence of the presence of meridional flows might be to decrease stellar oblateness due to centrifugal and/or magnetic fields.