Charged perfect fluid around kerr black hole

Audrey Trova[1], Kris Schroven[1], Eva Hackmann[1], Vladimír Karas[2], Petr Slaný[3], Jiří Kovář[3]

[1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), Bremen, Germany
[2]Astronomical Institute, Academy of Sciences, Prague, Czech Republic,
[3]Institute of Physics, Faculty of Philosophy and Science, Silesian University in Opava, Opava, Czech Republic

Abstract

We are presenting an analytical approach for the equilibrium of electrically charged perfect fluid surrounding a rotating charged compact object ($Q \neq 0$), embedded in an asymptotically large scale uniform magnetic field ($B \neq 0$). The vertical and radial structure of the torus are influenced by the balance between the gravitational and the magnetic force. Following our previous study of rotating charged test fluids around a non rotating black hole, this time, we show that according to the spin of the black hole the existence of such structures change. In this work, we focus our attention on orbiting structures in permanent rigid rotation. We prove, in this rotating case also, the existence of equilibrium configurations in the equatorial plane (tori) and on the polar axis such as charged polar clouds. The equilibrium highly depends on the model parameters, such as the spin and the charge of the black hole, the uniform magnetic field and the angular velocity. We are also showing that in the case ($B = 0$, $Q \neq 0$) and ($B \neq 0$, $Q = 0$), the rotation of the black hole allows the possibility of equilibrium fluid in both configurations.

Introduction

Our purpose is the study of the equilibrium of charged perfect fluid encircling a charged Kerr black hole. These equilibrium toroidal configurations are important to understand the physics of accretion discs around compact objects [1, 2]. Many studies of perfect fluid tori (equilibrium/dynamics) have been done with various spacetimes, from the Schwarzshild, the Reissner-Nordström-de Sitter to the Kerr background [3, 4]. Other works have been done by adding the impact of a magnetic field (dipolar, uniform,...)[5, 6].

Set-up of the model and hypotheses

We have the same background as in [6] but we include effects of the rotation of the black hole.

- The self-gravitational and the electromagnetic field produced by the fluid are neglected.
- The fluid has a polytropic equation of state ($p = \kappa\rho^{\Gamma}$) and has an organized rotational motion.
- We are working with a constant angular velocity ω (permanent rigid rotation).
- the turbulence and the viscosity are neglected and the conductivity of the medium is set to zero.

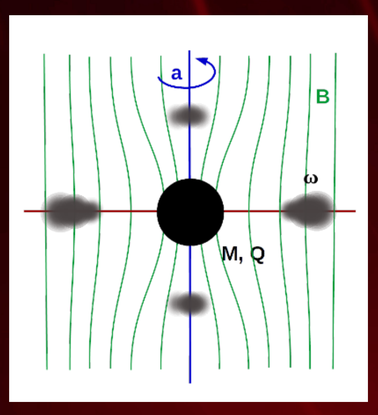

Figure 1: Background of our work

We focus our study on two different configurations:

- a regular one, located in the equatorial plane (toroidal configurations)
- a unique one, located on the polar axis of the black hole (polar clouds configurations), see Fig.1.

The whole system is immersed in an asymptotically uniform magnetic field

Equilibrium of charged perfect fluid

The figures 2, 3 and 4 show the effective potentiel map of an equilibrium polar cloud and two equilibrium tori, respectively.

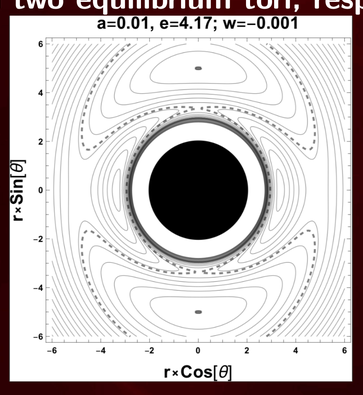

Figure 2: Enthalpy map of polar cloud

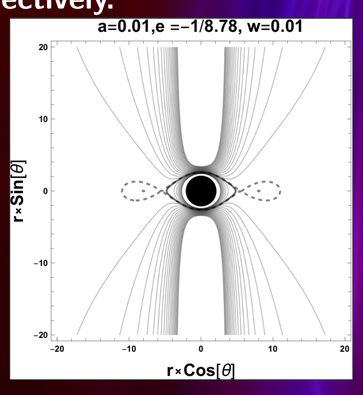

Figure 3: Enthalpy map of eq. tori

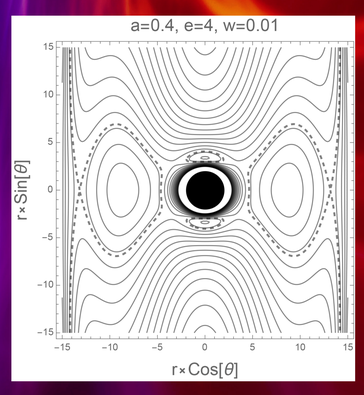

Figure 4: Enthalpy map of eq. tori

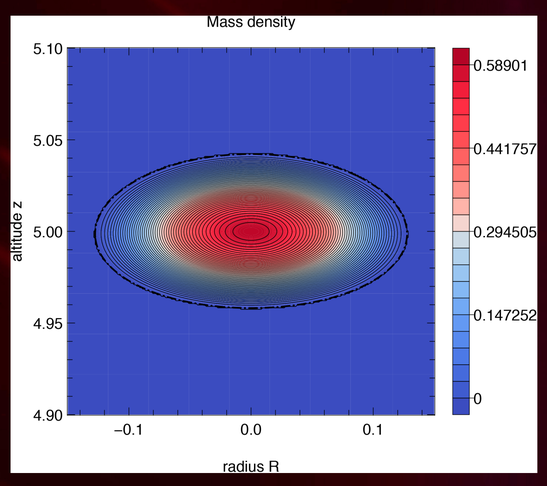

Figure 5: Density map of polar cloud ($a = 0.01$)

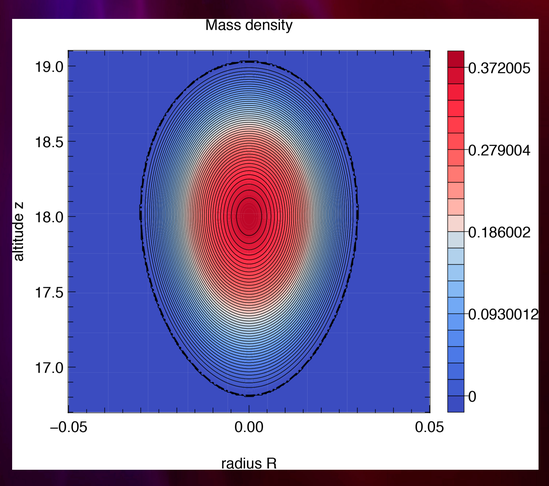

Figure 6: Density map of polar cloud ($a = 0.9$)

Influence of the rotation of the black hole on the fluid

To study the influence of rotation of the black hole, we play with the parameter a. Figure 5 and 6 shows, via the density function, the equilibrium configuration of a polar-cloud type for two different values of a: (i) $a = 0.01$ (slowly rotating black hole, Fig. 5), (ii) $a = 0.9$ (fast rotating one, Fig. 6).

- In the slow case, the morphology is basically the same as in the non rotating case, i.e. ellipsoidal shape.
- In the case of a fast rotating black hole, the morphology move to an oblate spheroid.
- In the polar cloud case, we showed that increasing the value of a, increase the distance from the central mass, where a tori can exist.

Effective potential

The fluid equilibrium is described by the effective potentiel derived from the conservation laws and Maxwell's equations.

$$h = -\ln|U_t| - \ln(1 - \omega l) + \int_S f(S)dS \qquad (1)$$

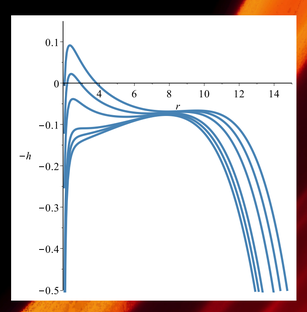

Figure 7: top $a = 0.9$, bottom $a = 0.01$

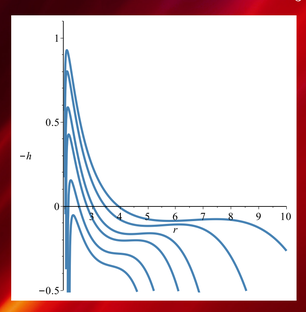

Figure 8: top $a = 0.9$, bottom $a = 0.01$

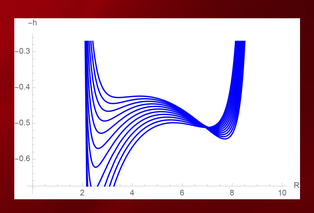

Figure 9: top $a = 0.9$, bottom $a = 0.01$

Particular cases

We also worked on two limiting cases ($B = 0$, $Q \neq 0$) and ($B \neq 0$, $Q = 0$).

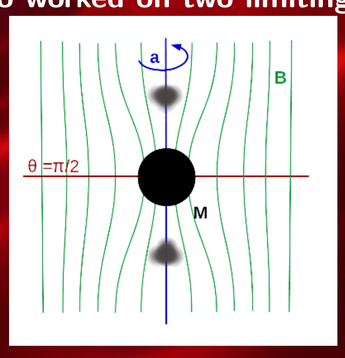

Figure 10: $B \neq 0$, $Q = 0$

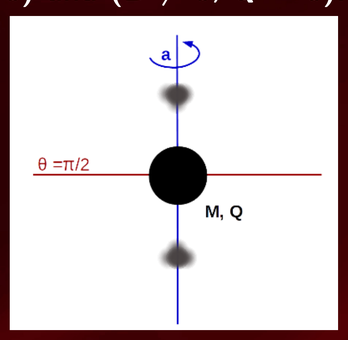

Figure 11: $B = 0$, $Q \neq 0$

In [6], in the polar cloud configuration, no solution was possible. The conditions of existence with $a = 0$ was not satisfied.
New result → EQUILIBRIUM POLAR CLOUDS CAN EXIST
Note → Solutions relatively close can be found.
Implication → In absence of charge Q or magnetic field B, the rotation of the black hole is crucial and allows the possibility of polar equilibrium solution in rigid rotation.

Ongoing work

- **What about the constant angular momentum case ?**
- **Realistic charged density ?**
- **Self-gravity ?**

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E-mail: audrey.trova@zarm.uni-bremen.de
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