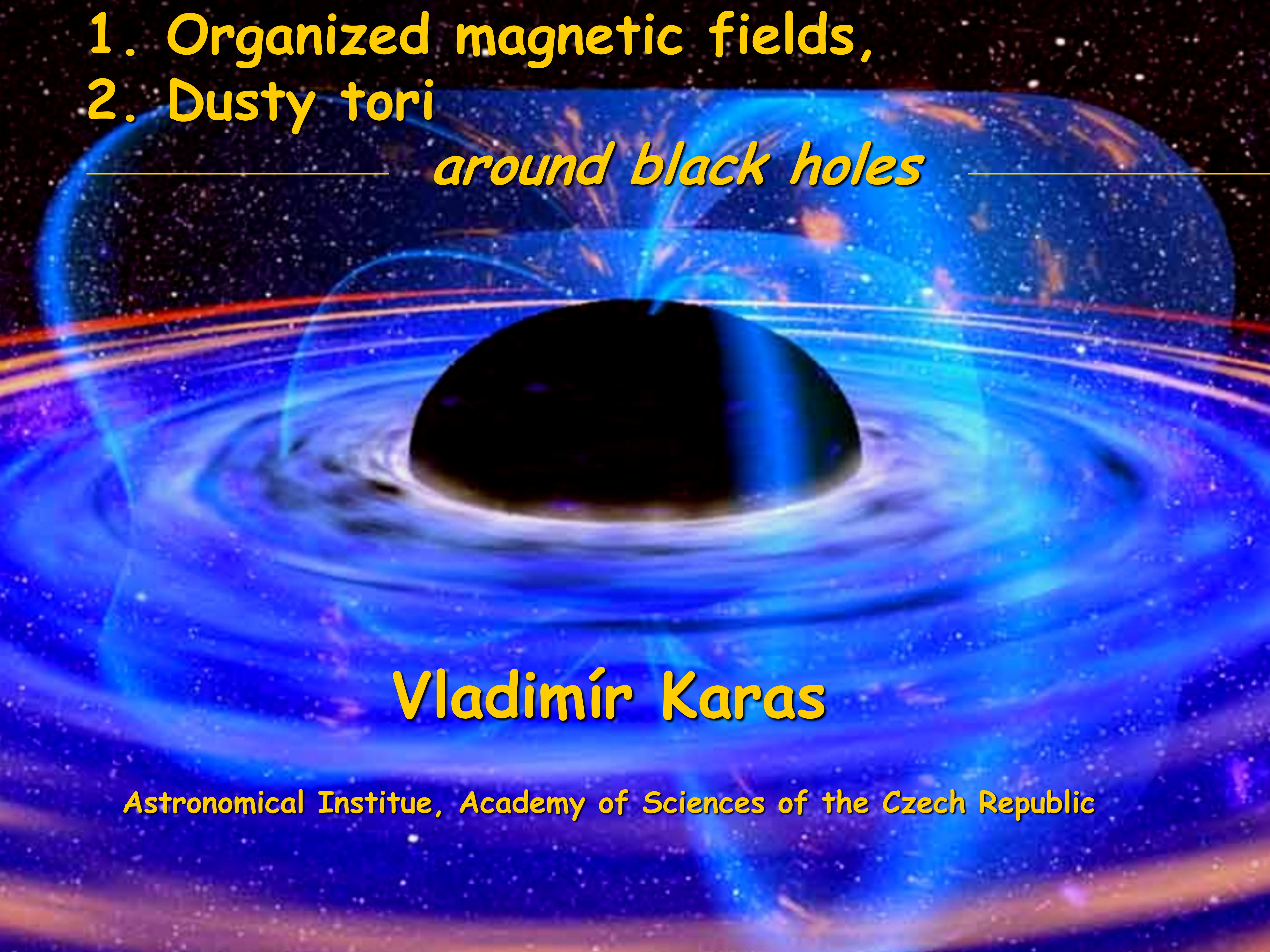
1. Organized magnetic fields,
2. Dusty tori

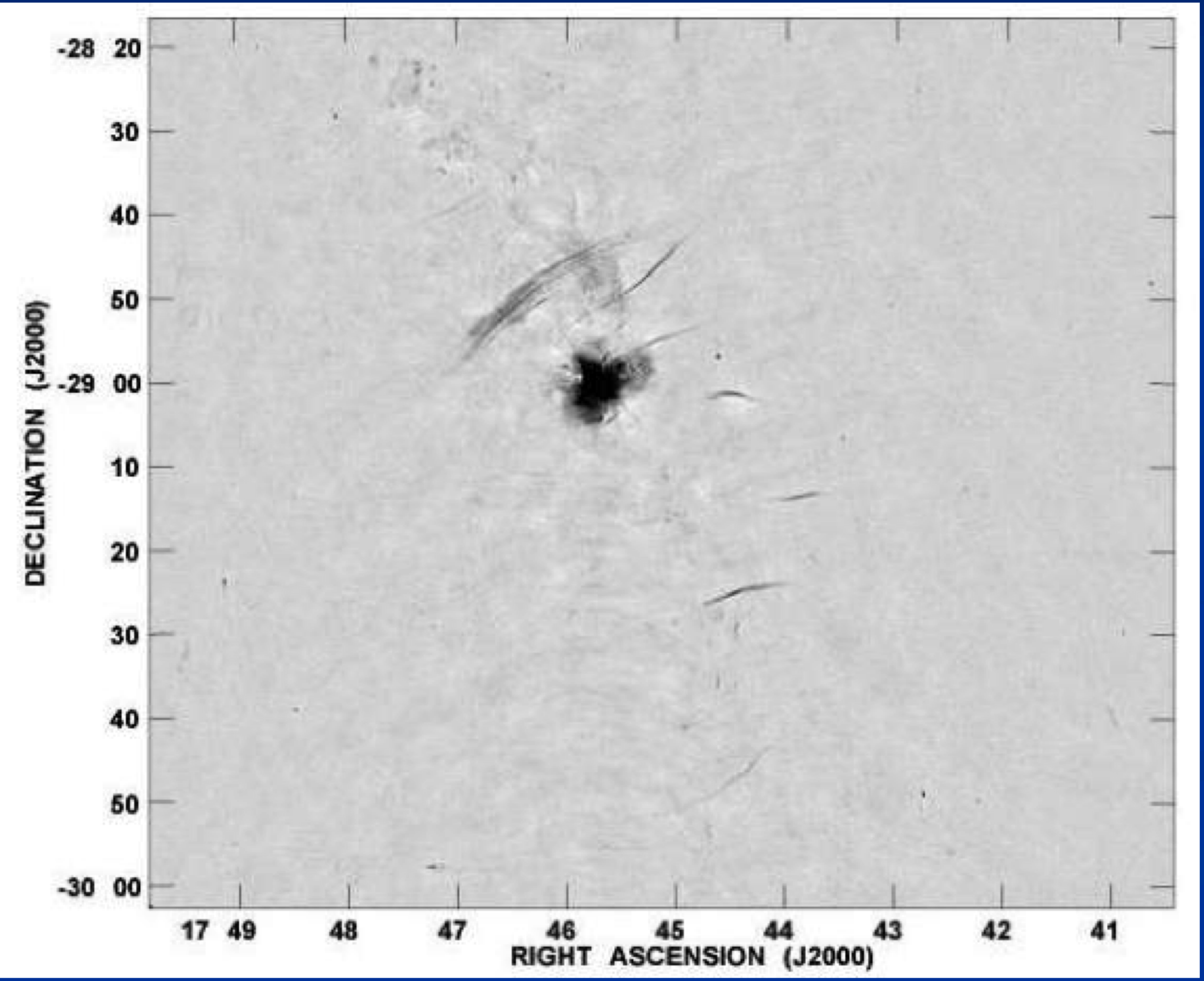
around black holes



Vladimír Karas

Astronomical Institue, Academy of Sciences of the Czech Republic

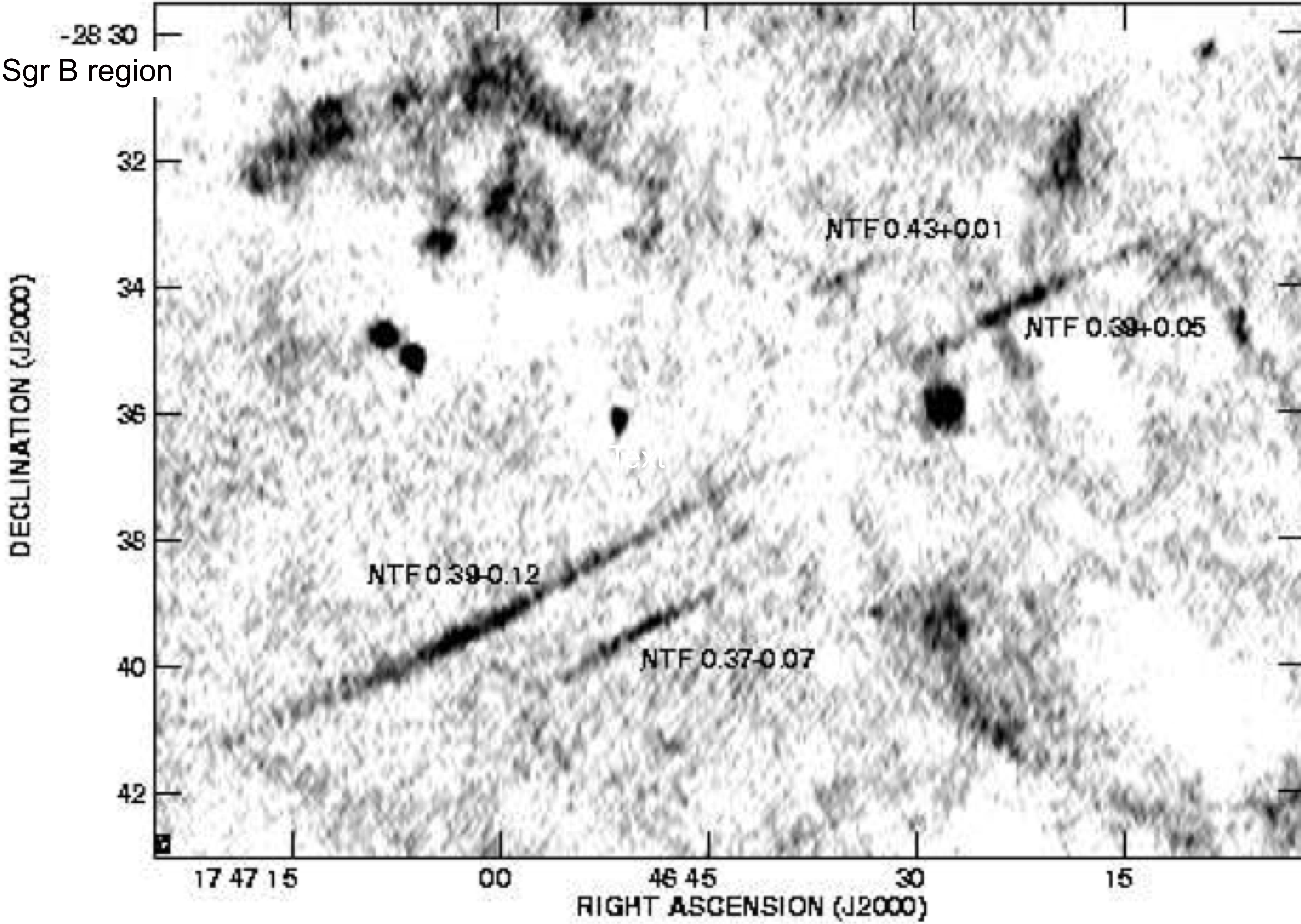
Motivation:
Non-thermal filaments in Galactic Center



The inner GC region and NTFs at 90 cm radio map; the inner ~1° region, resolution ~10″

(LaRosa & Nord 2004)

Sgr B region



-28 30
32
34
36
38
40
42
DECLINATION (J2000)
NTF 0.43+0.01
NTF 0.39+0.05
NTF 0.39-0.12
NTF 0.37-0.07
17 47 15
00
46 45
30
15
RIGHT ASCENSION (J2000)

- Filaments remain straight along their length (~1 x 40 pc)
- They cross the Galactic plane (almost) perpendicularly with little bending, $\pm 20°$
- Unique to GC, within ~150 pc from Sgr A*
- Non-thermal spectrum
- Strong linear polarization (~50%)

- Kinked shape can be seen in some filaments ("Snake")
- B can reach ~ 1 mG inside the filaments, but only ~10 μG elsewhere in the ISM (?)
- The filaments may be transient (unconfined) structures (?)

Curved spacetime

- Space-time metric: $g_{\mu\nu}(r,\theta) = \mathrm{Kerr\ black\ hole}$
- Weak, electromagnetic test-fields in a given, fixed background spacetime.

- ◇ Anile A. M., & Choquet-Bruhat Y. (eds.) (1989), *Relativistic Fluid Dynamics*, Lecture Notes in Mathematics 1385 (Springer, Berlin)
- ◇ Lichnerowitz A. (1967), *Relativistic Hydrodynamics and Magnetohydrodynamics* (Benjamin, New York)
- ◇ Znajek R. M. (1976), *Black Hole Electrodynamics*, PhD Dissertation (Univ. of Cambridge)
- ◇ Phinney E. S. (1983), *A Theory of Radio Sources*, PhD Dissertation (Univ. of Cambridge)

$c = G = 1$, and the signature of metric $-$+++

Conservation laws

- Conservation of the particle number:

$$(\rho_0 u^\alpha)_{;\alpha} = 0, \qquad \rho_0 = mn,$$

m is the particle rest mass,
n numerical density,
u^α four-velocity.

Note: we do not consider a possibility of pair creation.

- Normalization condition for four-velocity:

$$u^\alpha u_\alpha = -1$$

- Energy-momentum conservation:

$$T^{\alpha\beta}{}_{;\beta} = 0.$$

Energy-momentum tensor

$$T^{\alpha\beta} = T^{\alpha\beta}_{\rm matter} + T^{\alpha\beta}_{\rm EMG}$$

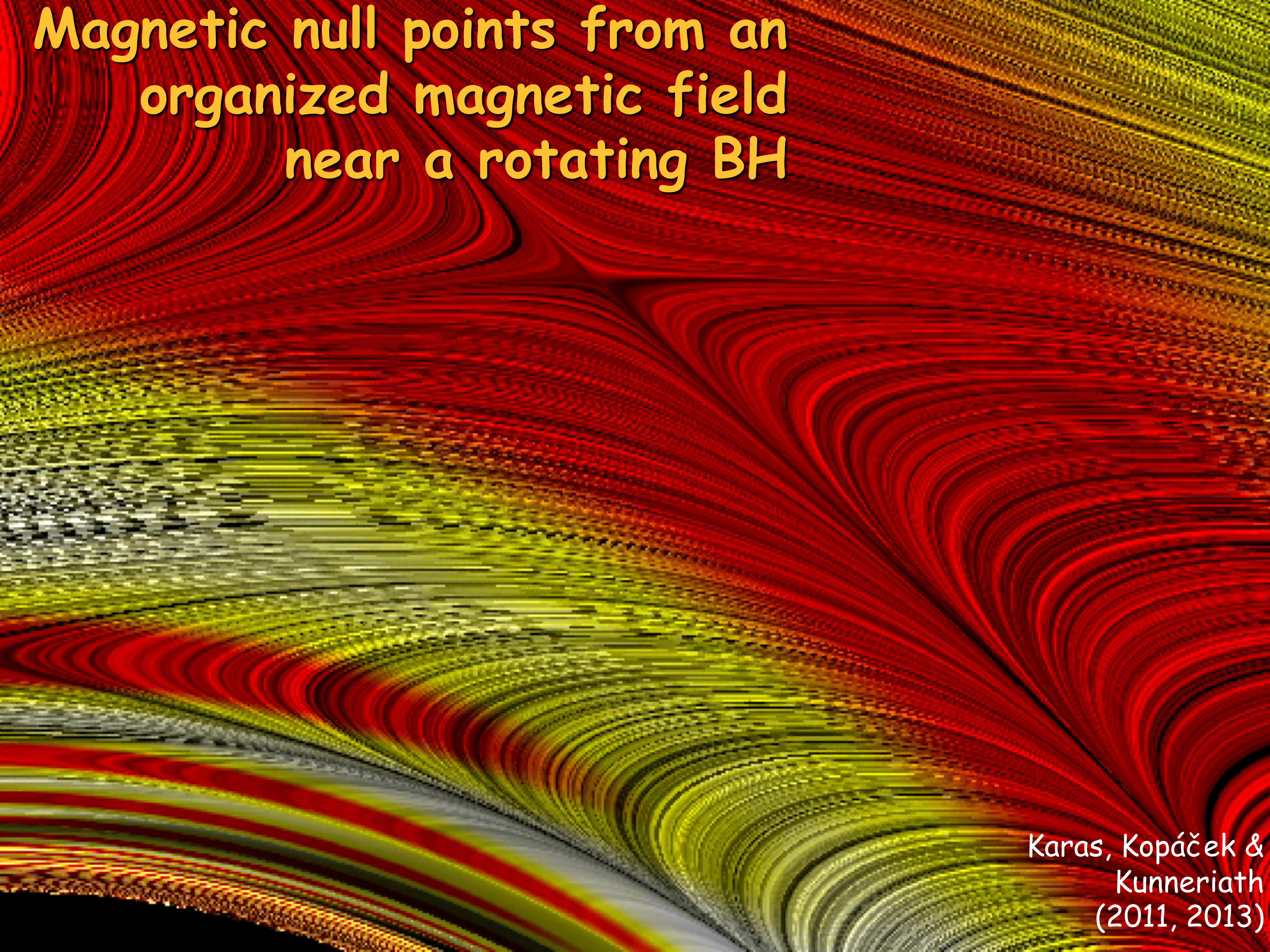
with

$$\begin{aligned} T^{\alpha\beta}_{\rm matter} &= (\rho + p)u^\alpha u^\beta + p g^{\alpha\beta}, \\ T^{\alpha\beta}_{\rm EMG} &= \frac{1}{4\pi}\left(F^{\alpha\mu}F^{\beta}_{\mu} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}g^{\alpha\beta}\right). \end{aligned}$$

Electromagnetic field tensor:

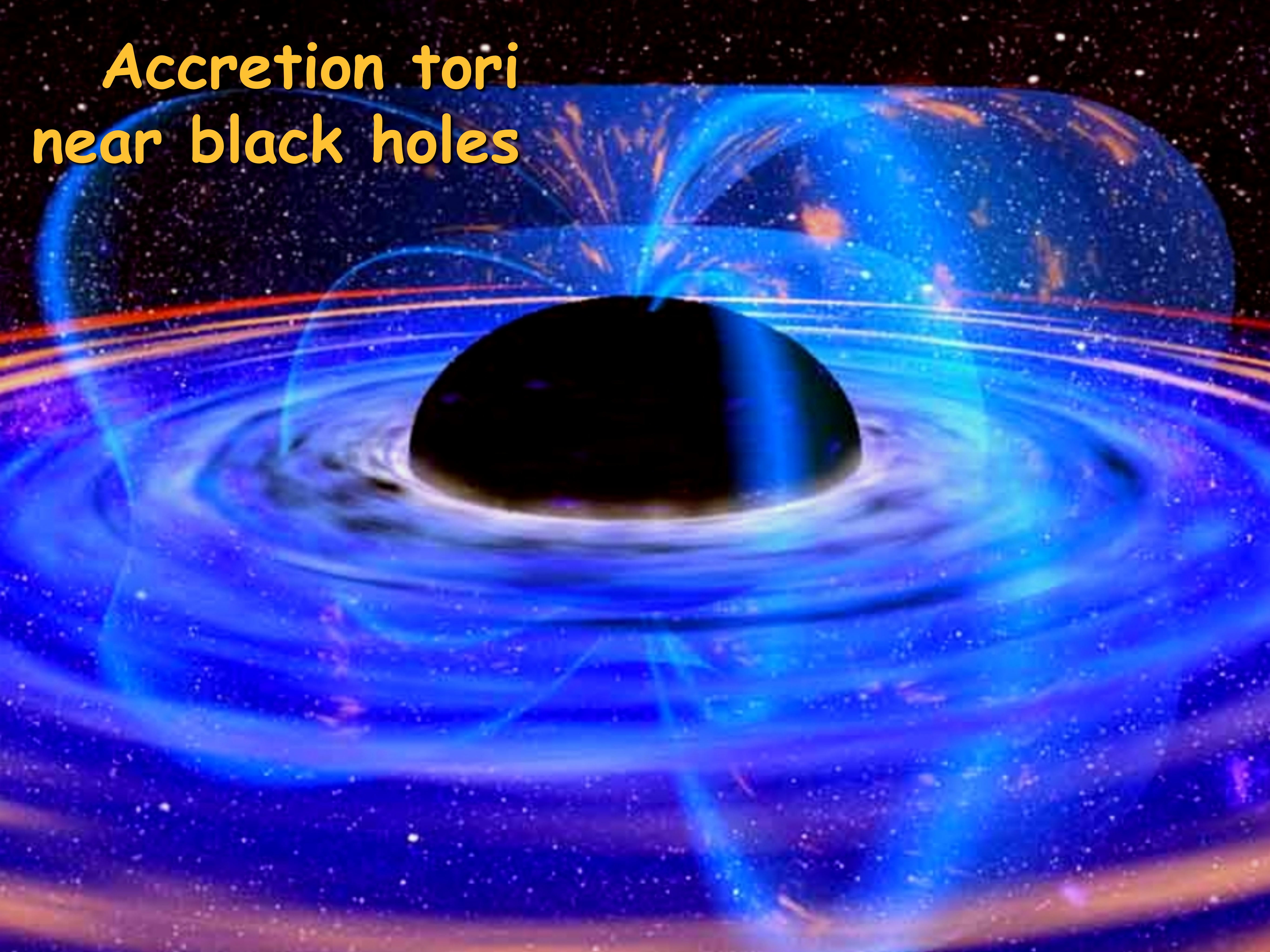
$$F_{\mu\nu} = A_{\nu,\mu} - A_{\mu,\nu}.$$

Magnetic null points from an organized magnetic field near a rotating BH

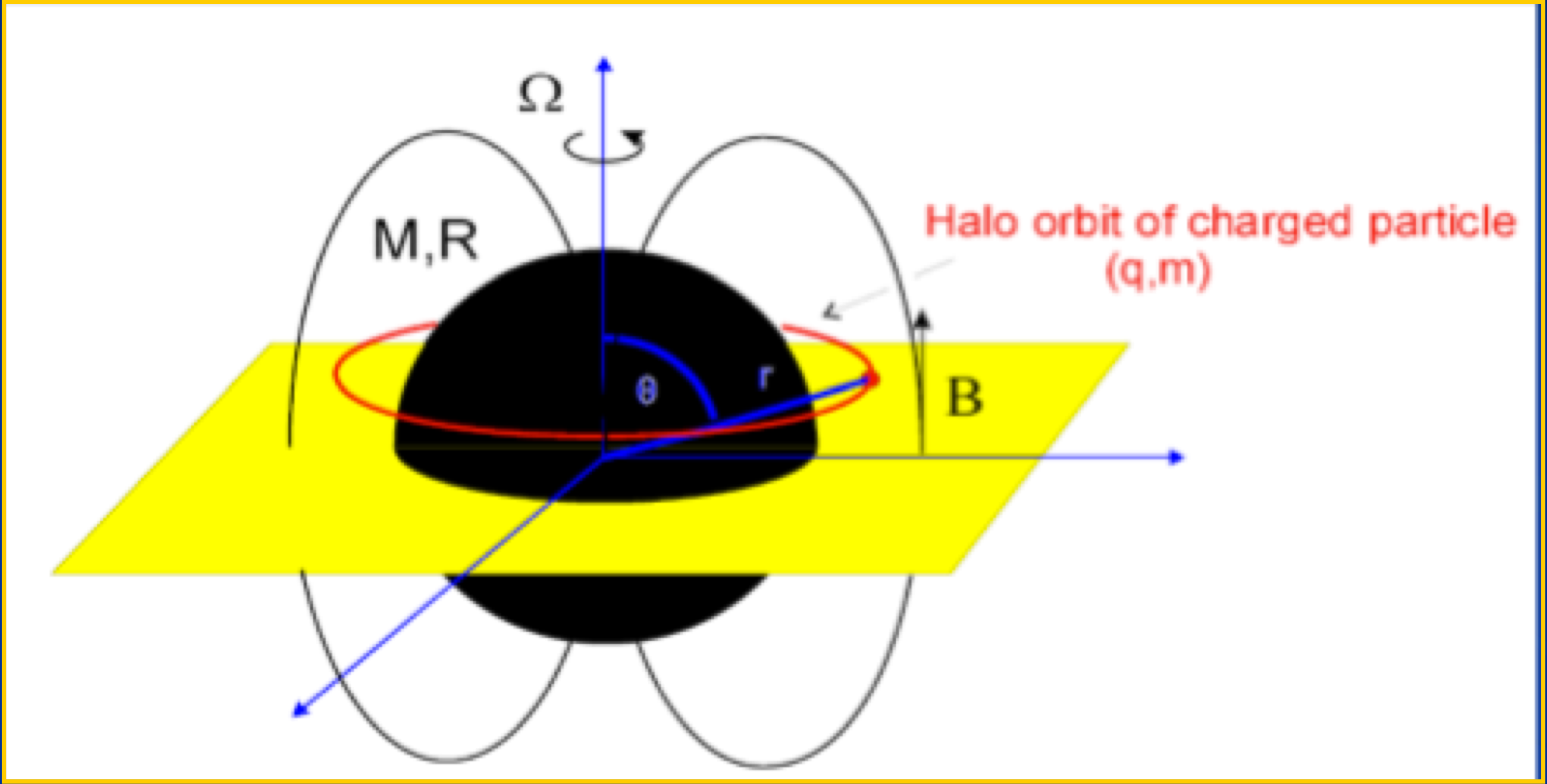


Karas, Kopáček & Kunneriath (2011, 2013)

Accretion tori near black holes

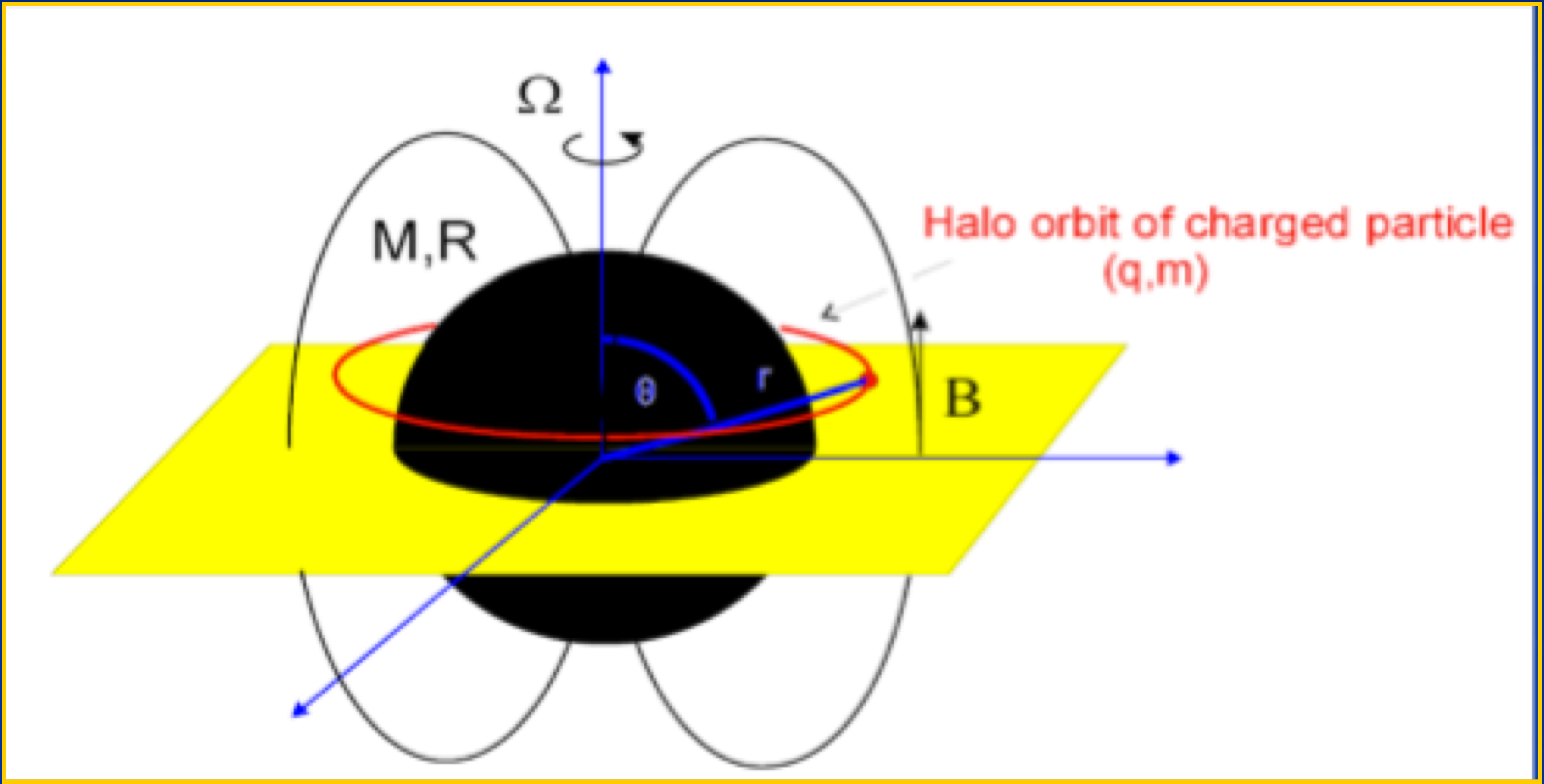


Context of particle orbits



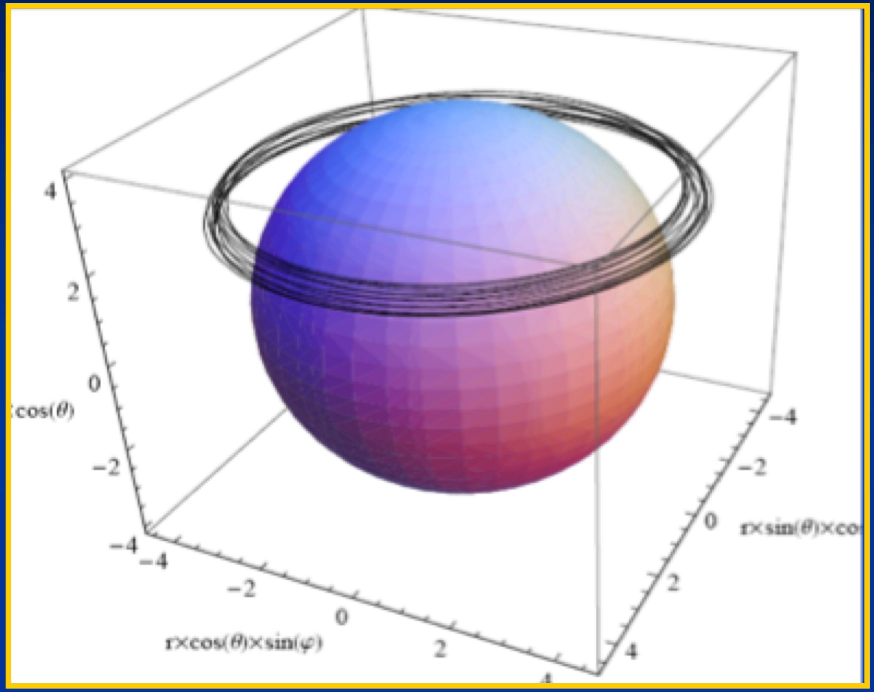
Context of particle orbits

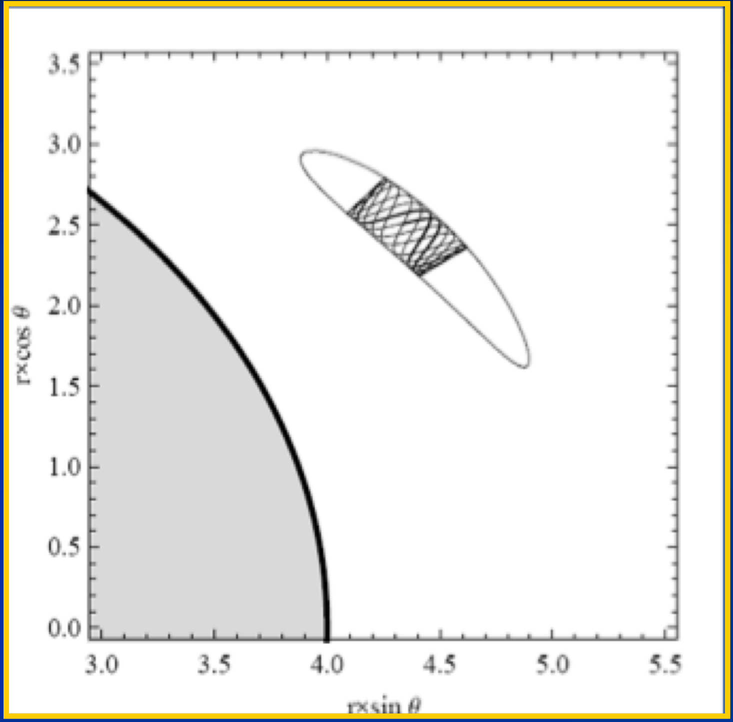
- **'Halo orbits'** – off-equatorial circular orbits at constant r and θ

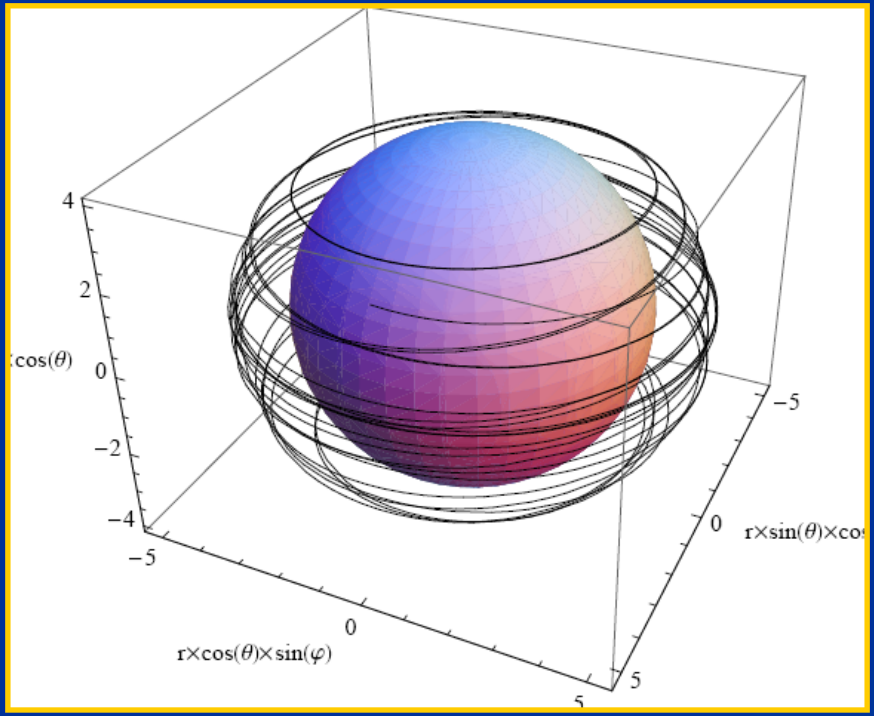


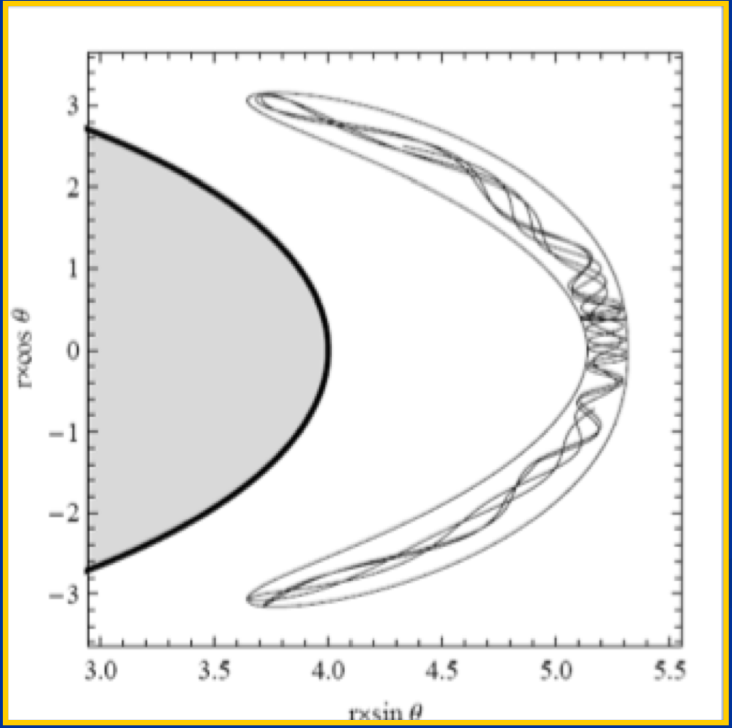
Schwarzschild geometry + rotating dipole MF	slowly rotating neutron star
Kerr geometry + uniform magnetic field	Kerr BH embedded in MF
Kerr-Newman geometry	Kerr-Newman BH

Effective potential and examples of trajectories









(Kovář et al., CQG, 2010)

Dusty plasmas

Coulomb vs gravitational forces on dust grains,

$$G\,\frac{m_1\,m_2}{d^2} = \frac{q_1\,q_2}{4\pi\epsilon_0 d^2}\;e^{-\frac{d}{\lambda_{\mathrm{D}}}}$$

$$m_i \simeq \tfrac{4}{3}\pi a^3\rho, \quad q_i \simeq 4\pi\epsilon_0 a\phi$$

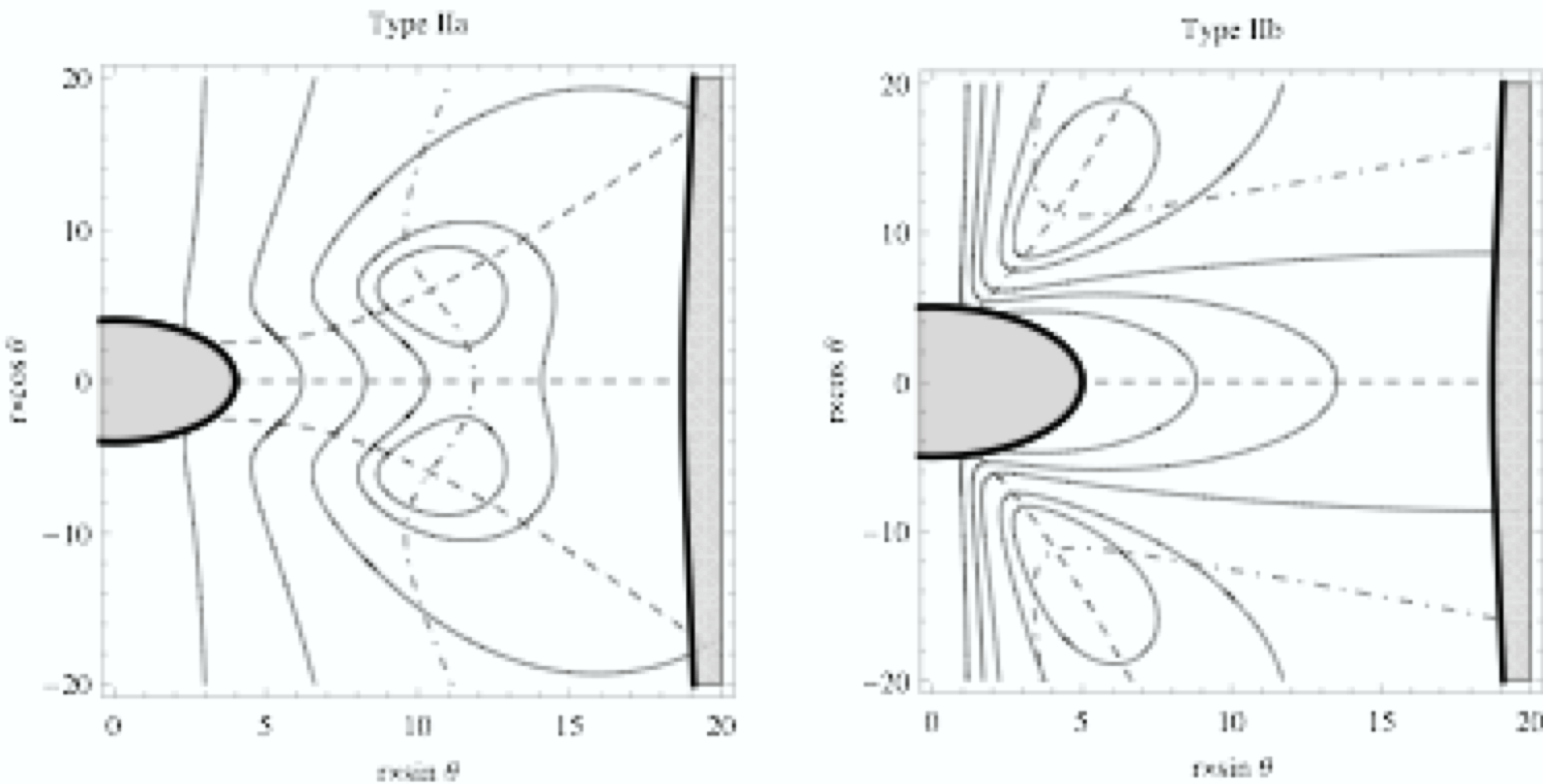
(Horányi 1996; Ishihara 2007)

In a case where the electron and ion thermal currents are the only charging currents, the equilibrium potential of a grain in a plasma is

$$\varphi = -\beta kT/e.$$

In 1 eV hydrogen plasma $\varphi = -2.5$ V.

a~1 μm radius particle will collect ~1800 extra electrons. Charges fluctuate around their equilibrium value.



Type IIa
Type IIb
r sin θ
r cos θ

Summary

We construct a charged thick torus model around black-hole in GR.

We also construct charged tori in Newtonian limit of central gravitational and dipole magnetic fields.

We find off-equatorial structures emerging above the equatorial plane.

Karas, Kovář, Slaný, Stuchlík, Cremaschini, & Miller (2011, 2013)