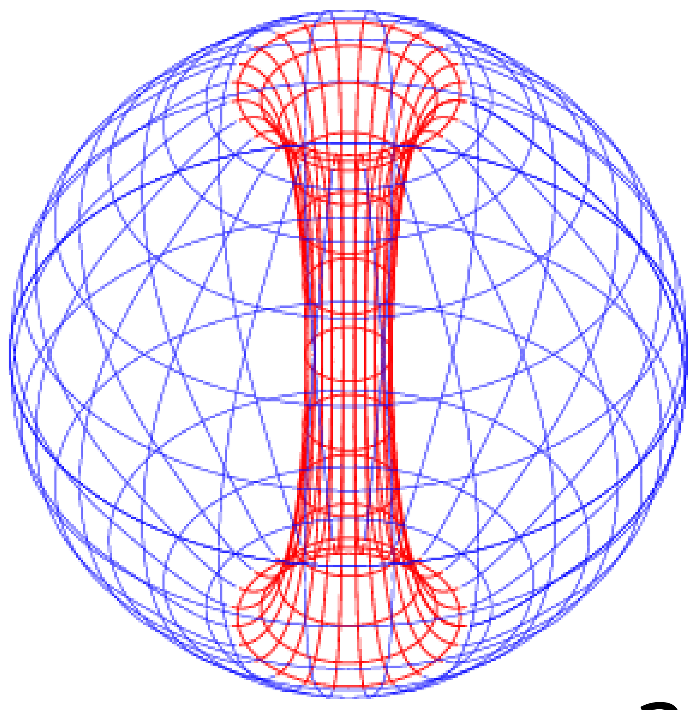

Determination of chaotic behaviour in time series

generated by charged particle motion around magnetized Schwarzschild black holes

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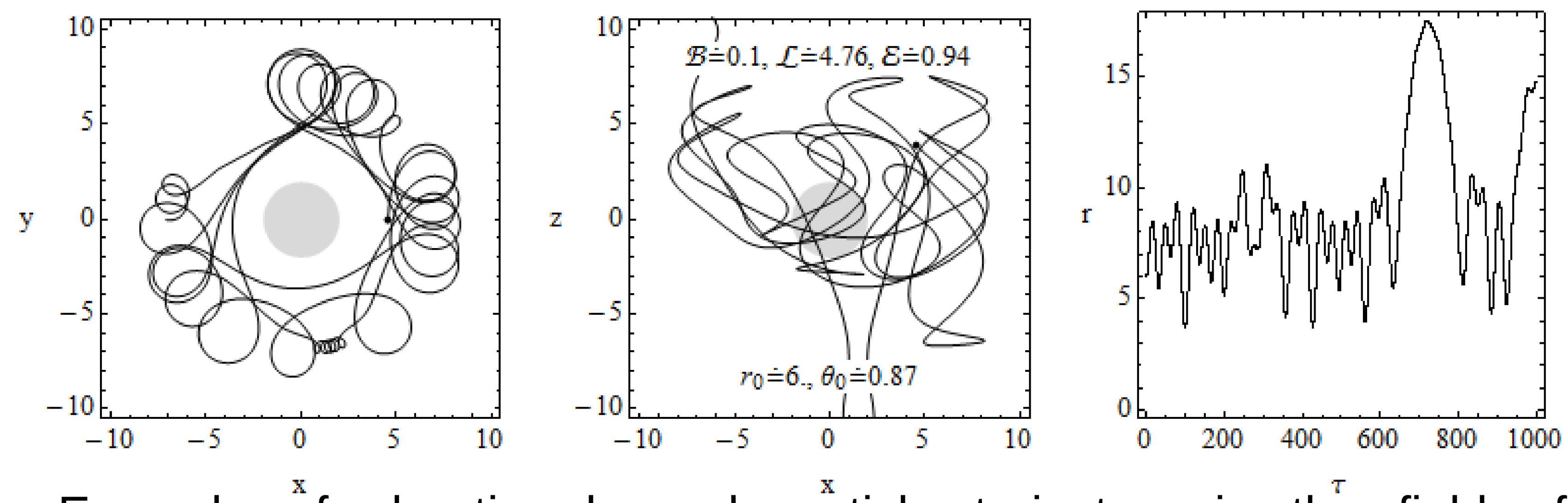
OVERVIEW AND RESULTS

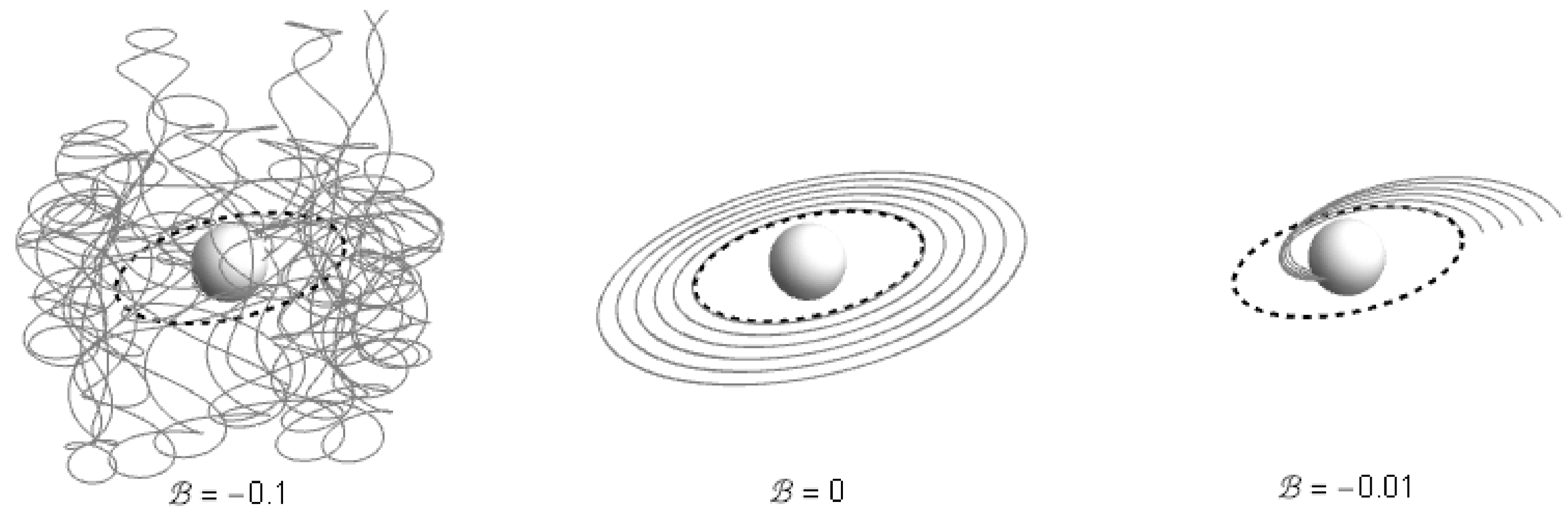
We study behaviour of ionized region of a Keplerian disk orbiting a Schwarzschild black hole immersed in an asymptotically uniform magnetic field. The motion of charged particles in the field of a magnetized black hole demonstrates a mixture of regularity and deterministic chaos. Deterministic chaos is a hardly predictable and apparently random behaviour which can appear in dynamical systems, being detectable by non-linear methods only. In dependence on the magnetic parameter *B*, and inclination angle θ of the disk plane with respect to the magnetic field direction, the charged particles of the ionized disk can enter three regimes: a) regular oscillatory motion, b) destruction due to capture by the magnetized black hole, c) chaotic regime of the motion. In order to study transition between the regular and chaotic type. We have explored the accretion disk destiny for many various initial conditions and among other things new machine learning approach was tested.

EXAMPLE OF A CHAOTIC TRAJECTORY



Example of chaotic charged particle trajectory in the field of a magnetized Schwarzschild black hole. On the left and central figures in the row, the trajectories has been plotted, while the figure on the right represent the time series of the radial coordinate r(τ), which serves as the input of the non-linear methods of chaos detection.

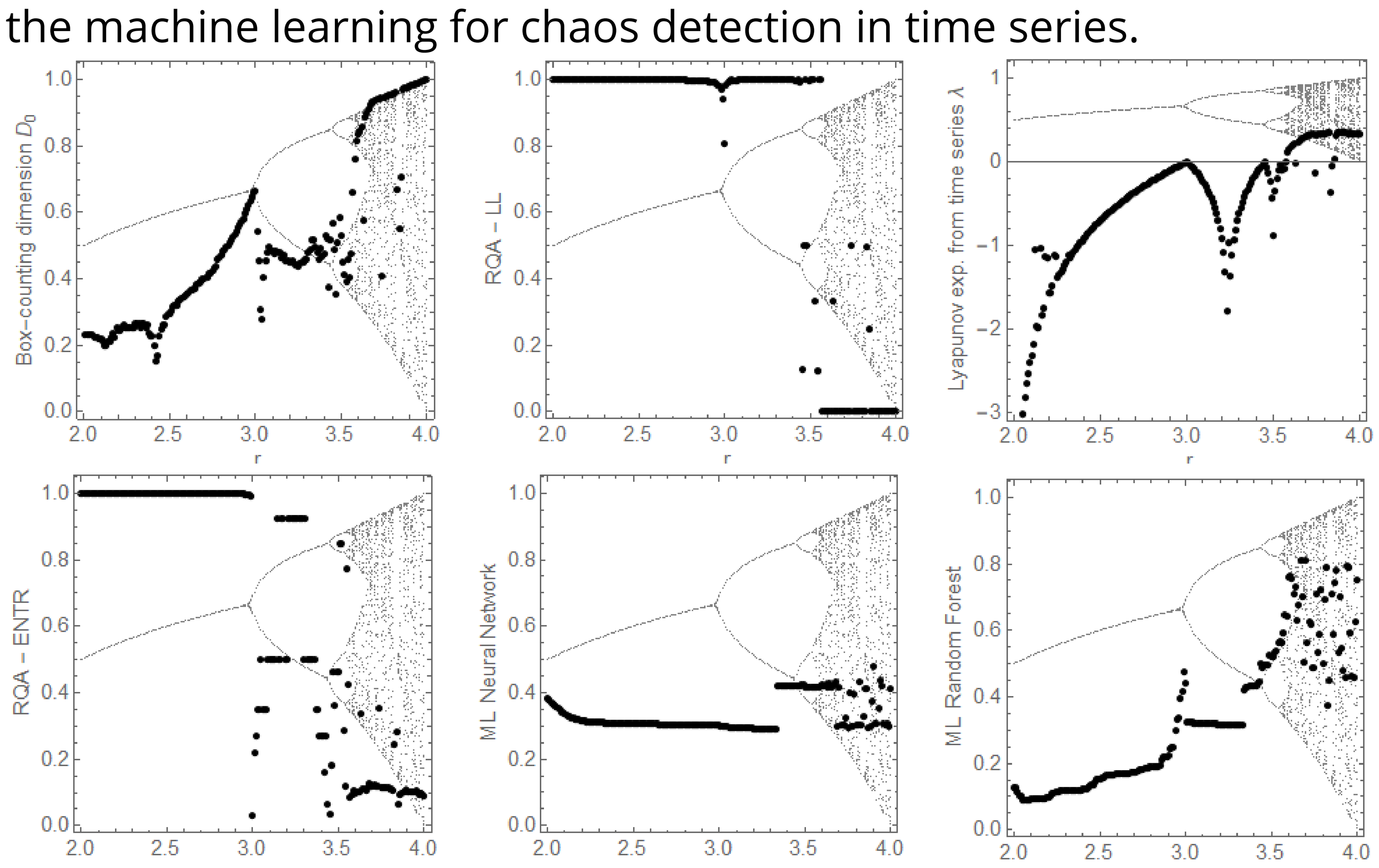
EXAMPLE OF KEPLERIAN DISKS



The Keplerian disks (here) are made of several trajectories with the same initial inclination θ = 1.37 and various initial radial coordinates *r* and different values of magnetic field parameter *B.*

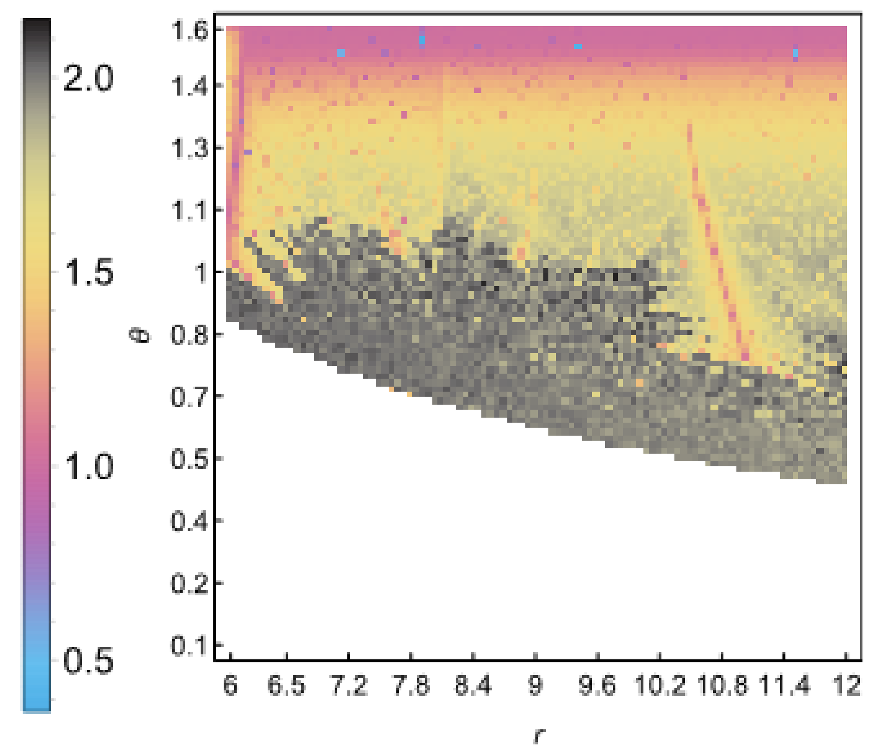
METHODS DETECTING CHAOS

We tested several classical numerical methods as box counting, correlation dimension, Lyapunov exponent, recurrence analysis and the machine learning for chaos detection in time series.



Superposition of bifurcation diagram of logistic map $x_{n+1} = rx_n(1-x_n)$ and the numerical chaos measure by given method. Logistic map is simple polynomial map producing chaos in dependence on the parameter *r.* Bifurcation diagram (gray) shows the values visited (vertical ax.) or asymptotically approached as a function of bifurcation parameter (*r*, horizontal ax.). The chaotic behaviour starts when r ≳ 3.65. The black dots represent the chaos measure of time series corresponding to given value of the chaos causing parameter *r*.

Every point in this figure represents one charged particle trajectory for given initial conditions (r, θ.), and mag. field parameter *B*=0.1. Overall 100*100 = 10^4 pairs of initial conditions (trajectories) has been analyzed by the methods of chaos detection (here correlation dim.), each of length 10^4. The bar shows scale of different chaos measure values.



White area represents the particle trajectories captured by black hole. Figure can be seen as composition of many accretion disks, every single one is represented by horizontal slice with constant inclination θ.

FUTURE TASK

The study of the real observational (BIG) data e.g. RXTE (Rossi X-ray Timing Explorer) and also its deterministic/stochastic structure by effective application of the described methods.

Test various astrophysical theories on that data in the large scale.

REFERENCES

This poster is based on the following article:

Pánis, R., Kološ, M. & Stuchlík, Z. Eur. Phys. J. C (2019) 79: 479.