INAF ISTITUTO NAZIONALE DI ASTROFISICA

IASF Istituto di Astrofisica Spaziale e Fisica cosmica Palermo

CNOC XII

Congresso Nazionale Oggetti Compatti XII

Università degli Studi di Palermo

Cefalù & Astronomy

COMUNE DI Cefalù

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Joint work with the COSMOGRAV GROUP at SSM

Exploring metric departures from Schwarzschild black hole geometry

Motivations of my talk

- We consider a general static and spherically symmetric metric in f(R)=R^k

$$ds^2 = -e^{\nu(r)}\mathrm{d}t^2 + e^{\lambda(r)}\mathrm{d}r^2 + r^2(\mathrm{d}\theta^2 + \sin^2\theta\mathrm{d}\varphi^2)$$

- General solution

$C_1 \in \mathbb{R}$

$|\epsilon| \ll 1$

$$e^{\nu} = r^{\frac{2\epsilon(1+2\epsilon)}{1-\epsilon}} + \frac{C_1}{r^{\frac{1-4\epsilon}{1-\epsilon}}},$$

$$e^{\lambda} = \left\{\left[\frac{(1-\epsilon)^2}{(1-2\epsilon+4\epsilon^2)\left[1-2\epsilon(1+\epsilon)\right]}\right]\left(1+\frac{C_1}{r^{\frac{1-2\epsilon+4\epsilon^2}{1-\epsilon}}}\right)\right\}^{-1}.$$

- Particular solution

$\epsilon = -0.01$ $\quad C_1 = -r_0^{1.01}$ $\quad r_{\rm h} \equiv r_0 = 2.01M$ $\quad$ (M=1)

$$e^{\nu(r)} = \frac{1}{r^{0.02}} - \frac{2.02}{r^{1.03}},$$

$$e^{\lambda(r)} = \frac{1.02}{1-\frac{2.02}{r^{1.01}}}.$$

$r_{\rm obs} = 10^{10}M$ $\Rightarrow$

$$\lim_{r\to r_{\rm obs}} e^{\nu(r)} = 0.64,$$

$$\lim_{r\to r_{\rm obs}} e^{\lambda(r)} = 1.02.$$

What are the astrophysical strategies we can employ in order to distinguish between Schwarzschild geometry and our metric?

Proposed approach

Employing the combination of different astrophysical strategies depending on the context under study

(1) presence of gravity

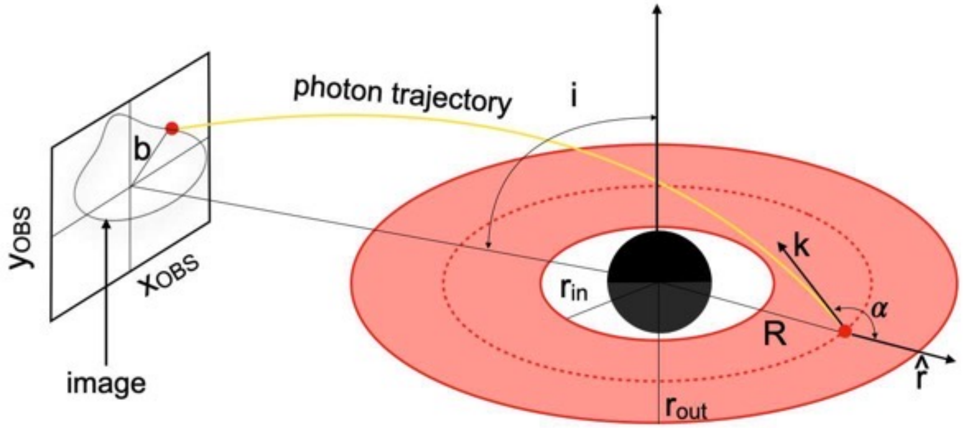
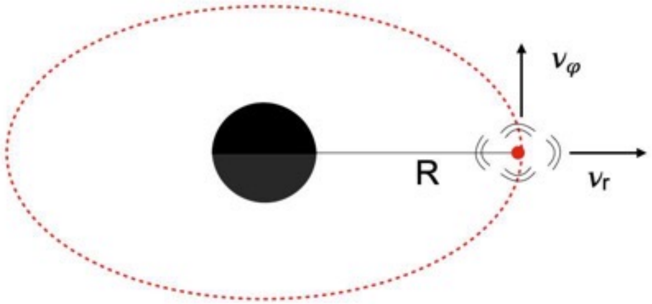
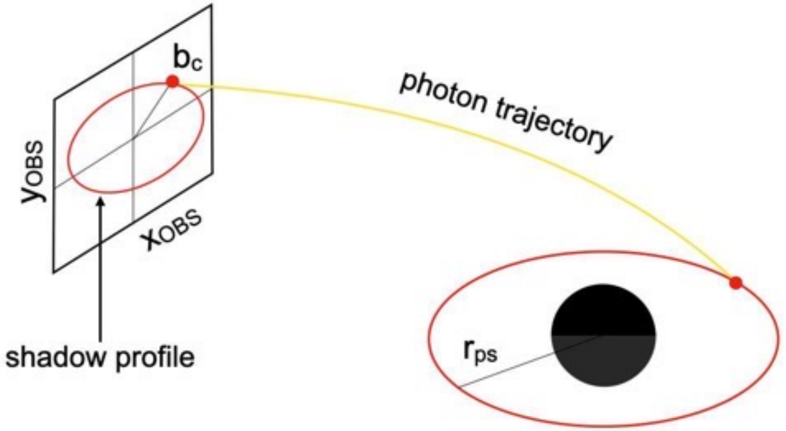


IMAGE OF A BLACK HOLE

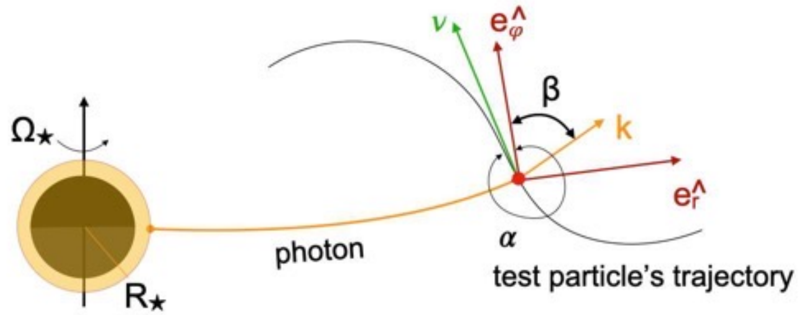


EPICYCLIC FREQUENCIES



SHADOW OF A BLACK HOLE

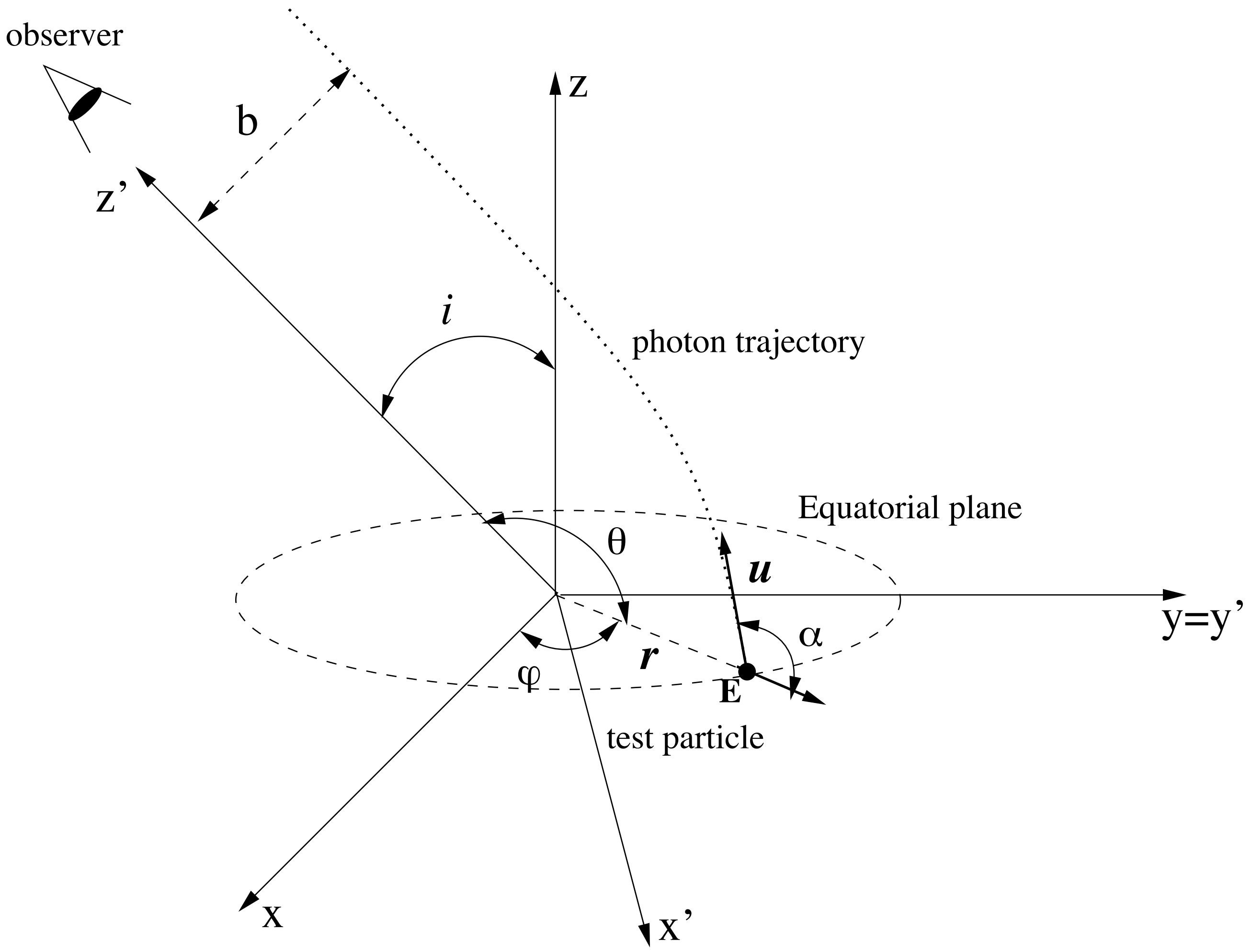
(2) presence of gravity and radiation processes



RELATIVISTIC POYNTING-ROBERTSON EFFECT

Ray-tracing approach

We consider the case of *static and spherically symmetric geometries*



The formula of the impact parameter is

$$b = \frac{R\sin\alpha}{\sqrt{e^{\nu(R)}}}$$

The critical impact parameter b_c is

photonsphere

$$b_c = b(\alpha = \pi/2, R = r_{\rm ps})$$

For $b>b_c$ photon reaches the observer's location otherwise not

SIMULATION PARAMETERS

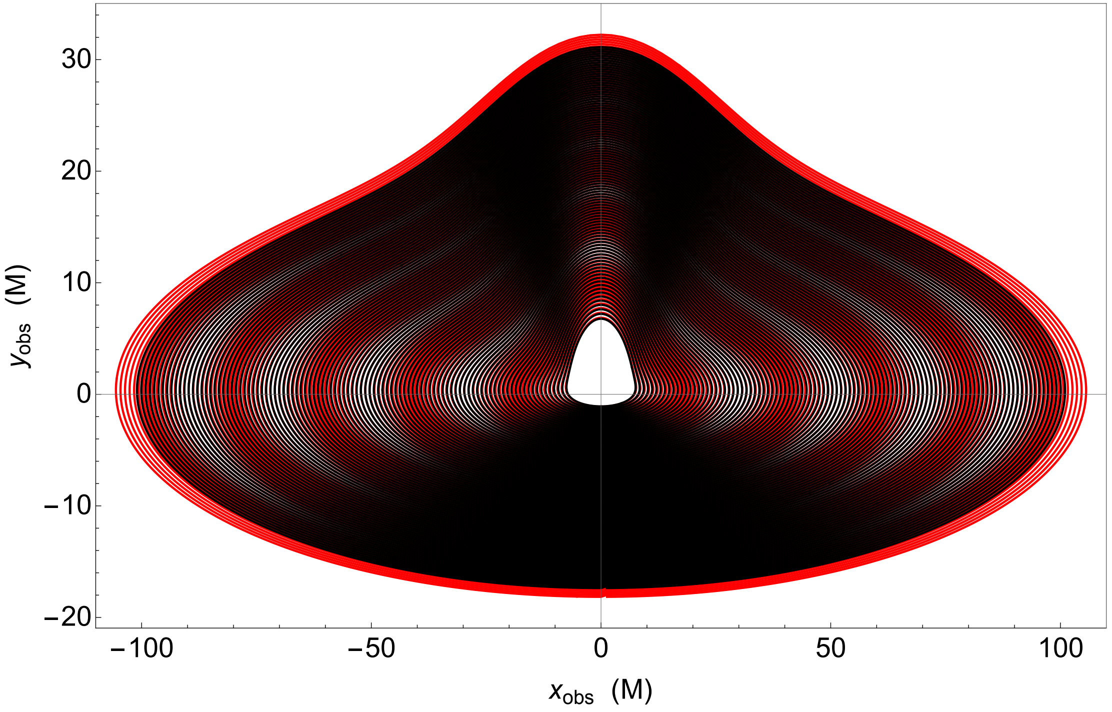
i=80°

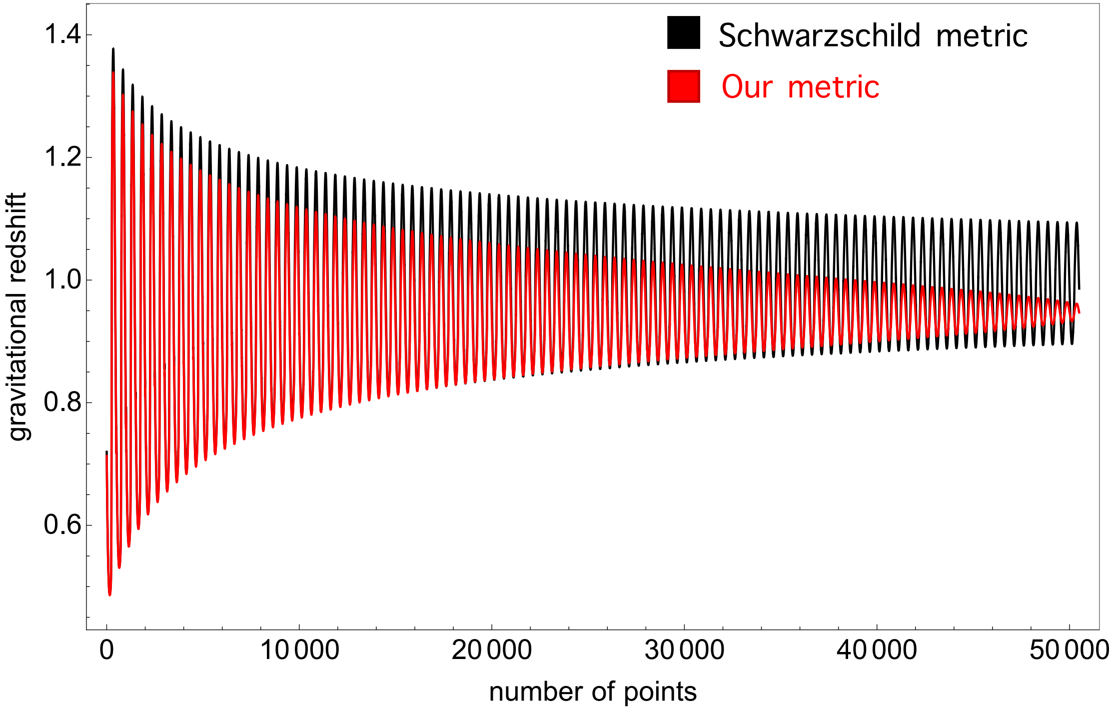
rin=6.23M

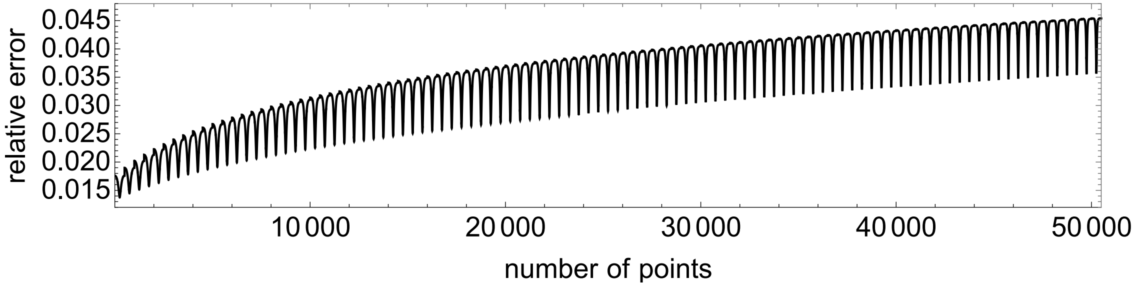
rout=100M

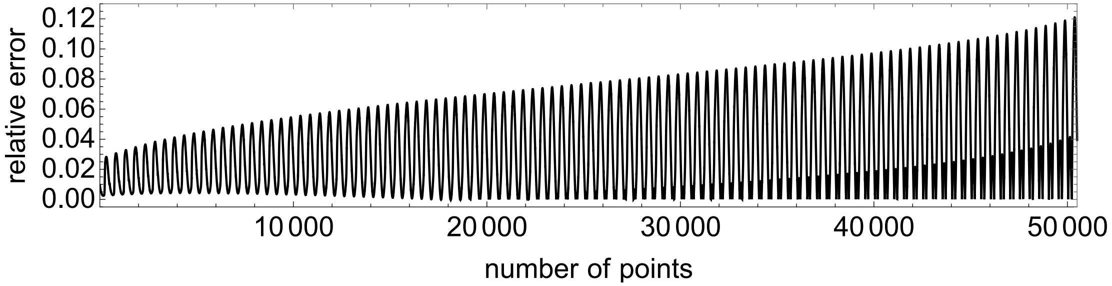
Image of a black hole

The matter in the accretion disk moves on Keplerian orbits.



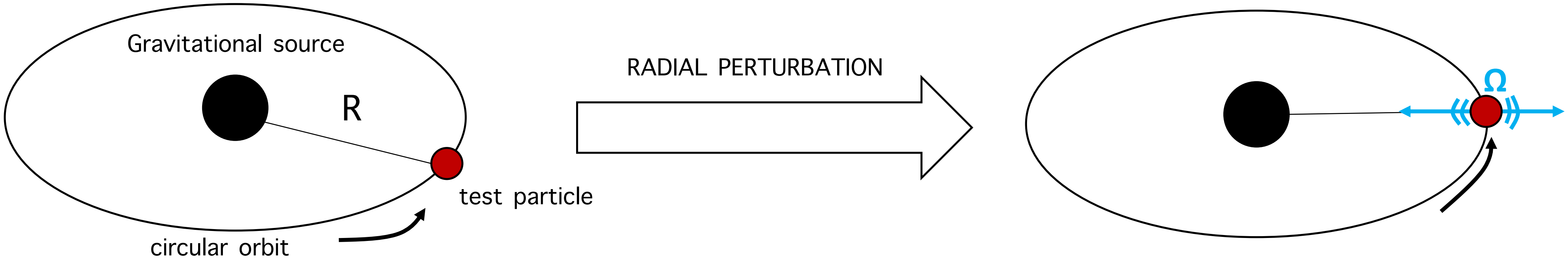




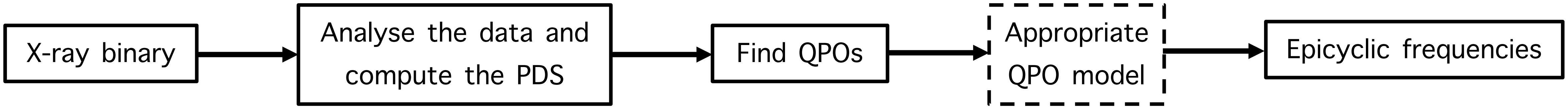


Epicyclic frequencies

Let us consider the motion of a test particle influenced by an *isotropic radial force*



The epicyclic frequencies $\{\Omega_r, \Omega_\varphi, \Omega_\vartheta\}$ have a strong dependence on the underlying *spacetime geometry* and are frequently observed in *X-ray binaries.* How to proceed for obtaining information on epicyclic frequencies?

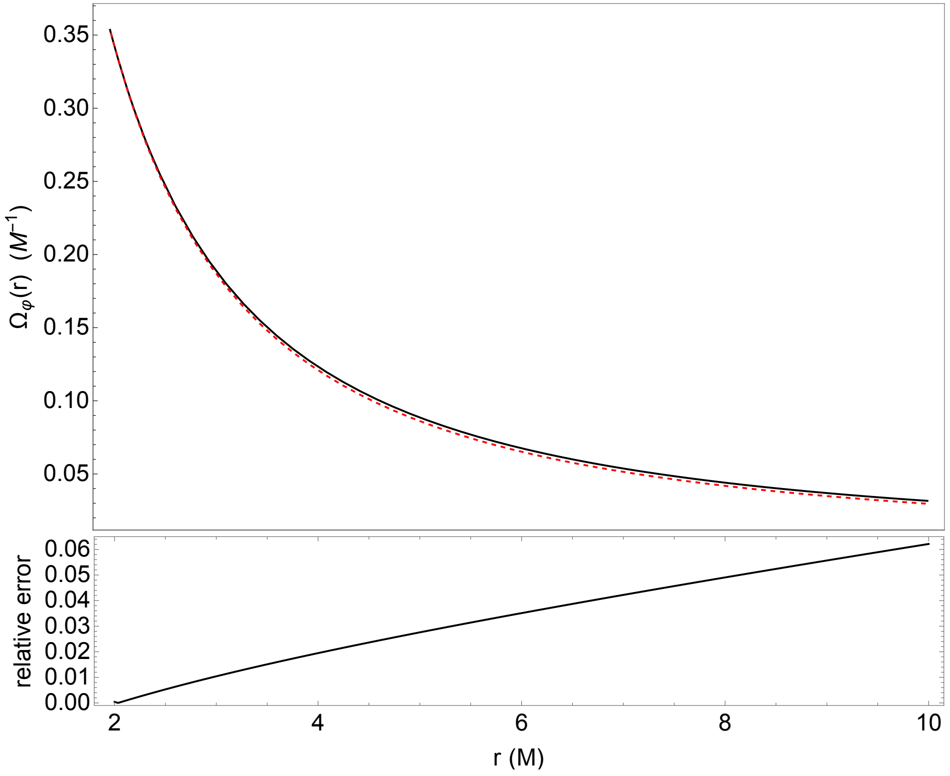


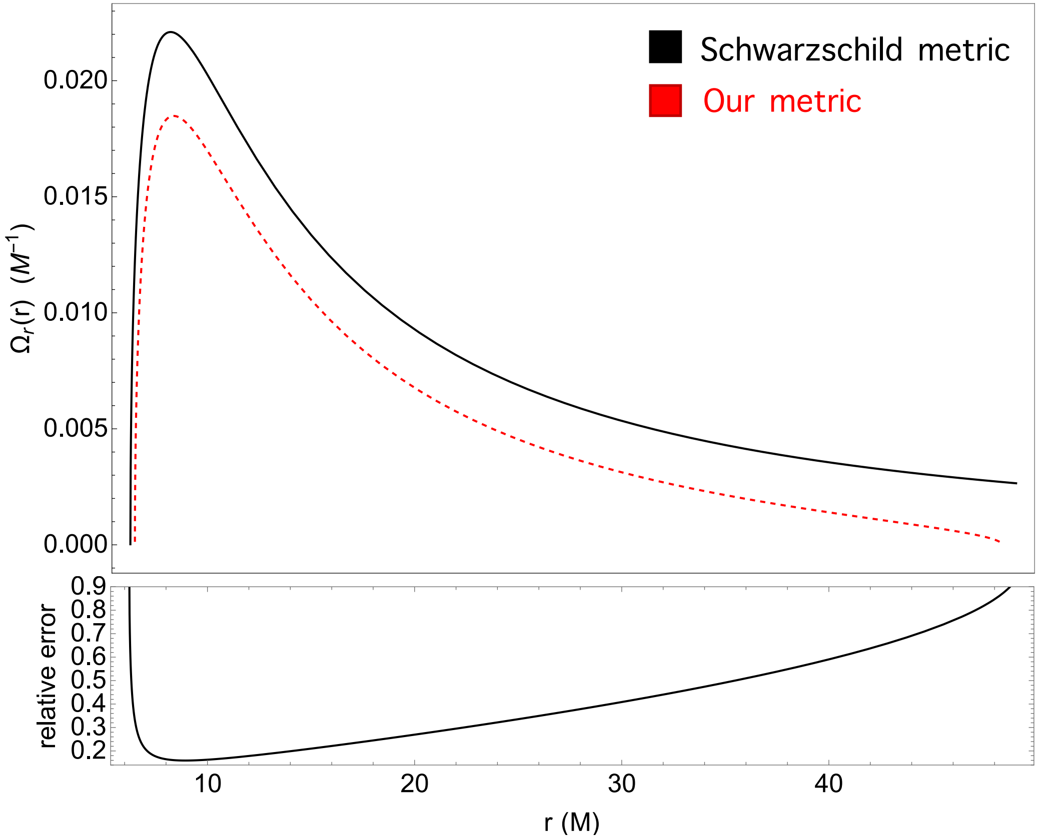
Epicyclic frequencies

The formula of the epicyclic frequencies are

$$\Omega_\varphi := \sqrt{\frac{-g'_{tt}(r)}{2r}} = \sqrt{\frac{e^{\nu(r)}\nu'(r)}{2r}},$$

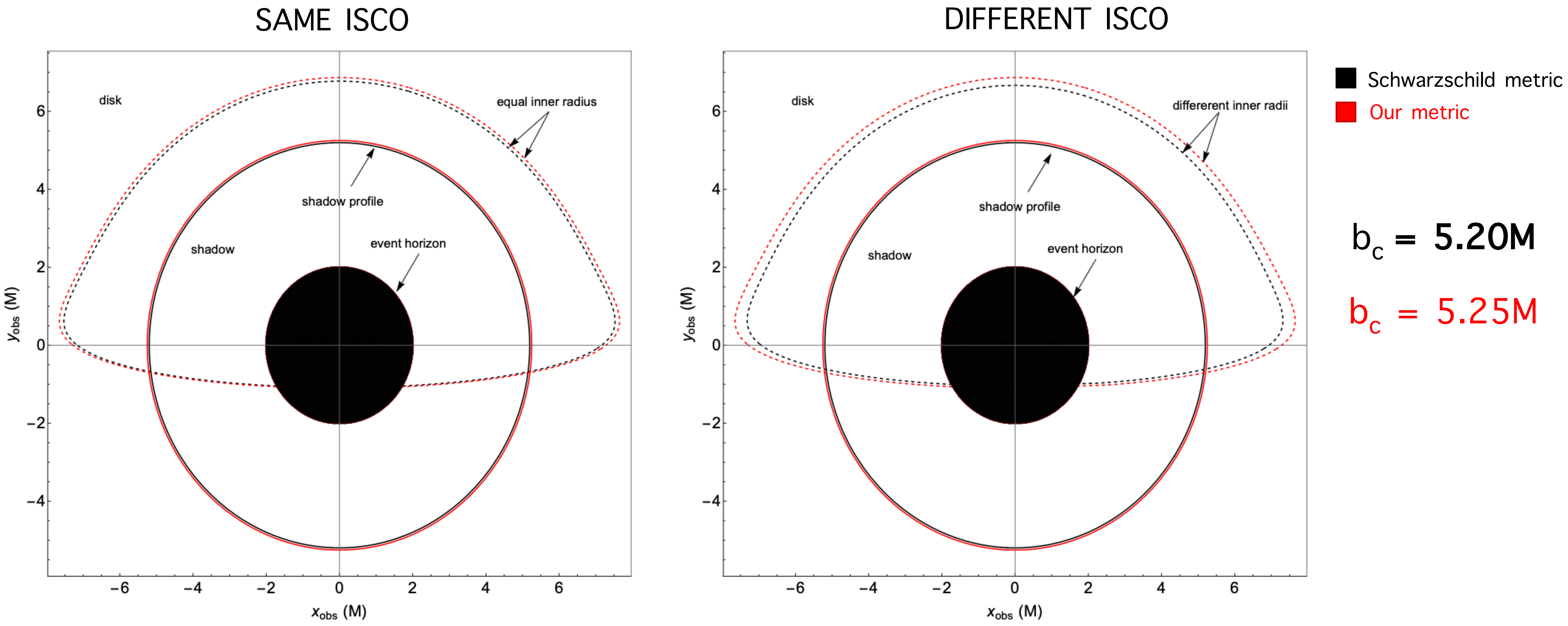
$$\Omega_r := \sqrt{\frac{g_{tt}^2(g^{tt})'' + 6\Omega_\varphi^2}{2g_{rr}}} = e^{\nu(r)}\sqrt{\frac{e^{-\nu(r)}\left[r\nu''(r) - r\nu'(r)^2 + 3\nu'(r)\right]}{2re^{\lambda(r)}}}.$$





BH shadow profile

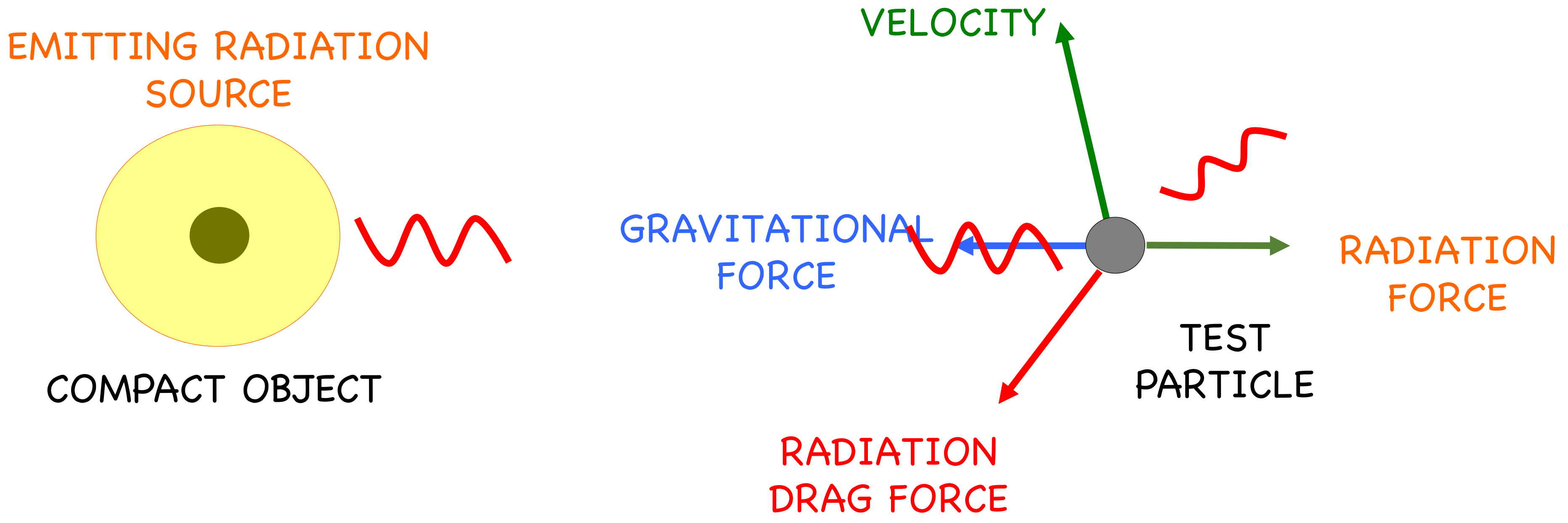
In spherically symmetric spacetimes the shadow profile reduces to a circle of radius b_c



$b_c = 5.20M$

$b_c = 5.25M$

General relativistic Poynting-Robertson (PR) effect



action of the electromagnetic radiation on a moving body, configuring as a dissipative force

General relativistic Poynting-Robertson (PR) effect

The input parameters of this model in static and spherically symmetric metrics are

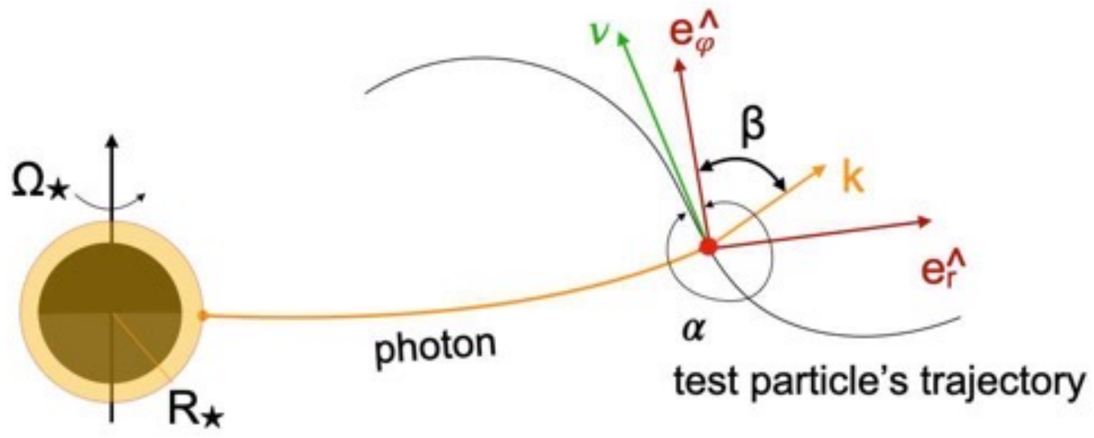
$\underbrace{M}_{\text{gravitational field}}$

$A=(0.1,\ 0.4,\ 0.6)$ $\quad R_\star=2.5M$ $\quad \Omega_\star=(0,\ 0.09,\ 0.16)\ M^{-1}$

$\underbrace{A,\ b \longrightarrow R_\star,\ \Omega_\star}_{\text{radiation field}}$

$r_{ISCO}\Omega_K(r_{ISCO})$

$\underbrace{(\nu_0,\alpha_0,r_0,\varphi_0)=(\nu_K,0,r_{ISCO},0)}_{\text{test particle's initial conditions}}$



RELATIVISTIC POYNTING-ROBERTSON EFFECT

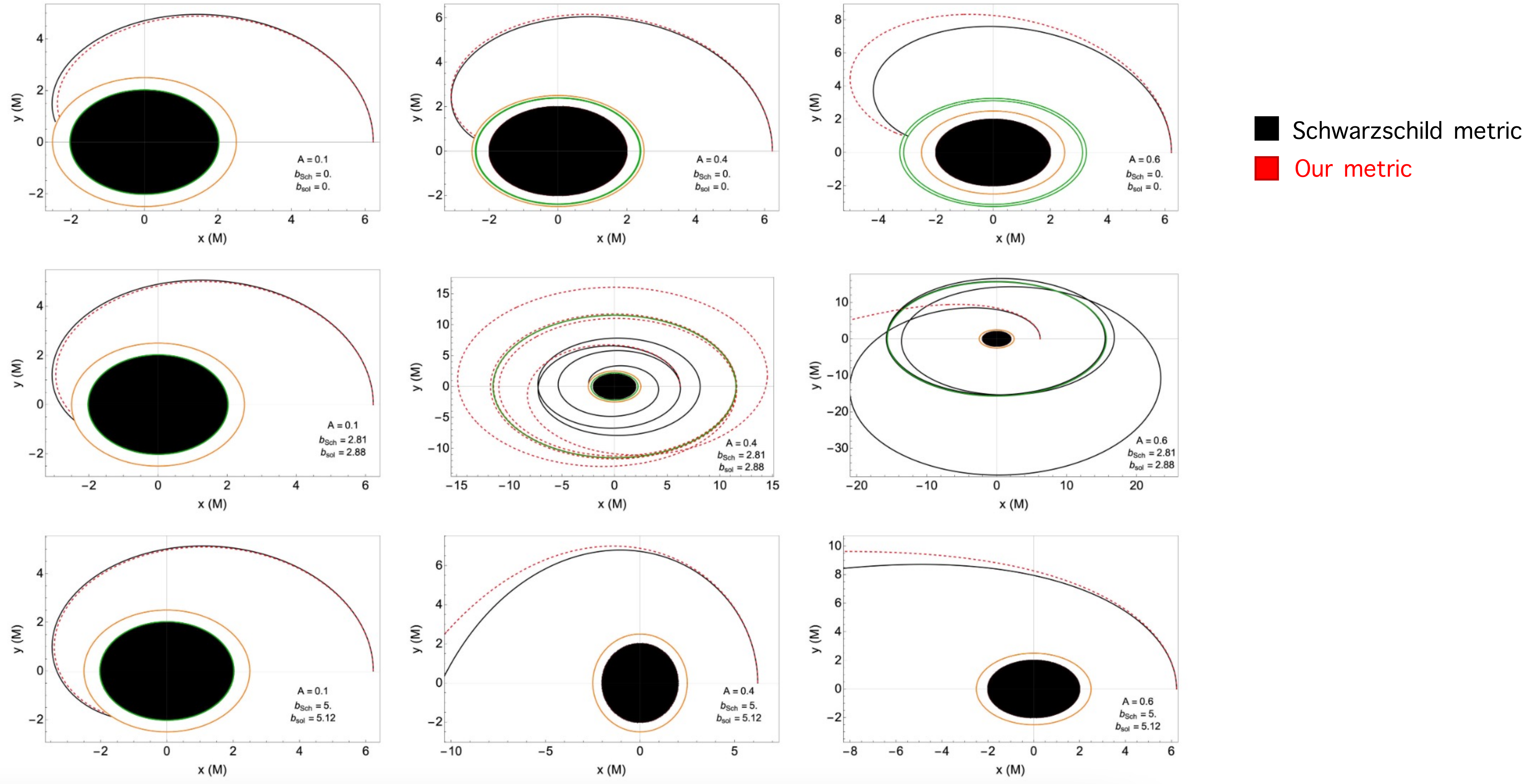
The PR effect has a ***sensitive dependence from the initial conditions***

(1) Different initial velocity

(2) Different initial radius and velocity

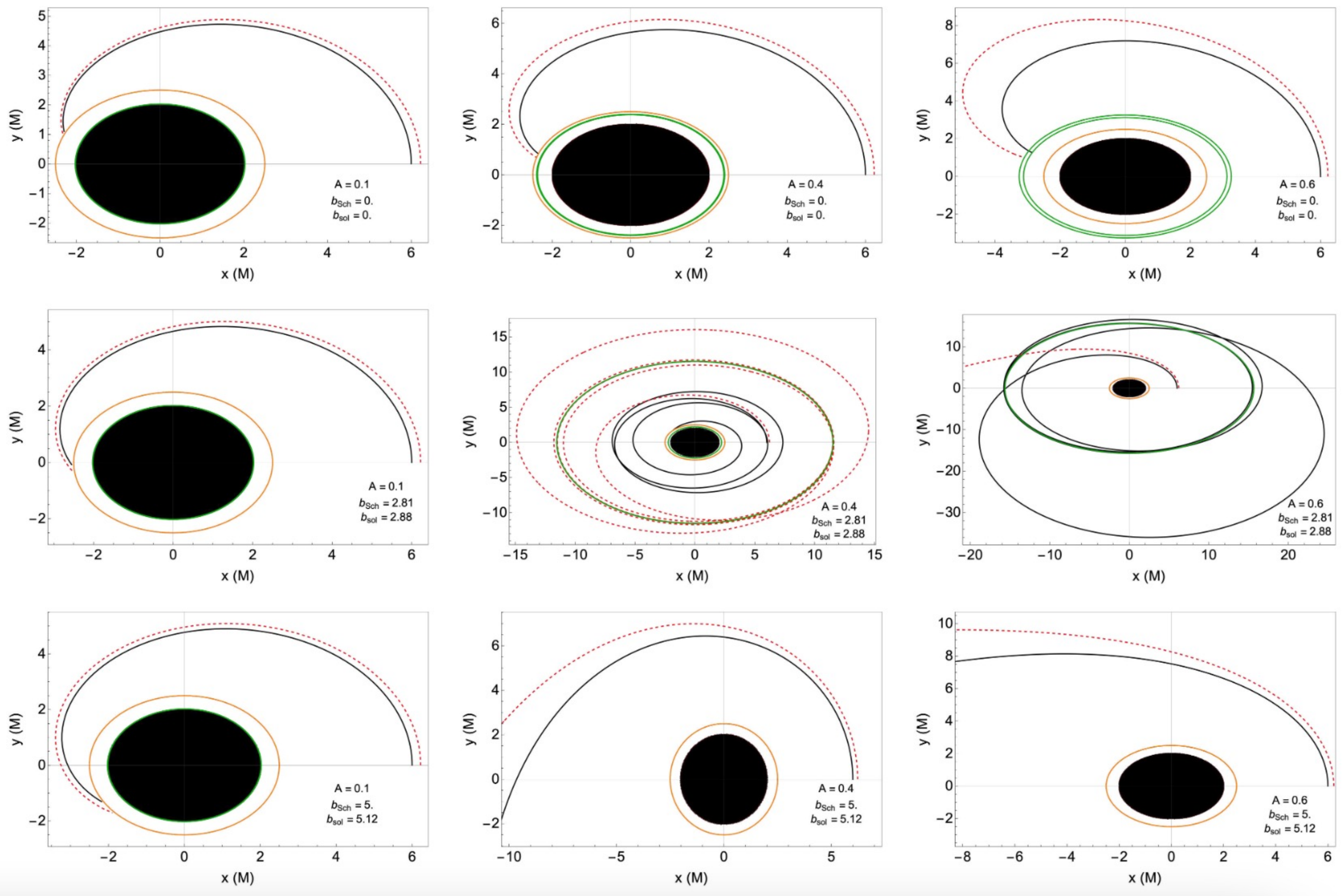
General relativistic Poynting-Robertson (PR) effect

(1) Different initial velocity



General relativistic Poynting-Robertson (PR) effect

(2) Different initial radius and velocity



Schwarzschild metric
Our metric

Conclusions

ADAVANTAGES OF THE PROPOSED METHOD

- Complementarity and full range gravitational regimes
- Availability of data for epicyclic frequency
- PR effect alone is a very powerful tool

LIMITS OF THE PROPOSED METHOD

- Lack of sensitivity in EHT data
- Having all data on the same source

FUTURE PERSPECTIVES

- Include new astrophysical methods
- Extension to stationary and axially symmetric metrics


THANK YOU
FOR YOUR
ATTENTION