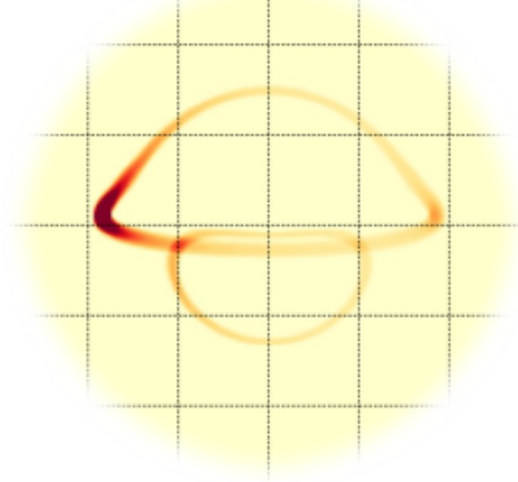


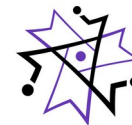
# Observational properties of bosonic stars at the galactic centre



João Luís Rosa  
POTOR8 – Warsaw, Poland

**In collaboration with:**

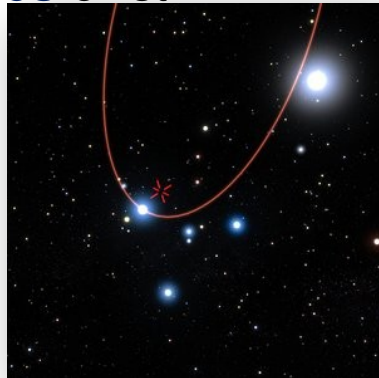
Vítor Cardoso, Paulo Garcia, Frederic  
Vincent



Eesti Teadusagentuur  
Estonian Research Council

# MOTIVATION

Recent observations indicate that objects which behave like **black-holes** exist



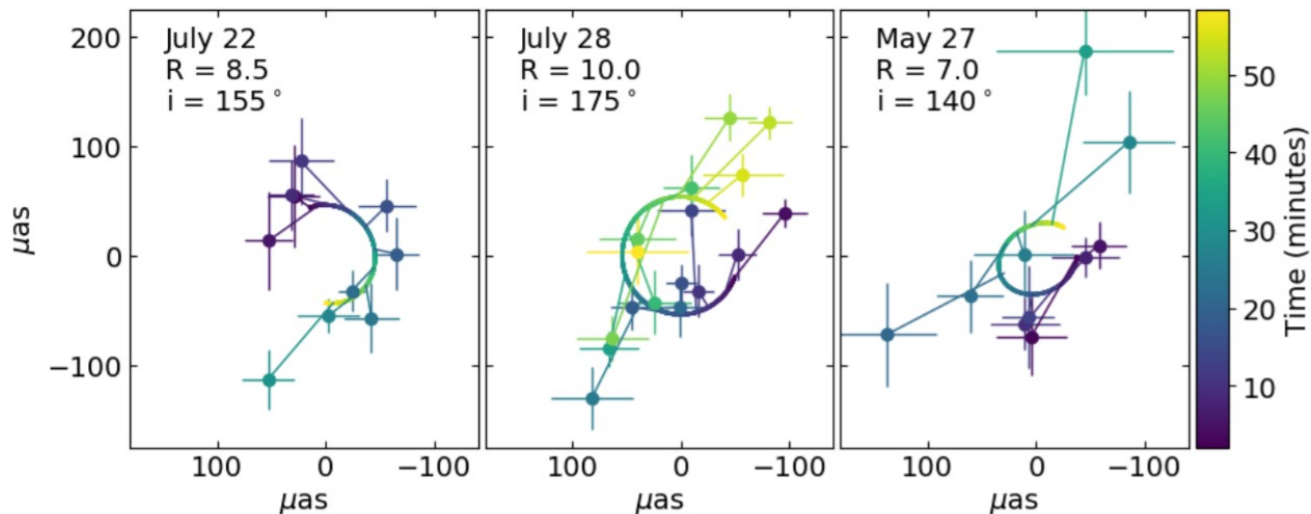
**S2 Star  
orbit**

← ESO (2016)



**M87 BH  
Shadow**

EHT (2019) →



**Flares!**  
ESO (2020)

← A&A 635, A143 (2020)

# FRAMEWORK

**Einstein-Klein-Gordon theory:** addition of a complex and massive scalar field.

$$S = \int_{\Omega} \sqrt{-g} \left( \frac{R}{16\pi} - \nabla_a \Phi^* \nabla^a \Phi - \mu^2 \Phi^* \Phi \right) d^4x$$

**Einstein-Proca theory:** addition of a complex and massive vector field.

$$S = \int_{\Omega} \sqrt{-g} \left( \frac{R}{16\pi} - \frac{1}{4} F_{ab}^* F^{ab} - \frac{1}{2} \mu^2 A_a^* A^a \right) d^4x$$

**Look for solutions with the following characteristics:**

1. Spherically symmetric
2. Localized bosonic fields

$$(\square - \mu^2) \Phi = 0$$

$$\nabla_b F^{ab} = \mu^2 A^a$$

# SCALAR/VECTOR FIELDS

**Metric:** assume a general static and spherically symmetric metric of the form:

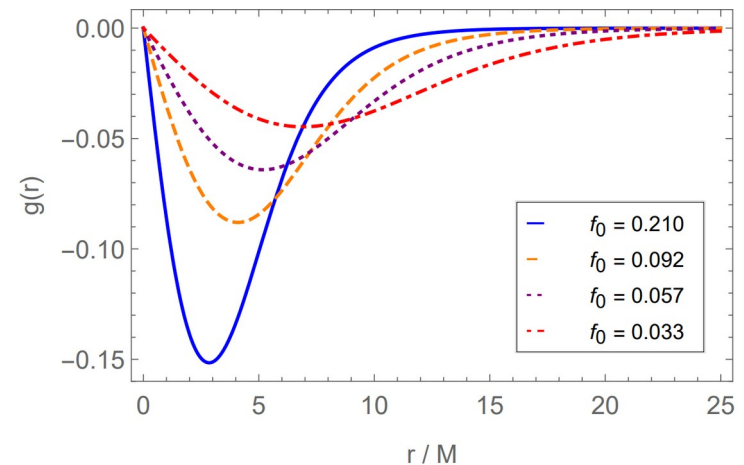
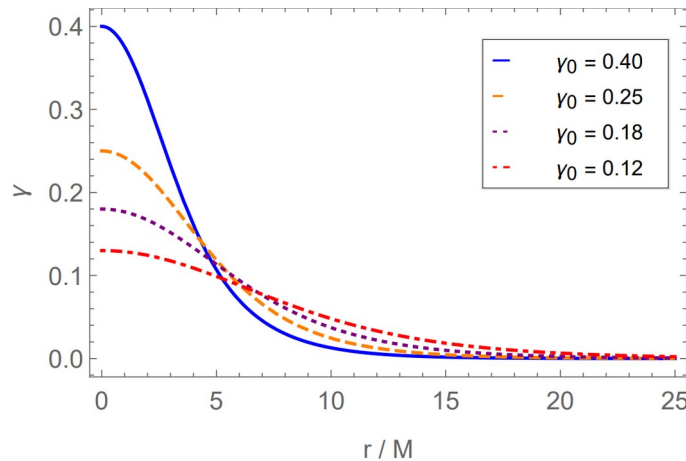
$$ds^2 = -e^{\nu(r)} dt^2 + e^{\lambda(r)} dr^2 + r^2 (d\theta^2 + \sin^2 \theta d\phi^2)$$

**Ansatz for the fields:**

U(1) symmetry preserves staticity

$$\Phi(r, t) = \psi(r) e^{i\omega t}$$

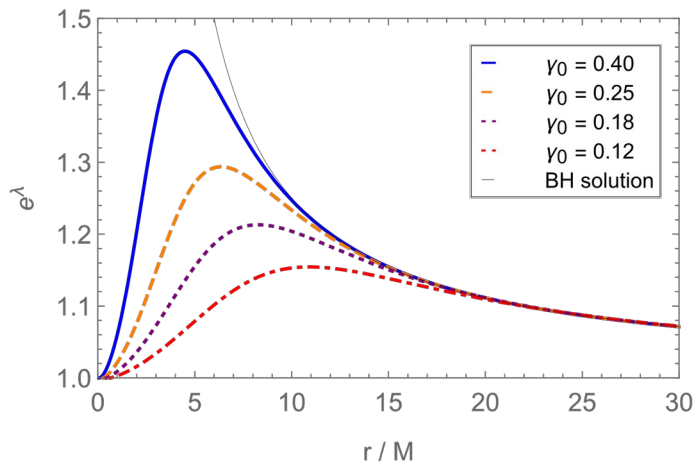
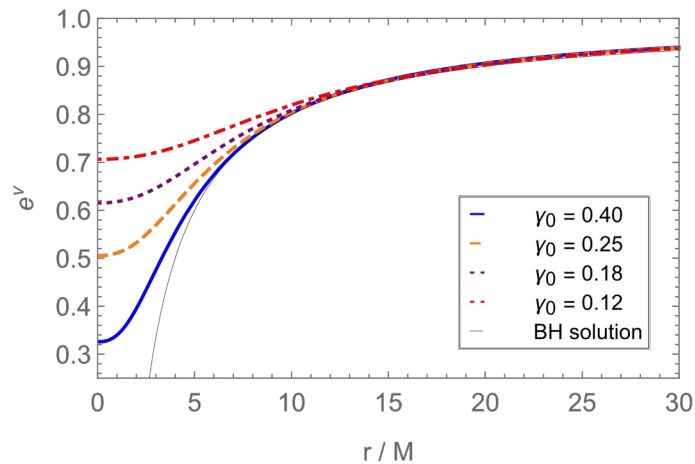
$$A_a = e^{i\omega t} (f(r), ig(r), 0, 0)$$



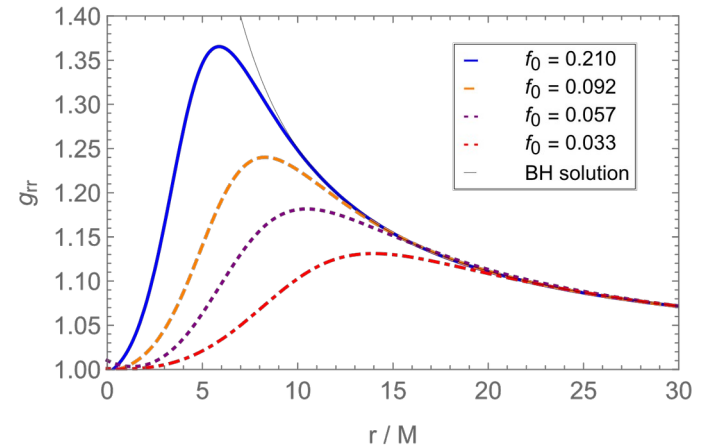
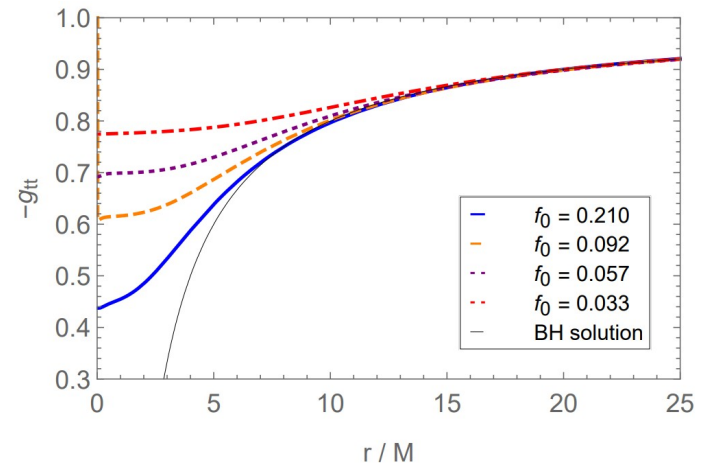


# SPACETIME METRICS

## Boson star

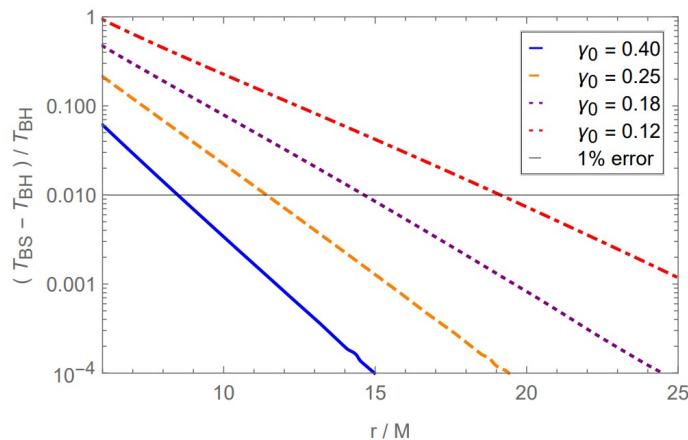
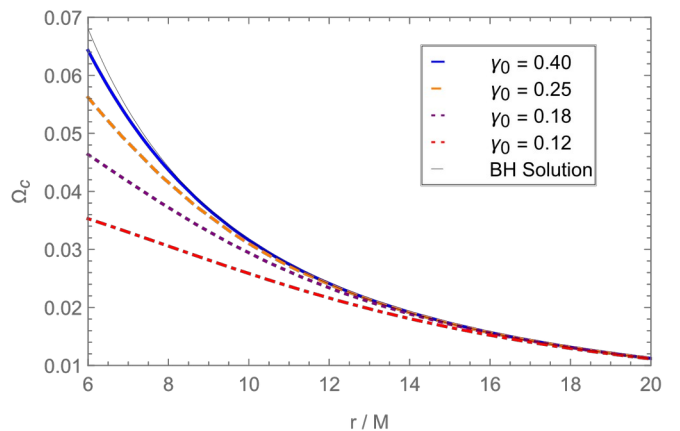


## Proca star

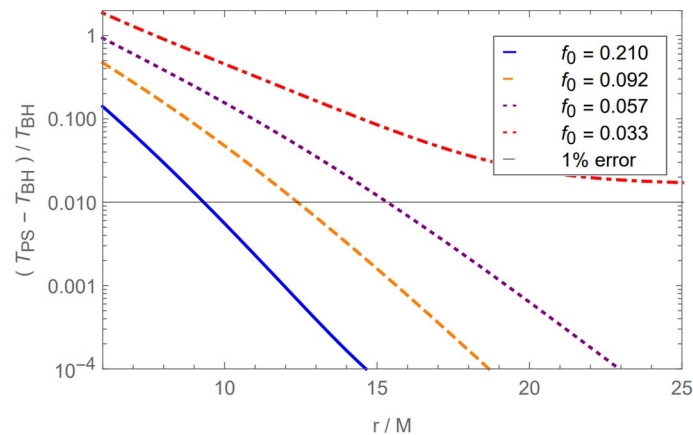
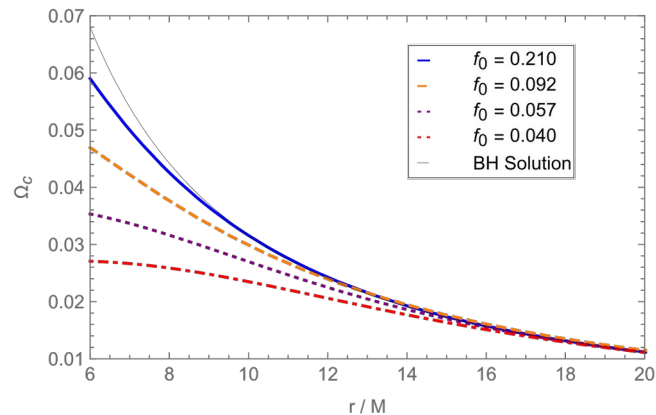


# ORBITAL MOTION

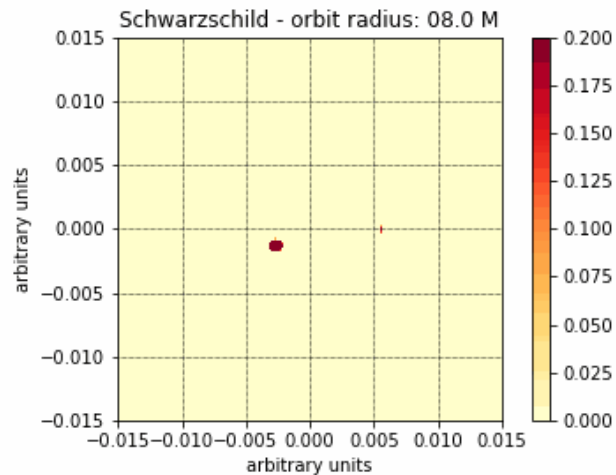
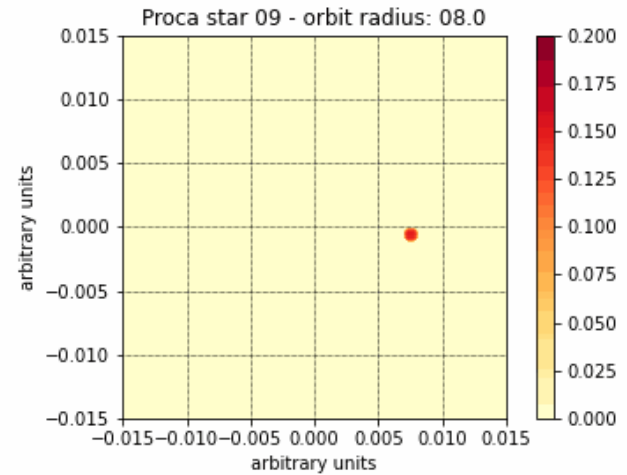
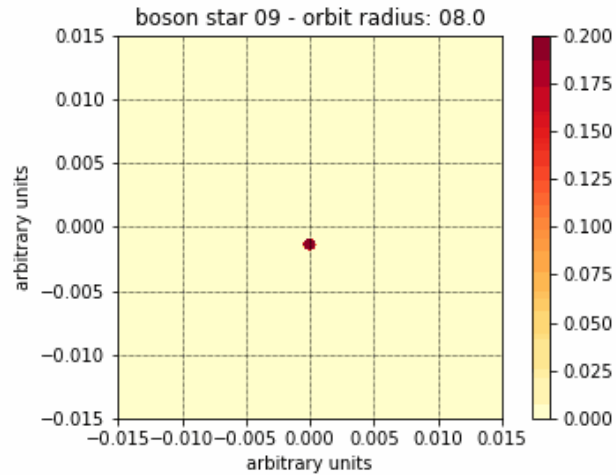
## Boson star



## Proca star



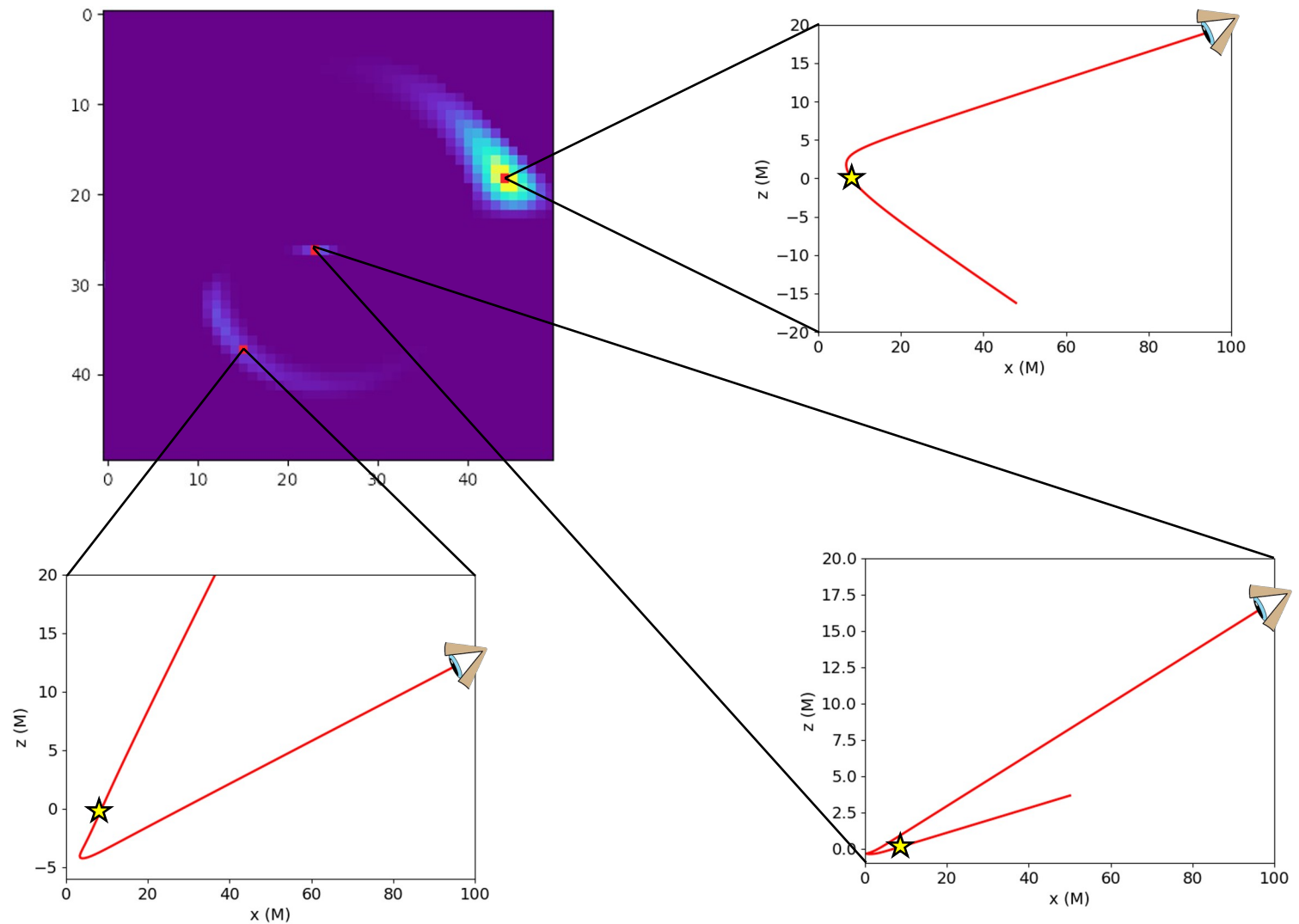
# EXAMPLES OF ORBITS



## Main differences:

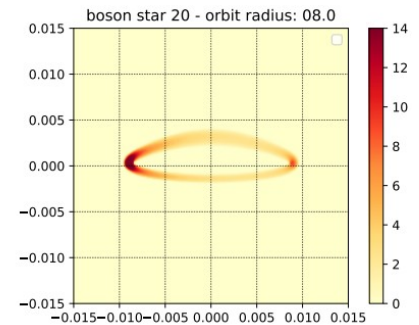
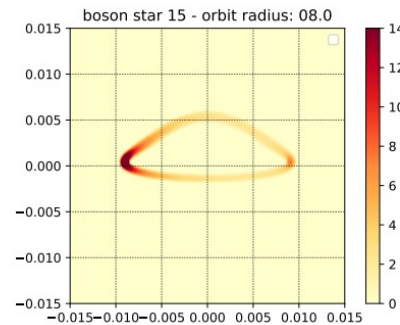
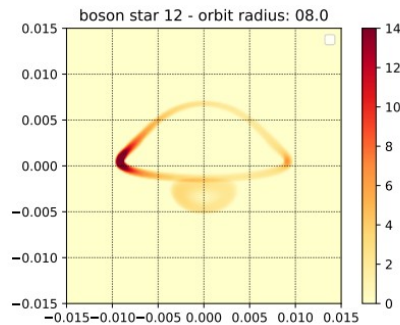
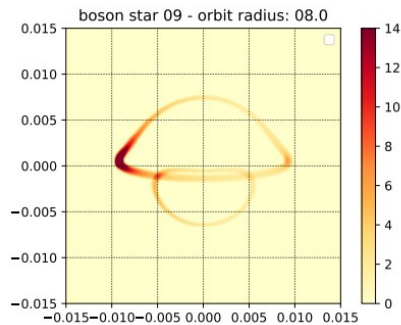
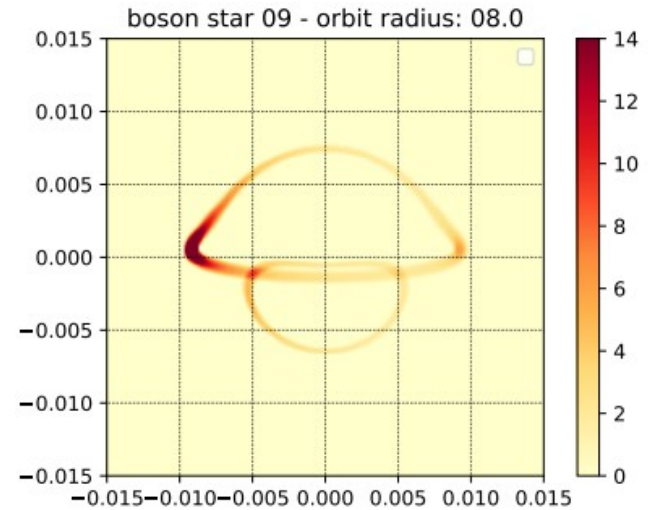
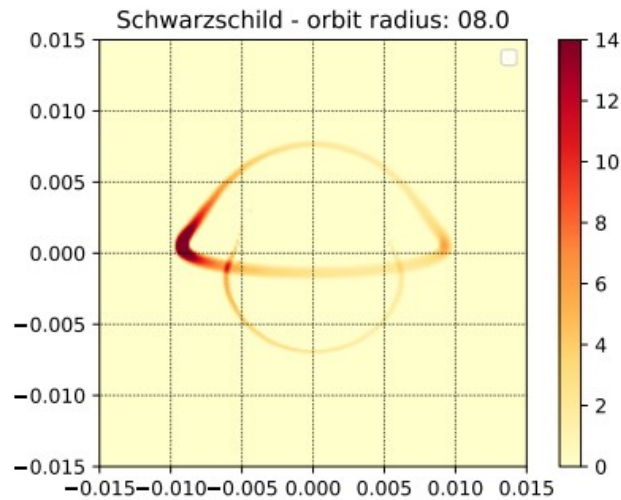
1. Apparition of third image
2. Different image shapes
3. Different flux intensities
4. Different deflection angles

# GEODESICS

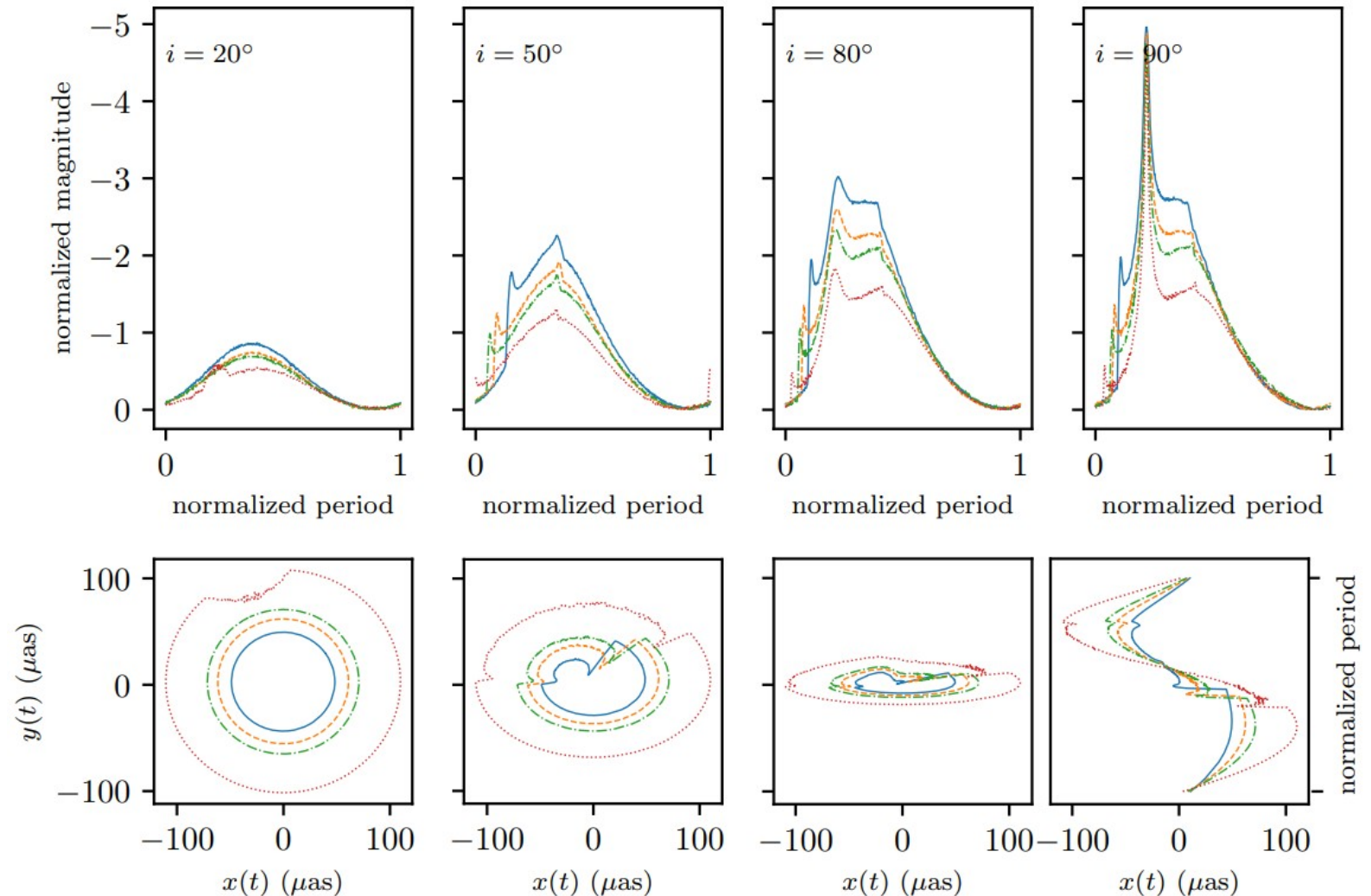




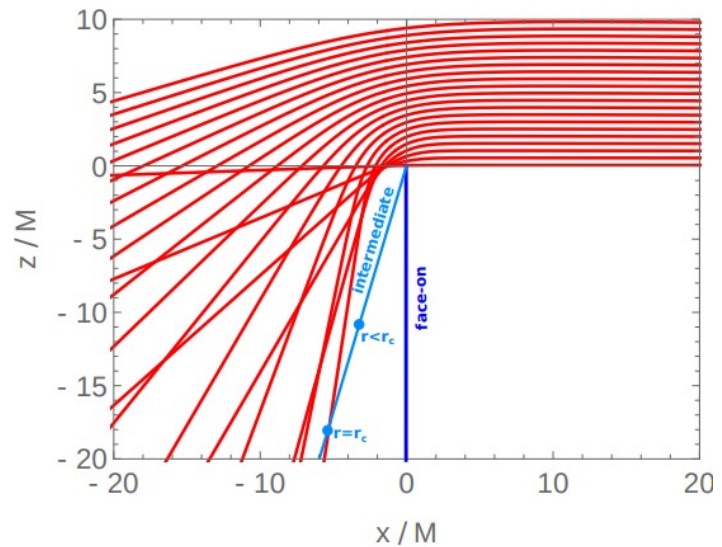
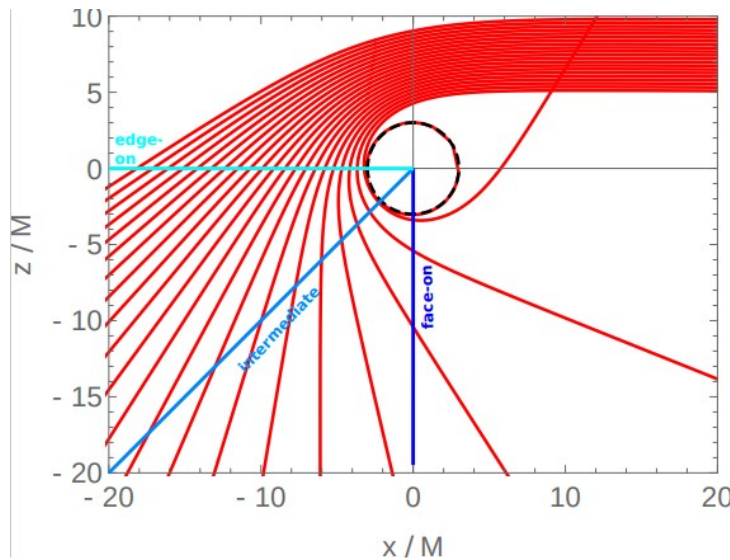
# INTEGRATED FLUX



# MAGNITUDE AND CENTROID



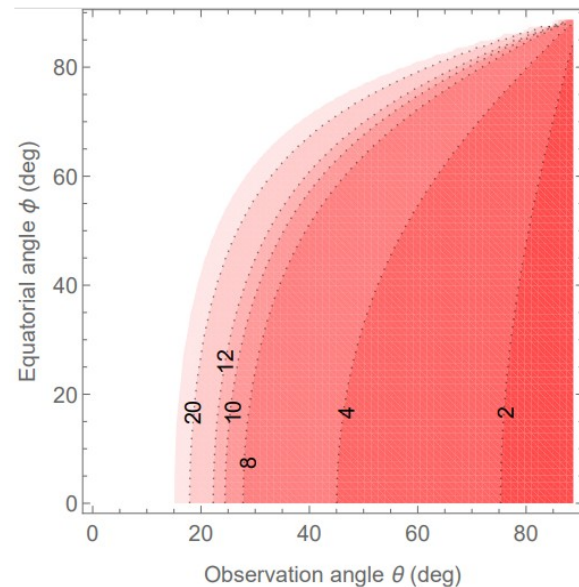
# LONG-RANGE EFFECTS



**Top left:** BH congruence

**Top right:** BS congruence

**Bottom right:** BS critical angles

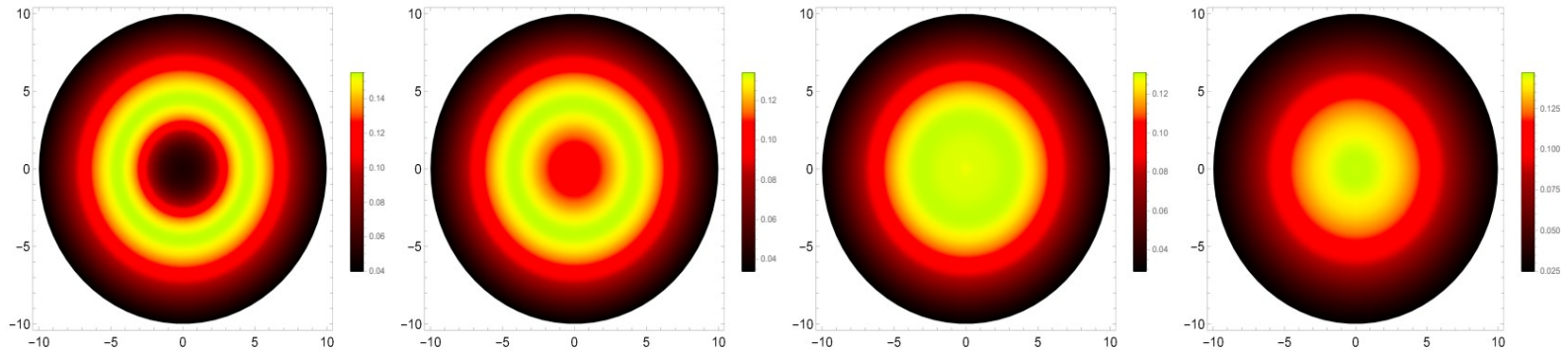




# ONGOING WORK

1. Comparison of models with experimental data;
2. Simulations of shadows in systems with accretion disks;

**In collaboration with:** Diego Rubiera-Garcia, [arXiv:2204.12949](#)  
[gr-qc]



## THANK YOU FOR YOUR ATTENTION