Relativistic orbits in the Galactic center and General Relativity tests with

G R A V I n T erferomtr Y

General
Relativity
Analysis
Vlt

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Advisors

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GPhys's day May, 27th 2014

l'Observatoire de Paris

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Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

$G_{\Phi\Sigma}$

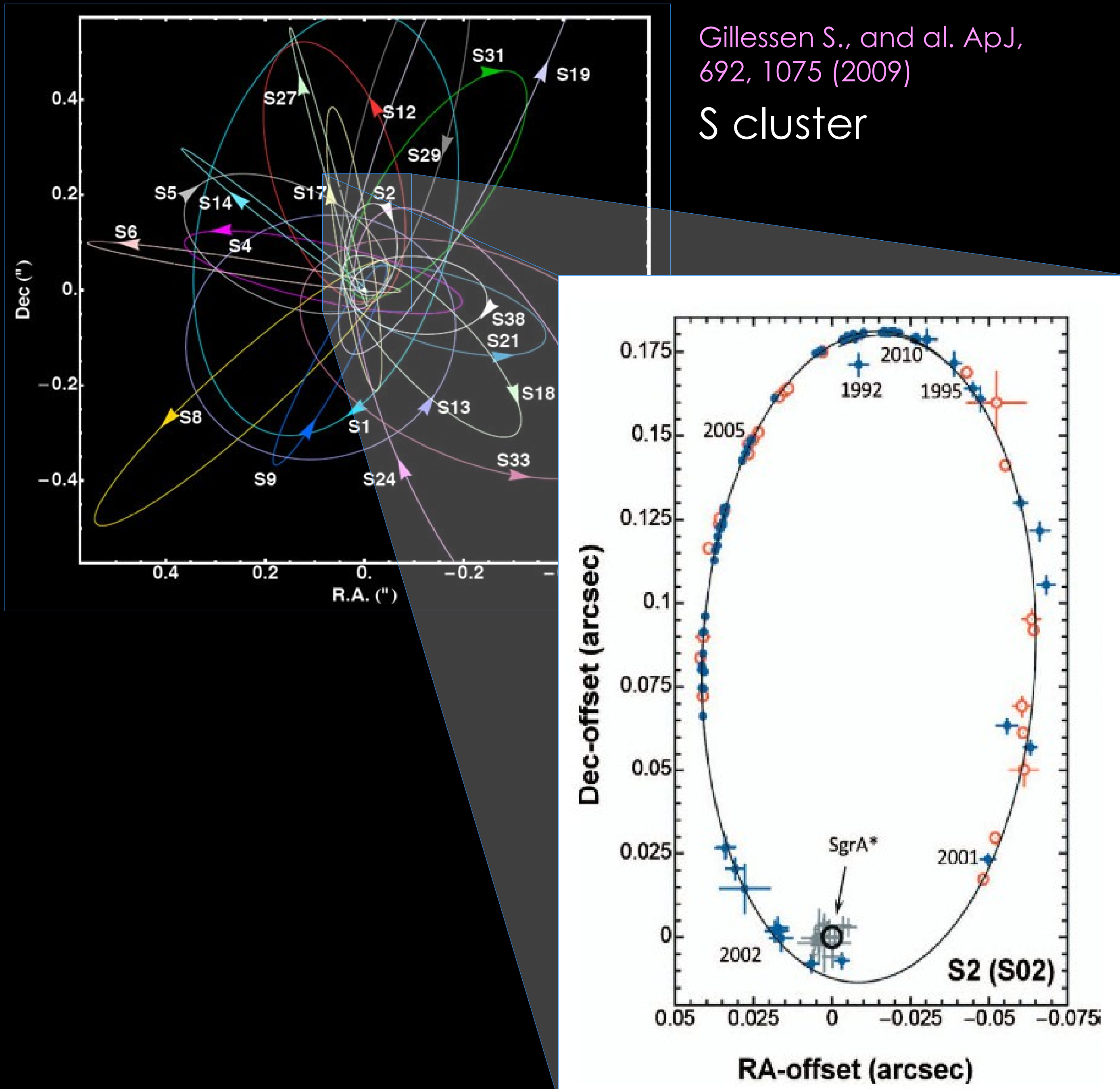
ED A&A

École Doctorale d'Astronomie & Astrophysique d'Île-de-France

Content

- The Black hole at the center of the Galaxy
  - Central mass estimation
  - Apparent size of a Schwarzschild black hole
- Test of the no-hair theorem
  - The no-hair theorem
  - Apparent relativistic orbits model
- Einstein ring study with GYOTO
- Perspectives

Central mass estimation



Gillessen S., and al. ApJ, 692, 1075 (2009)

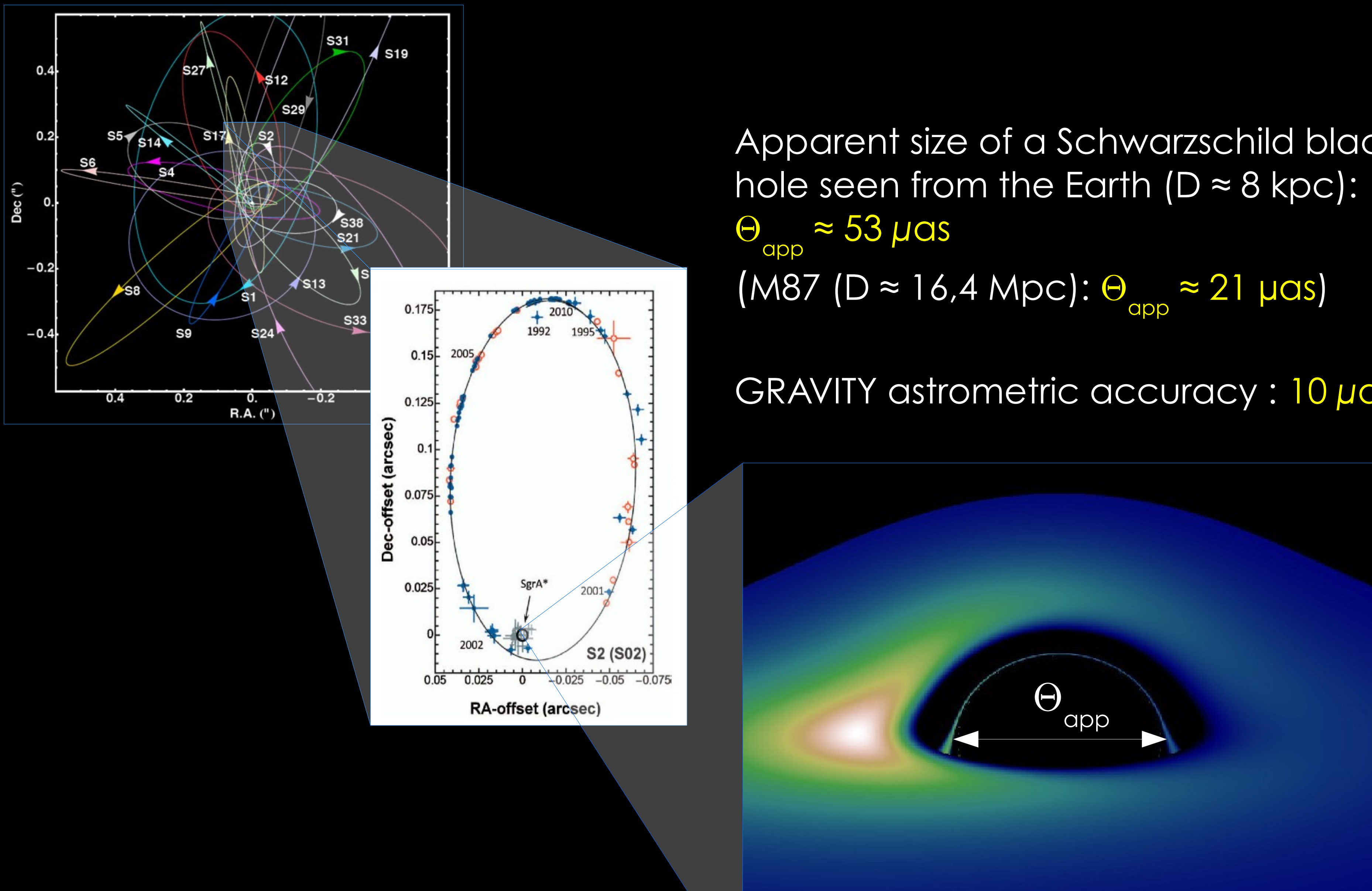
S cluster

Genzel, Einsenhauer & Gillessen, RMP 82, 3121 (2010)

Orbit of S2

$M_{bh} = 4.31 \pm 0.6 \times 10^6 M_{\odot}$

Apparent size of a Schwarzschild black hole



Simulated image by GYOTO*, of an accretion disk around a Schwarzschild black hole

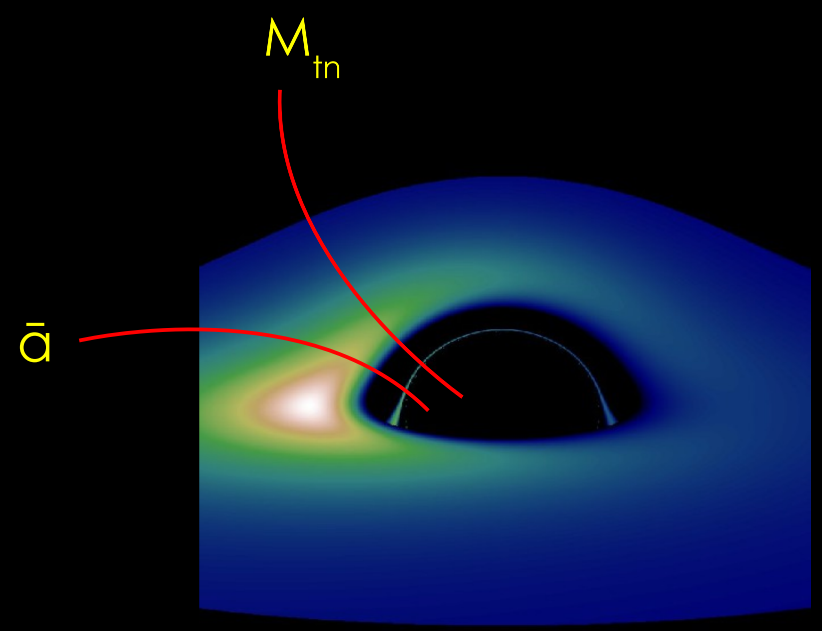
Apparent size of a Schwarzschild black hole seen from the Earth (D ≈ 8 kpc):
$\Theta_{app} \approx 53\ \mu as$
(M87 (D ≈ 16,4 Mpc): $\Theta_{app} \approx 21\ \mu as$)

GRAVITY astrometric accuracy : 10 μas !

* Vincent, Paumard, Gourgoulhon & Perrin, CQG 28, 225011 (2011)

The no-hair theorem

→ Test of the no-hair theorem using the Galactic center black hole, SgrA*.



<u>The no-hair theorem :</u>

Vitaly L. Ginzburg, Yakov B. Zeldovich et Igor D. Novikov, 1960

Black holes are described by only two parameters, their mass M_{tn} and their spin $\bar{a}$.

Apparent relativistic orbits model

→ Test of the no-hair theorem using the Galactic center black hole, SgrA*.

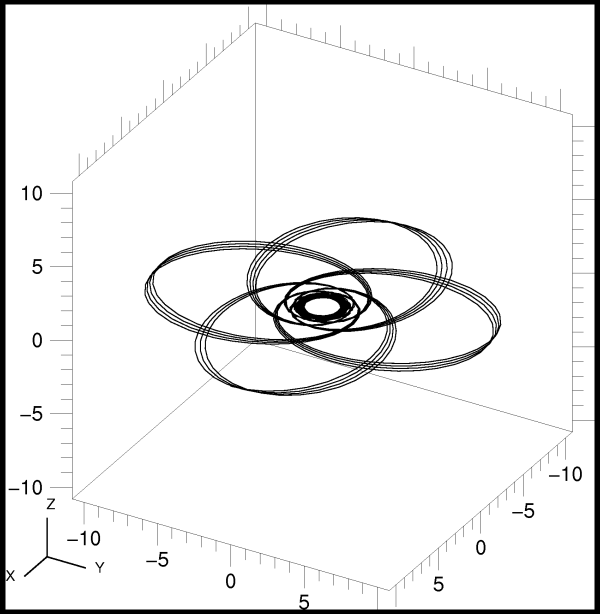
→ Create an apparent relativistic orbits model.

Apparent relativistic orbits model

→ Test of the no-hair theorem using the Galactic center black hole, SgrA*.

→ Create an apparent relativistic orbits model.

→ Use the relativistic orbit tracer GYOTO* (General relativitY Orbit Tracer of Observatoire de Paris).



Orbit of a star around a Kerr black hole
[$\bar{a}$ = 0,995 and M_{tn} = 4 x $10^6 M_\odot$]

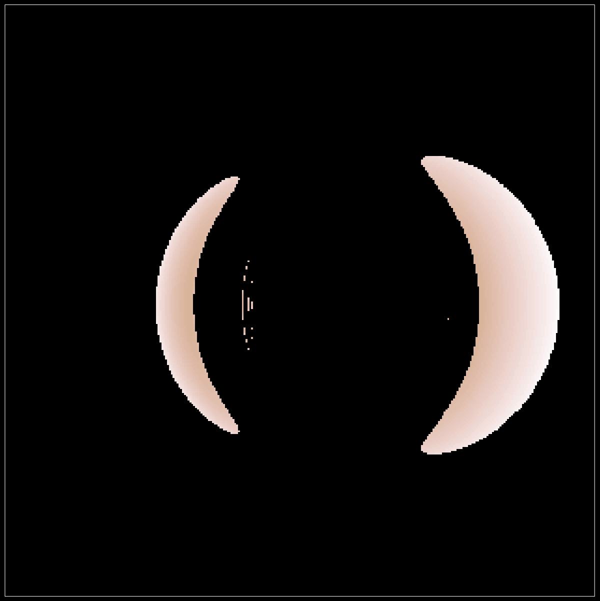
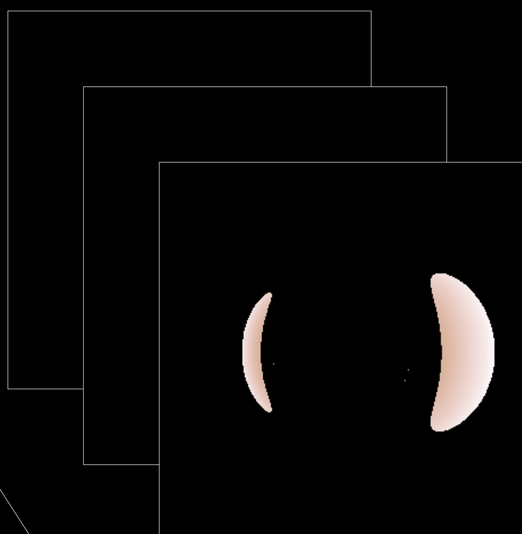


Image of a star around a Kerr black hole
[$\bar{a}$ = 1 et M_{tn} = 4 x $10^6 M_\odot$]

* Vincent, Paumard, Gourgoulhon & Perrin, CQG 28, 225011 (2011)

Apparent relativistic orbits model

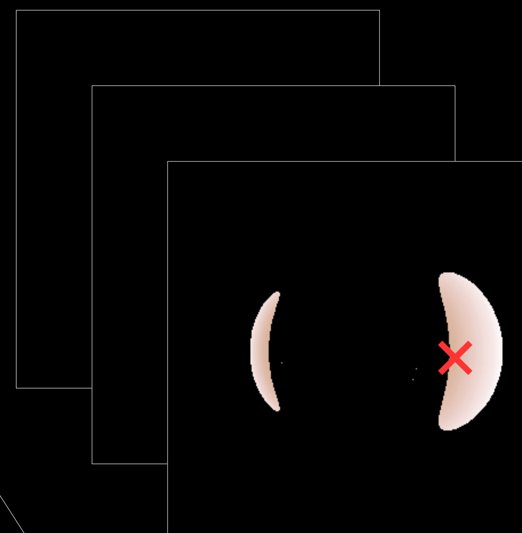
1



time

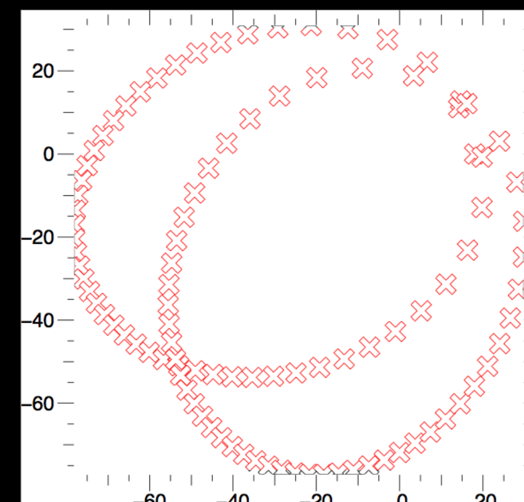
Images of the star obtained for several dates.

2



Apparent positions of the star (α,δ) for each date.

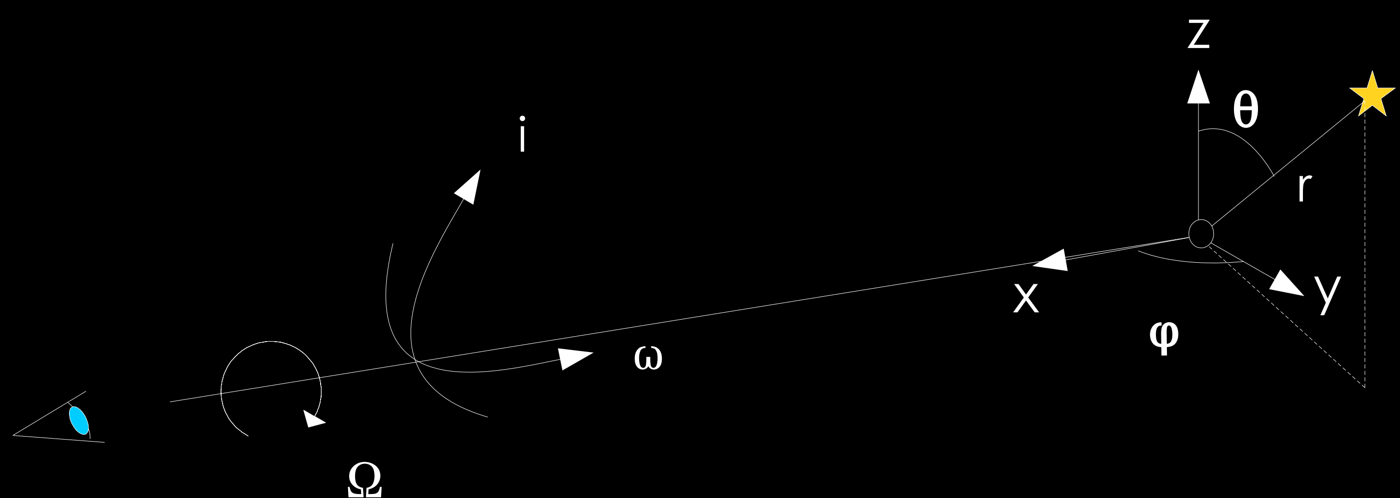
3



Apparent relativistic orbit of the star.

Apparent relativistic orbits model

- fit parameters to the futures astrometrics data of GRAVITY :
  - black hole parameters [$\bar{a}$, M_{tn}] and its distance from the Earth D,
  - position and velocity of the star [(r, θ, φ), (v_r, v_θ, v_φ)],
  - angles of the observer plane [i, ω, Ω].

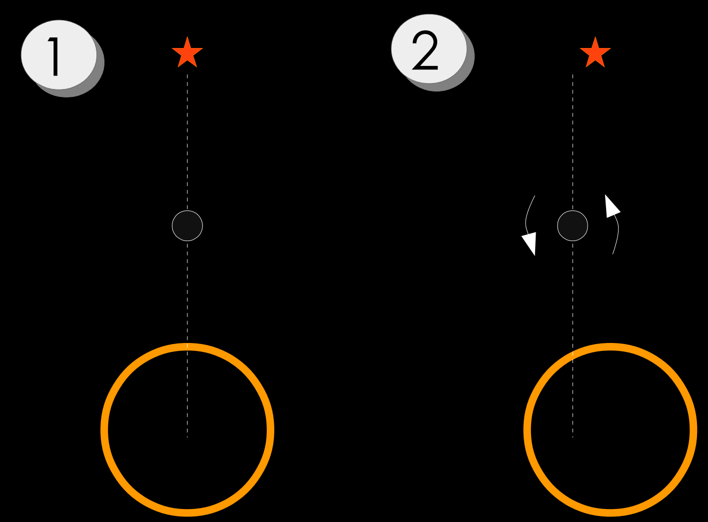


Einstein ring study with GYOTO

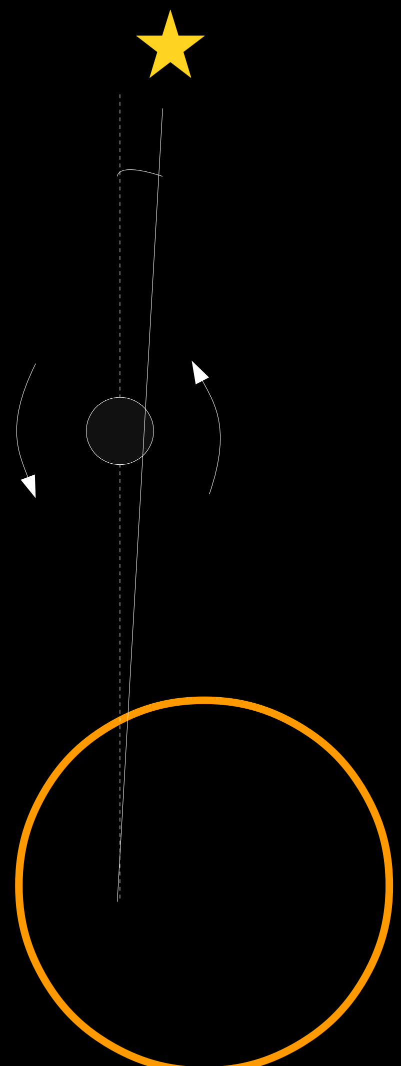
→ validate GYOTO in weak deflection limit (photons do not wind around the black hole).

<u>Einstein ring :</u>

Image formed when a source is placed behind a massif object (e.g : black hole).

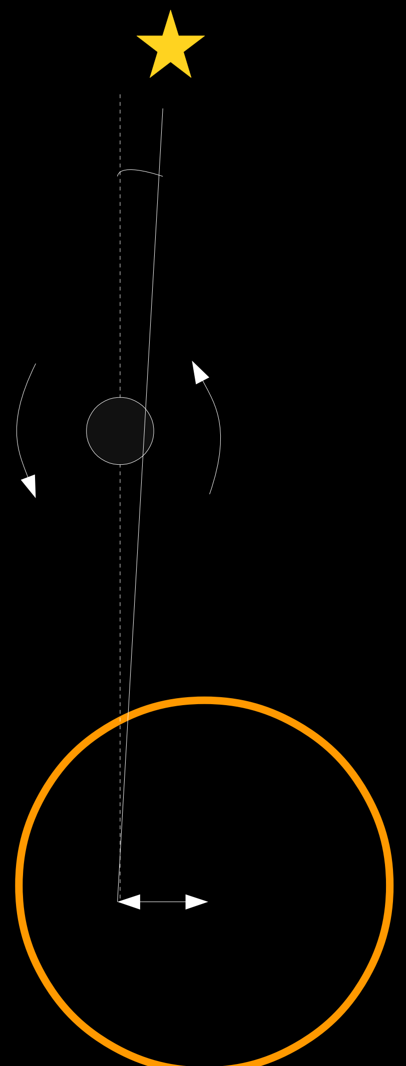


Einstein ring study with GYOTO



Sereno & De Luca, Phys. Rev. D 74, 123009 (2006)
Analytical Kerr black hole lensing in weak deflexion limit :

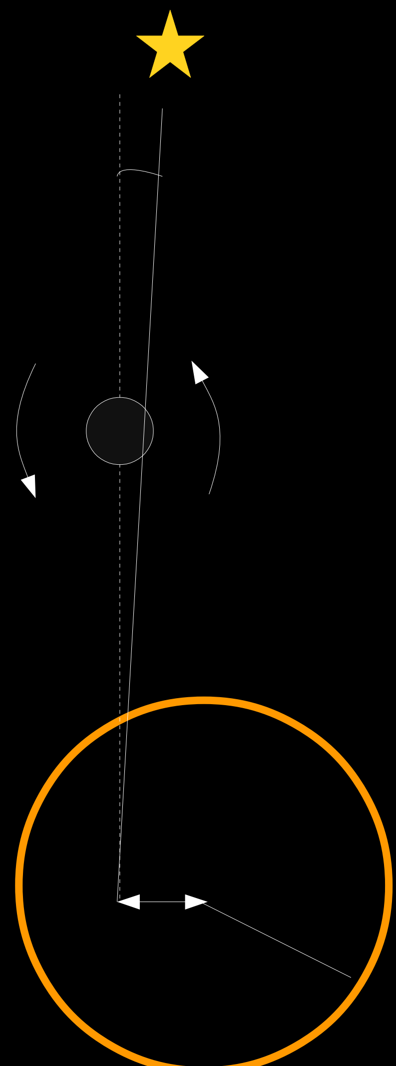
- angular position of the star needed to form the ring,



Sereno & De Luca, Phys. Rev. D 74, 123009 (2006)

Analytical Kerr black hole lensing in weak deflexion limit :

- angular position of the star needed to form the ring,
- offset of the ring,



Sereno & De Luca, Phys. Rev. D 74, 123009 (2006)

Analytical Kerr black hole lensing in weak deflexion limit :

- angular position of the star needed to form the ring,
- offset of the ring,
- angular size of the ring.

Perspectives

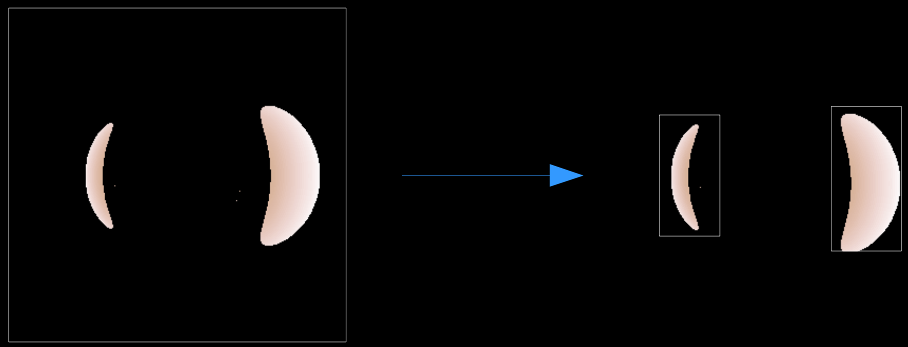
1. Finish the study of the Einstein ring with GYOTO :

→ measure of the three analytical formulas in Sereno and al. (2006) thanks to GYOTO.

→ error bars estimation thanks to the noises generated by GYOTO.

2. Establishment of the apparent relativistic orbits model :

→ Find one/several method(s) allowing to search the positions of the primary and secondary images :



- measure accuracy << 10 μas,
- reasonable computational time (fitting of 11 parameters):
  - Where secondary images can be neglicted ?
  - Where gravitational lensing effects can be neglicted ?