General relativistic effects on the orbit of the S2 star with GRAVITY

Marion Grould

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l'Observatoire de Paris | LUTH
Laboratoire Univers et Théories

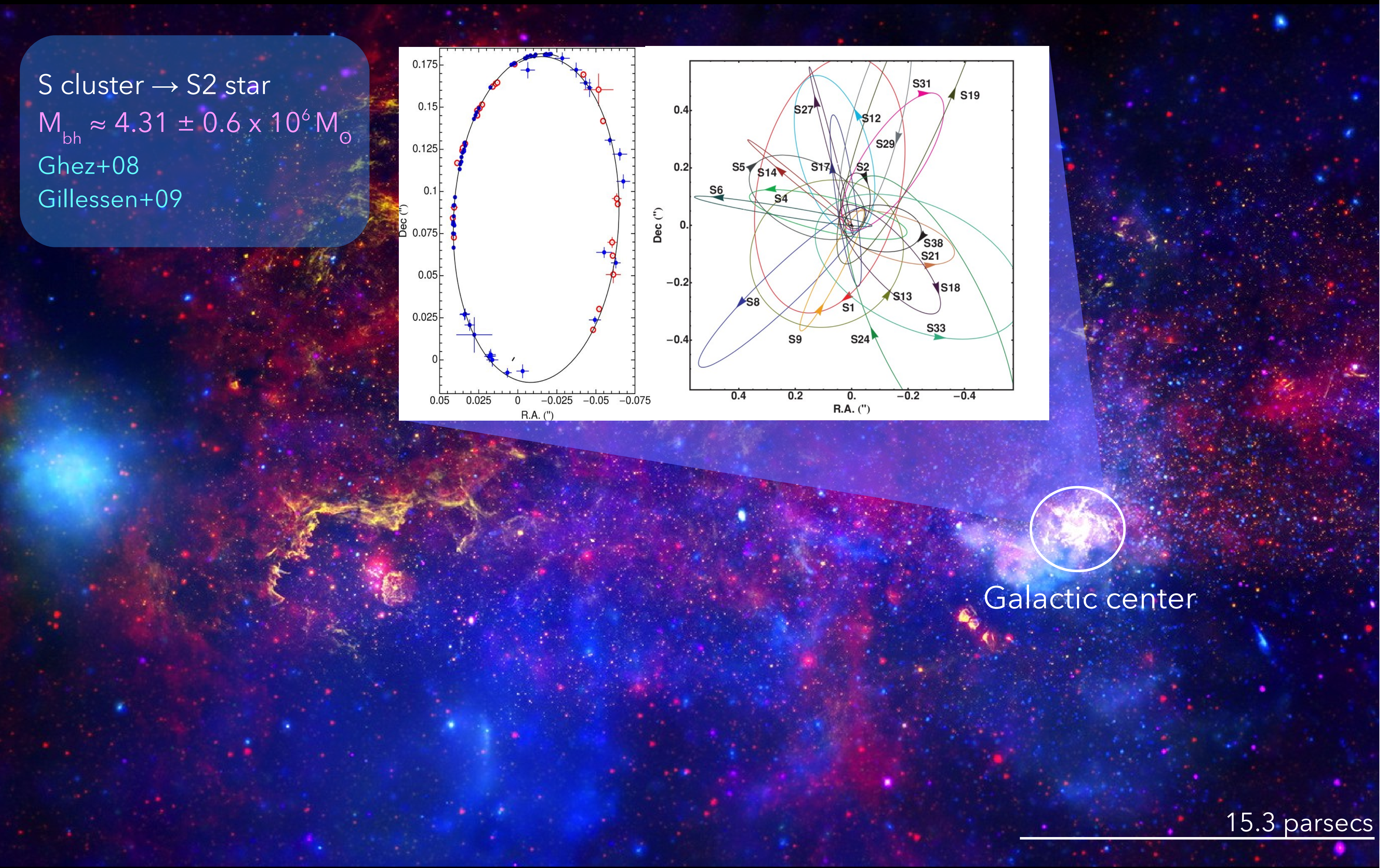
The Galactic center – the S2 star

S cluster → S2 star

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

Ghez+08

Gillessen+09



Infrared, visible and X-ray, sources : NASA, ESA, SSC, CXC, and STScI

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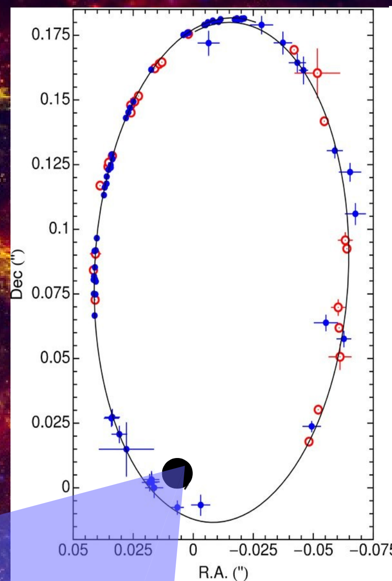
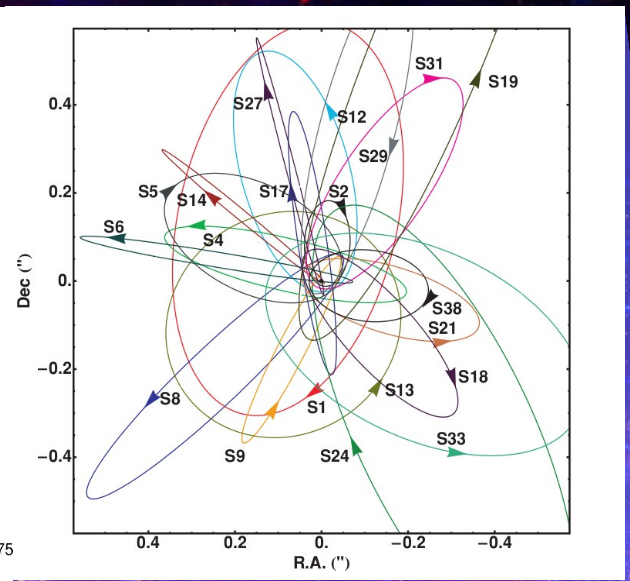
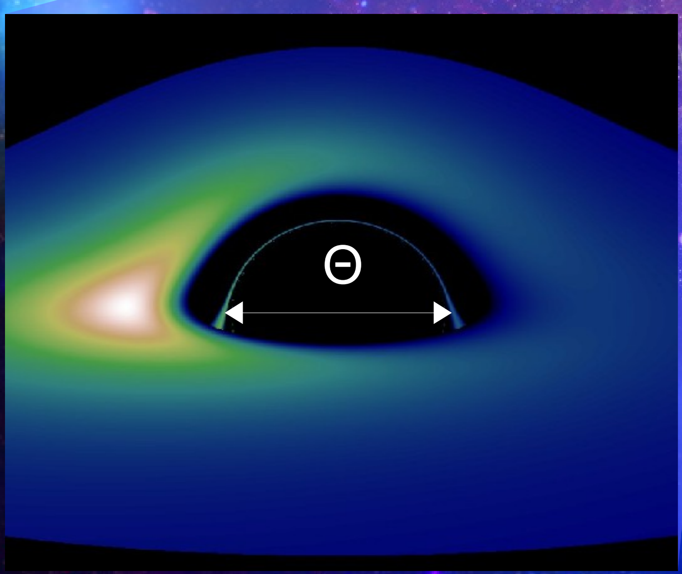


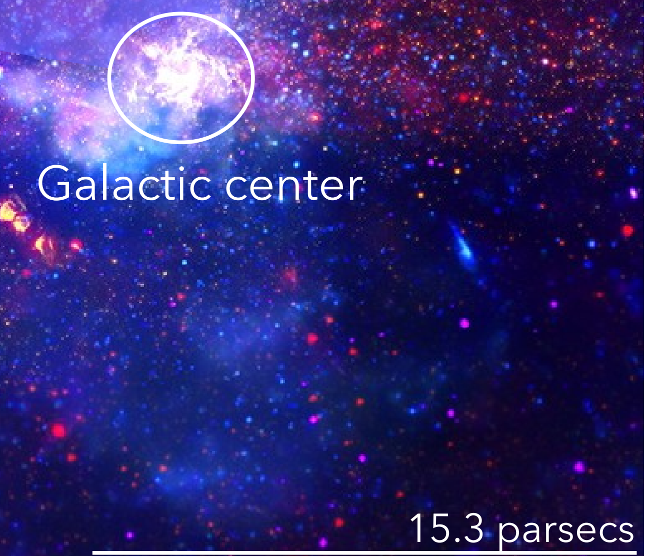




Apparent size :

$\Theta \approx 53$ µas

Biggest apparent black hole



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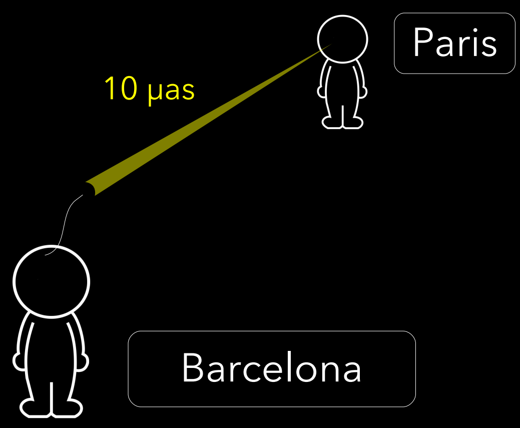
The GRAVITY instrument

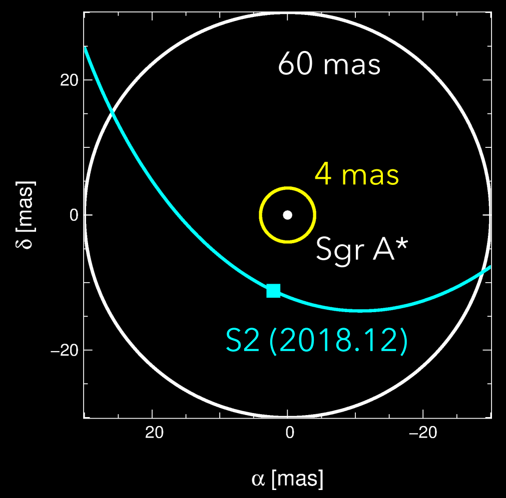
(Eisenhauer+11) Major goals of GRAVITY

- detect relativistic effects with a high accuracy
- constrain the nature of the object located at the Galactic center

INTERFEROMETER

- installed during the summer 2015 at VLT
- near-infrared
- VLT FOV = 2''
- Scientific FOV = 60 mas
- <u>imaging</u>:
  angular resolution = 4 mas
- <u>astrometry</u>:
  astrometric accuracy = 10 μas





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My aim

Estimate the minimal observation times needed for GRAVITY to detect relativistic effects with the S2 star

Determine whether GRAVITY can constrain the spin of the central black hole with S2

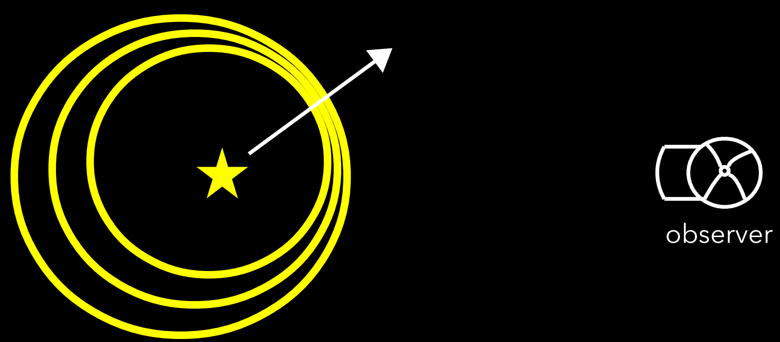
Relativistic effects on the S2 star

Special relativity :
(TD) transverse Doppler effect

General relativity :
- effects on the star trajectory
  - (PA) pericenter advance
  - (LTS) Lense-Thirring
- effects on the photon trajectory
  - (LTP) Lense-Thirring
  - (GR) gravitational redshift
  - (GL) gravitational lensing

Effects	Astro. (µas)	Spectro. (km/s)
(TD)	/	100

Maximal impact of the effect on S2 observations obtained during 3 orbital periods (47 years)



Maximal near S2 pericenter

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Effects	Astro. (µas)	Spectro. (km/s)
(TD)	/	100
(PA)	10^3	34

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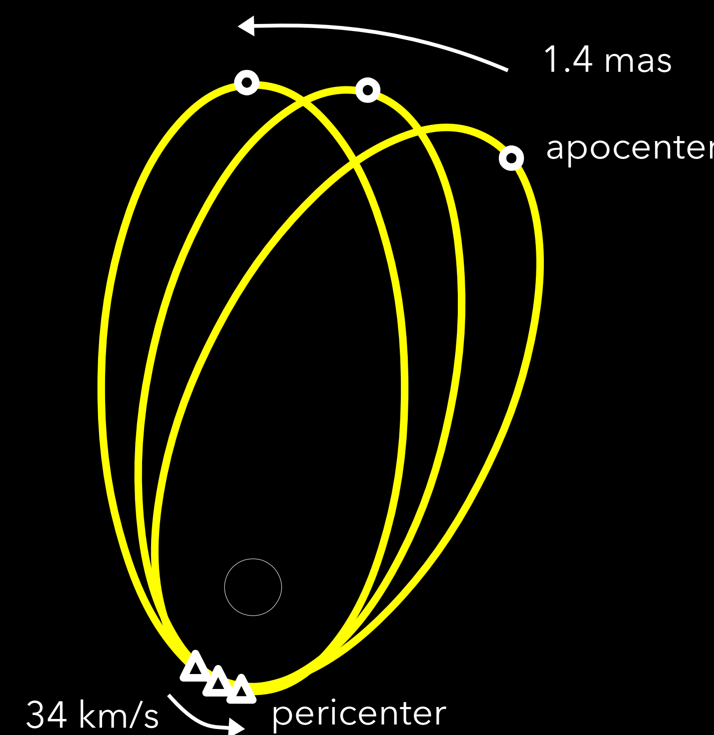

Astro. : maximal near S2 apocenter

Spectro. : maximal near S2 pericenter

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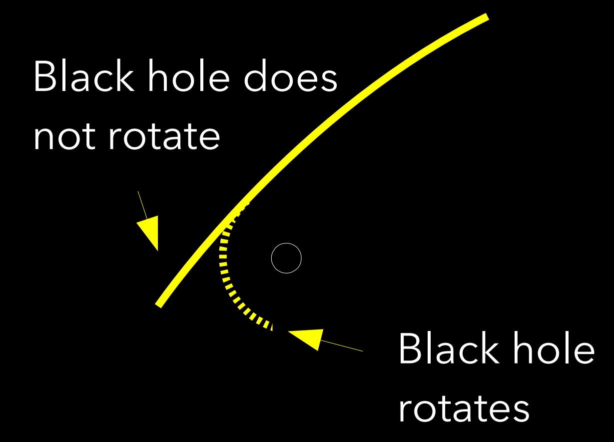
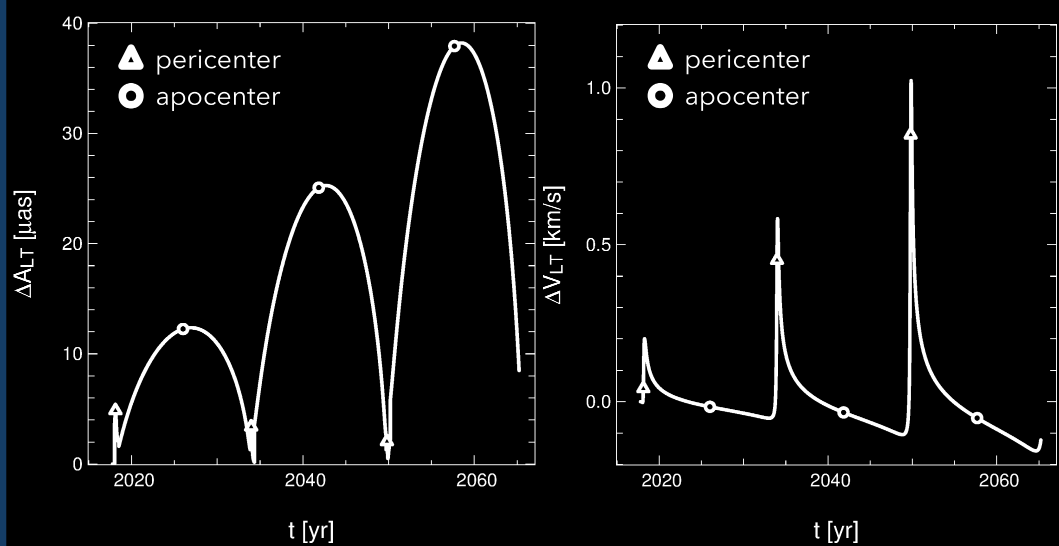
Effects	Astro. (µas)	Spectro. (km/s)
(TD)	/	100
(PA)	10^3	35
(LTS)	40	1
(LTP)	<< 1	<< 1

Maximal impact of the effect on S2 observations obtained during 3 orbital periods (47 years)



a = 0,99, Ω' = 160°, i' = 45°



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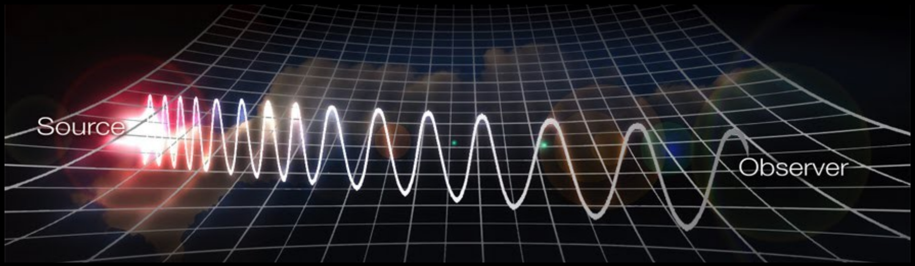
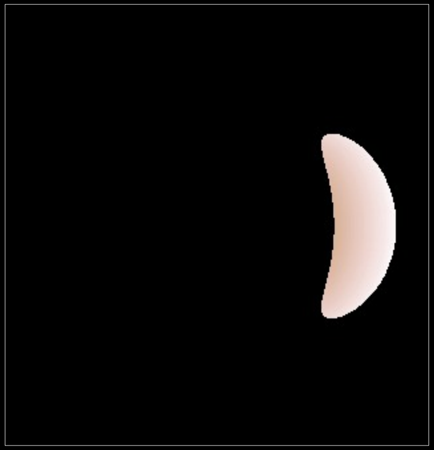
(PA)	10^3	35
(LTS)	40	1
(LTP)	<< 1	<< 1
(GR)	/	100
(GL)	20	/

Maximal impact of the effect on S2 observations obtained during 3 orbital periods (47 years)

Gravitational redshift



Gravitational lensing



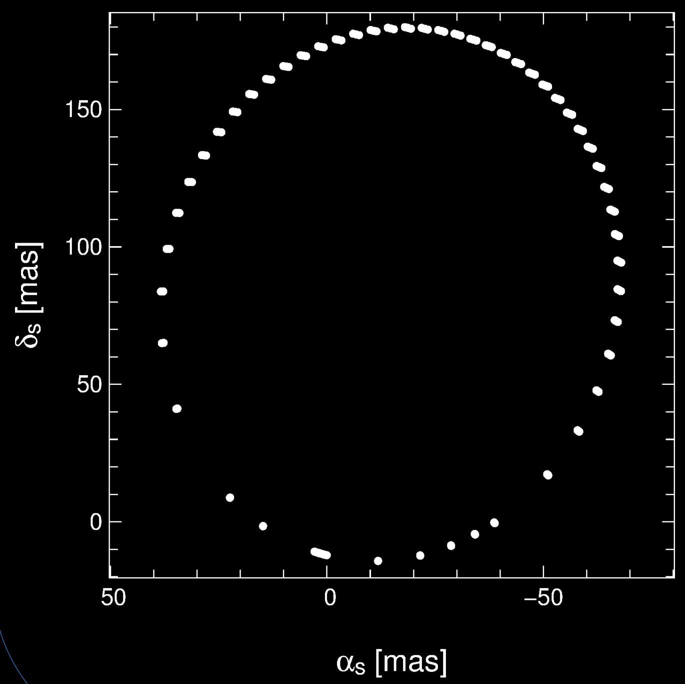
Maximal near S2 pericenter

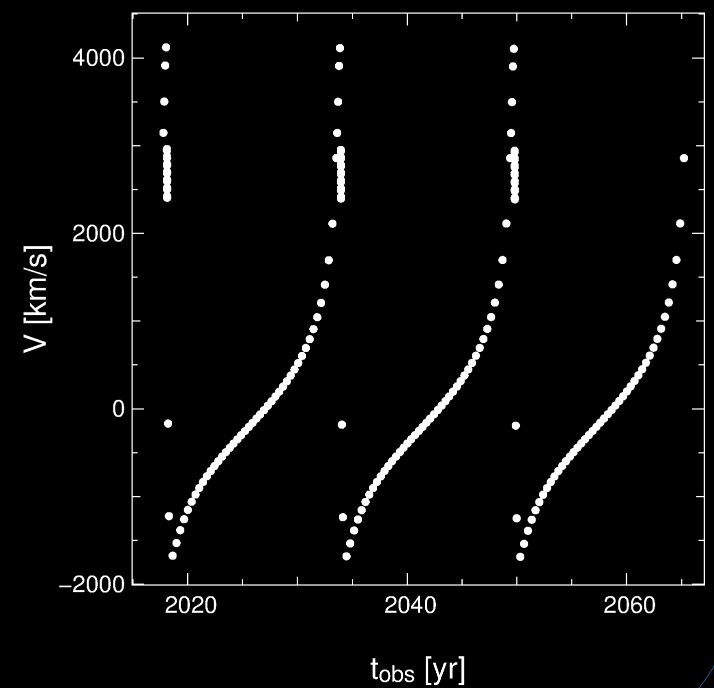
Detection of relativistic effects with the S2 star

Stellar-orbit models

Effects	A	B	C	D
(TD)				
(GR)				
(PA)				
(LTS)				
(GL)				
(LTP)				

Observations generated with the D model





Fit the A, B and C models to observations generated with the D model

Detection of relativistic effects with the S2 star

Stellar-orbit models

Effects	A	B	C	D
(TD)				
(GR)				
(PA)				
(LTS)				
(GL)				
(LTP)				

Minimal observation times needed to detect relativistic effects

Detected Effects			
(TD) (GR)	A	10 μas	30 μas
	1 km/s	1 month	1 month
	10 km/s	2 months	4 months
(PA) (GL)	B	10 μas	30 μas
	1 km/s	6 months	12 years [8 years]
	10 km/s	6 years	18 years [8 years]
(GL)	C	10 μas	30 μas
	1 km/s	6 months	> 30 years
	10 km/s	6 years	

Detection of
- transverse Doppler effect and gravitational redshift within a few months
- pericenter advance within a few years
- gravitational lensing within a few years

Detection of relativistic effects with the S2 star

Can we constrain the spin of the black hole with GRAVITY and S2 ?

→ use a C+ model including lensing effects : analytical formulas from Sereno+06

Effects	A	B	C	C+	D
(TD)					
(GR)					
(PA)					
(LTS)					
(GL)					
(LTP)					

σ_a = 10 µas

σ_V = 10 km/s

$a = 0{,}99$, $\Omega' = 160°$, $i' = 45°$

	16 years	47 years
a	$0{,}98_{-0.39}$	$0{,}93_{-0.11}$
Ω' [°]	-20^{+47}_{-61}	125^{+26}_{-22}
i' [°]	80^{+32}_{-33}	45^{+15}_{-13}

Fitted parameters and 1-σ uncertaities

Summary

Combinaison of GRAVITY and the spectrograph SINFONI at VLT will allow the detection of the

- transverse Doppler effect and gravitational redshift within a few months (≈ 2- 4 months)

- gravitational lensing within a few years (≈ 6 years)

- pericenter advance within a few years (≈ 8 years)

- constraint on the spin parameters within several years (> 16 years)

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Combinaison of GRAVITY and the spectrograph SINFONI at VLT will allow the detection of the

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- pericenter advance within a few years (≈ 8 years)
- constraint on the spin parameters within several years (> 16 years)

Thank you