Simulating observations to study strong-field general relativity at the galactic center

SF2A Day - June 21st, 2011

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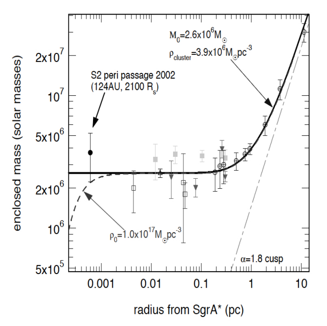
1. The galactic center
2. GYOTO ray-tracing code
3. The GRAVITY instrument and its astrometric performance
4. Simulating a flare orbiting close to the last stable orbit with GYOTO, and its observation with GRAVITY
5. Perspectives : future work
6. Conclusion

The Galactic center at large scale

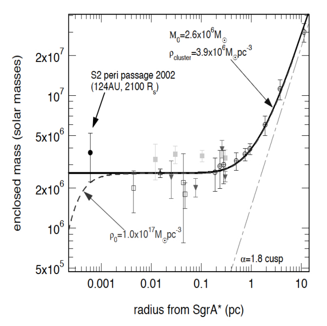
Chandra X-ray image : typical size 1 °



Source : Schödel et al. 2002

The central dark mass

- Astrometric measurements of very close stars → central mass.
- Highly probable : **SMBH of 4.3 10^6 $M_\odot$, $R_S \approx 10$ μas**



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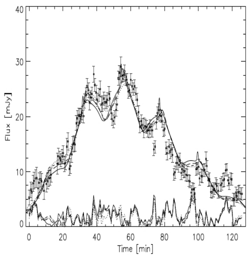

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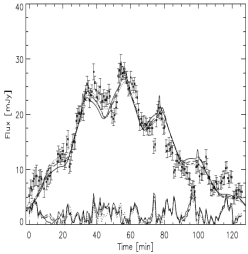
Flares

- Flare = outburst of radiation during $\approx$ 1h, with $\approx$ 20 min pseudo period.
- Nature of a flare ? Not clear. Maybe a **hot spot** orbiting close to the last stable orbit of the BH.

How to study this phenomenon ?

- Theoretical challenge : need to simulate precisely this scenario $\rightarrow$ GYOTO ray-tracing code
- Instrumental challenge : need to follow the motion of the spot $\rightarrow$ GRAVITY instrument



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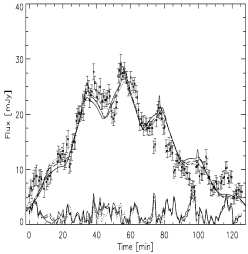

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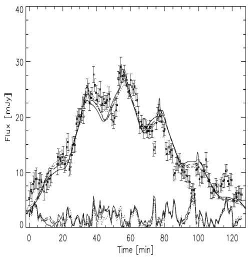

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GYOTO ray-tracing code in a nutshell

- Integration of geodesics in Kerr metric
- Integration in a 3+1 numerically computed metric
- Radiative transfer included in optically thin media
- In C++ (very modulable)
- With a user-friendly interface
- Intended to be made public

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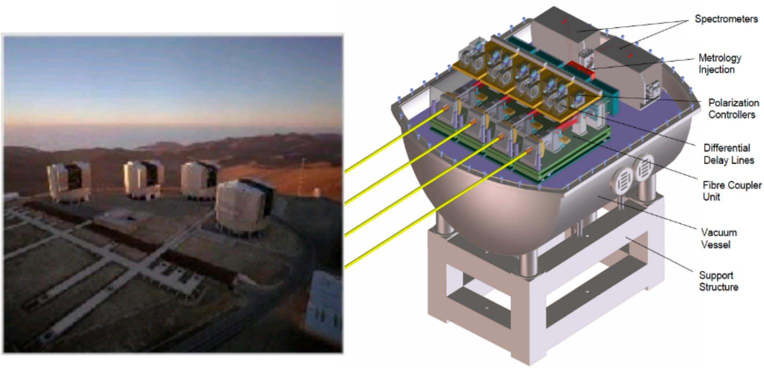
GRAVITY (2014)



VLT four main telescopes will be combined by GRAVITY

GRAVITY's astrometric performance

- Goal for astrometric precision : $\approx$ 10 μas $\approx$ black hole radius $\approx$ a coin on the Moon...
- Integration time needed to reach this precision : a few minutes

So what ?

- GRAVITY should manage to follow the motion of a hot spot orbiting near the last stable orbit !
- Question : can such a precision be achieved ?

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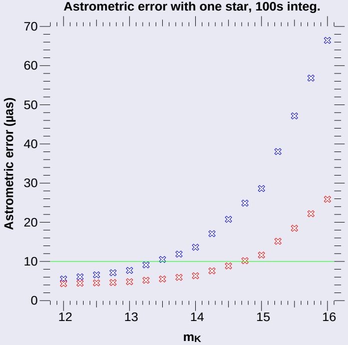
Astrometric precision with a single source in the field



Errors in the direction of the major and minor axes of the PSF

GRAVITY has access to Schwarzschild radius scale astrometry

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The GC flares

- Studied model : the hot spot model.

The hot spot

- Scenery : BH + permanent disc + magnetic field
- Shear near ISCO $\rightarrow$ bending $\vec{B}$ $\rightarrow$ reconnection
- Heated electrons swirl around BH in $\vec{B}$ $\rightarrow$ periodic synchrotron radiation
- Shear $\rightarrow$ emission region extend along ISCO

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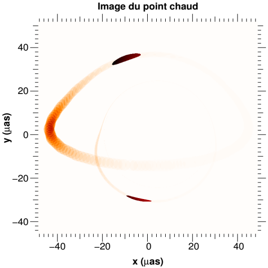
Hot spot numerical model

- Bright spot distorted by shearing = spot+arc
- With azimuthal and temporal gaussian modulation (for heating and cooling phases)



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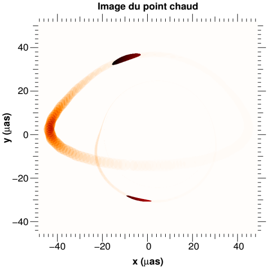

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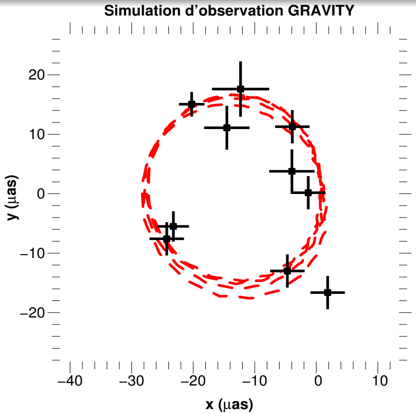
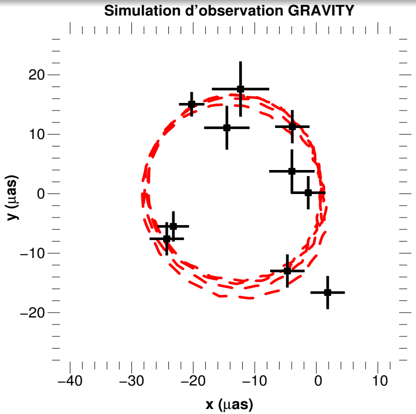


Simulating an observation by GRAVITY

- Using a code simulating the instrument for the error bars
- hot spot trajectory ; retrieved positions after 100 s of integration
- Quantity of interest : dispersion of retrieved positions



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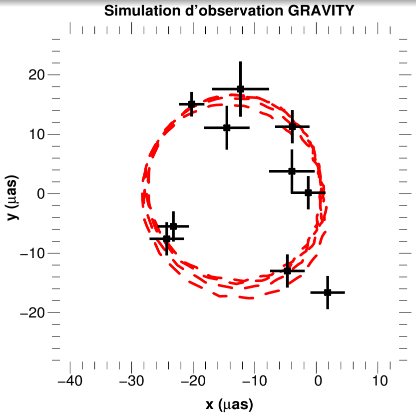

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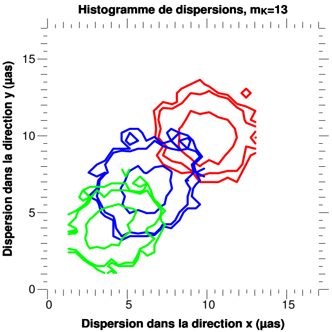

Constraint on the black hole's inclination

- Depending on the measured dispersion → constraint on inclination (60 - 40 - 20)

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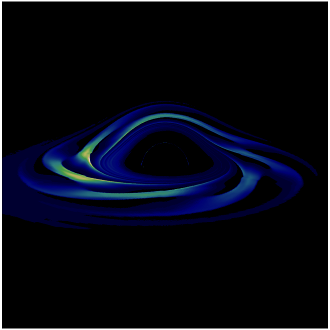
An alternative model for flares : RWI in the disk



- Already shown to be able to explain observations : Tagger & Melia (2006), Falanga et al. (2007)
- Simulations of observations in this model
- Question : is it possible to disentangle with the hot spot model ?

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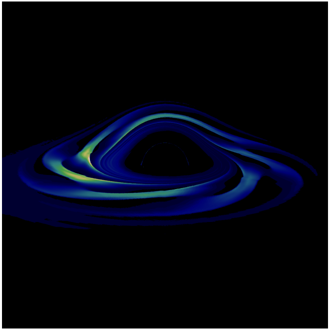

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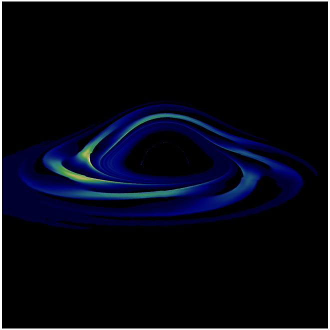

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- GC : ideal lab to study strong GR,
- Immediate vicinity : hot spot = perfect probe of strongest gravity,
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