Probing Sgr A* flares with VLTI/GRAVITY

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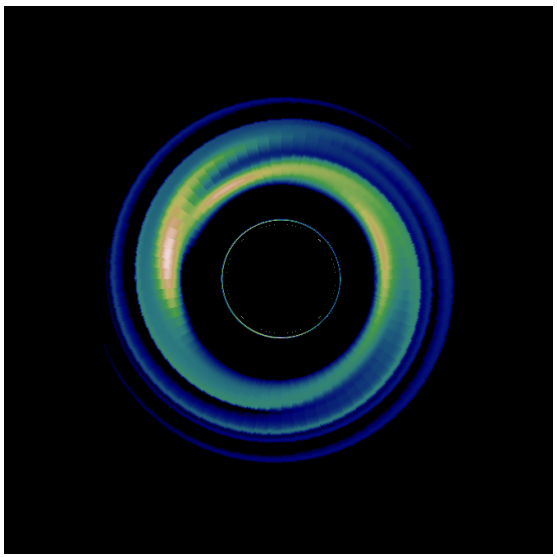
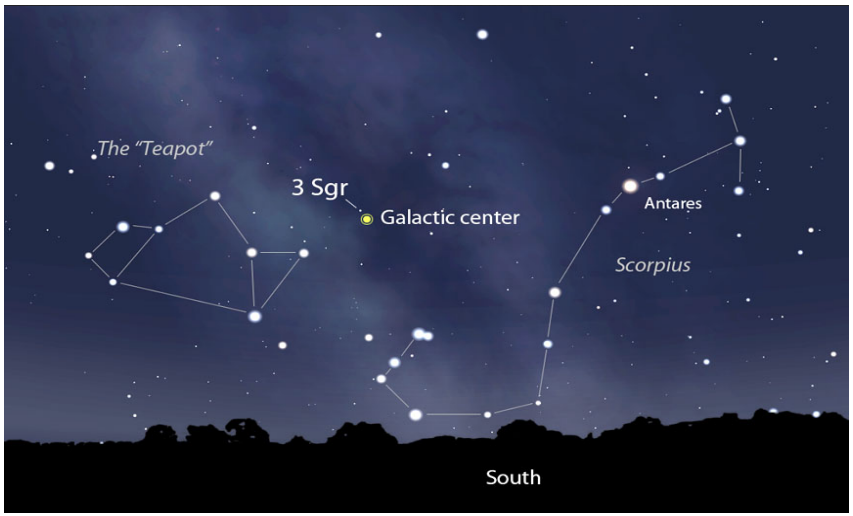
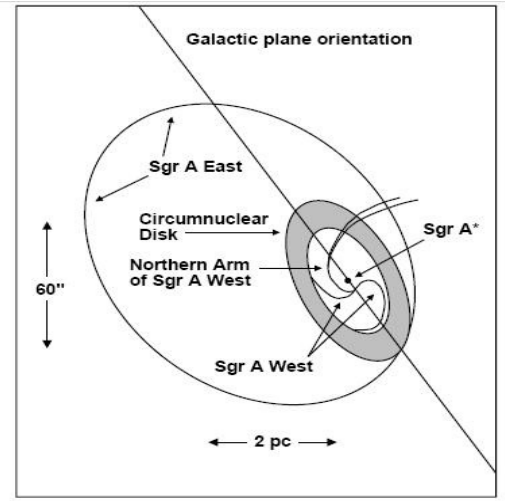
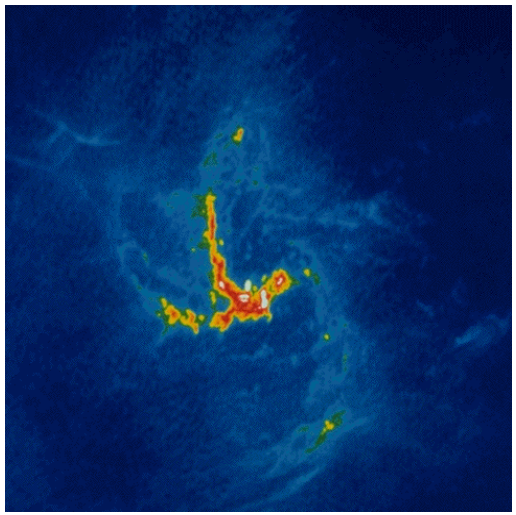


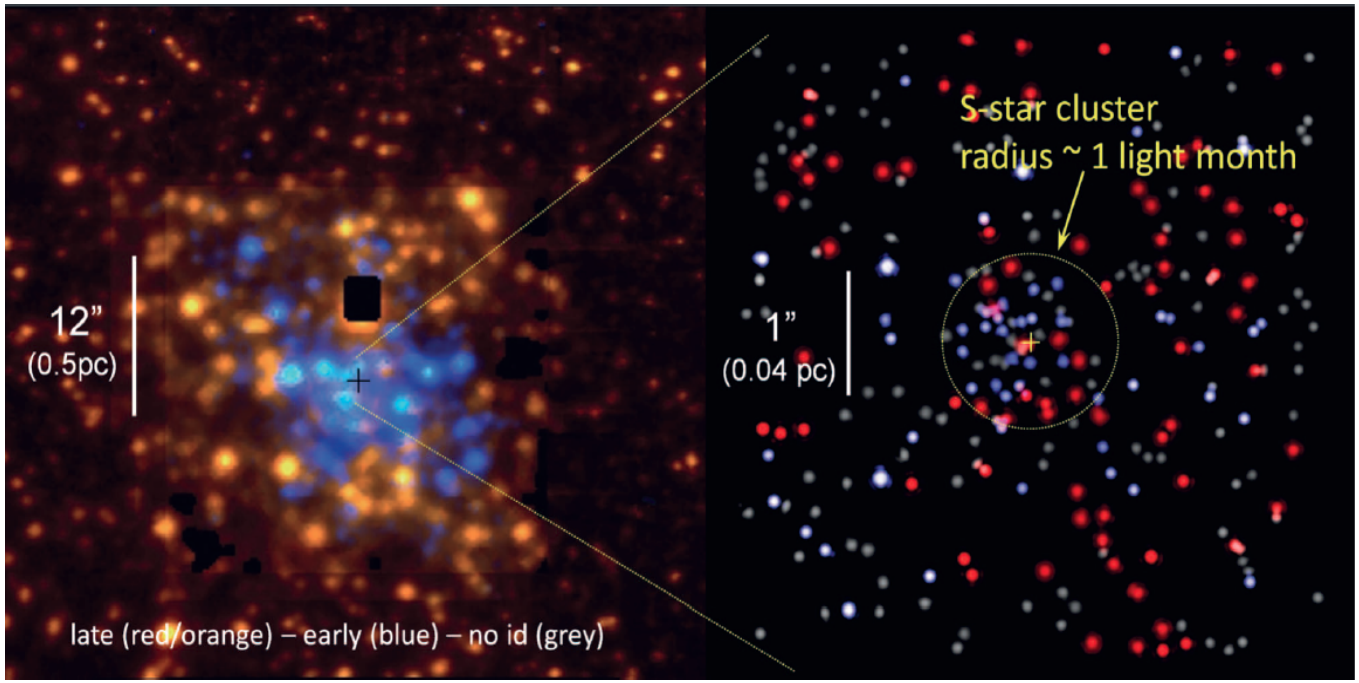


Credit : Stellarium, Bob King

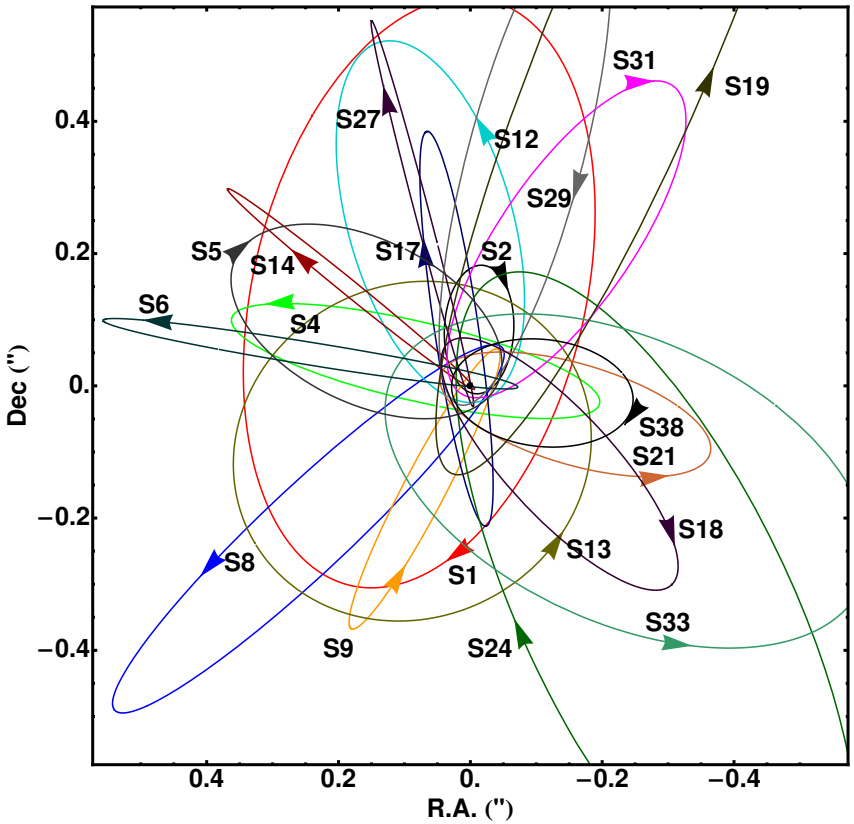


Baganoff+03: size = **1' ≈ 2 pc**





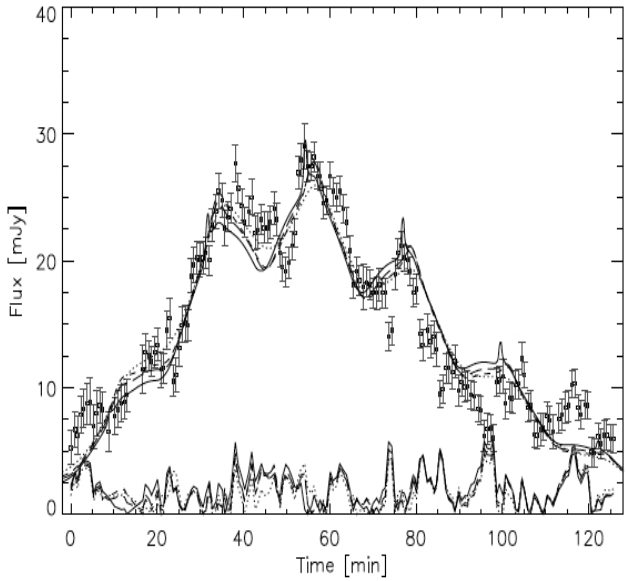
Genzel+10: size = **10" ≈ 0.5 pc**



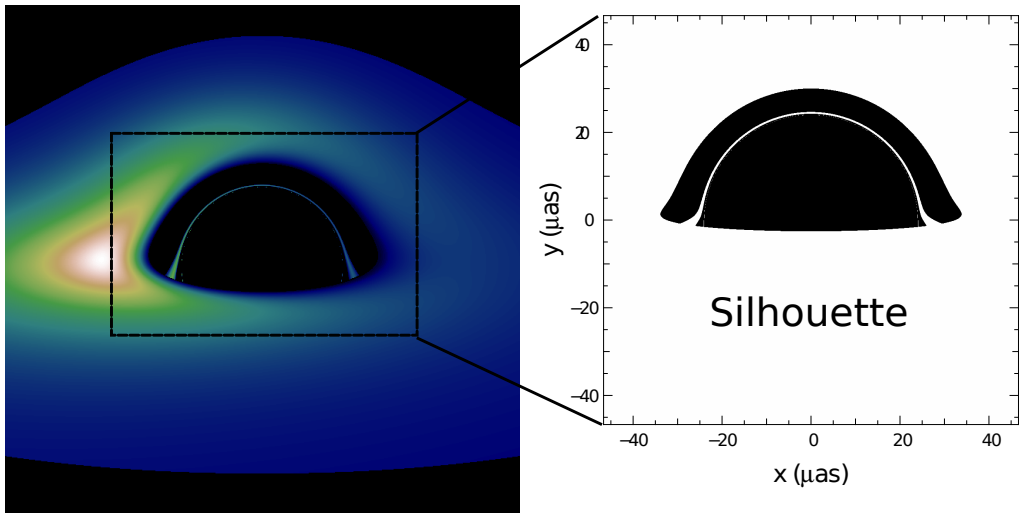
S-stars cluster (Gillessen+09): size = **1" ≈ 0.05 pc**

The central dark mass

- Astrometric measurements of close stars → central mass.
- Sgr A* ≈ **SMBH of 4.3 10^6 $M_\odot$,** $\theta_{\mathrm{app,Sch}}$ **≈ 50 μas**



Sgr A* *flare* : light curve (Hamaus+09)

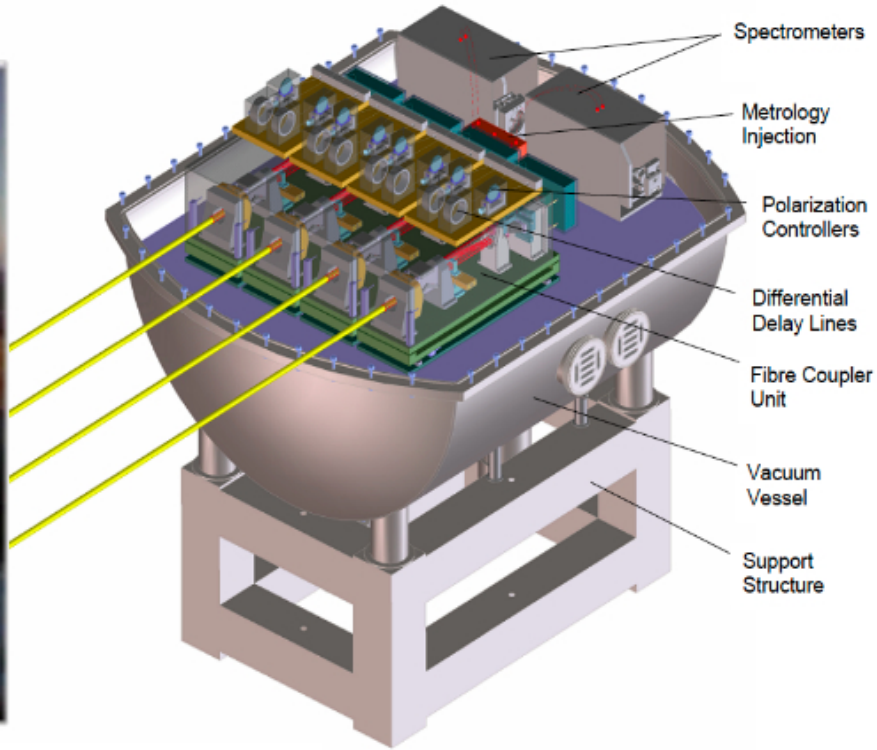


Sgr A* *silhouette*

Probing the vicinity of the horizon

- Variability: flares (**period** $\approx$ **30 minutes**) - cause??
- Imaging: silhouette - GR probe

GRAVITY



VLT **4 main telescopes** will be combined by GRAVITY in **infrared**

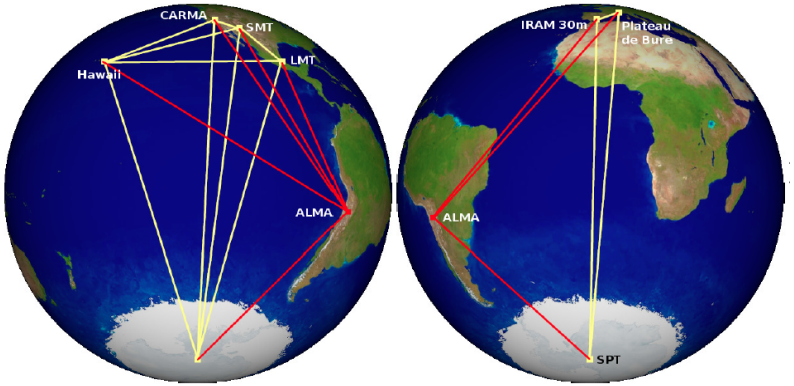
- **First light end of 2015!**

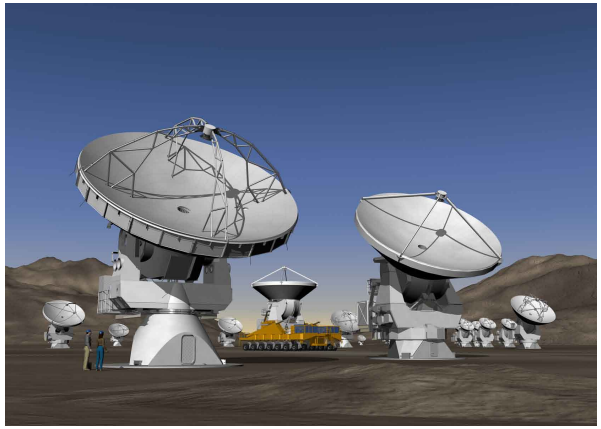
GRAVITY's astrometric performance

- **Astrometric precision: $\approx$ 10 μas**
- Integration time needed: a few **minutes**

So what?

- Follow the motion of a source very close to Sgr A*
- **Can GRAVITY help understand what Sgr A* flares are?**

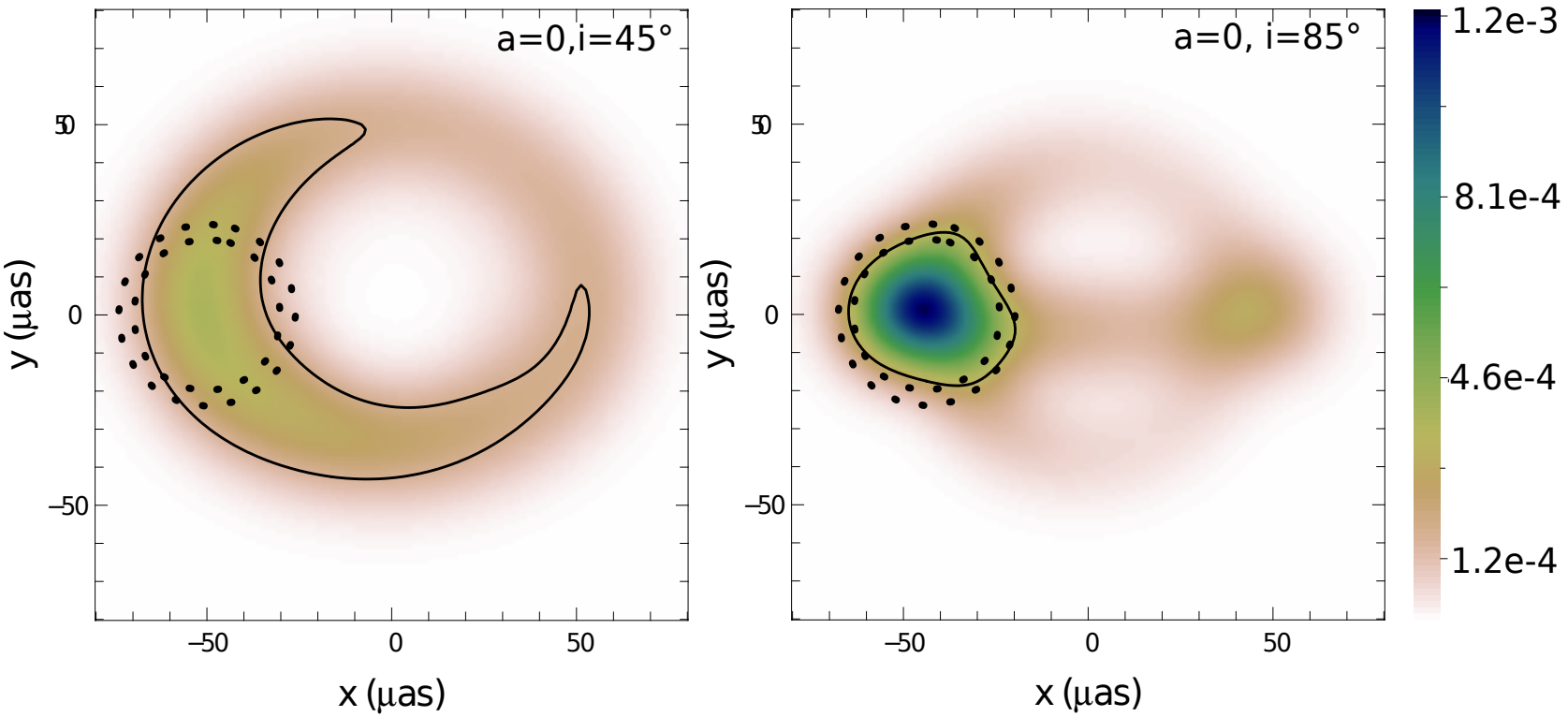




Event Horizon Telescope (2015-2020)

Quiescent state imaging

- **Sub-mm** VLBI network
- $\approx$ 10 stations worldwide (including ALMA)
- **Imaging resolution 15 μas**
- Testing strong-field general relativity
- Complementary with GRAVITY



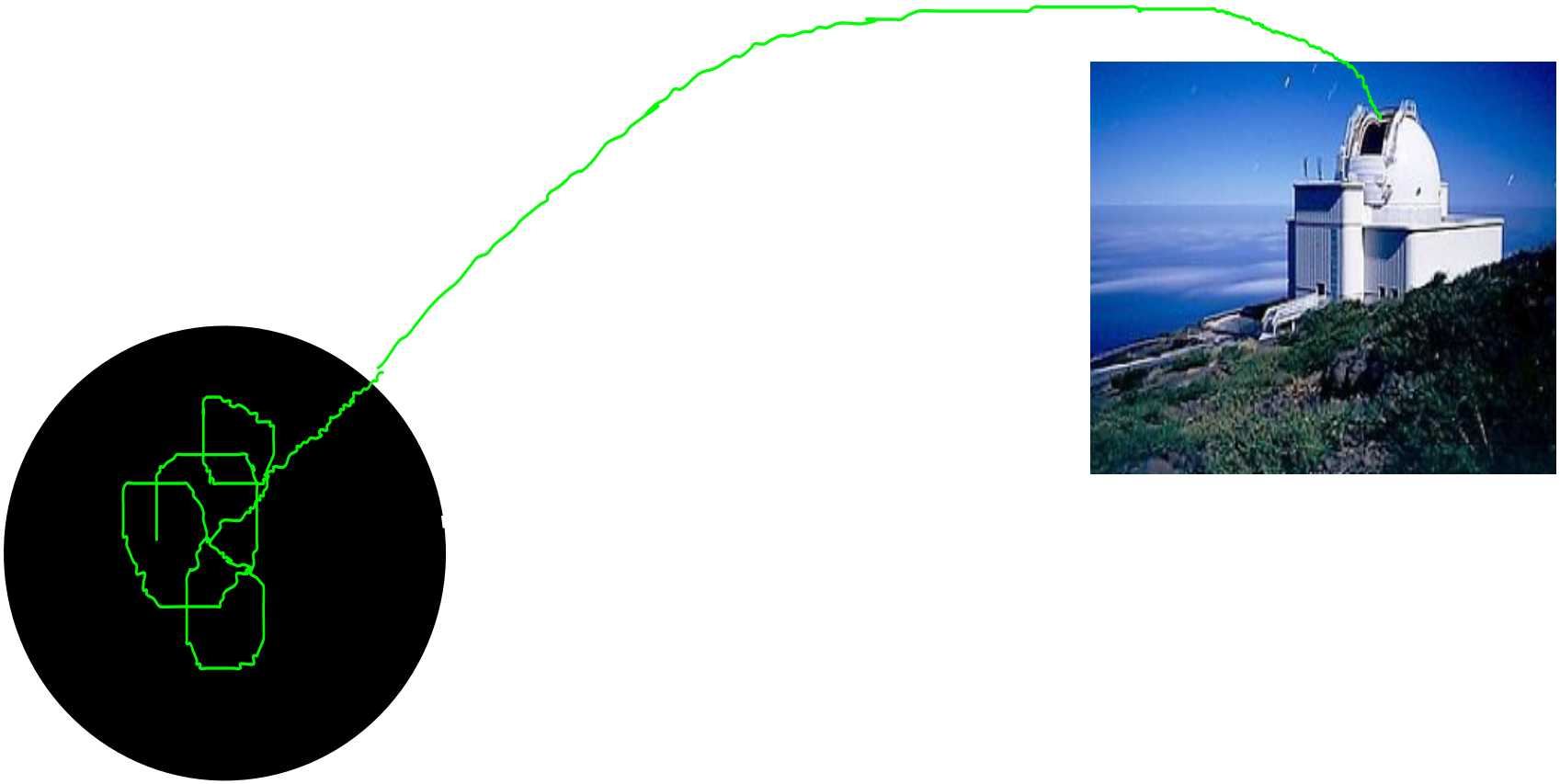
→ Vincent, Yan, Straub, Zdziarski, Abramowicz, A&A, 574, 48 (2015)

EHT constraints

- Imaging the vicinity of Sgr A*
- Constraining the black hole properties?

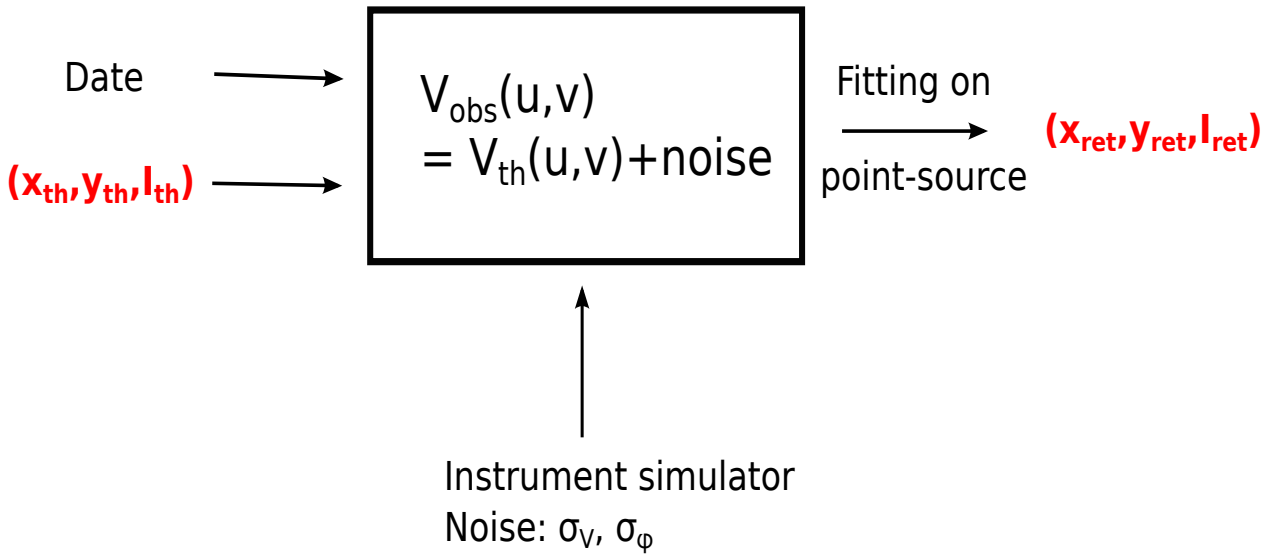
GRAVITY observation simulation

- Using **GYOTO** to ray-trace light curves
- Using **GRAVISIM** to simulate GRAVITY data



Ray-tracing: GYOTO

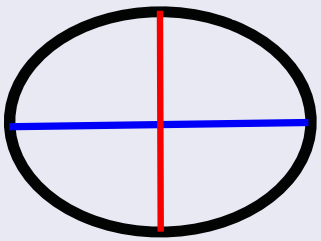
- Integrates light rays to distant observer
- Radiative transfer inside the source
- Open-source: `gyoto.obspm.fr`

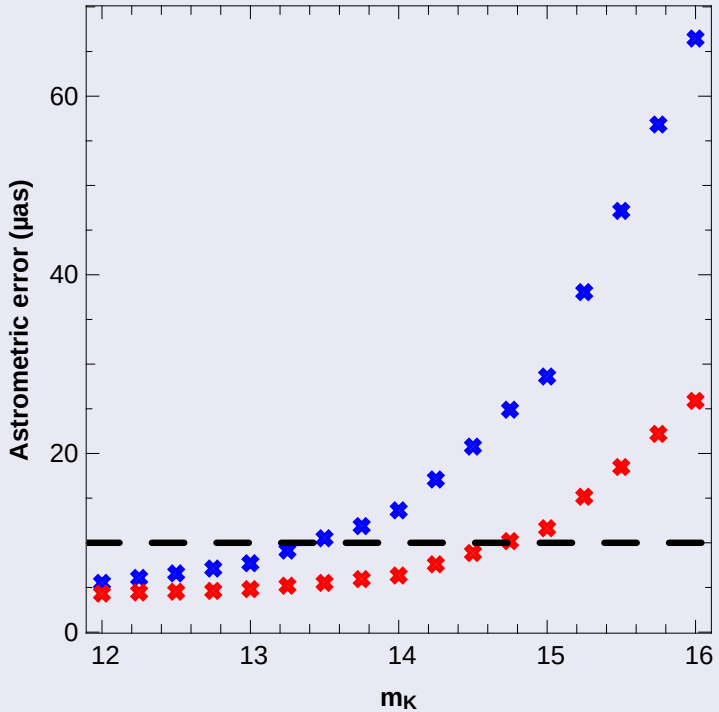


Generating astrometry: GRAVISIM

Astrometric precision with a single source in the field

PSF





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

GRAVITY has access to Schwarzschild radius scale astrometry

→ Vincent et al. 2011 *MNRAS* **412** 2653

Hot spot

- **Hot spot**

  [Genzel et al., 2003]

- **Rossby wave**

  [Tagger & Melia, 2006; Falanga et al., 2007]

Weather forecasting

- **Red noise**

  [Do et al., 2009]

Ejection

- **Plasmon**

  [Van der Laan, 1966; Yusef-Zadeh et al., 2006]

- **Jet**

  [Falcke & Markoff, 2000; Markoff et al., 2001]

Three astrometric classes of models

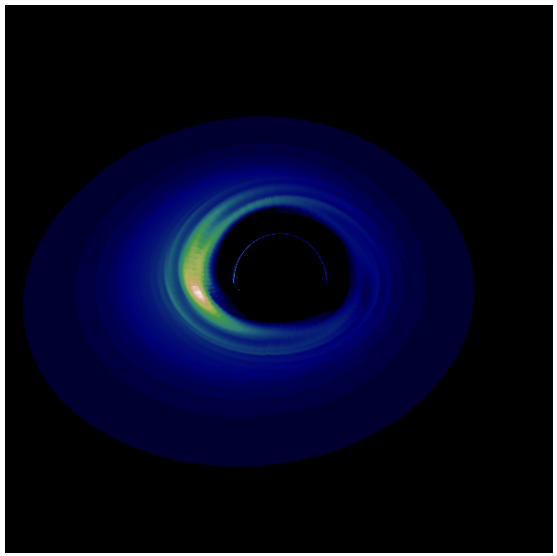
- Hot-spot like, **equatorial plane**
- Weather forecasting, **equatorial plane**
- Ejection, **out of the equatorial plane**

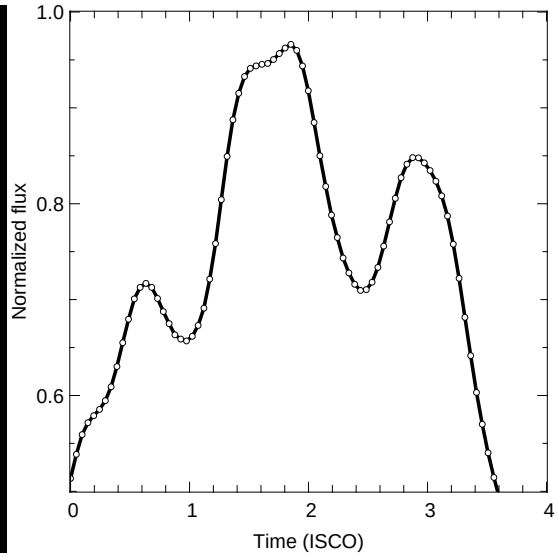
Question

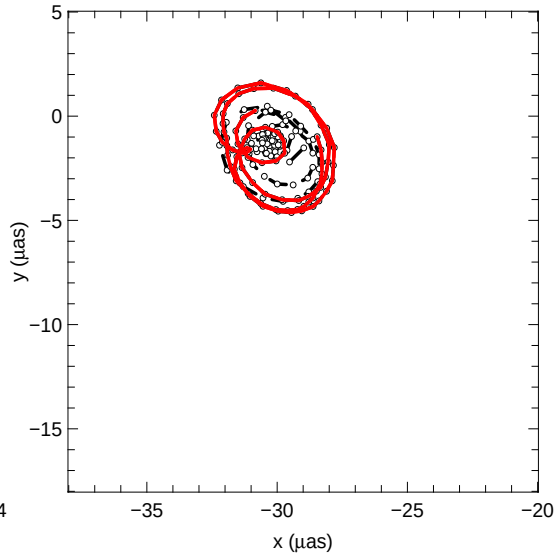
- Can GRAVITY distinguish these classes?

Three models

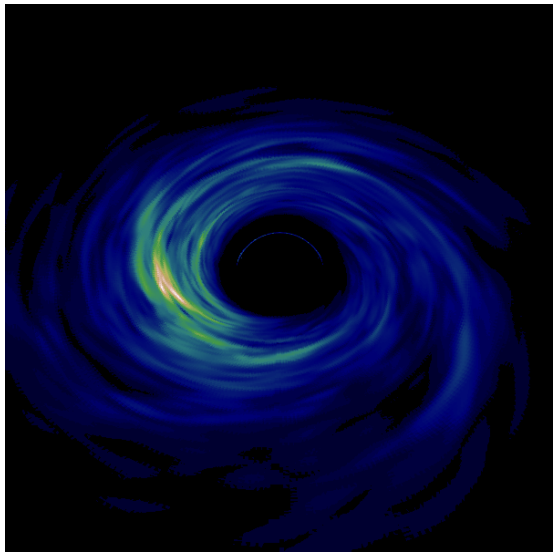
- **Rossby wave**: hydro, 2D disk, pseudo-Newtonian potential, synchrotron emission
  [P. Varniere]
- **Red noise**: MHD, 2D (vertically-averaged) disk, pseudo-Newtonian potential, B-stress proxy emission
  [P. Armitage]
- **Ejected blob**: MHD, axisymmetric 3D blob ejection, pseudo-Newtonian potential, synchrotron emission
  [F. Casse]

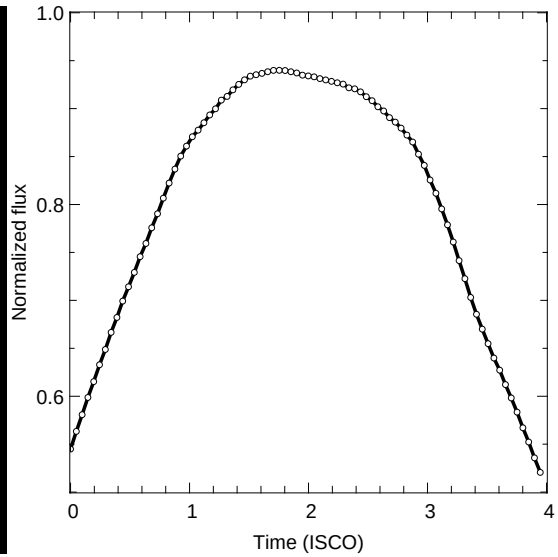


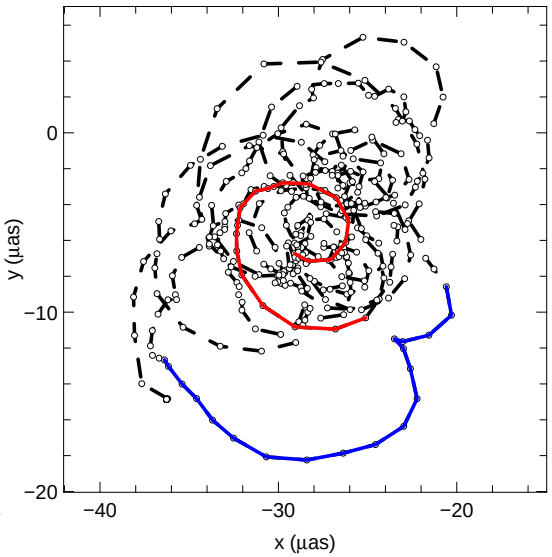

1.0
0.8
0.6
Normalized flux
0
1
2
3
4
Time (ISCO)


5
0
−5
−10
−15
y (µas)
−35
−30
−25
−20
x (µas)

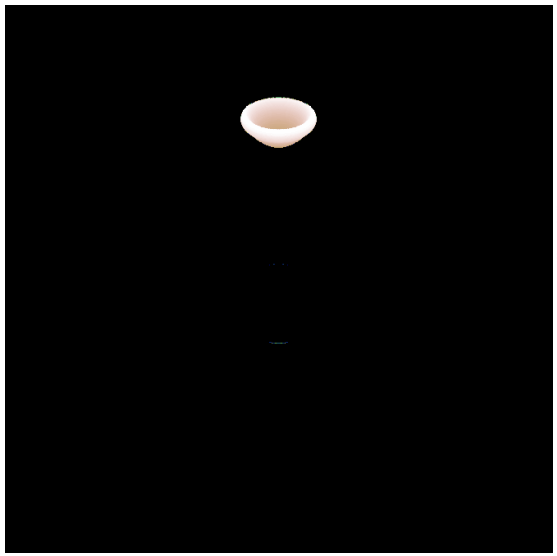
Rossby Wave

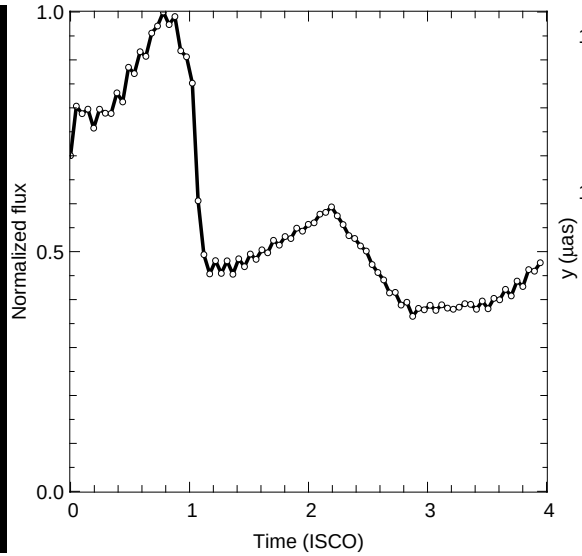


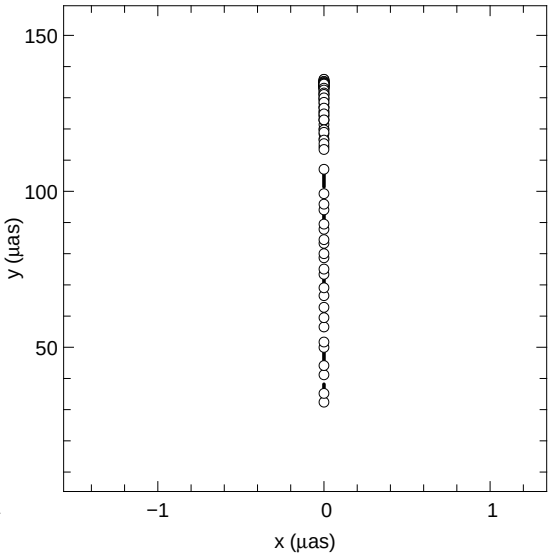

1.0
0.8
0.6
Normalized flux
0
1
2
3
4
Time (ISCO)


0
−10
−20
y (µas)
−40
−30
−20
x (µas)

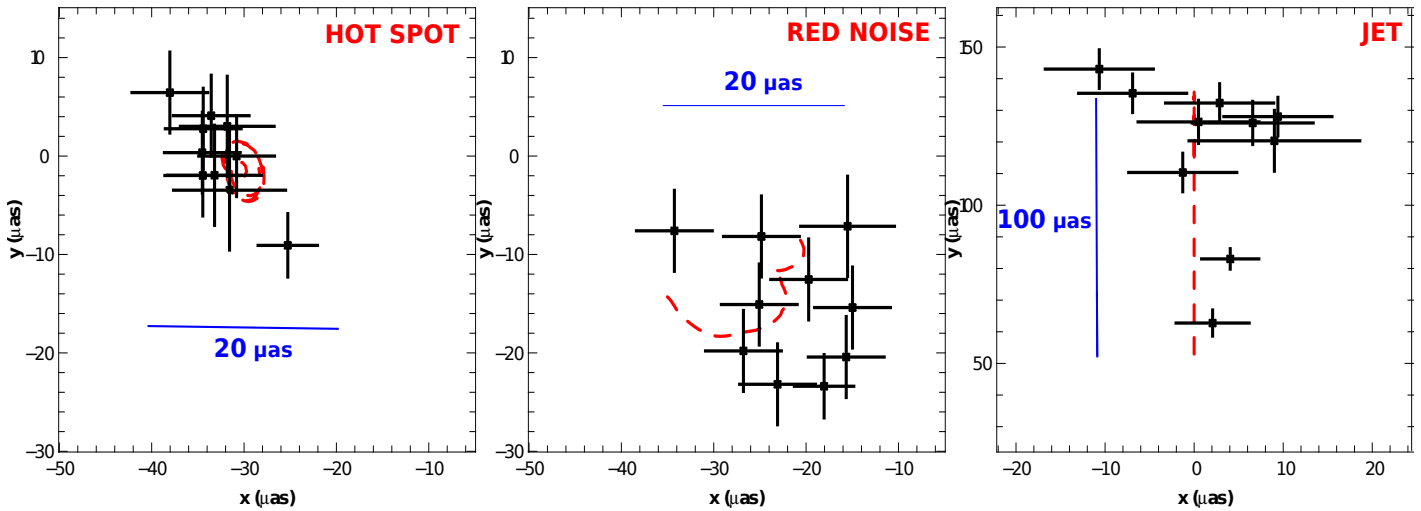
Red Noise





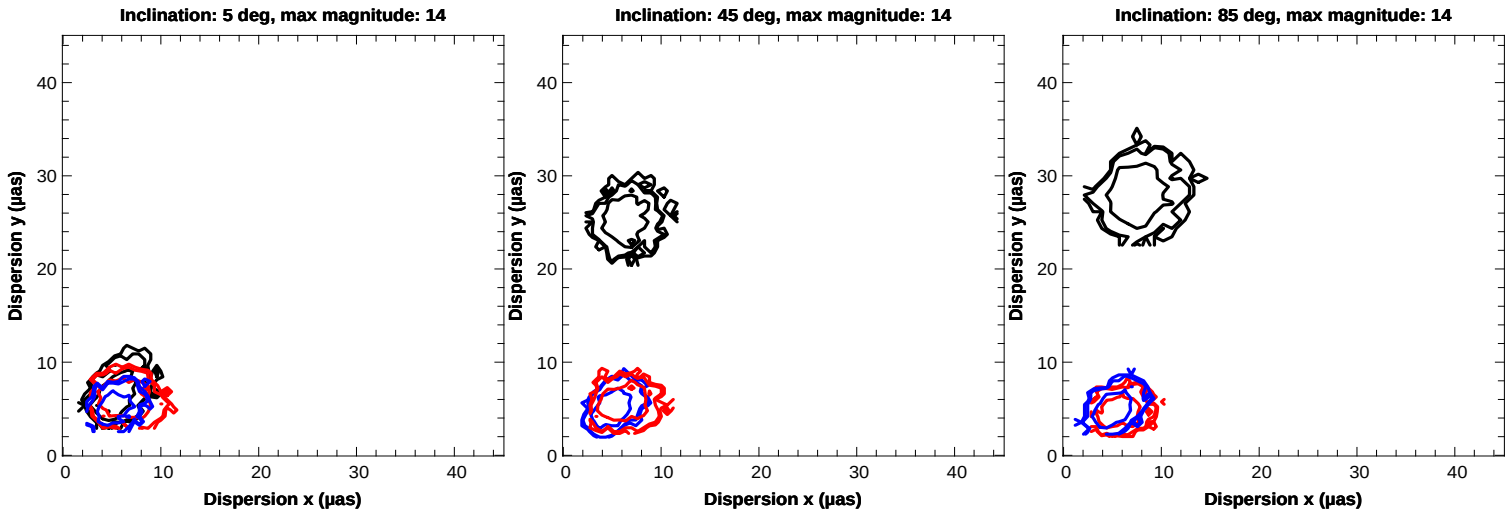


Ejected blob



1 night GRAVITY observation: Rossby / Red Noise / Blob

- 45° inclination, $m_{\mathrm{K}} = 14$



Dispersion of retrieved positions

- Inclination: 5°, 45°, 85° inclination, $m_K = 14$, $\Delta t = 2\ h$

Section conclusion

- GRAVITY can distinguish an **ejected** blob from "**disk-glued** models"
- This is valid for a typical flare ($\boldsymbol{m_K = 15,\ \Delta t = 1\ \mathrm{h}\ 30}$)
- First possibility to start distinguishing flare models

$\rightarrow$ Vincent, Paumard, Perrin, Varniere, Casse, Eisenhauer, Gillessen, Armitage, MNRAS, 441, 3477 (2014)

Conclusion

- **Sgr A* flares**:
  - Today: impossible to distinguish models
  - With **GRAVITY** (2015): will distinguish an ejected blob
- **Sgr A* imaging**:
  - Today: no direct observation of an accretion structure
  - With **EHT** (2015-2020): astrophysical probe near Sgr A*, testing strong-field GR?
- *Thanks for your attention!*

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