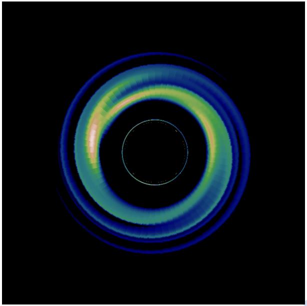
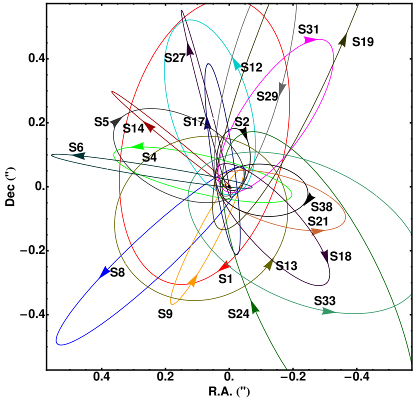
Black hole variability: from Galactic center to microquasars

Frédéric VINCENT[1]

[1]Centrum Astronomiczne M. Kopernika, Warsaw, Poland



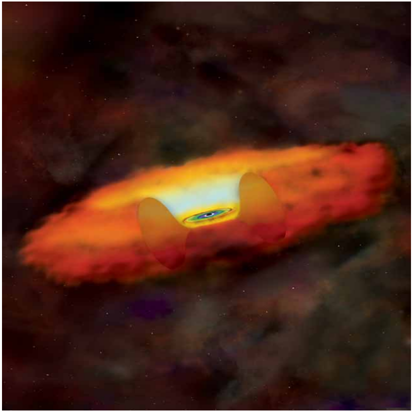
1. Variability: Sgr A*, microquasars
2. Constraining Sgr A* flare models with GRAVITY
3. Modeling microquasars QPOs: oscillating torus model
4. Conclusion



S-stars cluster (Gillessen et al. 2009): size = **1" ≈ 0.05 pc**

Innermost Galactic center: Sgr A*

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

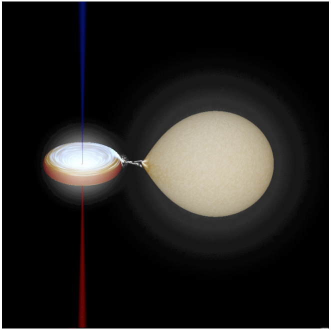


Credit M. Weiss

Accretion structure

- Accretion disk / torus?
- Radiation from Sgr A* originates there

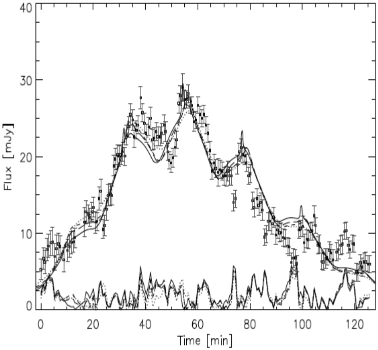
Microquasar



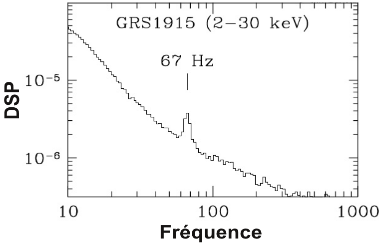
Credit R. Hynes

The central dark mass

- Central BH $\approx$ **10 M$_\odot$**, $\theta_{\rm app} \approx 10^{-5}$ **μas**



GC *flare* : flare light curve (Hamaus+09)



Microquasar *QPO*: GRS1915+105 power spectrum (Remillard+06)

Variability: data

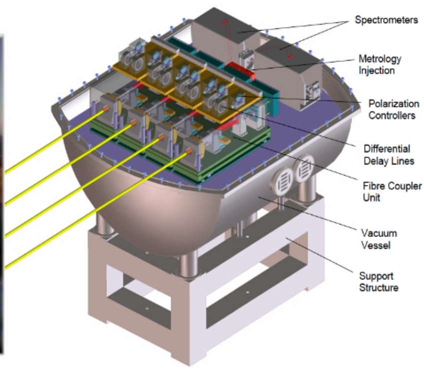
- Light curve / power spectrum
- Characteristic time scales with BH mass:
- $T_{\rm ISCO} \propto M \approx 30\,\mathrm{min} - 1\,\mathrm{ms}$

Black hole variability

Today's topics

- What can GRAVITY tell us about Sgr A* flares?
- How to make double-peak QPOs with an accretion torus?

GRAVITY



VLT four main telescopes will be combined by GRAVITY

- **First light May 2015!**

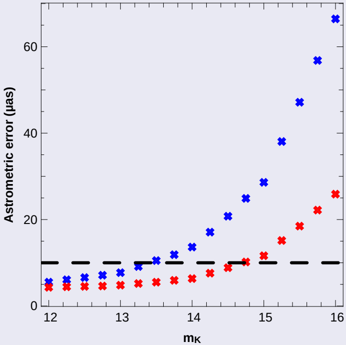
GRAVITY's astrometric performance

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

So what?

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

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

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

Competing models for Sgr A* flares

- **Plasmon**

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

- **Jet**

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

- **Hot spot**

  [Genzel et al., 2003]

- **Multi-resonance**

  [Kotrlova et al., 2013]

- **Rossby wave**

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

- **Red noise**

  [Do et al., 2009]

Three astrometric classes of models

- *circular, confined single-source* motion
  [hot-spot, Rossby wave]
- *complex multi-source* motion
  [red noise]
- *linear, large-scale* motion
  [plasmon,jet]

Question

- Can GRAVITY distinguish these classes?

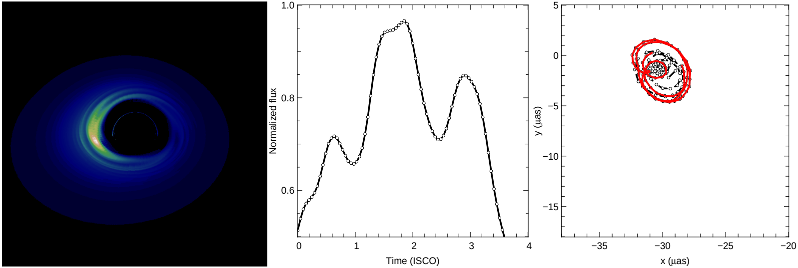
Three models

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

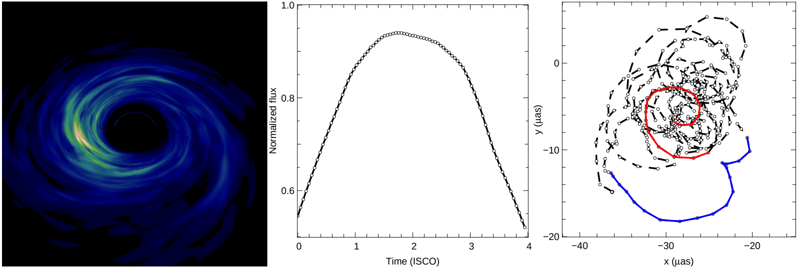
Observation simulation

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

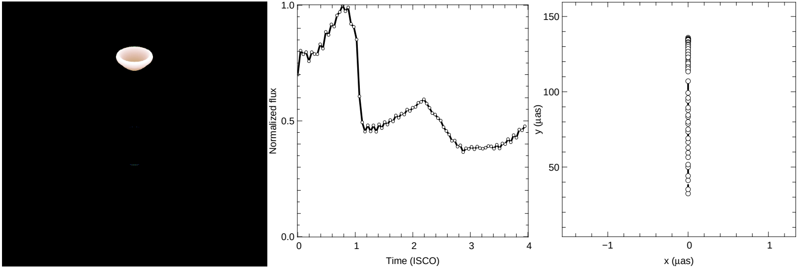
`gyoto.obspm.fr`


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)

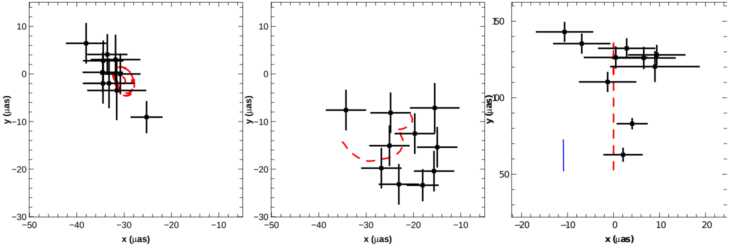
Rossby Wave


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

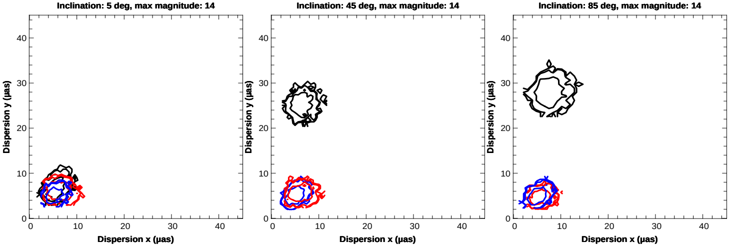


Ejected blob



1 night GRAVITY observation: Rossby / Red Noise / Blob

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



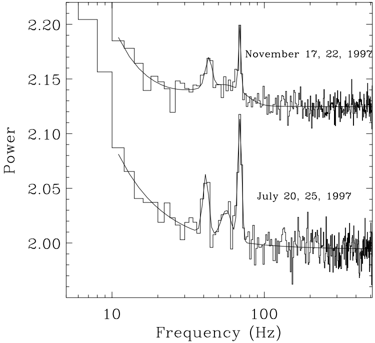
Dispersion of retrieved positions

- Inclination: 5°, 45°, 85° inclination, $m_{\mathrm{K}} = 14$, $\Delta t = 2\ h$

Section conclusion

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

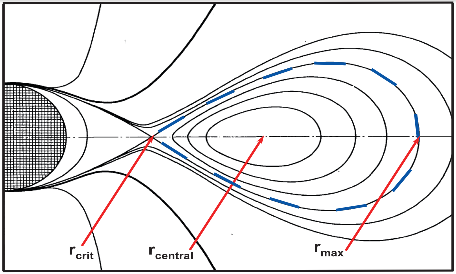
→ Vincent, Paumard, Perrin, Varniere, Casse, Eisenhauer, Gillessen, Armitage, submitted to *MNRAS*



Strohmayer (2001) - GRS1915+105

Double-peak QPO

- 3:2 resonance in some microquasars
- Natural idea: two oscillation modes of a resonating cavity
- Cavity = accretion torus
- Works: Abramowicz & Kluźniak, Rezzolla, Zanotti, Blaes...



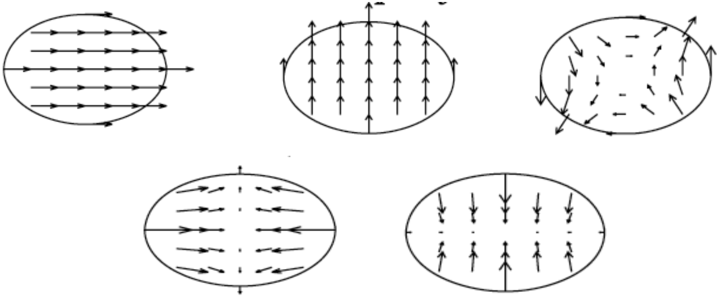
Polish doughnut (Abramowicz et al. 78)

A simple model of accretion torus

- Polish doughnuts [Abramowicz et al. 1978]
- Oscillation modes of Polish doughnuts: Blaes et al. 2006, Straub & Sramkova 2009
- Everything known analytically

Question

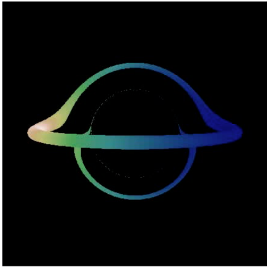
- What is the observable signature of an oscillating Polish doughnut?



Blaes et al. 2006

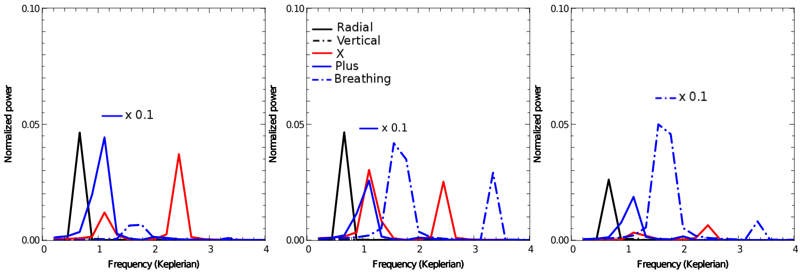
Five lowest order modes for slender tori

- Vertical, X modes (constant emitting area)
- Radial, Plus and Breathing modes (varying emitting area)



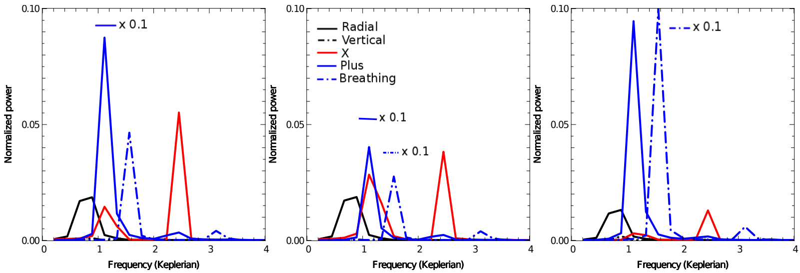
Torus oscillations: 85° inclination, Schwarzschild

- Plus, Breathing modes



Power spectra, Schwarzschild

- Inclination 5°, 45°, 85°
- Radial, Vertical, X, Plus, Breathing
- Radial and Plus are in 3:2 ratio



Power spectra, Extreme Kerr

- Inclination 5°, 45°, 85°
- Radial, Vertical, X, Plus, Breathing
- Radial and Plus are in 3:2 ratio

To conclude

- Different modes / i / a lead to *very* different PSD
- 3:2 resonance? Rad./plus, vert./breathing, rad./vert.
- Models must explain differences of power (ray-tracing!)

Future

- Comparison to GRMHD simulations of perturbed tori
- Predict some model-specific observable features (LOFT?)

$\rightarrow$ Vincent, Mazur, Straub, Abramowicz, Kluźniak, Török, Bakala, A&A just accepted

Conclusion

- **Sgr A* flares**:
  - Today: impossible to distinguish models
  - With GRAVITY: will distinguish an ejected blob
- **QPOs**:
  - 3:2 resonance natural feature of torus model
  - Importance of ray-tracing in PSD calculation
  - Needs more work to compare to data (and instrument!)
- *Thanks for your attention!*

Conclusion

- **Sgr A* flares**:
  - Today: impossible to distinguish models
  - With GRAVITY: will distinguish an ejected blob
- **QPOs**:
  - 3:2 resonance natural feature of torus model
  - Importance of ray-tracing in PSD calculation
  - Needs more work to compare to data (and instrument!)
- *Thanks for your attention!*