Black hole variability: from Galactic center to microquasars

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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 = $1'' \approx 0.05$ pc

**Innermost Galactic center: Sgr A***

- Astrometric measurements of S-stars $\rightarrow$ central mass.
- $\text{Sgr A}^* \approx \text{SMBH of } 4.3 \times 10^6 M_\odot$, $\theta_{\text{app}} \approx 50 \mu\text{as}$
Accretion structure

- Accretion disk / torus?
- Radiation from Sgr A* originates there
The central dark mass

Central BH $\approx 10 \, M_\odot$, $\theta_{\text{app}} \approx 10^{-5} \, \mu\text{as}$
Intro GRAVITY Torus

GC flare: flare light curve (Hamaus+09)

Variability: data

- Light curve / power spectrum
- Characteristic time scales with BH mass:
- $T_{\text{ISCO}} \propto M \approx 30 \text{ min} - 1 \text{ ms}$
Today’s topics

- What can GRAVITY tell us about Sgr A* flares?
- How to make double-peak QPOs with an accretion torus?
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VLT four main telescopes will be combined by GRAVITY

- **First light May 2015!**
**GRAVITY’s astrometric performance**

- Goal for astrometric precision: $\approx 10\ \mu\text{as} \approx$ 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]
Rossby Wave
Red Noise

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Ejected blob
1 night GRAVITY observation: Rossby / Red Noise / Blob

- 45° inclination, $m_K = 14$
Dispersion of retrieved positions

- Inclination: $5^\circ$, $45^\circ$, $85^\circ$ 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 ($m_K = 15, \Delta t = 1\ h\ 30$)
- First possibility to start distinguishing flare models

→ Vincent, Paumard, Perrin, Varniere, Casse, Eisenhauer, Gillessen, Armitage, submitted to *MNRAS*
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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...
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?
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 $5^\circ, 45^\circ, 85^\circ$
- 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?)

→ Vincent, Mazur, Straub, Abramowicz, Kluźniak, Török, Bakala, A&A just accepted
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  - 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!*
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