

High-frequency polarimetry as a tool for testing properties of accreting super-massive black holes

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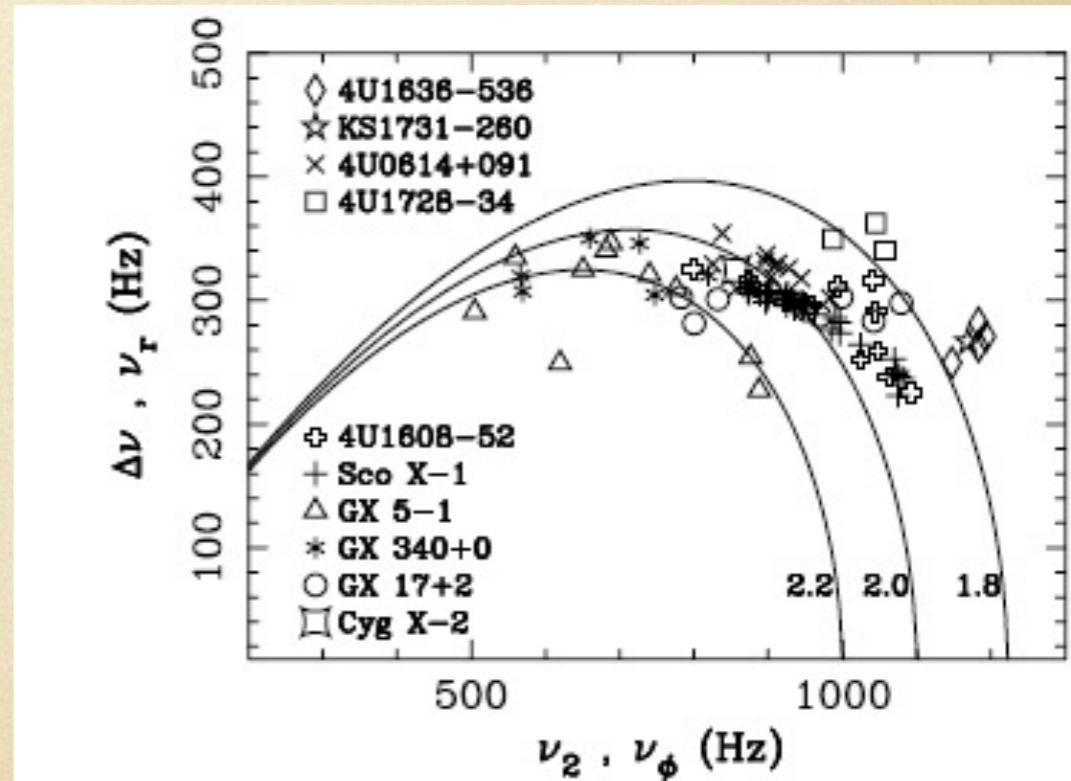
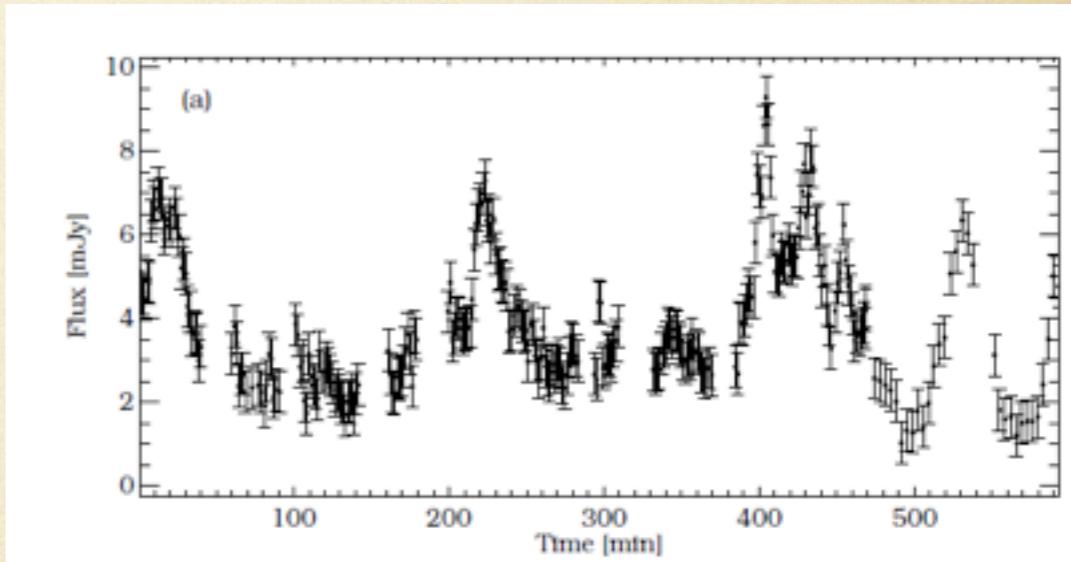
MAX-PLANCK-GESELLSCHAFT



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BH variability

- Several massive black holes exhibit flux variability on time-scales that correspond to source sizes of the order of few Schwarzschild radii
- Disk oscillations, g-modes, p-modes
(Nowak, Wagoner 1991,1992; Nowak et al. 1997, Kato 2001,2008, 2009) (Milsom, Taam 1997; Kluzniak Abramowicz 2001,2002)
- Disk warping, precession (nodal)
(Cui et al. 1998; Markovic, Lamb 1999; Fragile et al. 2001) (Merloni et al. 1999; Karas 1999)
- Parametric and forced non-linear oscillator epicyclic resonance
(Kluzniak & Abramowicz 2001, 2002a,b, 2004; Torok et al 2006; plus works by Horak, Stuchlik etc.)
- Relativistic precession (periastron + nodal)
(Stella, Vietri 1998a,b 1999; Merloni et al, 1999, Stella et al. 1999)
(Psaltis, Norman 2000; Psaltis 2001; plus works by Bakala, Stuchlik,)



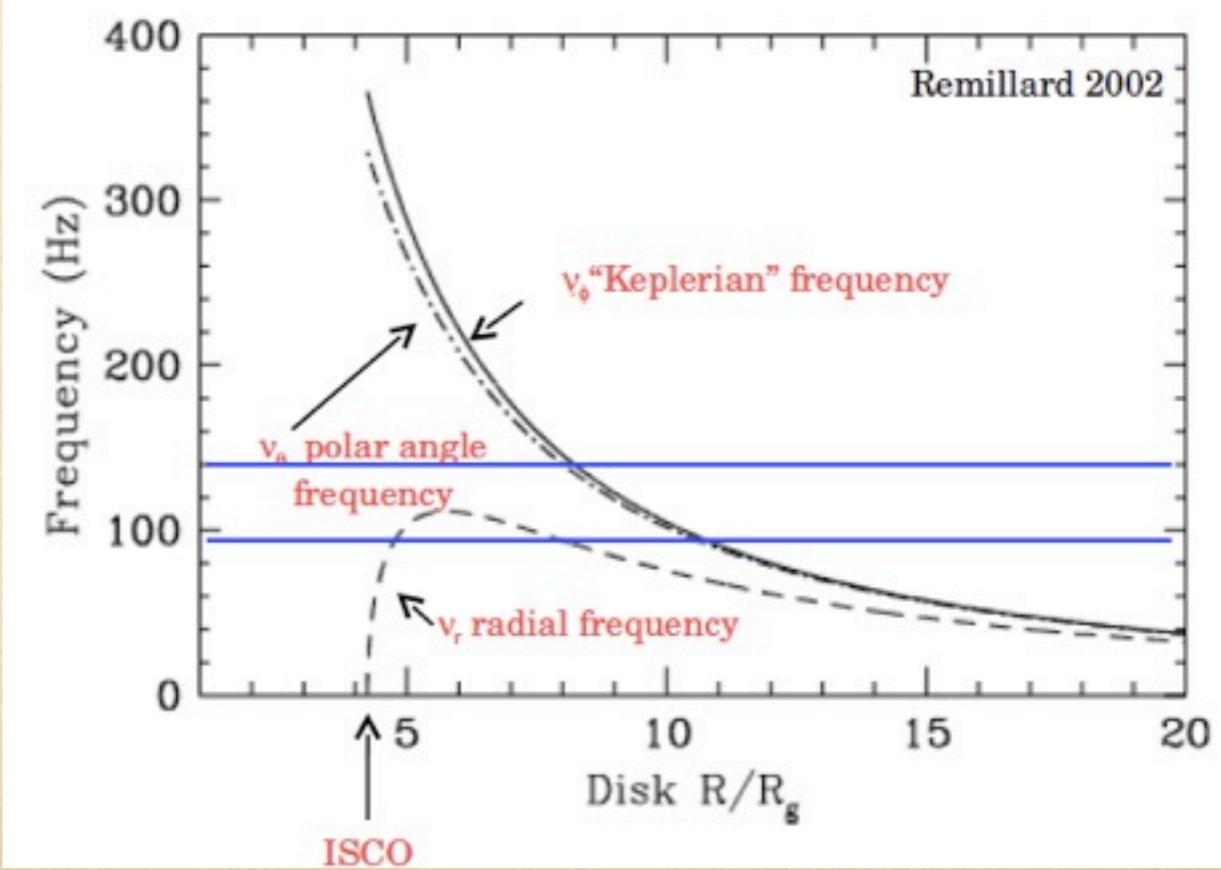
Stella & Vietri 1999

BH variability

- Size of the emitting region
- Periodic signals
- Nature of the variability

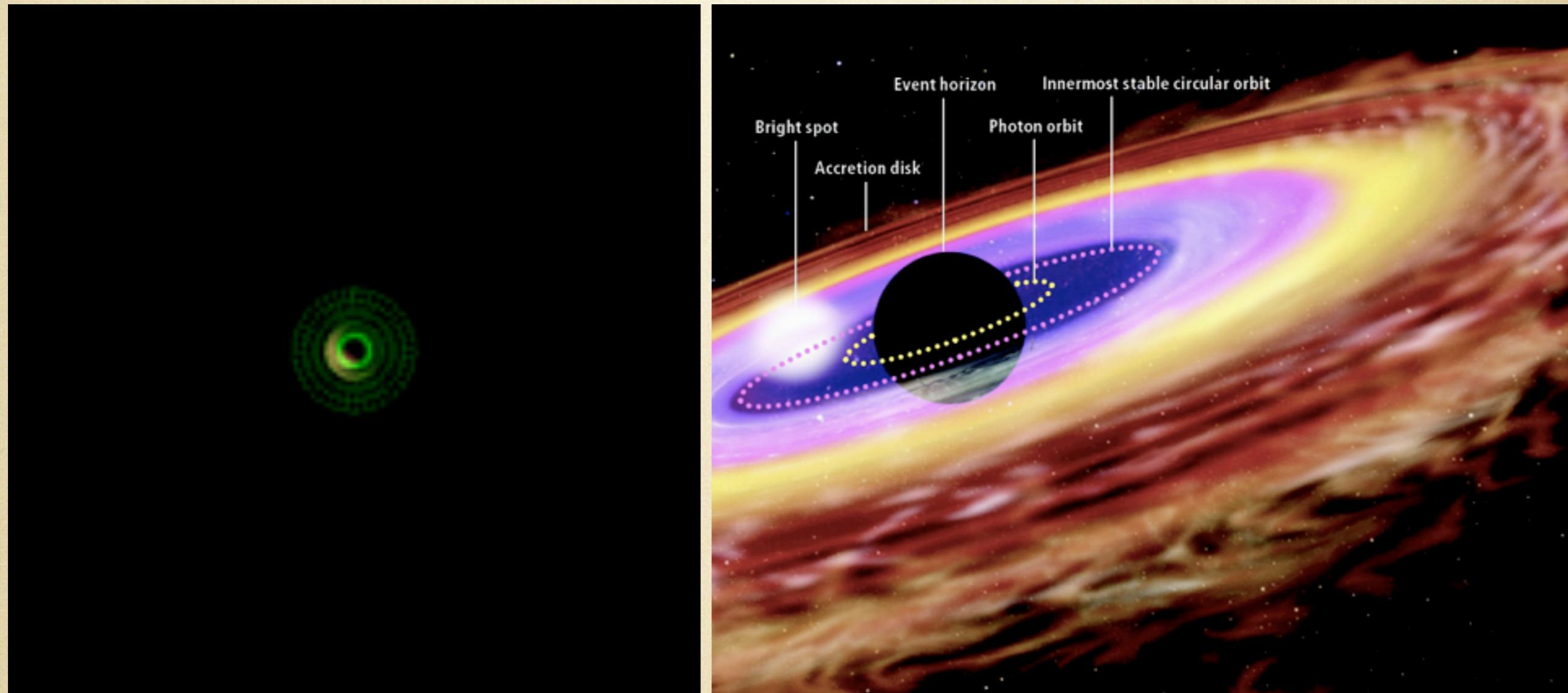


XTE J1550–564 $M_x \sim 9.6$, $a_* \sim 0.5$



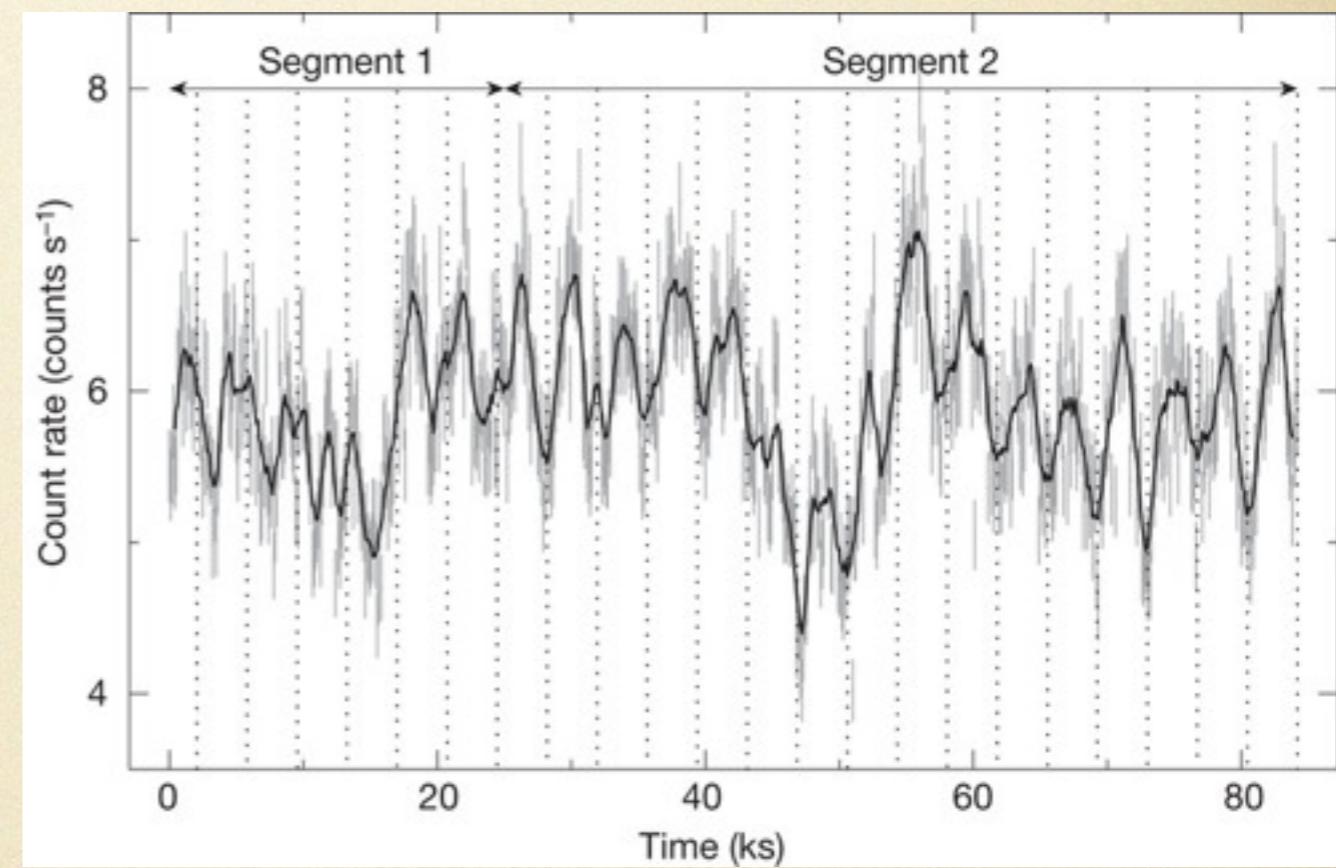
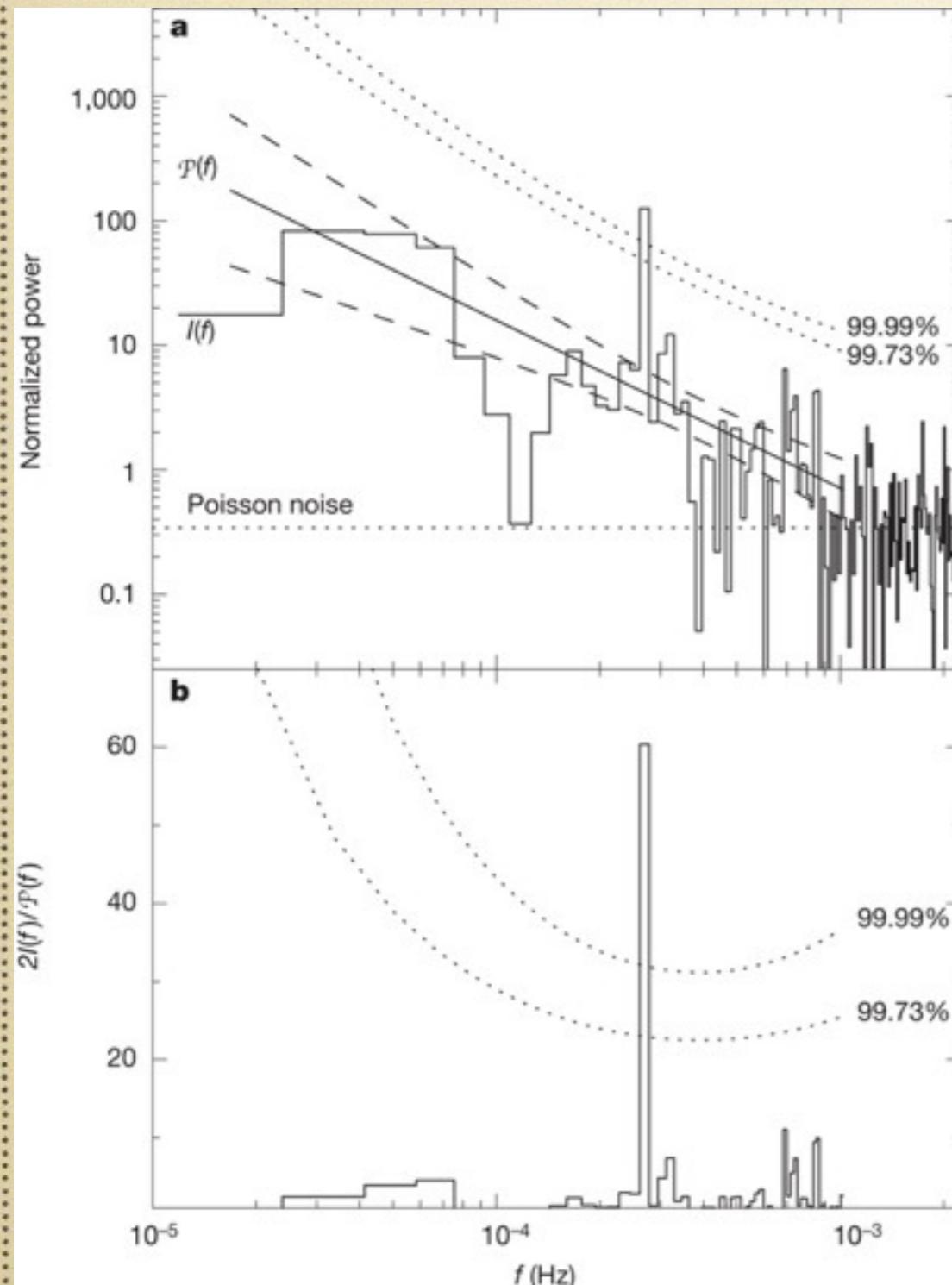
Stella & Vietri 1999

Accretion disk instabilities+GR



Credit: A. Broderick & A. Loeb

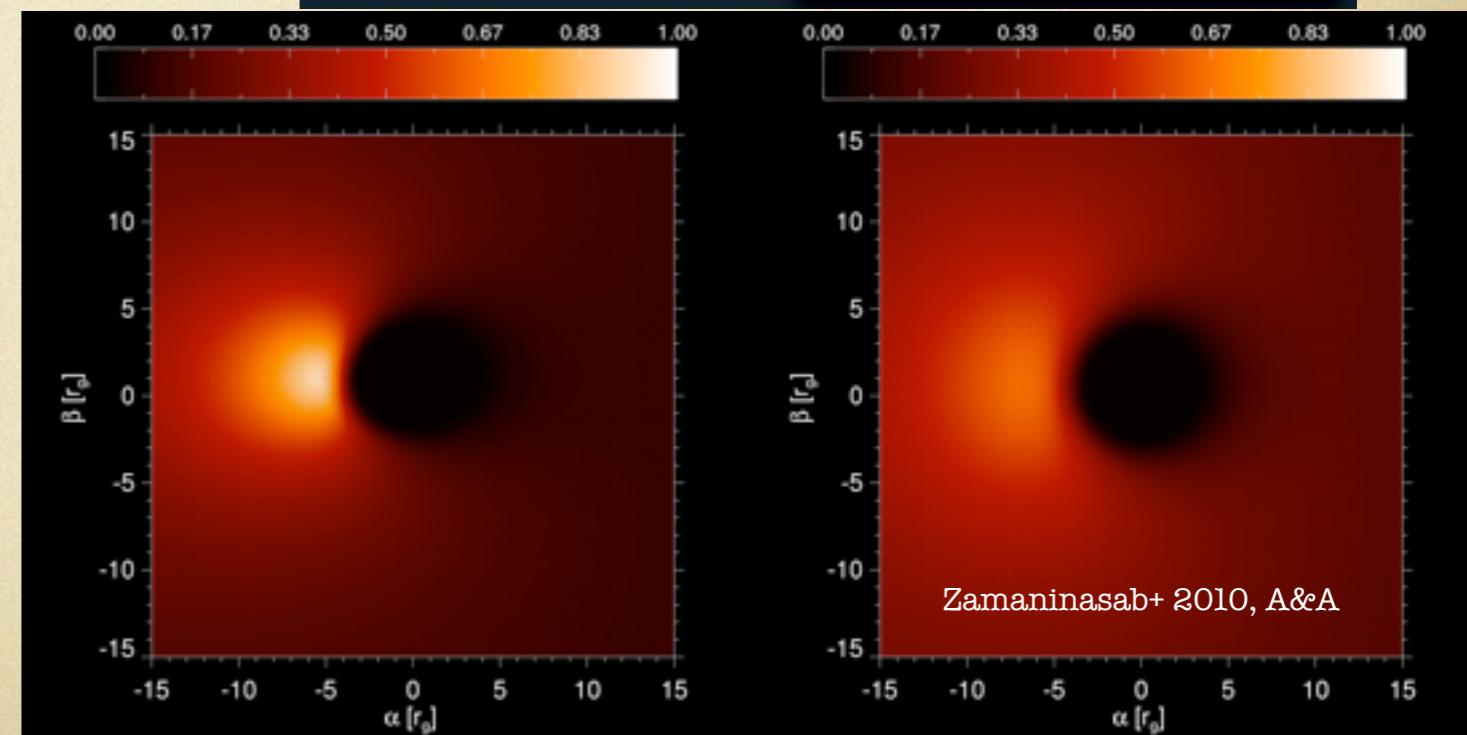
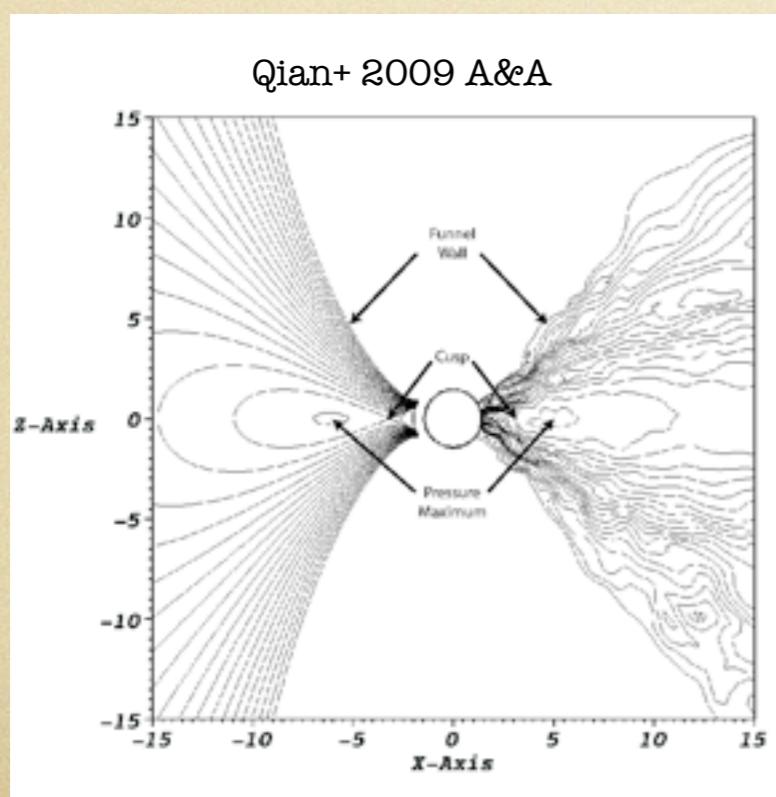
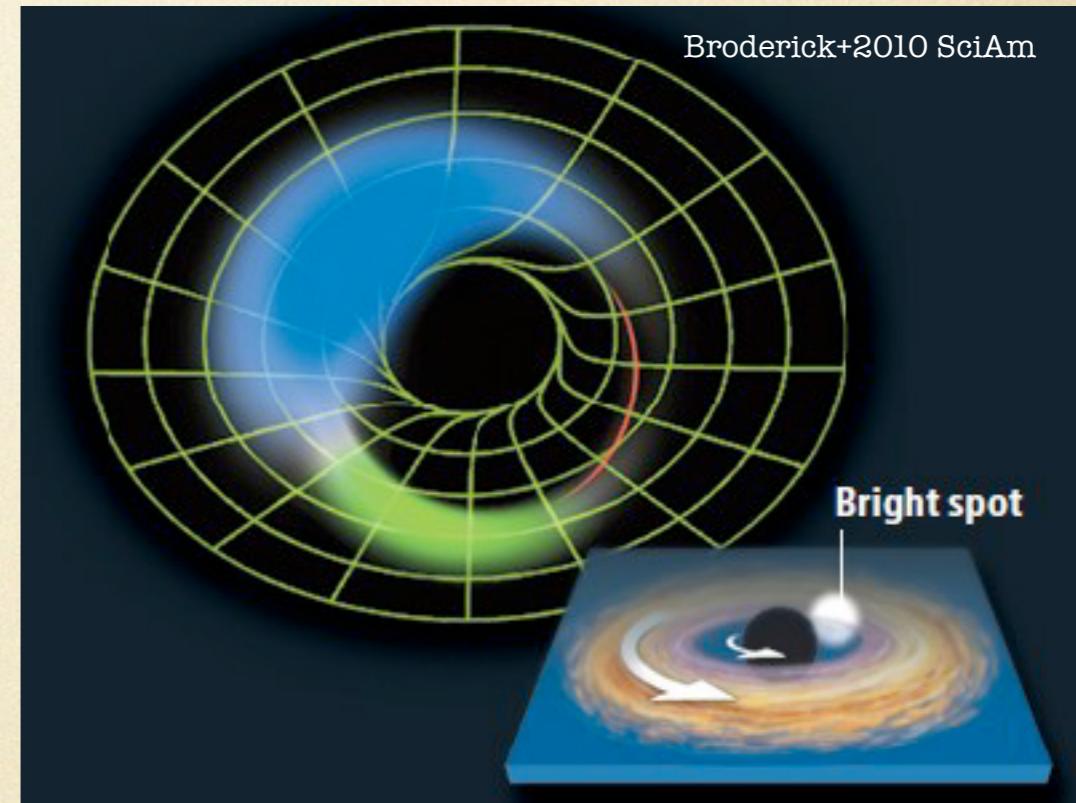
Timing analysis



RE J1034+396: Gierliski+ 2008, Nature 455, 369

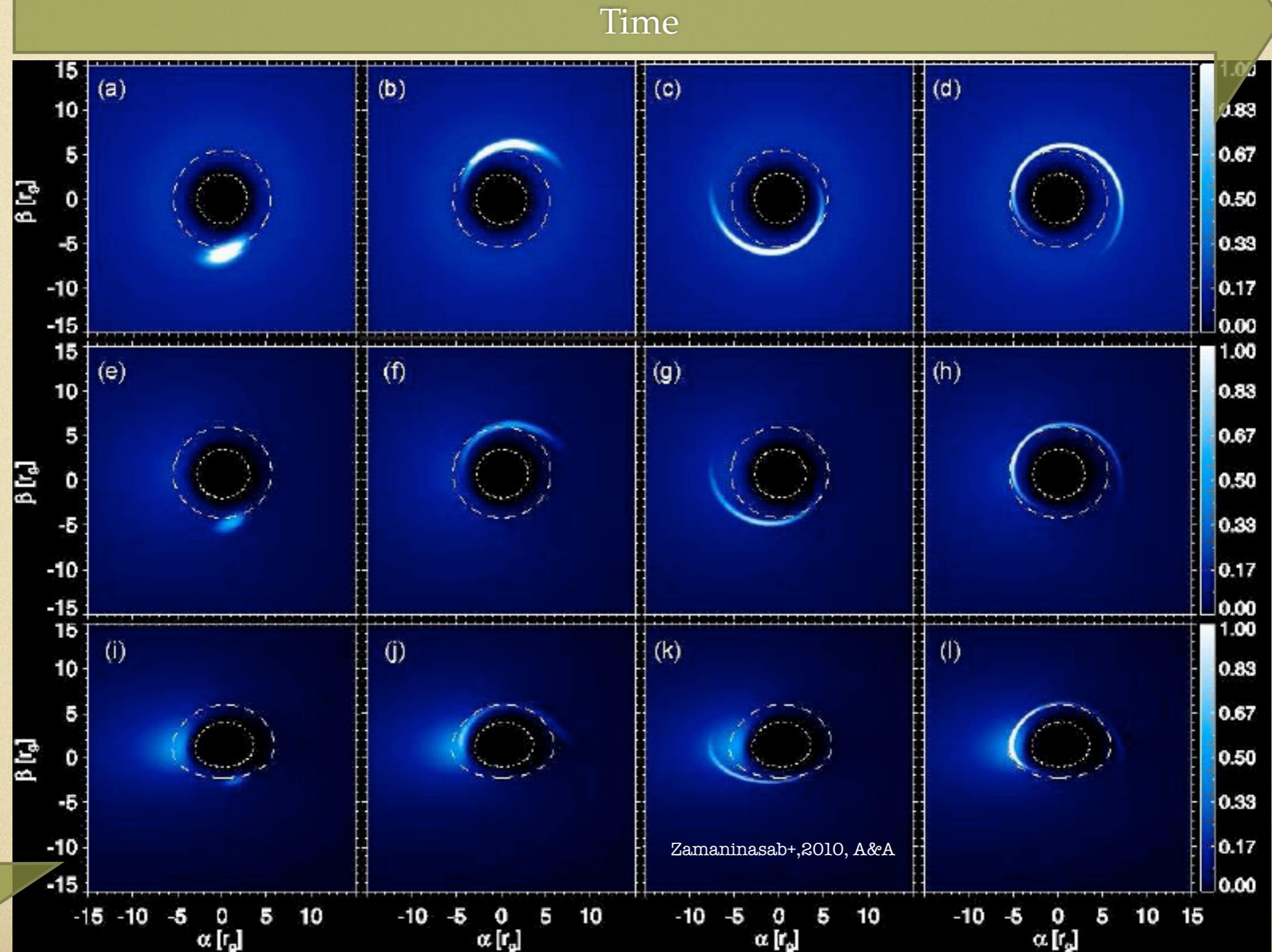
Polarized ray-tracing

- Emission: Synchrotron, SSC
- Dynamics: Polish doughnut

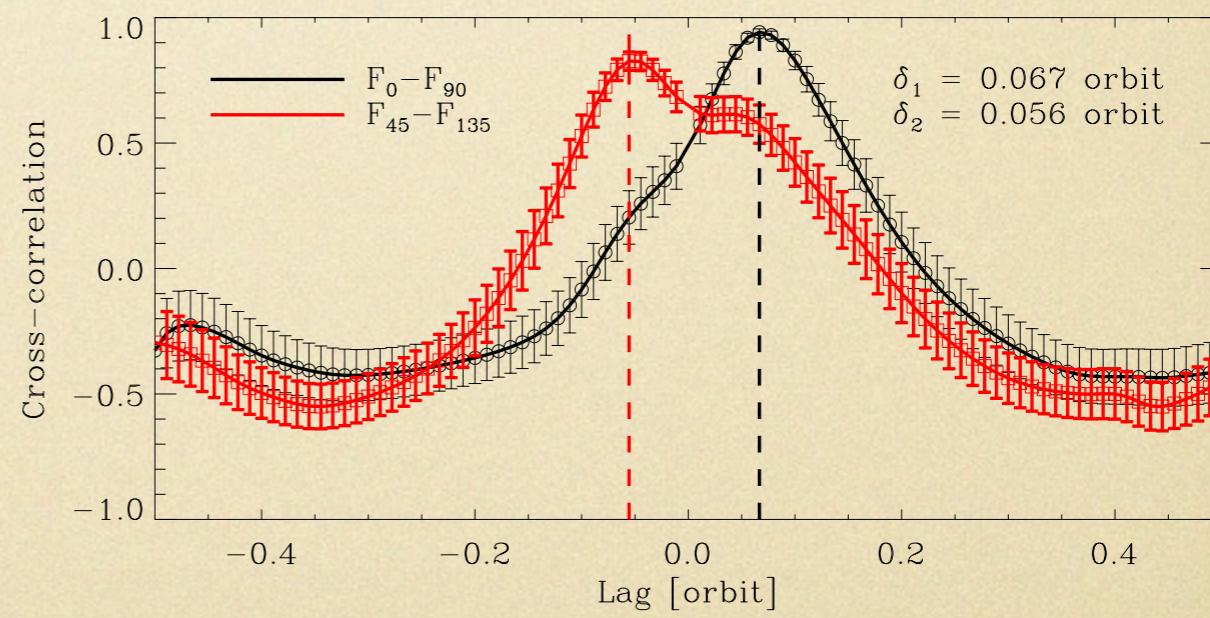
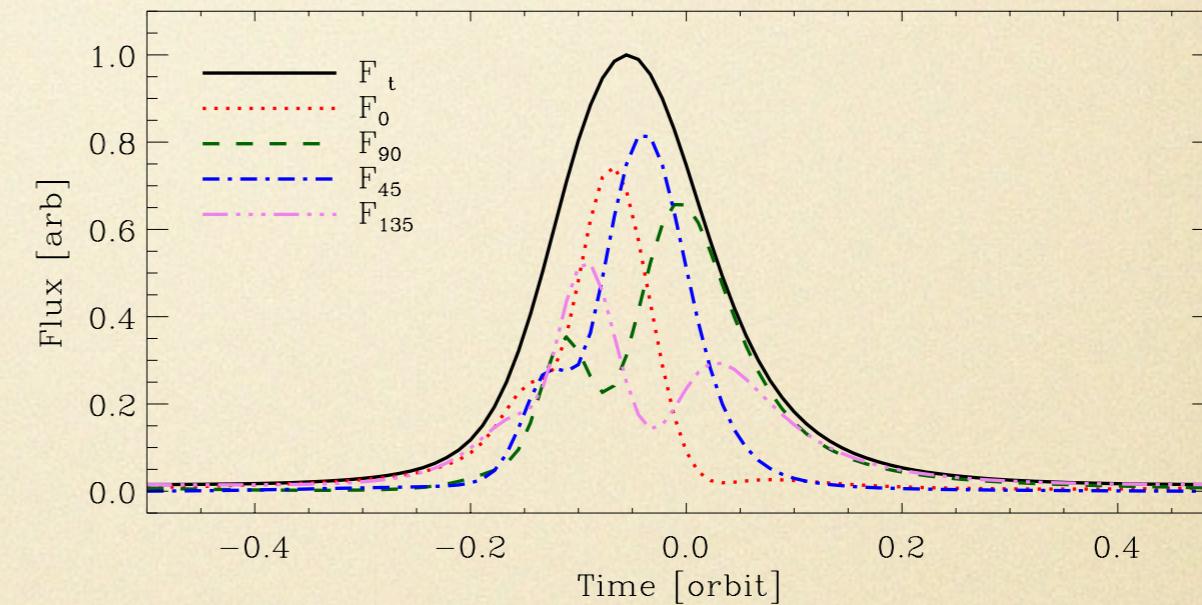
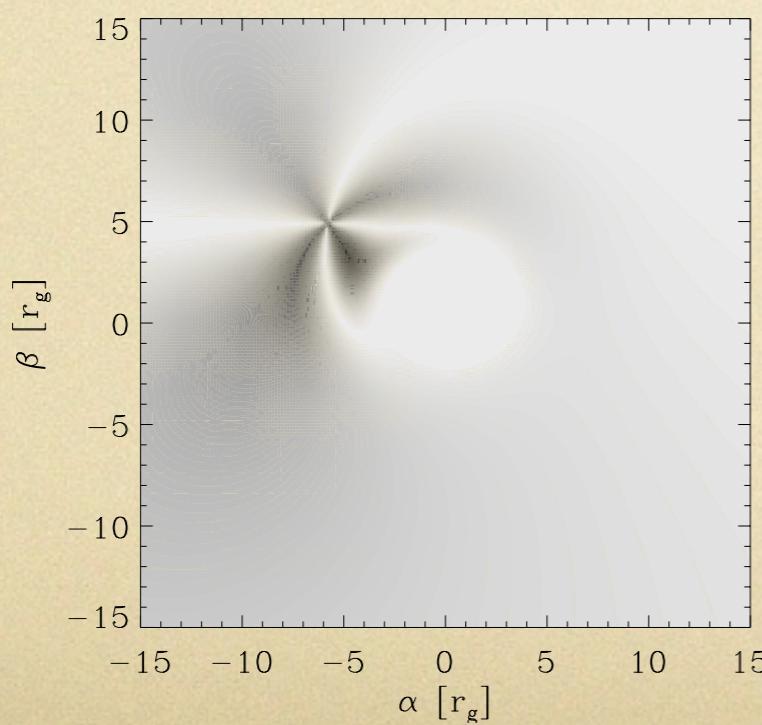
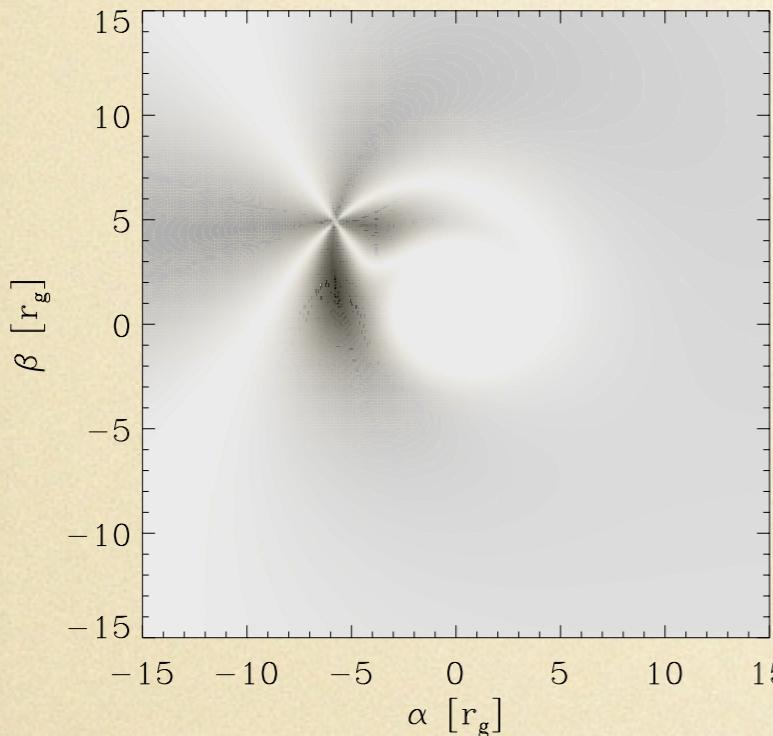


Polarized ray-tracing

Inclination

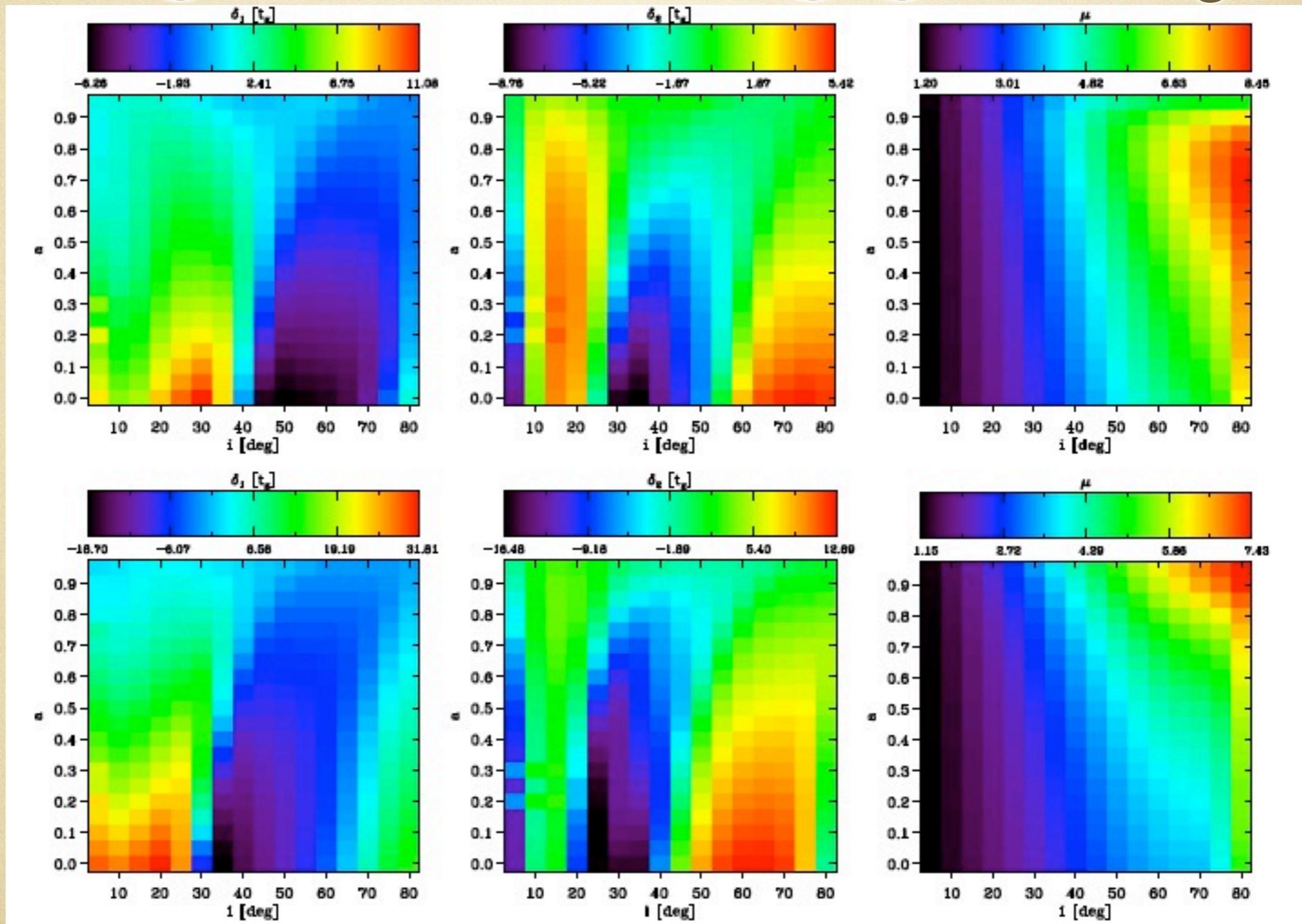


Signs of strong gravity



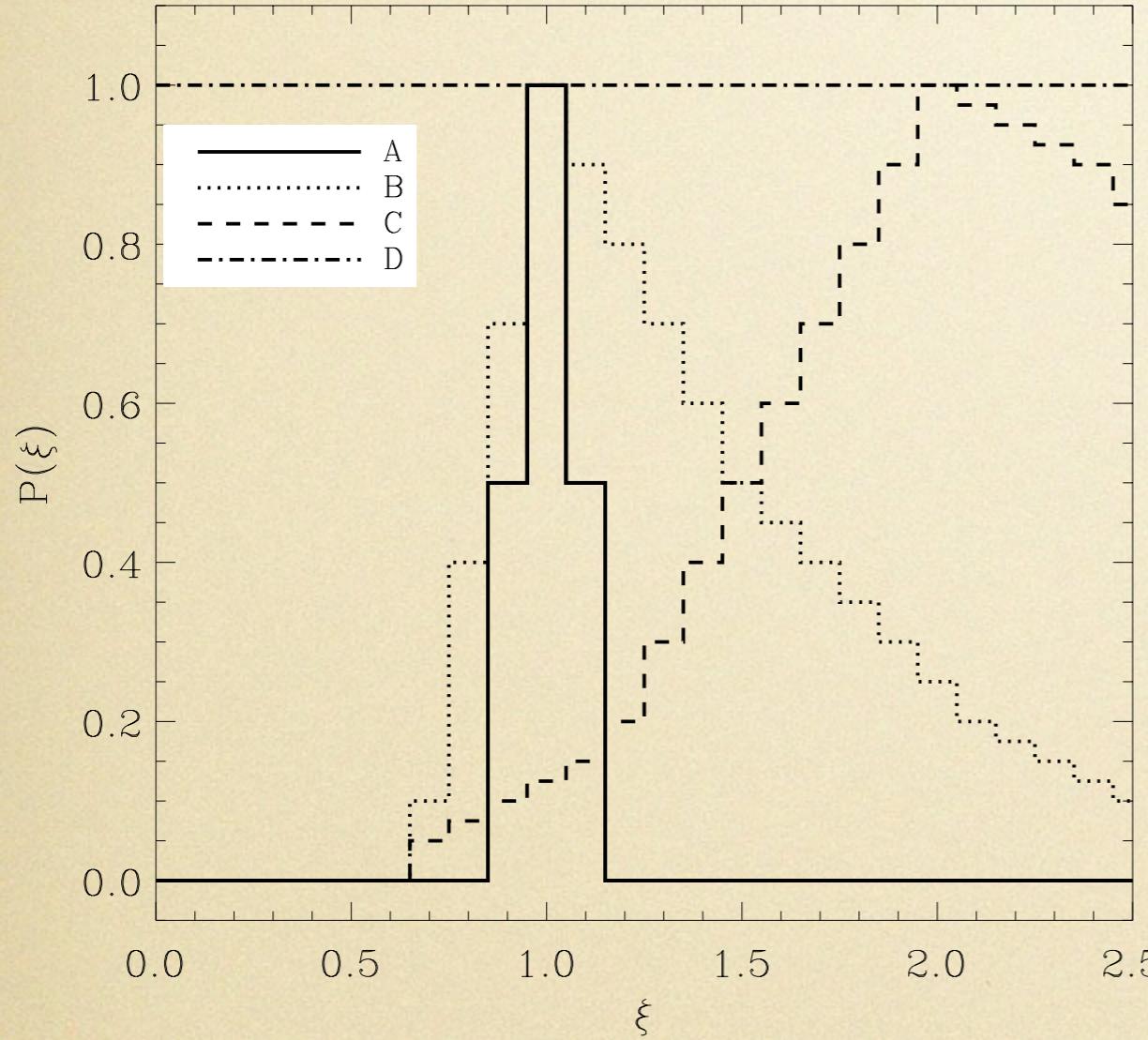
Zamaninasab+ 2011, MNRAS

Signs of strong gravity



Zamaninasab+ 2011, MNRAS

Bayesian parameter estimation



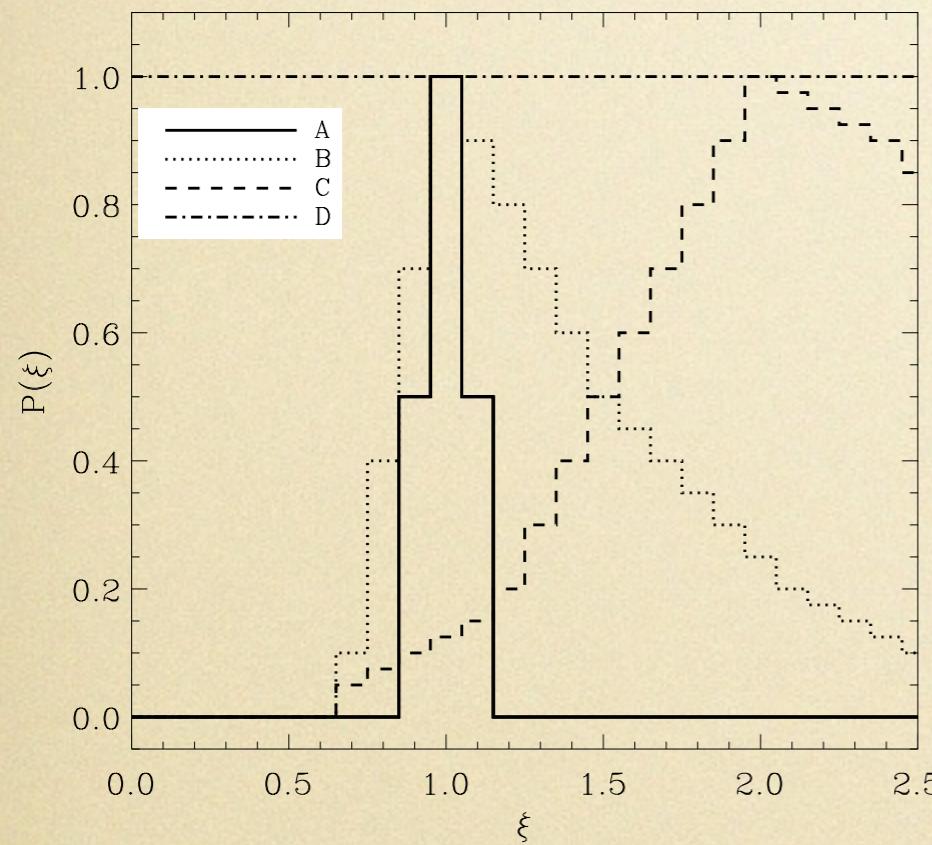
$$P_j(x_j|a, i, \theta, \xi) = \frac{1}{\sqrt{2\pi}\Delta x_j} \exp\left\{-\frac{[x_j - x(a, i, \theta, \xi)]^2}{2\Delta x_j^2}\right\} dx_j.$$

$$P(\{\delta_{1j}, \delta_{2j}, \mu_j\}|a, i, \theta, \xi) = P(\delta_{1j}|a, i, \theta, \xi) \times P(\delta_{2j}|a, i, \theta, \xi) \times P(\mu_j|a, i, \theta, \xi).$$

$$\begin{aligned} p(a, i, \theta, \xi | \{x_j\}) &= \frac{P(\{x_j\}|a, i, \theta, \xi) \wp(a) \wp(i, \theta) \wp(\xi)}{\int da di d\theta d\xi P(\{x_j\}|a, i, \theta, \xi) \wp(a) \wp(i, \theta) \wp(\xi)} \\ &= \frac{P(\{x_j\}|a, i, \theta, \xi) \sin(i)}{\int da di d\theta d\xi P(\{x_j\}|a, i, \theta, \xi) \sin(i)}. \end{aligned}$$

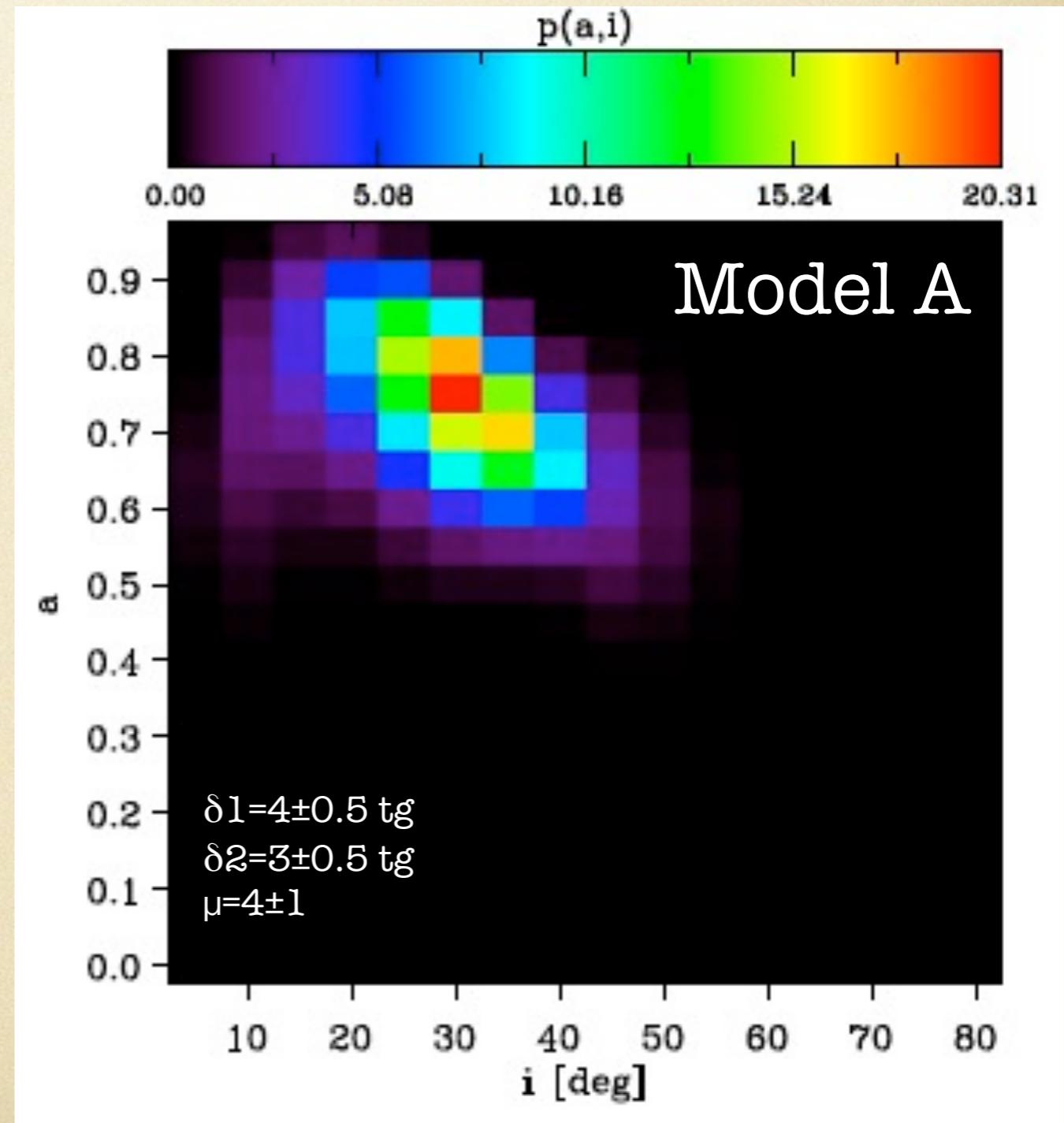
Bayesian parameter estimation

Using:



to marginalize over ξ :

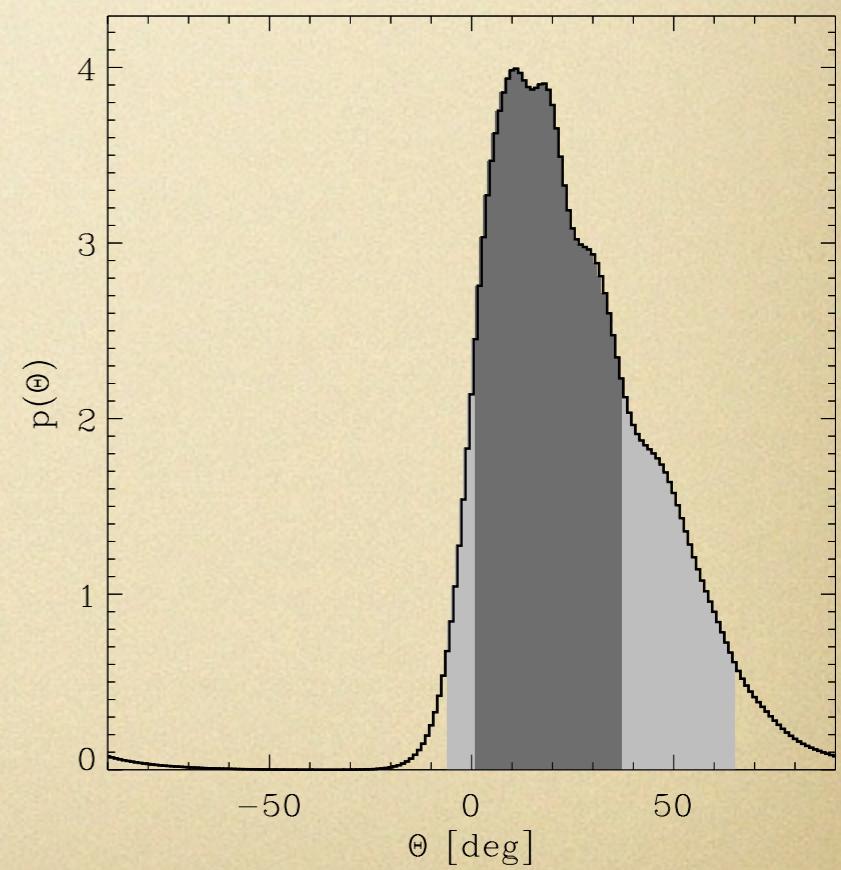
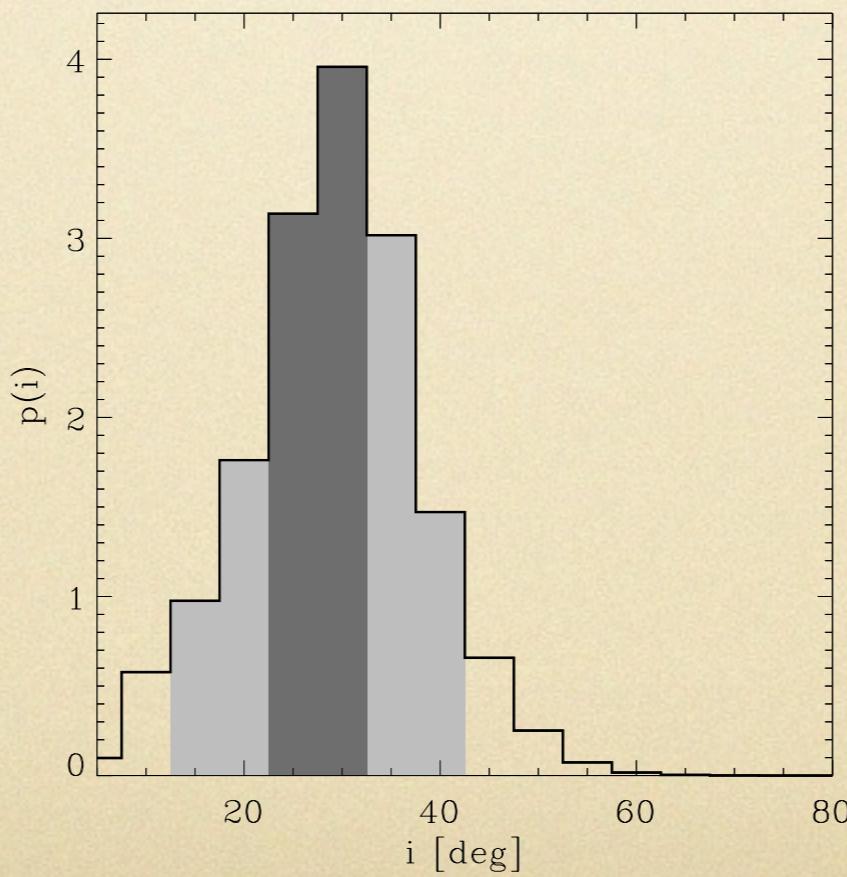
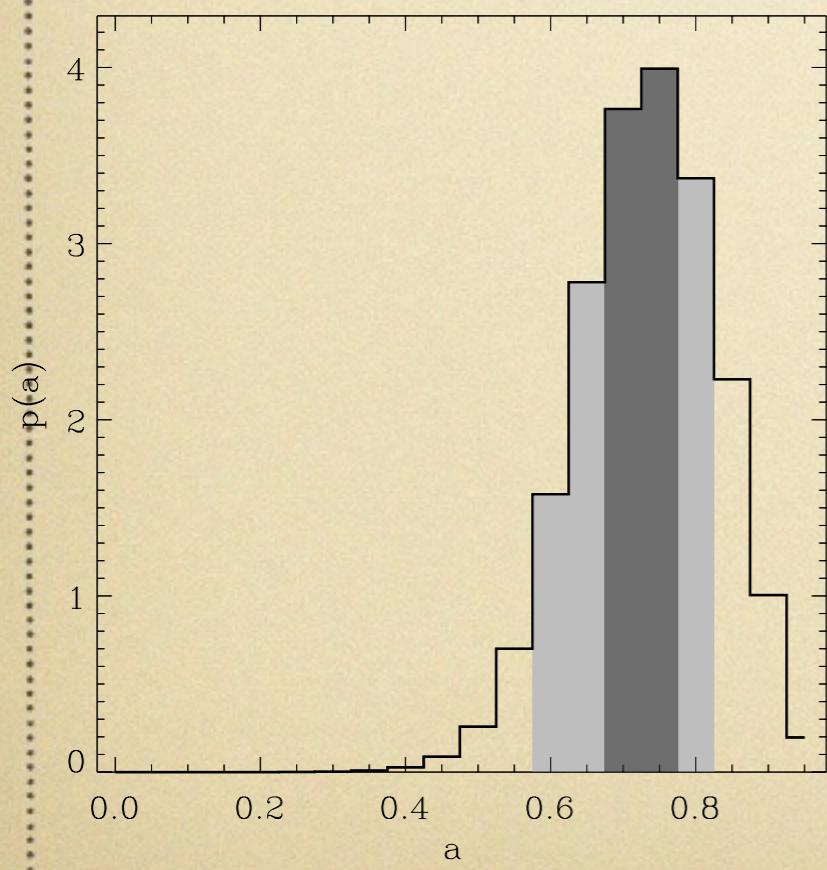
$$p(a, i) = \int d\theta \, d\xi \, p(a, i, \theta, \xi | \{x_j\})$$



Bayesian parameter estimation

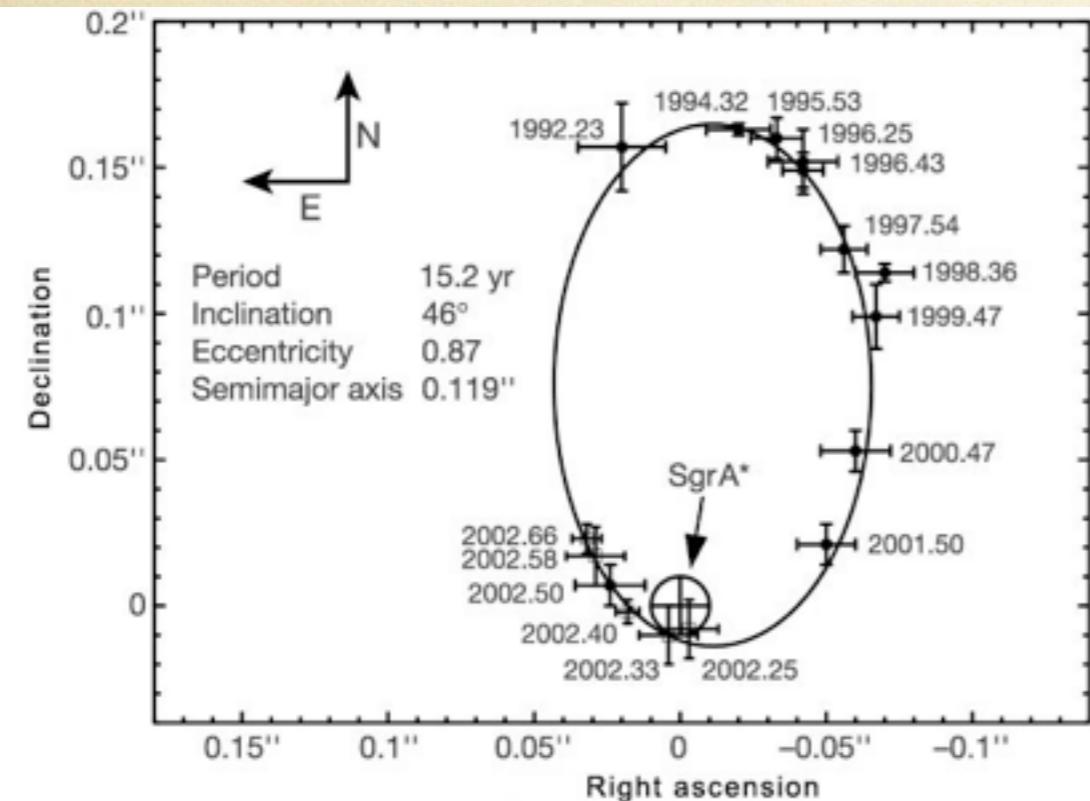
One can marginalize more:

$$P(>p) = \int_{p(\omega) \geq p} p(x) dx$$

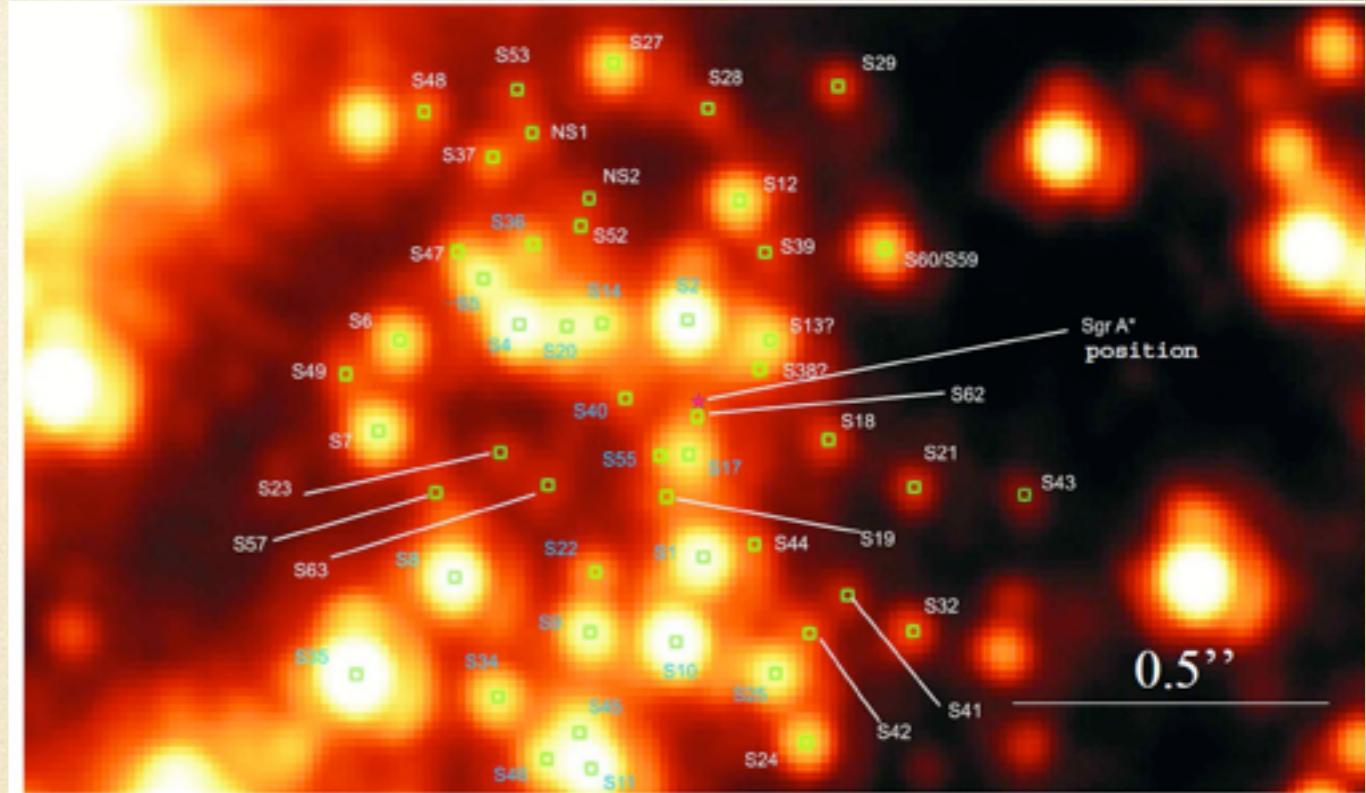


$$\begin{aligned} p(a) &= \int d\theta \, di \, d\xi \, p(a, i, \theta, \xi | \{x_j\}) \\ p(i) &= \int d\theta \, da \, d\xi \, p(a, i, \theta, \xi | \{x_j\}) \\ p(\theta) &= \int di \, da \, d\xi \, p(a, i, \theta, \xi | \{x_j\}). \end{aligned}$$

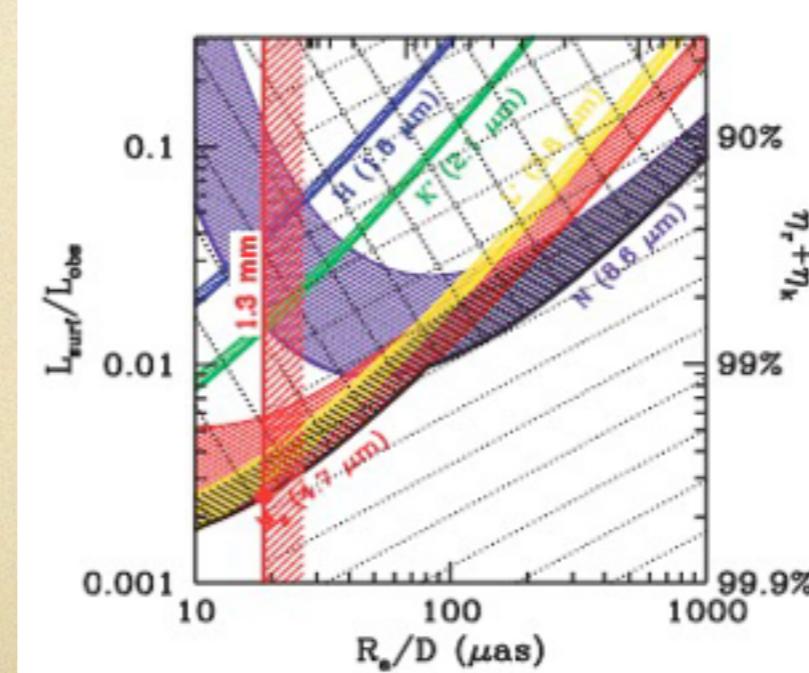
The Galactic BH: Sagittarius A*



Schoedel+ 2002 Nature



Sabha+ 2010 A&A



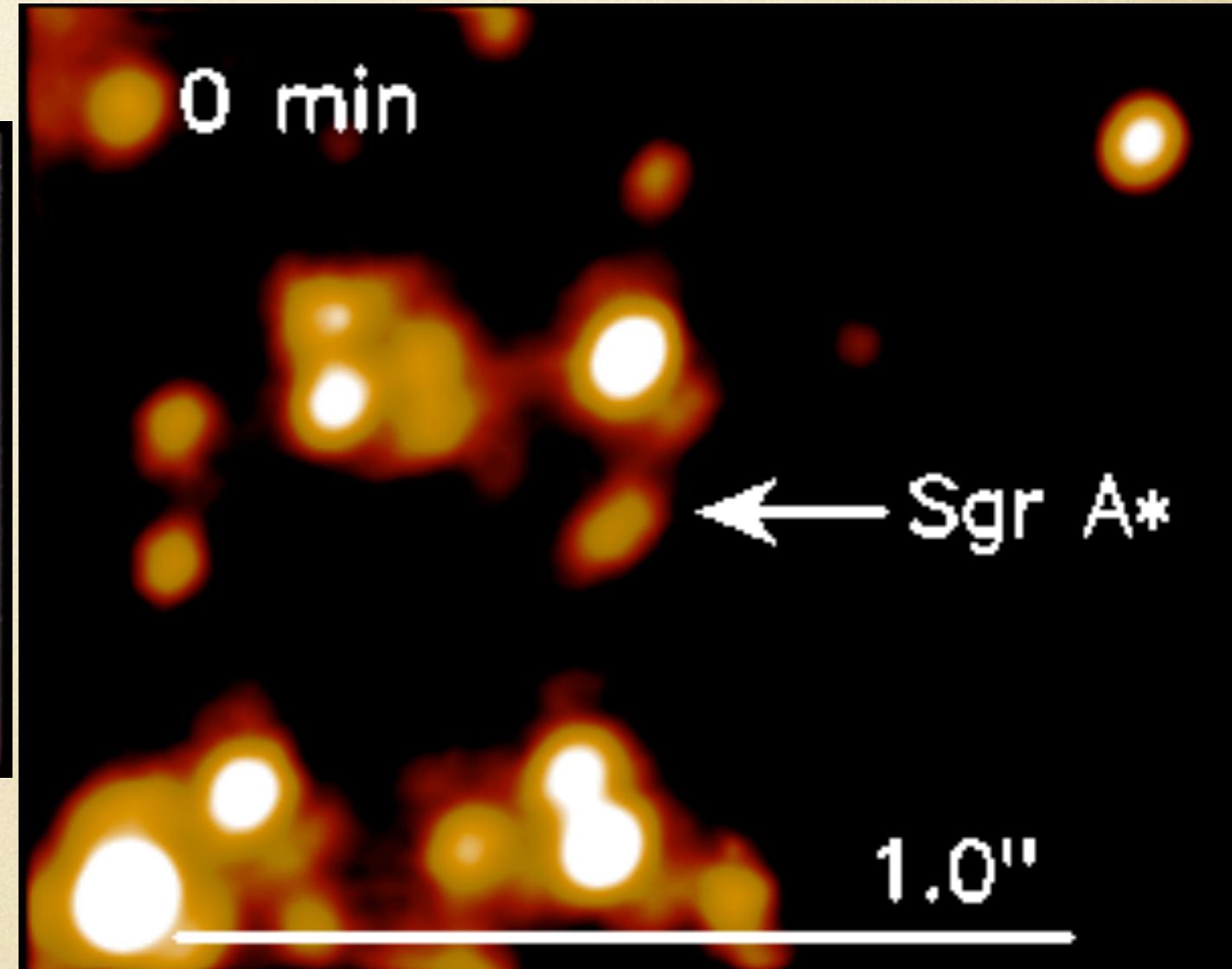
Broderick+ 2009 ApJ

Sagittarius A *

Sgr A * shows variability across all the electromagnetic spectrum

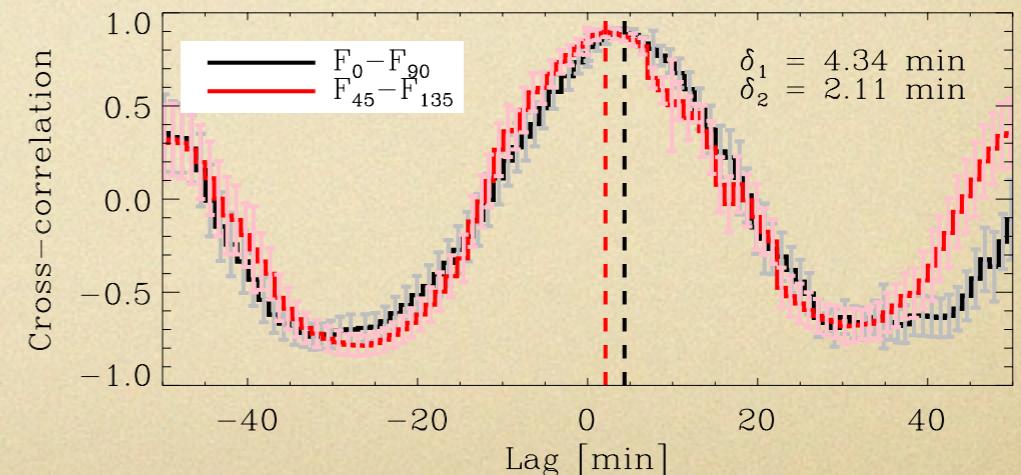
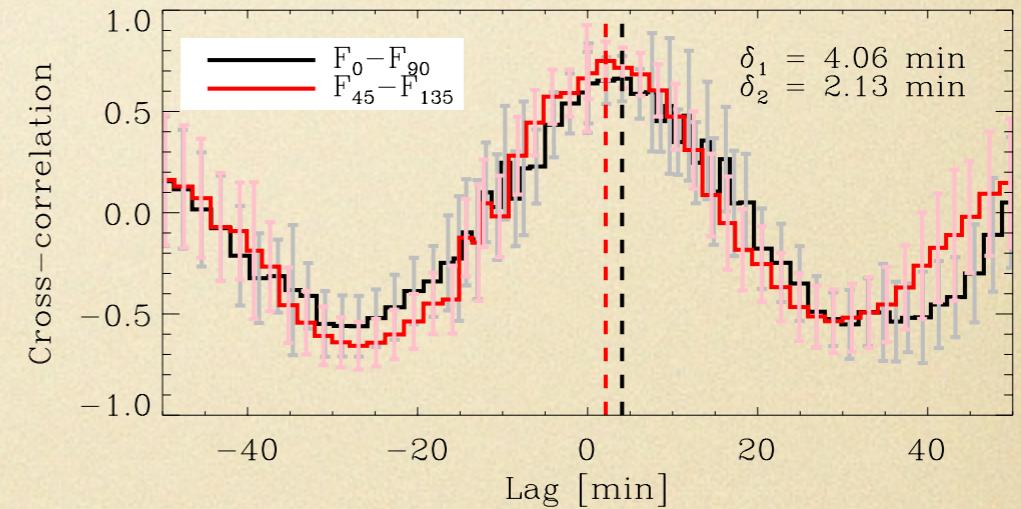
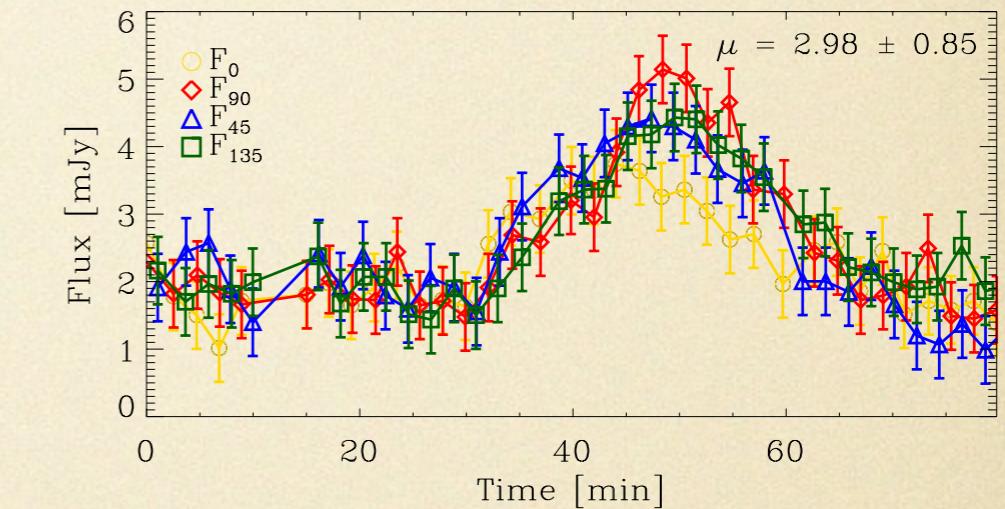
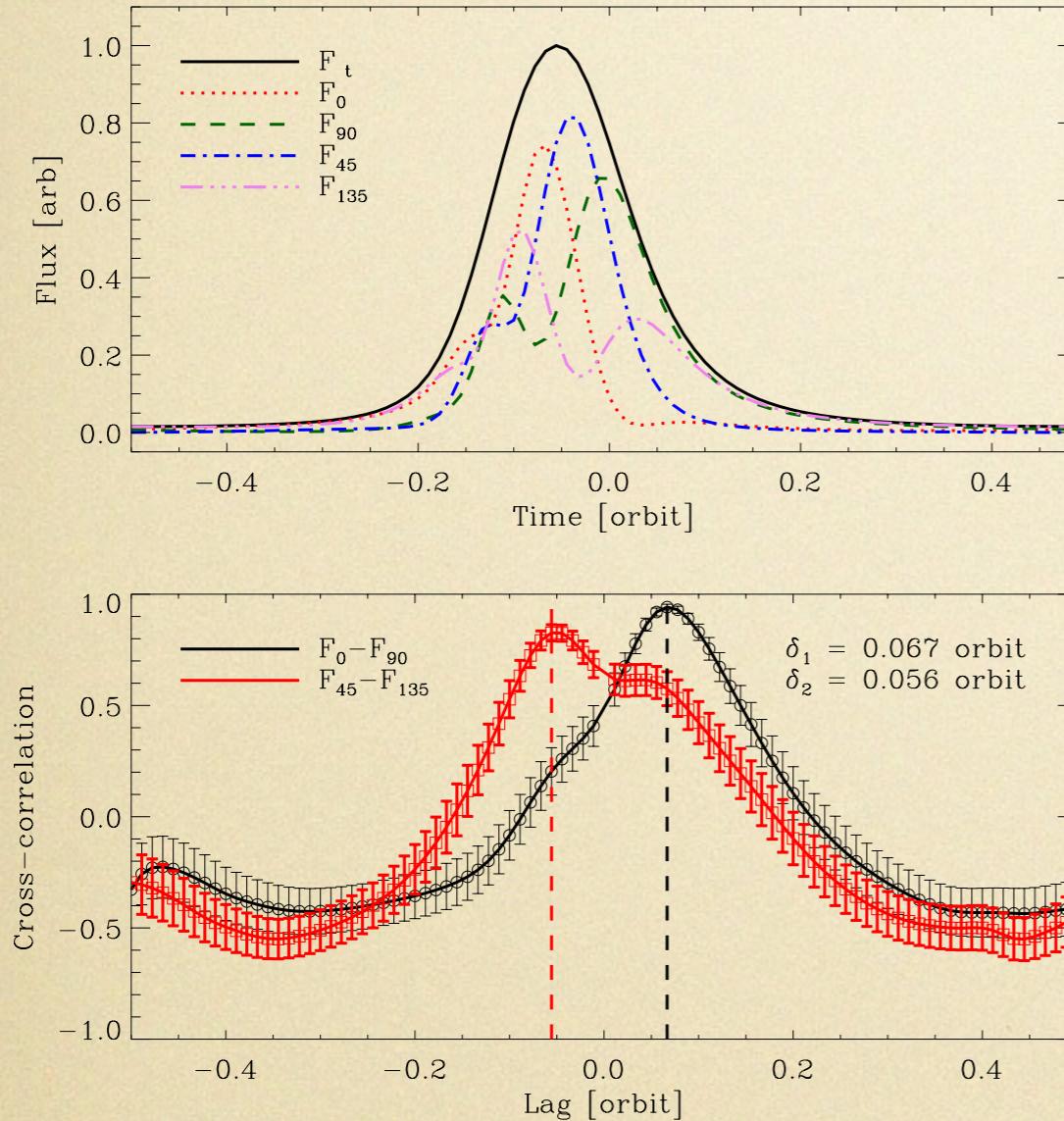


ESO VLT

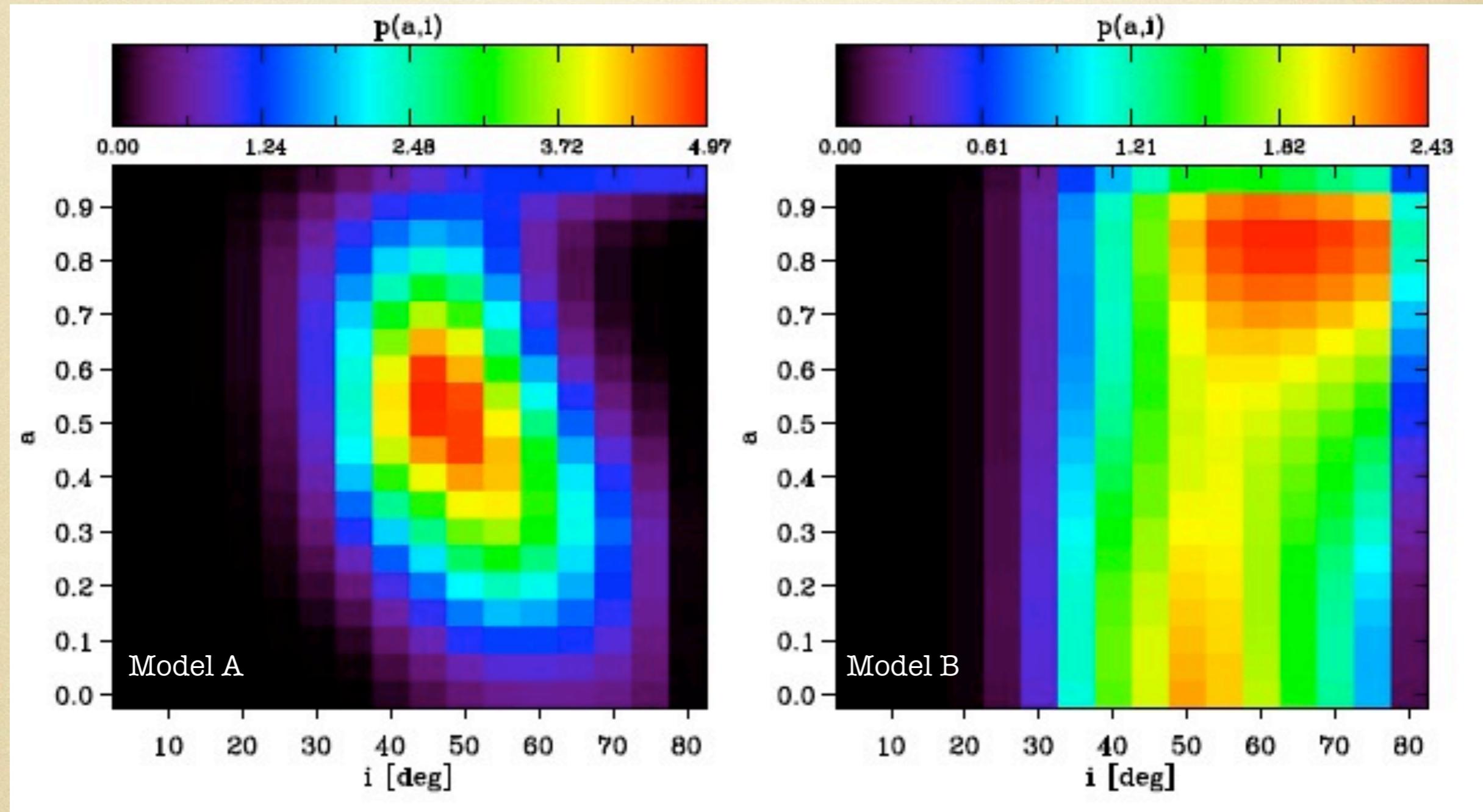


Sgr A * at $2.2 \mu\text{m}$
(G. WItzel, R. Schödel)

Sagittarius A *

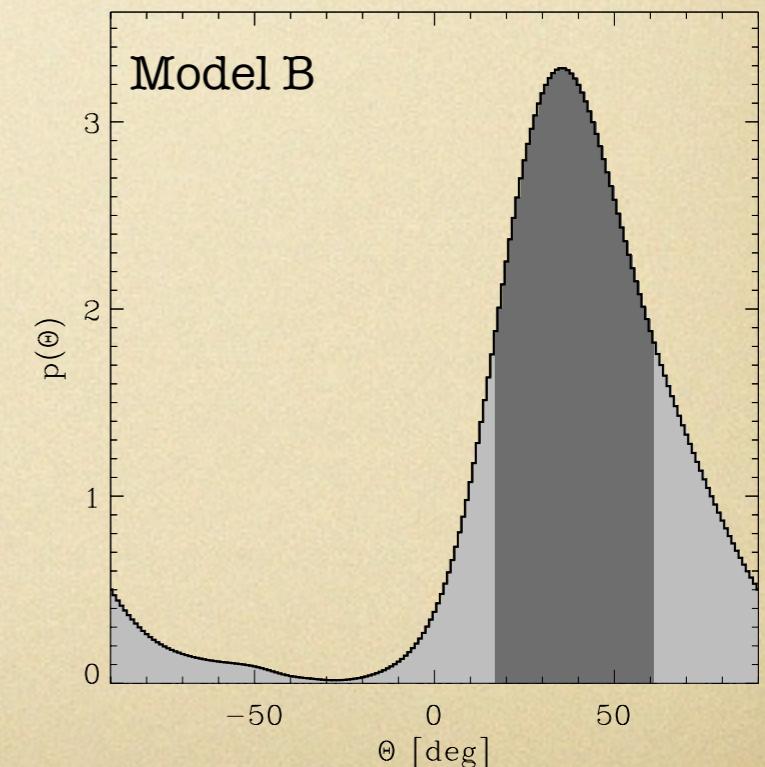
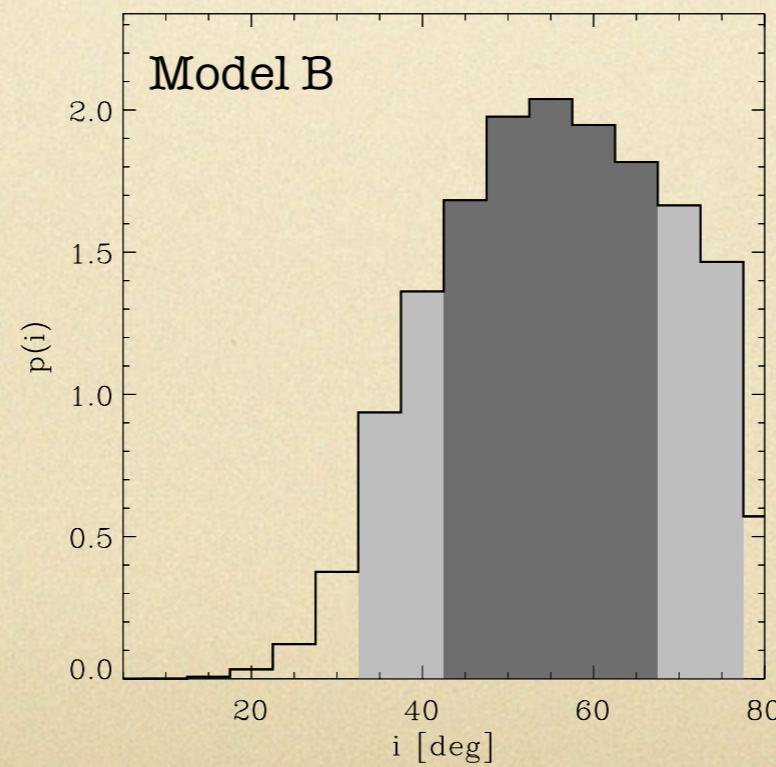
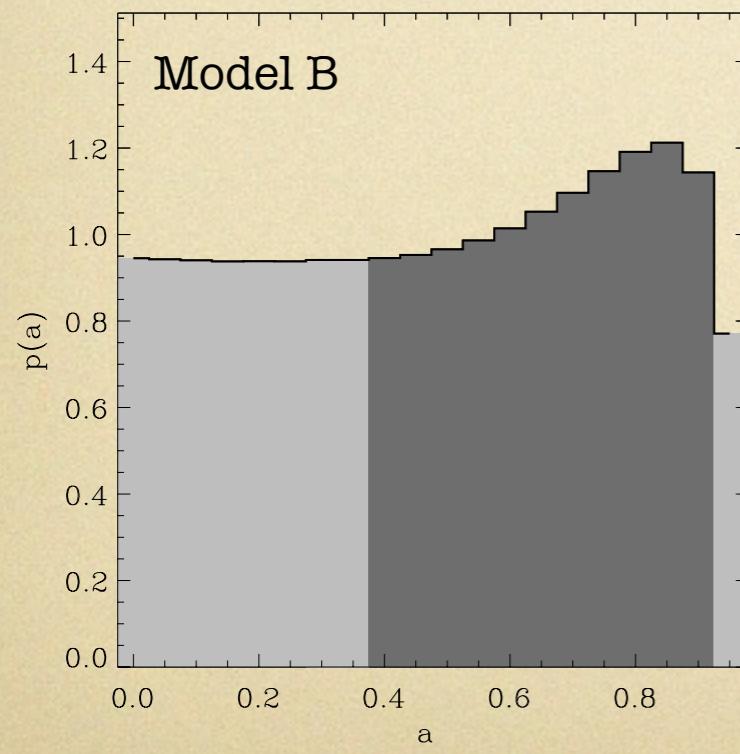
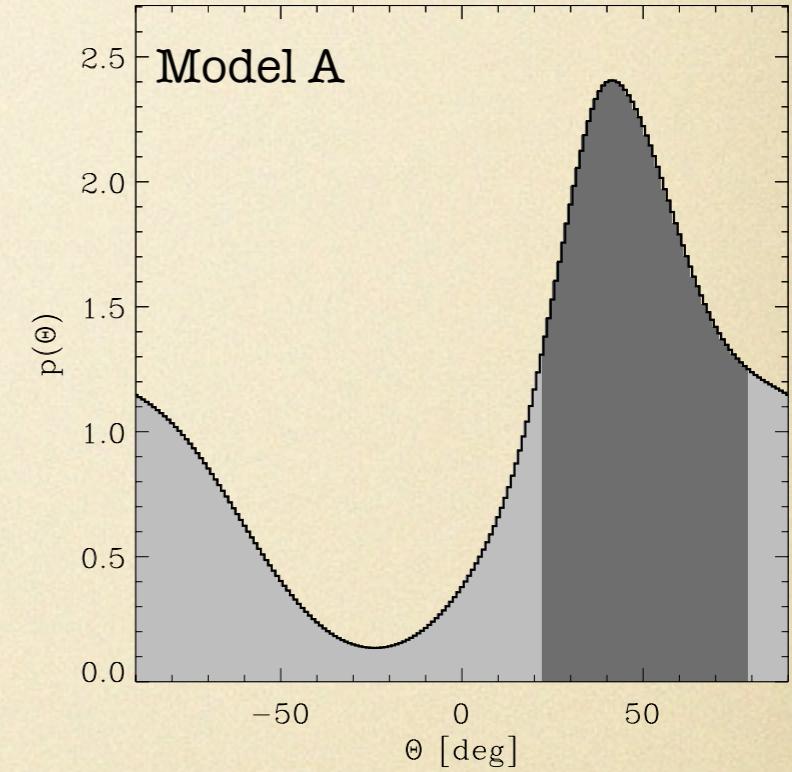
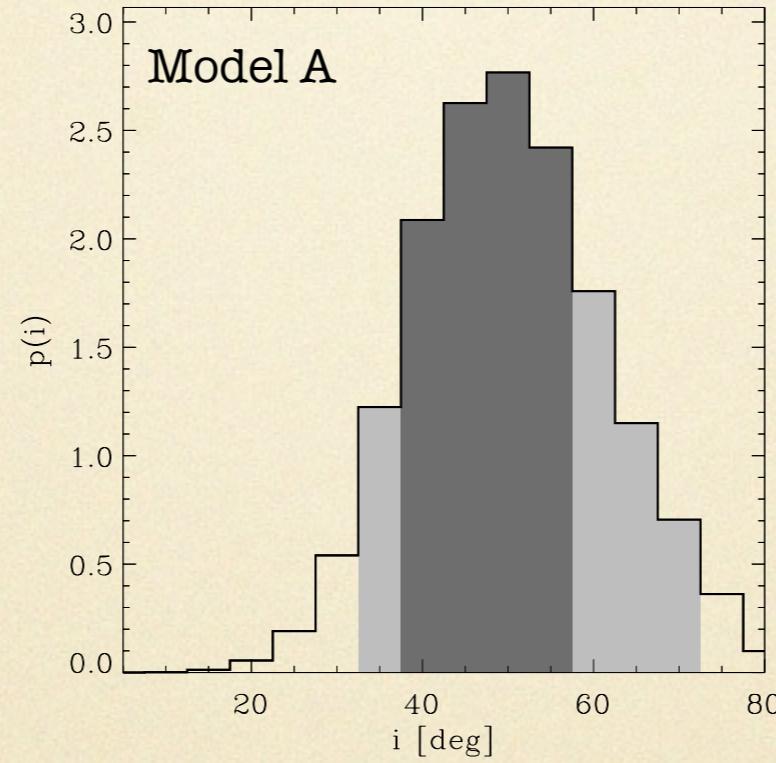
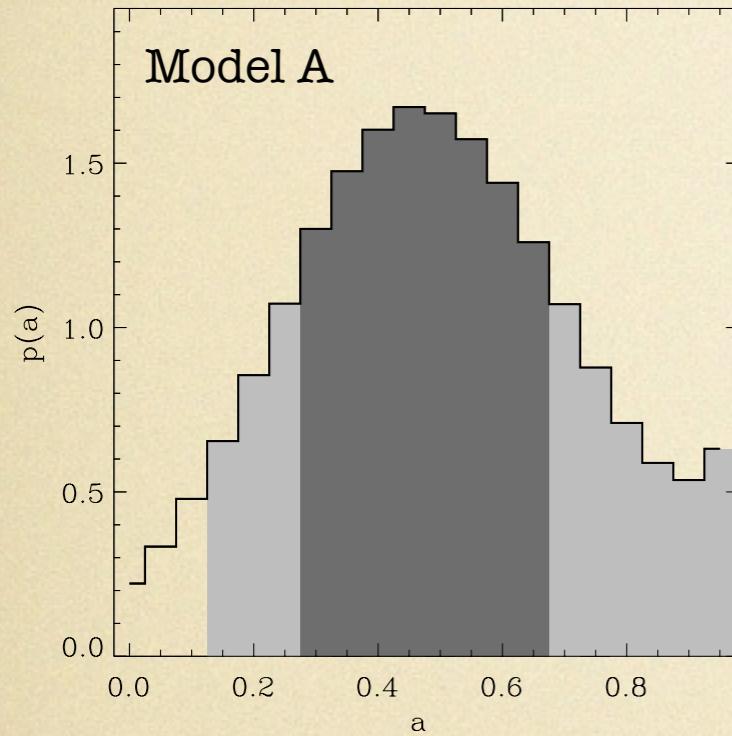


Sagittarius A*



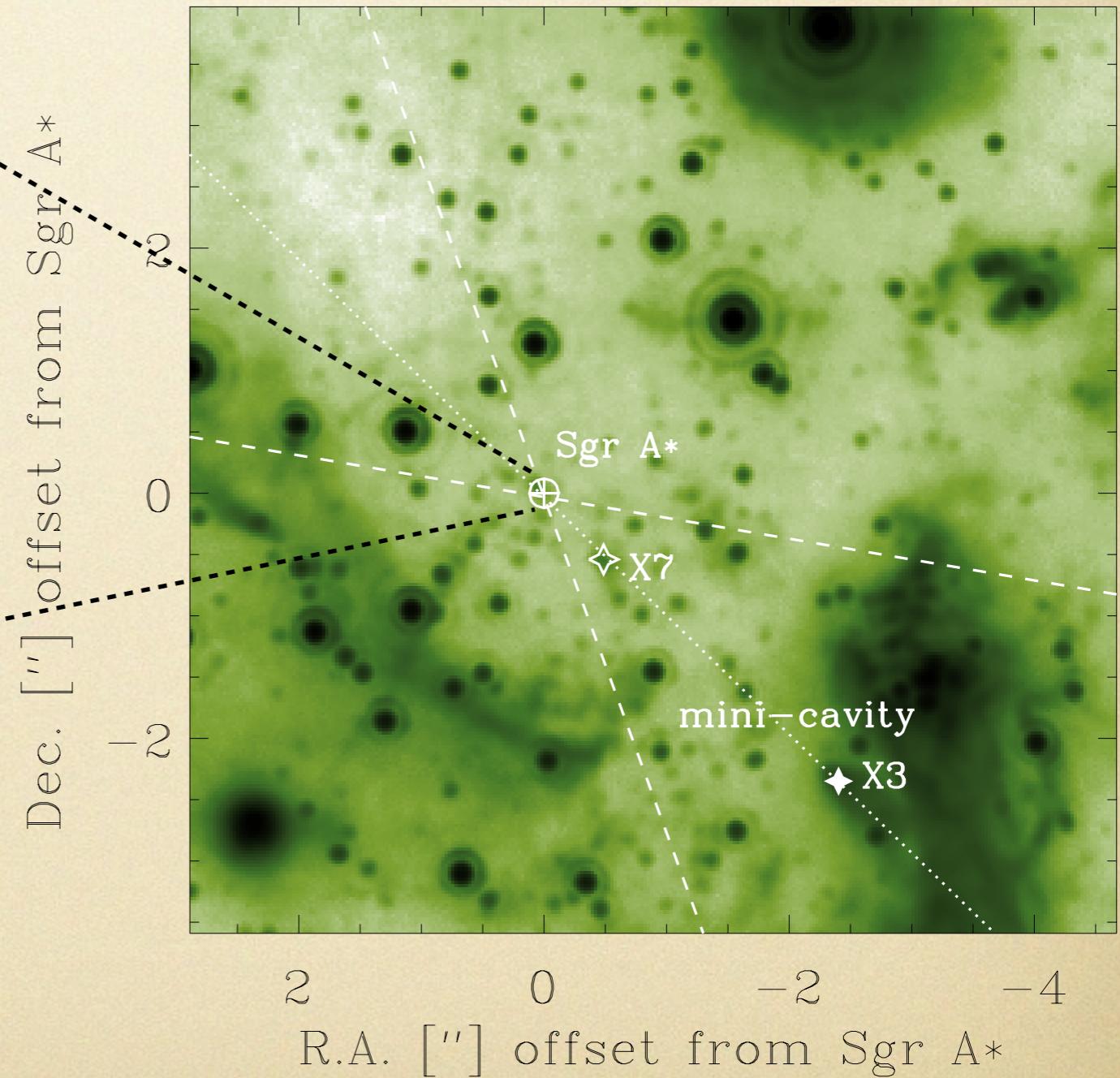
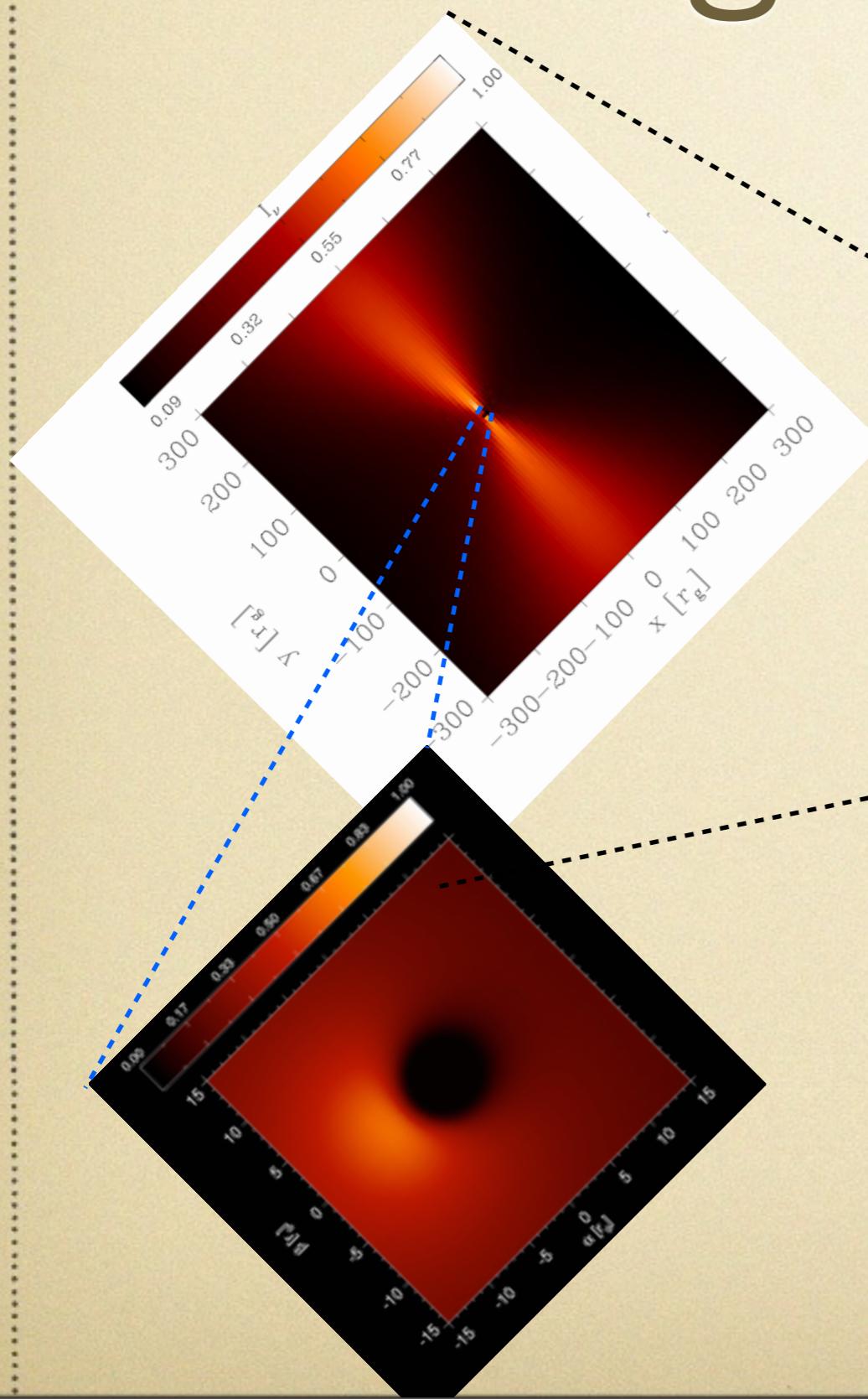
Zamaninasab+ 2011, MNRAS

Sagittarius A*



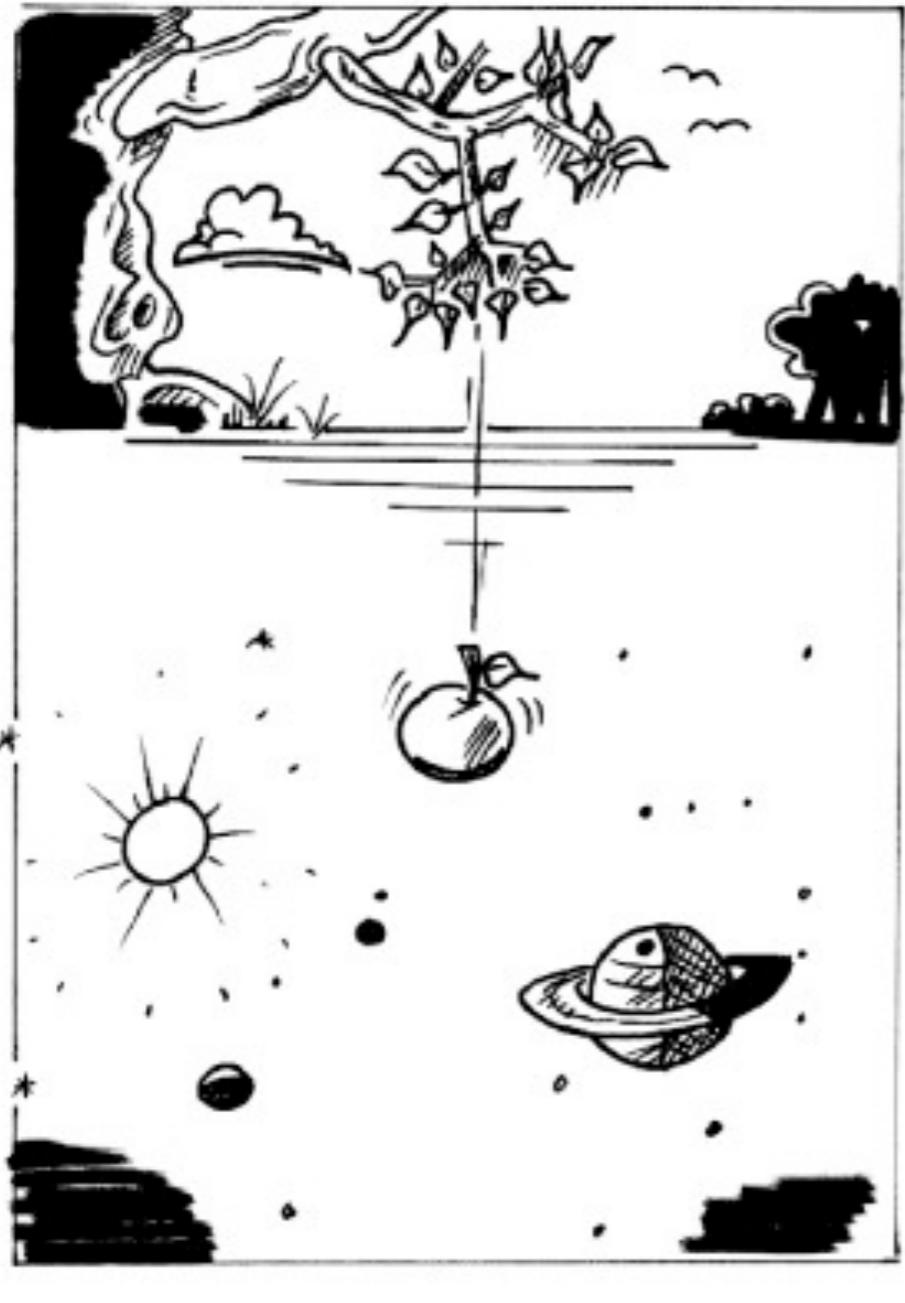
Zamaninasab+ 2011, MNRAS

Sagittarius A*

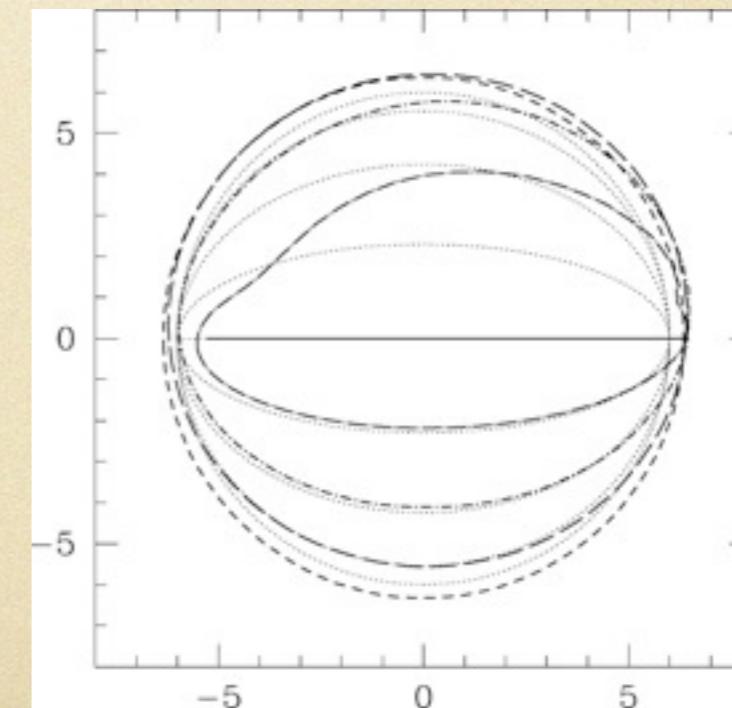


Zamaninasab+ 2011, MNRAS

Next generation of VLTI GRAVITY

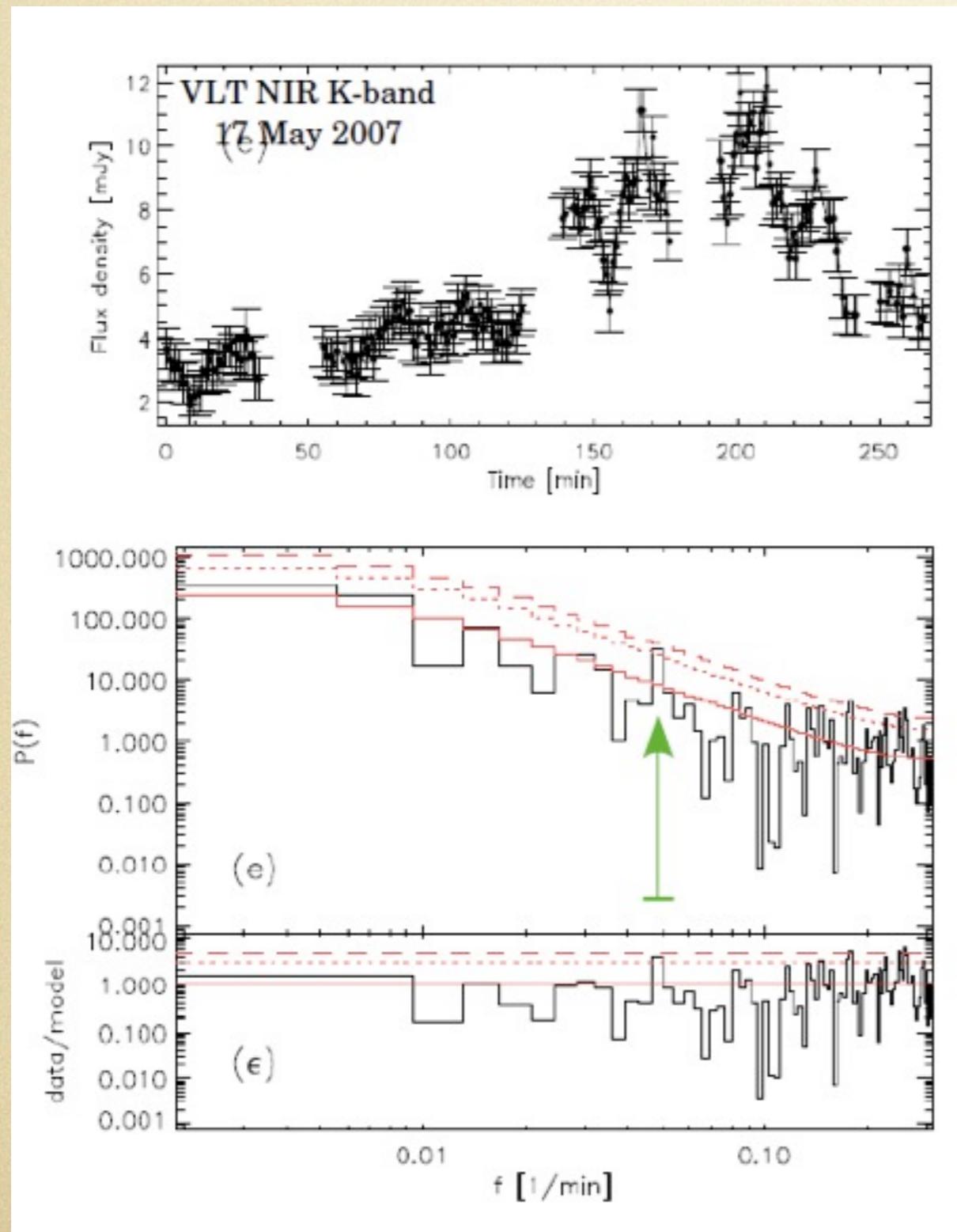


GRAVITY
MPE, MPIA, Paris, Lisbon, Cologne



Broderick+ 2005 MNRAS, Zamaninasab+ 2008 JPHCS

Timing analysis



Zamaninasab+ 2010, A&A