Signatures of Strong Gravity in the Polarized Emission of Sgittarius A*

Accretion Processes in X-rays: From White Dwarfs to Quasars

July 13 – 15, 2010, Boiston, MA, USA

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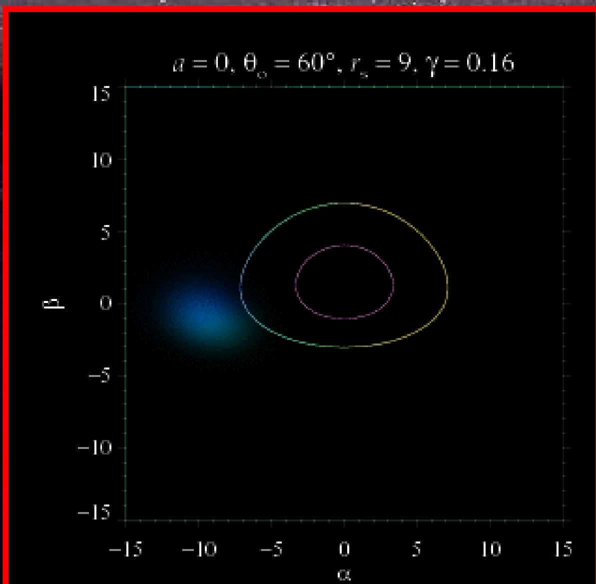
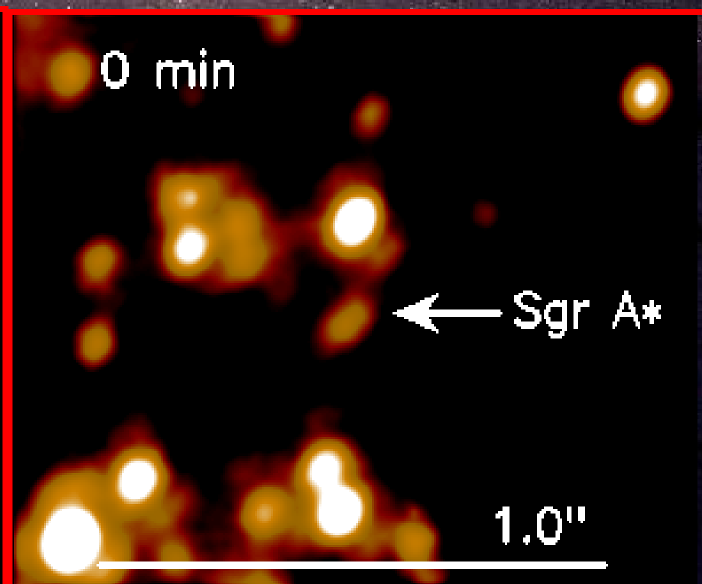
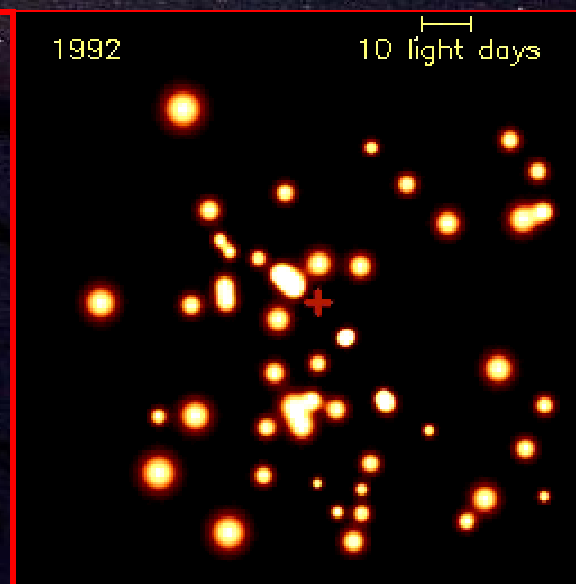
Max-Planck-Institut für Radioastronomie, Bonn

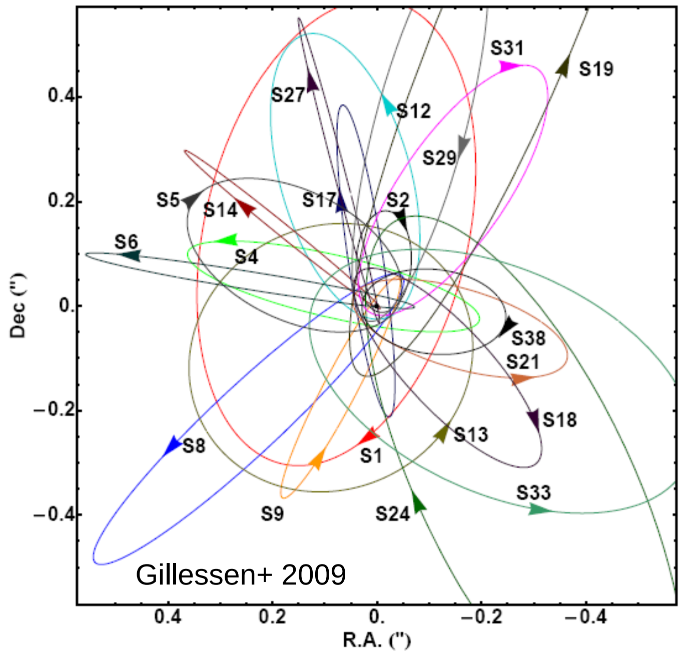


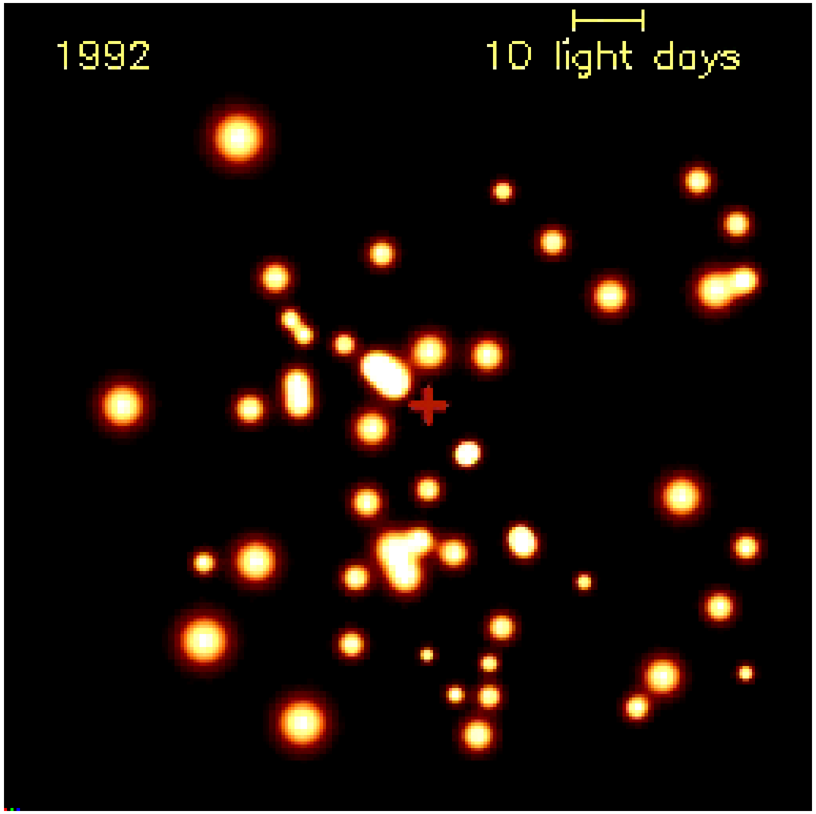




Extreme Physics

Orbits of High Velocity Stars
in the Central Arcsecond

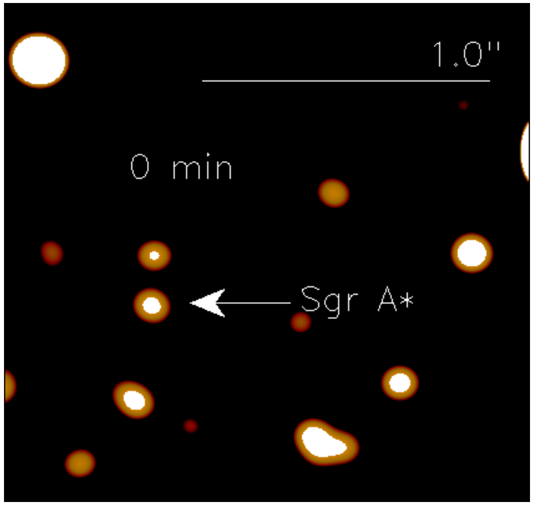




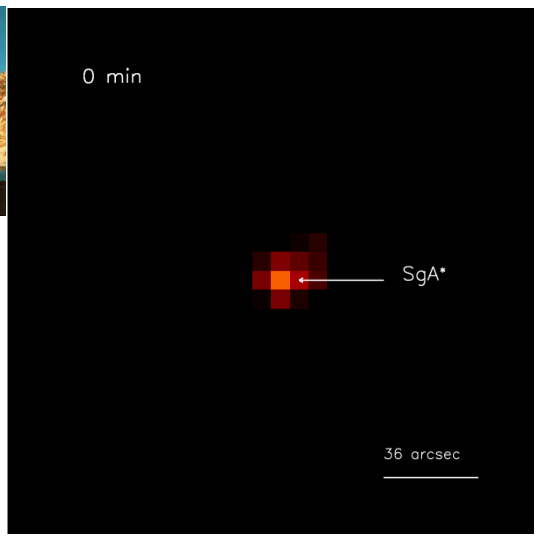
Eckart & Genzel 1996/1997 (first proper motions)
Eckart et al. 2002 (S2 is bound; first elements)
Schödel et al. 2002, 2003 (first detailed elements)
Ghez et al 2003 (detailed elements)
Eisenhauer 2005, Gillessen et al. 2009
(improved elements on more stars and distance)

~4 million solar masses
at a distance of
~8.3+-0.3 kpc

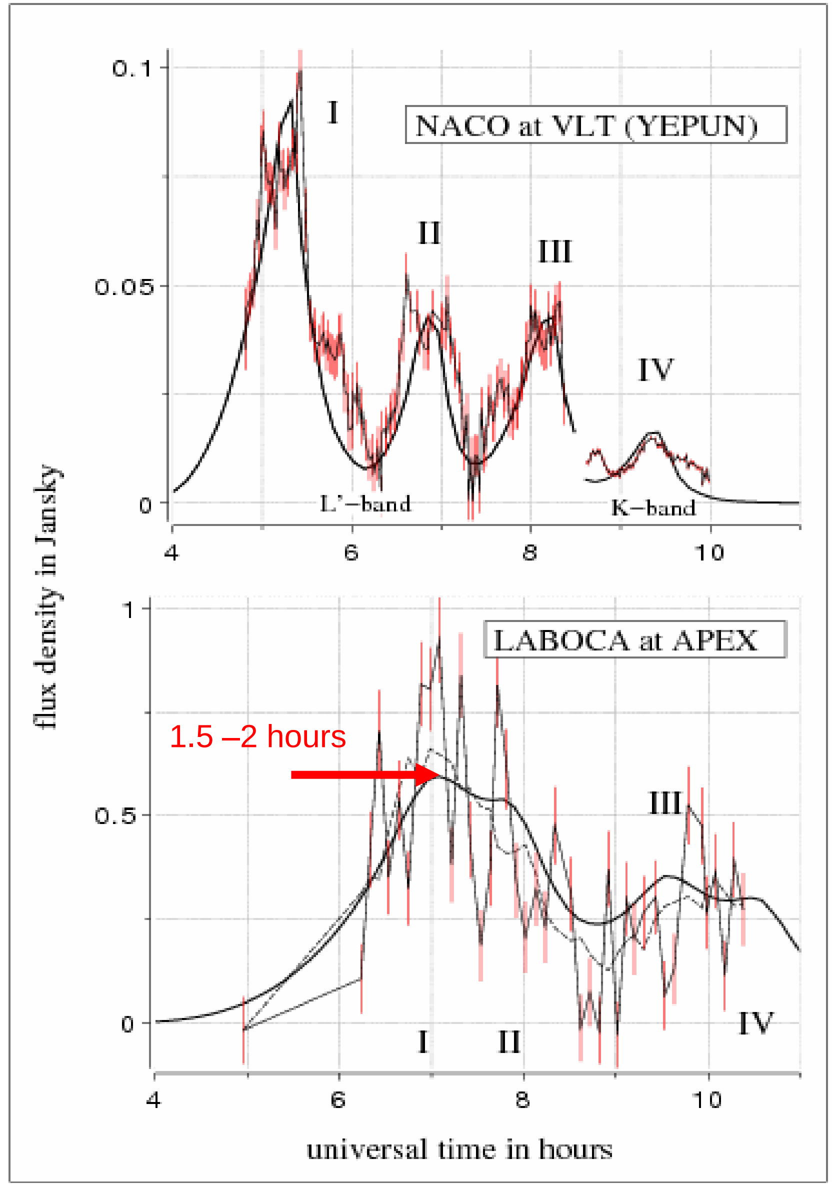
SgrA* on 3 June 2008:
VLT L-band and APEX
sub-mm measurements



VLT UT4
L-band

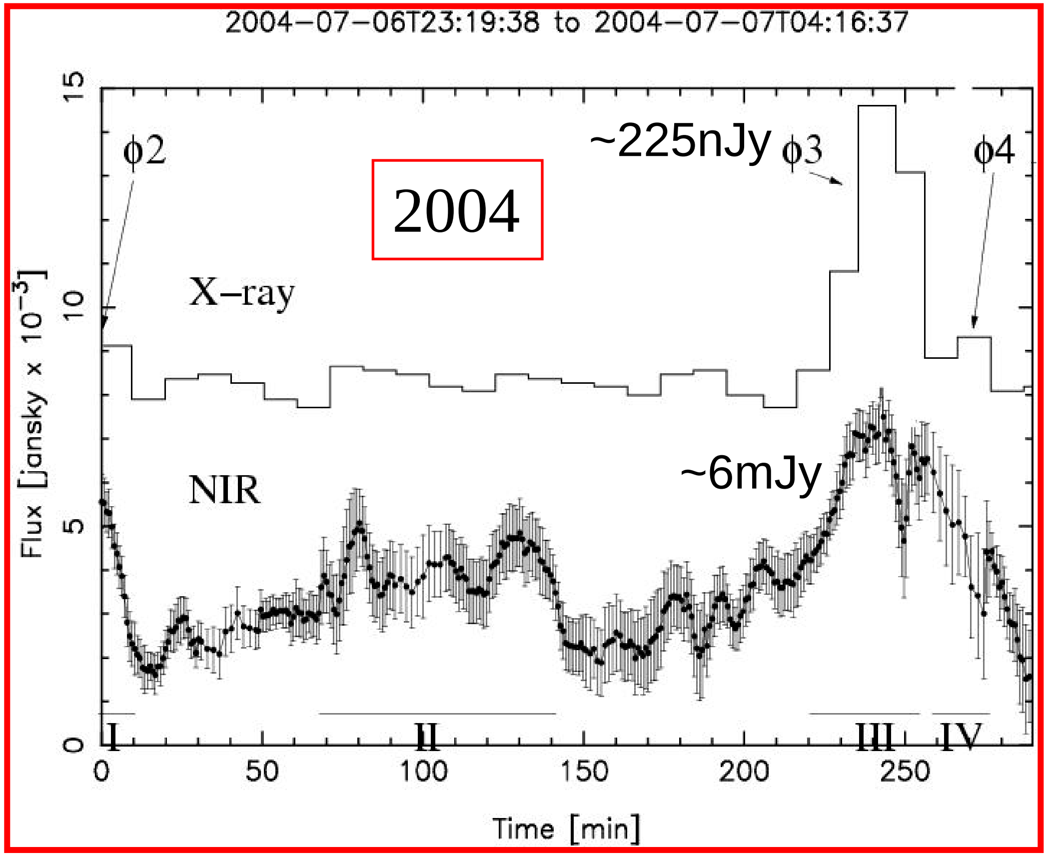


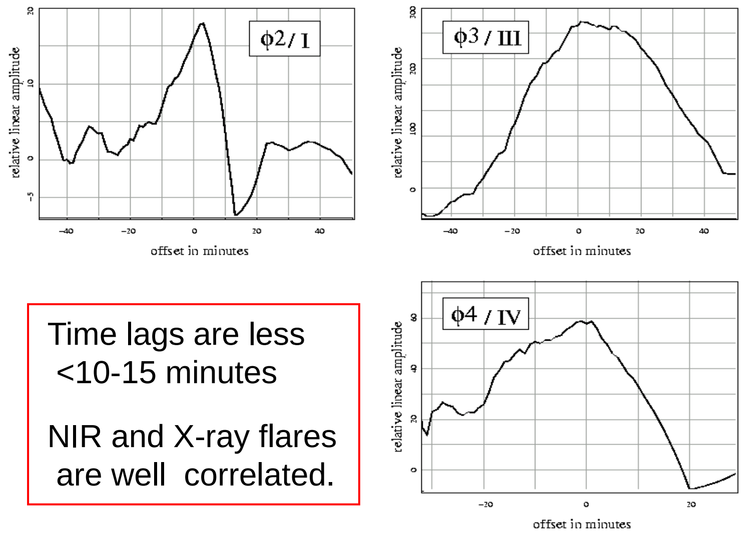
APEX
1.3 mm



v(exp) = 0.006 c
Eckart et al. 2008; A&A 492, 337
1.5 – 2 hours lag between NIR/sub-mm

Simultaueous NIR/X-ray Flare emission 2004





Time lags are less <10-15 minutes

NIR and X-ray flares are well correlated.

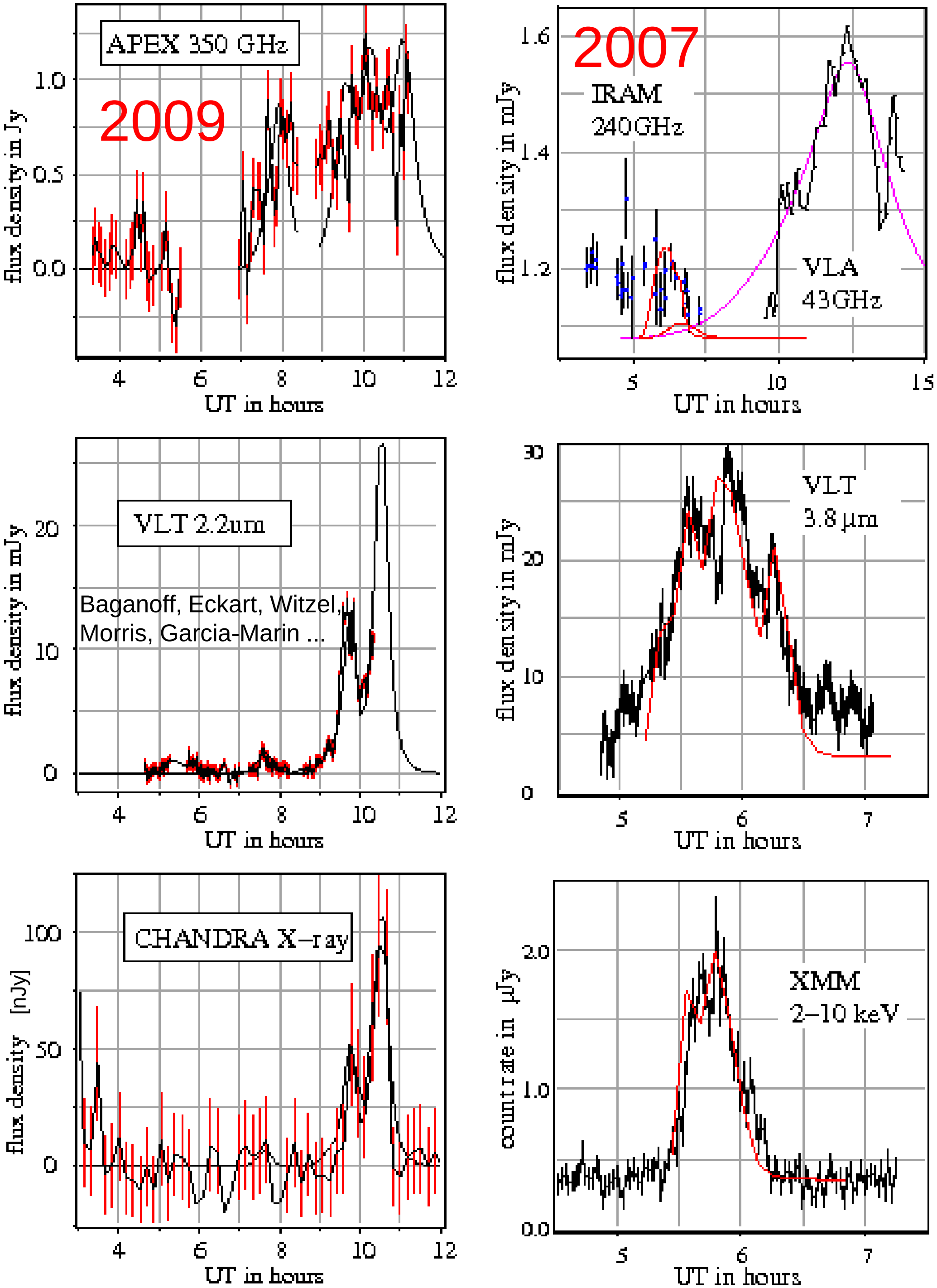
Flare emission originates from within <10mas form the position of SgrA*

First simultaneous NIR/X-ray detection

2003 data: Eckart, Baganoff, Morris, Bautz, Brandt, et al. 2004 A&A 427, 1

2004 data: Eckart, Morris, Baganoff, Bower, Marrone et al. 2006 A&A 450, 535

see also Yusef-Zadeh, et al. 2008, Marrone et al. 2008

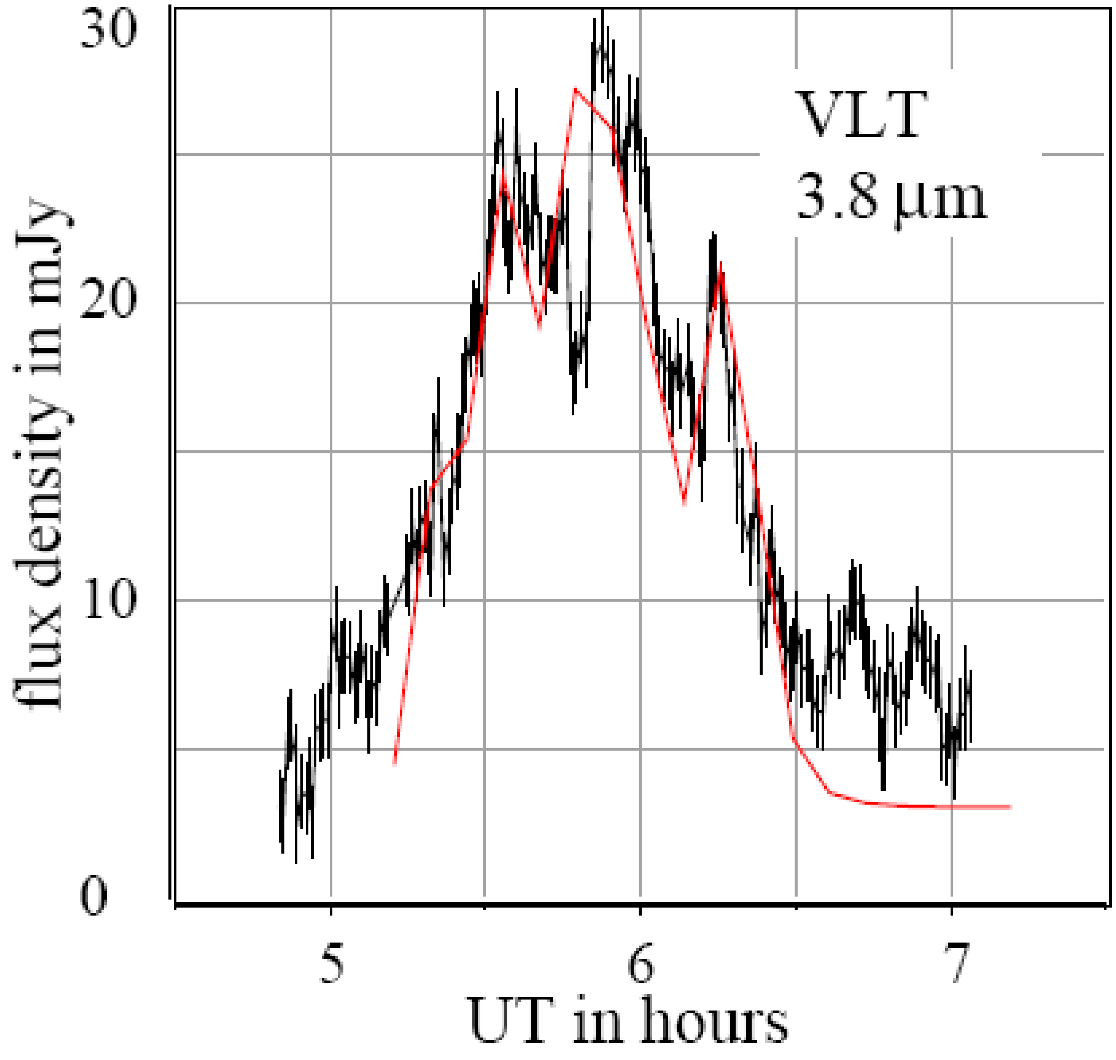


Simultaneous NIR/X-ray flares

Porquet et al. 2008
Dodds-Eden et al. 2009, 2010
Yusef-Zadeh et al. 2009

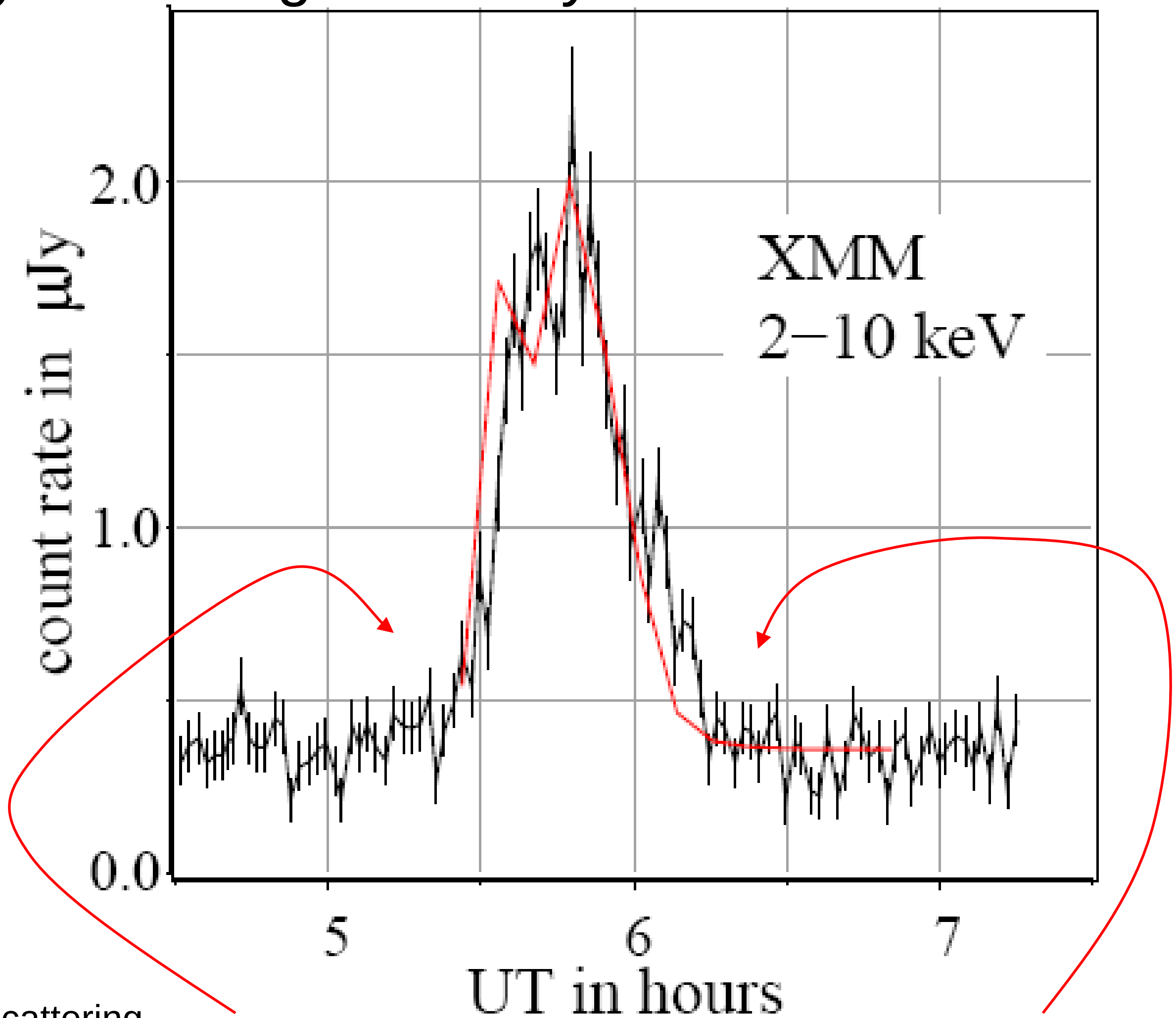
Sabha et al. 2009

High Power X-ray Flare: VLT



High Power X-ray Flare: XMM

X-ray scattering efficiency:

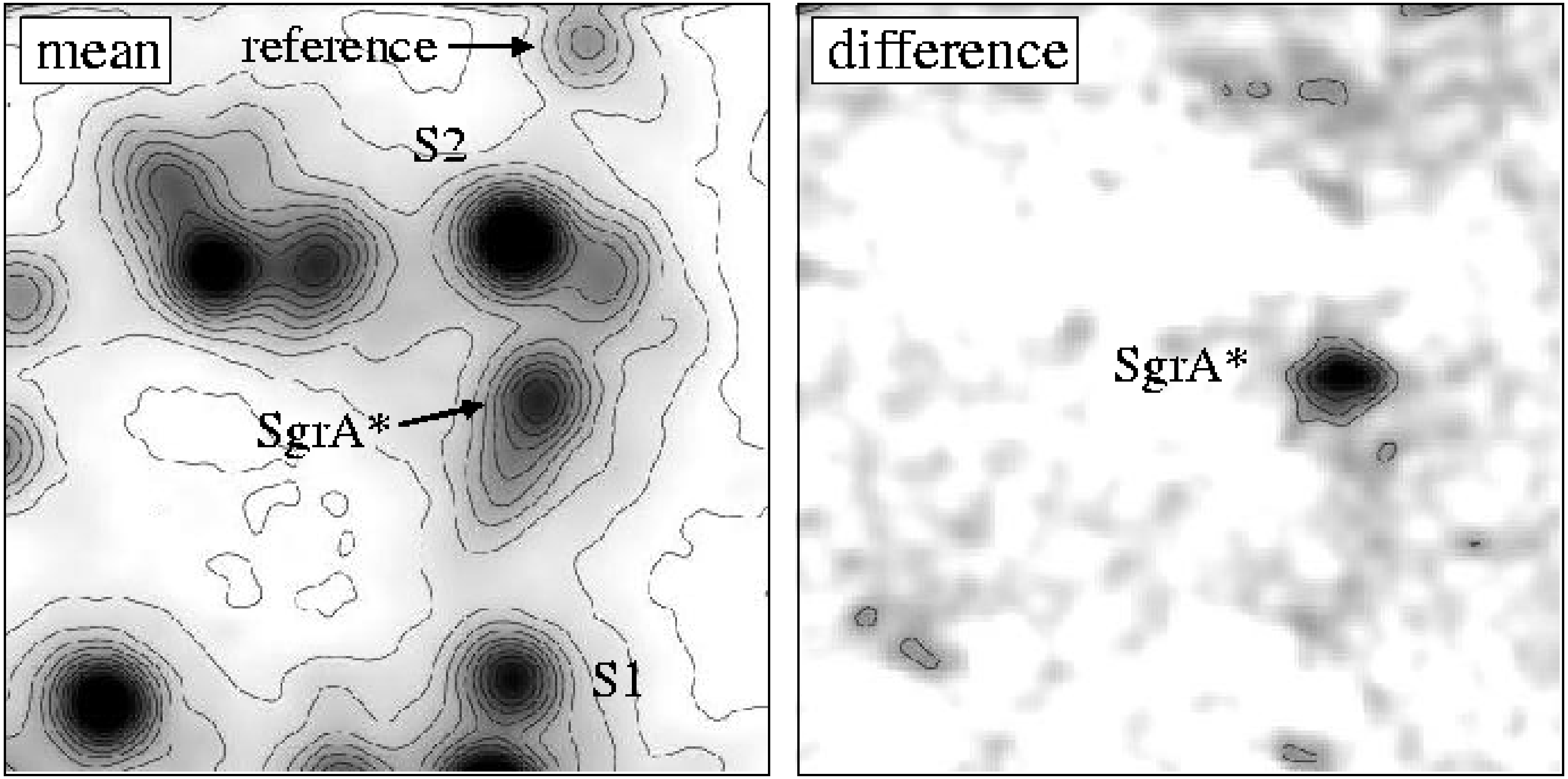


A 25% smaller S_m or larger θ results in the required decrease in scattering efficiency and a 3 times lower B during the bright flare phase.

$$S_{\nu}^{SSC}(E_{keV}) \propto \theta^{-2(2\alpha+3)} S_m^{2(\alpha+2)}$$

$$B \propto \theta^4 S^{-2}$$

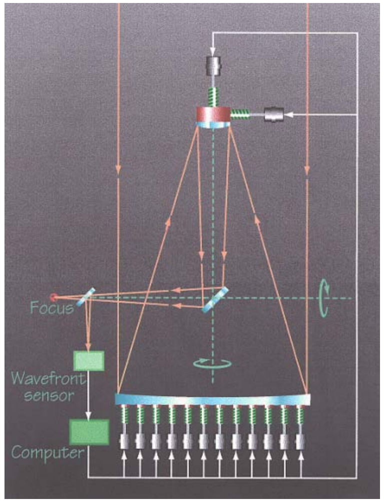
Precision of NIR Polarization measurements

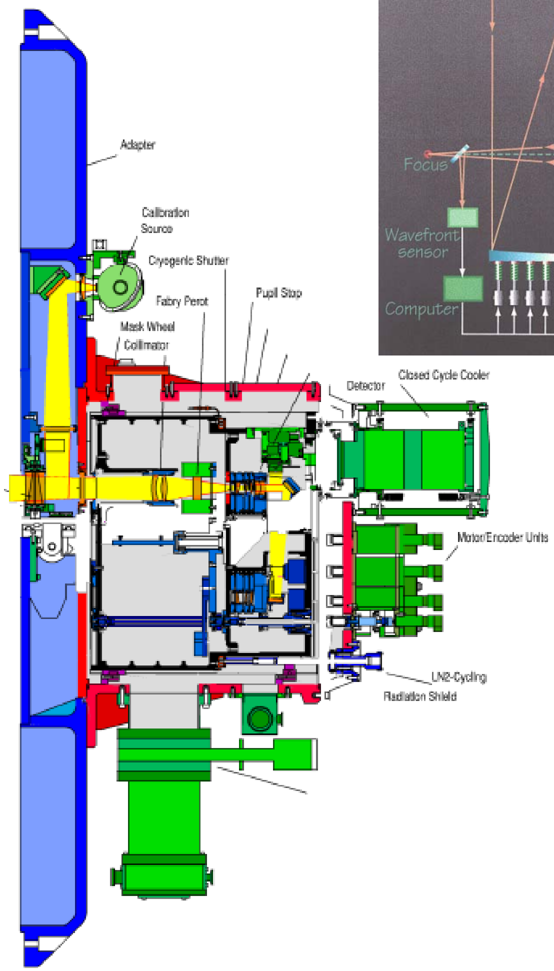


mean flux at 0 and 90 degrees　　difference between flux at 0 and 90 degrees

July 2005: VLT NACO Wollaston prism plus $\lambda/2$ retarder wave-plate

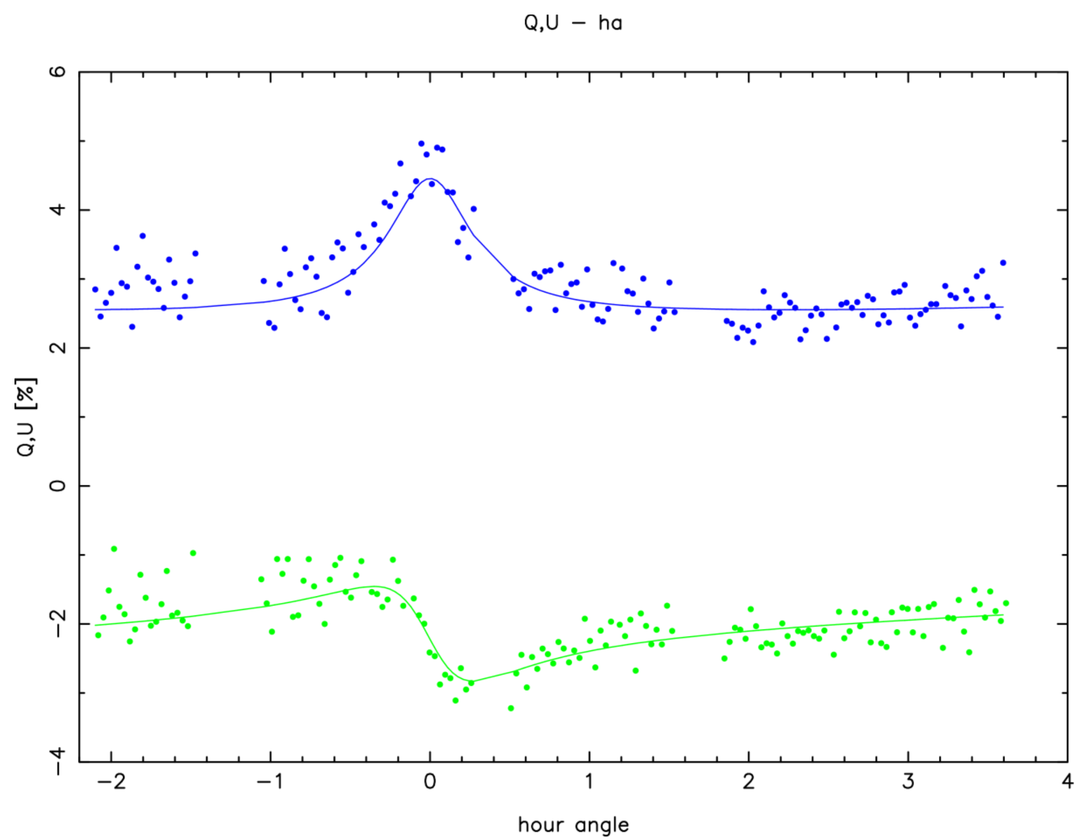
Precision of NIR Polarization measurements





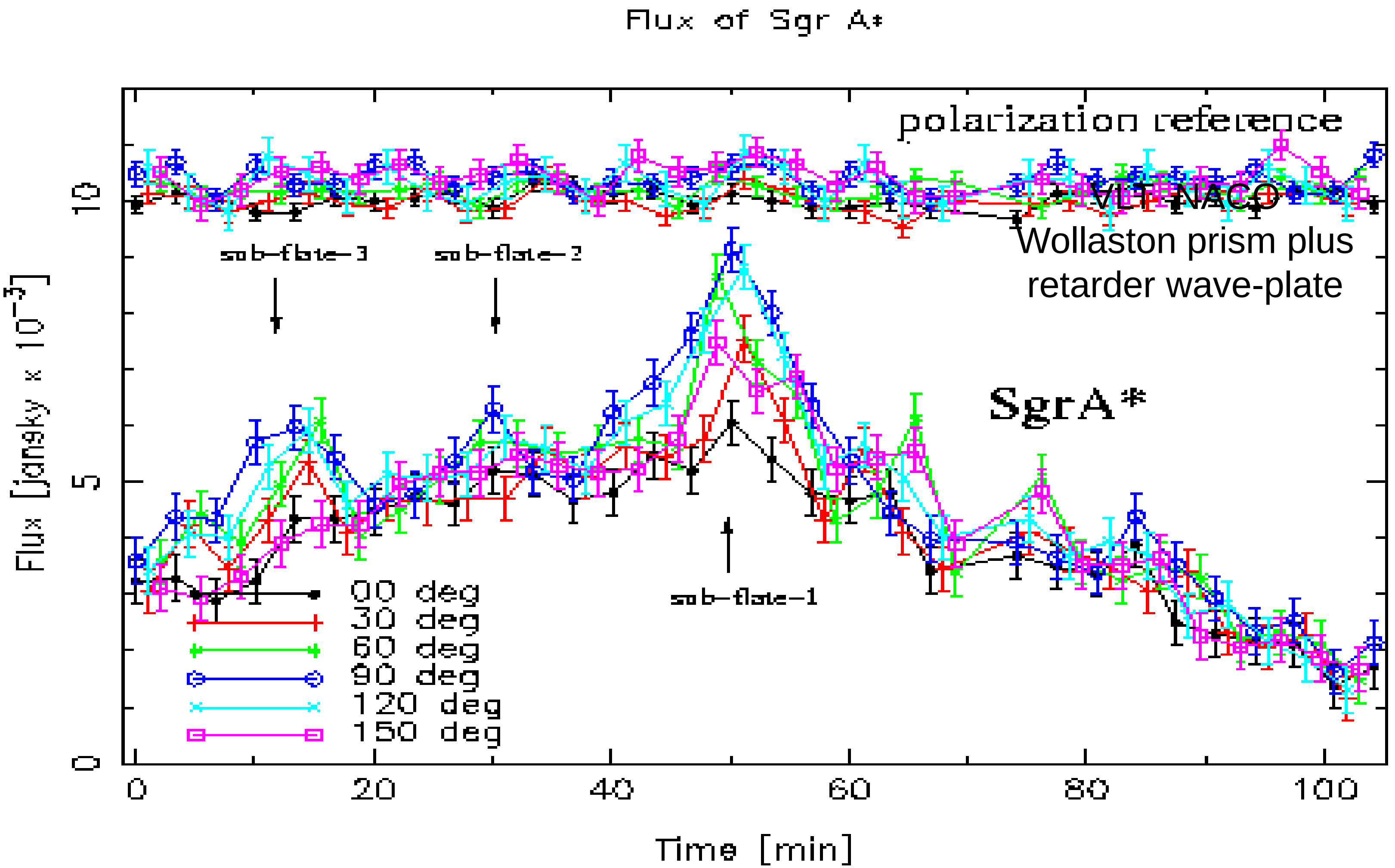
Instrument calibrated to ~1%

Current limit due to systematics ~3-4%



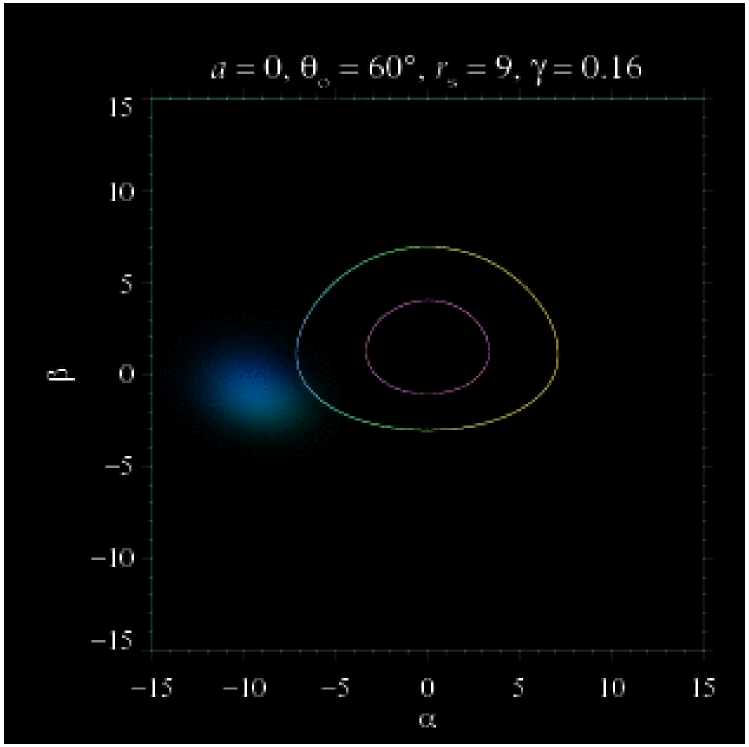
Witzel, G., et al. 2010 sumitted.

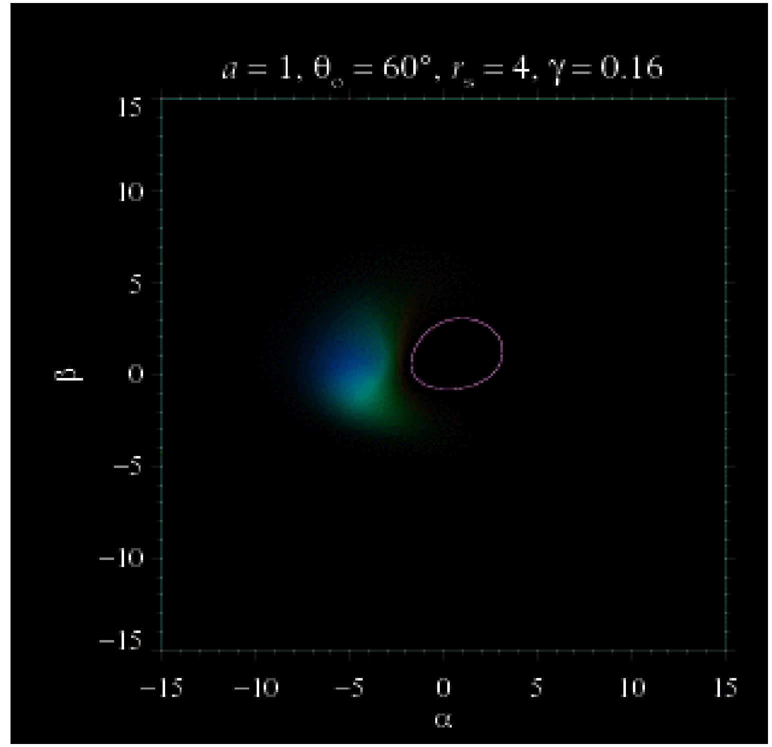
NIR Polarized Flux Density from SgrA*



Eckart, Schödel, Meyer Trippe, Ott, Genzel
2006, A&A 455, 1

Flares from SgrA*: A spotted disk?

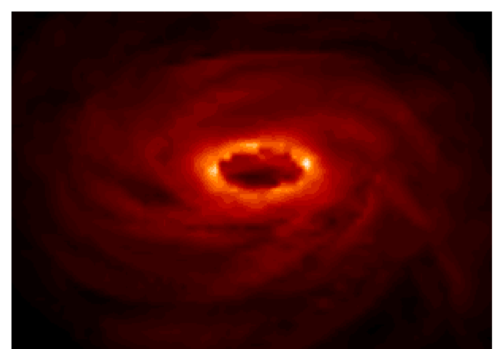




Dovciak, Karas & Yaqoob 2004, ApJS 153, 205
Dovciak et al. 2006

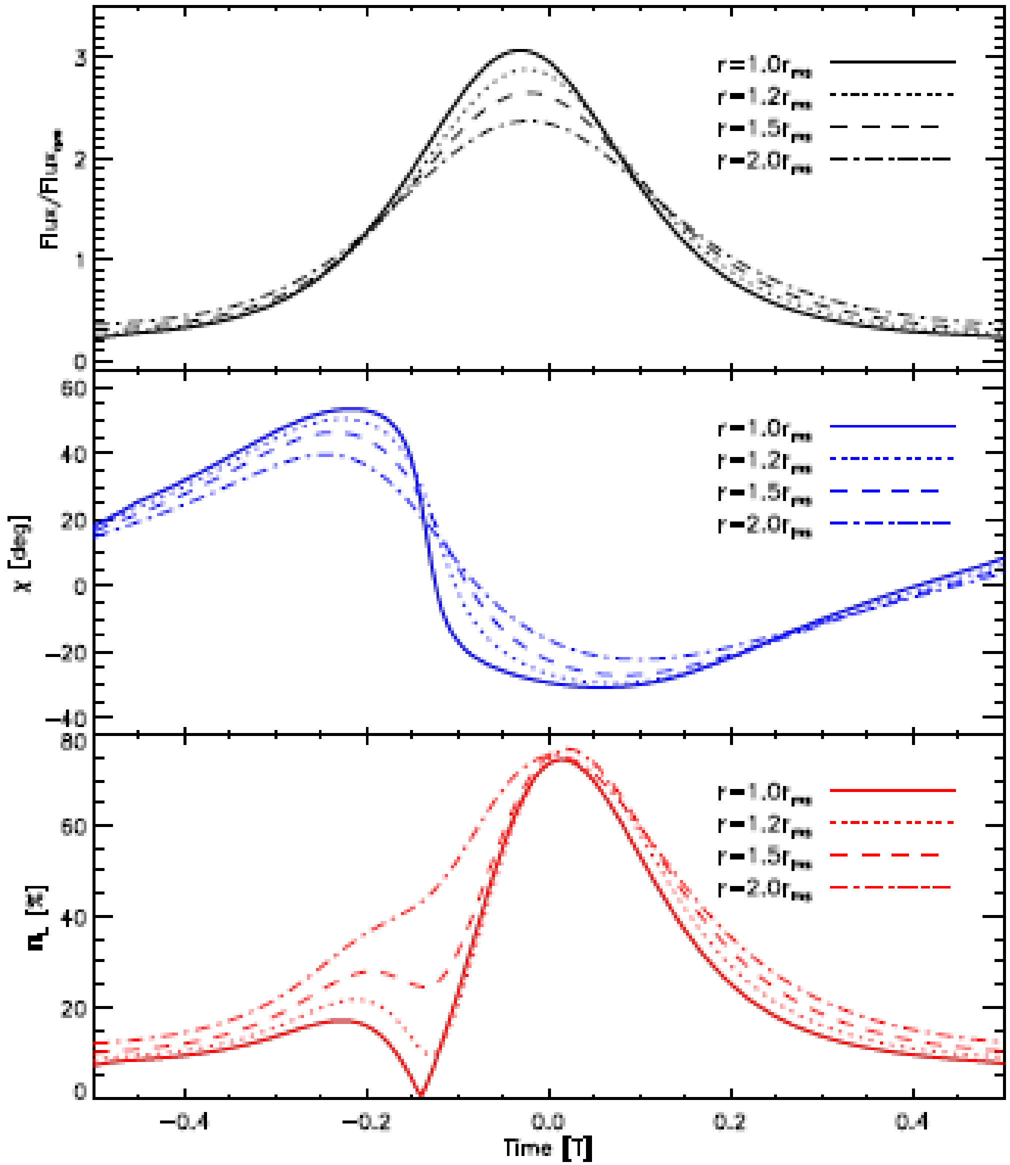
Goldston, Quataert & Igumenshchev 2005, ApJ 621, 785

see also Broderick & Loeb 2005ab



~4min prograde
~30min static
for ~4x10**6Msol

Pattern of a NIR spot orbiting at the ISCO



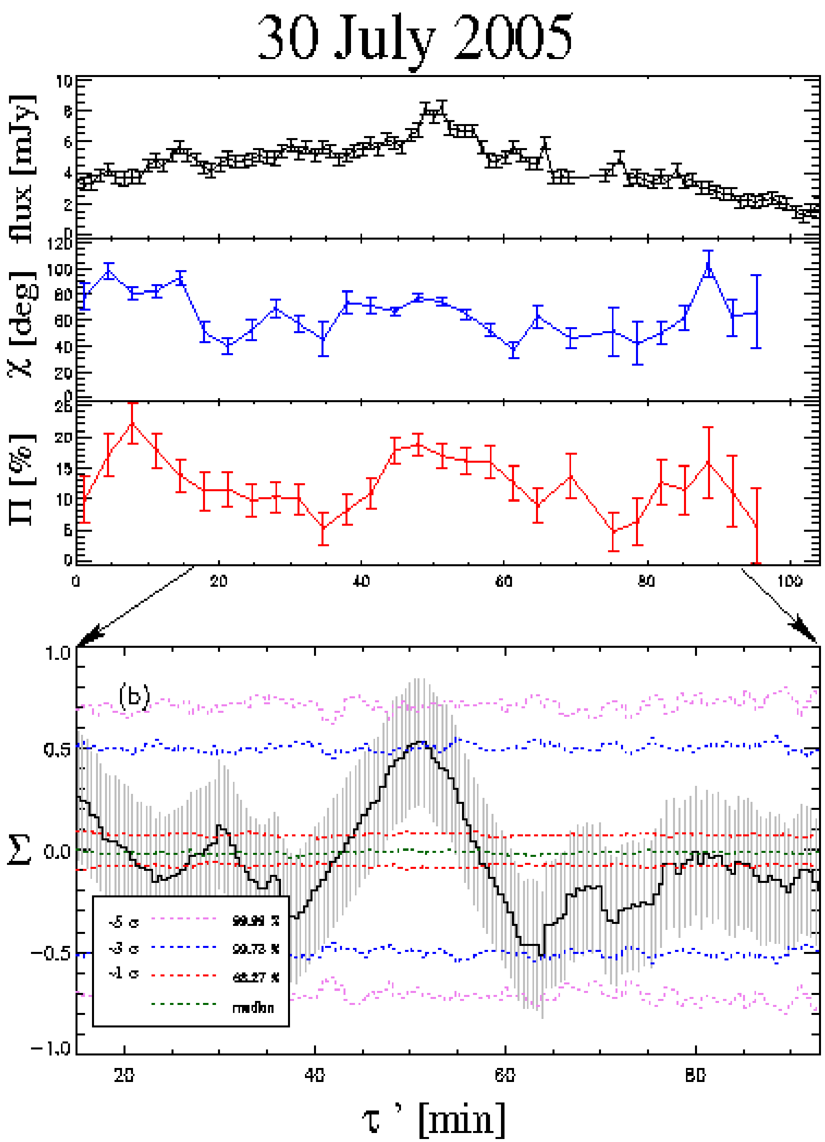
total intensity

polarization angle

polarization degree

Zamaninasab et al. 2009

Pattern recognition against polarized red noise



total intensity

polarization angle

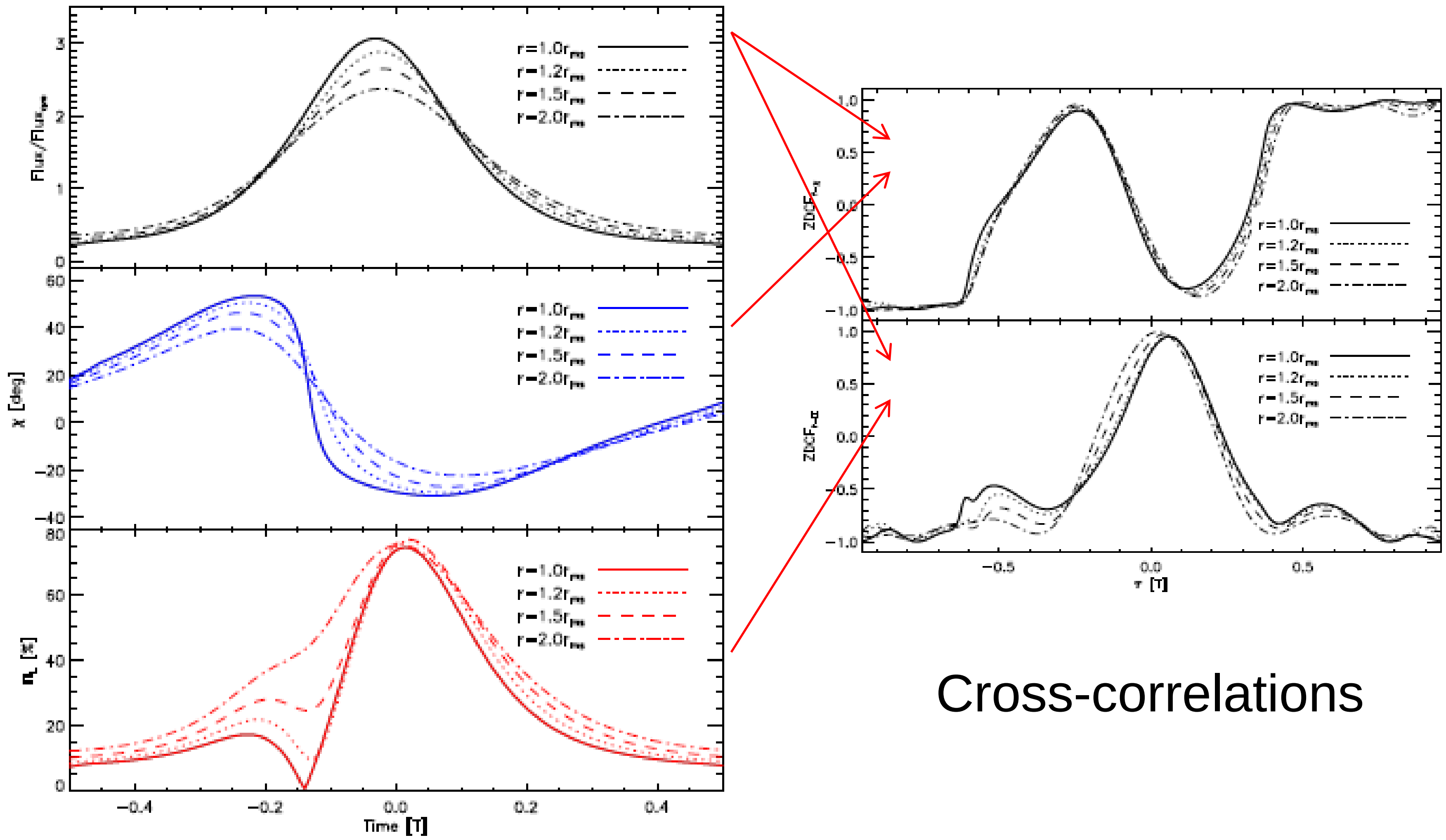
polarization degree

5σ
3σ
1σ
mean

randomly
polarized
red noise

Zamaninasab et al. 2009

Pattern of a spot orbiting at the ISCO



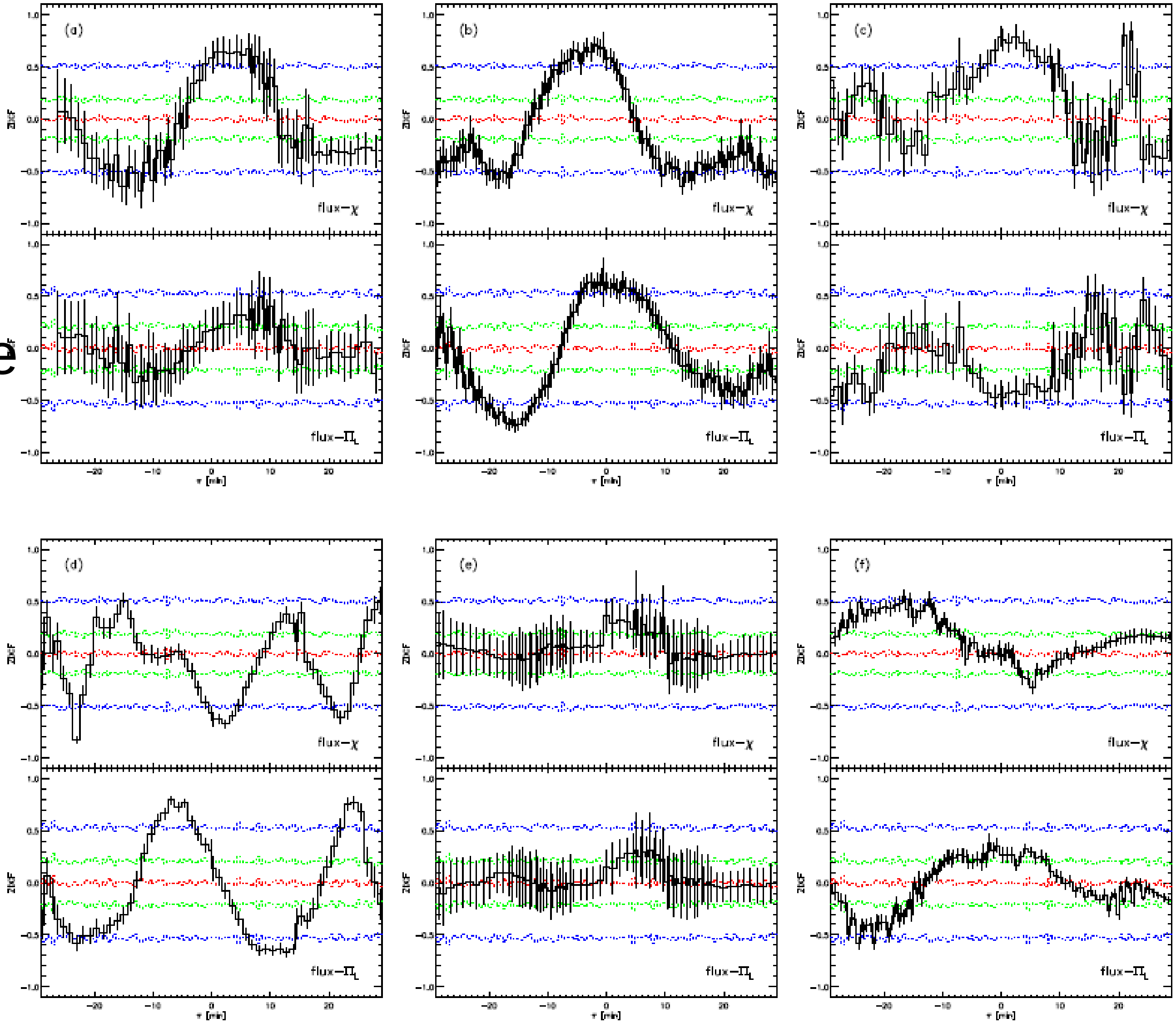
Cross-correlations

Zamaninasab et al. 2009

Pattern recognition against polarized red noise

flux and angle

flux and degree



Zamaninasab et al. 2009

Polarized flares as the

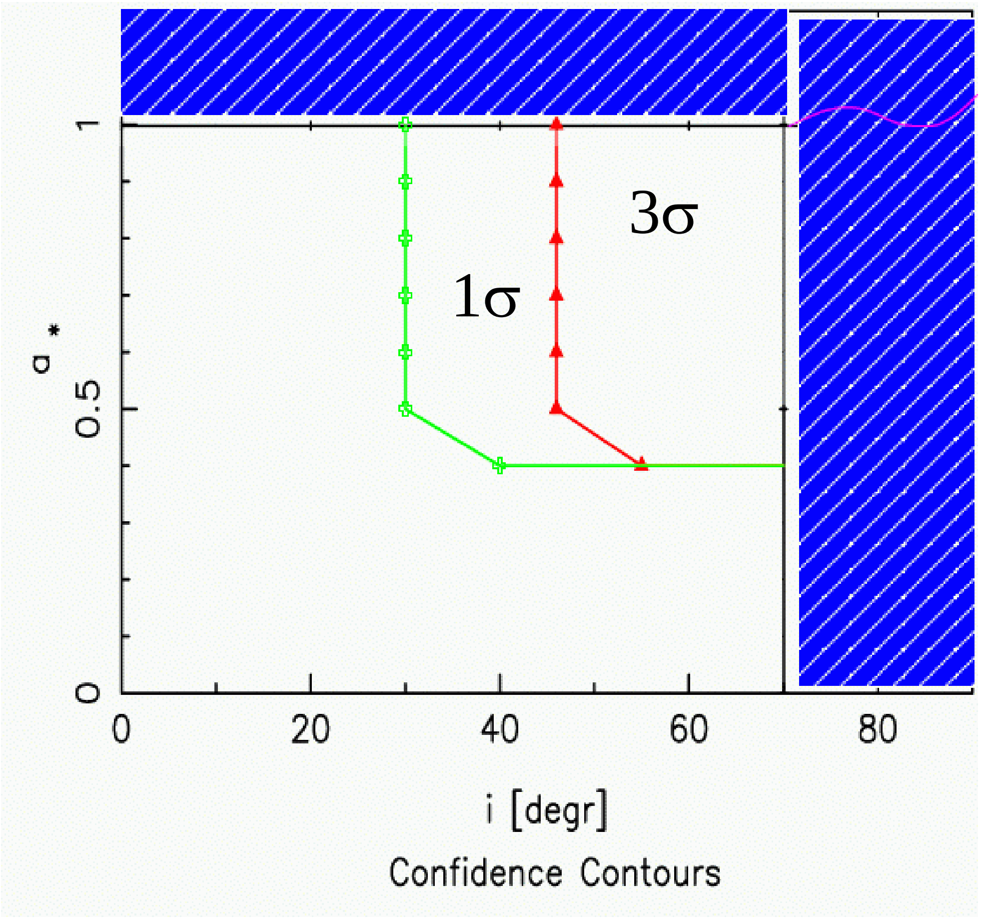
signature of strong gravity

are significant against

randomly polarized red noise

Polarization data are consistent with the orbiting spot hypothesis

NIR Polarized Flux Density from SgrA*

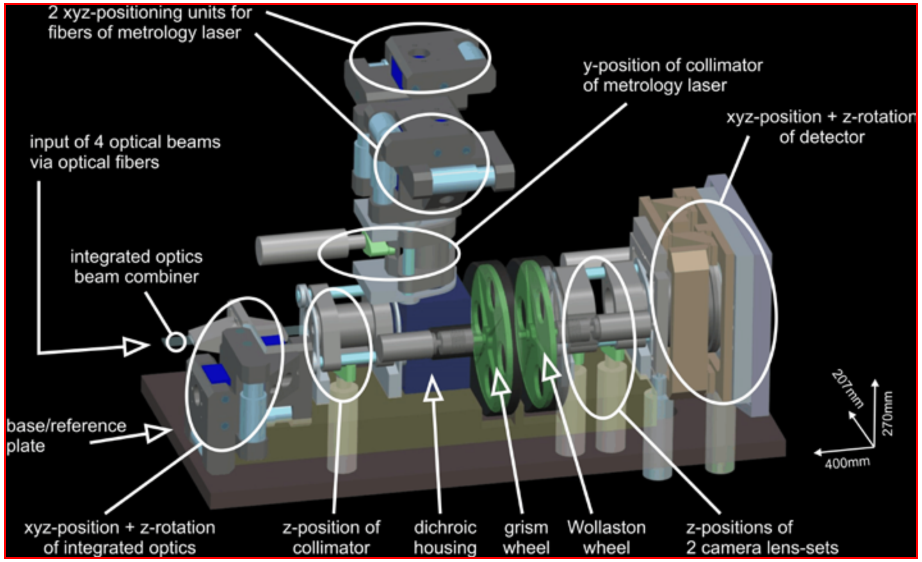


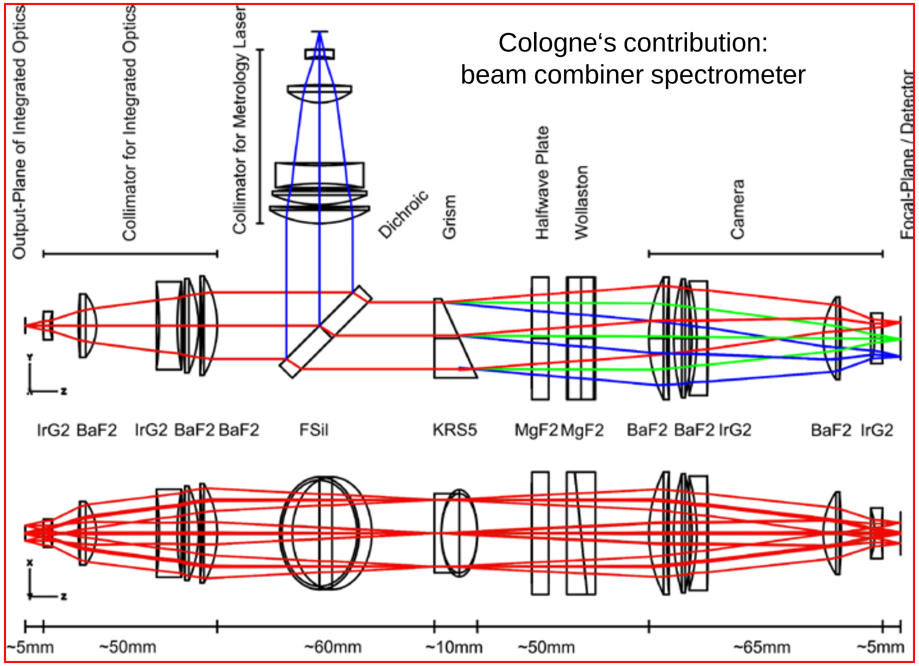
χ^2 analysis indicates
a= 0.4-1
i=50^o-70^o

Meyer, Eckart, Schödel, Duschl, Muzic, Dovciak, Karas 2006a
Meyer, Schödel, Eckart, Karas, Dovciak, Duschl 2006b
Eckart, Schödel, Meyer, Ott, Trippe, Genzel 2006

~4min prograde
~30min static
for 3.6x10**6Msol

VLTI: GRAVITY





MPE, Garching (P.I. F.Eisenhauer)
MPIA, Heidelberg
Observatoire Paris-Medon
Cologne University
SIM, Portugal

see talk by S. Gillessen

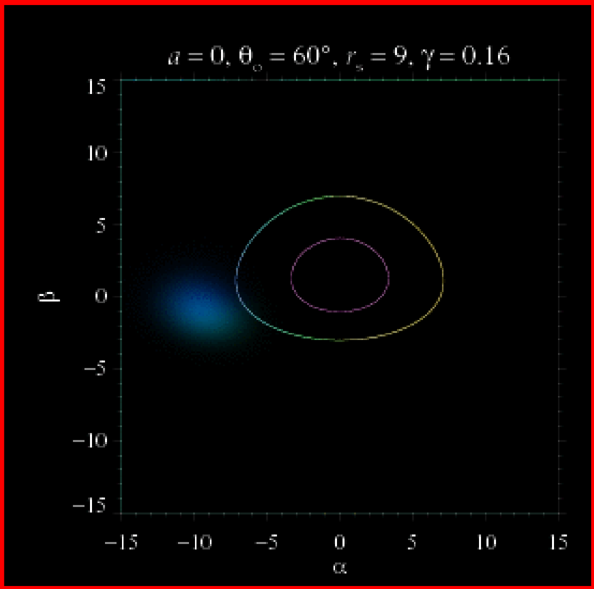
The Galactic Center

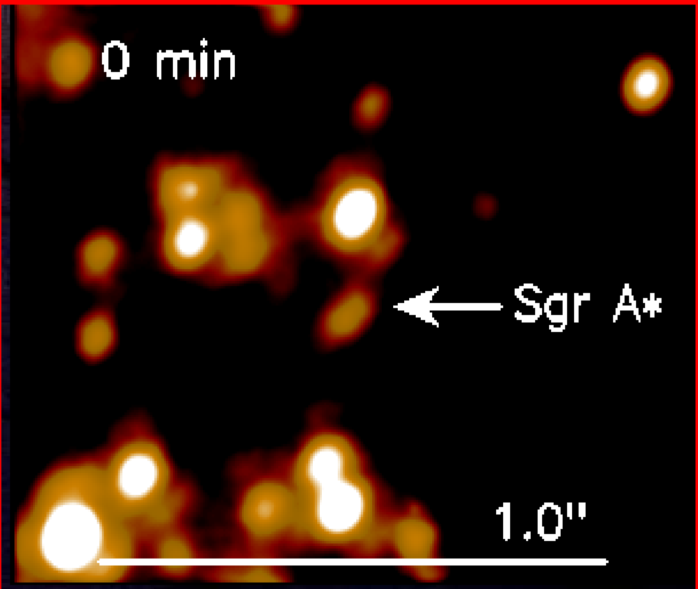
A prime target for GRAVITY will be SgrA* - the radio/infrared counterpart of the super massive black hole at the Center of the Milky Way. Prime goals are:

Detection of relativistic signatures of strong gravity in

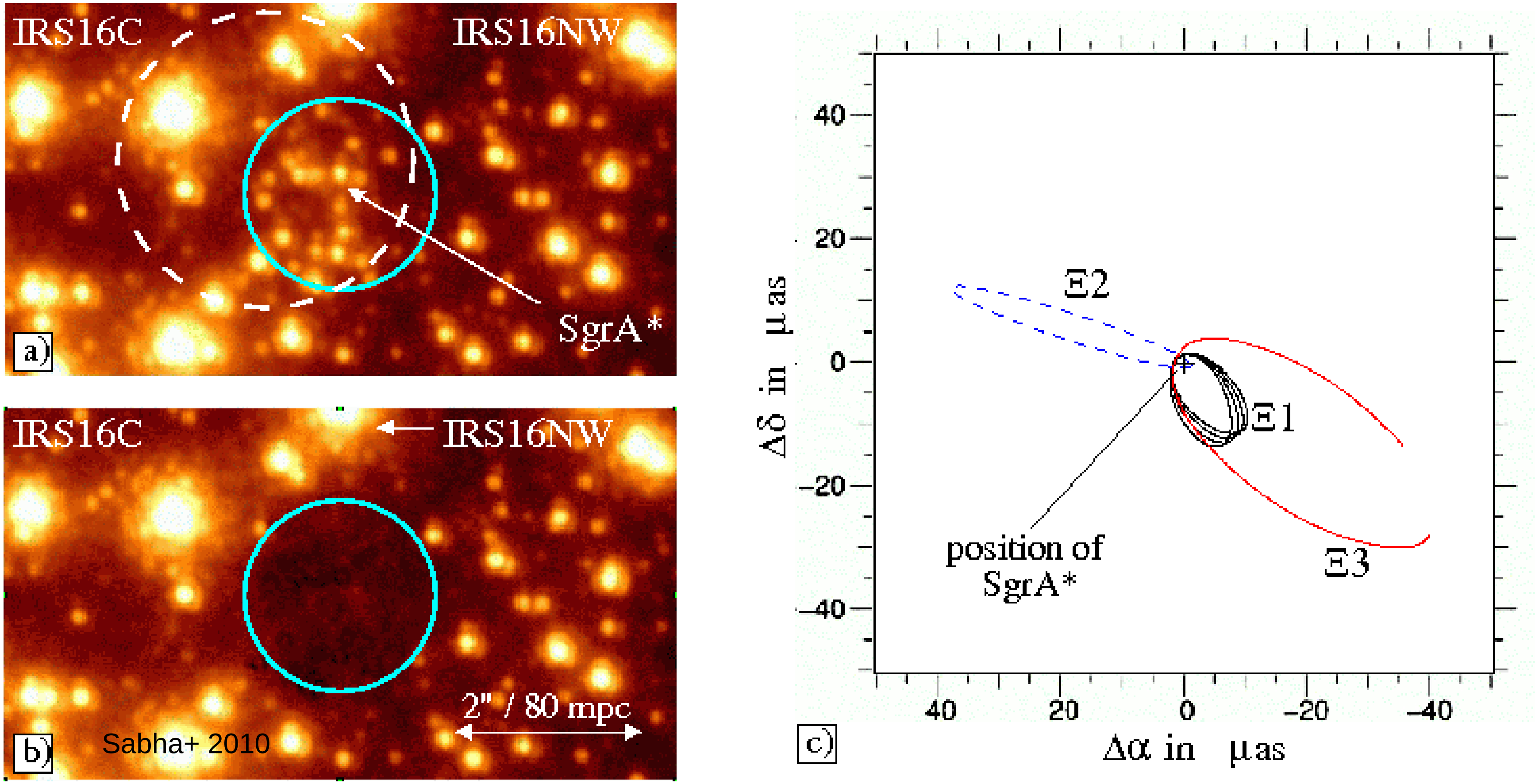
-- stellar orbits --

-- flare emission --





GRAVITY: search for stars closest to SgrA*



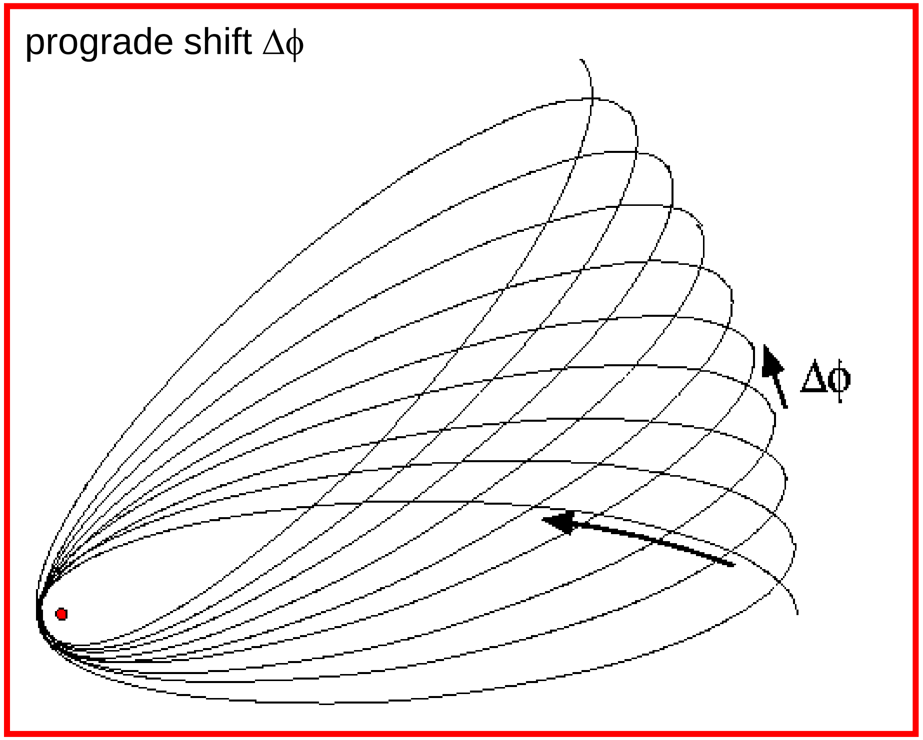
central S-star cluster

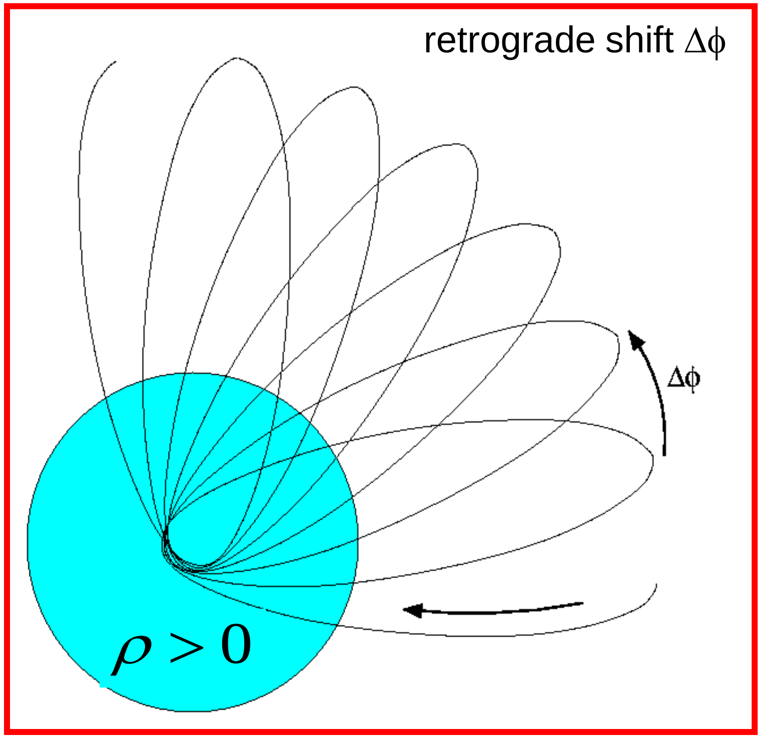
GRAVITY fringe tracker FOV

Strong gravity through stellar orbits

Relativistic periastron shift

Newtonian periastron shift

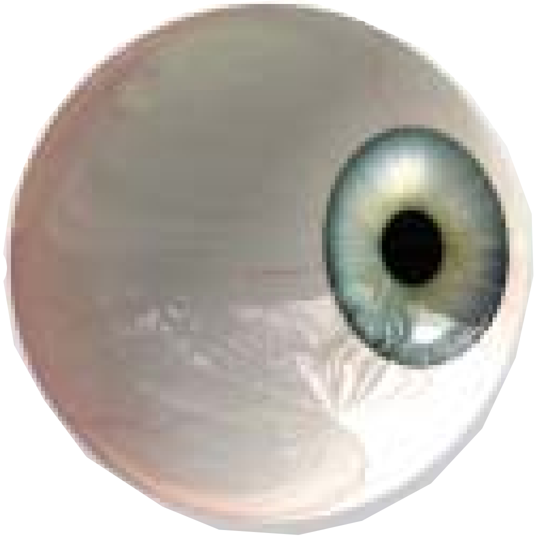




Studies on relativistic effects (periastron shift or redshift) and limits on the mass inclosed by stellar orbits e.g.:

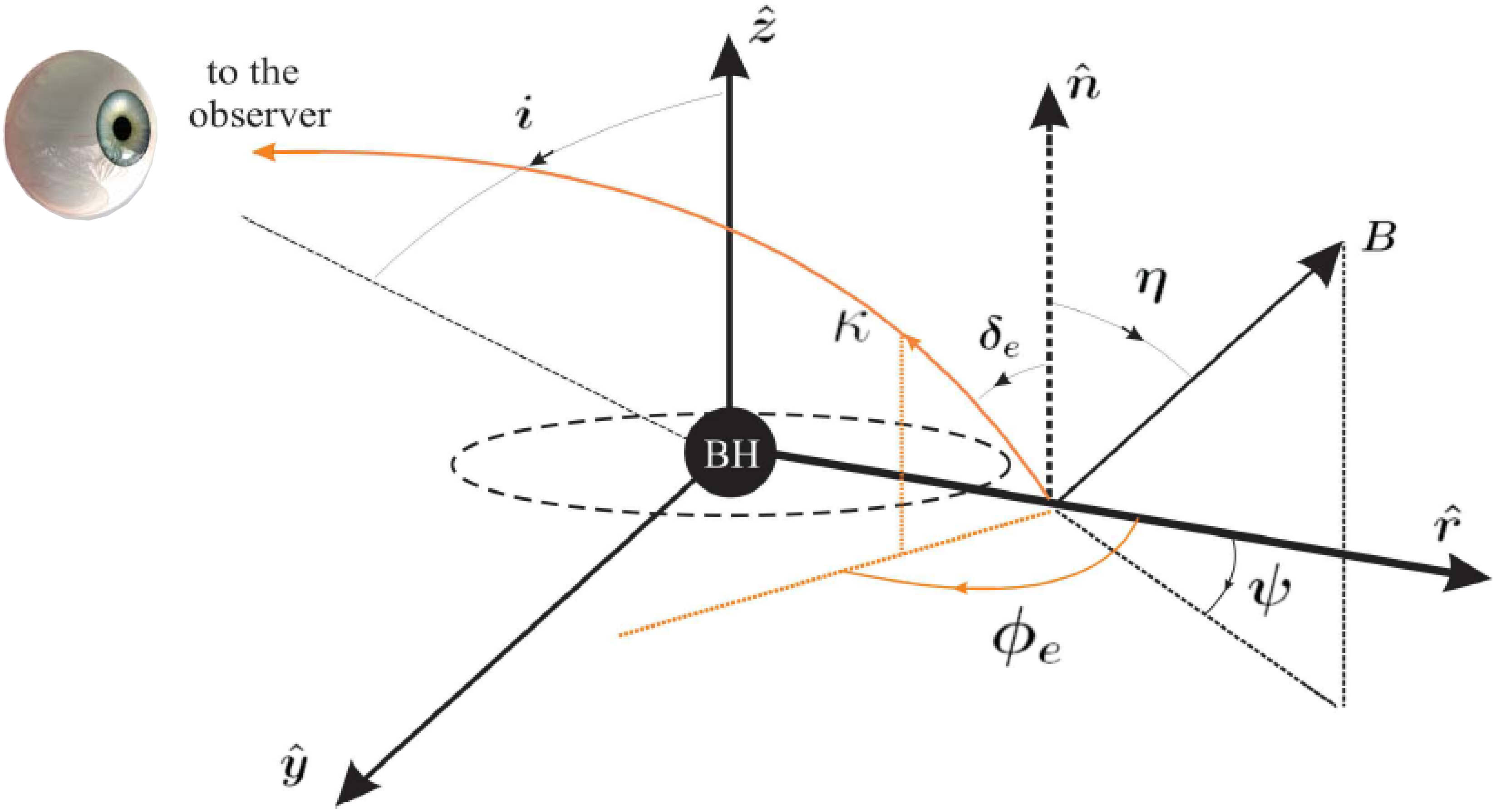
Rubilar & Eckart 2002; Mouawad + 2005; Zucker + 2006; Gillessen+ 2009

GRAVITY will be sensitive to the spot motion



A moving hot spot will measurably (by several 10μas) alter the position of the SgrA* NIR photocenter. Foreseen capability of GRAVITY: 10μas narrow angle astrometry..

Relativistic disk geometry for modeling SgrA*

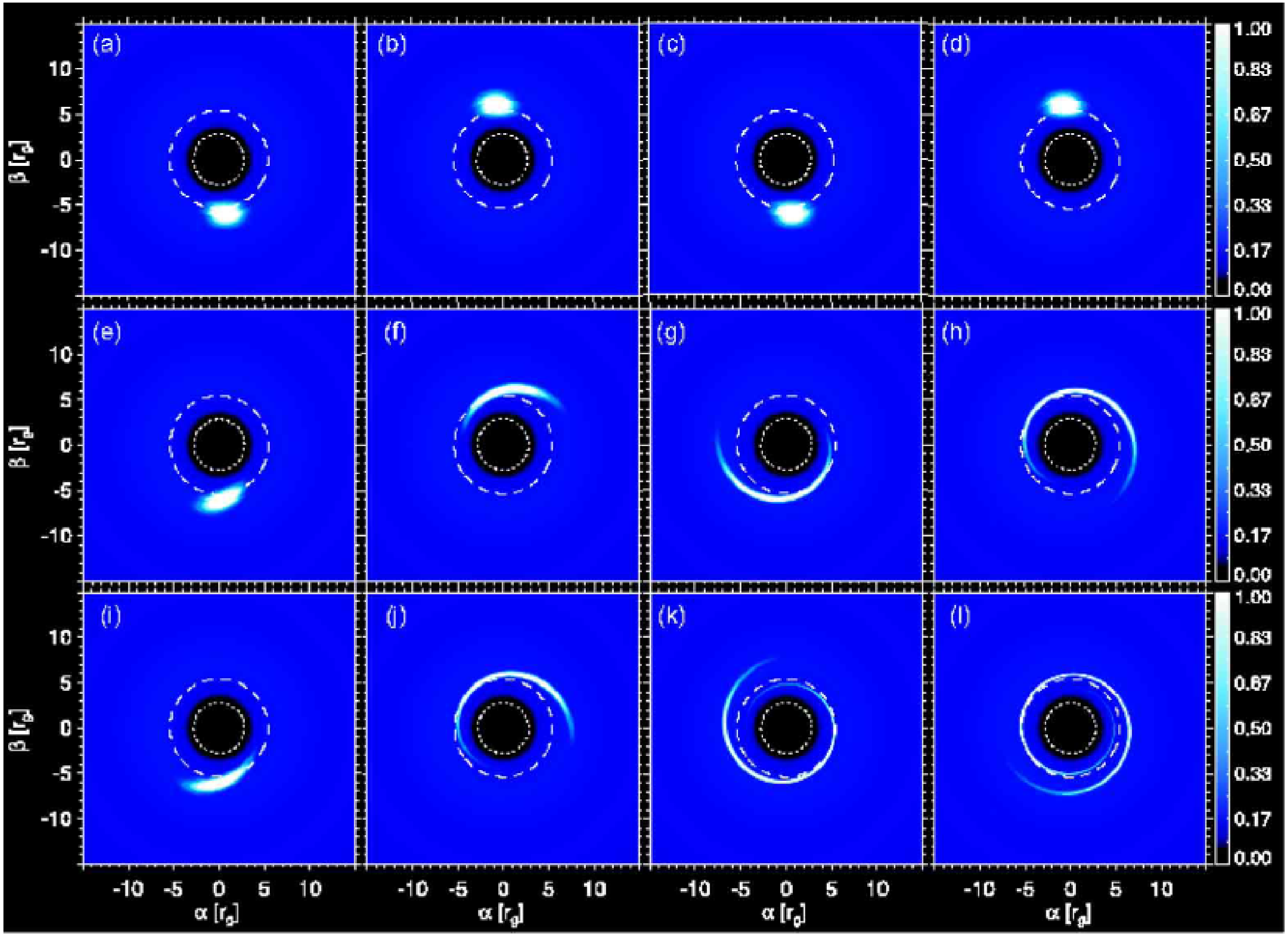


Spot evolution in a differentially rotating disk

face on view
i=0; a=0.5

at times after
1/4T, 3/4T,
5/4T and 7/4T
(left to right).

different degrees of spot shearing

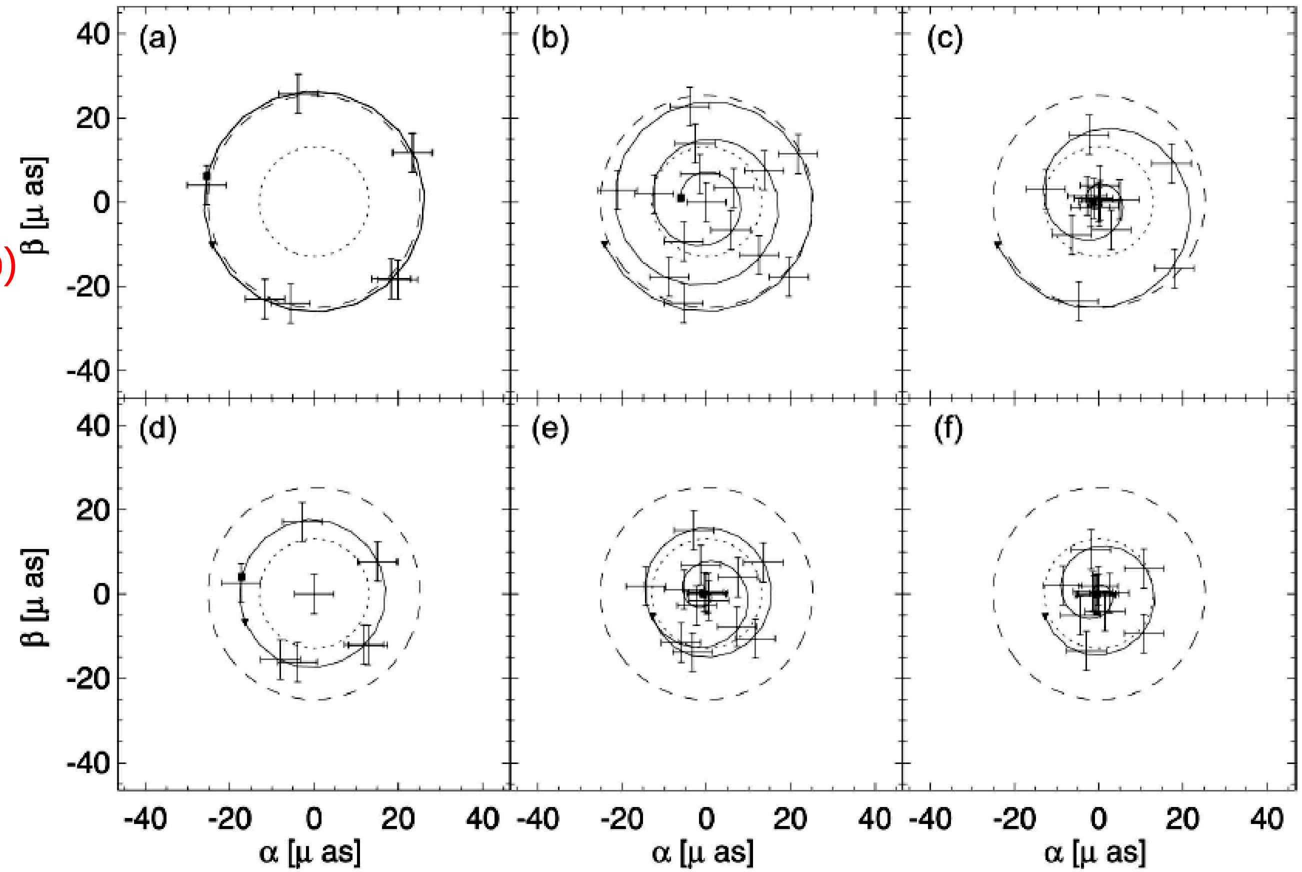


Zamaninasab et al. 2009

Spot evolution in a differentially rotating disk

The centroid motion of NIR images viewed from i=0 above the orbital plane for a Kerr black hole with a spin of 0.5.

see also
Paumard et al. (2005)
Broderick & Loeb (2006a,b)
Hamaus et al. (2009)



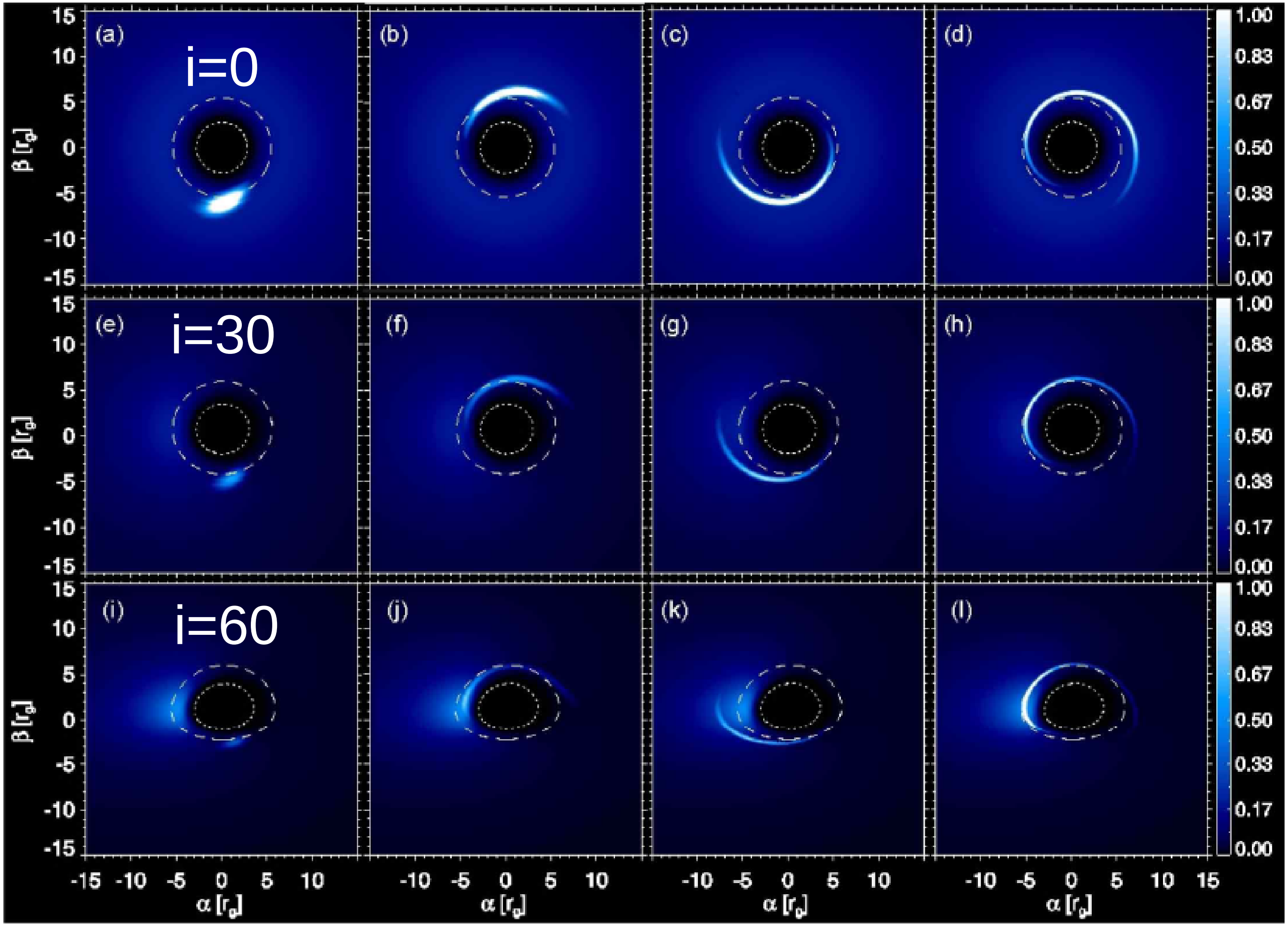
Zamaninasab et al. 2009

With (B) and without (A) background-subtracted images for different values of the and gravitational shearing time scales >>2.0, 2.0 and 1.0 from right to left.

Spot evolution in a differentially rotating disk

different inclinations
a=0.5

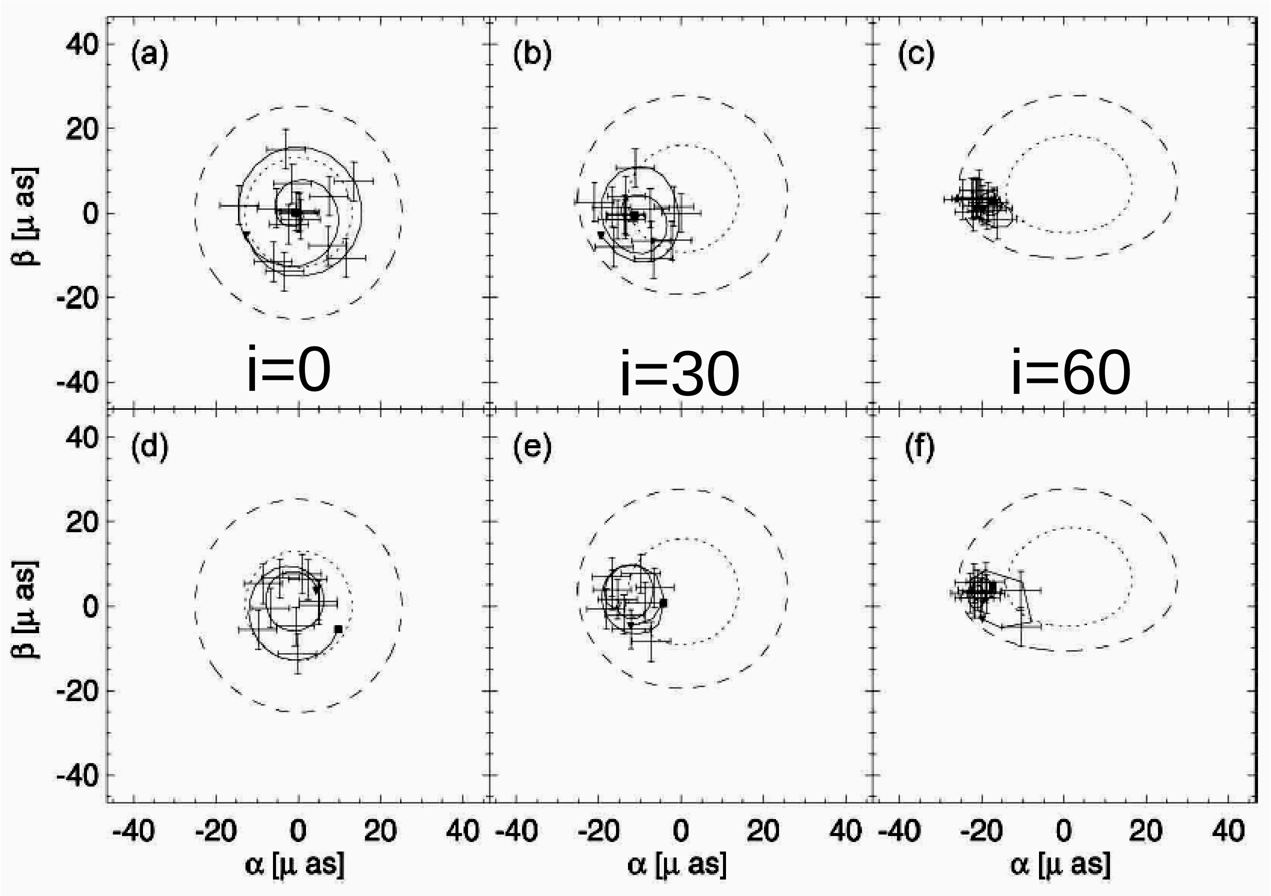
at times after 1/4T, 3/4T, 5/4T and 7/4T (left to right).



Zamaninasab et al. 2009

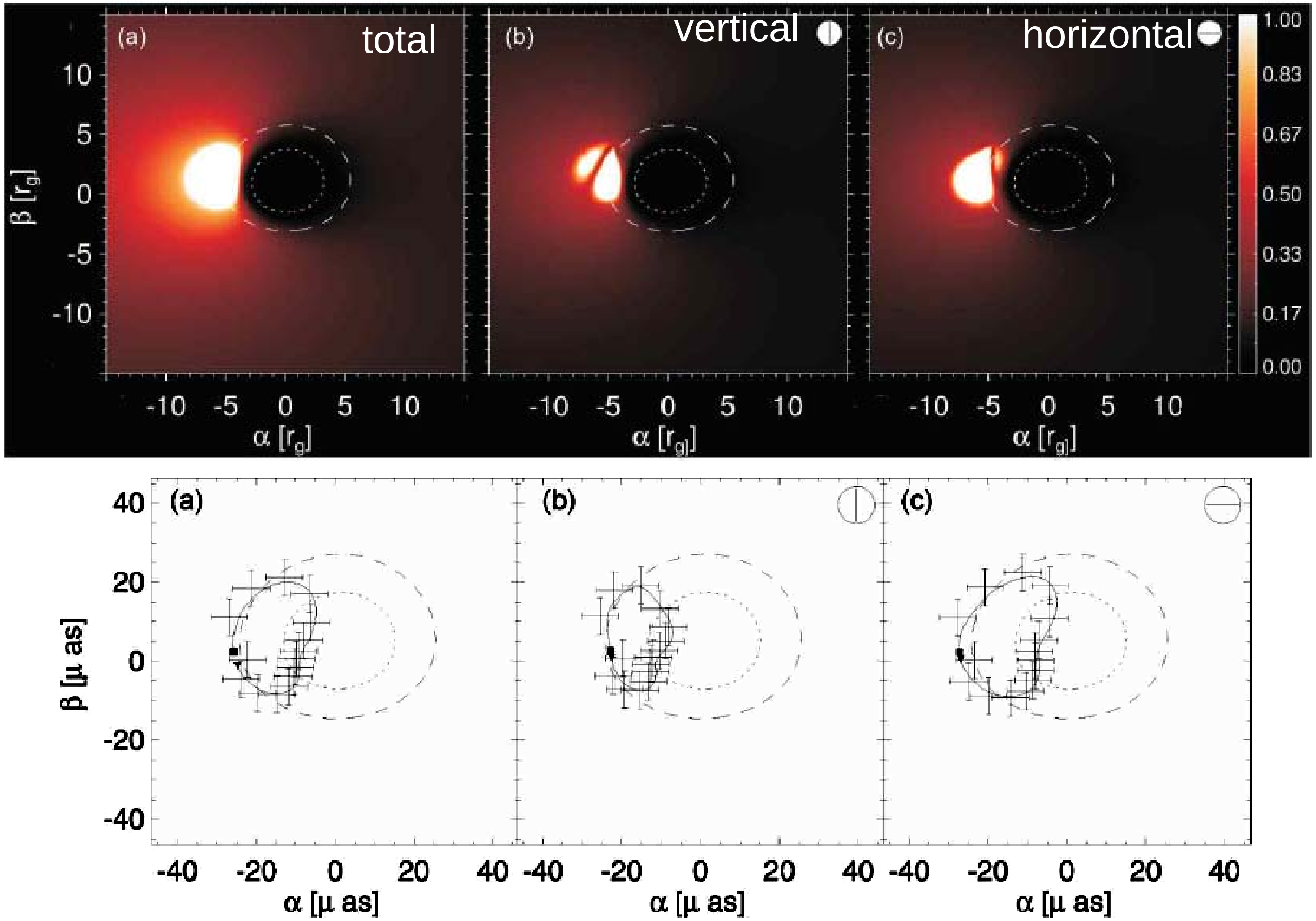
Spot evolution in a differentially rotating disk

The centroid motion of NIR images viewed at different inclinations for a Kerr black hole with a spin of 0.5.



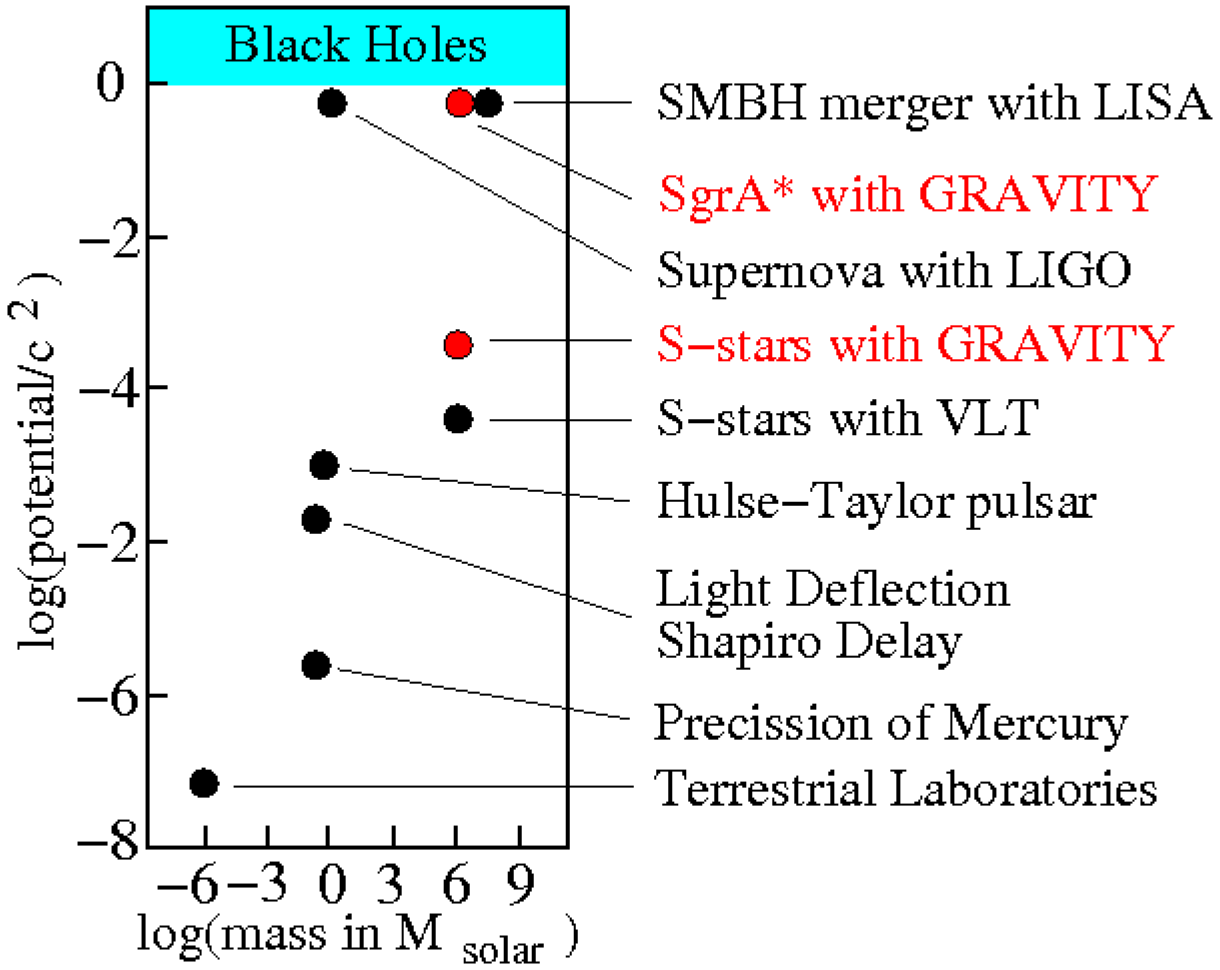
With (B) and without (A) background-subtracted images for a gravitational shearing time scale of 2.0.

Relativistic polarization modeling for SgrA*



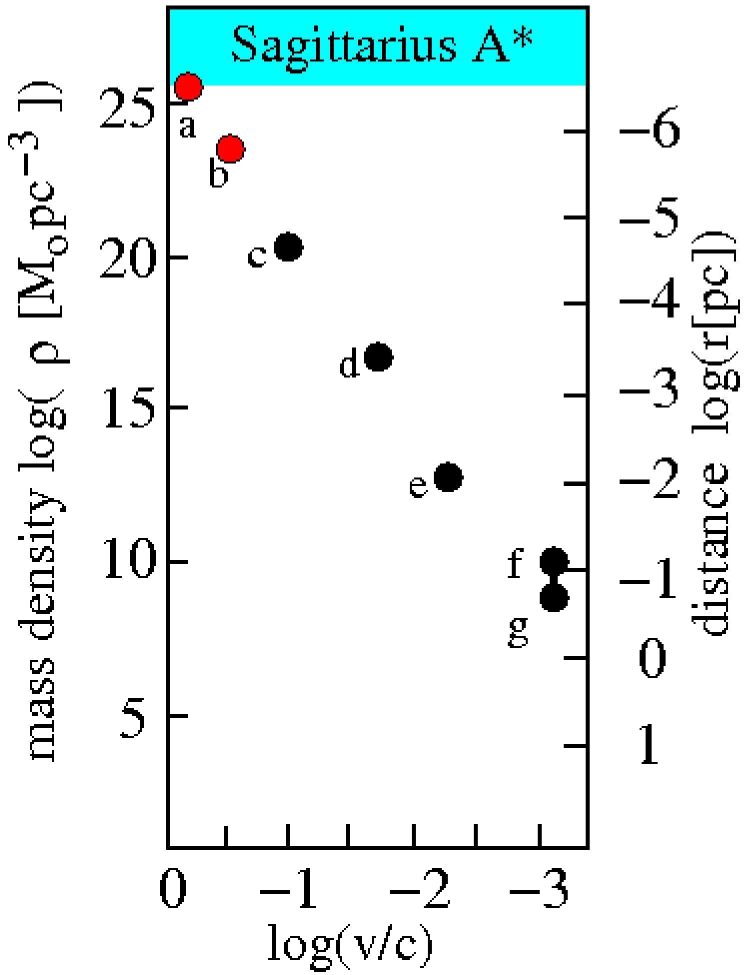
Apparent images and centroid measurements at i=45 inclination
in total flux (a), ordinary (b) and extra-ordinary polarized channels (c).

GRAVITY probes relativity in the GC



Psaltis (2004), Eisenhauer et al. (2008)

GRAVITY probes relativity in the GC



a 1 Rs: hot spot radius for a=1

b 3 Rs: hot spot radius for a=0

c possible disk size

d S−stars with GRAVITY

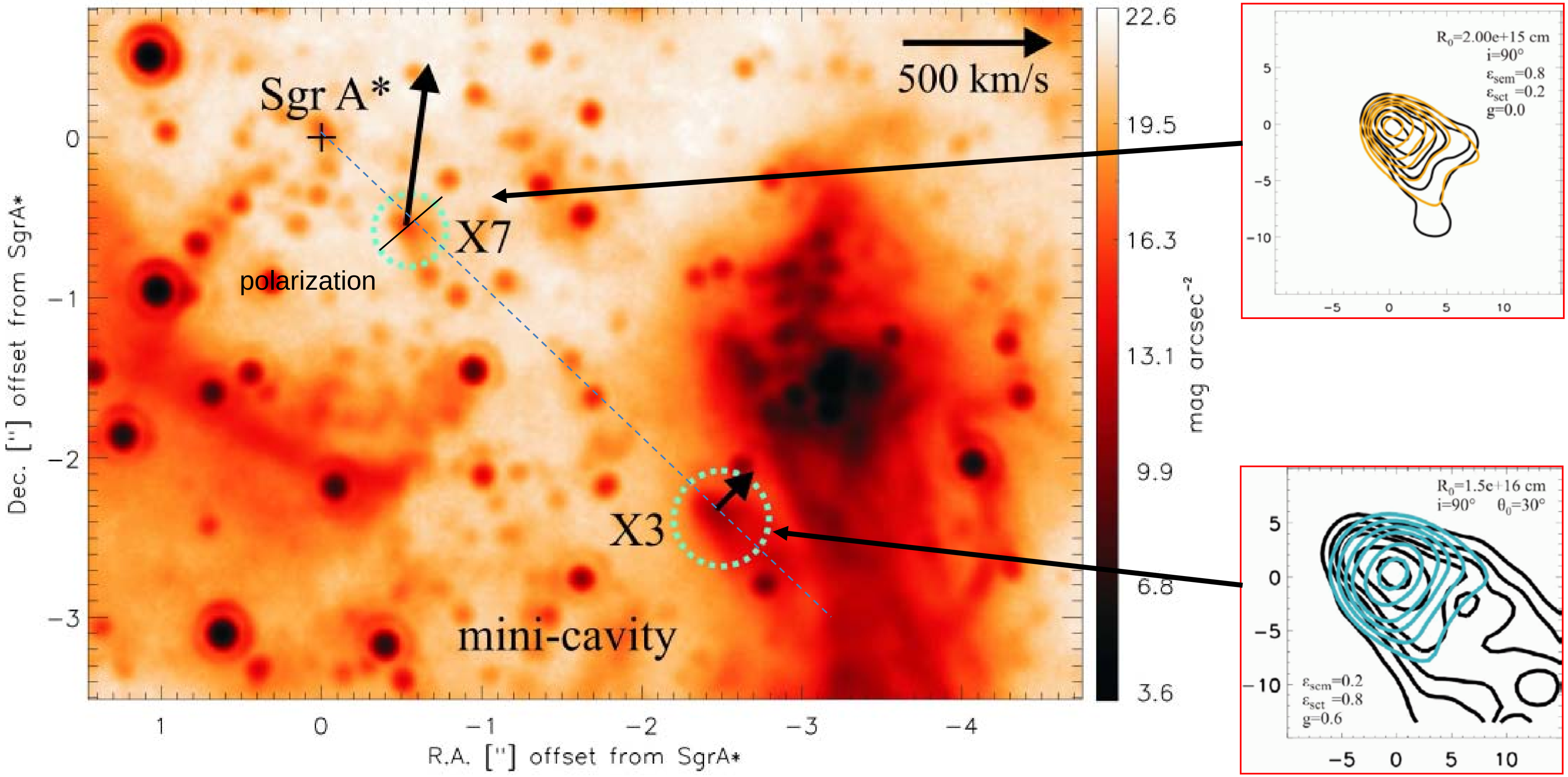
e S−stars with VLT

f He−stars

g min−spiral

Eckart et al. (2010)

Cometary Sources: Shaped by a wind from SgrA*?



X7 polarized with 30% at PA -34+-10
Mie → bow-shock symmetry along PA 56+-10
includes direction towards SgrA*

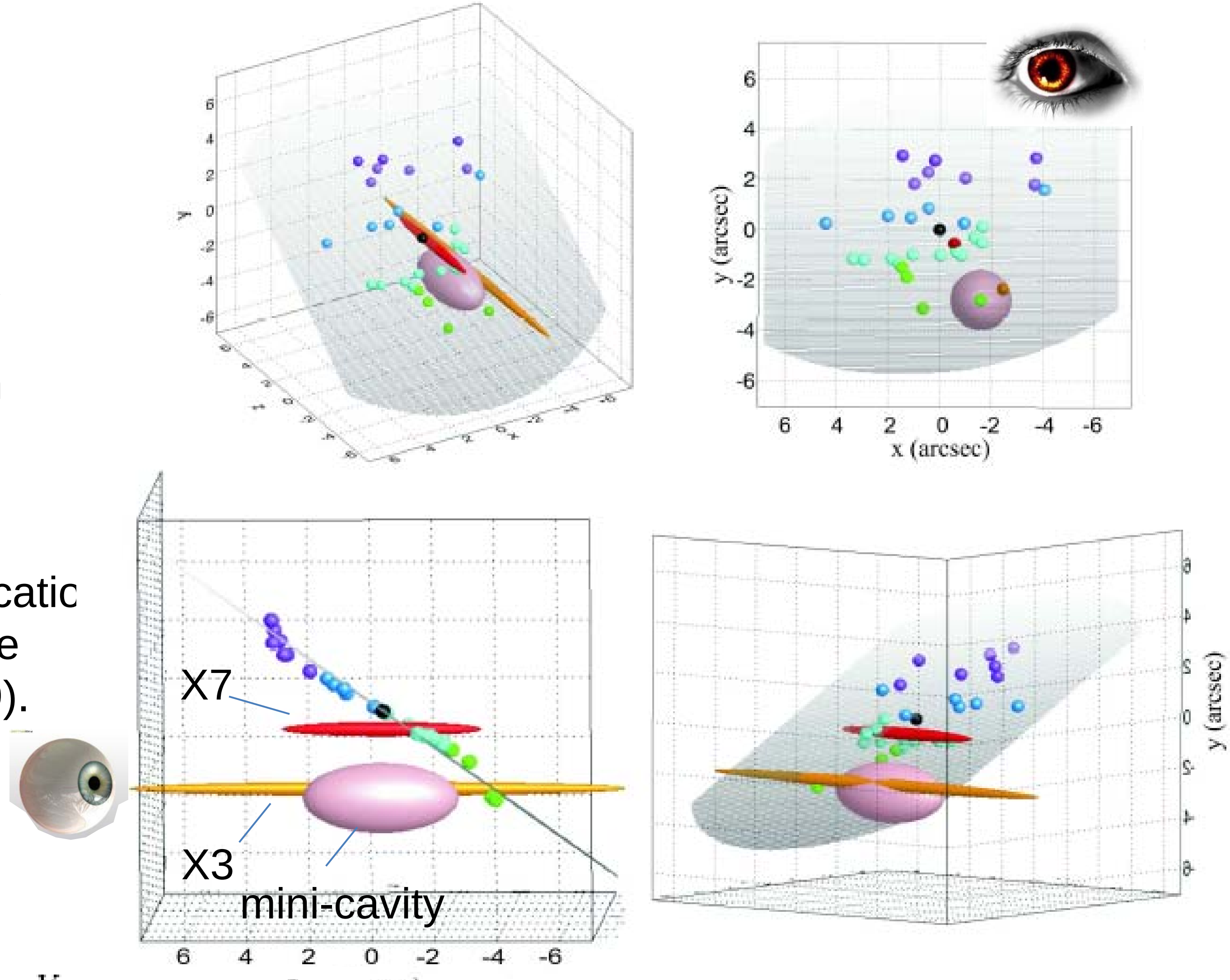
Besides the Mini-Cavity – the strongest indication for a fast wind from SgrA*!

Muzic,Eckart, Schödel et al. 2007, 2010

Cometary Sources: Source Location

At least X7 is located within +-3.2“ of the plane of the sky with a 67% probability.

However, X3 may be co-spatial with the locatic of the mini-cavity (see also Zhao et al. 2009).



$$P(V > V_{PM}, r) = 1 - \frac{1}{\sigma^2} \int_0^{V_{PM}} v \; exp\left(\frac{-v^2}{2\sigma^2}\right) dv$$

Muzic, Eckart et al. 2010

Examined stellar wind sources

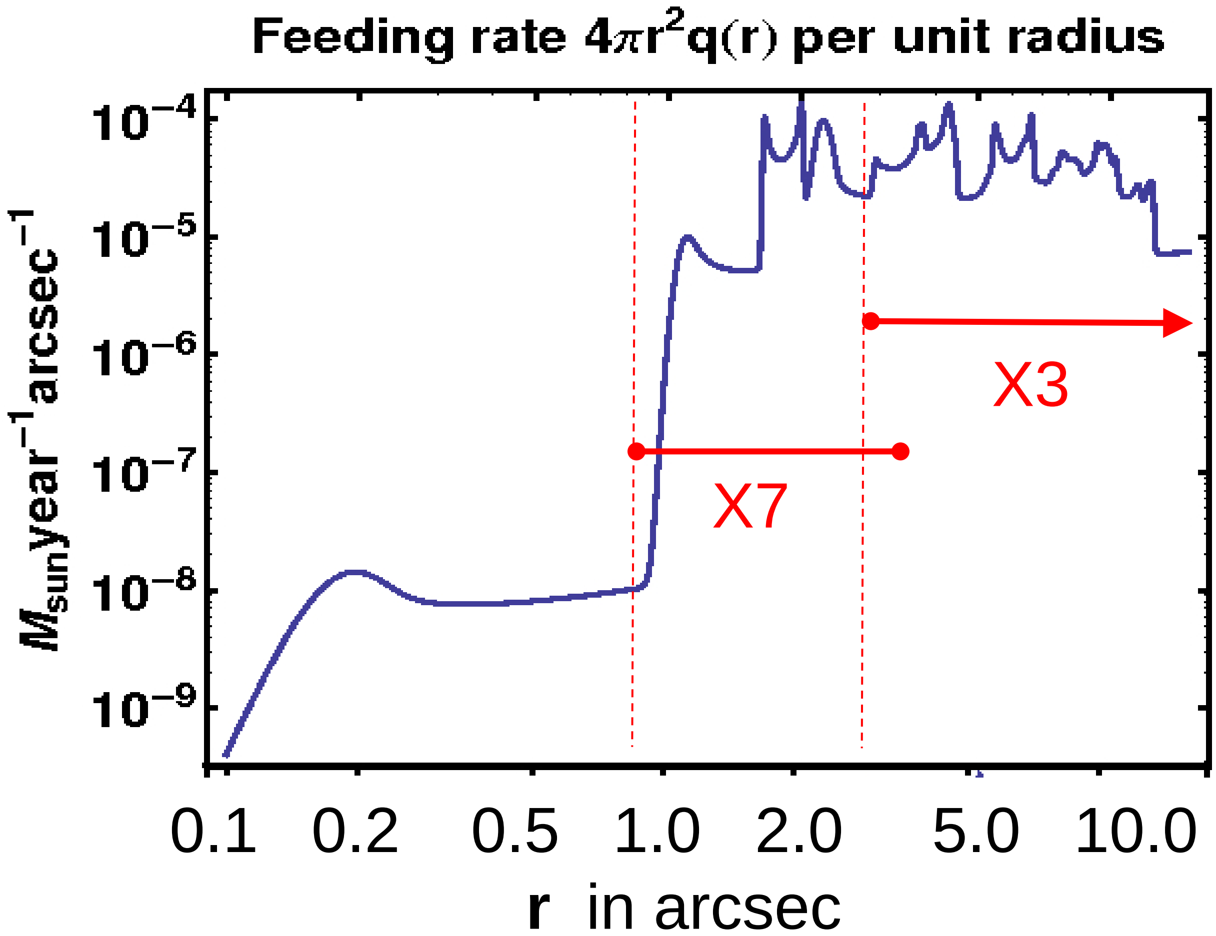
- Late B-type main sequence stars (B7-8V)
- Herbig Ae/Be stars
- Central stars of Planetary nebulae (CSPN)
- Low-luminosity Wolf Rayet (WR) stars (WC-type stars)
- Main sequence stars
- Dust-blob (X3, not X7)

Muzic, Eckart et al. 2010

Examined stellar wind sources

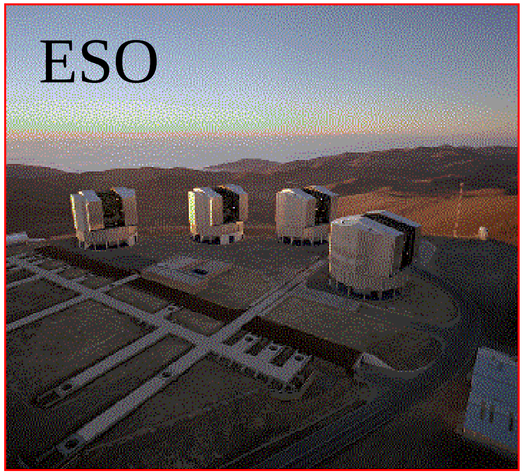
Not a wind from a single star of the GC young (He-)stars but only a collective wind from heavily mass loosing stars can potentially explain the bow-shock structure of X3 and X7.
However, such a global wind only emerges on scales of ~10“, where as the distance of X7 and X3 is only 0.8“ to 3.4“ and the fact that the bowshocks are elognated and point towards SgrA* is not explained.

Accretion onto SgrA*



Mass input into the feeding region around the BH on the upper panel. Square averaged wind velocity vw on the lower panel. Feeding is averaged over stellar orbits. Each wiggle represents a turning point of a single orbit. Only S02 star feeds matter within 0:8".

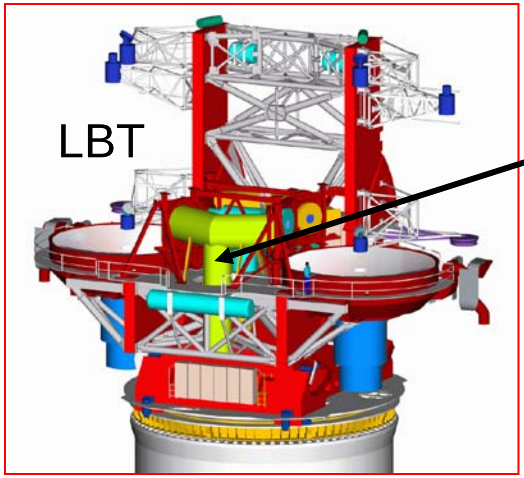
Shcherbakov & Baganoff ApJ, 2010



NL leads Euro-Team
University of Cologne
participation
METIS @ E-ELT

MPE, MPIA, Paris, SIM
University of Cologne
participation
GRAVITY @ VLTI

The Galactic Center is a unique laboratory in which one can study signatures of strong gravity with GRAVITY



NIR Beam Combiner:
University of Cologne
MPIA, Heidelberg
Osservatorio Astrofisico di Arcetri
MPIfR Bonn

Cologne
contribution to
MIRI on JWST