# Interactions between the SMBH SgrA* and its Environment

## *Central Massive Objects:*
## *The Stellar Nuclei – Black Hole Connection*
**2 2 – 25 June, ESO, Garching, Germany**

**Andreas Eckart**

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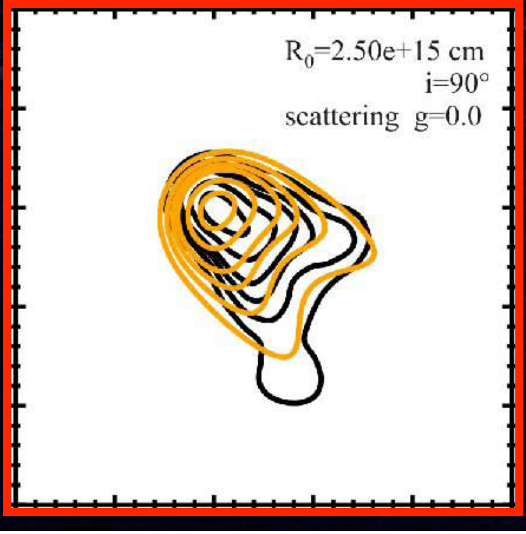
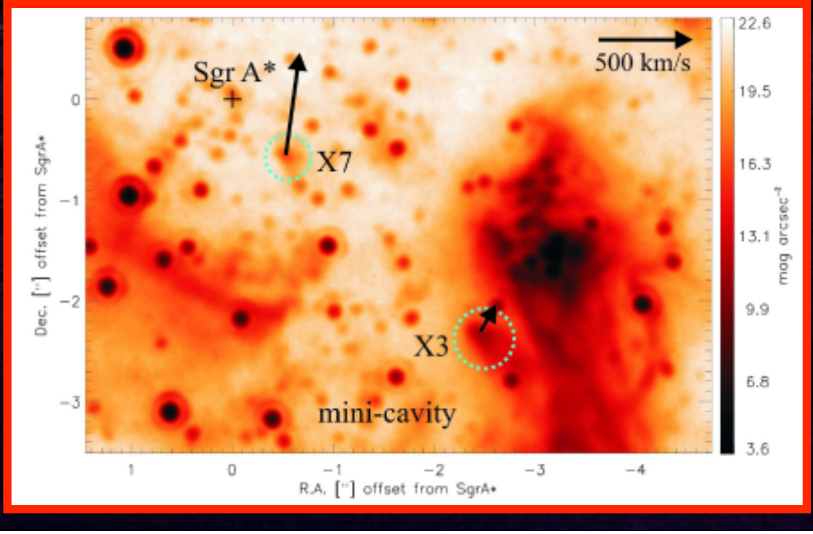
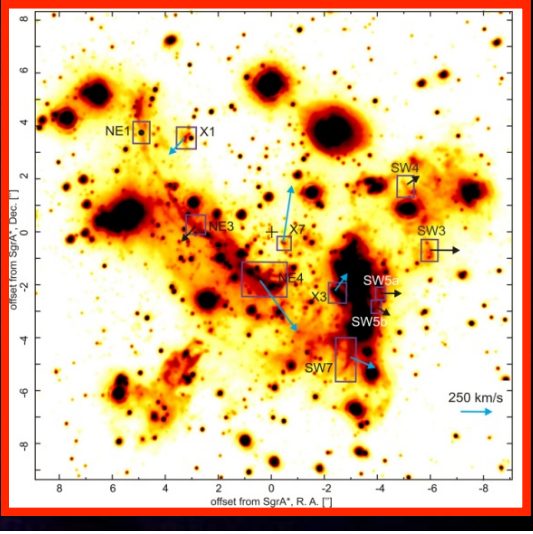
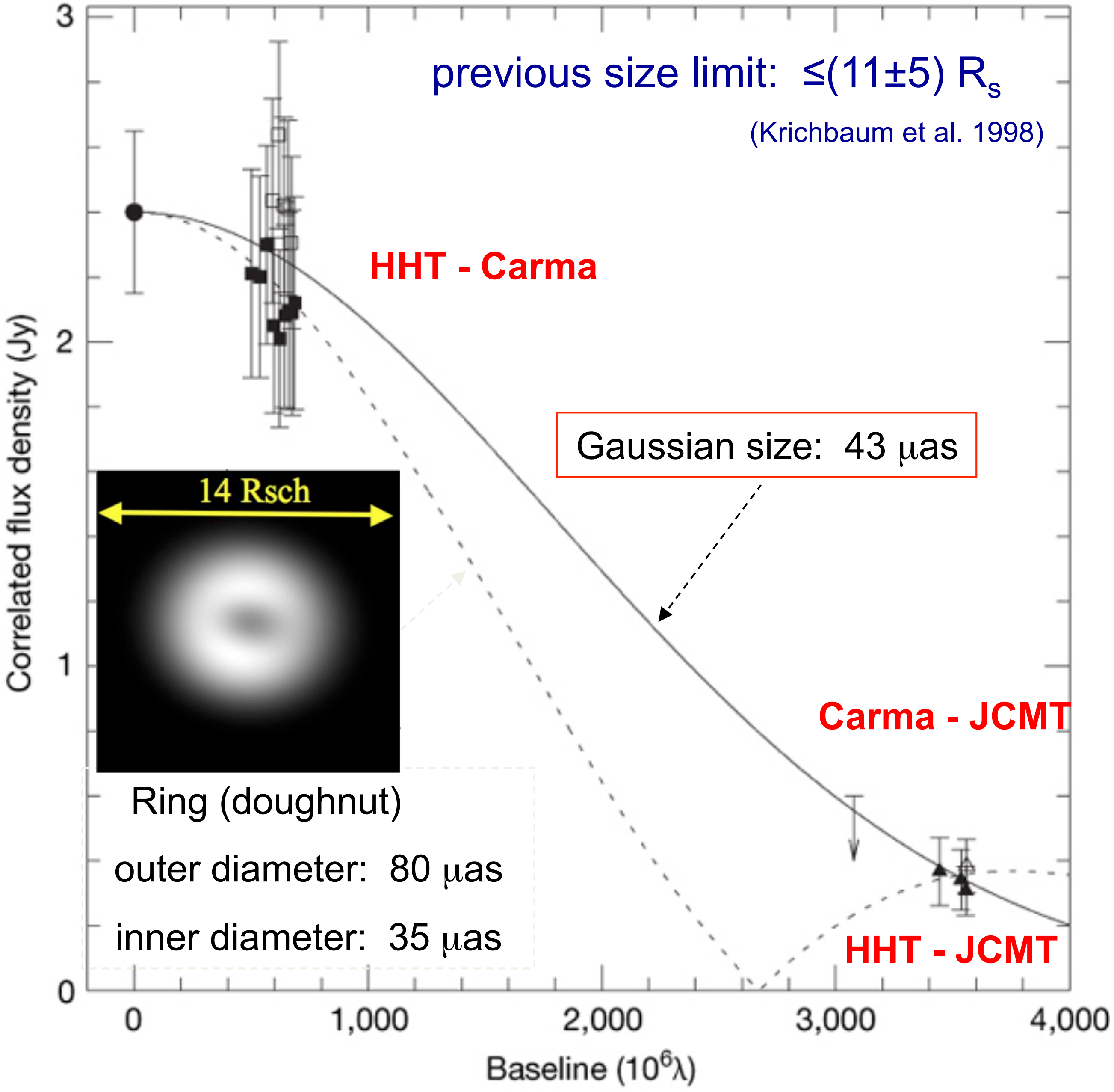
*Max-Planck-Institut für Radioastronomie, Bonn*







# VLBI at 230 GHz (1.3 mm wavelength)



previous size limit: ≤(11±5) $R_s$

(Krichbaum et al. 1998)

**HHT - Carma**

Gaussian size: 43 μas

**Carma - JCMT**

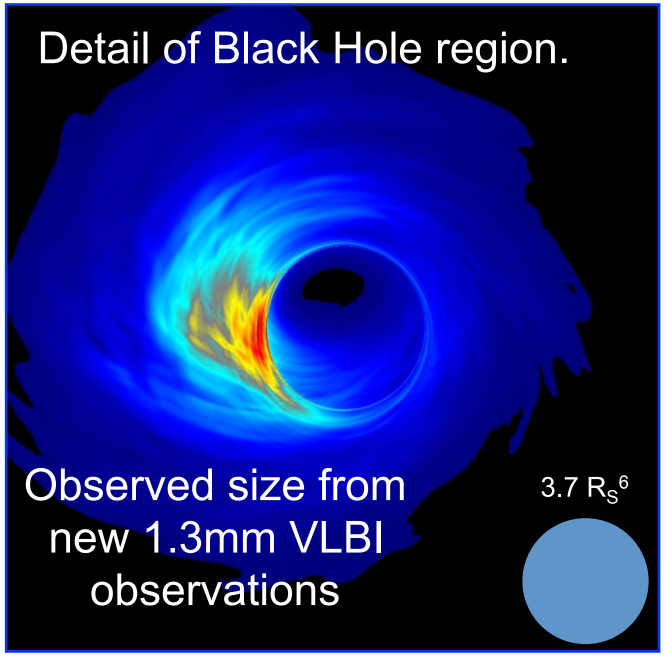
**HHT - JCMT**

Ring (doughnut)

outer diameter: 80 μas

inner diameter: 35 μas

Doeleman *et al.* *Nature* **455**, 78-80 (2008)



Detail of Black Hole region.

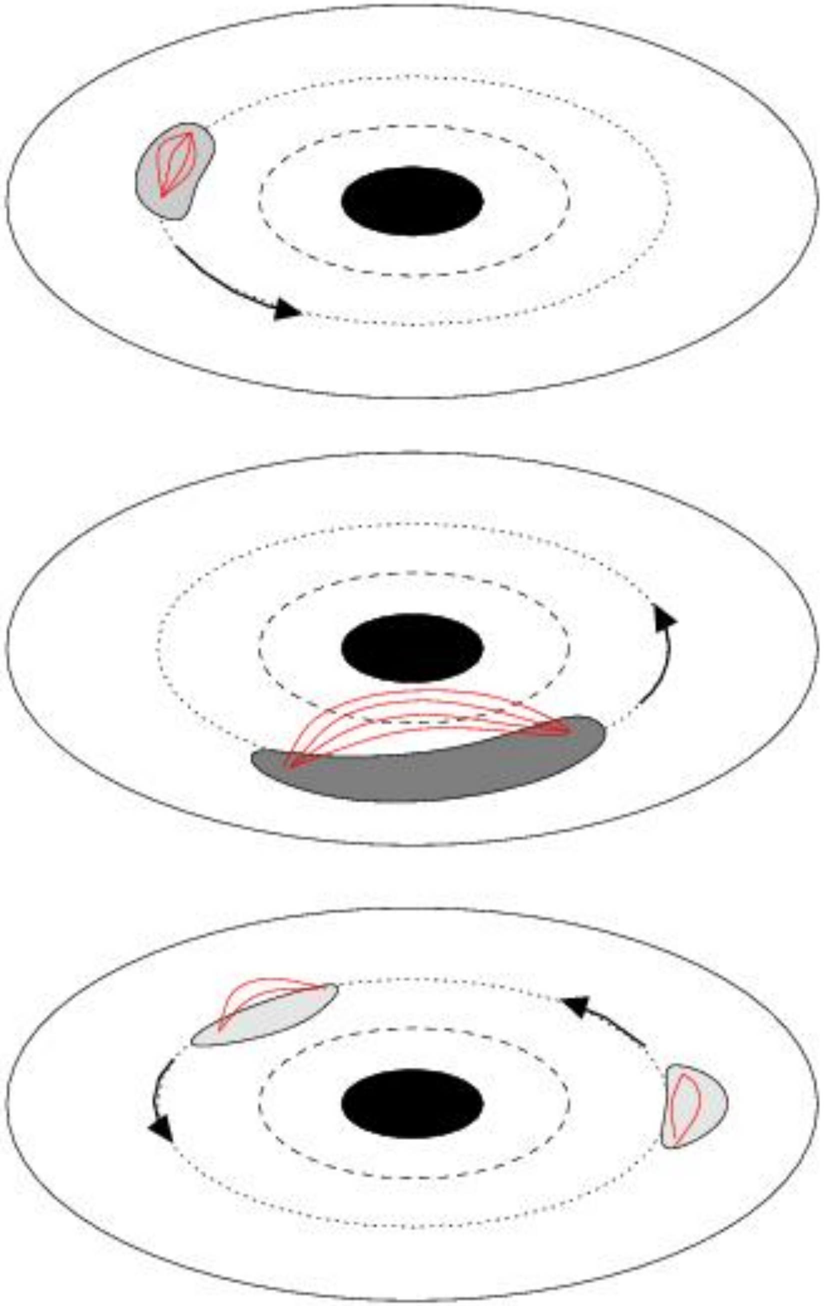
Observed size from new 1.3mm VLBI observations

observed size:

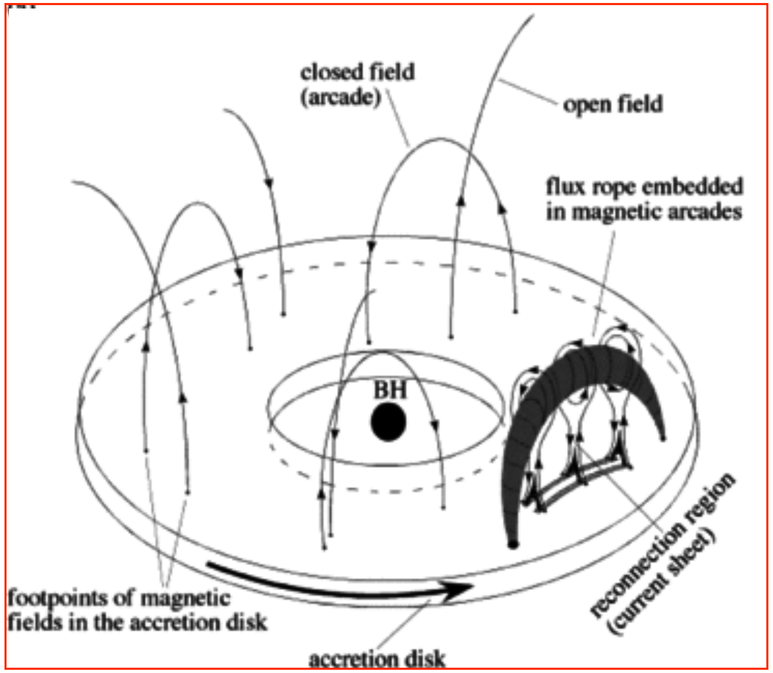
43 (+14/-8) μas

deconvolved :

37 μas (3.7 $R_S$)



Yuan et al. 2009, Balbus & Hawley 1998, Balbus 2003



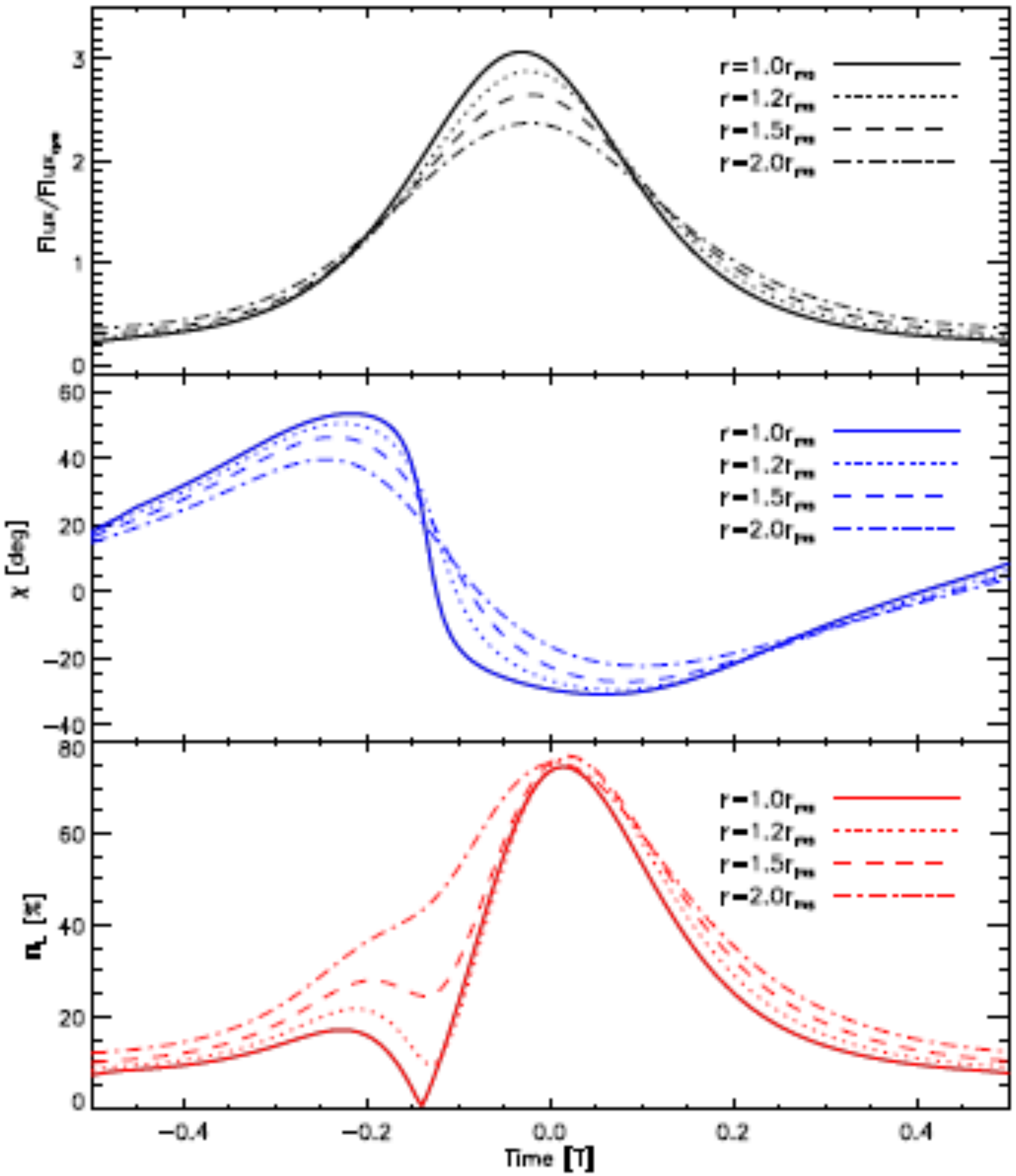
Yuan et al. 2009

# Adiabatic Expansion of Source Components in the Temporary Accretion Disk of SgrA*

● Black Hole
– – – – – Last stable orbit
········ reference orbit
—— magnetic field lines
—— outer edge of disk

Eckart et al. 2008, ESO Messenger
Eckart et al. 2009, A&A 500, 935

# Pattern of a NIR spot orbiting at the ISCO



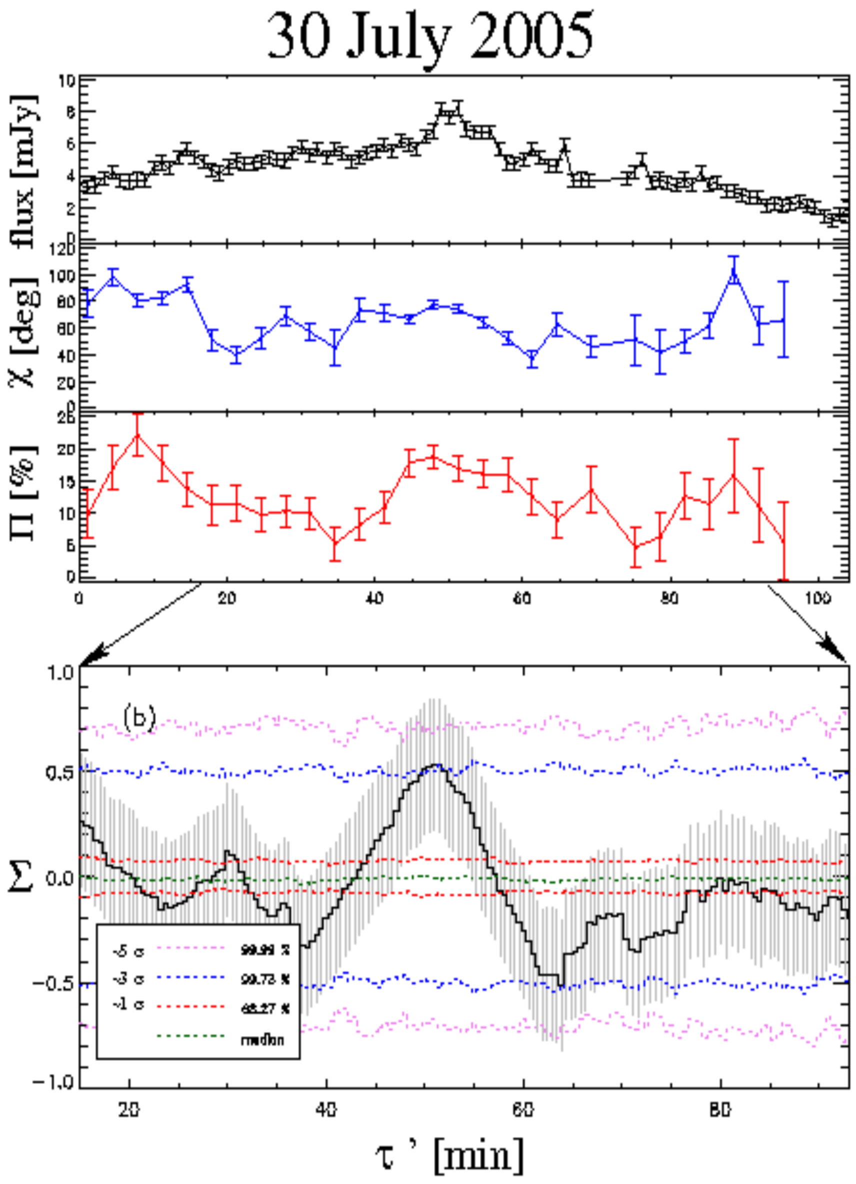
total intensity

polarization angle

polarization degree

Zamaninasab et al. 2009

# Pattern recognition against polarized red noise



total intensity

polarization angle

polarization degree

5σ

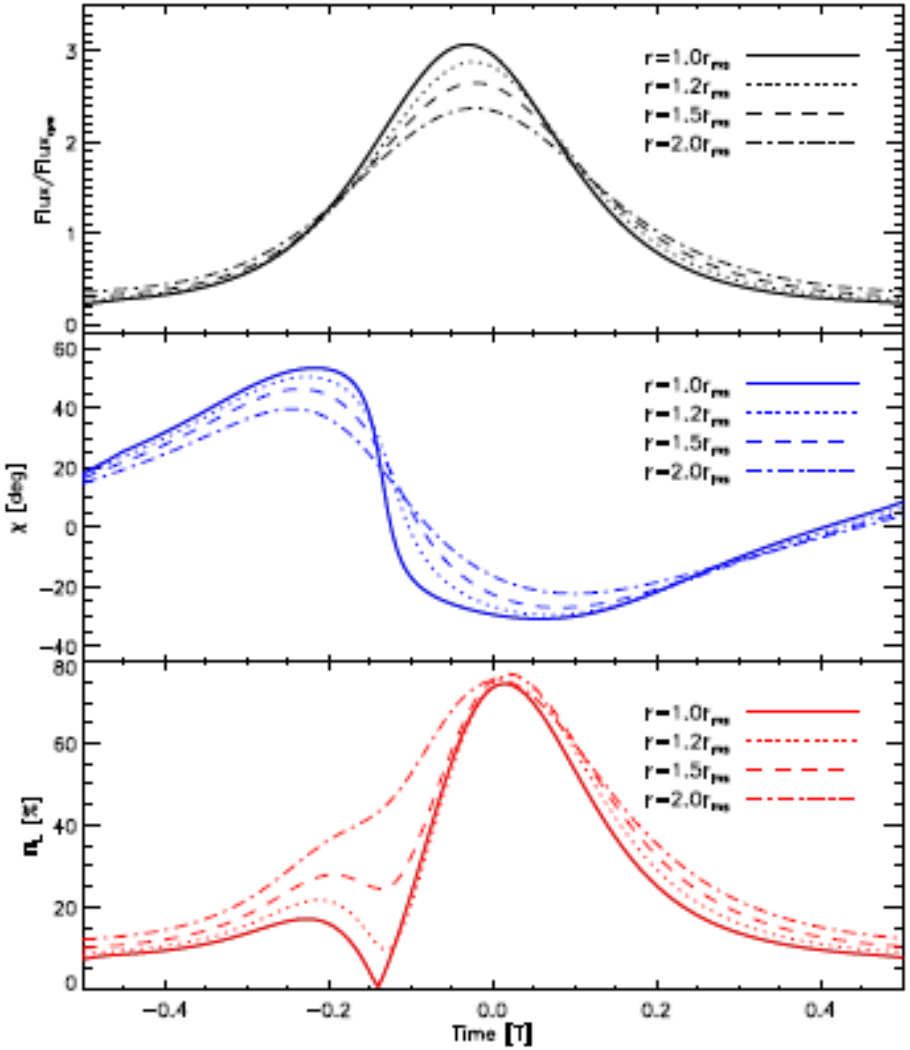
3σ

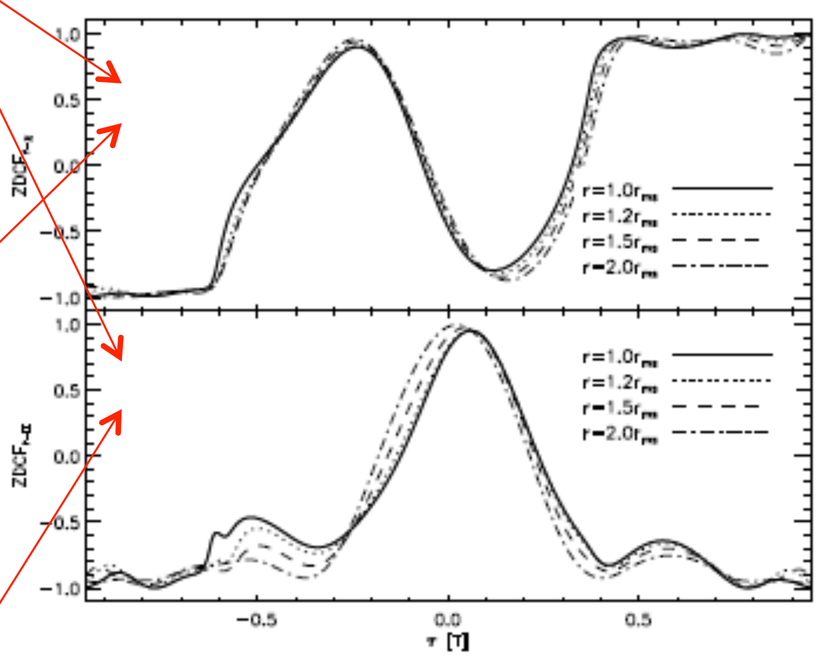
1σ

mean

Zamaninasab et al. 2009

# Pattern of a spot orbiting at the ISCO





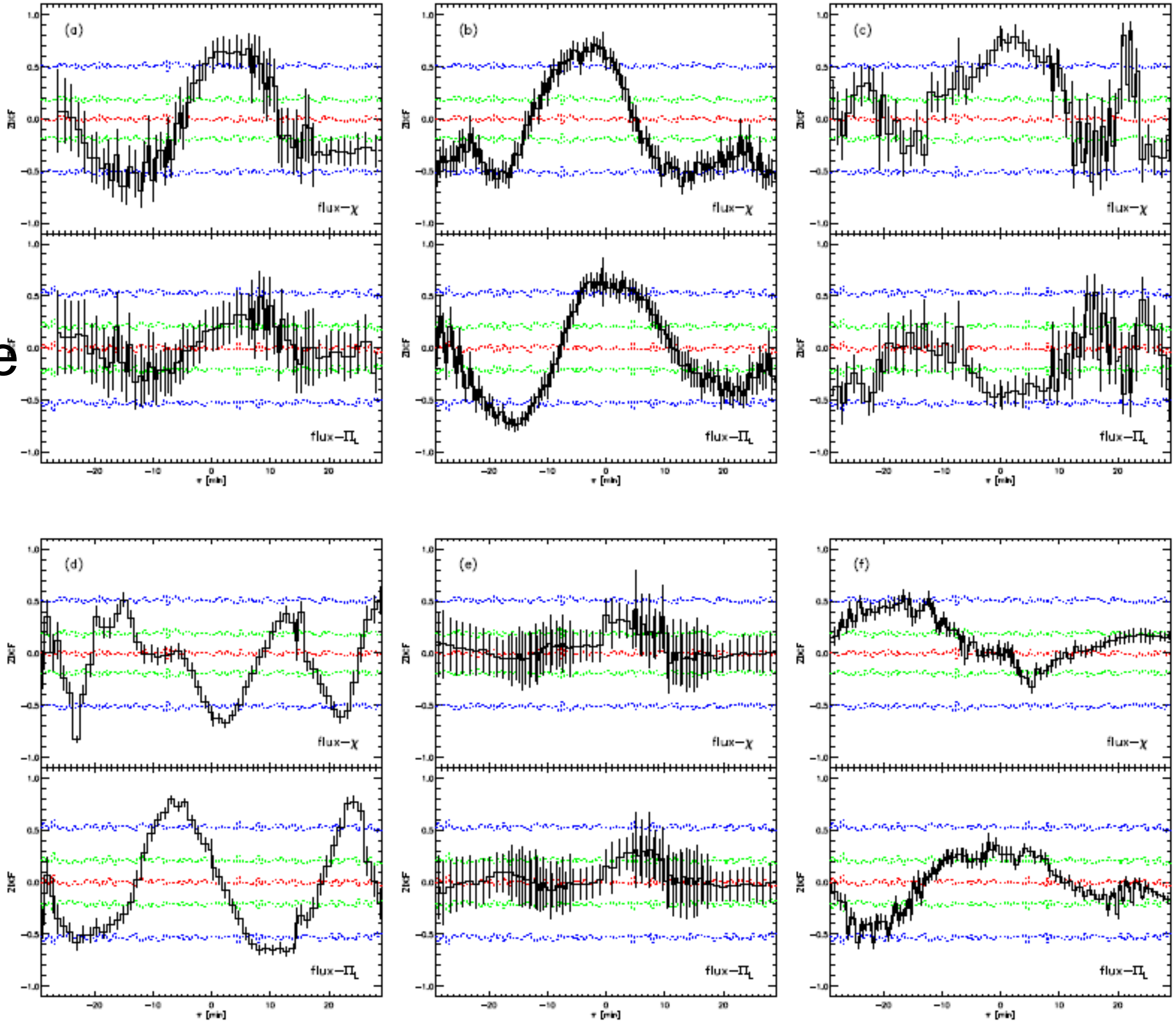
Cross-correlations

Zamaninasab et al. 2009

# Pattern recognition against polarized red noise

flux and angle

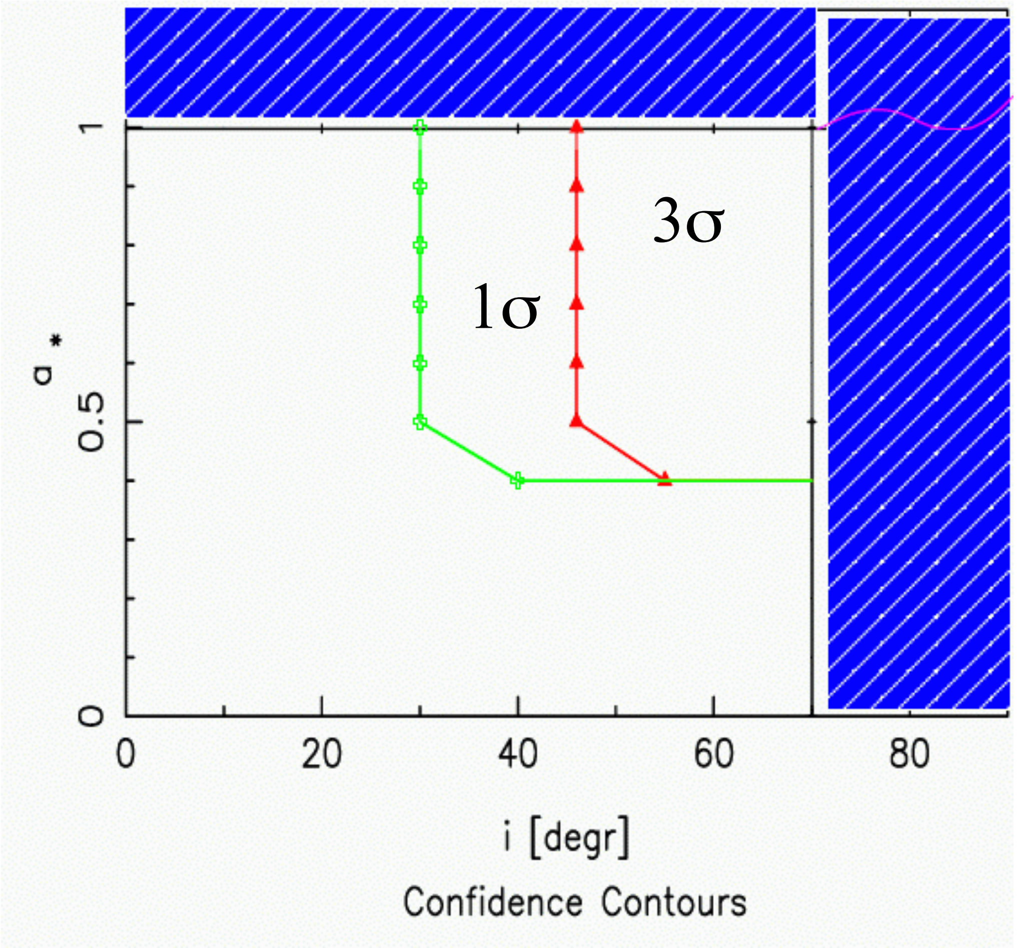
flux and degree



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*

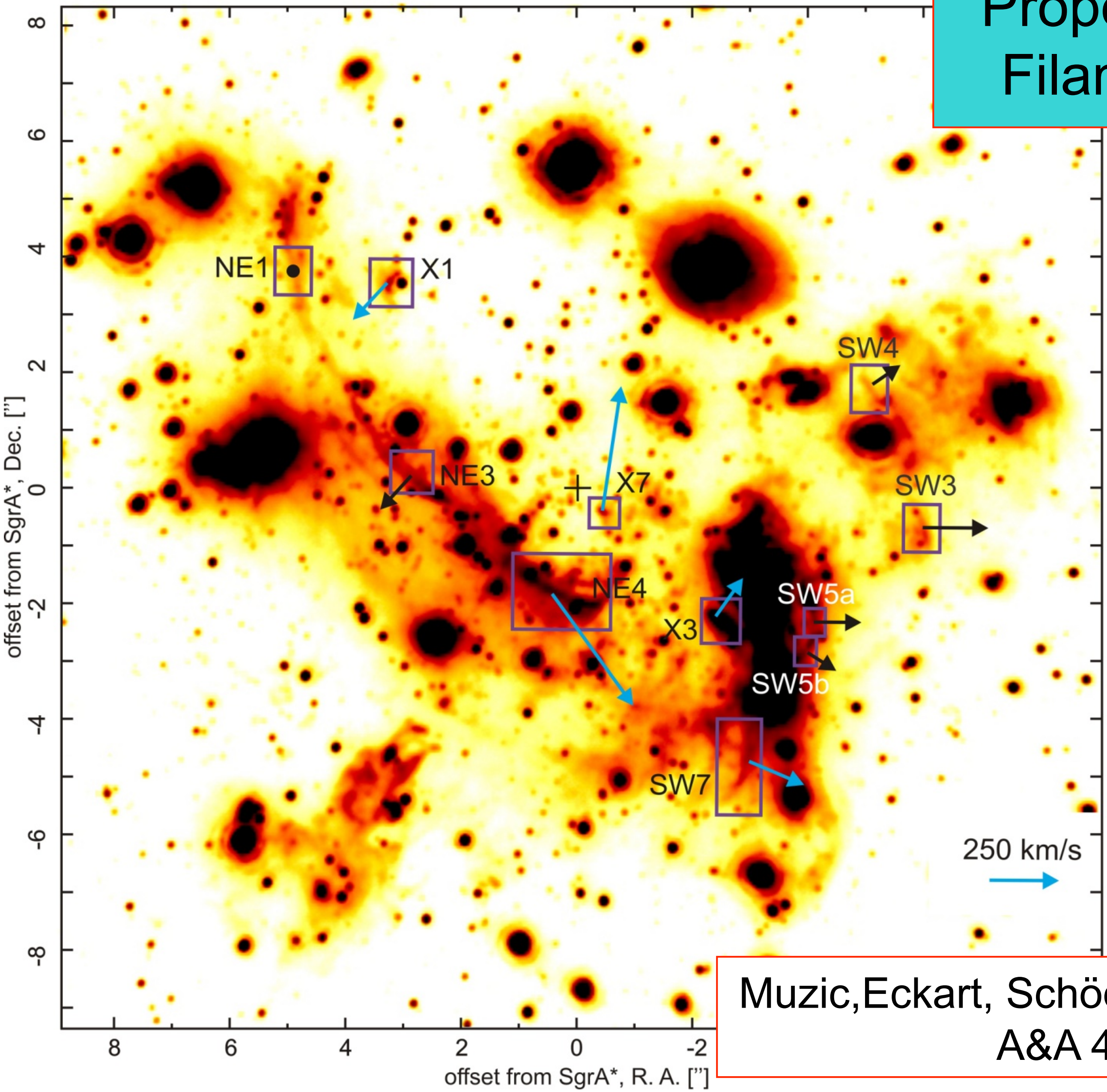


$\chi^2$ analysis indicates
a= 0.4-1
i=50$^{o}$-70$^{o}$

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

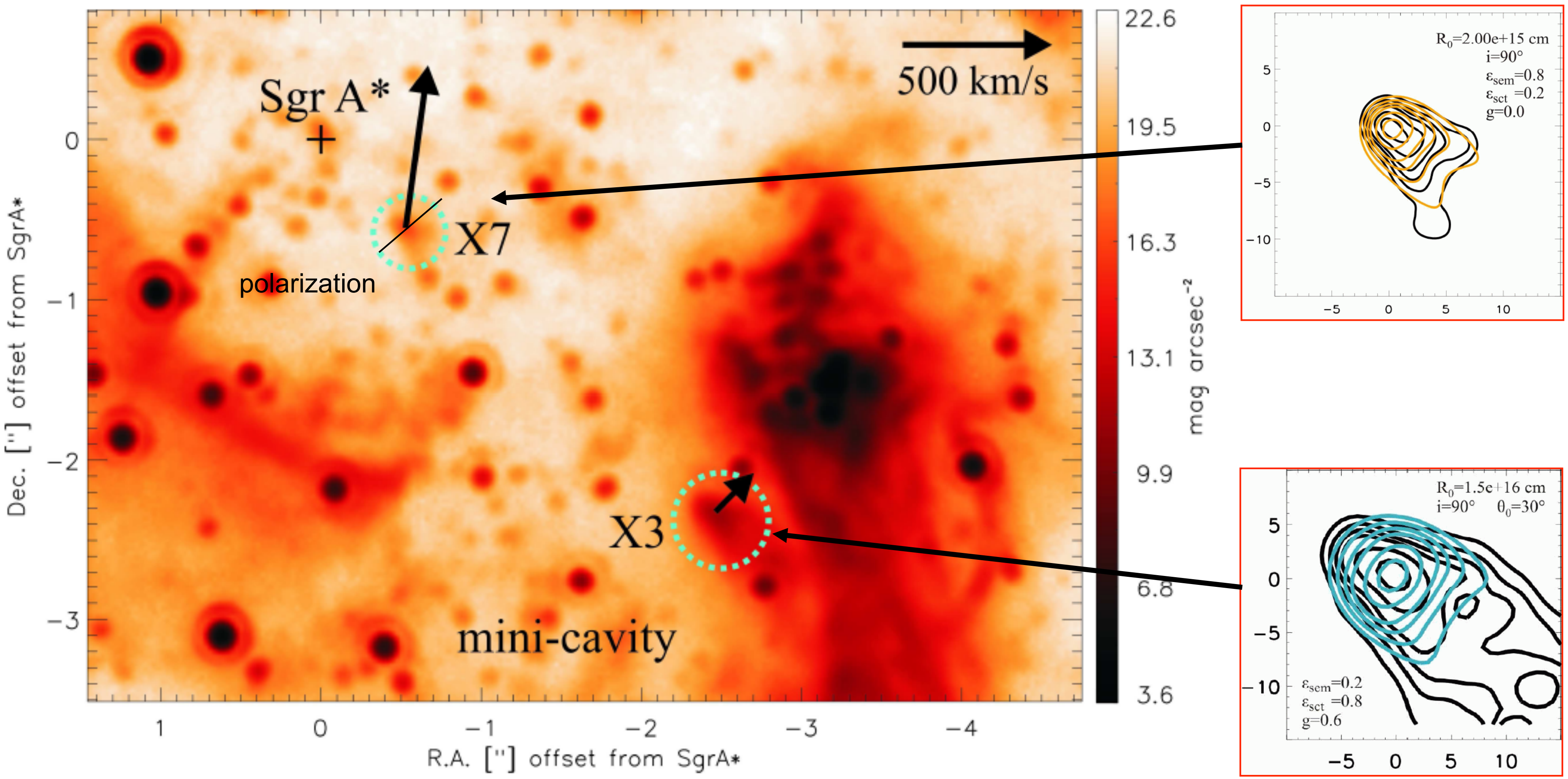
~4min prograde
~30min static
for 3.6x10**6Msol

# Proper Motion of Thin Filaments at the GC



Muzic,Eckart, Schödel, Meyer et al. 2007
A&A 469, 993

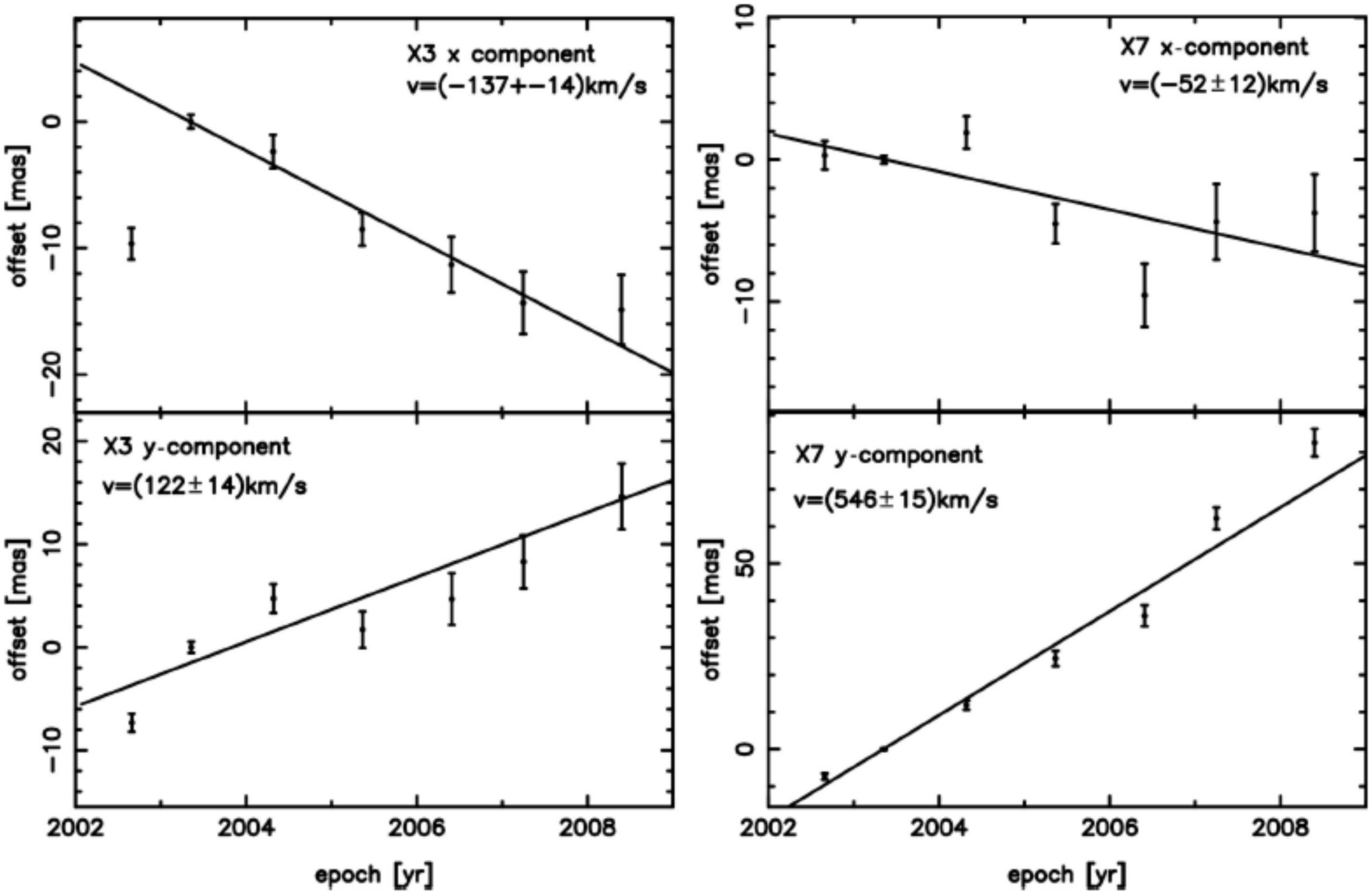
# Cometary Sources: Shaped by a Wind from SgrA*?



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

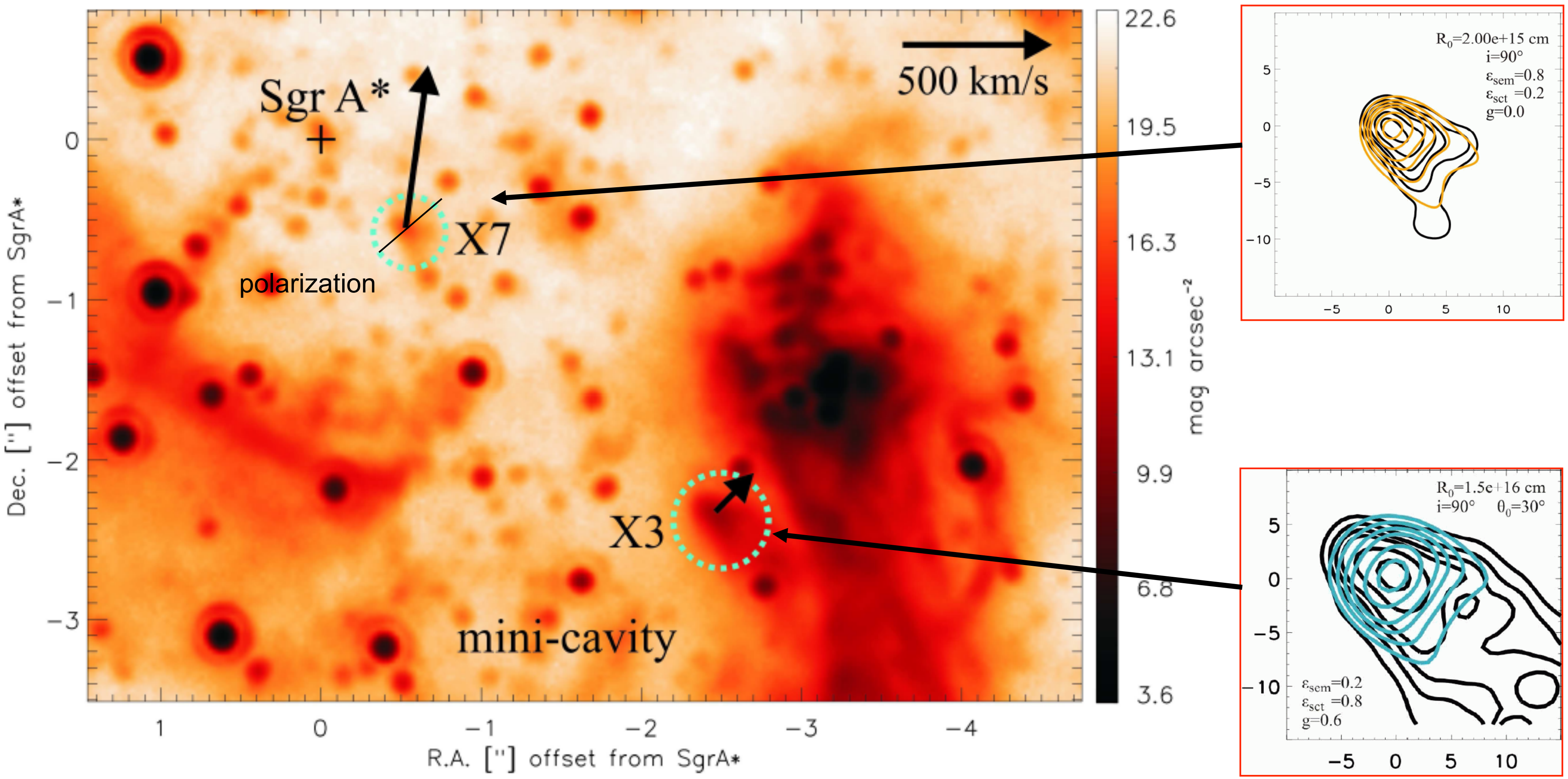
Muzic, Eckart et al. 2007, 2009, 2010

# Cometary Sources: Proper Motions



Muzic, Eckart et al. 2010

# Cometary Sources: Shaped by a Wind from SgrA*?



X7 polarized with 30% at PA -34+-10
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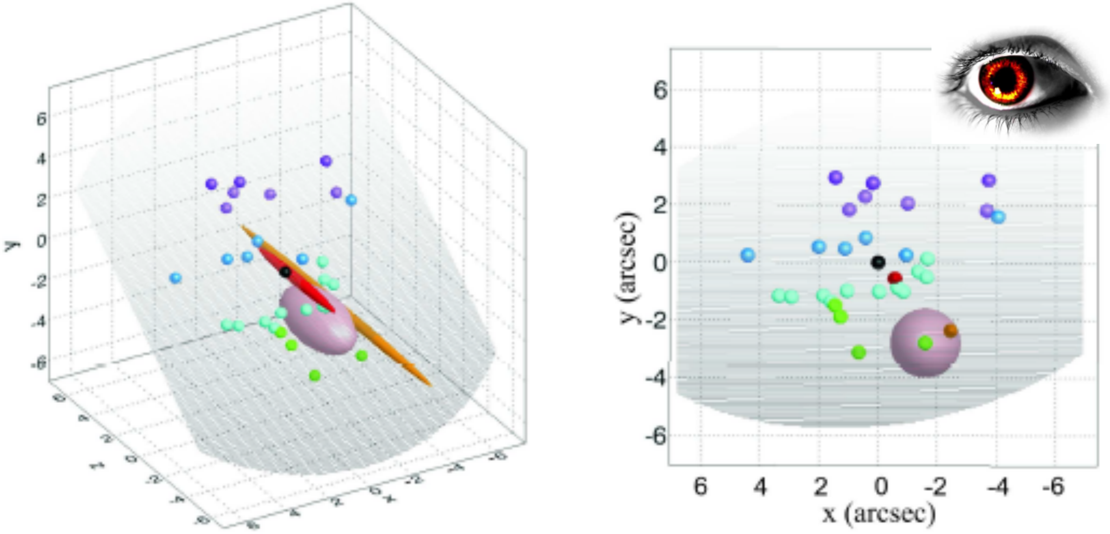
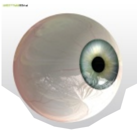
Muzic, Eckart et al. 2007, 2009, 2010

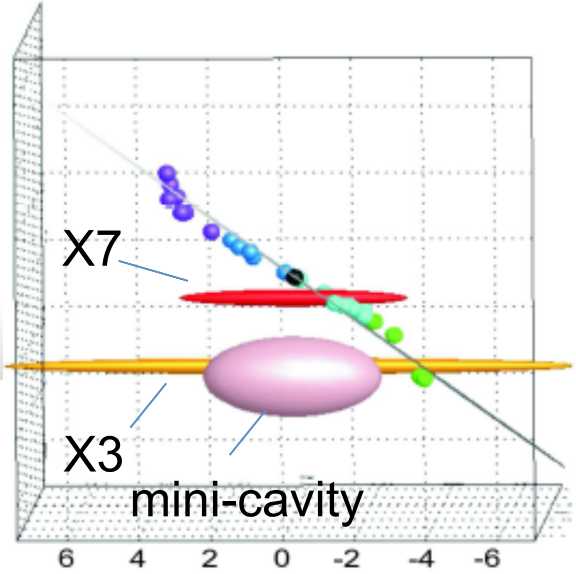
# Cometary Sources: Source Location

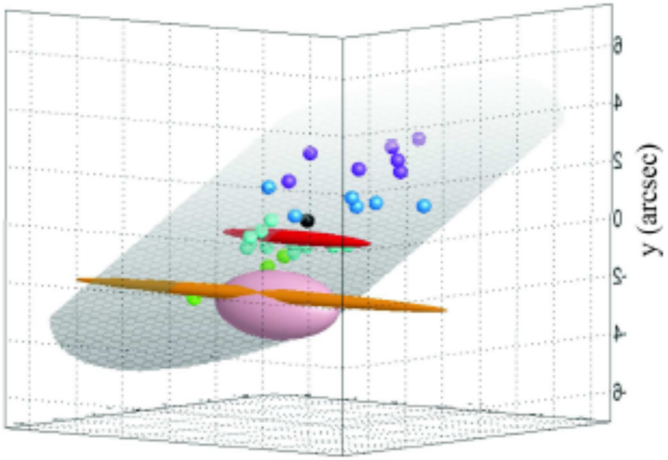


At least X7 is located within +-3.2“ of the plane of  the sky with a 67% probability.

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



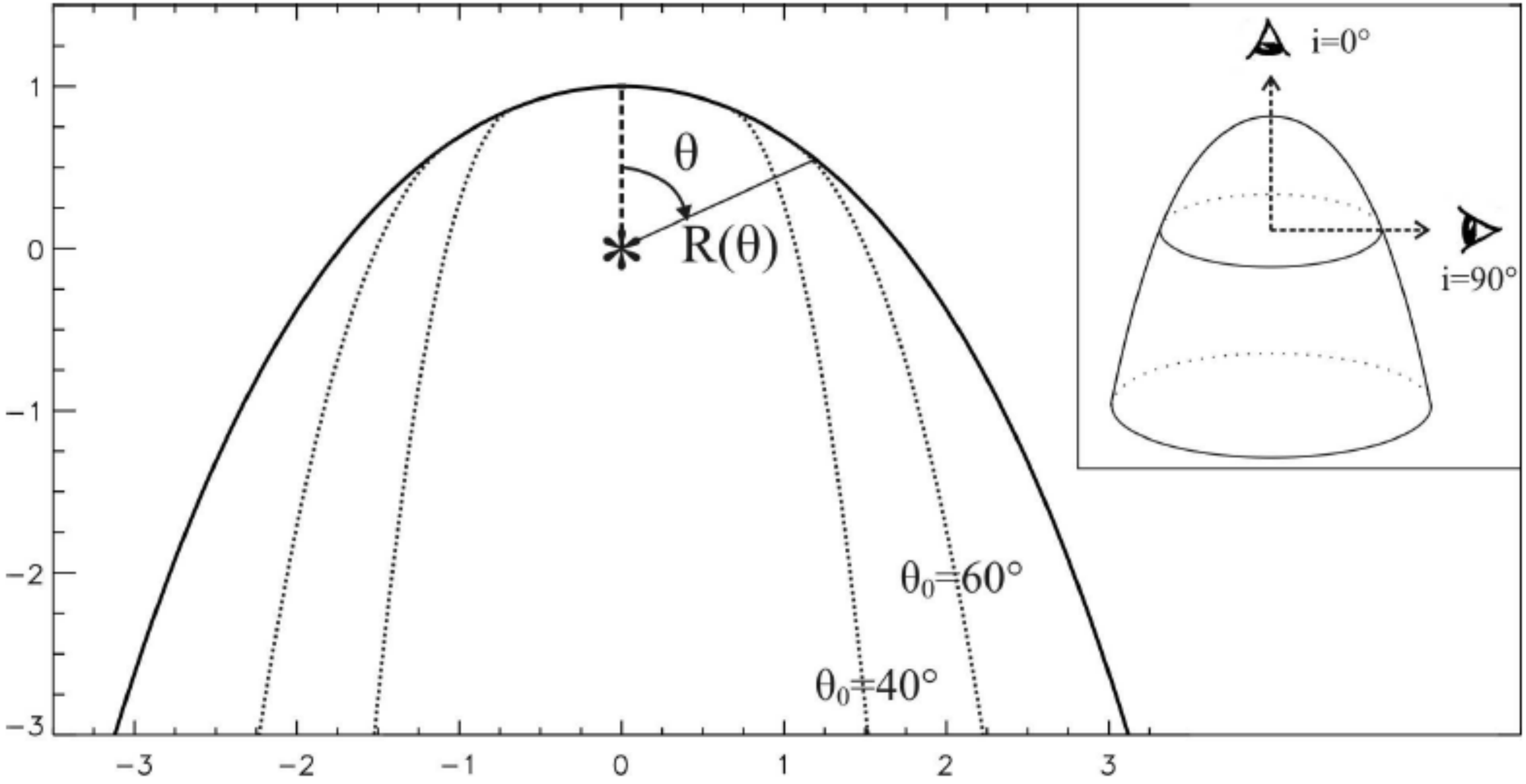




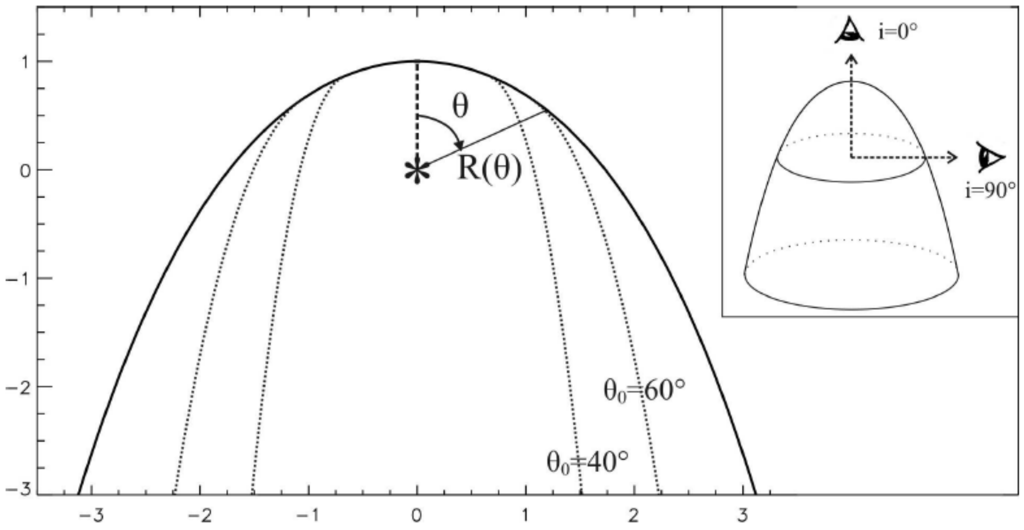
$$P(V > V_{PM}, r) = 1 - \frac{1}{\sigma^2}\int_0^{V_{PM}} v \; exp\left(\frac{-v^2}{2\sigma^2}\right) dv$$

Muzic, Eckart et al. 2010

# Cometary Sources: Wind modeling



# Cometary Sources: Wind modeling



Bow-shock shape

$$R(\theta) = R_0 \csc\theta \sqrt{3(1-\theta\cot\theta)}$$

standoff distance

of the **shock f**rom the star

$$R_0 = \sqrt{\frac{\dot{m}_w v_w}{\Omega \rho_a v_a^2}} \qquad \Omega = 2\pi(1-\cos\theta_0)$$

optical depth throughout the shock

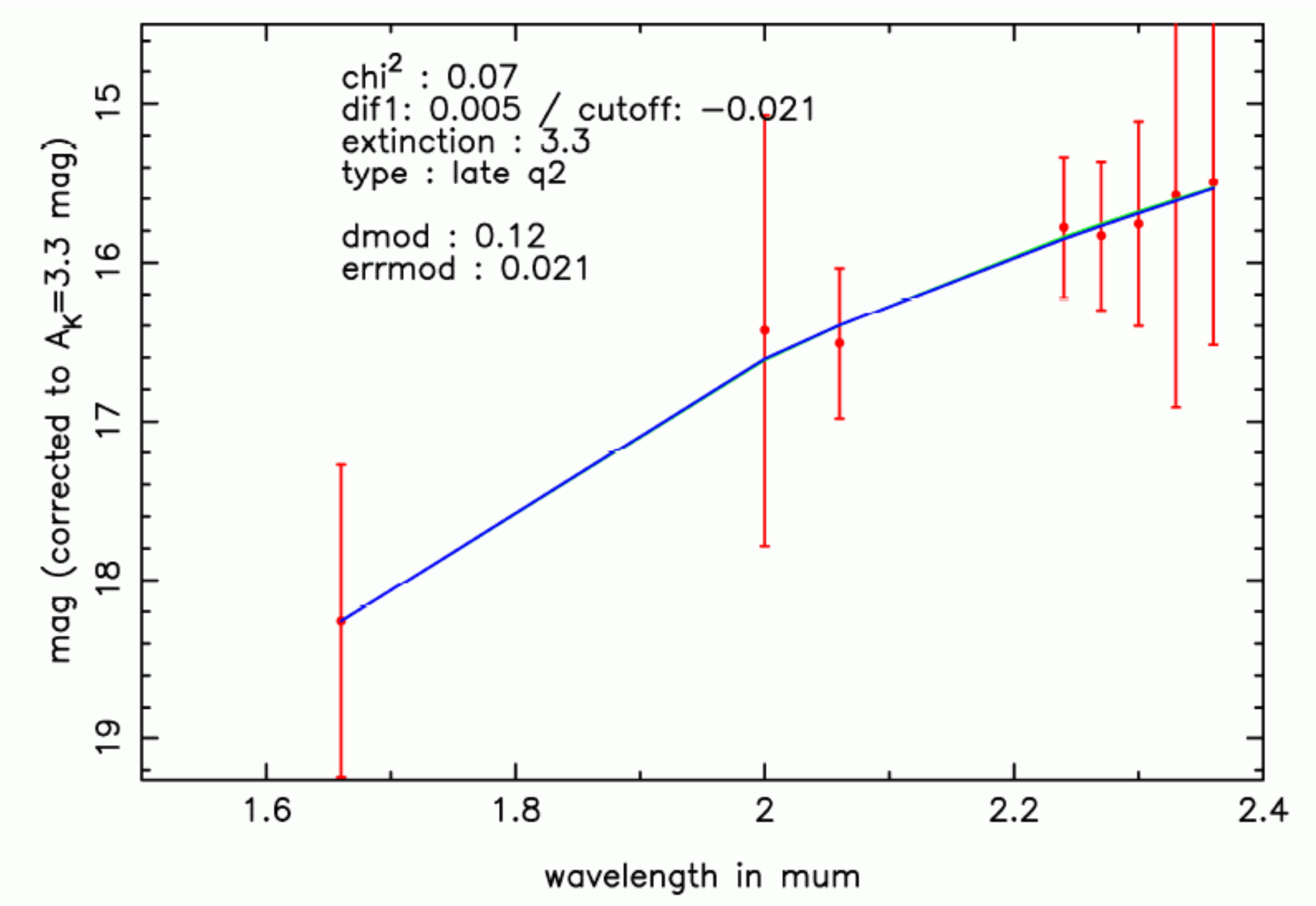
$$\tau(\lambda) = \tau_{abs}(\lambda) + \tau_{sca}(\lambda) = L\int_{a_-}^{a_+} n_d(a) C_{ext}(a,\lambda)\,da$$

extinction coefficient

$$C_{ext} = \pi a^2 (Q_{abs} + Q_{sca})$$

# Cometary Sources: Wind modeling

X7



# 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

# Cometary Sources: Wind modeling

Luminosity from
emission and scattering

$$L = L_{sca} + L_{th}$$

$$L_{th} \propto B(T_d)(1 - e^{-\tau_{abs}})\epsilon_{th}$$

$$L_{sca} \propto \mathrm{d}^{-2}\epsilon_{sca} P(\theta_{sca}) e^{-\tau_{sca}}$$

dust temperature close
to the central star
(VanBuren & McCray 1988; Krügel 2003)

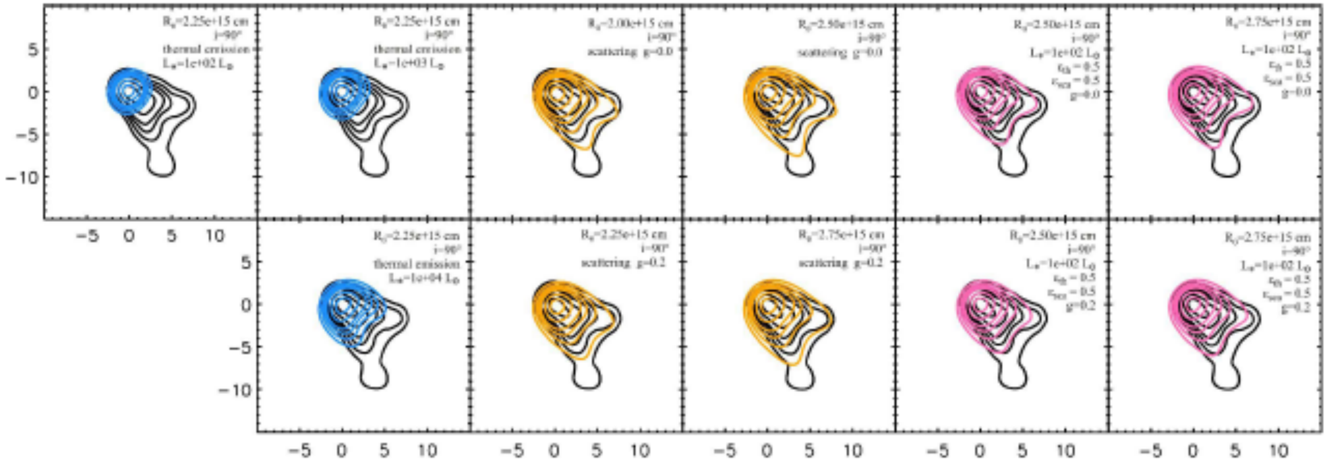
$$T_d = 27\, a_{\mu m}^{-1/6}\, L_{*,38}^{1/6}\, d_{pc}^{-1/3}\, \mathrm{K}$$

normalized scattering
function

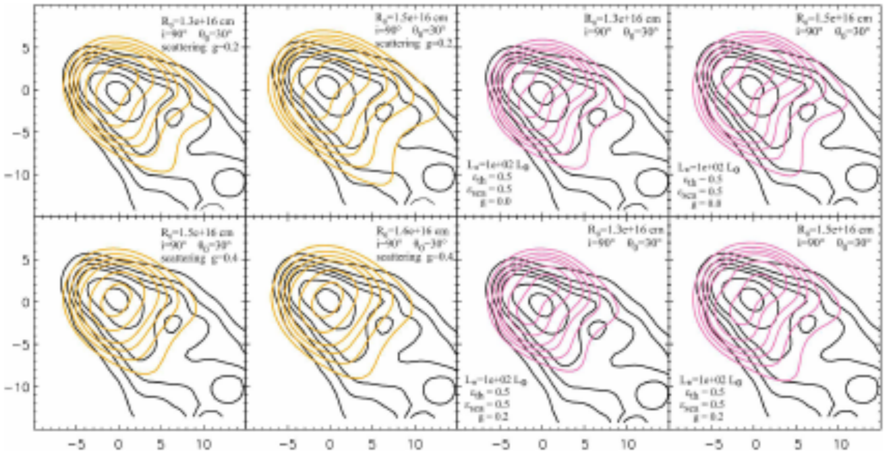
$$P(\theta_{sca}) = \frac{1 - g^2}{1 + g^2 - 2g cos(\theta_{sca})}$$

# Cometary Sources: Wind modeling

X7

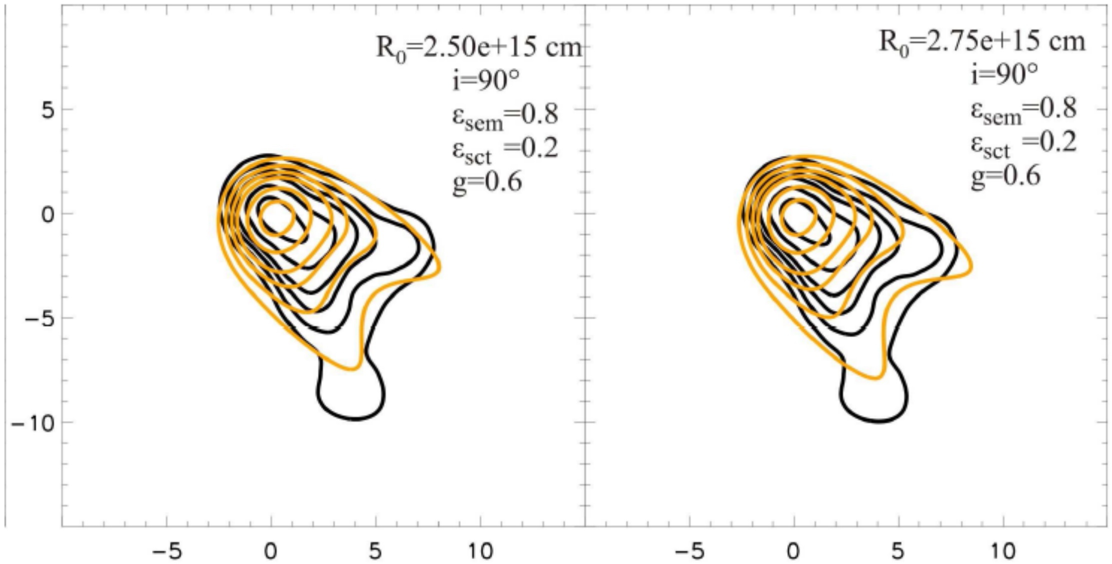


X3

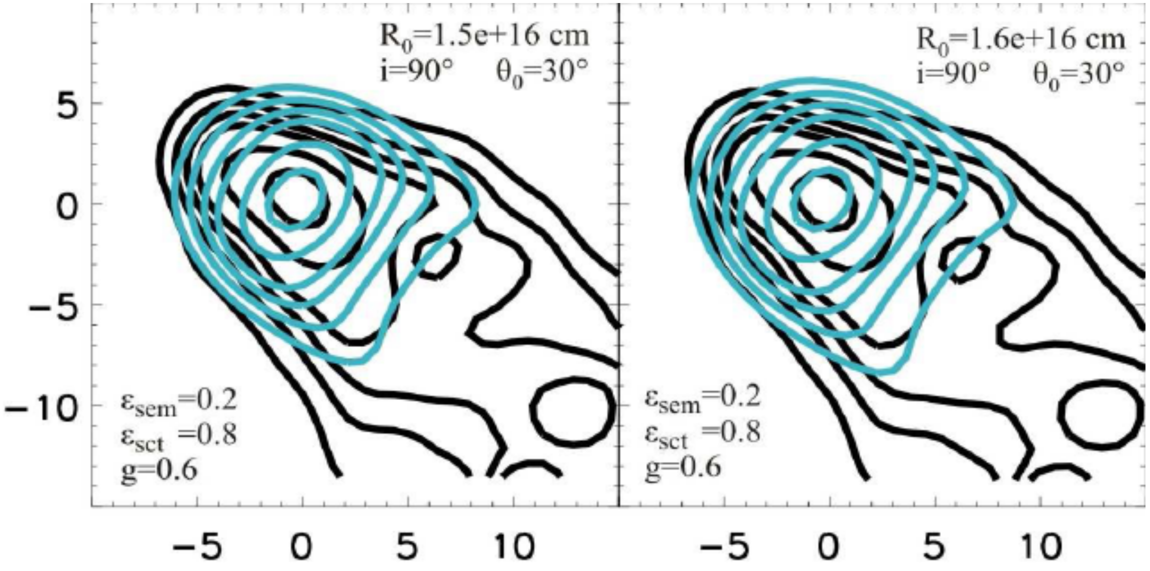


# Cometary Sources: Wind modeling

X7



X3



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.

# Standard Accretion Theory

With an estimated total wind mass loss - that could be accreted - of

$$\dot{M} \approx 2 \times 10^{-4} M_{\odot} yr^{-1}$$

that corresponds to an accretion rate in Eddington units of

$$\dot{m} \approx 1 \times 10^{-3}$$

for a black hole mass of

$$(3-4) \times 10^{6} M_{\odot}$$

# Standard Accretion Theory

From the bolometric luminosity of $L \approx 2.1 \times 10^{36}\, erg/s$

one obtains an efficiency of

$$\eta_{eff} = \frac{L_{bol}}{\dot{M}_{Edd}\, c^2} \approx 5 \times 10^{-6}$$

For the estimated accretion rate this would imply a much larger bolometric luminosity than actually observed:

$$L \approx 0.1 \times \dot{M}_{Edd}\, c^2 \approx 4 \times 10^{43}\, erg/s$$

This is larger by a factor of about $10^7$

SgrA* is either very ineffciently accreting matter of very little of the matter available for accretion actually reaches the MBH, while the rest is blown away.

# Dynamical Model for Accretion
# Ineraction between the ‘starburst’ and the black hole

Massloss from stars

$10^{-4} M_o yr^{-1}$

radiation efficiency
of SgrA*

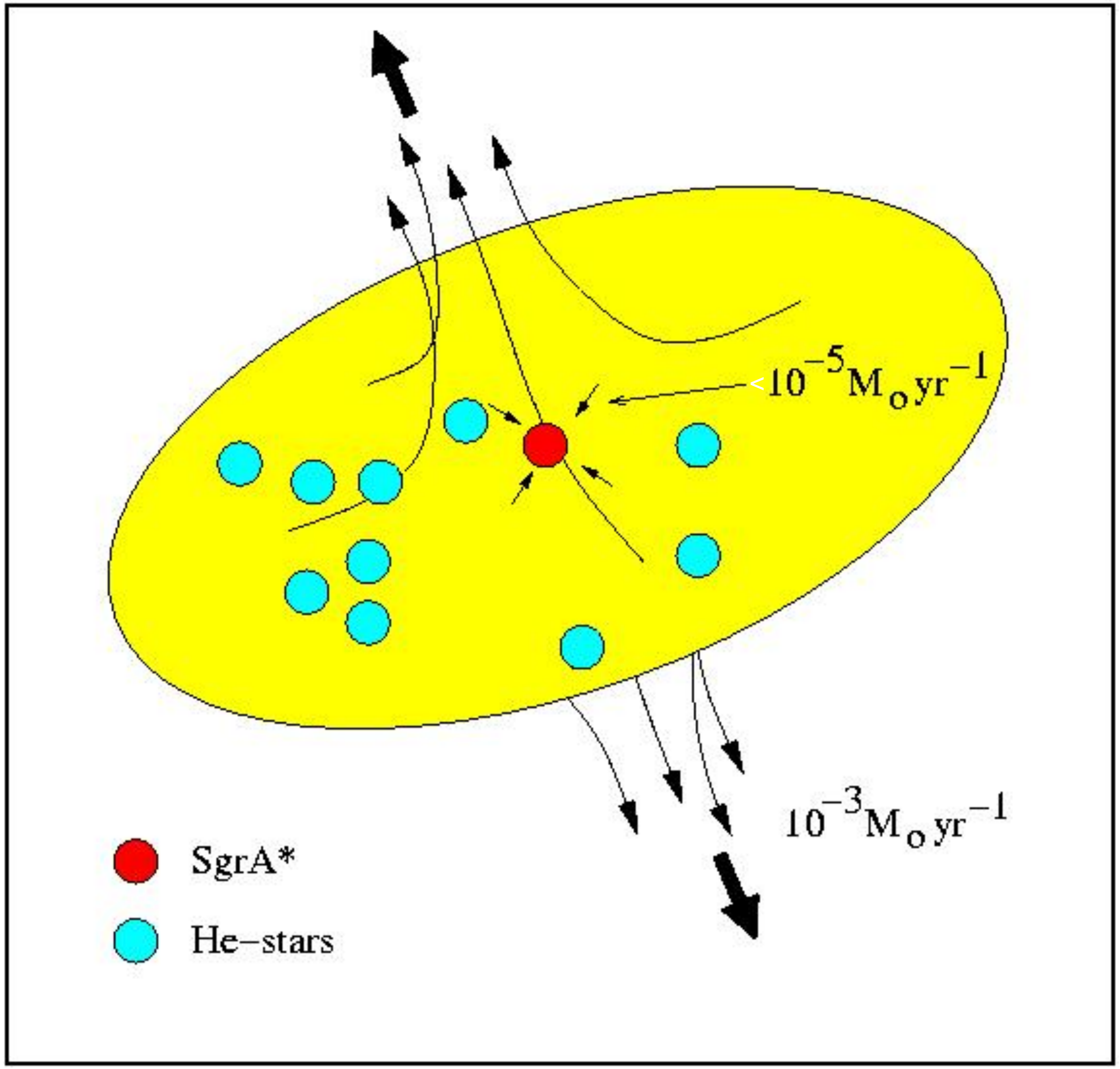
$\approx 10^{-7}$

Bower et al. 2003:
RM of linear polarized
flux rules out large
accretion rates

Quataert 2003:
hydrodynamic calculations show
that almost the entire mass gets
blown away in a central wind.

Available for accretion:

$< 10^{-5} M_o yr^{-1}$



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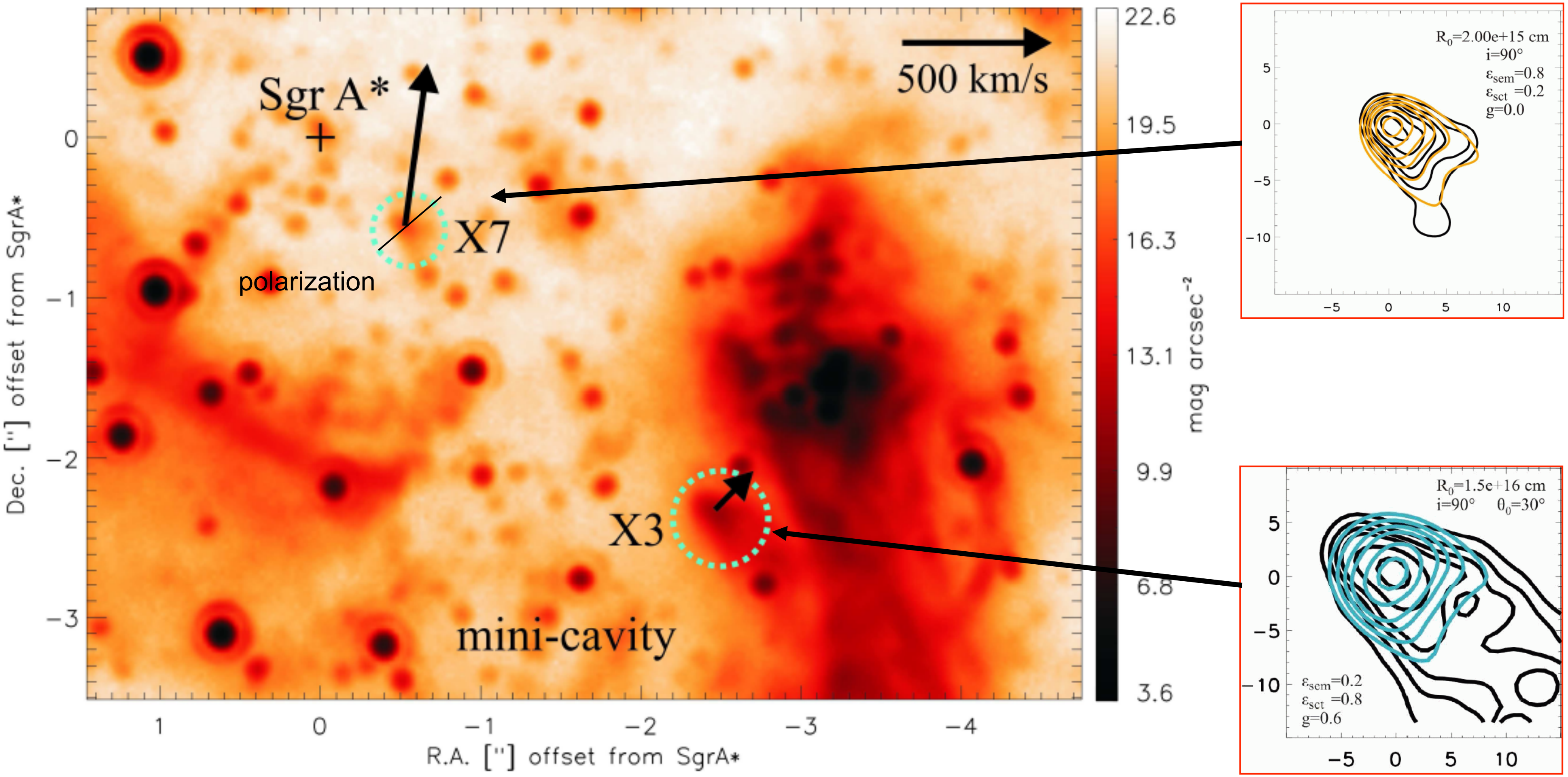

X7 polarized with 30% at PA -34+-10
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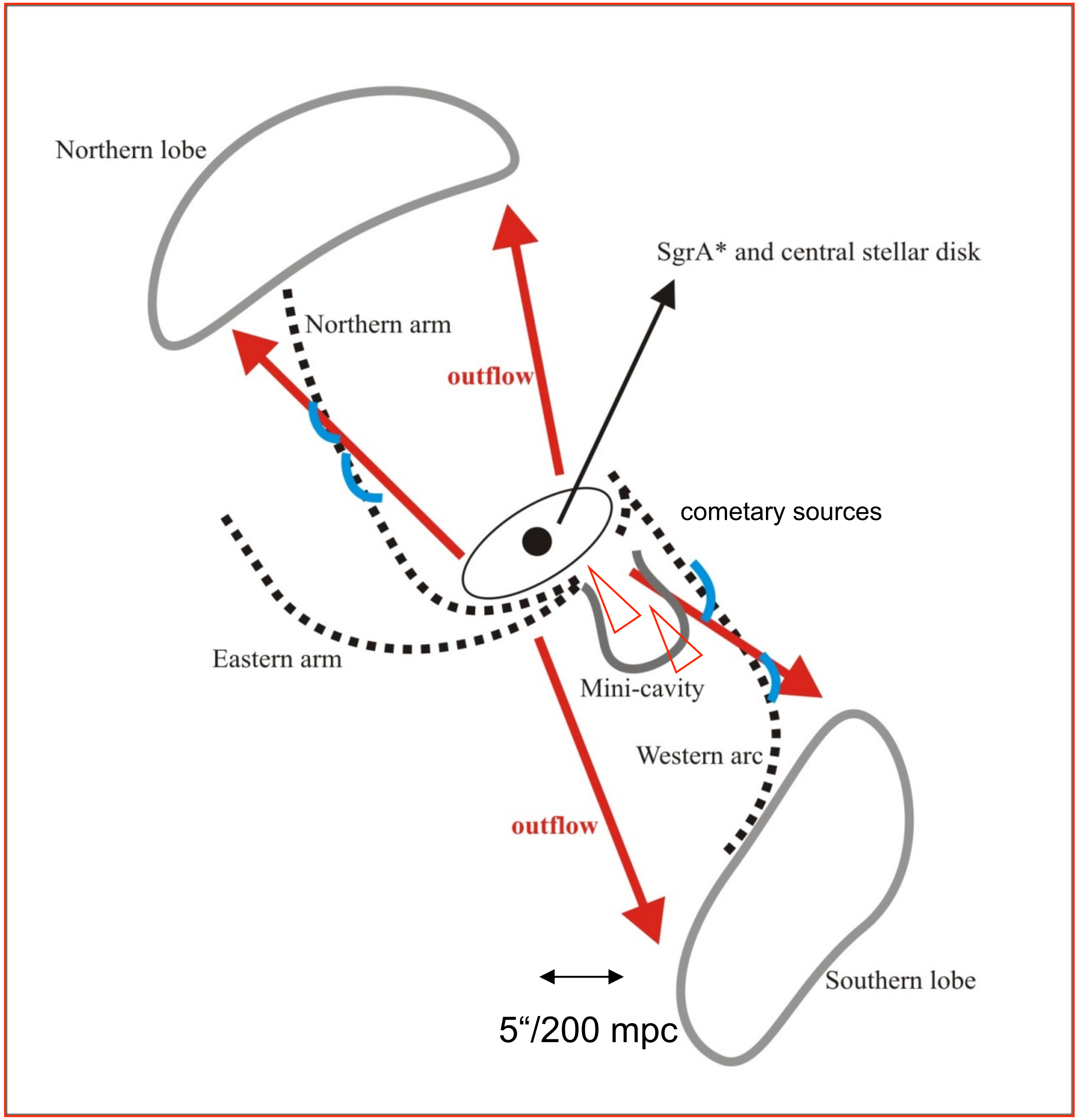
includes direction towards SgrA*

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

Muzic, Eckart, Schödel et al. 2007, 2009, 2010

# Sketch of an Outflow Model: The Combined Wind from the Cluster of Hot Stars and SgrA*



Muzic, Eckart, Schödel et al. 2007
A&A 469, 993
Sabha, Eckart, Witzel, et al. 2009

# GC SMBH interaction with the ISM

The following aspects need to be considered:

- accretion through a preferred plane?
- presence of a temporary relativistic disk
- inefficient accretion
- preferred direction of a wind from SgrA*
  in addition to a wind from all mass loosing
  stars (min-cavity and bow-shock stars)

END