High Frequency VLBI of SgrA*: Getting to the Event Horizon

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XRay Variability

Rise Time ~ 300 seconds
Light Crossing ~ 9 Rsch

Also: Porquet et al 2003
see 200 sec rise time
in XMM flare: 7 Rsch.

Baganoff et al 2001
IR Variability

VLT: Genzel et al 2003

Rise Time ~ 15 minutes: 30 Rsch

Periodicity ~ 17 minutes
If modulation by orbiting material then R < 6 Rsch

Modeling Accretion Disks

Accretion Flow at 450 GHz: starting to become optically thin.

Goldston, Quataert, Igumenshchev 2005
‘Shadow’ in MBH Emission

Shadow for both rotating and non-rotation MBH is \( \sim 3 - 5 \) Rsch wide.

Falcke, Agol, Melia 2000

SgrA*: Relevant Size Scales

- XRay Flaring: \( \sim 9 \) Rsch
- IR Variability: \( \sim 6 - 30 \) Rsch
- Modeling:
  - Inner parts of accretion disks \( \sim 3 \) Rsch at 450GHz (e.g. Goldston et al 2005).
  - Strong GR Effects at MBH: Shadow \( \sim 5 \) Rsch
  - SSC Xray Flux \( \sim \theta^{-8} \). (Eckart: 1 Rsch size)
Very Long Baseline Interferometry

Singularly high resolution.

For 5000km baseline at 230GHz:
\[
\frac{\lambda}{D} = 54 \mu \text{arcsec}
\]
\[
= 6 \text{Rsch}
\]

VLBI Primer

- Visibilities \(\xrightarrow{\text{FT}}\) Map
- Sparsely Sampled
- Map must be real valued
- Usually most of map is blank

Closure Quantities:
Scattering of VLBI Images

Due to turbulence in ionized ISM.

SgrA* is scattered into an ellipse.

Size $\sim \lambda^2$.

Spectral Turnover: Optically Thin?

T. An et al : Astro-ph; D. Marrone et al (SMA)
SgrA\(^*\) Requires High Frequency VLBI

- Resolution \(\sim \lambda\).
- Scattering \(\sim \lambda^2\).
- Starts to become optically thin.
- Faraday Rotation \(\sim \lambda^2\).

High Frequency VLBI Challenges

- Sensitivity limited by
  - atmospheric coherence,
  - telescope apertures,
  - bandwidth,
  - weather (opacity and coherence).
- Baseline coverage: small number of high demand sub/mm telescopes.
- Receiver Electronics noisier.
Challenges cont’d
• Scheduling mm/submm telescopes is difficult.
• Array phasing: difficult to phase submm arrays into single aperture.
• Hydrogen masers: very stable but at high frequencies they introduce signal loss.
• Amplitude calibration is difficult: array phasing, pointing, atmosphere, gain curves.
• Major improvements can be expected in some of these areas.

Sensitivity: a solution.
• Higher sensitivity: detection within Tcoh, SgrA* has been too faint.
• Old conventional wisdom: collecting area.
• New technical developments – new wisdom
  – 1983 VLBI BW: 224Mb/s,
  – 2004 VLBA BW: 512Mb/s.
  – New disk based VLBI recording systems will allow multi Gb/s data rates
Mark 5B VLBI Data System

Mk5 cost ~ $15K
700 GB disks expected ~2005 – 12 hours @ 2 Gbps unattended

Tape vs. Disc Price Comparison
Sensitivity: a solution.

- Old conventional wisdom: collecting area.
- New technical developments – new wisdom
  - 1983 VLBI BW: 224Mb/s,
  - 2004 VLBA BW: 512Mb/s.
  - New disk based VLBI recording systems will allow multi Gb/s data rates: 2Gb/s x N
  - New digital VLBI backends (collaboration with Berkeley SSL): 4 Gb/s x N
  - Over few years BW up by x8, cost down by x20.

mm/submm VLBI Progress

- 2002: Carried out successful 129, 147 GHz VLBI on Pico Veleta, KittPeak12m, SMTO triangle:
  - High resolution: Pico-SMTO fringes – 49μas
  - SiO Masers
  - Collaborators: MPIfR, IRAM, Onsala, Metsahovi, Arizona Radio Observatory
v=1 J=3-2 SiO Masers in VY CMa

- First 129GHz VLBI image using all phase and amp information.
- Relative astrometry small fraction of beam.

mm/submm VLBI Progress

- 2001-present: focus on 1-2mm VLBI
- 2002: Carried out successful 129, 147GHZ VLBI on Pico Veleta, KittPeak12m, SMTO triangle:
  - High resolution: Pico-SMTO fringes – 49µas
  - SiO Masers
- 2003: Carried out 230GHz VLBI using Pico, KittPeak, SMTO, Plateau de Bure
  - Detected Pico-SMTO 1.3mm fringes – 34µas on 3C279
  - World Record: equivalent to 3 R_{SCH} of SgrA* MBH
  - Used new generation of VLBI recorders.
Ultra Wideband VLBI Project

- Received funding to implement wideband VLBI.
- Outfit largest cm antennas (Effelsberg, Arecibo, GBT, WSRT, Jodrell bank) with 4Gb/s recording systems: <1µJy/beam rms.
- Outfit best mm sites with 4Gb/s systems: JCMT, SMTO (CARMA, LMT, SMA, ALMA, APEX)
- Target science requiring sensitivity: SNR in ULIG mergers, GRBs, Grav. Lenses, Stellar VLBI, SgrA*!!
- Submm VLBI on SgrA* feasible.

230GHz VLBI Observations

Proposed VLBI on JCMT-HHT baseline.

Just a detection will provide a firm upper size limit.

Scheduled for early 2006.

CARMA may participate.
Signatures of Asymmetry using closure phase

What we really want: the Shadow

Free fall

Orbiting

Evidence for an Event Horizon.
Summary

• Technical improvements in VLBI developing rapidly: BW up x10, cost down x 20.
• Initial experiments show 230GHz VLBI on SgrA* possible.
• Timeline:
  – Jan 2006: 230GHz VLBI on SgrA*: JCMT-HHT.
• ‘Shadow’ imaging within 5-7 years.

END