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

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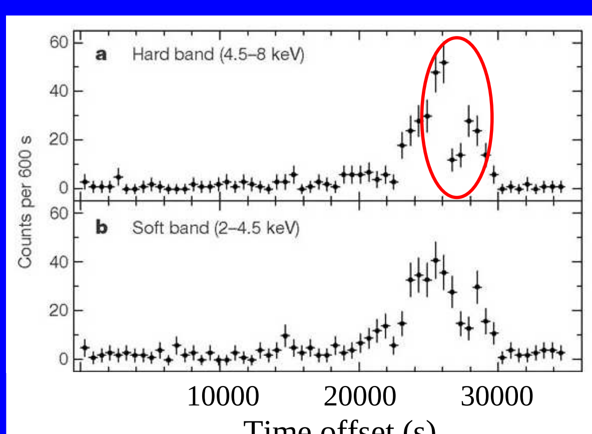
U of Arizona, JCMT, IRAM

XRay Variability

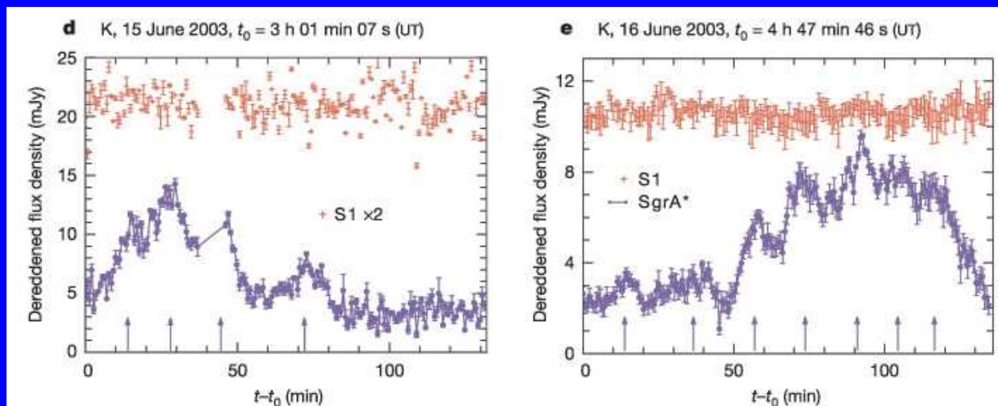


Baganoff et al 2001

Rise Time ~ 300 seconds
Light Crossing ~ 9 Rsch

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

IR Variability

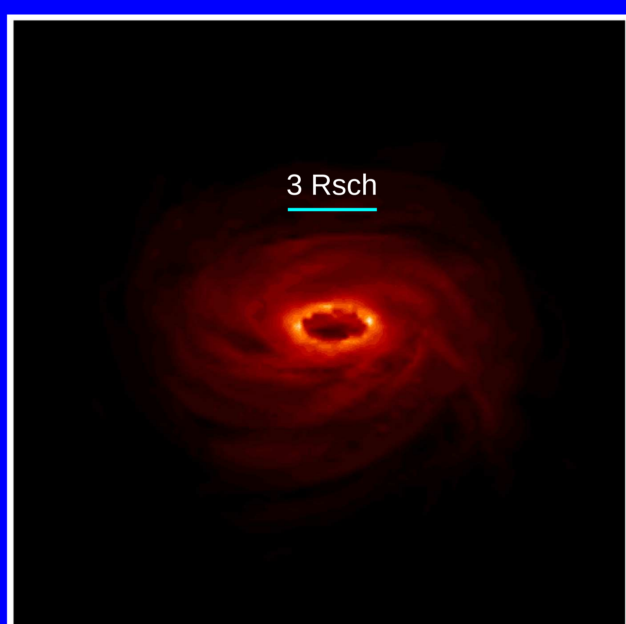


VLT: Genzel et al 2003

Rise Time ~ 15 minutes: 30 Rsch

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

Modeling Accretion Disks



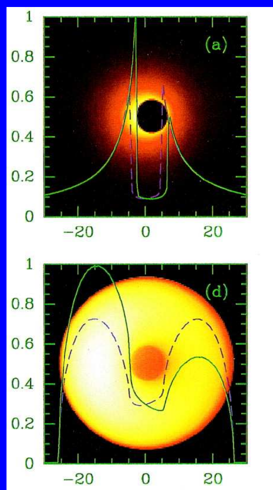
Accretion Flow at 450 GHz: starting to become optically thin.

Goldston, Quataert, Igumenshchev 2005

‘Shadow’ in MBH Emission

free fall — rotating

orbiting — non-rotating



GR Code

Falcke, Agol, Melia 2000

Shadow for both rotating and non-rotation MBH is ~ 3 – 5 Rsch wide.

SgrA*: Relevant Size Scales

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

Very Long Baseline Interferometry

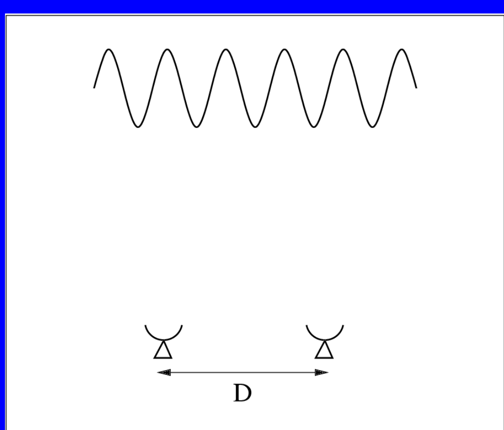
Singularly high resolution.

For 5000km baseline at 230GHz:

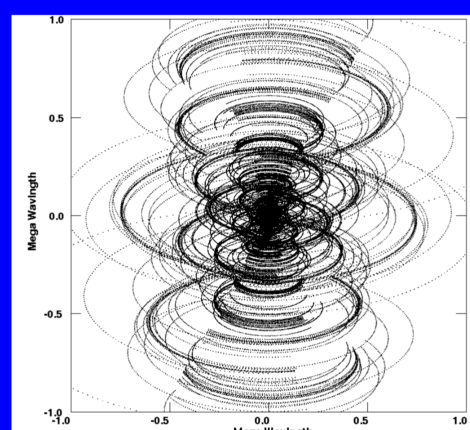
$\lambda/D = 54\ \mu$ arcsec

$= 6$ Rsch

VLBI Primer

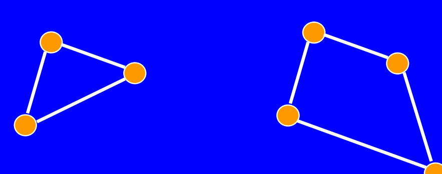


Earth Rotation

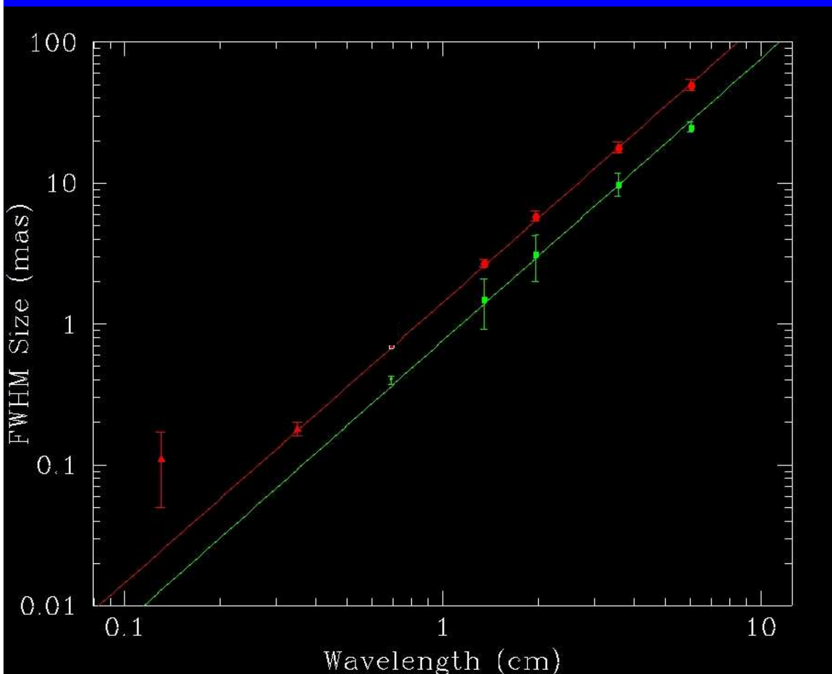


- Visibilities —F T→ Map
- Sparsely Sampled
- Map must be real valued
- Usually most of map is blank

Closure Quantities:



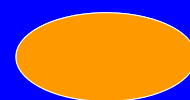
Scattering of VLBI Images



Due to turbulence in ionized ISM.

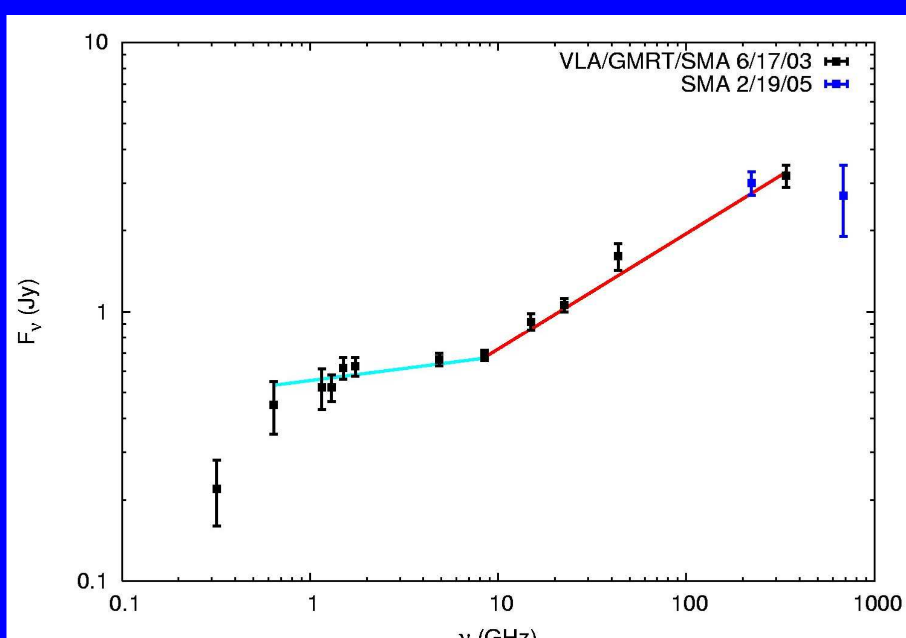
SgrA* is scattered into an ellipse.

Size ~λ^2.



<7mm Lo et al, 7mm Bower et al, 3mm Doeleman et al, 1mm Krichbaum et al.

Spectral Turnover: Optically Thin?



T. An et al : Astro-ph; D. Marrone et al (SMA)

SgrA* Requires High Frequency VLBI

- Resolution ~ λ.
- Scattering ~ λ^2.
- Starts to become optically thin.
- Faraday Rotation ~ λ^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.

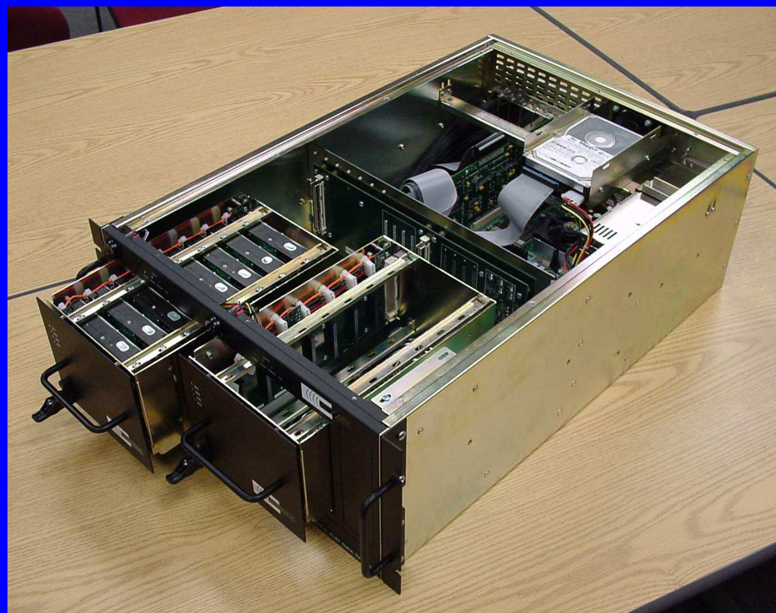
Challenges cont'd

- 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

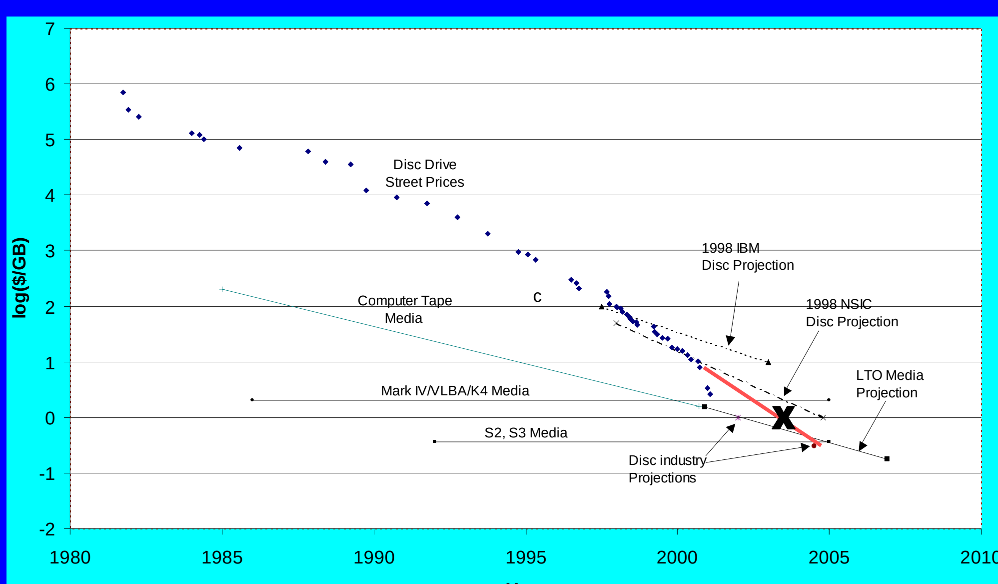
Mark 5B VLBI Data System



Mk5 cost ~ $15K

700 GB disks expected ~2005 – 12 hours @ 2 Gbps unattended

Tape vs. Disc Price Comparison



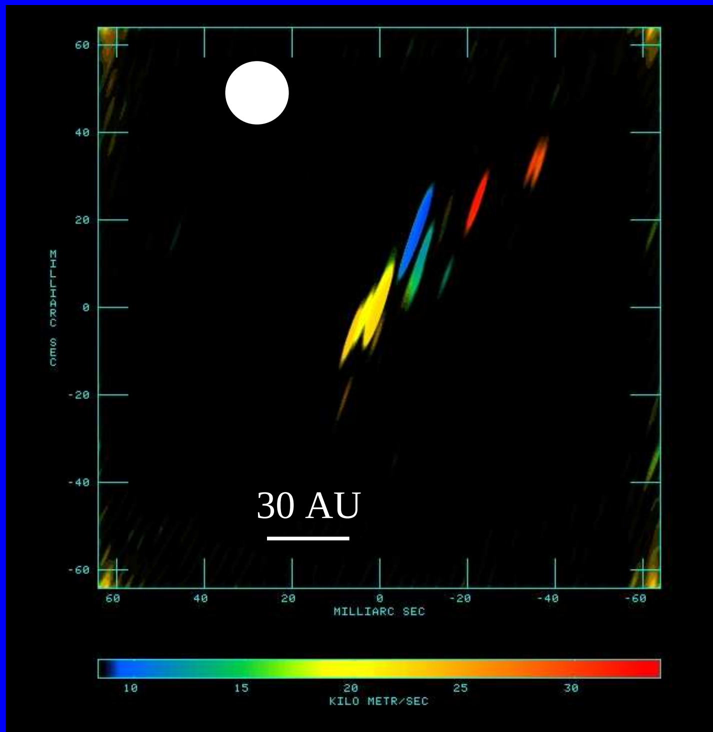
Sensitivity: a solution.

- 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.

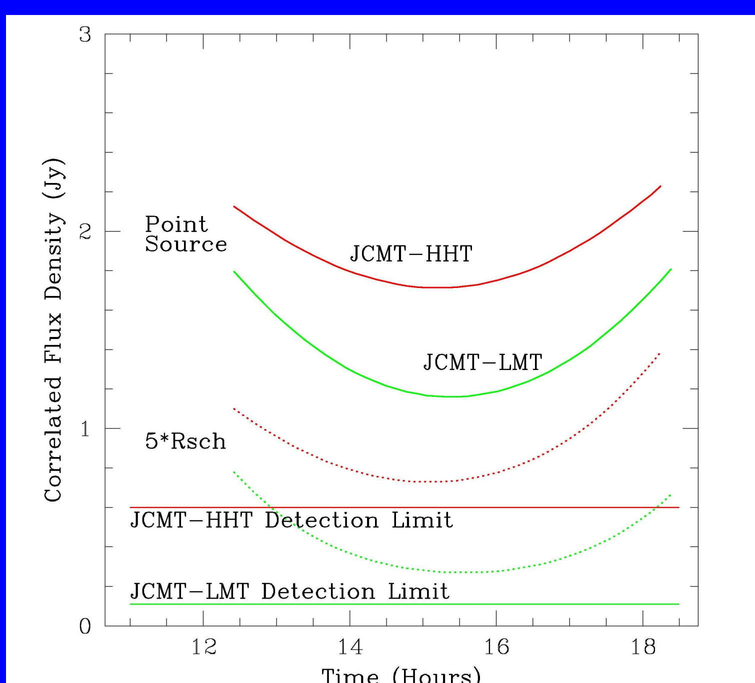
mm/submm VLBI Progress

- 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



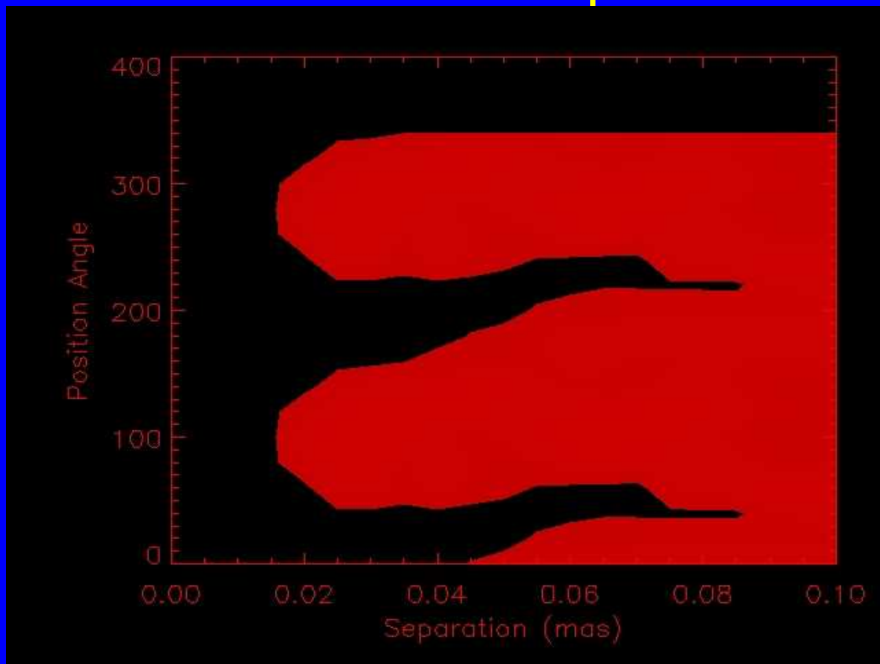
Proposed VLBI on JCMT-HHT baseline.

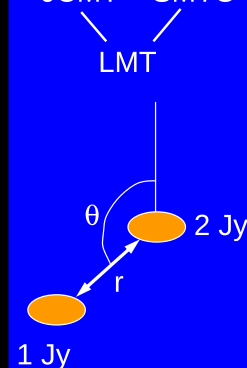
Just a detection will provide a firm upper size limit.

Scheduled for early 2006.

CARMA may participate.

Signatures of Asymmetry using closure phase

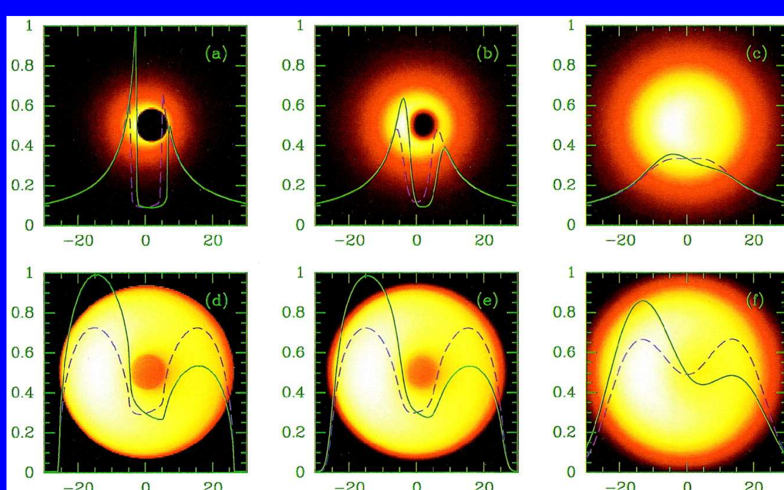




Closure phase
Very sensitive to
Most of parameter
Space.

What we really want: the Shadow

Falcke et al



free fall | rotating
orbiting | non-rotating

GR Code | 0.6mm VLBI | 1.3mm VLBI

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.
  - Jan 2007: 230GHz VLBI: JCMT-HHT-CARMA-ALMApt-APEX-SMA. Test 345GHz systems.
  - Jan 2008: 230/345 GHz VLBI: add LMT.
- ‘Shadow’ imaging within 5-7 years.

END