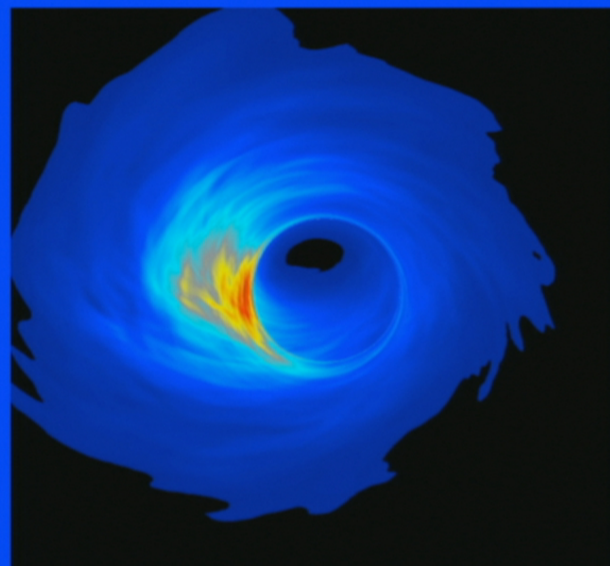
Title: Introduction to the EHT

Date: Nov 10, 2014 09:05 AM

URL: http://pirsa.org/14110061

Abstract: The Event Horizon Telescope is a project to assemble a global Very Long Baseline Interferometric (VLBI) array that operates at mm and submm wavelengths. With stations ranging from Hawaii to the South Pole, the array will have the angular resolution to image the nearest super massive black holes, and the sensitivity to time resolve dynamics at the event horizon. The central goal is to spatially resolve a region of space time where gravity is dominant, and to detect strong field GR signatures. This introductory talk will outline the project history, enabling technical developments, planned observations, and excellent prospects for exciting new results in black hole studies.

Building an Event Horizon Telescope: Imaging and Time Resolving Black Holes



Sheperd Doeleman
MIT Haystack Observatory & SAO

Broad Science Themes

- Talks: Math, Physics, Astronomy

- Is there an Event Horizon?
- Does GR hold near BH?
- How does matter accrete/outflow near a BH?
- Do Black Holes have spin?
- How do Black Holes launch jets?
- Quantum nature of BH's…

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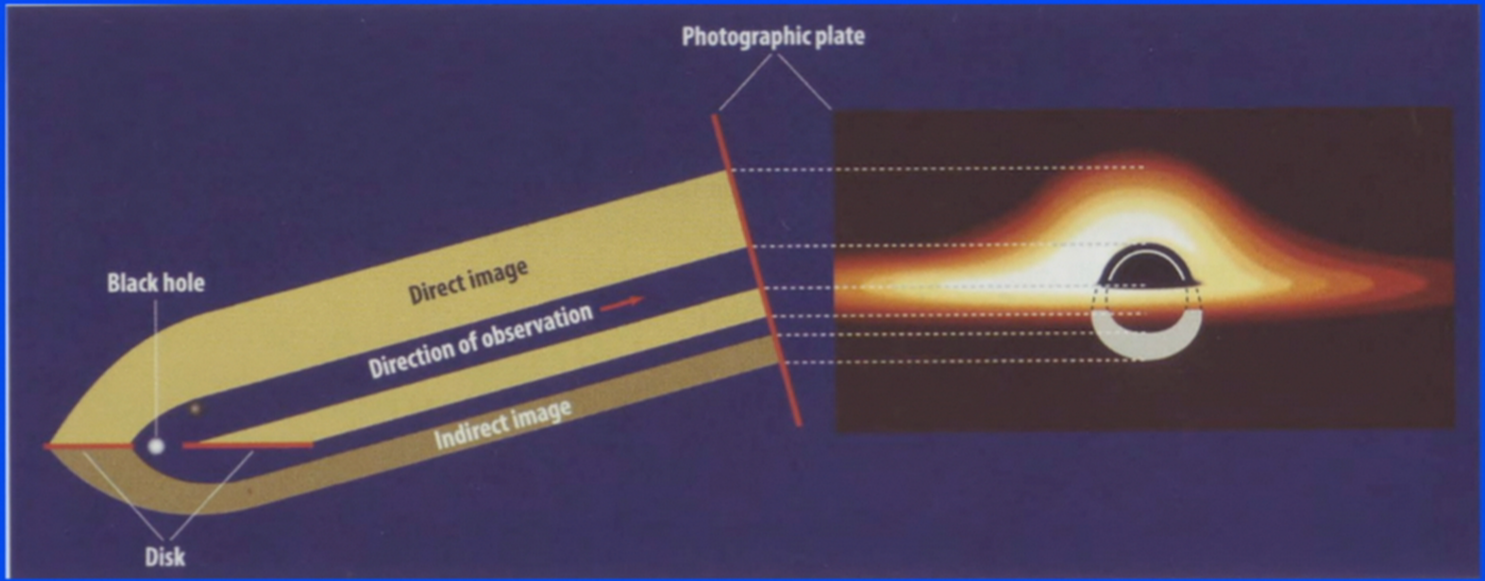
Strong GR: The Black Hole Shadow



Bardeen 1973
Luminet 1979

Shadow Diameter:

Non-spinning (a=0)
Dsh = sqrt(27) * Rsch

Spinning (a=1)
Dsh = 9/2 * Rsch

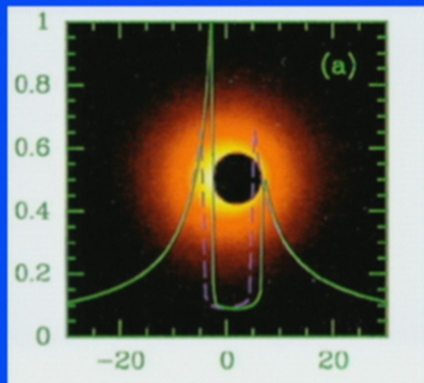
Shadow size and shape encodes GR (e.g., Johannsen & Psaltis 2010).

Strong GR: The Black Hole Shadow

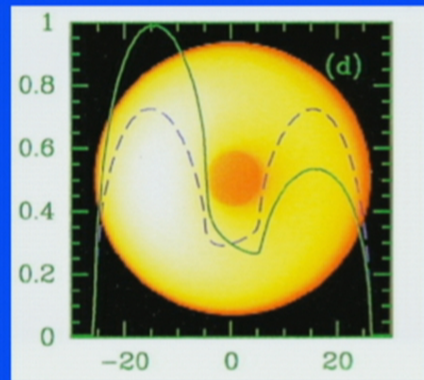
$$Dsh = 9/2 * Rsch$$

Shadow size and shape encodes GR (e.g., Johannsen & Psaltis 2010).

Theoretical Views

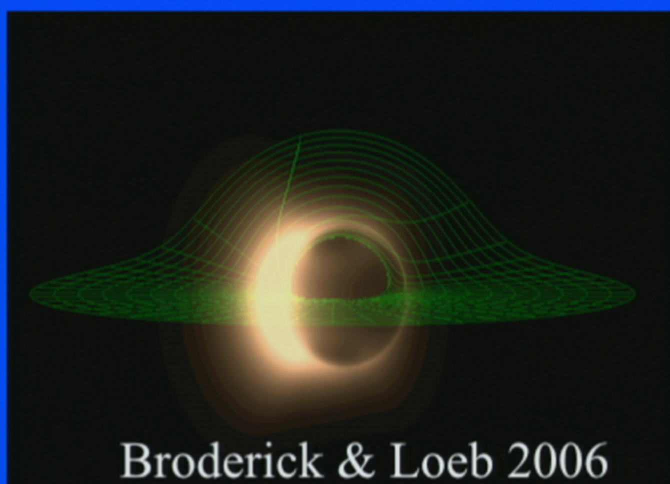


Spinning (a=1)

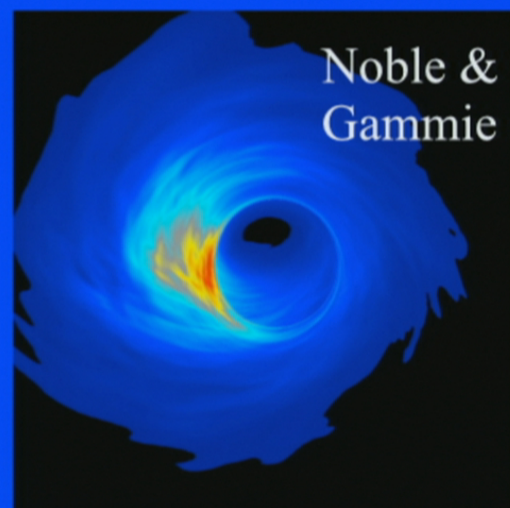


Non-spinning (a=0)

Falcke
Melia
Agol
2000



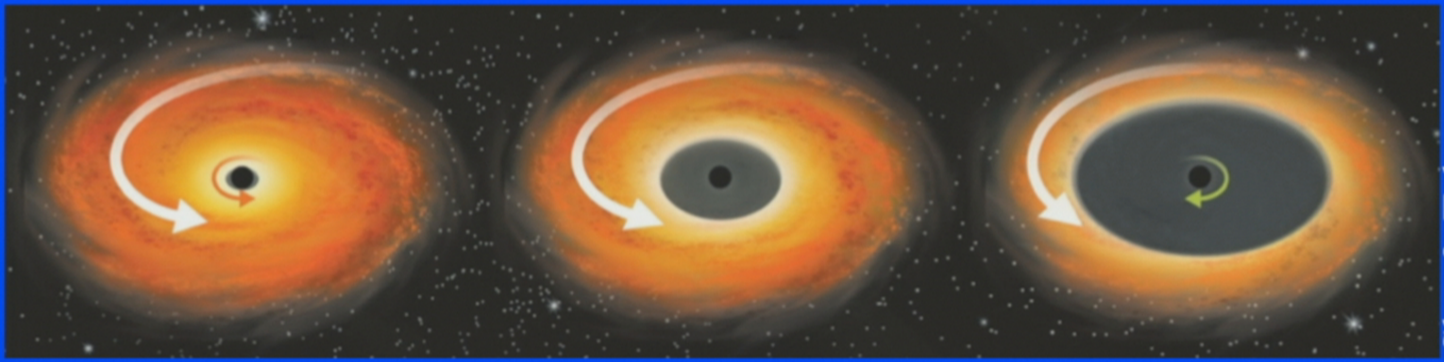
Broderick & Loeb 2006



Noble &
Gammie

Strong GR Effects:

- Innermost Stable Circular Orbit Size.

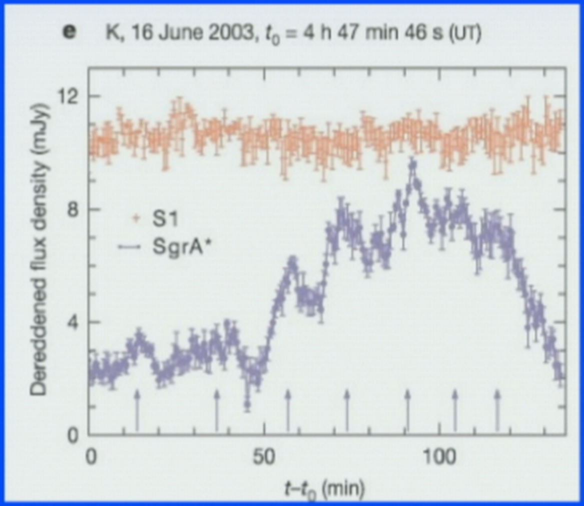


Sky & Telescope

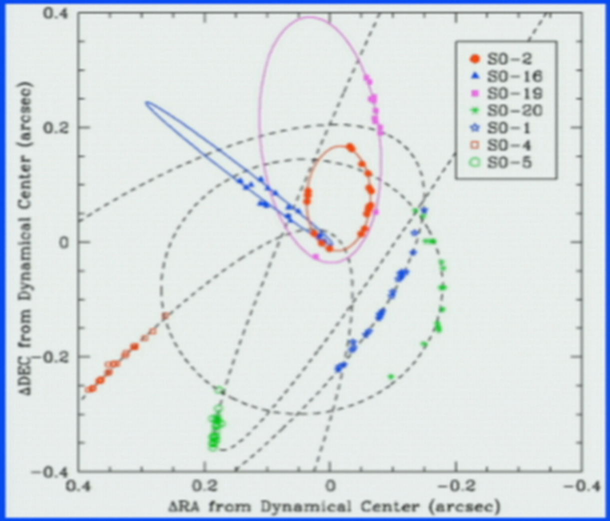
Max. Prograde	No Spin	Max Retrograde
ISCO_d = 1 Rsch	ISCO_d = 6 Rsch	ISCO_d = 9 Rsch

5

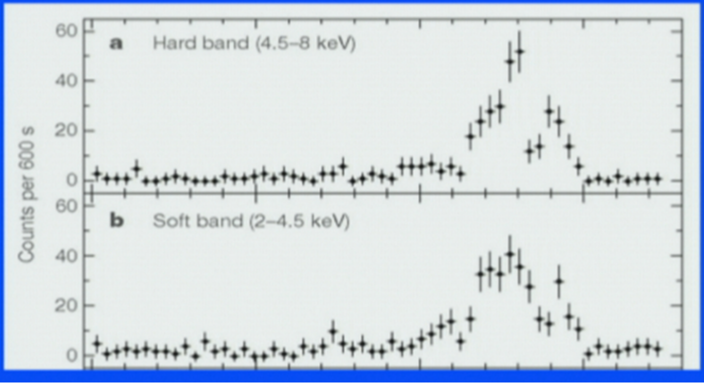
SgrA*: Best Case for a SMBH



VLT: Genzel et al 2003

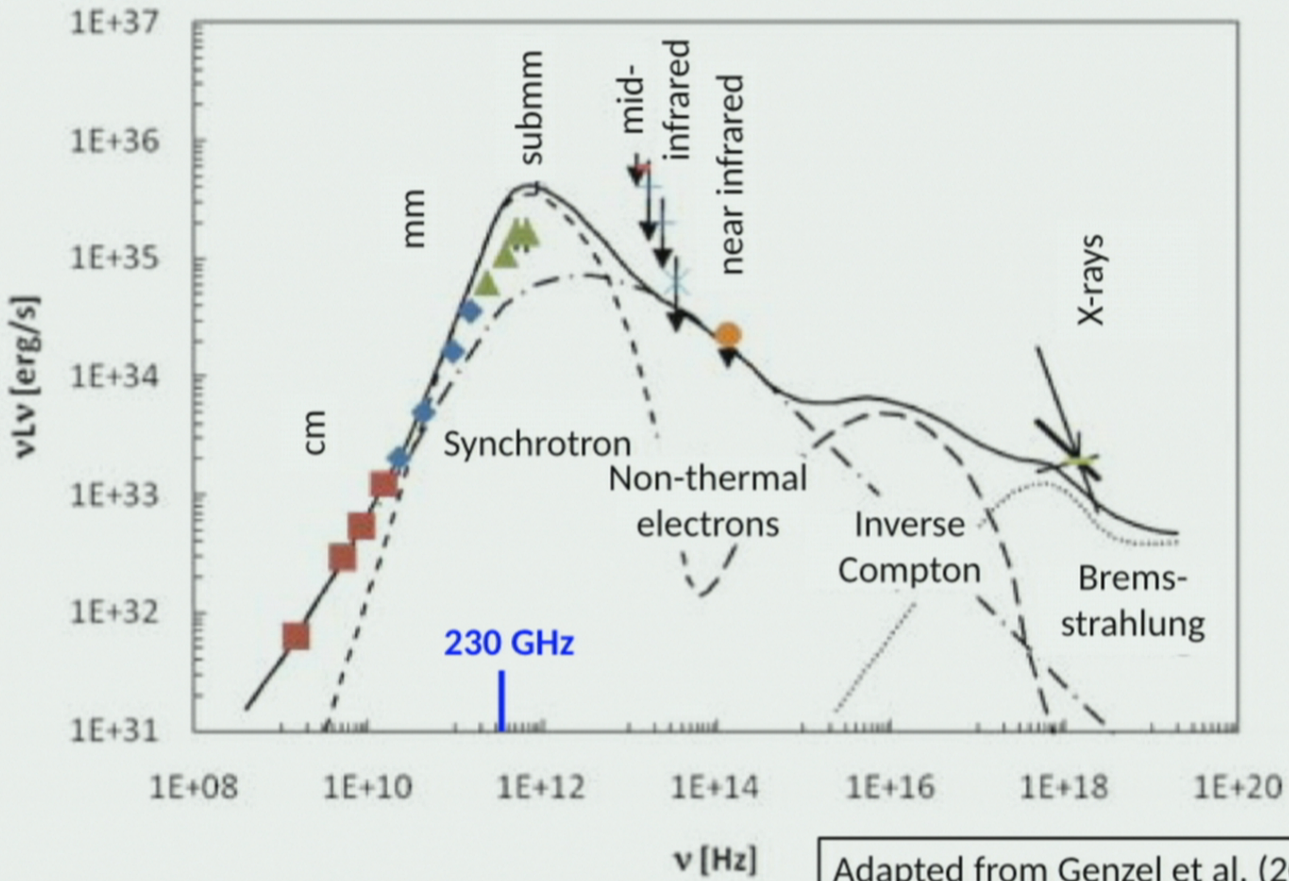


Ghez et al 2005



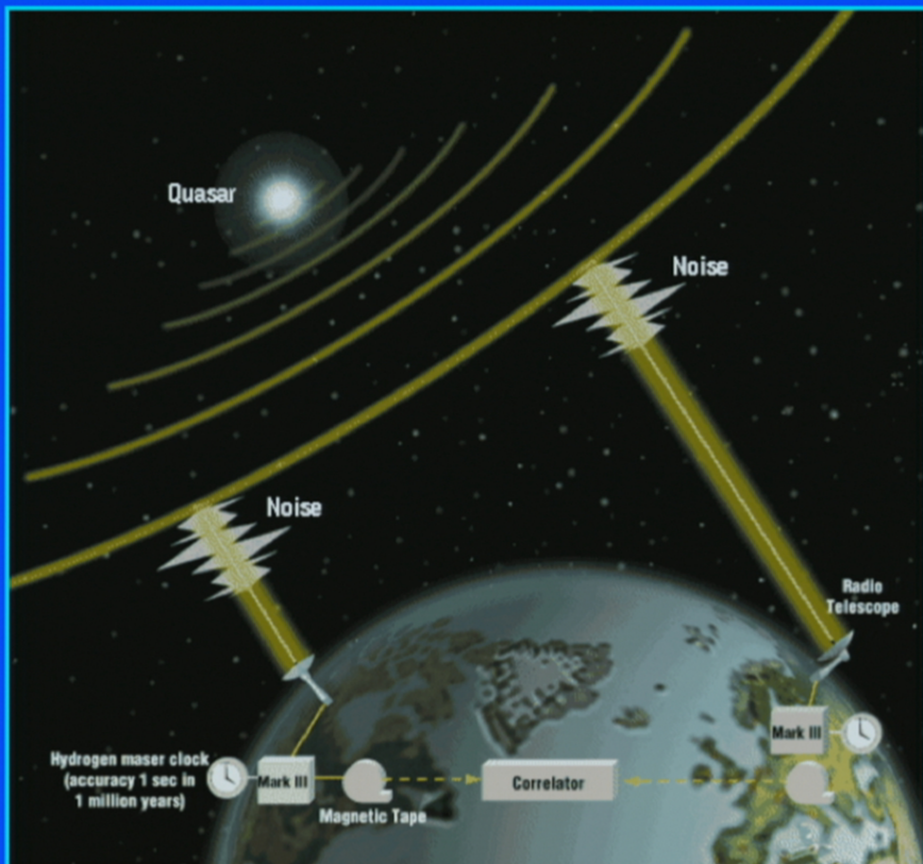
Baganoff et al 2001

Sgr A* Spectrum



Adapted from Genzel et al. (2010)

Short Wavelength VLBI



<u>Resolution:</u>

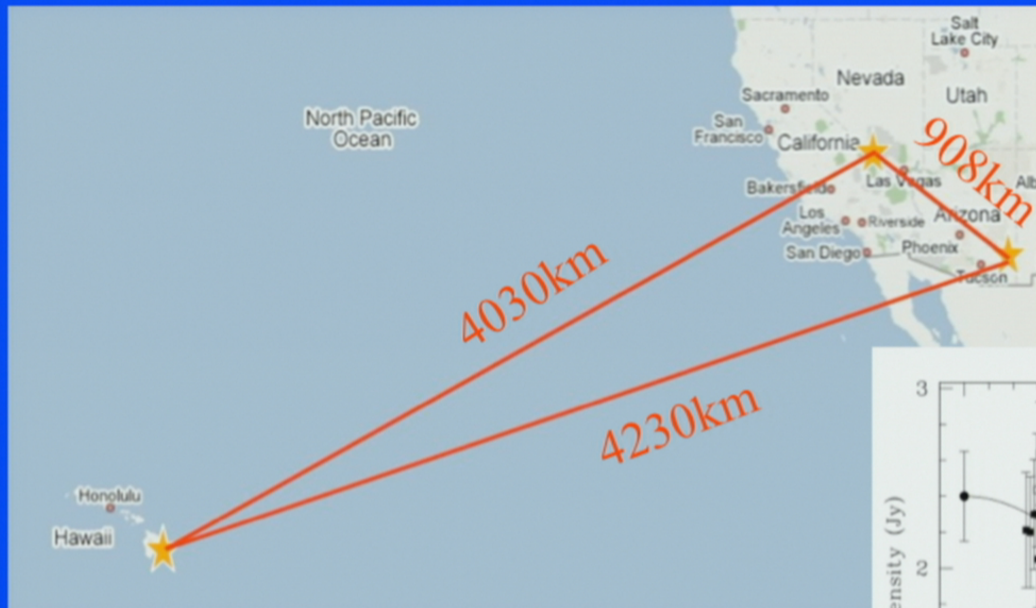
λ/D (cm) ~ 0.5 mas
λ/D (1.3mm) ~ 30 μas
λ/D (0.8mm) ~ 20 μas

<u>ISM Scattering:</u>

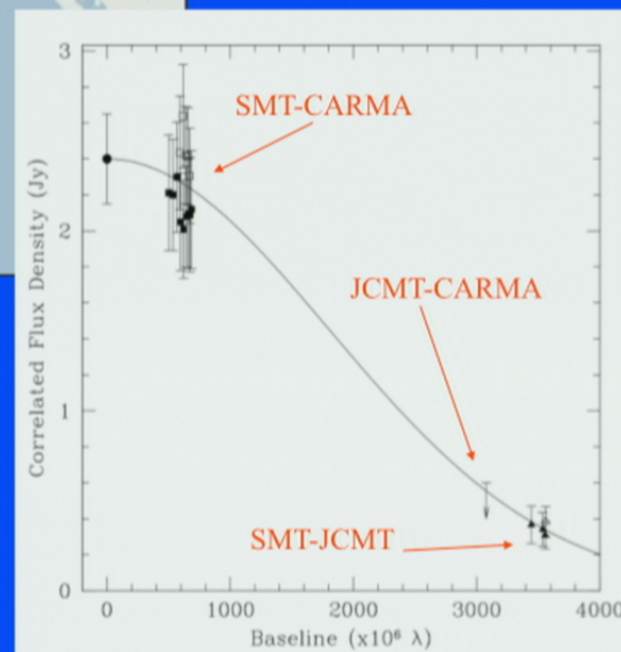
Θscat ~ λ^2

Shadow size (SgrA*): 50 μas

SgrA*: Event Horizon Structure Confirmed



Doeleman et al 2008

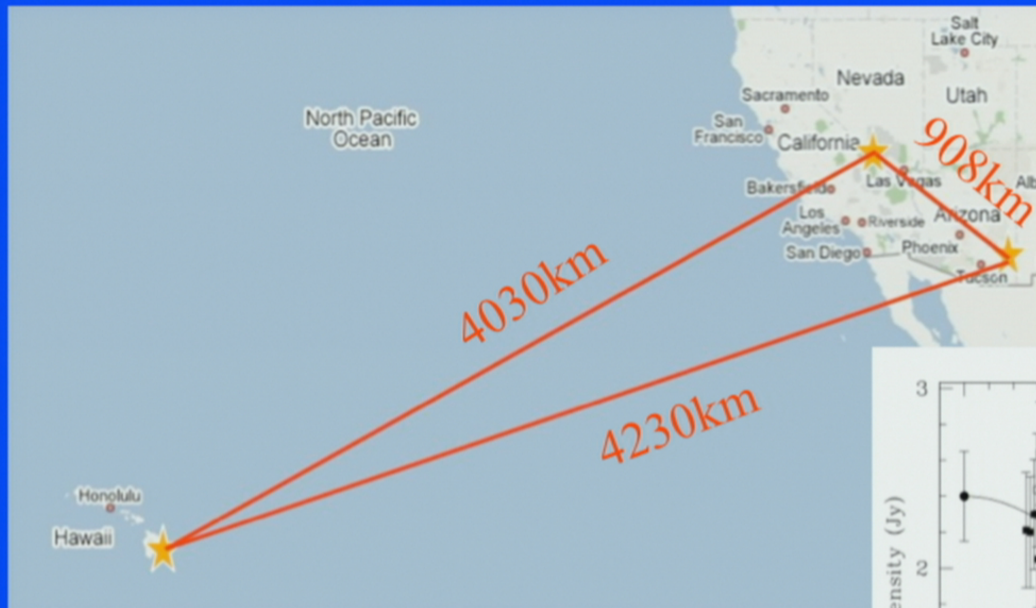


About 4 Schwarzschild radii across.

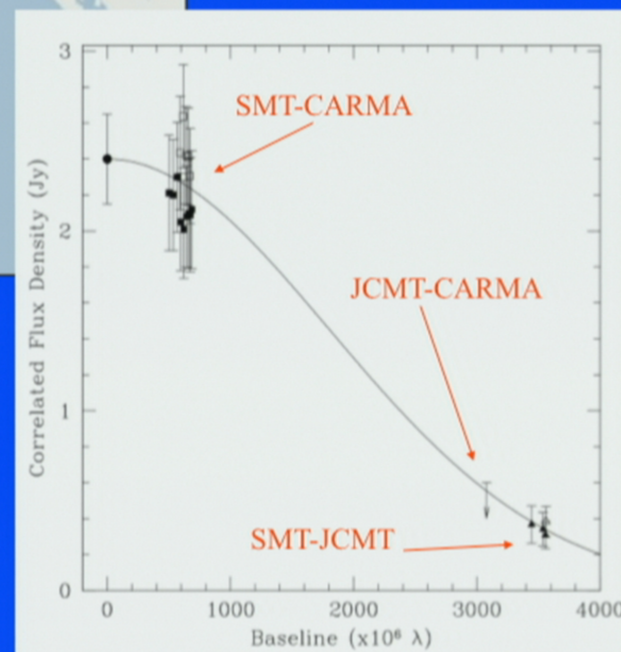
$$\rho = 10^{23} M_{\odot} pc^{-3}$$

4 million suns within the orbit of Mercury.

SgrA*: Event Horizon Structure Confirmed



Doeleman et al 2008



About 4 Schwarzschild radii across.

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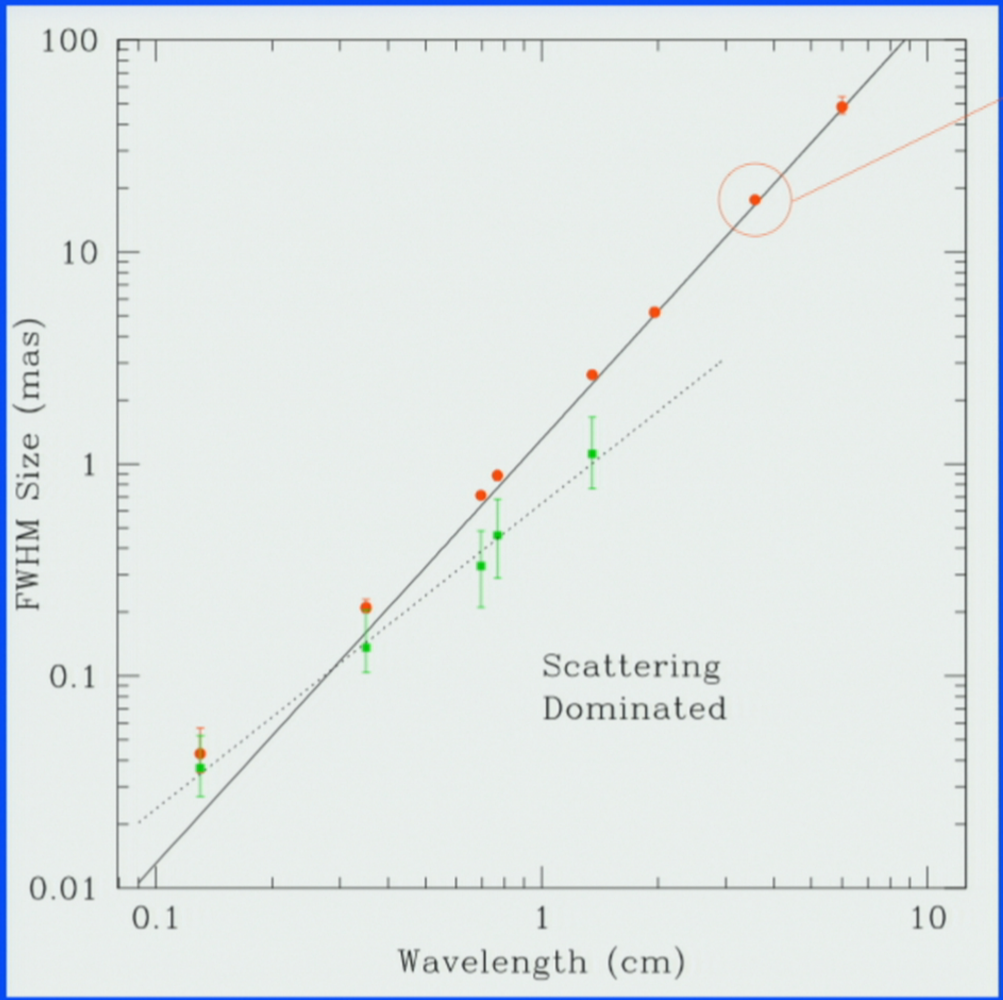
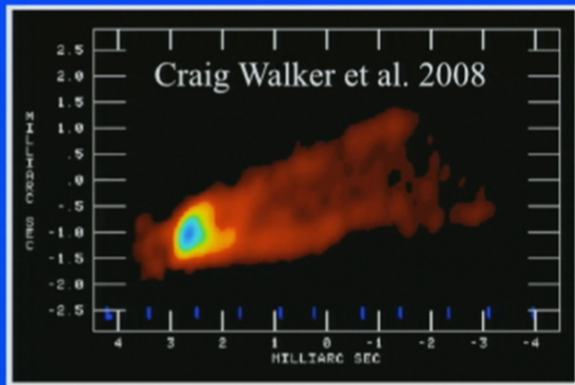
4 million suns within the orbit of Mercury.

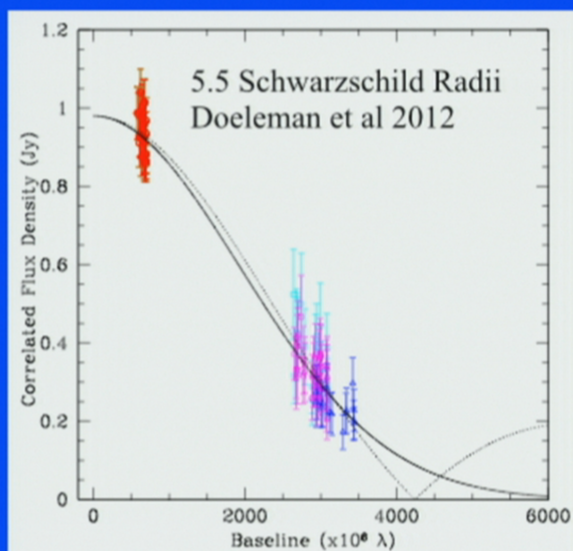
SgrA*: Piercing the Scattering Screen

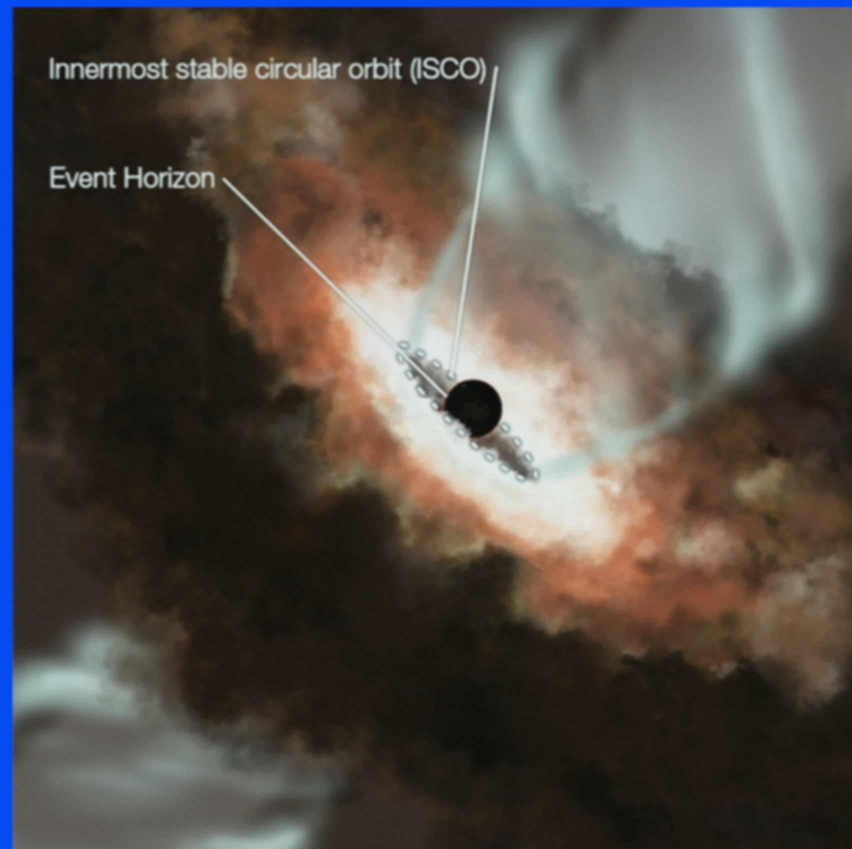


Lo 1975
Jauncy 1989

M87: BH Origins of a Relativistic Jet



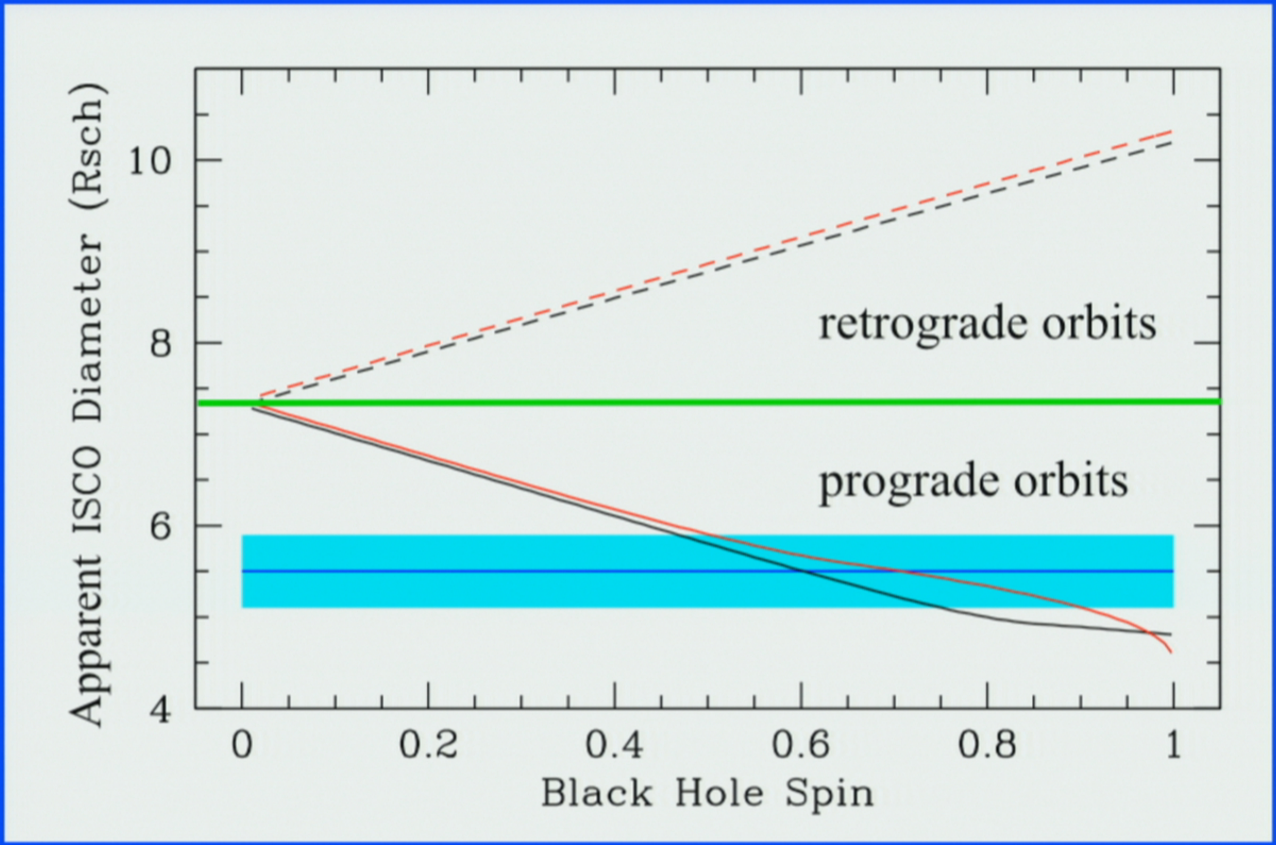




Graphic: Broderick

Strong GR Effects:

- Smaller than the expected ISCO: prograde disk.

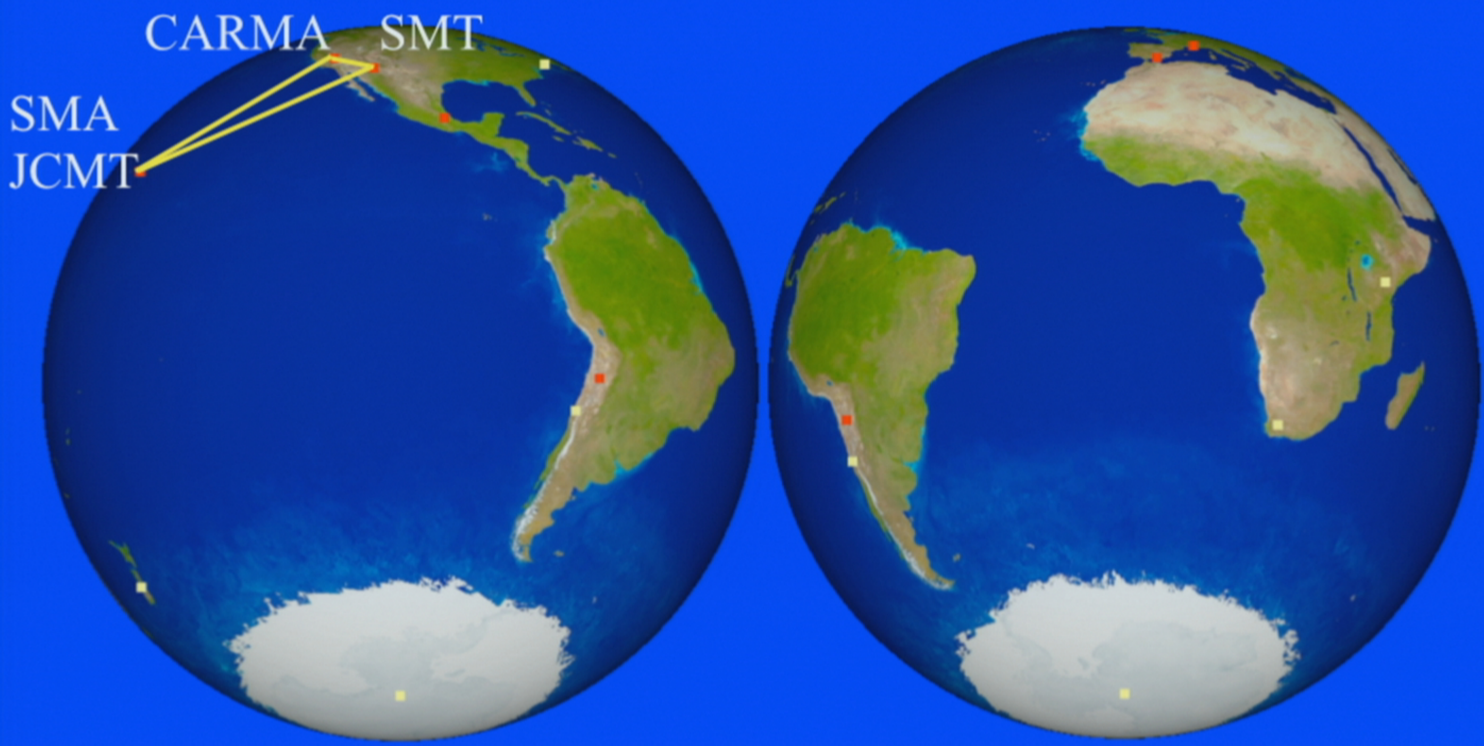


Doeleman et al 2012

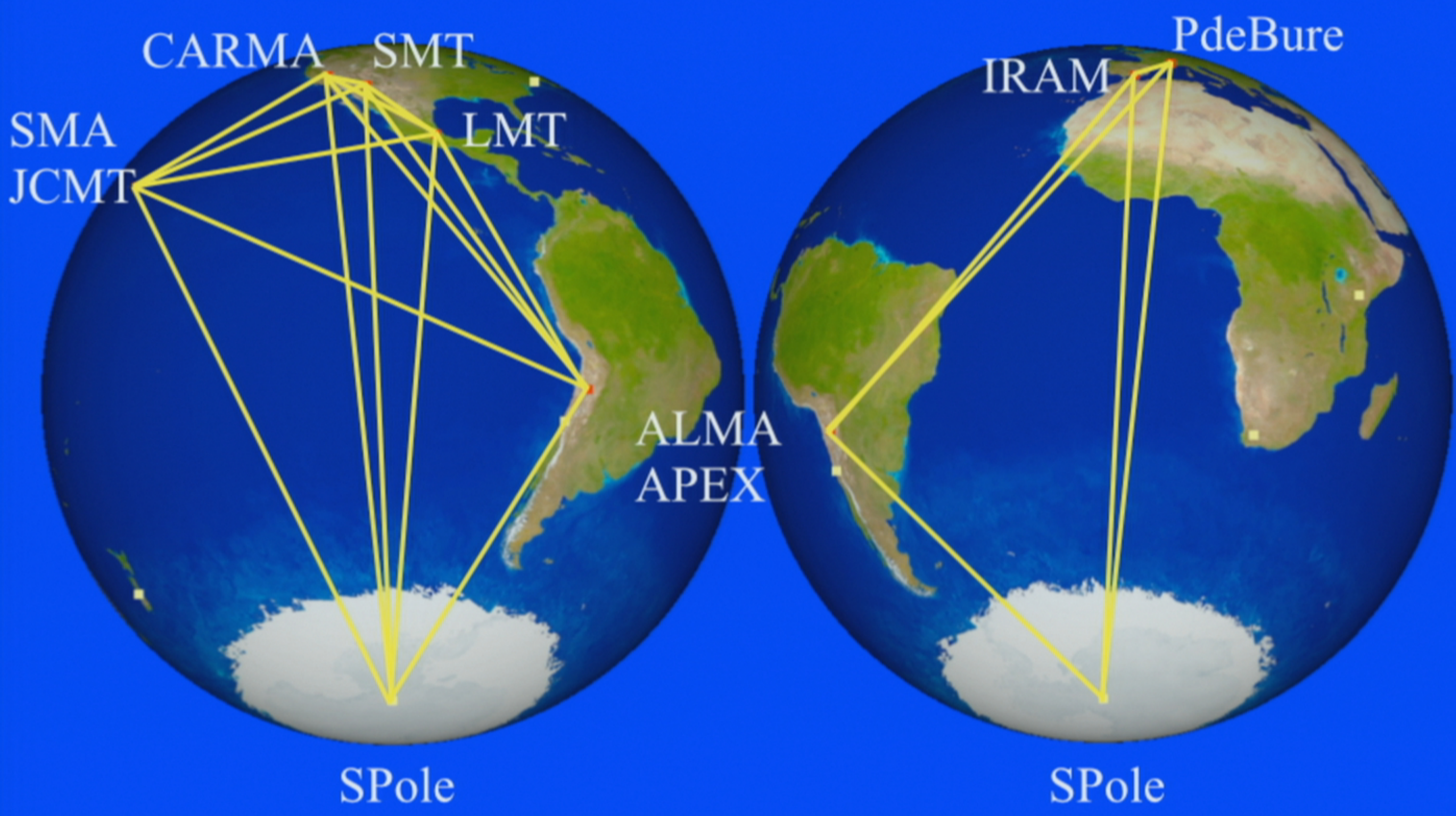
EHT Specifications: The Next 2-3 Years

- Increase stations from 3 to 8: baseline number grows from 3 to 28 (n*(n-1)/2).
- Bandwidth increase from 1 GHz to 16 GHz.
- Collecting area increase by x10.
- Impact:
  - Sensitivity increase by x40: Long baselines.
  - Full closure phase information: modeling/imaging.
  - Full polarization information: magnetic fields.
  - Time domain: time resolving BH/jet dynamics.

SgrA*'s view of the EHT



SgrA*'s view of the EHT



3mm VLBI with the LMT

Requires new 1.3mm Receiver for EHT work.

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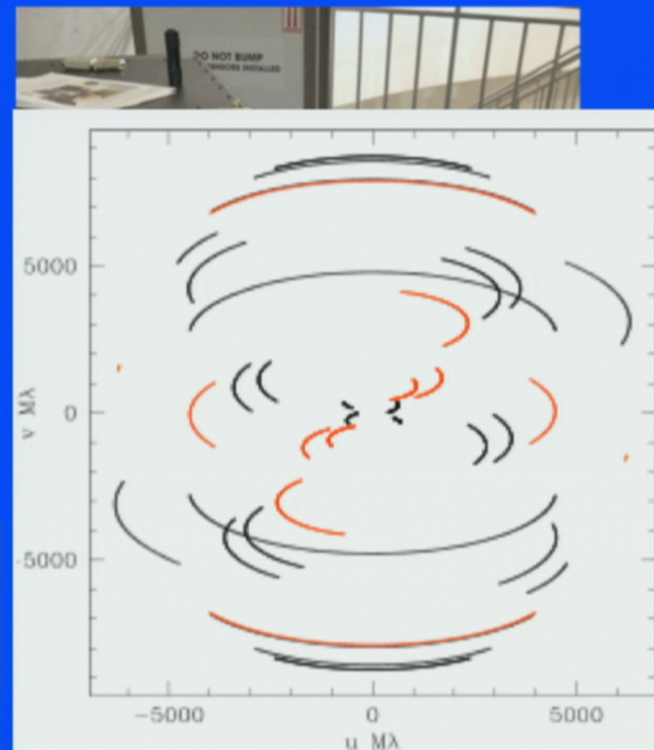
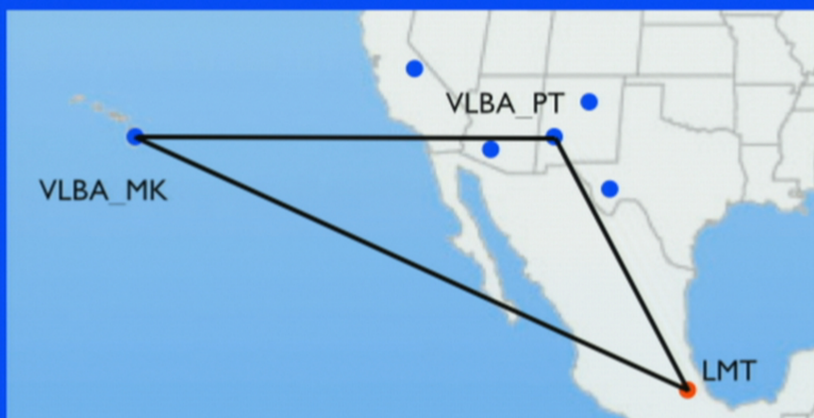
3mm VLBI with the LMT





Requires new 1.3mm Receiver for EHT work.

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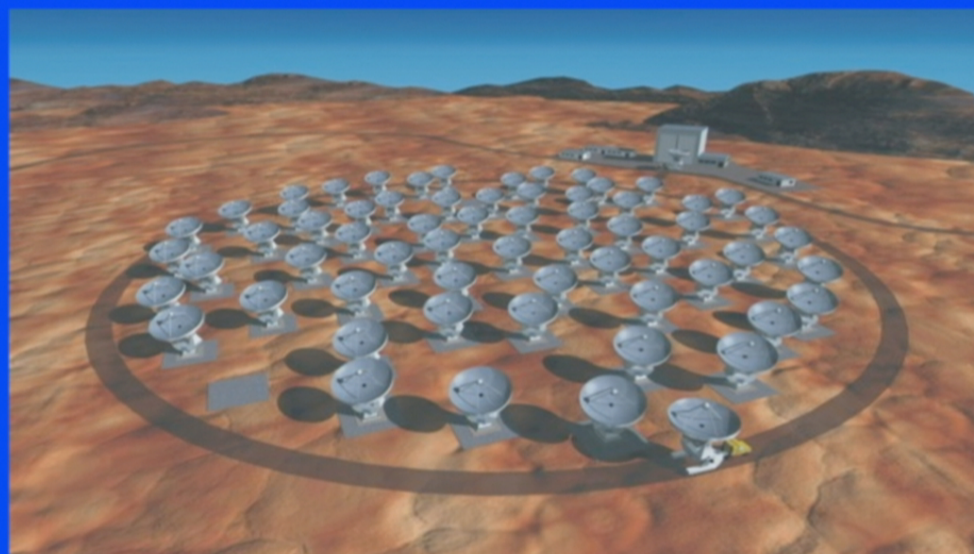
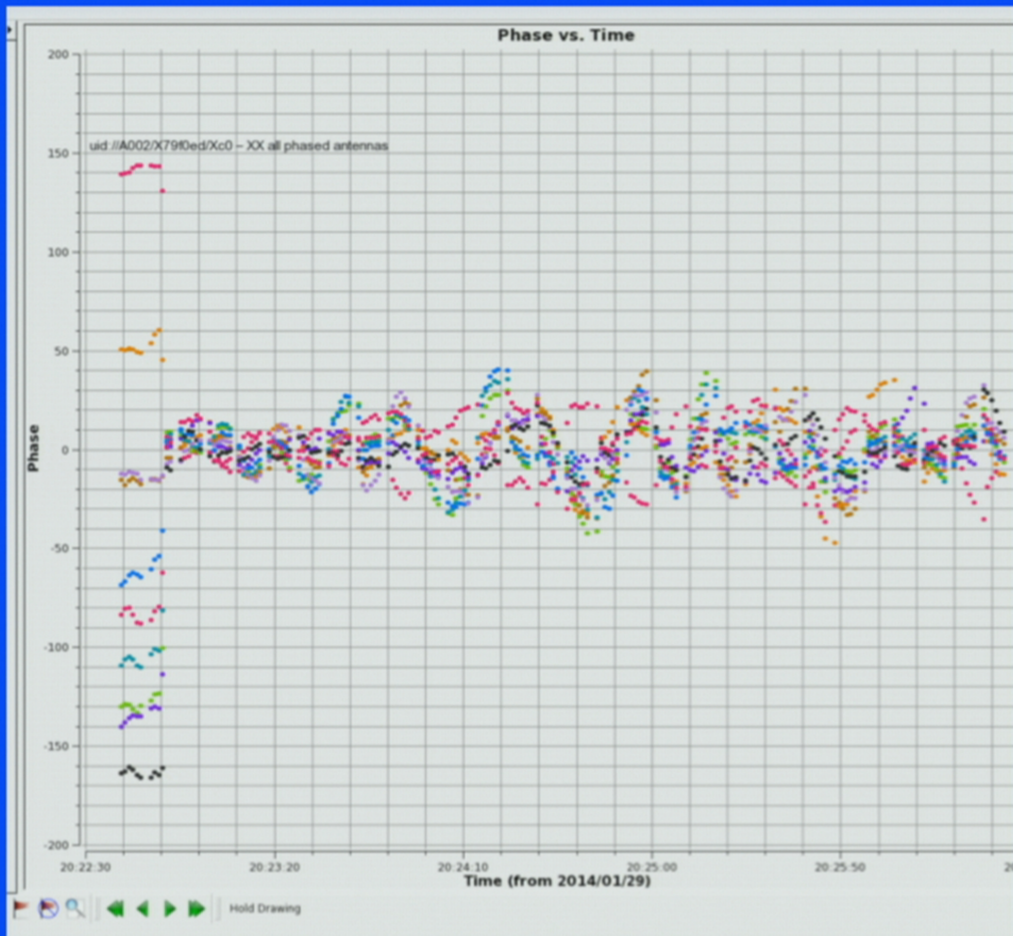
Phasing ALMA

- Single most important objective for EHT.
- Increases resolution by x2, sensitivity by x10.
- First ALMA VLBI scheduled 2015.



Phased ALMA

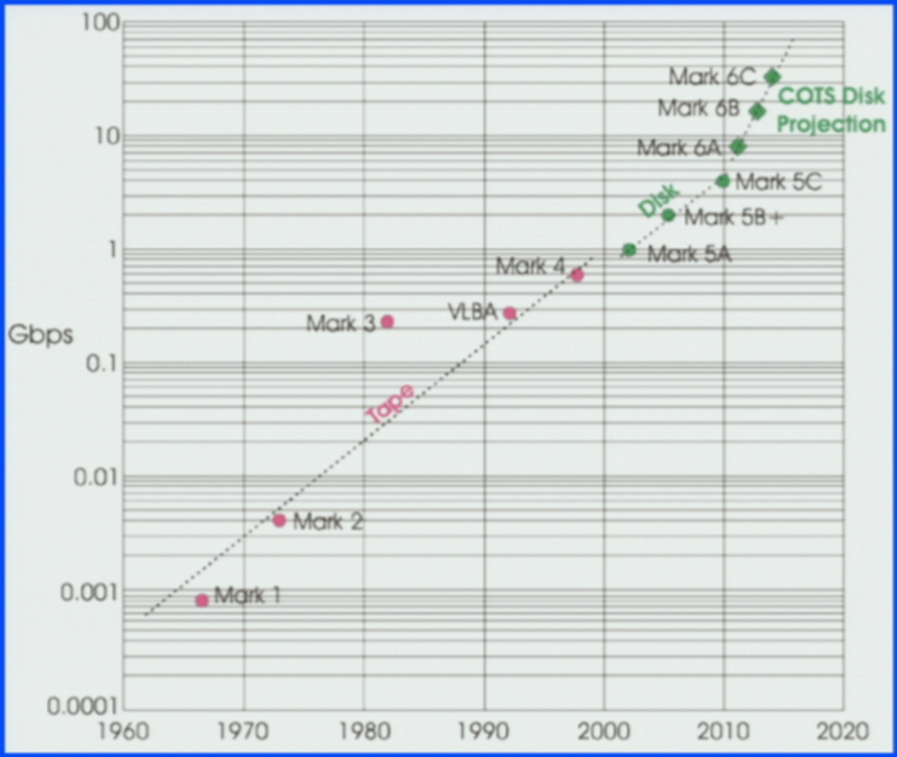


Excellent phasing in marginal weather.

Next Gen VLBI Technology: Keeping up with Moore

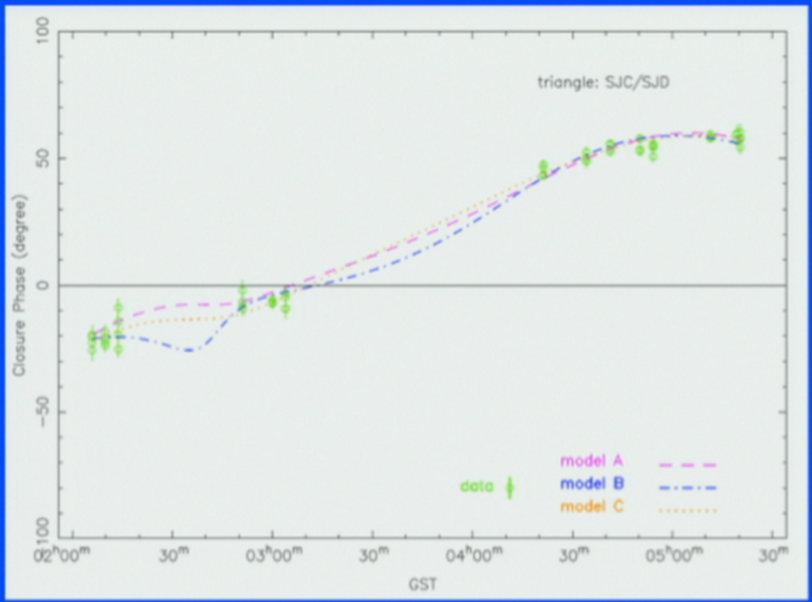
Digital Backend (DBE)

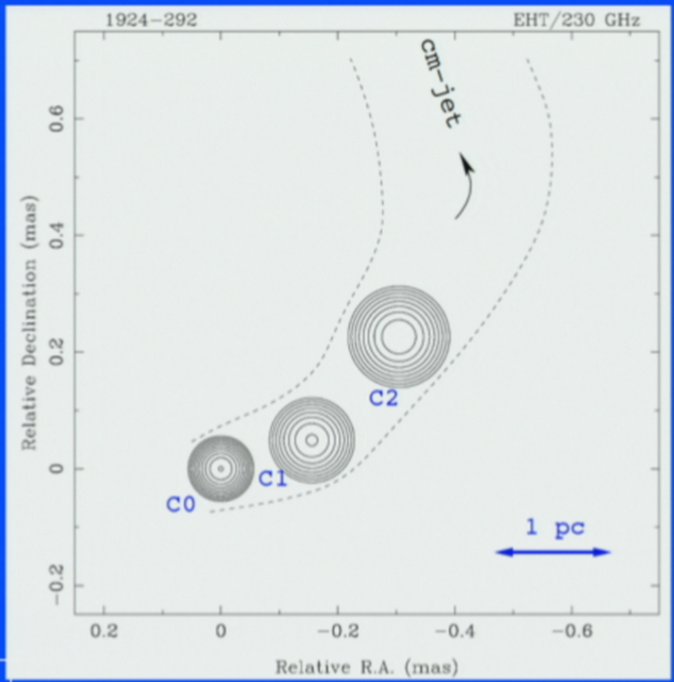
Digital Recorder (Mark6)



Current capability: 16 Gb/s.
Data per session: ~7 PetaBytes.

Robust 1.3mm VLBI Closure Phases on quasar 1924-292

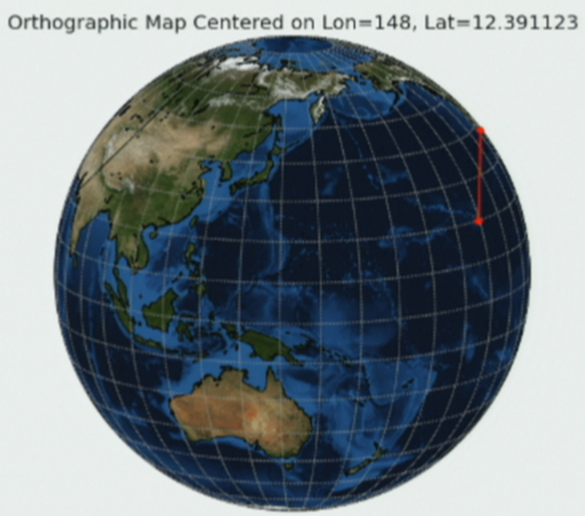


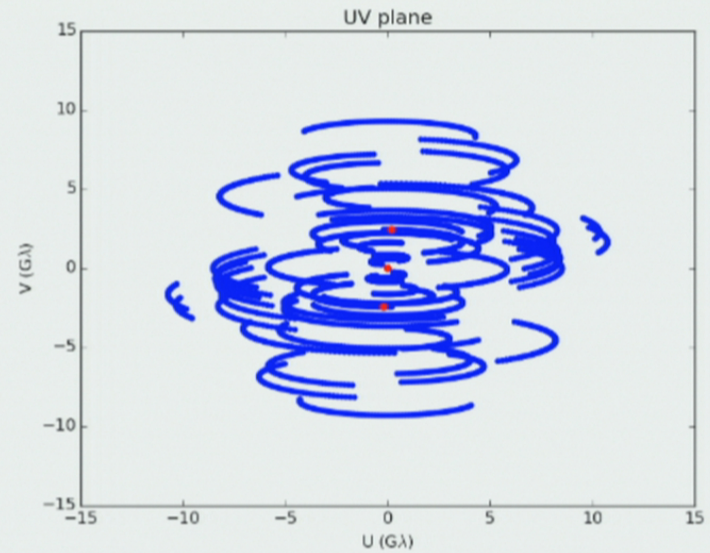


Closure Phase: sum of interferometric phase around closed triangle of VLBI baselines.

Rusen Lu et al 2012

Future EHT Coverage: M87





Animation: Laura Vertatschitsch (SAO)

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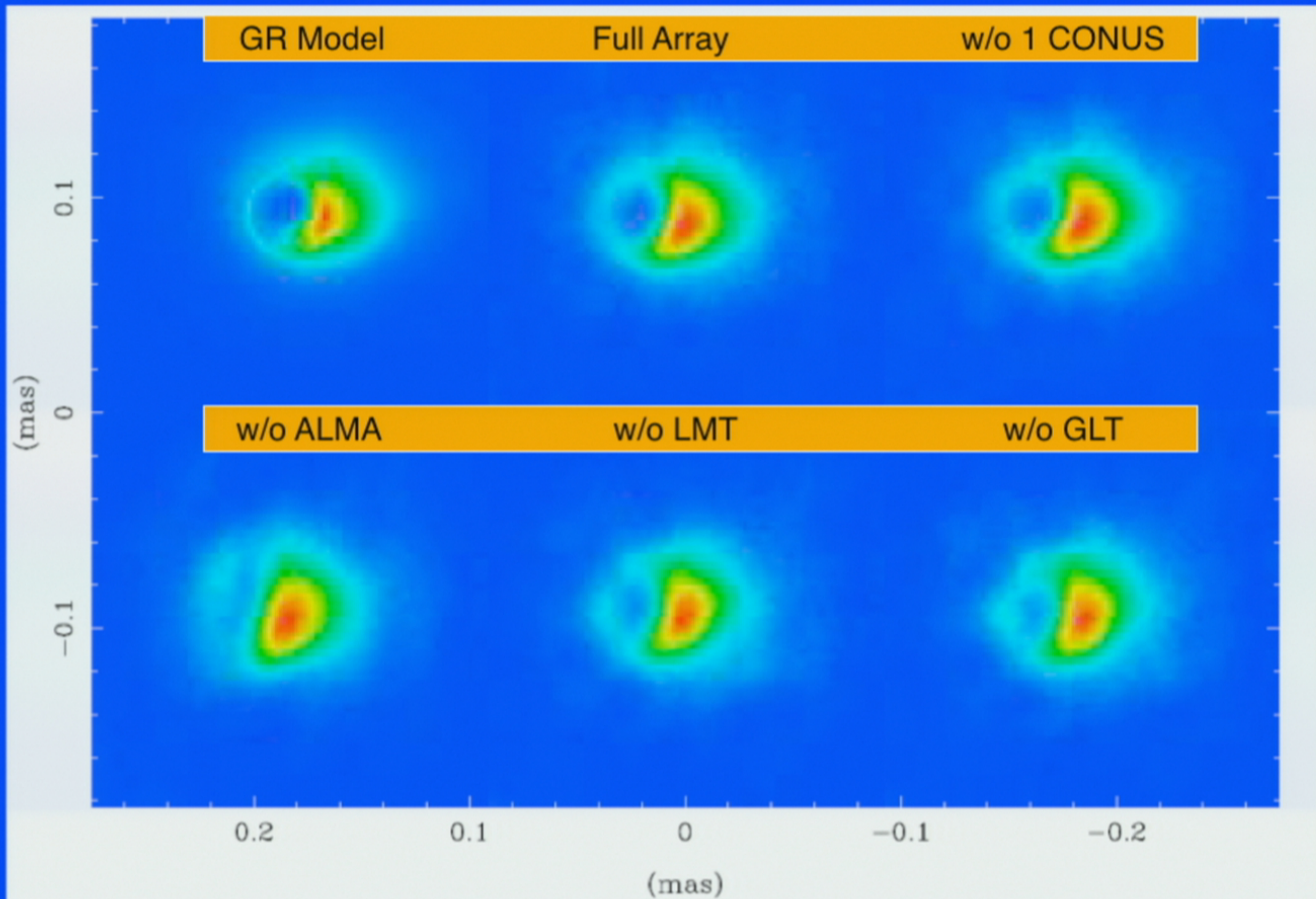
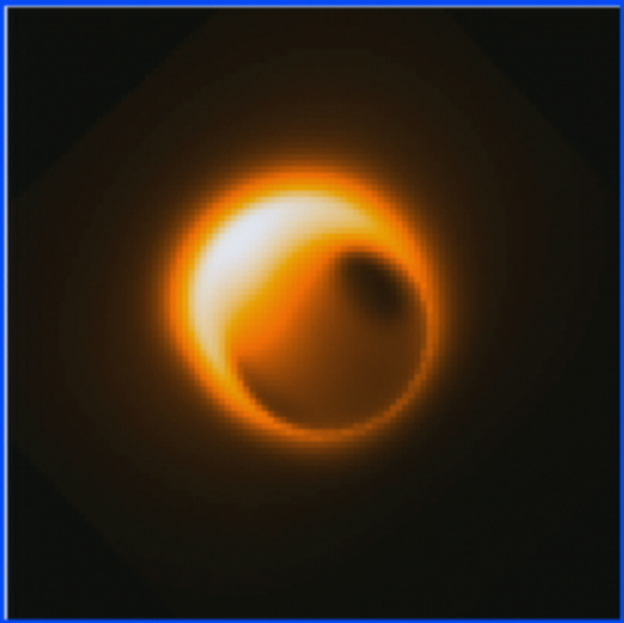
EHT Imaging: Optical Algorithms



Lu, Broderick, Baron, Monnier, et al, ApJ, v788, 120L, 2014

De-blurring SgrA*



Fish et al, ApJ, v.795, p.134, 2014.

M. Johnson’s Friday Talk

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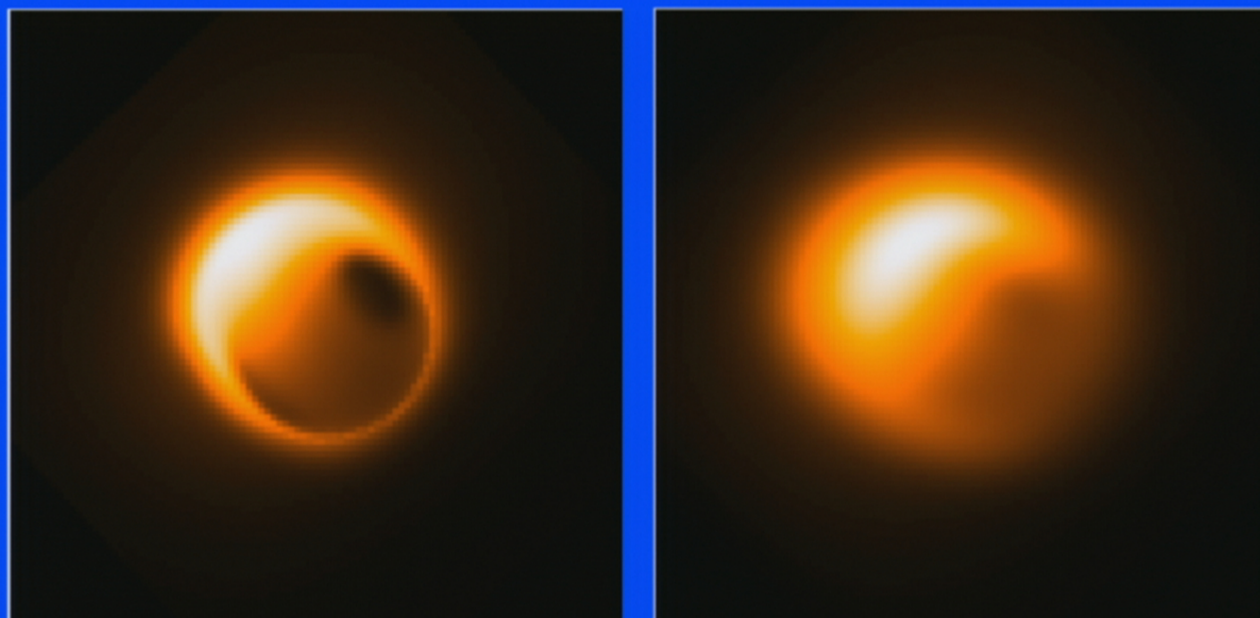
De-blurring SgrA*

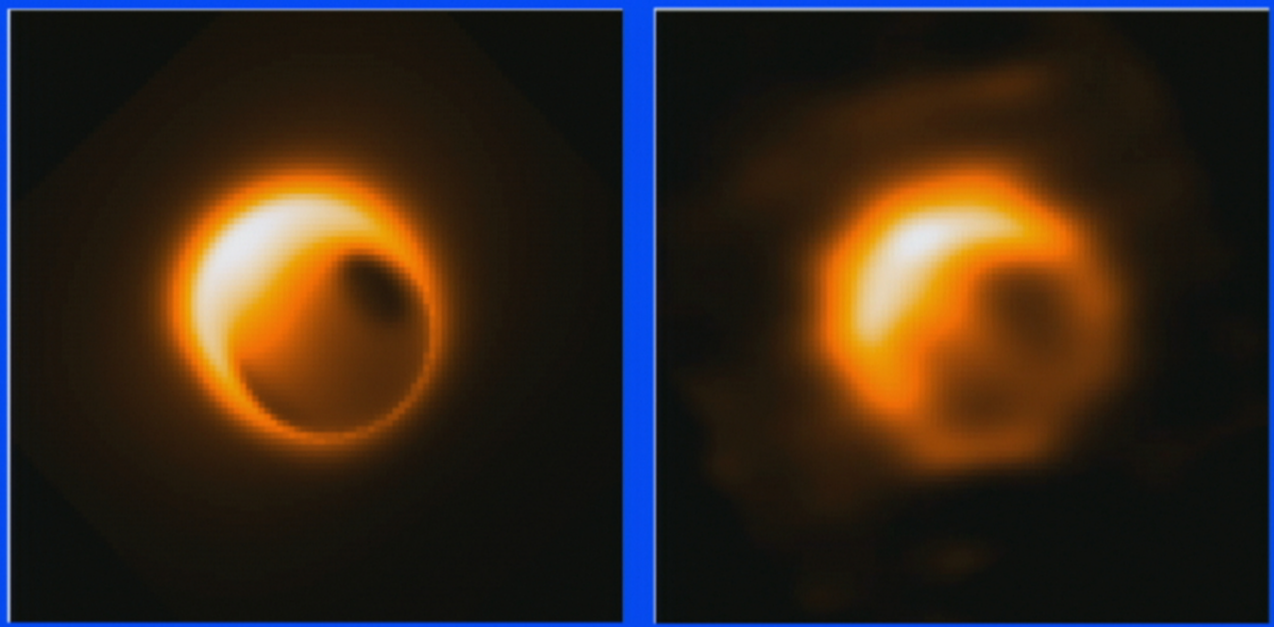


Fish et al, ApJ, v.795, p.134, 2014.

M. Johnson’s Friday Talk

23

De-blurring SgrA*



Fish et al, ApJ, v.795, p.134, 2014.

M. Johnson’s Friday Talk

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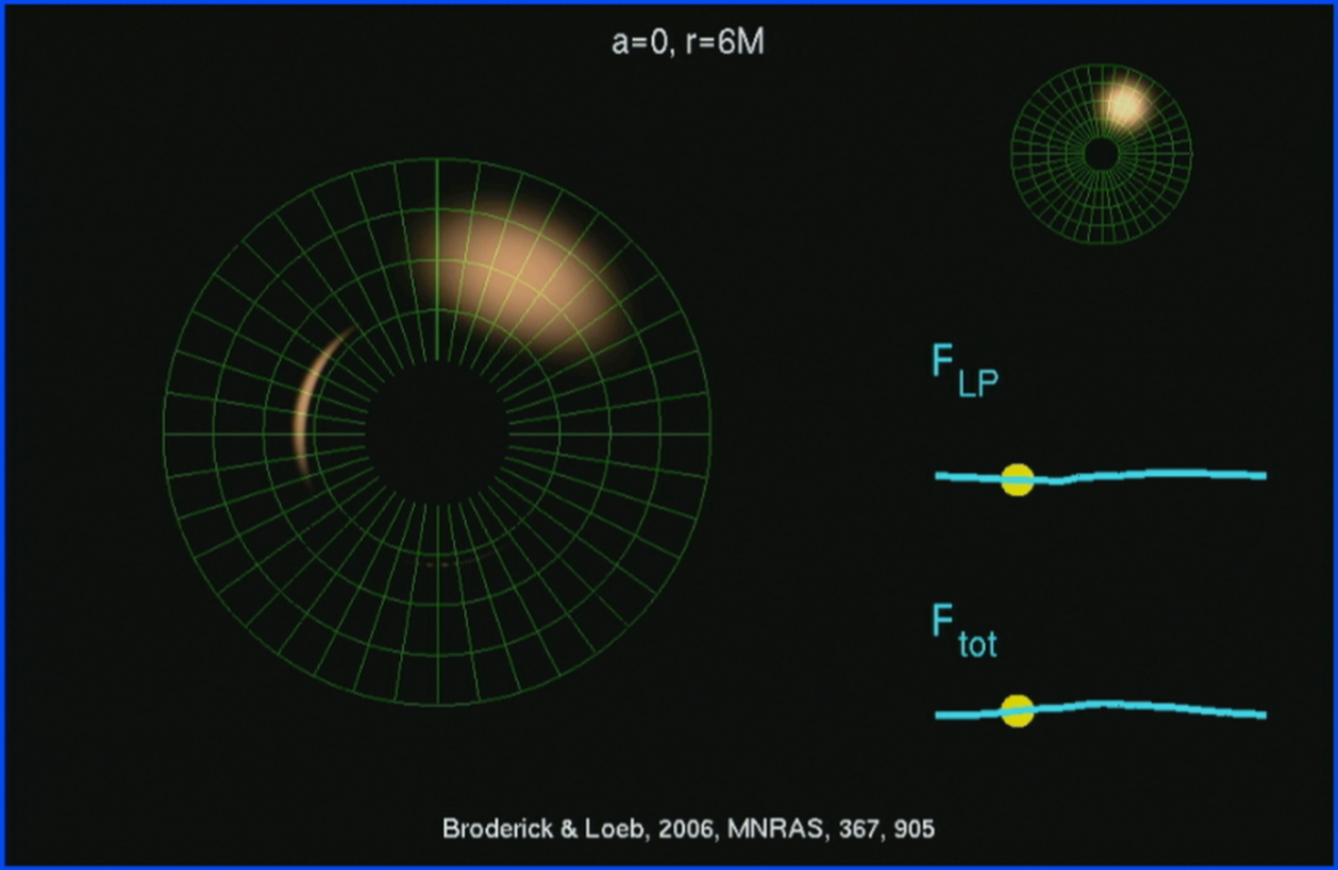
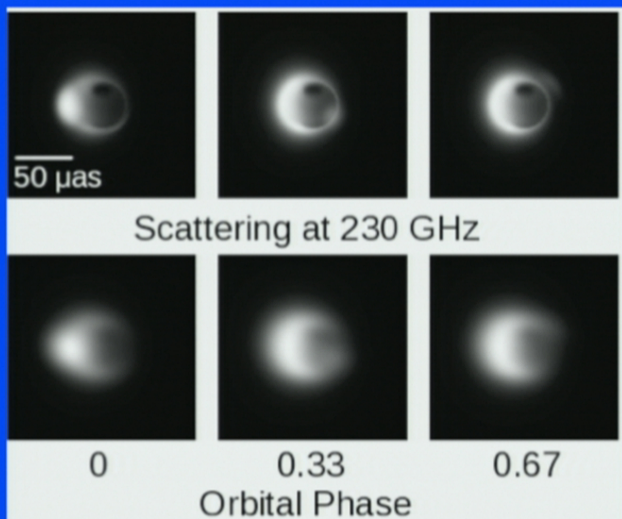
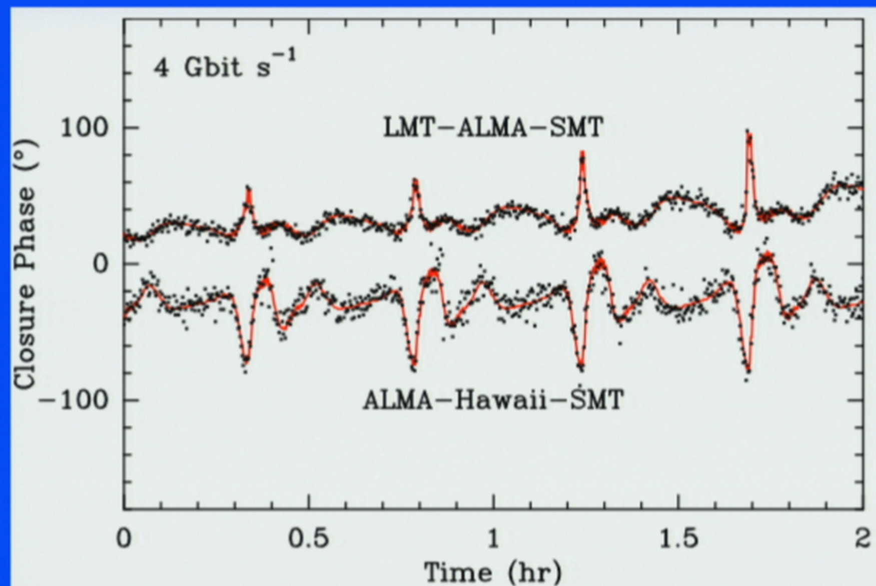
Hot Spot Model for SgrA* Flares



Time Resolving BH Orbits

- Full EHT can measure closure phase on 10s intervals (25 times faster than smallest ISCO Period).





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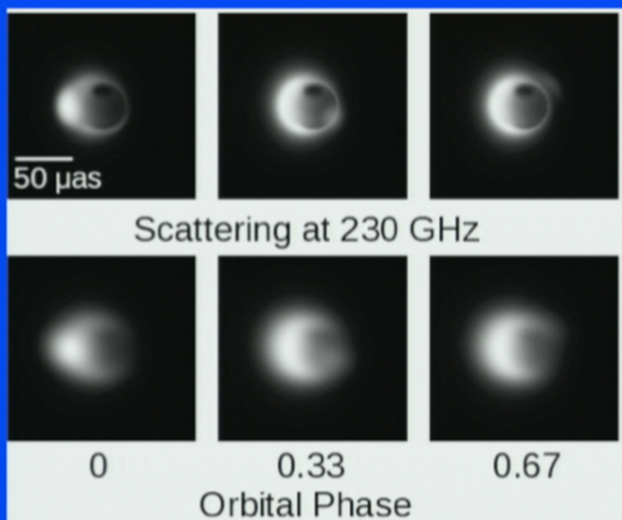

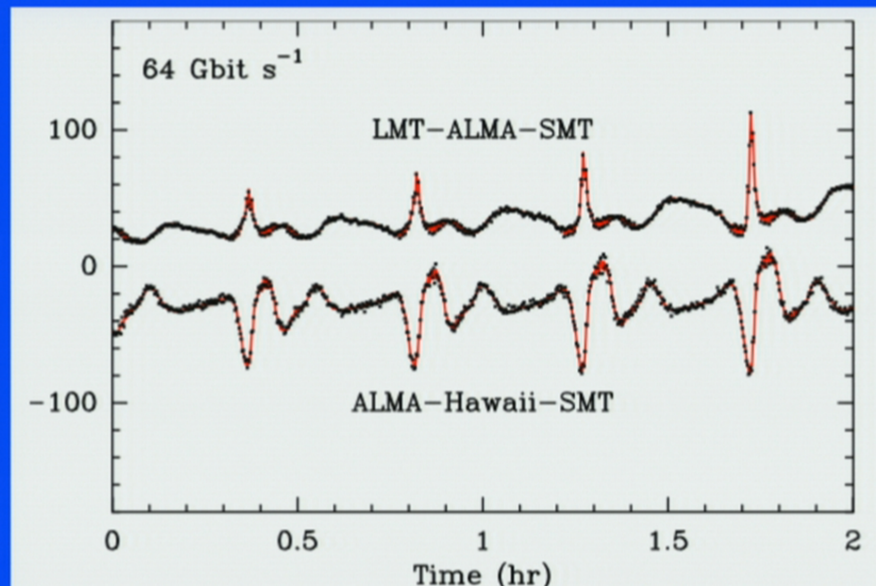

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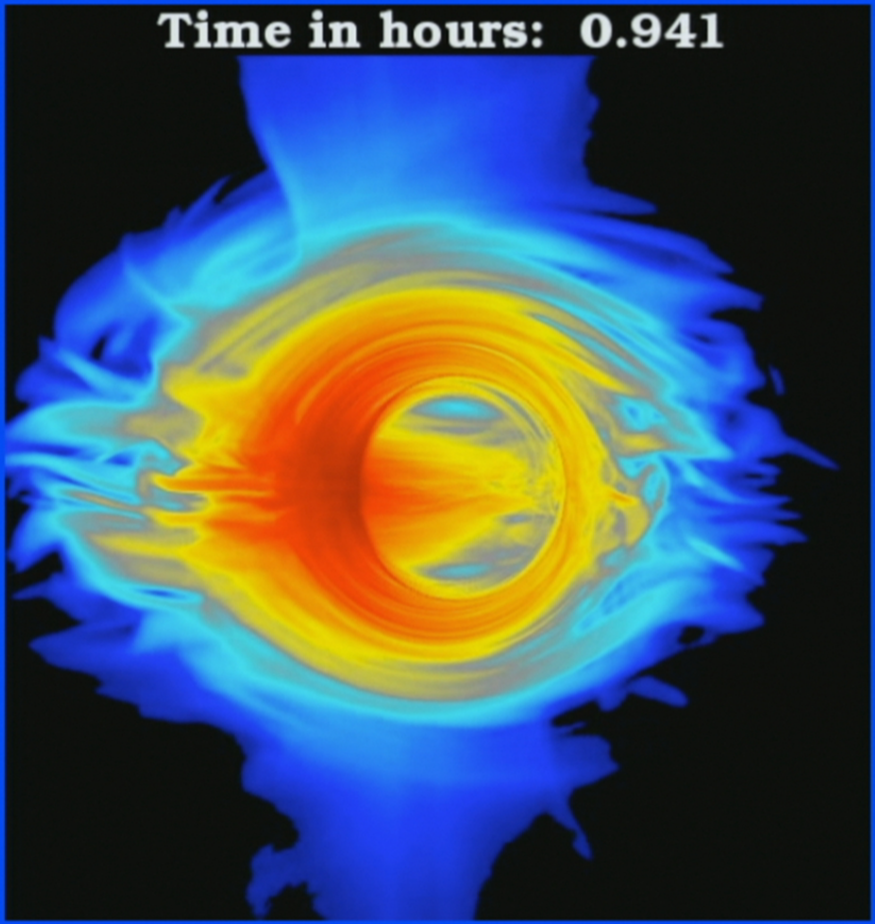
GRMHD Simulation of SgrA*



Dolence, Gammie et al

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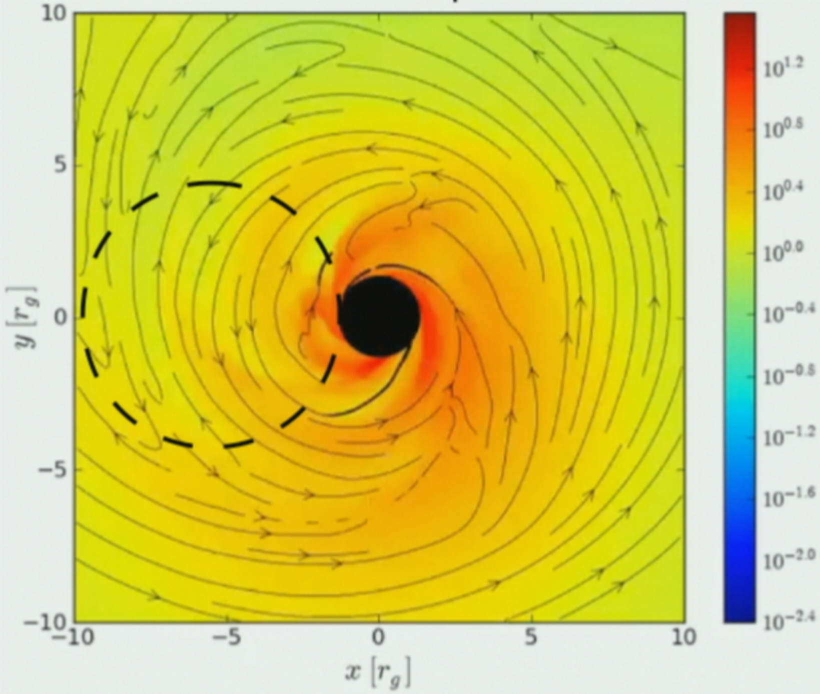
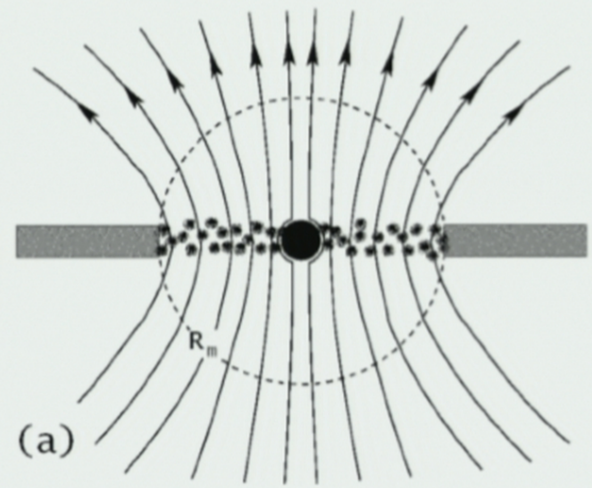
Ordered Fields?

Sheared Fields in Keplerian Flow



McKinney et al. (2012)

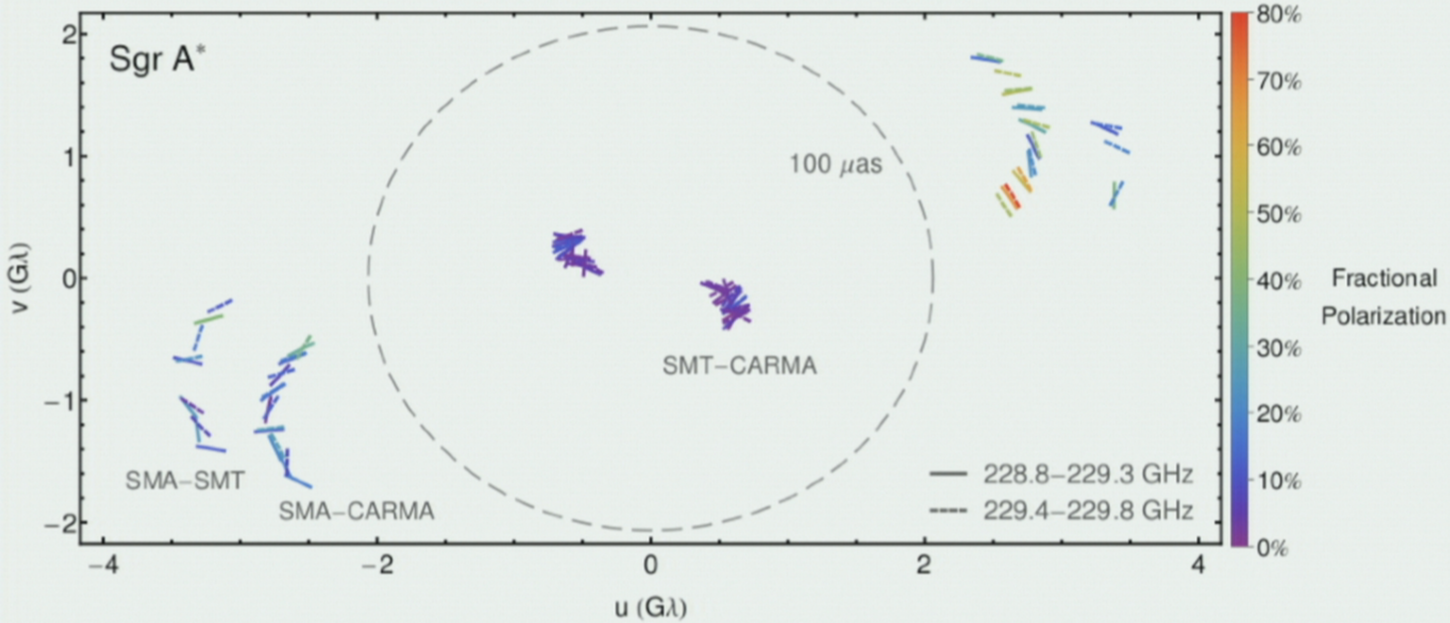
Magnetically-Arrested Disk



Narayan et al. (2003)

Sgr A*

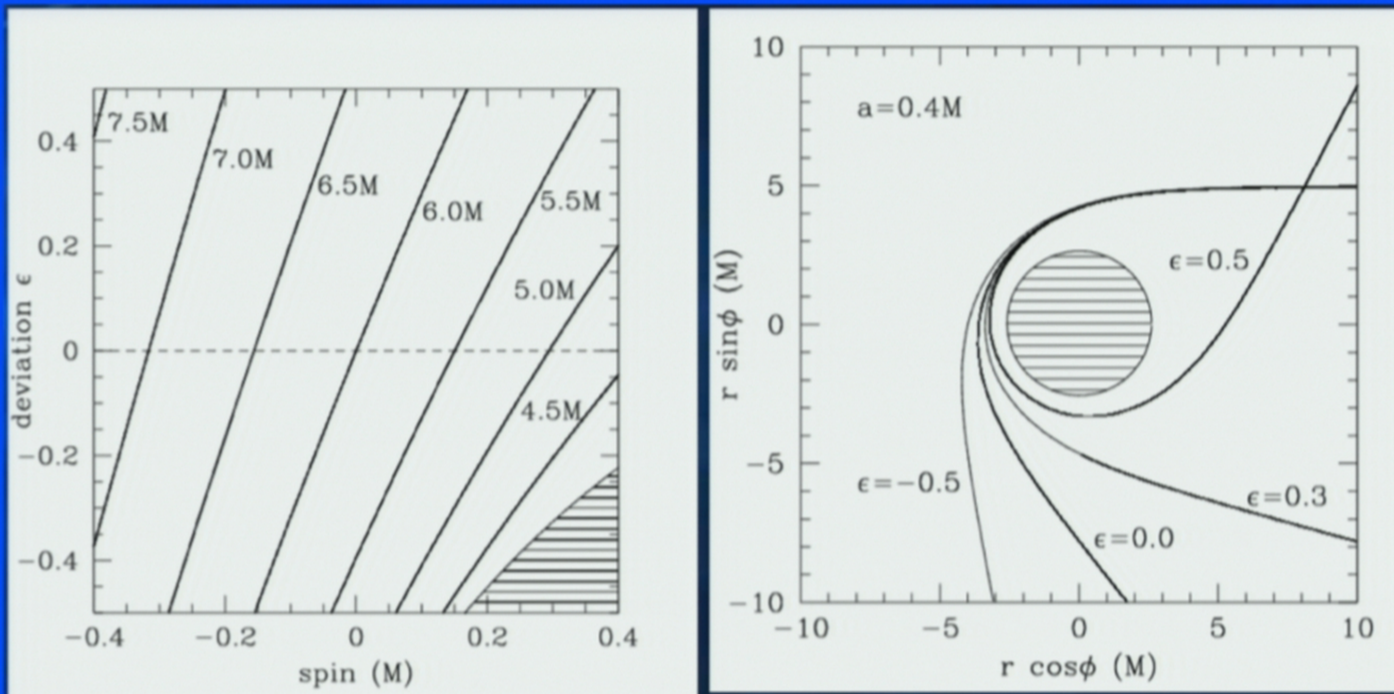
2013 EHT Data (Preliminary)



M. Johnson et al (in prep)

Perturbing the Kerr Metric: Quasi-Kerr

$$Q' = -a^2/M^2 + \varepsilon$$



Location of the ISCO

Lightbending

Johannsen & Psaltis: (2010), (2011)

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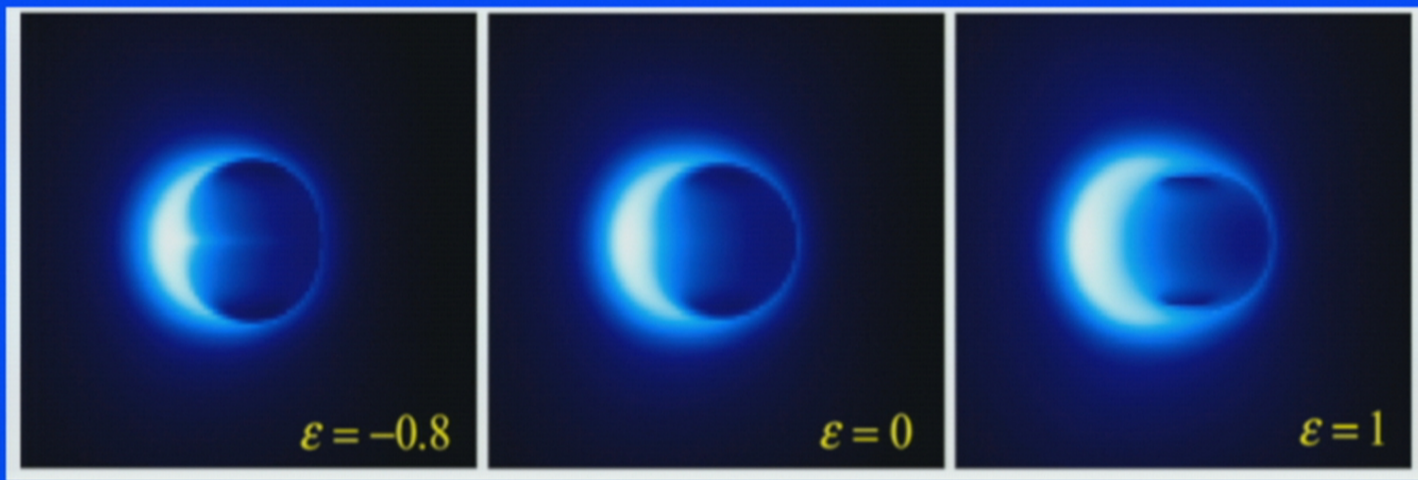
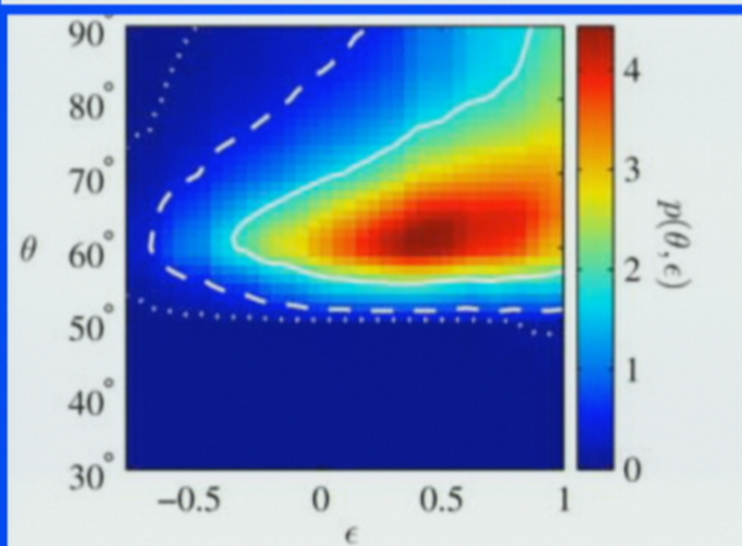
Tests of GR





Broderick, Johannsen, Loeb & Psaltis, ApJ, v784, 7B, 2014

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EHT Roadmap

- Fringes to APEX in Spring 2013.
- 3mm VLBI test @ LMT completed: 1.3mm Rx.
- Greenland Tel. plans underway (dish retrofit).
- South Pole VLBI by 2015:funded through NSF.
- ALMA ready by early 2015.
- IRAM 30m, PdeBure upgrades: MPIfR +ERC
- JCMT: Now operated by EA-consortium
- SMA: new phased array/backend underway.
- NSF MSIP award for EHT operations and final build-out: correlator, data pipeline.

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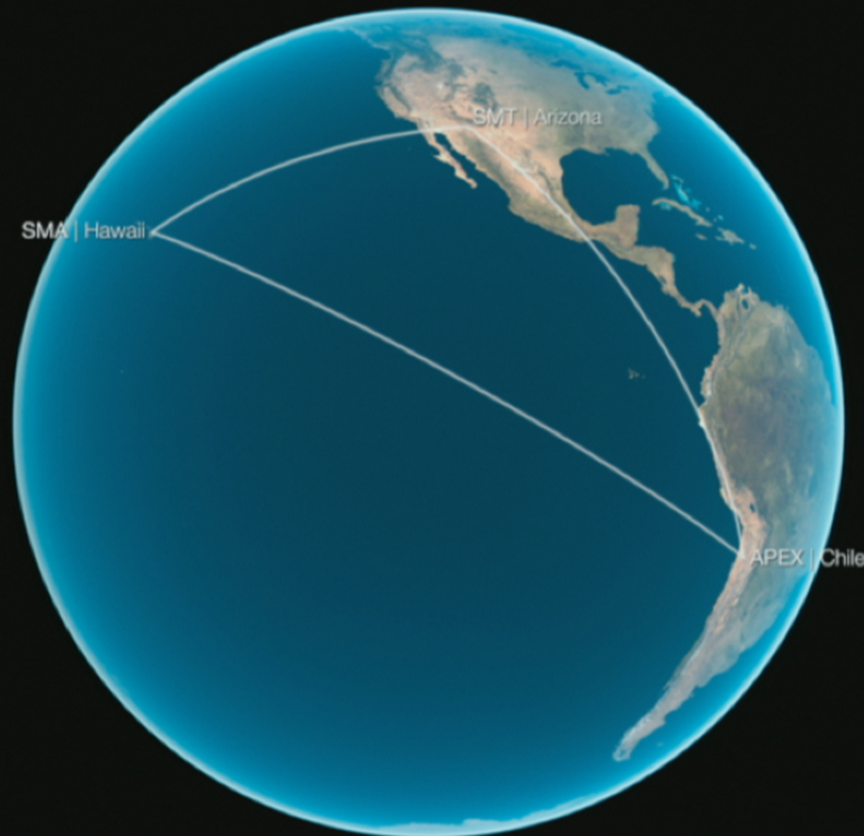
EHT Roadmap



EHT

MPIfR - Bonn
ASIAA
SAO/CfA
MIT Haystack
CARMA
NAOJ
U. Arizona
BHC

NRAO
UC Berkeley
IRAM
APEX
JCMT
U. Concepcion
UNAM

Perimeter Institute
U. Illinois UC
UMD
Onsala Space Obs.
U. Mass Amherst
LMT
INAOE

The Event Horizon Telescope (2012): Bringing Black Holes into Focus

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Summary

- Enabled by pre-cursor observations, EHT is nearing technical readiness for full operations.
- Imaging an Event Horizon and observing BH orbits are within reach in <3 years. Instrumentation is funded.
- Challenges: EHT sites under pressure (CARMA) - some key community discussions to have.
- This Conference:
    - Explore EHT Science in broad context.
    - Review and plan technical elements.
    - Organizational Discussions.
- www.eventhorizontelescope.org