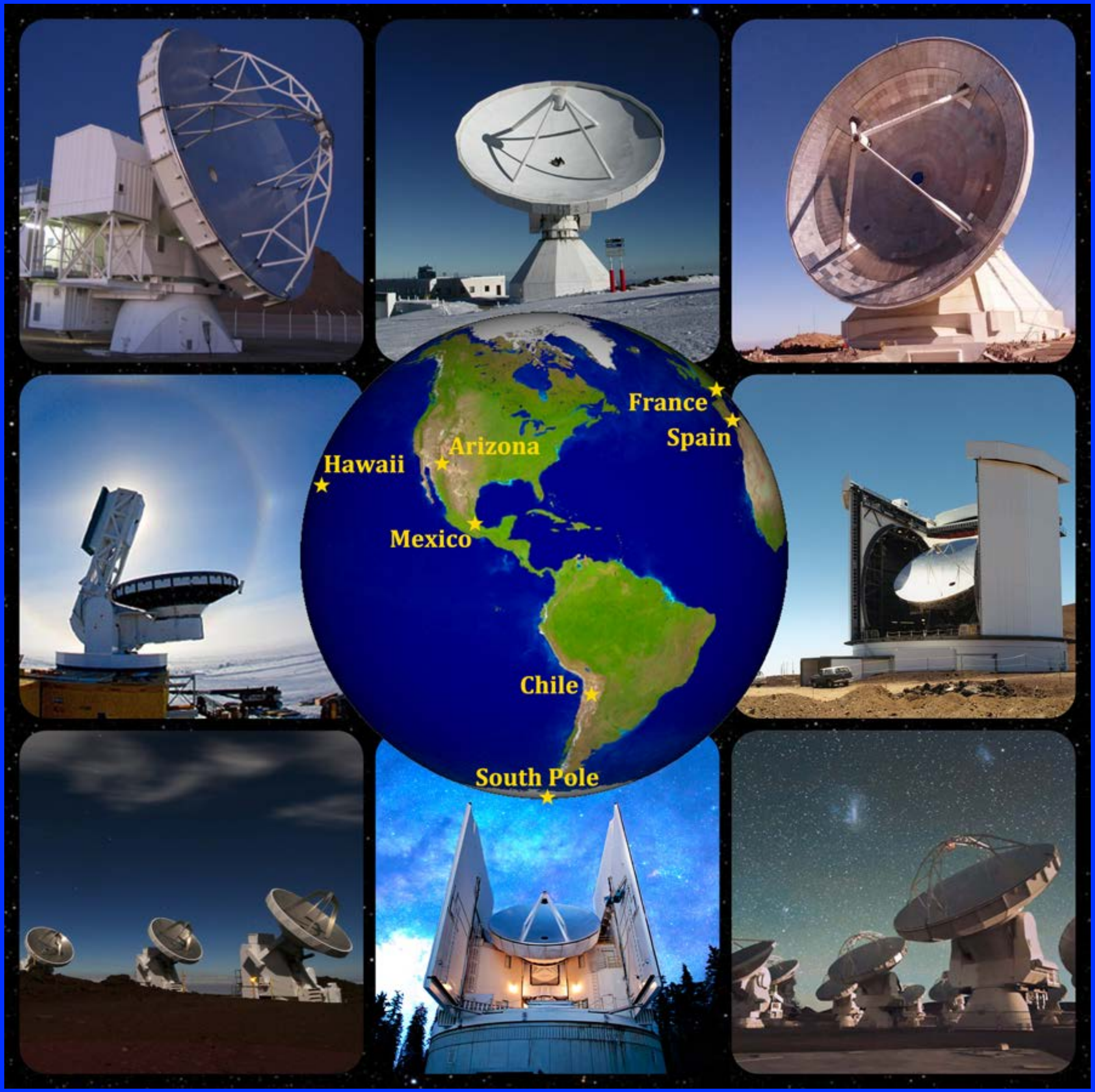
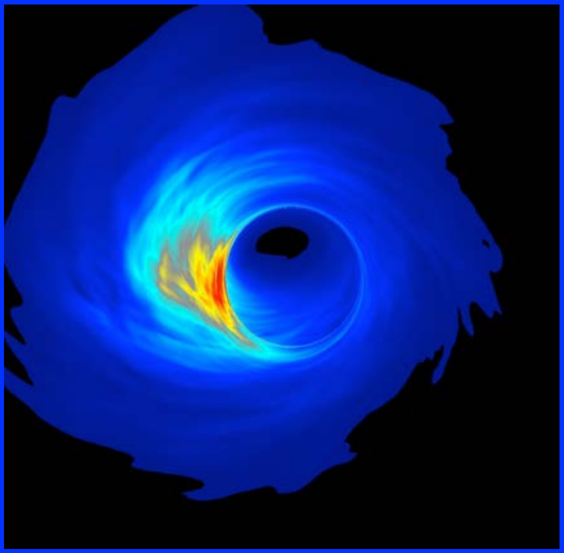
Resolving and Imaging Black Holes with the Event Horizon Telescope

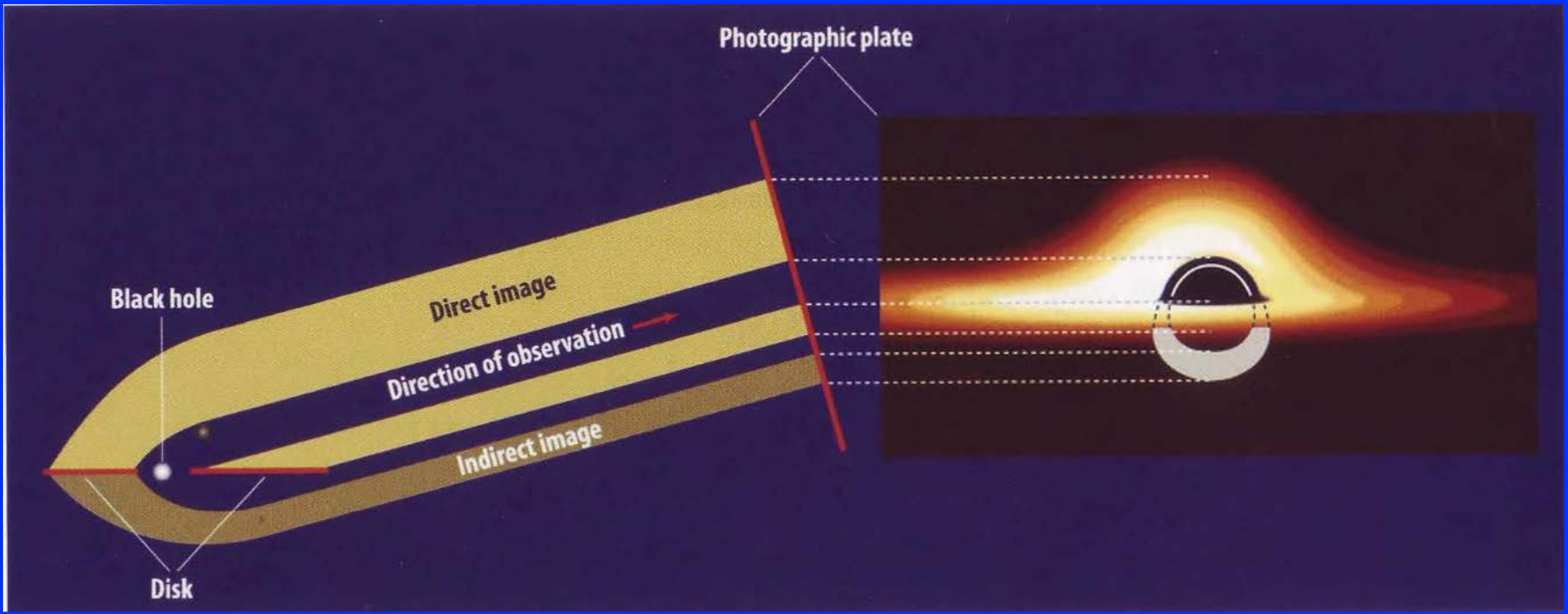




Sheperd Doeleman (CfA)

Centaurus A: Radio

Strong GR: The Black Hole Silhouette



Bardeen 1973
Luminet 1979
Falcke. Melia & Agol 2000
Takahashi 2004

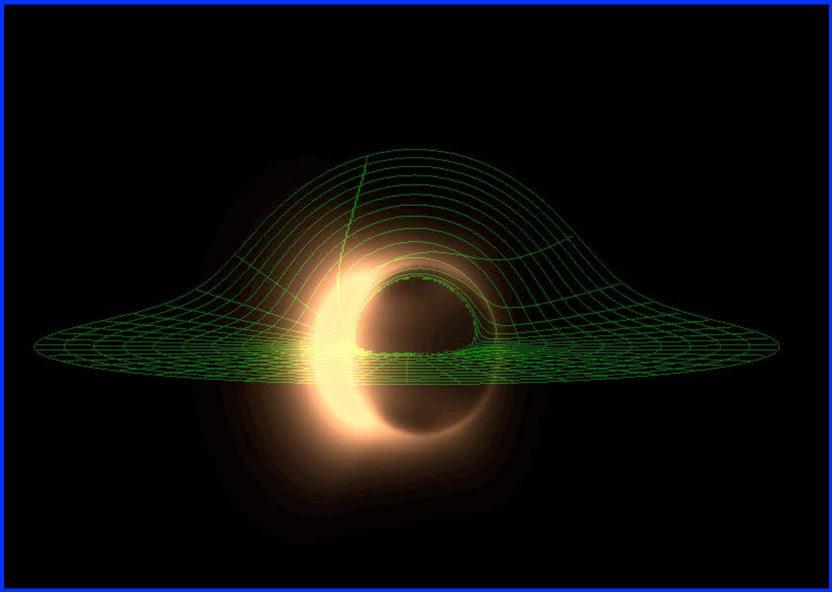
Shadow Diameter:

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

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

Shadow size and shape encodes GR (Dimitrios & Johansen 2010).

Theoretical Simulations



Broderick & Loeb

Psaltis et al

Mościbrodzka et al

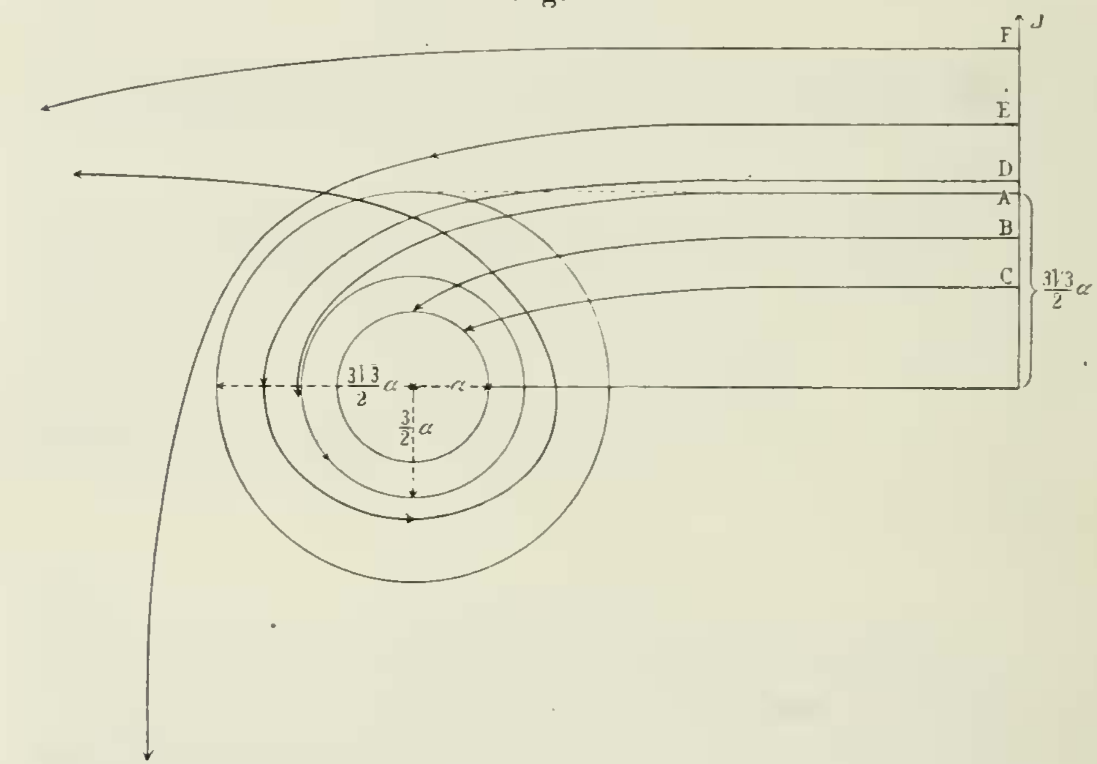
Asymmetry due to Doppler boosting.

Radio emission from synchrotron process.

Max van Laue - 1921

Daraus ziehen wir in Anlehnung an Poincarés Zykeltheorie den überdies recht anschaulichen Schluß: Der Lichtstrahl, der im Unendlichen auf den Abstand $\Delta = \frac{3\sqrt{3}}{2}\alpha$ hinzielt, biegt sich nach innen und nähert sich auf einer Spirale asymptotisch dem Kreise $r = \frac{3}{2}\alpha$. Dann ergibt sich für die Gesamtheit der betrachteten Strahlen die Fig. 23. Sie zeigt uns die Kreise $r = \alpha$,

Fig. 23.



an welchem jeder herankommende Lichtstrahl endigt (ist doch dort die Lichtgeschwindigkeit 0), ferner $r = \frac{3}{2}\alpha$ und $r = \frac{3\sqrt{3}}{2}\alpha$.

Die Grundlagen der Physik.

(Zweite Mitteilung.)

Von

David Hilbert.

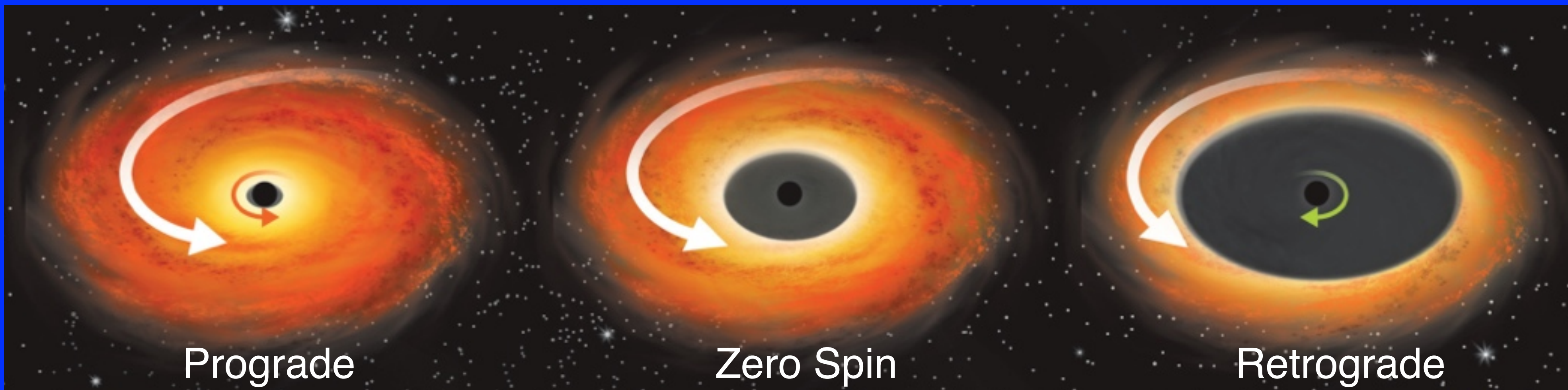
Vorgelegt in der Sitzung vom 23. Dezember 1916.

Allgemein erhalten wir für die Lichtbahn aus (56) wegen $A = 0$ die Differentialgleichung

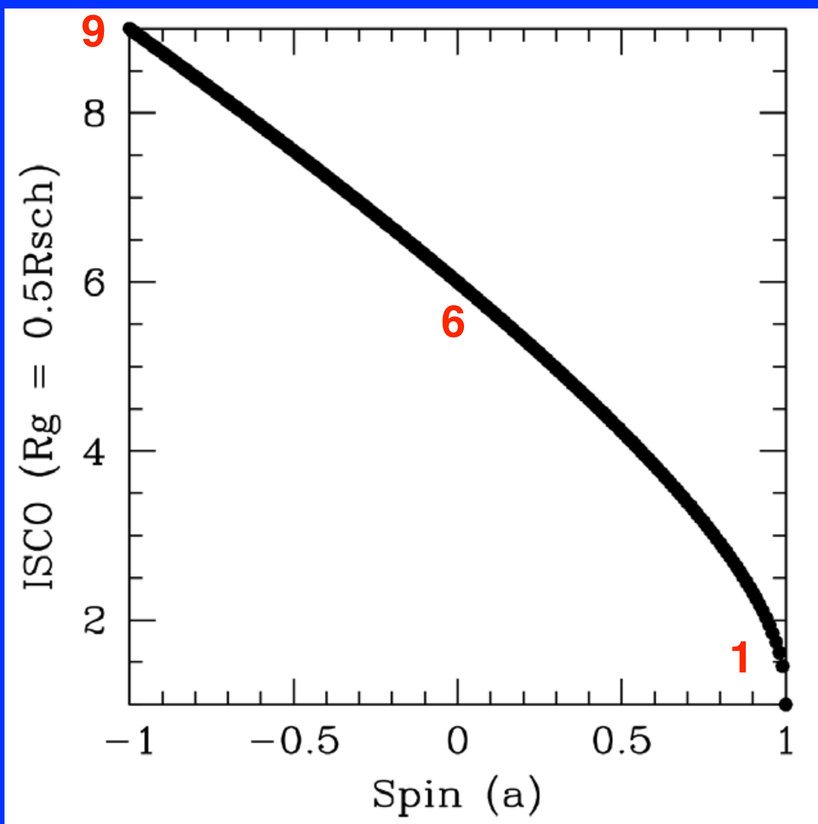
$$\left(\frac{d\varrho}{d\varphi}\right)^2 = \frac{1}{B^2} - \varrho^2 + \alpha\varrho^3; \tag{62}$$

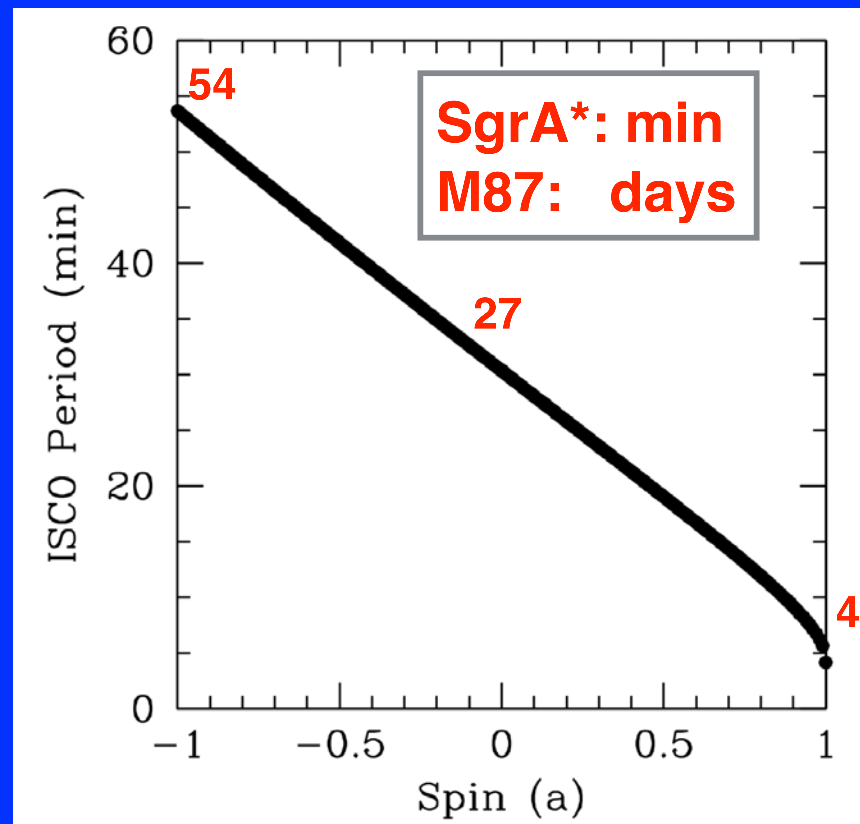
dieselbe besitzt für $B = \frac{3\sqrt{3}}{2}\alpha$ den Kreis $r = \frac{3\alpha}{2}$ als Poincaréschen

Innermost Stable Circular Orbit

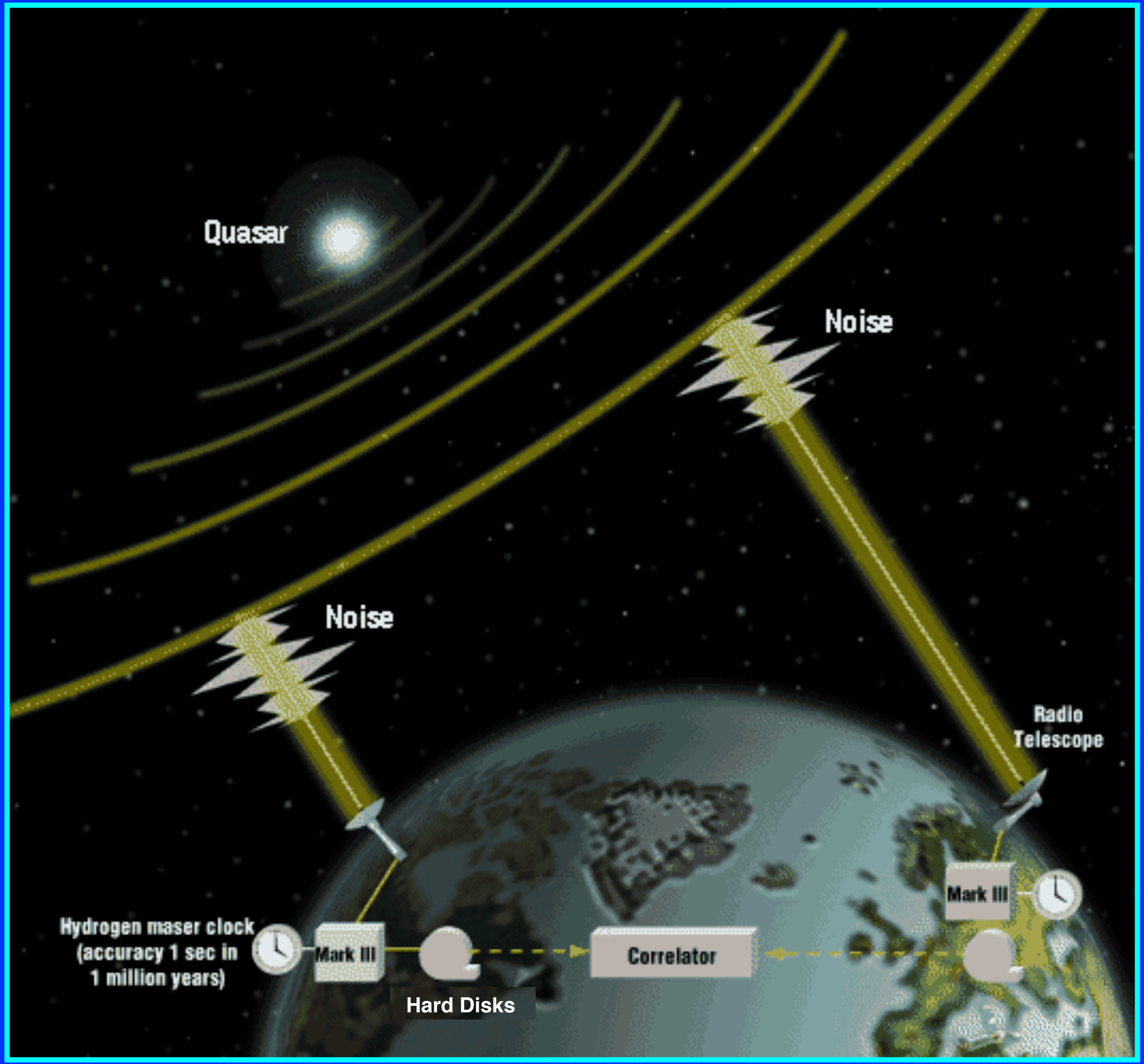


Sky & Telescope



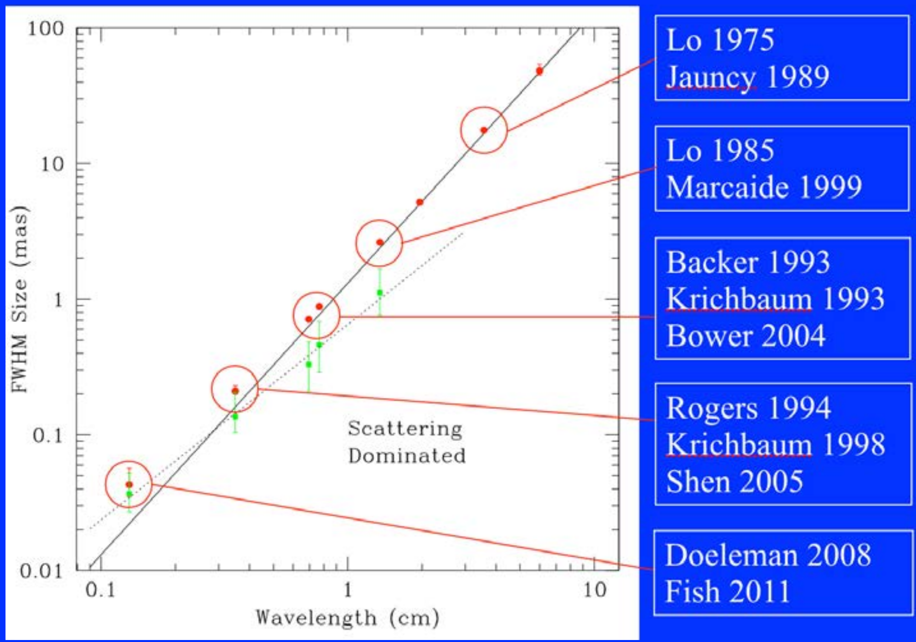


Short Wavelength VLBI



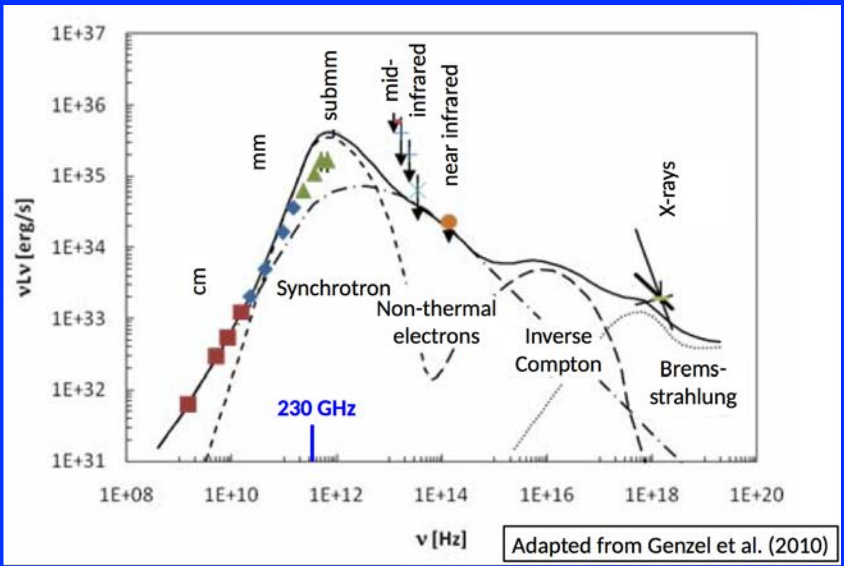
A Goldilocks Situation

- Resolution: 1.3mm/D_earth < shadow size.
- Earth's Atmosphere: turbulent but opacity<1.
- ISM: free electron scattering ~ lambda^2.



A Goldilocks Situation

- Resolution: 1.3mm/D_earth < shadow size.
- Earth's Atmosphere: turbulent but opacity<1.
- ISM: free electron scattering ~ lambda^2.
- Accretion Flow optically thin.



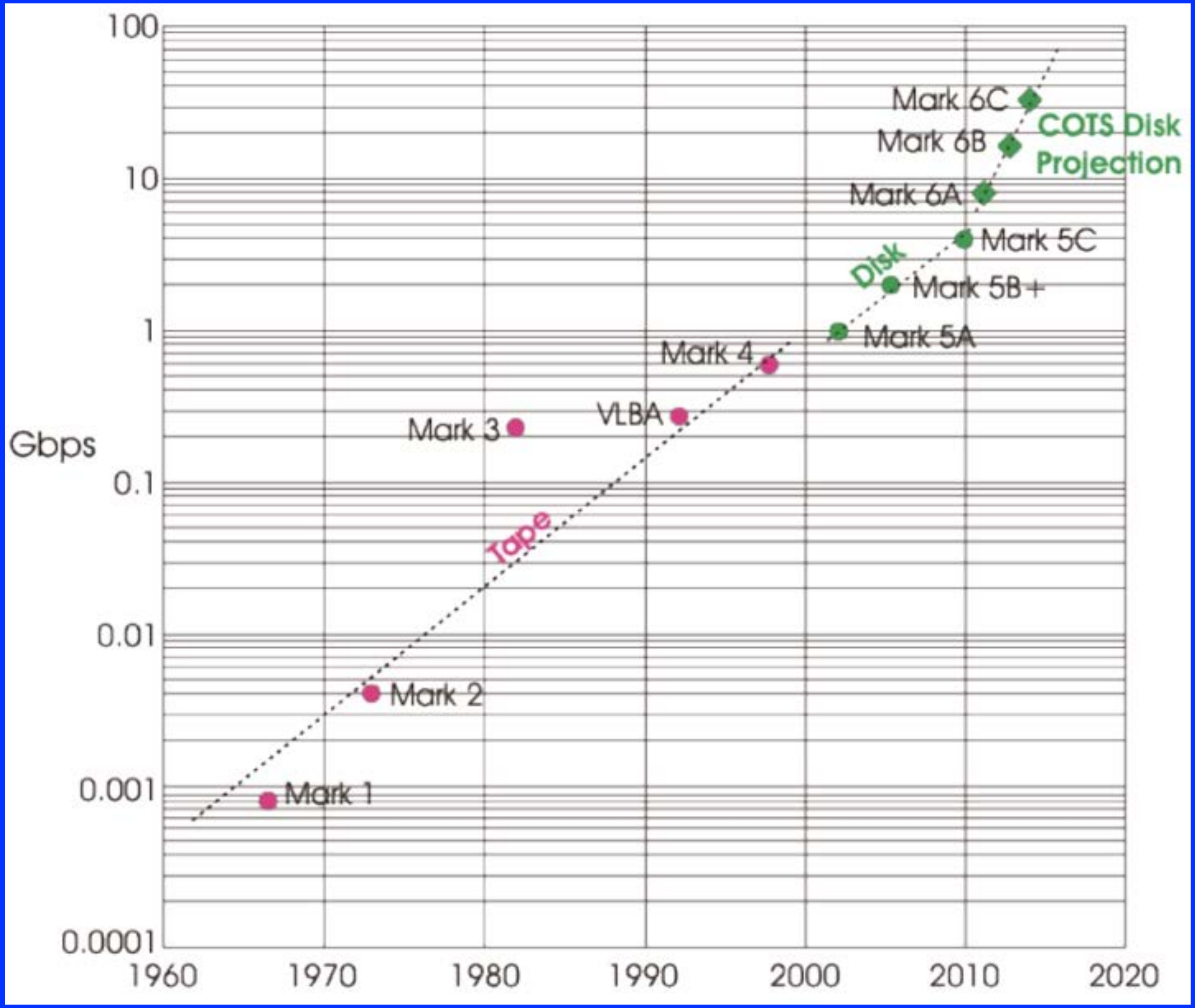
A Goldilocks Situation

- Resolution: 1.3mm/D_earth < shadow size.
- Earth’s Atmosphere: turbulent but opacity<1.
- ISM: free electron scattering ~ lambda^2.
- Accretion Flow optically thin.
- Sensitivity: Bandwidth and Apertures.

Next Gen VLBI Technology: Keeping up with Moore

Roach Digital Backend (R2DBE)

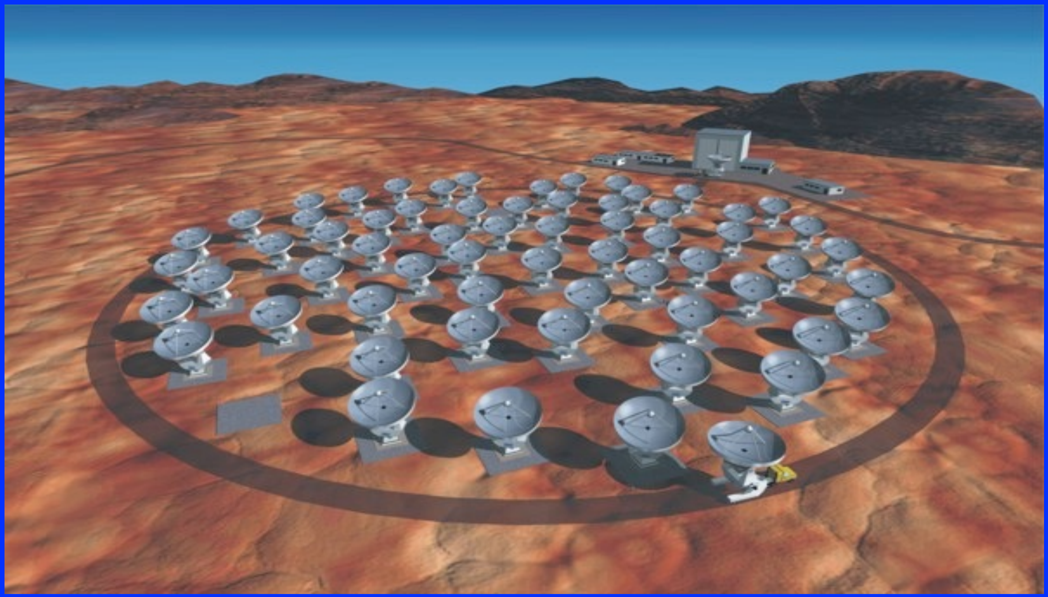
Digital Recorder (Mark6)

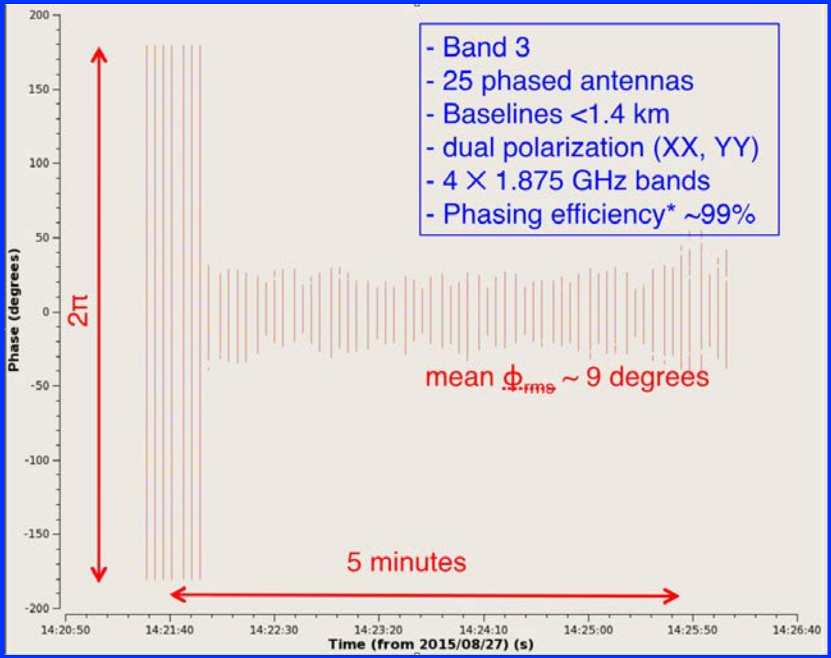


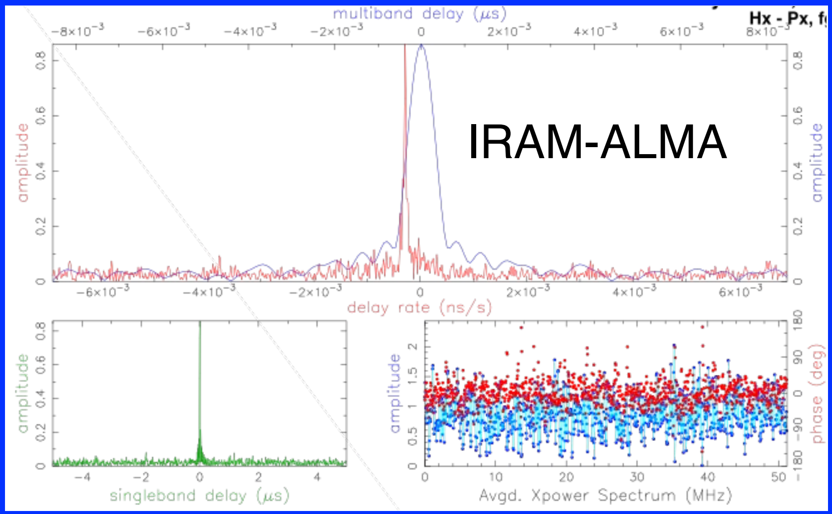
Current capability: 16 Gb/s.
Data per session: ~7 PetaBytes.

Laura Vertatschitsch (2015)

Adding ALMA to the EHT







- *Several Successful Campaigns*
- *1.3mm VLBI Fringes to multiple sites.*

EHT adds the South Pole Station

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Press Release 15-041

Planet-sized 'virtual telescope' expands to the South Pole to observe black holes in detail

NSF-supported South Pole Telescope incorporated as part of global network

The South Pole Telescope.
Credit and Larger Version

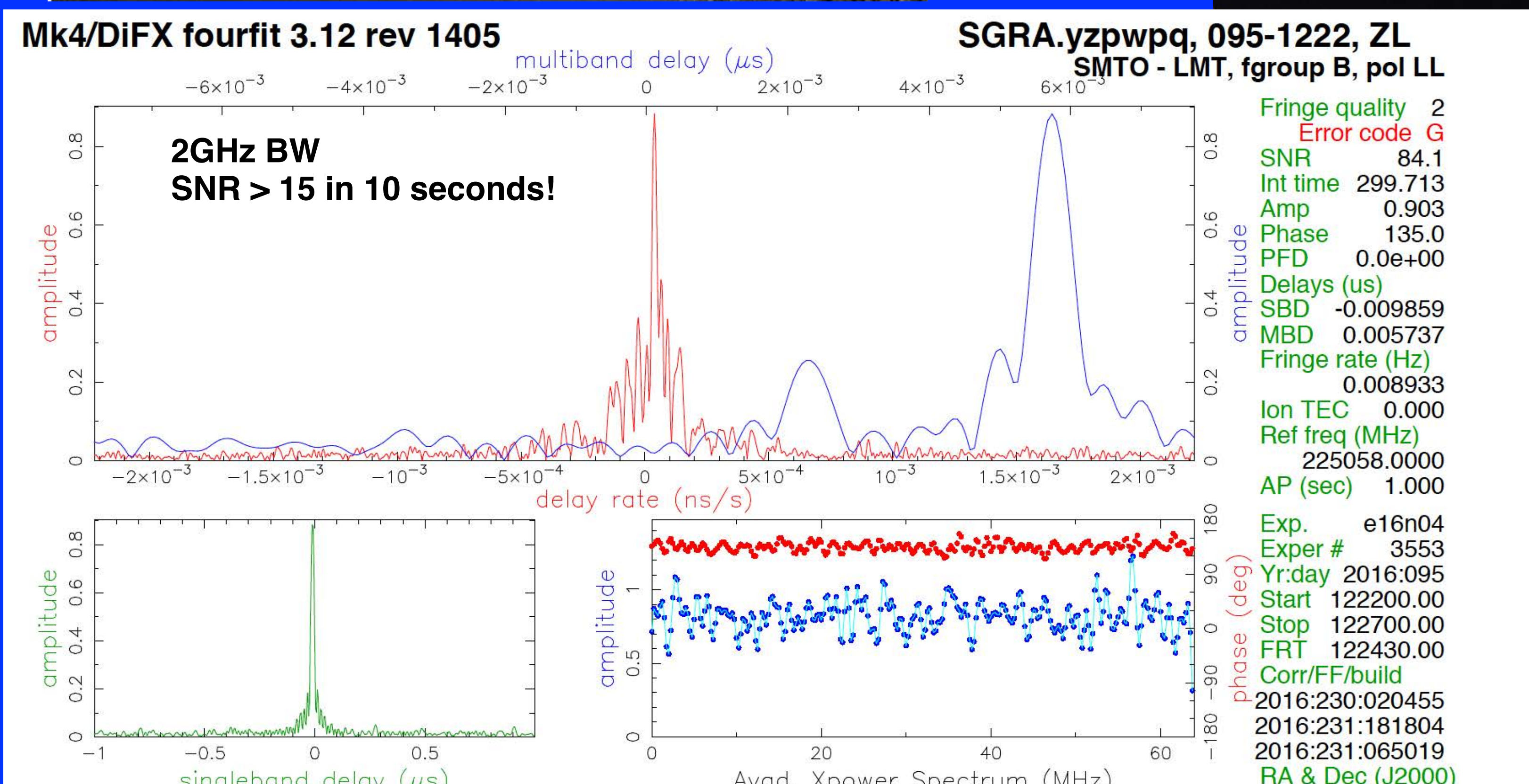
April 21, 2015

B-roll of the South Pole Telescope is available from NSF's Dena Headlee, dheadlee@nsf.gov / (703) 292-7739.

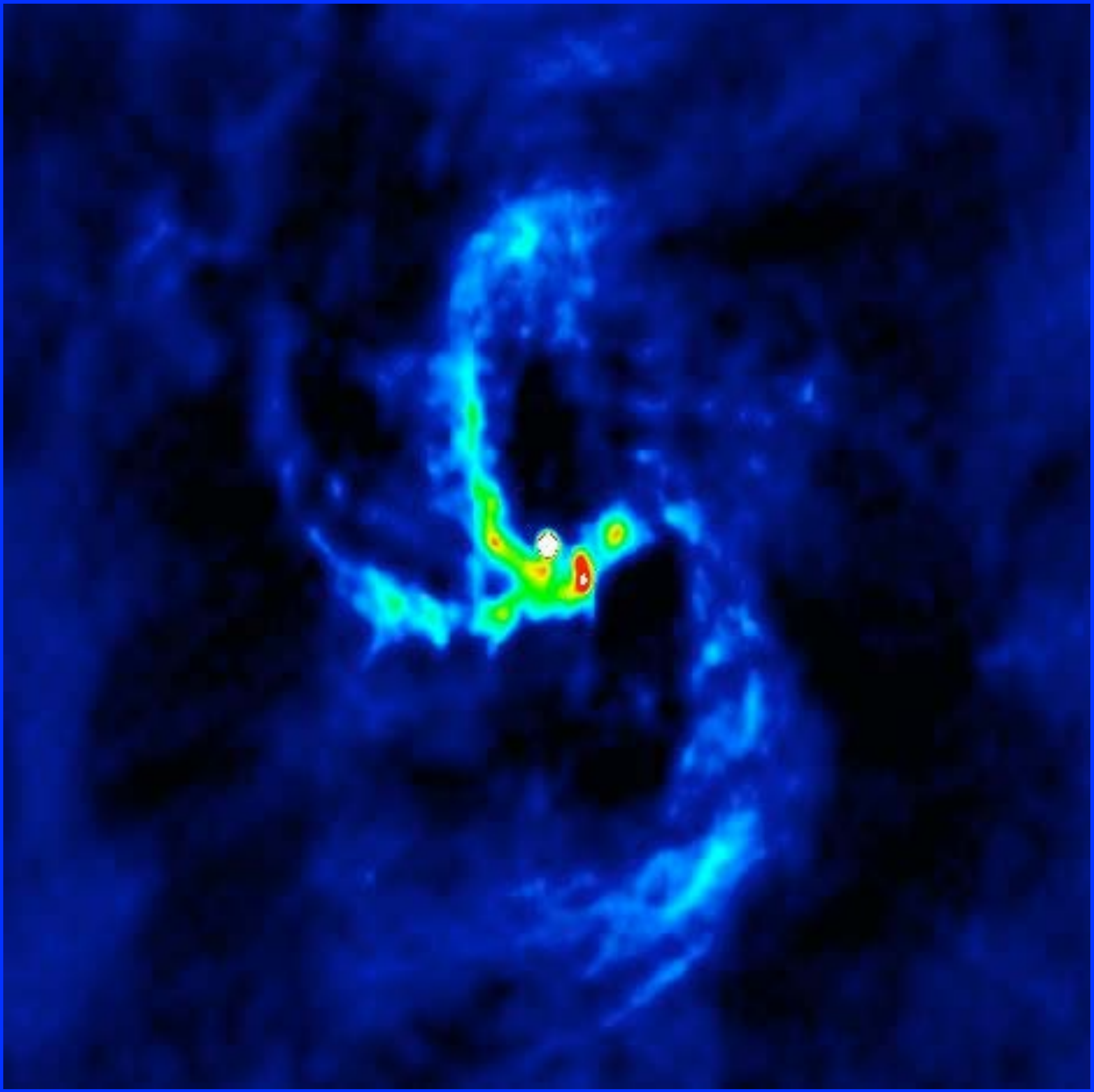
Astronomers building a globe-spanning virtual telescope capable of photographing the "event horizon" of the black hole at the center of our Milky Way have extended their instrument to

Led by Dan Marrone (UA)

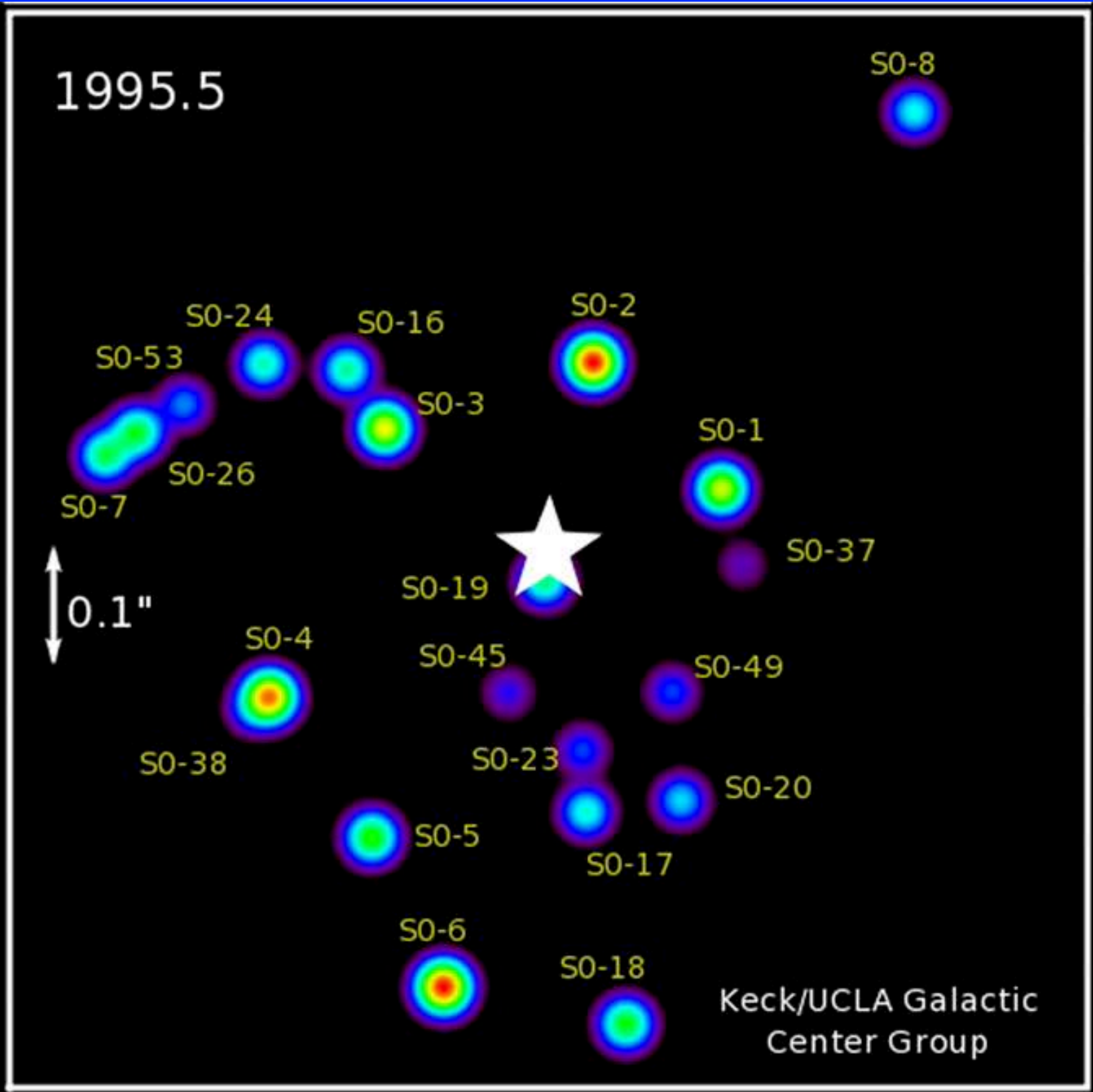
VLBI with the LMT



SgrA*: A Supermassive BH at the Milky Way Center



Stars Orbiting SgrA*

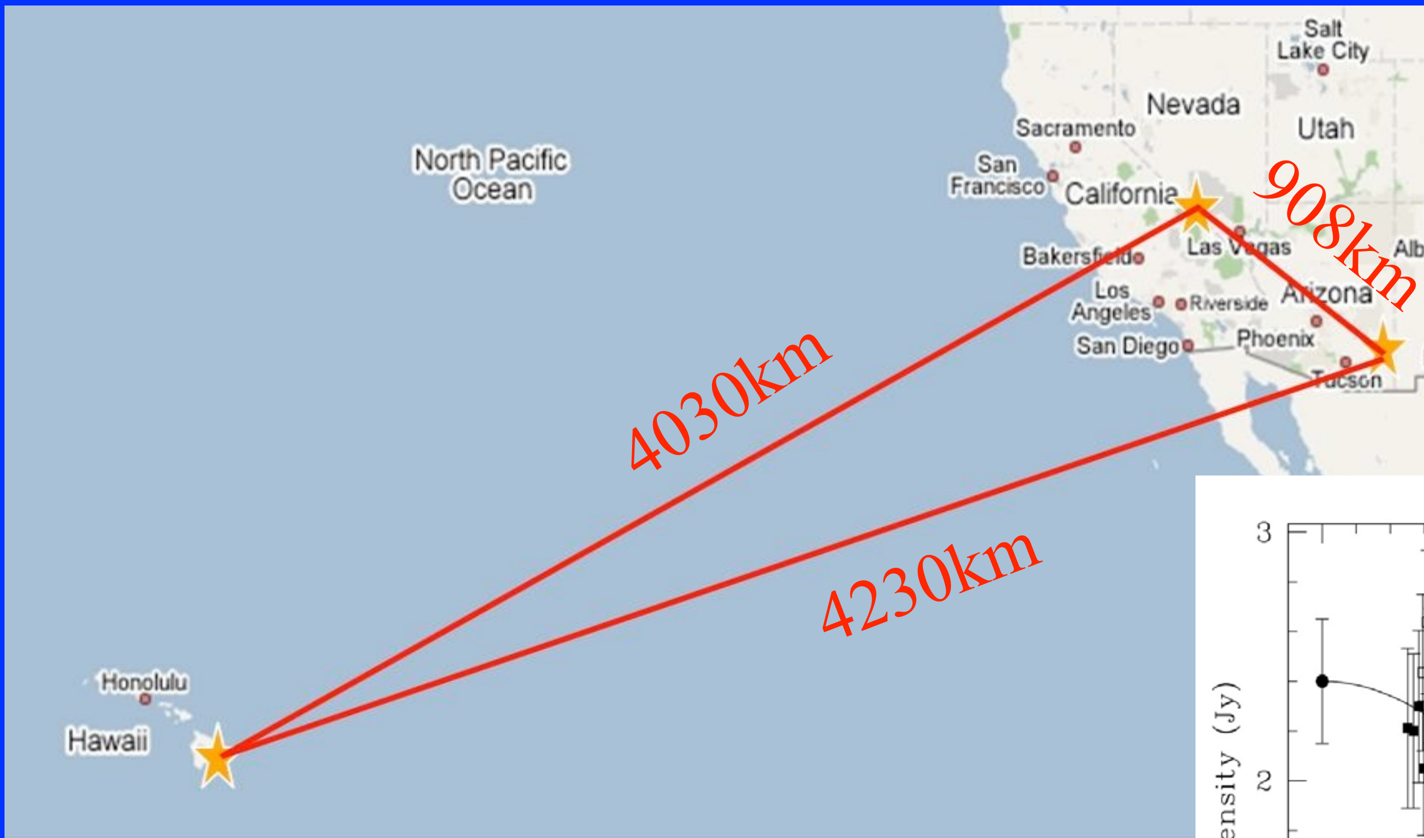


Central Mass
$M \sim 4x10^6 M_\odot$

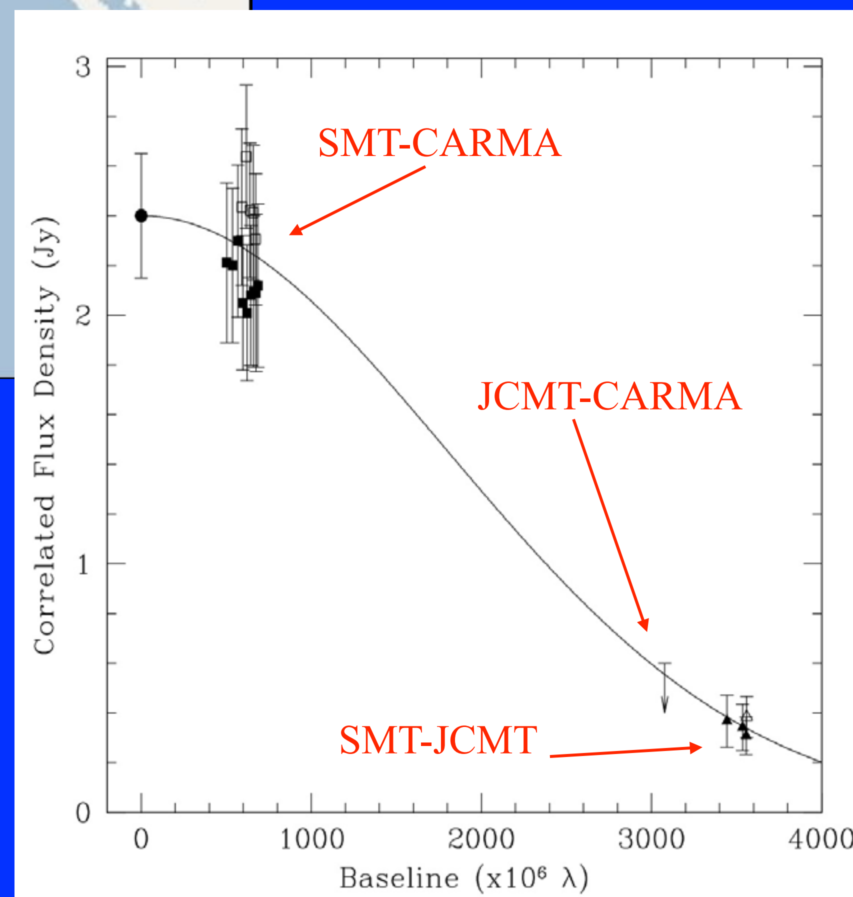
Shadow Diameter is: 50 micro arcseconds

Equivalent to seeing a grapefruit on the moon!

SgrA*: Event Horizon Structure Confirmed



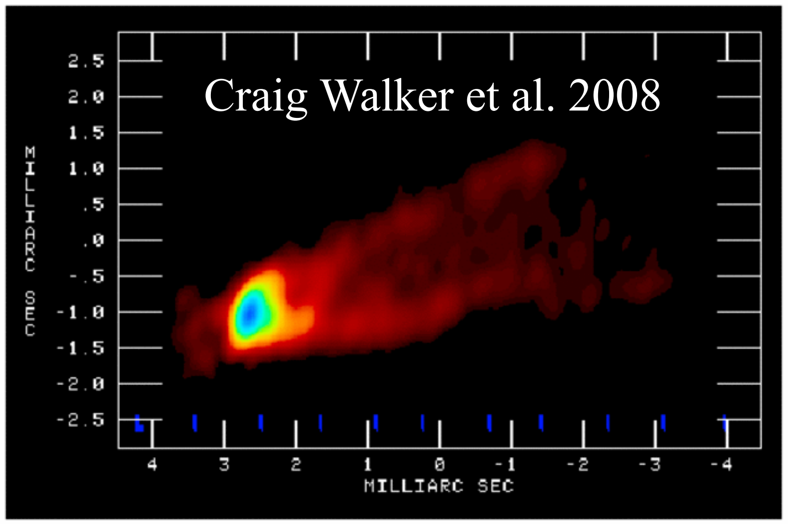
Doeleman et al 2008

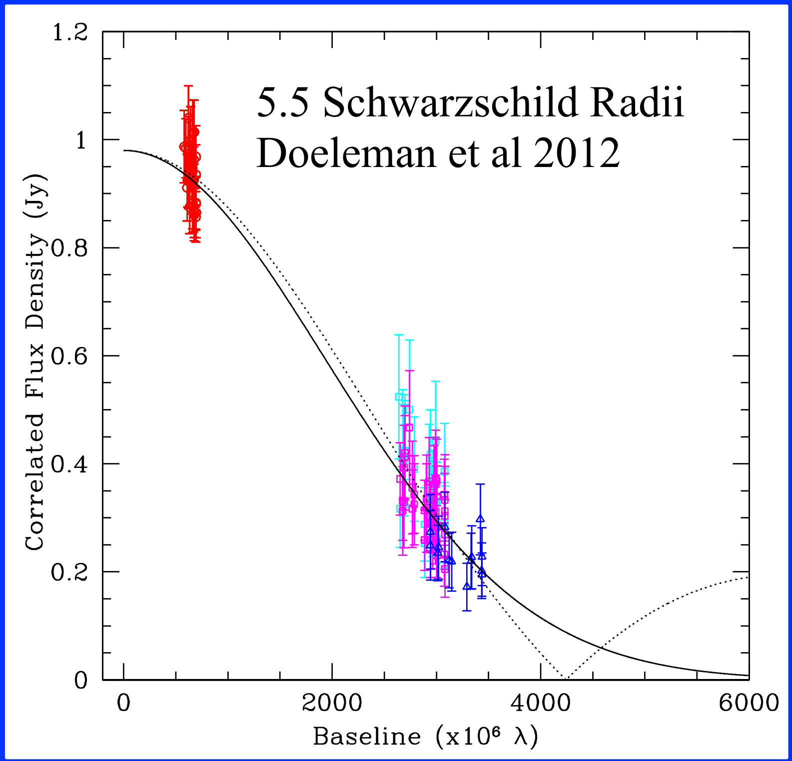


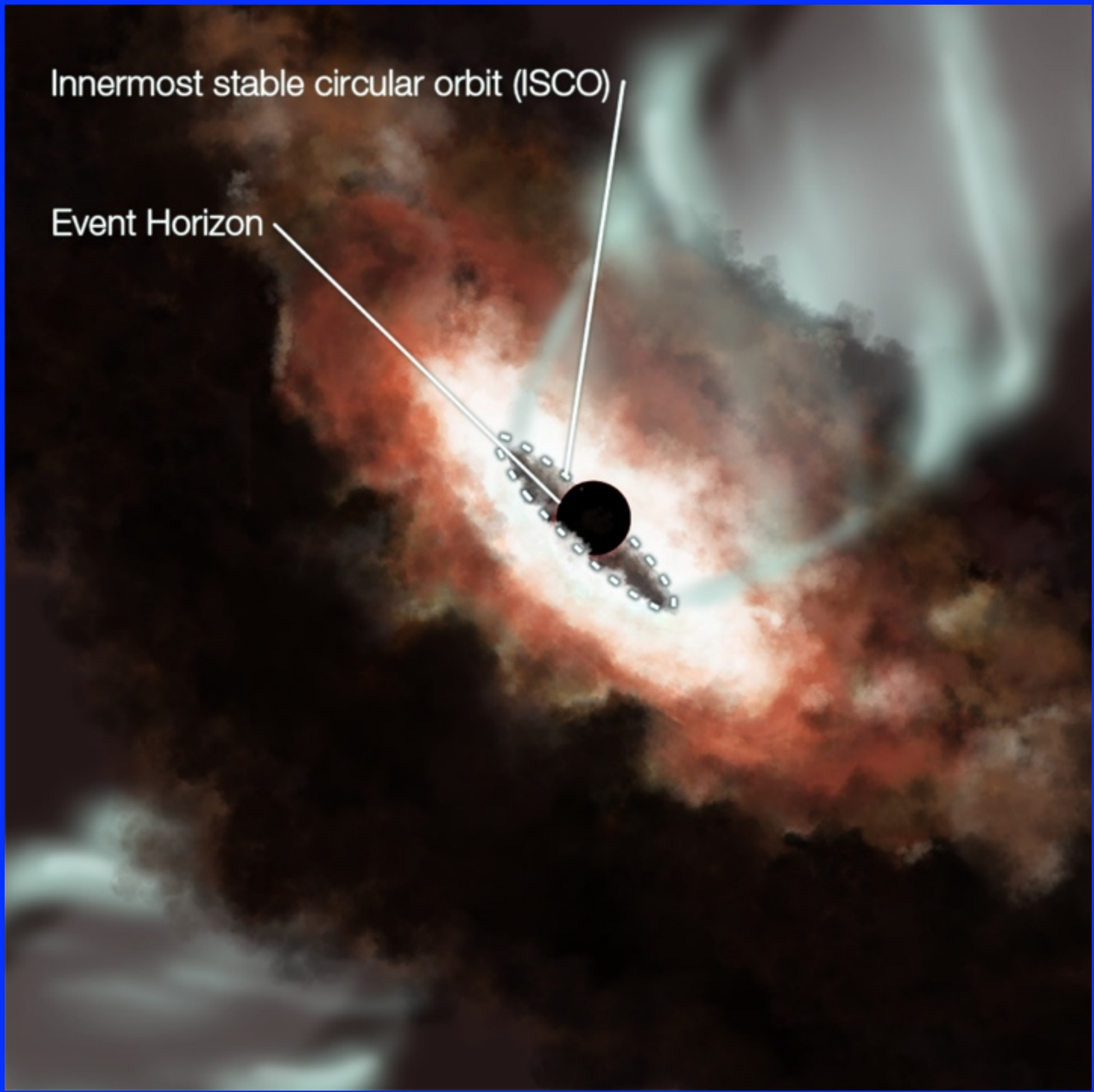
About 4 Schwarzschild radii across.

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

M87: BH Origins of a Relativistic Jet



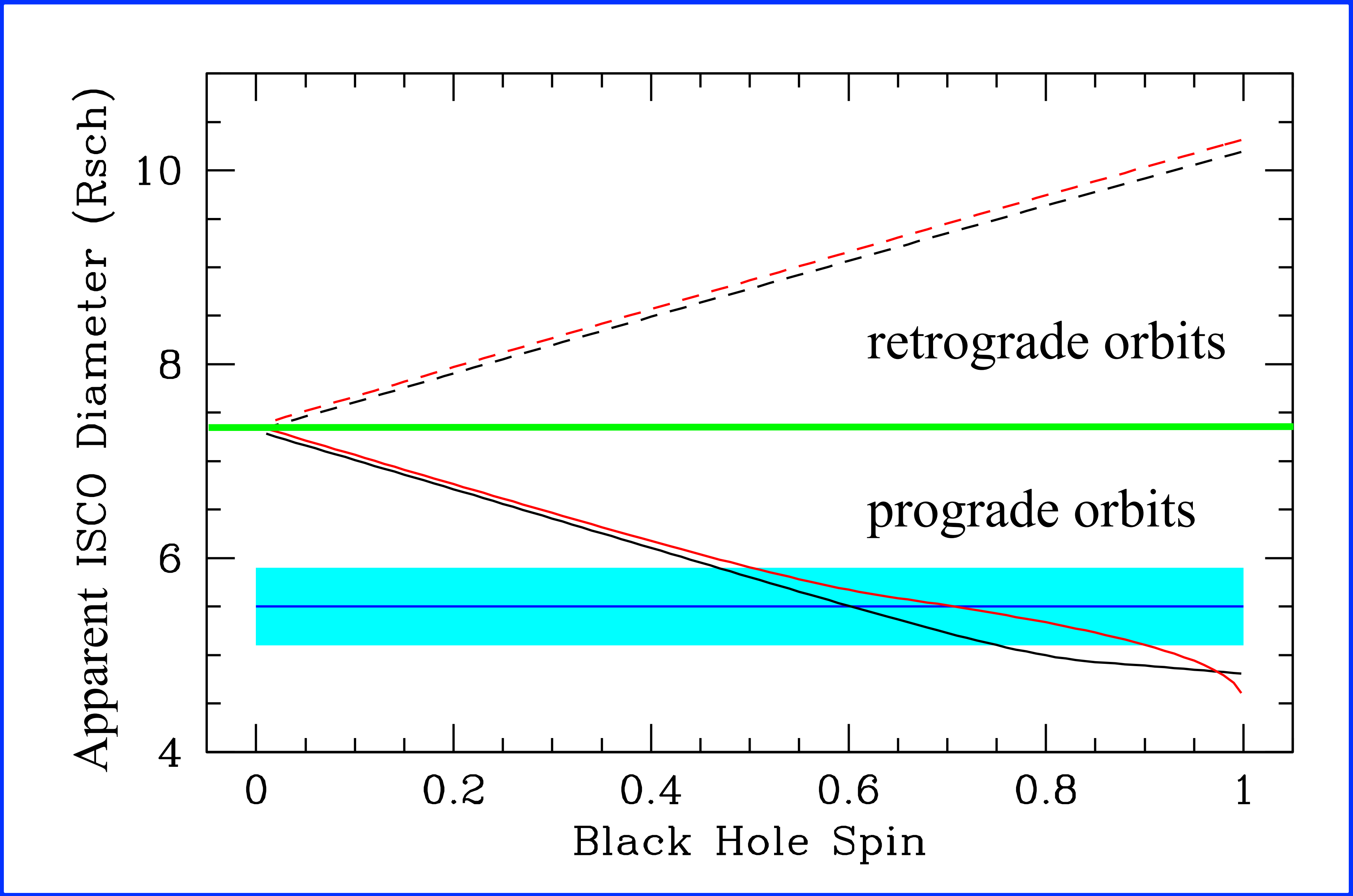




Graphic: Broderick

Strong GR Effects:

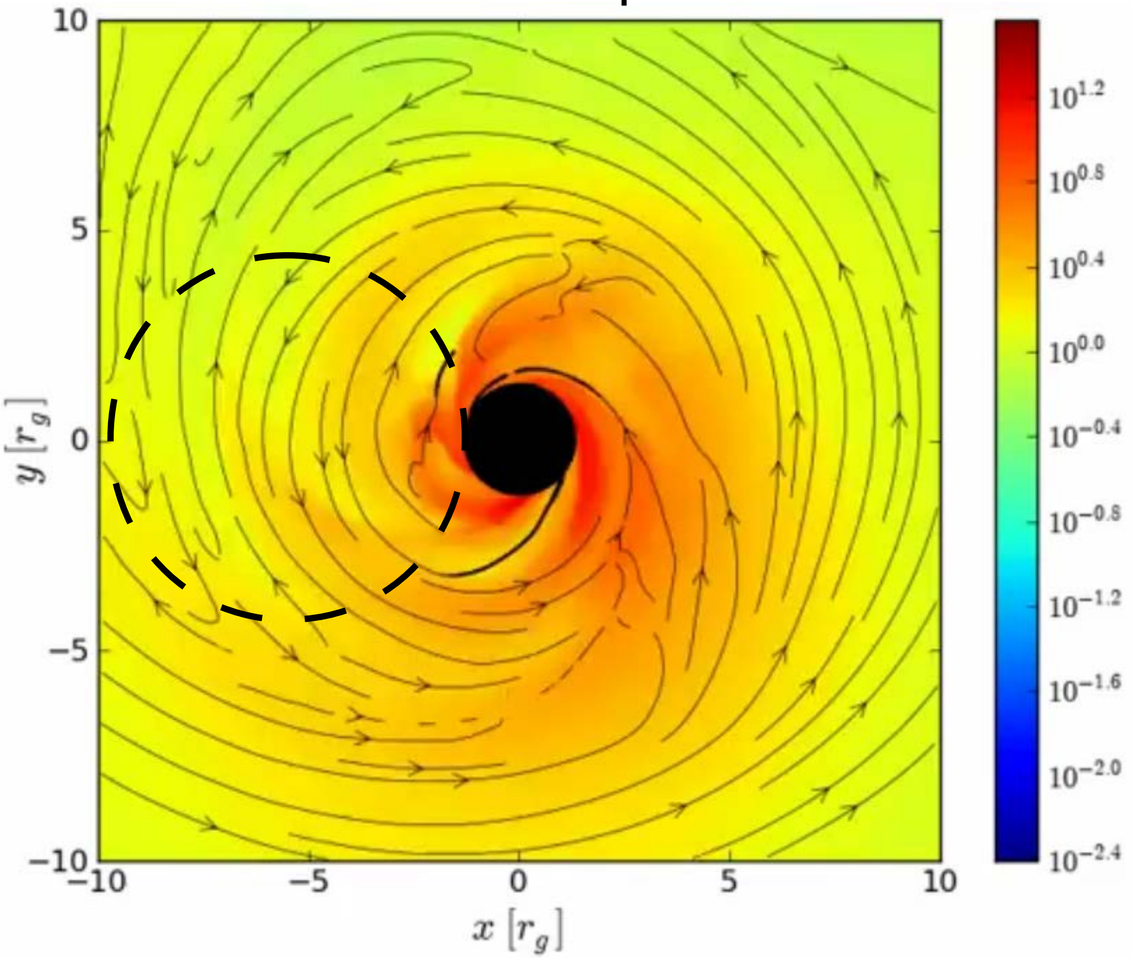
- Smaller than the expected ISCO: prograde disk.



Doeleman et al 2012

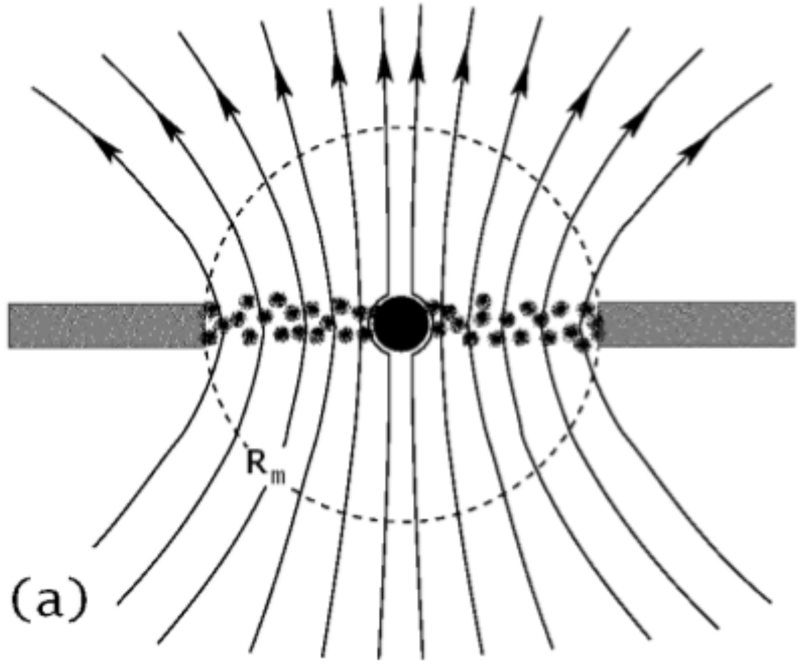
Ordered Fields?

Sheared Fields in Keplerian Flow



McKinney et al. (2012)

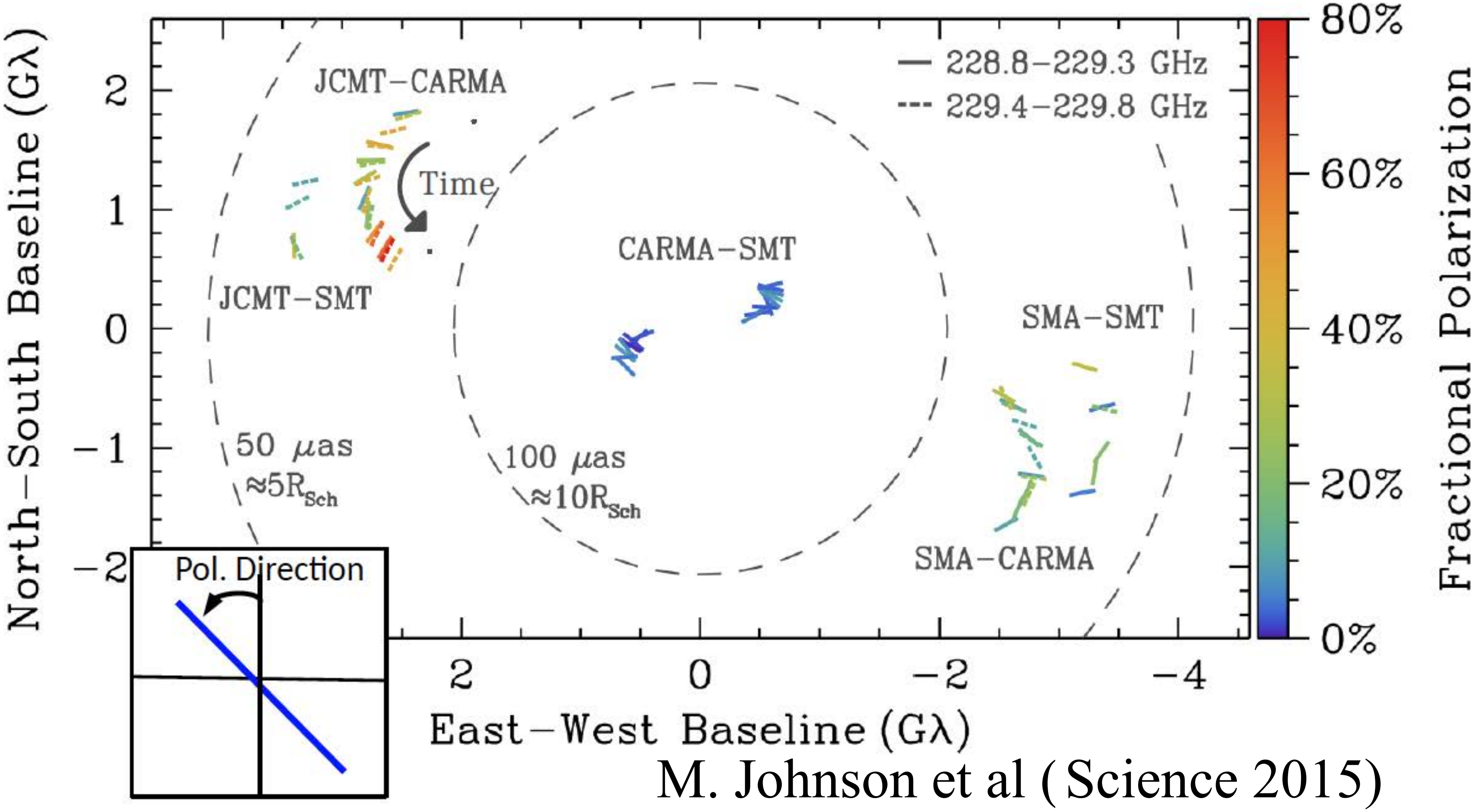
Magnetically-Arrested Disk



Narayan et al. (2003)

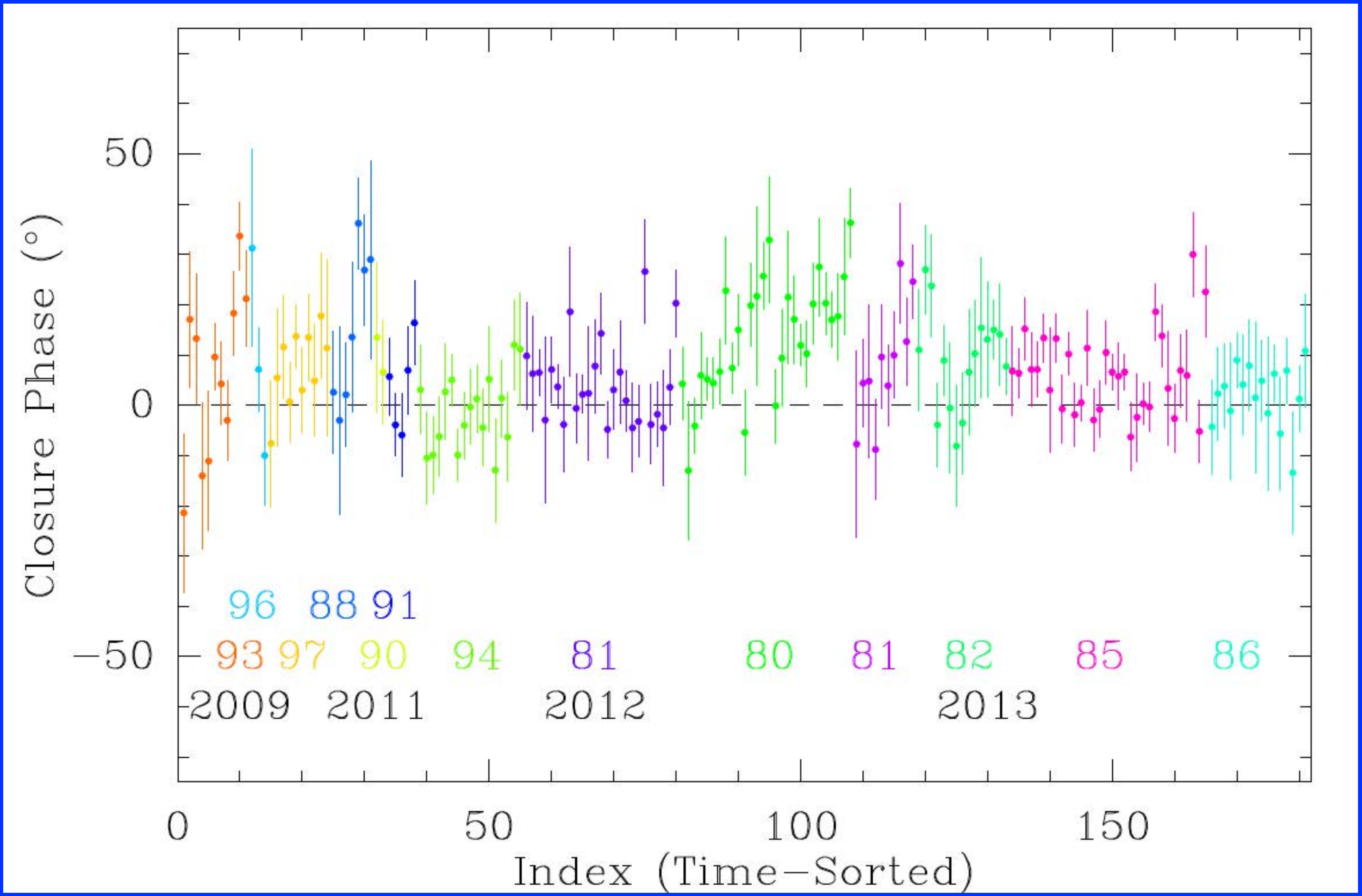
Sgr A* with the EHT

2013 EHT Data



M. Johnson et al (Science 2015)

Asymmetry in SgrA*

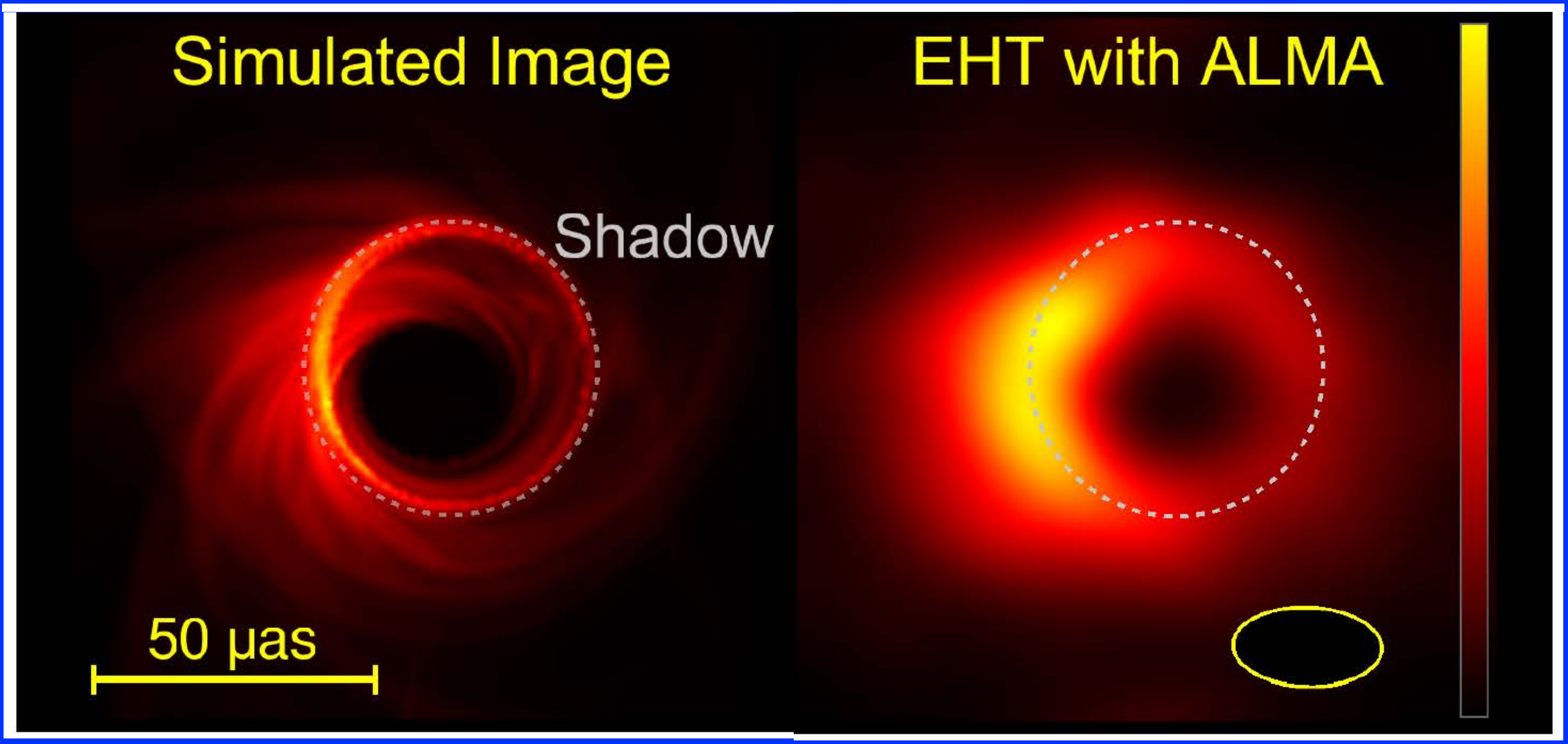


Fish et al 2016

The EHT from the Center of the Milky Way

+Greenland - 2018

Imaging SgrA*'s Shadow



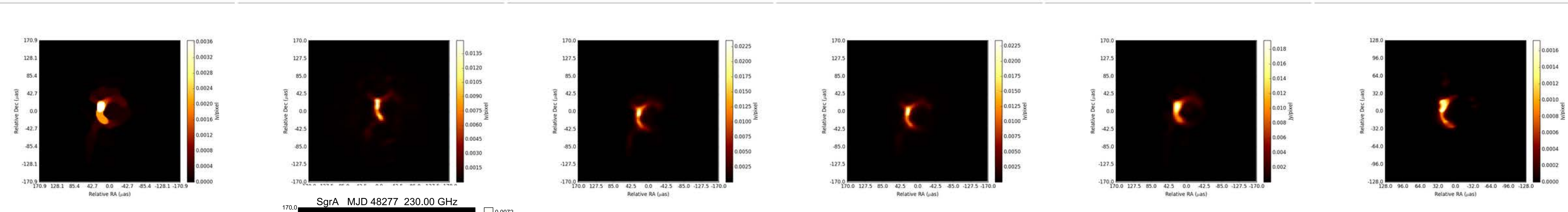
MEM: Andrew Chael+ 2016

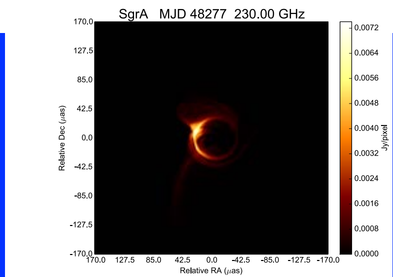
EHT Imaging Olympics

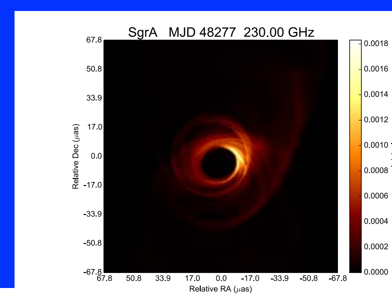
- Advertised to EHT community.
- Entrants include: MEM, Bispectral Imaging, CHIRP, Sparse Sampling.

Noise: Thermal only

18000467	49319591	85727464	89453452	74324712	21358612

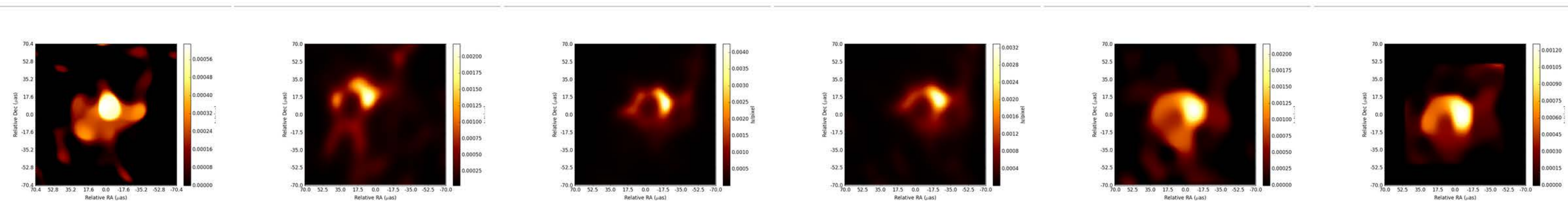






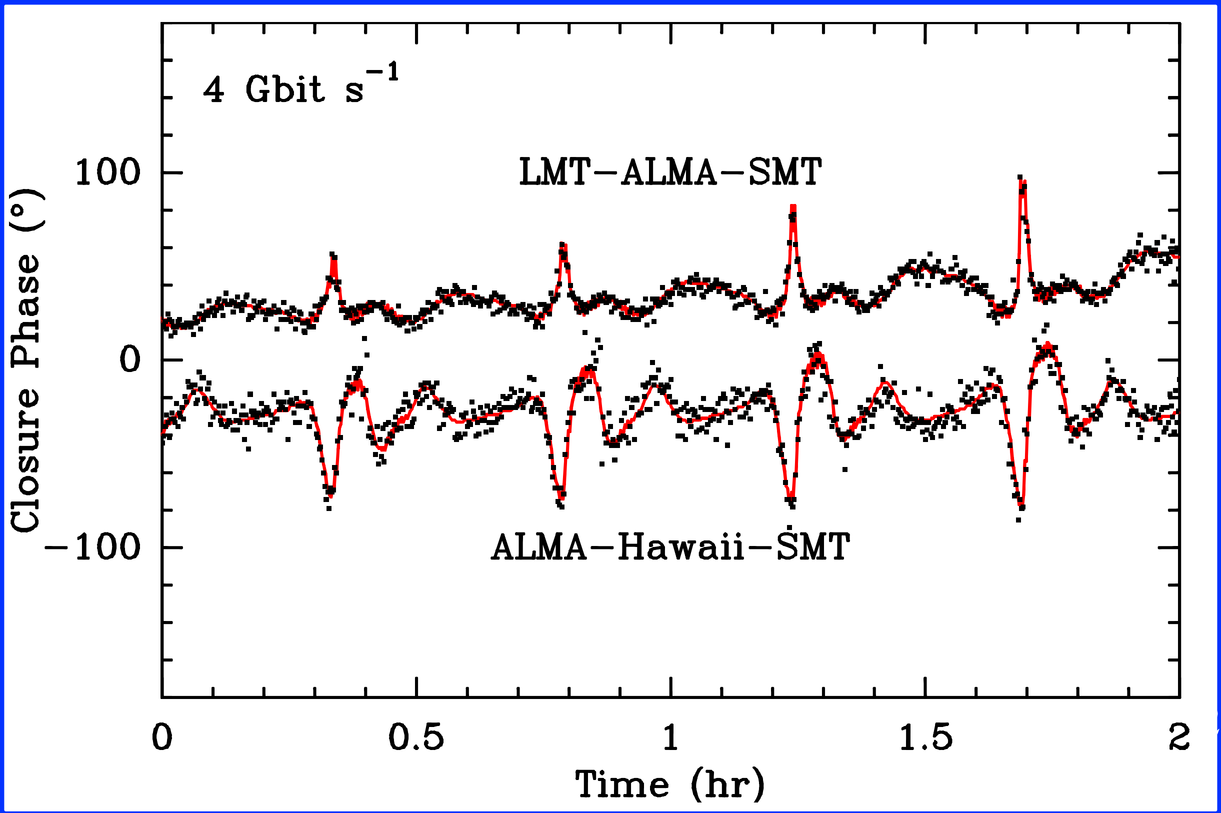
Noise: Thermal, Atmospheric, Systematic

18000467	49319591	85727464	89453452	74324712	74324712b



Time Resolving BH Orbits

Broderick & Loeb (2006); Doeleman et al (2009)



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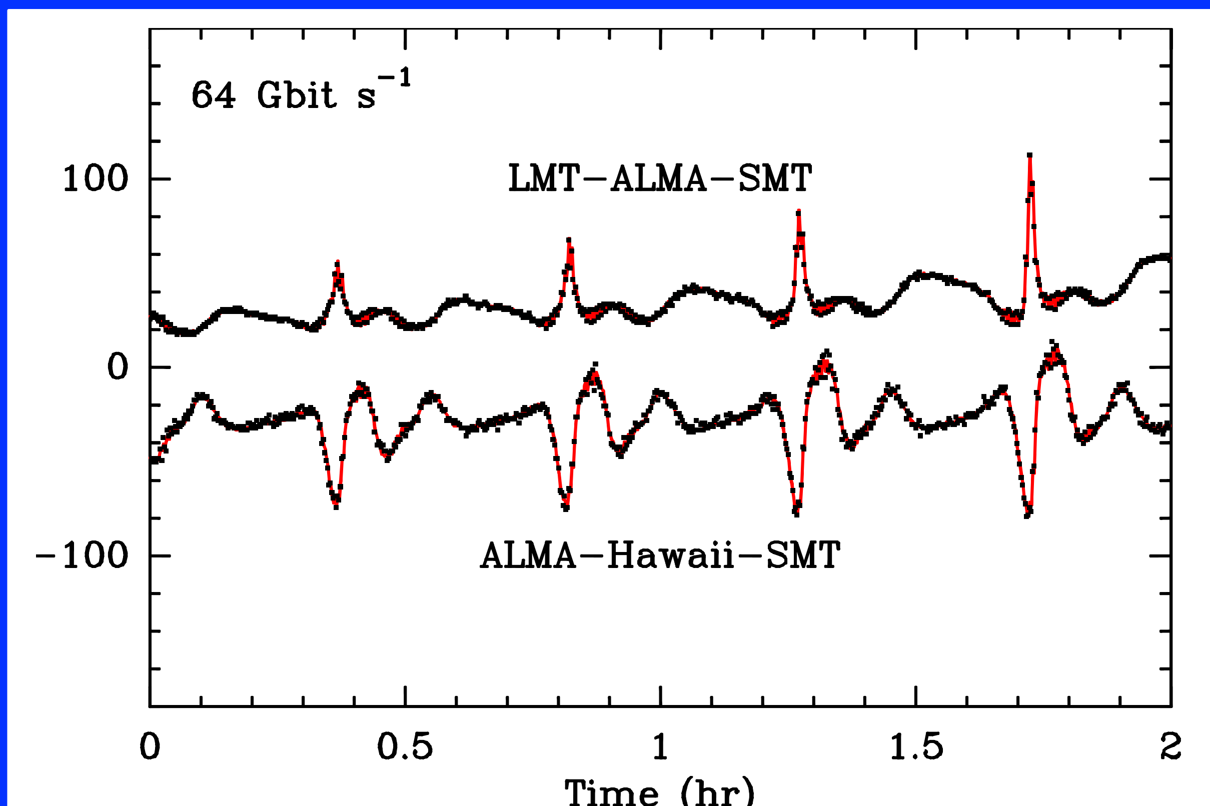
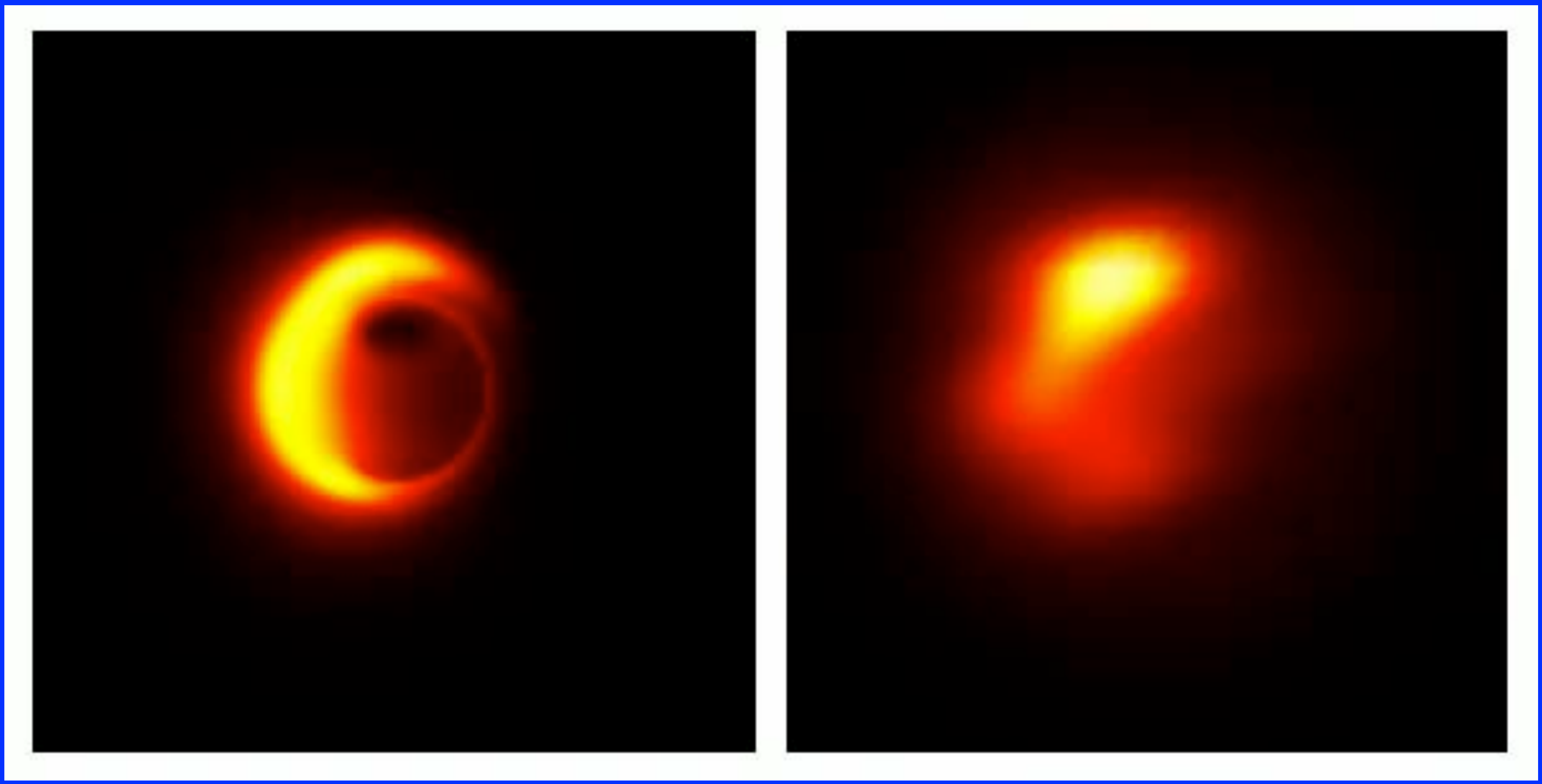
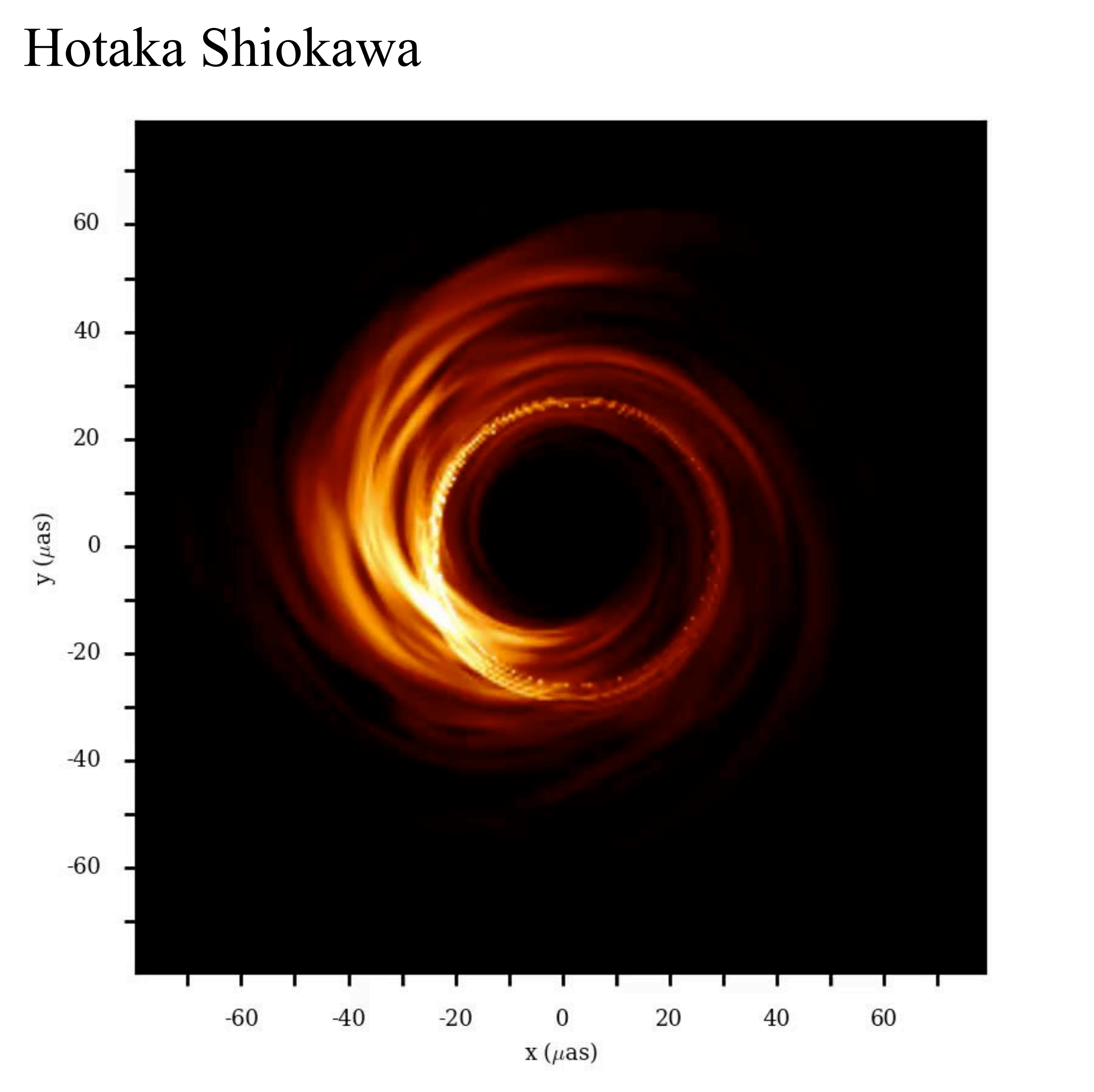


Reconstructing Orbits



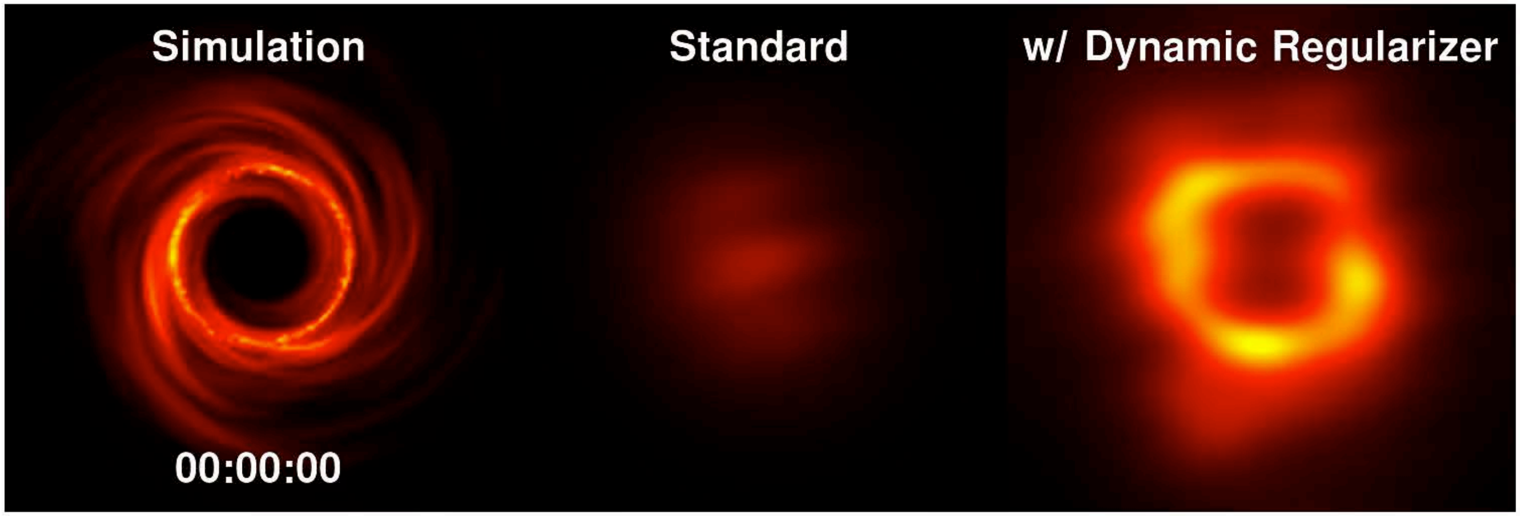
Michael Johnson (CfA)

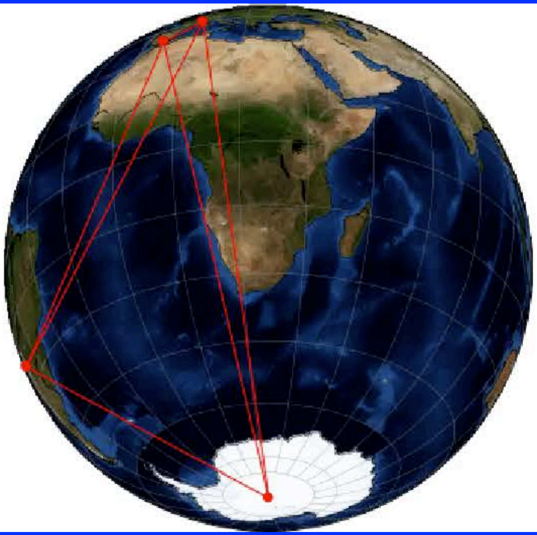
Complex motions near the Horizon



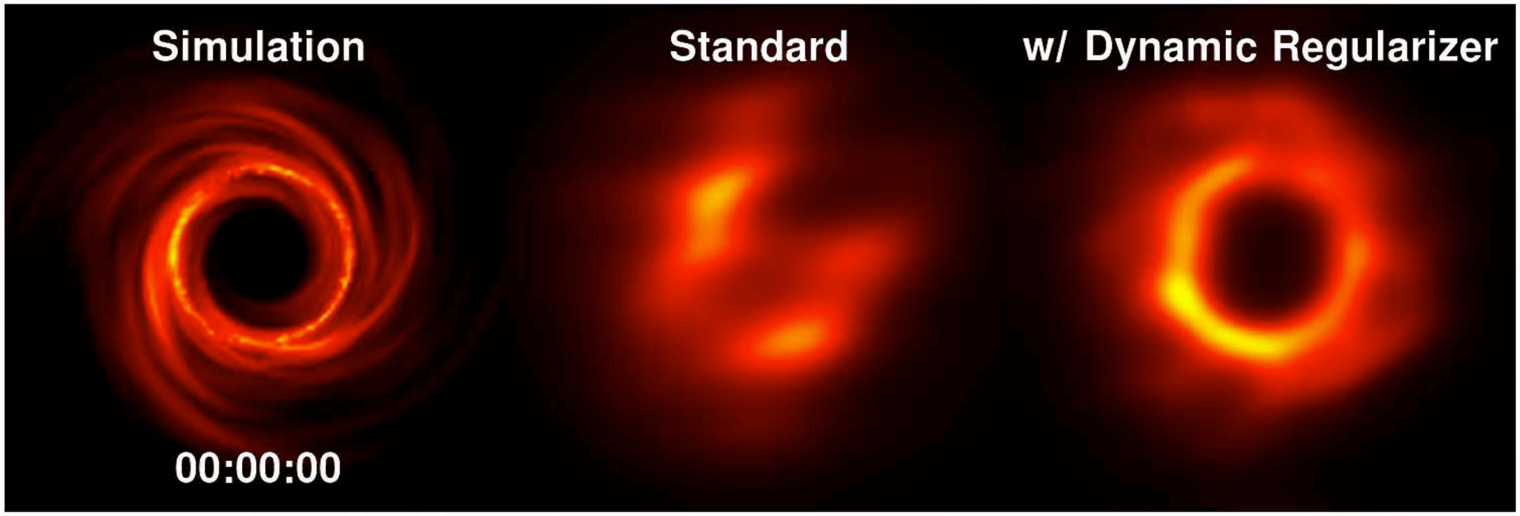
Making Movies

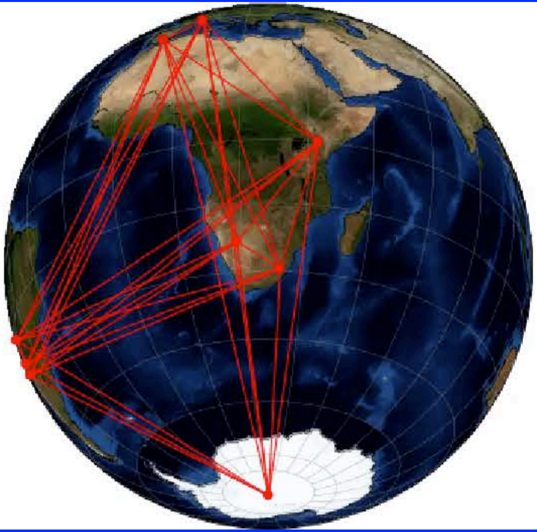
EHT 2017





EHT 2025

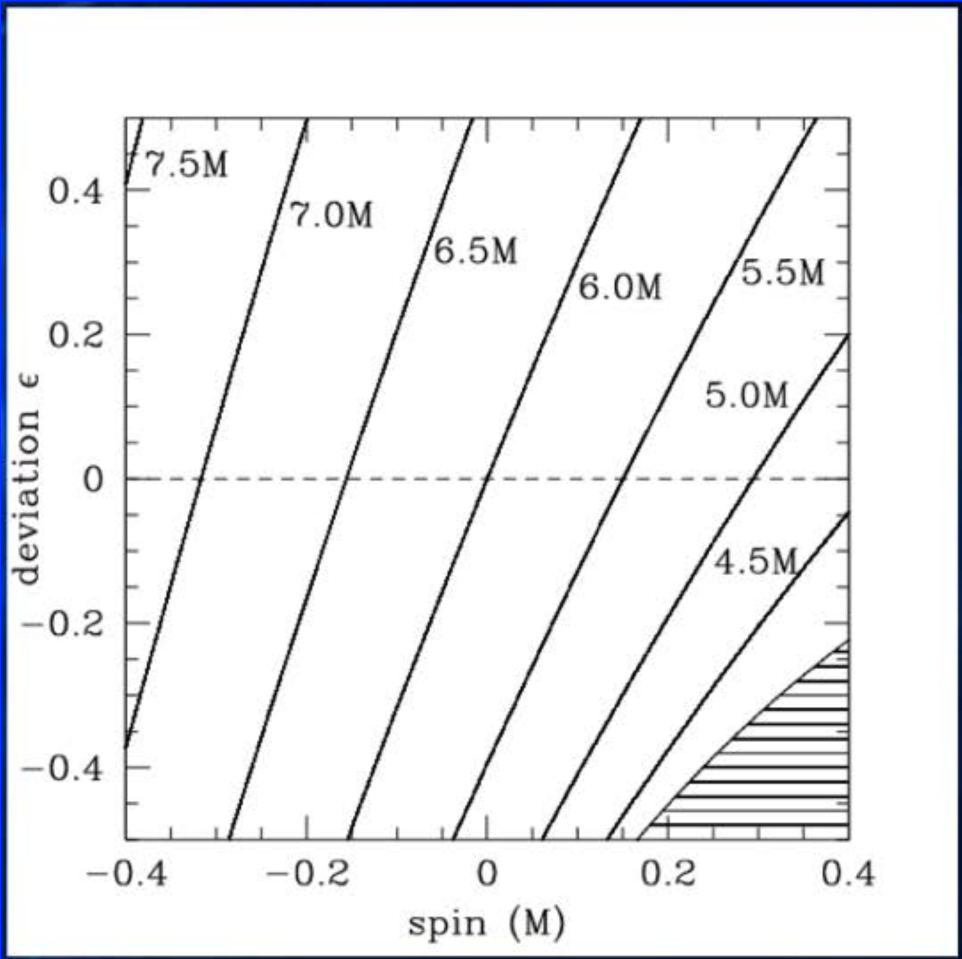




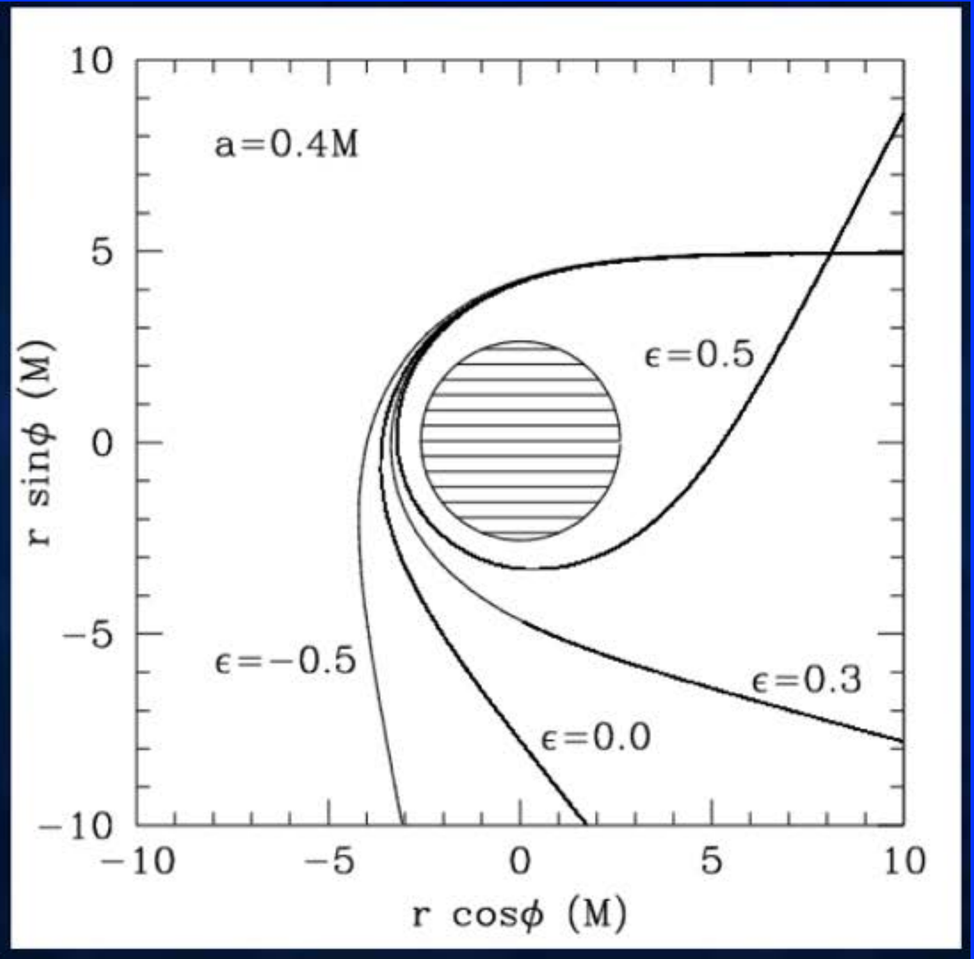
Michael Johnson et al - in preparation.

Perturbing the Kerr Metric: Quasi-Kerr

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



Location of the ISCO

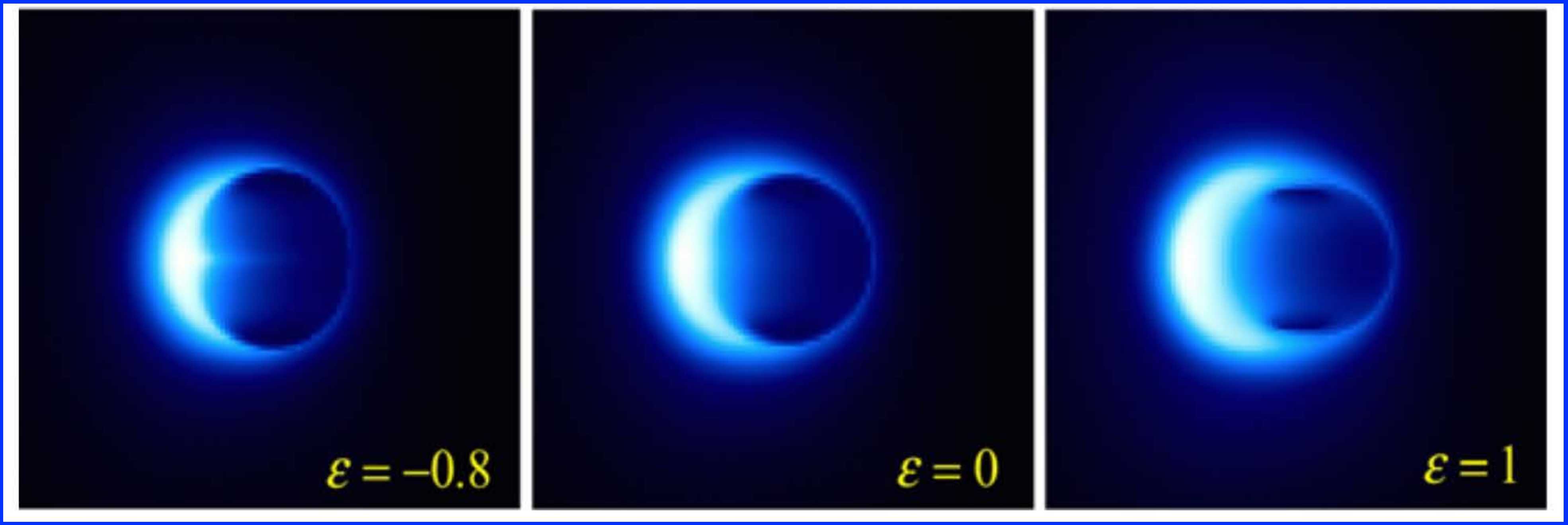


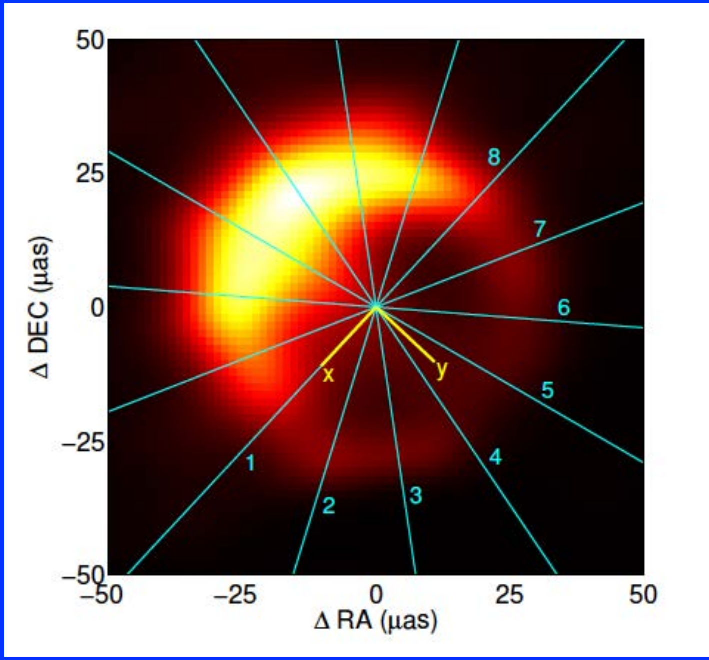
Lightbending

Johannsen & Psaltis: (2010), (2011)

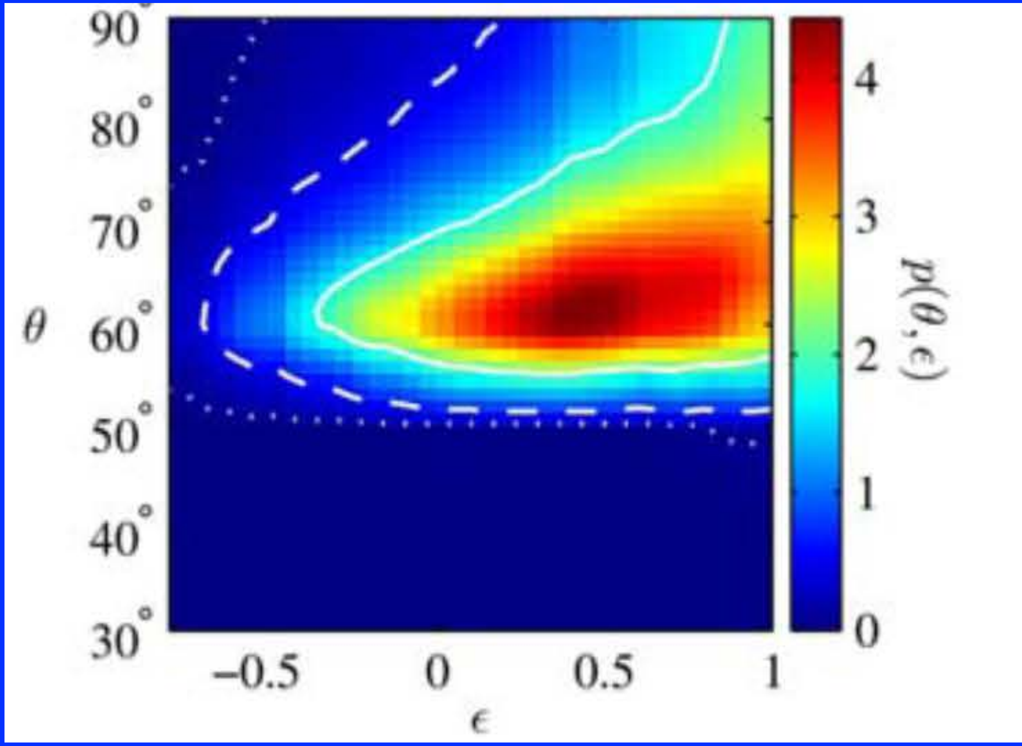
Tests of GR

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

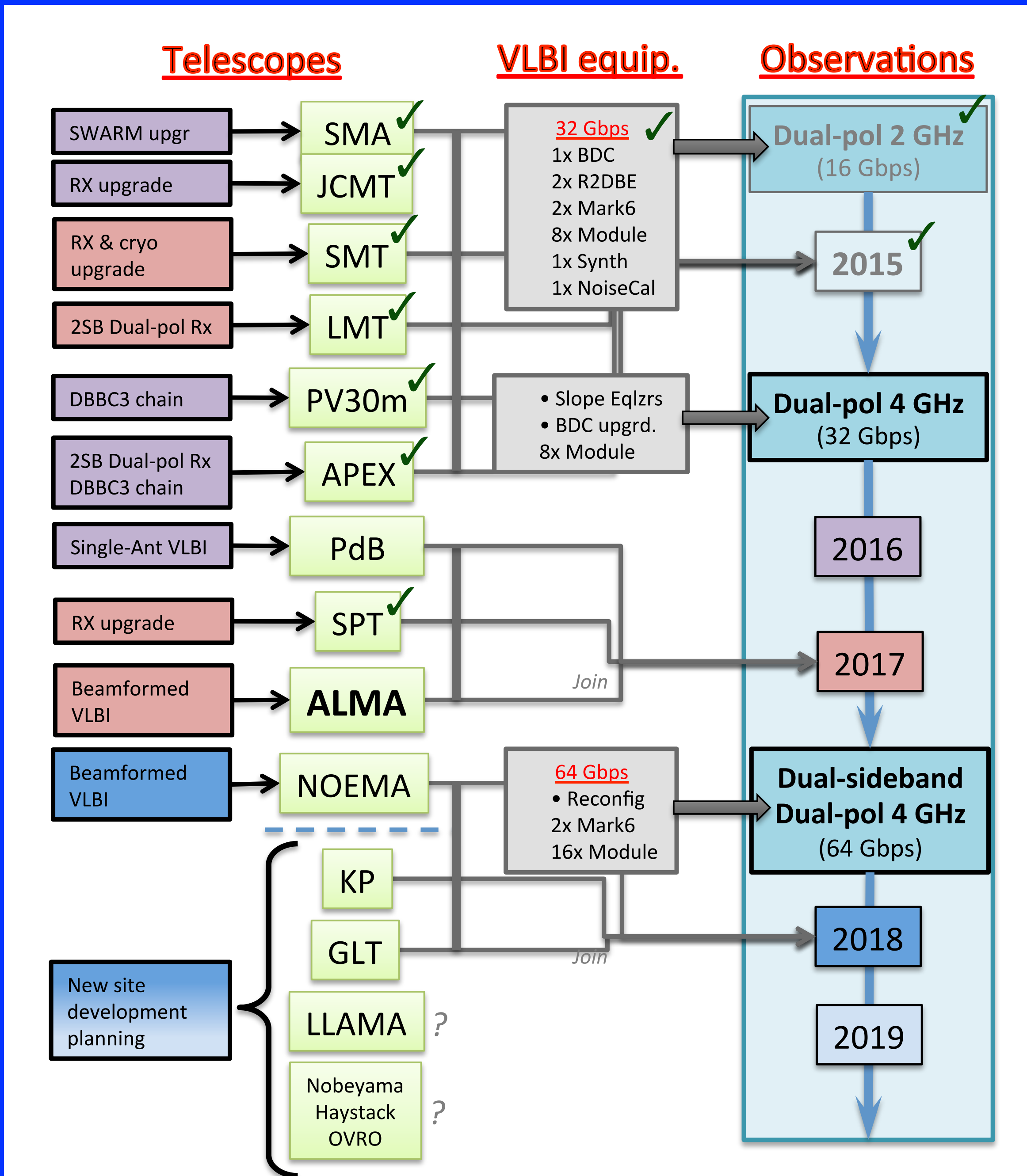




Johannsen et al 2015



EHT Roadmap



Activities/Results:

- *EHT Global Observations in 2015.*
- *EHT Global Observations in 2016.*
- *1.3mm VLBI Detections to:*
  - *South Pole*
  - *LMT*
  - *IRAM 30m*
  - *APEX*
  - *Phased ALMA*
- *ALMA Phasing Project accepted for Cycle 4.*
- *Resource allocation for build-out to 64Gb/s.*

- *Elements of GLT shipped to Thule.*
- *ALMA prototype now at KittPeak.*
- *NOEMA in progress.*

EHT Team and Support

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

Planning the EHT (2010)
MIT Haystack Observatory

EHT2012: Bringing Black Holes into Focus
Tucson, AZ

EHT2014: Perimeter Institute

EHT 2016: Here in Cambridge
28 Nov - 2 Dec

EventHorizonTelescope

Science | Technology | Array | Collaborators | News | Publications | Meetings

- EHT 2016
- Accommodations
- Committees
- Contact Information
- Program
- Registration

Event Horizon Telescope Conference 2016

Conference Dates:
November 28 - December 2, 2016

Location:
Cambridge, Massachusetts USA

The Event Horizon Telescope is the first astronomical instrument capable of imaging the horizon of a known black hole. By assembling a global network of existing millimeter and sub-millimeter wavelength observatories, the EHT can access the extraordinary resolutions required via Very Long Baseline Interferometry. Already it has detected horizon scale structure around the supermassive black holes at the centre of the Milky Way and the giant elliptical galaxy M87.

It is an exciting time in the project with first observations that include the ALMA array scheduled for April 2017, and the prospects for horizon-resolving science more promising than ever. This collaboration meeting (EHT 2016) will be an opportunity to review EHT science goals, theoretical advances, data analysis, technical developments, observing strategies, and project organization.

This is the third in a meeting series designed to bring together the full EHT community, from instrument builders to theoretical modelers, for the purpose of fully exploiting the unique opportunities that the EHT provides. Past EHT meetings have followed a traditional format of talks by EHT scientists as well as experts from a diverse set of fields. For EHT 2016 - with critical observations and organizational efforts underway - the meeting structure will

Credit: APEX, IRAM, G. Narayanan, J. McMahon, JCMT/JAC, S. Hostler, D. Harvey, ESO/C. Malin
Click here for larger view.

The Future

- April 2017 observations: first ‘imaging’ run and dynamical probes.
- EHT Consortium focus on data processing, analysis and science.
- April 2018: increase to 64Gb/s and addition of Kitt Peak, Greenland and NOEMA.
- Gaze shifts to continued operations and development of:
  - higher BW
  - more telescopes (smaller diameter).