Observing Event Horizons with High-Frequency VLBI

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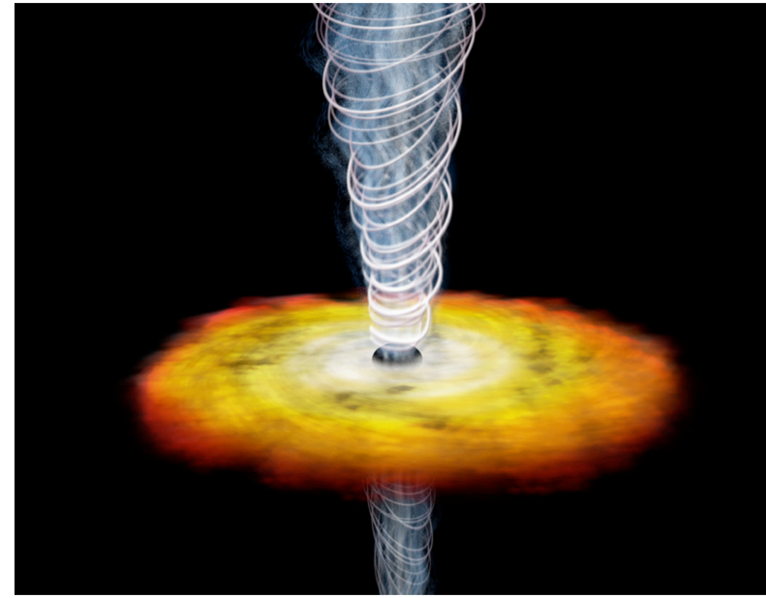
Motivations



Understand black hole physics
- accretion/outflow
- general relativity

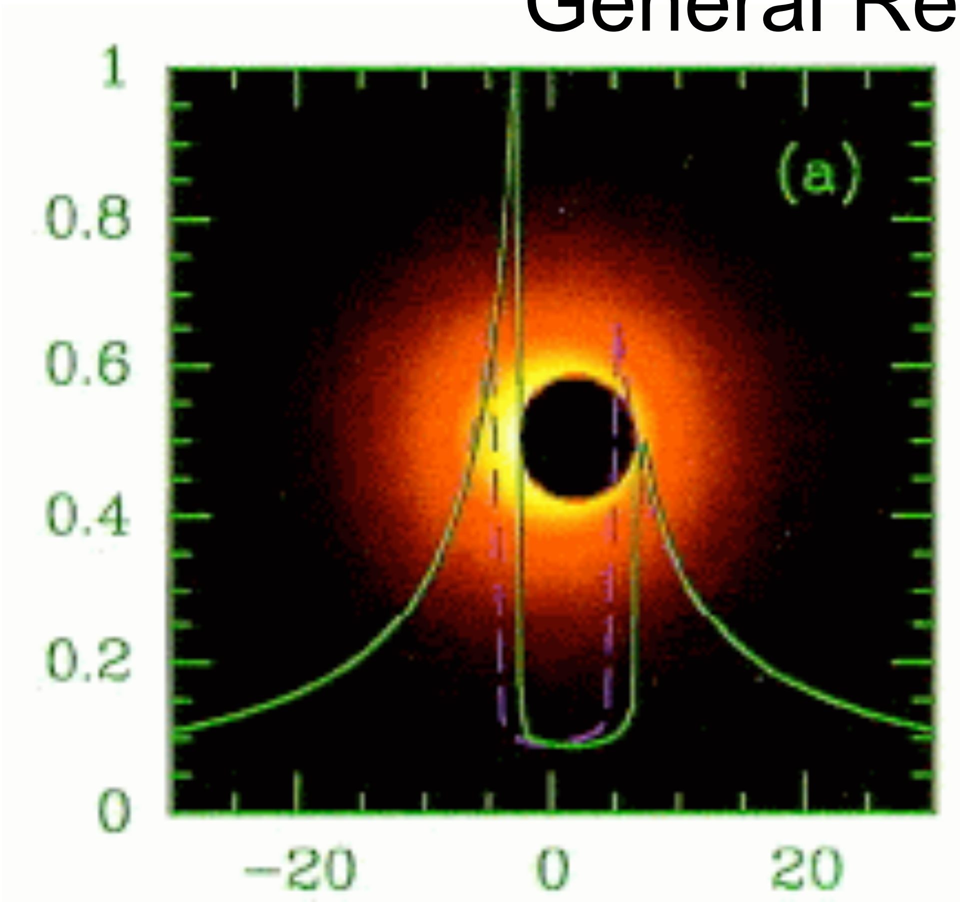
Largest apparent event horizon:
- Sgr A* $R_{sch} \sim 10\ \mu as$
- M87 similar

Event horizon scale resolution possible with millimetre VLBI
- Hawaii-Chile and Europe-Chile: 30 μas (230 GHz)
  20 μas (345 GHz)

High-frequency observations needed due to scattering, opacity

Now: non-imaging VLBI observables
Future: imaging

General Relativistic Effects



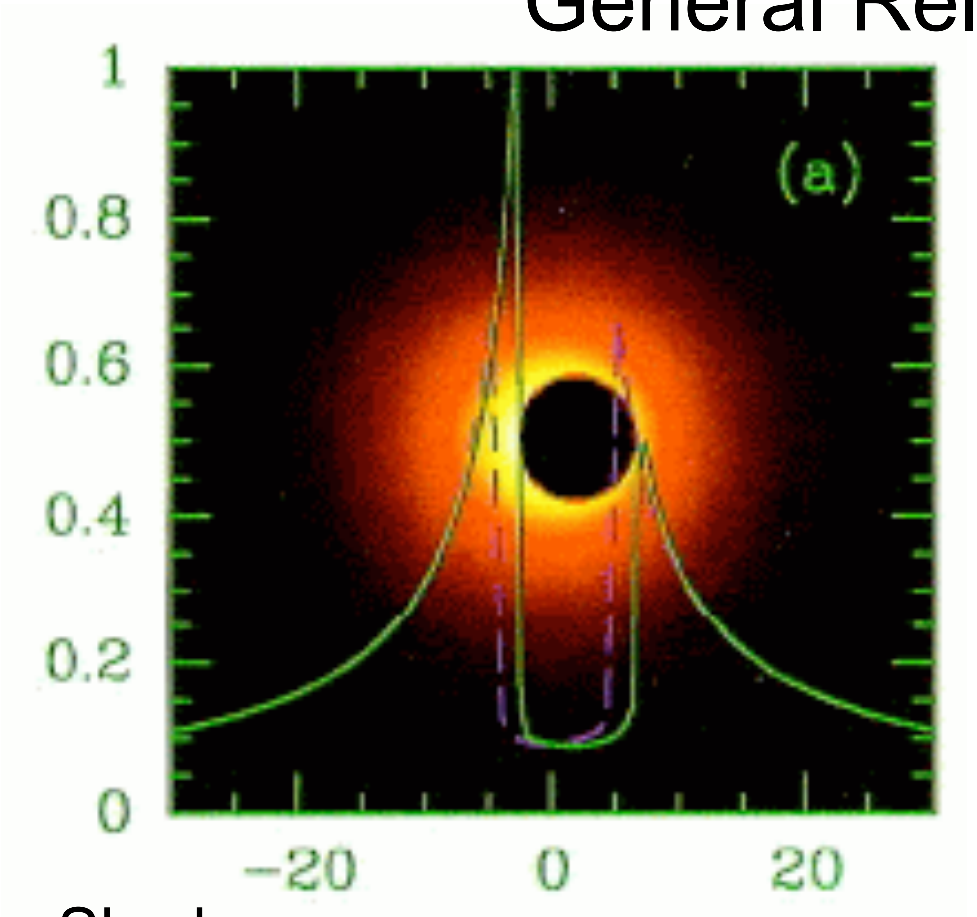
Shadow

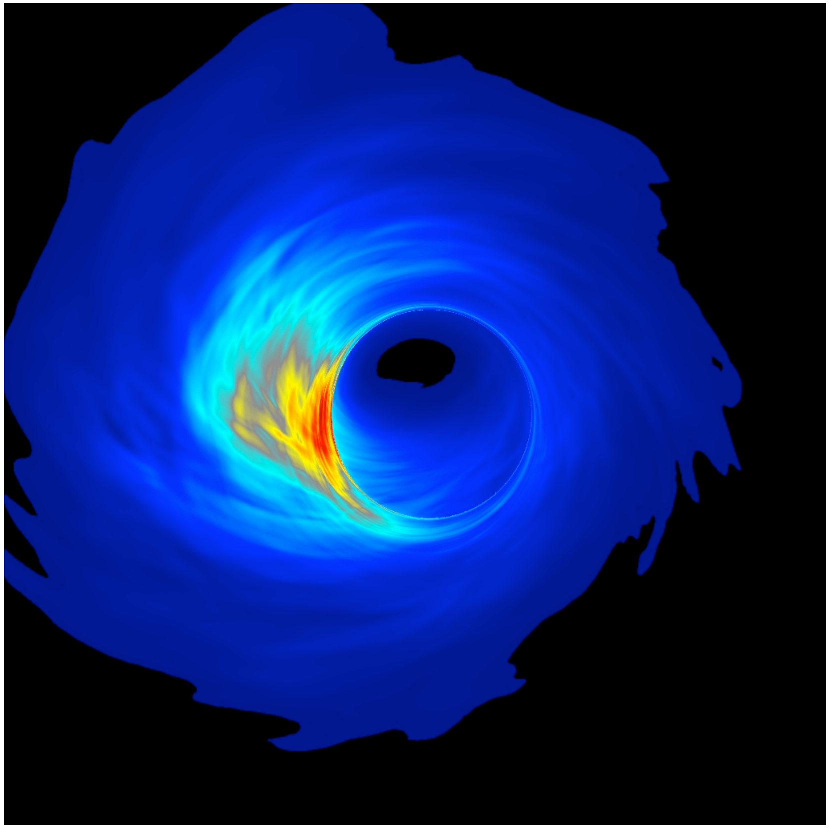
Doppler beaming

Photon orbit

Innermost stable circular orbit: 4 - 30 min (depending on spin)

General Relativistic Effects





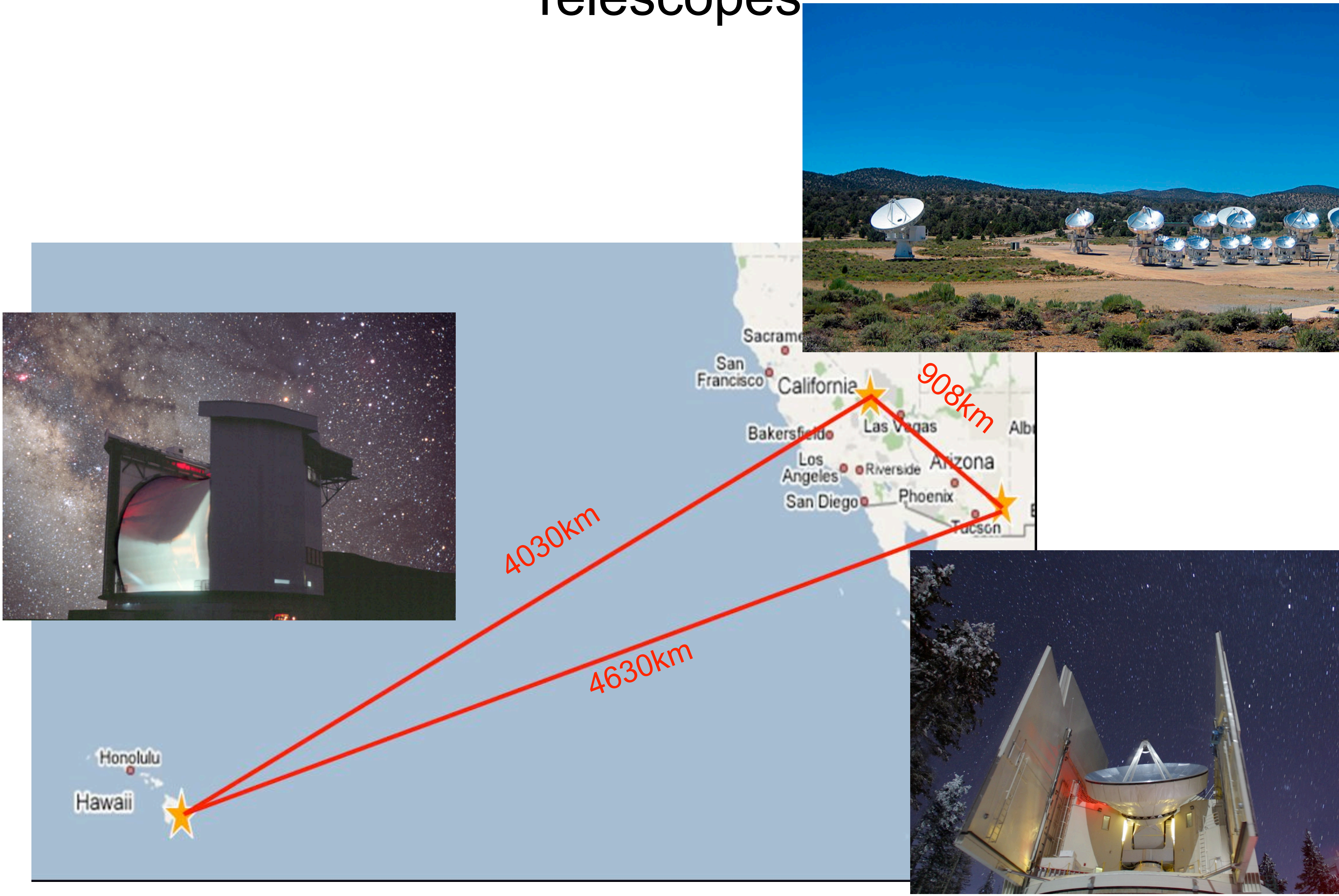
Shadow

Doppler beaming

Photon orbit

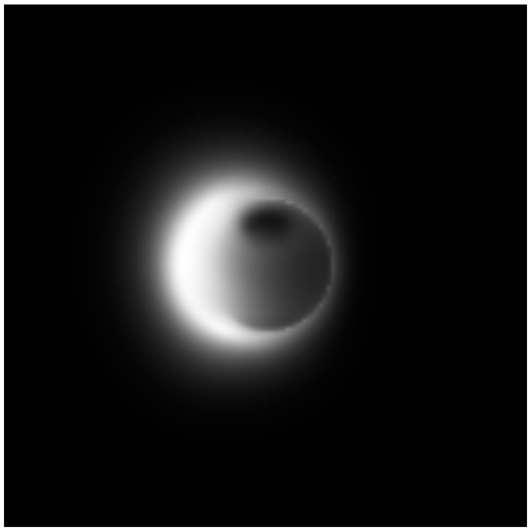
Innermost stable circular orbit: 4 - 30 min (depending on spin)

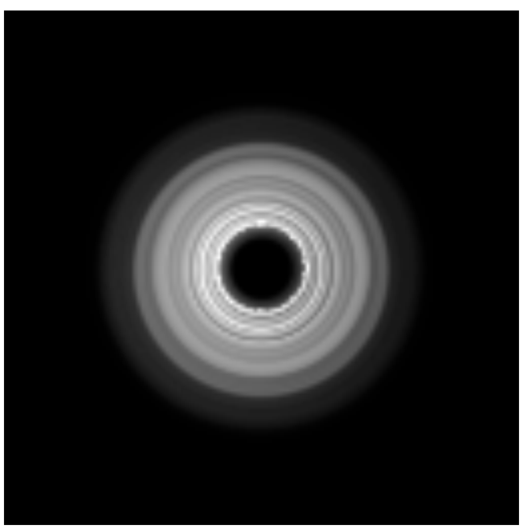
Telescopes

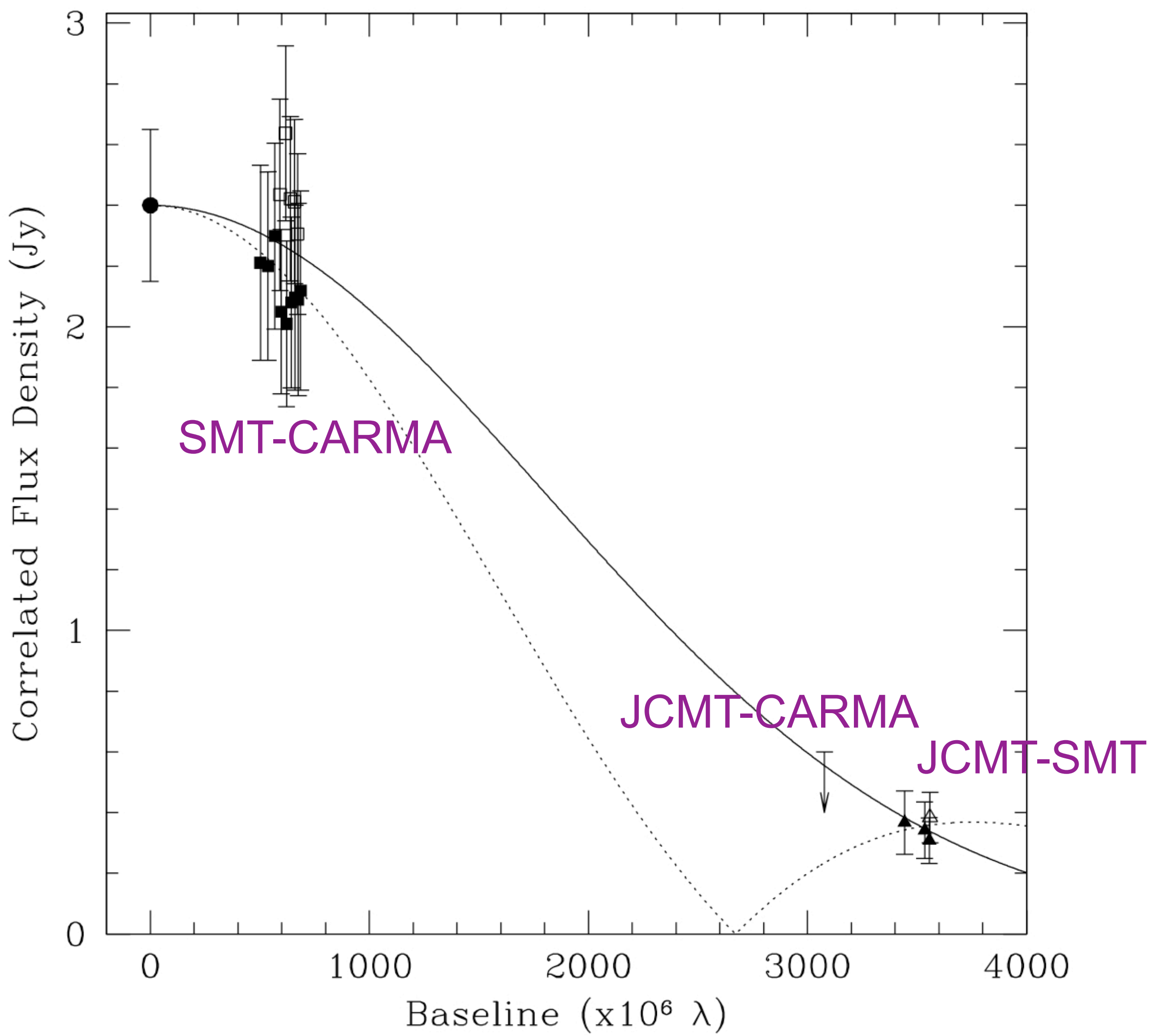


San Francisco
California
Los Angeles
Riverside
Phoenix
San Diego
Honolulu
Hawaii
908km
4030km
4630km

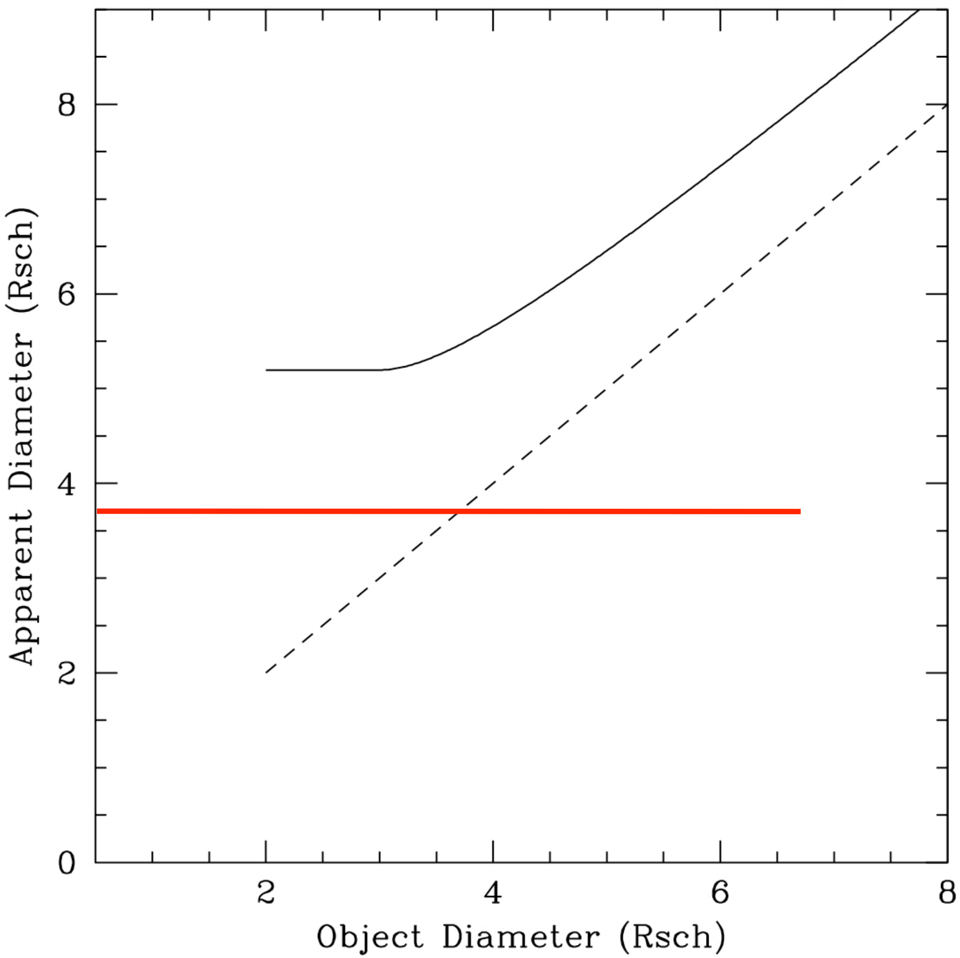
2007 Data



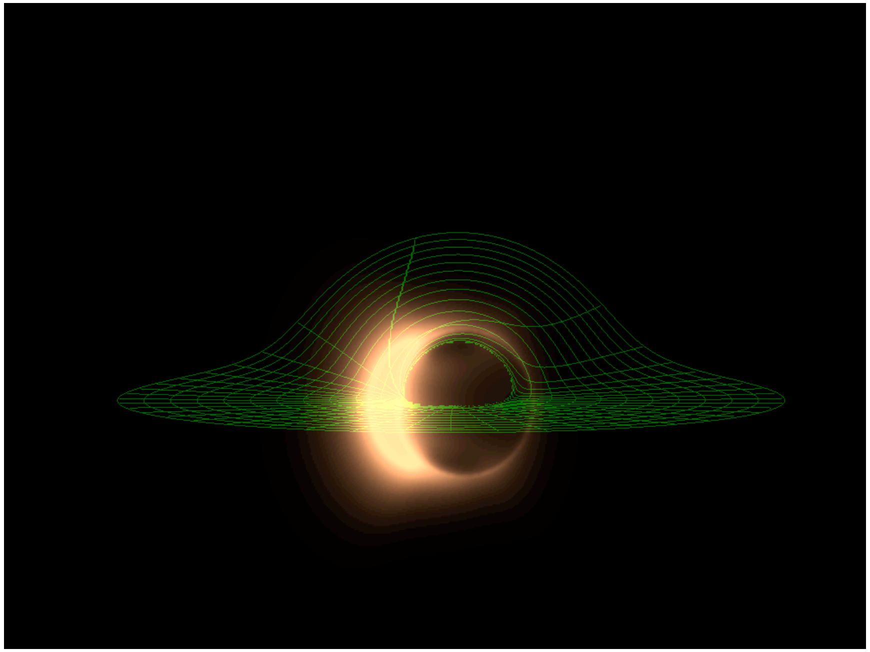



Correlated Flux Density (Jy)
Baseline (x10⁶ λ)
SMT-CARMA
JCMT-CARMA
JCMT-SMT
0
1
2
3
0
1000
2000
3000
4000

The Compact Emission is Small



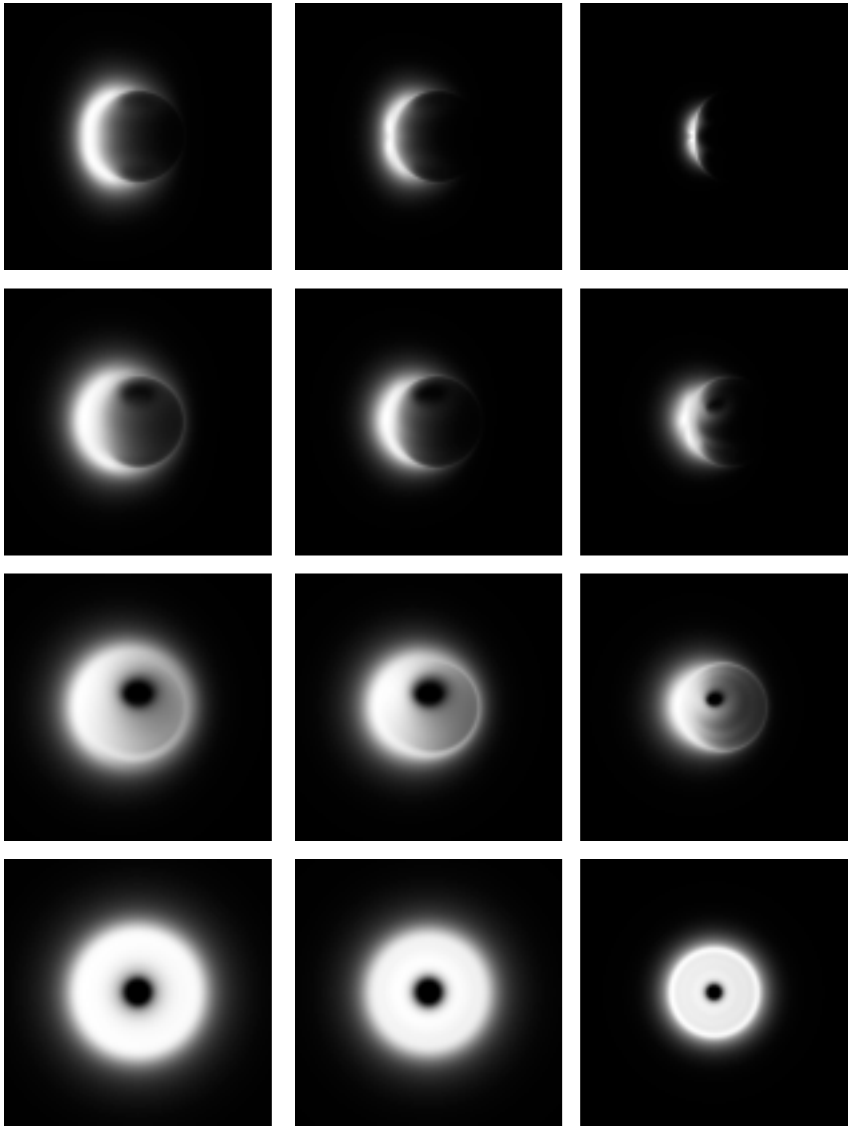
43 µas (measured)
37 µas (deconvolved)

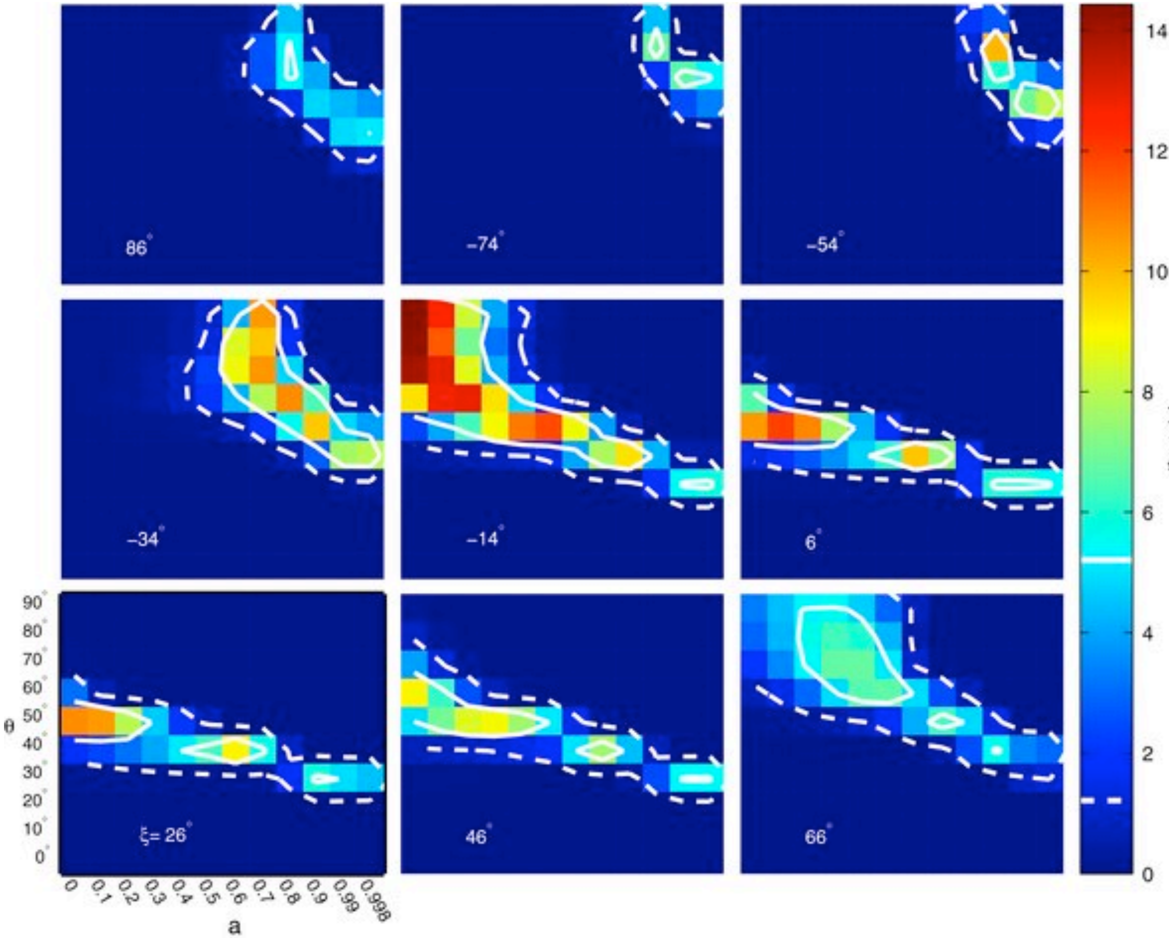


Broderick & Loeb

Emission cannot be optically thick and centered on black hole

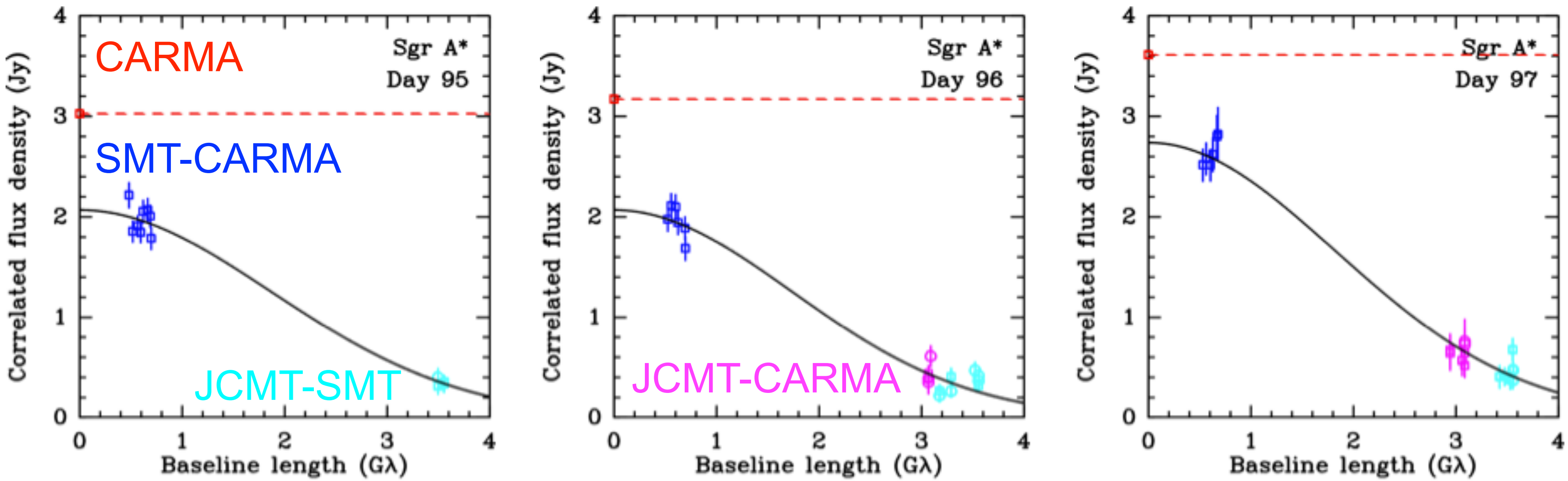
Model Parameter Estimation

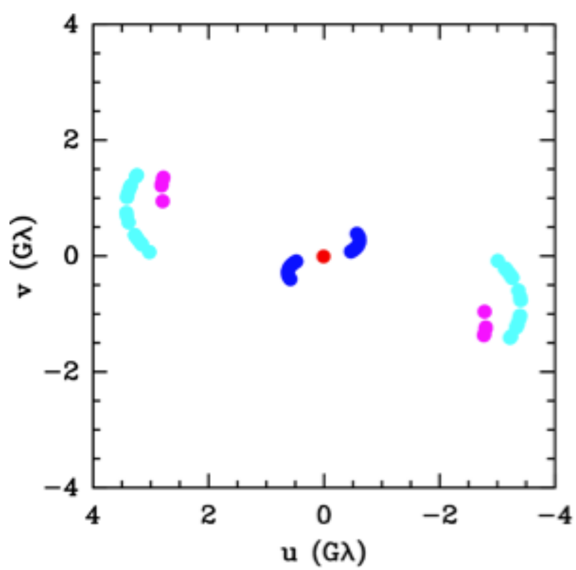




Broderick et al. 2009

2009 Data





large-scale component

JCMT-CARMA detections disfavour
face-on disk models

compact component variable
but constant size

asymmetric?

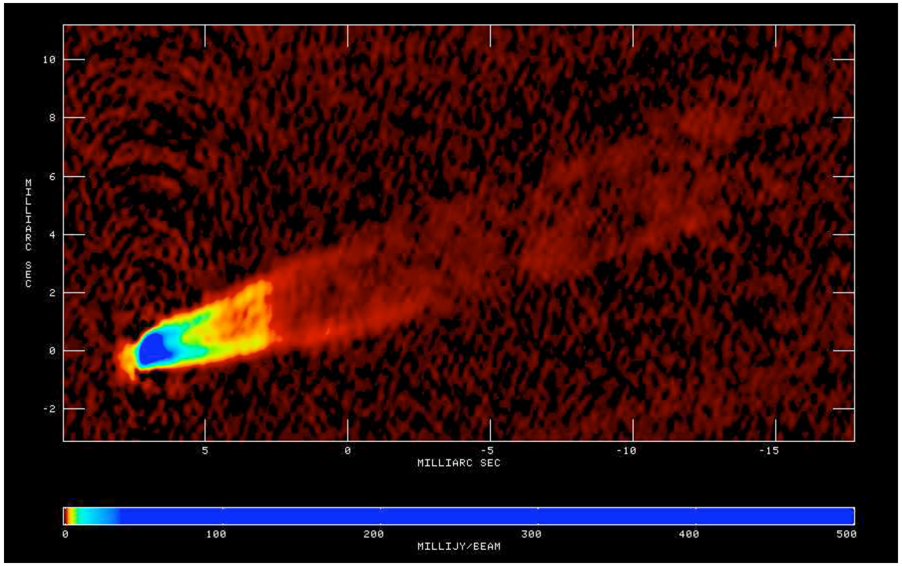
M87

More luminous class of AGN

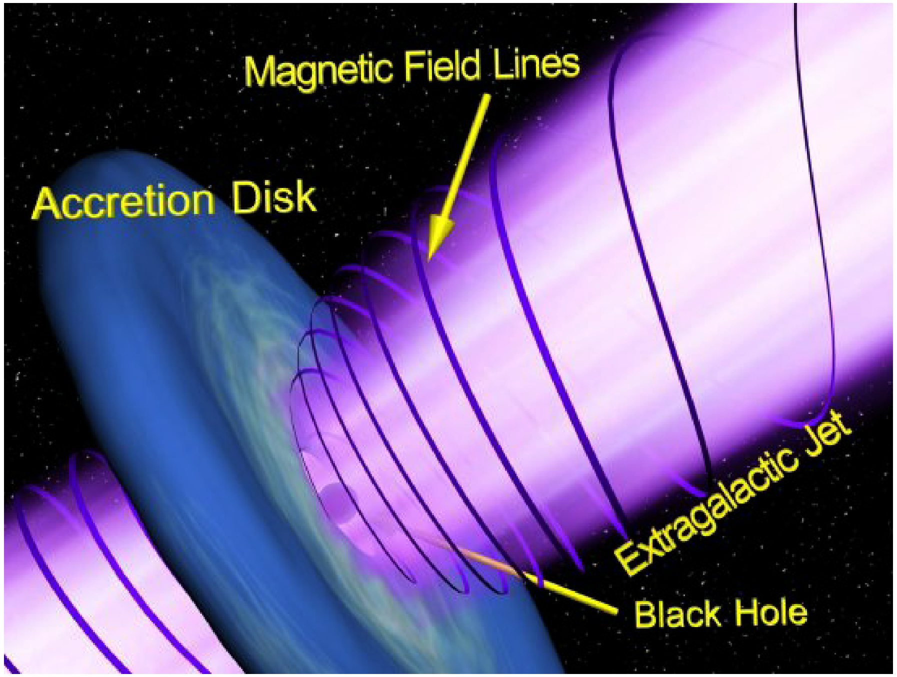
More massive central black hole, known jet source

Innermost stable circular orbit ~ 50 μas

This scale is relevant for TeV photon generation and jet formation

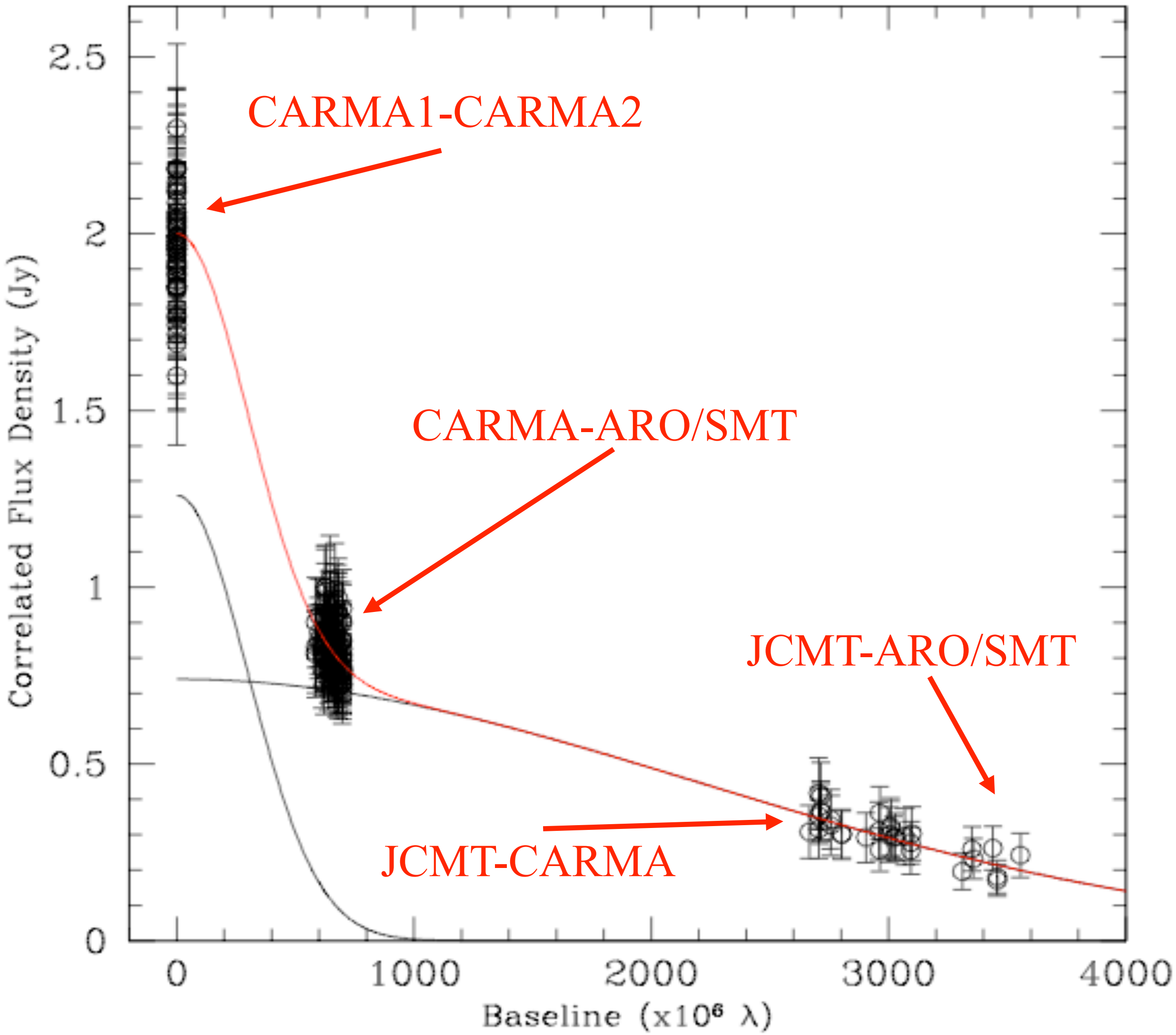


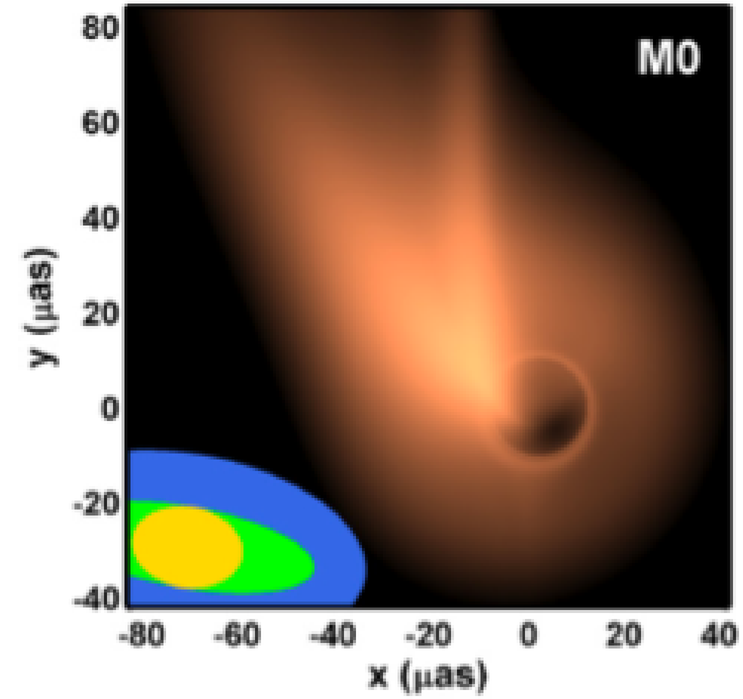
43 GHz VLBA image (Walker et al. 2008)

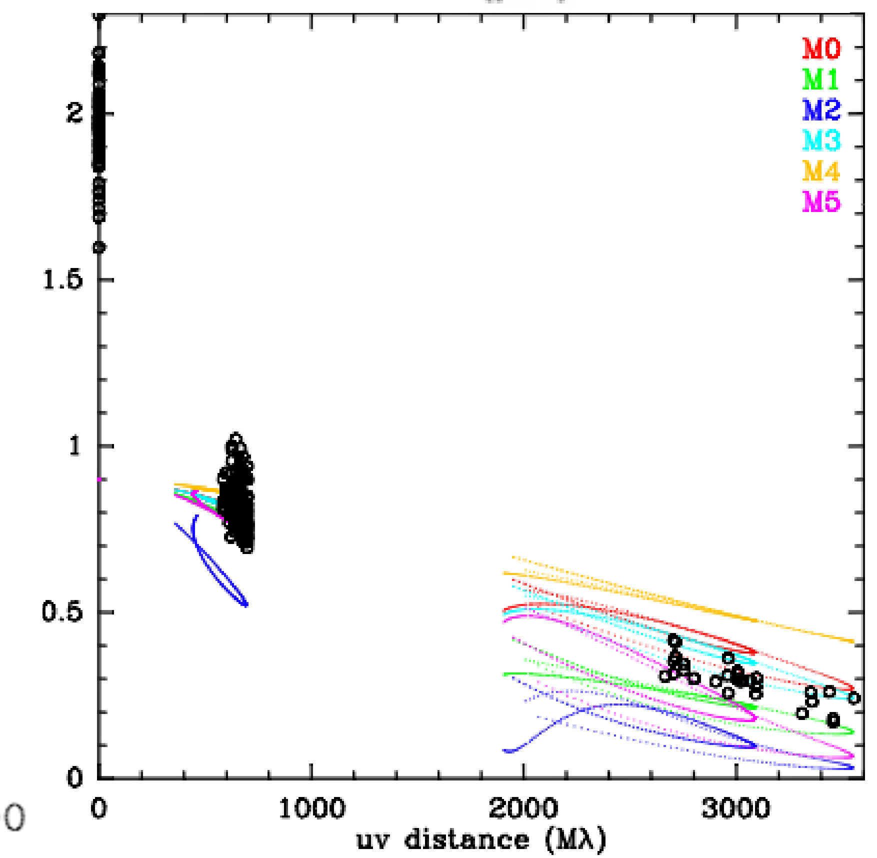


M87

Long VLBI detections may constrain jet models







Summary

Sgr A* has now been detected on all baselines between
Hawaii, California, and Arizona

We can already place strong constraints on models of the emitting region

Variability seen in compact component, although no change in size

Future observations will be more sensitive...
- phased-array processor
- wider bandwidth

...and have greater angular resolution