Anatomy of the horizon-scale structure of Sgr A* with a resolution of ~3 Rs

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in collaboration with

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& the EHT collaboration

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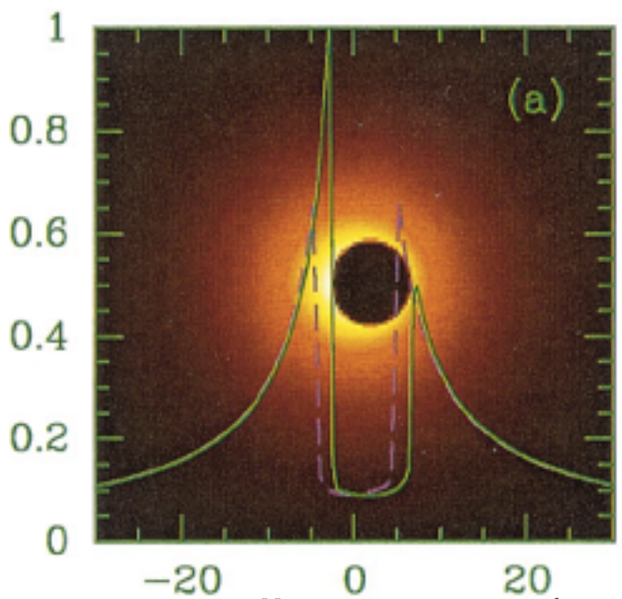
Sgr A*: the best for imaging a black hole

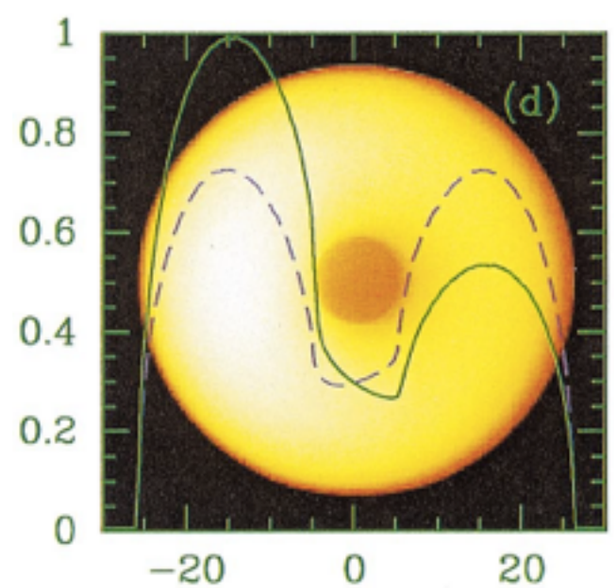
-largest apparent event horizon among any black holes in the universe: Rs = 10 μas

- Horizon-scale structure exists
- A place that allows to test GR in strong fields
- Close enough to watch materials swirling towards the horizon



maximally spinning (a=1)

size = 4.5 R_s =45 μas



non-spinning (a=0)

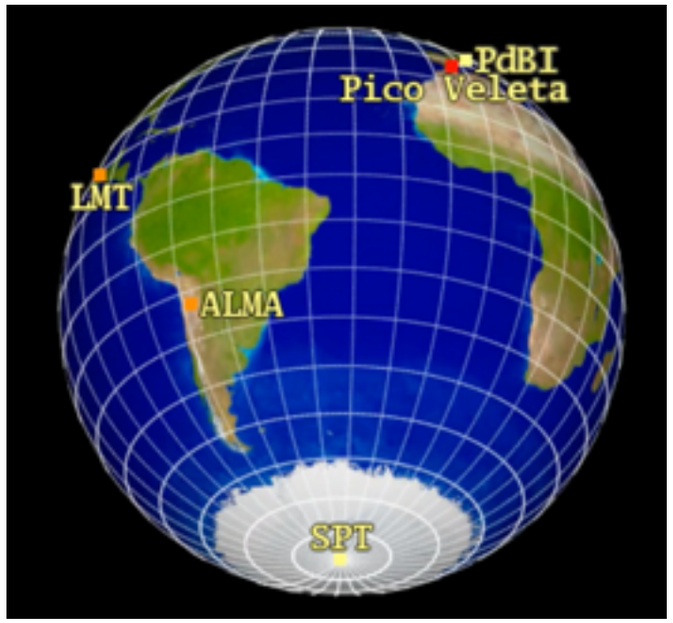
size = 5.2 R_s= 52 μas

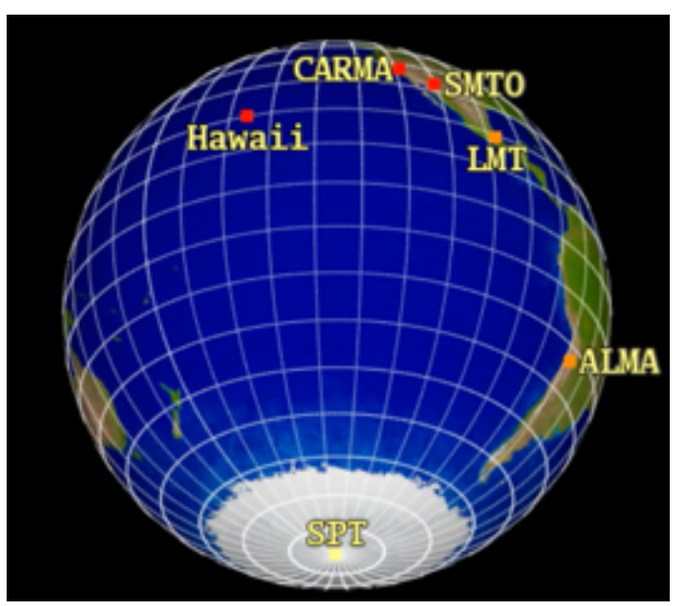
(Bardeen 1973, Falcke, Agol & Melia 2000)

global 1.3mm-VLBI provides well-matched resolution!

~ 20-30 μas

Current development of 1.3 mm-VLBI -EHT collaboration

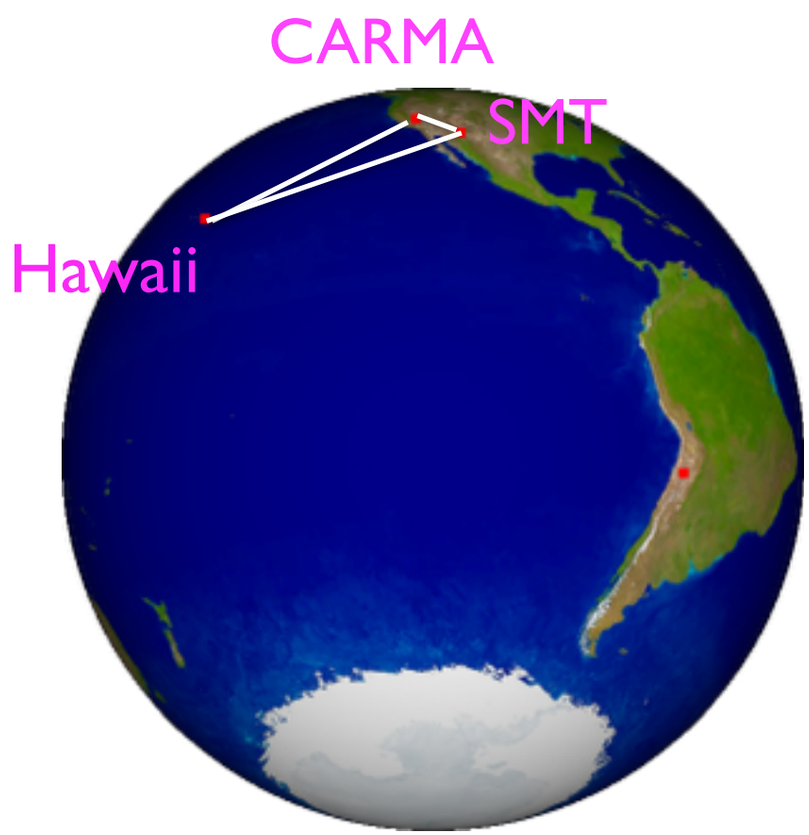


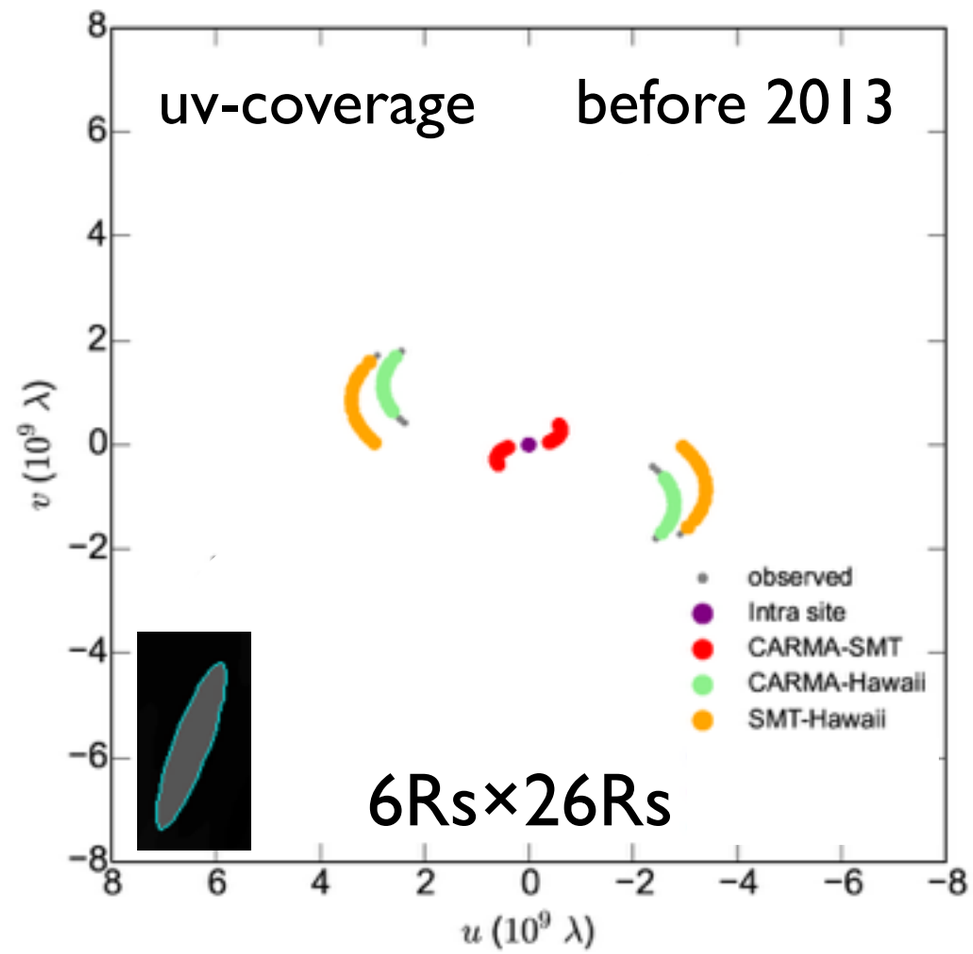


EHT as viewed from Sgr A*

- SMA & JCMT, Hawaii
- SMT, Arizona
- LMT, Sierra Negra, Mexico
- APEX & ALMA, Chile
- Pico Veleta, Spain
- Plateau de Bure/NOEMA
- South Pole Telescope
- Greenland Telescope

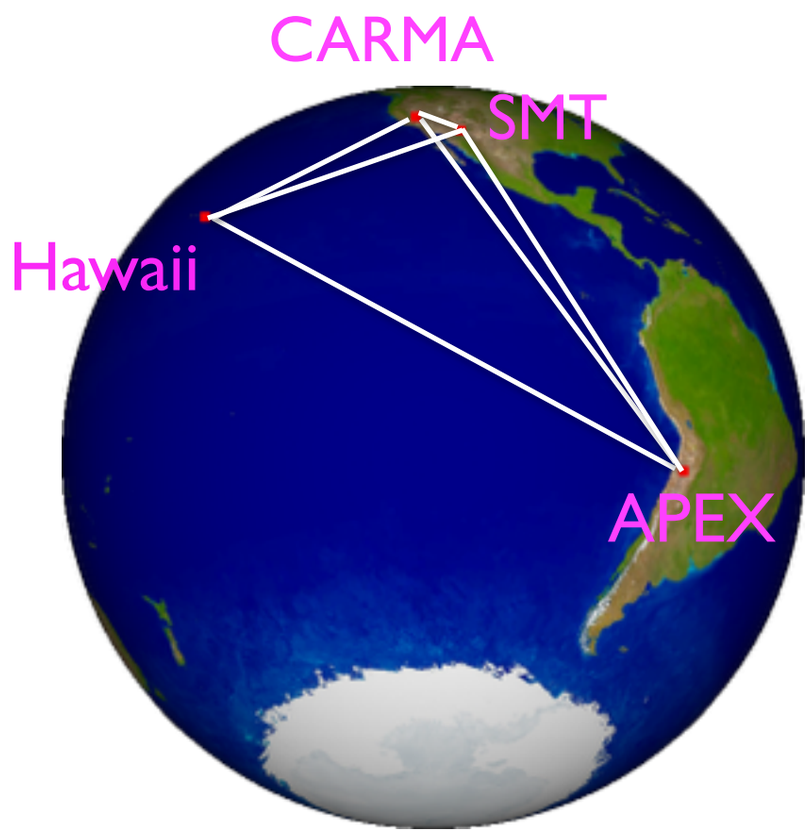
1.3mm-VLBI observations of Sgr A* before 2013:

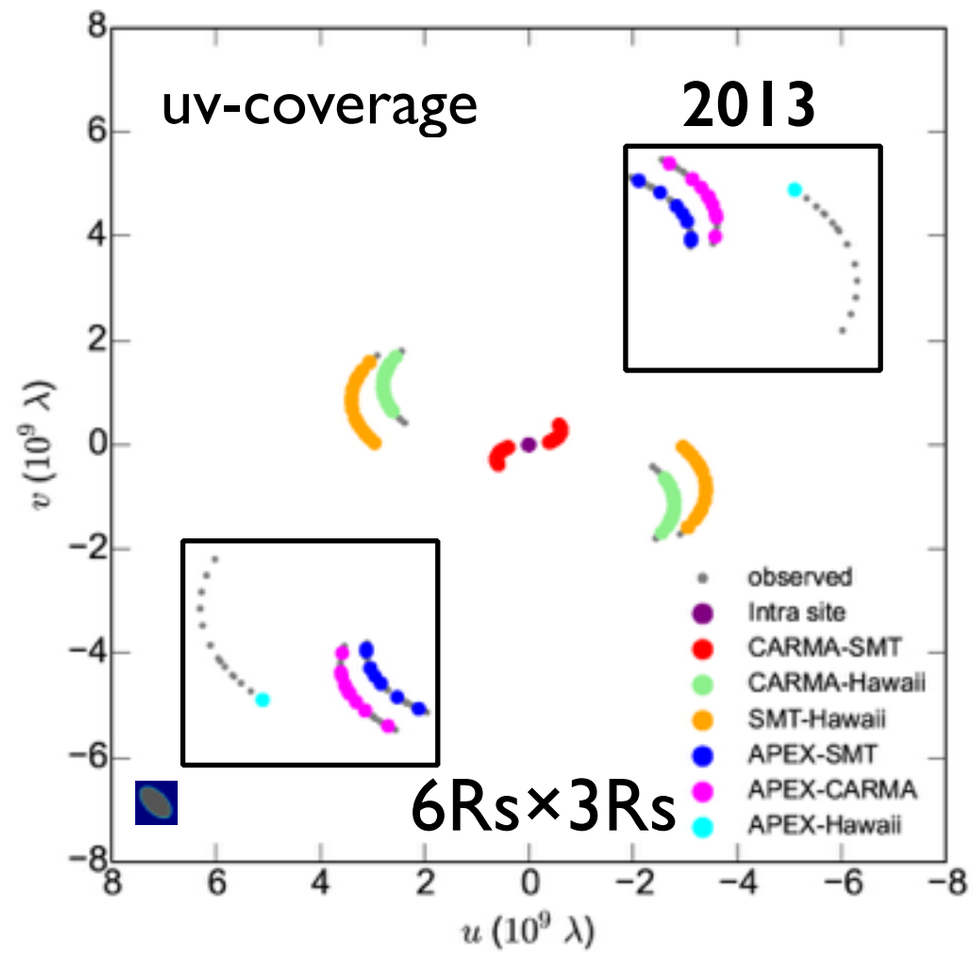




1.3mm-VLBI observations of Sgr A* in 2013:

-APEX detected Sgr A*: 3 Rs resolution achieved





Baseline length:

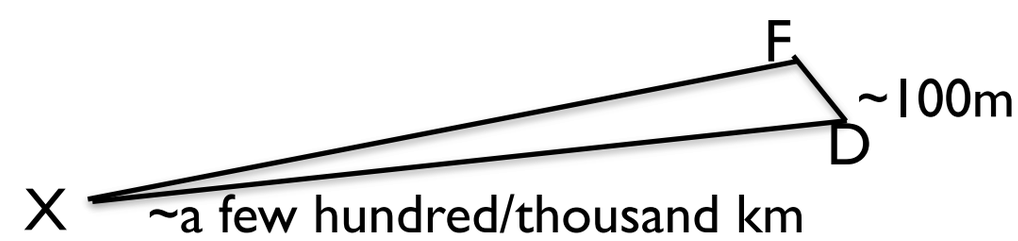
92m (intra-site) — 9447 km (with APEX)

Amplitude “gain” calibration

1. Identify zero-spacing flux S_0 (measured by connected interferometer)

2. calculate residual gain factors to make the calibrated parallel hand visibilities on intra-site baselines approximately equal to S_0.

“pseudo-closure amplitude relationship”



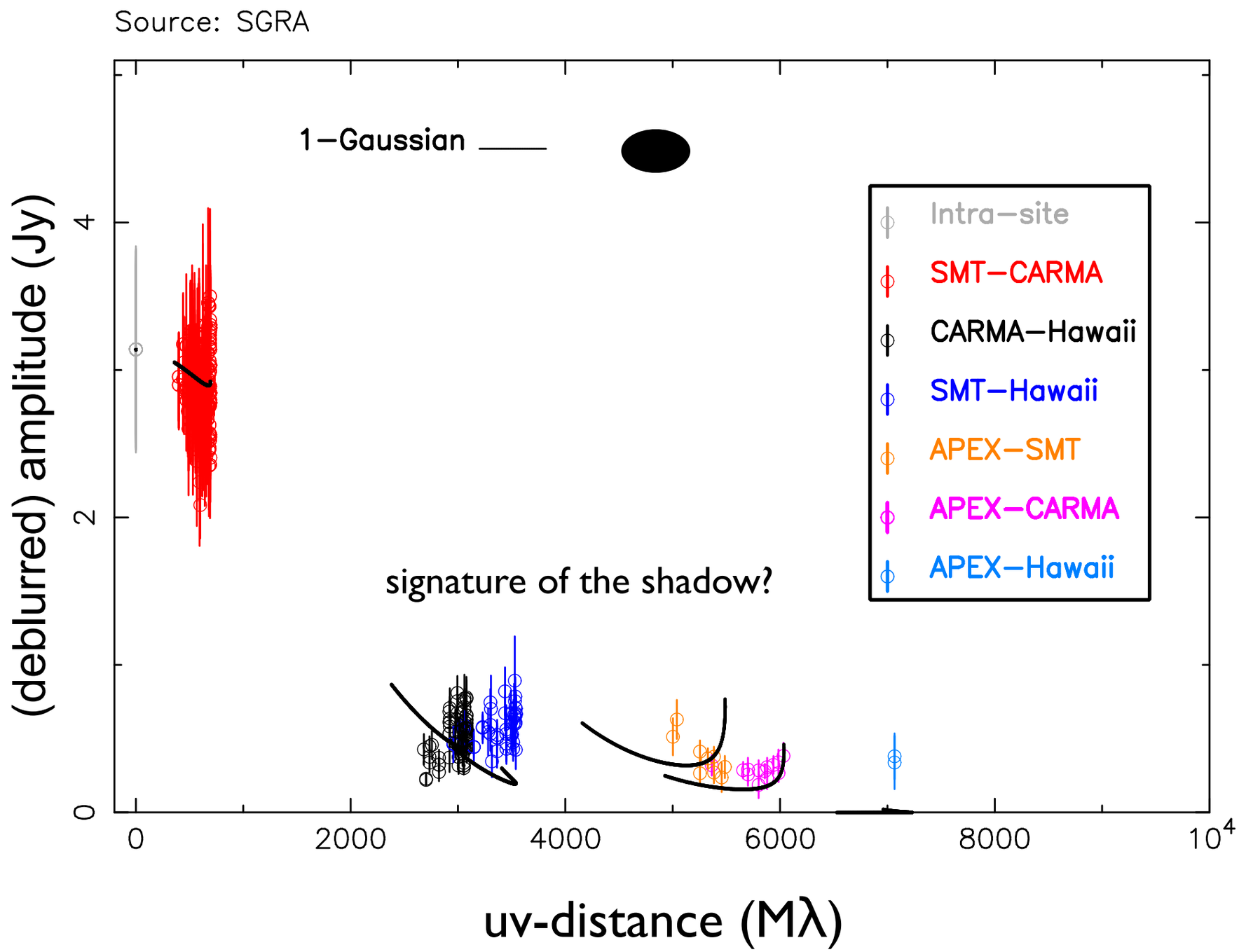
e.g., for FD baseline, one finds:
$gF*gD*FD_{obs} = S_0$ and $gF*XF_{obs} = gD*XD_{obs}$ (in practice, this could involve multiple `X’ stations)

⇨ gF, gD

3. residual gains for SMT, APEX are not set in an “absolute” sense, but assuming not too far from unity.

1.3mm-VLBI observations of Sgr A* in 2013

-new signatures seen



APEX doubles the uv-range to 7000Mλ!

Lu et al., in prep.

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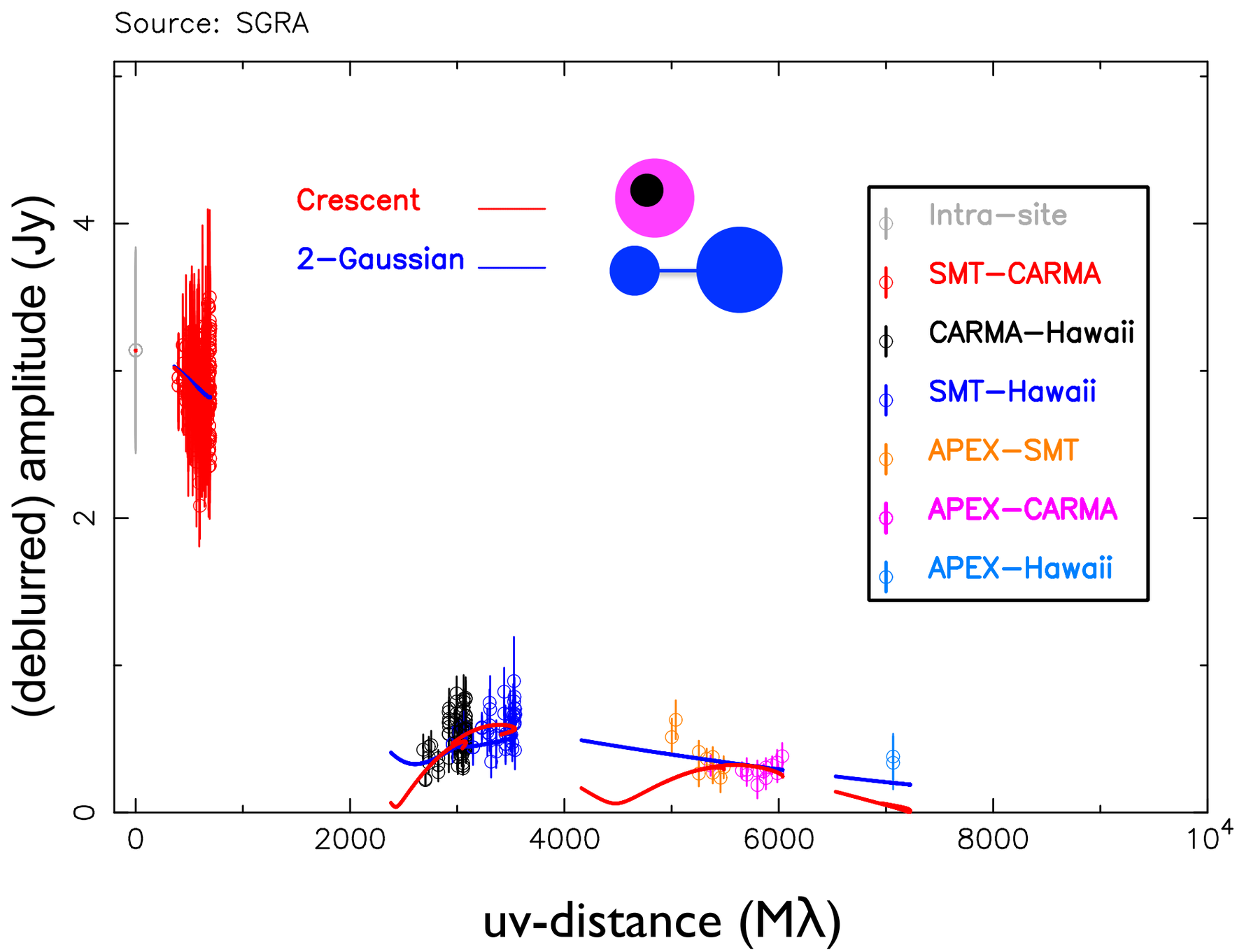

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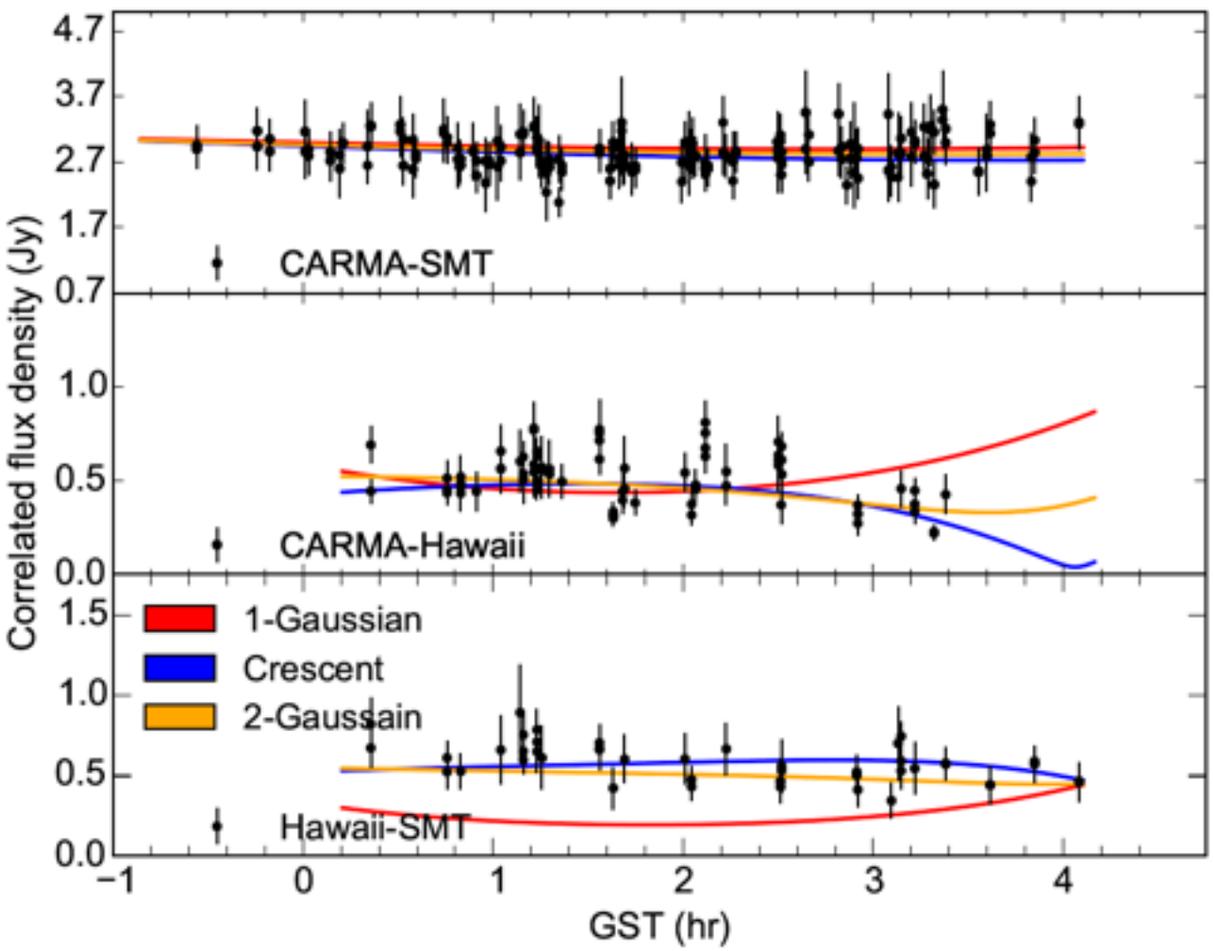
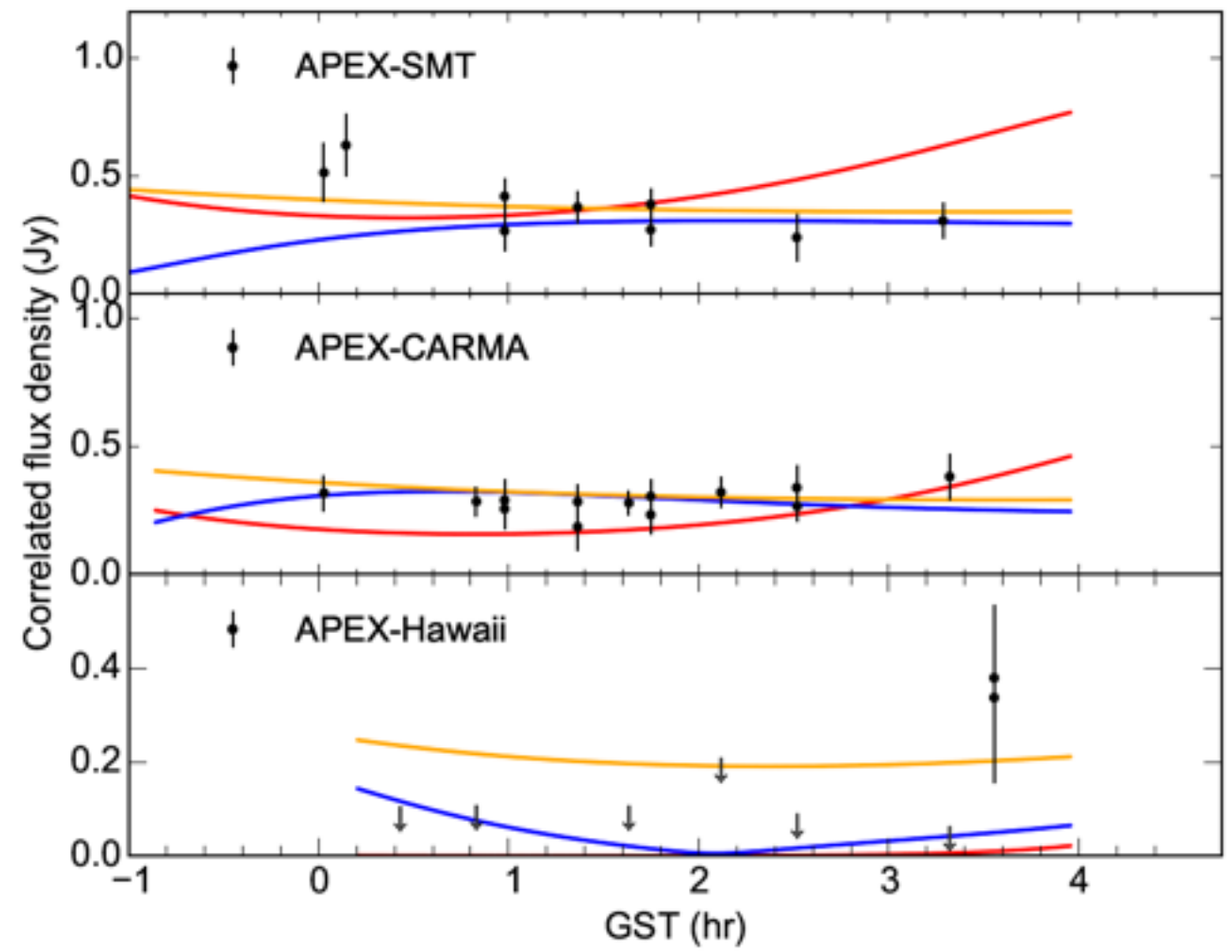


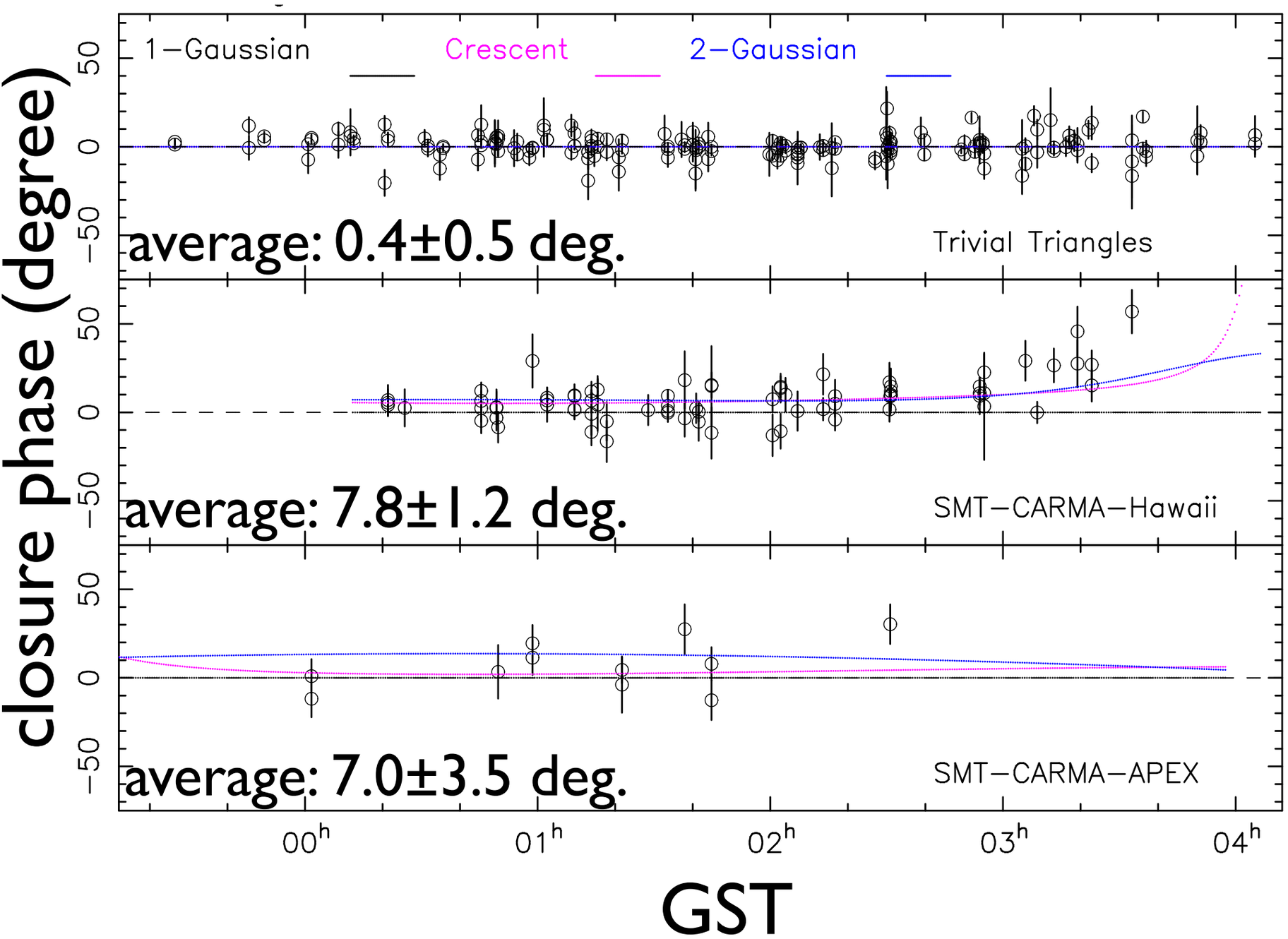


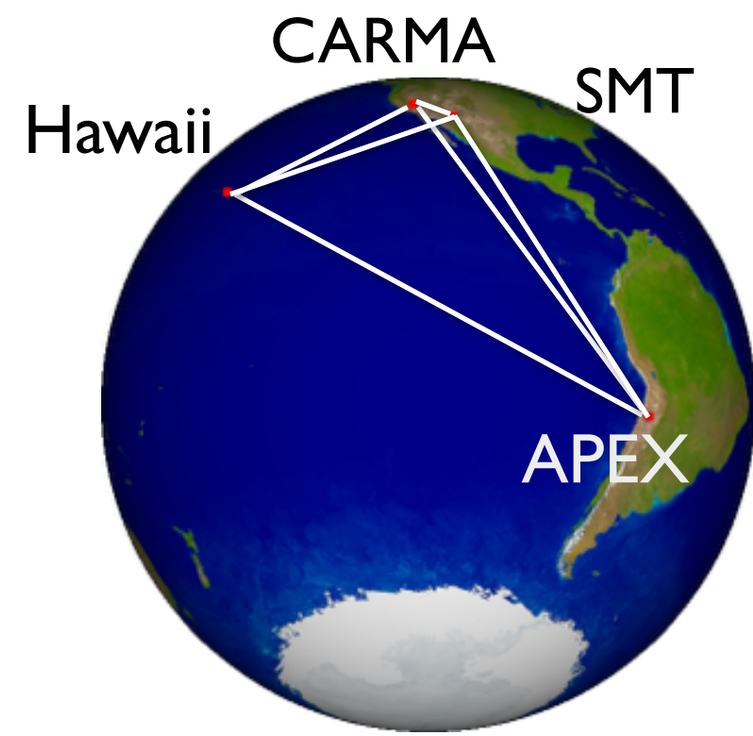
Time

Time

1.3mm-VLBI observations of Sgr A* in 2013

-Non-zero closure phase



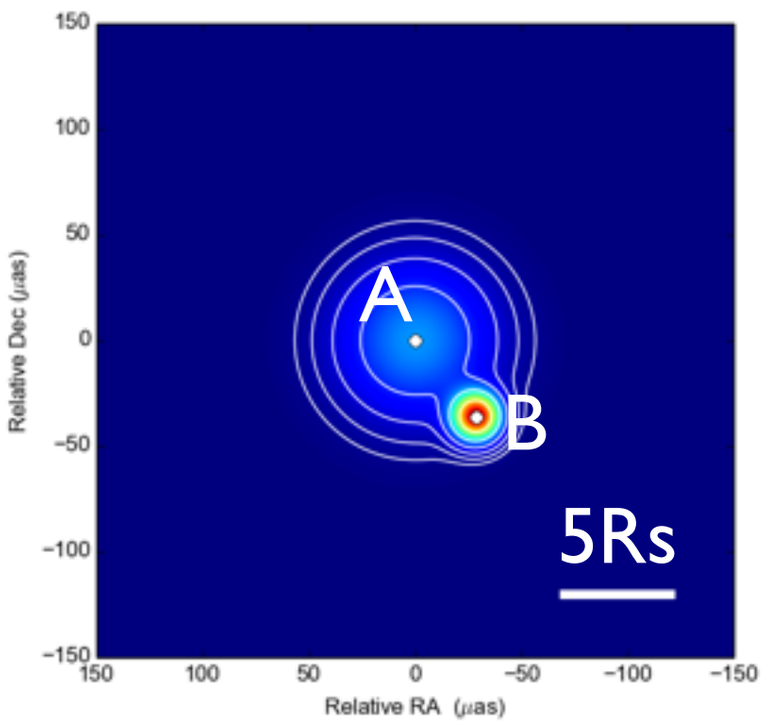


-non-zero closure phase (consistent with Fish+2016)

-Structure is asymmetric and non-pointlike!

1.3mm-VLBI observations of Sgr A* in 2013

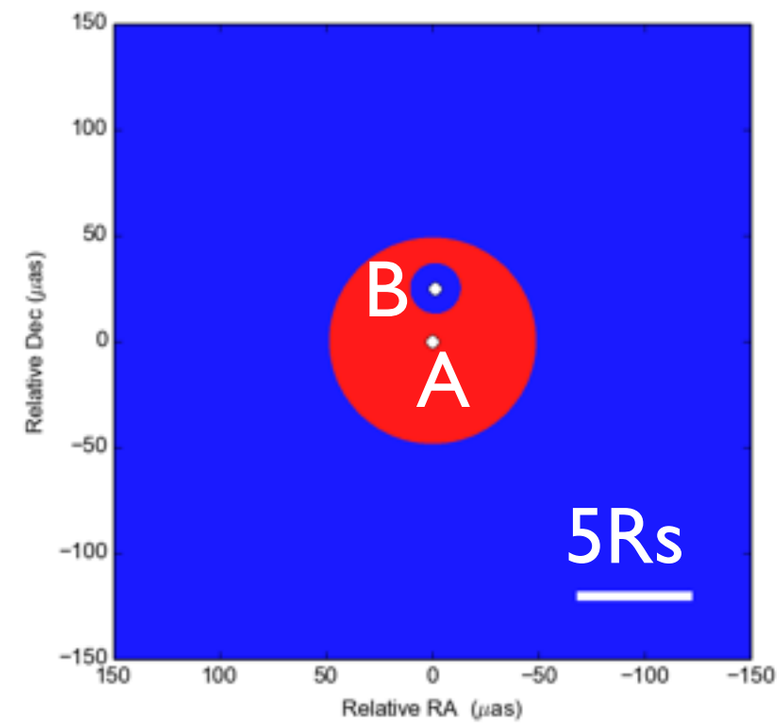
2-component Gaussian (χ^2_ν=1.22)



-very compact structure (1Rs ~10 μas)

	flux (Jy)	r (Rs)	Θ(deg)	Φ(Rs)
(A)	2.37	0	0	5.8
(B)	0.77	4.6	-128.3	1.8

Crescent model (χ^2_ν=1.21)



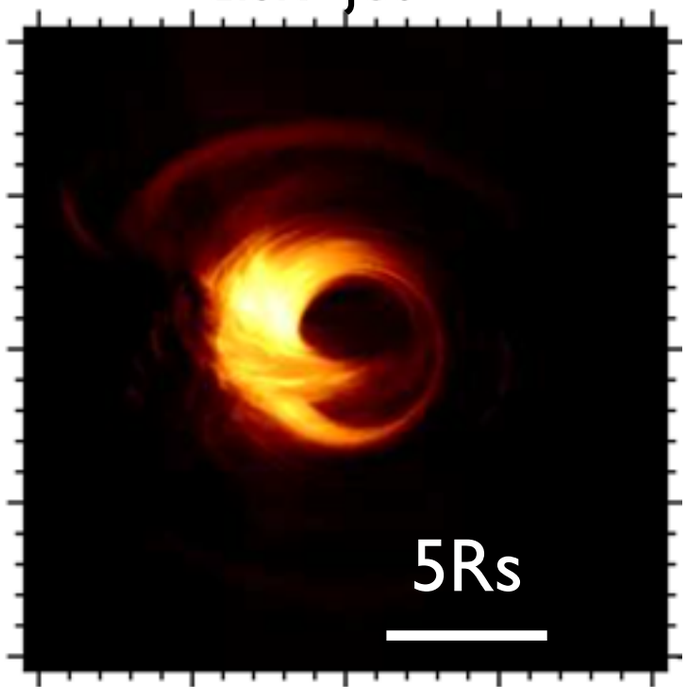
-not a sharp crescent!

flux (Jy)	r (Rs)	Θ(deg)	Φ(Rs)
3.34	0	0	4.9
0.2	2.5	3.0	1.2

-component separation comparable to the expected diameter of the black hole "shadow" !

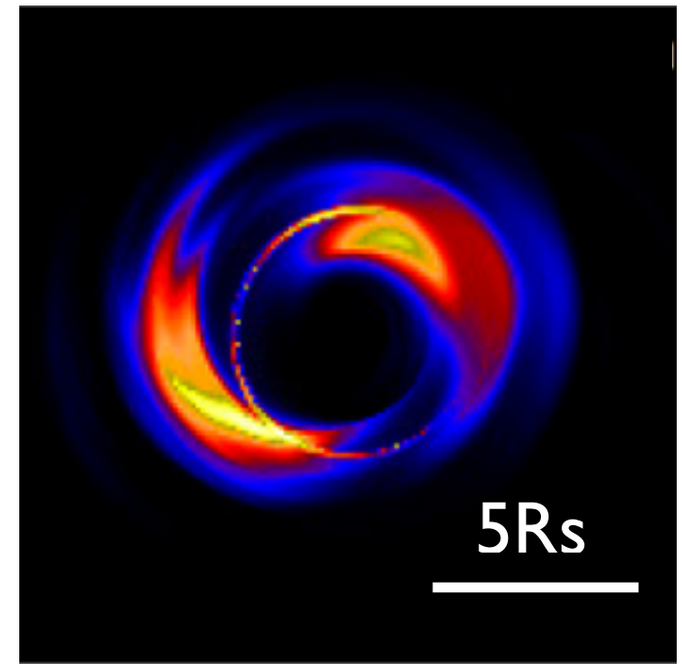
Zoo of theoretical models: what do we see?

disk+jet



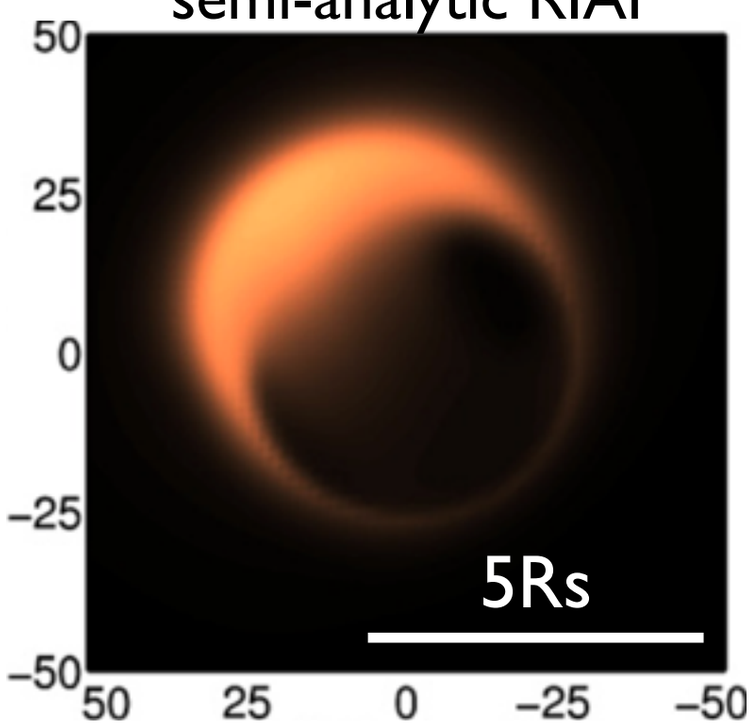
Moscibrodzka et al. 2014

"tilted" disk



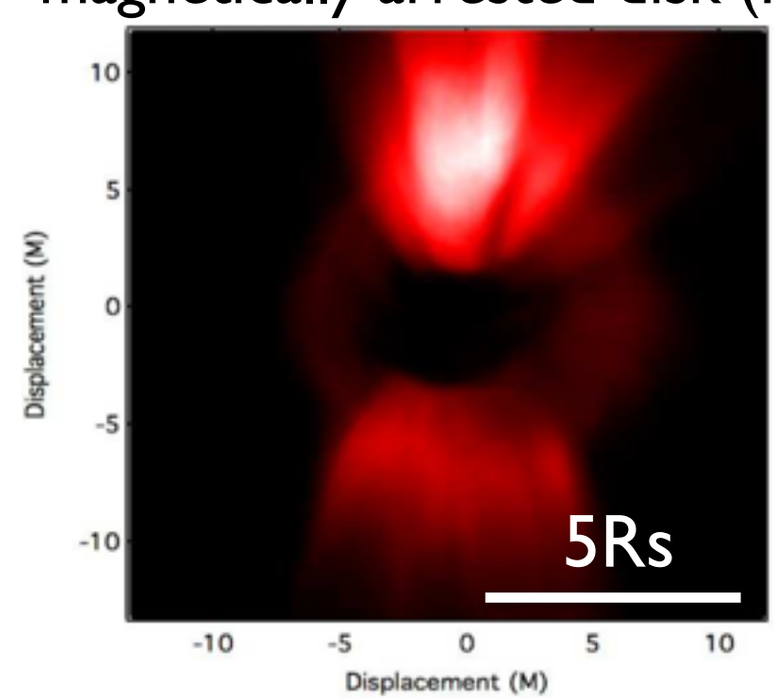
Dexter & Fragile, 2013

semi-analytic RIAF



Broderick et al. 2011

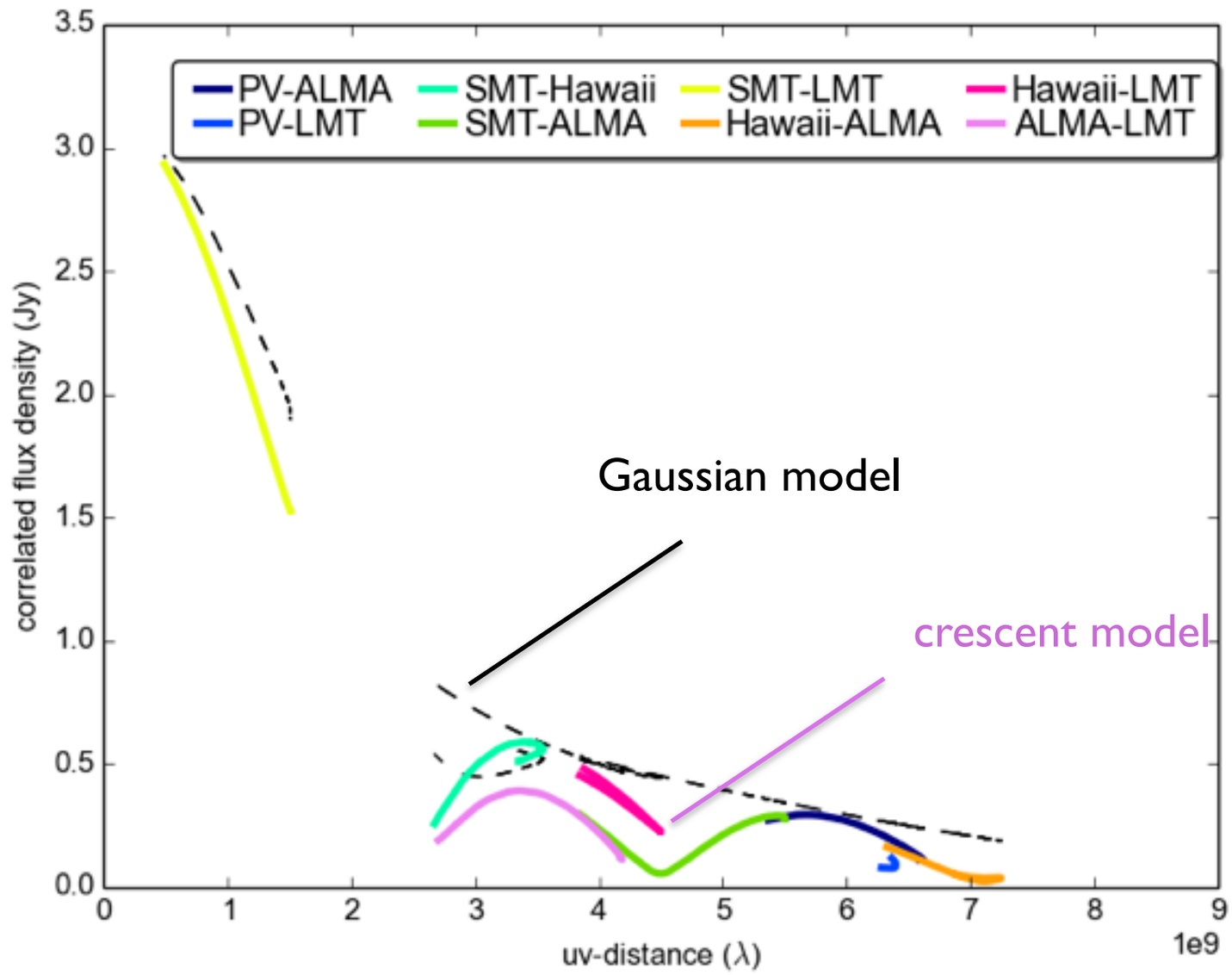
magnetically arrested disk (MAD)



Chan et al. 2015

Looking forward

model predicted visibilities



Assumed stations: Pico Veleta (PV), SMT, Hawaii, ALMA, LMT

Summary

Millimeter-VLBI is a unique tool to study horizon-scale structures of Sgr A*

The (sub)mm-VLBI array (EHT) is growing fast (new fringes, higher data rates…)

New observations point towards “complex” and extremely compact structures in Sgr A*

Imaging black hole shadow in Sgr A* will be within reach in next few years