Title: Detection and Variability of Closure Phases in Sgr A*

Date: Nov 10, 2014 02:30 PM

URL: http://pirsa.org/14110070

Abstract: Closure phases measured on the Arizona-California-Hawaii triangle of the EHT over multiple years indicate that the 1.3 mm structure of Sgr A* is asymmetric on scales of a few Schwarzschild radii. The closure phase data provide new constraints on models of the quiescent emission from Sgr A*. Time variability in the closure provides evidence of structural changes on scales resolved by millimeter-wavelength VLBI.
We discuss these results as well as other implications of the data.

Products of Radio Interferometry

Each baseline has instantaneous "(u,v)" coordinates that correspond to the spatial frequency being measured

After correlation and calibration, end up with a complex visibility on each baseline

Van Cittert--Zernike theorem tells us the visibility is related to the Fourier transform of the image

Amplitude: How much power is on this spatial frequency?

Phase: Where is that power located?

Phase information is especially powerful

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The importance of phase

IM_1 IM_2

Ampl- IM_1, Phase IM_2

Ampl- IM_2, Phase IM_1

(Skarbnik+ 2010)

Strategies to mitigate atmospheric corruption

Amplitude: Cannot use coherent (vector) averaging directly
- Use incoherent (scalar) averaging + noise debiasing -or-
- Use prior phase information (e.g., from similar baseline)

Phase: Cannot derive a meaningful visibility phase
- Use closure phase

$$\varphi_{ABC} = \varphi_{AB} + \varphi_{BC} + \varphi_{CA}$$

$$\varphi_{AB,obs} = \varphi_{AB,src} + \sigma_{A,atm} - \sigma_{B,atm} + \varepsilon$$
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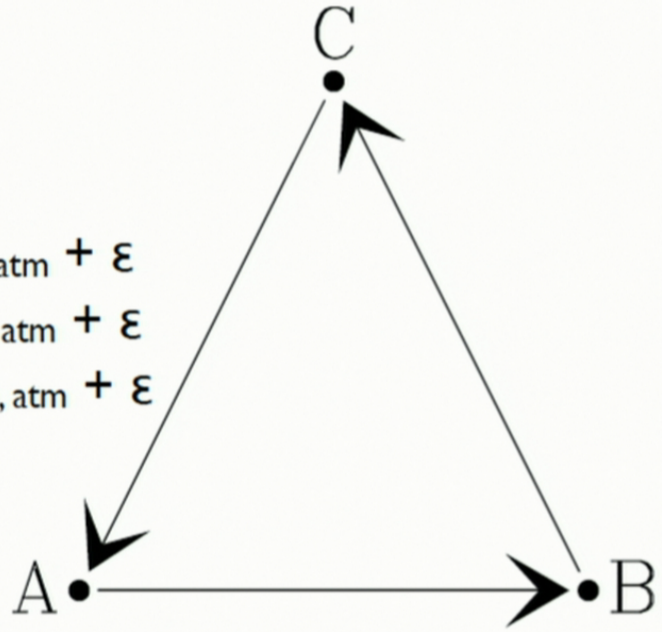
$$\varphi_{ABC,obs} = \varphi_{ABC,src} + \varepsilon$$



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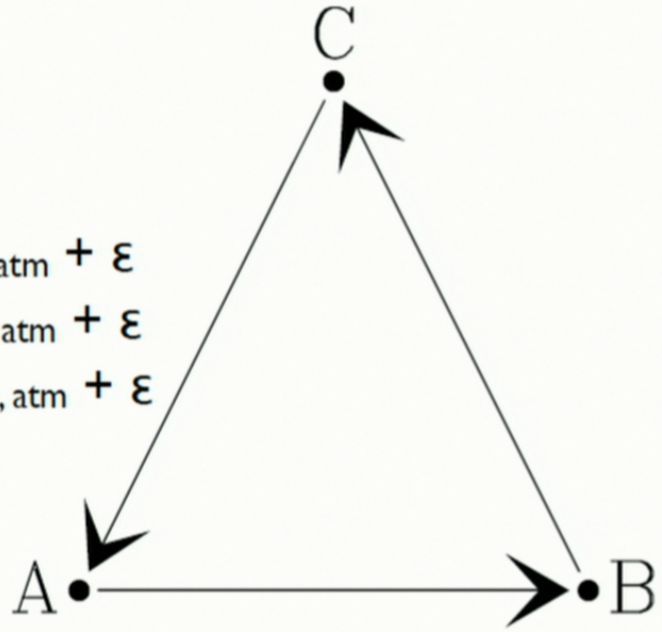

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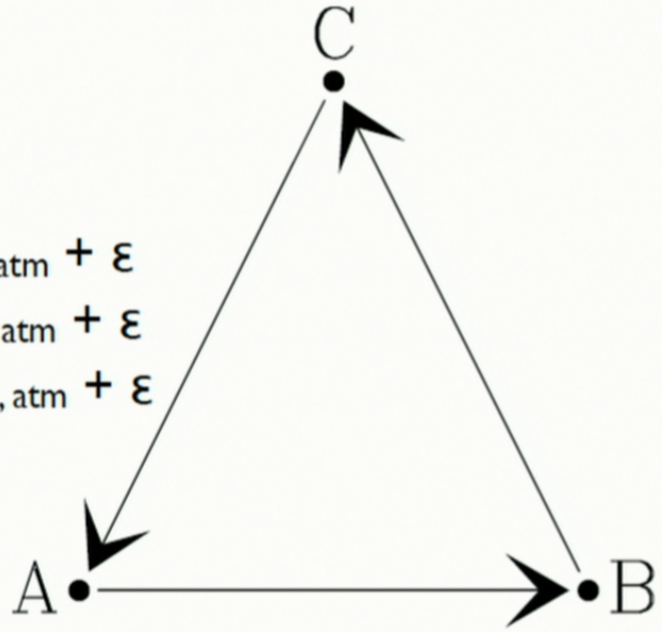
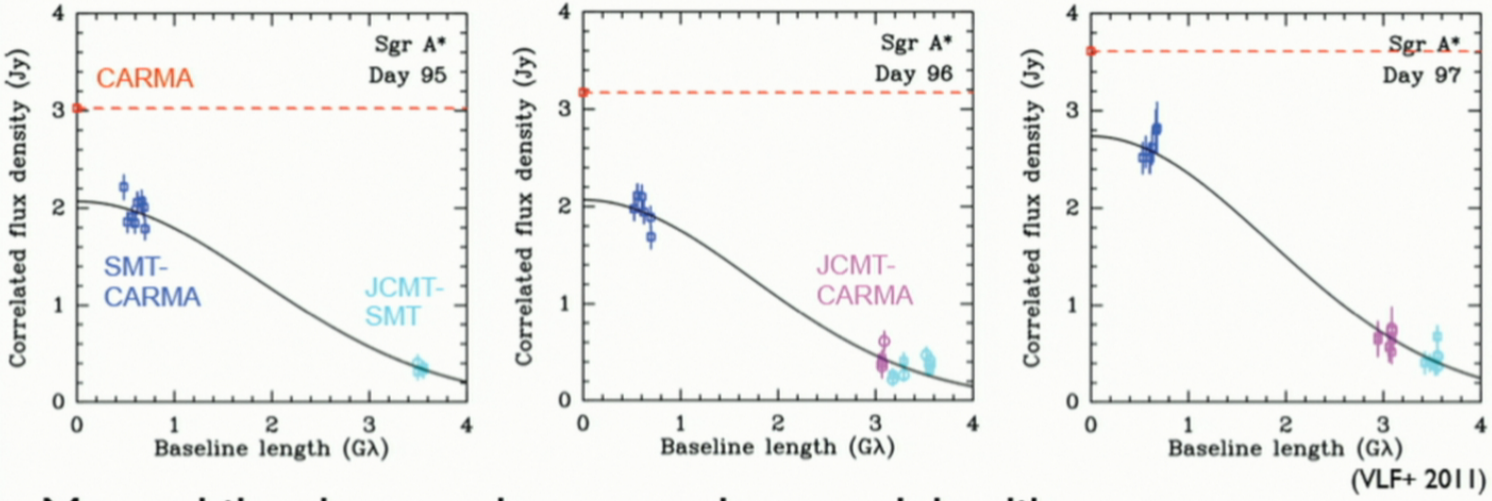


Prior EHT observational status

2007: Long-baseline detections of Sgr A* on JCMT-SMT baseline (Doeleman et al. 2008), amplitudes only

2009: Long-baseline detections of Sgr A* on JCMT-SMT and JCMT-CARMA baselines, amplitudes only + limit on closure phase: within 40 degrees of zero)



(VLF+ 2011)

Meanwhile, closure phases used to model calibrator sources (Lu et al. 2012, 2013; several in prep. by other authors)

Progress toward better closure phase estimates

Algorithmic:

- Fixed bug in fourfit that introduced additional phase error
- Introduction of fourfit mode designed to optimize closure phase estimation
- Ad hoc phase capability to increase S/N on weak baselines
- Delay and rate closure to find weak fringes

Sensitivity:

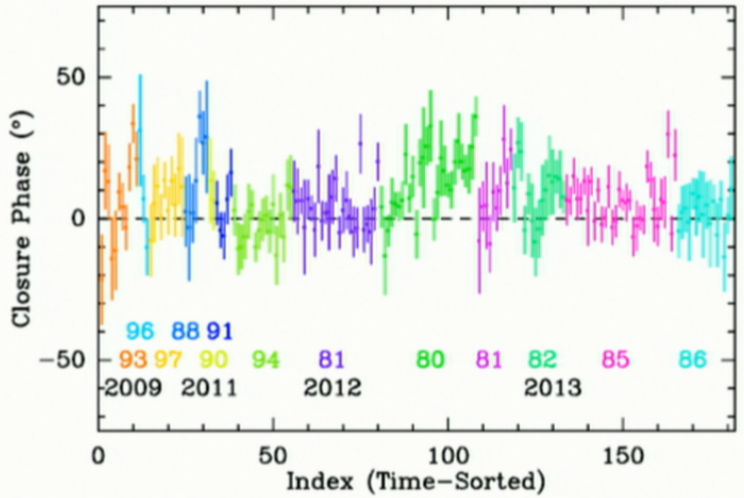
- Use of phased-array stations
- Better weather in 2013
- More data thanks to dual-polarization systems
- Large accumulated number of data points

Sgr A* closure phases

Evidence of nonzero closure phase as early as 2011, but not statistically significant enough

New data points from 2012 & 2013 indicate a (mostly) consistent sign of the closure phase on intra-US triangle

California-Hawaii-Arizona



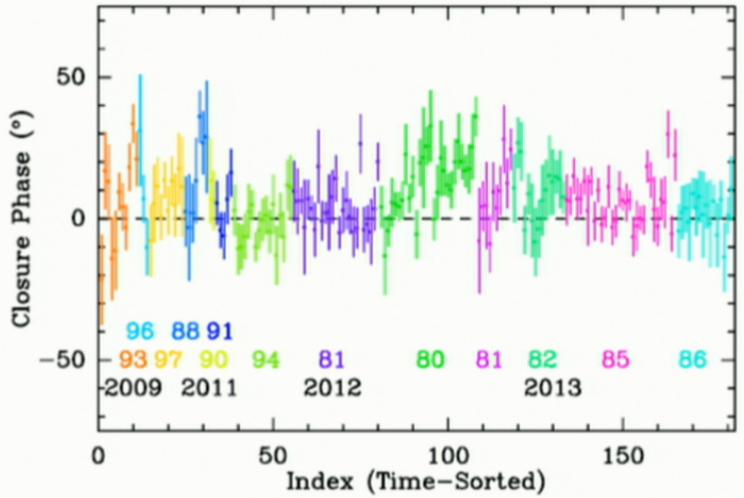
Nonzero closure phase

The closure phase is nonzero at high statistical significance

Weighted mean: 6.5 deg +/- 0.7 deg

Median: 6.3 deg (3.5-7.7 deg at 99.7% confidence)

A bootstrap analysis of the median found only positive values over 10^8 trials

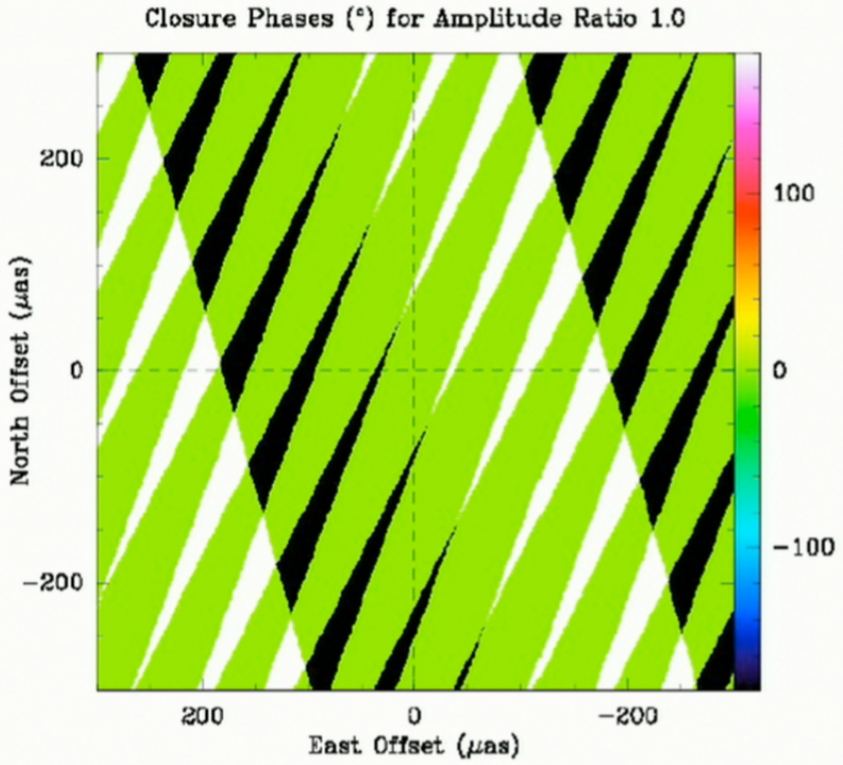


Implications of nonzero closure phase

Rules out point-symmetric brightness distributions

Sgr A* is not an elliptical Gaussian, a ring, or a symmetric double

Constraints provided by two-point-source models (example predictions for one scan)

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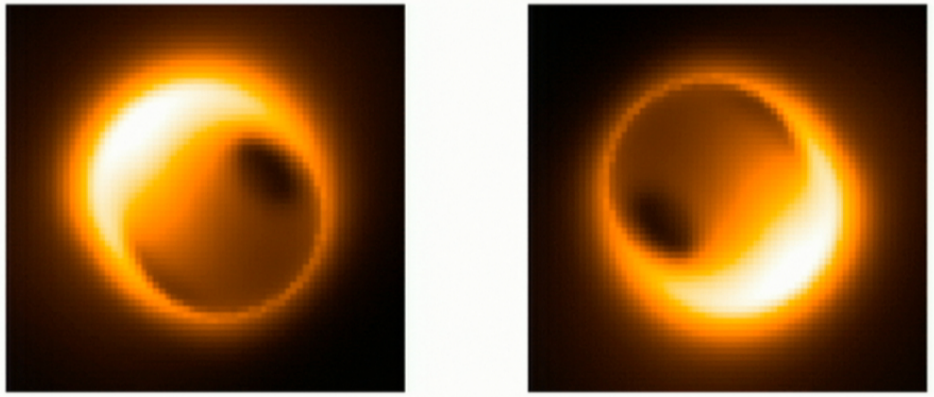
Allowed region given all
detected closure phases

Results applicable to some other point-symmetric geometries,
but not to reflection-symmetric geometries

Implications of nonzero closure phase

Closure phases place constraints on all models

Closure phases break the 180-degree rotational degeneracy of models

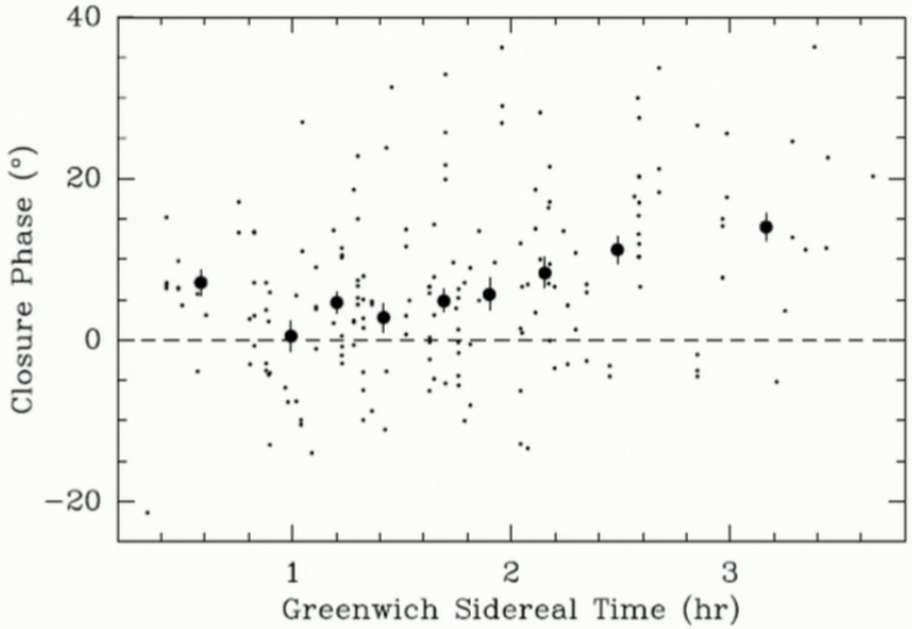


(Broderick+ 2011)

Dependence on GST

Trend for closure phase to be larger toward the end of the night

Likely due to the changing projection of the baselines



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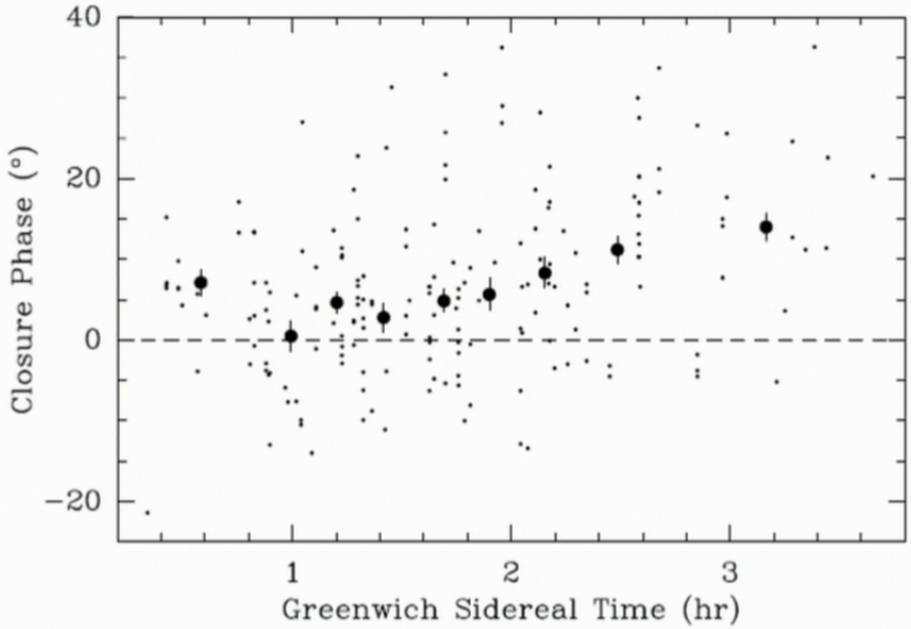
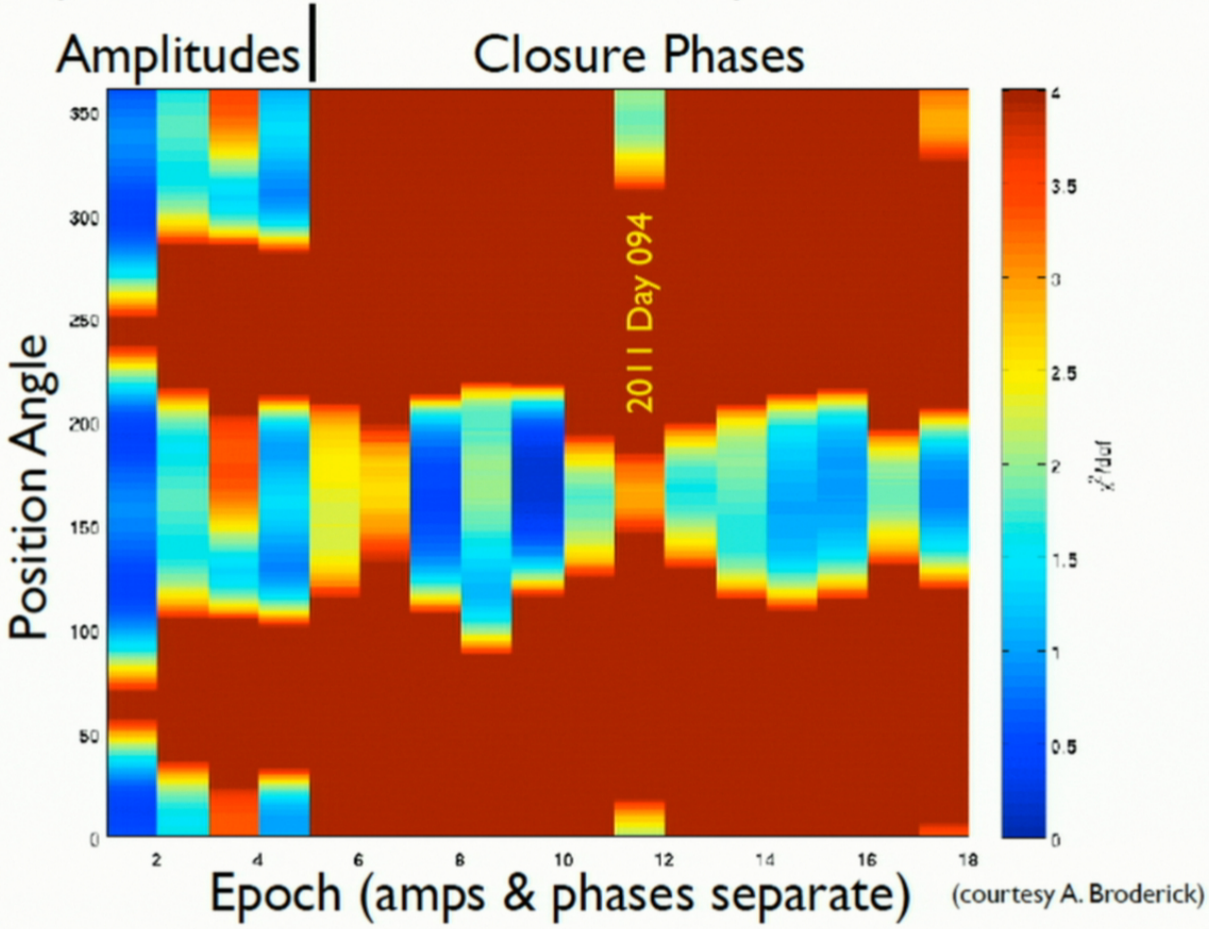


RIAF model fitting: Position Angle

Closure phase data are consistent with prior estimates

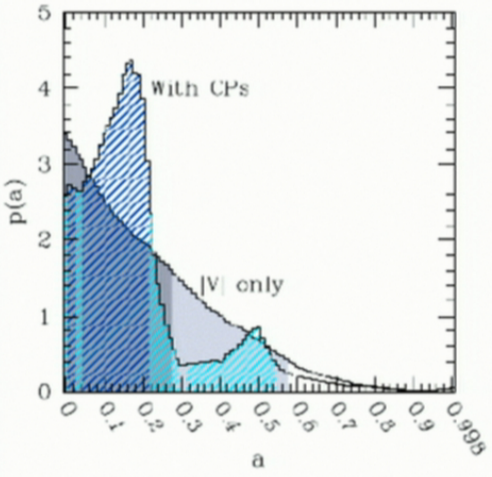


RIAF model fitting: Position Angle

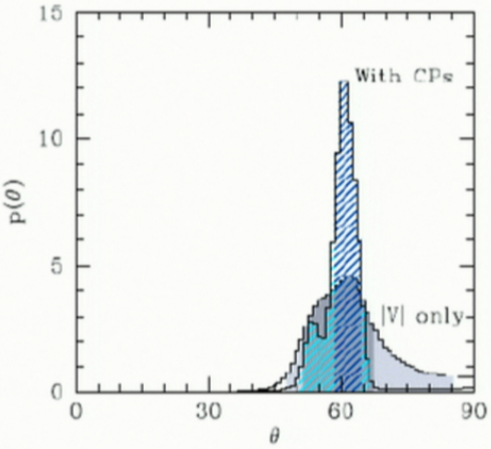
Closure phase data are consistent with prior estimates

Model parameters are (mostly) consistent with those derived from amplitude data alone

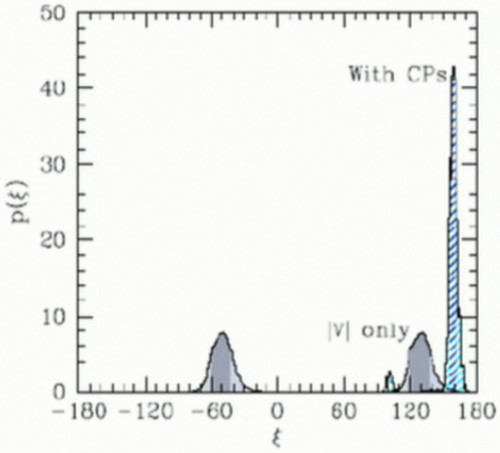
spin



inclination



position angle



(courtesy A. Broderick)

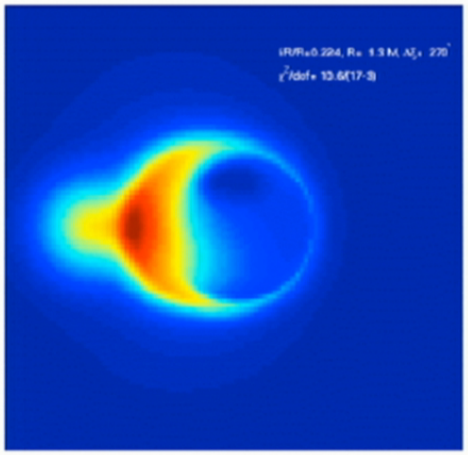
Interpreting variability within RIAF model

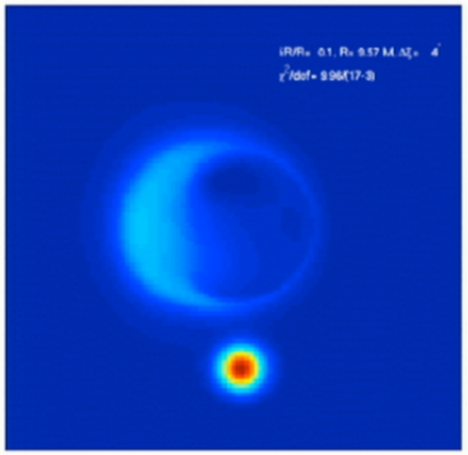
Within RIAF context, variability could be due to a new feature

Additional flux prefers position angle of disk or jet

Currently highly speculative

More data will help!





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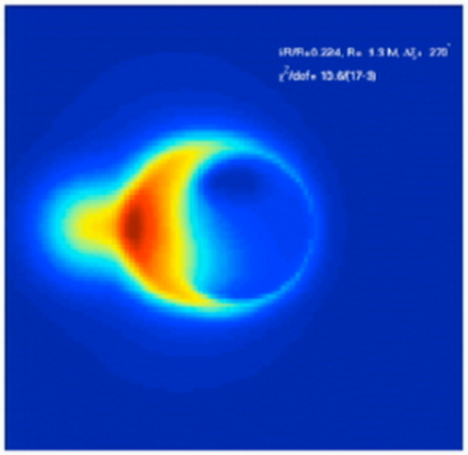

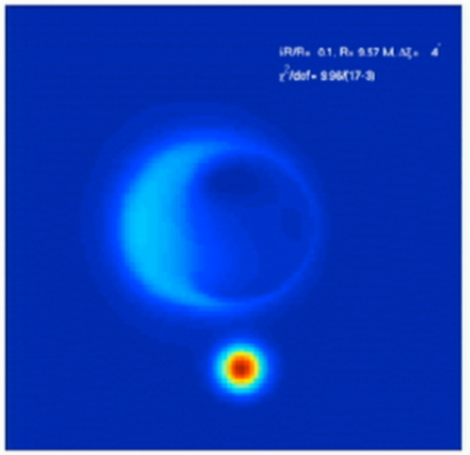

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Connections to refractive effects

Refractive noise from interstellar scattering will dominate on very long baselines (probably > 1 Earth diameter)

Effect already seen at 1.3 cm

Stability of closure phases at 1.3 mm indicates that

- Detected closure phases are from source, not scattering
- Longer ground-based baselines may not have substantial refractive phase noise (though still significant amplitude loss!)

Longer-baseline data at 1.3 mm (and better data at 3 mm and longer) will help us understand scattering properties better

Deblurring may be possible (talk by M. Johnson on Thursday)

Summary

We have detected nonzero closure phases on Sgr A*

Implies asymmetry, places strong constraints on emission models

Small-scale structural variability detected

Refractive scattering likely not a serious issue on these baselines

More sensitive data, bigger triangles coming soon!

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