Christiaan Brinkerink
c.brinkerink@astro.ru.nl

Radboud University

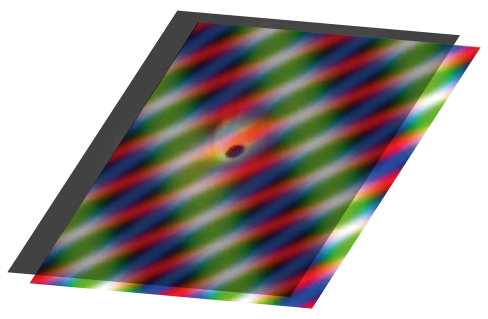
Testing emission models for Sagittarius A*

what closure phase measurements can tell us about source structure

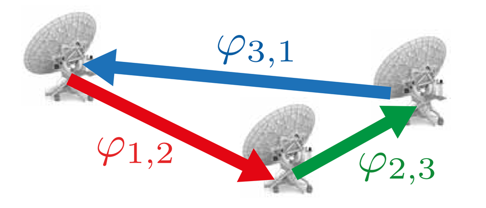
Christiaan Brinkerink , Monika Moscibrodzka , Raquel Fraga-Encinas

Introduction Direct imaging of the central supermassive black hole of our Galaxy at observing frequencies of 3.5mm and 1.3mm is notoriously difficult, due to issues of limited UV coverage and calibration. Closure phase measurements provide a robust tool for constraining the geometry of the accretion flow in this context. We have performed simulated observations of Sgr A* at both these frequencies for two different emission models. We present results that show the expected performance of a 3.5mm measurement and a 1.3mm measurement.

Closure phase



- Is calculated by adding visibility phases around a triangle of baselines
- Is unaffected by station-based phase errors
- Is indicative of asymmetric source brightness distribution
- Is nontrivial to interpret directly
- Is relatively unaffected by interstellar scattering (source image blurring)
- Allows for model fitting
- Can aid in phase calibration for imaging

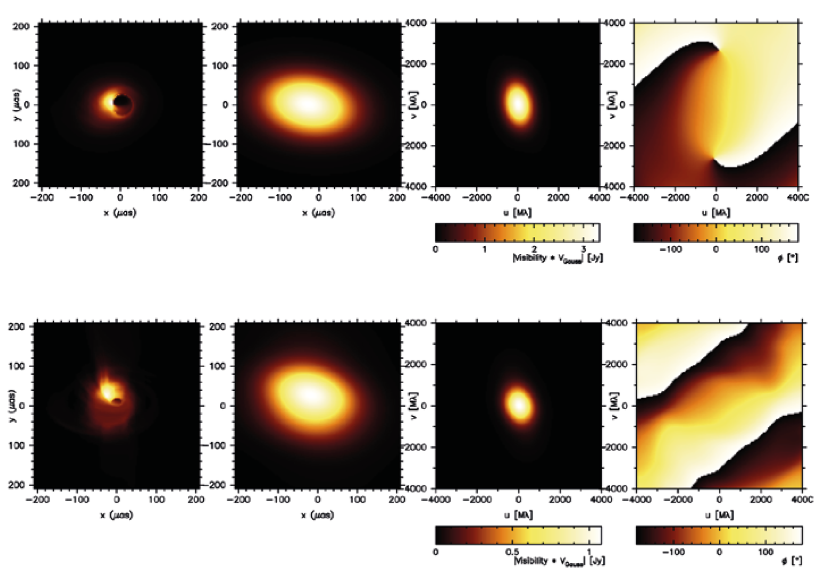


$$\varphi_c = \varphi_{1,2} + \varphi_{2,3} + \varphi_{3,1}$$

Schematic depiction of a triangle of stations, forming 3 baselines in a closed loop. The visibility patterns sampled by each baseline are indicated on the sky in their appropriate colours. The closure phase can alternatively be calculated by multiplying the complex visibilities around the triangle and taking the argument of the result.

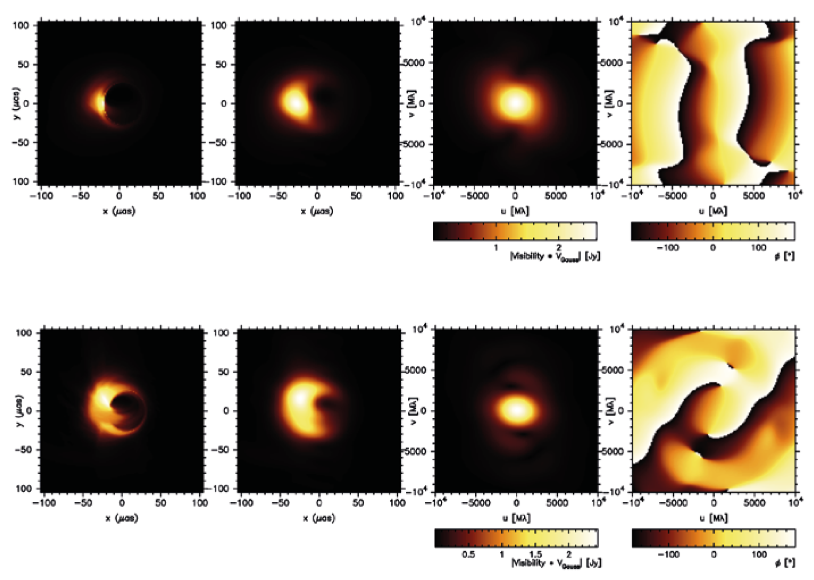
Our picture of Sagittarius A*

- Current models indicate low Eddington ratio (~10^{-8}) accretion, low density plasma
- Spectrum looks like synchrotron emission from electrons: optically thick flow in radio, switching to optically thin in submm regime
- Radio spectrum is compatible with compact jet but source is hitherto unresolved: open question
- Source is significantly blurred by interstellar scattering at frequencies over ~230 GHz
- Orientation of accretion torus on the sky is not well-constrained



Raytraced images and derived visibility function at an observing wavelength of 3.5mm. From left to right: Original raytraced image, image convolved with interstellar scattering kernel, visibility amplitudes, visibility phases. The top row shows the 'cool jet' model, the bottom row shows the 'hot jet' model. Although the scattered image appears to contain practically no useful structure information, closure phase measurements should be able to pick out subtle source asymmetries.

Images by M. Moscibrodzka

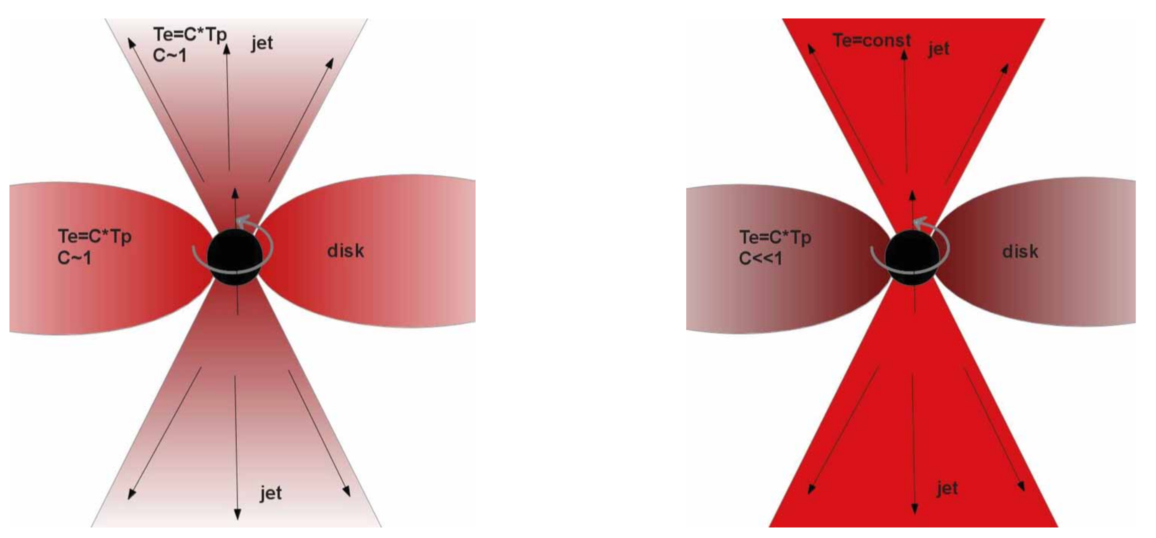


Raytraced images and derived visibility function at an observing wavelength of 1.3mm. From left to right: Original raytraced image, image convolved with interstellar scattering kernel, visibility amplitudes, visibility phases. The top row shows the 'cool jet' model, the bottom row shows the 'hot jet' model. The asymmetries in the scattered images are much more pronounces than in the 3.5mm case, and the expected closure phase measurement values are correspondingly larger.

Images by M. Moscibrodzka

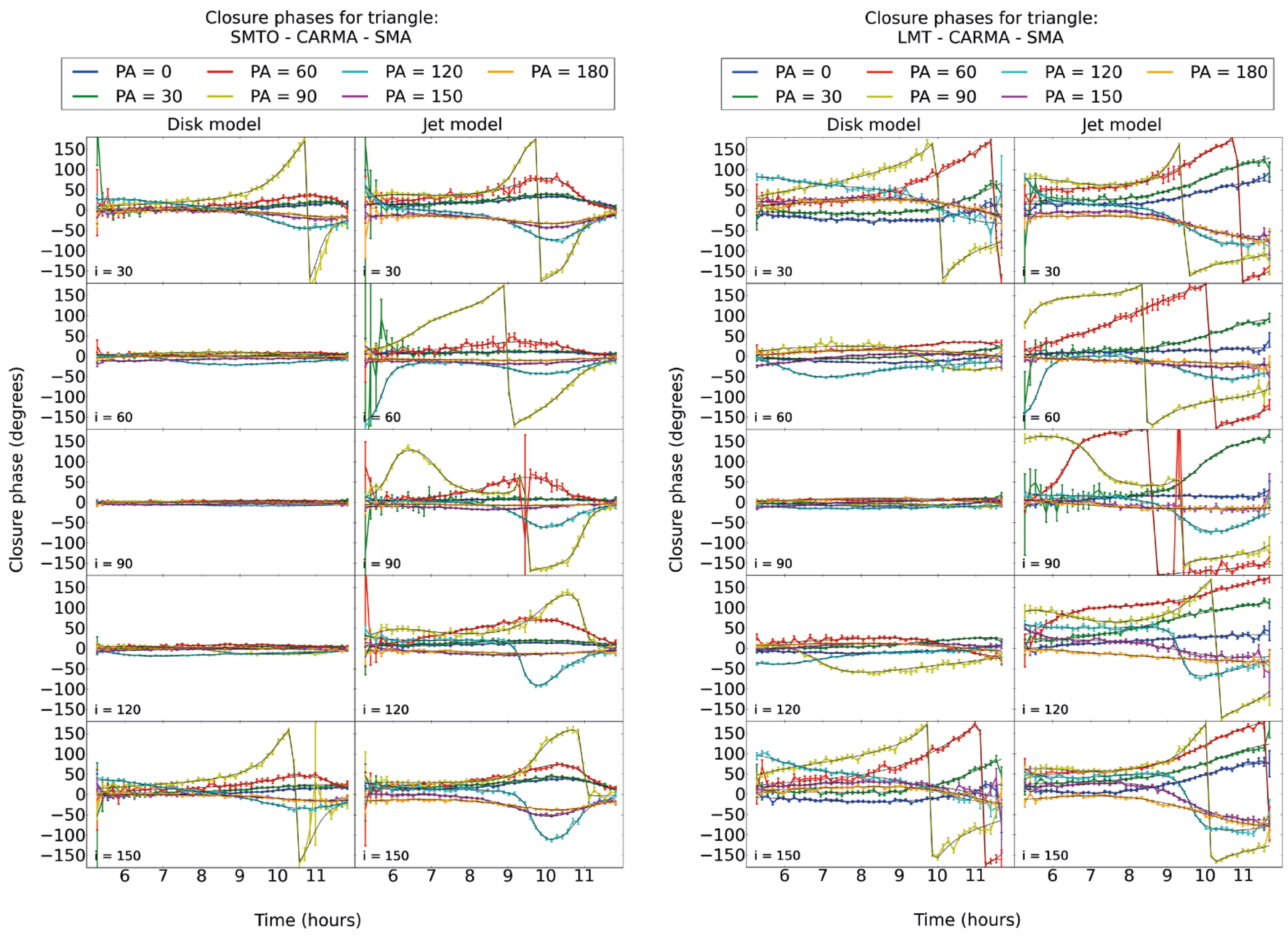
Emission models

- Consist of electron temperature prescriptions applied to GRMHD simulation results, raytraced in Kerr metric
- 2 zones defined in simulation region: accretion torus (bound) and jet (unbound)
- 2 Models were used: one with $T_e = C * T_p$ everywhere ('cool jet'), the other with $T_e = C * T_p$ in the torus and T_e = const in the jet ('hot jet')
- Hot jet model is physically motivated: electron acceleration likely to take place in jet boundary region, keeps electron temperature up



The two emission models, presented in simplified schematic form. The 'cool jet' model (left image) is the baseline model, and it uses the same prescription for the electron temperature throughout the simulation domain. The 'hot jet' model (right image) is more physically motivated: it supposes a weaker coupling between ions and electrons in the disk (because of low plasma densities), and it includes a jet region where the electron temperature is constant. This component is motivated by the expectation that the jet boundary exhibits behaviour that is conducive to electron acceleration (strong shear flow, transient shocks, magnetic reconnection).

Images by M. Moscibrodzka



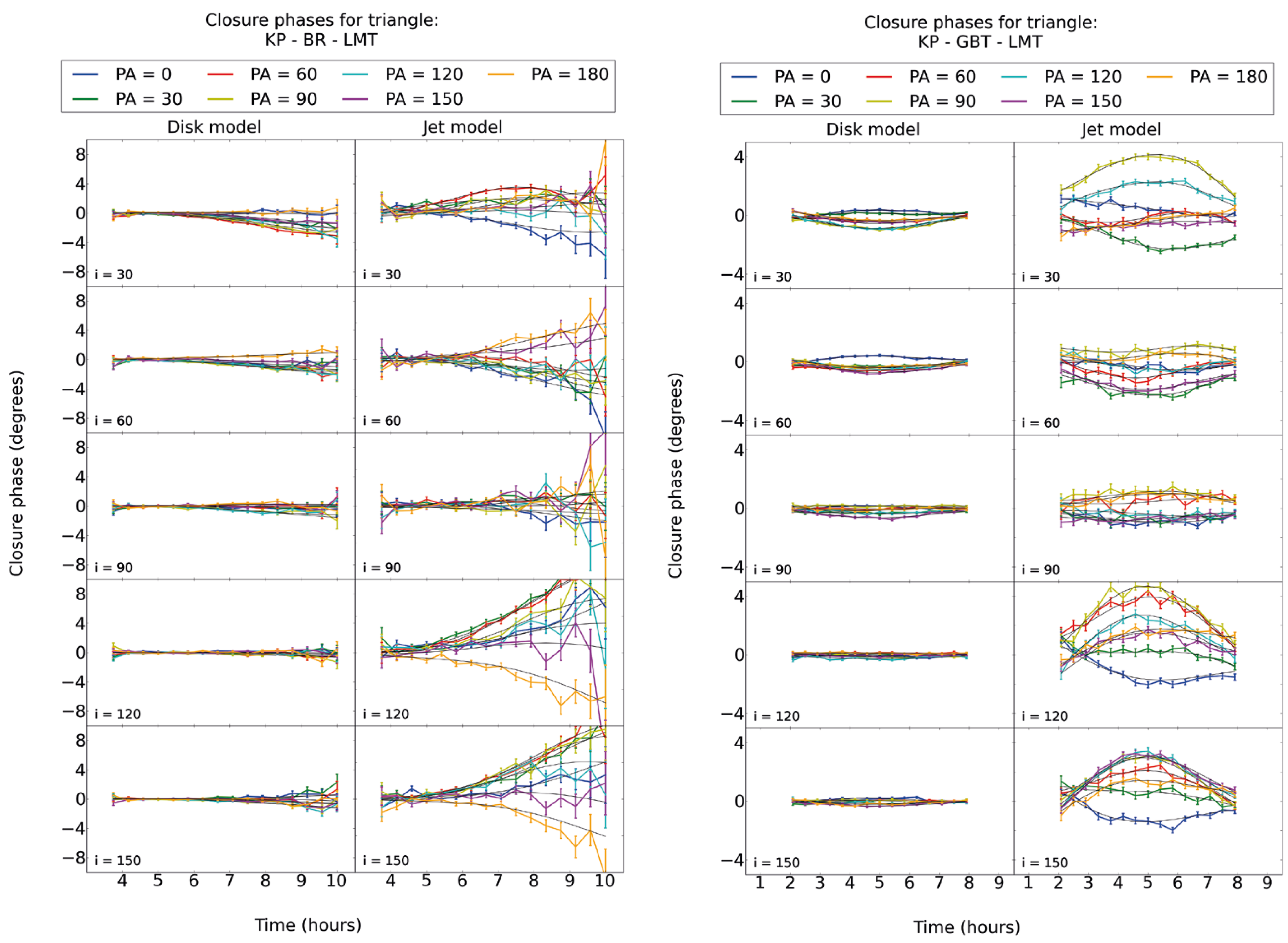
Plots of closure phase evolution with time at 1.3mm, for two different triangles of stations. Each plot shows the predicted closure phase evolution for the 'cool jet' model in the left column, and the predictions for the 'hot jet' model in the right column. The 'hot jet' model predicts on average larger closure phase fluctuations because of its larger intrinsic asymmetry. However, for a range of position angles on the sky and system inclinations the 'hot jet' model is compatible with existing EHT closure phase measurements. The measurements have been time-averaged over 500 seconds (50 scans of 10 seconds each).

Predictions at 1.3mm

At 1.3mm we predict much larger closure phase variations than in the 3.5mm case. Most position angles for the jet model yield closure phases on the SMTO-CARMA-SMA triangle that are in conflict with existing EHT measurements. Including the LMT in future EHT observations will allow us to make further constraints on the geometry of Sgr A* at 1.3mm.

Predictions at 3.5mm

At 3.5mm the predicted closure phases are only a few degrees at most for either model, for any orientation on the sky. Using the VLBA by itself, noise levels would be so high as to preclude any measurement indicating the nonzero values of any closure phase measurements. Including the LMT and GBT enhance the sensitivity of the array such that these nonzero closure phases can be distinguished from a null result.



Plots of closure phase evolution with time at 3.5mm, for two different triangles of stations. Each plot shows the predicted closure phase evolution for the 'cool jet' model in the left column, and the predictions for the 'hot jet' model in the right column. The predicted closure phase values are much smaller than for the 1.3mm cases, but the combined VLBA + GBT + LMT array should be able to discern even modest deviations from zero. The measurements have been time-averaged over 1500 seconds (150 scans of 10 seconds each).