Astrophysics with Closure Phases

EuroWinter School

Observing with the Very Large Telescope Interferometer

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J.D. Monnier

Harvard-Smithsonian Center for Astrophysics

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Astrophysics with Closure Phases
Outline

Review of Closure phases (and related quantities)

Quantitative Astrophysics – "Precision Interferometry" (Model Fitting)
 – Binary Systems
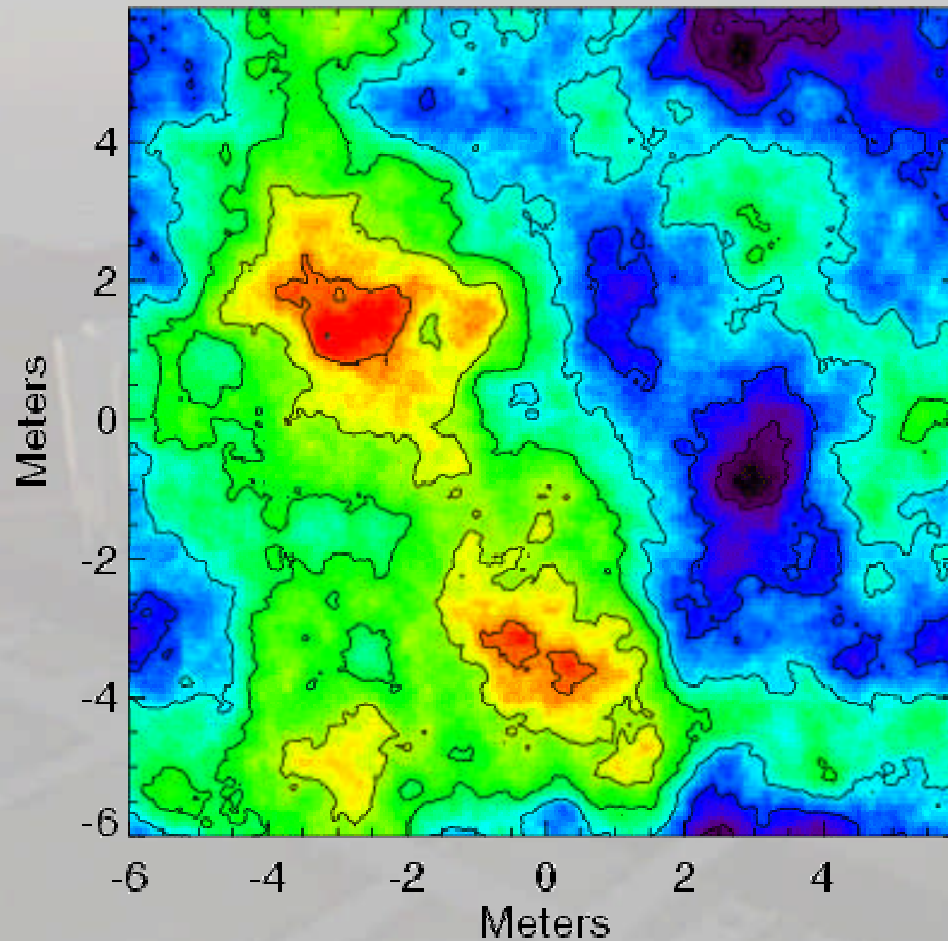 – Stellar Surfaces

Qualitative Astrophysics
 – Asymmetries
 – Protoplanetary Disks around Young Stellar Objects
 – Lots of new things!

Interferometric Imaging
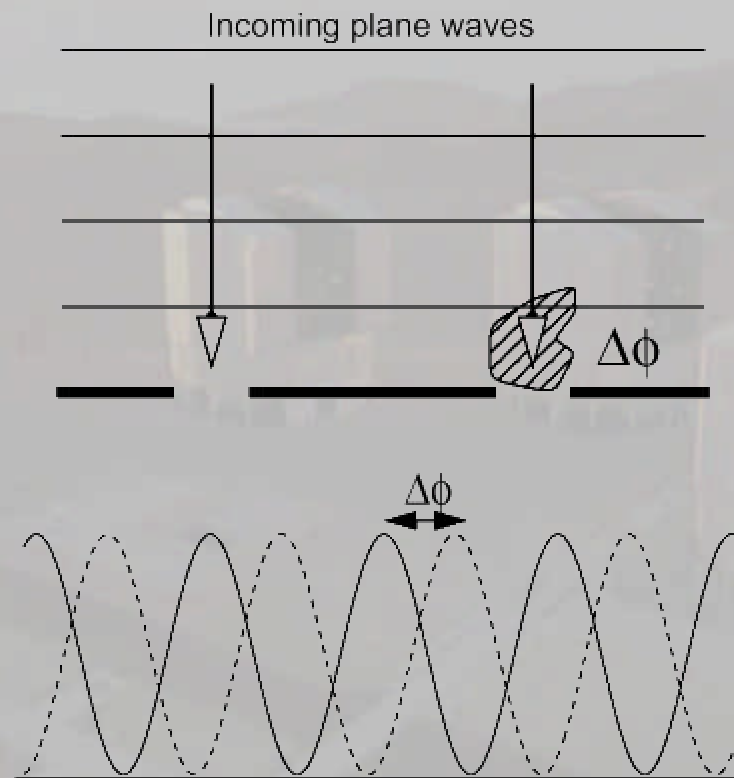
The Atmosphere…

Phasescreen

A 12m x 12m patch of atmosphere during typical good seeing

Each contour is one radian of phase delay of 2-micron light

Atmosphere Corrupts the Phase

Telescope-based Errors

$$\tilde{E}_i^{\mathrm{measured}} = \tilde{G}_i \tilde{E}_i^{\mathrm{true}}$$

$$= |G_i| e^{i\Phi_i^G} \tilde{E}_i^{\mathrm{true}}.$$

Telescope Phase Shift
(e.g., atmospheric piston,
bad baseline, thermal drifts)

Telescope Gain
(e.g., coupling efficiency
into single-mode fiber)

$$\mathrm{Since} \qquad \tilde{\mathcal{V}}_{ij} \propto \tilde{E}_i \cdot \tilde{E}_j^*,$$

Phase shift of
detected Fringe

$$\tilde{\mathcal{V}}_{ij}^{\mathrm{measured}} = \tilde{G}_i \tilde{G}_j^* \tilde{\mathcal{V}}_{ij}^{\mathrm{true}}$$

$$= |G_i||G_j| e^{i(\Phi_i^G - \Phi_j^G)} \tilde{\mathcal{V}}_{ij}^{\mathrm{true}}$$

Big trouble…
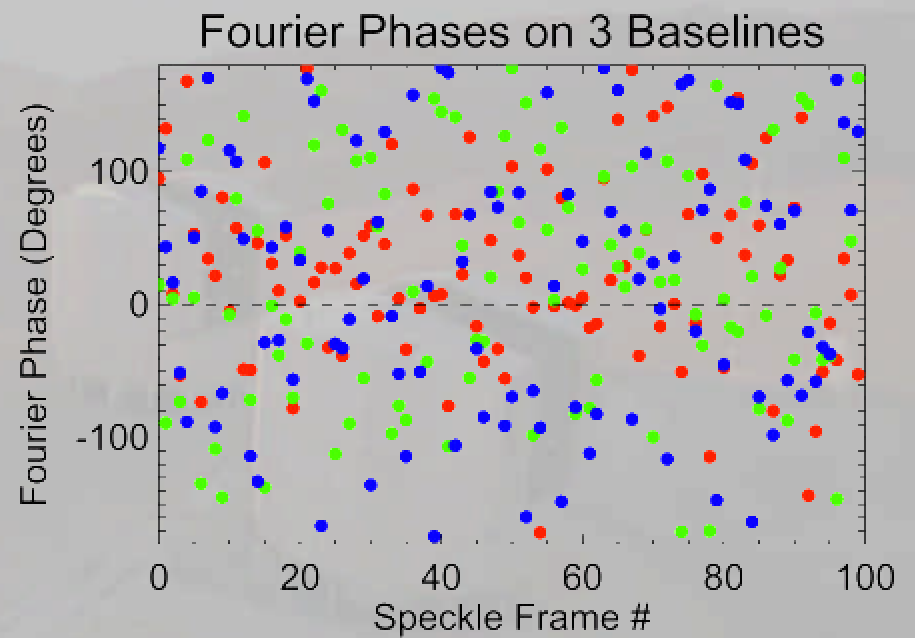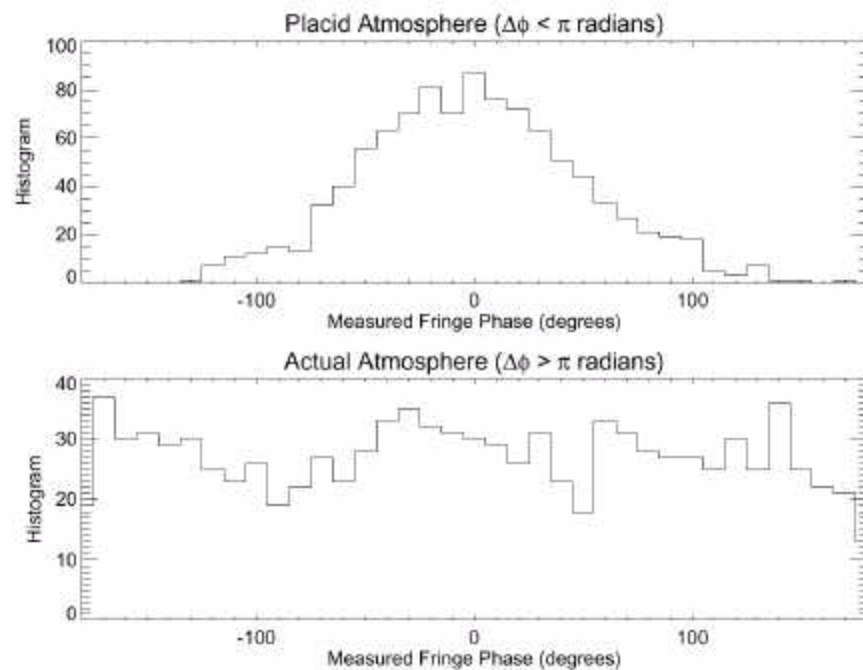
Phase Referencing

Phase Referencing can be used to recover phases

- Dual-star mode (using nearby reference star)
- Differential Phase

Useful Applications for Differential Phase:

- For narrow spectral lines when you know the what the continuum complex visibility is (e.g. H-alpha around hot star)
- Broadband phase referencing can also be done, but the attainable precision will critically depend on the stability of

Atmospheric (and Lab) Dispersion

(e.g., Keck Interferometer recently decided in favor of vacuum long delay lines to avoid excess water vapor variations for the Planet Search project)
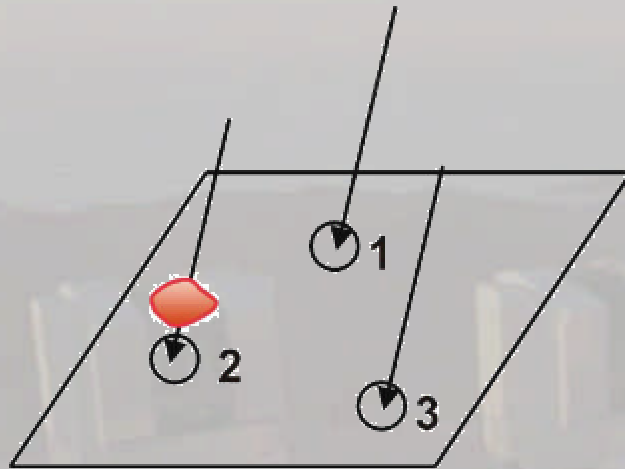
Atmospheric Dispersion Variations -- Water Vapor

ZOOM-up on K-band
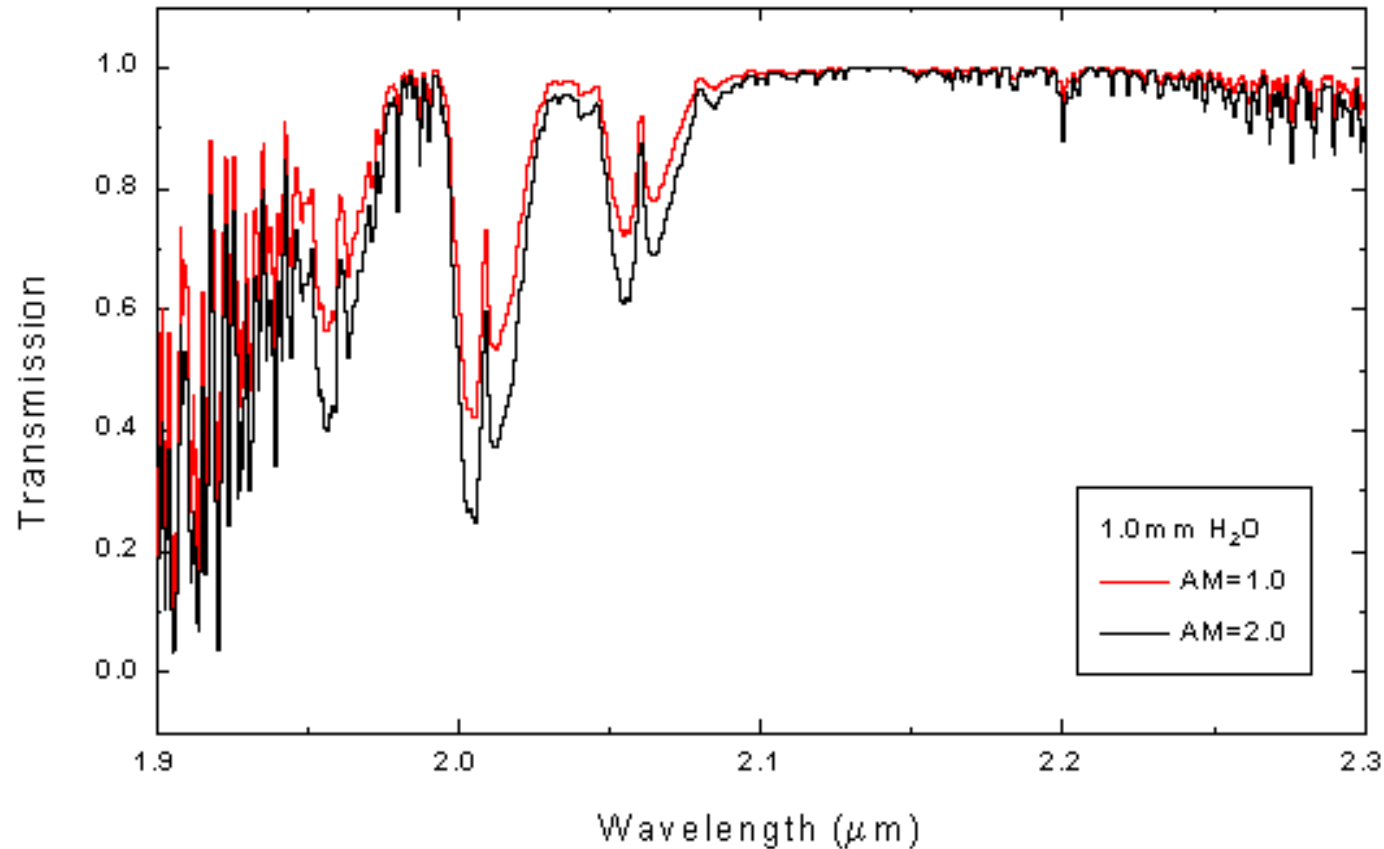
From Gemini webpages
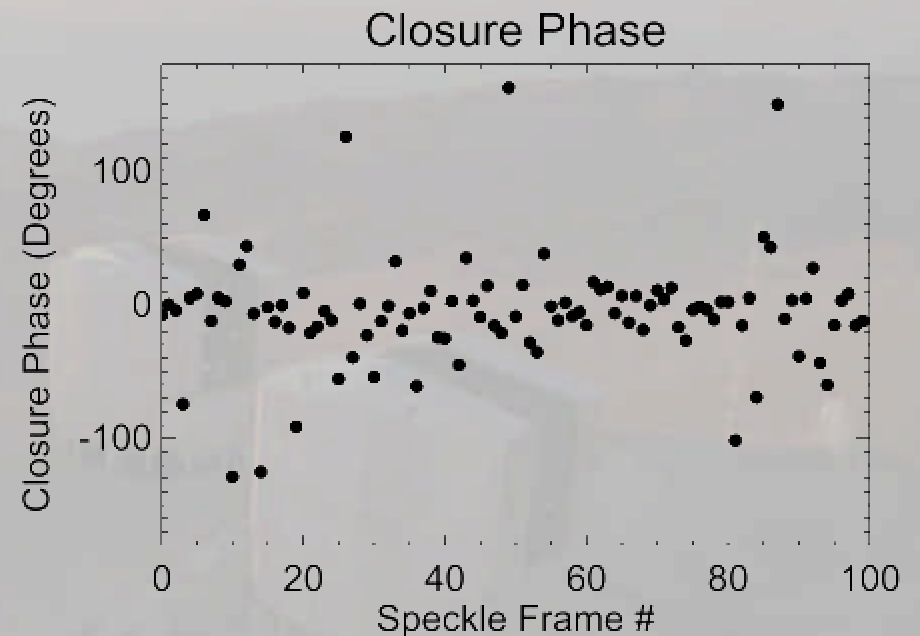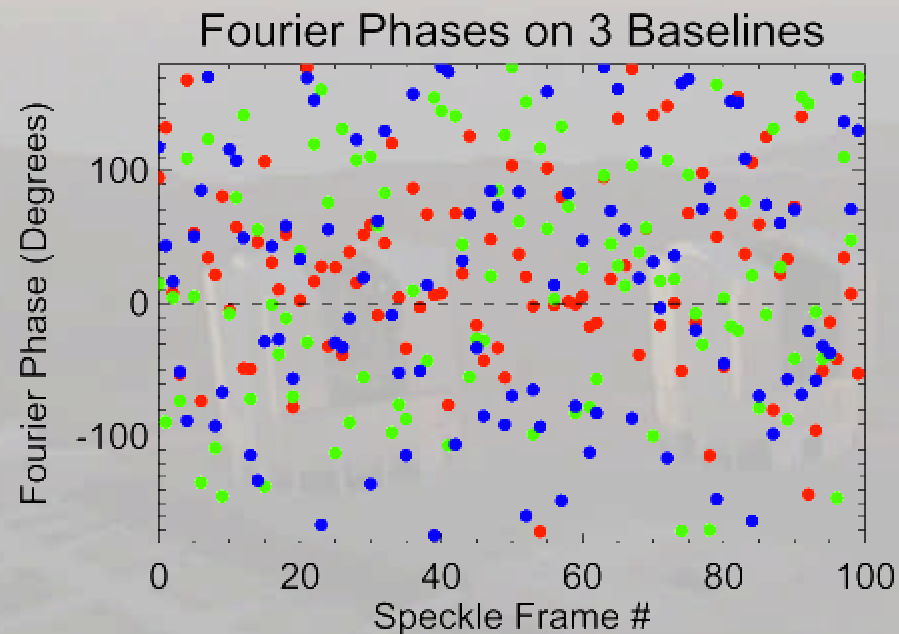
The "Closure Phase" Is Not Corrupted

Observed	Intrinsic	Atmosphere
$\Phi(1\text{-}2)$ =	$\Phi_\circ(1\text{-}2)$ +	$[\phi(2)\text{-}\phi(1)]$
$\Phi(2\text{-}3)$ =	$\Phi_\circ(2\text{-}3)$ +	$[\phi(3)\text{-}\phi(2)]$
$\Phi(3\text{-}1)$ =	$\Phi_\circ(3\text{-}1)$ +	$[\phi(1)\text{-}\phi(3)]$

Closure Phase (1-2-3) $= \Phi_\circ(1\text{-}2) + \Phi_\circ(2\text{-}3) + \Phi_\circ(3\text{-}1)$

Related to the Bispectrum, B_{ijk}, used in Speckle Interferometry

$$
\begin{aligned}
\tilde{B}_{ijk} &= \tilde{\mathcal{V}}_{ij}^{\text{measured}} \, \tilde{\mathcal{V}}_{jk}^{\text{measured}} \, \tilde{\mathcal{V}}_{ki}^{\text{measured}} \\
&= |G_i||G_j| \, e^{i(\Phi_i^G - \Phi_j^G)} \, \tilde{\mathcal{V}}_{ij}^{\text{true}} \cdot |G_j||G_k| \, e^{i(\Phi_j^G - \Phi_k^G)} \, \tilde{\mathcal{V}}_{jk}^{\text{true}} \cdot |G_k||G_i| \, e^{i(\Phi_k^G - \Phi_i^G)} \, \tilde{\mathcal{V}}_{ki}^{\text{true}} \\
&= |G_i|^2 |G_j|^2 |G_k|^2 \, \tilde{\mathcal{V}}_{ij}^{\text{true}} \cdot \tilde{\mathcal{V}}_{jk}^{\text{true}} \cdot \tilde{\mathcal{V}}_{ki}^{\text{true}}.
\end{aligned}
$$

Closure Phase is a Good Observable

Fourier Phases on 3 Baselines — Speckle Frame # vs Fourier Phase (Degrees)

Closure Phase — Speckle Frame # vs Closure Phase (Degrees)

__Aperture Masking Example__