Interferometric phase
and
Science with MIDI

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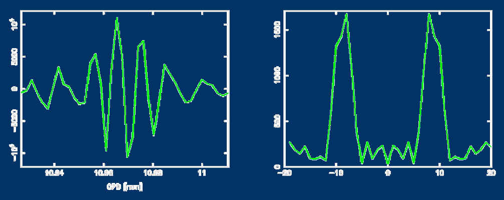
Contents

This is three talks really:
•Coherent and incoherent reduction
•Interferometric phase with MIDI
•Some examples of MIDI science

Coherent vs incoherent

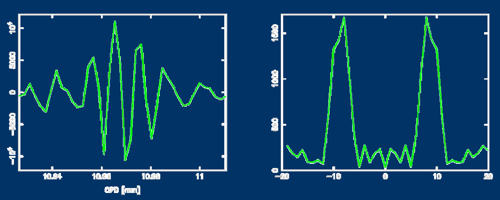
•Incoherent analysis is "passive"
a bit like speckle interferometry
- Rainer's code
•Coherent analysis is "active"
a bit like adaptive optics
- Walter's code

Incoherent



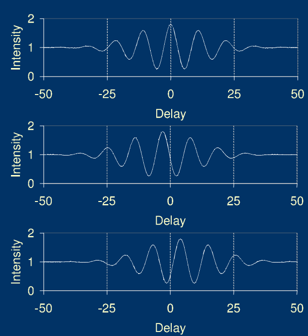
(from Rainer's talk)

Incoherent

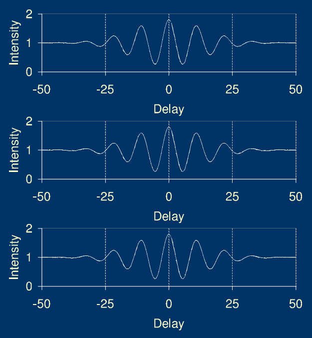


Summed

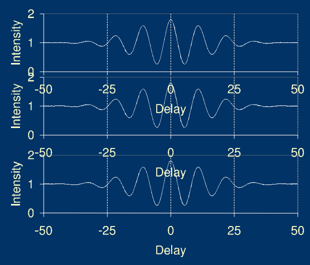
Coherent



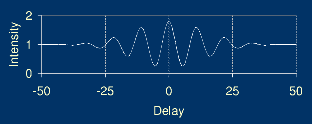
Coherent



Coherent



Coherent



Summed

Incoherent vs coherent

Incoherent analysis

•Phase information is lost

•Can work with slightly fainter sources

Coherent analysis

•Phase information is kept

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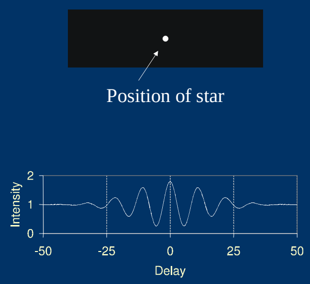
Interferometric Phase

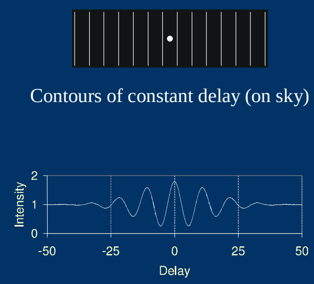
The phase of the fringes in an interferometer depends on the position of the source and on phase errors introduced by the atmosphere (seeing)

Interferometric Phase

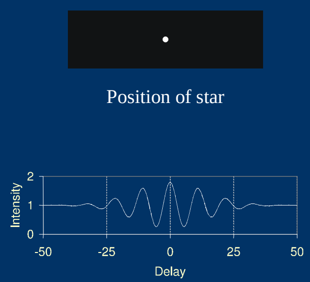


Interference fringes

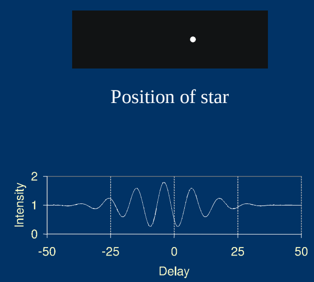
From Walter's talk



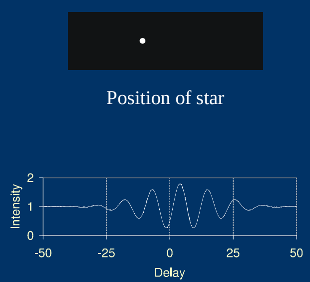
Interferometric Phase



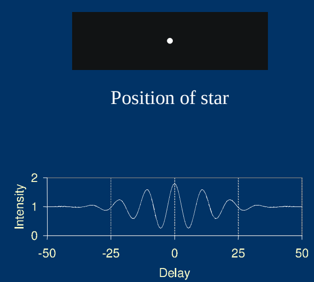
Interferometric Phase



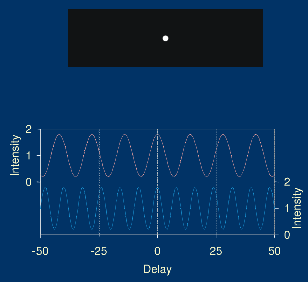
Interferometric Phase



Interferometric Phase

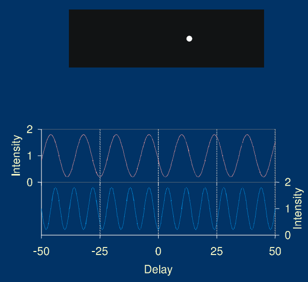


Interferometric Phase



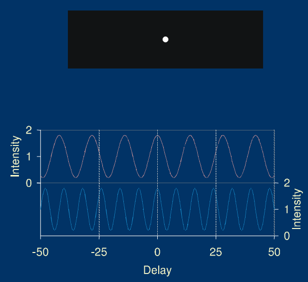
Two spectral channels

Interferometric Phase



Two spectral channels

Interferometric Phase



Two spectral channels

Atmospheric Seeing

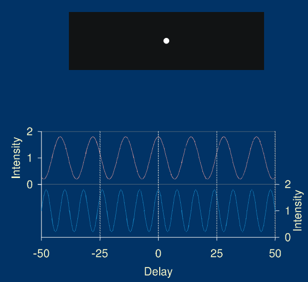
- However, atmospheric seeing also causes the fringes to move
- The atmospheric fringe motion is random, and makes direct phase measurements impossible

Atmospheric Seeing

The fringes at different wavelengths are effected by the seeing in a closely related and predictable way, which depends (via refractive index) on:

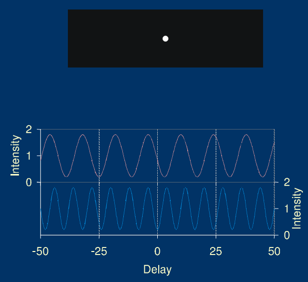
- Column density of air the beams have travelled through from the star
- Column density of water vapour the beams have travelled through from the star

Interferometric Phase



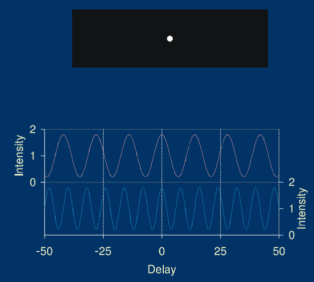
Effect of seeing

Interferometric Phase



Effect of seeing

Interferometric Phase



Effect of seeing

Applications

So how can the interferometric phase be used?

•We can measure the phase difference between different spectral channels

•To first order the effects of seeing are eliminated when measuring the phase difference between two spectral channels (more channels gives even better subtraction of seeing effects)

Application to Astronomy

What can the difference in phase between two spectral channels measure astrophysically?

•The change in the symmetry of a source with wavelength (or spatial frequency)

•The size of the source if the observations cover a visibility null

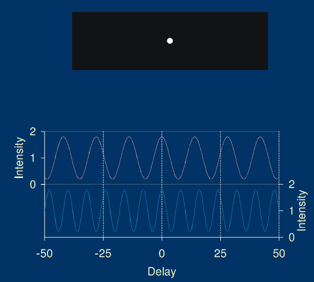
Application to Astronomy

•The same data used for differential phase measurements can also be used for measuring visibility amplitudes

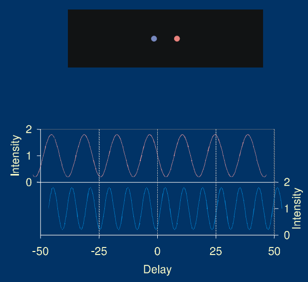
•Differential phase measurements can be used in conjunction with visibility amplitude measurements to further constrain astronomical models

•Coherent analysis is required (Walter’s software)

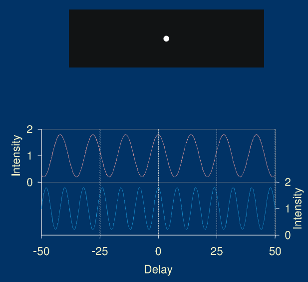
Symmetry Measurements



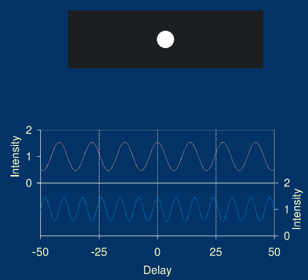
Symmetry Measurements



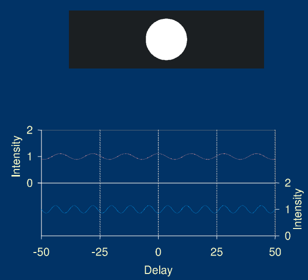
Size of Source



Size of Source



Size of Source



Atmospheric Seeing

In reality there are two atmospheric unknowns:

•Column density of air the beams have travelled through from the star

•Column density of water vapour the beams have travelled through from the star

Phase Measurements

However, MIDI has 200 spectral channels in GRISM mode, so we can still constrain the source geometry.

•We have 200 measurements per observation, and only 2 atmospheric unknowns, so with good signal to noise quite a lot can be determined about the astronomical source

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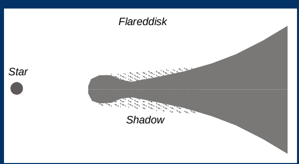
Symmetry Measurements

What can a measurement of the symmetry of a source with wavelength tell you about astrophysics?

Massive YSOs

An example is theoretical (radiative transfer) models* of massive YSOs



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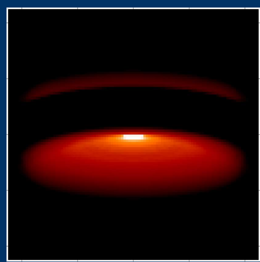
*Dullemond, C. P., 2002, A&A 395, 853

Massive YSOs

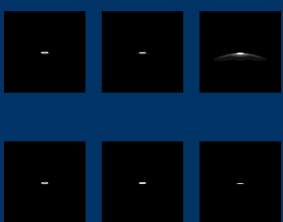


Logarithmic scale image from Kees Dullemond

Massive YSOs

9.7 µm wavelength

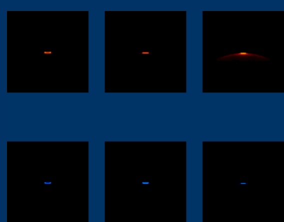
8.0 µm wavelength



Inclination angle 70° 75° 78°

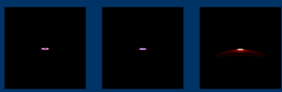
(Linear greyscale images)

Massive YSOs



Inclination angle 70° 75° 78°

Massive YSOs



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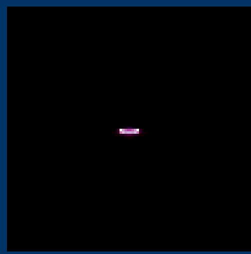
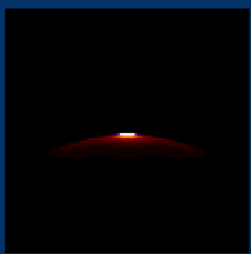


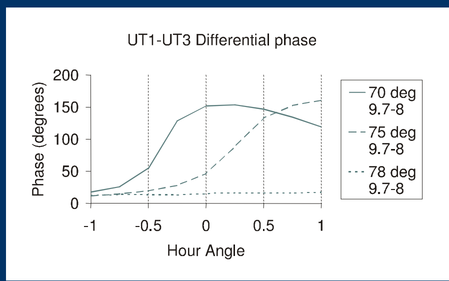
Inclination angle 70°

Massive YSOs

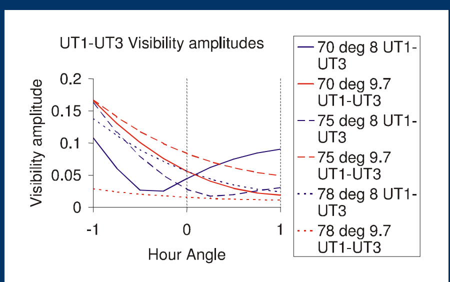


Inclination angle 78°

Massive YSOs



Massive YSOs



Size Measurements

How can the size of a source be constrained using differential phase measurements?

•Remember *uv* coordinates have units of wavelengths

W Hydrae Observations

I will demonstrate the method of measuring the size of a source using MIDI data from W Hydrae

- The data was taken in PRISM mode, with ~25 independent spectral channels
- The data was taken on a night with stable humidity

W Hydrae

- W Hydrae is a semi-regular variable AGB star
- A molecular shell is expected around the star at ~2r$_*$ – this will determine the geometry of the emission across the N-band

(similar to Mira stars – see e.g. Tuthill et al 1999 MNRAS 306, 353, Mennesson et al 2002, ApJ 579, 446, Weiner 2004 ApJ 611, L37, Perrin et al 2004 A&A in press)

Calibration

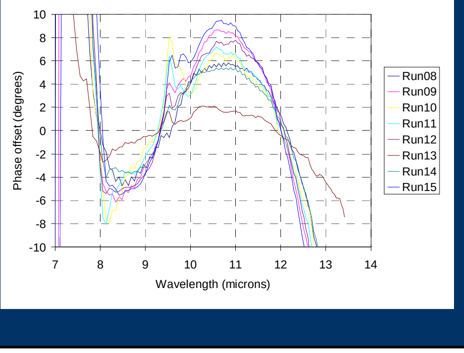
- I first used Walter's software to measure differential phases on calibration stars
- I checked that data from all the calibrator observations on the same night as the W Hydrae observation were consistent with each other

Walter's software

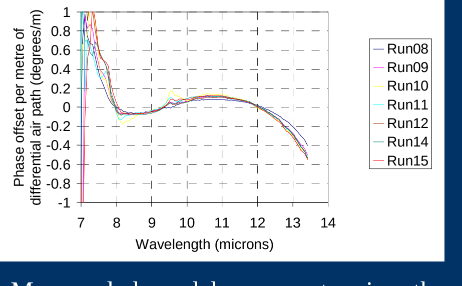
Walter's software subtracts two terms from the measured data:

- The OPD error (the gradient of phase with frequency)
- The mean phase (which corresponds to the dispersion in air to first-order)

Night of 2003/06/12

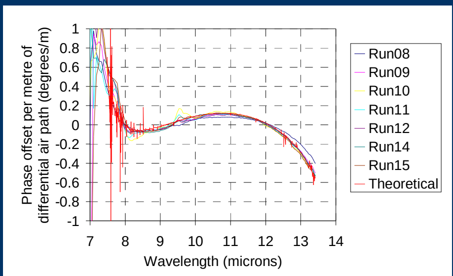


Night of 2003/06/12



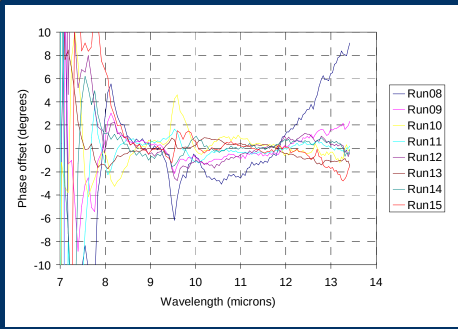
Measured phase delay per metre air path

Night of 2003/06/12



Theoretical prediction from Mathar 2004 ApOpt 43, 928

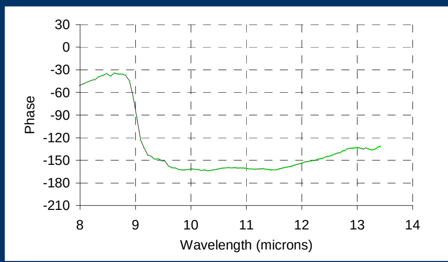
Residual phase errors



Differential phase errors

- On the night that W Hydrae was observed the differential phase curves agree to better than 1 degree for consecutive calibrator observations
- On the next night, phase variations of over 10 degrees are seen
- On the following night the phases again agree to within 1 degree apart from two runs

W Hydrae differential phase



Unknown OPD offset and phase offset

Walter's software

Walter's software subtracts two terms from the measured data:

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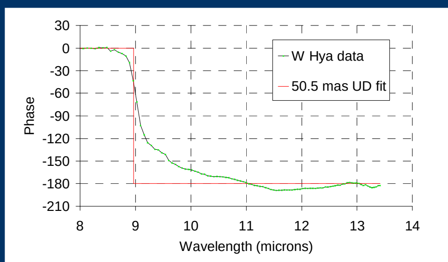
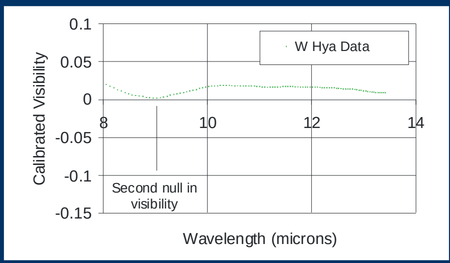
- The mean phase (which corresponds to the dispersion in air to first-order)

Differential phase



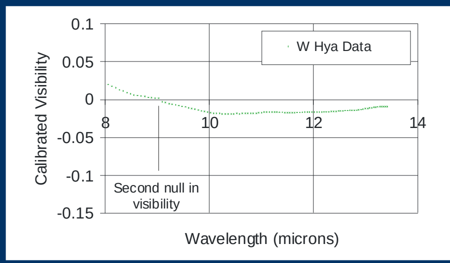
My guess for the OPD offset and phase offset

Calibrated visibility



Assuming calibrator to be 14.7 mas UD
W Hydra geometry may change with wavelength

Calibrated visibility



Using differential phase data to constrain the position of the visibility null

Conclusions (1)

- The phase of interference fringes is perturbed by the atmosphere
- We can avoid atmospheric effects by comparing the difference in the phases measured at different wavelenghs
- These differential phases can be measured with high accuracy

Conclusions (2)

However:

- Differential phase is only sensitive to certain properties of the source (asymmetry, or size *if* the baseline is chosen carefully)
- On nights with rapid humidity fluctuations, differential phase measurements may have large errors

Conclusions (3)

- Differential phase measurements are best used in conjunction with visibility amplitude measurements to provide additional constraints on the astronomical source
- The same data can be used for both differential phase and visibility amplitude measurements