Practice work

Introduction to closure phases

The overall aims of these exercises are to:

- Learn how to visualize closure phases in ASPRO; at the moment this is best done with a different interface to the one you used in the previous practical sessions.

- Familiarise yourselves with the properties of closure phases: how they relate to the source brightness distribution and uv coverage.

- Learn about some of the issues encountered when fitting a model to a real dataset.

This document describes the exercises for both Wednesday and Thursday morning; on Thursday you can start from wherever you reached at the end of the previous session.

Using ASPRO to visualize closure phases

Here is an outline description of how to plot closure phases for a simulated observation using ASPRO. More detailed instructions are given in the first few exercises below. Please note that the instructions in this document only apply to the standalone version of ASPRO (not the web version).

1. Start ASPRO and select Choose|AMBER, Period 82 from the menu bar. Note that we are not using the "Full ASPRO interface" that you used for the earlier practical sessions, because that has a less intuitive interface for plotting closure phases.

2. Use ASPRO to define UV coverage and a model for the source. This is very similar in the AMBER-specific and full interfaces and hence should be familiar from the practical sessions on Monday/Tuesday.

3. Bring up the interferometric observables explorer tool (UV PLOTS| Interferometric Observables Explorer (optical)).

4. Plot the closure phases by selecting one of the PhaseClosure vs XXX options and clicking GO (Refresh Plot).

Note that the AMBER interface to ASPRO generates spectrally-dispersed data (i.e. visibility amplitude or closure phase in a number of wavelength channels for each observation time). We will use wavelength-independent model brightness distributions, and take advantage of the enhanced uv coverage provided by the spectral dispersion.

1 Closure phase dependence on resolution

> Aims of this exercise:
> - Practice visualising closure phases in ASPRO
> - Illustrate how the amplitude of the closure phase signal varies with angular resolution

In this exercise you will generate a binary model with separation distance 1 mas, position angle 45° and flux ratio 0.5.

1. Choose the object named "HR_5999" using OBJECT|Get CDS Object By Name.

2. The window All About my CDS Source will appear. In the entry fields beneath "Choose a Parametric Model for the Source", enter the parameters of the binary model described above, as in the earlier practical sessions.

3. Click Proceed to Observational Setup. The window Setup for Observation will appear. Under Less used observing constraints, **use the sliders** to set the start and end hour angles to approximately zero and 1 hour respectively — this will result in only one set of measurements (3 visibility spectra and one closure phase spectrum), at a single epoch, for each array configuration.

4. Choose each of the following configurations of 3 telescopes in turn, clicking GO for each one For the second configuration, set the RESET FRAME option to "No." This will give a single UV table containing both configurations. What can you say about these configurations? How do they compare with each other?

    - E0 G0 H0
    - A0 D0 H0

5. Click Proceed to Visibility Panel. The Interferometric Observables Explorer will appear. Plot squared visibility against wavelength as in the previous practical (select Vis2 vs Wavelength. Select INDIVIDUAL plots so that each telescope configuration has a separate plot). Are you resolving the object with each of the configurations?

6. In the Interferometric Observables Explorer , select PhaseClosure vs Wavelength and OVERLAY. Ensure Add Errorbars to Plot is set to "No". Click GO to generate the plot, which should show the closure phase as a function of wavelength for each configuration of 3 telescopes.

7. Increase the binary separation by a factor of 2. Do you observe the same closure phase dependence on resolution?

8. What happens if you rotate the axis of the binary by 90°?

2   Closure phase of a binary system

> Aims of this exercise:
>
> - Illustrate how the amplitude of the closure phase signal depends on the fraction of asymmetric flux in the source

Use the model definition tool to generate a binary model consisting of two stars separated by 3 mas with position angle 0° and the following flux ratios: 1, 0.1, 1e-2, 1e-4, 1e-5.

1. Simulate an observation of this target using the telescope configuration UT1, UT2 and UT4. Restrict the observation to a narrow hour angle range as in the previous exercise, to obtain a single set of visibility and closure phase spectra.

2. Plot the visibility as a function of uv radius for each model. Using your experience from the earlier practical sessions, you should be able to explain how the visibility amplitude depends on the flux ratio.

3. Plot the closure phase for each model. What is the maximum amplitude of closure phase variation for each flux ratio? What can you say about its dependence on flux ratio? Can you explain why some the closure phases are 180° for a flux ratio of unity?

3   Closure phase of a disk+star+hot spot (or companion)

Aims of this exercise:

- Demonstrate that point-symmetric sources have closure phases of zero or 180°

- Demonstrate the corollary of the above; that measuring other closure phase values immediately tells you that your symmetric model is wrong!

- Practice finding triangles of baselines that are sensitive to particular features you want to detect
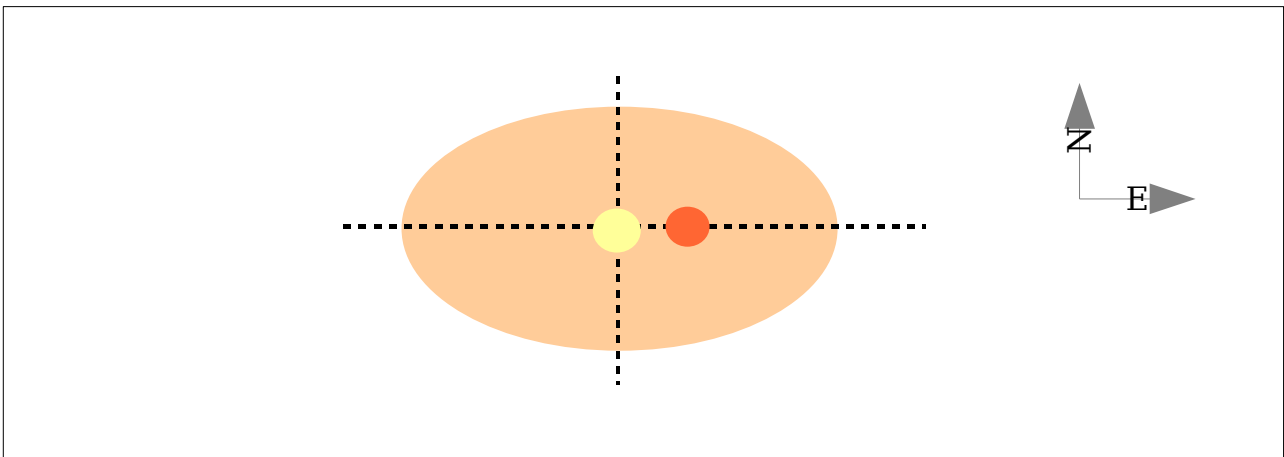
Figure 1: Cartoon of disk+star+hot spot model

Use the model definition tool to generate an elliptical elongated disk with 4 mas major axis, 2 mas minor axis, and 90° orientation. Add a point source at the ellipse photo-center, to represent the star. The star/disk flux ratio should be 0.2.

1. Convince yourself that, whatever the telescope configuration you use you cannot observe a closure phase variation.
2. Now replace the point source by a binary oriented along the major axis, with 0.5 mas separation. The primary star should have a flux 10 times that of the companion. This simulates the presence of a hotspot or companion inside the disk (see Figure 1).
3. Find the 3-telescope configuration that maximizes the closure phase signal amplitude. Remember you can set RESET FRAME to "No" in order to plot multiple configurations at once.

4 A real observation

Aims of this exercise:
- Illustrate the typical uncertainties on measured closure phases and visibility amplitudes
- Practice fitting a progressively more complicated model
- Practice astrophysical interpretation of real (sparse) data

For this exercise, you will have to retrieve the following files:

1. `betel_905nm_vis2.oifits` – COAST data on Alpha Ori, squared visibilities only

2. `betel_905nm.oifits` – COAST data on Alpha Ori, squared visibilities and closure phases

3. `betel_disk.model` – template disk model

4. `betel_disk_hotspot.model` – template disk plus hotspot model

In this exercise, you will use some of the data published in Young et al. (2000), MNRAS 315, 635 (just because I have access to it!).

We will use the mfit software package, in particular its graphical interface "fitgui".

Using mfit is simply a matter of selecting a data file (containing reduced, calibrated data – usually squared visibilities and/or closure phases) and a model file. The latter defines a superposition of simple functions ("components") such as point sources, or uniform or limb-darkened disks. The parameters of these functions can either be fixed at a user-specified value, or chosen as variable parameters, in which case a Gaussian prior is assumed, with user-specified mean and sigma. The position of the prior peak is also used as the initial guess for the parameter value. You can also ask mfit to plot the data and corresponding model points.

Note that the area for editing the model in fitgui is quite small, so you may wish to edit the model file in an external text editor, then read it into fitgui.

1. Start fitgui and select data and model as follows. Select [1] as the data file. Click Load model and choose the disk model file [3].

2. Examine the data without attempting to fit the model by selecting the Don't fit checkbutton. You can now select any of the plot choices (only "uv" and "vis2" are useful for data file [1]), and optionally choose ranges for the X and/or Y axis of the plot. Click Go to make the plot.

3. Now fit the disk model to the data, varying the disk diameter only. Enter an initial guess for the diameter as "shape_param" and a Gaussian prior width for "shape_param_prior". Make sure Don't fit is unchecked, and click Go. The results of the fitting process will be displayed in the scrolling area at the bottom of the fitgui window. If you selected a plot choice, this will show the data points and the corresponding points predicted by the best-fit model. Examine the posterior probability distribution by selecting "post" as the plot choice and re-fitting.

4. Examine the closure phases. Fit the disk model to the complete dataset, and observe the discrepancies between data and best-fit model. Where is the largest difference between model and data? Is this a systematic difference, or

could it be due to one or two potentially bad data points?

5. Load the disk plus hotspot model and fit this to the complete dataset, varying the disk diameter and the flux and location of the hotspot. Note that mfit normalises the model so that its total flux is unity. A good initial guess for the disk diameter is the value found in step 4. I've helped you by choosing initial values for the other parameters that fit the data reasonably well.

6. By plotting cuts through the posterior, confirm that the solution found by mfit is a local minimum (note that mfit does its own check as well). Can you identify the strongest correlations between model parameters?

7. By trying different starting models, investigate whether the solution is a global minimum.

8. If you have time, find out to what extend the data constrain the limb-darkening parameter ("ld_param") as well as the disk diameter and hotspot parameters.