The 10th VLTI School of Interferometry

Practice session I
Interferometry basics with ASPRO

Corrections
Short version

Corrections

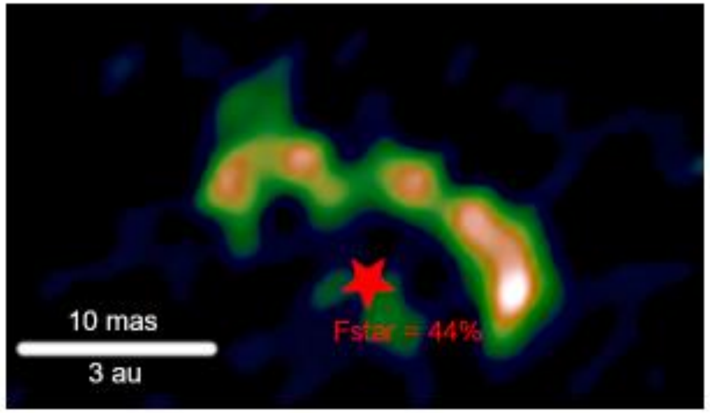

Figure 1: VLTI/PIONIER image of FS CMa. The star position (removed during the image reconstruction) and contribution to the H-band flux are shown in red (adapted from Kluska et al. (2020)

Question : What do we see in the PIONIER image? Why is it asymmetric?

Question : What do you except to see in MATISSE image in the L band? In the N band?

Question : What physical parameters could be constrained from MATISSE observations?

In PIONIER H-band image we mainly see the Inner-rim of FS Cma dusty disk as the H-band is mainly sensitive to material with a temperature above 1500K

MATISSE wavelength is larger than PIONIER , it will probe colder material thus farther for the central source:

- L-band : material with T>700K
- N-band : material with T>200K

The dusty disk density, temperature and chemical composition

Corrections

Question : What are FS CMa right ascension (α) and declination (δ)?

α = 06:28:17.42 δ = -13:03:11.13

Now go to the **Observability** tab. The star is currently not observable (in June). You can change the date of observation in the **Constraints** box on the upper right of ASPRO2 interface. Verify also that the **Min. Elevation** is set to 30° which is a standard value for both VLTI and CHARA. Pointing lower than that is not recommended unless you cannot do otherwise.

Question : When is the star observable at VLTI?

From September to April

Question : Optimise the observing date to have the longest Observability

December or January

Question : Does this date depends on α? What about δ?

Optimal date only depends on α
But the Observability also depends on δ

Question : What is the point of moving telescopes between observations?

Moving telescopes allows to obtain measurements with different baseline lengths and orientations, thus improving the sampling of the Fourier space (also called UV coverage)

Let's go back to our observability problem and to the **Observability** tab. Change the selected VLTI instrument to MATISSE, GRAVITY and then PIONIER and check the observability for each of them.

Question : Does the observability depends on the selected instrument?

No

Now try to change the telescope configuration.

Question : Does this affect the observability?

Yes

Question : Which configuration offers the longest observability? the shortest?

Longest observability : A0-B2-D0-C1
Shortest observability : A0-G1-J2-J3

Question : Is the shortening of observability symmetric in time?

No

Question : Find the two main reasons for the shortening of the observability

1) Delay lines constraints reduce the observability on the longest baselines
2) Shadowing from the UTs (mainly with J3)

Now, let's check if the star is observable with CHARA? We might want to perform some observations later in another band with this Northern facility.

Question : Is the star observable at CHARA?

Yes

Question : Is the observability longer or shorter than at the VLTI? Why?

Observability is shorter as the star is quite South for CHARA ($\alpha \approx$ -13° for CHARA $\approx$ +35°)

Name	Right Ascension	Declination
HD 50138	06 51 33.34	-06 57 59.9
HD 62623	07 43 48.43	-28 57 17.7
HD 85567	09 50 28.54	-60 58 02.9
MWC 297	18 27 39.5	-03 49 52.0
HD 200775	21 01 36.92	+68 09 47.7

Table 1: Some Herbig and B[e] stars

Question : Without using ASPRO2 determine where and when can we observe these targets[1]?

CHARA ⇔ δ > -25° (= 35° - 60°) (observation above 30°)
VLTI ⇔ δ < 35° (= -25° + 60°)

α = 0 is September 21 (Equinox) then +2 per Month

HD 50138 : Both January
HD 62623 : VLTI February
HD 85567 : VLTI March
MWC 297 : Both July
HD 200775 : CHARA August

3 UV-Coverage

Question : What is the origin of these tracks and why are the baselines length and orientation changing during the night?

The tracks are due to earth rotation.
The projected baselines on the sky-plan changes during the night as the star ''moves'' on the sky.

The shape of the tracks are elliptic. Add two fake stars to your target list :

- a star at the equator: **06:00:00 00:00:00**
- a star close to the south pole : **06:00:00 -80:00:00**

Question : Why didn't we choose a star at the real pole (δ=-90:00:00)?

Not observable at the VLTI : δ > - 85° = -25° - 60°

Question : Are the tracks similar for these two objects and FS CMa?

No
Objects at the the equator have linear UV-tracks
Objects at the pole have circular UV-tracks.

4 Setting-up a model for our object

Question : How would you model the star for our MATISSE observation?

The star will not be resolved at all by MATISSE.
Point source is then the most relevant.
But a Uniform disk with D=0.16mas is also correct

For the ring, in the H-band, we will consider the following parameters:

- Minor-axis diameter: 10 mas
- Elongation ratio: 1.5
- Width: 4 mas
- Orientation of the major-axis: 70°

Create a model with these two components and parameters values in the **Target Editor** menu.

Question : Which of these parameters are excepted to be constant between the H-band and the N-band and which will depends on the wavelength? How?

Minor-axis diameter: **Constant** as it represent the dusty disk inner rim
Elongation : **More or less constant** if we assume that the disk is geoemtrically thin (elongation is only due to a projection effect)
Width: **Larger in L, and even larger in N** as these bands probes colder materials than the H band
Orientation : **Constant**

Now go to the **OIFits Viewer** tab and plot the **VIS2DATA** & **T3PHI** (i.e. Closure phase) as a function of the **SPATIAL_FREQ**. Note that it is the default view, so normally you don't have to change it. Select the three ATs configurations simultaneously and choose **Station configuration** in the **Color by** scrolling menu (bottom right of the interface). You can also select the **Draw Lines** option in the lower right corner.

In the plot we see the visibility decreasing and then oscillating around a plateau.

Question : What is the cause of the oscillation?

Ring lobes

Question : What determine the level of the plateau?

Flux ratio between the star (point source) and the circumstellar disk (ring)

Question : Conclude on the expected visibility curve for the L, M, and N bands

The level of the plateau should decrease as the relative flux of the star decreases with λ

Question : Do you expect the real closure phase to be different to a one of our very simple model? Why?

Yes, as our object is centro-symmetric (0° phase) whereas the real object is highly assymetric due to the skewedness of the inner rim

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5 About the instrumental sensitivity

Question : With such noise on the data, are the observation still useful?

Yes the noise is very small actually.
This is due to the brightness of the source compared to MATISSE sensitivity.

You can change the **Atmosphere quality** value in the **UV Coverage** tab. When hovering a value, the definition in term of seeing and coherence time (t_0) is given. For instance, the **AVERAGE** atmosphere correspond to a seeing of 1" and t_0=3.2ms.

Question : Is there a significant gain in term of data quality for observation under GOOD atmosphere quality? What about EXCELLENT?

Not really because the star is very bright.

Question : Is the data always useful even under AWFUL quality?

Yes, even if the errors are larger

Question : Do the same with MATISSE_N instrument

Errors are larger on the N band (instrument is less sensitive + problem with sky emission)
However, the star is still very bright and observable under every atmospheric conditions.

Finally, let's assume a much dimmer target, for instance with a L_band flux of 1 Jy. Change the Flux in the **Target Editor** menu. Don't forget to switch back to MATISSE_LM.

Question : Under which atmospheric quality will the data be useless?

Now the data is completely useless under BAD and AWFUL atmospheric conditions (WORSE is kind of limit too)

Before continuing, put back the 39.7Jy flux for the L band and a GOOD atmosphere quality.

6 Finding Calibrators for our observations with SearchCal

Question : Find a good calibrator for MATISSE L&M bands (the best one might not be the first in the list)

There are many good calibrators for the L band.

The best might be HD44462 at it is at the same time, one a the brightest (Lmag = 2.99 = 18Jy) and closest (2°), and it is also barely resolved (V > 0.8)

You can send the selected calibrator (right click on it first) back to ASPRO2 using the SearchCal **Interop** menu.

Question : Is this calibrator a good calibrator for MATISSE N band observation? (Check in the OIFits viewer tab. Why?)

No, it is too faint : Nmag=2,9 = 2.5 Jy
MATISSE sensitivity is about 25 Jy in the N band

Let's now find a N-band calibrator. Select **MATISSE_N** in ASPRO2 **Instrument** scrolling menu, verify that FS CMa is still selected in the **Targets** list and send it again to SearchCal

Question : What has change in the SearchCal interface?

The band is now set to N : the magnitude given in the N band one, i.e. -1.23.
There are less calibrators found than for L band!

Question : Find a good calibrator for that band and send it back to ASPRO2

HD43635 is a fairly good one : bright -0.539 and yet not too resolved V>0.74 and not too far 14°.

Now you have two calibrators, one for the L&M bands, and one for the N-band. You can plot their excepted visibility curve in ASPRO2 **OIFits Viewer** tab.

Question : Is the N-band calibrator a good calibrator for MATISSE L band observation? Why?

No it is much too resolved in the L band.
Resolution in L with 130m : 250 λ/B ≈ 5.7 mas
This is very closed to HD43635 diameter 5.4 mas

8 Bonus : Beyond our MATISSE Observation

8.1 Resolving the stellar surface

Question : Is it possible to constrain the stellar diameter using the VLTI? What are the two advantages of using CHARA for that purpose?

No the object is fully unresolved : V>0.99
CHARA => 330m (2.5 gain in resolution, VLTI => 130m)
SPICA => R band (2.5 gain in resolution compared to H)
Total gain in angular resolution = 6.25

Switch to the CHARA array in the **Interferometer** scrolling menu. In the **Period**, choose **CHARA Future** and finally, in **Instrument** choose **SPICA_6T**.

Question : Can we constrain the stellar diameter with CHARA/SPICA? What about the limb darkening or a putative stellar surface flattening?

Yes we can constrain the diameter (V≈0.81 for B=330m). However, we need a good accuracy on the measurements!
No we cannot constrain the limb darkening or flattening as the the is not resolve enough

8.2 Studying the circumstellar gas geometry and kinematics

Interferometric observations with a high-enough spectral resolution (R>500) allows to separate circumstellar gas and dust by looking at narrow spectral features such as emission lines of hydrogen. It also enables the study of the gas kinematics.

Question : Which VLTI and CHARA instrument(s) offer(s) a high-enough spectral resolution to resolve emission lines?

On VLTI, GRAVITY and MATISSE
On CHARA : SPICA and MYSTIC

Question : How is it possible to constrain kinematics using spectro-interferometry? What resolution is needed to measure velocities of the order of 100km/s?

Doppler effect : shift of the wavelength of the light when receiver and emitter have a relative velocity Δv.

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta v}{c}$$

To detect 100km/s shift ⇔ $R = \frac{\lambda}{\Delta\lambda} = \frac{c}{\Delta v} = 3000$

Load the model **model_FSCMa_HIGH_BrAlpha.fits**. It contains a model of a star surrounded by rotating gaseous disk and the inner rim of a dusty disk. It is computed in 201 narrow spectral channels centred on the Brα (4.055μm) emission line.

Select **MATISSE_LM**, and **SI_PHOT_LM_MEDIUM** instrument mode (in the UV Coverage tab). Uncheck **Add error noise to data** and finally look at the VIS2DATA and T3PHI plots.

Question : Do you see the effects of the emission line on the visibility and closure phase? Explain them (Use the zoom on the plot). Change the resolution to HIGH and VERY_HIGH...

The visibility is rising in the emission line because the environment appears smaller.
As the object is not centro-symmetric through the line because of the there is the phase signal in the line
This can help constrain the object kinematics