Practical Introduction to Model Fitting

examples of model fitting, all on real data : to be made **successively**

1. fitting of a **simple** model on **one** file
2. fitting with **parameters sharing** on several files
3. fitting with **degeneracies**
4. fitting **a star + environment**
5. Additional exercises, if time and for fun

In red, questions or suggestions

You may ask a teacher at every moment.

"wrap-up pauses" during the session

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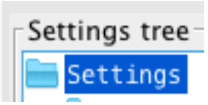
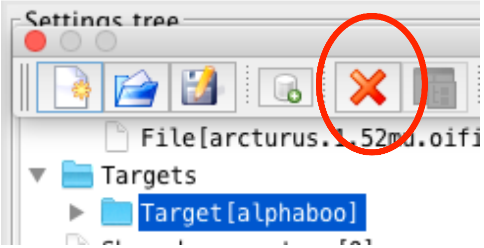
Preliminaries

- Directives and data at https://app.nuclino.com/VLTIschool/School-workspace/
  → Model-fitting
- Launch LITpro, OIFITsExplorer, SAOImageDS9
- One setting by exercise
  - open settings *File > New settings* or shortcut 
  - click *Load oifiles* for loading data
  - save settings *File > Save settings* or shortcut 

    (you may name the setting with the name of exercise)
- *Personal notebook* visible at any time from 

  & almost any Panel
  - initially empty
  - saved with the setting

- Possibility to remove elements of the tree (except Files) if selected



- Multiple **?** for help

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Exercise 1- simple fit 1.1

- Load the file **arcturus.1.79mu.oifits**

  What kind of data did you load ?

- Explore the data
  - Settings Tree → *Files*

    in *Files Panel*, *Plot VIS2DATA…, UV coverage,…*

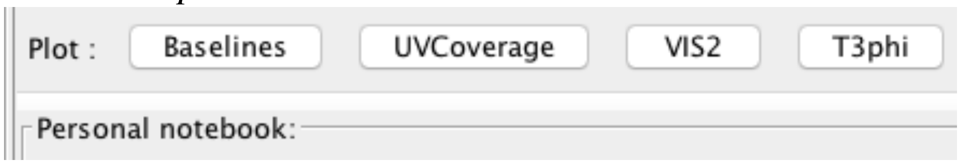
  What clue do you get from the OI_T3 data ?

- Build a model
  - Settings Tree → *Targets*
  - *Add new target*
  - In Target Panel :
    - */Fitter setup*: *Normalize total flux* ON, select the data to fit (for ex. VIS2)
    - */Model List*: add a model function (for ex. disk)
  - Initialize the parameters (for ex. diameter = 0, 10, 20 mas ..)

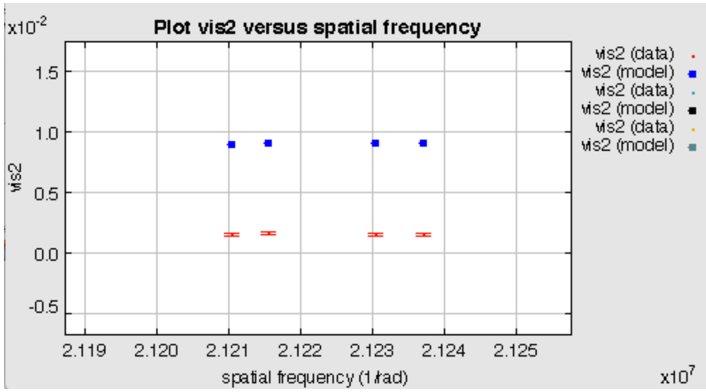
- *Run fit* (bottom of the Settings tree)

Exercise 1- simple fit 1.1

- Visualize the result of the fit:
  - Settings Tree →*Results* (and personal notebook)
    What do you can deduce from Chi2 value?
  - with plots from *Plot model Panel* : Plot Radial (ex: VIS2, try "Residuals", "overplot model")
  - To Notice: plotting the fitted data or the array is also possible from *Result panel*



    - if VIS2 plotted, residuals are also automatically plotted (other plot to open from Settings tree/Results/Fit Results
    - possibility to zoom (draw with the mouse the zone to be zoomed. (Reset zoom button on right top corner)



- Try a fit after removing the setting "Normalize total flux":
  Explain the value of the flux_weight parameter and of Chi2

*** wrap-up pause***

Exercise 1- simple fit 1.2

- Open a *New setting* and load the file **arcturus.1.52mu.oifits**

- Process as Exercise 1.1
  ex: same model function *disk*

- *Run fit* from various initial values of the diameter (*value* = 0 mas, 20 mas, 25 mas)
  How are the results of these fits ?

- Explore the "Chi2 space" for analyzis:

Plot Chi2 1D with Parameter[diameter1) (*log* & *reduced* selected) (min= 0, max= 30, #samples=100)

What do you observe ?

Why the final Chi2 is not so good when fitting from the global minimum ?

- Try another model: a center to limb-darkening model, for ex. *limb_power*

*** wrap-up pause***

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Exercise 2 - Fit with sharing of parameter

- **Aim** : on **2** data sets, one by wavelength, fit a model of center-to-limb darkening (e.g. power law) considering that:
  - the diameter of the photosphere (therefore common to both groups) is achromatic
  - the center-to-limb darkening coefficient is chromatic

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Exercise 2 - Fit with sharing of parameter

- Open a New setting and load the files **arcturus.1.52mu.oifits** **and** **arcturus.1.79mu.oifits**
  - *Add new target* for file arcturus.1.52mu.oifits and select *limb_power* ---> group1
  - *Add new target* for file arcturus.1.79mu.oifits and select *limb_power* ---> group2

- Share the diameter between both groups, using contextual menu (mouse right click) in the Parameters table:
  - for *diameter1*: *share this parameter*
  - for *diameter2: link* it with *diameter1*
  - you may verify with *Shared parameters* of the Settings tree

- *Run fit*

- Plot all the data and fitted models on the **same** graph:
  - use the *Common plots panel* accessible when clicking on Settings Tree →*Plots*
  - select both targets

- Plot an image of the final model

*** wrap-up pause***

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Exercise 3 - Fit with degeneracies 3.1

- **Aim**: estimate the separation of a binary

- Open a New setting and load the file **2018-07-17T085626_94Aqr_B2D0C1-mj2.fits**

- See the data (files → plot VIS2) Look at VIS2
  - Which indication do you deduce for the model of the object?

  - Coud you estimate roughly some parameters of the model?

  - Load the file in OIFITsExplorer for a better view of the data and easier measures.

  - You may take a pen for the formula and

click on different points on the *VIS2DATA vs SPATIAL_FREQ* view for the measurements.

*** wrap-up pause***

to see formula and some estimation

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Exercise 3 - Fit with degeneracies 3.1

- Build the model:
  - combine 2 *puncts*
  - select **VIS2** and **T3phi**
  - leave the parameters x1,y1 fixed at 0: the main component is centered (it is the default case)
  - bound the flux_weight to [0,1] and take as initial value the ones you have estimated from the VIS2 plot
  - bound the parameters x2, y2 regarding the order of magnitude of ρ

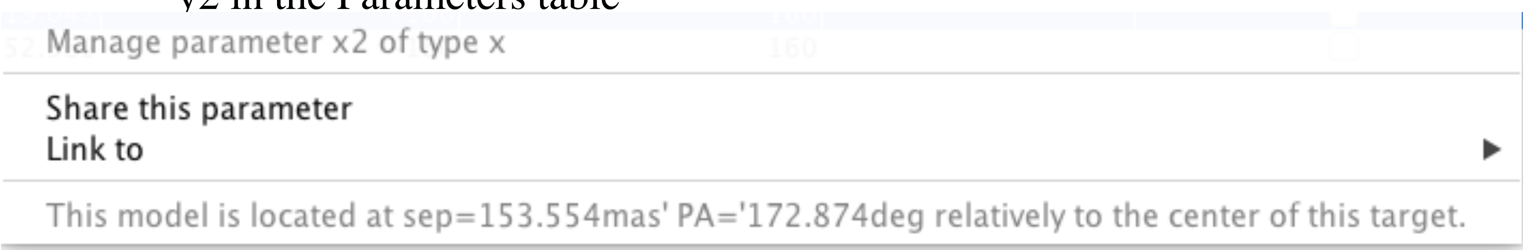
- Use ***Plot Chi2 2D*** with parameters (x2, y2) - increase the sampling (eg #samples100)
- Observe the Chi2 map
  - explain the valleys and their orientation
- Take the values of (x2,y2) of the first minimum as initial values for the fit, and fit
  - what happens?

- So, what to do for resolving the binary 94 Aqr ?
  - you may ask a teacher

*** wrap-up pause***

Exercise 3 - Fit with degeneracies 3.2

- In the current setting, add the file **2018-07-17T085626_94Aqr_A0-mj2.fits** and select it
- Use again ***plot chi2 2D*** with (x2, y2) (increase the bounds to for ex. **160mas**)
    - set the (x2,y2) corresponding to the best minimum of chi2, as well as both flux_weights and fit.
    - See the possibility to convert (x2,y2) in polar coordinates: use **contextual menu** on x2 or y2 in the Parameters table



you may check your answer with a teacher

*** wrap-up pause***

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Exercise 4: star with circumstellar environment

- **Aim**: recognize artifacts from chromatic object in the data. Use of a chromatic model

- Open a new setting and load some V854Cen data : V854Cen-Hband-Kband.fits

 Real data from AMBER/VLTI

 V854Cn is a R Coronae Borealis (RCB) star (small group of carbon-rich supergiant)

Exercise 4: star with circumstellar environment 4.1

- See T3phi data
  - What could you deduce?
- Build a first model with an unresolved star and a simple environment (a shell)
  - punct + for ex. gaussian centered and both fixed at (0,0) or a disk
  - bound the parameters (flux_weights [0,1], fwhm of the shell [0,30mas]
  - select VIS2 and T3phi data for fittin
- ***Plot Chi2 1D*** (fwhm) → initial guess
- *Run fit* with this initial guess
- Observe the results and the radial plots of VIS2 and T3phi
  - How explain the commas in VIS2 data?

  i.e. the alignments of data points whose values increase with spatial frequency.
  - You may open files with OIFits Explorer
  - You may check with a teacher
- Conclusion?

*** wrap-up pause***

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Exercise 4: star with circumstellar environment 4.2

- Build a chromatic model with **blackbody functions** (with the "_BB" suffix)
  - **see the help** of these modeling functions to know how the blackbody is introduced
  - you **may start the fit from the achromatic solution in 4.1** with two radial components, but affected now by a Planck function (→ black body components)

    ex. central punct + gaussian or disk → *punct_BB* + *gaussian_BB* or *disk_BB*

Hypothesis

from *Bright, S. N., Chesneau, O., Clayton, G. C., et al. 2011, MNRAS, 414, 1195* : the temperature of the star is **6750K** →the temperature of punct_BB may be fixed for the fit.

- Leave "Normalize Total Flux" selected on VIS2 & T3phi
- But take care to not bound the flux_weights, which are no more the flux_ratio
  - you may see a teacher for explanation.

*** wrap-up pause***

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Exercise 4: star with circumstellar environment 4.3

- Could you improve the model ?
  - look again the VIS2 data with OIFITsExplorer *with Color by "Baseline or triplet"*
  - see for ex. the D0-C1 data : compare them with the model (with frame "Model VIS2 of target" of your previous fit.
  - conclusion ? which model could you build?

*** wrap-up pause***

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5- Additional Exercises

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5.1 Theta Ori C

- Open a New setting and load the file **Theta1Ori2007Dec03_2.fits**
- See tha data and build a modl of a binary woth two unresolved components:
  - select **VIS2 only**
  - proceed as for Exercise 3 (***Plot Chi2 2D*** with parameters (x2, y2))
  - observe the symmetry of the Chi2 map
- To the binary, add the file **Theta1Ori2007Dec05_2.fits**
- Use again ***plot chi2 2D*** with (x2, y2)
  - set the (x2,y2) corresponding to the best minimum of chi2, as well as both flux_weights and fit the VIS2 only
- Find the two best solutions and compare them.
- On the same setting, add now the T3phi for the fit
  - run fit from one of the best set of fitted parameters
  - run fit from the second best set of fitted parameters
  - Conclusion?
- Compare your result with the published one: **Kraus S.** et al, 2009, A&A. **497**-1, pp. 195-207
- Observe the behavior of the VIS2 versus the spatial frequencies:
  - infer how to improve the model

5-Additional Exercises
5-2 HD87643

- Open a new setting and load **HD87643-bandK.fits**
  - data obtained on AMBER/VLTI in K band.

  (F.Millour et al., 2009, A&A 507, pp317-326)

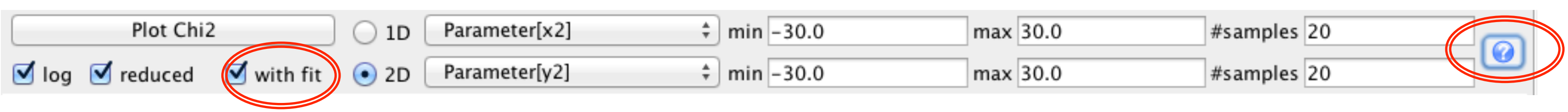
- Observe the data, VIS2 and T3phi, and guess the possible shape for this object.

- Build a suitable model and find your best solution.
  - you should get chi2 < 17 at the end.

5-Additional Exercises
5-3 2004-Interferometry Imaging Beauty Contest

- Open a new setting and load **2004-BSC1948I.fits**
  - data were simulated for the 2004-Interferometry Imaging Beauty Contest (Lawson et al, SPIE Proceedings)

- **Aim**: discover the option "with fit" of Plot Chi2
- Proceed as for Exercise 3
  - You may select directly 2 disks, but for the first step, fix the diameters value to 0 in order to explore the chi2 map with 2 puncts.
  - ***Plot Chi2 2D*** with parameters (x2, y2) as before: difficulty to find a global minimum and then the best guess for fitting.
  - You may use ***Plot Chi2 2D*** "with fit" : **read the Help**



→ find the global minimum →*Run fit* from the best guess
→ make then the diameters free and *Run fit* again → the binary is resolved