

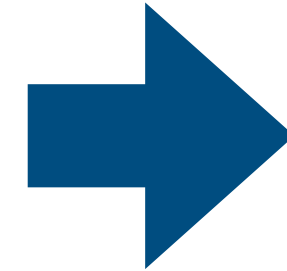
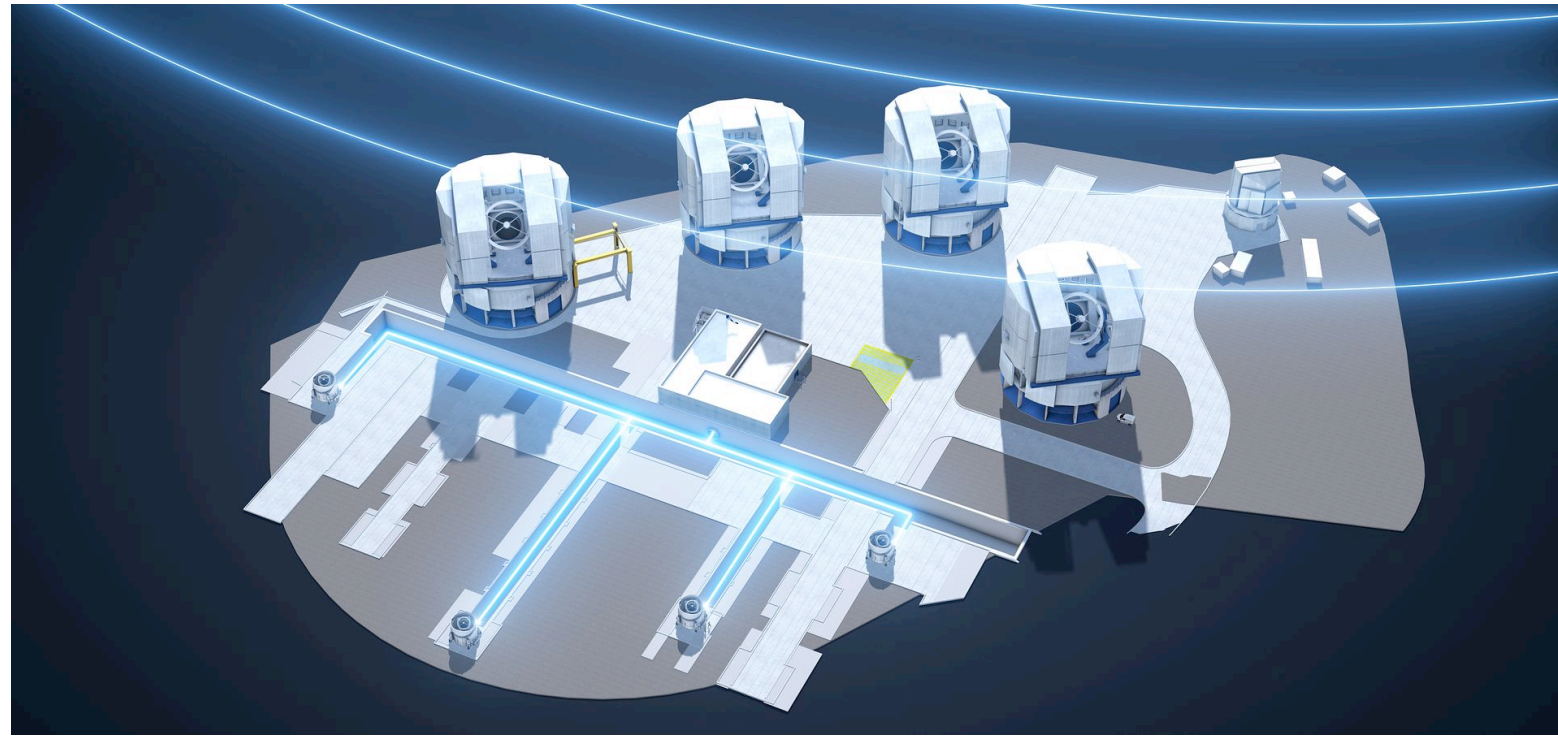
# Image Reconstruction and Model Fitting tools for Optical Interferometry

Data analysis softwares proposed in Expertise Centers

Ferréol Soulez, G. Mella, A. Matter, A. Kaszczyc and L. Bourges

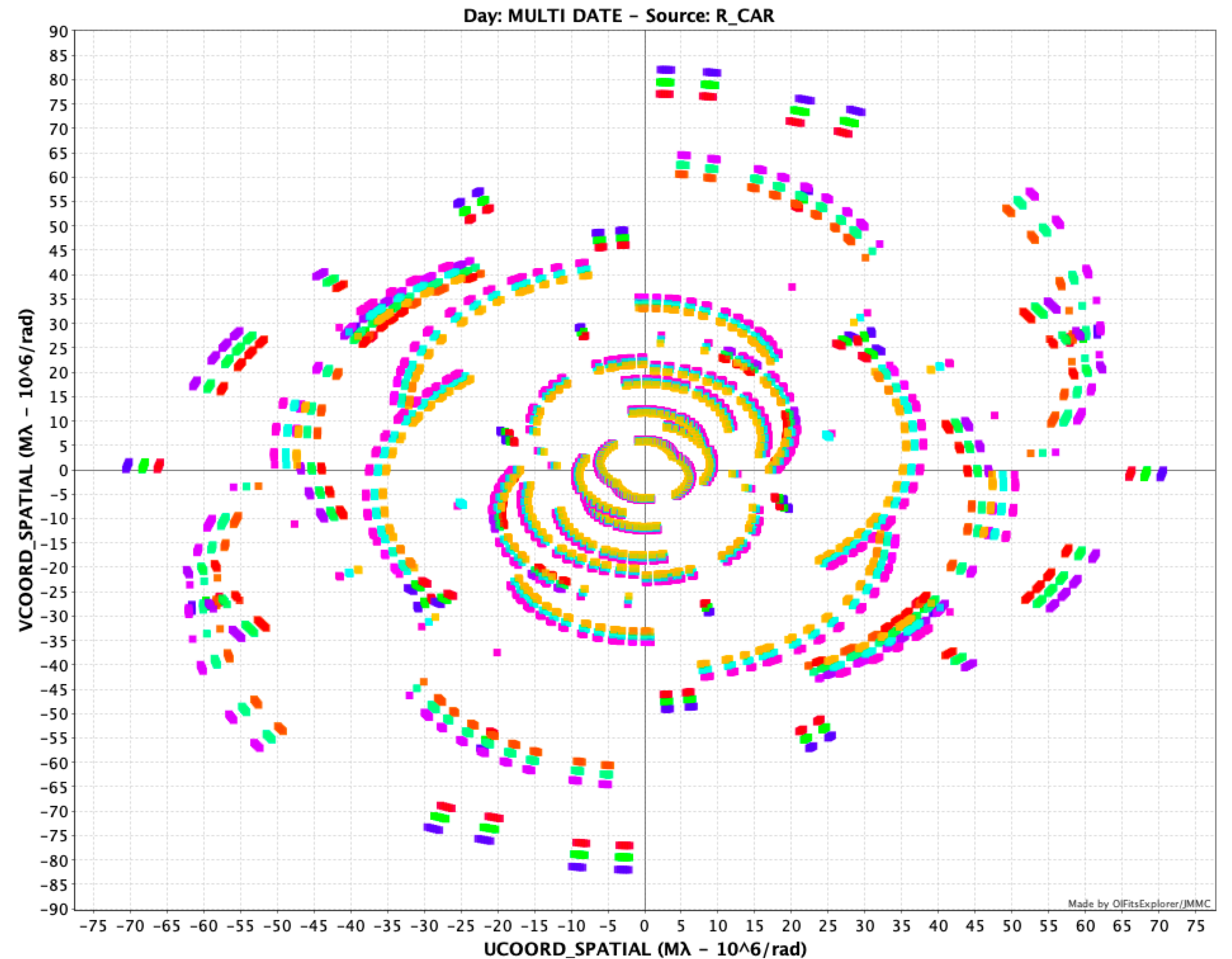
The logo for JMMC (Jeu de Miroirs et de Modèles) is displayed in a stylized, 3D font. The letters are rendered in a gradient of red and orange, with a metallic sheen and a slight shadow effect, giving it a dynamic and modern appearance.

# Interferometric data

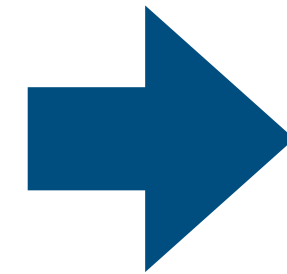
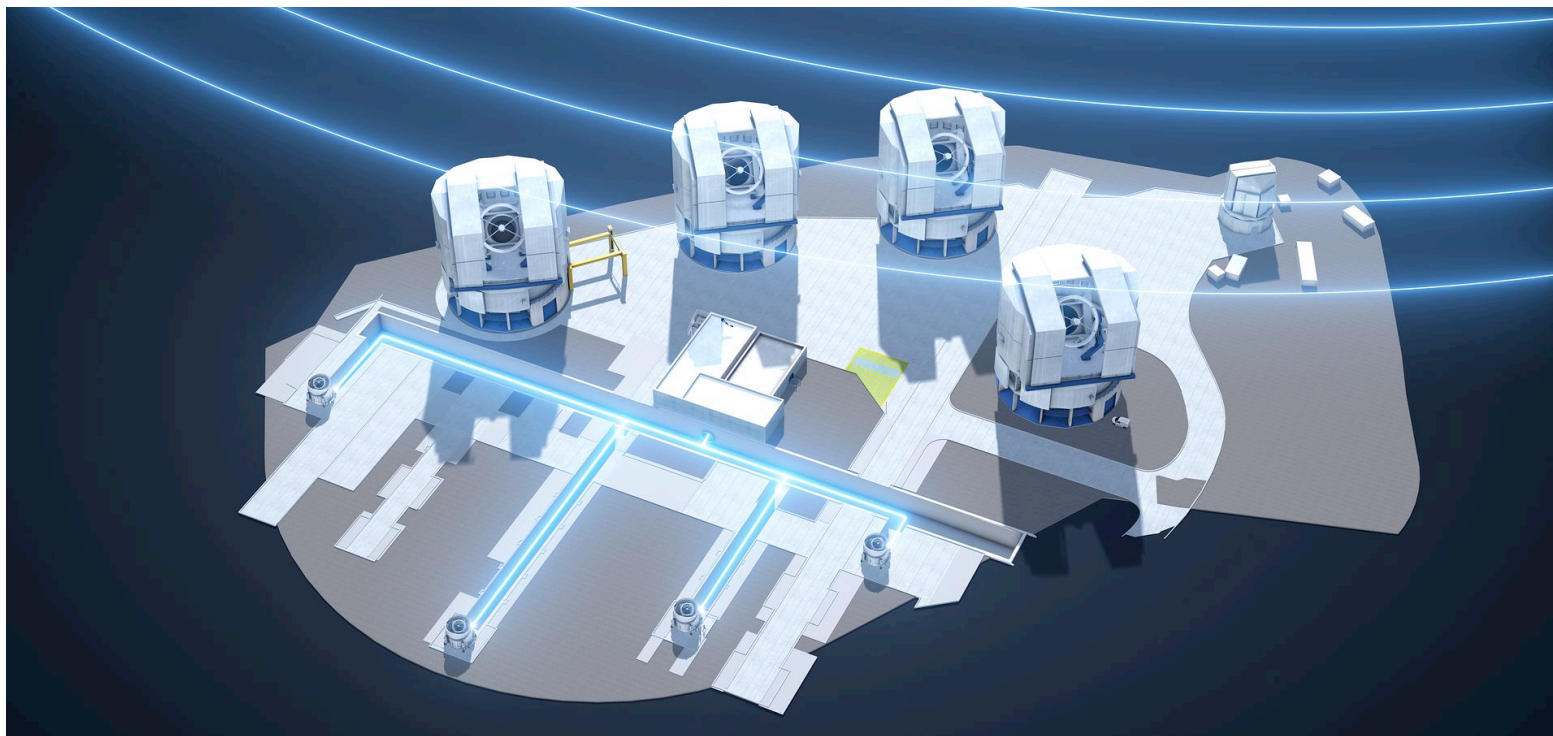


## ● Interferometric data:

- Fourier domain
- few measurements



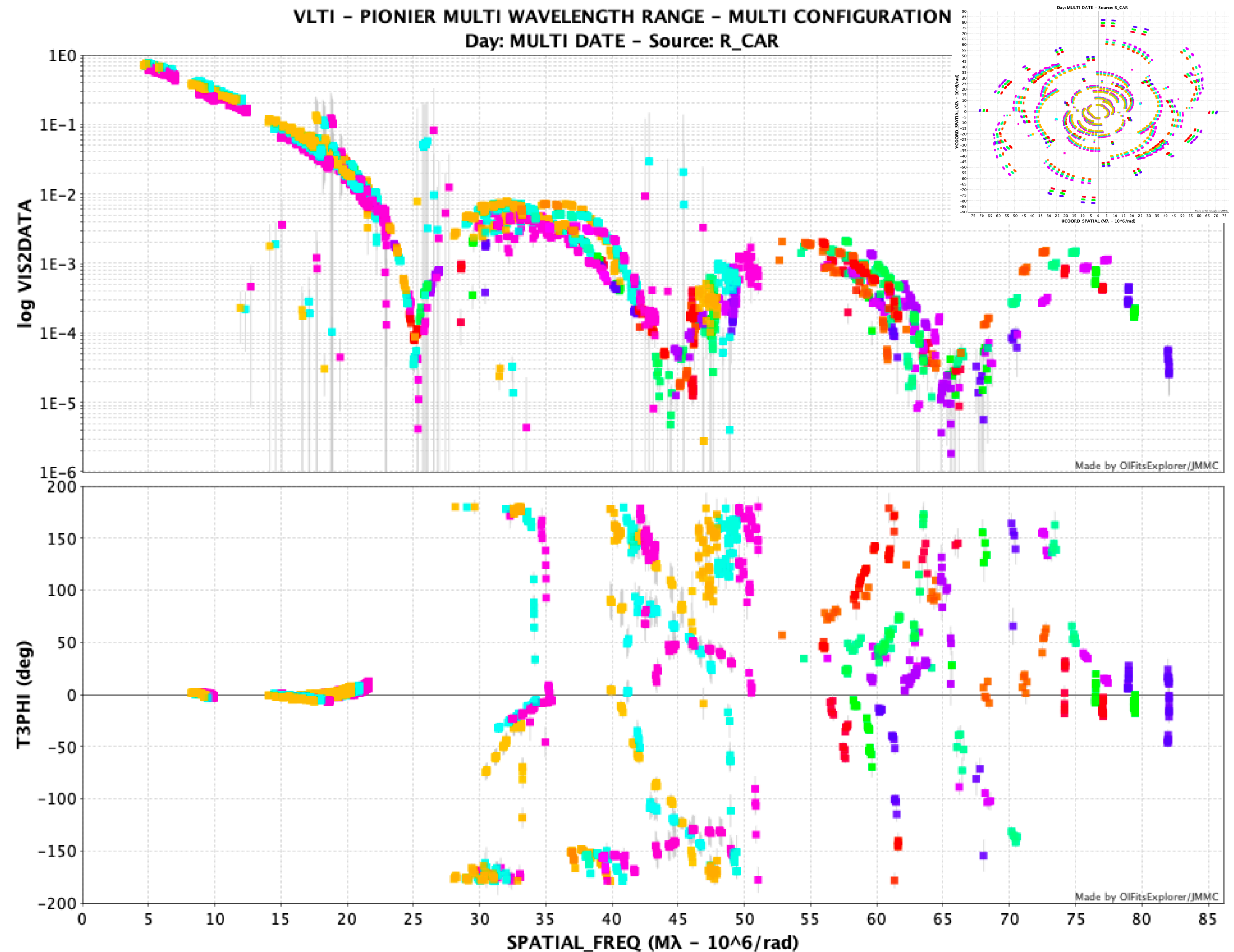
# Interferometric data



## ● Interferometric data:

- Fourier domain
- few measurements
- (differential) visibilities,
- squared visibilities,
- bispectra

**difficult to interpret**



# Interferometric data analysis

## Model Fitting

### Parametric model

- separation,
- diameter,
- limb-darkening,
- temperature,
- ...

- need few data points
- priors in the model definition
- error bars & covariance
- no parameter to tune

review: (Baron, 2020)

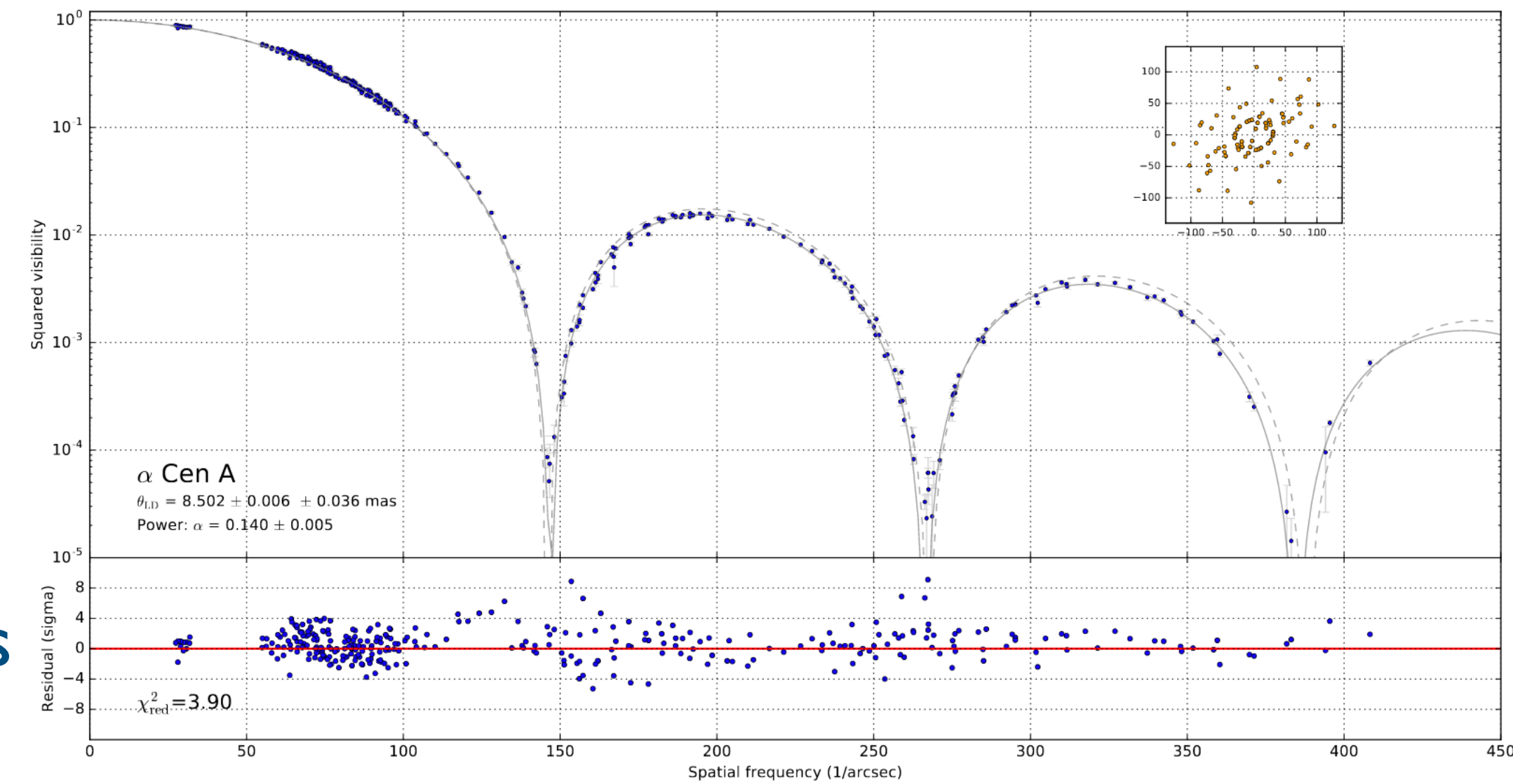
Fit

## Image reconstruction

- Image reconstruction
- one parameter per pixel
- Fourier transform

- need more data points
- prior enforced by regularization
- some parameters to tune

review: (Thiébaut & Young, 2017)



Kervella et al, 2017

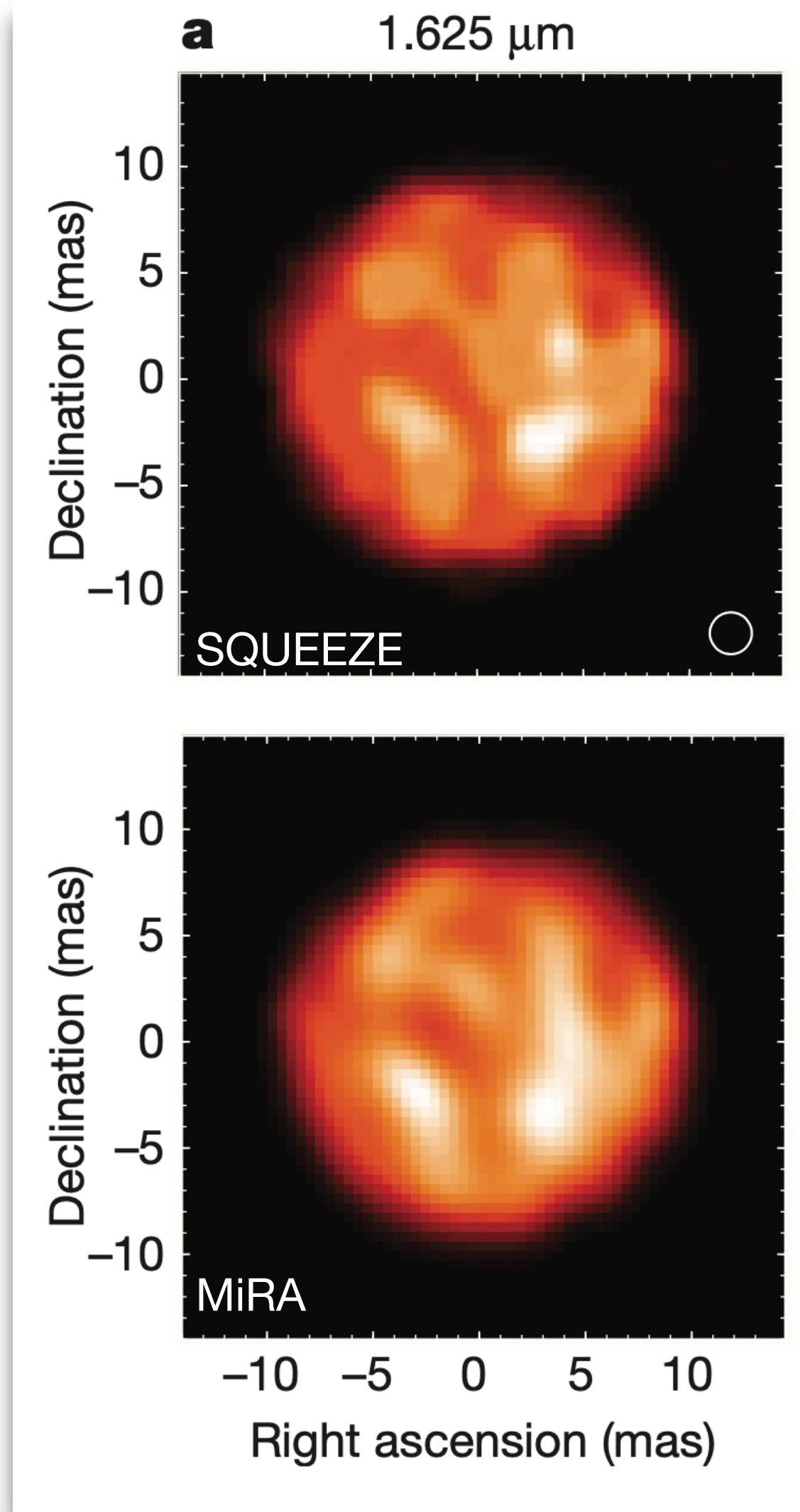
# Model fitting tools

- © **Custom scripts**
- © **LITPro** (Tallon-Boc et al, 2008)
- © **MFIT** (Young, 2010)
- © **PMOIRE** (Mérand)
- © **OITTOOLS.jl** (Baron et al, 2019)

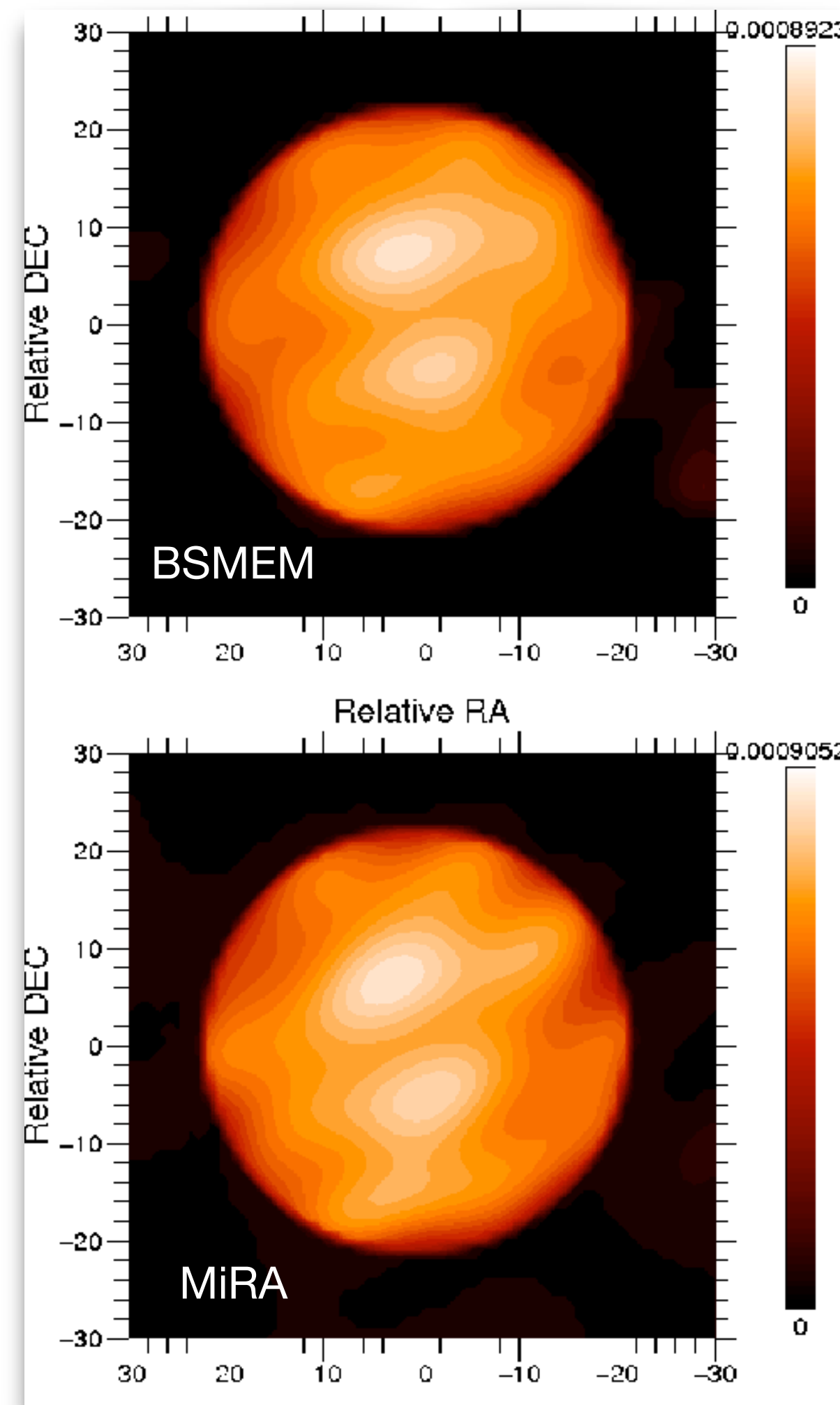
# Image reconstruction softwares

- ◎ **BSMEM** (Buscher et al, 1994) C
- ◎ **MACIM** (Ireland et al, 2006) C
- ◎ **MiRA** (Thiébaud, 2008) yorick
- ◎ **WISARD** (Mugnier et al 2008) IDL
- ◎ **SQUEEZE** (Baron et al, 2010) C
- ◎ **IRBIS** (Hoffman et al, 2014) C
- ◎ **SPARCO** (Kluska et al, 2014) yorick or C
- ◎ **ORGANIC** (Claes et al 2020) python
- ◎ **G<sup>R</sup>** (GRAVITY col., 2022) python

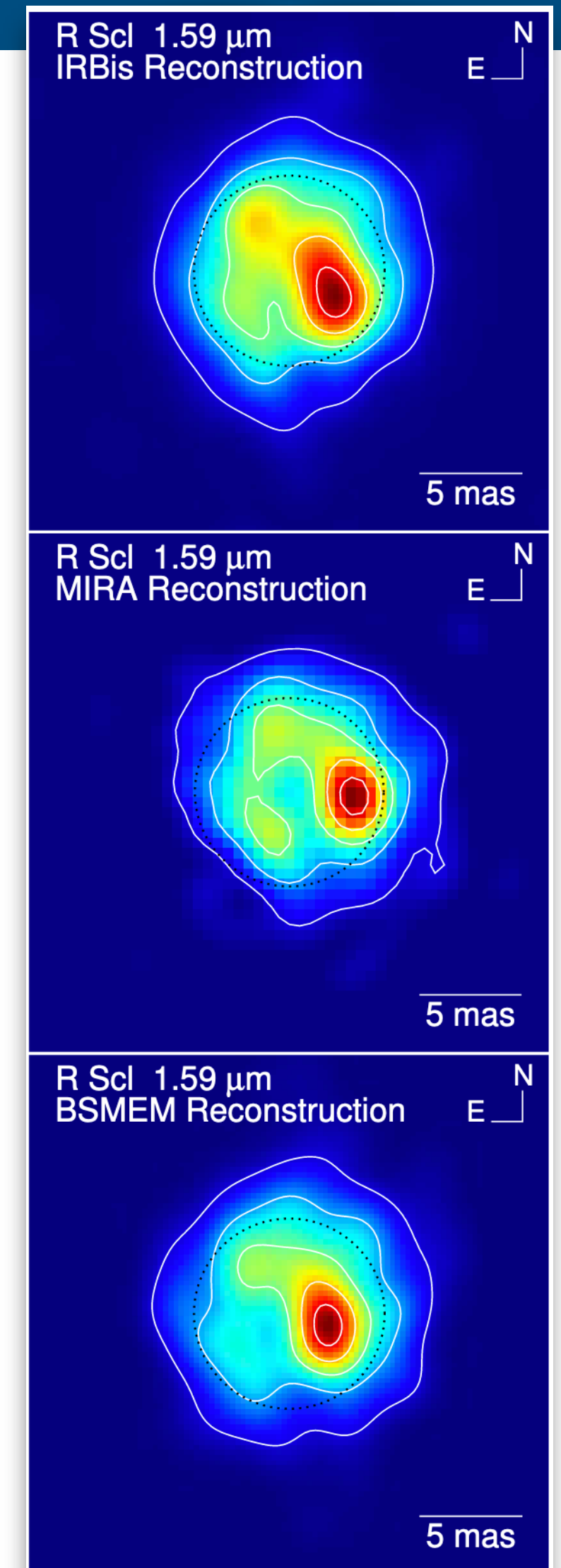
# Comparing reconstructions softwares



$\pi^1$  Gruis (Paladini, 2018)



Betelgeuse (Haubois, 2009)



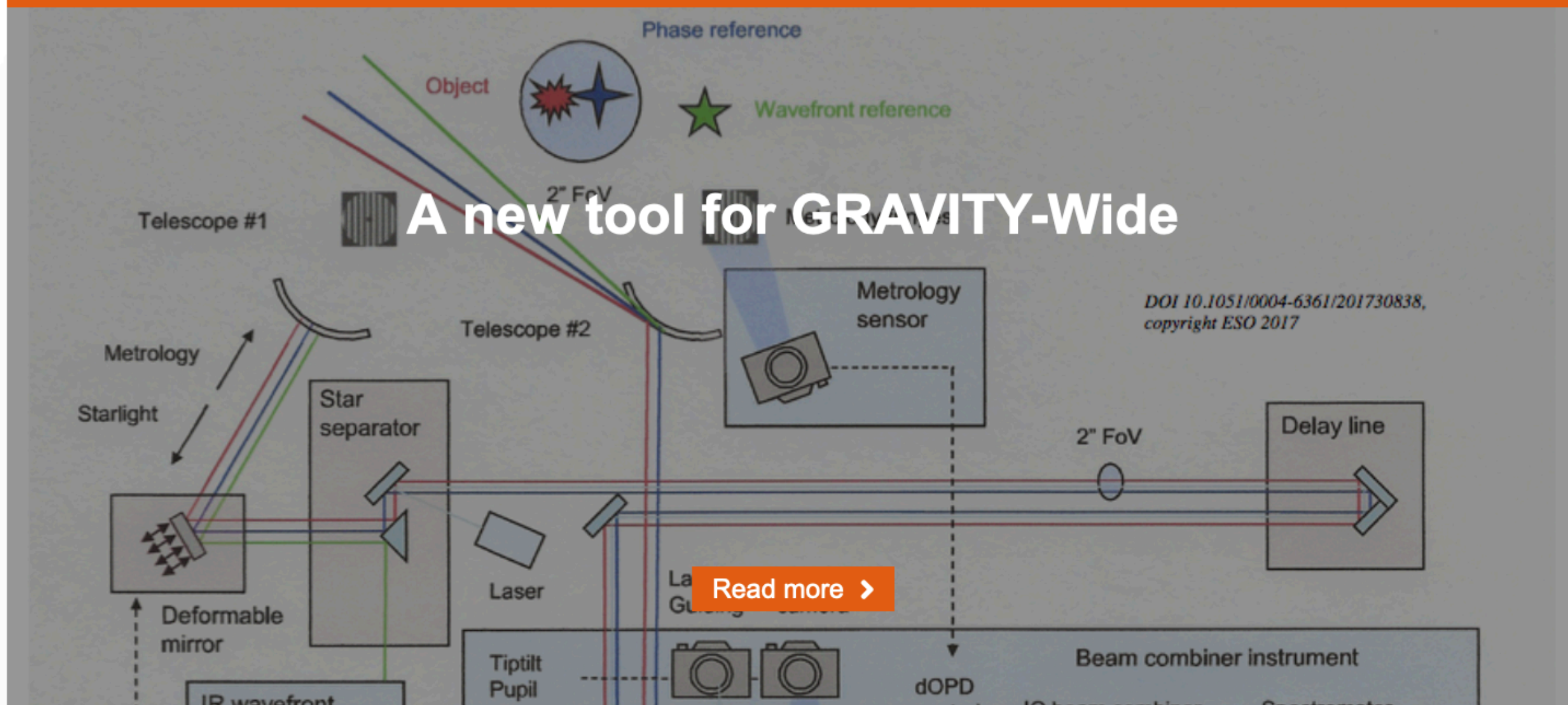
R Sculptoris (Wittkowski, 2017)

**You'll never  
walk alone**



# VLTI Expertise Center





## A new tool for GRAVITY-Wide

[Read more >](#)

### The Mission

The JMMC is the french center for optical interferometry. It aims at providing support for **the users** of the stellar interferometers currently in operation. This support is possible thanks to the development of efficient and using friendly tools for preparing the observations, analysing the data or archiving the results. The tools are accessible through the web site and linked to a **"Face to Face" help**, especially for the preparation of observations, the PIONIER, GRAVITY and MATISSE data reduction, and the data analysis.

[Who are we? >](#)

## JMMC User Support

The JMMC is committed to provide support to the users of the VLTi and other interferometers. For this purpose, a single **contact e-mail address** has been created. You can also fill the dedicated feedback form. Access by click on "Read more".

[Read more >](#)

ASPRO

SEARCHCAL

LITPRO

OIFITSEXPLORER

OIMAGING

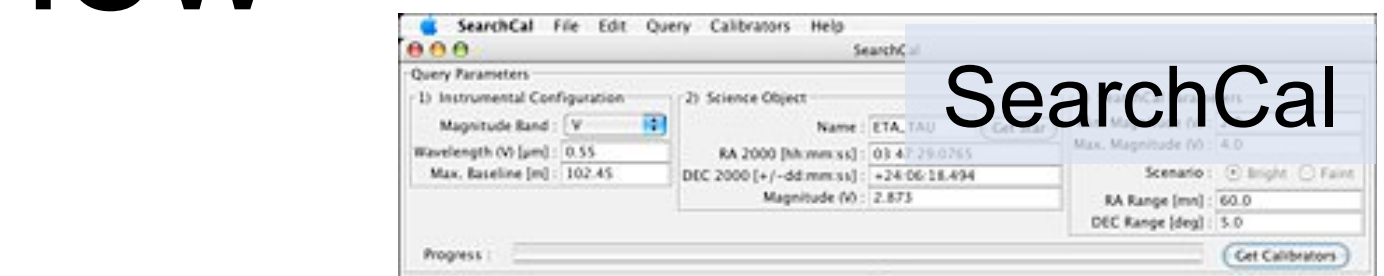
OIDB

# JMMC Service overview

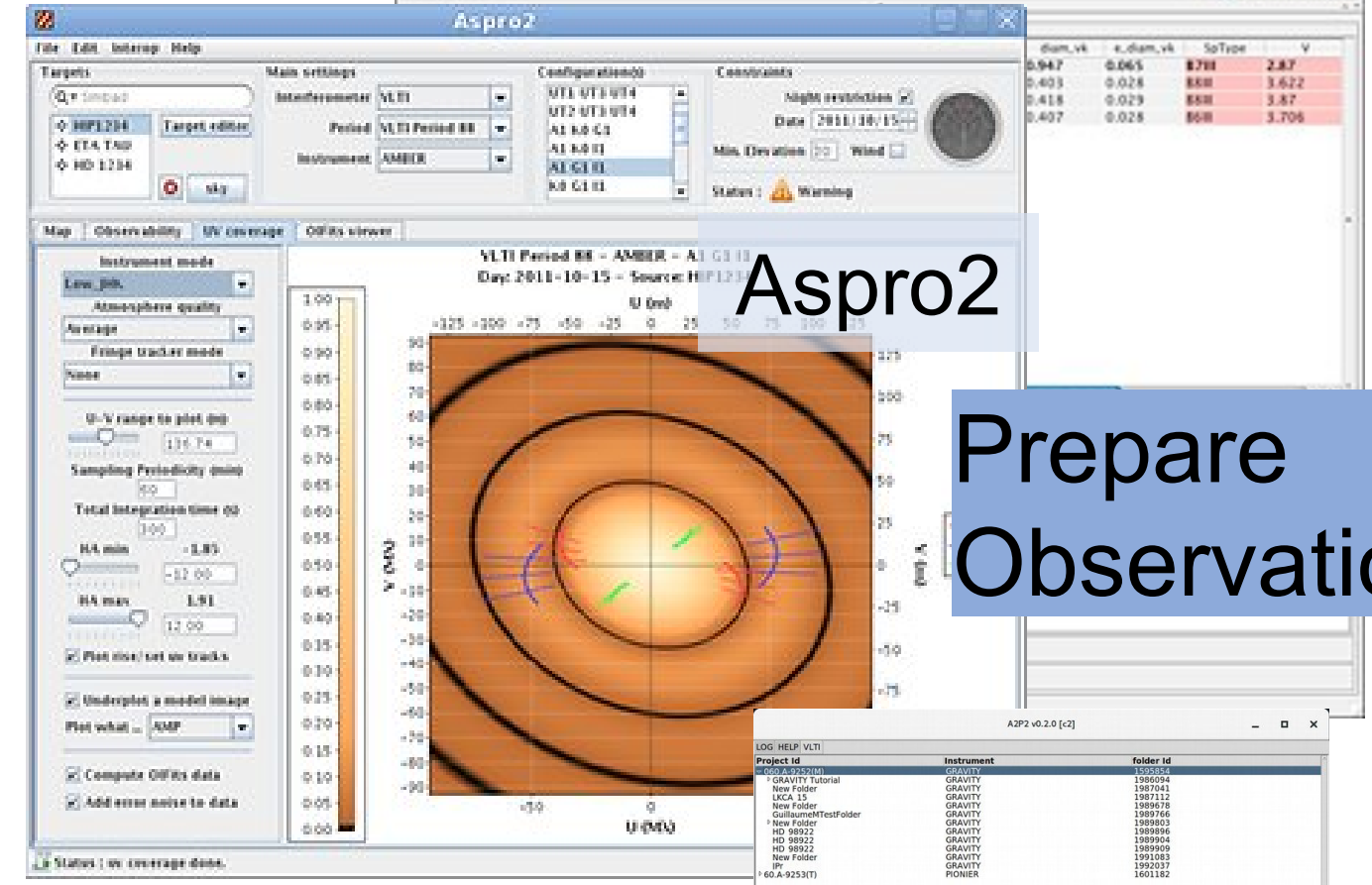


**SUV (VLT I Center):**

- + User Support
- + Training

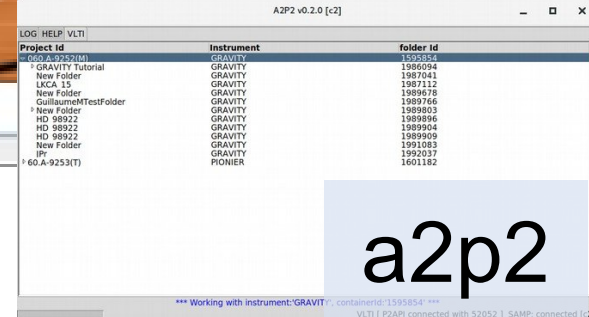


SearchCal



Aspro2

Prepare Observations



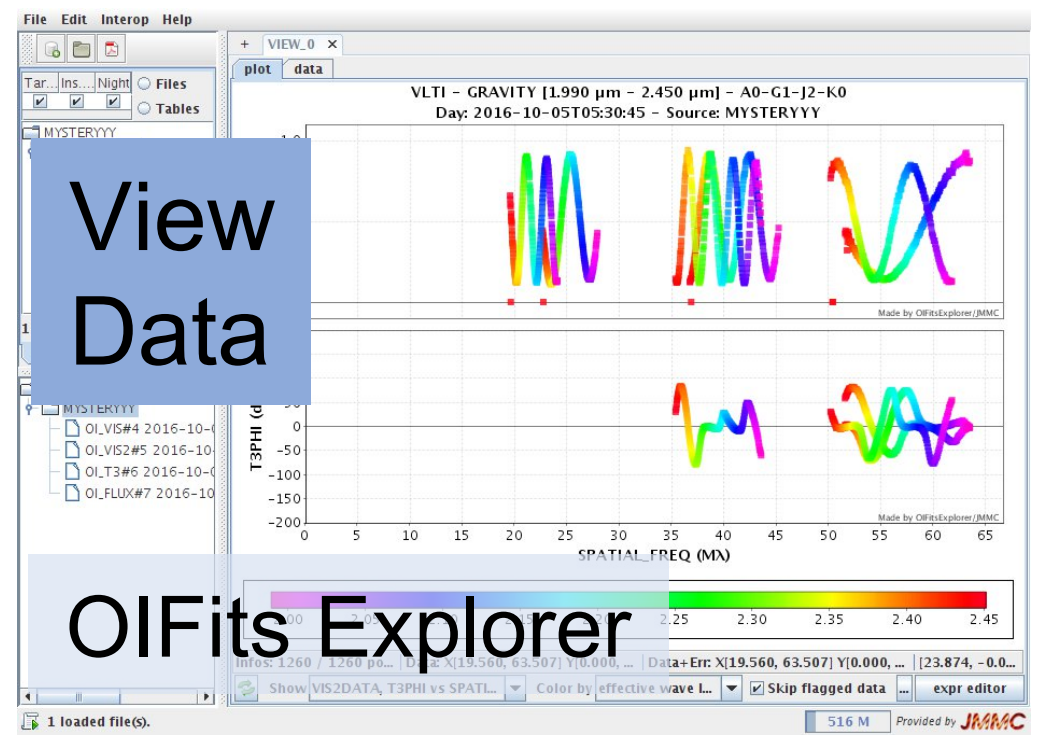
a2p2



AMHRA

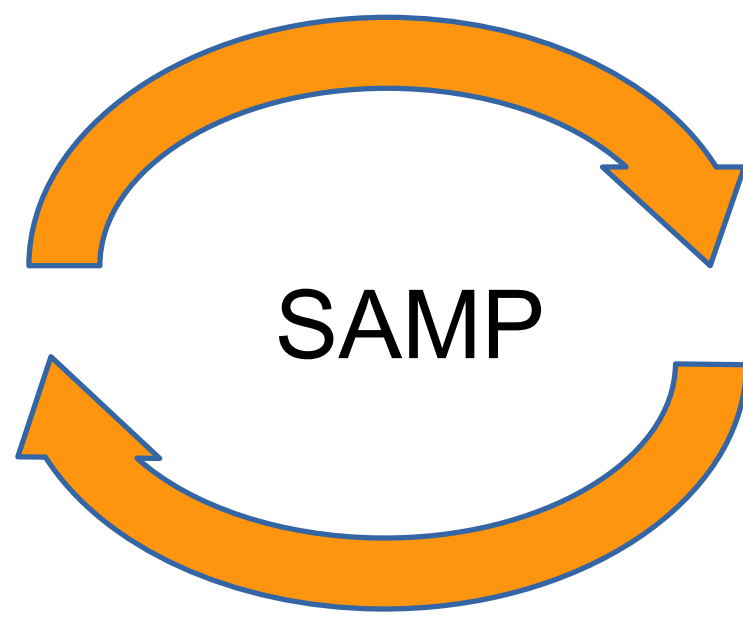
Reduce data

amdlib  
pndrs

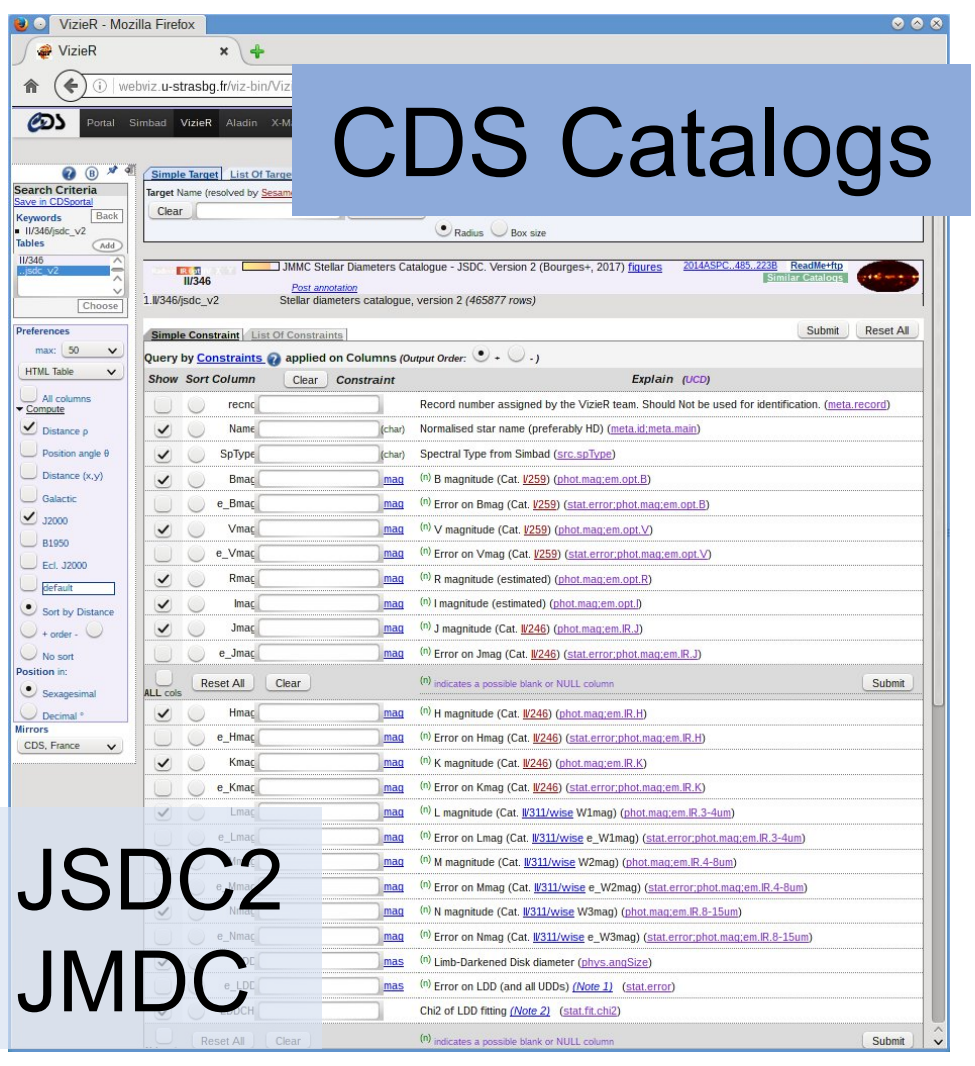


View Data

OIFits Explorer

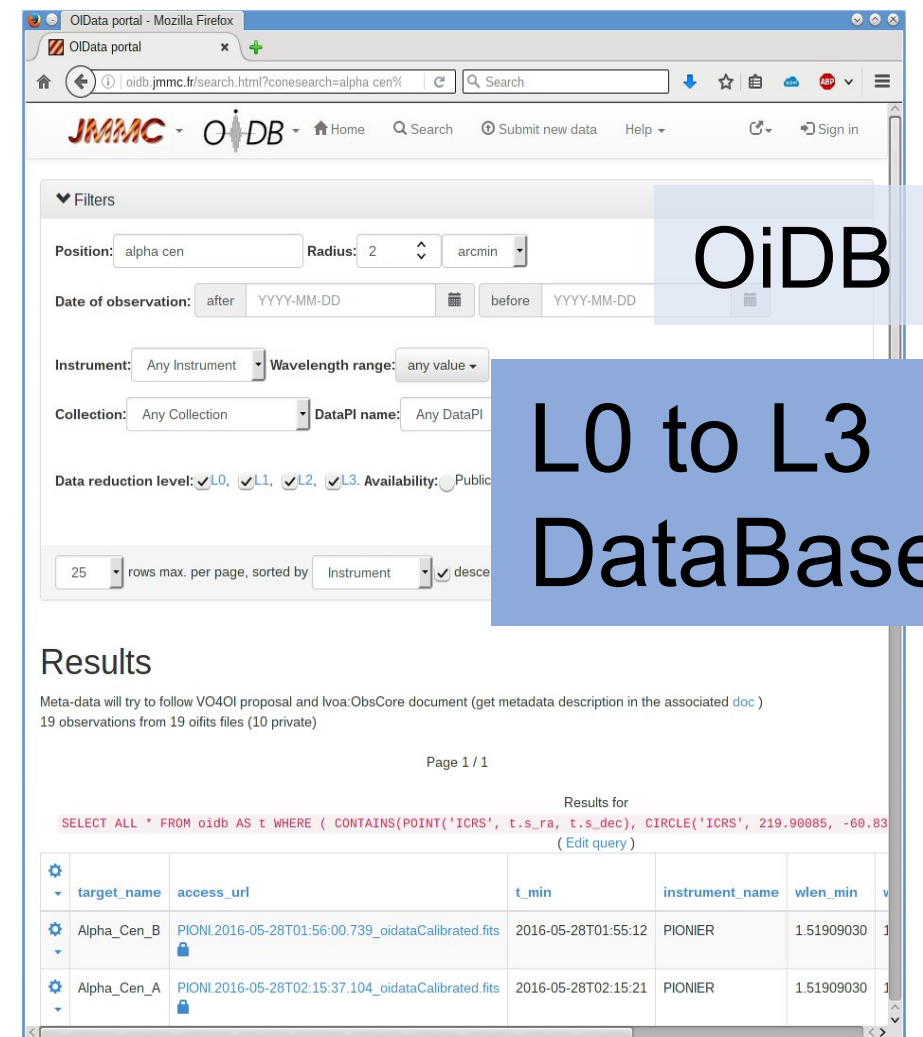


SAMP



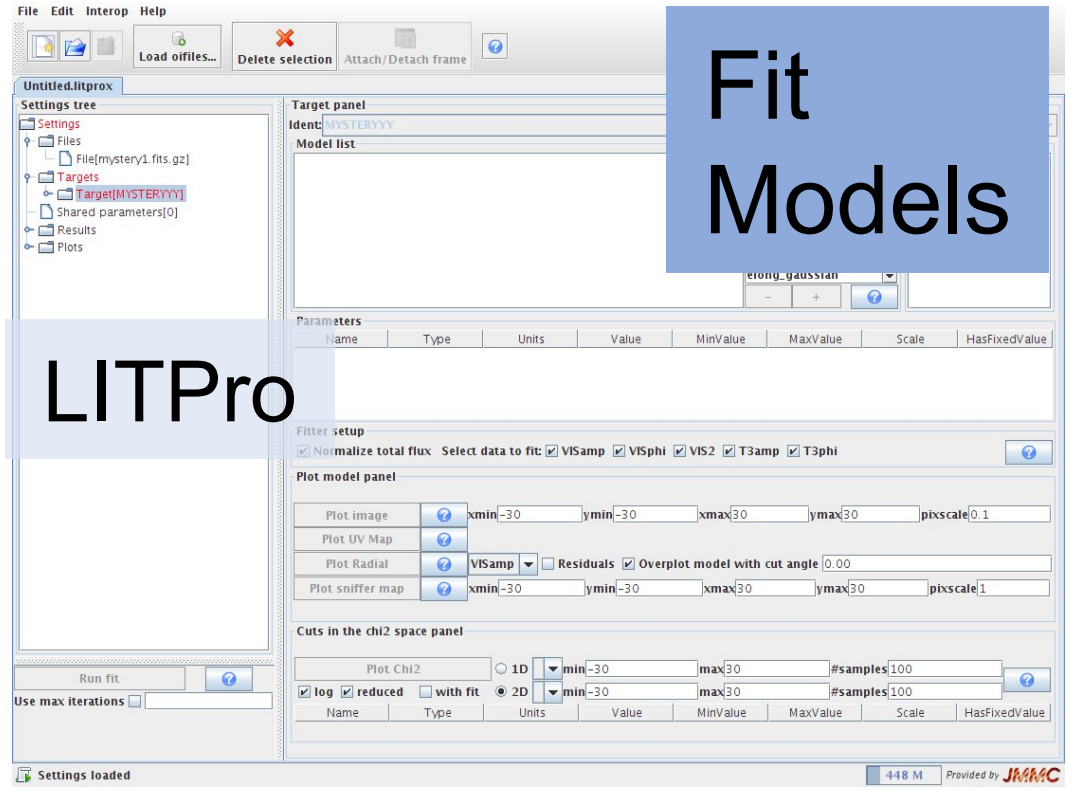
CDS Catalogs

JSDC2  
JMDC



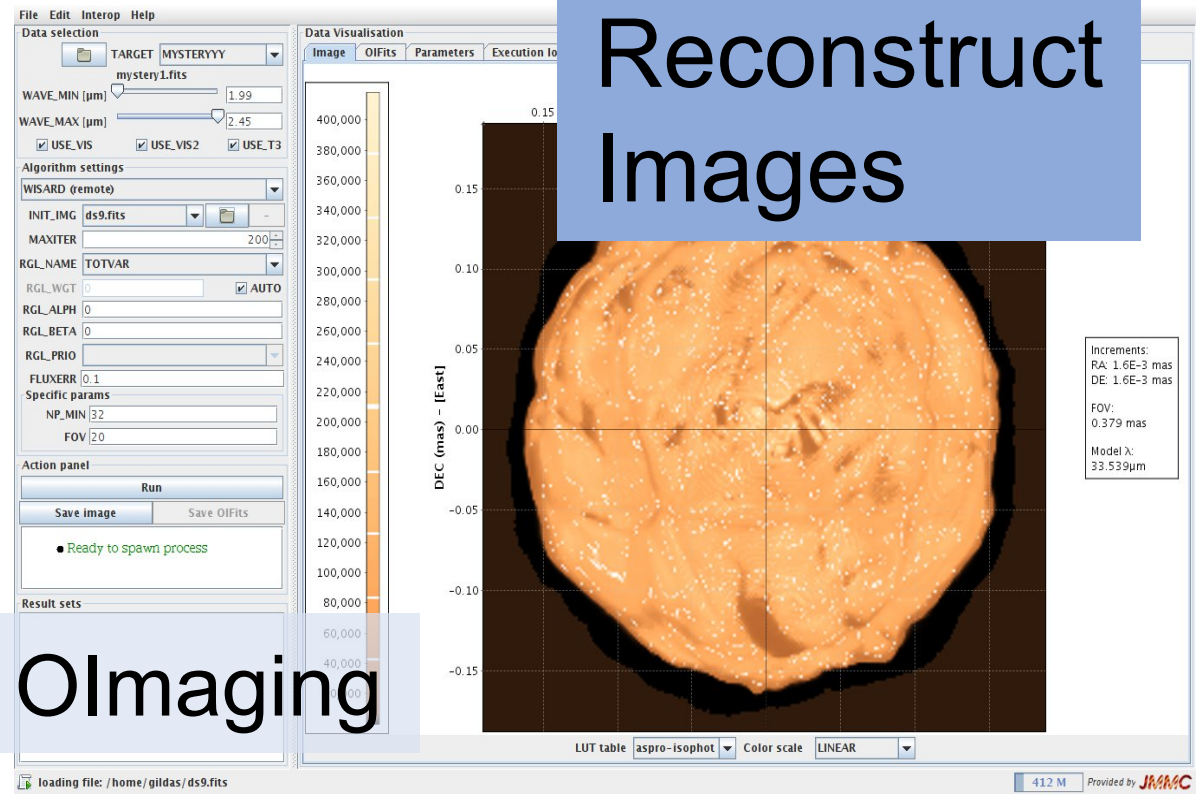
OidB

L0 to L3  
DataBases



Fit Models

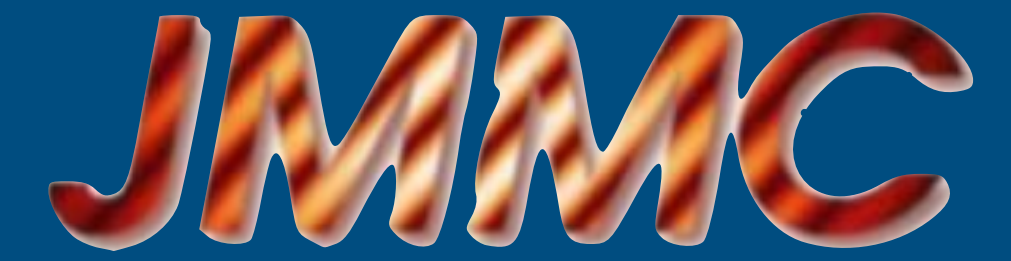
LITPro



Olmaging

Reconstruct Images

# Image reconstruction workflow

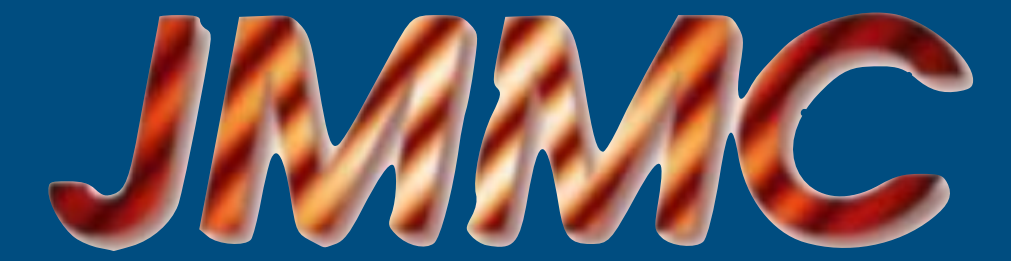


[https://youtu.be/YA3hvs\\_sOfE](https://youtu.be/YA3hvs_sOfE)

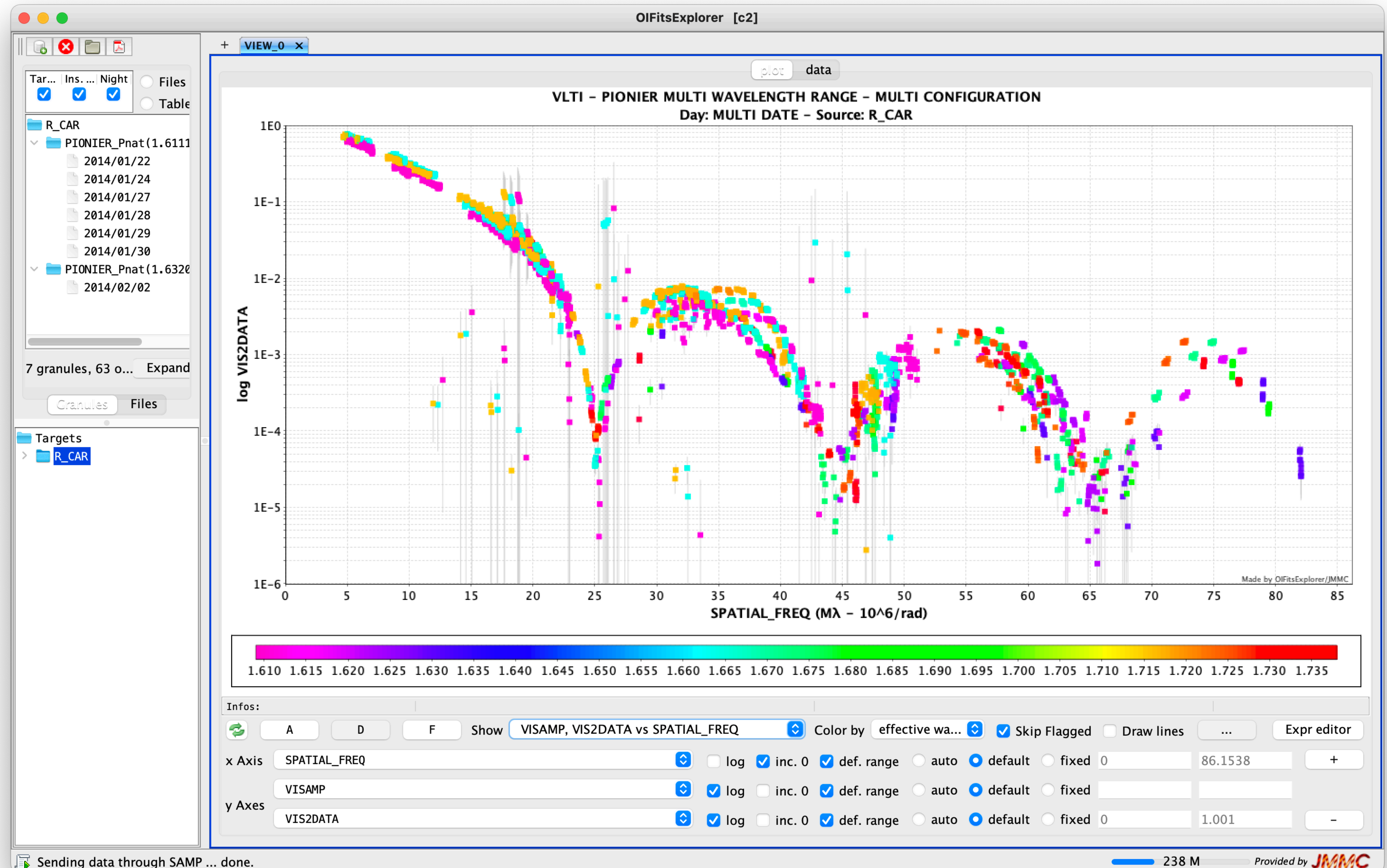
The screenshot displays the OIFits Explorer software interface. The main window shows two scatter plots. The top plot is titled "VLTI - PIONIER [1.6238  $\mu\text{m}$  - 1.7287  $\mu\text{m}$ ] / [1.624  $\mu\text{m}$  - 1.7296  $\mu\text{m}$ ] - A1-B2-C1-D0 / D0-G1-H0-I1" and shows log VIS2DATA on the y-axis (ranging from 1E-5 to 1E0) versus SPATIAL\_FREQ (MX) on the x-axis (ranging from 0 to 53). The bottom plot shows T3PHI (deg) on the y-axis (ranging from -200 to 200) versus SPATIAL\_FREQ (MX) on the x-axis (ranging from 0 to 53). A color bar at the bottom indicates effective wavelength from 1.625 to 1.730  $\mu\text{m}$ . The video player interface includes a play button, progress bar, and volume control.

Interferometric image reconstruction with OImaging

# OIFitsExplorer: data handling tool



Still in beta version



# Model fitting

## © LITpro

- GUI
- geometrical model
- temperature
- analytic estimate of uncertainties
- hidden features (ask for it)
- free to use (+citation)

## © PMOIRE

- python notebook
- geometrical model
- more spectral and temporal model
- uncertainties via bootstrapping
- A. Mérand asks to be co-author

## © A single interface

- 4 softwares: BSMEM, MiRA, SPARCO, WISARD
- results in a single table
- rating, comparing, ...
- saving reconstruction parameters with the image

The screenshot displays the OImaging software interface. The top section shows the 'Data Visualisation (RESULT)' tab with a heatmap of  $\Delta RA$  (mas) - [North] vs  $\Delta DE$  (mas) - [East]. The heatmap shows a central bright spot with a color scale from 0.0002 to 0.0030. The bottom section shows a table of results for the 'MIRA' software using the 'hyperbolic' method.

SOFTWARE	RGL_NAME	Index	RATING	Success	CHISQ	LAST_IMG	RGL_WGT	RGL_TAU	NITER	INIT_IMG
MIRA	hyperbolic	14	★★★★★	✓	1.167915696942	IMAGE-OI FINAL IMAGE-2022-04-14T13:09:34	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	11	★★★★★	✓	4.803045007319	IMAGE-OI FINAL IMAGE-2022-04-14T13:08:27	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	19	★★★★★	✓	4.106433052084	IMAGE-OI FINAL IMAGE-2022-04-14T13:31:40	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	17	★★★★★	✓	4.187646473487	IMAGE-OI FINAL IMAGE-2022-04-14T13:22:05	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	16	★★★★★	✓	4.227981722551	IMAGE-OI FINAL IMAGE-2022-04-14T13:10:31	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	15	★★★★★	✓	4.396579605637	IMAGE-OI FINAL IMAGE-2022-04-14T13:09:58	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	5	★★★★★	✓	11.24294920184	IMAGE-OI FINAL IMAGE-2022-04-14T13:05:49	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	24	★★★★★	✓	14.35654643468	IMAGE-OI FINAL IMAGE-2022-04-14T13:53:40	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	23	★★★★★	✓	17.07859731137	IMAGE-OI FINAL IMAGE-2022-04-14T13:52:14	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	22	★★★★★	✓	28.40581845984	IMAGE-OI FINAL IMAGE-2022-04-14T13:51:12	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	21	★★★★★	✓	4.16876781497	IMAGE-OI FINAL IMAGE-2022-04-14T13:44:59	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	20	★★★★★	✓	2.459183524334	IMAGE-OI FINAL IMAGE-2022-04-14T13:44:25	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	18	★★★★★	✓	4.136819195696	IMAGE-OI FINAL IMAGE-2022-04-14T13:22:48	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	13	★★★★★	✓	4.461844063944	IMAGE-OI FINAL IMAGE-2022-04-14T13:08:53	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	12	★★★★★	✓	4.627356096337	IMAGE-OI FINAL IMAGE-2022-04-14T13:08:40	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	10	★★★★★	✓	5.481244922455	IMAGE-OI FINAL IMAGE-2022-04-14T13:08:00	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	9	★★★★★	✓	5.582906390672	IMAGE-OI FINAL IMAGE-2022-04-14T13:07:42	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	8	★★★★★	✓	5.805248428908	IMAGE-OI FINAL IMAGE-2022-04-14T13:07:31	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	7	★★★★★	✓	6.365336910097	IMAGE-OI FINAL IMAGE-2022-04-14T13:06:30	1.000	1E-06	51	IMAGE-OI INI
MIRA	hyperbolic	6	★★★★★	✓	11.12439154204	IMAGE-OI FINAL IMAGE-2022-04-14T13:06:03	1.000	1E-06	51	IMAGE-OI INI

# OI-Interface: a single format to connect them all

A unified way to call reconstruction softwares

- Every information in a single OI-FITS file
- Simpler interaction with softwares
- Reproducible results

The screenshot displays the GitHub interface for the repository `JMMC-OpenDev / OI-Imaging-JRA`. The repository is public and has 6 watchers, 6 forks, and 4 stars. The main content area shows a commit history table and the README file content.

File	Commit Message	Author	Date
<code>.github/workflows</code>	Update main.yml		last month
<code>doc</code>	Add keywords CONVERGE and PROCISOFT in OUTPUT PARAM t...		last month
<code>.gitattributes</code>	Initial commit		7 years ago
<code>.gitignore</code>	Initial commit		7 years ago
<code>README.md</code>	fix typo in README		last month

The README file content is as follows:

## OI-Interface

Design and specification of an interface to image reconstruction and model fitting from optical interferometric data.

### Contents

- [Unified Image Reconstruction Description](#) exploits the *inverse problem* framework to present the general principles of image reconstruction from interferometric data.
- [Interface to Image Reconstruction](#) is a draft document giving the specifications for a graphical user interface to control image reconstruction algorithms.
- Directory `doc` contains the sources of the various documents.



# You'll never walk alone

## Subpages:

Overview VLTI Expertise Centre Support

# VLTI Expertise Centres

Structured development of optical interferometry requires leaping towards a European network of VLTI Expertise Centres. These centres are the backbone of dissemination activities to new VLTI users, by organising observing preparation and **data reduction schools**, by co-organising with ESO VLTI open days, and being the end-points of the **Fizeau staff exchange programme**.

The leap aims at bringing the impact and return of the programme in spreading know-how in Europe to a new level. It follows at a smaller scale the successful experience of the ALMA Regional Centres, where researchers travel to the expertise centres to reduce their data. The centres will be the visible first contact point for astronomers interested in using VLTI.

The present network of VLTI Expertise Centres includes three partners from the OPTICON Horizon 2020 networking activity:

- **Jean-Marie Mariotti Centre (JMMC) - Service aux Utilisateurs du VLTI**, (SUV) France - a structure that aggregates manpower from different observatories:
  - **Observatoire des Sciences de l'Univers de Grenoble (OSUG)**
  - **Observatoire des Sciences de l'Univers de Lyon (OSUL)**
  - **Observatoire de Paris-Meudon (OPM)**
  - **Observatoire de la Côte d'Azur (OCA)**
- **Portuguese VLTI Expertise Centre**, Portugal
- **University of Exeter**, United Kingdom

two interferometry JRA (Joint Research Activities; WP8) lead partners:

- **Lagrange Laboratory/OCA**, France
- **KU Leuven**, Belgium

and two new nodes from the **OPTICON/RadioNet Pilot (ORP)** program:

- **Leiden Observatory**, The Netherlands
- **Konkoly Observatory**, Hungary

An overview of the support provided by each VLTI Expertise Centre and the data protection policy can be found [here](#).

Visitors wishing to travel to the above centres to reduce their VLTI data or prepare observations are encouraged to use the **Fizeau Programme**.

## Welcome onto the JMMC User Feedback Form !

(\* : required field )

Application: SUV (VLTI center) ▼

Type: Support Needed ▼

Your Email \* : your@email ✉

Summary \* :

Comments \* :

Version: Optional V.

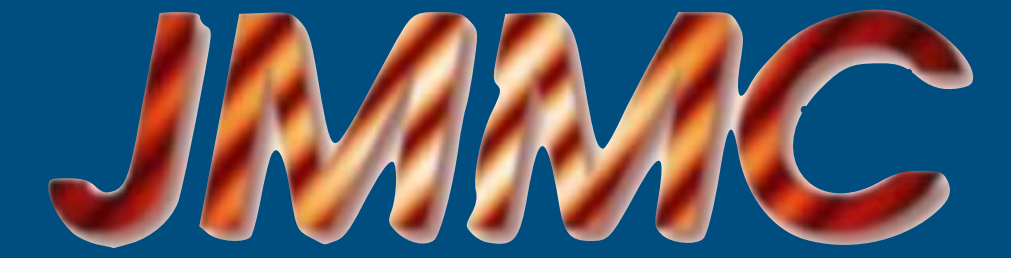
Effacer

Envoyer

# Ask for help and give feedback

- ◎ **Expertise center gather experts that are willing to help**
- ◎ **Use Fizeau program to travel to your expertise center**
- ◎ **Request features**
- ◎ **Knowing user needs help us to tailor softwares**
- ◎ **Research on methodology are fueled by requests**

# OImaging: a collective project



## © The big chiefs:

I. Tallon-Bosc  
J-P. Berger  
G. Duvert

## © The developers:

L. Bourgès  
A. Kaszczyc  
G. Mella  
M. Pratoussy



## © The reconstruction software fathers:

G. Duvert  
J. Kluska  
L. Mugnier  
E. Thiébaut  
J. Young

## © The beta-testers:

J. Kluska  
M. Montargès