

An image reconstruction workflow @ JMMC

The logo for the Joint Multi-Mission Campaign (JMMC), featuring the letters 'JMMC' in a bold, stylized font with a red-to-orange gradient and a slight 3D effect.

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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^R** (GRAVITY col., 2022) python

Reconstruction algorithms in a nutshell

Most algorithms follow a MAP framework:

● Reconstructed image $\mathbf{o}^+ = \arg \min_{\mathbf{o} \in \mathbb{D}^N} \mathcal{L}(\mathbf{o}) + \mu \mathcal{R}(\mathbf{o})$

● Strict priors
(eg non-negativity)

● Likelihood:
measures the compatibility of
the image with the data

● Hyper-parameter:
balances priors and likelihood

● Regularization:
enforces priors

Reconstruction algorithms in a nutshell

Likelihood Most algorithms use Gaussian likelihood for the three main measured quantities

- Visibilities
- Squared-visibilitys
- Closure phase

Regularizations One of the following:

- Quadratic smoothness
- Soft support
- Edge preserving smoothness
- Entropy

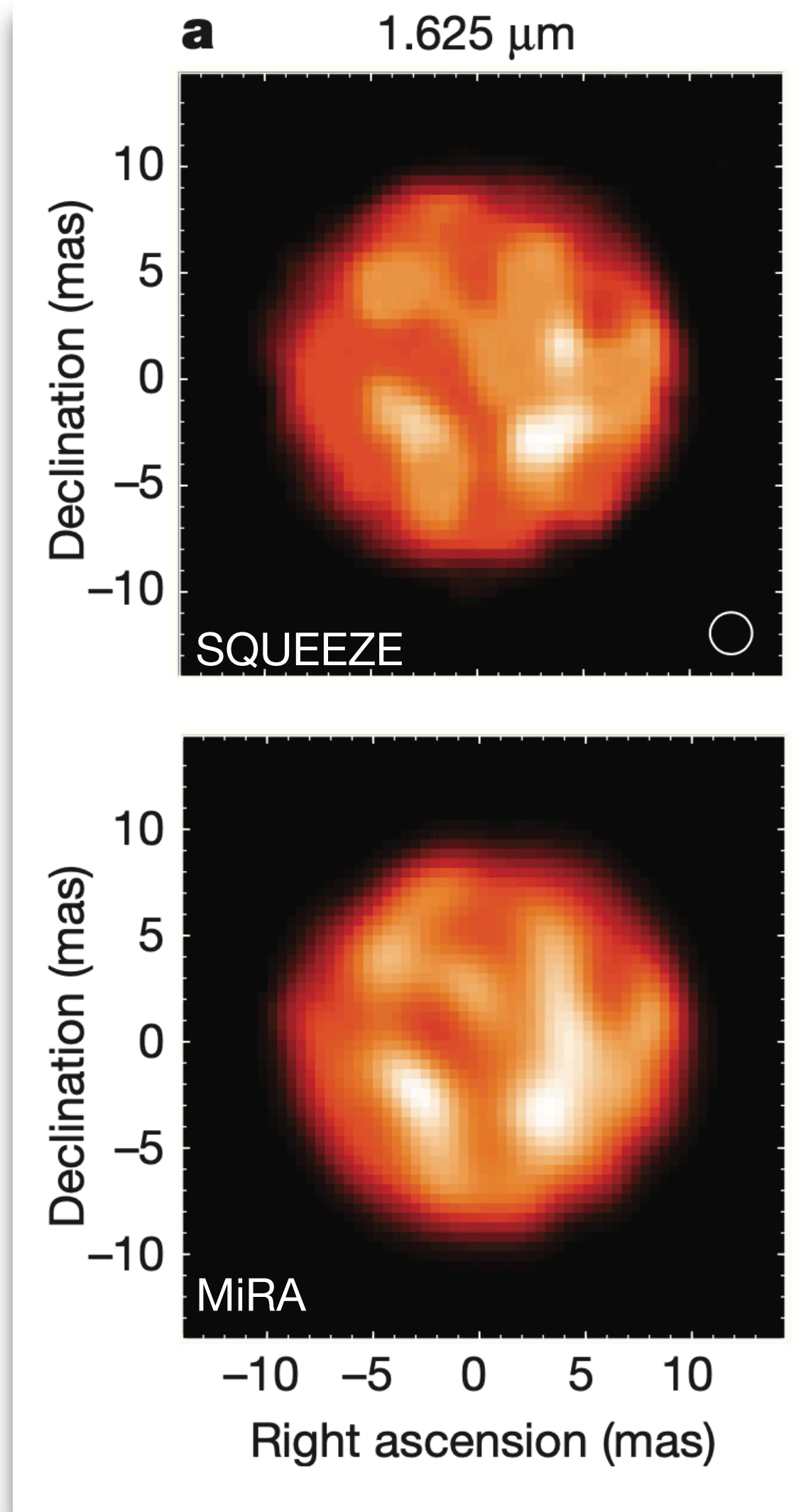
$$f_{\text{prior}}(\mathbf{x}) = \|\mathbf{D} \cdot \mathbf{x}\|^2$$

$$f_{\text{prior}}(\mathbf{x}) = \sum_i x_j^2 / x_j^{\text{prior}}$$

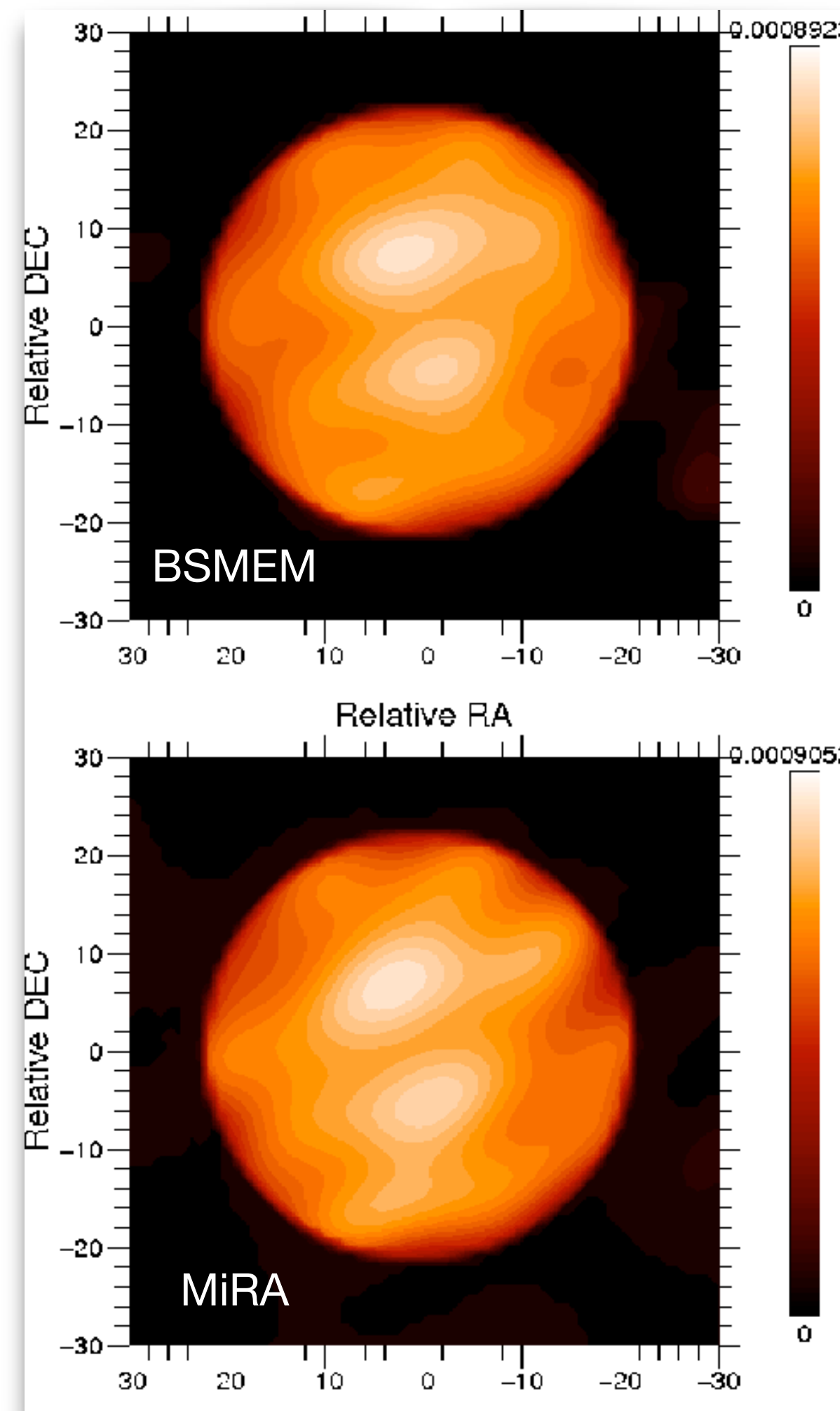
$$f_{\text{prior}}(\mathbf{x}) = \mu \sum_{j,k} \left(\sqrt{(\mathbf{D}_j \cdot \mathbf{x})_k^2 + \epsilon^2} - \epsilon \right)$$

$$f_{\text{ent5}}(\mathbf{x}; \mathbf{x}_{\text{prior}}) = \sum_j \left[x_j^{\text{prior}} - x_j + x_j \log \left(x_j / x_j^{\text{prior}} \right) \right]$$

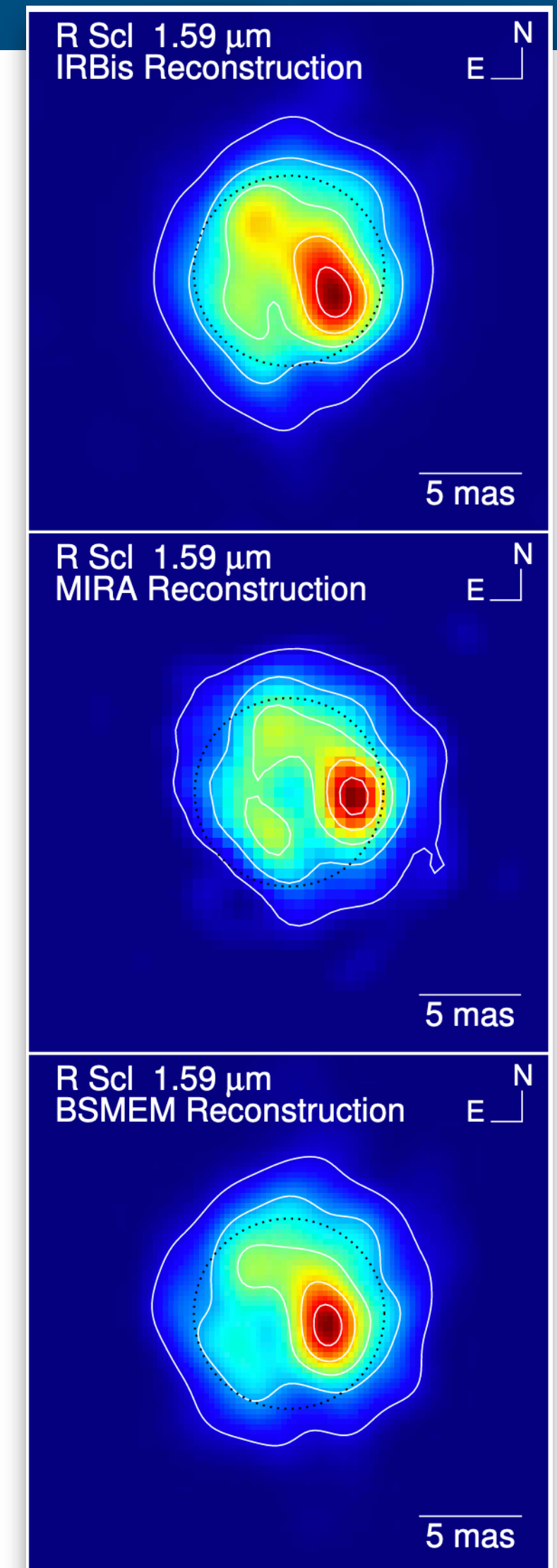
“Classical” softwares give similar results



π^1 Gruis (Paladini, 2018)



Betelgeuse (Haubois, 2009)



R Sculptoris (Wittkowski, 2017)

Reconstruction algorithms in a nutshell

Input:

- ◎ Initial image
 - size
 - sampling
- ◎ Data
 - selection parameters
- ◎ Parameters
 - priors
 - hyper-parameters
 - number of iterations
 - ...



reconstruction algorithm

Output:

- ◎ Reconstructed image
- ◎ Model of the data
- ◎ Output parameters
 - Chi-square
 - cost function value
 - ...

© 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 ΔRA (mas) - [North] vs ΔDE (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 with columns for SOFTWARE, RGL_NAME, Index, RATING, Success, CHISQ, LAST_IMG, RGL_WGT, RGL_TAU, NITER, and INIT_IMG.

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

OImaging

Comparing results

Input Results

OIFits data Images Execution log Parameters

Set as Init Img Modify image

IMAGE-OI FINAL IMAGE

Id: IMAGE-OI FINAL IMAGE result#94 hdu#0

Δ RA (arcsec) - [North]

Δ DE (arcsec) - [East]

Coordinates:
RA: 00:00:00
DE: +00:00:00

Increments:
RA: 1.94E1 mas
DE: 1.94E1 mas

Image FOV:
0.813 arcsec

Pixels:
42 x 42

Id: IMAGE-OI FINAL IMAGE result#98 hdu#0

Δ RA (arcsec) - [North]

Δ DE (arcsec) - [East]

Coordinates:
RA: 00:00:00
DE: +00:00:00

Increments:
RA: 1.94E1 mas
DE: 1.94E1 mas

Image FOV:
0.813 arcsec

Pixels:
42 x 42

Id: IMAGE-OI FINAL IMAGE result#89 hdu#0

Δ RA (arcsec) - [North]

Δ DE (arcsec) - [East]

Coordinates:
RA: 00:00:00
DE: +00:00:00

Increments:
RA: 1.94E1 mas
DE: 1.94E1 mas

Image FOV:
0.813 arcsec

Pixels:
42 x 42

Id: IMAGE-OI FINAL IMAGE result#96 hdu#0

Δ RA (arcsec) - [North]

Δ DE (arcsec) - [East]

Coordinates:
RA: 00:00:00
DE: +00:00:00

Increments:
RA: 1.94E1 mas
DE: 1.94E1 mas

Image FOV:
0.813 arcsec

Pixels:
42 x 42

Continue Restart Update parameters Save OIFits file

Table editor

Compare

Delete

Index	TARGET	SOFTWARE	RGL_NAME	RGL_WGT	NITER	CHISQ	FPRIOR	SFLUO	SFLU1	Success	RATING	INIT_IMG
94	Mysterious_Obj2	SPARCO	hyperbolic	50000.000	334	269.5922423157	1.205	0.250	0.750	✓	☆☆☆☆	IMAGE-OI INITIAL IMAGE
98	Mysterious_Obj2	SPARCO	hyperbolic	50000.000	329	142.8914856893	0.800	0.200	0.800	✓	☆☆☆☆	IMAGE-OI INITIAL IMAGE
89	Mysterious_Obj2	SPARCO	hyperbolic	50000.000	506	2.055324225632	0.698	0.150	0.850	✓	☆☆☆☆	IMAGE-OI INITIAL IMAGE
96	Mysterious_Obj2	SPARCO	hyperbolic	50000.000	187	22492.5854826	1.936	0.100	0.900	✓	☆☆☆☆	IMAGE-OI INITIAL IMAGE
76	Mysterious_Obj2	BSMEM		1.312E7	1000	31279.23				✓	☆☆☆☆	OUTPUT1000-2022-07-19T14:20:59
72	Mysterious_Obj2	BSMEM		1.310E7	1000	30888.71				✓	☆☆☆☆	OUTPUT1000-2022-07-18T23:47:17
71	Mysterious_Obj2	BSMEM		1.308E7	1000	30388.41				✓	☆☆☆☆	OUTPUT1000-2022-07-18T23:46:54
70	Mysterious_Obj2	BSMEM		1.305E7	1000	29753.43				✓	☆☆☆☆	OUTPUT1000-2022-07-18T23:46:43
69	Mysterious_Obj2	BSMEM		1.301E7	1000	28978.64				✓	☆☆☆☆	OUTPUT1000-2022-07-18T23:46:31
68	Mysterious_Obj2	BSMEM		1.296E7	1000	28048.35				✓	☆☆☆☆	OUTPUT1000-2022-07-18T23:46:20

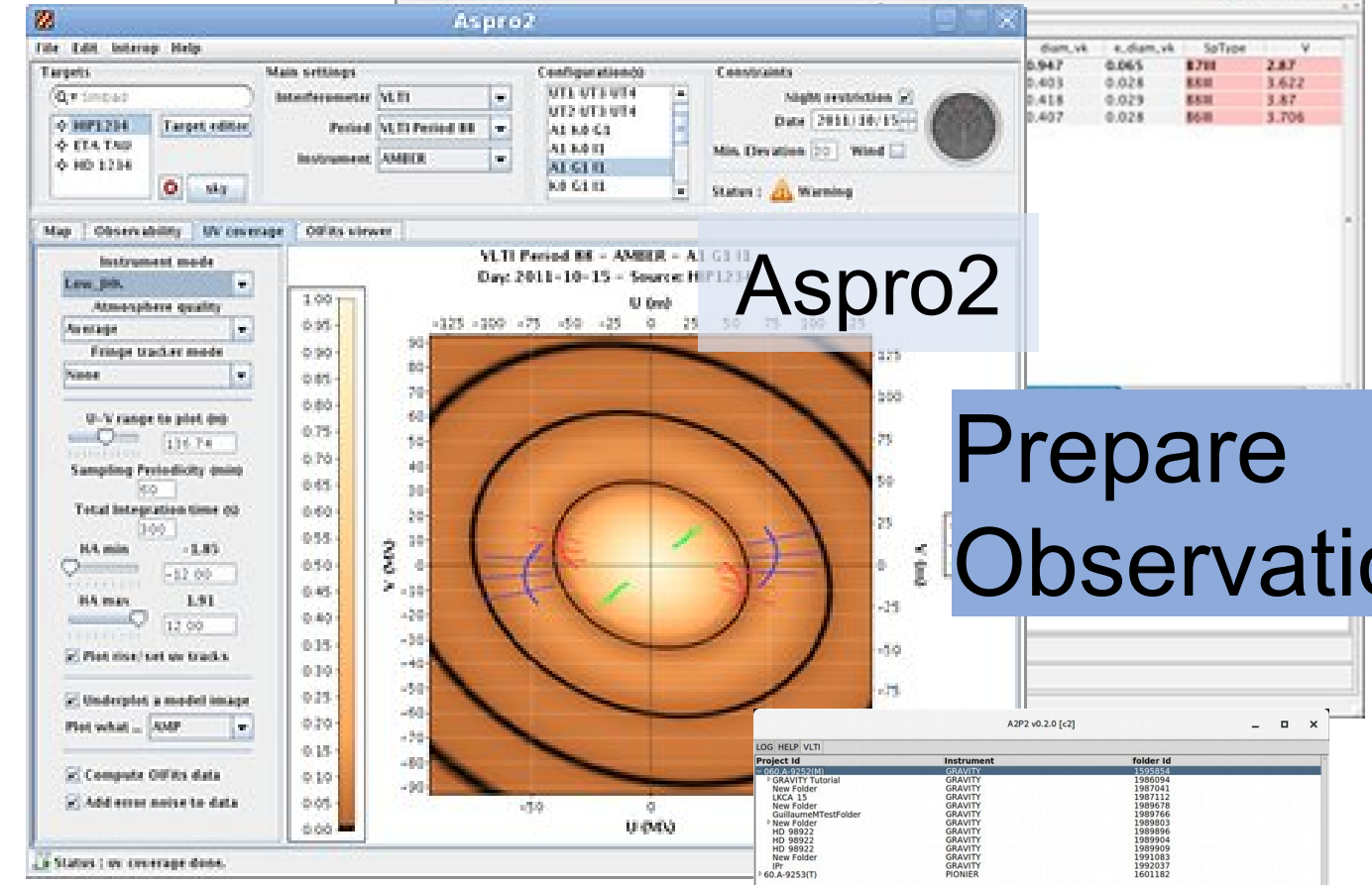
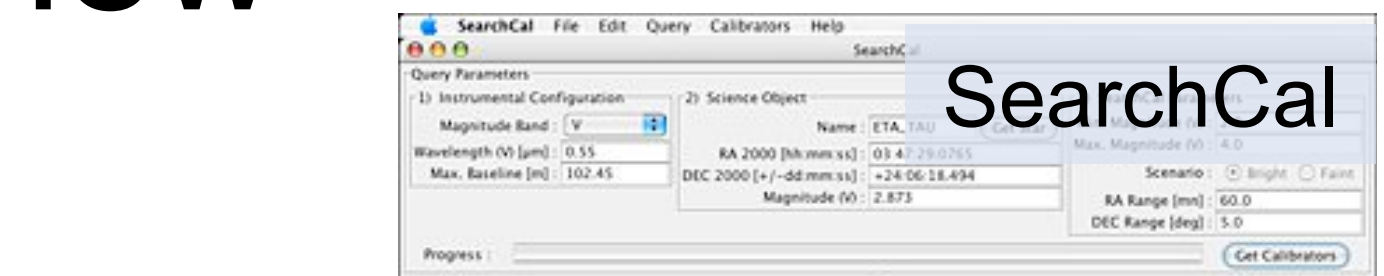
Spawn SPARCO process
1247 M
Provided by JMMC

JMMC Service overview



SUV (VLTI Center):

- + User Support
- + Training



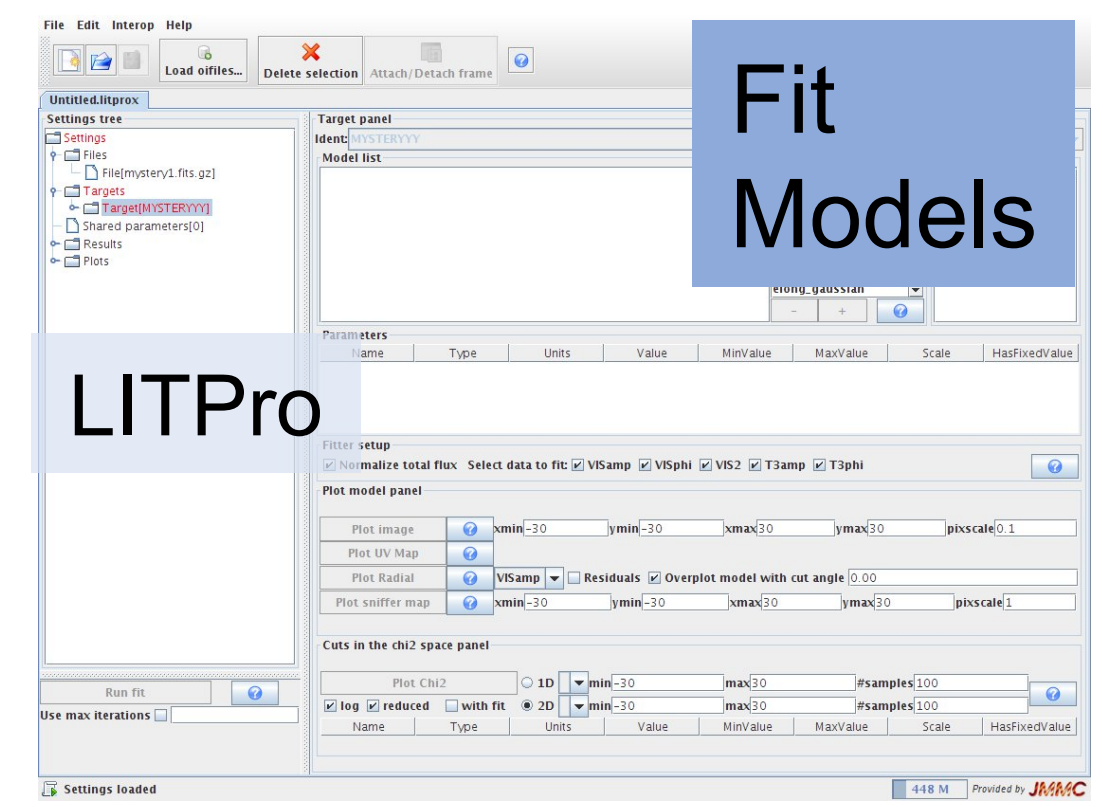
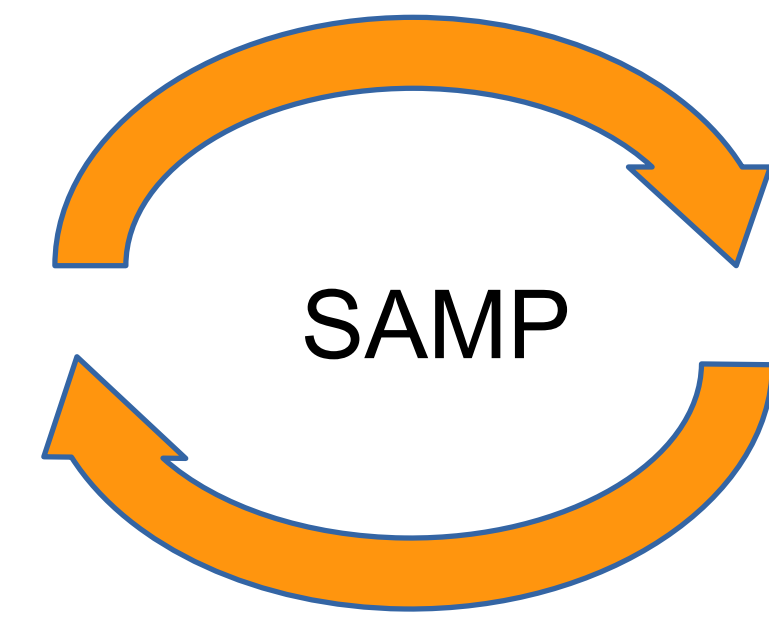
Reduce data

amdlib
pndrs



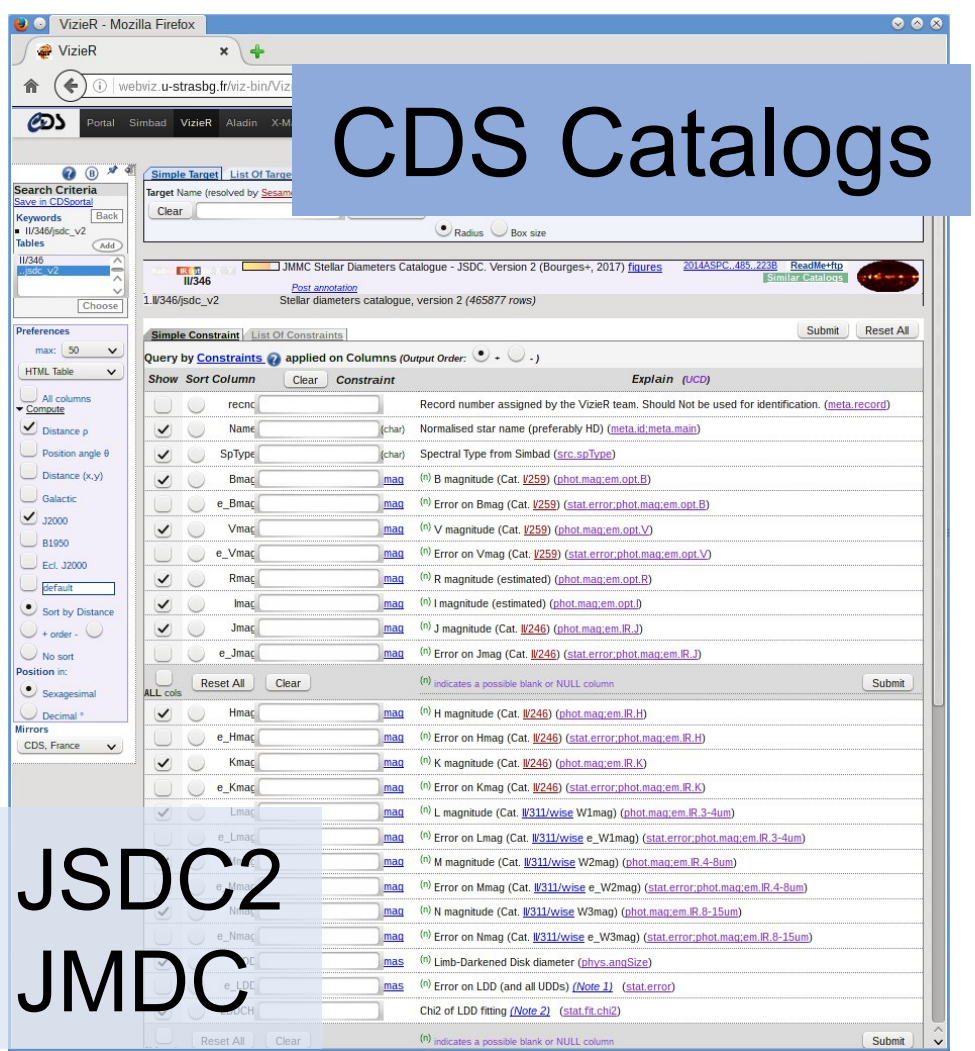
View Data

OIFits Explorer

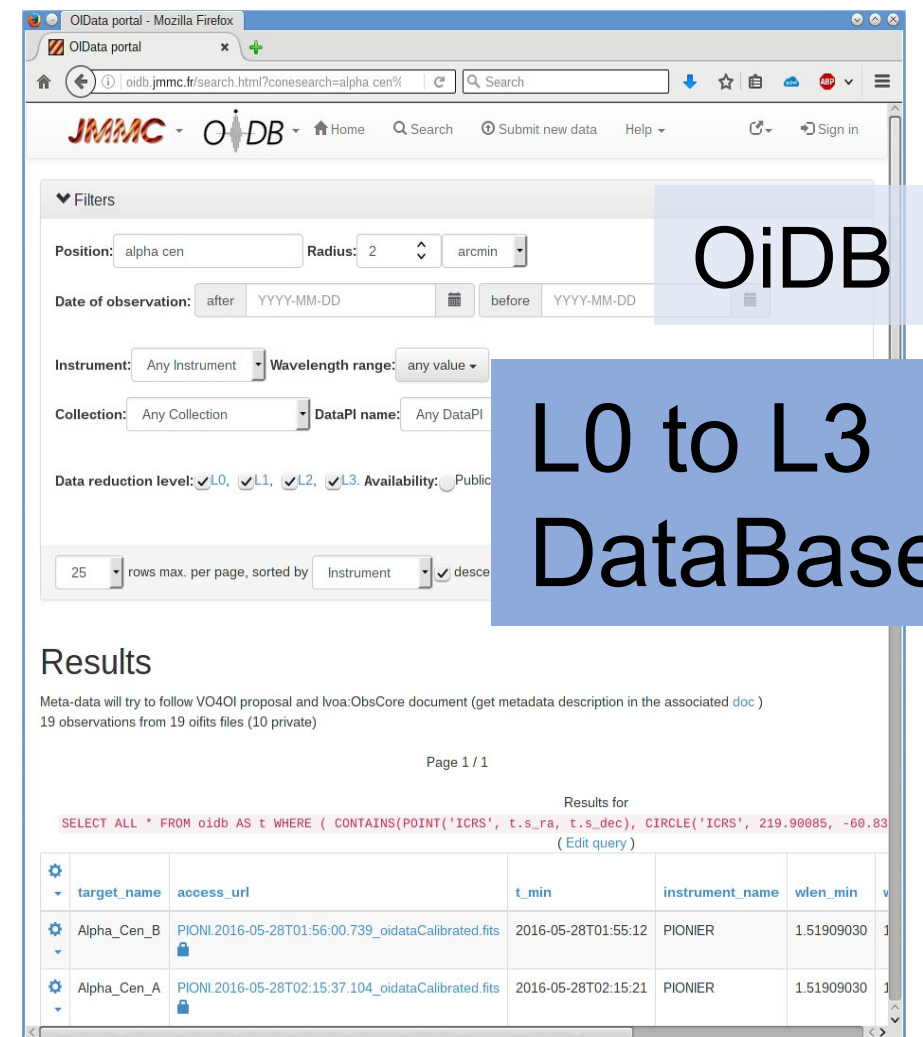


Fit Models

LITPro

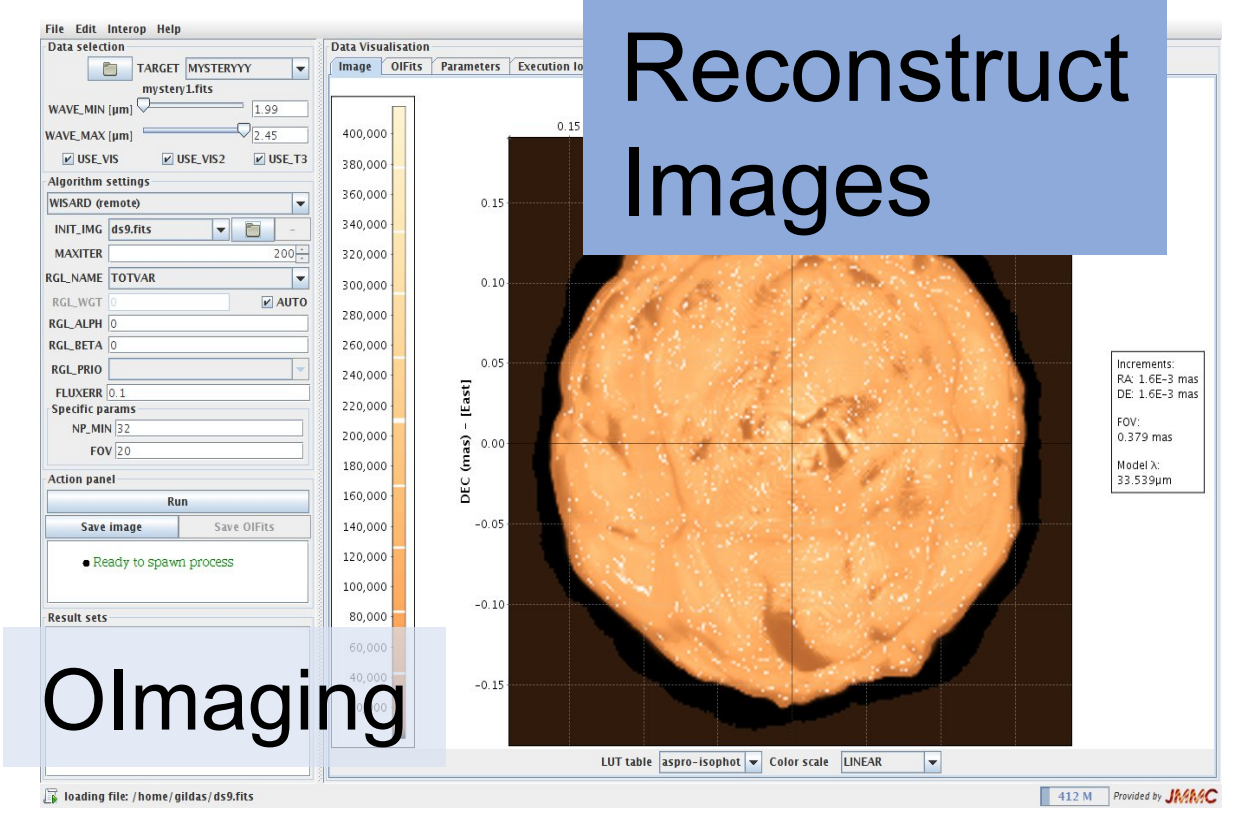


CDS Catalogs



OidB

L0 to L3
DataBases

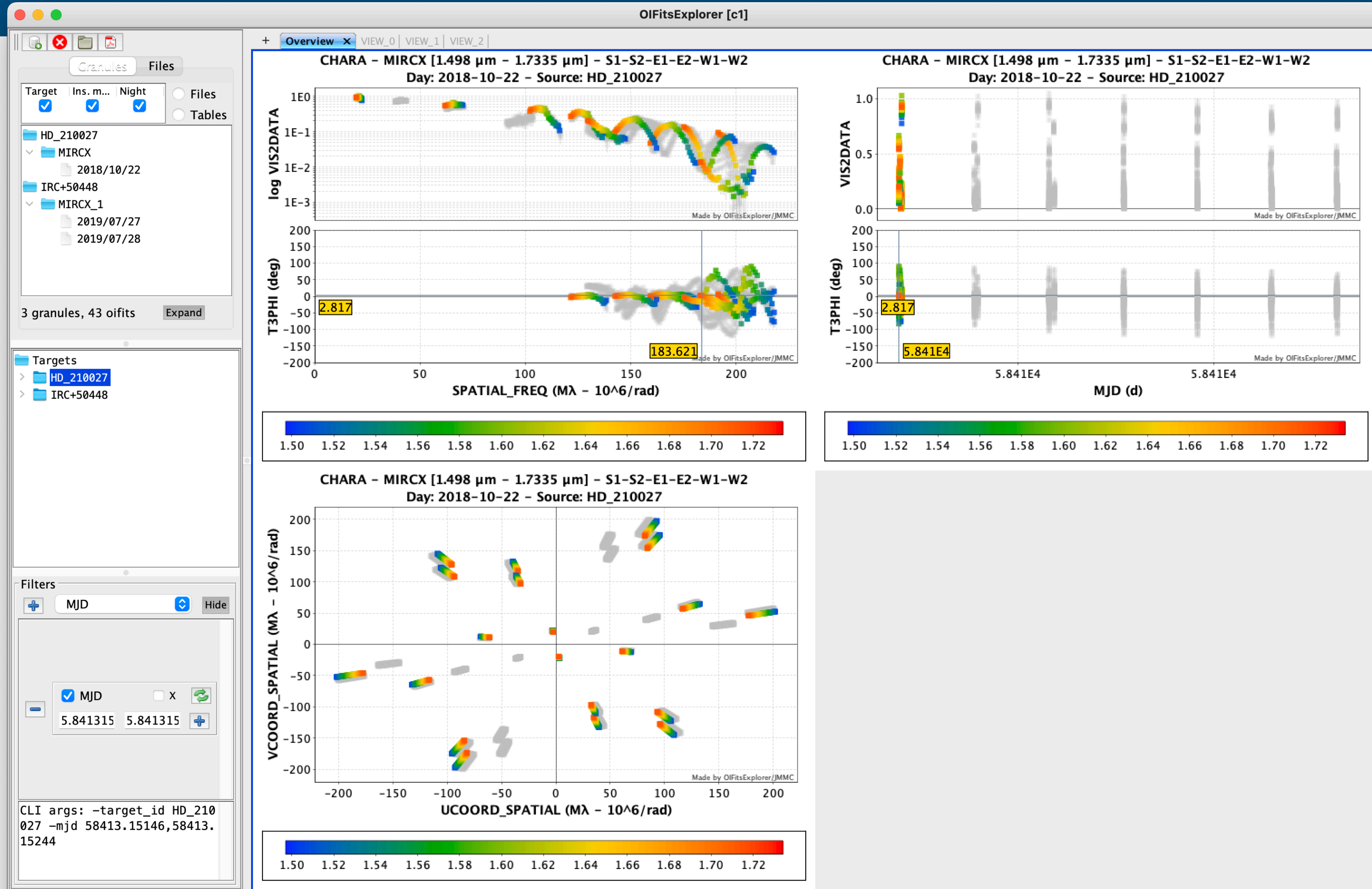


Reconstruct Images

Olmaging

OIFitsExplorer

- inspect
- merge files
- filter



Workflow example: CL Lac

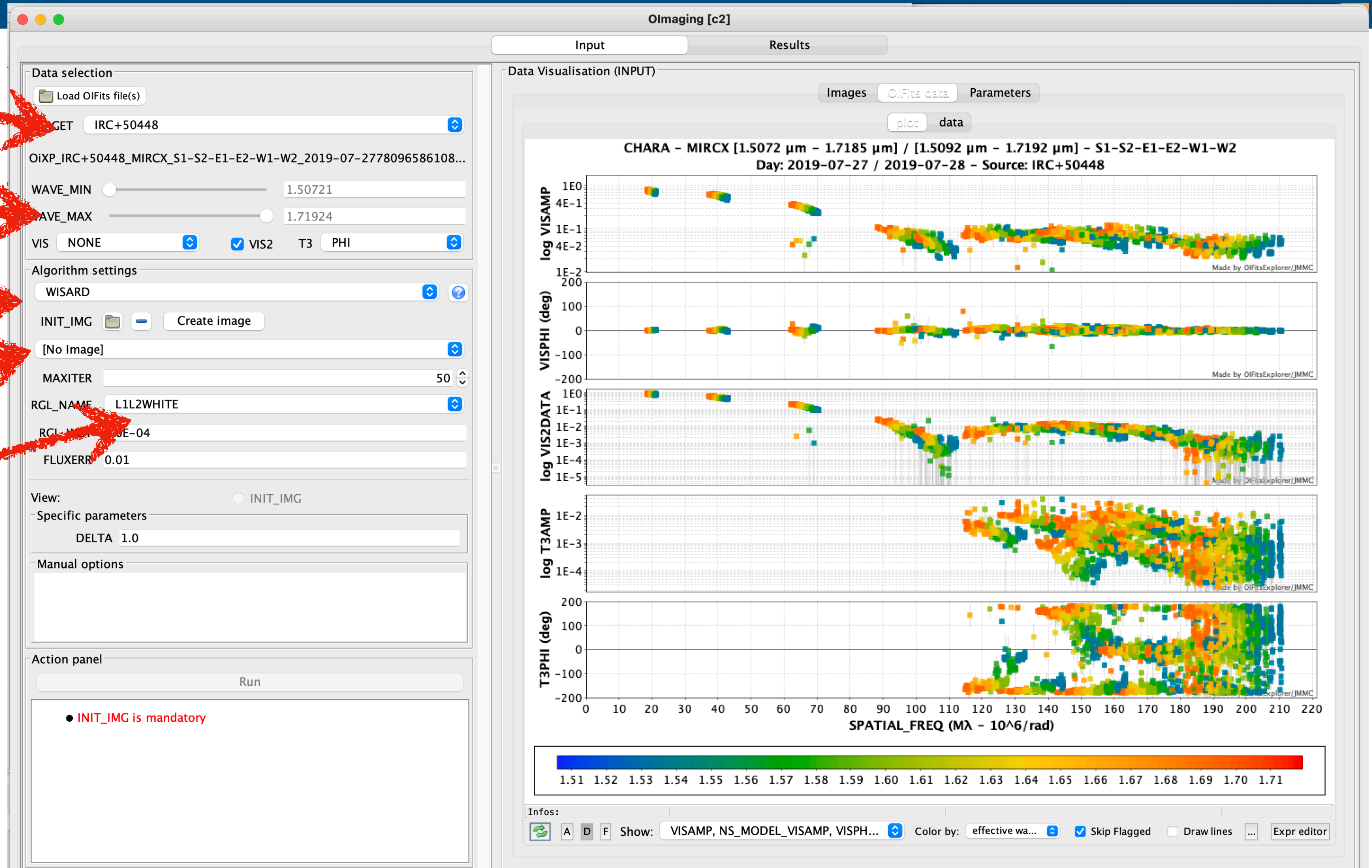
● (single) outfits file

● selection

● algorithm

● initial image

● parameter



Workflow example: initial image

- simple gaussian
- use models
- use LITPro



The screenshot displays the OImaging [c2] software interface, divided into 'Input' and 'Results' tabs. The 'Input' tab is active, showing the following settings:

- Data selection:** TARGET: IRC+50448; OIXP_IRC+50448_MIRCX_S1-S2-E1-E2-W1-W2_2019-07-2778096586108...
- Wave parameters:** WAVE_MIN: 1.50721; WAVE_MAX: 1.71924
- Visualization options:** VIS: NONE; VIS2; T3: PHI
- Algorithm settings:** WISARD; INIT_IMG: [No Image] (with a 'Create image' button); MAXITER: 50; RGL_NAME: L1L2WHITE; RGL_WGT: 1.0E-04; FLUXERR: 0.01
- View:** INIT_IMG (selected)
- Specific parameters:** DELTA: 1.0
- Manual options:** (empty)
- Action panel:** Run button; A message: **INIT_IMG is mandatory**

The 'Results' tab shows 'Data Visualisation (INPUT)' with three plots: VISAMP, PHI (deg), and T3PHI (deg). A 'Create image' dialog box is overlaid on the plots, showing the following parameters:

- FOV (mas): 354.620
- Increments (mas): 0.489 (adjusted to: 0.488)
- Image size: 726
- FWHM (mas): 10.000
- HDU_NAME: untitled

The bottom of the interface shows a color bar for 'effective wa...' ranging from 1.51 to 1.71, and an 'Infos' section with various controls like 'Show: VISAMP, NS_MODEL_VISAMP, VISPH...', 'Color by: effective wa...', 'Skip Flagged', 'Draw lines', and 'Expr editor'.

initial image

● Fit a coarse model using LITpro (eg limb darkened disk)

The screenshot shows the LITpro software interface for fitting a model to data from target IRC+50448. The interface is divided into several panels:

- Settings tree:** Shows a hierarchical view of the project settings, including Files, Targets (with Target [IRC+50448] selected), Shared parameters, Results, and Plots.
- Target panel:** Displays the target name (IRC+50448) and the fitter setup options, including "Normalize total flux" and "Select data to fit" (with VIS2 selected).
- Model list:** A list of available models, including limb_power, flatten_gaussian, flatten_ring, gaussian, gaussian_BB, limb_linear, limb_nonlinear_Claret, limb_power, and limb_quadratic.
- Parameters table:** A table listing the parameters for the selected model (limb_power).

Name	Type	Units	Value	MinValue	MaxValue	Scale	Has
limb_power1.flux_weight1	flux_weight			1	0		
limb_power1.x1	x	mas	0				
limb_power1.y1	y	mas	0				
limb_power1.diameter1	diameter	mas	2.602		0		
limb_power1.power1	power		0.476		0	1	
- Plot model panel:** Contains options for plotting the image, sniffer map, radial profile, and UV map. The radial profile plot is currently selected, showing the VIS2 data and the model fit with a cut angle of 0.00.
- Cuts in the chi2 space panel:** Allows for selecting parameters to plot in the chi2 space. The current selection is for the power1 parameter, with a 2D plot and a reduced chi2 value.
- Personal notebook:** A text area displaying the results of the fit, including the number of evaluations (61), the stopping reason (trust region is too small), and the final values and standard deviations for the fitted parameters:

```
Number of evaluations of the model: 61
Stopping alibi: trust region is too small (less than 1e-6 * norm of parameters)
Final values and standard deviation for fitted parameters:
diameter1 = 2.6021 +/- 0.00416 mas
flux_weight1 = 1 +/- 0.132
power1 = 0.47565 +/- 0.0123
--- Covariance matrix ---
diameter1 flux_weight1 power1
```

initial image

- Fit a coarse model using LITpro (eg limb darkened disk)
- export image to Olmaging

The screenshot displays the LITpro software interface for fitting a model to data from IRC+50448. The interface is divided into several panels:

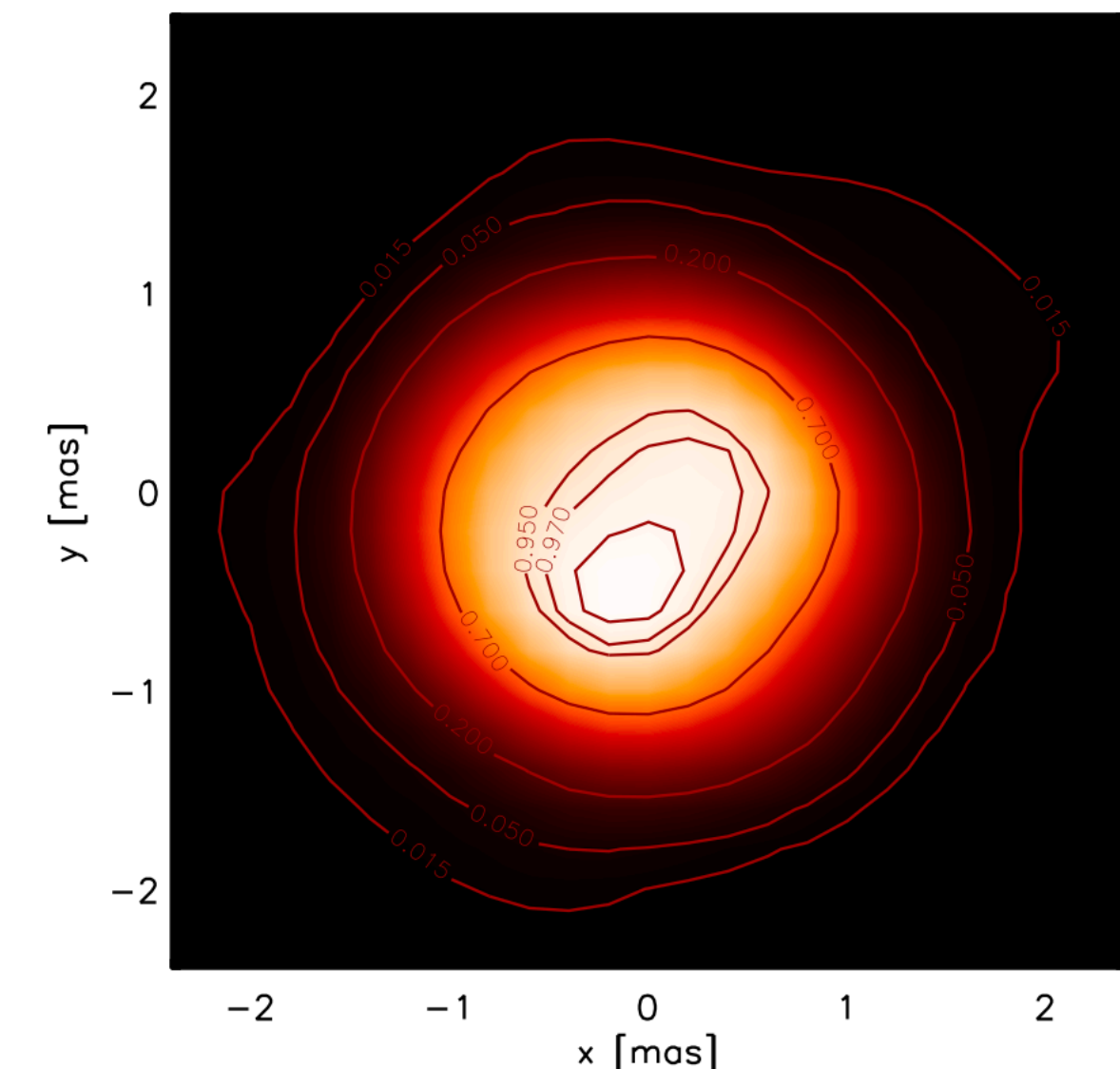
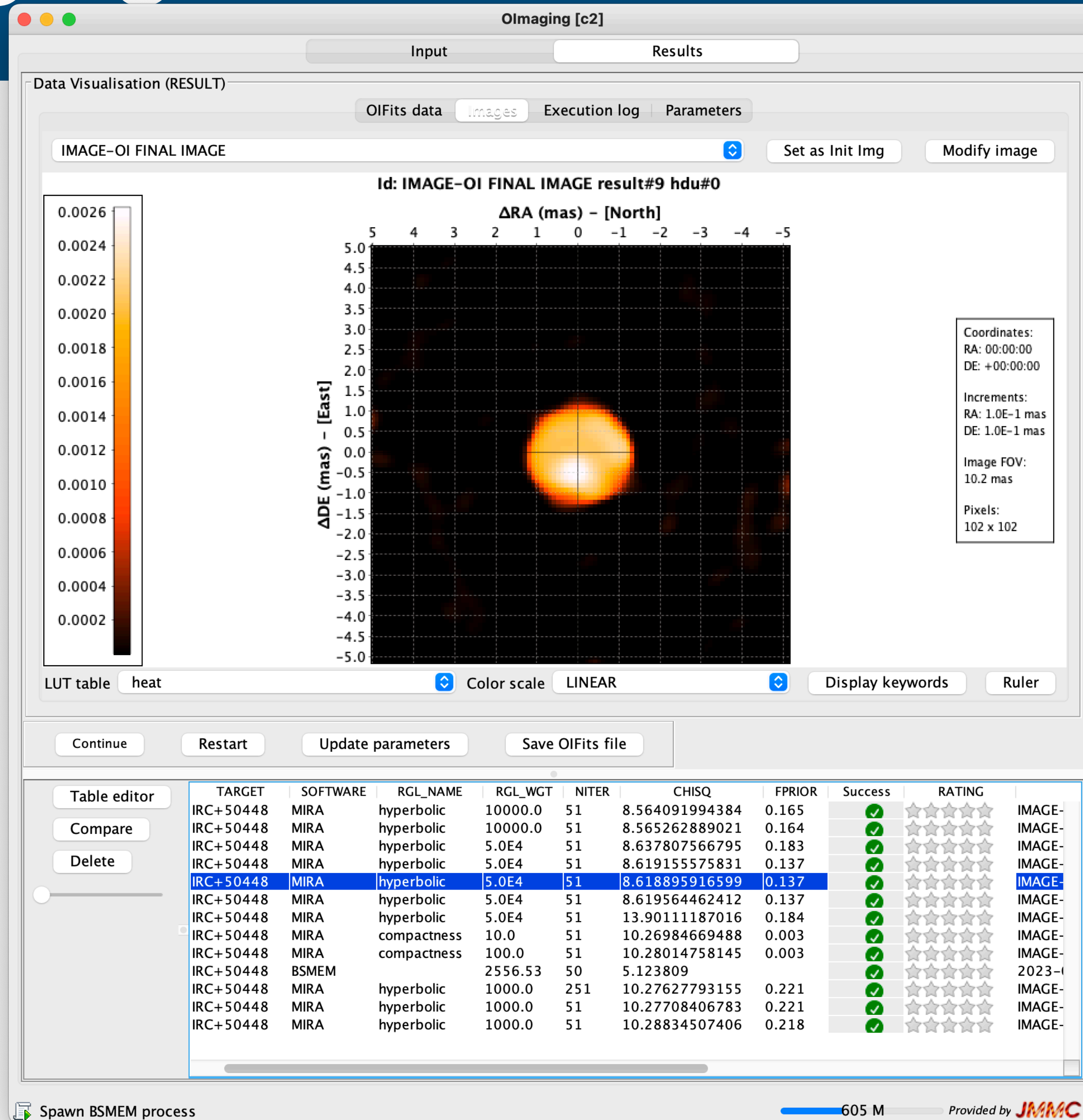
- Settings tree:** Shows the project structure, including 'Settings', 'Files', 'Targets', 'Results', and 'Plots'. The 'Target [IRC+50448]' folder is selected.
- Fitter setup:** Includes a 'Normalize total flux' checkbox and a 'Select data to fit' section with radio buttons for 'VISamp', 'VISphi', 'VIS2' (selected), 'T3amp', and 'T3phi'.
- Model list:** A list of models to fit, including 'limb_power', 'flatten_gaussian', 'flatten_ring', 'gaussian', 'gaussian_BB', 'limb_linear', 'limb_nonlinear_Claret', and 'limb_power'.
- Parameters:** A table listing the parameters for the 'limb_power' model:

Name	Type
limb_power1.flux_weight1	flux_weight
limb_power1.x1	x
limb_power1.y1	y
limb_power1.diameter1	diameter
limb_power1.power1	power
- Plot model panel:** Contains buttons for 'Plot image', 'Plot sniffer map', 'Plot Radial', and 'Plot UV Map'. The 'Plot image' button is active, and the 'pixmap' is set to 0.
- Cuts in the chi2 space panel:** Includes a 'Plot Chi2' section with radio buttons for '1D' and '2D'. The '2D' option is selected, and the 'log' and 'reduced' checkboxes are checked.
- Personal notebook:** A text area showing the current Chi2 value: 'Chi2: initial= 1.695e+05'.

Overlaid on the right is a window titled 'Model Image of IRC+50448'. It displays a 2D intensity map of the star, with a color scale ranging from 0 to 0.00234. The axes are labeled with position angles α (mas, increasing towards East) and δ (mas, increasing towards North). The map shows a central bright spot with a surrounding diffuse ring, characteristic of a limb darkened disk.

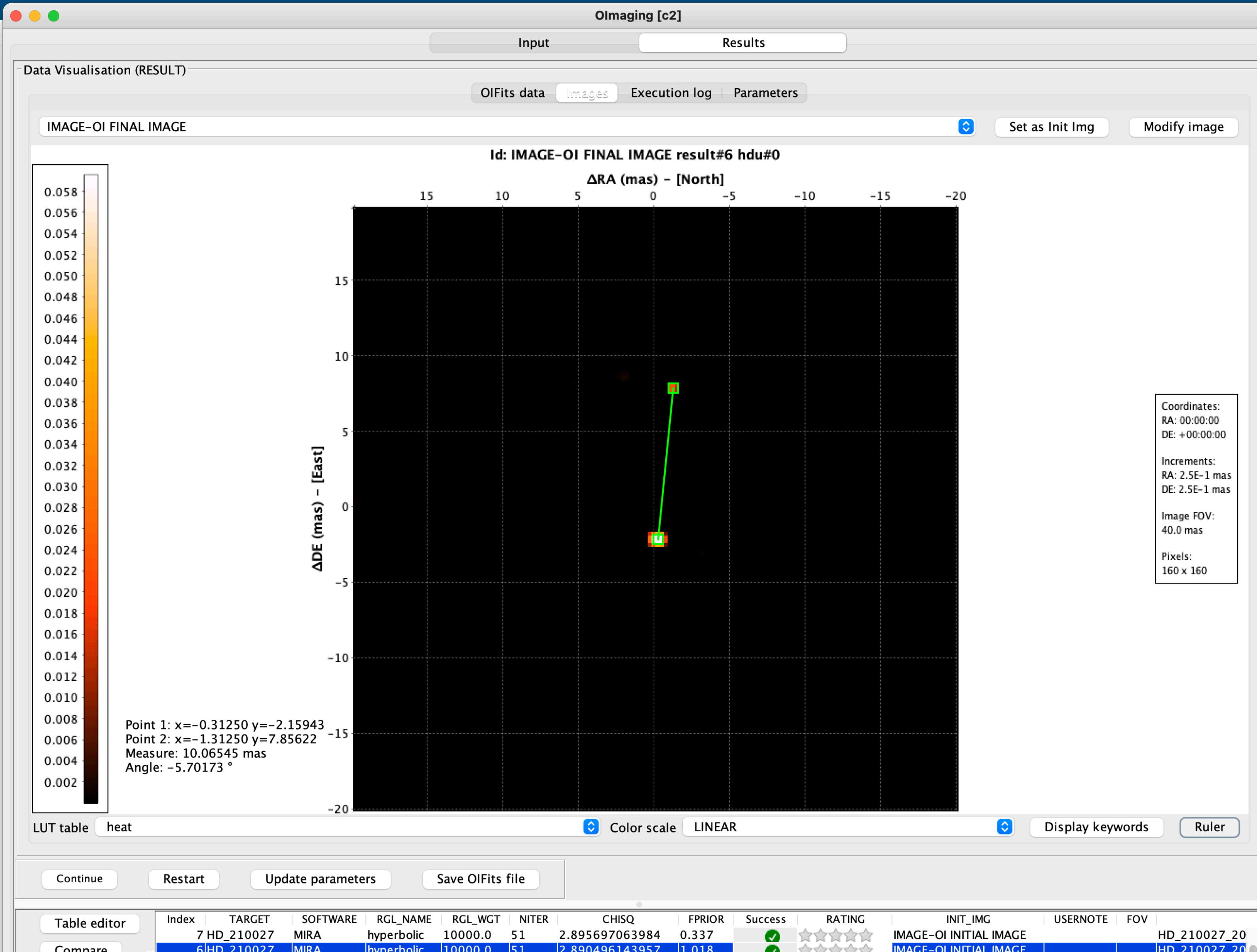
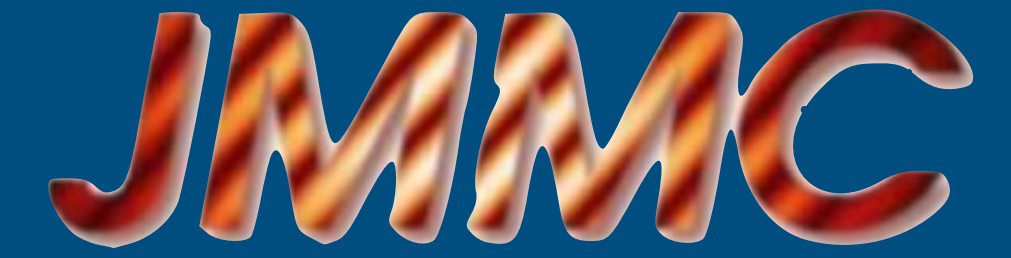
At the bottom of the interface, a status bar indicates 'getModellImage process finished' and '241 M'.

OImaging



Chiavassa et al 2020

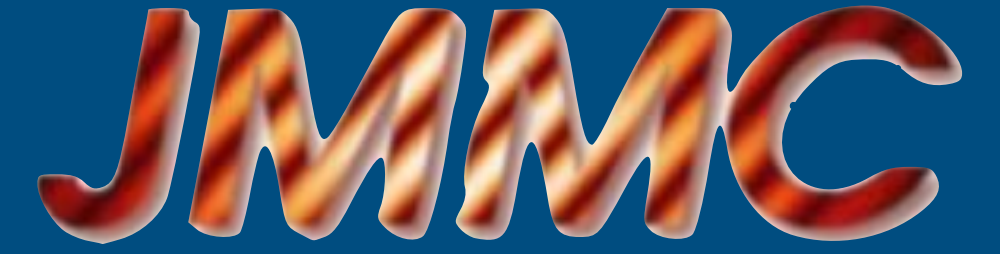
OImaging: preparing model fitting



squeeze + modeling			
UT date	$F_{pri/sec}$	sep, ρ (mas)	pos ang, PA (deg)
2018-10-22	4.55 ± 0.04	10.0352 ± 0.0176	354.7005 ± 0.019

Anugu et al 2020

OImaging: reproducibility enabled



Reconstructed image + data + all parameters in a single OIFits file

The screenshot shows the OImaging software interface with two tabs: 'Input' and 'Results'. The 'Results' tab is active, displaying a table of output parameters. Below the table, there are buttons for 'Continue', 'Restart', 'Update parameters', and 'Save OIFits file'. At the bottom, there is a 'Table editor' section with a table of results.

Keyword Name	Value	Description
EXTNAME	IMAGE-OI OUTPUT PARAM	extension name
NAXIS2	1	number of table rows
EXTVER	1	extension version
LAST_IMG	IMAGE-OI FINAL IMAGE	Identifier of the final image
NITER	51	Total iterations done in the current program run

Keyword Name	Value	Description
EXTNAME	IMAGE-OI INPUT PARAM	extension name
NAXIS2	1	number of table rows
EXTVER	1	extension version
TARGET	sig Ori	Identifier of the target object to reconstruct
WAVE_MIN	1.493695663157E-6	Minimum wavelength to select (in meters)
WAVE_MAX	1.737057914397E-6	Maximum wavelength to select (in meters)
USE_VIS	NONE	Use complex visibility data if any
USE_VIS2	true	Use squared visibility data if any
USE_T3	ALL	Use triple product data if any
INIT_IMG	IMAGE-OI INITIAL IMAGE	Identifier of the initial image
MAXITER	50	Maximum number of iterations to run
RGL_NAME	hyperbolic	Name of the regularization method
RGL_WGT	500.0	Weight of the regularization
AUTO_WGT	true	Automatic regularization weight
FLUX	1.0	Total flux (sum of pixels)
FLUXERR	0.0	Assumed standard deviation for the total flux
RGL_PRIOR		Identifier of the HDU with the prior image
RECENTER	T	Recenter starting images
REPEAT	2	Number of algorithm repetitions
XFORM	nfft	Image to complex visibility transform
SMEAR_FN	none	Smearing function
SMEAR_FC	1.0	Smearing factor
RGL_TAU	0.0001	Spatial gradient threshold
PXL_MIN	0.0	Minimum allowed pixel value

Index	TARGET	SOFTWARE	RGL_NAME	RGL_WGT	NITER	CHISQ	FPRIOR	Success	RATING	INIT_IMG	USERNOTE	FOV
18	sig Ori	MIRA	hyperbolic	500.0	51	0.6251376842437	0.688	✓	☆☆☆☆☆	IMAGE-OI INITIAL IMAGE		sig_Ori_2023-03-1
17	sig Ori	MIRA	hyperbolic	500.0	51	0.6730478218627	0.674	✓	☆☆☆☆☆	IMAGE-OI INITIAL IMAGE		sig_Ori_2023-03-1
16	sig Ori	MIRA	hyperbolic	500.0	51	0.7945341096828	0.677	✓	☆☆☆☆☆	IMAGE-OI INITIAL IMAGE		sig_Ori_2023-03-1

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) v

Type: Support Needed v

Your Email * : your@email *

Summary * :

Comments * :

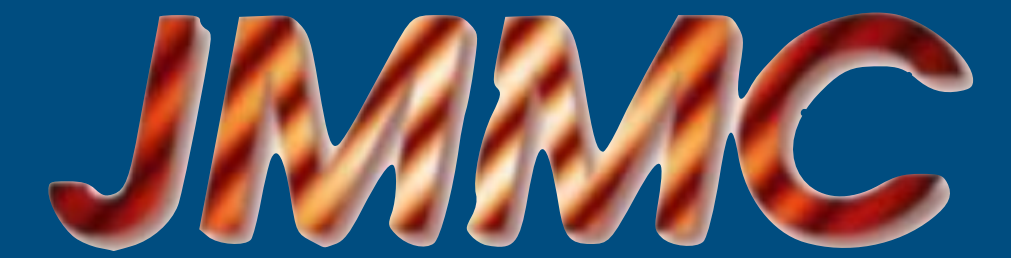
Version: Optional V.

Effacer

Envoyer

© + video tutorial on JMMC website

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

OImaging: preparing model fitting

