LITpro

Lyon's Interferometric Tool prototype

a model fitting software

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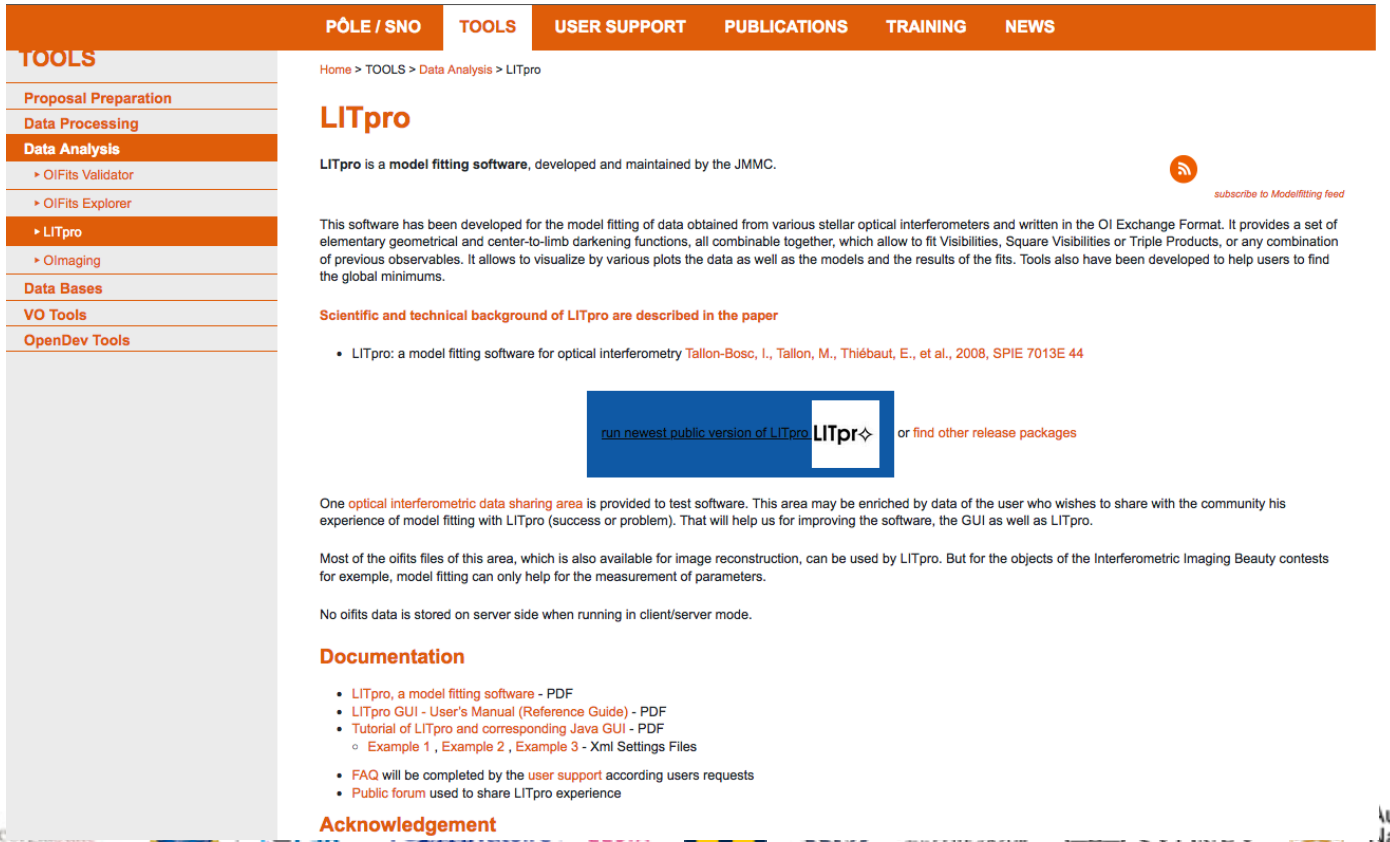
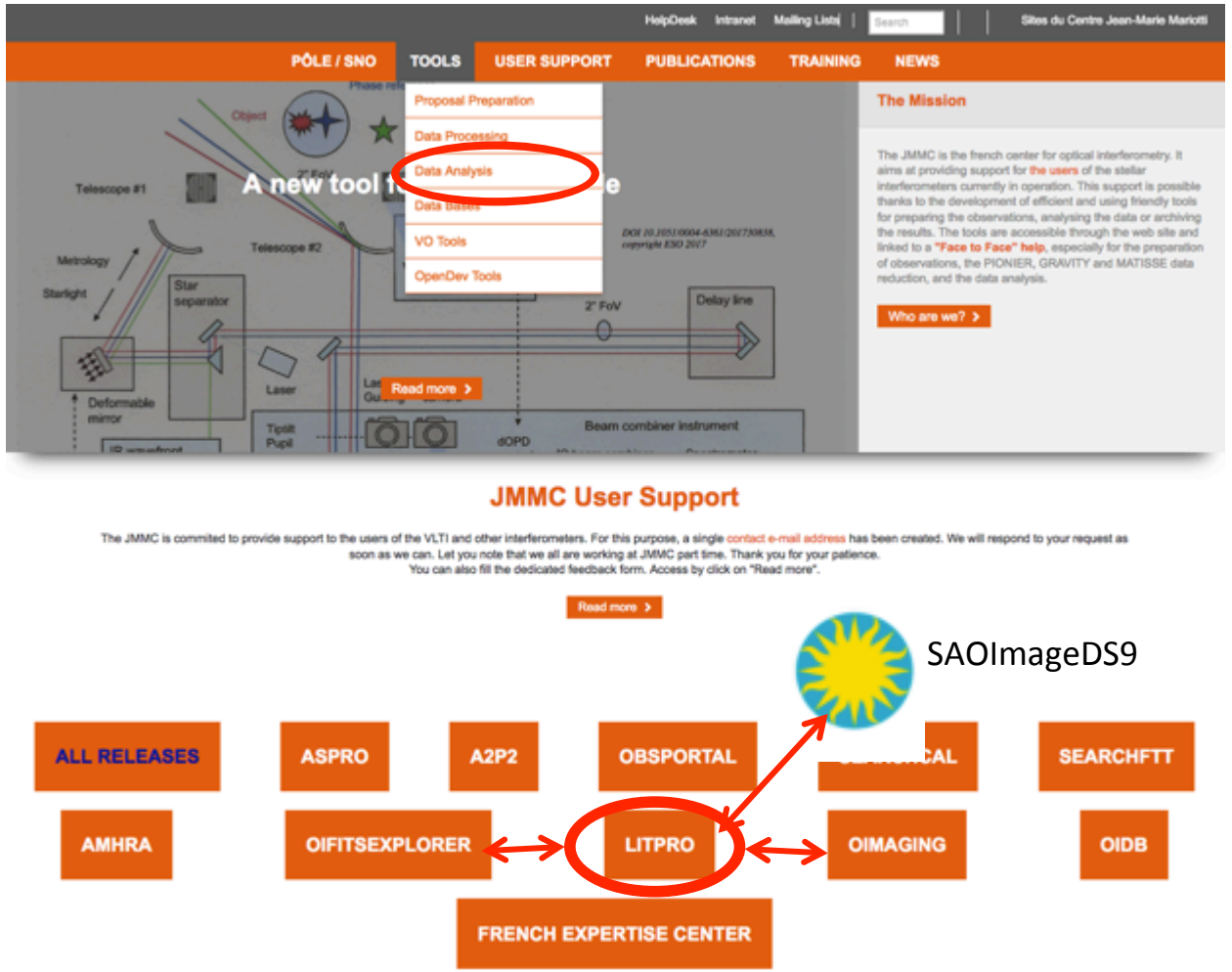
Ferréol Soulez, Laurent Bourgès, Hervé Beust,



LITpro assets

- accessible via a graphical User Interface
  - easy to use
- documented
- integrated into "JMMC"
  - interoperable with other tools



Model fitting: an adventure

with LITpro

Successive steps − in general -:

- observe your data
- build a model
- explore the "chi2 space"
- fit
- analyse the results carefully

- also with OIFitsExplorer
- create a setting = data +model
- to fix the initial guess of the fit
- Levenberg-Marquardt algorithm (modified)
  - Combined with a Trust Region method
  - Bounds on the parameters
  - Partial derivatives of the model by finite differences
- reduced chi2, sig_chi2, correlation matrix, plots

run newest public version of LITpro LITpro or find other release packages

https://releases.jmmc.fr/index.html

How to use LITpro

- some demos
  - a UD /LB disk *CL Lac*
    - basic functionalities
    - helpful plots: chi2_slice, image, uvmap
    - advices: fill a notebook, save setting regularly
  - a circumstellar disk *gam Cas*
    - data files loaded from OIFITsExplorer
- practice together on a binary

lpb_punct() - Single point (Dirac function)
lpb_background() - Background
lpb_disk() - Uniform disk with normalized total flux
lpb_disk_polar() - Uniform disk with normalized total flux
lpb_nonorm_disk() - Not normalized uniform disk
lpb_circle() - Circle
lpb_gaussian() - Gaussian
lpb_ring() - Uniform ring
lpb_gaussian_ring() - Gaussian ring
lpb_square() - Uniform square
lpb_modulated_circle() - Circle modulated with 1+cos
lpb_elong_disk() - Ellipse (elongated disk)
lpb_nonorm_elong_disk() - Not normalized ellipse (elongated disk)
lpb_elong_gaussian() - Elongated Gaussian
lpb_elong_ring() - Elongated ring
lpb_elong_limb_power() - Ellipse (elongated disk)
lpb_flatten_disk() - Ellipse (flattened disk)
lpb_nonorm_flatten_disk() - Not normalized Ellipse (flattened disk)
lpb_flatten_gaussian() - Flattened Gaussian
lpb_flatten_ring() - Flattened ring
lpb_stretched_disk() - Stretched Gaussian
lpb_stretched_gaussian() - Stretched Gaussian
lpb_limb_power() - Limb-darkened disk with power law
lpb_limb_linear() - Limb-darkened disk with linear law
lpb_limb_quadratic() - Limb-darkened disk with quadratic law
lpb_limb_sqrt() - Limb-darkened disk with square root law
lpb_limb_nonlinear_Claret() - Limb-darkened disk with the new non-linear law of Claret (2000)
lpb_blackbody() - Weight with relative flux of black-body
lpb_background_BB() - Background with black-body emission
lpb_punct_BB() - Single point (Dirac function) with black body emission
lpb_disk_BB() - Uniform disk with black body emission
lpb_elong_disk_BB() - Elongated disk with black body emission
lpb_stretched_disk_BB() - Stretched disk with black body emission
lpb_gaussian_BB() - Uniform disk with black body emission
lpb_stretched_gaussian_BB() - Stretched Gaussian with blackbody

lpb_stretched_gauss_bspline1_ring2() - Stretched gaussian ring modulated by cubic B-splines
lpb_stretched_gauss_bspline1_ring4() - Stretched gaussian ring modulated by cubic B-splines
lpb_stretched_gauss_bspline1_ring8() - Stretched gaussian ring modulated by cubic B-splines
lpb_stretched_gauss_bspline1_ring16() - Stretched gaussian ring modulated by cubic B-splines
lpb_stretched_gauss_bspline1_ring32() - Stretched gaussian ring modulated by cubic B-splines
lpb_stretched_gauss_bspline3_ring2() - Stretched gaussian ring modulated by 8 cubic B-splines
lpb_stretched_gauss_bspline3_ring4() - Stretched gaussian ring modulated by 8 cubic B-splines
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lpb_stretched_gauss_bspline3_ring16() - Stretched gaussian ring modulated by 16 cubic B-splines
lpb_stretched_gauss_bspline3_ring32() - Stretched gaussian ring modulated by 32 cubic B-splines
lpb_stretched_gaussian_ring() - Stretched Gaussian Ring
lpb_stretched_modulated_circle() - Stretched circle modulated by 1+cos
lpb_stretched_modulated_gaussian_ring() - Stretched modulated gaussian ring

disk functions

A large library of models, built from requests

for ex.: stretched_gauss_bspline3_ring32

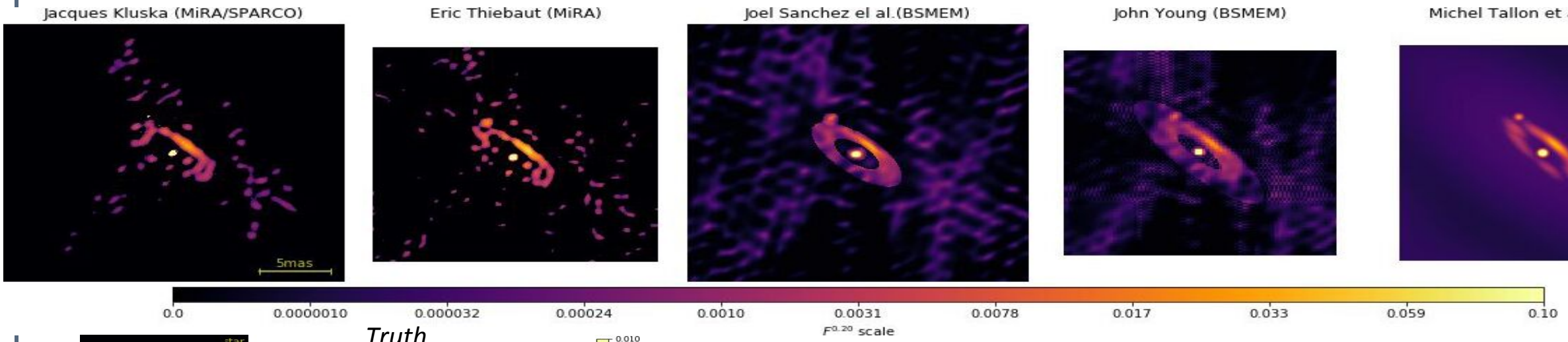
- azimuthal variation of intensity
  - linear combination of 32 cubic B-splines

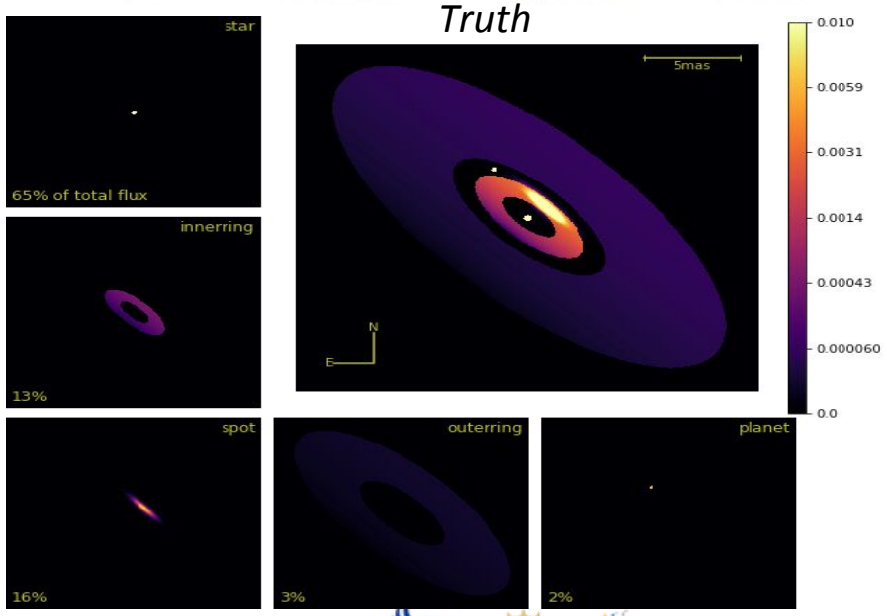
+ radial gaussian profil

+ anamorphosis (orientation & amplitudes variable)

- exact in the uv plane
  - the image is calculated from the expressions in the Fourier plane

Image Reconstruction Contest, SPIE 2018





Mérand et al. 2018

Model fitting & Image Reconstruction: complementarity

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black-body functions

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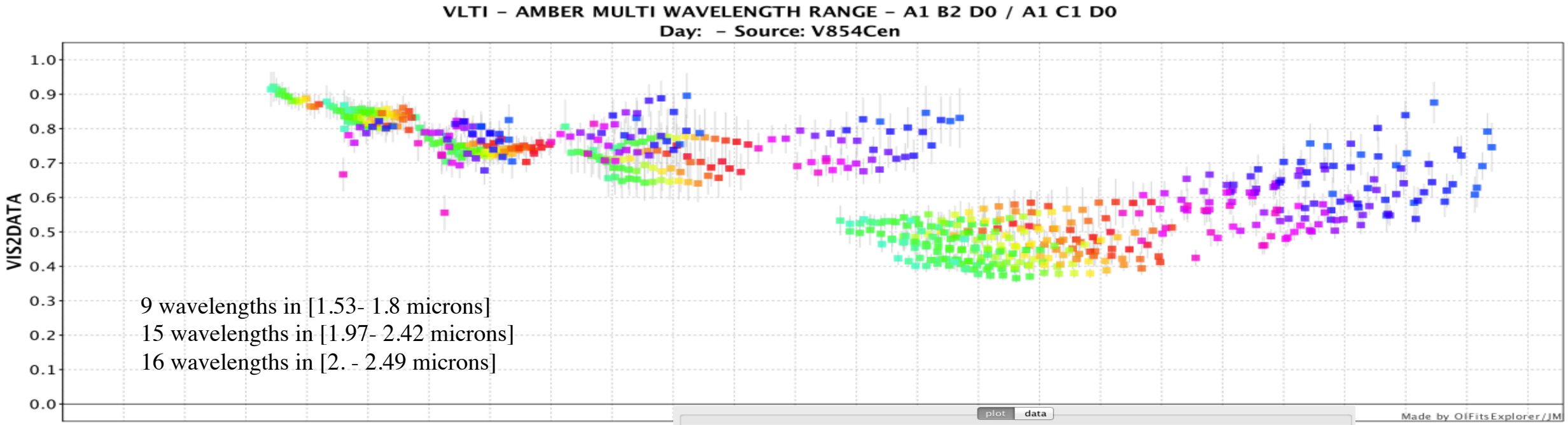
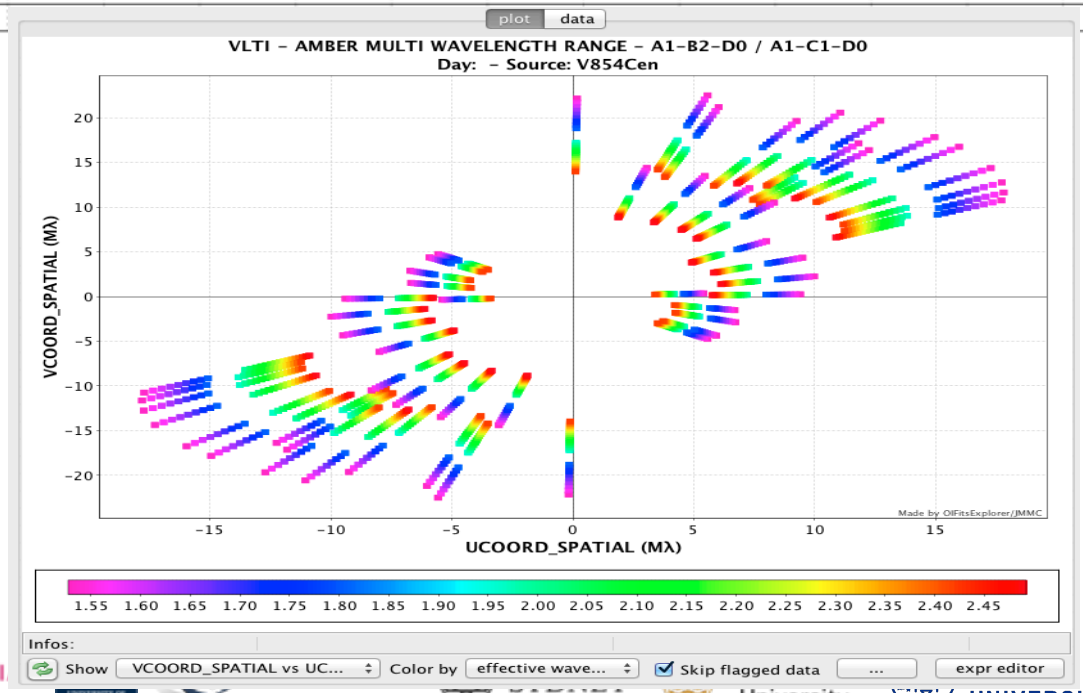
elementary functions affected by a Planck function



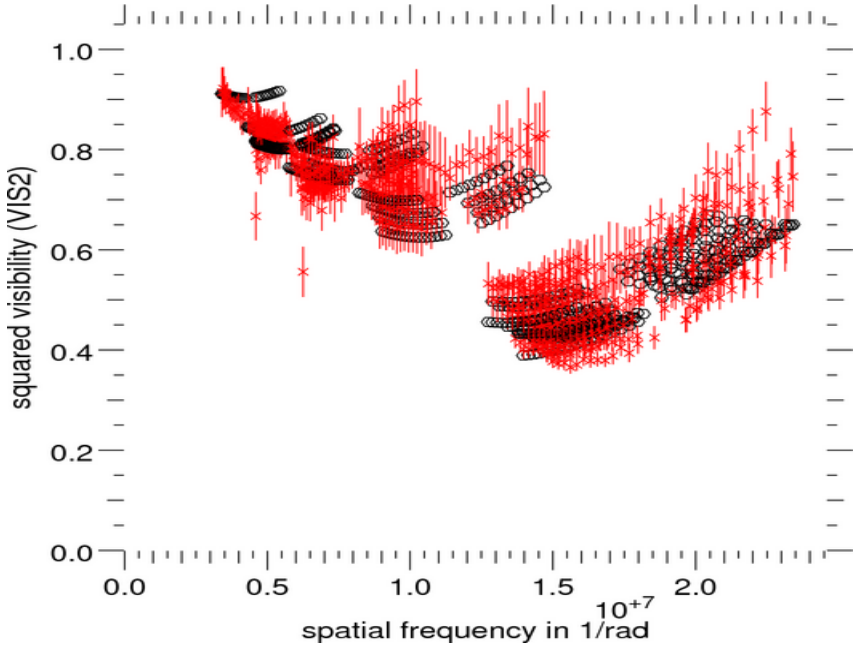
"Commas" in VIS2 are a chromatic artifact



V853 Cen: a star with circumstellar environment

VIS2 & T3phi with central punct_BB (T_1=6750 fixed) & stretched_gaussian_BB

reduced Chi2 final= 2.128
fwhm2 = 10.814 +/- 0.192 mas
flux_weight1 = 325.89 +/- 16.4 punct
flux_weight2 = 31.273 +/- 1.86 shell
stretch_pos_angle2 = **35.785** +/- 1.16 degree
stretch_ratio2 = **0.72**009 +/- 0.0119
temperature2 = 1606.2 +/- 35.6 Kelvin



Compatibility with the published results

Chesneau O., Millour F. et al., A&A 569, L4 (2014)

Extracted from the paper : "Our best-match model for the compact array is a two-component model, consisting of an unresolved uniform disk ($\Theta \leq 2.5$ mas, star component), and a flattened Gaussian (shell component) with a FWHM of the minor axis of 8 ± 1 mas, and a major axis of 11 ± 3 mas.

The orientation of the major axis is 126 ± 29°. The quality of the fit is relatively good with a reduced $\chi 2$ of 1.5."

➔ *stretch_ratio = **0.72*** & *orientation of the major axis =126-90 = **36 deg**.*

To compare with the published results

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➔ *stretch_ratio =* ***0.72*** *& orientation of the major axis =126-90 =* ***36 deg.***

Fit VIS2 & T3phi with central punct_BB (T_1=6750 fixed) & stretched_gaussian_BB

reduced Chi2 final= 2.128
fwhm2 = 10.814 +/- 0.192 mas
flux_weight1 = 325.89 +/- 16.4 punct
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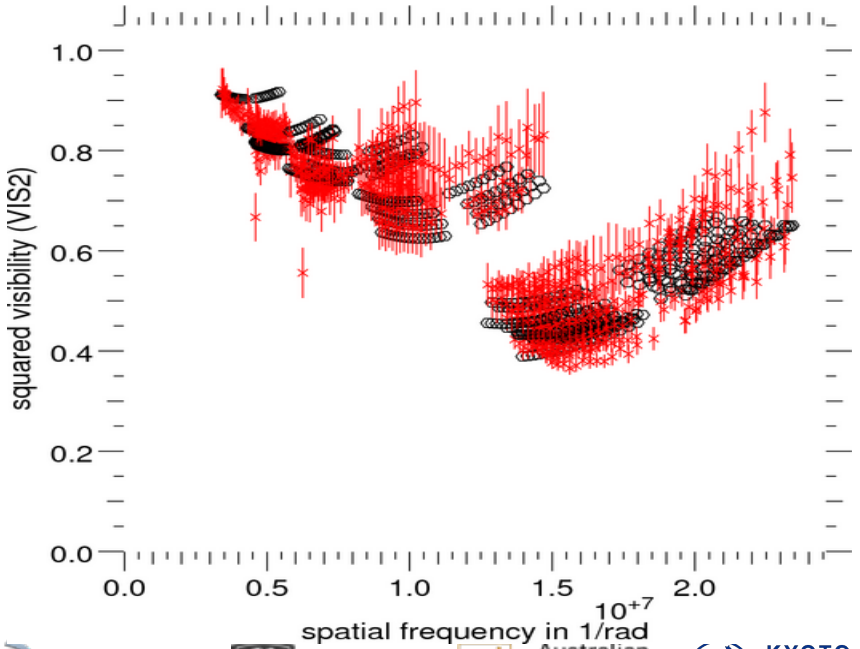
stretch_pos_angle2 = **35.785** +/- 1.16 degree
stretch_ratio2 = **0.72**009 +/- 0.0119
temperature2 = 1606.2 +/- 35.6 Kelvin

see the help of the function streched_gaussian_BB for a better knowledge of the parameters



Compatibility (except for chi2 value)

How to use LITpro

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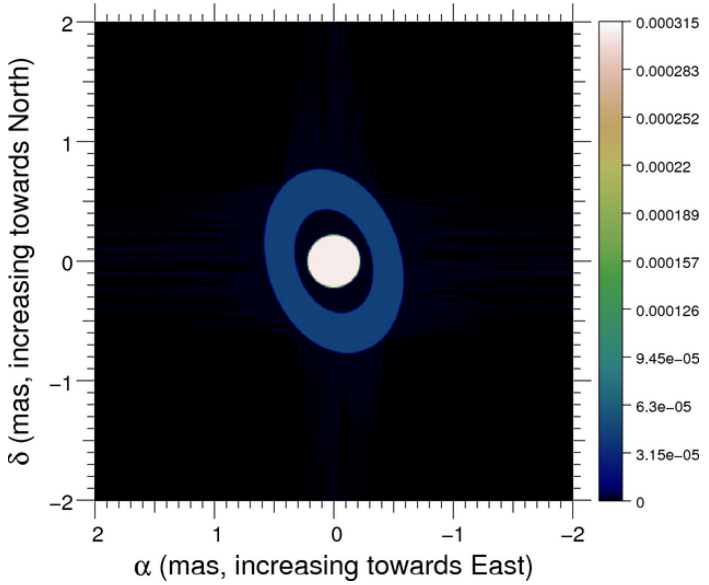
  - a UD /LB disk *CL Lac*
    - basic functionalities
    - helpful plots: chi2_slice, image, uvmap
    - advices: fill a notebook, save setting regularly
  - a circumstellar disk *gam Cas*
    - open a new setting
    - data files loaded from OIFITsExplorer
- practice together on a binary

How to use LITpro

a circumstellar disk (H band) gam Cas



comparable to the paper but...

Stee et al. (2012)

reduced Chi2: final= 6.803 - sigma= 0.0454311
Number of degrees of freedom = 969
Number of iterations: 15 (max number= 200)
Number of evaluations of the model: 164
Final values and standard deviation for fitted parameters:
flatten_ratio3 = 1.4076 +/- 0.0322
flux_weight1 = 0.46723 +/- 0.133
flux_weight2 = 0.12415 +/- 0.0137
flux_weight3 = 0.40861 +/- 0.138
major_internal_diameter3 = 0.89034 +/- 1.18 mas
minor_axis_pos_angle3 = 107.57 +/- 1.01 degrees
width3 = 0.3409 +/- 0.792 mas

reduced chi2 ~ 4
flatten_ratio3 = 1.39 ± 0.08
minor_axis_pos_angle3 = 102 ± 9 (adding 90°)
width3 = 0.25 ± 0.26
flux_weight1 =?
flux_weight2 = 0.14 ± 0.01
flux_weight3 = 0.41 ± 0.06

How to use LITpro

- some demos
  - a UD /LB disk *CL Lac*
    - basic functionalities
    - helpful plots: chi2_slice, image, uvmap
    - advices: fill a notebook, save setting regularly
  - a circumstellar disk *gam Cas*
    - open a new setting
    - data files loaded from OIFITsExplorer
    - model to improve
- practice together on a binary

- binary: V1334 cepheid and its companion

v1334_Cyg_2012Jul27.oifits

Galenne et al. 2013

- disk

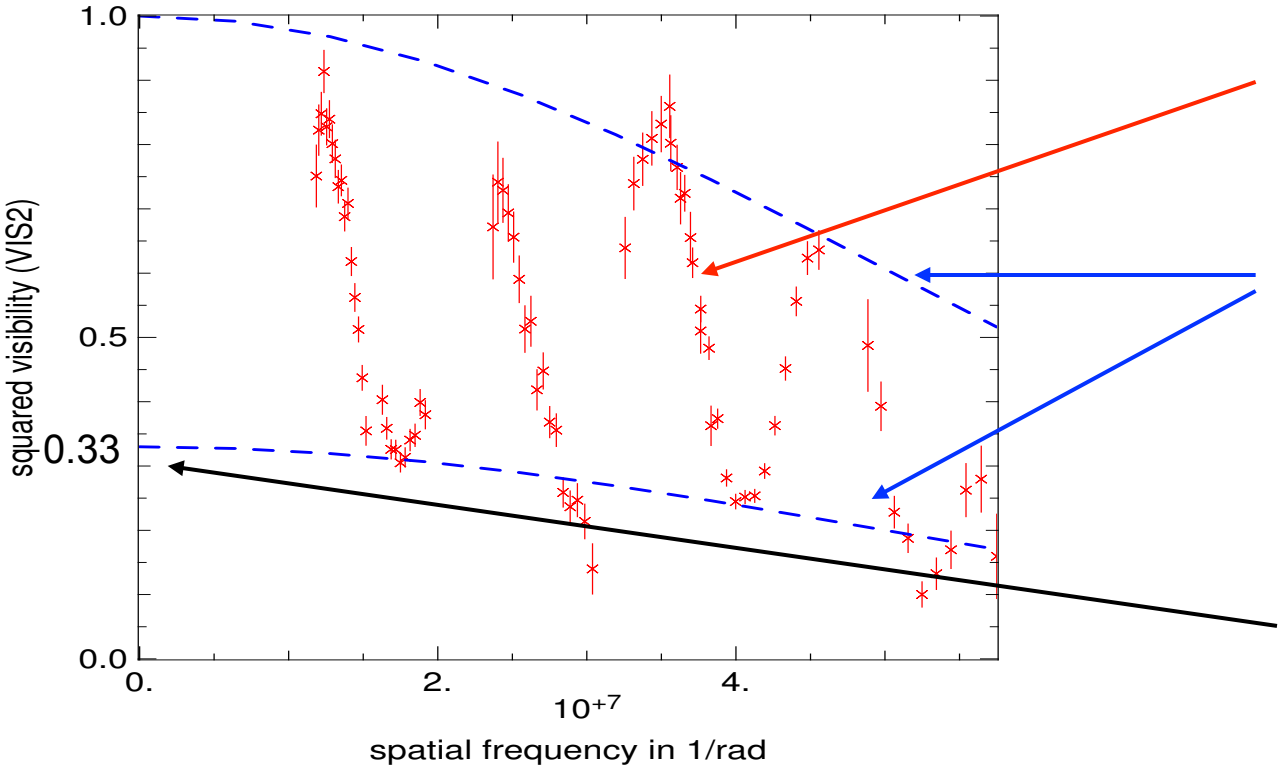
- then disk+punct

- flux ratio estimable without any fit

- Plot Chi2 **"with fit"**

warning / time calculation

extract from VLTI School 2021



$$V^2_{\min} = 0.33 \Rightarrow r = 0.27$$

Modulation = binary (or >2 components)

Attenuation = components resolved

{ binary convolved by an extended function

⇩

Fourier transform multiplied by a window

Minimum of modulation gives intensity ratio of the components:

$$r = \frac{1 - \sqrt{V^2_{\min}}}{1 + \sqrt{V^2_{\min}}}$$

here V^2_{min} ~ 0.9 → r ~ 0.026

reduced Chi2: initial= 0.5026 - final= 0.4203 - sigma= 0.0922531
Number of degrees of freedom = 235

Number of iterations: 6 (max number= 200)
Number of evaluations of the model: 77

Final values and standard deviation for fitted parameters:
diameter1 = 0.51481 +/- 0.0167 mas
flux_weight1 = 0.96973 +/- 0.0626
flux_weight2 = 0.030268 +/- 0.00243
x2 = -1.1525 +/- 0.0299 mas
y2 = -8.8381 +/- 0.0168 mas

comparable

Galenne et al. 2013

Table 4. Summary of the parameters estimated from the model fit.

	2012-07-27	2012-10-01
Single star model		
θ_{UD} (mas)	0.565 ± 0.052	0.487 ± 0.045
θ_{LD} (mas)	0.575 ± 0.052	0.496 ± 0.045
χ^2_r	1.63	2.08
Binary model		
θ_{UD} (mas)	0.494 ± 0.053	0.436 ± 0.045
θ_{LD} (mas)	0.503 ± 0.053	0.444 ± 0.045
f (%)	3.15 ± 0.15	3.08 ± 0.09
$\Delta\alpha$ (mas)	-1.153 ± 0.030	-0.113 ± 0.014
$\Delta\delta$ (mas)	-8.836 ± 0.017	-8.359 ± 0.009
χ^2_r	0.34	1.24

How to use LITpro

- practice yourself

and enjoy!

we are not far