EUROPEAN ASTRONOMICAL SOCIETY

ANNUAL MEETING

UNIVERSITY COLLEGE CORK, IRELAND

23 - 27 JUNE

eas 2025 Cork

LS7: Observing with VLTI, it is easier than you think!

Speakers: Farin Drewes (Southampton U., UK) - Evgenia Koumpia (ESO, CL) - Emma Bordier (Cologne U., DE) - James Leftley (Southampton U., UK) - Jens Kammerer (ESO, DE)

Organisers: Antoine Mérand (ESO) - Rebeca Garcia-Lopez (University College Dublin) - Claire Lykou (Konkoly Observatory)

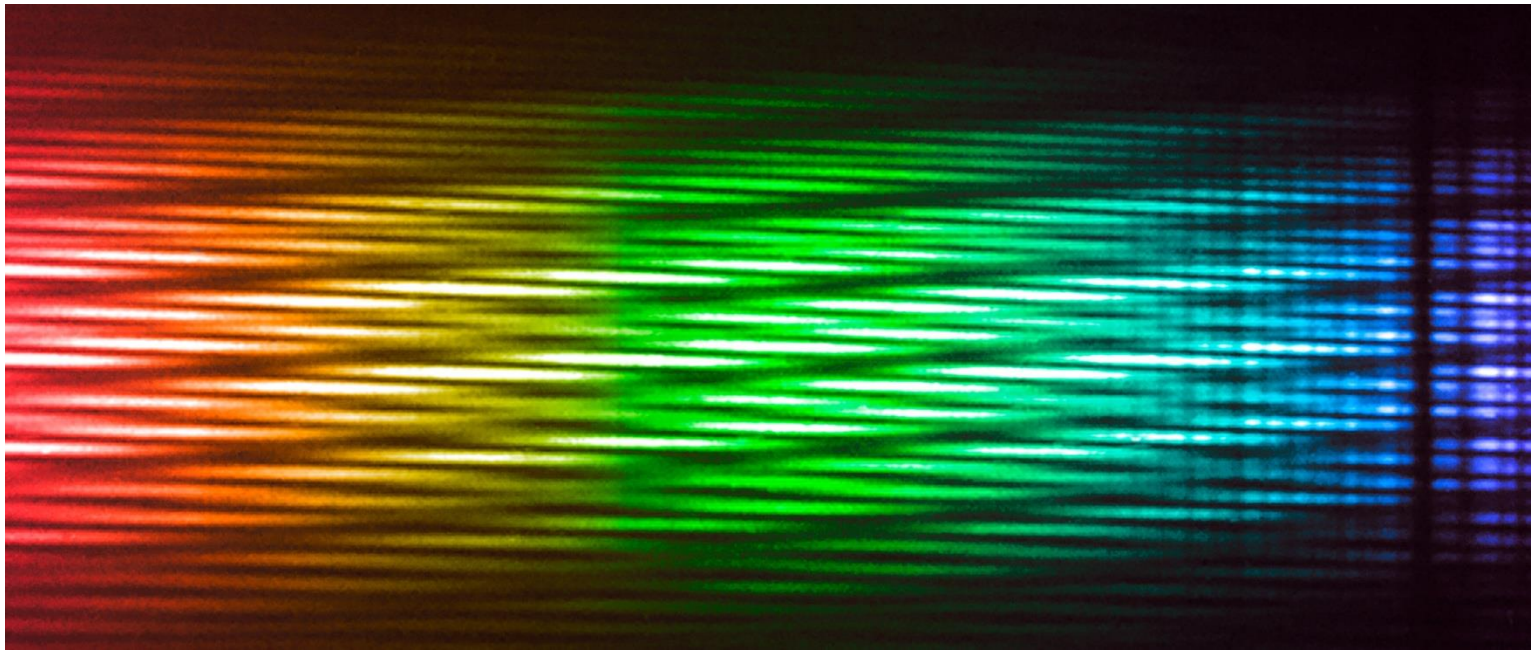
Find me on github!

An introduction to VLTI

Farin Drewes (he/they)

What is Optical Interferometry?

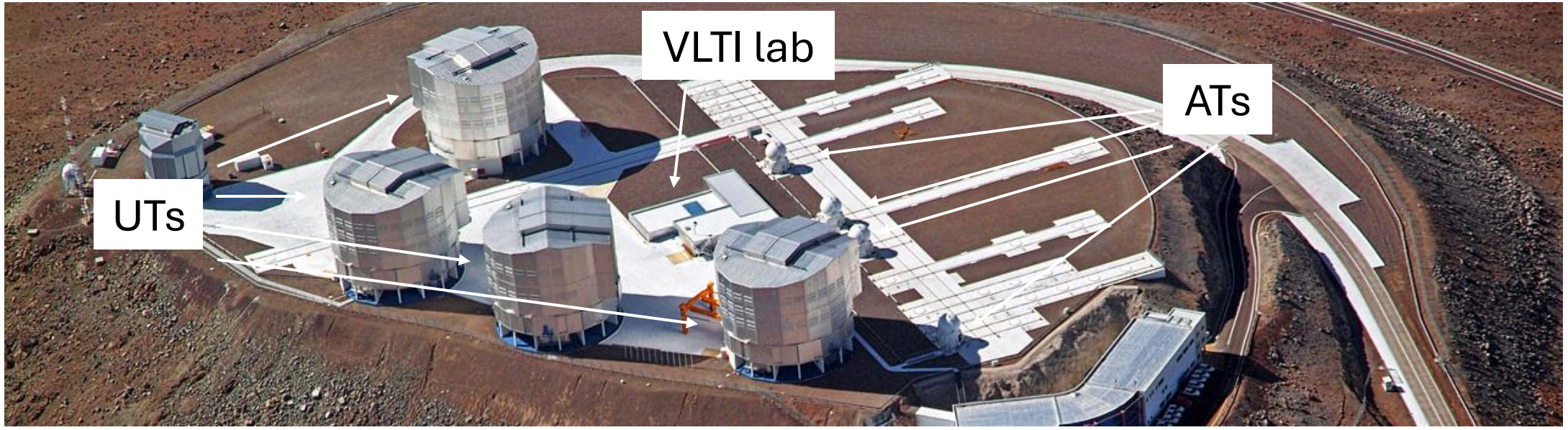
- Interference of light from several telescopes to obtain extremely high angular resolution data



MATISSE first fringes; ESO/MATISSE Consortium

What is the VLTI?

- Very Large Telescope Interferometer – interferometry infrastructure at the VLT
- Can combine either 4 ATs (1.8 m) or 4 UTs (8.2 m)

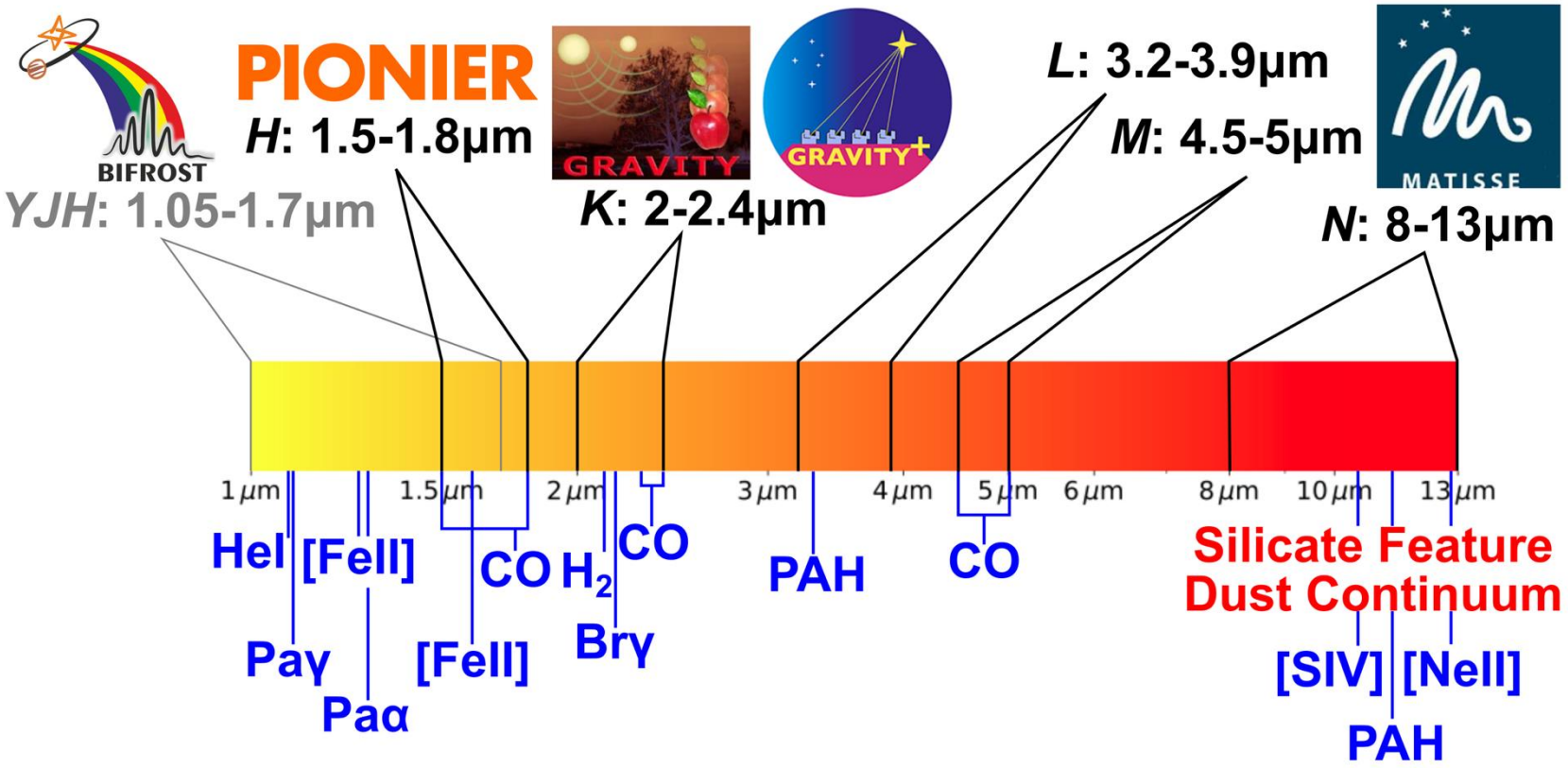


Credit: J.L. Dauvergne & G. Hüdepohl/ESO

Why use the VLTI?

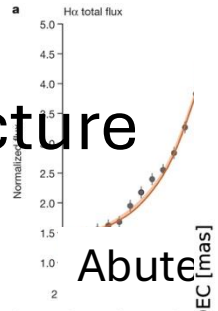
- Study source morphologies and geometries inaccessible with any other technique!
- *Nominal* resolution limits (λ/B)*
  - ATs: *H* – 1.7 mas; *K* – 2.3 mas; *L* – 3.5 mas; *N* – 8.3 – 13 mas
  - UTs: *H* – 2.5 mas; *K* – 3.5 mas; *L* – 5.4 mas; *N* – 13 – 20 mas
- Large wavelength range: 1.5 – 13 µm
  - Probe temperature/chemical radial profiles
- High sensitivity (better than it used to be, especially from 2026)*
  - *H*: 6 – 9 mag; *K*: 8 – 18 mag; *L*: 0.01 – 1 Jy; *N*: 0.1 – 17 Jy
- Simple data analysis – really!

VLTI Instruments Wavelength Coverage



Some VLTI Science until now...

Internal AGN Structure



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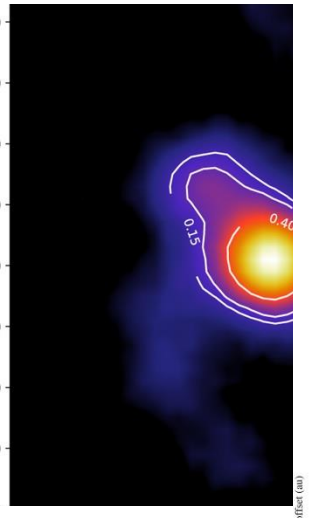
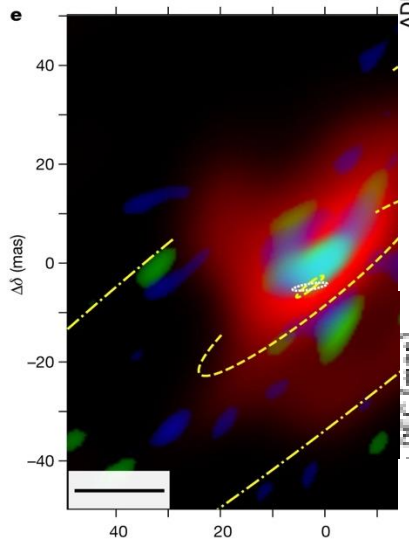
Stellar Surfaces and Environments



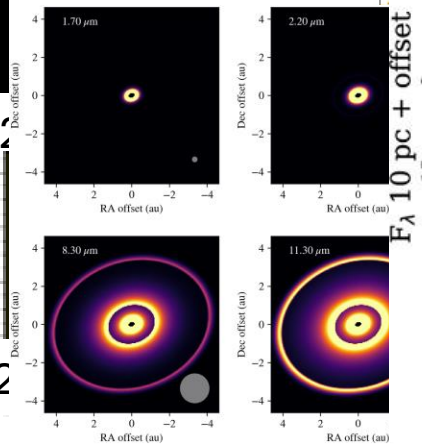
Planquart et al. 2

YSOs and Disks

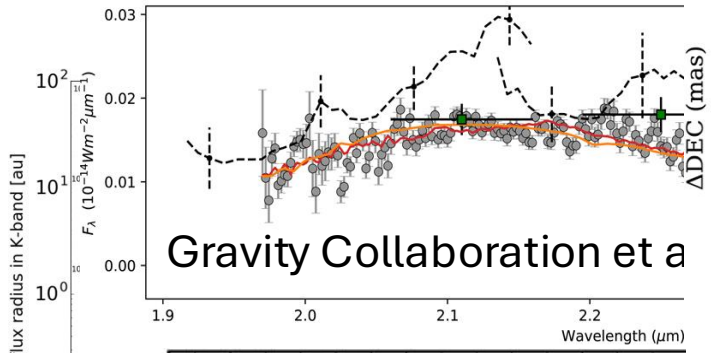


Gámez Rosas et al. 2022

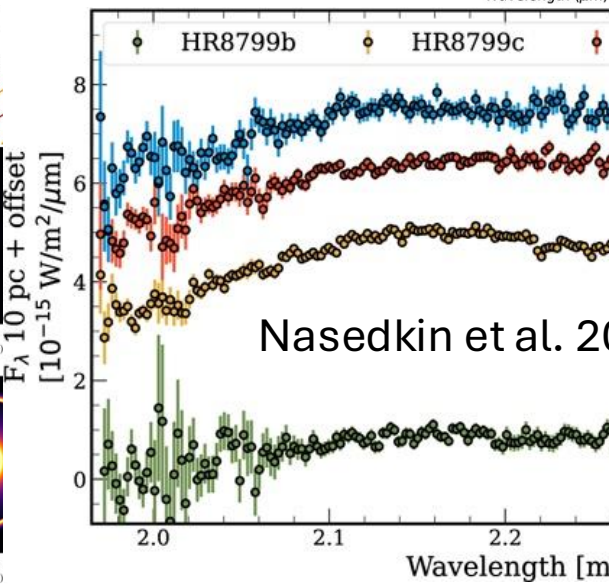
Drevon et al. 202



Exoplanets

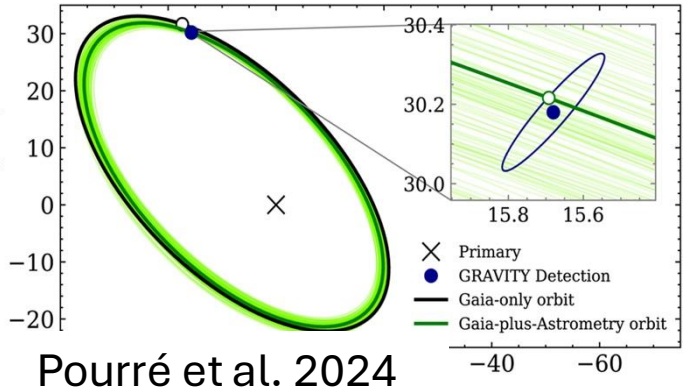


Gravity Collaboration et a

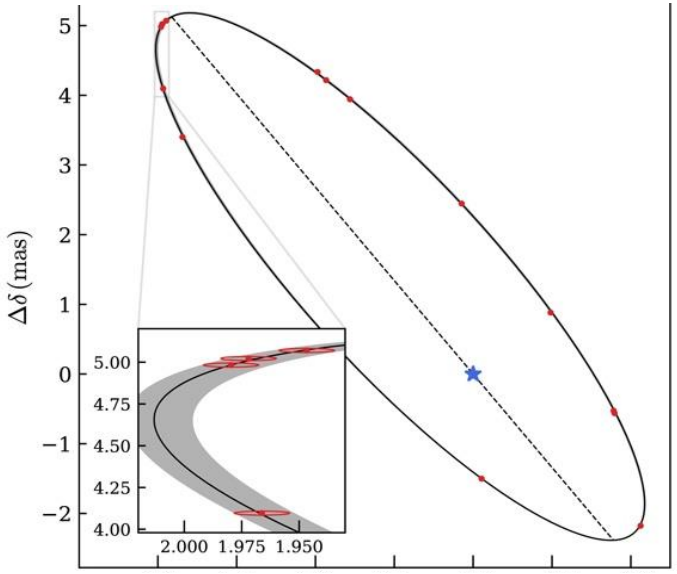


Nasedkin et al. 2(

High Precision Astrometry



Pourré et al. 2024



Gallenne et al. 2023

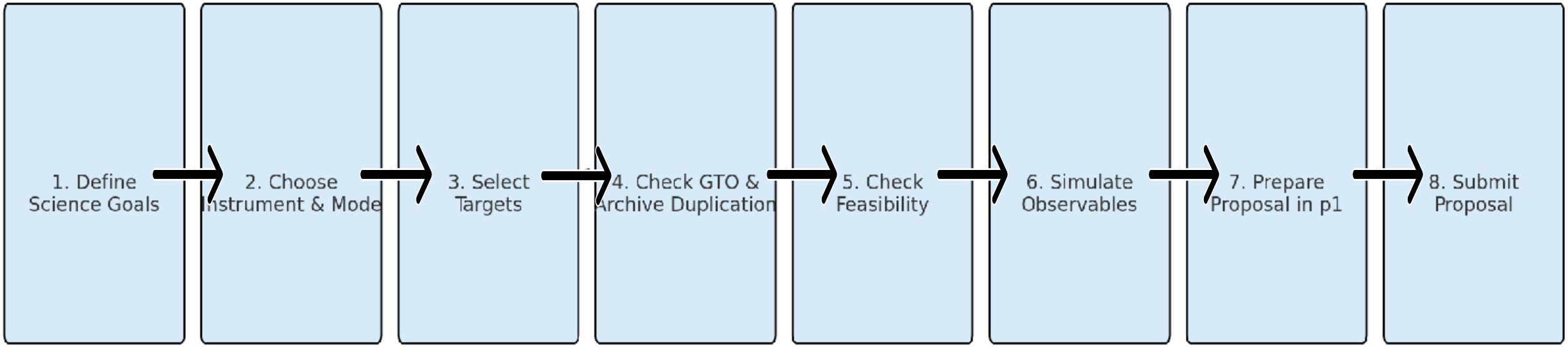
From Idea to Proposals

Evgenia Koumpia

Feasibility Checklist – From Idea to Proposal

- **Key message:** Match your science goal to the VLTI instrument and configuration.

  Science question → spatial scale → wavelength → instrument



Feasibility Checklist – From Idea to Proposal

Target feasibility

- Is my target technically observable? Is the **RA/Dec** of the target observable from Paranal? https://www.jmmc.fr/english/tools/proposal-preparation/getstar-61/ (information from Simbad & ViZier catalogs)
- Can my target be tracked? (AO/Guiding Feasibility) https://www.eso.org/sci/facilities/paranal/telescopes/vlti/documents/VLT-MAN-ESO-15000-4552_v116.pdf

For UTs (GPAO):

- Is the **V-band (Grp) magnitude** ≤ 12.5 for **on-axis GPAO guiding**?
- If using **off-axis guiding**, is there a suitable guide star within 57.5" of the target?

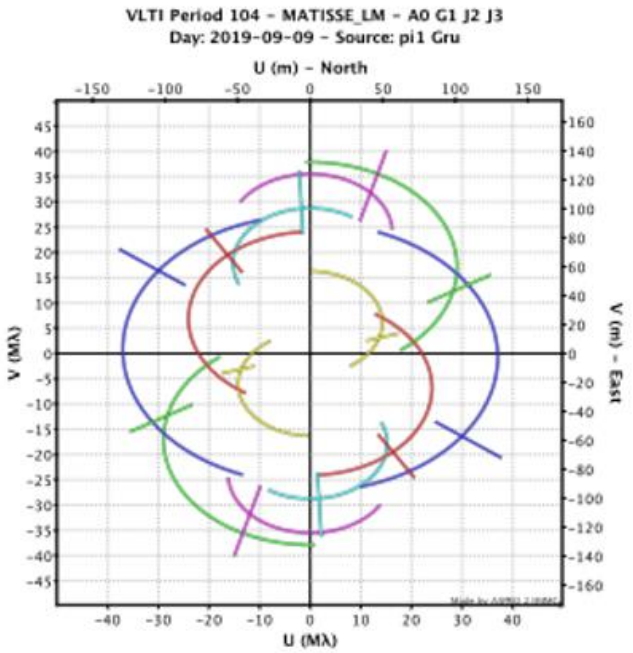
For ATs (NAOMI):

- Is the **Gaia G magnitude** ≤ 12.5 (service mode)?
- Is the guide star within 50" of the science target and correctly offset in RA (±10")?

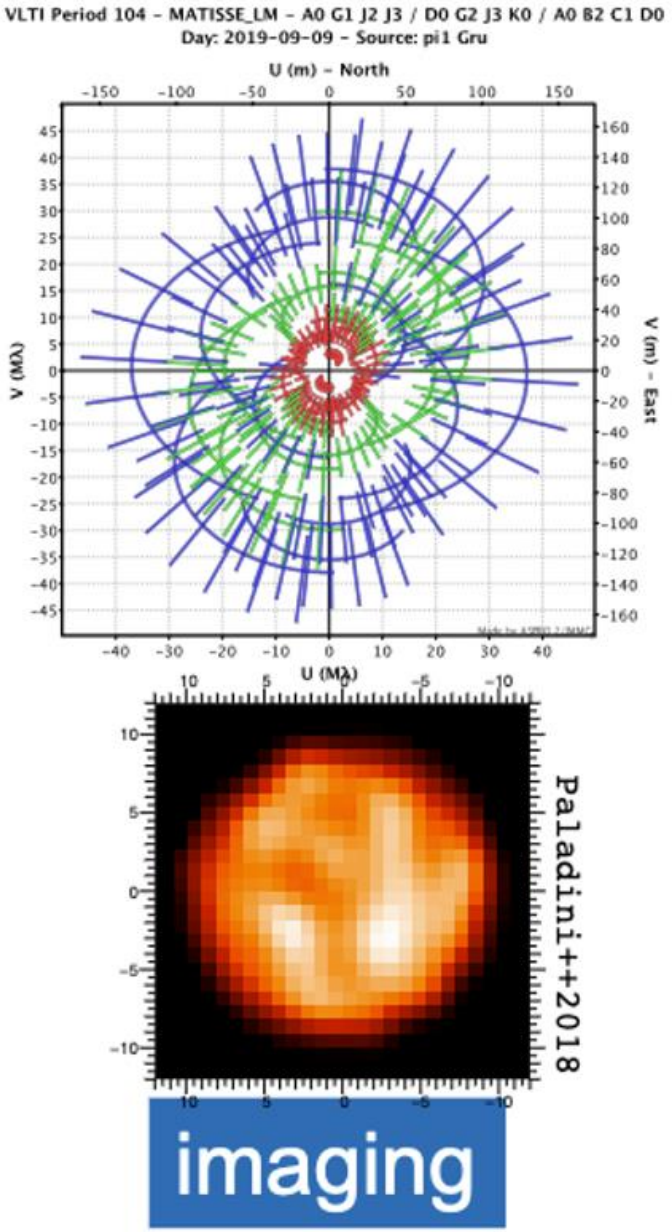
Feasibility Checklist – From Idea to Proposal

Instrument Setup

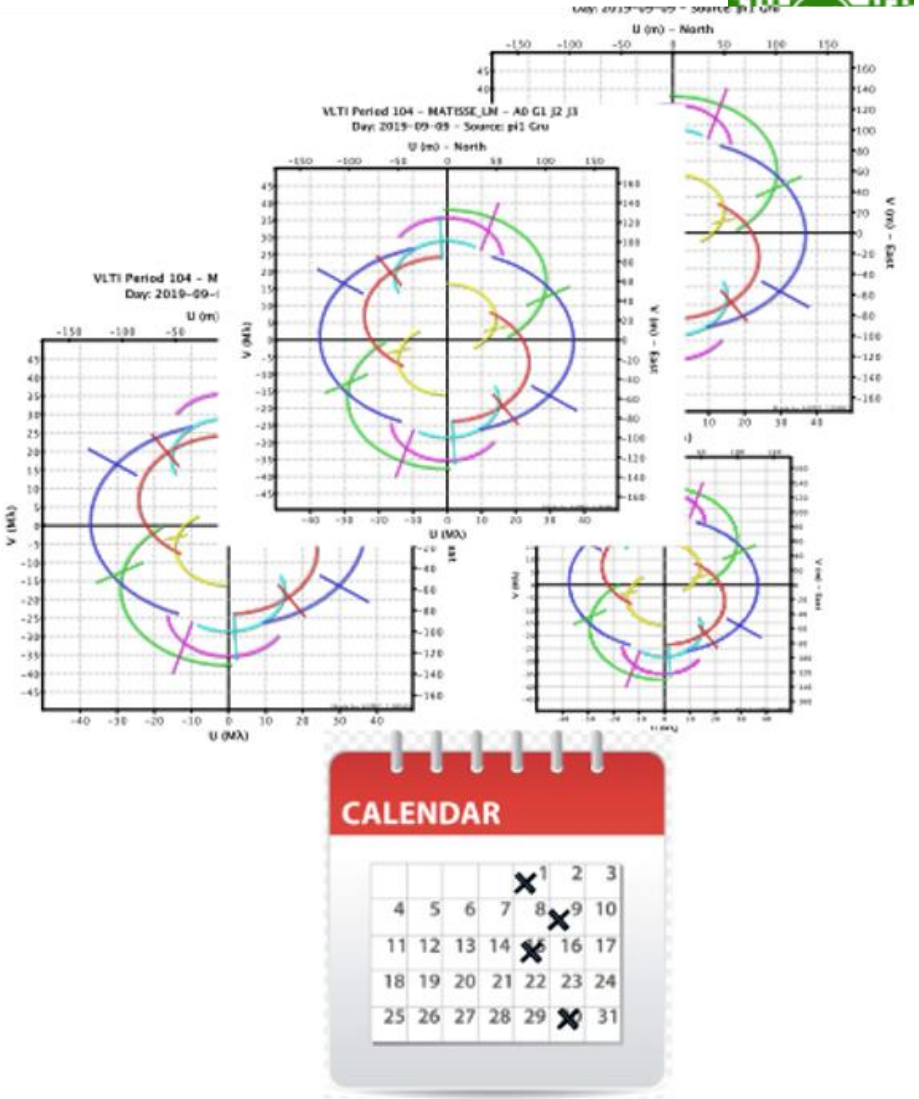
- Which **instrument** is best for my science? (PIONIER: H-band; hot photospheric emission, **GRAVITY**: K-band, **MATISSE**: L/M/N bands; thermal dust, extended emission, ASGARD (visitor instrument)
- What resolution/accuracy is required (visibility vs. phase)?
- Do I care about lines too or only continuum?
- What ***spectral resolution*** do I need to achieve my science goals? (up to R~4000 for GRAVITY and MATISSE)
- What is the optimal ***observing mode***? (snapshots, imaging, time-series?)



snapshot



imaging



Time-series

Feasibility Checklist – From Idea to Proposal

Target feasibility : *Duplication Checks*

- Has my target already been observed with VLTI?
- Are similar instrumental setups or science goals already covered?

Search the ESO Science Archive to avoid duplication! *http://archive.eso.org/eso/eso_archive_main.html*

- Is my target on a GTO list (*https://www.eso.org/sci/observing/teles-alloc/gto/116.html*)? Check if the required observing mode or configuration is blocked (relevant for GRAVITY and MATISSE)

When in doubt, ask! You can raise a Helpdesk ticket to inquire whether your proposed target or mode conflicts with a protected GTO program.

Feasibility Checklist – From Idea to Proposal

Target feasibility

- *Does my target meet instrumental sensitivity limits?* --> check the most recent documentation ***ALWAYS*** !
  (*https://www.eso.org/sci/facilities/paranal/instruments.html*)

Table 1. K-band limiting correlated magnitudes on the ATs

		T ≤ 10% seeing ≤ 0.6" τ_0 > 5.2ms	T ≤ 30% seeing ≤ 0.8" τ_0 > 4.1ms	T ≤ 50% seeing ≤ 1.0" τ_0 > 3.2ms	T ≤ 85% seeing ≤ 1.4" τ_0 > 1.6ms
single-field on-axis	SC (=FT)	9.0^m	8.5^m	8.0^m	7.0^m
single-field off-axis	FT (no SC)	9.5^m	9.0^m	8.5^m	7.5^m
dual-field on-axis (sep. < 2.7")	FT	9.0^m	8.5^m	8.0^m	7.0^m
	SC	16.0^m	15.5^m	15.0^m	14.0^m
dual-field off-axis (1.17" < sep. < 4.0")	FT	9.5^m	9.0^m	8.5^m	7.5^m
	SC	16.5^m	16.0^m	15.5^m	14.5^m
dual-field wide (4.0"<sep.<30.0")	FT	9.5^m	9.0^m	not offered	
	SC	14.0^m	13.0^m	not offered	

Table 2. K-band limiting correlated magnitudes on the UTs (updated for P116 with new GPAO limits [+1 mag])

		T ≤ 10% seeing ≤ 0.6" τ_0 > 5.2ms	T ≤ 30% seeing ≤ 0.8" τ_0 > 4.1ms	T ≤ 50% seeing ≤ 1.0" τ_0 > 3.2ms	T ≤ 85% seeing ≤ 1.4" τ_0 > 1.6ms
single-field on-axis	SC (=FT)	11.0^m	10.5^m	10.0^m	9.0^m
single-field off-axis	FT (no SC)	11.5^m	11.0^m	10.5^m	9.5^m
dual-field on-axis (sep. < 0.6")	FT	11.0^m	10.5^m	10.0^m	9.0^m
	SC	18.0^m	17.5^m	17.0^m	16.0^m
dual-field off-axis (0.27" < sep. < 2.0")	FT	11.5^m	11.0^m	10.5^m	9.5^m
	SC	18.5^m	18.0^m	17.5^m	16.5^m
dual-field wide (2.0"< sep.< 30.0")	FT	11.5^m	11.0^m	not offered	
	SC	18.0^m	17.0^m	not offered	

Feasibility Checklist – From Idea to Proposal

Target feasibility

- *Does my target meet instrumental sensitivity limits?* --> check the most recent documentation ***ALWAYS*** ! (*https://www.eso.org/sci/facilities/paranal/instruments.html)*

*GRAVITY and MATISSE users should use the **dedicated ETC** for visibility calculations and their feasibility (https://www.eso.org/observing/etc/)*

- *Are calibrators available?* (**SearchCal** https://www.jmmc.fr/english/tools/proposal-preparation/search-cal/ or **CalVin** https://www.eso.org/observing/etc/bin/gen/form?INS.NAME=CALVIN+INS.MODE=CFP
- Is there a calibrator star nearby? (the closer the better)
- Is it unresolved and are its spectral type and brightness similar to the target?

Feasibility Checklist – From Idea to Proposal

Configuration - *Telescope Choice* (UTs vs. ATs)

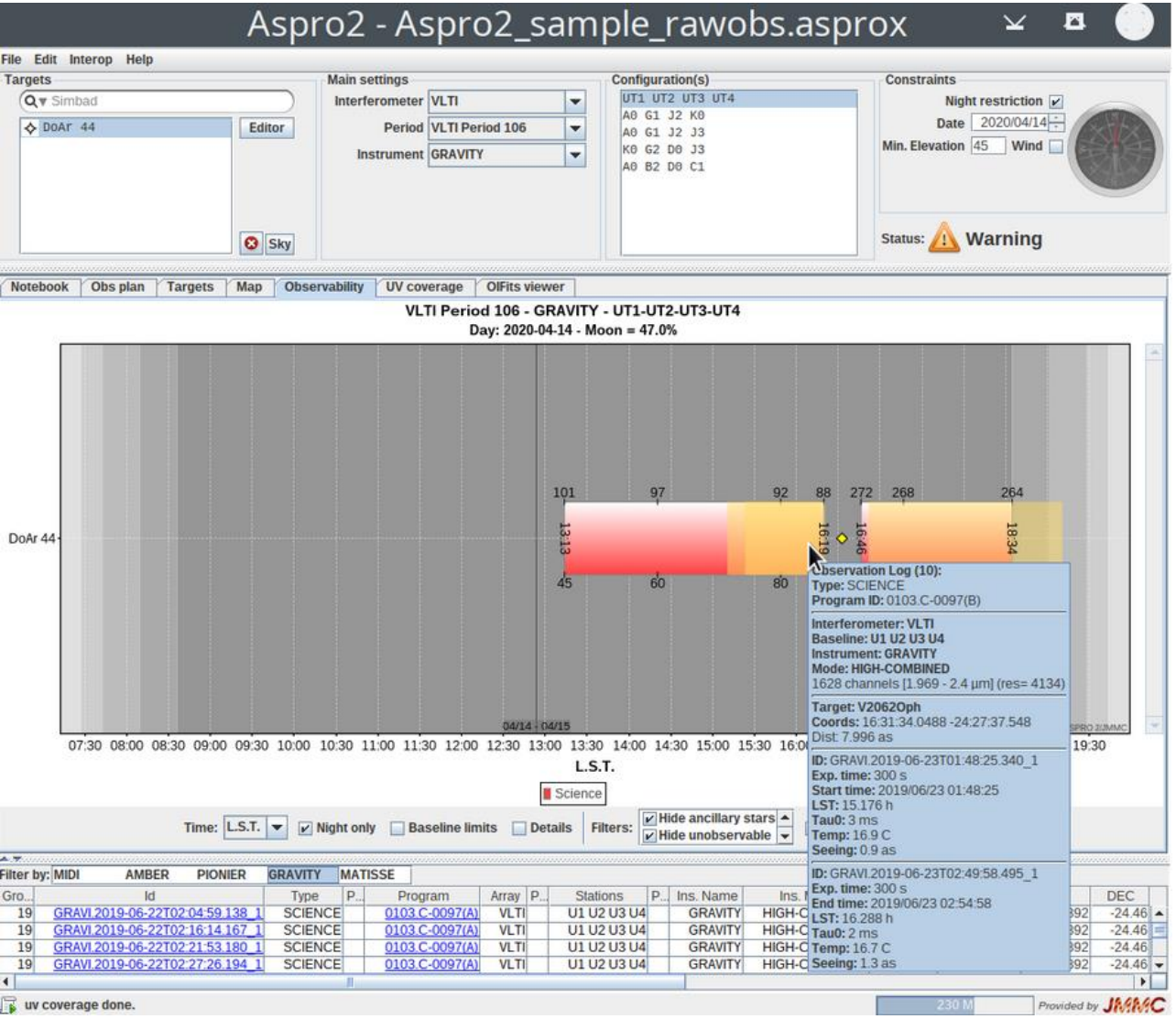
- Does my science case require the higher sensitivity of the 8-m UTs or the flexible baseline configurations of the 1.8-m ATs?
- If ATs, is the configuration compatible with my science? (small, medium, large, extended)
- Have I verified the **uv-coverage and visibility amplitude** with **Aspro2 or VisCalc**?

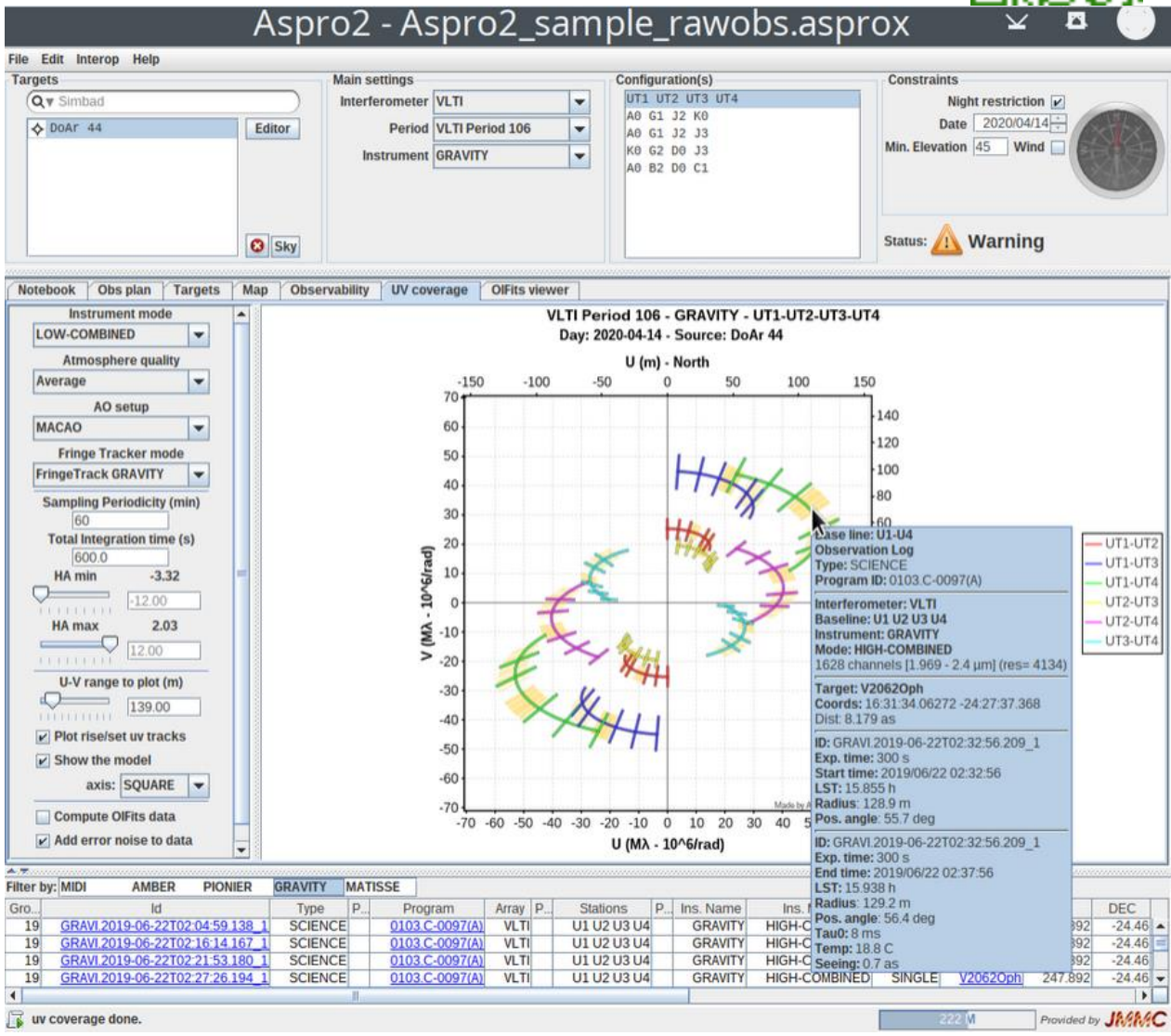
Simulating your VLTI observables

- **Key message:** Simulate what your model would look like to predict visibilities and closure phases.

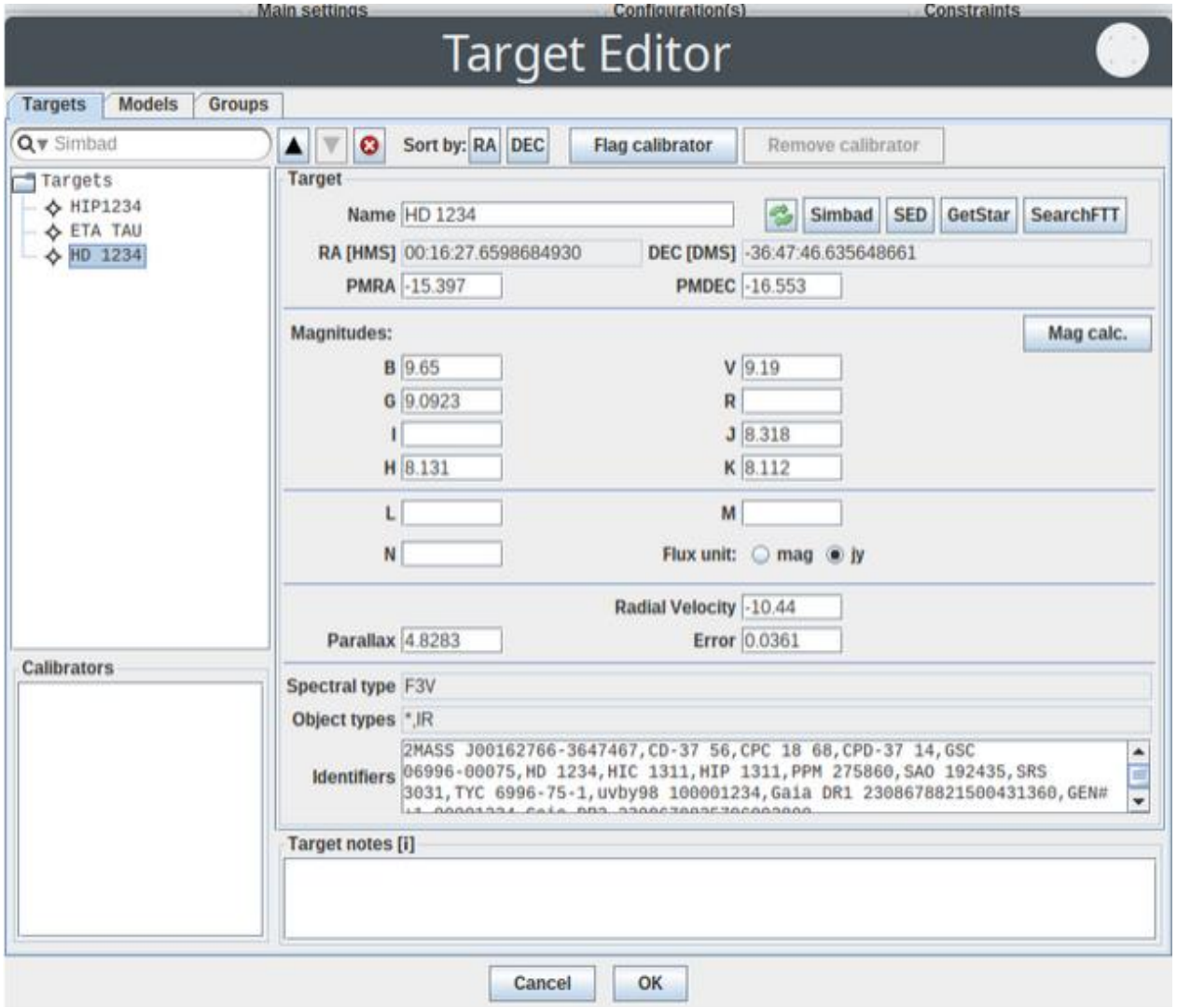
- **TOOLS**:
- Use **radiative transfer** or just toy models (e.g., disc, binary)
- Simulate:
  - Intensity map → FFT → visibilities
  - Use JMMC tools https://www.jmmc.fr/english/tools/proposal-preparation/ **Aspro2** (simulate uv-sampled observables)
  - Model → predicted V^2/closure phases → match to Aspro2 coverage

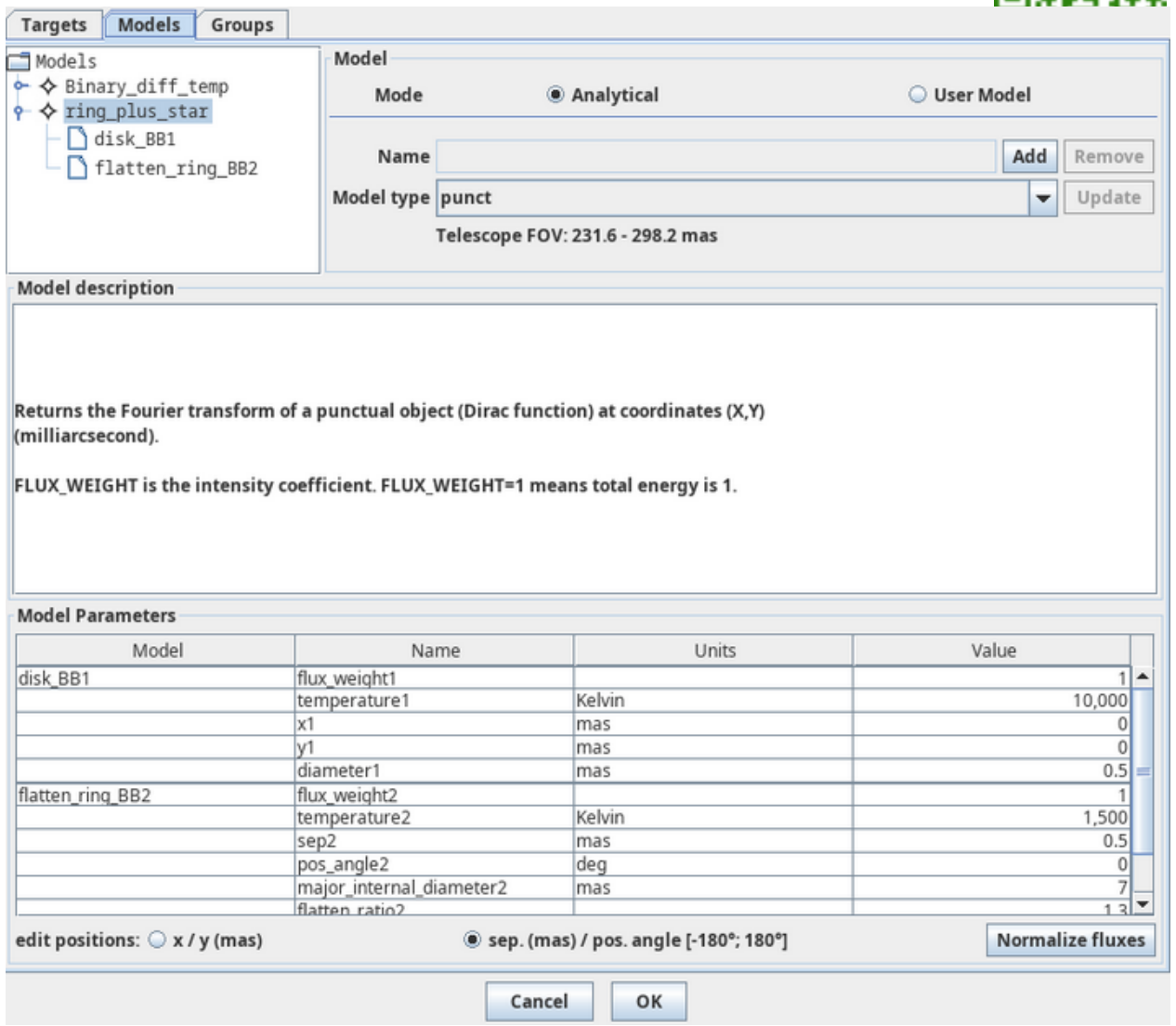
Simulating your observations - Aspro



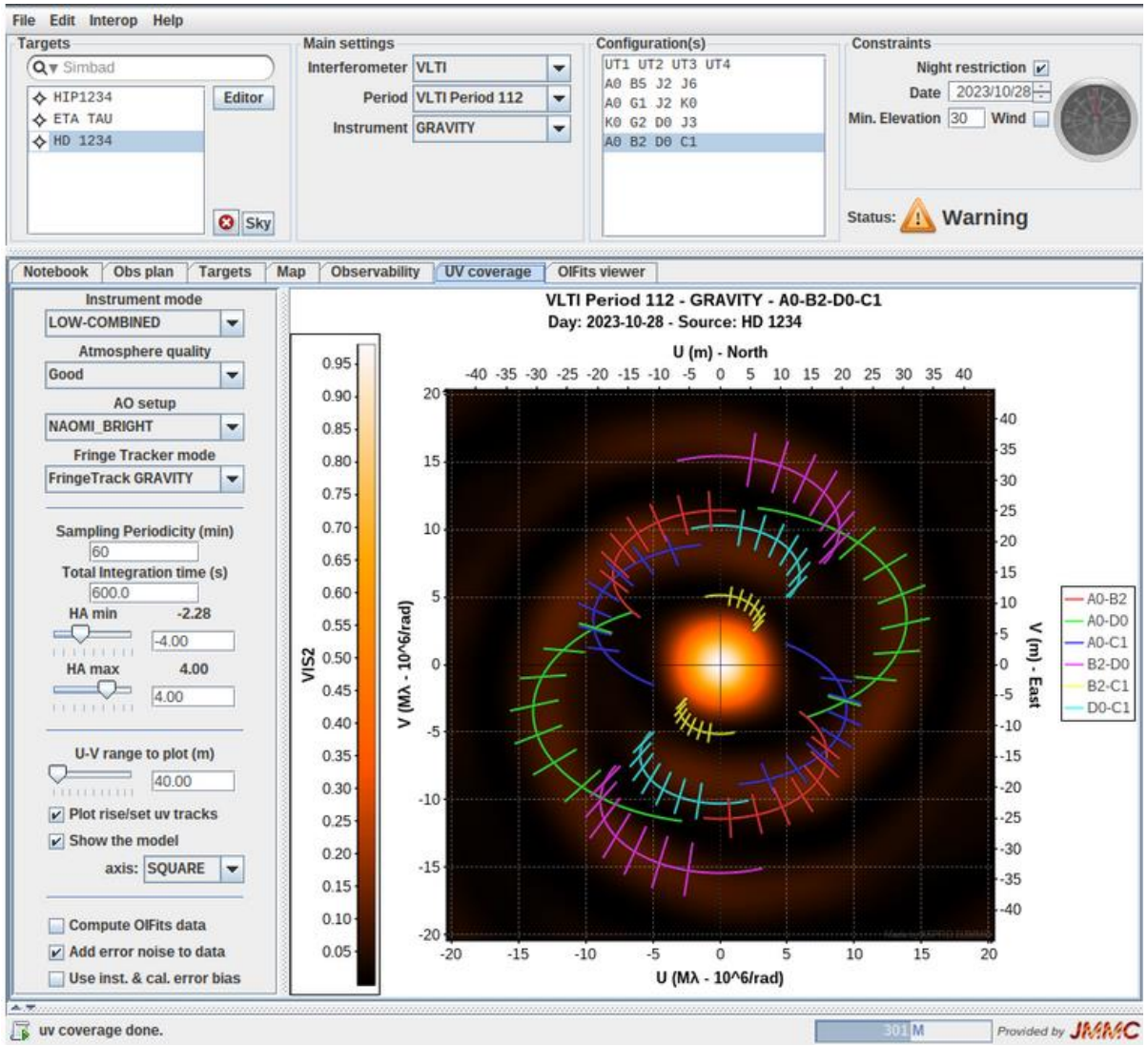


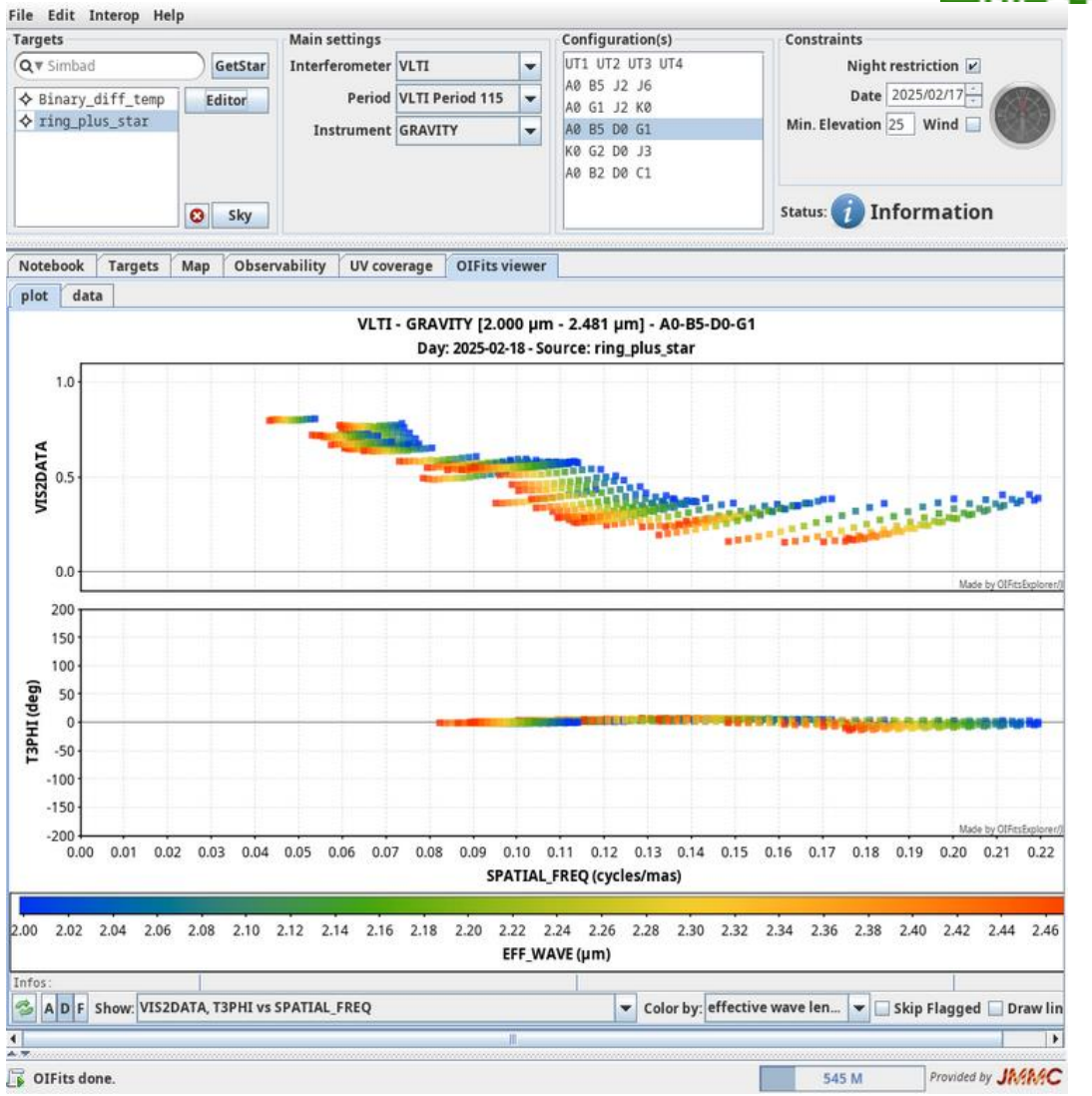
Simulating your observations - Aspro





Simulating your observations - Aspro





From Idea to Proposal - Takeaways

- *Let your science case guide the VLTI setup*

  → Choose the instrument, mode, and configuration that best addresses your scientific goals.

- *Always test feasibility early*

  → Use tools like **Aspro2** and **ESO ETC** to validate observability, fluxes, and visibility coverage.

- *Simulate your observables*

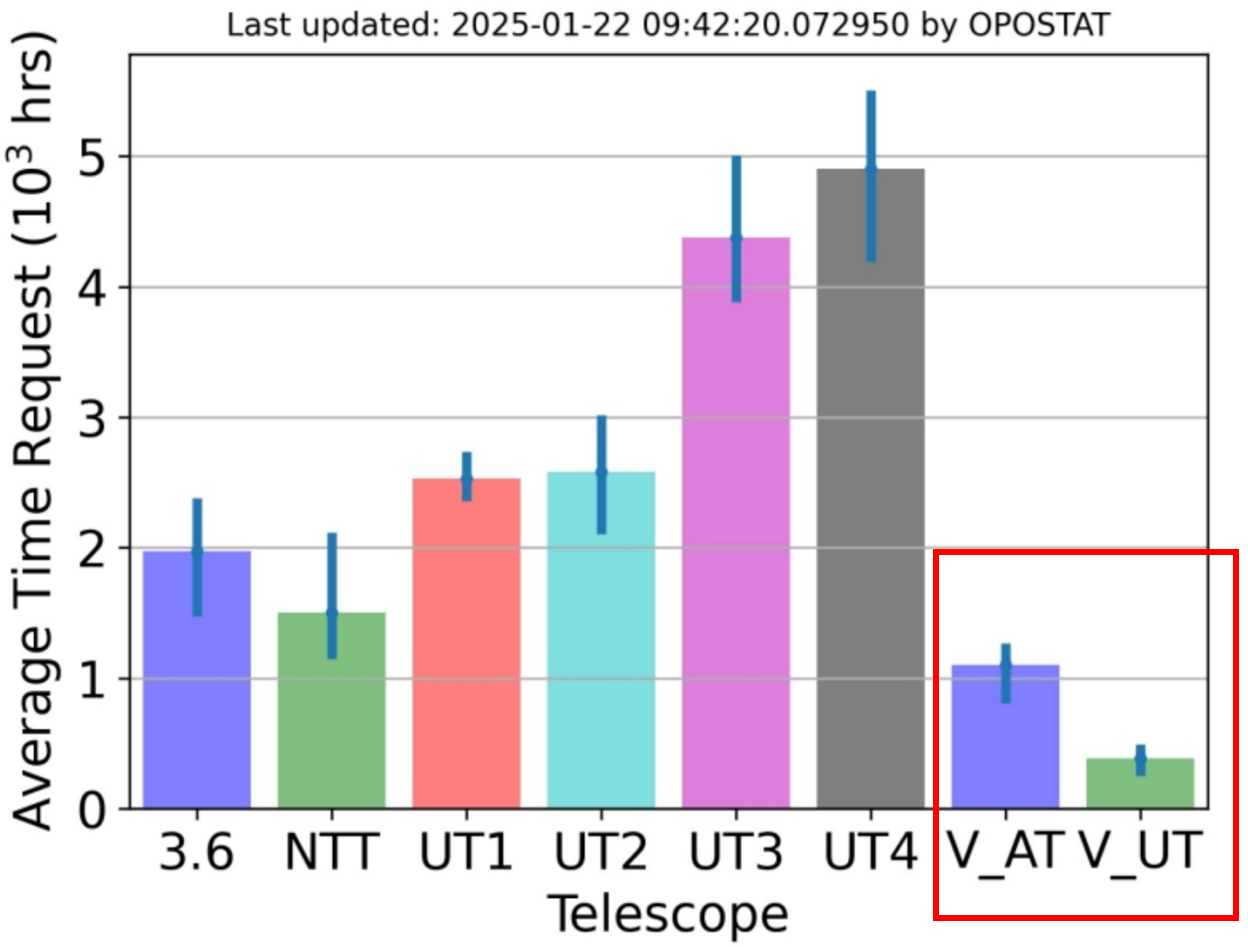
  → *Generate mock data to check if your signal is detectable and to prepare your analysis workflow.*

Your proposal: preparing phase 1

Emma Bordier (she/her)

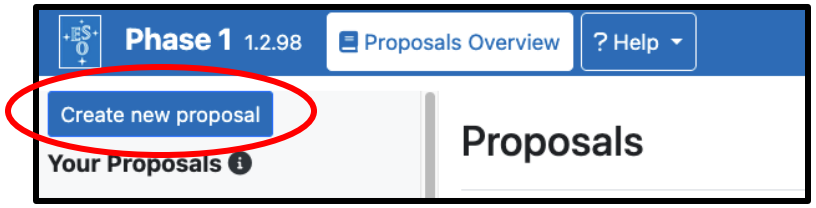
Submitting a VLTI Proposal? Your odds are better than you think

Statistics between P108 and P116



VLTI proposals: submit like any other ESO proposal on the p1 tool

https://www.eso.org/p1/



What you need to know before starting:

- Telescope configuration
- Instrument set up
- Type of interferometric observations
- Coudé Guide Star (CGS)

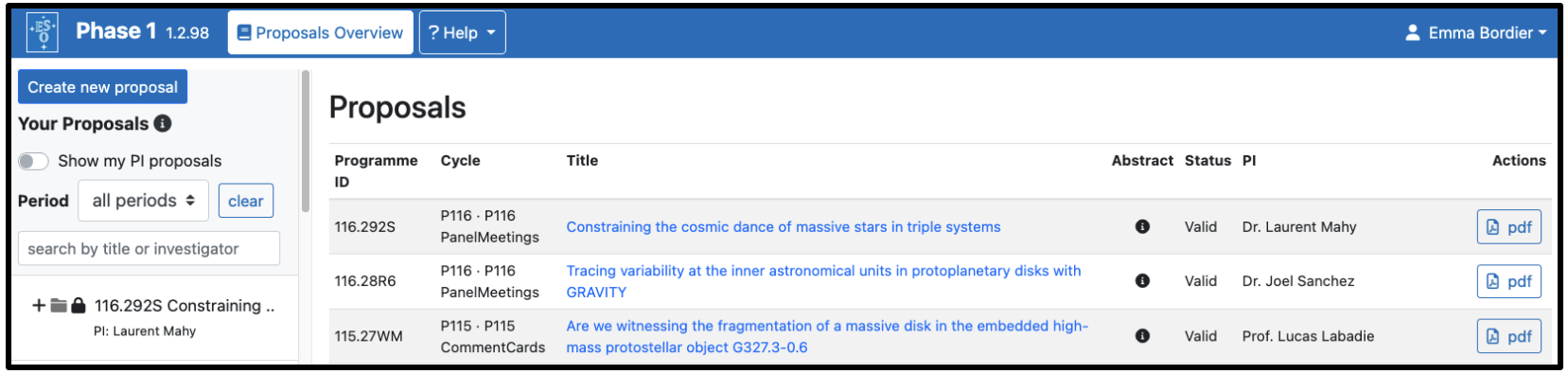
What you DON'T need to provide for p1:

- Calibrators
- Detailed integration settings like science DIT, number of science and sky frames

Phase 1 – proposal submission interface

- Create an account on the ESO user Portal and access the P1 tool

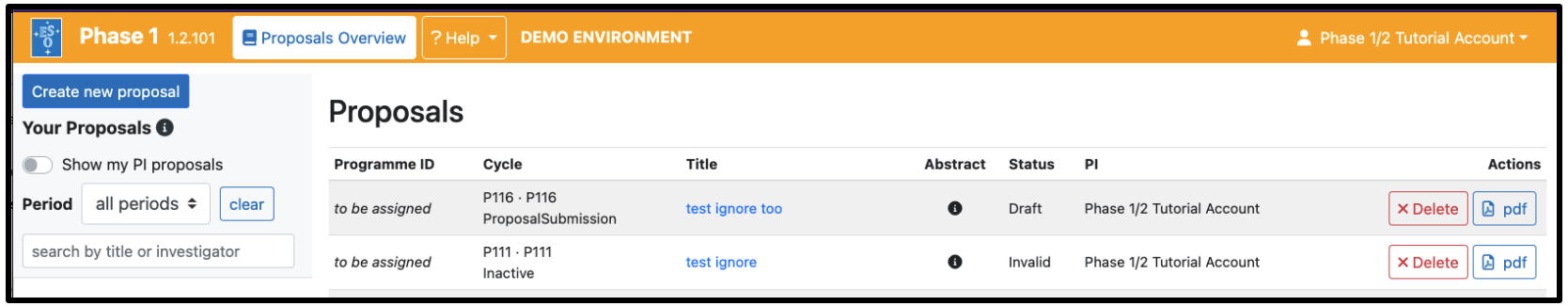
https://www.eso.org/p1/



- If you don't have an ESO account, you can alternatively open the P1 demo tool

https://www.eso.org/p1demo/

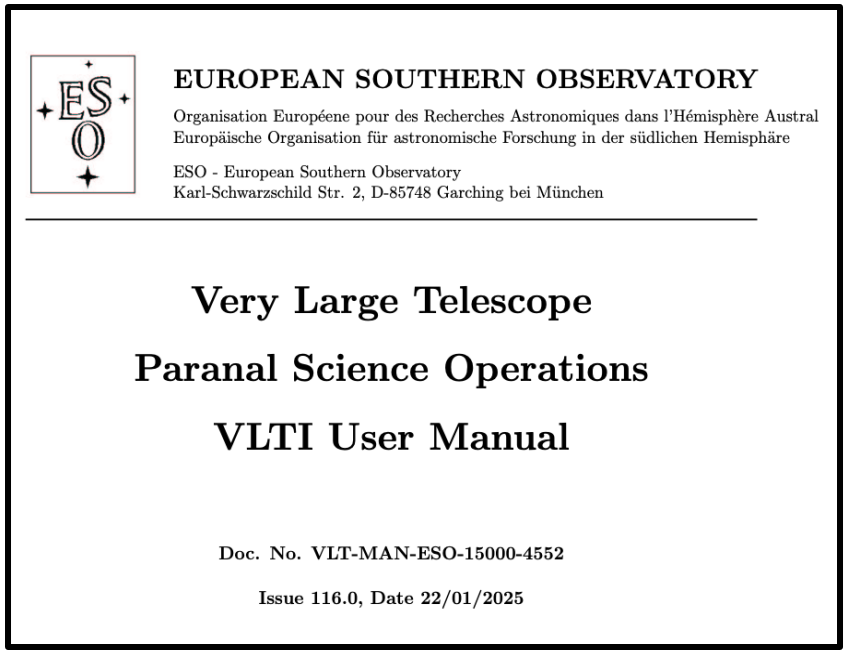
(No submission can be done through the demo)



When the ESO call is out, check these 2 manuals:

https://www.eso.org/sci/observing/phase1/p116/CfP116.pdf

https://www.eso.org/sci/facilities/paranal/telescopes/vlti/documents/VLT-MAN-ESO-15000-4552_v116.pdf



EUROPEAN SOUTHERN OBSERVATORY

Organisation Européene pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

ESO - European Southern Observatory
Karl-Schwarzschild Str. 2, D-85748 Garching bei München

Very Large Telescope

Paranal Science Operations

VLTI User Manual

Doc. No. VLT-MAN-ESO-15000-4552

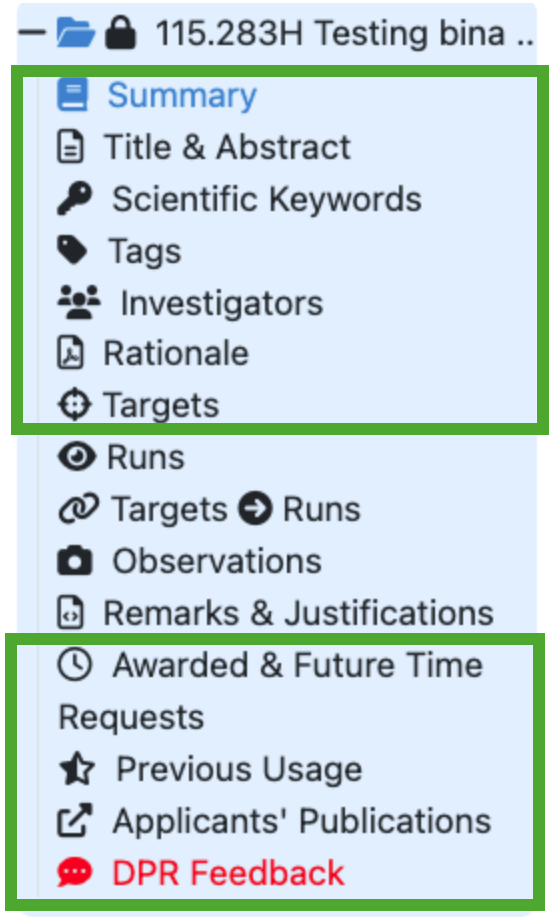
Issue 116.0, Date 22/01/2025

Why is it important?

- Telescope configurations can change from one period to another (for the ATs)
- New observing modes may be introduced (e.g. GRAVITY-WIDE, use of GPAO etc)
- Updated instrument performance
- Some modes may no longer be available (e.g. MACAO)

VLTI proposals: no new tool to learn

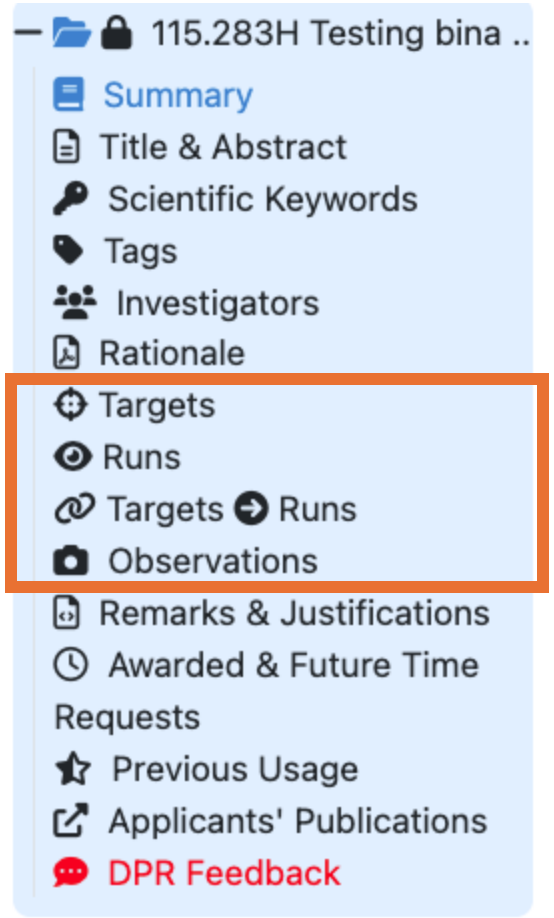
If you have written ESO proposals before, **the process is the same as for any other instrument.**



Tips:

- Don’t hesitate to include Co-I(s) who are familiar with VLTI and can support you throughout the proposal process

VLTI proposals: what is critical for phase 1?



Targets:

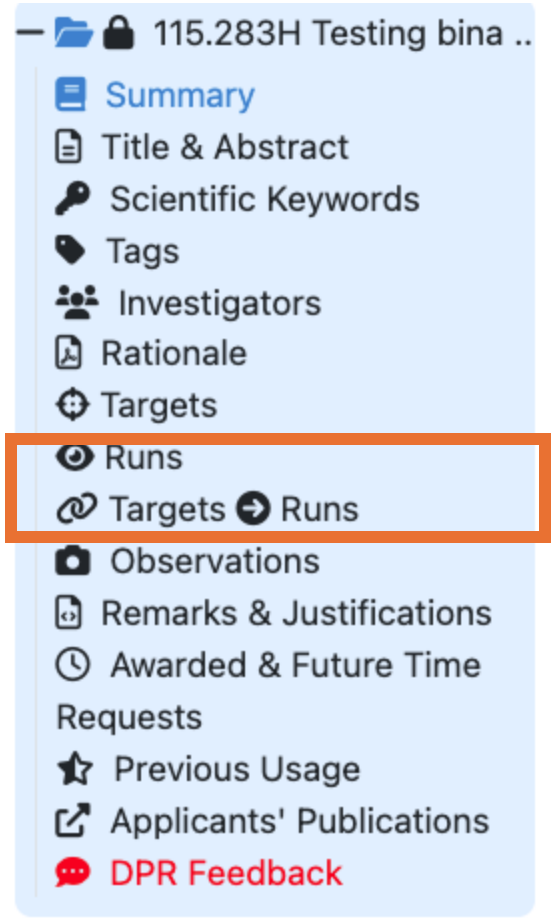
- Ensure your targets meet the sensitivity requirements
- Provide the Coude Guide Star in the target list if different from the Science target

→ Find all these details in the instrument user manual and VLTI user manual

It can be a critical point for certain science cases, e.g. MYSOs, science cases in the Galactic Centre and in highly extincted regions

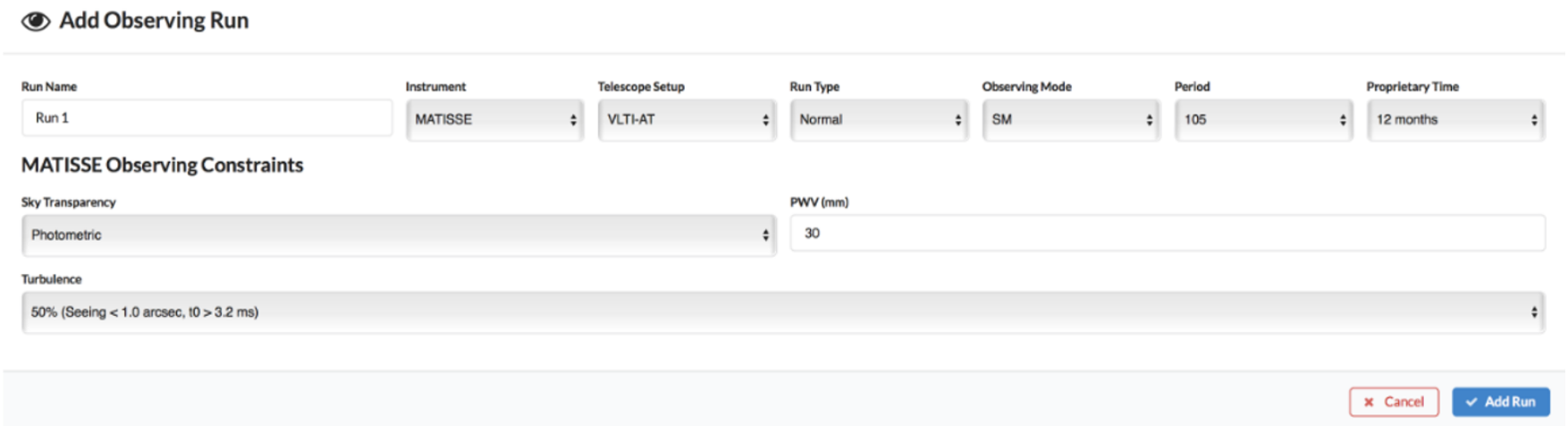
- **No need to provide calibrators at this stage.**
- HOWEVER: make sure there is a suitable star for calibration (e.g. SearchCal)

VLTI proposals: what is critical for phase 1?



Runs:

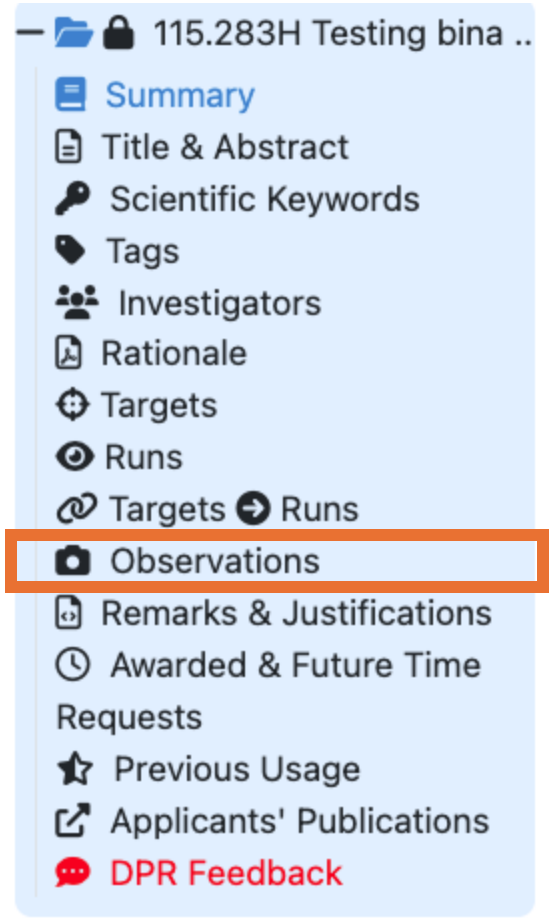
- Weather constraints (driven by your target and instrument sensitivity -> check the manuals!)
- Template (single/dual- field, on-axis/off-axis etc)
- What AO system do you need? Mainly depends on the V mag. No choice on the ATs (NAOMI)
- The interferometric array (e.g. check with ASPRO)
- Type of interferometric observations (snapshot, time series/ image reconstruction)

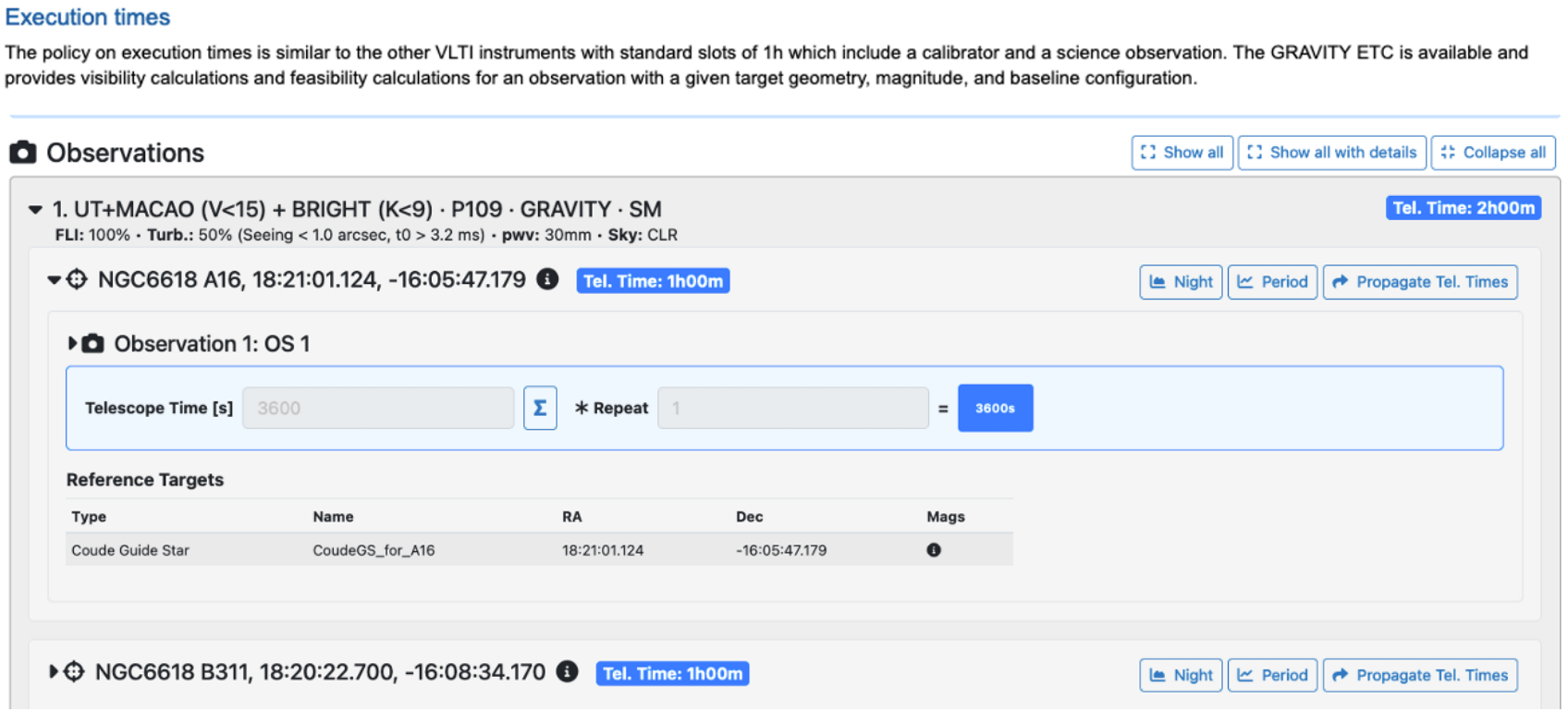


VLTI proposals: what is critical for phase 1?

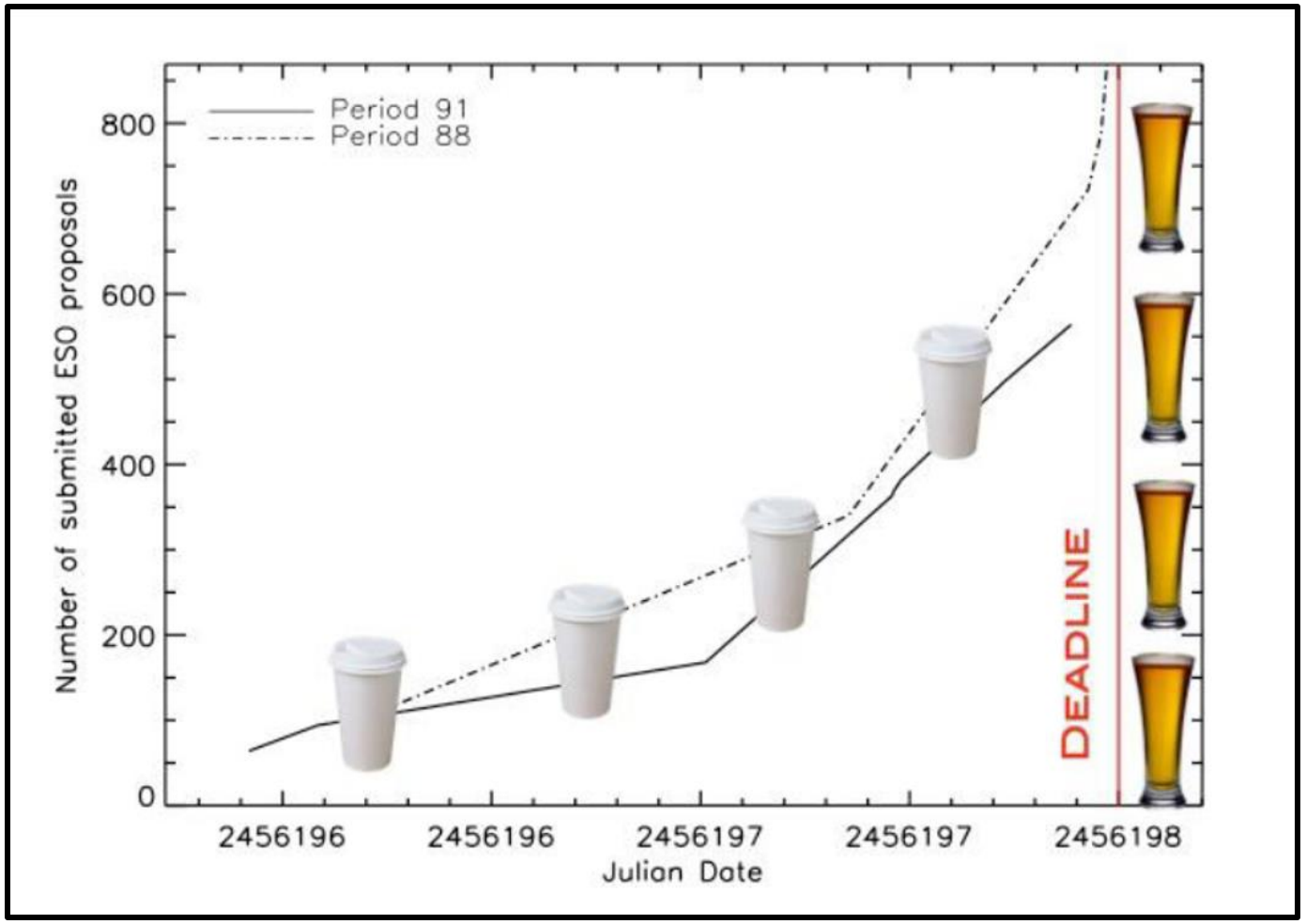
Observations:

- Check the ETC for the telescope time
- Typical time for one snapshot (including calibrator) is 1h.
- **No need to provide NDIT*DIT** at this stage, nor number of science and sky frames → done in P2.





Final tips



- When you have an idea try first to convince your collaborators
- **Check carefully your targets**
- Read the manuals, contact VLTI expertise centers, watch videos of the previous VLTI schools, approach VLTI users that can and will surely help you throughout the process
- Do not start the day before the deadline (at least try)…

- SUBMIT WITHIN THE DEADLINE!

Preparing observations: phase 2

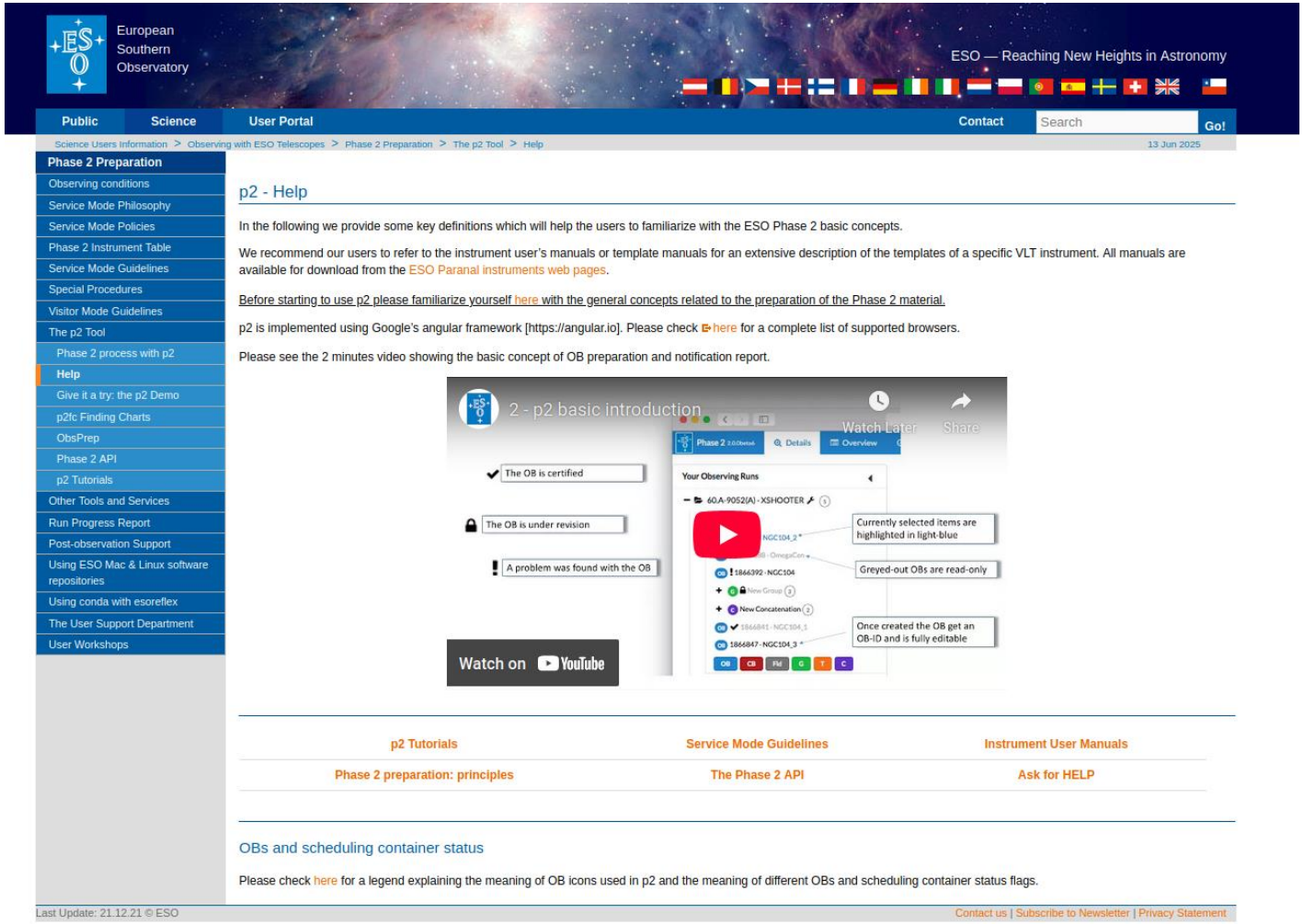
James Leftley (he/him)

Resources

- You are not alone, help is always available
  - **USD** (user service department) help desk is an official ESO service to help with observation setup (p1+p2)
  - **JMMC help desk** is also available to help with any part of your VLTI project, including setting up proposals
  - Links at end of presentation
- Setup is less VLTI specific than you might think
  - Nearly everything is similar to other observing techniques
- Almost all technical considerations will be selected in P1

P2 for VLTI

- If you have observed with ESO, you will most likely have encountered P2
- If not, ESO provide full tutorials on how to use it
- In this talk, I will present important parts specific to the VLTI

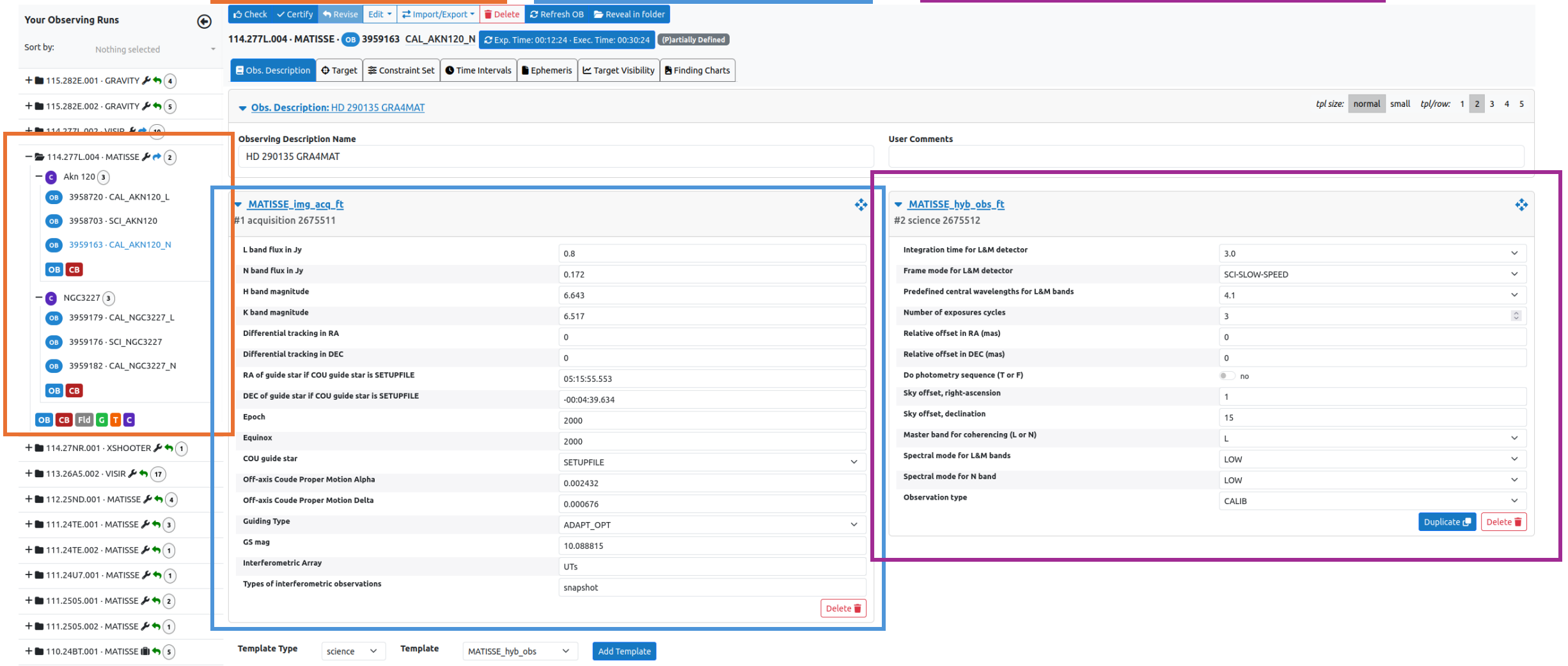


P2

Programme organisation

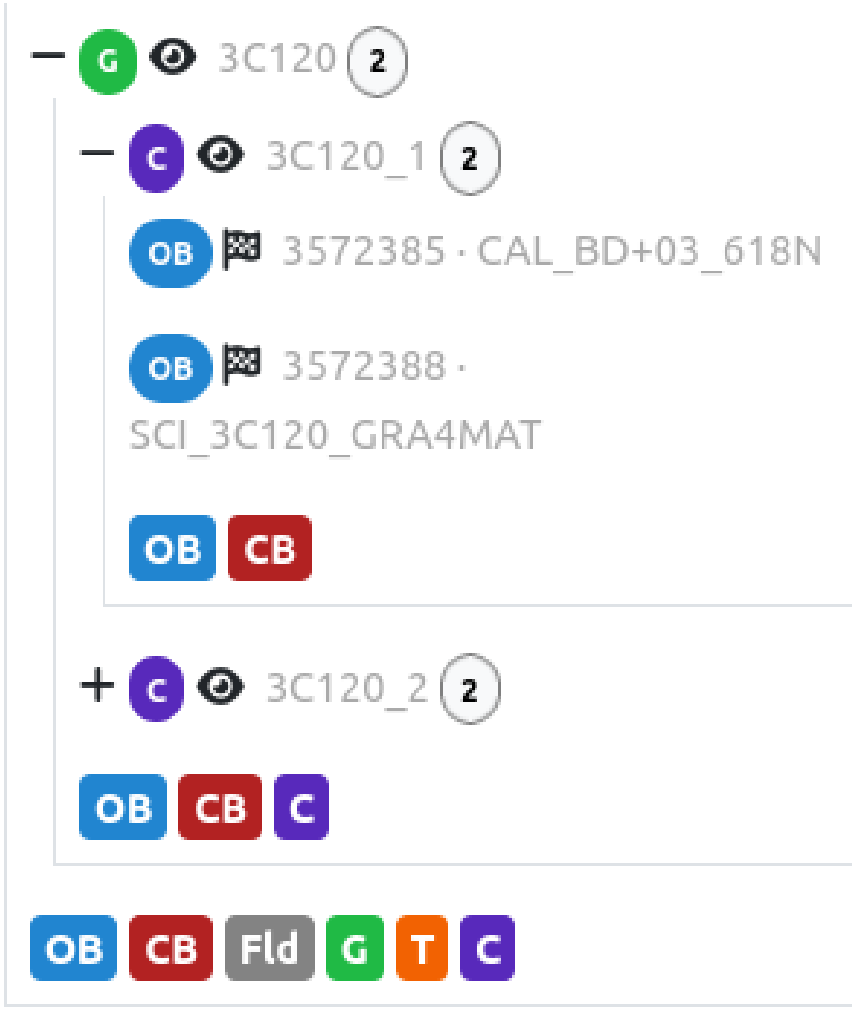
Aquisition

Observation



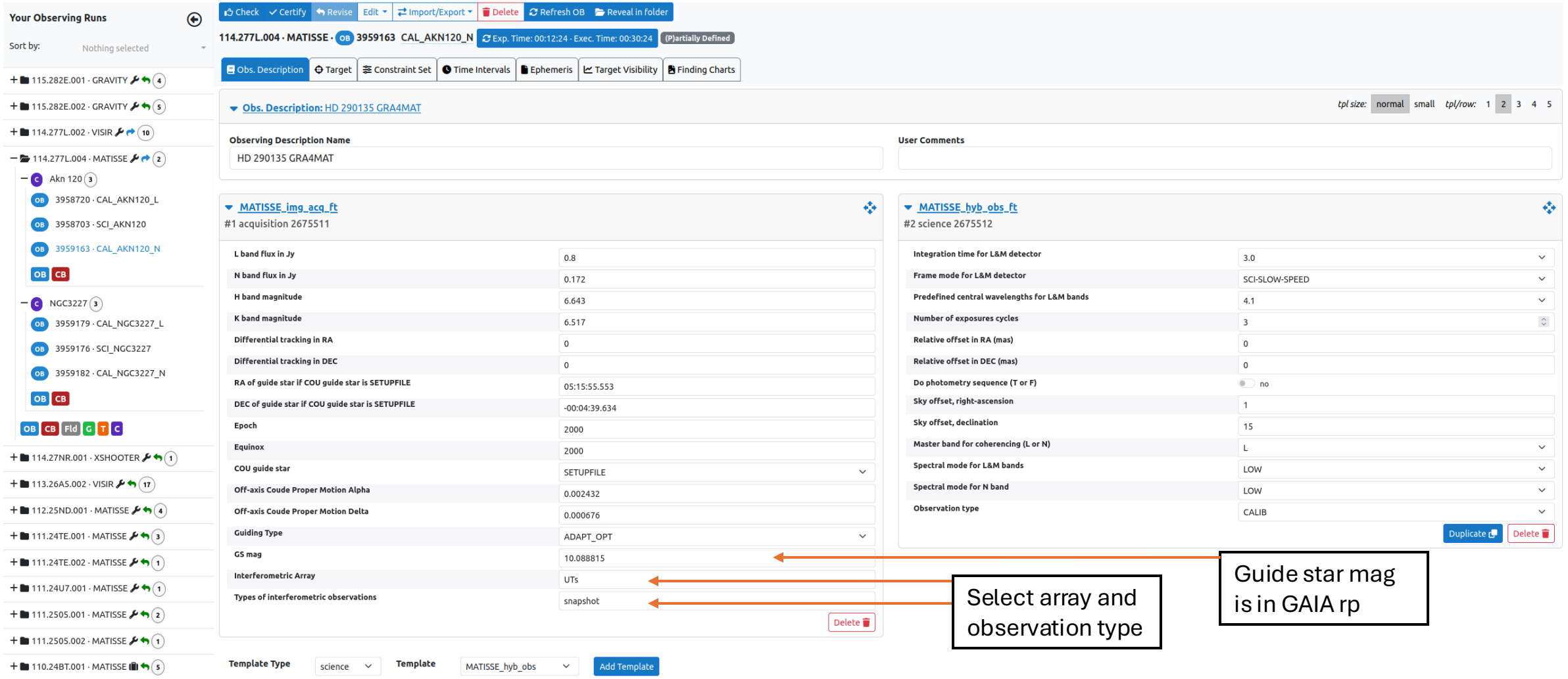
P2 for VLTI

- Unlike some instruments, concatenations are necessary in almost all cases
  - Calibrators must be requested and observed close in time
  - Concatenations >1hr require a waiver
  - Waiver will be needed in many/most cases
- Just like for other instruments:
  - You can use groups to link multiple observations of one target
    - Needed for observations with multiple snapshots
  - Timelinks can be used but they are more restrictive, usually for time series



P2

- Otherwise, rest of P2 is very similar to any instrument



Observation templates

PIONIER_obs_science
#2 science 2012086

Number of fringe tracks	5

Duplicate Delete

GRAVITY_dual_obs_exp
#2 science 2012089

Science integration time (DIT in s)	0.3
Number of science frames (NDIT)	32
Number of sky frames (NDIT)	32
Sky dRA offset in milliarcsecond	2000
Sky dDEC offset in milliarcsecond	2000
Sequence of HWP offsets (deg)	0
Sequence of observations Object (O) and Sky (S)	O S
Sequence of SC relative RA offsets (mas)	0
Sequence of SC relative DEC offsets (mas)	0

Duplicate Delete

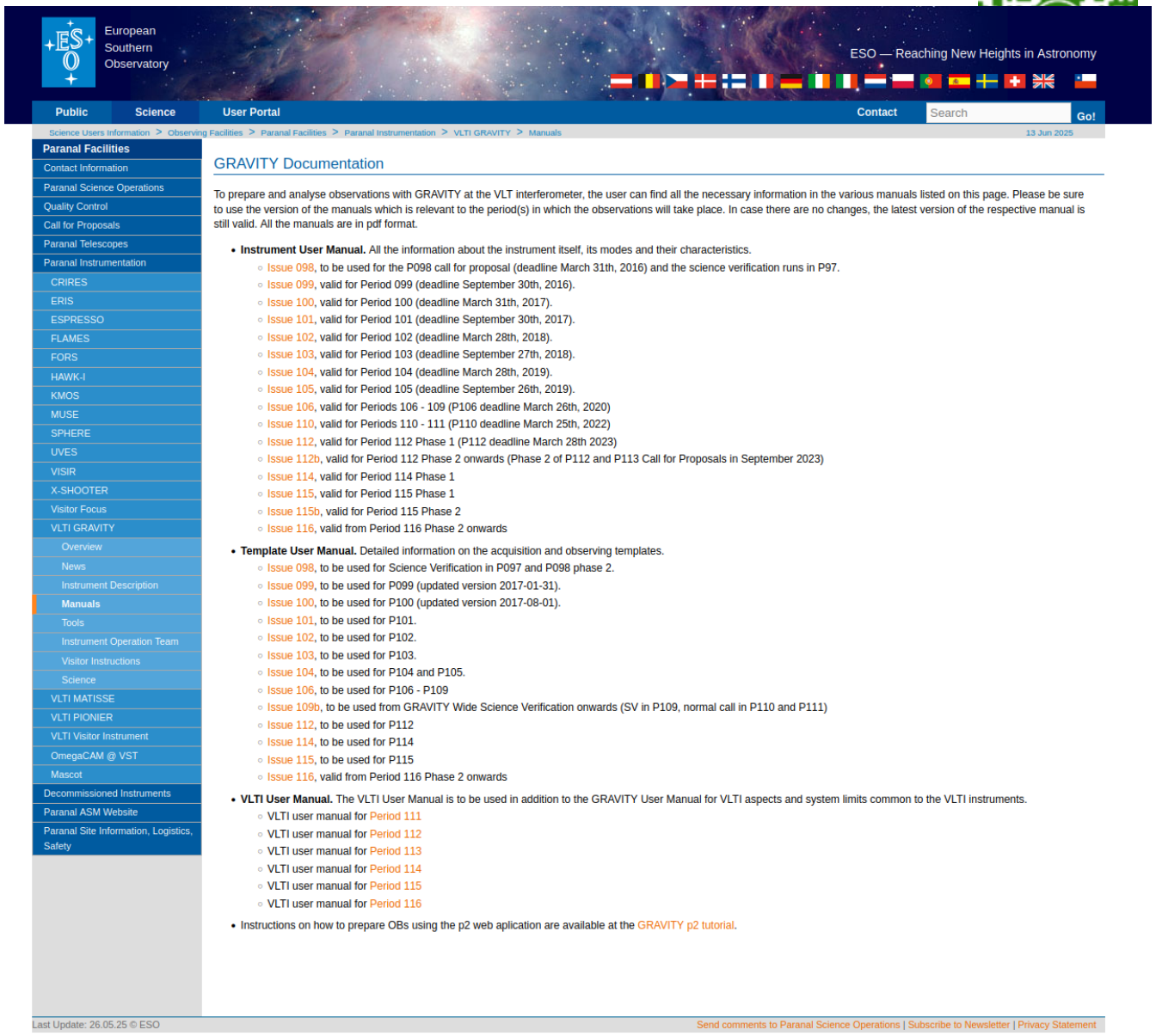
MATISSE_hyb_obs
#2 science 2011894

Integration time for L&M detector	0.111
Frame mode for L&M detector	SCI-SLOW-SPEED
User central wavelength for L&M bands	0
Predefined central wavelengths for L&M bands	3.5
Number of exposures cycles	1
Do photometry sequence (T or F)	yes
Sky offset, right-ascension	1
Sky offset, declination	15
Master band for coherencing (L or N)	L
Spectral mode for L&M bands	LOW
Spectral mode for N band	LOW
Observation type	CALIB

Duplicate Delete

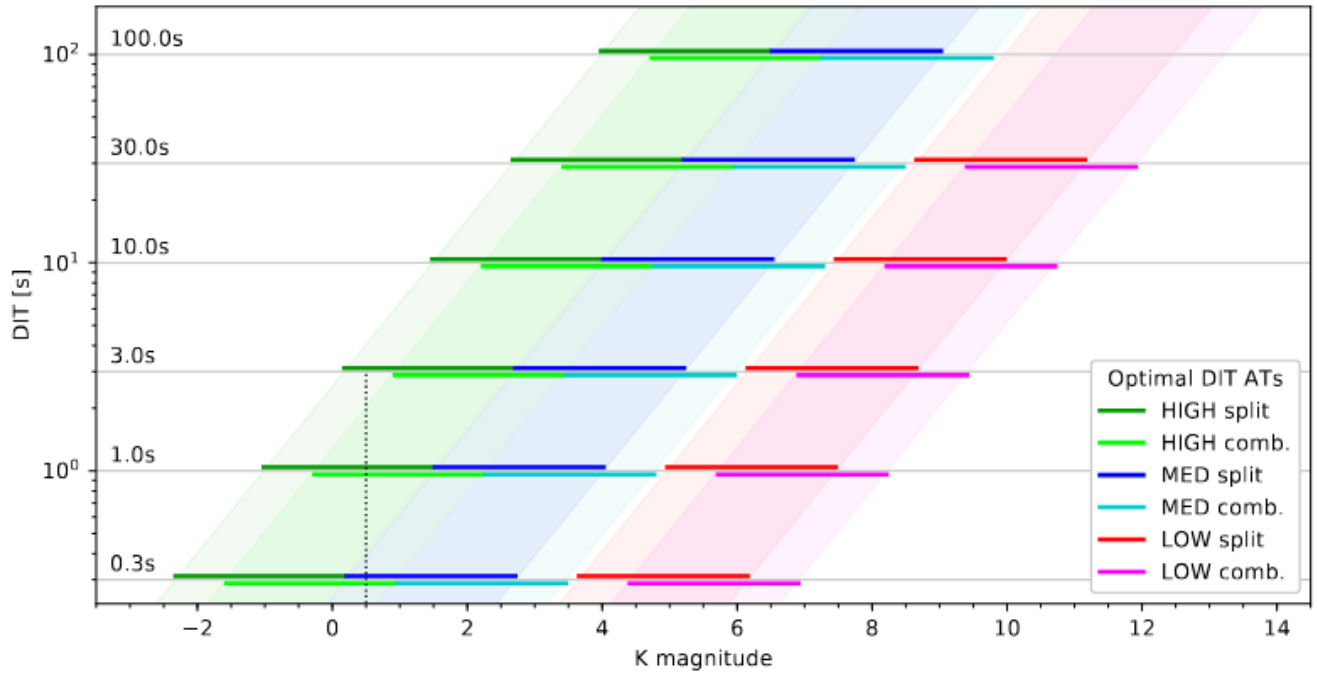
Manuals

- Similarly to any ESO instrument, manuals are available
- Unlike other instruments, there is a manual for the instrument AND the VLTI
  - VLTI is common to all VLTI instruments
- Template manual is for details on p2 templates



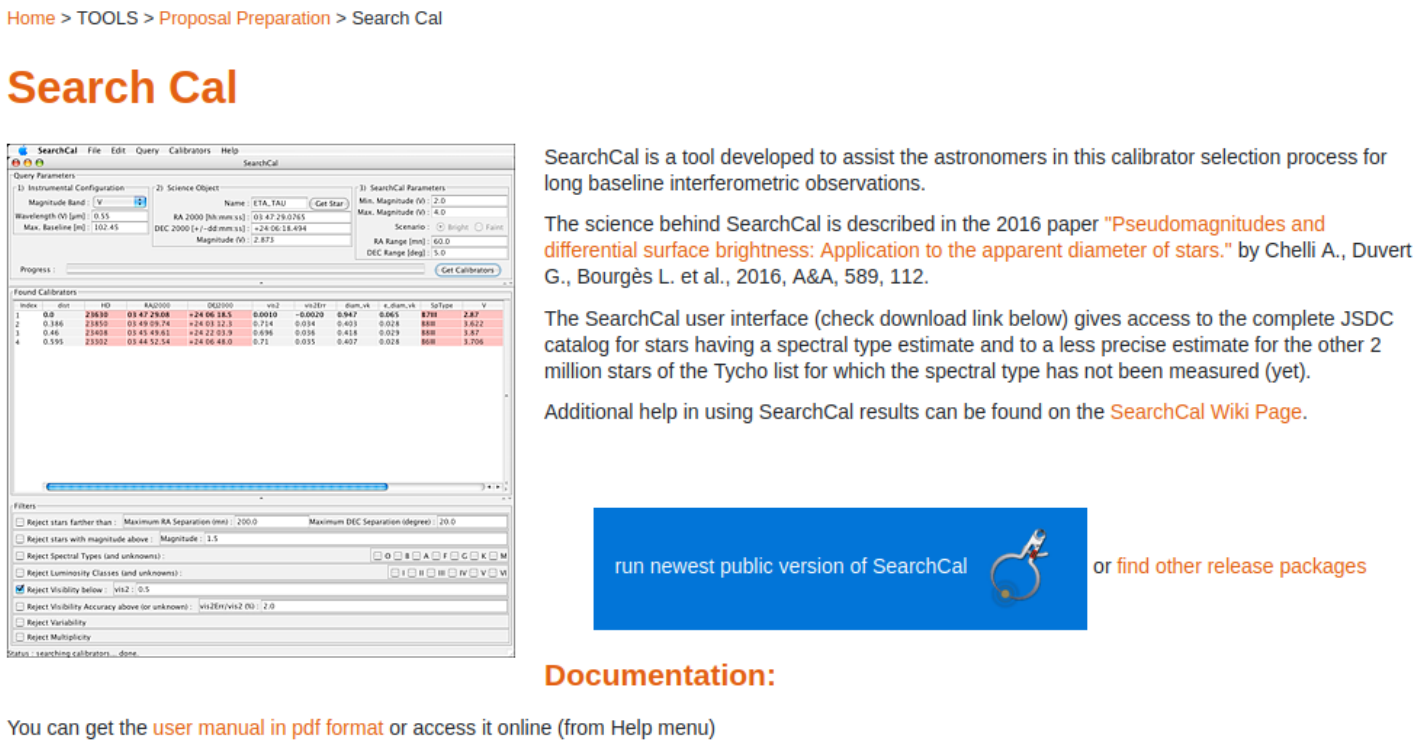
Setup choices

- In P1 you will have already mostly selected your setup
  - P2 will have some fine additional details but the broad strokes are already complete
    - e.g. Integration time will be known, but DIT*NDIT can be finetuned
  - Manuals explain all the options



Selecting a calibrator

- Perhaps most important in P2 is calibrator selection
  - True for all observing, doubly so for interferometry
- Similar to other methods but there are a few key differences
- Fluxes per band
  - Similar flux to science is helpful
  - CAL/SCI/CAL?
- Spectroscopic requirements?
  - Unusually, most cases don't need one
    - Visibility and phase are ratios
  - Only if you need absolute or correlated flux
  - Probably want CAL-SCI-CAL if needed
- Sizes!
  - A resolved star adds uncertainty
  - Most spectroscopic calibrators are resolved to some baselines
- Avoid binaries
- **JSDC/SearchCal**



File Edit Query Calibrators Interop Help

Query Parameters

1) Instrumental Configuration

Magnitude Band : L

Wavelength (L) [µm] : 3.5

Max. Baseline [m] : 102.45

2) Science Object

Name : ES0323-G77

RA 2000 [hh:mm:ss] : 13 06 26.1214861728

DEC 2000 [+/-dd:mm:ss] : -40 24 52.595604396

Flux [L] (Jy) : 0.1

3) SearchCal Parameters

Max. Flux [L] (Jy) : 0.631

Min. Flux [L] (Jy) : 0.0158

Scenario : Bright Faint

RA Range [mn] : 240.0

DEC Range [deg] : 20.0

Nearby is better

Ideally 1 or close

Similar to sci

Progress :

Get Calibrators

Found Calibrators (4958 sources, 4907 filtered)

Index	dist	HD	RAJ2000	DEJ2000	vis2	vis2Err	diam_chi2	LDD	e_LDD_rel	GroupSize	SIMBAD	SpType	ObjTypes	flux_L	flux_M	flux_N	UD_L	UD_M	UD_N
1	0.549	113599	13 05 20.8776	-39 54 24.9480	1.0	1.996E-5	1.09	0.083	2.93	0	HD 113599	K1III	,Star,*,IR,	0.104	0.062	0.013	0.082	0.082	0.083
2	0.759	114229	13 09 42.4898	-40 51 06.7032	0.998	8.823E-5	1.0	0.193	2.417	0	HD 114229	K0/1III	,Star,*,IR,	0.487	0.276	0.061	0.19	0.191	0.192
3	0.891	113644	13 05 41.5260	-41 17 40.8444	0.998	9.399E-5	0.05	0.196	2.496	0	HD 113644	K0(III)	,Star,*,IR,	0.481	0.281	0.06	0.193	0.194	0.195
4	0.952	113257	13 02 56.6933	-39 44 09.3804	0.999	6.119E-5	0.554	0.16	2.455	0	HD 113257	K0III	,Star,*,IR,	0.352	0.202	0.044	0.157	0.158	0.159
5	1.503	113776	13 06 28.8948	-38 54 43.4232	0.997	1.383E-4	0.083	0.231	2.659	0	HD 113776	K2III	,Star,*,IR,	0.606	0.352	0.076	0.227	0.228	0.229
6	1.648	113765	13 06 27.0480	-42 03 43.9884	0.998	1.399E-4	1.0	0.221	2.942	0	HD 113765	K1/2III	,Star,*,IR,	0.579	0.336	0.072	0.217	0.218	0.219
7	1.743	114693	13 12 43.6248	-39 09 32.7528	0.999	7.014E-5	0.706	0.174	2.356	0	HD 114693	K1III(CNIV/V)	,Star,*,IR,	0.398	0.221	0.047	0.172	0.173	0.173
8	1.795	113572	13 05 05.3671	-38 38 18.5892	0.998	7.564E-5	0.024	0.182	2.339	0	HD 113572	K1III	,Star,*,IR,	0.434	0.236	0.052	0.179	0.18	0.181
9	1.925	112345	12 56 26.8915	-40 08 08.4948	0.998	9.491E-5	1.542	0.202	2.378	0	HD 112345	K0III	,Star,*,IR,	0.523	0.306	0.067	0.199	0.2	0.201
10	1.935	112777	12 59 41.7384	-41 52 30.5148	0.998	7.813E-5	1.0	0.182	2.416	0	HD 112777	K0/2(III)	,Star,*,IR,	0.42	0.235	0.051	0.179	0.18	0.181
11	1.943	112315	12 56 13.6745	-40 29 11.0544	0.998	8.326E-5	1.0	0.193	2.283	0	HD 112315	K0/1(III)	,Star,*,IR,	0.476	0.276	0.059	0.19	0.191	0.192
12	1.997	113790	13 06 44.8980	-42 24 38.9304	0.999	8.17E-5	0.303	0.164	3.118	0	HD 113790	K0III	,Star,*,IR,	0.354	0.197	0.043	0.161	0.162	0.163
13	2.152	115008	13 14 54.4450	-39 00 32.8716	0.998	1.226E-4	0.217	0.227	2.427	0	HD 115008	K2III	,Star,*,IR,	0.62	0.345	0.076	0.224	0.225	0.226
14	2.275	113233	13 02 54.3170	-42 35 27.6504	0.998	9.33E-5	0.101	0.201	2.356	0	HD 113233	K1III	,Star,*,IR,	0.512	0.287	0.063	0.198	0.199	0.2
15	2.302	115327	13 17 07.1806	-39 21 53.9208	0.998	7.361E-5	0.32	0.179	2.339	0	HD 115327	K0III	,Star,*,IR,	0.437	0.245	0.053	0.177	0.177	0.178
16	2.338	115579	13 18 36.3269	-40 08 11.2848	0.997	1.213E-4	0.036	0.228	2.386	0	HD 115579	K2III	,Star,*,IR,	0.614	0.355	0.077	0.225	0.226	0.227
17	2.374	113821	13 06 54.2083	-42 47 13.2072	0.999	7.472E-5	0.104	0.171	2.623	0	HD 113821	K0III	,Star,*,IR,	0.373	0.21	0.046	0.168	0.169	0.169
18	2.427	112531	12 57 52.8634	-42 14 05.6184	0.998	9.121E-5	0.795	0.206	2.197	0	HD 112531	K0III	,Star,*,IR,	0.549	0.327	0.068	0.203	0.204	0.205
19	2.47	115526	13 18 22.6865	-39 29 09.7800	0.999	5.242E-5	0.576	0.15	2.394	0	HD 115526	K0III/IV	,Star,*,IR,	0.306	0.173	0.037	0.147	0.148	0.149
20	2.523	112683	12 59 00.2458	-42 31 09.3288	0.998	9.9E-5	0.861	0.214	2.21	0	HD 112683	K0III	,Star,*,IR,	0.567	0.341	0.073	0.211	0.212	0.213
21	2.544	115481	13 18 02.1271	-41 42 57.2940	0.998	1.11E-4	0.447	0.221	2.334	0	HD 115481	K0III	,*inCl,*iC,*,IR,	0.619	0.377	0.096	0.217	0.218	0.219
22	2.687	112630	12 58 33.6883	-38 12 03.3012	0.998	9.472E-5	0.324	0.208	2.247	0	HD 112630	K1III	,Star,*,IR,	0.541	0.315	0.068	0.205	0.205	0.206
23	2.985	115129	13 15 50.4718	-42 49 40.2960	0.998	8.031E-5	0.562	0.18	2.528	0	HD 115129	K0III	,Star,*,IR,	0.428	0.242	0.052	0.178	0.178	0.179
24	2.991	114021	13 08 05.9513	-37 26 28.6476	0.999	6.467E-5	0.596	0.157	2.668	0	HD 114021	K0III	,Star,*,IR,	0.335	0.189	0.041	0.155	0.156	0.156
25	3.552	112454	12 57 13.8290	-43 31 38.2728	0.998	8.04E-5	0.088	0.189	2.302	0	HD 112454	K0(III)	,Star,*,IR,	0.494	0.266	0.058	0.186	0.187	0.188
26	3.555	113234	13 02 53.1859	-43 54 29.9772	0.998	9.731E-5	0.09	0.206	2.355	0	HD 113234	K0III	,Star,*,IR,	0.535	0.315	0.068	0.203	0.203	0.204
27	3.641	114752	13 13 14.6179	-43 49 47.5644	0.998	1.016E-4	0.446	0.193	2.782	0	HD 114752	K0III	,Star,*,IR,	0.499	0.286	0.061	0.19	0.191	0.192

Filters

- [x] Reject stars farther than : Maximum RA Separation (mn) : 10.0 Maximum DEC Separation (degree) : 10.0
- [ ] Reject stars with magnitude : below : 0.0 and above : 10.0
- [x] Reject Spectral Types (and unknowns) : [x] O [x] B [x] A [x] F [x] G [ ] K [ ] M
- [x] Reject Luminosity Classes (and unknowns) : [ ] I [ ] II [ ] III [x] IV [x] V [x] VI
- [x] Reject Visiblity below : vis2 : 0.5
- [ ] Reject Visibility Accuracy above (or unknown) : vis2Err/vis2 (%) : 2.0
- [ ] Reject Variability
- [x] Reject Multiplicity
- [x] Reject Invalid Object Types
- [x] Diameter quality : Maximum chi square : 2.0 Maximum relative error (%) : 10.0

searching calibrators... done.

127 M

Provided by JMMC

Take home points

- Ensure good calibrator selection with available tools
- Concatenations are important for CAL-SCI
- Manuals provide choices for setups dependent on science

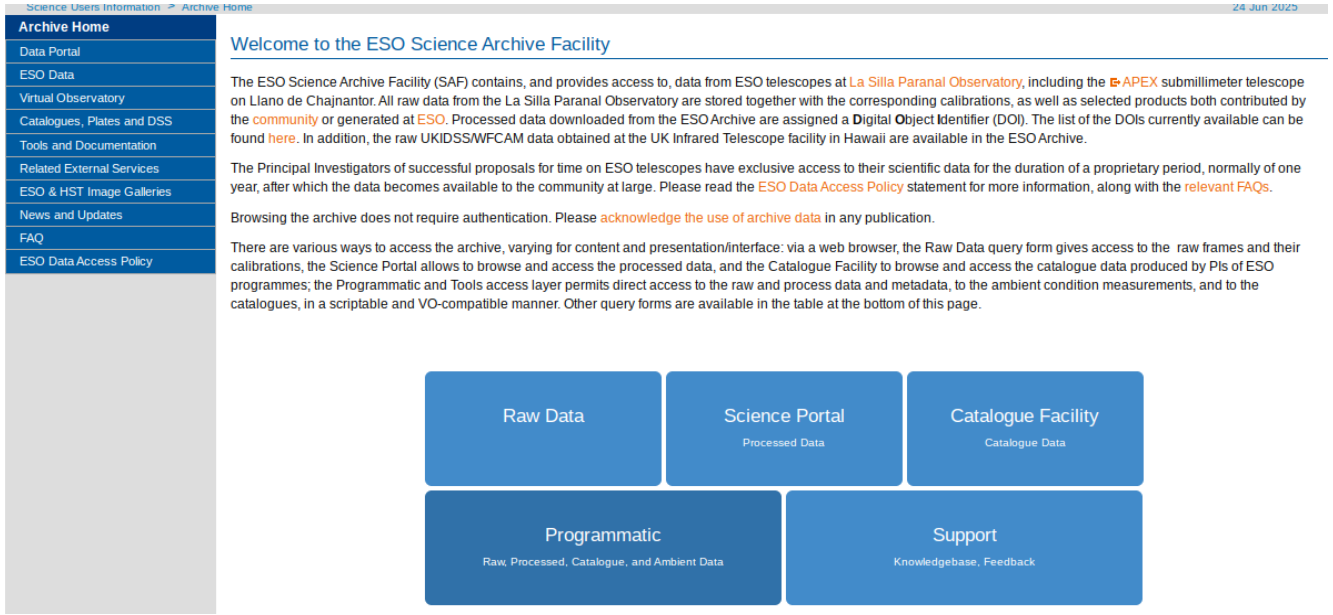
If in doubt, contact the help desks

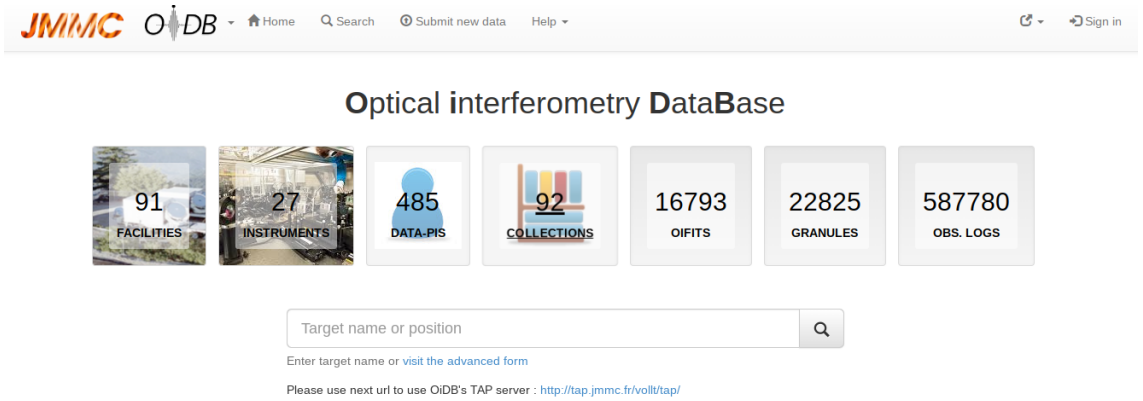
Data reduction and VLTI Expertise Centres

Claire Lykou

Data reduction

- **BEFORE** thinking about applying for time or even reducing data, look at Phase3 products in the archives!
  - ESO archive: archive.eso.org
  - Most of PIONIER data already reduced and ready to use
  - GRAVITY data curation will be available soon
  - Optical Interferometry Database (incl. CHARA): http://oidb.jmmc.fr/index.html





Data reduction

- **Easy-to-use with ESOReflex**
  - Install software (https://www.eso.org/sci/software/esoreflex/)
  - Install pipelines (https://www.eso.org/sci/software/pipe_aem_table.html)
  - Read the manuals/cookbooks!
  - Try the demo data!

	GRAVITY	2025-03-12	1.9.0	1.9.0				Tutorial: 1.6.0 Demo Data: 0.9	yes	Active
	HARPS	2025-02-27	3.3.6	3.3.6			Static Calibration WAVE & DLL Matrixes (17 MB)	Tutorial: 3.3.6 Demo Data: 0.2.0		Active
	HAWKI	2025-03-27	2.5.11	2.5.11				Tutorial: 2.5.11 Demo Data: 0.5	yes	Operational on hold
	ISAAC	2024-05-15	6.2.5	6.2.4			Static Calibration Files (50 MB)			End of maintenance
	KMOS	2025-03-12	4.5.1	3.6				Tutorial: 5.1 Demo Data: 2.2.0	yes	Active
	MATISSE	2025-02-07	2.2.0	2.2.0				Tutorial: 2.2.0 Demo Data: 0.4	yes	Active
	MIDI	2024-05-15	2.9.6	2.9.5						End of maintenance
		2025-02-						Tutorial: 4.4.2		

- *r)*

Data reduction

- **Easy-to-use with ESOReflex**
  - Install software (https://www.eso.org/sci/software/esoreflex/)
  - Install pipelines (https://www.eso.org/sci/software/pipe_aem_table.html)
  - Read the manuals/cookbooks!
  - Try the demo data!
  - Before you reduce your data:
    - Make sure to check observing conditions (night logs, ASM)
    - Make sure you download all auxiliary files per instrument, as well as calibrator data
    - Happy reducing!
    - What you get are OIFITS files (modeling, analysis, image reconstruction)

- ***For more advanced users:*** *try the consortia/community toolboxes (e.g. MATISSE Fcorr)*
  - *ExoGravity:* https://gitlab.obspm.fr/mnowak/exogravity
  - *MATISSE Python tools:* https://github.com/Matisse-Consortium/tools

- **Ask for help! Reach out to the VECs**

VLTI Expertise Centres

- **What we do…**
  - Organise the VLTI schools
  - Co-organise ESO VLTI Open days
  - End-point for staff exchange visits
- **What we offer…**
  - Preparation of VLTI observing proposals
    - *Tools for your science case!*
  - Help with data reduction
  - Help with data quality assessment
    - *Modelling software*
    - *Image reconstruction*

https://european-interferometry.eu/vlti-expertise-centers/

Data analysis

Jens Kammerer

Van Cittert-Zernike theorem

- For constructive (phase-referenced) interferometry (current VLTI instruments):
- Interferometer measures mutual spatial coherence function V(u), or "complex visibility"
- Van Cittert-Zernike theorem:

$$\int I(\vec{\alpha}) e^{-ik\vec{u}\cdot\vec{\alpha}} d\vec{\alpha} = V(\vec{u}),$$

- I(α) is sky brightness distribution ("the image")

Model fitting

- Construct a model for the source (e.g., star + Gaussian disk)
- Calculate its Fourier transform
- Fit it to the observed visibilities (the measured data)
- *Shape of visibility function can provide information on the target (e.g., stellar surface, binary, disk)*

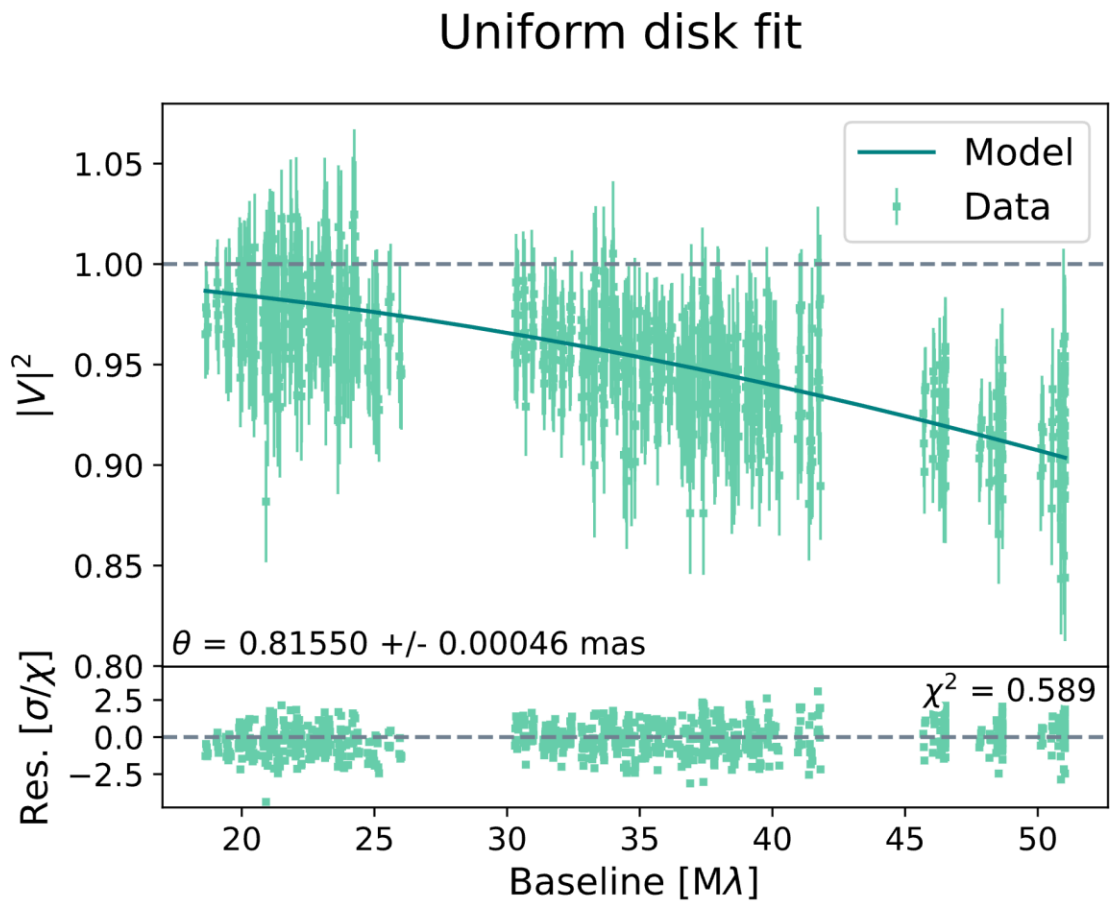
Model fitting

- Some examples:
- Unresolved point source (Dirac function) $V(\rho) = 1$

- Uniform disk $$V(\rho) = 2\frac{\mathrm{J}_1(\pi a \rho)}{\pi a \rho}$$

- Binary $$V(\vec{u}) = \frac{1 + f e^{-2\pi i \vec{\alpha}\cdot\vec{u}/\lambda}}{1+f}$$

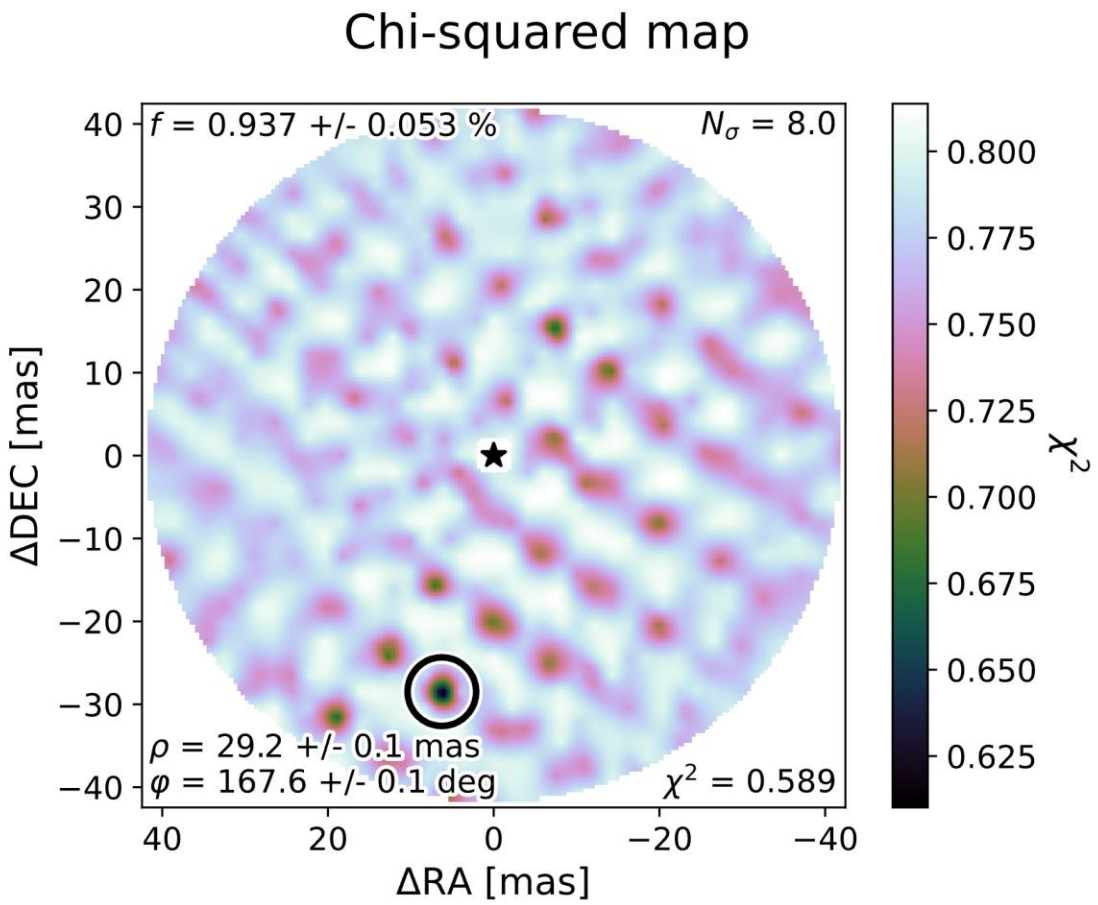
Model fitting



Made with
fouriever

Model fitting

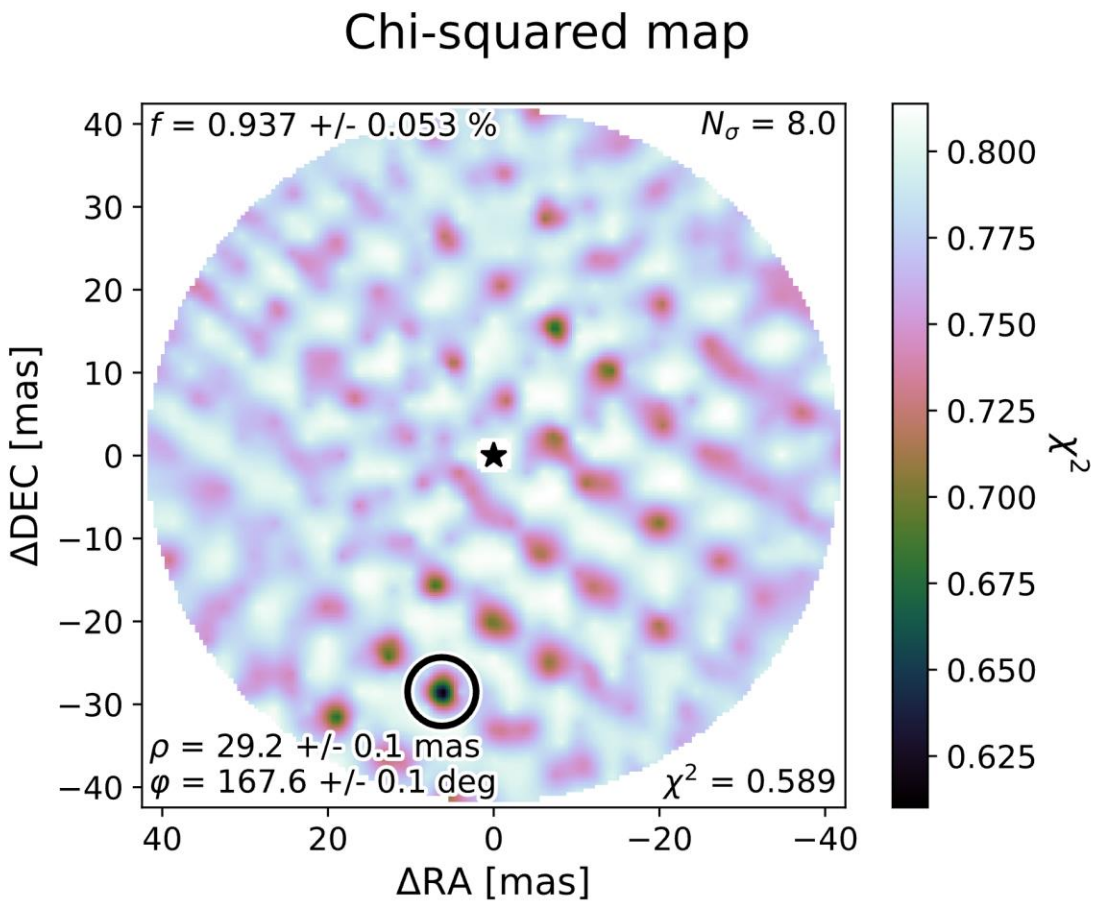
Companion search



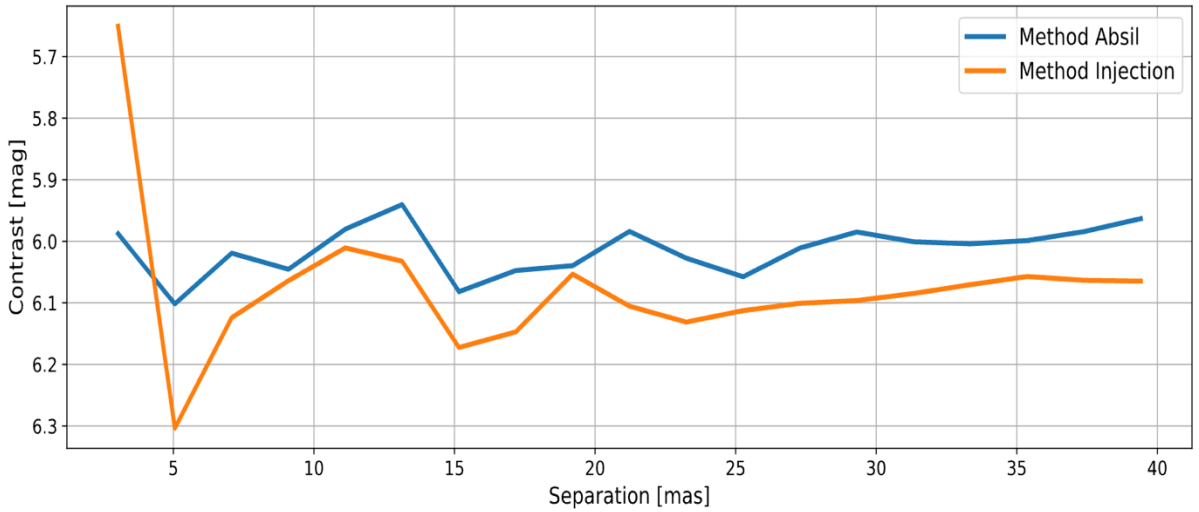
Made with
fouriever

Model fitting

Companion search



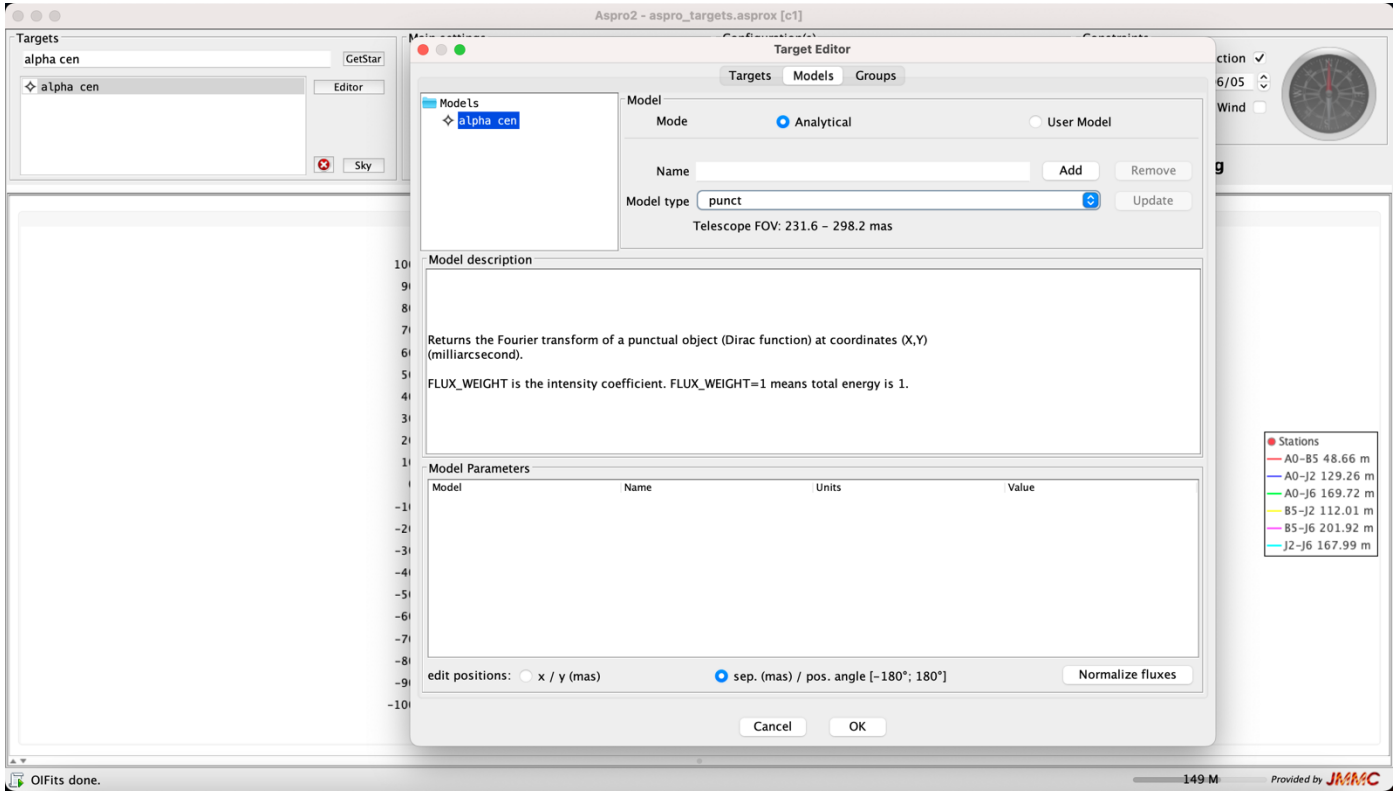
Detection limits



Made with **fouriever**

Model fitting

Aspro can simulate & visualize a lot of different models

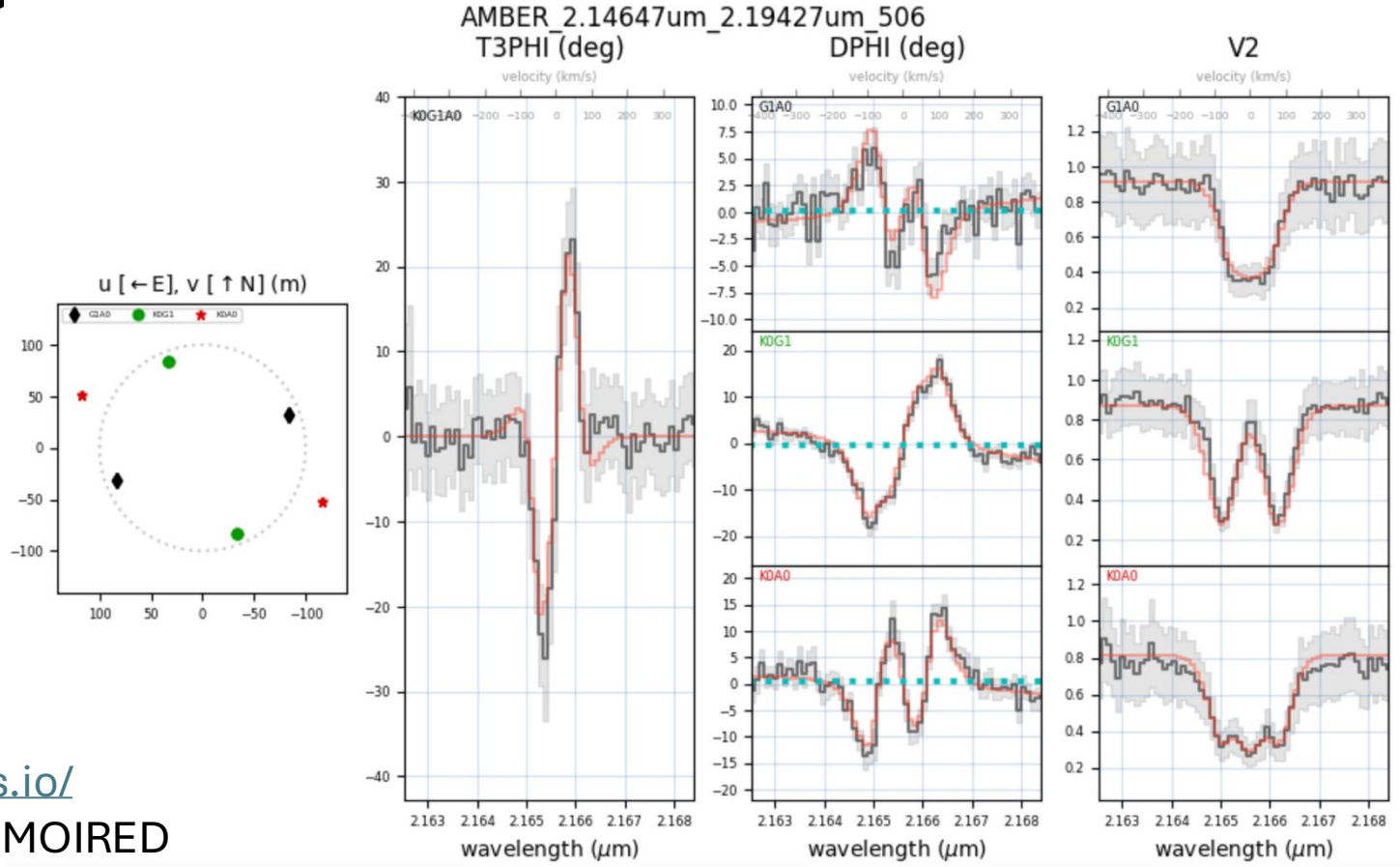


Model fitting

- So far, we have looked at the visibility as a function of spatial frequency
- Through spectroscopy, we can measure a range of baselines simultaneously
- However, so far, we looked at monochromatic models
- We can also construct more complex models with chromatic features, e.g., emission lines
- This is called "spectro-interferometry"

Model fitting

Tools like PMOIRED, OIMODELER, or LITpro can model
more complex scenes:
e.g., star + Gaussian disk + Keplerian disk with emission line (Br-gamma)



https://oimodeler.readthedocs.io/
https://github.com/amerand/PMOIRED

```
chi2 with Meilland+2012 parameters: 3.789
[dpfit] 7 FITTED parameters: ['V0', 'ac', 'al', 'kep,Vin', 'kep,incl', 'kep,line_1_EW', 'kep,projang']
[dpfit] epsfcn= 1e-08 ftol= 1e-05
```


Made with **PMOIRED**

Image reconstruction

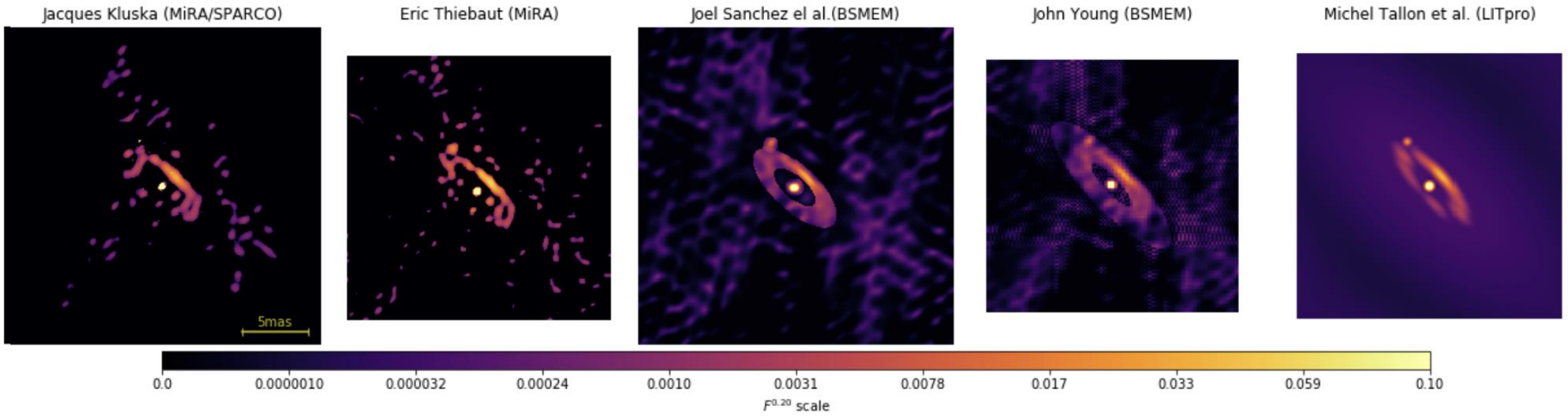
- Attempt to solve the (inverse) Fourier transform
- Problem: V(u) is only measured (constrained) on some spatial frequencies so the solution is not unique
- Need:
  - As much uv-coverage as possible (imaging observations)
  - Regularization to enforce convergence of the minimization problem
- Remember: the VLTI is not like ALMA!
  - 6 vs 2145 baselines is a huge difference

Image reconstruction

- Non-ML tools
  - MiRA: direct minimization of a penalized likelihood using regularization term; language: Yorick
  - SQUEEZE: based on Markov Chain Monte-Carlo (MCMC) exploration of the imaging probability space; language: C
  - SPARCO: semi-parametric approach for image reconstruction of chromatic objects; describe spectral characteristics of both the central object and the extended structure
  - BSMEM: BiSpectrum Maximum Entropy Method
- ML tools
  - Organic: Object Reconstruction with Generative Adversarial Networks from InterferometriC data; language: Python
  - CASSINI-AUTOMAP: Neural Network with adaptive activation functions to find an optimal mapping system between the infrared interferometric data and the reconstructed images; language: Python

Image reconstruction

A good overview can be found in the OI Image Reconstruction Contest at SPIE every 2 years



Mérand et al. 2018

Image reconstruction

An example with OImaging

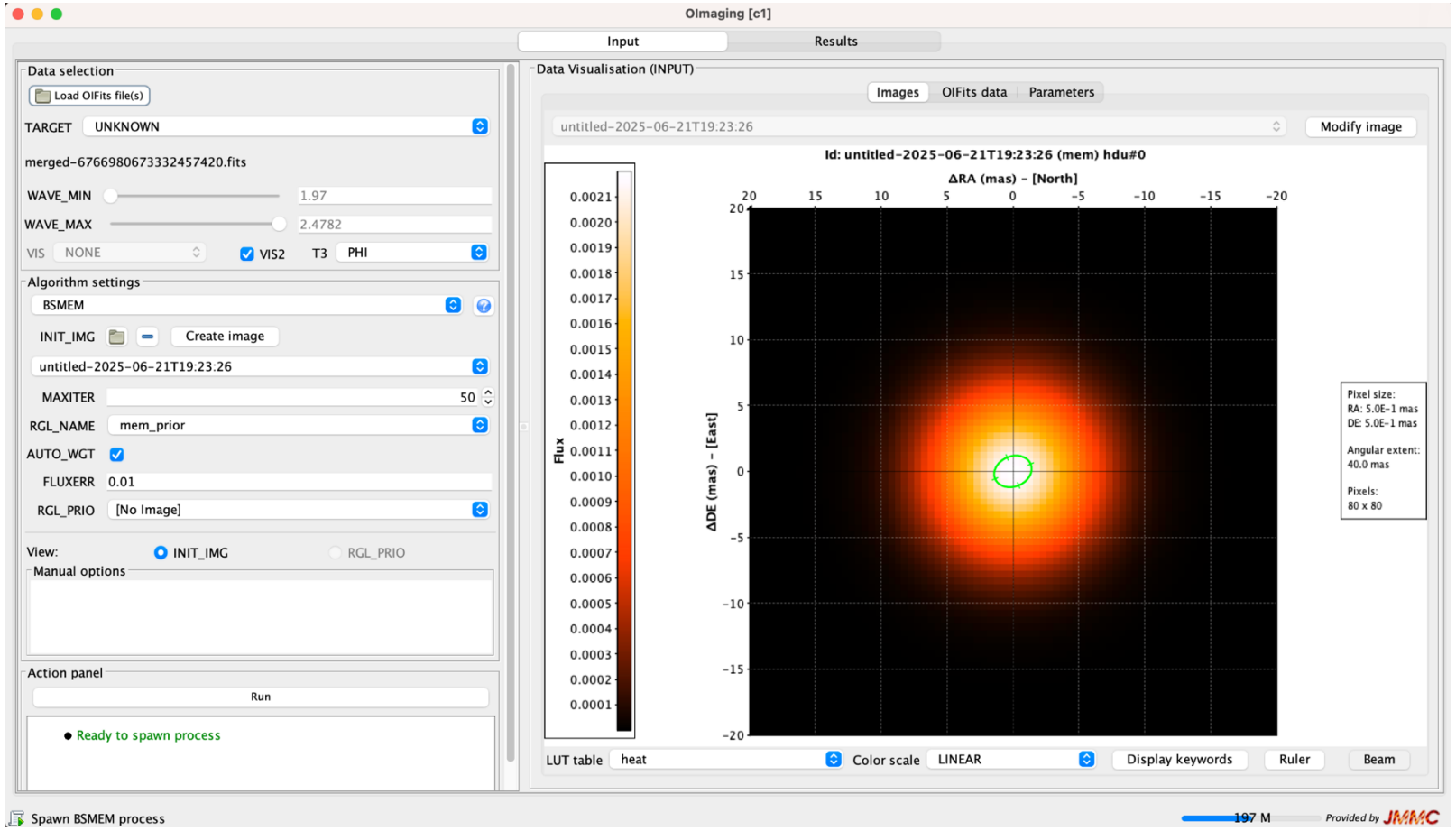
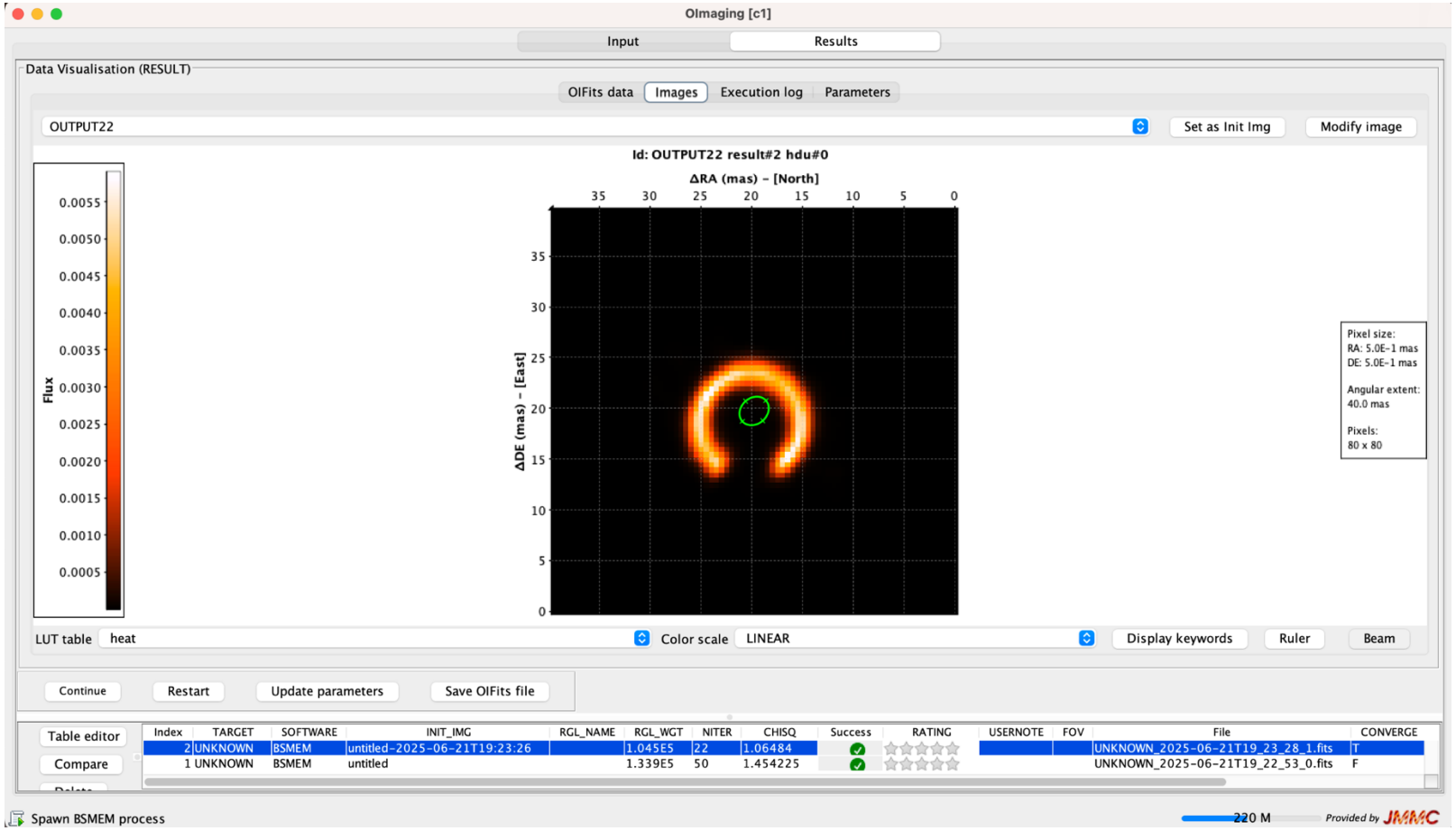


Image reconstruction

An example with OImaging



Useful links

https://github.com/amerand/easyVLTI2025

- Support and assistance:
  - ESO USD https://support.eso.org/en-GB
    - P1 + P2 support
  - JMMC helpdesk https://www.jmmc.fr/english/user-support/expertise-center/
    - Support for any step
- Trainings, JMMC tools and tutorials:
  - VLTI Summer School 2021 material: https://www.jmmc.fr/schools/vltischool2021/
  - VLTI Summer School 2024 material: https://zenodo.org/communities/vltischool2024/records?q=&l=list&p=1&s=10&sort=newest
  - JMMC tools (OIfits Explorer, ASPRO, SearchCal, OIDB): https://www.jmmc.fr/
  - Video tutorials: https://www.jmmc.fr/english/training/tools-tutorials/
- P1
  - Call for proposals: https://www.eso.org/sci/observing/phase1/p116/proposalsclosed.html
  - P1 tool: https://www.eso.org/p1/
  - P1 demo tool: https://www.eso.org/p1demo/
  - Anonymisation rules: https://www.eso.org/sci/observing/phase1/dual-anonymous-guidelines.html
  - Manuals for a given period can be found on the webpages of the instruments: e.g. GRAVITY: https://www.eso.org/sci/facilities/paranal/instruments/gravity/doc.html
- P2
  - SearchCal https://www.jmmc.fr/english/tools/proposal-preparation/search-cal/
  - P2 demo https://www.eso.org/p2demo
- Data analysis
  - Useful in general
    - Aspro: https://www.jmmc.fr/~betaswmgr/Aspro2/
  - Model fitting
    - LITpro: https://www.jmmc.fr/apps/public/LITpro/
    - CANDID: https://github.com/amerand/CANDID
    - PMOIRED: https://github.com/amerand/PMOIRED
    - fouriever: https://github.com/kammerje/fouriever
    - OIMODELER: https://github.com/oimodeler/oimodeler
  - Image reconstruction
    - MiRA: https://github.com/emmt/MiRA
    - SQUEEZE: https://github.com/fabienbaron/squeeze
    - Organic: https://github.com/DePrinsT/organic
    - CASSINI: https://github.com/cosmosz5/CASSINI
    - OIMAGING: https://www.jmmc.fr/english/tools/data-analysis/oimaging/
    - BSMEM: https://www.astro.phy.cam.ac.uk/research/ResearchFacilities/software-for-astrophyiscs/bsmem