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ASPRO2: get ready for VLTI's instruments GRAVITY and MATISSE

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ABSTRACT

ASPRO2 is a complete observation preparation tool developed and maintained by the JMMC that allows to prepare interferometric observations with the VLTI or other interferometers (CHARA, SUSI, NPOI). Available since 2010, ASPRO2 is regularly updated to provide new features, enhancements and to follow the instrumental changes for each ESO & CHARA Call For Proposals.
As the new 2nd generation VLTI instruments GRAVITY & MATISSE, will be soon available to the community, ASPRO2 is evolving to support them. For example, the noise modelling has been improved for the MATISSE instrument which covers new L+M bands by including the thermal noise contribution and atmospheric transmission. Moreover, the OIFITS simulator has been rewritten to generate correctly correlated quantities for the interferometric observables (VIS2, VIS, T3) and will support OIFITS-2 soon. It is already supporting the commissioning of the GRAVITY instrument through its capability to create Observing Blocks compatible with the ESO P2PP tool.

Keywords: Interferometry, Observation preparation, VLTI

1. INTRODUCTION

The Jean-Marie Mariotti Center (JMMC)* is the French Center for Infrared and Optical Interferometry that provides software tools and support to the community dedicated to the observation preparation, data processing & data analysis of optical interferometric data, as shown in a previous SPIE poster [1] .

ASPRO2 is the second version of the Astronomical Software to PRepare Observations (ASPRO) and is available on the JMMC website at http://www.jmmc.fr/aspro. It was first released in 2010 and its main functions (observability, UV Coverage and OIFITS simulation) were presented in a poster [2] at ADASS XX. It improved a lot since, thanks to the regular releases imposed by ESO & CHARA Call for Proposals and the great feedback from the user community.

ASPRO2 supports all optical interferometers in operation (VLTI, CHARA, SUSI, NPOI) and their instruments†, but hereafter this paper will be focused on the VLTI interferometer and its 2nd generation instruments GRAVITY [3] (K band) and MATISSE [4] (L, M & N bands). This article will present ASPRO2 main features, explain in details the improvements made on the OIFITS simulator and noise modelling, noticeably for the MATISSE instrument and finally present some perspectives for future enhancements.

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*JMMC website: http://www.jmmc.fr

†ASPRO2 can also be used for single telescope operations (1.93m telescope at the Observatoire de Haute Provence) and for educational purposes (DEMO interferometer at the pole).

2. MAIN FEATURES

To prepare VLTI observations, ASPRO2 provides many important features:

- define the science and calibrator targets (using CDS Simbad and our SearchCal services) and can manage many targets for large programs. Every object can have either an analytical or user model (see 2.2) and ASPRO retrieves automatically the apparent diameter of stars classified as calibrators,
- define the observation setup by selecting the interferometer & the ESO Period, the instrument, configuration (baselines), the observation date and other constraints,
- display the observability of all targets and the UV coverage of the target along with its model to evaluate which of the proposed configurations (small, medium or large in the VLTI case) is best suited to provide the expected scientific return of the planned observation (see Fig. 1),
- produce a simulated observation, including accurate noise modelling, that other tools can use to perform model-fitting or image reconstruction (see 3).

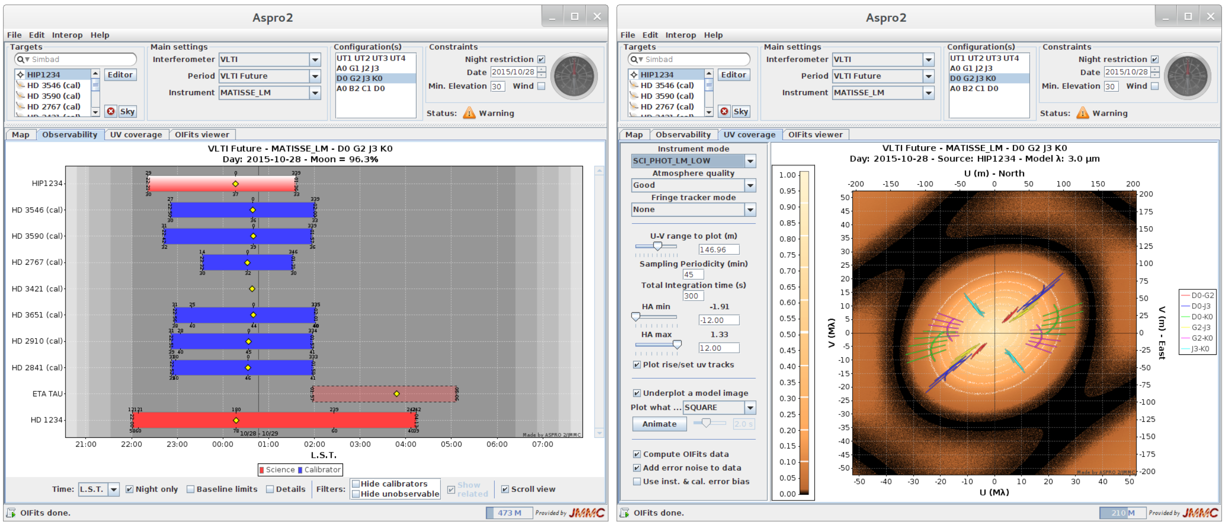

Figure 1. This figure shows the observability and the UV Coverage plots for a MATISSE L+M observation

To determine the source observability at the VLTI interferometer i.e. which time ranges can be observed, ASPRO2 takes into account the night limits at the observation date, the chosen minimum elevation, telescope horizons (shadowing) using, e.g. for VLTI, new profiles recently released, UV coverage restrictions due to the limited optical path compensation for the selected configuration (quadruplets), and the moon avoidance rules. Finally ASPRO2 handle in real time telescope pointing restrictions due to the wind direction that can happen during the night at the telescope to adjust the observation strategy.

The UV coverage plot shows the projected baselines of the target on the Fourier plane sampled regularly within its observability ranges. Each UV sampled segment represents the spectral range of the instrument mode. Besides, the analytical or user model is computed (complex visibility) and scaled (amplitude or phase) to the same field of view.

2.1 VLTI GRAVITY and MATISSE configuration

Since 2014 ASPRO2 provides the GRAVITY and MATISSE instruments in its configuration module in the VLTI “Future” period (experimental support) thanks to the collaboration between JMMC and members of the instrument consortia. The quadruplets are those proposed in Period 96 plus the new quadruplets proposed in Period 98.

As the GRAVITY instrument will be available to the community in the period 98, it is available in the VLTI "Period 98" period with the official quadruplets, but also remains in the VLTI "Future" Period with more quadruplets (requested during the GRAVITY commissioning). It is basically described in ASPRO2 as a 4-telescope instrument in the K band (1.9 to 2.5 μm) with LOW, MEDIUM & HIGH resolutions (respectively 50, 1100, 8000) with a low noise detector and an internal fringe tracker in the H band (max integration time up to 60 seconds). However, the effective medium or high resolution modes officially supported by ESO are still not defined in the ASPRO2 configuration as the commissioning is still in progress. Moreover, ASPRO2 does not yet support the dual-field observation mode.

The MATISSE instrument is still in the testing & integration phase and should arrive at the VLTI in late 2017. Its support in ASPRO2 is preliminary in the VLTI "Future" period but many improvements are already implemented to handle this "polychromatic" infrared instrument (3.5 to 13.5 μm). For now, ASPRO2 has two different 4-telescope instruments MATISSE_LM and MATISSE_N to distinguish the two different detectors (independent and non contiguous spectral ranges) which have their own specifications and observation modes. The MATISSE_LM instrument corresponds in ASPRO2 to the full L+M bands (2.8 to 5.0 μm) with LOW, MEDIUM, HIGH & VERY HIGH resolutions (respectively 30, 500, 950, 4000) and the MATISSE_N instrument to the full N bands (7.5 to 13.5 μm) with LOW & MEDIUM resolutions (respectively 30, 300). Moreover, these large spectral ranges must be refined in the future to match the detector windowing constraints (high resolution spectra can not fit on the detector area) and the read-out speed. Then a work is in progress with the MATISSE team to define properly the effective spectral ranges and the observations modes. For now, ASPRO2 has two modes per resolution: the SCI_PHOT mode corresponds to simultaneous interferometry and photometry measurements (with 2/3 and 1/3 ratio) and the HIGH_SENS mode to the interferometry measurement only (maybe plus some photometry measurements in the observing sequence). Finally MATISSE may benefit from the GRAVITY fringe tracker in the future to stabilize fringes (H band) and allow longer integration times.

2.2 User Models

To provide an object model, ASPRO2's Target editor proposes either Analytical models or User models as shown in Fig. 2. As the spectral resolution of GRAVITY and MATISSE instruments is important, it becomes very important to use polychromatic models, i.e. object models that depend on the wavelength.

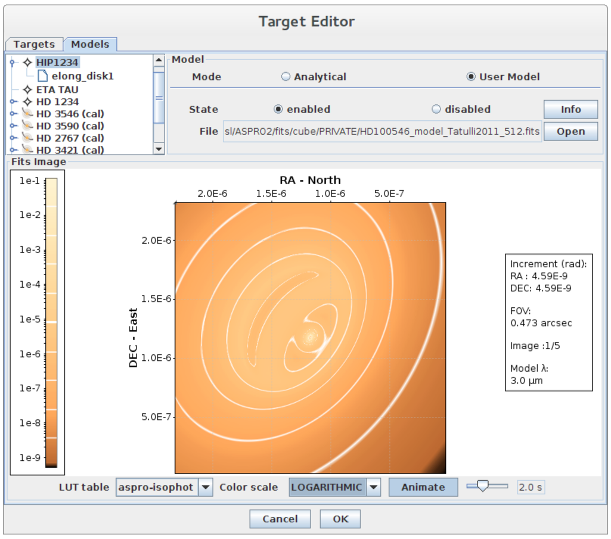

Figure 2. This figure shows the Target Editor for a MATISSE user model (5 channels)

All analytical models are "gray" models i.e. the model parameters does not depend on the wavelength, but User models consist in FITS images (monochromatic models) or FITS cubes (polychromatic models) representing the object flux over the sky (spatial axes RA/DEC) versus the spectral axis (3rd axis).

ASPRO2 interprets the FITS image keywords[‡] to extract the spatial and spectral increments but also their coordinate references and units. Typically these keywords for the spectral axis define the initial wavelength and the spectral increment expressed in the following supported units: meter, micron, nano-meter, hertz. Such polychromatic models allow to compute properly the complex visibilities for the spectral channels of the instrument mode. ASPRO2 determines which image corresponds to every spectral channel by selecting the image whose wavelength is the closest to the spectral channel (within the spectral bandwidth and increment). However, sub-sampling (less images than channels) or super-sampling (multiple images per channel) may happen and ASPRO2 reports such situations (and handles them).

2.3 Observing Blocks

ASPRO2 can export the observation setup for VLTI instruments (AMBER, MIDI, PIONIER) as Observing Blocks (OB) compatible with the ESO P2PP tool (version 3) to simplify the ESO Phase 2 preparation (service or visitor mode). It produces an OB per target (science or calibrator) but also produces the container OB aggregating the science object with its calibrators.

Since May 2016, ASPRO2 can generate correct Observing Blocks for GRAVITY observations in the single field mode only, where the polarization mode is set according to the ASPRO2's instrument mode (COMBINED or SPLIT). To support the dual-field mode, ASPRO2 will be enhanced in the future to manage the association and constraints between the two objects, in a similar manner as the science / calibrator associations. Finally ASPRO2 does not generate Observing Blocks for the MATISSE instrument yet as the ESO MATISSE templates are still not available.

3. OIFITS SIMULATOR

ASPRO2 simulates observation data according to the OIFITS [5] standard (version 1) and provides the OIFITS viewer, derived from our OIFITS Explorer tool, to plot observables quantities (OI_VIS, OI_VIS2, OI_T3 tables) as shown in Fig. 3, as a function of many parameters: spatial frequency, time, wavelength... This section will describe how ASPRO2 simulates observation data in the OIFITS format.

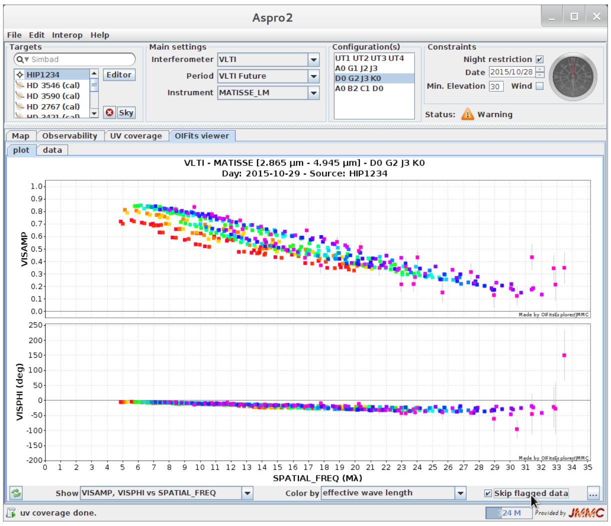

Figure 3. This figure shows the OIFITS viewer representing the simulated visibility (VISAMP and VISPHI, respectively the amplitude and the argument of the complex visibility) vs. the spatial frequencies for a MATISSE observation

‡For more details on the FITS format for user models, please look at the documentation: http://www.jmmc.fr/twiki/bin/view/Jmmc/Software/JmmcAspro2#User_defined_model

3.1 Principle

To simulate the observation, ASPRO2 needs an observable target to determine the sampled hour angles (HA) and its position (azimuth, elevation) within the observability range as shown on the Observability plot. The selected interferometer and configuration fixes the projected baseline vectors between each telescope pair then the sampled UV points for the observable hour angles. The selected instrument mode fixes the spectral dispersion i.e. the spectral channels and their bandwidth to give the concrete spatial frequencies for each spectral channel, as shown on the UV Coverage plot.
To summarize, the observable quantities (OI_VIS, OI_VIS2, OI_T3 tables) are computed at the spatial frequencies (u_{freq}, v_{freq}) corresponding to the sampled HA and baselines (UV points stored in table rows) and per spectral channels λ (stored in the quantity value as an array).

Using the target model (analytical or user model), ASPRO2 computes the complex visibilities C_{vis} at the spatial frequencies (u_{freq}, v_{freq}) for each spectral channel (λ) organized as a 2D table [rows][channels]. ASPRO2 uses the noise modelling component to compute the error on the complex visibilities σ_{vis} derived from square coherent flux formula (see 4) per row and spectral channel. Finally ASPRO2 derives observable quantities (VIS, VIS2, T3) and their errors from C_{vis} and σ_{vis} using the sampling approach described below.

It should be noted that calibrating an observation introduces new uncertainties as the transfer function (instrument plus atmosphere response) evolves between calibrator observations (typically within a CAL–SCI–CAL sequence). Unfortunately, this "calibration error" is a bias and not an additional gaussian error term, as it is currently the case in ASPRO2. It will be improved in the future but this task is complex: simulate both science and calibration observations with their errors (square coherent flux), add the transfer function variability (to be modelled) and then perform the calibration to obtain realistic square visibilities and (ultimately non-gaussian) errors. As such non-gaussian errors are awkward to deal with in the inverse problem of image reconstruction, those programs should better try to restore under some continuity constraints simultaneously the unknown object and the known calibrator(s) instead of using only calibrated data.

3.2 Sampling approach

ASPRO2 uses sampling distributions as multivariate normal distribution $D(variance = 1) = N_r(0,1) + iN_i(0,1)$ with 1024 samples i.e. both real and imaginary parts are independent normal distributions as shown in Fig. 4.

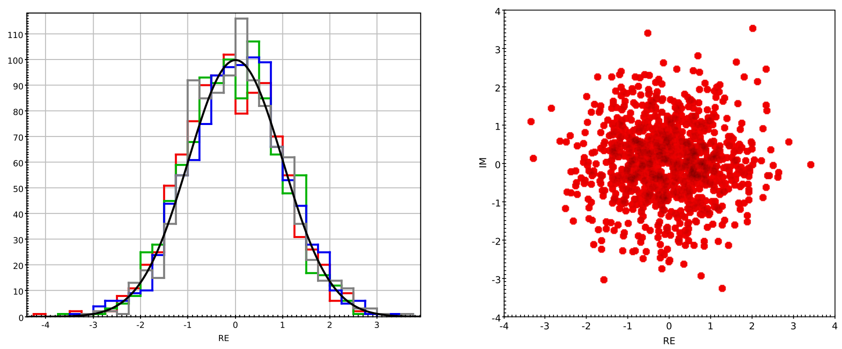

Figure 4. This figure shows several normal distributions (1024 samples) on the left and one complex normal distribution represented in the real and imaginary plane

To generate samples of the complex visibility with a circular-symmetric error distribution with $\sigma = \sigma_{vis}$, the distribution $C_{sample} = C_{vis} + D(\sigma_{vis}^2)$ is computed that gives $\Re_{sample} = \Re_{vis} + N_r(0, \sigma_{vis}^2)$ and $\Im_{sample} = \Im_{vis} + N_i(0, \sigma_{vis}^2)$.

To compute correlated quantities VIS, VIS2 and T3 for the related UV points (baseline or triplets), ASPRO2 uses one distribution D per UV point but determine randomly a sampling index j for each hour angle and

Table 1. Complex visibilities of the triplet (1 2 3) for 1 sampled hour angle and 1 spectral channel

C_{vis} (Re, Im)	σ_{vis}	Baseline (stations)	D (distrib.)	sample index
C_{12}	σ_{12}	1-2	D_1	j
C_{23}	σ_{23}	2-3	D_2	j
C_{13}	σ_{13}	1-3	D_3	j

spectral channel that will be used to get consistently the jth sample of each observable quantity, as described in the table 1.

ASPRO2 uses complex visibility samples to numerically compute samples of the observable quantities (see 3.2.1 and 3.2.2) and estimate the appropriate mean and variance of these sampled variables and provide a numerical but consistent error estimation.

For angular variables (VISPHI, T3PHI), ASPRO2 performs two passes to compute first the average angle avg_angle (using the sum of sine and cosine[§] and secondly the variance as the sum of the squares of the distance [0..180 deg] between the sampled angle from the average angle avg_angle.

Finally the jth sample of each sampled variable is retained as the "noisy" observable quantity, that produces "correlated" quantities having the same hour angle, baseline(s) and wavelength.

3.2.1 OI_VIS & OI_VIS2 tables

ASPRO2 computes the following variables for the square visibility and the theoretical visibility, as the visibility estimation is strongly dependent on the instrument data reduction algorithm (differential):

- $VIS2DATA = |C_{sample}|^2 - bias = \Re^2_{sample} + \Im^2_{sample} - 2\sigma^2_{vis}$
- $VISAMP = |C_{sample}| = \sqrt{\Re^2_{sample} + \Im^2_{sample}}$
- $VISPHI = \arg(C_{sample}) = atan2(\Im_{sample}, \Re_{sample})$

Note: the unbiased VIS2DATA samples may be negative or exceed the typical range [0..1].

3.2.2 OI_T3 table

To compute the bi-spectrum $T3$, ASPRO2 uses 3 different complex visibility distributions (from C_{12}, C_{23}, C_{13}) to have 6 independent variables (real and imaginary parts are independent) and compute the following variables:

- $T3_{sample} = C_{12}C_{23}\overline{C_{13}} = \Re_{T3\_sample} + i\Im_{T3\_sample}$
- T3AMP $= |T3_{sample}| = \sqrt{\Re^2_{T3\_sample} + \Im^2_{T3\_sample}}$
- T3PHI $= \arg(T3_{sample}) = atan2(\Im_{T3\_sample}, \Re_{T3\_sample})$

[§] as described in the wikipedia page "Mean of circular quantities" at: https://en.wikipedia.org/wiki/Mean_of_circular_quantities

4. NOISE MODELLING IMPROVEMENTS

ASPRO2 applies the approach described in the JMMC document "Noise Model for Interferometric combiners"¶ that models a generic interferometer and recombiner observing the science object that has been recently refined to include the thermal background noise.

The photons from the science object are affected by the atmosphere transmission, the adaptive optics system (Strehl ratio) to perform injection into the spatial filter of the recombiner‖, and finally by the interferometer and instrument transmission. Let $N(\lambda)$ define the photon count of the science object per second, per beam and per spectral channel (see 4.2 for its expression) and $N_{th}(\lambda)$ the photon count of the thermal background per spectral channel (see 4.1 for the MATISSE instrument). Of course, the spectral channels depend on the instrument mode (wavelength range and spectral resolution) and their bandwidth may be non-linear.

The instrument recombiner is modelled by one Interferometric channel and several Photometric channels (one per telescope beam) measured by a CCD detector (read-out noise σ_{det}) where the incoming photons are spectrally dispersed on interferometric and photometric pixels, respectively per spectral channel n^I_{pix} and n^P_{pix} per photometric beam. Besides, the fractions f_I and f_P describe the proportions of the incoming photons in the interferometric and photometric channels.

ASPRO2 determine the number of frames without saturating the detector (total flux in a single interferometric pixel during 1 *dit*). Moreover, a fringe tracker may help stabilizing the fringes (at the expense of a small transmission loss) and ASPRO2 will determine the frame integration time t_{int} without saturation (longer than *dit* with the fringe tracker).
The total integration time, defined by the user in the ASPRO2 interface (typically 300s), corresponds to the total time spent on the science object and determines the number of frames that improves the signal-to-noise ratio by $\sqrt{n_{frame}}$. ASPRO2 does not work in terms of the duration of an observing block (OB) including overheads, chopping, etc, in contrary to other ETC tools, but this behaviour could be implemented in the future.

To convert the photon count per second to the number of photo-electrons per frame, ASPRO2 uses the following formula including the quantum efficiency of the detector (≈ 50% in mid. infrared):

$$N_I^{e^-}(\lambda) = f_I N(\lambda) Q_E t_{int},$$

$$N_P^{e^-}(\lambda) = f_P N(\lambda) Q_E t_{int},$$

and for the thermal background:

$$N_{I\_th}^{e^-}(\lambda) = f_I N_{th}(\lambda) Q_E t_{int},$$

$$N_{P\_th}^{e^-}(\lambda) = f_P N_{th}(\lambda) Q_E t_{int}.$$

ASPRO2 computes the square visibility error $\sigma(|V|^2)$ from the the interferometric and the photometric contributions to the square coherent flux error:

$$\sigma(|V|^2) = \frac{|V|^2}{\mathrm{SNR}(|V|^2)},$$

$$\frac{1}{\mathrm{SNR}(|V|^2)^2} = \frac{1}{\mathrm{SNR}(|F_c|^2)^2} + \frac{2}{\mathrm{SNR}(F_p)^2},$$

where F_c is the coherent flux and F_p the photometric flux for the baseline B_{ij} (stations i and j) as the SNR on the photometric fluxes F_p^i and Fp^j are equals. The SNR of the square coherent flux is

$$\mathrm{SNR}(|F_c|^2) \approx \frac{N_I^{e^-} V_{inst}|V|}{\sqrt{2N_{tel}(N_I^{e^-} + N_{I\_th}^{e^-}) + 2n^I_{pix}\sigma^2_{det}}}\sqrt{n_{frame}},$$

¶the JMMC-MEM-2800-0001 document is available at
http://www.jmmc.fr/doc/index.php?search=JMMC-MEM-2800-0001

‖The model is valid only for spatially filtered interferometers.

and the SNR of each photometry is

$$\mathrm{SNR}(F_p) = \frac{N_P^{e^-}}{\sqrt{N_P^{e^-} + n_{exp}^P(N_{P\_th}^{e^-} + n_{pix}^P \sigma_{det}^2)}} \sqrt{n_{frame}},$$

where V_{inst} is the total instrumental visibility, N_{tel} the number of telescopes (beams) and n_{exp}^P is the number of photometric exposures per photometric beam to take into account the possible chopping for mid. infrared observations.

Finally the complex visibility error is derived from

$$\sigma(|V|) = \frac{\sigma(|V|^2)}{2V} = \frac{|V|}{2\mathrm{SNR}(|V|^2)}$$

and is equally distributed on both real and imaginary parts to have a circular-symmetric distribution.

4.1 MATISSE setup and thermal background noise

In ASPRO2's configuration, an instrument describes instrument setups (noise modelling parameters) and instrument modes (wavelength range and spectral resolution). For example, the MATISSE_LM instrument has two instrument setups SCI_PHOT and HIGH_SENS that gathers noise modelling parameters (typical *dit*, flux fractions f_I & f_P, detector's quantum efficiency Q_E and read-out noise σ_{det}, average pixel count per spectral channel n_{pix}^I and n_{pix}^P) that are not depending on the spectral resolution. Besides, the instrument setup gives the exposure sequence (SCIENCE, SKY, PHOTOMETRY...) to describe MATISSE's chopping ($n_{exp}^P = 2$), and optionally the interferometry / photometry sequential exposures in the HIGH_SENS mode.

Each instrument mode describes the instrument spectral dispersion either basically by giving the wavelength range and spectral resolution or by using a data table to provide a finer description. Actually, this table provides the spectral channel description (λ and $\Delta\lambda$ per resolution element i.e. not per pixel) and related noise modelling parameters per telescope (UT or AT): the photon count of the thermal background $N_{th}(\lambda)$ per second, the interferometer + instrument transmission $T_{ins}(\lambda)$ (without Strehl nor Q_E) and the instrument visibility V_{inst}. Of course, the table values are computed theoretically by the MATISSE team (IDL code) to take into account the instrument parameters (background emissivity, transmission, spatial filter ...) and incorporated in the ASPRO2 configuration, as illustrated on the Fig. 5.

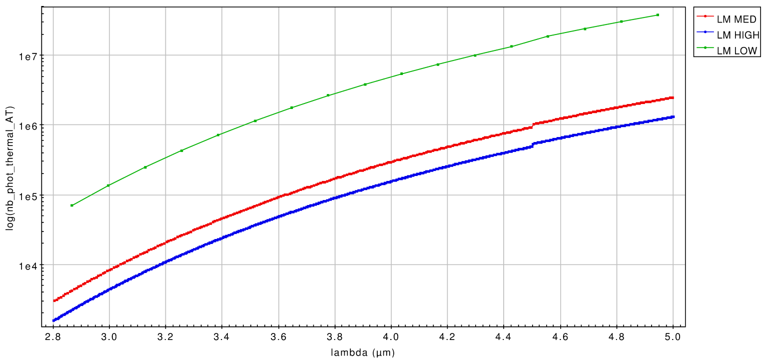

Figure 5. This figure shows the photon count of the thermal background $N_{th}(\lambda)$ per second (log axis) for the MATISSE L+M bands (2.8 to 5.0 μm) on AT telescopes at LOW, MEDIUM and HIGH resolutions

This solution allows a good description of the spectral channels (supporting variable bandwidths) and spectrally dependent parameters: the thermal background increases along the spectral axis (and depends on the the channel bandwidth) and the transmission and visibility are different between L, M and N bands. Finally, the data tables for MATISSE's instrument modes will be updated with more accurate values during the test or commissioning phases.

4.2 Object photon count

ASPRO2 uses the object magnitudes corresponding to the instrument mode to compute its flux in the instrument bands. These magnitudes can be retrieved automatically from CDS's SIMBAD for B, V, J, H, K bands but should be given manually for L, M, N bands (from the WISE catalog).
The object flux is given by $flux(\lambda) = \phi_0(band)10^{-0.4mag(band)}$ in $m^{-2}.s^{-1}.m^{-1}$ where ϕ_0 is the zero-magnitude flux in the corresponding band. This approach is very basic and will be improved in the future to obtain either the flux from polychromatic user models (FITS cube) or from theoretical or observed spectra.
The total number of photons (per beam, per second) is given by

$$N(\lambda) = flux(\lambda)\Delta\lambda S_{tel} Strehl(\lambda, elevation)T(\lambda),$$

where S_{tel} is the surface of the telescope, $Strehl(\lambda, elevation)$ the Strehl ratio depending on the wavelength and the object elevation on the sky (see 4.2.2) and $T(\lambda)$ the global transmission. It combines the atmosphere transmission $T_{atm}(\lambda)$ (see 4.2.1) and the interferometer and instrument transmissions $T_{ins}(\lambda)$ (but without the Strehl ratio or quantum efficiency that are already handled), that gives $T(\lambda) = T_{atm}(\lambda)T_{ins}(\lambda)$.

4.2.1 Atmosphere transmission

ASPRO2 uses now one atmosphere transmission spectra at high resolution (60000) for average observation conditions (yearly, airmass = 1 arcsec, PWV = 2.5mm) at zenith provided by the ESO SkyCalc** tool (Cerro Paranal Advanced Sky Model) described in articles [6,7]. According to the instrument mode (spectral channels and their bandwidths), ASPRO2 resamples its atmosphere transmission spectra to obtain the atmosphere transmission $T_{atm}(\lambda)$ as illustrated in Fig. 6. The impact of the atmosphere transmission is important at the band boundaries, between L & M bands or at higher resolution. Different weather conditions (PWV, airmass) or the target elevation could be handled in the future, but such refinements seem less important than having a more accurate object flux (spectra).

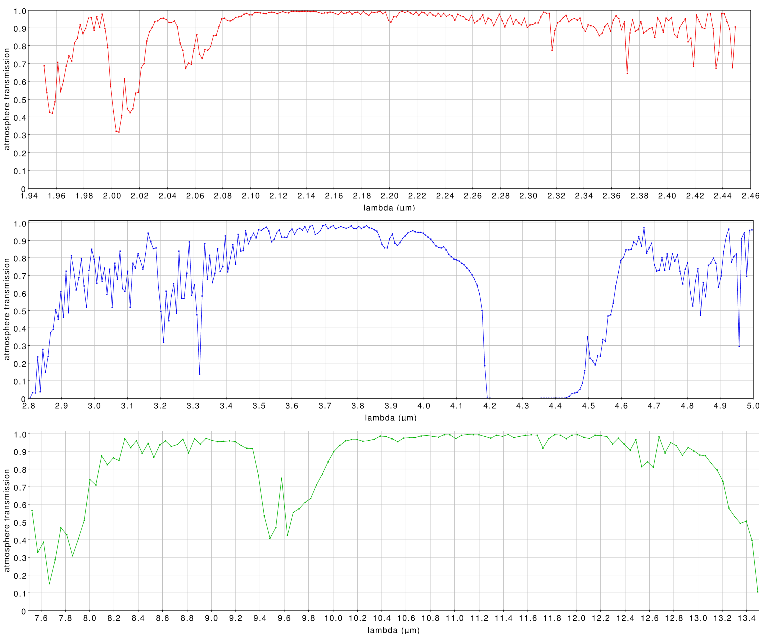

Figure 6. This figure presents the atmosphere transmission for GRAVITY & MATISSE instruments at medium resolution; top: GRAVITY K band, middle: MATISSE L+M bands, bottom: MATISSE N band

**ESO SkyCalc is available at:
https://www.eso.org/observing/etc/bin/gen/form?INS.MODE=swspectr+INS.NAME=SKYCALC

4.2.2 Strehl ratio

ASPRO2 takes into account the zenithal angle ($\gamma = 90 - elevation$) of the object on the sky to estimate the Fried parameter r_0 from the seeing θ (arcsec) at the observing wavelength λ (μm) ($\lambda_V = 0.55\mu m$):

$$r_0 = 0.251 \cos(\gamma)^{3/5} (\frac{\lambda_V}{\theta})(\frac{\lambda}{\lambda_V})^{6/5}.$$

Finally the strehl ratio S for each spectral channel is computed as described in the AMBER document (AMB-IGR-011) and the article [8] :

$$S = \exp(-\sigma_\phi^2) + \frac{1 - \exp(-\sigma_\phi^2)}{1 + (\frac{D}{r_0})^2}$$

$$\sigma_\phi^2 = \sigma_{\text{alias+fit}}^2 + \sigma_{\text{photons}}^2 + \sigma_{\text{fixed}}^2,$$

$$\sigma_{\text{alias+fit}}^2 = 0.87 N_{\text{act}}^{-5/6} (\frac{D}{r_0})^{5/3},$$

$$\sigma_{\text{photons}}^2 = 1.59 \times 10^{-8} (\frac{D}{r_0})^2 (\frac{\lambda}{\lambda_V})^{-2} N_{\text{act}} 10^{0.4 mag_V},$$

$$\sigma_{\text{fixed}}^2 = -\log S_{max}$$

where D is the telescope diameter, and S_{fixed} is the maximum strehl ratio due to fixed aberrations (see 2).

Table 2. Strehl ratio limit in function of the observing bands

Band	B	V	R	I	J	H	K	L	M	N
S_{max}	0.48	0.5	0.65	0.75	0.77	0.84	0.93	0.972	0.985	0.996

5. CONCLUSION AND PERSPECTIVES

ASPRO2 is now 5 years old and the JMMC makes its best to maintain and improve it according to user feedbacks and support new instruments such as GRAVITY and MATISSE thanks to our collaboration with instrument consortia. This is an ongoing effort to refine the offered observing mode in ASPRO2 (and noise modelling parameters) to propose a "realistic" simulated instrument to the end-user (neither optimistic nor pessimistic) as these instruments are providing high resolution and polychromatic observations.

Here is a list of future improvements:

- Define new target associations (guiding star, dual field) as calibrator-like relationships and allow user-defined tags (priorities, programs...) to targets
- Export Observing blocks for GRAVITY (dual-field mode) and MATISSE
- OIFITS 2 support & OIFITS Explorer improvements
- Target flux from FITS cube (polychromatic model) or from user-given spectrum ?
- Noise modelling improvements: adjust parameters for GRAVITY / MATISSE, chopping correction factor (MATISSE)

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