Holographic Optical Element to measure the atmospheric transmission with AuxTel

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+ Marc Betoule and Laurent Le Guillou (LPNHE)
PCWG-Workshop 25/may/2018

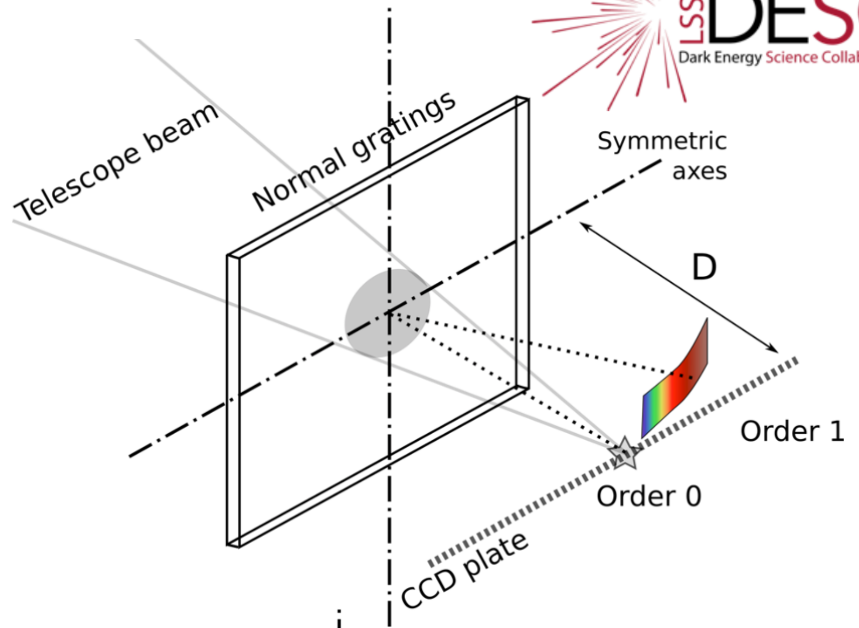
HOE for AuxTel

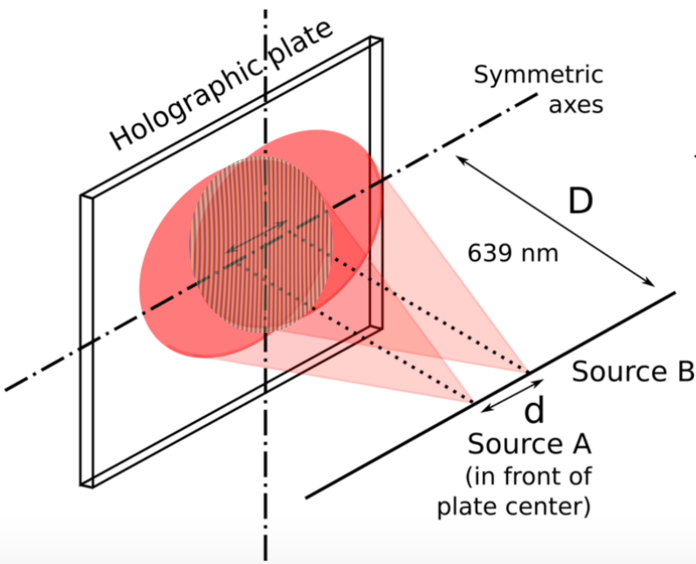
Usual gratings:

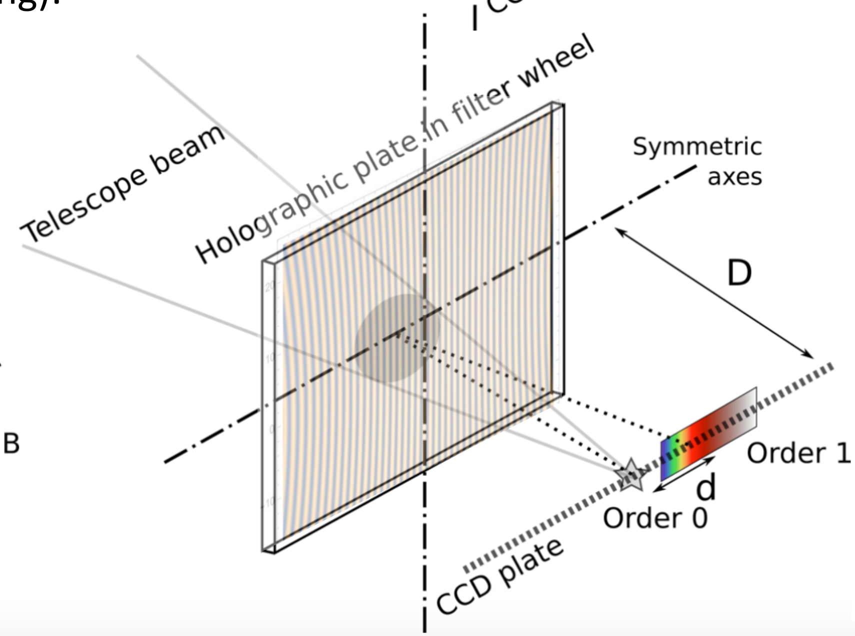
- all wavelengths not focused simultaneously due to optical path variation with the diffraction angle
- Distorsions (astigmatism) due to converging beam (not parallel)

Holograms:

- Focusing forced on the focal plane at all wavelengths
- No distorsions by design of the hologram
- Theoretical hologram (linear phase encoding): only -1, 0, +1 orders

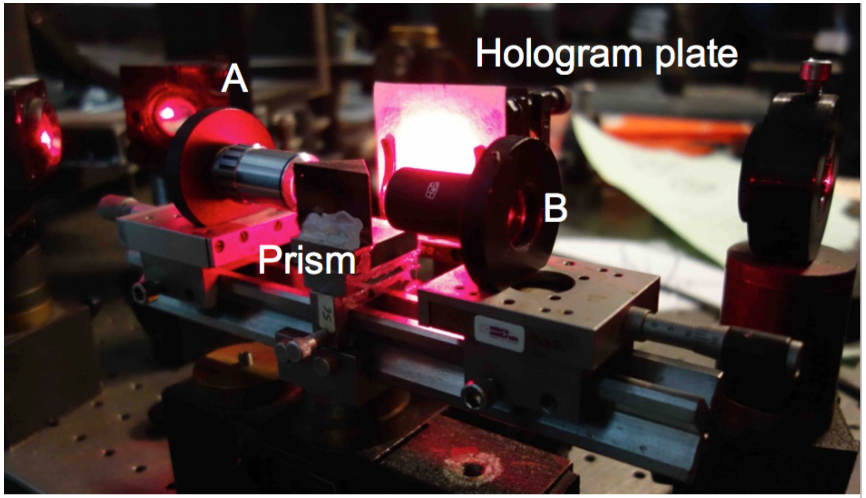


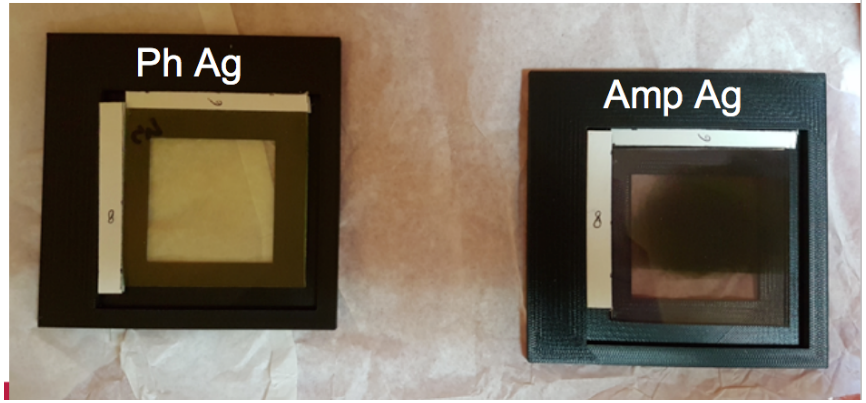




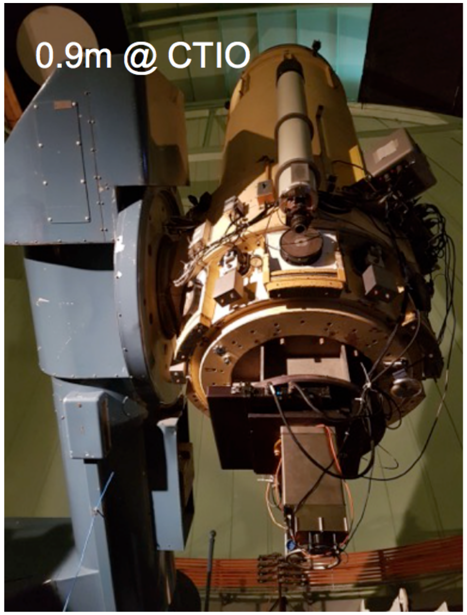
Realization of the HOE
(Holographic Optical Element)

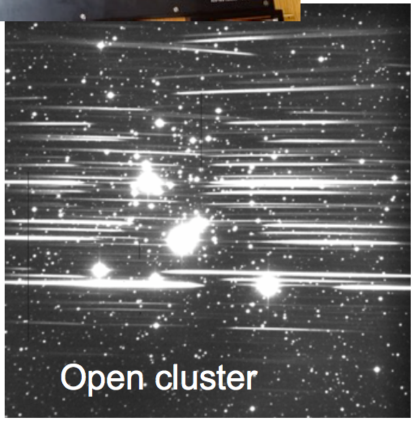
- **Ultimate holography company**: *makes the best holograms in the world. Director (Mr Gentet) was the head of a Thales laboratory producing holographic windows for rafale planes until the end of cold war.*
- 3 technologies:
  - Amplitude holograms: transmission modulation
  - Phase holograms: phase modulation (2 techniques)
- Tested together with **Ronchi** and **blazed gratings** during may-june 2017 CTIO run (18 nights)

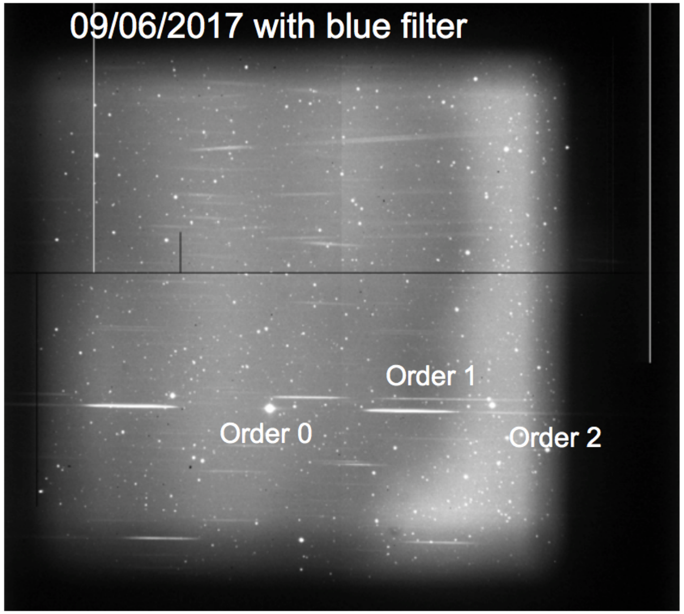


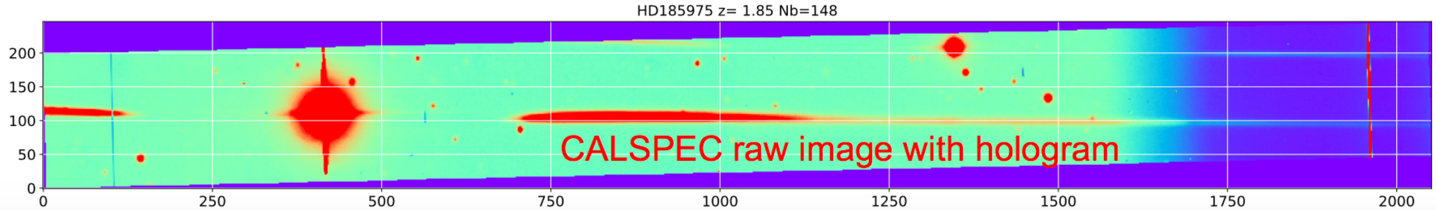


Holograms on a telescope









Tests on telescope : 27 may-13 june 2017

Objectives

- Compare **Ronchi, blazed gratings and holograms (phase & amplitude)**
- Obtain data with various atmospheric conditions

Observations made

- 16 clear nights with variable conditions
- Measures and comparisons of spectra from:
  - **Standards HST** spectro-photométriques (**CALSPEC**)

    Extended series of consecutive measurements with variab airmass

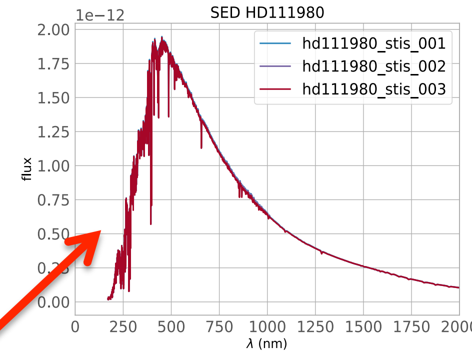
  - **Planetary nebulae**

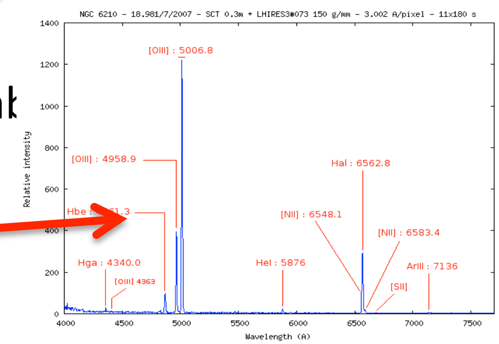
    Narrow and strong emission lines

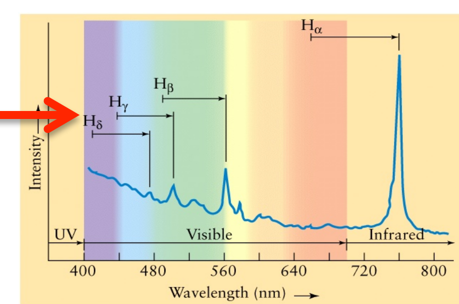
    -> to study the dispersion law and estimate spectral resolution

  - **Quasars**

    Strong redshifted $H\alpha$ *-> to test R et IR spectrscopy*

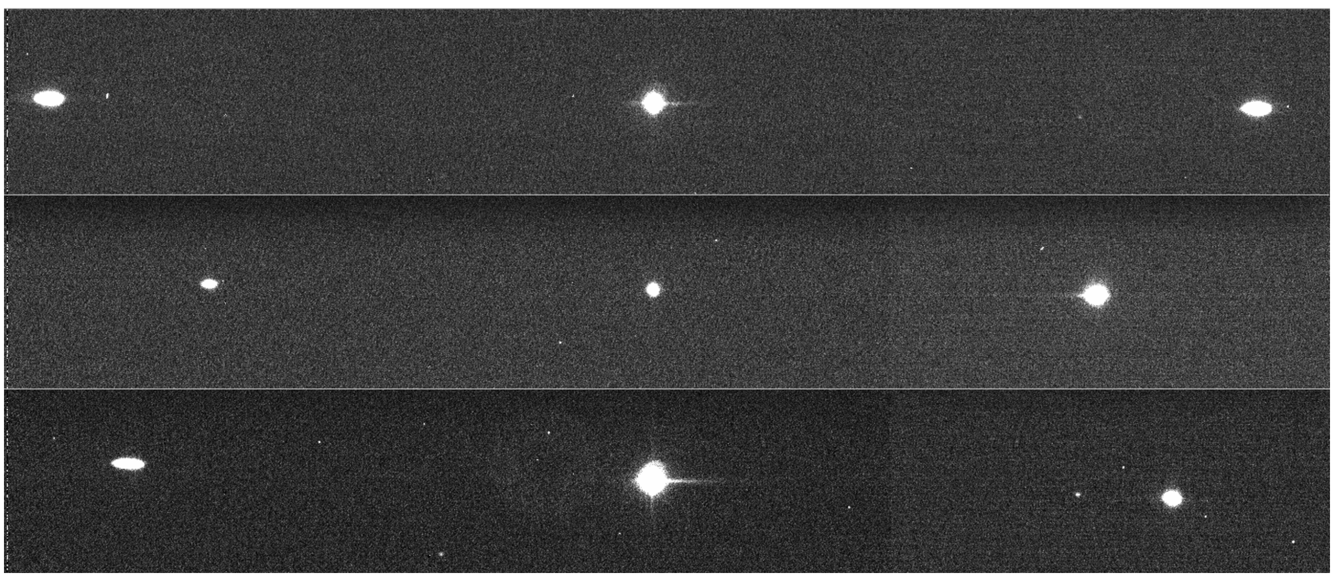






Disperser performances

- HOE designed to compensate geometrical distortions for 1rst diffractive order, by design
  - Tests with narrow H_{α} filter (FWHM = 6.4 nm)
  - Best results with the +1 order of the hologram



Ronchi
400 lines/mm

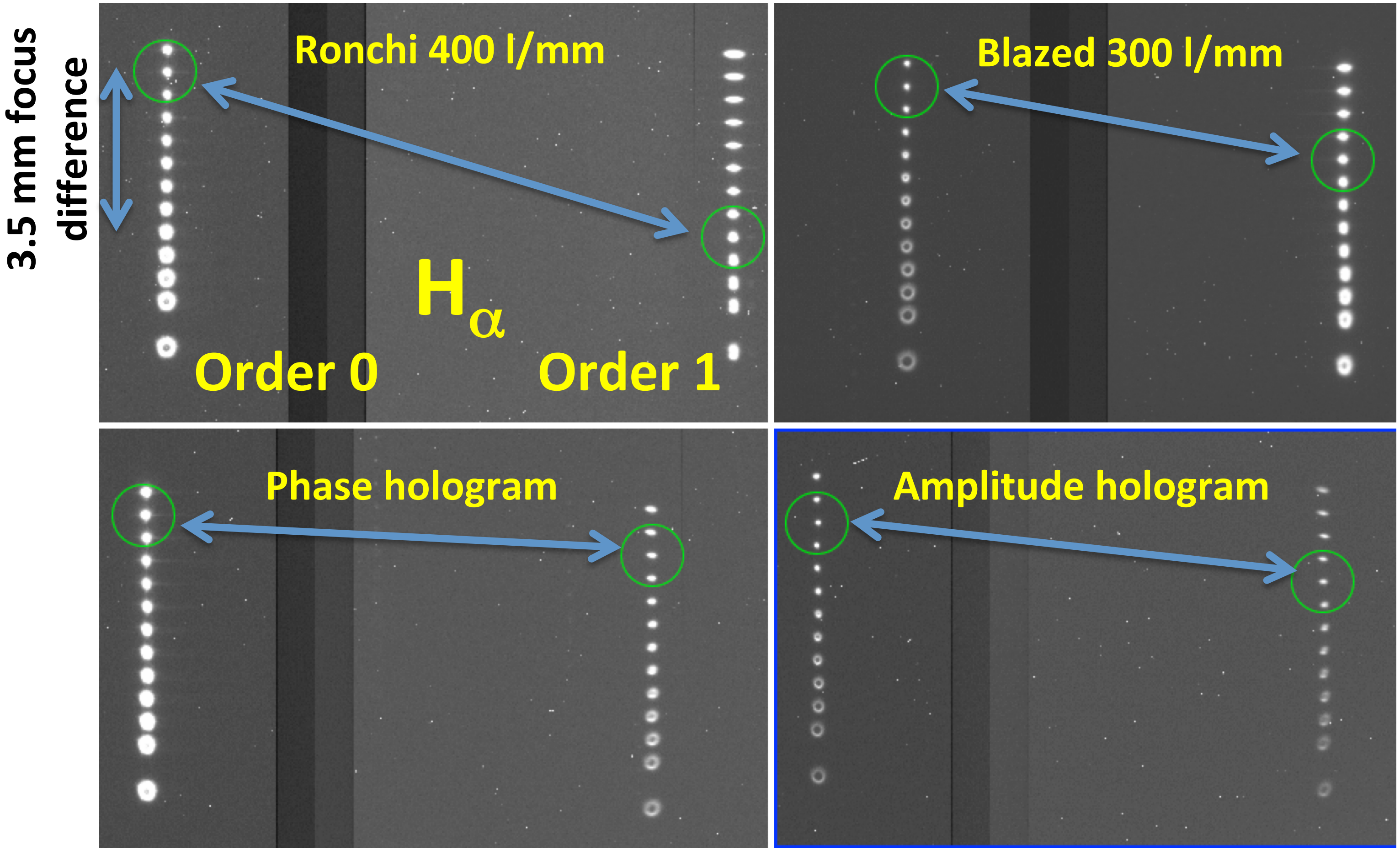
Blazed grating
300 lines/mm

Phase hologram
~365 lines/mm

Order -1 **Order 0** **Order +1**

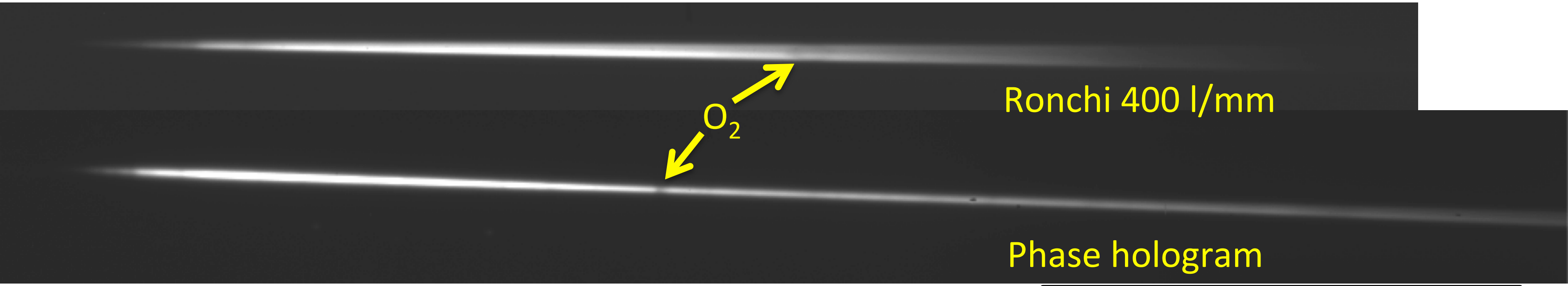
Let's look in more details

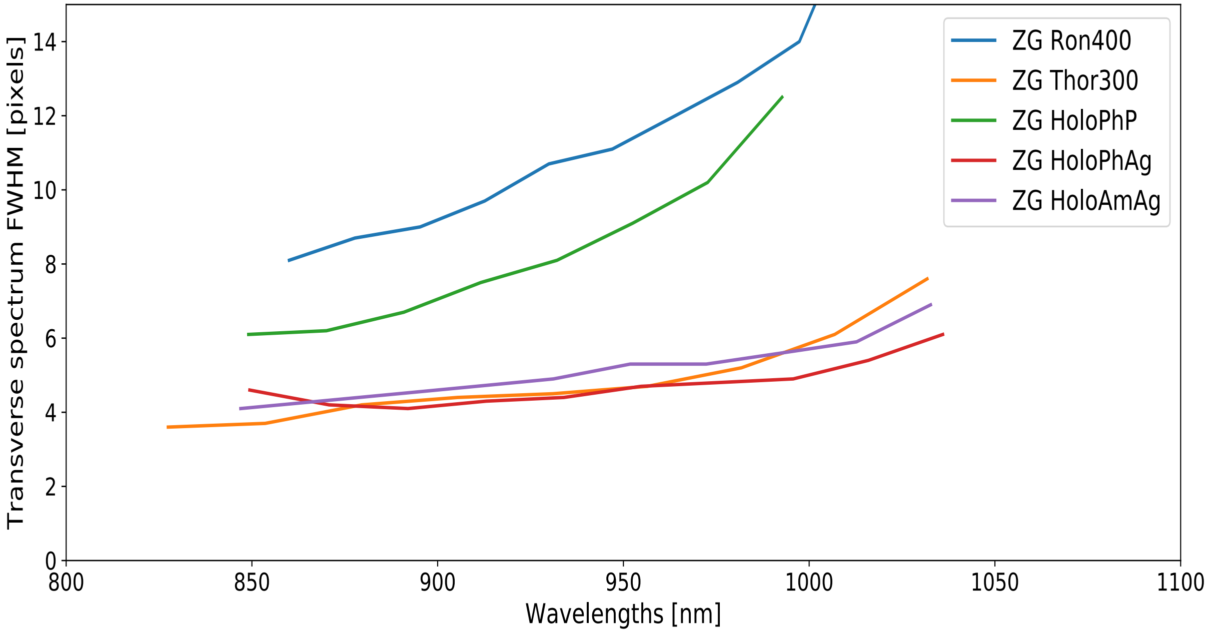
- *SIMULTANEOUS focus procedures with the Hα narrow filter.*
  - 0 order focus (left) vs +1 order focus (right)



HOE performances: focus, resolution

Spectrum profile of CALSPEC standard star





Estimates of spectral finesse R=λ/Δλ @Hα

Gratings

- Ronchi 400 l/mm: **R ~ 70**
- Blazed 300 l/mm: **R ~ 125**

Holograms

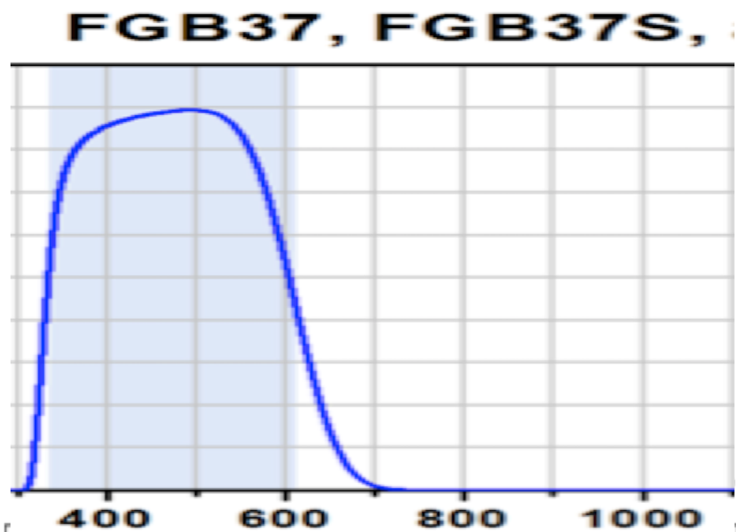
- Photopolymer : **R ~ 130**
- Phase argentic : **R ~ 280**
- Amplitude Ag : **R ~ 390**

Profile width of the dispersed first order light, as a function of the wavelength (Gunn-z passband)

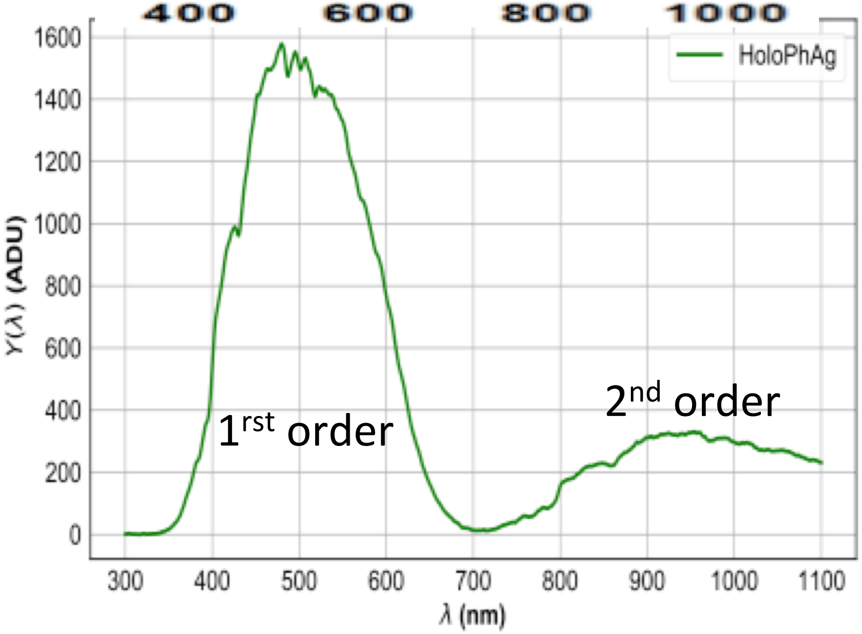
-> Commensurable with the expectations from simulations (ZEMAX)

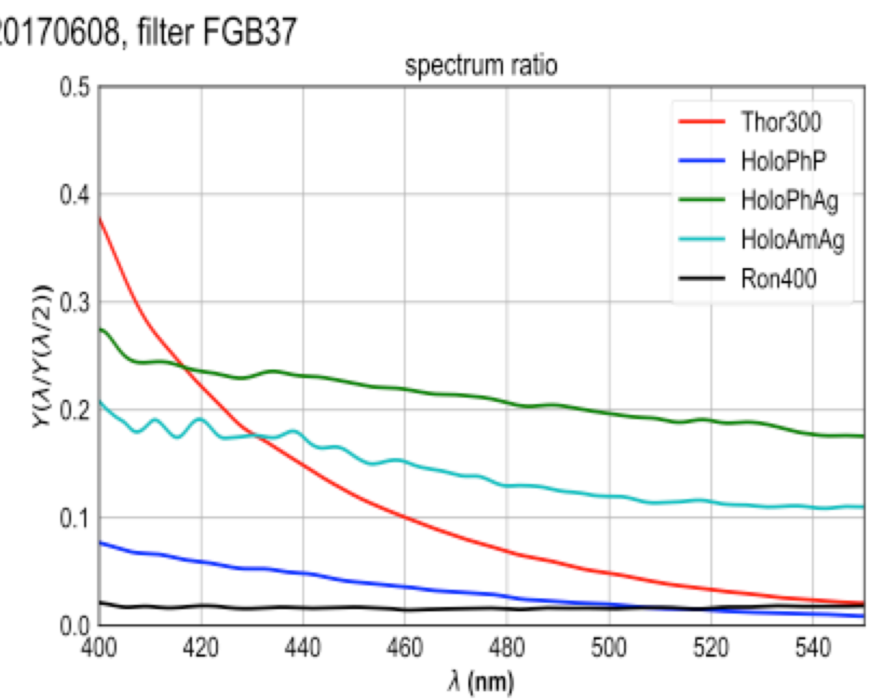
-> Low performance of the photopolymer hologram due to protective layer (not anti-reflective)

Disperser performances: 2^{nd} order

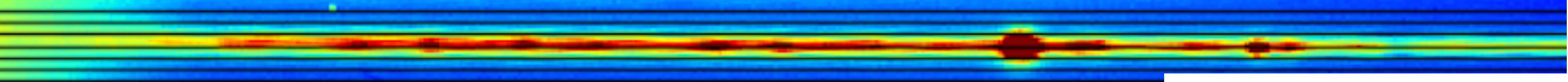


- Blue filter allows to split $1^{rst}/2^{nd}$ orders





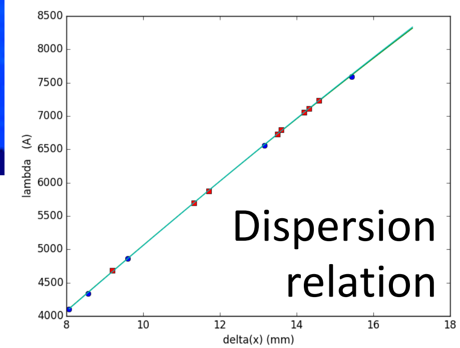
HOE performances: planetary nebula



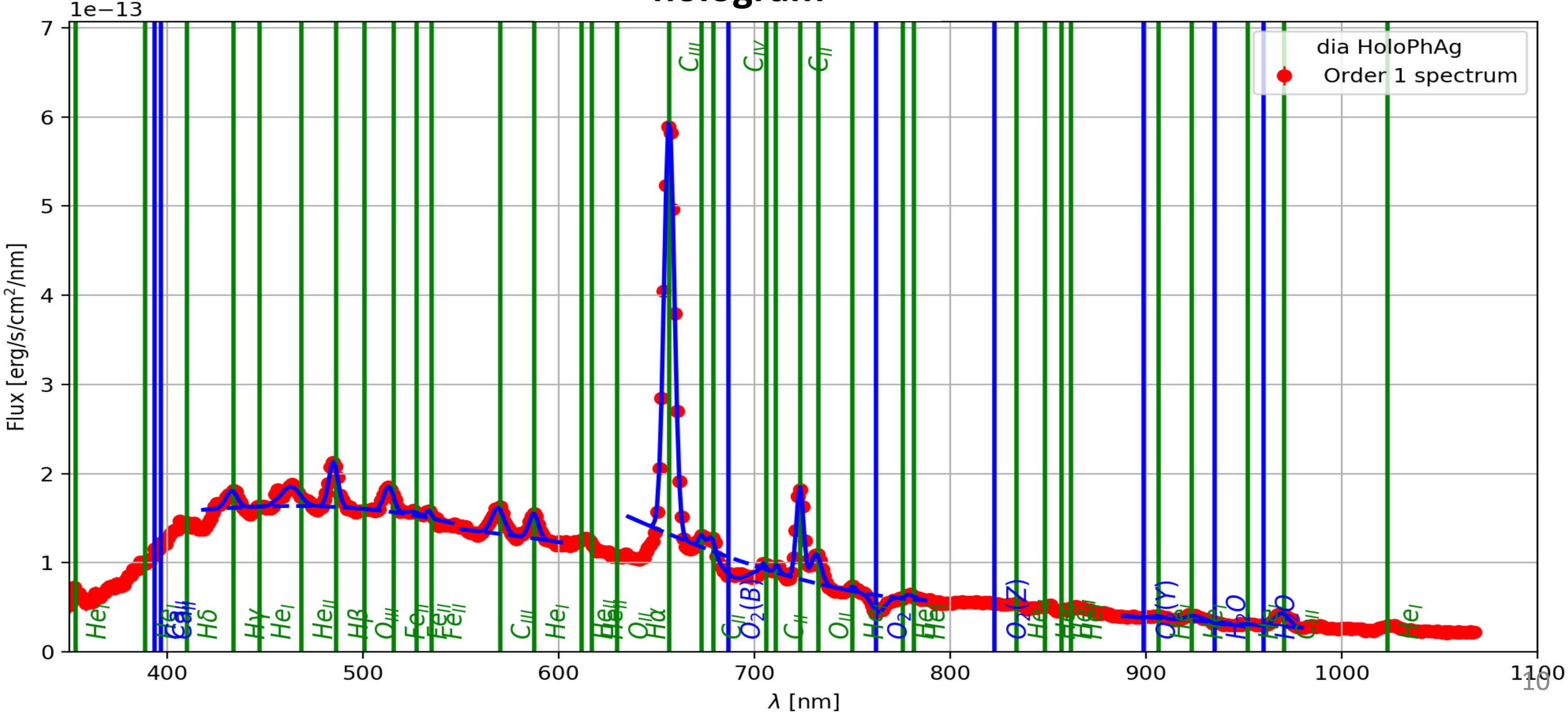
Why? narrow emission spikes with measured intensities

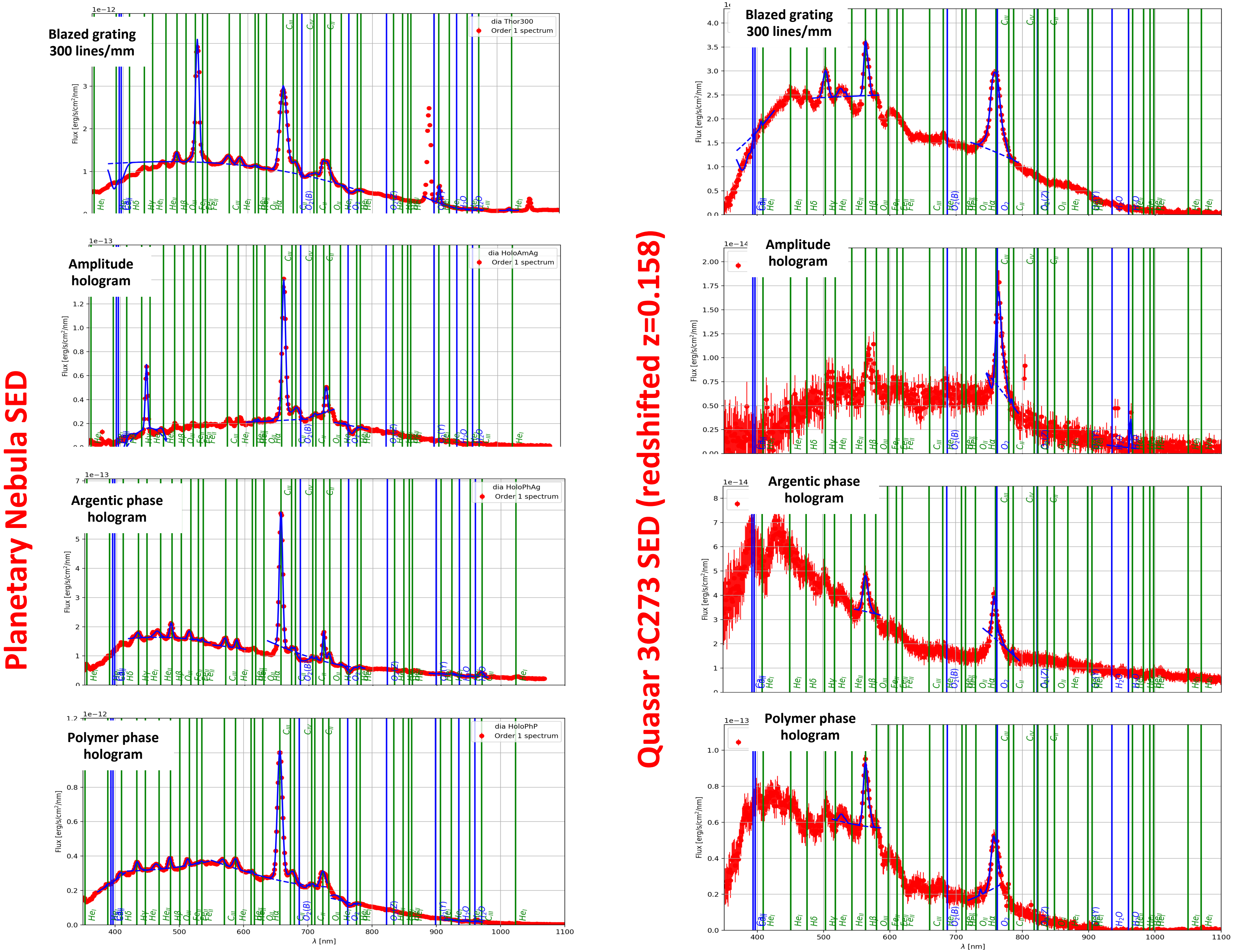
-> λ calibration, resolution, and $(\varepsilon_{CCD} \times \varepsilon_{diffraction})(\lambda)$ estimates

Planetary nebula PNG032.9-02.8 emission spikes



Argentic phase hologram





Planetary Nebula SED
Quasar 3C273 SED (redshifted z=0.158)
Blazed grating 300 lines/mm
dia Thor300
Order 1 spectrum
Amplitude hologram
dia HoloAmAg
Argentic phase hologram
dia HoloPhAg
Polymer phase hologram
dia HoloPhP
Flux [erg/s/cm²/nm]
λ [nm]

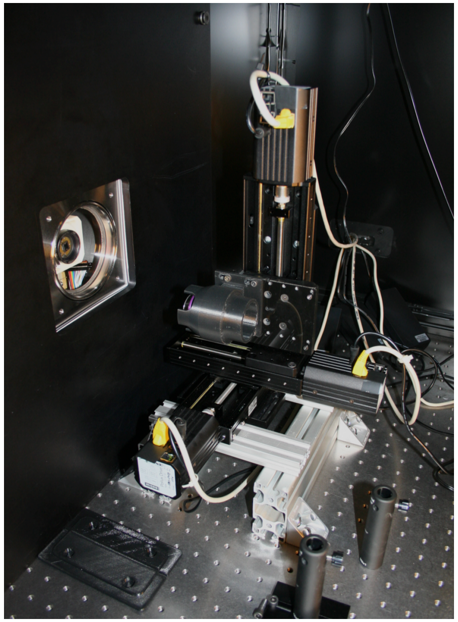
Optical Test-bench at LPNHE

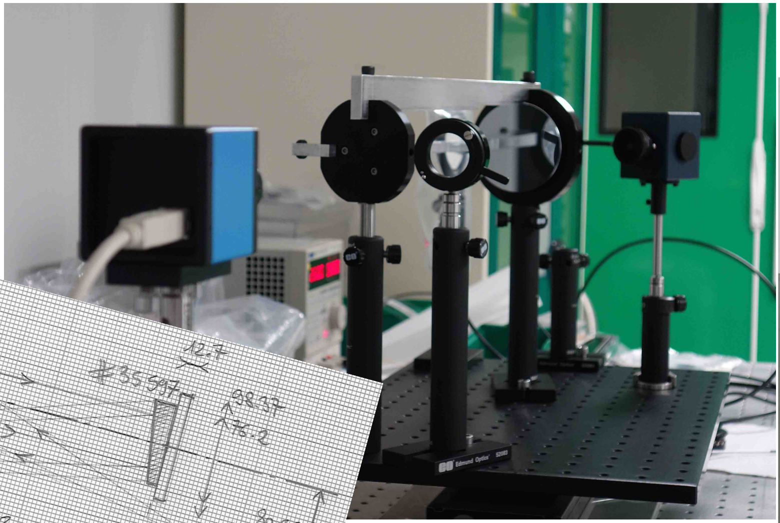
Simulation of the AuxTel convergent beam

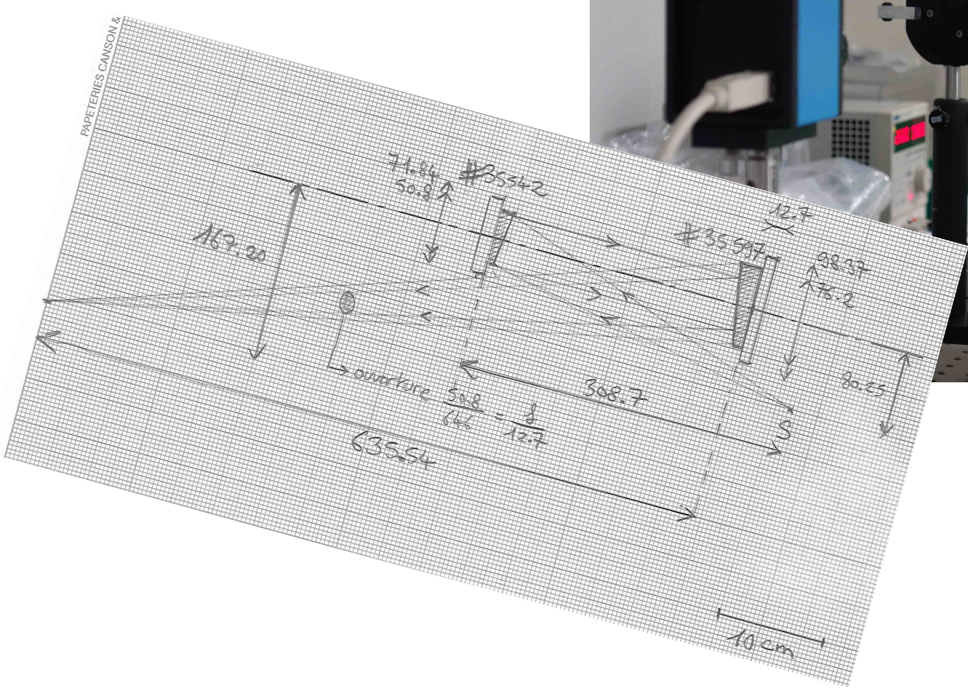
- Focus on a LSST-type CCD sub-arcsec equivalent PSF from converging beam
- Focus independent from the wavelength (mirrors)
- Uniform beam density obtained with integrating sphere + 20μ hole
- Hologram installed on a XYZ mounting

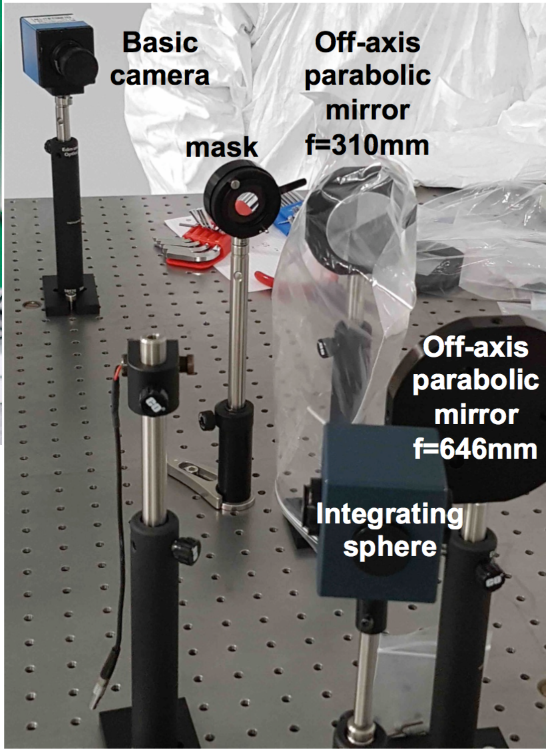
Measurements to do on every disperser

- Volume of validity ΔXΔYΔZ for acceptable use (>10mm10mm4mm)
- Spectral resolution λ/Δλ with emission line lamp and monochromator
- Transmission as a function of λ.









HOE: schedule

- **Janvier 2017**: tests préparatoires au CTIO (Chili)
- **Mai 2017**: premiers prototypes d'hologrammes
- **Juin 2017**: tests de prototypes sur télescope au CTIO (Chili)
- **Eté 2017**: analyse des tests
- **Automne-hiver 2017**
  - simulations optiques et atmosphériques
  - Analyse: étude de la largeur équivalente de la bande d'absorption de l'eau (proche IR) et de l'absorption par les aérosols (bleu)
- **Spring-summer 2018**
  - production of finalized holograms (several technologies, 2/1 orders minimized; *first order could take up to 80% of the light*)
  - measurements/characterization with the LPNHE test-bench
- **End 2018-beginning 2019**
  - Start operations on AuxTel
- **2019 – 2020**
  - Calibration of the system
  - Extensive observations of the various atmospheric conditions on-site

Atmospheric attenuation estimation update on CTIO data (jun 2017)

Sylvie Dagoret-Campagne
Marc Moniez
Jérémy Neveu
Olivier Perdereau

Outline

① CTIO may-jun 2015 ➔ 16 nights

- ✧ Focus only on « 4 photometric nights »
- ✧ CALSPEC/ 2 Filters Red/Blue / 2 grating, 3 Holograms

② Reconstructed the star spectra and wl calibration

- ✧ Optimize reconstruction pipeline
- ✧ Still systematics under study (disperser dependent)

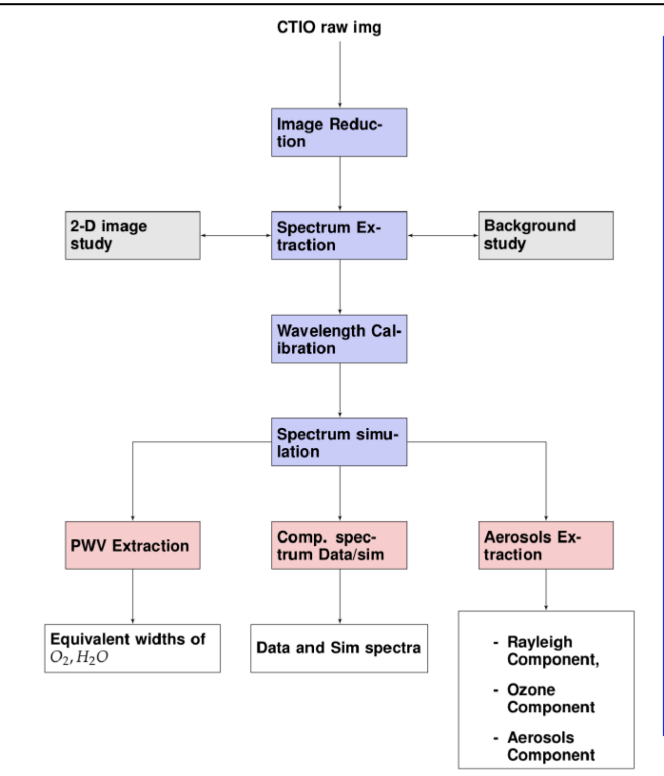
③ Extract atmospheric feature (knowing calspec SED)

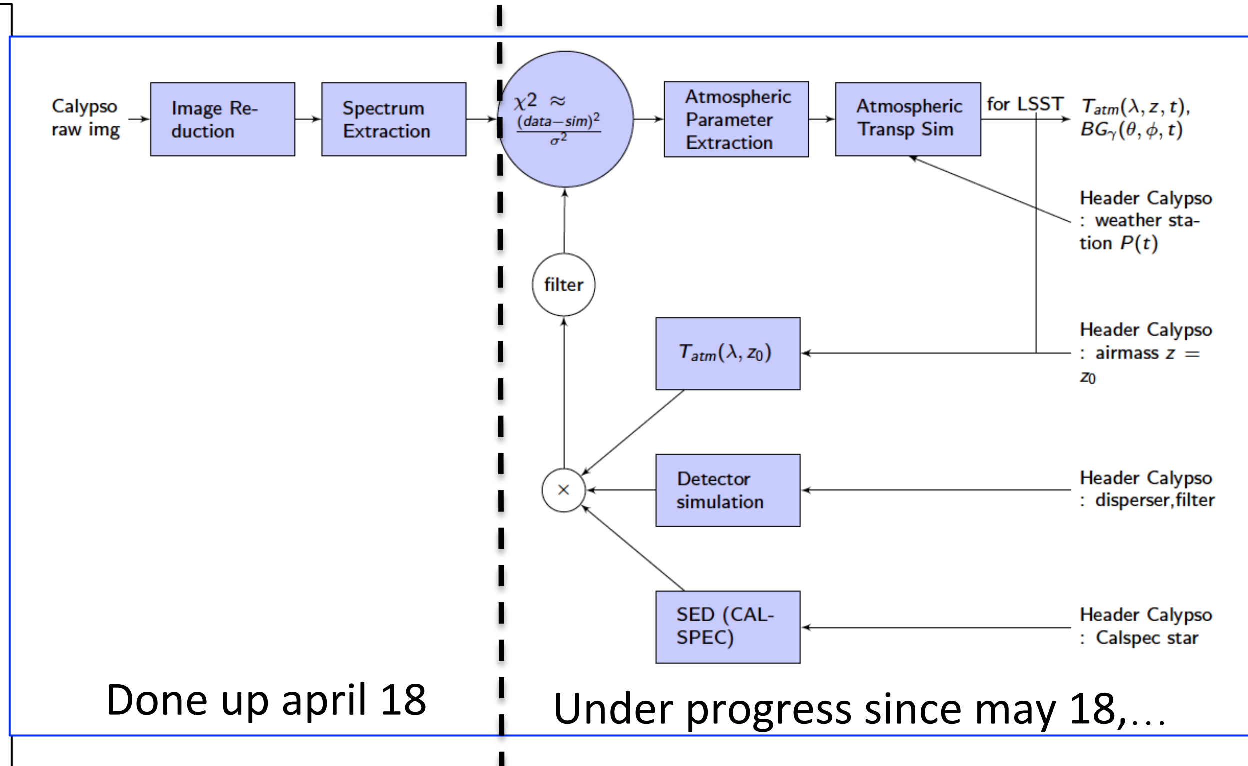
- ✧ Set of time varying « atm. estimators» to be monitored
- ✧ To feed into simulation in order to reproduce spectra data
- ✧ External required info : overall throughput (telescope + CCD+ disperser)

④ Predict LSST atmospheric transmission for every exposure

Software Design & Analysis Progress

Old fashion → *Pipeline designed for mass production (>3000 images)*





① Parallel reconstruction of data & sim spectra (clear sky, aver. Sky, merra2 sky)

② Spectrum Extraction (data) → spectra in erg/cm2/s/nm

③ Being done : the automated close loop with chi²/likelihood func

- ➢ Require the effective throughput

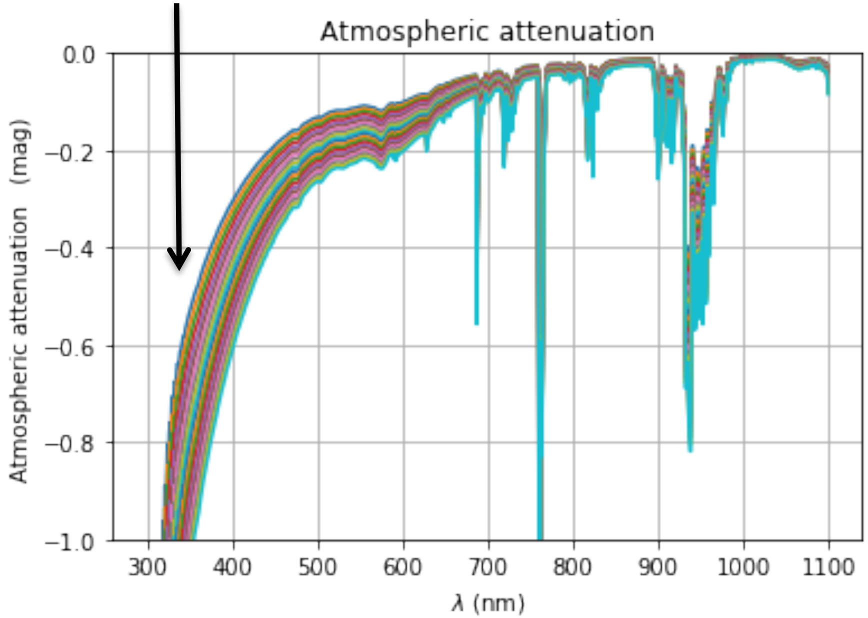
Principle of the Bouguer lines Methods

Proof on simulation

- Generate atm transm.
- Airmass : 1-2
- Clear sky

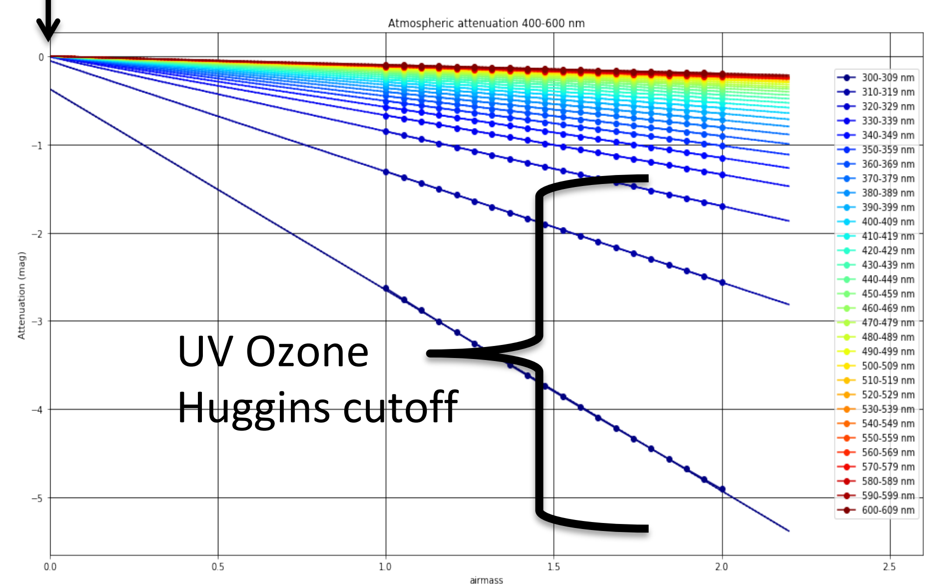
- Fit bouguer line in wavelength bins

Ozone
Huggins cutoff

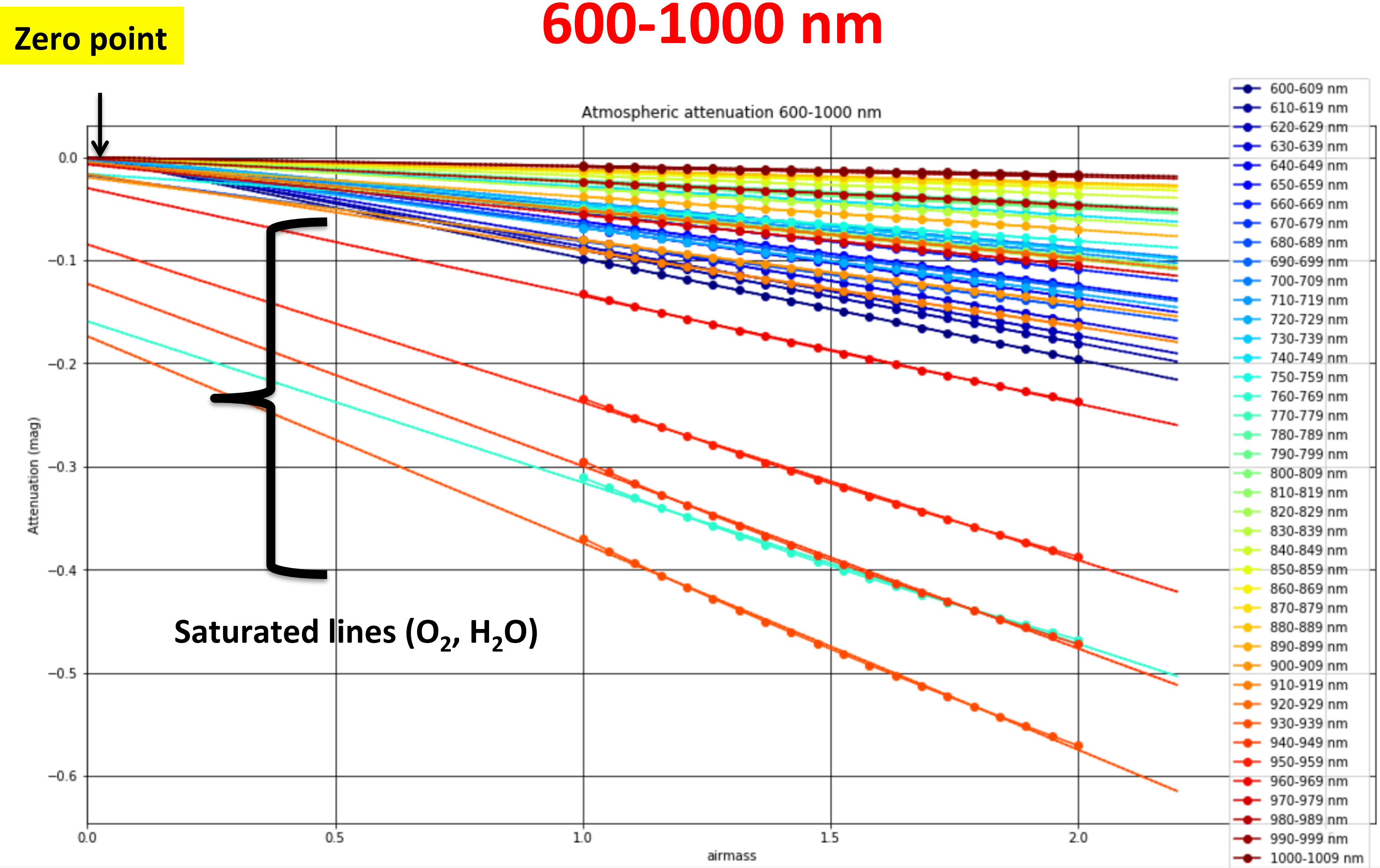


Zero point

400-600 nm



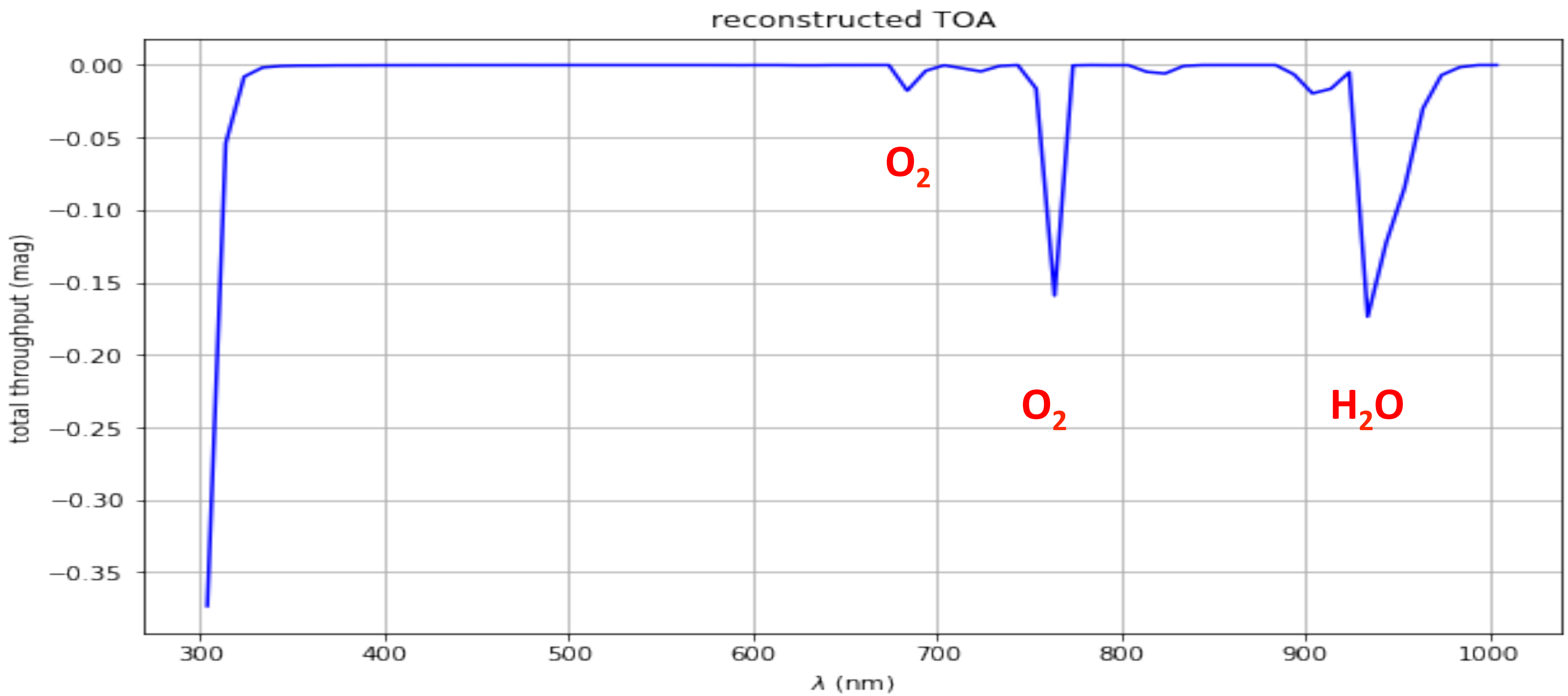
Saturation at molecular absorption 600-1000 nm



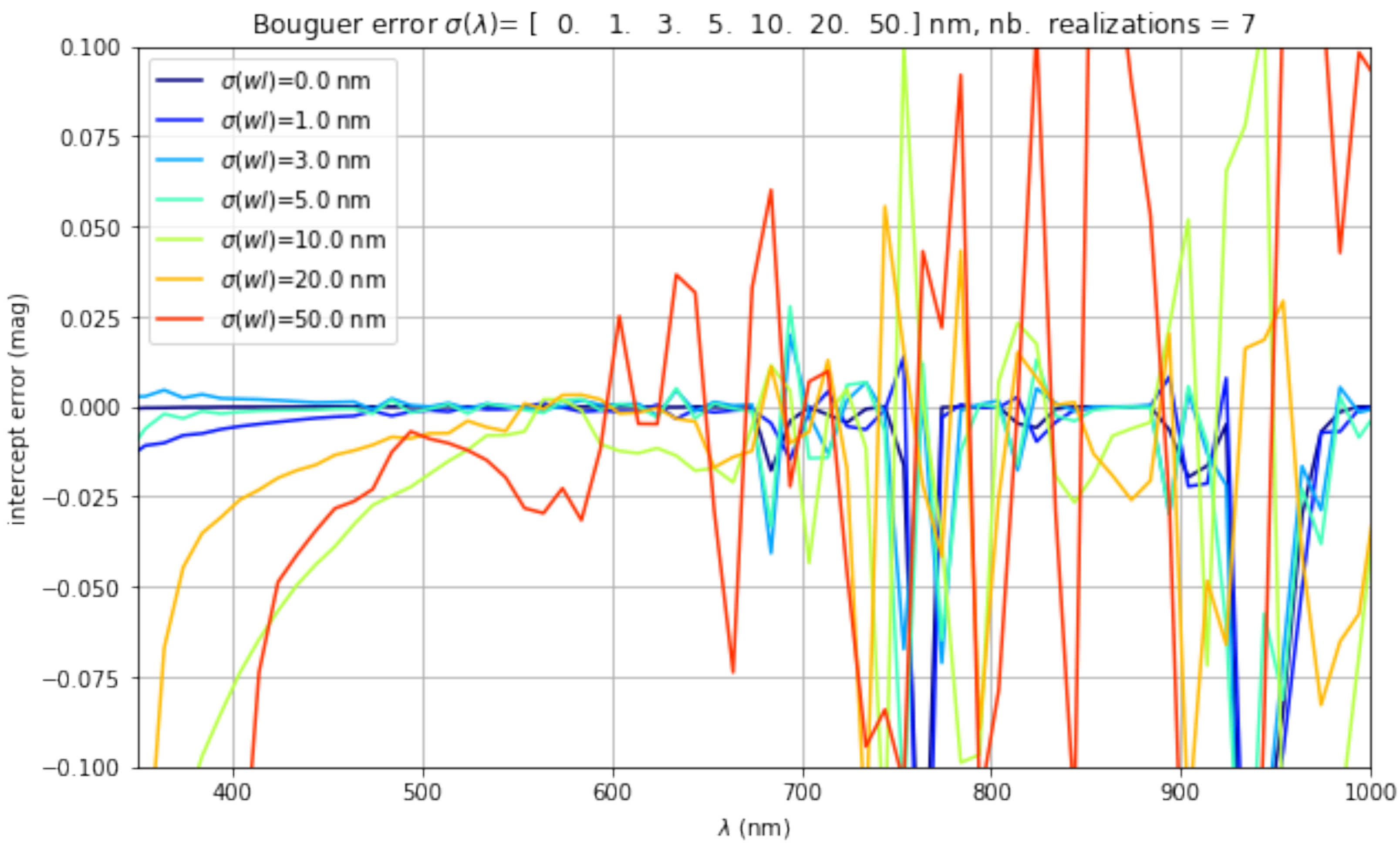
Reconstruction of light at TOA
(Top of Atmosphere)

Intercept of Bouguer lines (airmass z=0)

Molecular absorption saturates :
Extinction α z → α √z



Bouguer line fit : effect of wavelength zero point accuracy : σ(λ)=2nm



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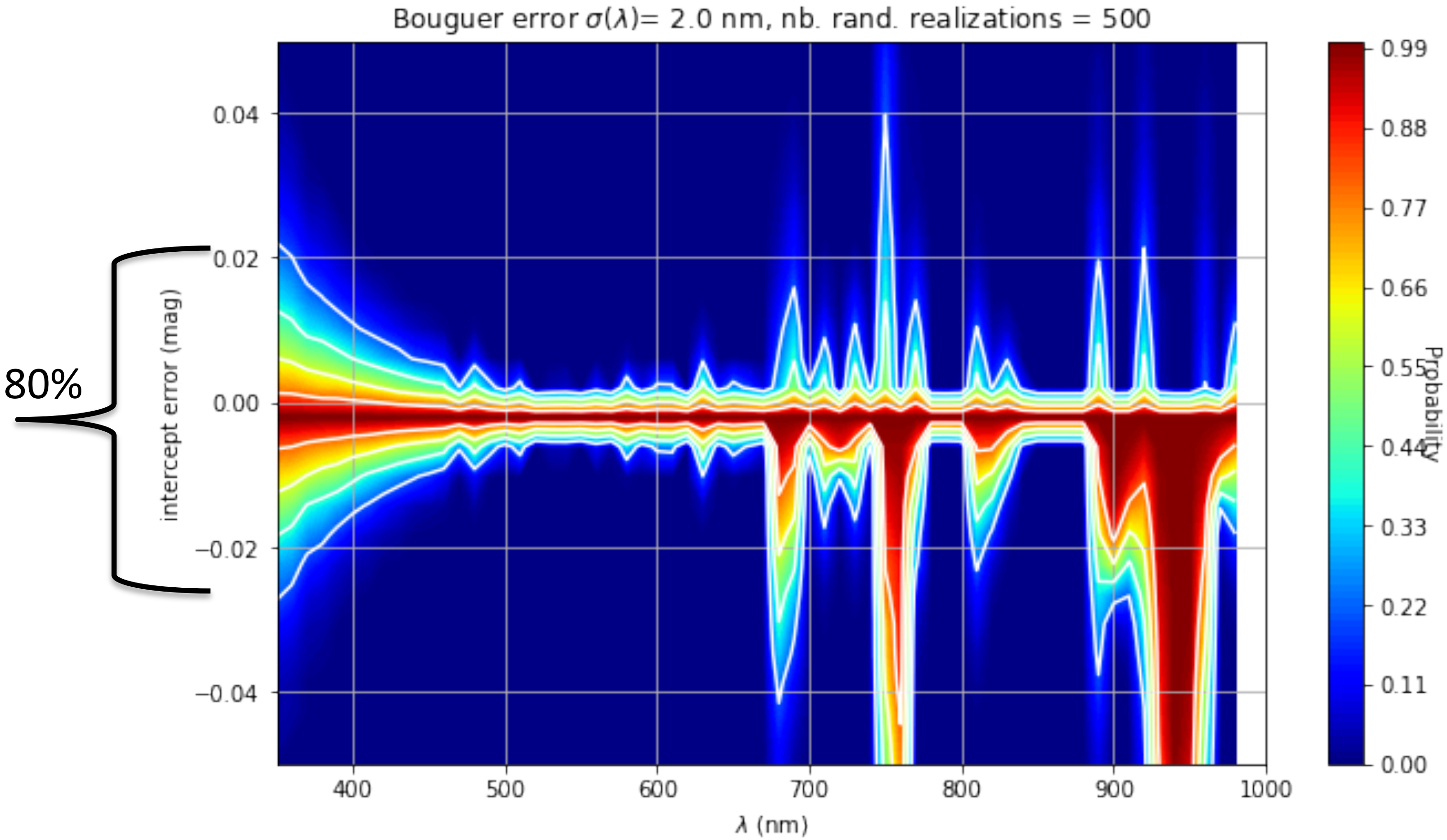
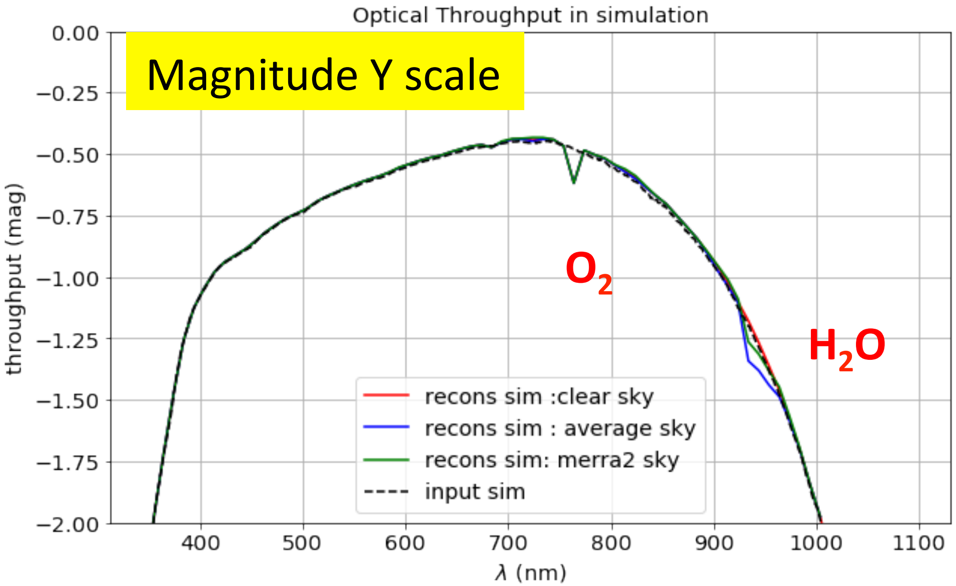


Requires a disperser with a very good wavelength accuracy σ(λ)=2nm

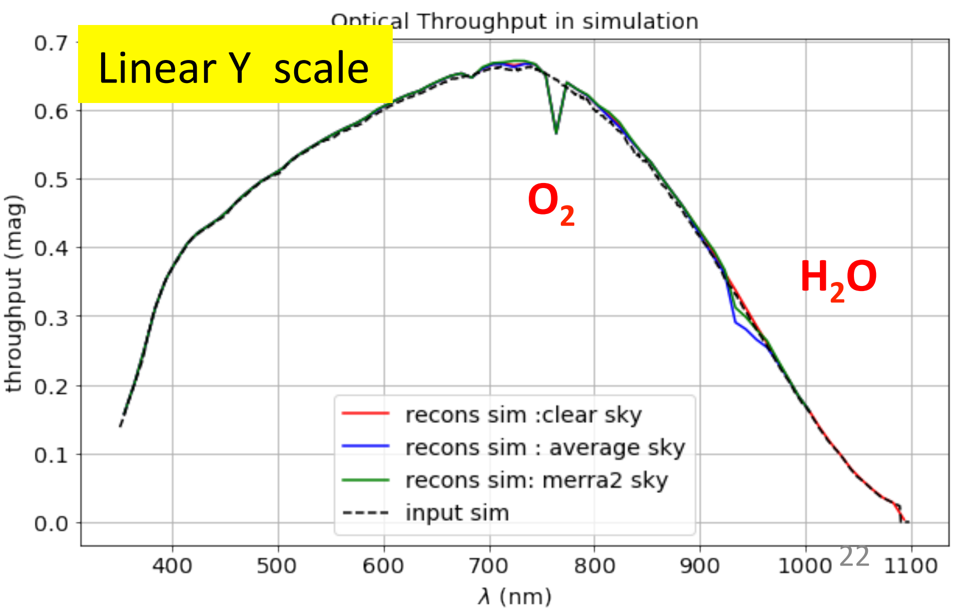
Simulation : Bouguer lines fit method to get back throughput



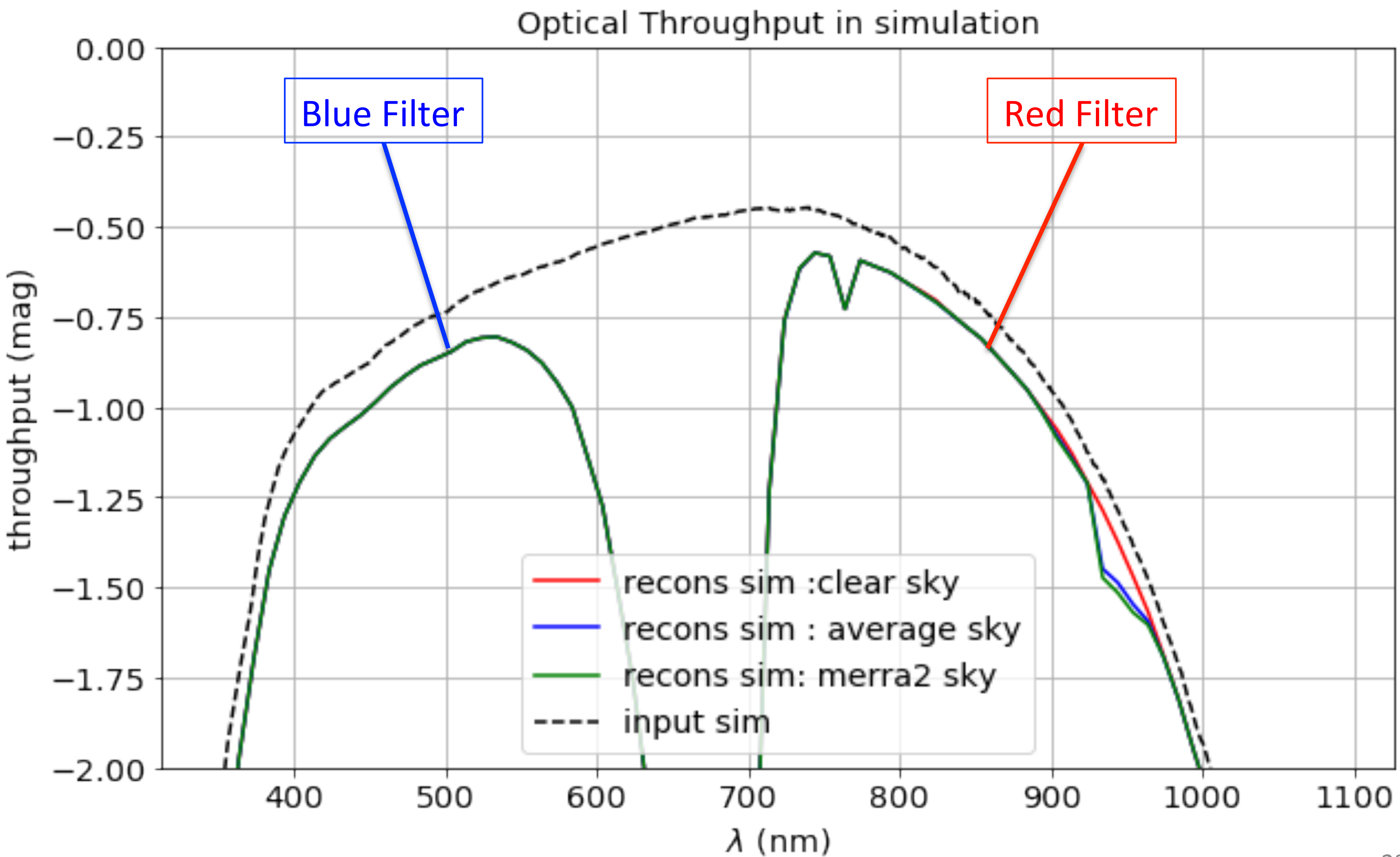
<u>3 atm. simulations</u> :

- Clear sky, (no aerosol, no PWV)
- Average sky
  (aer=0.05, PWV=4mm)
- Merra sky (NASA/GMAO)

Fit Method OK, except
At molecular absorption
Line and bands

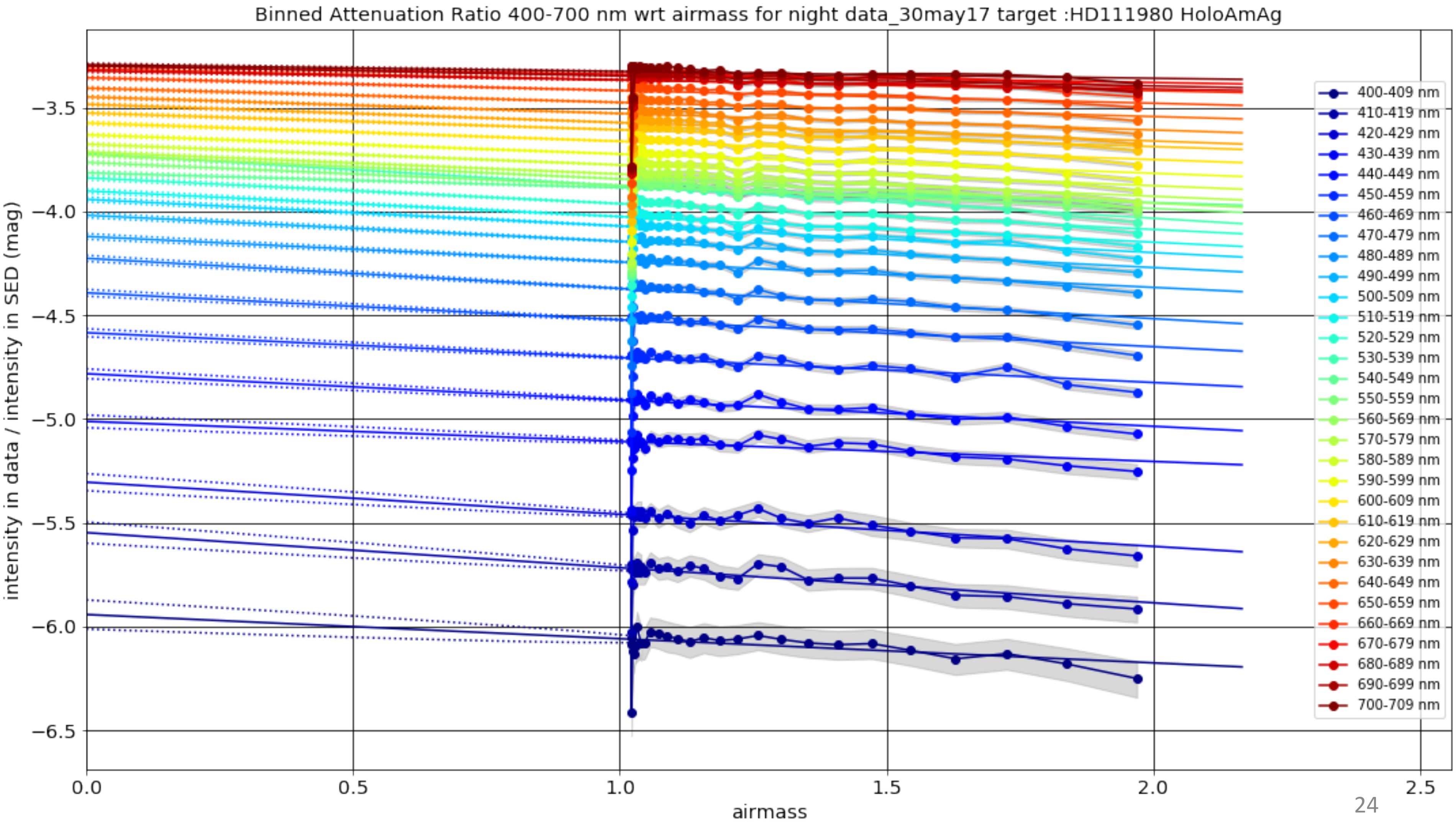


Simulation : Throughput : Use of Blue/Red filters



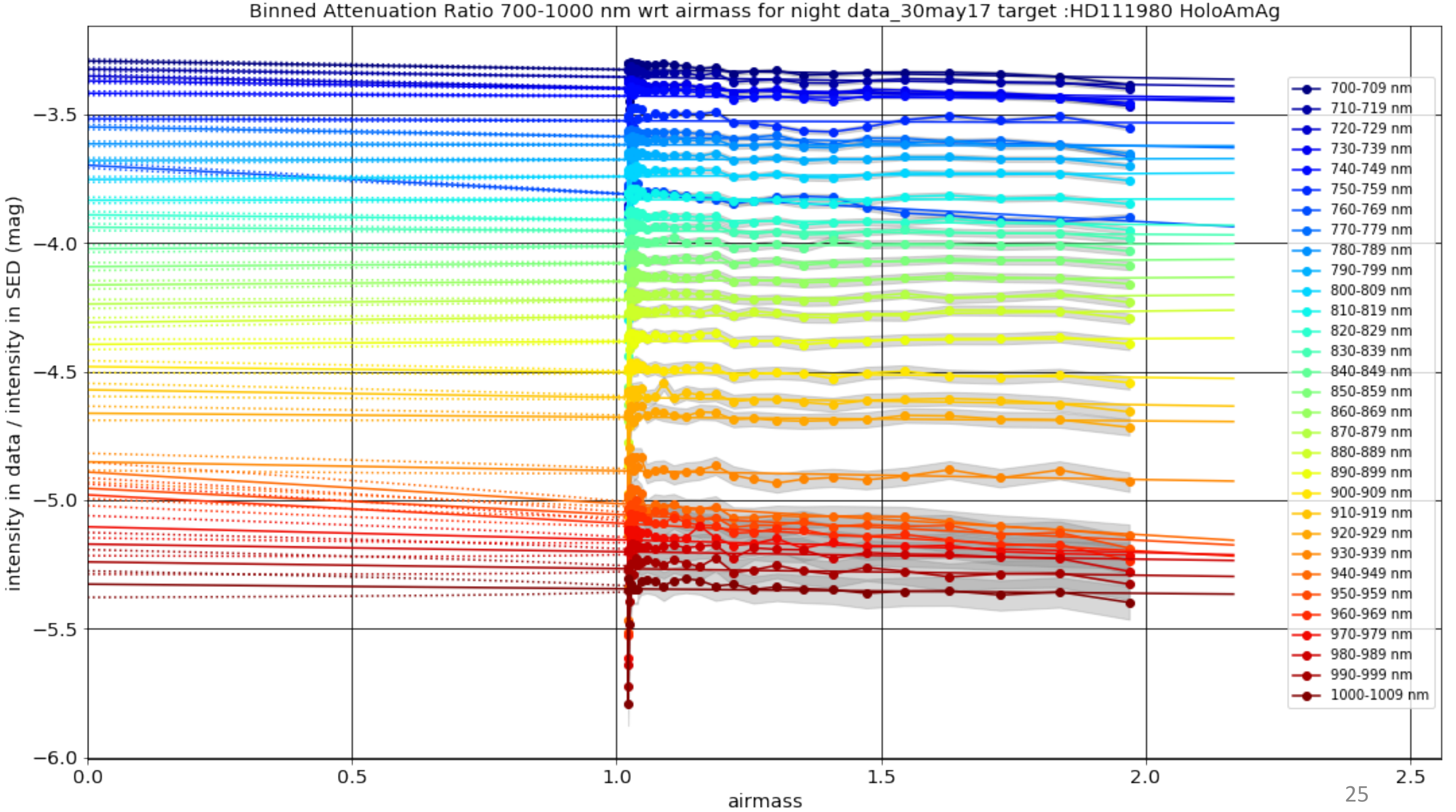
DATA : Fit of Bouguer lines on HoloAmAg

400-700 nm : ratio = $\text{Spectrum}_{flam}(\lambda)/\text{SED}(\lambda)$

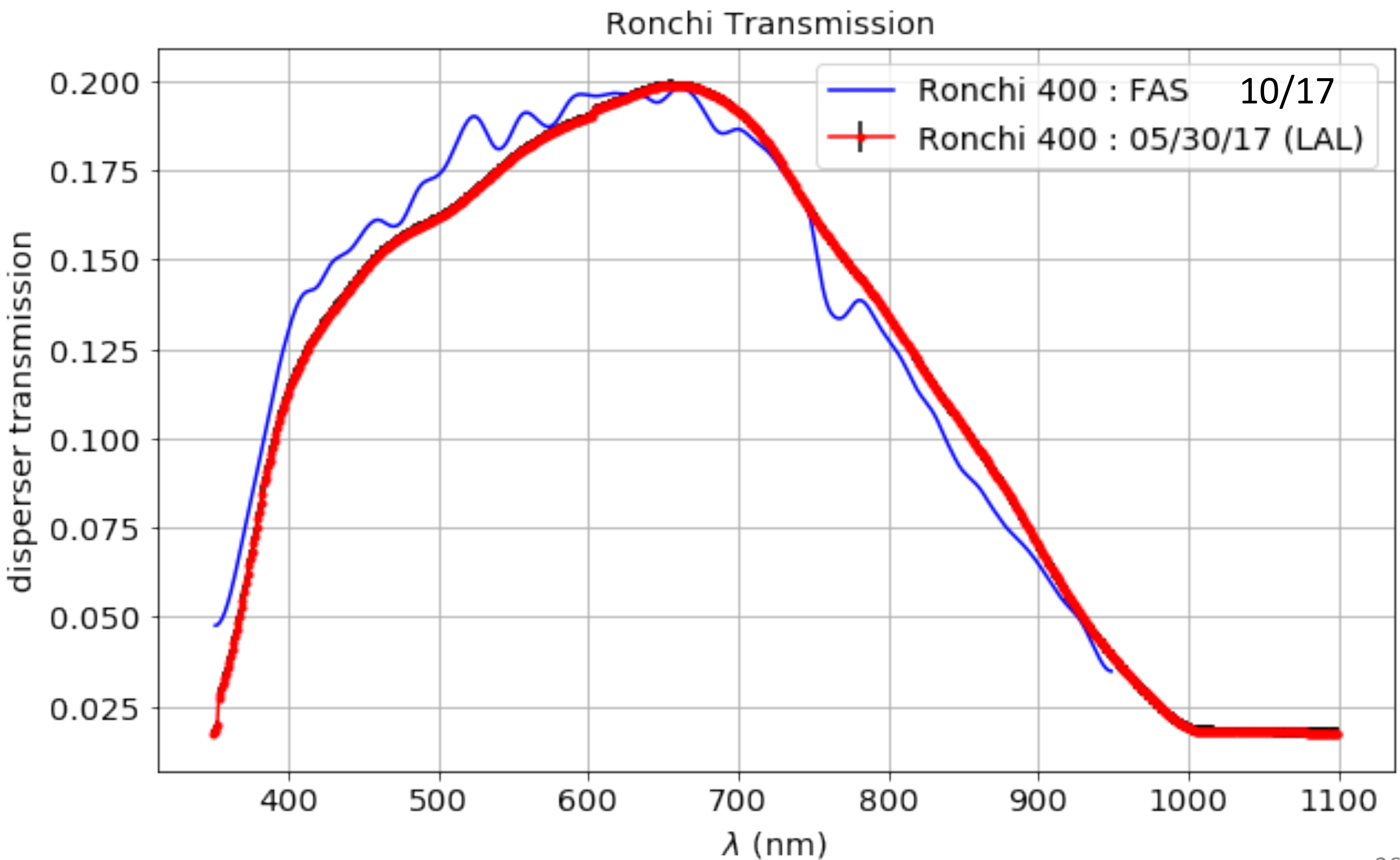


DATA :Fit of Bouguer lines on HoloAmAg

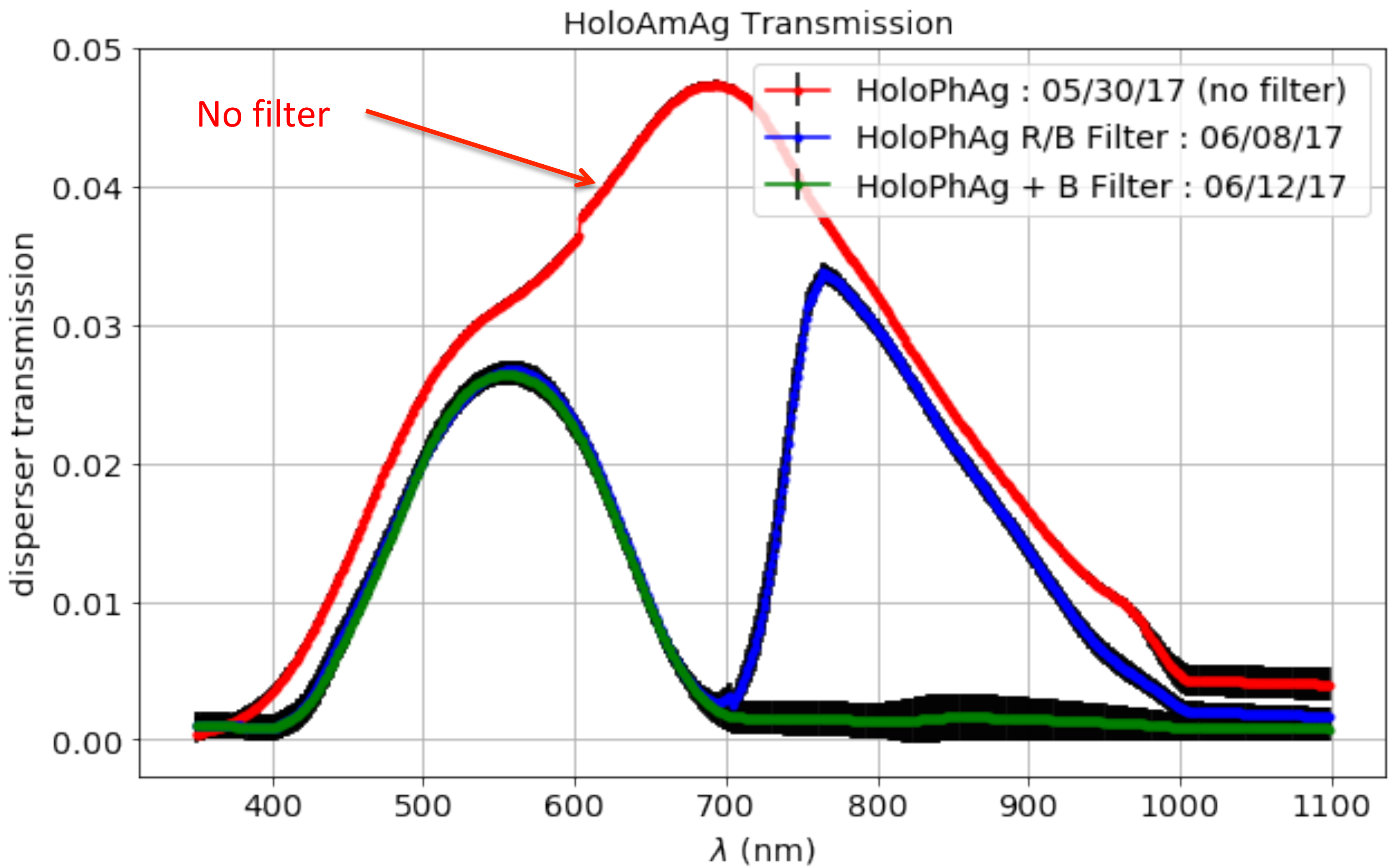
700-1000 nm : ratio = Spectrum(λ)/SED(λ)



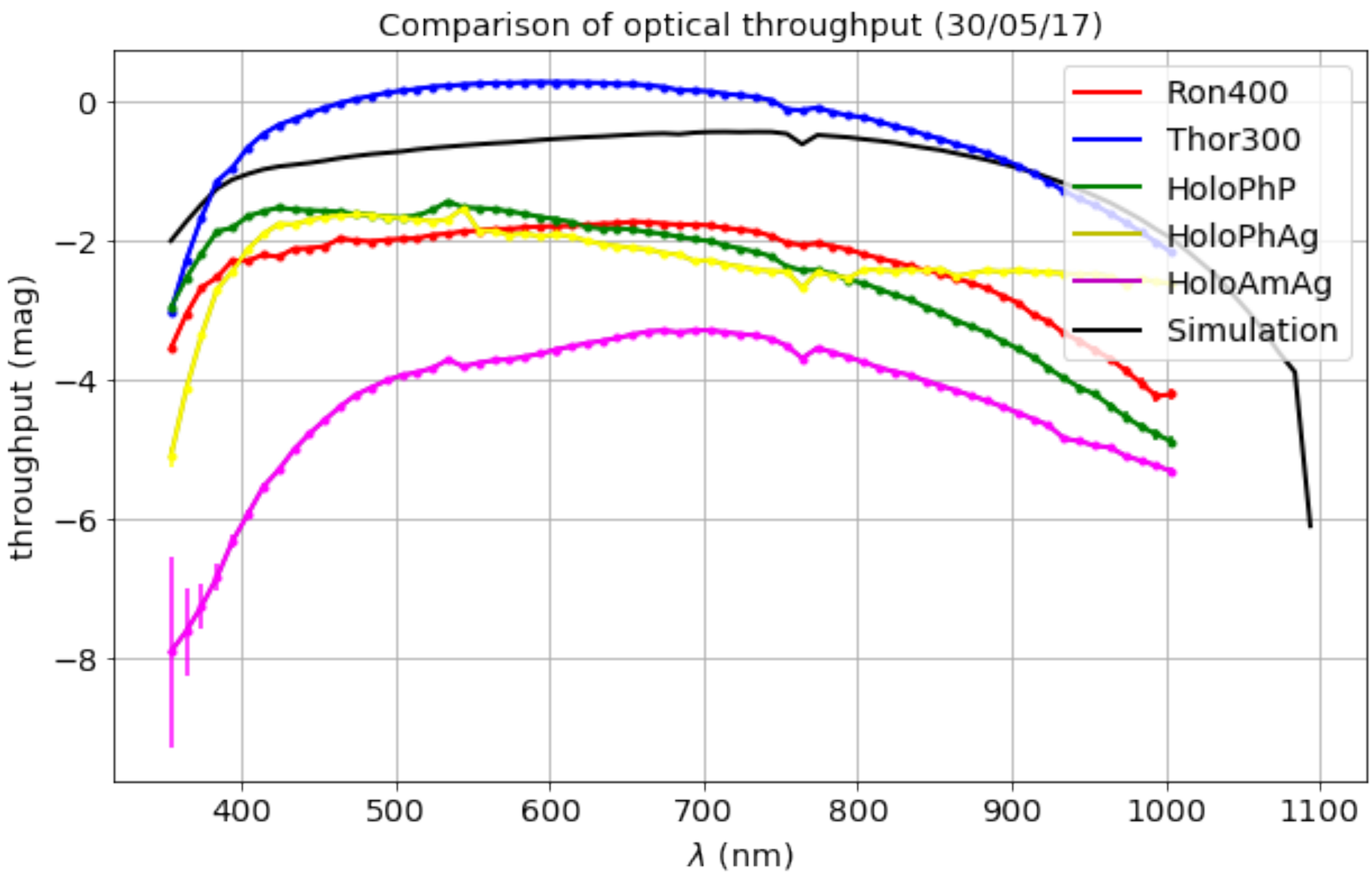
Absolute Throughput with Ronchi (Qe x optics x 1st order disperser)



Throughput with HOE
(Qe x optics x Filter x 1st order disperser)



Throughput comparison night 30/05/17
No filter



Extraction of atmospheric parameters spectrum by spectrum

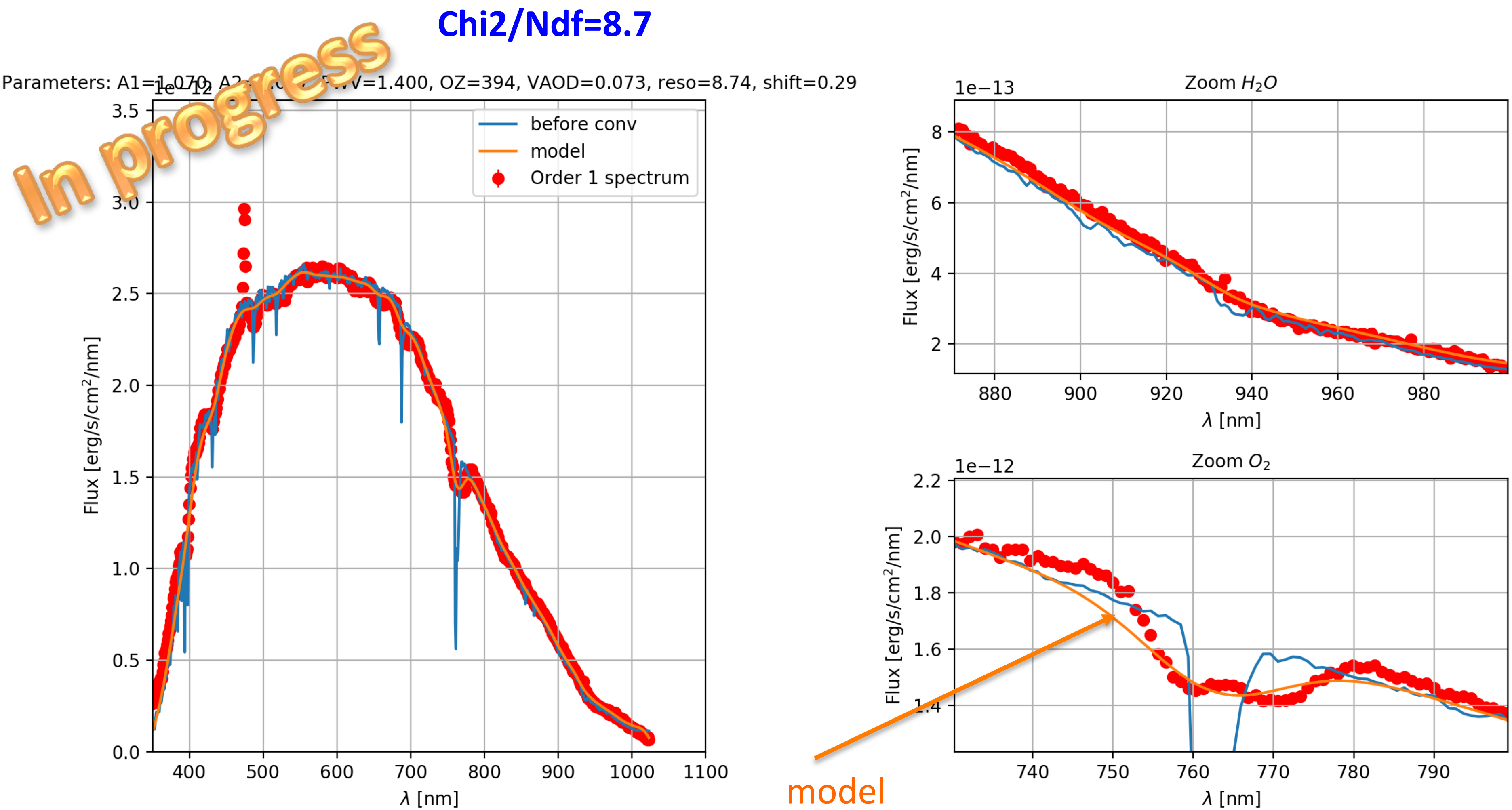
In progress

Jérémy N.

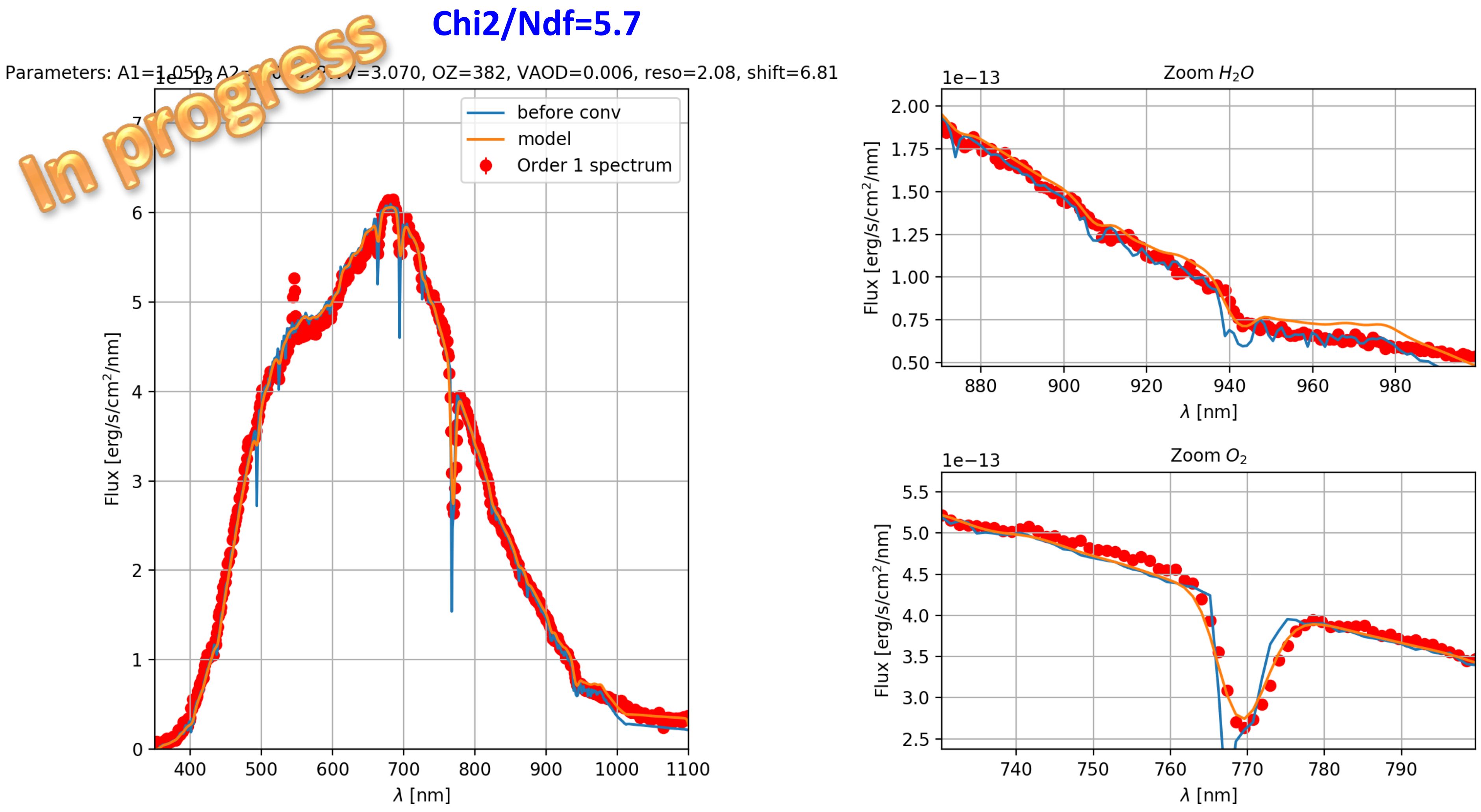
- Estimate the best model parameters:
  - **PWV,**
  - **aerosols,**
  - **ozone,**
  - **σ(pix) (seeing)**
  - **δλ**-shift
  - Using LibRadTran as the atmospheric model
  - Using the Throughput measured
- Extraction performed by MCMC techniques
- Model : Order 1+ Order 2

$$S(x) = [\, A1 \times (Simu(x - shift) + A2 \times Sim((x - shift) / 2)] * Gaussienne(reso))$$

Ronchi 400 spectrum

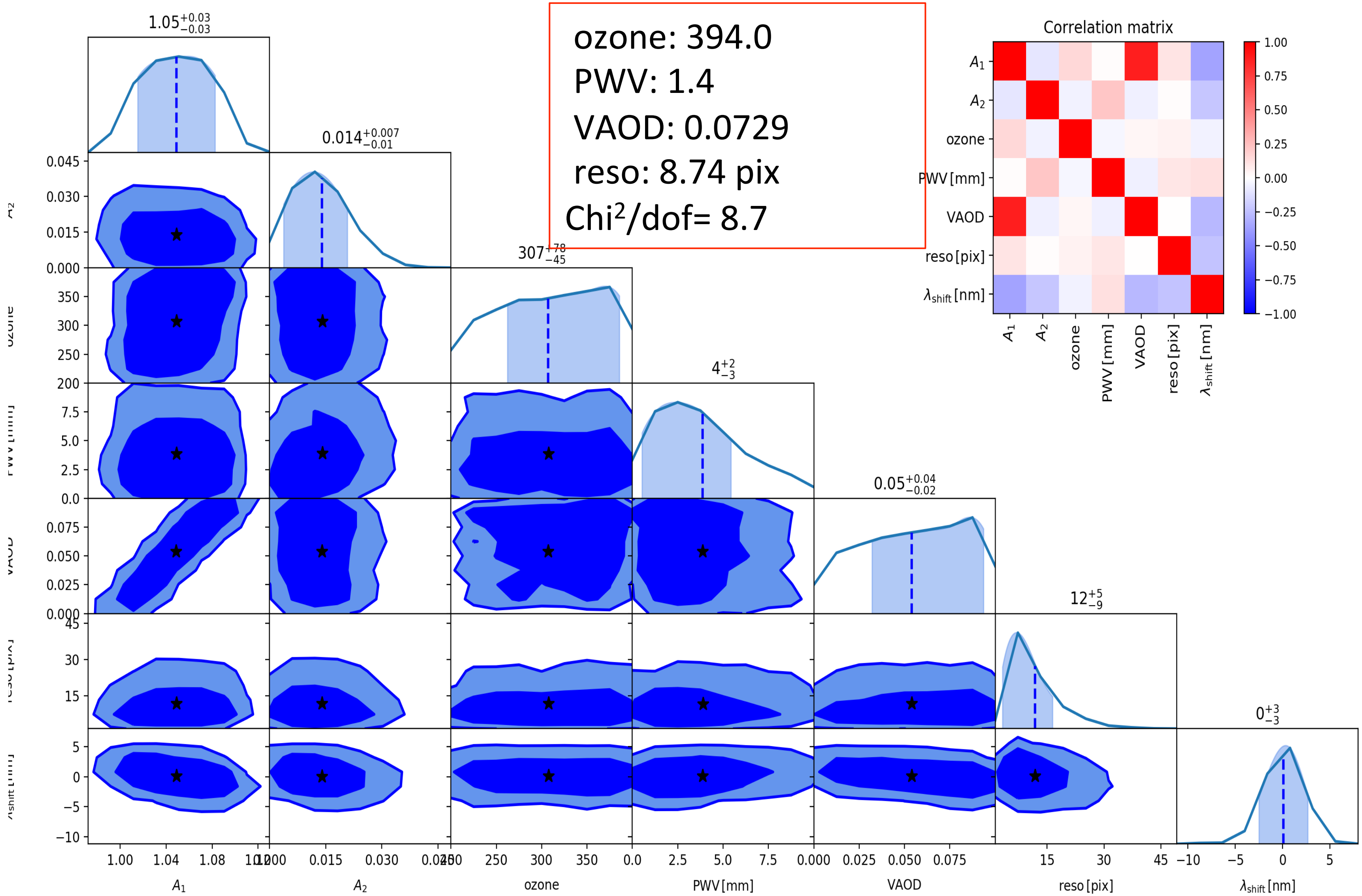


Hologram HoloAmAg



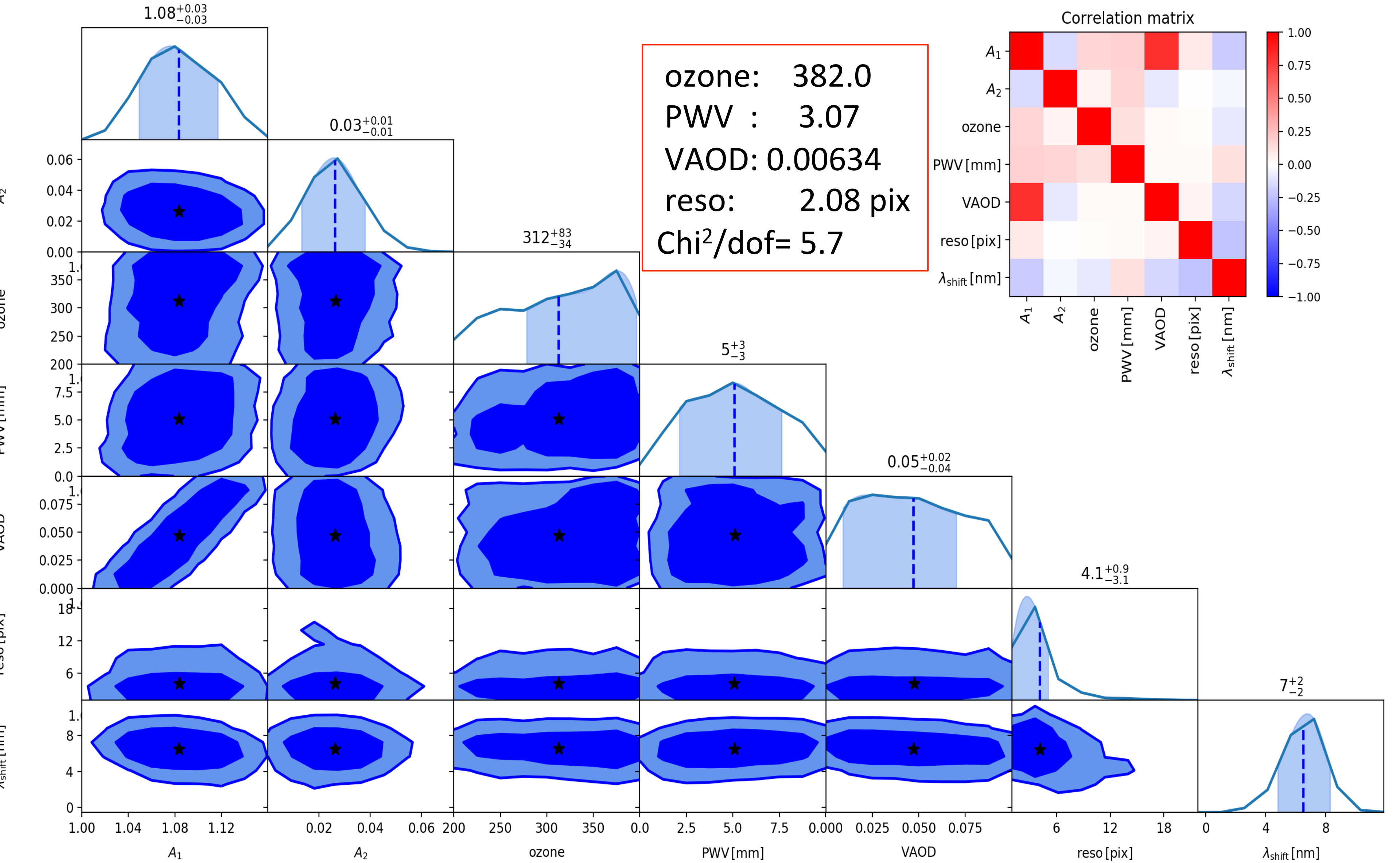
Covariance matrix for Ronchi400

ozone: 394.0
PWV: 1.4
VAOD: 0.0729
reso: 8.74 pix
Chi^2/dof= 8.7



Ozone PWV VAOD $\sigma_\lambda(\lambda)$ $\delta\lambda$

Covariance matrix for HoloAmAg



ozone: 382.0
PWV : 3.07
VAOD: 0.00634
reso: 2.08 pix
Chi²/dof= 5.7

Comments on the MCMC fit

- First encouraging determinations of atmospheric parameters
- Still room for progress
- O_2 line and H_2O band are much better fitted for HoloAmAg than for Ron400

CONCLUSION

- Progress in software chain including:
  - Spectrum extraction/background subtraction
  - Wavelength calibration, and λ=0 point
  - Detector Throughput (Ronchi400, HoloAmAg)
  - Extraction of parameters
- Still poor in data (only 4 photometric nights)
  - Not enough to accumulate variations over time
- Need further transmission measurement at HOLOSPEC test-bench

Mini-Data Challenge for atmospheric calibration

Sylvie Dagoret-Campagne

LAL

Motivations

→***Setup methods to estimate atmospheric transmission***

→**Different teams will Evaluate the performances of their methods**

→Evaluate the relative contribution of LSST alone config and (Auxiliary Telescope + LSST) config

- →Set requirements on Auxiliary Telescope

→ On a fake but realistically simulated Dataset

Data Product

- N_{vis} **visits** **(** i=1,…,N_{vis}) scheduled by minion16 cadence
- N_{obj} **objects sampled from a catalog of SED selected (**j=1,…,N_{obj})
- F_i is the filter used for visit i
  - F_i = U, G, R I, Z, Y according a cadence (minion16)
- **Airmasses** z_i **of each visit** i **and the instrumental magnitude** M_{ij} for **each object** j in the field :

  the dataset : $\{ z_i, F_i, \{M_{ij}, \delta M_{ij}\}_j \}_I$
- **One spectrum (undelivered SED) of a reference star in the field** (to combine with auxiliary telescope data)

List of Tasks

- Selection of star catalog : Phoenix → Done
- SED Sampling according the magnitude distribution in SNLS → almost done
- Atmospheric parameters distribution according MERRA2 → Done
- Atmospheric transparency calculated by libradtran → Done
- True effective LSST Filter → Done

Last Task : Calculation of Magnitudes and errors

How to go from

cadence (z_{am}, sky) + SED + atm transm. + $F_i \rightarrow$ ***{M_{ij} , δM_{ij}}***

Two options can be used:

- saunerie (Nicolas R expert), python2
- LSST_SIM_MAF (python3) provides official LSST Filter Transmission
  - (still need to learn how to use lsst.sims.photUtils)

Validation of SIMS_MAF use

- Learn LSST_SIMS_MAF by comparing the results to saunerie

- Check with Nicolas R, how we extract the parameters we want.

<u>Diffused background light</u> with librandtran comparison of clear sky and sky with aerosols

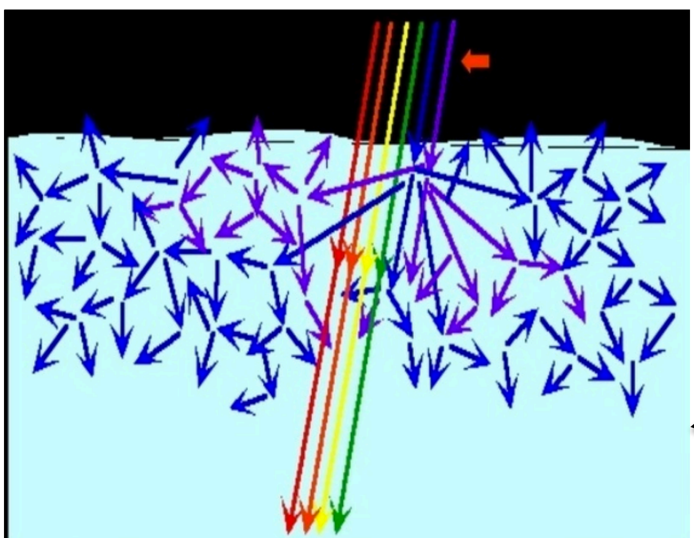
Sylvie Dagoret-Campagne and Arve Kylling

December 2015

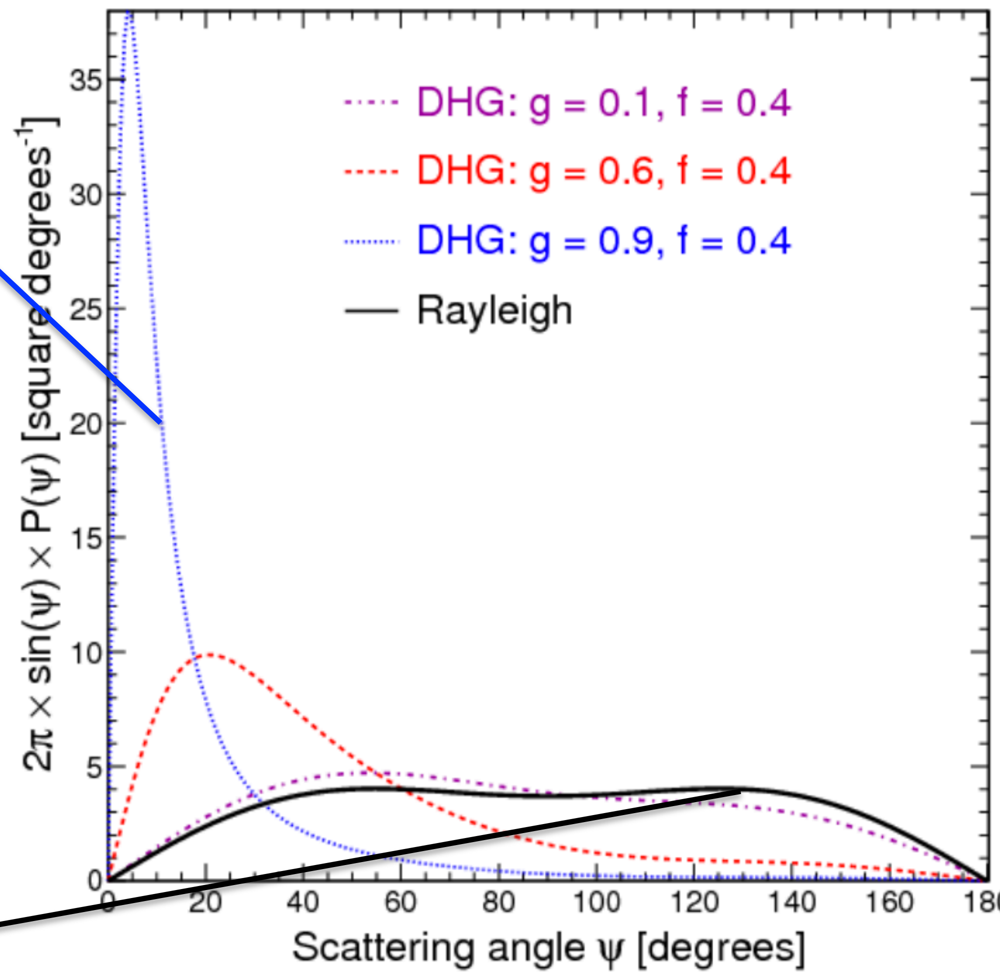
Scattering properties of atmosphere

Mie scattering peaked forward

Rayleigh scattering



Angular cross-section



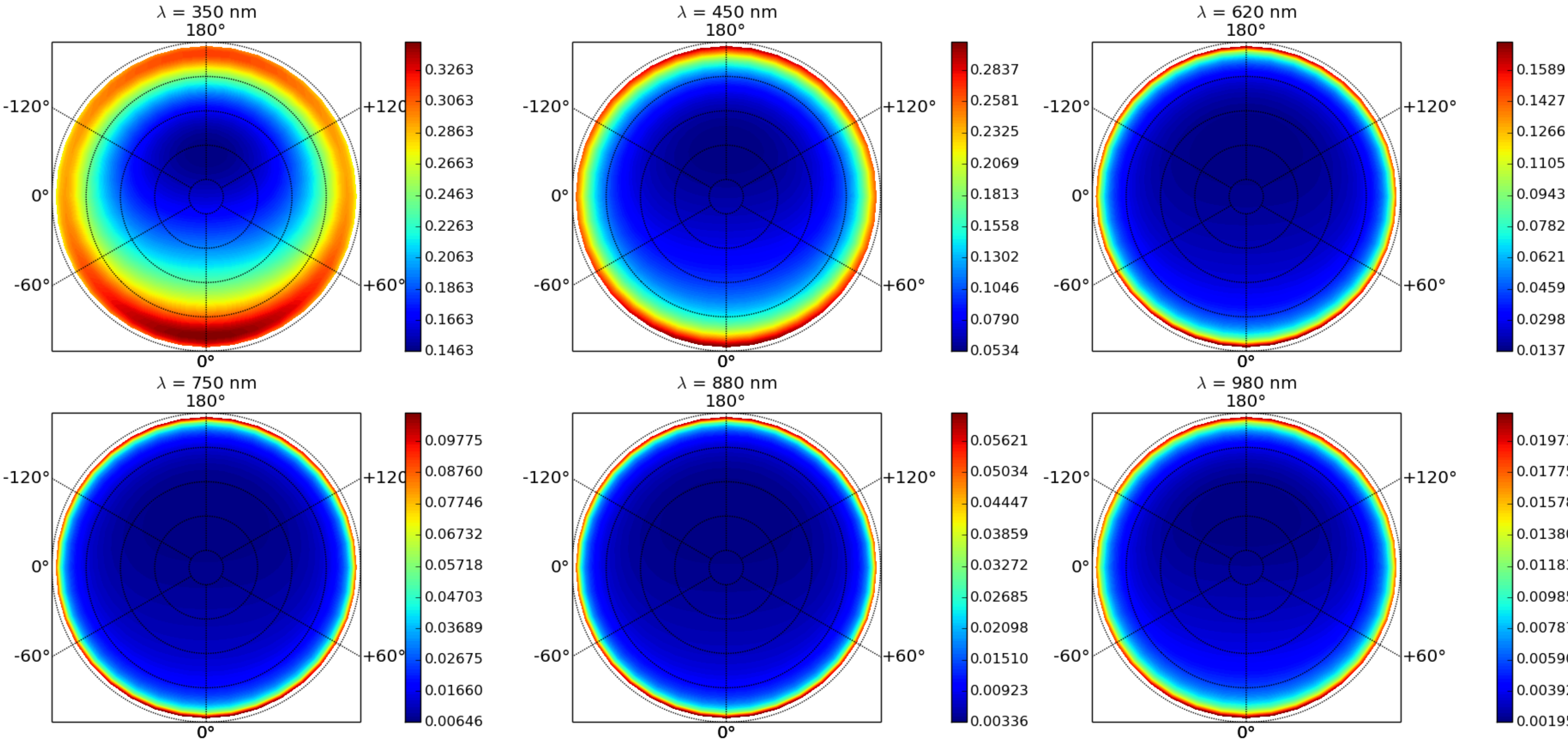
Application to sky diffused background

- Libradtran simulate not only direct light
- But also diffused background

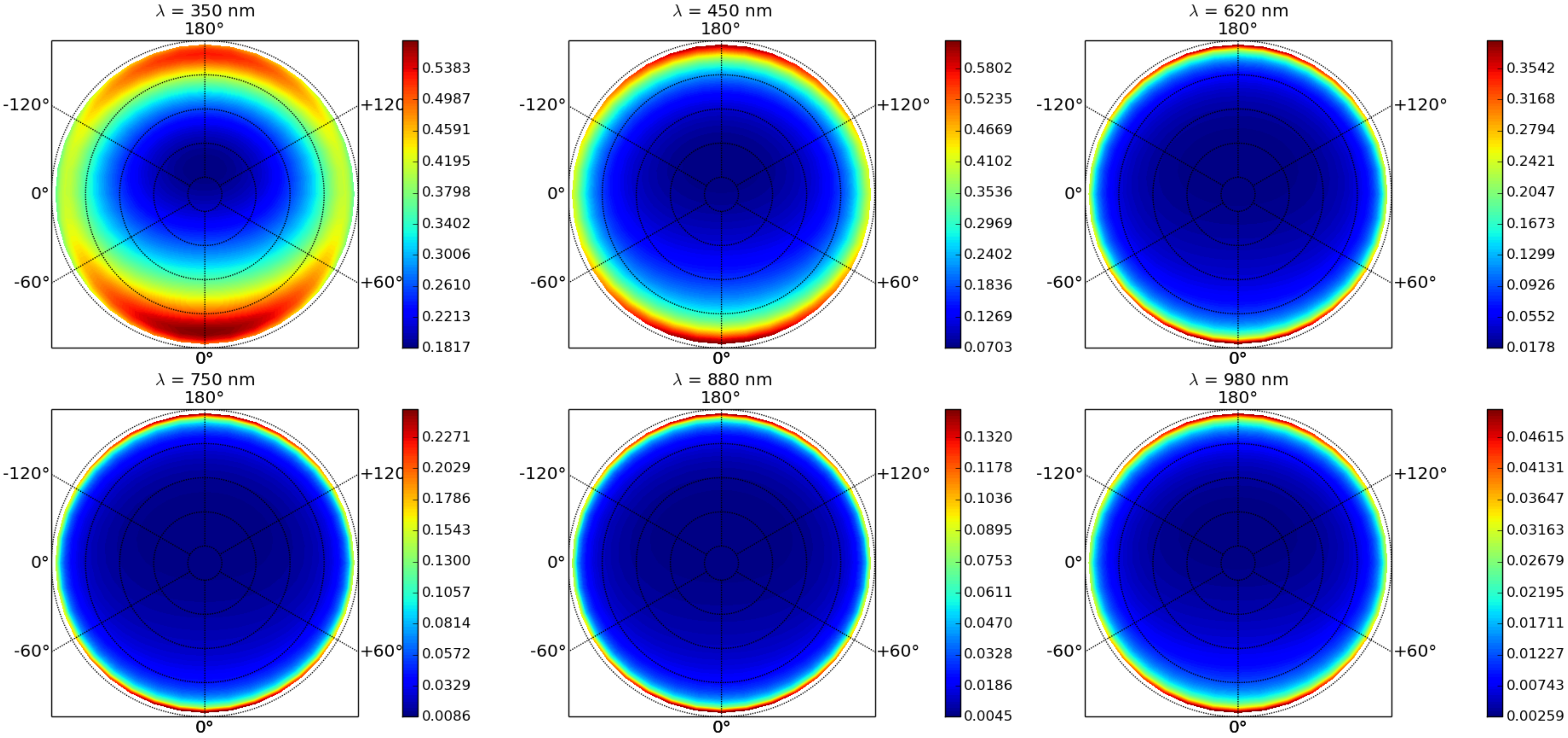
  – Diffused background requires earth albedo (albedo for rocks also depend on weather conditions : wet/dry,snow,…)

    - To be studied

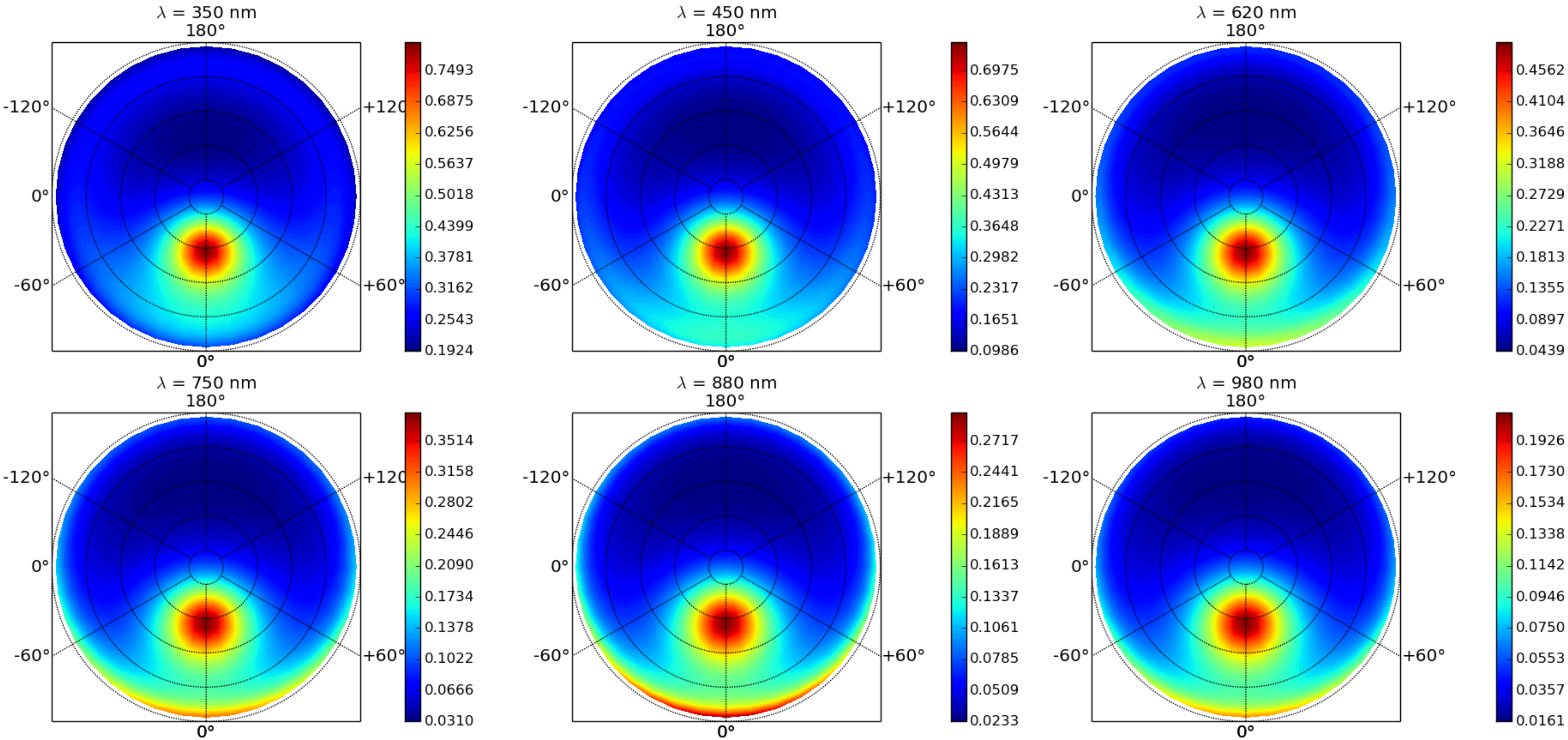
Map of Clear sky diffused light sun at 30° zenith angle



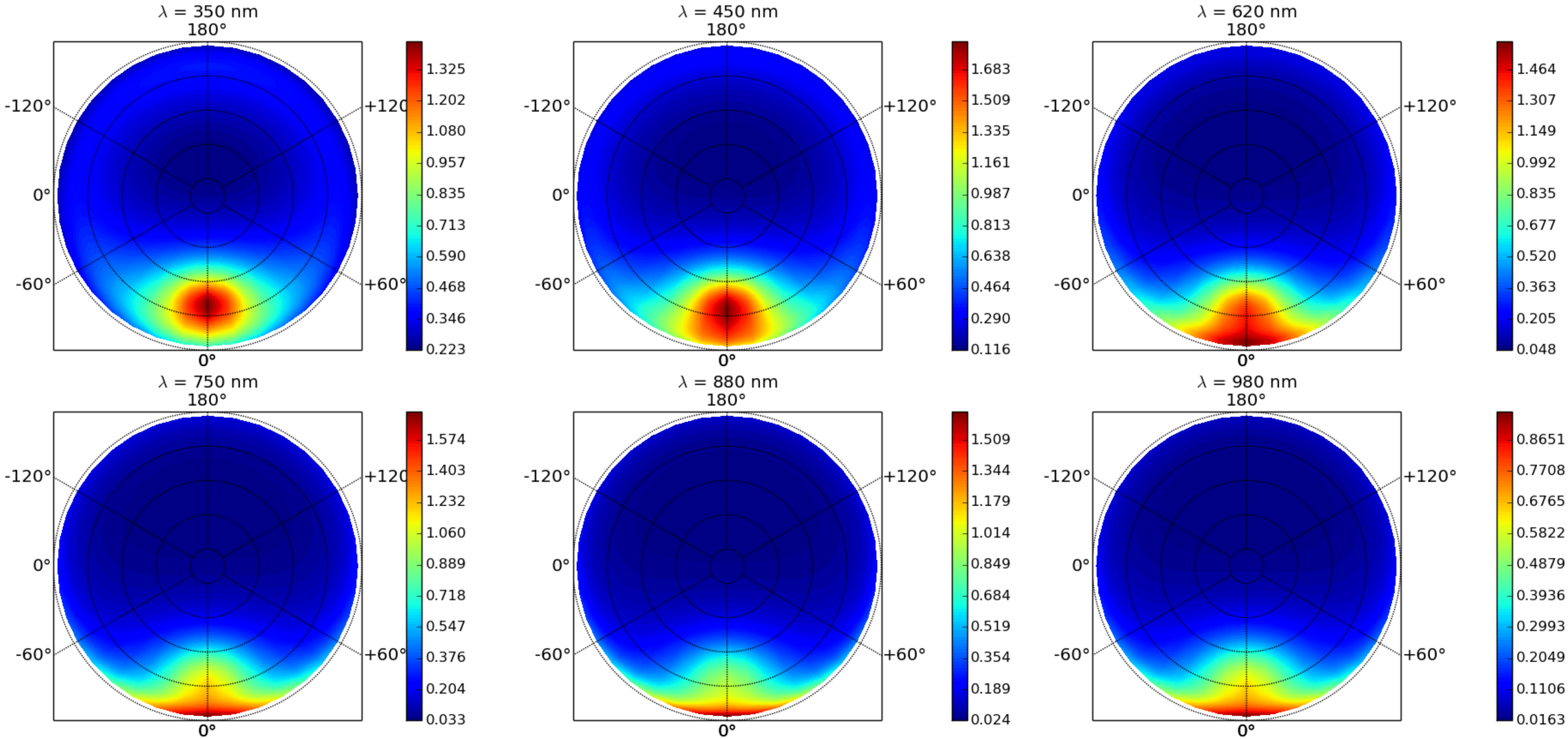
Map of Clear sky diffused light sun at 60° zenith angle



Map of diffused light with aerosols sun at 30° zenith angle

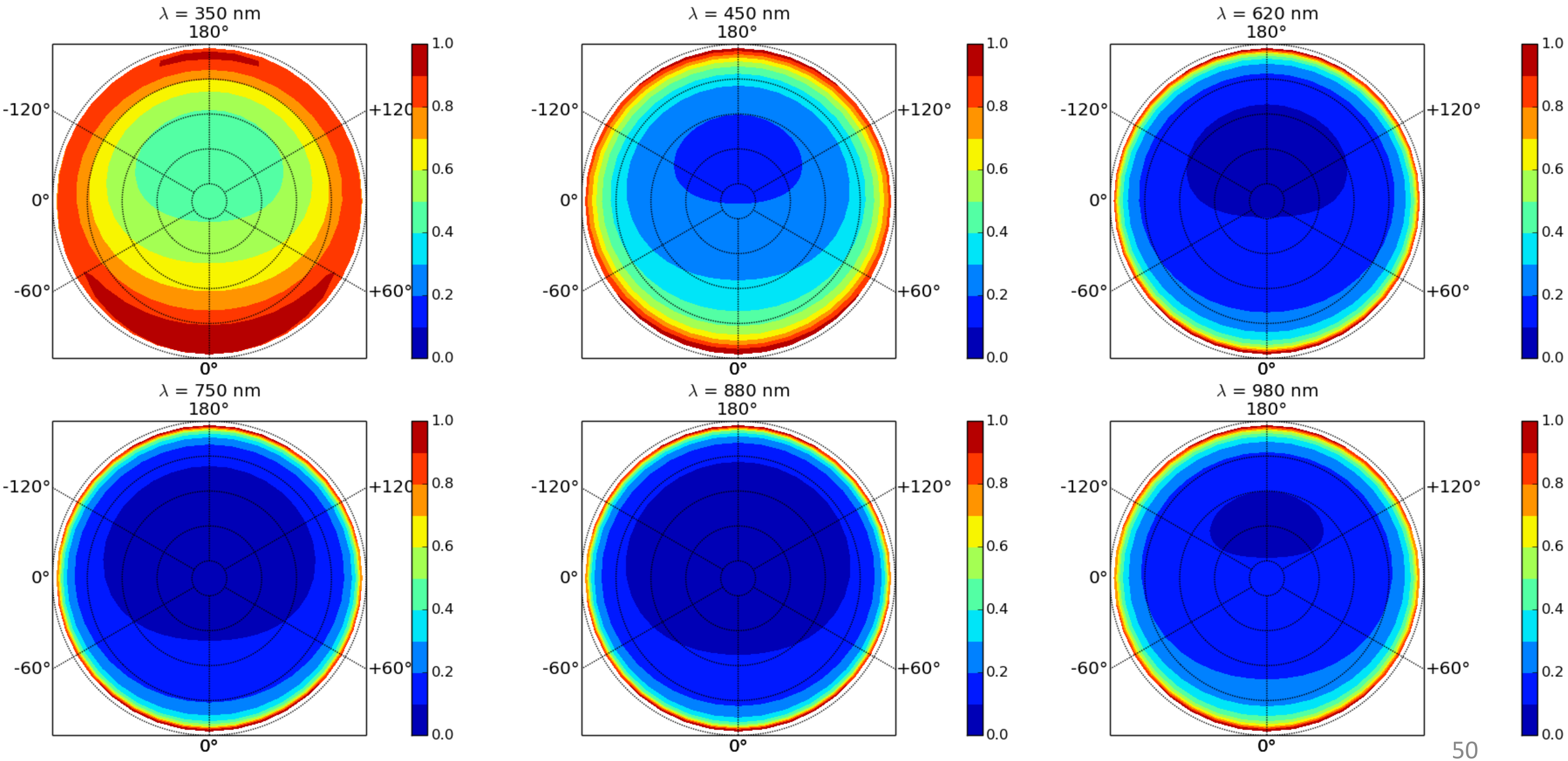


Map of diffused light with aerosols sun at 60° zenith angle

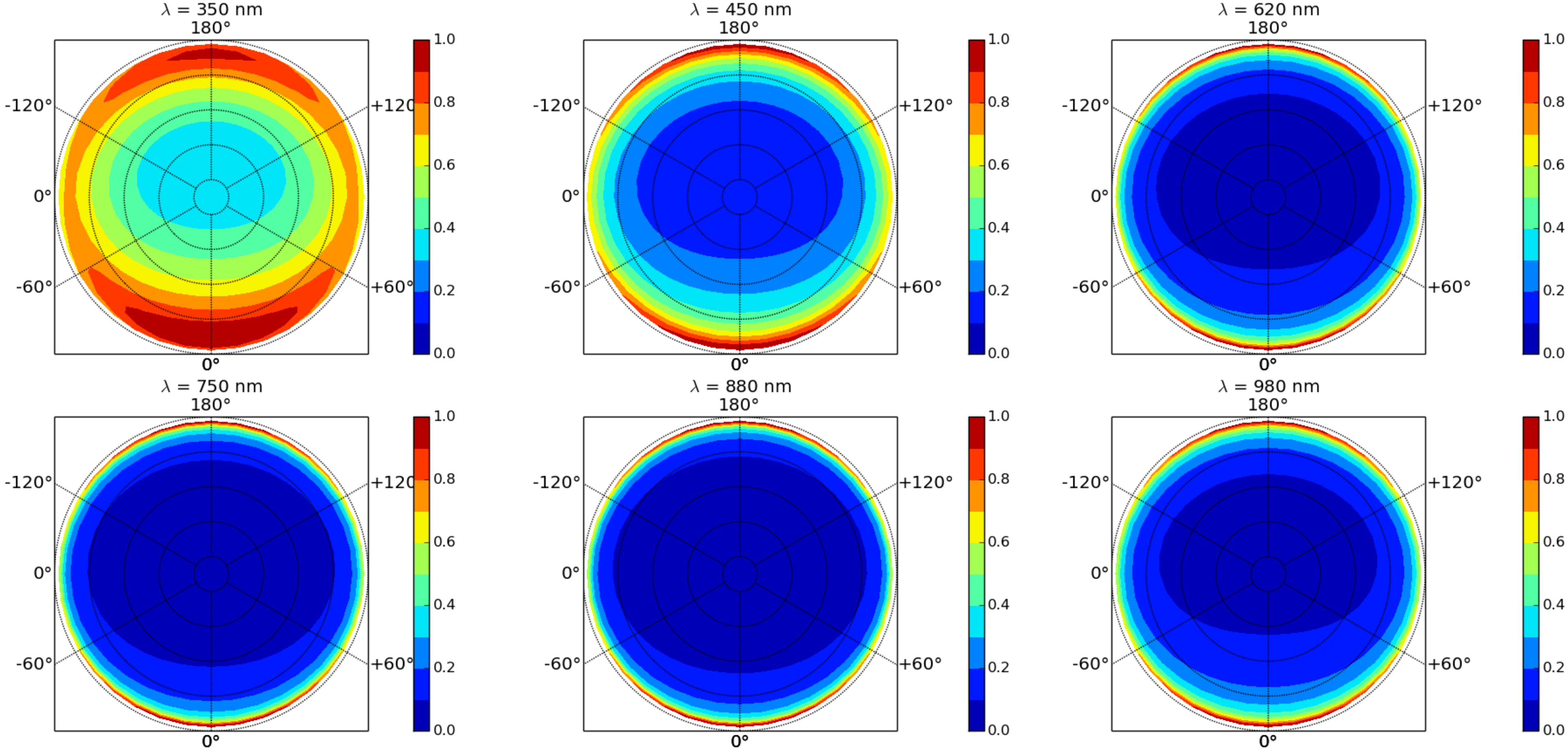


NORMALIZED LIGHT

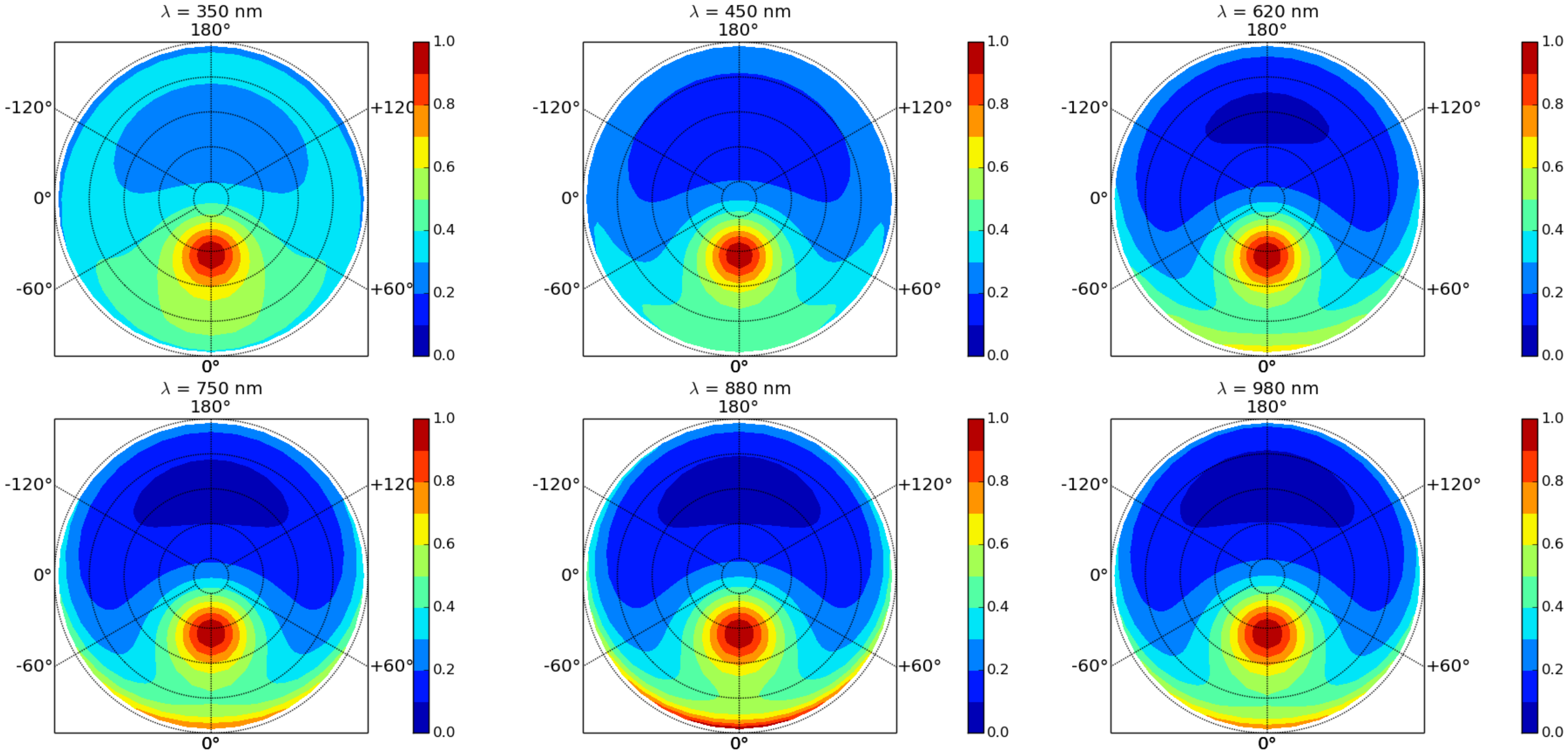
Map of Normalised **clear sky diffused light**
sun at 30° zenith angle



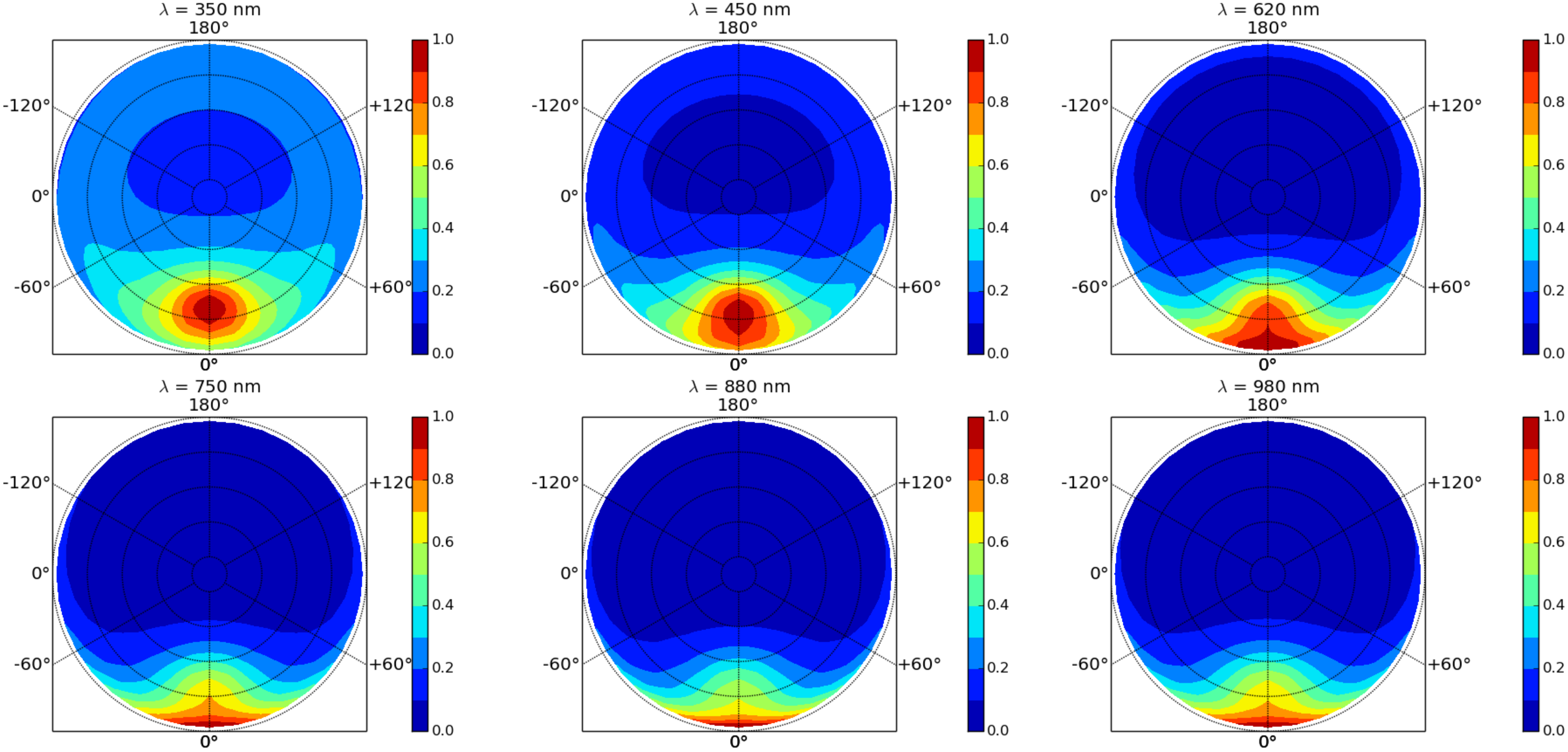
Map of Normalised **clear sky diffused light** sun at 60° zenith angle



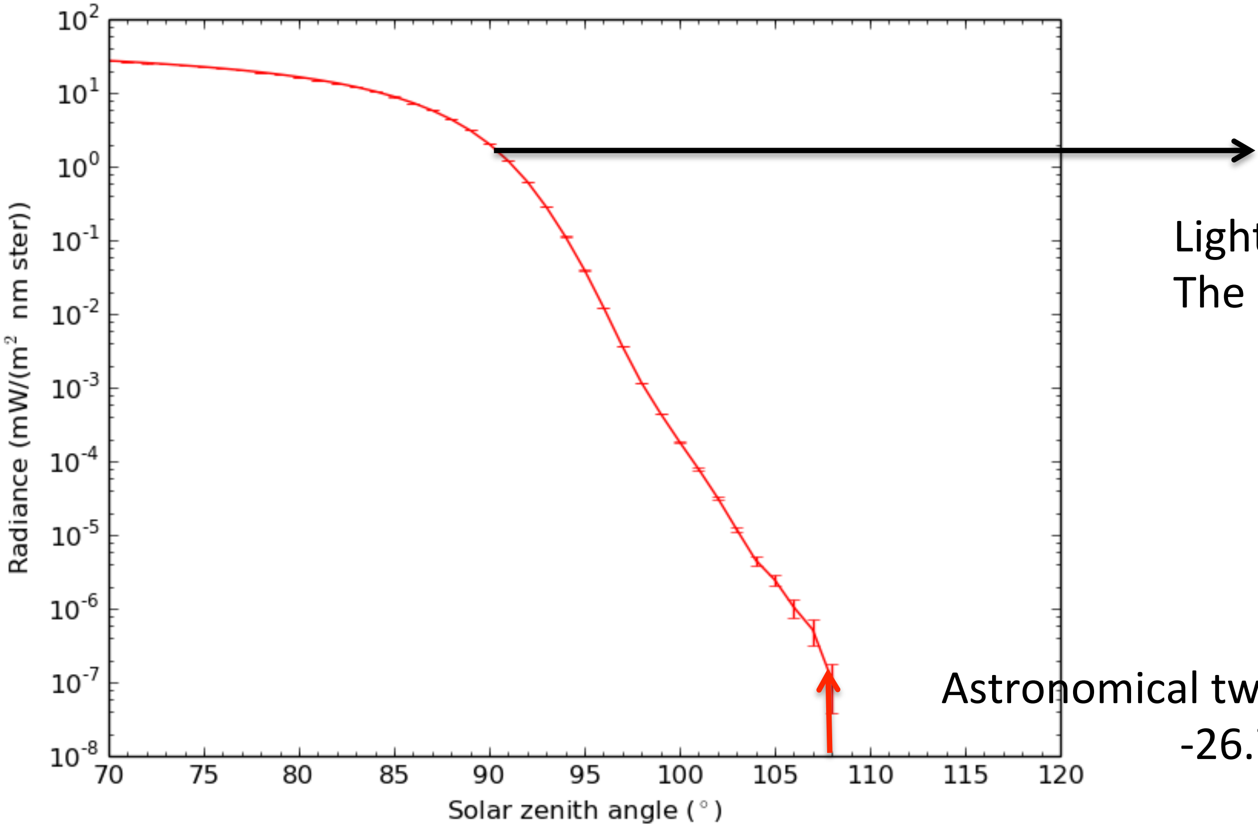
Map of normalised diffused light with aerosols sun at 30° zenith angle



Map of normalised diffused light with aerosols sun at 60° zenith angle



Radiance decrease with zenithal angle



Light diffused above
The horizon

Astronomical twillight : 10^8 radiance drop
-26.74 + 20 magnitudes

= - 6.74 magnitude