Commissioning of the Hologram at the auxiliary telescope

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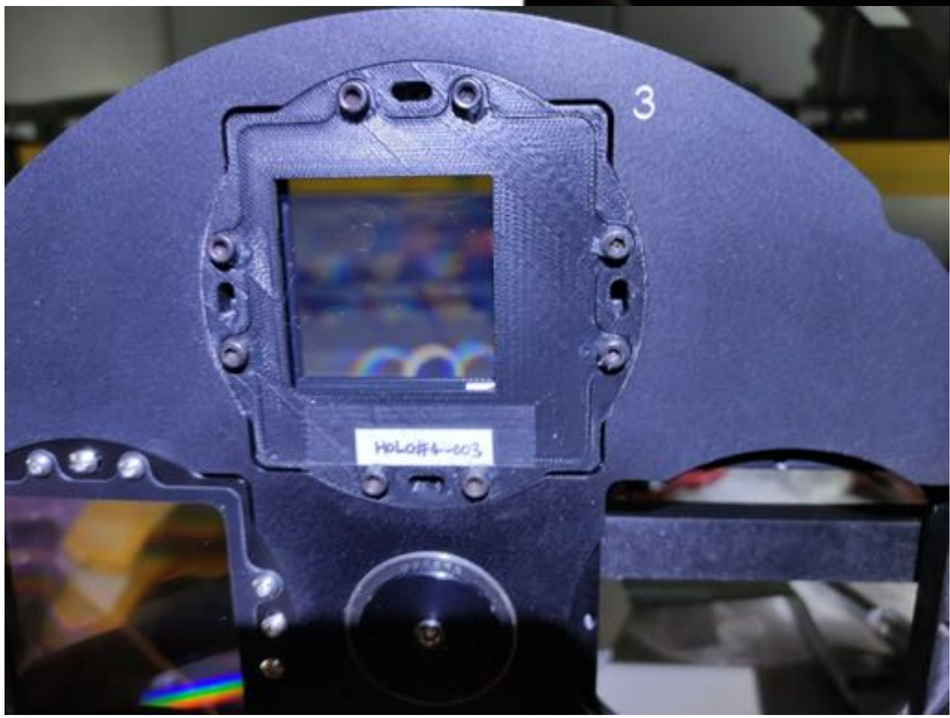
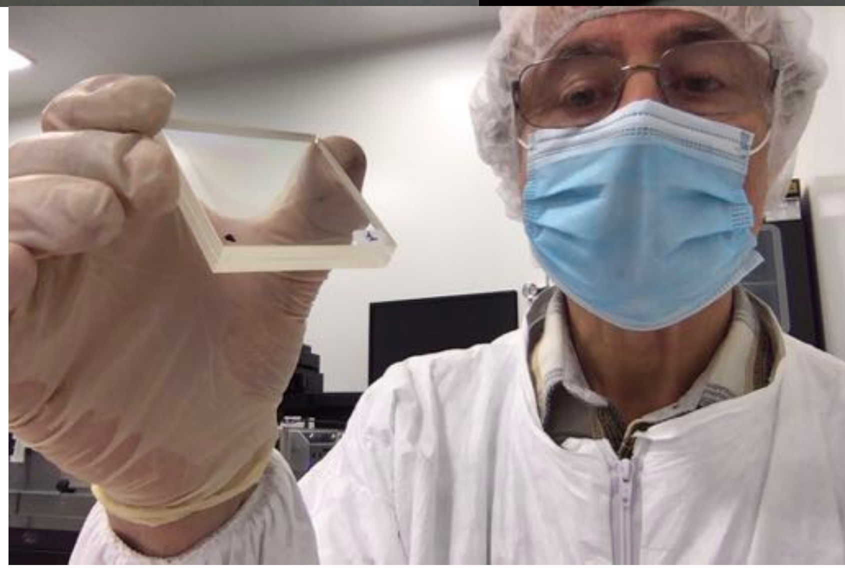
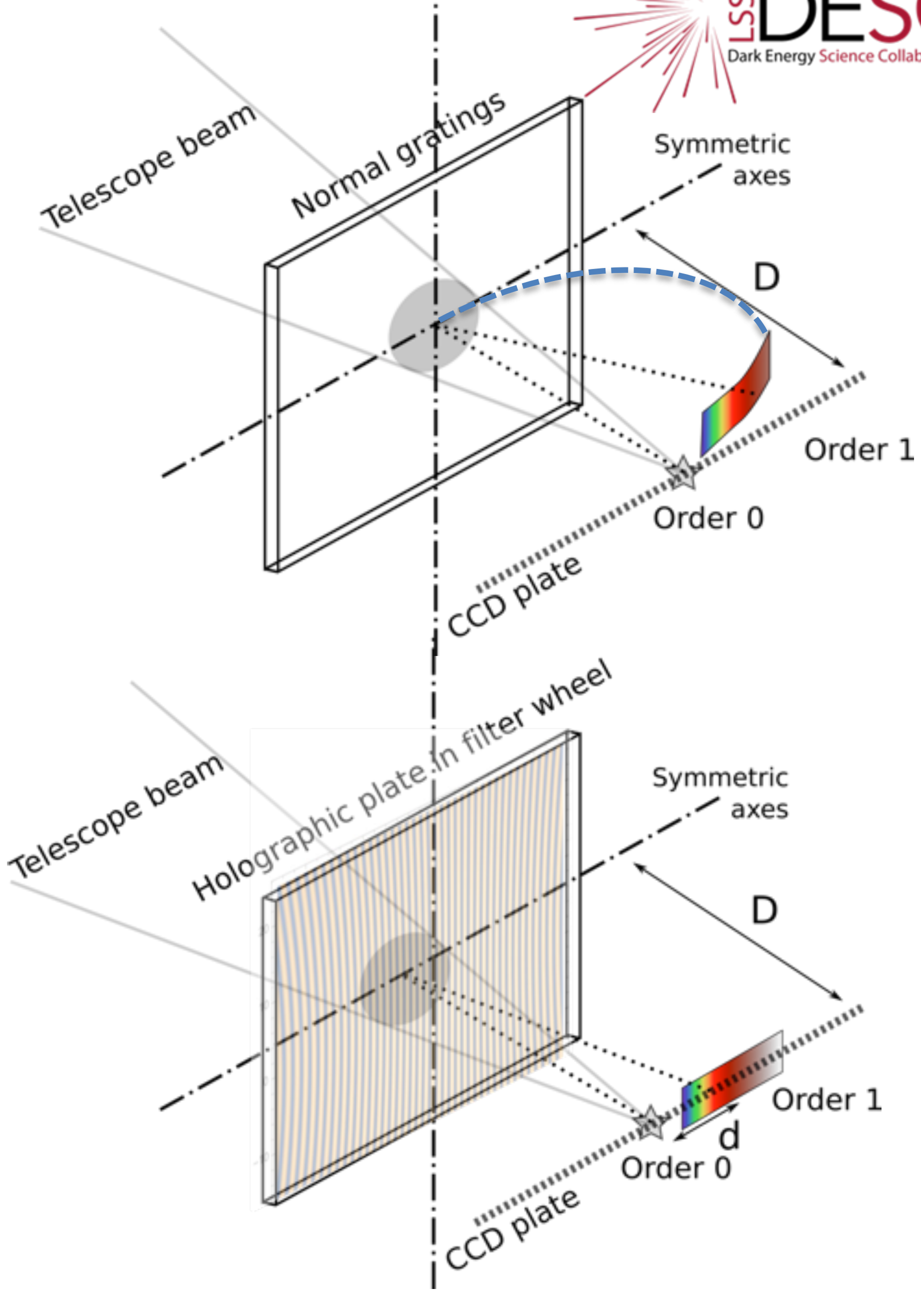
How it looks like



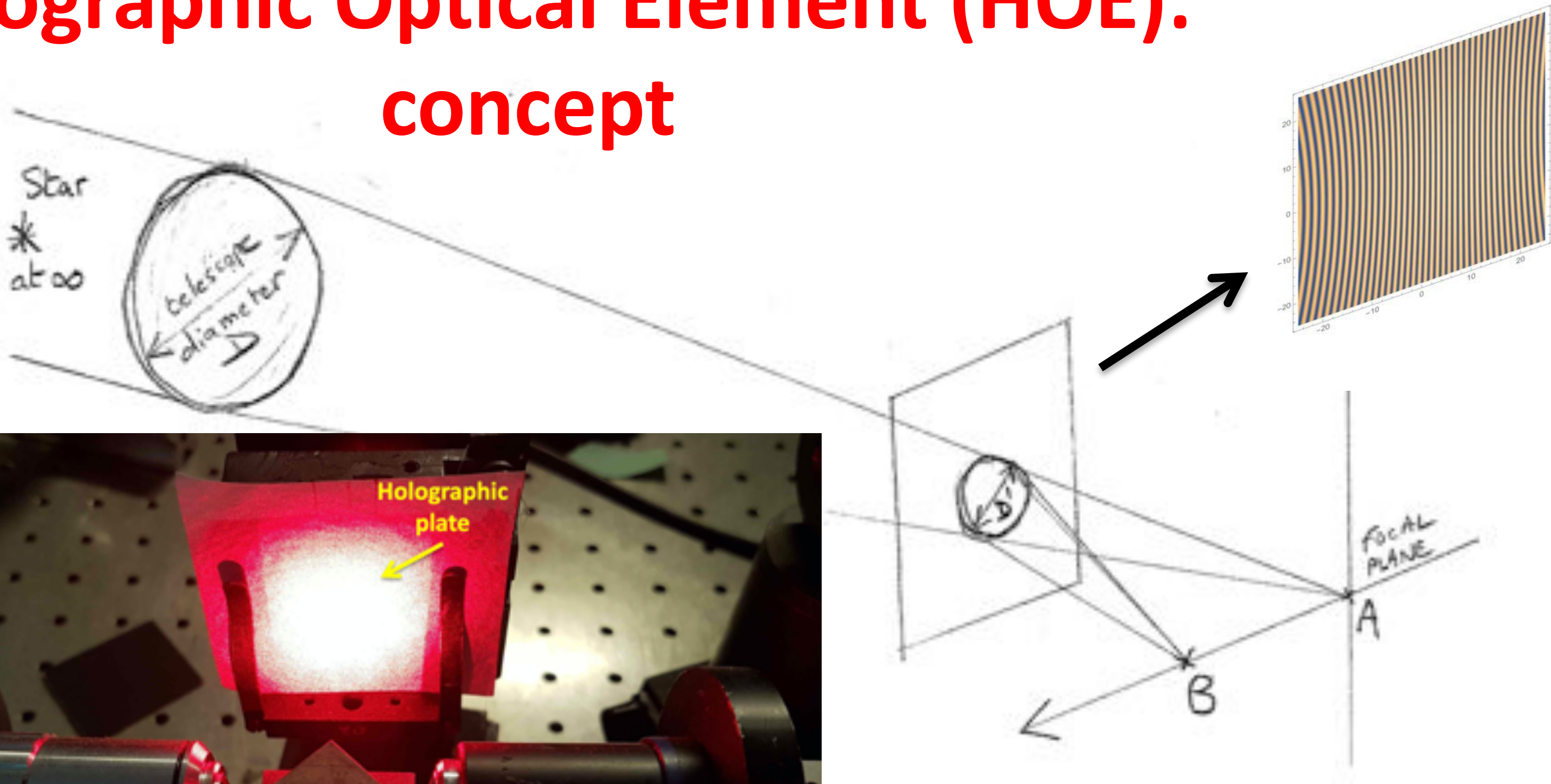


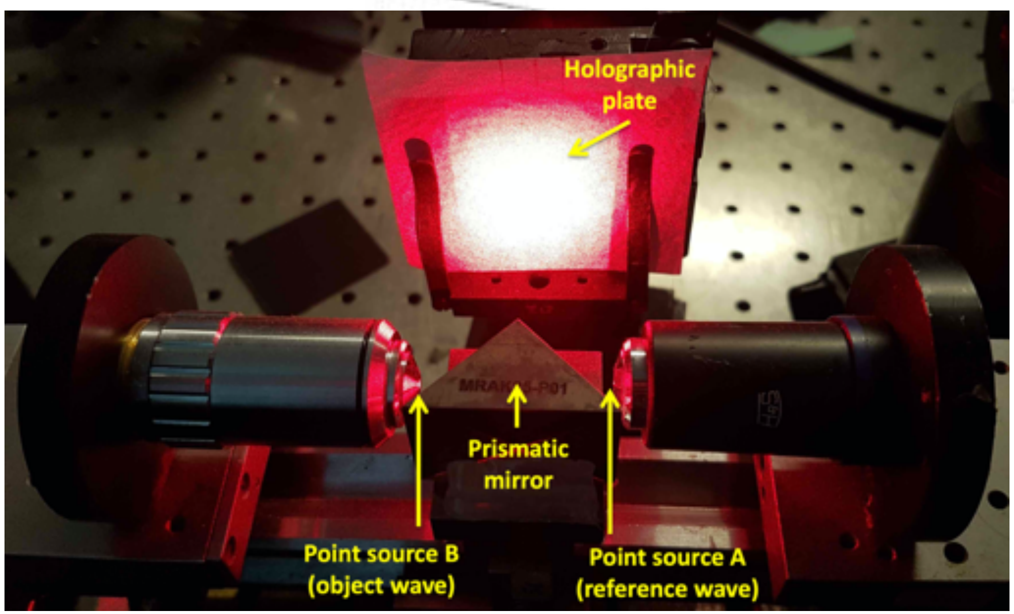
Holograms for AuxTel

- **Goal :** constrain atmospheric parameters by extracting spectrum of standards
- **Constraints**
  - Easily switch imager / spectro.
  - Incident beam perpendicular to CCD-plane
- **Periodic gratings:**
  - **Strong defocus** due to optical path variations with the diffraction angle
  - Distortion when used with a converging beam
- **Holographic grating:**
  - forced focus on the focal plane at all wavelengths: **0th and 1rst order at same focus**
  - No distortion by design



Holographic Optical Element (HOE): concept





Record the hologram: record interference pattern of coherent point-sources A and B at the λ = 639nm

Read the hologram: when illuminated by a beam converging in A, 1rst diffraction order **image at B for λ = 639nm**, and **close to AB line for other λ.**

Time-line of the R&D

- **January 2017**: first on-sky observations with the Ronchi grating at CTIO (Chile)
- **May 2017**: **3 prototypes** for CTIO delivered (generation zero)
- **June 2017**: 18 nights of observations at CTIO
- **Summer 2017**: first analysis -> **technique of phase hologram chosen**
- **October 2017** : scientific council at LAL approval for R&D
- **June 2018** : **first generation** of hologrammes for AuxTel
- **September 2018** : test on LPNHE test-bench equipped with a beam-telescope simulator
- **October-november 2018** : test of **second generation**
- **February 2019** : tests at the Pic du Midi 1m telescope, and on the AuxTel spectrograph in Tucson.
- **July 2019** : **third generation**.
- **September 2019** : measurements with test-bench to optimise the parameters of the final hologram.
- **December 2019** : **Final production** with anti-reflective coated glass by LMA (5 variants)
- **February-march 2020** : measurements/characterisation at LPNHE. COVID…
- **December 2020** : One hologram sent to Chile.
- **15 February 2021** : Hologram inserted in the AuxTel spectrograph.
- **March-april 2021** : **First spectra**……….
- **april 2021**: COVID (again), stop observations until june

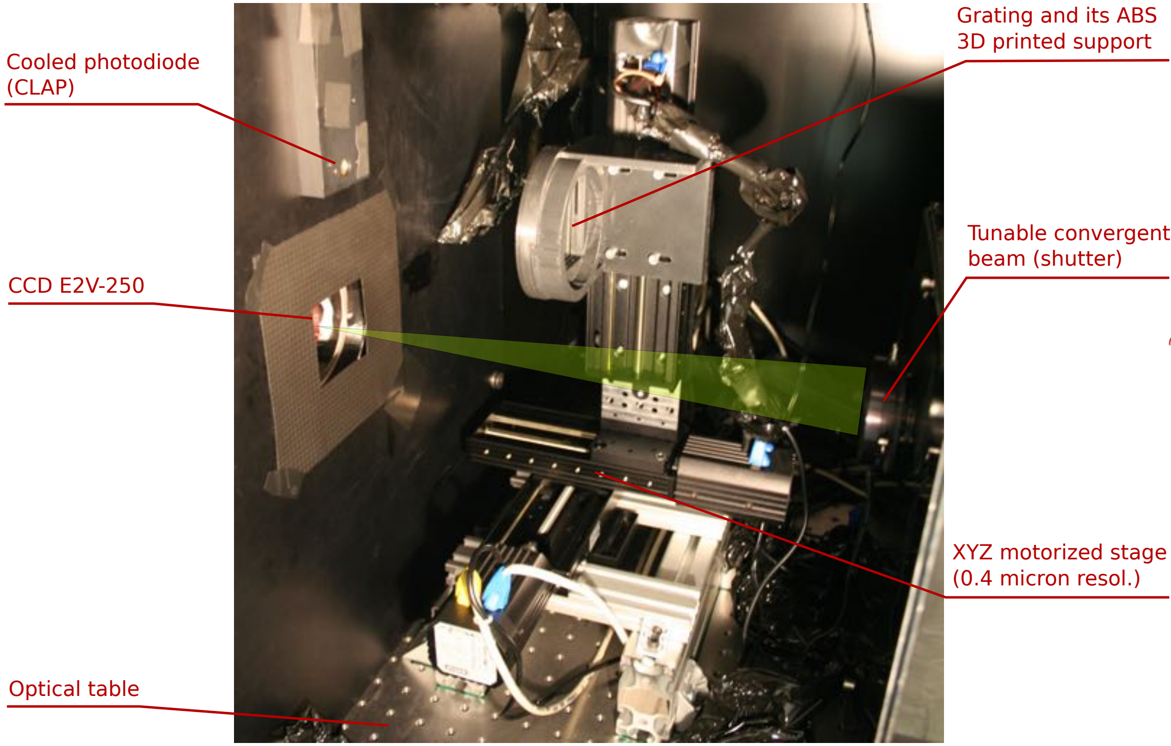
Optical Test-bench at LPNHE

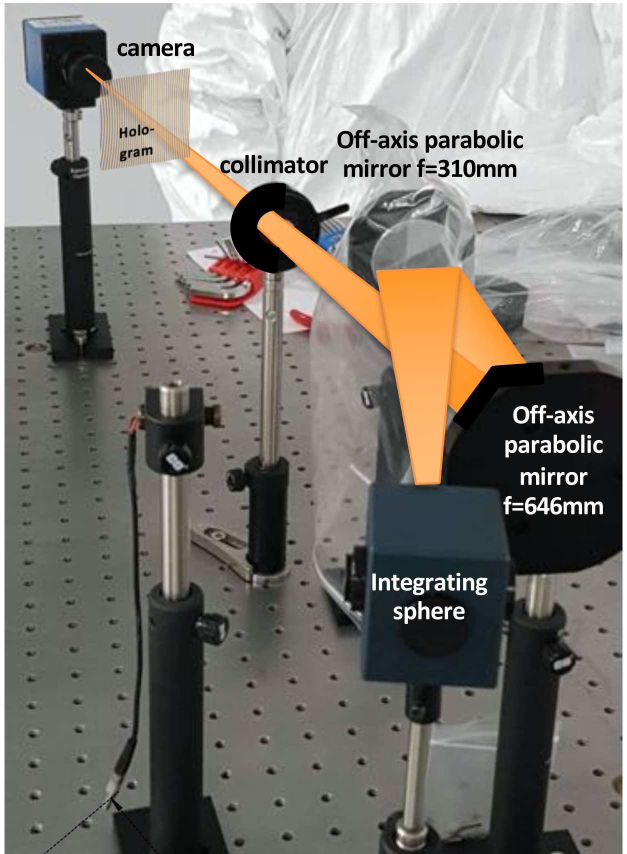
Simulation of the AuxTel convergent beam

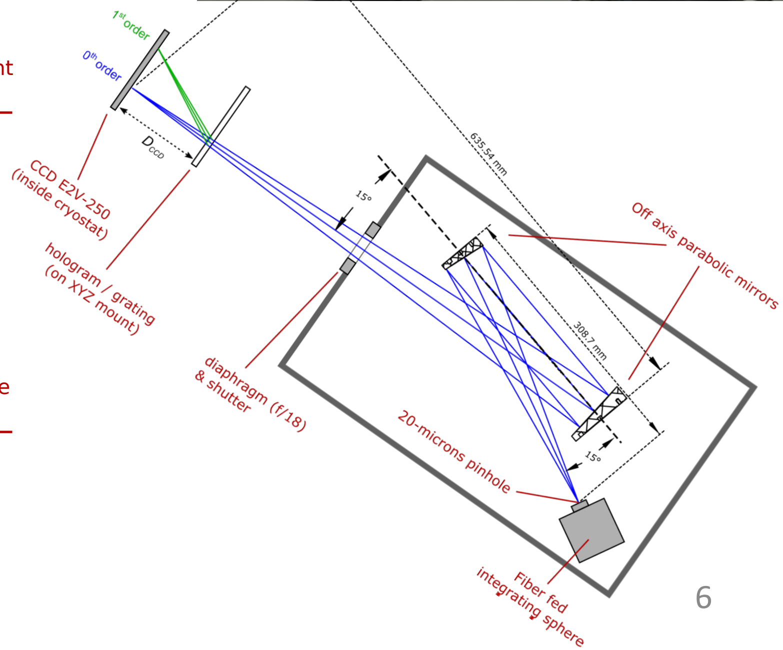
- Focus on a LSST-type CCD sub-arcsec equivalent PSF from converging beam
- Focus independent from the wavelength (mirrors)
- Uniform beam density obtained with integrating sphere + 20μ hole
- Hologram installed on a XYZ mounting

Measurements done 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.

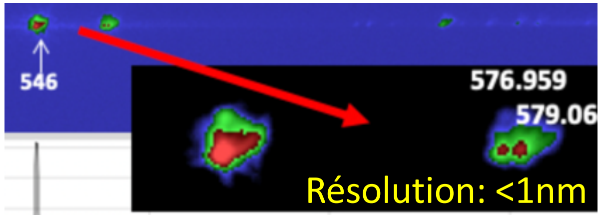


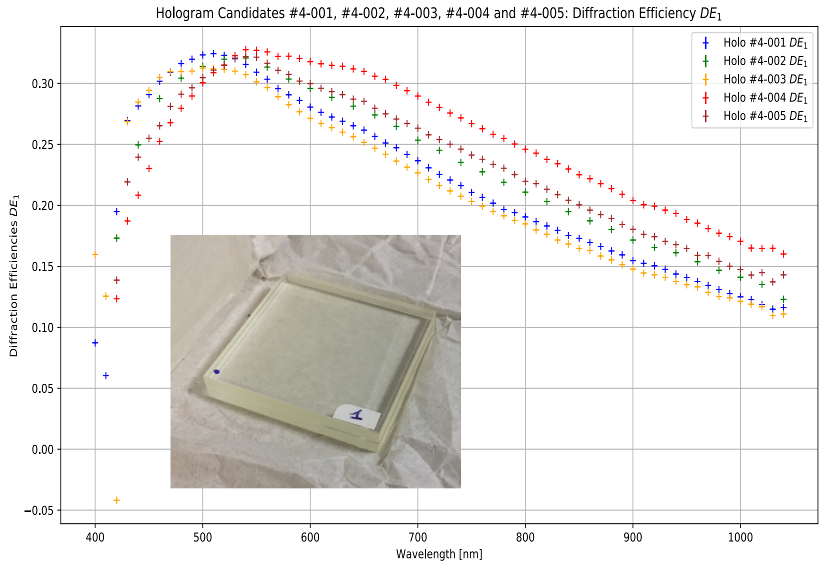


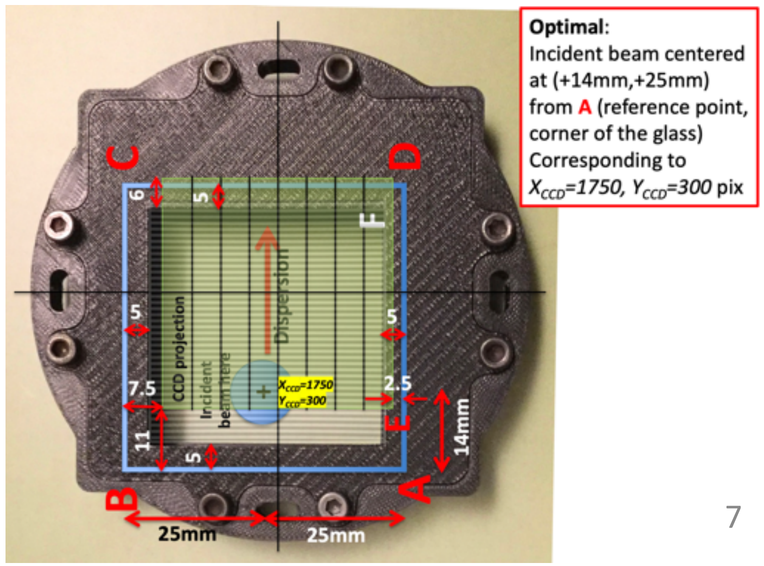


HoloSpec: final

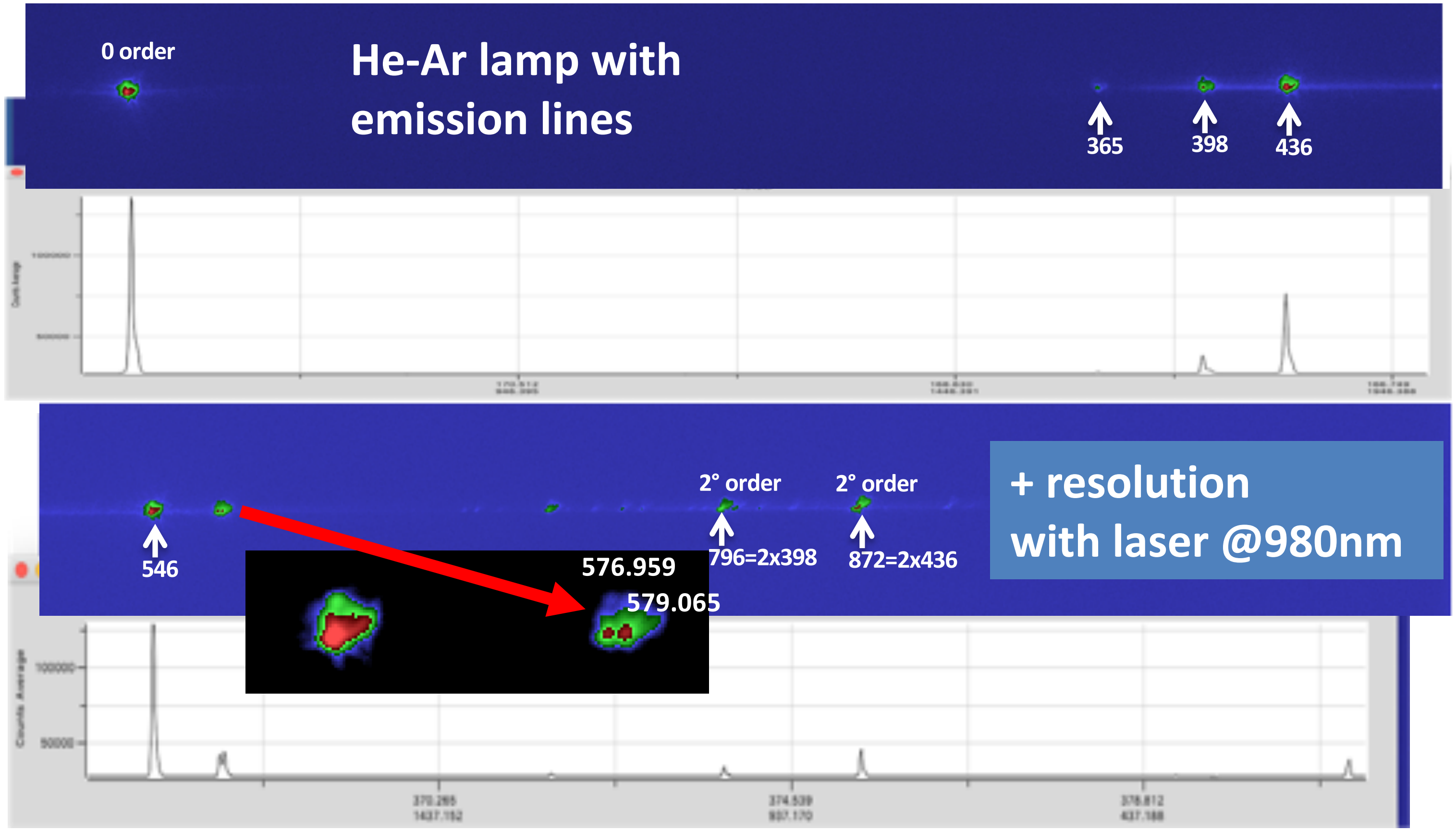
- After 4 iterations, 5 variants of holograms produced
  - **Adapted to AuxTel**, i.e. with Dispersion such that the 1rst order spectrum spread over the full CCD
  - Wide band anti-reflective coating at **LMA**
- Characteristics measured with beam simulator
  - *Homogeneous (excellent) imagery from 380nm to 1050nm within a sweet pot* ***(ΔX, ΔY, ΔZ) = +/- (5, 10, 30)mm***
  - ***sub-nm spectral resolution***
  - *Transmission order 1 vs λ: not far from the theoretical max. ($4/\pi^2$ ~ 40.5%)*
- Asymetrical tilted frame
  - 1° tilt to avoid ghosts (checked at test bench and at pic du Midi)
  - 2 asymetrical frames allowing 4 configurations depending on the CCD-registers to be used
- Holo#4-003 installed on the grating wheel of AuxTel since 15 feb. 2021





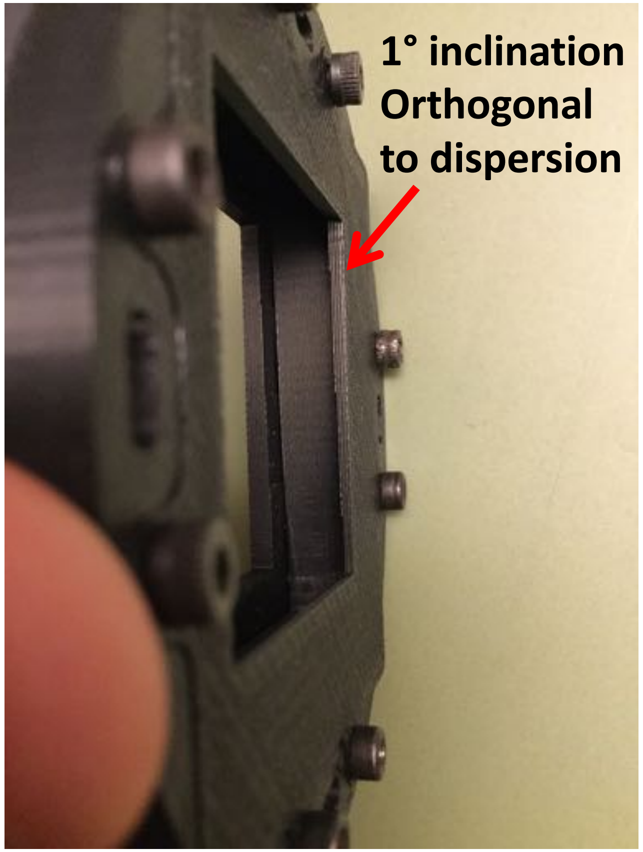


Final holograms : resolution check on bench



L. Le Guillou

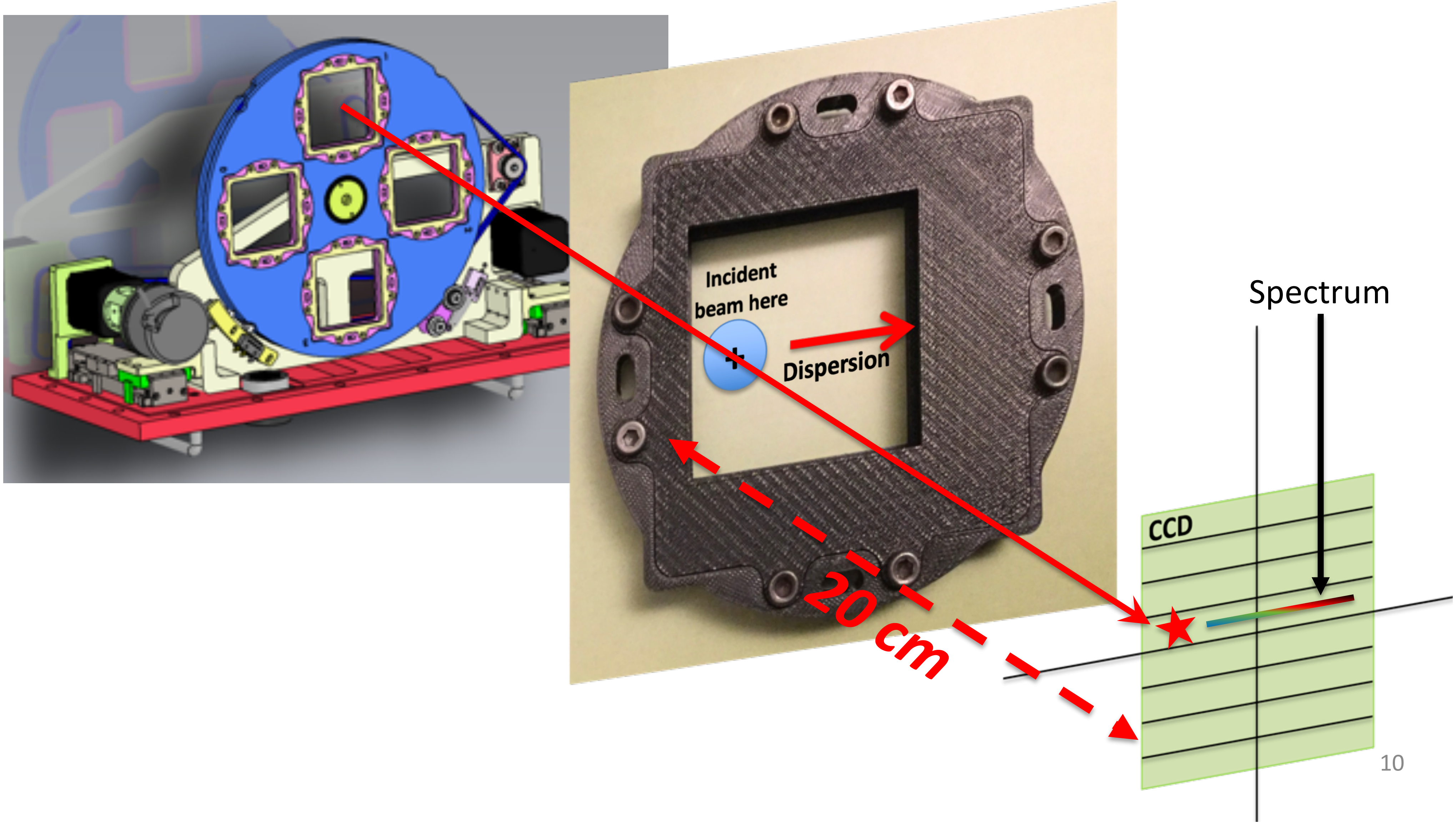
Inclination orthogonal to dispersion



1° inclination
Orthogonal
to dispersion

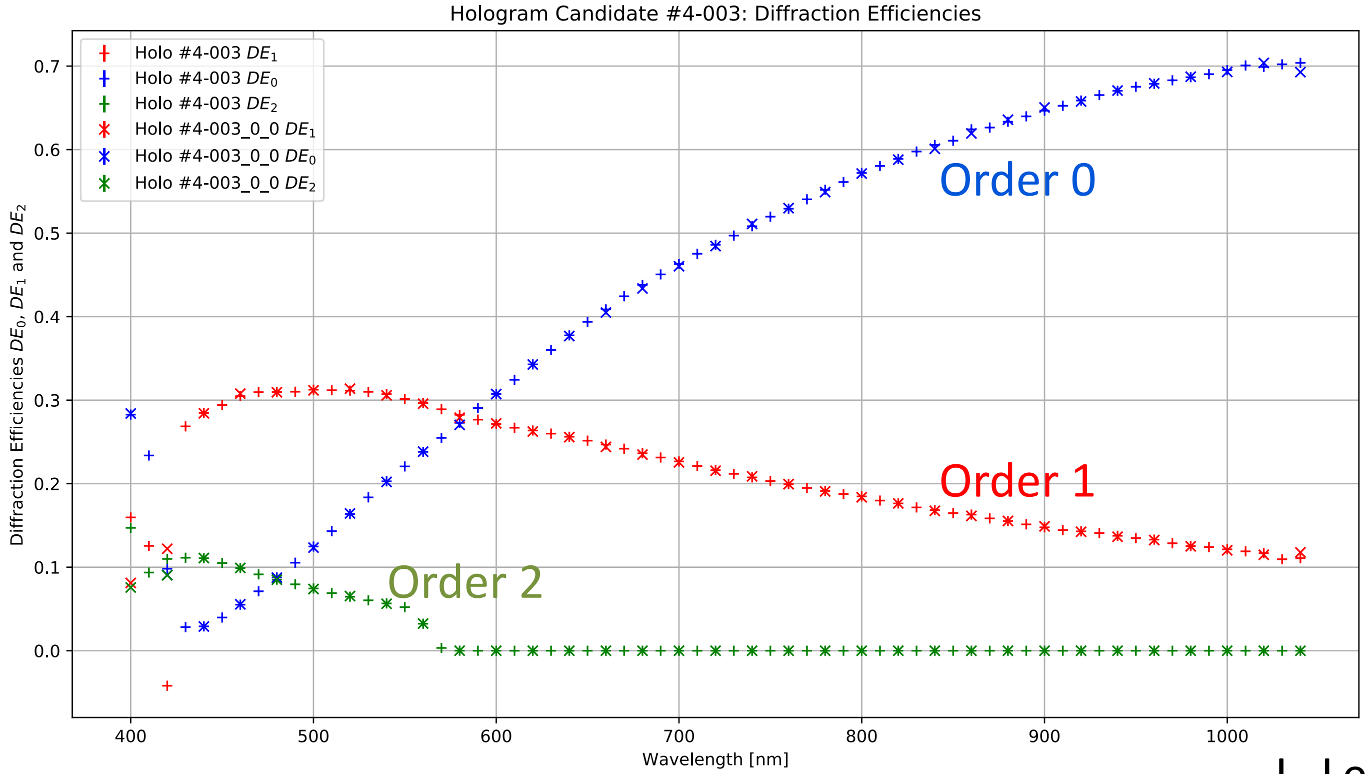
No inclination
Parallel to
dispersion

Hologram frame seen from the CCD



Efficiency of Holo#4-003 (in place)

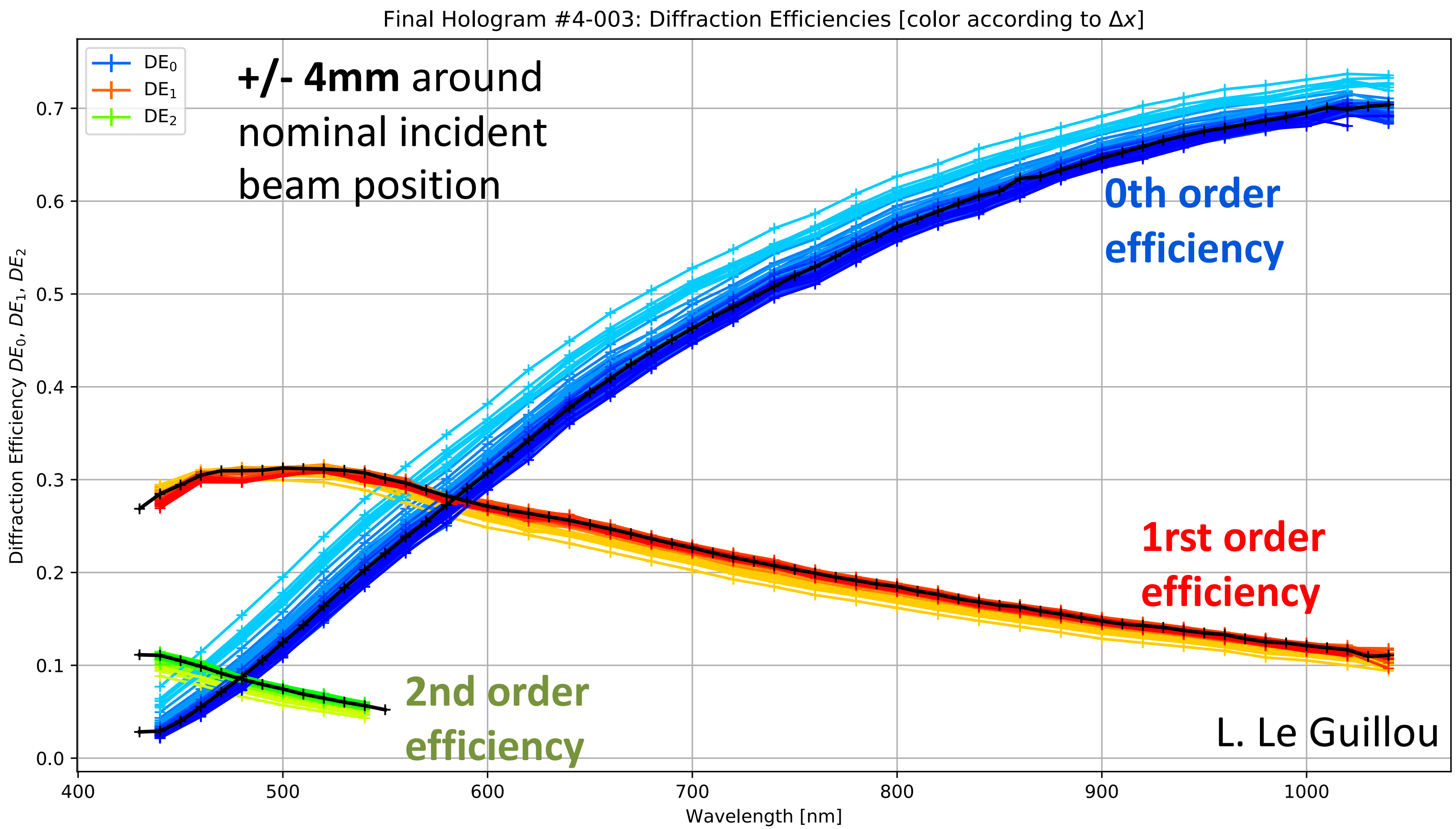
- Diffraction efficiency measured 2 times at nominal position on optical bench (L. Le Guillou): excellent reproducibility
- These curves are used by Spectractor code



L. Le Guillou

variability of the transmission with the position of the direct image

- Remember: Holograms have an optical center (since a Ronchi is a periodic grating, it is invariant by translation);
- -> Measure the variation of efficiency with 0th order image position up to 4mm from the nominal position (here Δx) – also needed by Spectractor

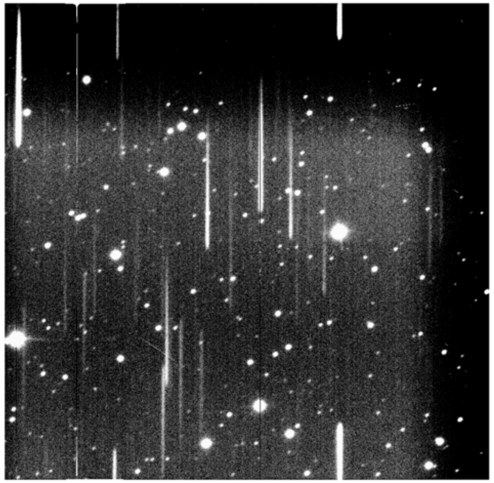


February-march runs

- Bad weather
- Technical problems with the AuxTel rotator
  - > the vast majority of images have poor PSF
  - > Only 5 images with hologram are passable
  - > A few basic checks done (focus, passband, resolution)

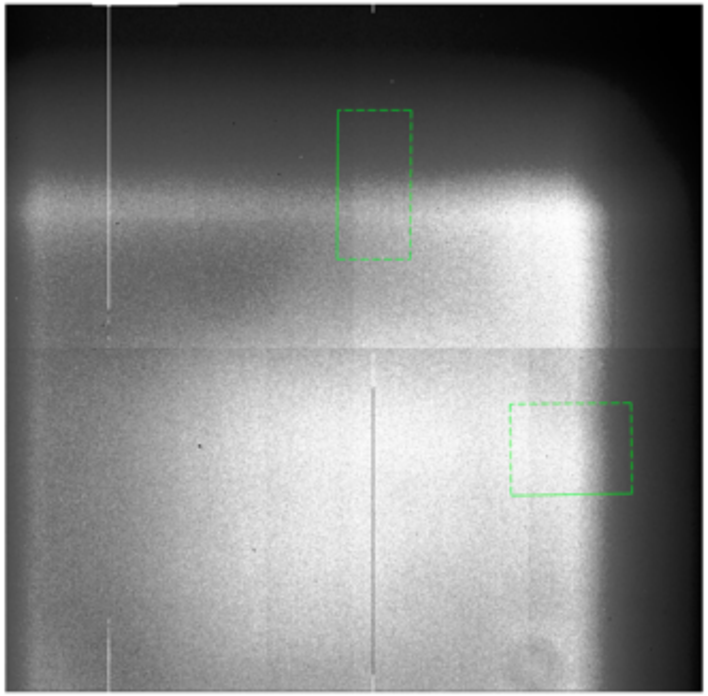
Runs of april and may cancelled (COVID)

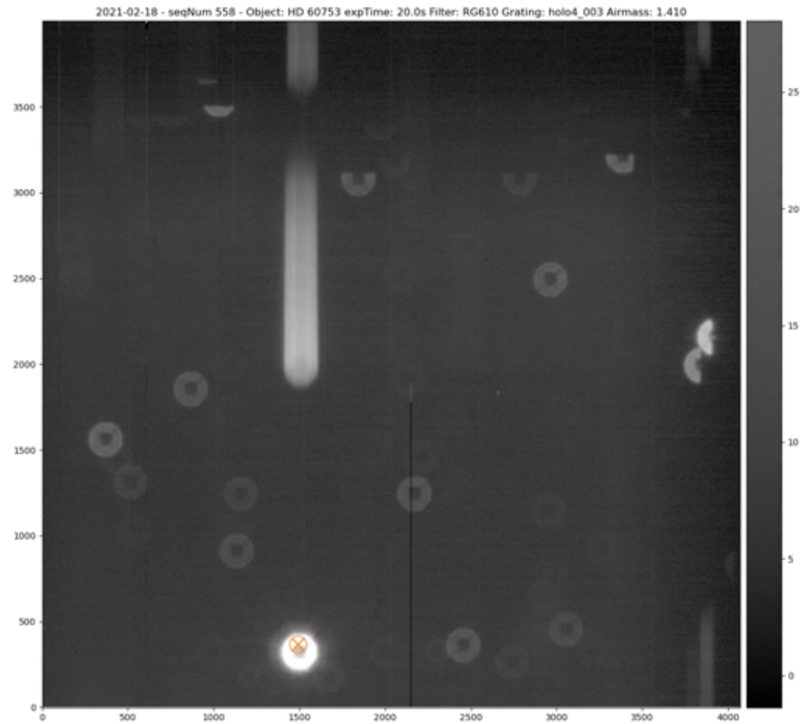
Commissioning: First checks and evaluations. Position of the frame of the hologram w/r CCD



- Dispersion power (2.73 pix/nm) provides D_{CCD} : **Z = 178mm** (instead of 200mm, tunable).
  - (Bonus result from close examination: No ghost induced by the hologram)
- Flat-field: half the light <-> half field-of-view
- Out-of-focus images: half pattern face edge of frame

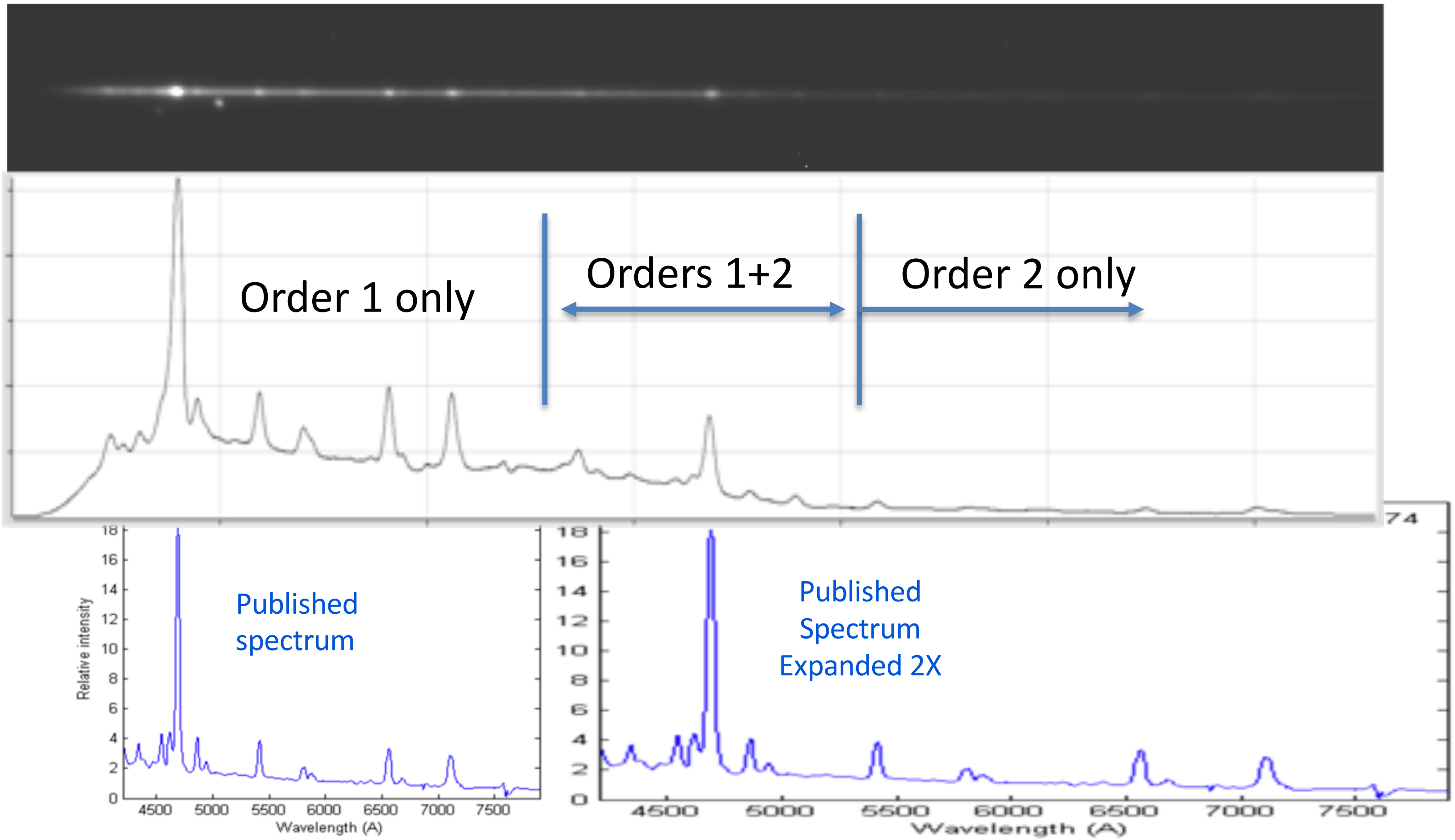
-> X, Y position corresponds to expectation within 1mm



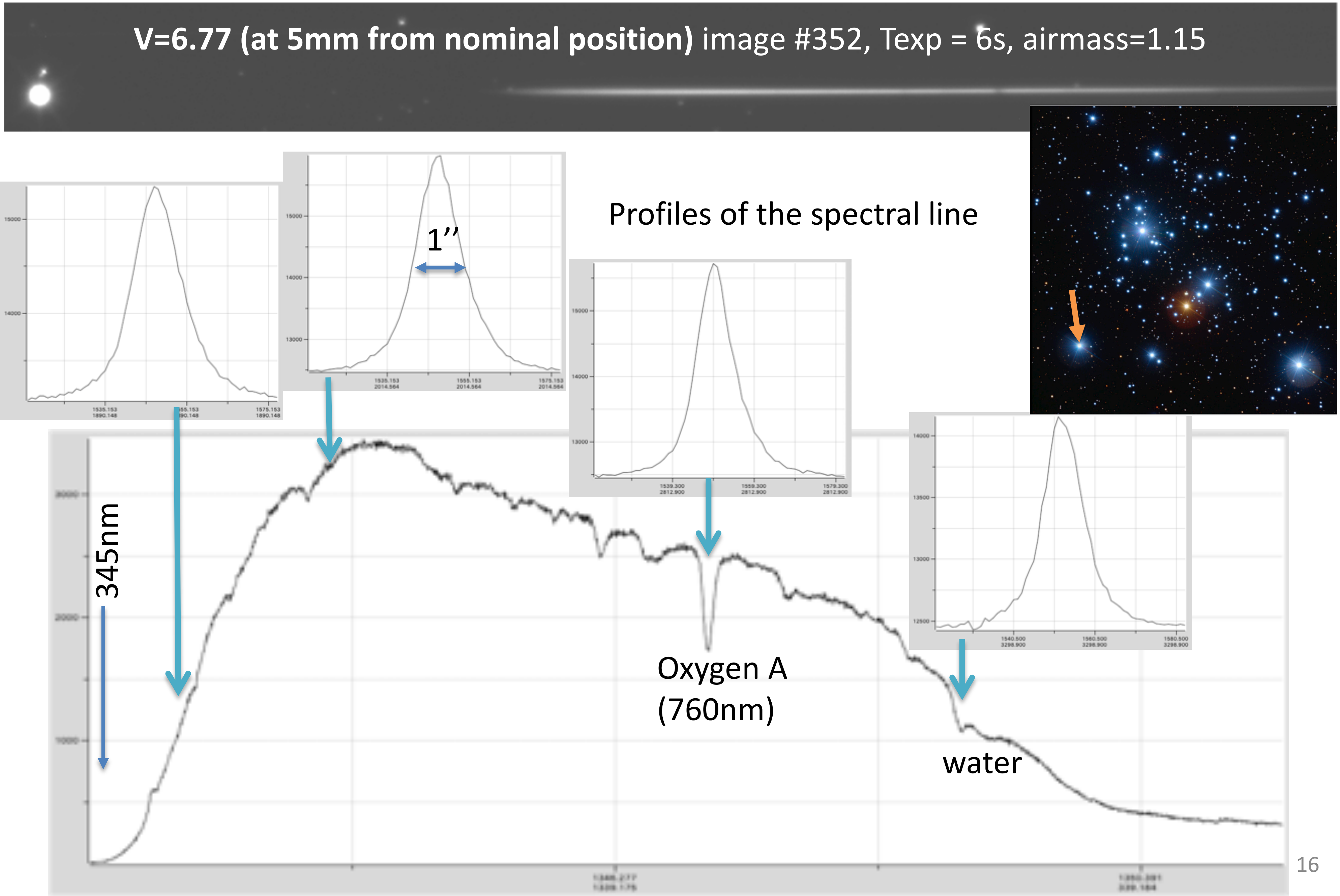


The very first spectrum…

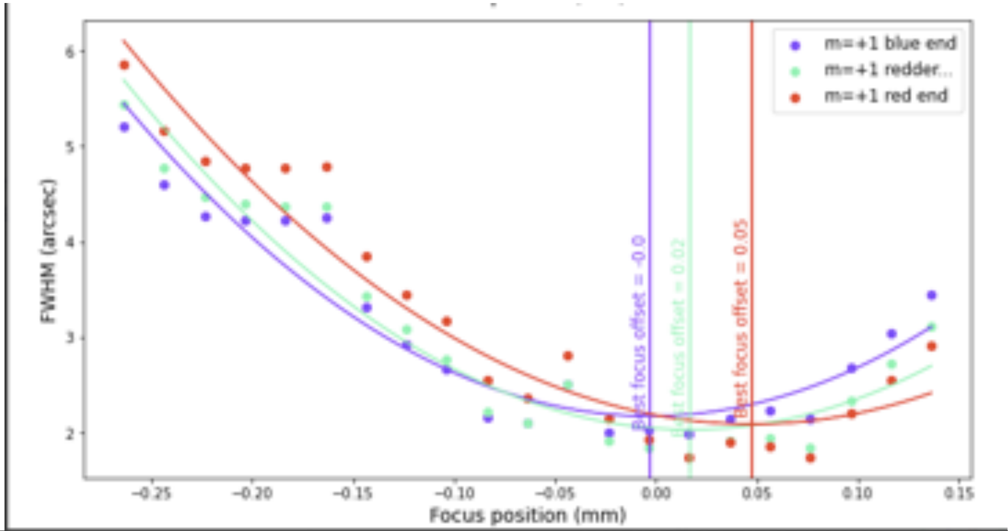
Wolf-Rayet 6 star, HD50896 (V=6.74). Image #209, Airmass=1.1, Texp=90s
0th order was out of CCD, nevertheless a nice spectrum



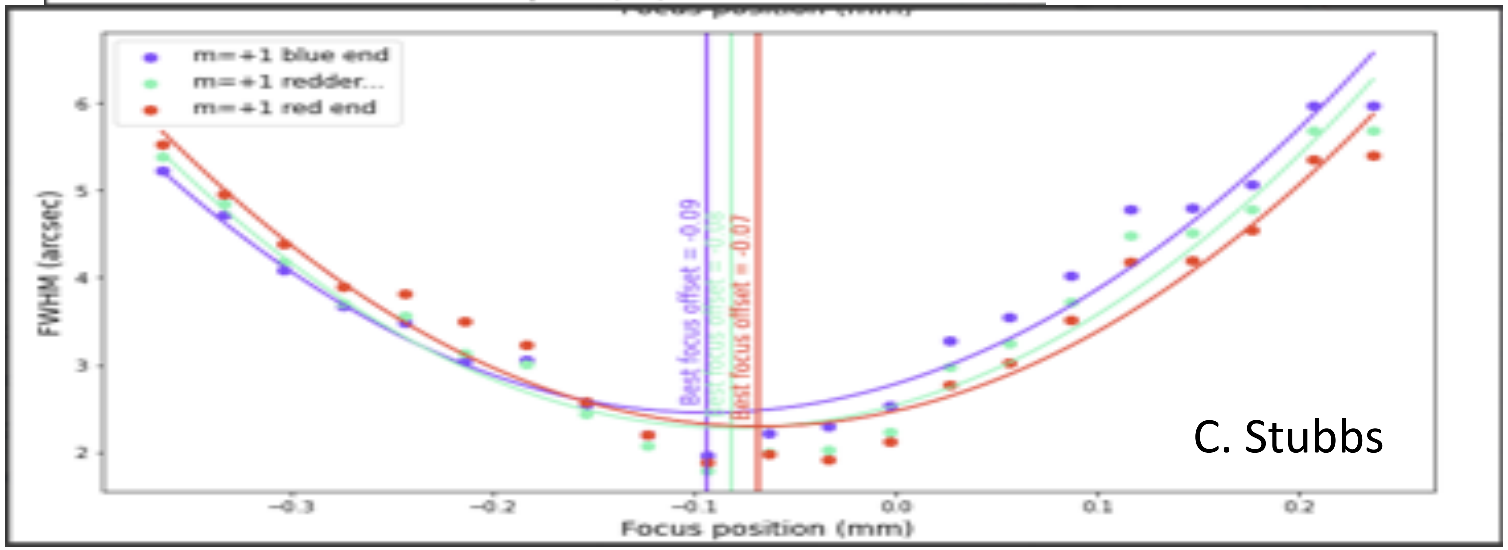
The jewel box (NGC4755): series of spectra in an open cluster



Focus of Hologram vs Ronchi170



- Focus measured for 3 colours
- Less dispersed with hologram (abscissa to be x40)
- Preliminary: to be measured again with better conditions



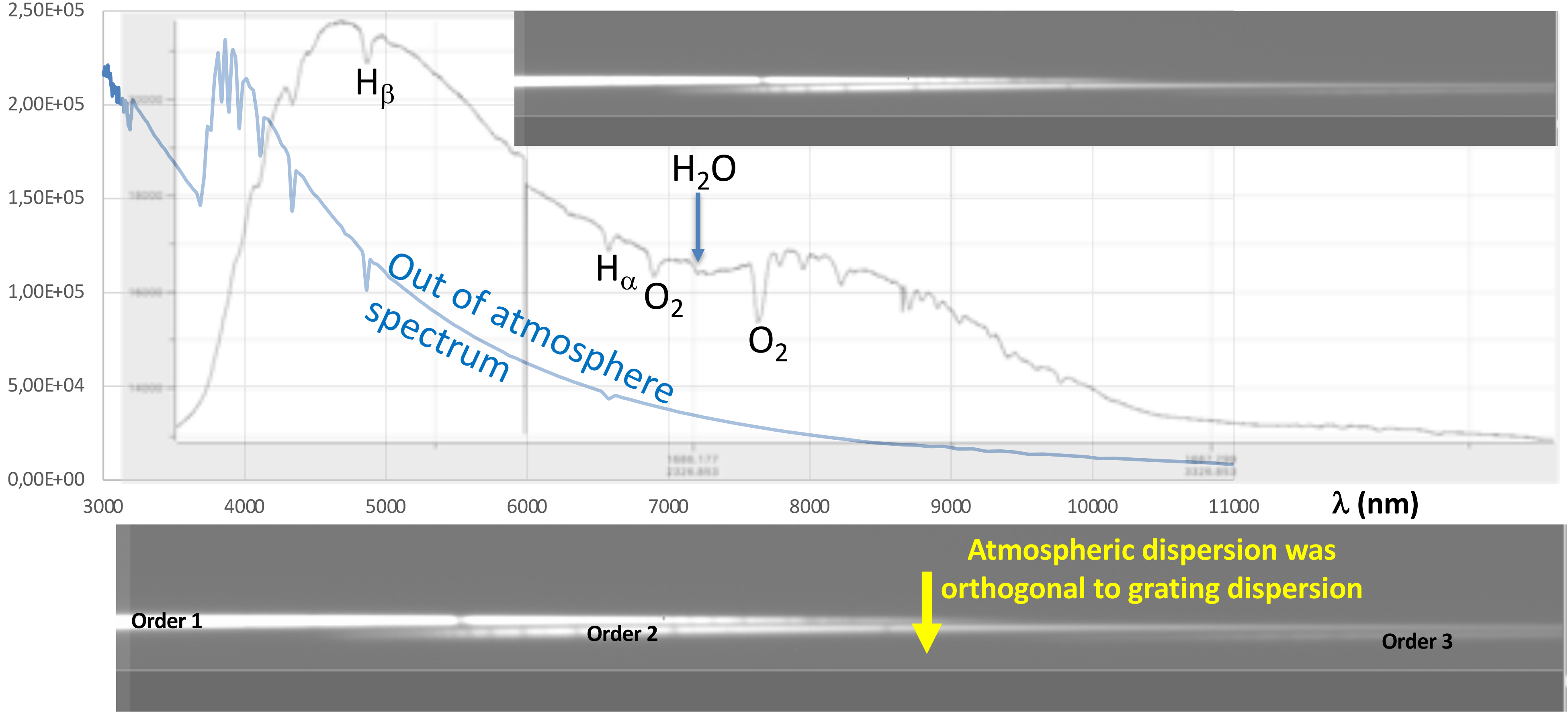
C. Stubbs

Holographic spectrum of HD60753

(18-19 feb. image 571, airmass=1.46, elevation 43°)

Dispersion: 2.73 pixels/nm

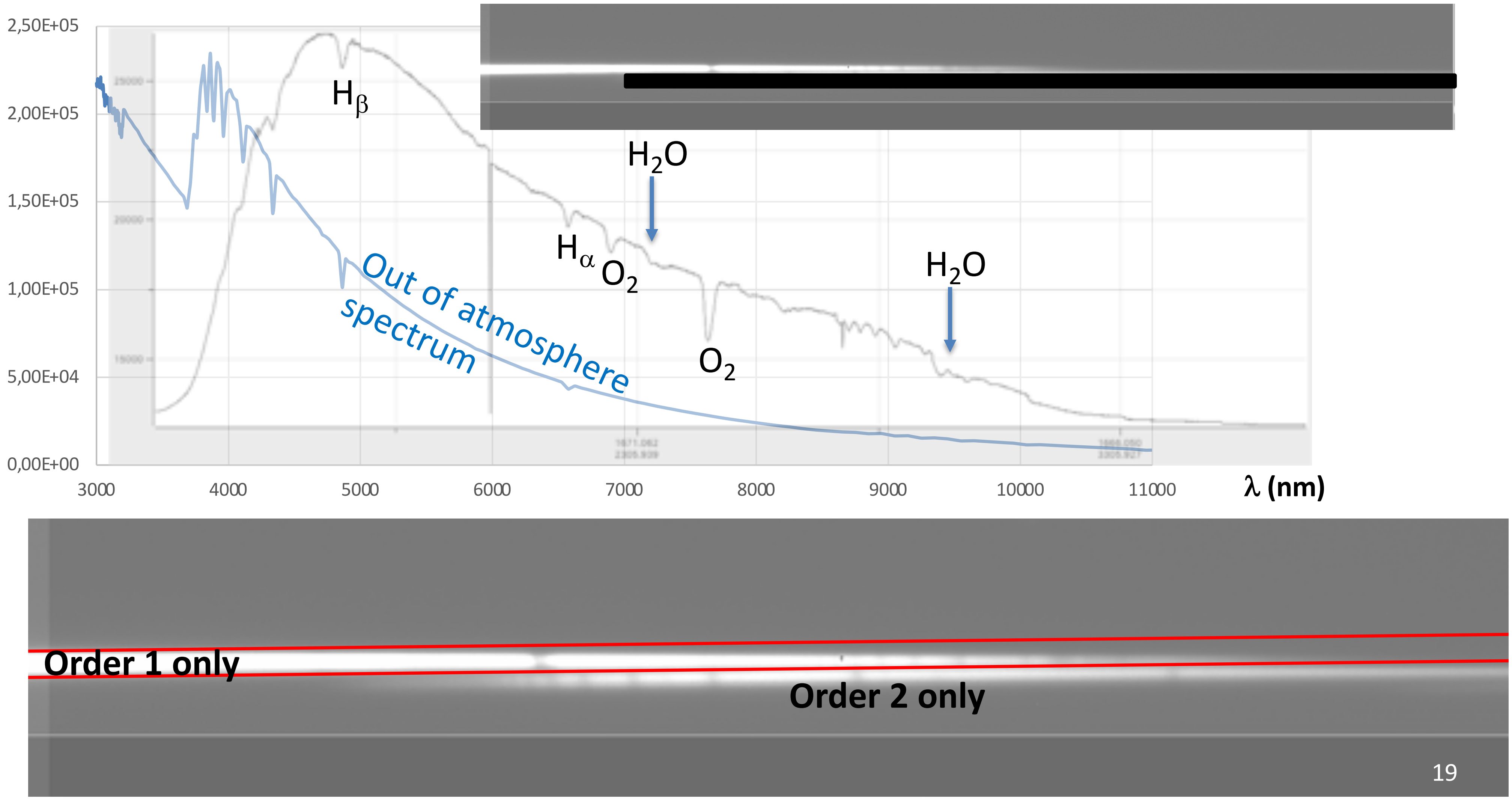
Spectrum (1rst order) extends from ~ 350nm to 1100nm



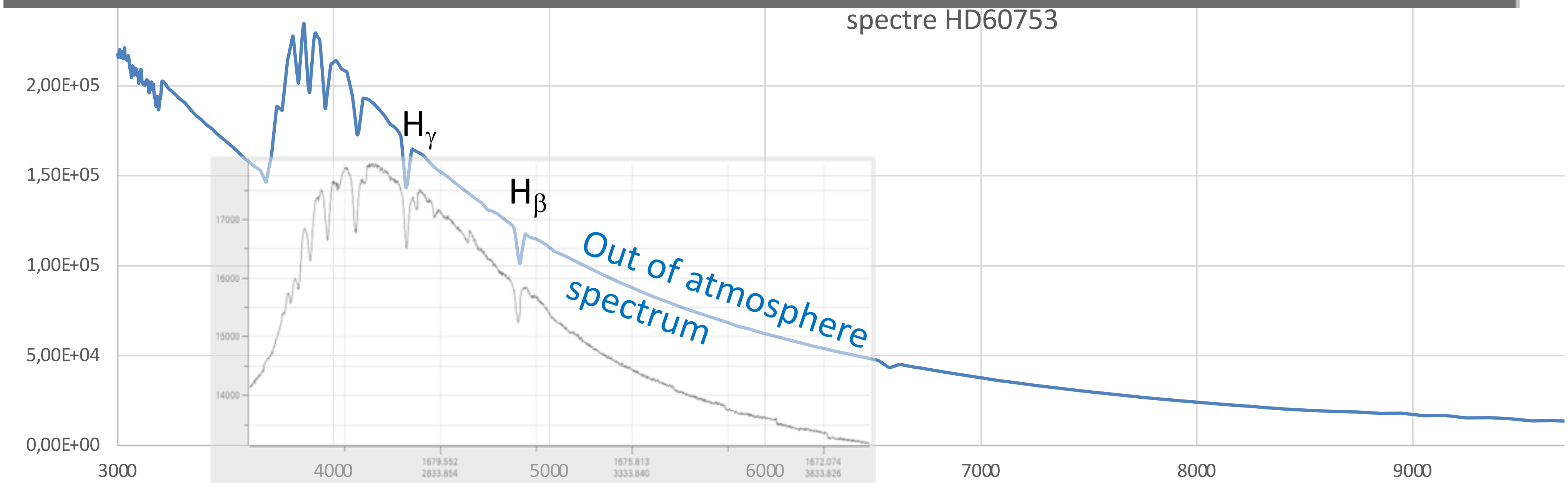
Width of a single line = seeing (here 1.4’’)

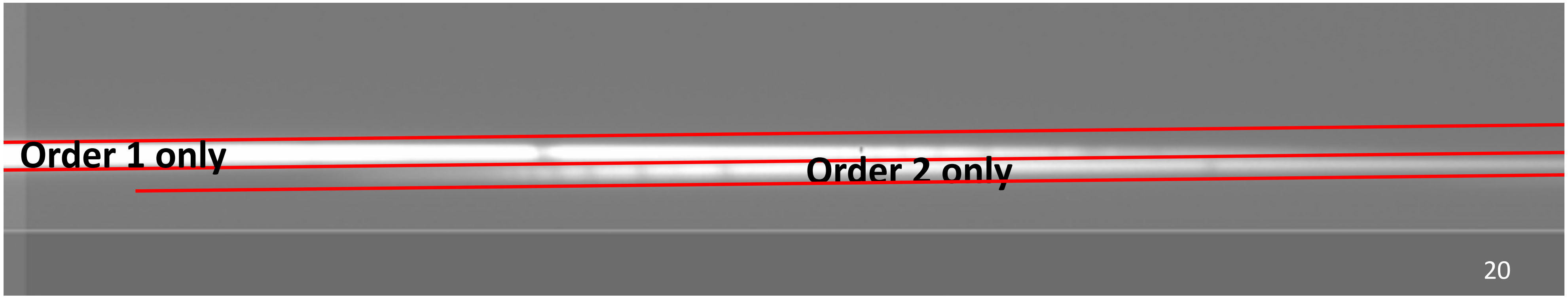
Total width (lines of 1rst and 2nd orders almost separated by atmospheric dispersion) < 2’’

HD60753: 1rst order (raw)

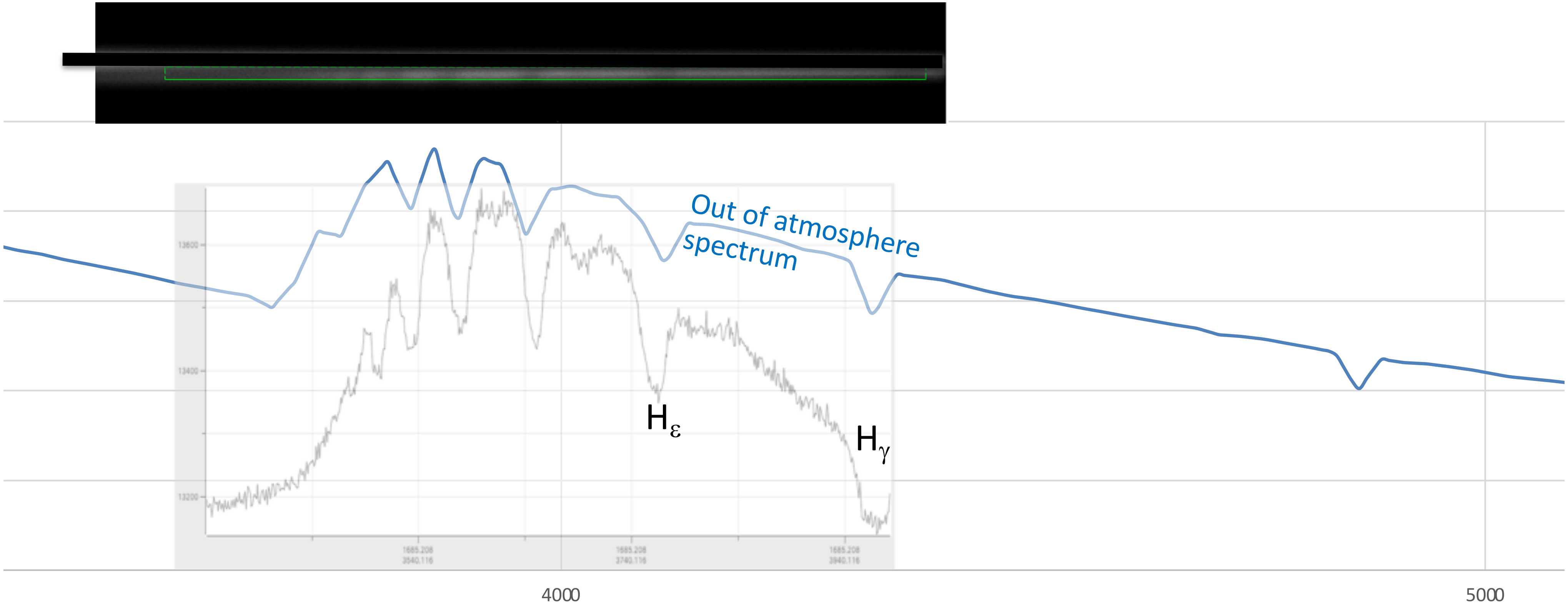


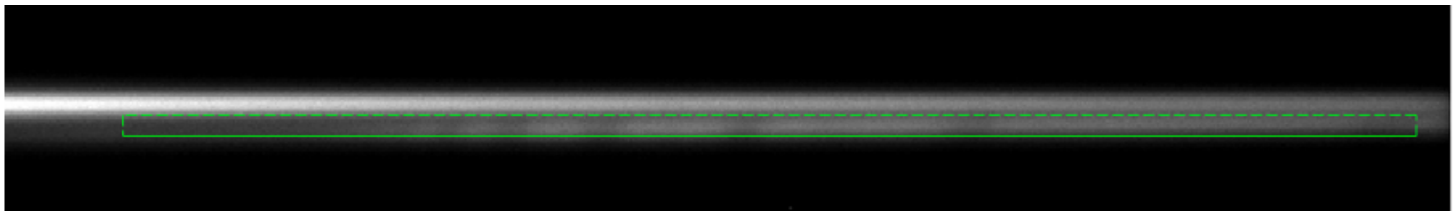
HD60753: 2nd order (raw)



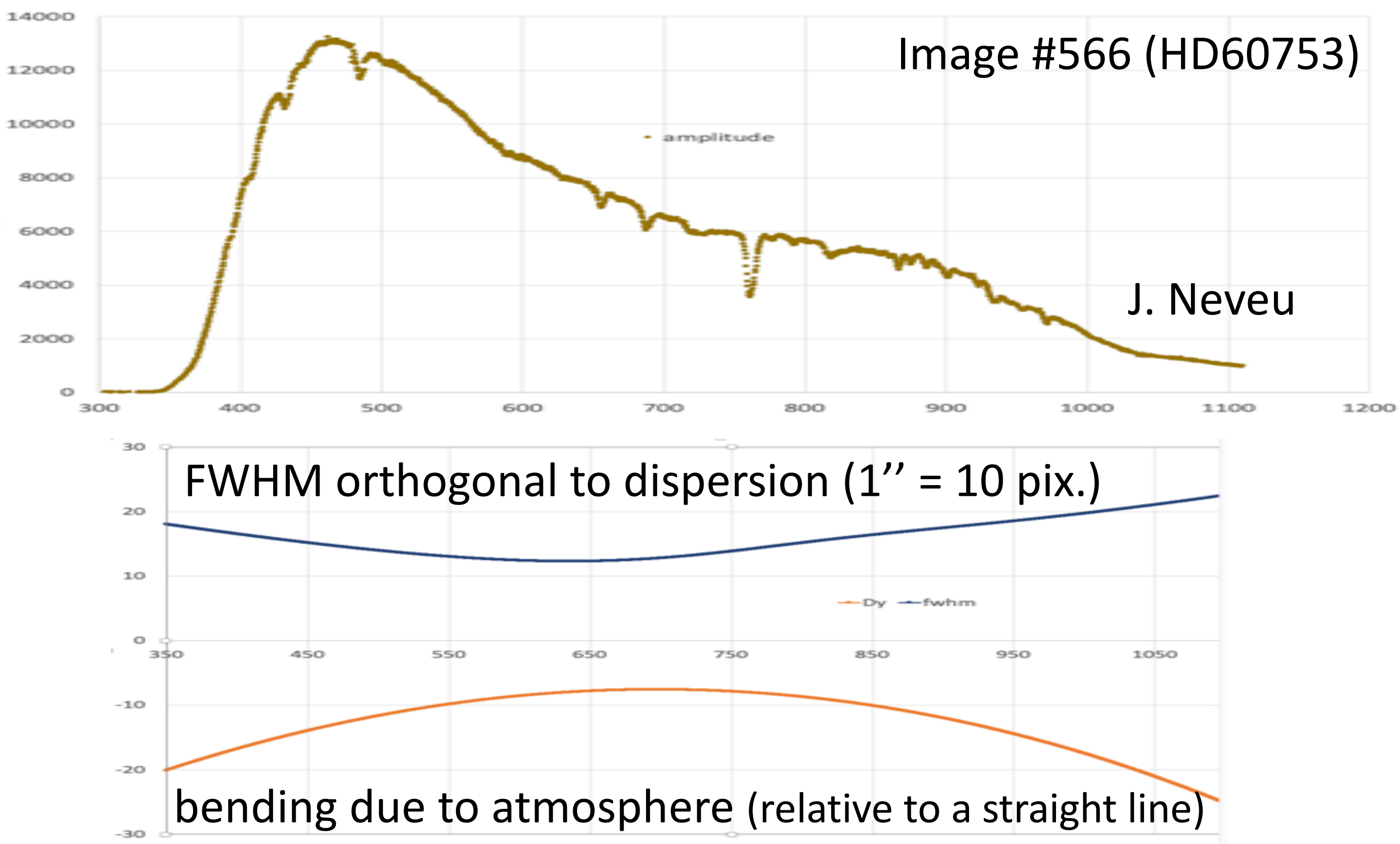


HD60753: 3rd order (raw)

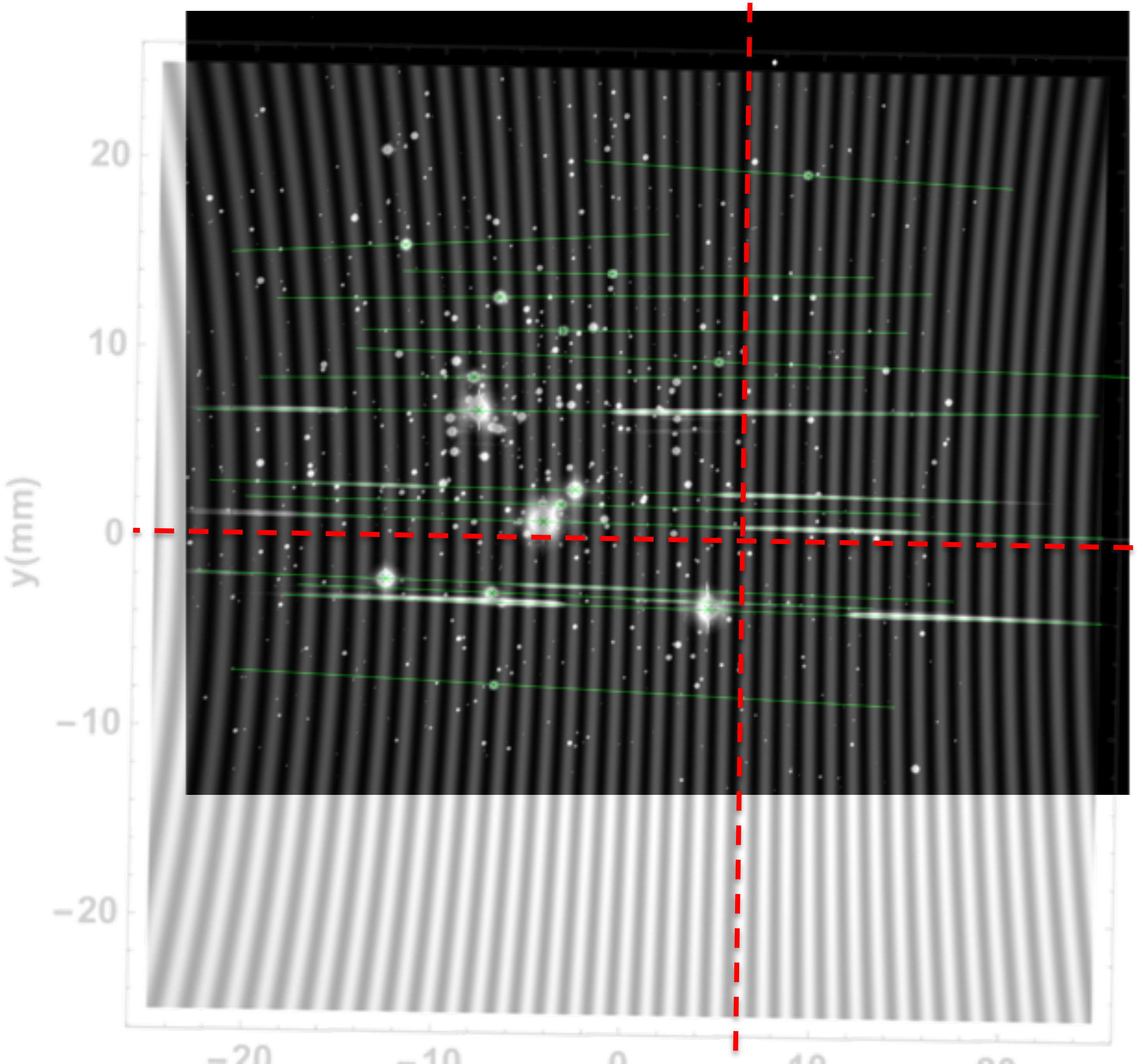




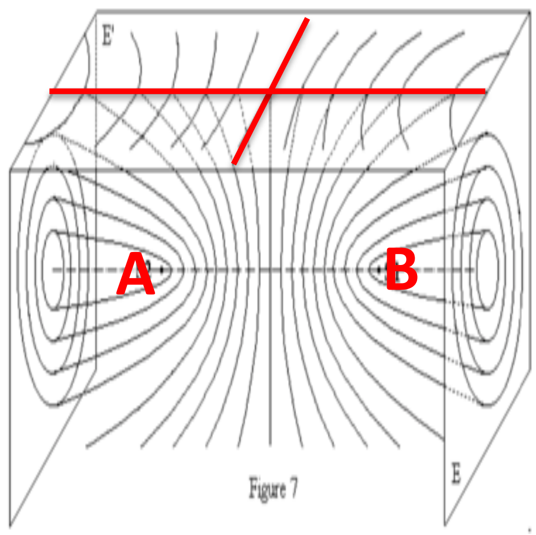
Transverse profile / bending due to atmosphere

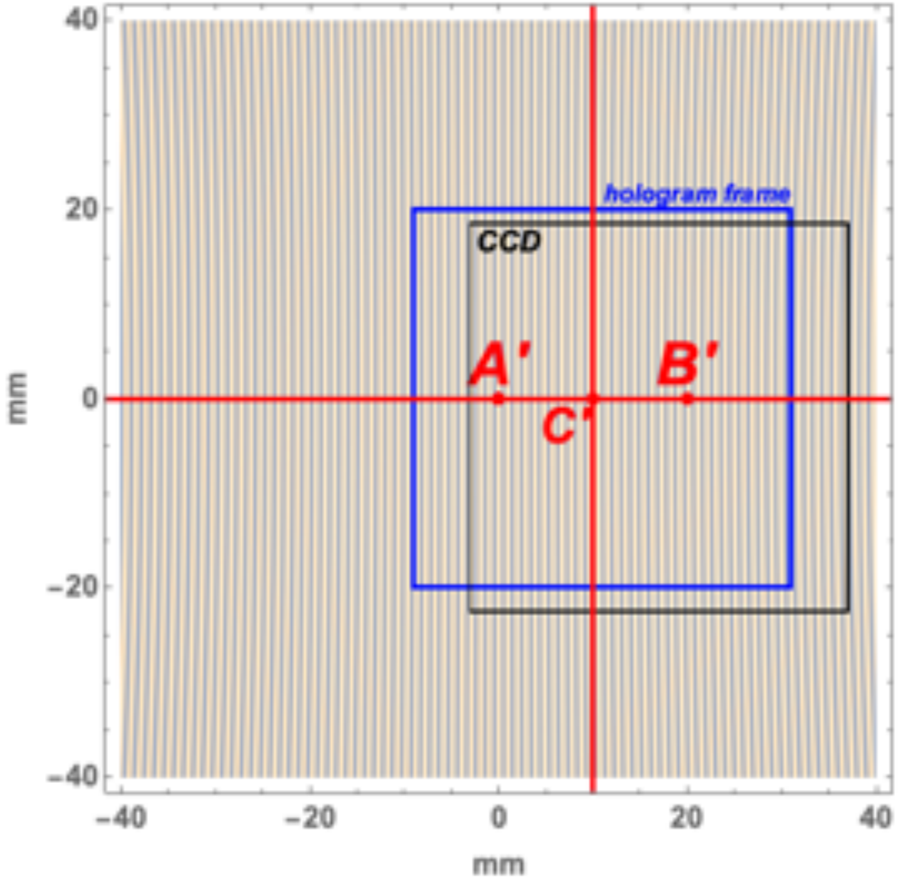


Series of spectral lines of open cluster allow to localise the symmetry axes



The orientation of the spectral lines is orthogonal to the local grating (@order 0 impact)
-> fit position of the axes (here for CTIO prototype)

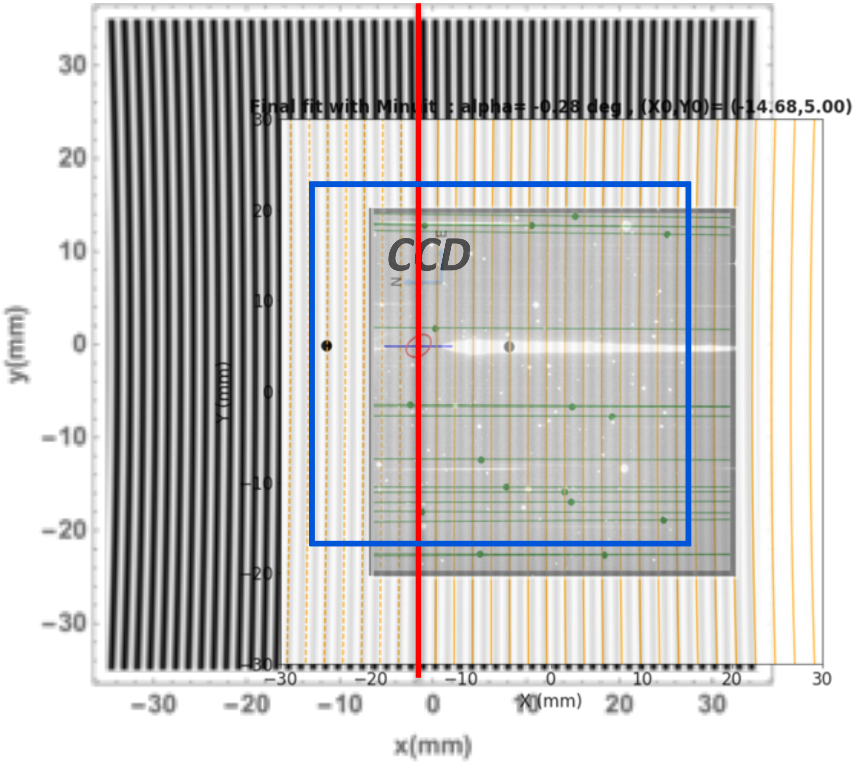




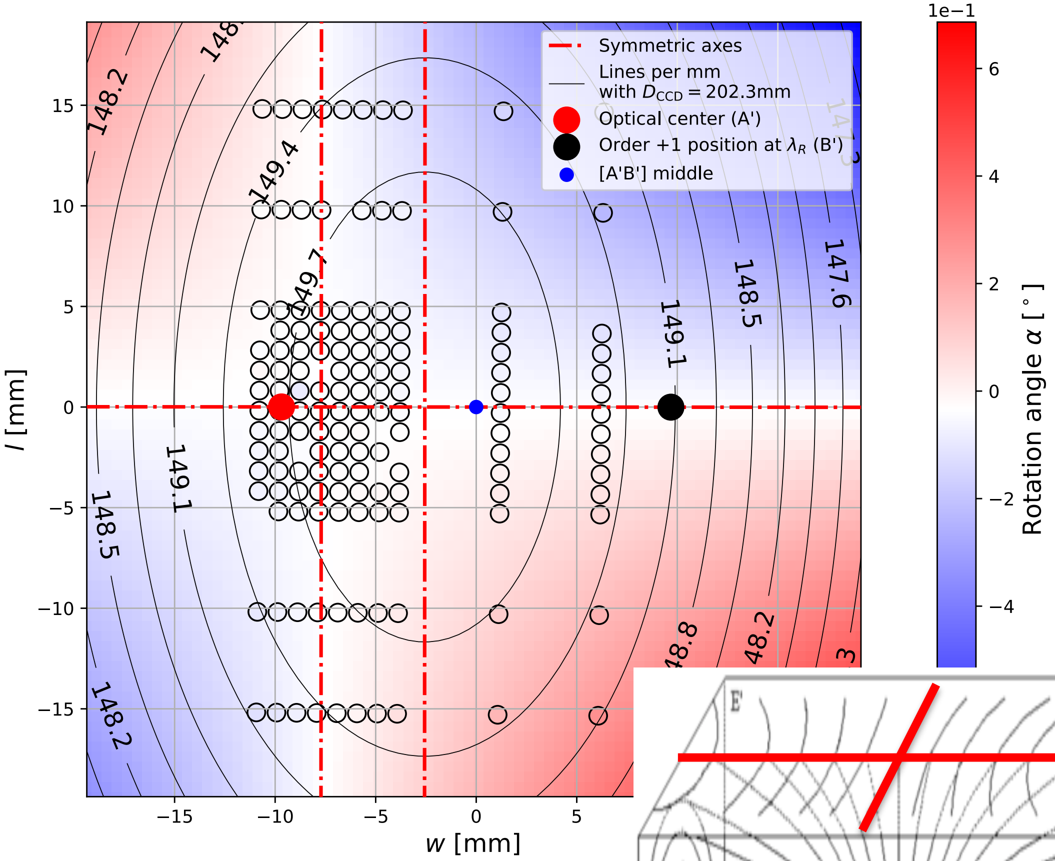
Same exercise for AuxTel

-> Surprise… Symmetry axis is off by 7mm

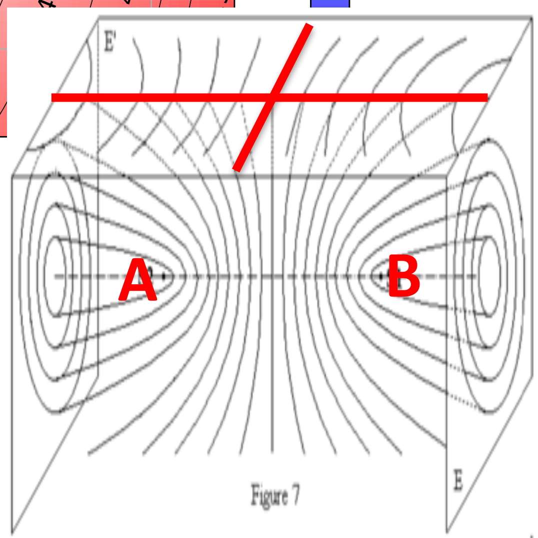
S. Dagoret-Campagne



Optical-bench confirmation



J. Neveu



Result of a scan varying impact of 0th order (holo#1 and #3)

- *Symmetry axis found different when considering angles or dispersion power*
- *Explanation: B was 0.7mm closer to the plate than A (plausibility confirmed by the maker)*

-> hyperboloids tilted

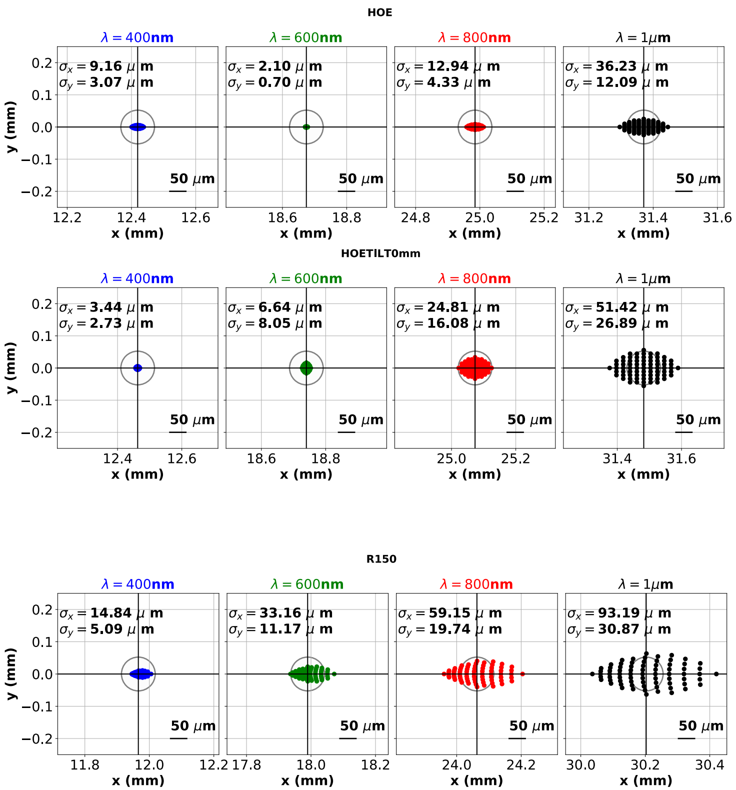
Consequences of this situation

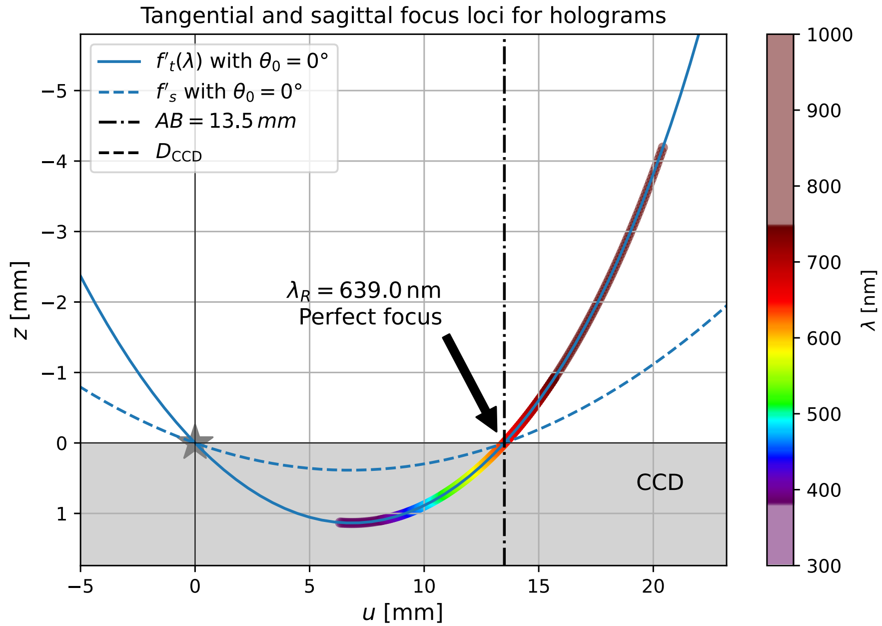
- Image @639nm is focused 0.7mm ahead the CCD
- Contributes to σ ~ 15µm @639nm

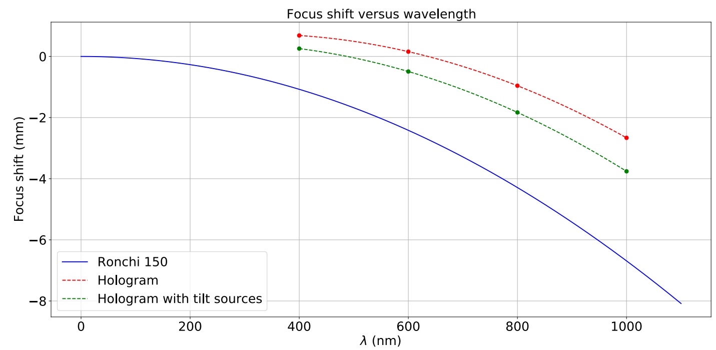
Perfect position

Shift B by 0.7mm

Ronchi







S. Dagoret-Campagne

Could be mitigated

- Inverting A and B
- Oth order at B -> 1rst order at A
- Then focus at A will occur beyond the CCD by 0.7mm
- Possible by turning the glass within the frame (with 2mm shift if we do not produce another frame)
- Is it worth it? -> not sure considering the very limited impact

What did we learn from the first observations?

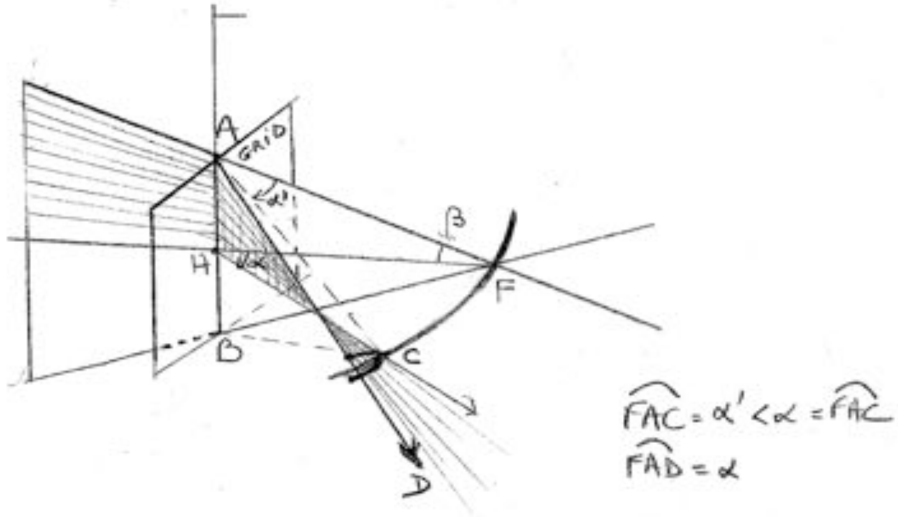
- Distance to CCD = 178mm (instead of 200); not critical
- Relative geometry of frame/CCD OK within <1mm
- Geometry of hologram not exact: Focus@639nm shorter by 0.7mm (impact 0.4'')
- Hologram focus is better than Ronchi (to be better measured soon)
- More light in the 1rst order / less in 0th order -> avoid saturation
- 1rst order efficiency starts (>0) from 350nm
- No ghost

What next?

- Next AuxTel run is the week of june 7th
  - A lot of engineering expected (telescope rotator); not easy to predict science production yet
- Spectroscopic data will be systematically taken with both hologram and Ronchi170
- **Short-middle term**
  - Spectra of planetary nebulae (narrow emission lines)
  - Test resolution limits with the best seeing
  - Test the faint limit by decreasing exposure time (to know if GAIA spectro standards could be used)
  - (RA,DEC) scan around the optical axis (consolidation of the model for analysis)
  - Bouguer lines to measure throughput (especially in UV)
  - Extraction of atmospheric parameters… Atmosphere monitoring
- **Long term**
  - Atmospheric studies to develop the procedures of photometry adjustment

COMPLEMENTS

Distortions with a converging beam



- **Vertical plane**

-> 1rst order not in plane.

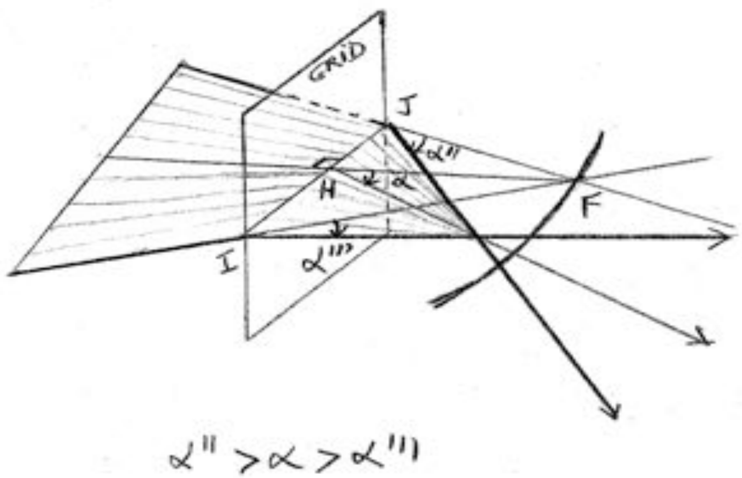
Spot extension in focal plane

$= \alpha(\lambda)/8.(f/D)^{-2}.HF$

$= 0.28rd(@700nm)14^{-2}x53mm/8$

$= 10\mu m$ (@700nm) $= 13\mu m$ (@900nm)

Cannot be compensated with re-focusing. Small enough?



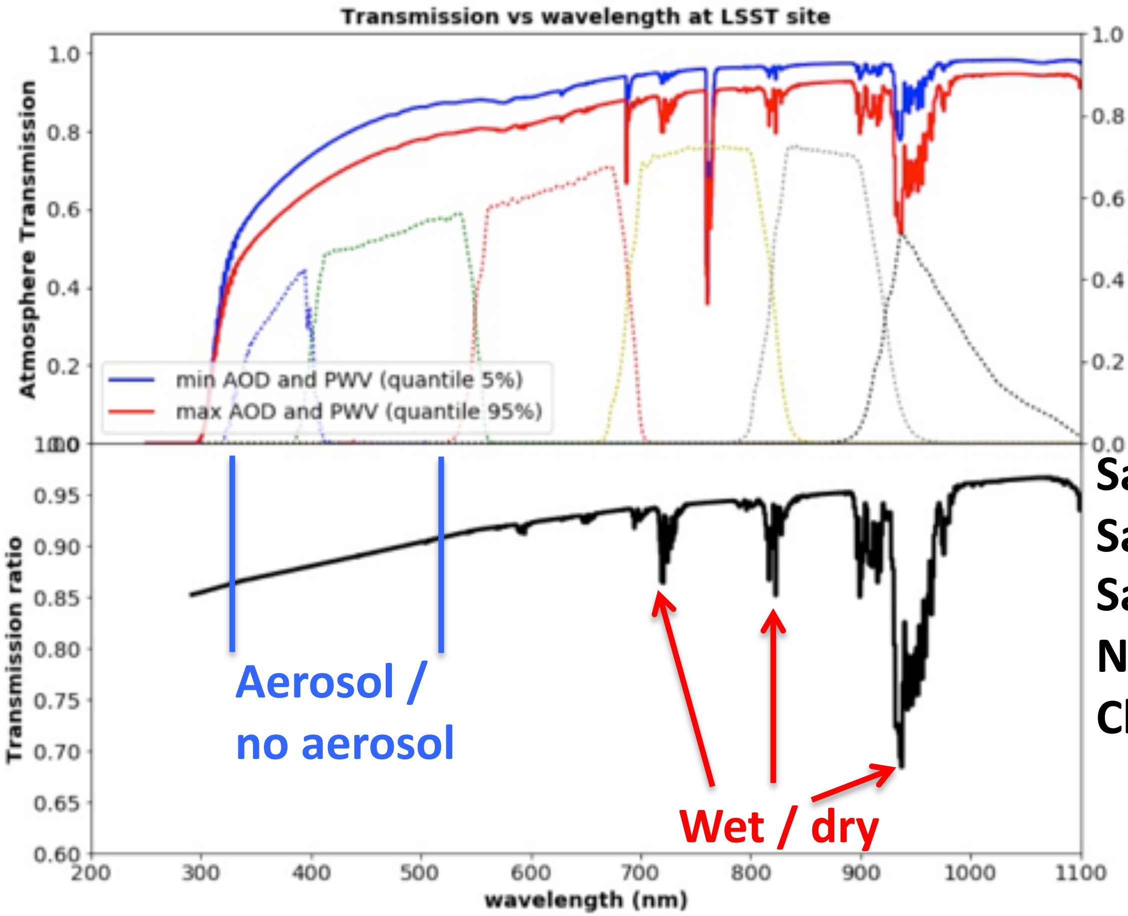
- **Horizontal plane**

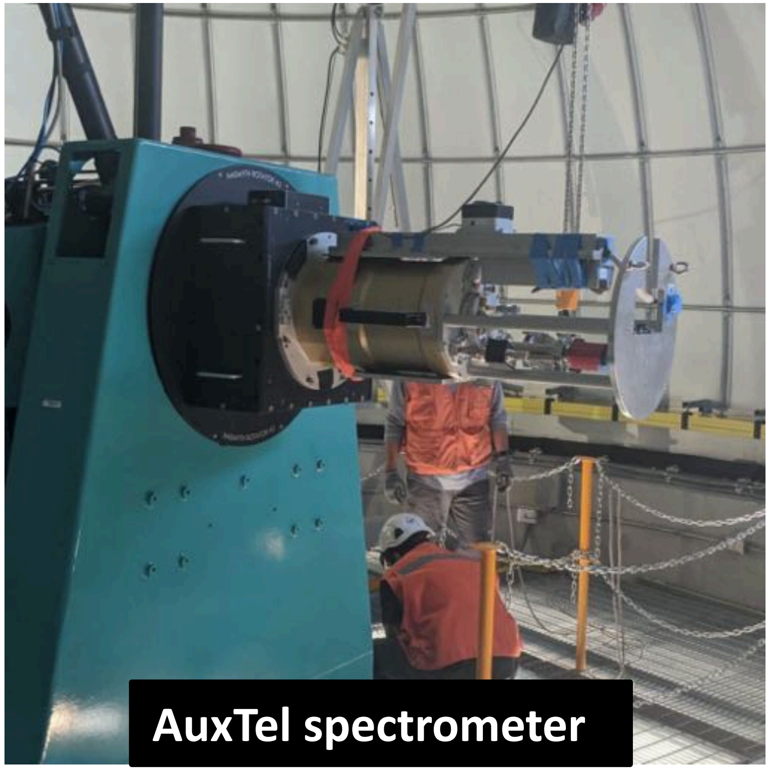
-> faster convergence in 1rst order.

Focalisation not at distance HF, but at $HFxcos(\alpha(\lambda)) = 0.96xHF = 51mm$ @700nm

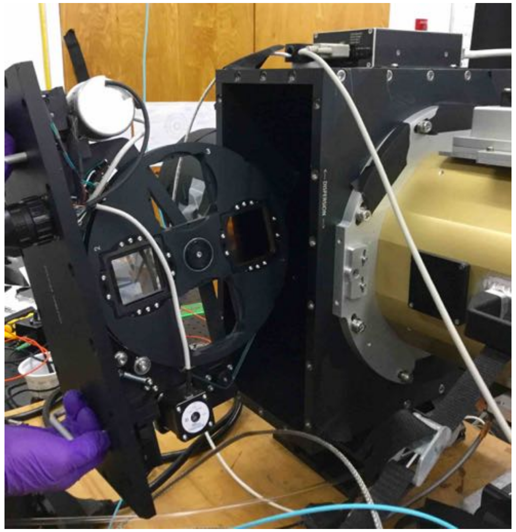
Defocusing effect to be added to pure rotation effect (already $HFxcos(\alpha(\lambda))$): 4mm (@700nm) / 7mm (@900nm)

AuxTel mission: Correct photometry from the Variations of the atmospheric transmission





Same airmass
Same O_2
Same O_3
No clouds (grey)
Change
H_2O (PWV)
Aerosols



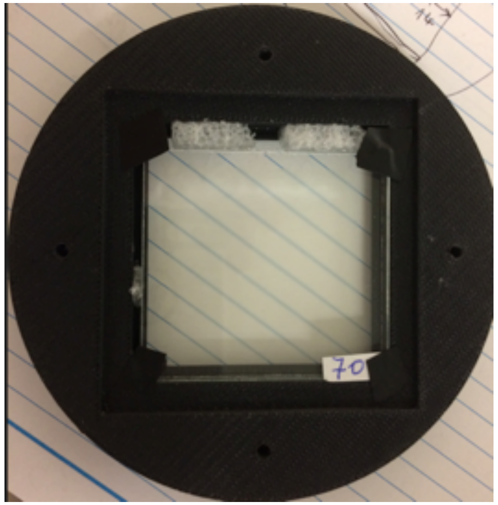
Analyse de la 3ème génération d'hologrammes (09/19)

4 paires d'hologrammes de phase

- Mesure d'efficacité de diffraction
- 4 réglages d'exposition 70 à 200ms

Compromis -> choix 150ms

- Efficacité élevée de l'ordre 1 en bleu et IR
- Contamination Minimale de l'ordre 2



Understanding the HOE diffraction efficiency

Basic interpretation of zeros and max

- Transmission **max** for λ_{max} such that

  $e.\delta n = (k+1/2)\lambda_{max}$

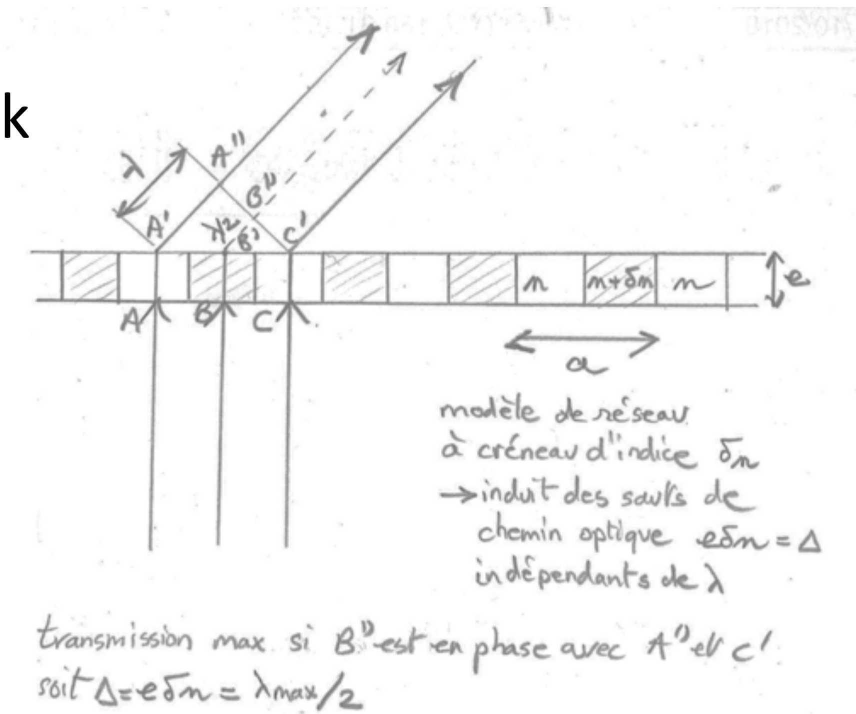
- Transmission **0** for λ_{min} such that

  $e.\delta n = k\lambda_{min}$

If $e.\delta n$ large, many zeros $\lambda_{min} = e.\delta n/k$

in $[400,1050]$nm $= [e.\delta n/k, e.\delta n/k']$

Number of zeros: $(k-k') = e.\delta n/646$nm



AuxTel Observations : strategy

What will we observe?

- Secondary spectrophometric standard stars (not enough CALSPEC)
  - Defined by others (GAIA…) or ourselves
    - -> Check stability / uniform spatial distribution / stellar types (cold)
- At various airmasses and atmospheric conditions (ideally all situations)

2 complementary approaches

- Determine global parameters of atmosphere (aerosols, precipitable water vapor)
- Directly measure atmospheric transmission within the current LSST field (real time); no need to modelise atmosphere

In both cases

- Observe CALSPEC standards through entire nights (to estimate atm. parameters) in various fields in (alt, az) to test the predictions from observations (1…N) to observation N+1 : « ronde des standards »
- build a catalog of secondary standards
- Then do the same game with secondary standards

We have also to compare the Ronchi grating with the HOE performances

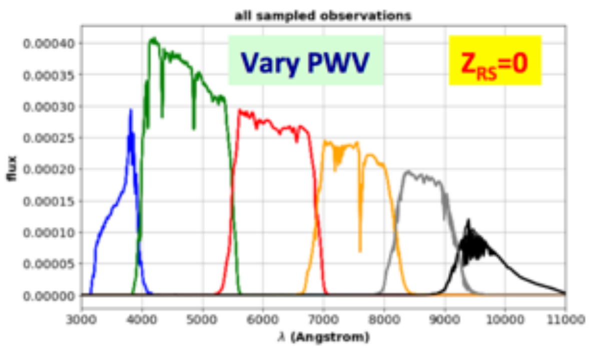
- Plan to observe at Cerro Pacon as soon as the final HOE are measured

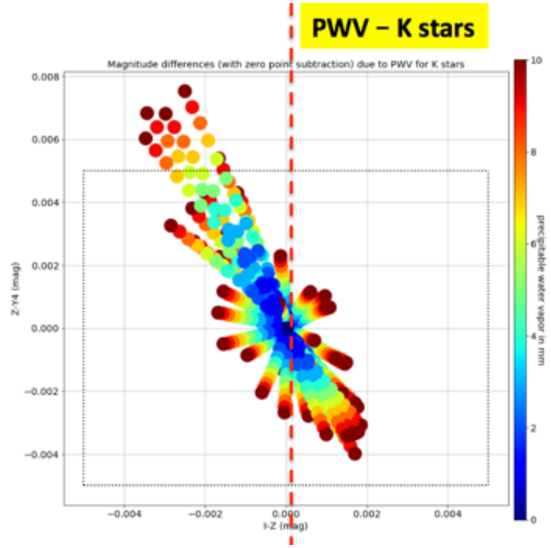
Max. expected colour changes (airmass=1)

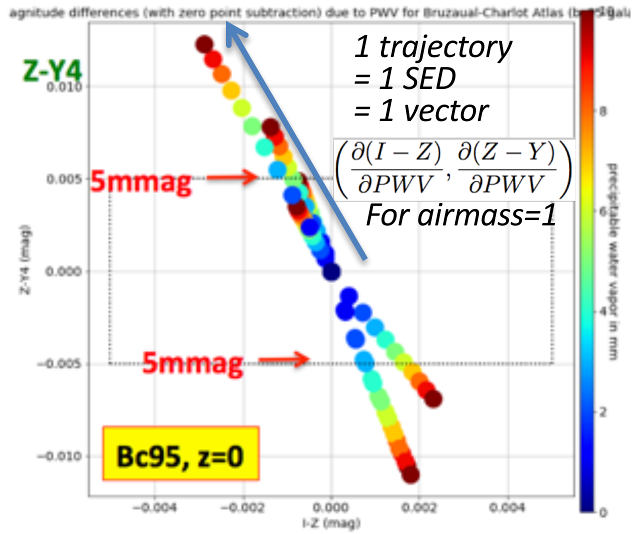
« Worst » stellar type

« Worst » galactic types

Water vapor







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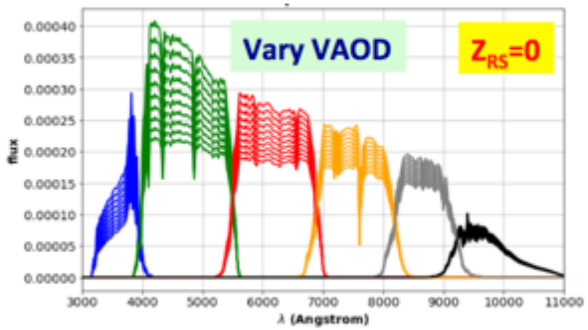
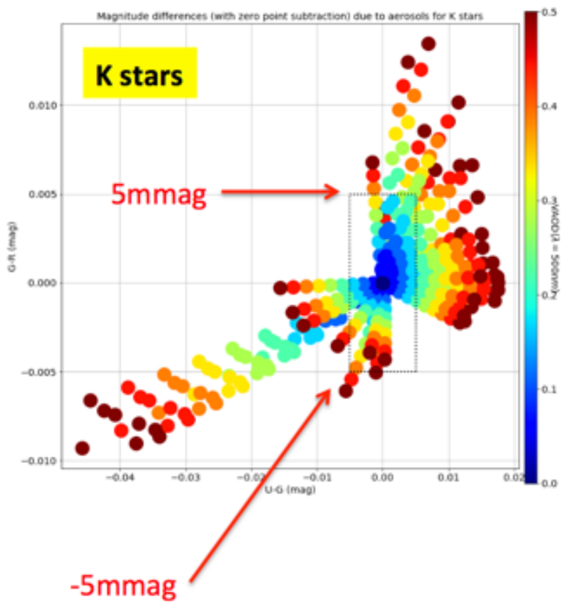
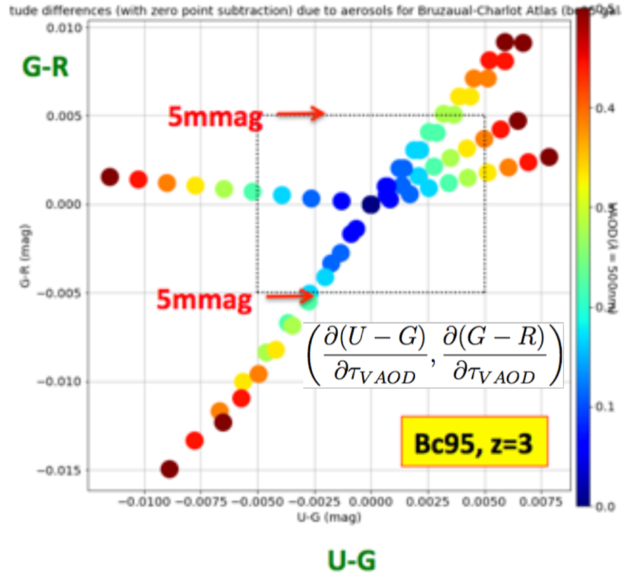
I-Z

Aerosols







HOE CALSPEC spectrum (pic du midi)