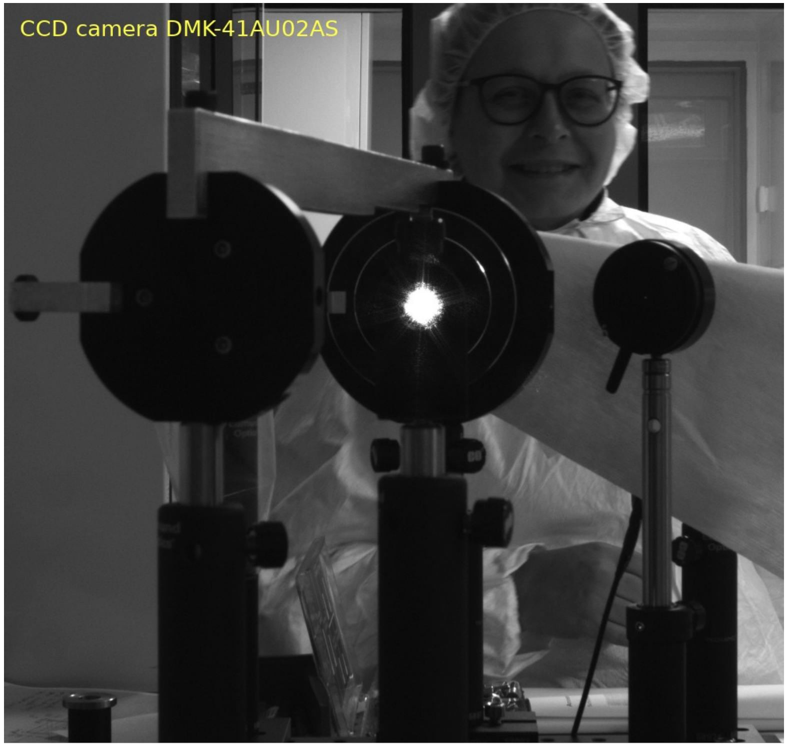

Testing holographic gratings candidates for AuxTel at LPNHE: Diffraction Efficiency

Laurent Le Guillou
(Sorbonne Université / LPNHE)

Journées LSST France
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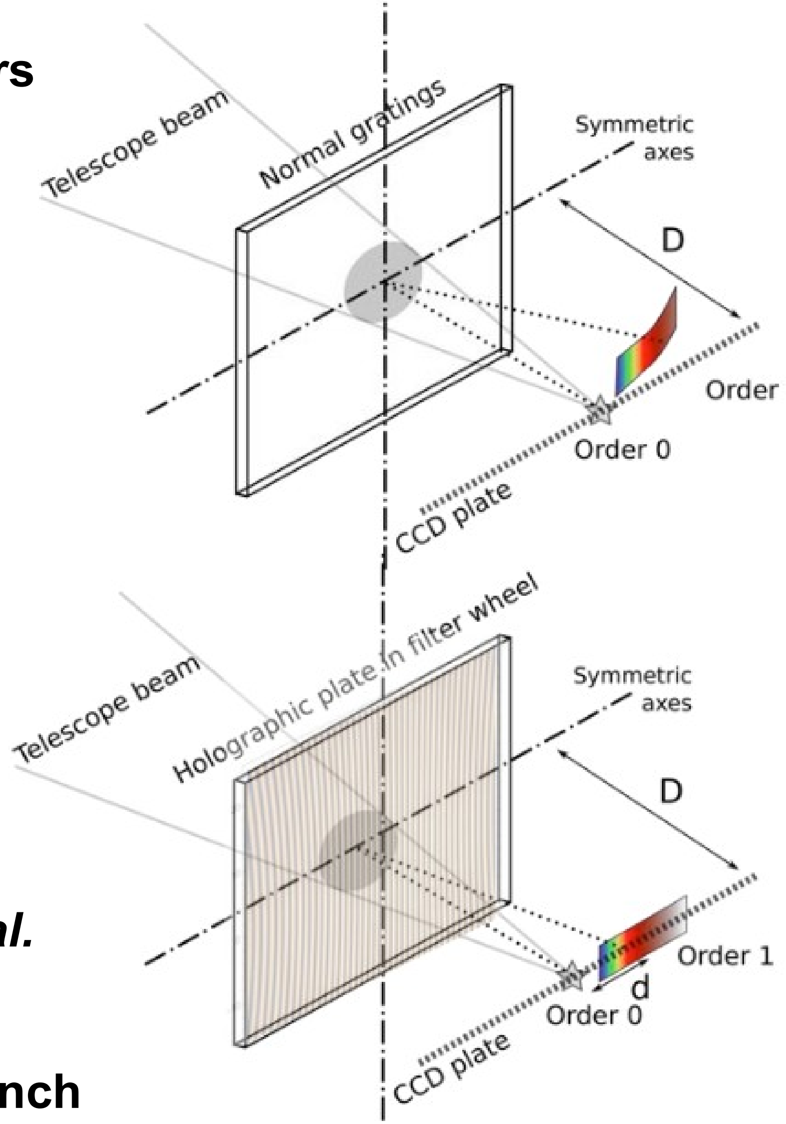
LAL : Sylvie Dagoret-Campagne, Marc Moniez, Jérémy Neveu, Olivier Perdereau
LPNHE : Pierre Antilogus, Pierre Astier, Marc Betoule, Patrick Ghislain, Claire Juramy-Gilles, Laurent Le Guillou, Philippe Repain, Eduardo Sepulveda, Arthur Vattier

Talk outline

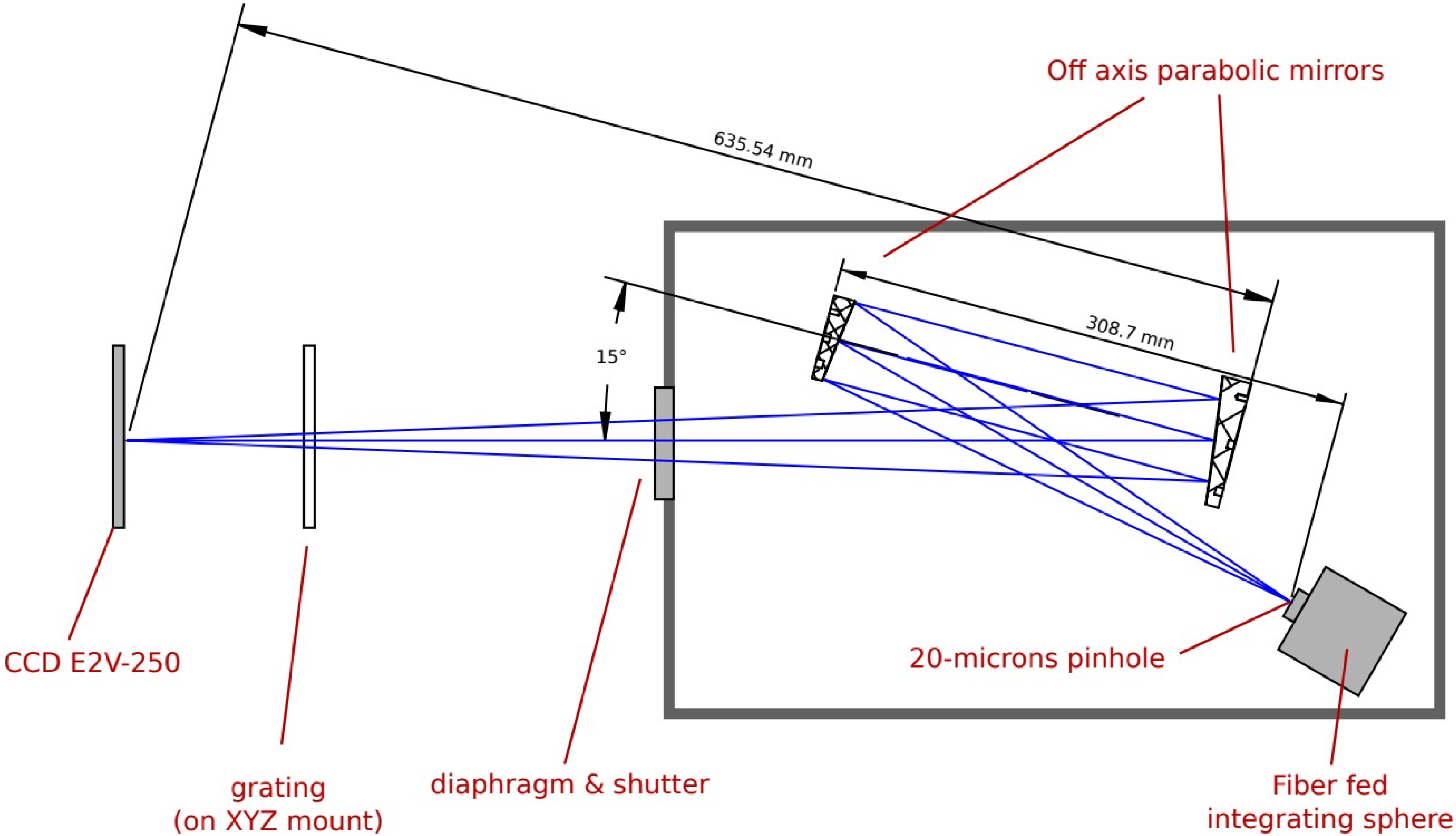
- Context : holographic gratings for AuxTel (HOE)
- Optical setup : λ-tunable convergent beam (à la AuxTel)
- Integration within the LPNHE testbench for LSST CCD
- Focusing tests : Thorlabs grating vs holograms
- Measuring throughput / diffraction efficiency for each grating
- Modeling the diffraction efficiency (DE) (tentative)
- Conclusions & perspectives

Holographic gratings for AuxTel

- **Goal :** measure **atmospheric absorption** by extracting **slit-less spectra** of **standard stars**
- Fast switching between imaging / spectroscopy modes
- Optical element **parallel to the CCD plane** to be put in one slot of the **gratings wheel**
- **Standard gratings** :
  - **Defocus** with the **diffraction angle**
  - Not designed for a **convergent beam**
- Proposal : a tailored **Holographic Grating**
  - **All wavelengths are focused (1st order)**
  - Limited distorsions
- **Prototypes tested at CTIO par M. Moniez *et al.***
- Needed **: a testbench to characterize the produced holograms → LPNHE LSST bench**



Convergent beam : optical setup

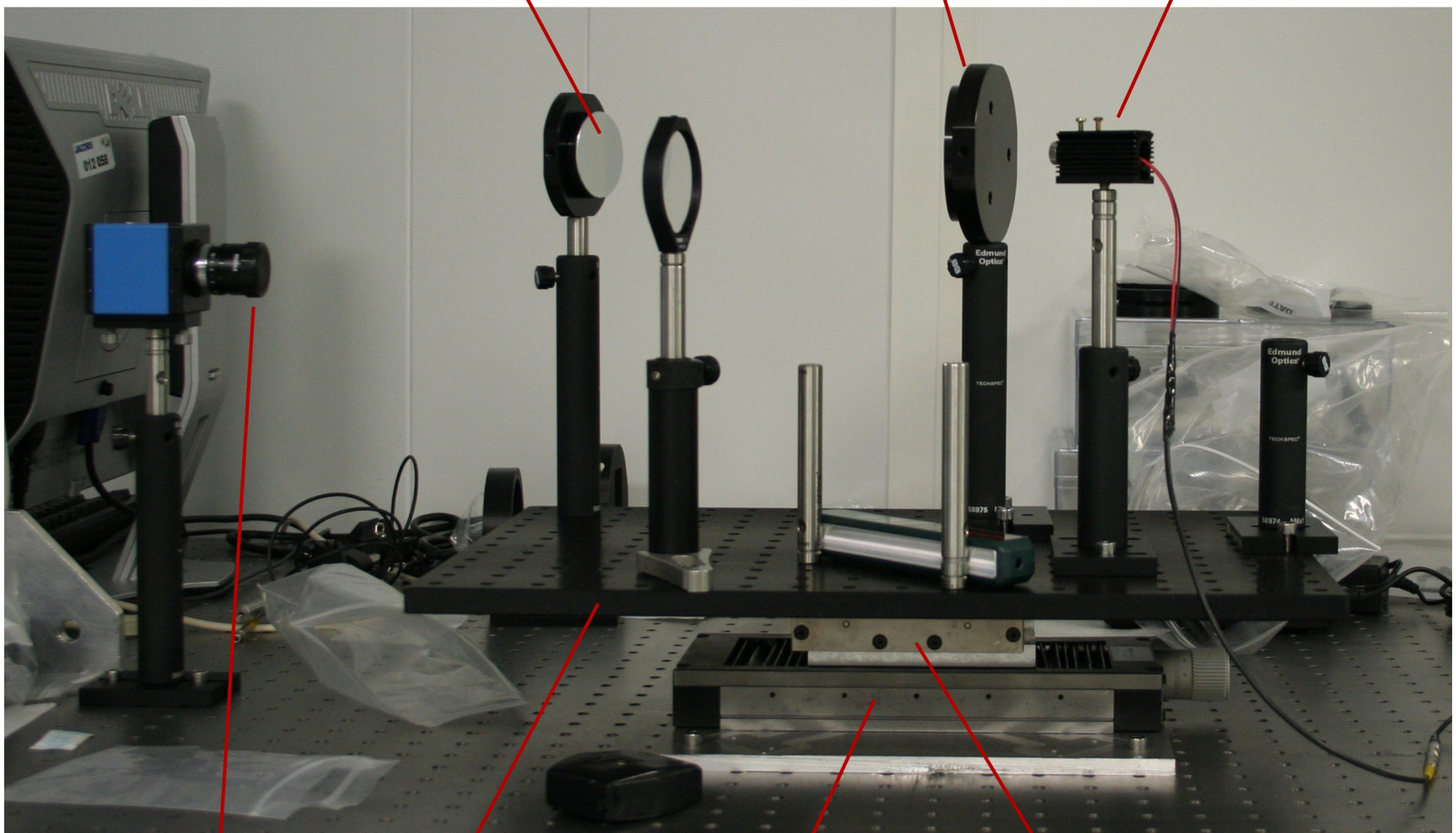


Convergent beam : optical setup

Off Axis parabolic mirror
f = 304.8 mm

Off Axis parabolic mirror
f = 635 mm

Source position
(here a laser for
alignemen)t



Small CCD camera

Optical table

Linear stage along
the optical axis
(focus)

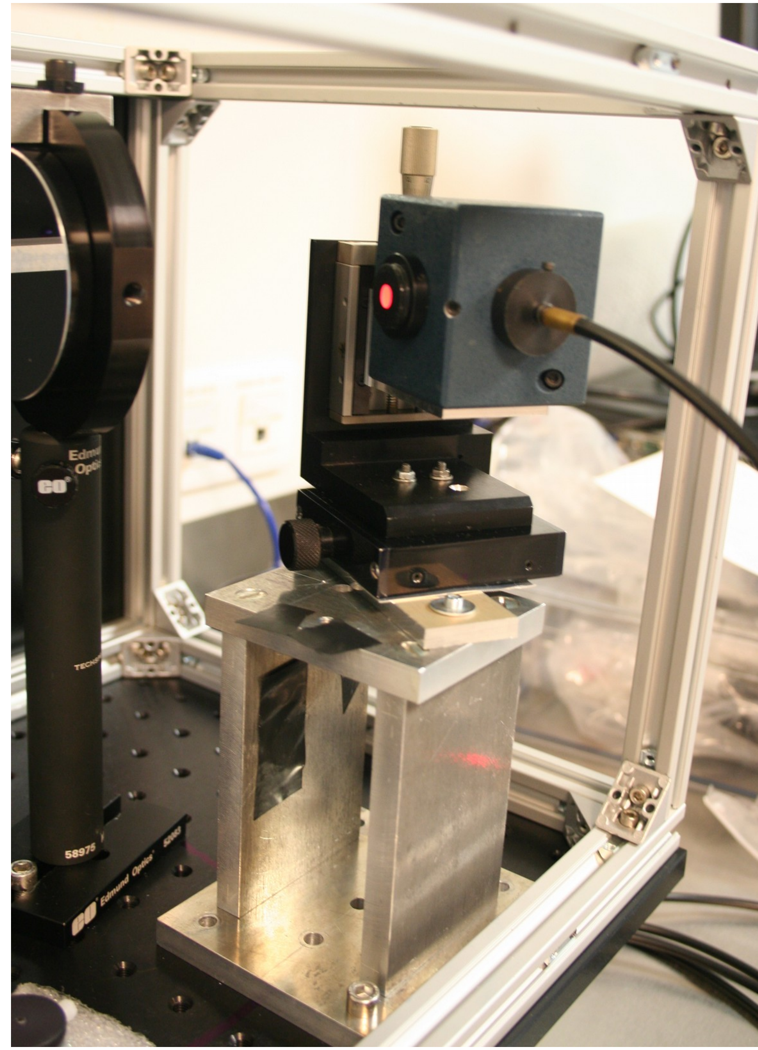
Horizontal linear
stage perpendicular
to the optical axis

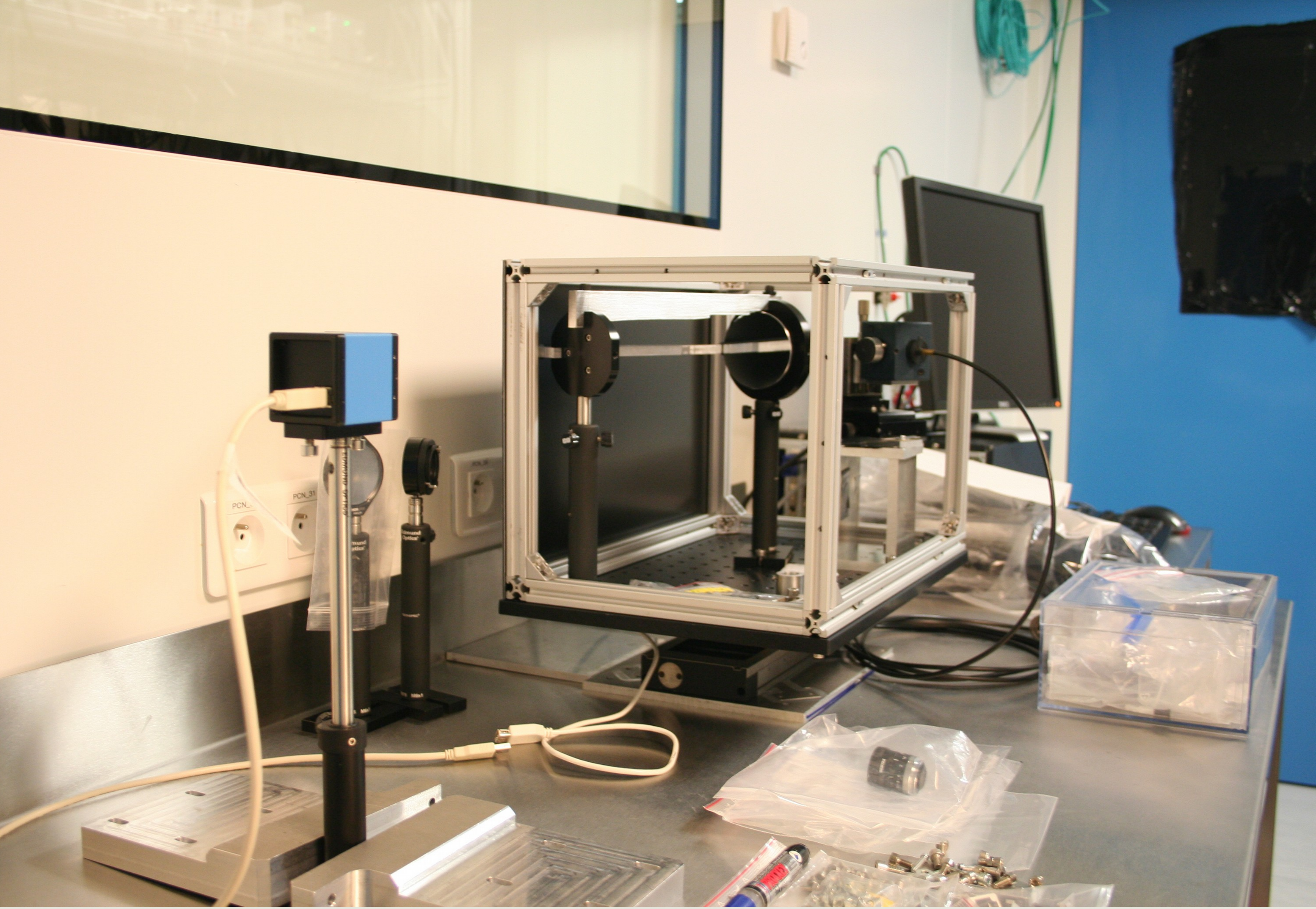
Convergent beam : optical setup

- Source : **integrating sphere**
- **Fiber fed** :
  - Lamps : incandescent, LEDs, HgAr
  - Continuum (QTH) + monochromator
- Exit = mirror focal point :

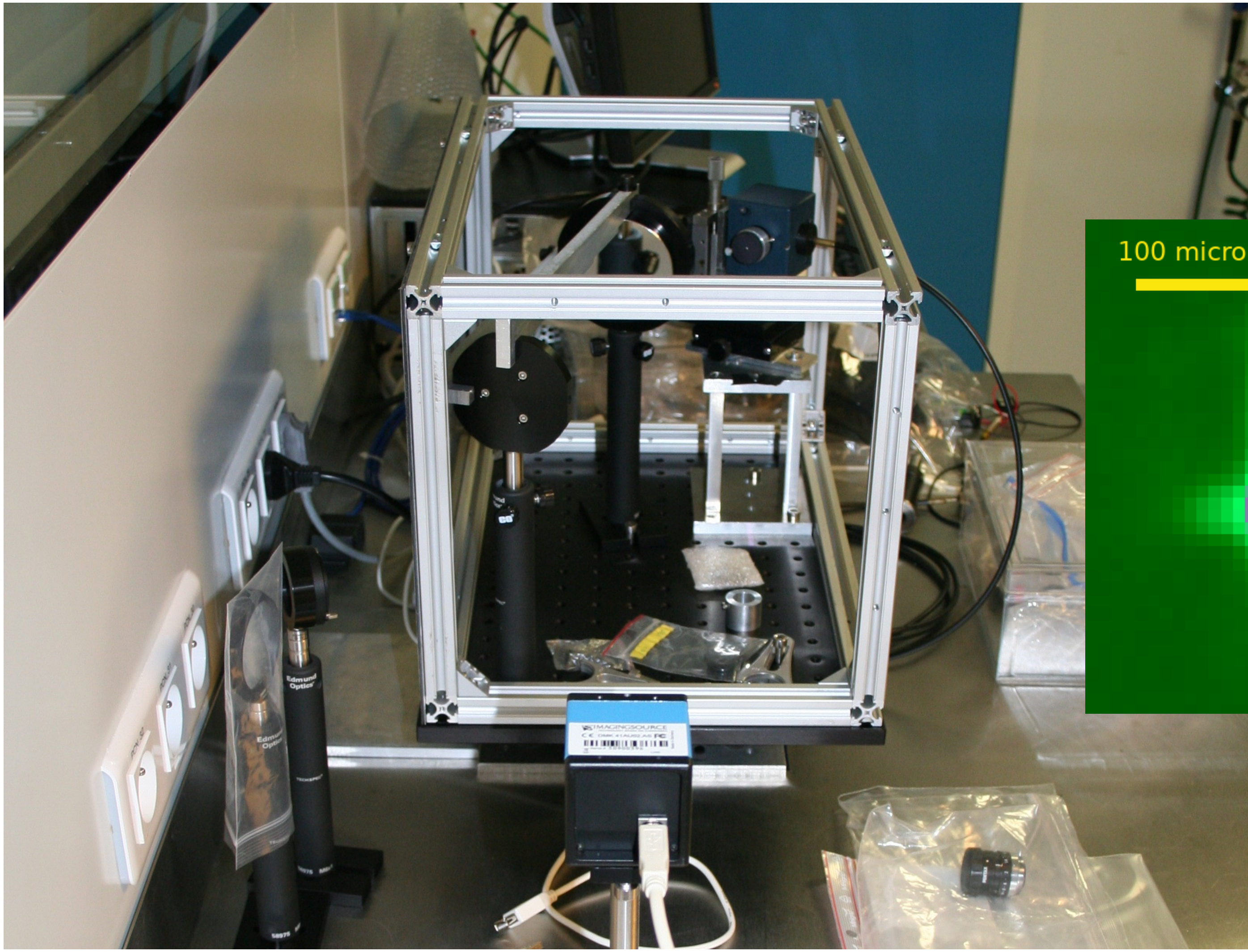
  → **pinhole** (20 microns)

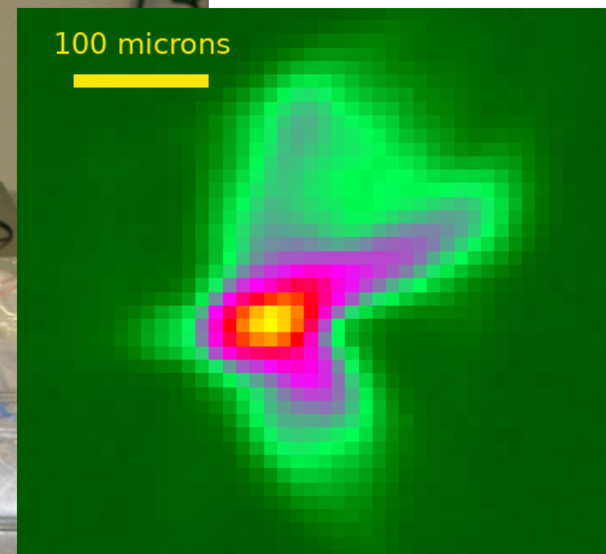
ge





Focusing



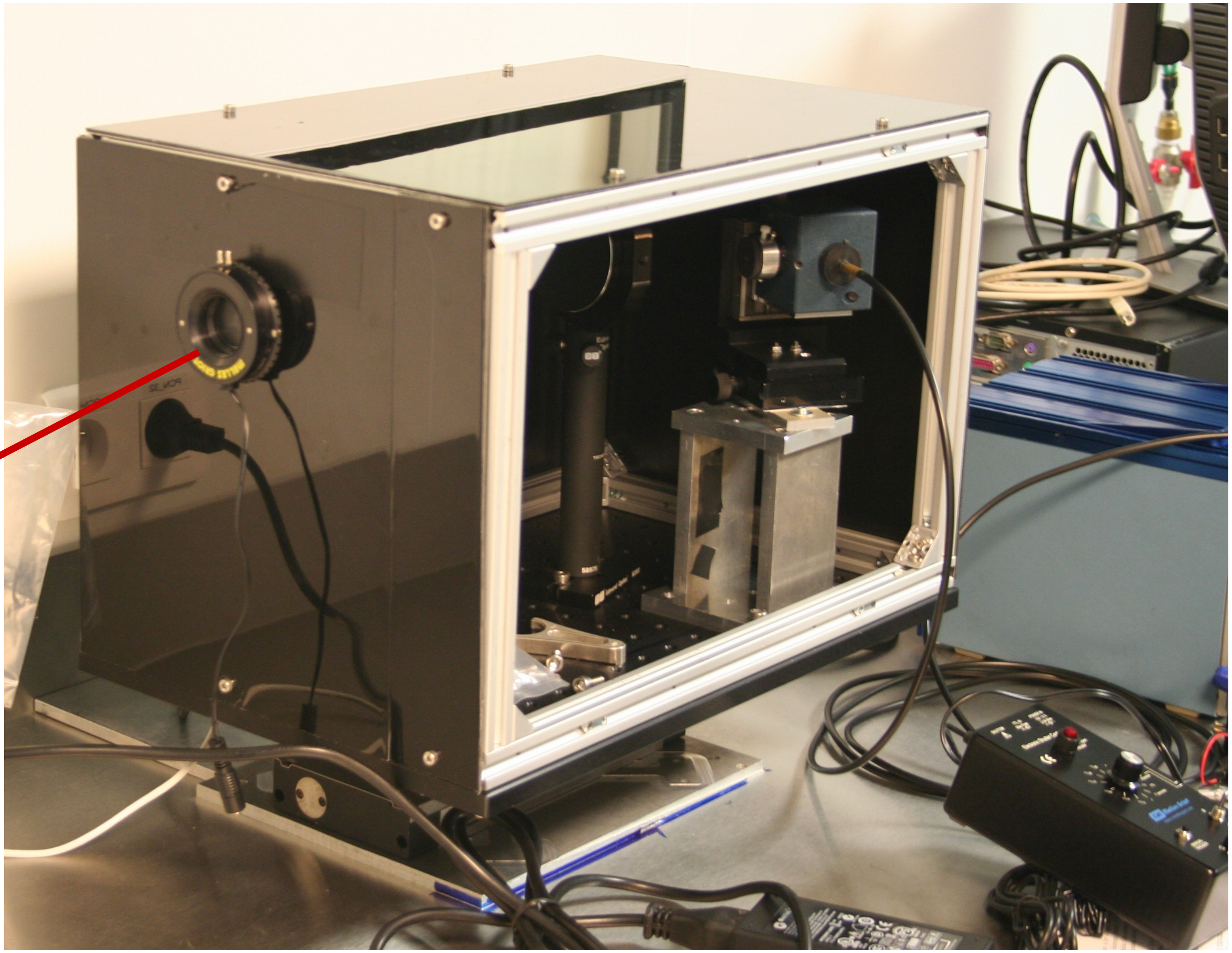


http://supernovae.in2p3.fr/~llg/LSST/AuxTel-holograms/hole-020mu-focus-trip.gif

Baffling & shutter

- **Shutter** : **triggered** by the **LSST REB** (« SHU » line)
- Beam : f/15 to f/...
  - (diaphragm)

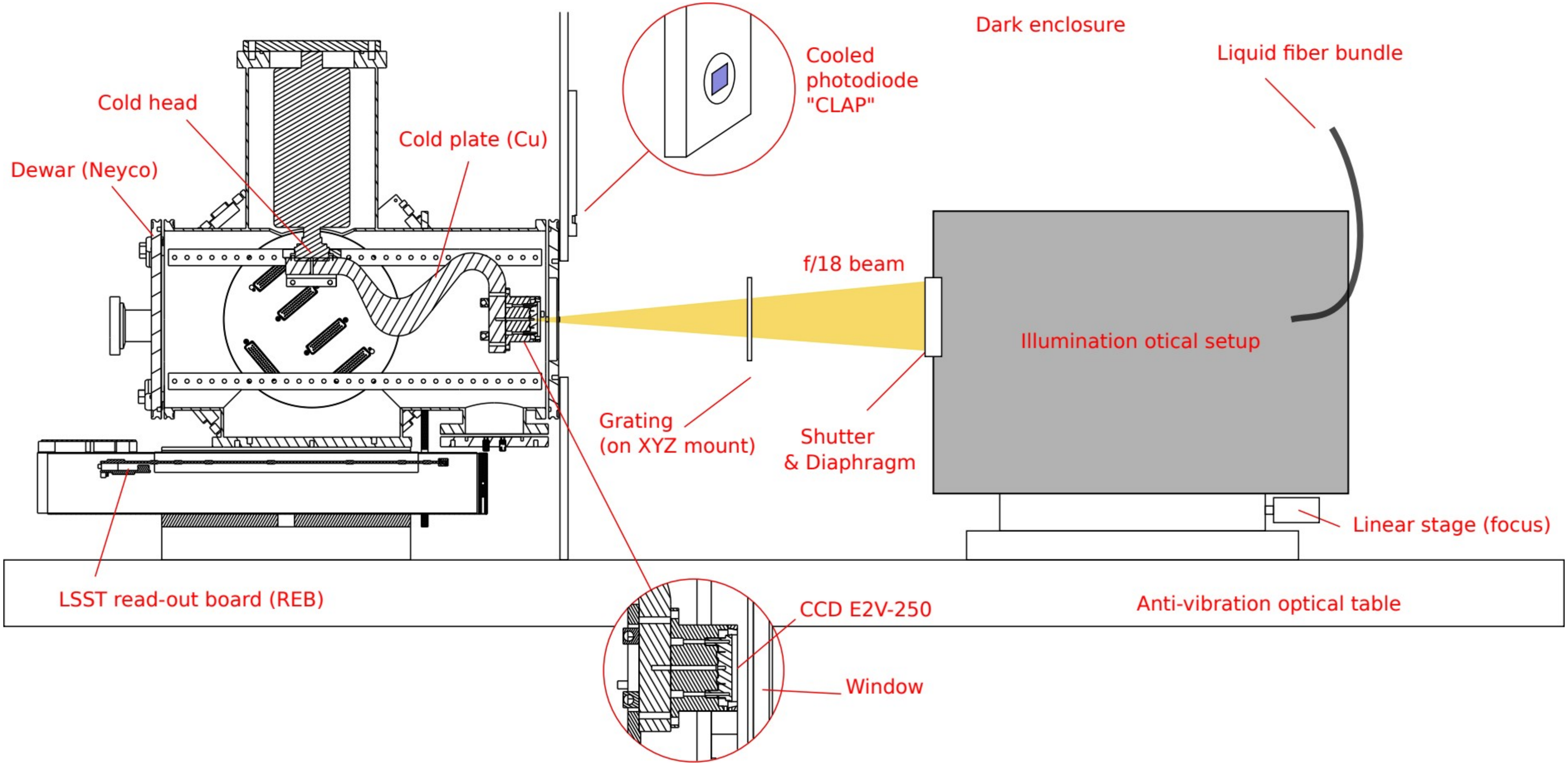
    AuxTel → f/18



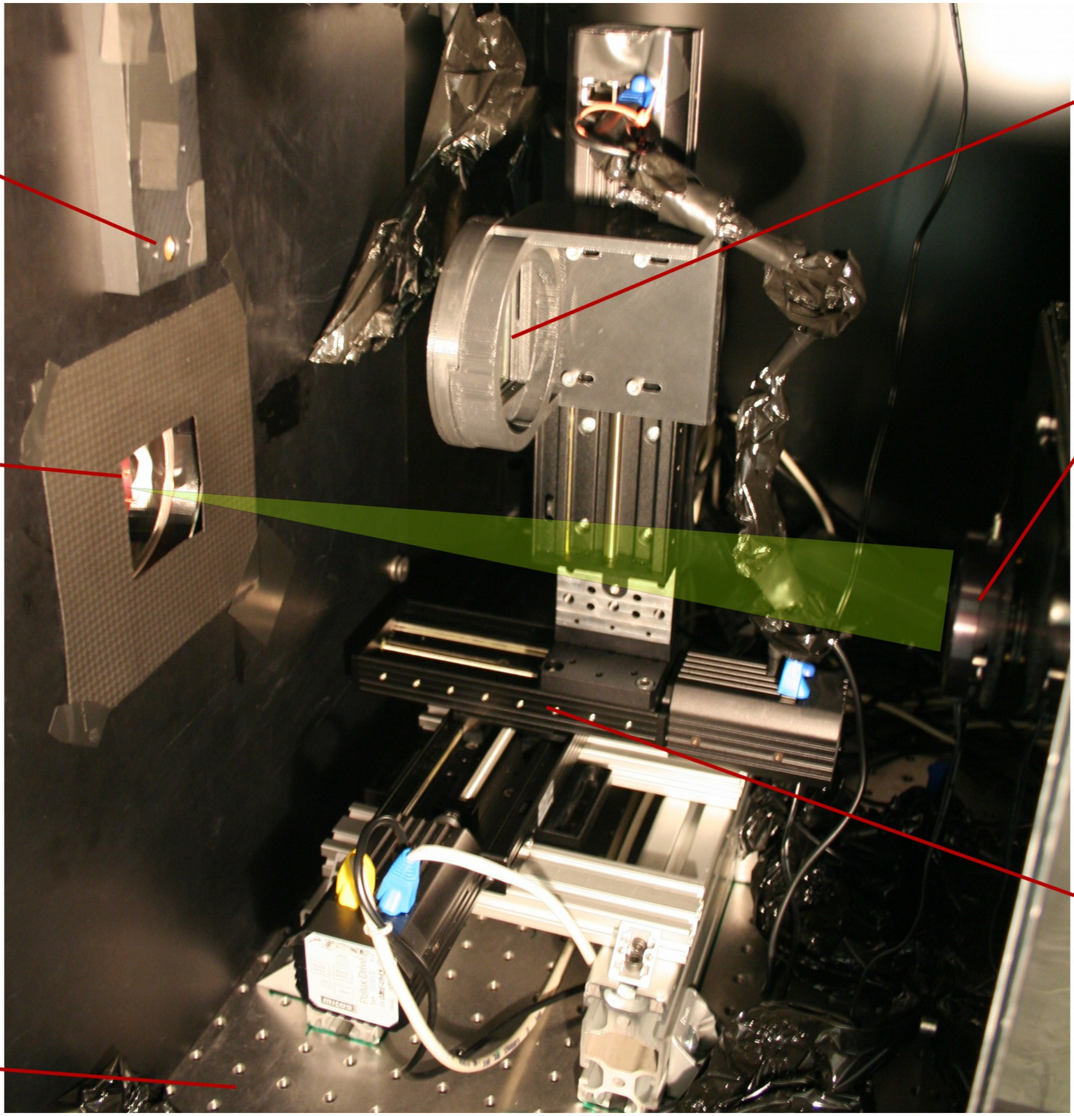
Shutter

& diaphragm

Integration within the CCD testbench

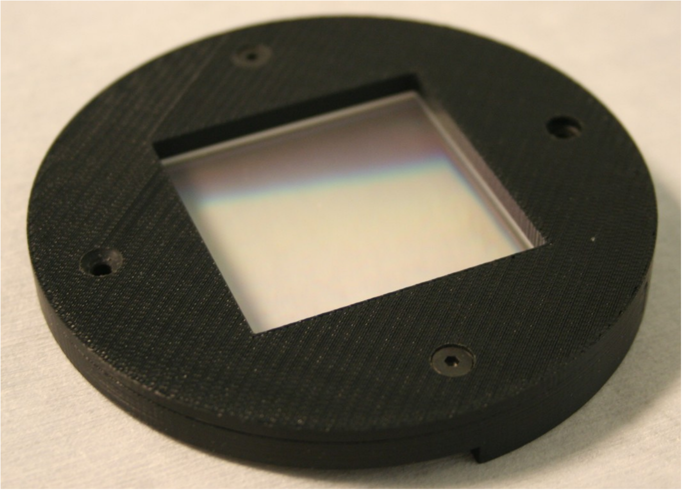


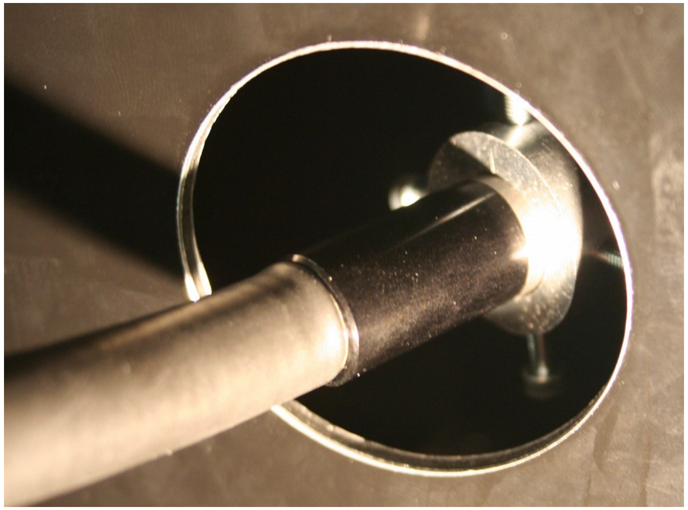
Integration within the CCD testbench



Integration within the CCD testbench

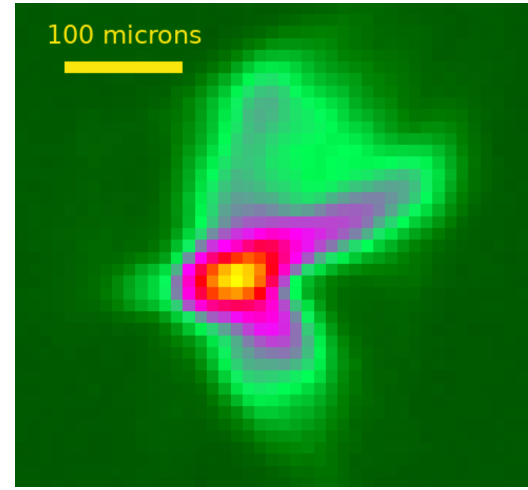
- Beam focused on the CCD E2V-250
- Frames read using the LSST REB
- Each grating to be characterized is mounted on a **3D printed removable support** → easy to exchange gratings on the setup
- The illuminator system is **fiber fed** :
  - Liquid fiber bundle fed by a **monochromator** and a continuum lamp → **wavelength scans**
  - Hg(Ar) PenRay lamp (Oriel 6035) → **focusing performance**
- XYZ motorized mount (0.4 microns resolution) :
  - **Precise positioning** of the grating in the beam
  - **Throughput / diffraction efficiency** : obtained by taking frames while **moving the grating in / out of the beam**

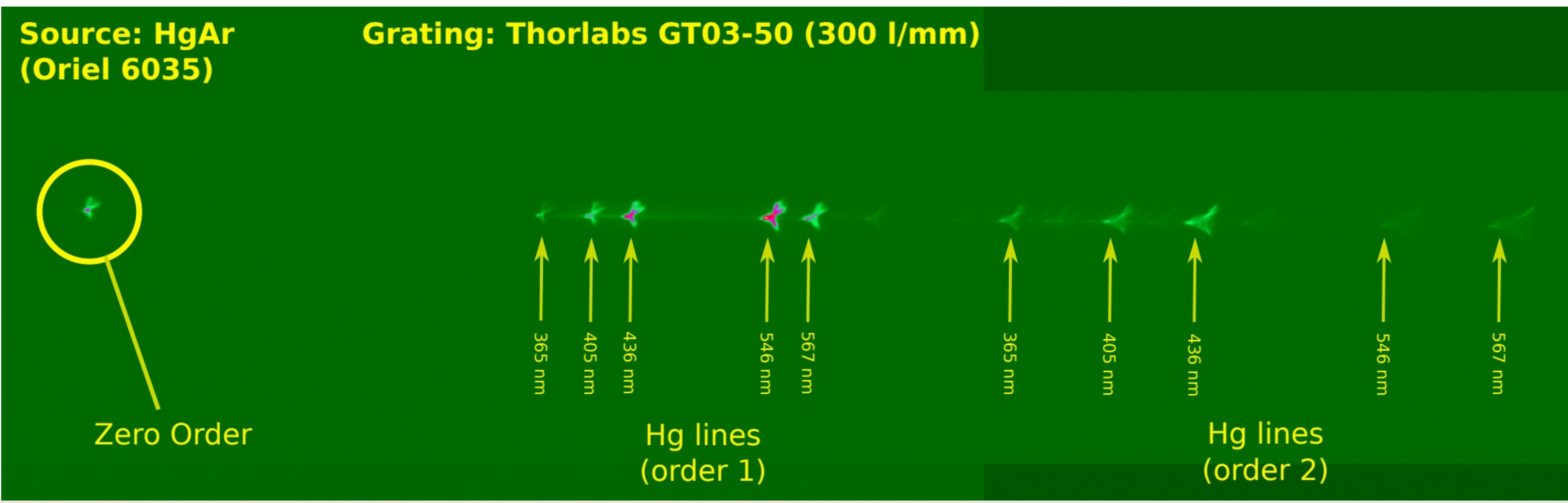




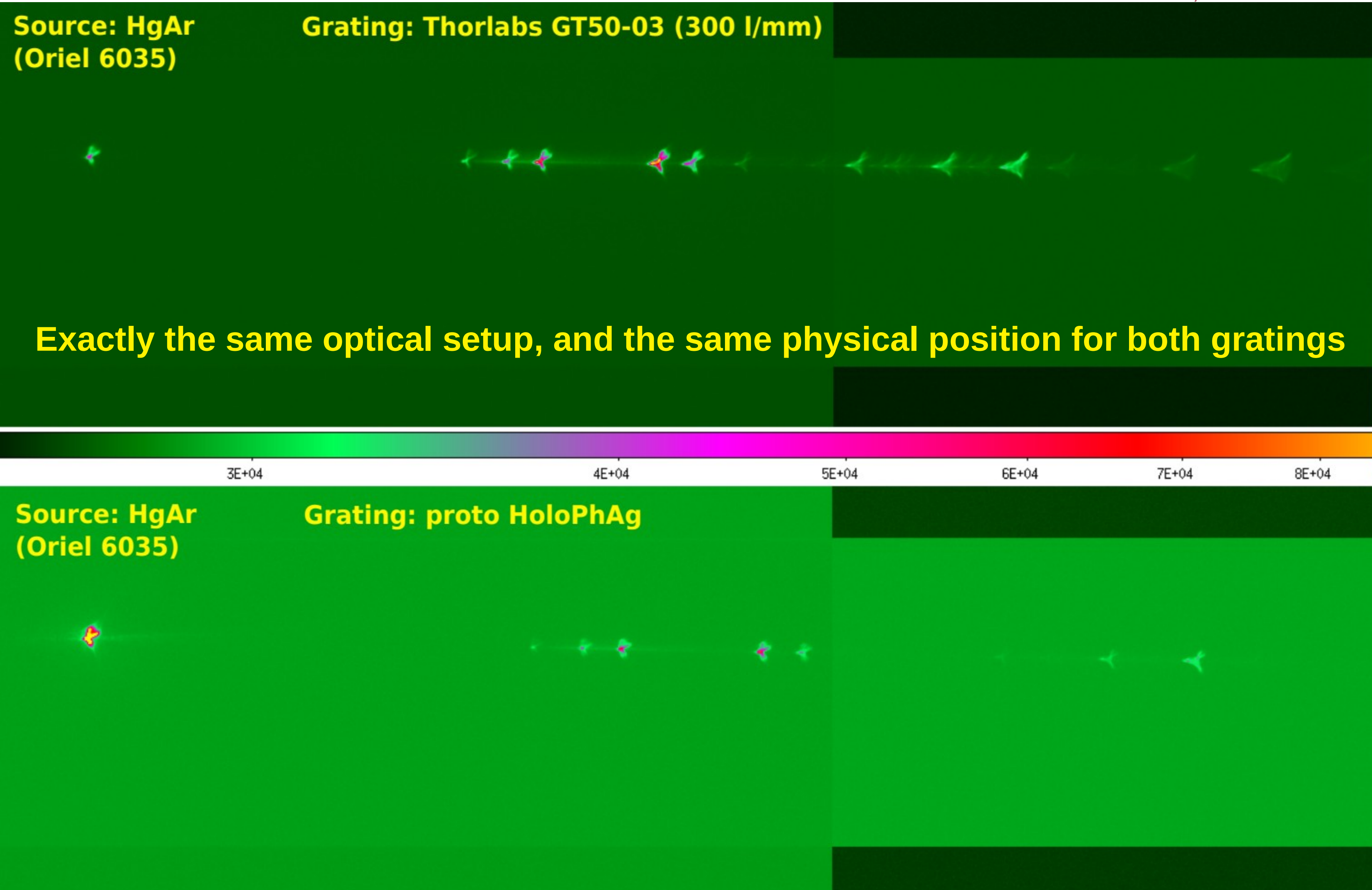
Valid. with Thorlabs GT50-03 grating

- Grating : blazed transmission grating, GT50-03, 300 g/mm
- Light source : PenRay Hg(Ar) *(Oriel 6035)*
- **Defocusing** with **increasing wavelength** clearly visible
- Our PSF is not circular, as we already know
- Small enough compared to AuxTel expected seeing

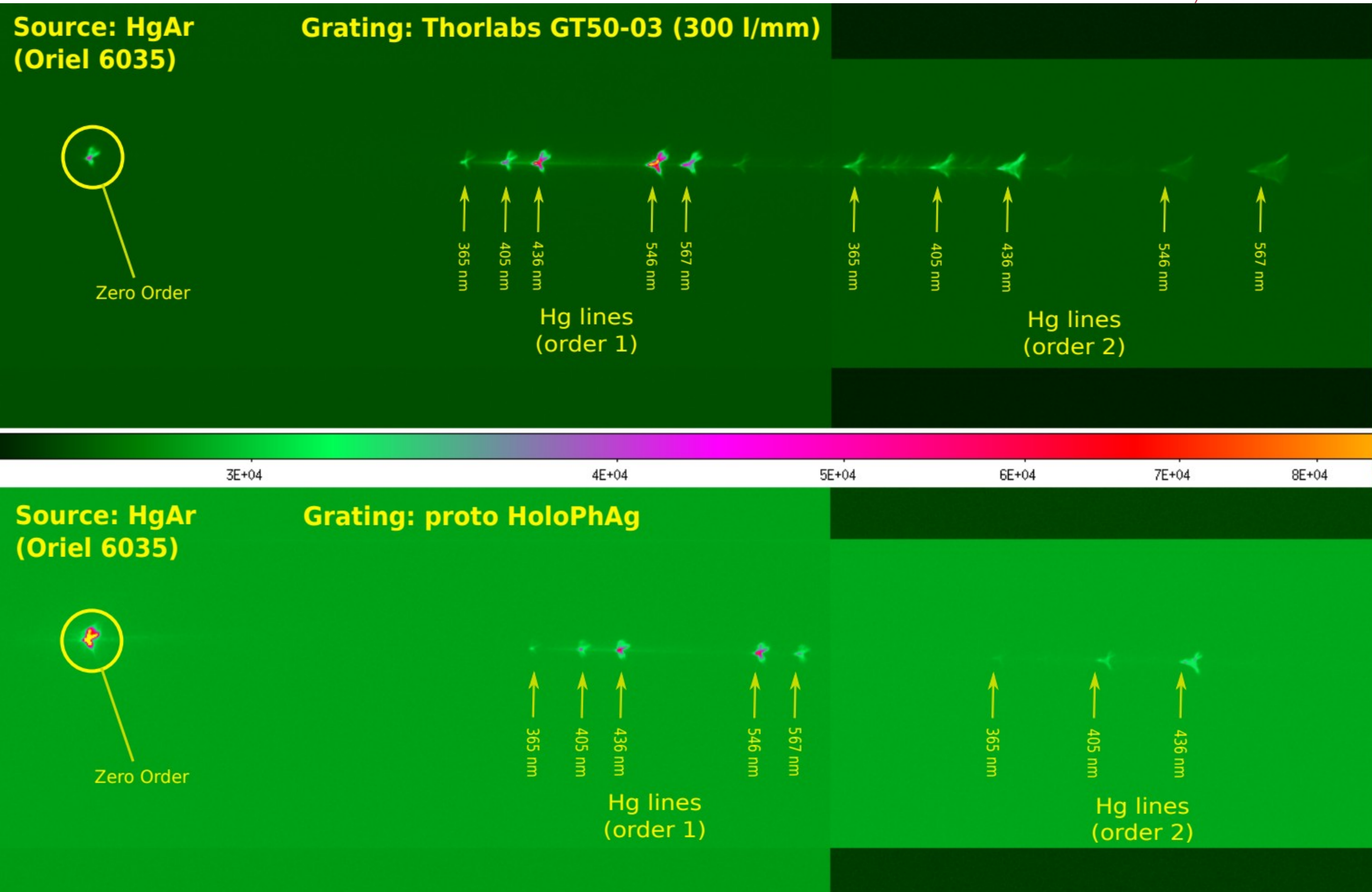




Focus : GT50-03 vs. hologr. HoloPhAg

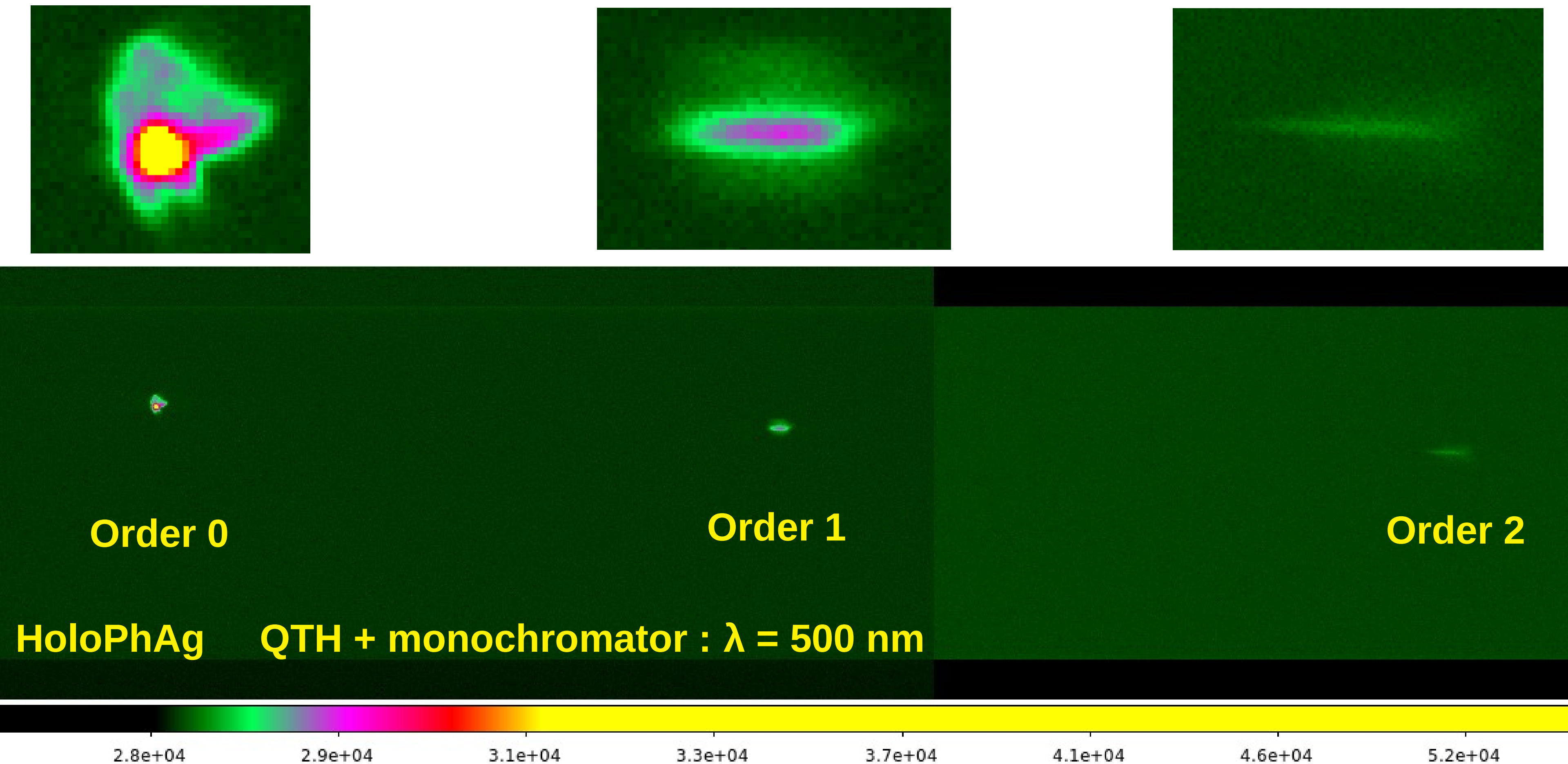


GT50-03 vs. hologram HoloPhAg



Throughput (efficiency)

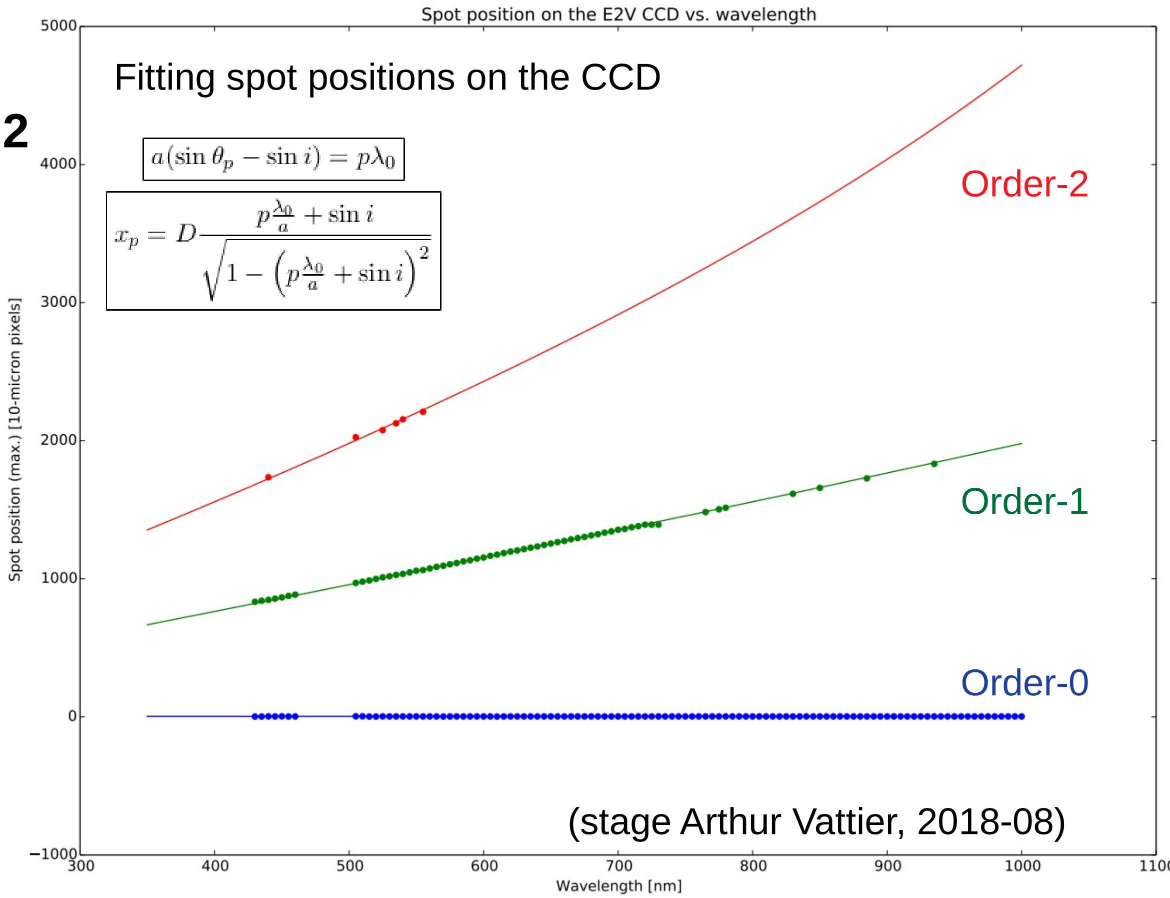
- **Scanning in wavelength** with QTH lamp and monochromator ;
- **XYZ mount : grating in the beam / out of the beam** : ON / OFF CCD frames



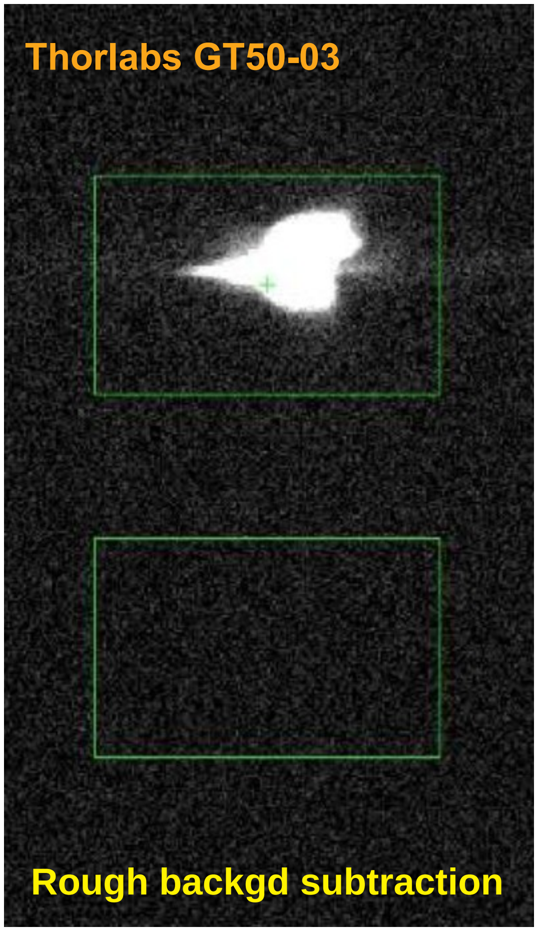
Gratings diffraction efficiency: analysis

- **Scanning in wavelength** with QTH lamp and monochromator ;
- ON / OFF CCD frames
- **Aut. detection of orders 0, 1, 2**
- **Fitting** spot positions
- Estimating the **total flux** (box) for each order (subtr. backgd)
- Estimating the **ratio** :

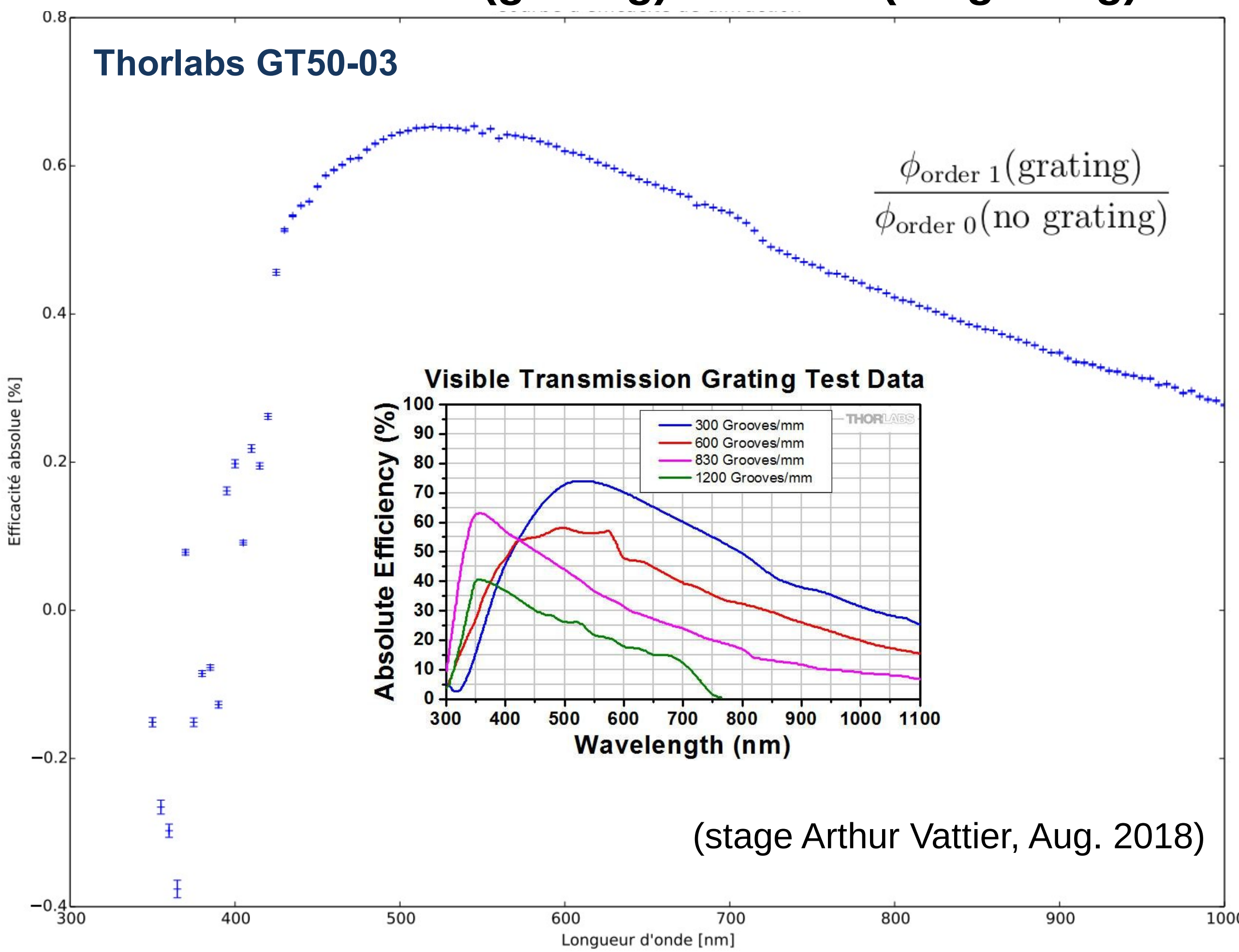
$$\frac{\phi_{\text{order 1}}(\text{grating})}{\phi_{\text{order 0}}(\text{no grating})}$$



Diffr. efficiency for Thorlabs GT50-03



Ratio : order-1 (grating) / order-0 (no grating)



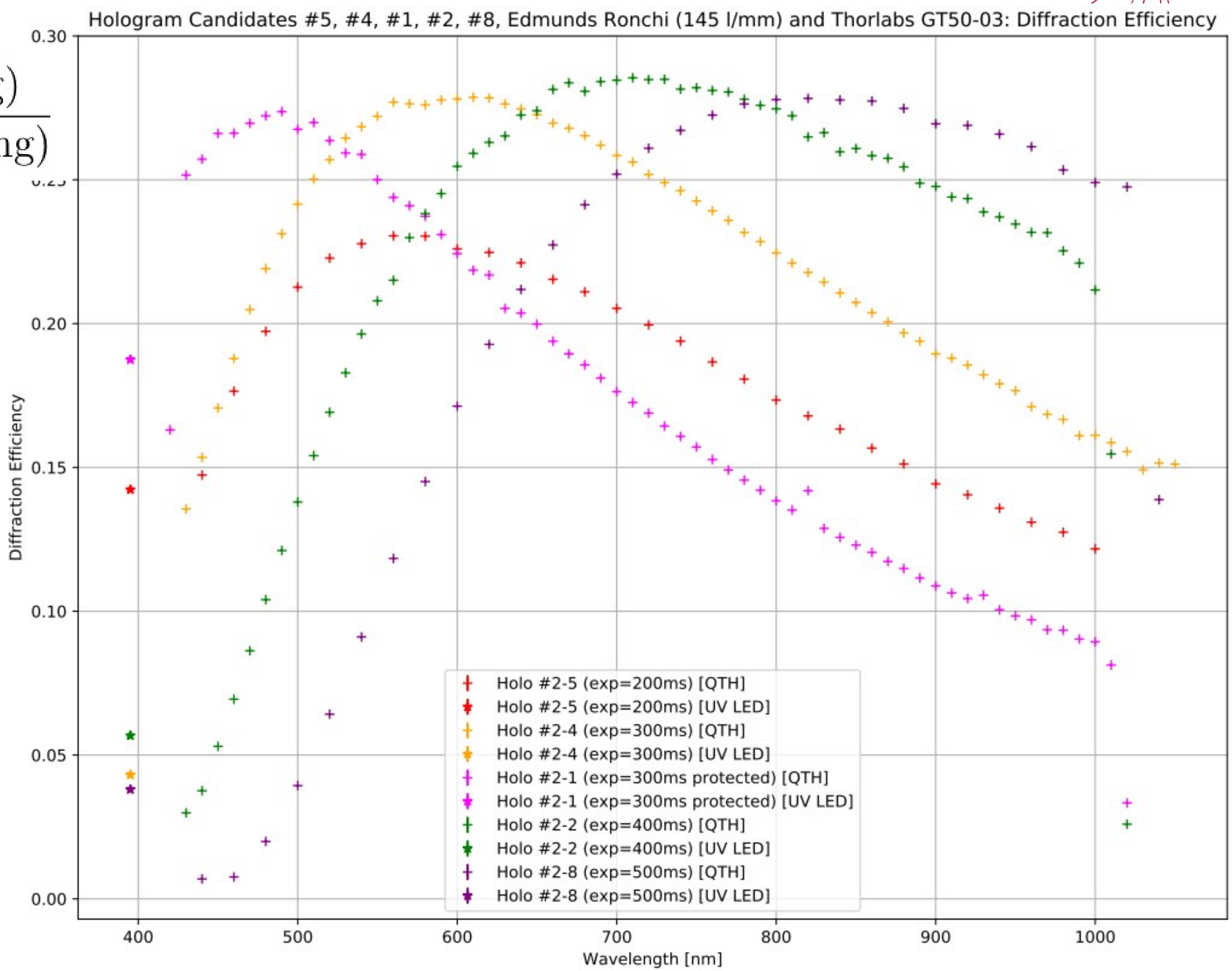
Tested gratings

Ref #	Type	Provider	Nom. dist. to sensor	Exposure time
Ronchi-145	Ronchi 145 l/mm	Edmunds	—	—
GT50-03	Blazed tr. 300 l/mm	Thorlabs	—	—
Holo-#1-1	Amplitude hologram	M. Gentet	58 mm	
Holo-#1-2	Phase hologram (PhP)	M. Gentet	58 mm	
Holo-#1-3	Phase hologram (Ag)	M. Gentet	58 mm	
Holo-#2-1	Phase hologram	M. Gentet	200 mm	300 ms (protected)
Holo-#2-2	Phase hologram	M. Gentet	200 mm	400 ms
Holo-#2-4	Phase hologram	M. Gentet	200 mm	300 ms
Holo-#2-5	Phase hologram	M. Gentet	200 mm	200 ms
Holo-#2-7	Phase hologram	M. Gentet	200 mm	500 ms
Holo-#2-8	Phase hologram	M. Gentet	200 mm	500 ms

Tested on sky At CTIO

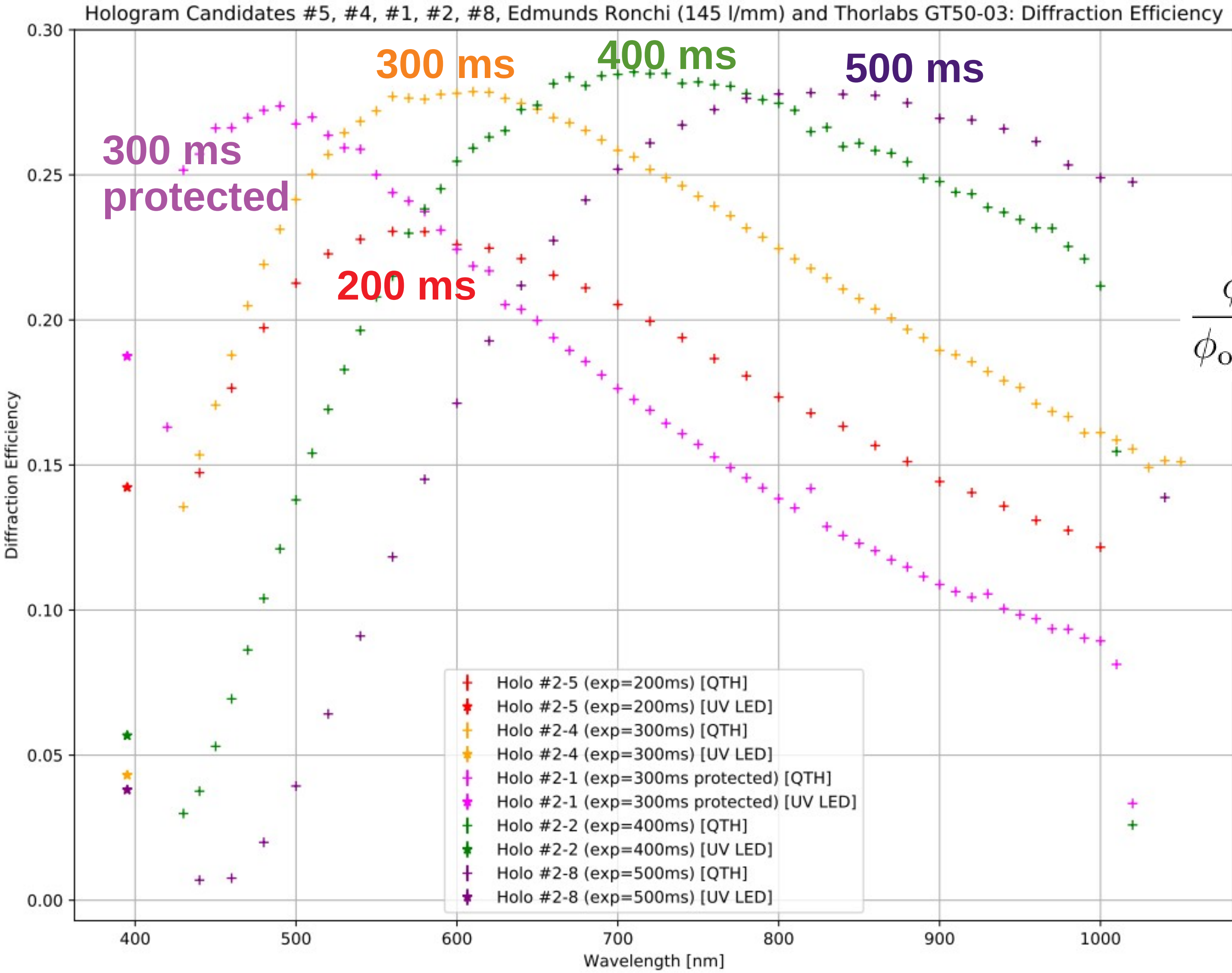
Diffraction efficiency: holograms

$$\frac{\phi_{\text{order 1}}(\text{grating})}{\phi_{\text{order 0}}(\text{no grating})}$$



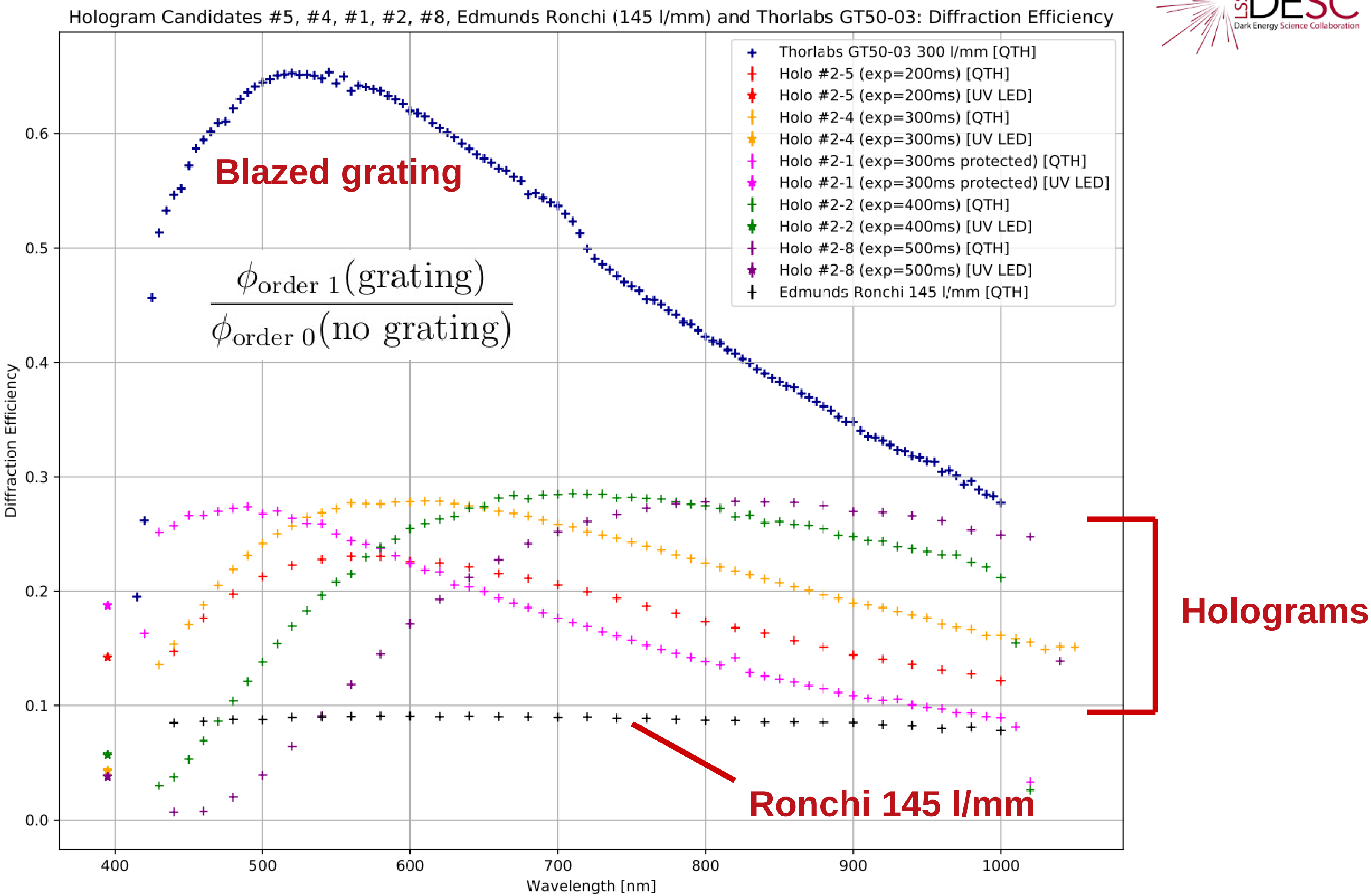
Extra UV data points with a 395 nm LED

Influence of hologram exposure time

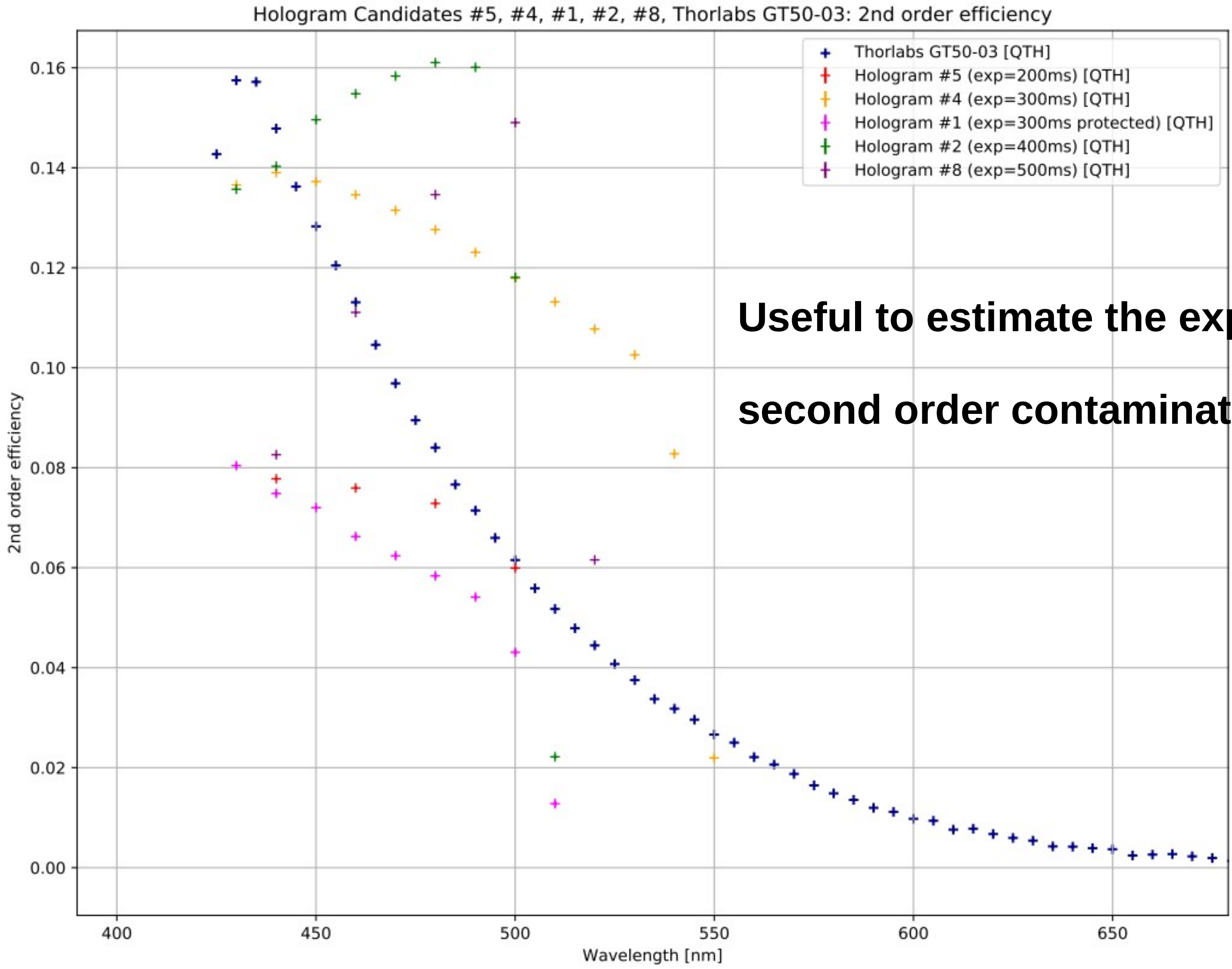


$$\frac{\phi_{\text{order 1}}(\text{grating})}{\phi_{\text{order 0}}(\text{no grating})}$$

Diffraction efficiency: all gratings

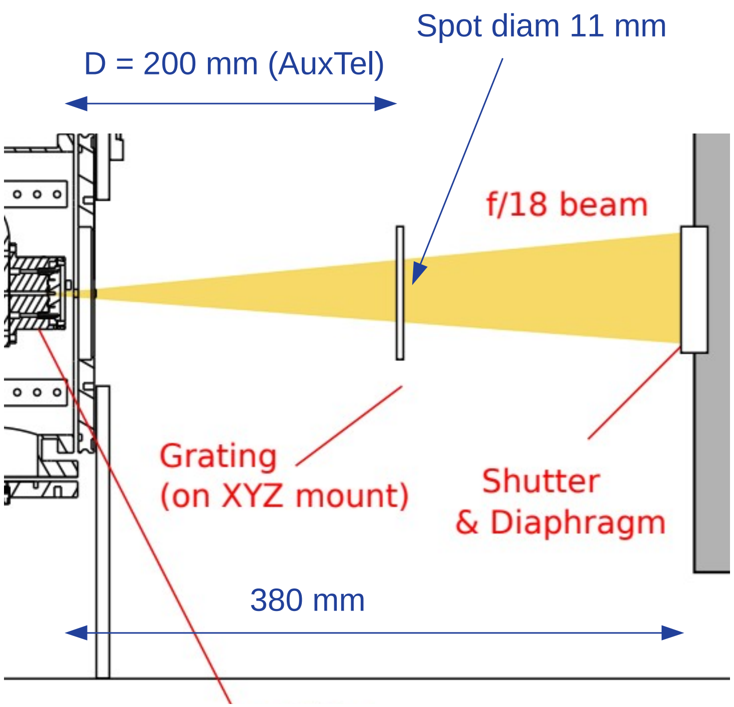


Order-2 “efficiency”

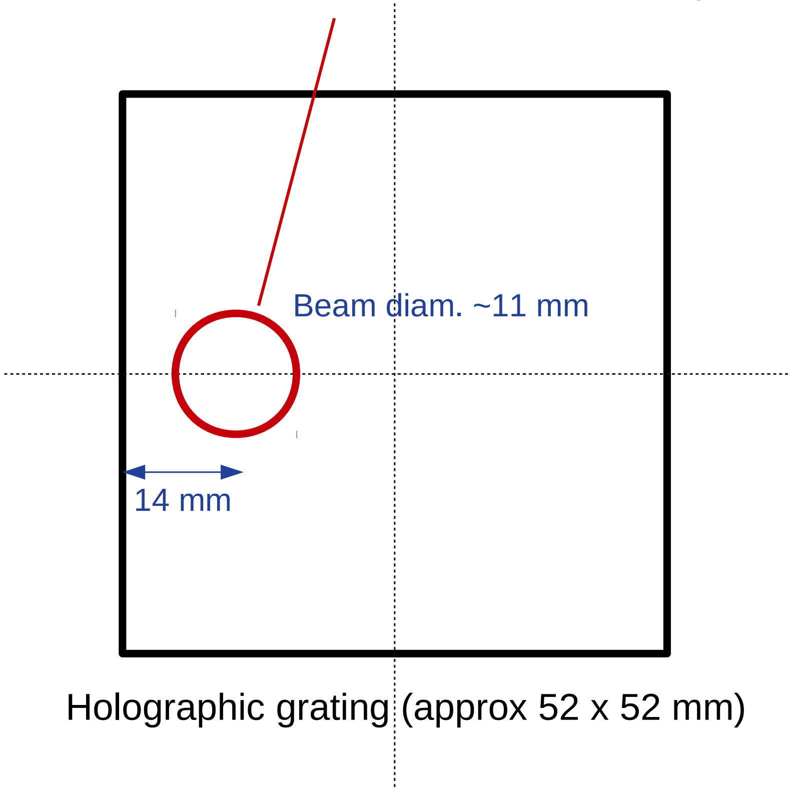


Useful to estimate the expected second order contamination

Influence of the impact parameter



Where the beam should hit the hologram

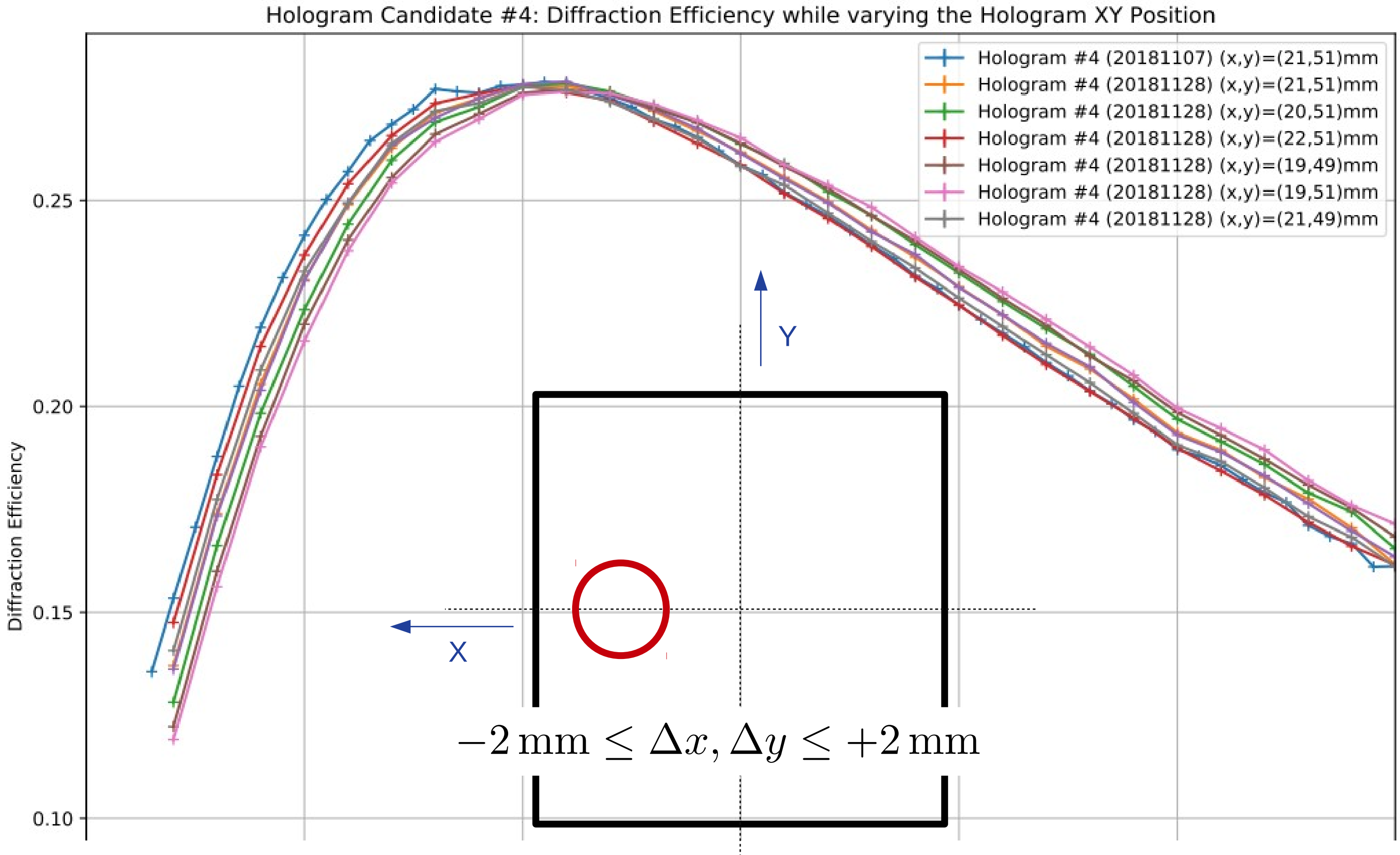


Holographic grating (approx 52 x 52 mm)

Holograms are **not translation invariant** in the transverse plane.

The beam should **hit a specific region** to get the expected performances

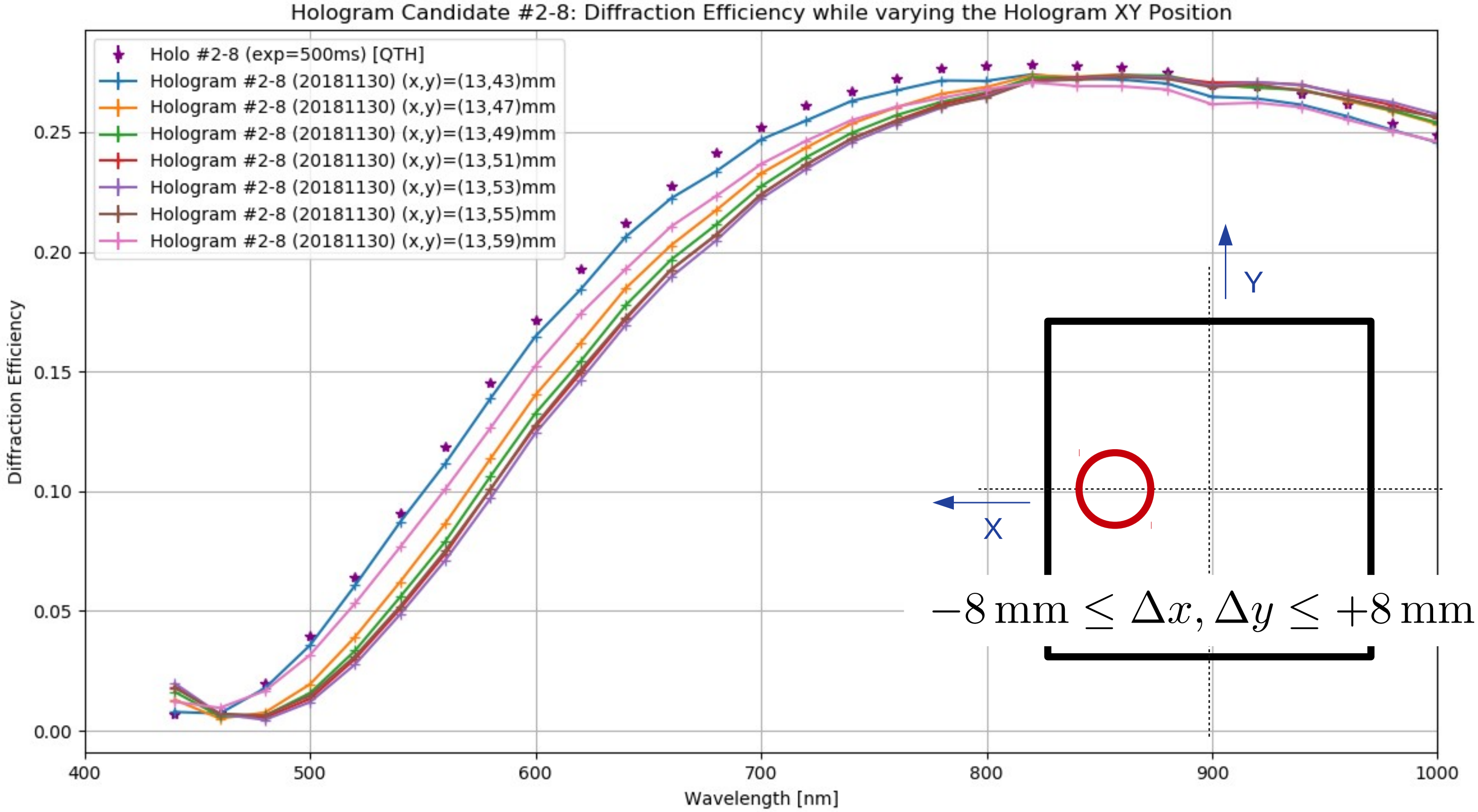
Influence of the impact parameter



Holograms are **not translation invariant** in the transverse plane.

The throughput **slightly depends** on the beam impact parameter on the hologram

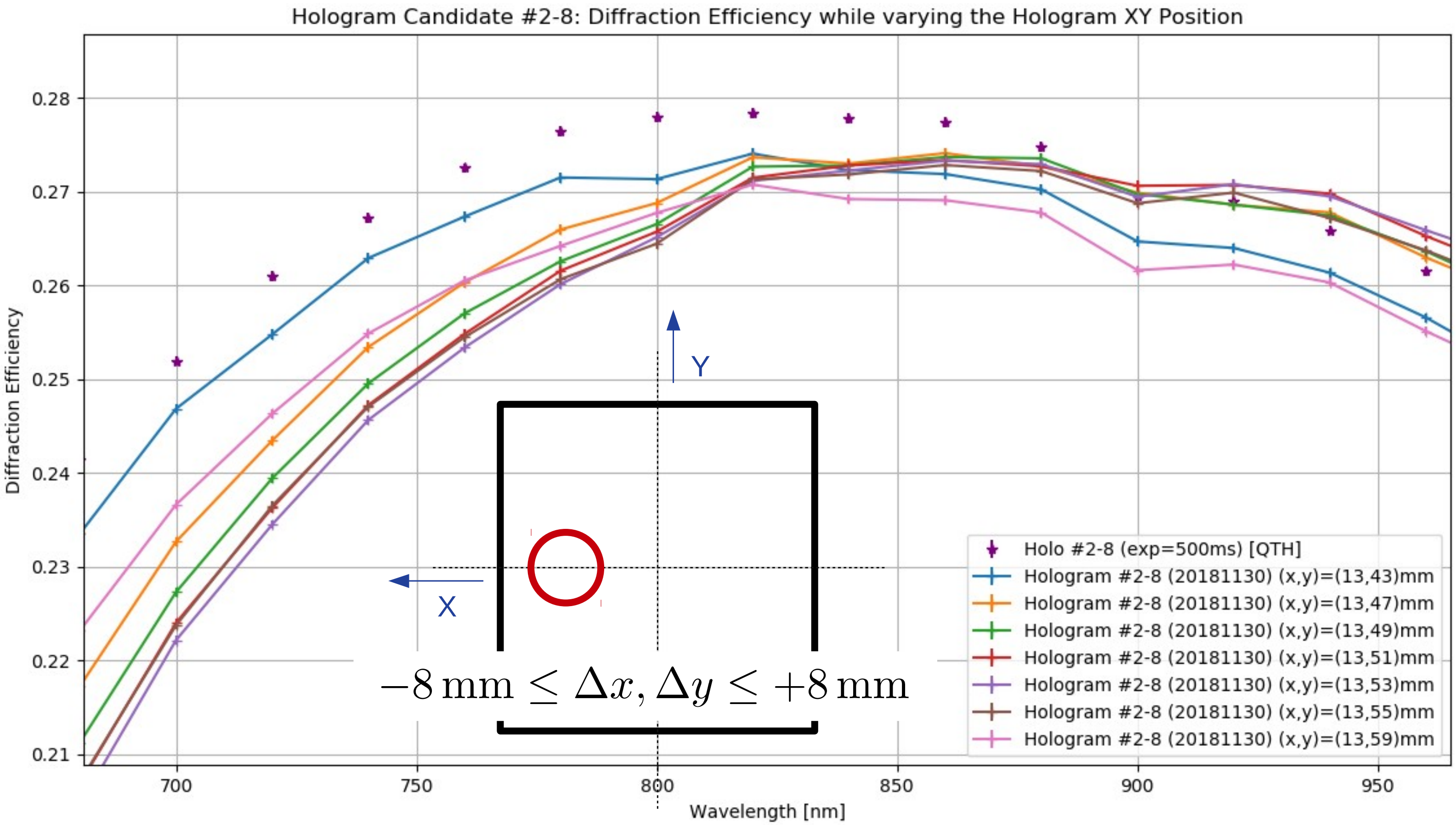
Influence of the impact parameter



Holograms are **not translation invariant** in the transverse plane.

The throughput **slightly depends** on the beam impact parameter on the hologram

Influence of the impact parameter



Holograms are **not translation invariant** in the transverse plane.

The throughput **slightly depends** on the beam impact parameter on the hologram

Modeling the throughput (DE) function, and its **dependency with position** ?

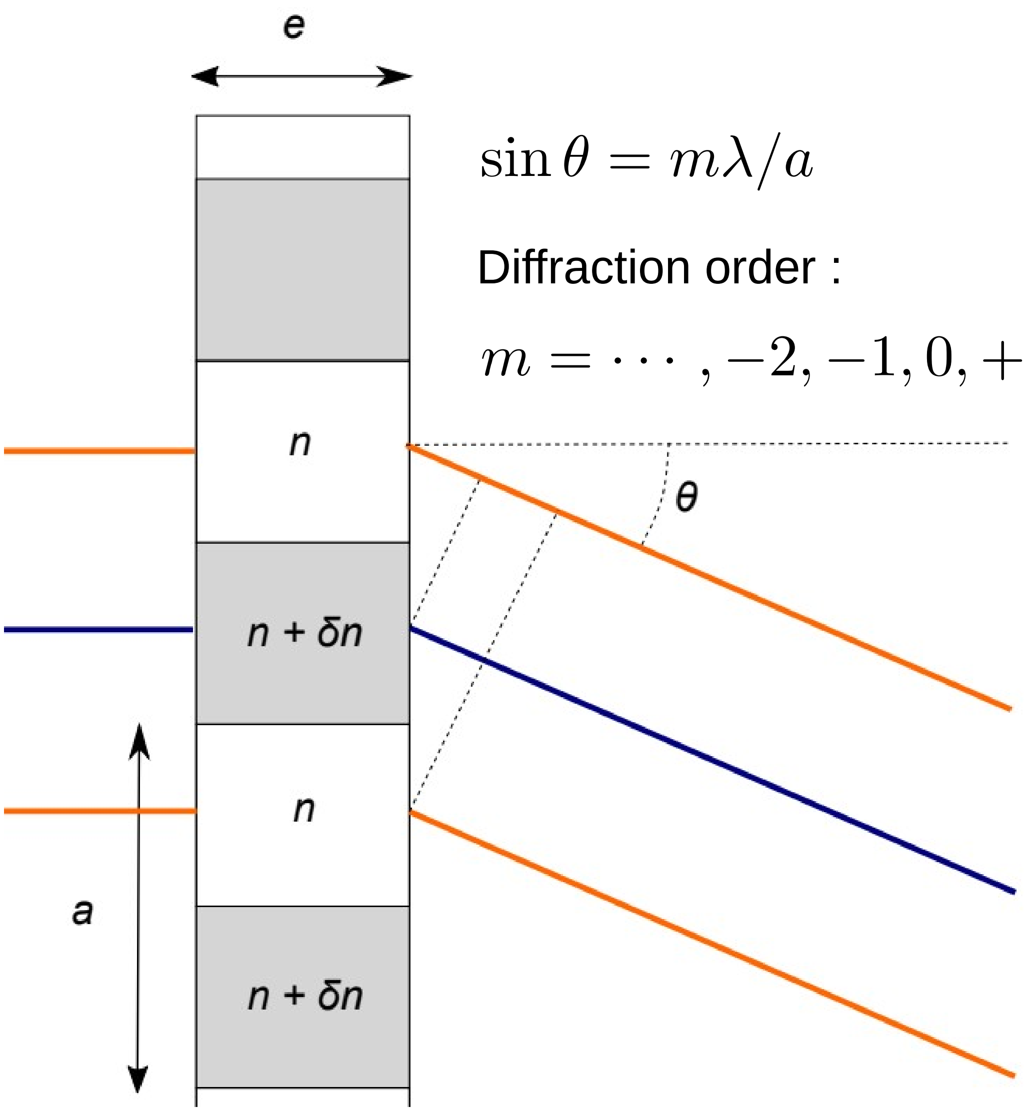
Tentative model of the phase hologram

Phase modulation in
the hologram substrate
due to index variation
In the emulsion

*(Rough model :
Square wave)*

Phase contrast :

$$\Delta\phi = 2\pi\, e\delta n/\lambda \propto 1/\lambda$$



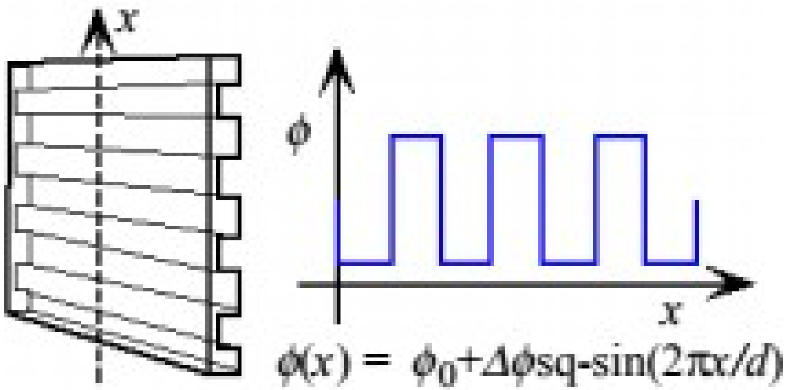
$$\sin\theta = m\lambda/a$$

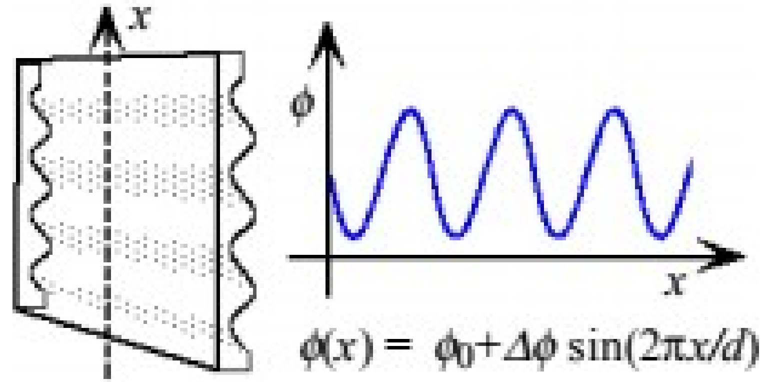
Diffraction order :

$$m = \cdots, -2, -1, 0, +1, +2, \cdots$$

Square or Sine Wave Phase Grating

For a regular grating : the diffraction efficiency (DE) is analytical





$$DE_{m=0} = \cos^2 \Delta\phi$$

$$DE_{m=\pm1} = \left(\frac{2}{\pi}\sin\Delta\phi\right)^2 = 40.5\%_{\text{max}}$$

$$DE_{m=\text{even}} = 0 \qquad \lambda_{\text{max}} \quad \text{when } \Delta\phi = \pi/2$$

$$DE_{m=\text{odd}} = \frac{1}{m^2} DE_{+1}$$

$$\sum_{m\neq0} DE_m = \sin^2 \Delta\phi = 100\%_{\text{max}}$$

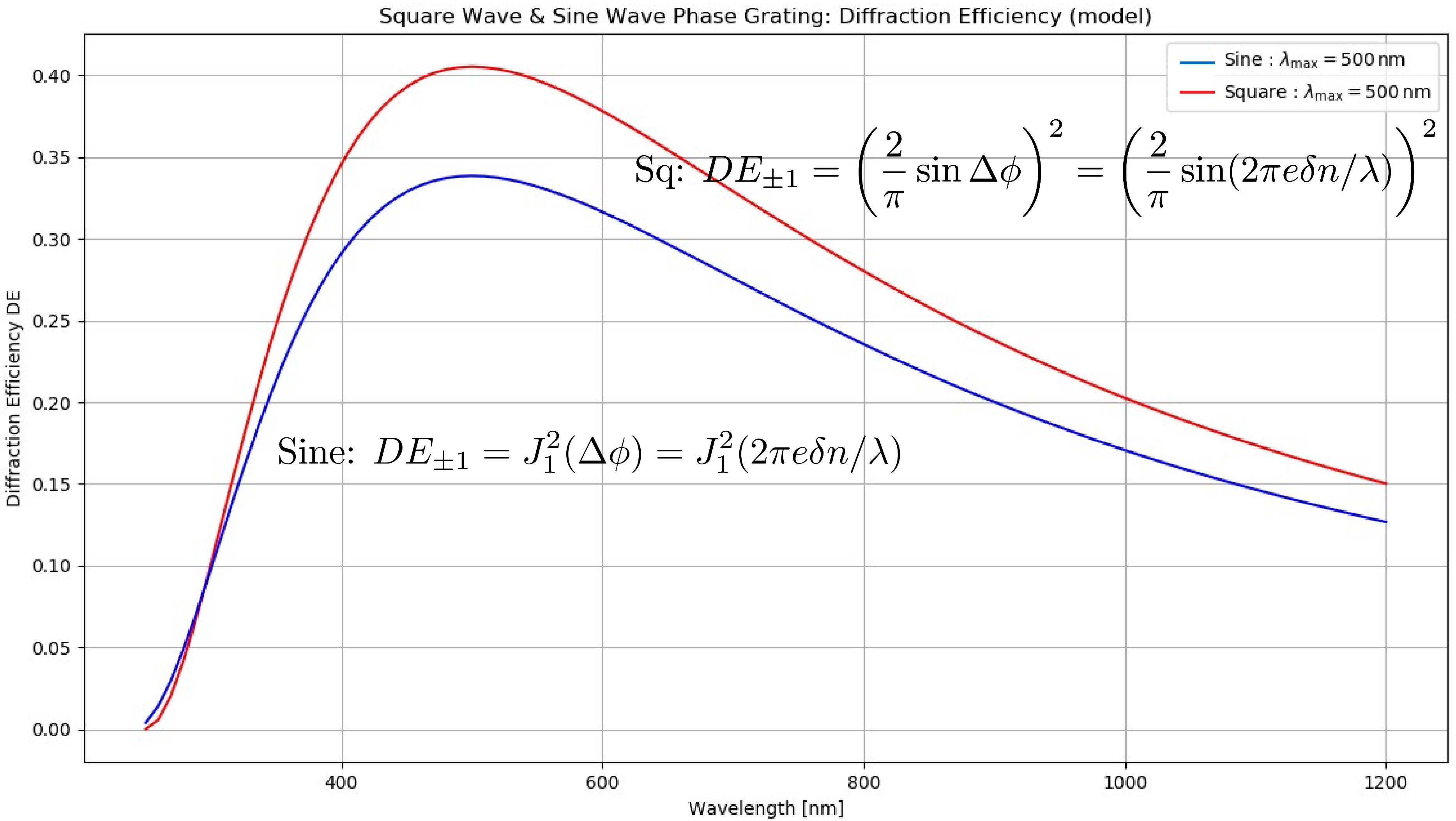
$$DE_{m=0} = J_0^2(\Delta\phi)$$

$$DE_{m=\pm1} = J_1^2(\Delta\phi) = 33.8\%_{\text{max}}$$

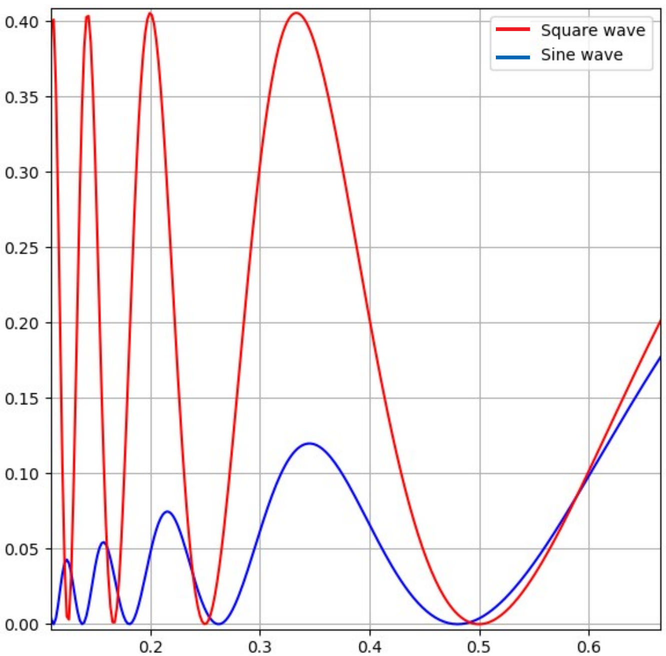
$$\sum_{m\neq0} DE_m = 1 - J_0^2(\Delta\phi) = 100\%_{\text{max}}$$

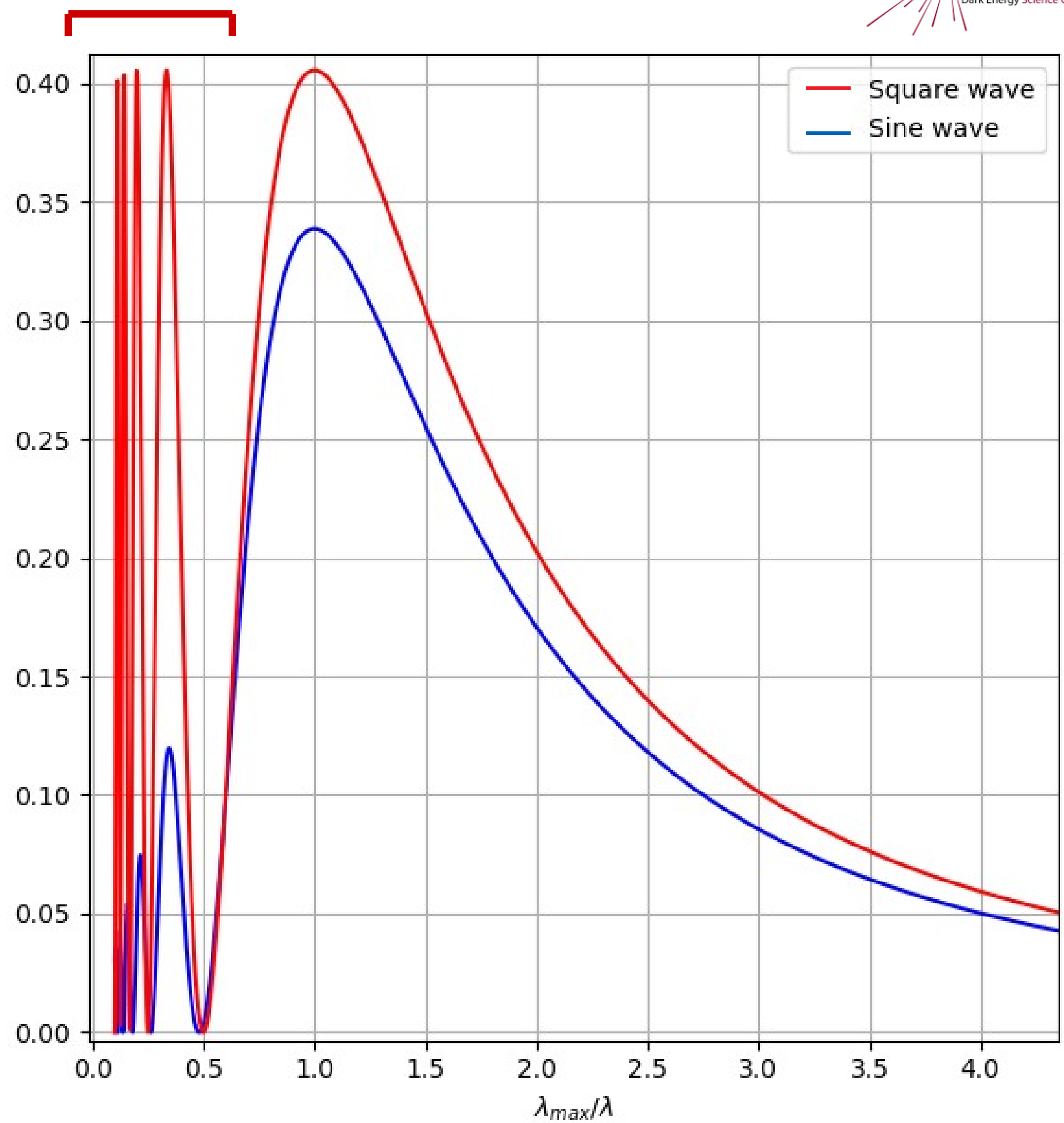
$$\lambda_{\text{max}} \quad \text{when } \Delta\phi = 0.586\pi$$

Square or Sine wave Phase Grating



Square or Sine wave Phase Grating

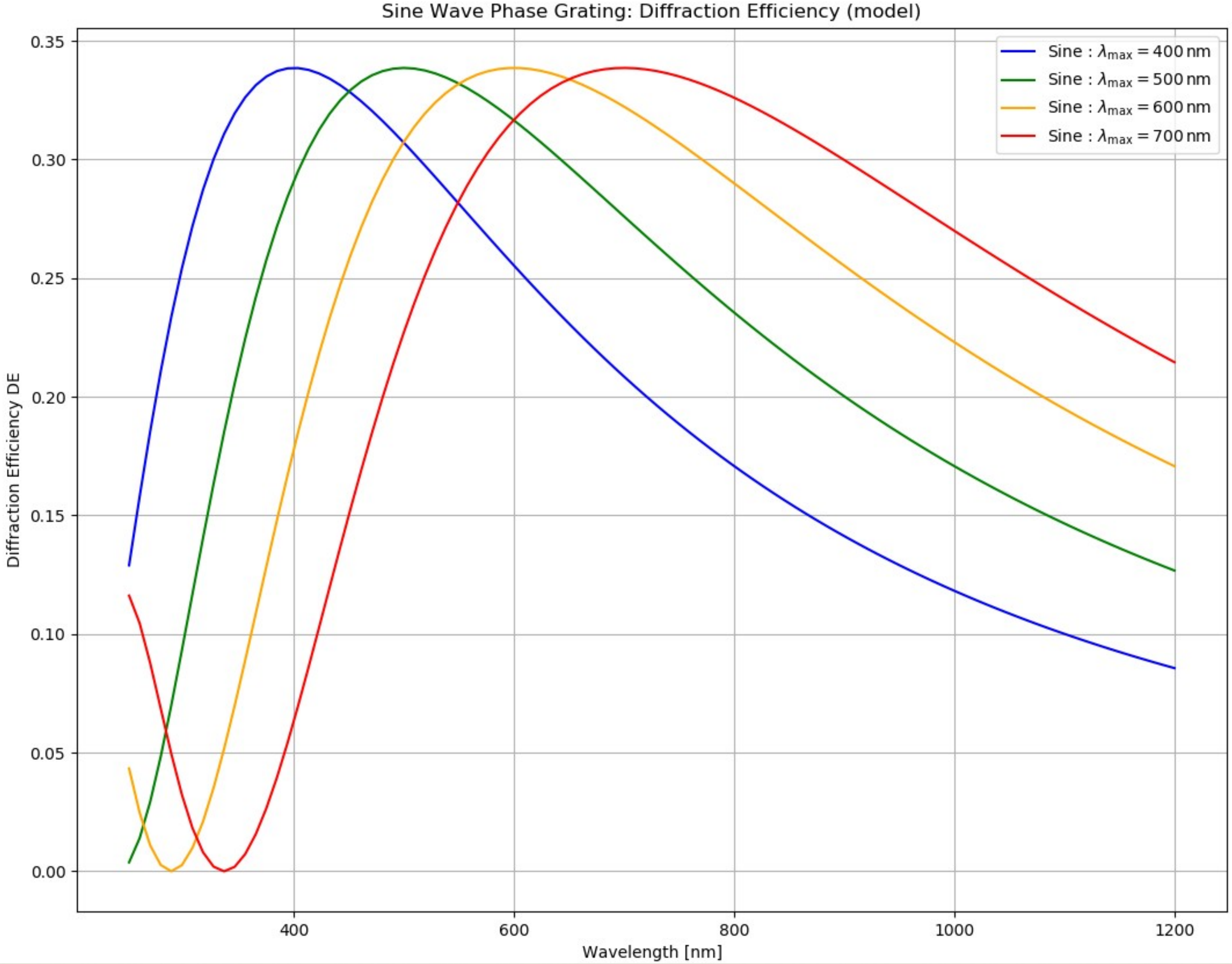




DE for sine / square wave

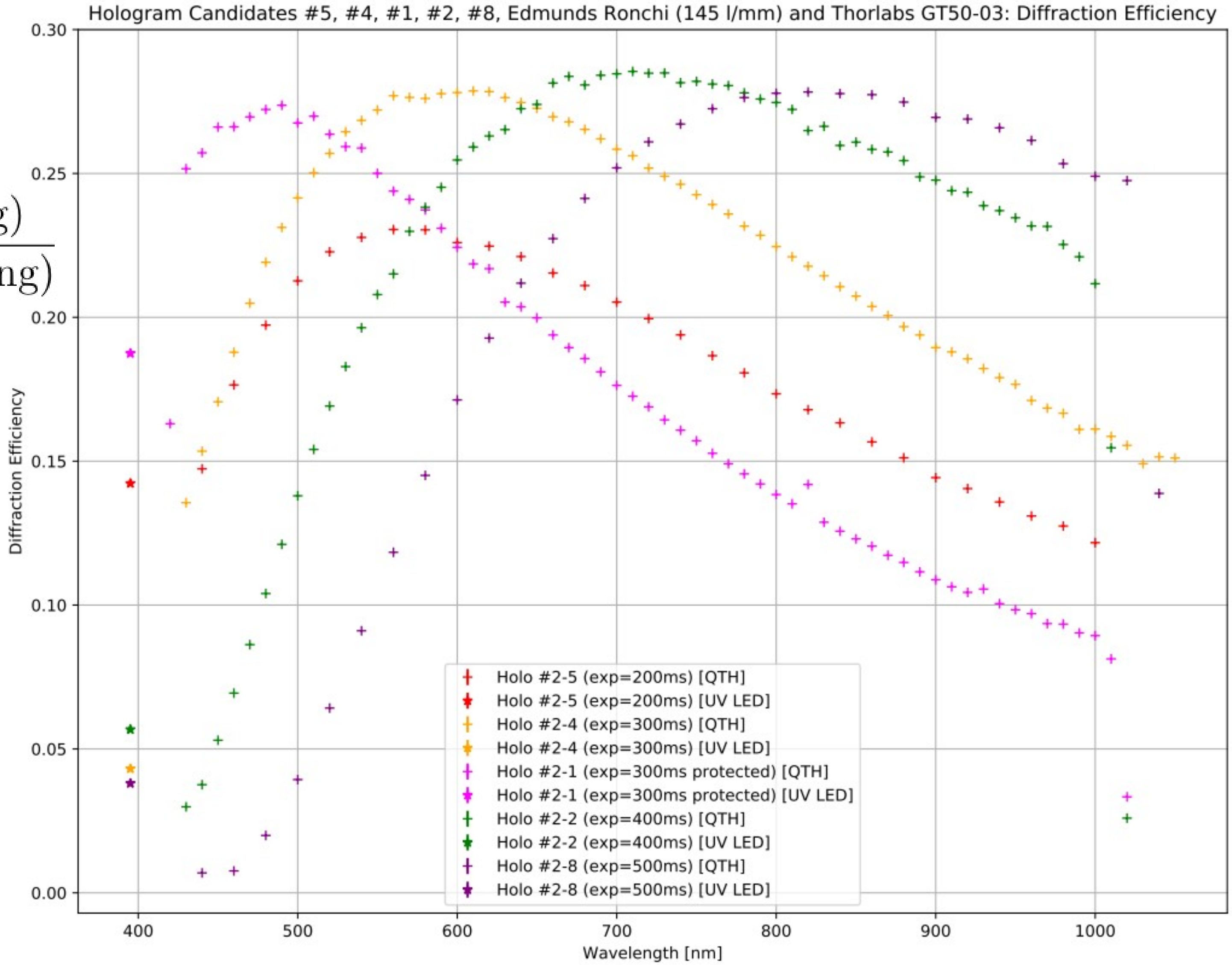
Very similar for $\lambda > \frac{\lambda \mathrm{max}}{2}$

Sine Wave Phase Grating with Lambda



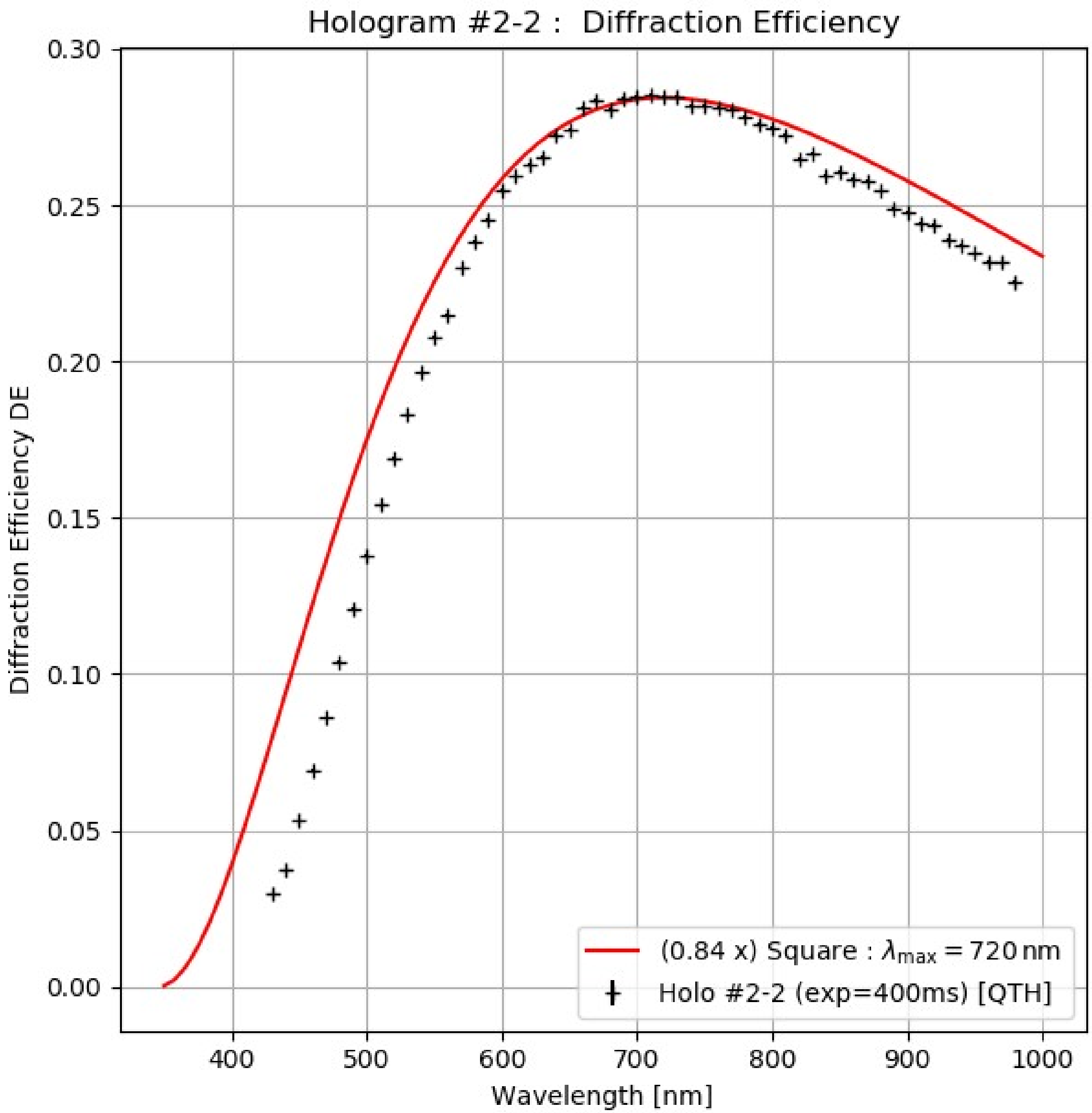
Diffraction efficiency: holograms

$$DE = \frac{\phi_{\text{order 1}}(\text{grating})}{\phi_{\text{order 0}}(\text{no grating})}$$



Extra UV data points with a 395 nm LED

Comparison with hologram data



Square or Sine wave grating DE does not fit the data very well…

Gelatin Transmittance ?

Glass (BK7 ?) ?

Approximate model anyway…

(ongoing work)

Conclusions

- We built a **dedicated testbench** at LPNHE to **characterize several holographic gratings**, candidates for the AuxTel instrument
- Validated with a Thorlabs blazed grating (GT50-03) ; first tested with **holographic prototypes already tested at CTIO**
- We used it to **characterize two series of holographic prototypes**
- **We measured their throughput (« DE » = « Diffraction Efficiency »)**
- We also studied a commercial Ronchi and a blazed grating (for comparison)
- Tentative model of the diffraction efficiency (*on going*)

→ **A DESC note in preparation with all the testbench results**

(more on focus improvements, throughput, etc)