



Testing holographic gratings candidates for AuxTel at LPNHE: Diffraction Efficiency

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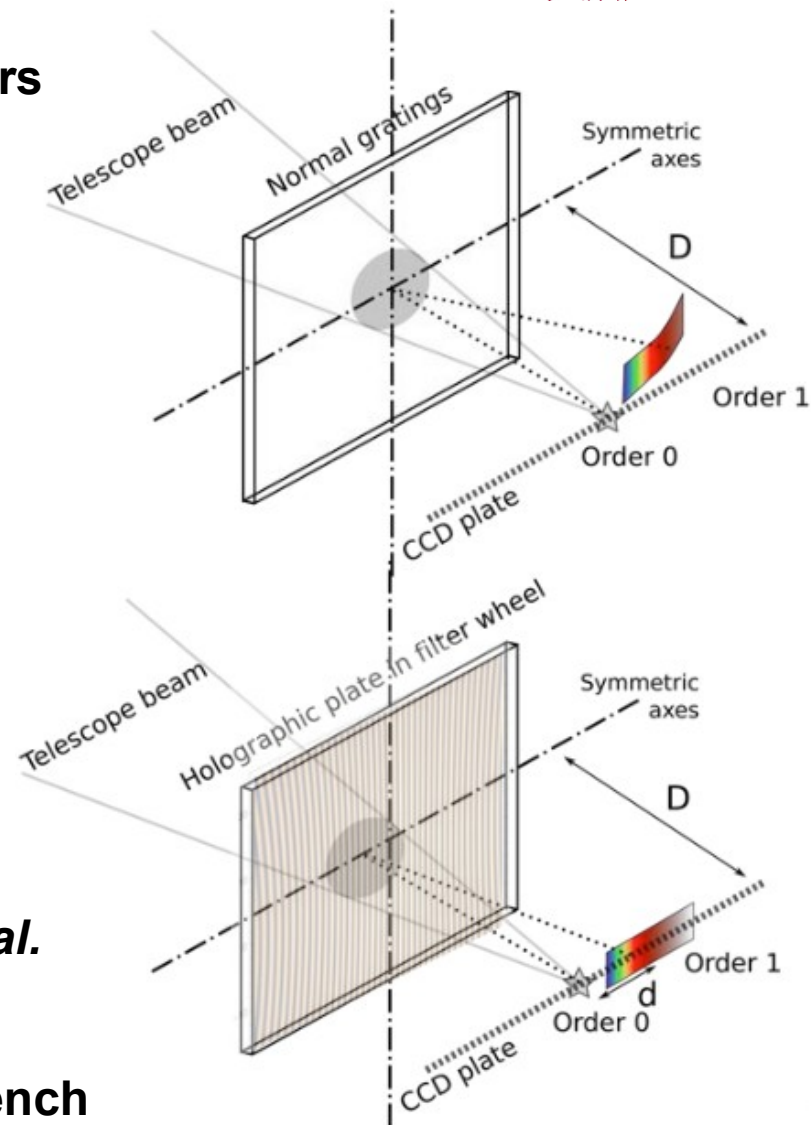
Talk outline



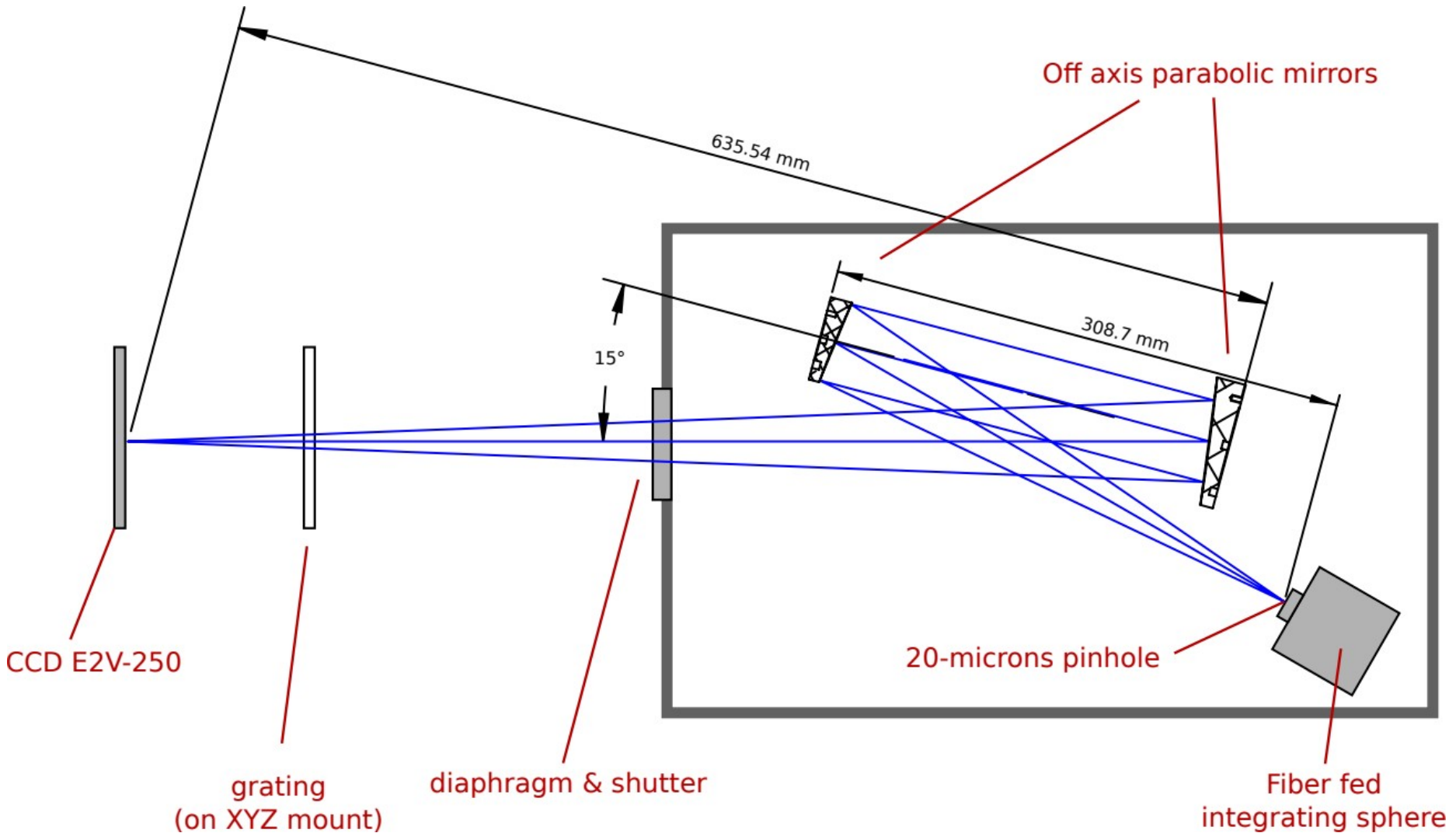
- **Context : holographic gratings for AuxTel (HOE)**
- **Optical setup : λ -tunable convergent beam (à la AuxTel)**
- **Integration within the LPNHE testbench for LSST CCD**
- **Focusing tests : Thorlabs grating vs holograms**
- **Measuring throughput / diffraction efficiency for each grating**
- **Modeling 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 distortions
- **Prototypes tested at CTIO** par **M. Moniez *et al.***
- Needed : a **testbench to characterize the produced holograms** → **LPNHE LSST bench**



Convergent beam : optical setup

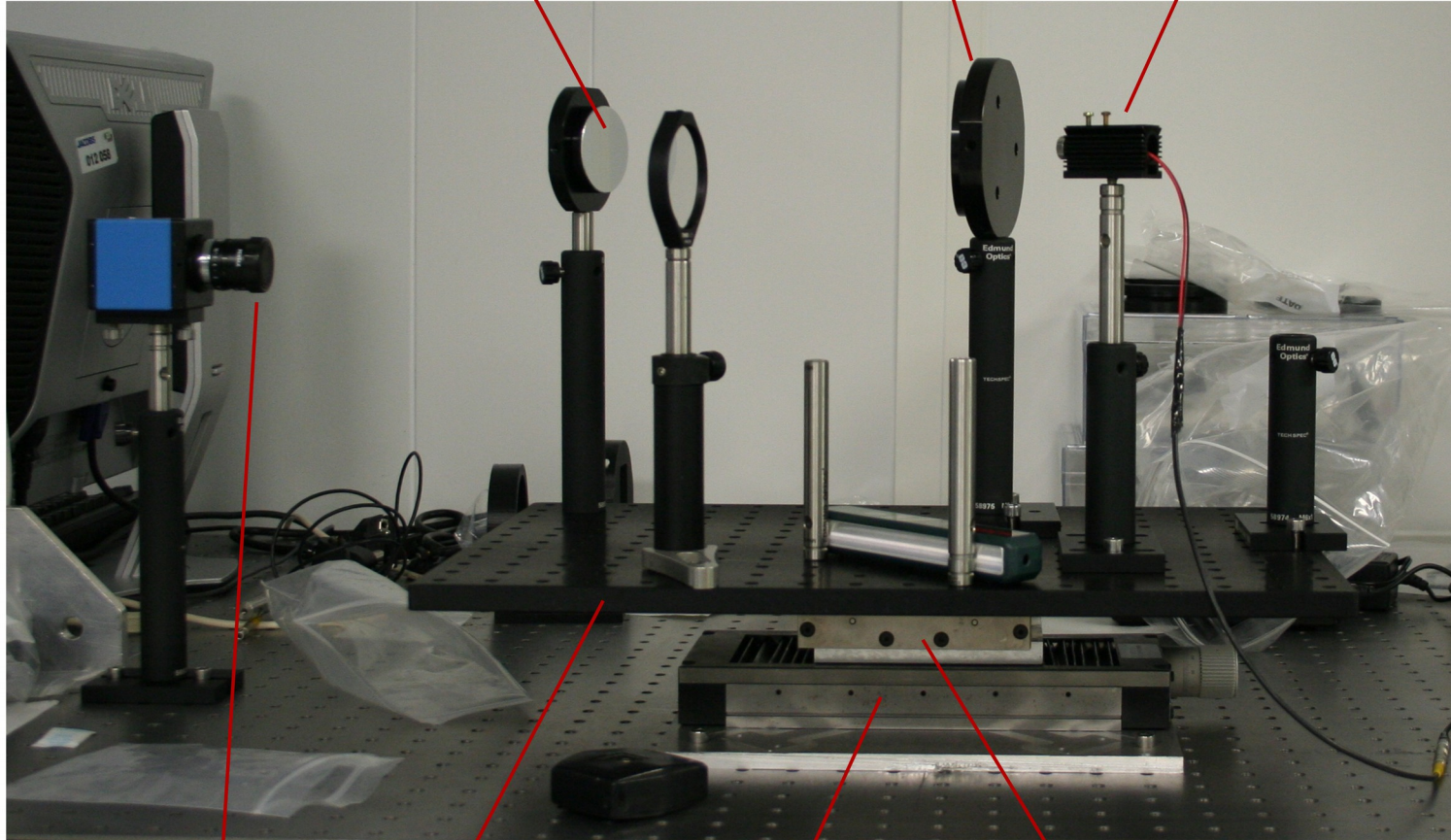


Convergent beam : optical setup

Off Axis parabolic mirror
 $f = 304.8$ mm

Off Axis parabolic mirror
 $f = 635$ mm

Source position
(here a laser for alignment)



Small CCD camera

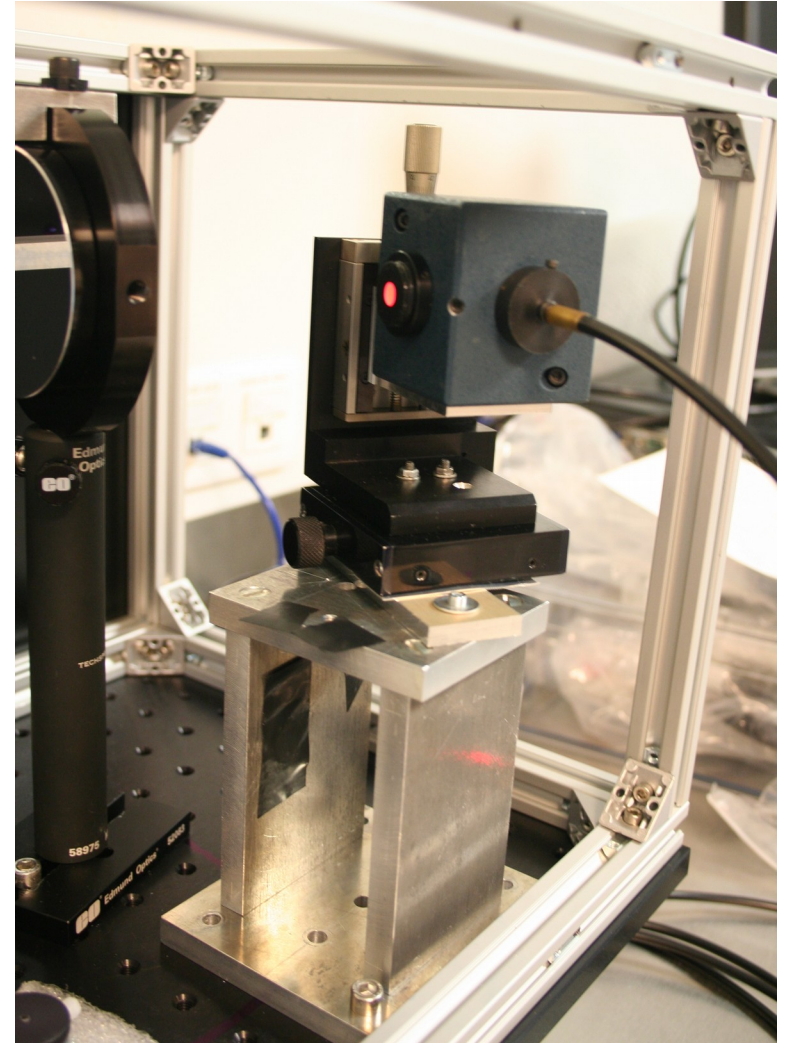
Optical table

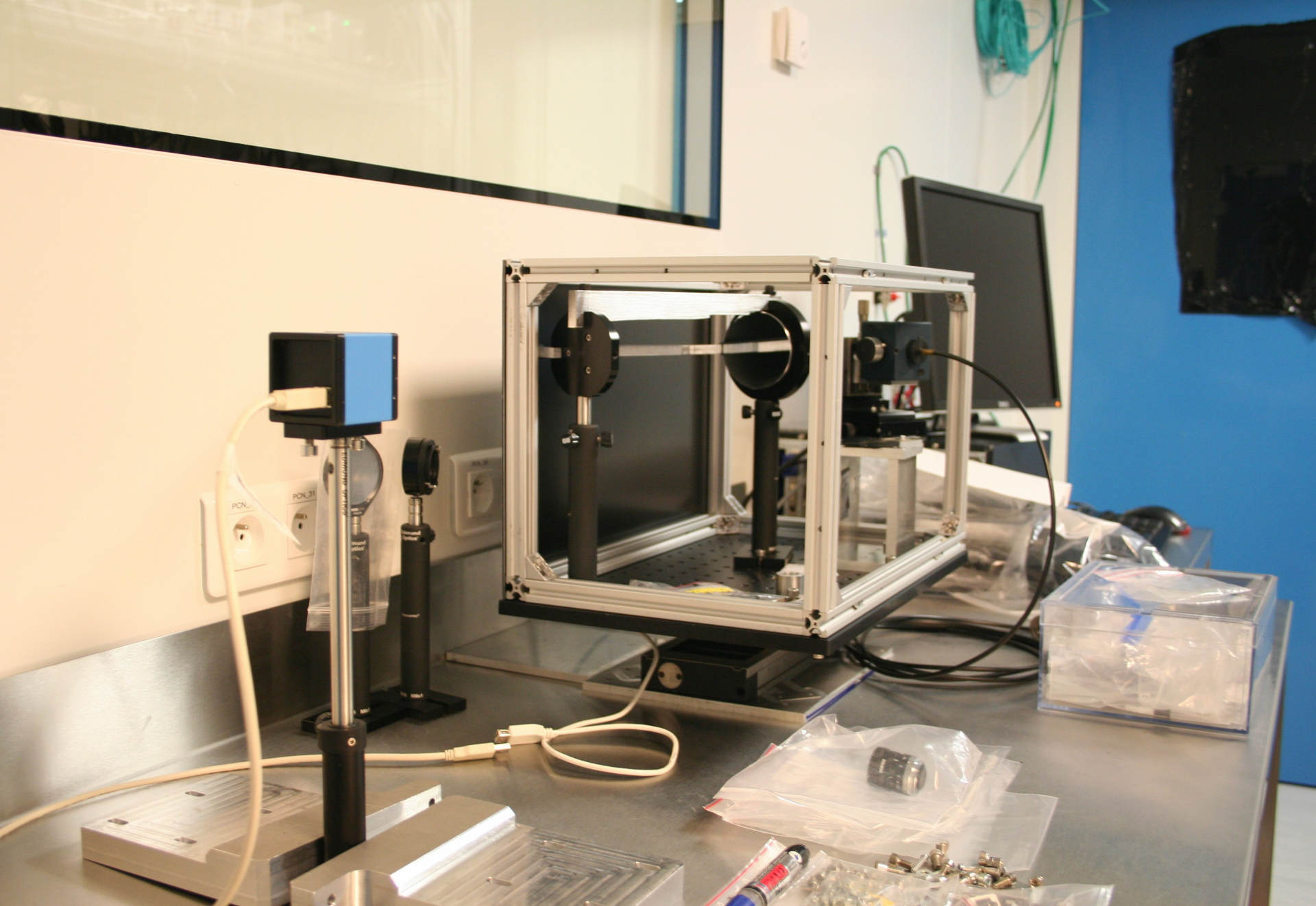
Linear stage along
the optical axis
(focus)

Horizontal linear
stage perpendicular
to the optical axis

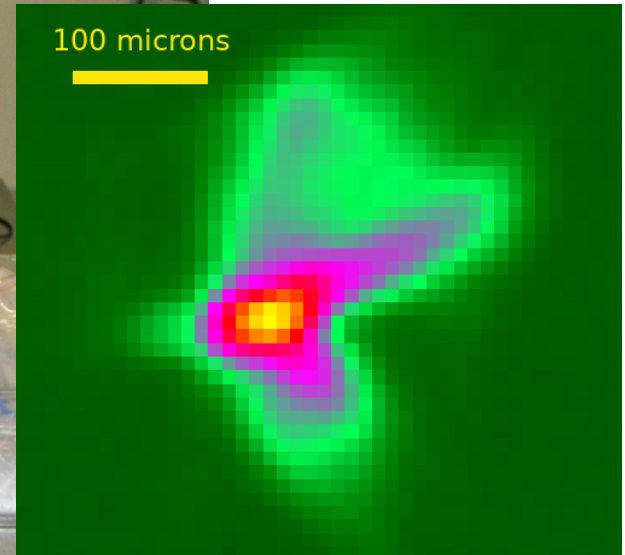
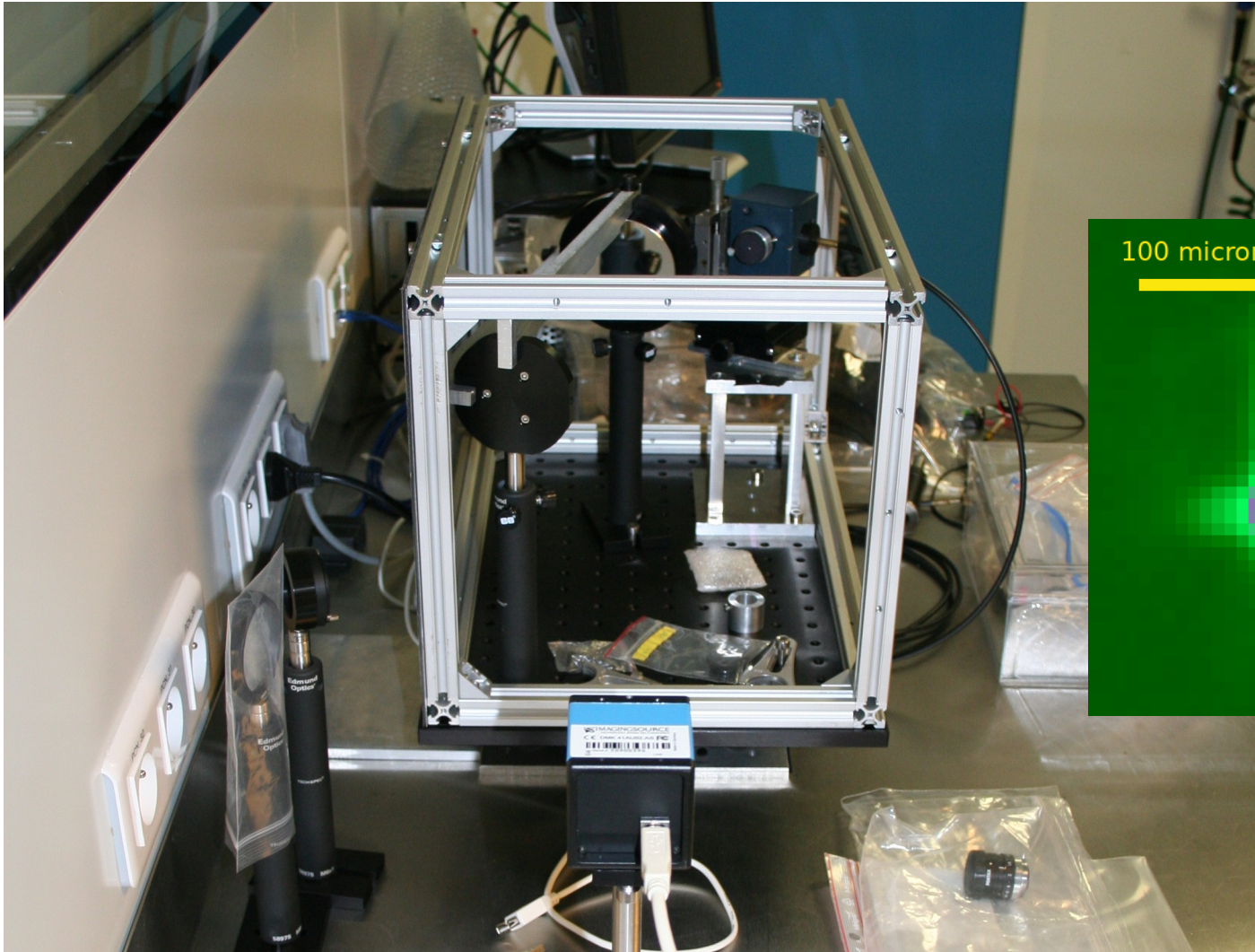
Convergent beam : optical setup

- Source : **integrating sphere**
- **Fiber fed :**
 - Lamps : incandescent, LEDs, HgAr
 - Continuum (QTH) + monochromator
- Exit = mirror focal point :
 - **pinhole** (20 microns)





Focusing

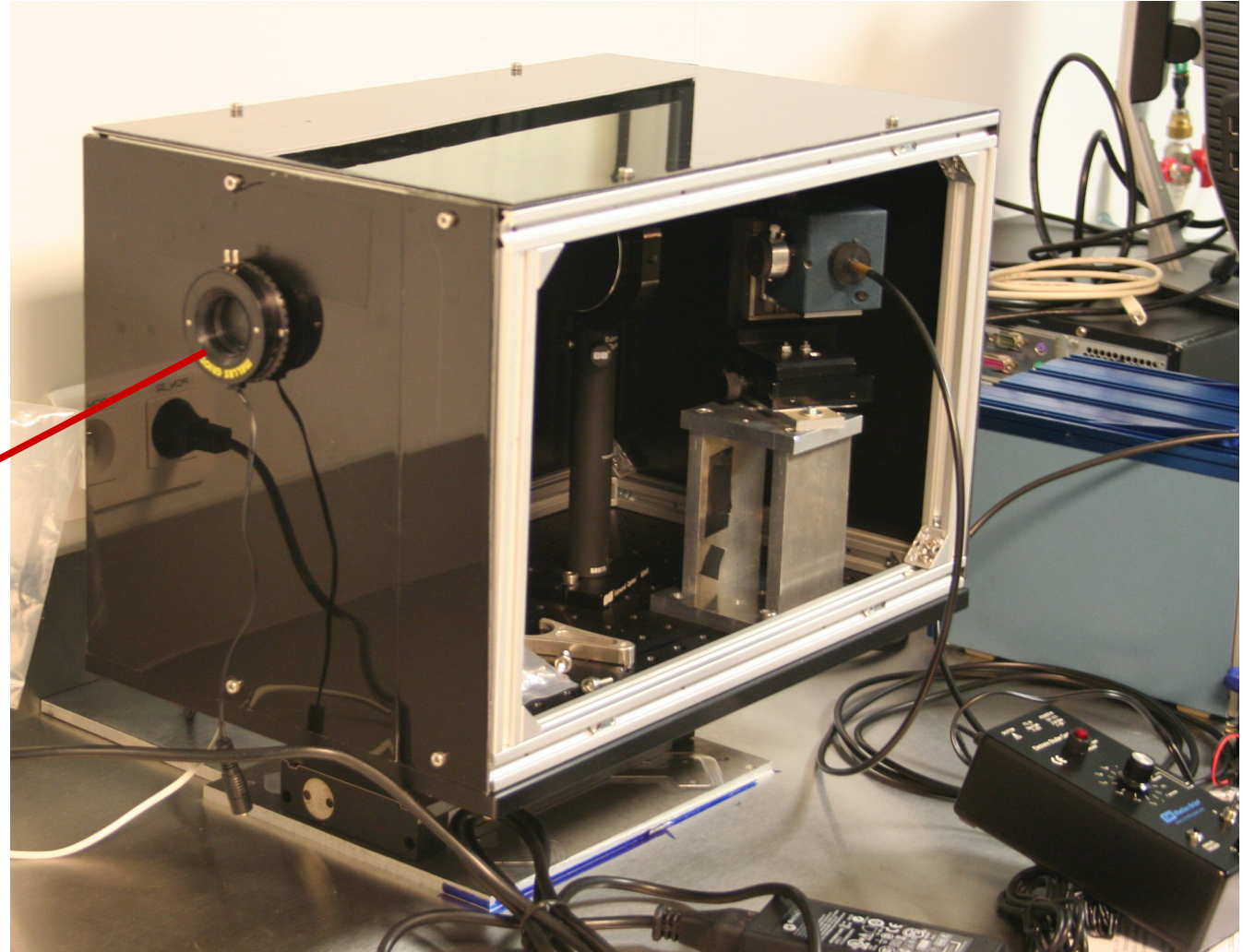


<http://supernovae.in2p3.fr/~llg/LSST/AuxTel-holograms/hole-020mu-focus-trip.gif>

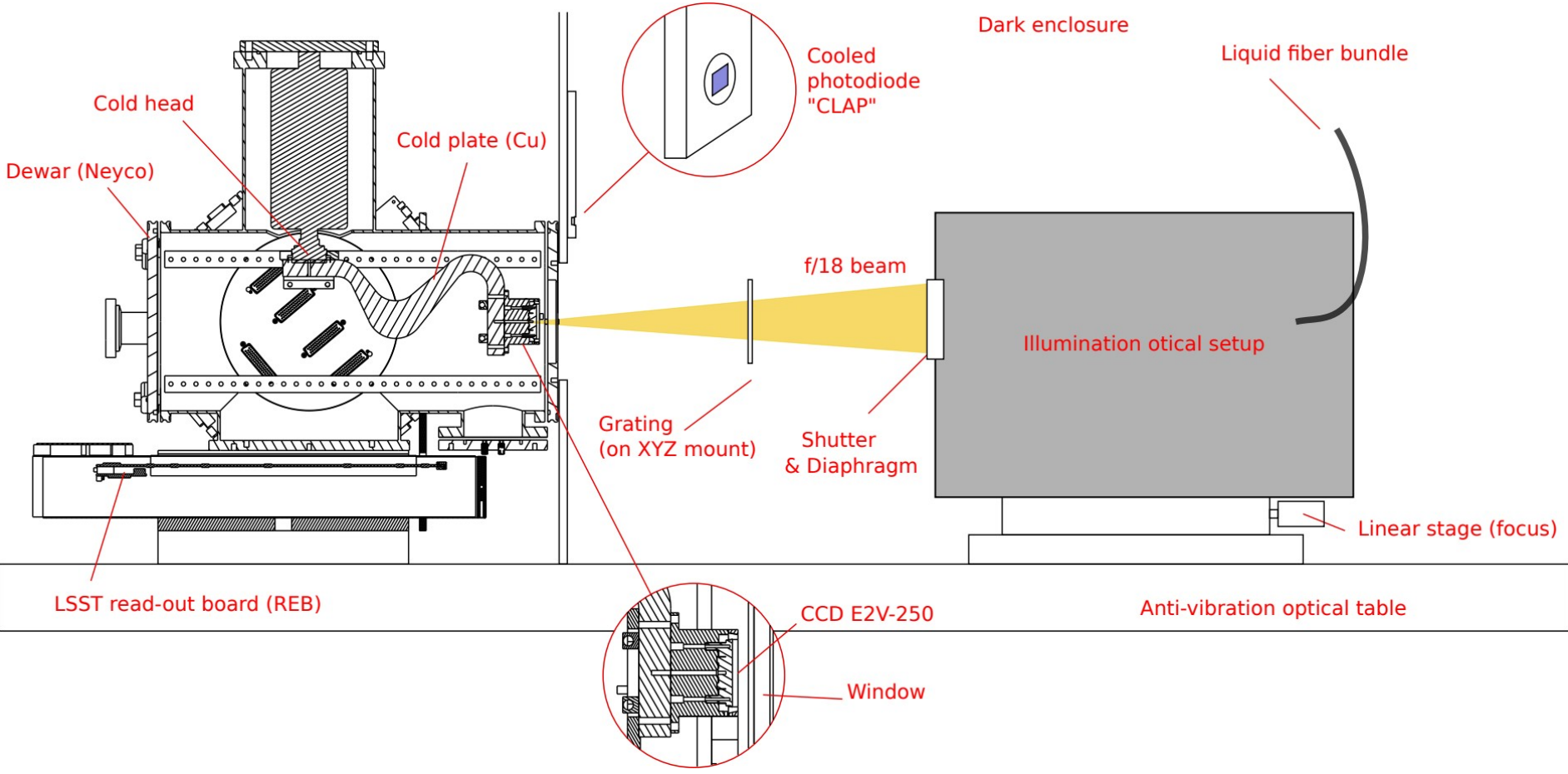
Baffling & shutter

- **Shutter** : triggered by the **LSST REB** (« SHU » line)
- Beam : f/15 to f/...
- (diaphragm)
AuxTel → f/18

**Shutter
& diaphragm**



Integration within the CCD testbench

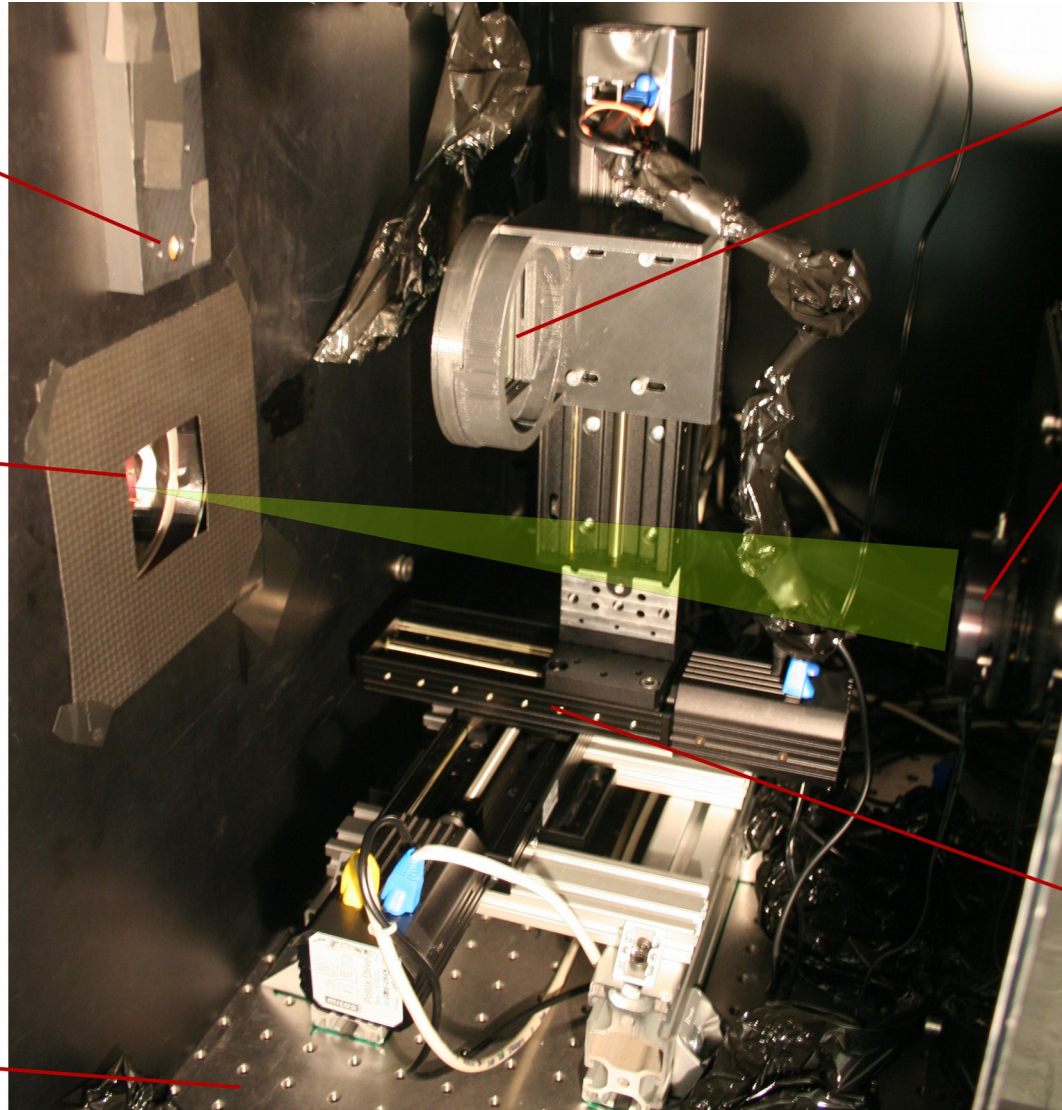


Integration within the CCD testbench

Cooled photodiode
(CLAP)

CCD E2V-250

Optical table



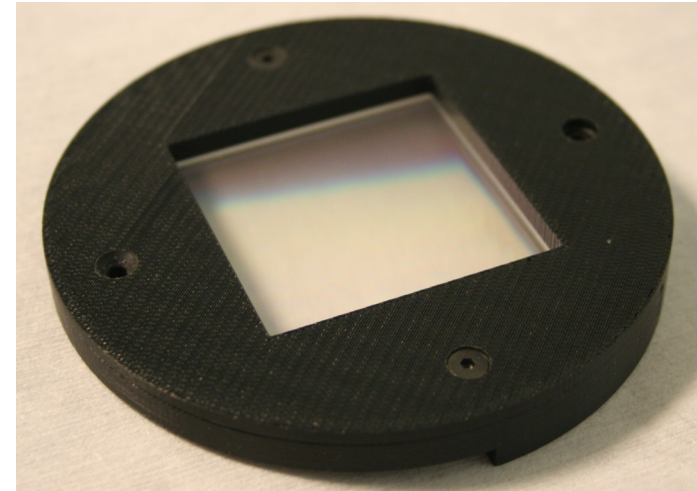
Grating and its ABS
3D printed support

Tunable convergent
beam (shutter)

XYZ motorized stage
(0.4 micron resol.)

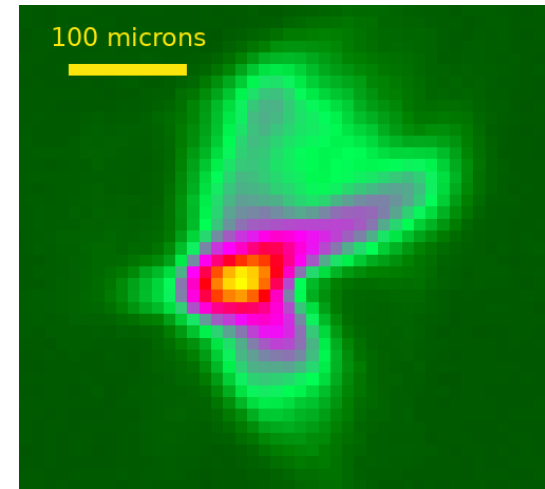
Integration within the CCD testbench

- 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**



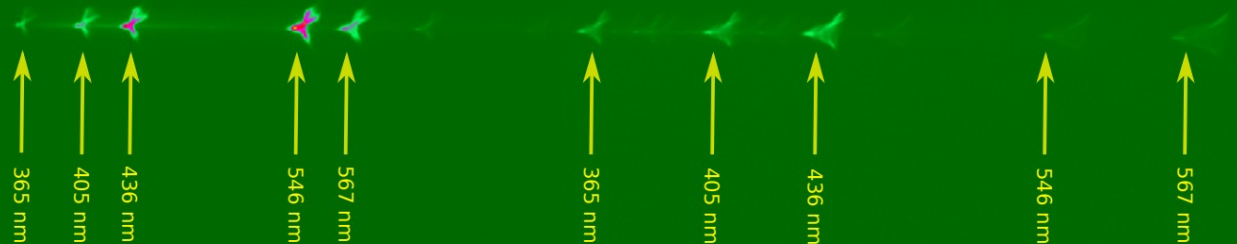
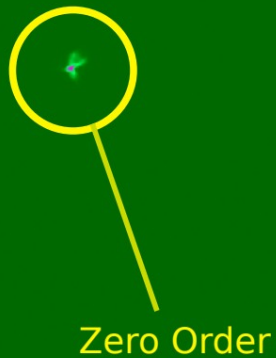
Valid. with Thorlabs GT50-03 grating

- 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



Source: HgAr
(Oriel 6035)

Grating: Thorlabs GT03-50 (300 l/mm)



Hg lines
(order 1)

Hg lines
(order 2)

Focus : GT50-03 vs. hologr. HoloPhAg

Source: HgAr
(Oriel 6035)

Grating: Thorlabs GT50-03 (300 l/mm)



Exactly the same optical setup, and the same physical position for both gratings

3E+04

4E+04

5E+04

6E+04

7E+04

8E+04

Source: HgAr
(Oriel 6035)

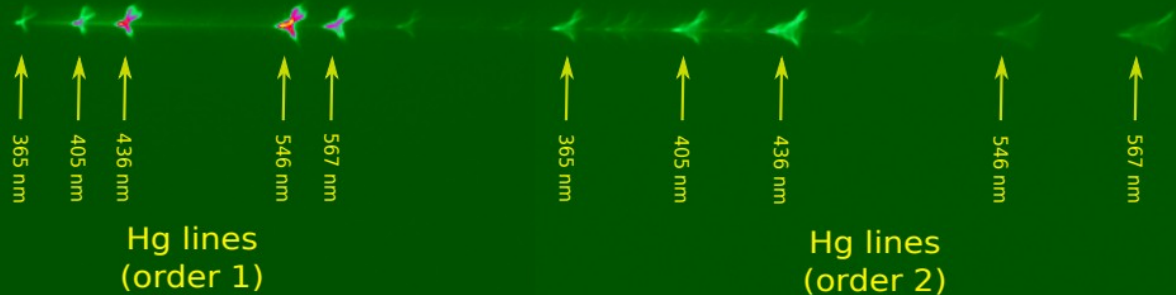
Grating: proto HoloPhAg



GT50-03 vs. hologram HoloPhAg

Source: HgAr
(Oriental 6035)

Grating: Thorlabs GT50-03 (300 l/mm)



3E+04

4E+04

5E+04

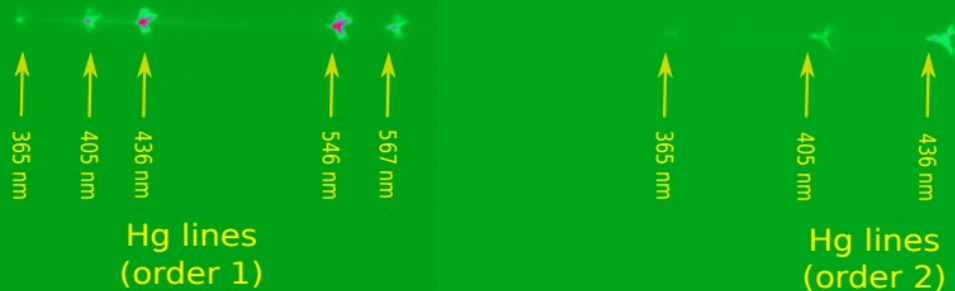
6E+04

7E+04

8E+04

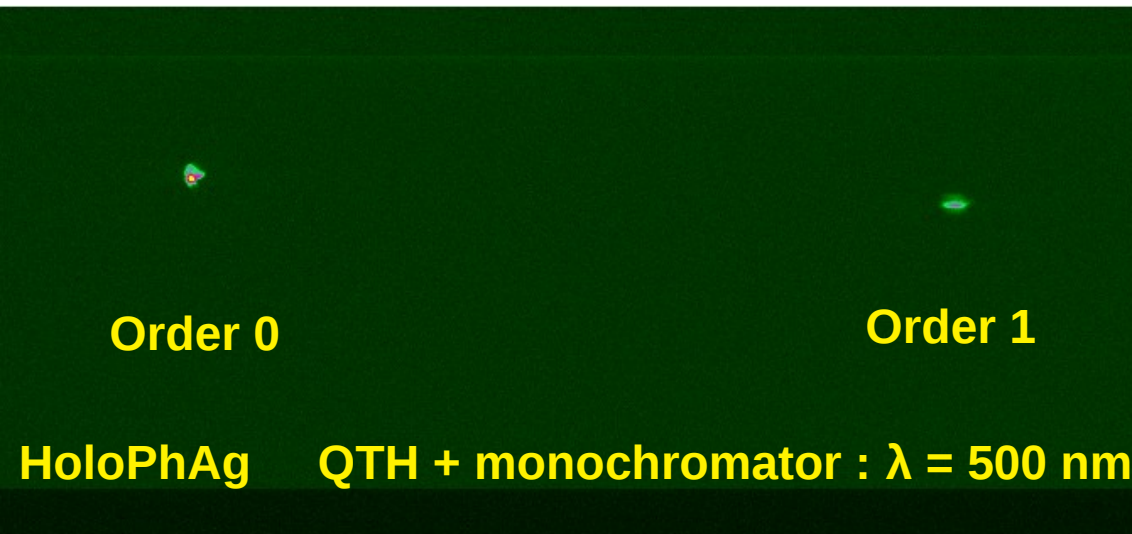
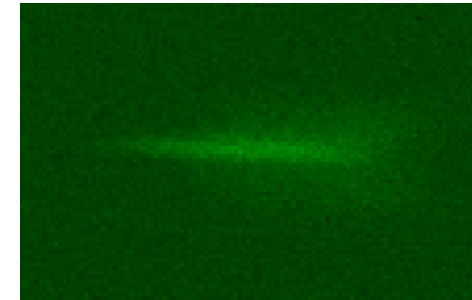
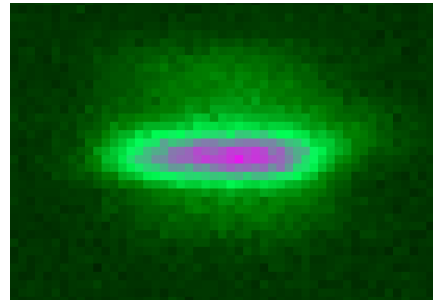
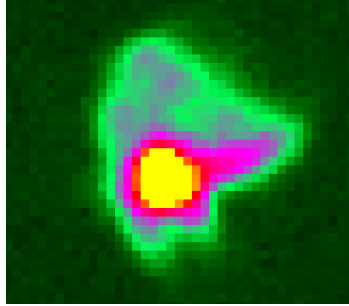
Source: HgAr
(Oriental 6035)

Grating: proto 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



Order 0

Order 1

Order 2

HoloPhAg QTH + monochromator : $\lambda = 500 \text{ nm}$

2.8e+04

2.9e+04

3.1e+04

3.3e+04

3.7e+04

4.1e+04

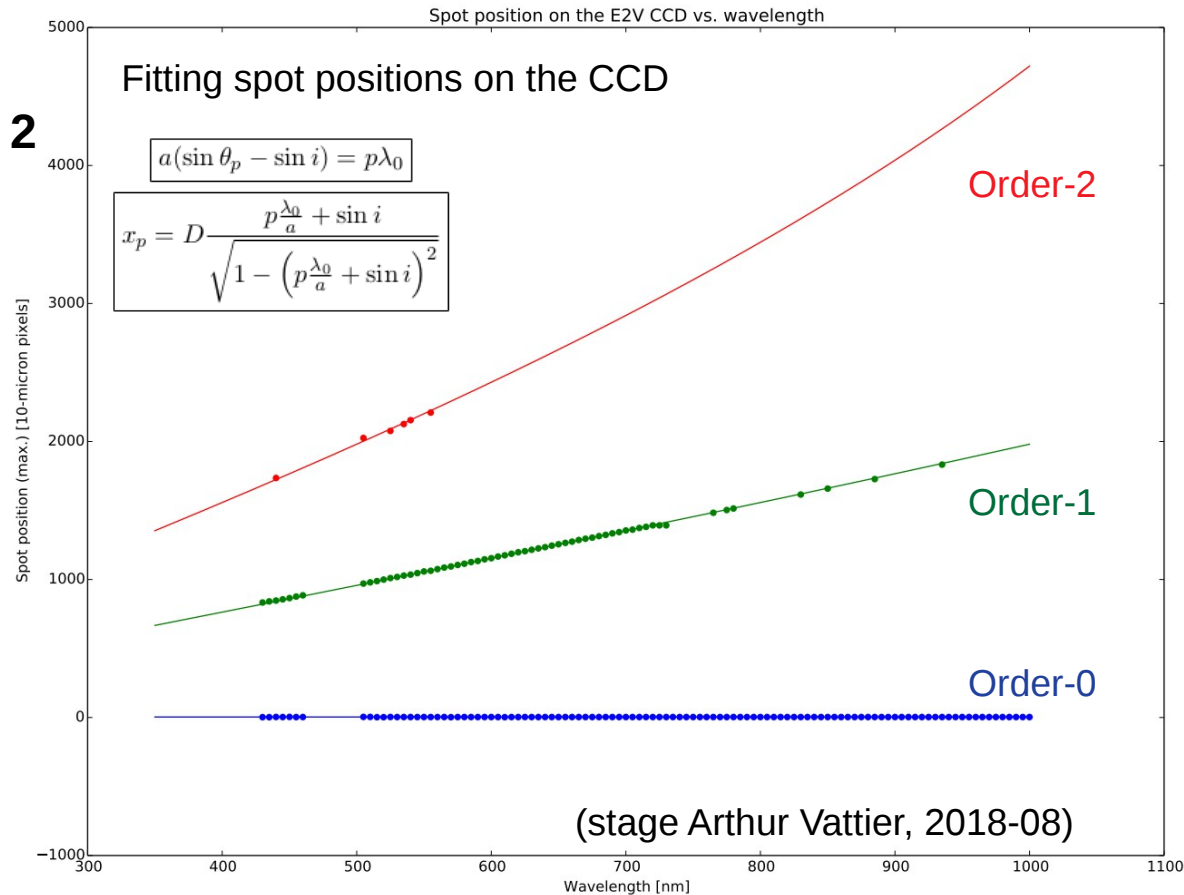
4.6e+04

5.2e+04

Gratings diffraction efficiency: analysis

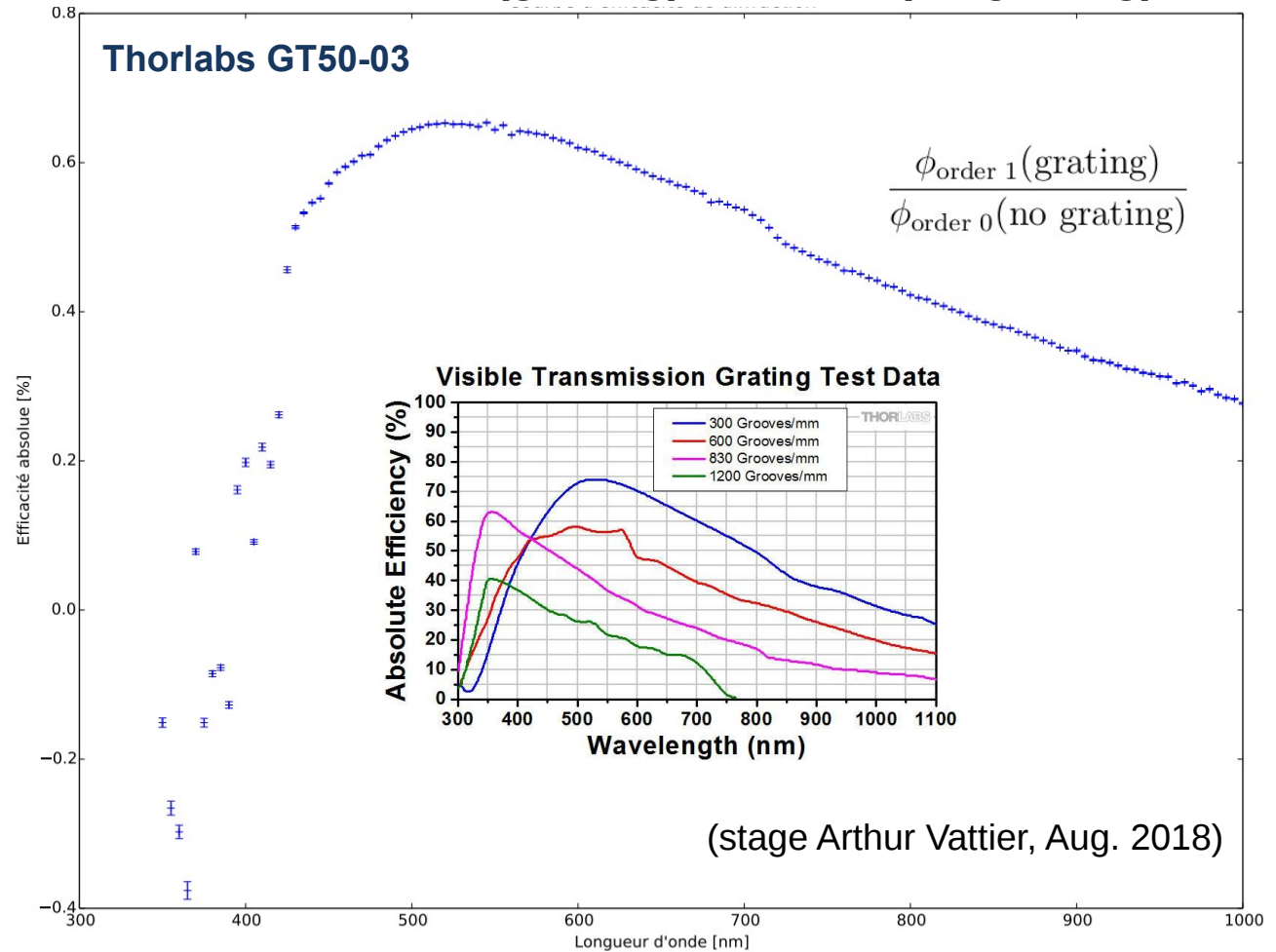
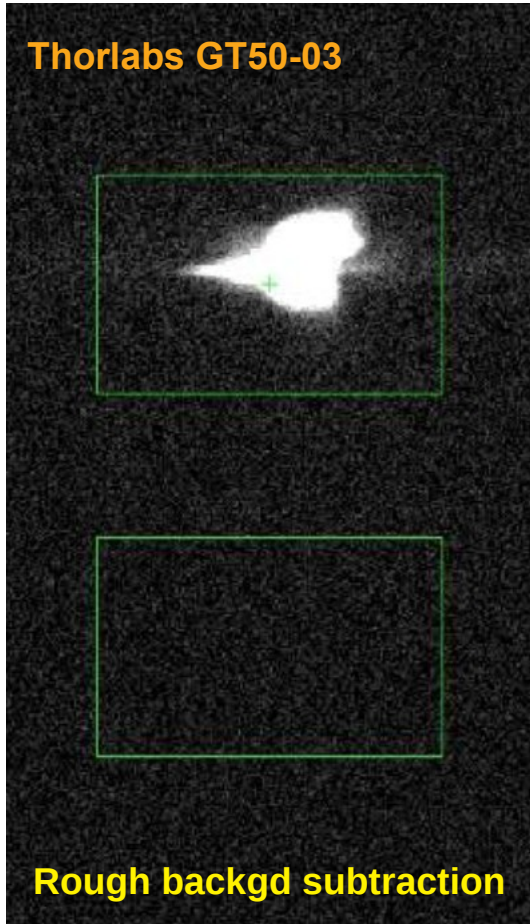
- **Scanning in wavelength** with QTH lamp and monochromator ;
- ON / OFF CCD frames
- **Aut. detection of orders 0, 1, 2**
- **Fitting** spot positions
- Estimating the **total flux** (box) for each order (subtr. backgd)
- Estimating the **ratio** :

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



Diffr. efficiency for Thorlabs GT50-03

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

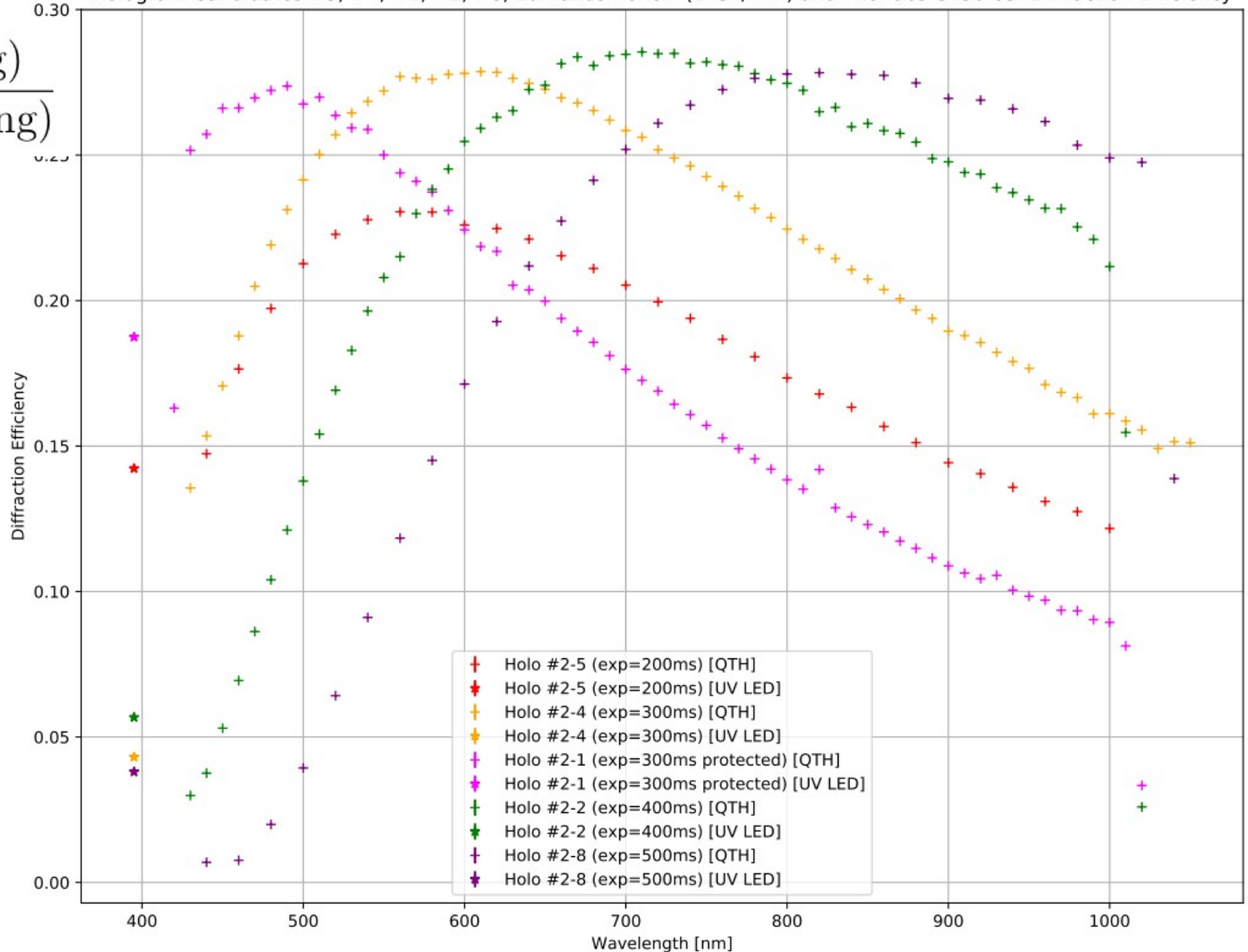


Tested gratings

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] Tested on sky At CTIO
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

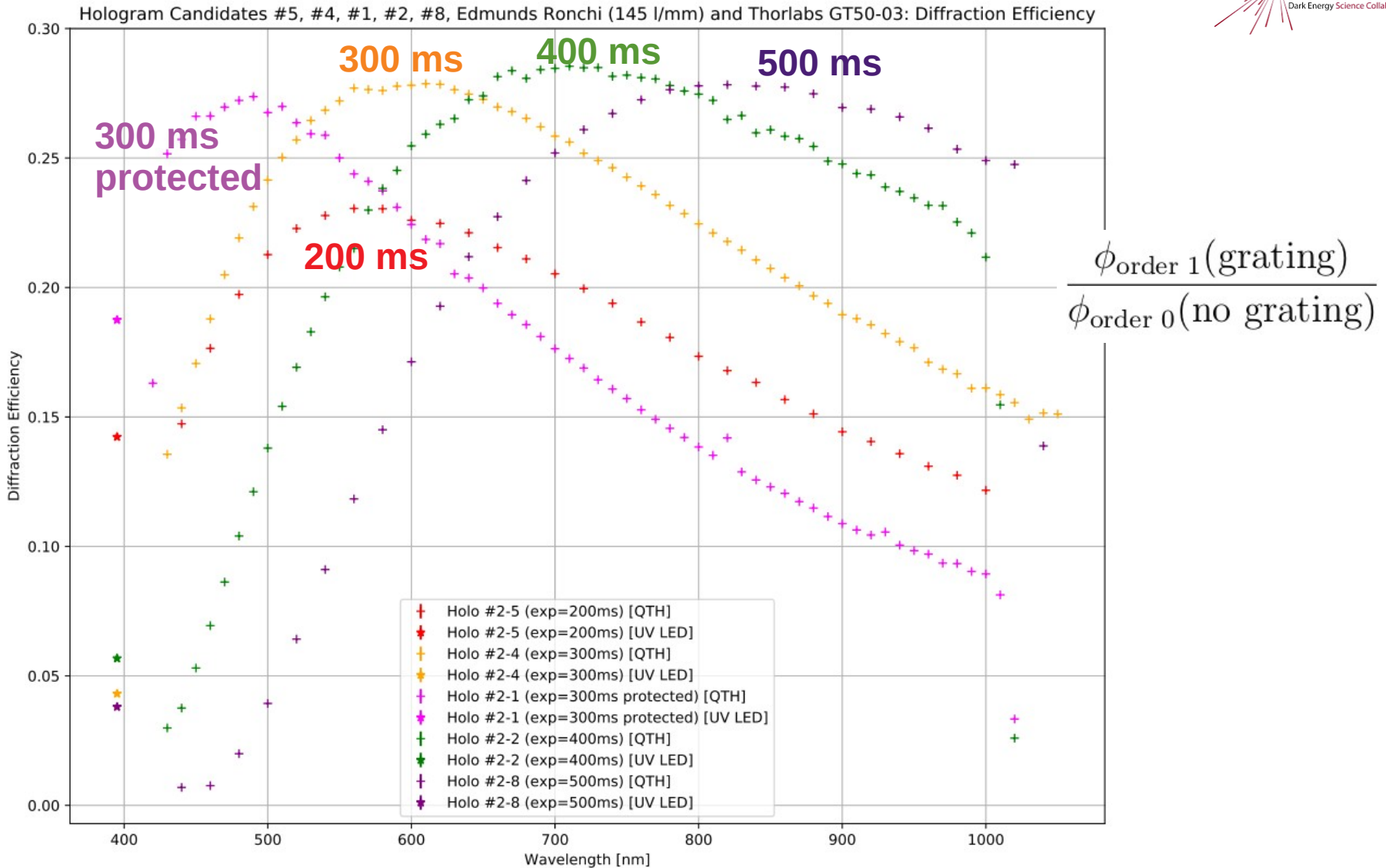
Diffraction efficiency: holograms

Hologram Candidates #5, #4, #1, #2, #8, Edmunds Ronchi (145 l/mm) and Thorlabs GT50-03: Diffraction Efficiency



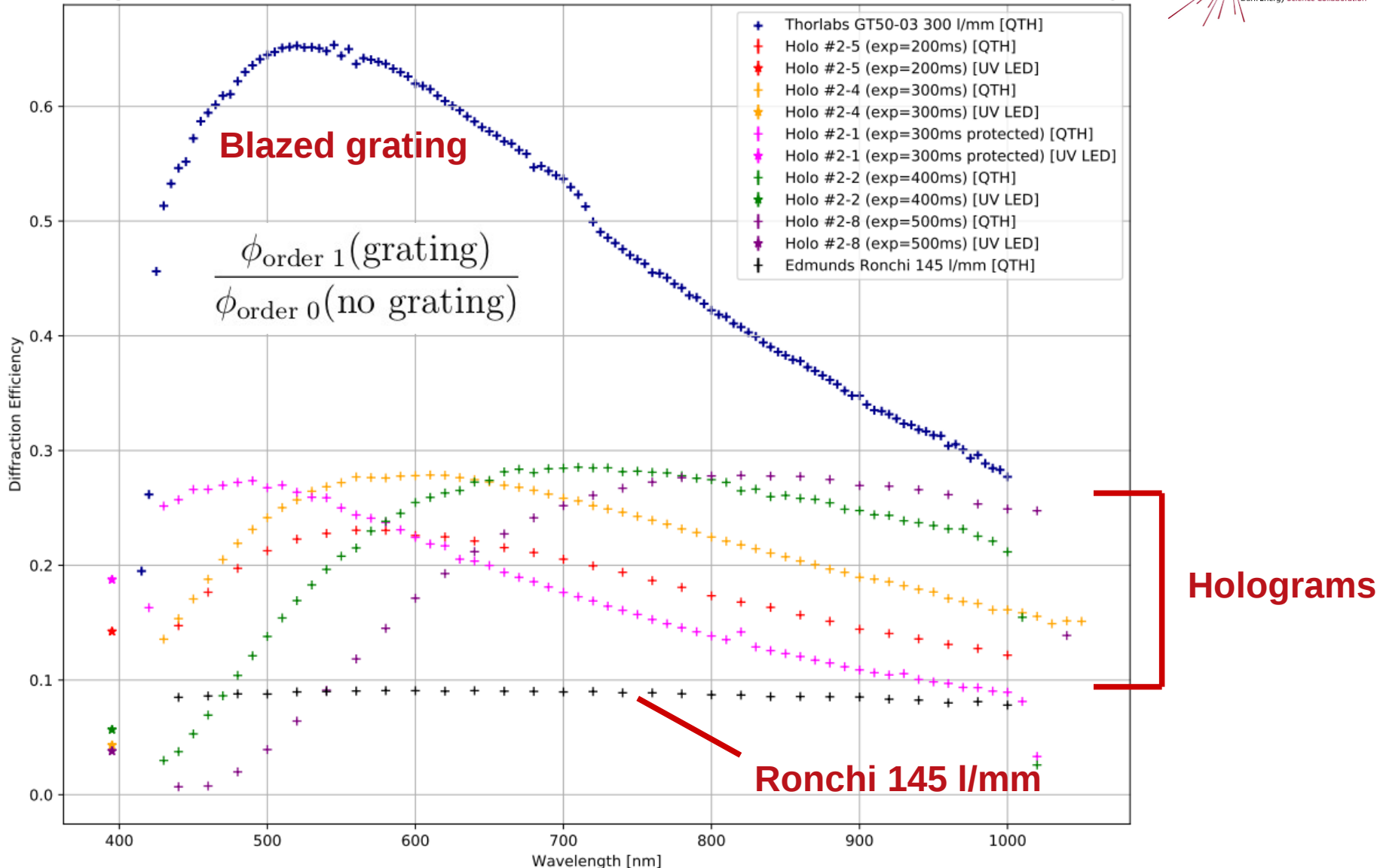
Extra UV data points with a 395 nm LED

Influence of hologram exposure time

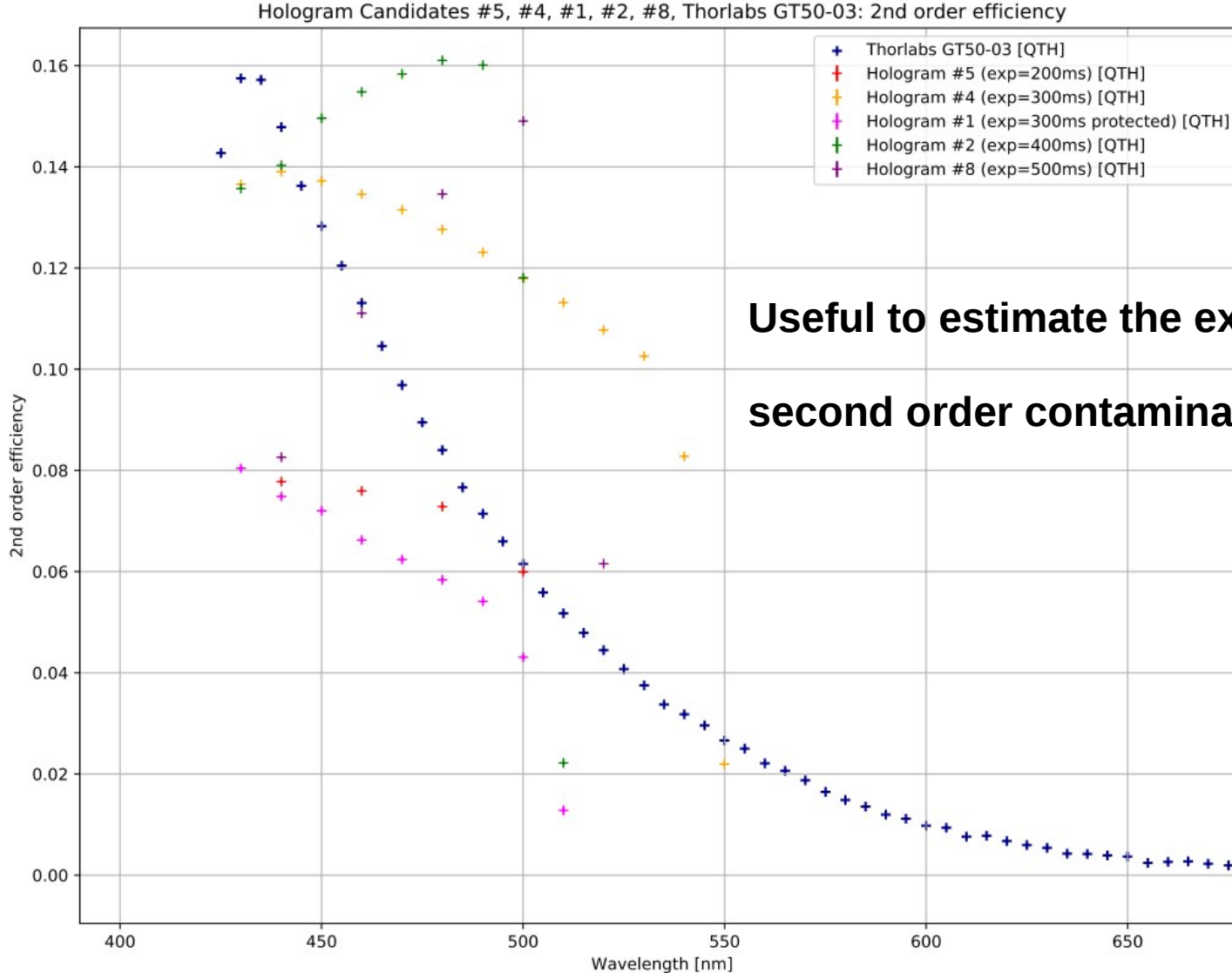


Diffraction efficiency: all gratings

Hologram Candidates #5, #4, #1, #2, #8, Edmunds Ronchi (145 l/mm) and Thorlabs GT50-03: Diffraction Efficiency

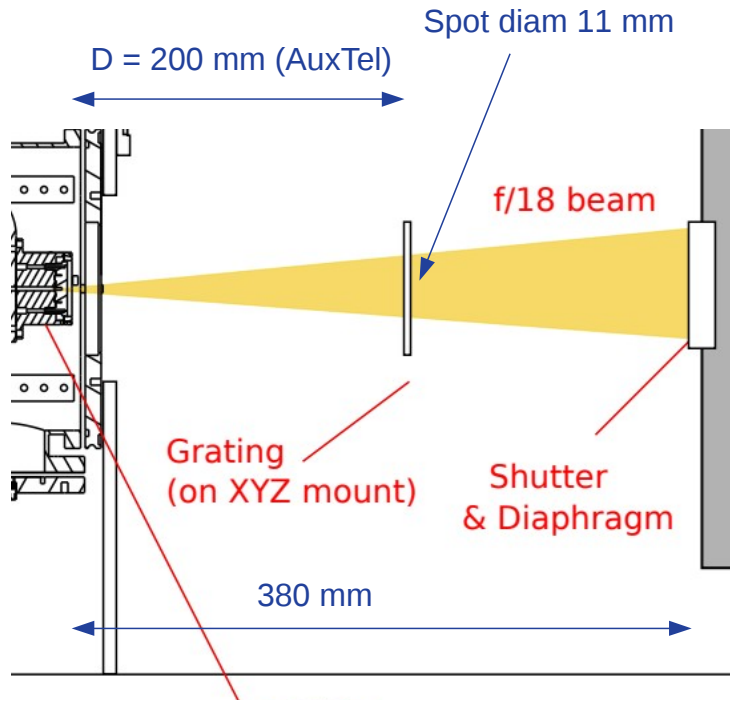


Order-2 “efficiency”

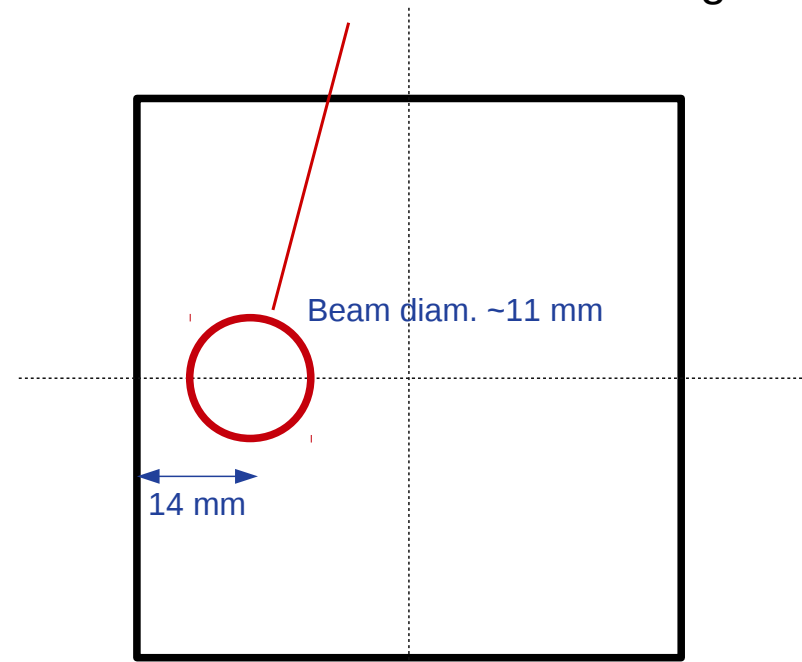


Useful to estimate the expected
second order contamination

Influence of the impact parameter



Where the beam should hit the hologram

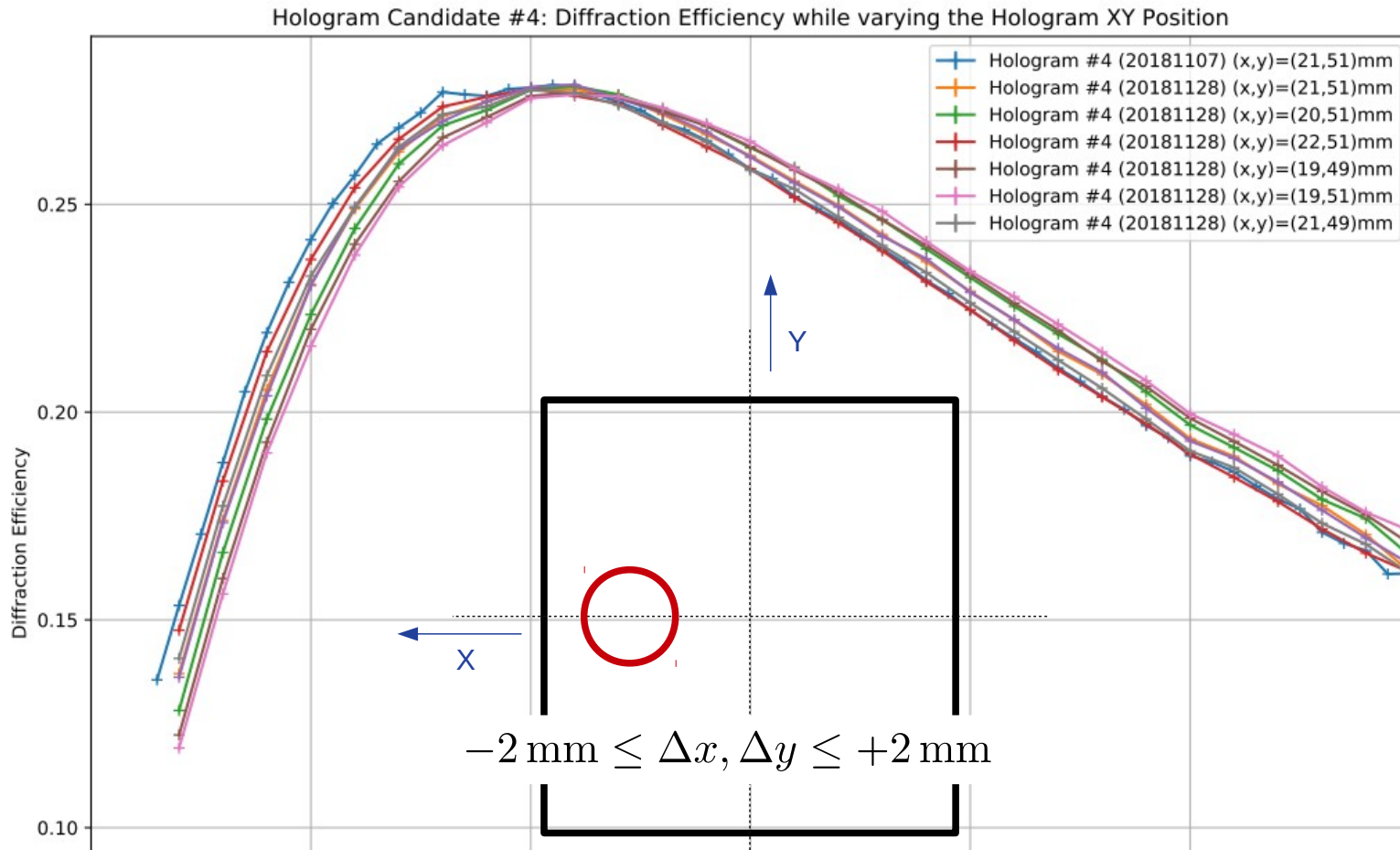


Holographic grating (approx 52 x 52 mm)

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

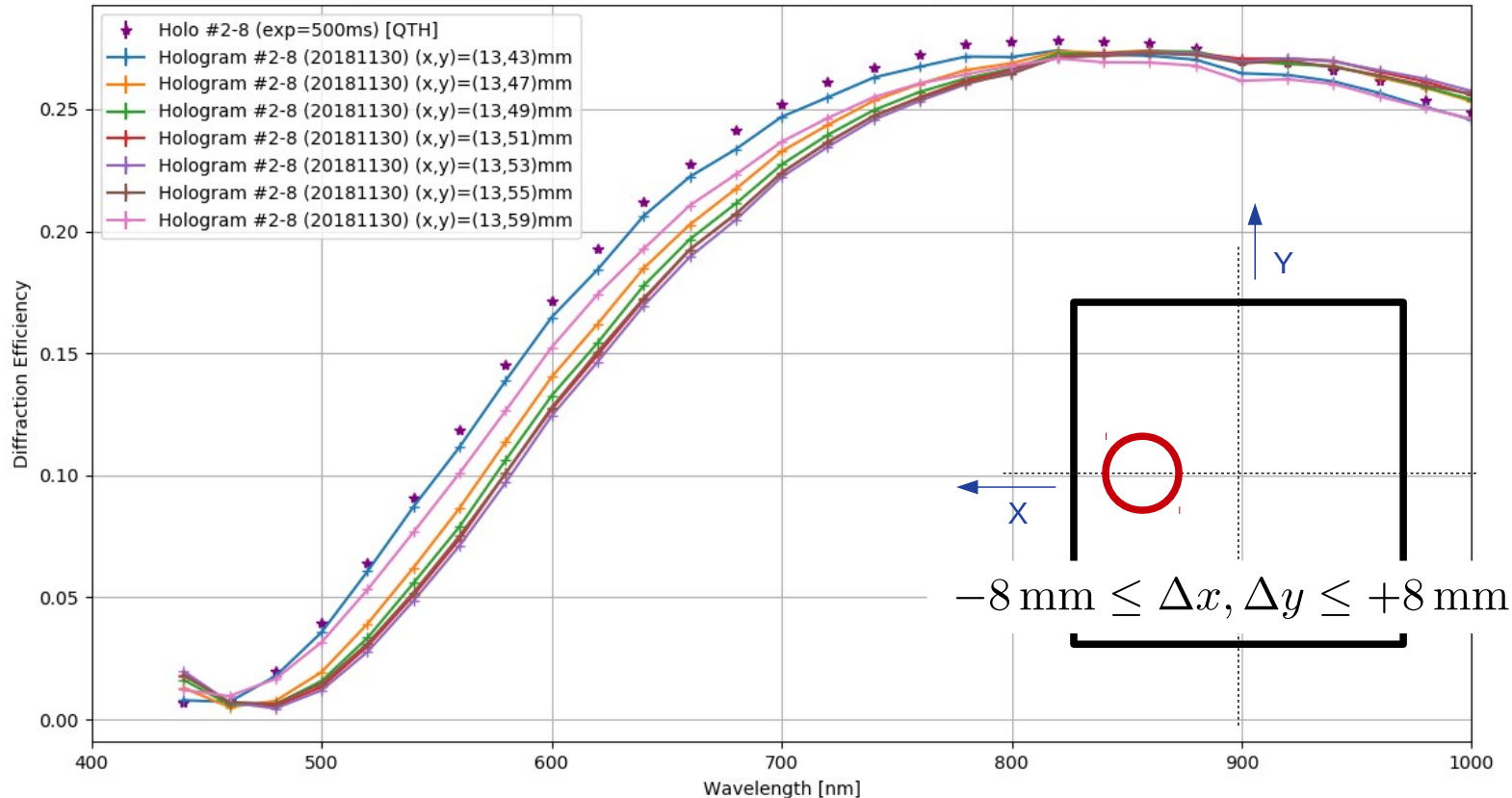


Holograms are **not translation invariant** in the transverse plane.

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

Influence of the impact parameter

Hologram Candidate #2-8: Diffraction Efficiency while varying the Hologram XY Position

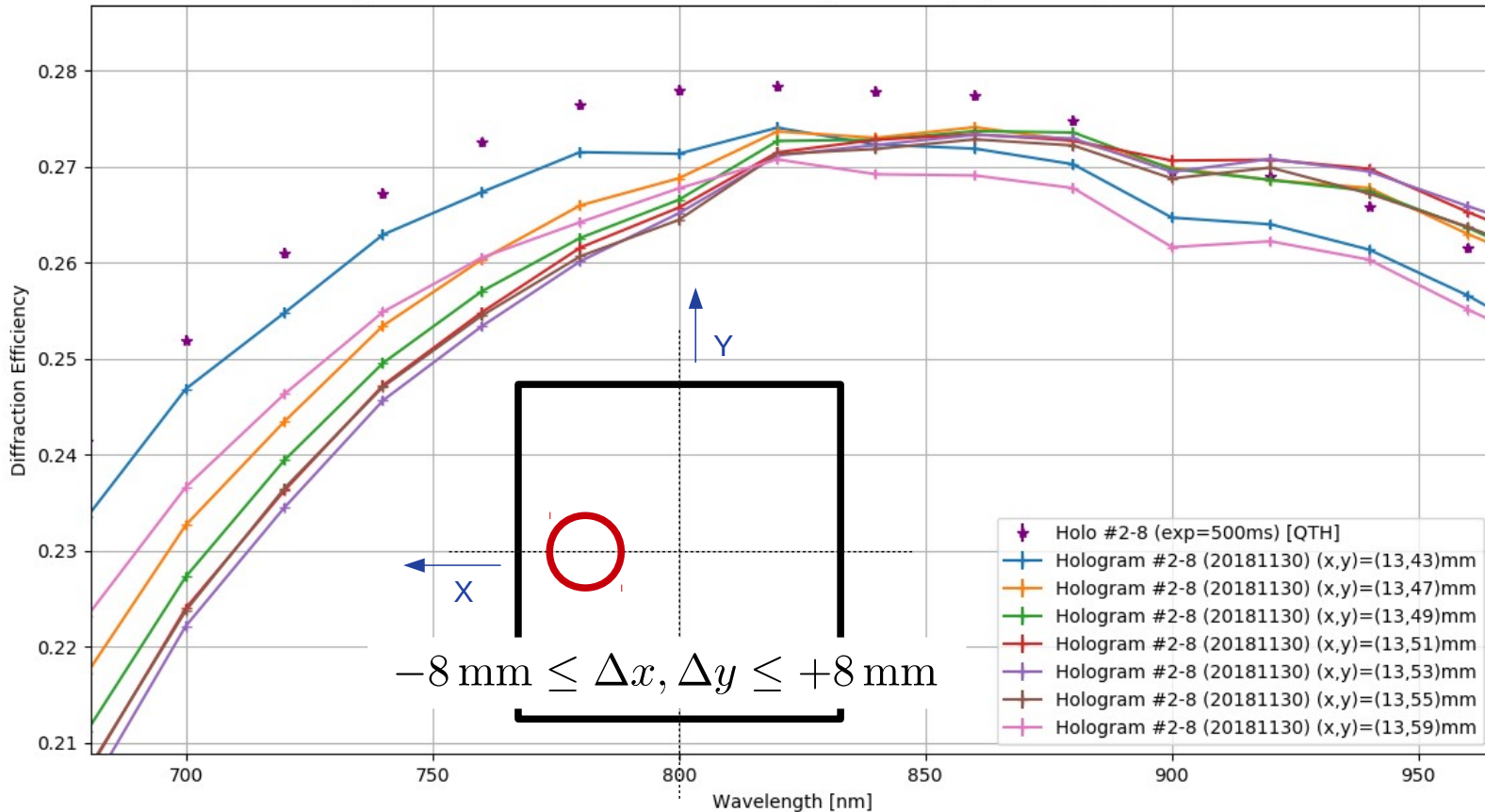


Holograms are **not translation invariant** in the transverse plane.

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

Influence of the impact parameter

Hologram Candidate #2-8: Diffraction Efficiency while varying the Hologram XY Position



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 ?

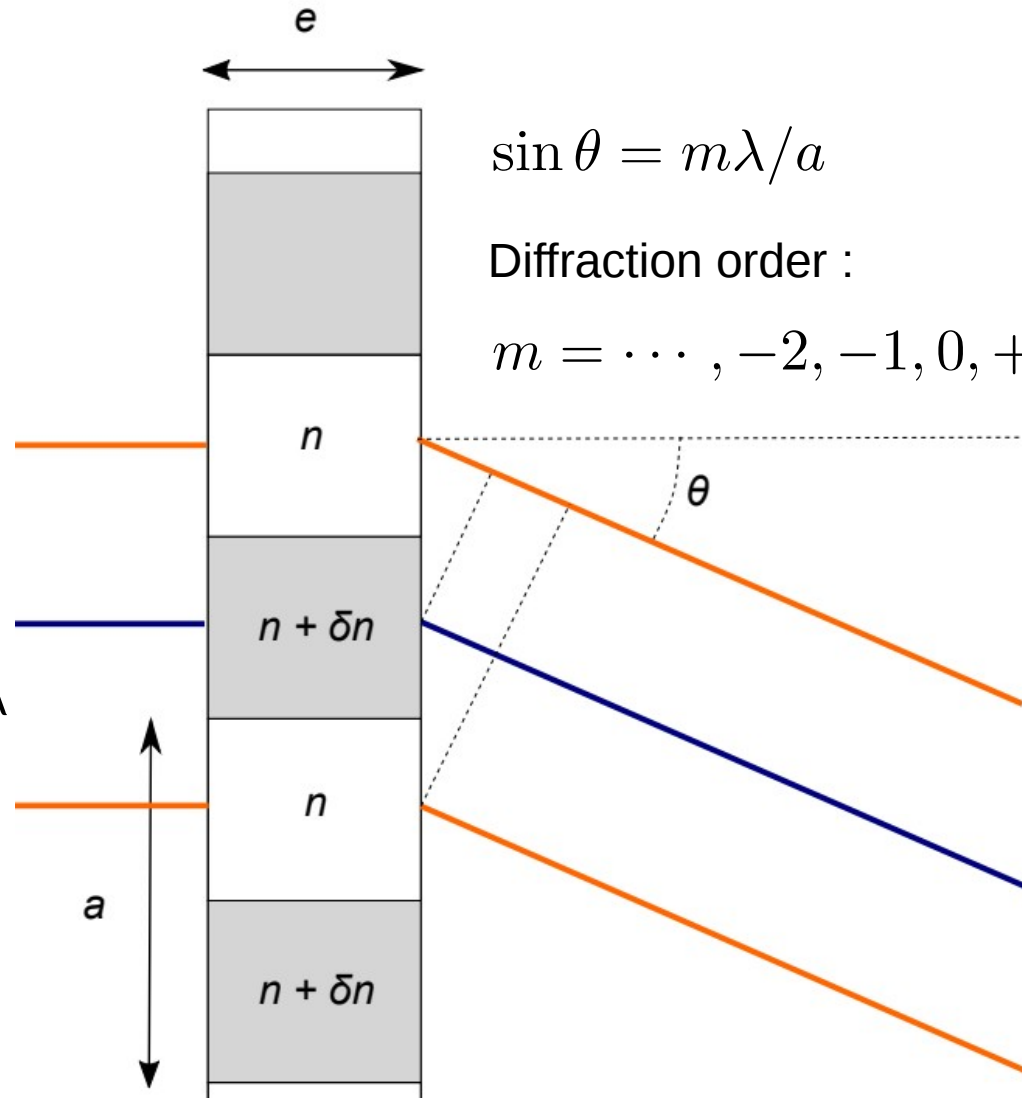
Tentative model of the phase hologram

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

(Rough model : Square wave)

Phase contrast :

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



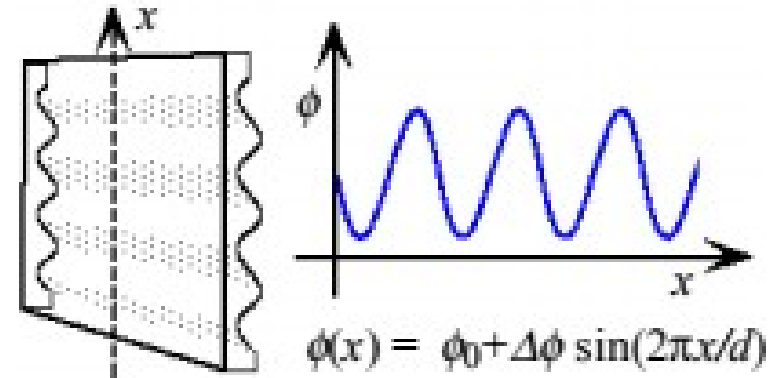
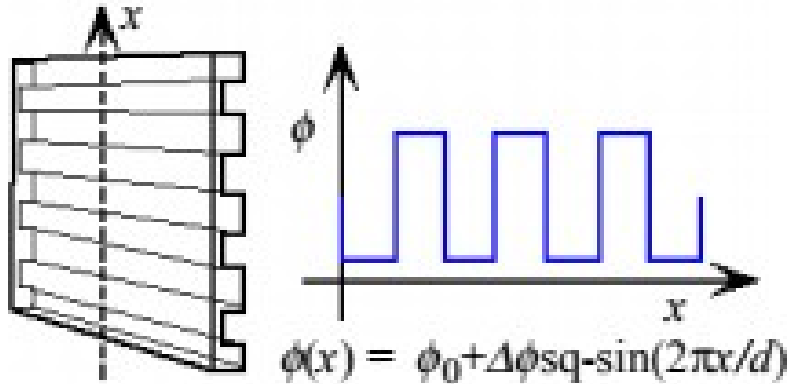
$$\sin \theta = m\lambda/a$$

Diffraction order :

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

Square or Sine Wave Phase Grating

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



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

$$DE_{m=\pm 1} = \left(\frac{2}{\pi} \sin \Delta\phi \right)^2 = 40.5\%_{\max}$$

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

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

$$\sum_{m \neq 0} DE_m = \sin^2 \Delta\phi = 100\%_{\max}$$

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

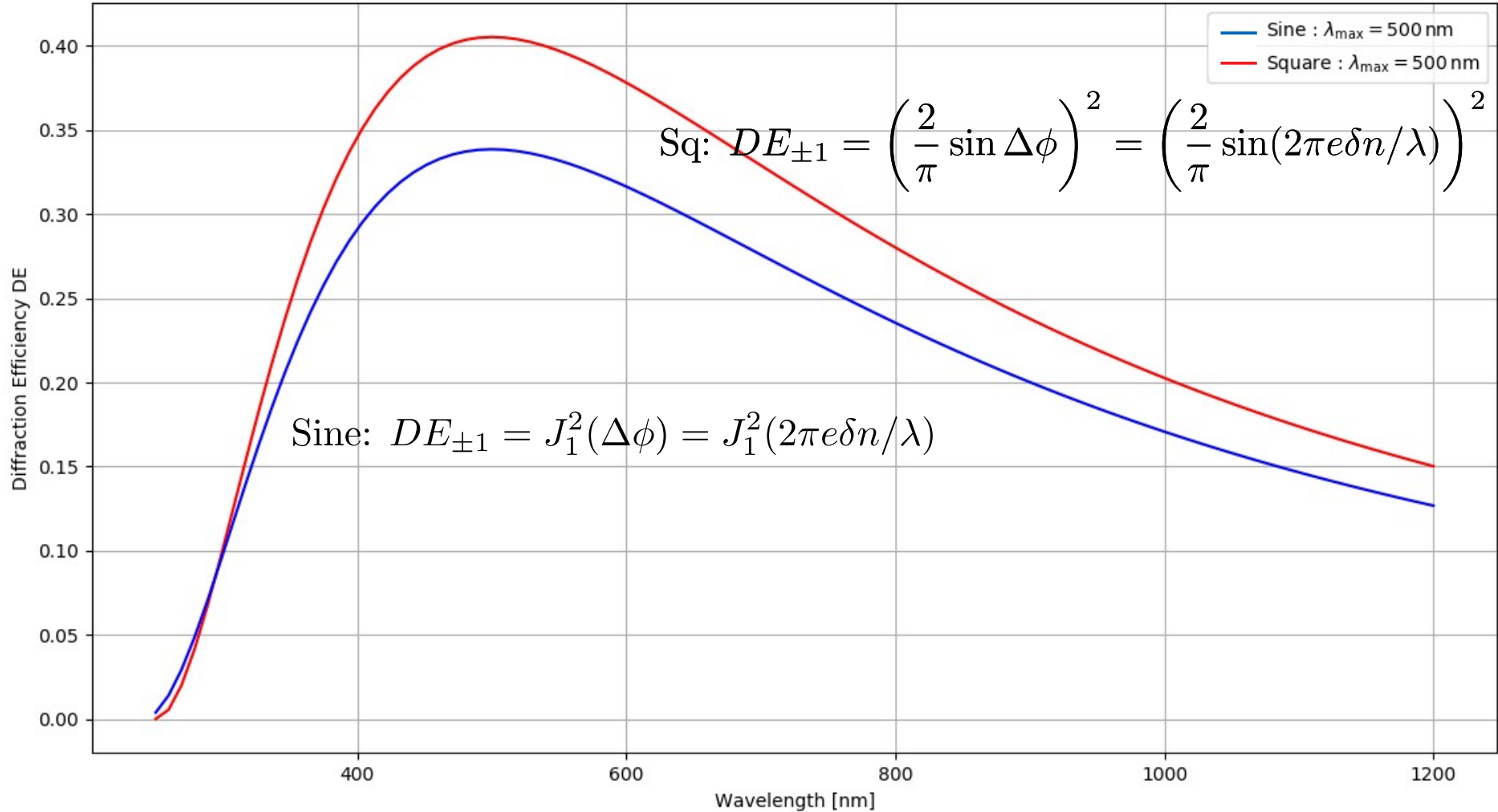
$$DE_{m=\pm 1} = J_1^2(\Delta\phi) = 33.8\%_{\max}$$

$$\sum_{m \neq 0} DE_m = 1 - J_0^2(\Delta\phi) = 100\%_{\max}$$

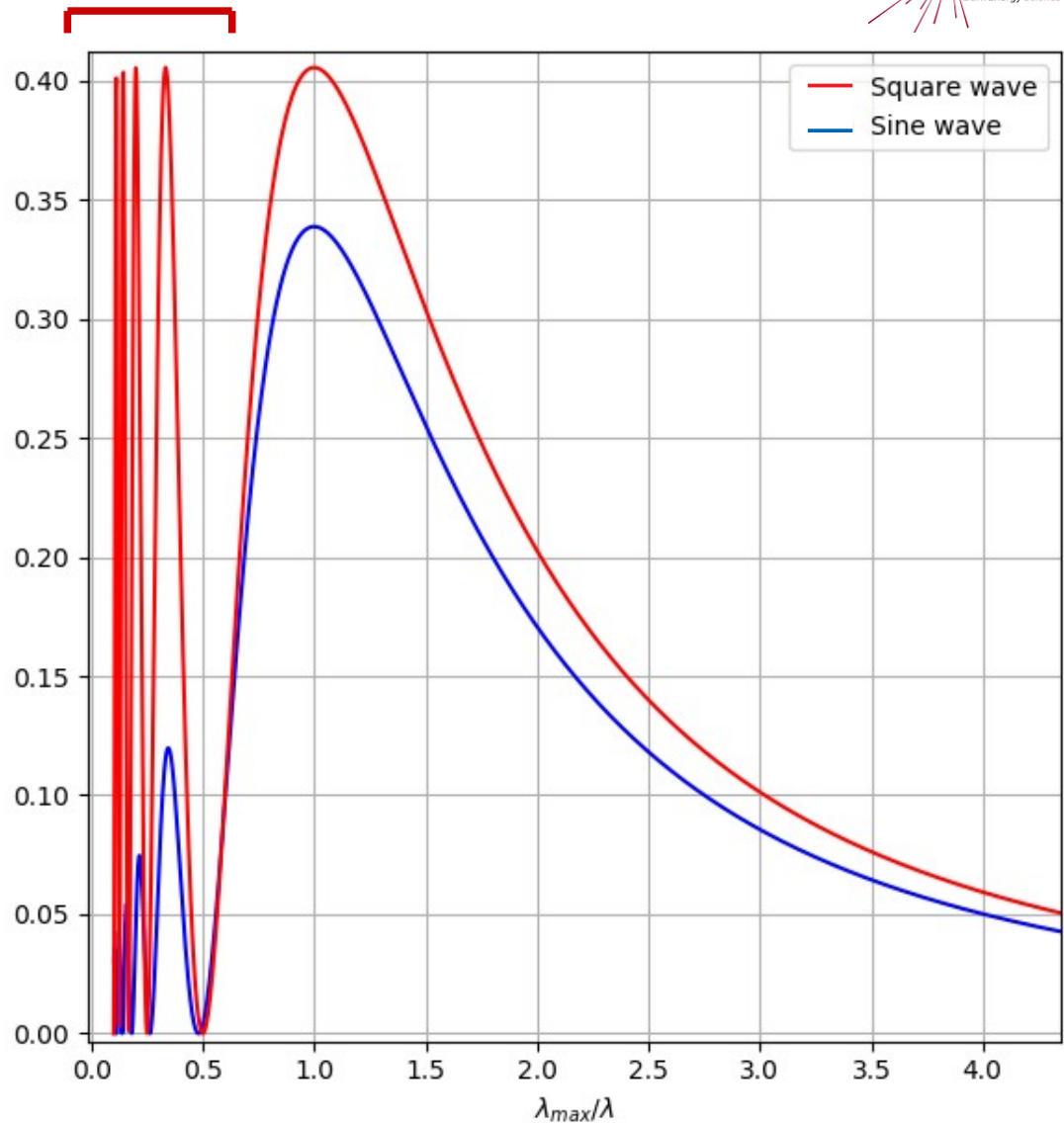
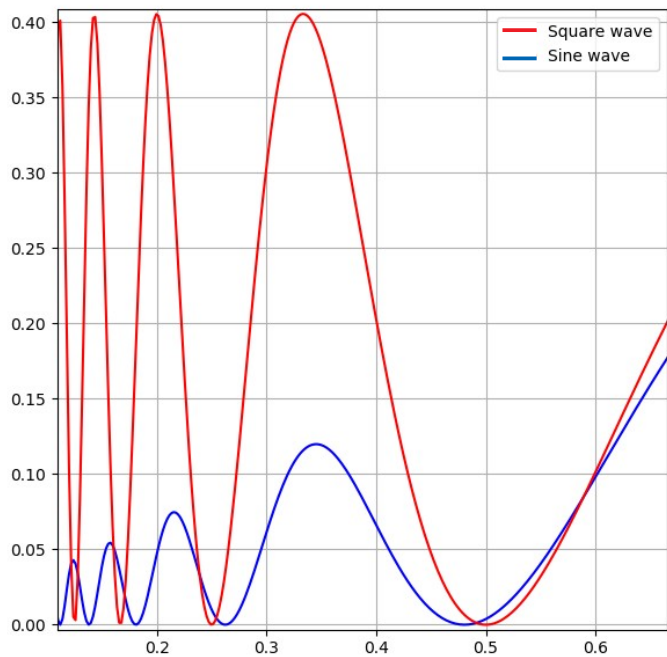
$$\lambda_{\max} \quad \text{when } \Delta\phi = 0.586\pi$$

Square or Sine wave Phase Grating

Square Wave & Sine Wave Phase Grating: Diffraction Efficiency (model)



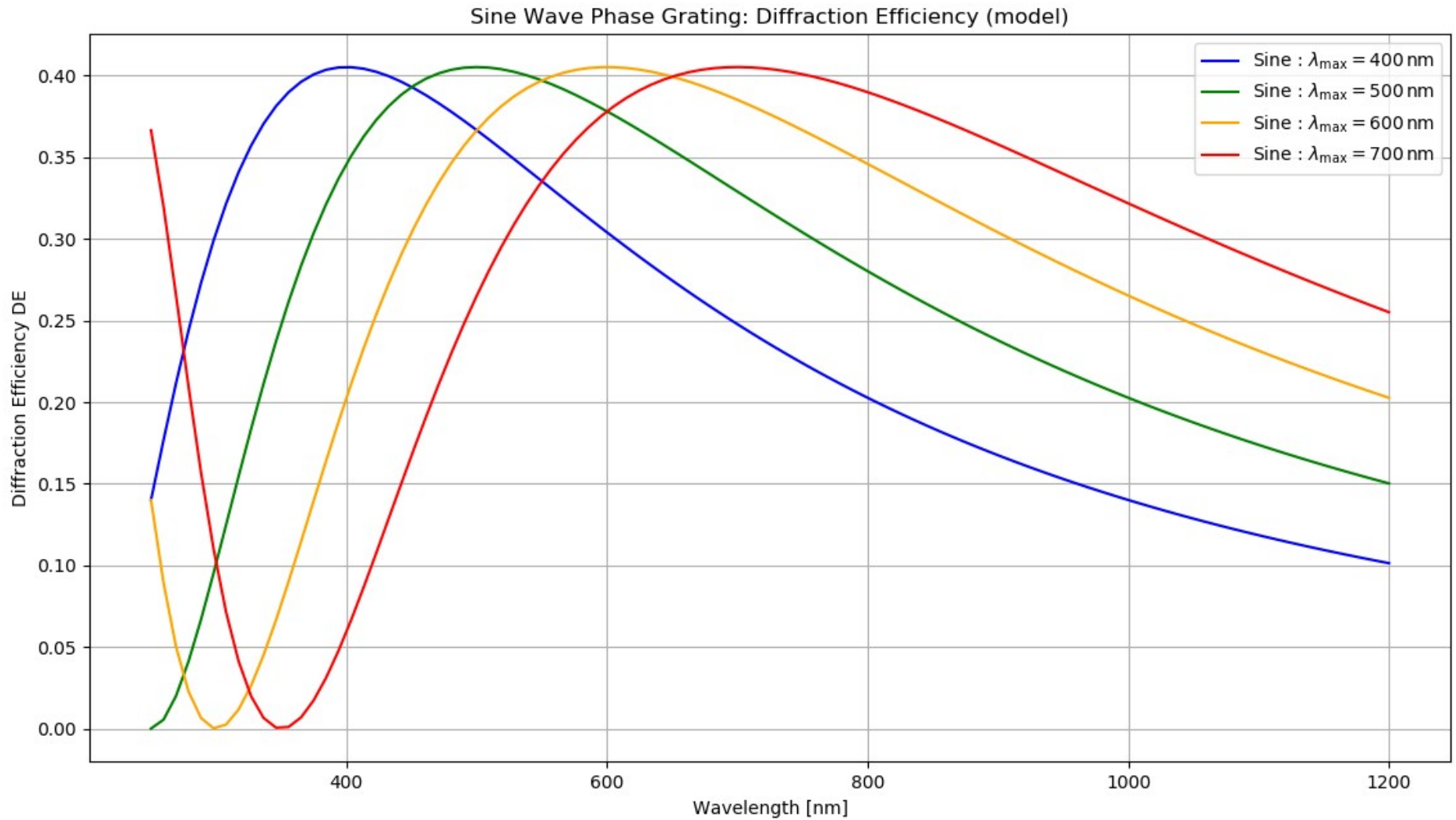
Square or Sine wave Phase Grating



DE for sine / square wave

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

Sine Wave Phase Grating with Lambda

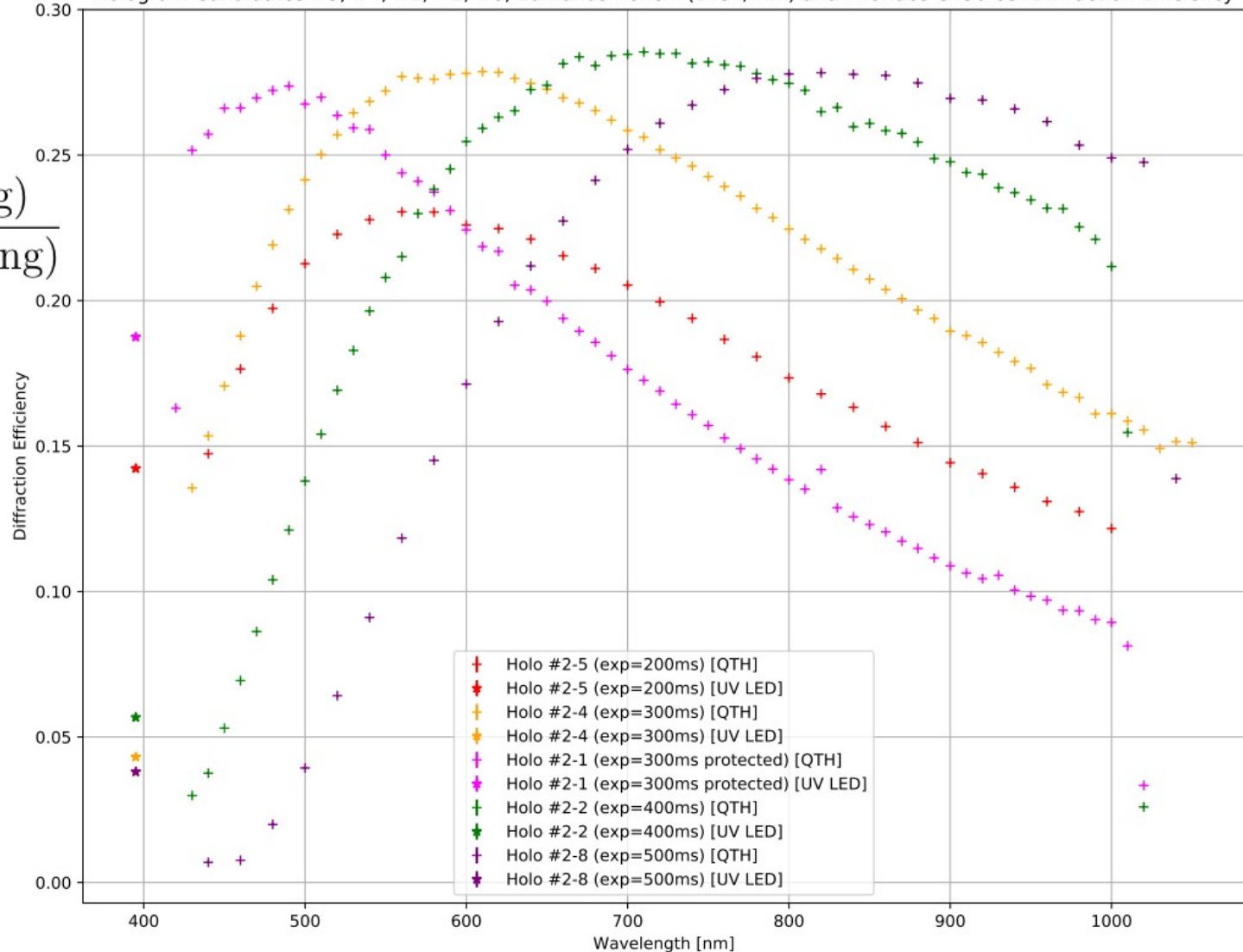


Diffraction efficiency: holograms

Hologram Candidates #5, #4, #1, #2, #8, Edmunds Ronchi (145 l/mm) and Thorlabs GT50-03: Diffraction Efficiency

$$DE =$$

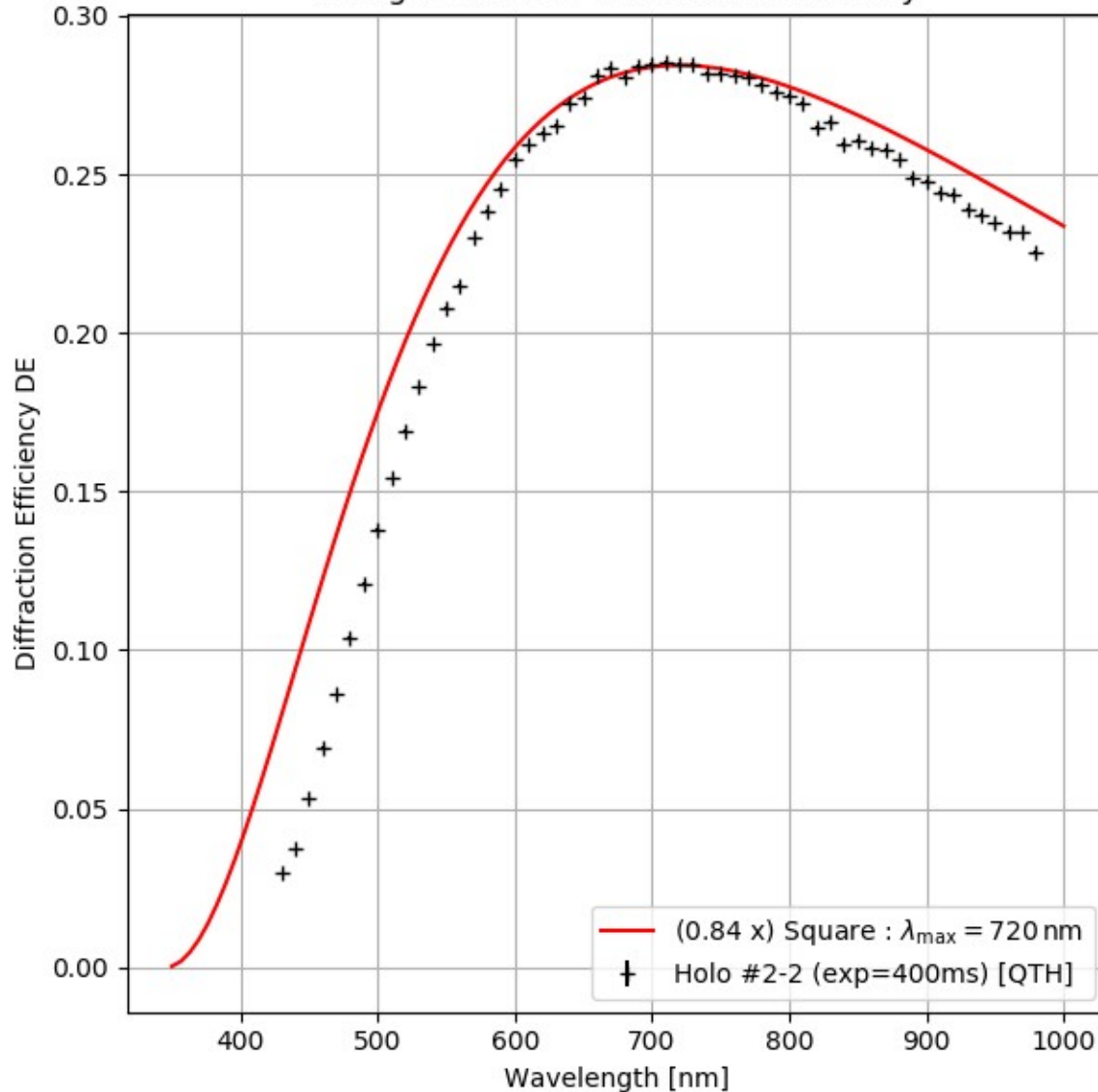
$$\frac{\phi_{\text{order 1}}(\text{grating})}{\phi_{\text{order 0}}(\text{no grating})}$$



Extra UV data points with a 395 nm LED

Comparison with hologram data

Hologram #2-2 : Diffraction Efficiency



**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)