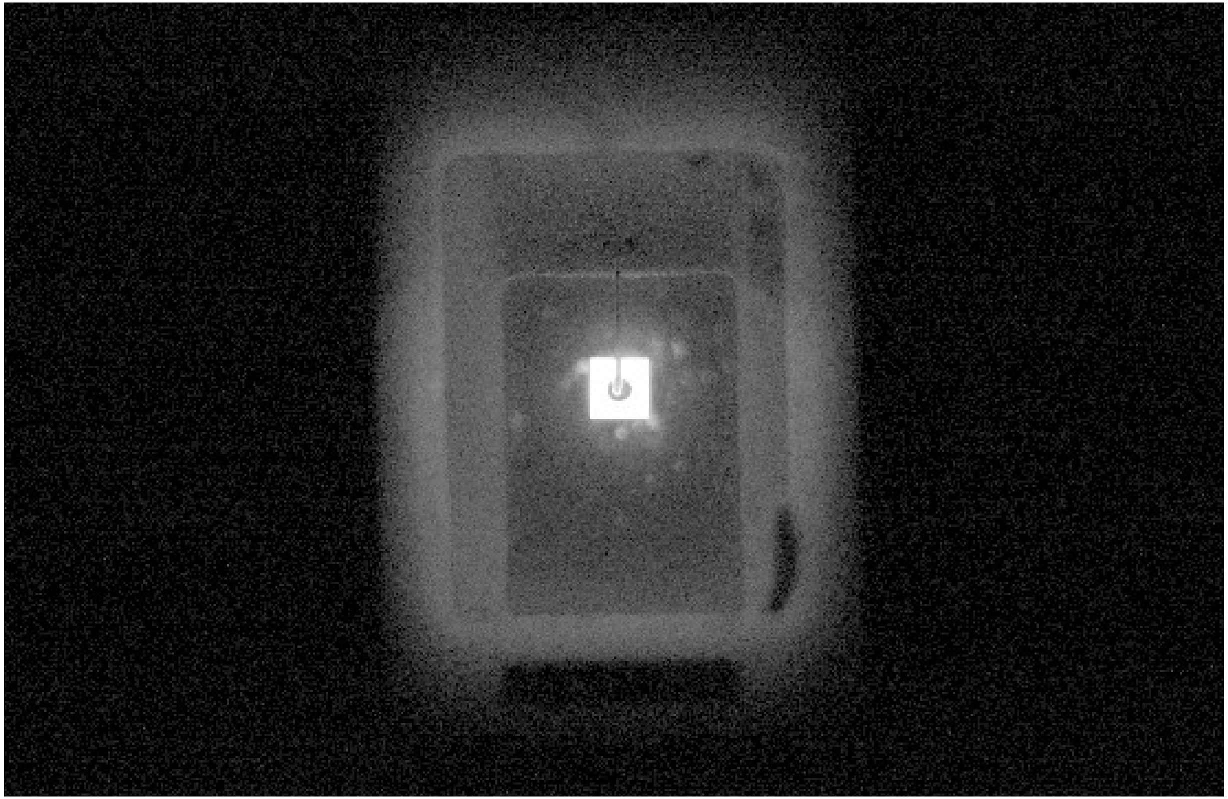
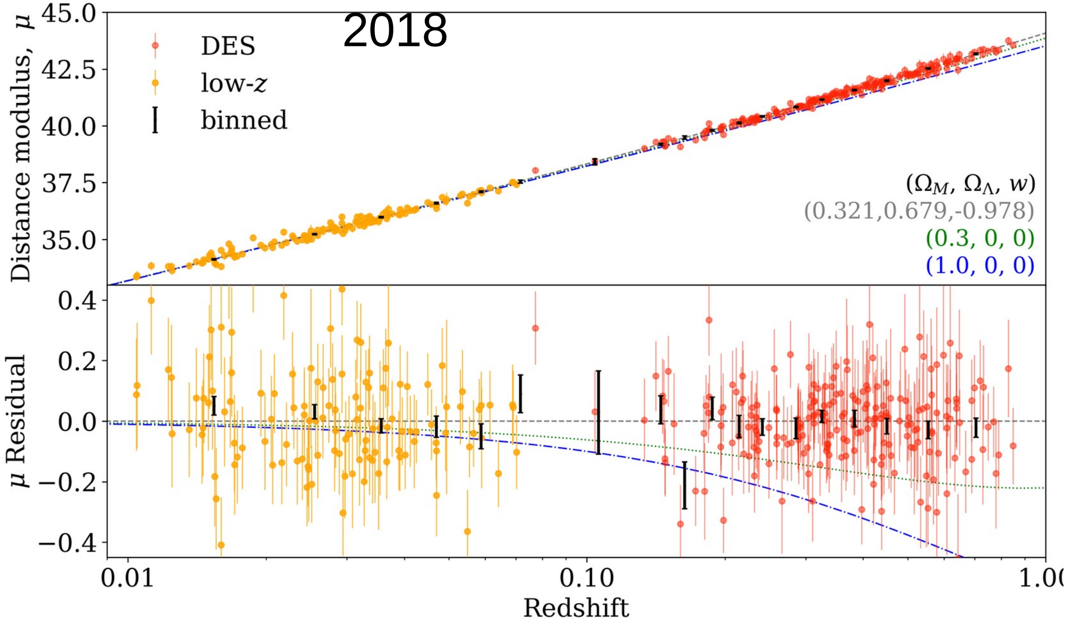
StarDICE upgrade: Status report

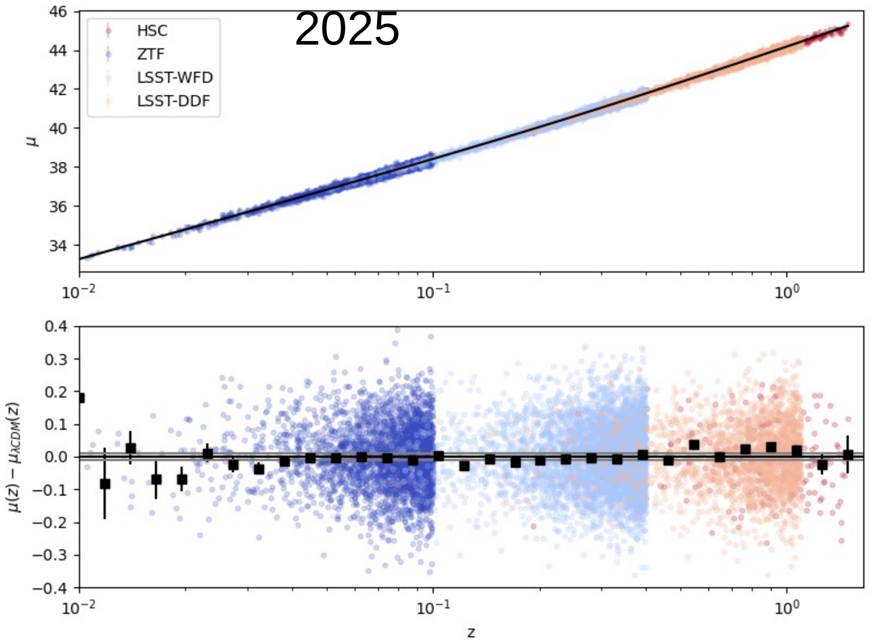
Marc Betoule (LPNHE)
LSST-France
Video-conference mai 2021



CPPM : O. Angelini, S. Beurthey, S. Deguero, F. Feinstein
LPNHE : P. Antilogus, Ph. Bailly, E. Barrelet, M. Betoule, S. Bongard, J. Coridian, M. Dellhot, P. Ghislain, A. Guyonnet, F. Hazenberg, C. Juramy, H. Lebbolo, L. Le Guillou, E. Pierre, J. Neveu, N. Regnault, Ph. Repain, M. Roynel, K. Schahmaneche, E. Sepulveda, A. Vallereau
LUPM : J. Cohen-Tanugi, Eric Nuss, B. Plez
IJCLab : S. Dagoret-Campagne, M. Moniez, O. Perdereau
OHP : Pierre-Eric Blanc, Auguste Le Van Suu

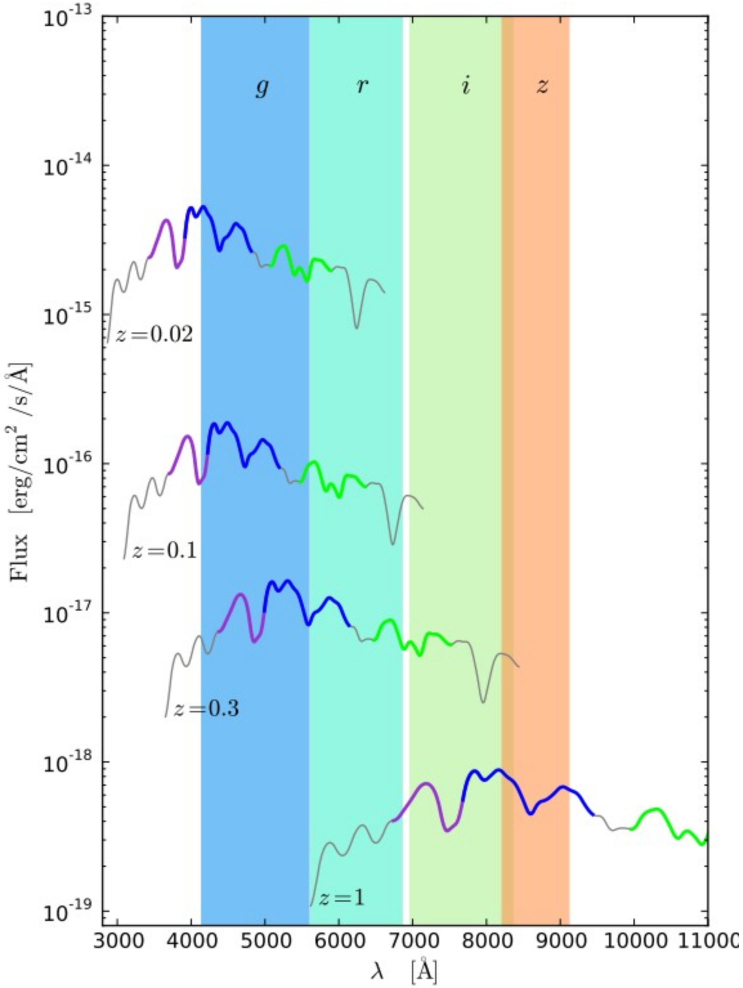
Supernovae systematics: better data needs rock solid calibration

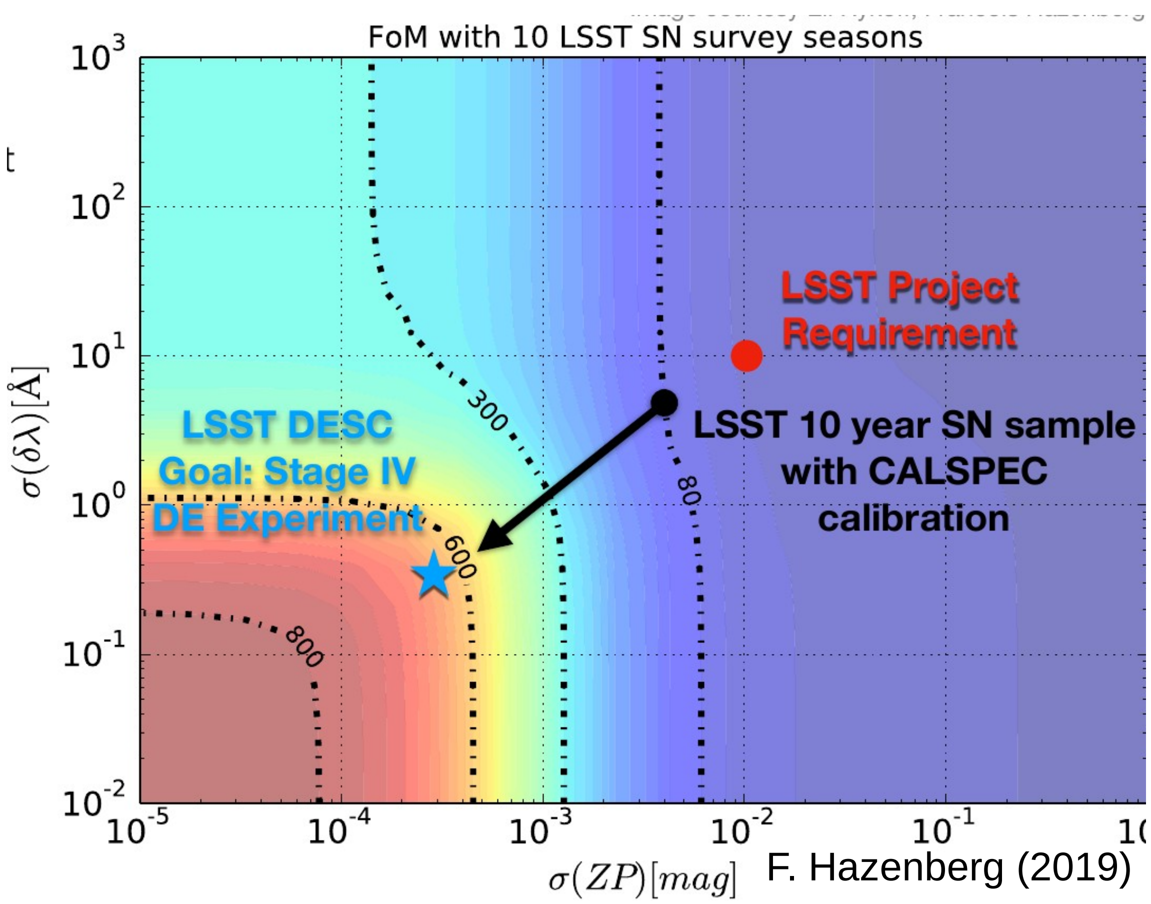




- The y axis is a measurement of apparent luminosity in a redshifted passband. Accuracy depends on:
  - Survey uniformity: improves with statistics (including external surveys)
  - Passband knowledge: improves with monitoring hardware
  - Accurate calibration references across the entire wavelength range

How accurate ?



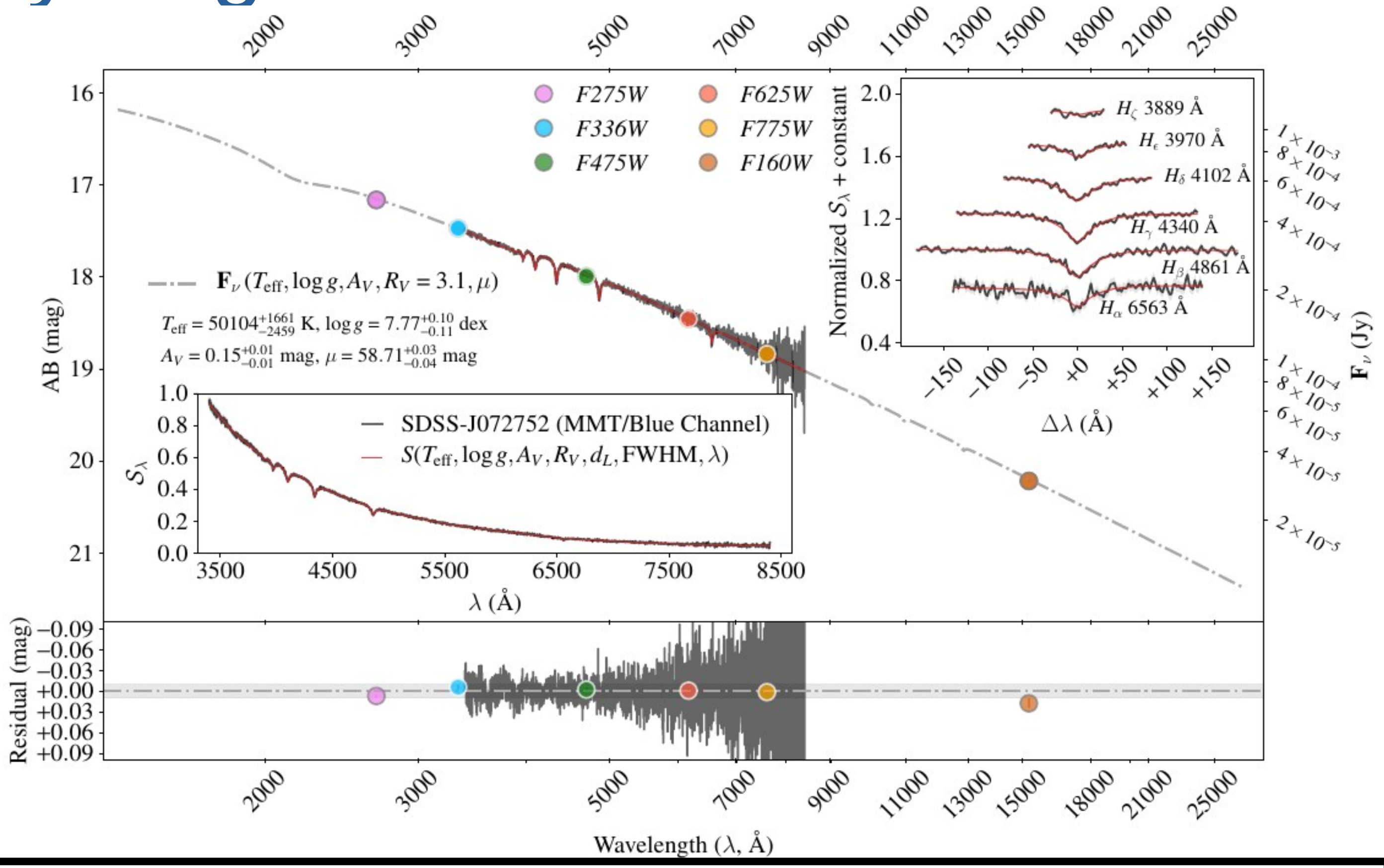


F. Hazenberg (2019)

- No significant level of auto-calibration (Cosmology nearly fully degenerated with calibration when SN model training is considered)
- Significant amount of the LSST statistical power is harnessed when σ(zp) < 0.001 mag

The only practical references to date are pure hydrogen WD

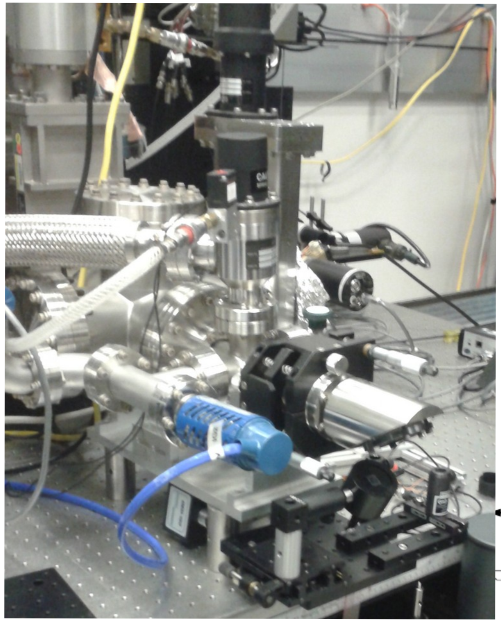
- Numerical model of the radiative transfer in the hydrogen atmosphere
- Model parameters infered from measurement of H profile in high-resolution spectrosopy
- Largest implementation to date : The cosmic flux standards program (Narayan et al. 2019)

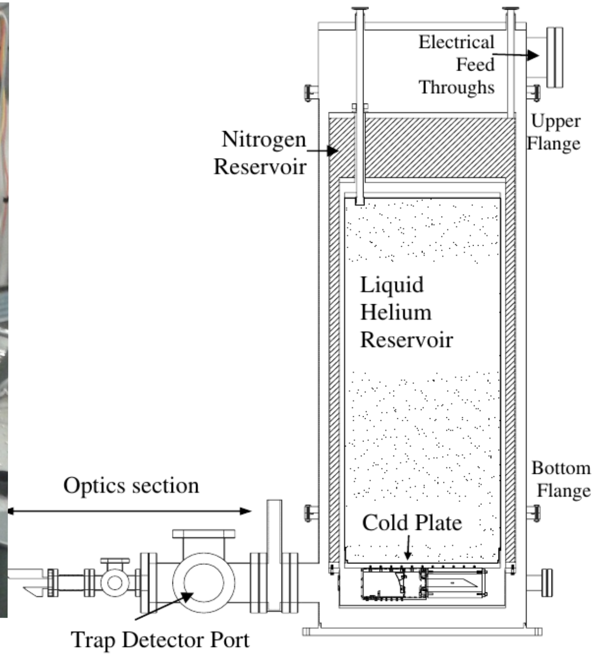


The proposal of the StarDICE experiment is to build an instrumental check of this model

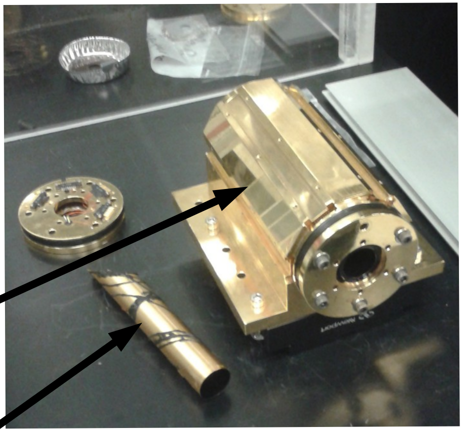
The alternative standard

POWR: the Primary Optical Watt Radiometer
(Brown et al. 2006, Houston et al. 2006)
high-accuracy electrical substitution cryogenic radiometer

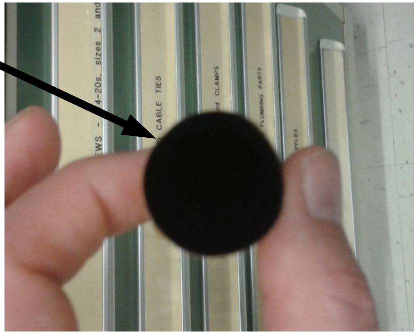




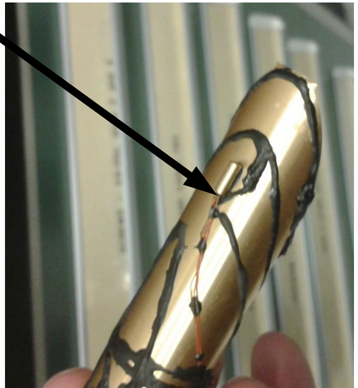
Cryogenic shelter



Black absorbing cavity

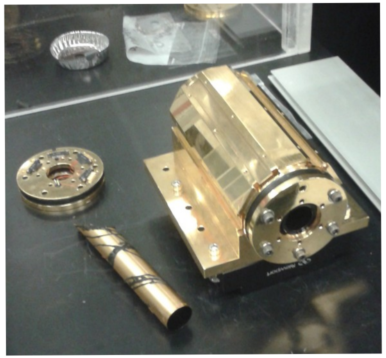


Germanium resistance thermometer



Claimed accuracy at the 10^{-4} level

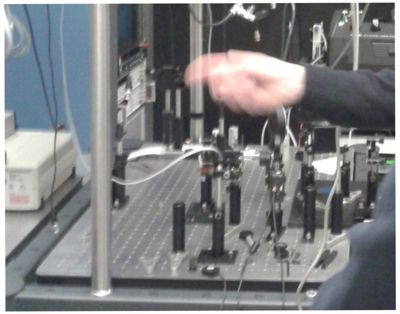
The required metrology chain



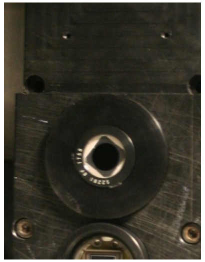
NIST POWR

10^{-3}W

NIST SCF



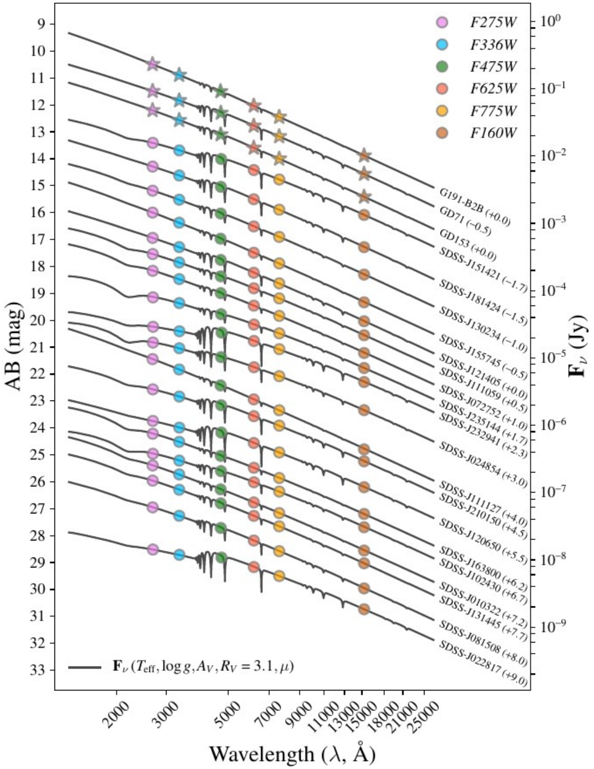
10^{-6}W



NIST Photodiodes

<10^{-19} W/cm²/nm

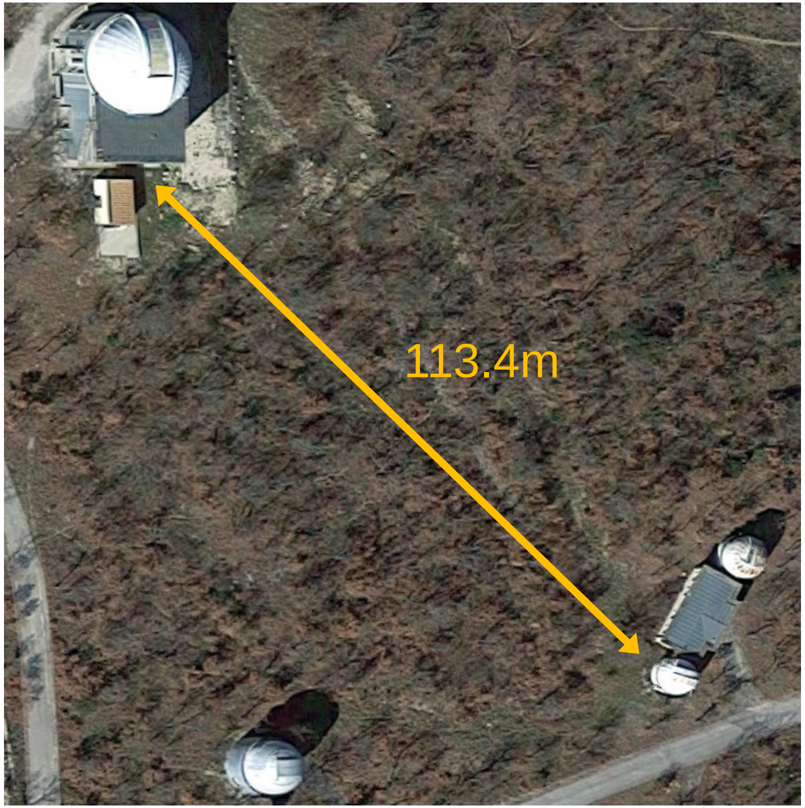
Spectrophotometric standard stars



A pathfinder (2016-2019)

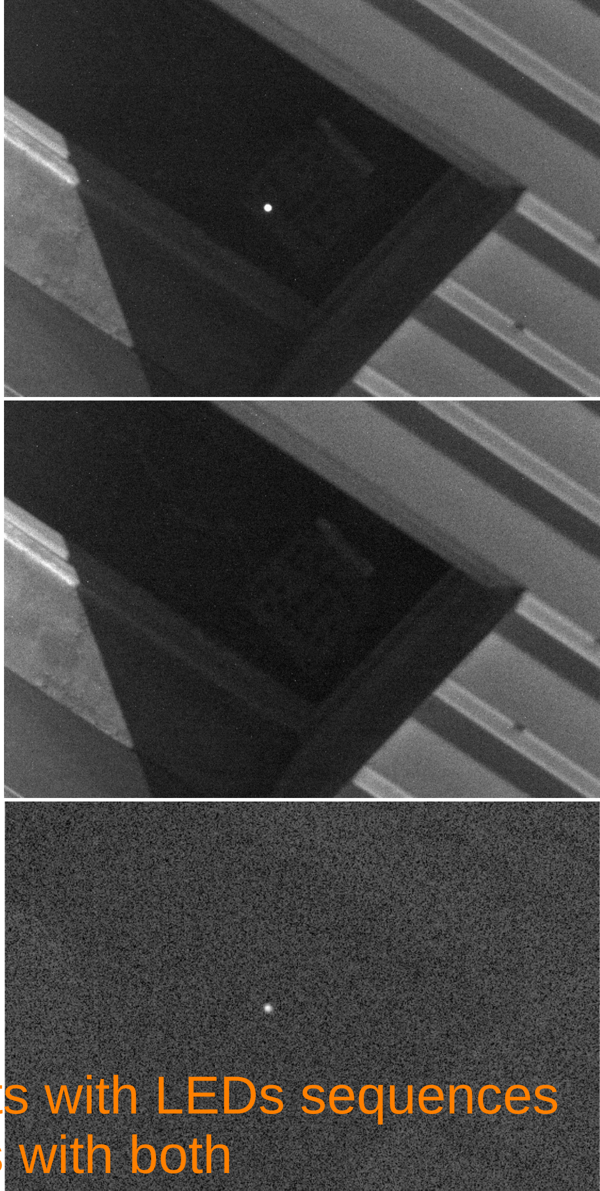
Source seen by the telescope

Telescope seen by the source



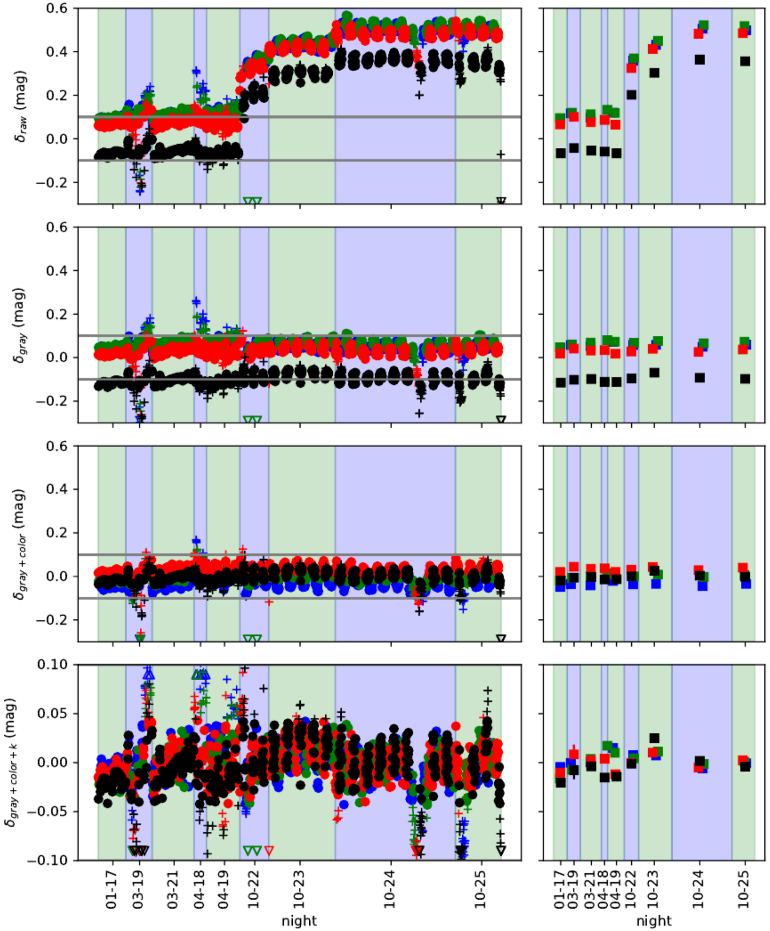
Example data

16 nights following stars



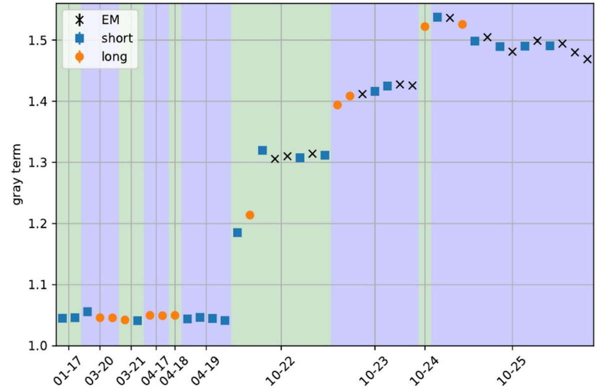
11 nights with LEDs sequences
9 nights with both

Compare measured and synthetic fluxes (F. Hazenberg 2019)



$$\frac{\Phi_{calspec}}{\int A(\lambda)T(\lambda)C(\lambda)d\lambda}$$

$$\kappa = \frac{\Phi_{led}}{\int T(\lambda)L(\lambda)d\lambda}$$

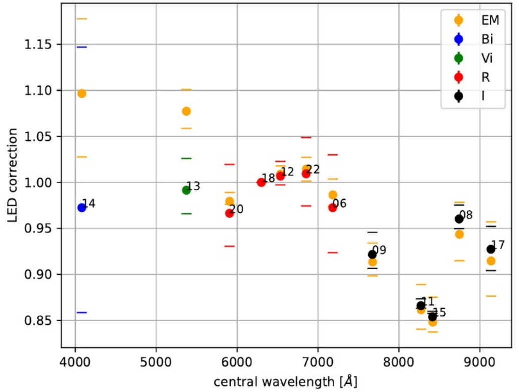


Applying a gray correction from LEDs

$$\frac{\Phi_{calspec}}{\kappa \int A(\lambda)T(\lambda)C(\lambda)d\lambda}$$

Applying the colored correction from LEDs

$$\frac{\Phi_{calspec}}{\int A(\lambda)\kappa_T T(\lambda)C(\lambda)d\lambda}$$



Zooming and fitting the color offset

B-V = 16 mmag ± 8 (stat) ± 91 (sys)
V-R = 38 mmag ± 7 (stat) ± 32 (sys)
V-I = 9mmag ± 7 (stat) ± 67 (sys)

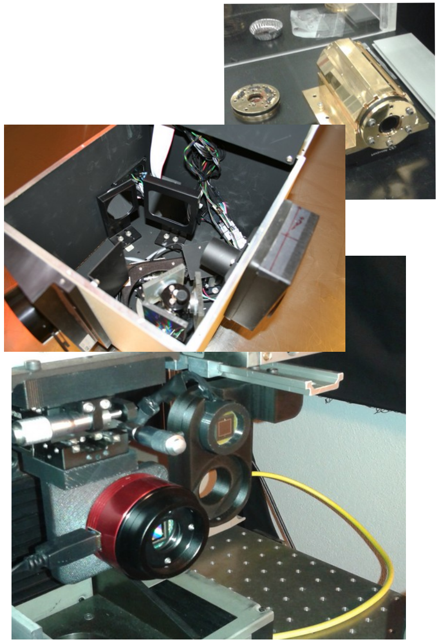
Design improvements after the pathfinder experiment

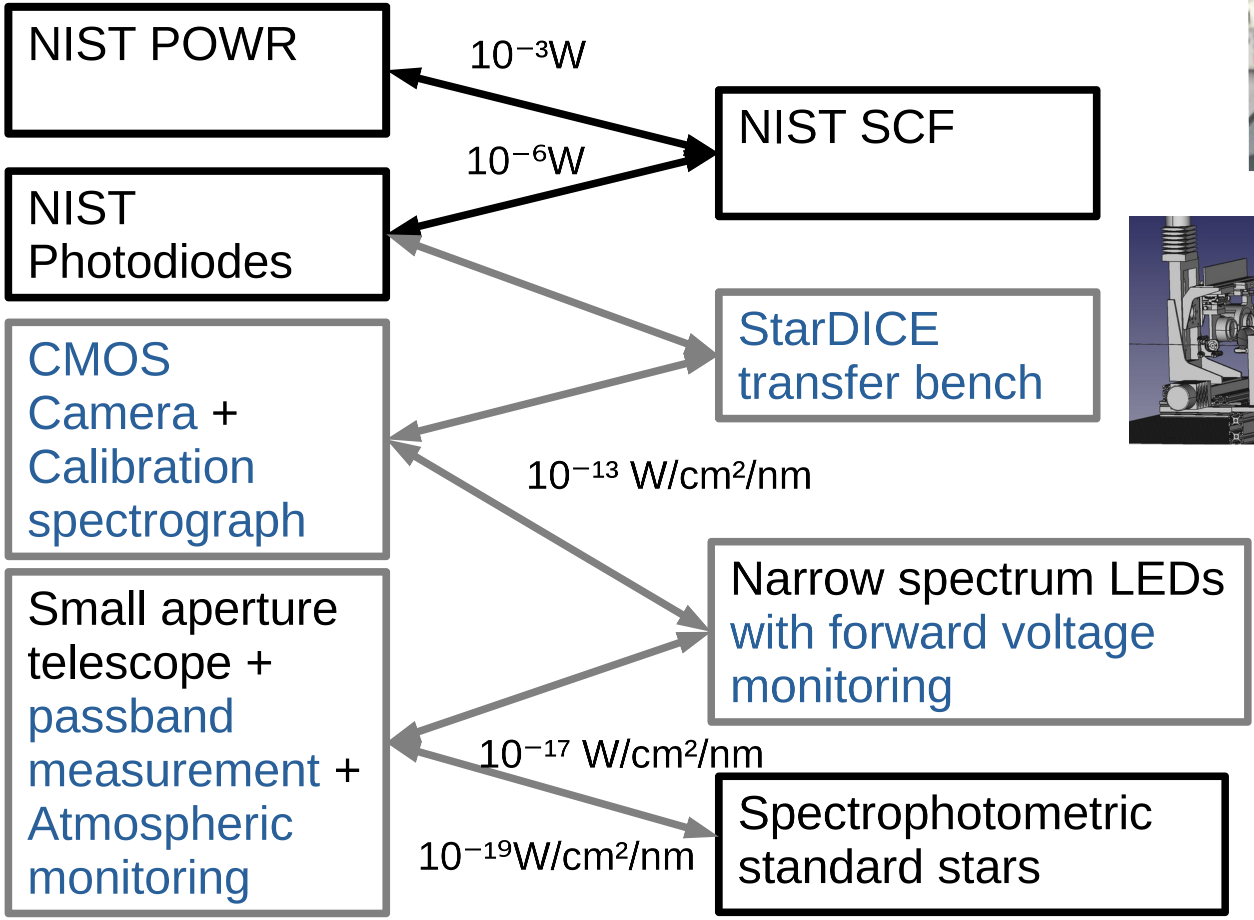
- Spectroscopy of the LED beam requires a dedicated instrument
- Absolute mapping of the LED irradiance cannot be made (fast enough) directly with the NIST photodiodes : Cooled CMOS camera calibrated on a transfer bench
- Deconvolution of the instrument passband from broadband LED data is not easy: A priori and a posteriori measurement with the CBP.
- Junction temperature of low flux LEDs is not well tracked by case temperature : forward voltage measurement
- Progress in spectrophotometry associated with the development of auxtel led
- Fast variations of the gray extinction is the main noise contribution to the nightly regression of the atmospheric transmission: IR monitoring of the cloud coverage

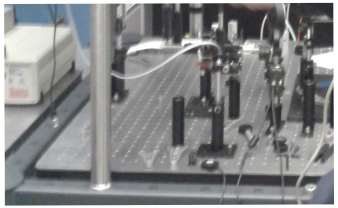
Source	$Vi-Bi$	$Vi-R$	$Vi-I$
Statistique	0.76	0.66	0.73
Erreur sur $\bar{\lambda}_l$	7.80	2.89	6.32
Standardisation LEDs	0.44	0.31	0.45
Position dans le faisceau	0.41	0.41	0.37
Variation grise	3.75	0.21	1.06
Atm. horizontale	2.24	1.00	1.00
Atm. verticale	1.54	0.03	1.61
Total	9.12	3.18	6.75
Total - $\sigma(\bar{\lambda}_l)$	4.73	1.32	2.36
Δc	5.38	3.56	1.98

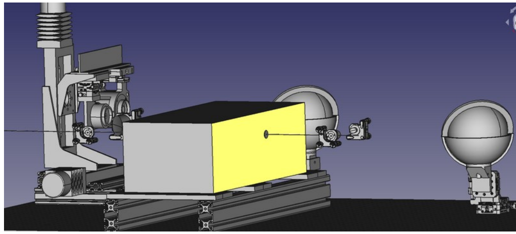
Hazenberg (2019)

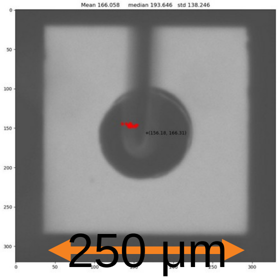
The StarDICE metrology chain





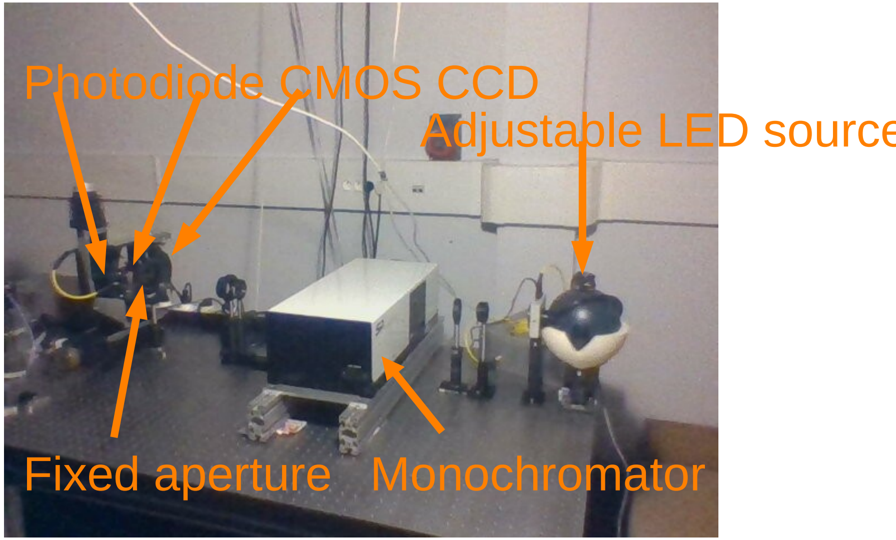


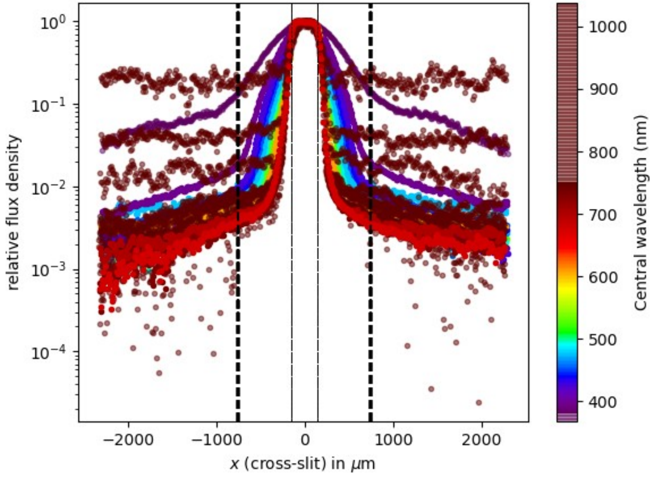




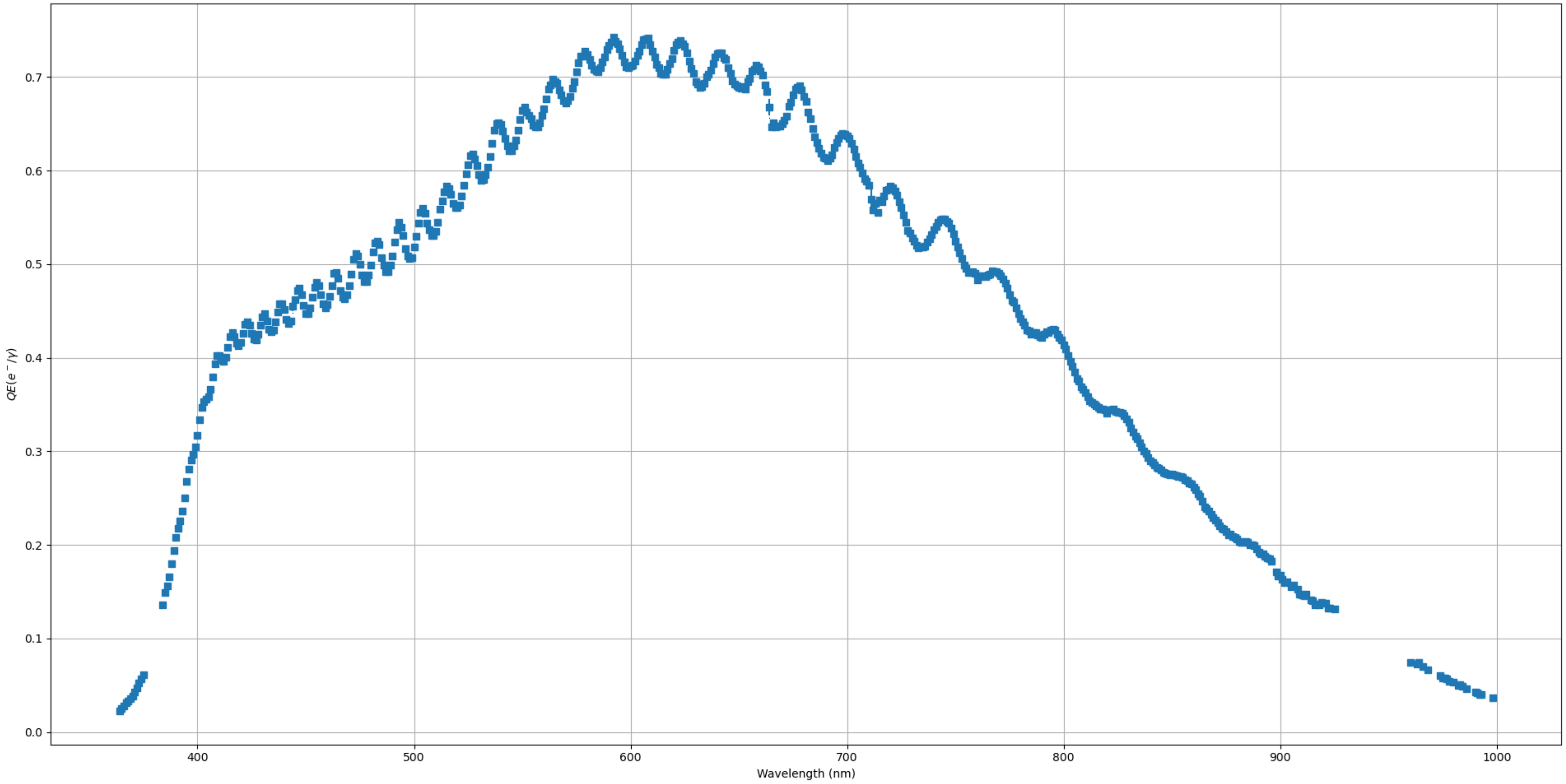
Calibration transfer from NIST to Cooled CMOS

- Arrays of millions of photodiodes
- CMOS pixels with dark current of the order of 0.001 e^-/s compared to the ~650ke^-/s of the NIST photodiode → Time integration
- Make mapping of the irradiance of the LEDs million times faster than with the NIST photodiode provided that they can be calibrated
- A fast iteration on a photodiode-CCD transfer bench in 2019 demonstrated the feasability of the transfer
- Accuracy was limited by avoidable chromatic effects in the optics



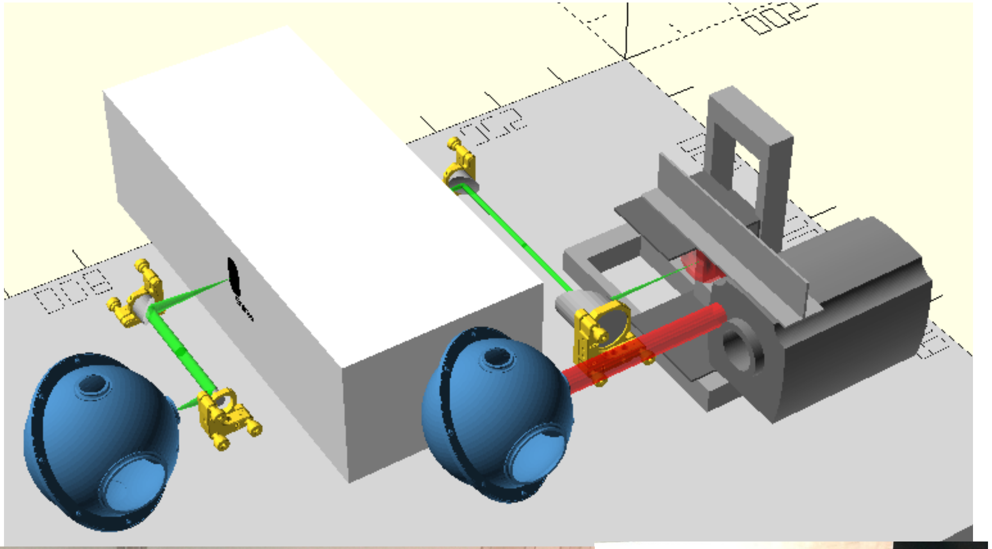


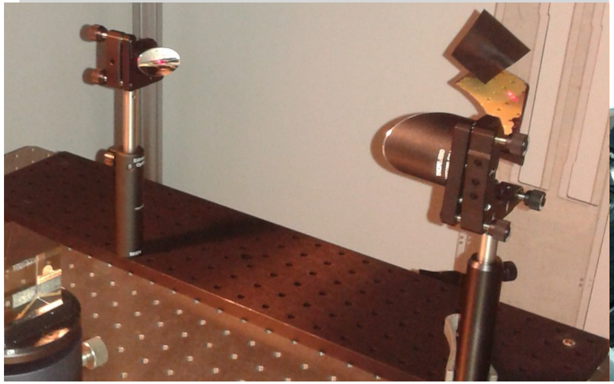
Fast iteration result: High res quantum efficiency curve of the pathfinder camera

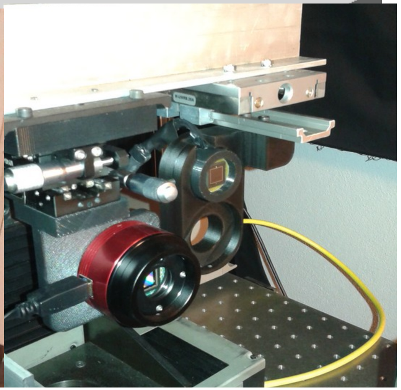


Calibration transfer bench: The final implementation

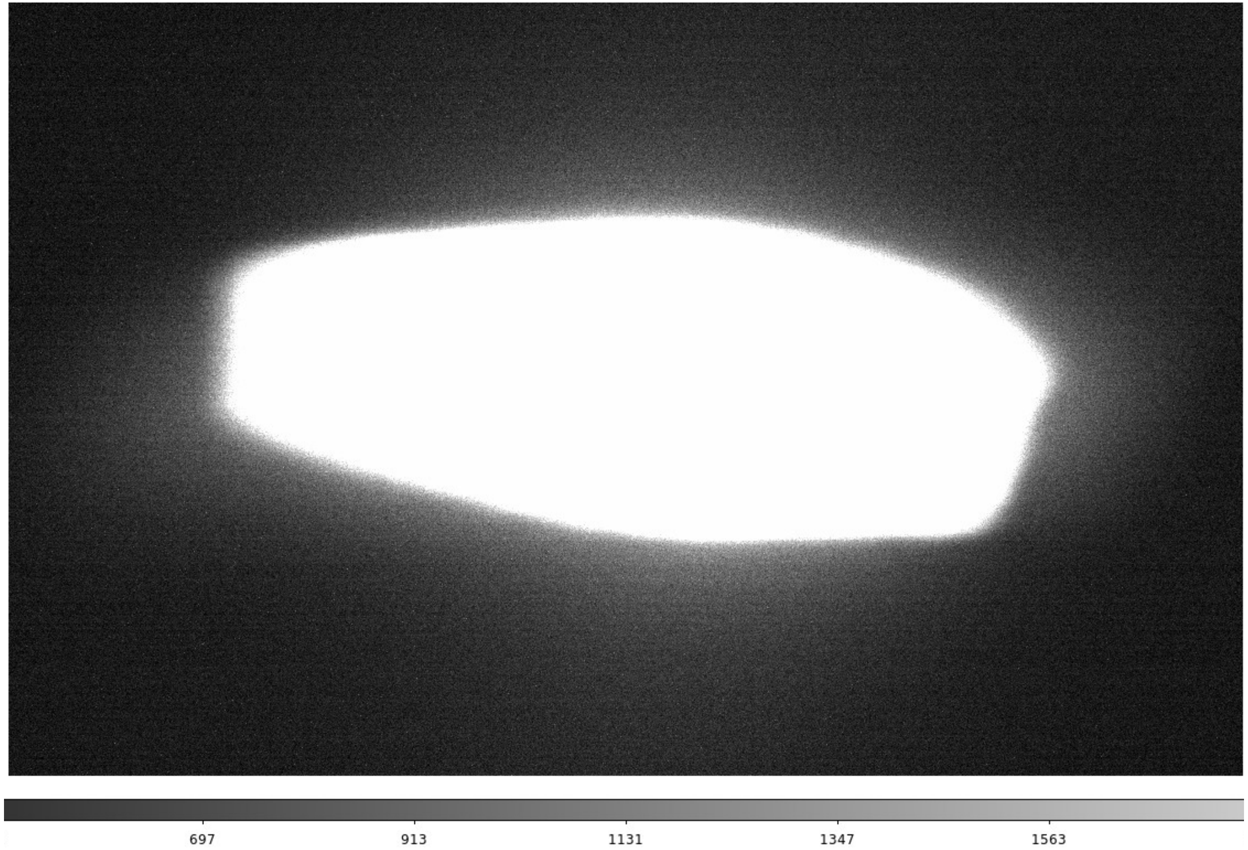
- Fully automated calibration transfer bench being build at LPNHE (dev. led by C. Juramy)
- 2 beams:
  - Monochromatic beam for QE measurement (in green)
  - Polychromatic beam for flatfields and Electronic studies (ir red)
- Fully achromatic optics (OAP relays)







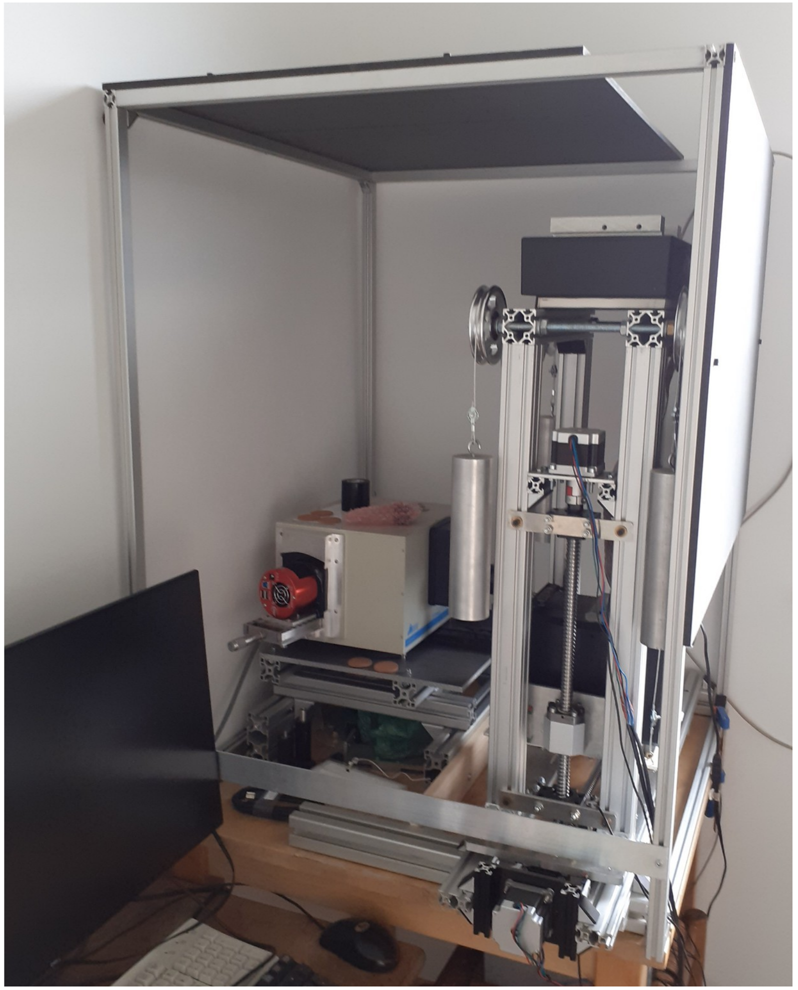
First Light of the new bench



- Not perfect (coma) but already fully contained within the detector
- And achromatic ! (this is white light through the monochromator 0th order)
- We are days away from the first scan

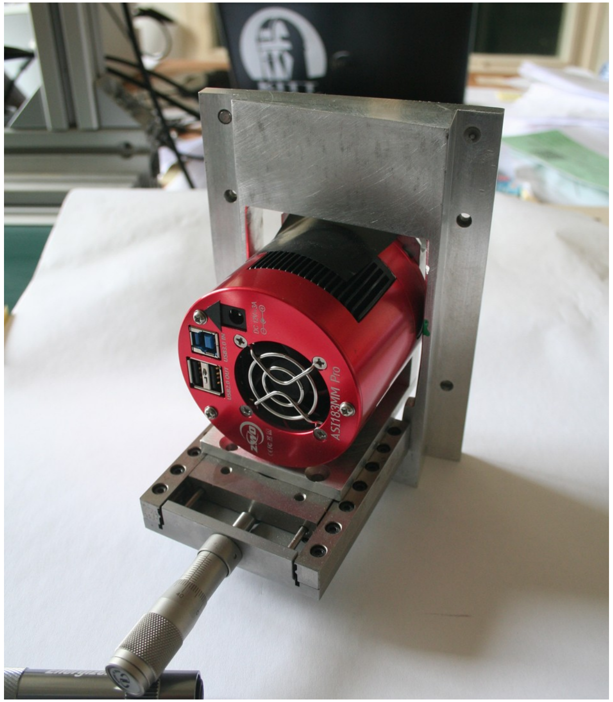
New spectrophotometric bench

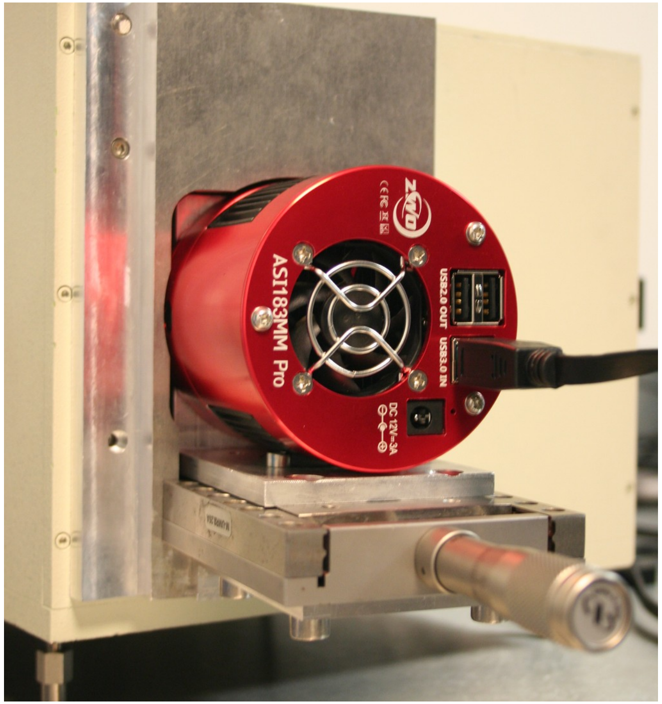
- Dev led by L. Le Guillou
- The goal is to precisely measure the spectra of our LEDs
- And how they evolve with temperature
- The difficulty is that the light level is extremely low (below the sensitivity level of lab spectrograph)

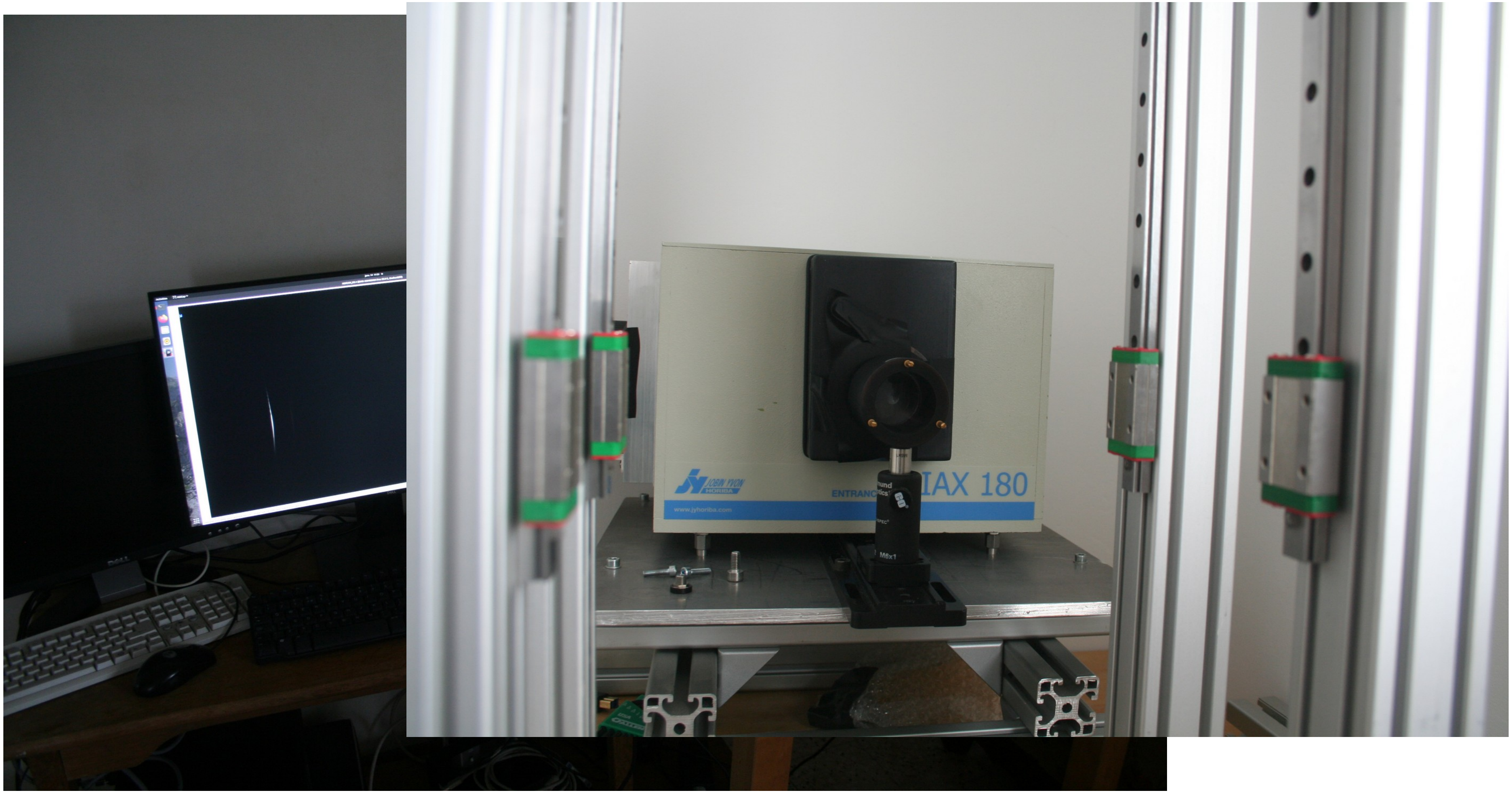


The key is a dedicated instrument

- Modify a monochromator to fit in one of the cooled CMOS camera
- Result is a highly sensitive spectrograph covering a (tunable) 50nm wavelength range with 0.01nm resolution



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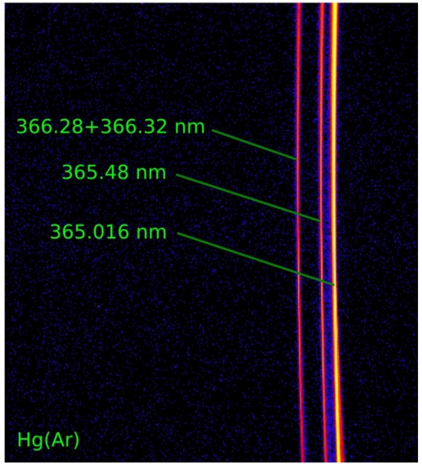
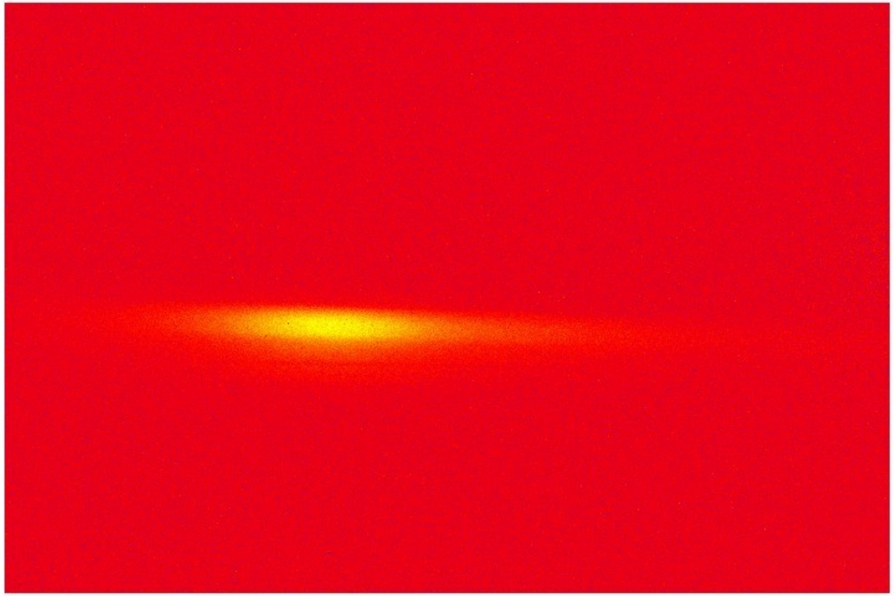
M6x1

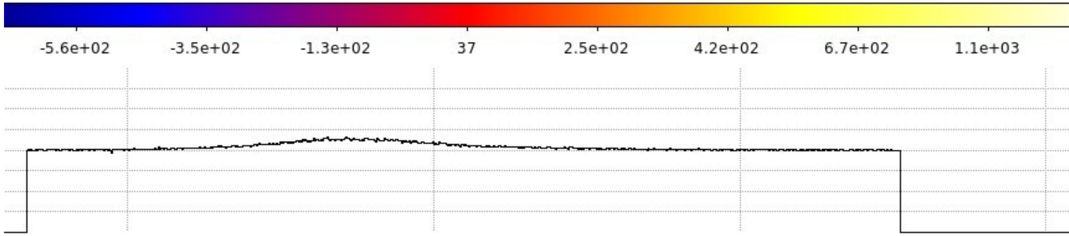
Sample data from the LED spectrograph



Wavelength
Calibration Data

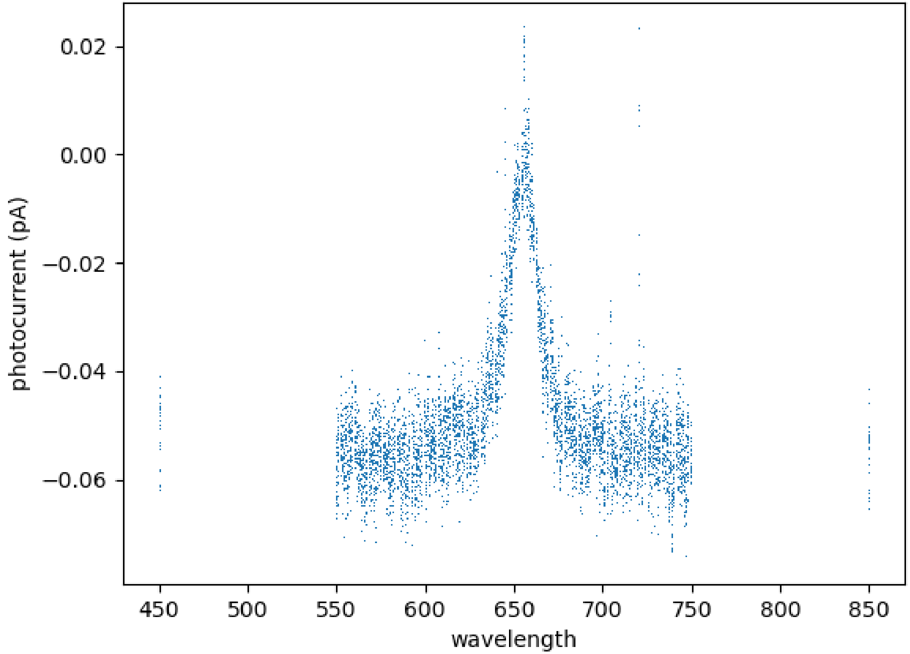
LED Data



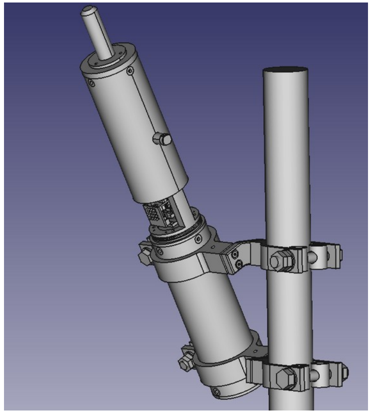


First LED spectra

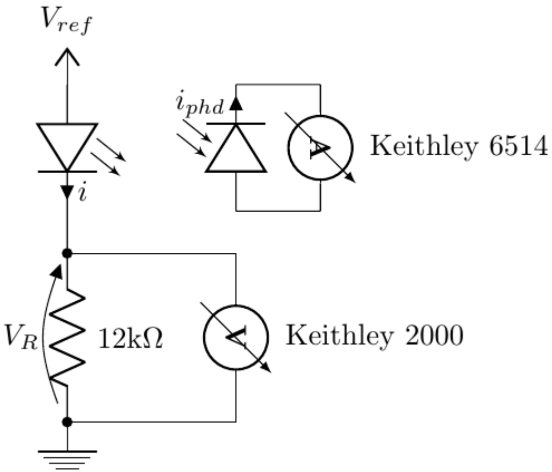
- Integration 3x200s
- To be compared with a 2000s scan of the same LED at higher flux with the old method

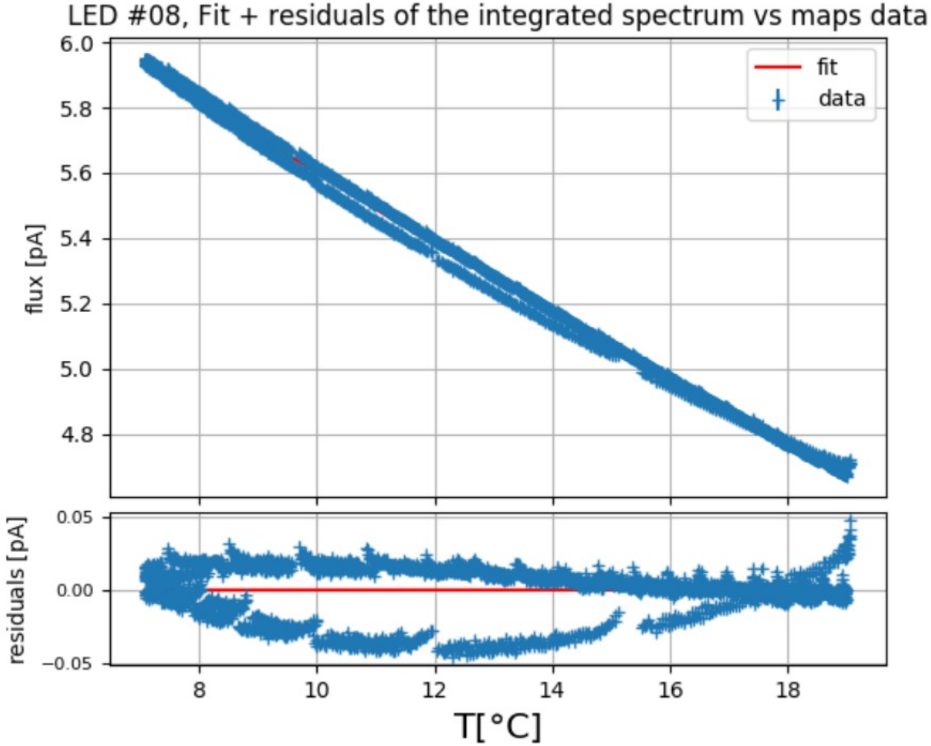


New artificial star developped to solve the instabilities we had in the pathfinder



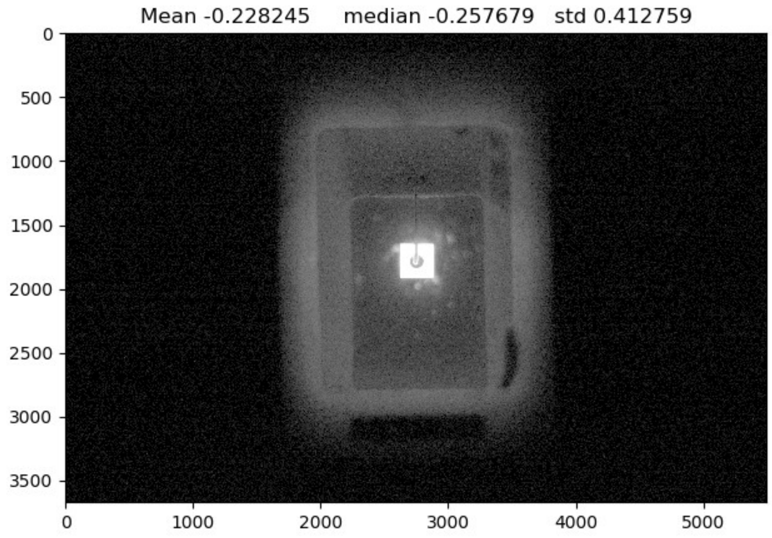
- New enclosure (CPPM)
- New drive electronic with embedded temperature proxy (E. Sepulveda)

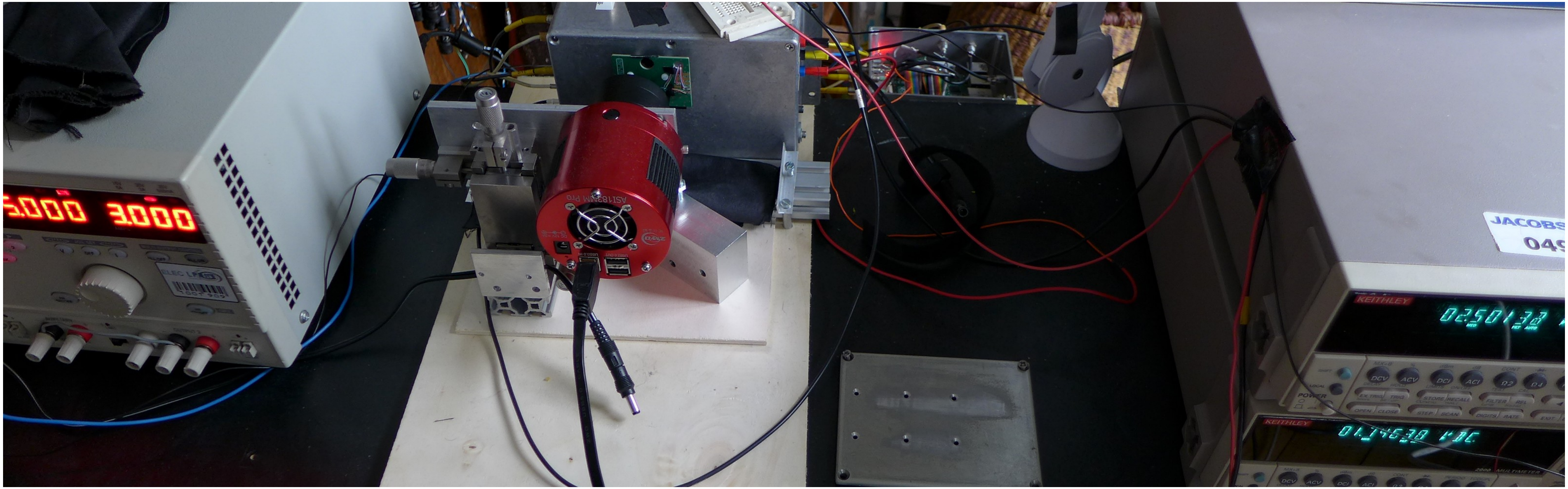




Prototype complete (taking data)

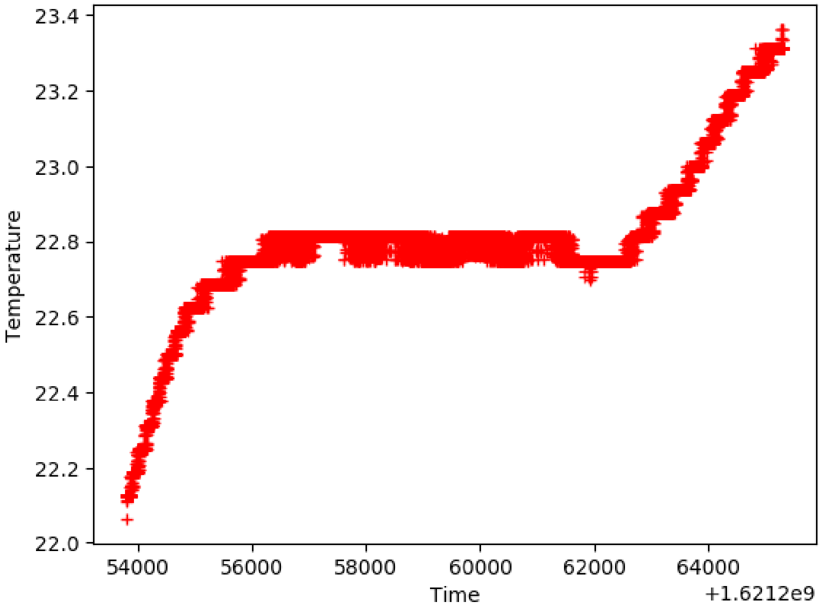
- Prototypical electronics with selected components (16x ADC and DAC)
- Photometric stability test bench with cooled CMOS Camera

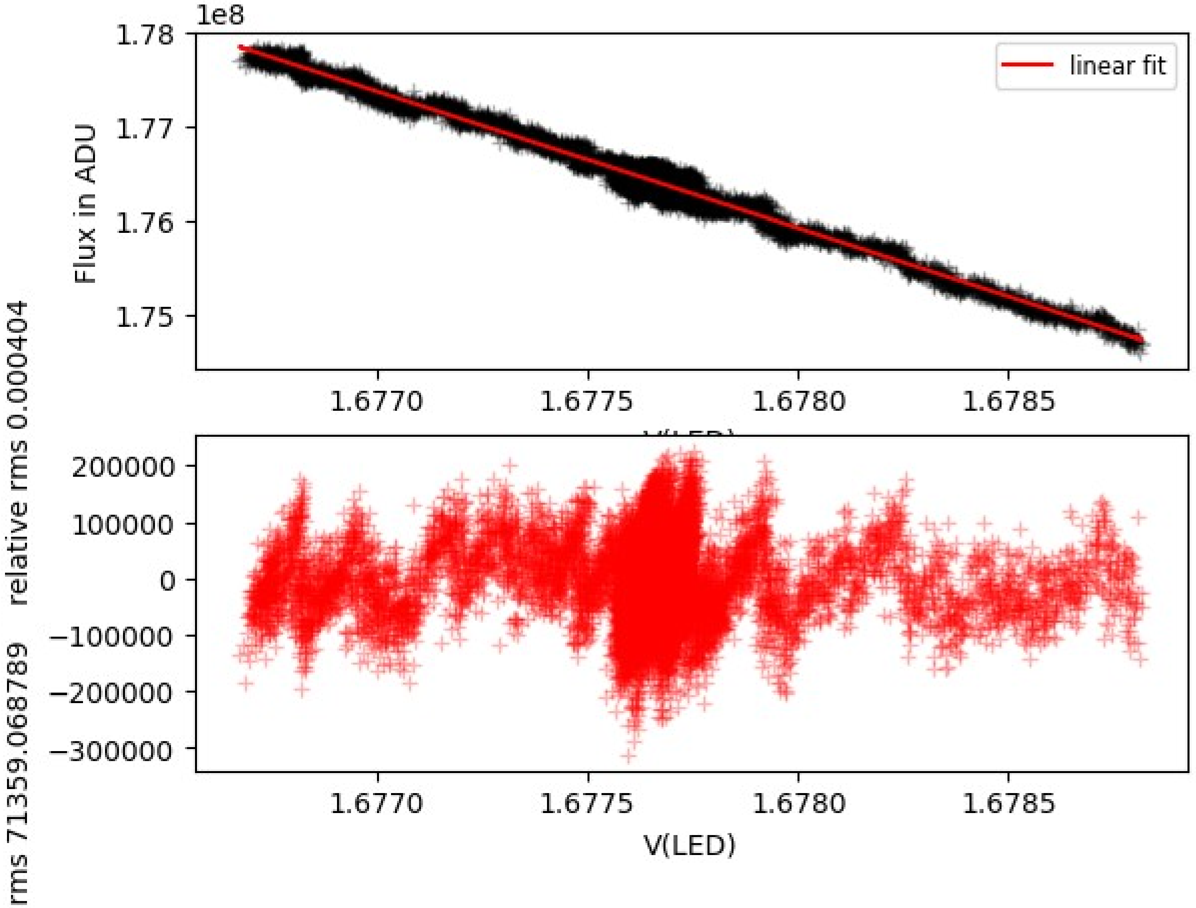




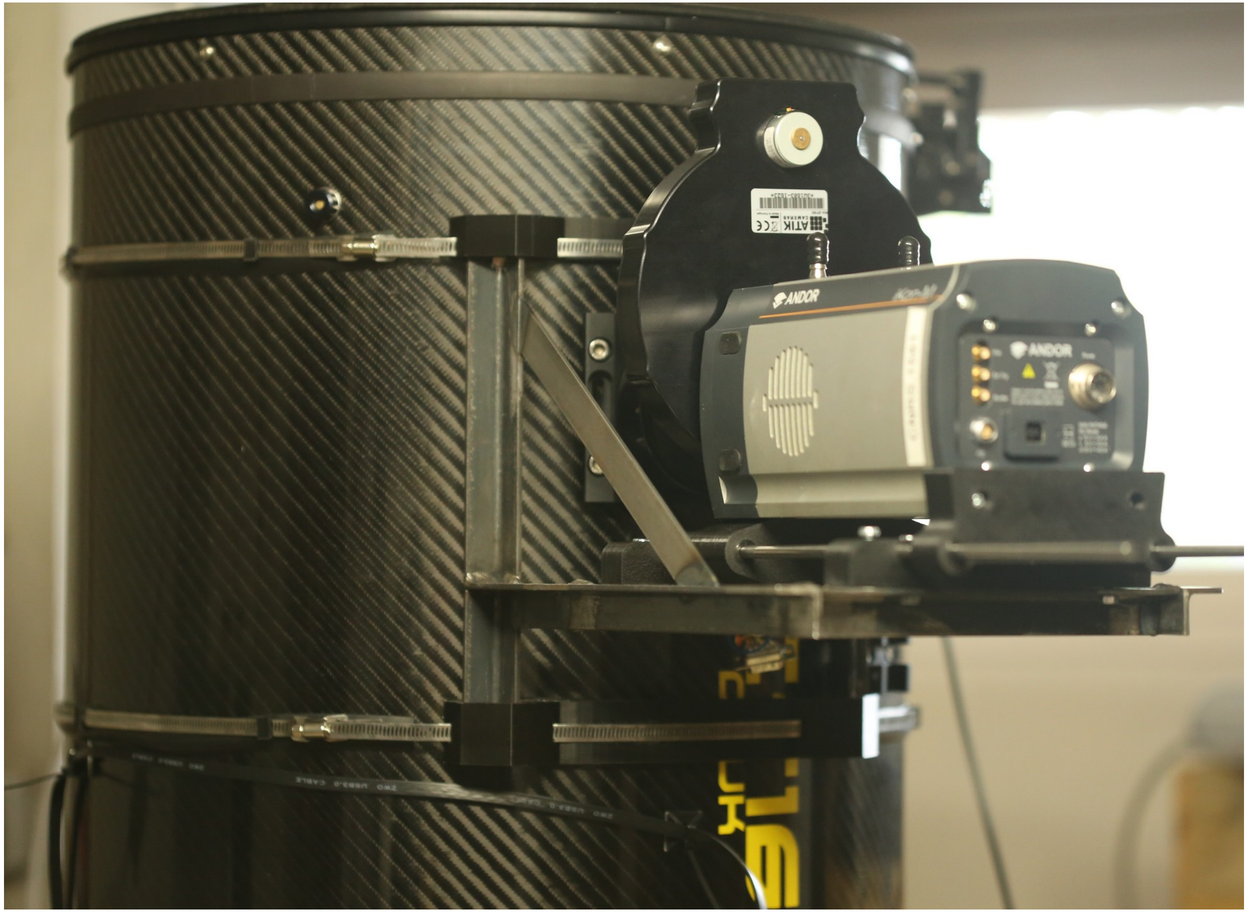
First result with the complete prototype electronics

- V_led standardize the LED flux at 0.04% over 10000s
- Production card drawn



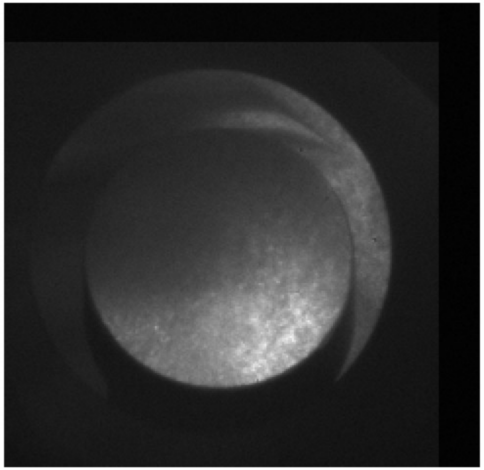


New photometric instrument ready for CBP measurement

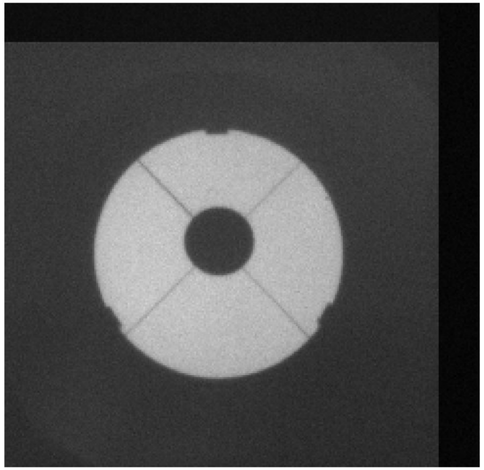


- Primary aperture 40cm
- Newton Secondary 11cm (lesson learn from pathfinder: avoid vignetting)
- Air-Cooled (-70°C) CCD camera
- 1024x1024 13 microns pixels
- Back illuminated deep-depleted CCD
- 6 broadband ugrizy filters + GRISM + Pinhole + hole
- As close as LSST as possible

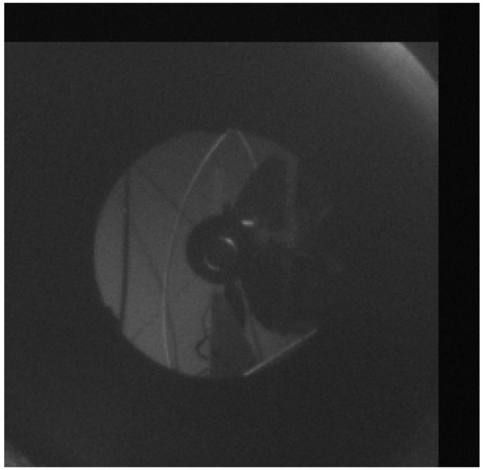
Telescope collimation



Centering of the image of the secondary mirror



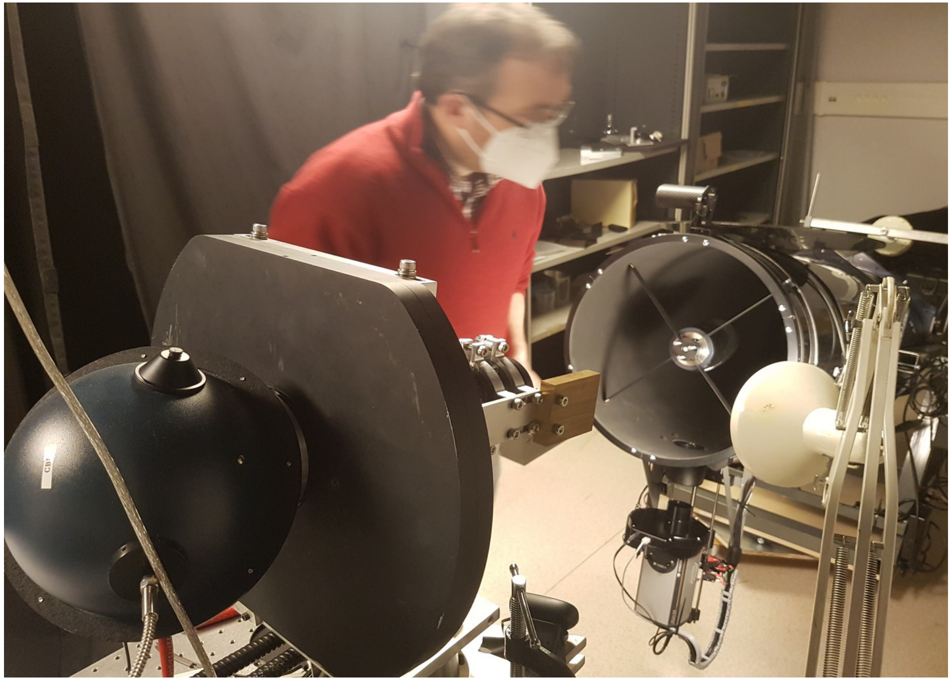
Centering of the image of the primary mirror

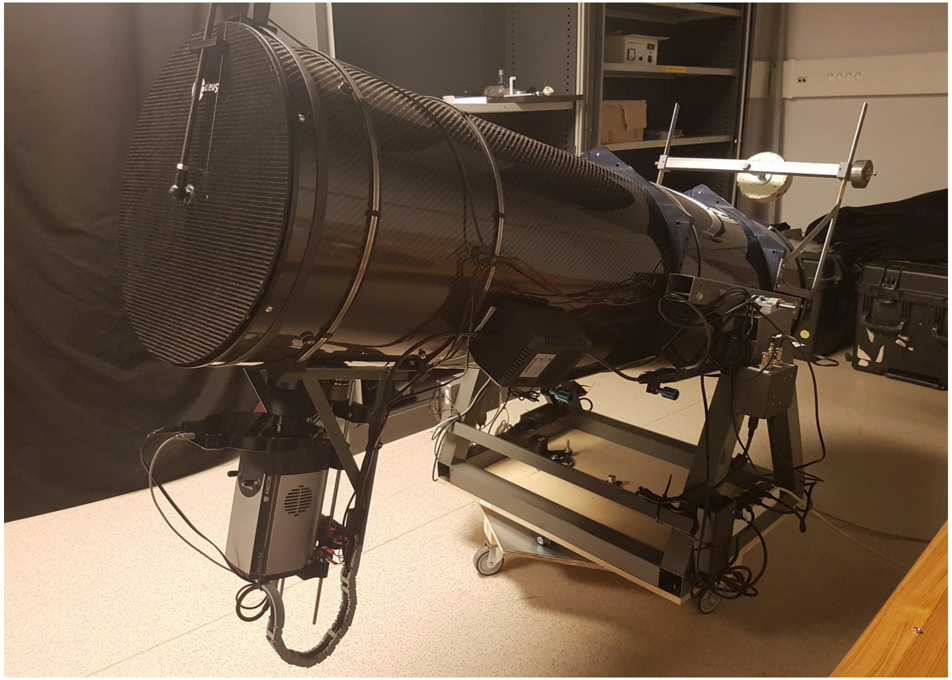


Centering of the image of the pinhole

Image of the CBP

The new telescope in front of the first CBP

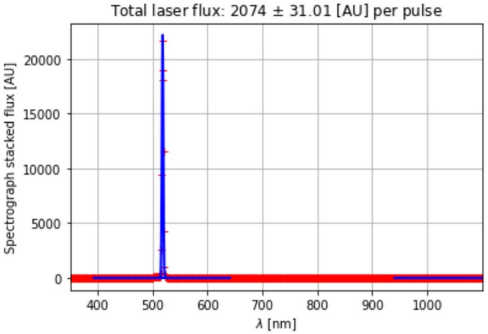




- Dev. led by J. Neveu and S. Bongard

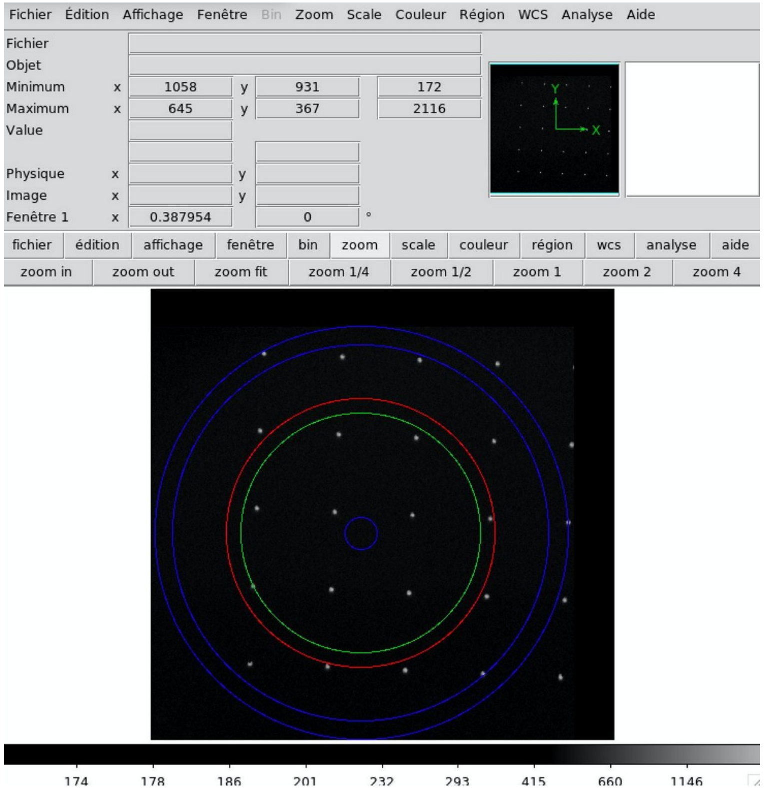
Scan gathering 3 kinds of data

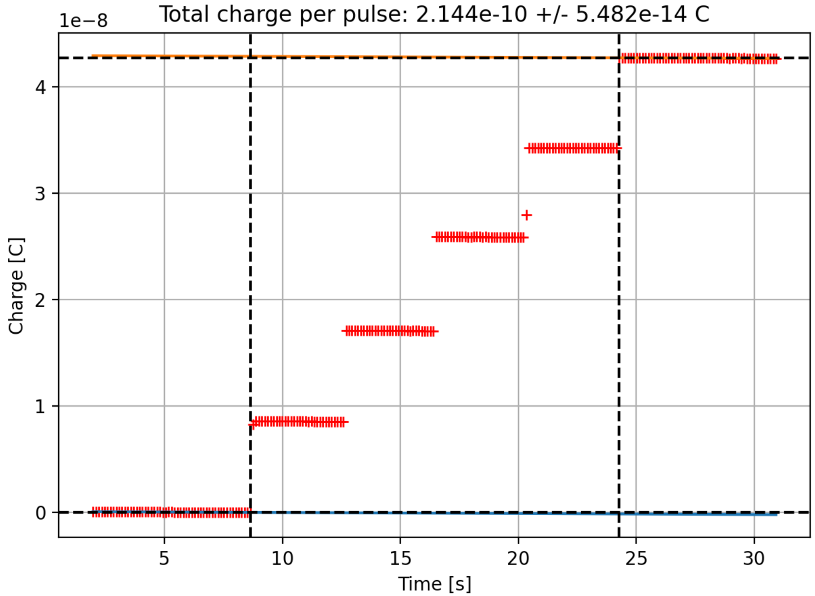
from the CBP spectrograph



Line	Tabulated nm	Detected nm	Shift nm	FWHM nm	Amplitude
L520	520.0	518.5613	-1.4387212	2.9191847	22255.23
LL532	532.0	532.027	0.026974846	0.35969415	358.0127
L520^(2)	1040.0	1036.434	-3.5660124	0.70053583	10.77955

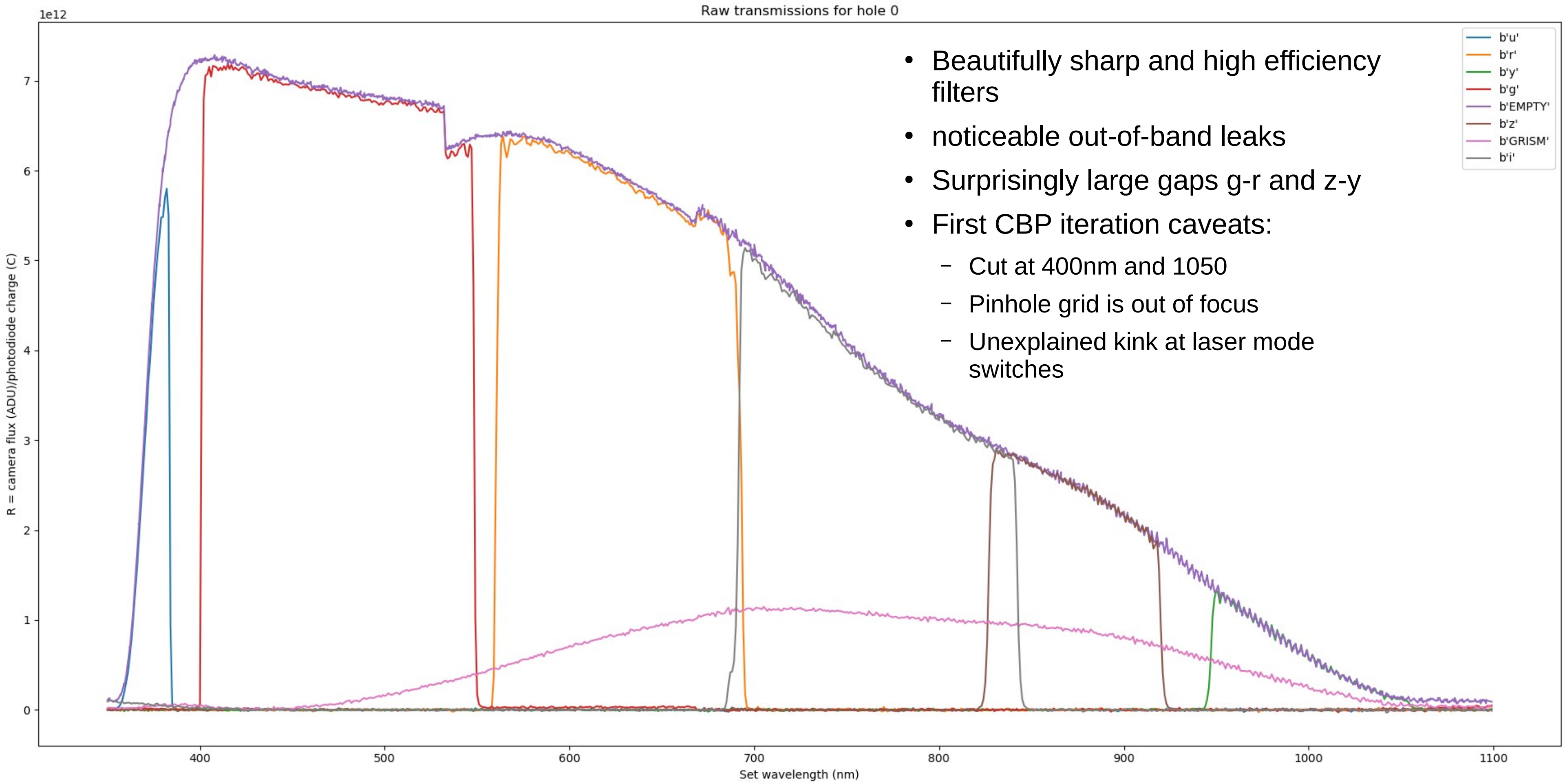
from the telescope camera





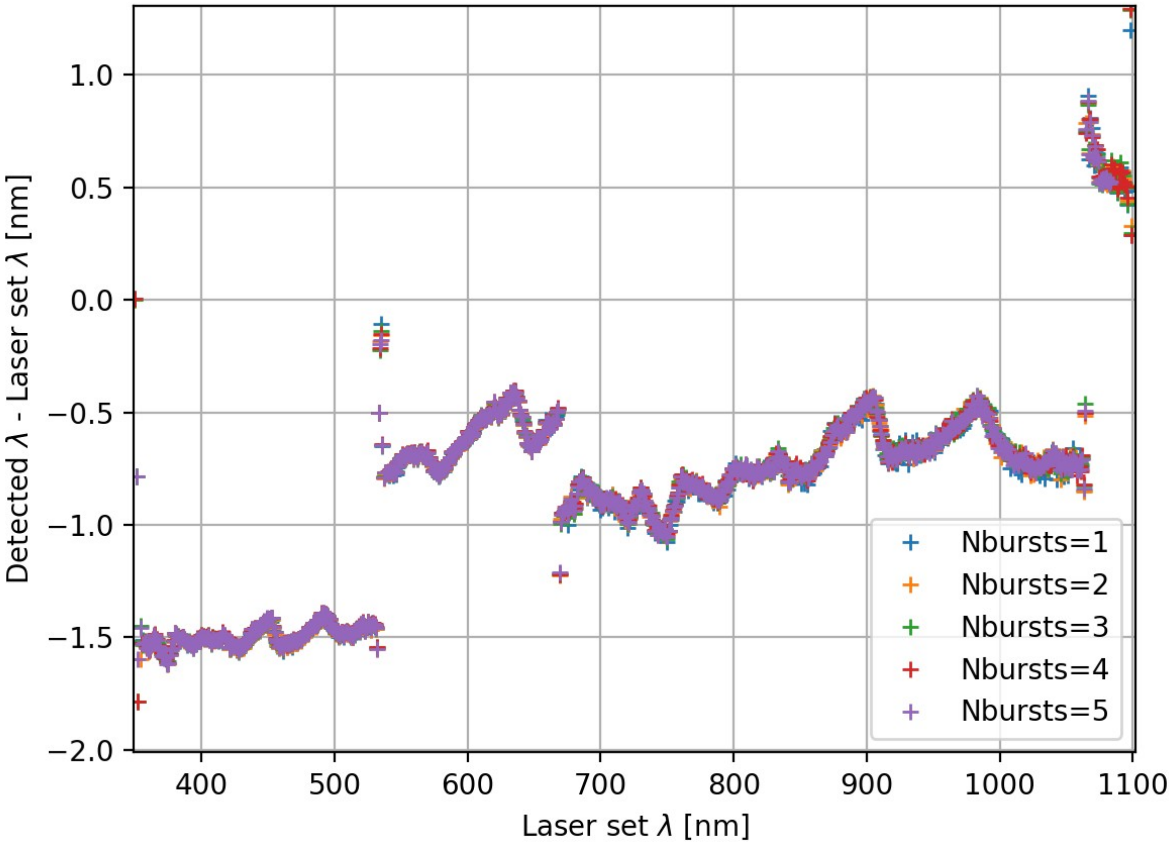
from the CBP photodiode

First transmission measurement



- Beautifully sharp and high efficiency filters
- noticeable out-of-band leaks
- Surprisingly large gaps g-r and z-y
- First CBP iteration caveats:
  - Cut at 400nm and 1050
  - Pinhole grid is out of focus
  - Unexplained kink at laser mode switches

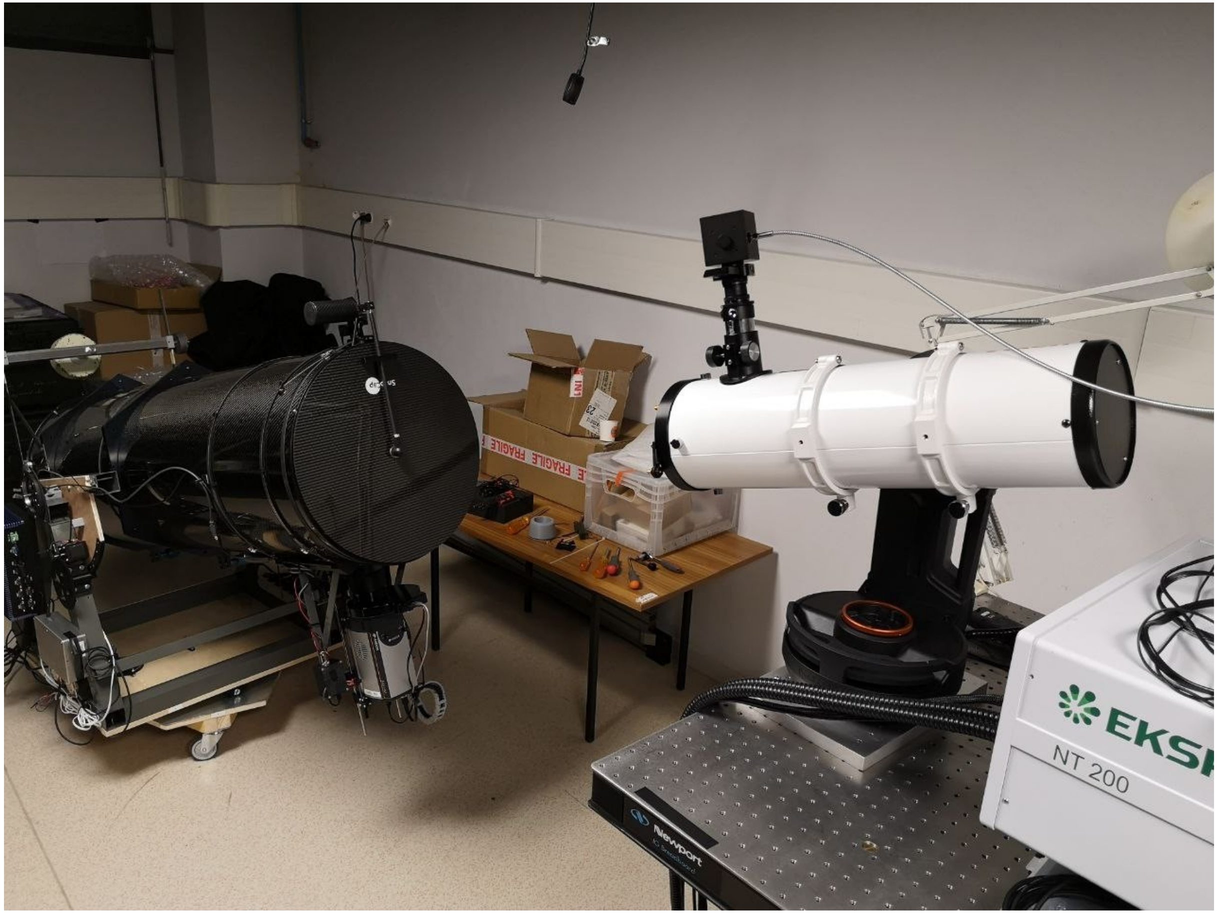
Wavelength calibration accuracy ?

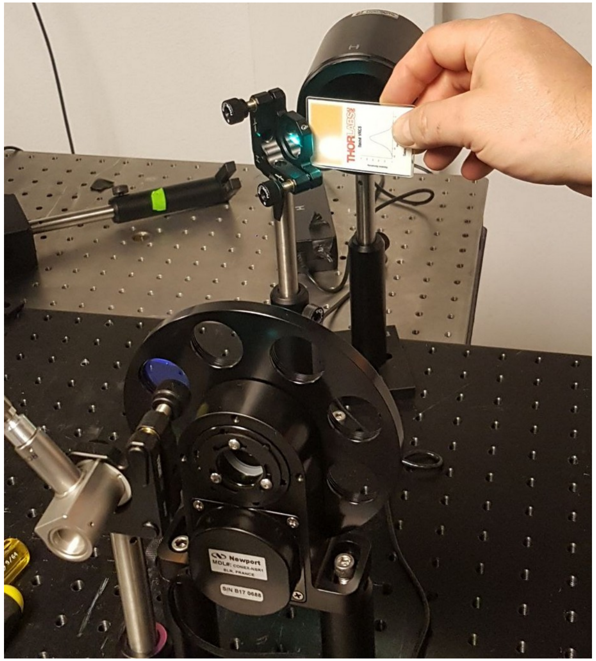


- A comparison of the wavelength calibration solution in three different scans
- Reproducibility better than .1nm
- Excellent news for StarDICE but also directly for LSST

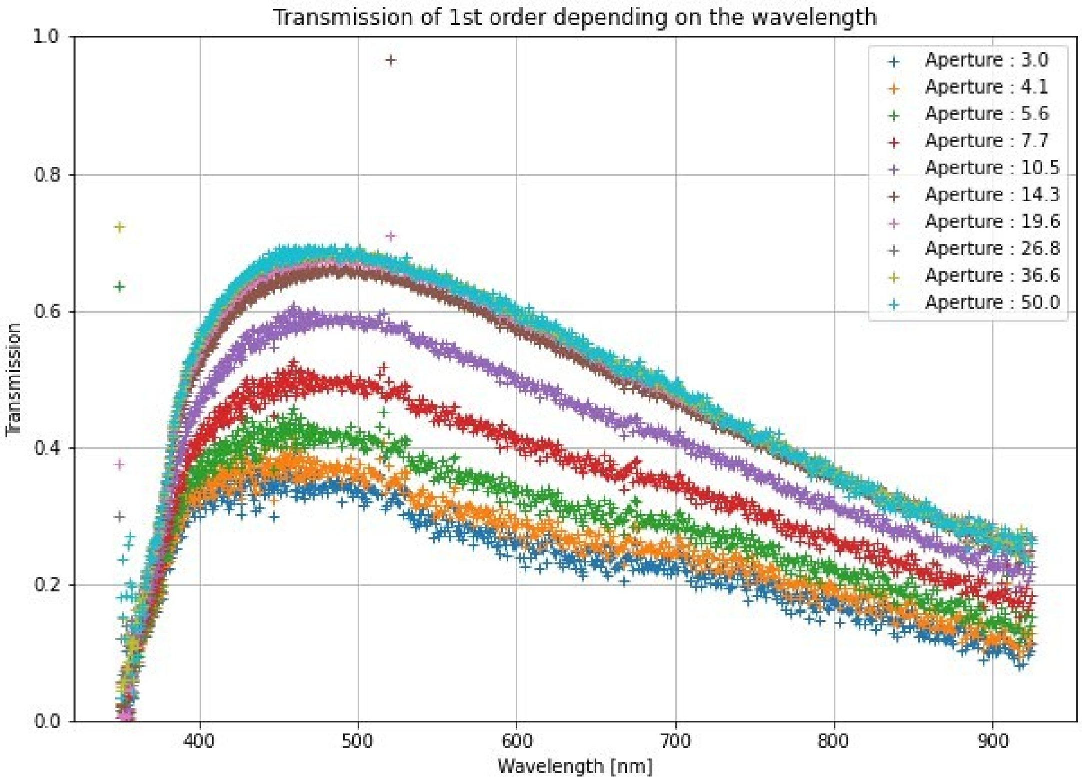
Second iteration of the CBP

- New achromatic collimating optics
- Smaller integrating sphere (more flux)
- Excellent mount (enable mirror scan)
- Laser beam wavelength cleaning with filters
- Currently integrating → end of June





Developping slitless spectroscopic capabilities

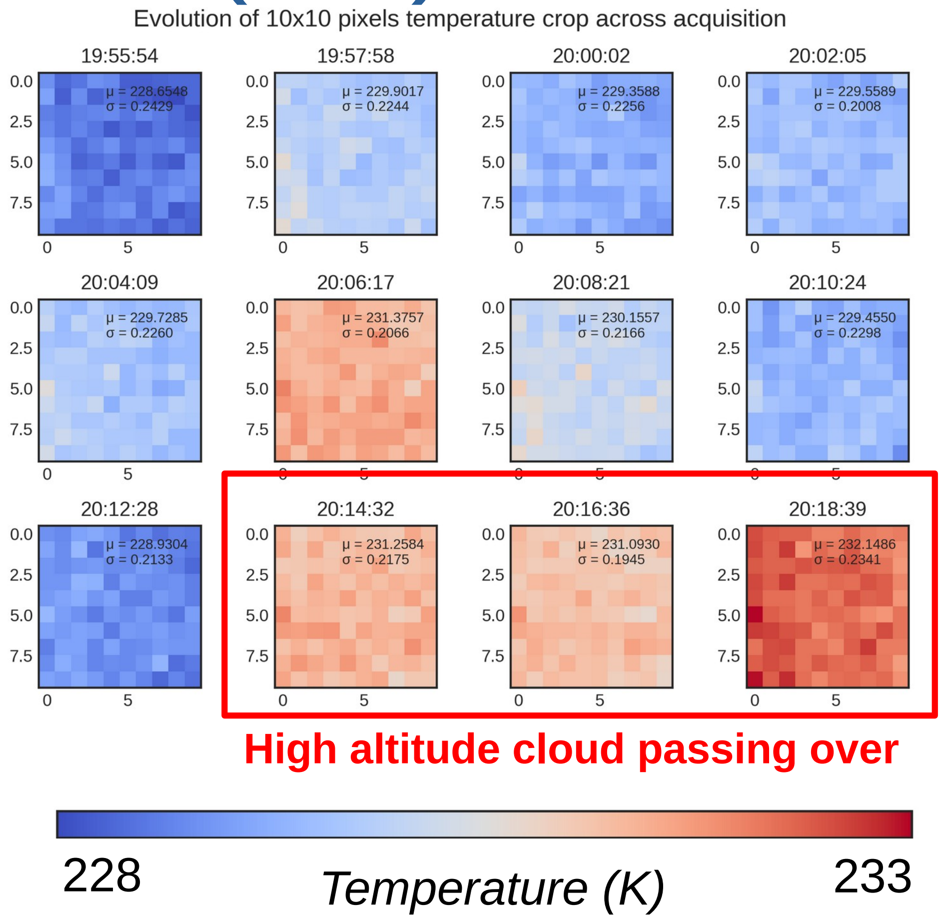


PhD Thesis Thierry Souverin

- Efficient GRISM with accurately known transmission
- 2nm theoretical resolution around optimum
- Opens interesting possibilities in StarDICE
  - Auxtel-like atmospheric solution
  - Self-calibrating LED-Observations
  - Slitless-spectrophotometry ?

IR Follow-up instrument (1/2)

- Lack of monitoring of the gray extinction is the main source of noise which prevents reaching the photometric calibration goals for SNe-Ia
- Additional atmospheric absorption in the 350-1200 nm range induced by thin high-altitude cirrus clouds
- Method : monitoring of the background sky in the LWIR band (8-13 µm)
  - Measure the relative variations of the sky brightness temperature with an IR camera
  - Establish a correlation model of the sky thermal flux and stellar flux measured by optical CCD camera

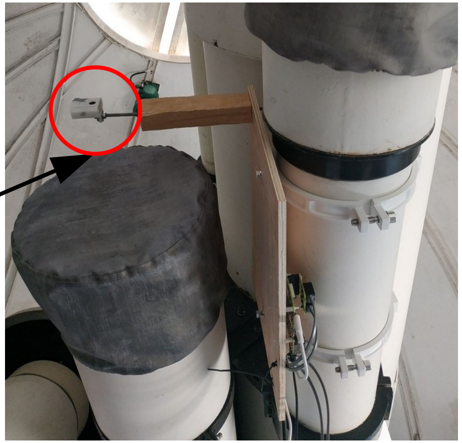


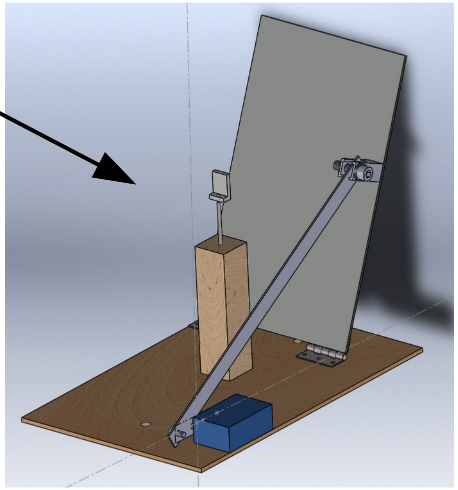
PhD Thesis Kélian Sommer

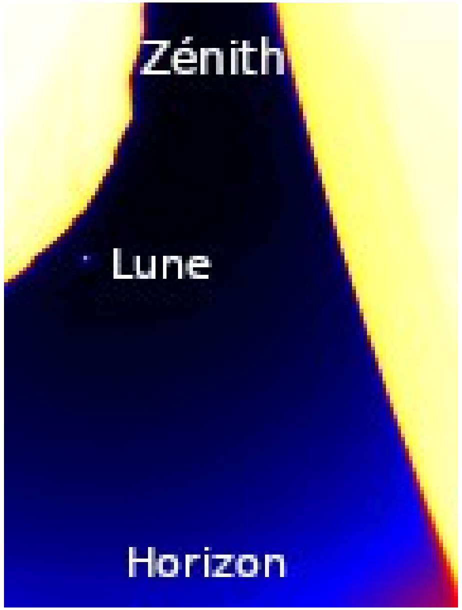
IR instrument (2/2)

- Characterization of the camera :
  - Establish a calibration process (impact of flat fields as e.g.)
  - Check the camera sensitivity performance
- Start of the first tests at UM* observatory with a prototype IR camera (FLIR Lepton)
- Design an automated flat-field mechanism for calibration to reduce non-uniformity of the bolometer array below pixel temporal noise to obtain high thermal resolution
- Coming up :
  - Simultaneous observations with IR and CCD cameras to provide optical photometry and thermal data at UM and OHP in June
  - Waiting for the new IR camera with better performances (FLIR Tau2)

*UM = Montpellier University



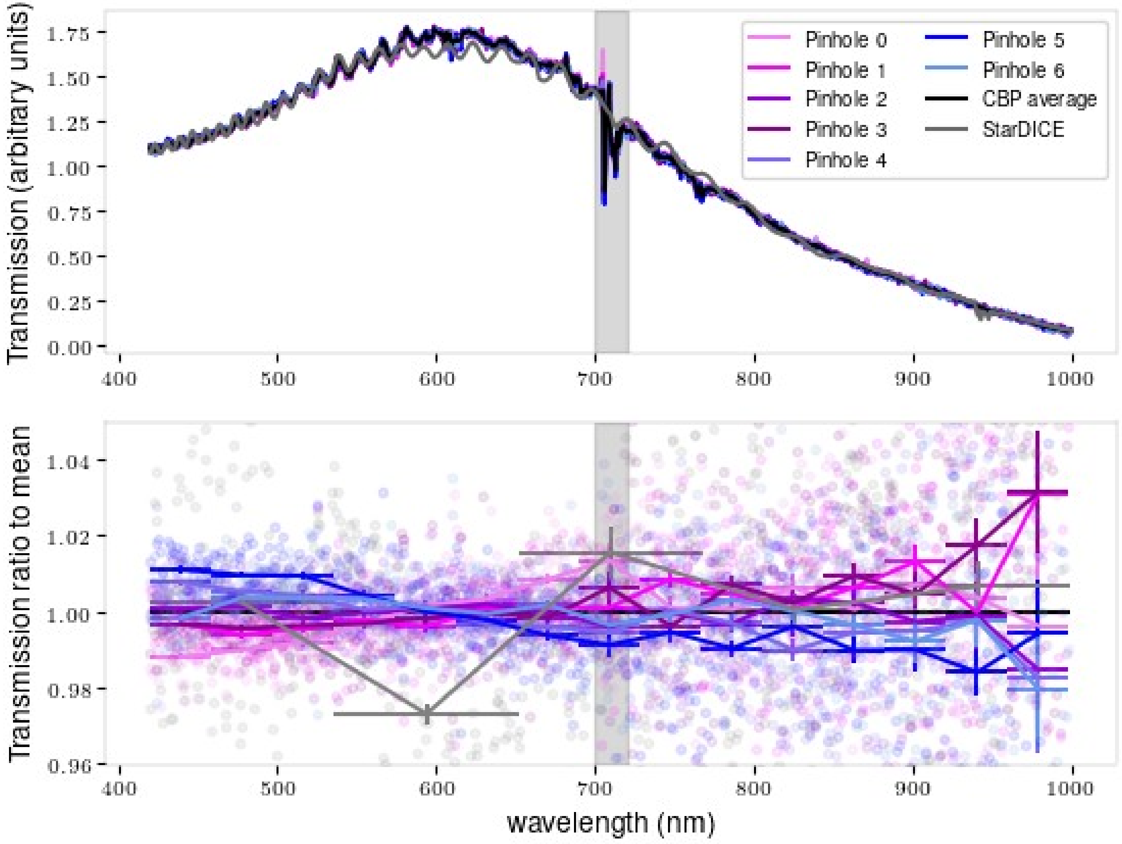




Conclusion: exiting times for StarDICE

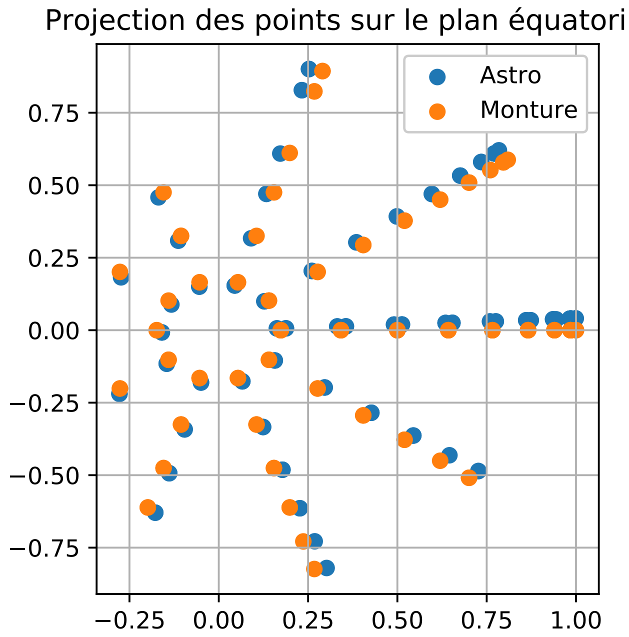
- Lessons learned from the pathfinder
- All pieces are coming together
- On track for a first light of the upgraded instrument this summer
- No obvious show-stopper for the development of the artificial star
- Fruitful collaborations within the PCWG (CBP and others)
- Exiting new developments (Spectroscopy and IR)
- Great work from every body in conditions far from optimal

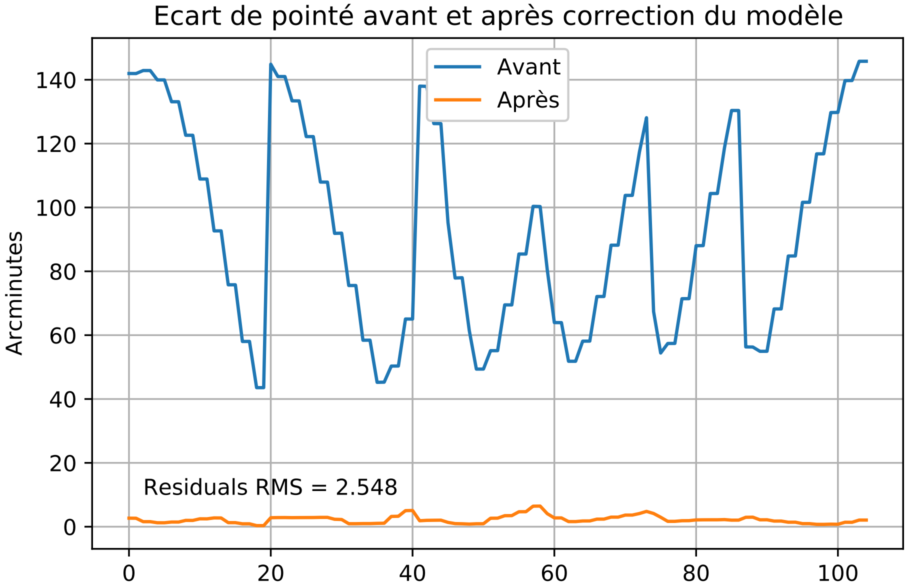
The old CBP measurement



- The Harvard CBP project calibrated monochromatic light on a portion of the StarDICE telescope aperture
- Ratio of the counts in the Stardice detector to emitted light gives the StarDICE transmission
- In our first iteration we obtained a measurement of the transmission between 400-1000nm at 6 position in the focal plane
- 3% chromatic variation across the focal plane easily spotted (to be confirmed by direct measurement of the sensor)
- Left for next step:
  - Change Laser to fix the degeneracy region around 700nm
  - Improve signal to noise (detector and CBP
  - Demonstrate pupil stitching

Solving the astrometry





We spend 4 days at OHP in July to write the new mount control command and gathered of first astrometric data set (120 images in 60 pointings) to train the pointing model.

- The 1.5m x 1.5m optical table now point toward stars with 2 arcmin accuracy
- Work done by a master student Alexeï Mollin