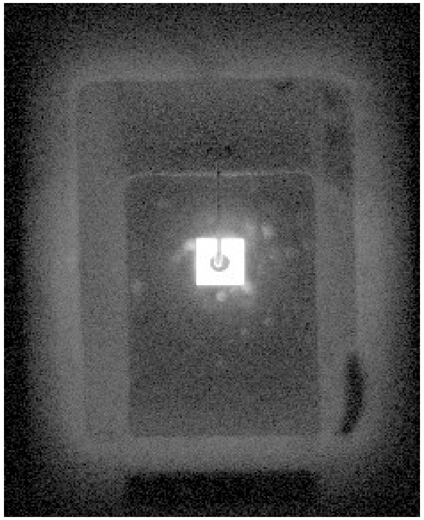

VRO-LSST / StarDICE Status Report

Laurent Le Guillou
(Sorbonne Université / LPNHE)

Journées LSST France
LPNHE, Paris
22-24 novembre 2021

CPPM : O. Angelini, S. Beurthey, S. Deguero, F. Feinstein

LPNHE : P. Antilogus, P. Astier, Ph. Bailly, E. Barrelet, M. Betoule, S. Bongard, J. Coridian, B. Delamour, M. Dhellot, A. Guyonnet, D. Hardin, F. Hazenberg, C. Juramy, H. Lebbolo, L. Le Guillou, E. Pierre, J. Neveu, N. Regnault, Ph. Repain, M. Roynel, K. Schahmaneche, E. Sepulveda, T. Souverin, A. Vallereau

LUPM : J. Cohen-Tanugi, Eric Nuss, B. Plez, K. Sommer

LAL : S. Dagoret-Campagne, M. Moniez

OHP : Pierre-Eric Blanc, Auguste Le Van Suu

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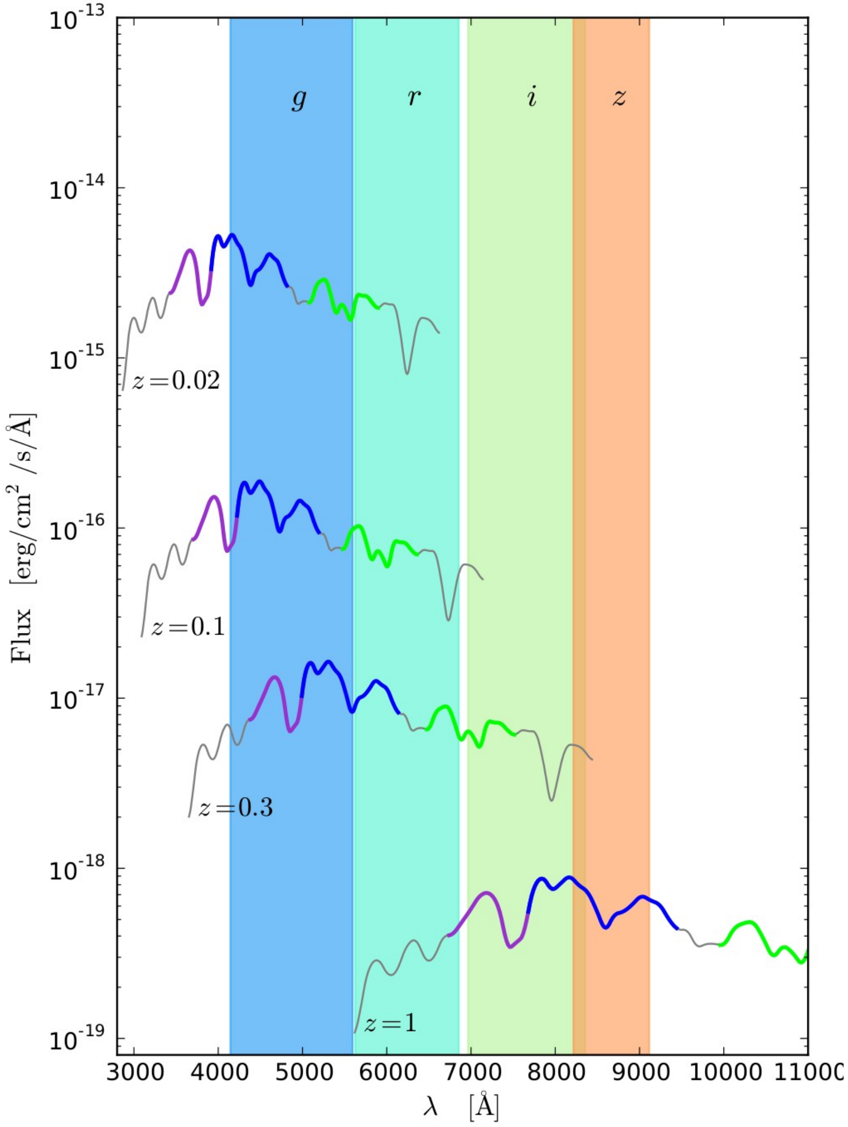
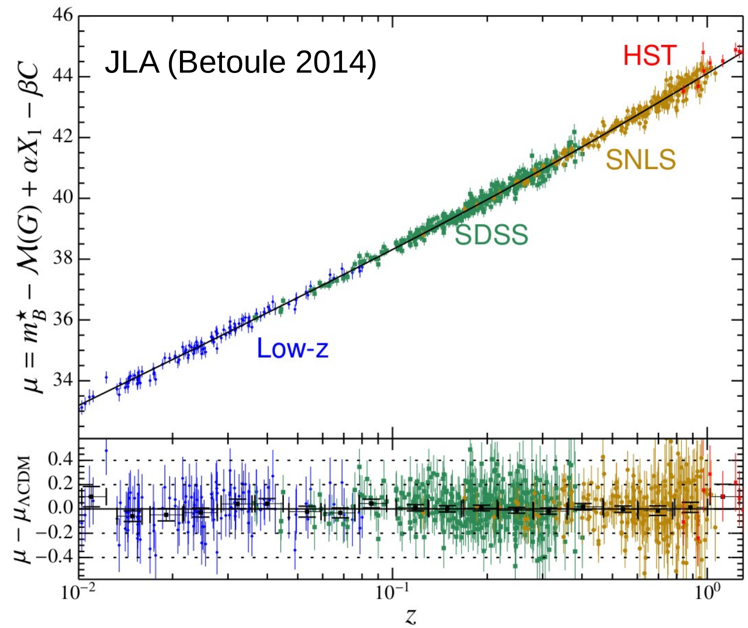
Cosmology with SNIa : Systematics



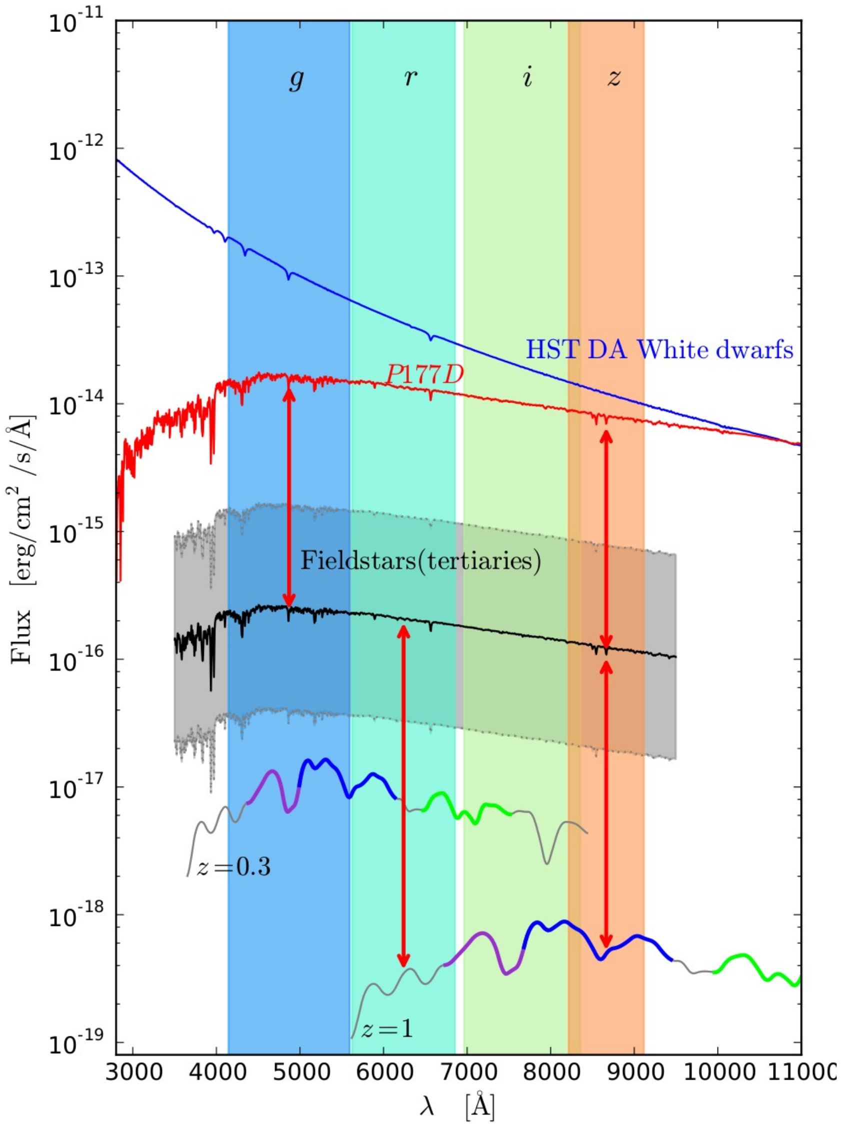


Distances measurements with SNIa : comparison of the integrated flux in **effective passbands** which are **shifting with the redshift**

→ **Passband knowledge** and accurate calibration across the whole wavelength range is needed.

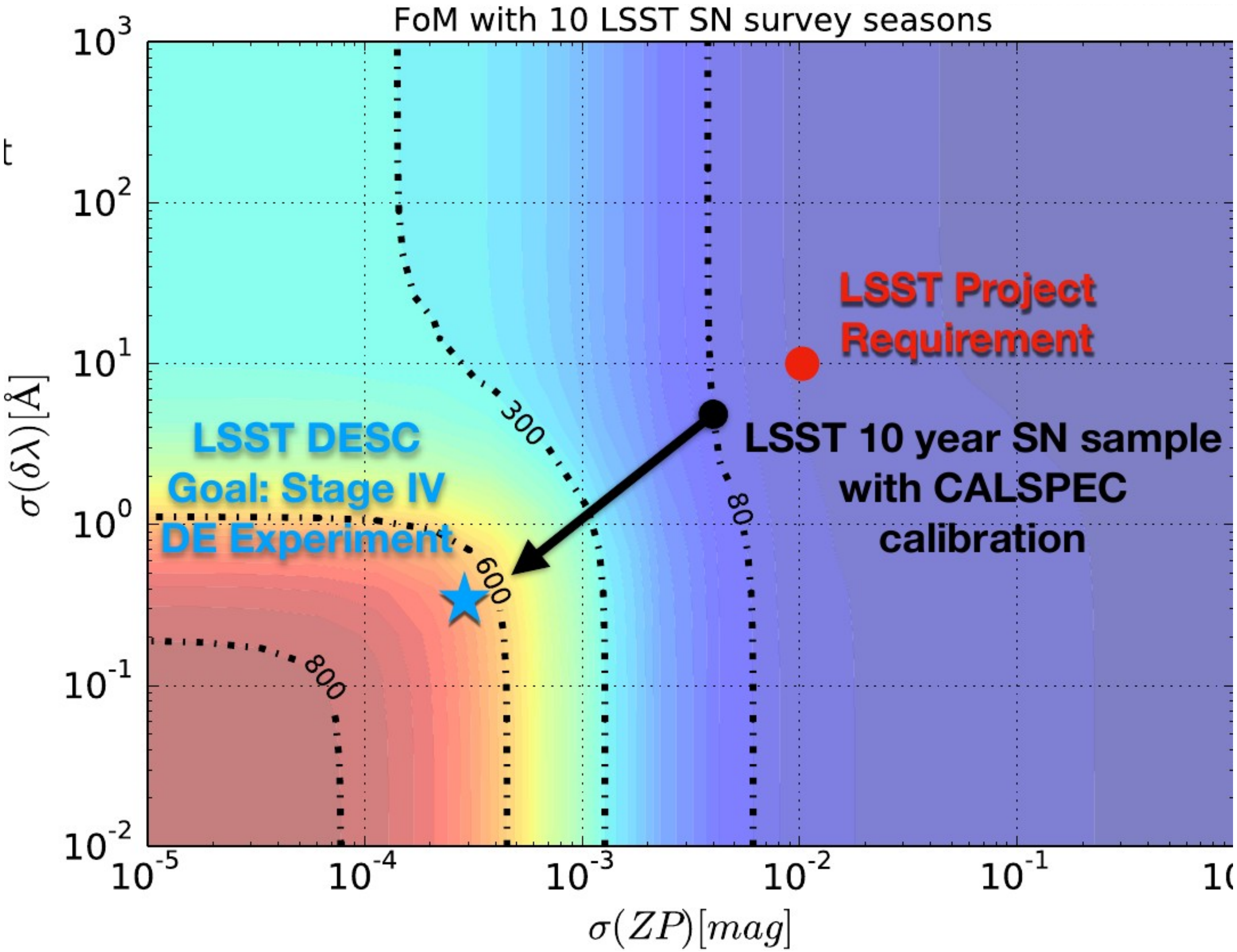
→ **Dominant systematic** for SNIa cosmology

SNIa calibration based on white dwarfs model



- Supernovae photometry done relatively to the **field stars** (~1 mmag, Astier 2014)
- Field stars calibrated with the **CALSPEC standard stars** (eg ~5 mmag Betoule 2013)
- CALSPEC stars calibrated using a few pure hydrogen **white dwarfs** measured with HST (Bohlin)
- Pure H White dwarf spectrum obtained through a **radiative transfer model** (Narayan et al. 2019)

Calibration accuracy needed for LSST/VRO



F. Hazenberg (2019)

To constrain *w at the %* level we need at least ZP calibration at 0.1 %

A signification amount of LSST statistical power is harvested when

σ(ZP) < 0.001 mag

VRO-LSST / StarDICE : goals & principles

- **Goals** :
  - **Check the white dwarfs calibration** through an alternative metrology path. To do so, **measure the CALSPEC stars** in *ugriz* and and **link** these photometric measurements to a **lab radiometric standard** (NIST)
- **Principles of the StarDICE project :**
  - Build a multi-wavelength **point source** (~ a few 10^{-4}) **calibrated** using a NIST photodiode
  - Observe and measure **simultaneously** our **calibrated light source** and the **CALSPEC stars**, with the **same instrument**
  - Precisely caracterize the **instrument** : sensor gain & QE, filters throughput, global instrumental throughput ;
  - **Model the atmospheric extinction** (airmass variations, atmospheric models) and correct for it.
- **Setup installed at the Observatoire de Haute-Provence**, an observatory already well equipped in various atmospheric monitors (lidars, atmospheric chemical composition monitoring, *etc*)

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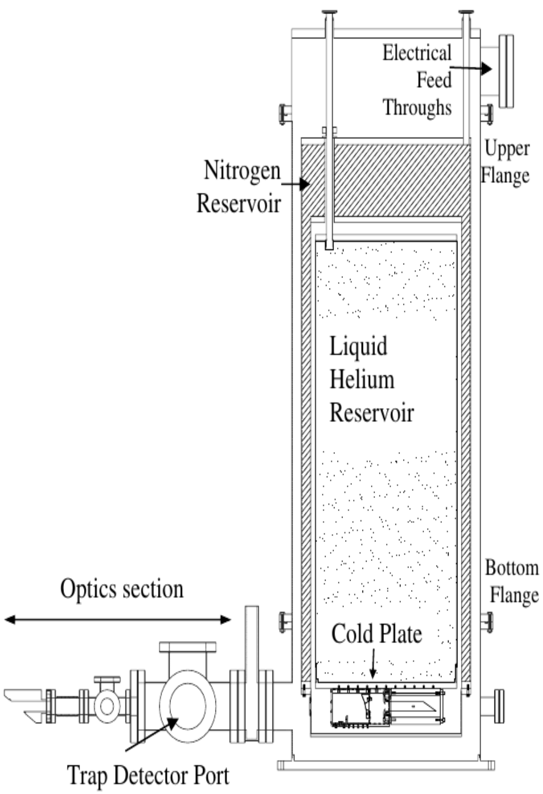
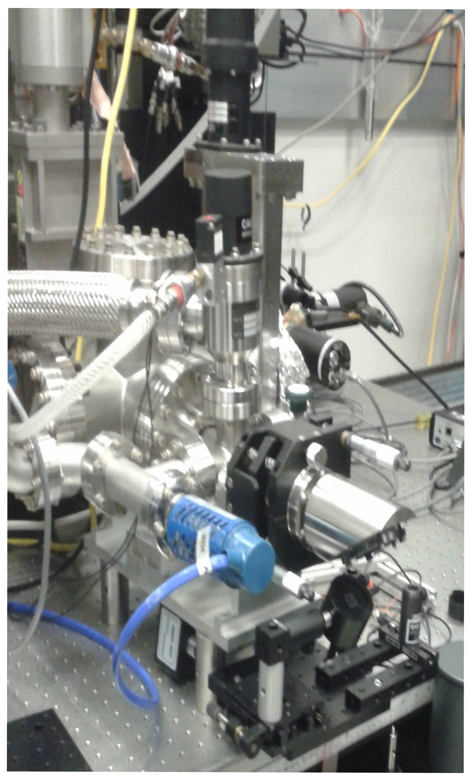
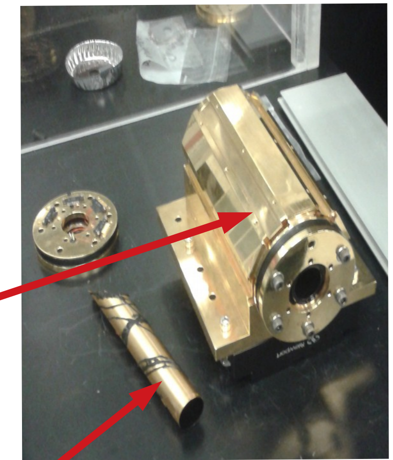
NIST Primary Standard

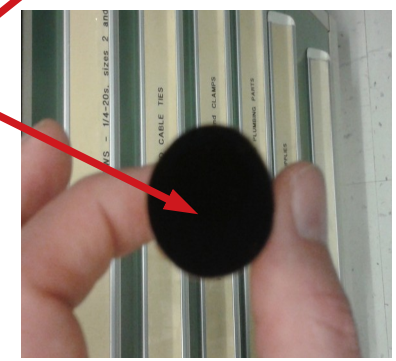
POWR: the Primary Optical Watt Radiometer (Brown et al. 2006, Houston et al. 2006) high-accuracy electrical substitution cryogenic radiometer → **relate radiometric power** to a **thermo-electric measurement**.



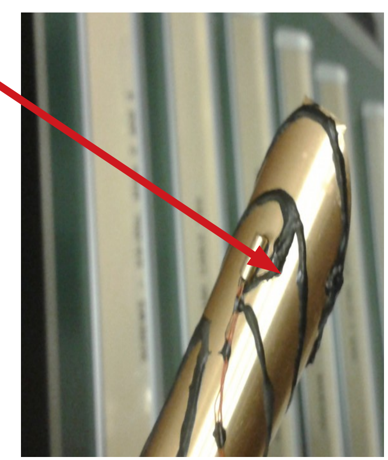




Cryogenic shelter



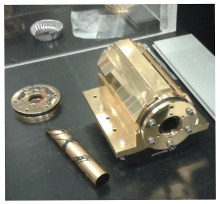
Black absorbing cavity



Germanium resistance thermometer

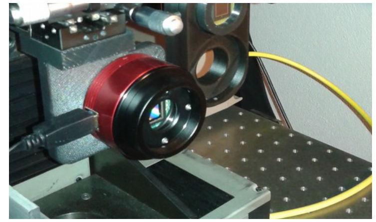
Claimed accuracy at the 10^{-4} level

StarDICE metrology chain (from NIST to stars)



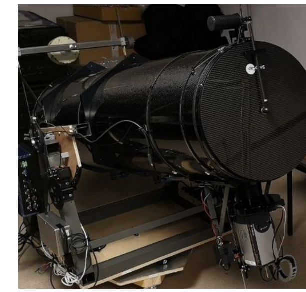
NIST POWR

NIST Photodiodes



CMOS Camera + Calibration spectrograph

Small aperture telescope + passband measurement + Atmospheric monitoring



mW

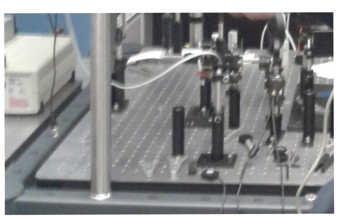
μW

10^{-13} W/cm²/nm

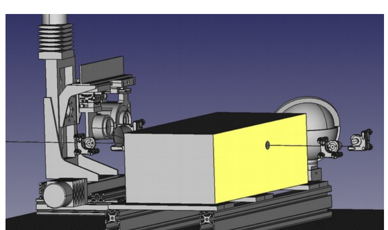
10^{-17} W/cm²/nm

10^{-19}W/cm²/nm

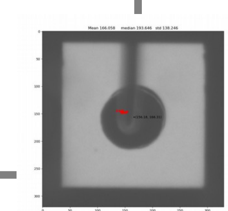
NIST SCF



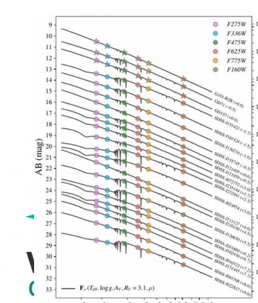
StarDICE transfer bench



Narrow spectrum LEDs with forward voltage monitoring



Spectrophotometric standard stars



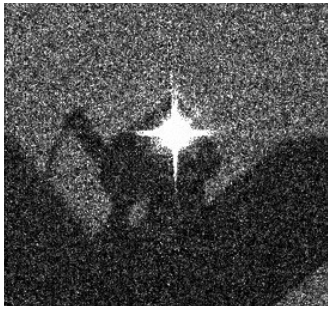
StarDICE *phase 0* : feasibility study (2016)

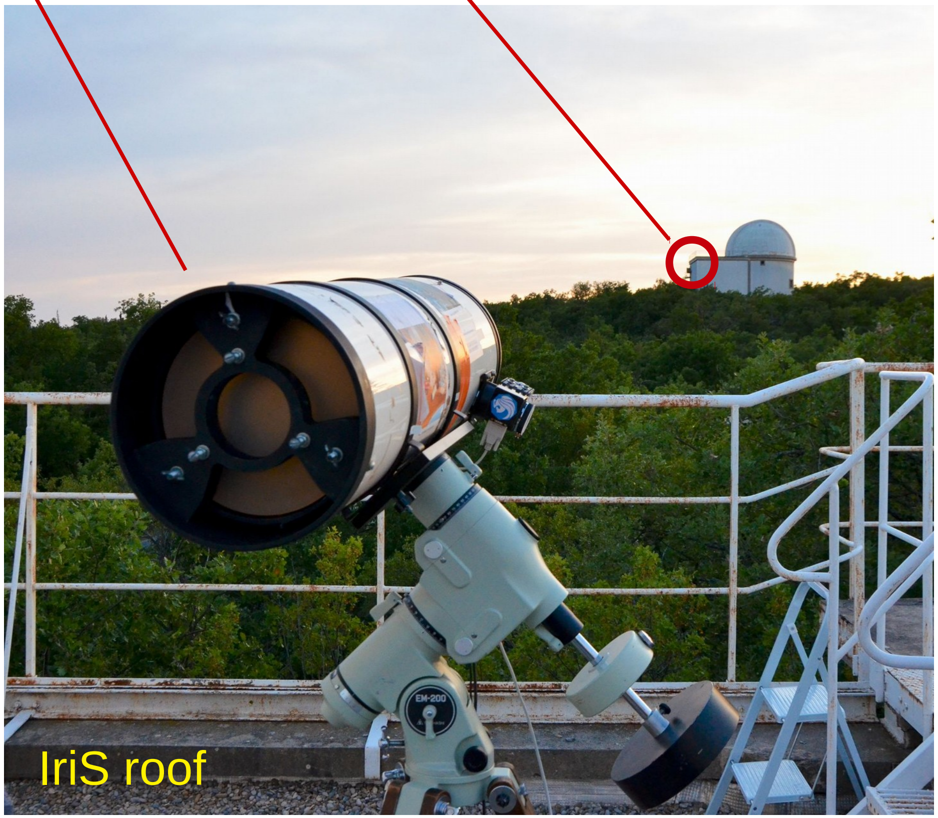
- **Proof of concept** performed at **Observatoire de Haute-Provence** (OHP)
  - Can focus and do photometry at ~200 m and at infinity with a small telescope
  - Similar PSF shape for LEDs and stars

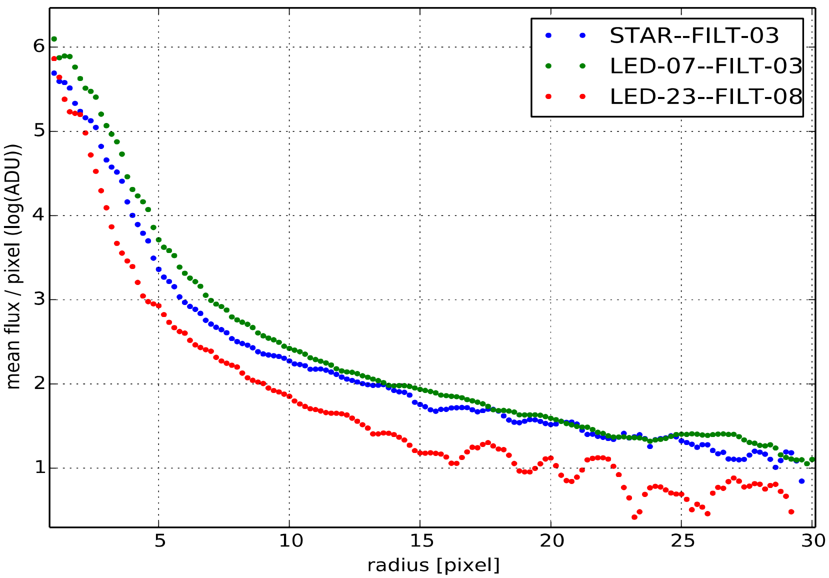
Newton Telescope
10 inch - f = 1500 mm
(LUPM)

SBIG CCD
ST7-ME
5 Bessel
filters

(Sky/SN)DICE
24 LEDs
calibrated
source [T152]
(LPNHE)



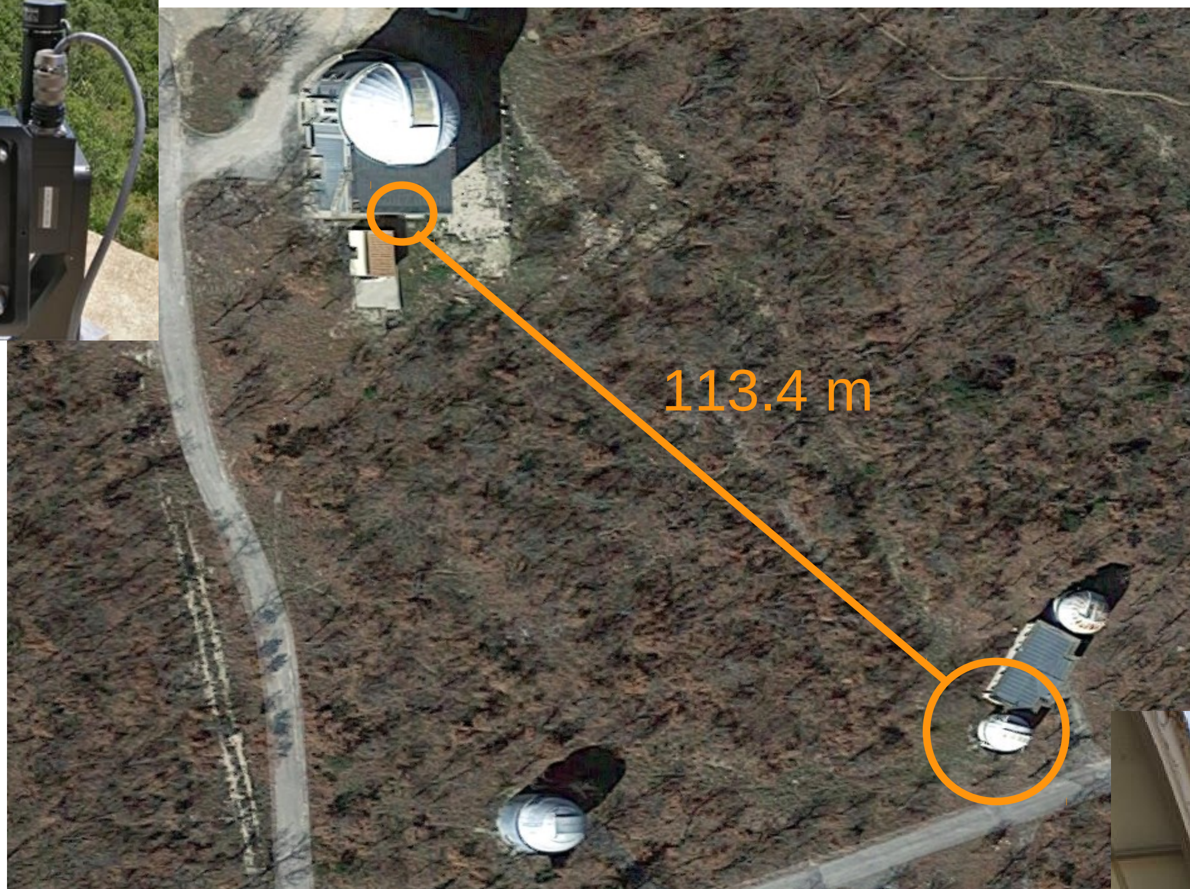




StarDICE *phase 1* : at the Jumelés (2017-19)

- **Permanent installation** in the western « Jumelés » (« twins ») coupola

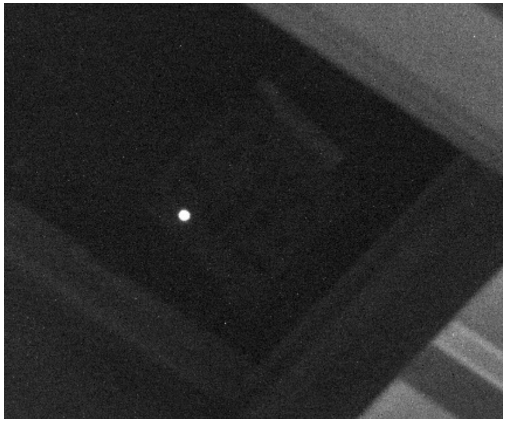
(Sky/ SN)DICE 24 LEDs calibrated source installed in the window of the T152 control room

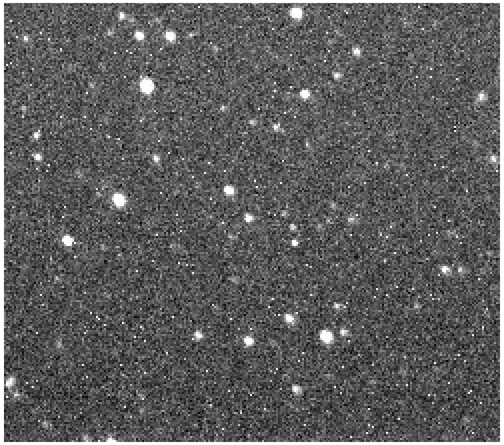


Same StarDICE telescope and SBIG CCD camera installed in the old western « Jumelés » coupola (equatorial plateform)

StarDICE *phase 1* : at the Jumelés *(pathfinder)*

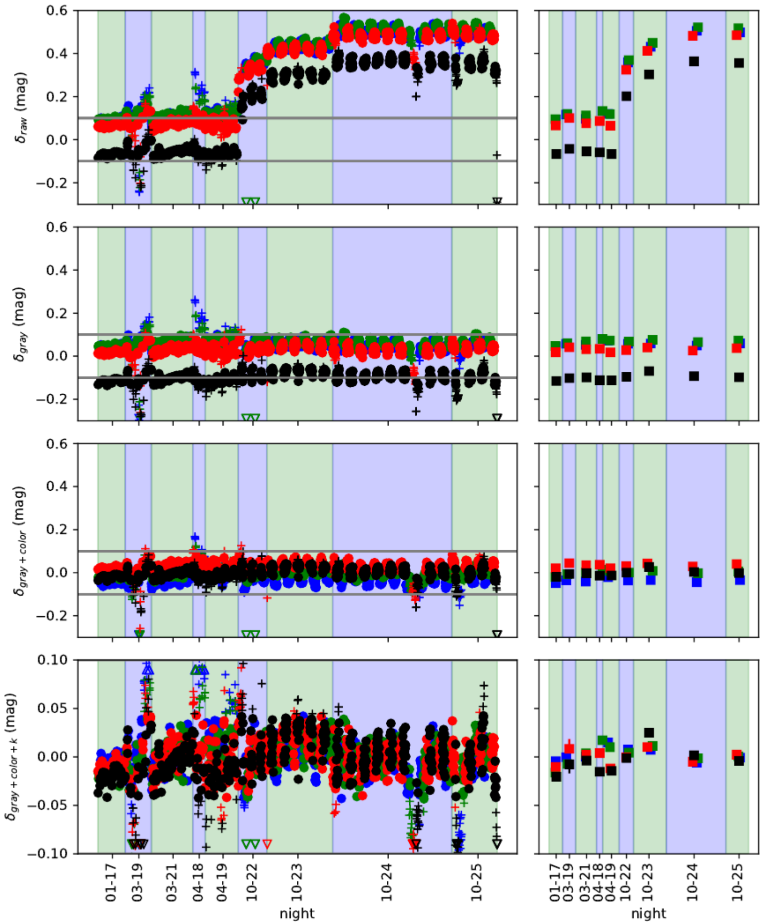
- **First complete dataset** with **photometry** of **both standard stars and calibrated LEDs** [stars (7 nights), LEDs (11 nights), both (9 nights)]
- Compared **measured fluxes** and **synthetic ones** (instrument model)





- Assessed the **stability of the LEDs**
- Evaluation of the **systematics**
- Estimated the needed statistics to reach 0.1 % (~400 nights)

F. Hazenberg PhD thesis (2019)

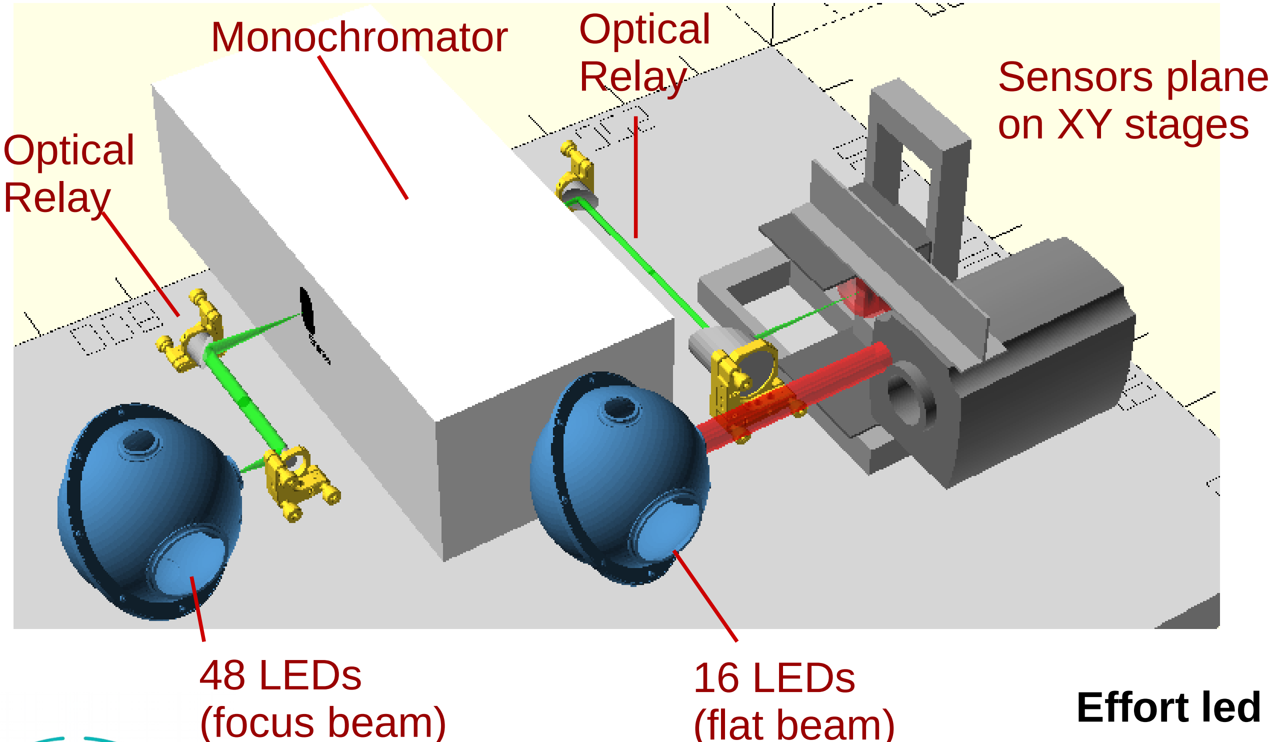


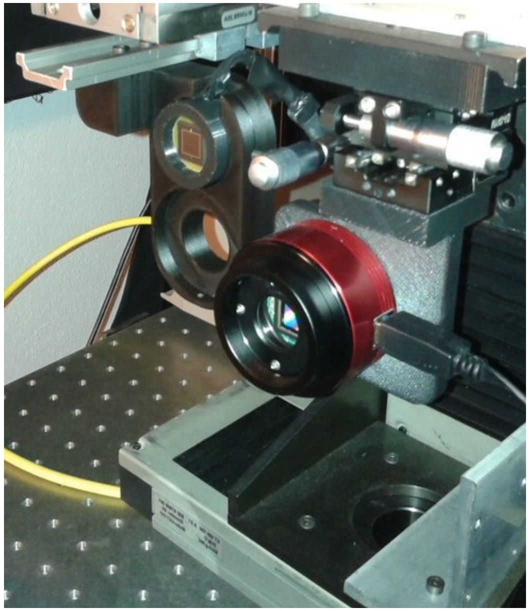
StarDICE *phase 1* : lessons for final design

- **Mapping the absolute irradiance** of the calibration LEDs with the NIST photodiode is too slow → Use a **cooled CMOS sensor, calibrated** with NIST photodiode on a **dedicated calibration transfer bench**.
- Due to low fluxes, the **spectroscopy of the LEDs** needs a **dedicated instrument** → Build a **dedicated testbench spectrograph**.
- Determining the **instrument passbands** only with broadband LED data is difficult → Complementary **throughput measurements with Harvard CBP**
- **LED spectra slightly change with temperature**, and monitoring the **junction temperature** is not satisfying with the (SN/Sky)DICE sources →**Design a new LED source** where we **monitor the forward current**.
- Take into account the progress made in **slitless spectrophotometry** with the developments done for **AuxTel** (VRO/LSST auxiliary telescope).
- Requires **hundreds of observation nights** → complete **automation of the StarDICE telescope, instruments & coupola** and **remote observing**
- **Fast variations of the gray extinction** is the main noise contribution to the nightly regression of the atmospheric throughput → **IR monitoring** of the cloud coverage

A dedicated Calibration Transfer Bench

- **Calibration transfers** between NIST photodiode, CMOS & CCD detectors
  - 2 beams : a **tunable monochromatic f/9 beam** for **QE measurements**, and a **polychromatic flat beam** for flat fields & electronics study.
  - **Achromatic optics** : optical relays made of off-axis parabolic mirrors.





Effort led by C. Juramy & M. Betoule

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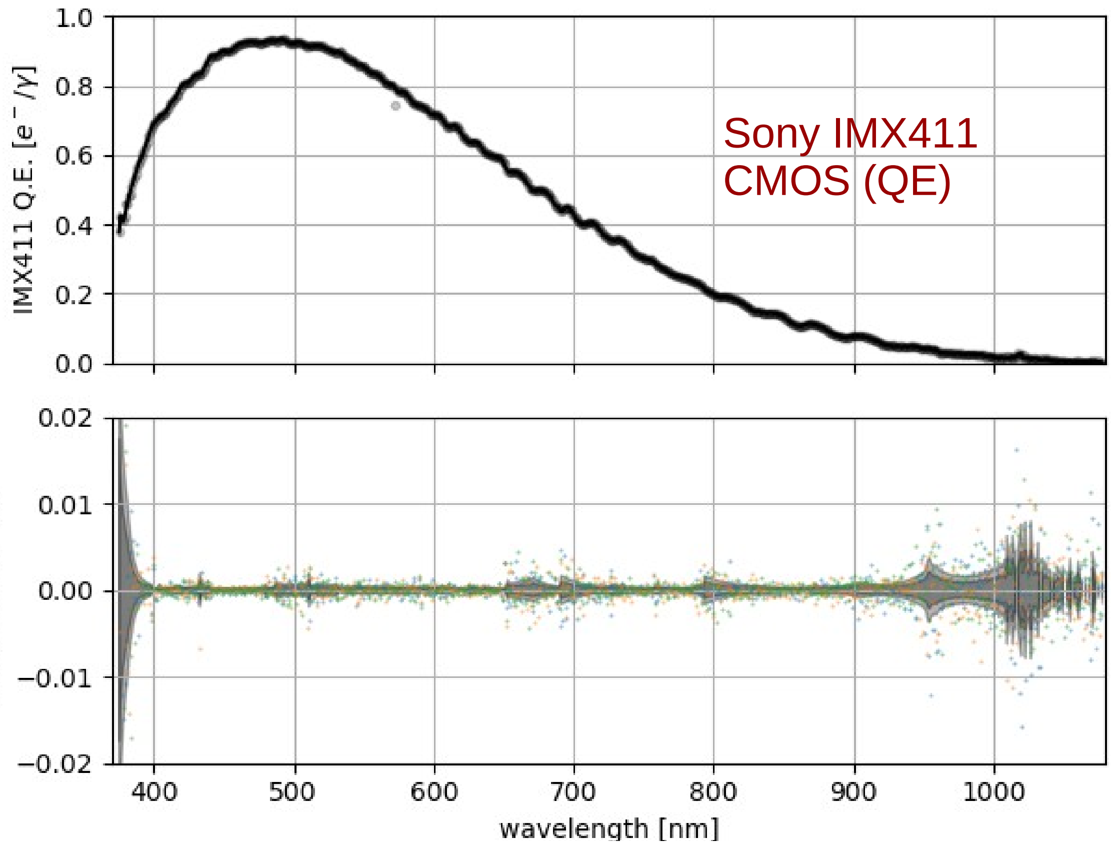
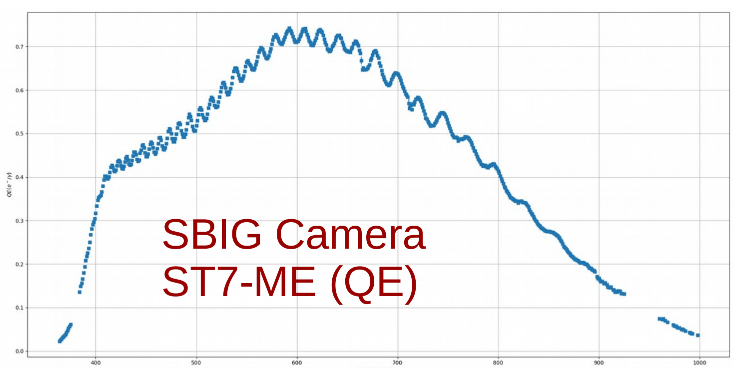
A dedicated Calibration Transfer Bench

- We already performed automated **QE measurements** for **several sensors** :
  - **Sony IMX411 CMOS** sensor as an intermediate **calibrator**
  - **ANDOR iKon-L CCD** for the **ZTF-II SED machine ; QHY for E. Bertin**
  - **SBIG** camera (*phase 1)*
- **Required precision reached** except in IR
  - Solution : **increase IR fluxes** on our testbench

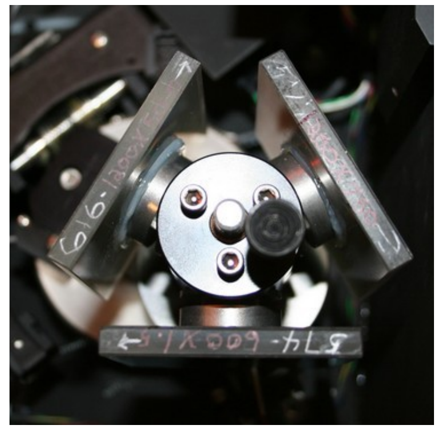


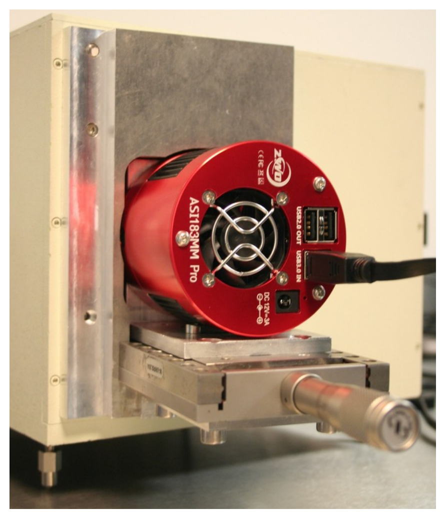


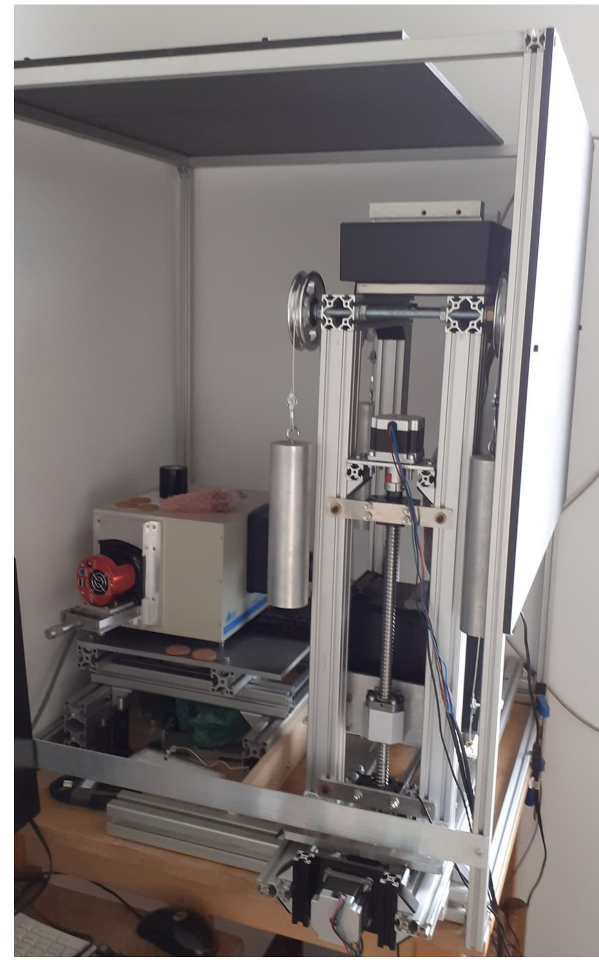
A low flux spectro-photometric testbench

- Our calibration LEDs are **much too faint** for a lab spectrograph. We built a dedicated spectrograph to measure the **LED spectra and their temperature dependency**.

- Modified a **Triax-180 monochromator** to replace the exit (broken) slit by a **cooled CMOS camera** with a large sensor (ZWO ASI 183 MM)
- Obtained a **highly sensitive spectrograph** covering a **tunable 50 nm range**, with **0.01 nm resolution**
- Built an automated motorized testbench to move each LED in front of the entrance optics







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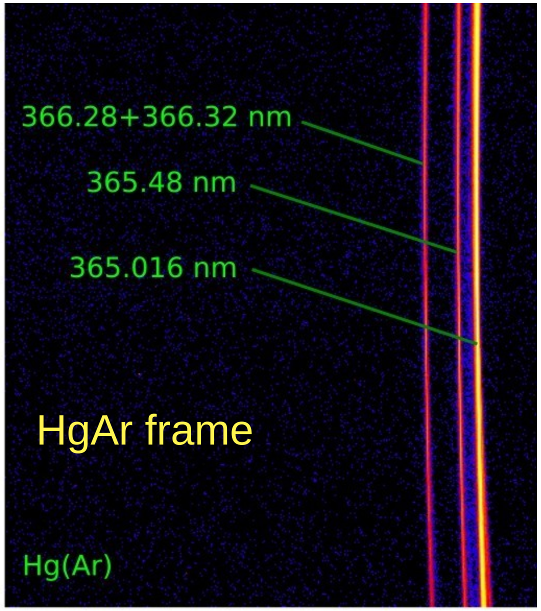
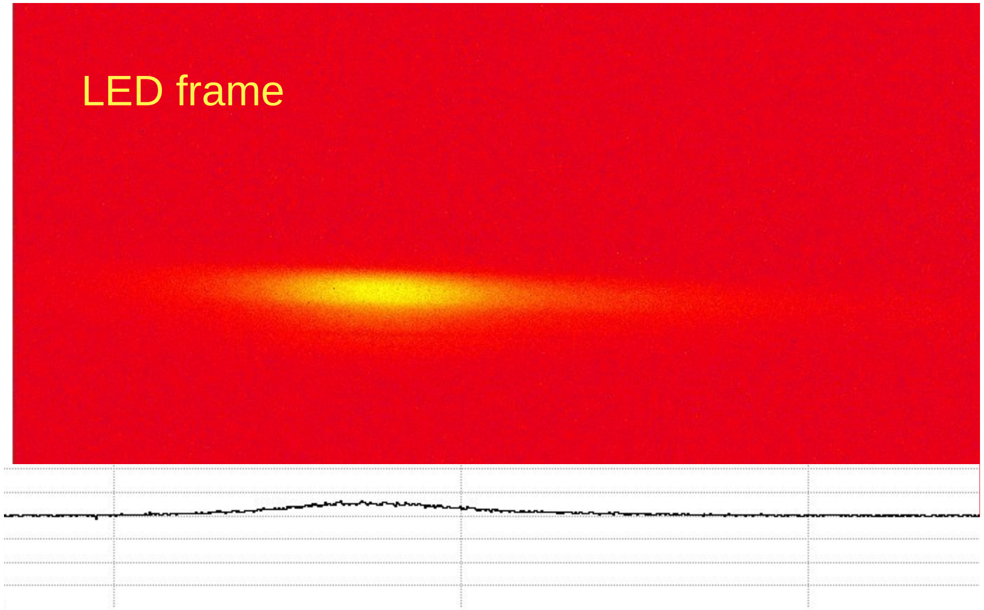
Effort led by L. Le Guillou & E. Sepulveda

A low flux spectro-photometric testbench

- We obtain **LED spectra much faster** compared to our previous spectrophotometric testbench (scan with a monochromator + NIST phd.).
- **Wavelength calibration** with **HgAr** ; **throughput correction** still to be performed with a **calibrated halogen lamp** (Ocean Optics HL-3P-CAL).
- A large dataset at temperatures 12°C – 30°C has been accumulated, analysis is ongoing.





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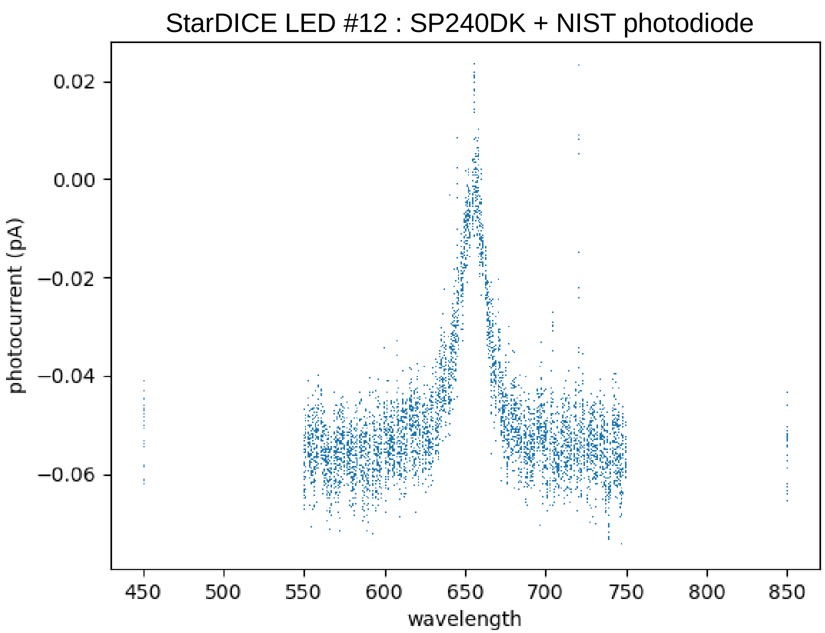
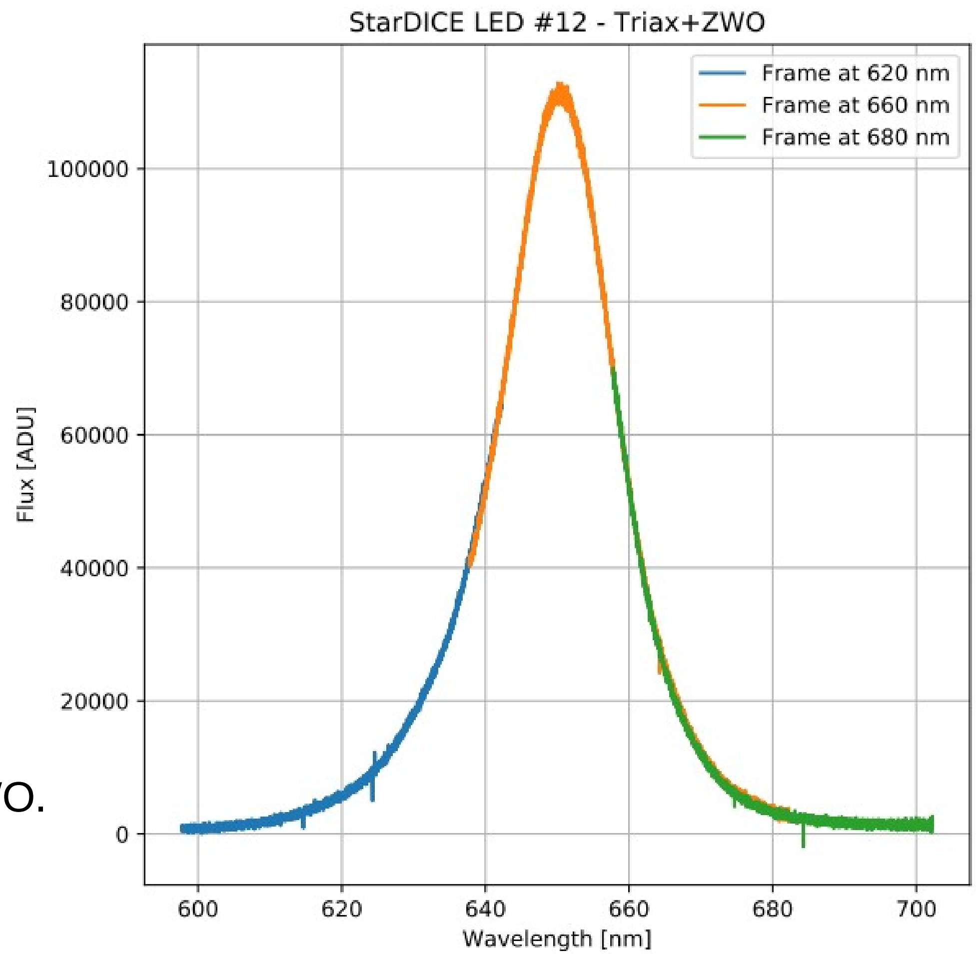
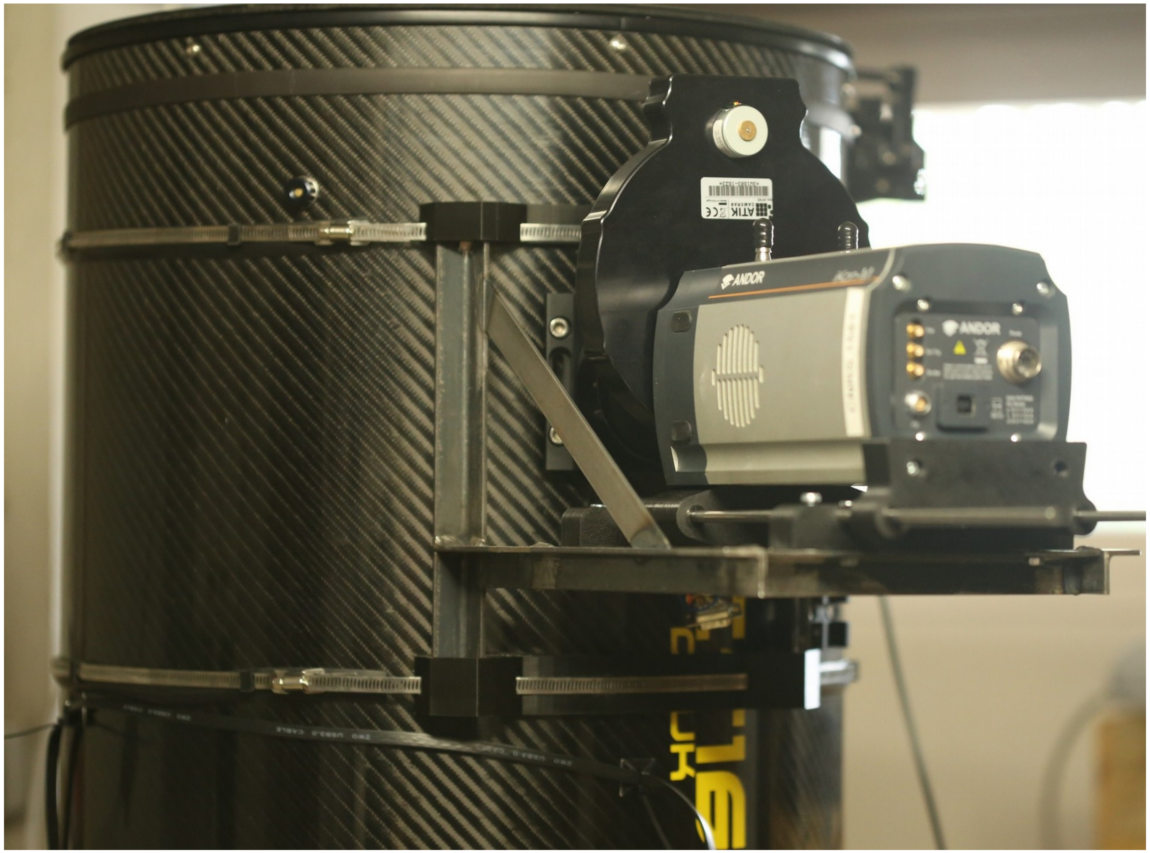




- LED #12 : 2000 s wavelength scan

  versus 3 × 200 s exposures with Triax+ZWO.

A new telescope and new CCD camera



40 cm Newton

ANDOR iKon-M CCD camera
1024x1024 13 µm pixels
Back-illuminated deep-depleted

Peltier cooling
Air-cooled : down to -70°C

Filter wheel with :
- **6 broadband *ugrizy* filters**
- **A pinhole**
- **A grism**
- **An empty slot**

As close as possible to LSST

Alt-Az home-made mount built to move the telescope **in front of the Harvard CBP.**

Effort led by M. Betoule

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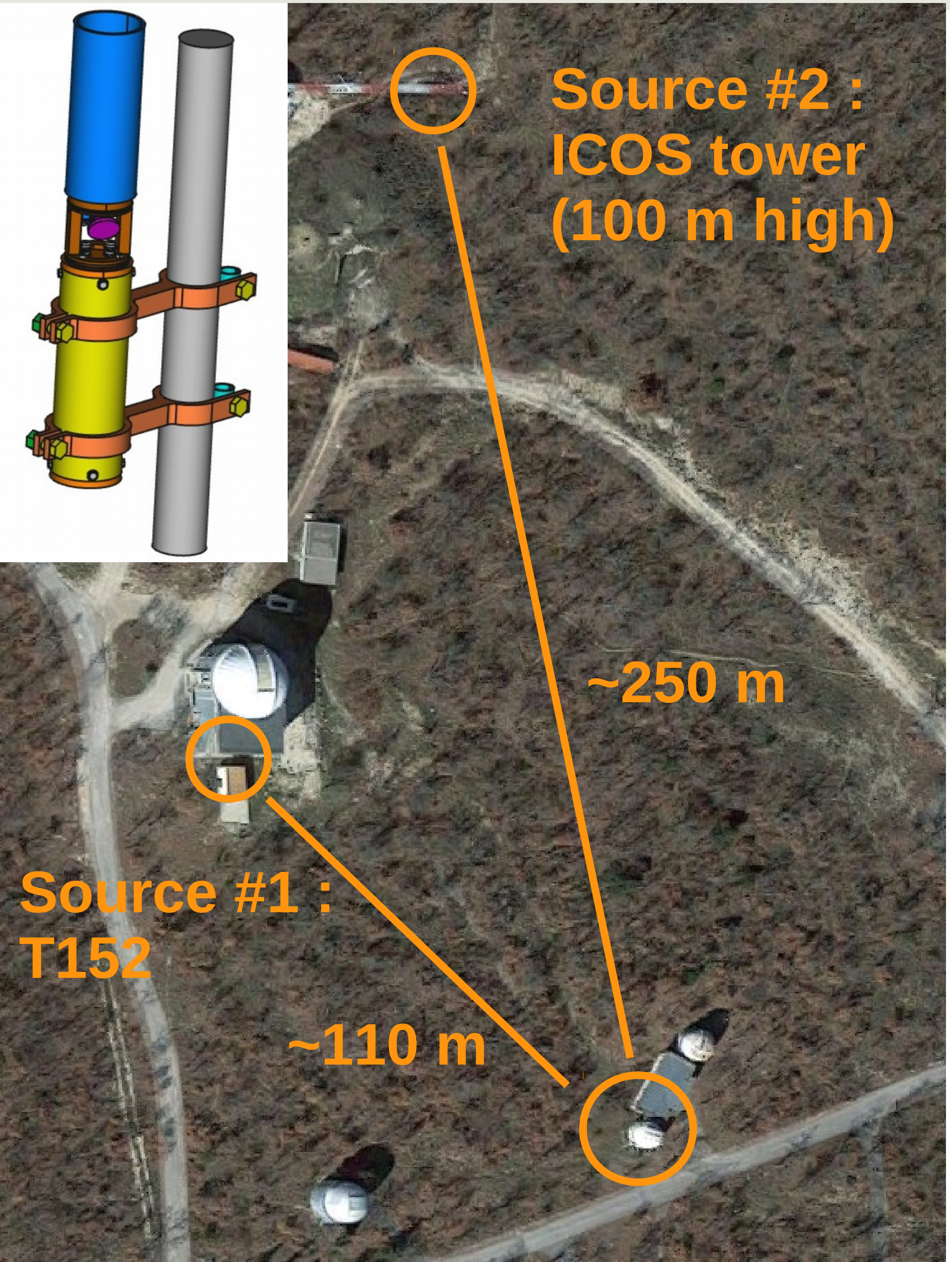
Instrument throughput meas. with the CBP

Effort led by J. Neveu & S. Bongard, see J. Neveu slides

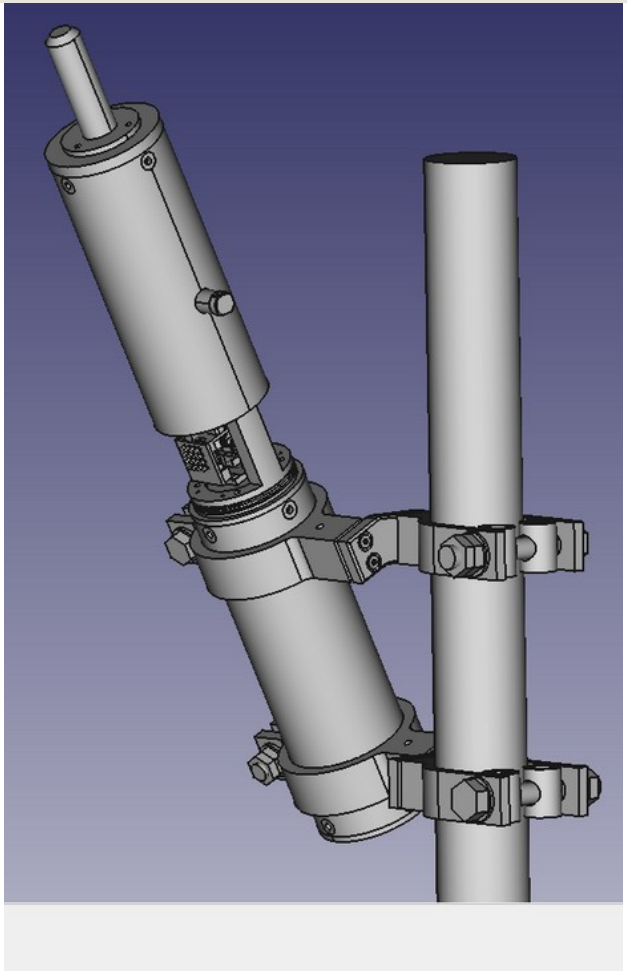
A new calibrated light source (*artificial star*)



- **2 sources** are being built → 2 lines of sight, to better understand the atmospheric extinction close to the ground.
- **2 new source enclosures**, robust and waterproof : one for the T152 and one for the 100 meter high ICOS meteo tower at OHP.
- Each enclosure is equiped with a **metallic cover** which could be remotely opened or closed, thus **protecting the calibrated source**.
- Enclosure for the ICOS tower has a motorized plate to remotely perform optical alignment.

effort led by S. Beurthey & F. Feistein (CPPM)

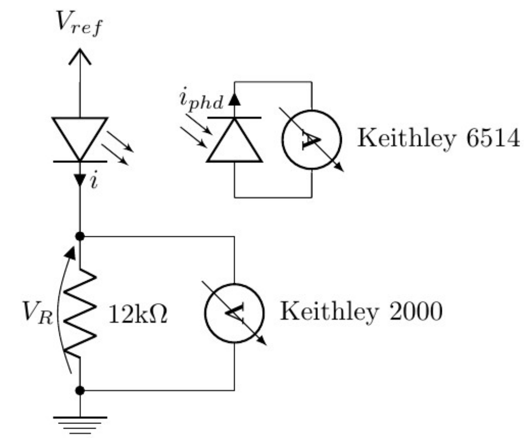
A new calibrated light source (LEDs)



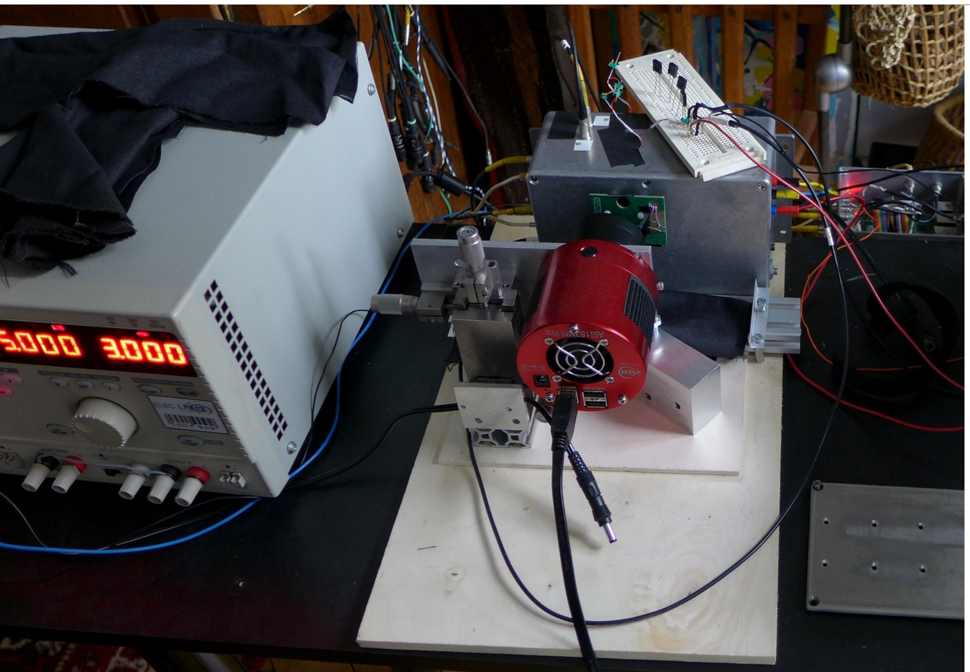
Source enclosure for the ICOS 100 meter tower

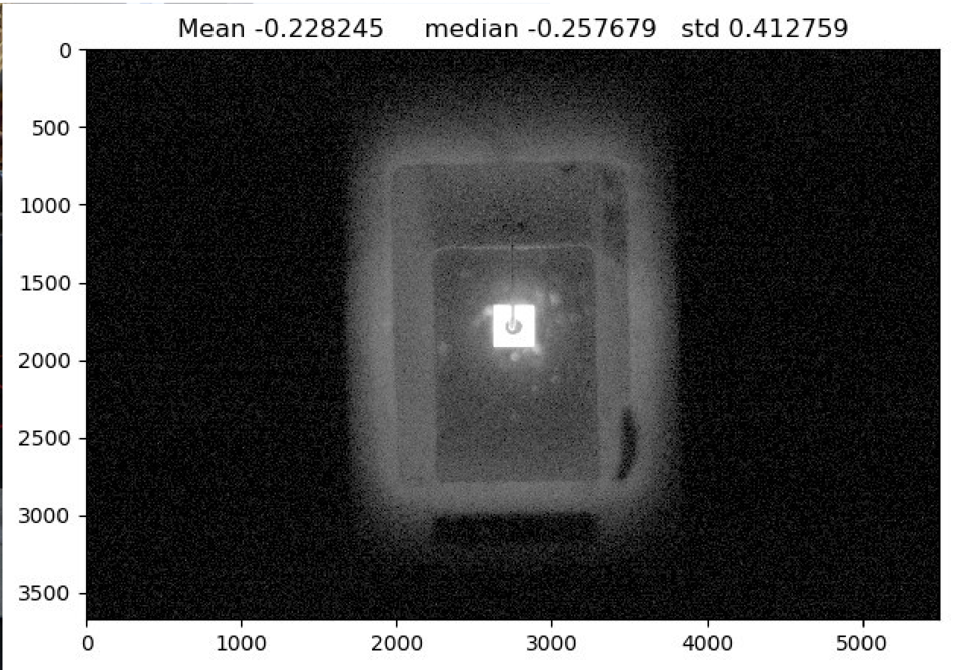
A new driving electronics for the LEDs

- A **16-channel driving board** for the LED currents has been designed ; ADC and DAC have been selected.
- The **prototype is currently extensively tested**.
- A dedicated testbench, with a **cooled CMOS camera** is used to performe **LED photometry and stability studies**



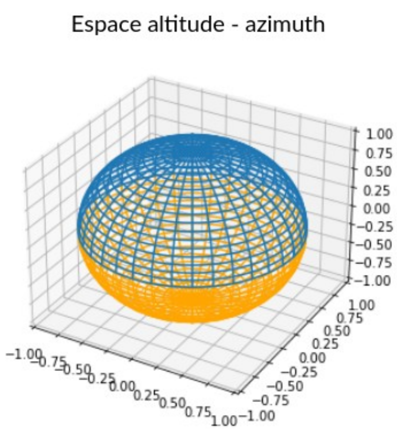
effort led by E. Sepulveda & S. Bongard

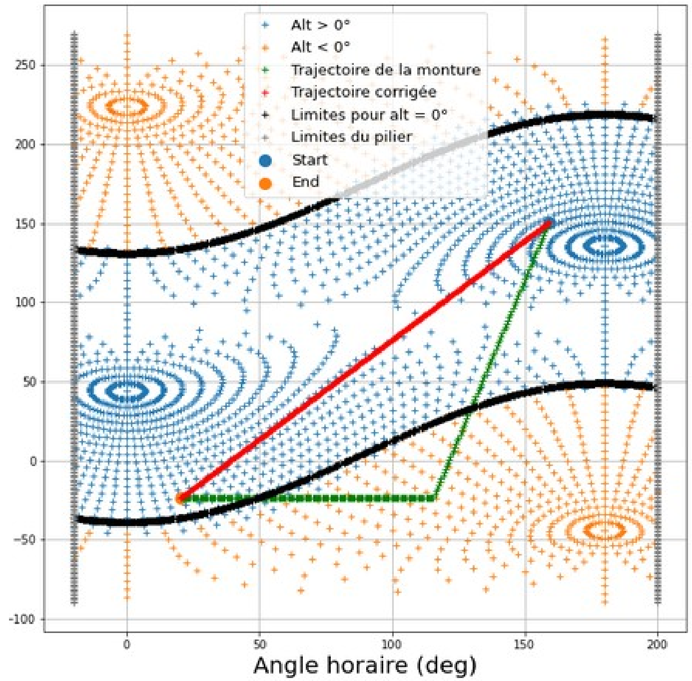


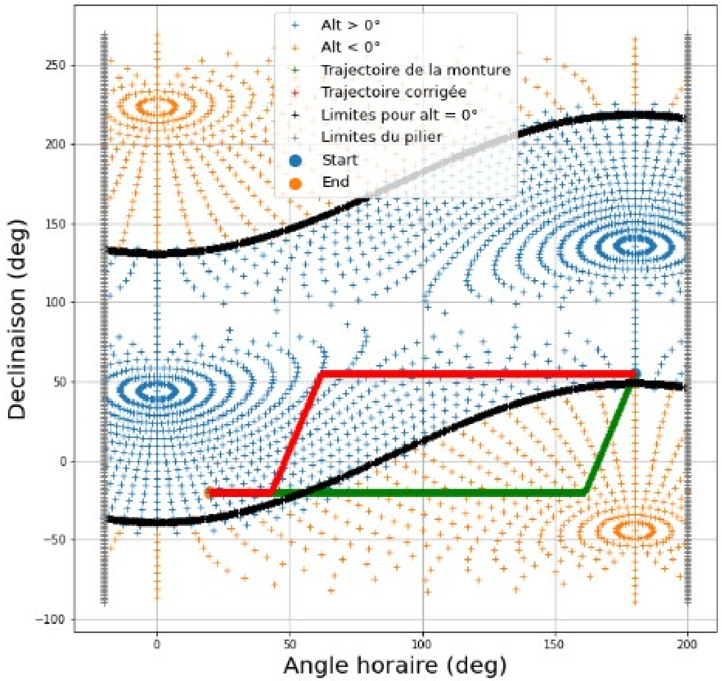


Telescope equatorial mount & plateform

- The existing **equatorial mount has been renovated**, and is now equipped with a **modern controller.** Software integration is done (M. Betoule).
- **Pointing model** developped (M. Betoule, A. Molins, J. Neveu), based on Buie 2003, and **tested on sky** with the *phase 1* telescope and a CMOS sensor. **Pointing error** is now **below 1 arcmin**.
- A **pointing strategy** has been elaborated (T. Souverin, J. Neveu) to **optimize the trajectory** of the telescope and **avoid forbidden positions**







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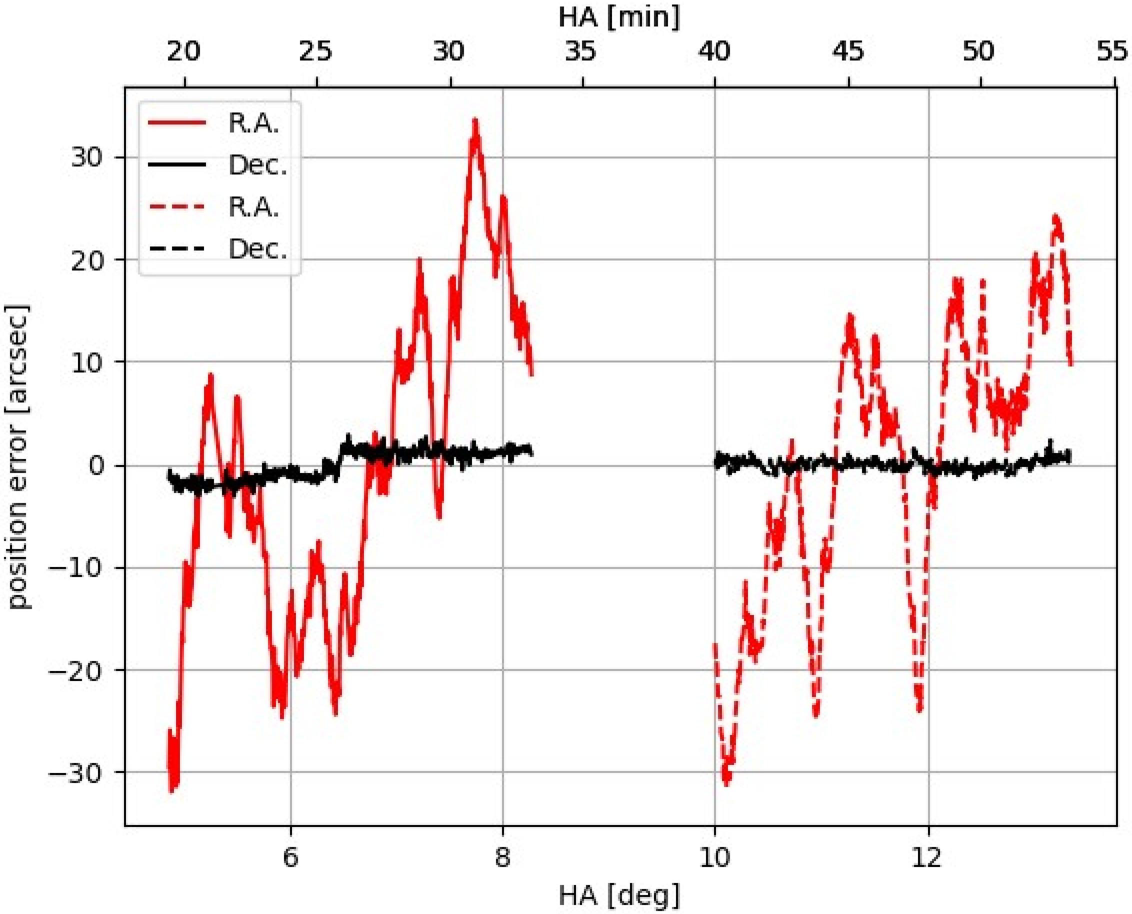
Equatorial mount : tracking

- The **tracking error** has been estimated using very short exposures.
- A mechanical **periodic error** is suspected on the RA axis ; t**he gear of the manual wheel for the RA axis** is also strongly suspected to contribute.
- An auxiliary telescope and a dedicated CMOS have already been ordered to **provide guiding** by the LUPM group (E. Nuss, K. Sommer, B. Plez, J. Cohen-Tanugi).
- Next step : set up, close and optimize the **guiding loop**.



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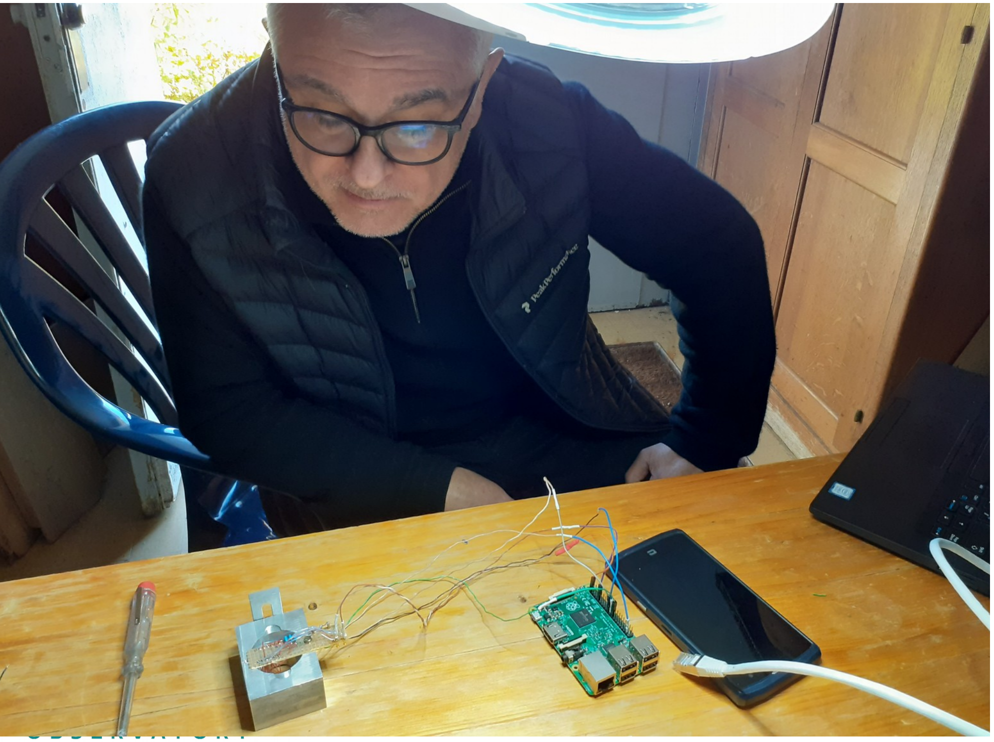
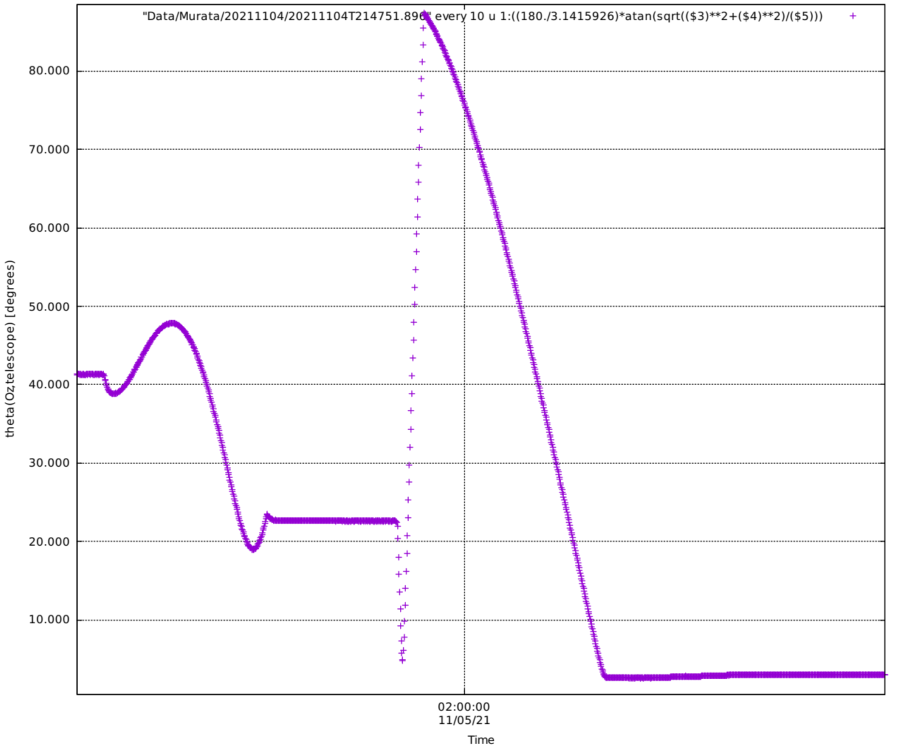
Telescope pointing using accelerometers ?

- Attached a **precision accelerometer** on the equatorial plateform, to test its performances and a possible use during **mount initialisation**.
- May provide an **independant measurement** of the telescope **orientation**.
- Statistical errors on angles **below 1 arcmin** ; to remove degeneracy, a second accelerometer (perp.) would be useful. It may even be possible to **point blindly** using only the data from (calibrated) accelerometers...

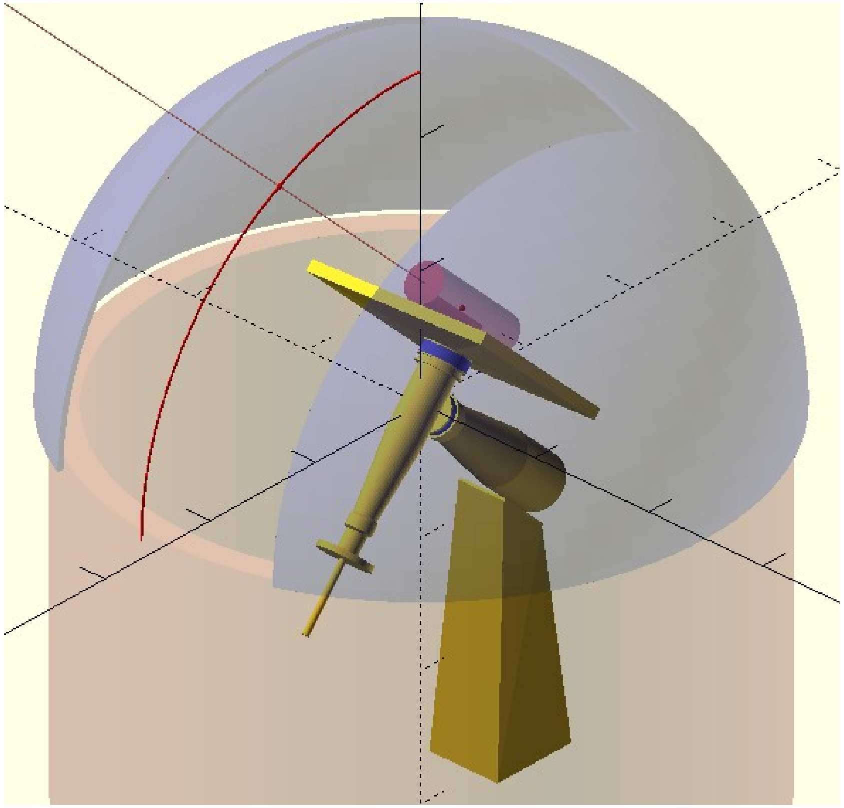




Coupola automation

- Existing **coupola motors** are currently **manually** controlled (buttons).
- Designed a simple system to **know the coupola position**, based on a home-made **revolution counter**, and a **RFID reader** and **RFID tags** to determine the coupola position at initialization.
- The manual command is now ***mechanically* bypassed** ; we plan to soon install **remote controlled 3-phase relays**, for the coupola rotation as well as for the slit opening.
- Developped a 3D model of the telescope, the german mount and the coupola to **optimize the coupola azimut during pointing**. Tested and validated.

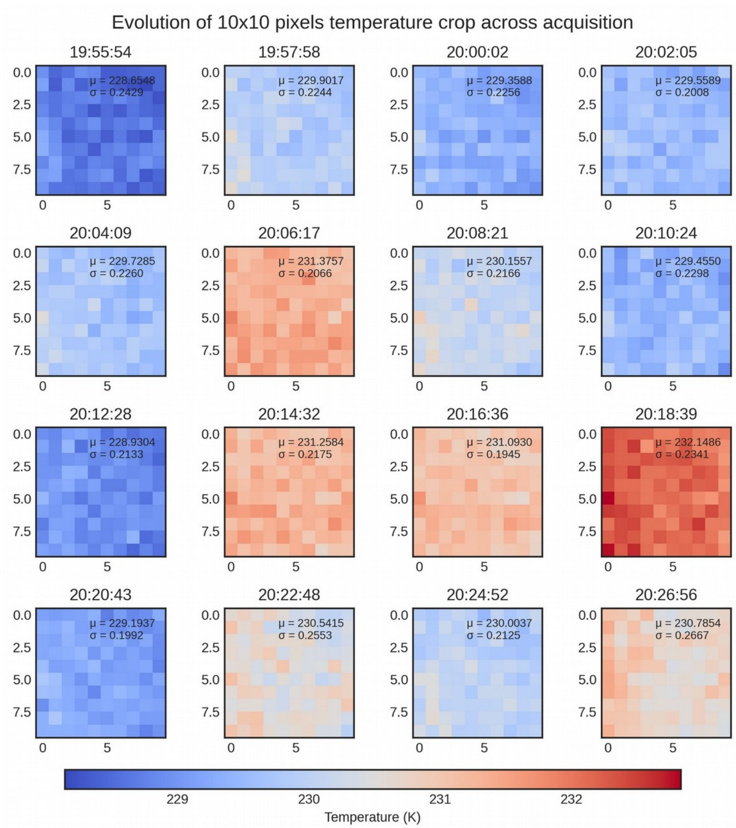
Effort led by E. Sepulveda & L. Le Guillou



(video coupole + telescope)

Clouds & sky extinction : IR instrument

- **Fast variations of the gray extinction** is the main noise contribution to the **nightly regression of the atmospheric throughput**
- Proposal : **IR monitoring of the cloud coverage** with a **dedicated IR camera** fixed on the equatorial plateform, along the main telescope, to **monitor the background sky in the LWIR band (8-13 microns)** to detect the **thin high altitude cirrus.**
- Measure the variations of the **sky brightness temperature** (IR camera) ;
- Correlate the **sky thermal flux** with the **stellar flux** measured with the main optical instrument.
- First tests with a FFC Lepton.

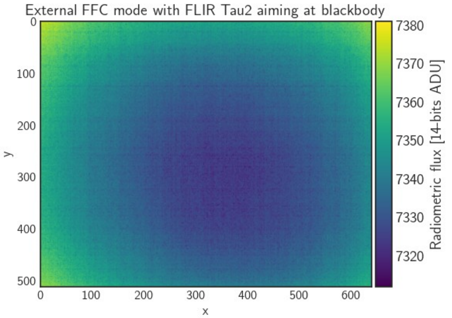


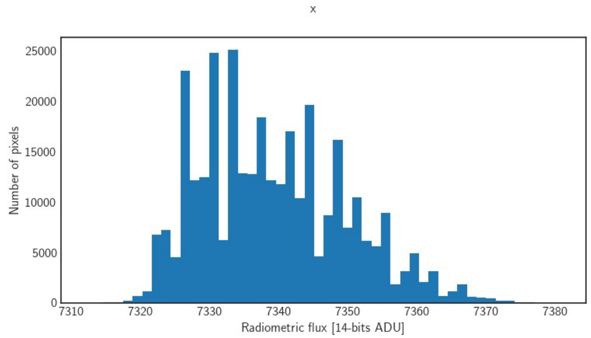
Effort led by K. Sommer (PhD thesis) and E. Nuss, B. Plez & J. Cohen-Tanugi

VERA C. RUBIN OBSERVATORY

Clouds & sky extinction : IR instrument

- Lepton IR camera : **limited sensitivity** ; a **new camera (FLIR Tau-2) has been bought** and is currently tested at LUPM.
- Tests on a Takahashi EM6 mount to be able to **perform simultaneous observations with a CCD and the IR camera** towards the same sky area ;
- IR sensor study with a **commercial blackbody** (response, uniformity, *etc*).





Conclusions & Perspectives

- **Lessons learned** from the project *phase 1 (pathfinder)* ***;***
- On track to **install the new instrument at OHP in early 2022** ;
- Great progress towards a **full** r**emotely controlled telescope, instrument, mount and coupola** ;
- The development of the new calibrated sources is going well ;
- StarDICE is well integrated within the PCWG and we developped **fruitful collaborations** (e.g. Harvard CBP with C. Stubbs et al.).
- Exciting **new developments** : IR instrument, spectroscopy, accelerometers, *etc.*

Despite the pandemic, lockdowns and travel restrictions, the StarDICE project stays on track.

Thanks to all people involved, and to OHP for their support on site.