The Direct Illumination Calibration Experiment

Marc Betoule for the DICE collaboration

LSST France, 7 dec. 2015

Introduction

Absolute Calibration ?

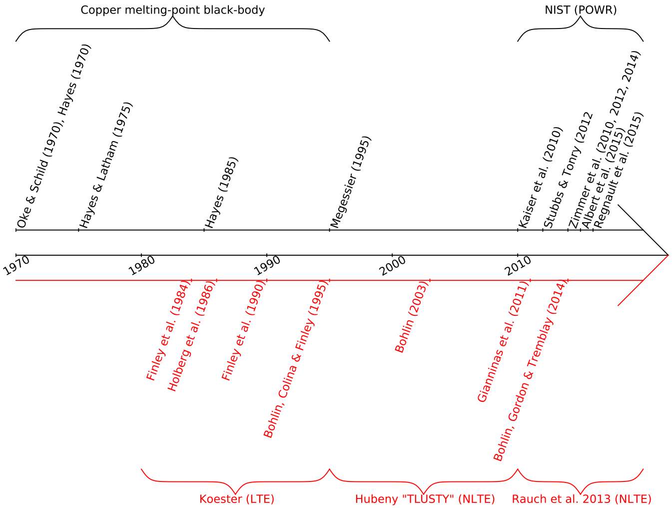
Goal: Set up a primary calibration source for telescope

- Light source of **known** SED
- Observable by astronomical instruments

2 historical approaches

- Measure the SED of standard stars (Vega, Sirius . . .)
- Model the SED of standard stars (Sun, WD. . .)

History of the astrophysical flux scale



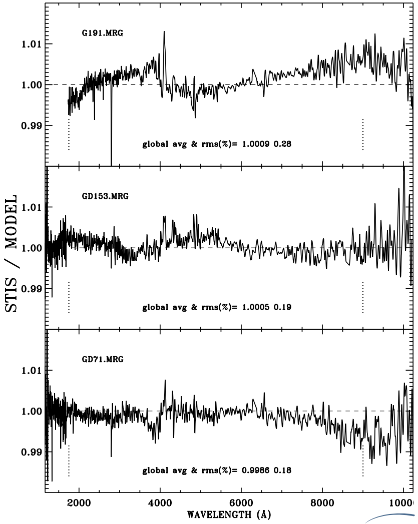
State of the Art

Bohlin, Gordon & Tremblay 2014

- Rauch et al 2013 NLTE model
- 3 DA WD: G191B2B, GD153, GD71

The average defines the HST/STIS calibration

- Residuals at the percent level in the visible range



(Bohlin et al. 2014)

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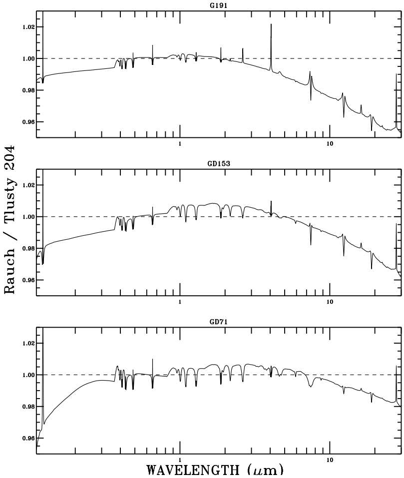
Limitations of the stellar atmosphere model approach

Uncertainty estimate based on:

- difference between 2 models
- implementing similar physics
- Amount to 4 mmag in color for $300 < \lambda < 1000$nm

What about unaccounted physics ?

- Metal lines found in high resolution spectrum of G191B2B
- Lyman/Balmer lines problem
- Other ?

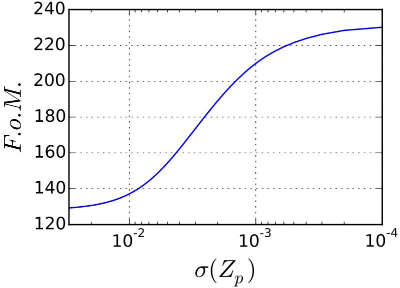


(Bohlin et al. 2014)

A revival of the field triggered by Dark Energy

- Flux measurements are key to the distance/redshift relation
- Flux calibration is today the limiting factor
- Next generation surveys require a $\times 5$ improvement

Dark energy figure of merit for an LSST supernovae survey as a function of the photometric zero point uncertainty



(forecast based on Astier et al. 2013)

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The revenge of laboratory standards ?

Laboratory standard have improved

- NIST facility claims 10^{-4}
- Convenient silicon detectors available at $2 \cdot 10^{-3}$

But the transfer to stars is difficult

- Faint objects require:
  - Telescopes (optics)
  - Observatories (not lab conditions)
- Atmospheric variation

Numerous design choices possible

- Spectroscopy or broadband photometry ?
- How to deal with the atmosphere ?
- ...

The DICE project

Project started in 2008: LPNHE/CFHT

P. Bailly, E. Barrelet, M. Betoule,
A. Guyonnet,
H. Lebbolo, L. Le Guillou,
N. Regnault, P. Repain, P.-F. Rocci,
K. Schahmaneche,
A. Vallereau, F. Villa, D. Vincent

... and ...

G. Barrick, T. Benedict, J.-C. Cuillandre, K. Ho, D. Salmon, Adam, Peter, Lisa, David

... and many others...

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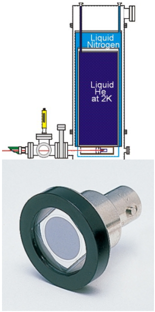
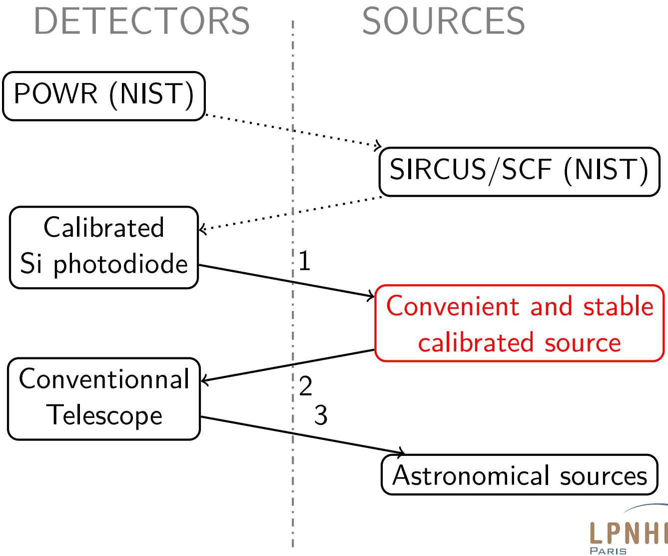
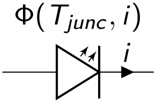
The proposed metrology chain





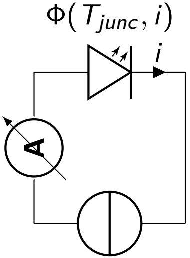
Design choice 1: An intrinsically stable light source



Quantum emmiter, emmission depends on:

- junction temperature
- current

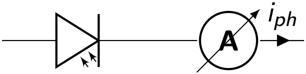
Design choice 1: An intrinsically stable light source

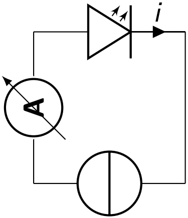


Monitor:

- Junction temperature
- Current
- Current source temperature

Design choice 1: An intrinsically stable light source





Redundancy

- Photodiode current

Design choice 2: no optics

Optics could be used to

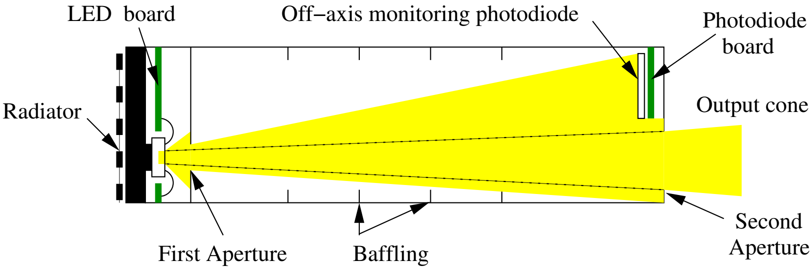
- Change the shape of the beam
- Select Wavelength

But would make the thing harder to control

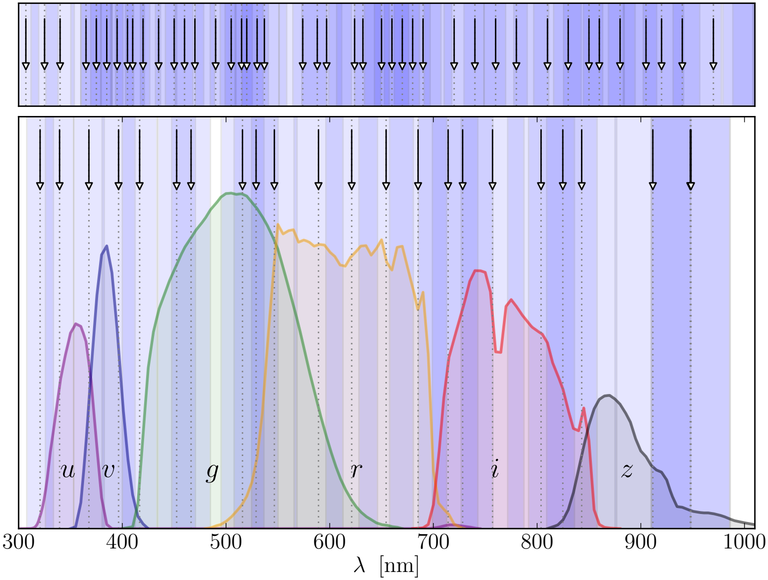
Other solutions

- Use geometry to get the beam you want
- Precise knowledge of the source narrow spectrum

This gives the following design for a single channel:



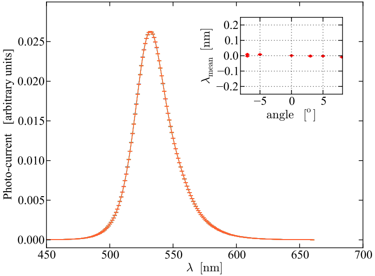
And we use 24 of them to cover the wavelength range:



Spectro or photo ? Spectro-Photometry

$$I = \int \lambda T(\lambda) d\lambda$$

$$I_i = \int \lambda T(\lambda) S_i(\lambda) d\lambda$$



(Regnault et al. 2015)

Accuracy on Broadband integrated quantities I

- Is what matters for cosmology
- Is hard to achieve in spectroscopic measurements

The solution we choose is to decouple the problems

- Use precise narrow band photometric measurements I_i
- To constrain a spectroscopic model of T

Measurements !

Results described in Regnault et al. 2015

Astronomy & Astrophysics manuscript no. 24471
June 30, 2015

The DICE calibration project design, characterization, and first results

N. Regnault[1], A. Guyonnet[1], K. Schahmanèche[1], L. Le Guillou[1], P. Antilogus[1], P. Astier[1], E. Barrelet[1], M. Betoule[1], S. Bongard[1], J.-C. Cuillandre[2], C. Juramy[1], R. Pain[1], P.-F. Rocci[1], P. Tisserand[3], and F. Villa[1]

[1] LPNHE, CNRS-IN2P3 and Universités Paris 6 & 7, 4 place Jussieu, F-75252 Paris Cedex 05, France
[2] Canada-France-Hawaii Telescope Corporation, Kamuela, HI 96743, USA
[3] Research School of Astronomy and Astrophysics, Australian National University, ACT 2601, Australia.

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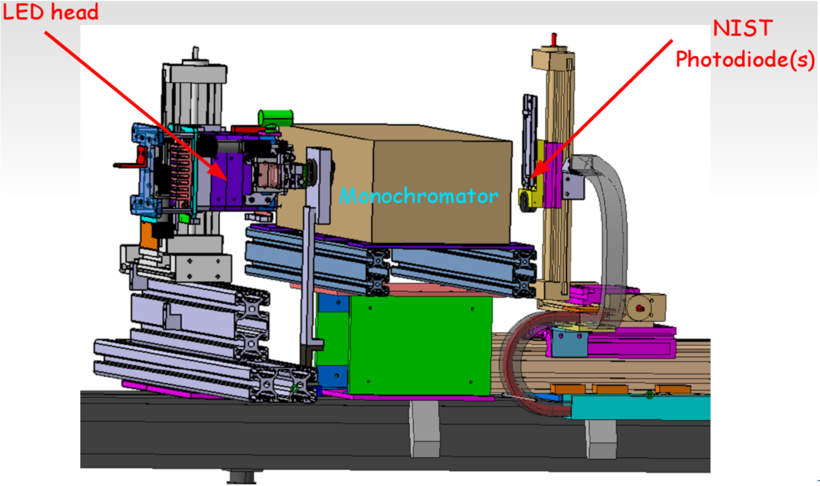
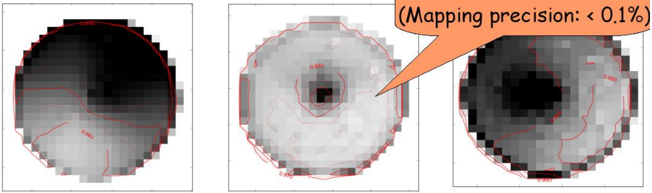
Measurements I: A spectrophotometric test-bench



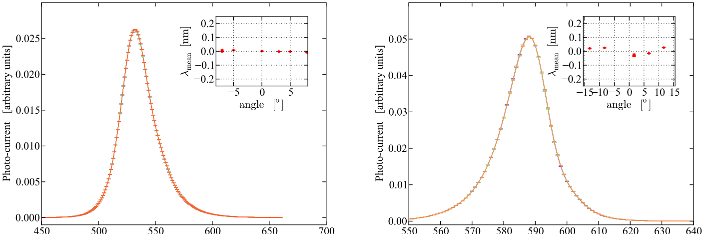
Measurements II: Precise mapping of the beam

Flux

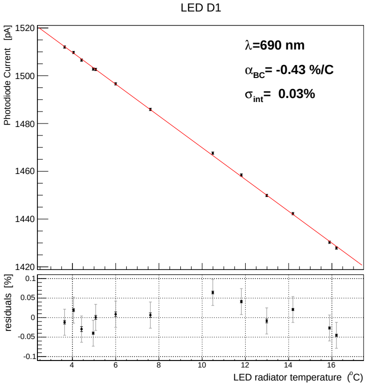


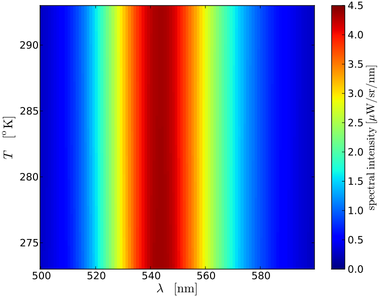
Uniformity: ~ 1%
(Mapping precision: < 0.1%)

And spectrum



Measurement III: In a temperature range





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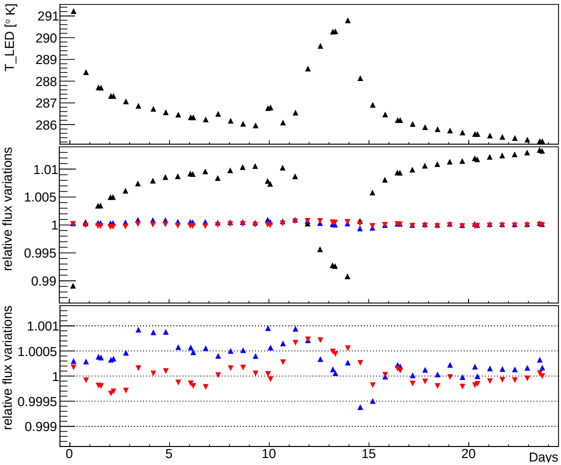
An convenient/extremely stable light-source: Done



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A range of application for such a source

Demonstrated using MegaCam@CFTH

- Readout electronics and optics monitoring (Barrelet in prep.)
- Instrument flat-fielding and passbands monitoring (Regnault et al. in prep)
- Absolute calibration of spectrophotometric standard stars observations

A dedicated instrument would eased last step

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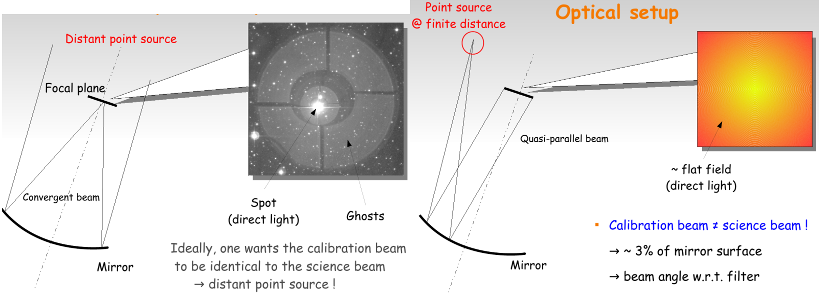
DICE as a calibrated star

We want a calibration beam as close as possible to the science beam

Prevent detector details to matter in the transfer

We cannot be close at CFHT



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A smaller focal length keep things at reasonable distance

If we target a source-detector distance of ~ 200m

Source close to infinity

- Hyperfocale distance: $H = f^2/Nc$
- For $c = 5 \cdot 10^{-6}$m and $N = 4$: $f < 60$mm

Point-source at long distance

- Transversal magnification for focused images $\gamma_t = f/(f - d)$
- $500\mu m$ source and 5μm image: $f < 2m$

But the instrument must reach mag 14 in reasonable time

$$N_{e^-} = \frac{1}{h}\int \epsilon(\nu)\frac{d\nu}{\nu}10^{-0.4(m_{ab}+48.6)} \quad (1)$$

$$= 5.48 \cdot 10^6 \cdot Q \cdot 10^{-0.4 m_{ab}} s^{-1} cm^{-2} \quad (2)$$

To collect $10^6 e^-$ in less than an hour (or equivalently sub-percent photometry in minute exposure):

- Assume top-hat logarithmic passbands with $\Delta\nu/\nu = 0.2$ and global efficiency $Q = 0.2$
- $t_{exp} \sim 160/\left(\frac{D}{cm}\right)^2$ *hours* to collect 10^6 photons
- $\rightarrow D > 13$cm (which excludes more or less the hyperfocal design)

Going through the atmosphere

CFHT

- Better site
- Joint spectroscopic observations with SNFactory to monitor the atmosphere (see the presentation by Sebastien Bongard at the last LSST France)

But

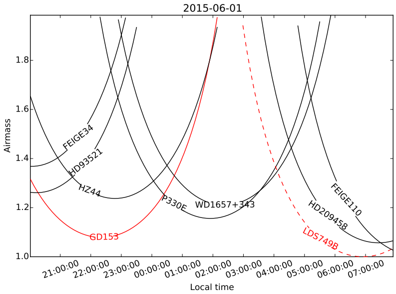
- Much less time available

With a small dedicated instrument and sufficiently fast mount we can

- Follow several standard stars in all bands over the course of the night
- Determine precise broadband extinction terms for each night in each band (and constrain a spectroscopic extinction model)
- Repeat observations for as many nights needed

An example observation campaign for June 2016

- 9 CALSPEC standard stars easily observable in June



- A couple of observations separated by an airmass ΔX gives a measurement of the atmospheric extinction $\sigma(k_{airmass}) = \frac{\sqrt{2}\sigma_{exp}}{\Delta X}$
- Spending 2min $\times 5$ bands on each star visit
- We can accumulate 48 visits in a night (or about 24 couples)
- Taking $\sigma_{exp} = 0.011$mag (values measured on Landolt at CFHT) and $\Delta X = 0.5$ would constrain the average $k_{airmass}$ to 7mmag in a single night in each bands

Conclusion

The experiment looks feasible with a small dedicated instrument using common hardware

We are building a test setup using available LUPM hardware to demonstrate the technique

Johann Cohen-Tanugi (LUPM), Bertrand Plez (LUPM), Fabrice Feinstein (CPPM), Auguste Le Van Suu (OHP)

- Validate the site at OHP
- Validate the setup
- Measure performances

Tentative Timeline

- First Observation campaign with the test hardware in June 2016
- Final design in Sept 2016
- Bench measurement of the final hardware by the end of 2016
- Installation of the final hardware at the beginning of 2017
- Decommissioning and bench stability measurements at the end of 2017

We have proposed a thesis on the project