INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

IASFPa Istituto di Astrofisica Spaziale e Fisica cosmica di Palermo

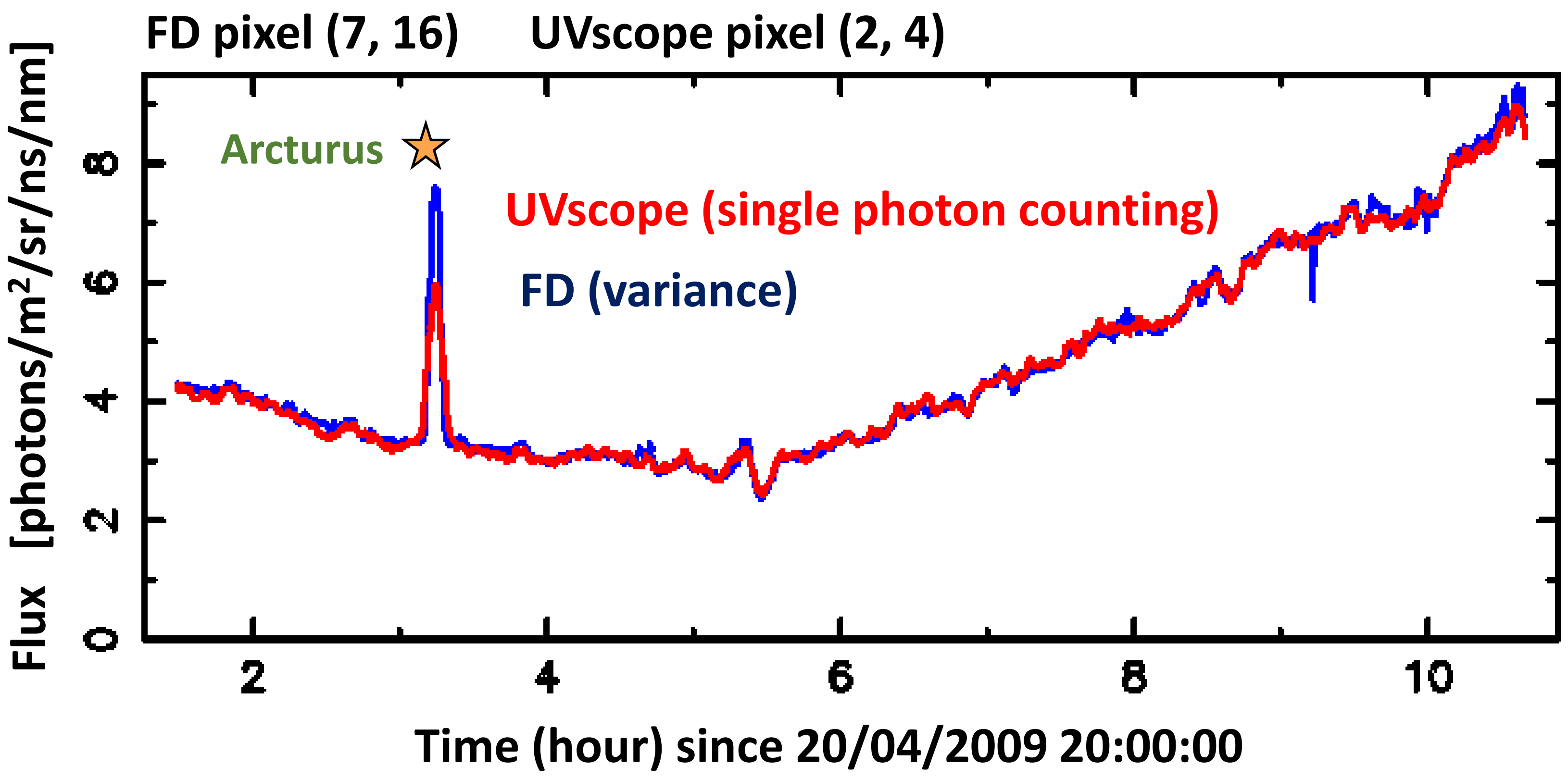
INFN Istituto Nazionale di Fisica Nucleare Sezione di Catania

FD long term monitoring and calibration using stars: Historycal review & New results

A. Segreto

Long Term Performance Meeting 25/02/2020

Single photon counting vs. “variance”



- NSB measurements with a single photon counting instrument (UVscope) showed that the **“Variance” is as good as “photon counting”** to measure the night sky background flux!

- Nov. 2009, A. Segreto, Collaboration meeting, Malargue: *"Night Sky Background: UVscope vs. Auger FD"*

From "variance" to photons

The "variance calibration constant"

- To convert "FD variance" to "photons" it is necessary to know (beside the "Drum calibration constant") the "Variance calibration constant":

$$K_V \doteq \frac{1}{0.2 \cdot G \cdot (1+\nu_g) \cdot F}$$

- G, ν_g, F : significative pixel to pixel differences and no accurate calibration measurements available, but ...

... there is no need to know G, ν_g and F separately!
K_V can be obtained directly from "Cal. A" runs!

4 Calibration of the FADC variance

Combining Eq. 1, 2, and 3, the end-to-end conversion formula to obtain the average flux (in photons/m^2/sr/ns/nm) of a slow-varying, non-monochromatic source fully illuminating the pixel, is expressed by:

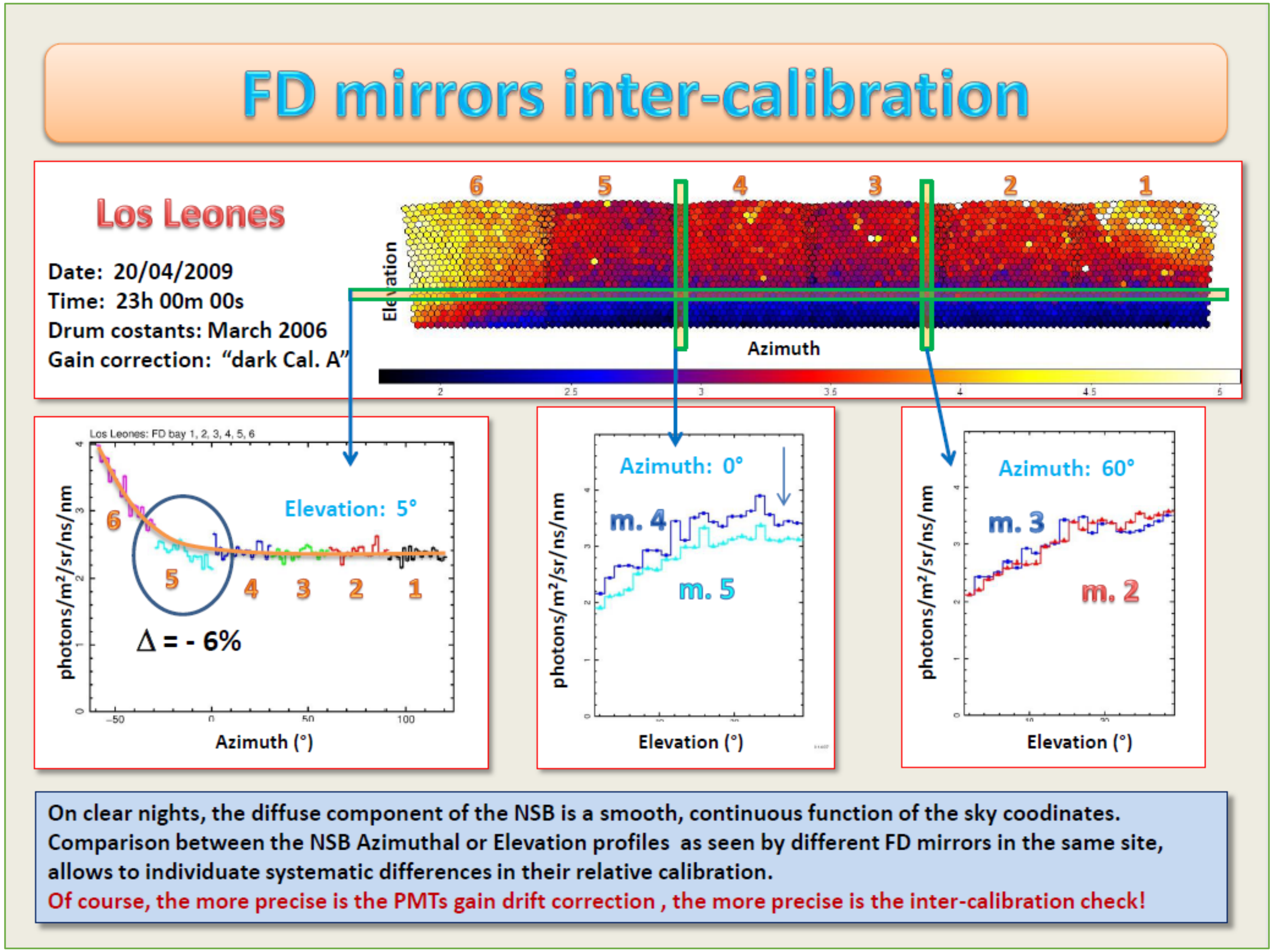
$$\begin{aligned} < \Phi_\lambda > &\doteq \frac{\int_0^\infty \Phi_\lambda \cdot F_\lambda \, d\lambda}{\int_0^\infty F_\lambda \, d\lambda} = \\ &= \frac{K_D \cdot K_V}{\Delta T \cdot A \cdot \Omega \cdot \int_0^\infty F_\lambda \, d\lambda} \cdot \sigma^2_{FADC} \end{aligned} \quad (4)$$

This formula then allows one to convert the variance signal recorded in the FD background files (after subtraction of

- Nov. 2010, A. Segreto, Collaboration meeting, Malargue: *"Nightly variability of FD PMT gains as measured by UVscope and Cal. A"*

- *"Night sky background measurements by the Pierre Auger Fluorescence Detectors and comparison with simultaneous data from the UVscope instrument",* A. Segreto, for the Pierre Auger Collaboration, Proc. 32nd ICRC, 2011, Beijing, Rep. of China

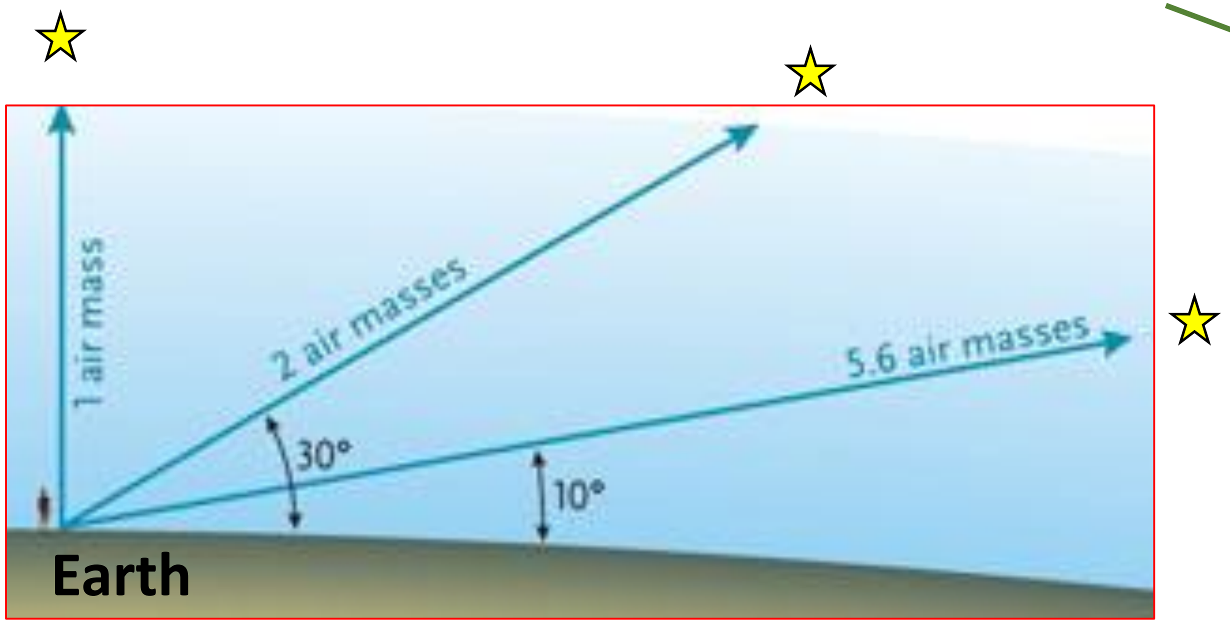
Intercalibration with diffuse Night Sky Background

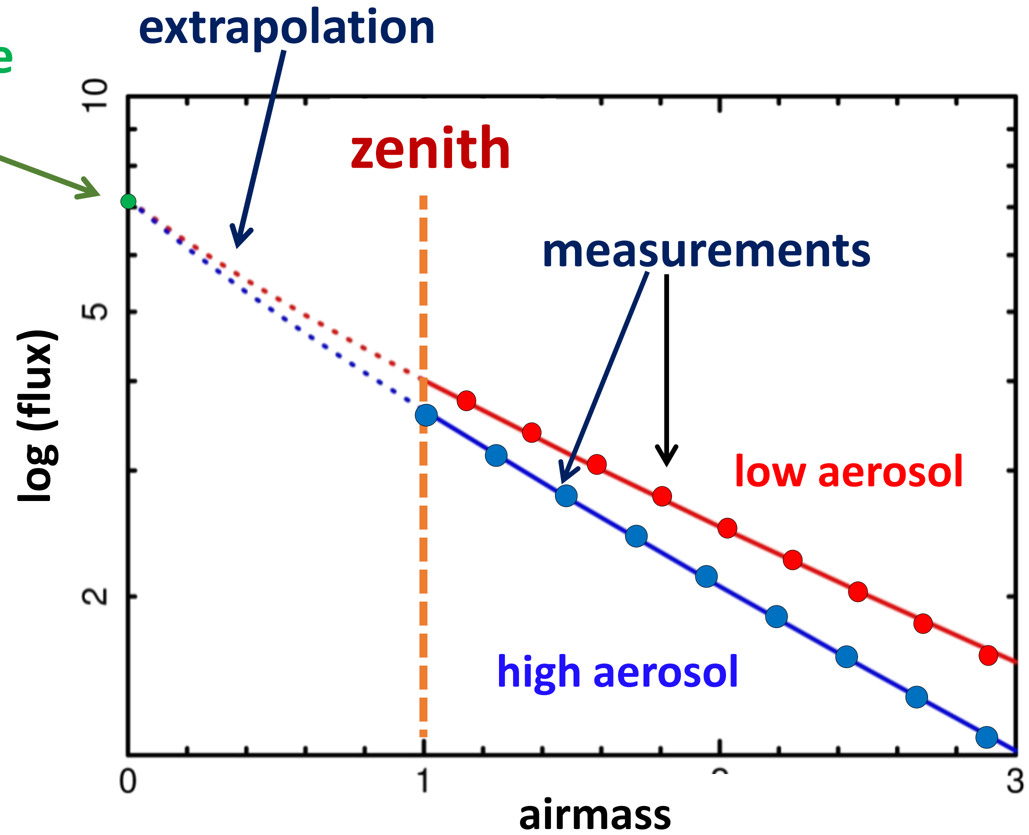


- **A straightforward application of the diffuse NSB measurements is for the intercalibration of adjacent FD Bays**
- **Disadvantage: not sensitive to a common drift of all the bays and seasonal variations**
- **An external reference light source is anyway necessary, at least for a few Bays**
- **Stars are the ideal reference sources for the long term monitoring**

- **Nov. 2010, A. Segreto, Collaboration meeting, Malargue:** [*"Nightly variability of FD PMT gains as measured by UVscope and Cal. A"*]

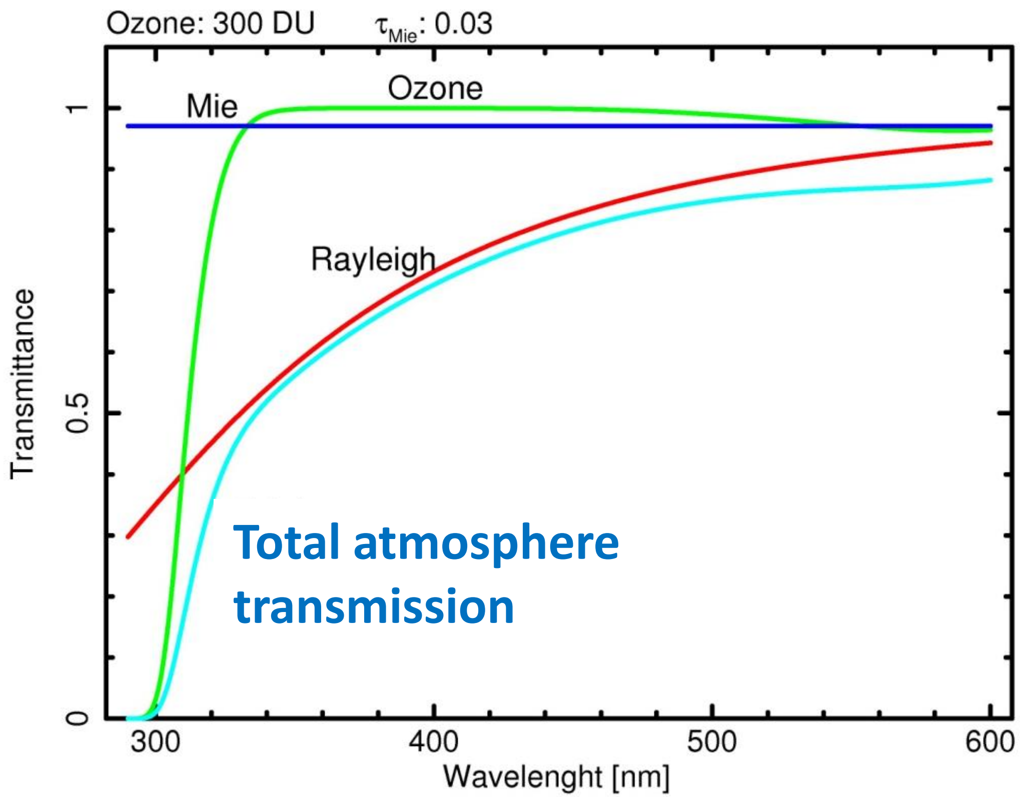
The Langley plot method

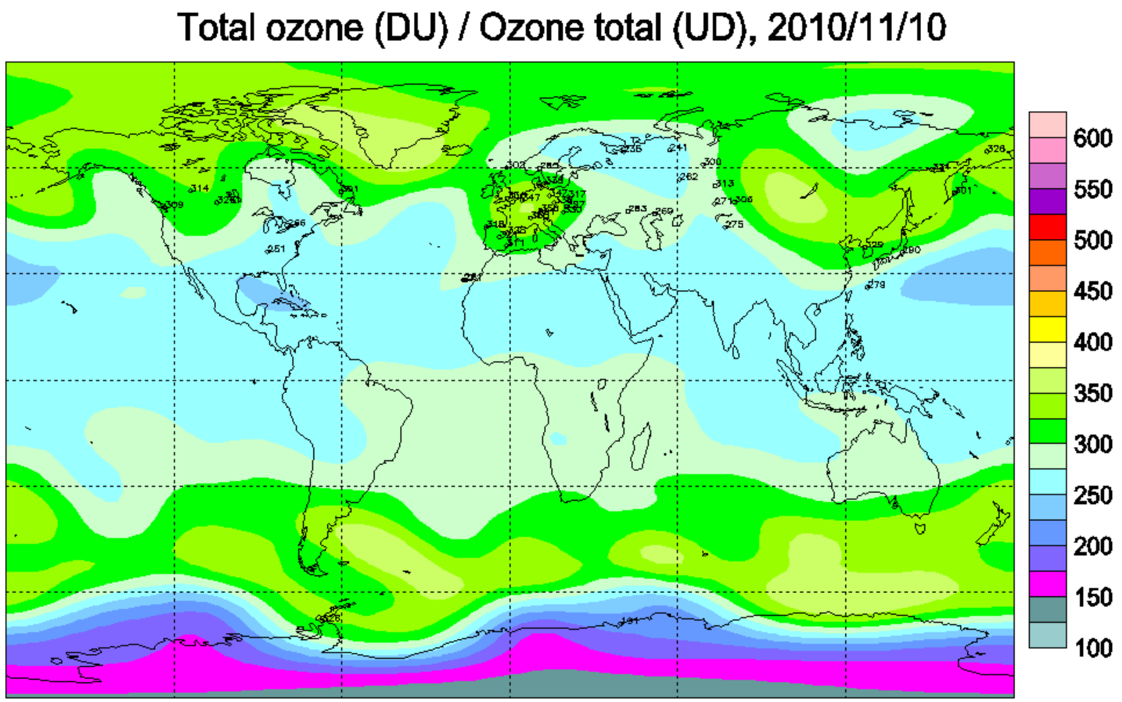




- A standard method to correct the ground based star flux measurements for the atmospheric attenuation, is to measure the star signal as a function of the "*air mass*"
- A fit to data provides the total atmosphere attenuation (the data slope), and (by extrapolation to zero air mass) the star flux that would be measured by the instrument if it were placed on top of the atmosphere
- In case of a wavelength dependent extinction, the data are actually on a slightly curved line (Forbes effect)

The atmospheric attenuation

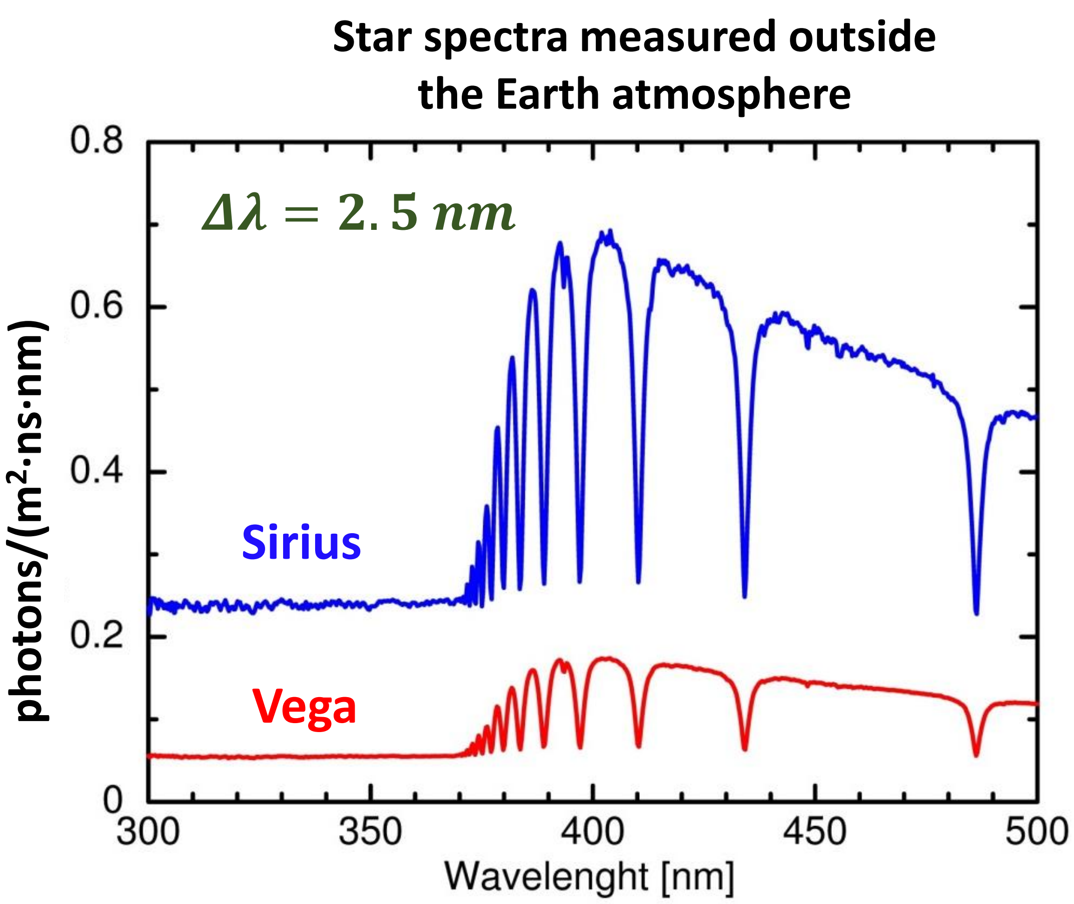


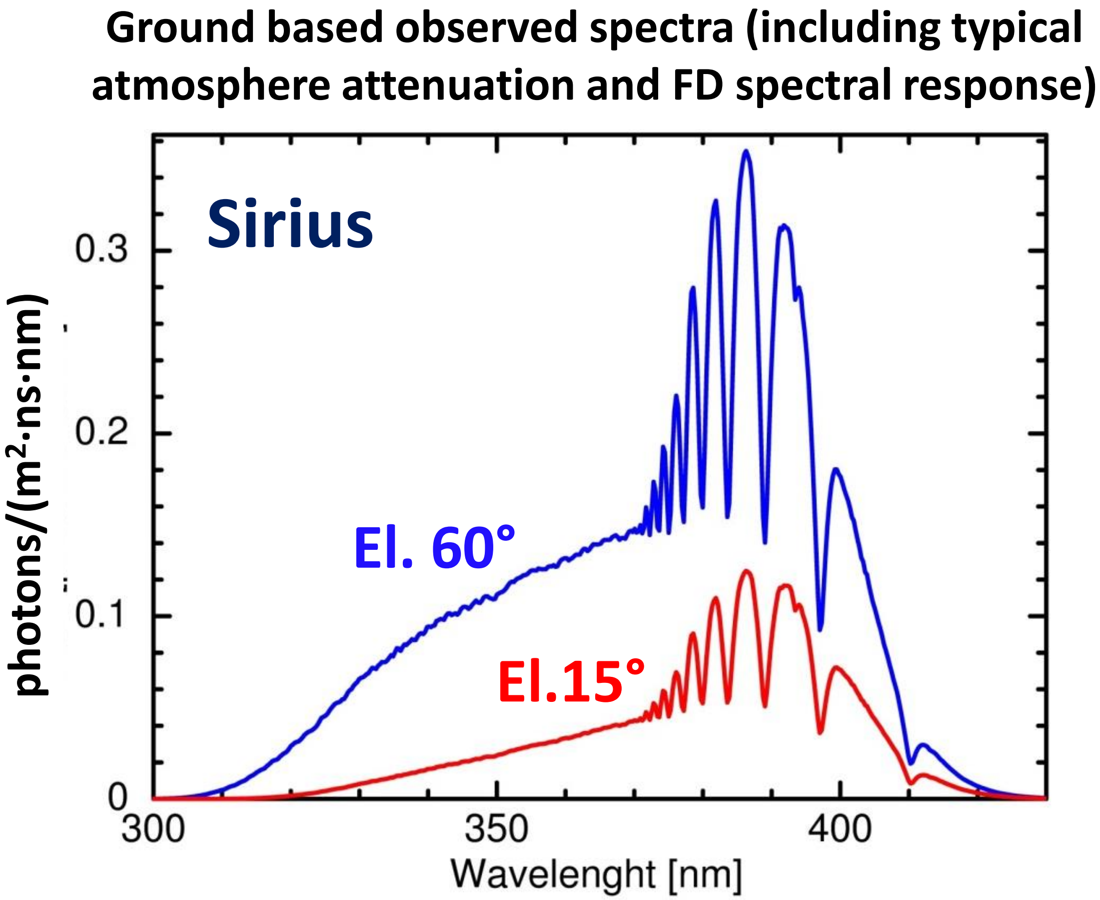


Atmosphere attenuation components (in the UV region):

- **Ozone absorption: (< 320 nm) daily ozone thickness maps are on the web**
- **Molecular (Rayleigh) scattering: can be computed from the local barometric pressure**
- **Aerosol scattering: highly variable from night to night as depends on local, unpredictable, aerosol density and composition. Aerosol thickness is a free parameter in the atmosphere model**

Spectra from stars

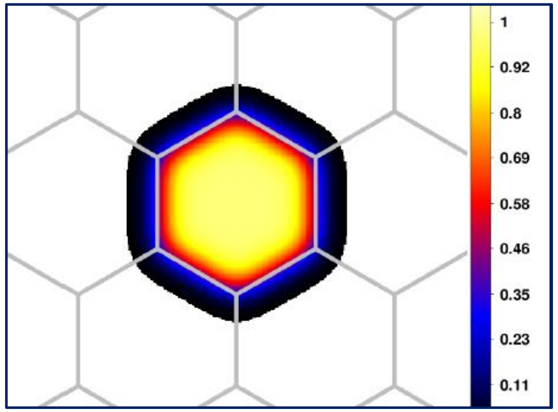




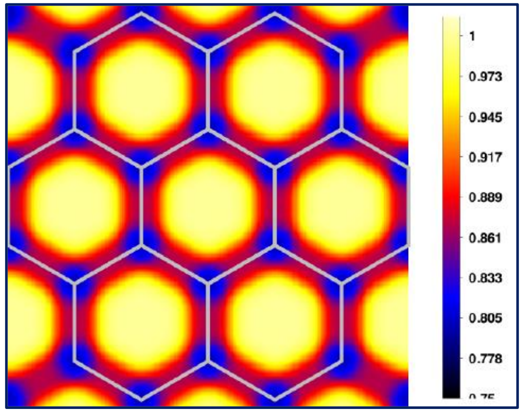
- The primary reference star for absolute astronomical photometry is Vega, however, in the Southern Hemisphere, Sirius is preferred as it can be observed at higher elevation angles; the absolute calibrated spectra of these reference stars measured "on top of the Earth atmosphere" can be retrieved from astronomical data bases
- The ground observed spectral distribution depend on the detector spectral response and on the atmospheric attenuation (which dependents on star elevation)

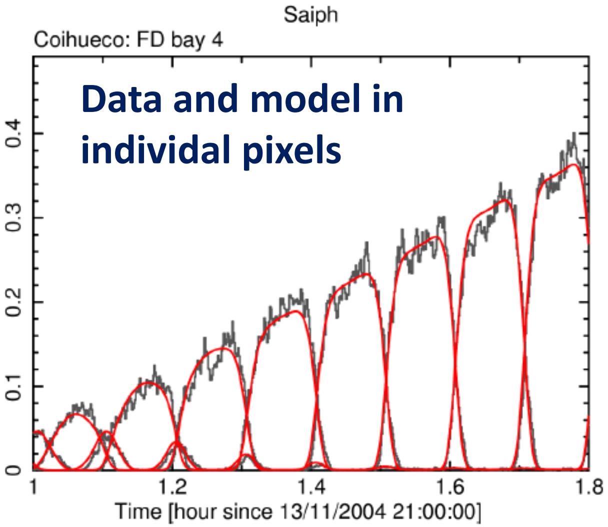
The 2D star PSF model

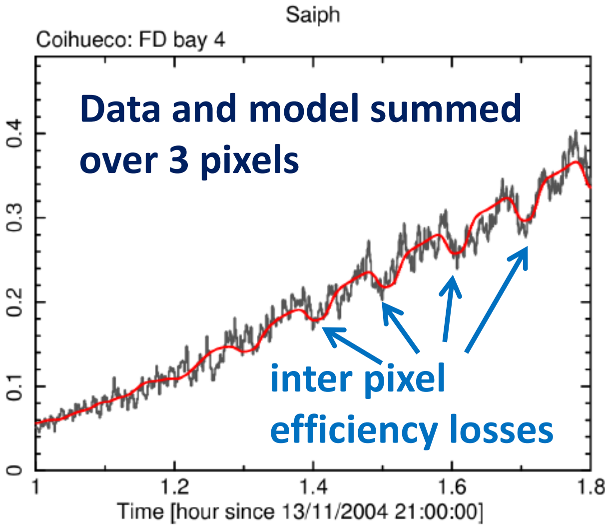
2D model of the star PSF

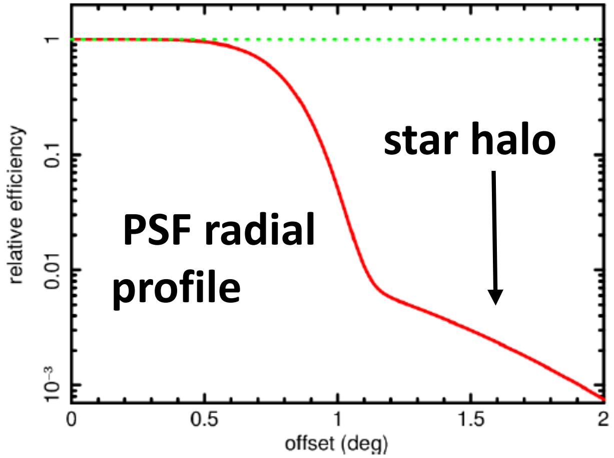


2D efficiency map





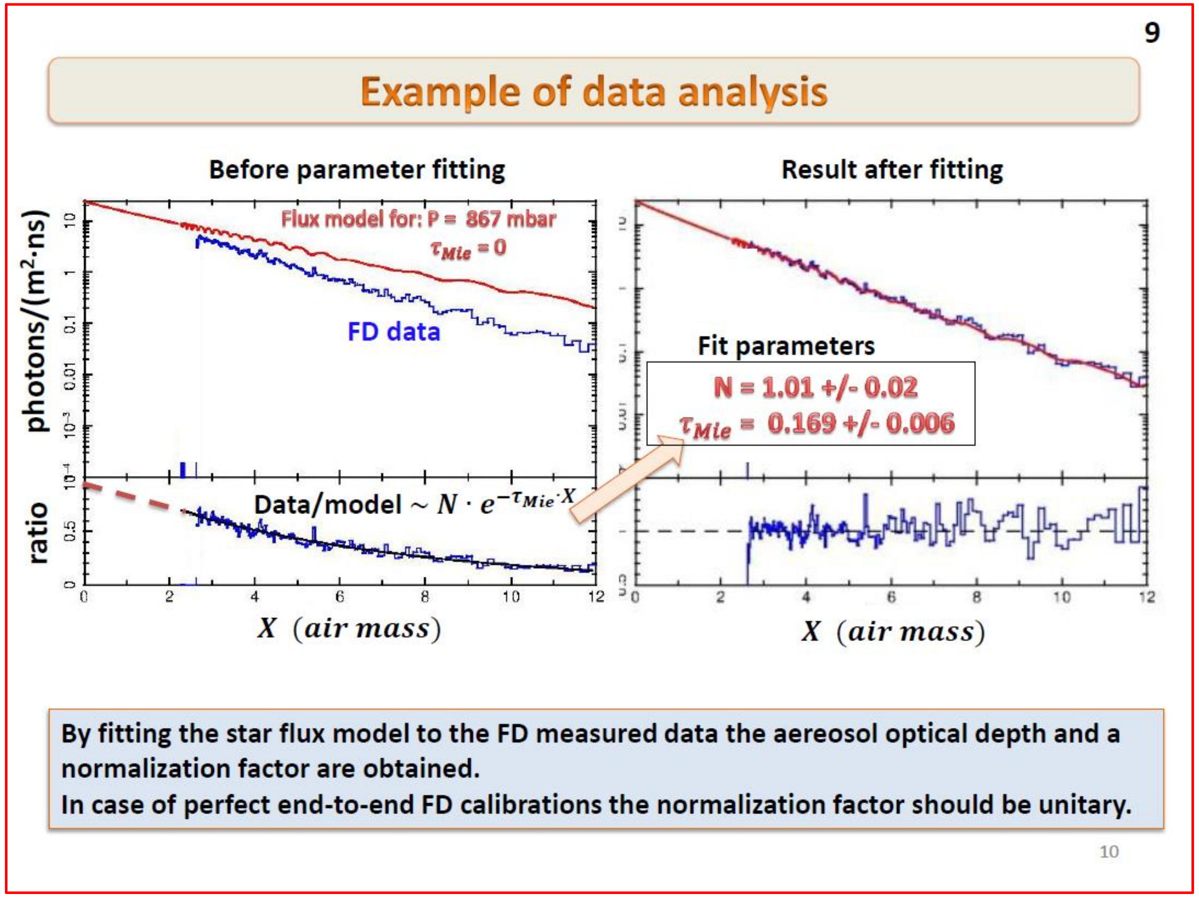


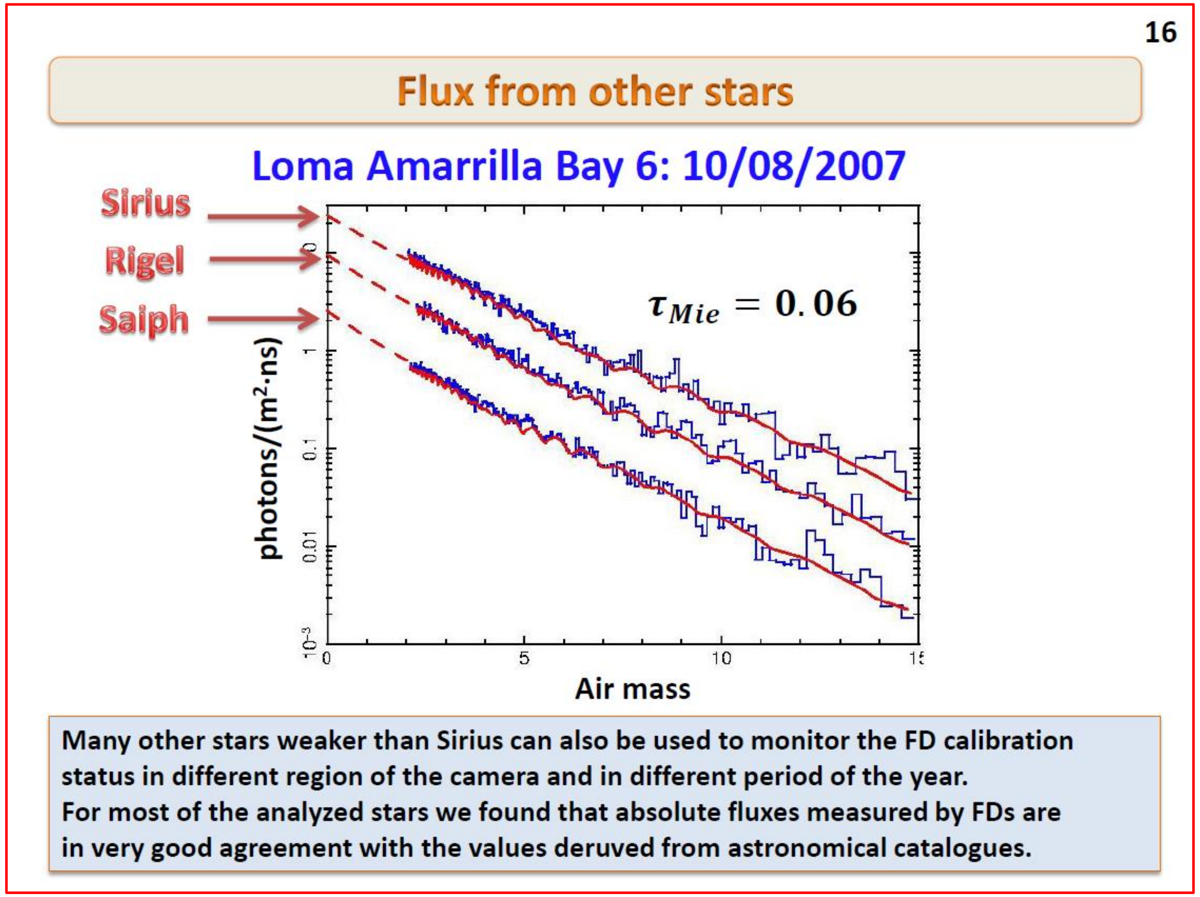


- **GAP2016_042: A. Segreto:** *Using stars to verify the end-to-end absolute calibration and for the long term monitoring of the Fluorescence Detector telescopes at the Pierre Auger Observatory"*

- **The star PSF is modeled by means of an analytical function whose parameters are tuned to reproduce the star signals as observed in individual pixels, including an extended halo. The 2D PSF model allow to reproduce the inter-pixel efficiency losses observed when the star crosses the pixel boundaries**

FD calibration with Sirius and other stars

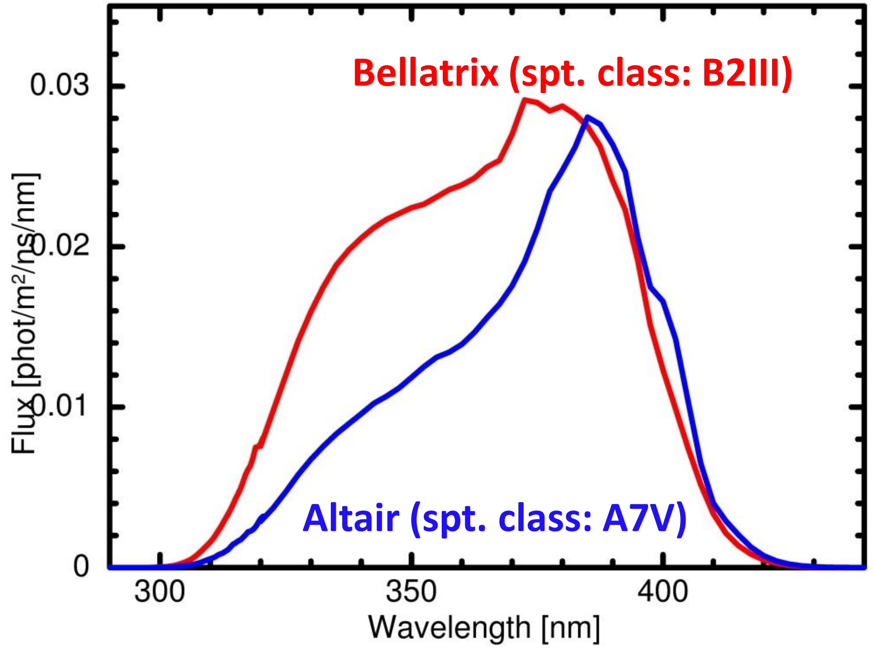




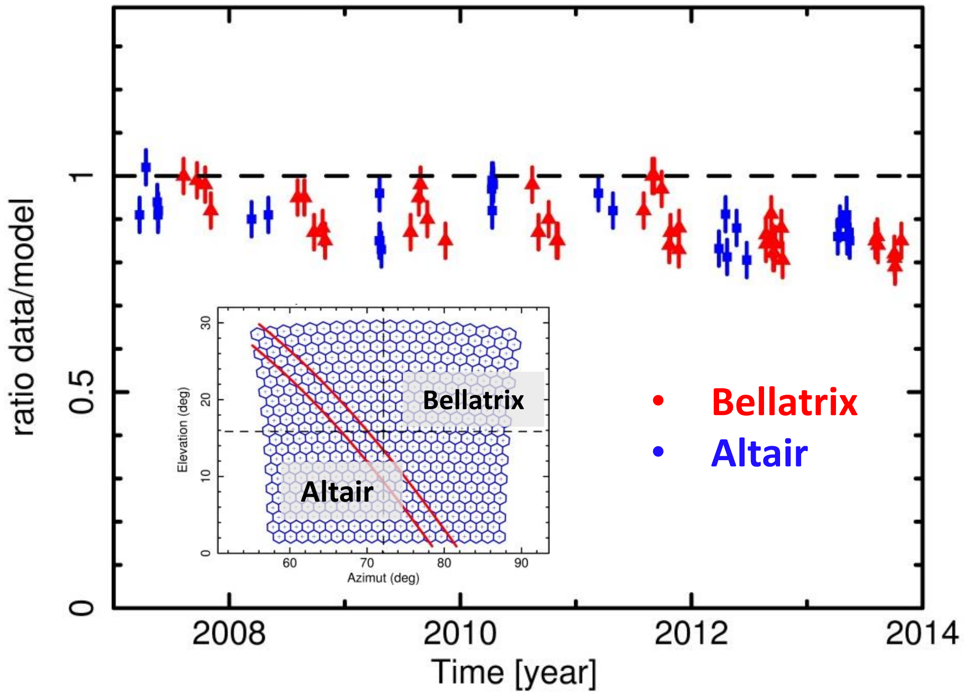
- **Nov. 2013, A. Segreto, Collaboration Meeting, Malargüe:** "Energy check and monitoring of th FD absolute calibration using stars"

FD Long term monitoring

spectral distribution of detected photons
(including atmosphere attenuation and FD spectral response)



Coihueco Bay 5



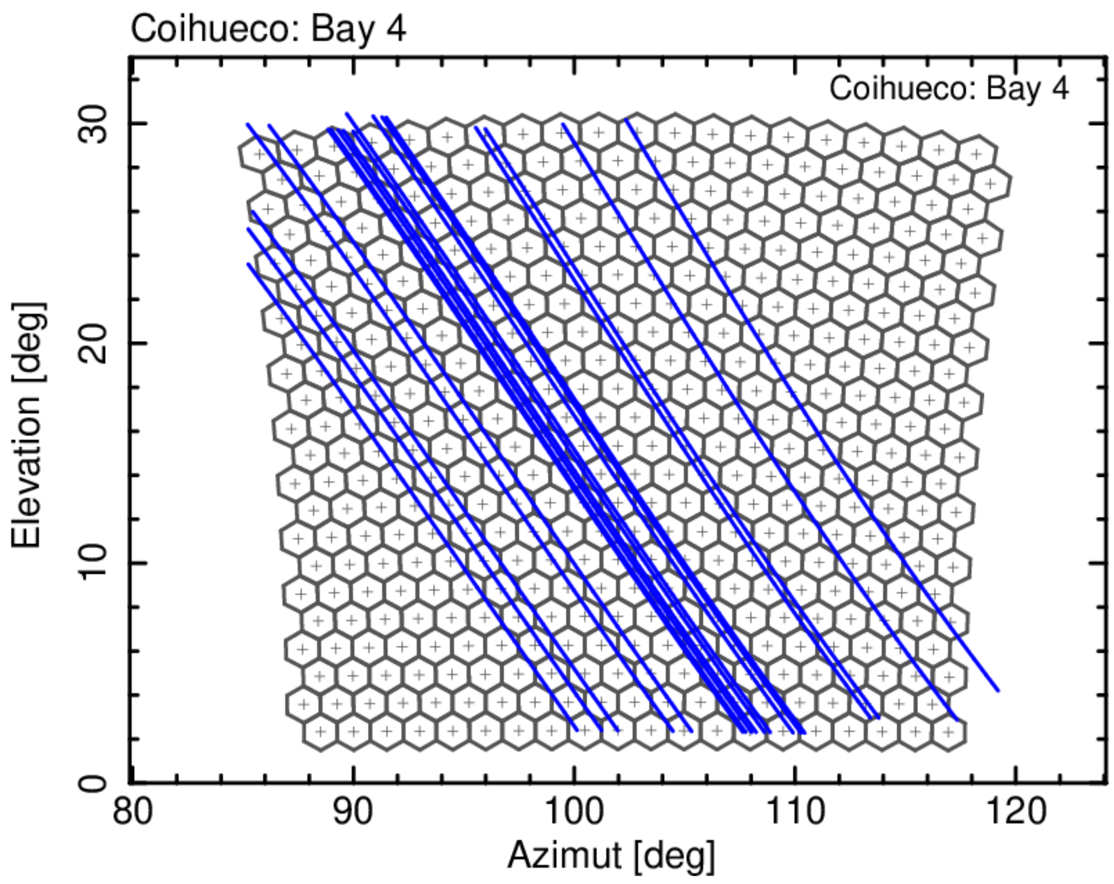
- ❑ Any star crosses nighttime the FD field of view only for a few months per year
- ❑ Data from different stars (different luminosity and different spectral class) can be combined to monitor the FD calibration status in different period of the year
- ❑ There are however not enough bright reference stars to monitor the FD calibration without temporal gaps

New results

Star selection in the FoV of Coihueco Bay 4

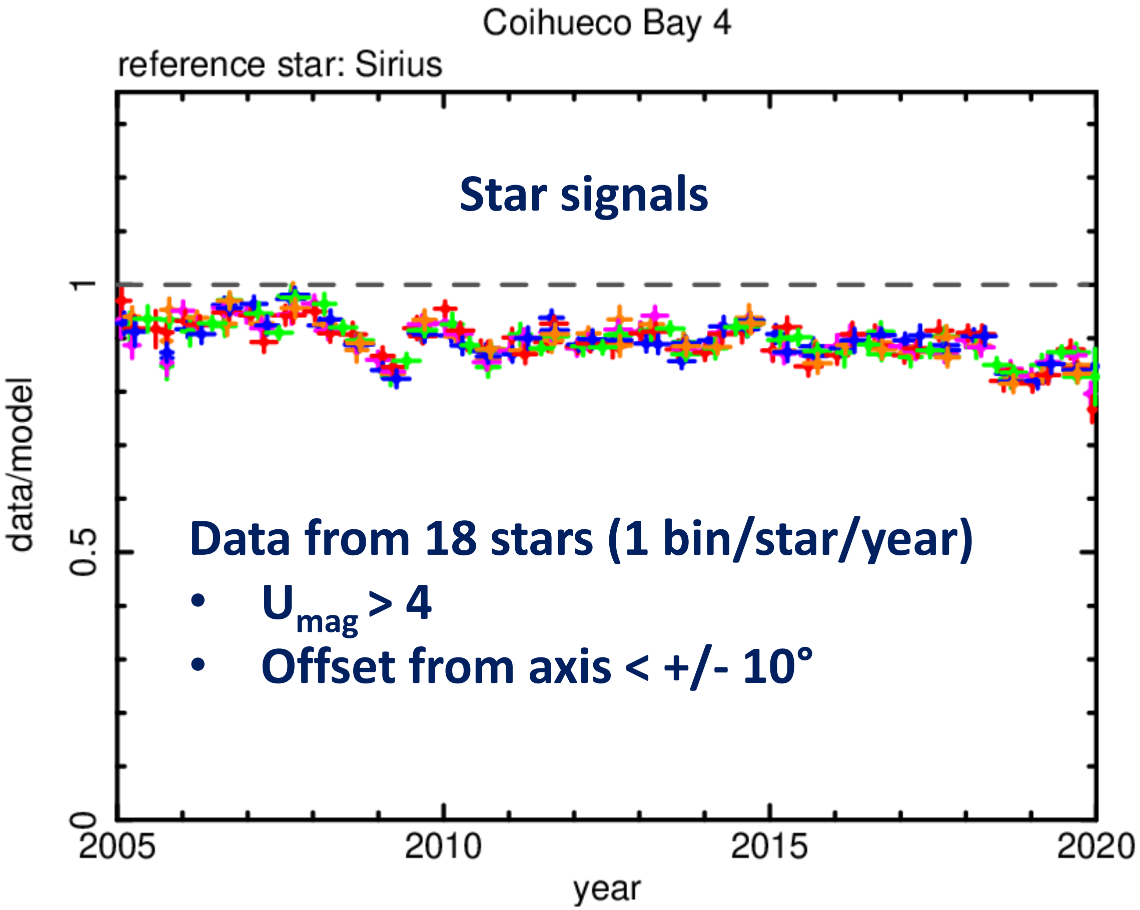
Name	Type	Offset[°]	Umag	R.A.[h]
1) Pi Cet	B7IV	+4.9	3.7	2.7
2) Mu Lep	B9III	+2.6	2.8	5.2
3) Lam Lep	B0.5IV	+5.6	3.0	5.3
4) Nihal	G3III	-2.0	3.6	5.5
5) Arneb	F0I	+0.9	3.0	5.5
6) Saiph	B0II	+9.1	0.9	5.8
7) Mirzam	B1III	+0.8	0.8	6.4
8) Sirius	A1V	+2.1	-1.5	6.8
9) Omi2 CMa	B3Iab	-5.1	2.1	7.1
10) Gienah	B8III	+1.2	2.1	12.3
11) Algorab	B9.5V	+2.3	2.8	12.5
12) Spica	B1 III-I	+7.6	-0.2	13.4
13) Zuben Elgenubi	A3IV	+2.7	3.0	14.8
14) Pi Sco	B1V+B2V	-7.3	1.8	16.0
15) Zet Oph	O9.5Vn	+8.2	1.7	16.6
16) Sabik	A2V	+3.0	2.6	17.2
17) Polis	B8Iab(e)	-2.3	3.6	18.2
18) Skat	A3Vp	+2.9	3.4	22.9

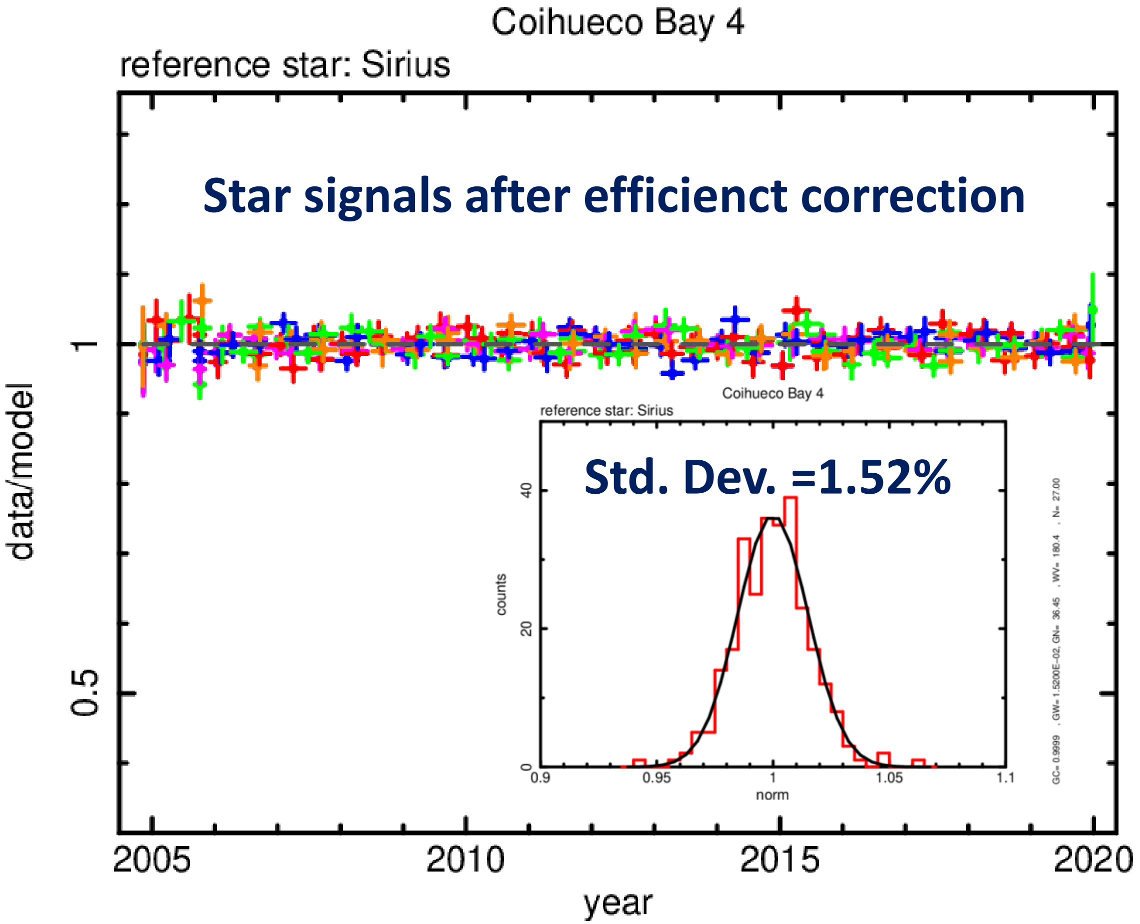
Tracks of 18 selected stars



- **To obtain a number of stars flux measurements sufficient to continuously monitor the FD calibration status along the whole year, we select group of stars, with magnitude in the U band > 4, that cross the central part of FD field (+/- 10° from the telescope center)**

Coihueco bay 4

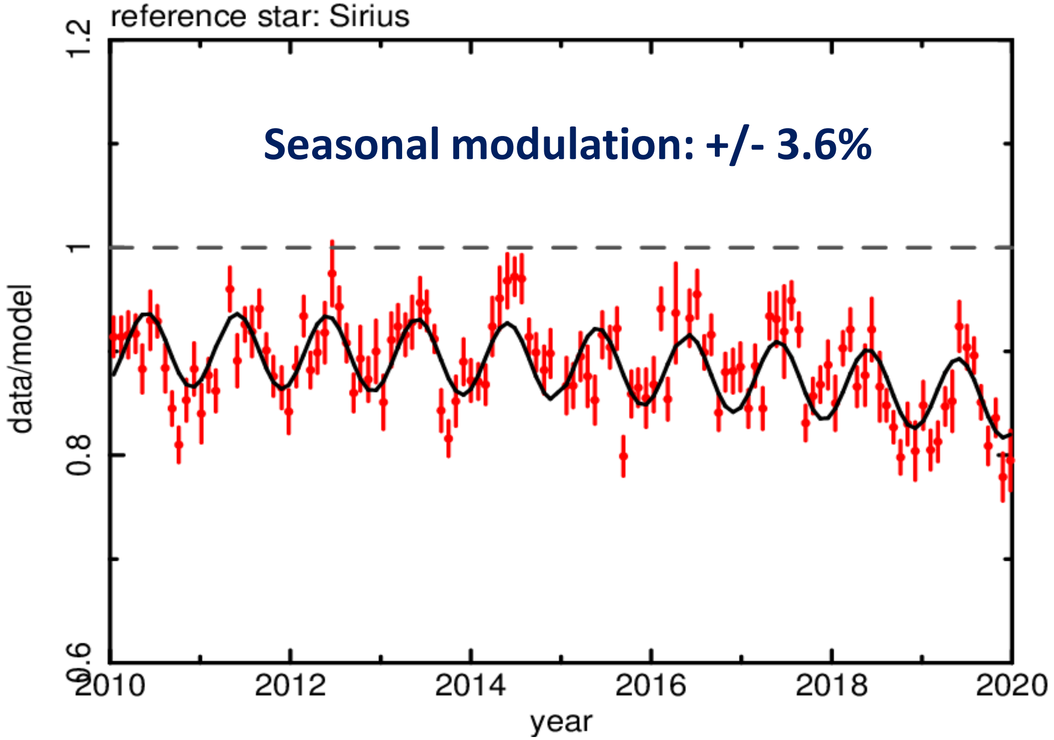




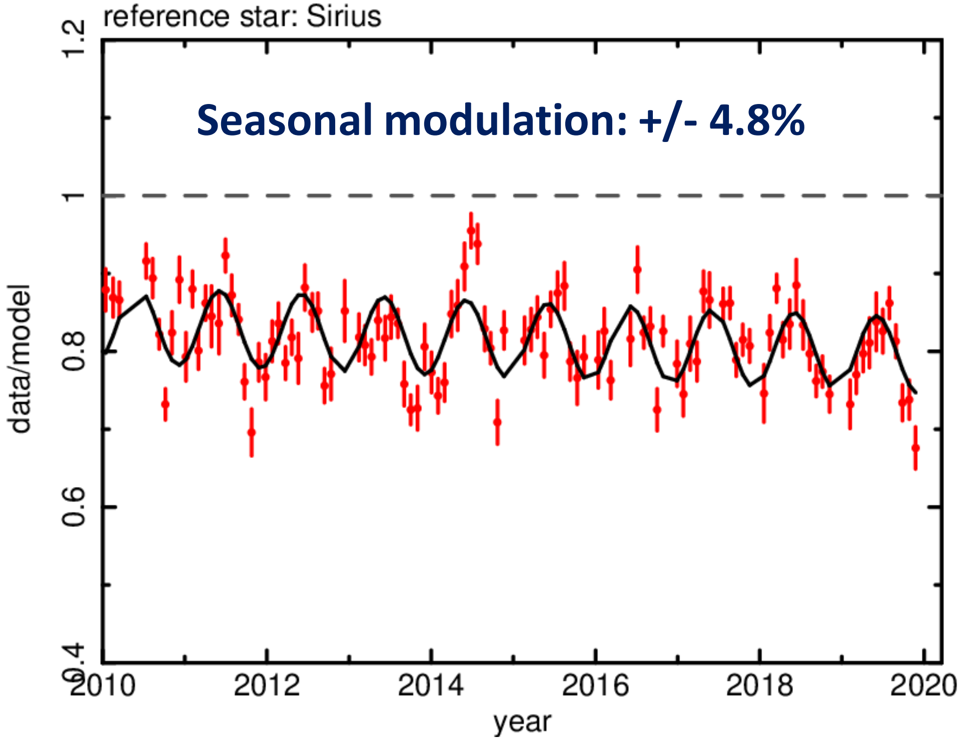
- ❑ Stars of different spectral type and different luminosity show coherent temporal behavior (spread < 2% std. dev.) along the 15 year of FD operation
- ❑ A few stars are used as absolute reference, the other are rescaled to match the reference stars

Seasonal modulation

Coiheco Bay 4



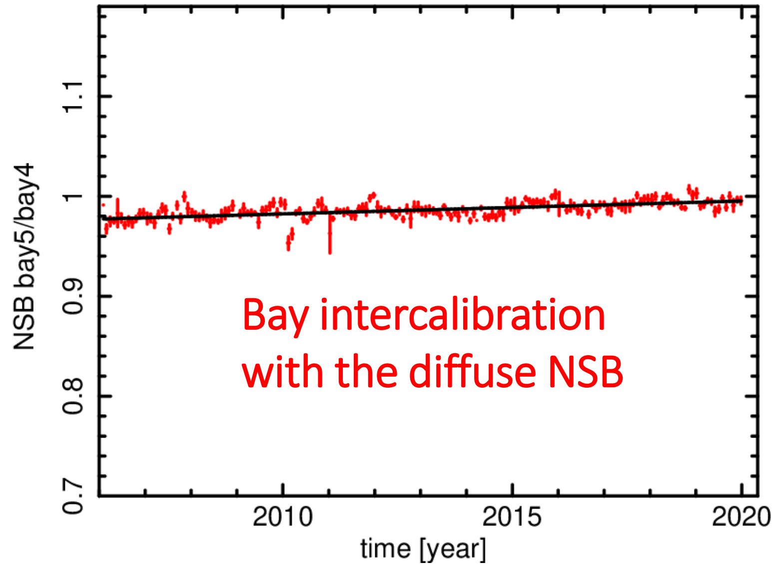
Loma Amarilla Bay 6



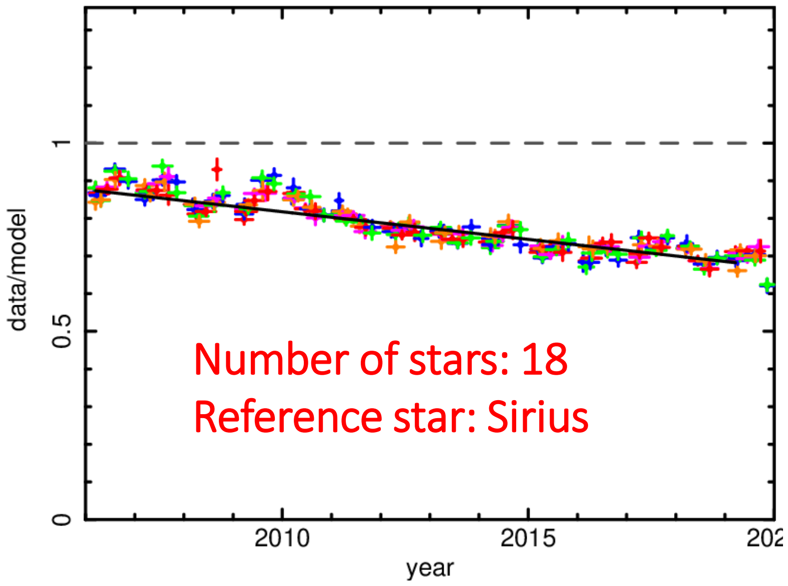
- In several FD Bays, a significant seasonal modulation is observed in the measured star fluxes vs. time

Intercalibration with the diffuse NSB

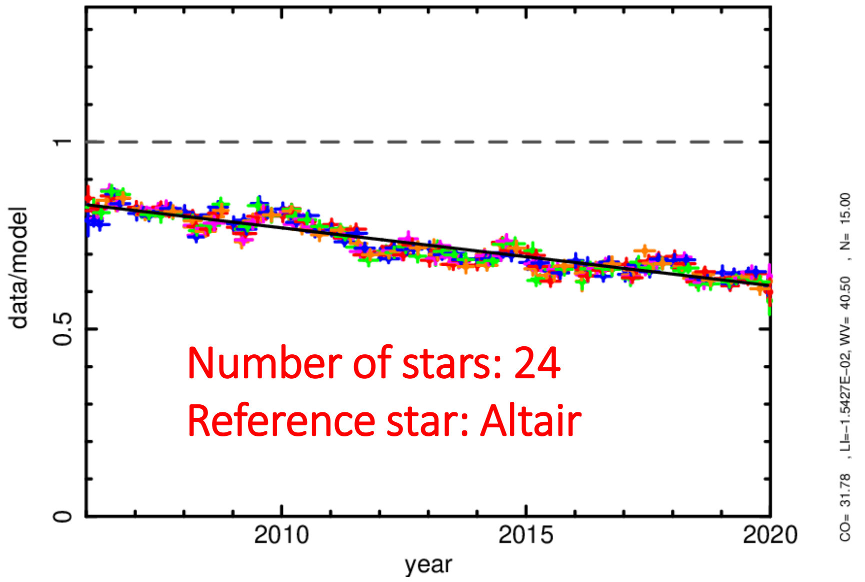
Los Morados bay 5/ bay 4



Los Morados bay 5



Los Morados bay 4



- ❑ **The diffuse component of the NSB background, as computed for the star flux analysis, can be itself used to verify the intercalibration status between Bays with adjacent FoV**
- ❑ **Applied to Bay4 and Bay5 in Los Morados, the NSB intercalibration method allow to monitor their relative calibration status with excellent statistics (<1% std. dev) but it is however not sensitive to their common long term drift (-1.5%/year)**

Summary

- FD signals from stars of different spectral type and luminosity show coherent (different from bay to bay) long term variations through the 15 year of FD operation, therefore providing a way to continuously monitor the long-term evolution of the calibration status of individual FD telescopes

- A few important correction are still to be implemented in the analysis software for a better evaluation of the FD star fluxes:
  - Analysis of Cal. A data taken with open shutters (in order to correct for the PMT gain shift and drift induced by the NSB)
  - Monitor and adjustment of the 2D star PSF model parameters for each individual Bay as a function of time