IN-SITU MEASUREMENTS OF THE REFLECTIVITY OF VERITAS TELESCOPES

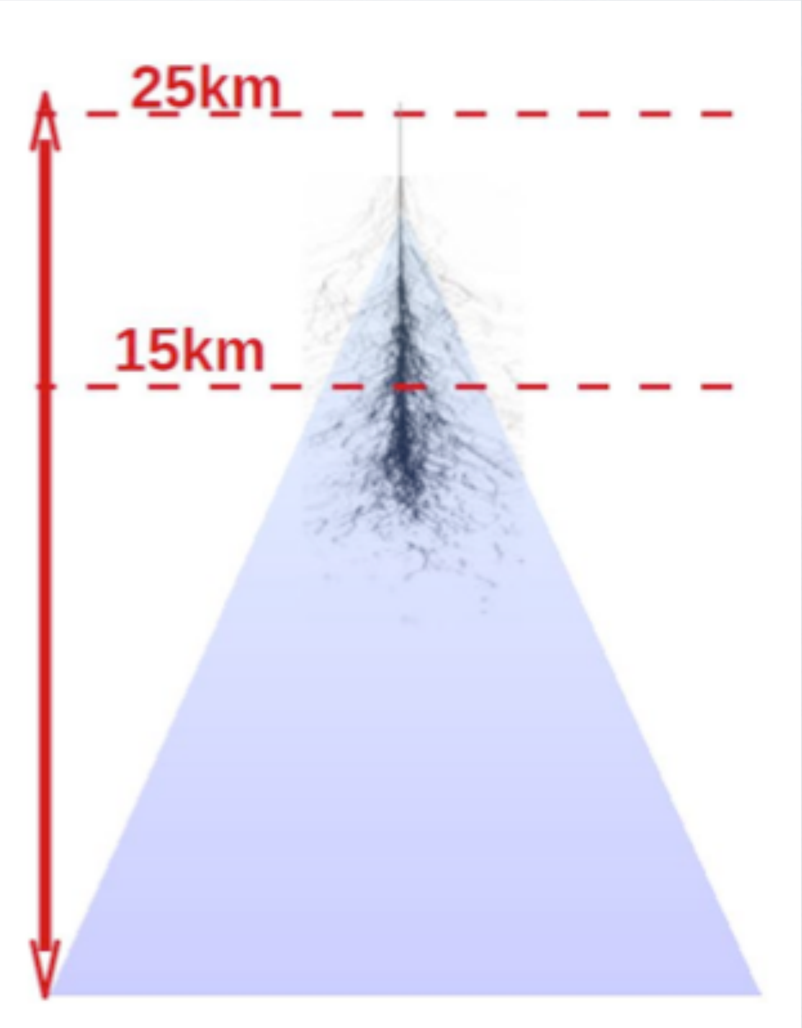
Simon Archambault

What is VERITAS?

- Four 12 m diameter Cherenkov telescopes
- ~100 collaborators among 21 institutions in 5 countries (USA, Ireland, UK, Canada and Germany)
- An hour south of Tucson, Az, at the Fred Lawrence Whipple Observatory

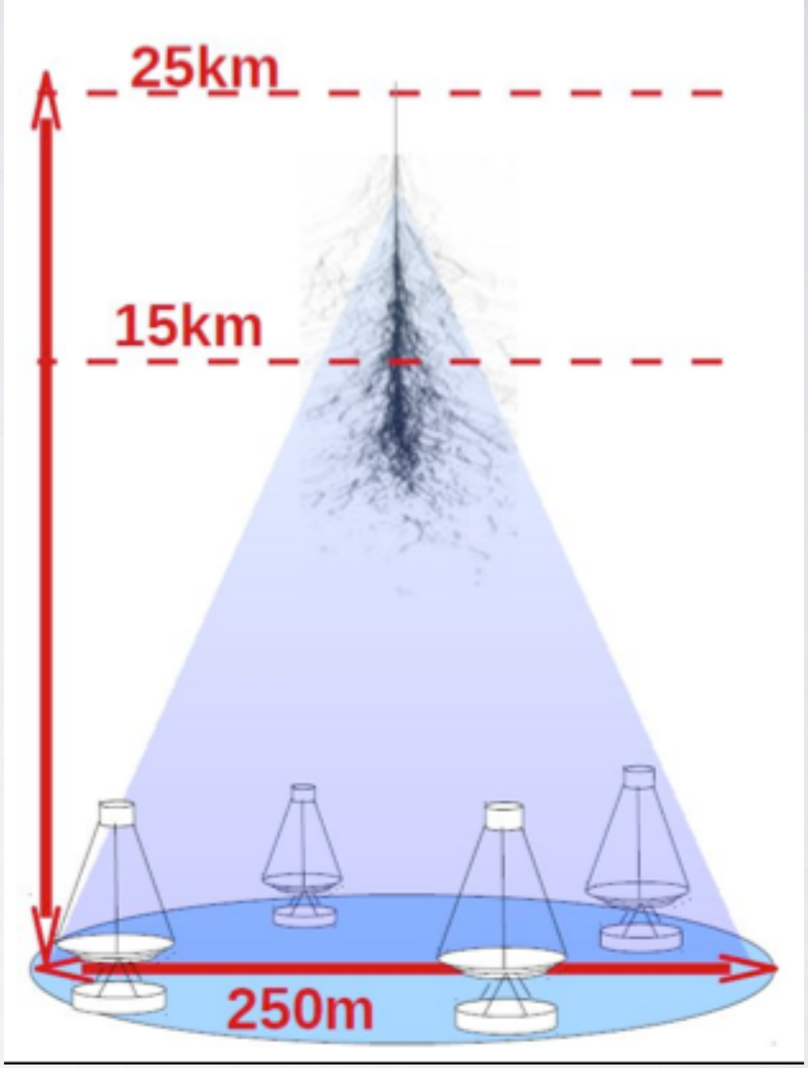
How does it work?

- VHE gamma rays interact in the upper atmosphere and cause an air shower
- The particles in the air shower have speed > c/n ⟶ Cherenkov radiation
- Creates a large pool of light on the ground : ~10^5 m^2
- In turn gives a large collection area



How does it work?

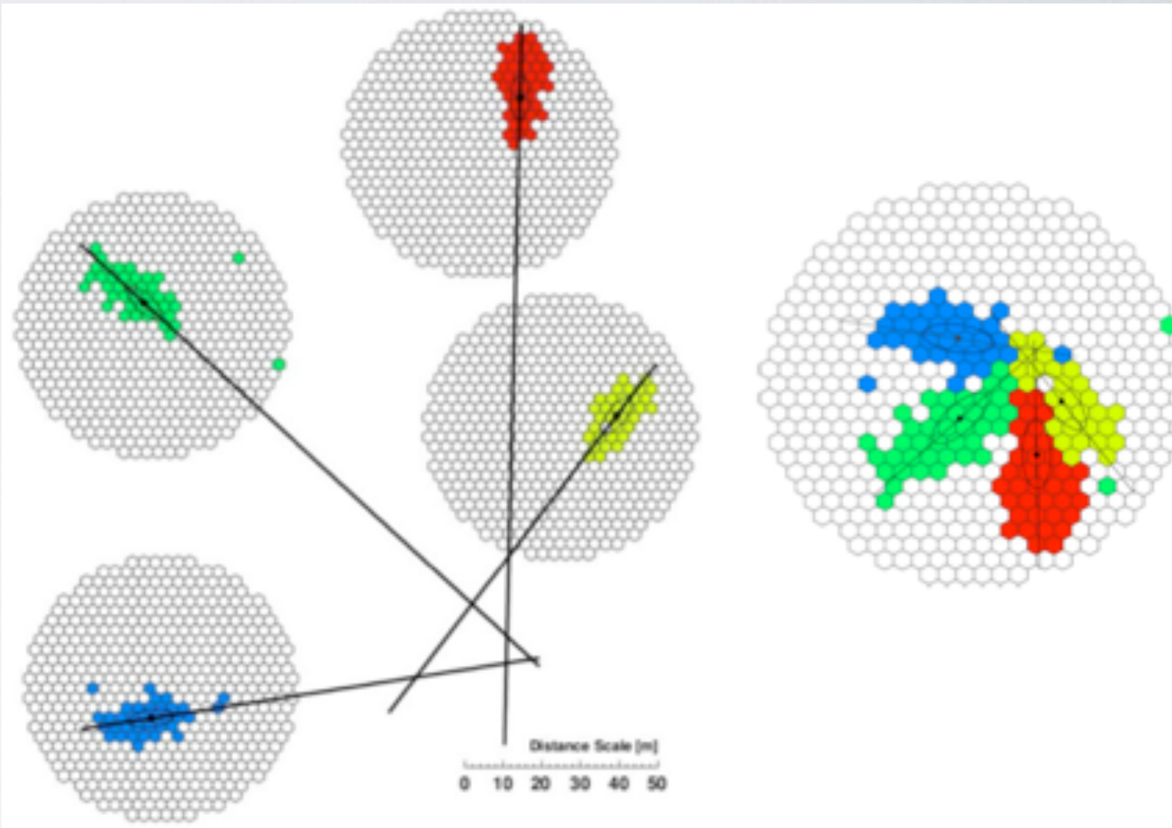
- Shower is imaged with telescopes on the ground
- VERITAS sees gamma rays from 85 GeV to 30 TeV
- 3.5° field of view
- Angular resolution < 0.1°
- Energy resolution : 15 to 25%
- Camera made of 499 PMTs :
- Different upgrades occurred over the years :
  - One telescope moved to increase sensitivity
  - Upgrade in the triggering system
  - Upgrade of the camera with new, more sensitive PMTs



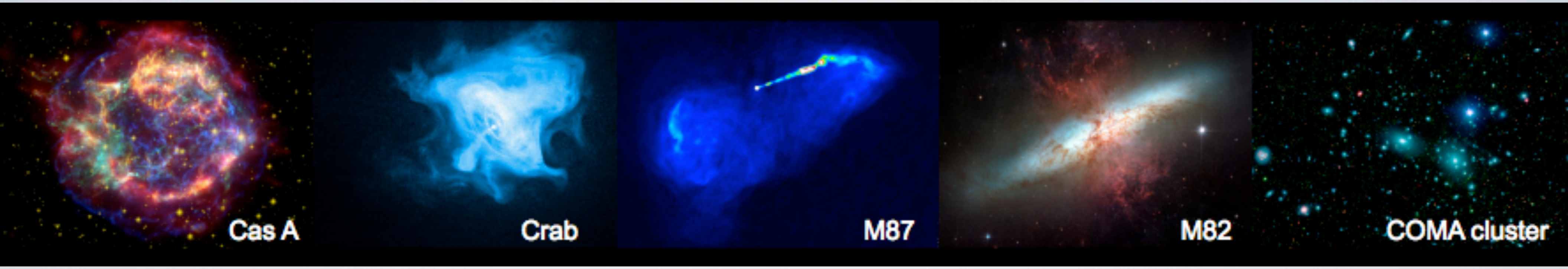
More details in Sean Griffin's talk : *The VERITAS Observatory Upgrade : Performace and Status* (T2-9)

How does it work?

- Telescopes see showers from different angles :
  - Allows for direction reconstruction :
    - Can find astronomical source of the gamma-ray that started the shower
    - Can find location of where the shower hits the ground



The Science of VERITAS



- Galactic :
  - SNR
  - Pulsar Wind Nebulae
  - Pulsar
  - Binaries
- Extra-Galactic :
  - Starburst Galaxies
  - Active Galactic Nuclei
    - Radio Galaxies
    - Blazars

Characterization of the Very High Energy Sky

Looking for acceleration of cosmic rays

Fundamental Science
-Dark Matter
-Lorentz Invariance Violation

Cosmology
-Extragalactic Background light constraints
-Magnitude of the intergalactic magnetic field

Calibration Measurements

- LED flashers emitting in UV (wavelength of Cherenkov light) aimed at PMTs for measuring gains

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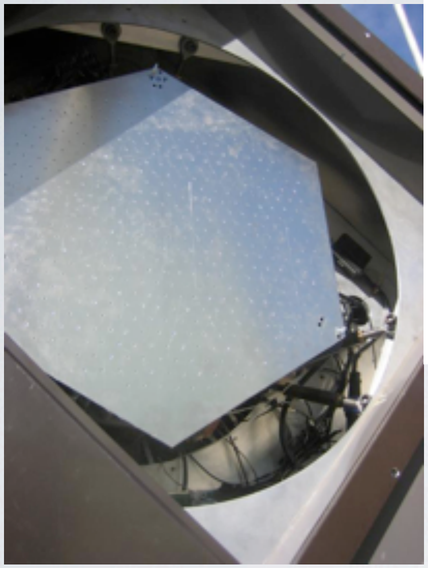
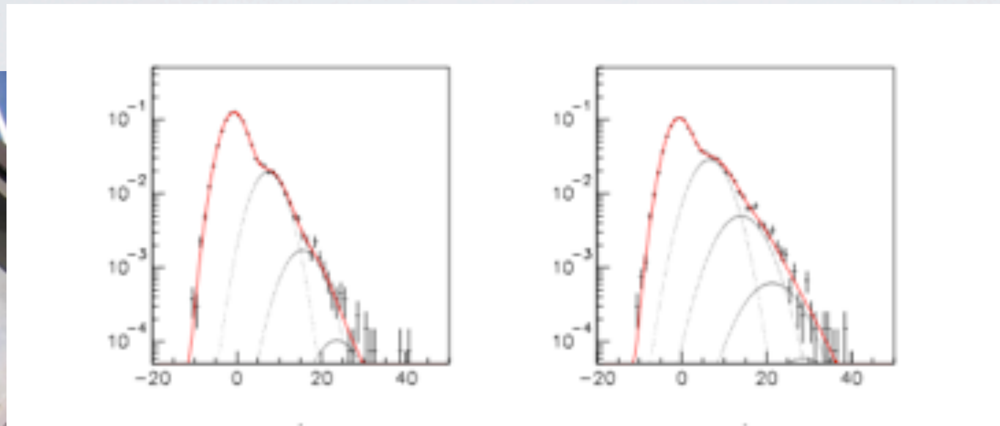
- Single P.E. measurements to determine the gain of the PMTs





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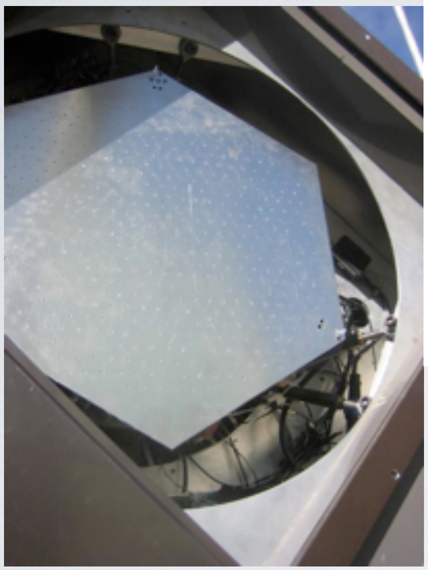
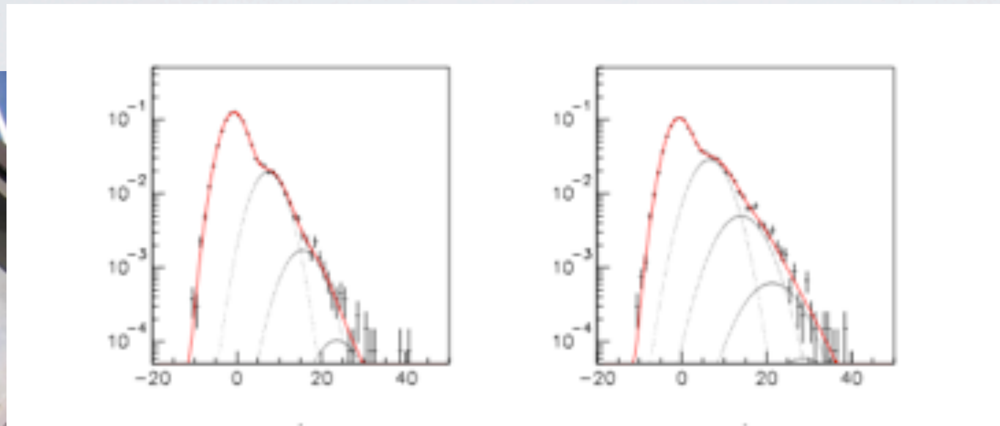
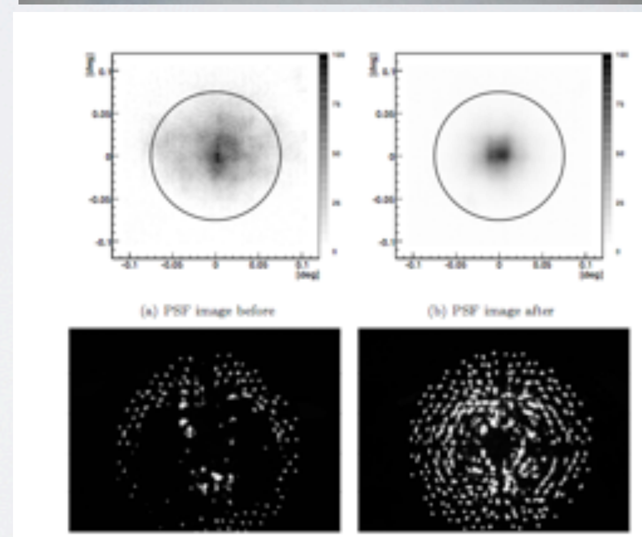




- Regular PSF measurement for improved event reconstruction :
  - Raster Scan used for alignment of mirrors and improved PSF



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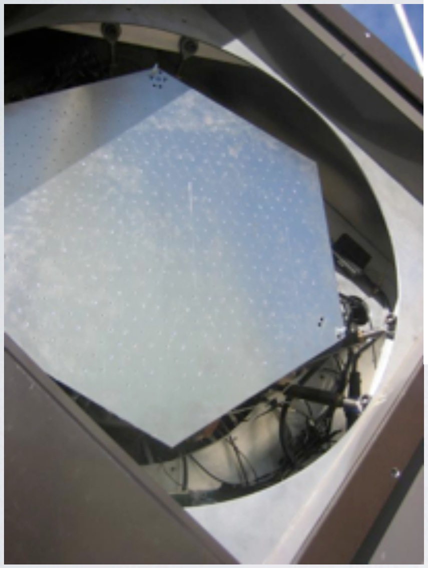

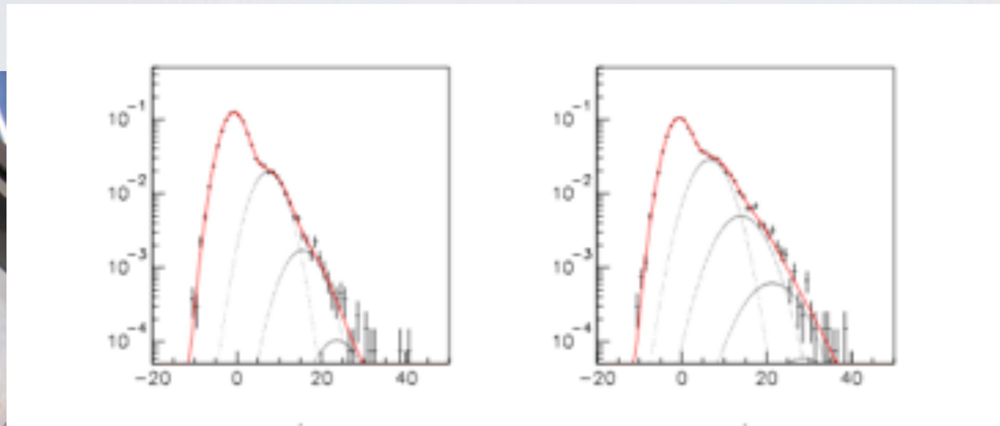

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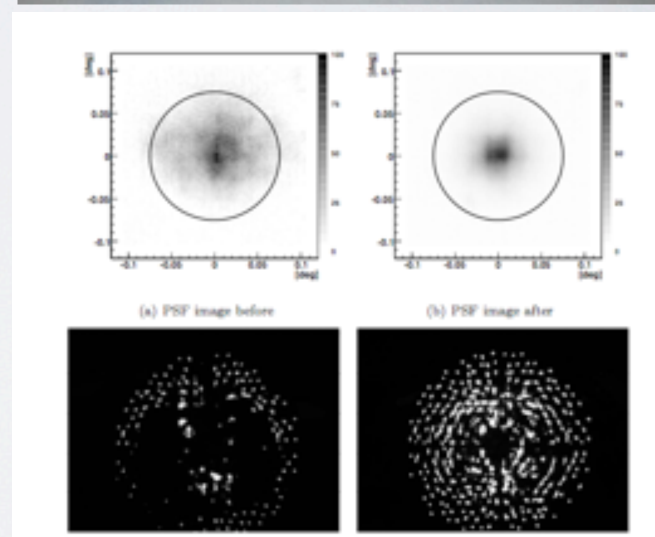

- Use raster scan of stars to measure the relative throughput of the telescopes
- Whole-dish reflectivity measurements for improved energy reconstruction

REFLECTIVITY : ORIGINAL IDEA FROM MAGIC

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A method to measure the mirror reflectivity of a prime focus telescope

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Abstract

We have developed a method to measure the mirror reflectivity of telescopes. While it is relatively easy to measure the local reflectivity of the mirror material, it is not so straightforward to measure the amount of light that it focuses in a spot of a given diameter. Our method is based on the use of a CCD camera that is fixed on the mirror dish structure and observes simultaneously part of the telescope's focal plane and the sky region around its optical axis. A white diffuse reflecting disk of known reflectivity is fixed in the telescopes focal plane. During a typical reflectivity measurement the telescope is directed to a selected star. The CCD camera can see two images of the selected star, one directly and another one as a spot focused by the mirror on the white disk. The ratio of the reflected starlight integrated by the CCD from the white disk to the directly measured one provides a precise result of the product of (mirror area × mirror reflectivity).
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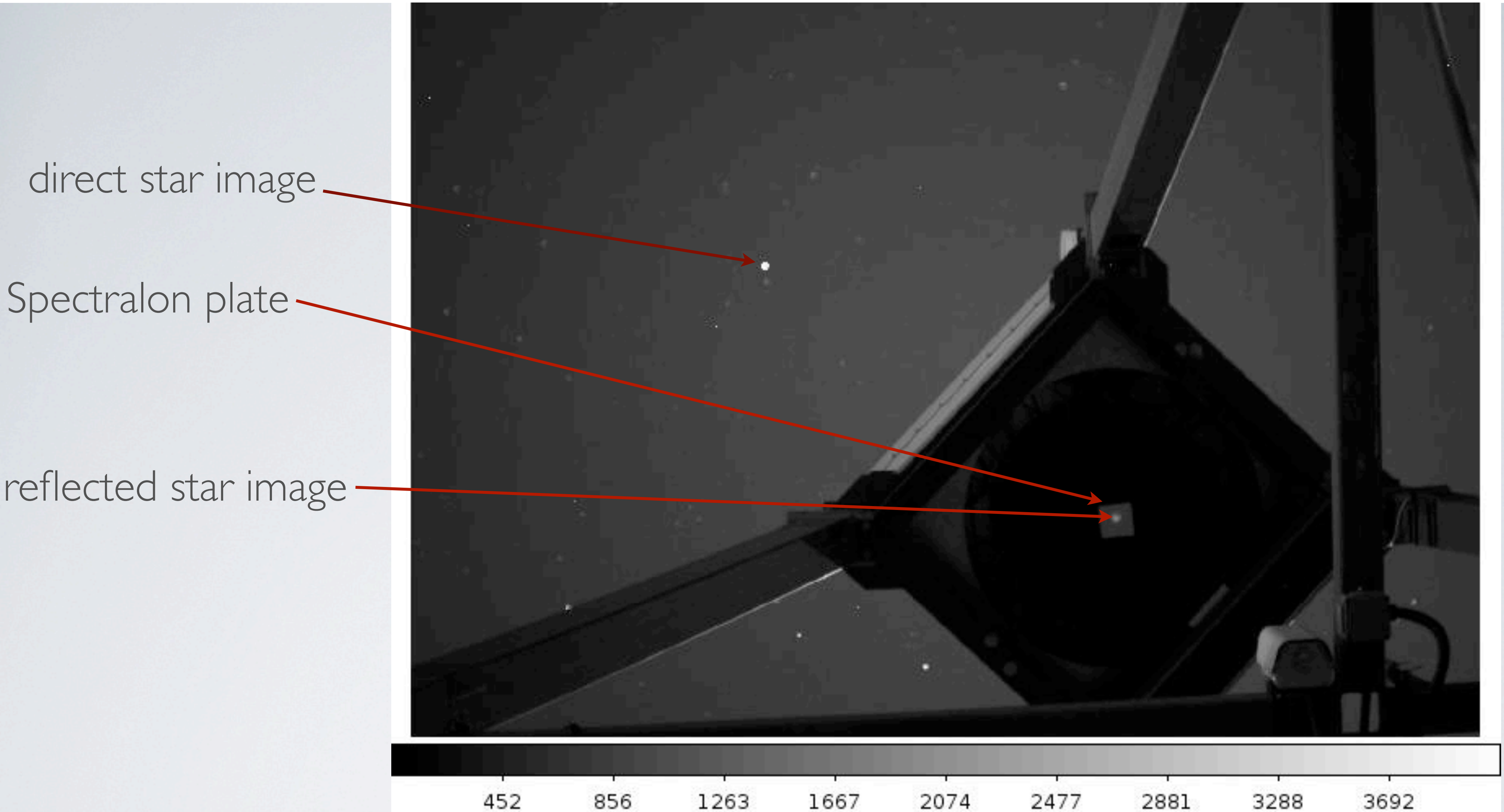
Keywords: Mirror reflectivity; Telescopes; IACT

Use a CCD Camera with a wide field-of-view and large dynamic range to view a bright star directly and its image at the focal plane



- The star's light is reflected onto a screen made of Spectralon, a highly reflective fluoropolymer with Lambertian behaviour (isotropic luminance)
- The CCD camera is focused on the Spectralon, the star itself is out of focus and avoids pixel saturation
- Pixel values corresponding to the star and the reflection are summed to get an estimate of the photon fluxes ($F_{reflected}$ and F_{direct})

- For
  - R = reflectivity of the spectralon
  - d = distance from the CCD camera to the focal plane
  - α = angle between the CCD-spectralon axis and the normal to the focal plane

we have

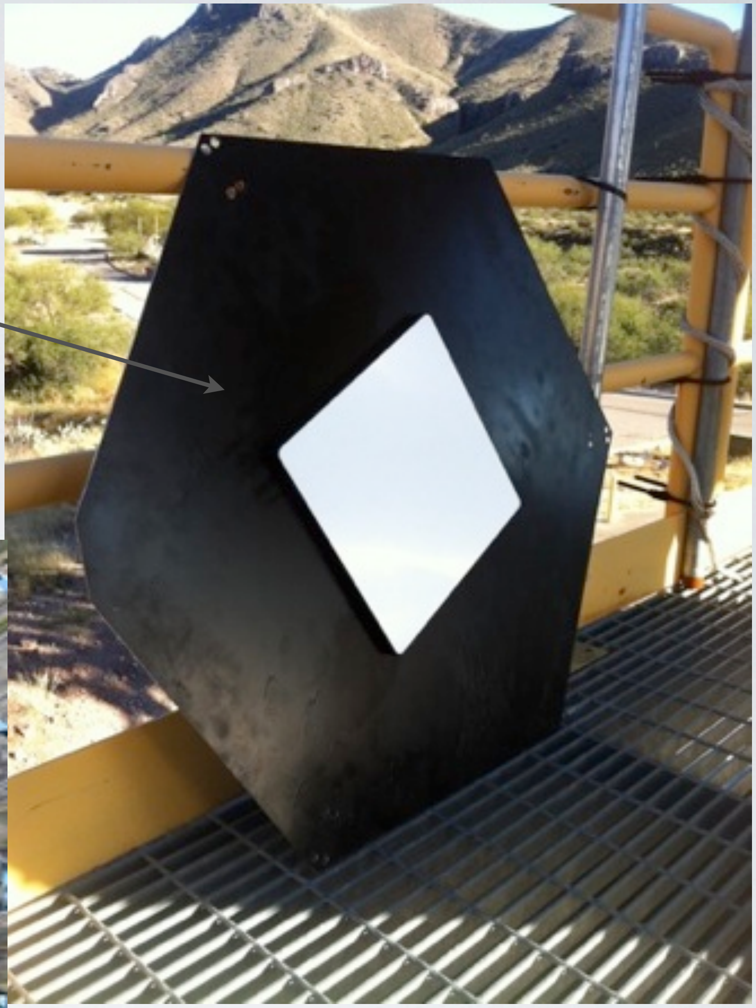
- $R_{mirror} \times A_{mirror} = (F_{reflected}/F_{direct})(\pi d^2/\cos\alpha)/R$

  where R_{mirror} is the global reflectivity of the mirror and A_{mirror} is its effective area (includes shadowing *etc*)

Application to VERITAS

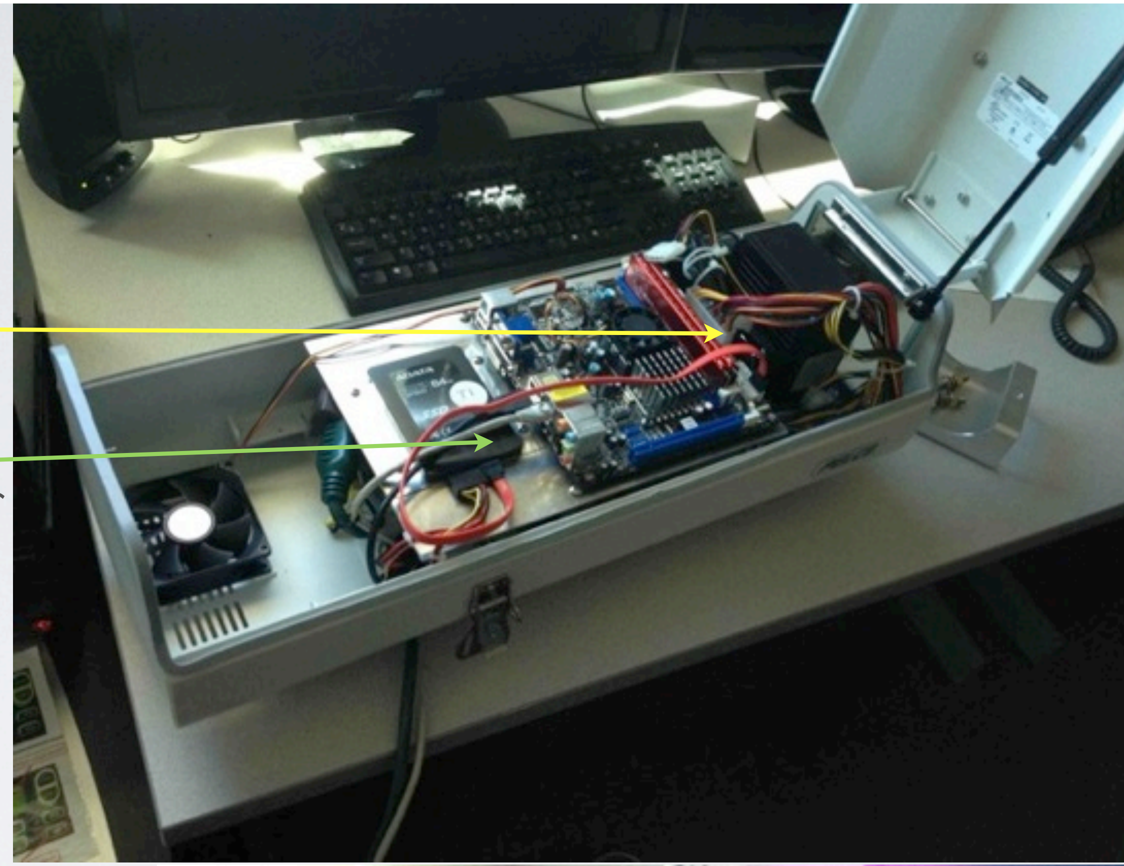
- Install the spectralon target on an aluminum mount
- Install a CCD camera near the centre of the dish

• Spectralon target mounted onto aluminum plate

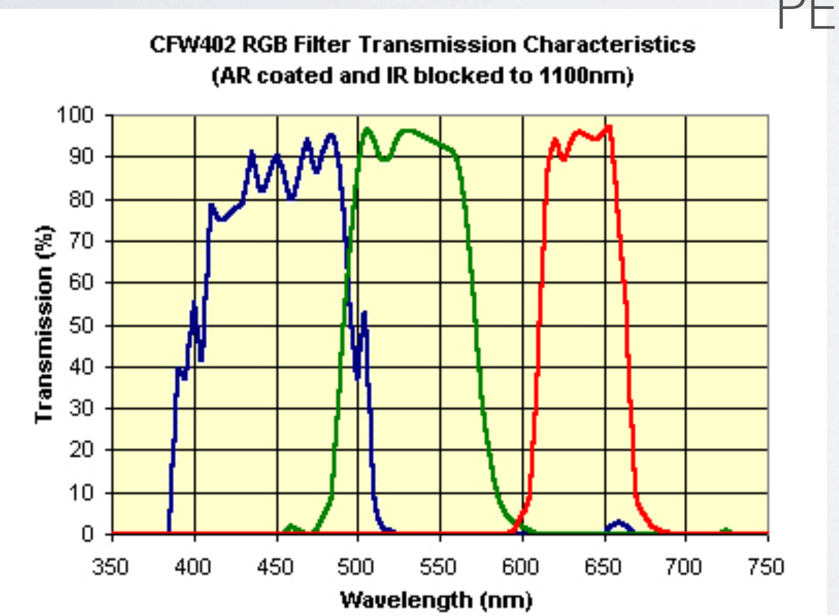


• Installed the CCD camera with integrated filter wheel inside weatherproof 'PELCO' box, mounted on the telescope replacing a mirror facet

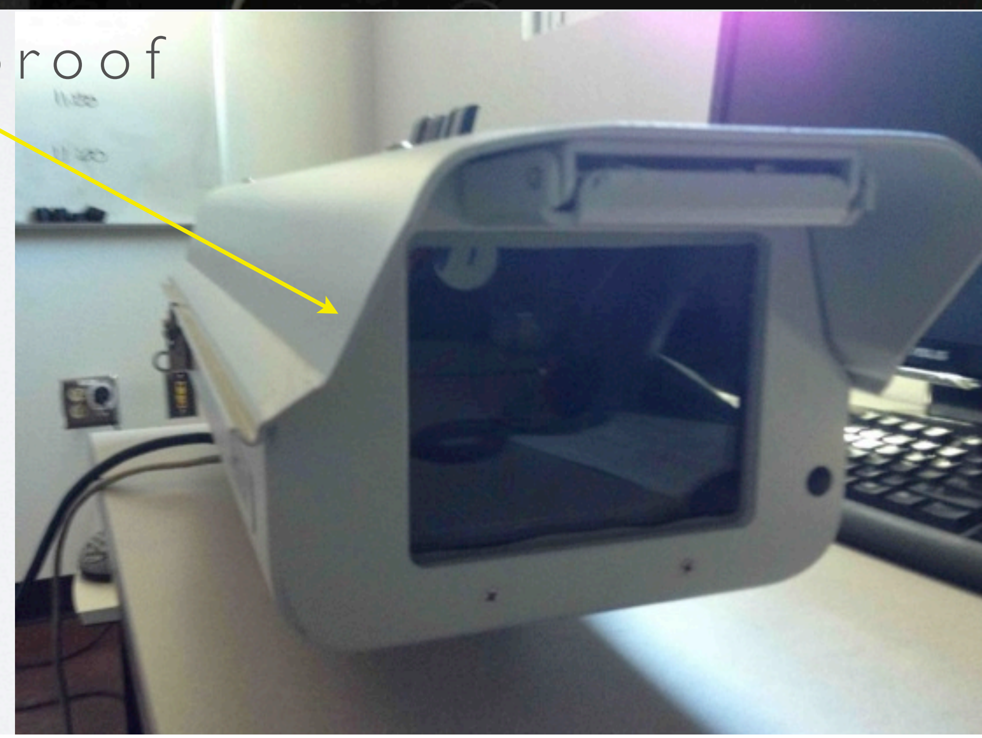
Mini-ITX computer



SBIG CCD camera
Cooling system
Highly sensitive CCD
Automatic dark-frame subtraction
Integrated filter wheel

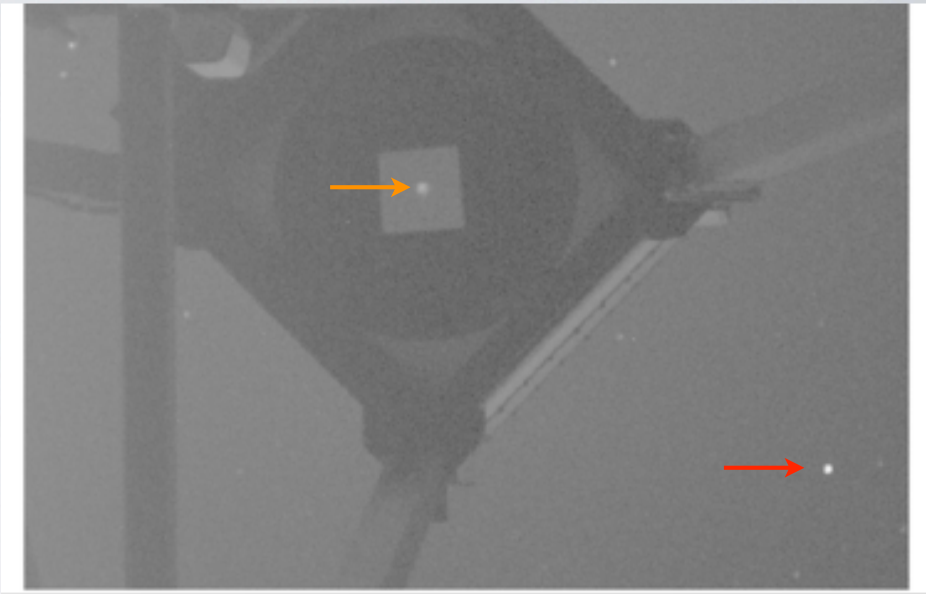


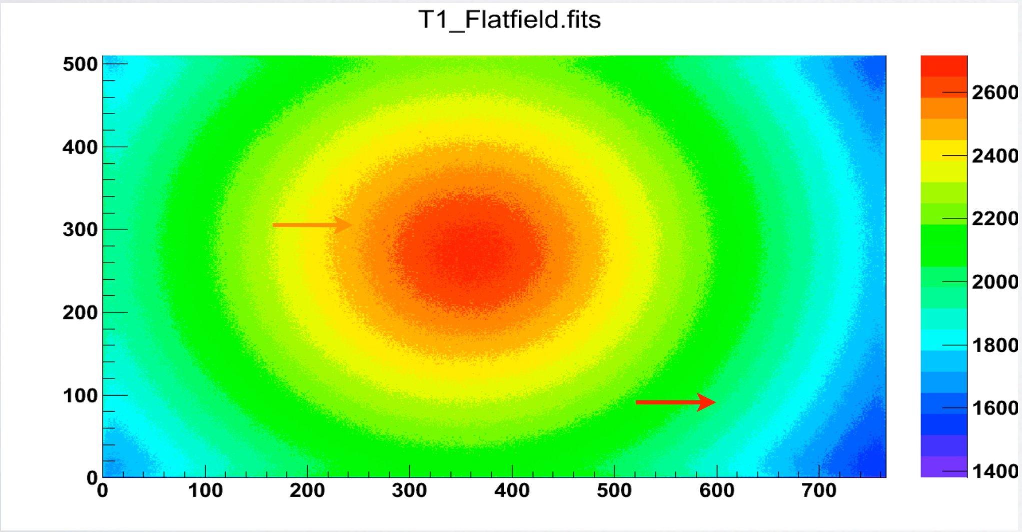
Weatherproof PELCO box



DATA ANALYSIS

- Start with FITS files
- Identify the approximate location of the star and the reflection
- Plot out 100x100 pixels centered on those locations
- Add multiple files and check for saturation

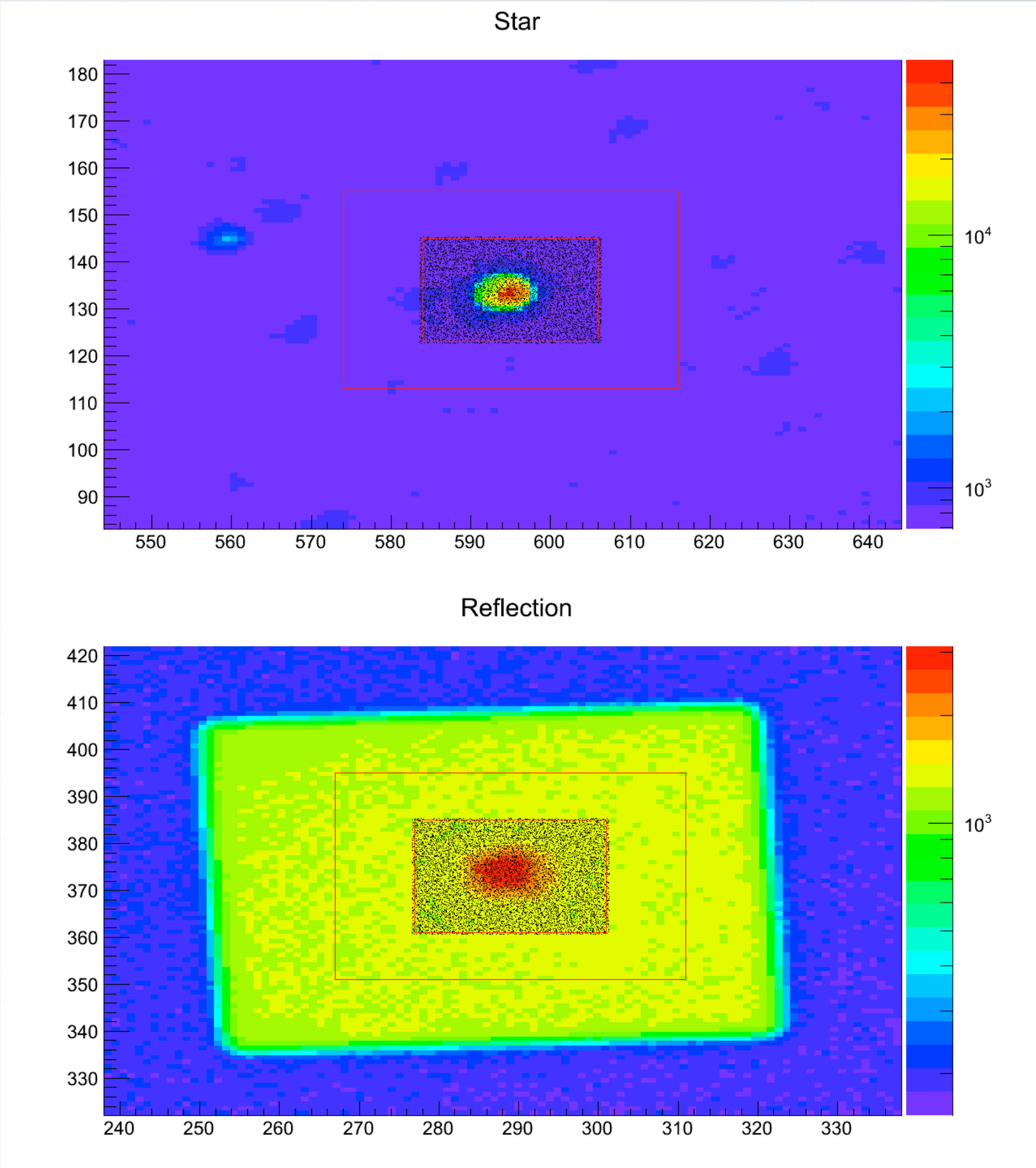




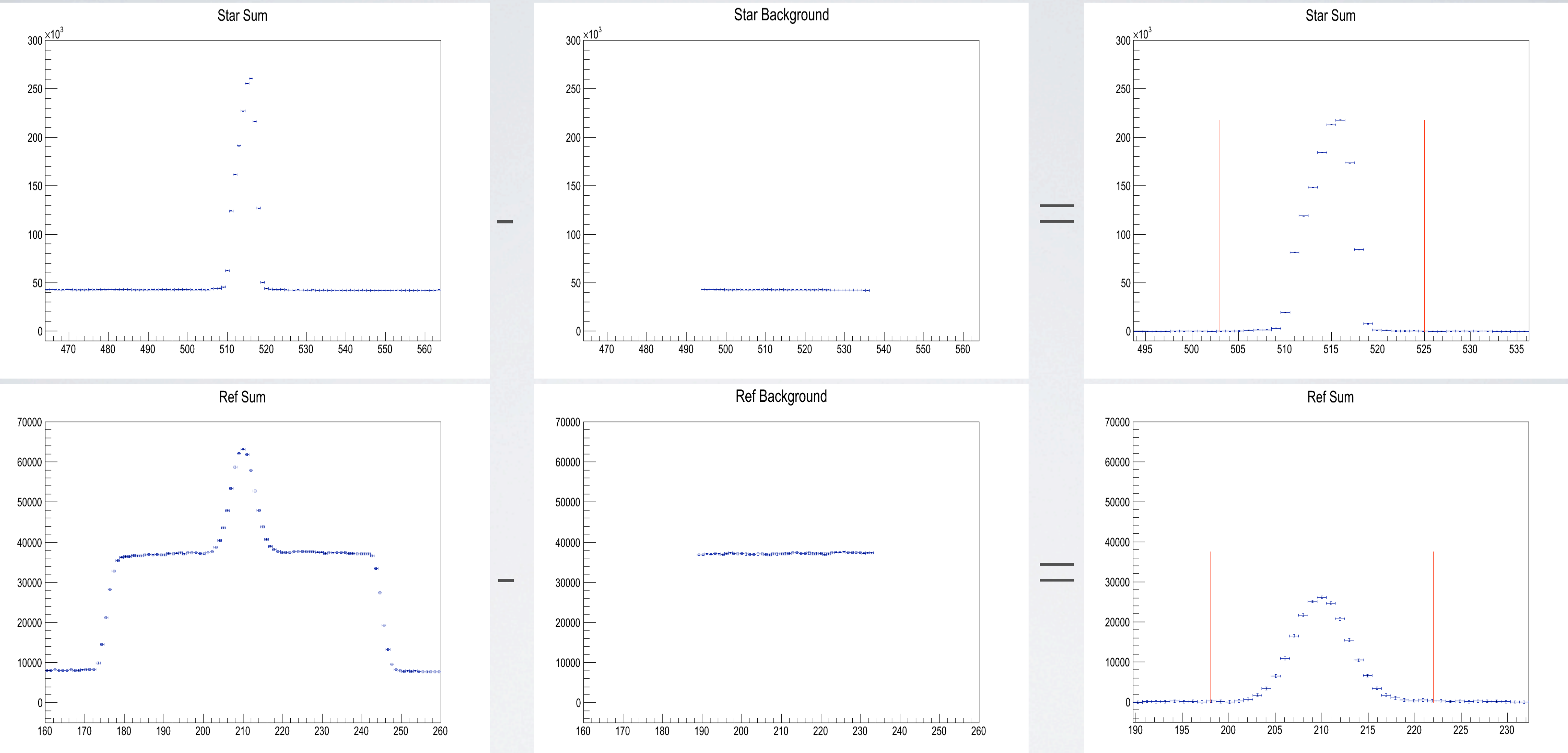
- Apply vignetting correction based on flat-field images acquired by imaging the zenith acquired at twilight
- Typical correction factor ~5 - 10 %

DATA ANALYSIS

- Find the center of the images
- Construct boxes 22x22 around star and 24x24 around reflection (based on reflection's PSF)
- Use area outside of inner square and inside outer as background estimate

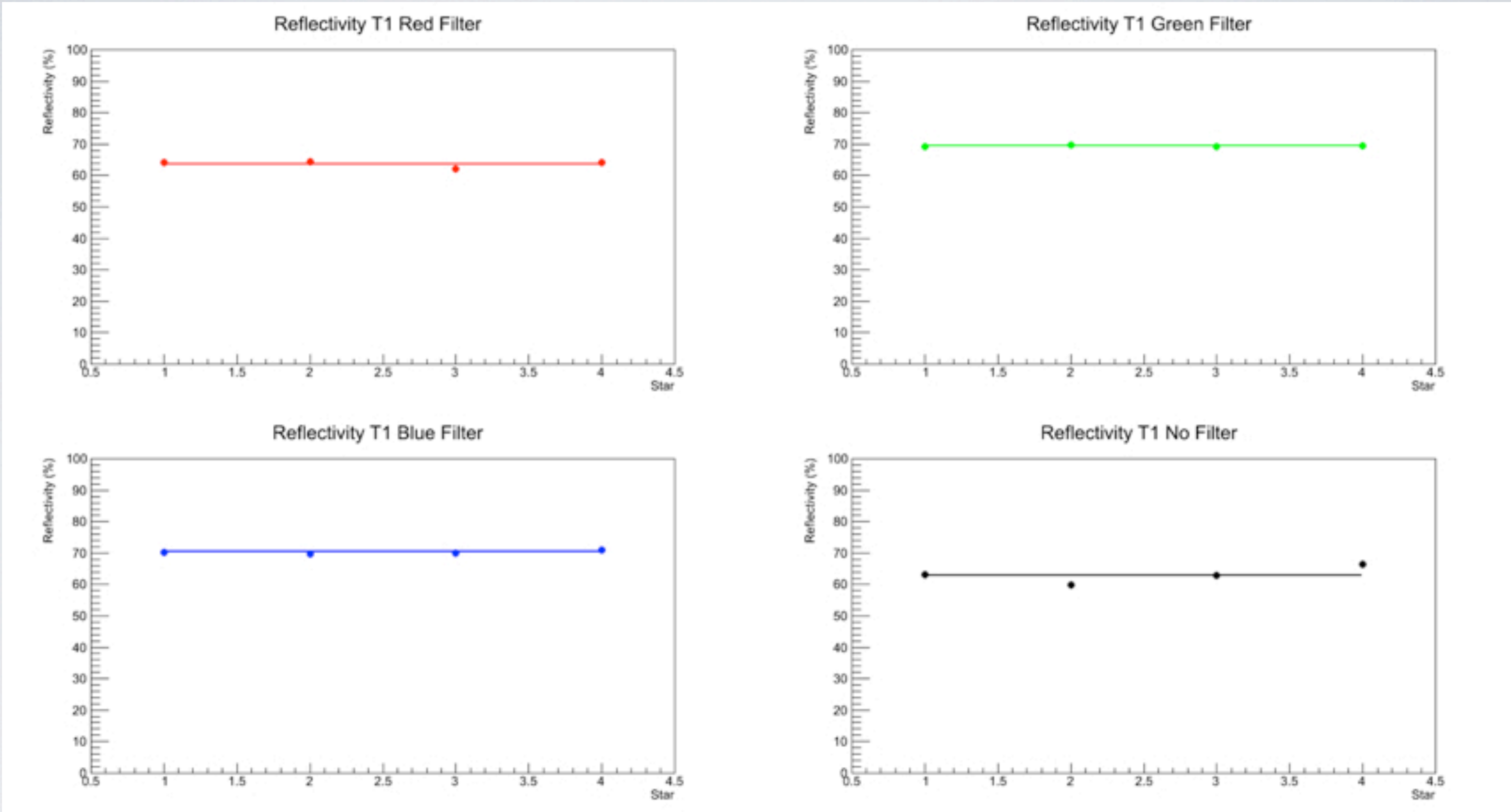


DATA ANALYSIS



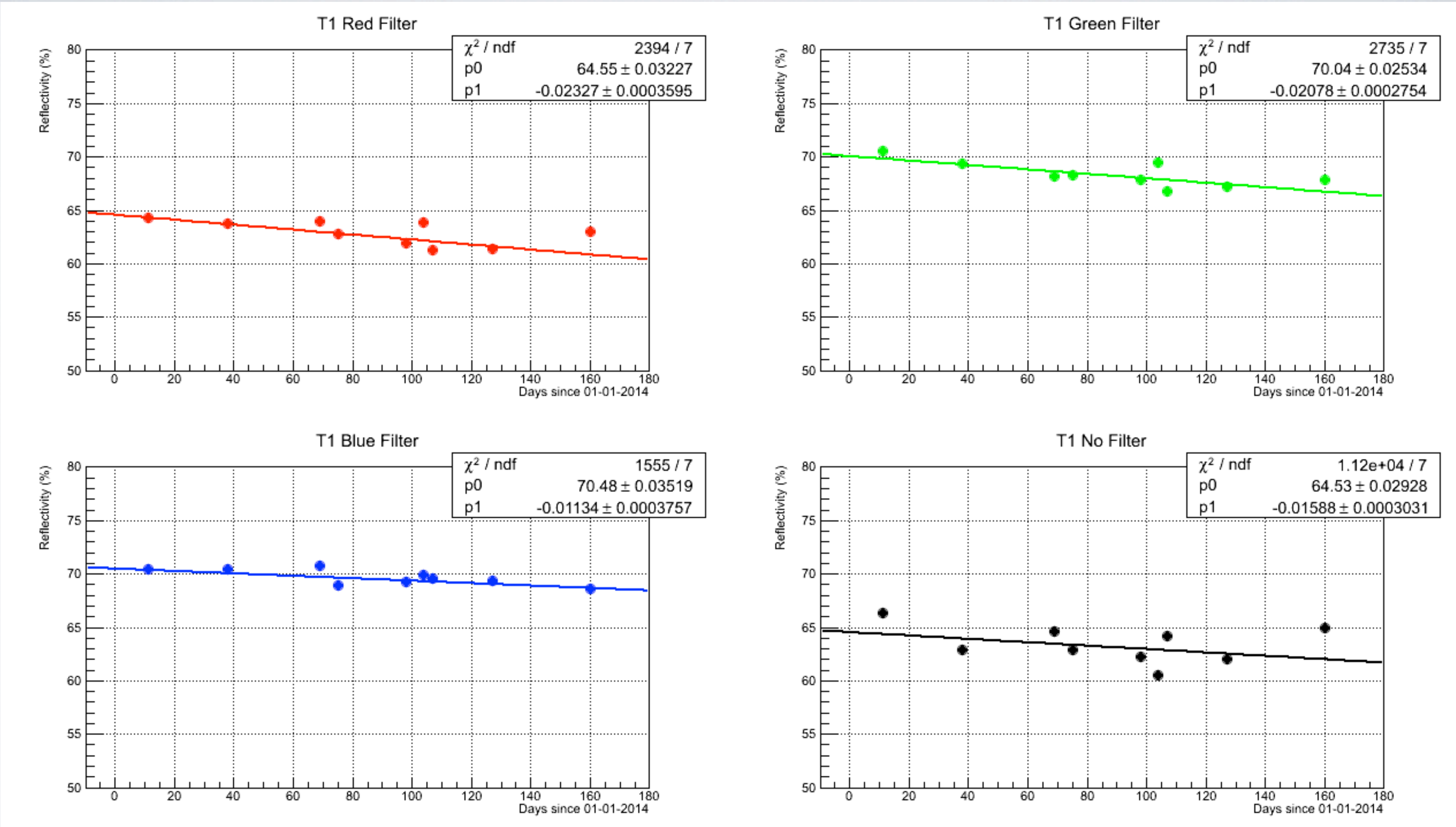
- Subtract background from signal region and sum to get flux estimate
- Check quality of background subtraction in resulting plot

GENERAL RESULTS



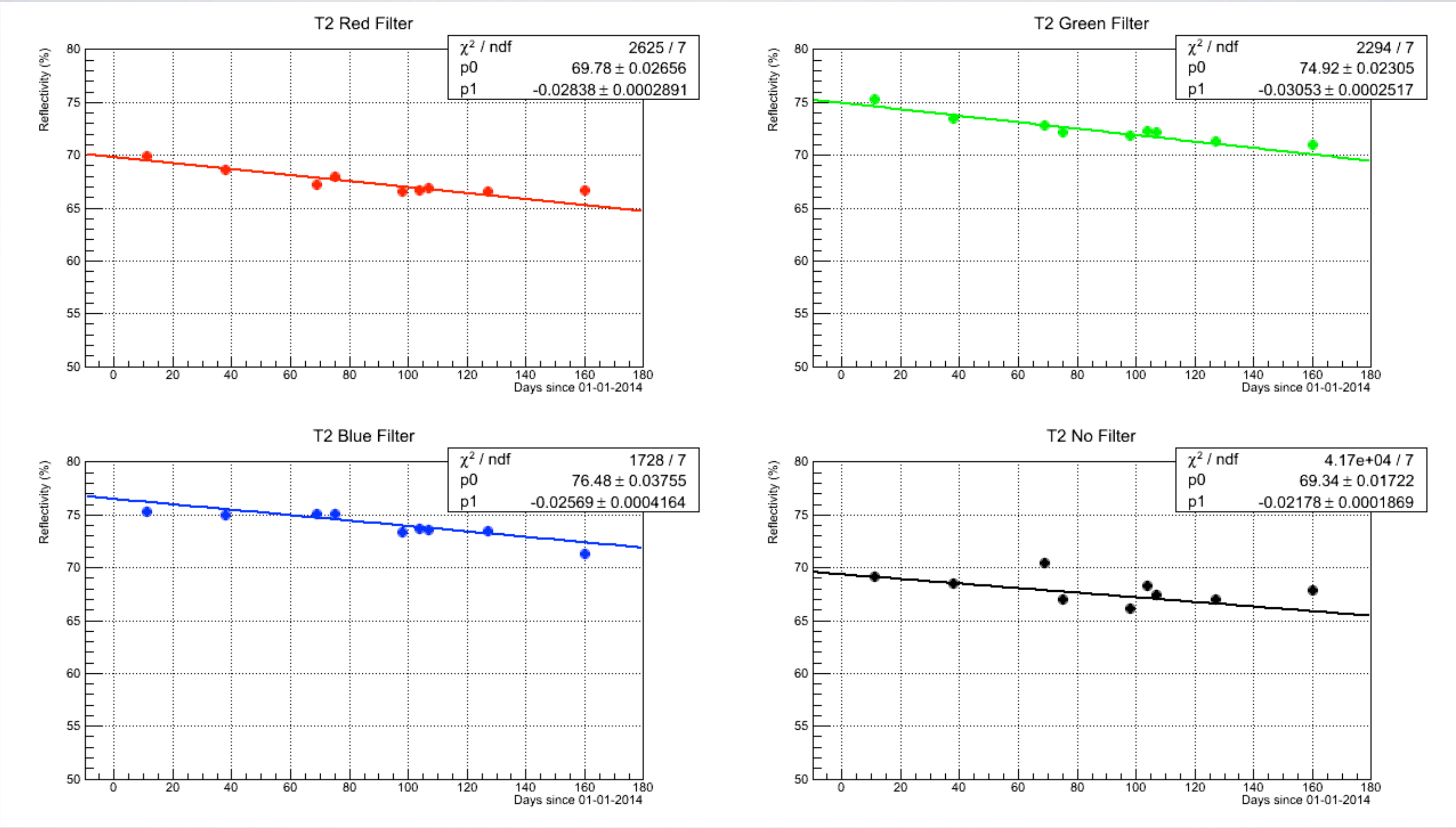
- Numbers are consistent from star to star
- The important one to look at is the blue filter : similar wavelength to Cherenkov light
- Fluctuation in 'No Filter' likely due to the stars' spectral types (i.e. different colors)
- Statistical uncertainty smaller than the points

GENERAL RESULTS
T1

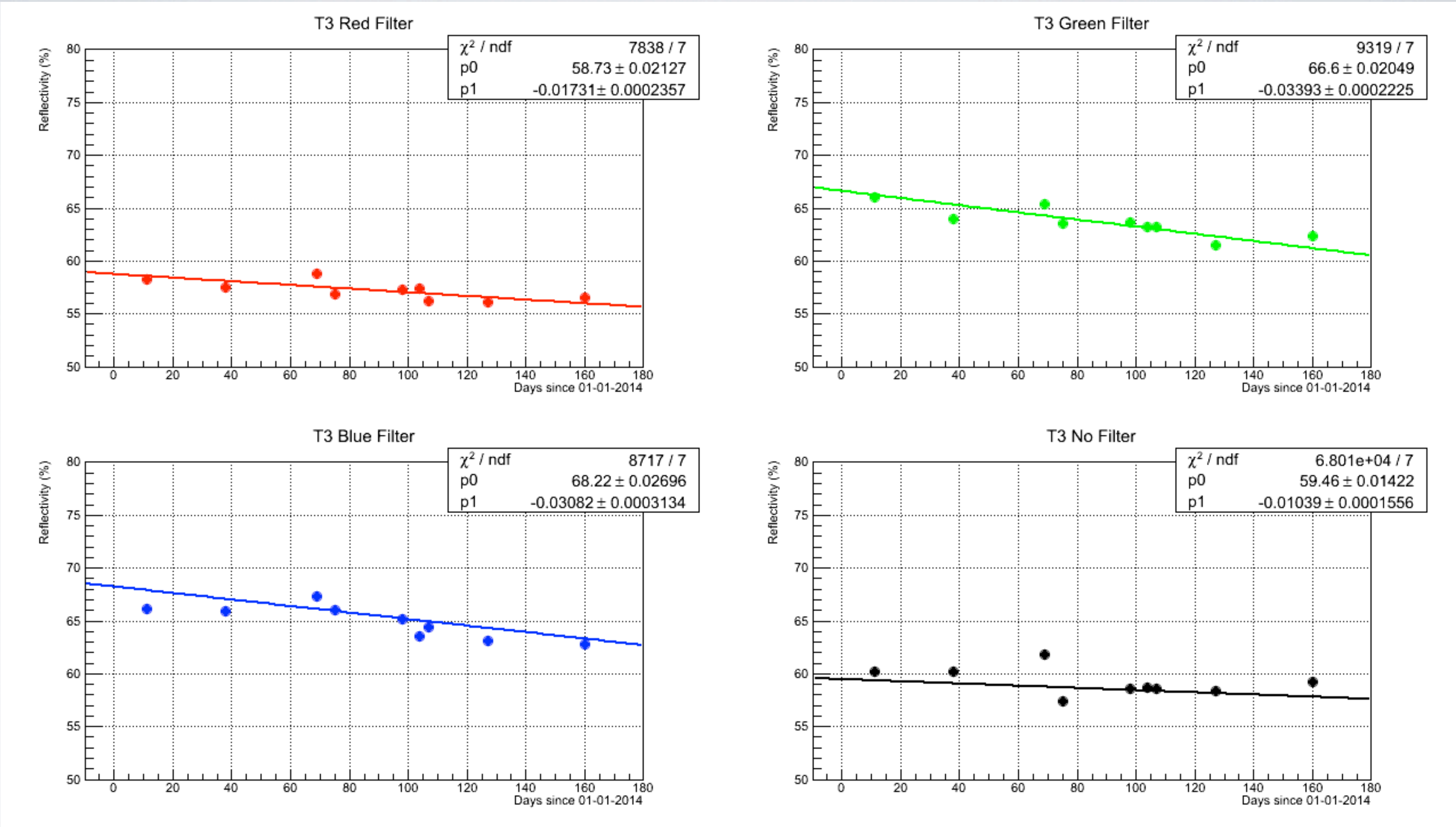


- Slow degradation over time due to dust and weather

GENERAL RESULTS
T2



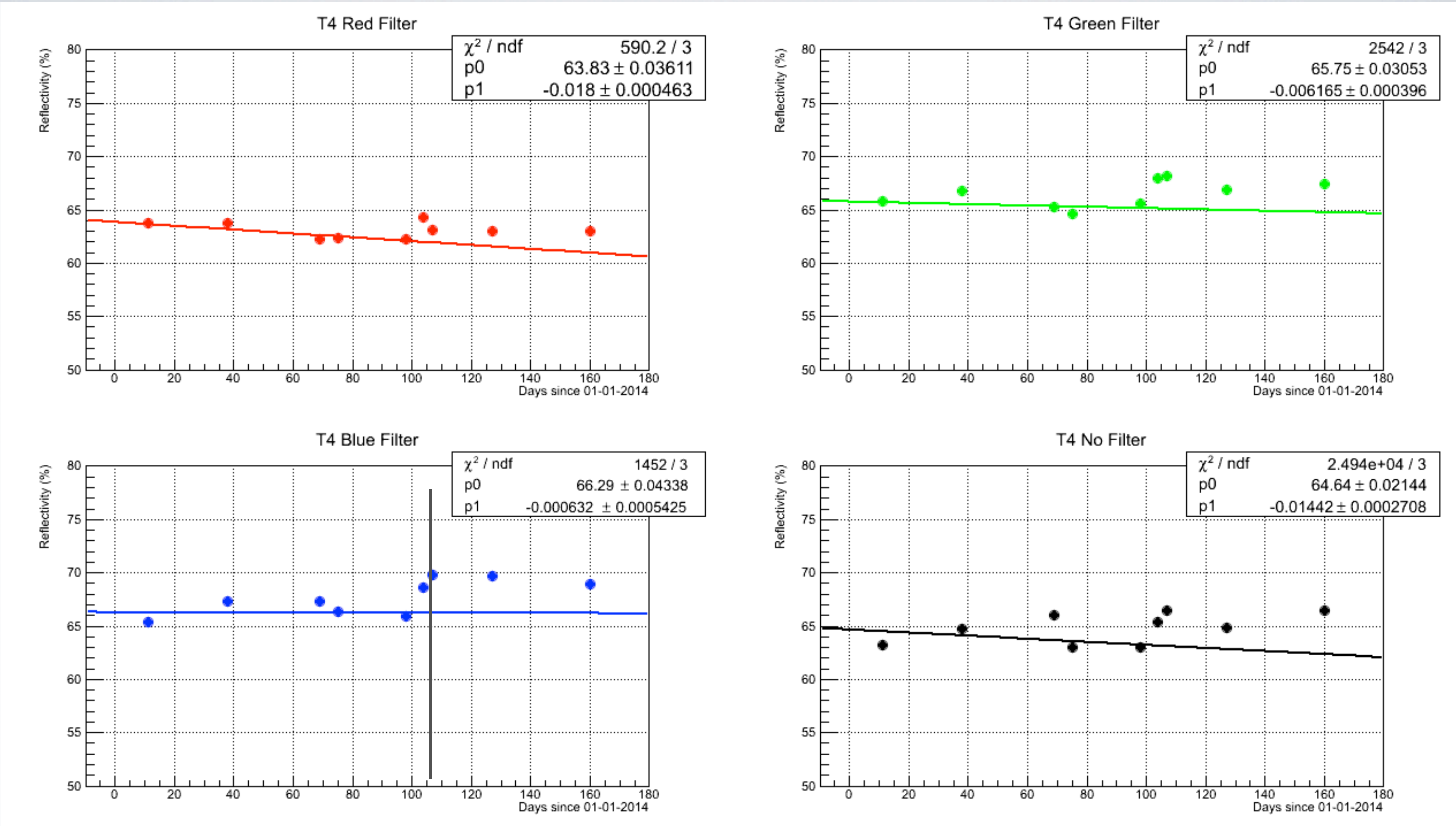
GENERAL RESULTS
T3



SWAPPING MIRRORS

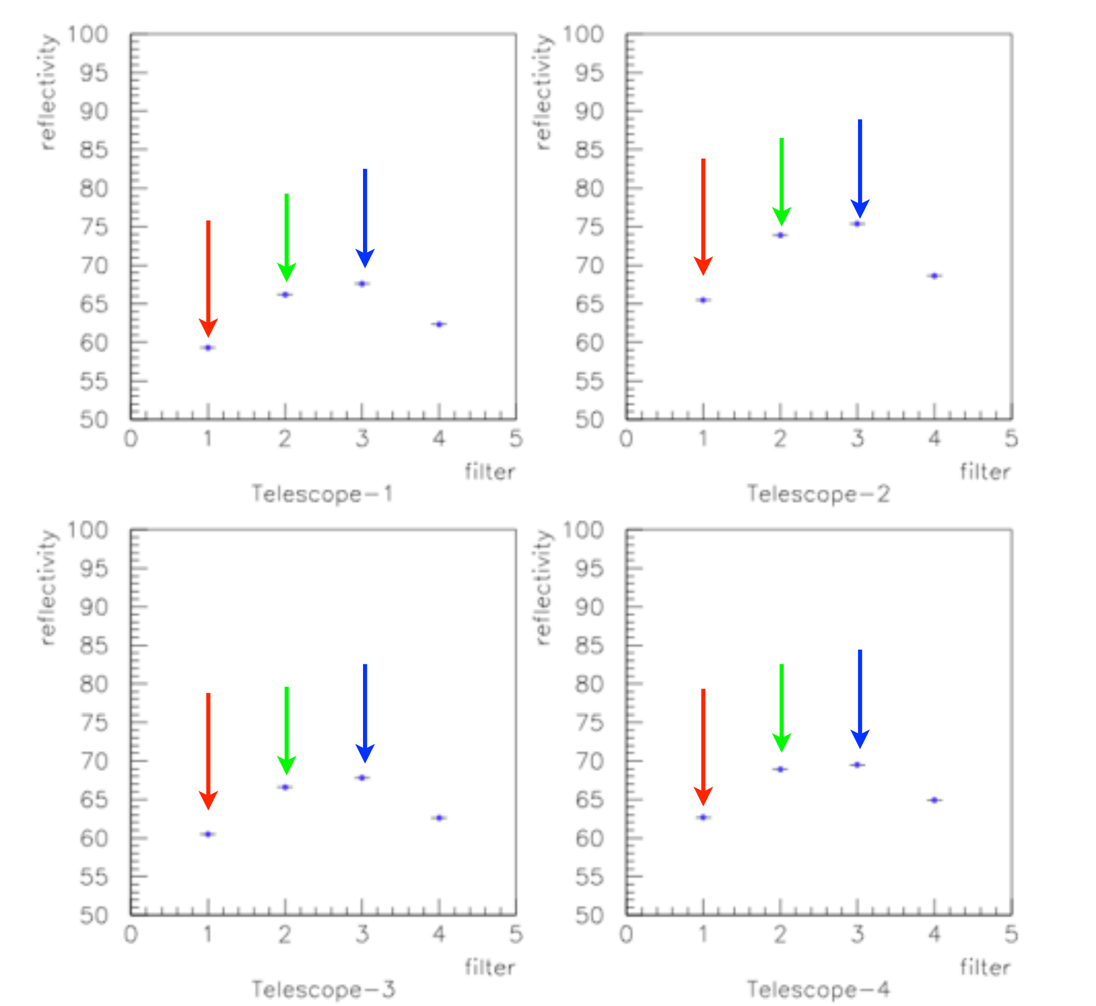
- Each telescope has 345 mirrors
- ~100 spare mirrors available
- Process in place to recoat mirrors in batches of 100
- Mirrors swapped regularly to maintain good reflectivity

GENERAL RESULTS
T4



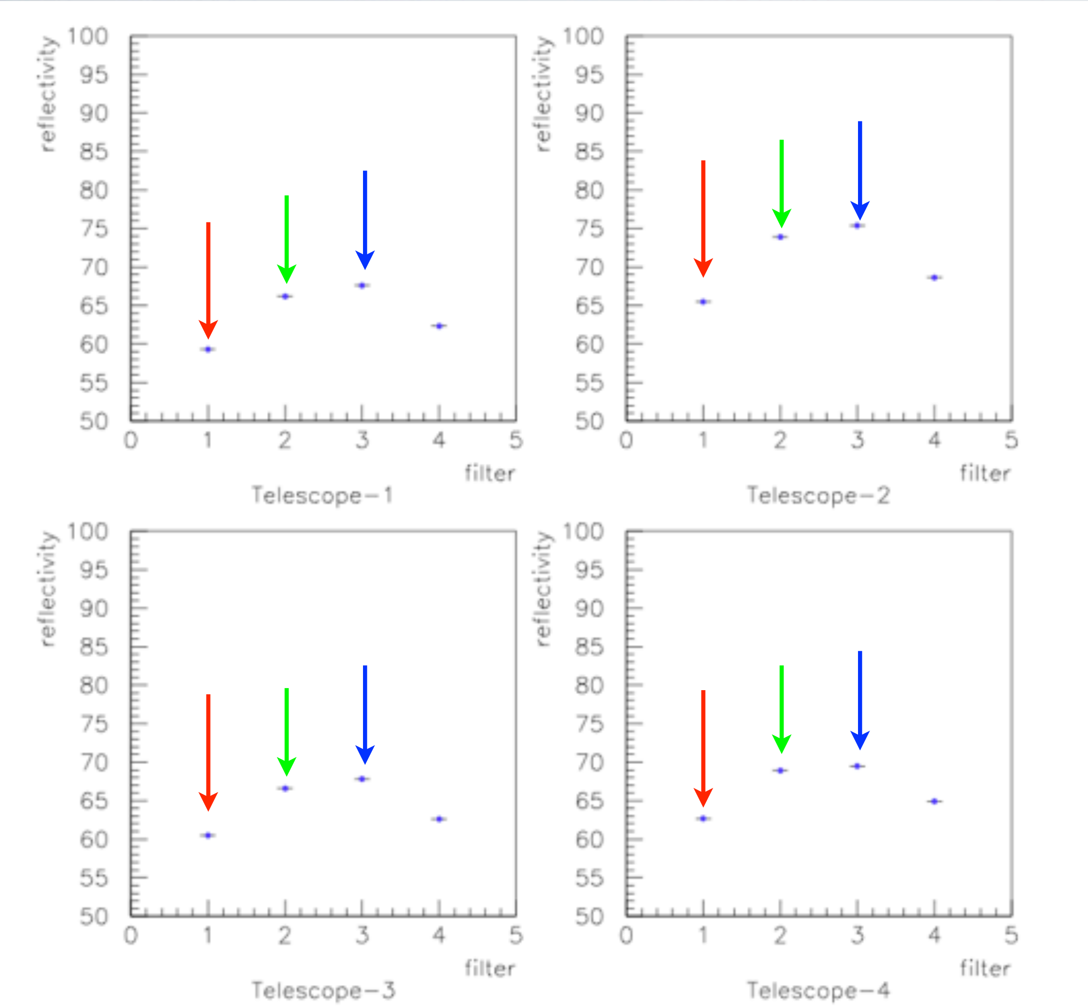
- Only one showing improvement
- Mirror swap noticeably improved reflectivity

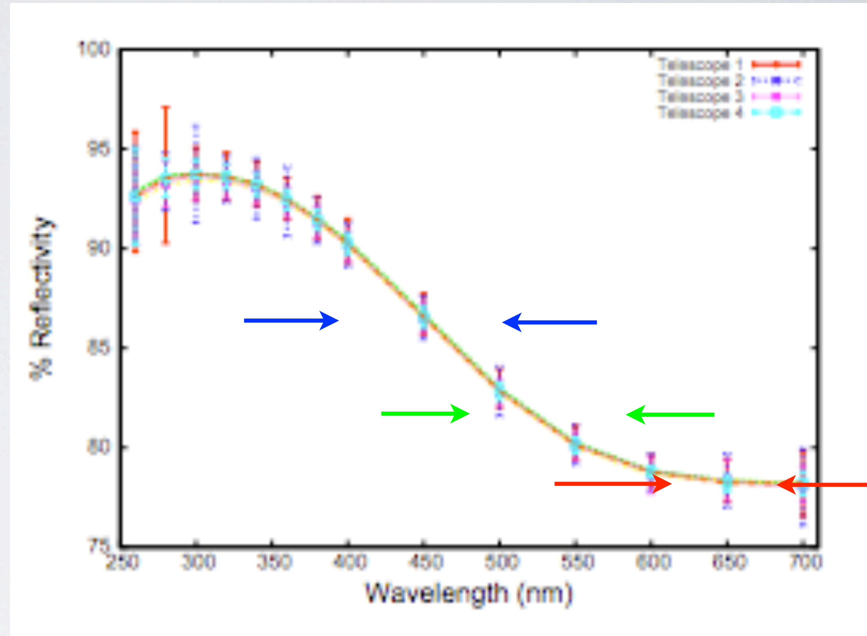
FEATURES



- Consistent behavior with respect to wavelength

FEATURES

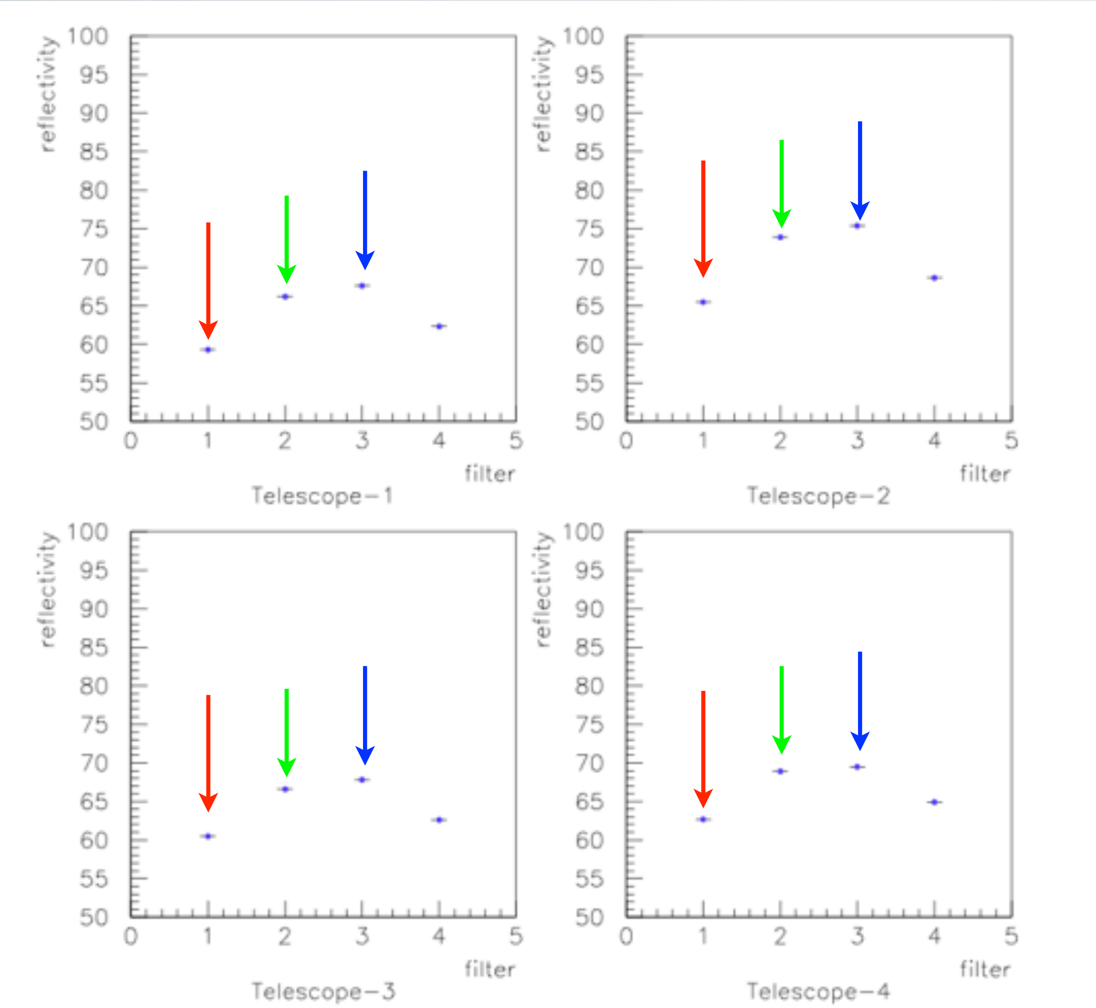


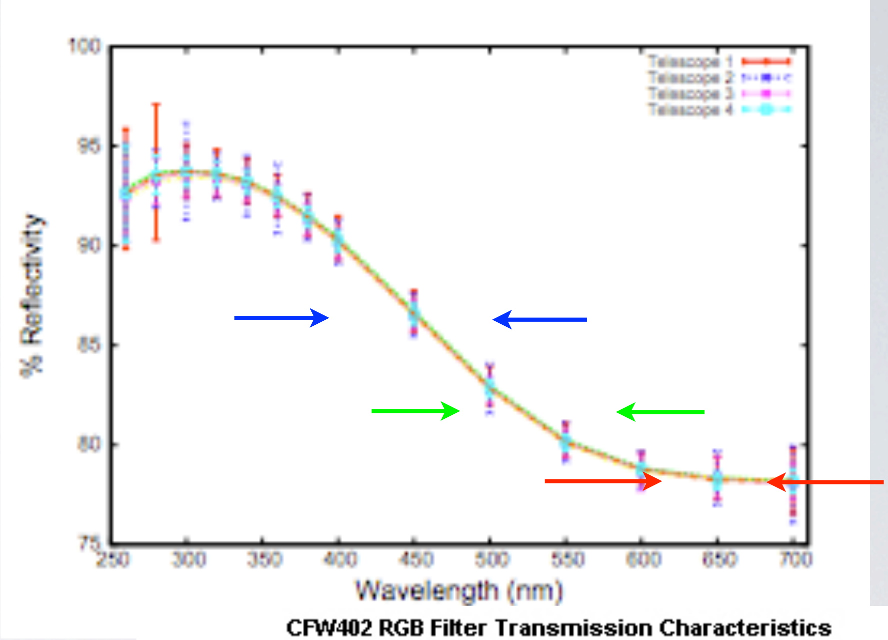


- Compare with reflectivity measurement of single mirror facet

- Consistent behavior with respect to wavelength

FEATURES





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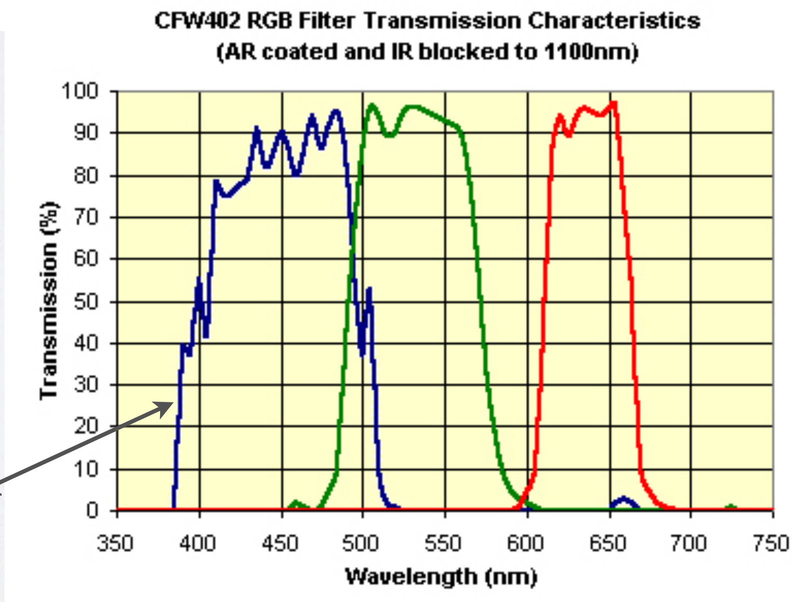

Transmission curves of the filters used

CONCLUSION

- We now have a simple, easy-to-use and analyze, low-cost (~2500$ per telescope), system to measure the whole-dish reflectivity of the VERITAS telescopes

- This method accounts for misaligned facets, shadowing effects from telescope structure, and other effects not taken into account when measuring reflectivity of individual mirror facets

- Need to understand systematic uncertainties that cause the small non-statistical scatter in the results