Development of a Raman LIDAR for CTA

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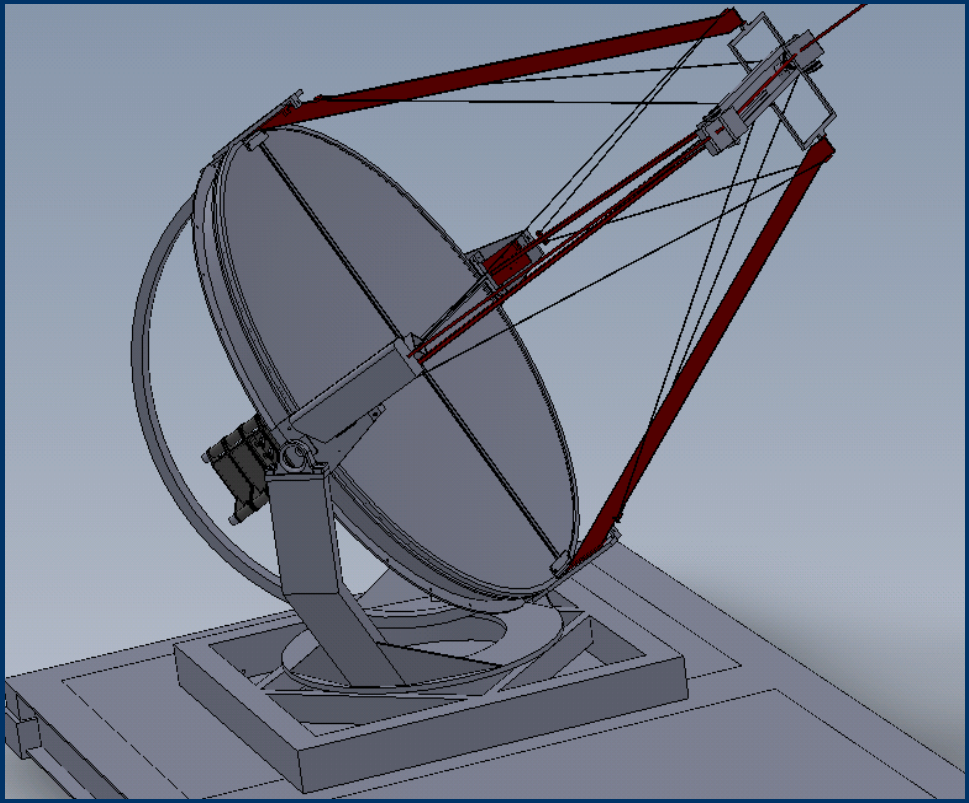


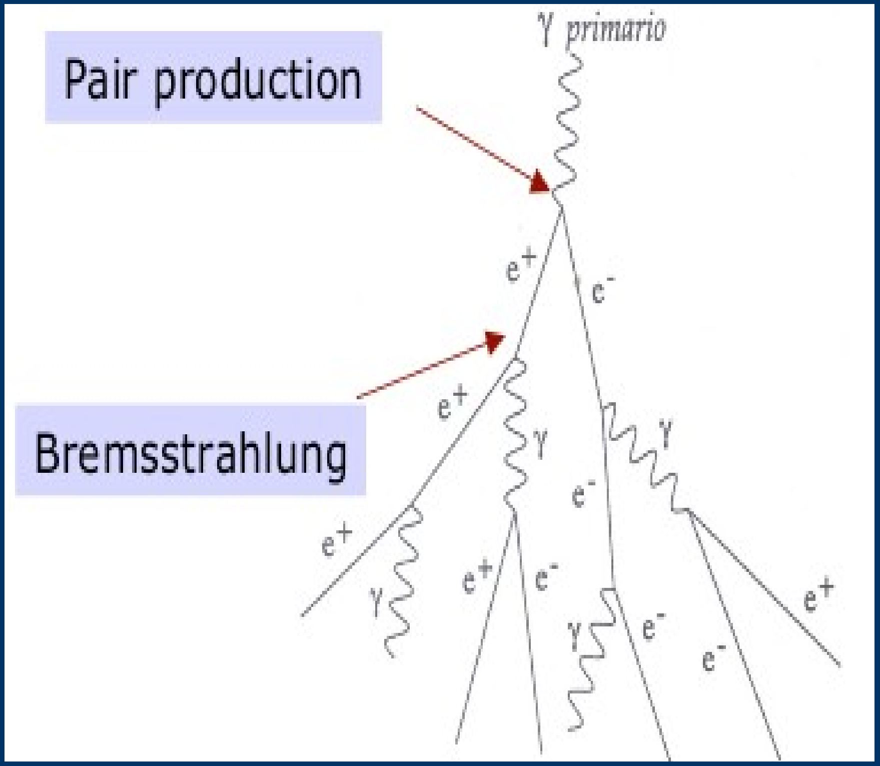
Introduction

Introduction

- Imaging Air Cherenkov Telescopes (IACTs) detect Cherenkov light (emission at 350nm) produced by gamma rays entering in the atmosphere (altitude ~ 10km).

- Atmosphere=calorimeter for Cherenkov astronomy -> atmospheric quality is crucial

- Improvements could be achieved by the use of a Raman LIDAR, to monitor the atmosphere transmission probability: reduce systematics and improve duty cycle



Introduction

- Analysis of backscattered light:
  - Elastically dispersed: *Rayleigh scattering*
  - Non-elastical and rotor-vibrational: *Raman scattering* -> wavelength shift characterisctic of every molecule
- Study backscattered light to know the optical depth and, hence, the amount of Cherenkov light really produced in the atmosphere
- LIDAR equation

$$P(r,\lambda)=P_0\frac{c\,t_0}{2}\beta(r,\lambda)\frac{A}{r^2}e^{-2\tau(r,\lambda)}$$

One equation, two unknowns!
Need to make approximations!

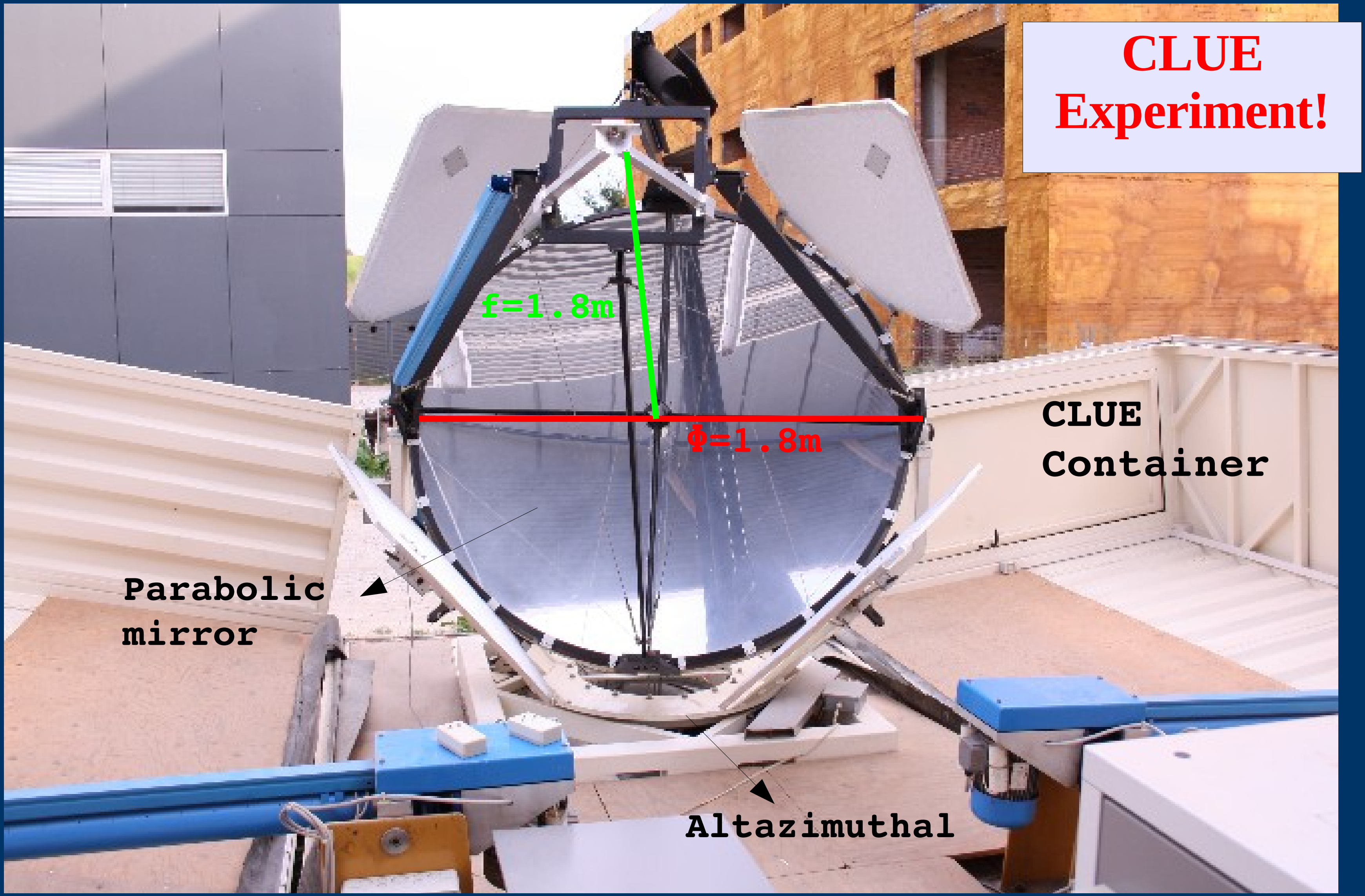
Optical depth as function of extintion

$$\tau(r,\lambda)=\int_{r_0}^{r}\alpha(r,\lambda)\,dr$$

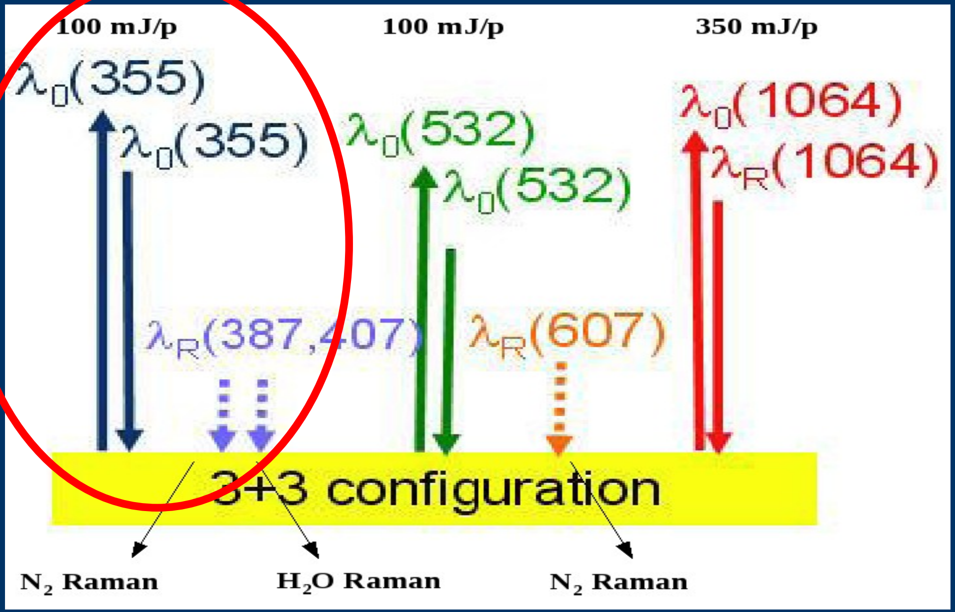
- Advantages of Raman LIDARs:
  - Diminish systematics errors when determining extinction
  - Break the degeneration
  - Reduce systematics due to the wavelength dependence
- Disadvantages:
  - Small backscattered cross section

The Device

The IFAE Raman LIDAR

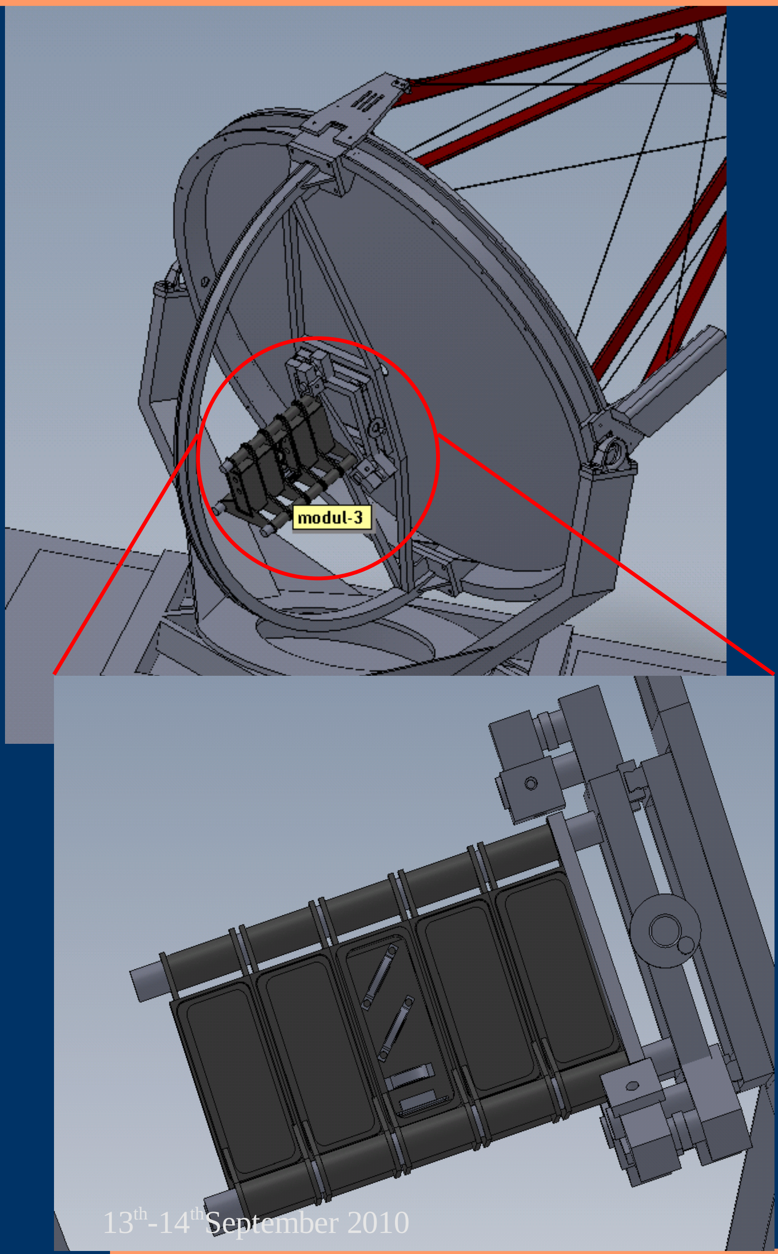


The IFAE Raman LIDAR. Laser

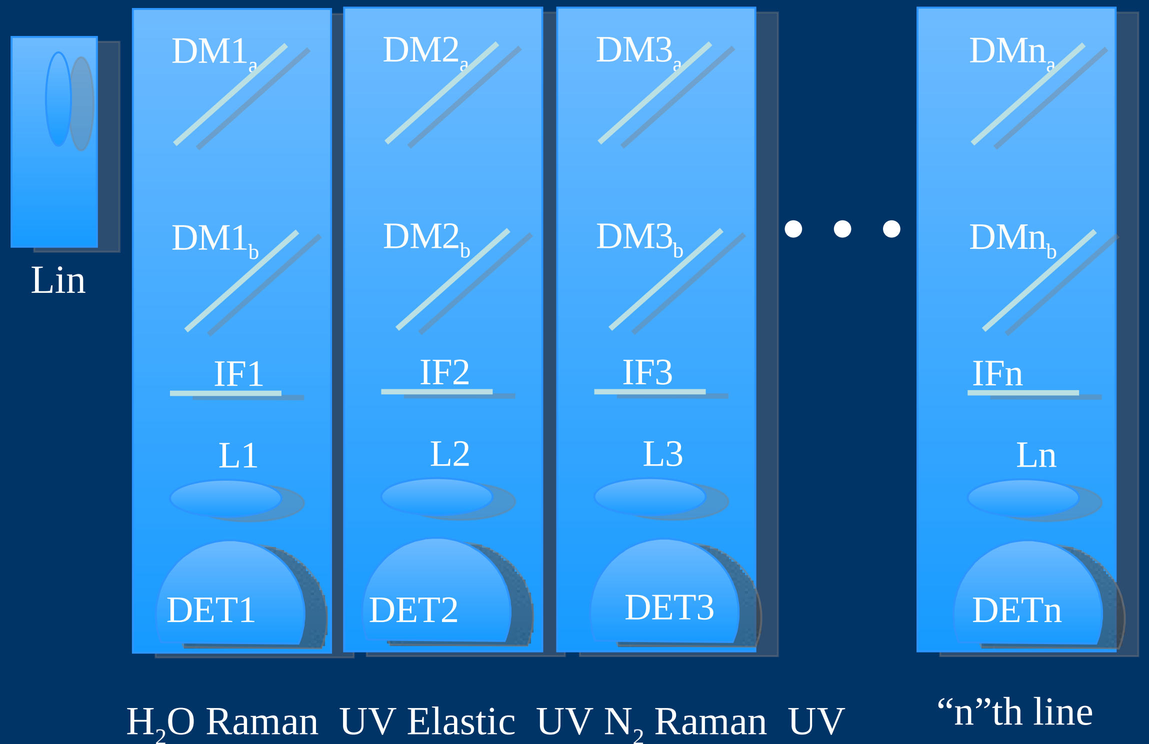


- Brilliant Nd-YAG 1064nm Laser with second and third harmonic generator at 532nm and 355nm
- Energy of emitted pulses: 360mJ/p, 100mJ/p and 100mJ/p for each wavelength
- Detection of Raman Nitrogen (387nm) and water vapor (407nm), our main interest because emission of Cherenkov light is located at 350nm. Also elastic third harmonic (355nm)
- 5ns pulses with 20Hz frecuency

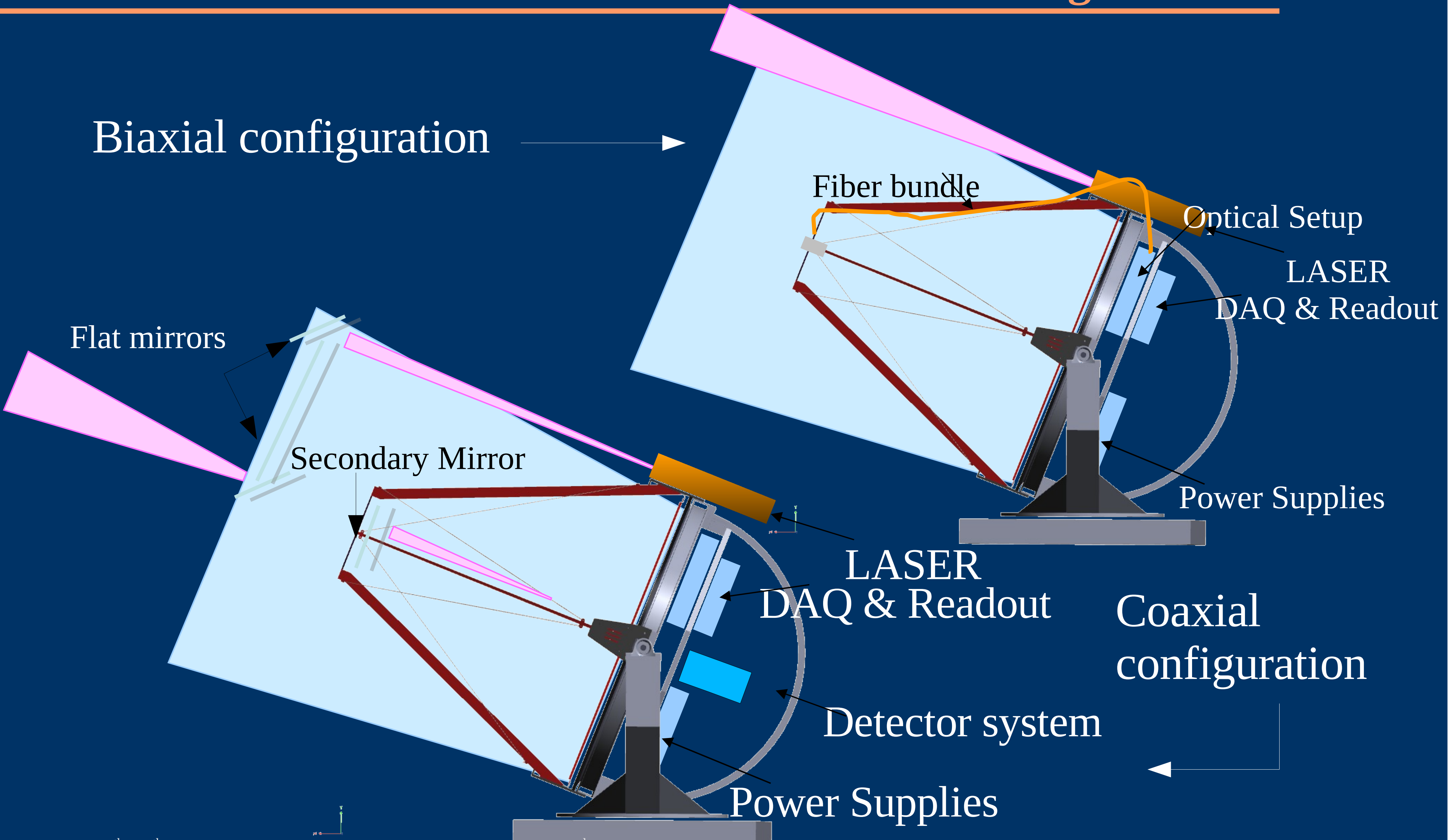
The IFAE Raman LIDAR. Modular Optics



- Goal: I vs t for each wavelength
- Detector made up of different modules with filters and dichroic mirrors
- Under development

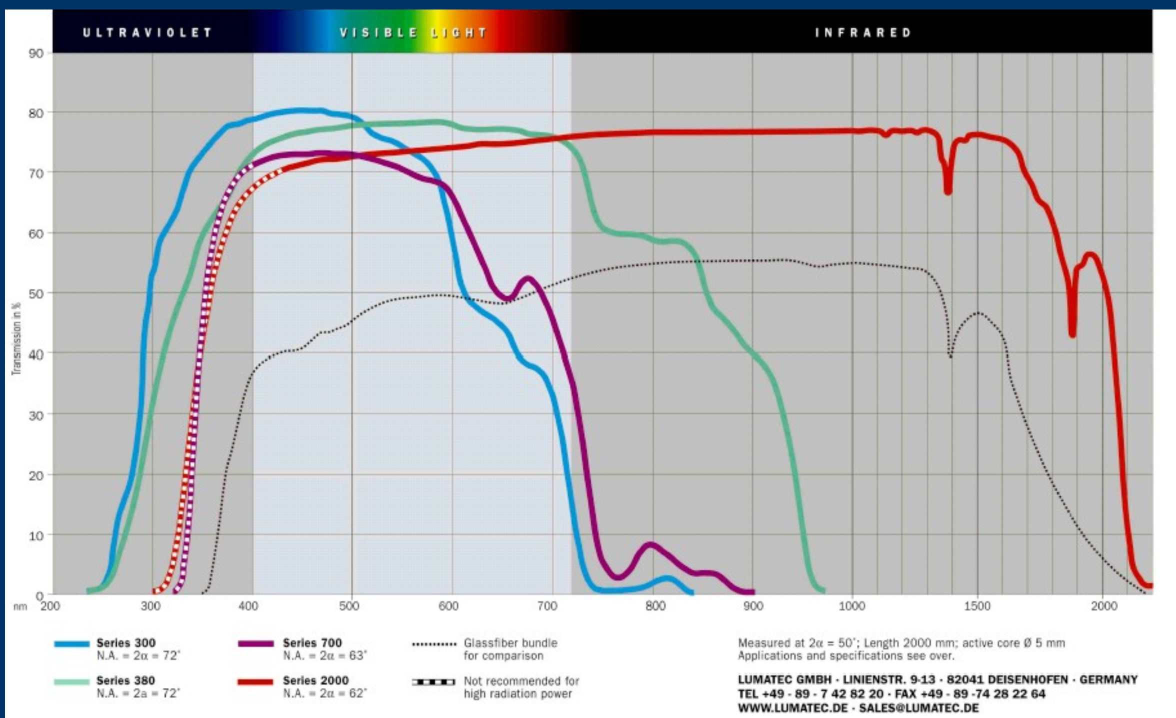


The IFAE Raman LIDAR. Configuration



The IFAE Raman LIDAR. Liquid Light guides

- High transmitivity (around 80% per meter in UV)
- Better flexibility than conventional optical fibers, so they're easier to operate
- Great aperture angle, needed because our f/D relation
- Lifetime could have been a problem due to liquid degration because of the formation of bubbles inside of them.



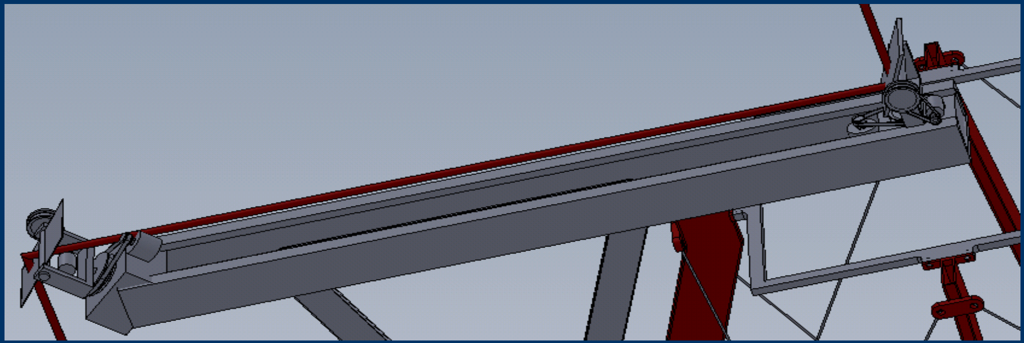
Source: www.newport.com

- To assure a long lifetime: Radiation exposure range should be 320-650nm and a temperature range 35º-50º C
  -> No bubble formation

The IFAE Raman LIDAR.

Aligment

- A precise aligment of telescope axis and laser is a must to reach high altitudes (good overlaping factor)
- XY table to move the laser
- Two parallel mirrors to have a coaxial system
- Feedback to align



Acquisition Electronics

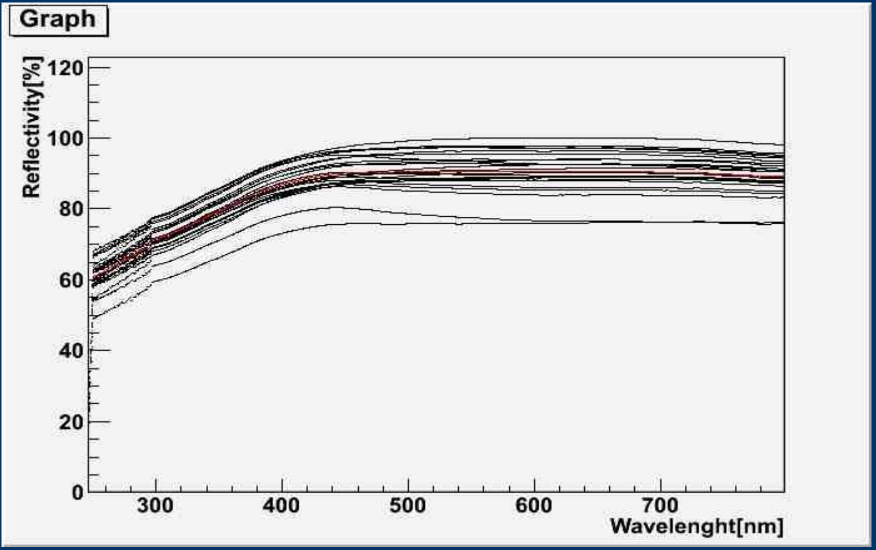
- Acquisition electronics
  - Low sampling rate:
    ~100ns integration (10Msps) for ~10m resolution
  - Big dynamic range data acquisition:
    Standard ADC / Oscilloscope for short distances
    At long distances photon counting is needed

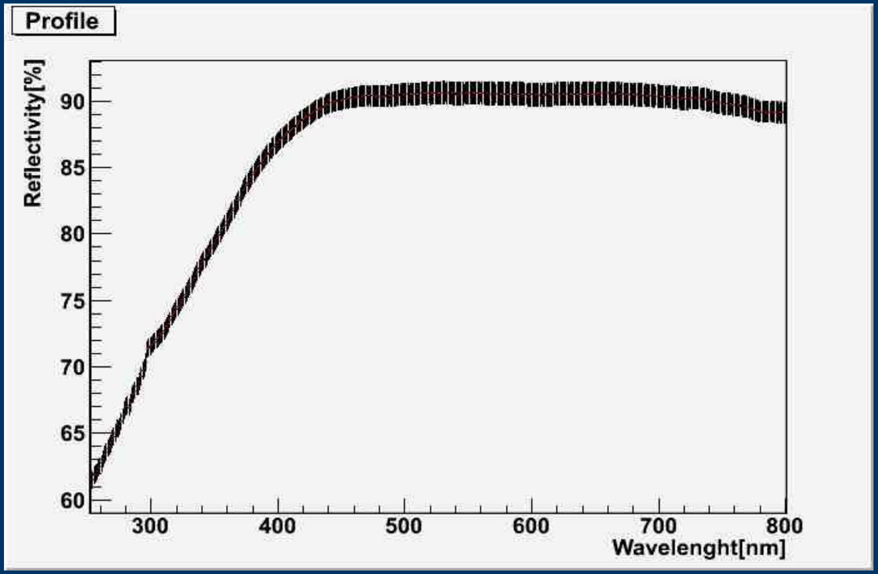
→ Working in a home-made solution

Measurements and Results

Reflectivity. Superficial reflectivity

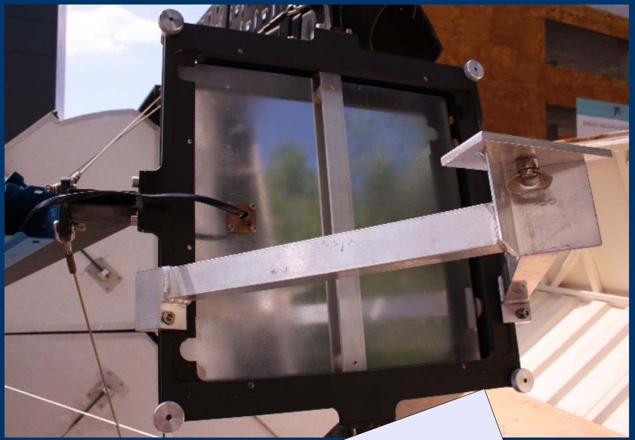
- Motivation: Important to understand the effective collection area for each of the recorded wavelengths
- Method: 24 measurements (12 positions twice) with Avalight Deuterium Source and Spectrometer
- Results:
  - Profile (*bottom*) well preserved although variations of reflectivity in the different points (*top*)
  - 10% dispersion, due to systematical errors (5%) and because some regions are more damaged
  - All positions present the same behaviour in terms of wavelength with deviations < 5%





Reflectivity. Focused reflectivity

- Motivation:
  Determine focused reflectivity of the mirror
- Method:
- Focalize solar light in the focal plane where a metalic piece would be placed and studying how its temperature varies we could know how much flux has been reflected by the mirror
- Measure the increase of T every second with the sensor
- First measurement done by focusing at the sensor: increase of temperature
- Second measurement focalising at the center: heat dispersion
- Relation between flux and temperature $flux = \frac{Q}{A \cdot t} = \frac{c \cdot m \cdot \Delta T}{A \cdot t}$

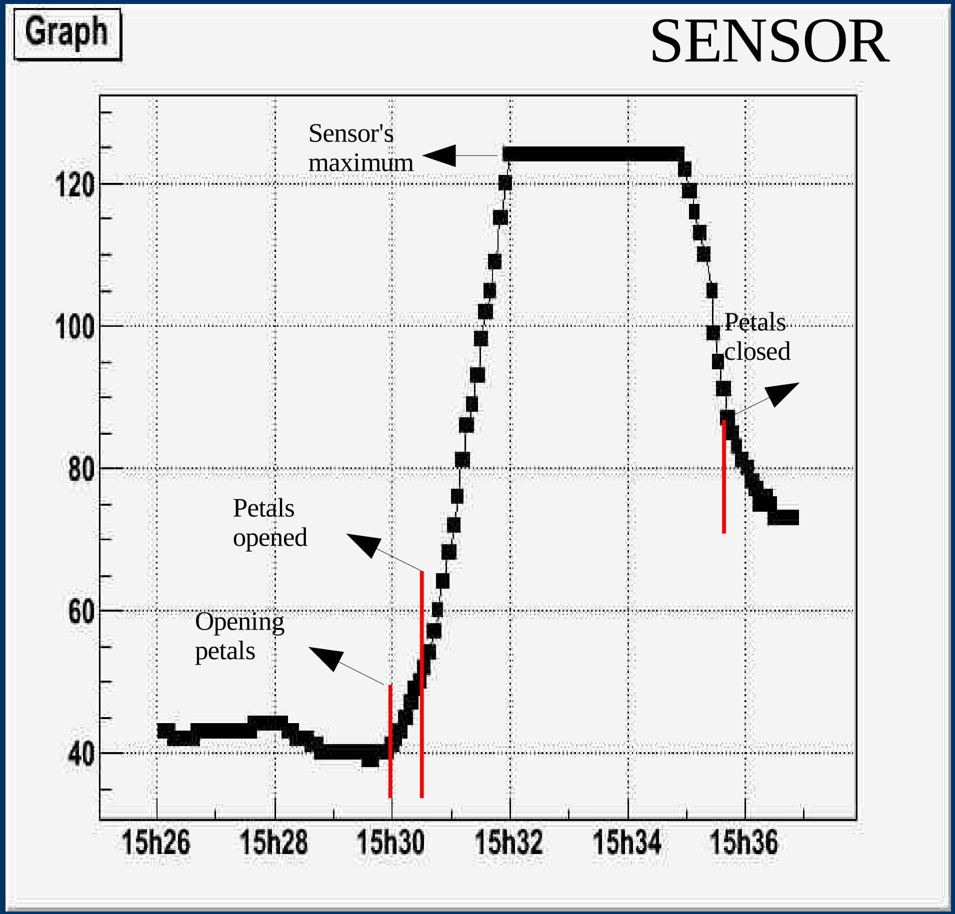


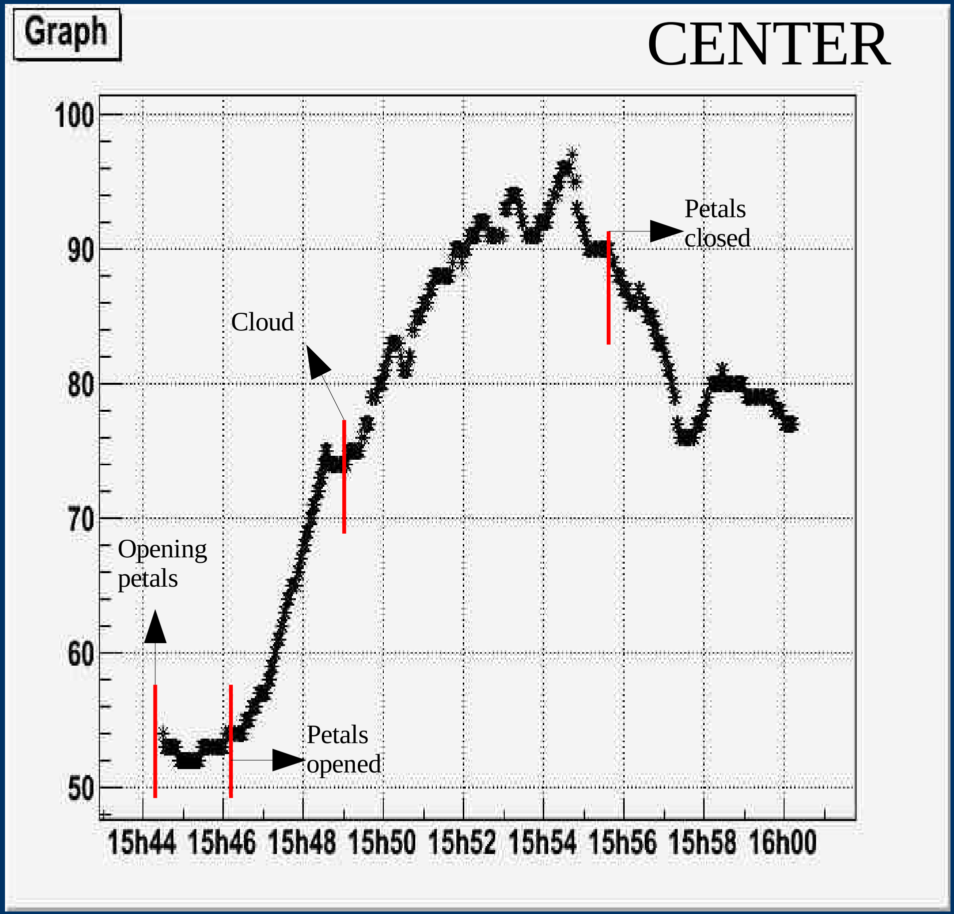
Material	c [J/kg/K]	Density [kg/m³]	Mass [Kg]
Steel	460	7850	7.92
Aluminum	880	2700	4.14
Copper	390	8960	9.34
Tin	230	7310	15.84
Iron	450	7874	8.09

Aluminum seems to be the best option

Reflectivity. Focused reflectivity

Measurements





Reflectivity. Focused reflectivity

- Preliminary results:
- Focused flux: $flux_{focused} = flux_{stored} + flux_{lost} \approx 495\, W/m^2$

  - Stored flux -> rising edge of the slope: $flux_{stored} \approx 215\, W/m^2$

  - Radiated flux ->negative slope with closed petals $flux_{lost} \approx 280\, W/m^2$

- Compute the expected flux by weighting the solar irradiance with the reflectivity profile $flux_{expected} \approx 625\, W/m^2$
- Correction factor to convert local reflectivity into focal $\left(\frac{flux_{focused}}{flux_{expected}}\right) = 0.79$
- Reduction of focal reflectivity due to mirror imperfections. No dependence in the wavelength expected
- It translates to 64% focal reflectivity @ 350 nm

Reflectivity. Focused reflectivity. Error estimation

- Uncertainties estimation

  - Statistics errors:

    *Uncertainties for rising (~2%) and falling slopes (~5 %) by error propagation

    $$flux_{stored} \approx 215 \pm 3\, W/m^2$$ $$flux_{expected} \approx 625 \pm 14\, W/m^2$$

    *Expected flux uncertainty dependent on superficial reflectivity error (~5%)

    $$flux_{expected} \approx 625 \pm 31\, W/m^2$$

  -Systematics errors:

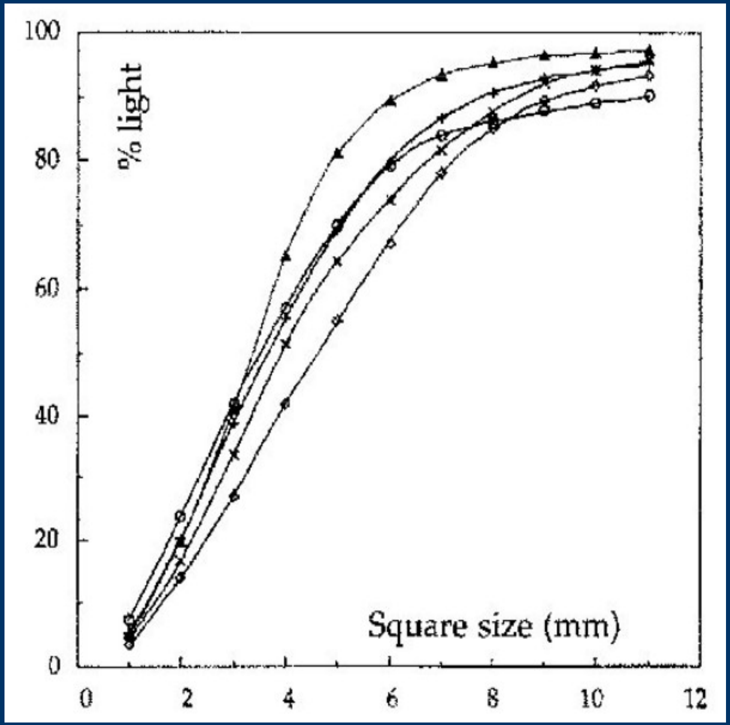
    *Day quality

    *Metal

    → To evaluate with further measurements

Point Spread Function

- Motivation:
- Aberrations and difraction spread the focused image over a finite area
- Why we want to measure it?
  - Optical quality could have decreased
  - Need to know the size of the spot to collect all the light in the fiber
  - Characterize our mirror
- Light collector, not same quality as imaging telescope but PSF not too large desired
- Method: acquisition of images of stars at different zenith angles and obtention of their PSF
- Preliminary result: 5 mm PSF (FWHM) with no zenith angle dependence



D.Alexandreas et al., *Status report on Clue.* NIM A360 (1995) 385-389

Future planning - Outlook

- Repeat measurements with sensor placed at different distances from the center and other materials
- Further PSF measurements
- Obtain PSF from focal: led located at focal plane
- Refine systemactic uncertainties
- Test the liquid light guide
- Install laser
- Build acquisition system
- ...

Summary and Conclusions

- Use of Raman LIDARs necessary to reduce systematic uncertainties and to increase IACTs duty cycle
- CLUE units from HEGRA experiment adquired by IFAE to develop a Raman LIDAR for CTA:
  - Coaxial set-up between mirror and laser
  - Liquid light guides to transport the radiation
  - Optical quality and reflectance have not diminish significantly
- The mirror is suitable to work as a Raman LIDAR for CTA
- IFAE LIDAR still under construction. LIDAR planned at ORM to work together with MAGIC

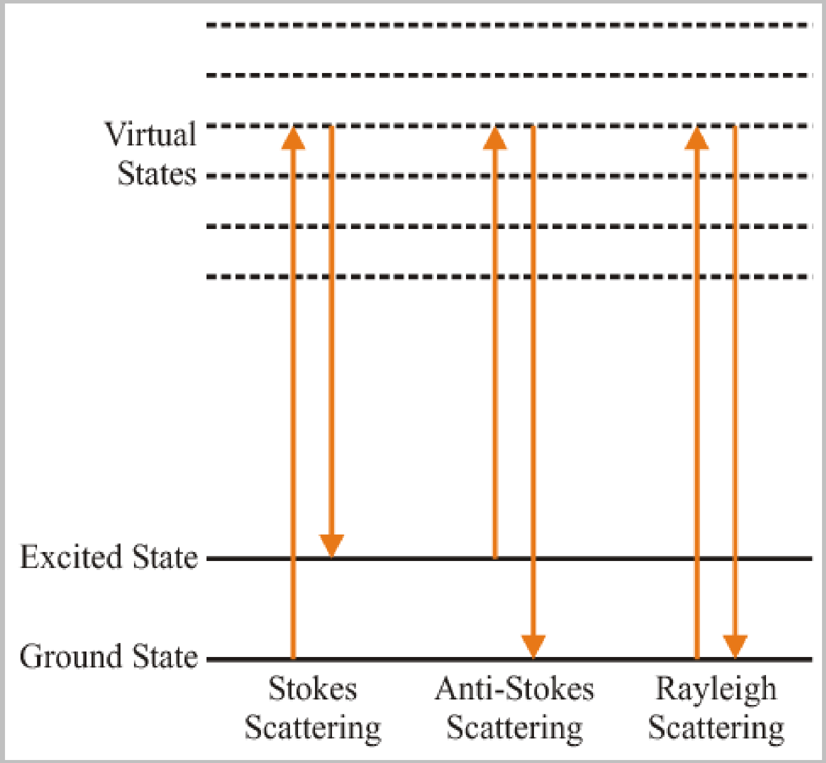
Additional Slides

2. The Raman LIDAR Technique

- Atmosphere=calorimeter for Cherenkov astronomy -> atmospheric quality taken into account

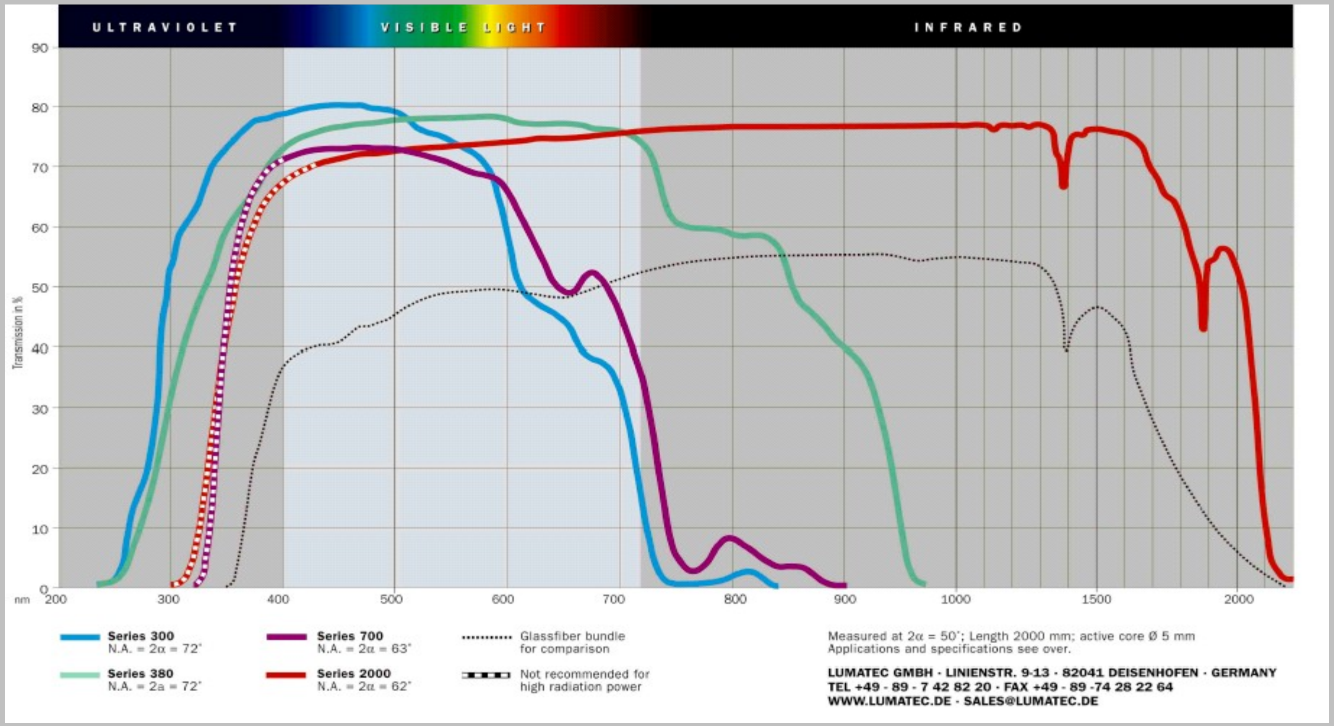
- Raman spectroscopy provides information of chemical and structural composition of the atmospheric components

- Analysis of backscattered light:
  - Elastically dispersed: *Rayleigh scattering* (no information)

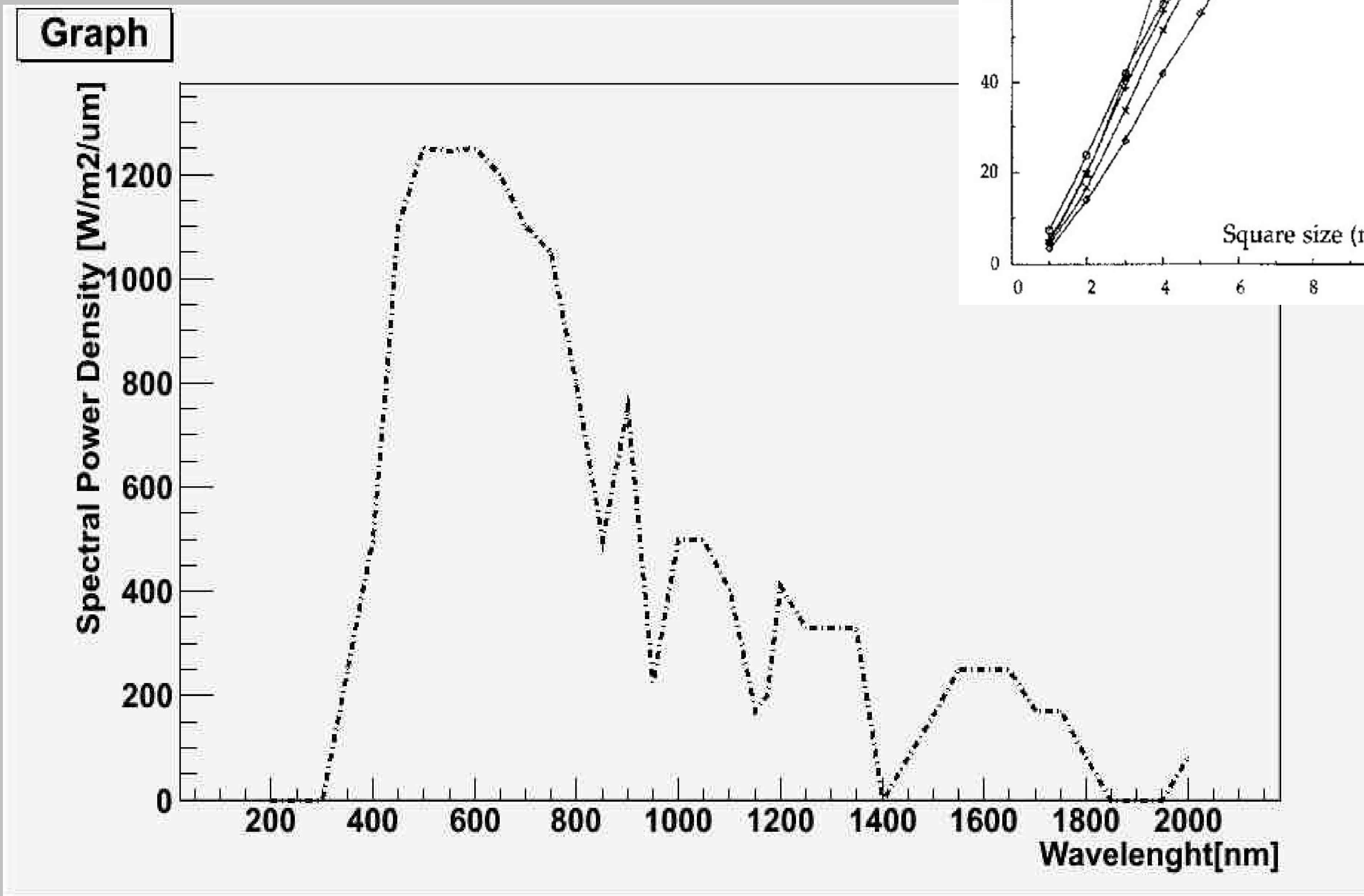


- Non-elastical and rotor-vibrational: *Raman scattering* -> wavelength shift: independent from incoming radiation, dependent of energy changes and characteristic of the physical state and chemical nature.
  + Stokes Scattering: final state more energetic than initial, emitted photon with lower frecuency
  + Anti-Stokes Scattering: photon with higher frecuency

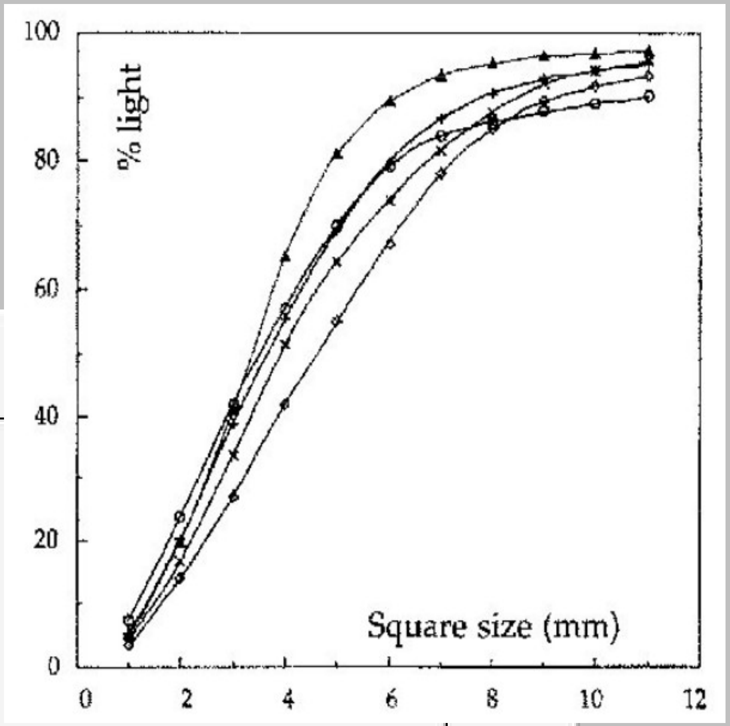
3. The IFAE LIDAR. Liquid light guides



- LUMATEC Liquid Light guides Series 300
- To assure long lifetime:
  - Radiation exposure range should be 320-650nm -> First harmonic forbidden
  - Temperature range: 35º-50º C -> No bubble formation
- 3.2m lenght, 8mm nucleus to collect all light, up to 70% transmitivity



Graph
Spectral Power Density [W/m2/um]
0
200
400
600
800
1000
1200
200
400
600
800
1000
1200
1400
1600
1800
2000
Wavelenght[nm]



% light
Square size (mm)
0
20
40
60
80
100
0
2
4
6
8
10
12

Reflectivity. Focused reflectivity

- Basically, the focused flux:

$$flux_{focused} = flux_{stored} + flux_{radiated} \approx 495\, W/m^2$$

- Stored flux is measurable by computing the gradient of temperatures:

$$flux_{stored} = \int \frac{c\,\rho\,\delta(V)}{A}\left(\frac{\Delta T}{\Delta t}\right)$$

$$\left(\frac{\Delta T}{\Delta t}\right)(r) = \left(\frac{\Delta T}{\Delta t}\right)_{sensor} \exp - \left(\ln\left[\frac{\left(\frac{\Delta T}{\Delta t}\right)_{sensor}}{\left(\frac{\Delta T}{\Delta t}\right)_{center}}\right]\right)\left(\frac{r}{d}\right)$$

- What leads to

$$flux_{stored} \approx 215\, W/m^2$$

- The radiated flux is calculated with the negative slope when the petals are closed, for both centered and sensor position

$$flux_{radiated} \approx 280\, W/m^2$$

Reflectivity. Focused reflectivity

- Compute the expected flux by weighting the solar irradiance with the reflectivity profile

$$flux_{expected} = \int R(\lambda) P(\lambda) \delta\lambda \approx \Sigma R(\lambda) P(\lambda) \Delta\lambda \approx 625\, W/m^2$$

- Ratio between focused and expected flux gives the correction factor to convert local reflectivity into focal

$$\left(\frac{flux_{focused}}{flux_{expected}}\right) = 0.79$$

- Reduction of focal reflectivity due to mirror imperfections
- No dependence in the wavelength expected
- It translates to 64% focal reflectivity @ 350 nm