Atmospheric Monitoring at the MAGIC site

AtmoHEAD, September 24, 2018

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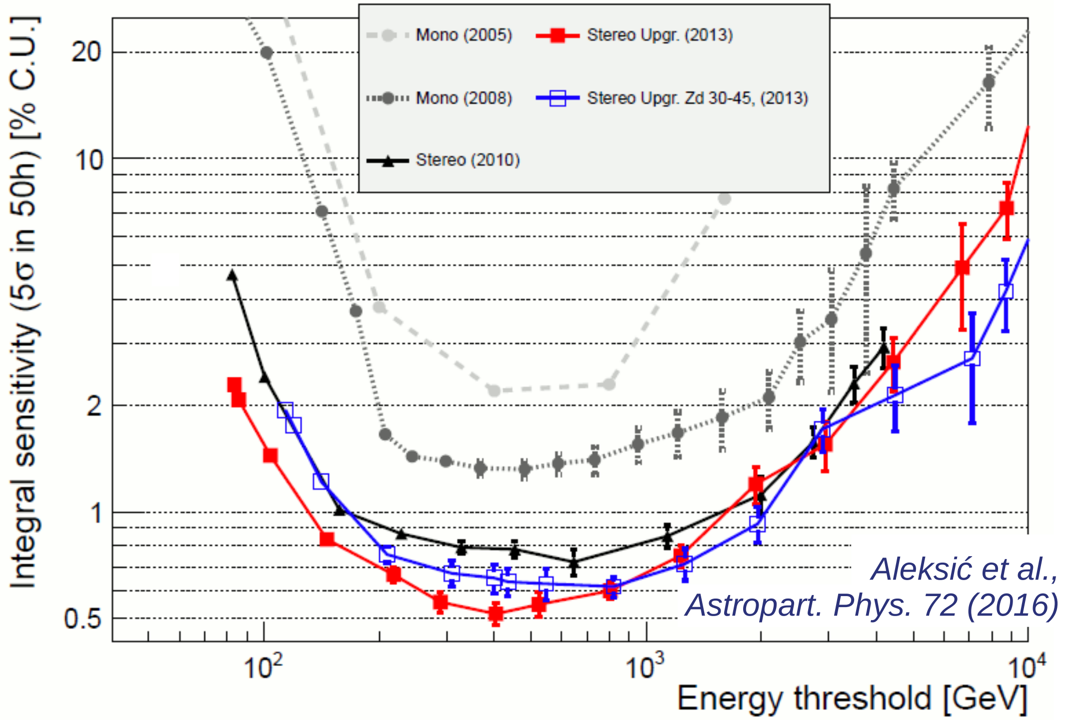
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The MAGIC Telescopes

- Stereoscopic System
  - 2 Imaging Atmospheric Cherenkov Telescopes
  - 17 m diameter, 236 m^2 each
- Operated for 15 years (9 years in stereo)

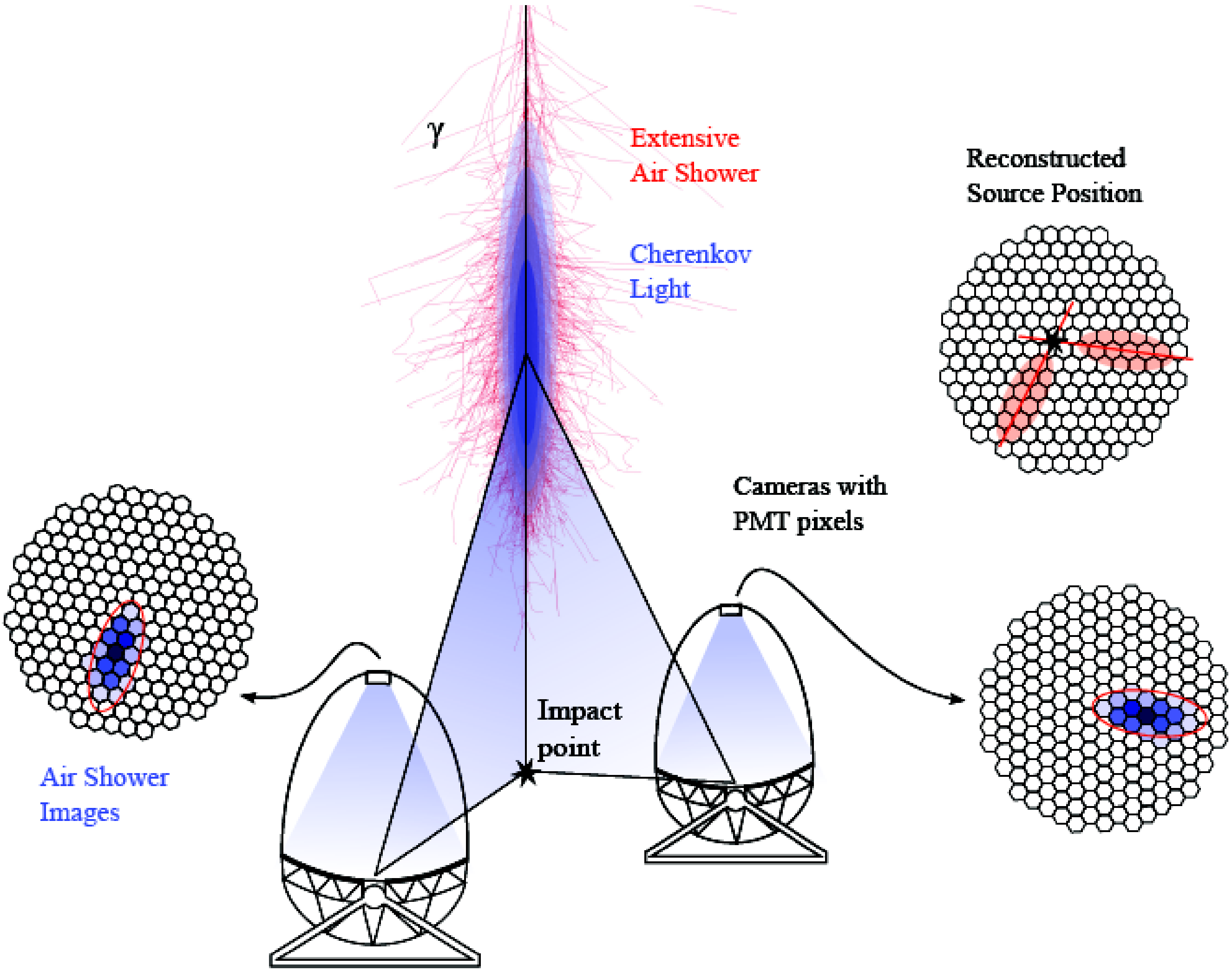
The MAGIC Telescopes

- Gamma ray energy range
  ~50 GeV to ~50 TeV
- Sensitivity ~0.66% Crab
  (5 σ in 50 h above 220 GeV)
- Energy resolution 15–24%
- Angular resolution 0.05–0.1º



- Weight ~70 tons
  Speed 7 deg/s (~30 s for 180°)
- Digitization 1.64 GS/s
  (~1TB per telescope per night)

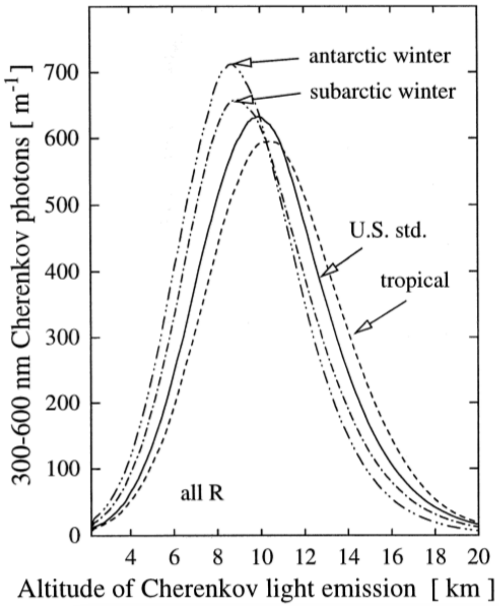
Detection Principle

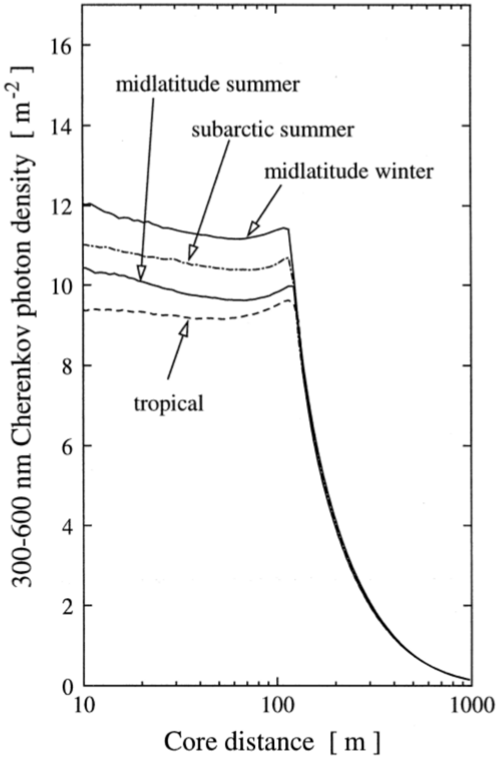


Influence of Atmosphere

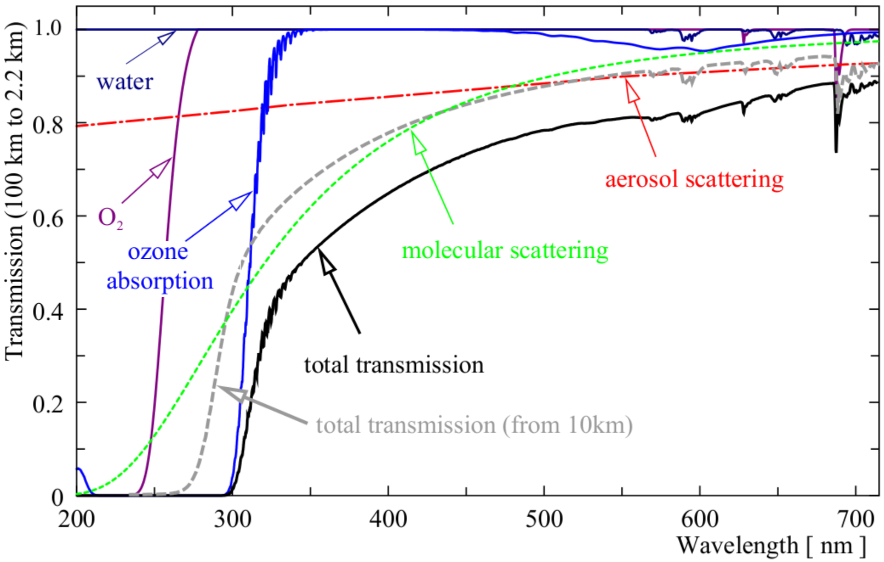
- Emission of Cherenkov light
  - Angle and light yield depend on refractive index
  - Function of pressure, temperature, vapor pressure

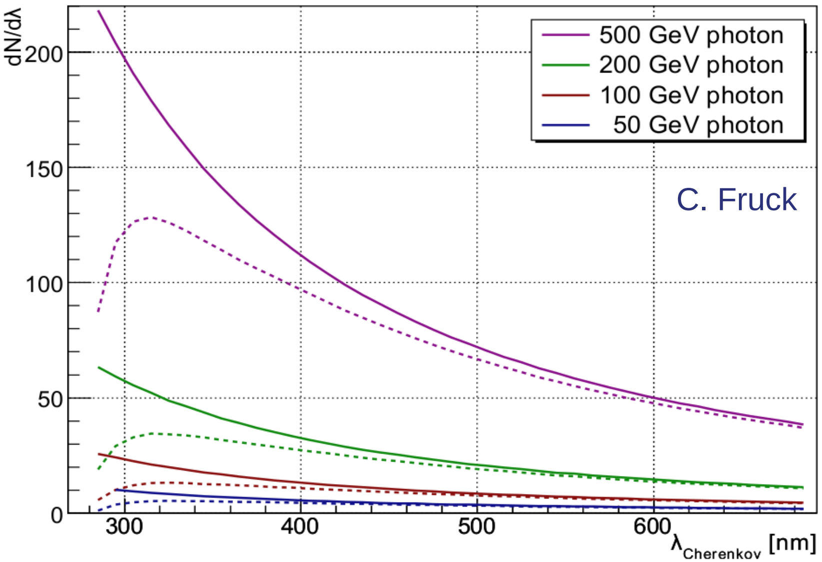
Bernlöhr, Astropart. Phys. 12 (2000)





Influence of Atmosphere

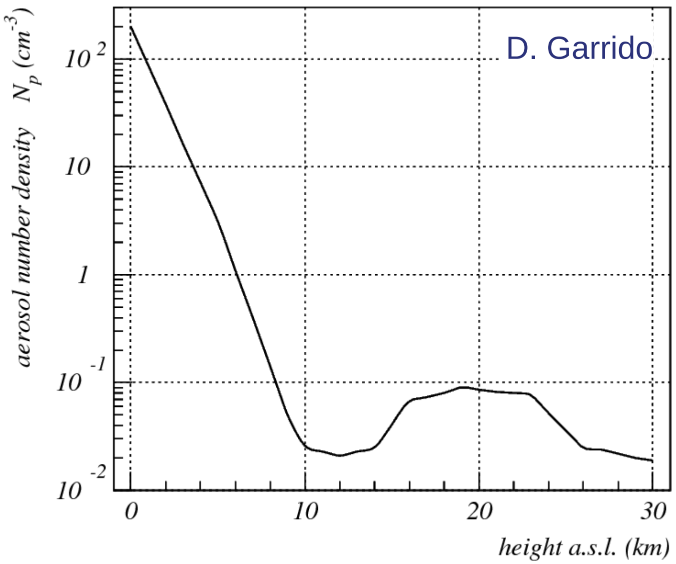


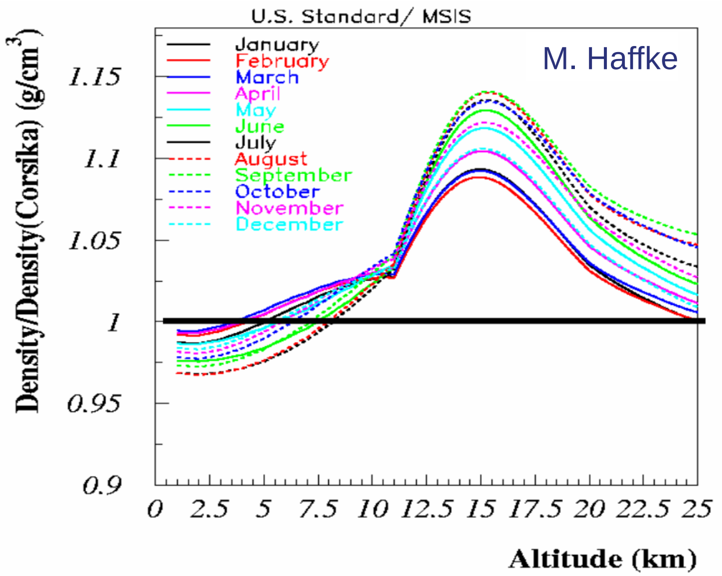


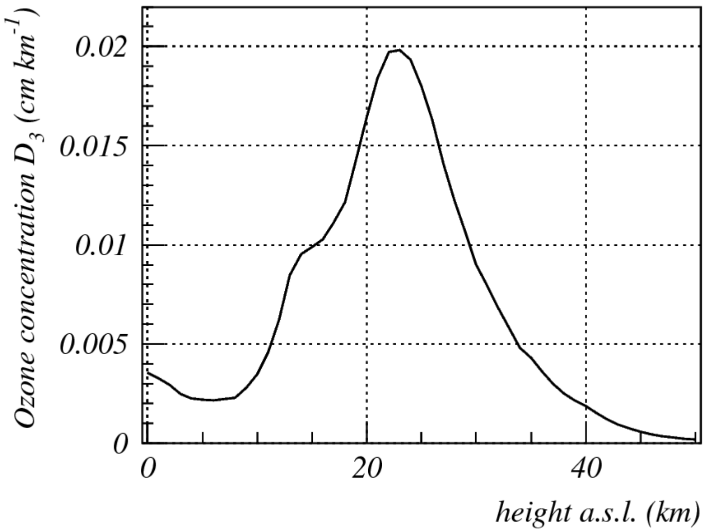
- Transmission of emitted light towards detector
  - The higher the aerosol density, the higher the E threshold and the lower the effective collection area
  - Aerosol attenuation highly variable and height of layer important, measured by LIDAR system and correction applied to data
  - Molecular scattering and ozone profile taken into account using atmospheric models

Implementation in MAGIC

- MC Simulation
  - CORSIKA photons propagated through atmosphere
  - Rayleigh scattering from parameterized La Palma atmosphere
  - Mie scattering and ozone absorption from clear standard Elterman model





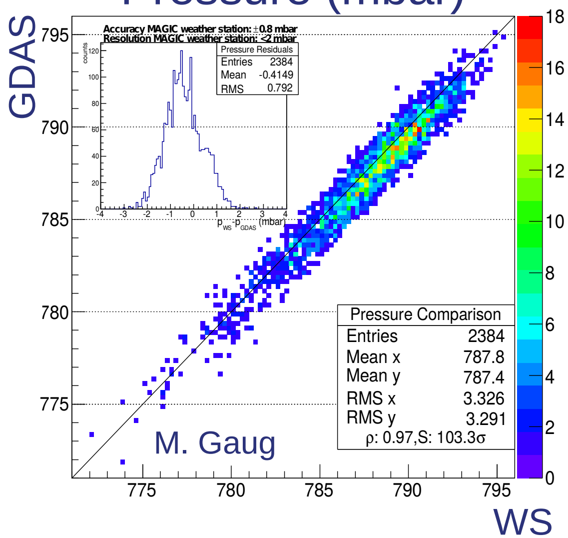


Implementation in MAGIC

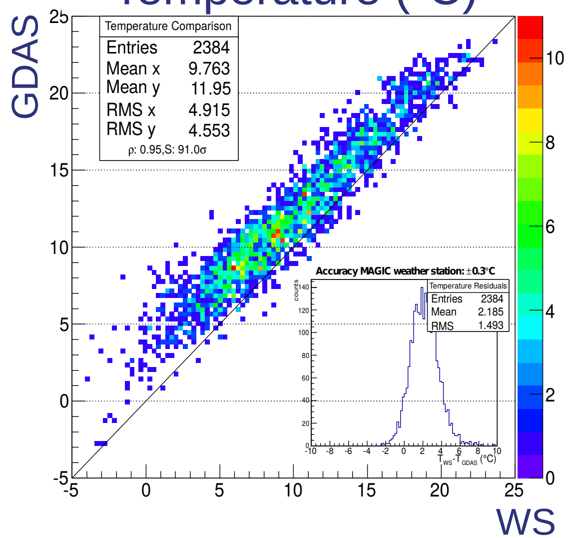
- Data Reconstruction
  - Energy bias and effective collection area correction using LIDAR data
  - Model data for molecular atmosphere used directly in LIDAR analysis

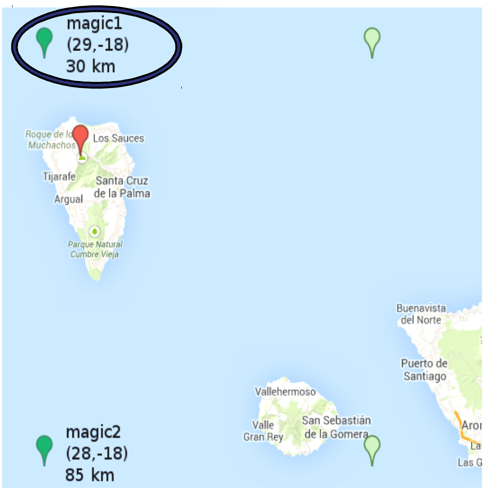
- *Global Data Assimilation System* (GDAS)
  - Model from global measurements and forecasts, available every 3 hours
  - Good agreement with local weather station data

Pressure (mbar)

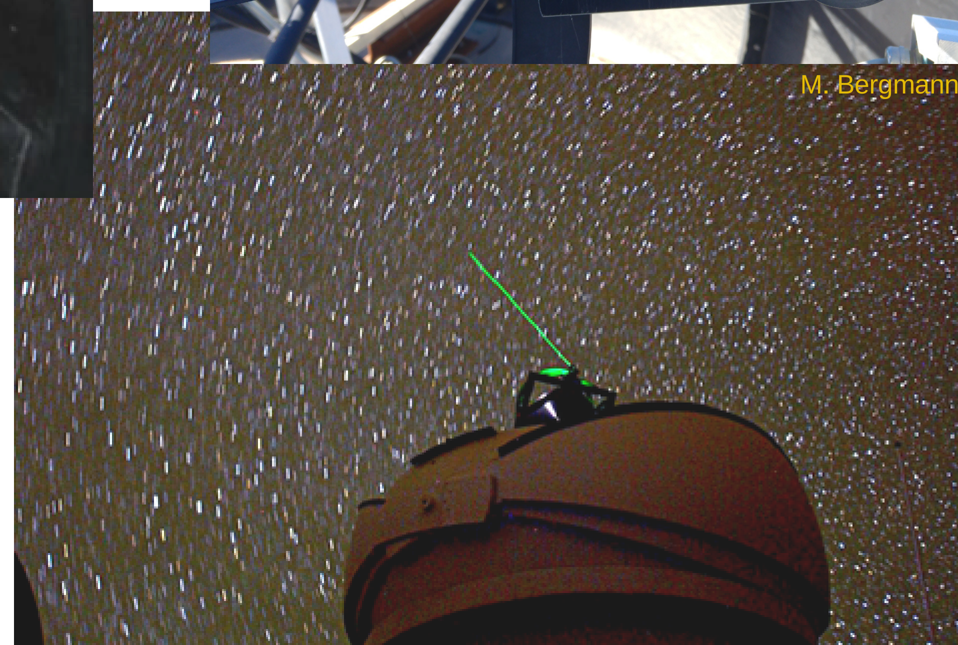


Temperature (ºC)





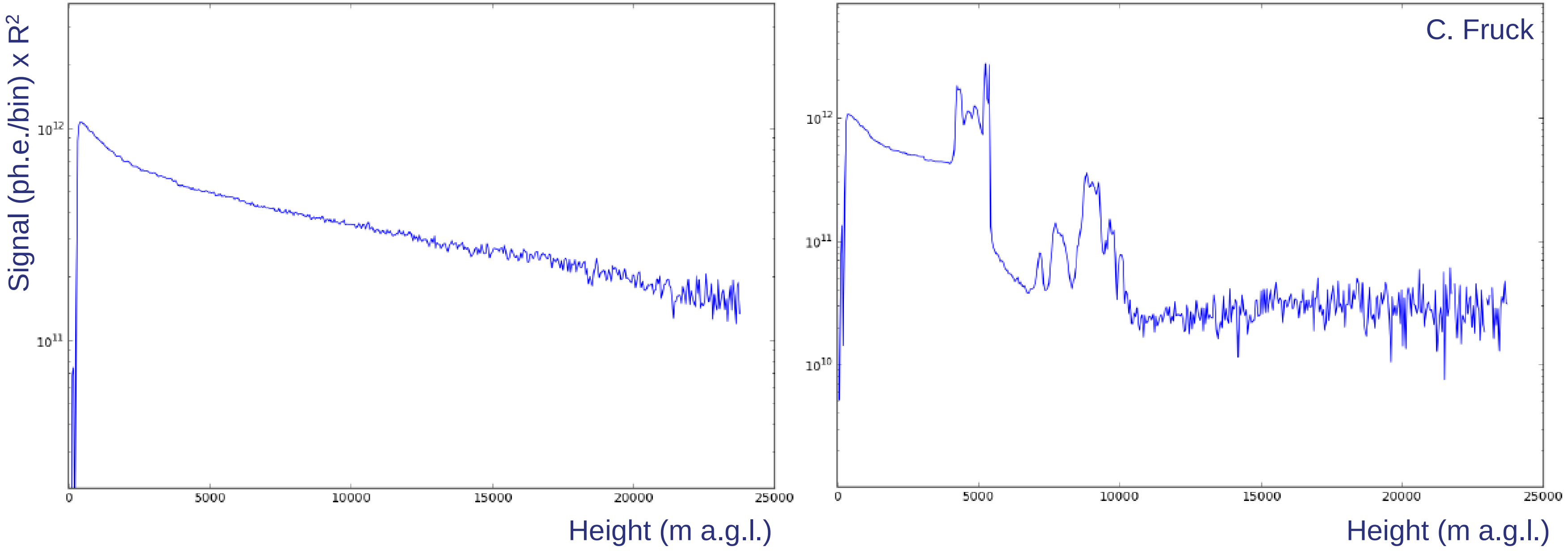
MAGIC LIDAR



- Technical Details
  - Nd:YAG laser (532 nm, 5 µJ)
  - 300 Hz (150 Hz Slow Mode)
  - Alum. mirror (Ø 60 cm, f 1,5 m)
  - Hybrid Photo Detector (HPD)
  - Baffle tube against side scatter

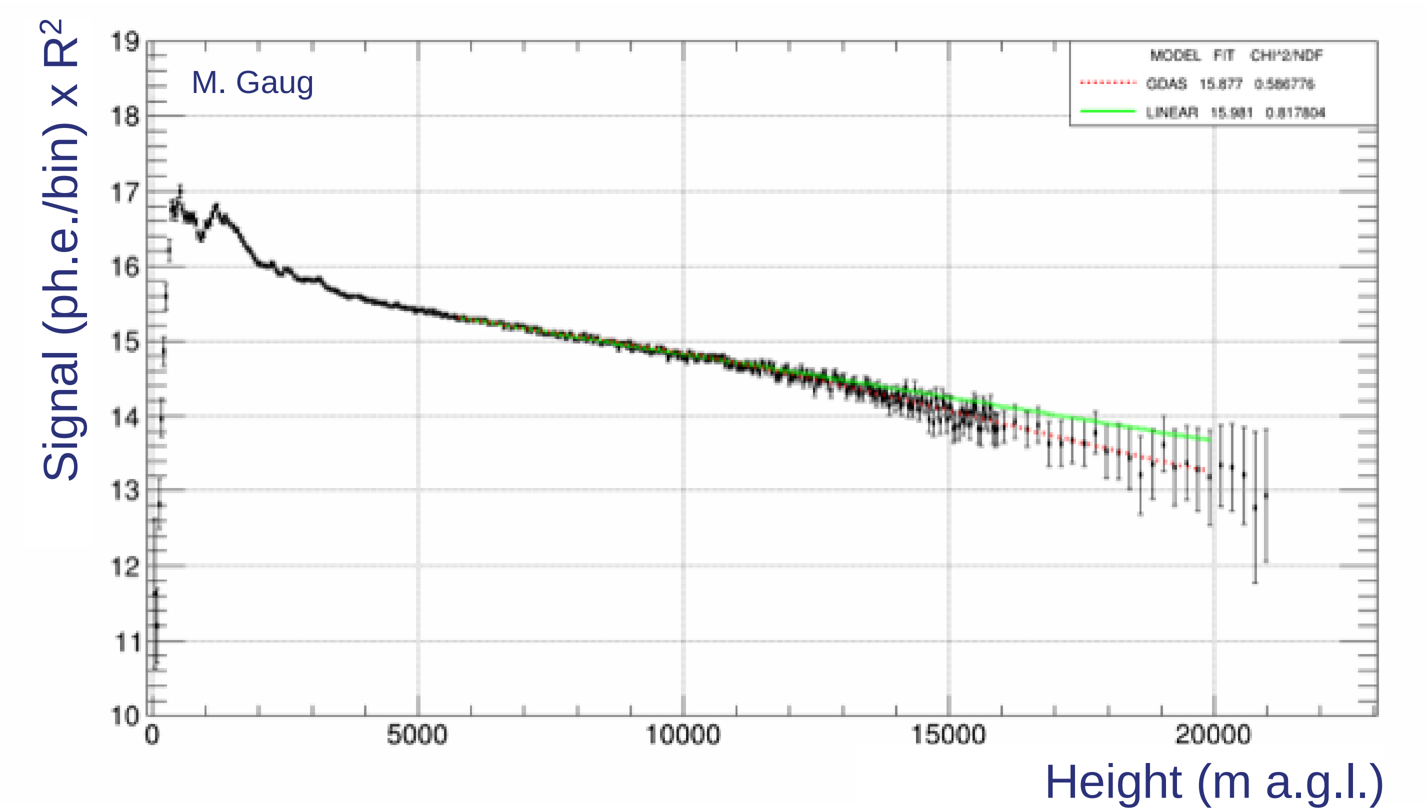
LIDAR Data

- Clouds and aerosol layers immediately visible to shifters
- For analysis data needs to be corrected



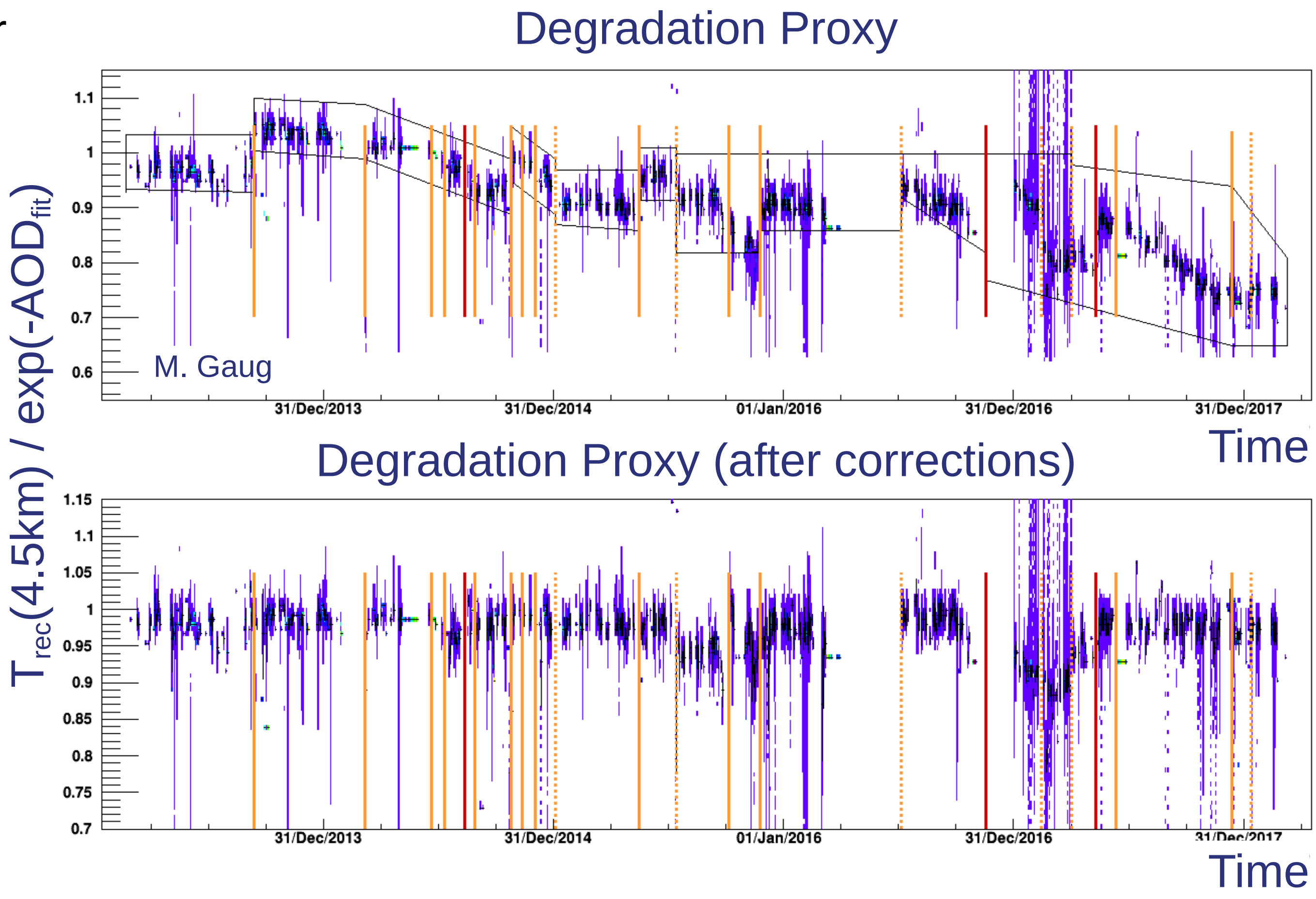
LIDAR Data Correction

- Analysis of backscatter data takes into account
  - GDAS model for molecular part of atmosphere (Rayleigh scattering)
  - Temperature effects (laser, HPD gain, ...)



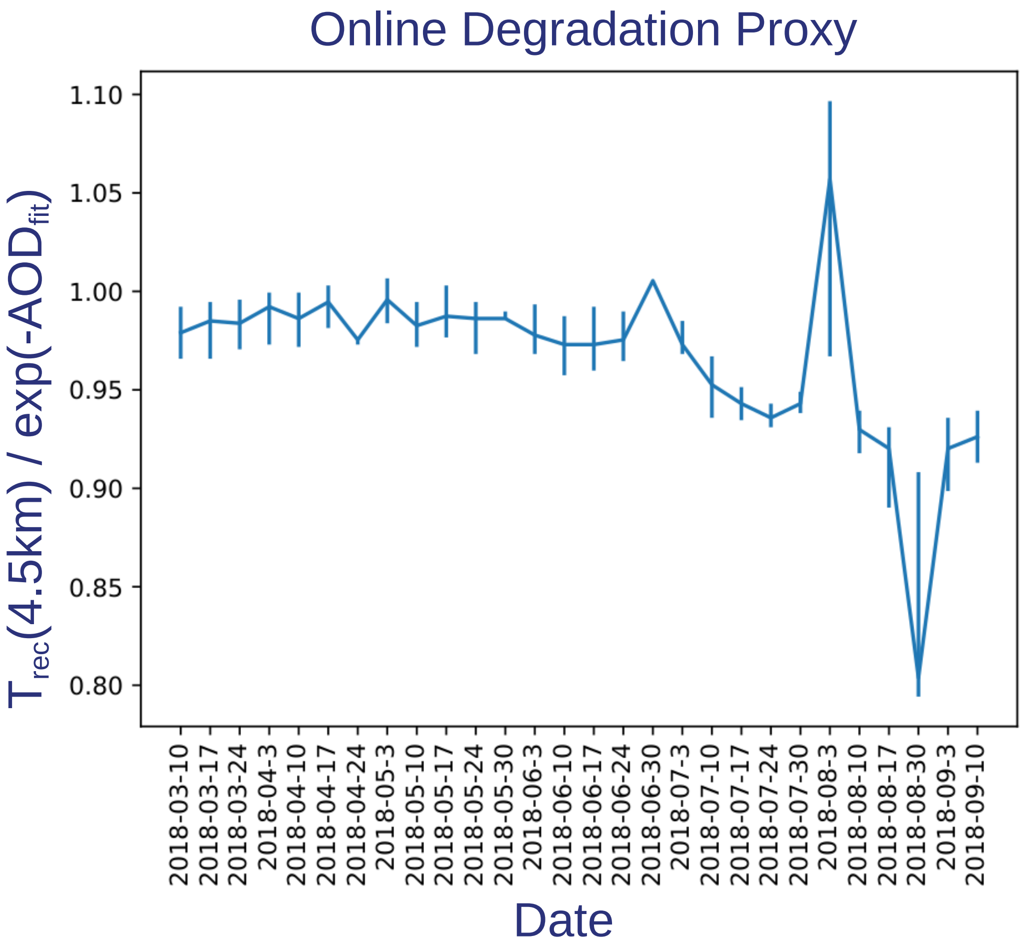
LIDAR Data Correction

- Correction of LIDAR data due to hardware changes and degradation
  - Obstruction of detector
  - Dust on mirror
  - Aging of laser
  - Alignment

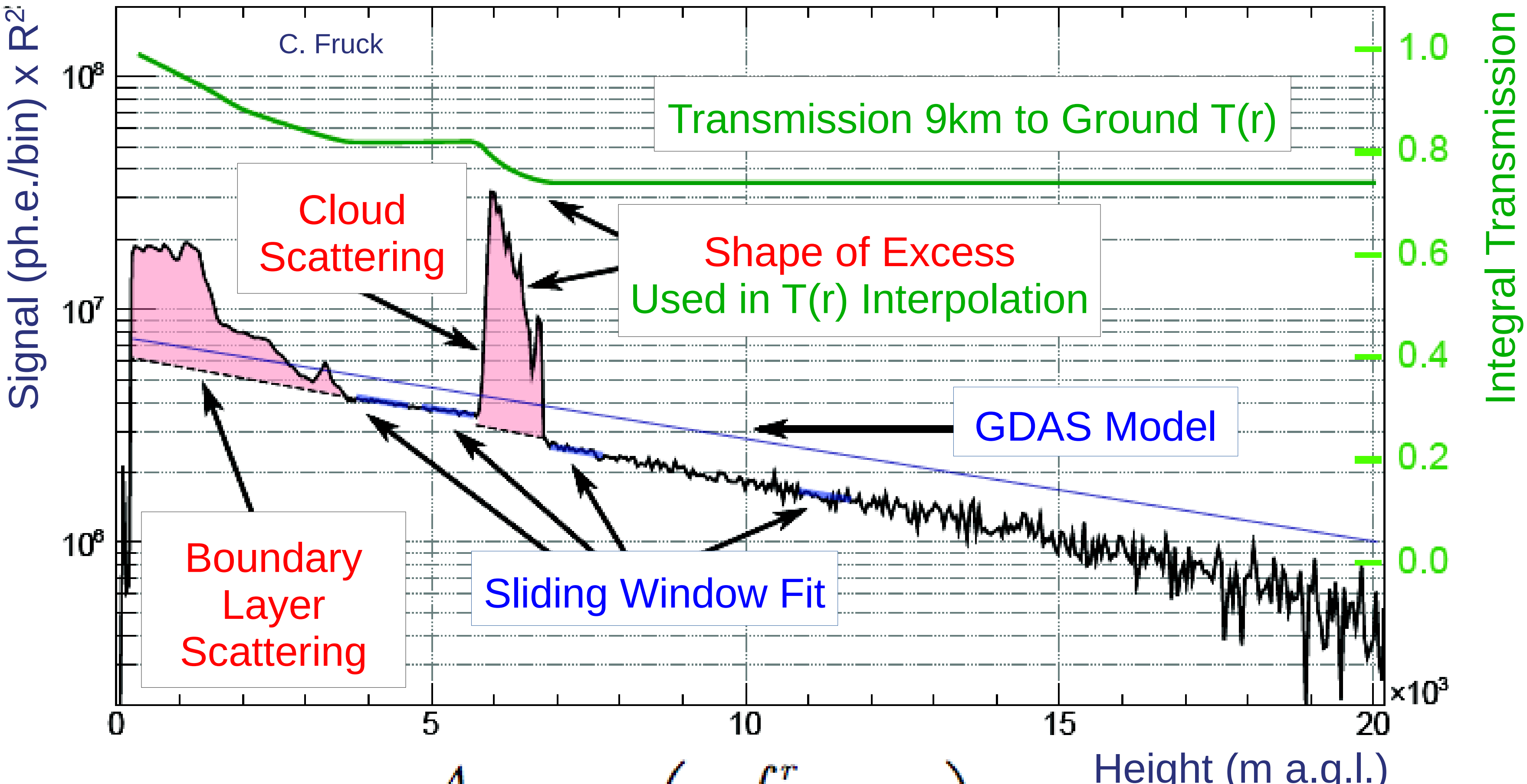


LIDAR Data Correction

- Correction of LIDAR data due to hardware changes and degradation
  - Obstruction of detector
  - Dust on mirror
  - Aging of laser
  - Alignment
- Applied to all LIDAR data
  - Offline for data analysis
  - Online for realistic judgment of conditions for data taking
  - Online correction still in testing phase



LIDAR Data Analysis

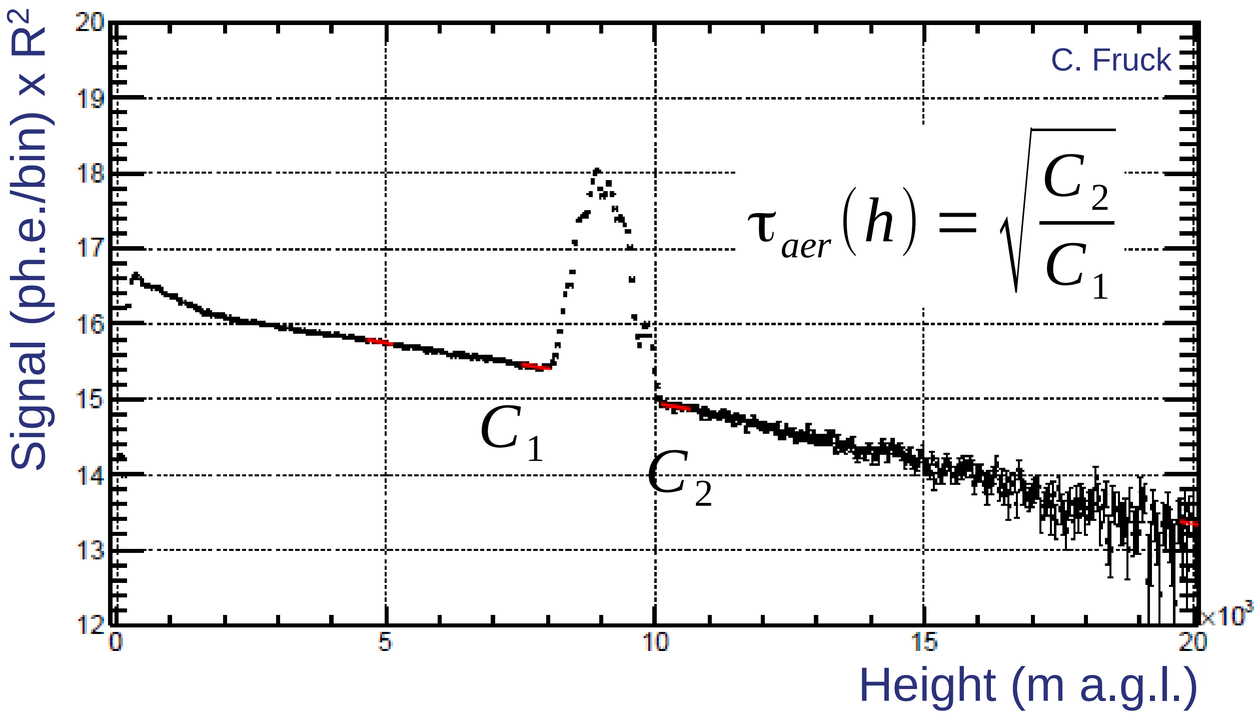


$$N(r) = N_0 C G(r) \frac{A}{r^2} \beta(r) \exp\left(-2\int_0^r \alpha(r')\mathrm{d}r'\right)$$

Calibration, Geometry — Backscatter — Transmission

LIDAR Data Analysis

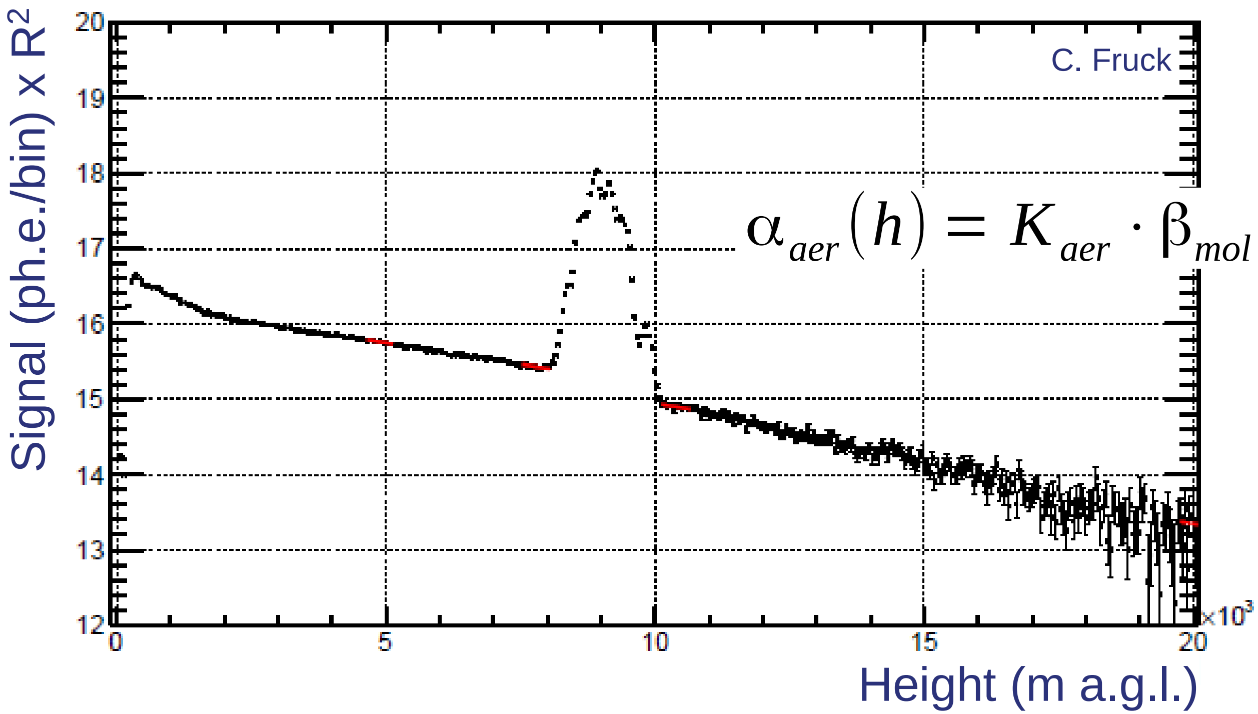
- “Extinction Method” assumptions
  - ▶ Rayleigh-dominated regions exist (also between aerosol layers)
  - ▶ Exponential atmospheric density profile
  - ▶ Light scattered above excess attenuated by twice layer opacity
- Extinction “measured” by comparing Rayleigh signal before/after cloud



LIDAR Data Analysis

- "LIDAR Ratio Method" assumptions
  - Small variations in transmission to backscatter ratio
  - Ratio is known and constant inside aerosol layer
  - Cloud is optically thin

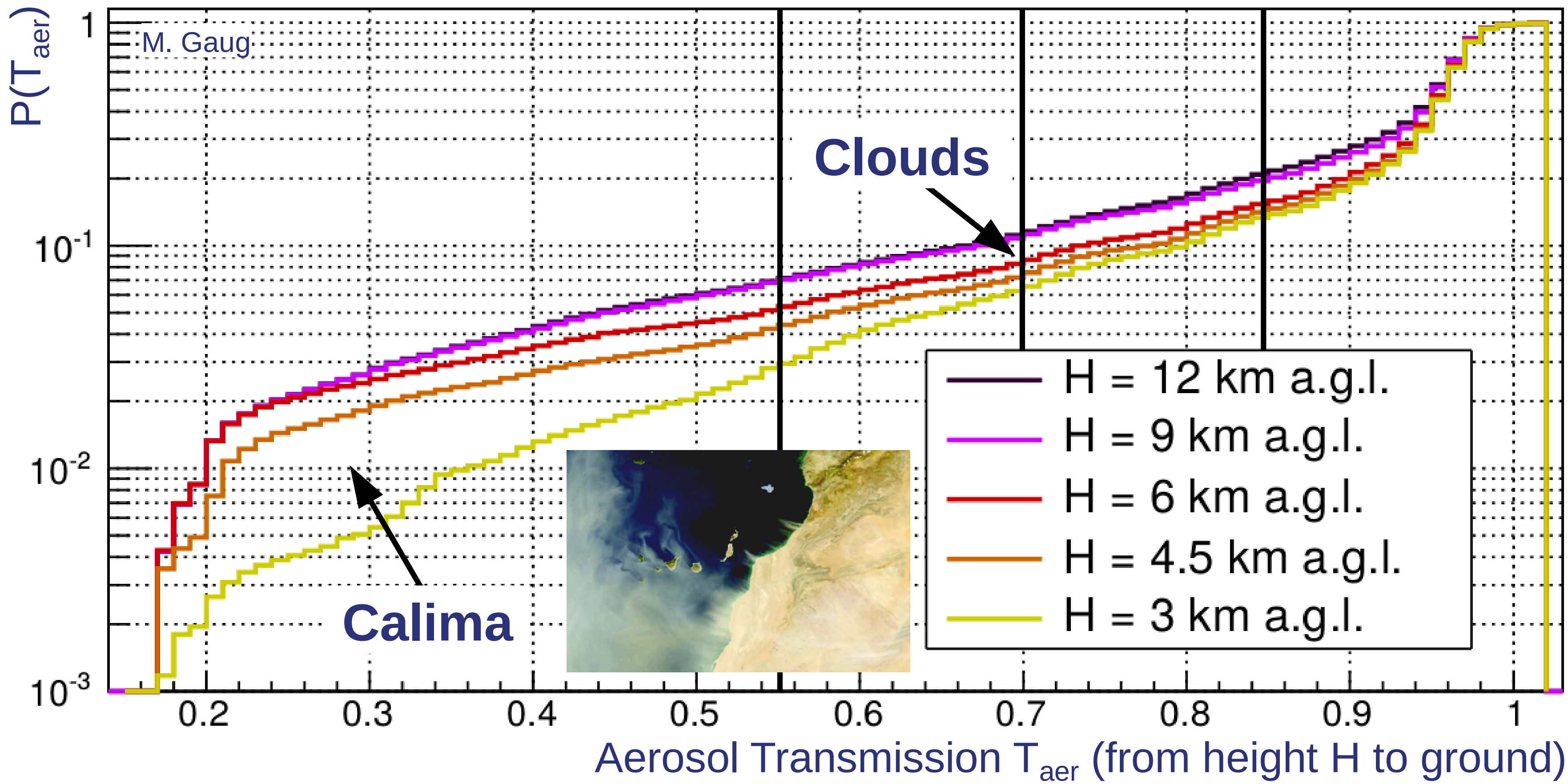
- Transmission calculated from aerosol scattering signal excess



$$\alpha_{aer}(h) = K_{aer} \cdot \beta_{mol}(h) \cdot S_x(h)$$

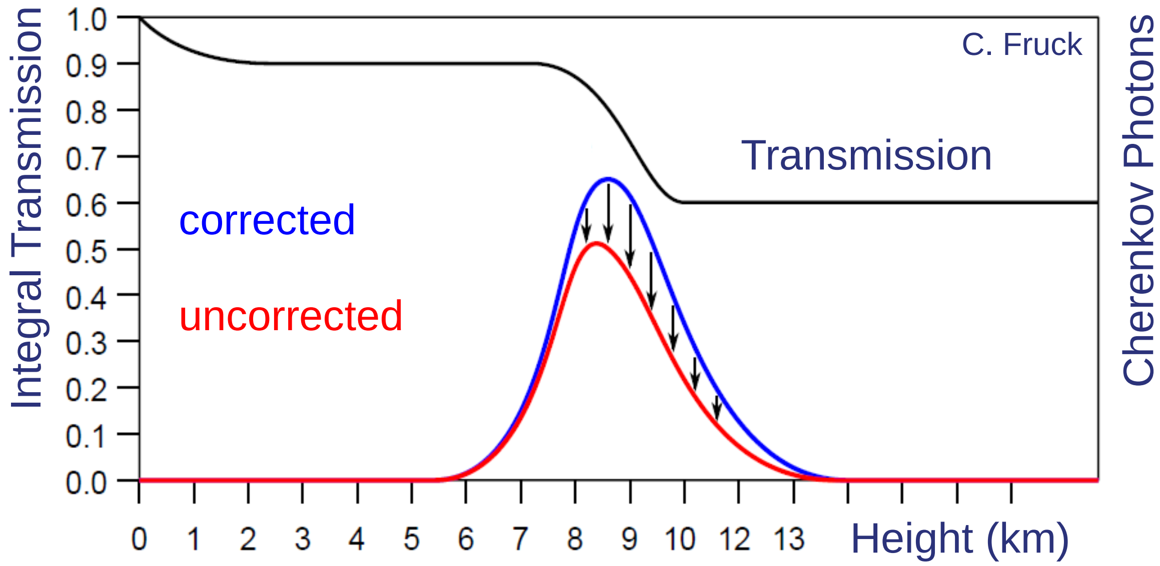
LIDAR Data Statistics

Aerosol Transmission (532 nm, 2 years LIDAR data)



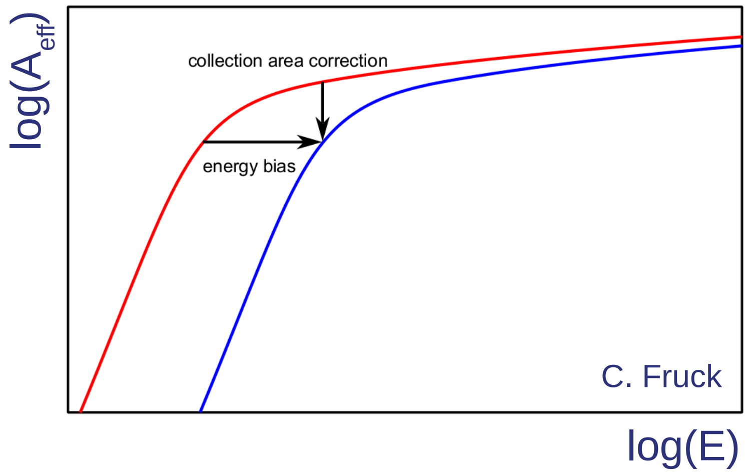
7%	4%	9%	80%

MAGIC Data Correction

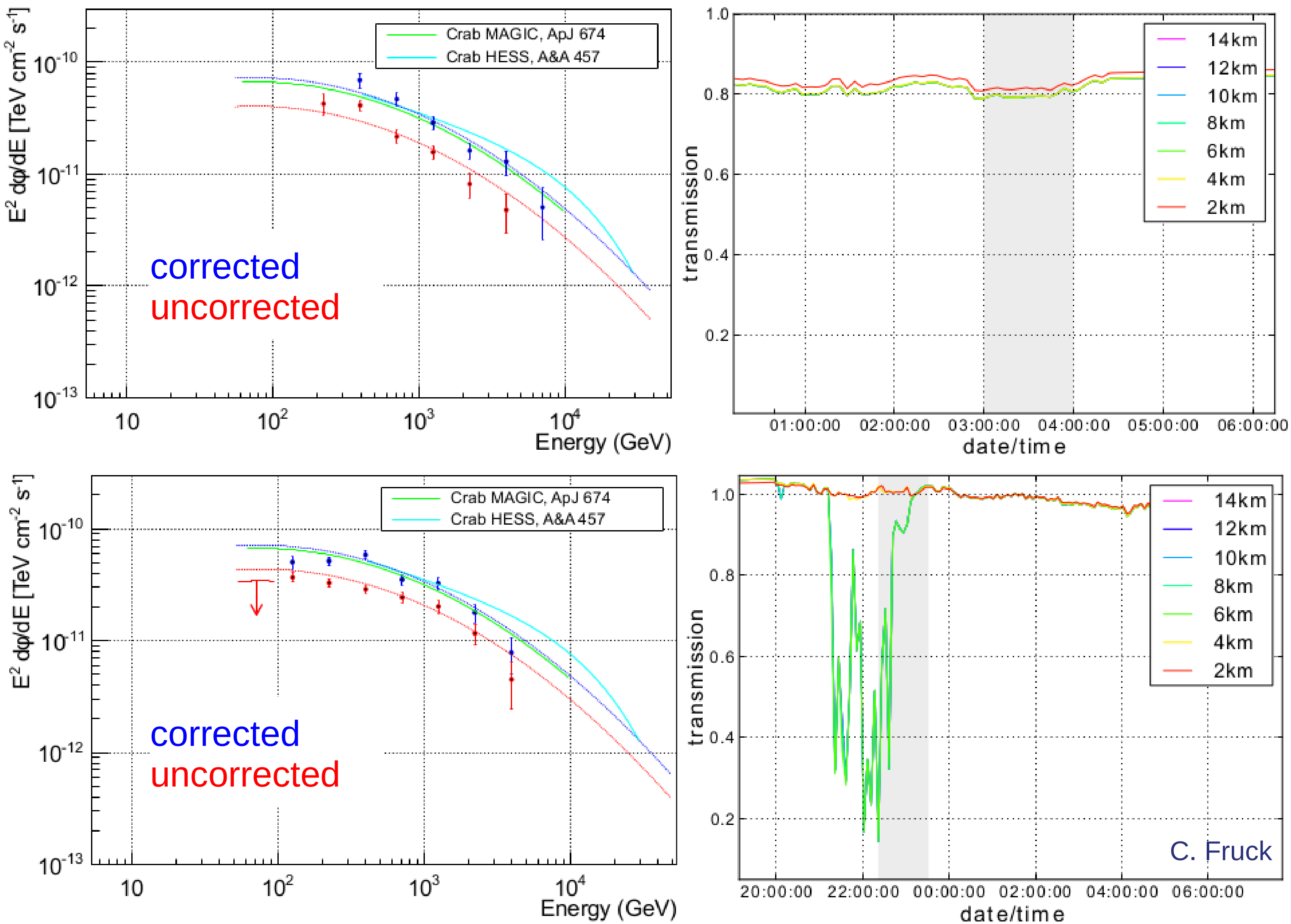


- Correction of energy
  - Number of photons underestimated
  - Bias depends on light emission and total transmission
  - $E_{corr} = E_{est} / \tau$

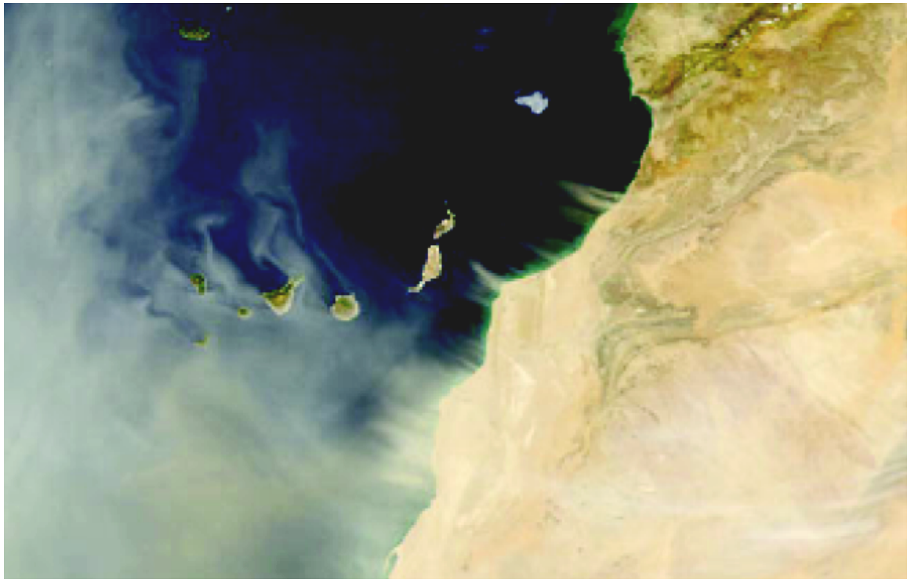
- Correction of effective collection area
  - Mainly depends on trigger efficiency which depends on tot. light yield
  - With clouds assumed coll. area too large
  - Flux at low E underestimated
  - Works until transmission values of 0.55



MAGIC Data Correction

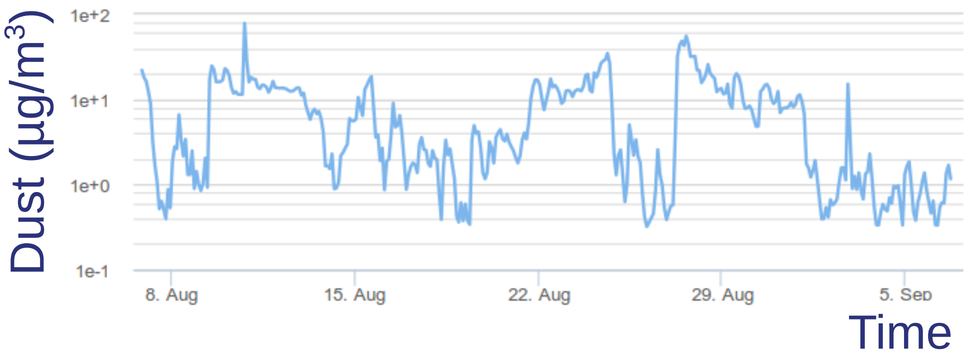


Dust Monitoring



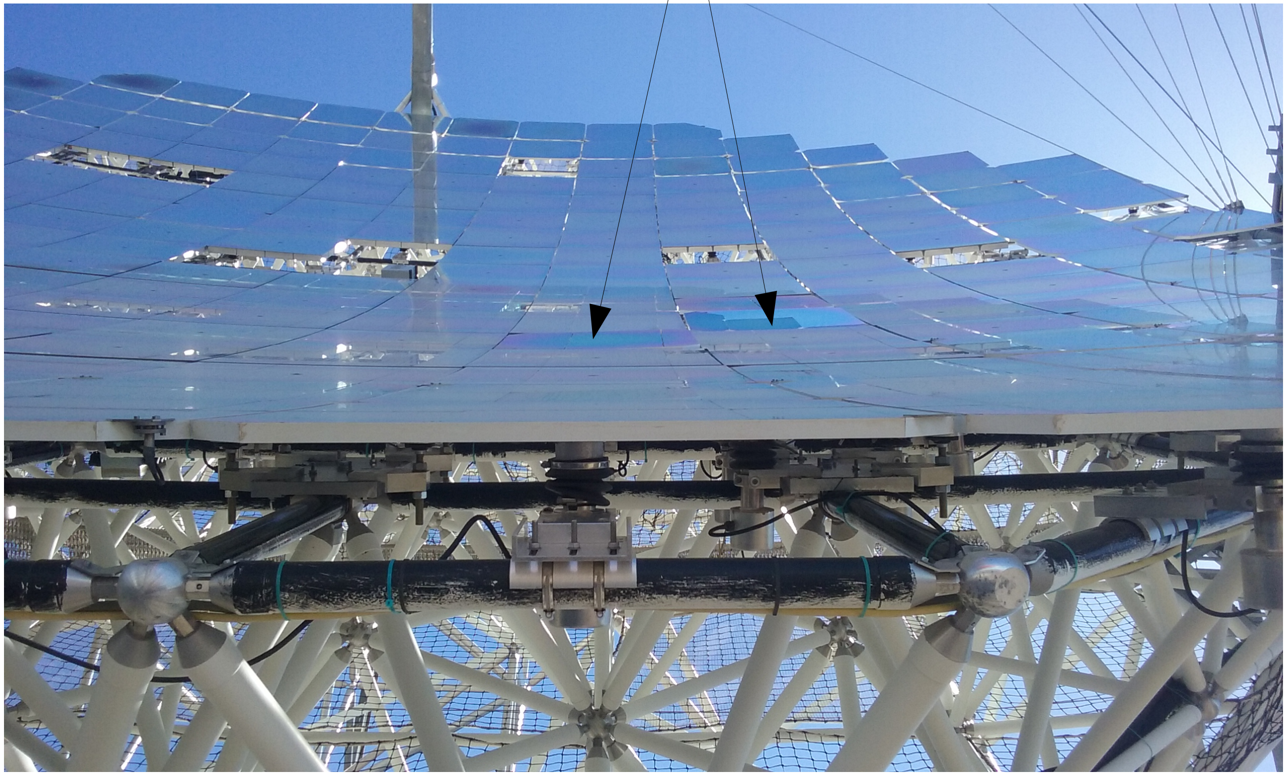
- Dust measurement at TNG
  - Automatic particle counter *Lasair II 310B*
  - Particle concentration from laser scattering
  - Size sensitivity 0.3, 0.5, 1.0, 3.0, 5.0, 10.0 µm
  - 2h cumulative density in µg/m³

- Dust affects operations
  - Short-term through increase of transmission
  - Long-term through decrease of mirror reflectivity



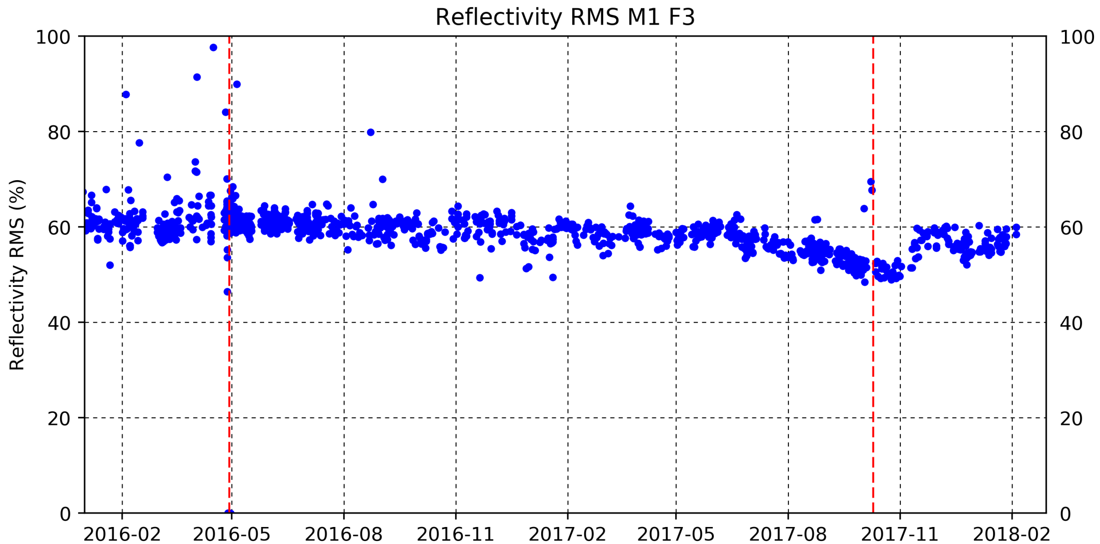
Mirror Reflectivity

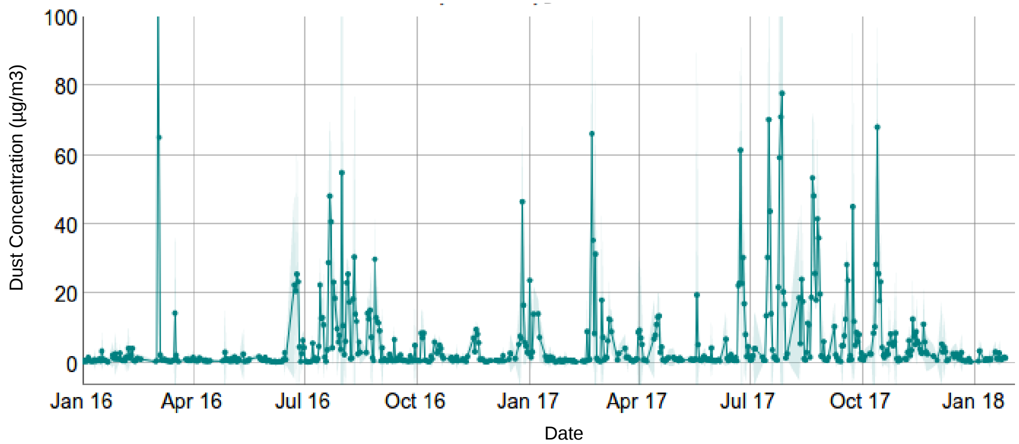
New mirrors



- Very extreme example from 2017

Mirror Reflectivity



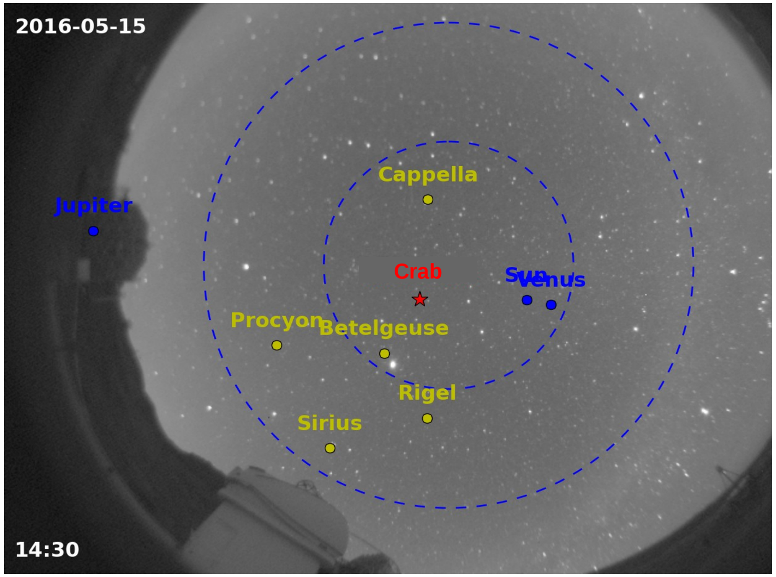


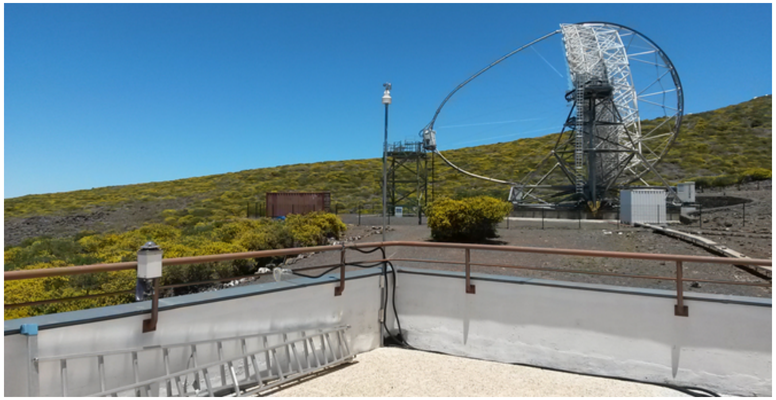
- Very extreme example from 2017

AllSky Camera

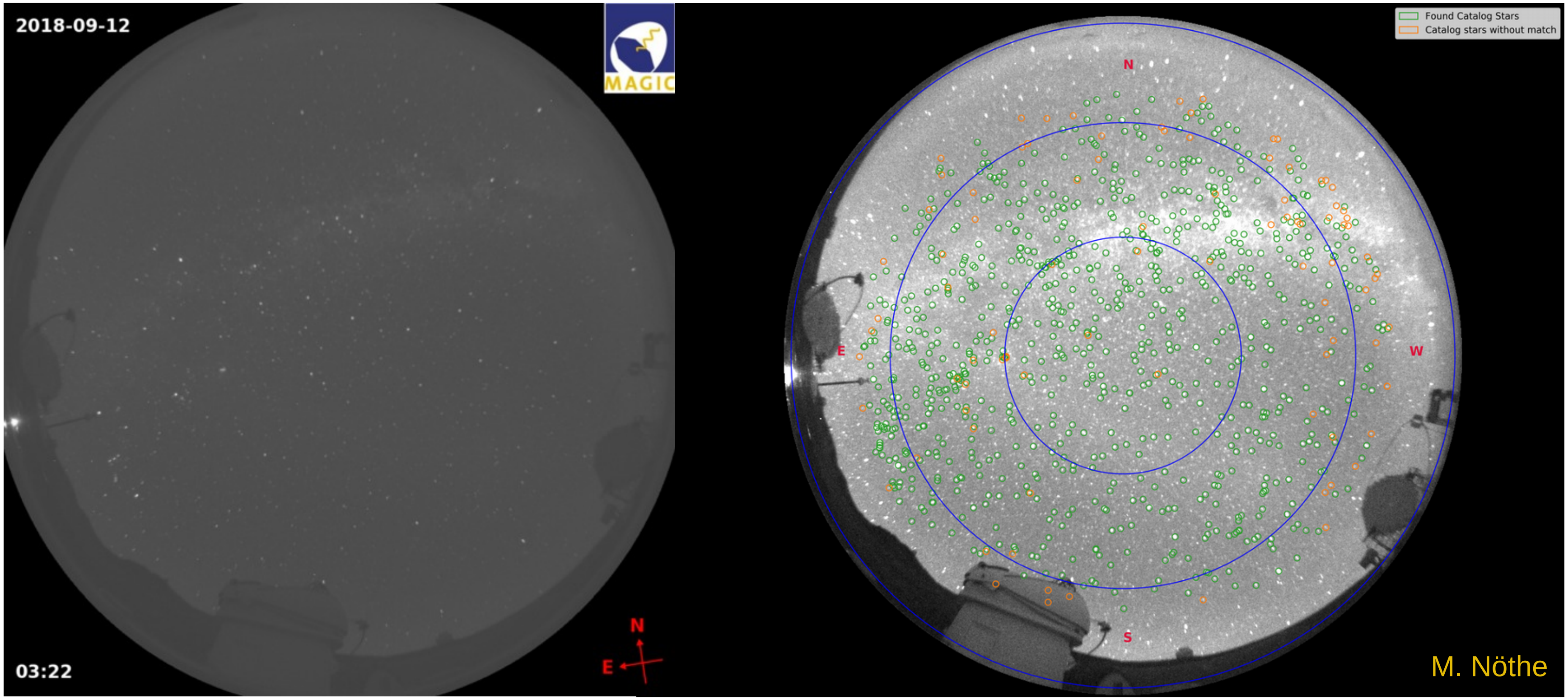
- *Starlight Express OCULUS*
  - 1.55mm, f/2 fish eye lens
  - 180° coverage
  - Water-proof housing
  - New image every 2 minutes





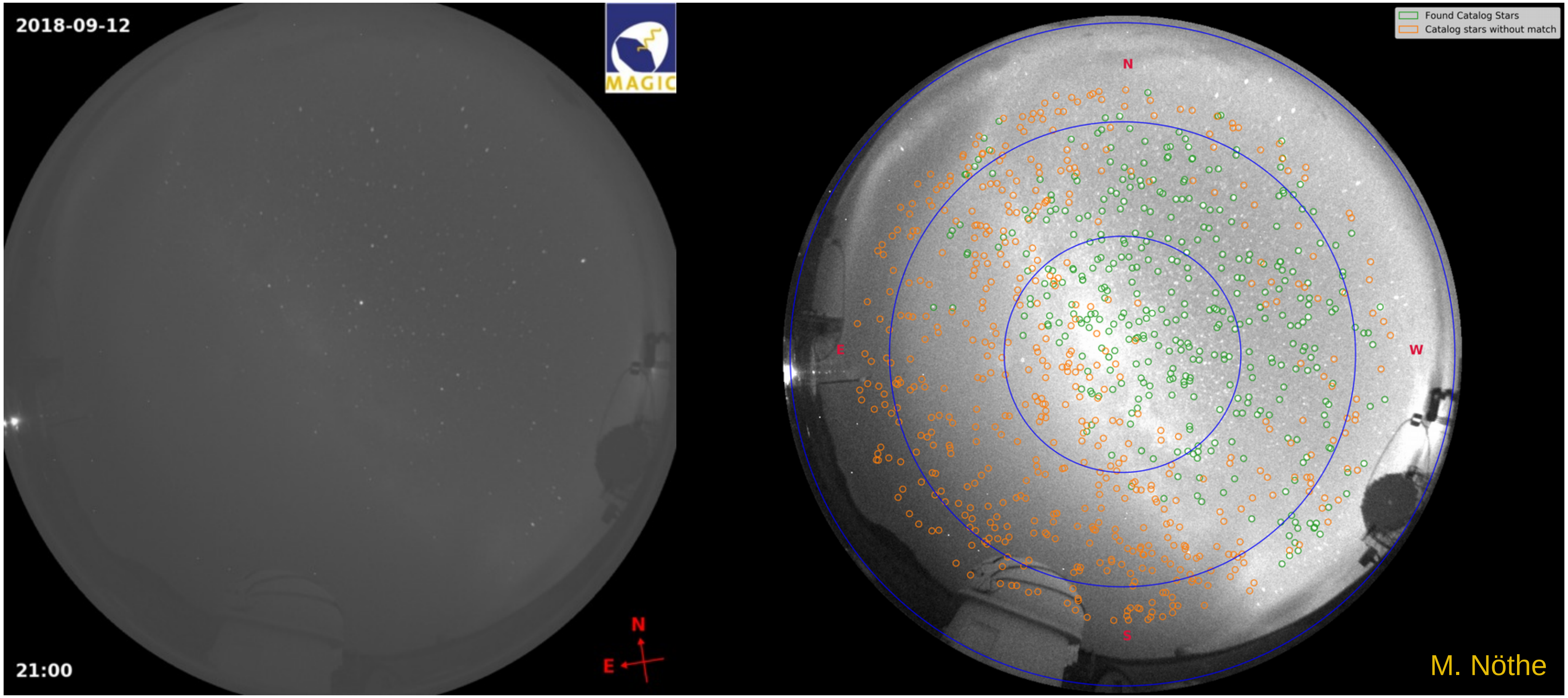


Cloud Detection



- Compare found with expected stars

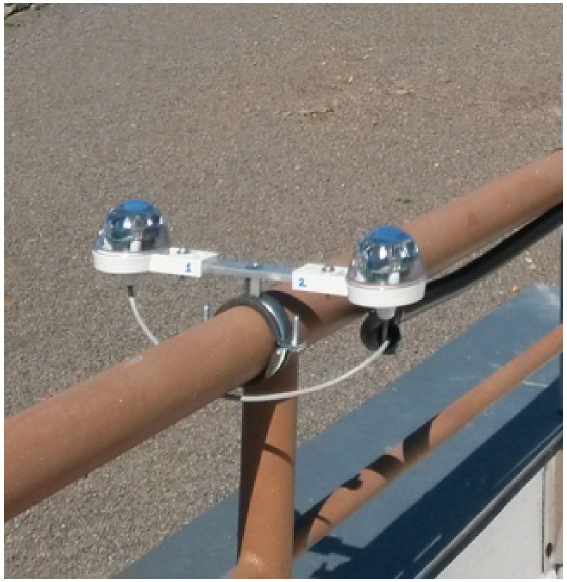
Cloud Detection

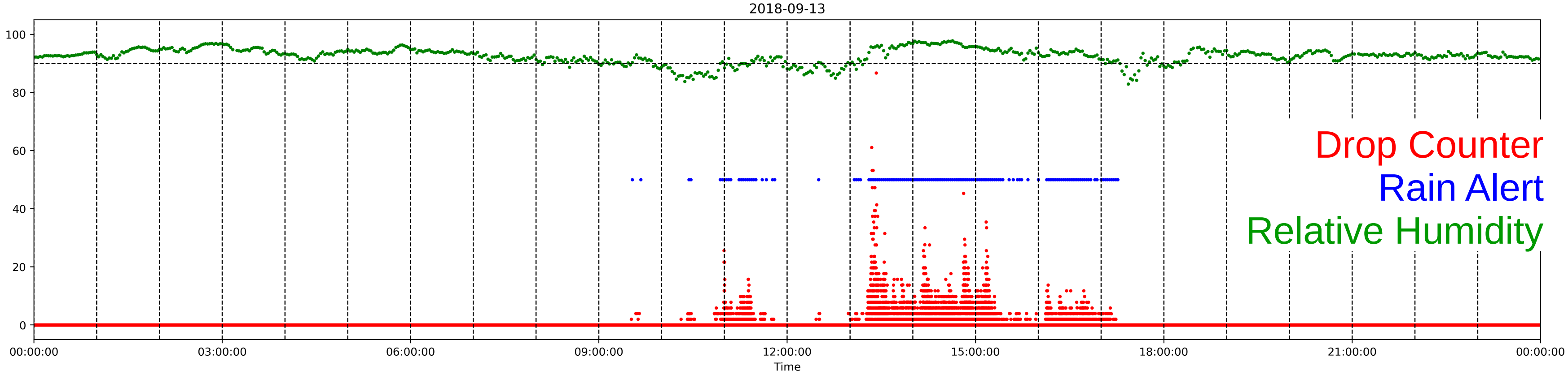


- Compare found with expected stars
- Cloud cover for entire sky and specific sources

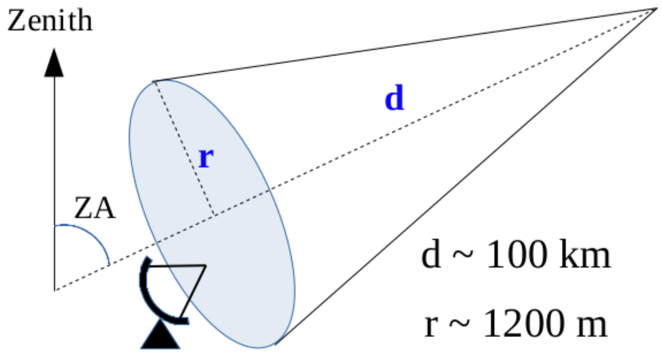
Rain Sensor

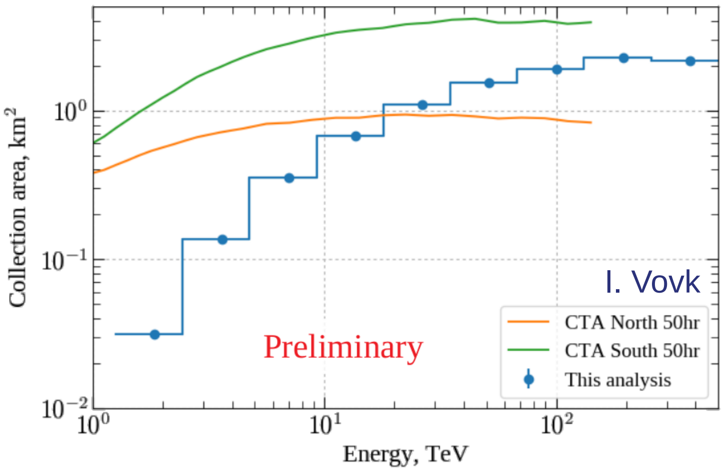
- Two sensors (drop counter & condensation)
  - Correlate with intensity of rain
  - 30 s integration as rain threshold
- Crosscheck with weather station data ongoing
  - Rain parameter seems to work
  - No false alarms so far
  - Warning issued before humidity crossed 90% threshold

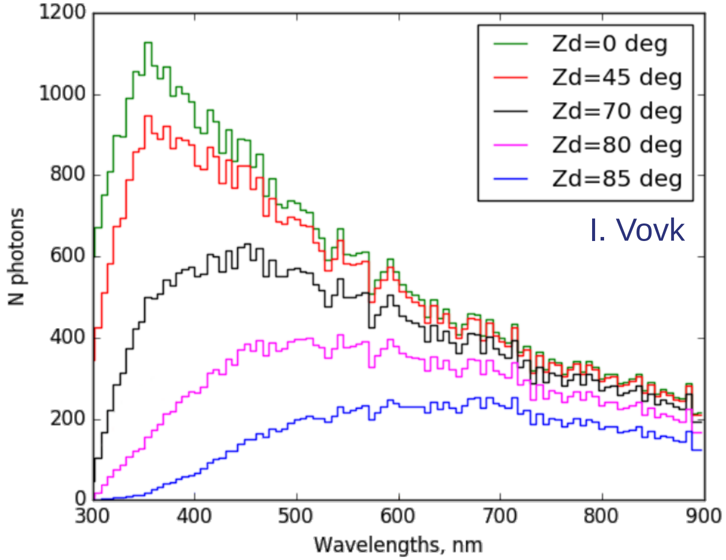




New Challenges – Large Zenith



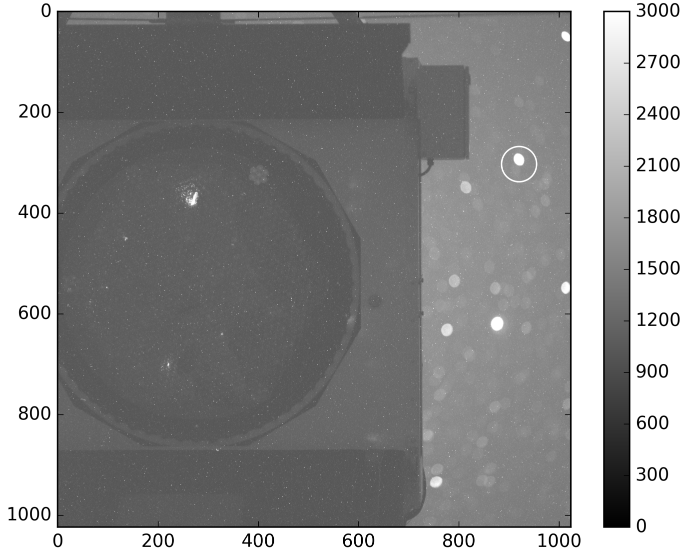


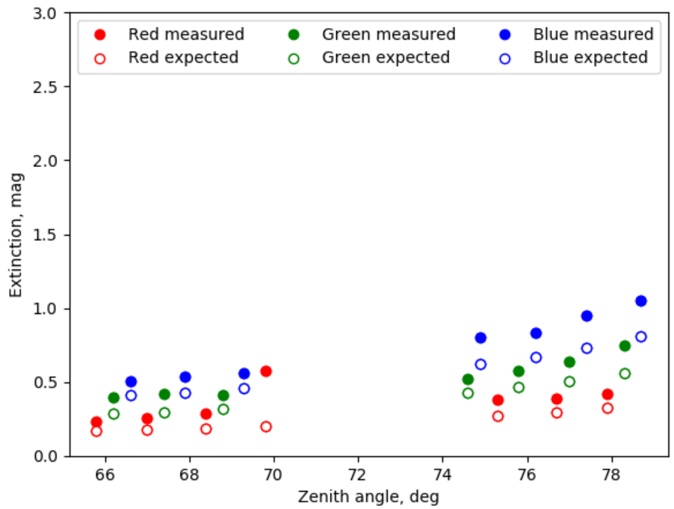


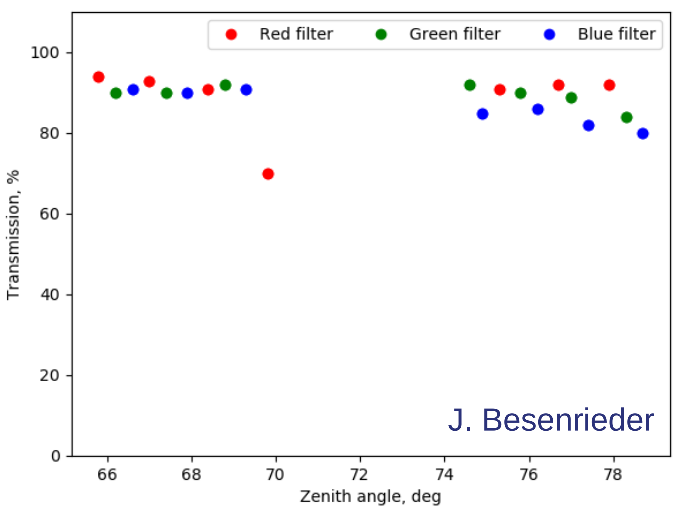
- Observations at zenith angle > 70°
  - Shower distance > 50 km
  - Collection area at 100 TeV comparable to CTA (at 20° Zd)
  - Larger light absorption
  - Higher energy threshold
- LIDAR transmission measurement
  - Laser not powerful enough
  - Mechanical restrictions of dome

New Challenges – Large Zenith

- Stellar Photometry
  - CCD camera used for PSF measurement and mirror alignment
  - 3 filters (RGB), 90s exposure
  - Extinction / transmission determined from star magnitude







Summary

- Several instruments and data available at MAGIC site
  - Weather station and GDAS model
  - Elastic LIDAR and infrared pyrometer
  - AllSky cameras, rain sensor and more...

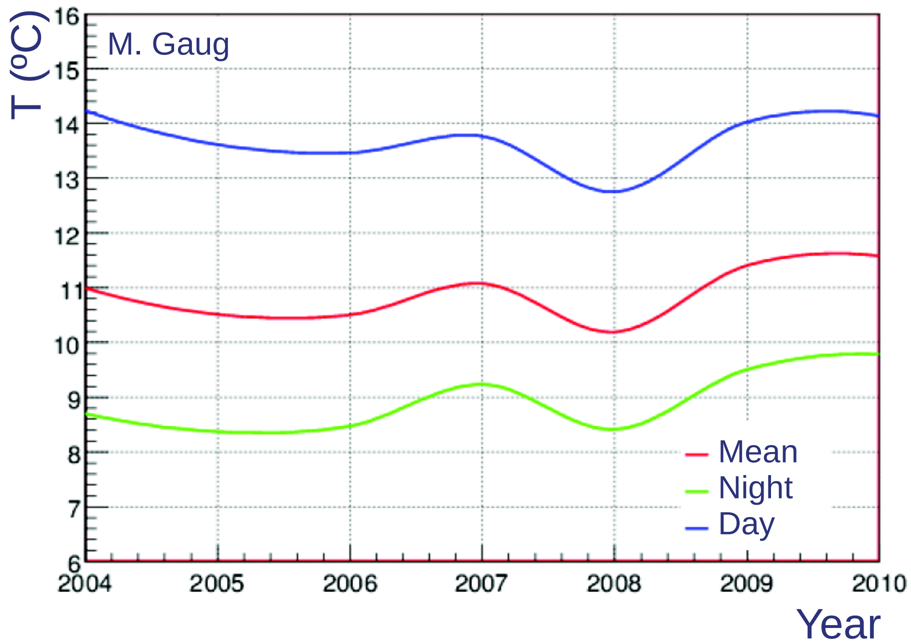
- Measurement of atmospheric parameters for over a decade
  - Safety of telescopes guaranteed
  - Quality of MAGIC data known
  - Correction of data taken under adverse conditions

- Still improving analyses and working on new challenges

- cta cherenkov telescope array atmosphere instruments incoming, MAGIC will benefit

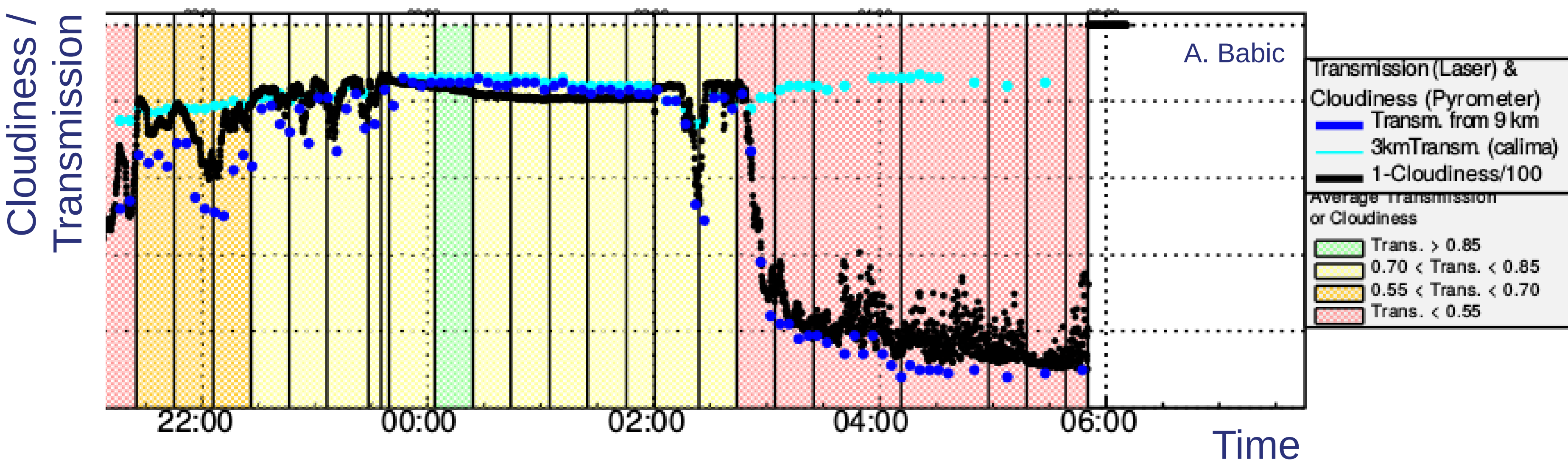
Weather Station

- Weather Station *Reinhardt MWS-55V*
  - Temperature, pressure, relative humidity, wind speed and direction
  - Most important instrument for safety of telescopes
  - Limits: wind gusts < 40 km/h (mean wind < 50 km/h) and humidity < 90%
- Publication of more than 15 years data at MAGIC site coming soon...



Infrared Pyrometer

- Pyrometer *Heitronics KT 19.82*
  - Mounted at MAGIC-I mirror, 2º FoV
  - Infrared measurement (8–14 µm)
- Measurement of sky or cloud temperature
- “Cloudiness” from zenith, ground and sky temperature



Summary of Parameters