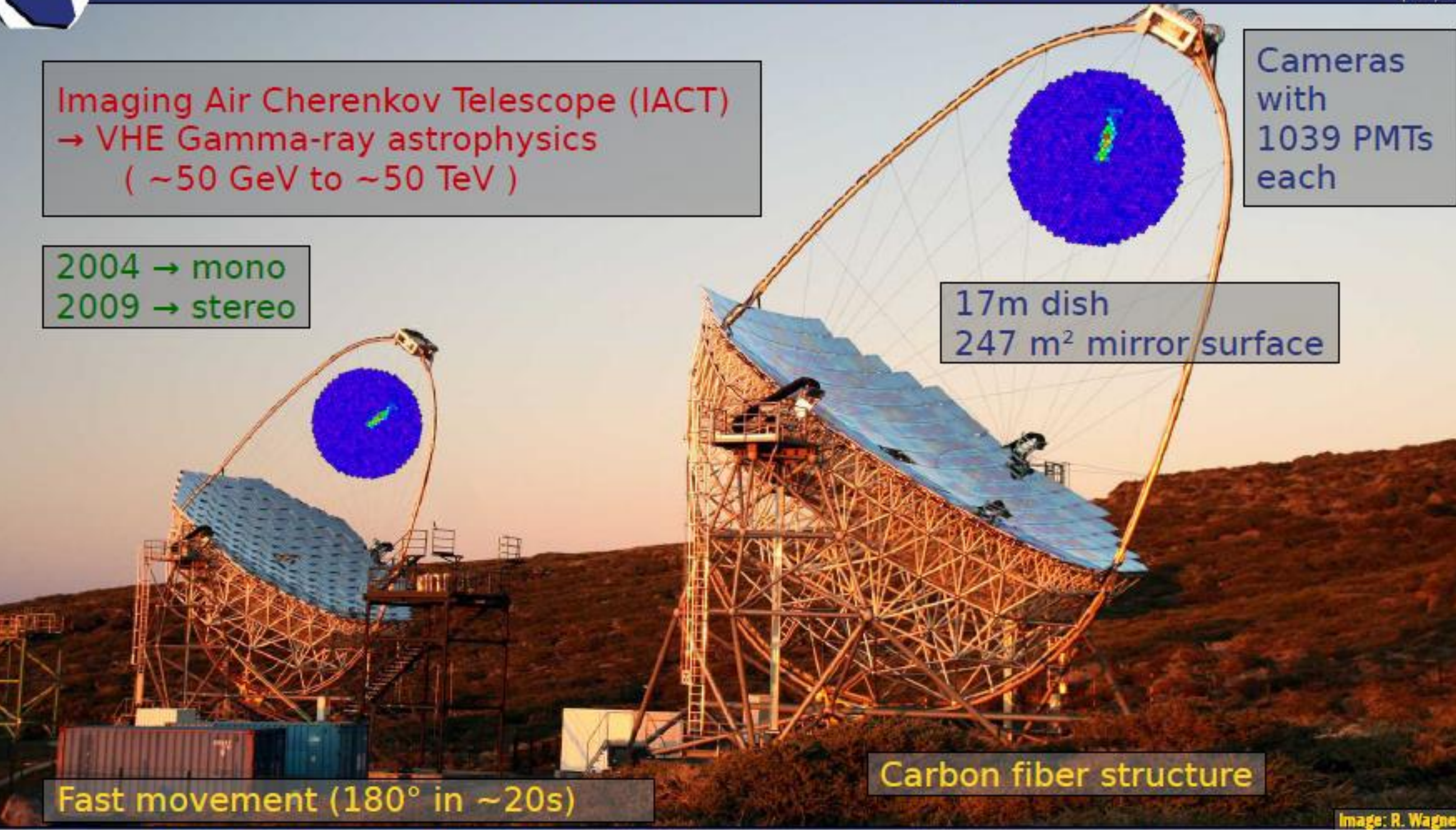
Expanding the Observational Limits of the Ground-Based Atmospheric Cherenkov Technique at Very High Energies

Razmik Mirzoyan
Max-Planck-Institute for Physics
Munich, Germany

The MAGIC Telescopes



The MAGIC Telescopes on La Palma

Site:

La Palma, Canary islands, Spain

Observatorio del Roque de los Muchachos, 2200m a.s.l.

The MAGIC Collaboration

~160 Collaboration members in 10 countries

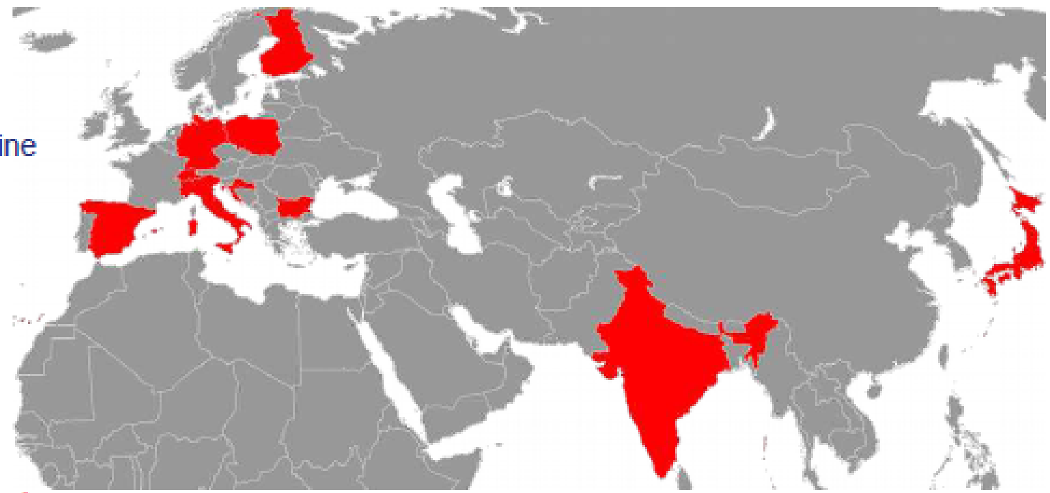
Germany:
Max-Planck-Institut für Physik, München
Technische Universität Dortmund, Dortmund
Deutsches Elektronen-Synchrotron (DESY) Zeuthen, Zeuthen
Universität Würzburg, Würzburg

Finnland:
Finnish MAGIC Consortium:
Tuorla Observatory, University of Turku,
University of Oulu, Finland, Piikkiö

Switzerland:
ETH Zurich, Institute for Particle Physics, Zurich

Poland:
Division of Astrophysics, University of Lodz, Lodz

Italy:
Università dell'Insubria and INFN Milano Bicocca, Como
Universita di Pisa , and INFN Pisa, Pisa
INAF - National Institute for Astrophysics, Roma
Università di Siena and INFN sez. di Pisa, Siena
Università di Udine and INFN, sezione di Trieste, Italy, Udine
Università di Padova and INFN sez. di Padova, Padova



Croatia:
Croatian MAGIC Consortium:
Institute R. Boskovic,
University of Rijeka,
University of Split,
University of Zagreb-FER, Zagreb

Spain:
Universitat Autònoma de Barcelona, Barcelona
Universitat de Barcelona, Barcelona, Spain
Institut de Ciencies de l'Espai (IEEC-CSIC), Bellaterra
Institut de Fisica d'Altes Energies (IFAE)
Instituto de Astrofisica de Canaria, La Laguna (Tenerife)
Universidad Complutense, Madrid, Madrid
CIEMAT, Madrid

Bulgaria:
Institute for Nuclear Research and Nuclear Energy, Sofia

India:
Saha Institute of Nuclear Physics, Kolkata

Japan:
Japanese
MAGIC Consortium:
Kyoto, Tokyo

Upgrades and performance (standard conditions)

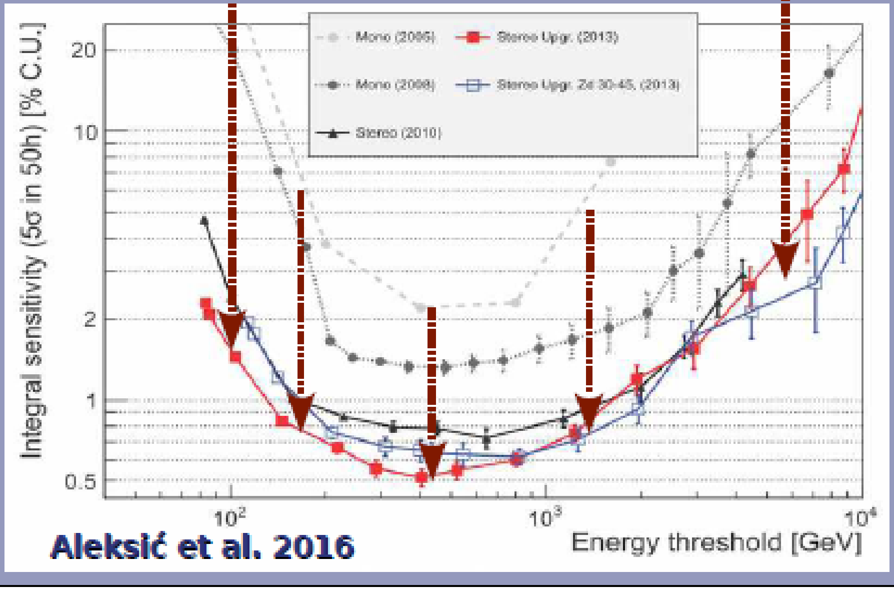
Upgrade history:

2007: new faster readout for MAGIC-I

2009: MAGIC-II built, stereo operations

2011-2012: new camera for MAGIC-I and upgrade of both readout systems

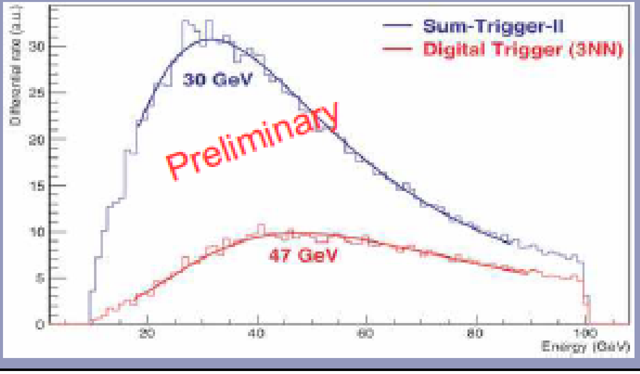
Aleksić et al. 2016, Aph, 72, 61



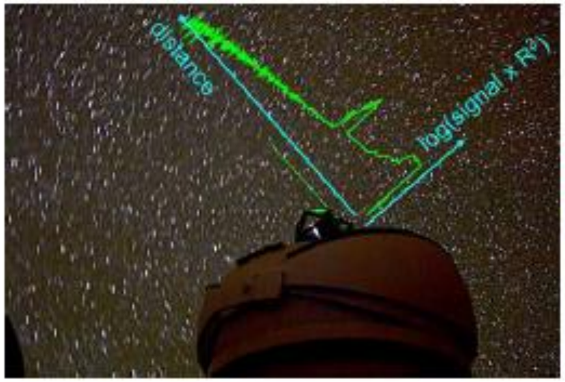
Key performance parameters:

- Integral sensitivity above 220 GeV:
  0.66% of Crab Nebula flux in 50h
- Angular resolution:
  0.1 deg – 0.05 deg
- Energy resolution:
  15-24%
- Energy threshold:
  50-70 GeV
  ~30 GeV (Sum Trigger II)
- All performance parameters in:

Aleksić et al. 2016, Aph, 72, 76

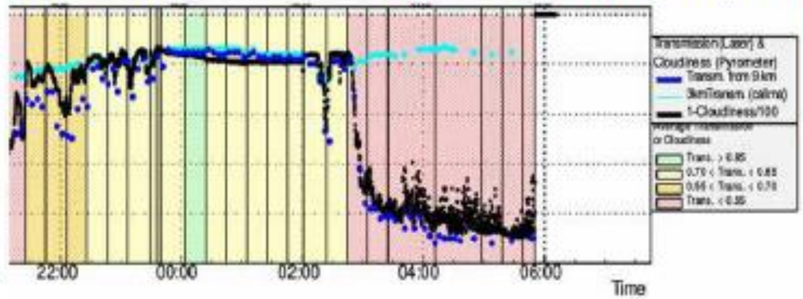


MAGIC instrumentation for atmospheric monitoring



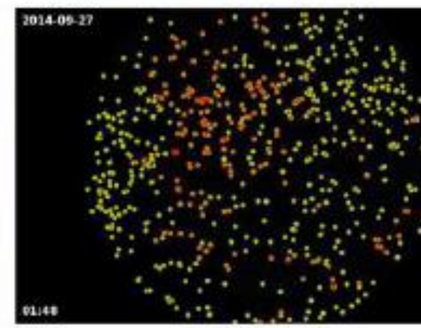
'micro'-LIDAR
(532 nm)

IR Pyrometer
(heat sensing, 8-14 μm)

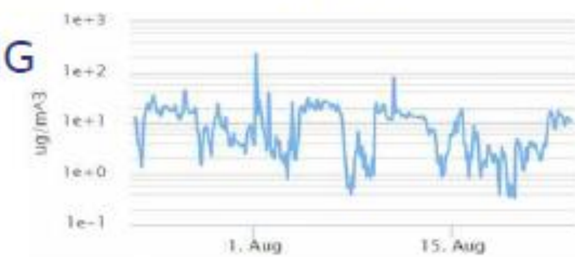


Starguider &
SBIG camera
(opt. CCD)

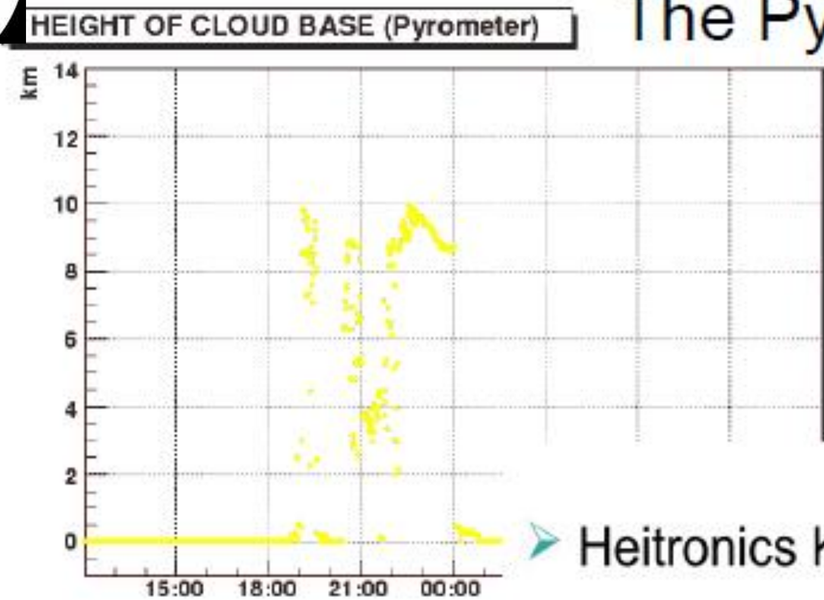
All-sky
Cameras
(opt. CCD)

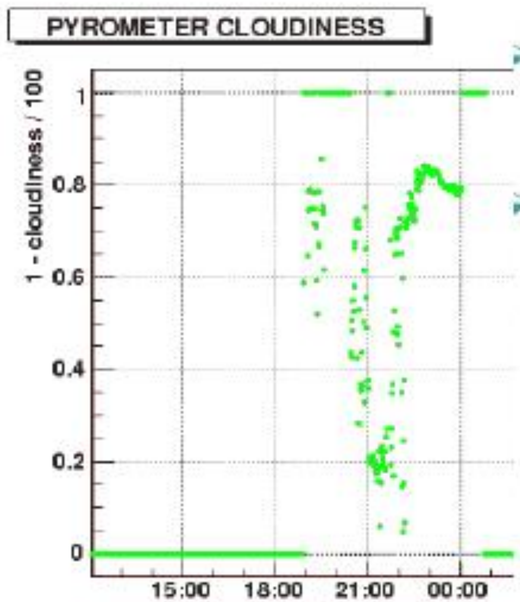


Dust particle counter of the TNG
(Telescopio Nazionale Galileo)
(Lasair II, model 310B, Particle Measuring System, Inc., particle sizes: 0.3, 0.5, 1.0, 3.0, 5.0 and 10.0 μm)



The Pyrometer





- Heitronics KT 19.82
- Located at side of M1 dish
- Measures sky temperature
  - infrared (8–14 μm)
  - -100°C to +3000°C
  - 0.01° resolution
  - 2° field of view

The all-sky camera

- Kodak KAI-340 CCD
  - 640 x 480 pixels
  - Fish eye lens 1.4 mm focal length, F/1.4
  - Images read out every 2 min by PC18 in LIDAR tower

Elastic micro-LIDAR system

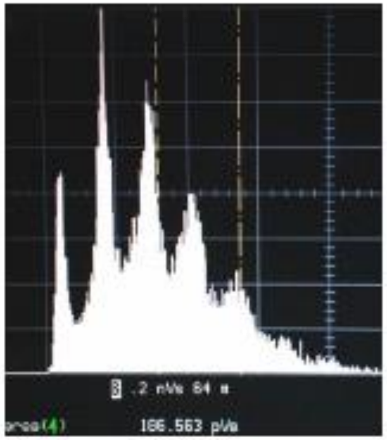
Control room:

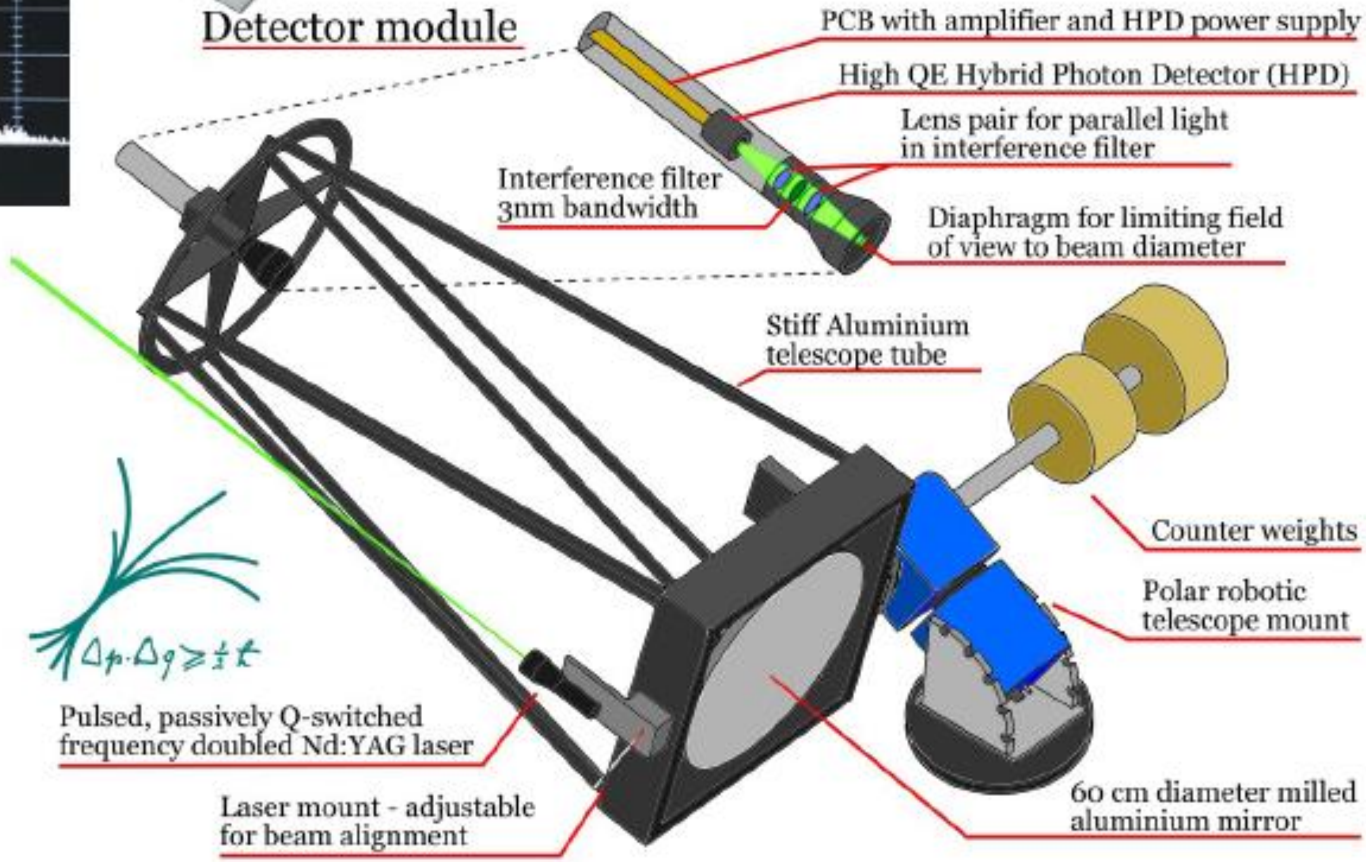
LIDAR mount/telescope:

LIDAR shooting:

- LIght Detection And Ranging (LIDAR) system operating alongside with MAGIC
- using 5 μJ pulse energy, 532 nm pulsed laser ('micro'-LIDAR)
- Hybrid Photo Detector (HPD) for single photon counting
- GAsP photocathode for high QE (> 50%)
- automatically slave-tracking MAGIC coordinates on robotic mount

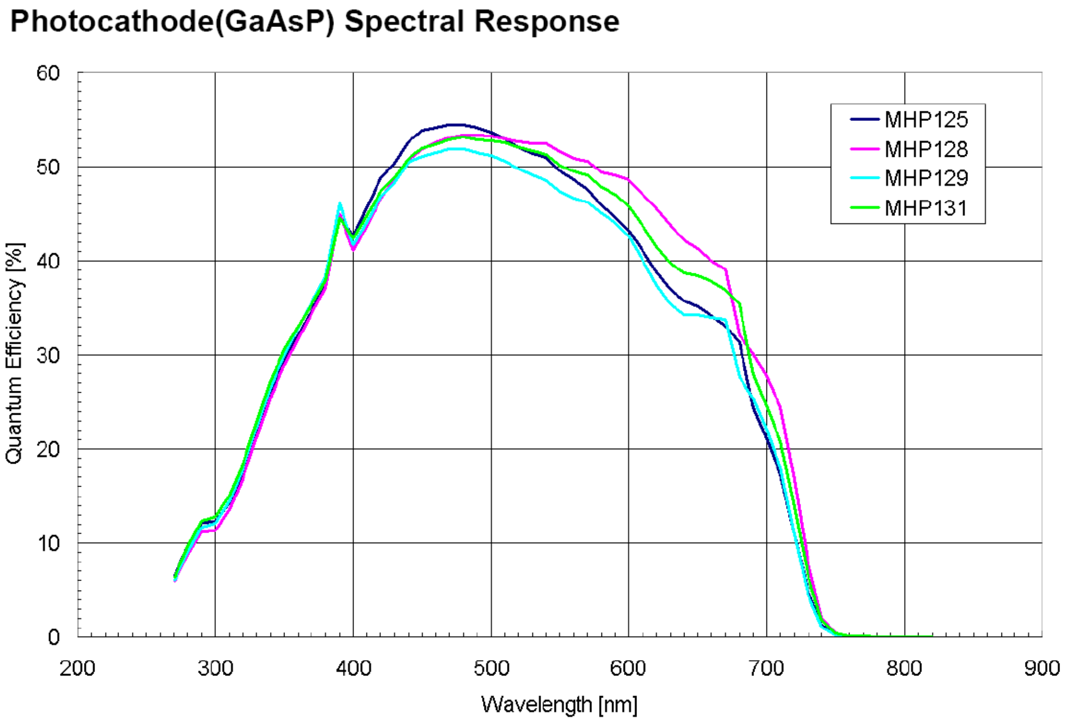
Elastic micro-LIDAR system

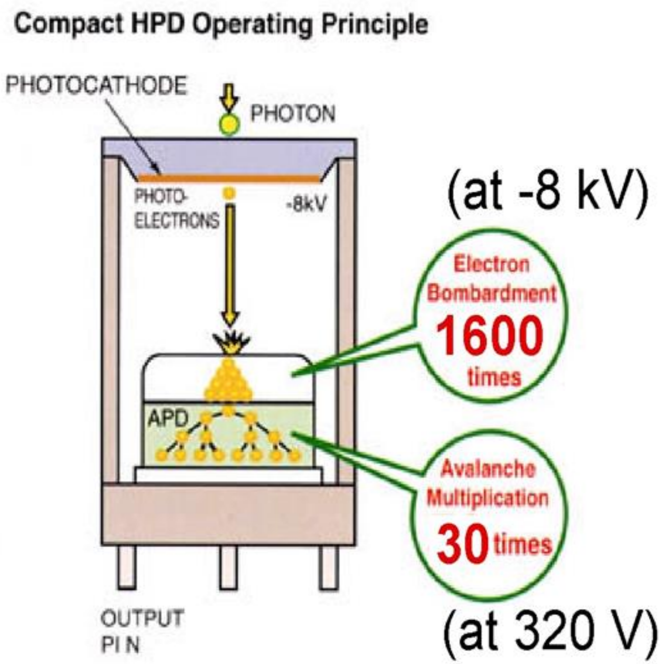




18-mm GaAsP HPD (R9792U-40) (we developed this together with Hamamatsu ~15 years ago)

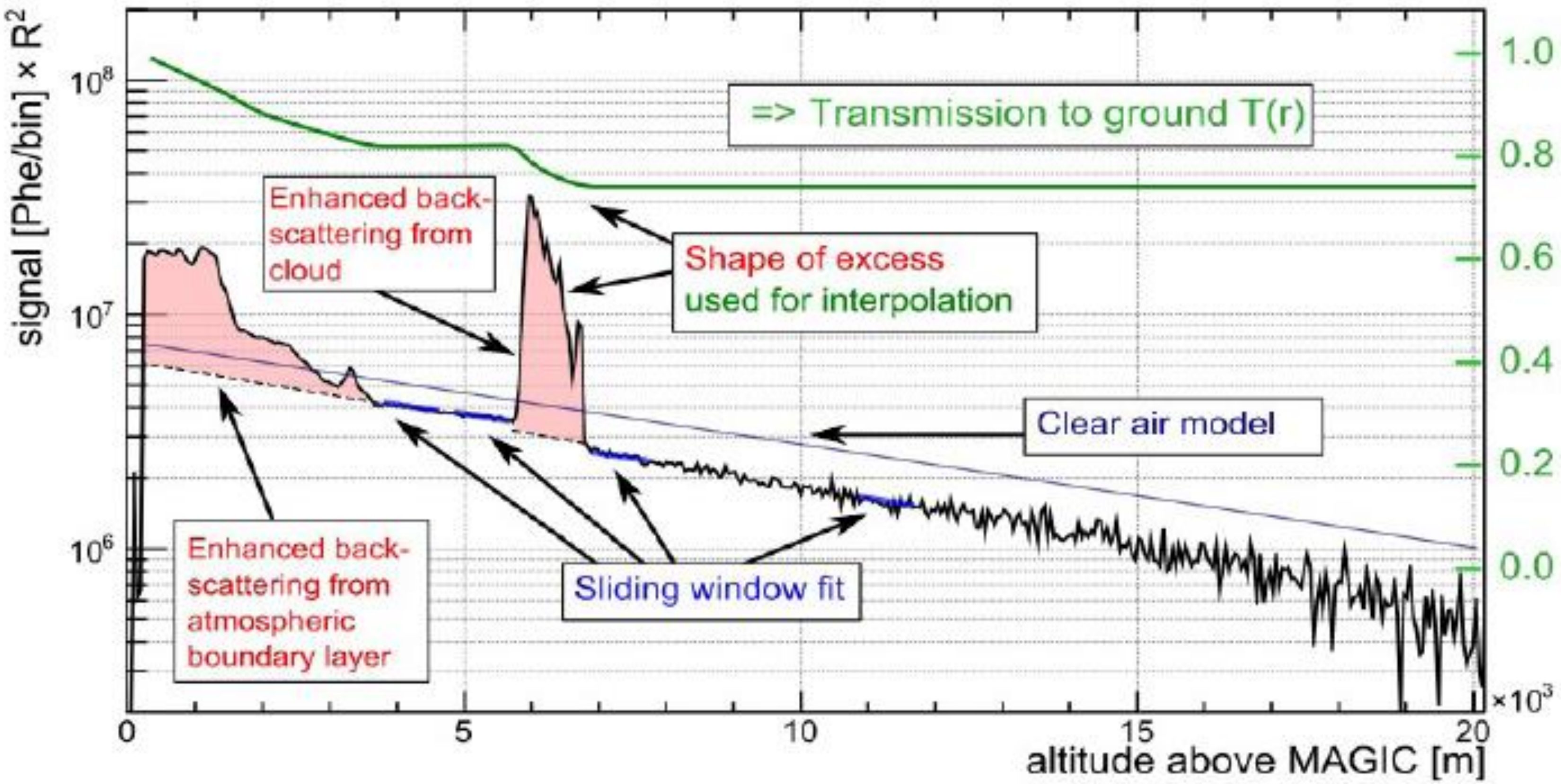
This commercial product is known under the name “MAGIC HPD”



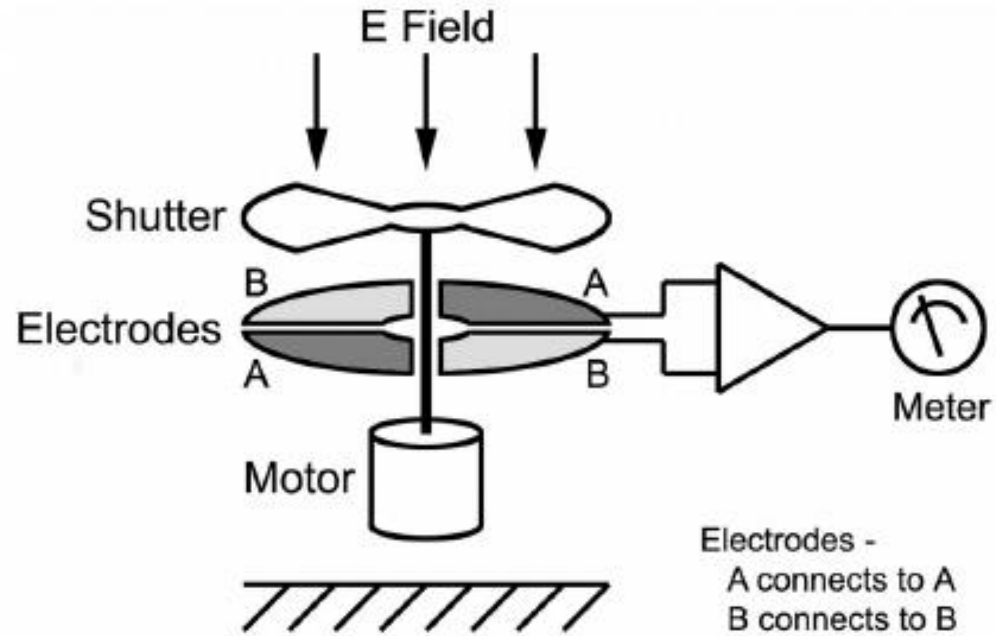


The elastic LIDAR system (signal analysis)

- LIDAR signal: ph.e. counts v.s. altitude from attenuated back-scattering
- Example: **real data with** cloud and aerosol layer (small zenith distance)
- Assumption: clear air regions with dominant Rayleigh scattering (532nm)
- Method: fitting/comparing Rayleigh model to LIDAR data in sliding window



The electric field mill

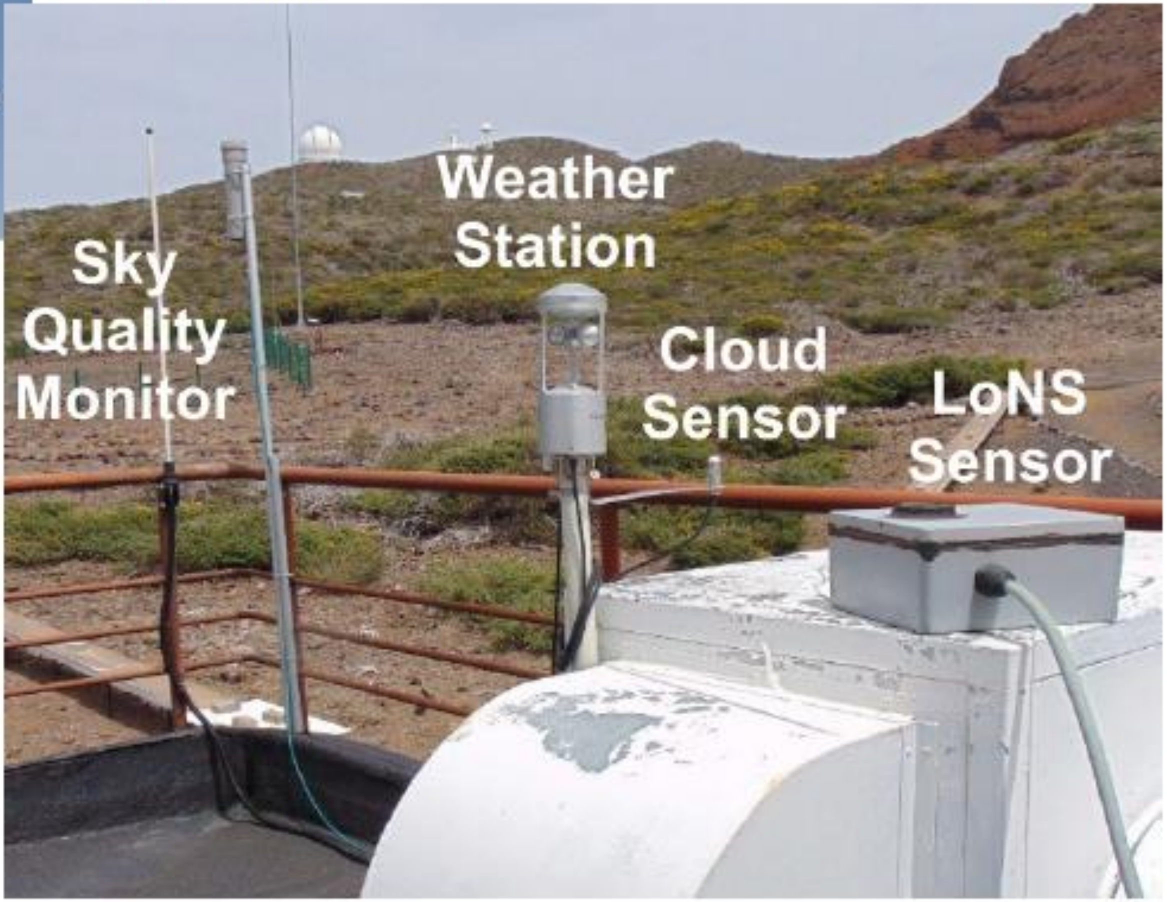


- Measures the atmospheric electrical field
- Detects clouds/thunderstorms/lightning
- At the moment connected to pc8 (Lidar PC)
- Runs at the moment with the windows software provided by the company
- Sends 10-times per second the measured value of the electrical field to pc8
- STATUS: broken AC-adapter (repaired?) but not operated and no implementation in SA yet

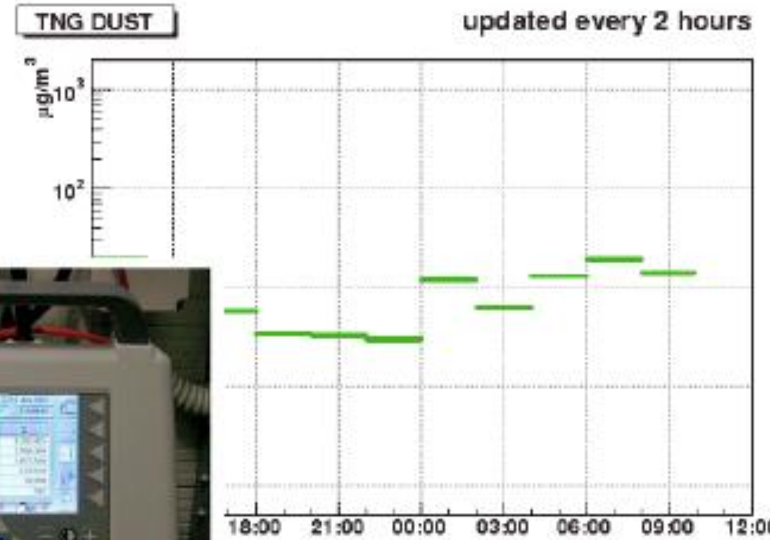
The ATMOSCOPE instruments

The „full“ ATMOSCOPE:

On La Palma:



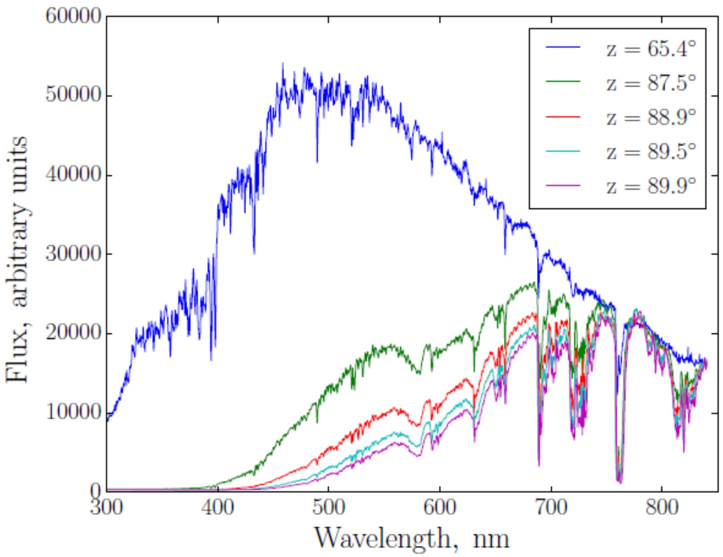
The dust counter of the TNG

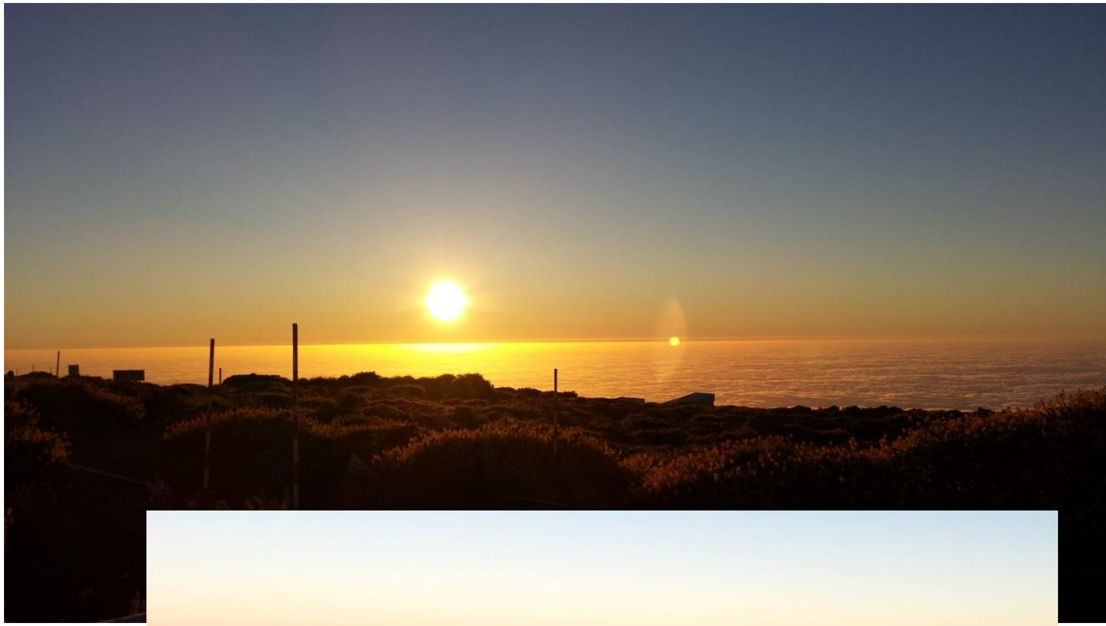


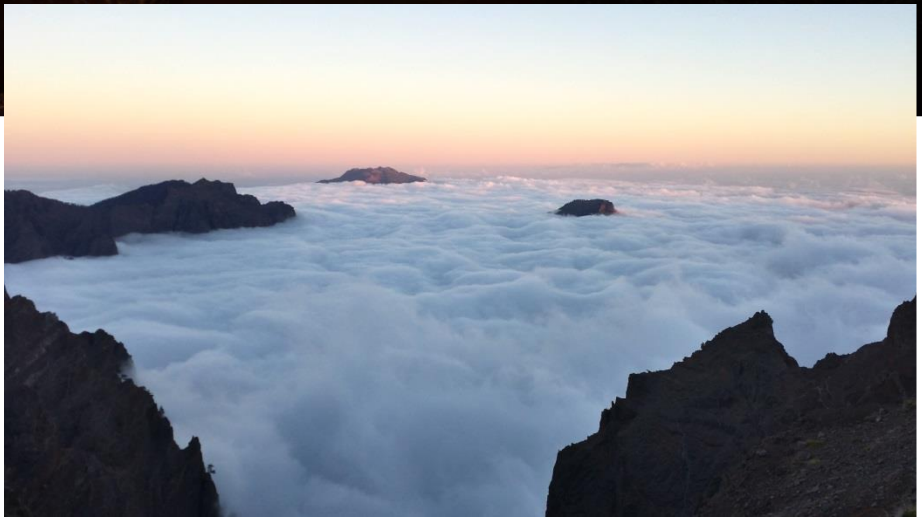
- Lasair II 310B
- Located at TNG site
- Measures dust density µg/m³
  - Every 2 hours
  - Concentration determined by laser scattering
  - Size sensitivity 0.3, 0.5, 1.0, 3.0, 5.0, and 10.0 µm
  - Very clean below 1 µg/m³, clean below about 5 µg/m³
  - During calima events up to 100 µg/m³
  - http://tngweb.tng.iac.es/weather/dust/

Auxilliary instrument operated by the TNG, ~500m from MAGIC site

Large zenith angle observations



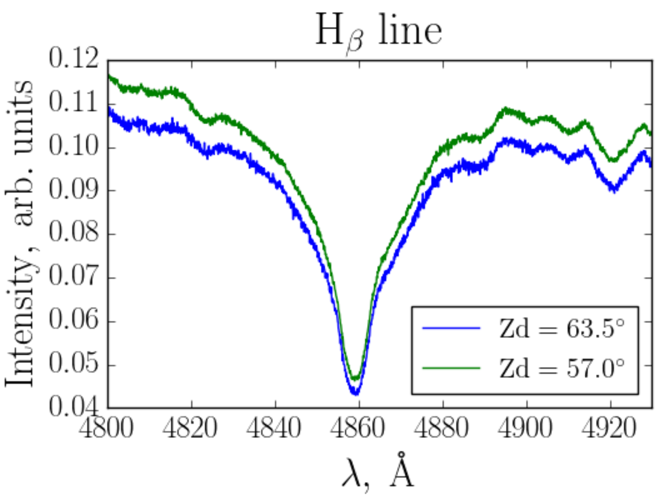


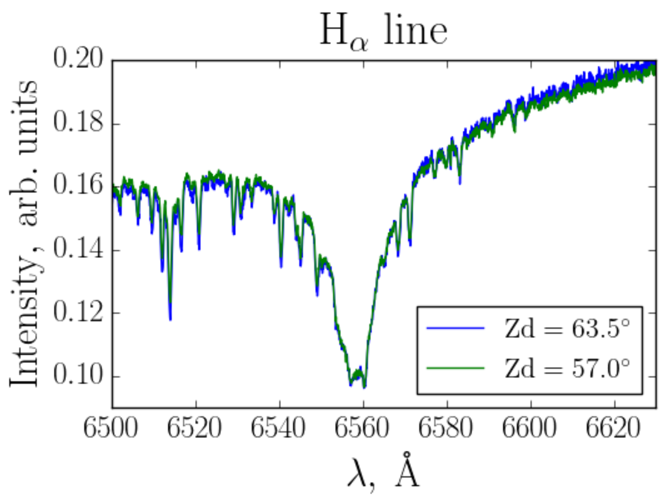


New Baches Echelle spectrograph for LZA atmospheric calibration next to MAGIC

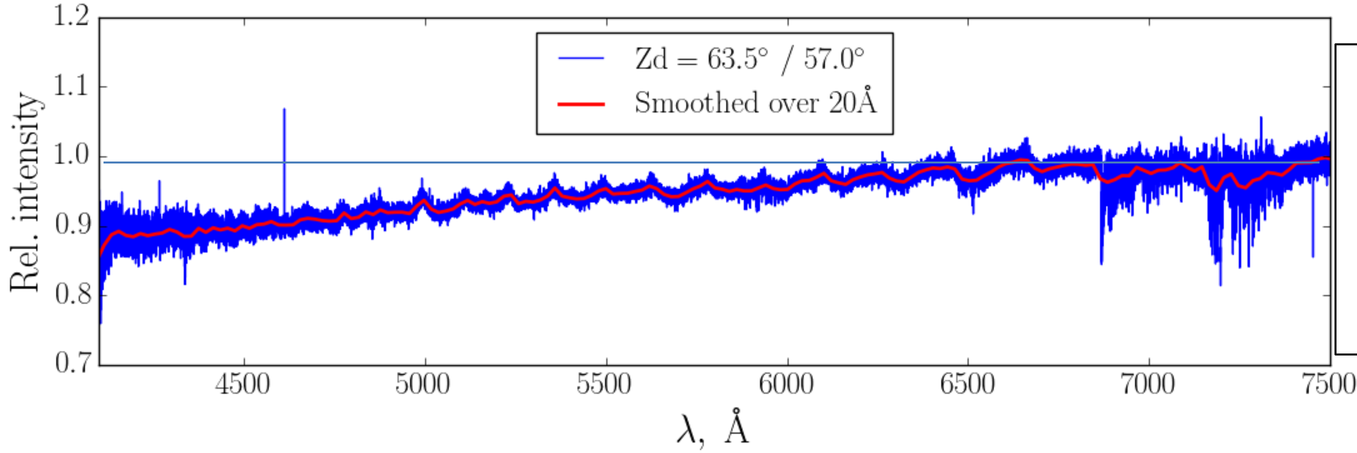
- MPI has purchased set of a spectrograph with a telescope
- Starting a tender for a dome for 11 inch
- Will be used to track stars next to the observation target, e.g. Zeta Tauri in Crab
- Spectrum differences with observation ZA provide data on momentary transmission

Spectrum from Altair observed from MPP roof @ 57° & 63.5° by 11' spectrograph





Measured by Ievgen Vovk on past Friday night



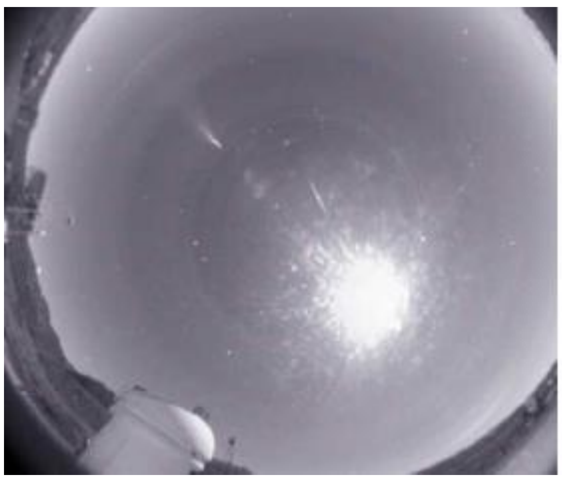
- Spectra normalized at 750 nm
- Exposure 5'
- Smoothed spectrum uncertainty ~0.3 %

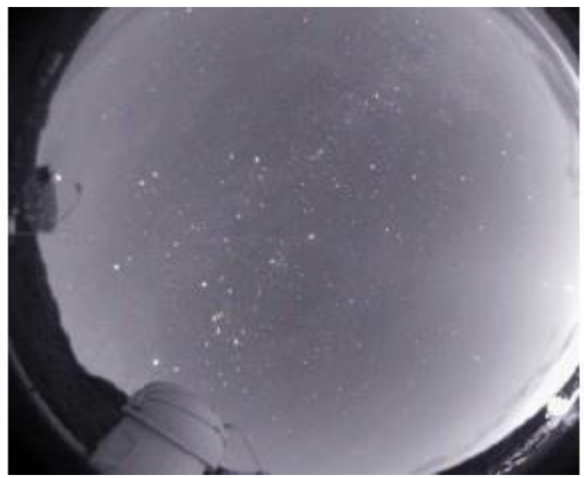
Operating MAGIC under “unusual” conditions

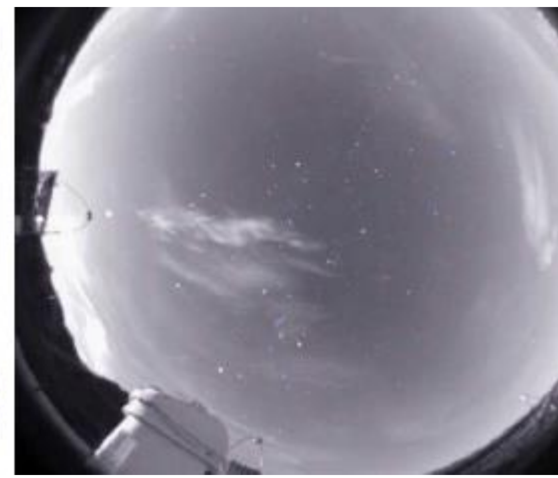
@ moderate till strong moon-light

@ large zenith angles, ~ 70°

@ the presence of dust & clouds





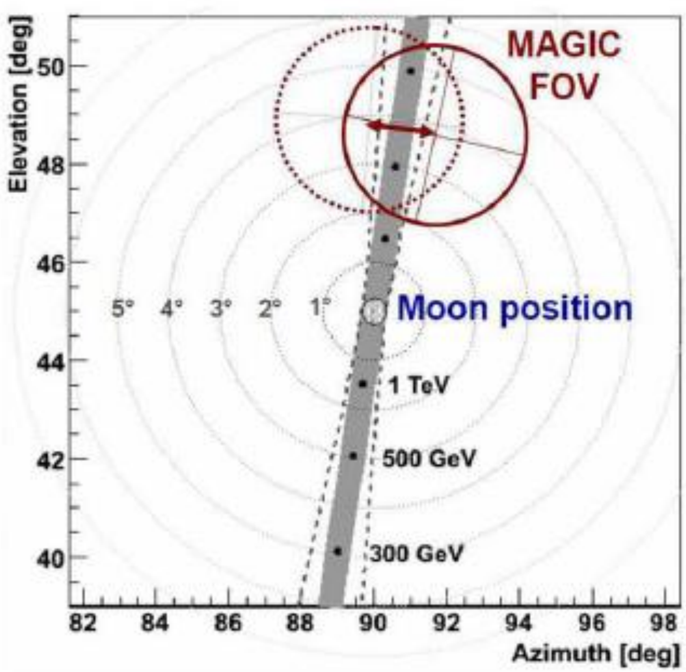


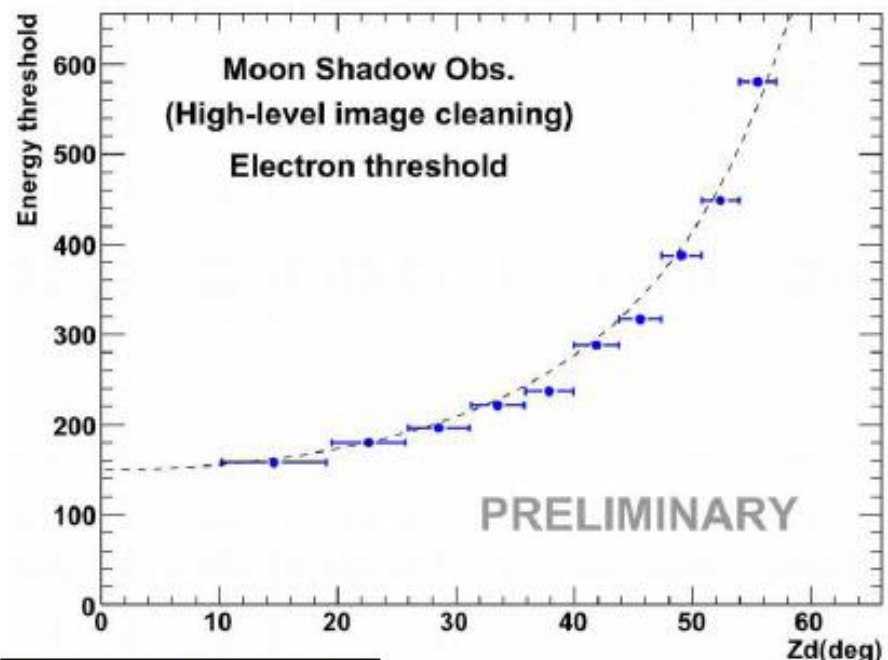
Moonlight observations with MAGIC

Probing the e+/e- ratio by using the moon shadow

- Moon blocks CR, e-, gamma, ...
- e-, e+ are deflected strongest by the Earth magnetic field
- Moon casts energy/charge dependent shadow

→ can be observed with MAGIC (with reduced HV settings)



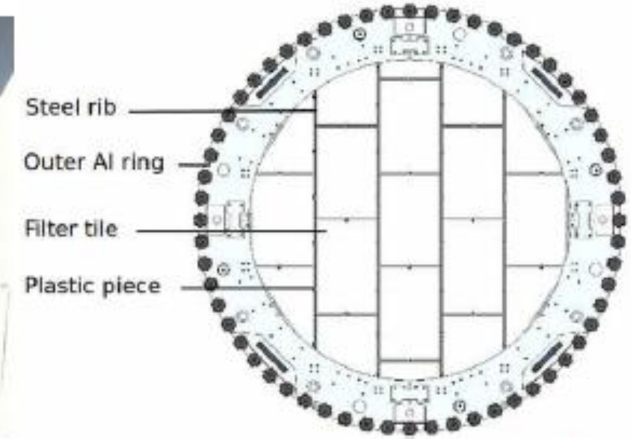


P. Colin, et al, ICRC 2011

Full moon observations using UV-pass filters

- NSB increased by several 10 x during full moon phase
- DC current very high even with reduced HV
- Need different way for reducing moonlight

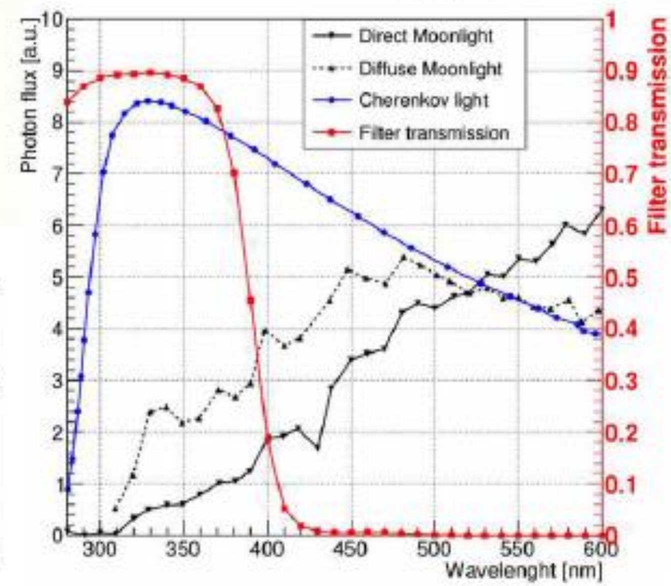
→ **MAGIC observes with UV-pass filters (experimental)**



D. Guberman, et al, ICRC 2015

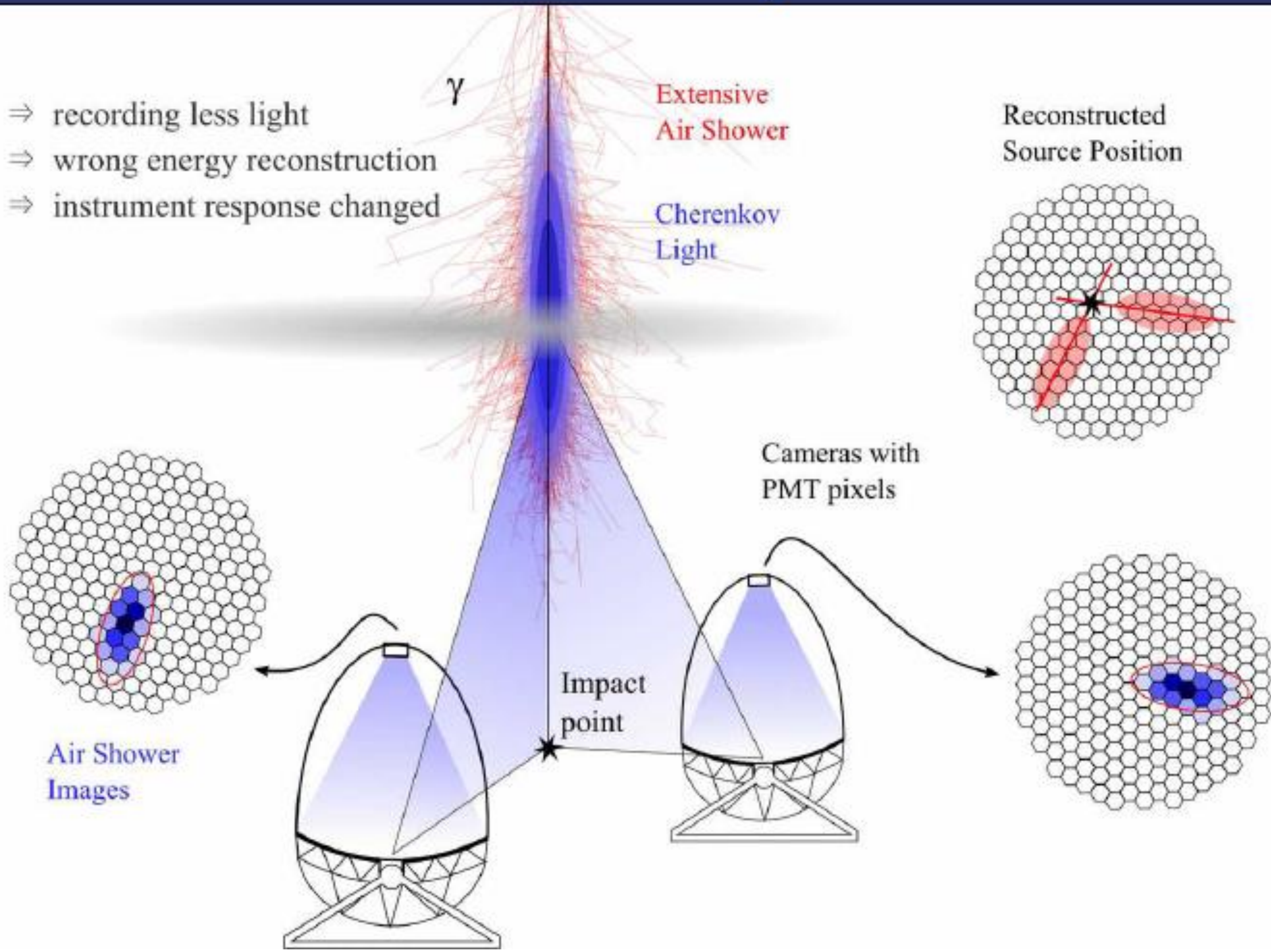
NSB [times *Dark NSB*]	N_{hr} [h]	DC in M1 (with filters) [μA]	Eq. DC (no filters) [μA]	E_{th} [GeV]	$S_{>300GeV}$ [% C.U.]
2.5 - 5	3.4	0.5 - 1	2 - 3.5	175	1.03 ± 0.10
5 - 10	1.2	1 - 2	3.5 - 7	195	1.13 ± 0.22
10 - 20	5.7	2 - 4	7 - 15	200	1.28 ± 0.10
20 - 40	4.1	4 - 6	15 - 30	215	1.31 ± 0.10

PRELIMINARY



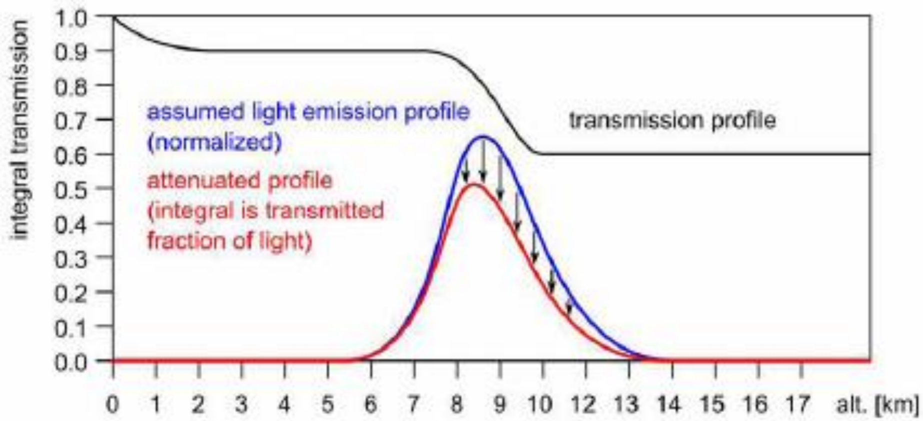
Dust from Sahara (Calima) over the Canary islands

Main effects of reduced atmospheric transmission



Correcting MAGIC data based on LIDAR measurements

Event wise energy correction strategy:

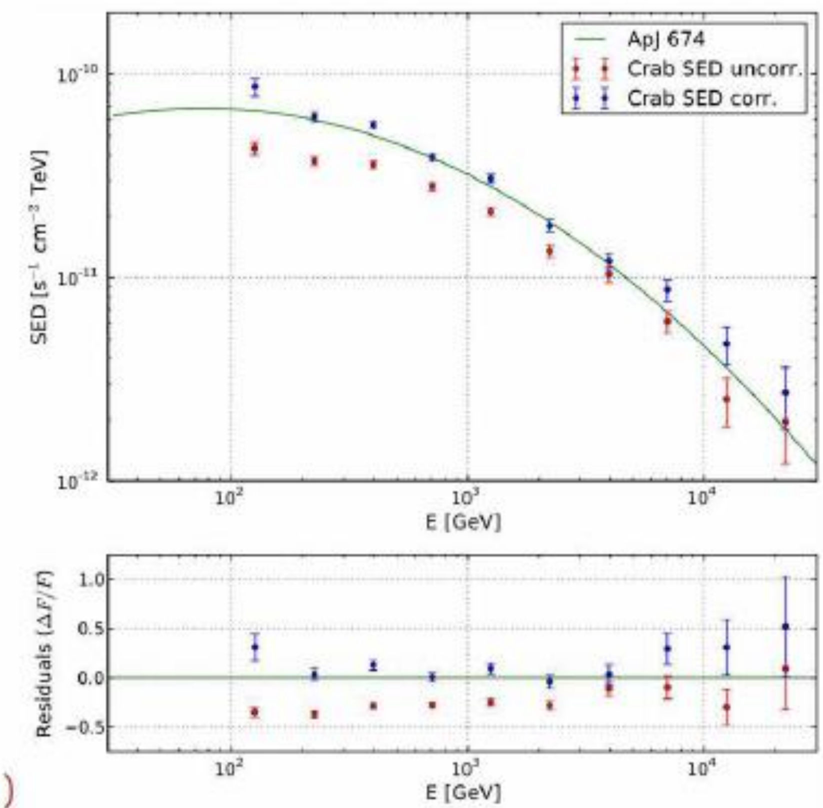


$$\bar{\tau} = \int_0^{h_{max}} \epsilon(h) \cdot T_{aer}(h)\,\mathrm{d}h,$$

$$E_{true} = \frac{E_{obs.}}{\bar{\tau}}$$

Treatment of the instrument response for these events:

→ using instrument response for energy before correction $A(E_{obs.})$



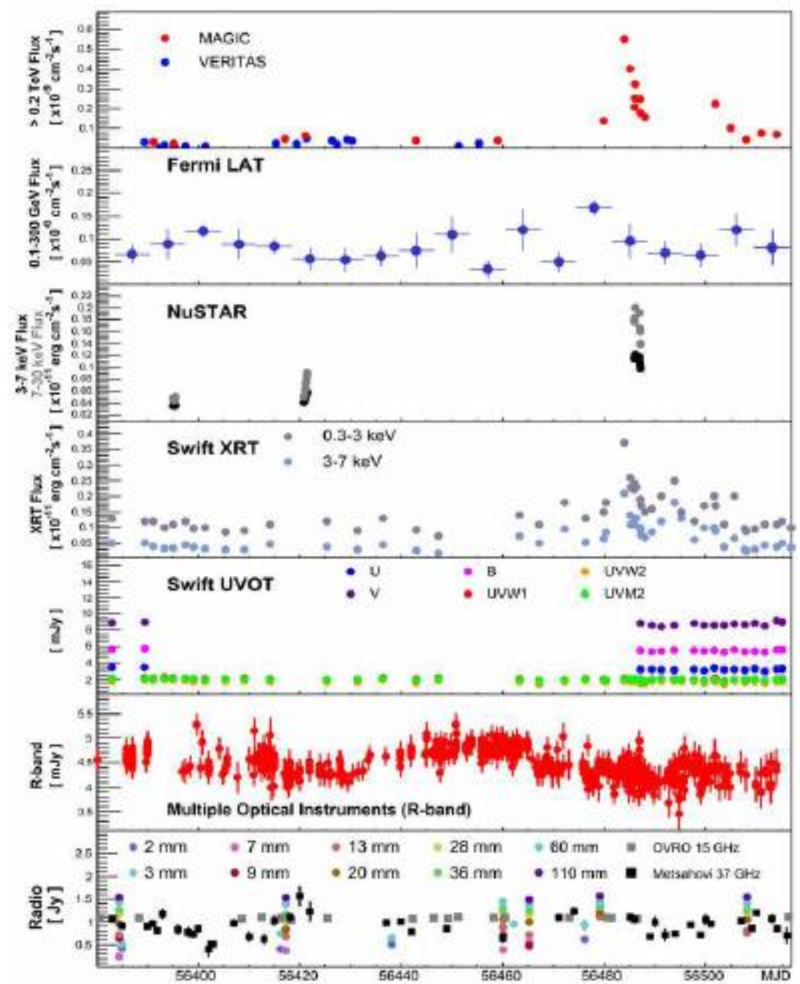
See also: PhD thesis C. Fruck

Applied corrections allow us to expand our science reach

<u>Corrections applied to part of data in two publications:</u>

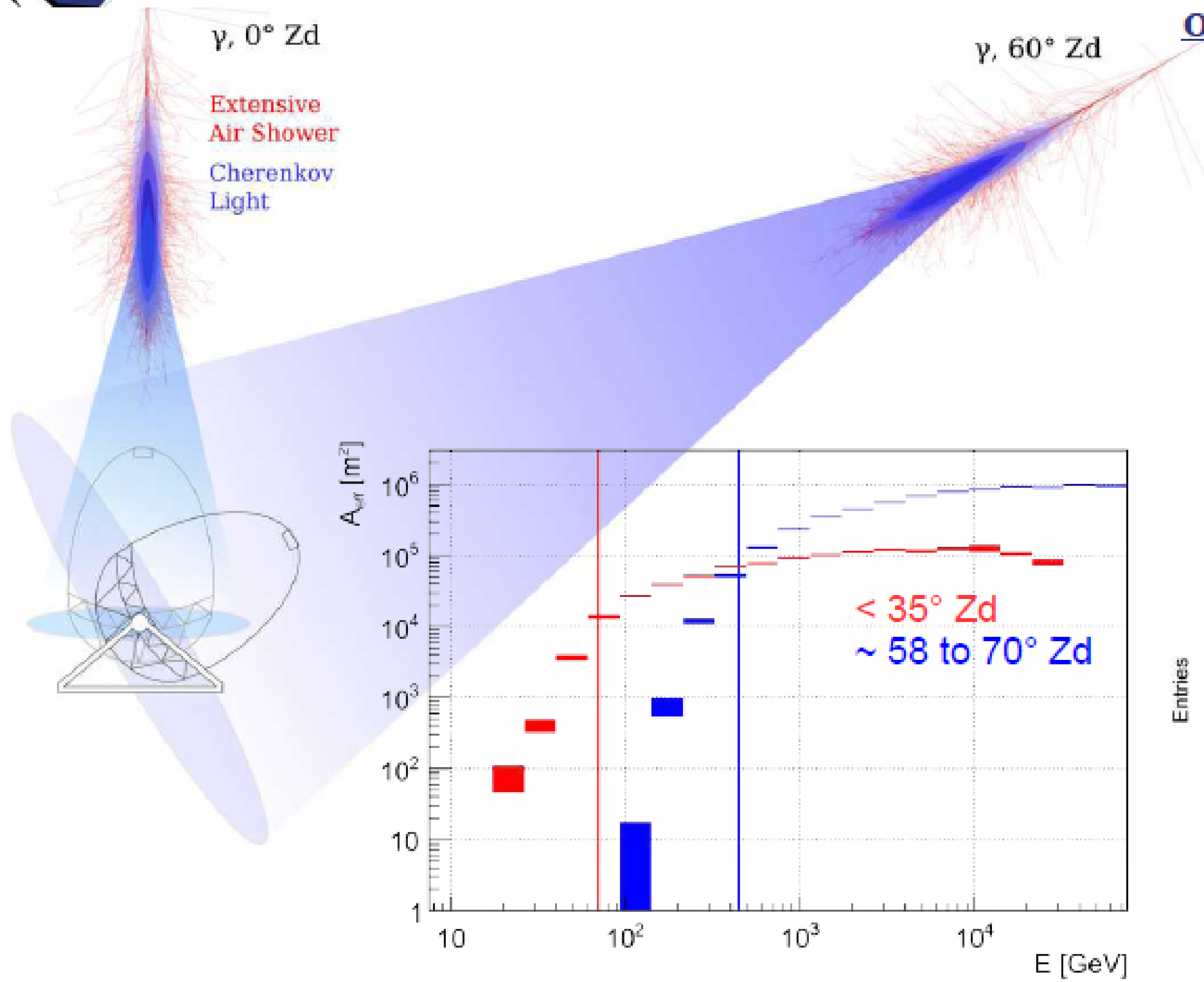
- Mrk501 MWL campaign (Furniss et al, ApJ, 812 (2015) 65)
- V339 Del nova outburst (Ahnen et al. A&A, (2015), 582, A67)

First NuSTAR Observations of Mrk 501 within a radio to TeV multi-instrument campaign:
“ … Using the Light Detection and Ranging (LIDAR) information we could recover 10 of the 17 hr which would have been rejected otherwise.”
(Furniss et al, ApJ, 812 (2015) 65)




Pushing on the
MAGIC horizon

Implications of observing at large Zd



Observing at large Zd:

- Shower travels through more target material at higher altitude

  → light emission starting at higher altitude and larger distances from the telescope

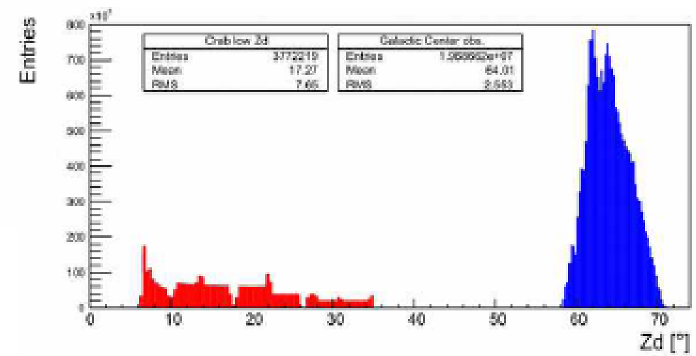
  → stronger adsorption of Cherenkov light

- Distance *d* to the telescopes is increased

  → light pool is more diluted

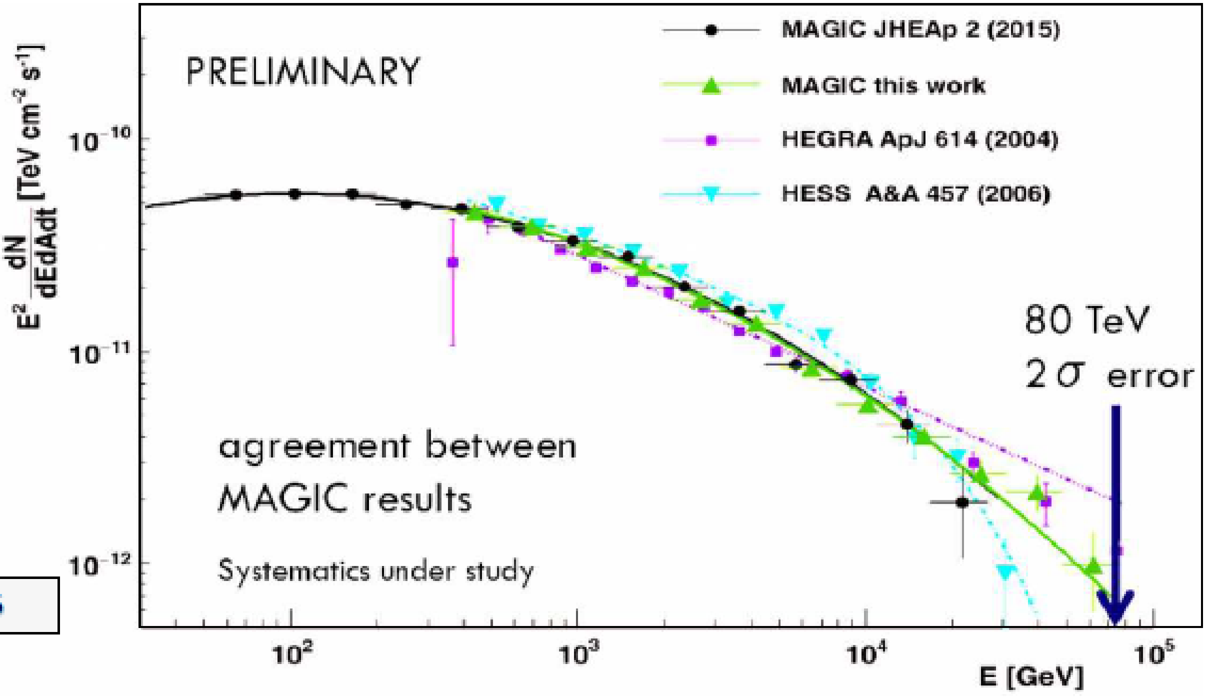
  → more collection area (~d^2)

  → higher energy threshold



Spectrum of the Crab Nebula up to 80 TeV

- Increased collection area at high energies (~ factor 10 above 10 TeV) enabled MAGIC to measure the spectum of the Crab Nebula up to 80 TeV
- Spectrum is compatible with a log-parabola and similar to previous measurements by HEGRA
- Cut-off excluded at 2σ level up to 15 TeV
- Klein-Nishina regime can be studied
- Total observation time of 60 h
- Zd range 50-70 deg

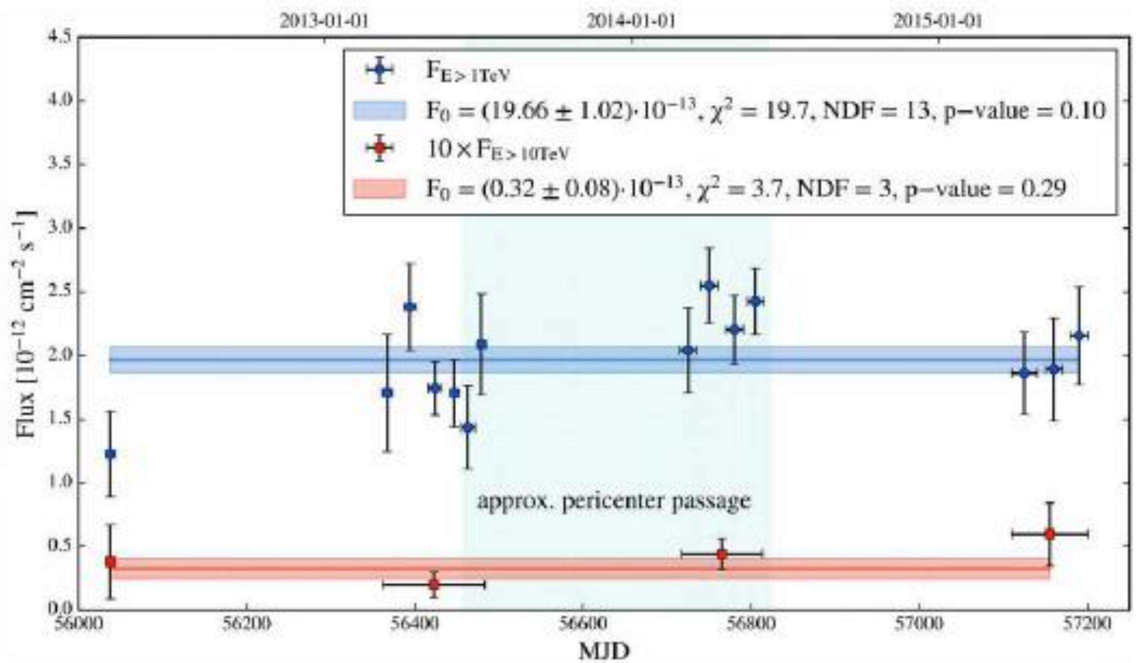


Zanin, R. et al, ICRC 2015

The multi year Galactic Center monitoring project

- Observed by MAGIC 2012/13/14/15
- 67h after very strict quality cuts
- Zd range 58 to 70 deg
- Triggered by pericenter passage of G2
- No variability in TeV (also not in other λ)

Image source: ESO

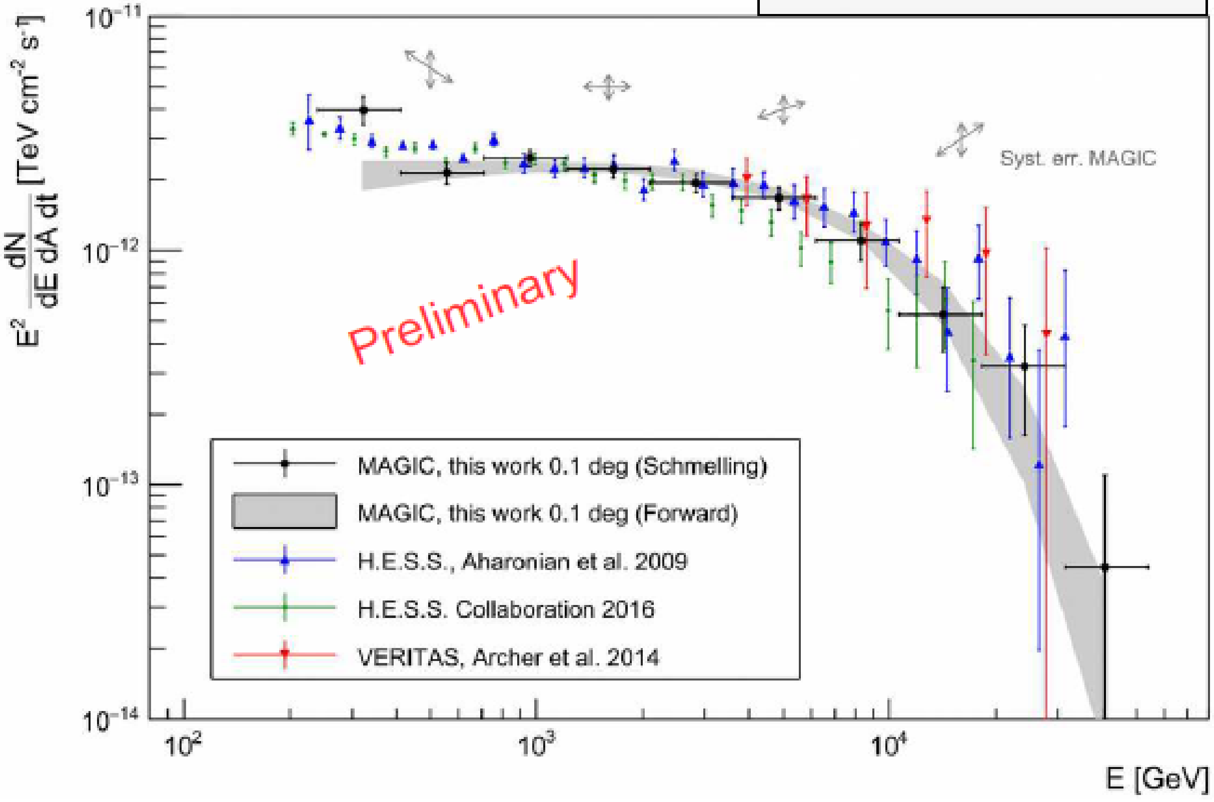


Paper submitted to A&A, see also PhD thesis C. Fruck

MAGIC spectrum of the central source (direction SgrA*)

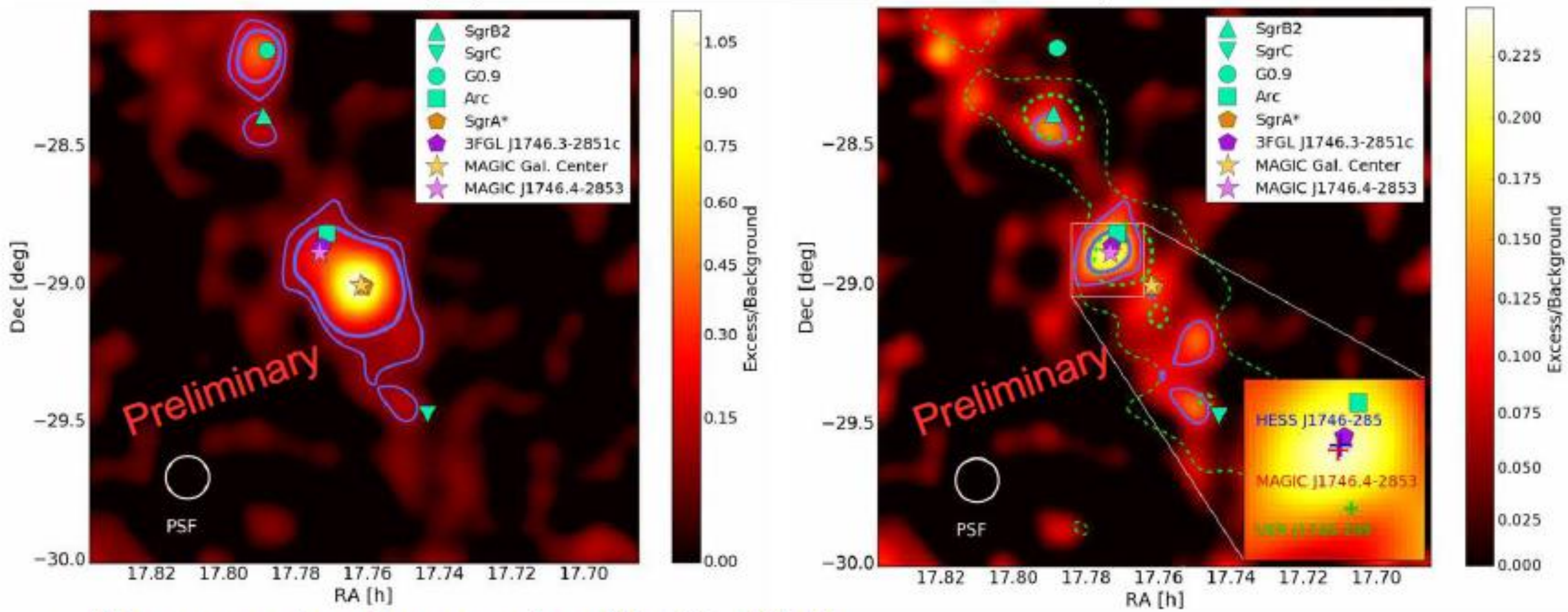
- SED of gamma-rays from within 0.1 deg of SgrA*
- Over more than 2 decades in energy
- Confirming previous measurements by H.E.S.S. and VERITAS
- Spectrum can be described by power-law (index 1.85±0.13) with exponential cut-off at 7.6±2.3 TeV
- Corrected for the migration of events due to imperfect reconstruction of the energy by applying the unfolding method of Schmelling (1994)

Paper submitted to A&A, see also PhD thesis C. Fruck



Morphological study of the 2° x 2° around the GC

Paper submitted to A&A, see also PhD thesis C. Fruck



- Sky maps showing events with E ≳ 1TeV
- Emission from G0.9 and the radio structures SgrB, SgrC compatible with the GC ridge discovered by H.E.S.S.
- Discovered new source of VHE Gamma radiation coincident with GC Arc (reported simultaneously with HESS and VERITAS at the 34th ICRC)

Conclusions

MAGIC observes during low to strong moonlight:

- By adjusting image cleaning, HV and use of UV-pass filters
- Significantly extending the duty cycle
- Allows for unique observational projects (moon shadow)
- At cost of moderately increased energy threshold

LIDAR system for treating data affected by clouds:

- Measuring diff. transmission along line of sight
- Method for correcting energy and est. Aeff
- Increased effective duty cycle (eg. for time critical obs.)

→ First IACT correcting Spectra/SEDs based on LIDAR data

MAGIC can observe at Zd up to 70 deg:

- Shifting the horizon for MAGIC towards lower declination
- Effective collection area is increased by up to factor 10
- Also energy threshold increases by about this factor

→ MAGIC can study the Crab Nebula up to 80 TeV

→ Monitoring Gal. Center for 4 years during G2 passage

→ No variability, SED over > 2 decades, new source (Arc)

Special thanks to Ch. Fruck for helping with slides