FRAM Next Generation at the Pierre Auger Observatory: cloud monitoring in the age of CMOS cameras

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for the Pierre Auger Colaboration

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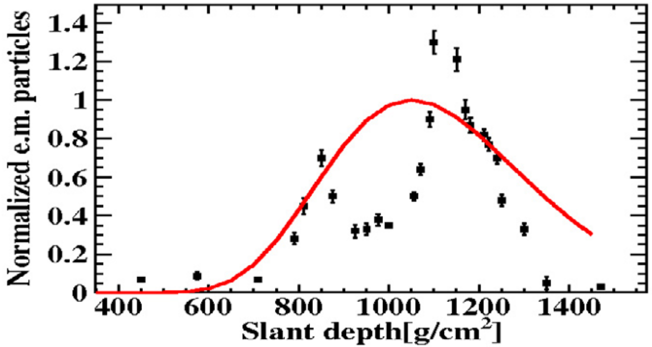
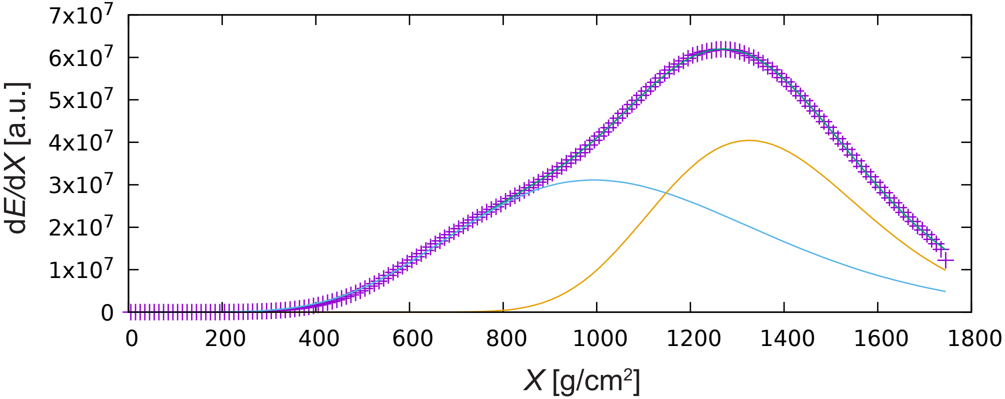
PIERRE AUGER OBSERVATORY

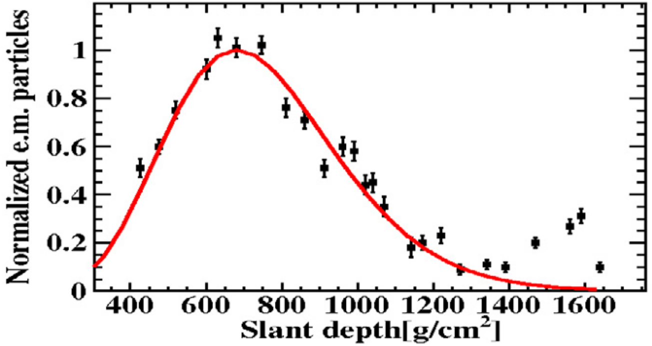
Clouds vs. fluorescence profiles of air showers

- fluorescence profiles
  - energy measurement
  - depth of maximum -> composition

- clouds
  - dip (absorption) or bump (scattering)
  - affect data quality
  - mimic anomalous showers







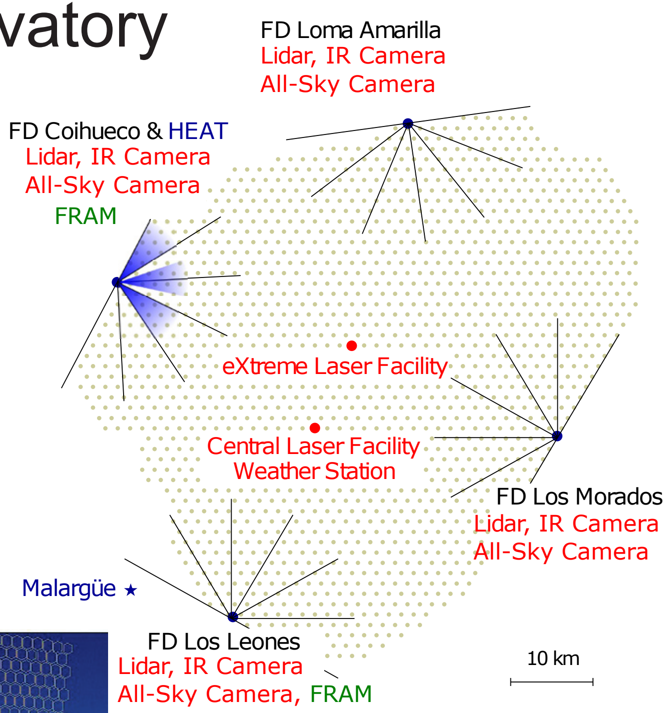
Clouds above the Pierre Auger Observatory

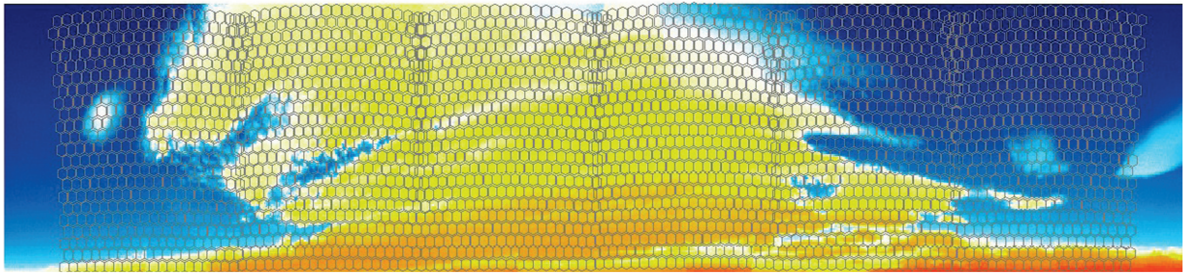
- Lidars at each FD station
    - not in FD field of view

- CLF/XLF, satellite data
    - limited information for FD field of view

- IR cloud cameras
    - pixel-per-pixel coverage in FD field of view
    - discontinued

- new method using FD sky brightness in development



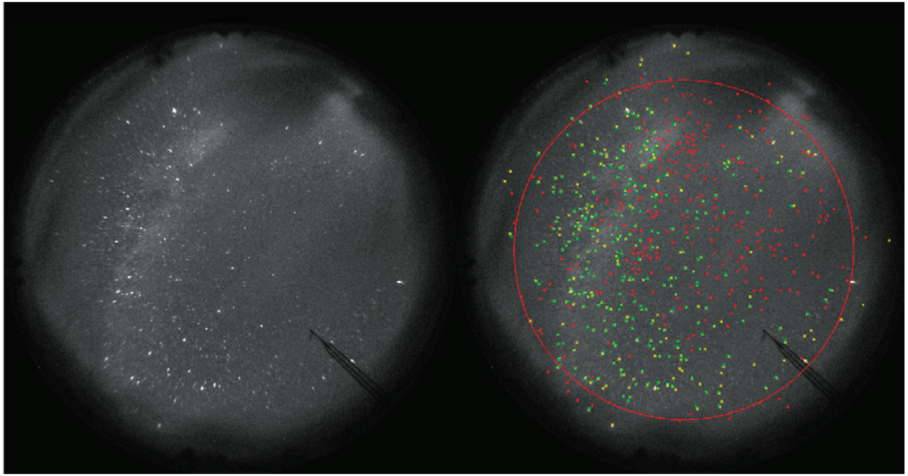


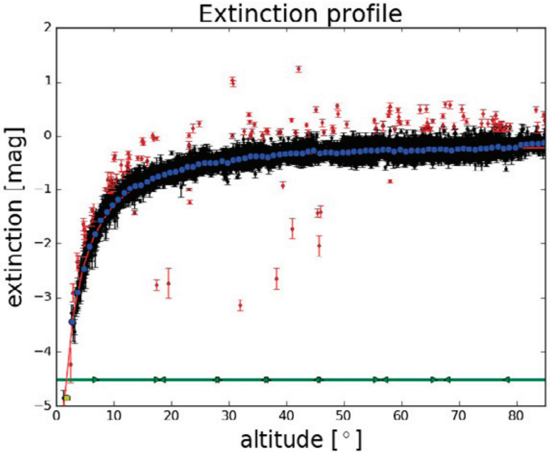
n.b.: FD field of view
2°–30° above horizon (+HEAT)
180° in azimuth

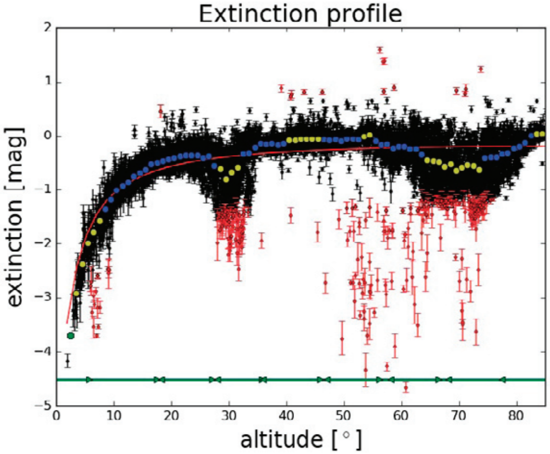
Cloud detection using stars

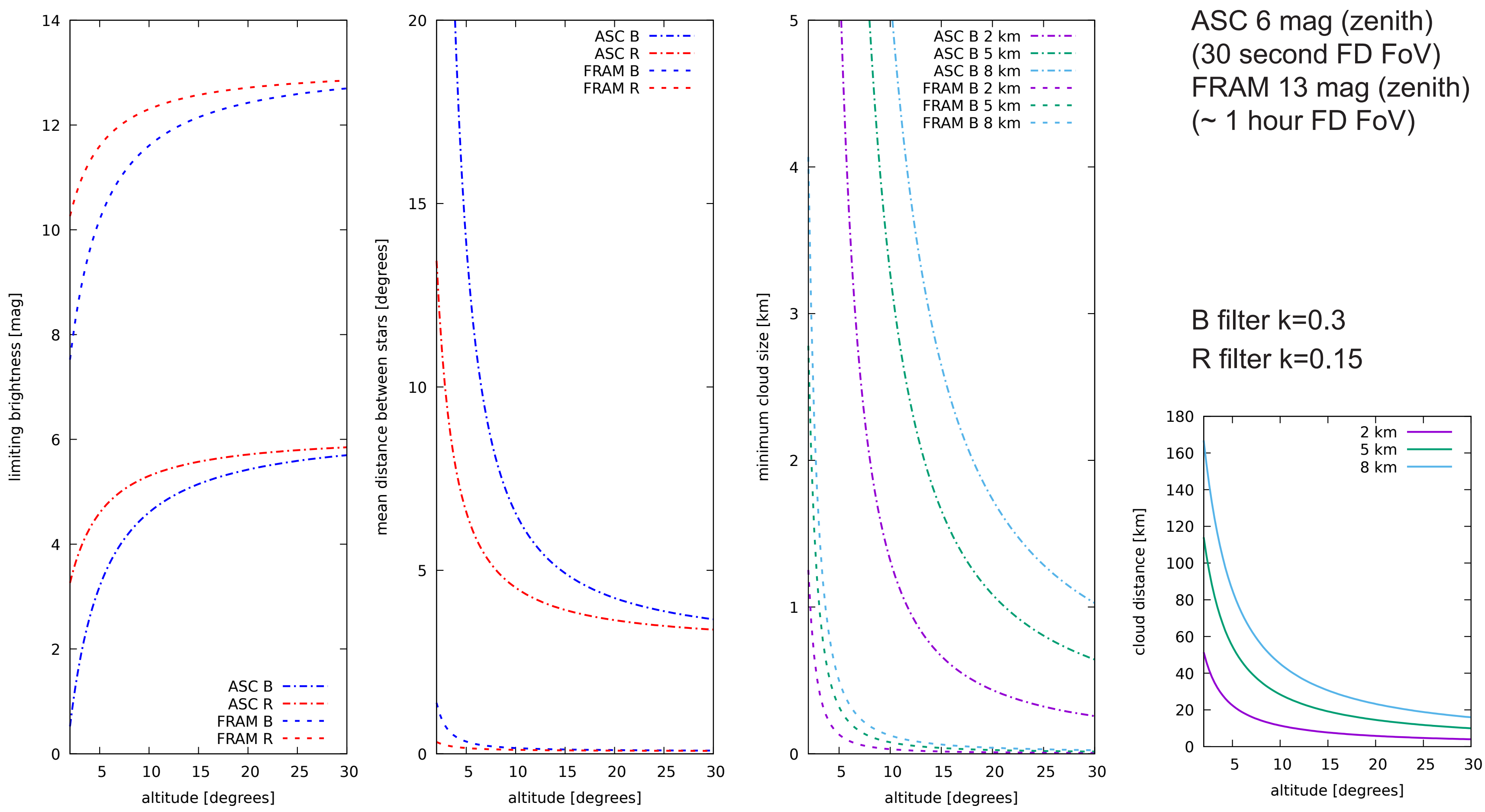
- All-sky cameras: instantaneous full sky coverage but low resolution close to the horizon

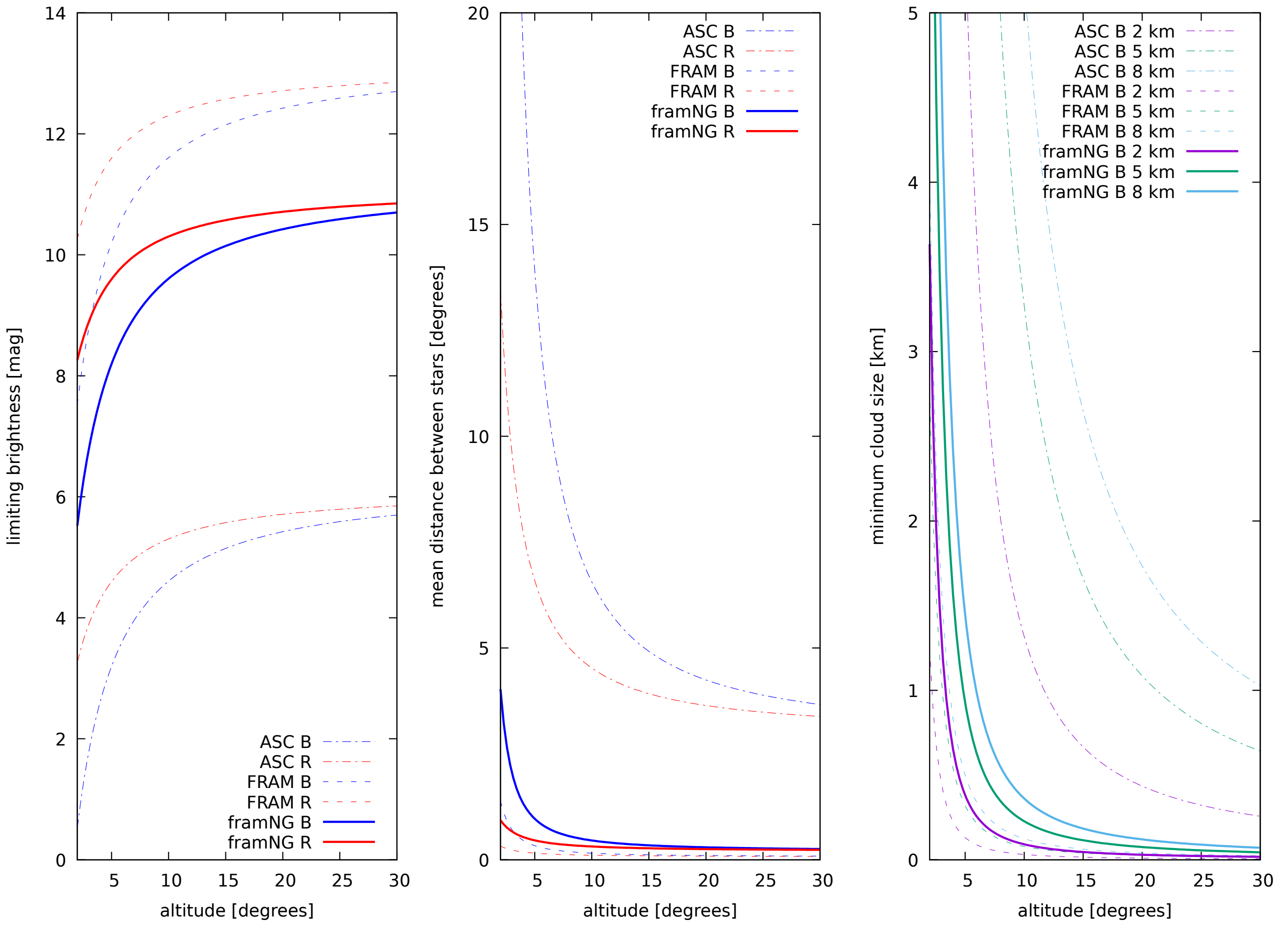
- FRAMs: high resolution, but only 7°×7° field of view
  - triggered on interesting showers to cover apparent path
  - only on 2 out of 4 FD stations





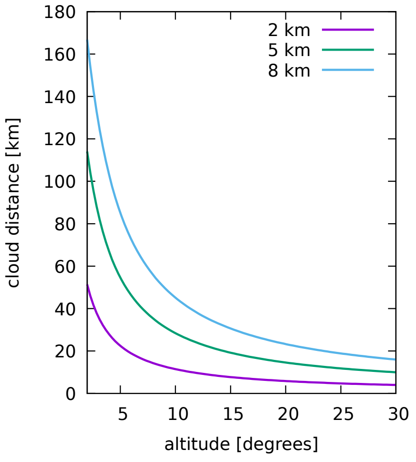



ASC 6 mag (zenith)
(30 second FD FoV)
FRAM 13 mag (zenith)
(~ 1 hour FD FoV)
B filter k=0.3
R filter k=0.15
limiting brightness [mag]
altitude [degrees]
ASC B
ASC R
FRAM B
FRAM R
mean distance between stars [degrees]
minimum cloud size [km]
ASC B 2 km
ASC B 5 km
ASC B 8 km
FRAM B 2 km
FRAM B 5 km
FRAM B 8 km
cloud distance [km]
2 km
5 km
8 km



ASC 6 mag (zenith)
(30 second FD FoV)
FRAM 13 mag (zenith)
(~ 1 hour FD FoV)
framNG 11 mag (zenith)
(30 second FD FoV)

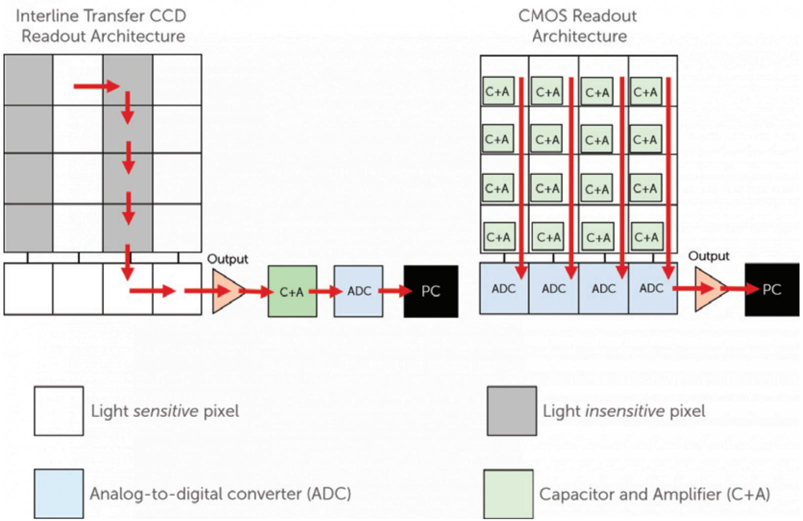
B filter k=0.3
R filter k=0.15



CMOS imaging sensors

- CCD in astronomy since 1970s
    - low noise, good homogeneity
    - long readout times

- CMOS developed 1990s
    - mostly consumer electronics
    - short readout times
    - in astronomy since ~2009



- improved noise and homogeneity to compete with CCD

- time domain applications: rapid optical transients, sky surveys, space debris, meteors ...

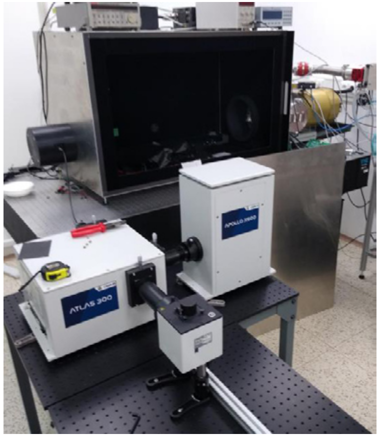
- CMOS taking over lower-end astronomy cameras
    - testing of CCD vs. CMOS at Cohuieco FRAM

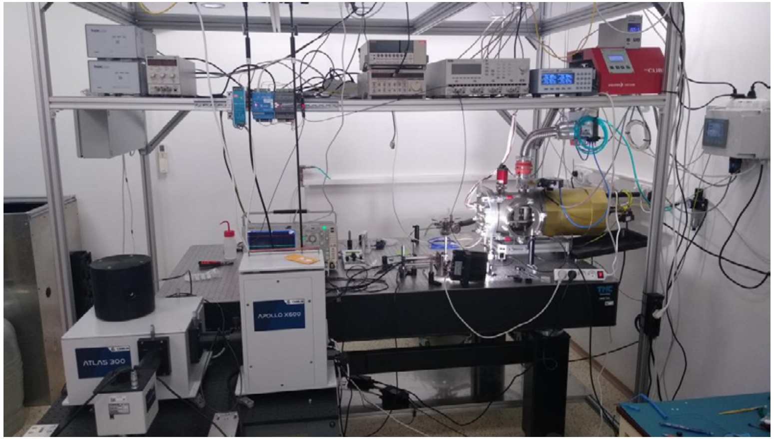
Laboratory for characterisation of photosensors at FZU

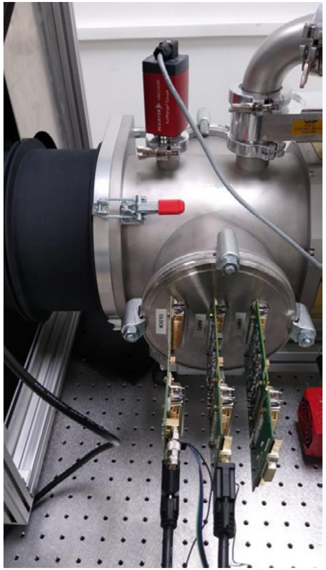
- monochromator, laser, optical table, dark box, vacuum chamber, calibrated diodes, radiation source...

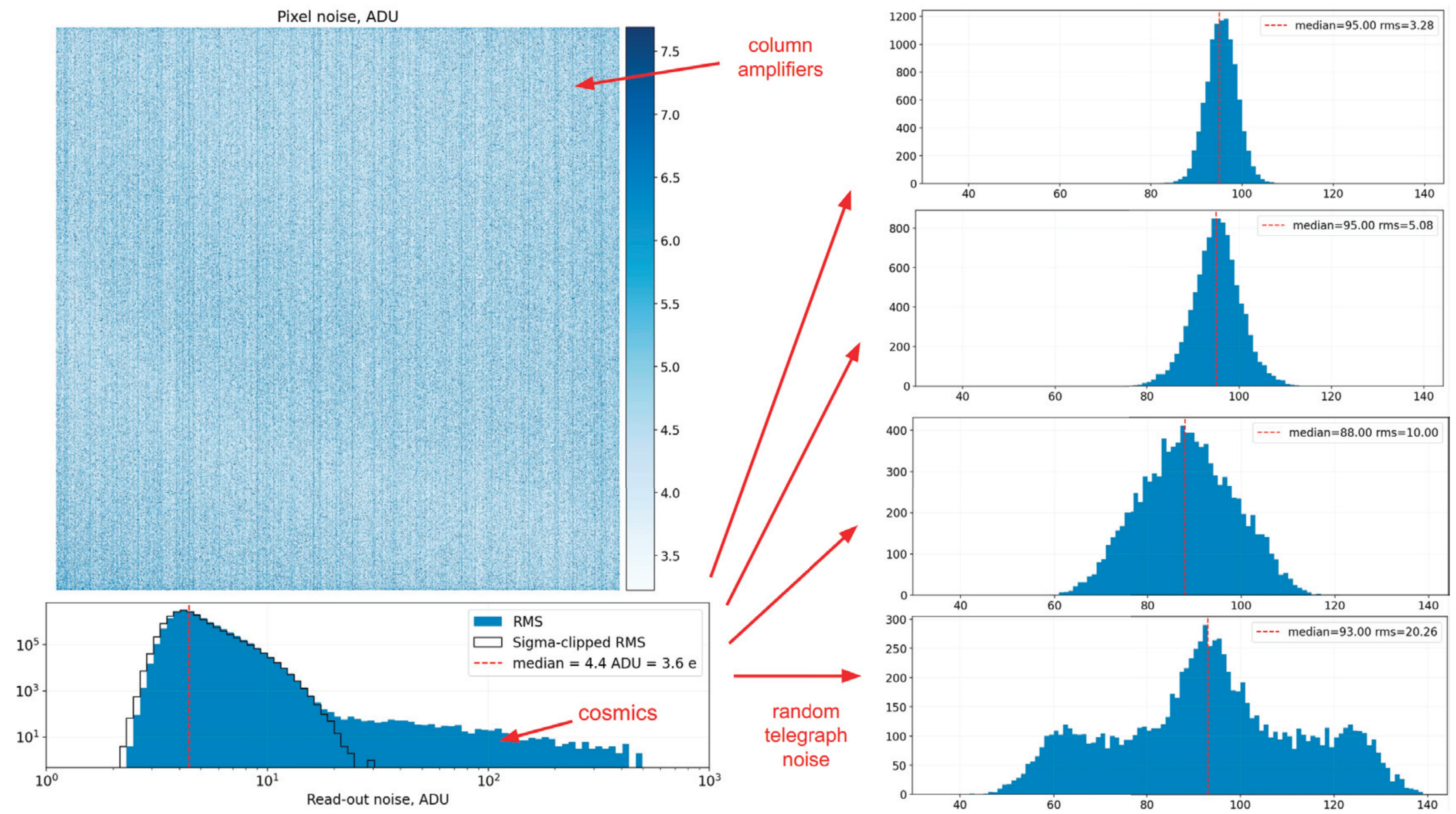
- study linearity, uniformity, low/high gain transition, bias level, gain stability ...

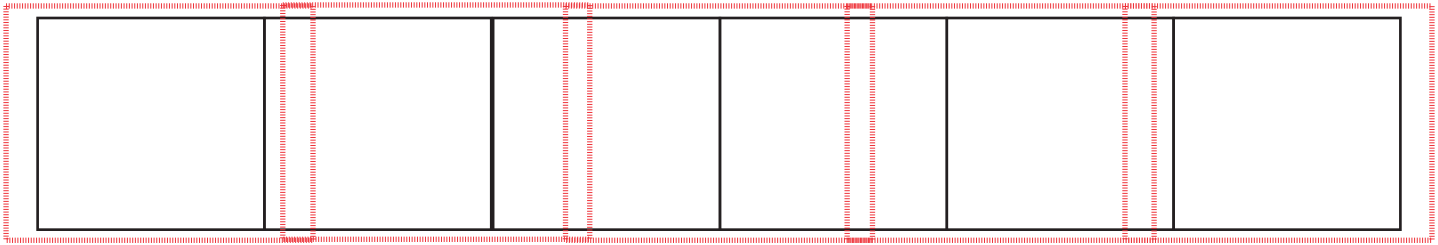
- development of advanced calibration and data processing methods







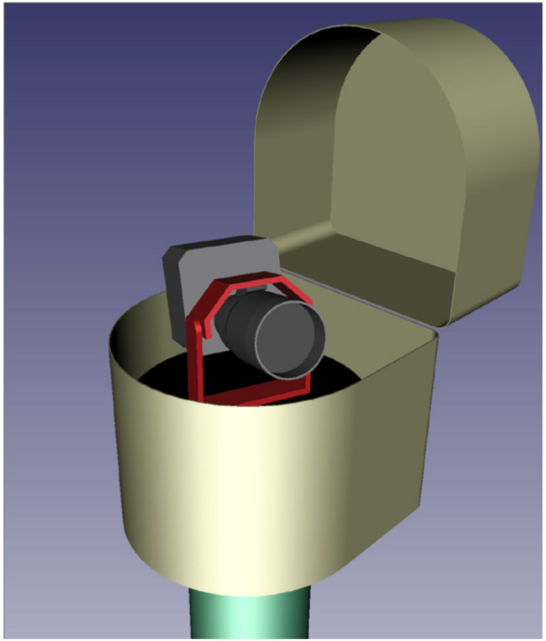

Pixel noise, ADU
column amplifiers
RMS
Sigma-clipped RMS
median = 4.4 ADU = 3.6 e
cosmics
Read-out noise, ADU
random telegraph noise
median=95.00 rms=3.28
median=95.00 rms=5.08
median=88.00 rms=10.00
median=93.00 rms=20.26

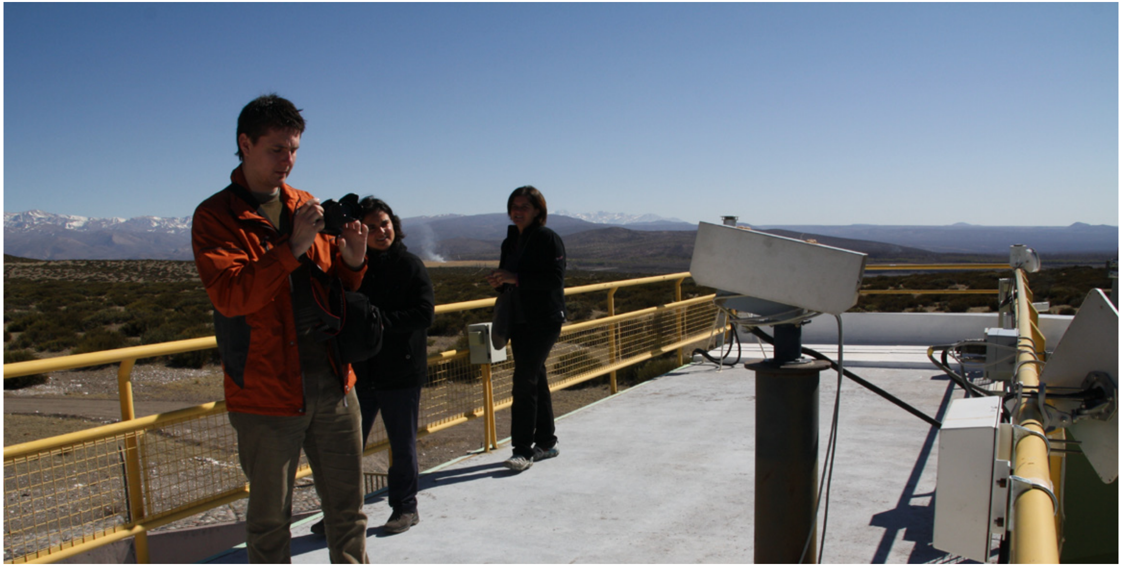


HW example:

- MII CMOS C5A-100M (16bit Sony IMX461 sensor 43.8×23.9 mm)
- full chip readout 0.66 seconds
- Nikon Z 58/0.95 - FoV 40.6°×31°
- 100 megapixel, 13 arcseconds/pixel

Fast readout = short exposures
- 1–3 s, stacking if needed
- no star tracking
-> no equatorial mount





Camera+lens fit in a sphere r = 20 cm
- rotating azimuthal table + altitude movement
    - HEAT + better self-calibration

- camera+lens 5 kg, enclosure max 20 kg (under intensive design)

- targetting FD roof = no extra infrastructure costs

framNG: the last word in star-based cloud monitoring

- a small optical device to monitor clouds in FD FoV using star detection
- can provide full FD FoV coverage twice a minute
- camera/lens/FoV/exposure/filter ... to be optimized (extensive testing in Prague)
- advances in CMOS detectors now allow efficient and affordable implementation
    - camera+lens ~20k EUR (depends on lens choice)
    - enclosure+azimuthal movement ~15k EUR vs. ~50k EUR for classic FRAM

Further possibilities:

- aerosols (VAOD measurement)
- sky background (variance predictions)
- exotic atmospheric phenomena?
- astronomy - variable sources, transients

- raw data volume ~ 1.5 TB/night from 1 framNG (4 framNGs = 1/4 Vera C. Rubin)
    - storage/transfer unrealistic = real-time processing needed for all applications

- cross-checks with FD background method and possibly IR cloud cameras


85 mm/1.8


70 mm/4