New developments in aerosol measurements using stellar photometry

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Aerosols from wide-field photometry

- fit extinction as a function of airmass
- get instrumental parameters simultaneously
- subtract molecular contribution
- can we reach 0.01 precision in VAOD with noninvasive method?

\[ m_{\text{inst}} = M m_{\text{cat}} + Z + k_i A + c_1 (B-V)(c_2 (B-V) + 1) + R_1 r (R_2 r + 1) + k_c A (B-V) + k_{A2} A^2 \]

- \( A \): airmass \quad B-V: color index \( (m_{\text{cat}} = B) \) \quad \( r \): radial position on frame
- \( M, c_1, c_2, R_1, R_2, k_c, k_{A2} \) held constant; \( (Z,k) \)-pair for each scan
FRAMs and data:

- Auger (Argentina): since 2005, suitable for VAOD since 03/2013, dedicated aerosol measurements since 01/2016
- CTA (Chile) since 09/2017
- see Petr Janeček's talk for details
"Moon effect" in both CTA and Auger data

also a small "Malargue effect"
Moon effect = background effect

- sort into two classes "dark" and "bright"
- "upper branch" seems related to a period of higher aerosols
CCD nonlinearity: the cause of background problem?

- Relation between incoming light and ADU counts not linear
  - manifests as non-linear measured/catalog magnitude relation
- Stronger for smallest fluxes
  -> explains correlation with background

![Graph showing non-linearity and correlation with background](image)
**CCD nonlinearity**

- Confirmed by laboratory measurement (using different intensity levels/exposures)
  - now actual darkroom, light source ...

- For installed cameras (Auger/CTA) curves must be determined remotely using moonlit sky/dome interior
Nonlinearity varies between cameras
Data processed with Non-linearity Correction (NLC)

- small spread for bright scans, large for dark scans
  - depends on outside temperature of CCD
Temperature corrections for bias signal

- Small dependence of bias signal on the temperature of camera electronics
- Not stabilized, but measured and fitted
- Important only in presence of NLC
- "Overscan" of dark areas of CCD chip

implemented: bias level for each image

\[
\text{mean bias frame [ADU]} = \begin{cases} 
0.006x^2 + 0.428x + 162.3 & \text{WF4} \\
-0.003x^2 + 0.685x + 551.5 & \text{WF6} \\
0.011x^2 + 0.38x + 508 & \text{WF7}
\end{cases}
\]
Corrected bias + non-linearity = almost perfect!
Realistic stellar spectra and molecular subtraction

• B-V dependence fitted on a set of spectra
  - good $k_c$ agreement (WF4: data 0.017, model 0.019)
  - ready to include molecular absorption for V and R

$T = 4\,000\,\text{K}$

$T = 10\,000\,\text{K}$
Dependence of VAOD on choice of cuts on stars

old analysis

new analysis

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How to choose the cuts?

• B<6.5 mag overexposed (lower exposure? very few stars...)
• including stars B>10 does not help much (Tycho2 errors)
• including airmass >8 does not help much (hard to see stars)
  - @ airmass 8 stars 7 times fainter (need for dynamical range!)
• cut on apparent, not catalogue brightness? (possible systematics in star populations/catalog?)
• largest known systematics on VAOD (0.005)
Sun/Moon Photometer campaign 03–05/2017 @ Auger

- Absolutely calibrated
  = one direction
- Unc. <0.01 day, <0.04 night
  - Moon illumination issues
- Calibration in GSFC

- Bad weather, very small data sample
- Only a few overlapping points for same Moon phase from different cycles
Sun/Moon Photometer @ CTA

- concurrent measurements 11/2017-07/2018 (and continue)
- FRAM outliers cut (see Petr's talk)
- 68 % of differences within 0.02
- Photometer calibration highly preliminary!
Moon phase correction using FRAM data?
Precision of measurements

- Statistical error of single measurements:
  - Auger 0.003–0.008
  - CTA 0.002–0.004 (larger FoV)

- Systematics? Known: ~0.007
  - 0.003 from molecular absorption (use MODTRAN/GDAS)
  - 0.003 from freedom in fitting the telescope parameters
  - 0.005 from the choice of cuts on maximal airmass/magnitude
  - ? from system spectral response
  - ? from possible trends in stellar properties/catalogs
  - ? from bias instability
  - ? from star rejection algorithm
  - ? from residual cloud contamination
  - what is the outlier effect on CTA?

- Ultimately limited by Tycho2: APASS project abandoned? GAIA broad bandpasses unsuitable...