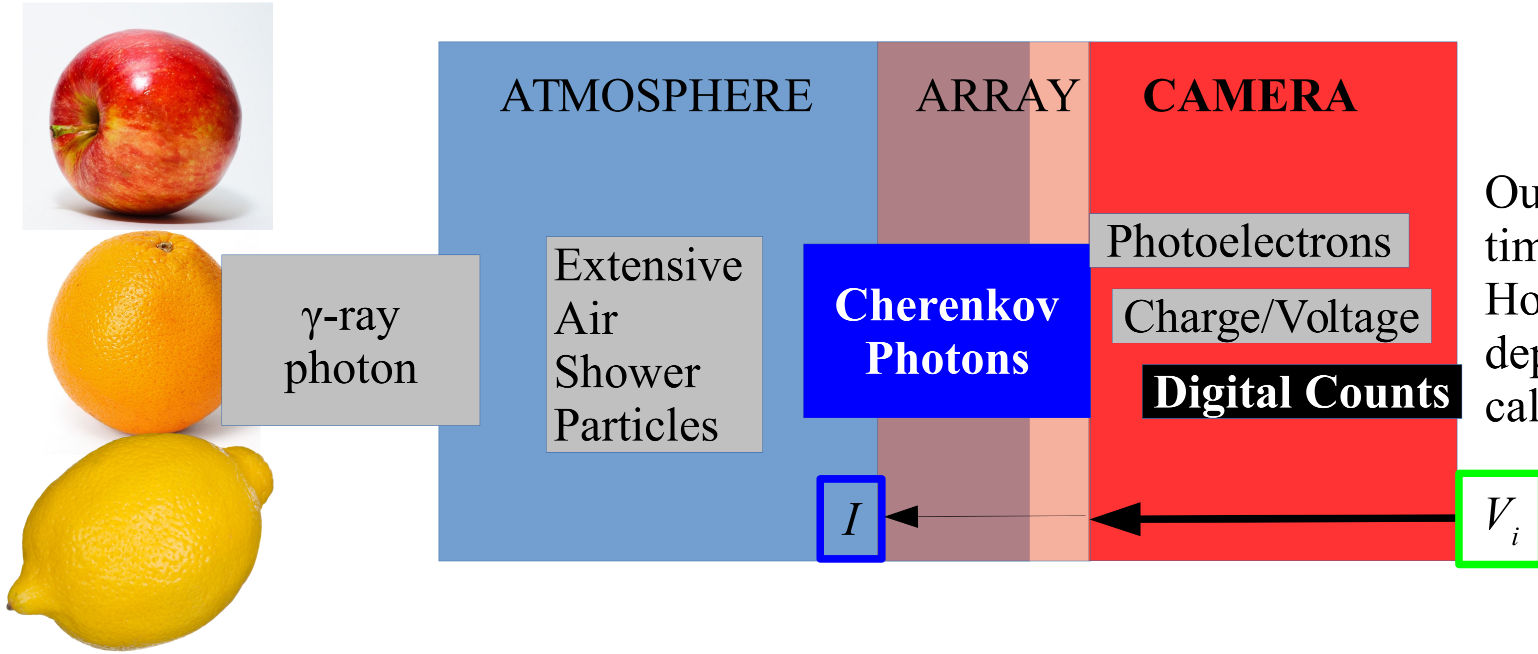
Array Calibration:
Overlap with Camera Calibration



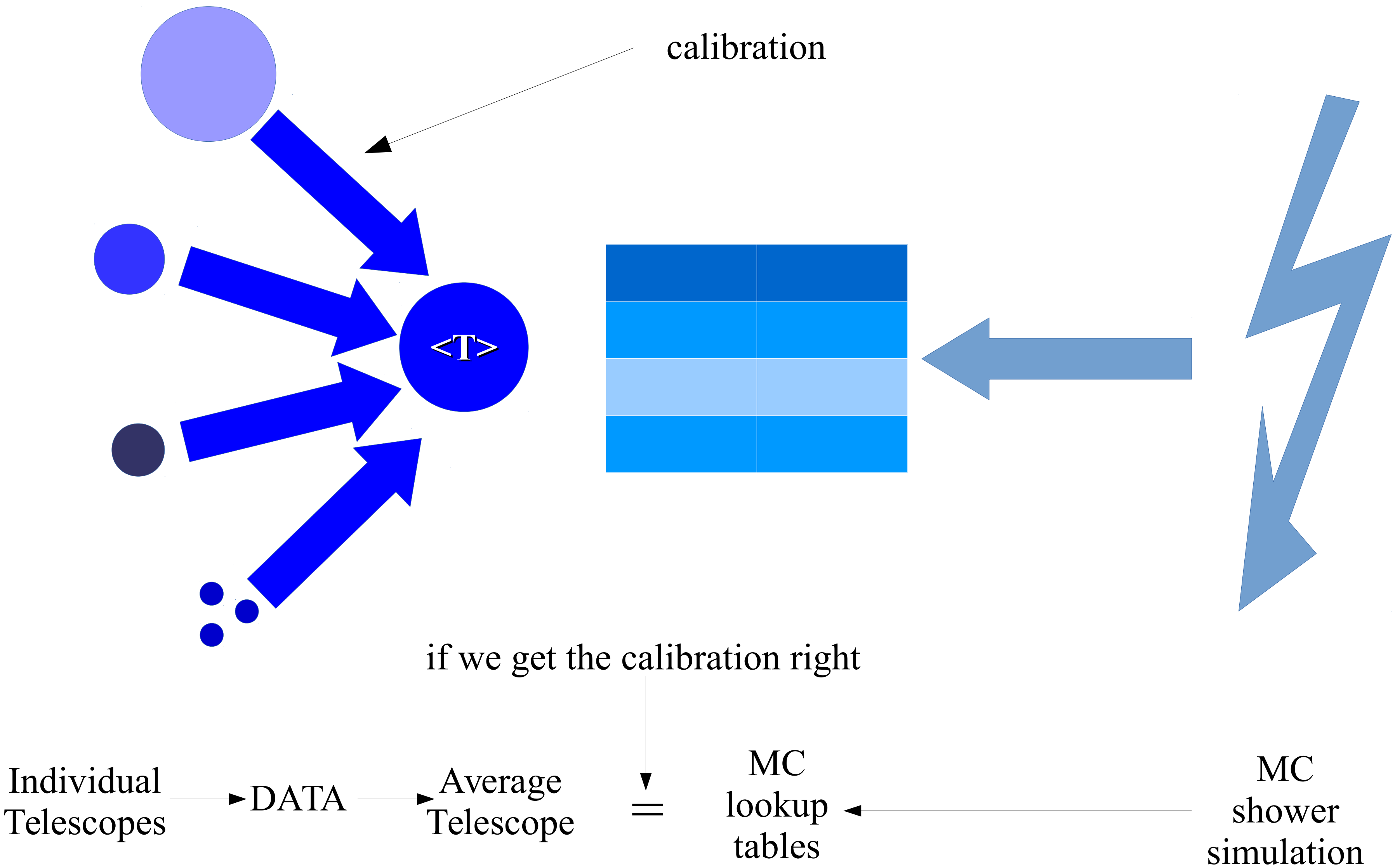
Our journey is to go back in time
How accurate the tale told depends on how accurate the calibration of the steps

A-PERF-2050 The systematic error on the measurement of the absolute intensity (i.e. photons per square metre) of the Cherenkov light (post-calibration) at the position of each telescope must be <8%.

A-PERF-2060 The goal systematic error on the measurement of the absolute intensity of Cherenkov light at the position of each telescope is 5%.

The conversion between Cherenkov photon density to a measured output in digital counts from a pixel is a combination of many multiplicative efficiencies and additive factors.

Cartoon of the data analysis flow process



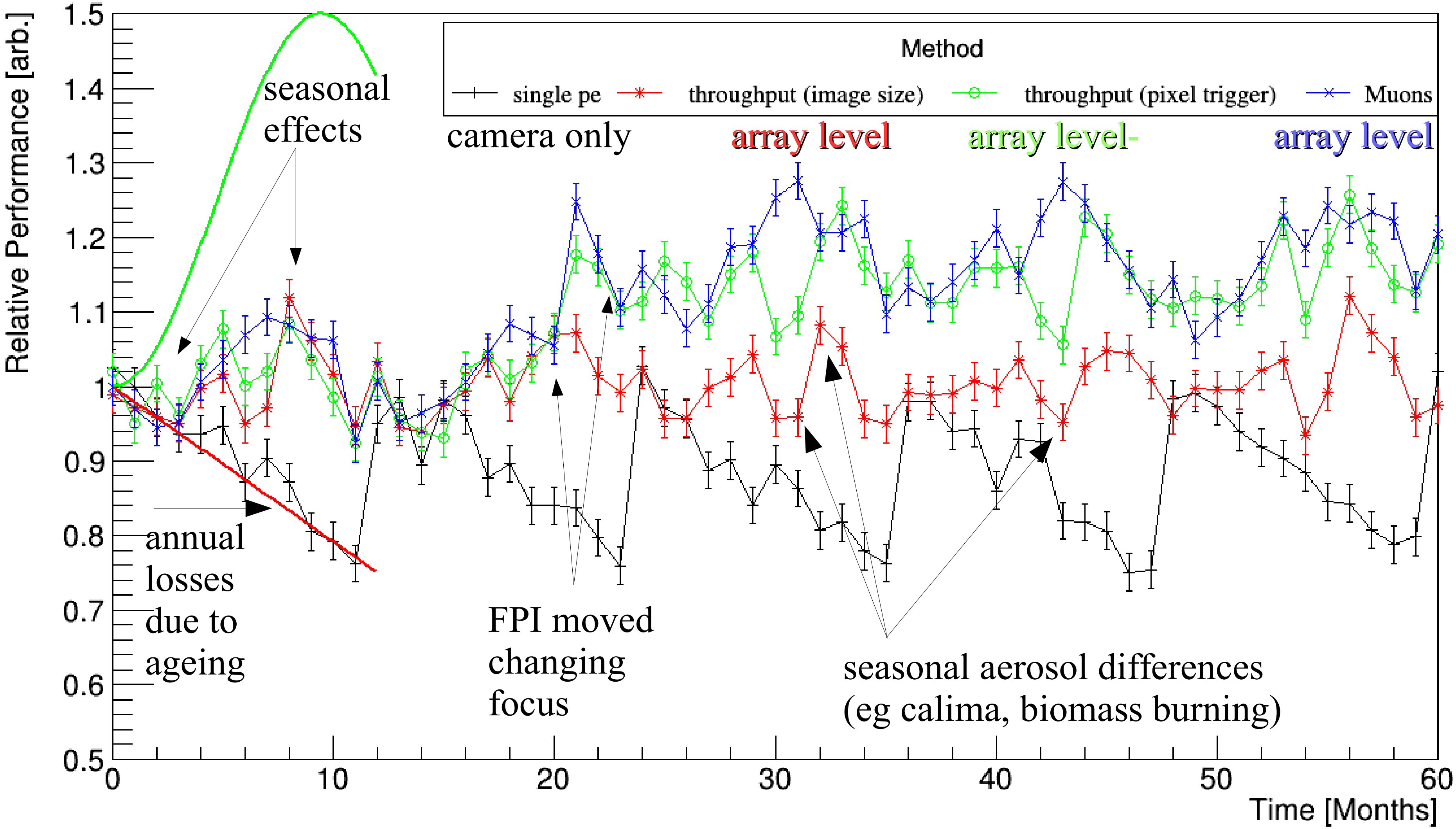
$$Q_i(B,t)=\iiint_{\Omega,\lambda} \overbrace{\underbrace{B(\Omega,\lambda,t)\cdot A_{eff}\cdot R_{mir}(\lambda)\cdot T_{F,i}(\Omega,\lambda)\,\mathrm{d}\Omega}_{\text{photon transmission efficiency}}}^{\text{Up to the Camera}}\cdot \overbrace{\underbrace{\eta_{\mathrm{QE},i}(\lambda)\cdot\eta_{\mathrm{coll},i}(\lambda)\,\mathrm{d}\lambda}_{\text{photon detection efficiency}}\cdot\underbrace{G_{S,i}\cdot G_{\mathrm{el},i}(t)\cdot \mathcal{T}(t-t')\,\mathrm{d}t'+p_i}_{\text{photon conversion efficiency}}}^{\text{Within the Camera}}$$

Q – integrated charge
B – Cherenkov photons
λ – wavelength
Ω – solid angle
t – time
A – mirror area
R – reflectivity
T – transmission through cones, window, etc
η_{QE} – quantum efficiency
η_{coll} – collection efficiency
G – gain in the sensor (s) and the digitising electronics (el)
$\mathcal{T}$ – electronic transfer function
p – pedestal

neglecting temperature effects, angular dependence, polarisation dependence,...

The calibration "constants" are unlikely to be constant in time.

Where possible it is a good idea to have multiple/redundant methods to provide cross-checks and estimate the systematic uncertainty



The camera calibration can be broadly split in to two categories

Real time calibration – nightly/weekly data available from on camera/telescope devices for immediate corrections to observation data

Long term monitoring – specialist devices taking less regular (monthly/yearly) measurements for input to MC simulations

Class (a) calibration:

- Pixel baseline & variance
- Flat-fielding

best measured with in-situ devices

Class (b) calibration:

- Photon Detection Efficiency:
  - Wavelength dependence
  - Collection Efficiency/Fill Factor
  - Angular dependence
- Photon Conversion Efficiency
  - photodetector gain
  - electronics gain
  - excess noise factor
- Pixel Timing
  - Charge Integration Window (where applicable)
- Event Timing

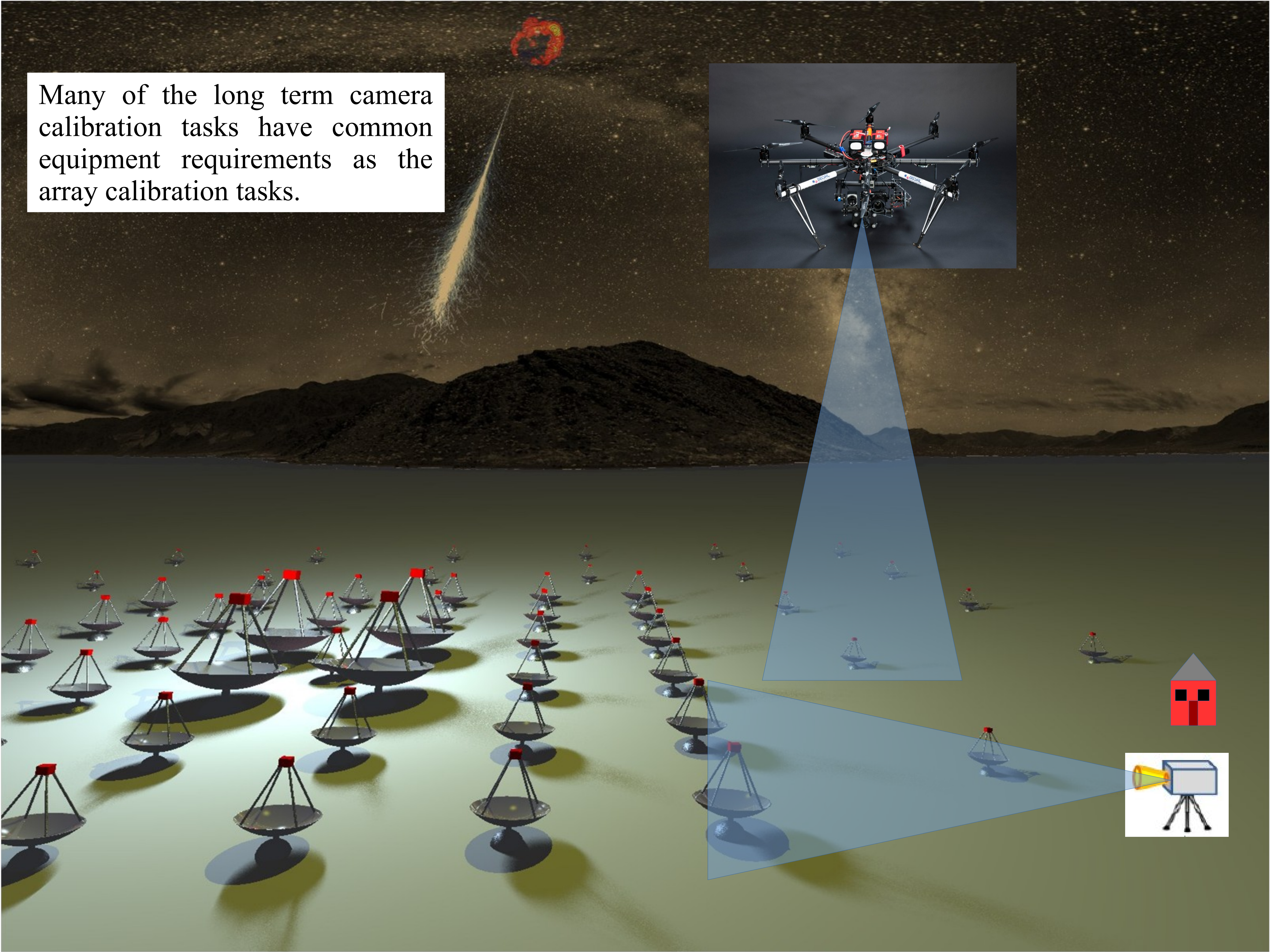
can be measured in the lab., with a few remote devices, eg **illuminator** or **octocopter**, or from known shower observables, eg muons.

CCF provides guidelines on calibration strategies to meet CTA requirements and surveys the camera team's solutions to see where common technology can be shared to reduce replicated effort.

To get calibrated data and from there reconstructed photon parameters we need to provide DATA/MC with methods/algorithms/values for the following:

- Pixel Waveform Integration
- Pixel Dark Baseline
- Pixel NSB Pedestal
- Dependency Pixel PhotoDetectionEfficiency vs Wavelength
- Dependency Pixel PDE vs Incident Angle
- Pixel Photon Conversion Efficiency: ADCPe ration determination
- Pixel Photon Conversion Efficiency: ENF determination
- Pixel Photon Conversion Efficiency: Linearity Correction
- Pixel Photon Conversion Efficiency: Cross-Talk Correction
- Camera Intensity Flat-Fielding Correction
- Camera Timing Flat-Fielding Correction
- Camera Excluded Pixels Determination

Some of these already have defined requirements, some need requirements defining such that we know when the array is meeting performance requirements, or when we need to intervene to get it back to meeting requirements.


Many of the long term camera calibration tasks have common equipment requirements as the array calibration tasks.

Requirements for high performance light flasher systems

- Available to characterise telescopes at longer intervals (~once per year)
- Combination of pulsed and DC light
- Pulsed light (Cherenkov light characterisation):
  - selectable wavelength over range of sensor sensitivity
  - selectable intensity over range of camera linearity
    - step size of ~1.5 in intensity sufficient
  - pulse length should match Cherenkov pulse length
  - relative light level should be calibrated with precision of better than 3%
  - absolute light level should be calibrated with accuracy of better than 5% (eg by calibrated photodiode)
  - standard interfaces to mount, align and trigger the flasher system should be defined
  - built-in battery and wireless control would increase flexibility for a remotely placed system.
- DC light (NSB characterisation):
  - selectable wavelength over range of sensor sensitivity
  - adjustable intensity up to saturation of detectors or bright (full) moonlight equivalent.

To be covered in the afternoon

Discussion

- What calibration is needed? → guidelines
- What instrumentation needed?
- What requirements needed / requirements modified?
- What MC needs and what MC is needed?