Astrometry and Photometry for Images of All-sky Cameras with KLCAM

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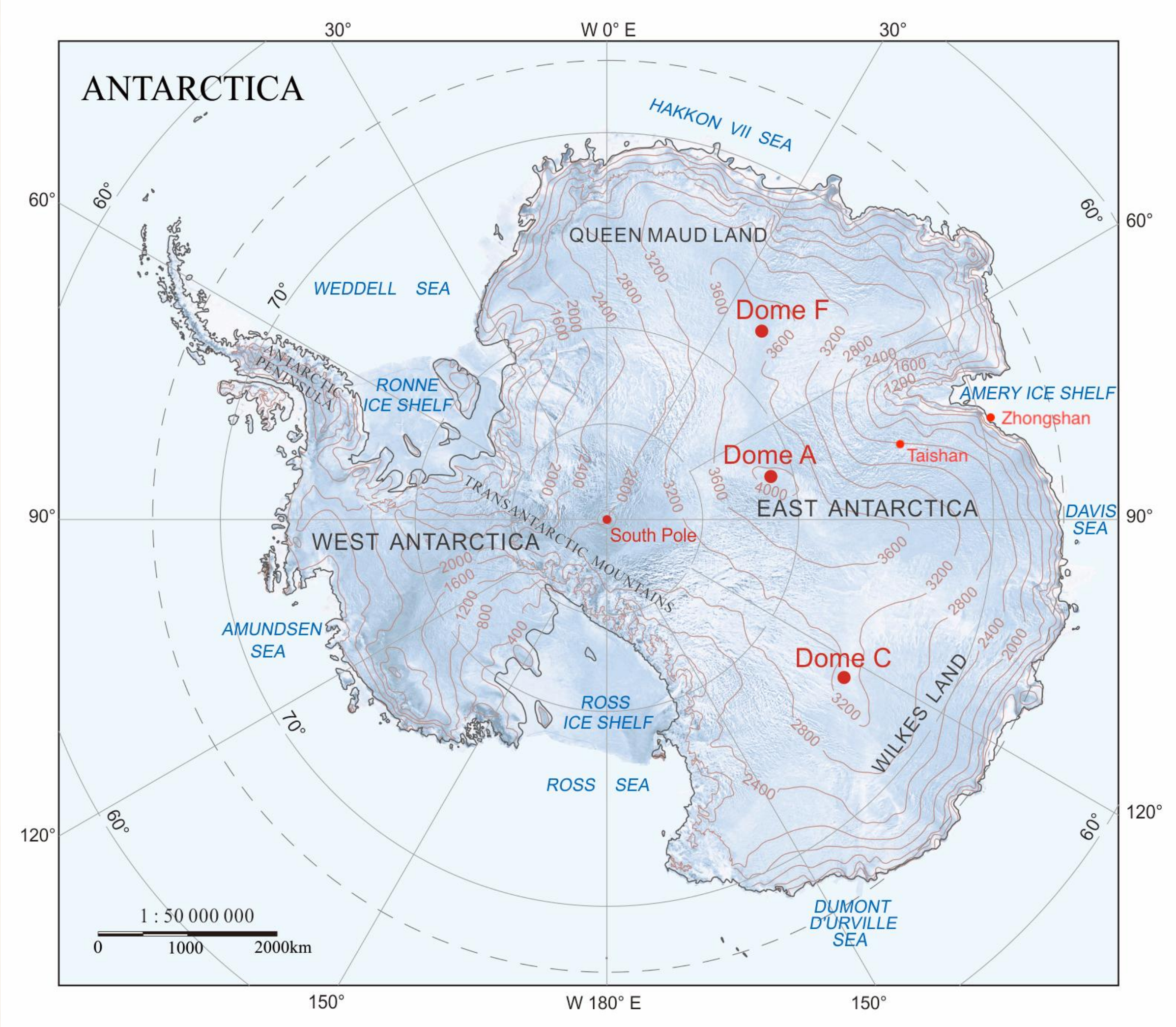
Outline

- Introduction
- Instrument
- Astrometry and Photometry
  - Astrometry
  - Photometry
  - Result
- Conclusion

Introduction：

Antarctica Plateau

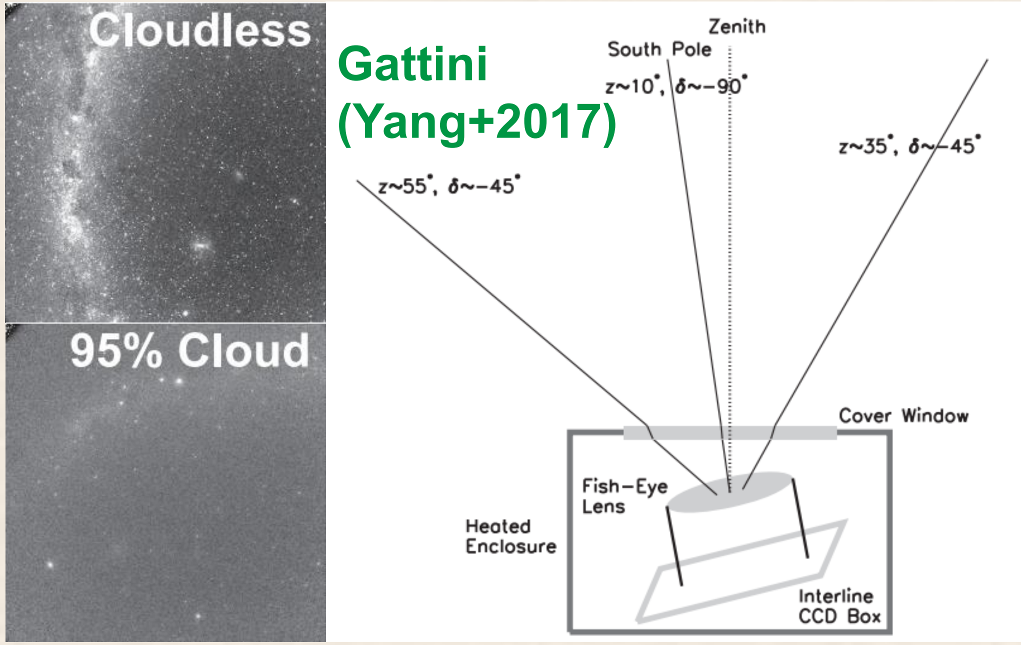
- Dome A:
  - highest plateau in Antarctica
  - 4093m elevation
- Advantages in Observation:
  - Stable atmosphere
  - Dry and cold air
  - Polar night
  - …



Introduction

Cloud and Aurora in Dome A:

- CSTAR (20 square deg):
  - 67% Photometric night (Zou et al. 2010)
  - 2% Aurora (Zou et al. 2010)
- Gattini (90° × 90°)
  - 62% Photometric night (Yang et al. 2017)
  - 50% Aurora(Sims et al. 2012)
- HRCAM (All-sky):
  - Decommissioned



CSTAR Cloud Analysis (Zou+2010)
Dome A vs. Mauna Kea

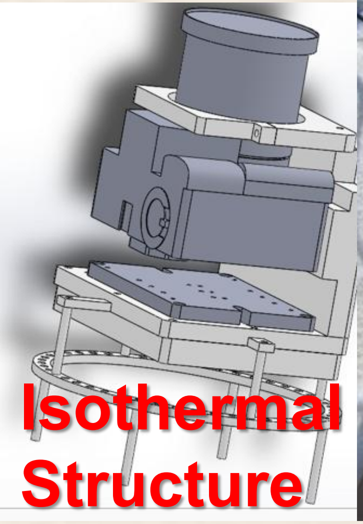
Mauna Kea (Gemini)			Dome A
Cloud Cover	Extinction (*V*)	Fraction	Fraction
Any other usable	>3	10%	0
Cloudy	2–3	20%	2%
Patchy cloud	0.3–2	20%	31%
Photometric	<0.3	50%	67%

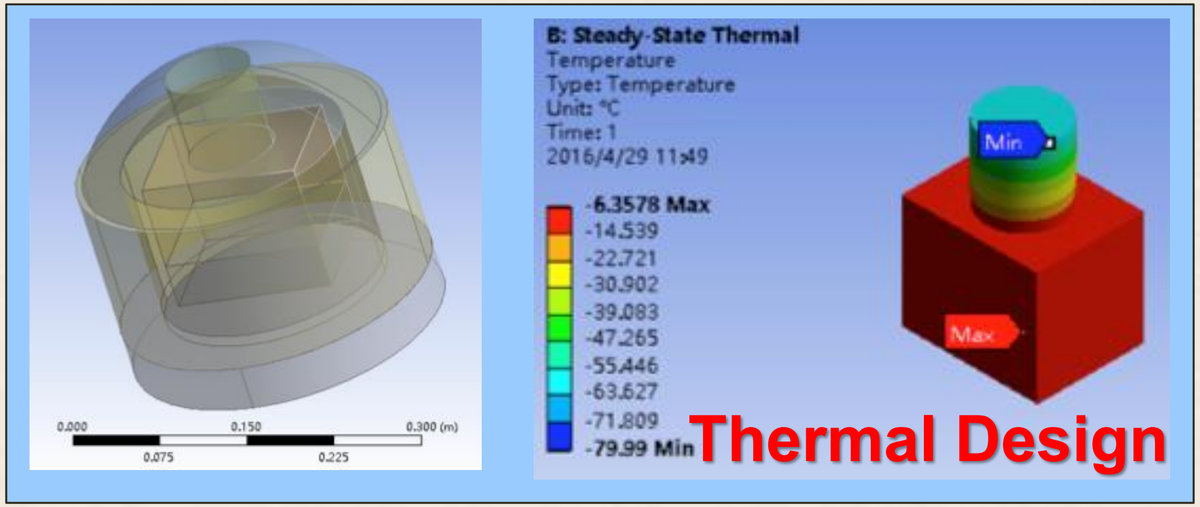
All-sky Cloud and Aurora Required

Instrument

KunLun Cloud and Aurora Monitor

- KLCAM Optical System:
  - Camera: Canon 100D/200D, 3.5k x 5k
  - Lens: Sigma 4.5mm f/2.8 fisheye
  - Control: Inside arm-based computer
  - Powered by PLATO-A (Ashley 2010)
- KLCAM Thermal design:
  - Work perfectly under -80℃
  - heat flow to top, prevent frost/snow
  - Active thermal control system
    - 8W+8W





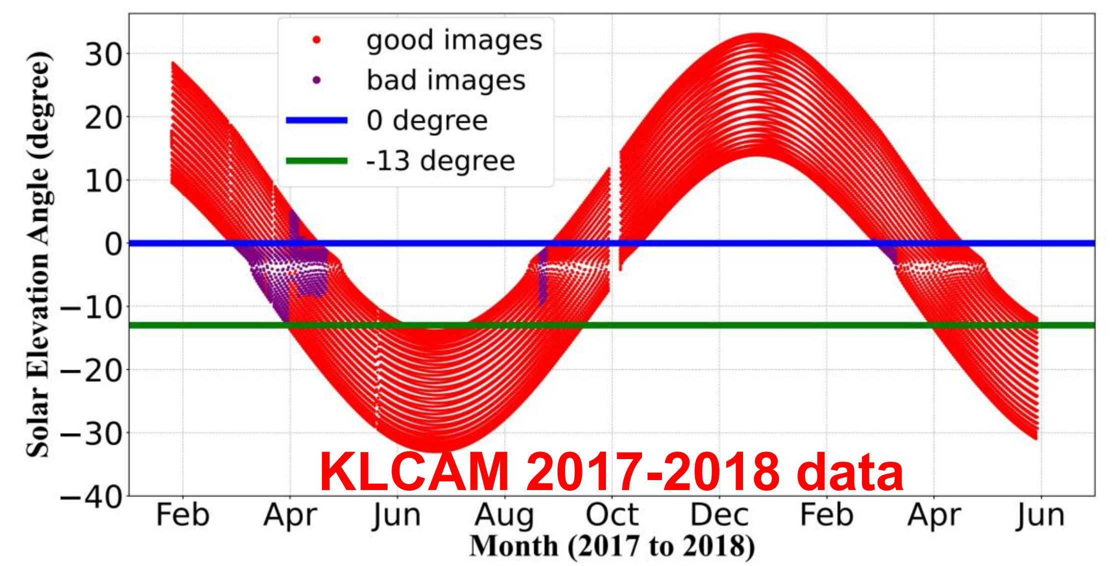
Instrument

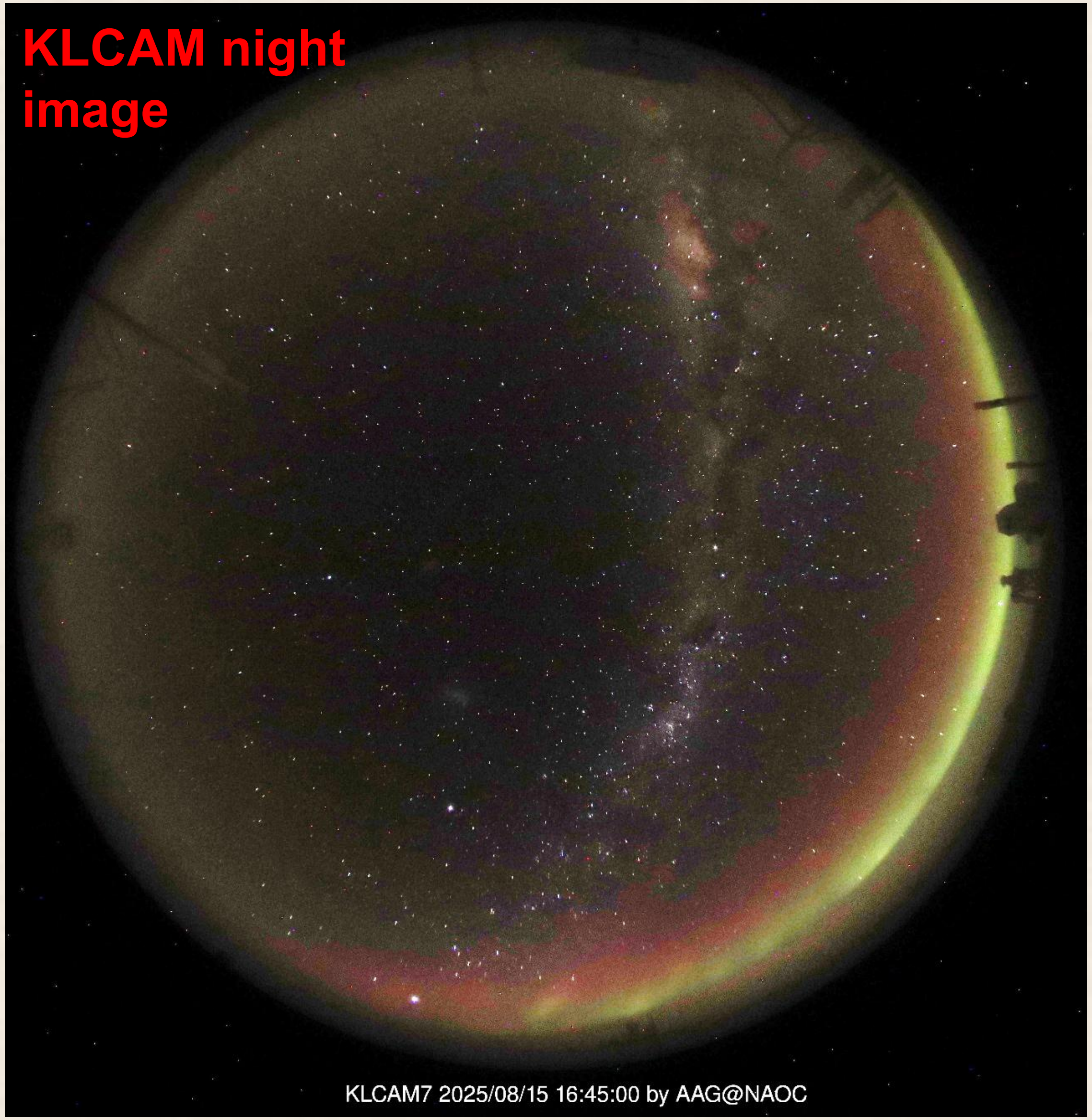
Long term monitoring: 2 KLCAMs on site

Operation of KLCAM

First season（2017.01-2018.05）

- Exposure：
  - 30s exposure (night) every 30min
- 490 days continuously, until ran out of fuel



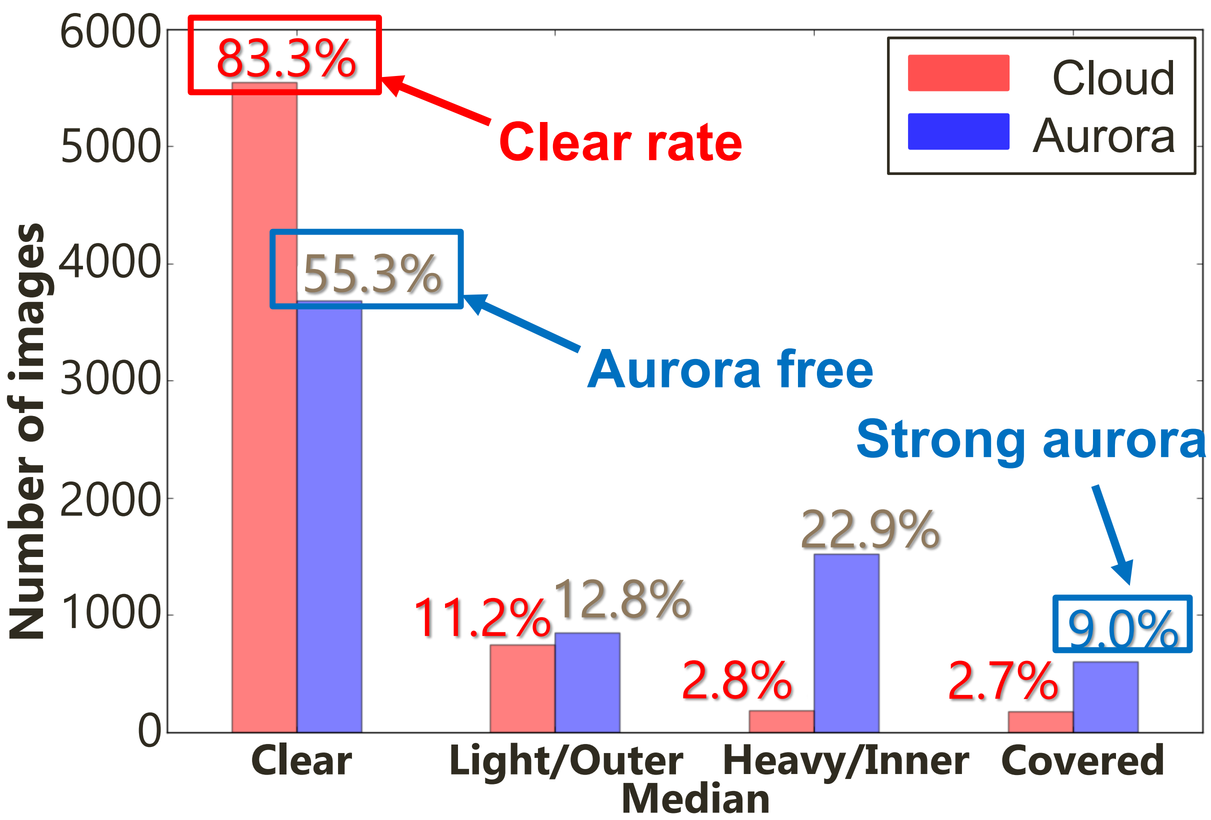


Instrument

First Result for Night-time Cloud and Aurora in Dome A

- 2017-2018 data, visual classification (Yang et al., 2021)
- Compare with TMT：
  - Best clear rate (83.3%)

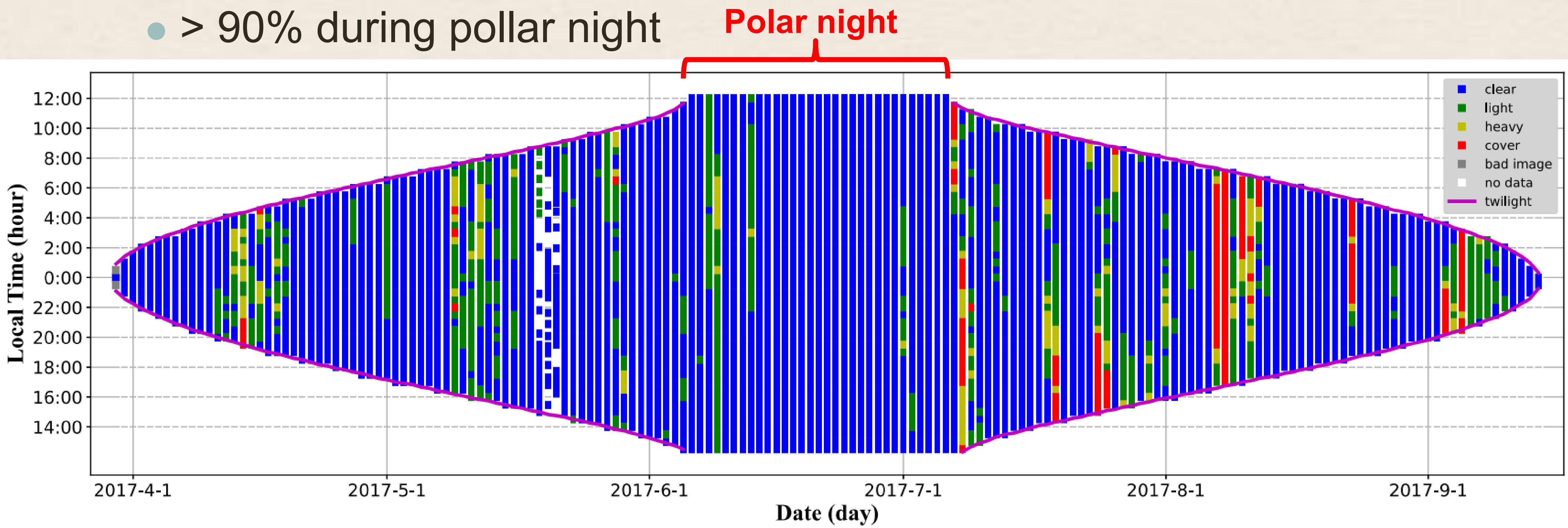
TMT sites	Dark hour	Clear Hour	Clear Fraction
Tolar (2,290m)	3390	2624	77.4%
Armazones (3,064m)	3392	2798	82.5%
Toloncha r (4,475m)	3373	2442	72.4%
SPM (2,830m)	3267	2373	72.6%
MK13N (4,050m)	3390	2404	70.9%
Dome A (4,083m)	2606	2136	83.3%



Instrument

KLCAM First Result: Daily Cloud Distribution

- 2017 all-year night-time result
  - Blue blocks: clear half-hours
  - > 90% during pollar night



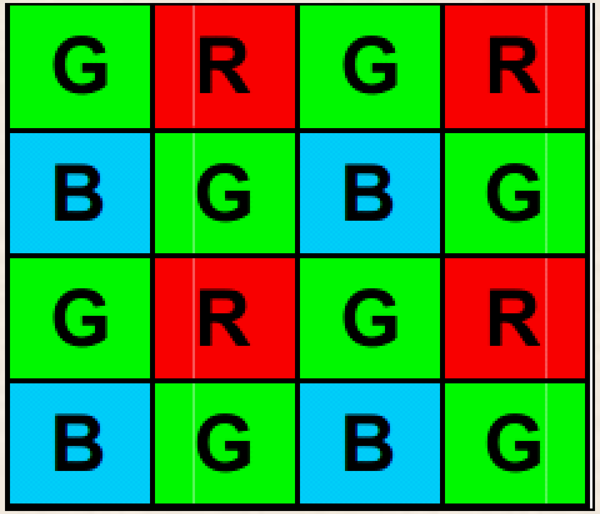
Astrometry and Photometry

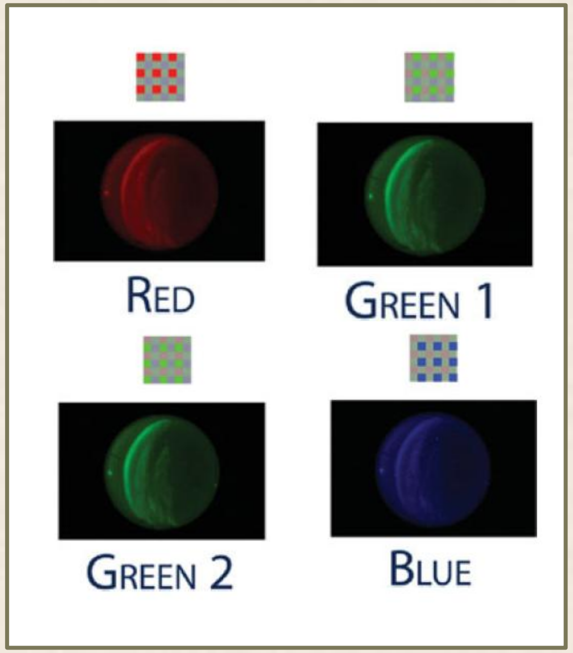
Quantitative Cloud and Aurora Analysis

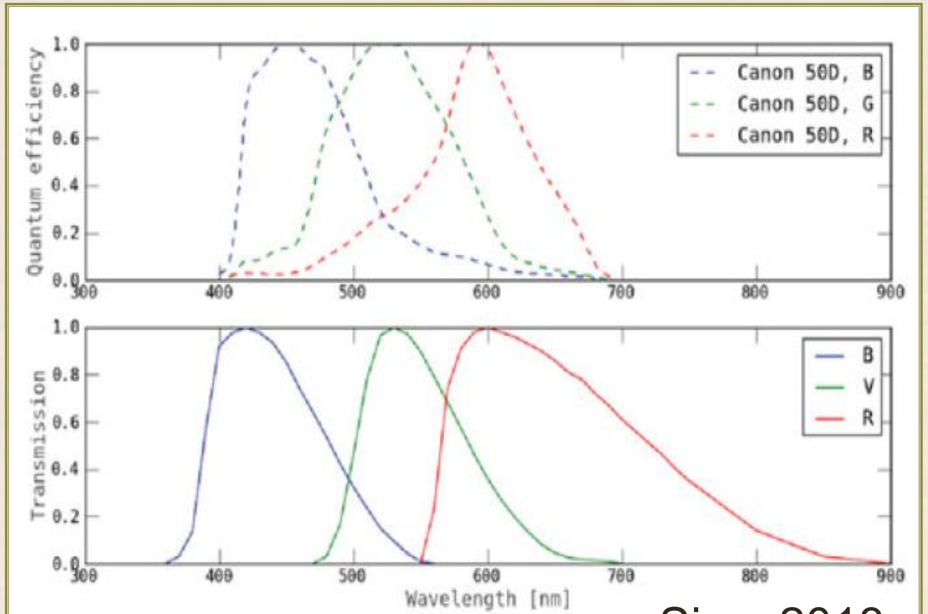
Human eye: half-quantitative

- Quantitative method:
  - Automatic
  - Real-time analysis
  - Spatial distribution

- Photometry works!
  - Cloud → less star
    → extinction
  - Aurora→ background





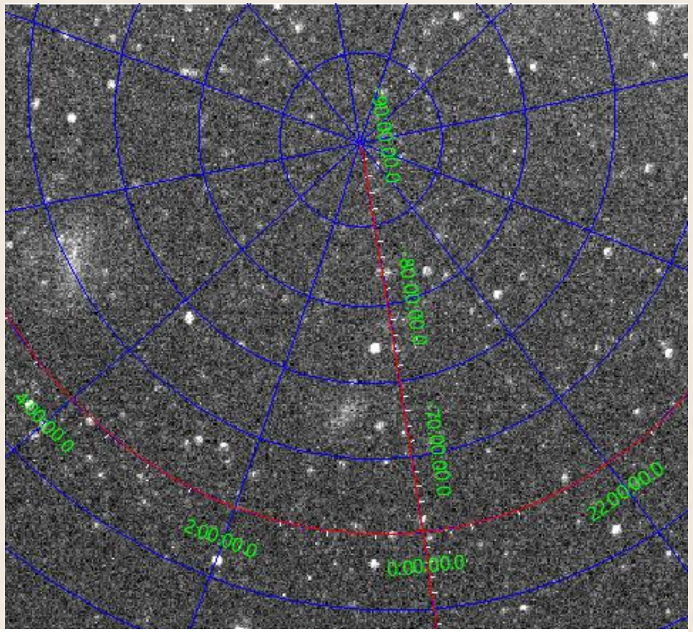


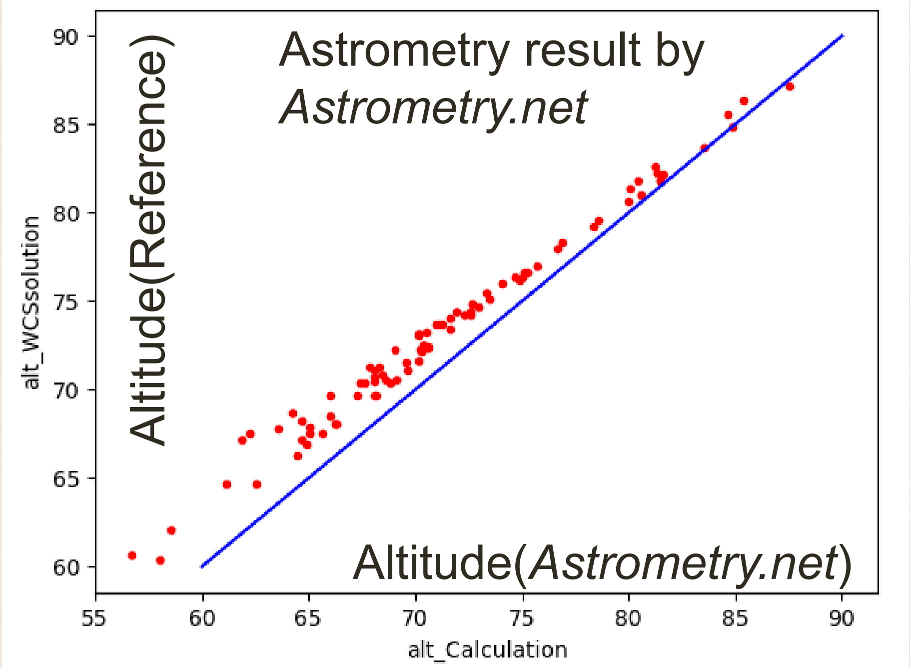
Sims 2013

Astrometry

Astrometry For Super-wide FOV images

- Problems with Traditional Methods
  - Tools:
    - *SCAMP*
    - *Astrometry.net*
  - Cannot applied directly
    - FOV too large
    - 5° difference @ 60° altitude
  - Hard to subdivide
    - Sub-images: need 5° or less
    - Insufficient stars
    - Distortions





Astrometry

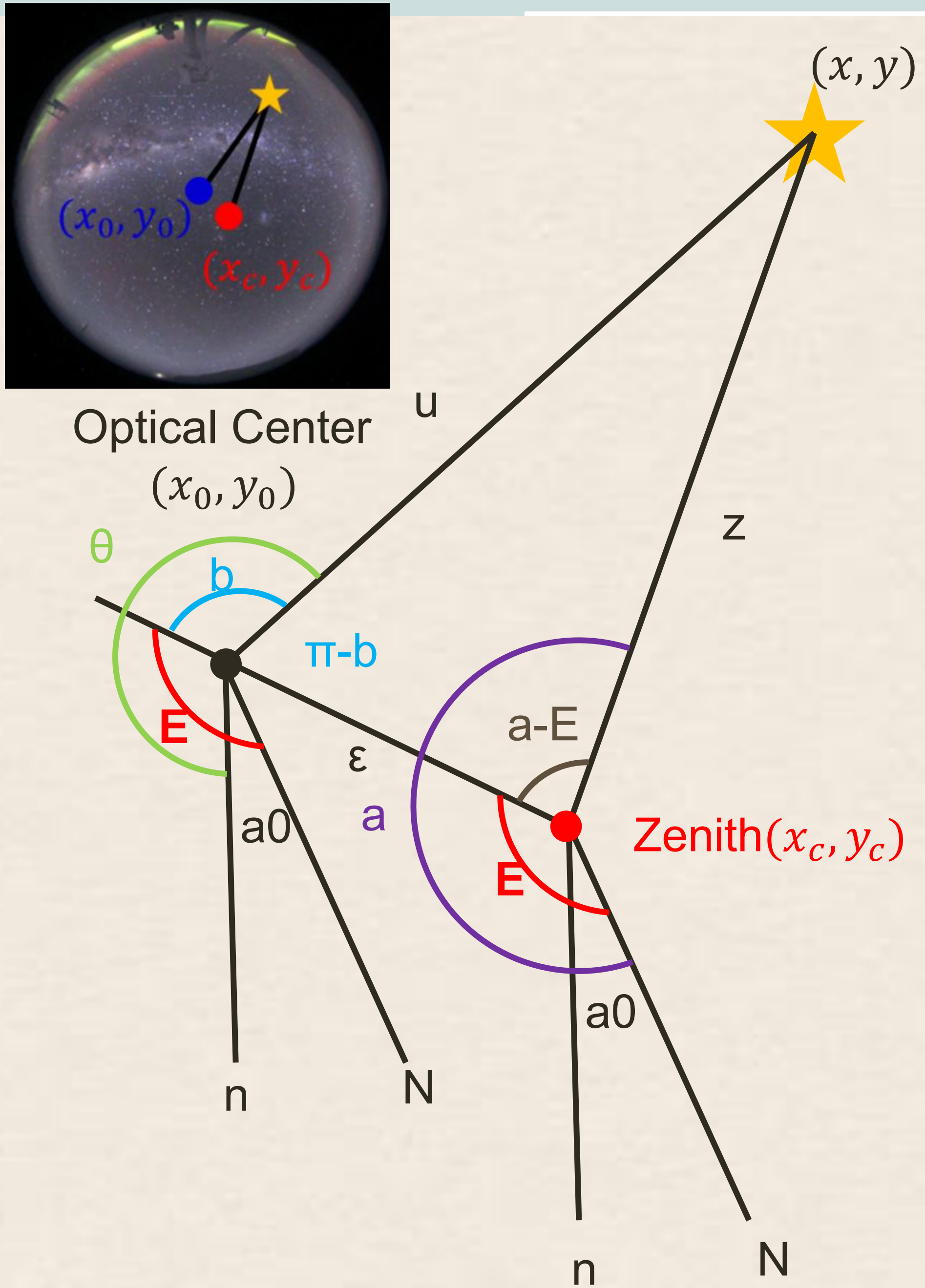
Direct astrometric solution:

- Basic idea: polar coordinate

$$x, y \to \theta, r \to b, u \to a, z$$

Plane→Polar→Spherical→Celestial

- Basical assumption:
  - Axisymmetrical



Astrometry

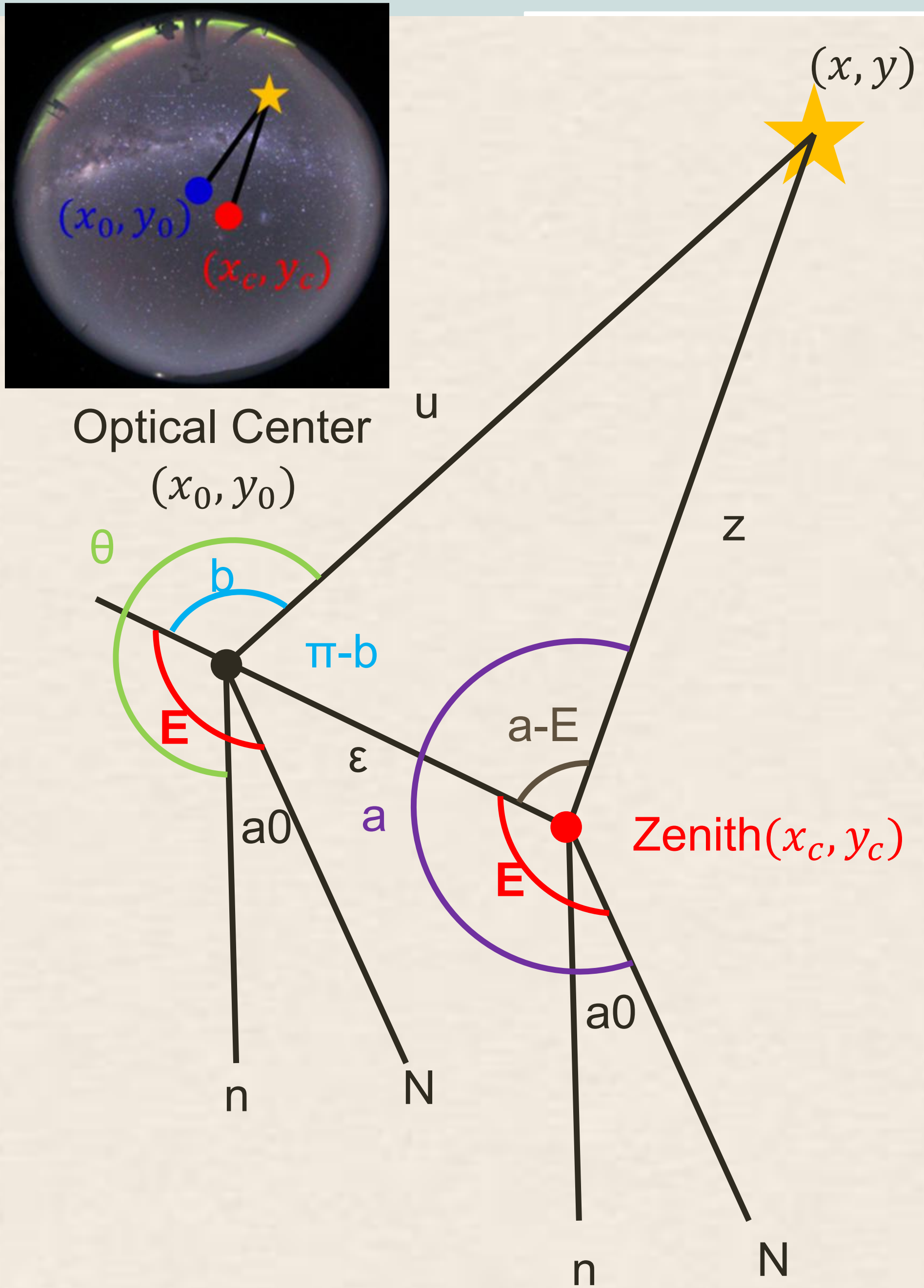
Direct astrometric solution:

- Basic model (Borovička 1995)

$$\begin{cases} b = a_0 - E + \overset{\theta}{\boxed{\operatorname{atan}\left(\dfrac{y - y_0}{x - x_0}\right)}} \\ u = Vr + S(e^{Dr} - 1) + P(e^{Qr^2} - 1) \end{cases}$$

$$\begin{cases} a = E + \operatorname{atan}\left(\dfrac{\sin b \sin u}{\cos b \sin u \cos \epsilon + \cos u \sin \epsilon}\right) \\ z = \operatorname{acos}(\cos u \cos \epsilon - \cos b \sin u \sin \epsilon). \end{cases}$$

- Problem:
  - too many parameters (13)



Astrometry

Direct astrometric solution:

- Simplified model (Barghini 2019)

θ

$$\begin{cases} b = a_0 - E + \boxed{\operatorname{atan}\left(\frac{y - y_0}{x - x_0}\right)} \quad F\operatorname{asin}\left(\frac{r}{R}\right) \\ u = \cancel{Vr + S(e^{Dr} - 1) + P(e^{Qr^2} - 1)} \end{cases}$$

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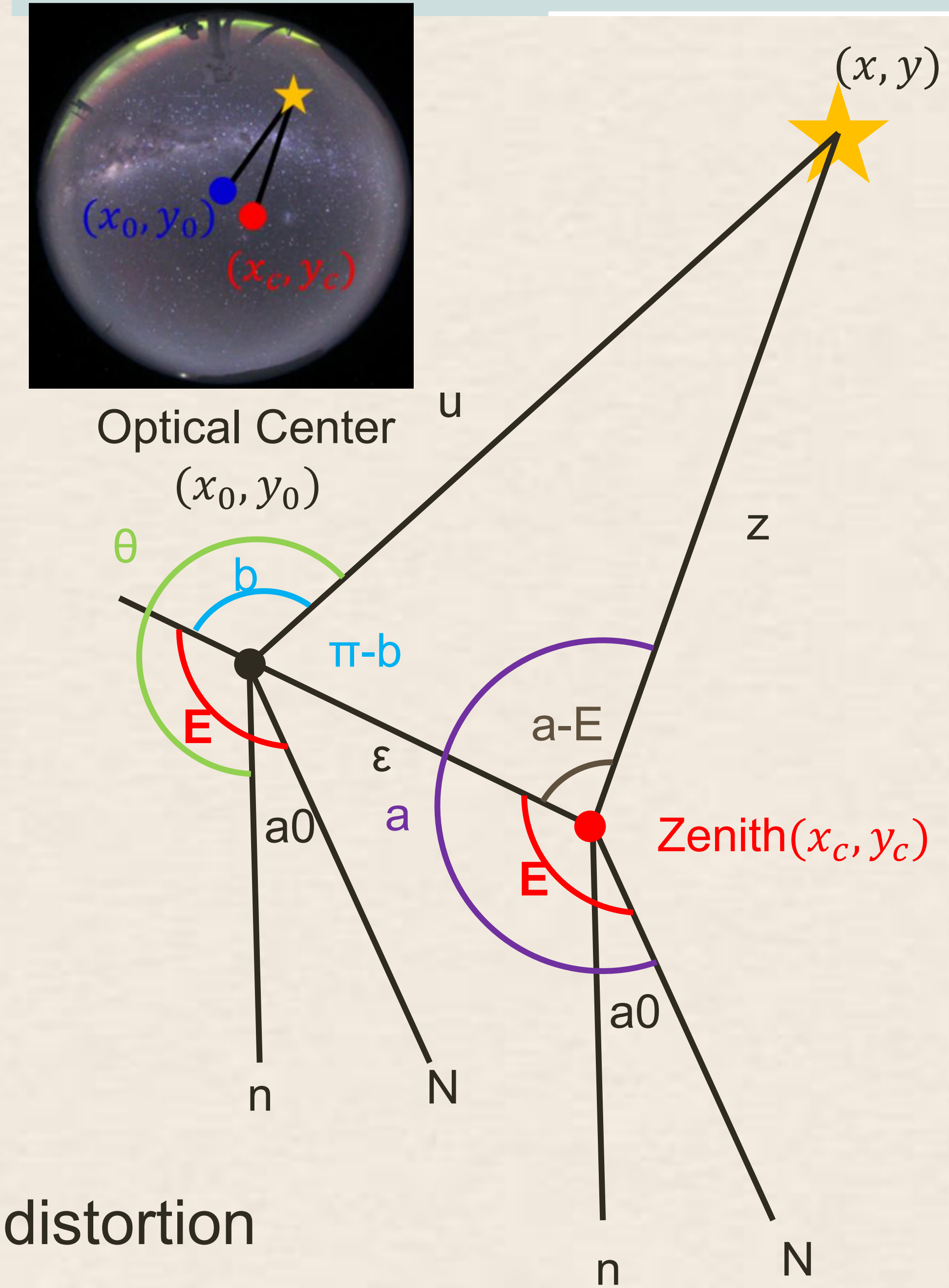


- Simplified Method:
  - No distortion
  - Commercial lens and camera introduces distortion

Astrometry

Direct astrometric solution:

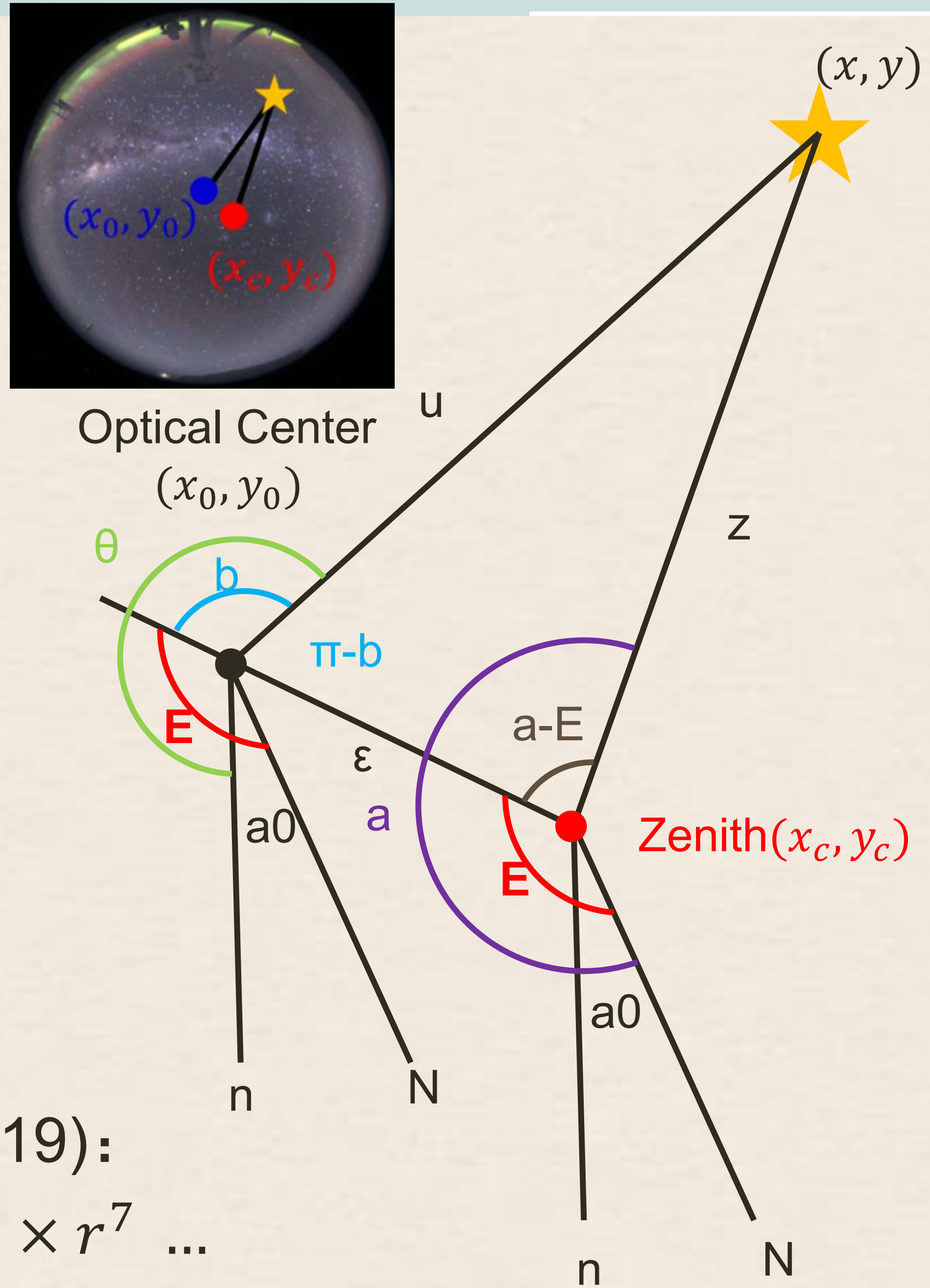
- Our model with distortion correction

$$\begin{cases} a = E + \arctan\left(\dfrac{\sin b \sin u}{\cos b \sin u \cos\epsilon + \cos u \sin\epsilon}\right) \\ z = \arccos\left(\cos u \cos\epsilon - \sin u \cos b \sin\epsilon\right) \\ b = a_0 - E + \arctan\left(\dfrac{y - y_0}{x - x_0}\right) \\ u = k_1 r + k_2 r^3 + k_3 r^5 + k_4 r^7 + \ldots \\ r = \sqrt{(x - x_0)^2 + (y - y_0)^2}. \end{cases}$$

$x_0\ y_0$ / *optical center*
$a_0\ \varepsilon\ E$ / *zenith*
$k_1\ k_2\ k_3\ k_4$ / *distortion*

- Distortion:
  - Kannala-Brandt (2006) model (Jeanne 2019)：

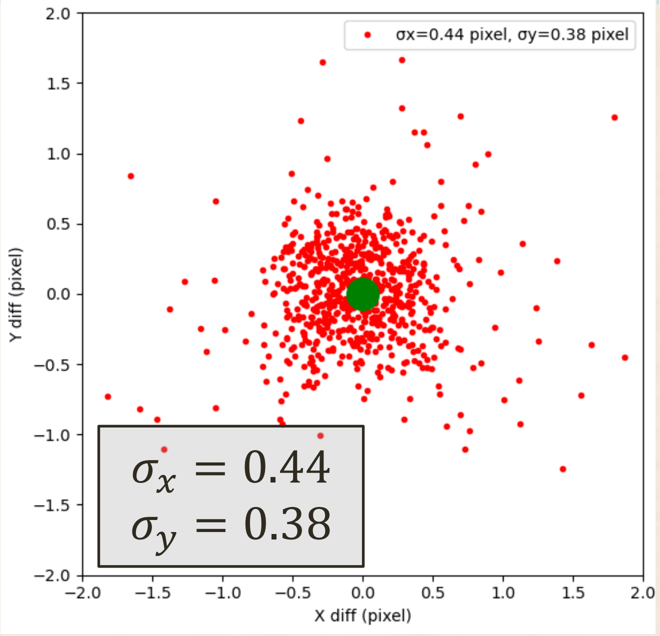
$$F \operatorname{asin}\left(\frac{r}{R}\right) = k_1 \times r + k_2 \times r^3 + k_3 \times r^5 + k_4 \times r^7 \ \ldots$$

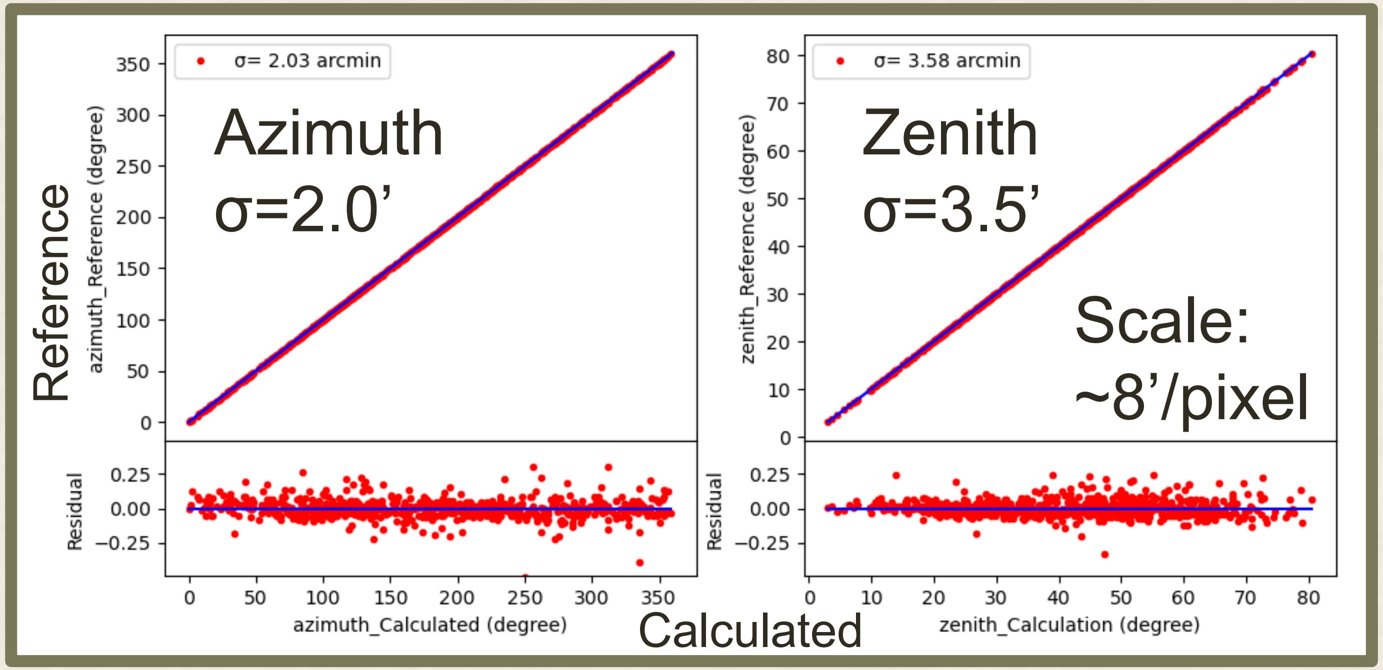


Astrometry

Implement and Result

- Implementation on KLCAM images:
  - 3-steps iteration
  - error: $\sigma_{(x,y)}$ ~ 0.4 pixel
- Can be used for:
  - General all-sky cameras
  - Any super-wide FOV images
- Code published:
  - https://github.com/XuYangNAOC/Astrometry4SWFOV
  - Yang et al., 2025 A&A

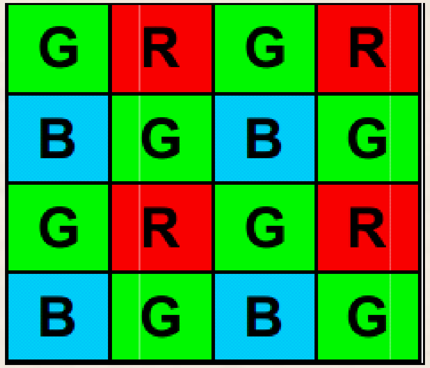


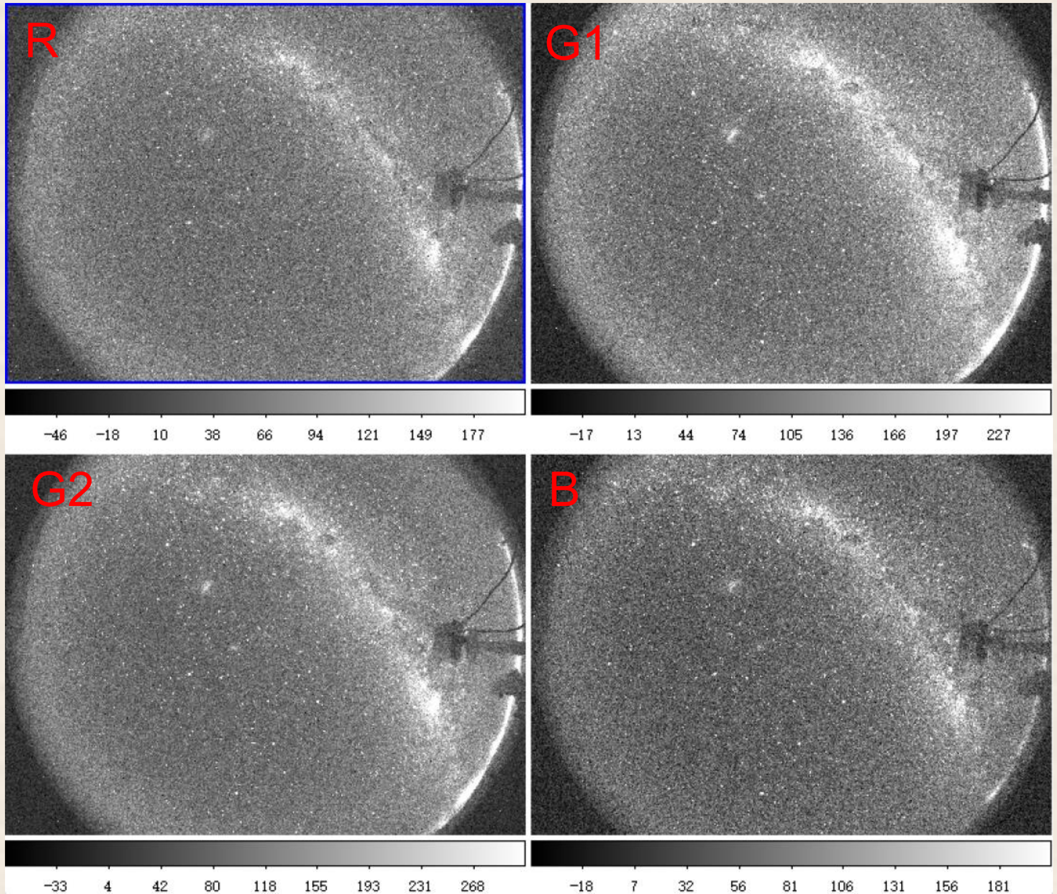


Photometry

Photometry method

- Data Preprocessing：
  - Raw → FITS
    - cr2: rawpy
    - cr3: C/C++ based on LibRaw
  - Pixels → 1/4 for each channel
  - Bias: surrounded areas
- First-step photometry：
  - SExtractor / Photutils
  - Aperture photometry

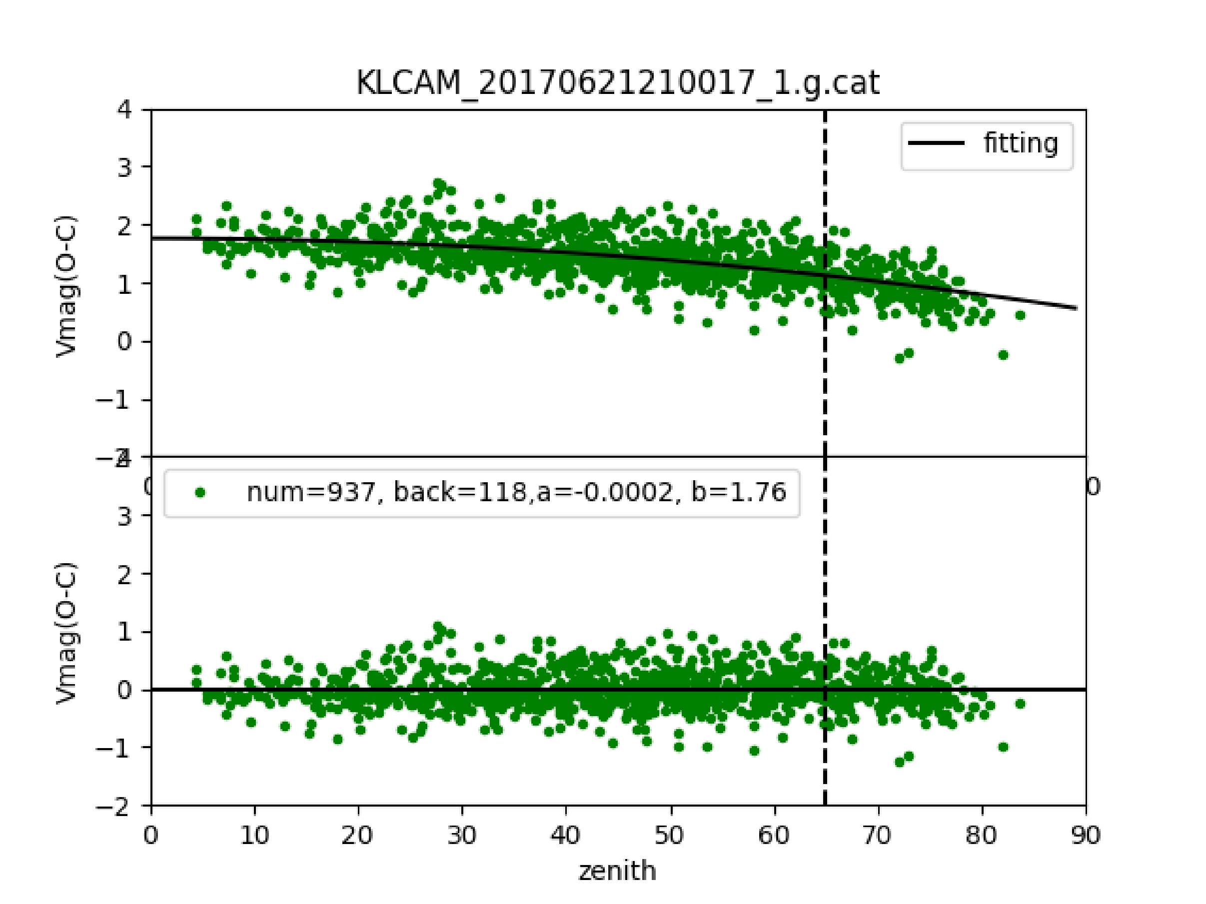




Photometry

Zero-point corrections

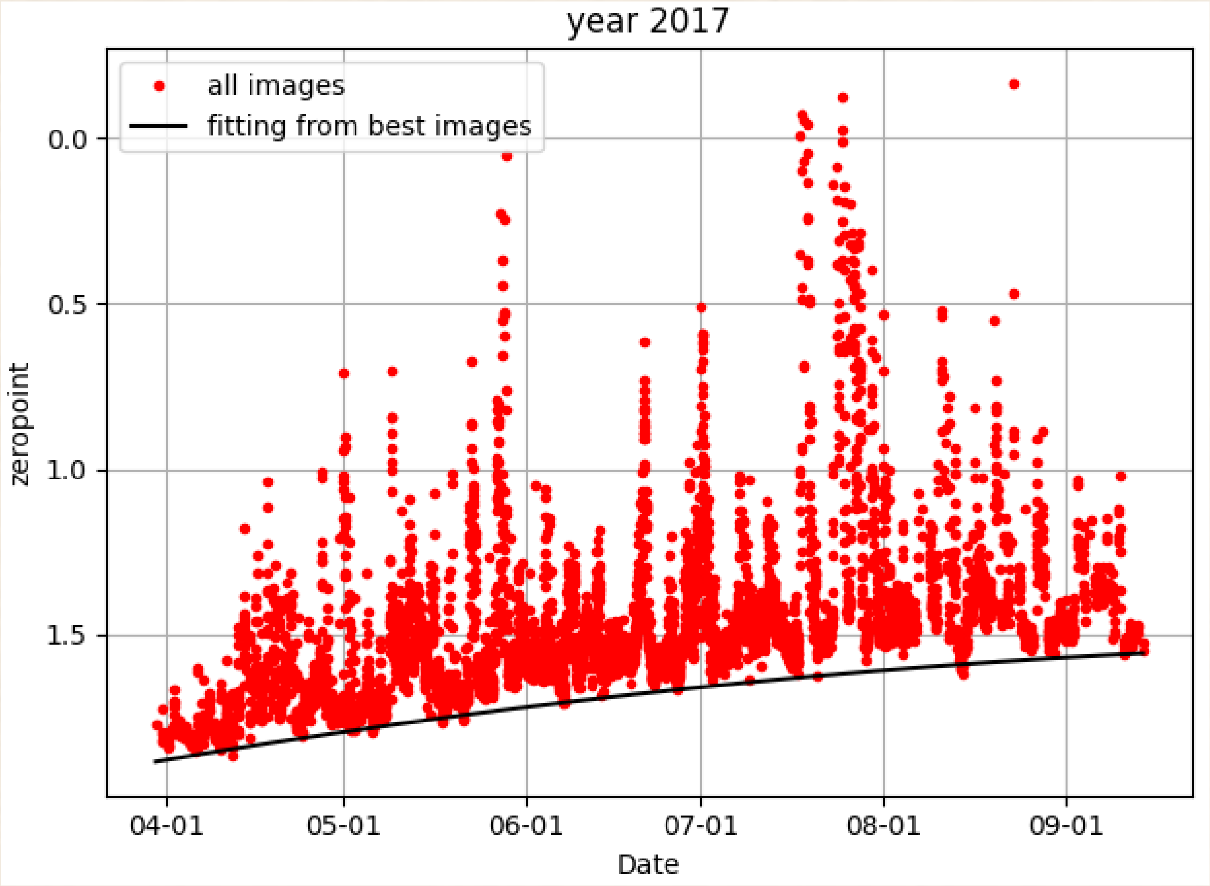
- Radial:
  - Significant trend detected:
    - Instrumental (Sims thesis)
    - Atmospheric extinction
    - …
  - Corrections:
    - zero-point change with zenith
    - de-trending by fitting
- Axial: No significant trend



Photometry

Zero-point corrections

- Long term correction:
  - Zero-point change with time:
    - As large as 0.3 mag
  - Correction:
    - Find the best images
      - star number
      - background
      - visual result
    - De-trending by fitting



Photometry

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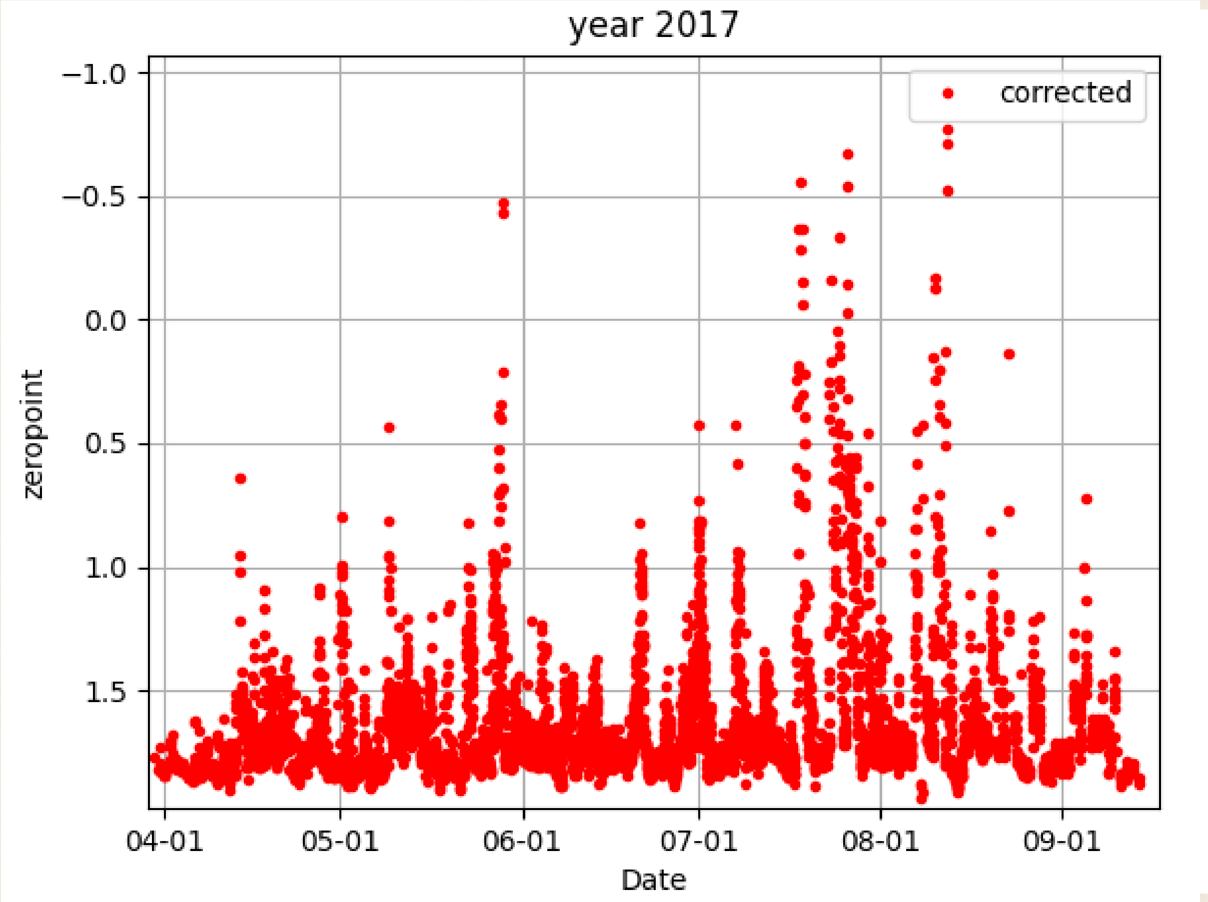
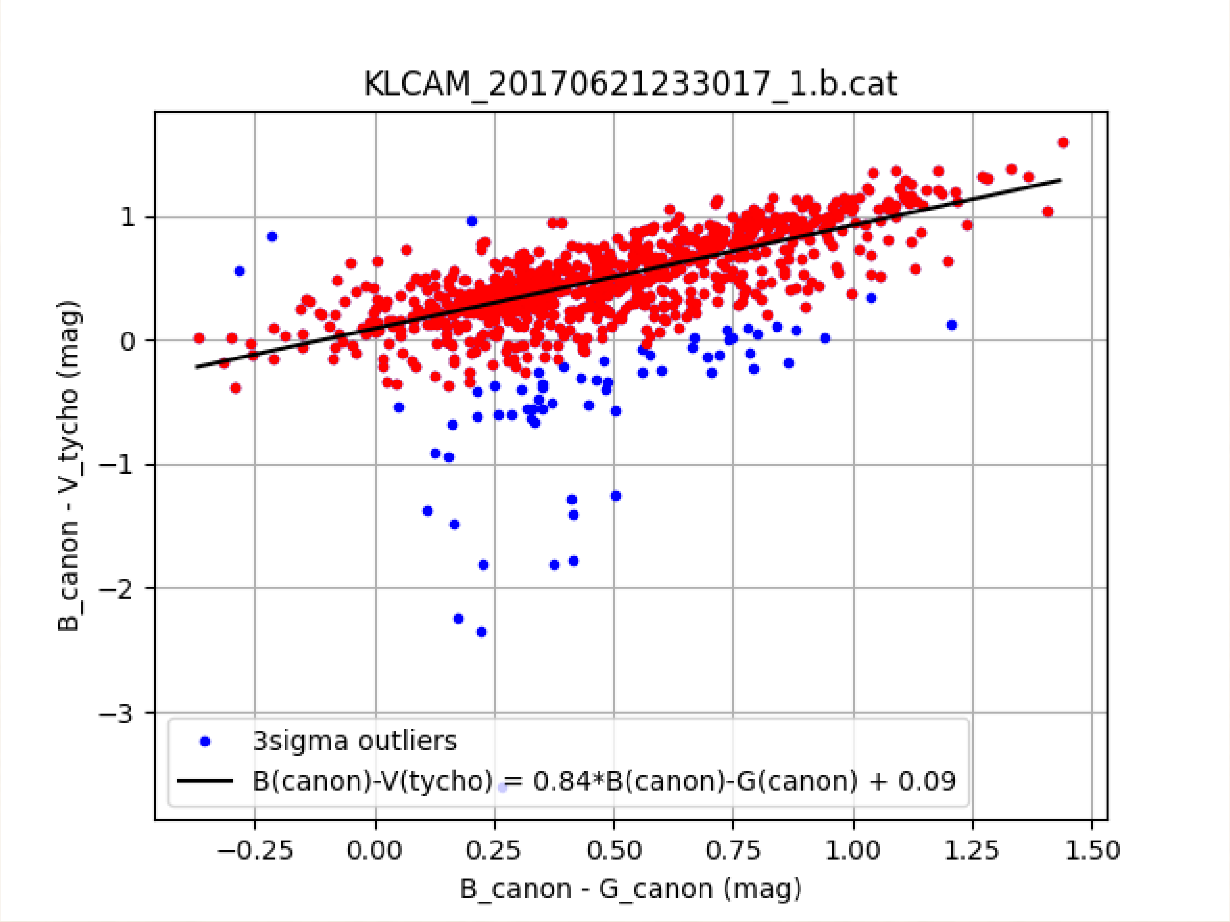


Photometry

Colour Correction

- Colour term fitting
  - Reference: Tycho V_T
  - Canon B + Canon G
  - Color term ~ 0.84

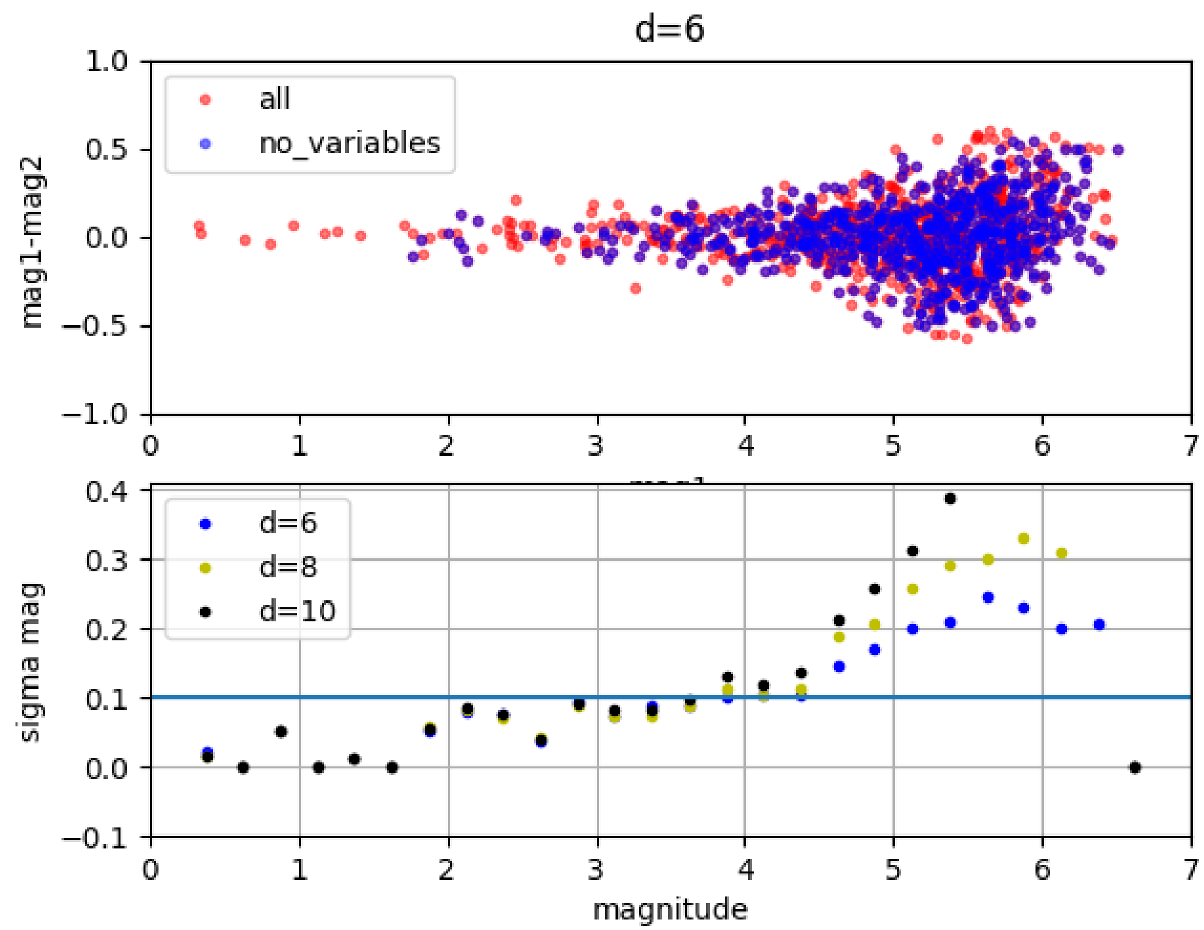
- Conversion formula:
  - V = 0.84G – 0.16B – 0.09



Photometry

Photometric Result

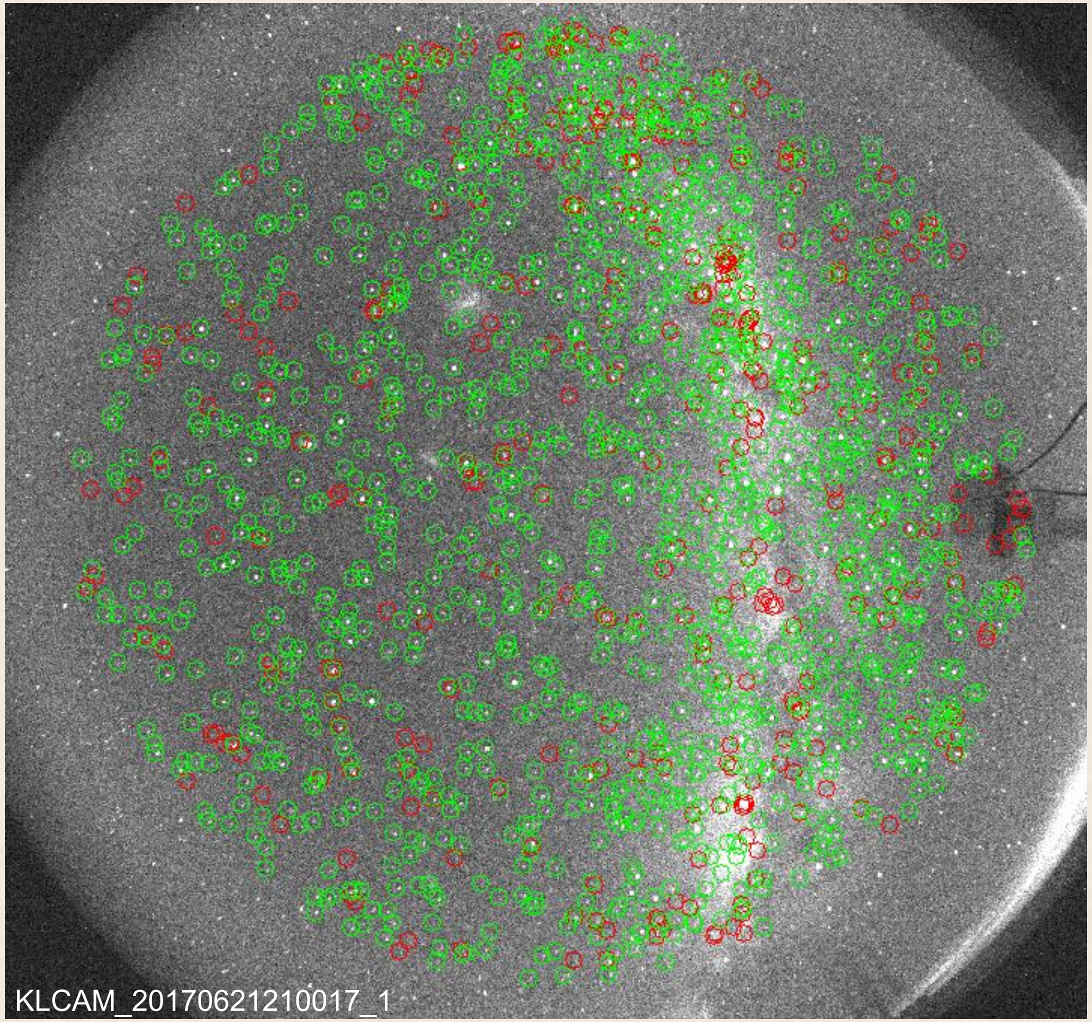
- Basic request for extinction：
  - TMT standard： <0.3mag
- Photometric error：
  - @4.5 mag： σ < 0.1 mag
  - @5.5 mag： σ < 0.2 mag



Photometry

Photometric Result

- Star detections
  - Zenith > 65°
    - green： star detected
    - red： standard stars
- Extinction
  - Magnitude difference
  - Equal area statistics



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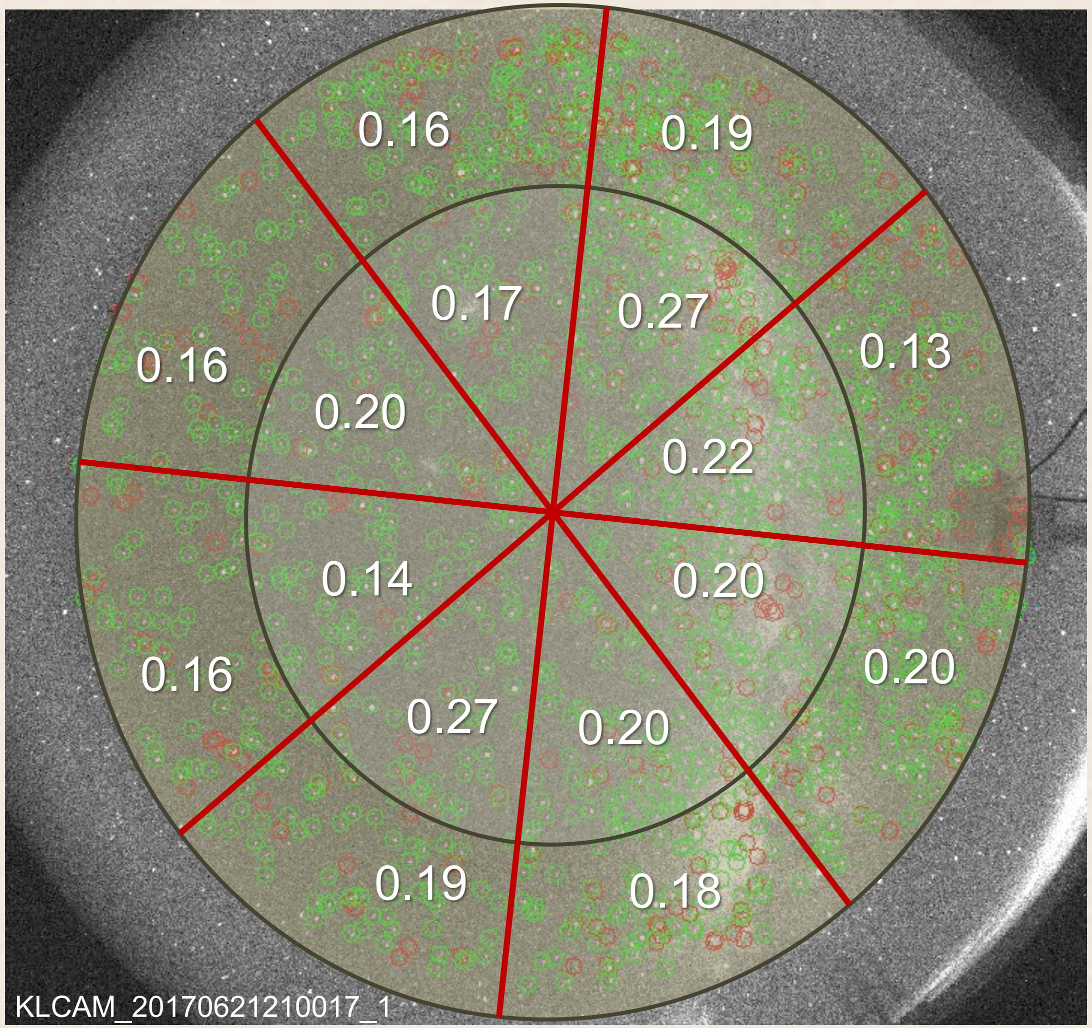
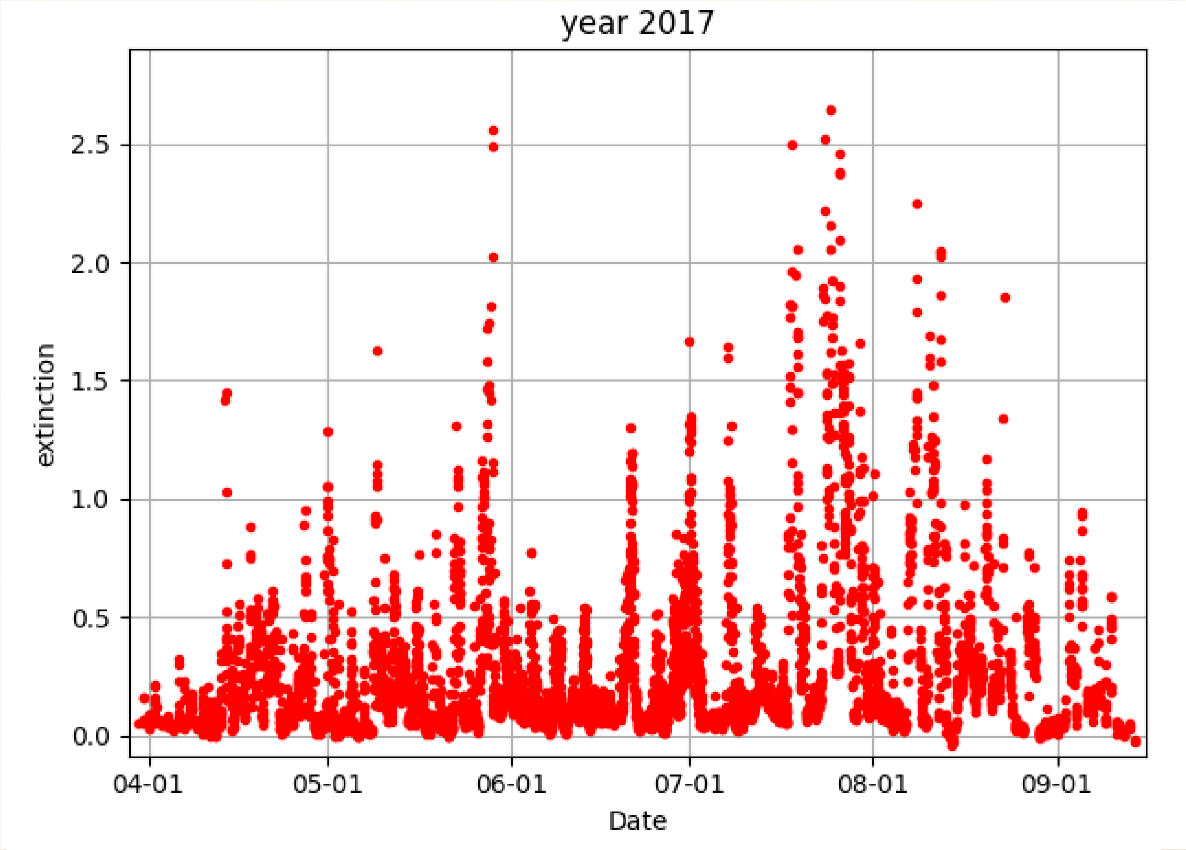


Photometry

Extinction distribution

- Extinction in 2017, Dome A
  - <0.3 75.17%
  - 0.3-2 24.78%
  - >2.0 0.04%

- Compare with visual result
  - extinction < 0.4: 82.6%
  - clear (visual): 83.3%



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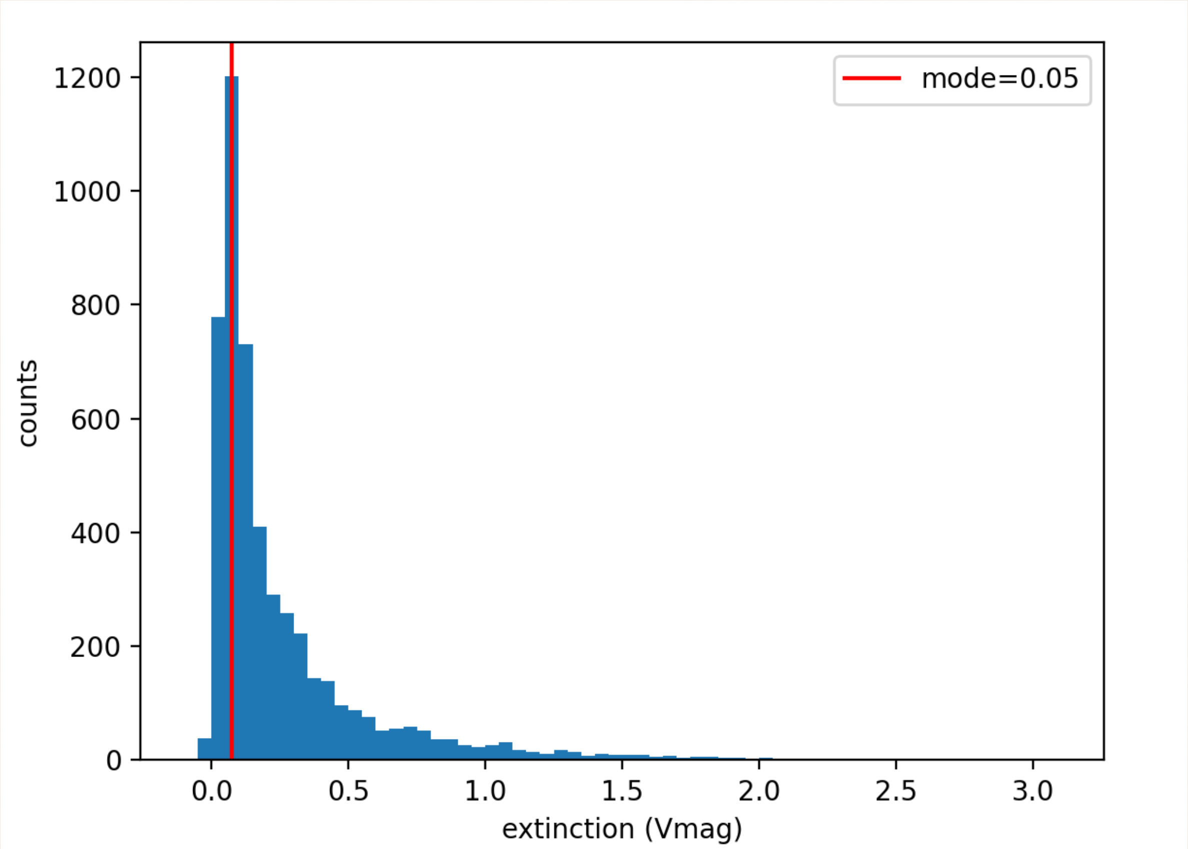
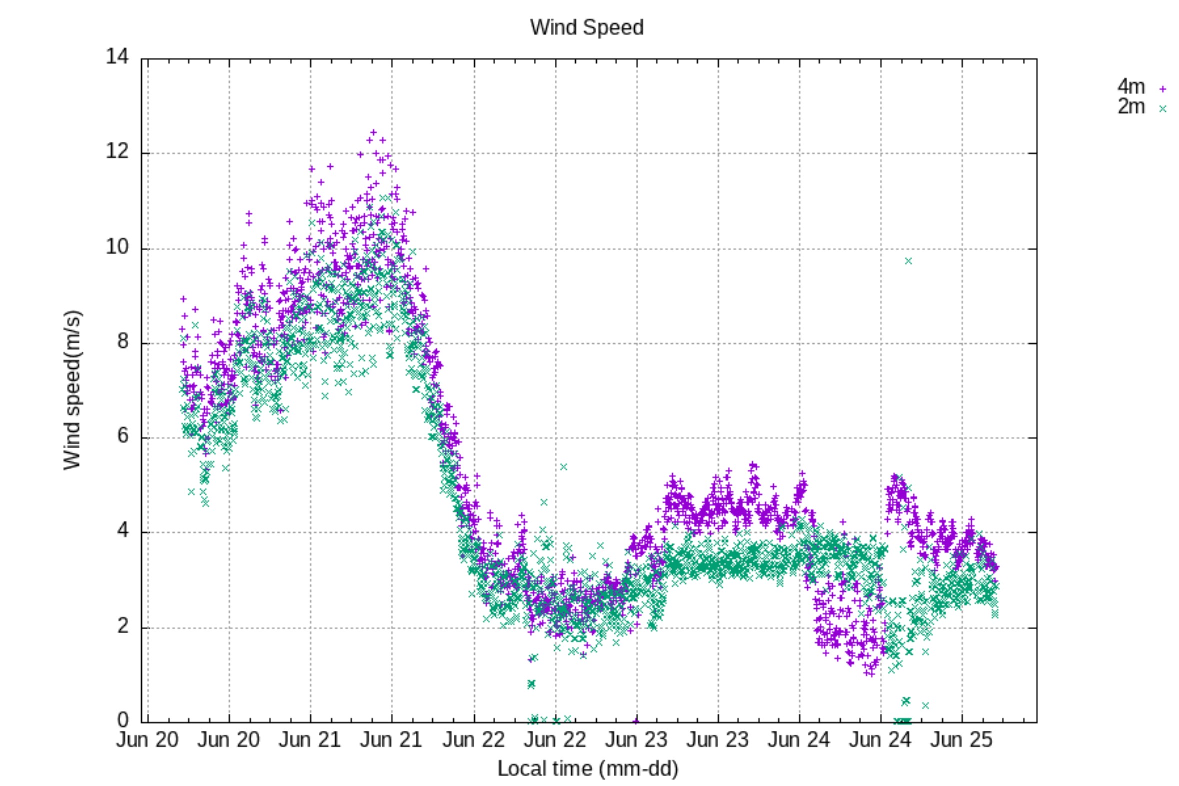
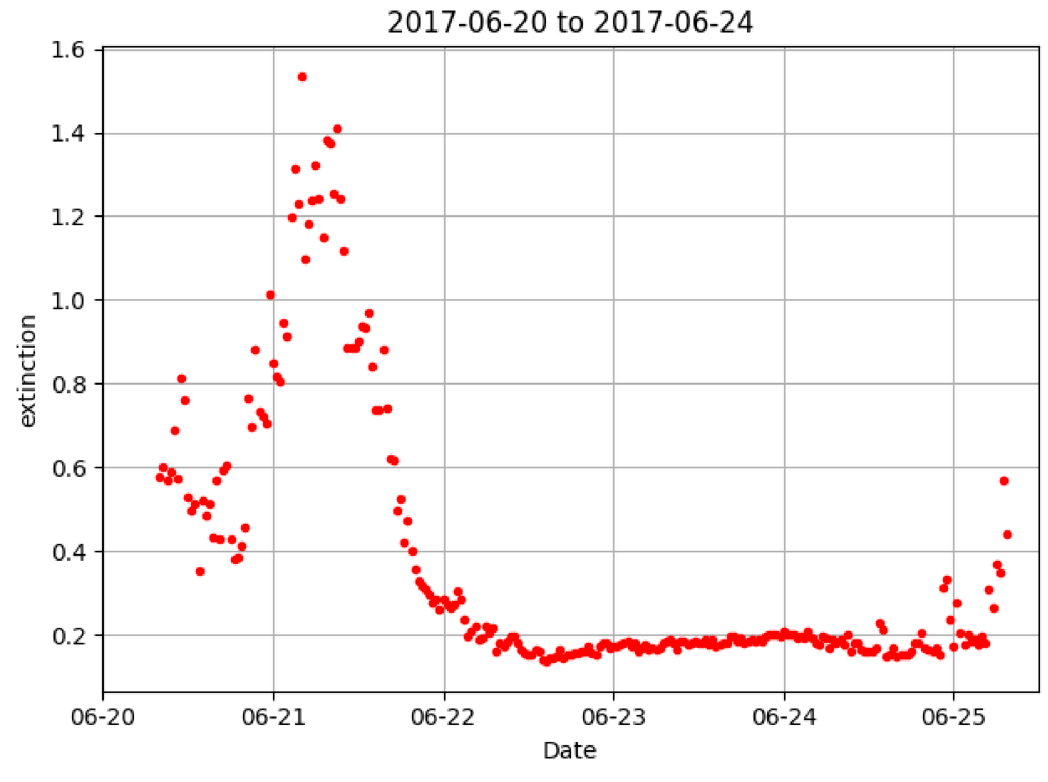


Photometry

Extinction distribution

- Cloud overrated?
  - blowing snow: wind speed vs. extinction



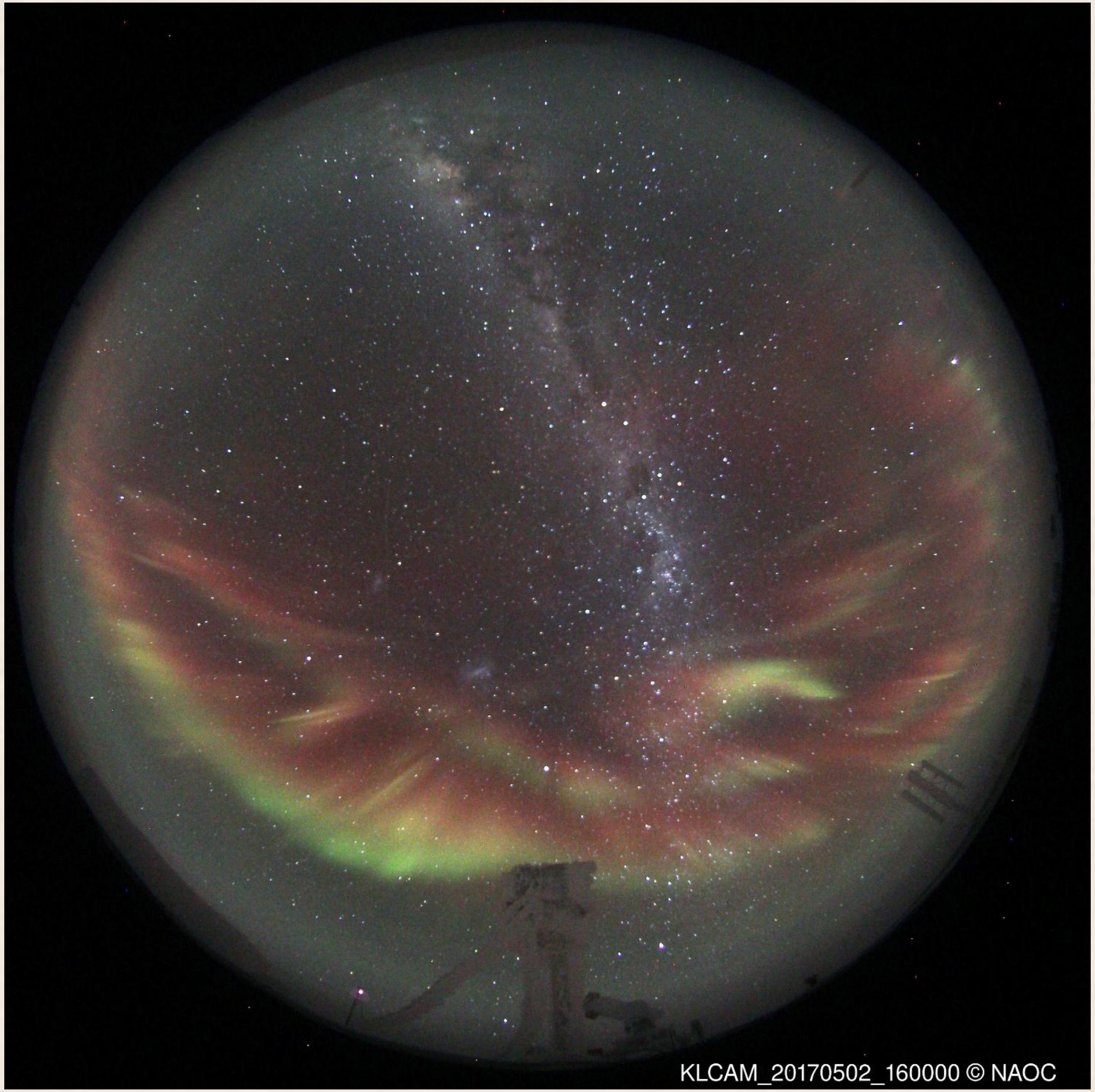


Conclusion

Astrometry and Photometry for Images of All-sky Cameras

- All-sky camera KLCAM：
  - Dome A all-sky cloud and aurora statistical result
  - 83% clear rate
- Astrometry method for super-wide FOV images (SWFOV)
  - Accurate and general method
  - Error < 0.5 pixel on KLCAM
- All-sky camera photometry method
  - Obtain cloud from extinction
  - 75% time extinction <0.3
  - Future works: automation, background (aurora) distribution…

THANKS!!

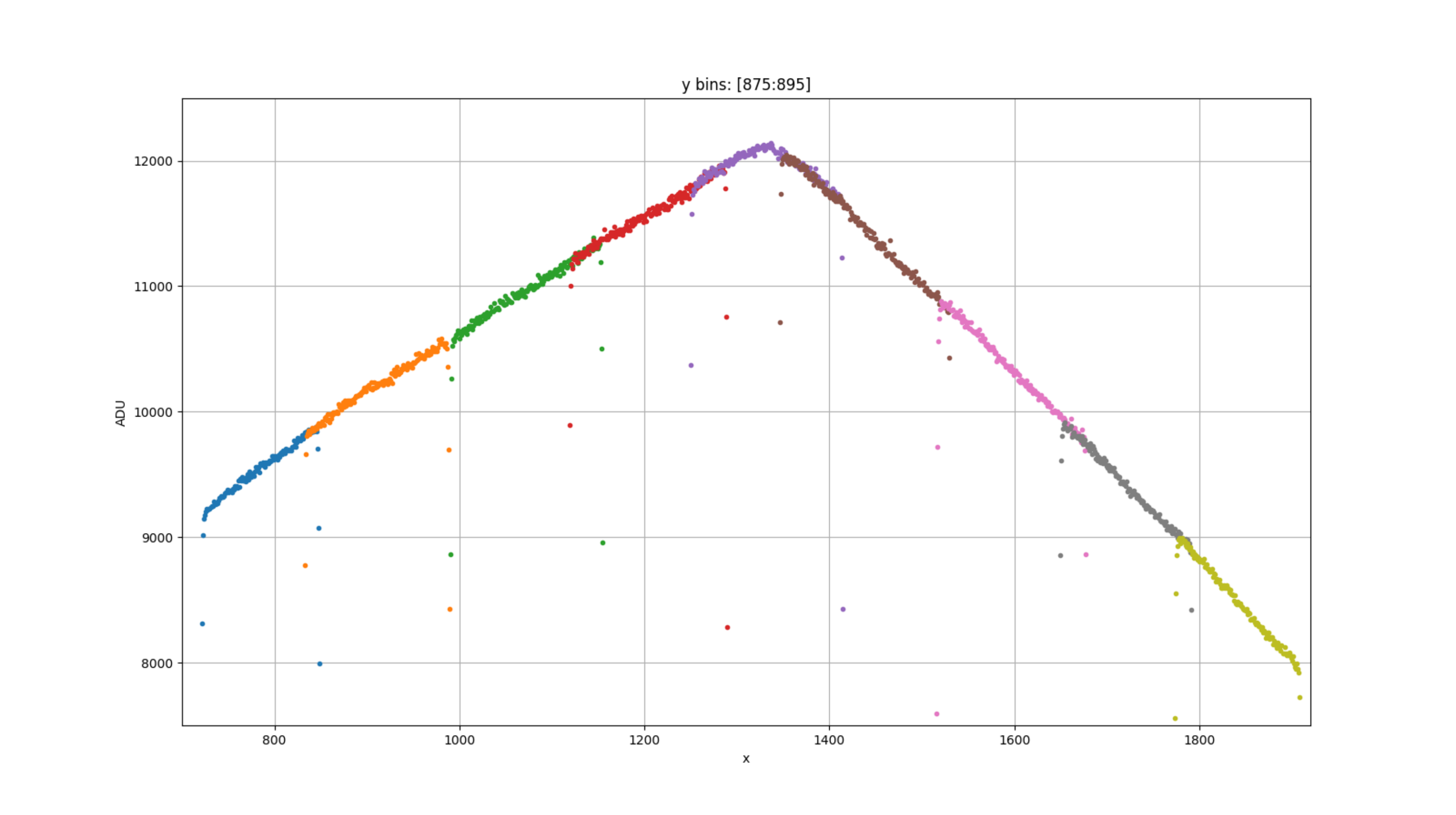


Photometry

Extinction

Photometry

Lab Test

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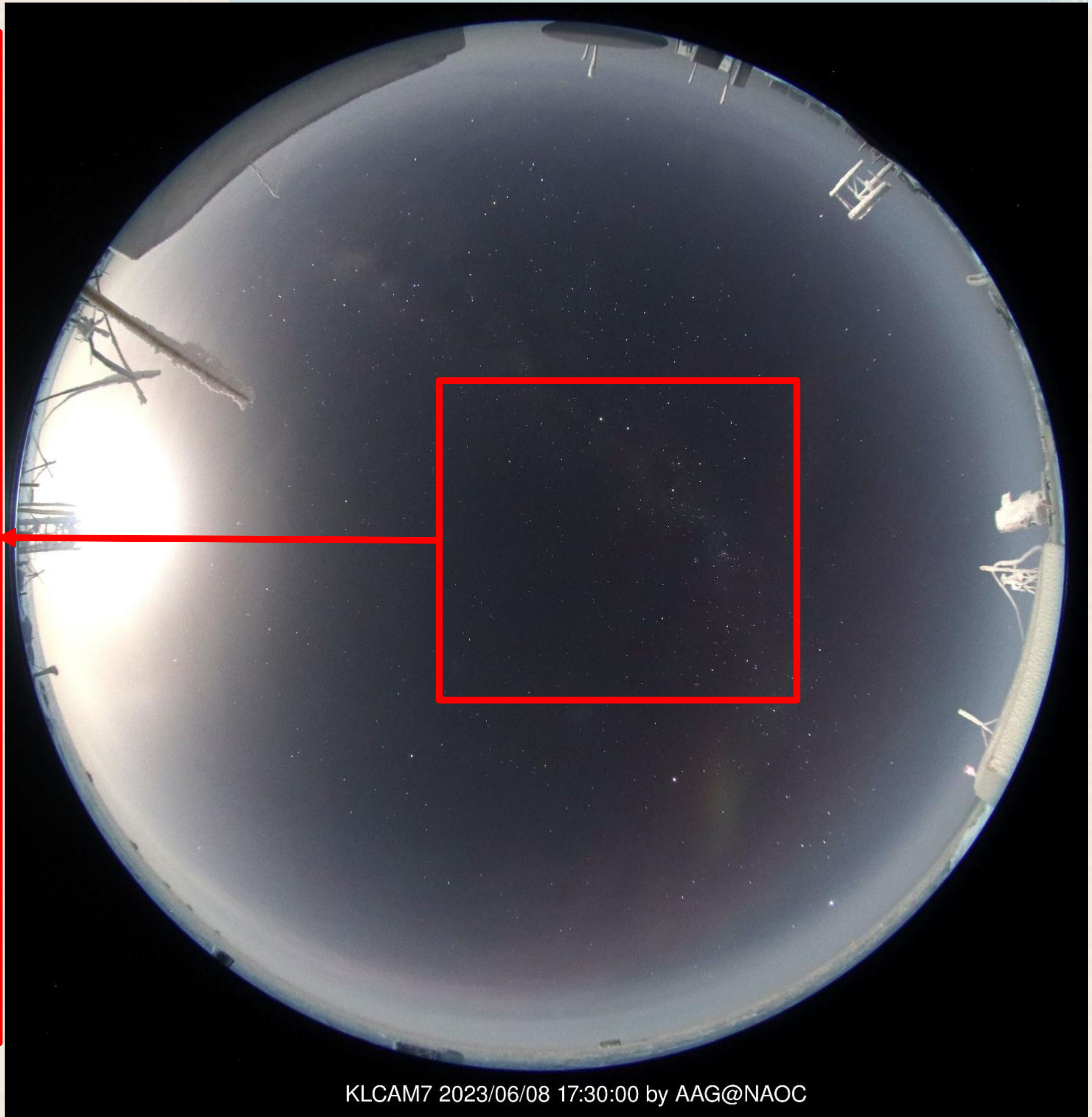
Camera 01


KLCAM7 2023/06/08 17:30:00 by AAG@NAOC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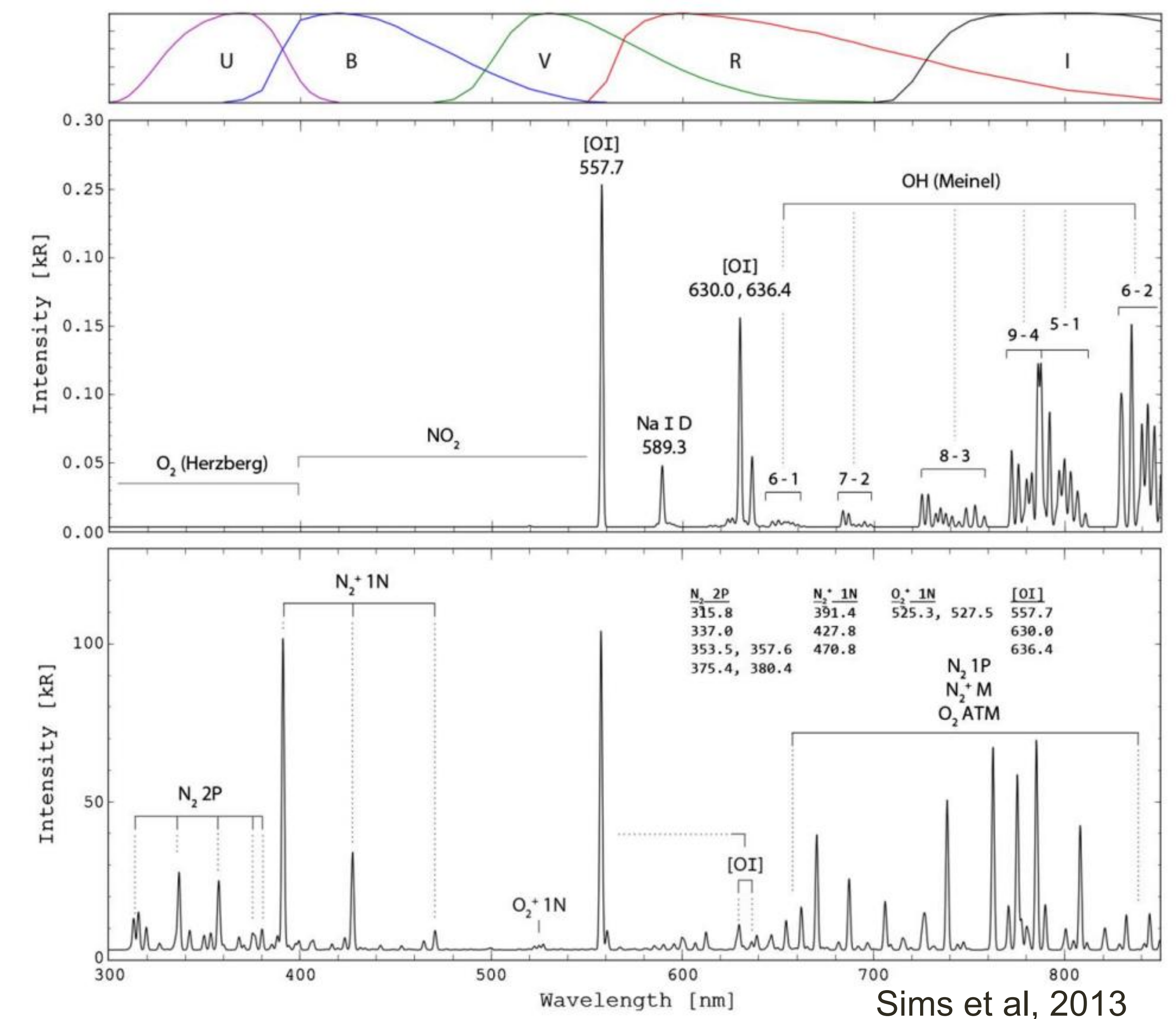
Photometry

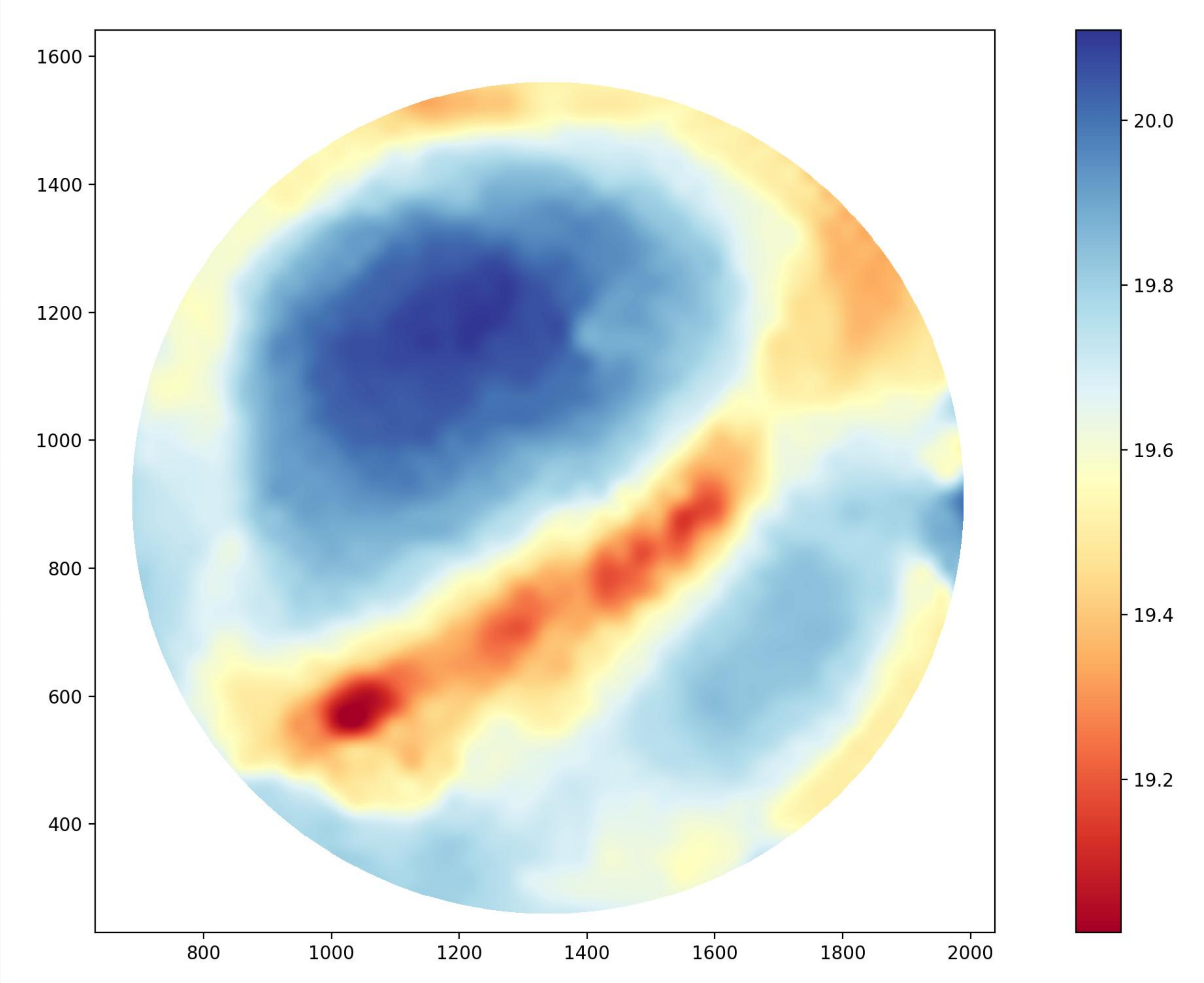
Aurora



Sims et al, 2013

Photometry

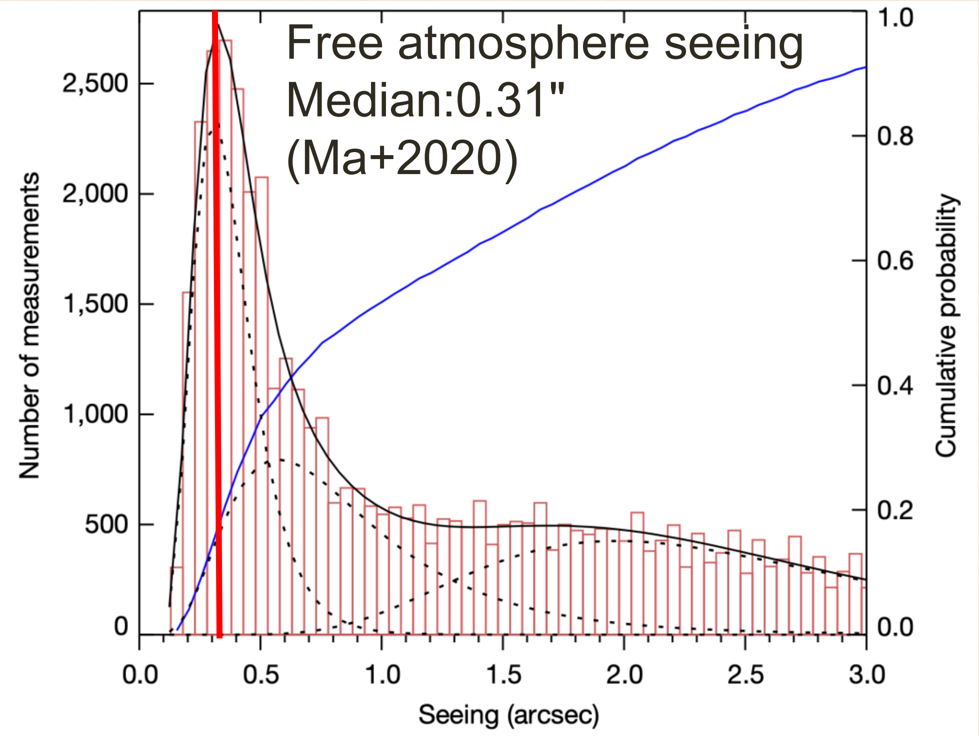
Background



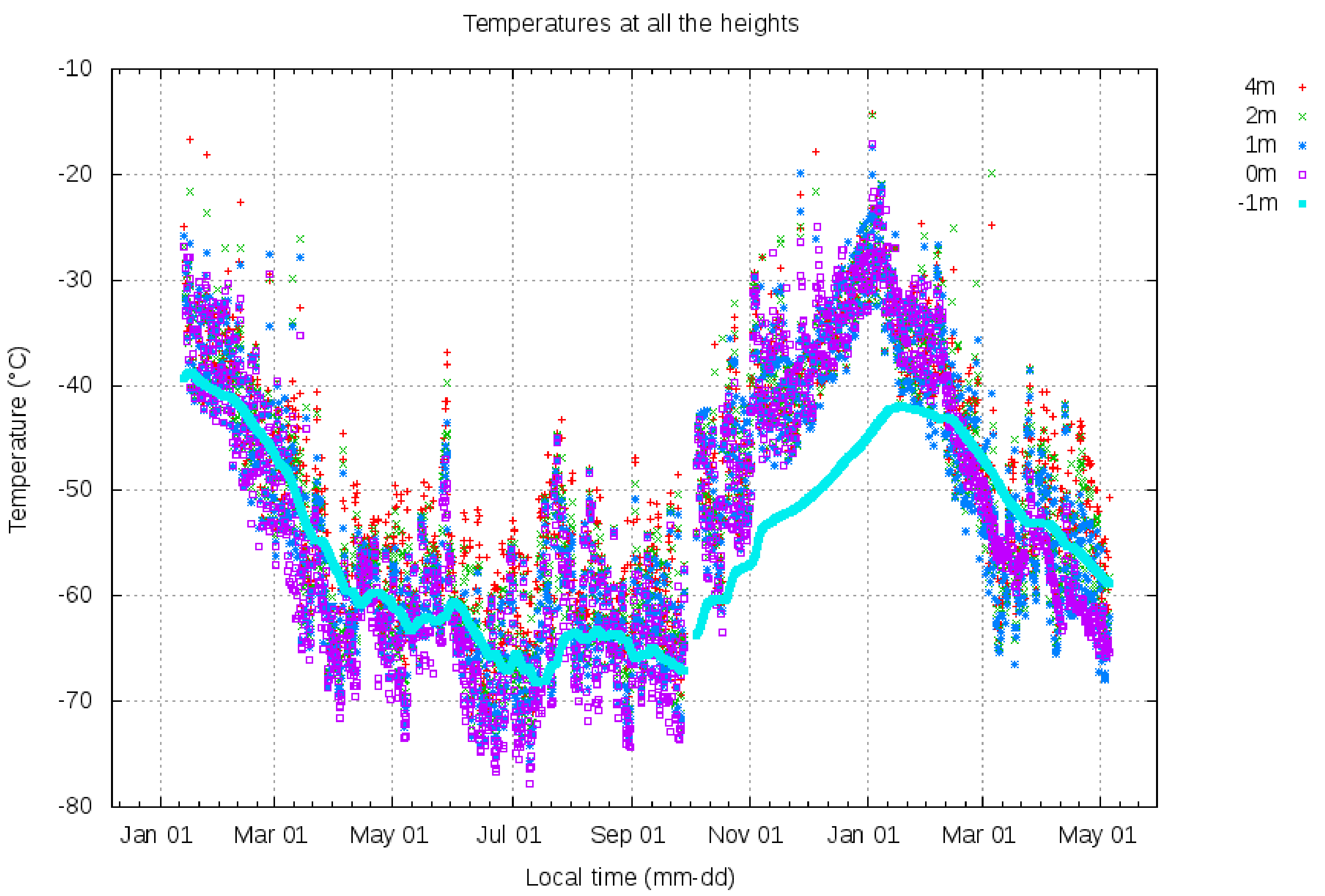
Introduction：

Dome A Site Testing Result：

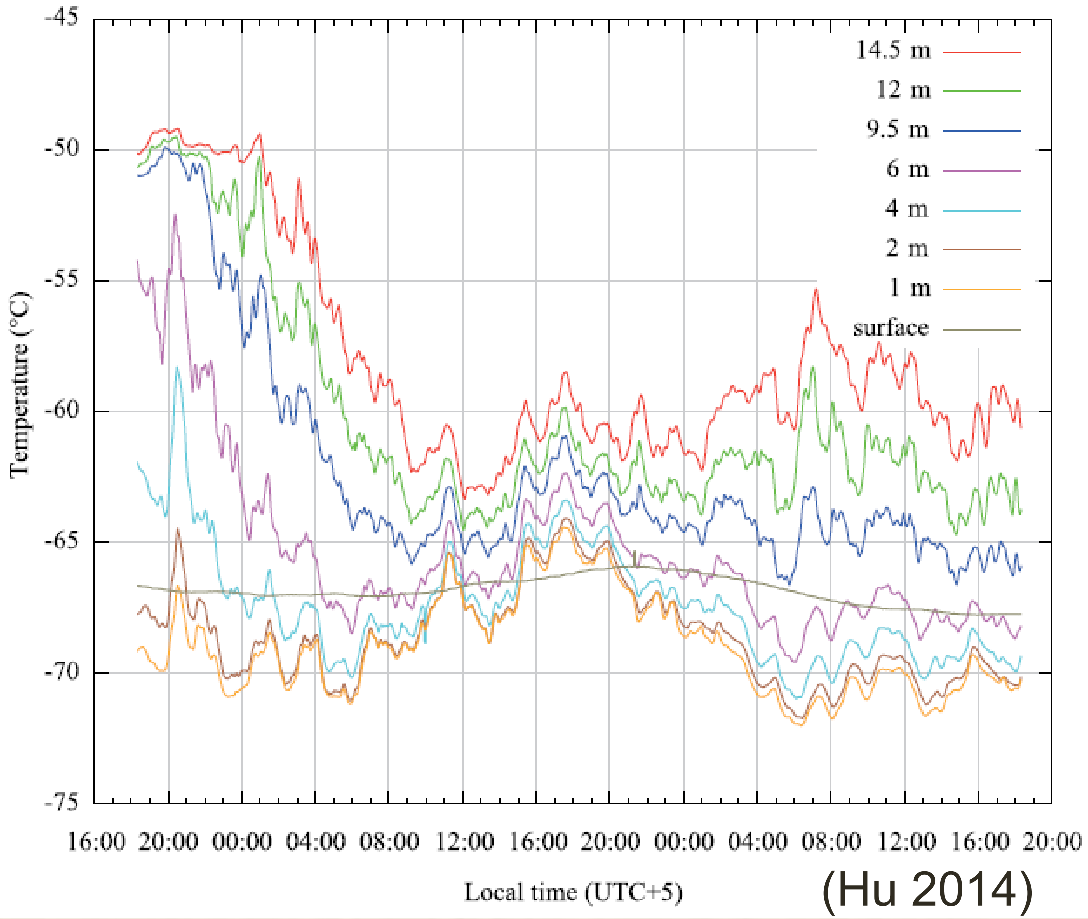
- Seeing (Ma et al. 2020) ：
  - KL-DIMM：First night-time seeing on 8m tower
  - Free-atmosphere seeing：0.31” (median)
  - Boundary Layer：only 13.9m (median)
- Meteorology (Hu et al., 2014, 2018)：
  - Wind：
    - < 4m/s @ 4m height
    - < 10m/s @ 10m（90% time）
  - Temperature
    - Long and strong temperature inversion



Temperature in 2017-2018



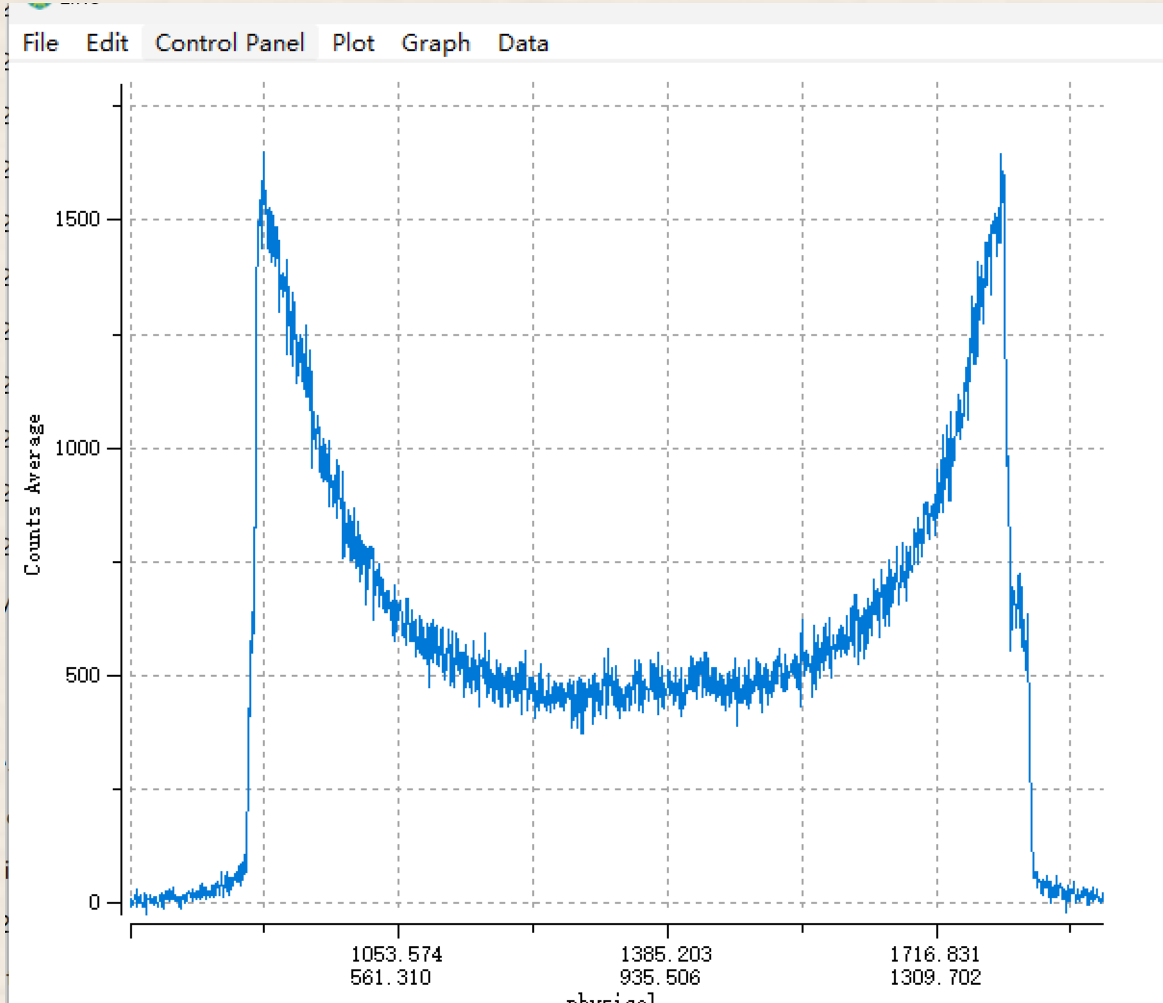
Strong temperature inversion

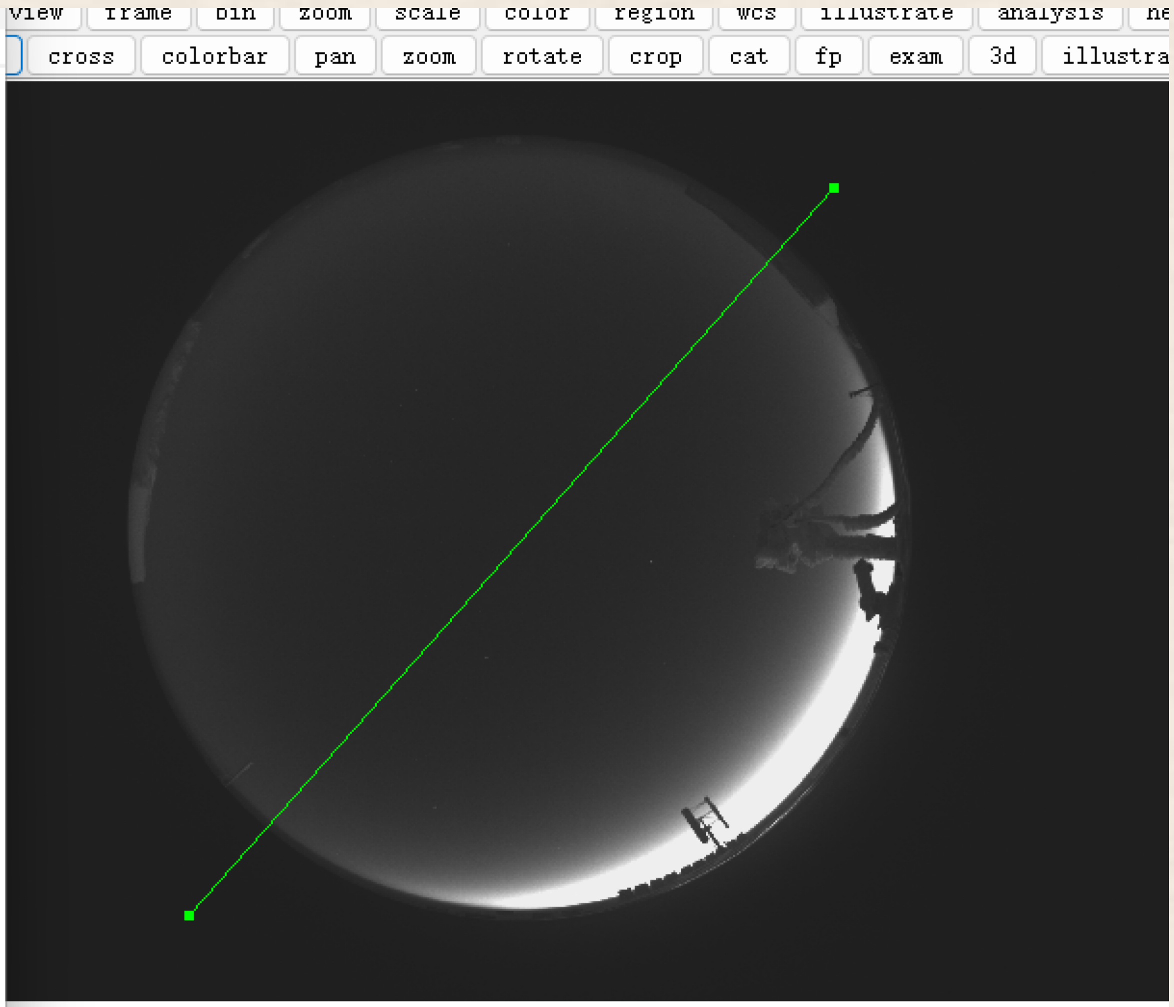


(Hu 2014)

Photometry

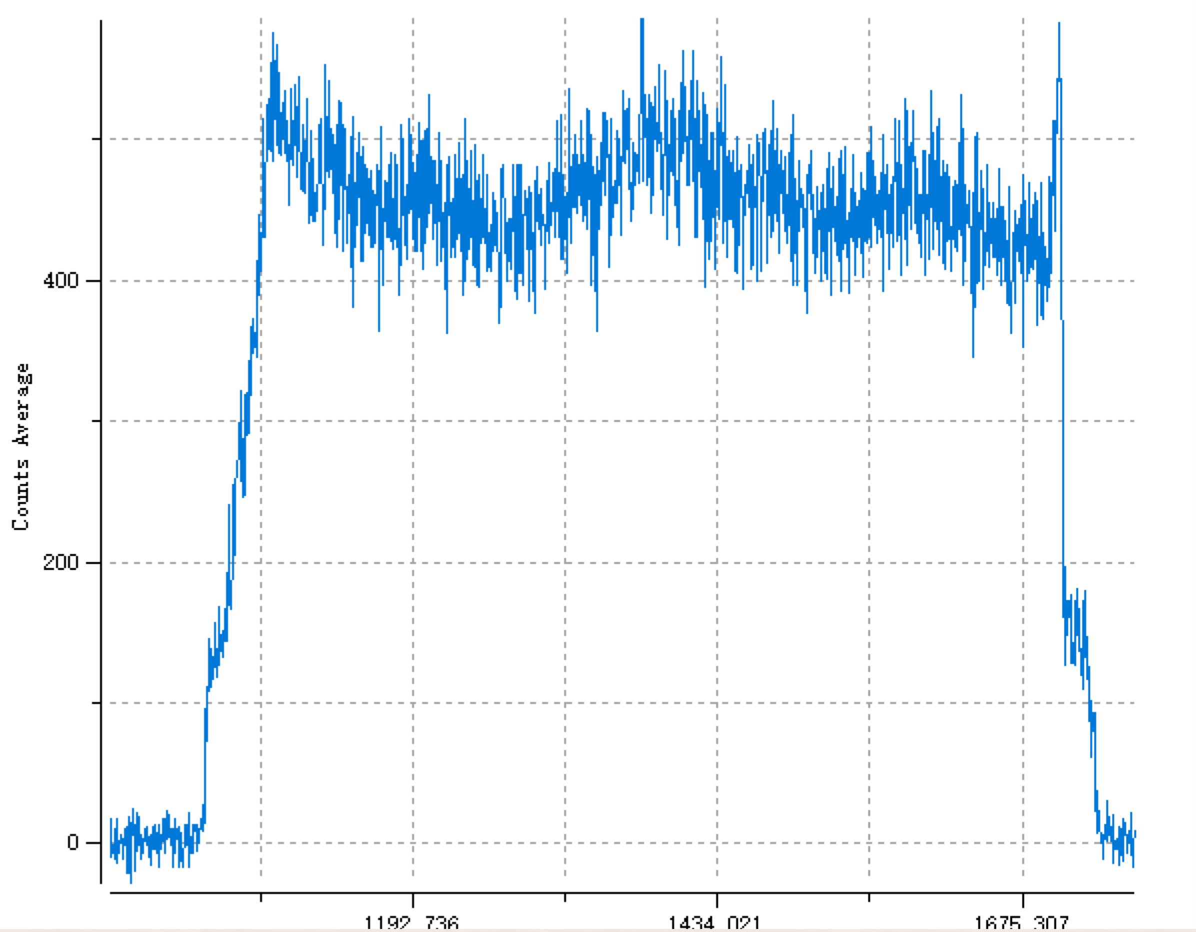
Background

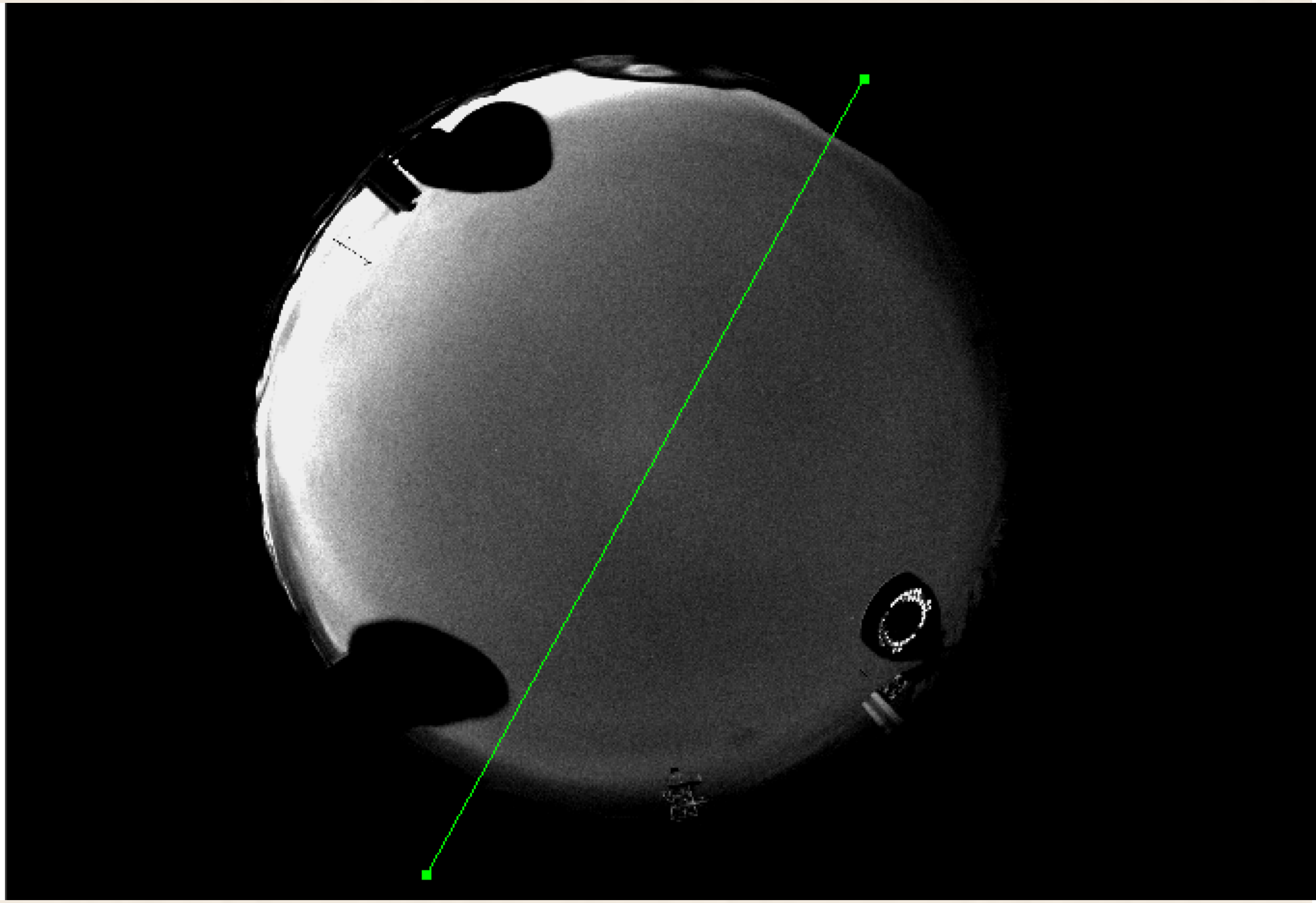




Photometry

Background





Photometry

Extinction