Using CSTAR to measure the sky brightness and transparency at Dome A, Antarctica

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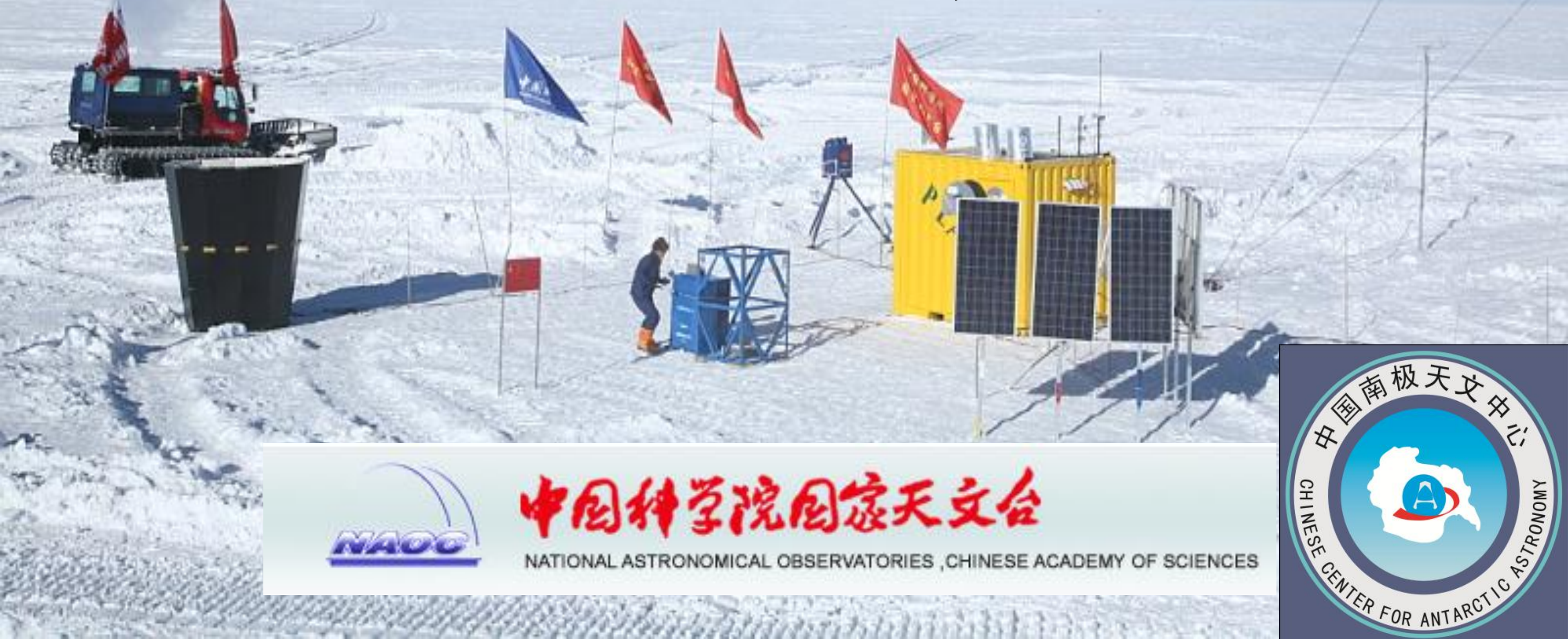
Chinese Center for Antarctic Astronomy (CCAA)

2010-10-8 Kislovodsk, Russian



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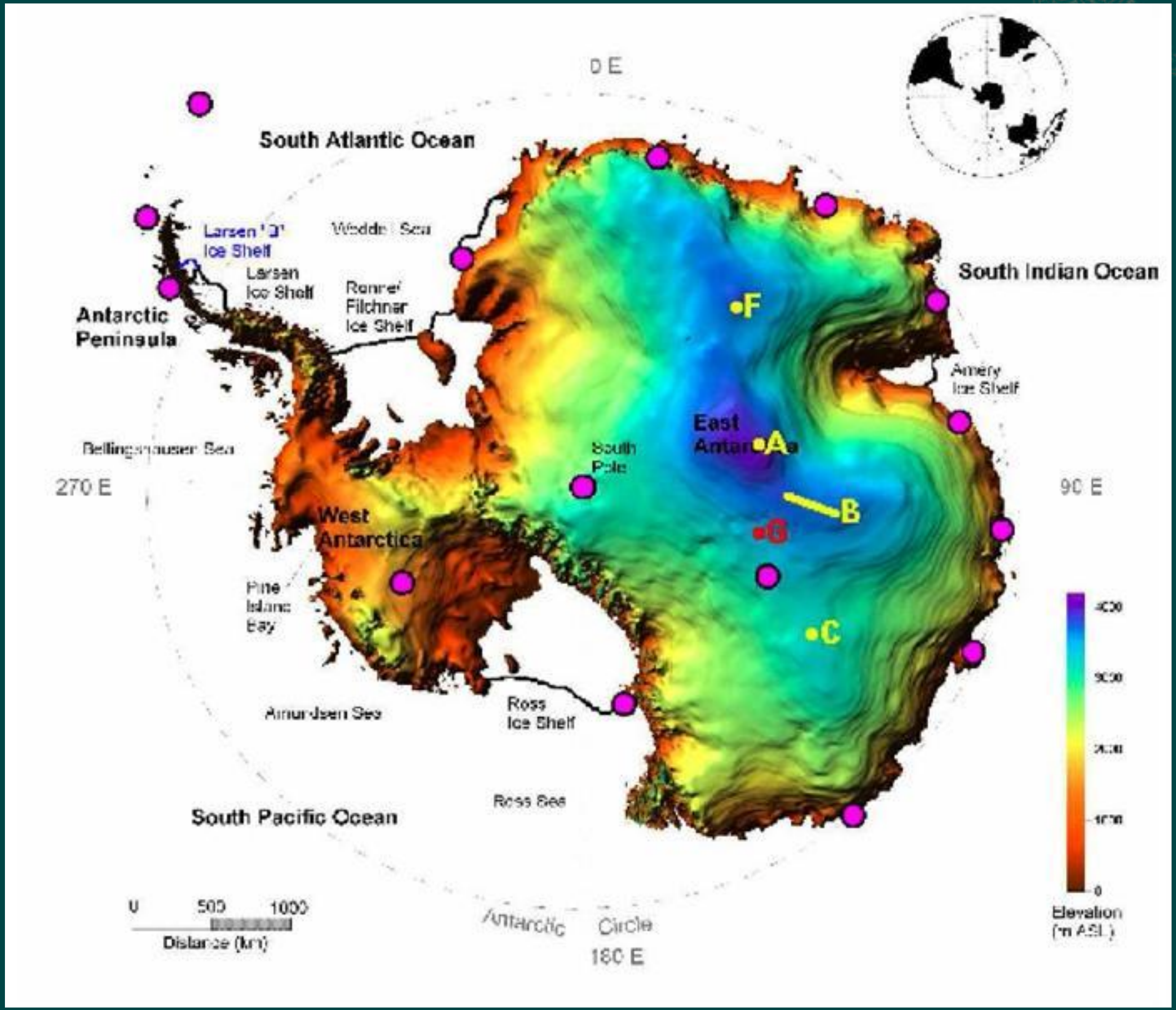
Outline

- Dome A
- CSTAR and Testing
- Observations and Data Reduction
- Some Results:
  - Variable stars
  - Sky brightness, transparency variation, cloud cover, aurorae
- Conclusions

Dome A

- Position:
  - 80.3° S, 77.5° E
- Temperature:
  - Mean: -50° C
  - Lowest: -80° C
- Altitude:
  - 4093m

  (Dome C: 3250m)



Will Saunders et al, 2009

Chinese Small Telescope ARray (CSTAR)

- Instruments
  - An array of 4 Schmidt telescopes, covered by filters: SDSS g, r, i and open bands
  - Aperture: 145mm (effective aperture: 100mm)
  - Focal Ratio: f/1.2
  - CCD: Andor1k x 1k
  - Pixel Size: 13μm (~15"/pixel)
  - FOV: ~4.5° x4.5°

Telescope optical design, CCD quantum efficiency and transmission curves of CSTAR filters

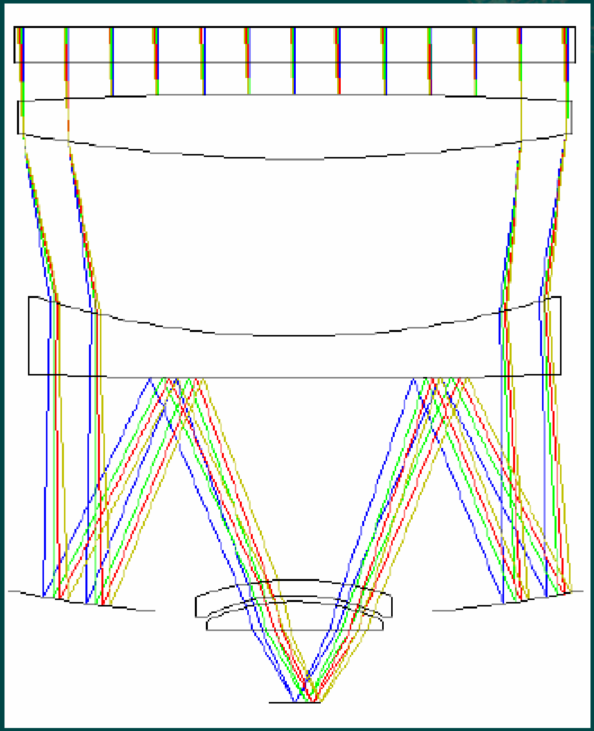
Main components: consist of a catadioptric objective with a spherical primary mirror

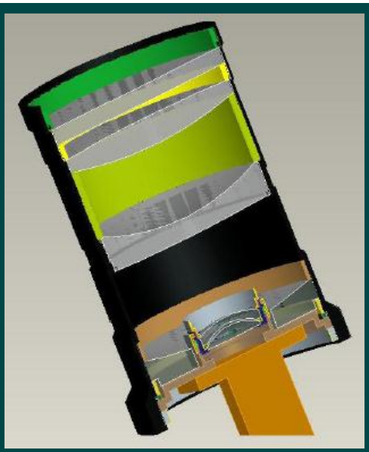
first plano lens: serves both as a window and as a filter

front window: electric current is passed through, providing ~ 10 W of power to keep the surface of the window warmer to clean the attached snow and ice

telescope tube: filled with pure nitrogen to avoid ice and frost formation on the internal optical surfaces

CSTAR is specifically designed for Antarctic operation, having no moving parts at all—including the optics and mechanical supporting system

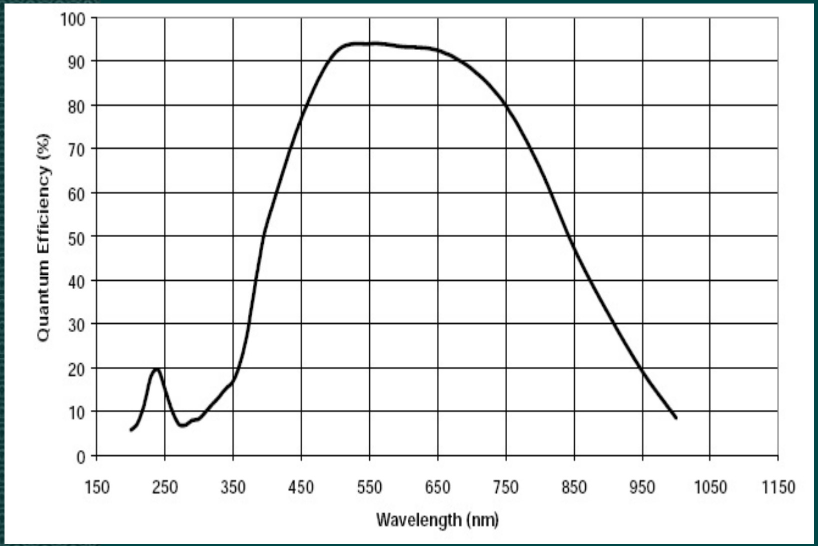




Telescope optical design, CCD quantum efficiency and transmission curves of CSTAR filters

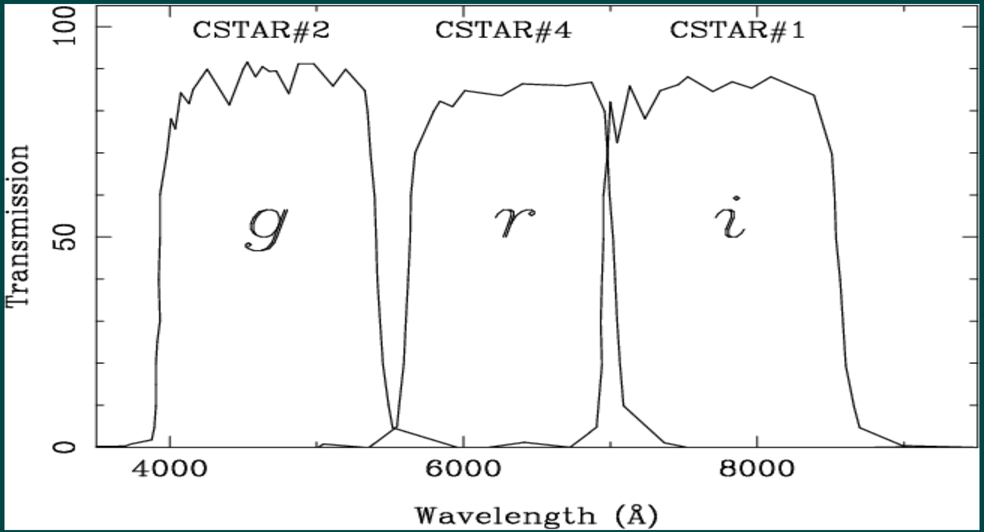
Andor DV435 1k×1k frame transfer CCD: advantage of requiring no mechanical shutter, ideal for fast imaging

CCD quantum efficiency



Filters, and transmission curves

telescope	CSTAR #2	CSTAR #4	CSTAR #1	CSTAR #3
filter	g	r	i	none
effective Wavelength (nm)	470	630	780	
FWHM (nm)	140	140	160	



Testing CSTAR

Most of the testing work was performed in Kalasu on the Xinjiang Pamirs of China at an elevation of 4450 m and at the Xinglong station of NAOC

four telescopes and the CCD can work at low temperatures down to nearly −80 ◦C, while the four control computers can work down to −30 ◦C

Dark current can be negligible under Antarctic conditions

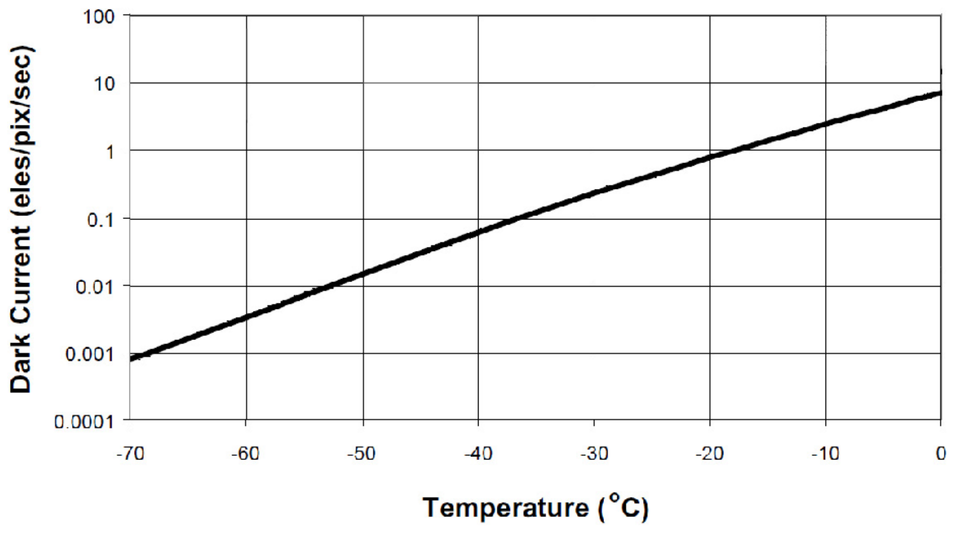


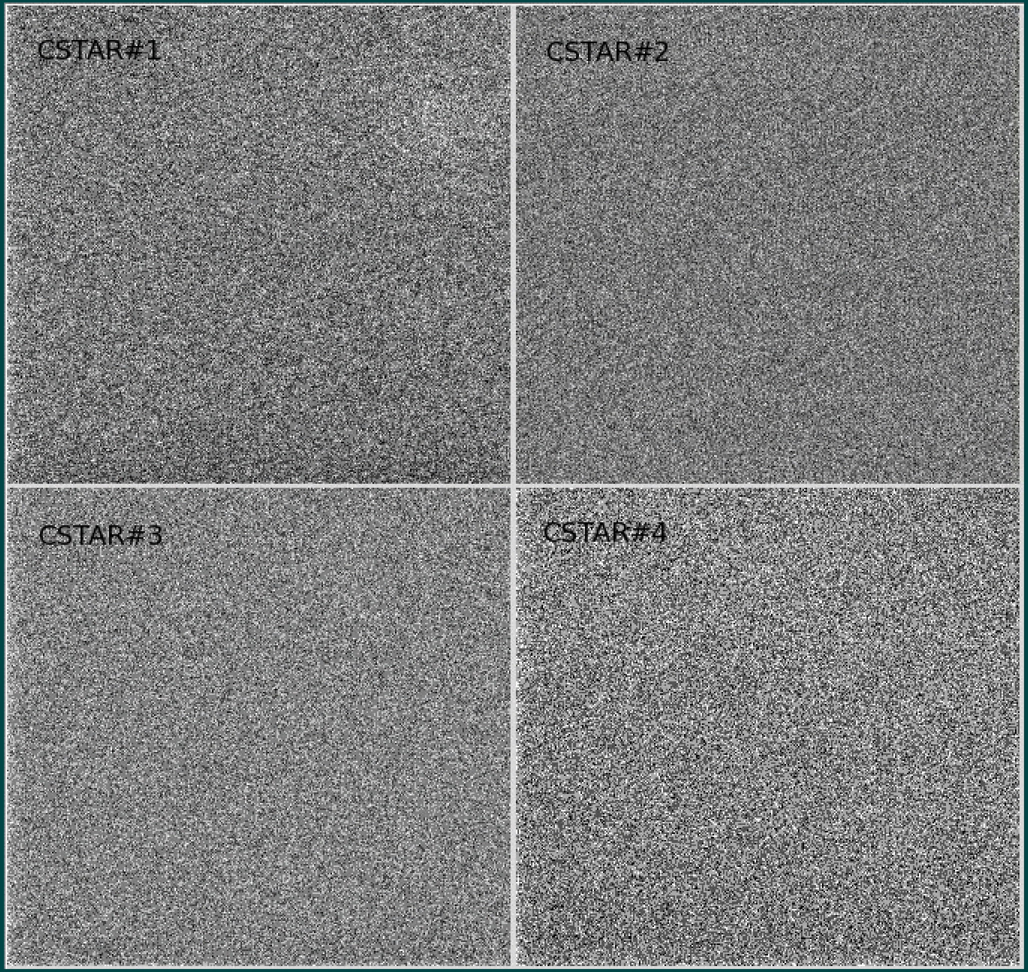
Fig. 7 Dark current of ANDOR CCD vary with the temperatures.

Testing CSTAR

Data collection system is tested under very low atmospheric pressure and temperature at Kalasu.

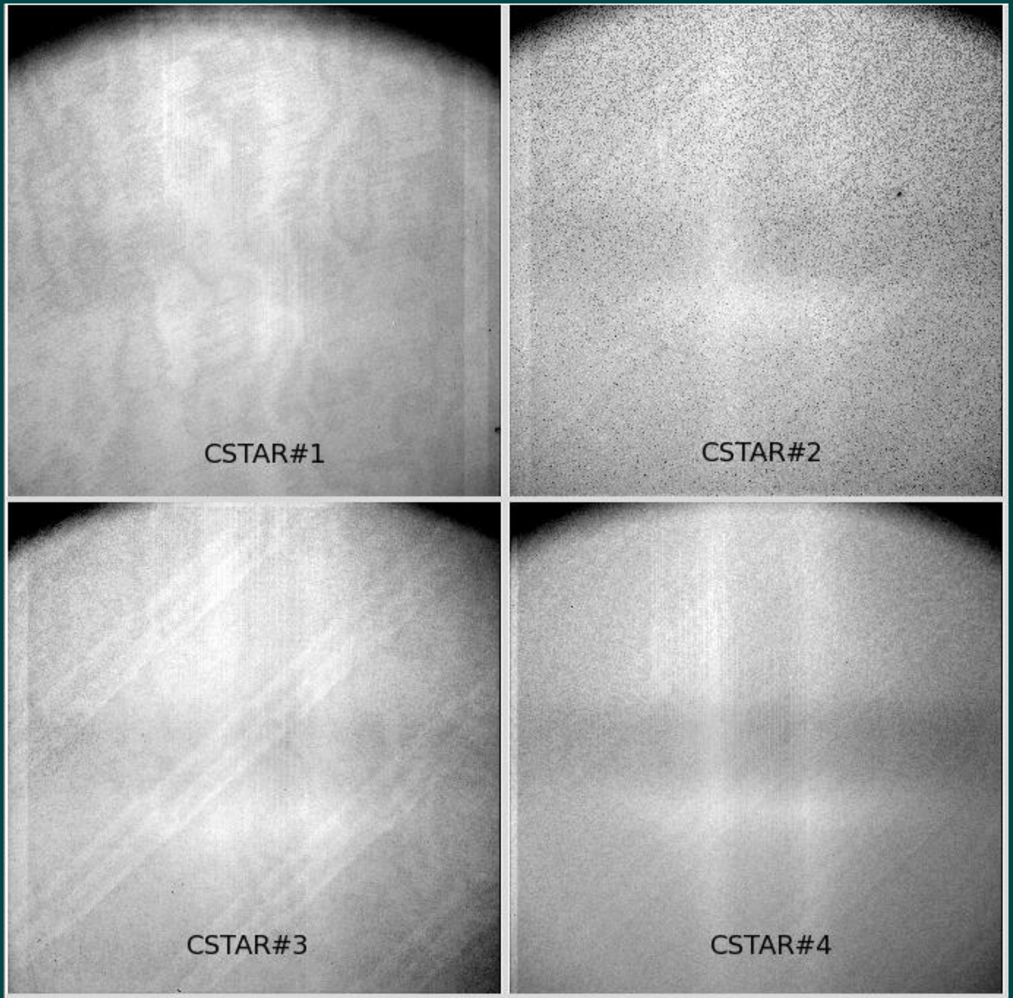
Testing CSTAR at Xinglong Station

'Super' bias: no obvious variation or structure
used for data reduction both from observations at Xinglong and from Dome A



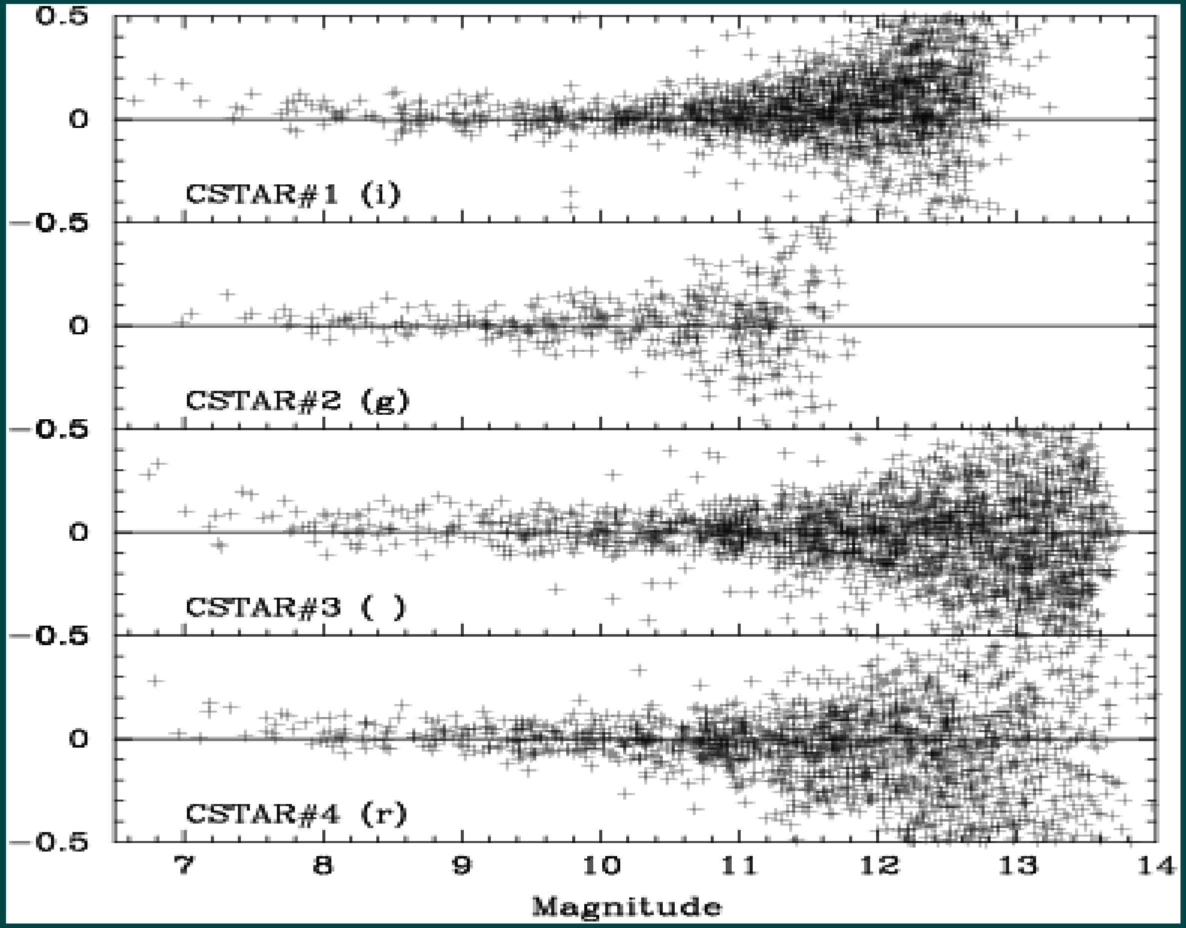
Testing CSTAR at Xinglong Station (Observation)

‘supersky’ flat-field images for each telescope: some obvious structures can be seen.



Testing CSTAR at Xinglong Station

Photometric errors for each telescope of CSTAR measurement errors are normally ±0.01 mag for bright stars



Scientific Purposes

- Site testing: transparency, sky background, cloud cover, auroras, etc.
- Detect variables in the South Pole Celestial field
- Variables with photometer and color, etc.
- Light curves of variables
- SNe, Novae, Orphan afterglows of γ outburst.
- Search for extra-solar planets.

CSTAR was successfully installed at Dome A, in Jan. 2008

Observations (in 2008)

- Field: the Celestial South Pole area
- Telescope: CSTAR#1 (with SDSS i band)
- Integrated Time: 20 or 30 s
- Date: March 4 to August 8, 2008
- Images: about 310,000 flames
- Accumulative exposure time: 1,728.61 hours
- Sources: more than 10,000, faint to ~16 mag.

CSTAR still worked well in 2009/2010

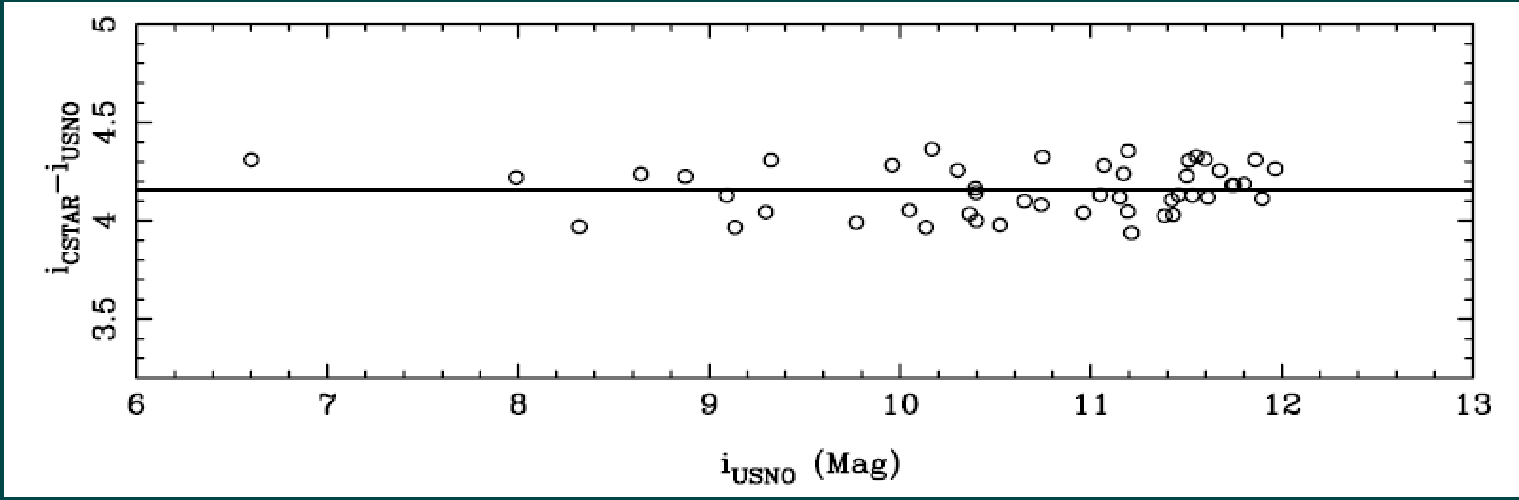
Our current work is only based on the data of 2008.

An Image from CSTAR

Data Reduction

Calibration

Comparison of the USNO-B1 i magnitudes and the CSTAR
i-band instrument magnitudes of 48 stars to do flux-calibration
Eorror is about 0.12 mag



Data Reduction

Catalogue:

Photometry of the sources in three different apertures

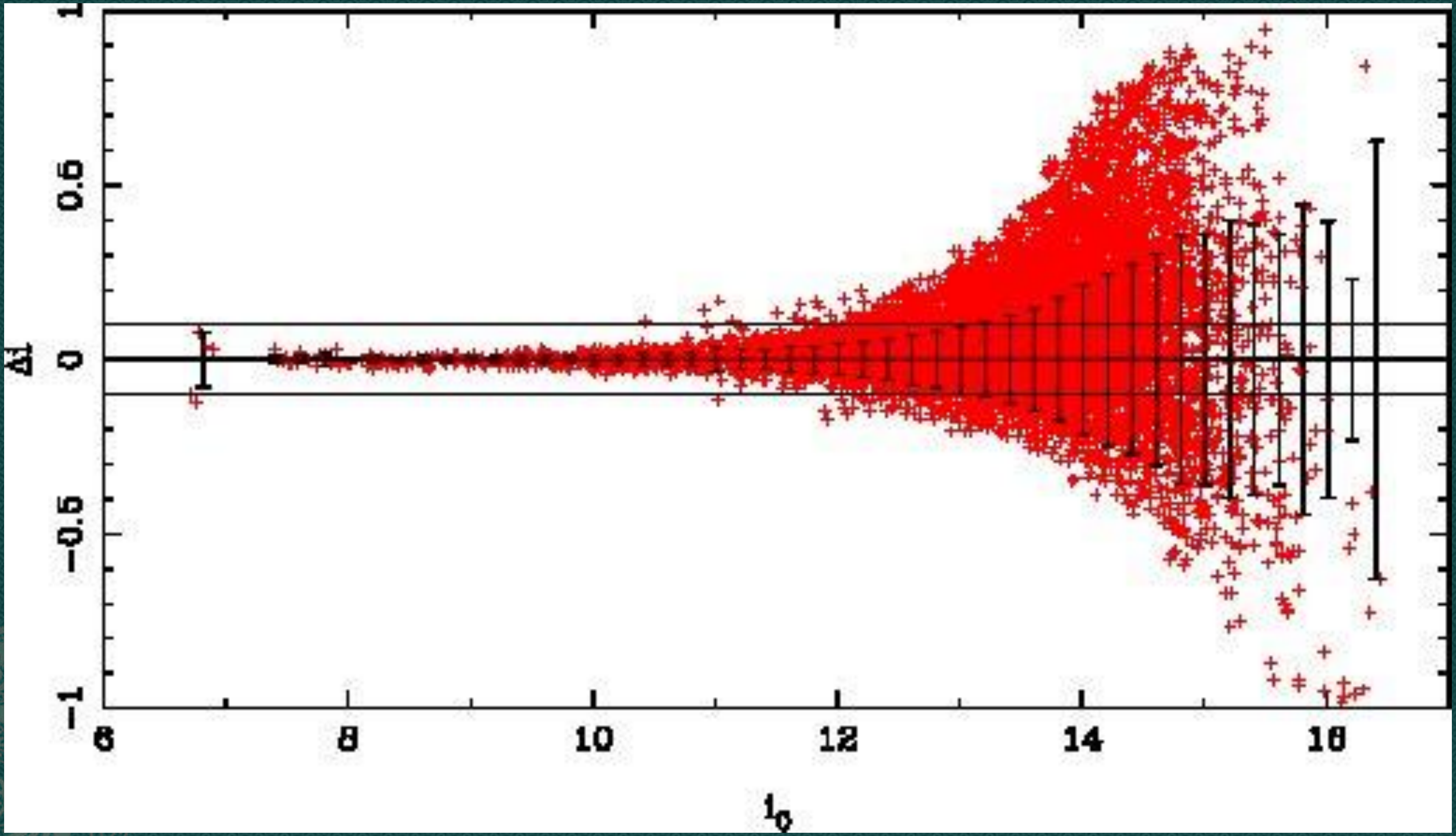
Table 1: The photometry of the sources in three different apertures.

-50 2008 May 12 17:50:06.92 20 352 A 12552

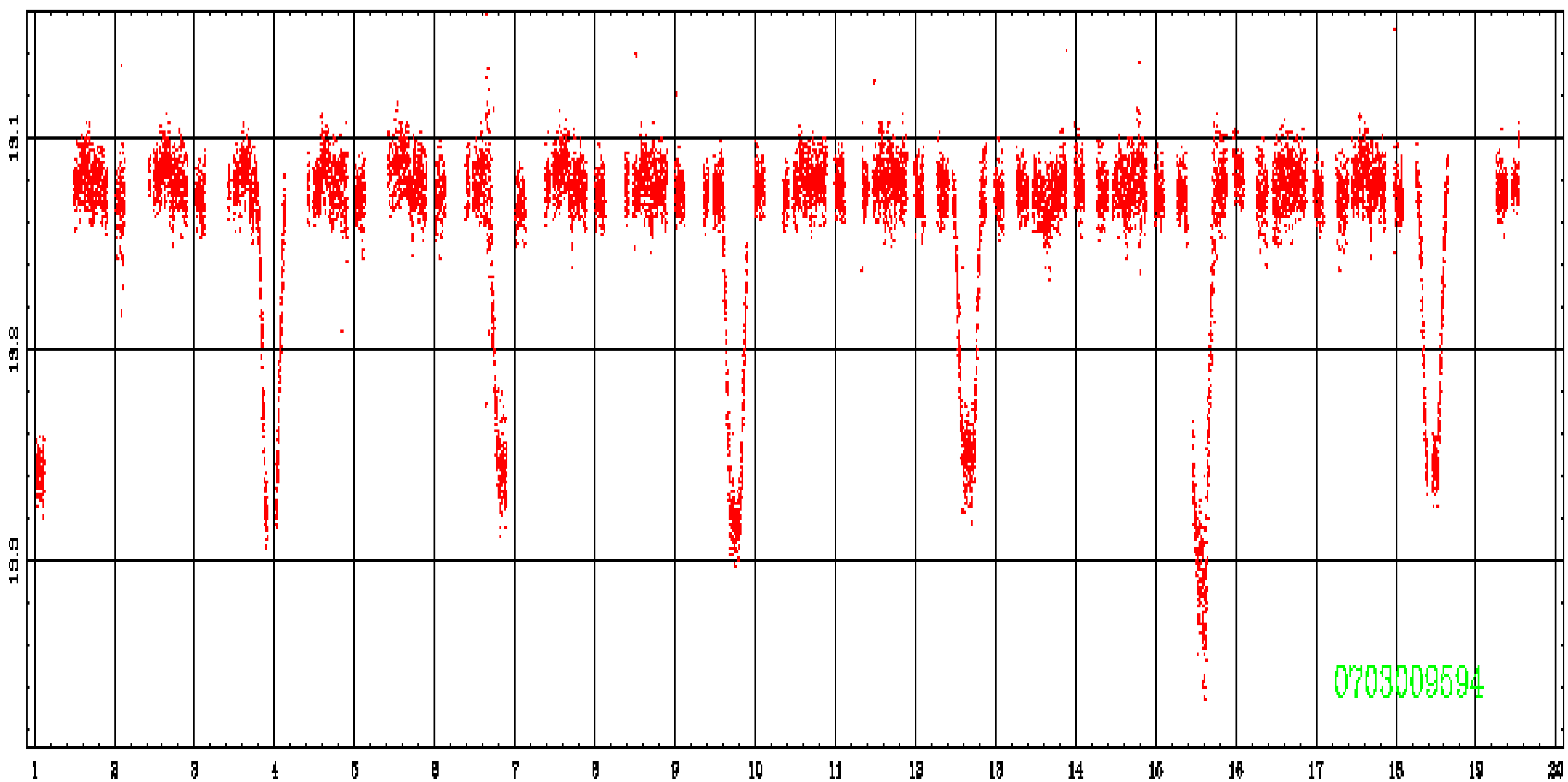
RA (J2000)	DEC (J2000)	M_1 (r=1 pixel)	σ_1	M_2 (r=2 pixels)	σ_2	M_3 (r=3 pixels)	σ_3
22:31:48.6	-88:45:47.5	10.257	0.024	10.161	0.027	9.919	0.019
15:22:46.9	-88:05:42.4	10.253	0.027	10.233	0.027	10.216	0.027
10:52:29.1	-87:19:54.9	10.259	0.024	10.234	0.027	10.221	0.027
14:52:24.1	-88:34:09.9	10.253	0.027	10.218	0.027	10.159	0.027
11:17:01.9	-87:45:40.3	10.263	0.024	9.970	0.019	9.401	0.011
20:00:40.9	-88:17:25.9	10.255	0.024	9.666	0.016	9.414	0.011
10:57:48.6	-88:02:11.0	10.286	0.024	10.258	0.024	10.237	0.027

Magnitude Limit:

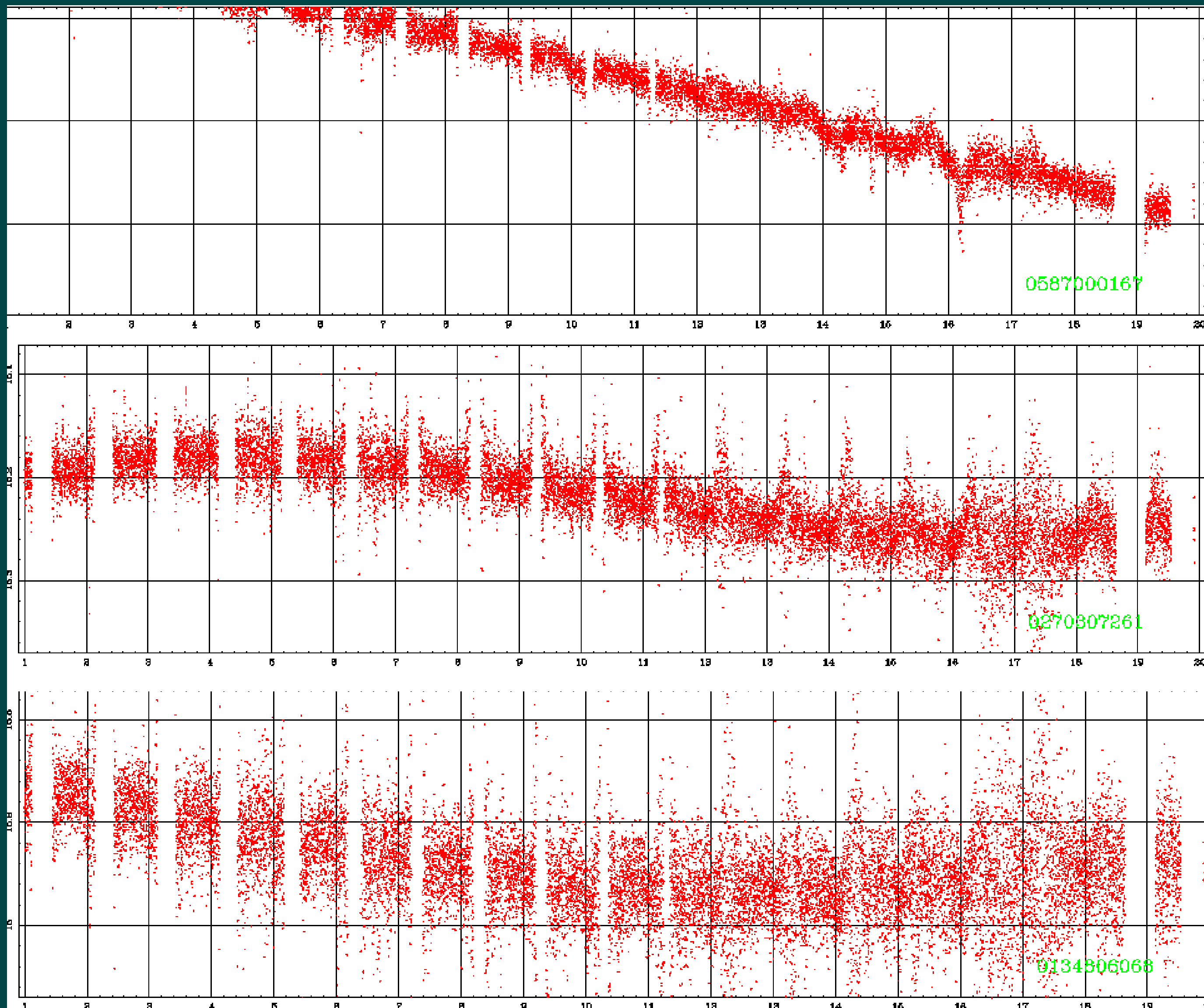
Errors are the magnitude differences between observed images and the best reference one. **Error bar** represents the dispersion in RMS. **Two lines** represent the $\triangle i$ =0.1, which is corresponding to the limiting magnitude at S/N=10.



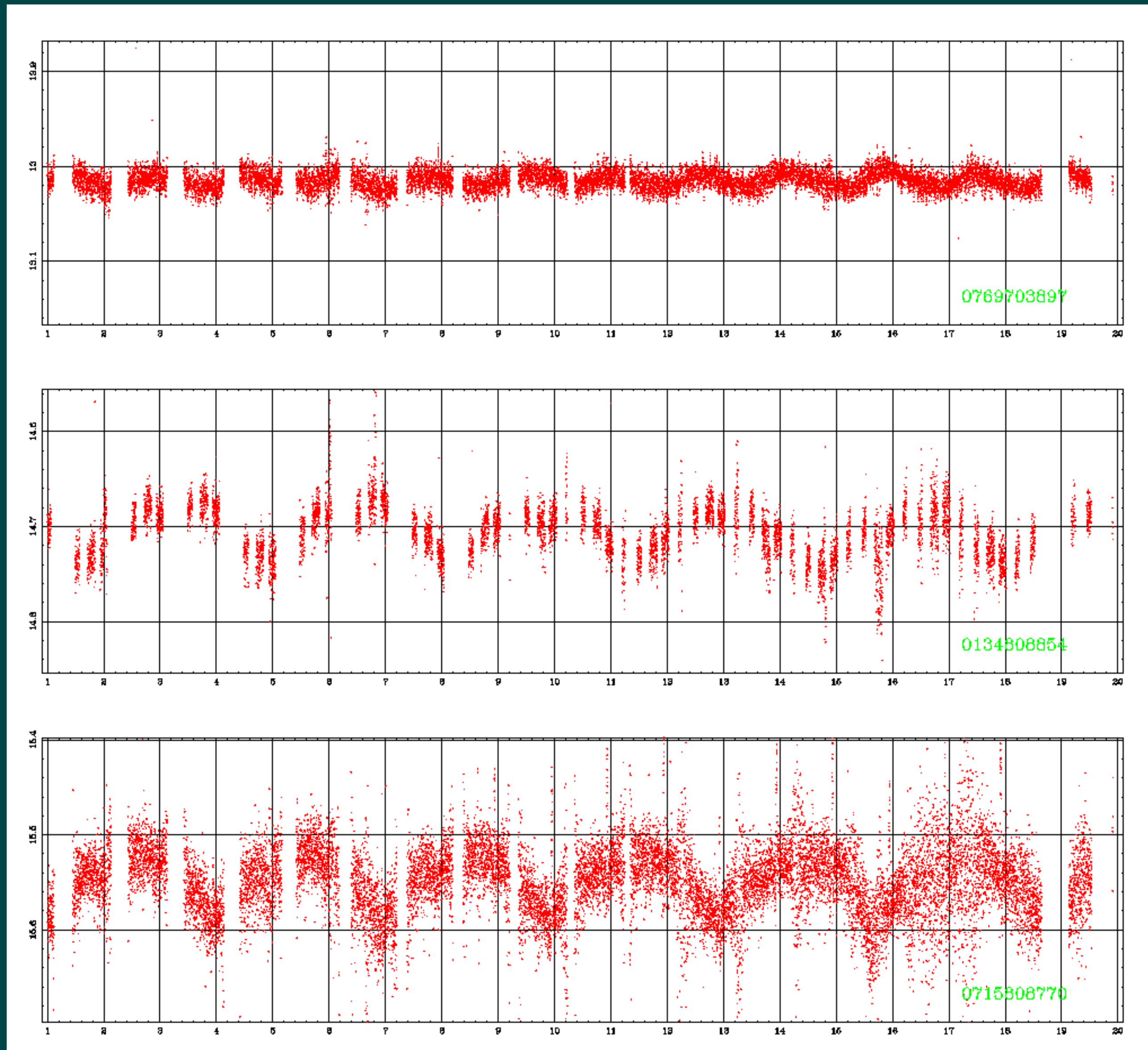
Some Results:
Light curves of some variable stars



Light curves of some variable stars



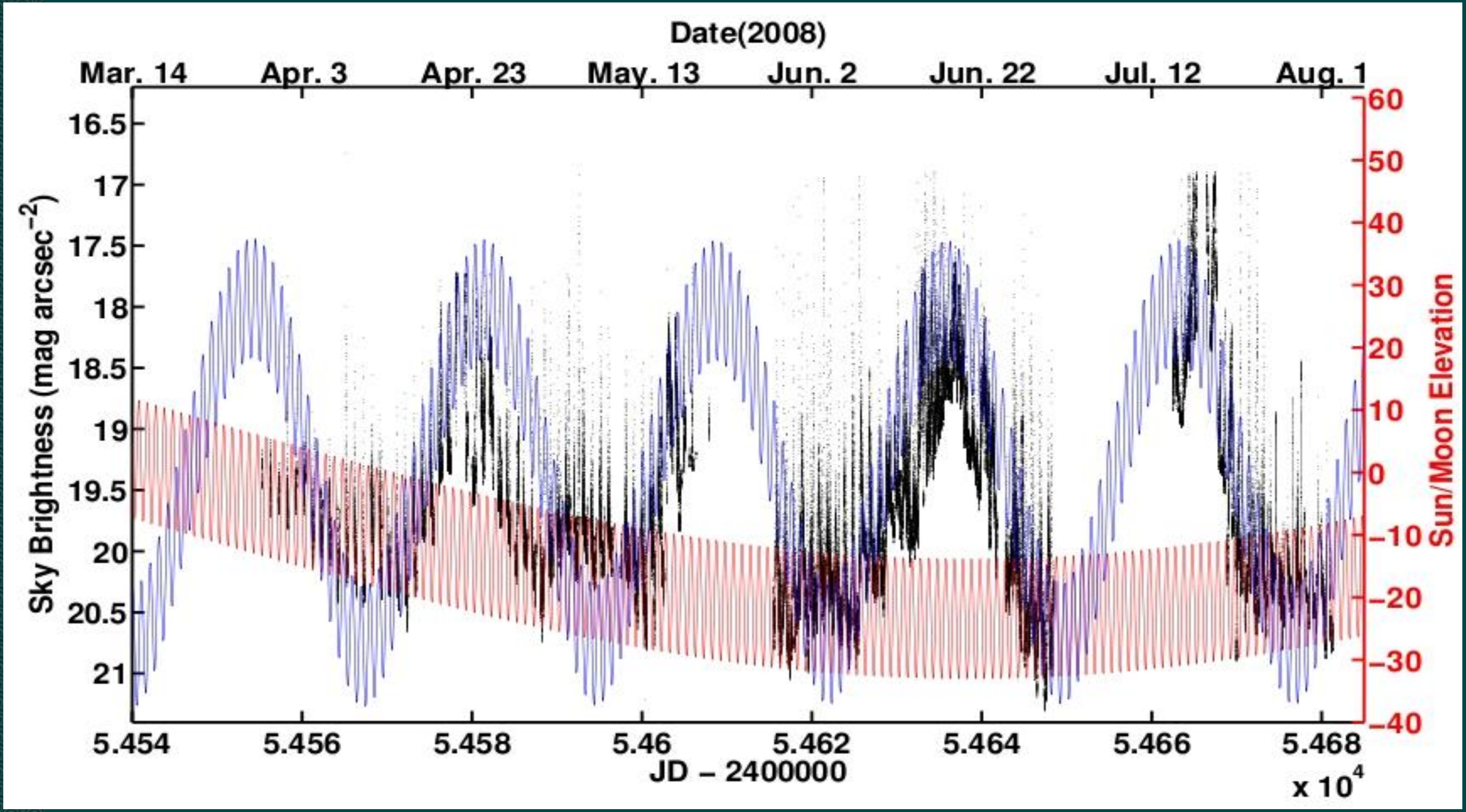
Light curves of some variable stars: will be studied in the near future



Night Sky Brightness

- Over all night sky Variation

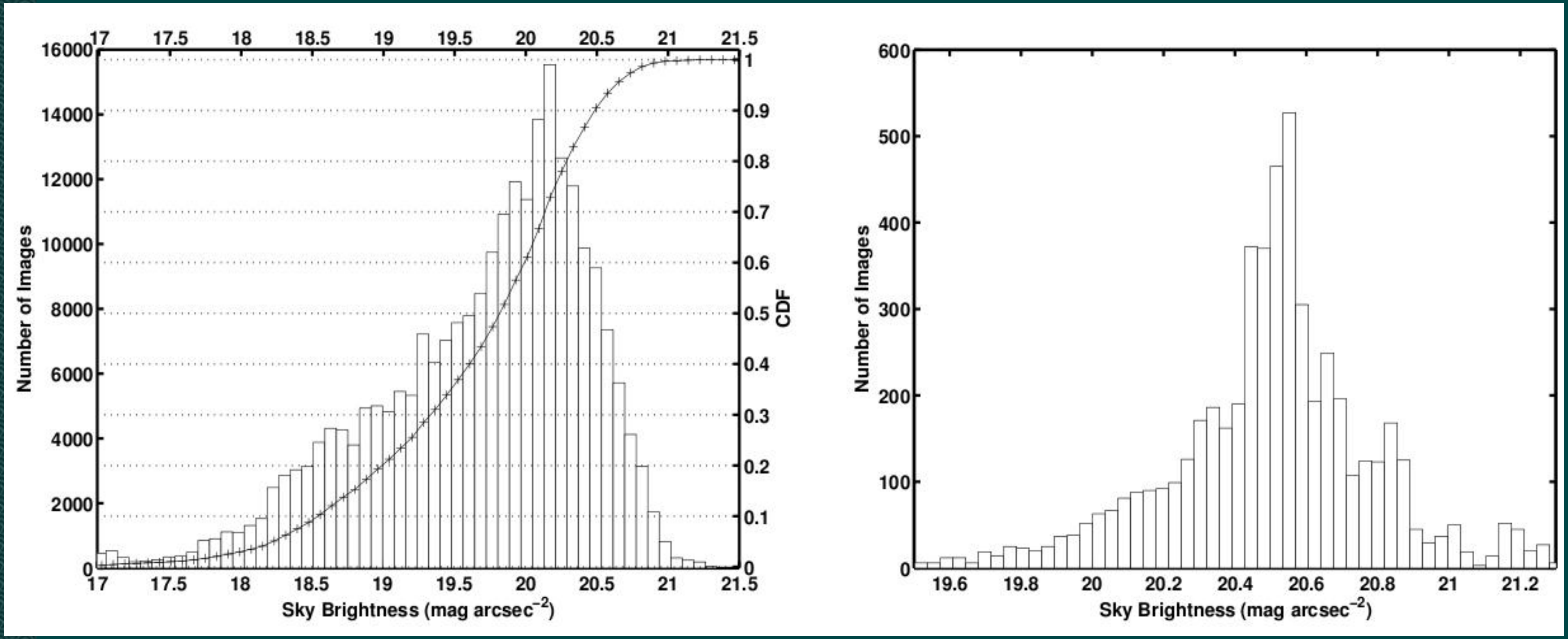
Black: sky brightness
Red: Sun elevation
Blue: Moon elevation



Night Sky Brightness

Over all night sky

- Median brightness of 19.8 mag arcsec^{-2} across all lunar phase (left panel in the following figure)
- Median of 20.5 mag arcsec^{-2} at moonless clear nights (right panel)
- Sky brightness from the Galactic background is estimated to be about 60 mmag



Sky background vs. other good sites at temperate latitudes (in magnitudes of i–band)

Dome A		20.5	
La Palm	20.10	Cerro Tololo	20.07
Paranal	19.93	Calar Alto	19.57

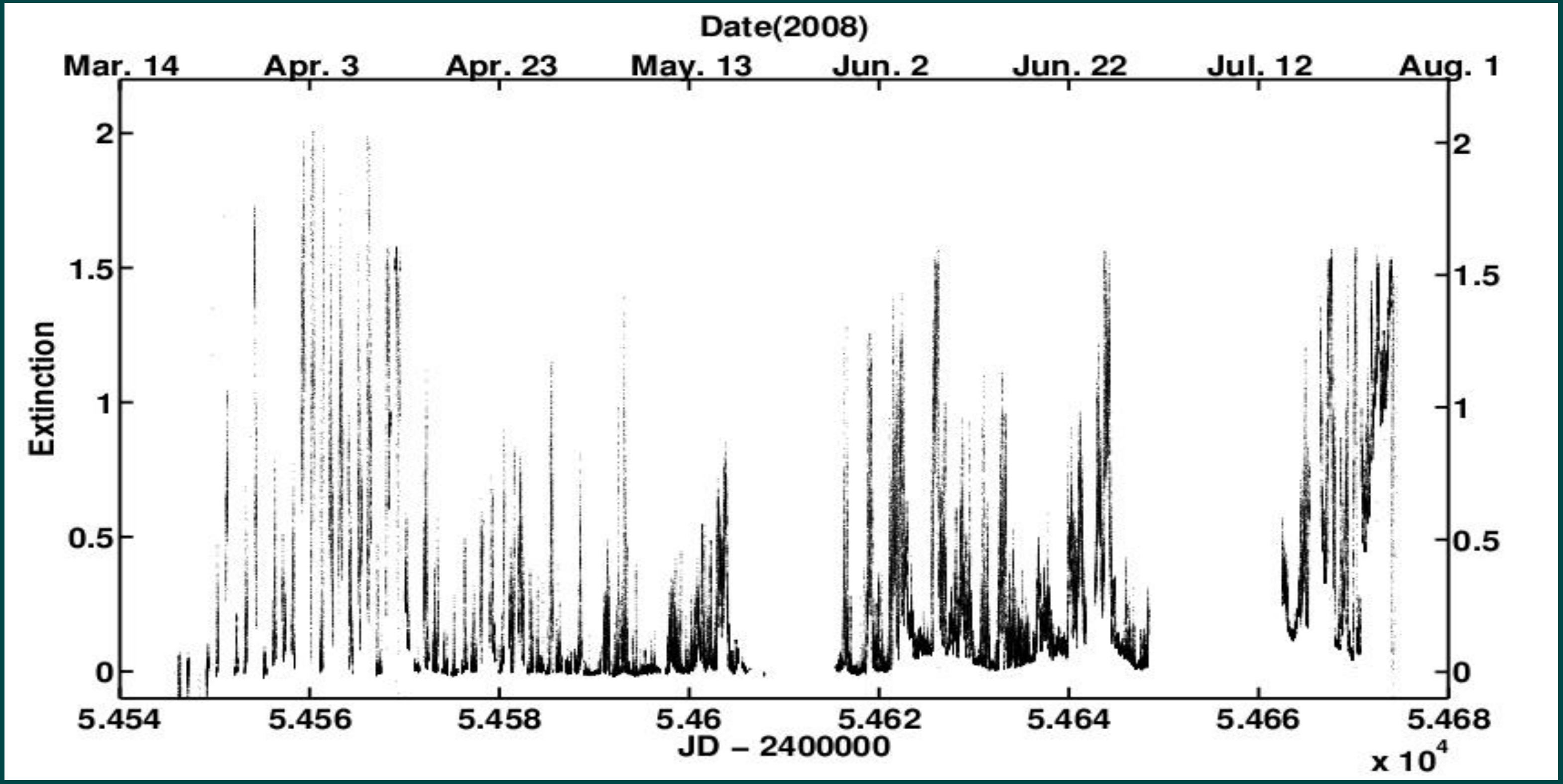
Dome A has a darker sky background than the above astronomical sites, even allowing for calibration and other uncertainties of up to several tenths of a magnitude

Transparency Variation and Cloud Cover

Over all transparency variation

Since the telescopes are fixed to point to the south pole, the absolute extinction is hard to be derived.

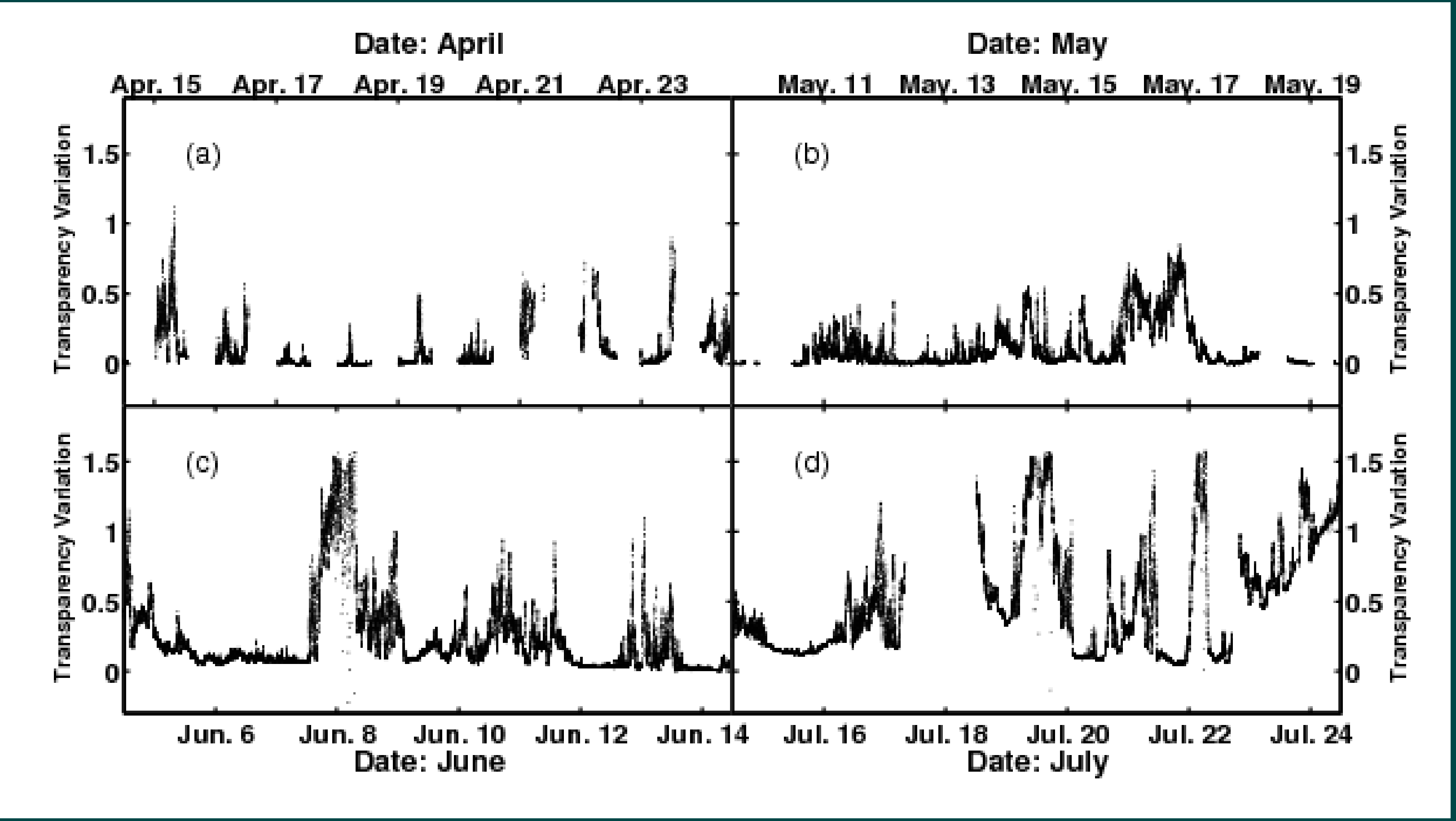
But, the relative transparency variations can be easily calculated by the differences between the observed image and the reference one.



Transparency Variation in each of four months

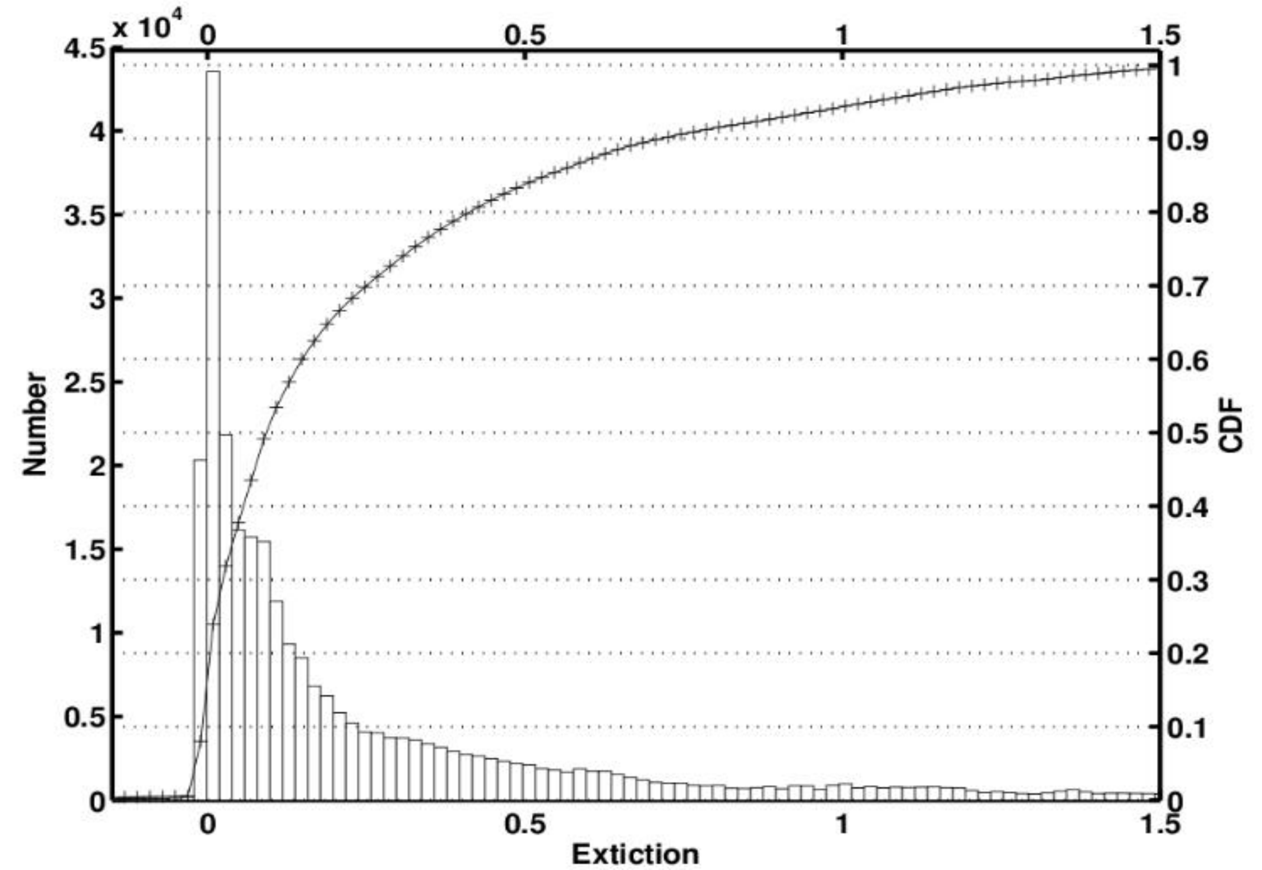
Median values of the transparency variation for months from April to July are 0.056, 0.016, 0.127, and 0.49.

Weather may be good in April and May, intermediate in June and bad in July.



Transparency variation distribution

90% of images: < 0.7 mag
80% of images: < 0.4 mag
More than half: < 0.1 mag



Cloud Cover

The Comparison of Cloud Cover Between Mauna Kea and Dome A

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%

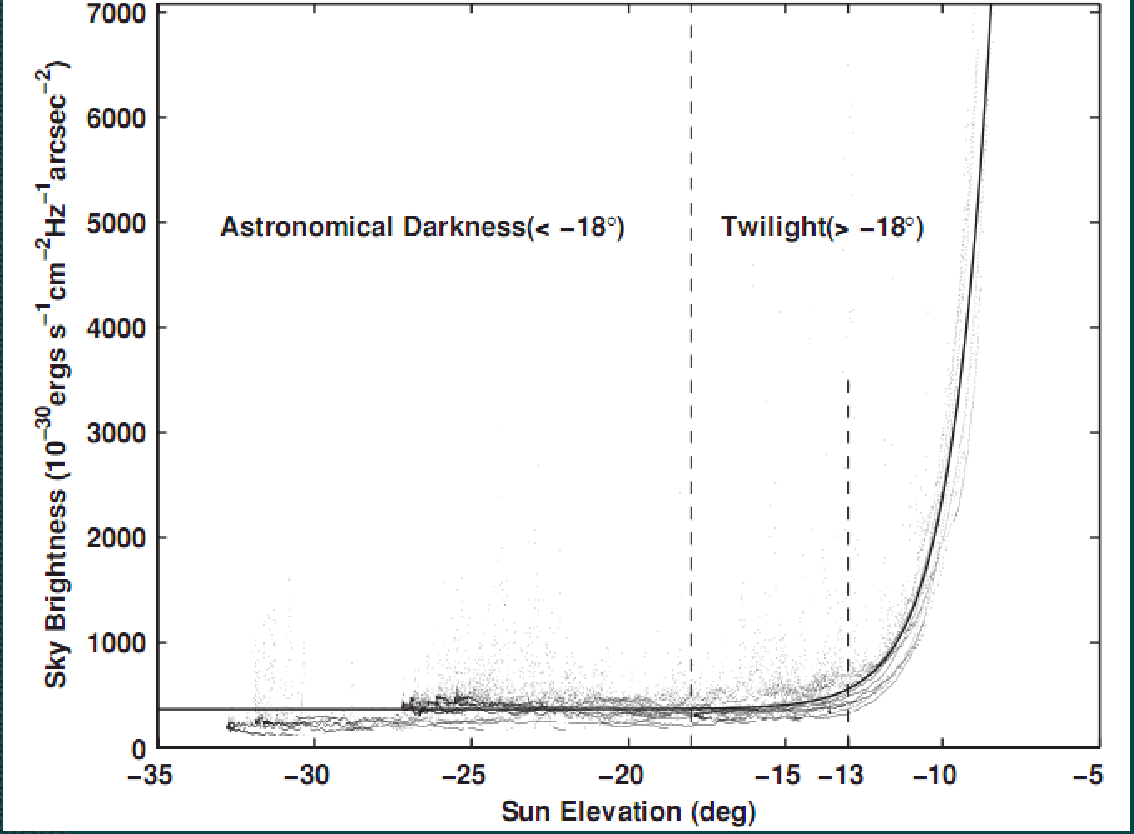
Notes. The definition of cloud cover is adopted from the Gemini Observatory. For comparison, we use $V - i = 0.07$ in extinction for the different transparencies of these two bands as presented in the text. Note that the term "photometric" as used here is just one kind of cloud cover category and it is different from the normal term "photometric night."

It seems that the transparency condition at Dome A might be better than Mauna Kea. However, it should be validated by more data (2009 and 2010), because the estimation is based only on a 20 deg^2 area of the sky and the transformation is very crude.

Aurorae

Method: after subtracting the contributions of sky brightness from the Sun, the Moon and clouds, then the residual sky should be the constant intrinsic sky background and auroral contribution.

Absolute flux from the Sun



Model

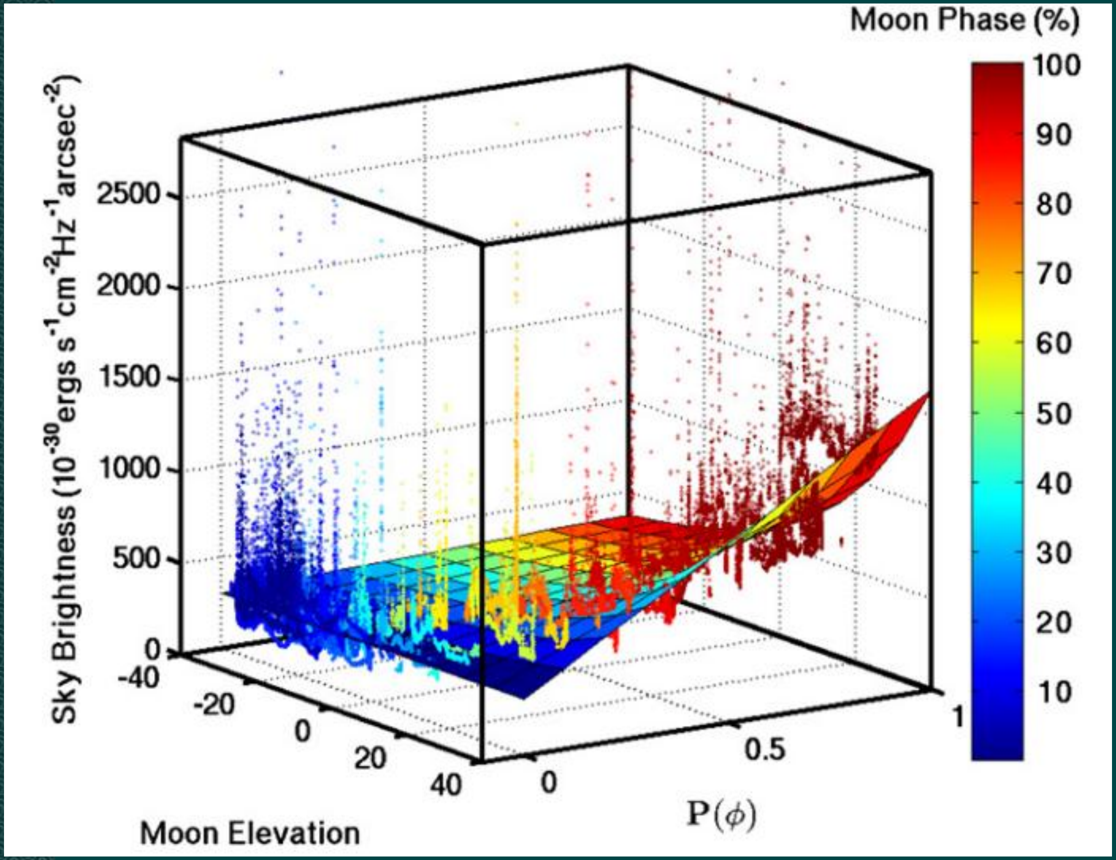
$$F_{\mathrm{Sun}} = a10^{b\theta} + c,$$

F is the sky surface flux, θ is the solar elevation, a, b and c are quantities to be fitted

Data points are the images observed at clear nights and without the Moon contribution.

Aurorae

Absolute flux from the Moon



Model

$$F_{\text{moon}} = A\,P(\Phi)10^{B\Theta} + C,$$

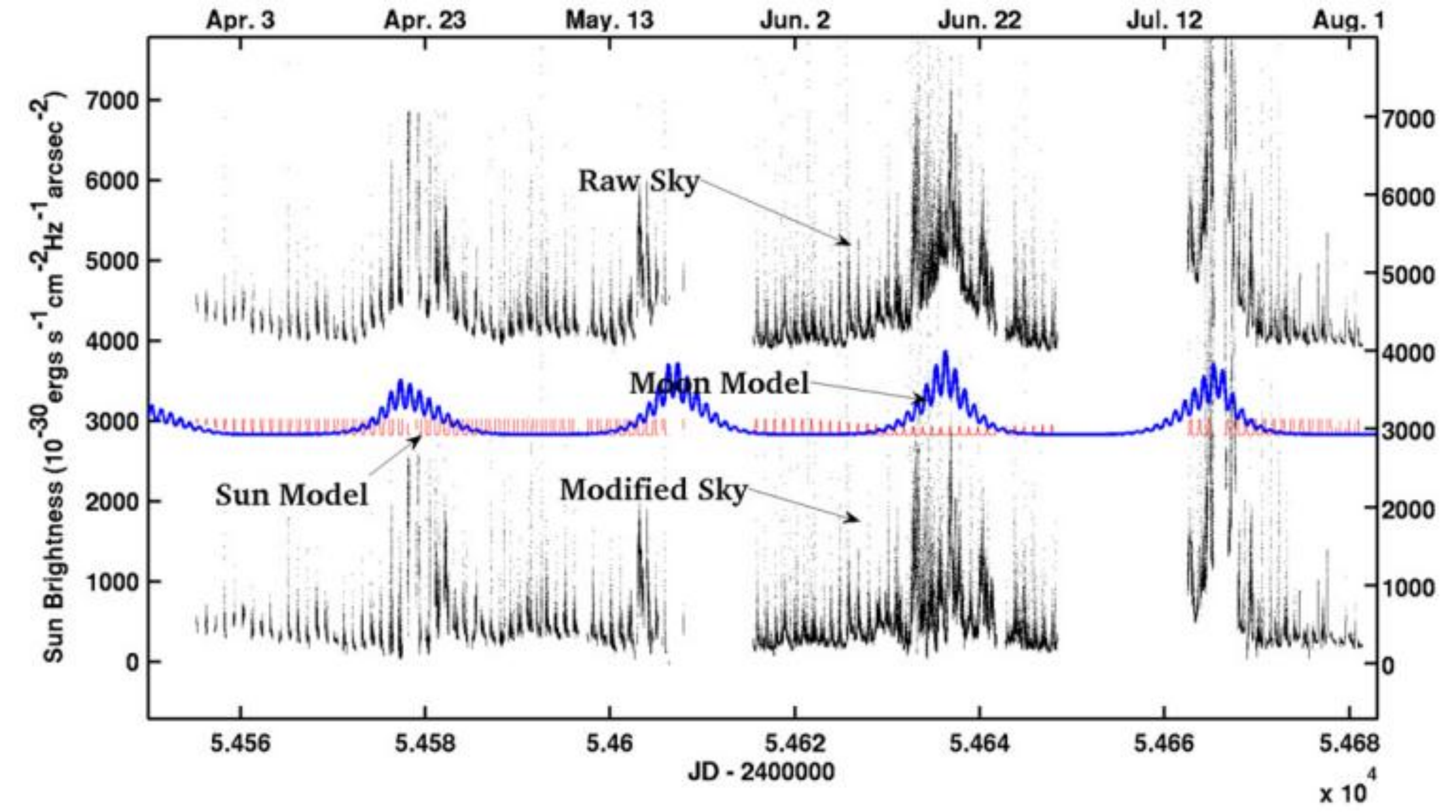
Φ is the moon phase angle and P(Φ) is the phase function which is 0 when the moon is new and 1 when the moon is full.

A, B and C are quantities to be fitted. C corresponds to the intrinsic sky brightness

Data points are the images observed at clear nights and without the solar contribution. Outliers should be the aurorae

Aurorae

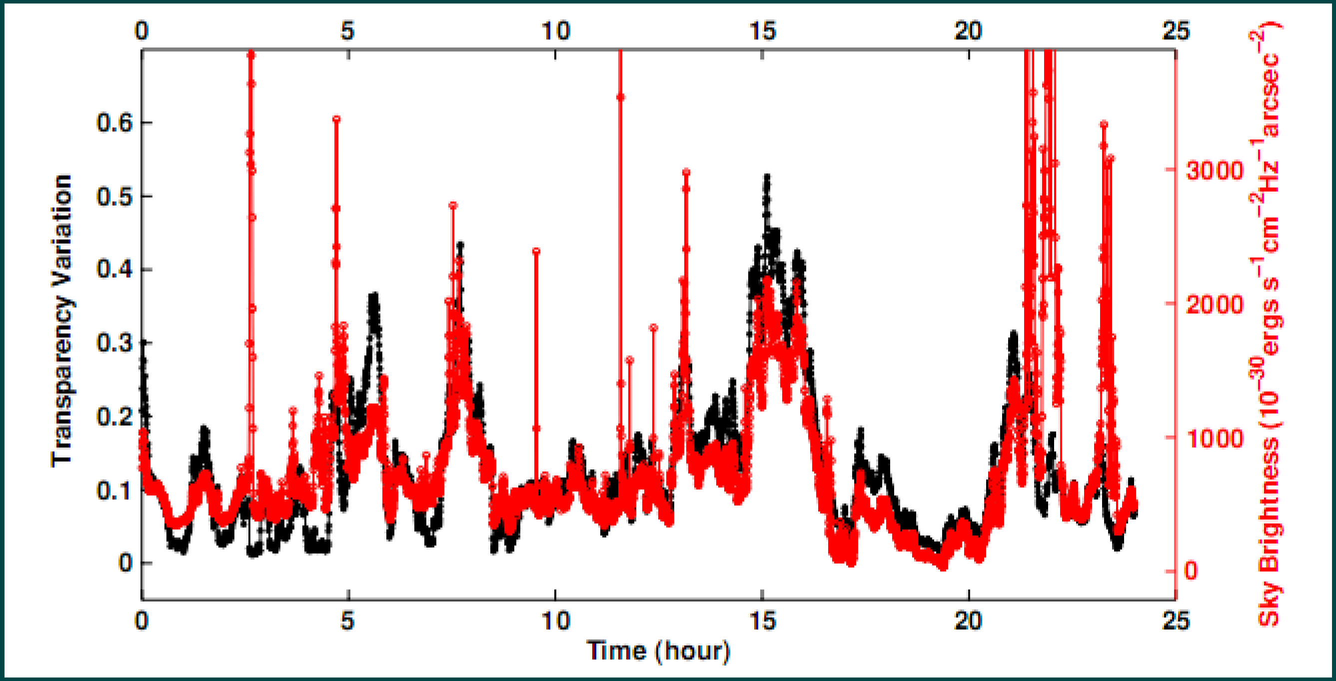
Remove the solar and lunar contribution



Aurorae

The sky brightness is proportional to both the extinction (cloud cover) and the total illuminance of the Sun and Moon when any of these two source is present, but should be inversely proportional to the extinction if no illuminant sources.

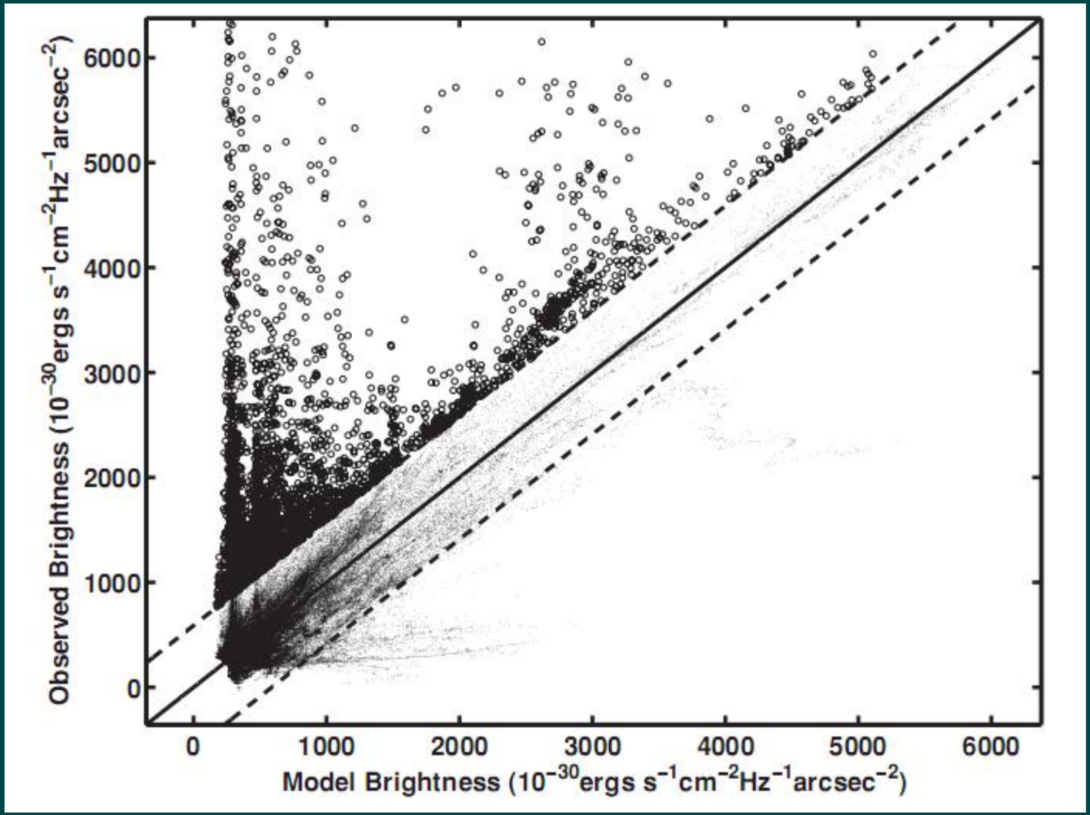
The transparency variation vs. the sky brightness on July 16 when the moon is full and the transparency is bad.



Aurorae

Model: construct the relationship among the sky brightness F, the solar and lunar contributions (F_{sun}+F_{moon}) and the transparency (E). a, b and c are parameters to be fitted. b should be minus.

$$F_{\mathrm{sky}} = a(F_{\mathrm{sun}} + F_{\mathrm{moon}})E + bE + c,$$



Outliers outside 3*RMS should be relatively strong aurorae:

About 1.7% of images are affected by aurorae.

Conclusions

- The median sky brightness is about 20.5 mag arcsec^{-2}

- The sky brightness in *i* band is as well as or even better than other temperate sites

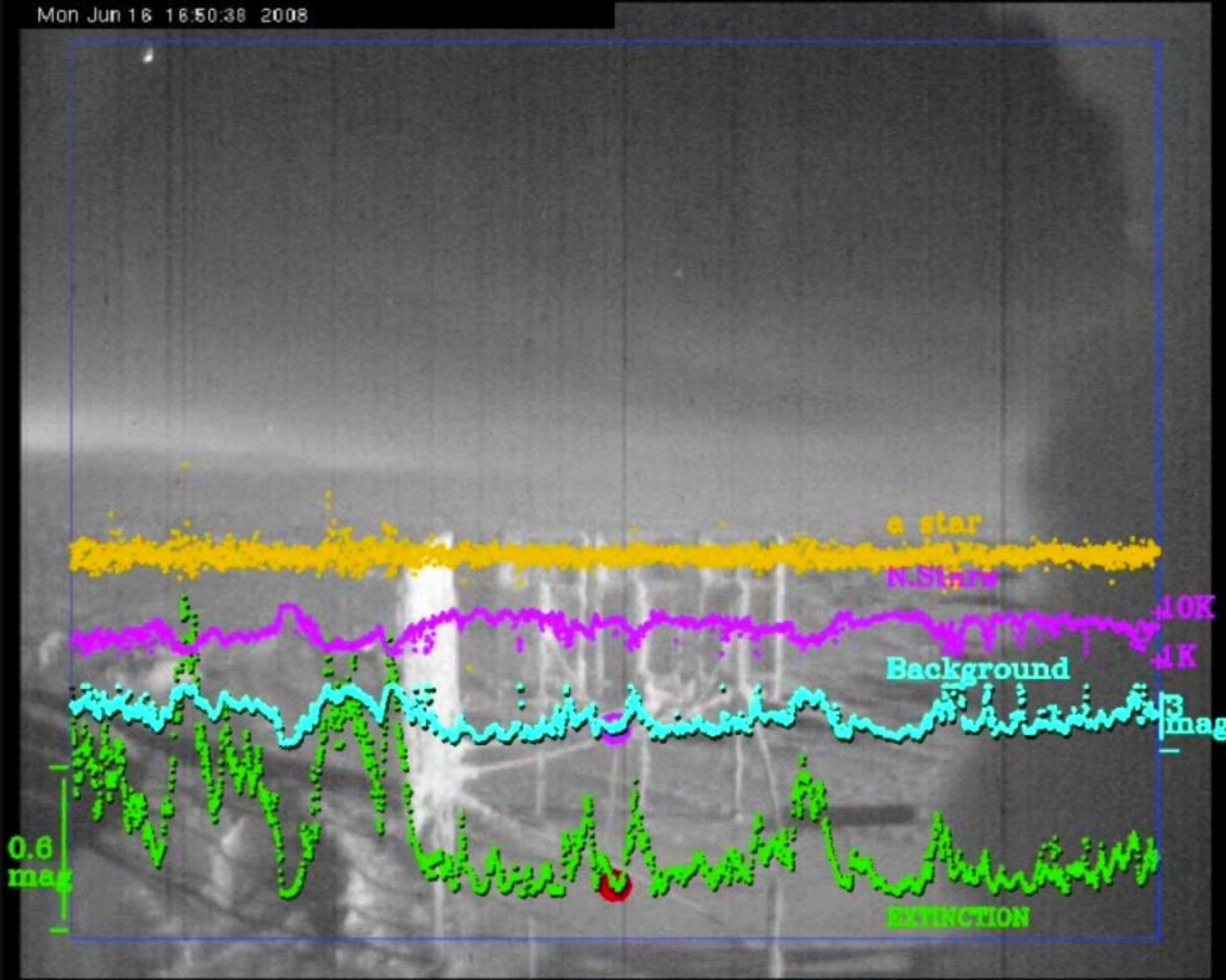
- The whether is relatively bad in June and July of 2008.

- The cloud cover seems to be better than that of Mauna Kea, which should be confirmed with more data of CSTAR in the next few years and from some other instruments.

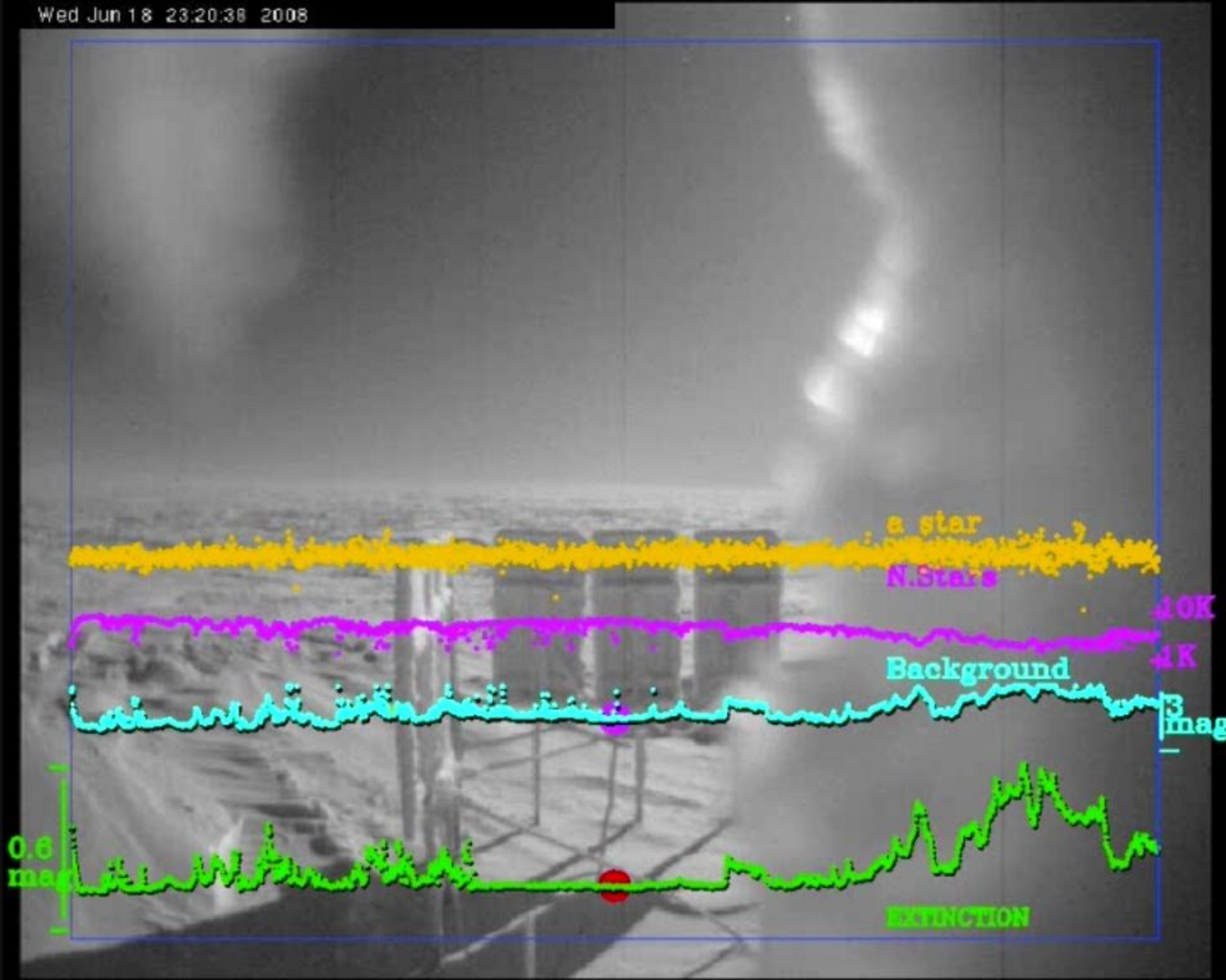
- The fraction of images affected by relatively strong aurorae is about 2%.

- A considerable light curves are gained for future studies.

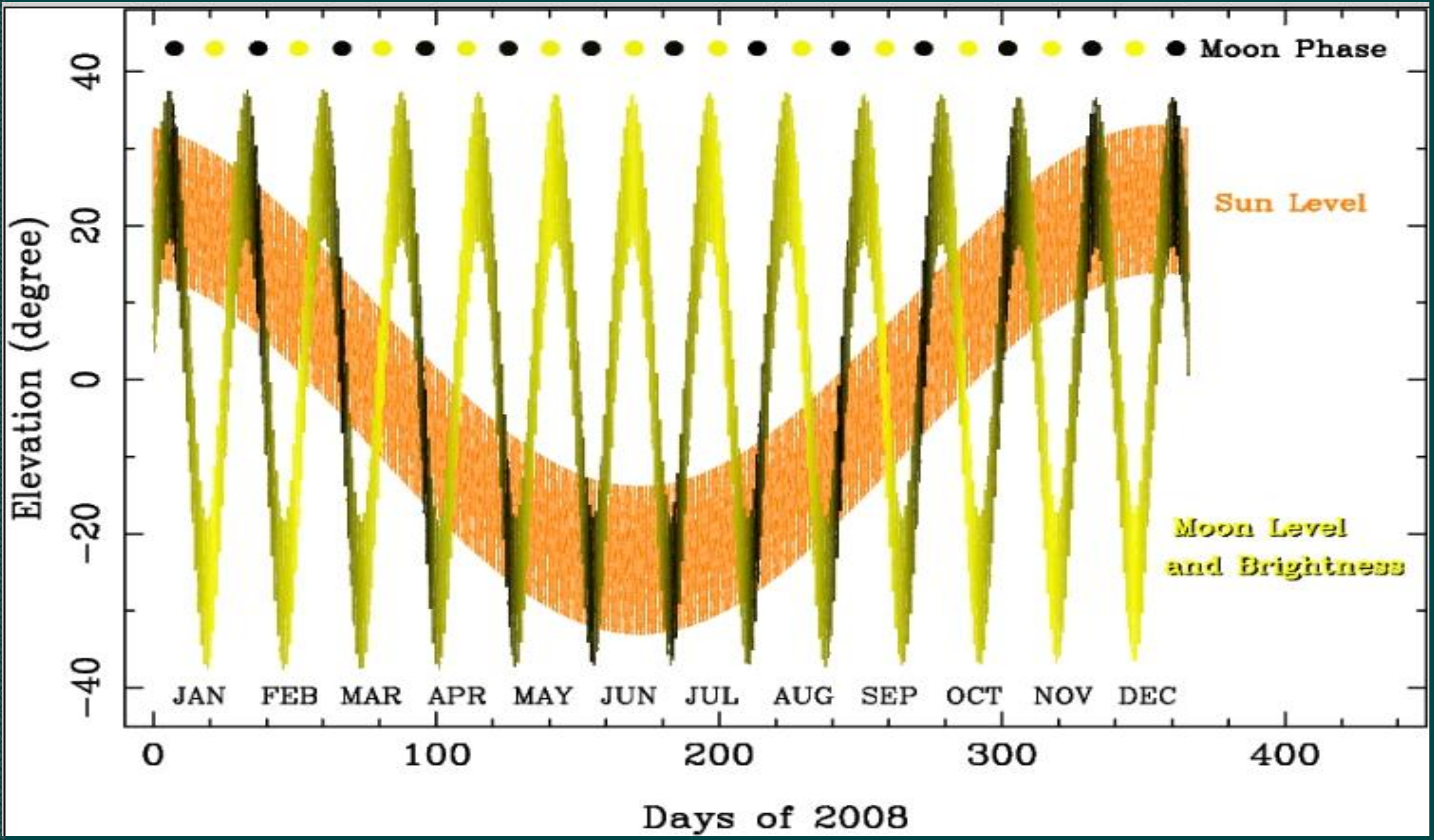
Thank you



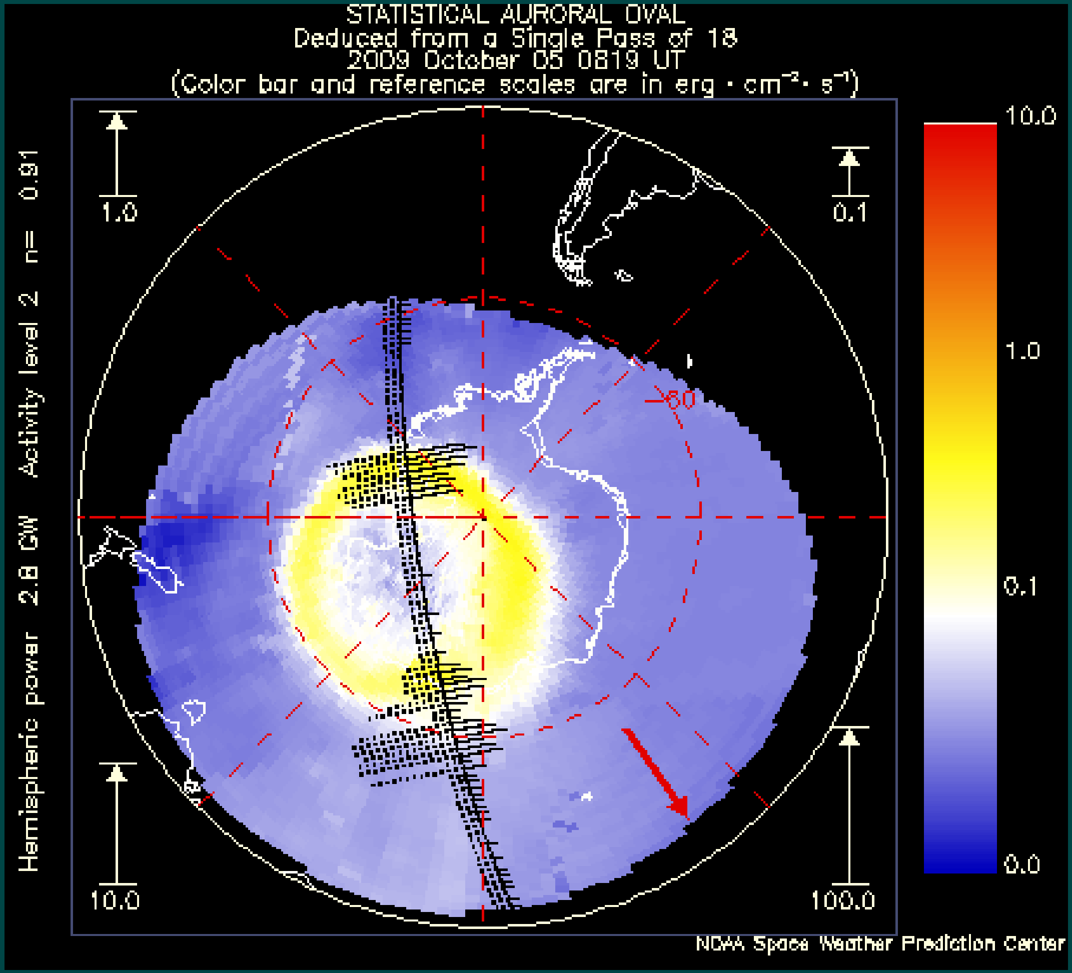
Mon Jun 16 16:50:38 2008
a star
N.Stars
10K
1K
Background
3
mag
0.6
mag
EXTINCTION


Wed Jun 18 23:20:38 2008
a star
N.Stars
10K
1K
Background
3
mag
0.6
mag
EXTINCTION

太阳与月亮高度 2008



极光环 (取自NOAA POES)



云图(2008六月from WDC)

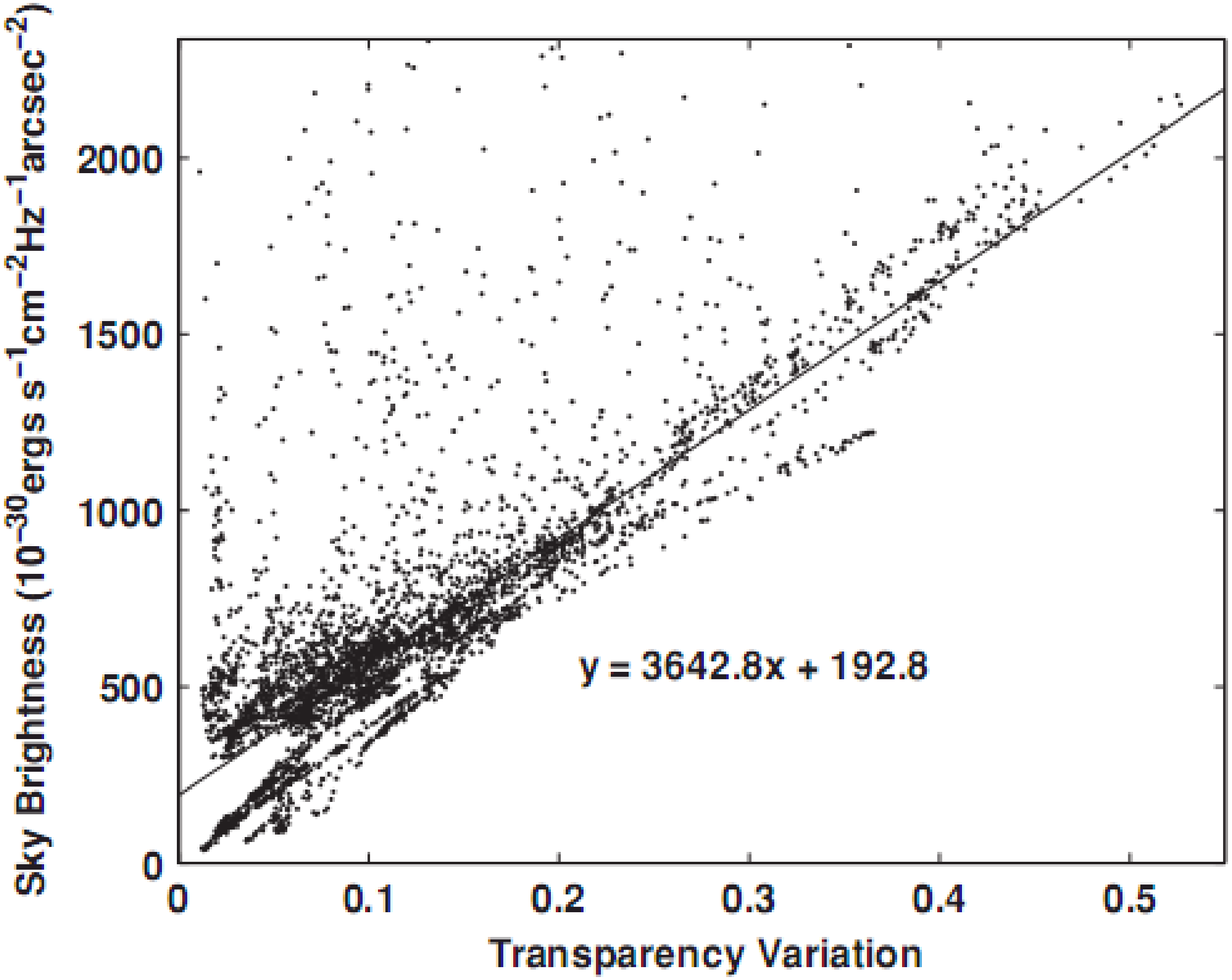


Figure 11. Correlation of the corrected sky brightness and transparency variation (in magnitudes). The data points are observations taken on 2008 June 16, when the average elevations of the Sun and the Moon are $-23^{\circ}.17$ and $25^{\circ}.12$, respectively, and the lunar phase was ~95% ($\Phi = 25.8$, $P(\Phi) = 0.54$). The straight line is the fitted relation with the equation shown.

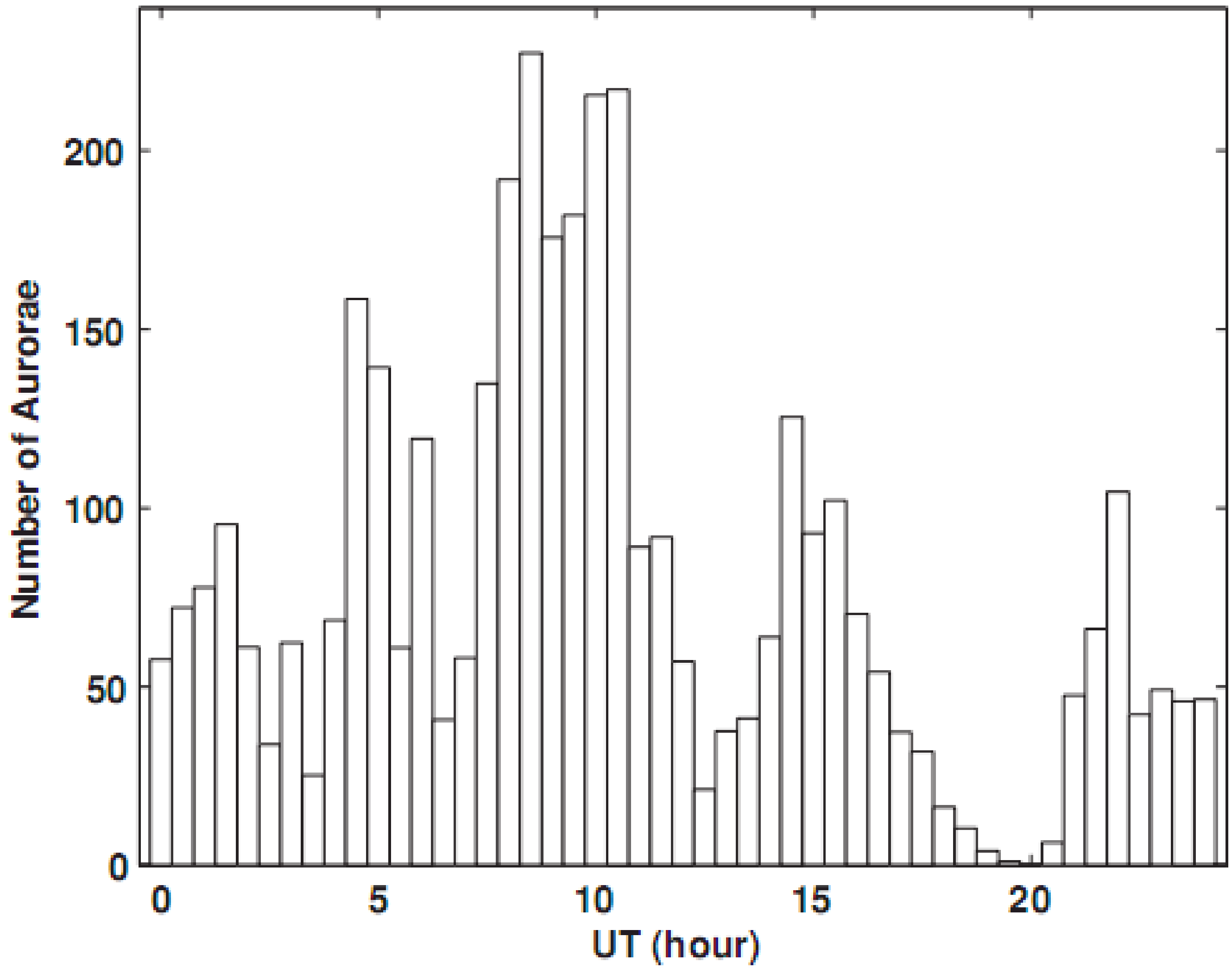


Figure 13. Time distribution of the images taken during 2008 that were affected by aurorae. The counts are corrected for the image-sampling time distribution.

Table 3
Hours Per Year at Different Sites When the Sun is Below a Given Elevation

Site	Latitude	Elevation (m)	Hours (<−18°)	Hours (<−13°)	Hours (<0°)
Dome A (Antarctica)	−80°22′	4093	1680	2606	4471
Mauna Kea (Hawaii)	+19°50′	4194	3395	3689	4394
Cerro Pachón (Chile)	−30°14′	2722	3330	3640	4404
La Palma (Spain)	+28°46′	2332	3313	3623	4381

The cloud cover type we defined

Table 1
Cloud Cover Conditions at Dome A

Flux	Excess Extinction (mag)	Fraction	Cloud Cover
<50%	>0.75	9%	Thick
50%–75%	0.31–0.75	17%	Intermediate
75%–90%	0.11–0.31	23%	Thin
>90%	<0.11	51%	Little or none

Notes. The first column is the observed flux of our standard stars relative to the reference image. The second column gives the *i*-band magnitude change (excess extinction) corresponding to the "flux." The last column gives the description of the cloud cover.