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Evolution of light pollution at ORM

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Overview

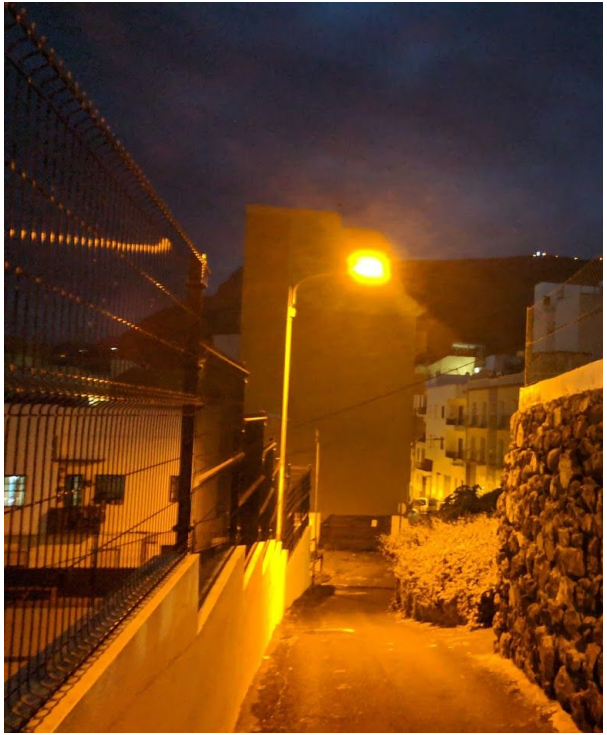
- What is light pollution?
- Lighting sources on La Palma.
- Methods (IDS archival data, calibration, proxies for weather).
- Measured light pollution over 25 years.
- Investigation into light pollution onsingle nights.
- Dependence on telescope azimuth and elevation.
- Conclusions

Sky Brightness

- Sky brightness at dark site at solar minimum is V = 21.9 mag arcsec^{-2}.
- Made of several sources, but most significant is the air glow emitted by atoms in upper atmosphere which are excited by solar UV during daytime.
- This natural airglow varies by season, and is ~6x brighter in winter.
- Airglow is present in the Sodium line doublet (NaD) at 5890/6Å.

Light Sources

- Different types of lighting used: High Pressure Sodium (HPS), LEDs and Mercury lamps.
- Most significant contribution is from Low Pressure Sodium (LPS) lamps.
- LPS lamp emission is concentrated in the NaD line doublet at 5890/6Å - the same as natural airglow.
- Thus NaD 5890/6Å intensity consists of natural airglow and LPS emission.



Effect on astronomical observations

- Sky brightness limits the faintness of objects that can be observed. Also adds noise to SNR calculations.
- LPS lamps have significant effect on observations which include 5890/6Å, both photometric and spectroscopic.
- Observatories are sited at locations with good seeing and low sky brightness, however the sky brightness can be artificially increased over time.
- LPS lamps are best choice of lighting near observatory sites - effect is well known and can be removed or avoided.
- Effect of weather is unknown.

Lighting on La Palma

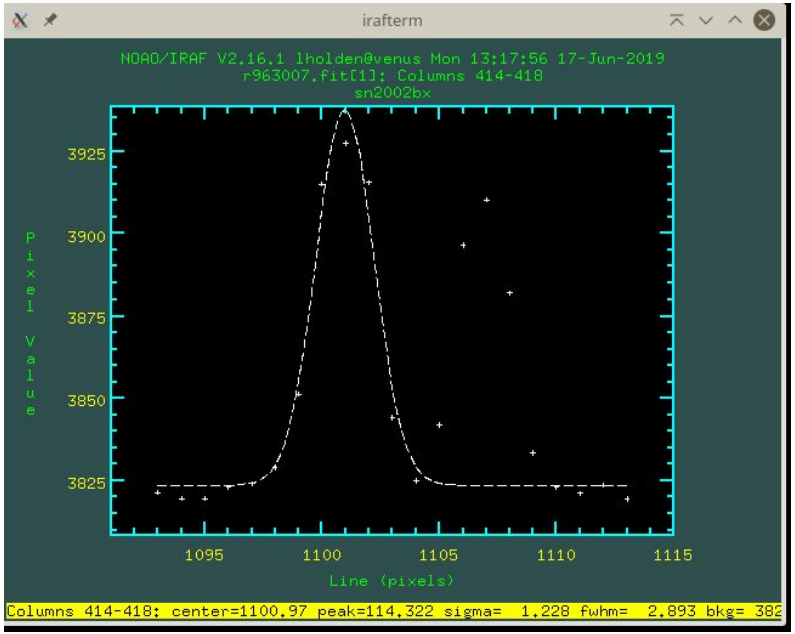
- La Palma is a dark sky and UNESCO Biosphere Reserve.
- Canary Sky Law was passed in 1992 to regulate exterior lighting on La Palma and Tenerife:
  - Types of lighting used
  - Power of lights
  - Orientation of lights
- Managed by sky protection office at the IAC.

Methods - IDS Archival Data

- Use archival data from IDS mounted on the INT from 1994-2019, following selection criteria:
  - The spectral range of the IDS grating + central wavelength setup must include 5890/6 Å
  - Nights must not be noted as with cloud, “bad weather” or “calima” etc. in observing log.
  - Exposures must be taken under dark sky condition (ie without Moon).
- Data from 4 different IDS detectors used: TEK3, TEK5, EEV10 and RED+2.

Methods - NaD Line Measurement

- Using grating dispersion and central wavelength of observation, pixel position of NaD line in spectral data calculated.
- Line measured using Gaussian fit in IRAF.
- A total of 144 IDS data points over 27 nights.



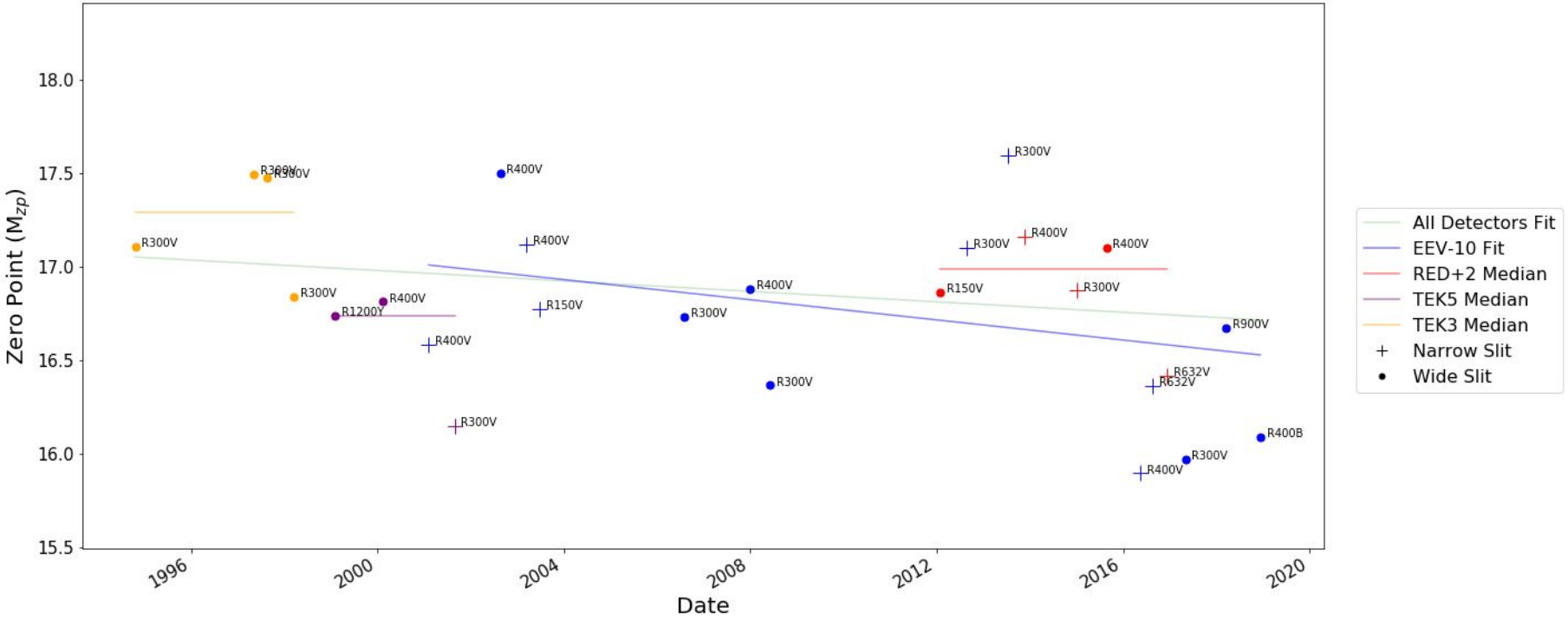
Methods - Calibration

- Spectrophotometric standard stars over ~25 years were measured for each IDS CCD.
- ‘Zero Point’ for each standard determined using

$$m_1 = -2.5log(\frac{F_1}{1}) + m_{zp}$$

- Corrected for detector and grating efficiencies.
- Can use resulting plot to see how gains, telescope + instrument throughput have changed over years.
- Medians taken for TEK3, TEK5 and RED+2.
- Straight line fit to EEV10 standard ‘zero-points’.

Methods - ‘Zero Points’



Methods - Calibration

- Can use these zero-points to calibrate measured NaD intensities over the years, accounting for change in detector gain, telescope + instrument throughput, etc.
- Binning, readout speed, CCD pixel scales also accounted for.

Methods - NOT Webcam

- Used NOT webcam archive to estimate below-observatory cloud level on a given night.
- Very hard to estimate level of cloud, especially at night.
- Archive only goes back to 2005.

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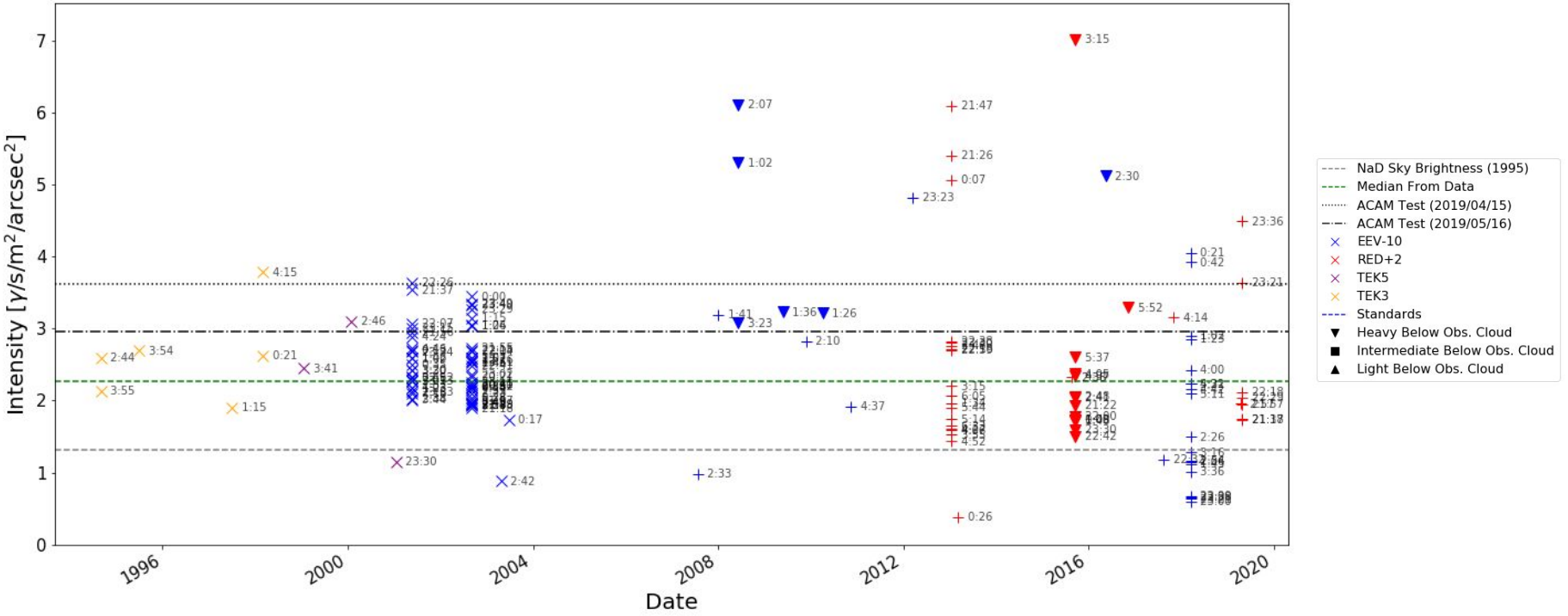
Light Pollution 1994-2019



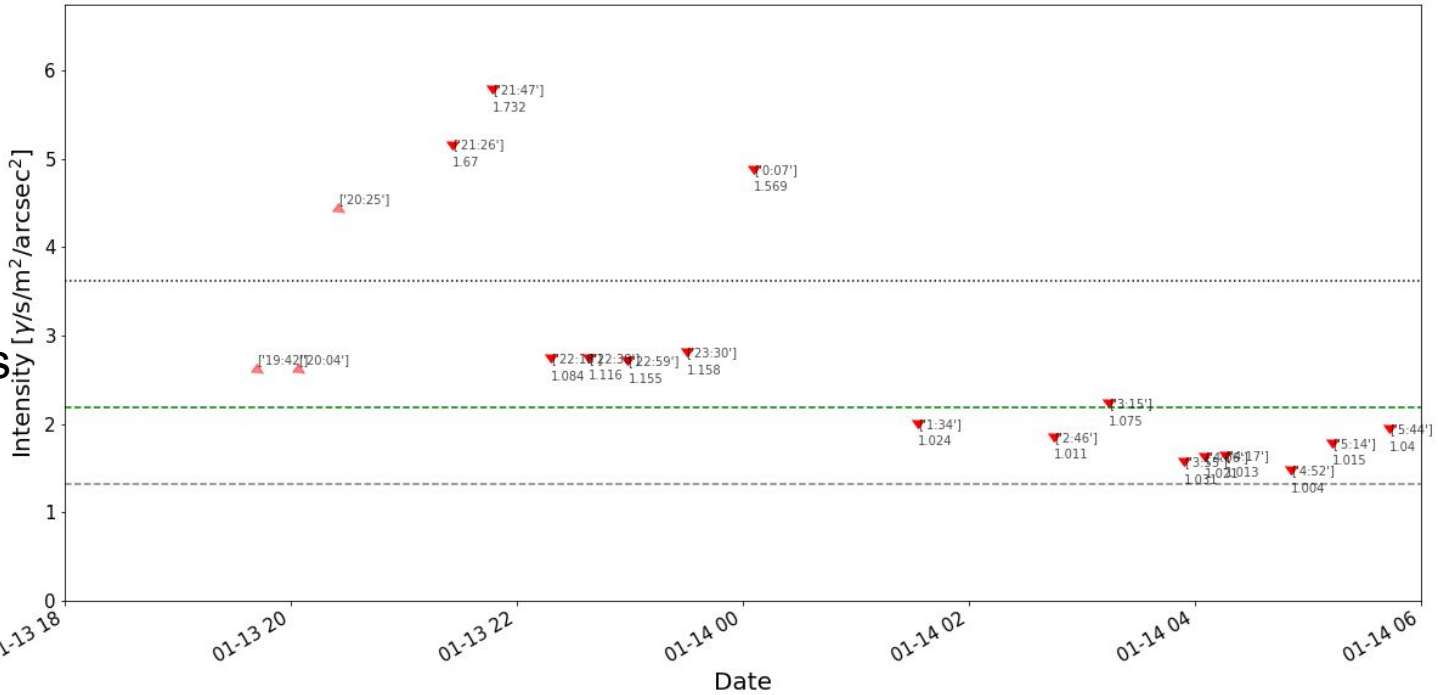
Light Pollution 1994-2019

- No apparent increase or decrease in NaD intensity over past 25 years.
- Much larger measured variation in NaD intensity in recent years than previously measured:
  - Weather effects?
  - Position on sky?
  - Time of night?
  - Time of year?

⇒ Need to disentangle these - look at individual nights.

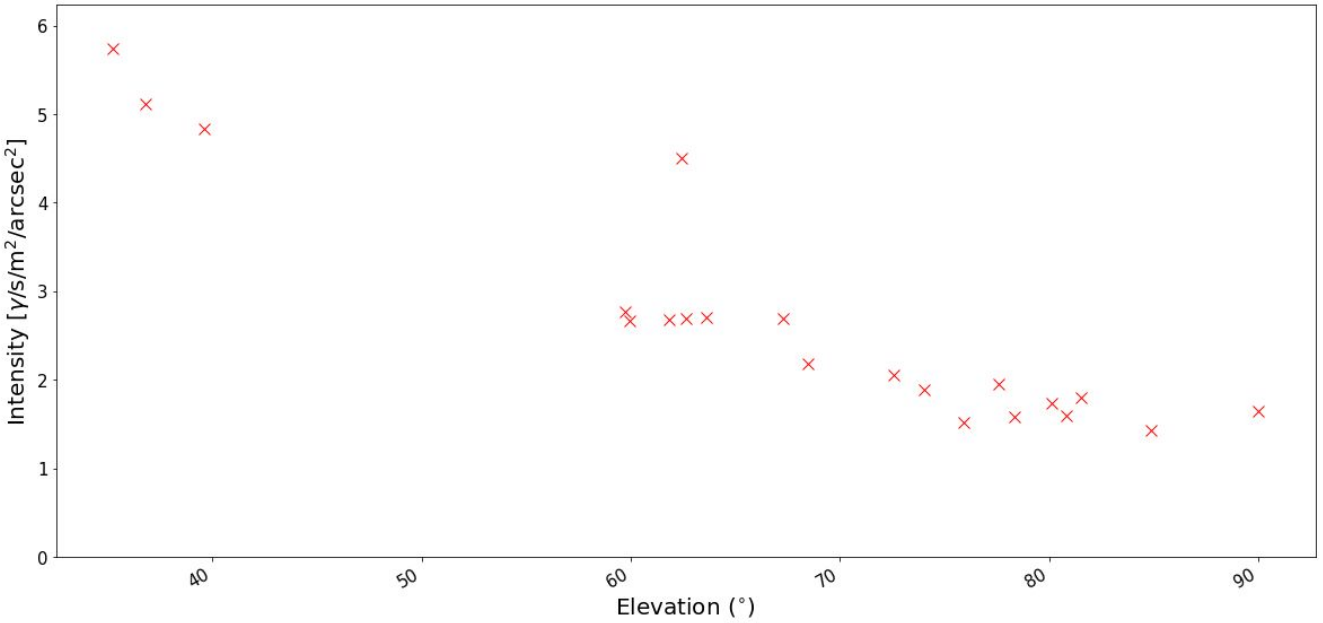
Single Night - 13/01/2013

- High variation in NaD levels throughout night.
- Higher intensity points have higher airmasses.



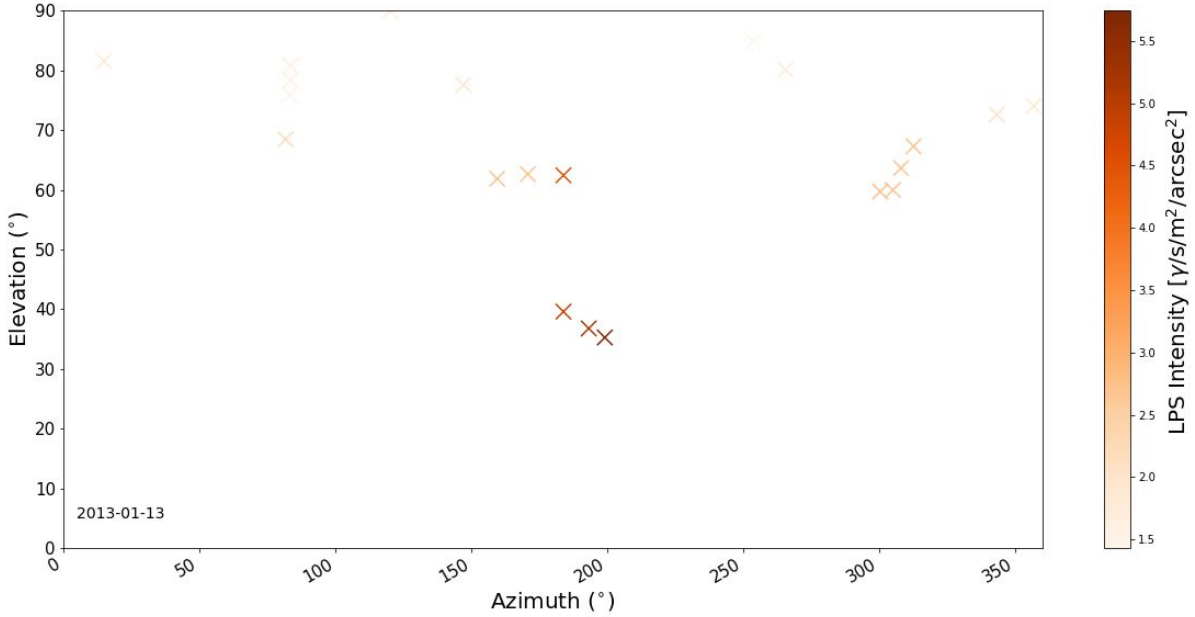
Dependence on Elevation

- Clear relationship between elevation and intensity.
- Much higher NaD intensity measured at low elevations.
- What about azimuths?



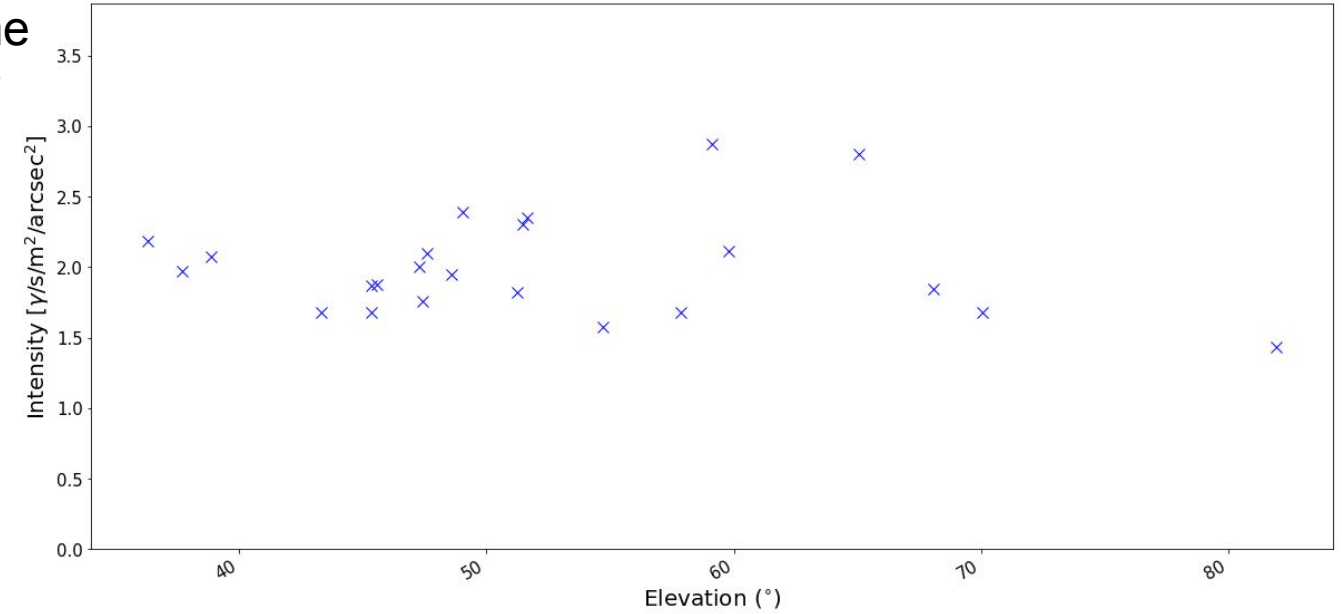
Dependence on Elevation

- Higher NaD intensity at low elevations around 200° azimuth.
- Maximum NaD intensity of ~5.6 photons/s/m^2/arcsec^2 found at Az = 200° and El = 30°
- Look at more nights.



Single Night - 20/05/2001

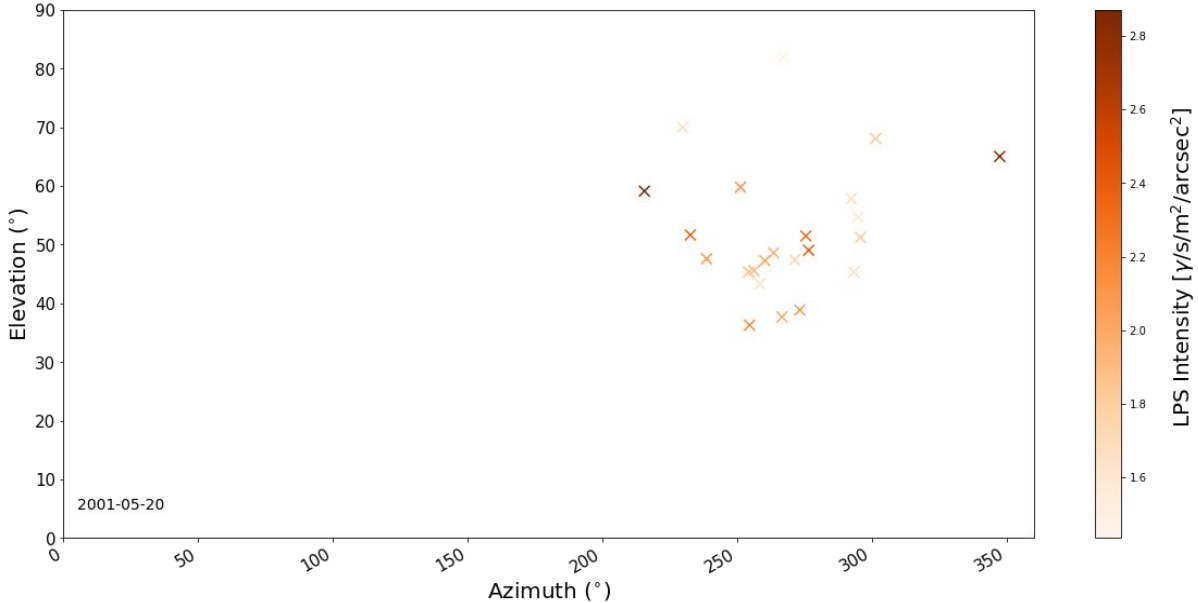
- Don’t see the same elevation-intensity relationship as before.
- Because of different azimuths?



Single Night - 20/05/2001

- Not much NaD increase with decreasing elevation.
- Azimuth now ~250°; maximum NaD intensity of ~2.8 photons/s/m^2/arcsec^2
- Before we saw twice as high intensity at Az = 200°.

What happened?

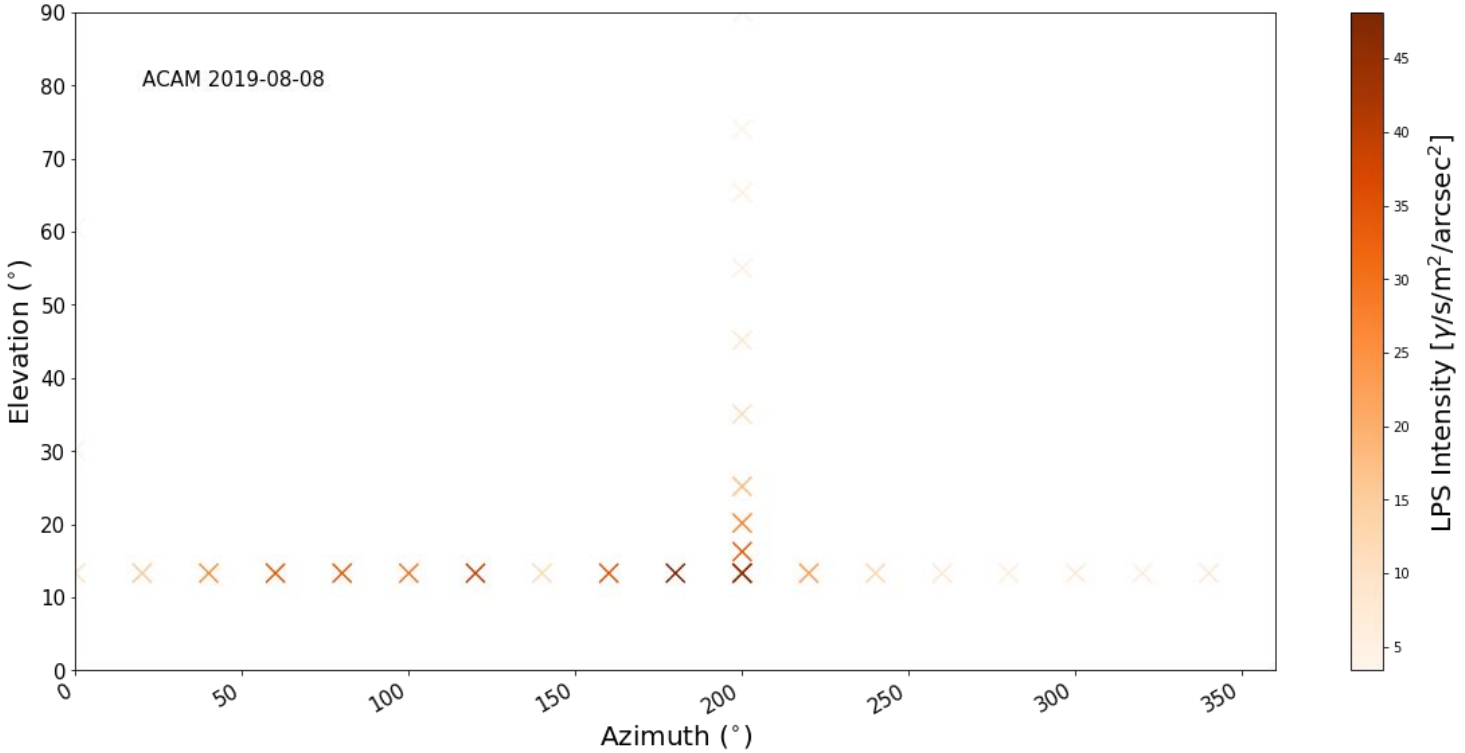


Dependence on Azimuth

- We find the NaD line intensity to be much higher at low elevations, but only at certain azimuths.
- This is because of the large towns found at these azimuths.
- In particular, massive NaD intensity spike around 200° azimuth and 30° elevation: this is consistent with the direction of Los Llanos + Tarzacorte + El Paso.

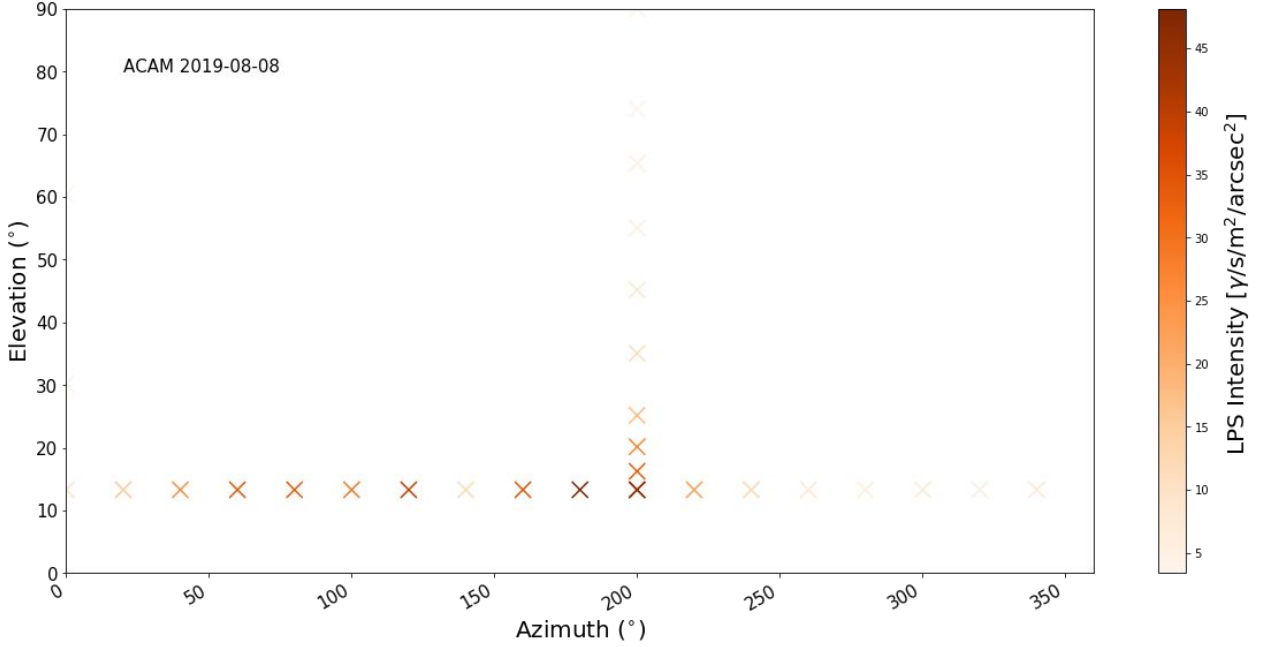
Town	Azimuth (°)
Barlovento	50
San Andreas y Sauces	110
Santa Cruz	125
Brena Alta/Baja	140
El Paso	180
Los Llanos + Tarzacorte	200
Puntagorda	280
Garafia	325

Sky Mapping - ACAM



Sky Mapping - ACAM

- Extremely high (>40 photons/s/m^2/arcsec^2) NaD line intensity found in the direction of Los Llanos.
- Slight increase in direction of S/C, but not as much (blocked by Caldera wall).



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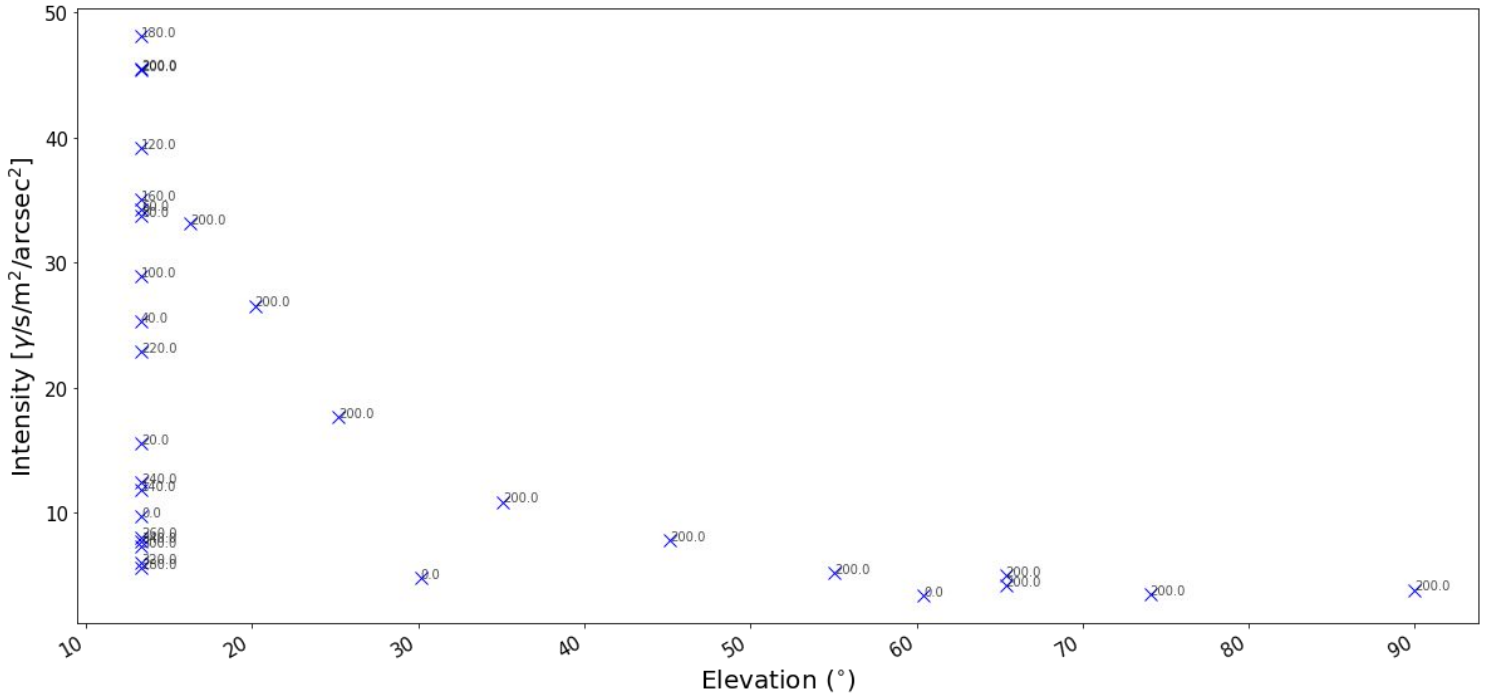
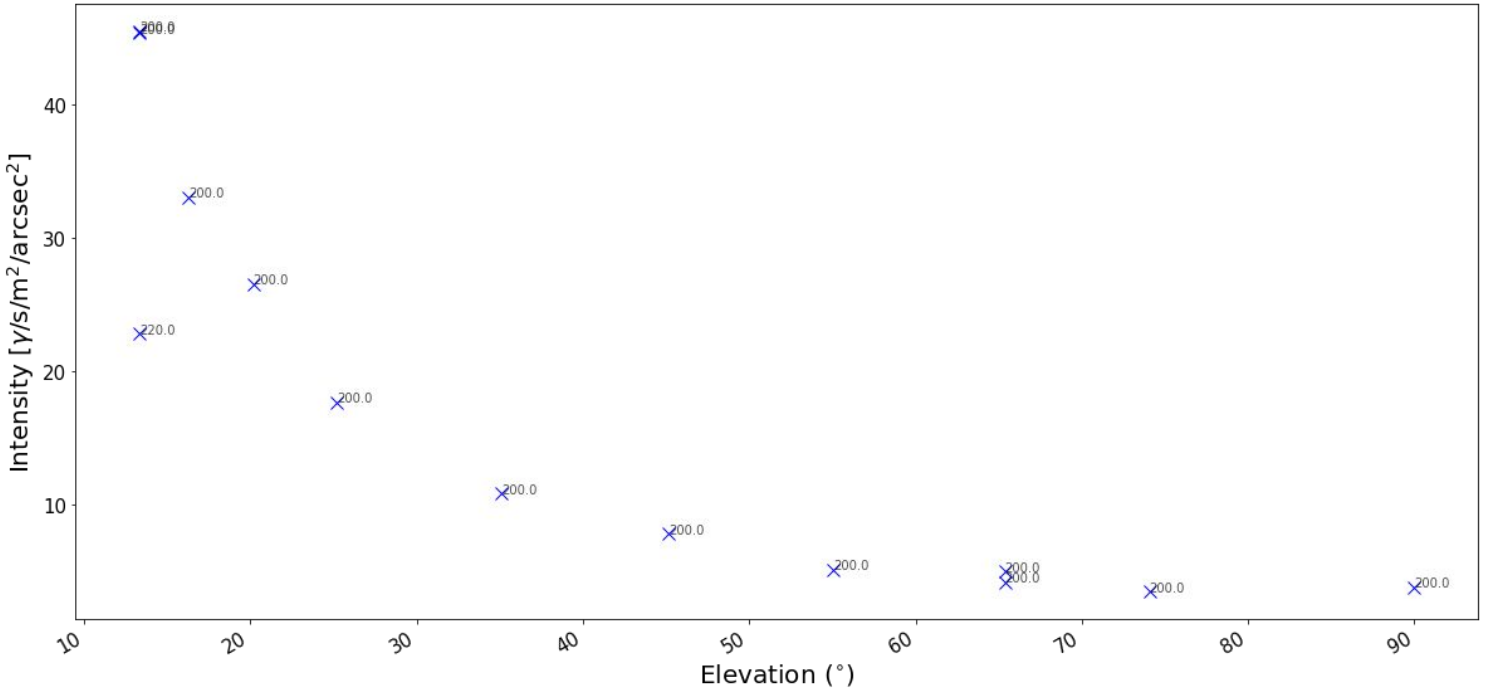


0° < Az < 360°

Sky Mapping - ACAM



180° < Az < 240°

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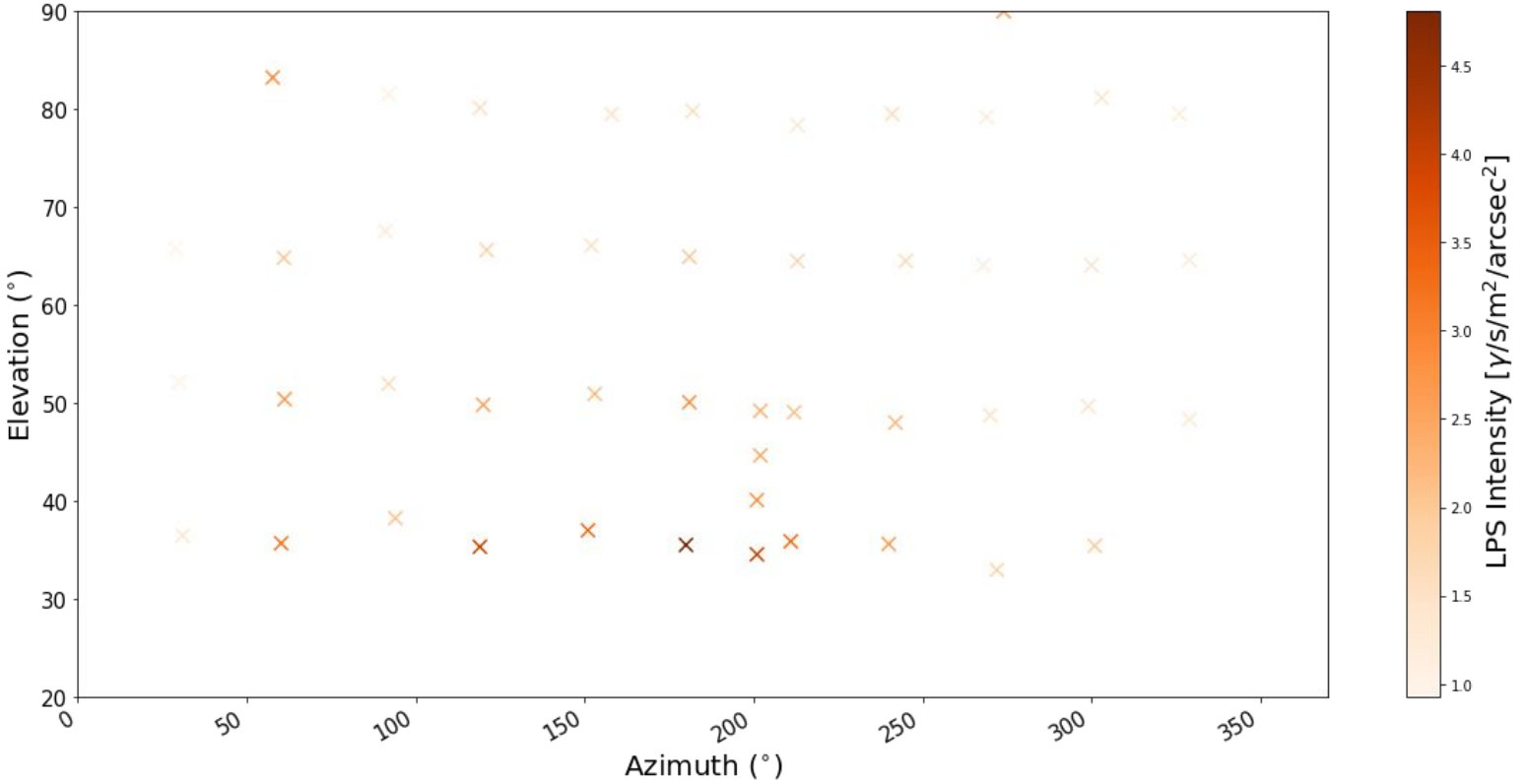
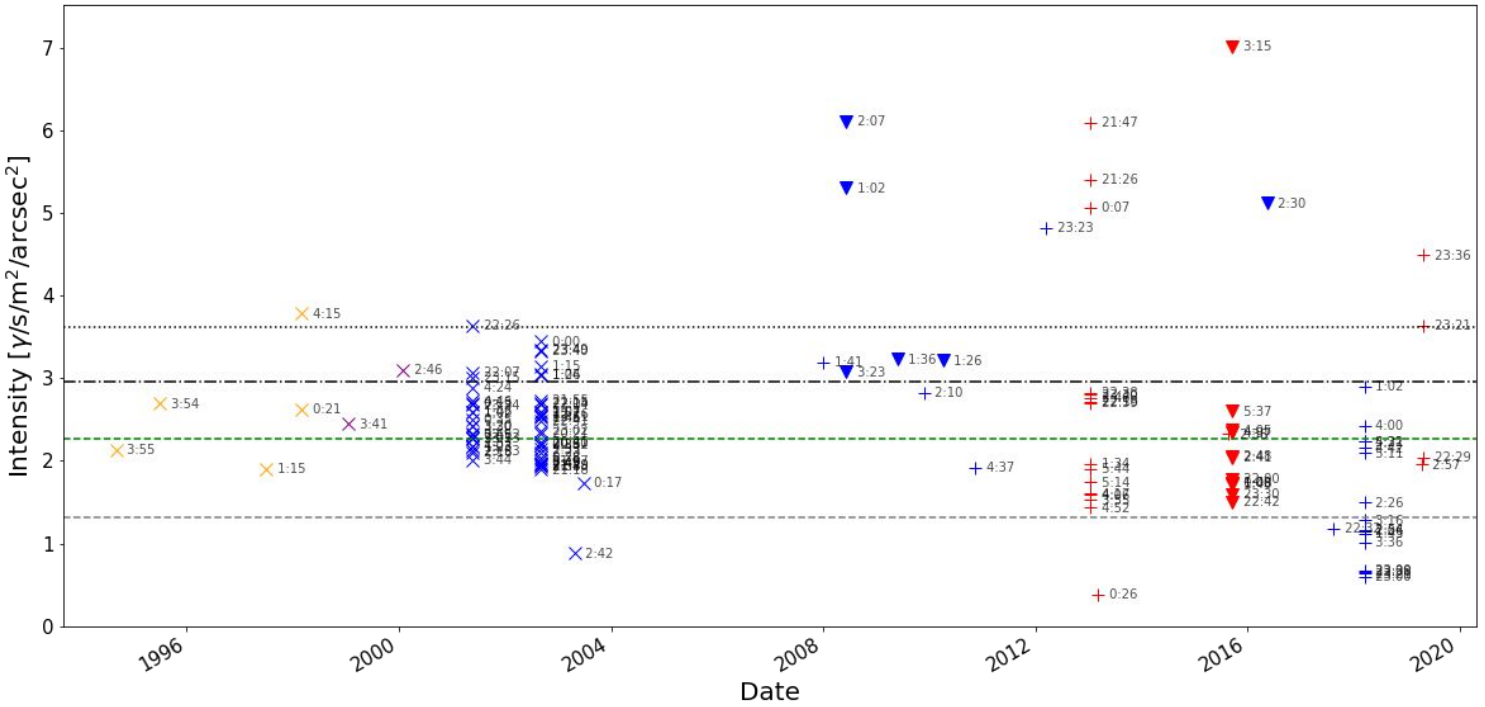
Sky Mapping - IDS



Dependence on Azimuth and Elevation

- Conclusions from this:
  - NaD intensity increases with decreasing elevation when pointing towards towns
  - This is much less prevalent for Santa Cruz
  - Above 50° elevation this relationship isn't seen
- Now that we have disentangled the effects of azimuth and elevation, we can use >50° as a limit to see how NaD intensity has evolved over years.

1994-2019 Revisited



Elevation > 50°

NaD Sky Brightness (1995)
Median From Data
ACAM Test (2019/04/15)
ACAM Test (2019/05/16)
EEV-10
RED+2
TEK5
TEK3
Standards
Heavy Below Obs. Cloud
Intermediate Below Obs. Cloud
Light Below Obs. Cloud

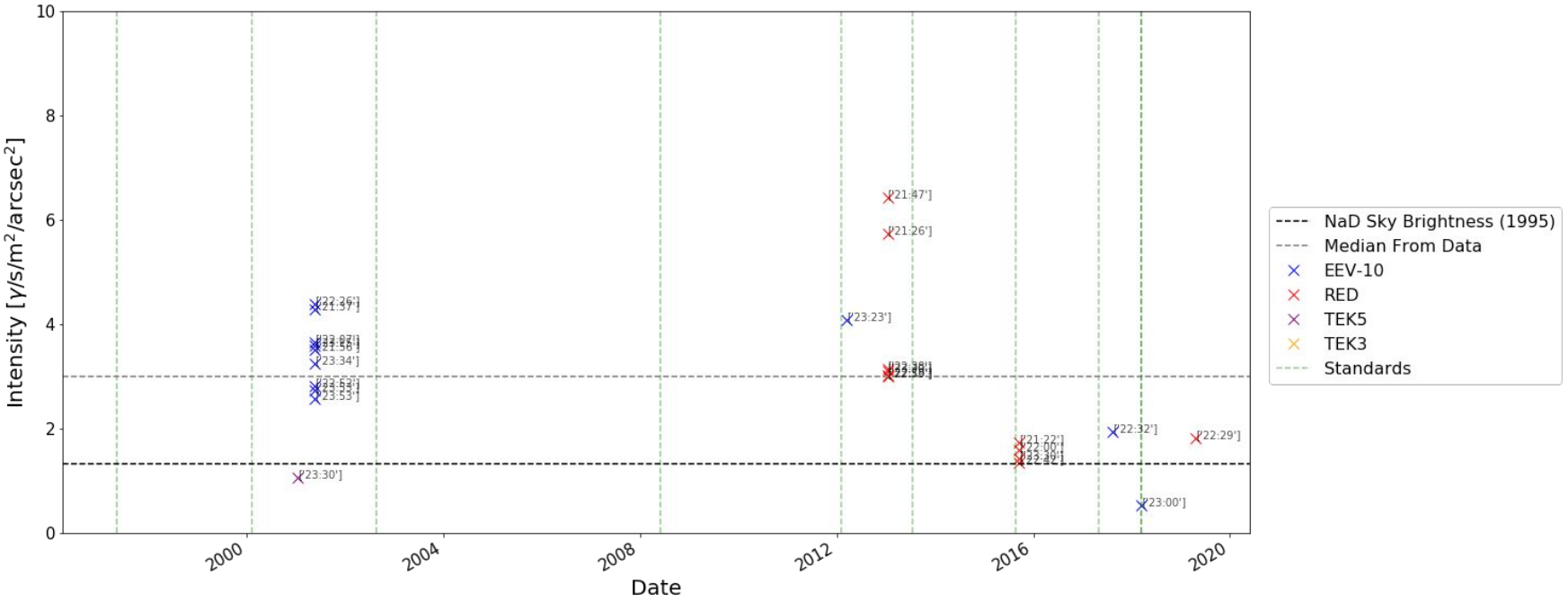
Conclusions

- No apparent increase or decrease in NaD (hence light pollution) levels from 1994 to 2019.
- NaD intensity much higher at low elevations when pointing toward certain towns on La Palma.
- Slight increase in NaD intensity at low elevations when not pointing towards towns.
- See the same pattern with both heavy calima and no calima.

Further Work

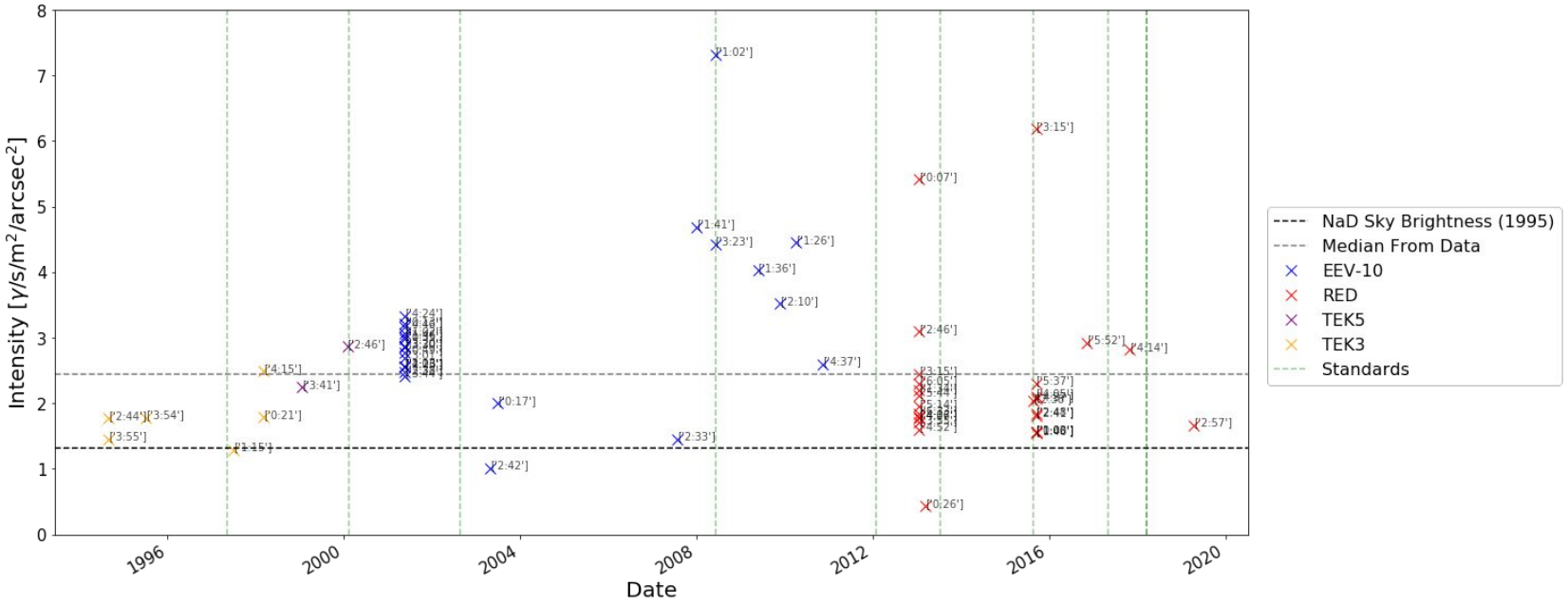
- Investigate Nik Robert's ISIS data and analysis - compare with IDS + ACAM data presented here.
- Further investigate and detangle seasonal variation and weather effects.
- Quantify the effect of moon on observations.

Before Midnight



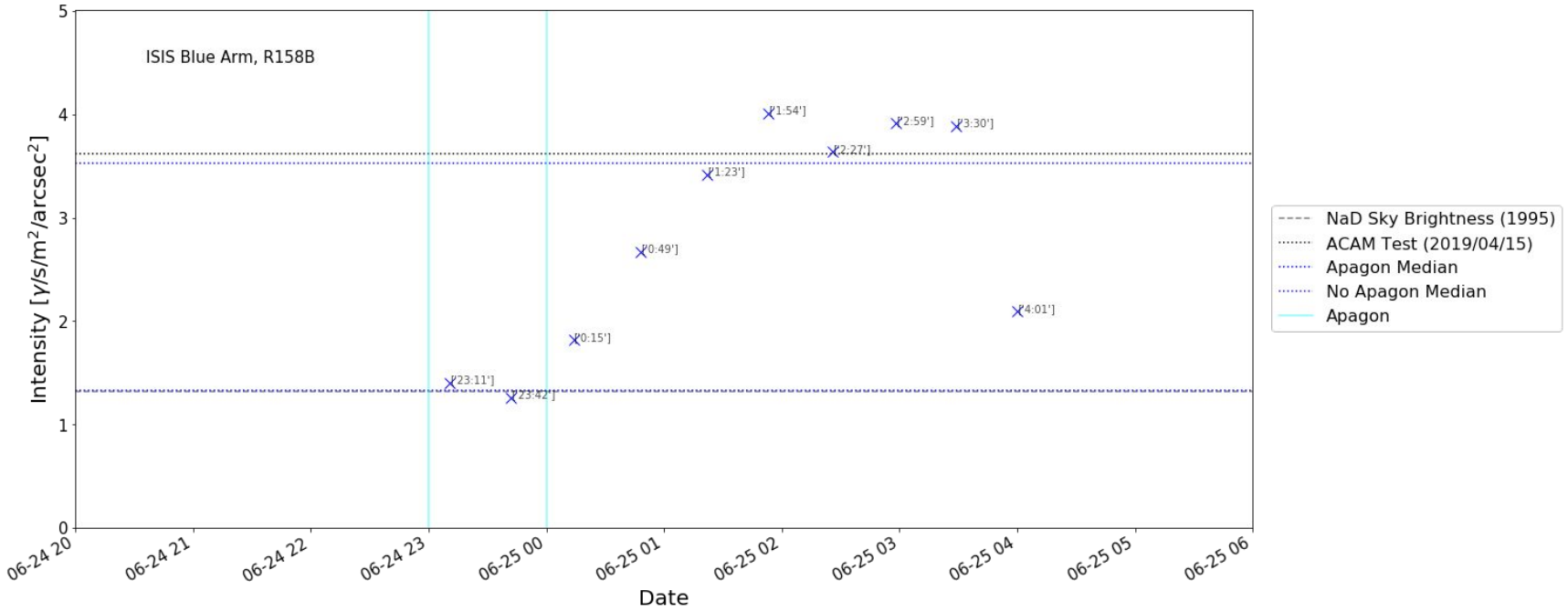
Median = 2.32

After Midnight



Median = 3.00

1995 Apagon



Apagon Median = 1.33 Non-Apagon Median = 3.52

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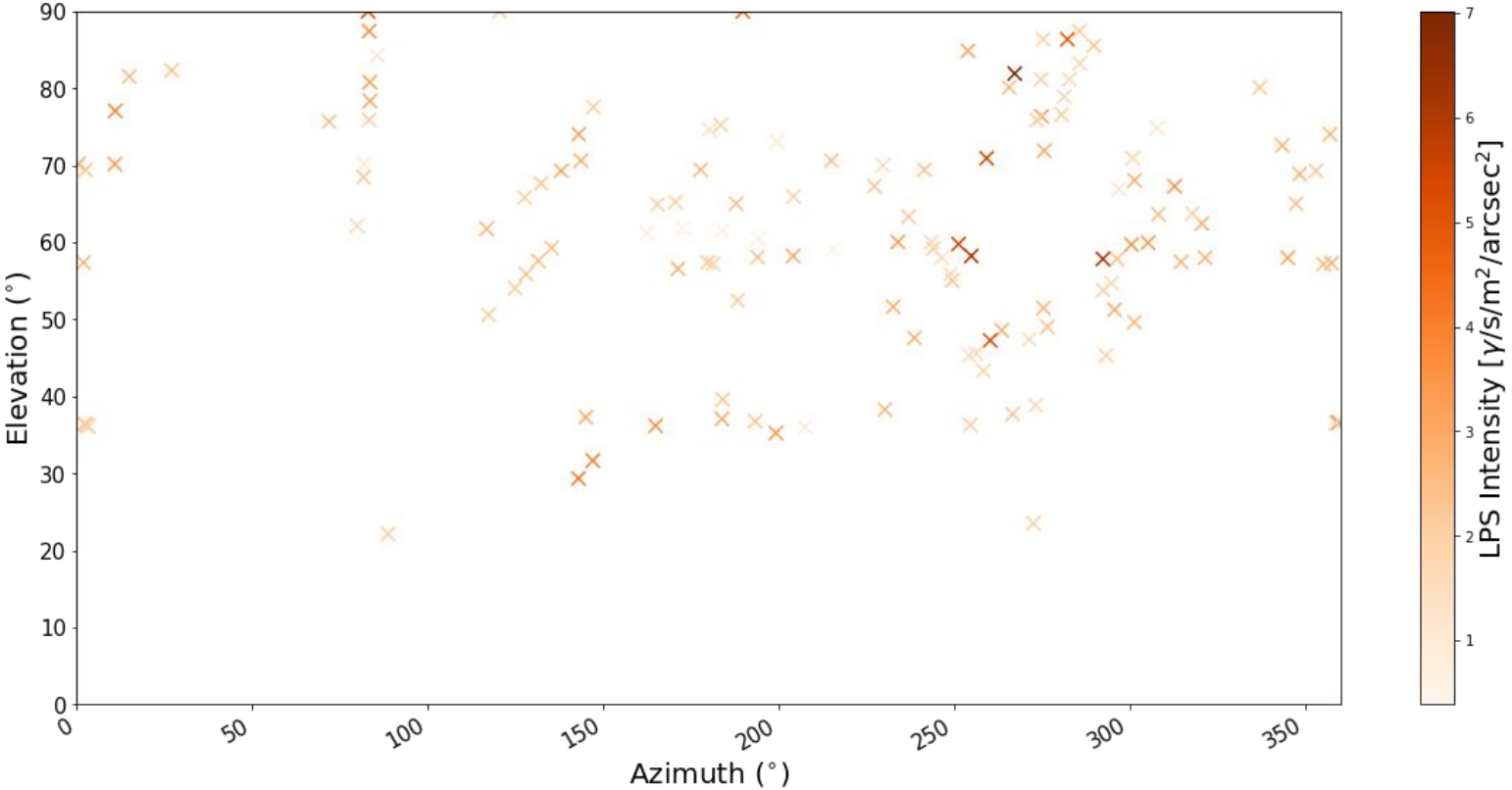
1994-2019 Skymap



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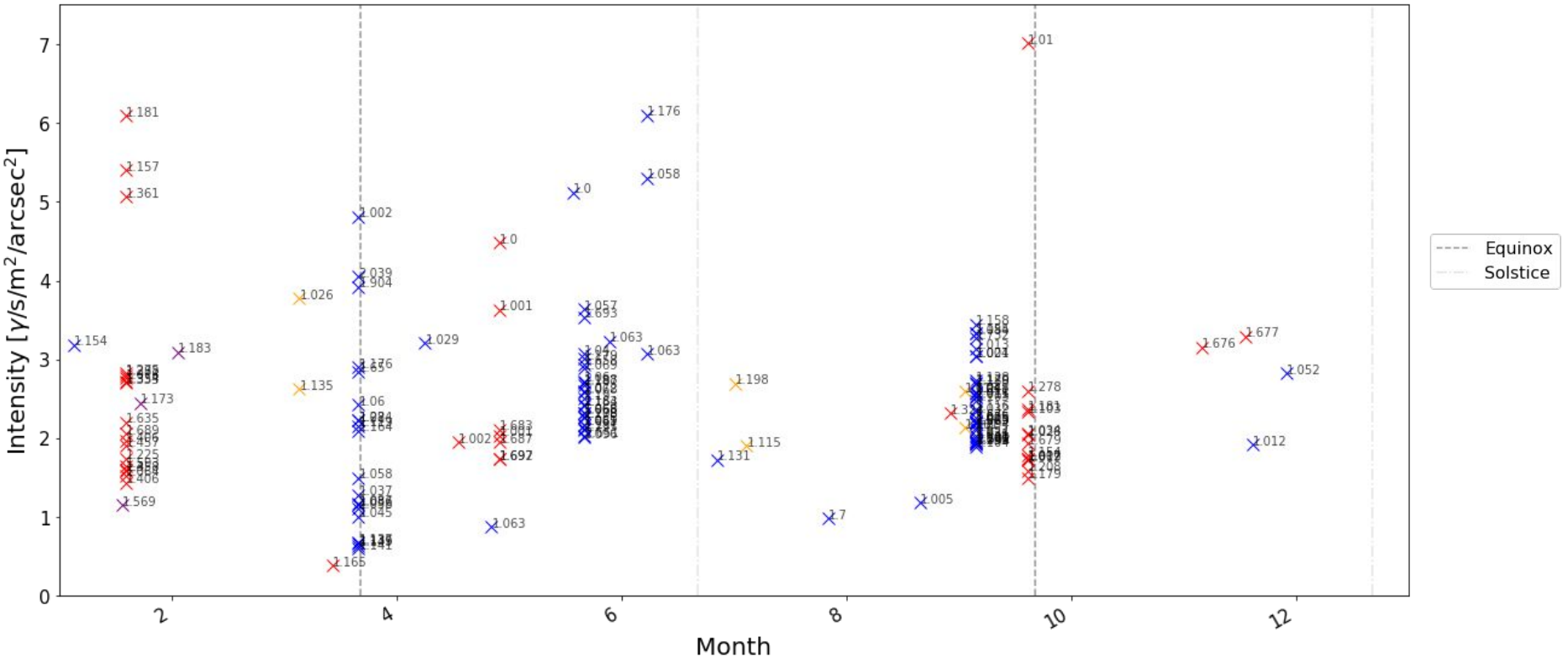
Seasonal Variation



Seasonal Variation

All Data Median = 2.2706429547768527
Number of Total Data Points = (144,)

Summer Median = 2.254144658573843
Winter Median = 2.623958088416378

Evolution of 200° Az