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Global Extinction:

Can We See Long-Term Atmospheric Changes within the GMOS Imaging Archive?

Eric Steinbring

Gemini North Talk, Hilo Hawai'i

On the (Portentous?) Occasion of Groundhog Day

2 February 2023

Global Extinction: What This Talk is Not About

An artist's rendering of the impact event 66 million years ago that ended the reign of dinosaurs. Credit: Roger Harris/Science Source; The New York Times, 15 February 2021

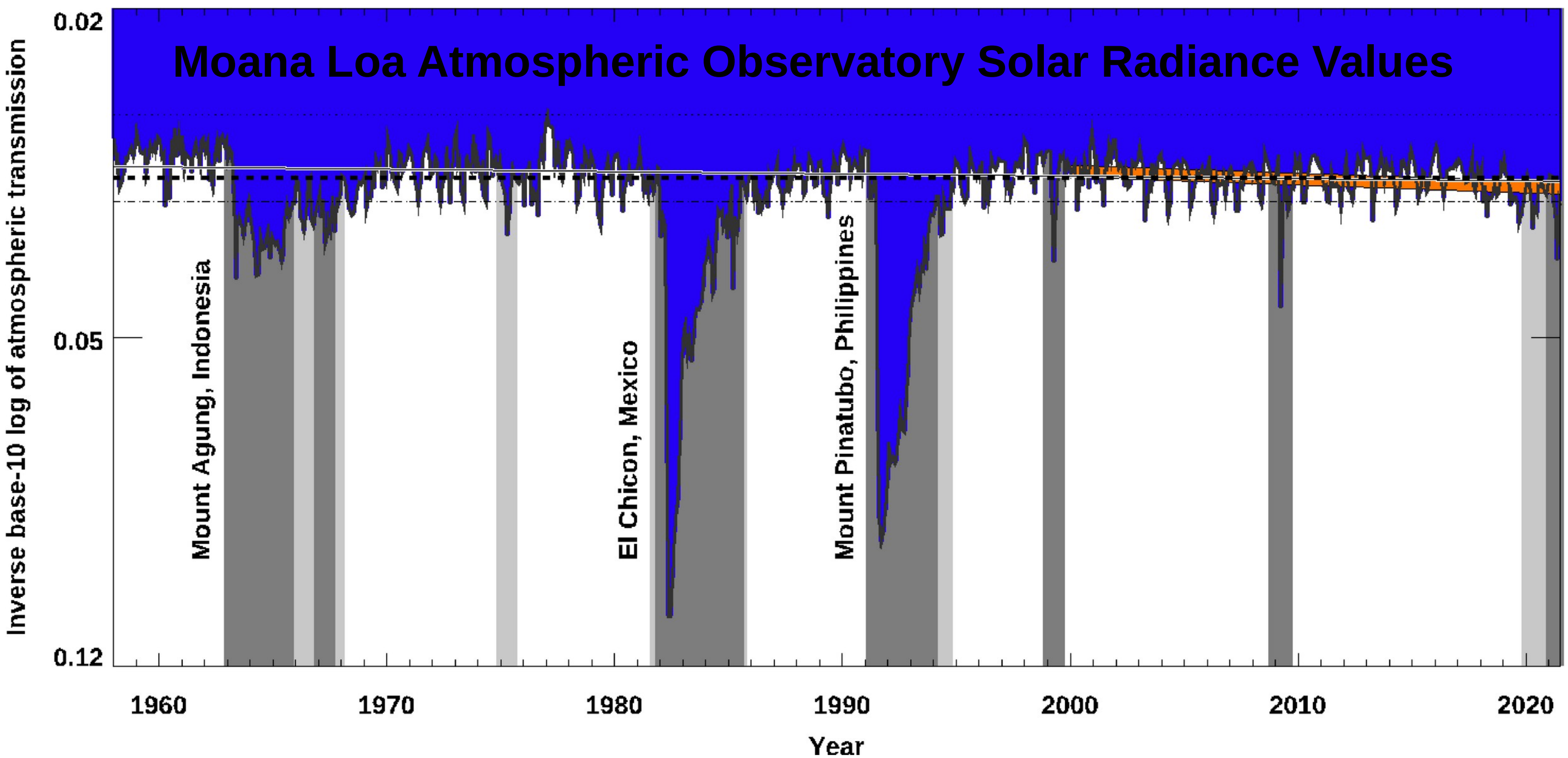
Global Extinction: Is Long-Term Optical Photometry from the Ground Consistent with Climate Change?

Image from Wikipedia: Groundhog Day on 2 February 2005 in Punxsutawney, Pennsylvania, with prognostication via rodent as to expectation for 6 more weeks of winter.

Atmospheric Transparency is Punctuated, but Getting Worse: Fewer Photons "Getting Through"

Long term change in transparency, **after removal of** already known volcanic episodes (or when below the mean for over three months)

and downward slope of about 0.17 percent per decade, since year 2000



See: Dutton et al. 2011, Science, 333, 866

Above figure, and to follow: Steinbring, E., 2022, PASP, 134, 125003, published 9 January 2023

Global Extinction: Motivation Behind the Analysis, Paper, and Goals of this Talk

Doing Percent-Level Accuracy Photometry

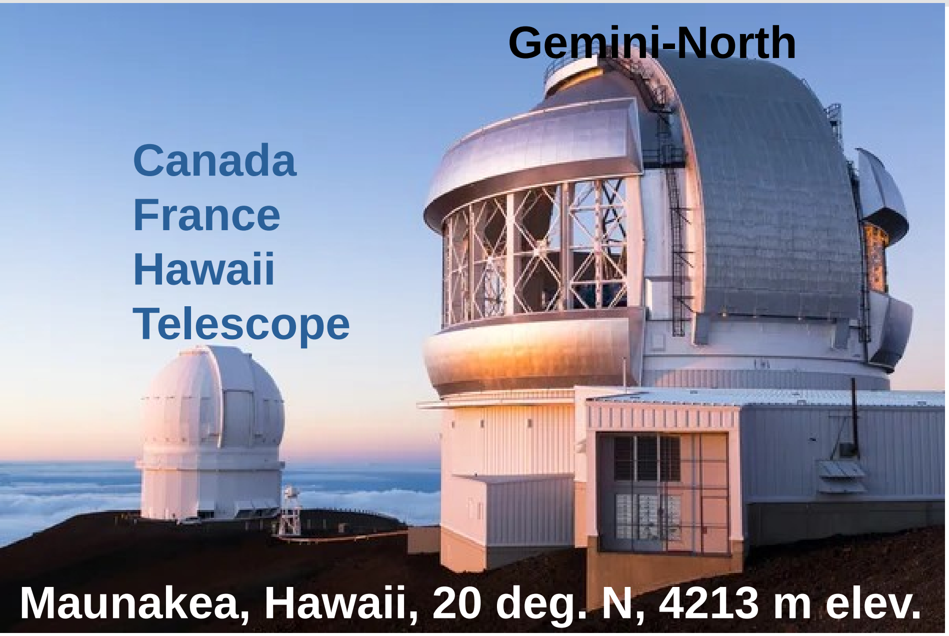
It’s hard to know the **zeropoint** (magnitude associated with, effectively, a single photon/second) for an instrument to the level of a percent in precision over the course of many years; mostly that is fluctuation of instrument throughput, which *goes up* abruptly about 20% for detector changes, and *goes down* about 1%-2% per year with coating decay, slowed by roughly 6-month cleanings, or re-instated by re-coatings every few years

Otherwise, air plus cloud, or **extinction**, varies at the level of 5% to 10% night-to-night, and changes in aerosols (apart from exceptional volcanic episodes like Krakatoa) can be similar to that year-to-year

One could try:

- Getting a long-baseline imaging dataset with well-known instruments that spans the whole sky over decades
- Doing photometry on many frames; every sufficiently-bright object in each frame, with many objects per frame
- Calibrating with an assumed fixed all-sky catalogue, that is, determine *relative* changes in photon flux
- Reporting change in atmospheric-component only of attenuation over time, that is, remove clouds
- Comparing with simple linear model of air density, assuming integration along telescope beam
- Testing the assumption of **attenuation** going up linearly with humidity and temperature, therefore straightforwardly tracking transparency (i.e. loss of photons, instead of animal species) with time

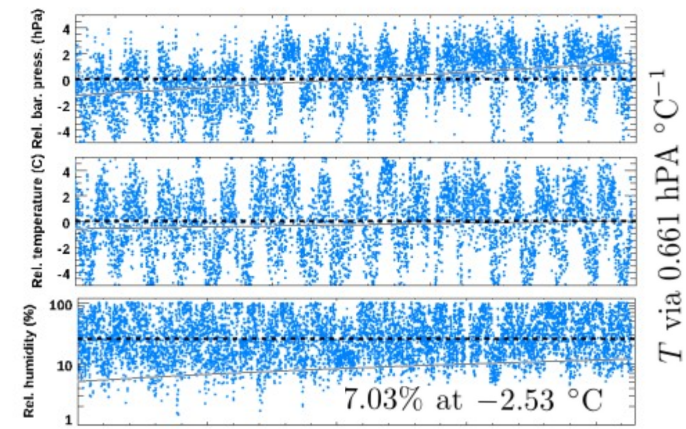
To First-Order, Attenuation (A) is Linear with Airmass (Z), and Surface Air Temperature (T)



Pressure (p), temperature (T) and relative humidity (rho) are all going up linearly together in time (t):

See: Steinbring, E., Cuillandre, J.-C., & Magnier, E. 2009, PASP, 121, 295

$$Z \propto p\rho/(\bar{p}\bar{\rho})$$



So, for initial attenuation (A0) and normally distributed photometric-errors as single variance (sigma) one gets:

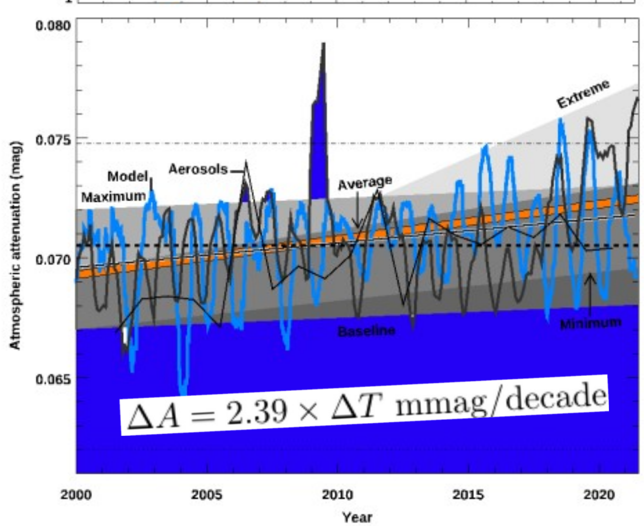
$$\bar{Z} = \frac{1}{\sqrt{2\pi}\sigma}\int_0^\infty \exp\left[-\frac{(Z-1)^2}{2\sigma^2}\right] \mathrm{d}Z = 1$$

$$A = A_{\mathrm{air}} + A_{\mathrm{cloud}} = A_0 + (\Delta A) \times Zt$$

Atmospheric Model

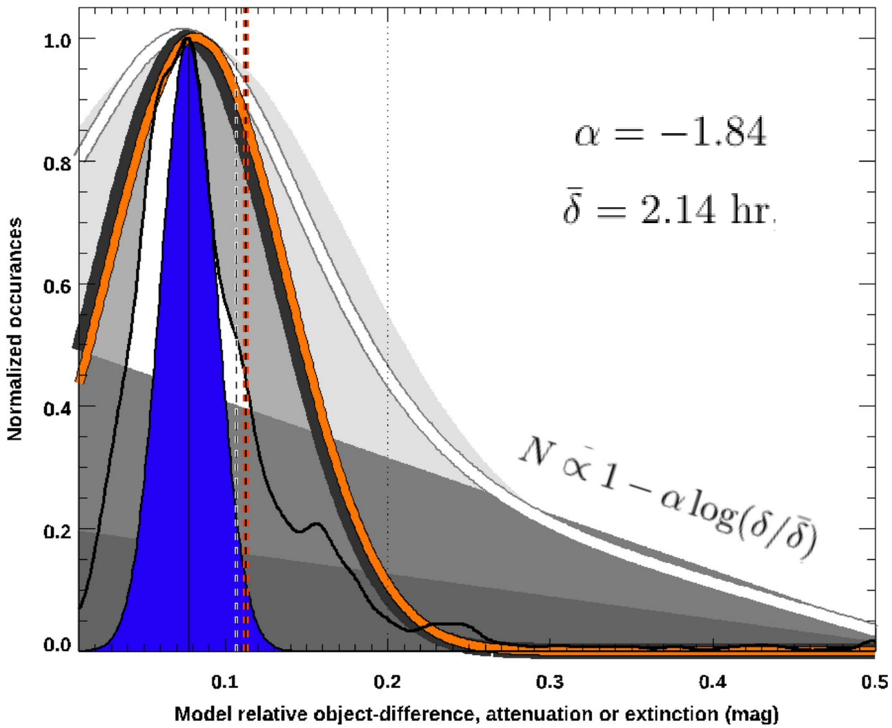
Label	Time Period	A_0 (mag)	ΔT ($\frac{^\circ\mathrm{C}}{\mathrm{decade}}$)	ΔA ($\frac{\mathrm{mmag}}{\mathrm{decade}}$)
Baseline	1958.0-2021.5	0.0625	0.1	0.2
Minimum	2000.0-2021.5	0.0670	0.2	0.5
Average	2000.0-2021.5	0.0695	0.7	1.7
Maximum	2000.0-2021.5	0.0720	1.3	3.1
Extreme	2000.0-2021.5	0.0670	2.0	4.8

Baseline and accepted 40-year averages: NOAA 2020, "State of the Climate: Monthly Global Climate Report for 2020"



Simple Model: a Shifted Distribution Including Effect of Persistent Thin (Median) Cloud

For constant very-thin cloud, one need only look for relative shift in the peak of the flux distribution (N):



Cloudiness duration (delta) has a strong power law (alpha): thin clouds are persistent, thick clouds increasingly rare.

A numerical calculation gives a nice single offset, because MLO to Gemini-N and Gemini-S to MLO happen to have similar pressure-altitude ratios:

$$A_{\text{offset}} = \tilde{A} - \hat{A} \approx 0.0307 \text{ mag}$$

And, of course, the difference in observed magnitude from the catalogue (outside the atmosphere) must also have the same distribution, so attenuation is

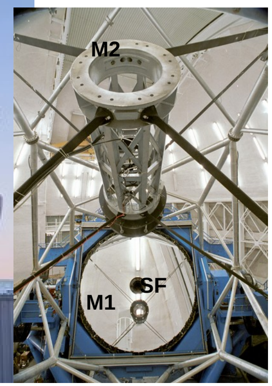
$$m_{\text{difference}} = m - m_{\text{catalog}} = A$$

Thus,

$$\hat{A} = \tilde{A} + (m_{\text{difference}} - m_0) - \tilde{m}_{\text{zeropoint}} - A_{\text{offset}}$$

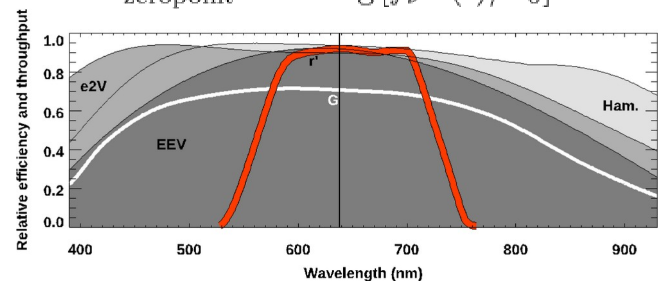
Instrument Simulation, Given Detector Efficiency, Rates of Coating Decay, and Number of Cleanings

The Gemini Multi-Object Spectrographs (GMOS N/S) are legacy products of DAO/Herzberg

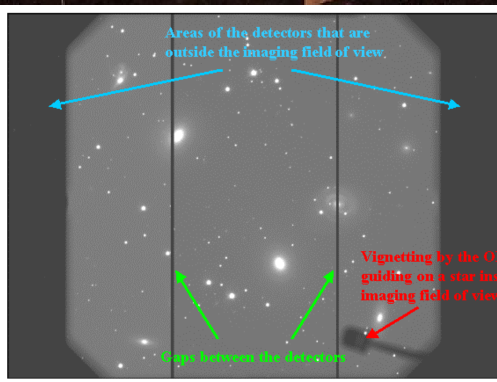


Zeropoint magnitude (m) is loss of photon flux (f) of frequency (nu) via train of efficiencies (F):

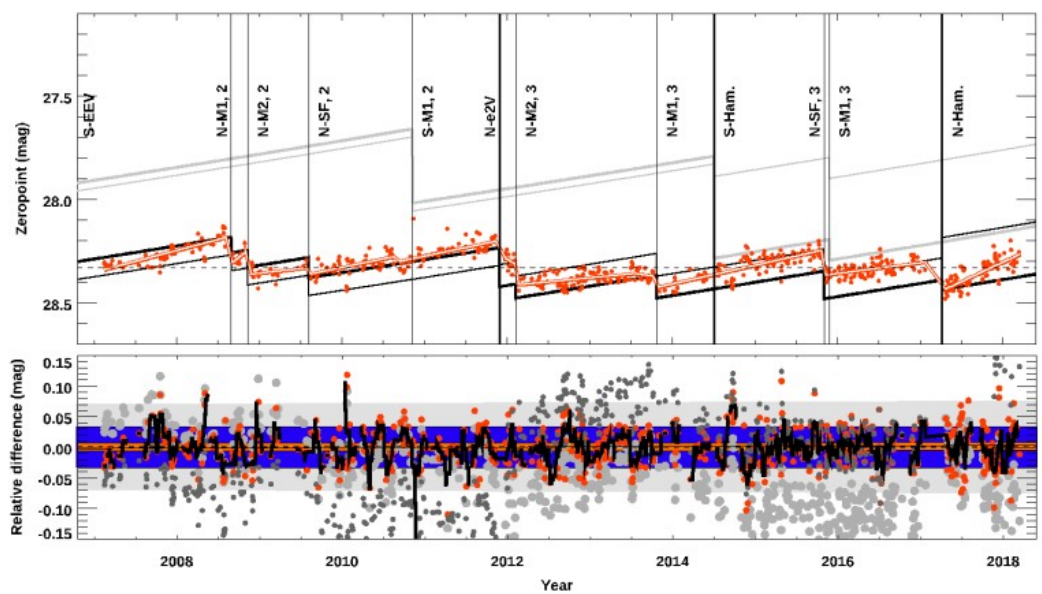
$$m - m_{\text{zeropoint}} = 2.5 \log[f_\nu F(t)/F_0] - A$$



GMOS 5 by 5 square-arcminute imaging, w/ existing zeropoint pipeline



Images: Gemini webpages (and above) GMOS operation manual



Bottom line: Need ~1000 frames per year

Global Extinction: All Archived Gemini GMOS-N/S Sloan-r’ versus the Gaia-G Catalogue

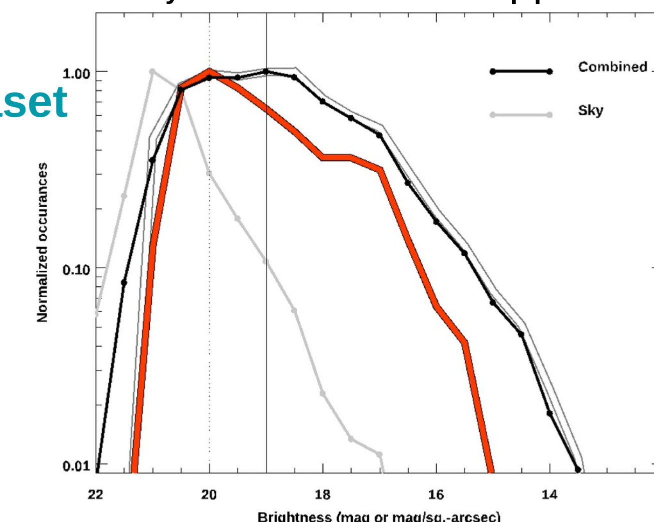
Gaia-G all-sky catalogue to ~21 mag

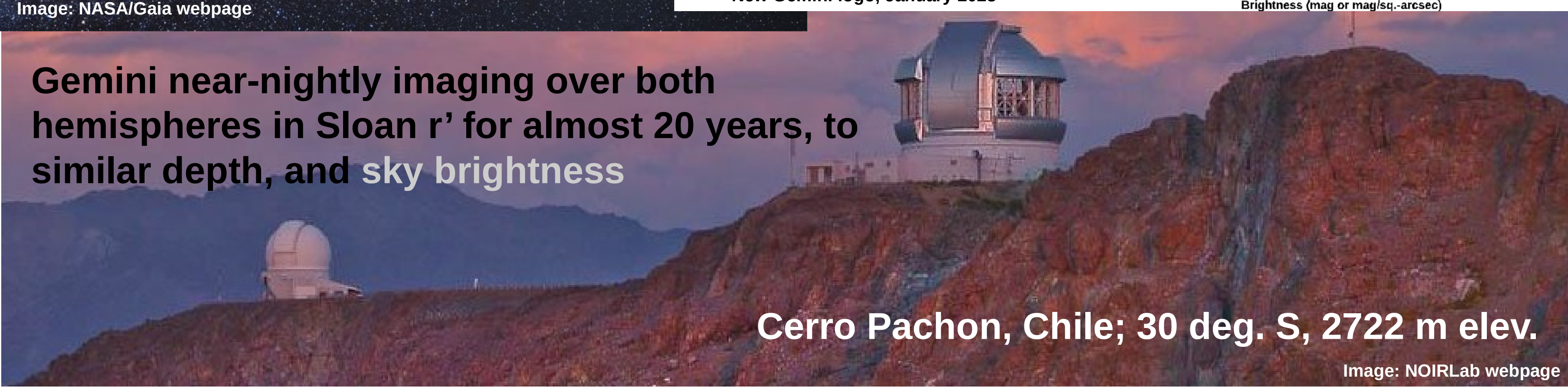
Image: NASA/Gaia webpage

Creating a Uniform, Combined Global Dataset

New Gemini logo, January 2023

Every available GMOS r’-band science frame from 2003 through 2021 processed in the same way with DRAGONS in an IDL pipeline



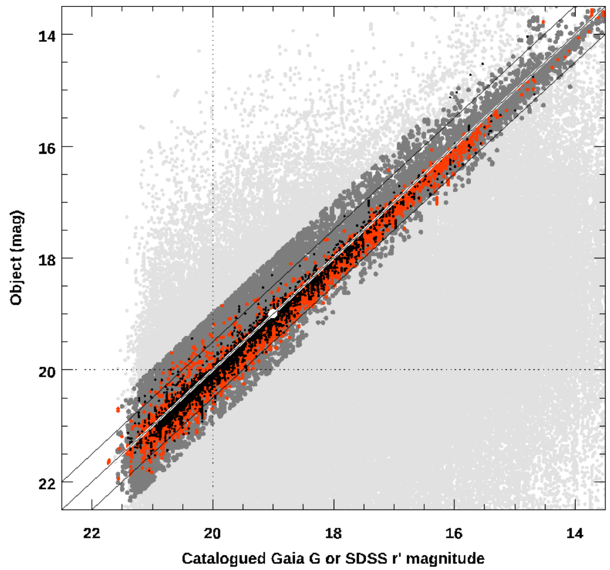


Gemini near-nightly imaging over both hemispheres in Sloan r’ for almost 20 years, to similar depth, and sky brightness

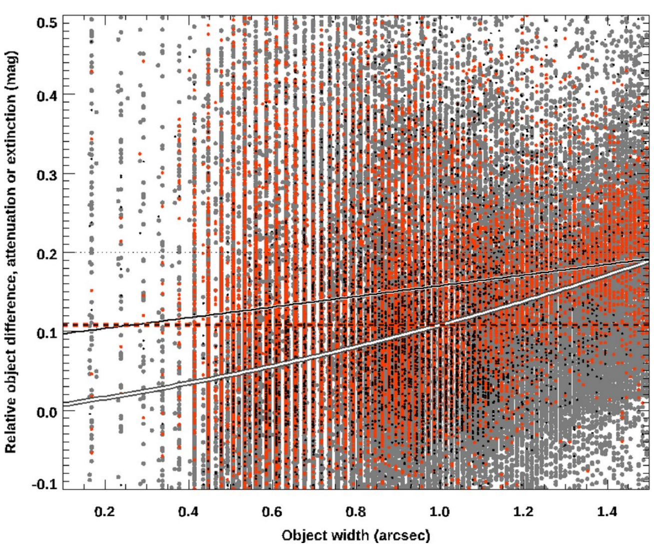
Cerro Pachon, Chile; 30 deg. S, 2722 m elev.

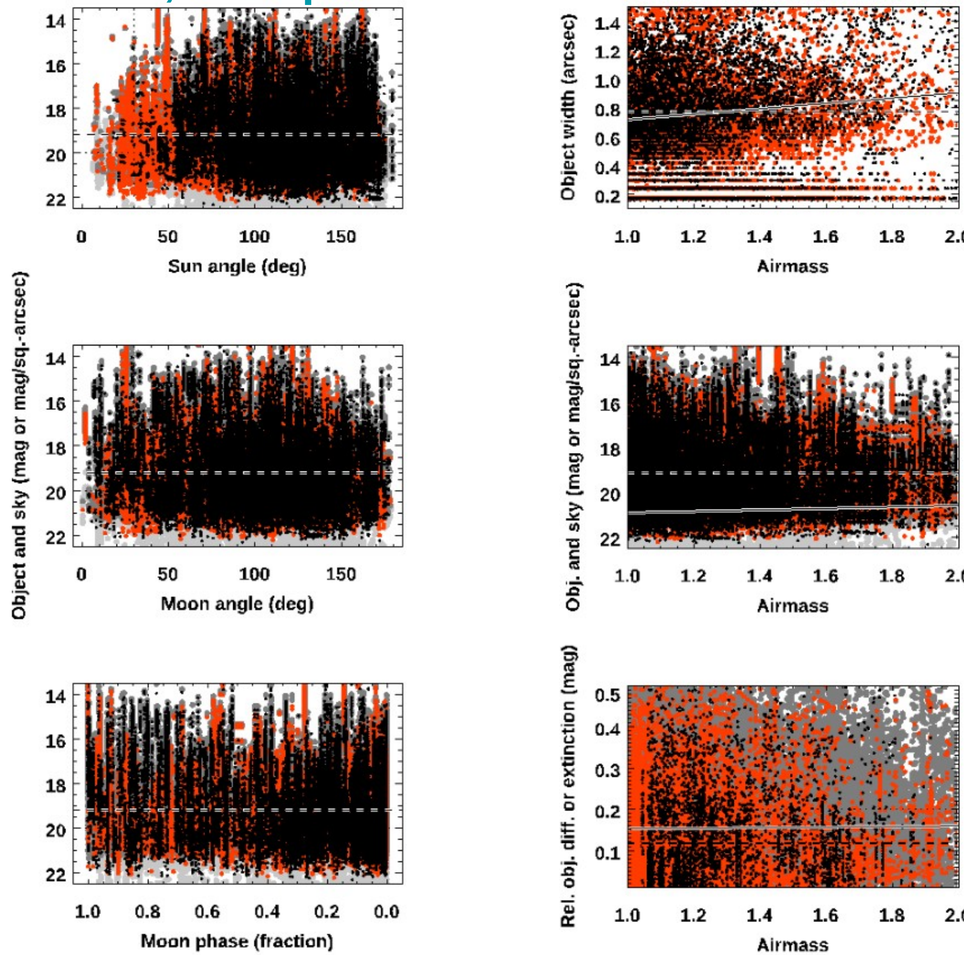
Image: NOIRLab webpage

Results: Sampling, and Considering Observational Biases

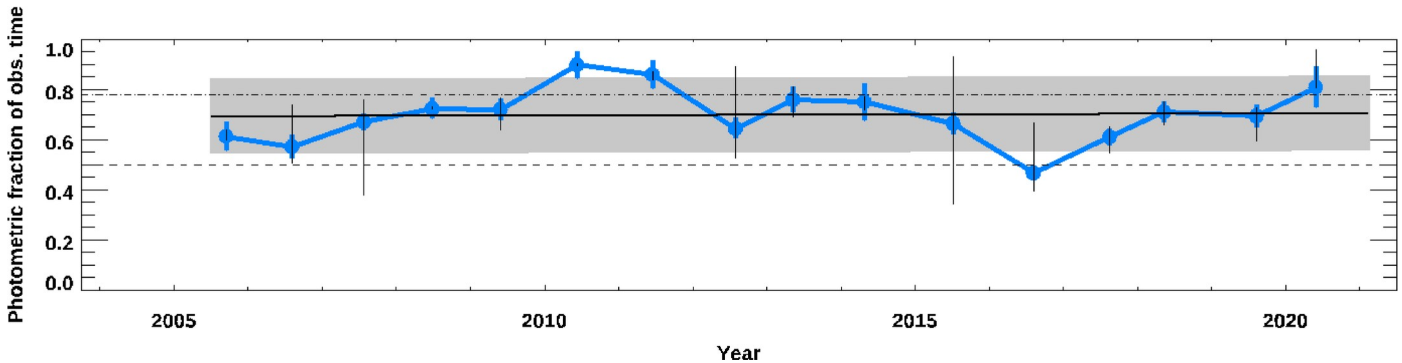


Since 2003, one million observations taken at every sky position over both hemispheres in all seasons and weather: best conditions give least attenuation, as expected





Results: Year-to-Year Clear-Sky Fractions



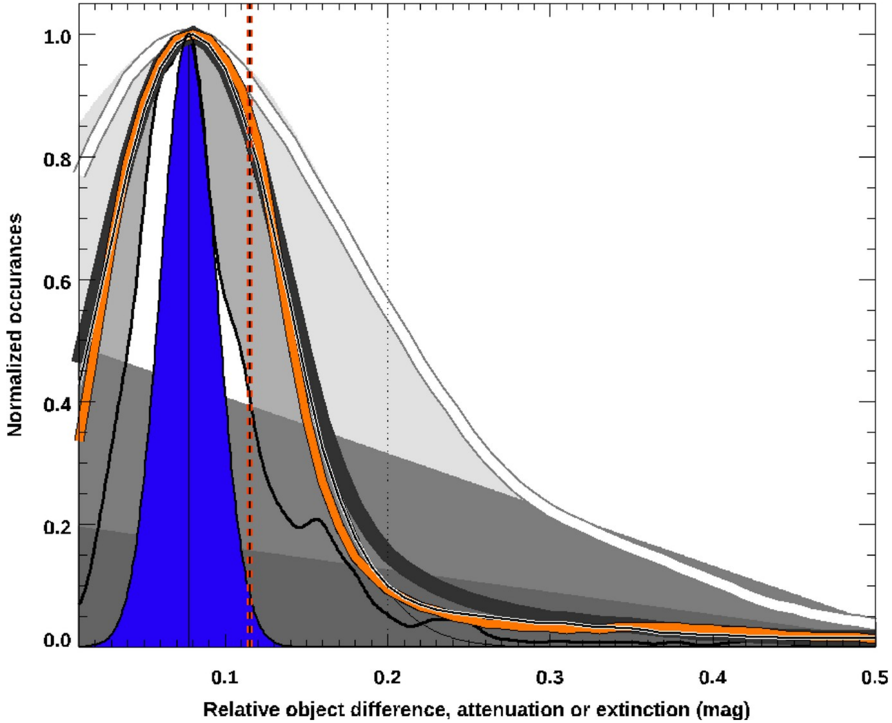
Photometric fraction of time (no visible clouds) from nightlog year-to-year has no trend, and Gaia / Sloan Digital Sky Survey sampling year-to-year is also fairly uniform over 17 years, since 2005, about 17,000 frames total

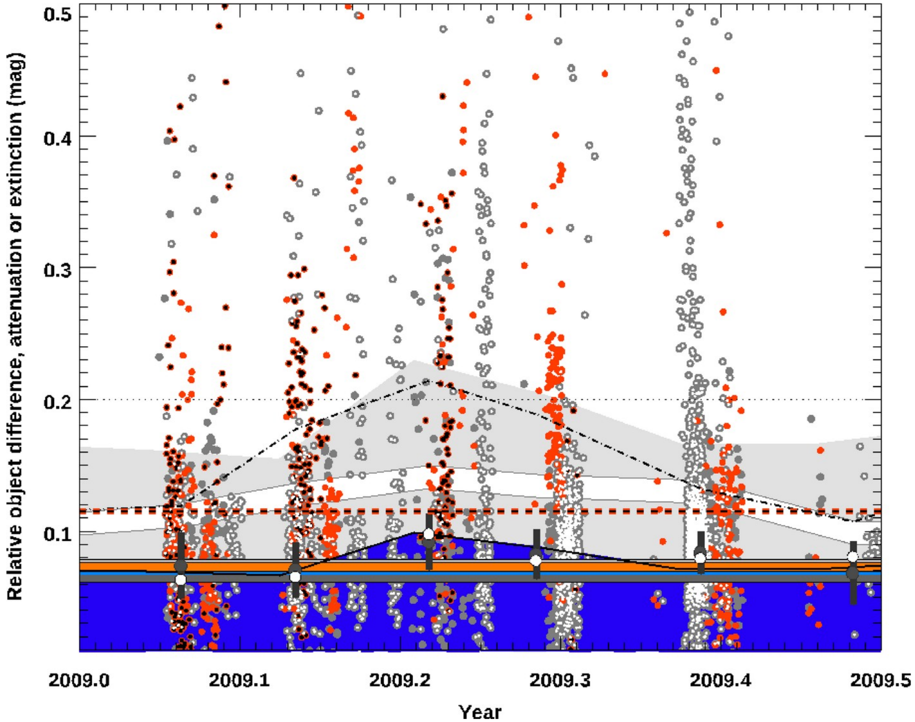
GEMINI OBSERVATIONS AND FRACTIONS OF TIME

				Observed Fractions				
						Sky Conditions		
	GMOS r′ *Gaia*-G Samples			Combined SDSS		Photometric		
Year	North	South	Both	North	South	North	South	Best
2005.7	6,672	4,326	10,998	0.29	0.02	0.60	0.64	0.54
2006.6	4,098	10,836	14,934	0.27	0.05	0.74	0.51	0.45
2007.6	9,047	39,422	39,422	0.29	0.15	0.38	0.76	0.58
2008.5	2,834	26,865	29,699	0.56	0.09	0.73	0.72	0.35
2009.4	9,711	17,652	27,363	0.34	0.11	0.64	0.77	0.67
2010.4	4,266	22,613	26,879	0.26	0.11	0.90	0.90	0.57
2011.5	6,807	16,754	23,561	0.43	0.17	0.84	0.87	0.72
2012.6	7,450	15,775	23,225	0.26	0.04	0.89	0.53	0.50
2013.4	12,720	9,634	22,354	0.50	0.03	0.81	0.69	0.66
2014.3	5,996	4,307	10,303	0.51	0.03	0.77	0.72	0.66
2015.5	12,430	10,297	22,727	0.38	0.01	0.93	0.35	0.60
2016.6	21,220	7,928	29,148	0.23	0.06	0.39	0.67	0.39
2017.6	12,677	19,887	32,564	0.64	0.08	0.55	0.65	0.39
2018.4	11,702	16,097	27,799	0.18	0.02	0.65	0.75	0.45
2019.6	5,490	18,109	23,599	0.21	0.04	0.59	0.73	0.39
2020.4	9,406	387	9,793	0.22	0.25	0.80	0.96	0.68
Total:	142,802	231,844	374,643	0.34	0.08	0.78	0.78	0.67

Results: Distributions of Attenuation, and Zoomed in on the Worst Period

Gaia-G (in Sloan-r') photometry might be 10% to 20% per frame, but quickly beaten down (by about 20 frames per month, when available) reaching ~2% per year, and more like 0.04%, or 0.4 mmag per 250,000 frames (combing all the best data)





Worst-period shift is roughly a similar amplitude as the long-term change in attenuation over two decades

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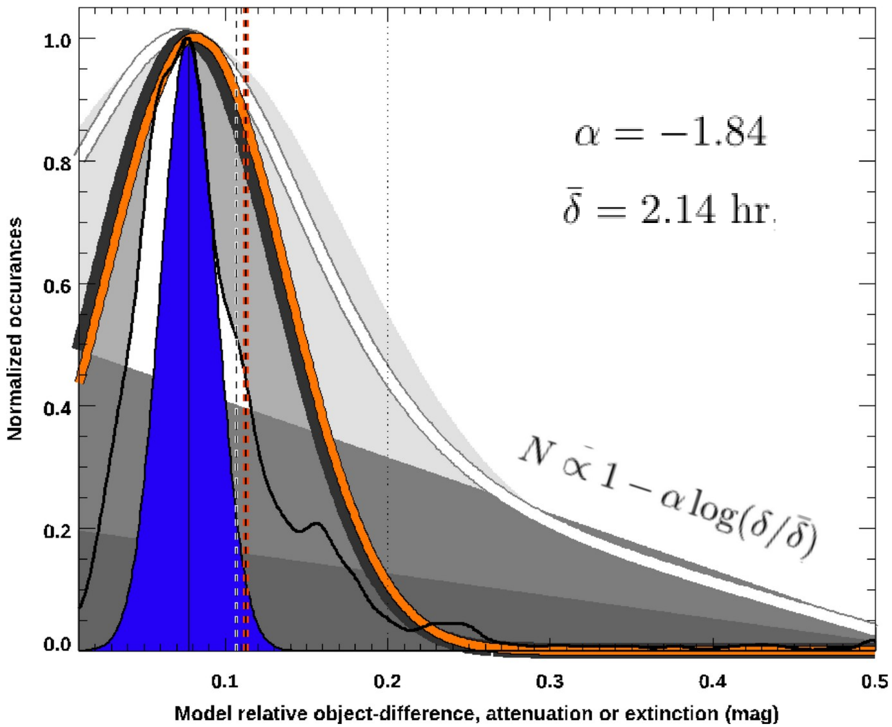

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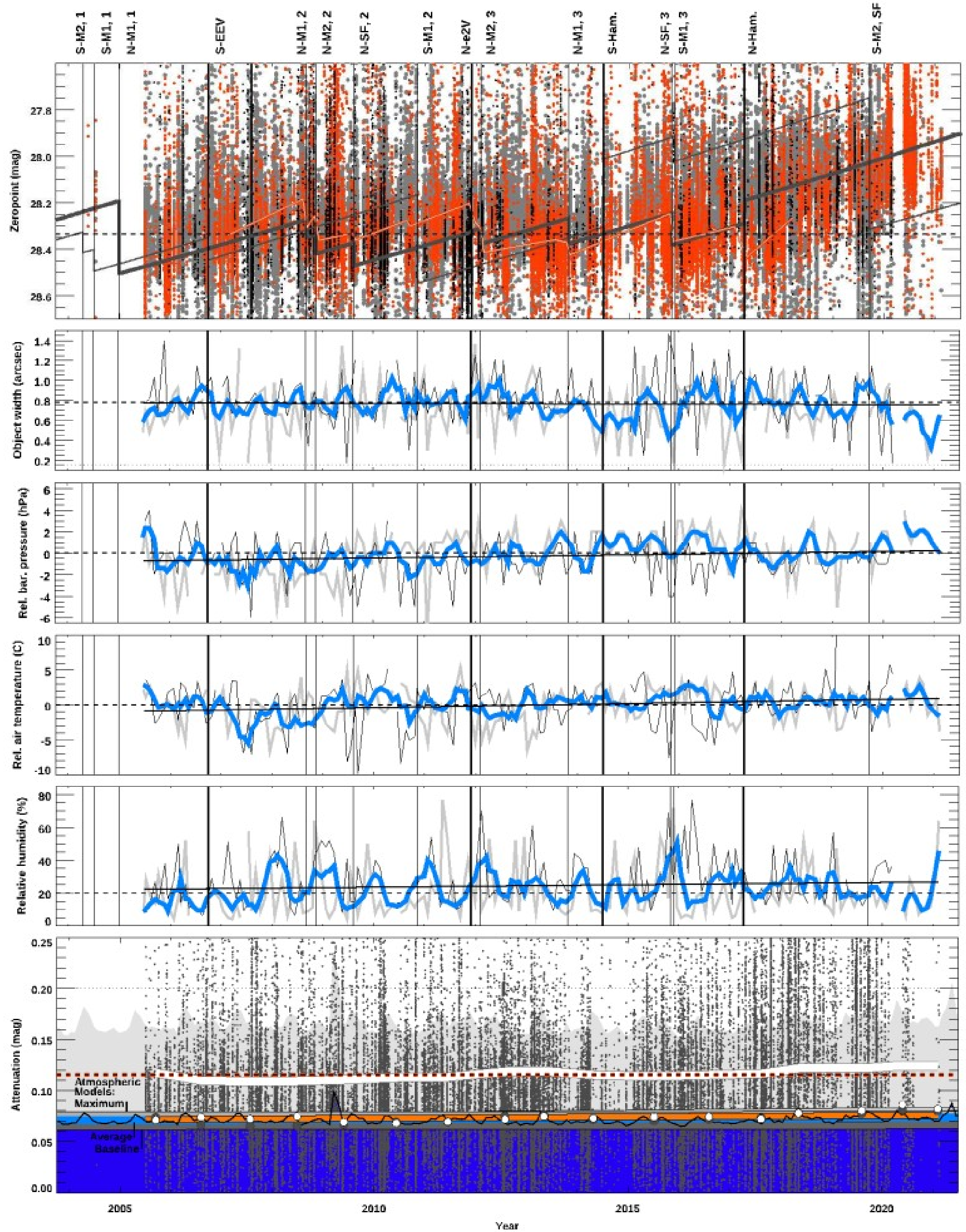
Results: Total

Long term change in atmospheric attenuation agrees with solar-radiance slope over same time period, and simple model of density with temperature, with approx. the same constant as found for CFHT-only meteorological data:
2.22 vs 2.39 mmag/deg. C

Attenuation Measurement Fits

Dataset	Time Period	Sky Conditions	A_0 (mag)	ΔA $\left(\frac{\text{mmag}}{\text{decade}}\right)$
MLO Solar Radiance				
Full[a]	1958.0-2021.5	Clear	0.0694	0.4 ± 0.2
Overlap[b]	2000.0-2021.5	Clear	0.0691	1.7 ± 0.5
Exclusive[c]	2010.0-2021.5	Clear	0.0688	4.0 ± 1.0
GMOS Photometry				
Initial[d]	2005.5-2013.5	Best	0.0700	1.3 ± 0.9
Both	2005.5-2021.0	Best	0.0711	2.7 ± 1.1
North	2005.5-2021.0	Photometric	0.0698	3.9 ± 1.4
South	2005.5-2021.0	Photometric	0.0648	4.3 ± 1.4

[a] Using all available data.
[b] Beginning at Gemini first light.
[c] Excluding data of 2009 episode and prior.
[d] Both telescopes, restricted to first half of available data.



Conclusion: Loss of Combined Gemini Throughput Seems to be Consistent with Global Warming

Weekly zeropoint calibration needed to track fluctuations, including due to volcanoes

Atmospheric attenuation at 0.6 microns seems to be growing at 2 mmag/decade, in agreement with global temperature rise beyond accepted 0.2 C/decade (by about 3X)

About 1% loss total for Gemini since 2000; equivalent to a 12 cm aperture per year per 8-m telescope (Heads up! That is times 13 worldwide, for all current ones.)

See: Steinbring, E., 2022, PASP, 134, 125003

Background Image: SkyNews

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THANK YOU

Eric Steinbring • Eric.Steinbring@nrc-cnrc.gc.ca