Mk4 Scattered Light Analysis
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Summary:
Mk4 calibrated intensity data from 2004 through early 2006 have been analyzed in an effort to understand instrumental and sky brightness values and variations. Data are calibrated using an opal glass attenuator. Its transmission value has an uncertainty of 30%. Wavelength is set by the quantum efficiency of the line array detector, RG695 cut on filter, and 950nm cut-off filter. The effective center wavelength is 775nm.

Thanks to Tony Darnell for fetching the data and to Pete Nelson and to Haosheng Lin for valuable discussions about these measurements.
**Best Image of the Day Time Series:**
The best images of the day were evaluated for total brightness (instrument, sky and corona) for three heights, 1.15, 1.41, 1.68, 1.94, 2.20, and 2.47 R-Sun using a solar radius of 960 arc seconds. These same heights are used throughout this analysis. One notices low values, an increase in time and low values again. These episodes are due to cleaning of the objective lens. Note how the brightness increases *immediately* following a lens cleaning. There is a possibility that following the best cleaning at the beginning of 2006, all the dirt was removed from the lens and remaining scatter is due to surface roughness alone. Even allowing for this possibility, scatter due to dirt dominates all or nearly all the time.
**Brightness vs. Airmass**

On a given day, total brightness can be plotted vs. air mass. The intercept shows the instrumental contribution (and for the lowest height some coronal contribution). The slope indicates brightness due to the sky. The following plot shows a typical Mk4 day. In the morning brightness decreases linearly with air mass. Approaching noon something happens and the scatter gets brighter. In the afternoon the sky brightness increases following a different path from the morning. There are a few really good days when morning and afternoon overlap. To infer instrumental scatter, the linear portion of the morning data points are extrapolated to zero air mass.
RMS Variation of Brightness at one height vs. Time of Day

The RMS brightness variation vs. scan azimuth at selected heights is fairly constant in the morning then approaching noon it increases. We know by looking out the dome slot that aerosols increase late in the morning and from other spar mounted imagers that seeing degrades, but the exact cause of this increase seen in Mk4 is not known. From the previous plot we see the total brightness increase when averaged in azimuth at each height. Perhaps this is just proportional to the background increase but the magnitude of the RMS increase seems excessive. It could be due to numerous unresolved aerosols near the telescope. Or perhaps it is due to spill around the occulter due to seeing?
**Instruments and Sky Brightness vs. Date**

Plots of brightness vs. air mass for every day in the time series were created. The contribution of instrument alone (plus some corona) determined from the zero intercept of the brightness vs. air mass curves is shown below. Note the same shape as the best image of the day plot but with a lot more noise due to whatever happened on particular days that affected the intercept of the brightness vs. air mass curve. These data do not reflect any selection for good days.
Sky Brightness vs. Date

The slopes of the curves of brightness vs. air mass give an indication of the sky brightness for each day. Slopes are strongly affected by variations due to whatever during the day so there is a lot of scatter. One thing of note is that the signature of objective lens cleaning has been completely removed. During the spring there are a lot of bad days, but the second half of 2004 and 2005 are consistently good. Viewing the brightness vs. air mass curves for many days, I conclude the large values in the spring are due more to brightness variations during the day causing widely varying slopes rather than an overall brighter sky. The median sky brightness vs. air mass slopes are shown for the six heights and are all close to $5 \times 10^{-7} \text{B-Sun per air mass}$. 

![Mk4 Sky Slope vs. Date](image-url)
Brightness vs. Height

For two days, one just before cleaning the lens and one just after cleaning the lens, brightness vs. height was plotted. These are the azimuthal averages for the daily average intensity maps for those two days. For a clean lens, brightness is about $6 \times 10^{-6}$ at 1.15 R-Sun and about $2.5 \times 10^{-6}$ at 2.5 R-Sun. The dirty lens shows about $25 \times 10^{-6}$ at 1.15 R-Sun and $10 \times 10^{-6}$ at 2.5 R-Sun, about the same ratio of brightness at a low height to that for an elevated height as shown by the clean lens.
Cleaning Day
Just for fun here is a plot of total brightness vs. air mass for six heights on the lens-cleaning day. The day starts with a high brightness slowly decreasing with air mass then jumps to a low curve that doubles back in the afternoon.

Conclusions
Mauna Loa is a good site in terms of typical sky brightness. Cleanliness of the objective dominates brightness for most days. To improve instrumental scatter we need to reduce objective scatter by about a factor of five for its contribution to be smaller than that of the median sky and we must keep dirt away from the objective.

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