Memorandum
Gemini 8m Telescopes Project

To: Matt Mountain
From: Doug Simons
Date: August 3, 1995
Re: Comparison of CFHT/CfA Seeing Measurements

Overview of Analysis

I have completed a preliminary comparison of image quality measured at CFHT and seeing measurements made at the 11.7 Ghz CfA monitor. Though it is not obvious that seeing would be correlated at such different wavelengths, there are a number of reasons such a comparison is useful, including:

1. Gemini will likely need some sort of seeing monitor and the viability of measuring the infrared seeing at 11.7 Ghz is intriguing.

2. Such a comparison provides insight into the physics of atmospheric seeing.

3. This type of comparison is potentially of interest to other groups working on adaptive optics for large telescopes.

The goal of this preliminary analysis is to simply assess seeing trends observed between CFHT and CfA measurements over the course of a ~6 month period in 1992. If the results look encouraging (i.e., we detect seeing correlation) we should proceed with a more extensive analysis over longer time frames. It was agreed between Colin Masson and myself that it would be best to make this preliminary analysis with the data immediately available to Colin, before dedicating a considerable effort into an analysis of all seeing data available.

CFHT Image Quality Data

The CFHT data are generated by a program called AIQE, or Automatic Image Quality Evaluation. Each time a CCD frame is recorded by an imaging instrument at CFHT, the raw image is passed through the AIQE program in the background, before the image is ultimately archived on optical disk. The program measures the FWHM values of all the detected stellar PSFs before recording the mean FWHM value for an entire image in a log file. A variety of other data, including a time stamp, air mass, etc.

are recorded for each AIQE entry in the log file. I have down loaded from CFHT seeing measurements made with HRCam (tip/tilt PF camera) and FOCAM (Cass mounted f/8 camera) for 1992, 1993, and part of the 1994.

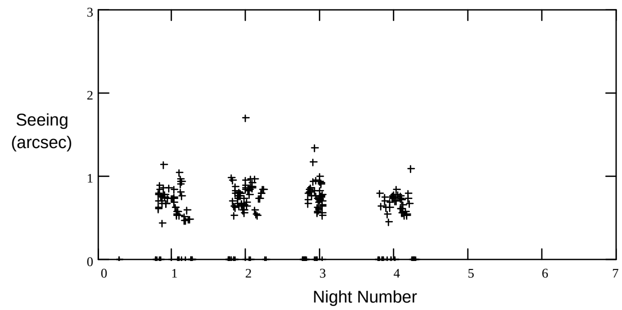


Figure 1 - A plot of CFHT image quality data is depicted above. Each cross represents a mean FWHM measurement of point sources found in an HRCam frame. Tick marks correspond to midnight HST along X and arcsec along Y.

CfA Seeing Data

The CfA installed in 1990 a seeing monitor that runs at 11.7 Ghz on the summit near JCMT and records seeing data continuously. It operates by measuring the phase difference between the signals measured by 2 receivers separated by a 100 m baseline. Colin kindly provided me with CfA data for the first 6 months of 1992, which include the rms path length phase difference and scatter. Though the monitor outputs measurements every minute, the data provided represent 90 minute averages. The most prominent features are peaks occurring daily which correspond to mid-afternoon heating of the atmosphere. As is evident in Figure 2, the amplitude of afternoon peak phase difference varies significantly between days.

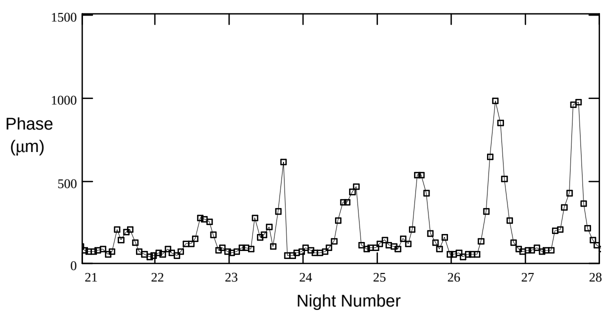


Figure 2 - A plot of a week of CfA seeing data is shown. Tick marks are defined in Figure 1. Obvious are diurnal peaks in phase difference, which vary from day-to-day be considerable amounts.

Caveats

There are several important differences in the way the CFHT and CfA seeing measurements are made that should be pointed out. First, the CFHT measurements are made under varying conditions including:

- air mass
- filter
- detector
- dome/mirror temperatures

For this reason CFHT prefers to call these measurements “image quality” not seeing measurements. By using information embedded in the CFHT logs I have attempted to compensate for some of the varying measurement conditions by scaling each AIQE value for the size of the CCD pixel used and normalizing all measurements to unity air mass, assuming FWHM scales as $\sec(Z)^{0.6}$. Compensating for the various filters used at CFHT would be a much more time consuming process, involving use of the CADC archives to track down the filter specifications. I therefore decided to limit my adjustments to the CFHT data to not include wavelength compensation and we should bear this factor in mind while assessing the results. To first order I would expect this to act as an additional random noise component in the CFHT seeing measurements and would not expect significant long-term trends to be created by filters. In comparison, the CfA data are recorded very methodically by the same receivers pointed in the same direction of the sky at the same frequency.

Time Calibration and Data Overlays

The CFHT data are time stamped according to Julian Day number while the CfA data are time stamped according to days elapsed since 0 hours HST, January 1, 1989. In order to overlay the two data sets I have phase shifted them by amounts needed to start both data sets at 0 hours HST on January 1, 1992.

Figure 3 shows the first 200 days of the 1992 HRCam data overlaid on the CfA data. In this and all subsequent overlays I have arbitrarily divided the CfA phase measurements by a constant (150) in order to make the midnight amplitude of the values comparable between the CFHT and CfA data. This is only done to simplify interpretation of the plots. Since the goal of this analysis is to merely look for common trends in the two data sets, dividing the CfA data by a constant should not effect the results. There are unfortunately only eleven nights during the first 6 months of 1992 that CFHT was using a CCD imager and the CfA monitor was recording data. I have not included the FOCAM 1992 measurements in this report because there is an amazing *anticorrelation* between the times FOCAM was on at CFHT and nights the CfA monitor was running during this 6 month period in 1992.

Plotted on the following pages are CfA and CFHT seeing measurements. Below

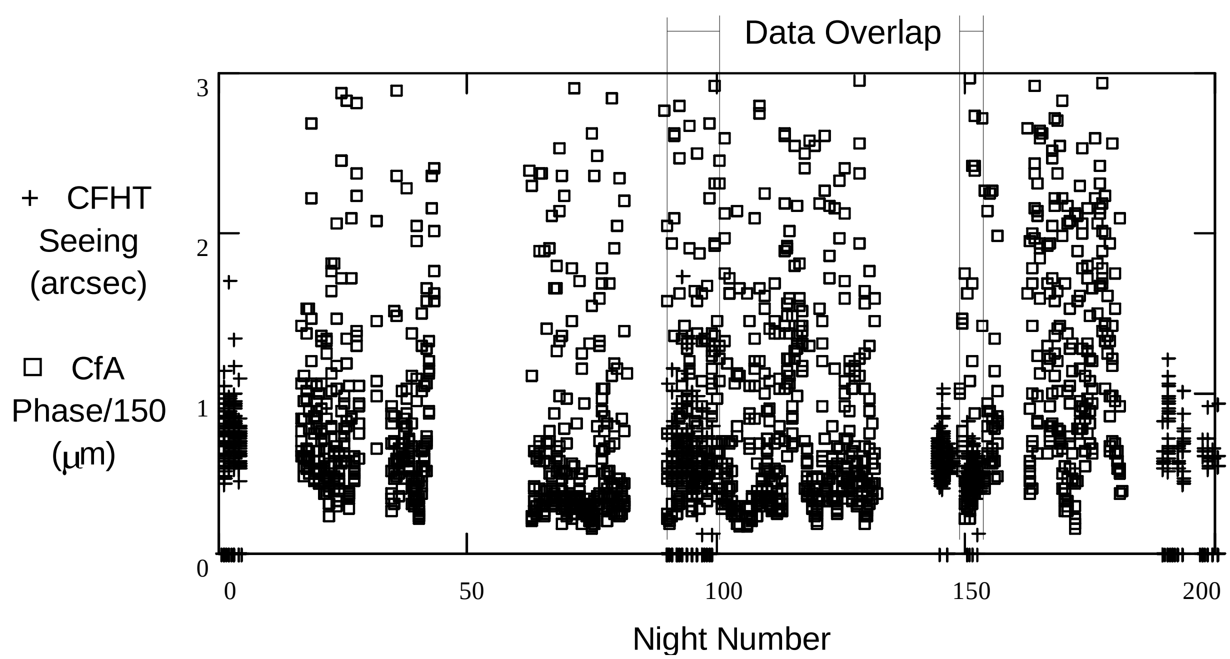


Figure 3 - An overlay of all CfA and CFHT data used in this analysis is shown. CFHT data are denoted by crosses, CfA data by boxes. Due to breaks in the two data sets and the limited amount of time HRCam was used during this period, only about 2 weeks of actual comparison is feasible.

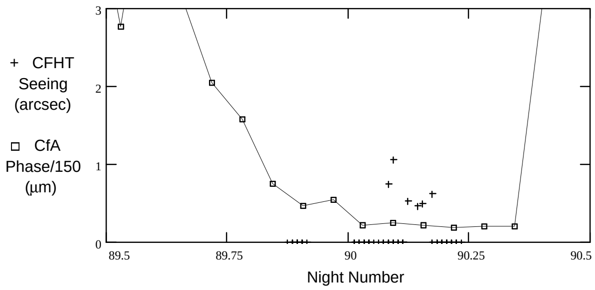
each plot is a brief description of the trends evident in the measurements. In all plots CFHT measurements are calibrated in arcseconds and are depicted by crosses. Likewise, all CfA data are calibrated in microns/150 and are depicted by boxes connected by a line. All overlays are centered at midnight HST and day numbers along the X axis correspond to days elapsed since January 1, 1992.

Conclusions

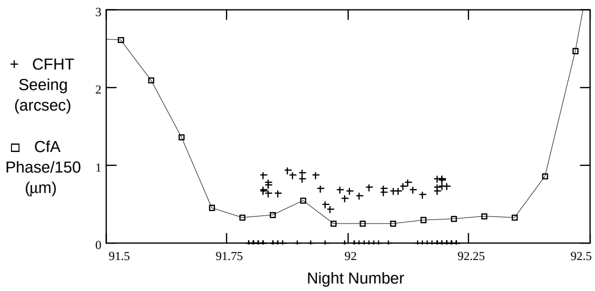
During several nights there are at least weak correlations between CFHT and CfA measurements. Night 98 arguably has the least correlation as a significant seeing improvement is observed at ~23:00 HST at CFHT with no corresponding improvement detected at the CfA monitor. In contrast, measurements made during night 96 clearly show a night of poor seeing at dusk with improvement throughout the night at both sites. Furthermore nights 150 and 151 show some correlation between both sites.

Overall my impression is that these results are encouraging enough to justify a further analysis on much larger data sets, encompassing at least 1992 and 1993 to hopefully get at least ~50 nights of data for comparison. I also propose to complete a formal statistical analysis of this larger data base to help quantify the confidence level of correlations found between optical and radio seeing measurements.

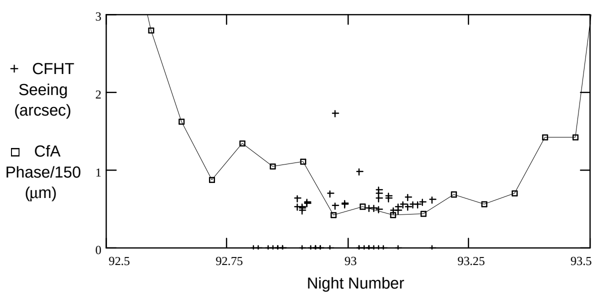
Finally, in the attached paper by Colin entitled “Seeing”, evidence is given that a Komolgorov structure function describes atmospheric turbulence at both radio and optical wavelengths, across a large range in receiver baselines. In the region of overlap between radio and optical baselines (at ~10 m) the ratio of typical radio to optical path length difference is ~50 µm/3 µm, or a factor of ~20. Colin points out that this is close to the change in refractive index of water across the optical to radio wavelength range. This suggests that optical seeing on ~10 m baselines may be dominated by water in the atmosphere, hence the rough correlation in seeing measurements found in this preliminary comparison of CFHT and CfA seeing may be consistent with Colin’s analysis. If true, we may expect better correlations with the larger baseline offered by Gemini.



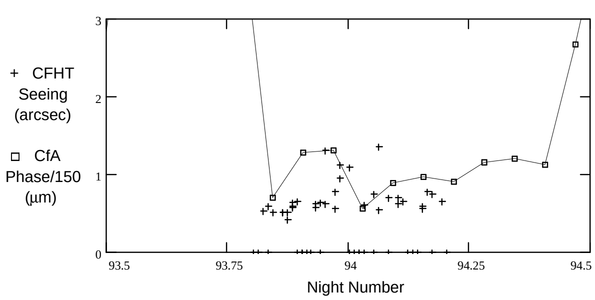
Night 90 - Only 6 CFHT data points are available (not many stellar PSFs imaged) hence a comparison is difficult.



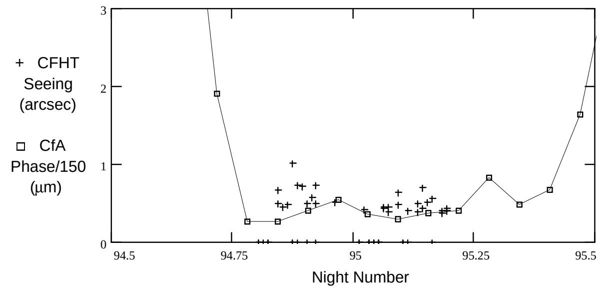
Night 92 - CFHT seeing appears systematically higher prior to ~22:00 HST, than later in the night. A similar weak trend is seen in the CfA data.



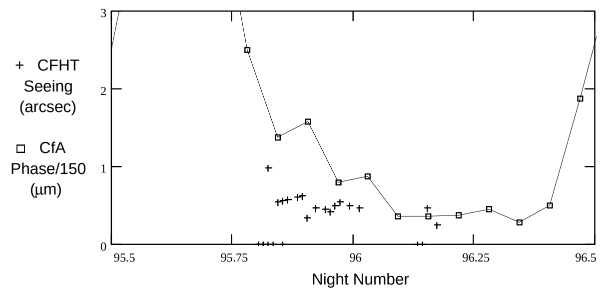
Night 93 - CfA data indicate poor seeing up until ~23:00. At CFHT the seeing is steady except for a couple of spurious points.



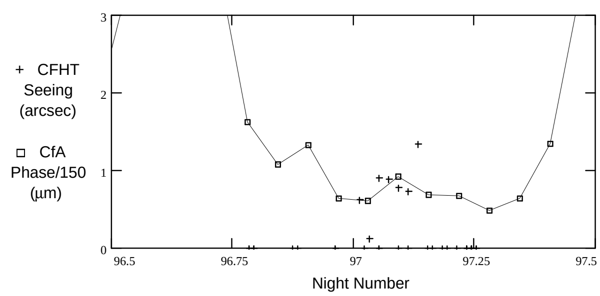
Night 94 - A period of bad seeing occurs around midnight at CFHT, with comparable seeing on either side of midnight. The CfA trend exhibits relatively bad seeing during a few hours prior to midnight. The seeing then improves at midnight before slowly degrading.



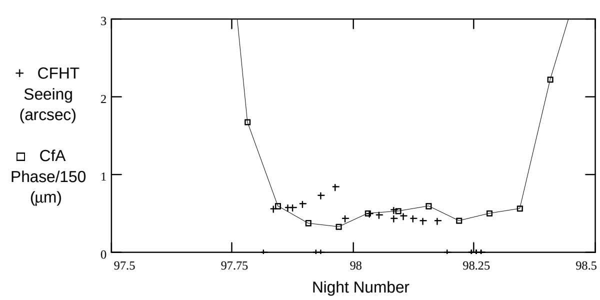
Night 95 - CFHT seeing is clumped on either side of midnight with comparable mean values. CfA seeing has a weak peak near midnight with comparable conditions on either side of midnight.



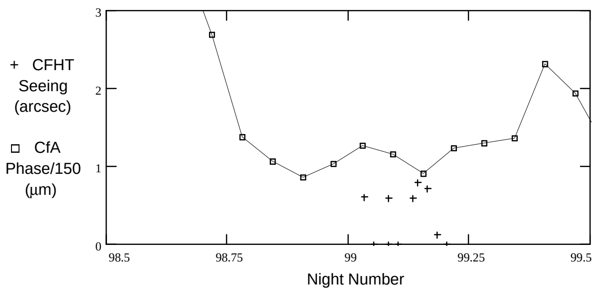
Night 96 - Both the CfA and CFHT sets exhibit improving seeing over the course of the night.



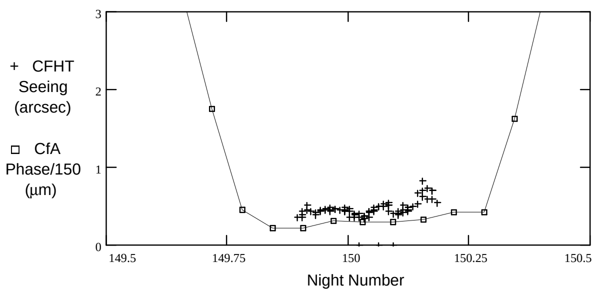
Night 97 - Like night 90, a comparison is difficult due to under sampling in the CFHT measurements.



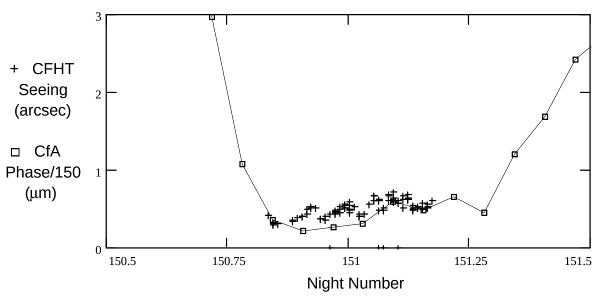
Night 98 - Seeing degrades up to ~23:00 at CFHT, at which time it improves significantly and remains steady. CfA seeing is fairly steady throughout the night.



Night 99 - Once again too few CFHT frames with stellar PSFs were recorded to make a meaningful comparison.



Night 150 - CFHT seeing is quite steady with a ~1 hr period of somewhat worse seeing at the end of the night. The CfA seeing is uniform throughout the night.



Night 151 - Both the CfA and CFHT seeing degrades over the course of the night.