Scintillation Notes for P3k

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1 Introduction

This short note contains some preliminary estimates of the effects of atmospheric scintillation on Palm 3k.

The expression for the log amplitude variance of a plane wave propagating through turbulence is

$$\sigma_\chi^2 = .5631 k_0^{7/6} \mu_{5/6} \tag{1}$$

Here k_0 is the wavenumber and the turbulence moment $\mu_{5/6}$ is defined as

$$\mu_m = \int_0^\infty dz\ C_n^2(z)\ z^m \tag{2}$$

Under typical turbulence conditions at Palomar, one finds a value of $\mu_{5/6} = 2.6 \times 10^{-10}$ m$^{3/2}$ at zenith.

The variance in the intensity is related to the log amplitude variance by

$$\frac{\sigma_I^2}{I^2} = 4\sigma_\chi^2 \tag{3}$$

Thus, the fractional variance of the intensity is four times the log amplitude variance, and the fractional standard deviation of the intensity is twice the standard deviation of the log amplitude. Figure 1 shows σ_I/I vs. wavelength at zenith under typical turbulence conditions at Palomar.

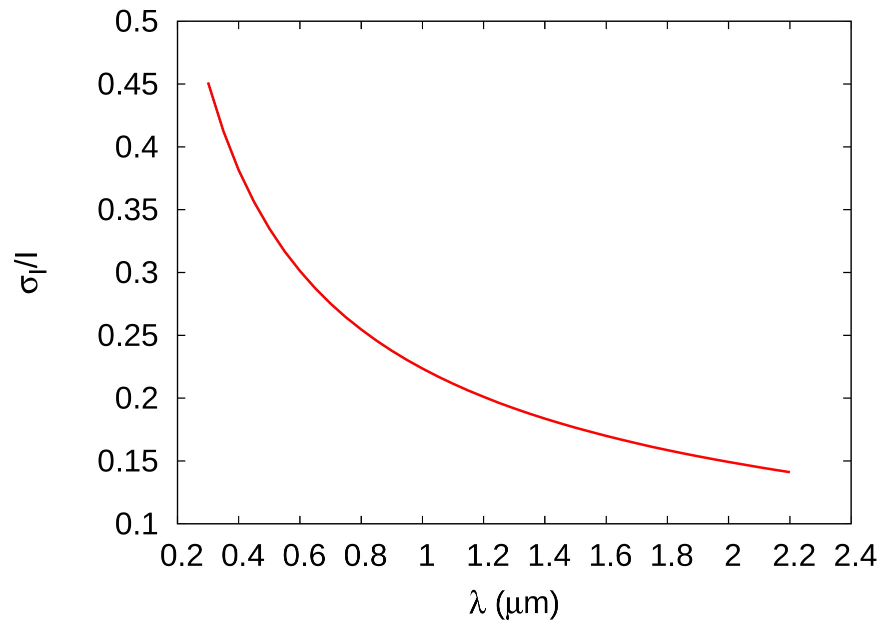

Figure 1: Fractional standard deviation of intensity in the telescope pupil plane as a function of wavelength for typical turbulence conditions at Palomar. Plane wave propagation through turbulence gives rise to the effect of scintillation, which generates fluctuations in the wave amplitude at the pupil plane of the telescope. The fractional fluctuation in the pupil plane intensity is plotted above.

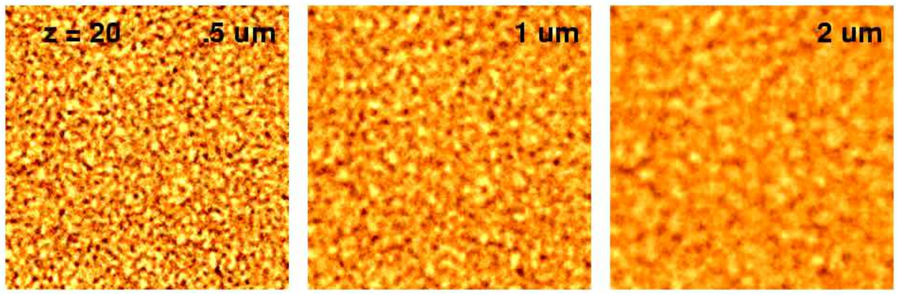

Figure 2: Simulation of wavefront amplitude fluctuations in the pupil plane of a telescope arising from scintillation. The panels shows amplitude fluctuations across a 5 meter patch of wavefront that arise from traversing a turbulence screen and propagating twenty kilometers. The Fried parameter of the screen used in this simulation was 65 cm at .5 μm. The three panels display an increase in the lateral coherence scale and a decrease in the strength of the amplitude fluctuations as one shifts from .5 μm to 2 μm observing wavelengths.

The intensity fluctuations in the pupil plane display a lateral coherence scale that depends on turbulence conditions and observing wavelength. This coherence scale is an important parameter in determining how the effects of scintillation average away in time and over finite apertures. An illustration of this lateral coherence scale of amplitude scintillation is shown in figure 2.

An expression for the aperture averaged log amplitude variance has been derived for the case in which the aperture is much larger than this coherence scale. The expression is

$$\sigma^2_{\chi A} = 4.34 \frac{\mu_2}{D^{7/3}} \tag{4}$$

where D is the aperture diameter. Under typical turbulence conditions at Palomar, one finds a value of $\mu_2 = 1.1 \times 10^{-5}$ m$^{8/3}$ at zenith. Note that the wavelength dependence drops out of $\sigma^2_{\chi A}$.

One can form a ratio between the non-aperture averaged log amplitude variance and the aperture averaged log amplitude variance as

$$\frac{\sigma^2_{\chi A}}{\sigma^2_{\chi}} = \left(\frac{D_c}{D}\right)^{7/3} \quad D \gg D_c \tag{5}$$

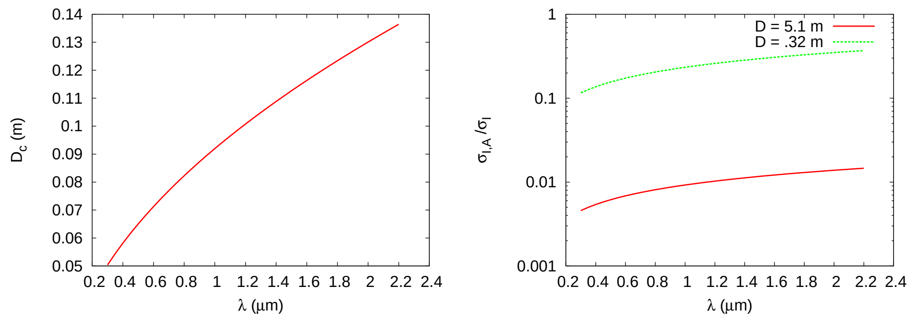

Figure 3: Plots of the lateral coherence scale and the fractional suppression of scintillation arising from aperture averaging. The left plot shows the lateral coherence scale as a function of wavelength. This parameter increases as $\sqrt{\lambda}$. The right plot shows the fraction by which the intensity fluctuations are suppressed due to averaging over a 5.1 and .32 m apertures.

where

$$D_c = .957\sqrt{\lambda}\left(\frac{\mu_2}{\mu_{5/6}}\right)^{3/7} \tag{6}$$

is the characteristic lateral coherence scale. The above ratio illustrates the degree of suppression that arises from aperture averaging. Figure 3 displays the characteristic lateral coherence scale and the ratio described above.

A few words on the implications of this analysis for high contrast observations. Using equation 4, one finds that for a 5.1 meter aperture, the standard deviation of the aperture averaged intensity is .2%. This does not mean that the entire point spread function on the Hale 5m telescope is varying by .2%. Instead, it means that there is a significant amount of variation in the PSF at a radius corresponding to the characteristic lateral coherence scale, which when averaged over the entire PSF leads to a .2% fluctuation in intensity. The radius corresponding to the lateral coherence scale is plotted in figure 4.

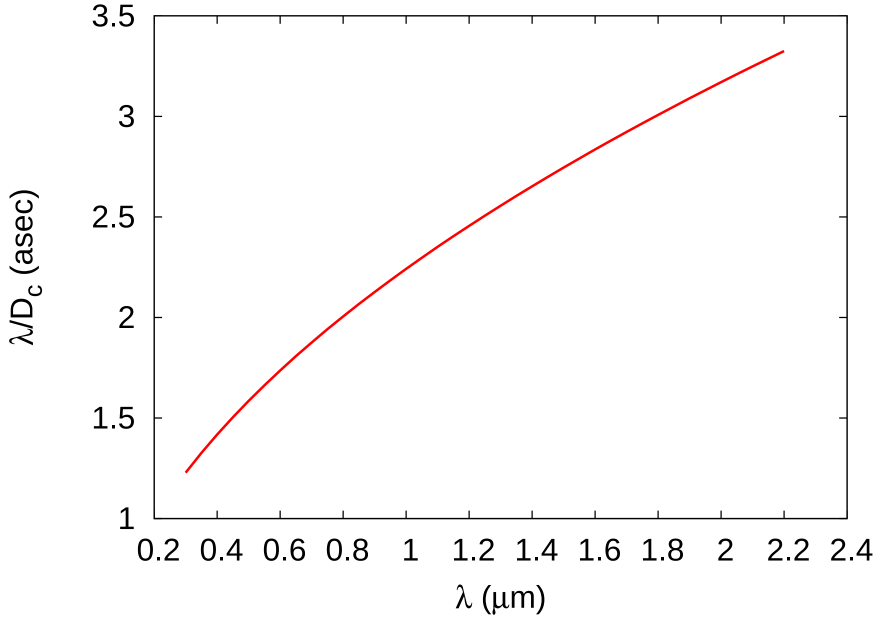

Figure 4: Plot of the critical radius corresponding to the lateral coherence scale as a function of observing wavelength. This is the characteristic radius to which light is scattered by the effects of scintillation.