Effects of Atmospheric Turbulence on Laser Propagation

Michael Mendoza and William Jones

with Joseph Harris and Prof. Christopher Davis

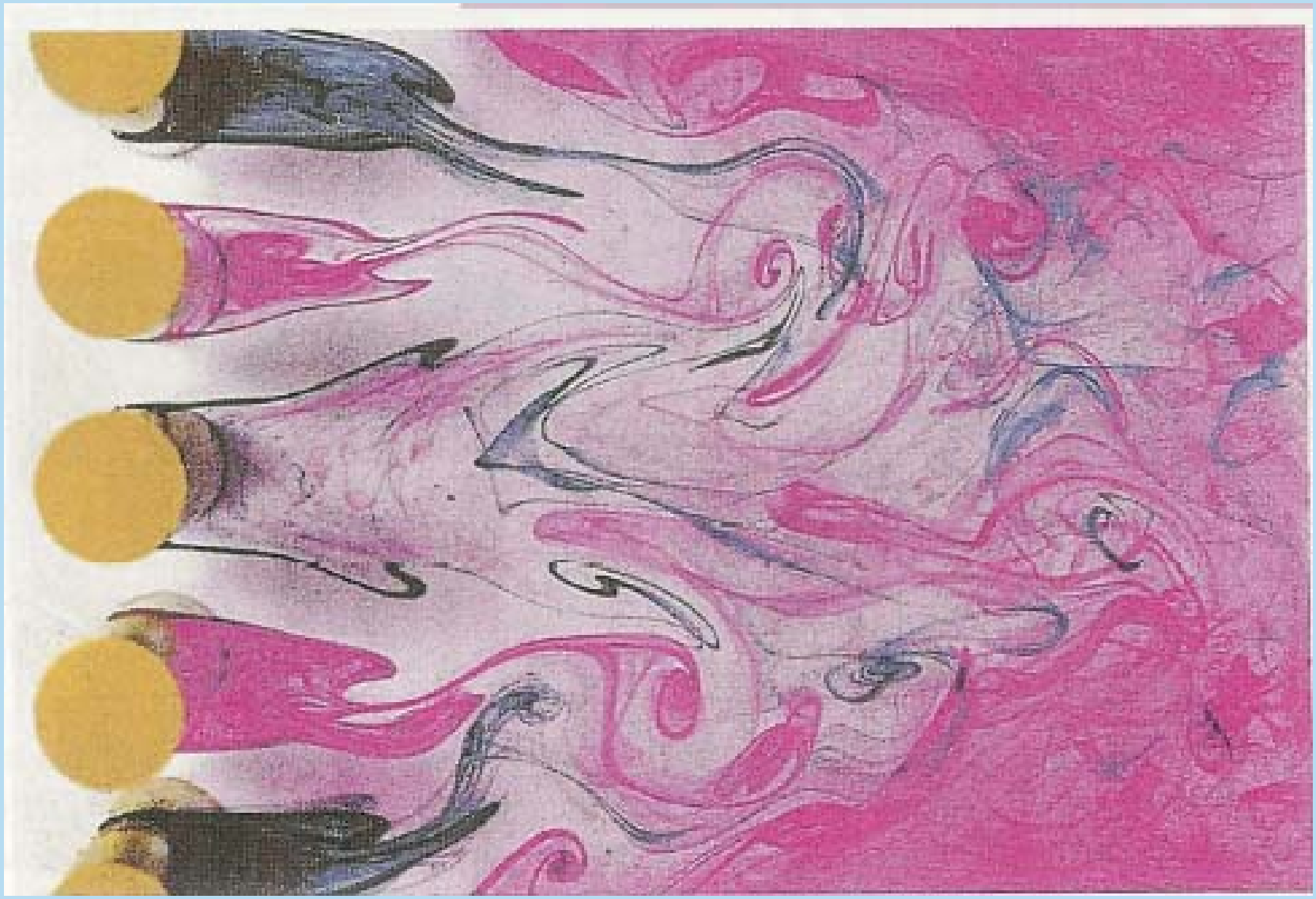
Purpose:

The focus of the current research is the characterization of the effects of atmospheric turbulence on the propagation of electromagnetic waves at optical wavelengths.

Two Fundamental Questions:

- How does atmospheric turbulence affect light?
- What can scattered light tell us about atmospheric turbulence?

Example of Turbulence



Tsinober plate 4

The Atmosphere as a Fluid

The Atmosphere is a flowing fluid and such it obeys the Navier-Stokes equations which describe the behavior of fluids flows:

$$\partial_t \mathbf{v} + (\mathbf{v} \cdot \nabla)\mathbf{v} = -\frac{1}{\rho}\nabla p + \upsilon \nabla^2 \mathbf{v} \qquad \nabla \cdot \mathbf{v} = 0$$

Atmospheric Turbulence

The Turbulence occurs when a fluid flow exceeds a critical Reynold's number, R.

$$\mathbf{v}\cdot\nabla\mathbf{v} = -\frac{1}{\rho}\nabla p + \frac{\eta}{\rho}\nabla^2\mathbf{v}$$

$$\upsilon \equiv \eta / \rho$$

$$R \equiv lu / \upsilon$$

This causes this non-linear term of the NSE to dominate which is characterized by the flow's chaotic behavior.

$$\frac{\eta}{\rho}\nabla^2\mathbf{v} \sim \eta u / \rho l^2$$

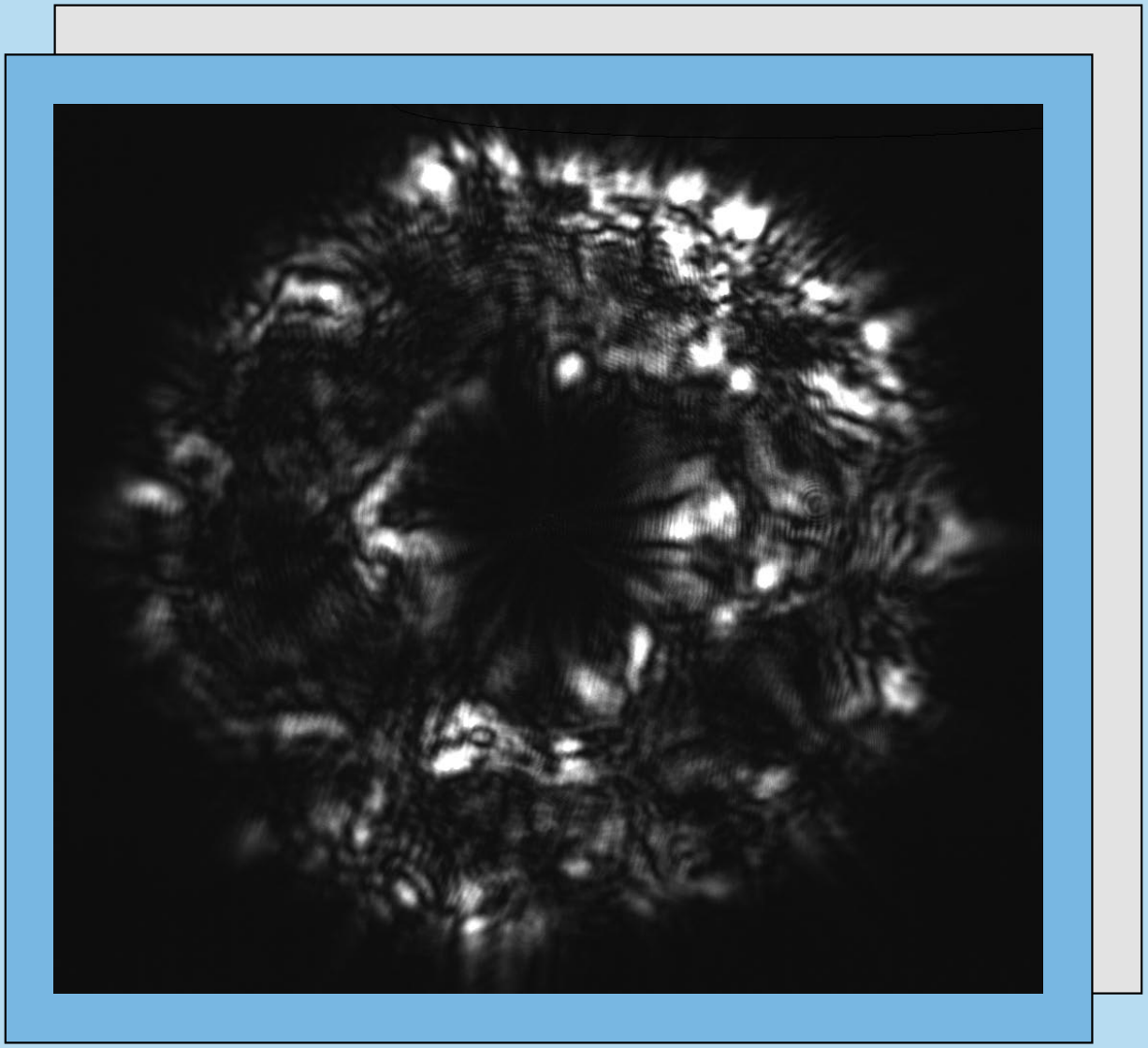
$$\mathbf{v}\cdot\nabla\mathbf{v} \sim u^2 / l$$

$$\frac{u^2 / l}{\eta u / \rho l^2} = \frac{ul}{\upsilon} = R$$

From Turbulence to Scattering

- Turbulent air carries pockets of different temperatures along with its flow.
- Pockets of air at different temperatures have different indices of refraction.
- These regions of different indices of refraction create a scattering problem.

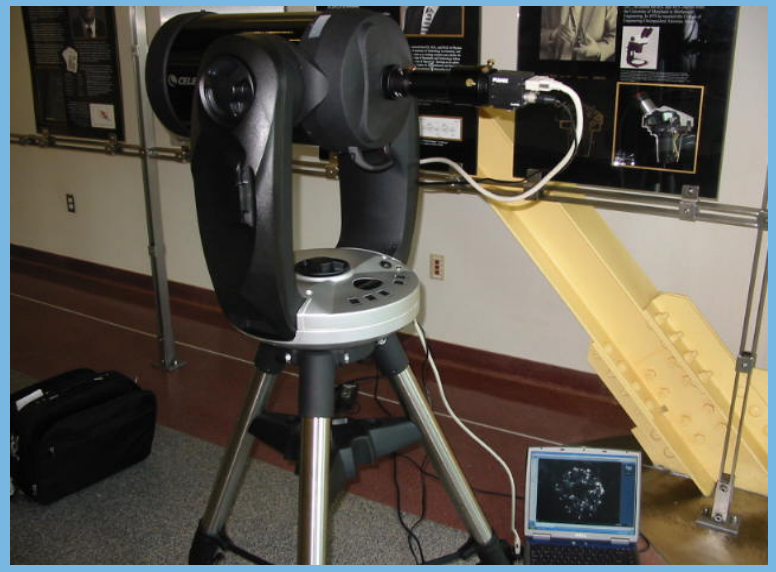
Scattered Light

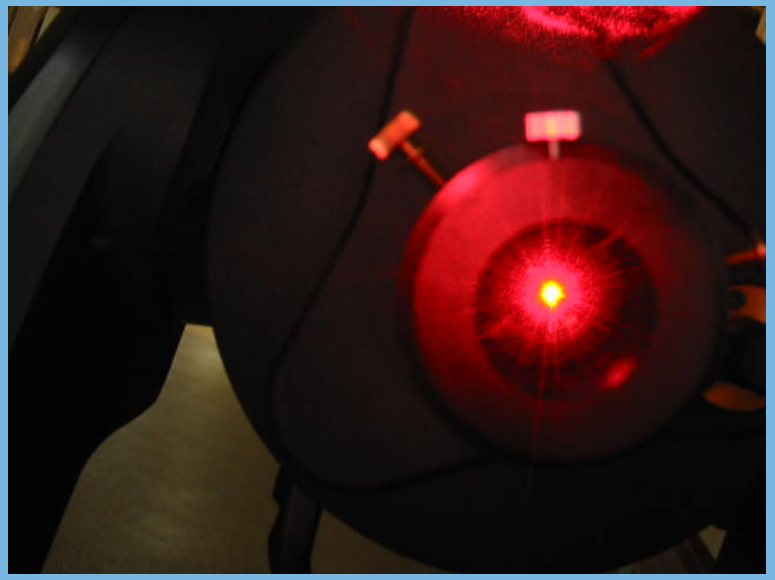


Experimental Setup

A Helium-Neon laser is directed at a distant Schmidt-Cassegrain telescope.

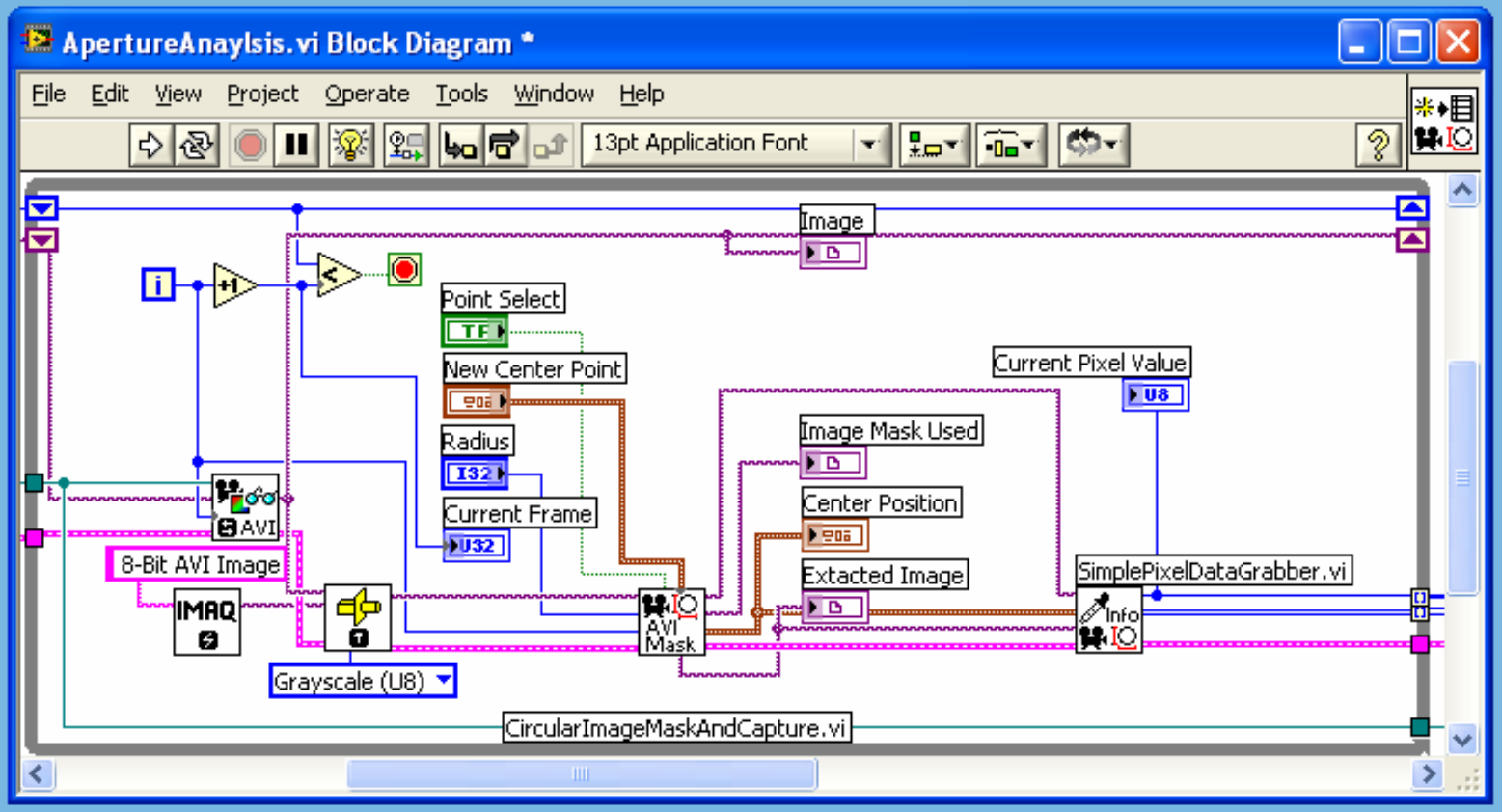
Experimental Setup





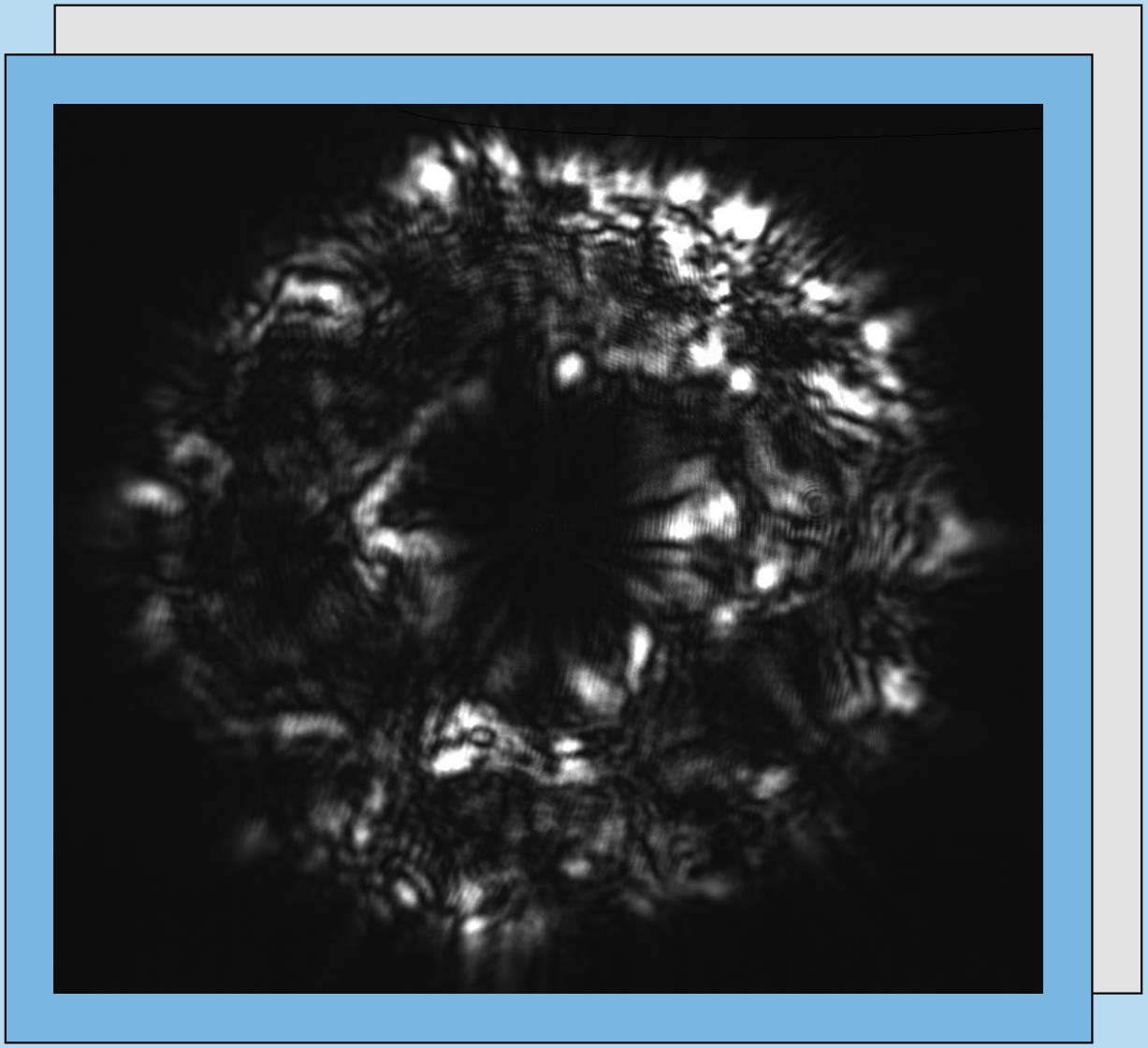
The intensity pattern at the front of the telescope is transferred to a high performance CCD camera connected to a laptop.

Experimental Setup



LabVIEW software is used to capture the desired data and analyze it

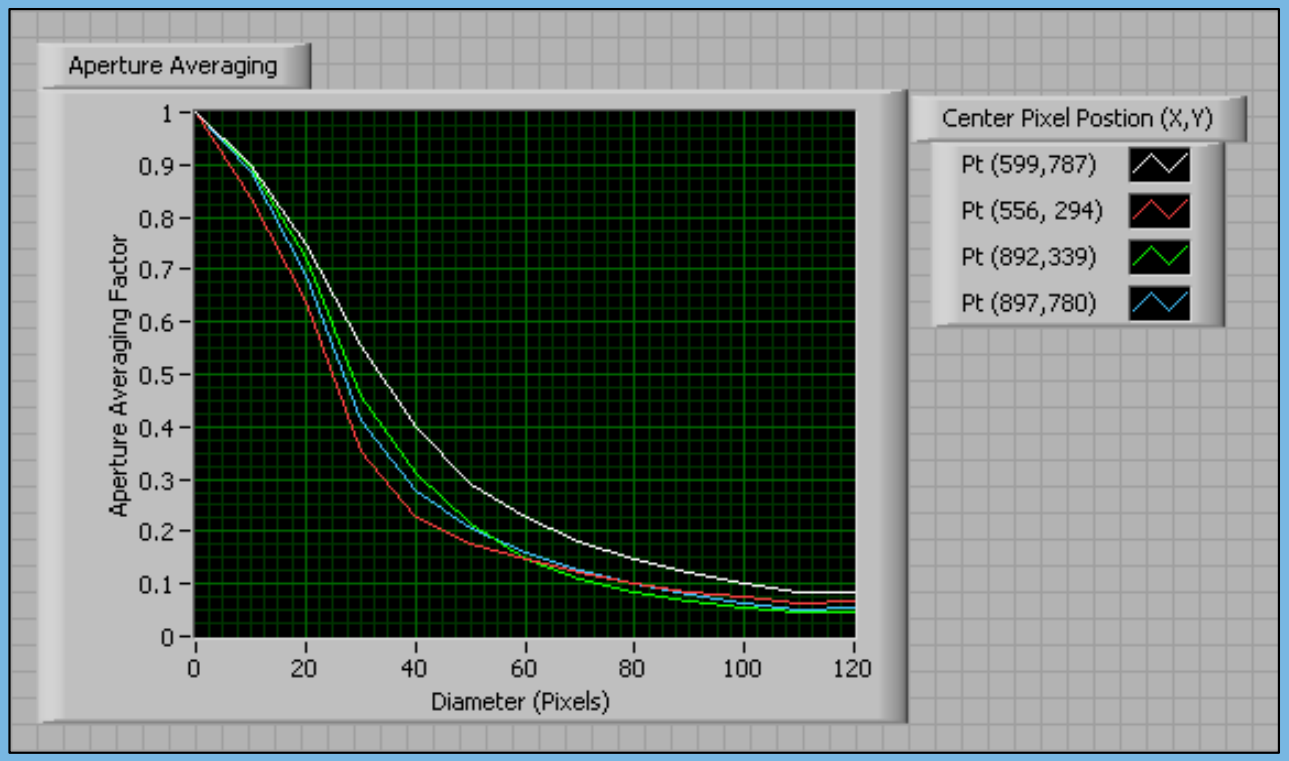
Image at the Front of the Telescope



Analysis

- Aperture Analysis
- Temporal Correlation
- Spatial Correlation

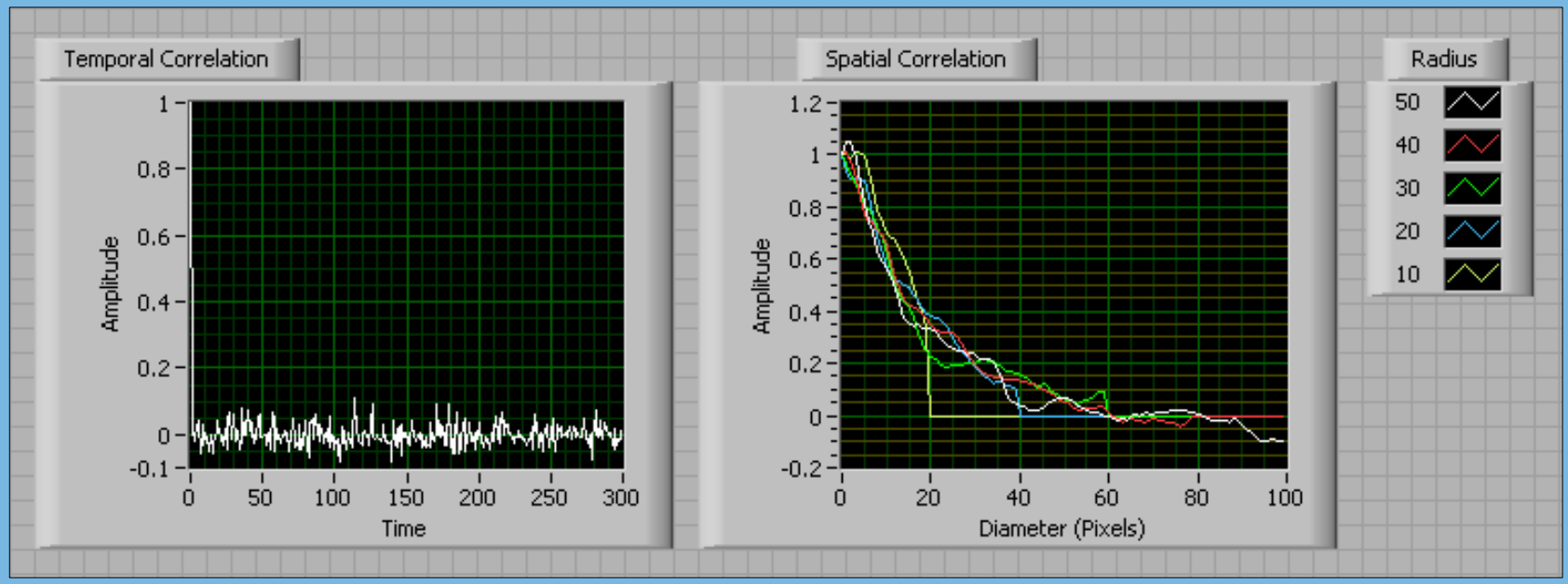
Aperture Averaging



$$F = \frac{\left(\frac{\sigma^2}{\mu^2}\right)_{PD}}{\left(\frac{\sigma^2}{\mu^2}\right)_{Aperture}}$$

- The Aperture Averaging Factor (F) is a ratio of normalized intensity variance of a receiver of some size to that of a point receiver.

Correlation Data



- Correlation is a measure of how neighboring pixels have related intensity values.

Conclusion

A system has been constructed that allows the effects of the atmosphere on a laser beam to be studied. This system will aid in the development of engineering applications and in the development of future mathematical frame work to describe the behavior of atmospheric turbulence.