Optical Techniques for Atmospheric Cross-Wind Profiling

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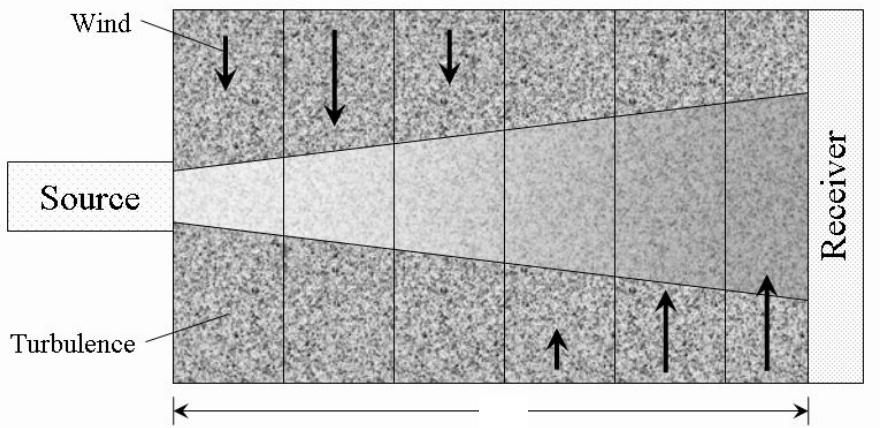
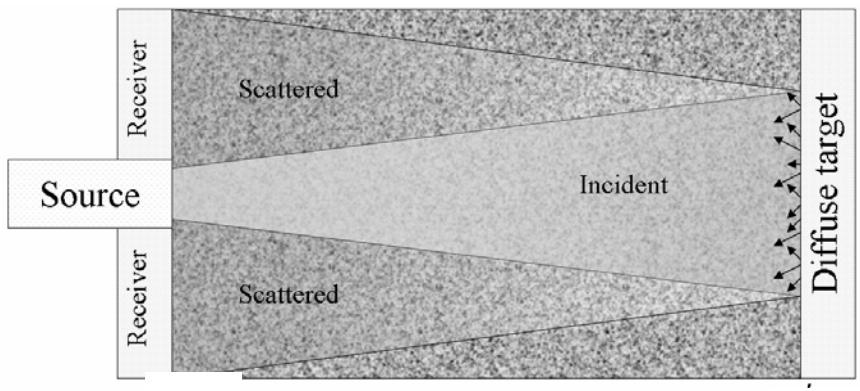
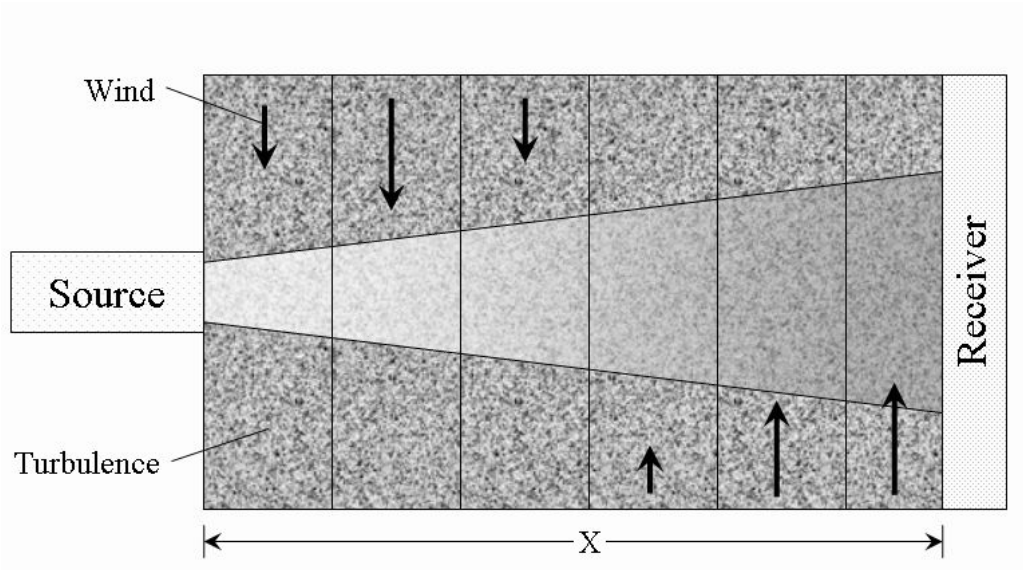
Single-pass propagation

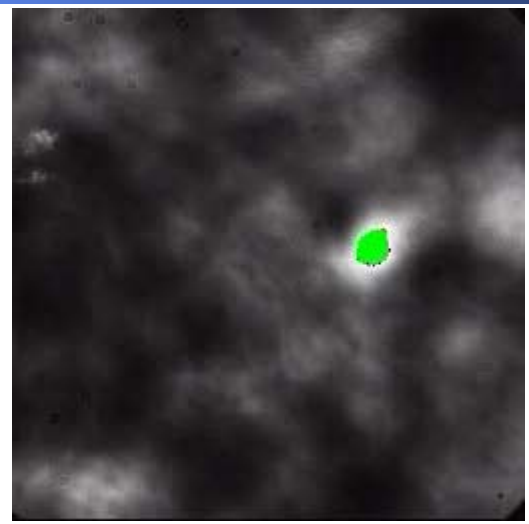


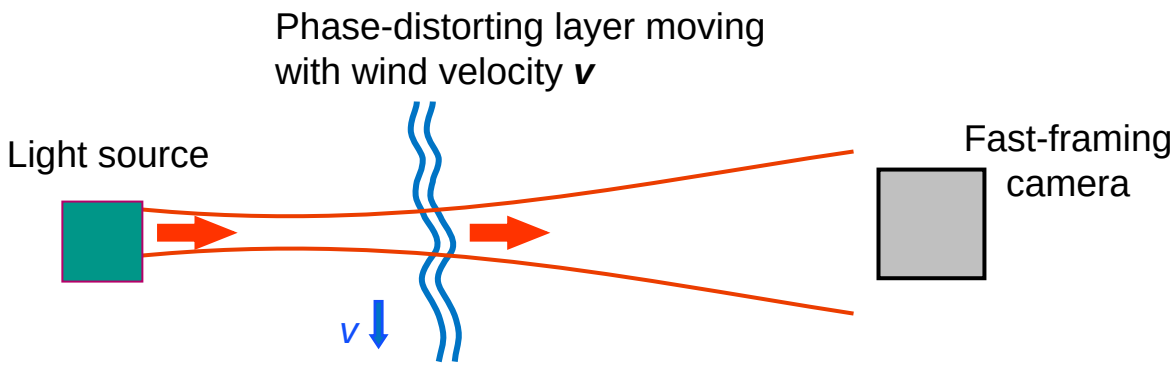
Double-pass propagation

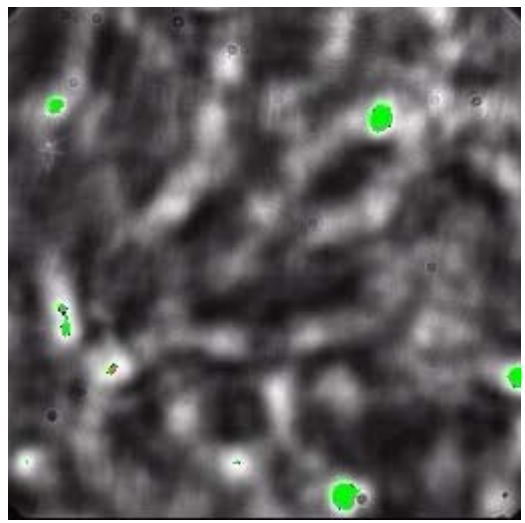


Wind-profiling Based on Intensity Scintillation Measurements

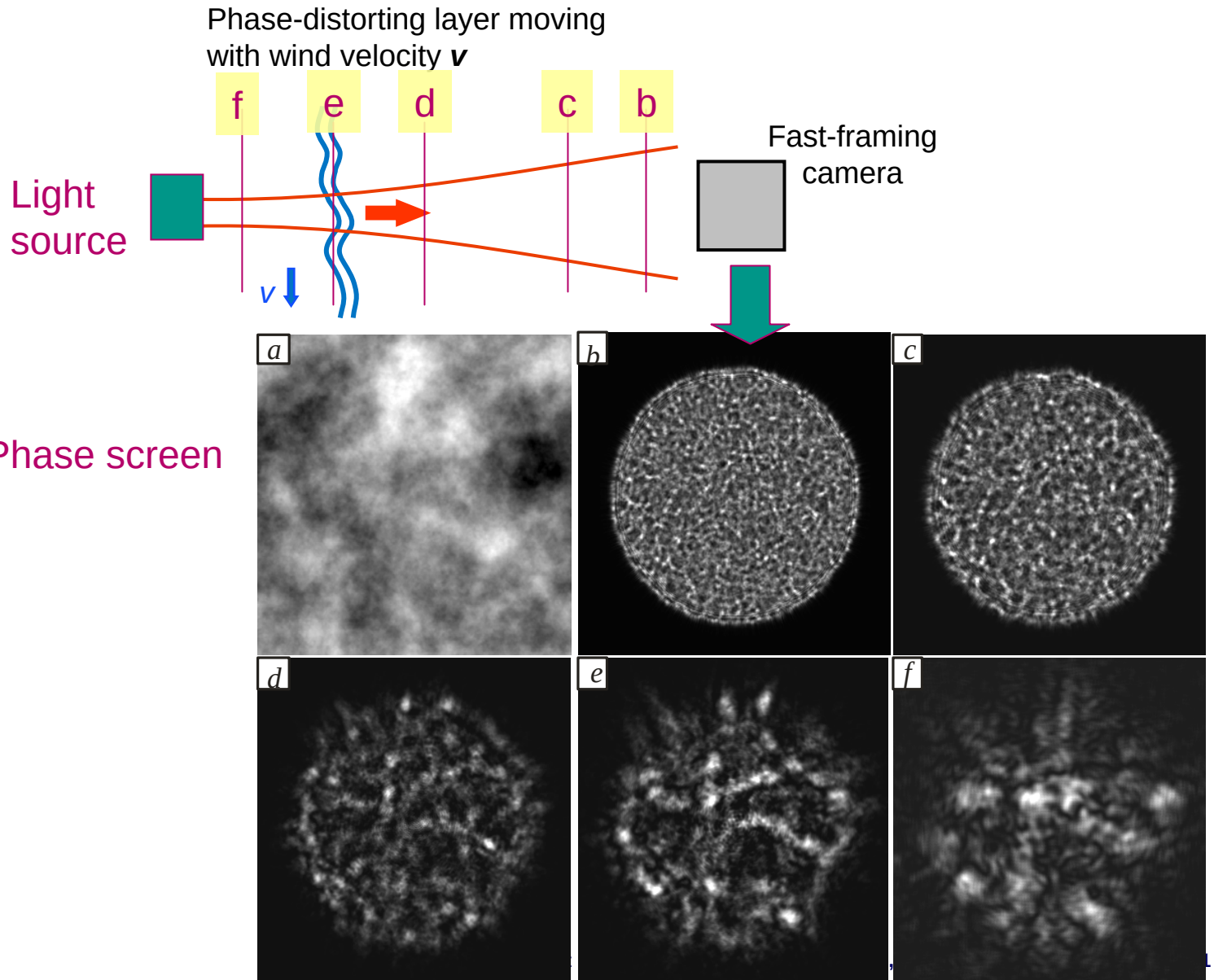








Phase Distorting Layer Location and Intensity Scintillations



Intensity Scintillation Correlation Technique: Single Turbulence Layer

•Correlation function

$$C(x_a, y_b, \Delta t) =$$

$$= \int I(x, y, t) I(x + x_a, y + y_b, t + \Delta t) dx dy$$

$I(x, y, t)$ Intensity distribution at time t

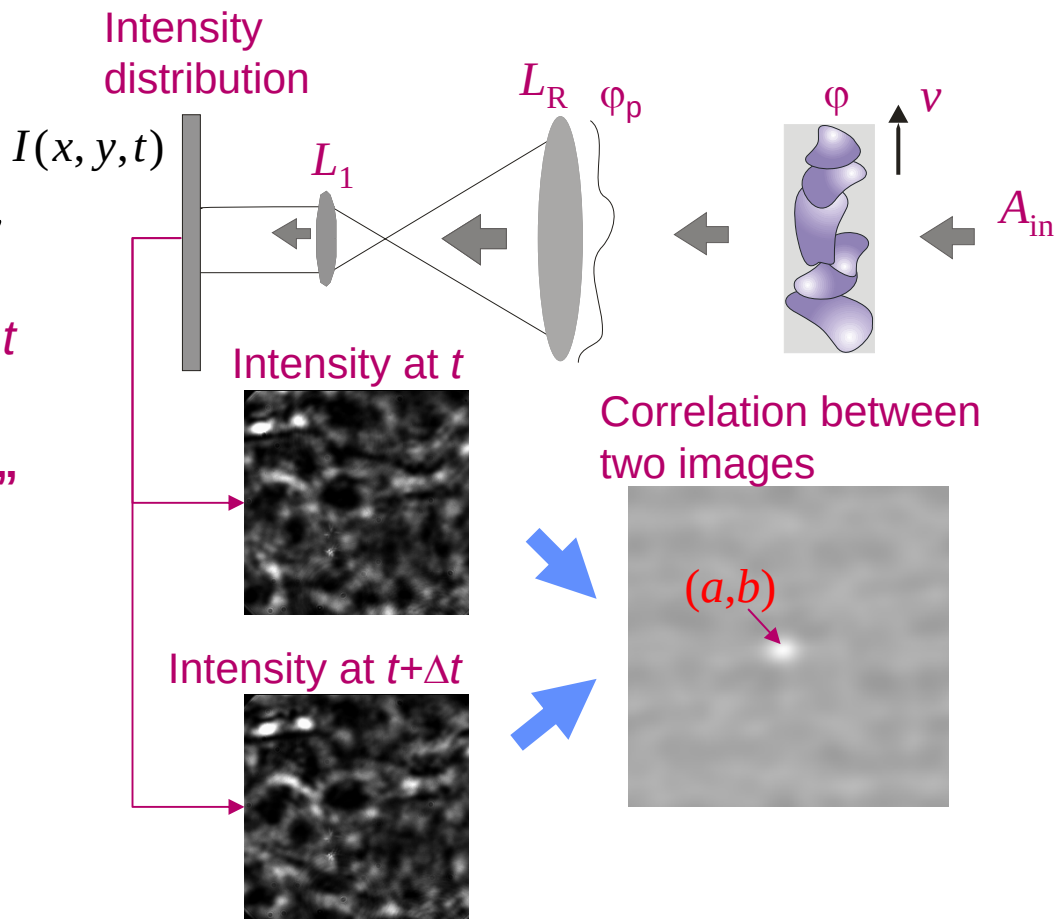
Taylor hypothesis:
Moving turbulent layers are "frozen"

(a,b) coordinate of the correlation peak maximum

$$a = v_x \Delta t \quad b = v_y \Delta t$$

$f_s = 1/\Delta t$ Sampling frequency

•Wind velocity: $v_x = \frac{a}{\Delta t}$ $v_y = \frac{b}{\Delta t}$



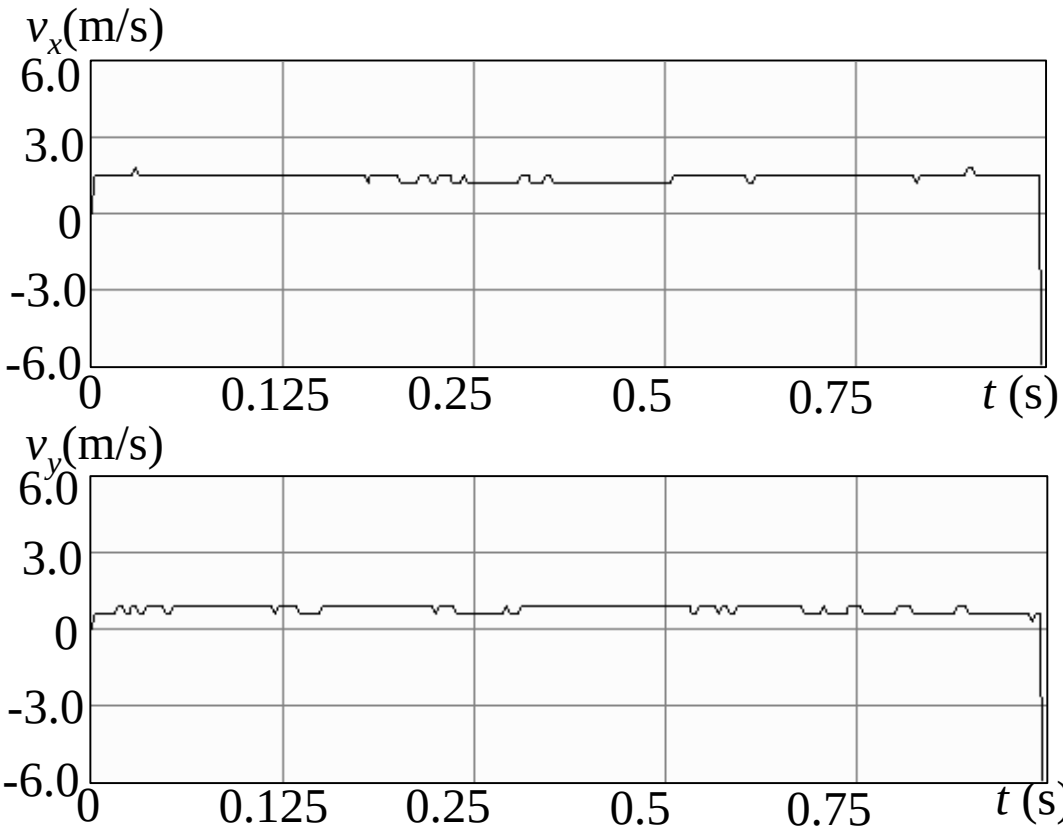
Digital Processing of a Set of Short-Exposure Scintillation Patterns

- Example 1: Sampling frequency 660 fr/sec.

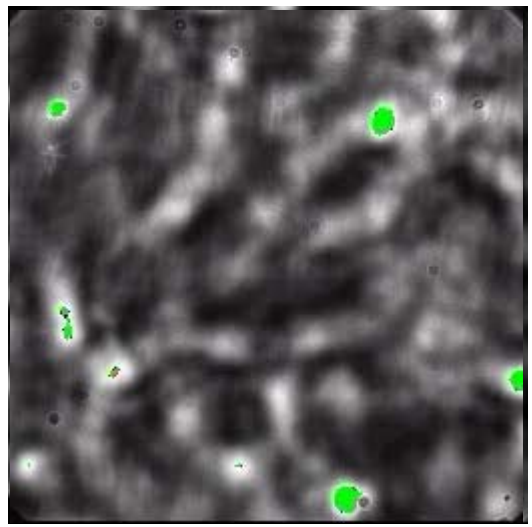
DALSA camera (256x256 pixels) receiver aperture diameter D=150 mm

Wind velocity $v_x \cong 1.35\text{m/s}$, $v_y \cong 0.81\text{m/s}$

1 pixel shift corresponds to 0.27m/s



Intensity at pupil plane



Wind direction

Digital Processing of a Set of Short-Exposure Scintillation Patterns

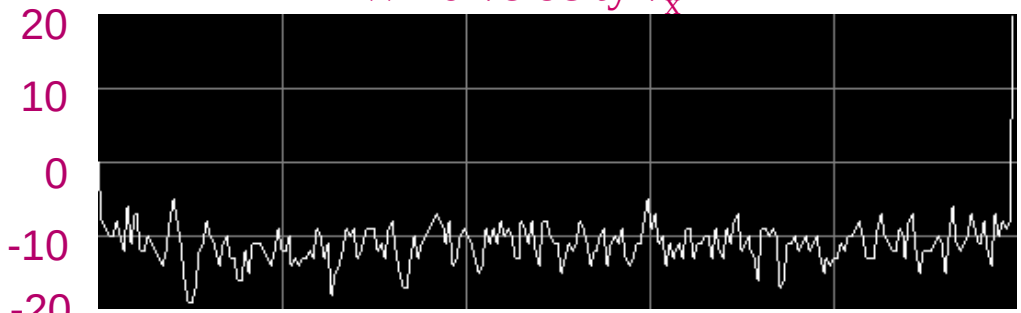
•Example 2: Sampling frequency 803 Hz, receiver aperture size 0.042cm×2×256

Wind velocity $v_x \cong$ 3.4-6.8 m/s, $v_y \cong$ 0 m/s

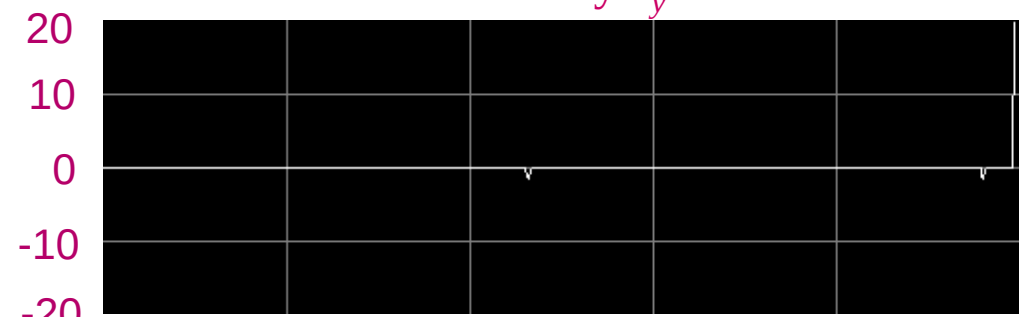
1 pixel shift/step= 0.042cm×803Hz=0.34m/s

Intensity at pupil plane

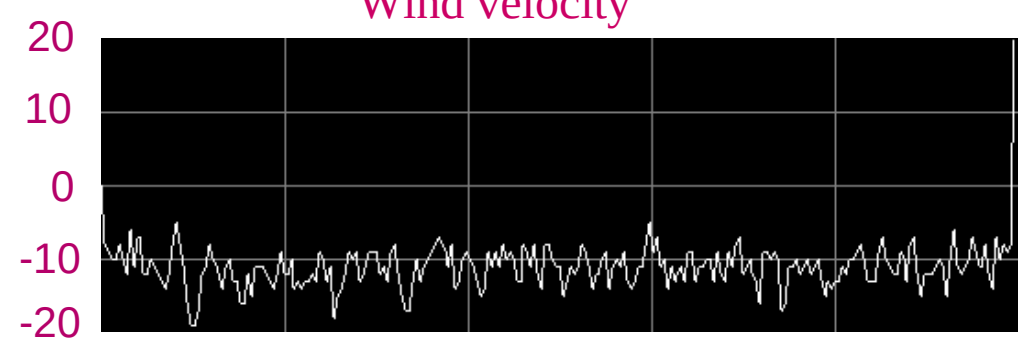
Wind velocity v_x



Wind velocity v_y

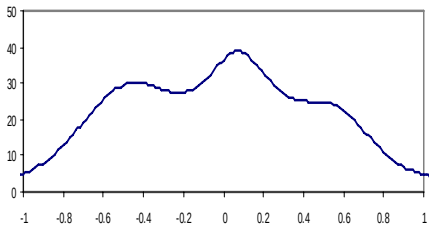


Wind velocity

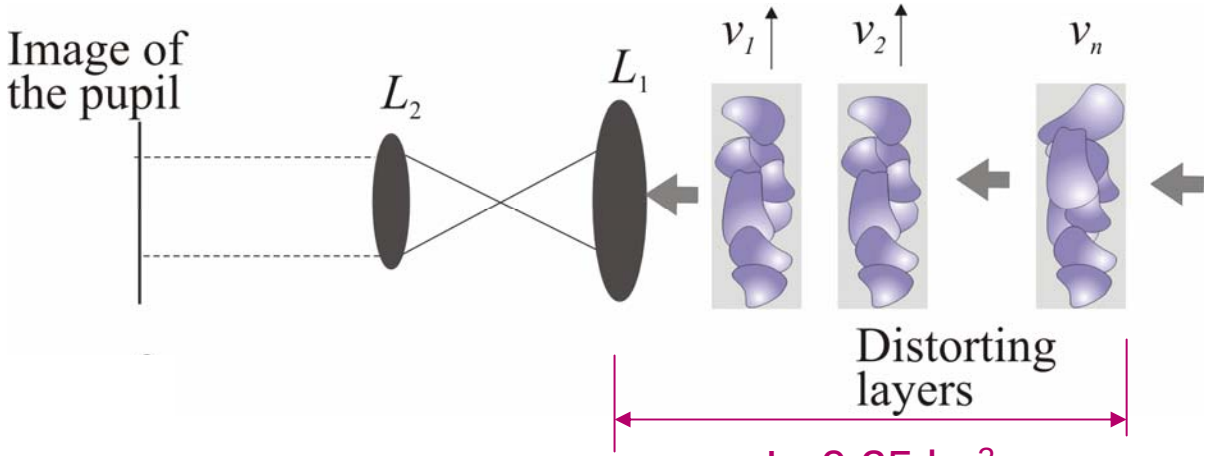


Multiple Turbulent Layers: Numerical Simulations

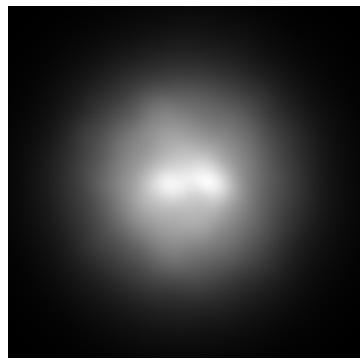
Image of cross-correlation

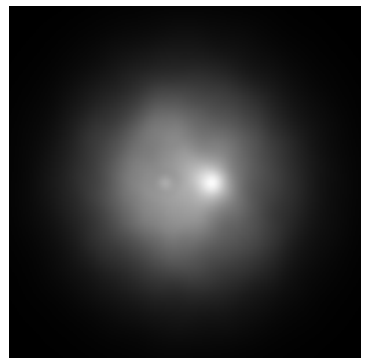


❖Multiple phase-distorting layers

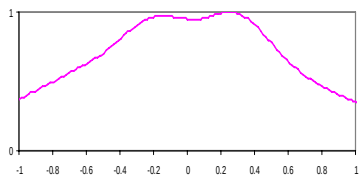


$L=0.25\ ka^2$

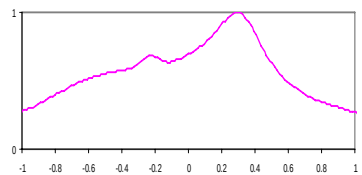




$dz_1=0.04$ $dz_2=0.045$



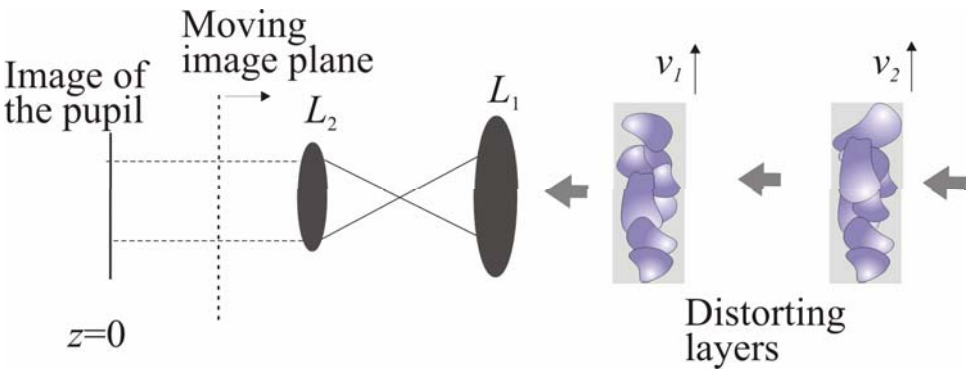
$dz_1=0.005$ $dz_2=0.04$



- Finding peaks of the correlation function corresponding to each phase-distorting layer
- The size of the peak corresponding to the distance of phase-distorting layer
- Sensitive to wind velocity difference between different phase-distorting layers and strength of turbulence

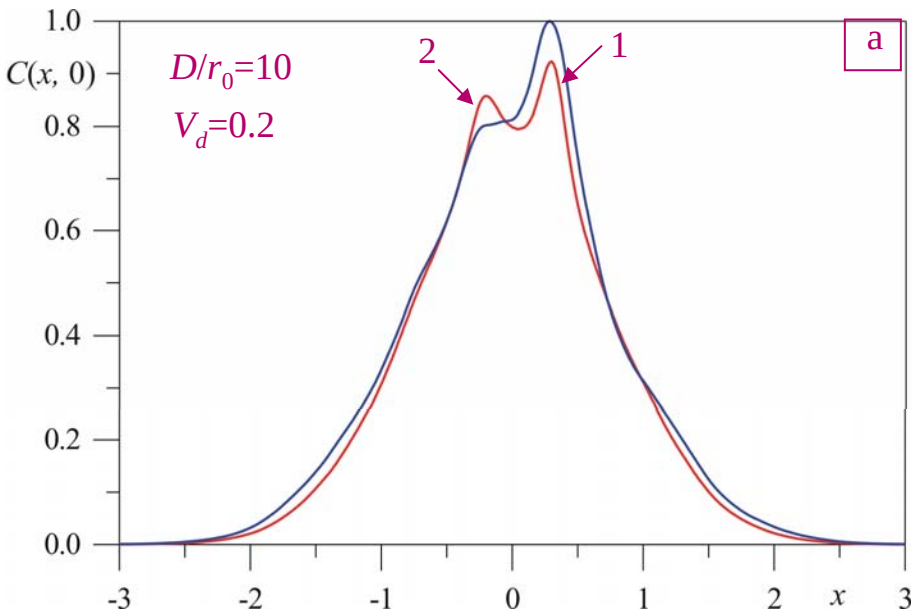
Correlation Peak Enhancement Via Moving Camera

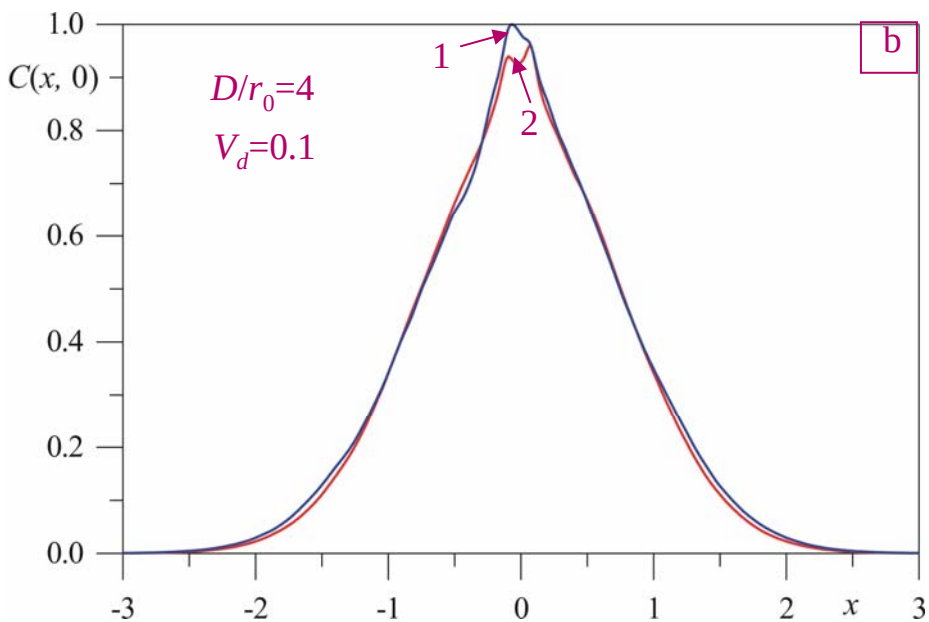
❖Two phase-distorting layers



- Scanning receiver image plane
- Enhance peaks of correlation function

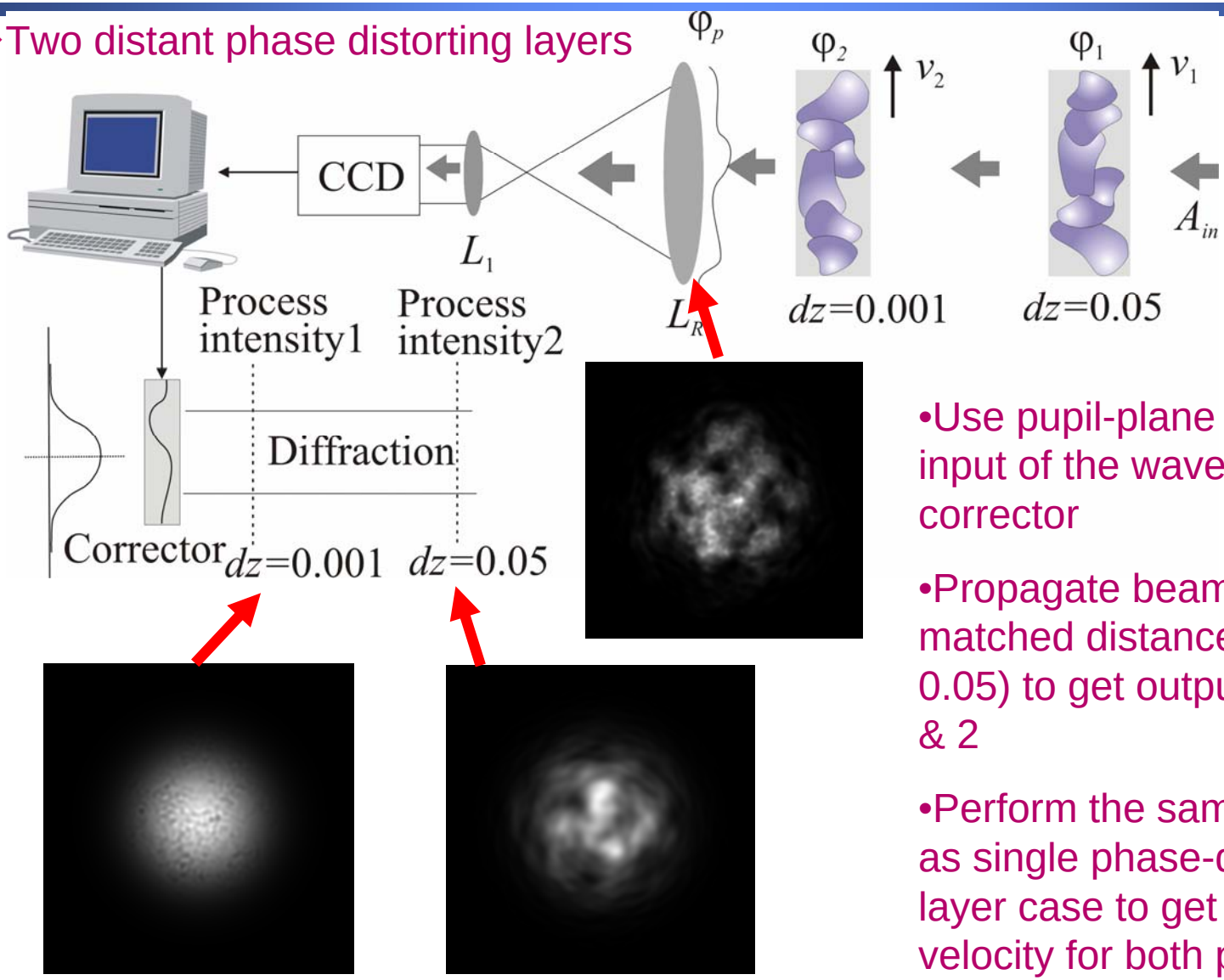
$$C_s(x,y) = \int_0^L C(x,y,z)dz$$





Correlation Peak Enhancement Via Phase-Image Diffraction

❖Two distant phase distorting layers



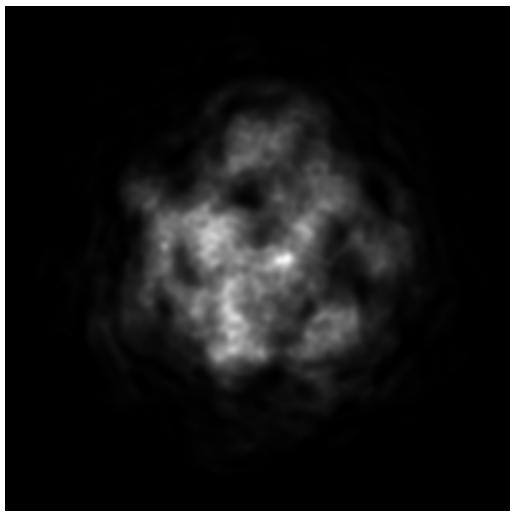
- Use pupil-plane intensity as input of the wavefront corrector
- Propagate beam to the matched distance (0.001 and 0.05) to get output intensity 1 & 2
- Perform the same process as single phase-distorting layer case to get wind velocity for both phase screens

Correlation Peak Enhancement Via Phase-Image Diffraction

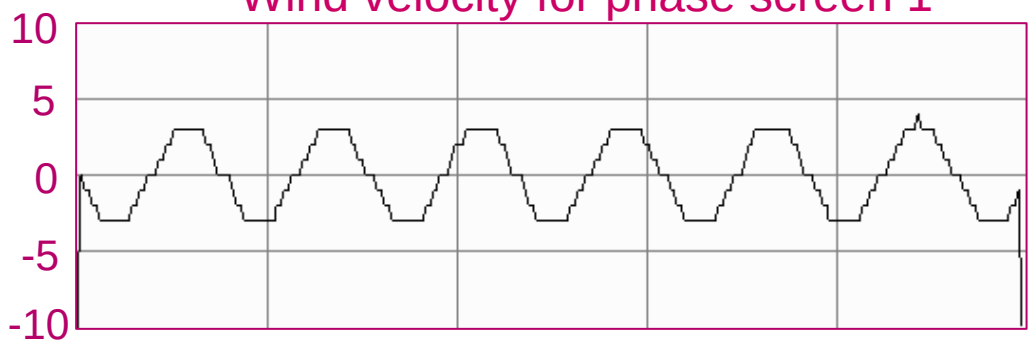
- Two distant phase-distorting layers
  - Example: simulation results

Input wind velocity: $v_1 = -\sin(n\Delta t / 2\pi)$ $\quad v_2 = 5$

Pupil-plane intensity



Wind velocity for phase screen 1

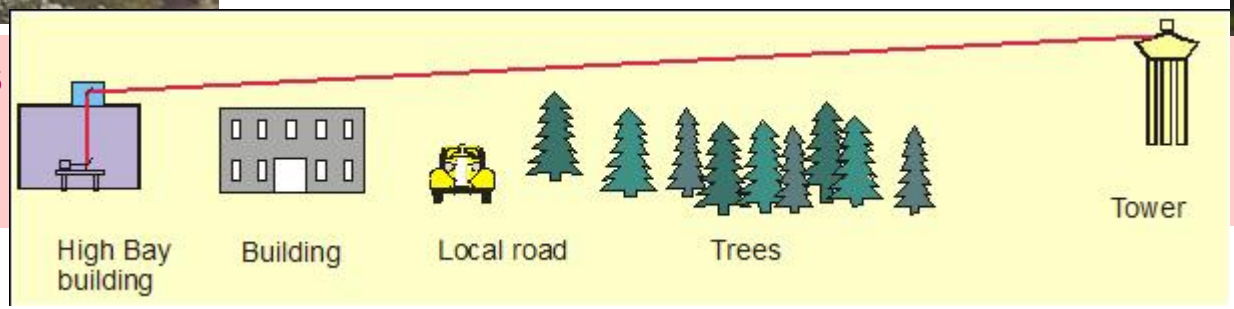


Wind velocity for phase screen 2

Wind Profiling Based on Intensity Scintillations Analysis: Atmospheric Experiment

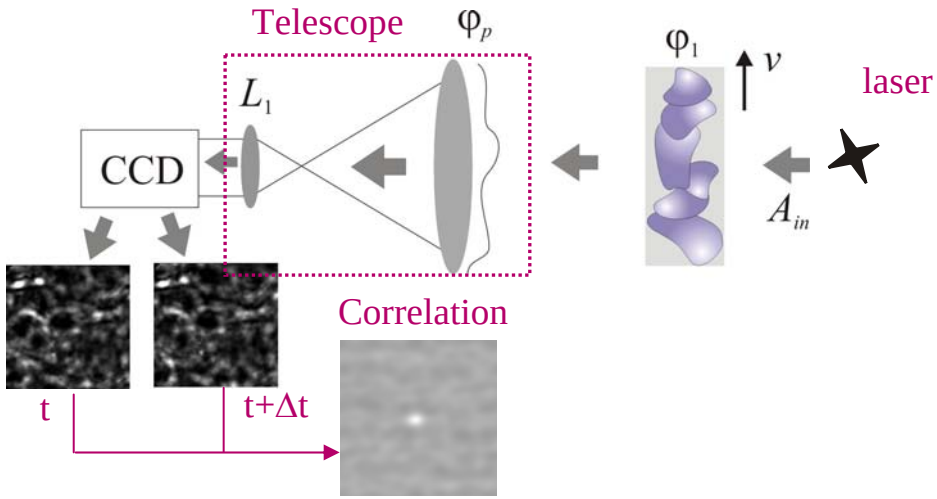
2.3 km

Intelligent Optics Laboratory



Water Tower

Wind Profiling Based on Intensity Scintillations Analysis: Experimental Results



Experimental Parameters:

- Telescope aperture size:15cm
- CCD camera sampling rate: 205 Hz
- Receiver aperture size resolution: 256×256
- Wind sensor located at the pupil plane

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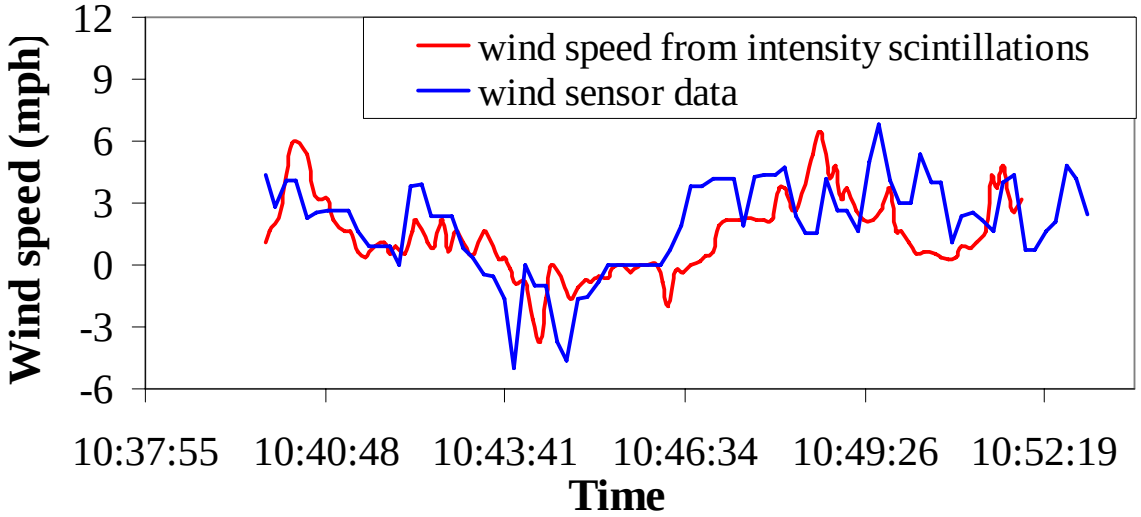
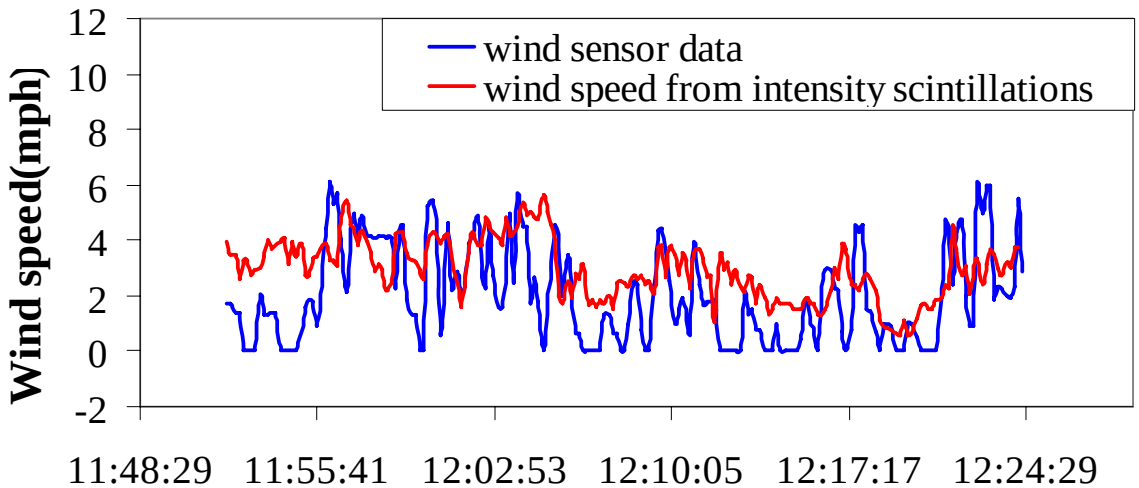
Wind Profiling Based on Intensity Scintillations Analysis: Experimental Results

Wind data acquired from 10:38am to 10:52am on July 5 2005:



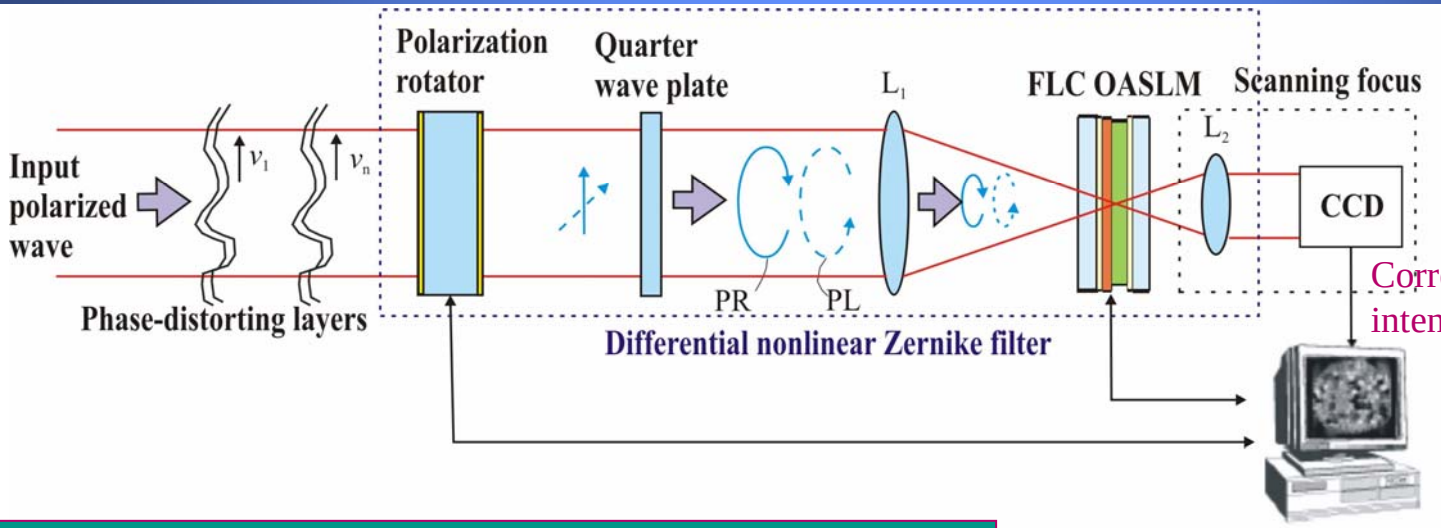
- Negative wind data corresponding to east wind and positive wind data corresponding to west wind
- Wind direction: south west to south east

Wind data acquired from 11:50am to 12:24pm on July 15 2005:

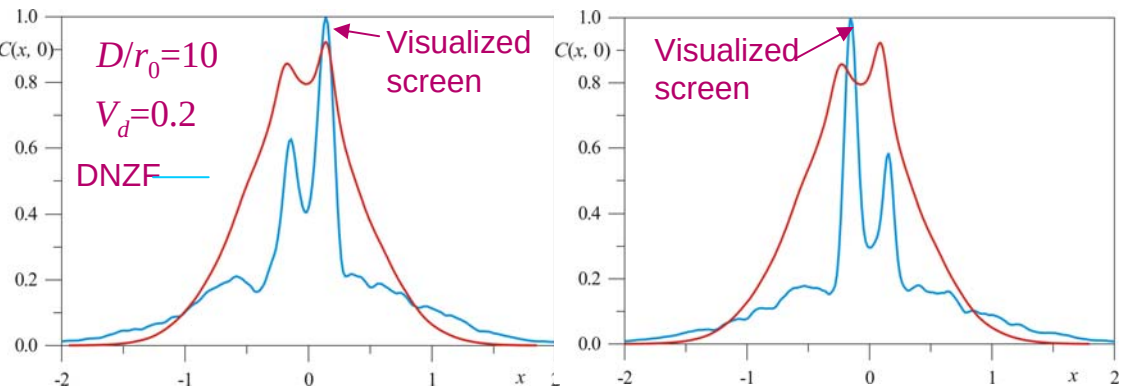


- Wind direction: east

Wind Profiling Using Differential Nonlinear Zernike Filter



$$I_{dif}(\mathbf{r}) = I^{+}_{zer}(\mathbf{r}) - I^{-}_{zer}(\mathbf{r}) = 8\pi F\sqrt{I_0(\mathbf{r})I_F(0)}\sin[\varphi(\mathbf{r}) - \Delta]$$



❖scanning and visualizing the image plane of each distant phase-distorting layer

❖the dominant correlation peak corresponds to the visualized phase-distorting layer

❖Comparison of correlation function using DNZF and without DNZF for two phase screens