

COHERENT COMMUNICATIONS, IMAGING AND TARGETING
PHASE PLATE CHARACTERIZATION

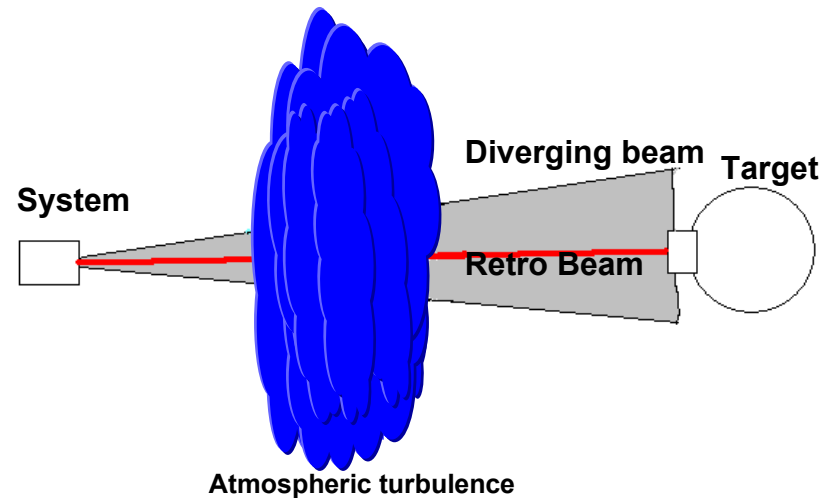
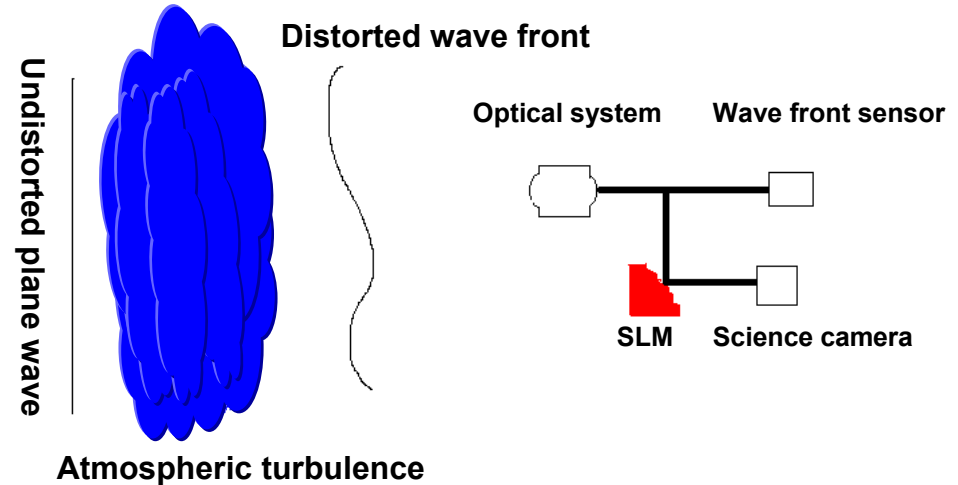
Oscar Azucena

OVERVIEW

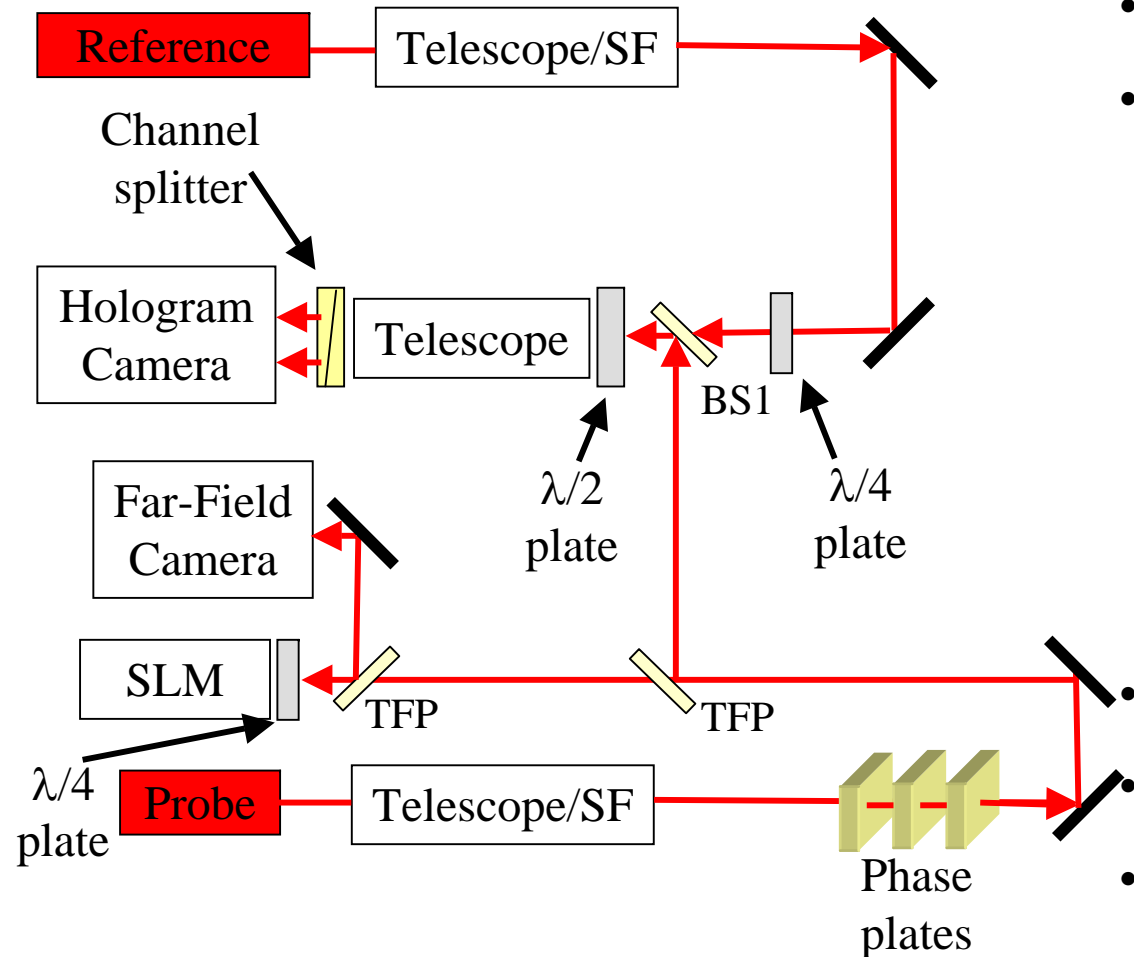
- **Introduction to Adaptive Optics and Coherent Communication, Imaging and targeting**
- **System Design**
- **Phase Plates**
- **Channel Splitter and Quadrature Receiver**
- **Unwrapping the Phase**
- **Using the unwrapped phase to determine the phase structure function**
- **Phase evaluation as a function of time**
- **Fitting our data to temporal power spectrum**
- **Conclusion**
- **References and acknowledgements**

Introduction to Adaptive Optics and Coherent Communication, Imaging and targeting

- Adaptive Optics are used to correct for atmospherically induced distortion in plane waves
- Coherent Communication, Imaging and Targeting also uses adaptive optics to correct for atmospherically induced distortions
 - A beam acquires target or Signal is sent to target
 - Retro beam is processed
 - Image of target
 - Communication signal
- The system corrects the distortions and a second signal is sent

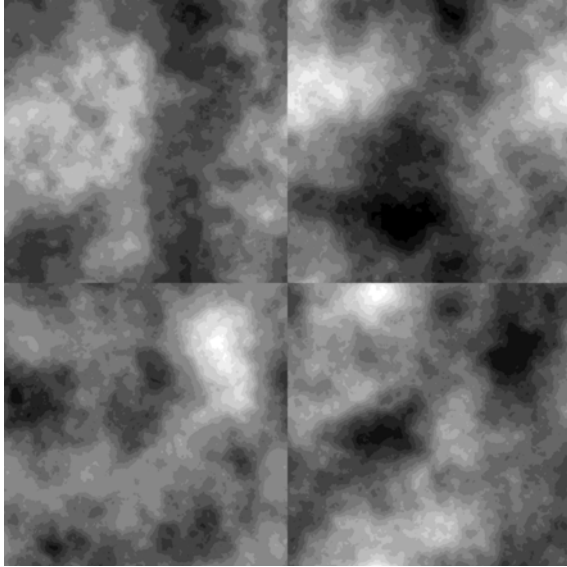


SYSTEM DESIGN



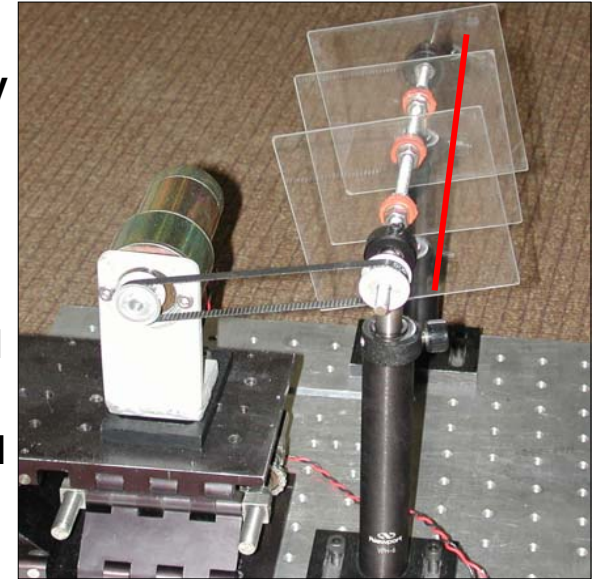
- Probe beam (linearly polarized) passes through phase plates
- The probe beam is combined with reference beam
 - the reference beam is circularly polarized by $\lambda/4$ plate
 - The probe beam is combined with the circularly polarized reference beam at BS1
 - The channel splitter separates the interferograms
 - $\text{Cos}(\varphi)$
 - $\text{sin}(\varphi)$
- The resulting interferograms are recorded by hologram camera
- The results are processed and the SLM is changed accordingly
- The resulting beam is sent to the far field camera

Phase Plates



Original Phase Profile

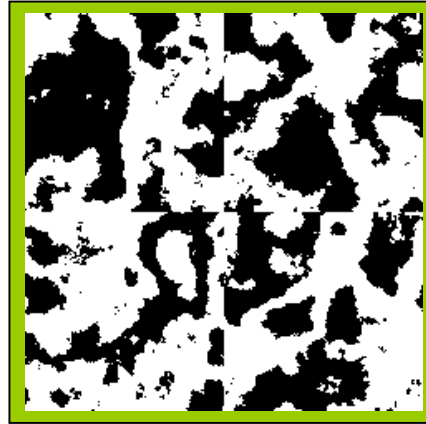
- The original phase was applied to the phase plates by etching four different masks on the plates
- Notice that each successive etch is half the previous
- The phase plates are rotated by a variable speed motor
- The center of the aperture will be at ~ 2 [cm] from the center of the square



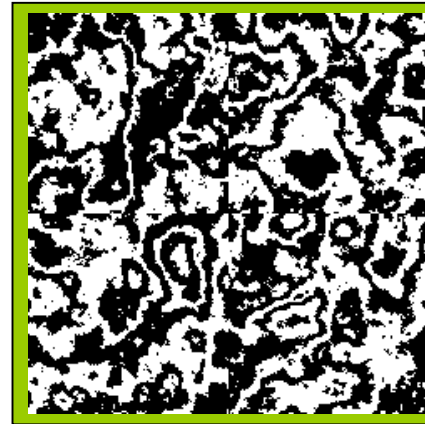
Phase plates on movable stand



Mask #1, 5 μm etch



Mask #2, 2.5 μm etch



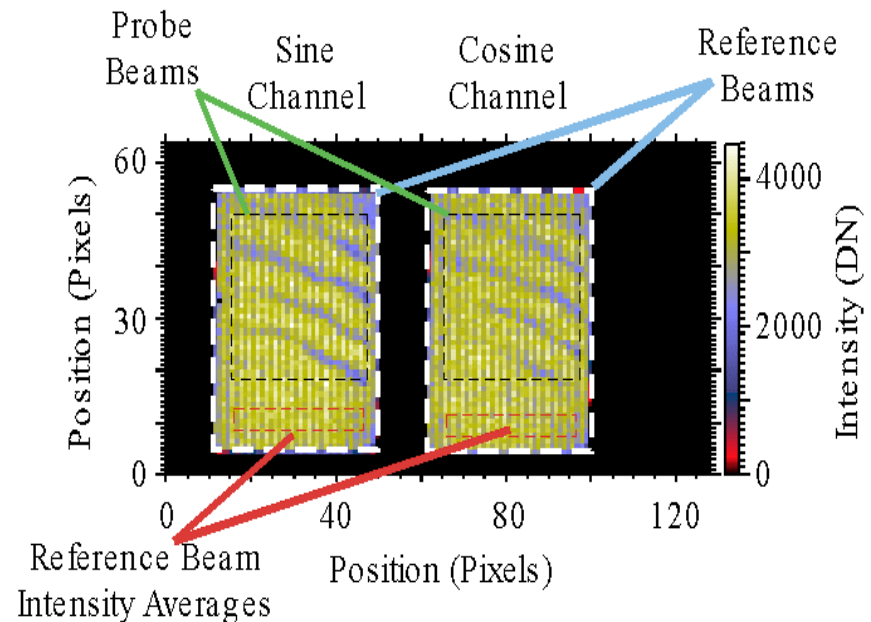
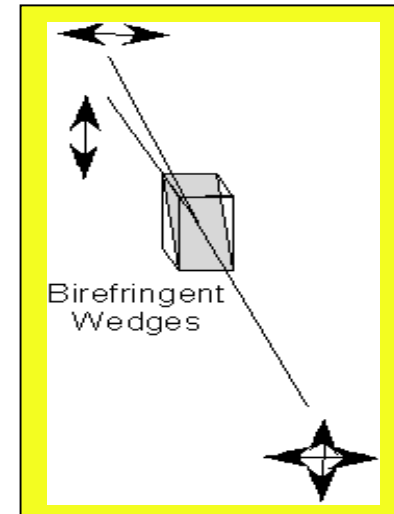
Mask #3, 1.25 μm etch



Mask #4, 0.625 μm etch

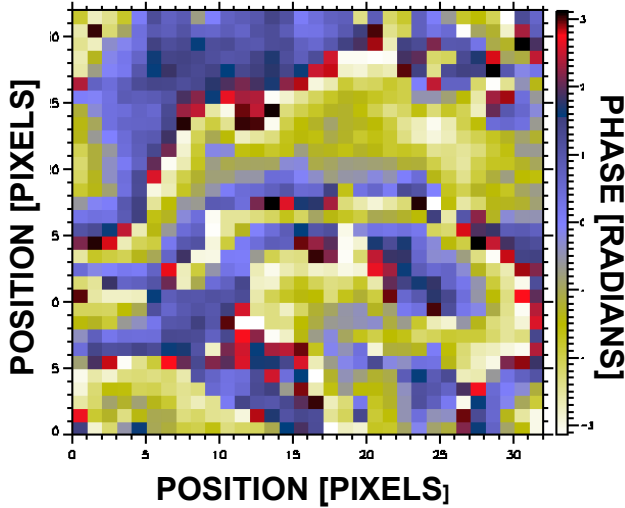
Channel Splitter and Quadrature Receiver

- The beam splitter consists of a Wollaston prism
- The Wollaston prism separates the vertical and the horizontal components of the interferograms
- The quadrature receiver (hologram camera) records the $I_{\sin(\varphi)}$ and $I_{\cos(\varphi)}$ intensities of the interferograms
- The phase is determined by the equation $\arctan(\sin(\varphi)/\cos(\varphi))$



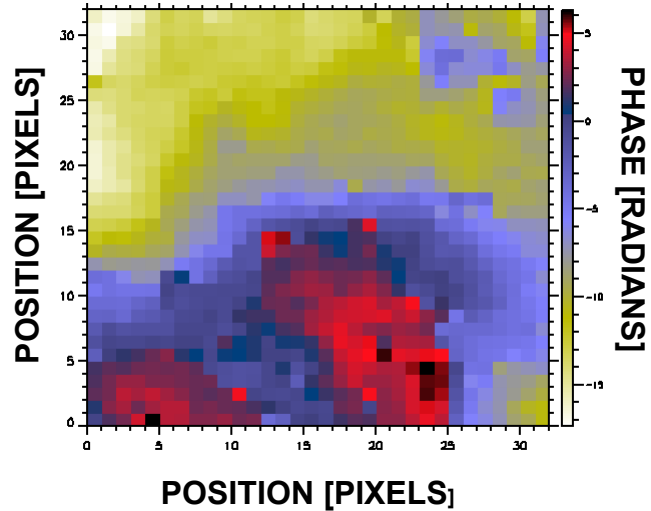
UNWRAPPING THE PHASE

PHASE THROUGH THREE PLATES

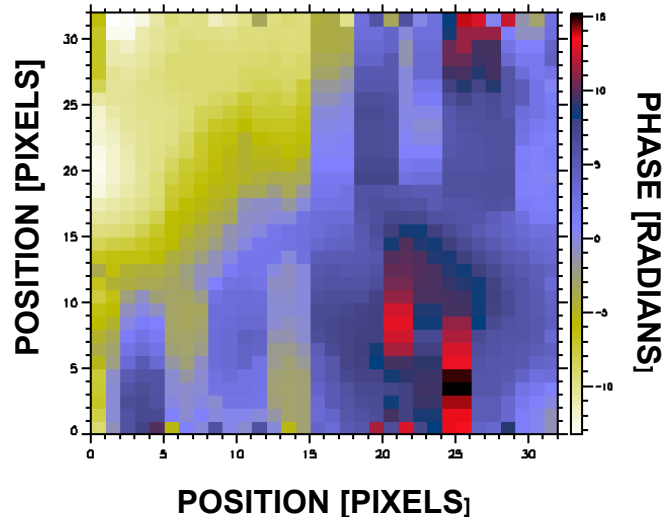


- The quadrature receiver records the Phase
- The phase is unwrapped
 - Flynn algorithm:
 - notice smoother transitions
 - Simple algorithm:
 - The transitions are not as smooth

FLYNN UNWRAPPING ALGORITHM

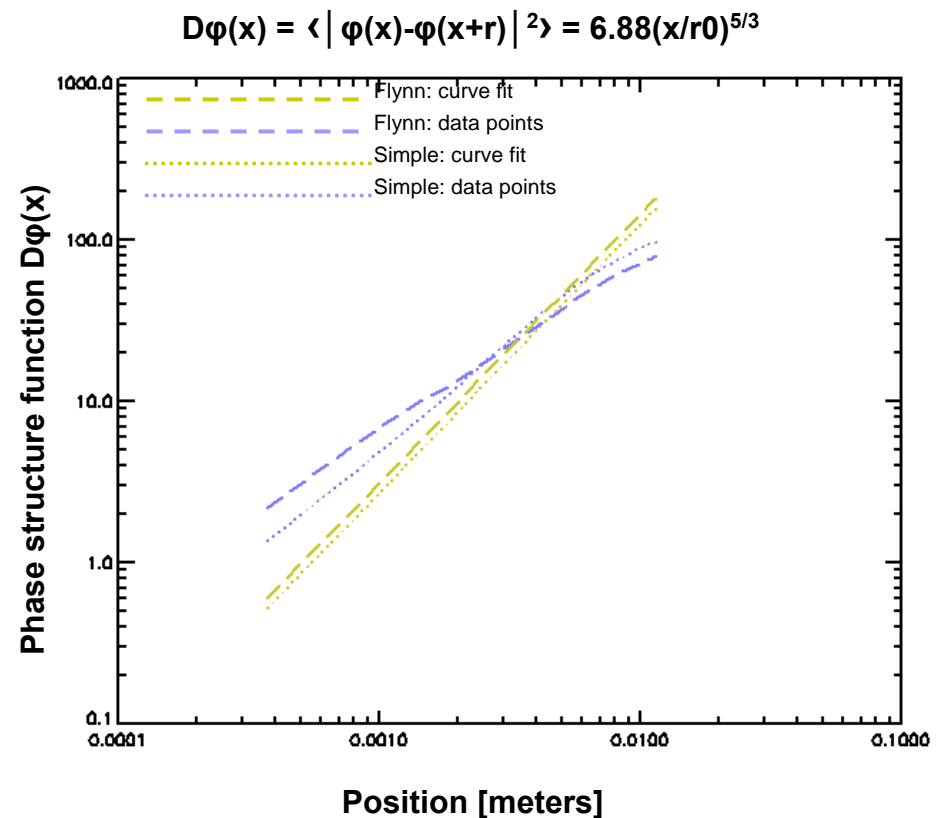


SIMPLE UNWRAPPING ALGORITHM



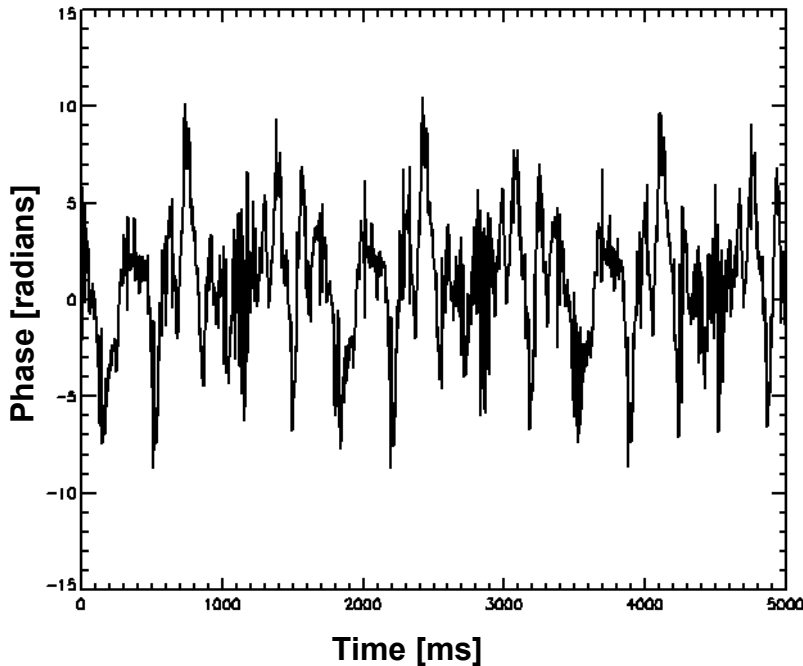
USING THE UNWRAPPED PHASE TO DETERMINE THE PHASE STRUCTURE FUNCTION

- The phase structure function
 $D\varphi(x) = \langle |\varphi(x) - \varphi(x+r)|^2 \rangle = 6.88(x/r_0)^{5/3}$
- The unwrapped phase is compared to a spatially shifted copy to determine $D\varphi(x)$
- $D\varphi(x)$ is fit to a curve which determines r_0
- We can see that the two fit curves are almost identical
 - $r_0 \sim 1.6$ [mm] for the flynn unwrapping algorithm
 - $r_0 \sim 1.7$ [mm] for the simple unwrapping algorithm

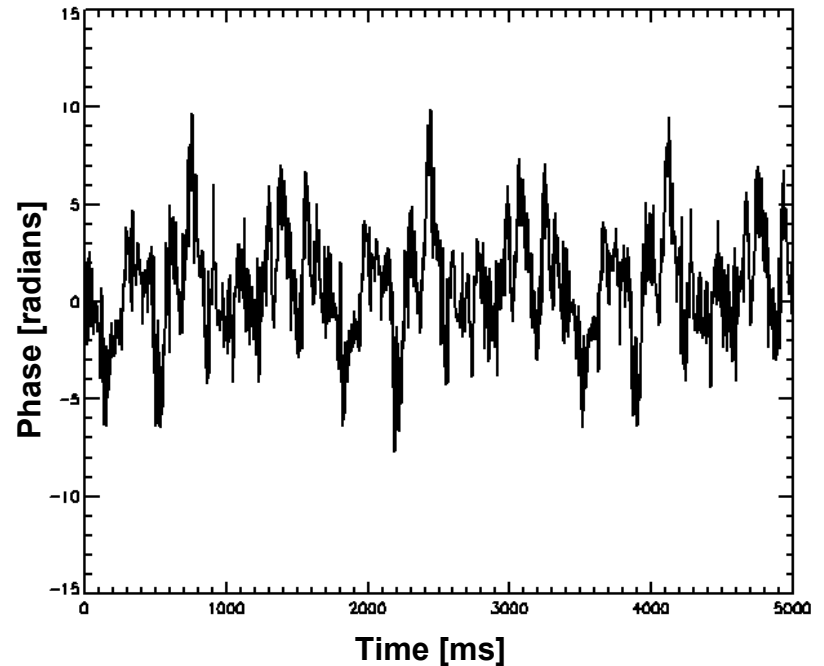


Phase Evaluation as a function of time

PHASE vs. TIME: Flynn



PHASE vs. TIME: simple



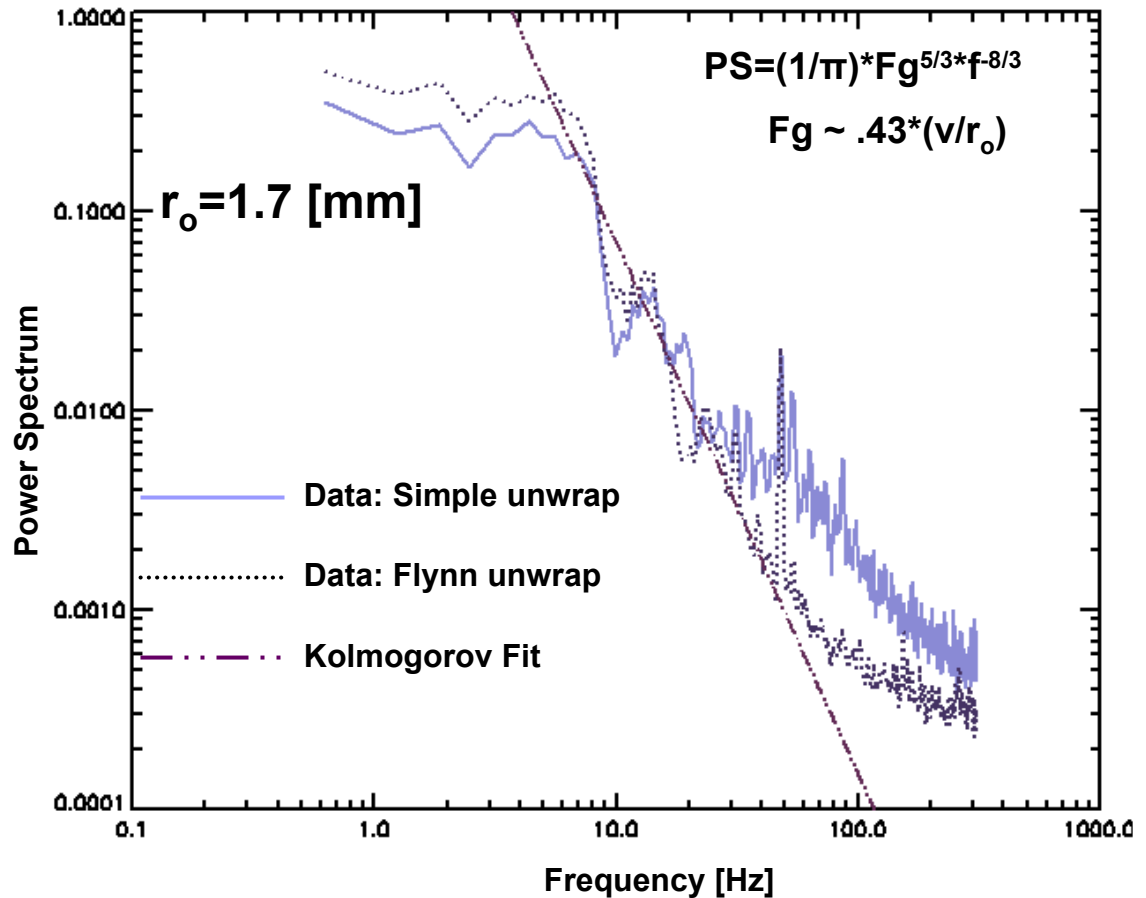
- The system records 3000 interferograms at ~ 580 [Hz]
- The graphs show that the Flynn unwrapping removes the higher frequency noise better than the simple unwrapping algorithm

Fitting our data to Temporal Power Spectrum

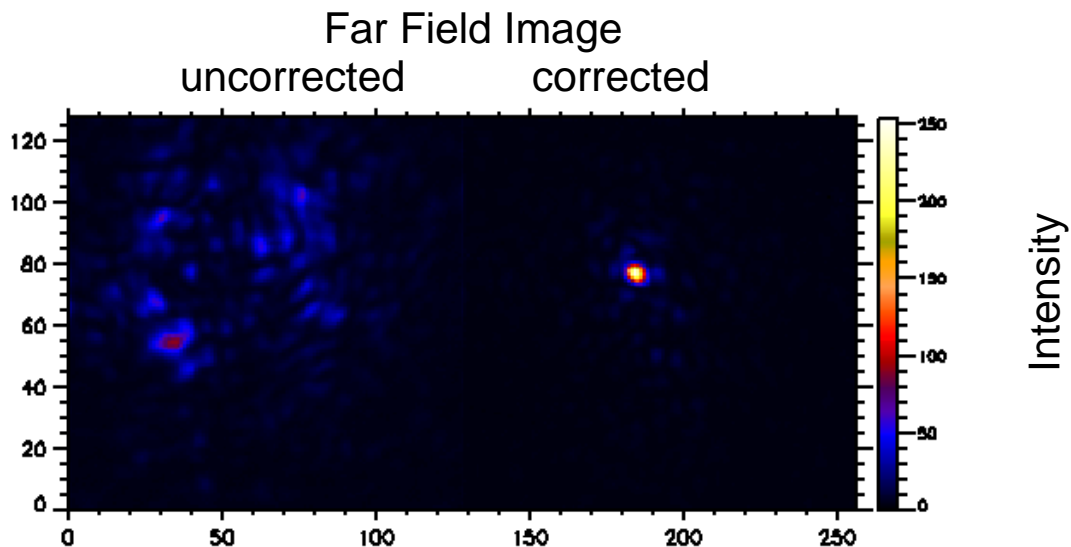
- The phase Plates were running at ~ 7.5 [cm/s] along the aperture

- The data was fit to Kolmogorov temporal power spectrum

- The results for r_0 agree with our previous estimate



SYSTEM PERFORMANCE



- The aperture of the system is ~ 11.5 [mm]
 - Given that r_0 (atmospheric coherent length) is ~ 1.7 [cm] we know that we need adaptive optics
- The system's aperture needs to be broken into smaller sub-apertures
 - The sub-apertures need to be smaller than r_0
 - Rule of thumb is $D_{\text{sub-aperture}} \sim r_0/3$
 - The system that we use had actuators apertures of 365 [μm]
- We can see from the corrected image of the laser that our system works

Conclusion

- The project consisted of characterizing the phase plates that were etched to simulate a Kolmogorov distribution.
- We established that the Flynn unwrapping algorithm performs better than the simple unwrapping algorithm
- From the phase structure function we were able to determine the Fried parameter, r_0 , to be approximately equal to 1.7 [mm]
- Based on the temporal power spectrum we were able to further verify the value for r_0
- The simulation of the phase plates help to determine how well the system performs
- The next step would be to compare the phase plates, and their simulation of the atmosphere, to an atmospheric path in an uncontrolled environment.

References and acknowledgements

References:

- 1) Thomas J. Flynn, “Two dimensional phase unwrapping with minimum weighted discontinuity”, J. Opt. Soc. Am. A 14, 2692-2701 (1997)

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