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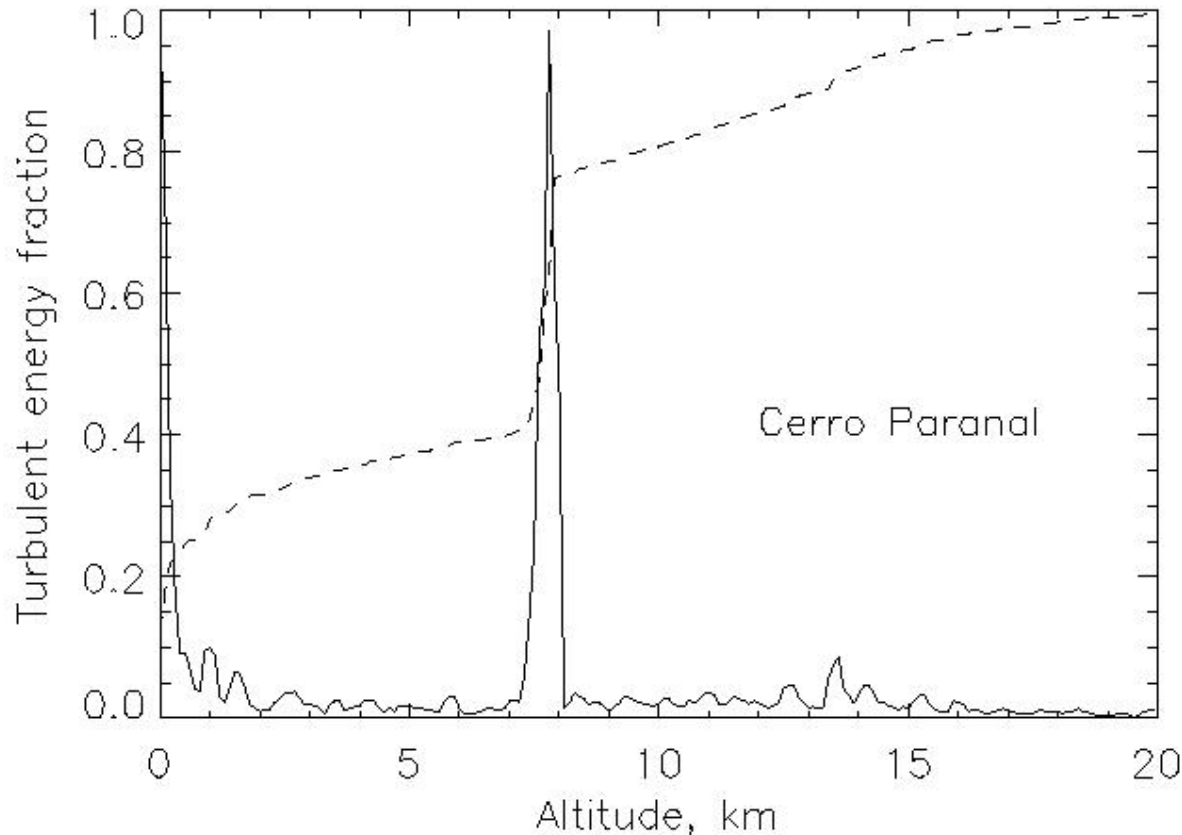
# Eliminating Scintillation Noise for Ground-Based High-Speed Photometry

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Richard Wilson and Vik Dhillon



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# Turbulence profile: Ground layer, 'Free atmosphere'

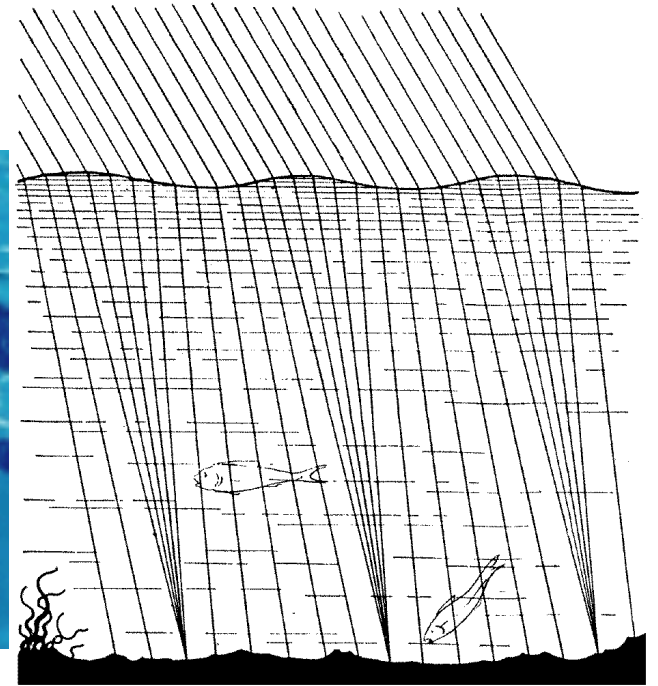


Turbulence profile recorded by a micro-thermal  
balloon probe at ESO Paranal Observatory, Chile



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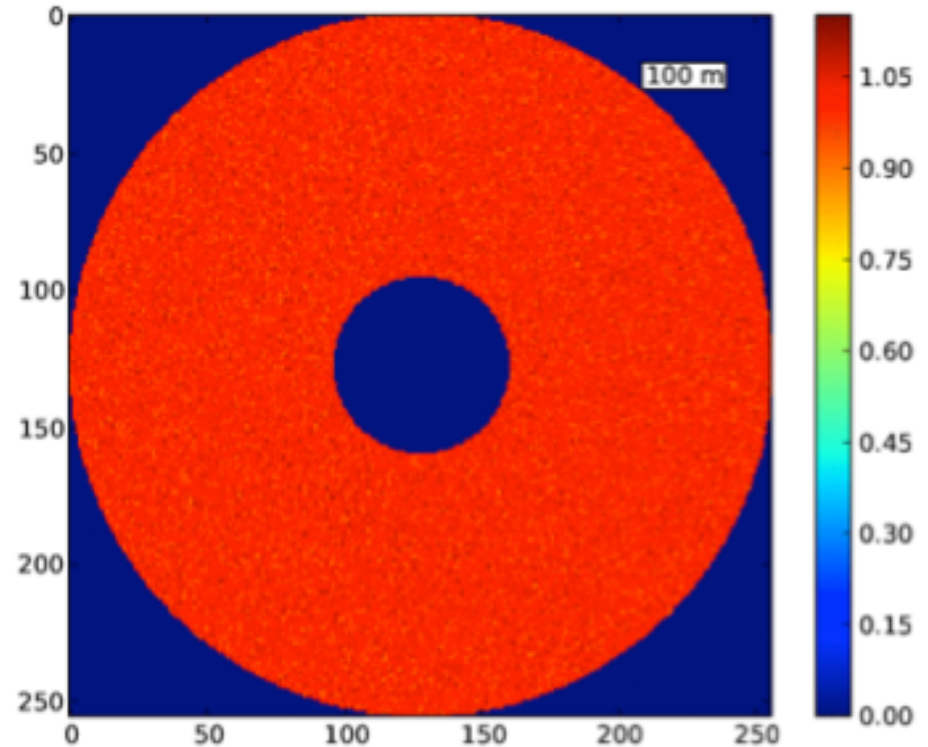
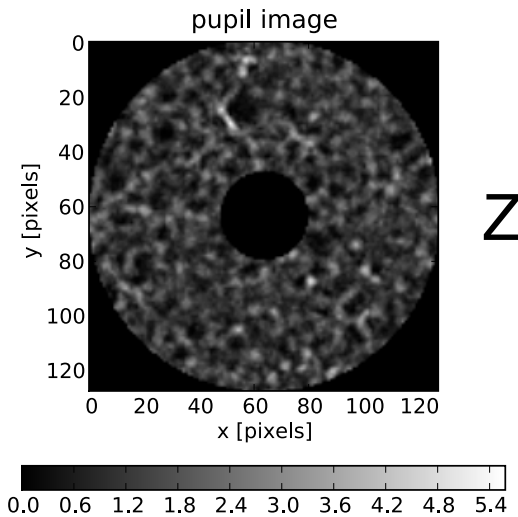
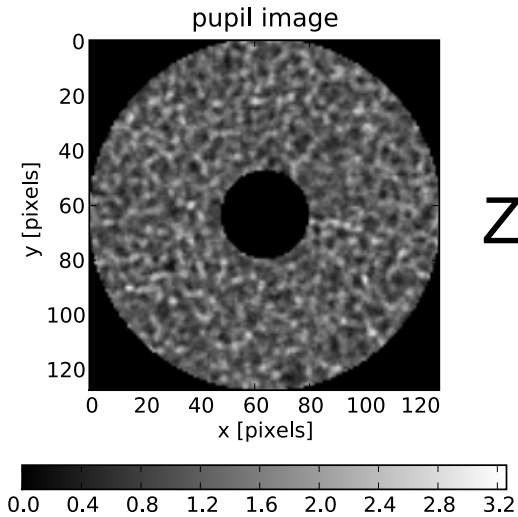
# Scintillation- Fresnel Propagation



‘Shadow Patterns’ in Water



# Spatial fluctuations



$D=2.5 \text{ m}$

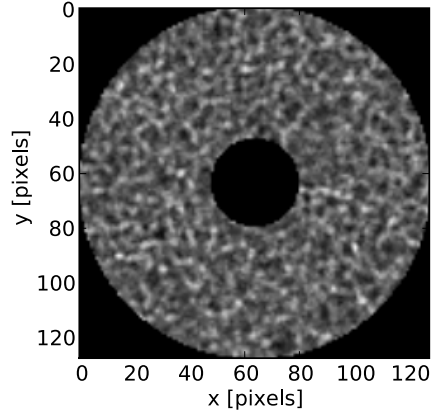
$r_F = \sqrt{\lambda z}$

$[z=10\text{km} \rightarrow r_F=0.07 \text{ m}]$

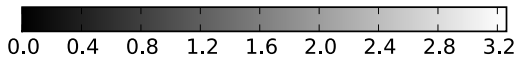


# Spatial fluctuations

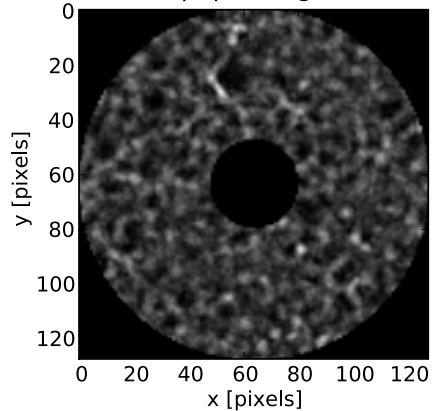
pupil image



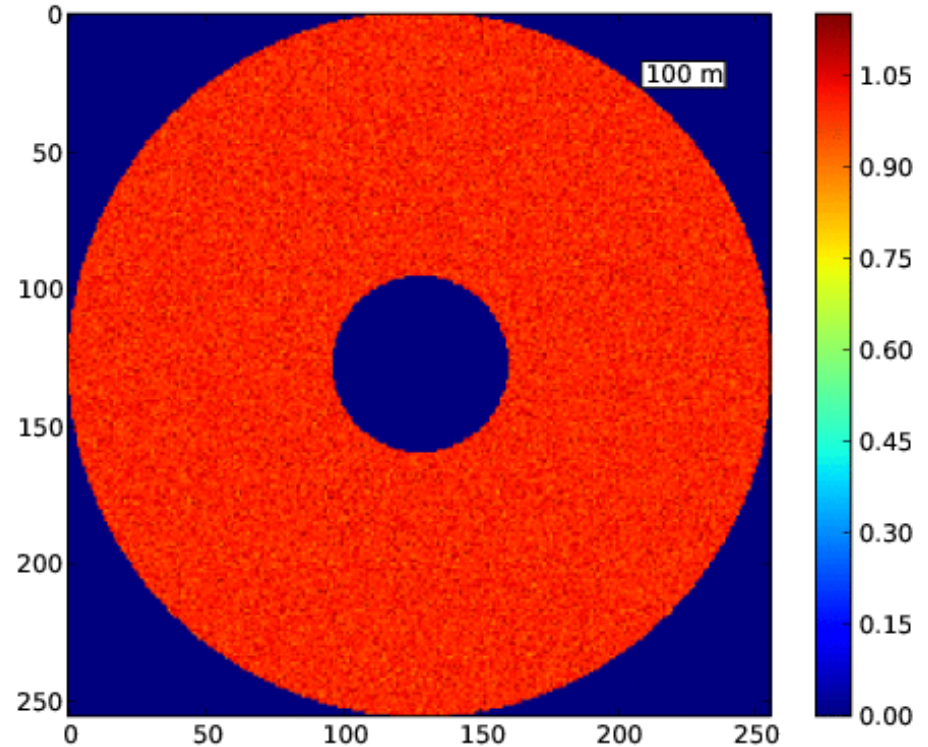
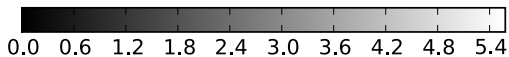
$Z = 5 \text{ km}$



pupil image



$Z = 10 \text{ km}$



$D = 2.5 \text{ m}$

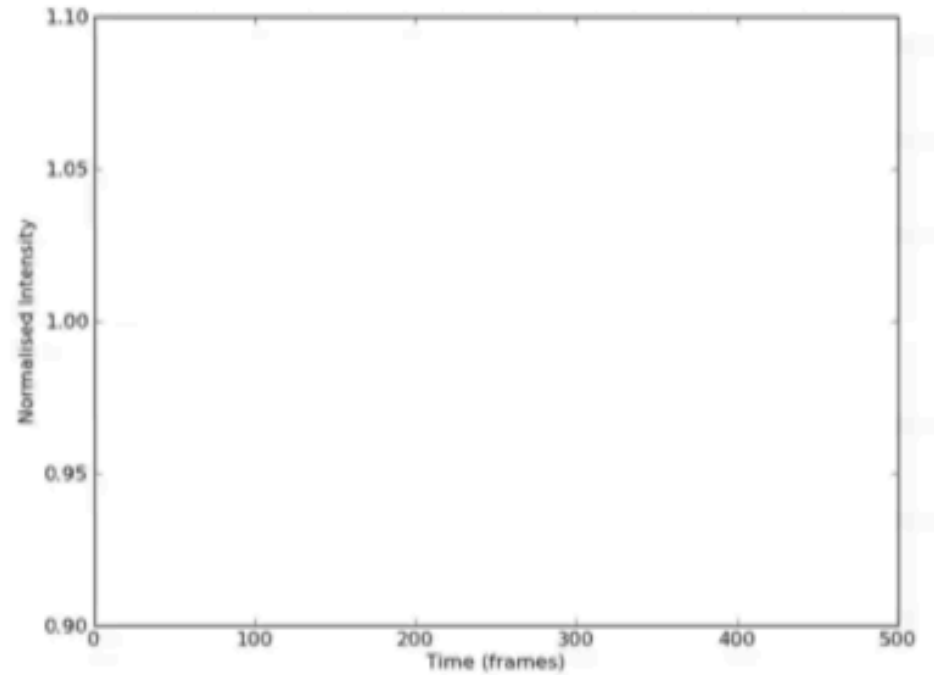
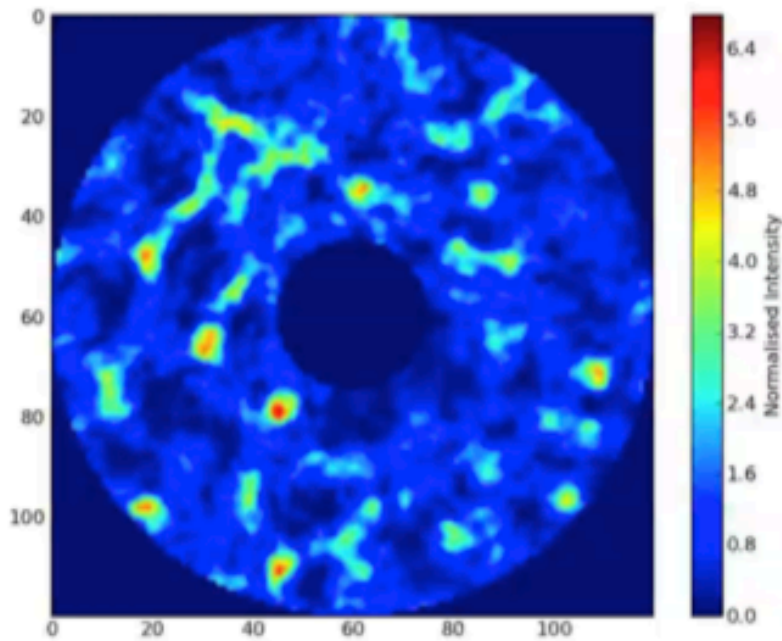
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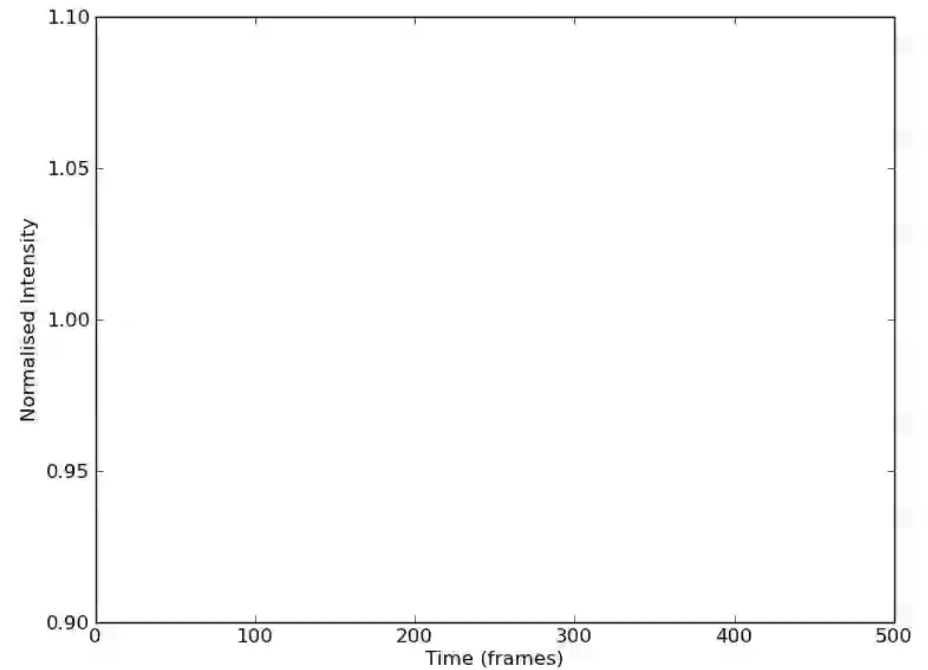
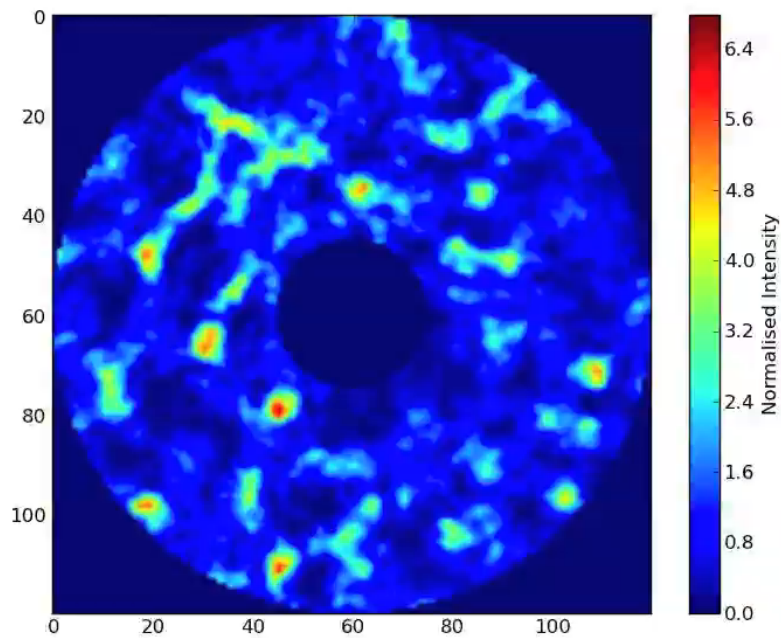
# Temporal fluctuations





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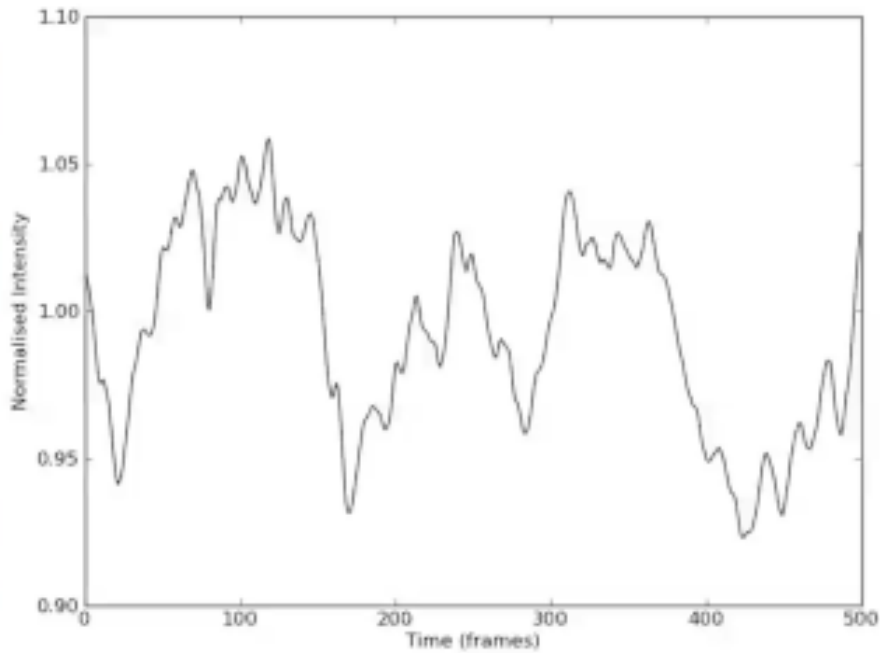
# Temporal fluctuations



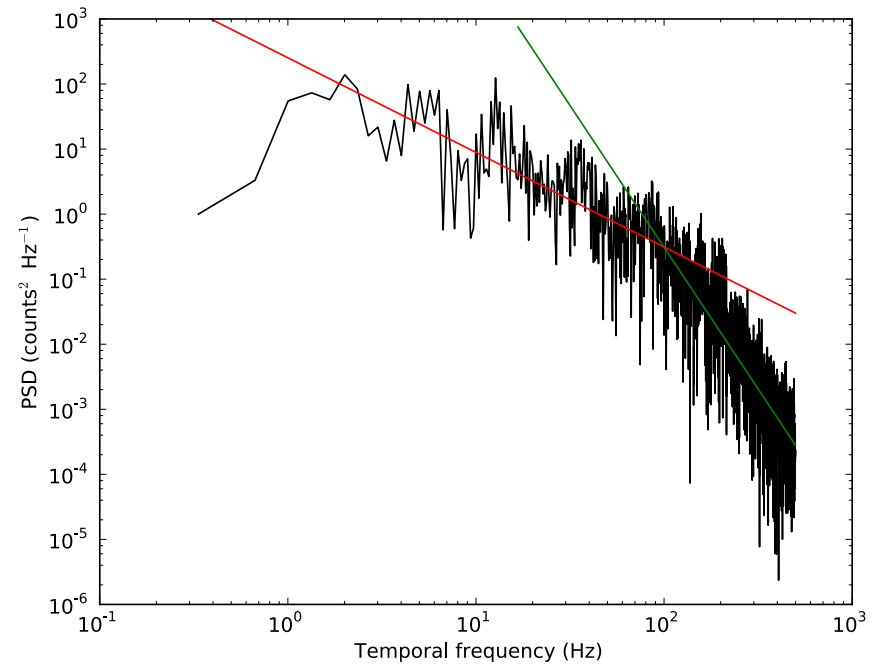


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# Temporal Power Spectrum



Intensity



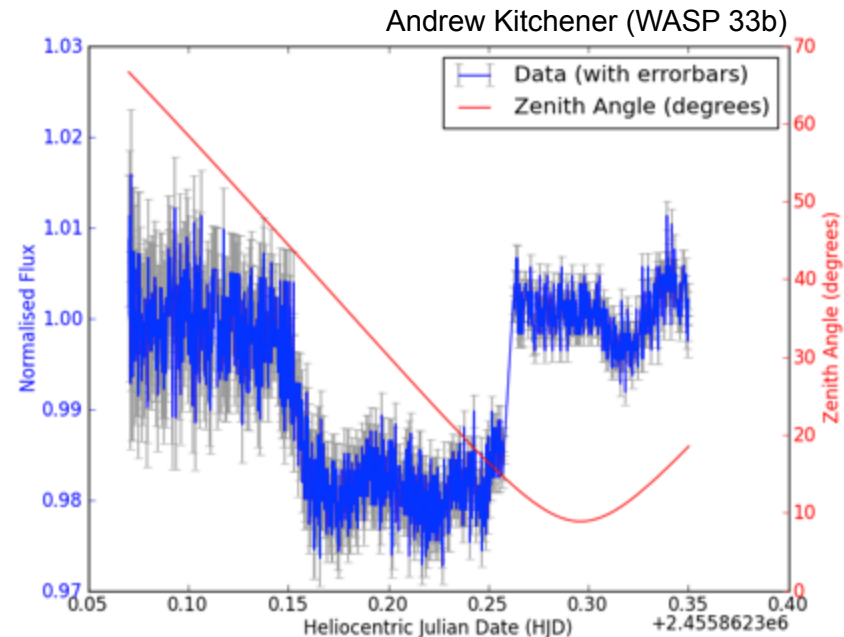
PSD



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# Scintillation and Photometry

- Adds uncertainty to measurement
- Companion targets will have different scintillation signals, increasing the noise component
- Scintillation noise magnitude changes throughout the night





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# Reducing Scintillation

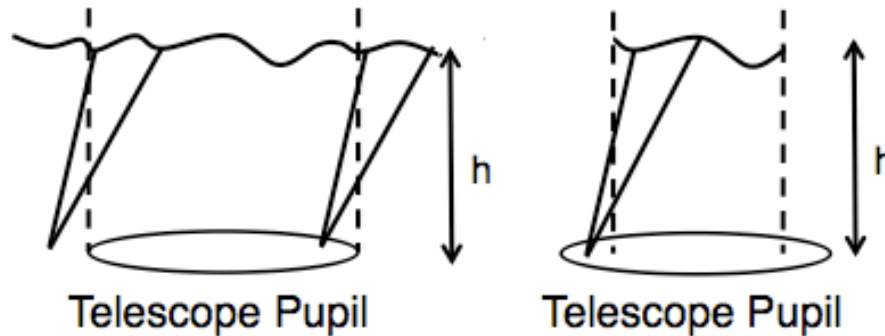
$$\sigma^2 = \begin{cases} 19.2\lambda^{-7/6} \int_0^\infty h^2 C_n^2(h) dh & D \ll r_F & \text{Small aperture, } D < 5\text{cm} \\ 17.3D^{-7/3} \int_0^\infty h^2 C_n^2(h) dh & D \gg r_F & \text{Larger aperture, } D > 30\text{cm} \\ 10.7D^{-4/3} t^{-1} \int_0^\infty \frac{h^2 C_n^2(h) dh}{V(h)} & D \gg r_F, t \gg (\pi D/V) & \text{Larger aperture and finite exposure time, } t > 0.5\text{s} \end{cases}$$

- Increase Telescope Diameter
- Increase Exposure Time (ratio of shot noise to scintillation noise remains the same)
- Something else...



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# Removing the scintillation

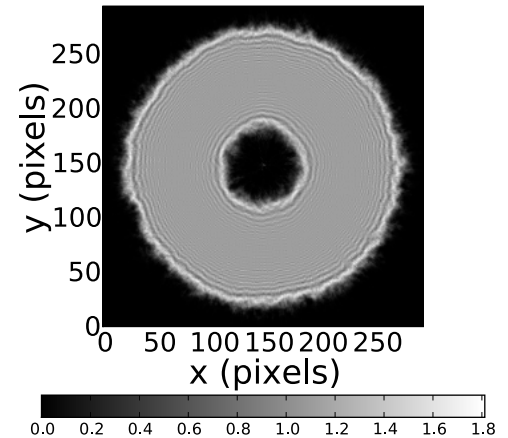
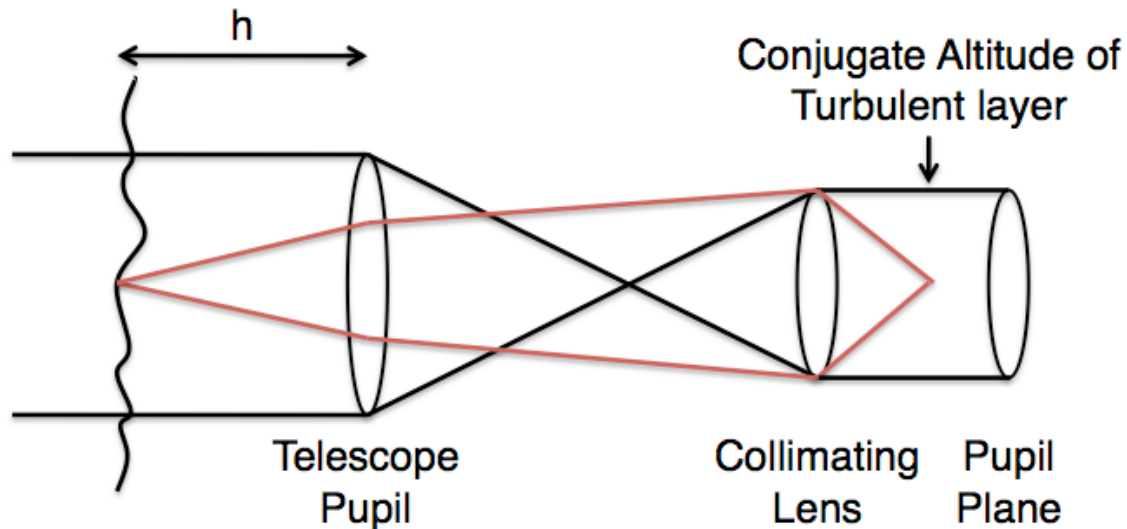
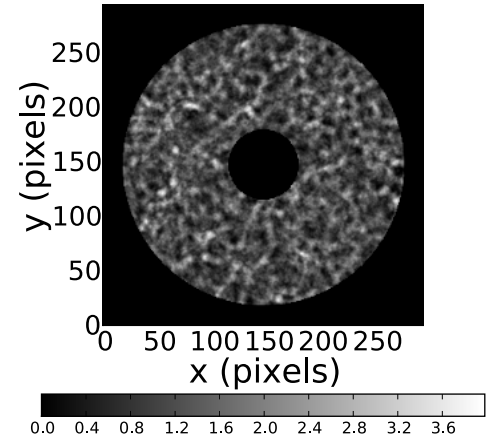
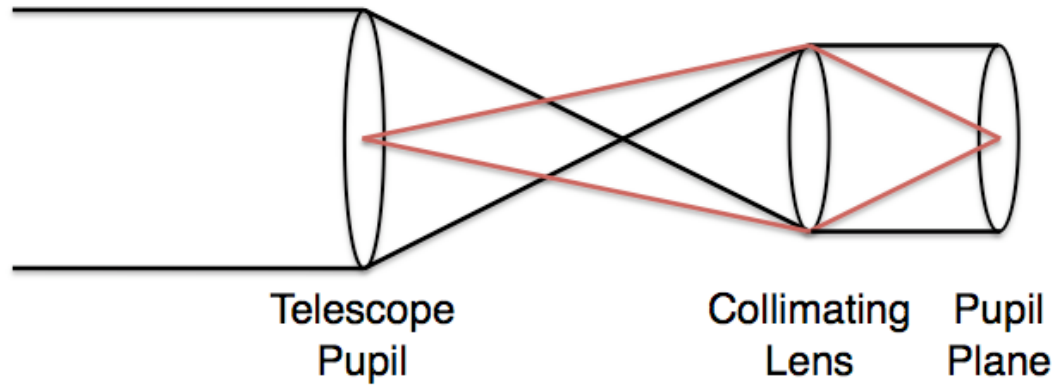


- Light is re-distributed in pupil plane
- Photons which should fall within pupil area are found outside of pupil and vice versa
- Apply theoretical aperture mask at altitude of layer



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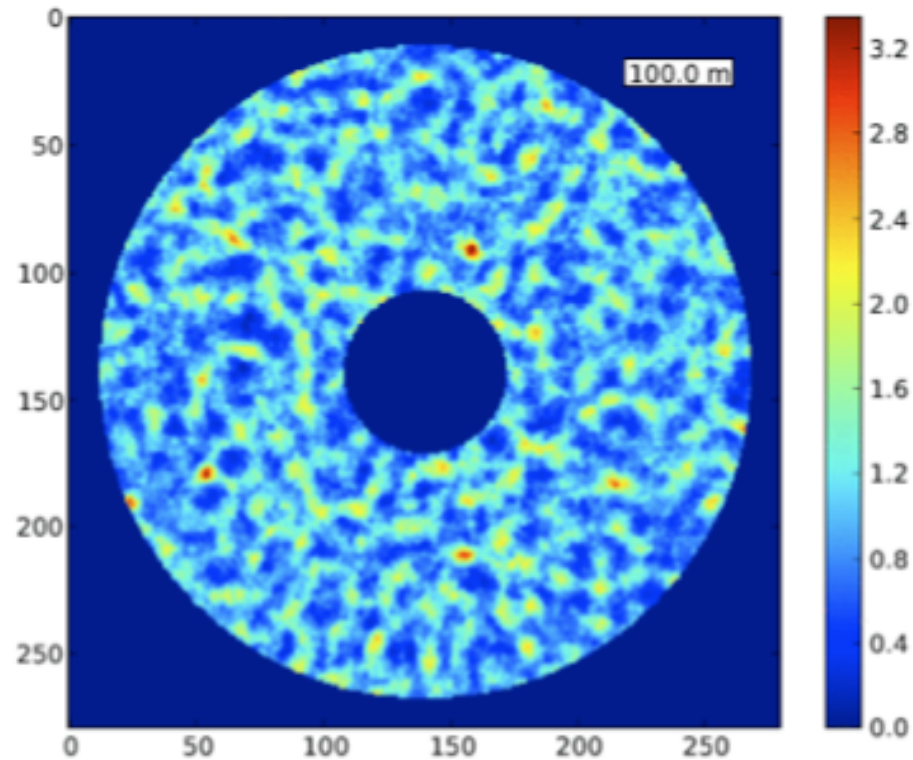
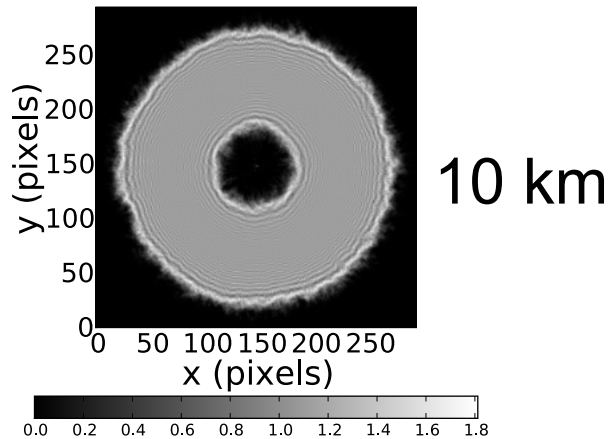
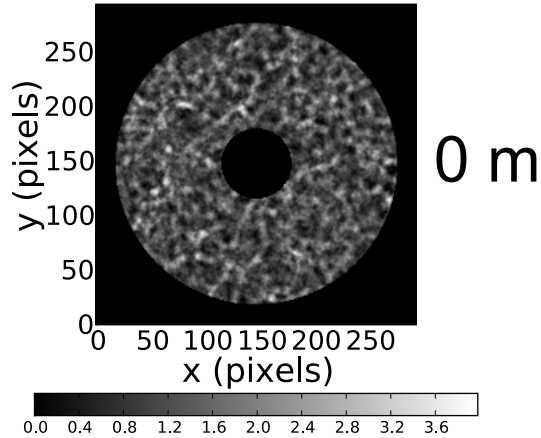
# Optical Conjugation





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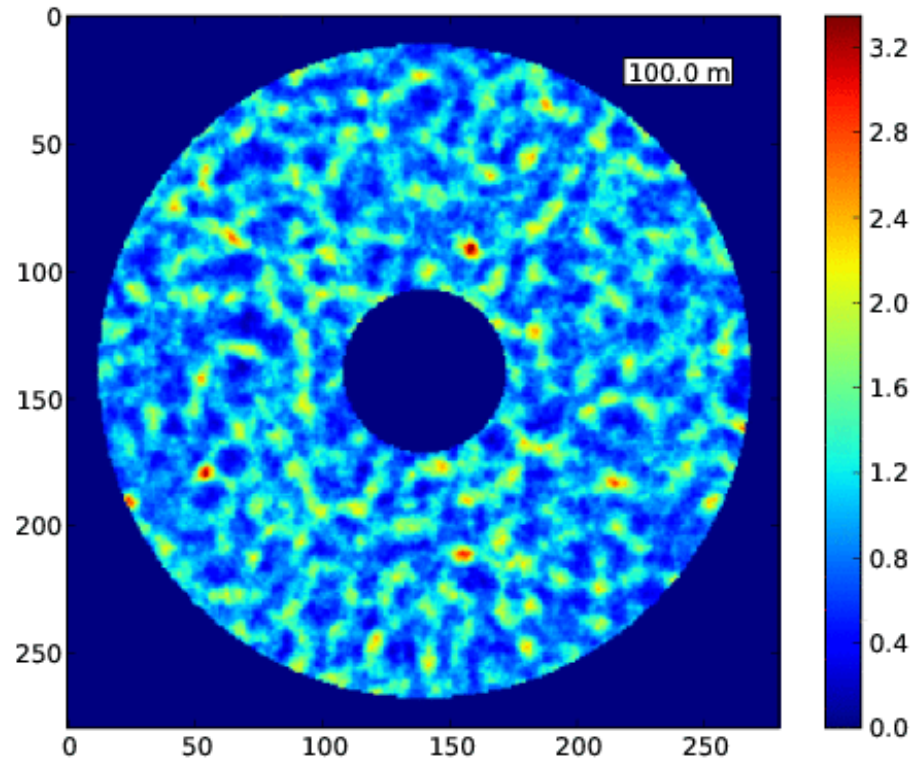
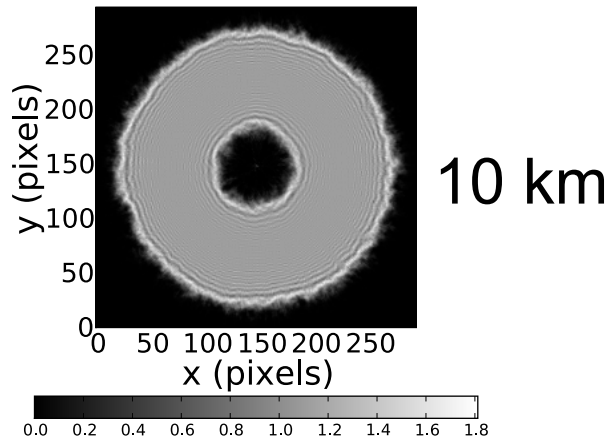
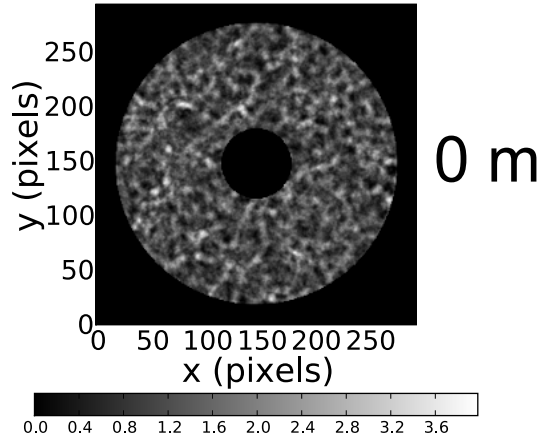
# Conjugate Pupil High Layer Only



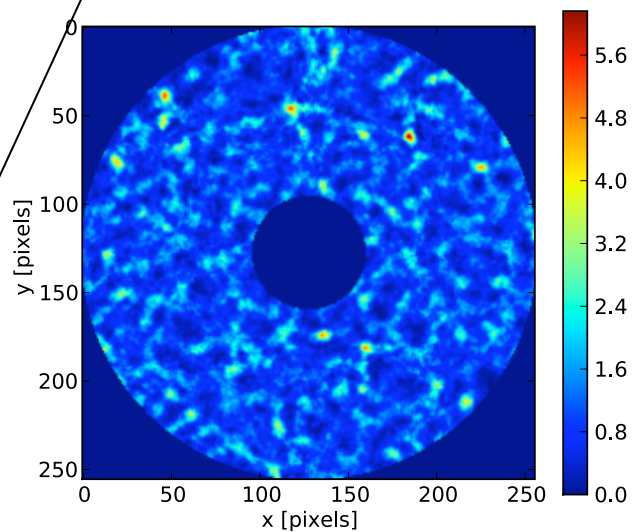
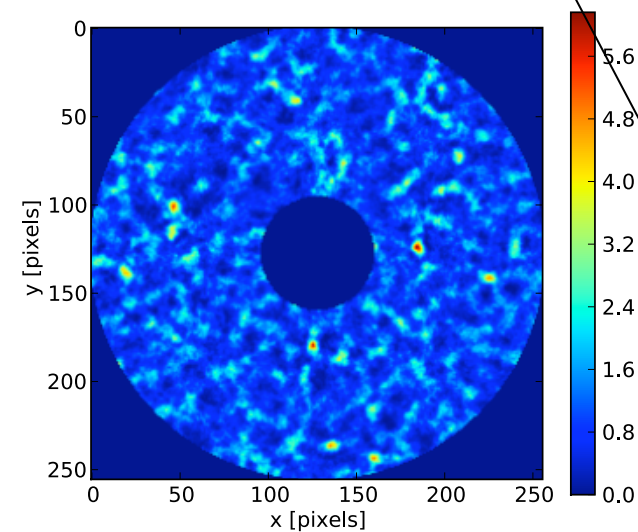
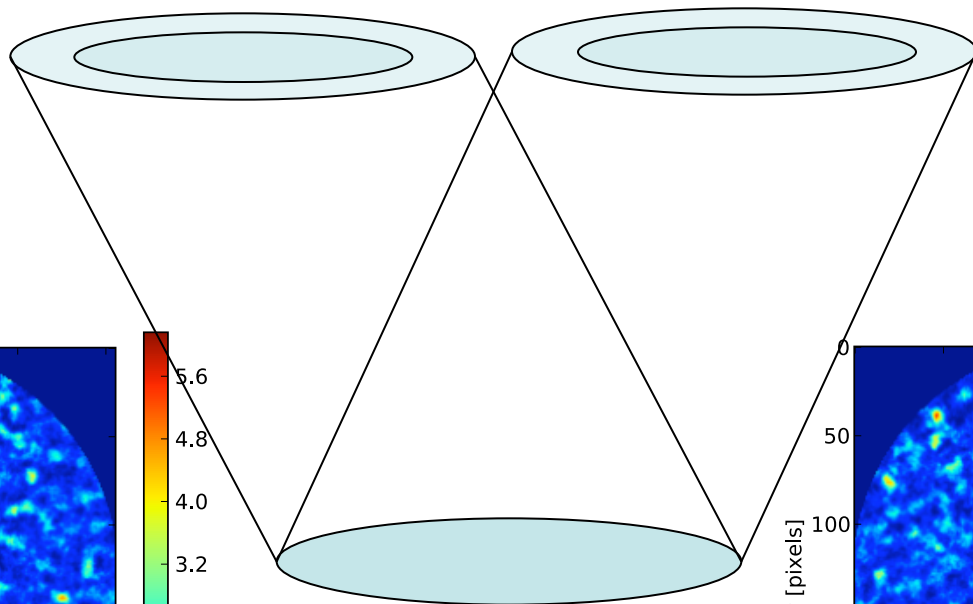
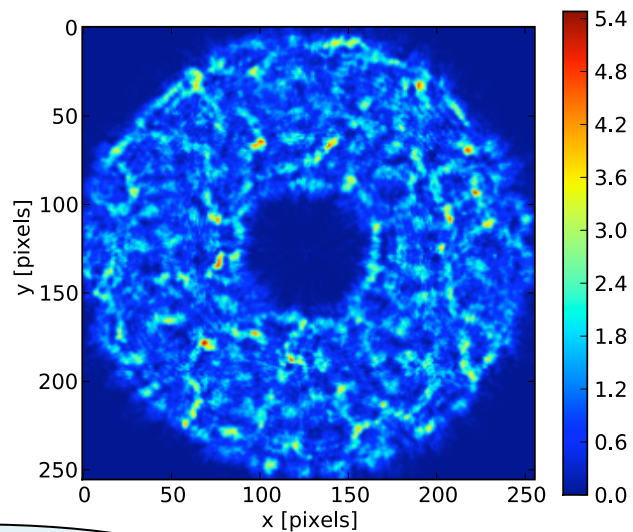
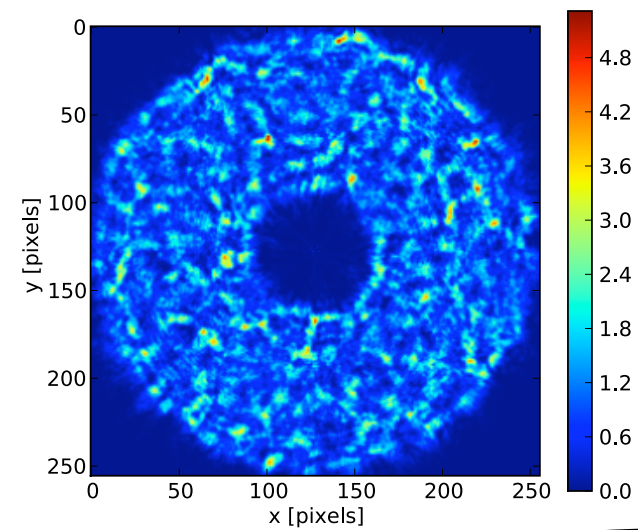


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# Conjugate Pupil High Layer Only



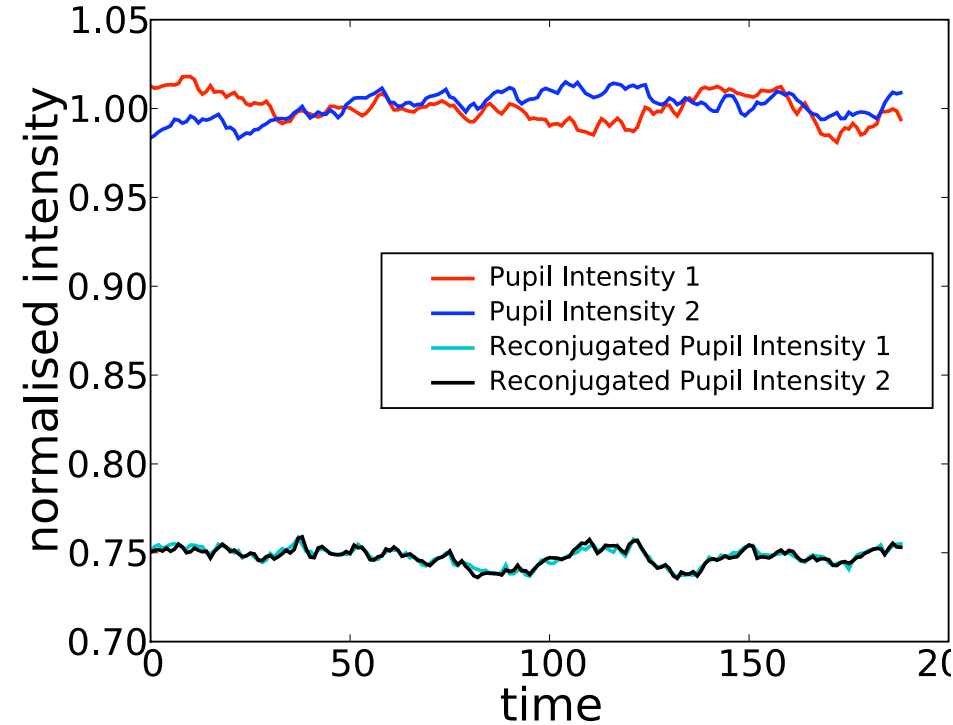
# What about the surface layer?





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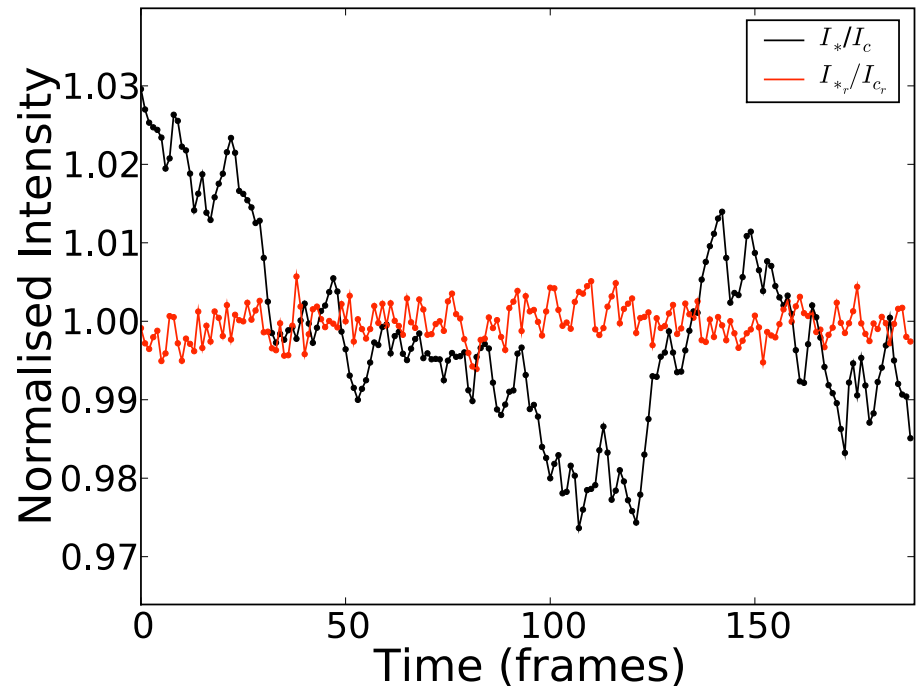
# Simulated Light Curves



$$\text{Var}(I_*/I_c) = 1.5 \times 10^{-4}$$

$$\text{Var}(I_{*r}/I_{cr}) = 5.1 \times 10^{-6}$$

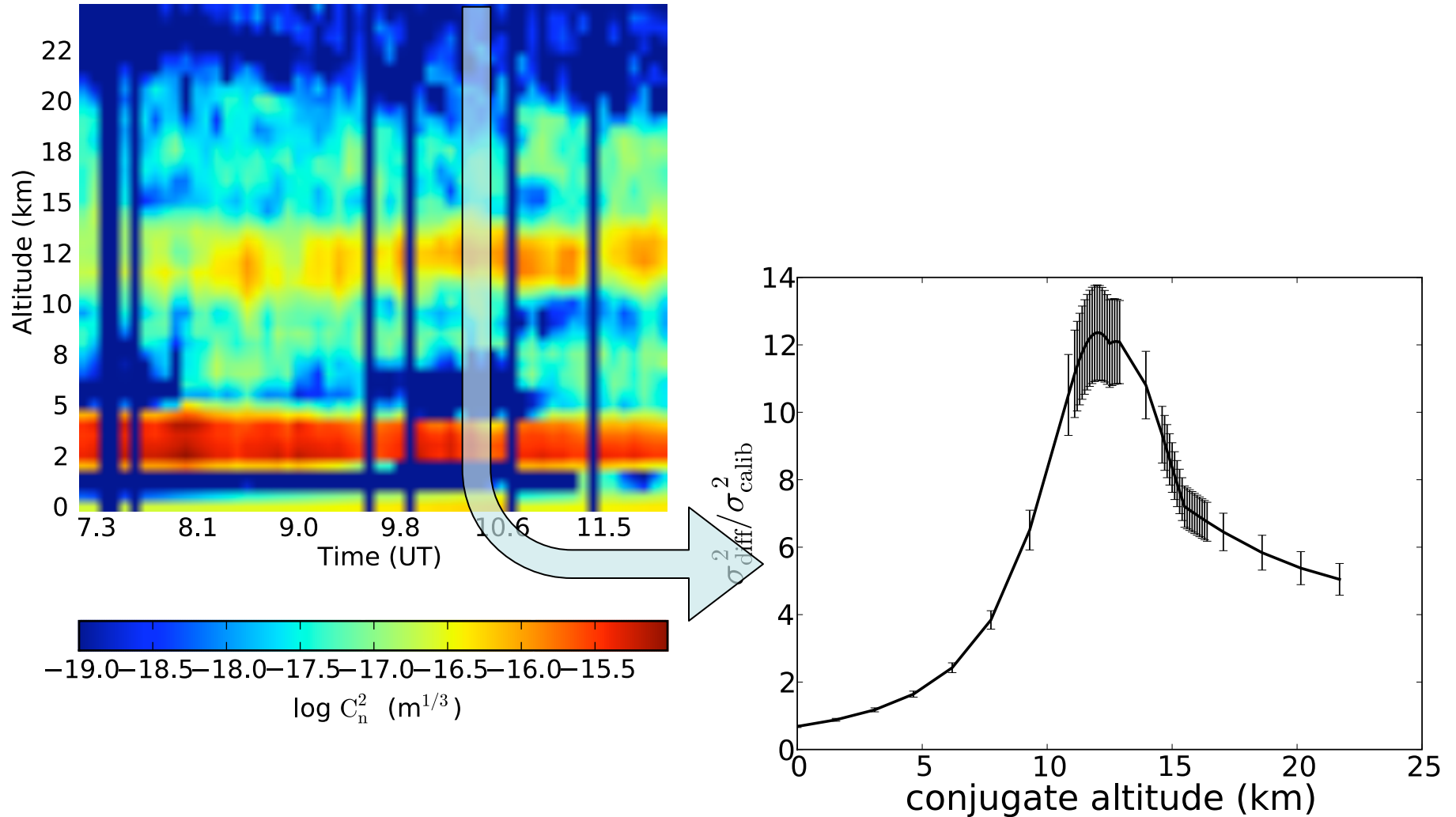
$$\text{Var}(I_*/I_c) / \text{Var}(I_{*r}/I_{cr}) = 29.9$$





# Real Profile - SCIDAR

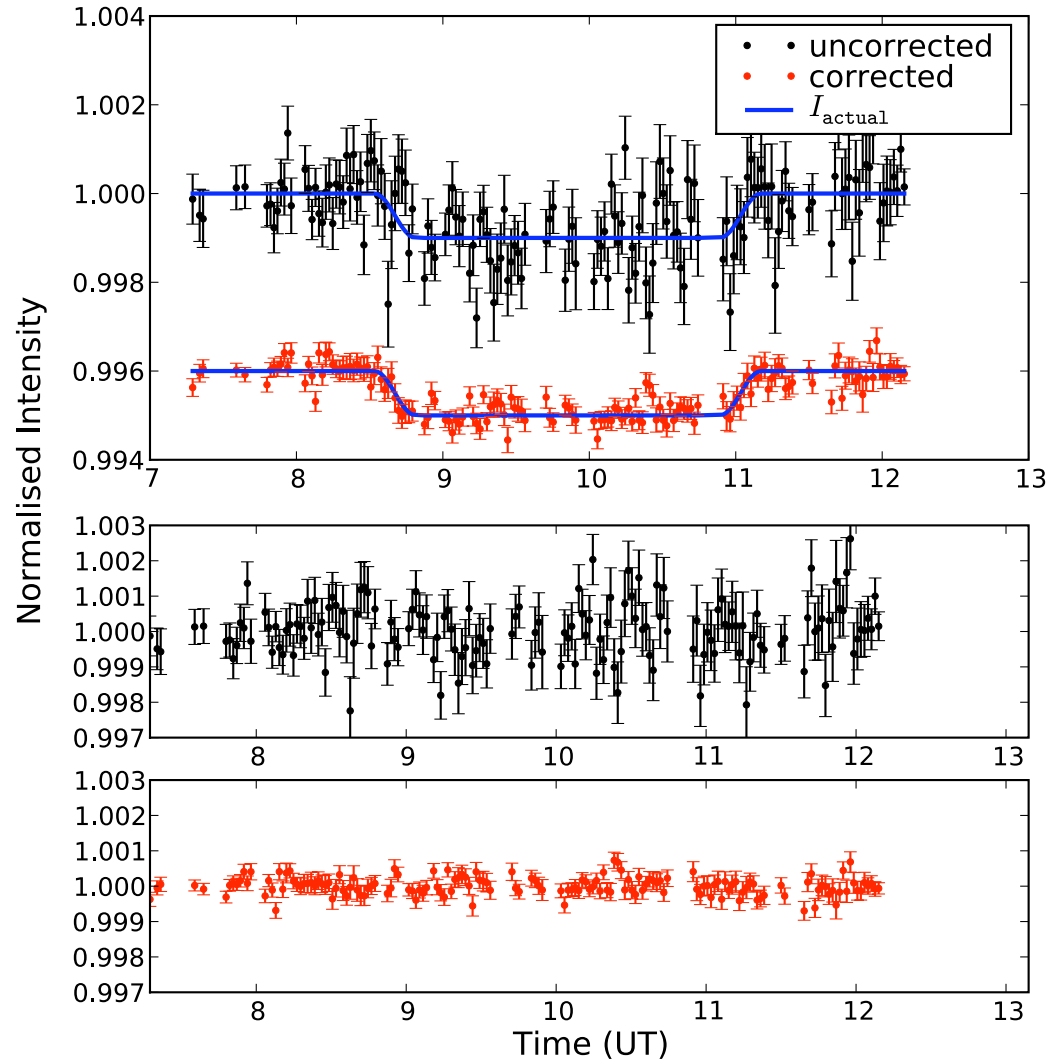
(Simulation results)





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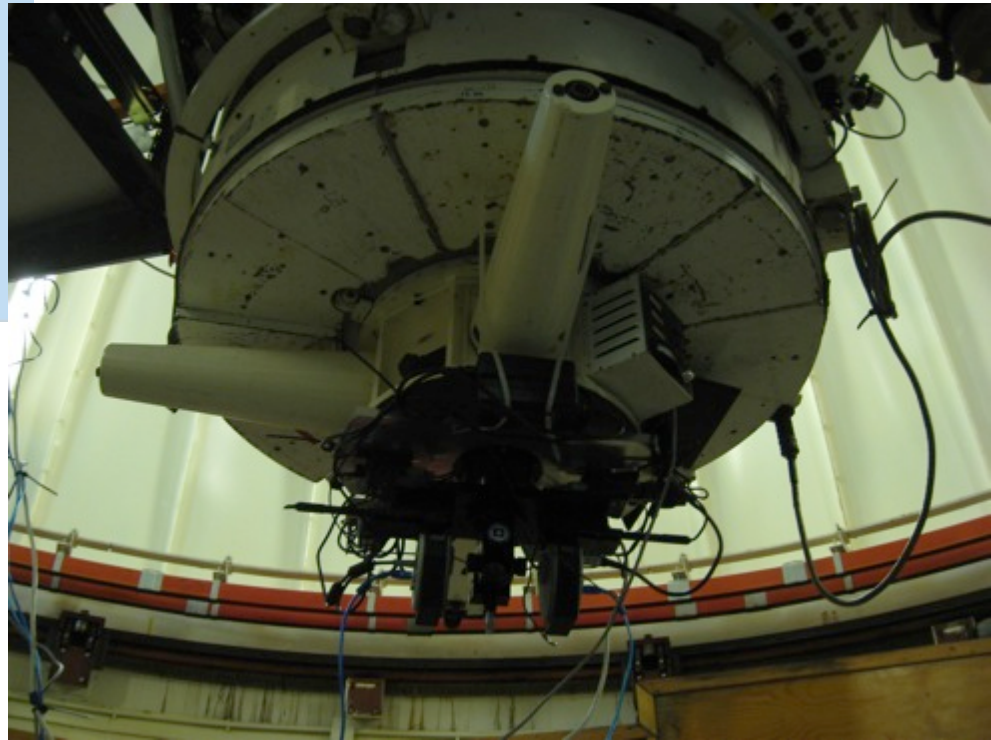
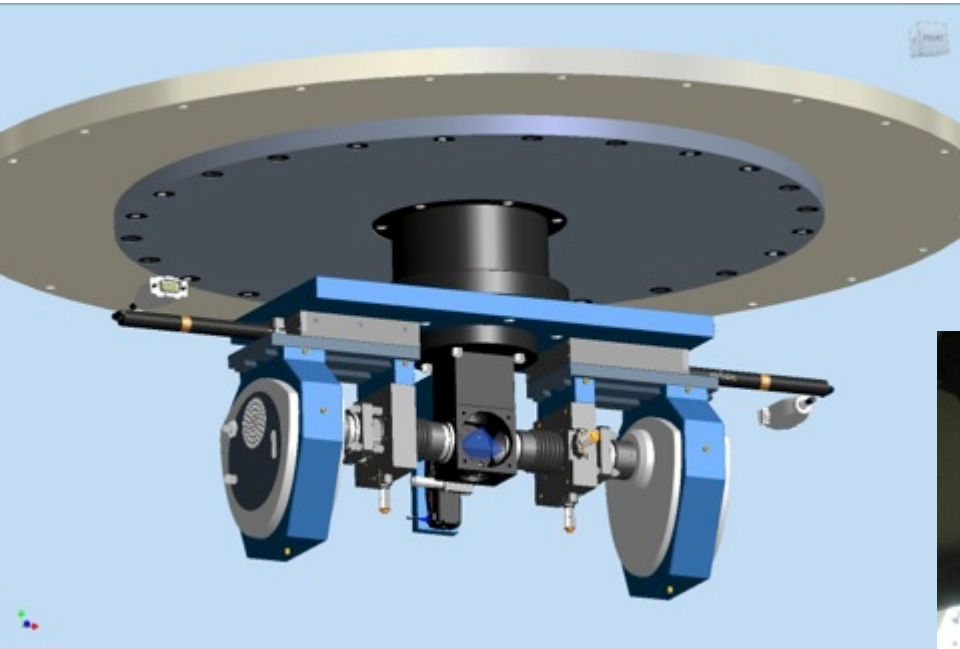
# Light curve example





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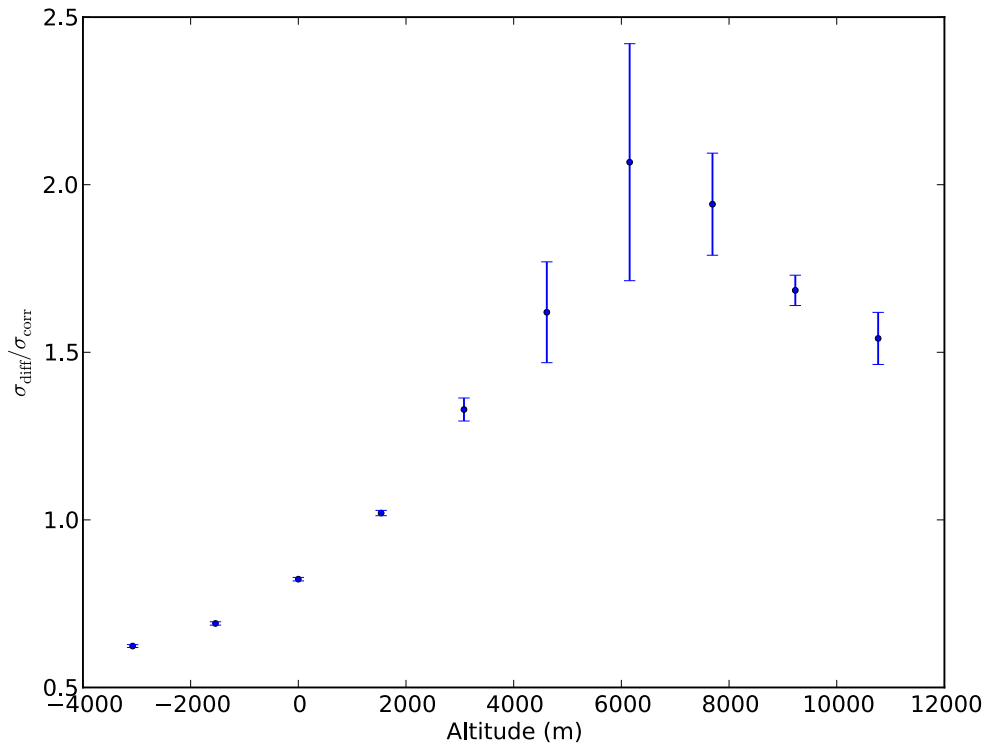
# Optomechanical design



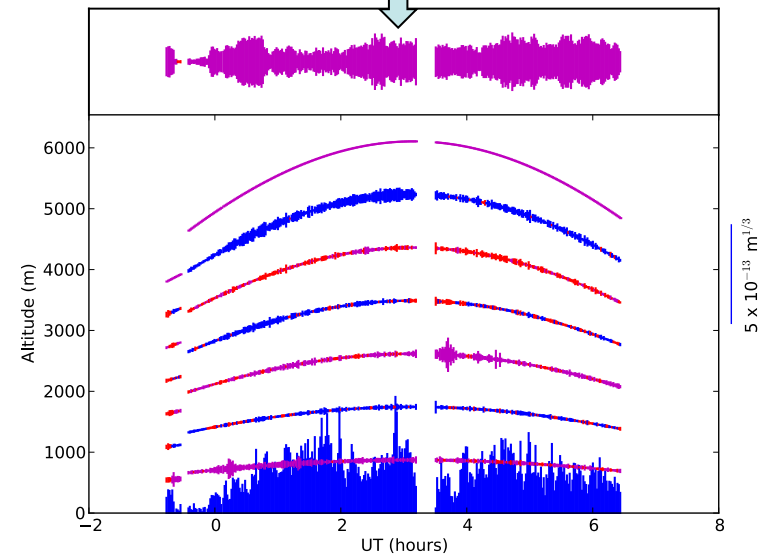


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# On-sky Results (NOT 25/03/13)



High layer strength changes with time, weak on this occasion

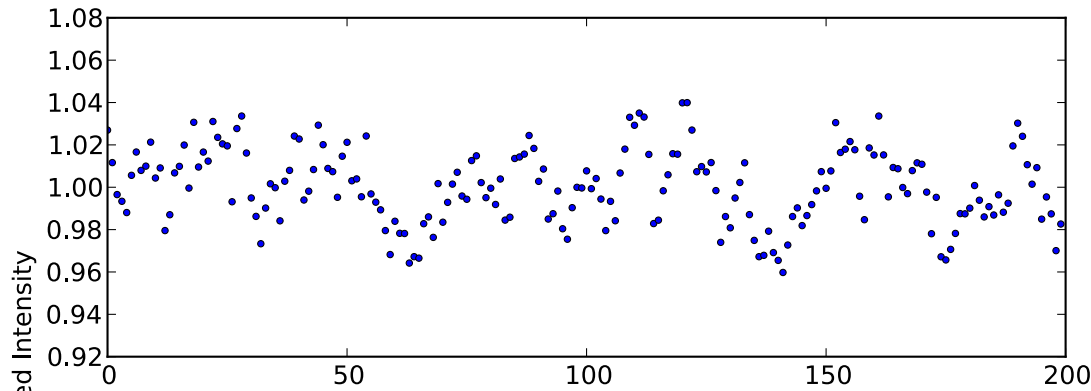


SLODAR  
turbulence profile



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# Noise analysis



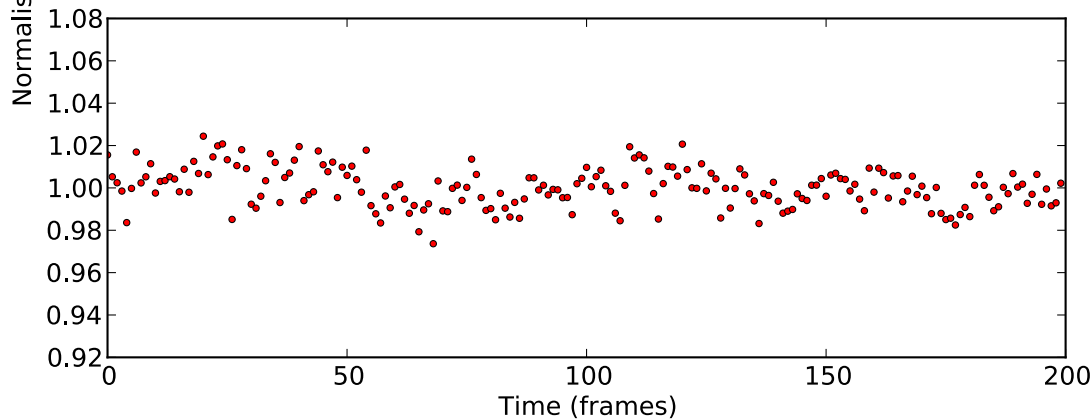
$\sigma = 13$  mmag

$\sigma_{\text{scint}} = 0.012$

$\sigma_{\text{shot}} = 0.006$

$\sigma_{\text{sky}} = 0.00024$

$\sigma_{\text{read}} = 0.00038$



$\sigma = 8$  mmag

$\sigma_{\text{scint}} = 0.006$

$\sigma_{\text{shot}} = 0.006$

$\sigma_{\text{sky}} = 0.00024$

$\sigma_{\text{read}} = 0.00038$



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# Conclusions

- Scintillation can be a dominant noise source, changes on time scale of minutes
- Conjugate Plane Photometry can reduce this noise
- Residual noise from diffraction and ground layer scintillation
- Factor of two is easily attainable but more should be possible in different conditions
- Reduce scintillation to constant level in all conditions