Performance of Coherent Lidar Receivers Using Atmospheric Compensation Techniques

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INTRODUCTION

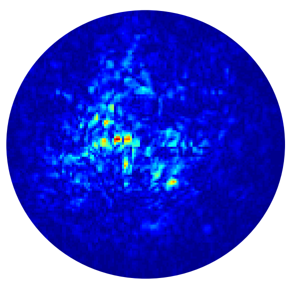
- Atmospheric turbulence coupled with target speckle can deteriorate coherent laser radar performance

- Speckle driven by turbulence reduces heterodyne mixing efficiency

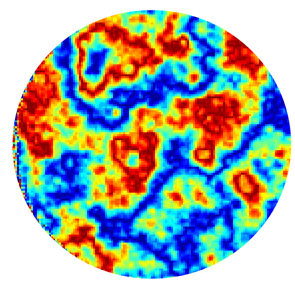
- Spatial and temporal diversity methods, along with phase correction techniques, can be applied to mitigate signal deterioration

- Measures of performance are required to estimate the effectiveness of the compensation methods

$\tau \sim 1\mu s$



Target Speckle



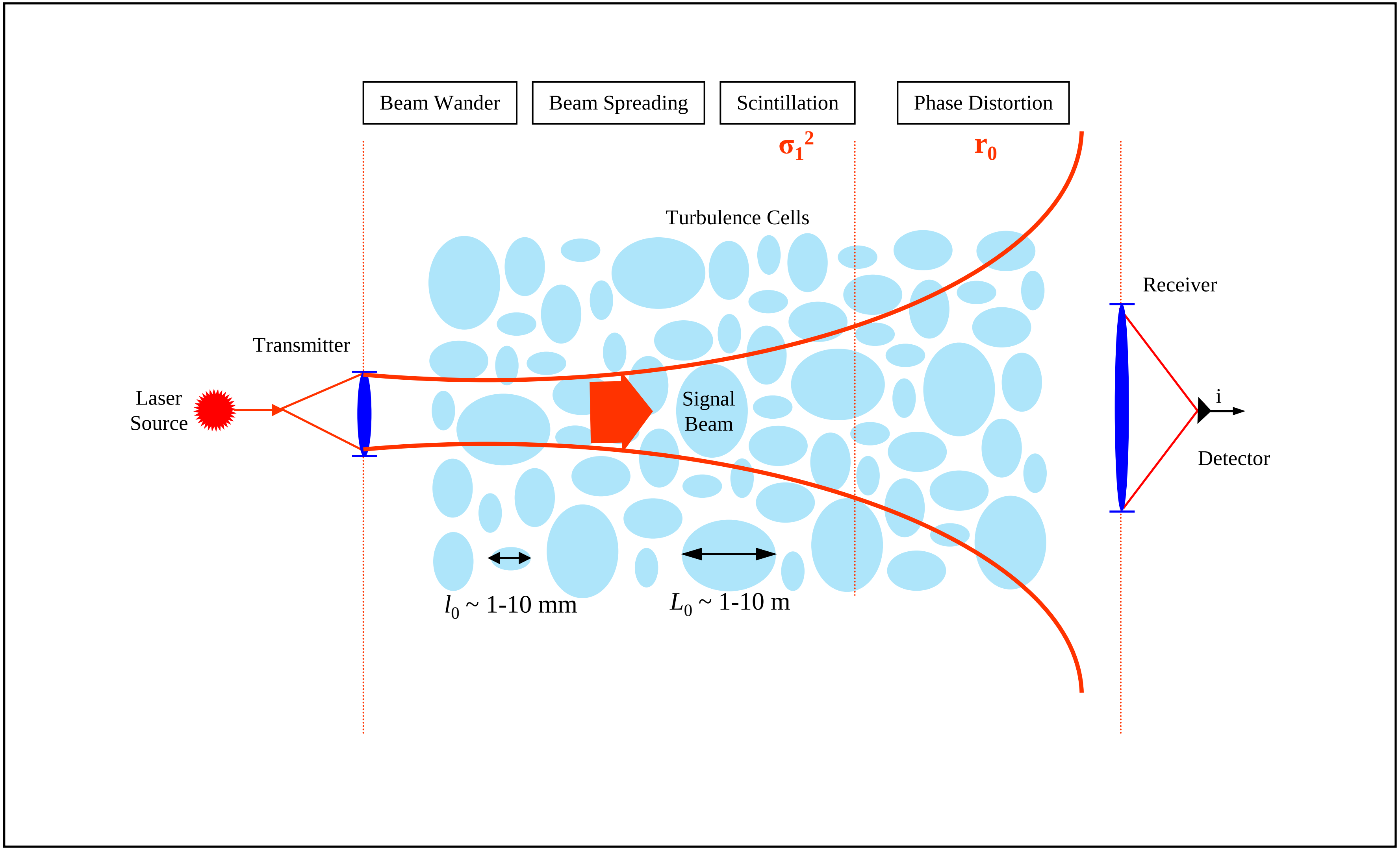
$\tau \sim 1ms$

Atmospheric Turbulence

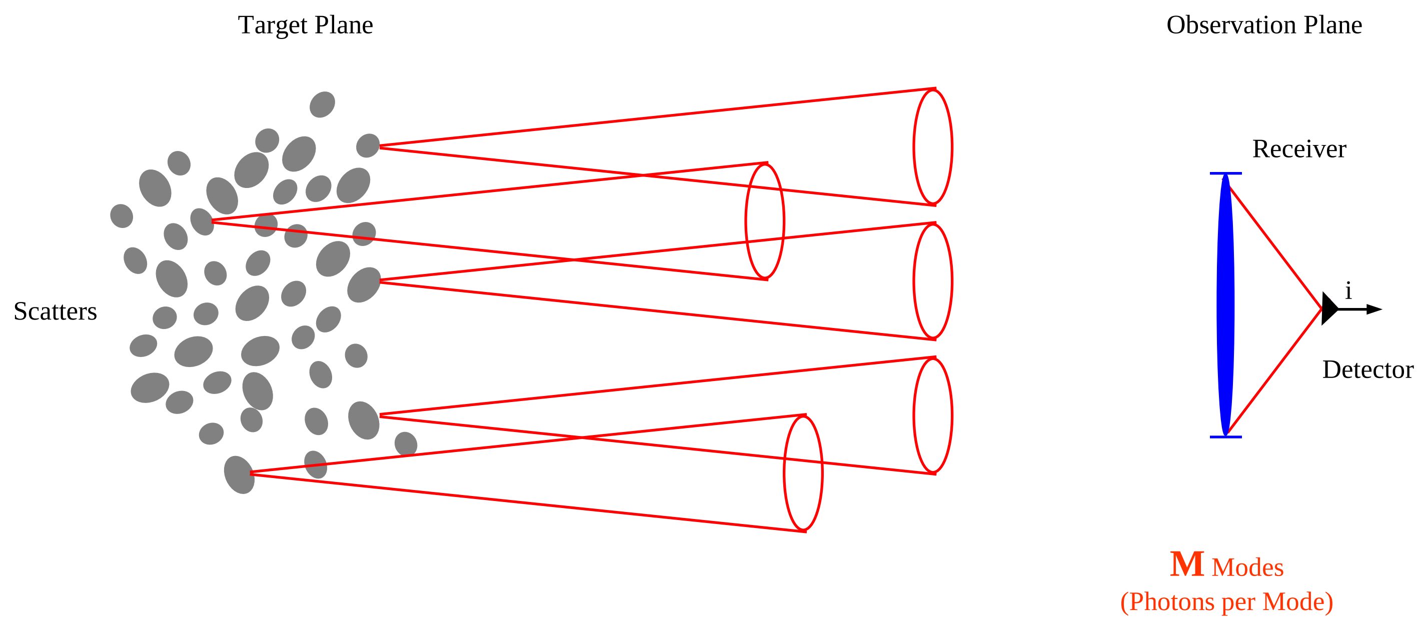
Outline

- **Introduction**
  - Atmospheric Turbulence and Target Speckle
  - Compensation Techniques
- **An Statistical Model for Coherent Lidar Signals**
  - Turbulence and Speckle Fading
  - Compound Statistics
- **Measures of Performance**
  - Average SNR and Amount of Fading
  - Outage probability and Mean Outage Rate
- **Conclusions**
  - Final Remarks and Research Opportunities

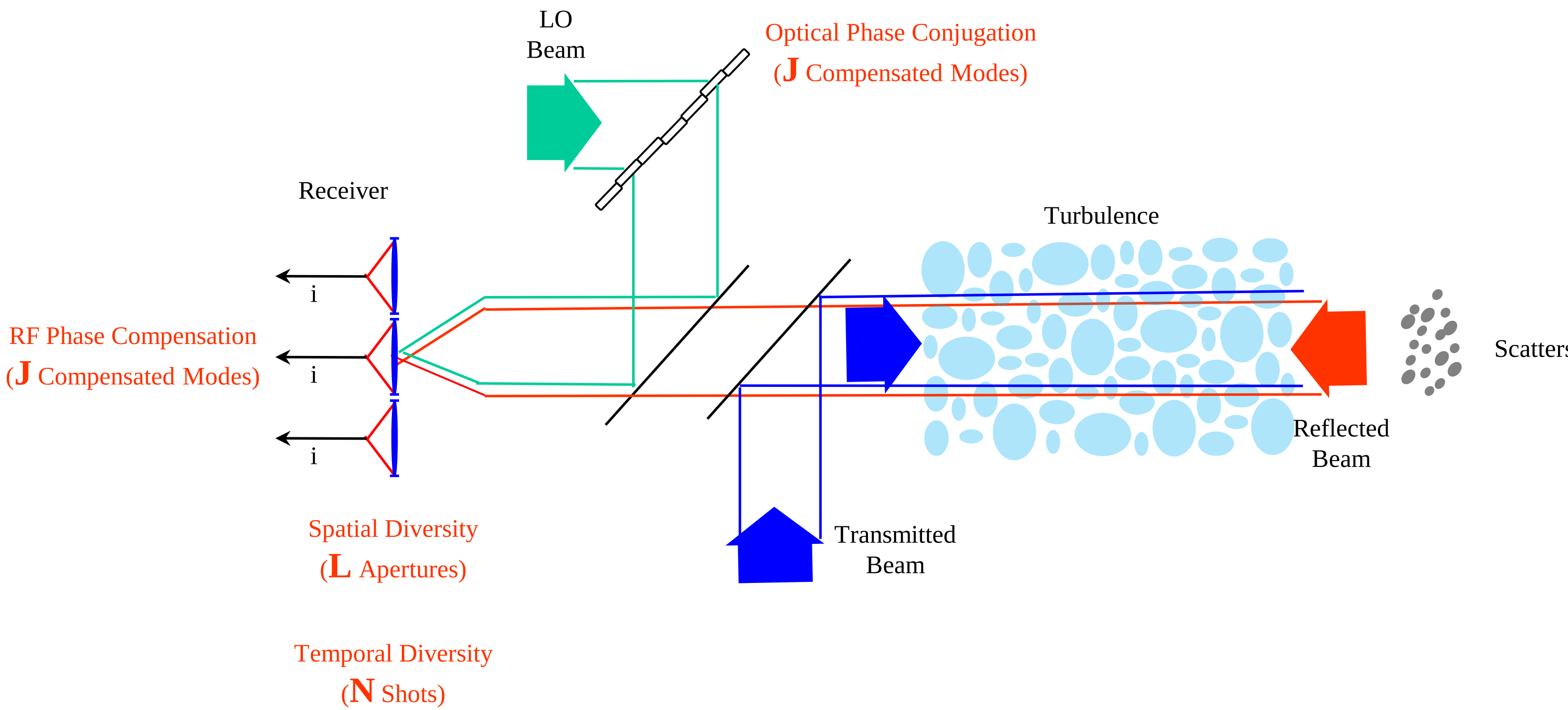
Atmospheric Turbulence Effects



Target Speckle Effects



Compensation Techniques on Coherent Systems



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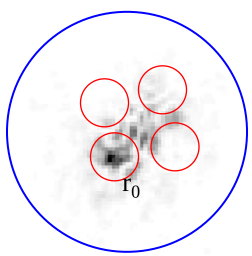
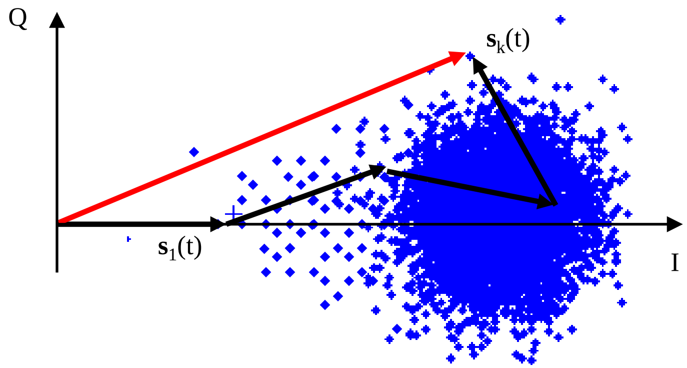
Turbulence Fading

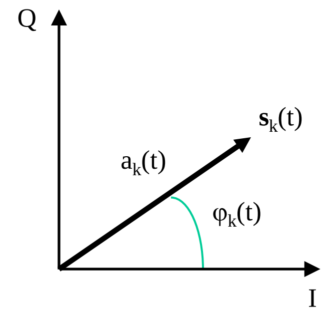
- Analyzing the receiver performance requires knowledge of the envelope statistics of the downconverted electrical signal. We find that the SNR γ is described by a noncentral chi-square distribution with two degrees of freedom

$$p_T(\gamma) = \frac{1+r}{\bar{\gamma}} \exp(-r) \exp\left[-\frac{(1+r)\gamma}{\bar{\gamma}}\right] I_0\left[2\sqrt{\frac{(1+r)r\gamma}{\bar{\gamma}}}\right]$$





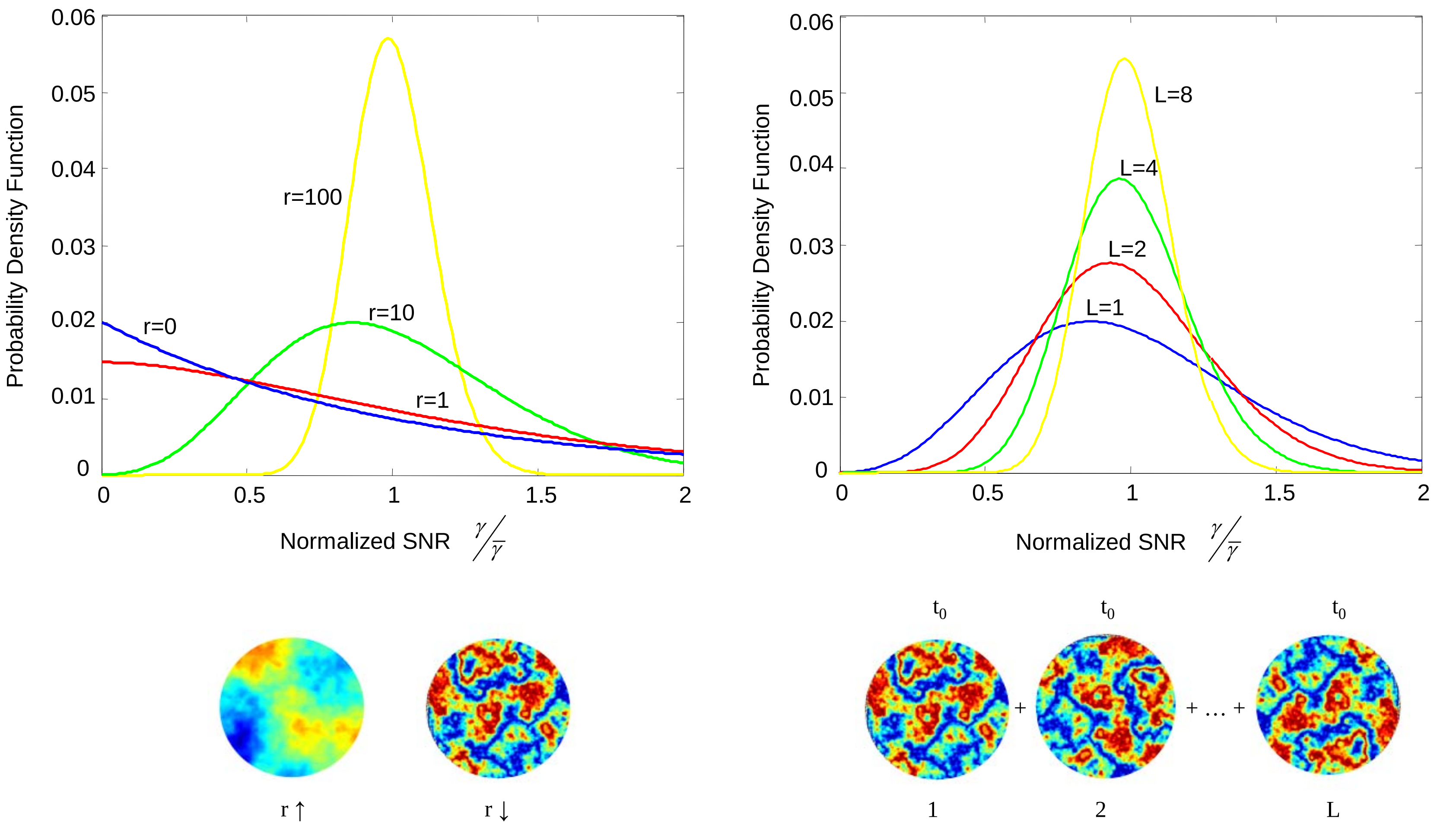
Multiplicative Turbulence Noise



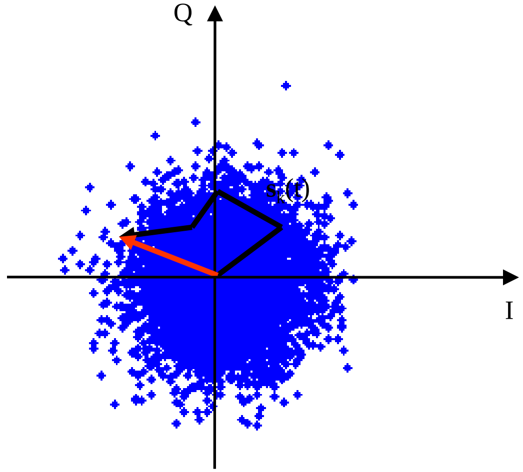
Log-normal a_k

Normal φ_k

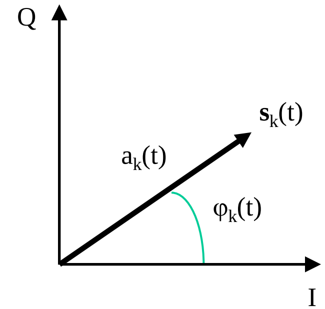
Turbulence SNR Statistics



Speckle Fading



Multiplicative Speckle Noise



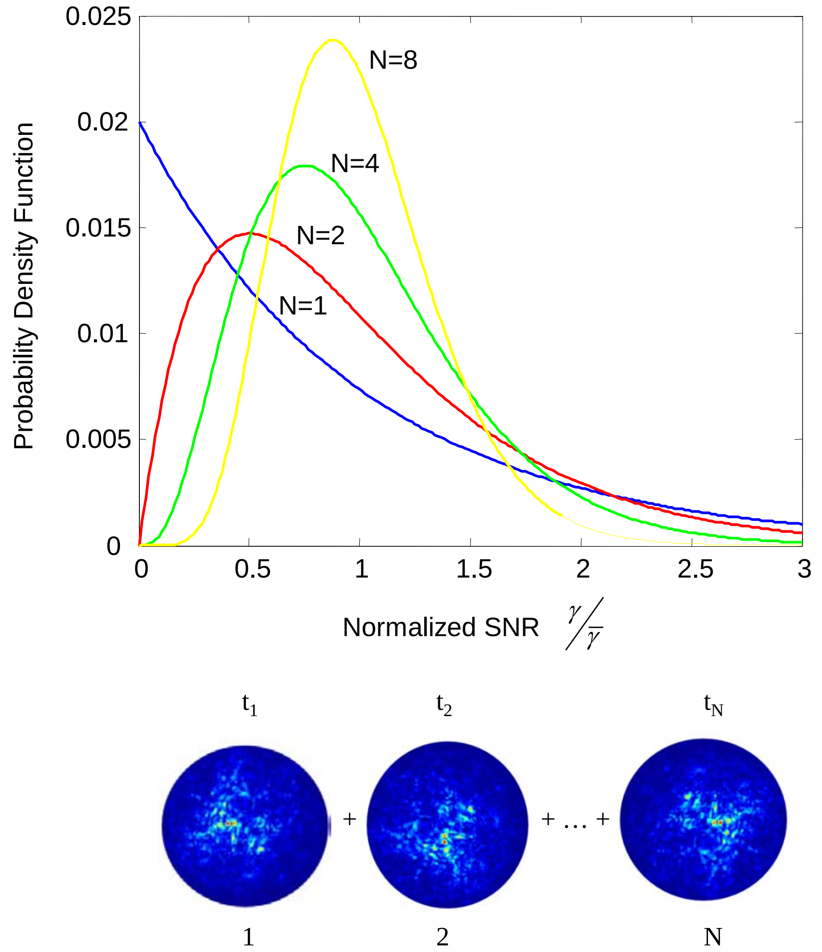
Rayleigh a_k

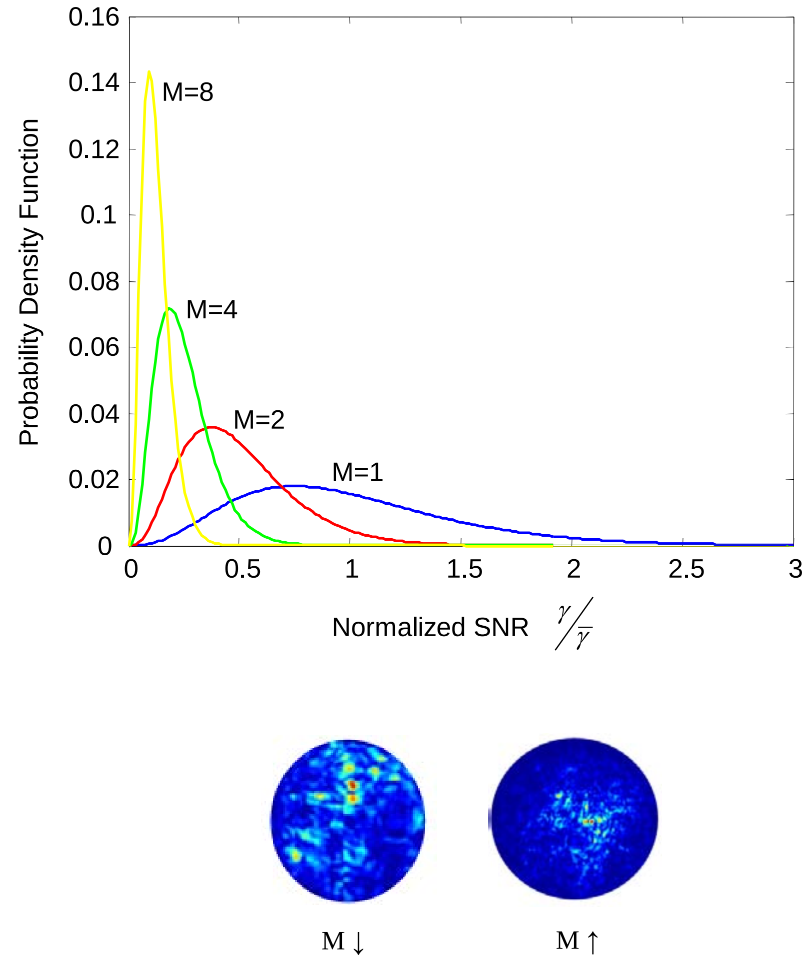
Uniform φ_k

•The SNR γ is described by a Gamma distribution with shape parameter *N* (accumulation shots) and scale parameter $\bar{\gamma}/M$ (degeneracy parameter)

$$p_S(\gamma) = \left(\frac{NM}{\bar{\gamma}}\right)^N \frac{\gamma^{N-1}}{\Gamma(N)} \exp\left(-NM\frac{\gamma}{\bar{\gamma}}\right)$$

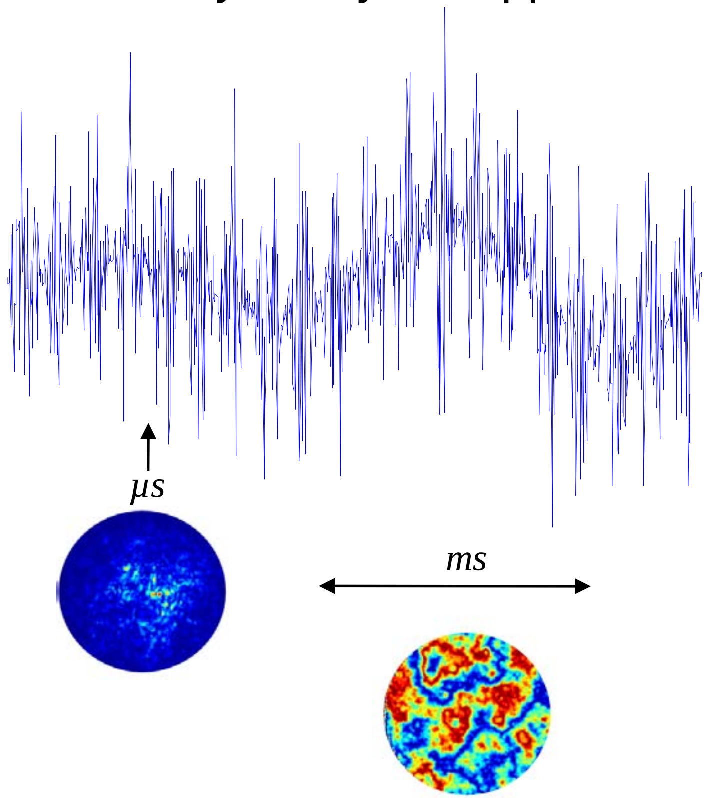
Speckle SNR Statistics





Speckle Driven By Turbulence

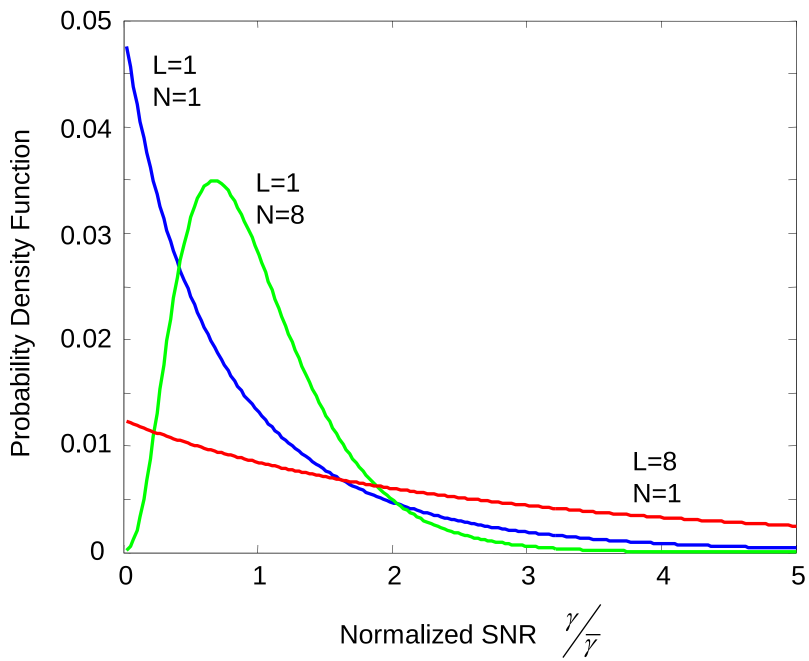
•The speckle process is driven by turbulence. The problem of compound speckle statistics can be analyzed by the application of conditional statistics.



$$p_\gamma(\gamma) = \int_0^\infty p_S(\gamma \,|\, v)\; p_T(v)\; d\gamma$$

Coherent Lidar Signal Statistics

•We suggest a continuous PDF from the family of K distributions, the gamma transform of a non-central chi-squared distribution, to model the smearing due to speckle of the SNR in a heterodyne lidar receiver affected by atmospheric turbulence.



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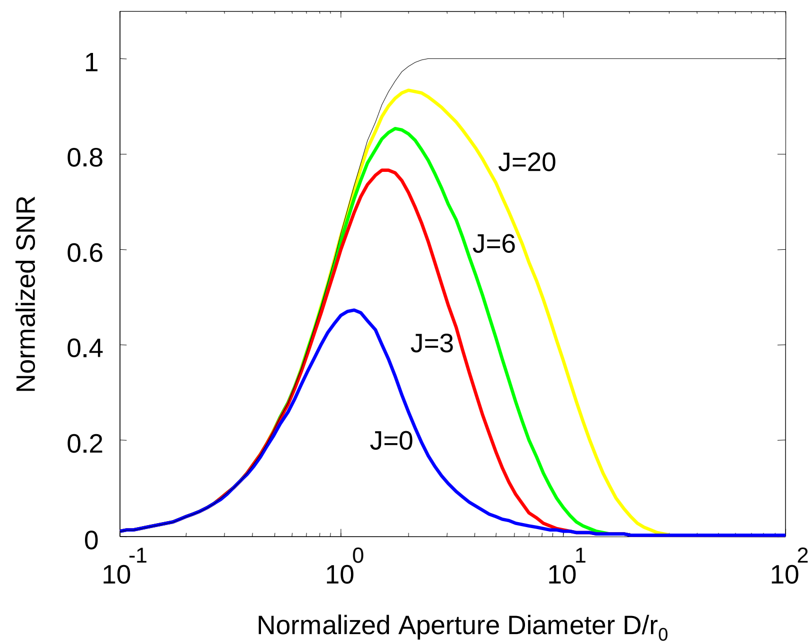
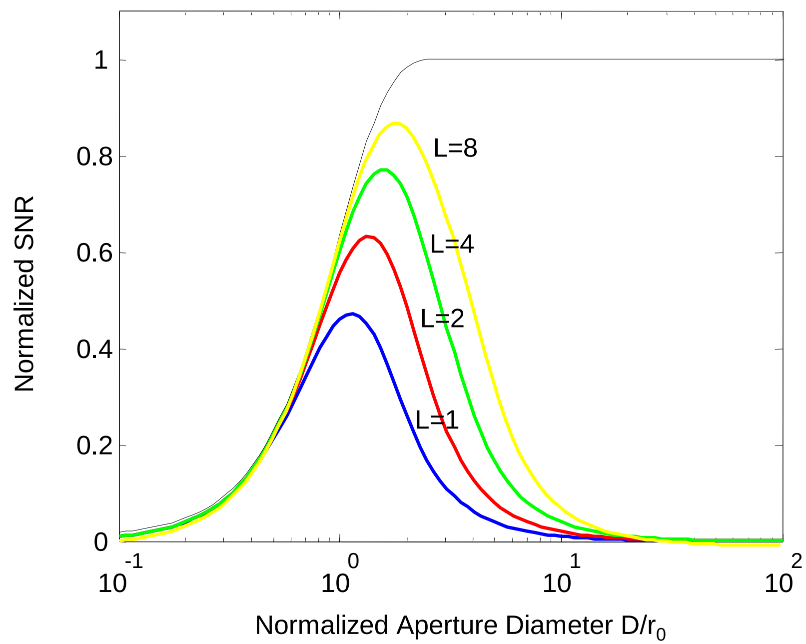
Mean SNR (Photocounts)

•For a shot-noise limited signal is the detected number of photons

$$\langle \gamma \rangle = \int_0^\infty \gamma \; p_\gamma(\gamma) \, d\gamma$$

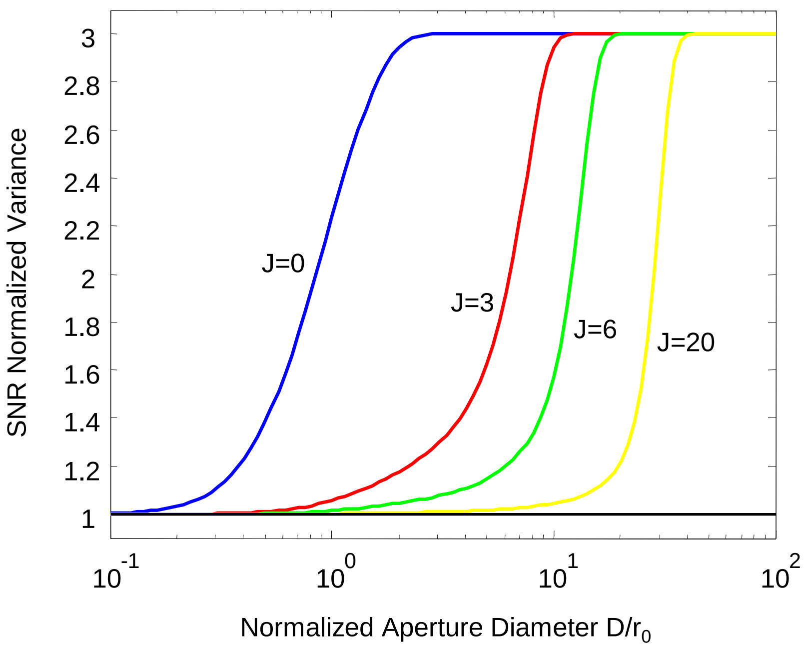


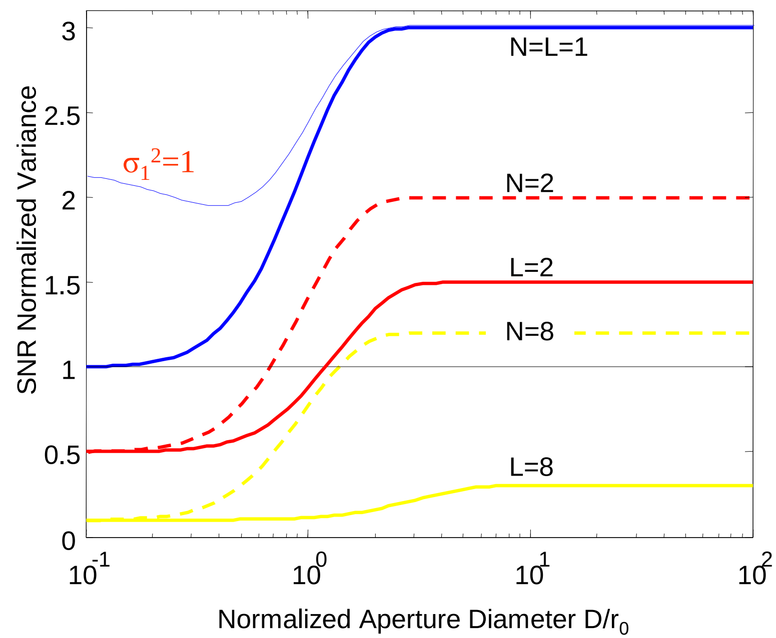


Amount of Fading

•In the context of diversity combining, the mean γ does not capture all diversity. Diversity also reduces fading-induced fluctuations

$$\langle \gamma^2 \rangle = \int_0^\infty \gamma^2 \; p_\gamma(\gamma)\, d\gamma$$

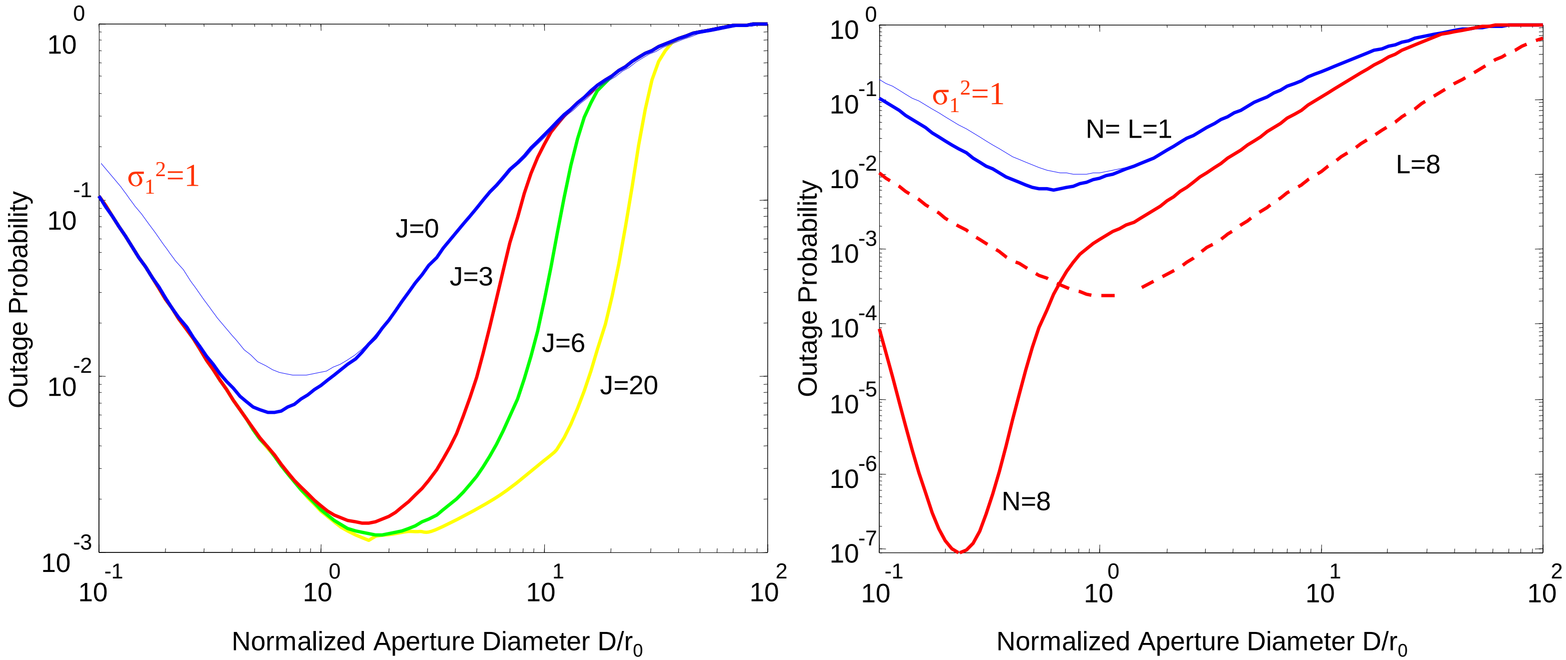




Outage (Fade) Probability

- Another standard performance criterion of diversity systems is the probability that the output SNR (Photons) γ falls below a certain specified threshold

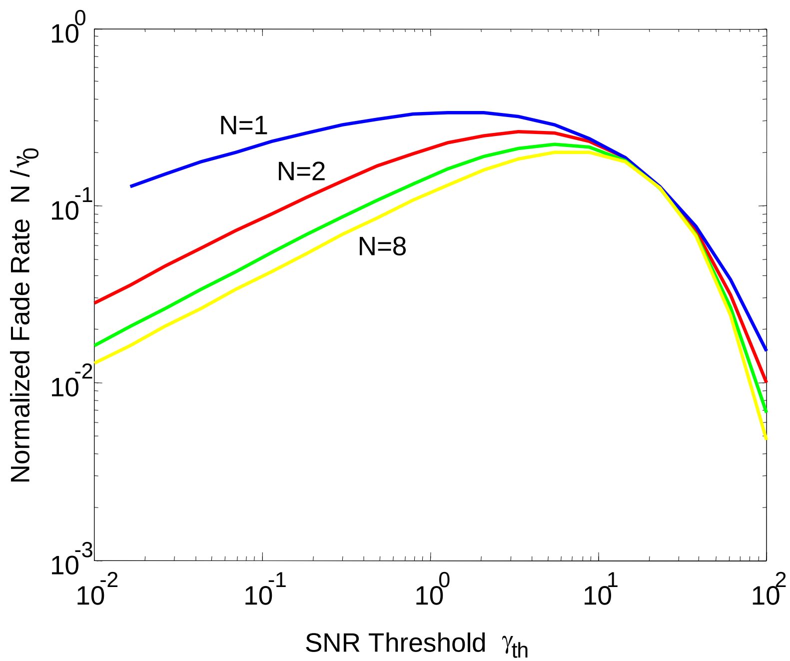
$$p_{out}(\gamma_{th}) = \int_0^{\gamma_{th}} p_\gamma(\gamma)\, d\gamma$$

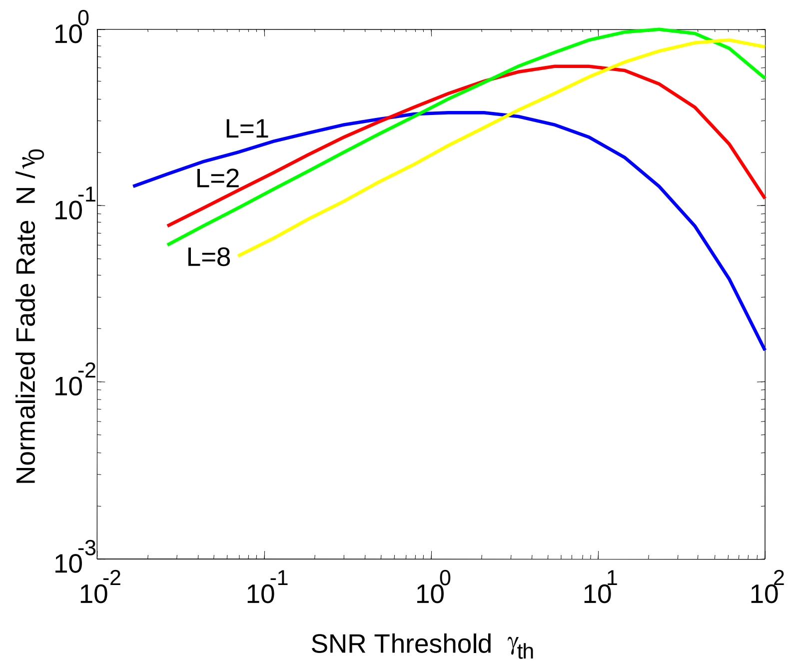


Level Crossing Rate

•The average outage (fade) duration and the frequency of outages are important performance criteria for the proper selection of transmission PRF, pulse length

$$N(\gamma_{th}) = p_\gamma(\gamma_{th}) \int_0^\infty \gamma' \, p_{\gamma'}(\gamma' | \gamma_{th}) \, d\gamma$$





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Final Remarks

•Atmospheric turbulence coupled with target speckle deteriorates coherent laser radar performance

•Spatial and temporal diversity methods, along with phase correction techniques, can be applied to mitigate signal deterioration

•Measures of performance are required to estimate the effectiveness of the compensation methods

•The speckle reflected from atmospheric scatters is a compounded effect of the atmospherically induced SNR fluctuations and the speckle fluctuations

•Our model helps to explore the various possibilities that exists to deploy compensation techniques