Characterization of speckle reduction with nanosecond-order pulses

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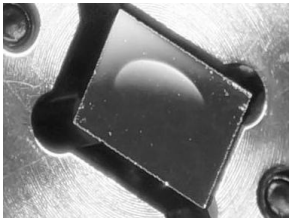
DYOPTYKA, Ireland.

Laser Display, Imaging, and Lighting Conference 2026, Yokohama, Japan.

2026-04-23

Speckle reduction with phase-randomizing deformable mirror (DM)



DM Inactive, surface approximately planar.

Laser diode pulse *DM Inactive* *diffuser* *image sensor.*

Close-up of speckle, contrast $C_I(104\,\text{ns}) \approx 0.13/0.31 \approx 42\%$

DM Active, random surface waves at 1.5 MHz.

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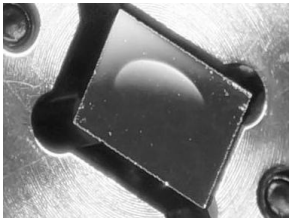

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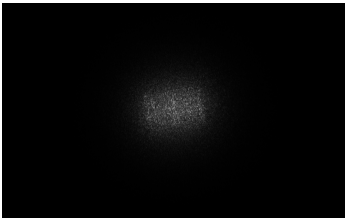

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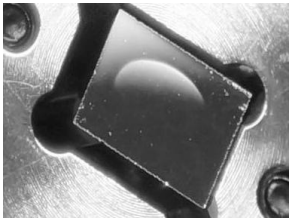

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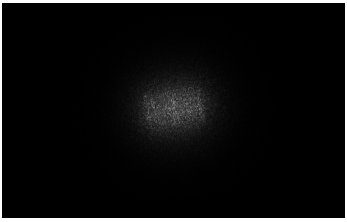

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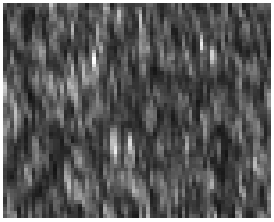

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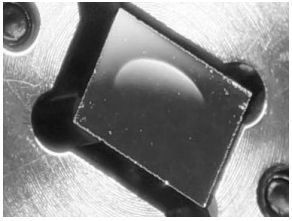

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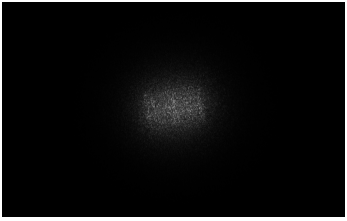

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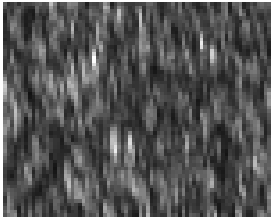

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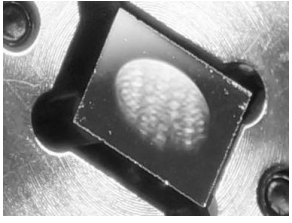

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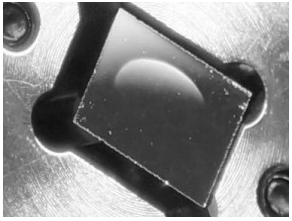

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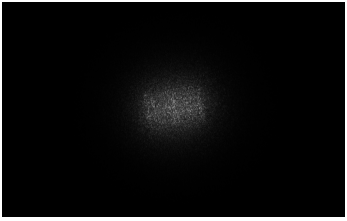

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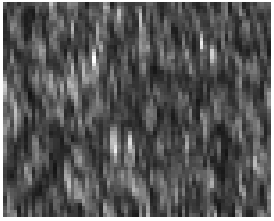

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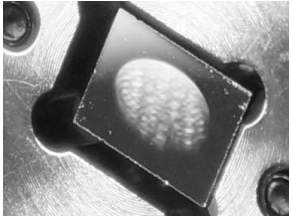

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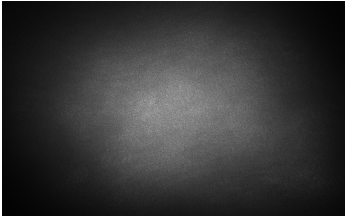

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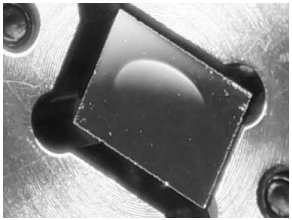

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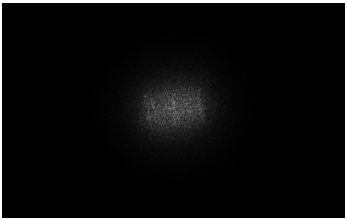

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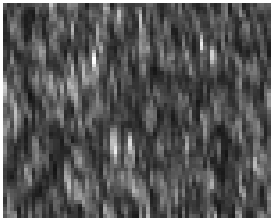

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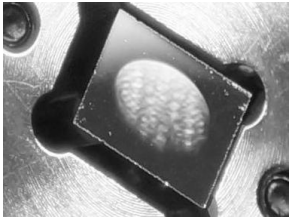

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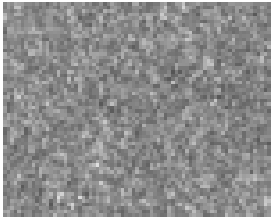

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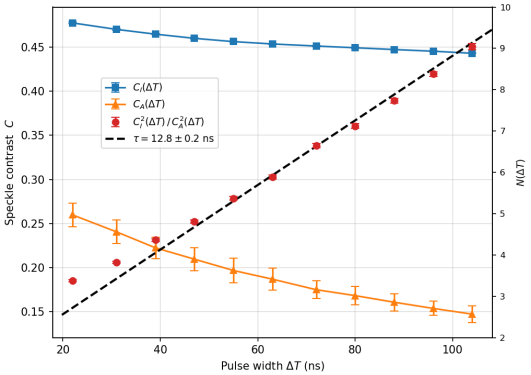
Modelling of speckle reduction from speckle contrast only



- For pulse widths $\Delta T = 6\,\text{ns}, 14\,\text{ns}, \ldots 129\,\text{ns}$, calculate $C_I(\Delta T)$ and $C_A(\Delta T)$.
- Assume $C_A(\Delta T) = C_I(\Delta T)/\sqrt{N(\Delta T)}$ or $N(\Delta T) = C_I^2(\Delta T)/C_A^2(\Delta T)$.
- Model $N(\Delta T)$ somehow, e.g. as $1 + \Delta T/\tau$, and solve for unknown params.

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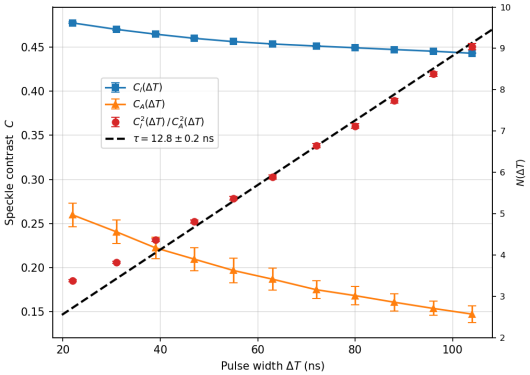

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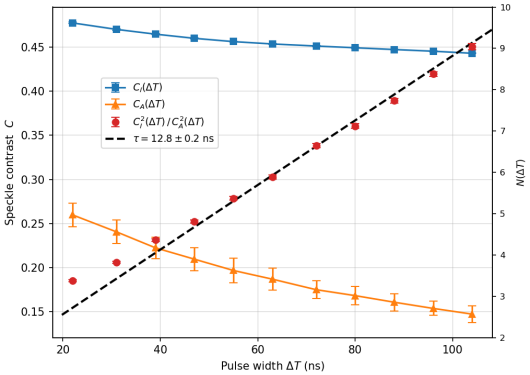

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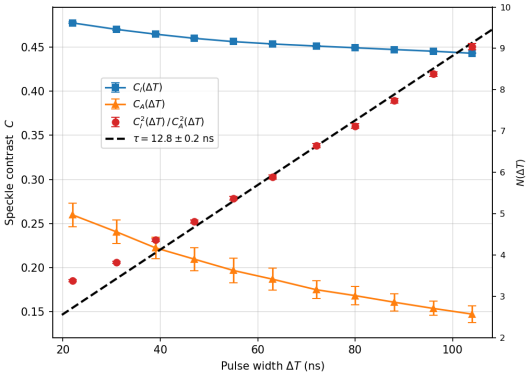

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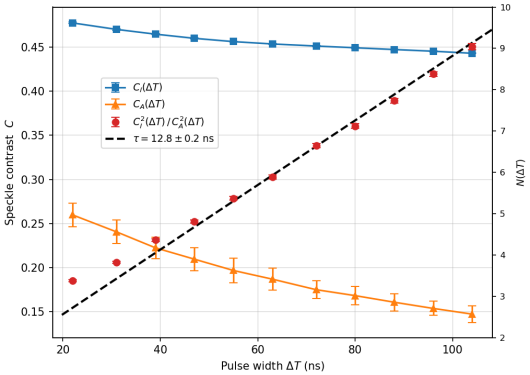

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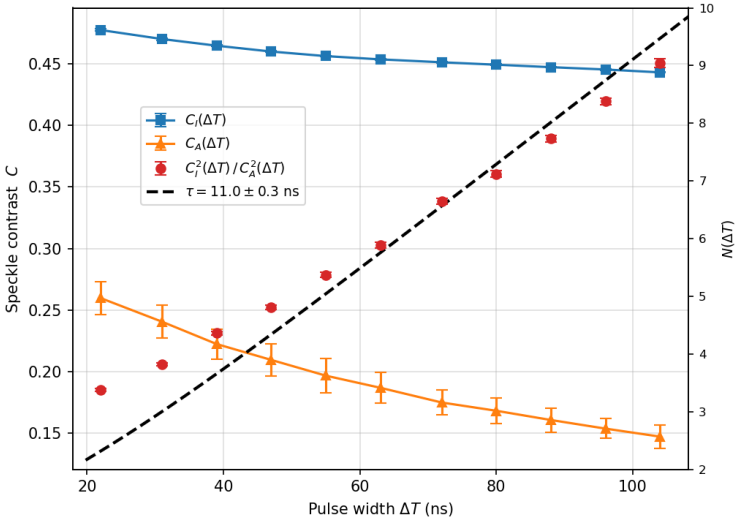
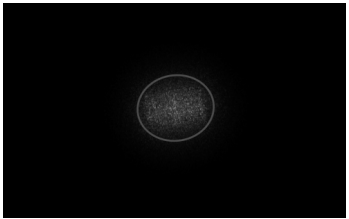
Continuous time model for $N(\Delta T)$



Assuming $N(\Delta T) = (\Delta T/\tau) \,/\, (1 - e^{-\Delta T/\tau})$.

Aperture differences between DM Inactive and DM Active



$\Delta T = 22\,\text{ns}$, *DM Inactive*,
$R_I(\Delta T) = 197$ *pixels*.

$\Delta T = 22\,\text{ns}$, *DM Active*,
$R_A(\Delta T) = 489$ *pixels*.

Contrast for □5.86 m *pixels*
100 mm *from diffuser.*

- Speckle grain size $\propto 1/R$ so different radii result in different speckle contrast.
- Another model parameter needed to account for $R_I(\Delta T)$ / $R_A(\Delta T) \neq 1$.

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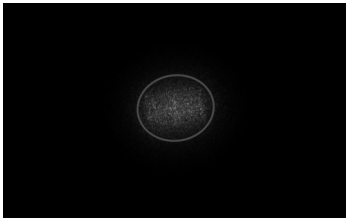

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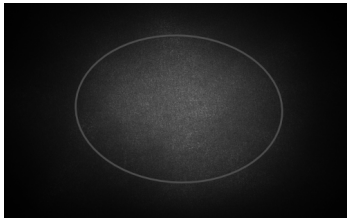

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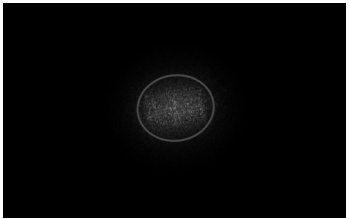

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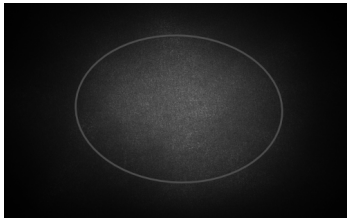

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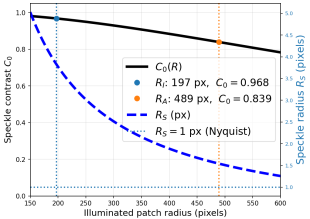

Contrast for □5.86 µm *pixels*
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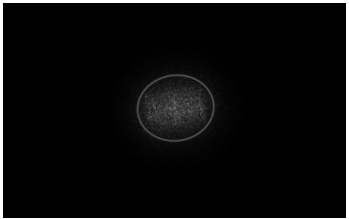

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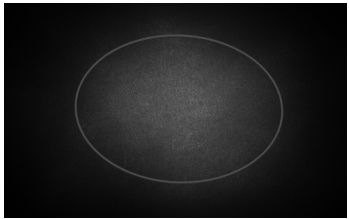

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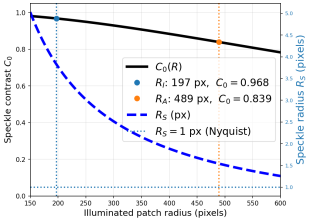

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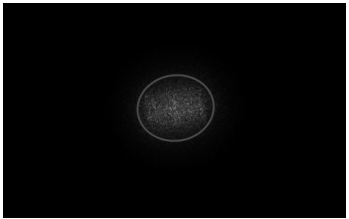

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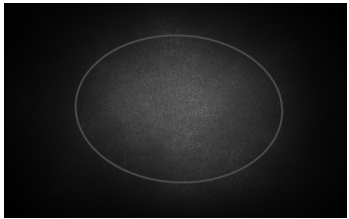

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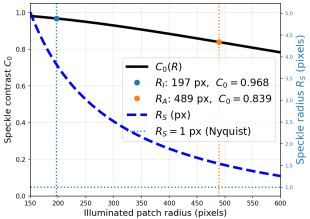

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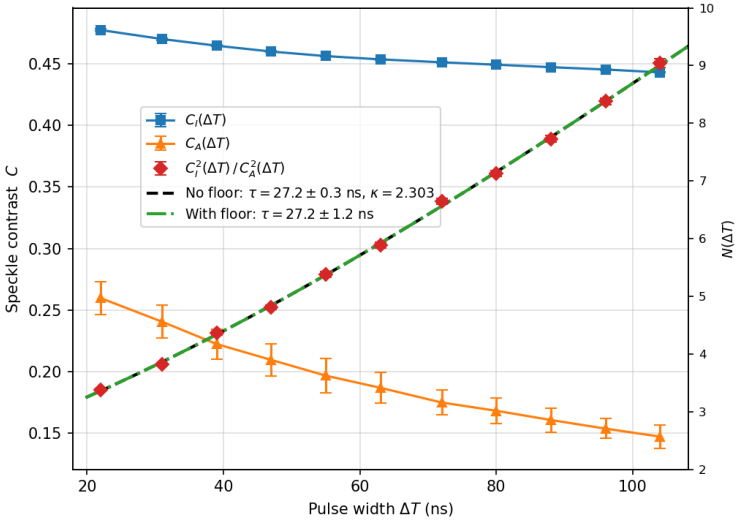
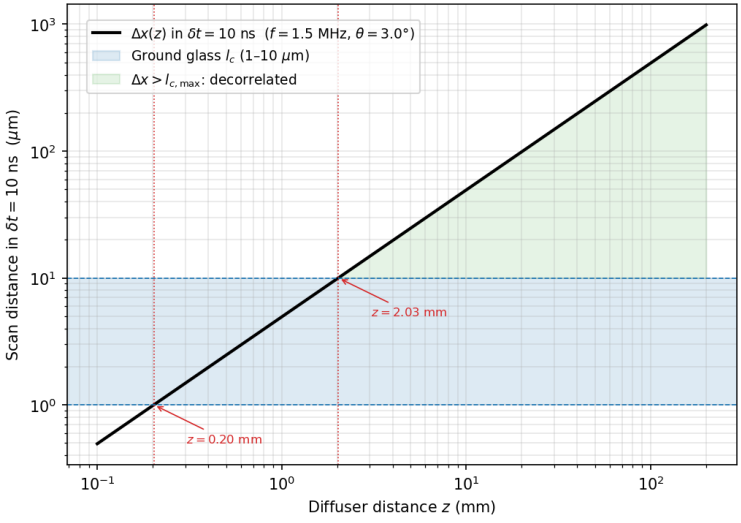
Spatial and continuous time model for $N(\Delta T)$



Assuming $N(\Delta T) = \kappa\,(\Delta T/\tau)\,/\,(1 - e^{-\Delta T/\tau})$.

DM to diffuser distance for decorrelation



Assuming $\delta t = \Delta T / N(\Delta T) \approx 10\,\text{ns}$.

Conclusions

- $N(\Delta T) = \kappa\,(\Delta T/\tau)\,/\,(1 - e^{-\Delta T/\tau})$ is a good fit to observed $C_I^2(\Delta T)/C_A^2(\Delta T)$.
- 10 µm decorrelation distance in $\Delta T/N(\Delta T) \approx 10$ ns is possible at $z > 2$ mm.
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Thank you!

Feel free to contact me to discuss:

fshevlin@dyoptyka.com