# Speckle reduction within nanosecond-order pulse widths for flash lidar applications

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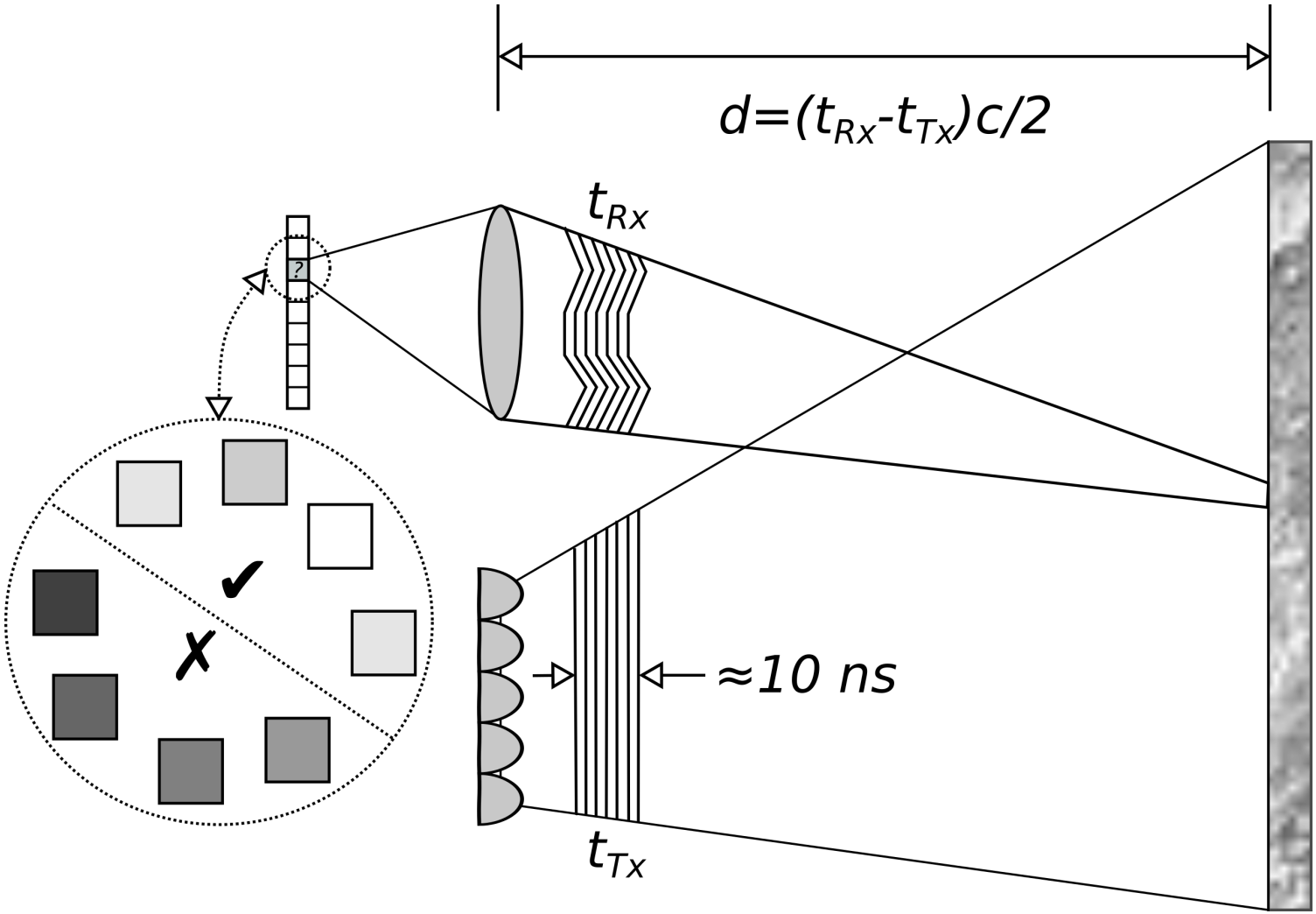
*Laser Display and Lighting Conference 2020*
*Yokohama, Japan.*

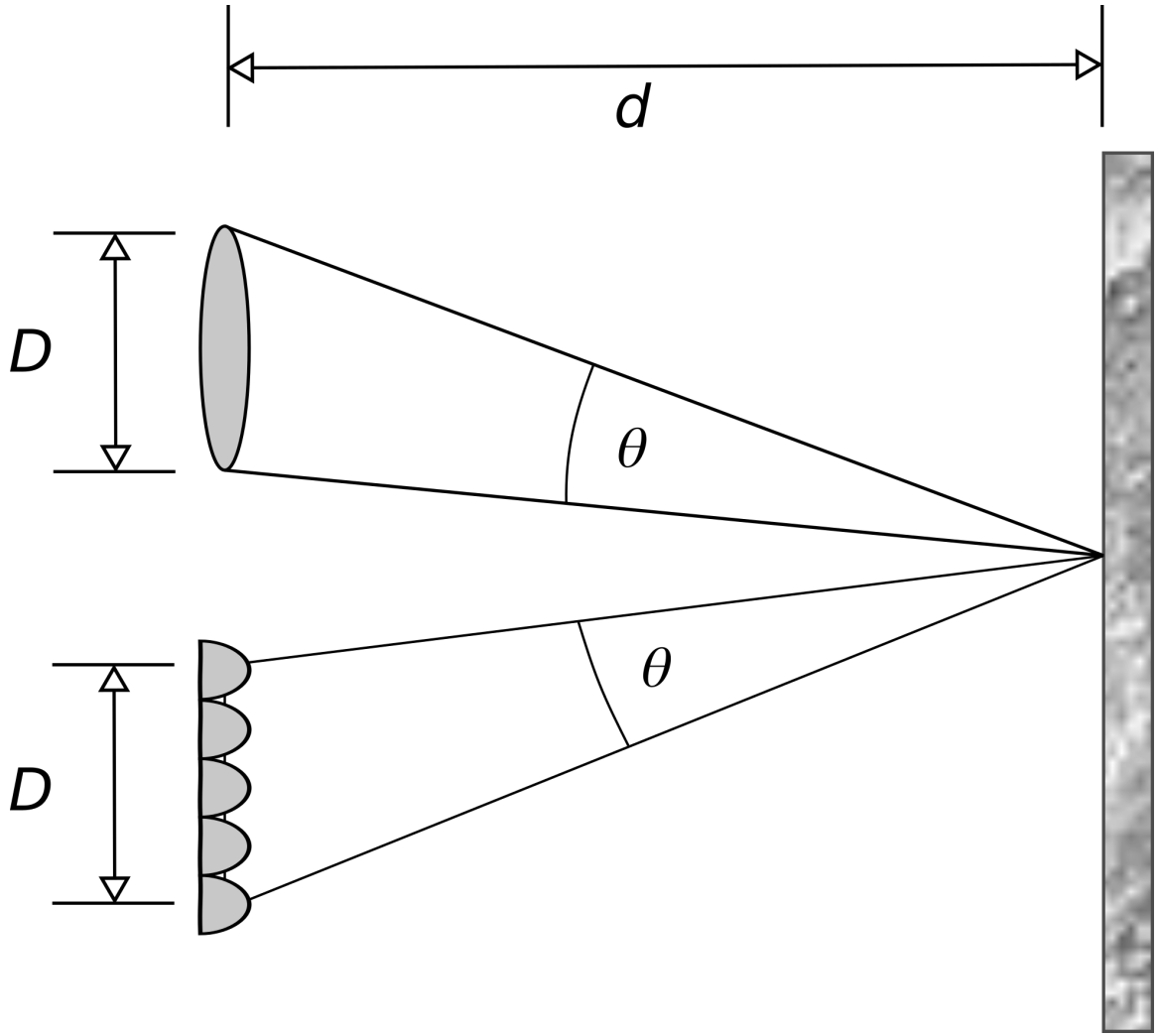
2020-04-21

# Direct time-of-flight systems



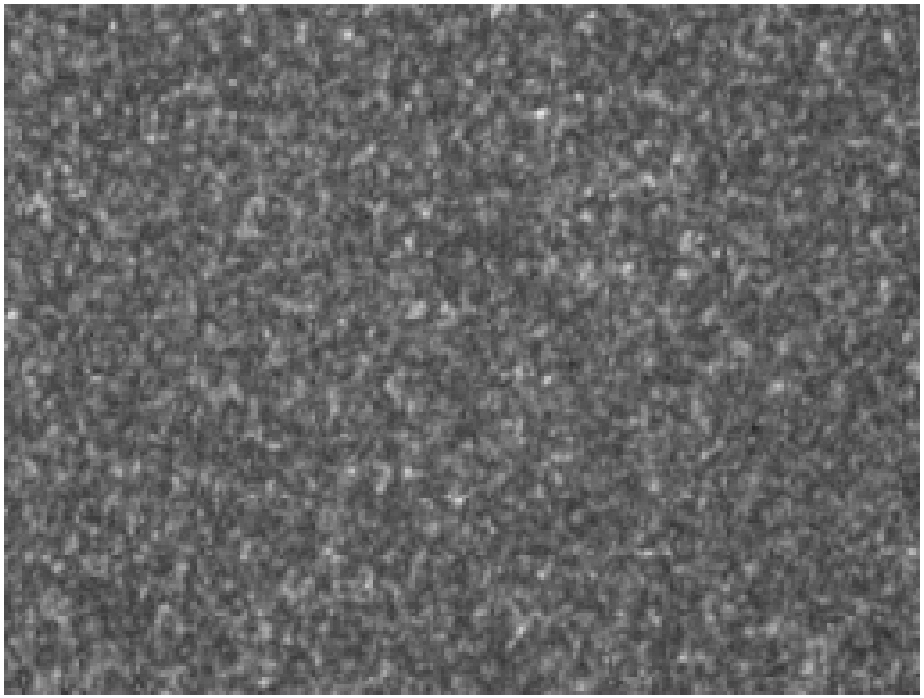

*Dark speckle causes non-detection of Rx pulse at some pixels.*

# VCSEL array sources

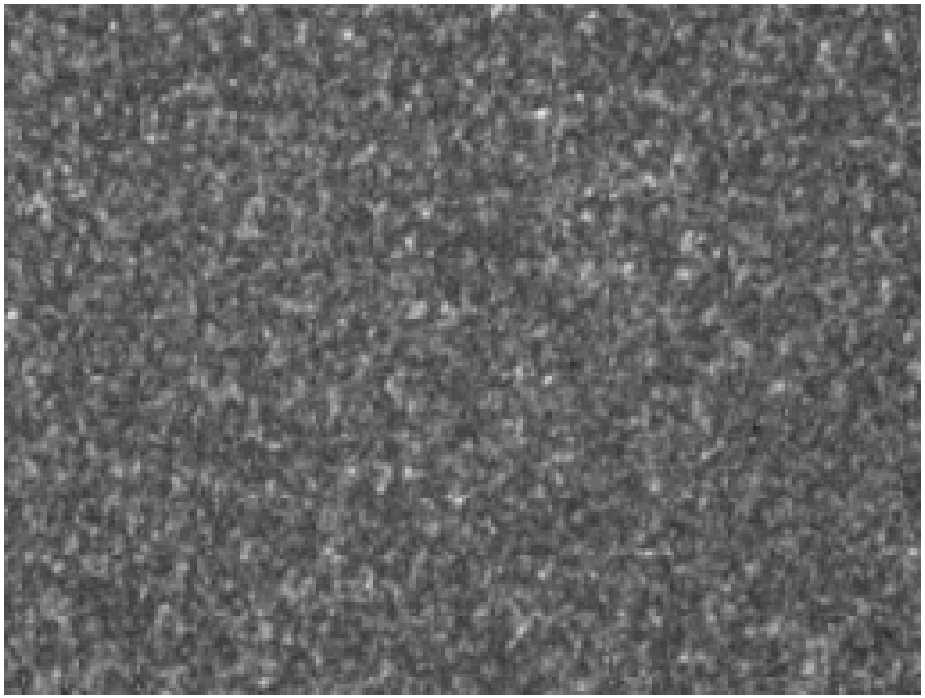



*Array dimensions similar to camera pupil diameter.*

# Speckle with *insufficient angular separation* of sources

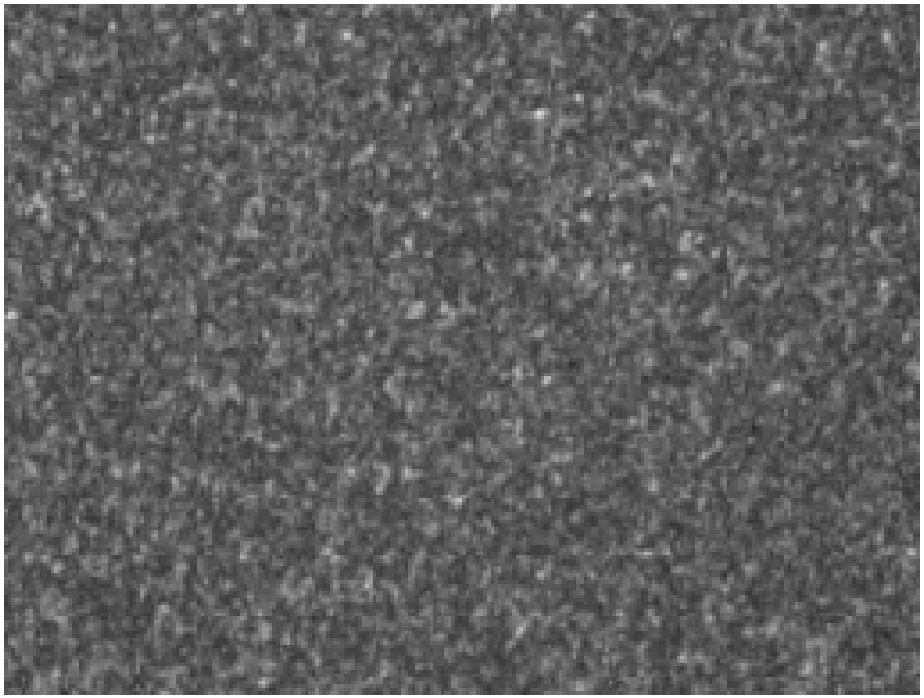


*Single* 22 ns *pulse image*,
$C_S \approx 24\%$.

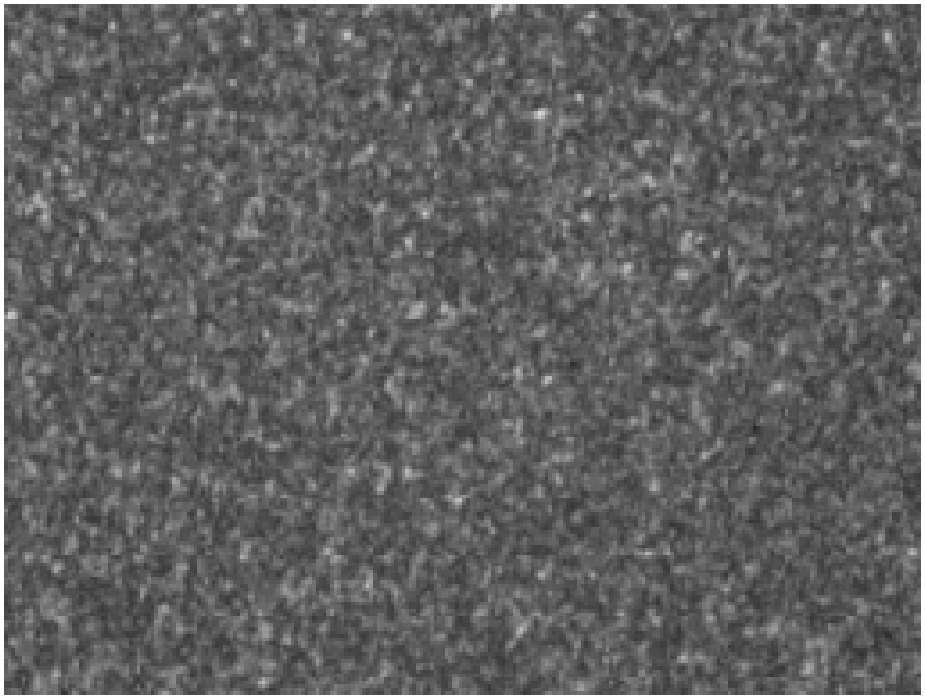


*Mean of* 100 *different* 22 ns *pulse images*,
$C_S \approx 24\%$.

# Speckle with *insufficient angular separation* of sources

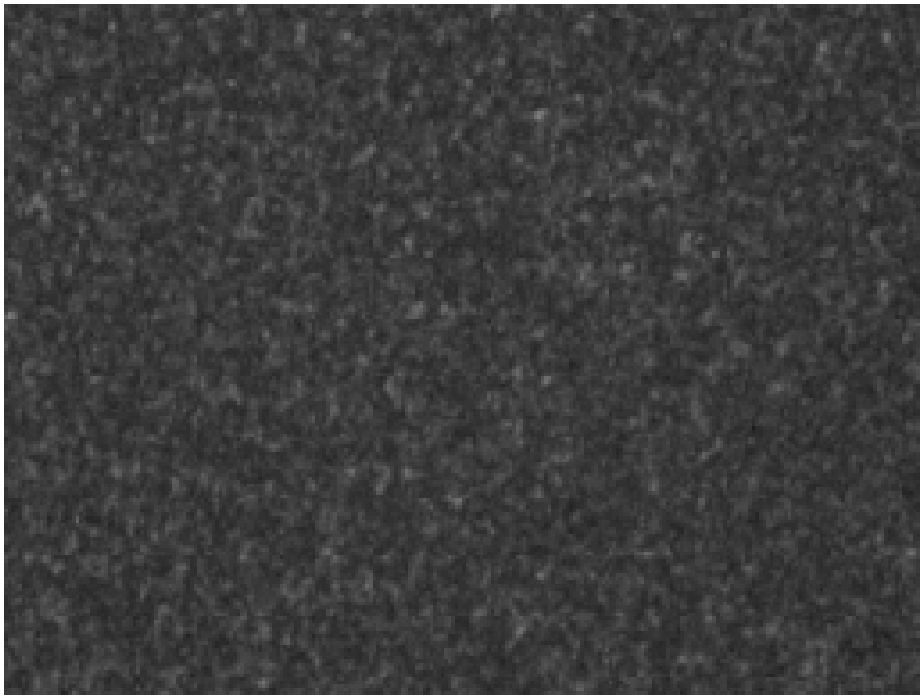


*Single* 14 ns *pulse image*,
$C_S \approx 24\%$.

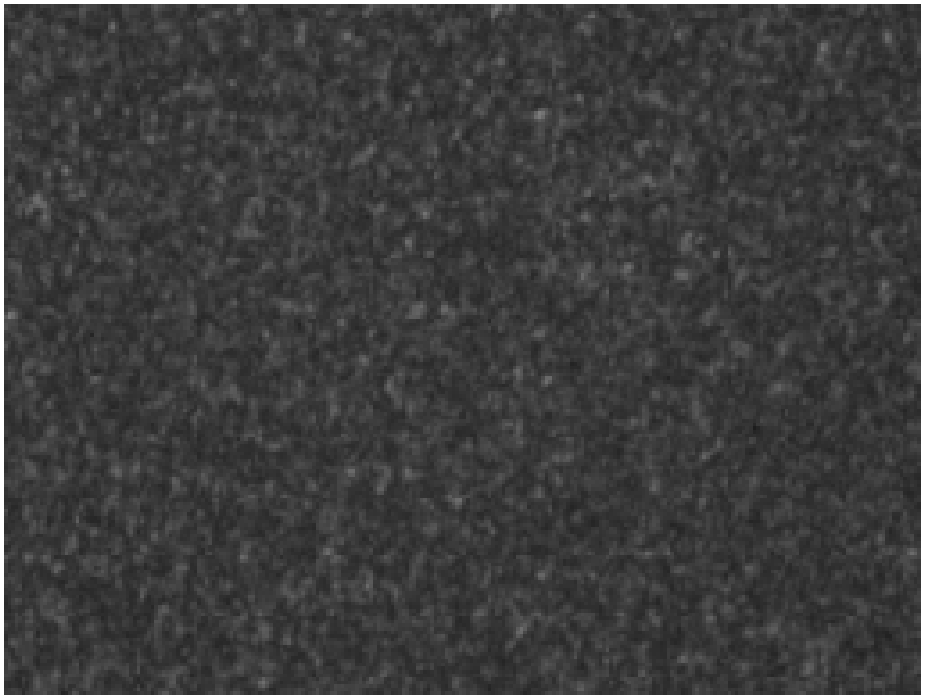


*Mean of* 100 *different* 14 ns *pulse images*,
$C_S \approx 24\%$.

# Speckle with *insufficient angular separation* of sources

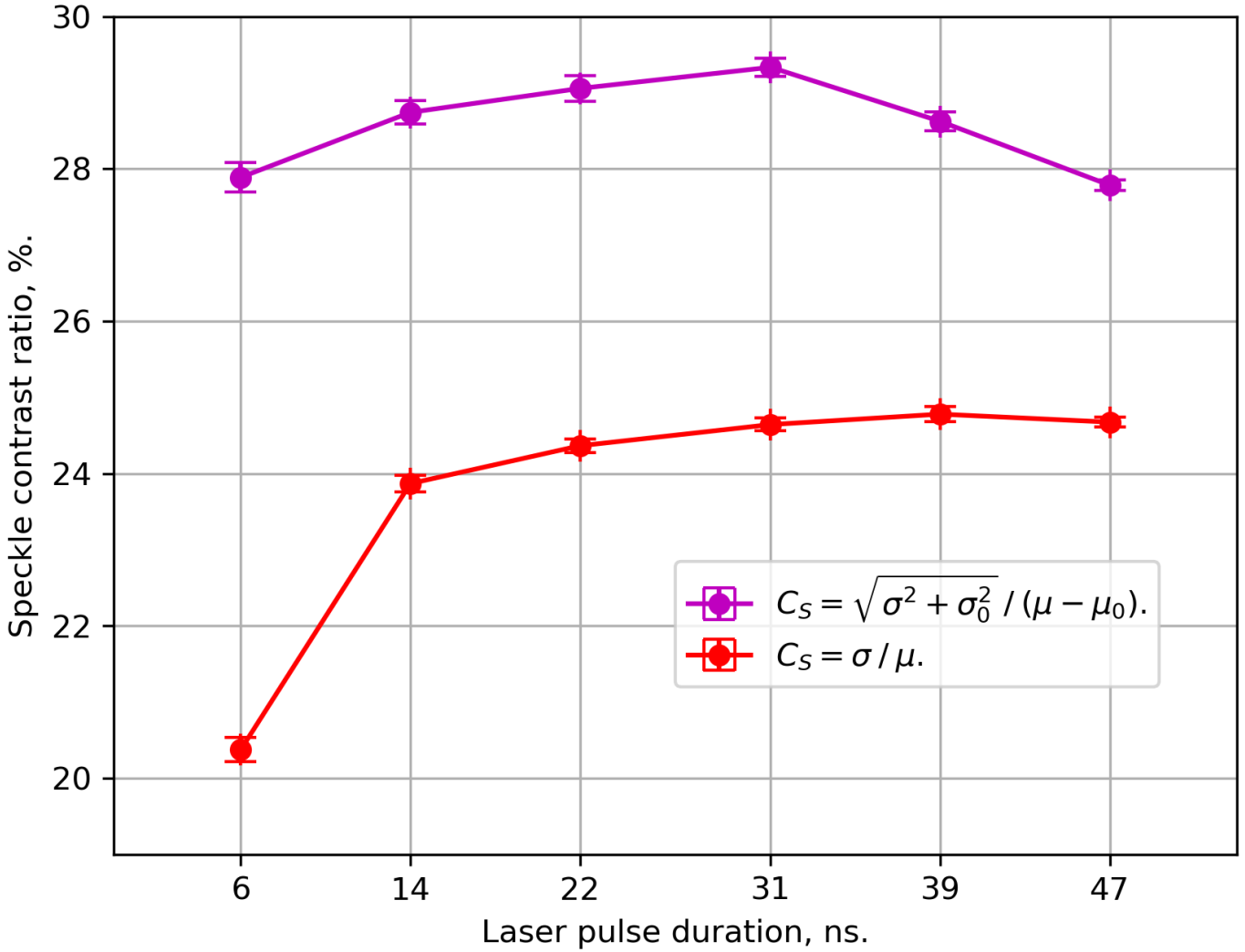


*Single* 6 ns *pulse image*,
$C_S \approx 20\%$.



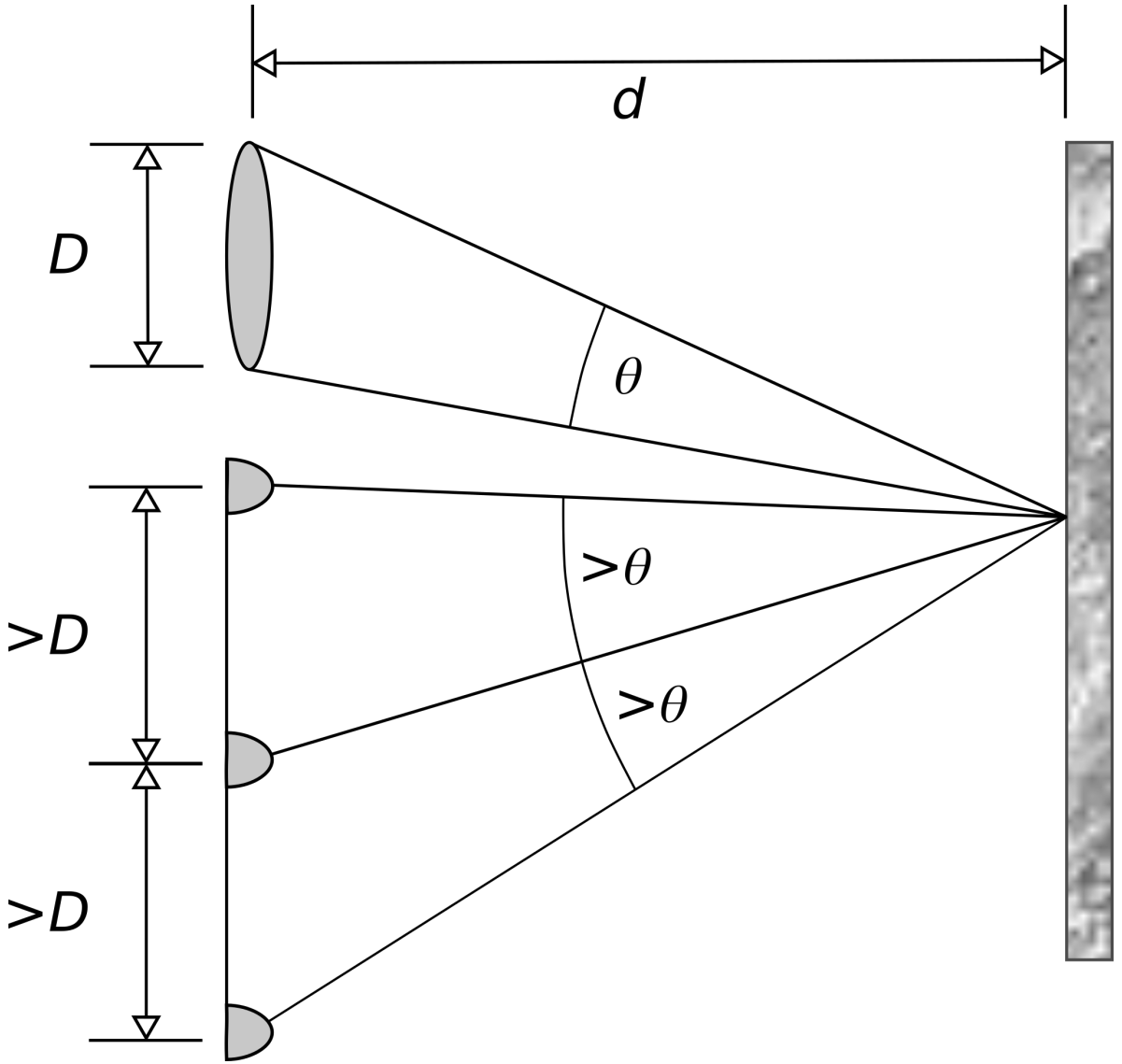
*Mean of* 100 *different* 6 ns *pulse images*,
$C_S \approx 20\%$.

# Speckle with *insufficient angular separation* of sources



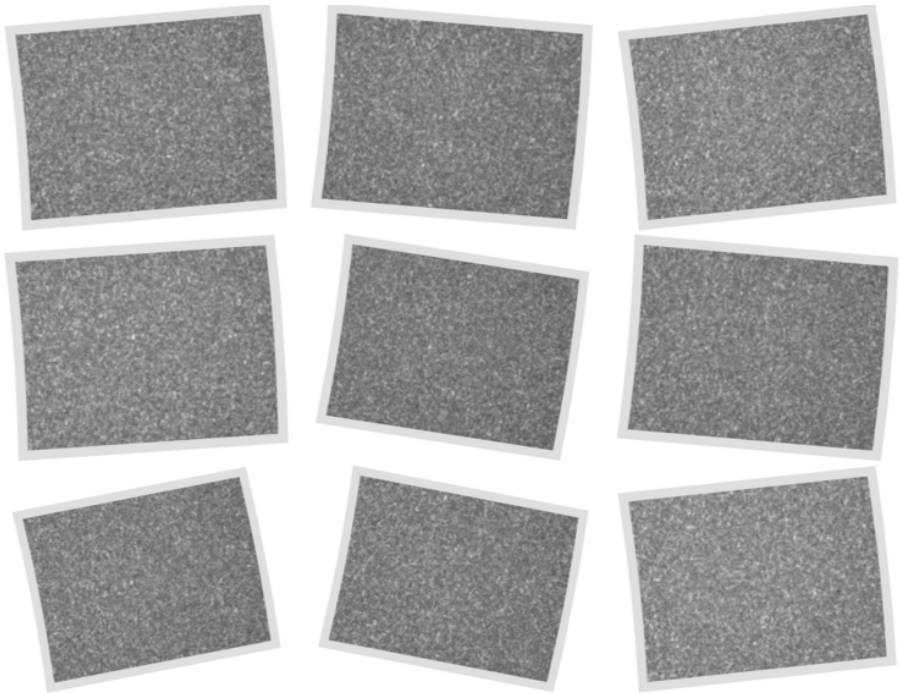

*$C_S$ for 100 different pulse images of each duration.*

# Alternative source configuration

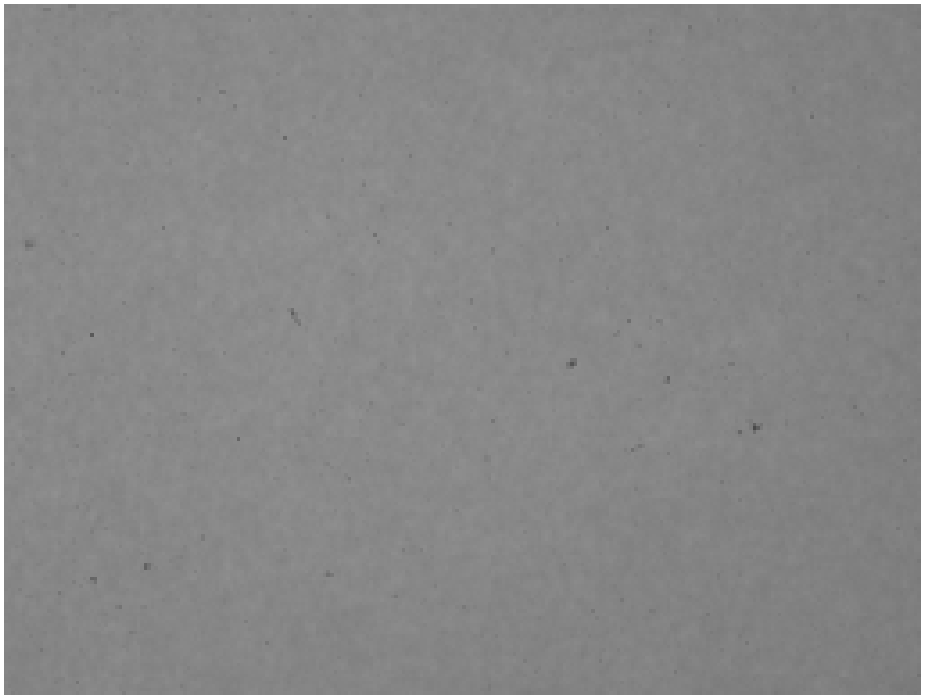



*Source separation greater than camera pupil diameter.*

# Speckle with *sufficient angular separation* of sources

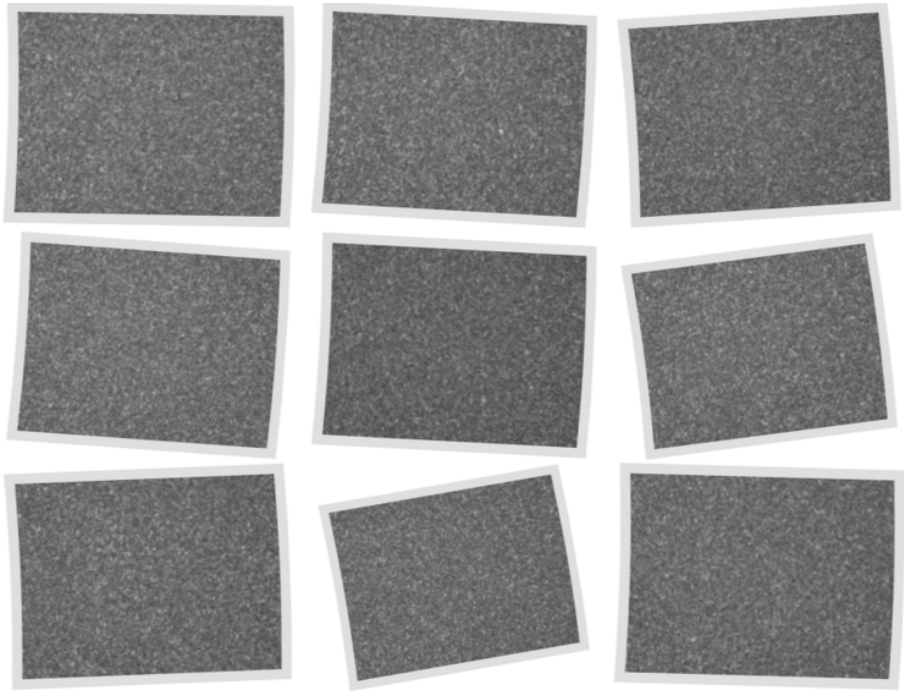


*Different* 22 ns *pulse images,*
$C_S \approx 24\%$.

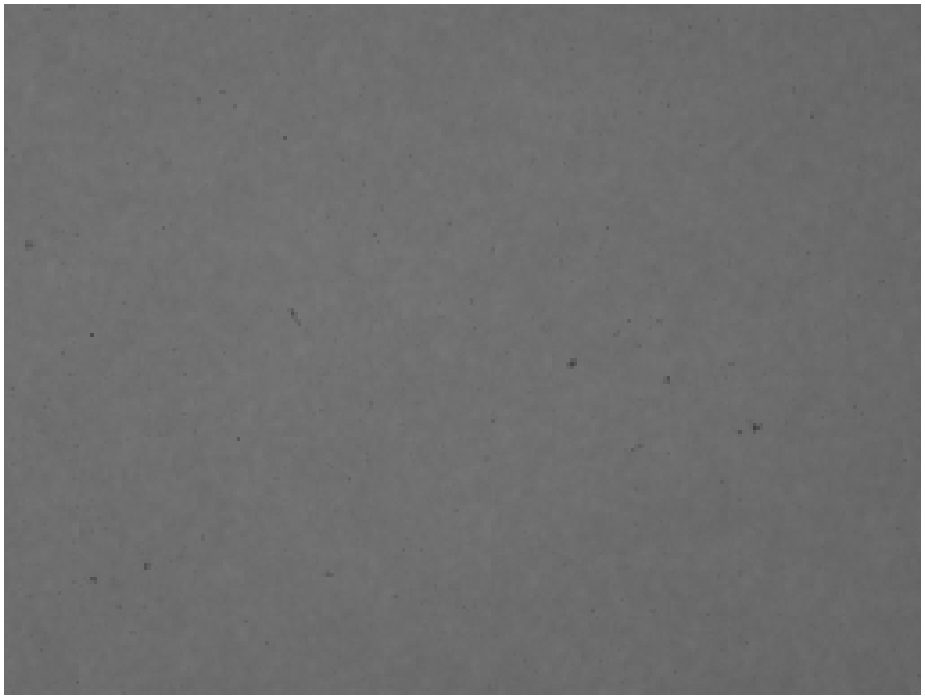


*Mean of* 100 *different* 22 ns *pulse images,*
$C_S \approx 3\%$.

# Speckle with *sufficient angular separation* of sources

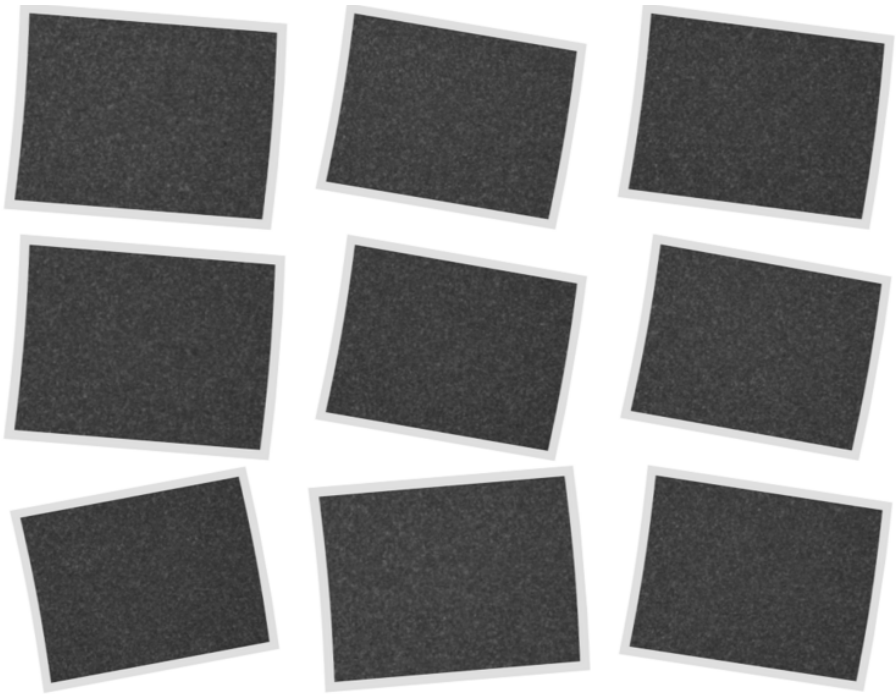


*Different* 14 ns *pulse images*,
$C_S \approx 24\%$.

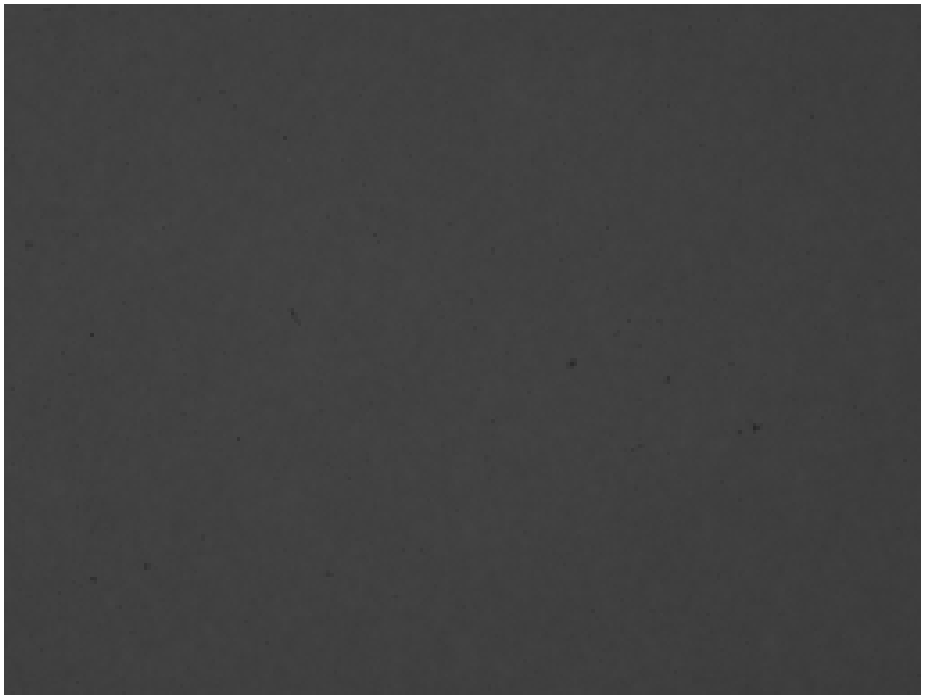


*Mean of* 100 *different* 14 ns *pulse images*,
$C_S \approx 4\%$.

# Speckle with *sufficient angular separation* of sources

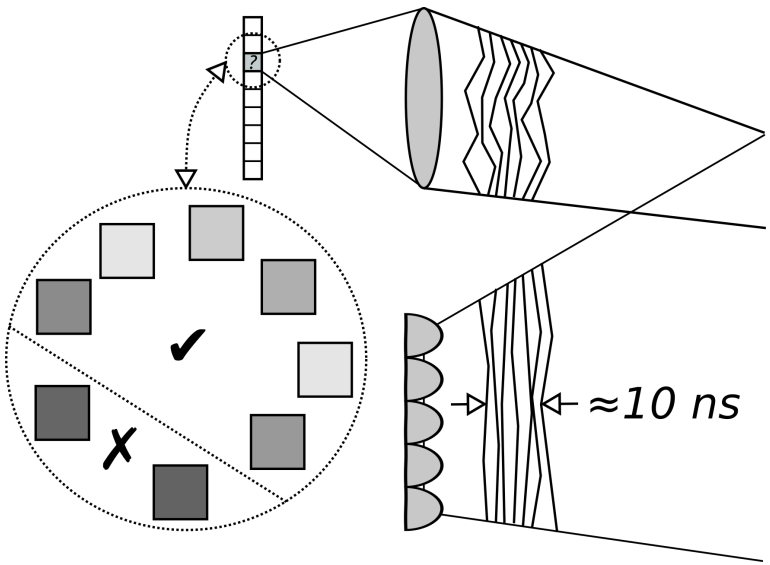


*Different* 6 ns *pulse images,*
$C_S \approx 20\%$.



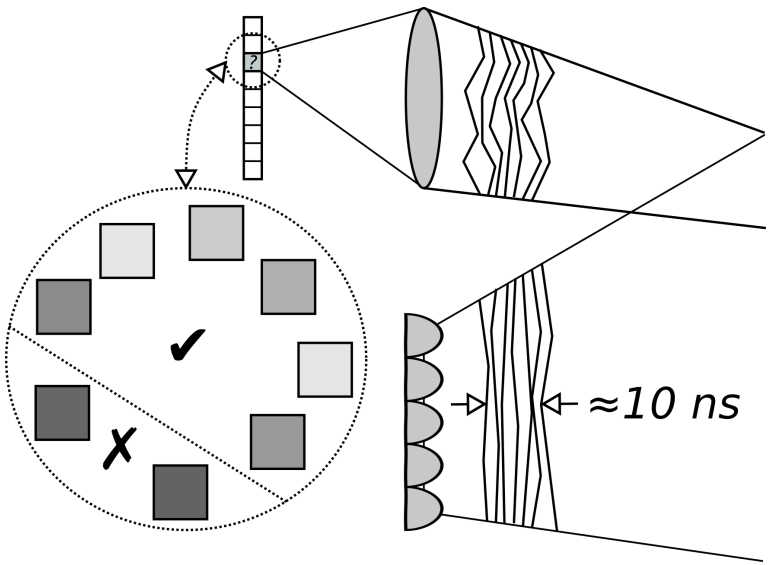
*Mean of* 100 *different* 6 ns *pulse images,*
$C_S \approx 3\%$.

# Speckle reduction *within* single pulse durations

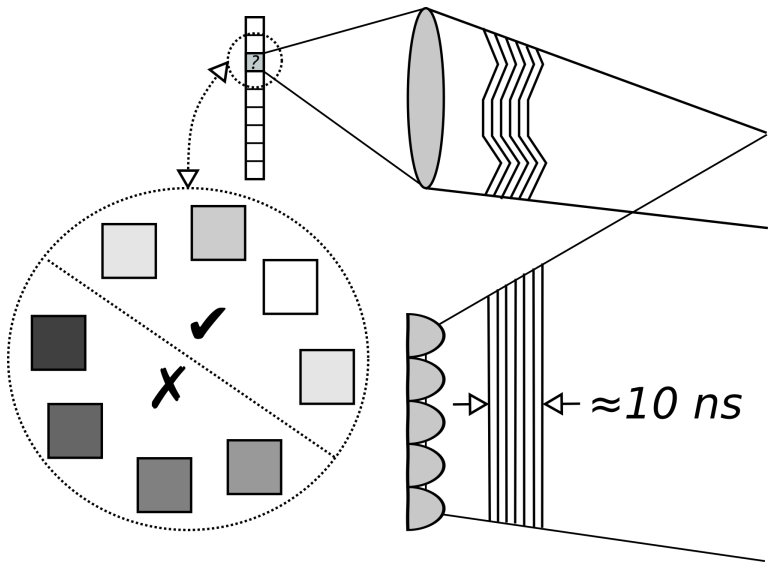



*Randomize $T_X$ pulse wavefronts so that $R_X$ wavefronts less correlated.*

# Speckle reduction *within* single pulse durations

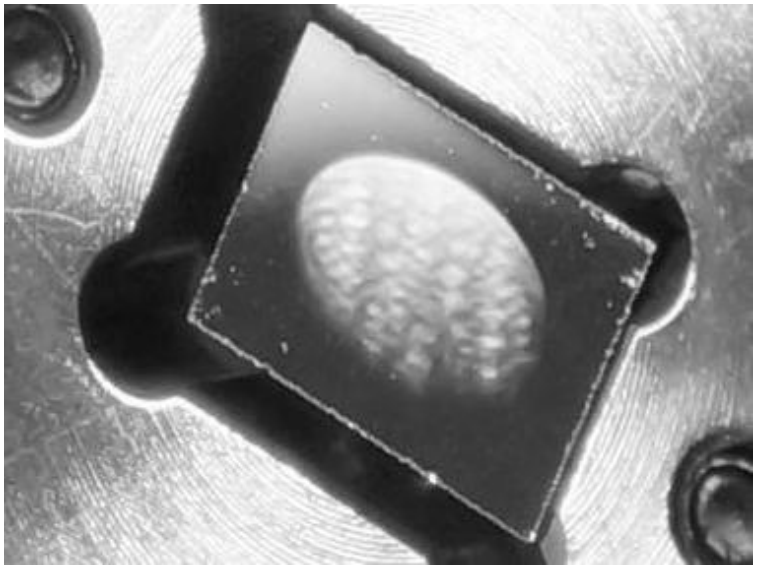



*Randomize $T_X$ pulse wavefronts so that $R_X$ wavefronts less correlated.*



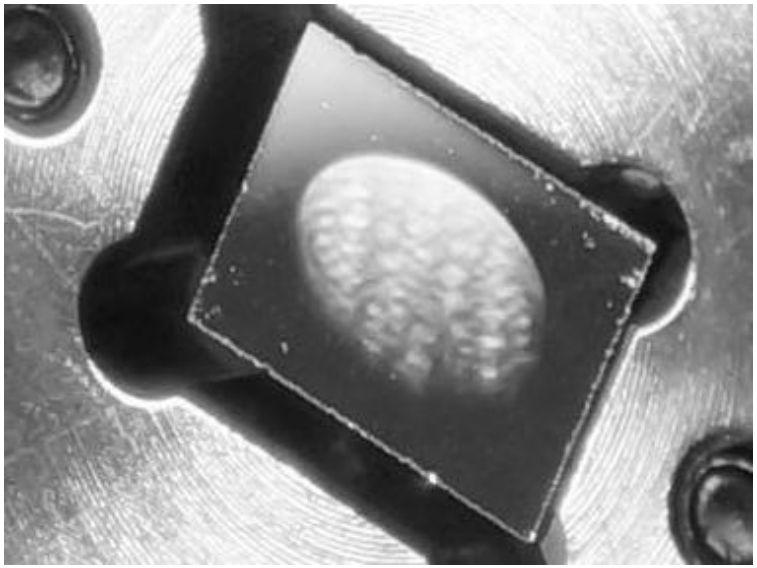

*$R_X$ pulse wavefronts highly correlated to rough surface.*

# DYOPTYKA deformable mirror

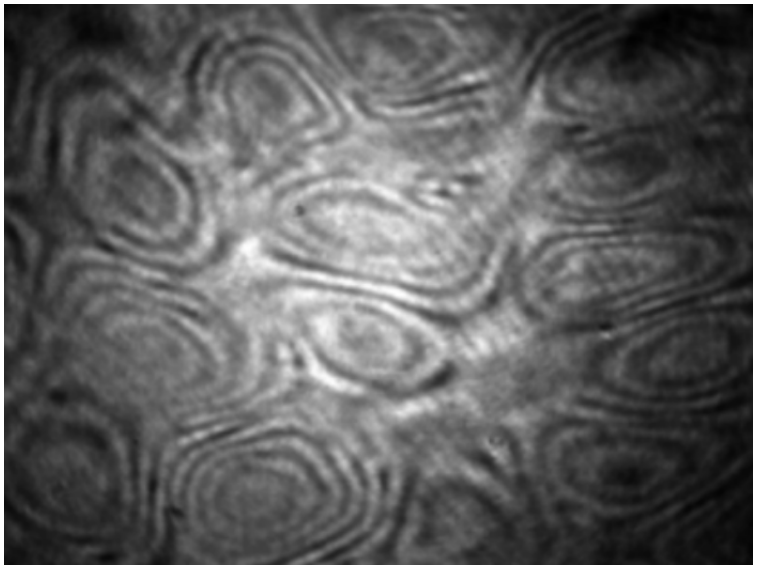


*Randomly-distributed surface deformations at frequencies up to tens of* MHz*.*

# DYOPTYKA deformable mirror

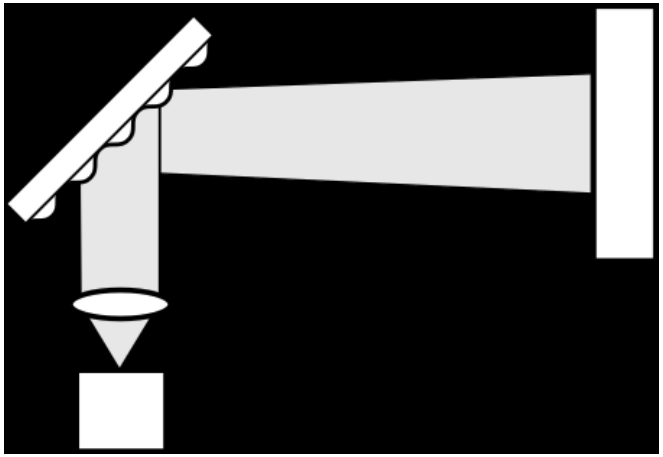


*Randomly-distributed surface deformations at frequencies up to tens of* MHz*.*



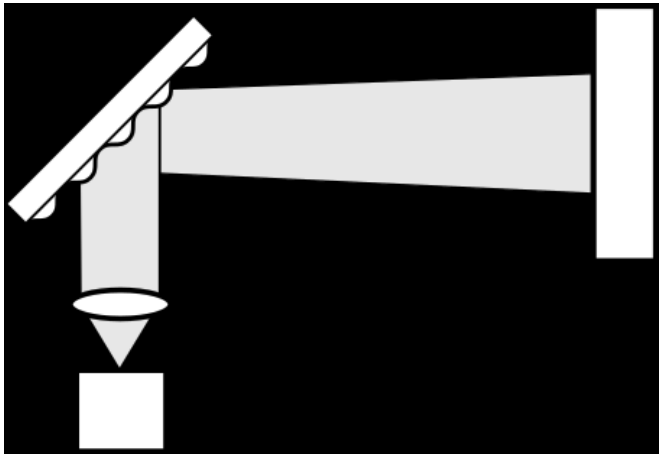
*Microscope interferometer fringes resulting from convex and concave surface deformations.*

# Apparatus configuration #1

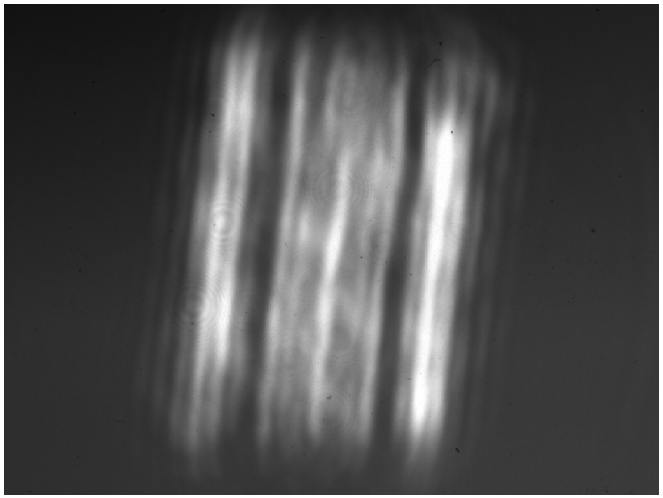


*LD, DM, BP.*

# Apparatus configuration #1

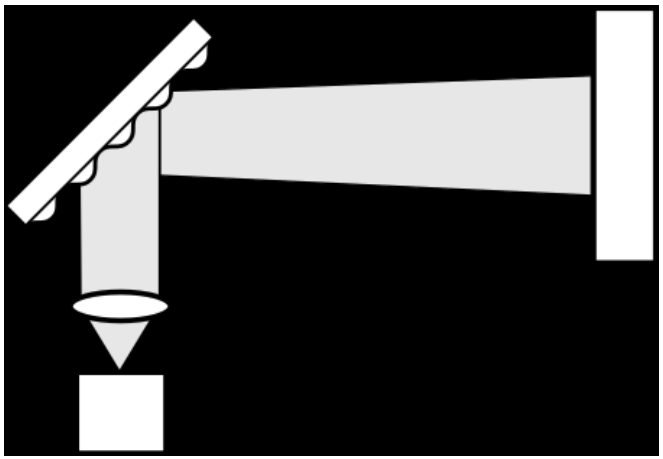


*LD, DM, BP.*

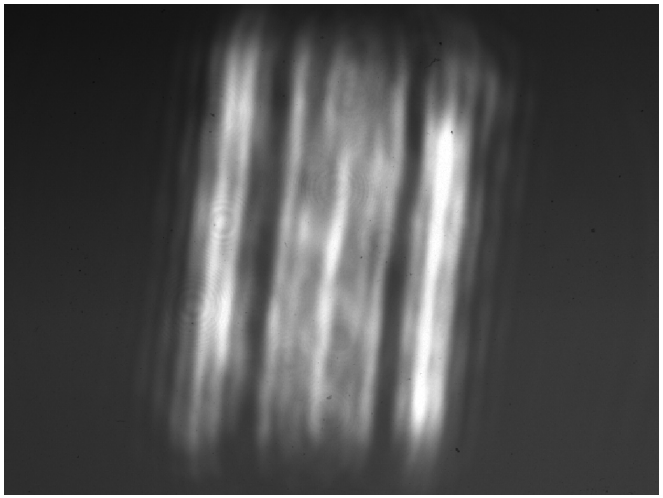


*LD emission, DM inactive.*

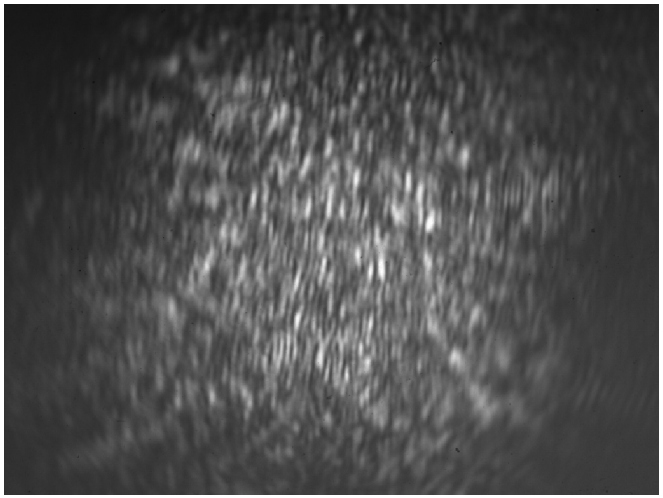
# Apparatus configuration #1



*LD, DM, BP.*

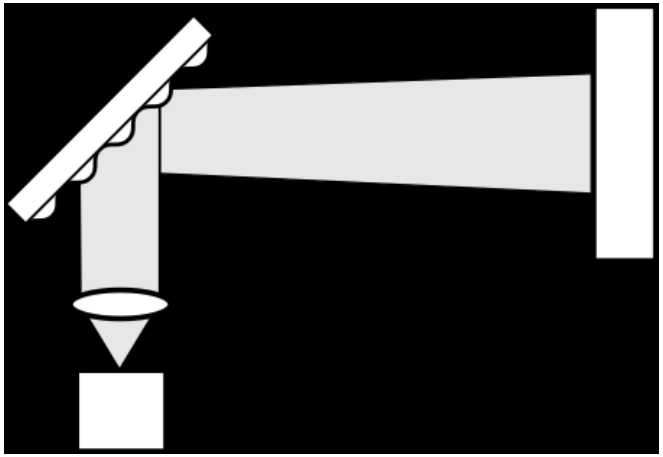


*LD emission, DM inactive.*

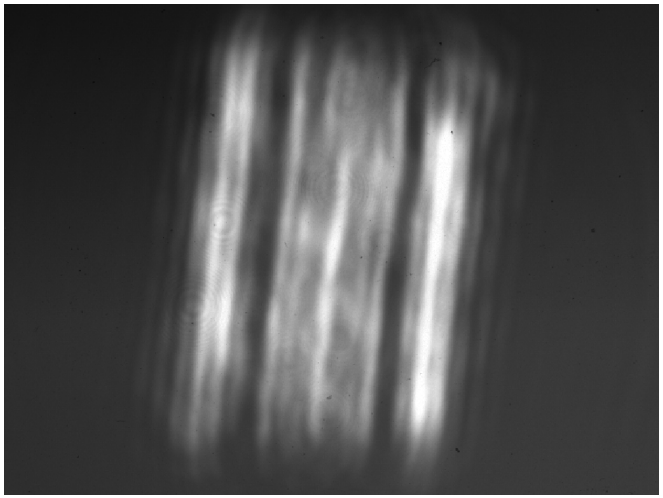


*LD* 6 ns *pulse, DM active.*

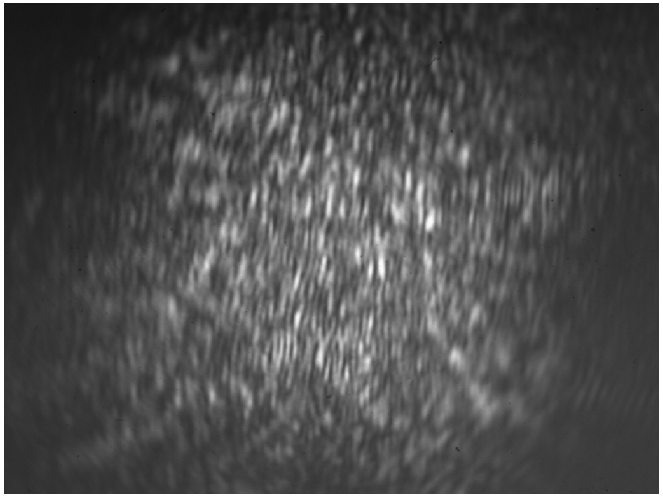
# Apparatus configuration #1



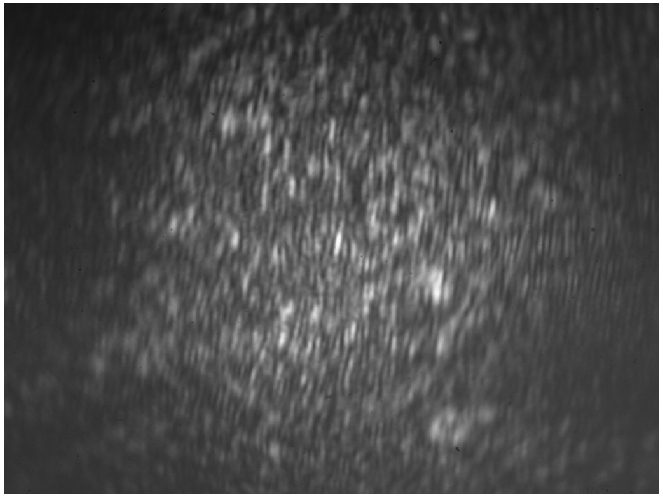
*LD, DM, BP.*



*LD emission, DM inactive.*

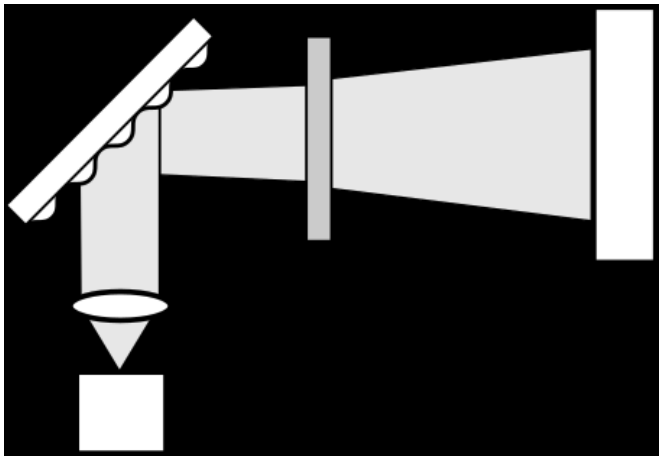


*LD* 6 ns *pulse, DM active.*



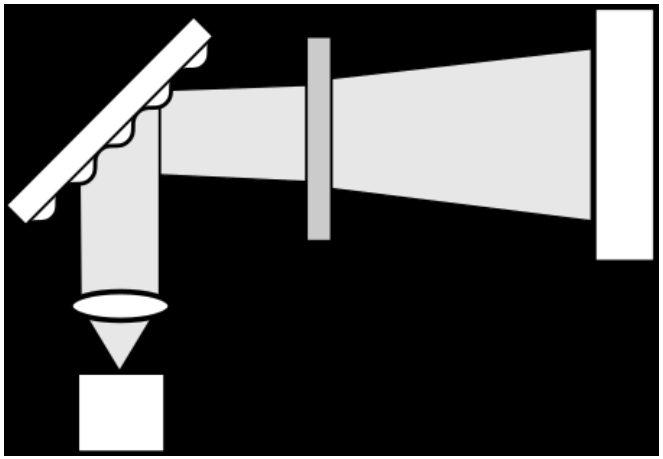
*LD* 6 ns *pulse, DM active.*

# Apparatus configuration #2

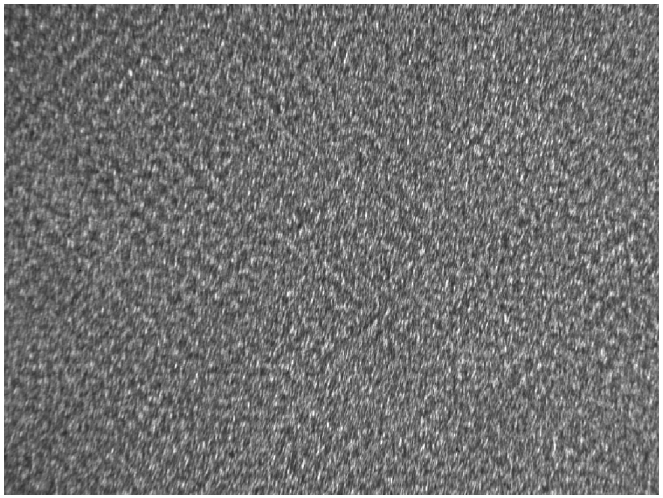


*LD, DM, ED, BP.*

# Apparatus configuration #2

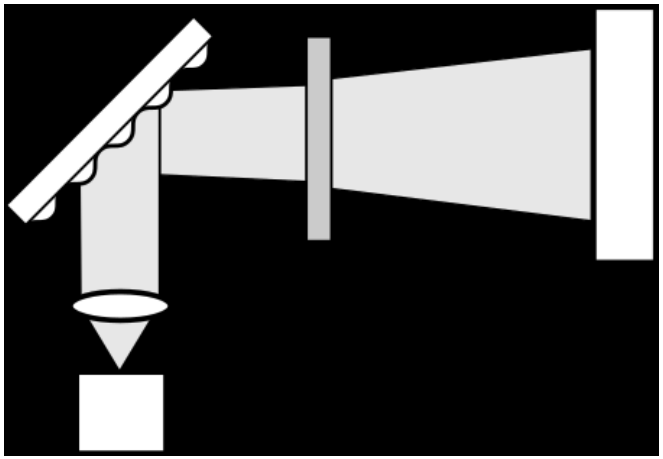


*LD, DM, ED, BP.*

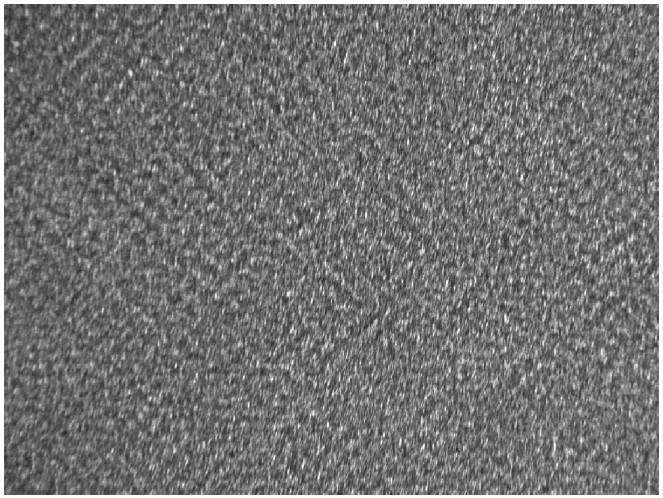


*ED pattern, DM inactive.*

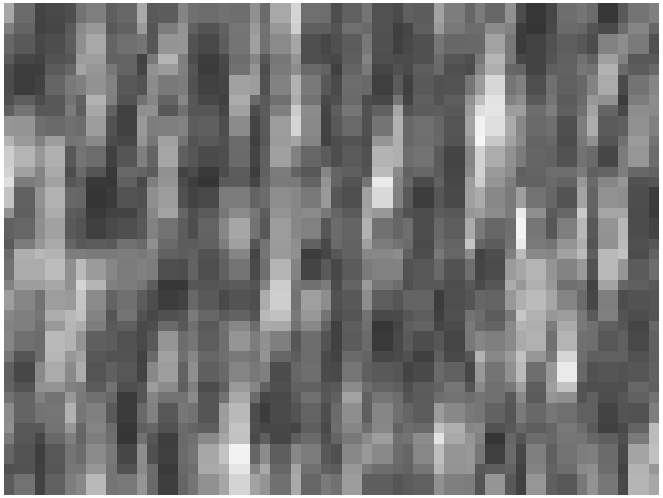
# Apparatus configuration #2



*LD, DM, ED, BP.*

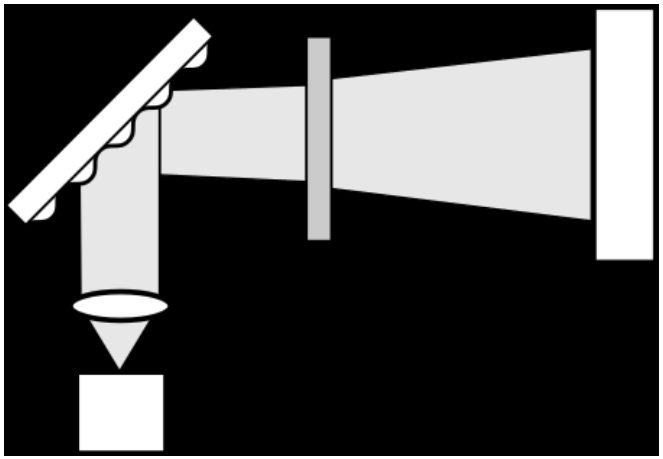


*ED pattern, DM inactive.*

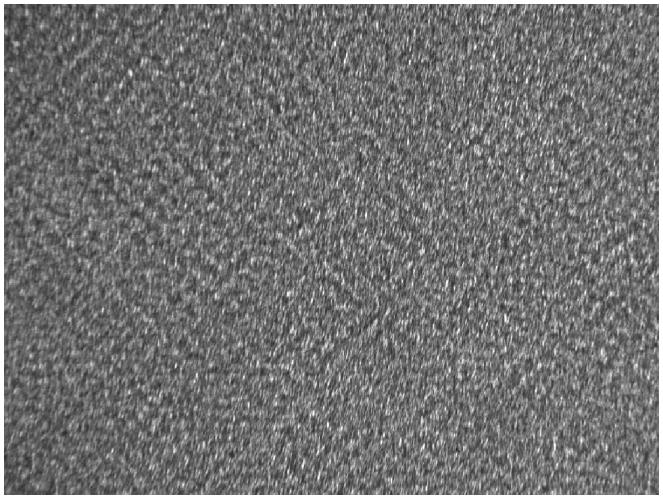


*Region,* 6 ns *pulse, DM inactive.*

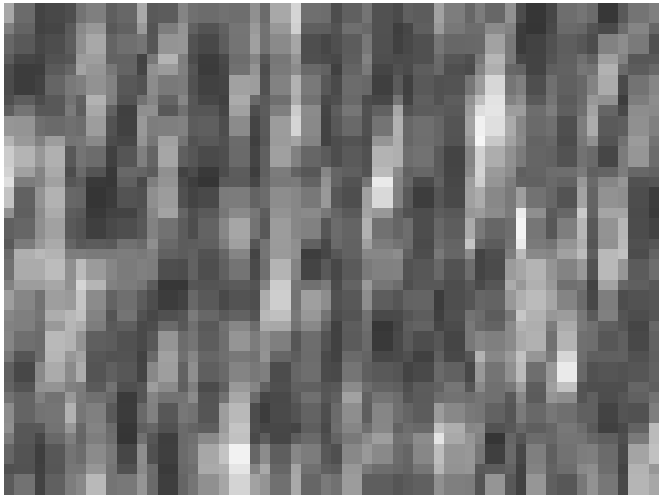
# Apparatus configuration #2



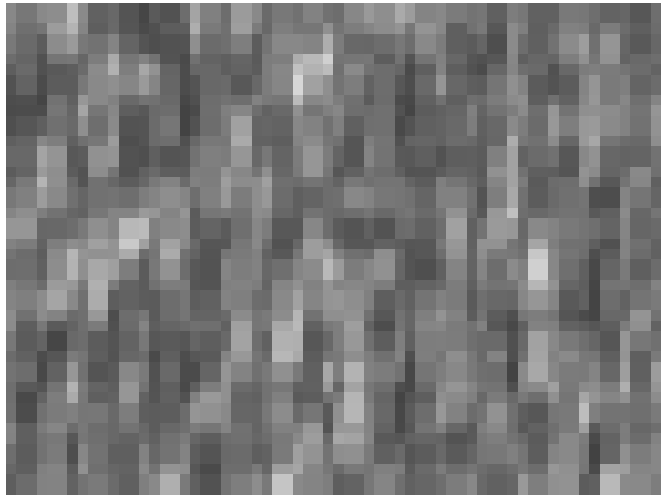
*LD, DM, ED, BP.*



*ED pattern, DM inactive.*

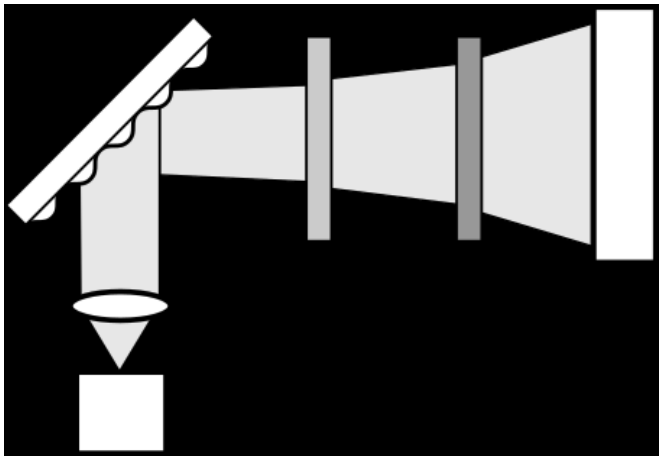


*Region,* 6 ns *pulse, DM inactive.*



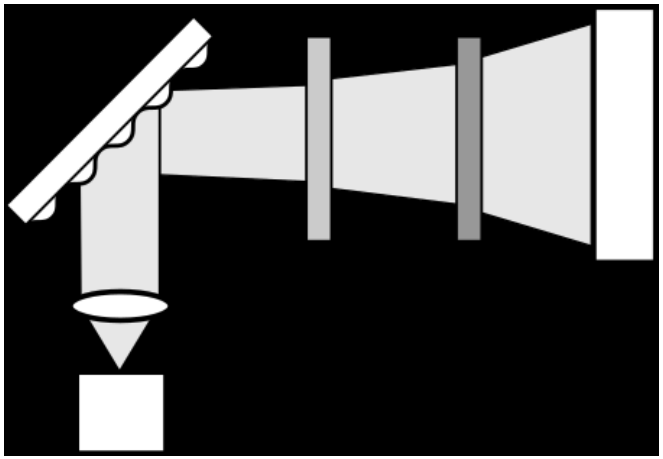
*Region,* 6 ns *pulse, DM active.*

# Apparatus configuration #3

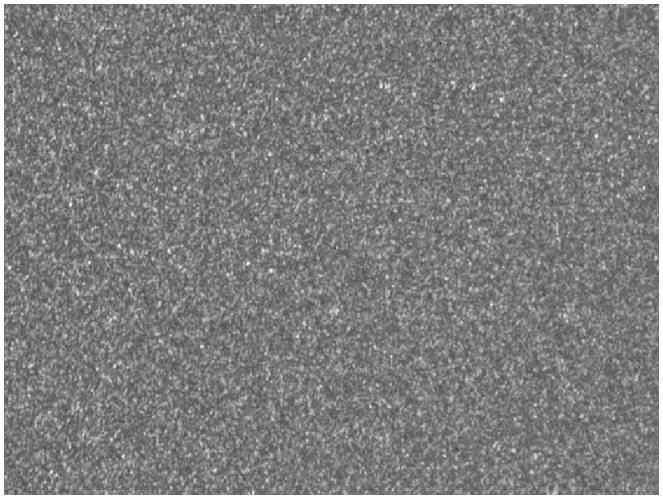


*LD, DM, ED, GG, BP.*

# Apparatus configuration #3

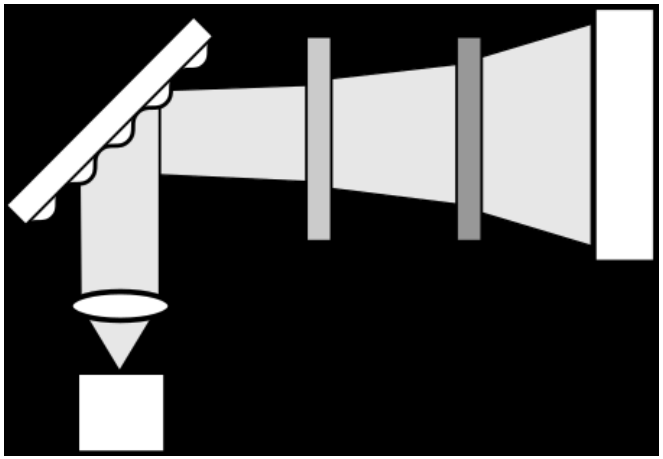


*LD, DM, ED, GG, BP.*

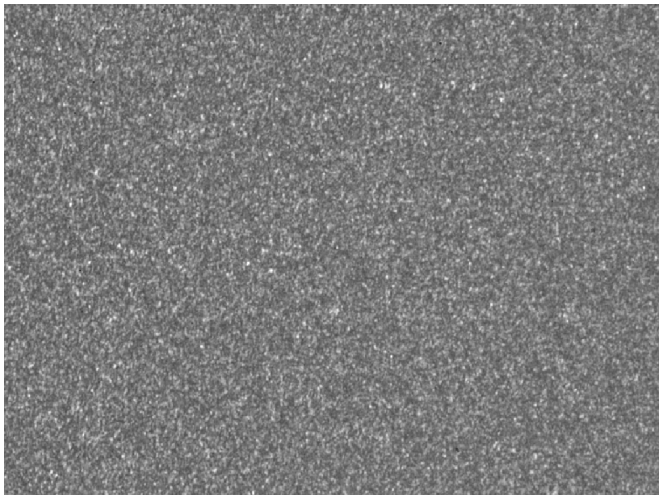


*GG pattern, DM inactive.*

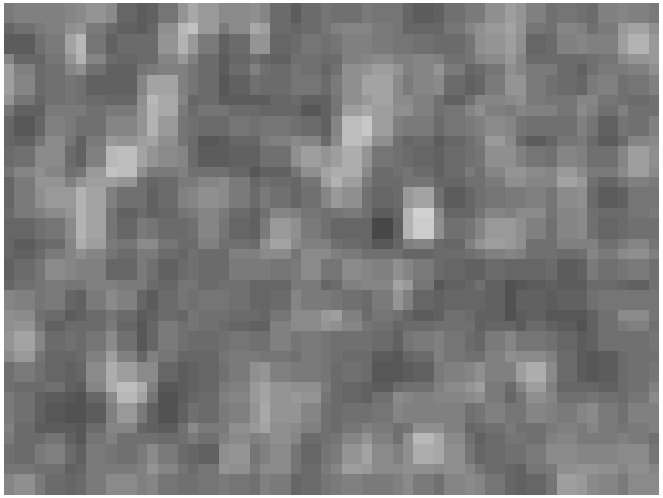
# Apparatus configuration #3



*LD, DM, ED, GG, BP.*



*GG pattern, DM inactive.*



*LD* 6 ns *pulse, DM inactive.*

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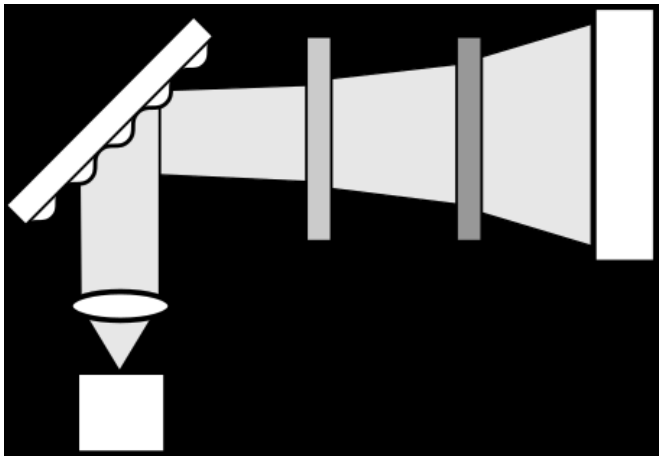

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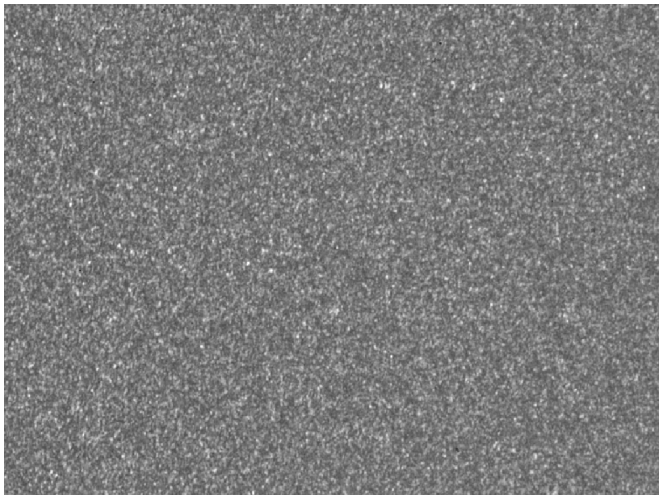
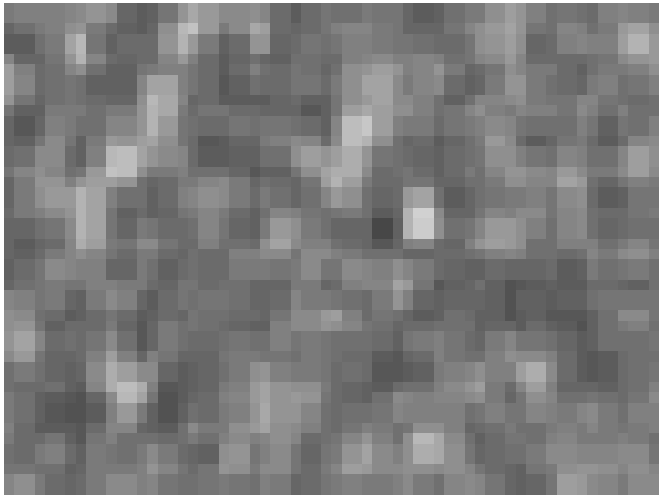
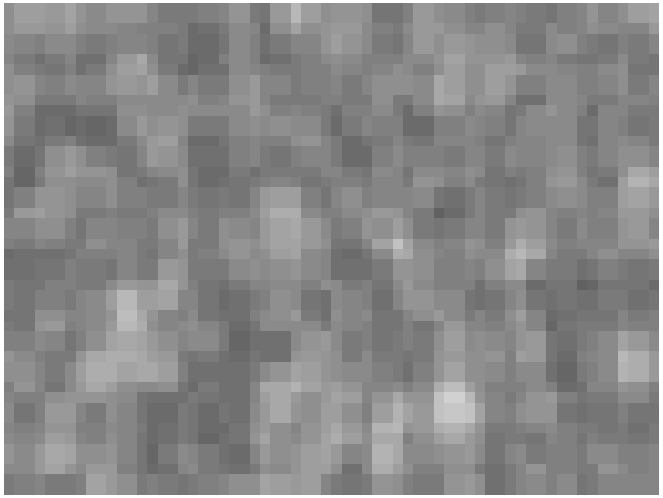


*GG pattern, DM inactive.*

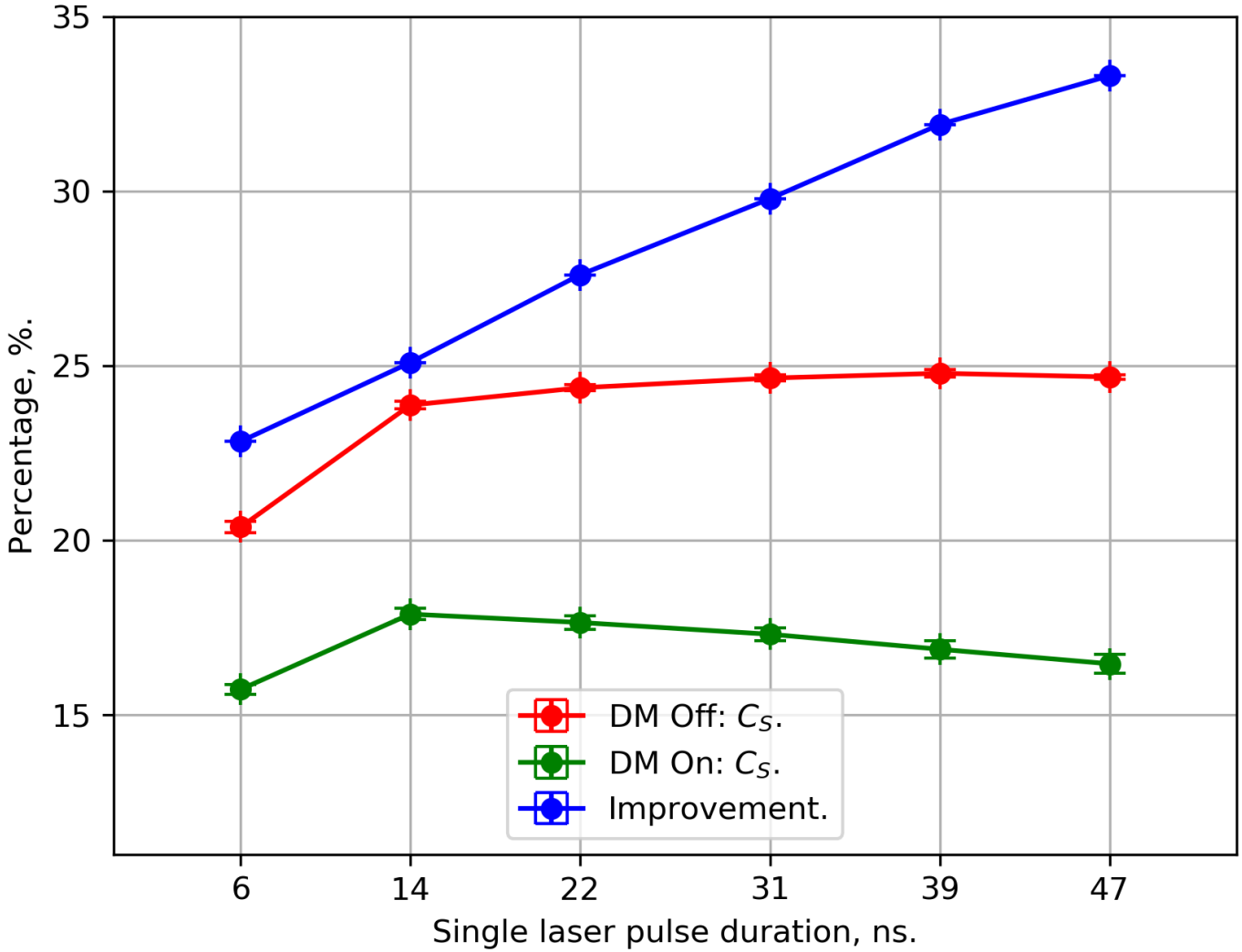


*LD* 6 ns *pulse, DM inactive.*



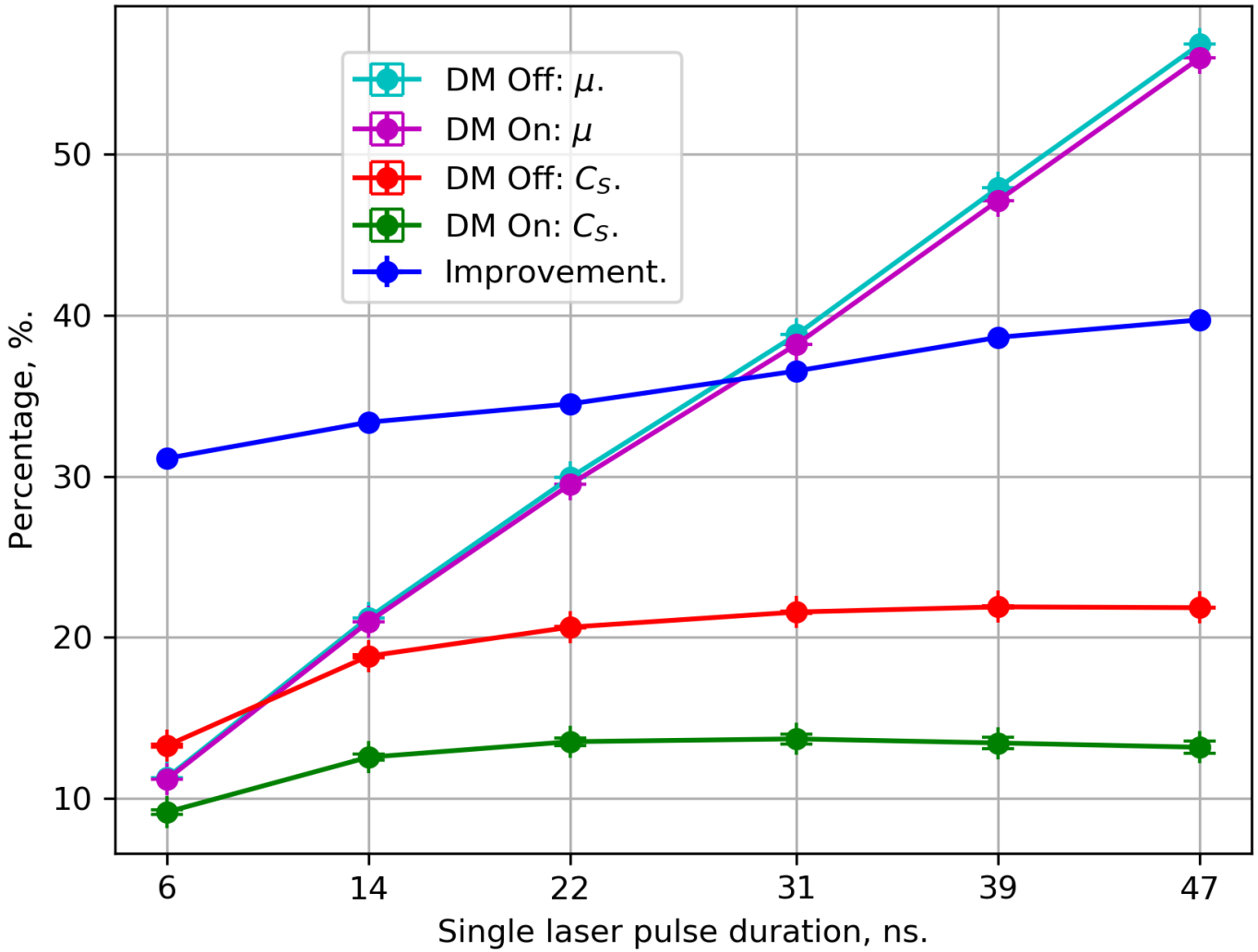
*LD* 6 ns *pulse, DM active.*

# Speckle reduction within single pulse durations



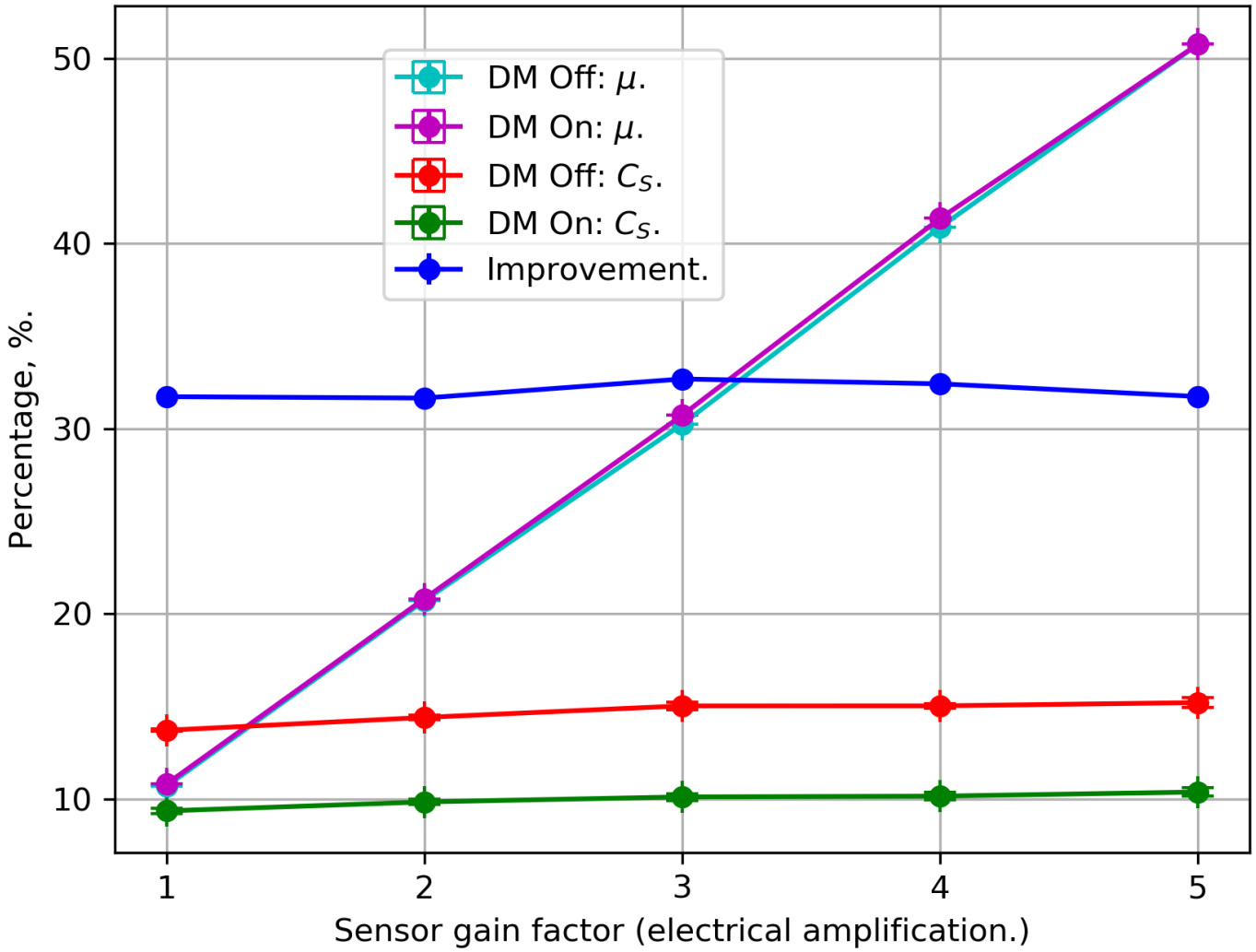

*For 100 different pulse images for each duration.*

# Verification for sensor sensitivity*



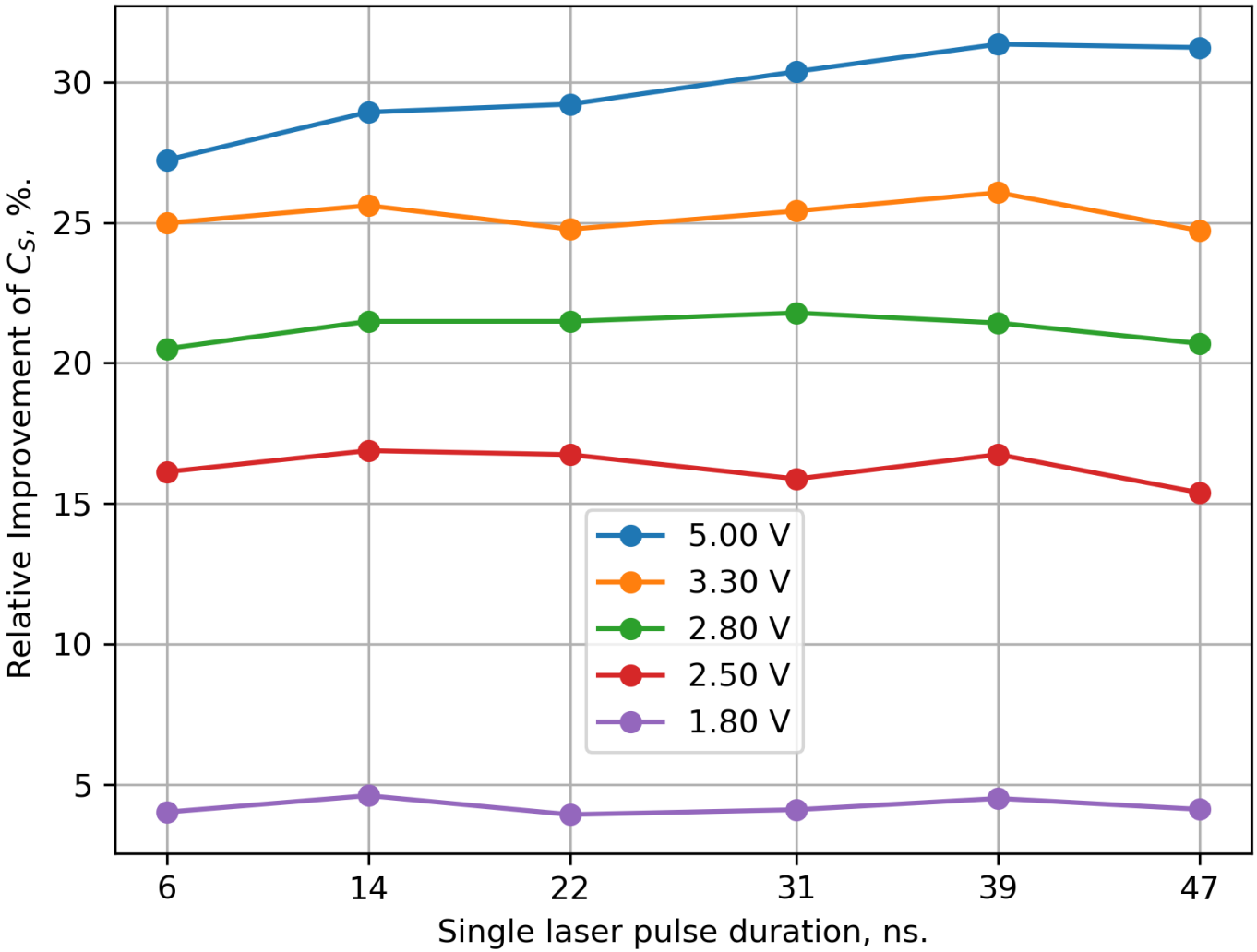

*For 100 different pulse images for each duration.*

# Verification for sensor gain*




*For 100 different* 6 ns *pulse images for each gain factor.*

# Verification for DM wave amplitudes**




*For 100 different pulse image pairs for each duration.*

# Conclusions

- Relative improvement of $> 20\%$ to speckle contrast ratio demonstrated and verified for $\geq 6\,\text{ns}$ pulse durations.
- Should improve spatial resolution . . .
  by reducing the need for averaging within a range image.
- Should improve temporal resolution . . .
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# Thank You!

Please contact me to discuss:

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