What affects LDV measurement accuracy?
- Rough surfaces produce spatially incoherent and statistically random interference patterns called speckle [3]
- Time variable speckle introduces noise into the observed ground velocity signal [4]
- The average speckle diameter is given by:
  \[ d_s = \frac{\lambda v}{n} \]

How does speckle cause measurement error?
- Scenario: rough surface moves at 5 cm/sec orthogonally to LDV laser beam (LDV should not record surface velocity).
- Result: speckle pattern changes with time and thus:
  - total light intensity on detector changes with time
  - effective phase of light on detector changes with time
  - ground velocity recorded by LDV is nonzero

Goal: Orbital Seismology
- What is a laser Doppler vibrometer (LDV)?
  - Robust, commercially available instrument [1]
  - Like a laser altimeter, but measures ground motion
  - Records Doppler shift of reflected laser beam [1]
  - Measures surface velocity in-line with the laser beam
  - Can be used to measure shaking from seismicity [2]

Why design an orbital LDV?
- Enables planetary seismology of small bodies
- Can be done from orbit, i.e. no landers
- See poster #1709 for description of instrument concept [2]

How can we remove speckle noise from LDV data?
- Solution: combine multiple signals
  - This method is known as diversity combining [5,6]
  - Each detector provides 2 signals by exploiting polarization

How does the data accuracy improve with the number of signals recorded?
- Multiple detectors significantly reduces speckle noise
- Large spikes are effectively removed with only two detectors
- Small low frequency noise require more detectors
- SNR improves proportionally with the \( \ln(n) \)
- Cost benefit analysis leads to optimal detector count

What is the minimum surface vibration velocity an LDV can record from orbit?
Consider a case where a 1 Hz harmonic surface oscillation with a given peak ground velocity is measured by an orbital LDV with 7 detectors. There are two measurement cases:
1. Laser beam targets the same spot on the ground
2. Laser spot moves along the surface

Case 1: peak ground velocity is measured by an orbital LDV with 7 detectors.
- Speckle noise increases with orbital velocity
- OSIRIS-Rex:
  - angular velocity, 0.0015 deg/s
  - linear velocity, 5 cm/s [7]

Case 2: peak ground velocity recorded by LDVs. We quantify the expected number of signals.
- Larger spikes are effectively removed with only two detectors
- Small low frequency noise require more detectors
- SNR improves proportionally with the \( \ln(n) \)
- Cost benefit analysis leads to optimal detector count

References: