Speckle Noise in Orbital Laser Doppler Vibrometry

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SUMMARY:
A Laser Doppler Vibrometer (LDV) records non-contact measurements of a surface's motion. We consider the possibility of recording seismic data from orbit around small planetary bodies using LDVs. The simplicity and appeal of using LDVs on orbiters is so landing on the surface is not required, and full coverage of the body can be achieved over time. However, to reap these benefits, the instrument must be able to operate on unprepared surfaces the same way laser altimeters do. Optically rough surfaces, the case for virtually all rocky materials found on planetary surfaces, produce random diffuse reflection patterns called speckle when illuminated by a laser. A time variant laser **speckle pattern** distorts the velocity signal recorded by LDVs. We quantify the expected signal distortion from an orbiting LDV and propose a method to eliminate this distortion by exploiting signal diversity. We show that signal diversity combining can overcome the limits of speckle noise for an orbital laser vibrometer. For slow orbital angular velocities, a laser Doppler vibrometer can record ground motion signals on the order of 1 μm/s.

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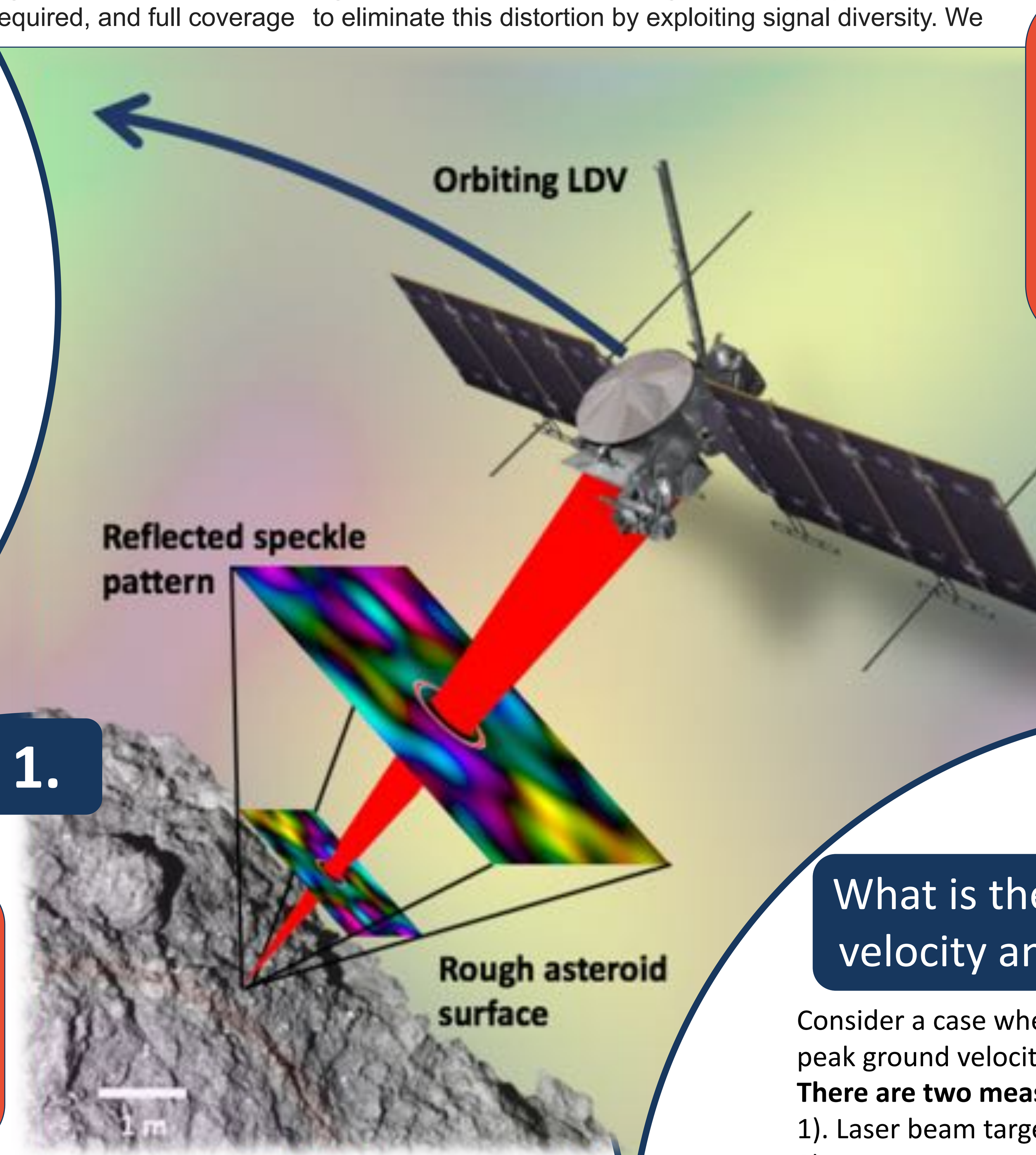


1.

Goal: Orbital Seismology

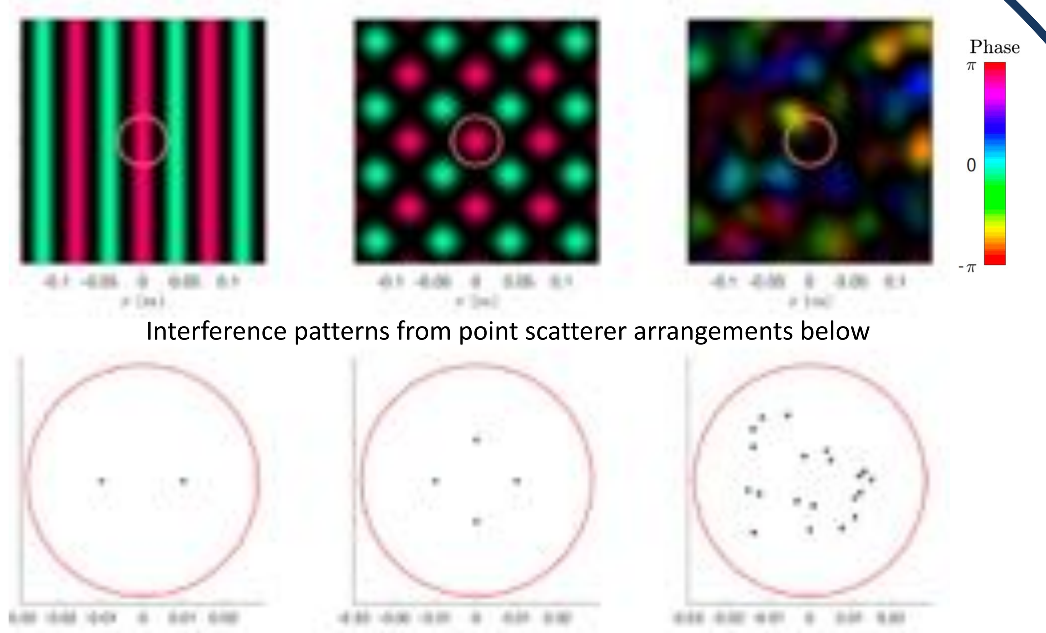
What is a laser Doppler vibrometer (LDV)?

- 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
- <u>Can be used to measure shaking from seismicity [2]</u>

Why design an orbital LDV?

- <u>Enables planetary seismology of small bodies</u>
- Can be done from orbit, i.e. <u>no landers</u>
- See poster #1709 for description of instrument concept [2]

2.



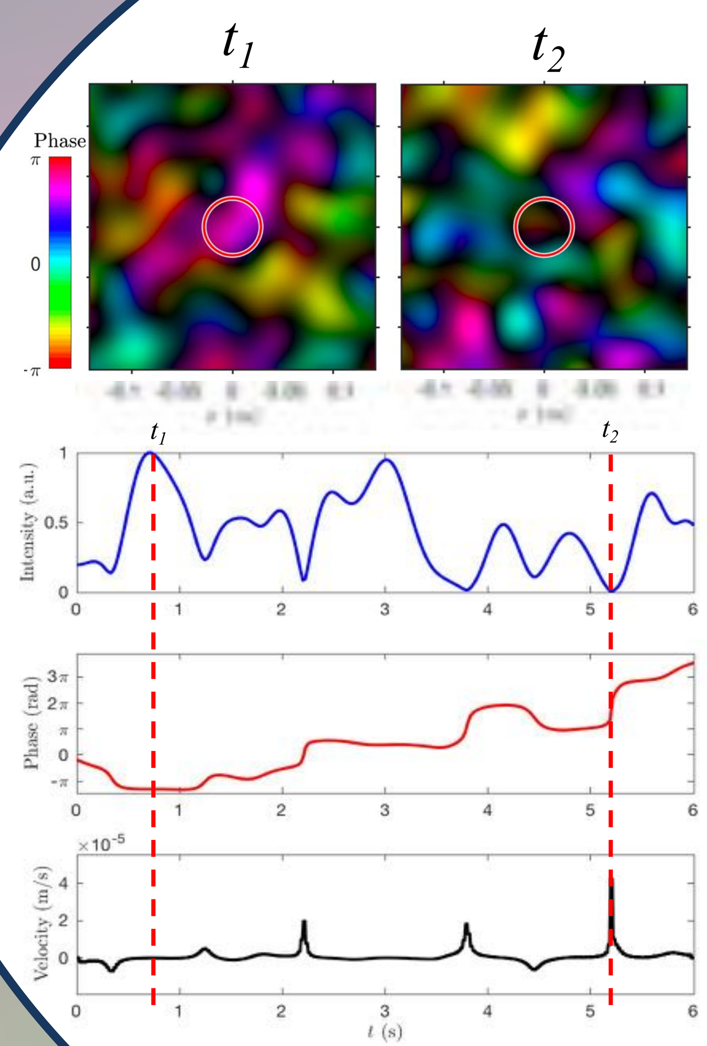
Interference patterns from point scatterer arrangements below

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:

$$d_s = \frac{4\lambda r}{\pi d_l}$$

3.



How does speckle cause measurement error?

<u>Scenario:</u> rough surface moves at 5 cm/sec *orthogonally* to LDV laser beam <u>**(LDV should not record surface velocity).**</u>

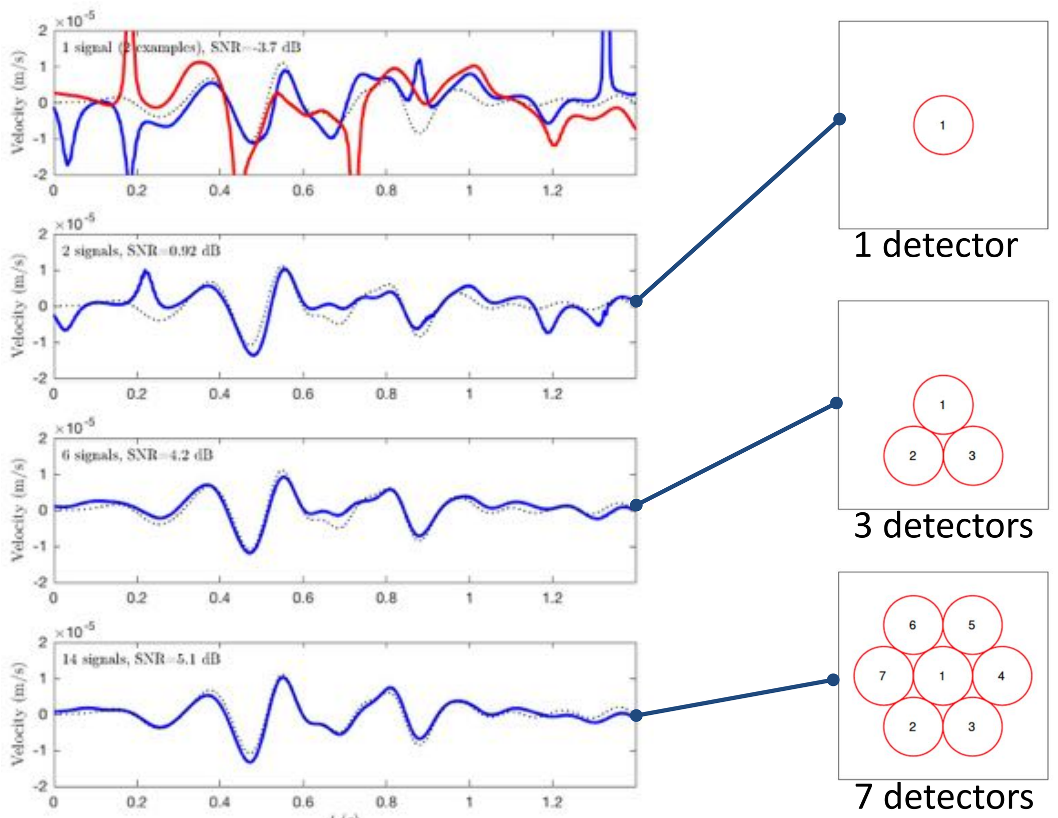
<u>Result:</u> speckle pattern changes with time and thus:

- total light intensity on detector changes with time
- effective phase of light on detector changes with time
- ground velocity recorded by LDV is <u>nonzero</u>

4.

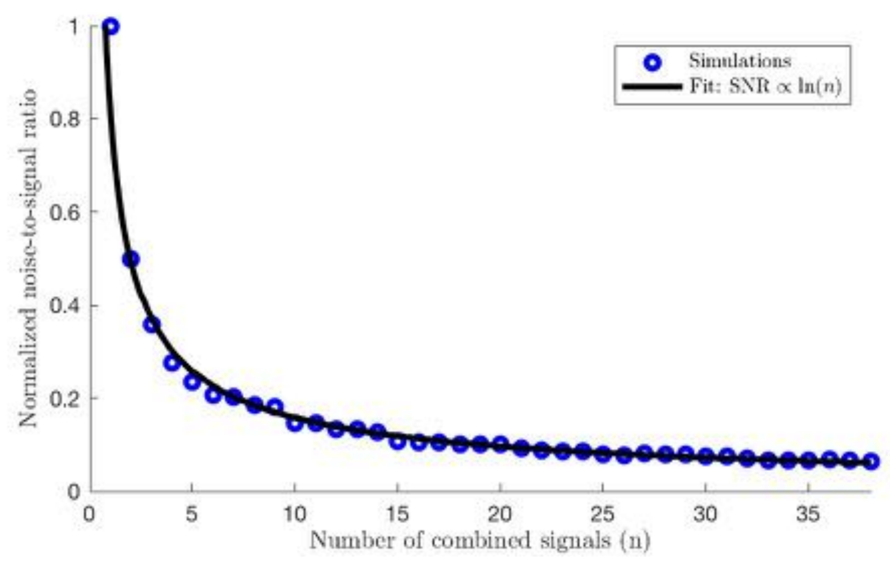
How can we remove speckle noise from LDV data?

<u>Solution:</u> combine multiple signals



- This method is known as <u>diversity combining</u> [5,6]
- Each detector provides 2 signals by exploiting polarization

5.



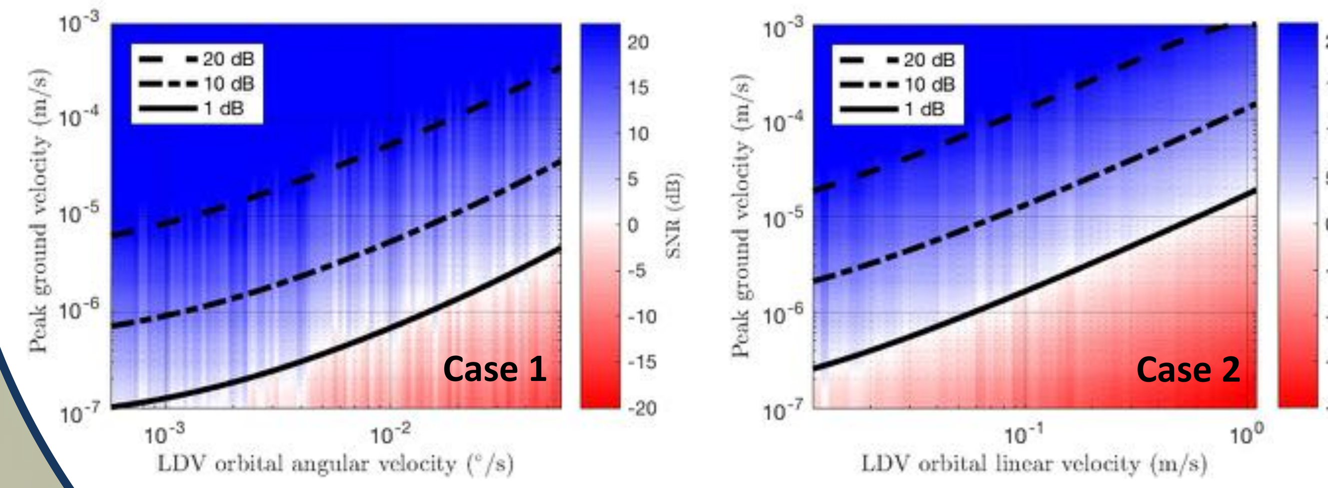
How does the data accuracy improve with the number of signals recorded?

- 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

6.

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



- <u>Speckle noise increases with orbital velocity</u>
- OSIRIS-Rex:
  angular velocity, 0.0015 deg/s
  linear velocity, 5 cm/s [7]

Can we mitigate speckle noise in orbital laser Doppler vibrometry? YES!

References:
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[5] A. Drabenstedt. *AIP Conf. Proc.*, 1600(1), 2014.
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[7] M. G. Daly et al. *Space Sci Rev*, 212, 2017.