

A Microresonator-Based Laser Doppler Velocity Sensor for Interplanetary Atmospheric Re-Entry

Ben Wise, Jaime DaSilva, and Elie Salameh
Adviser: Dr. Volkan Otugen

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**World Changers
Shaped Here**



SMU



Schiaparelli enters atmosphere

Time: 0 sec
Altitude: 121 km
Speed: 21 000 km/h

Heatshield protection during atmospheric deceleration

Time of maximum heating: 1 min 12 sec
Altitude: 45 km
Speed: 19 000 km/h



Parachute deploys

Time: 3 min 21 sec
Altitude: 11 km
Speed: 1700 km/h



Front shield separates, radar turns on

Time: 4 min 1 sec
Altitude: 7 km
Speed: 320 km/h



Parachute jettisoned with rear cover

Time: 5 min 22 sec
Altitude: 1.2 km
Speed: 240 km/h



Thruster ignition

Time: 5 min 23 sec
Altitude: 1.1 km
Speed: 250 km/h



Thrusters off; freefall

Time: 5 min 52 sec
Altitude: 2 m
Speed: 4 km/h



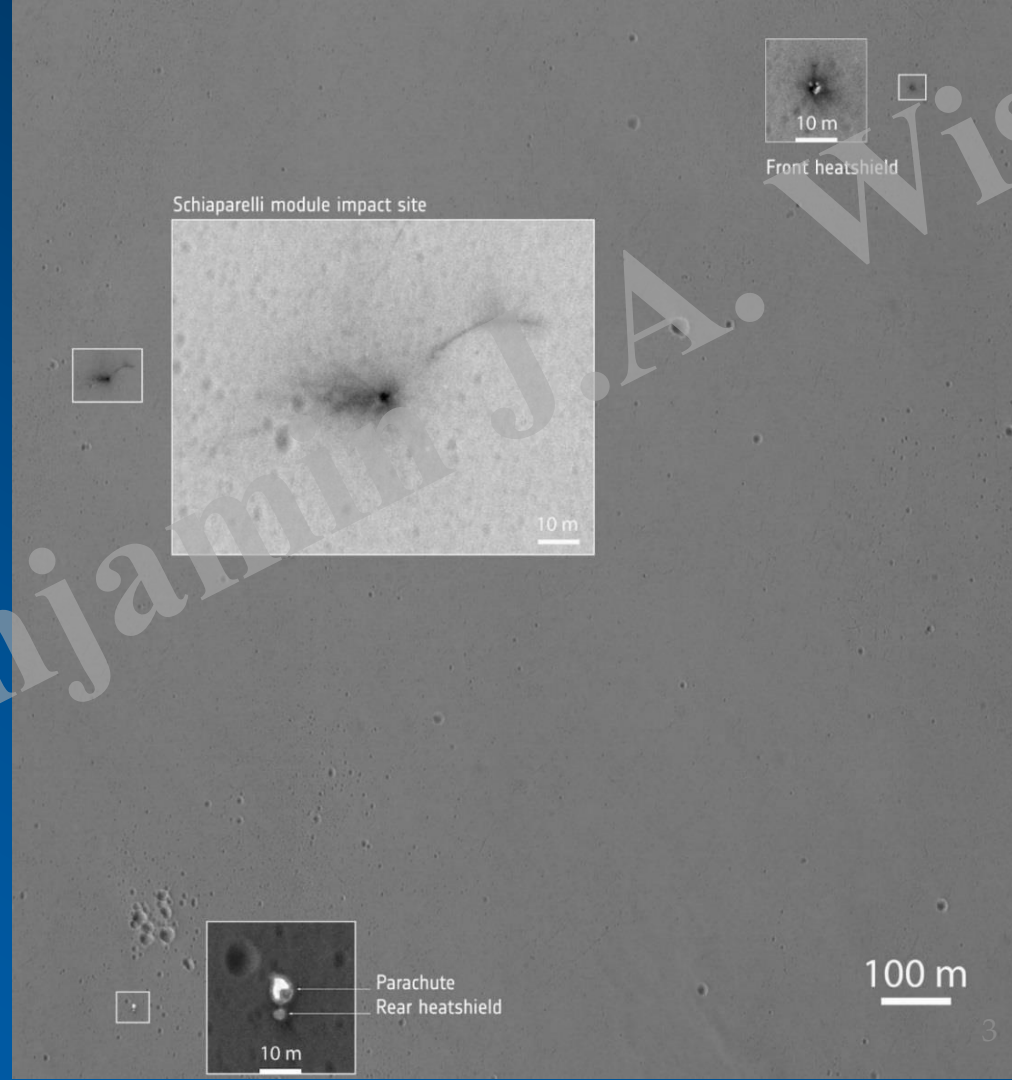
Touchdown

Time: 5 min 53 sec
Altitude: 0 m
Speed: 10 km/h

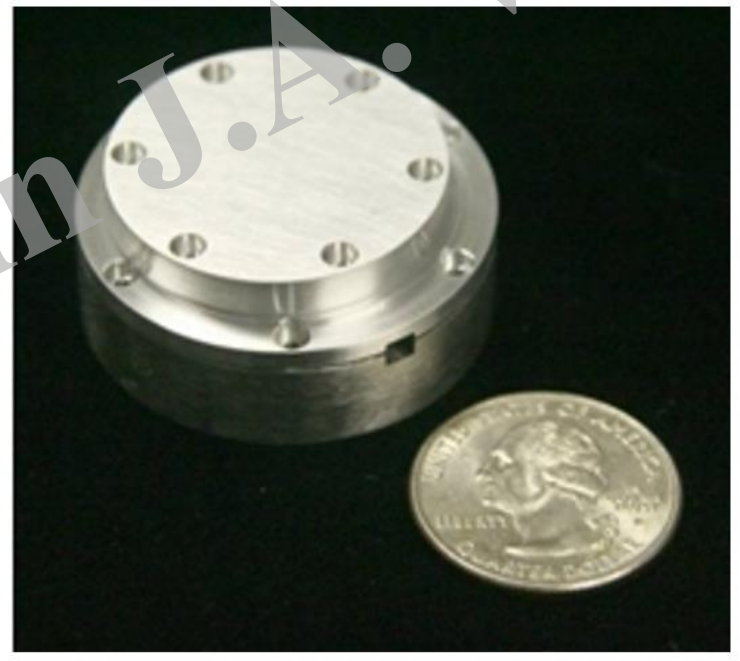
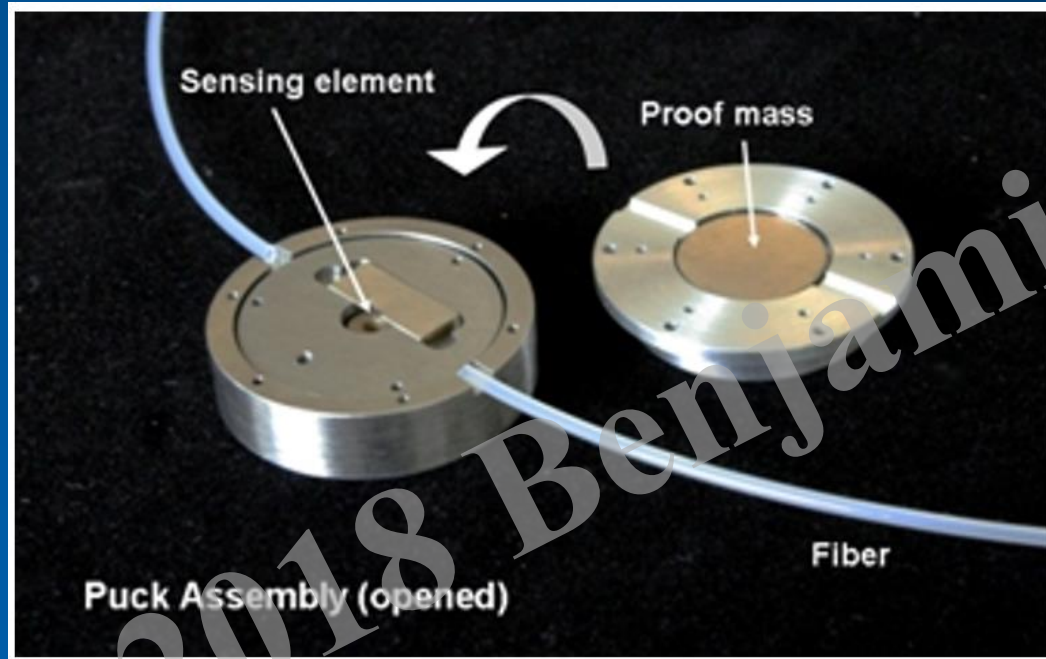


Crash Site

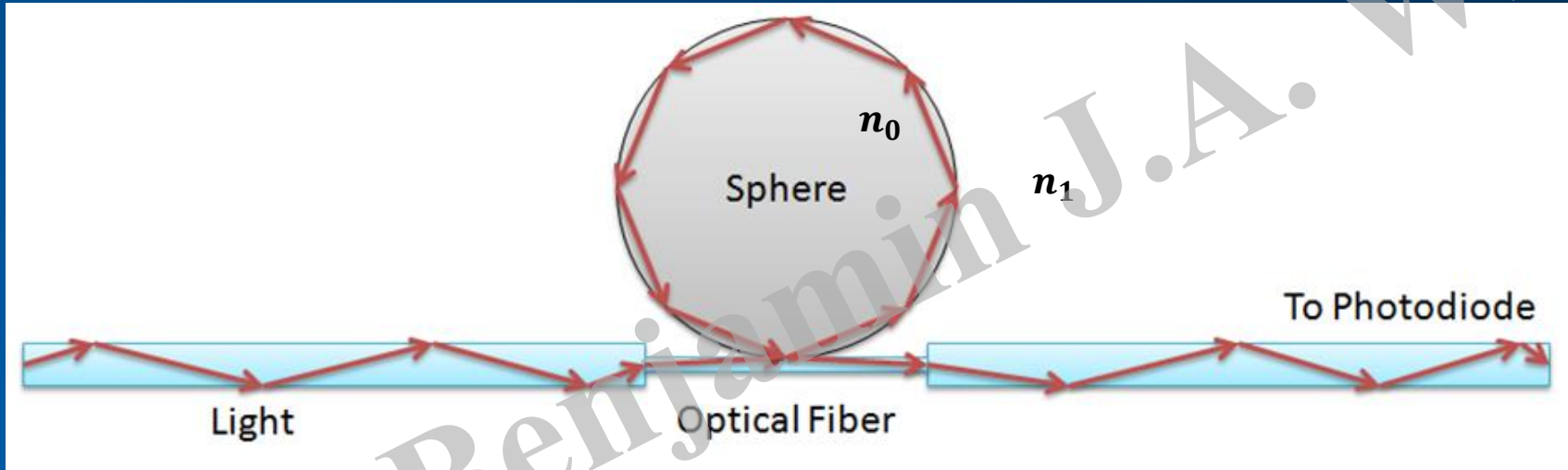
- Thrusters Off State
 - Burn Time: 3s (of >30s)
 - Altitude: 3.7 km
 - Velocity: 250 km/h
- Impact
 - Terminal Velocity
 - Estimated: 300-540 km/h



Why Whispering Gallery Mode Sensors?



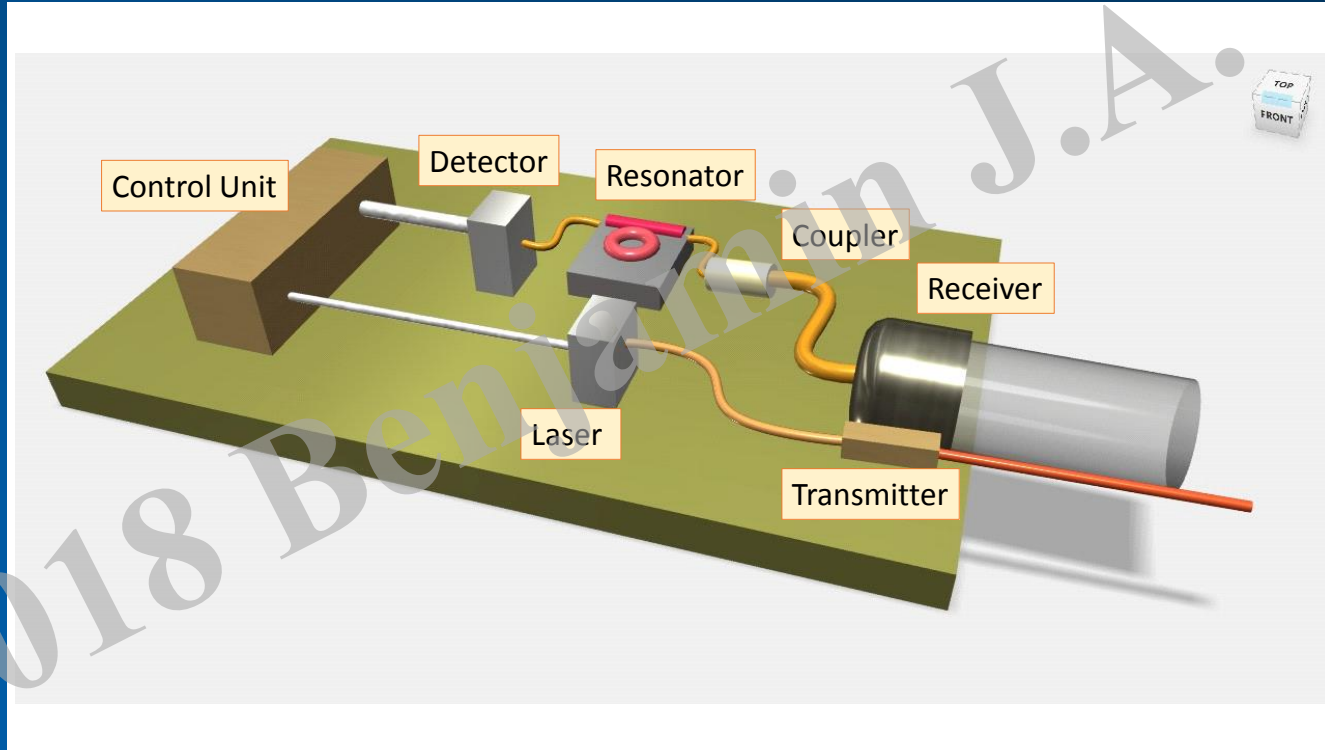
The Whispering Gallery Mode



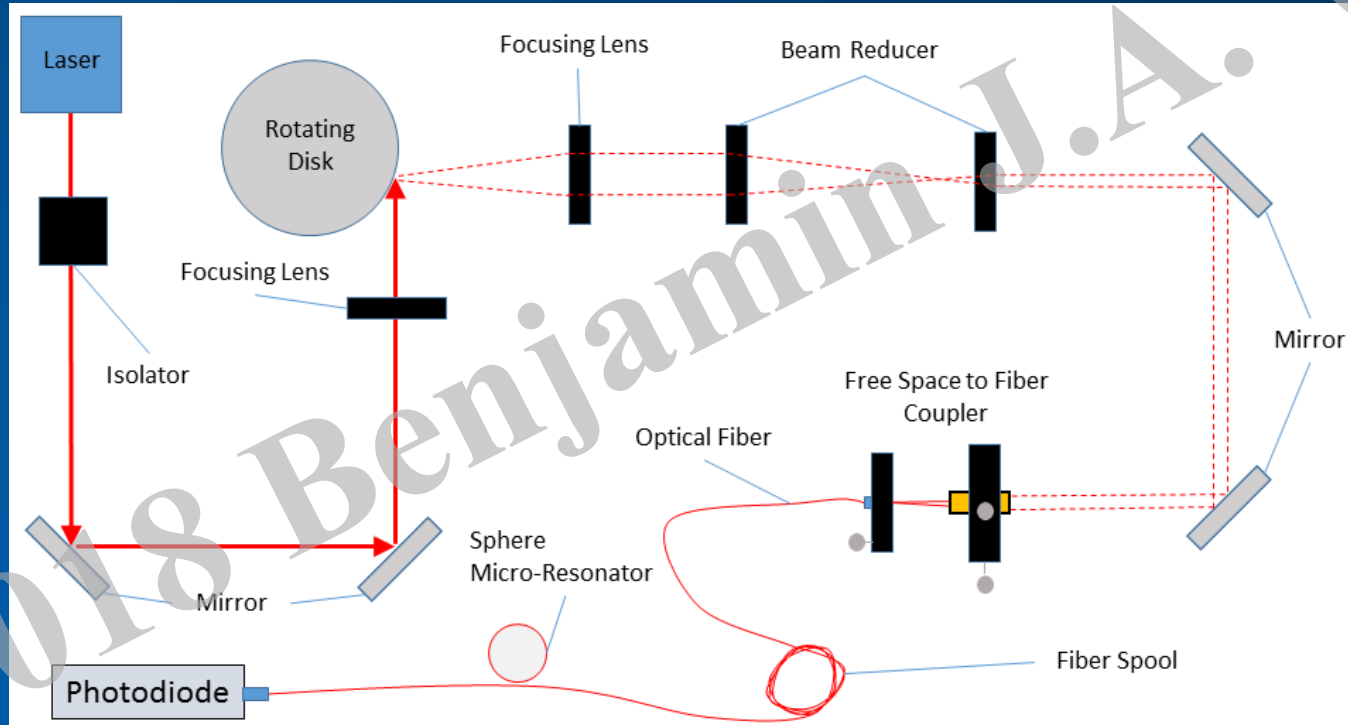
- Resonance Condition: $2 \pi r n_0 = l \lambda$ for $r \gg \lambda$
- Very High Q-Factor Sensing ($Q = \frac{\lambda}{\delta \lambda} > 10^7$)



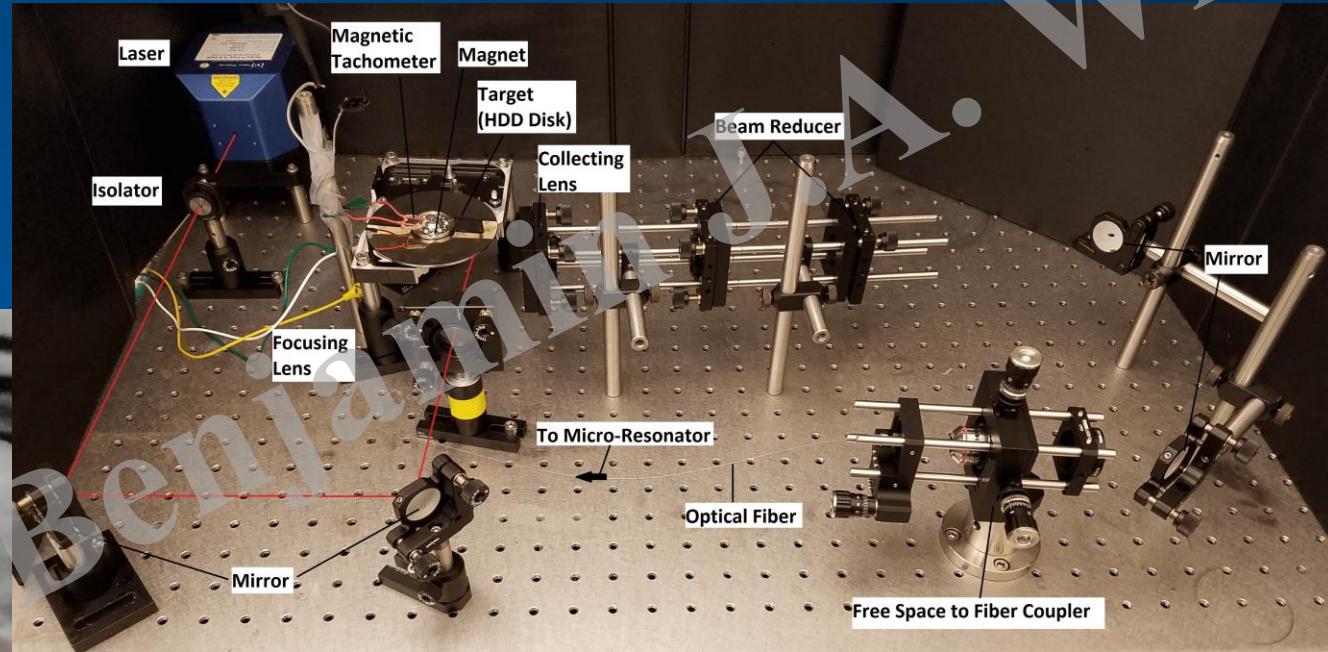
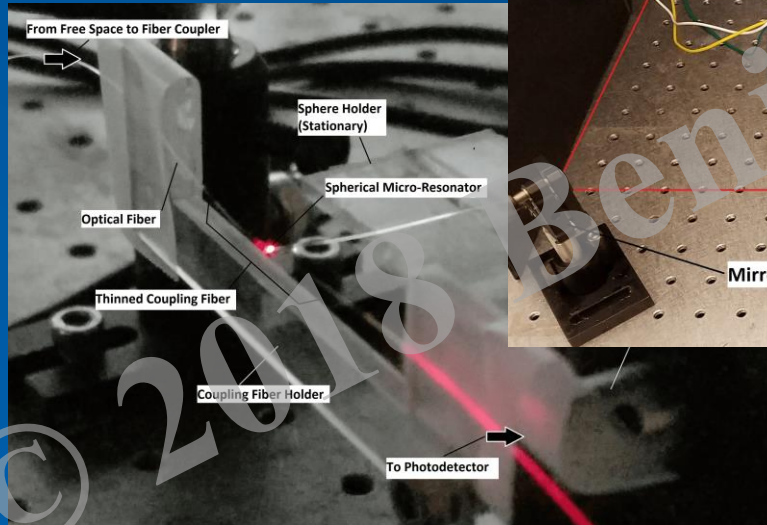
Overall System Schematic



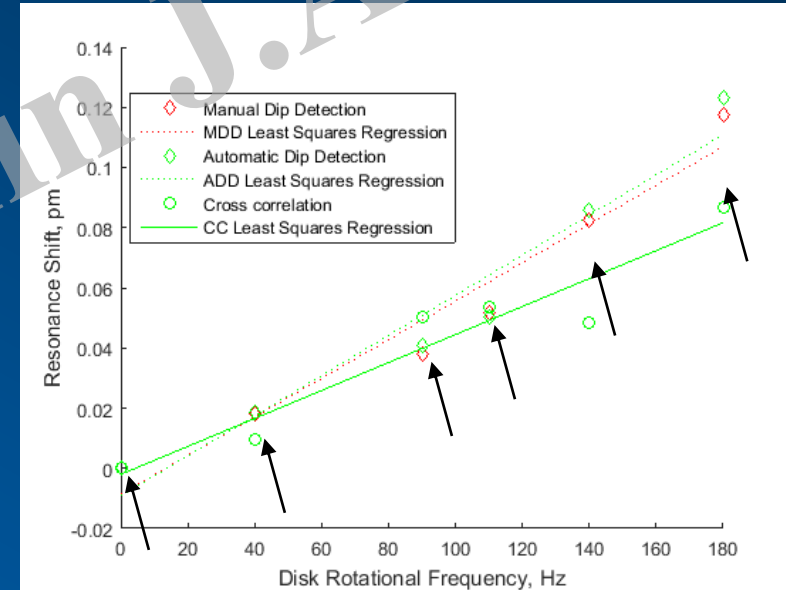
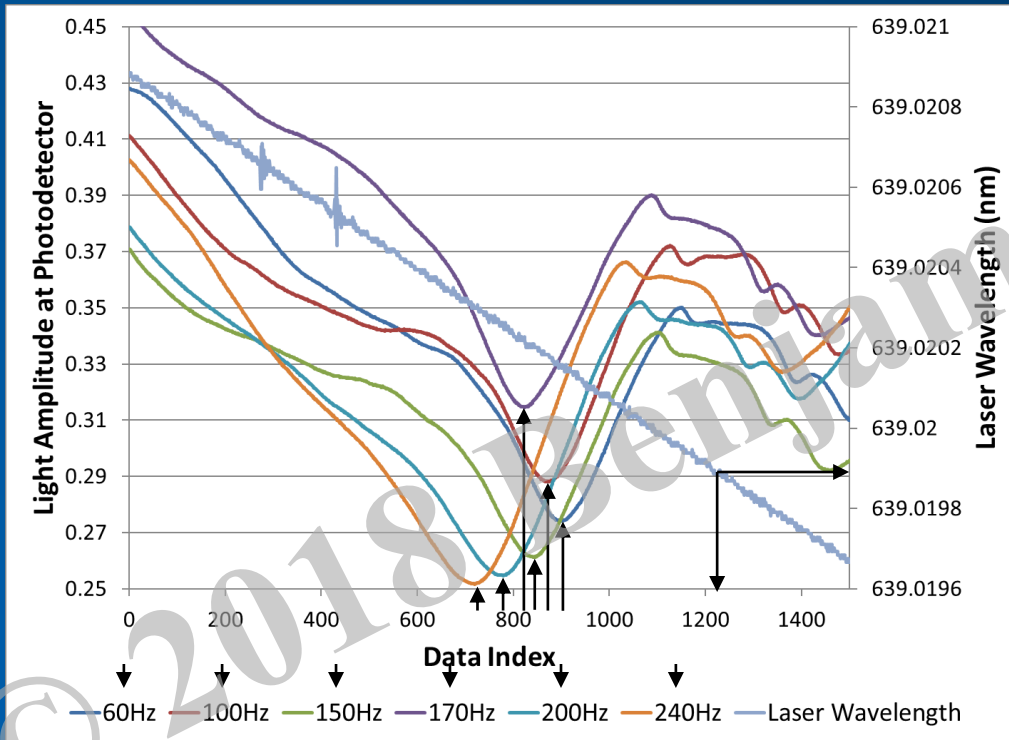
Laser-Modulated Resonance Excitation



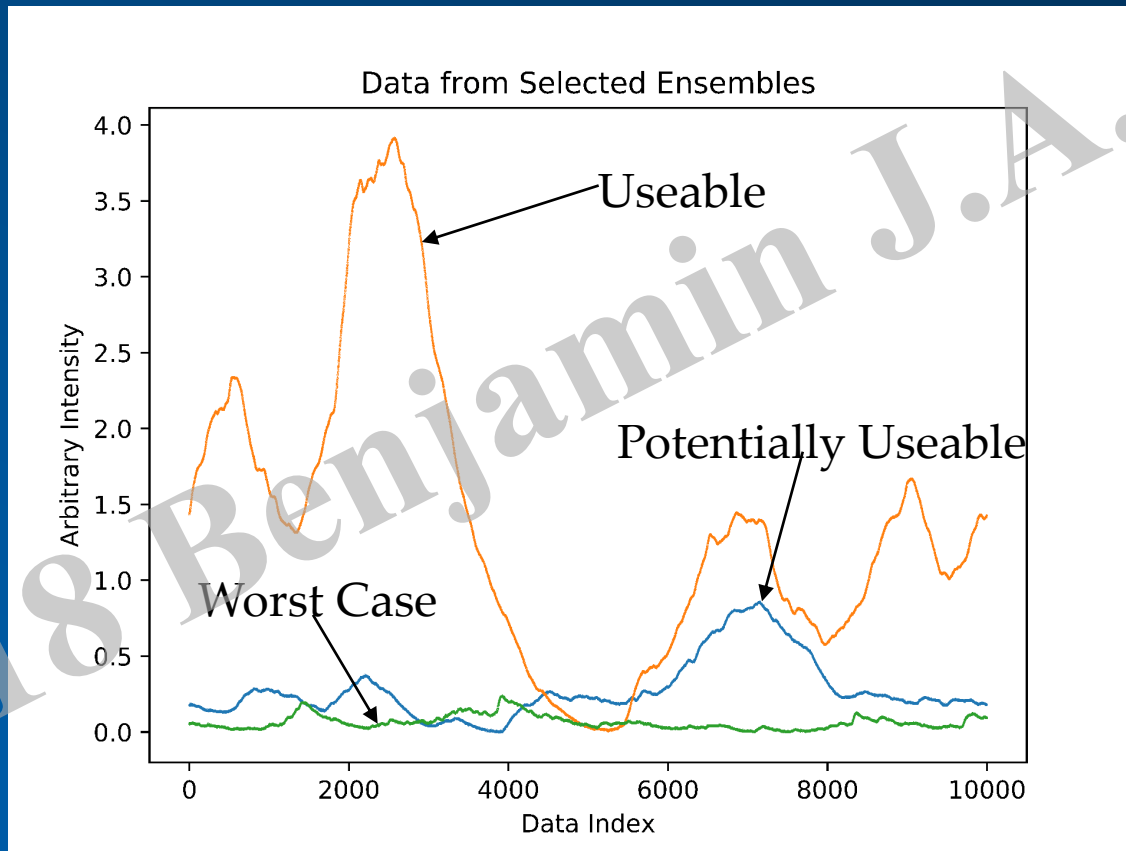
Laser-Modulated Resonance Excitation



Laser-Modulated Resonance Excitation Results

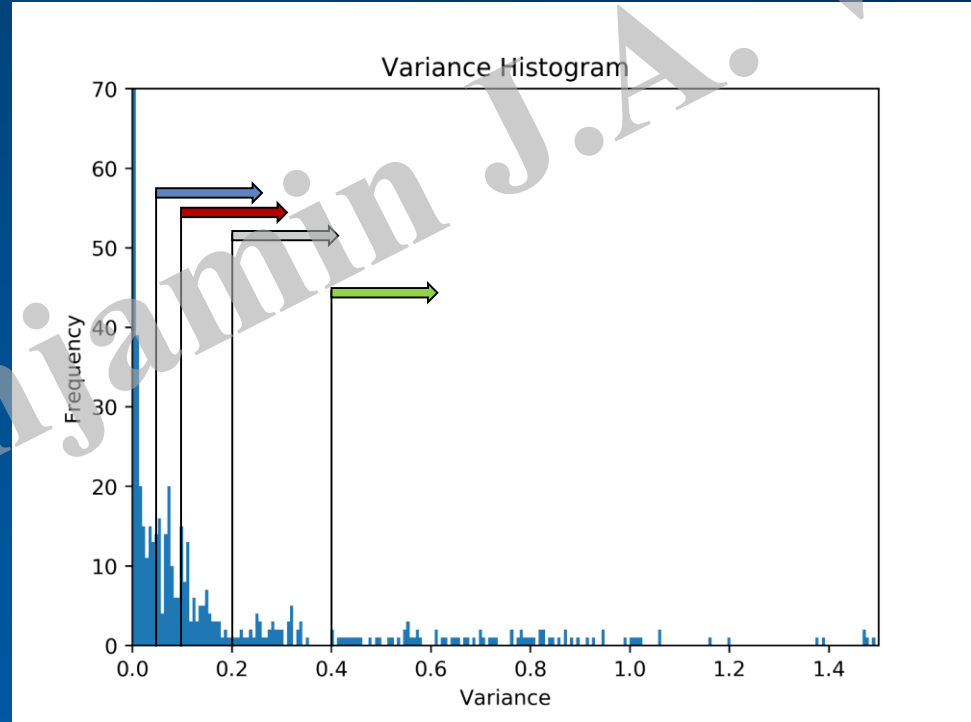


Signal Processing Motivation

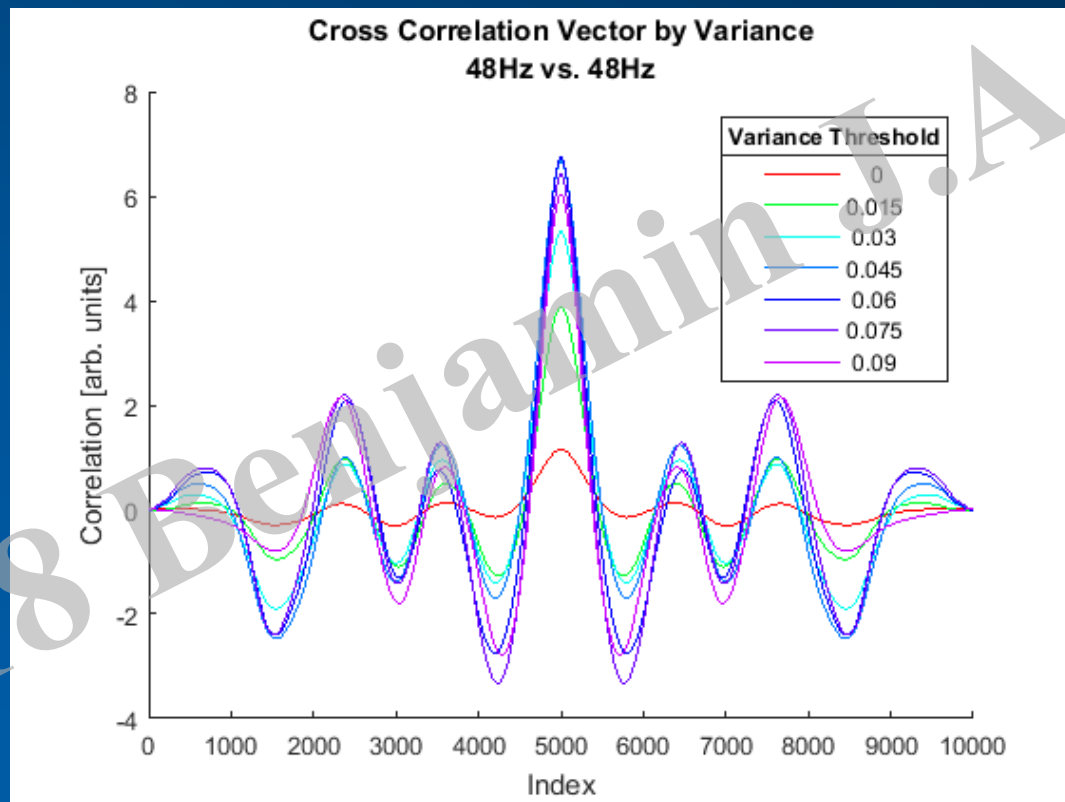


Variance Filtering

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2$$

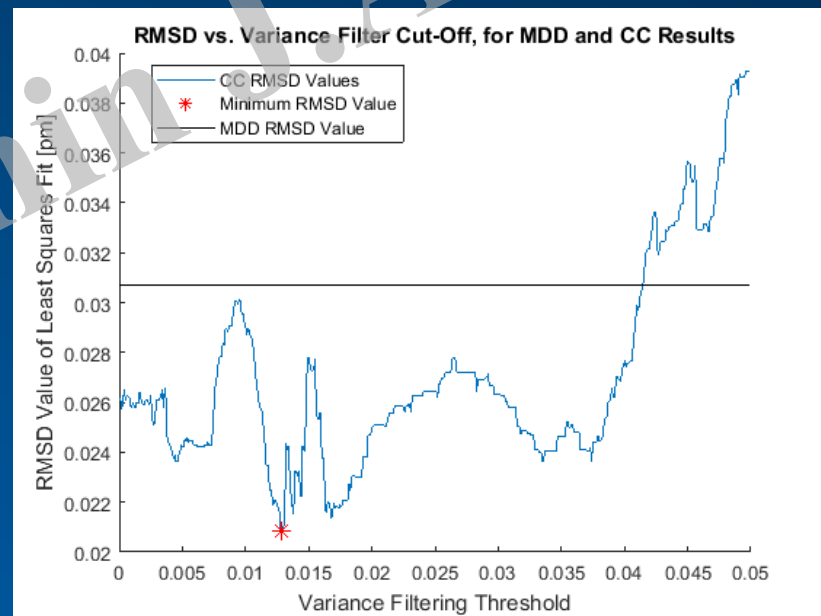
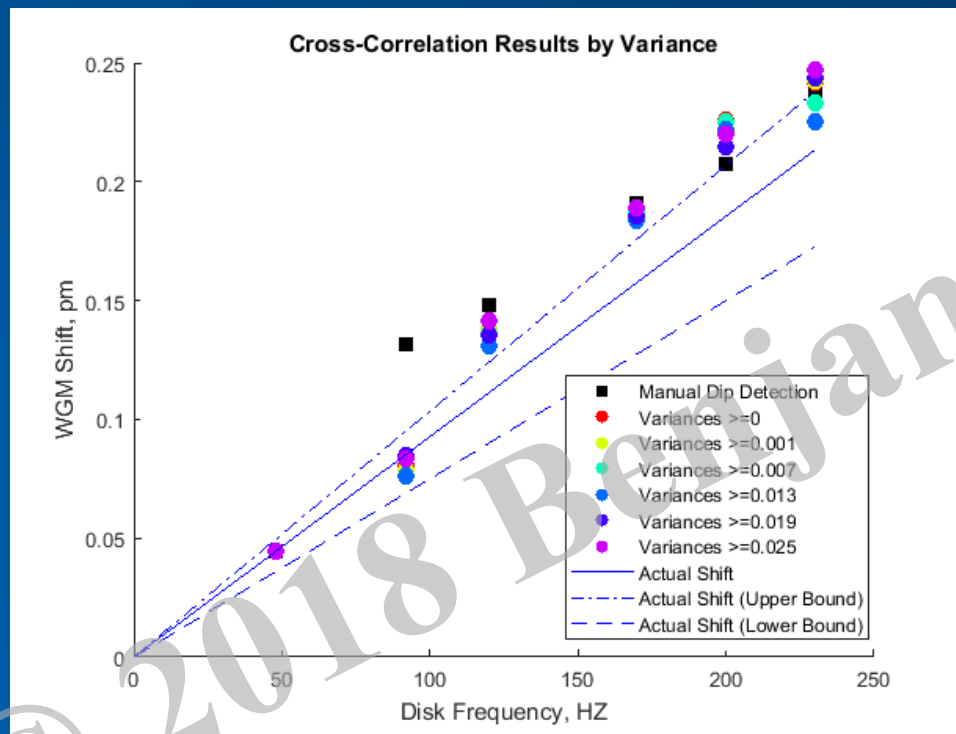


Variance Filtering Results



Variance Filtering Results

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{n}}$$



Conclusion

- Showed the Need for Accurate, High Resolution, Physically Small Velocity Sensors
- Showed How the WGM Phenomenon Occurs and a Design for a Velocity Sensor
- Demonstrated Doppler Shift Detection from a Solid Moving Target is Possible
- Demonstrated the Need for and Tested a New Signal Processing Approach to Mitigate Intermittent Signals
- Results Were Very Encouraging
 - At the Proof-of-Concept level, we were able to measure Doppler shift due to relative motion, with a miniaturized single-beam LIDAR device.
 - We were able to overcome or mitigate some of the major challenges of this method.
 - Moving toward direct measurement of a particle laden jet.



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