# A New Diagnostic for Flow Characterization of Liquid Metal (LM) Modules

M. M. Menon, Oak Ridge National Laboratory

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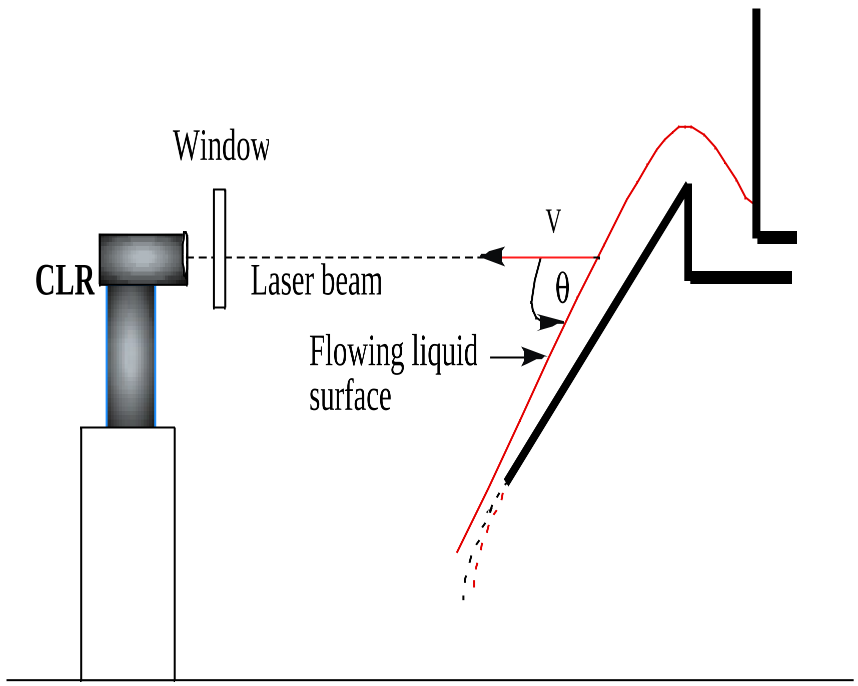
# A diagnostic is needed for characterizing LM flows in fusion environment

- Measurement of:
  - Flow velocity (up to 10 m/s).
  - Film thickness.
  - Flow instabilities during plasma discharges.
- Technique be compatible with fusion environment.
  - strong pulsed magnetic fields.
  - high temperature.
  - High vacuum.
  - Low vapor pressure materials.
- Conventional techniques are not adequate for conducting dynamic measurements under fusion plasma conditions.

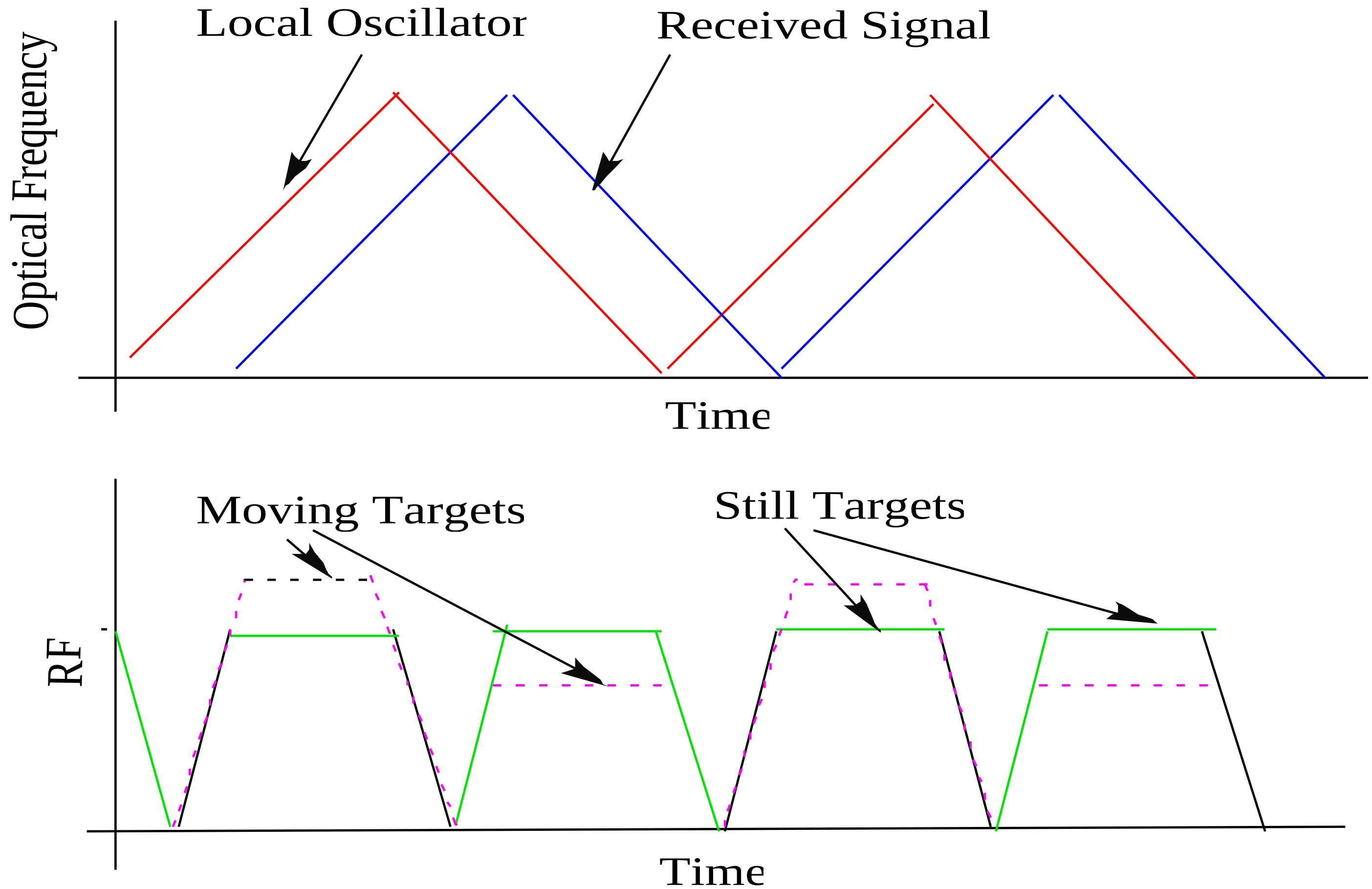
# Concept for free-surface flow characterization




- Truly remote measurements using Doppler effect:
  - Flow velocity distribution
  - Film thickness distribution
  - Flow instabilities
- $\mathbf{v} = \Delta f \, . \, \lambda_0$

  Where, **v** is the velocity component of the flow in the beam direction, and $\lambda_0$ is the laser wavelength, and $\Delta f$ is the Doppler shift in frequency.

# Principles



Local Oscillator
Received Signal
Optical Frequency
Time
Moving Targets
Still Targets
RF
Time

# Symmetric up-shift/down-shift modulation permits Doppler corrected range and velocity measurements.

- For a stationary target:

  $\mathbf{R} = [\mathbf{c}/2M_f]\ f_b$

  where R is the range, **c** is the velocity of light, $\mathbf{f}_b$ is the beat frequency, and $M_f$ is the constant rate of frequency modulation.

- When the target is moving, Doppler component $\mathbf{v}/\lambda_0$ is added to the beat frequency.

  $\mathbf{f}_{bu} = M_f\ (2\mathbf{R}/\mathbf{c}) + \mathbf{v}/\lambda_0$

  $\mathbf{f}_{bd} = -\ M_f\ (2\mathbf{R}/\mathbf{c}) + \mathbf{v}/\ \lambda_0$

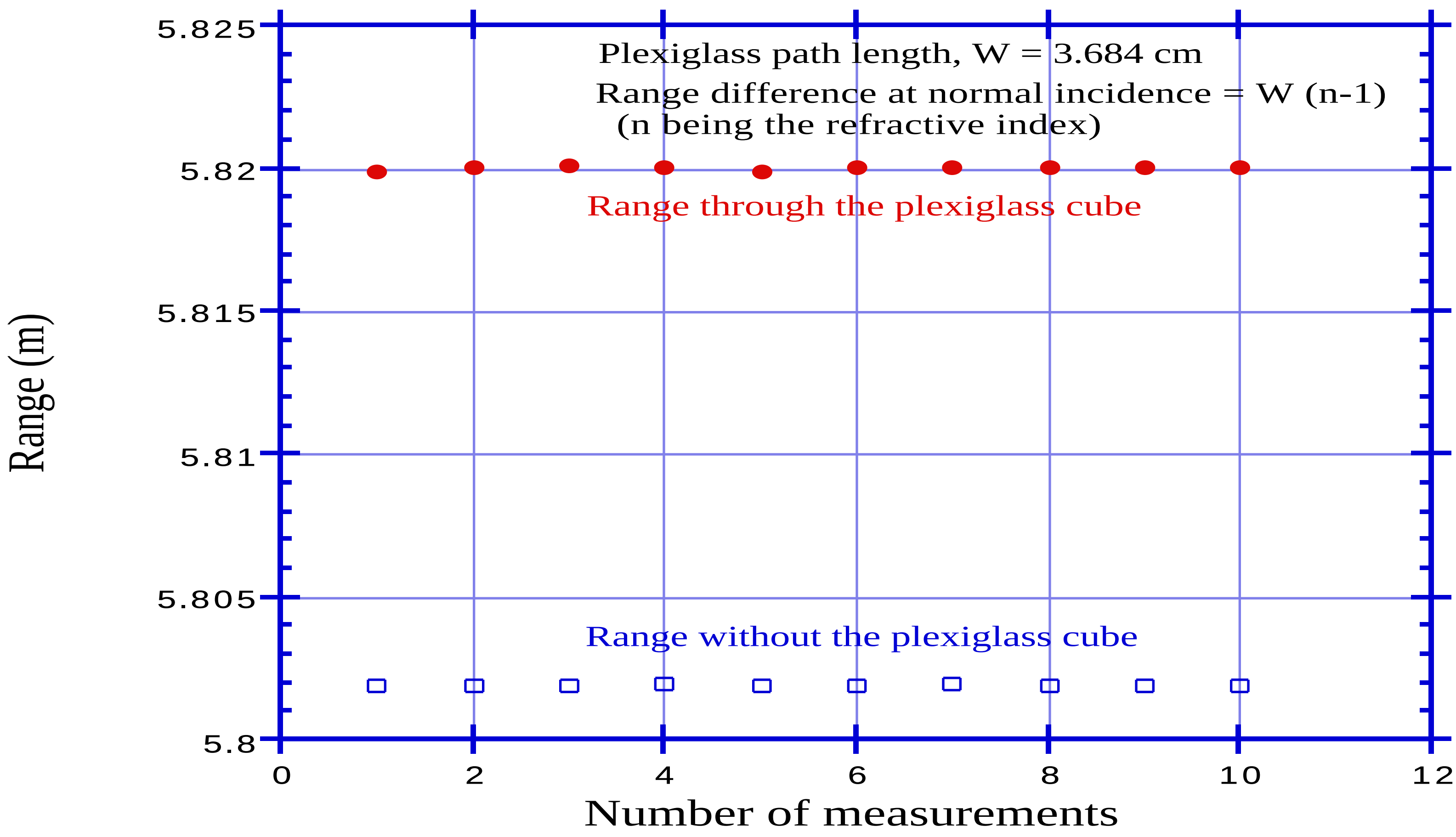
  $\mathbf{v} = \lambda_0(\mathbf{f}_{bu} + \mathbf{f}_{bd})/2$

  $\mathbf{R} = (\mathbf{f}_{bu} - \mathbf{f}_{bd})\ [\mathbf{c}/2M_f]$

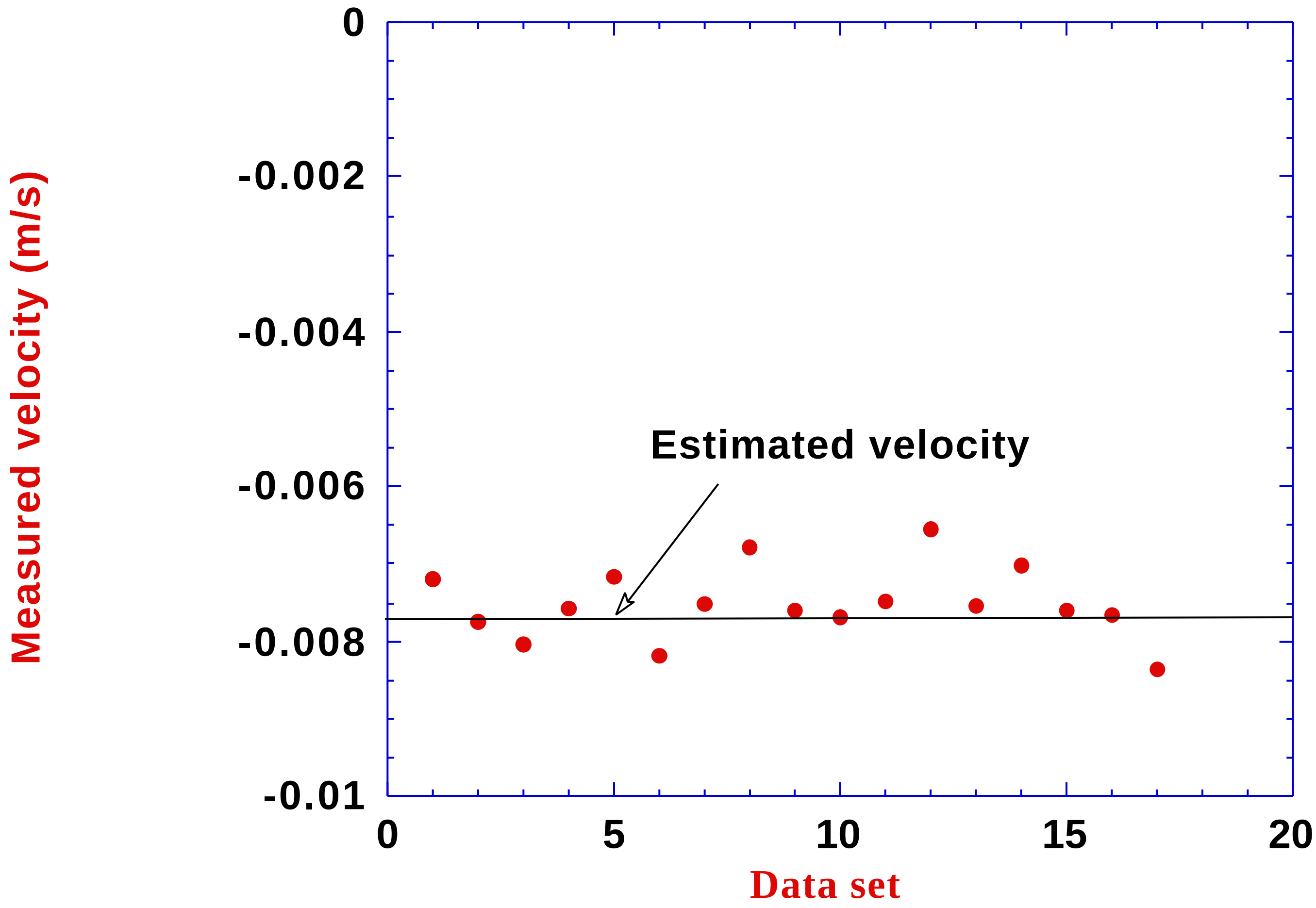
# The current FM CLR is optimized for metrology, and not velocity measurements

- Uses electromechanical scanning head.
- Bandwidth limits of DSP electronics.
- Speed limitation (250/s).
- Not compatible with fusion environment.

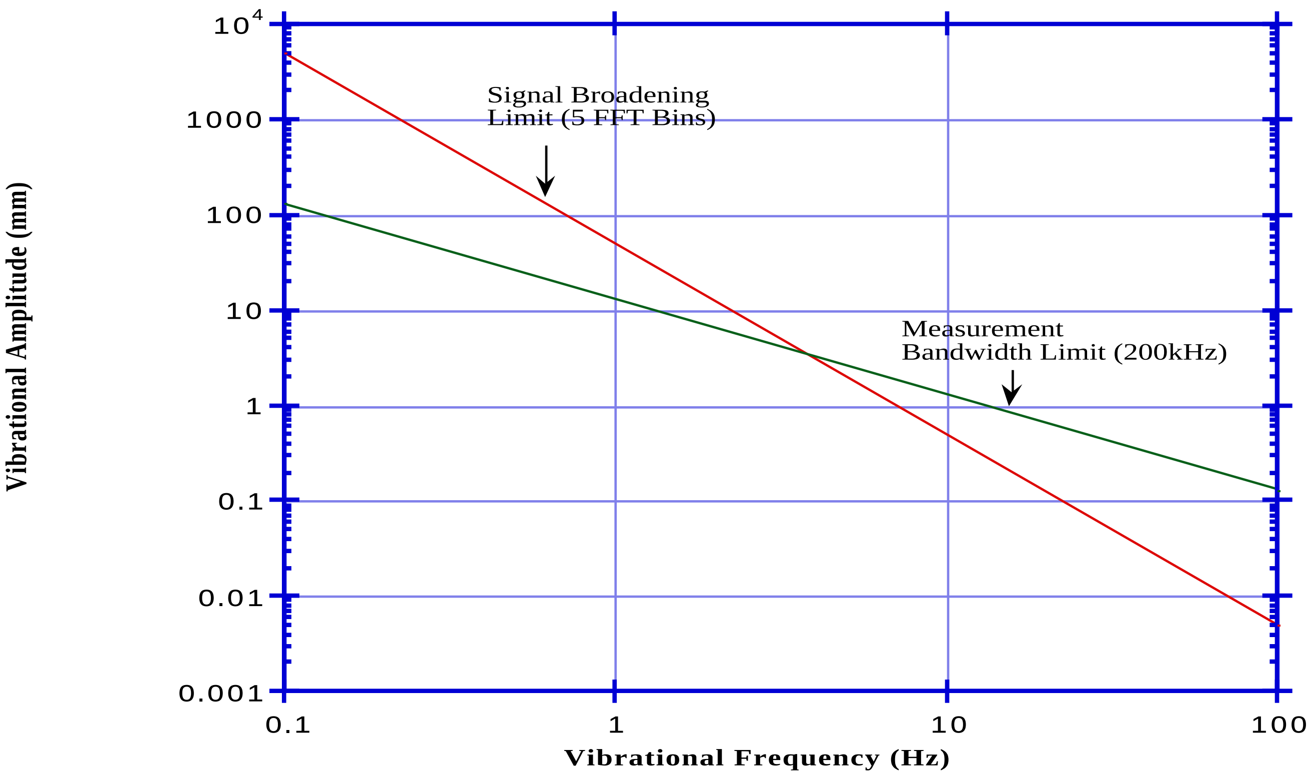
# Measurements can be done through a window (fully non-intrusive and avoids vibration effects)



# Proof-of-principle measurements with the laser aimed at a freely flowing chart recorder paper



# Digital signal processing limitations




- With the current version of FM CLR, maximum velocity that can be measured is only about 50 mm/s.
- Significantly higher velocities (~10 m/s) are anticipated in fusion applications.

# A new Doppler Laser Radar (DOLAR) is being developed to overcome the limitations

- Remote, precision measurements of both range (up to 5 m) and velocity (up to 10 m/s).
- Optical head, designed to operate in fusion environment, umbilically linked to the rest of the system.
- Acousto-optic scanning technique for fast scanning of the beam in one direction.
- Laser amplifier to boost the poor signal levels anticipated from reflective LM surfaces.
- Two different modes of operation, one for velocity measurement and the other for range measurement. Ability to switch between the two modes in a rapid manner.
- In each mode, ability to resolve small changes: 50 µm in range, and 100 µm/s in velocity.

# Summary

- A Doppler Laser Radar (DOLAR) is being developed to measure the film thickness, flow velocity, and certain instabilities of freely flowing liquid metal surfaces.
- DOLAR will be designed to conduct measurements during plasma discharge conditions.
- The measurements will be done in a truly non-intrusive manner.
- The optical head will be the only component located close to the fusion chamber.
- The DOLAR will also be designed for remote in-vessel metrology of plasma facing components in burning plasma experiments (the optical head will operate under vacuum, high temperature, and radiation environment).