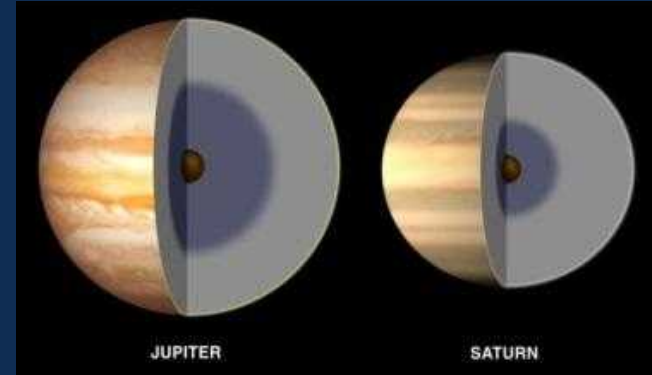
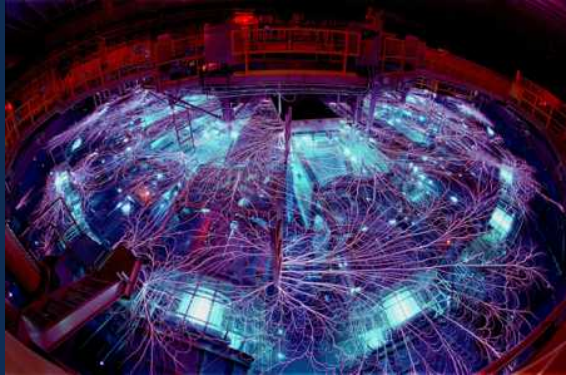


*Exceptional service in the national interest*



# Direct observation of an abrupt Insulator-to-Metal transition in dense liquid deuterium

**Marcus D. Knudson**

**Sandia National Laboratories**

**Albuquerque, NM**



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



# Acknowledgements

## Experiment Design/Analysis

Marcus Knudson

Ray Lemke

Kyle Cochrane

Devon Dalton

Dustin Romero

## Diagnostics

Charlie Meyer

Jeff Gluth

Devon Dalton

Anthony Romero

Dave Bliss

Alan Carlson

## QMD Calculations

Mike Desjarlais

Andreas Becker

Winfried Lorenzen

Ronald Redmer

## Planetary Modeling

Nadine Nettelmann

Andreas Becker

Ronald Redmer

## Pulse Shaping

Ray Lemke

Jean-Paul Davis

Mark Savage

Ken Struve

Keith LeChien

Brian Stoltzfus

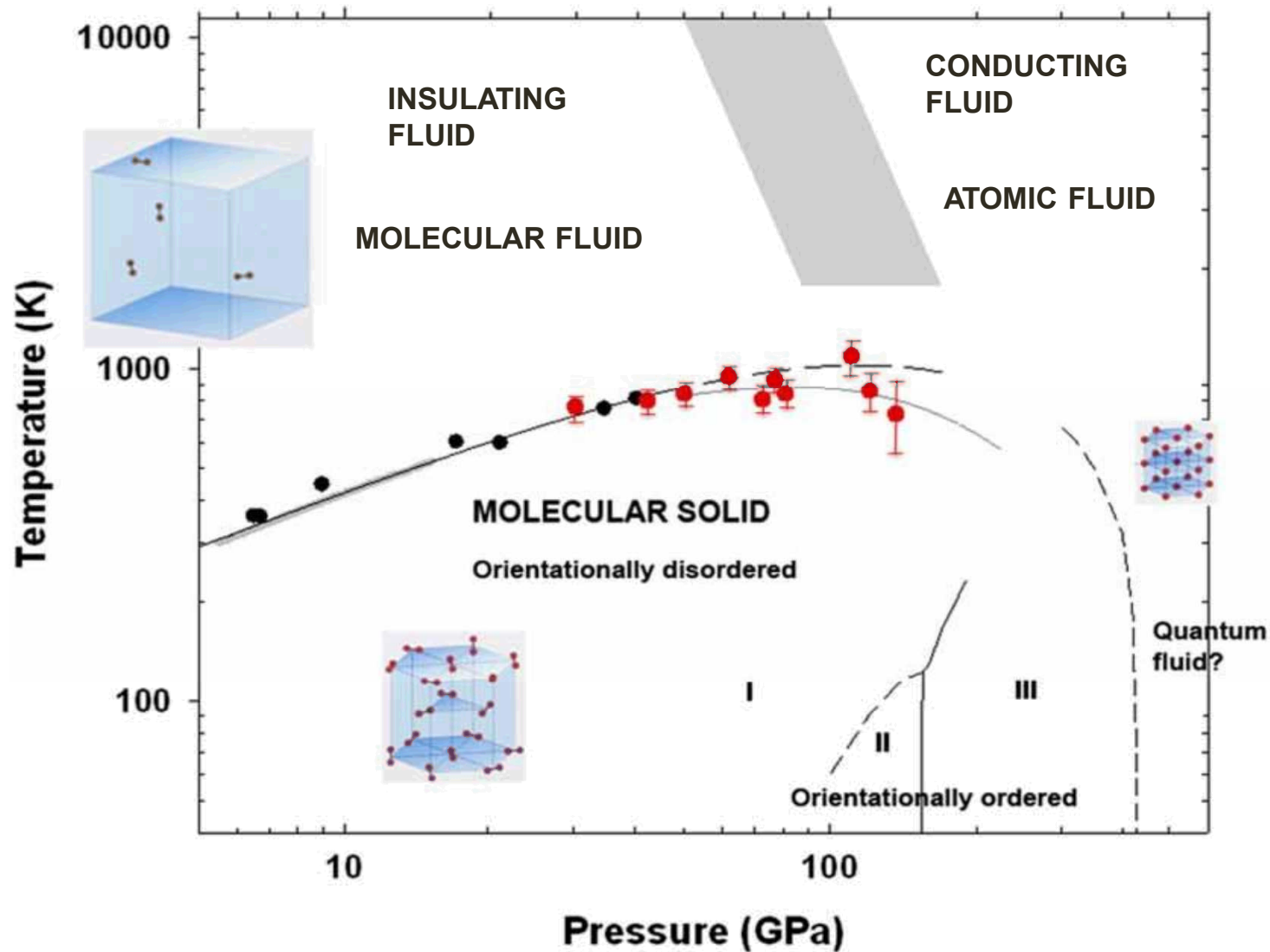
Dave Hinshelwood

Entire Z crew

University of Rostock

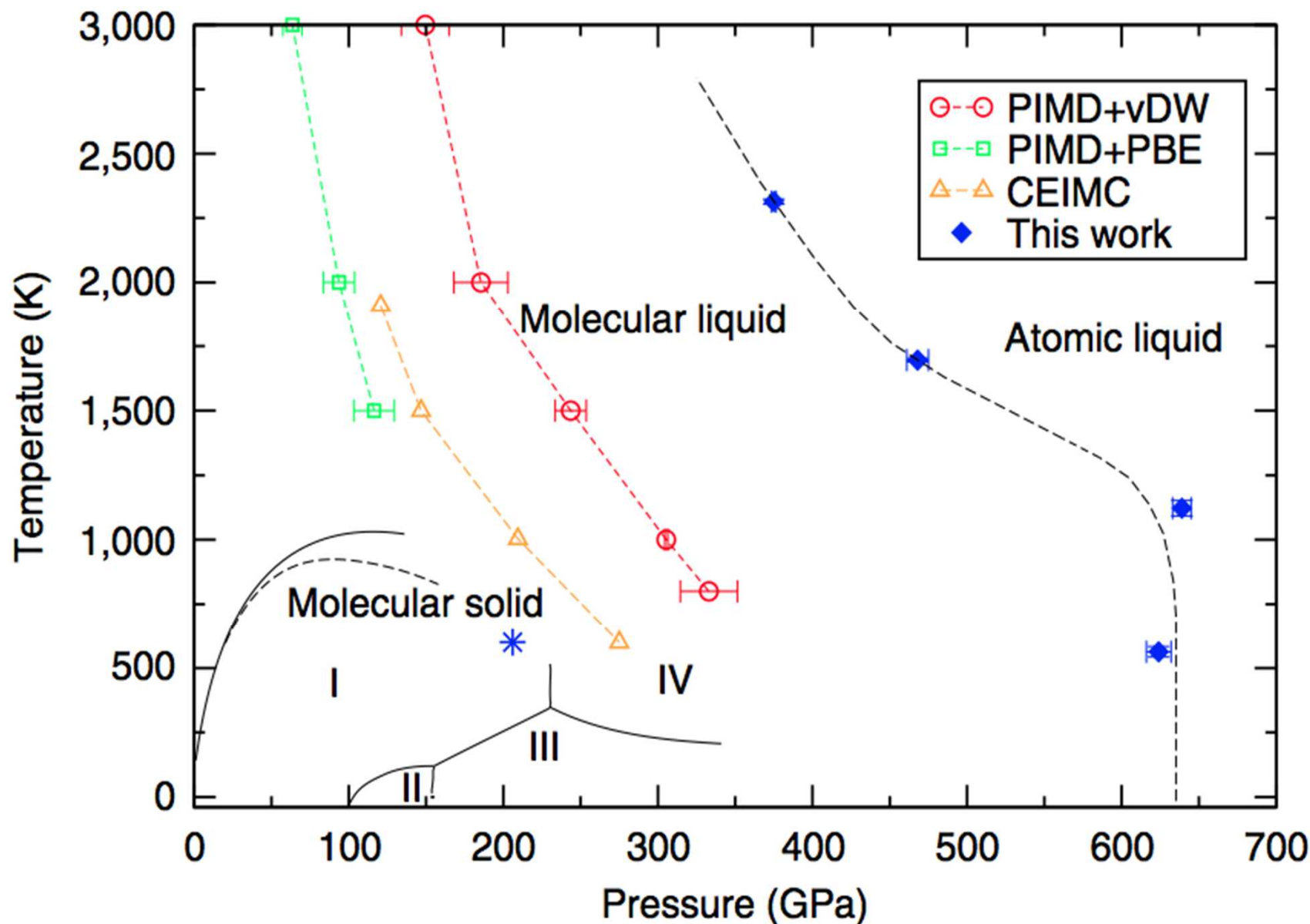


# Hydrogen at high pressures – the known phase diagram so far



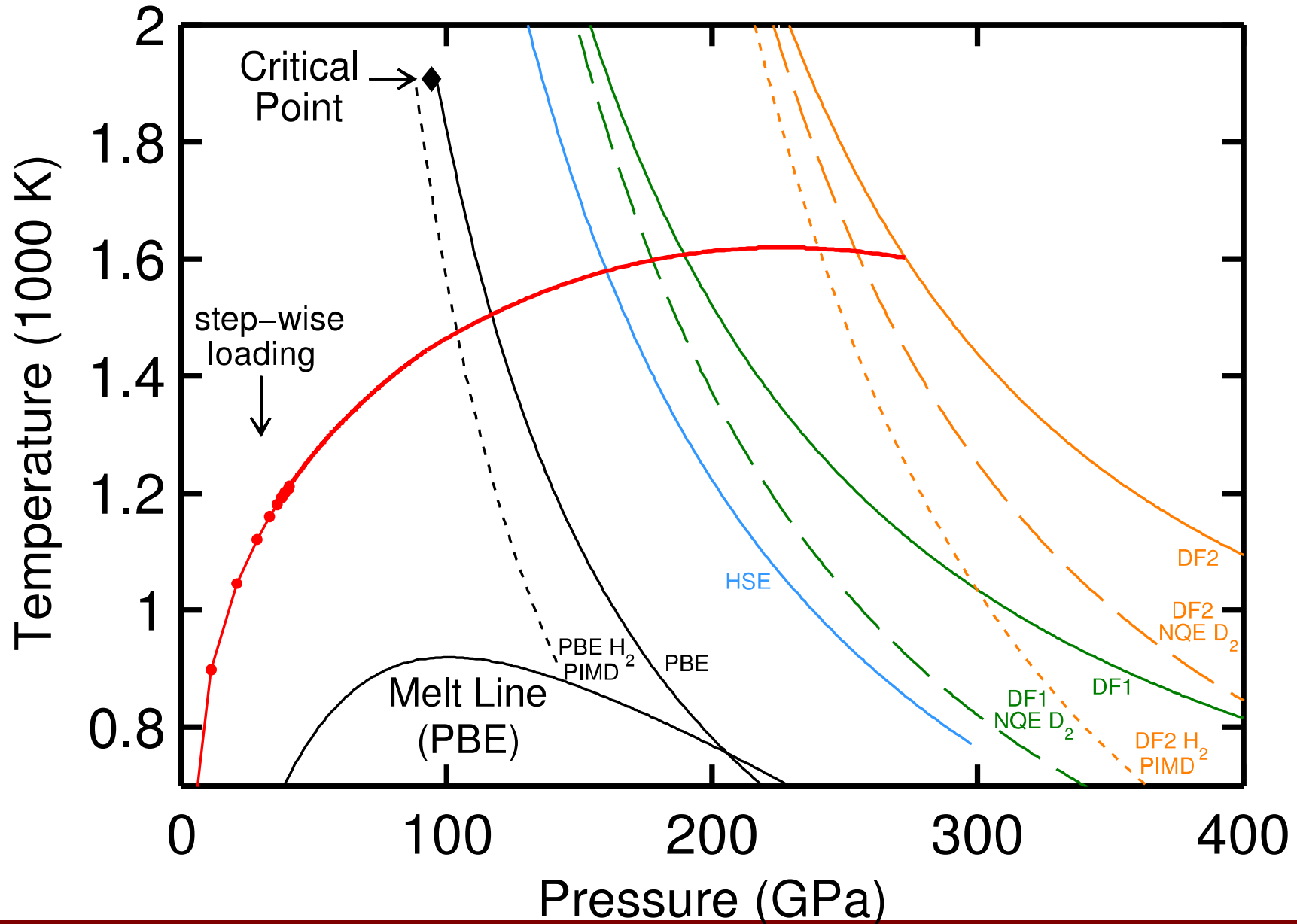


# Recent predictions of the LL-IMT in hydrogen



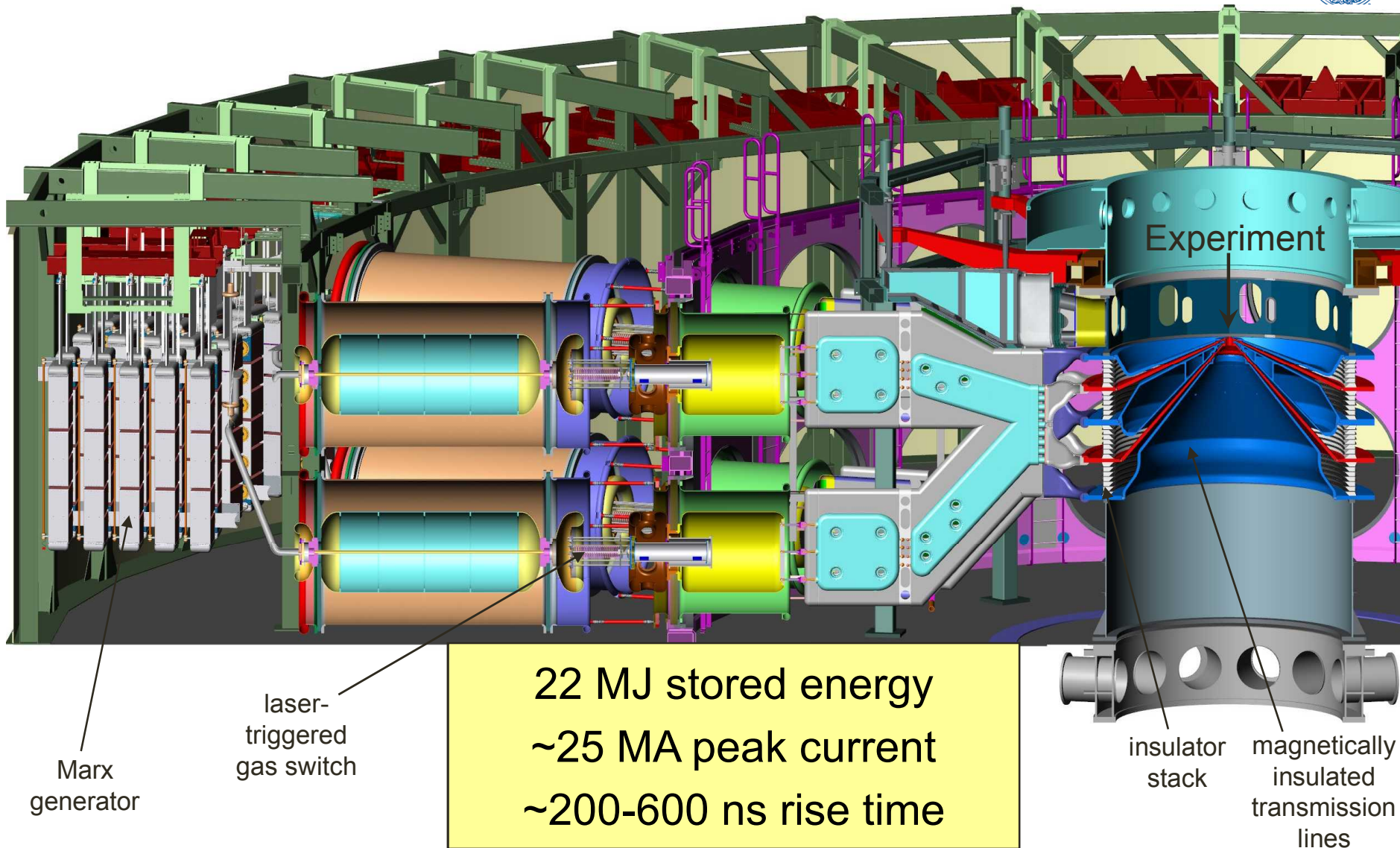


# Proposed Experiment: Shock - Ramp



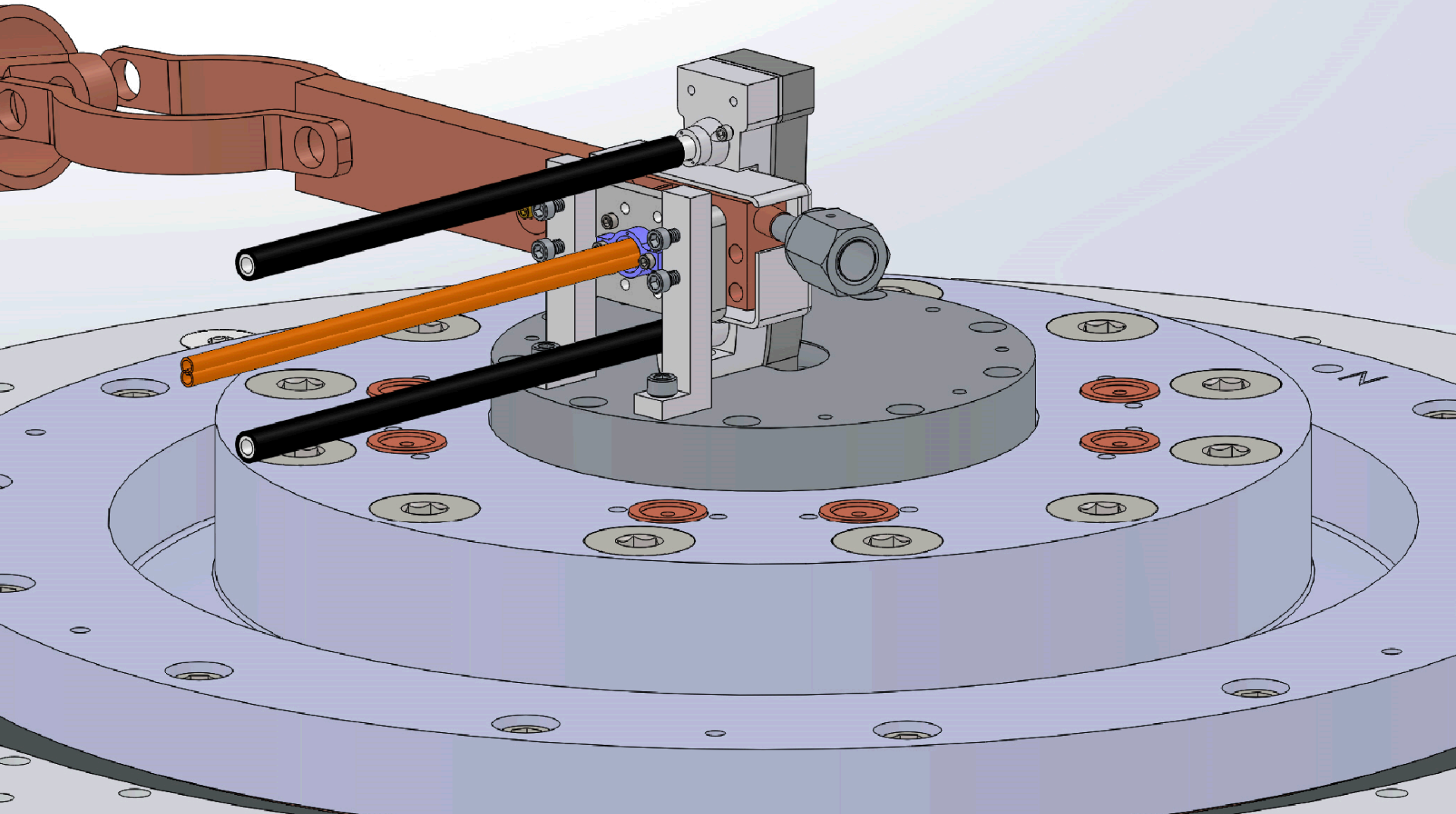


# Sandia Z Machine



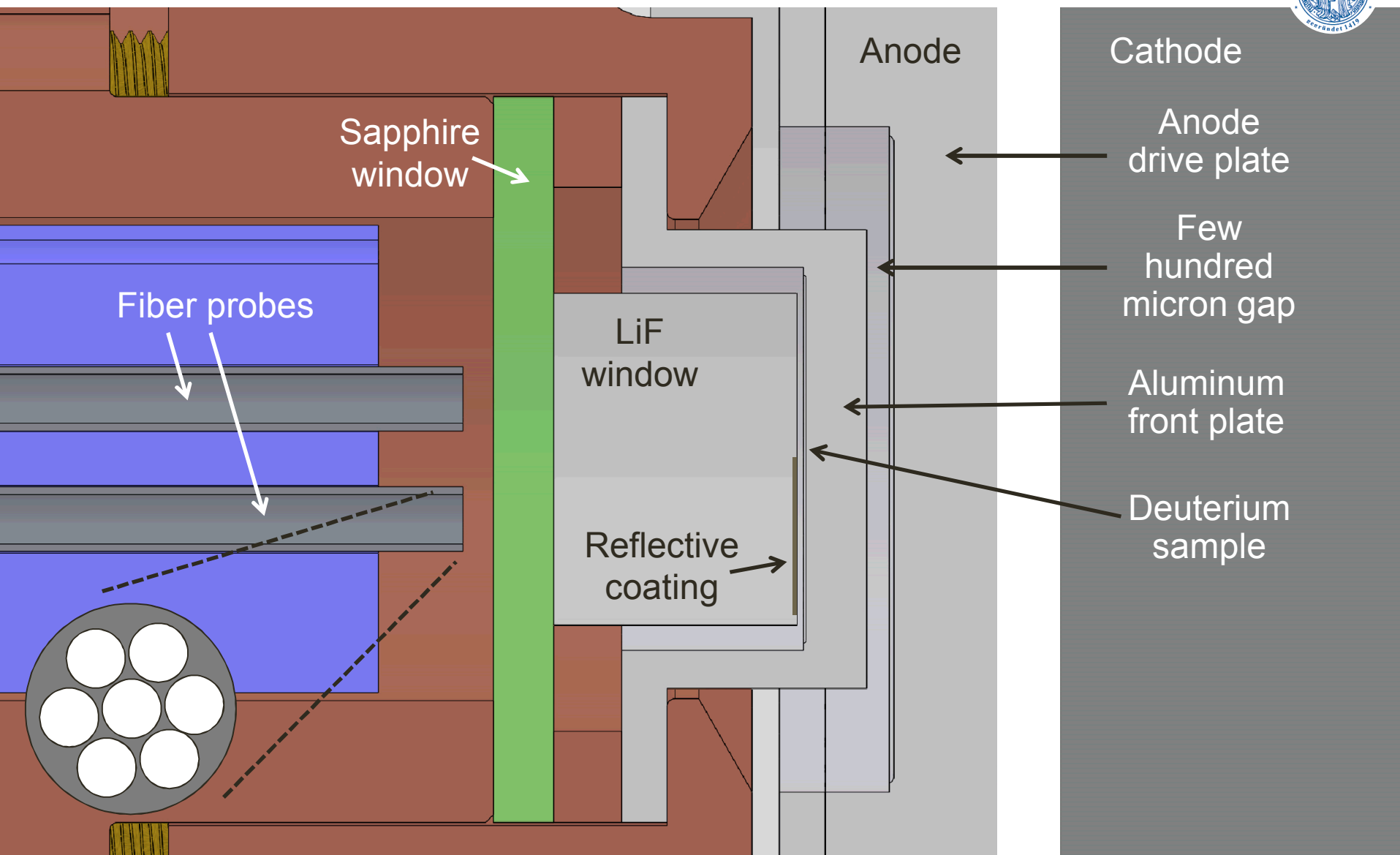


# Stripline experimental configuration



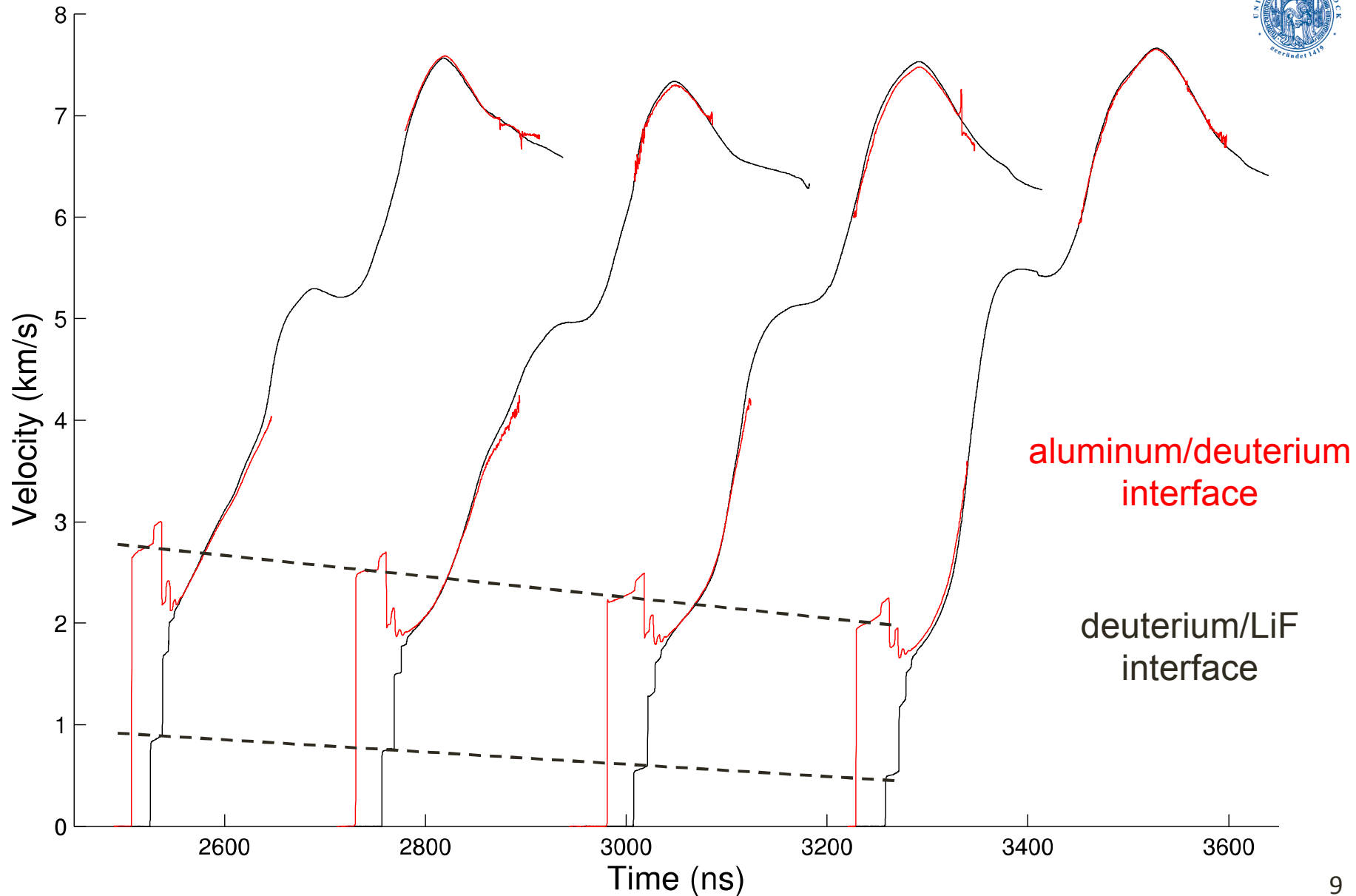


# Experimental configuration



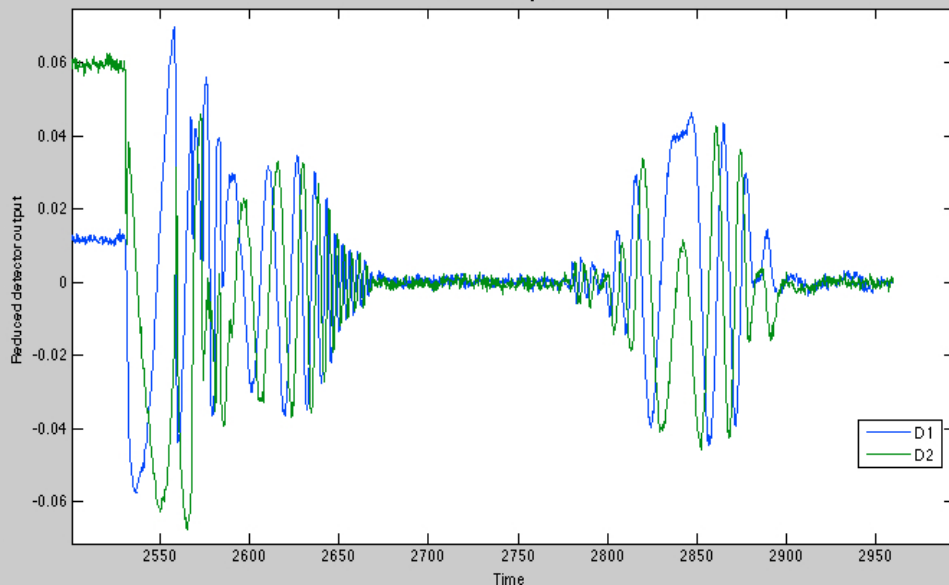
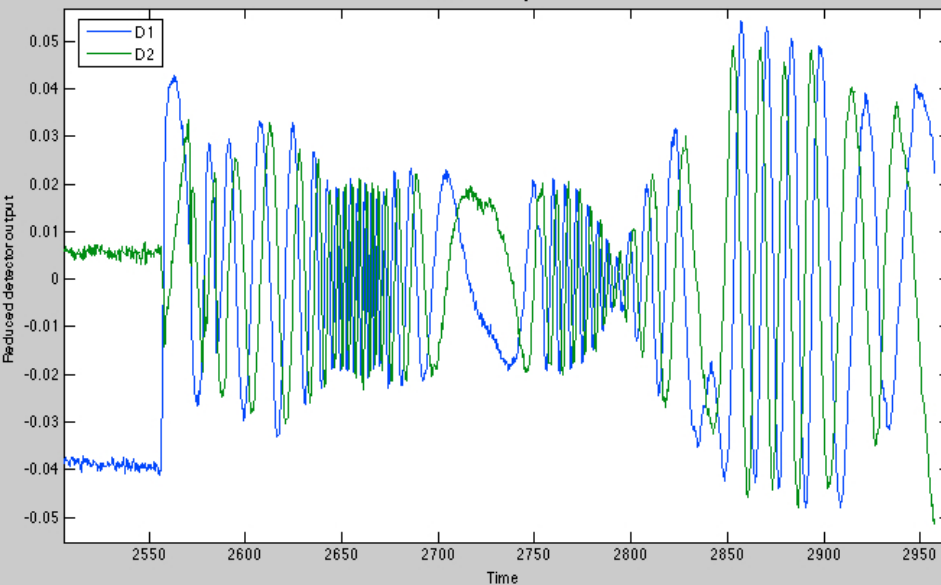
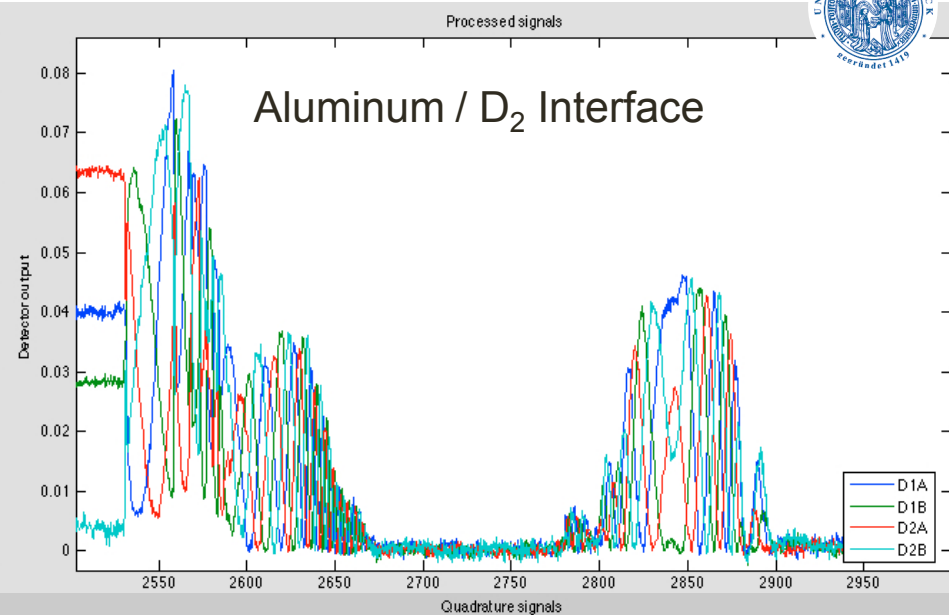
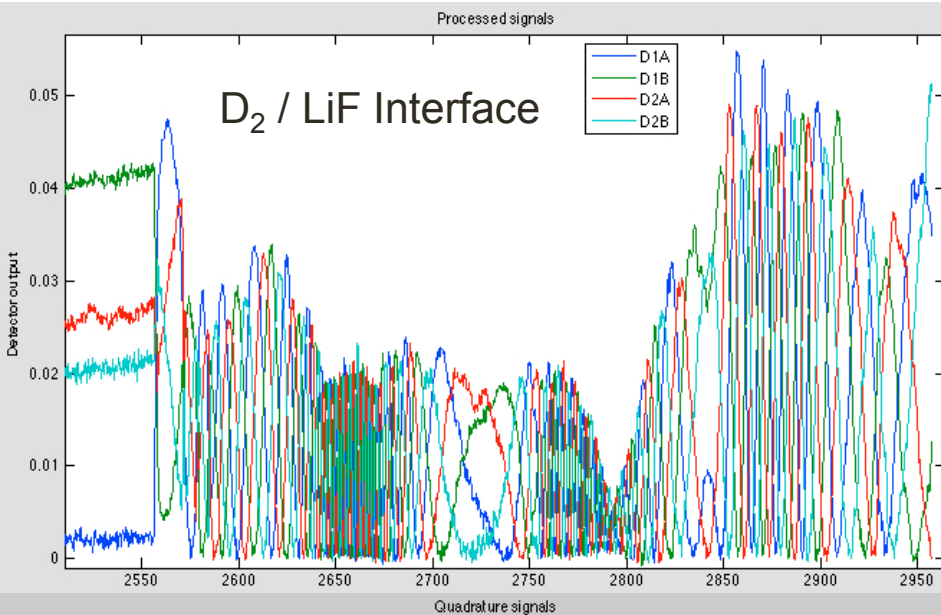


# Stripline experimental profiles





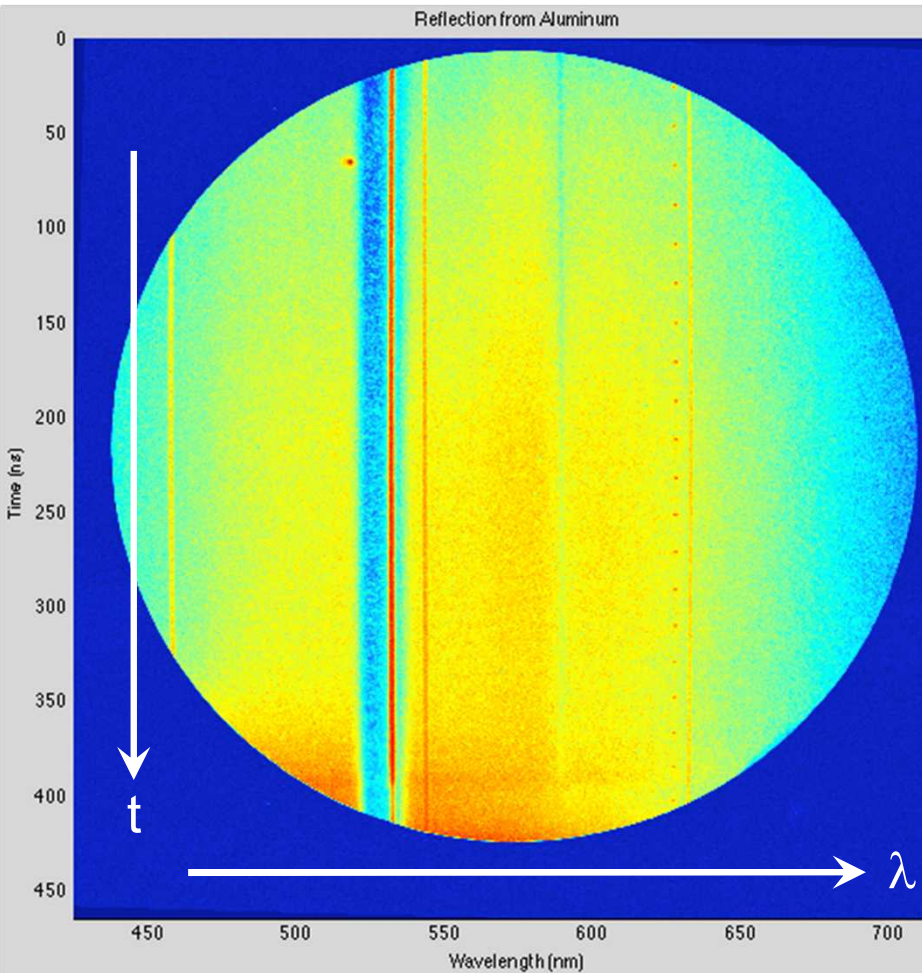
# Processed VISAR signals





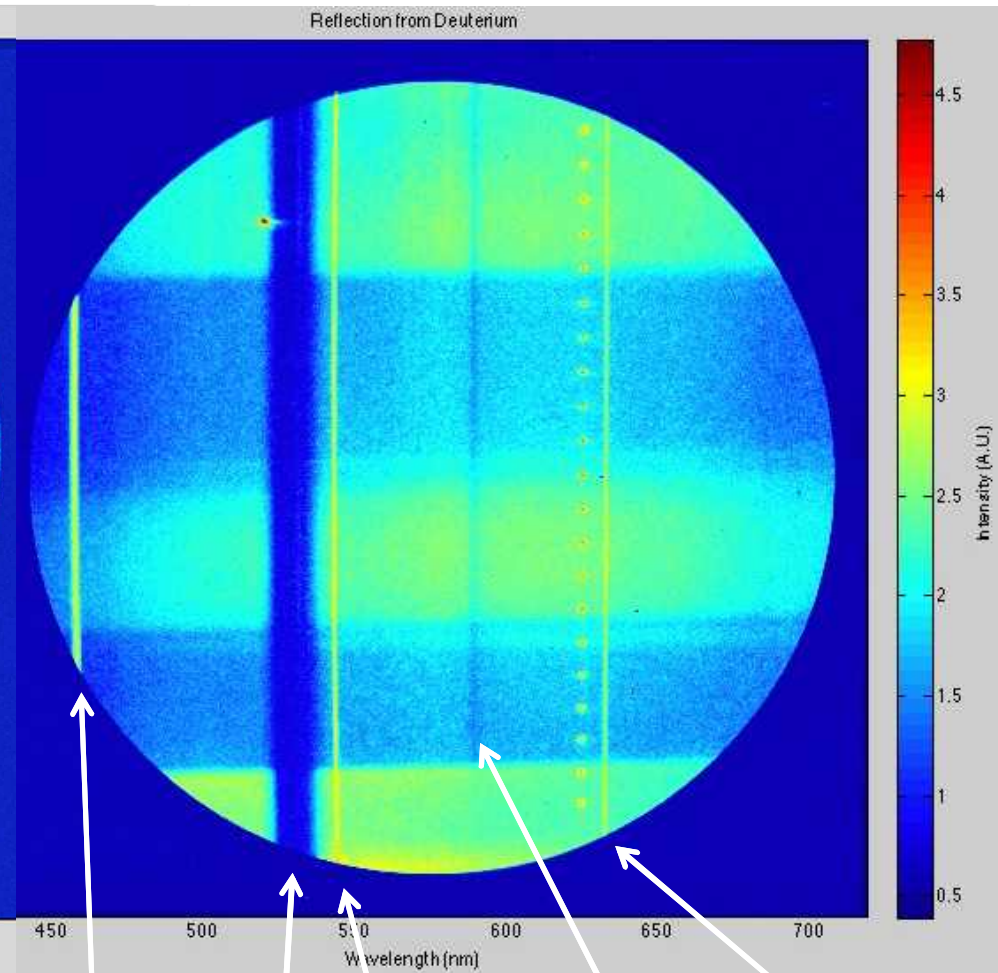
# SVS system provides data to infer reflectivity

## Reflection from aluminum coating



Wavelength range ~450-700 nm

## Reflection from deuterium



457.9 nm

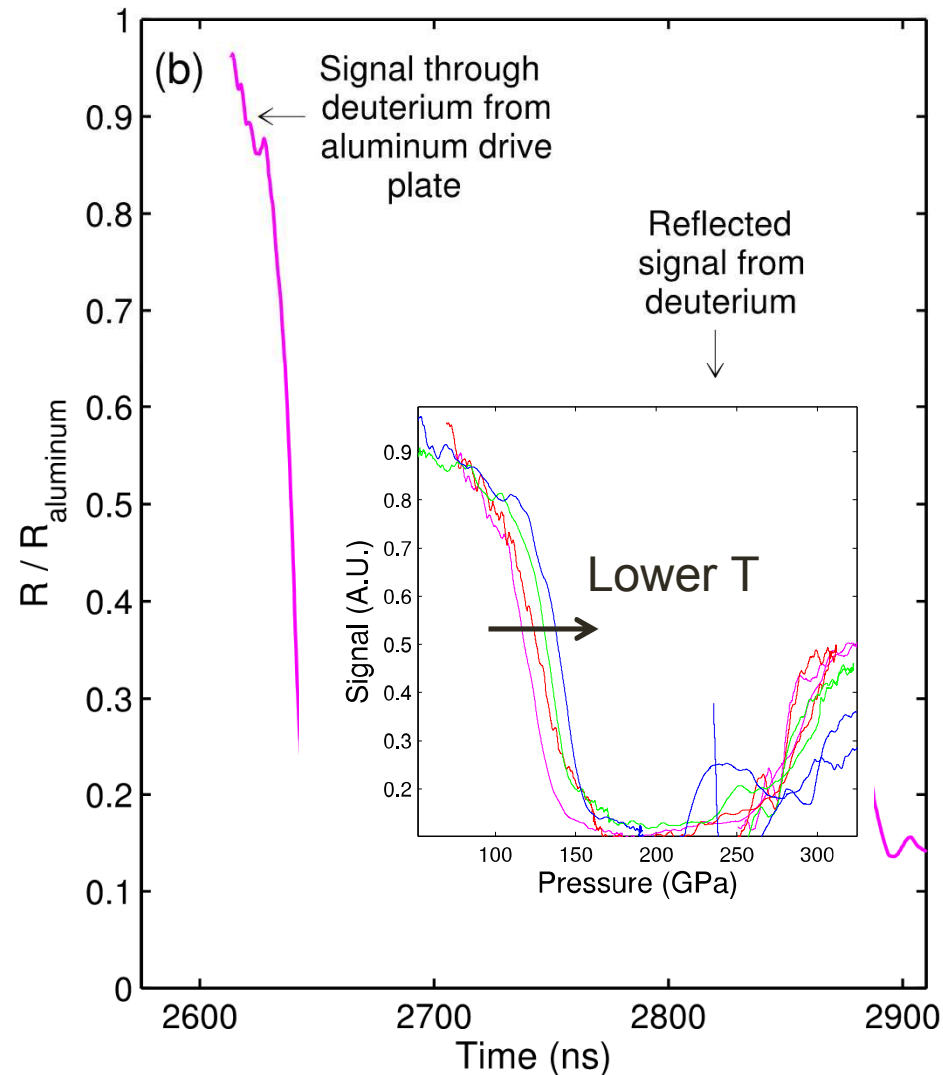
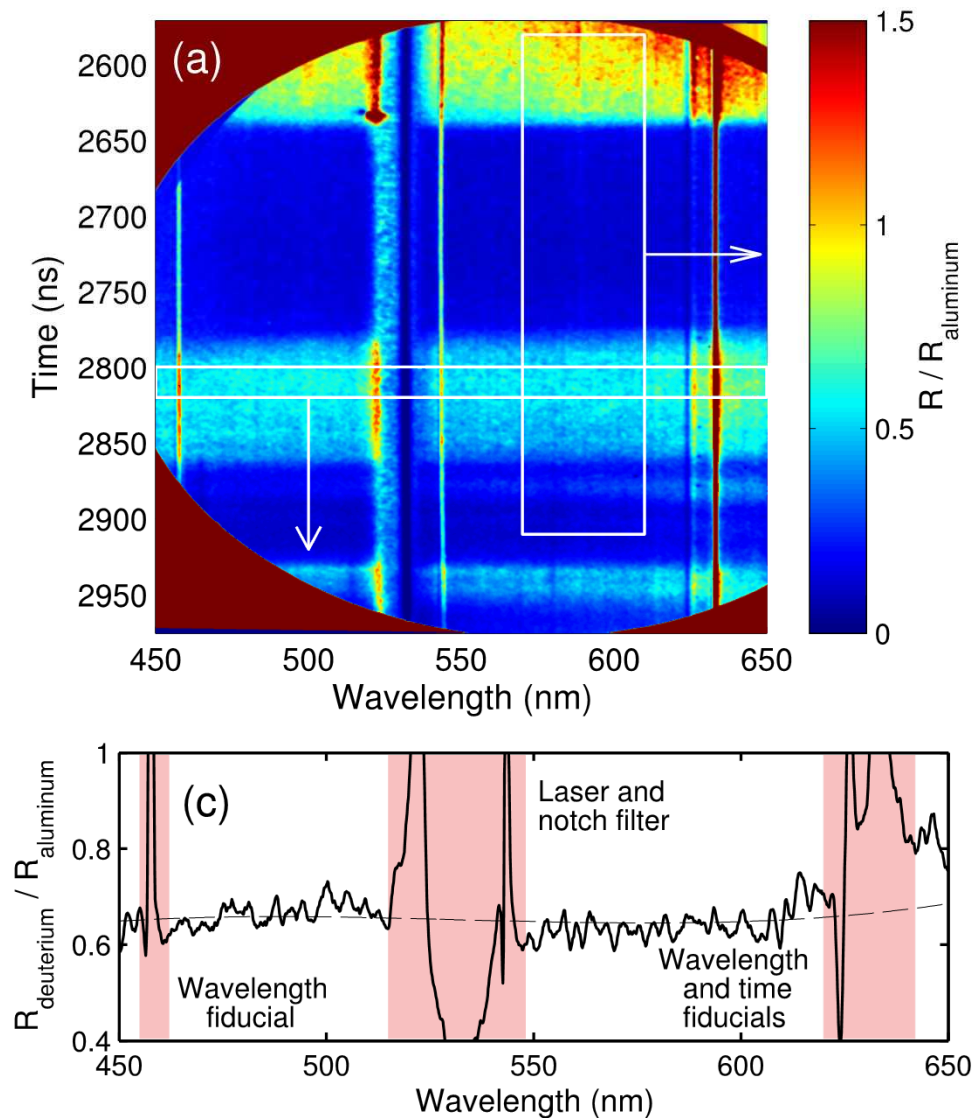
532 / 543.5 nm

589.3 nm

633 nm

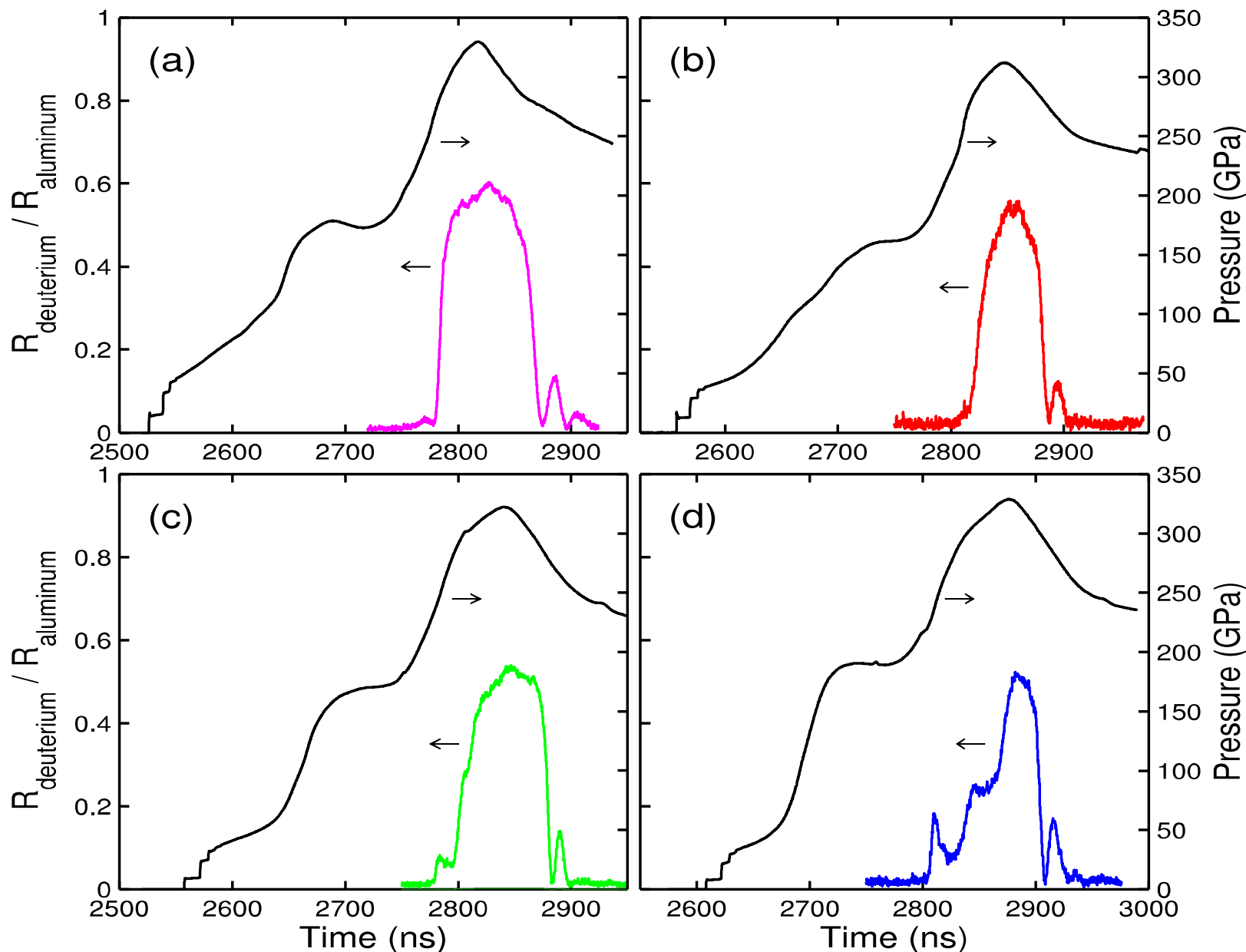


# SVS system provides data to infer reflectivity



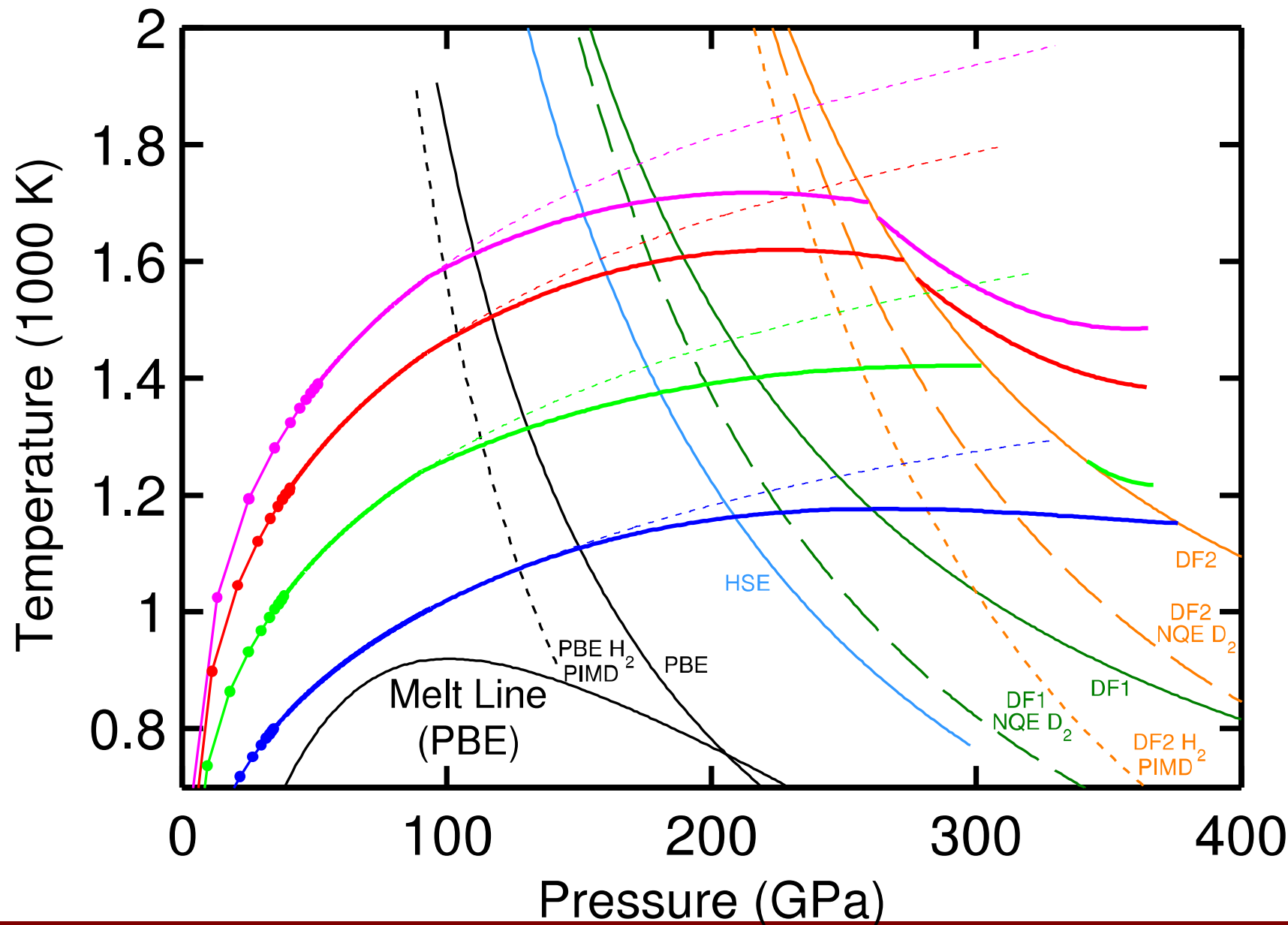


# Reflectivity and pressure vs. time from VISAR



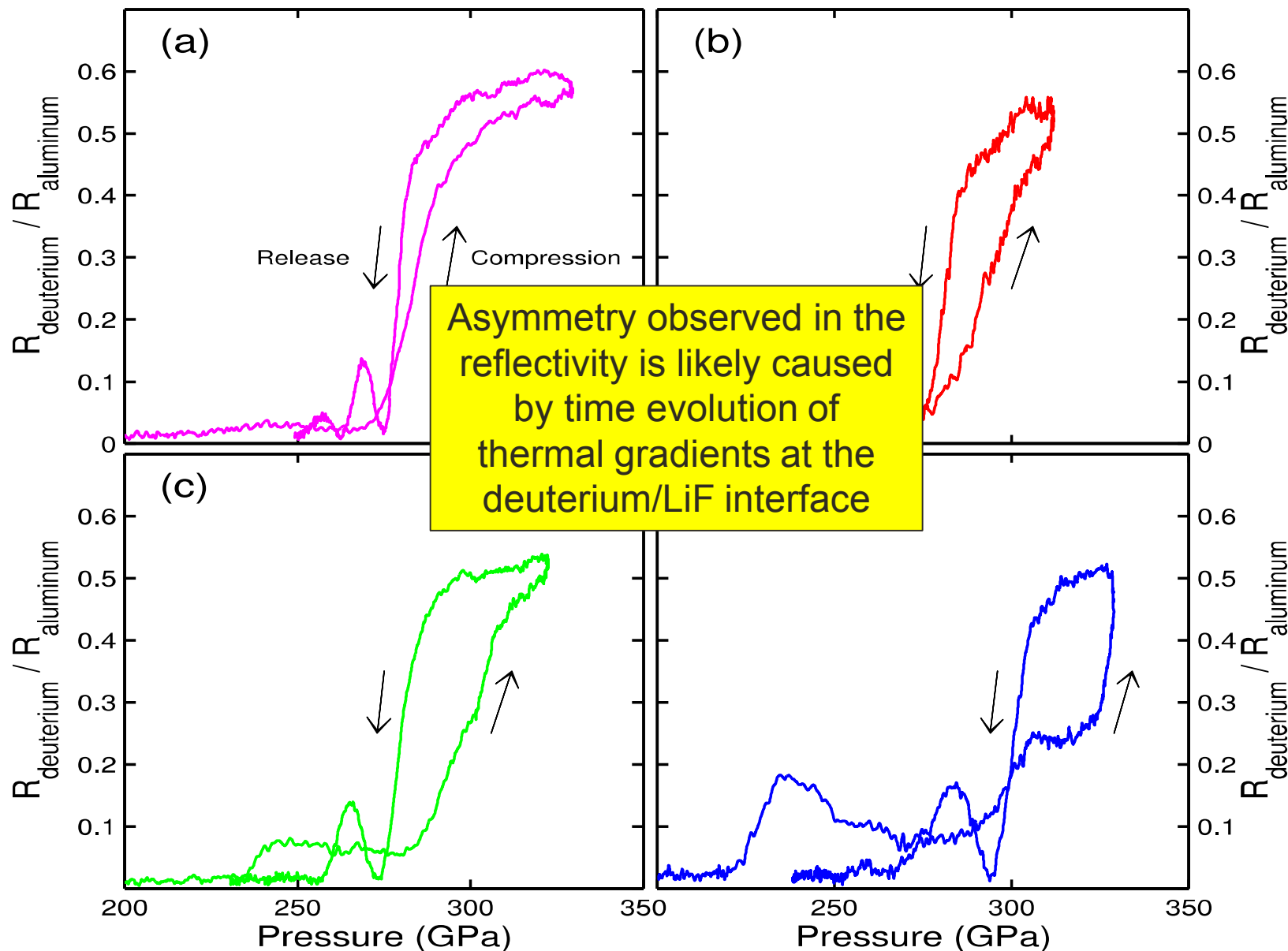


# Experimental PT Paths



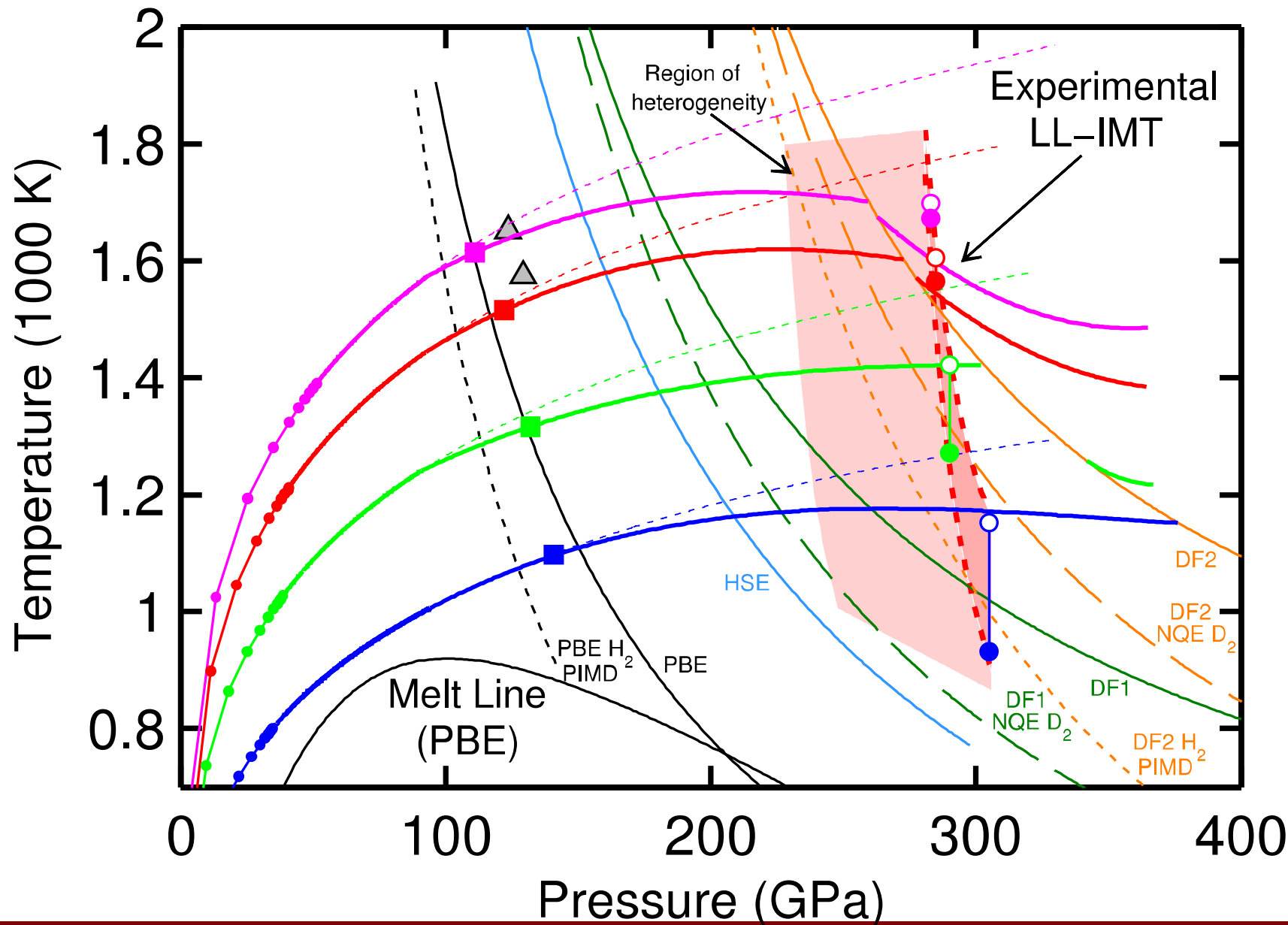


# Reflectivity signals mapped to pressure



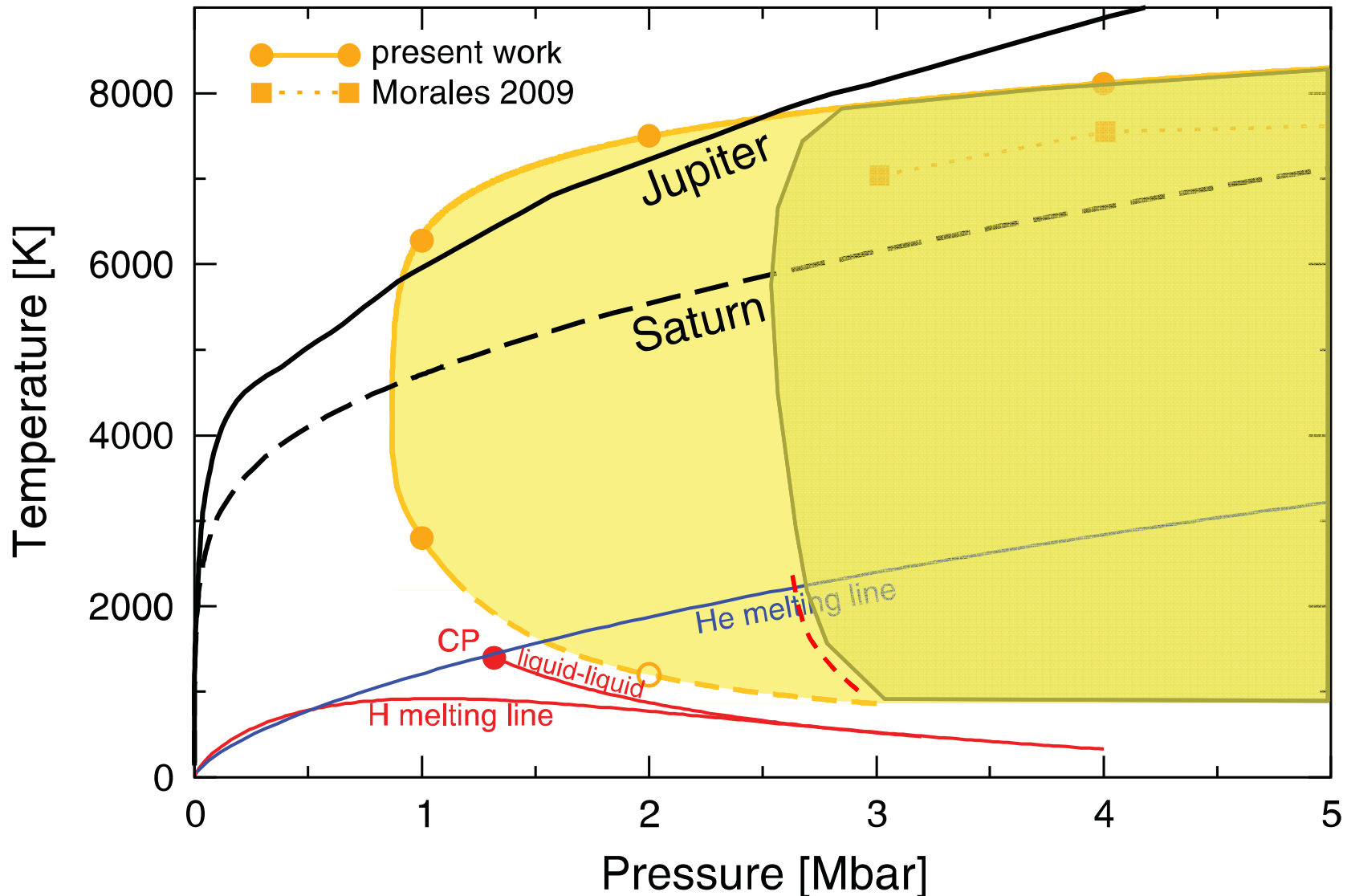


# Location of the LL-IMT in deuterium





# H-He de-mixing appears to be precipitated at low T and P by metallization in hydrogen





# Conclusions

- Shock-ramp technique enables experimental access to the region of phase space where the liquid-liquid, insulator-metal transition (LL-IMT) has been proposed for hydrogen
  - Temperature of the adiabat controlled by magnitude of initial shock
  - $P(t)$  in the experiments determined from the LiF equation of state
- Experiments above  $\sim 250$  GPa show clear evidence of metallization of deuterium
  - Very abrupt increase in reflectivity to  $\sim 40$ - $50\%$
  - Pressure state well above numerous first principles predictions
  - Indications suggest that the transition is first order
- Relative insensitivity to  $T$  suggests this is a  $\rho$ -driven transition
  - $\rho$  at the transition is inferred to be  $\sim 2$ - $2.1$  g/cc in deuterium



# Acknowledgements

## Experiment Design/Analysis

Marcus Knudson

Ray Lemke

Kyle Cochrane

Devon Dalton

Dustin Romero

## Diagnostics

Charlie Meyer

Jeff Gluth

Devon Dalton

Anthony Romero

Dave Bliss

Alan Carlson

## QMD Calculations

Mike Desjarlais

Andreas Becker

Winfried Lorenzen

Ronald Redmer

## Planetary Modeling

Nadine Nettelmann

Andreas Becker

Ronald Redmer

## Pulse Shaping

Ray Lemke

Jean-Paul Davis

Mark Savage

Ken Struve

Keith LeChien

Brian Stoltzfus

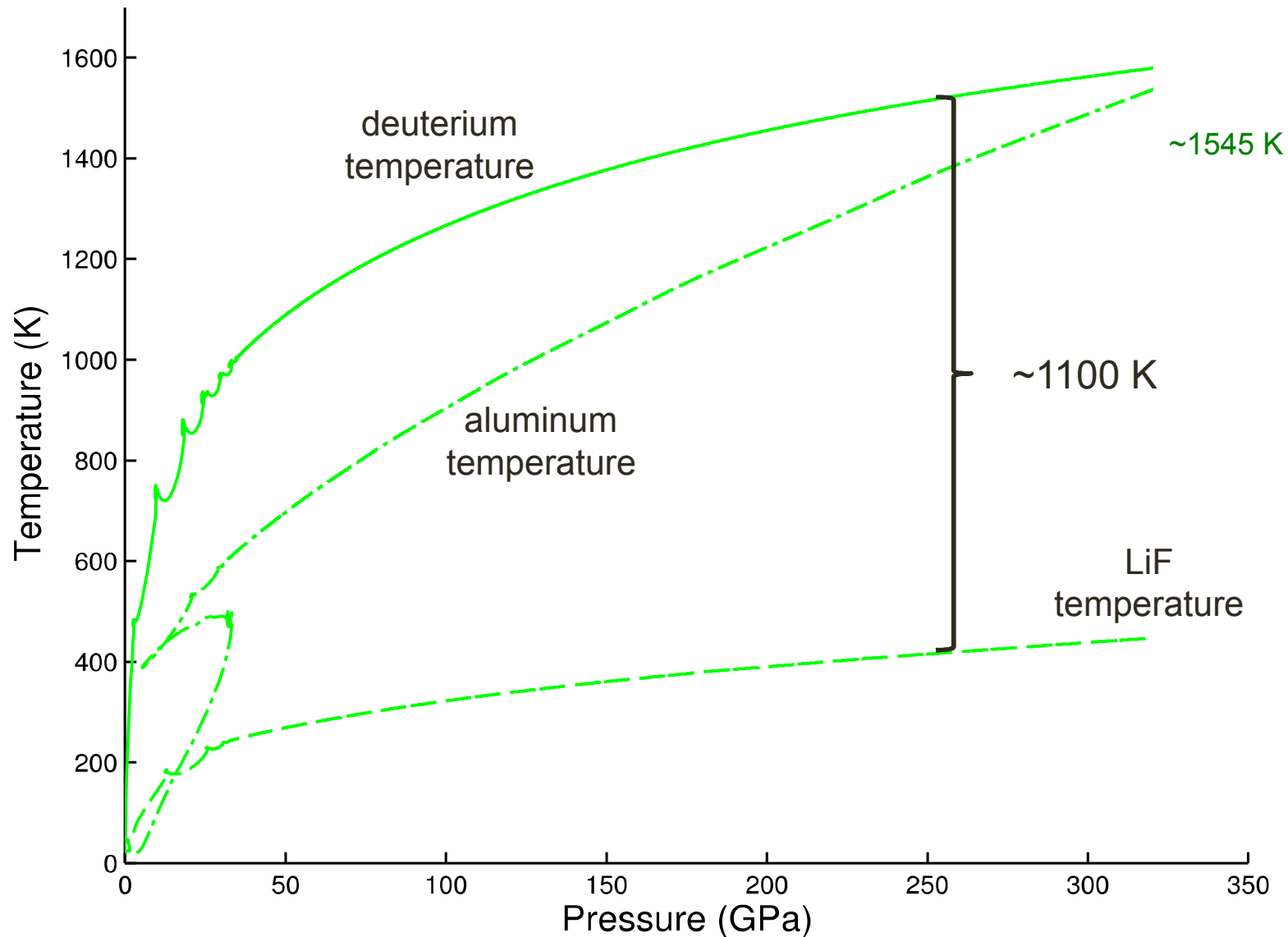
Dave Hinshelwood

Entire Z crew

University of Rostock

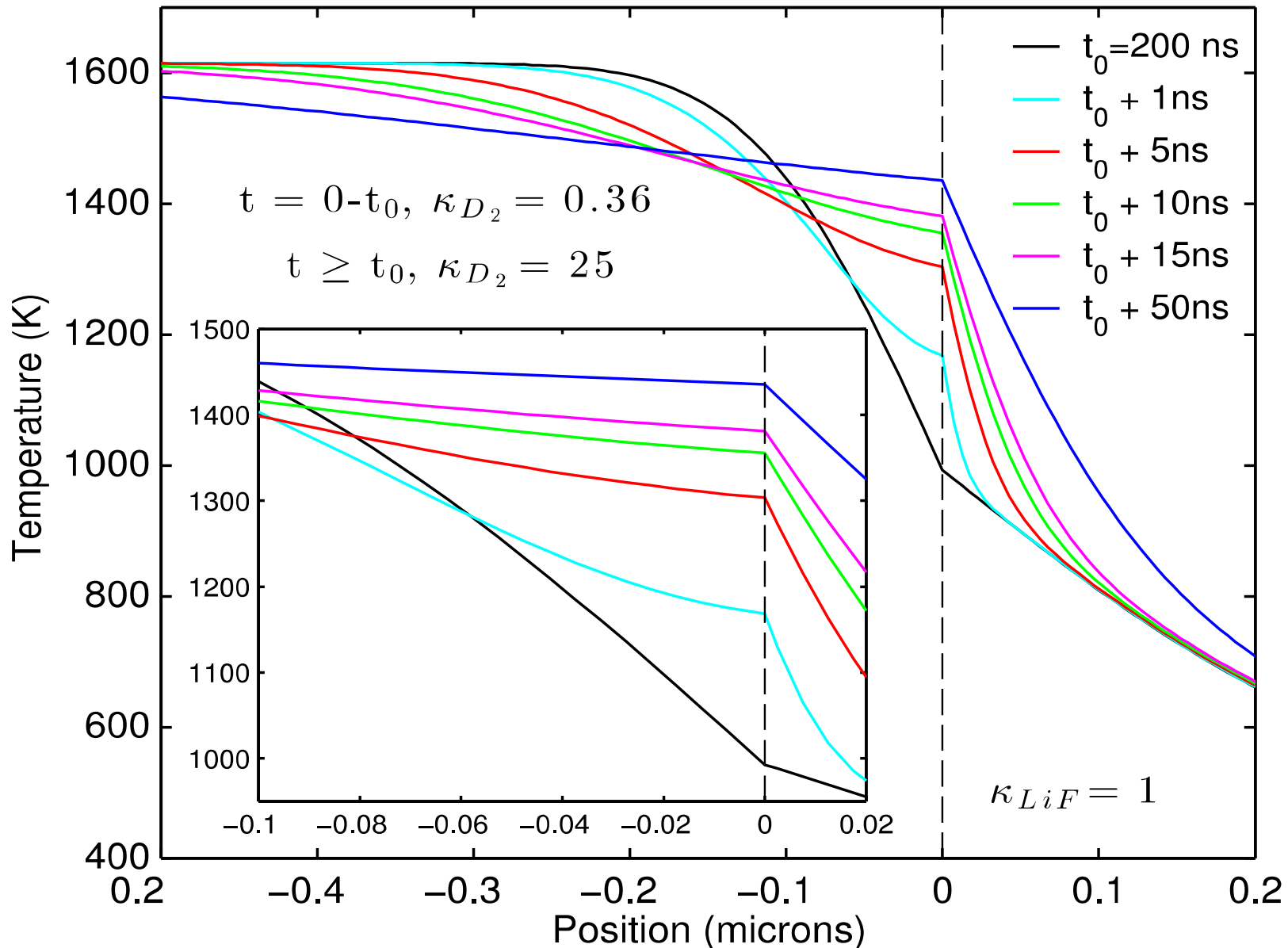


# There is a significant temperature difference at the deuterium/LiF interface





# Thermal conduction simulations





# Reflectivity signals mapped to pressure

