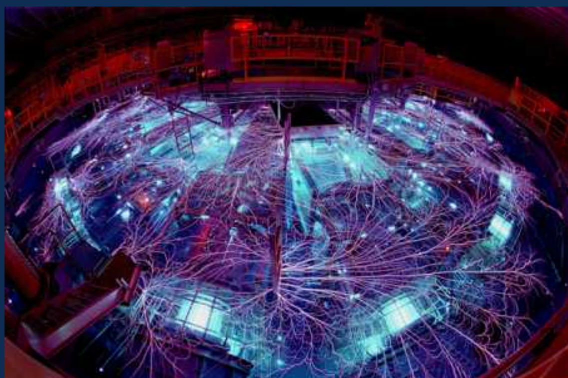
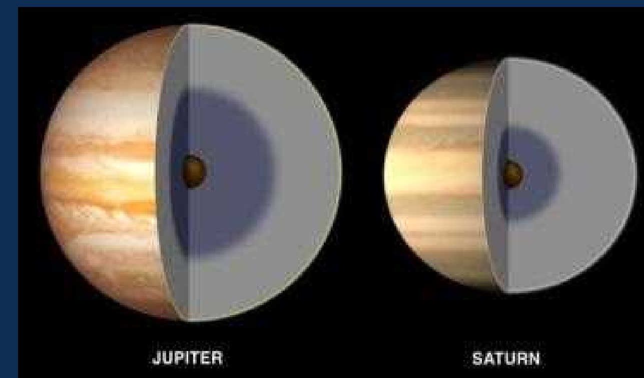
SAND2014-15175PE

Exceptional service in the national interest





Dynamic compression experiments on liquid deuterium above the melt boundary

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Albuquerque, NM

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Acknowledgements

Experiment Design/Analysis

Marcus Knudson

Ray Lemke

Kyle Cochrane

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Diagnostics

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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

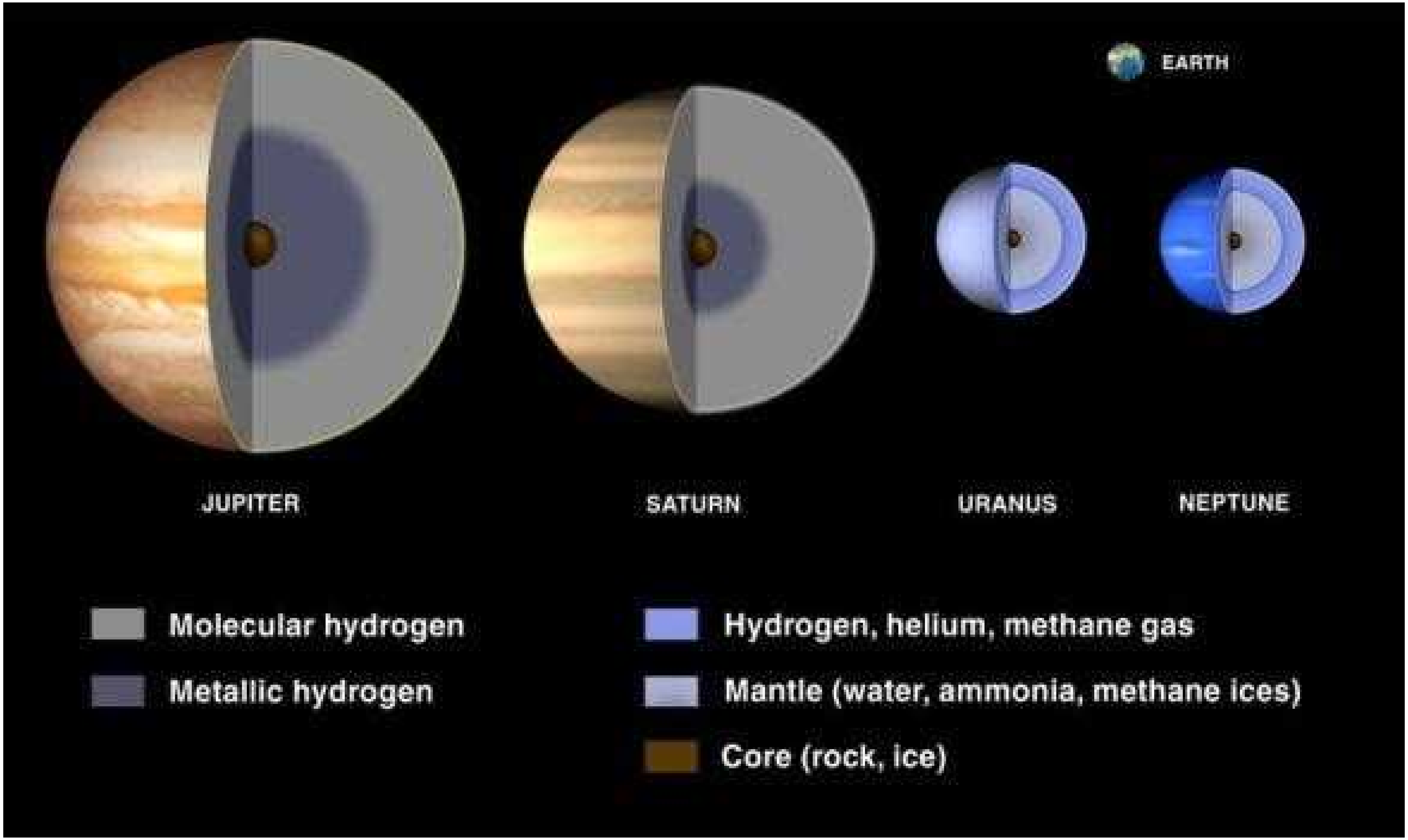
Dave Hinshelwood

Entire Z crew

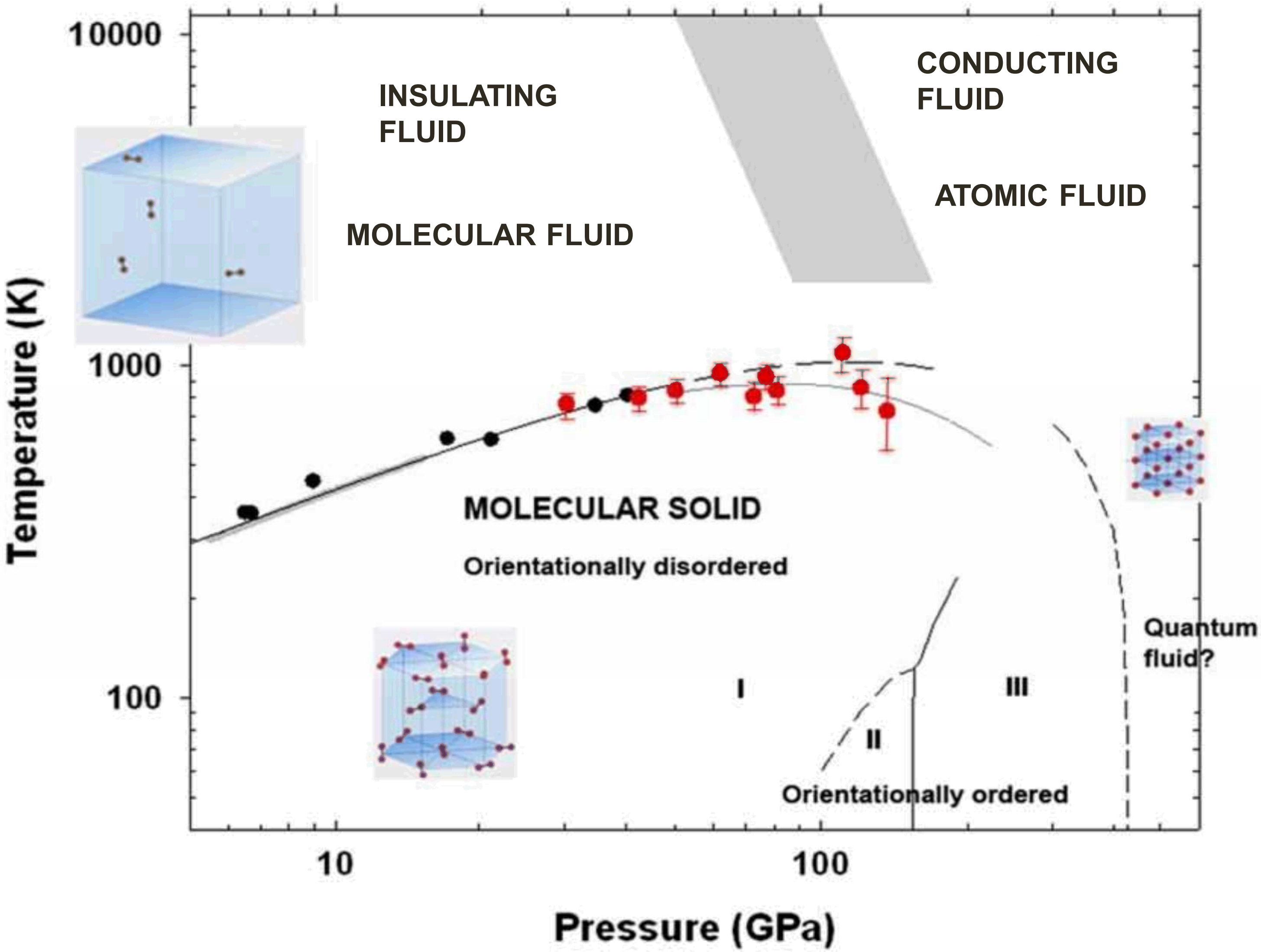
University of Rostock

Giant planets in the Solar system

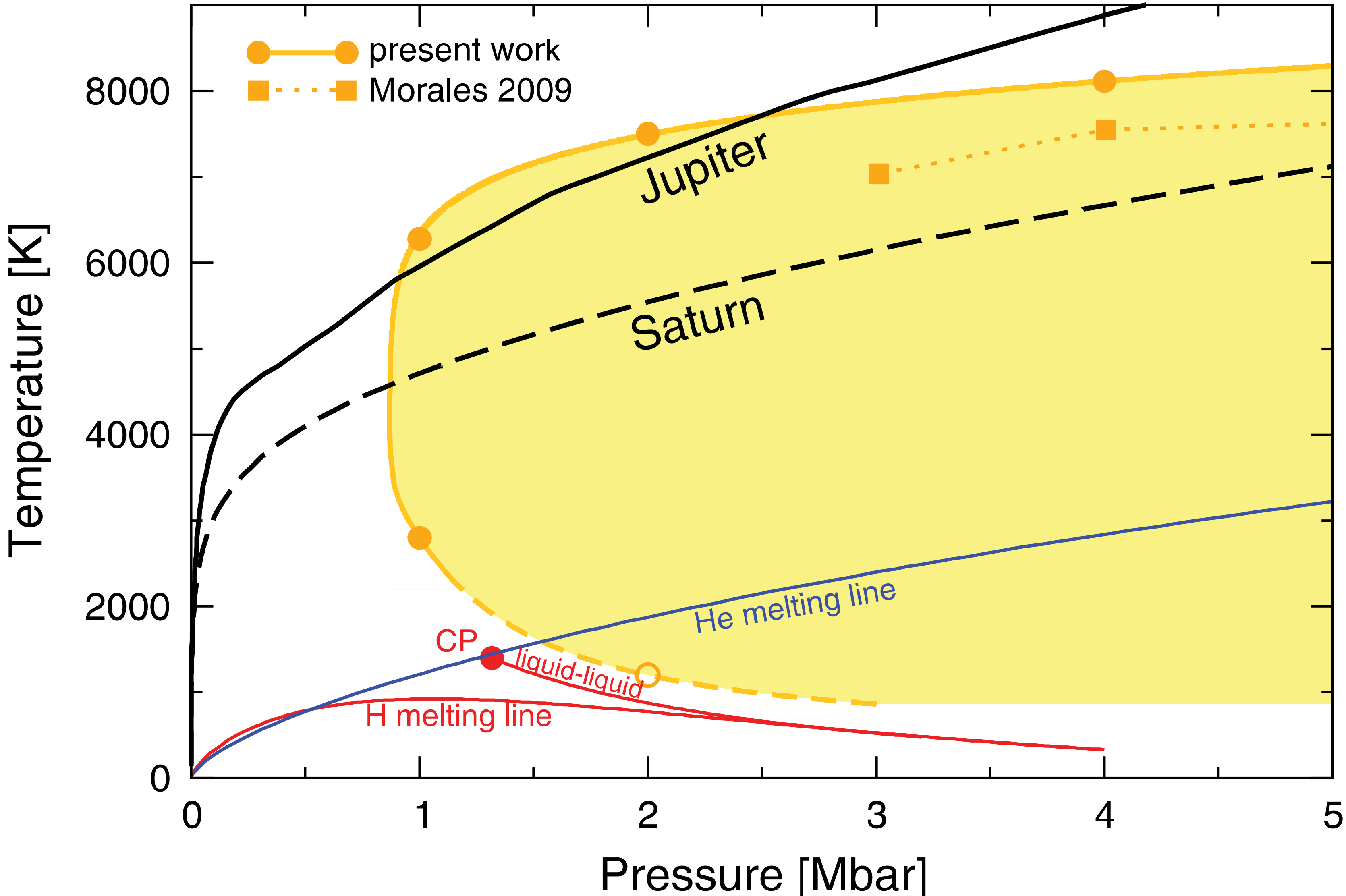
Interior composed of the lightest elements H & He, hydrides NH_3, OH_2, CH_4 (ices) and small amounts of heavier elements (cores)



Hydrogen at high pressures – the known phase diagram so far

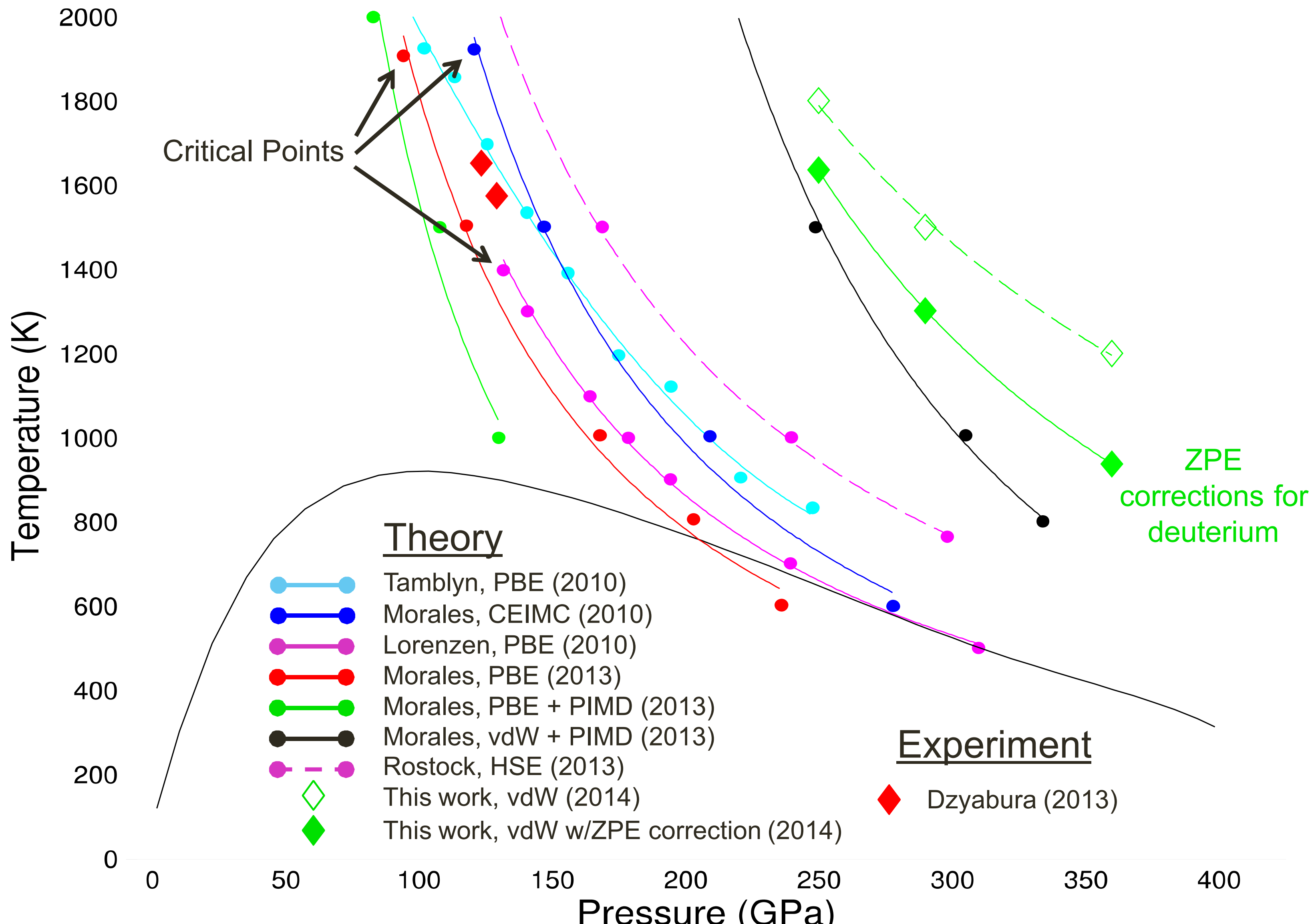


H-He de-mixing appears to be precipitated at low T and P by metallization in hydrogen

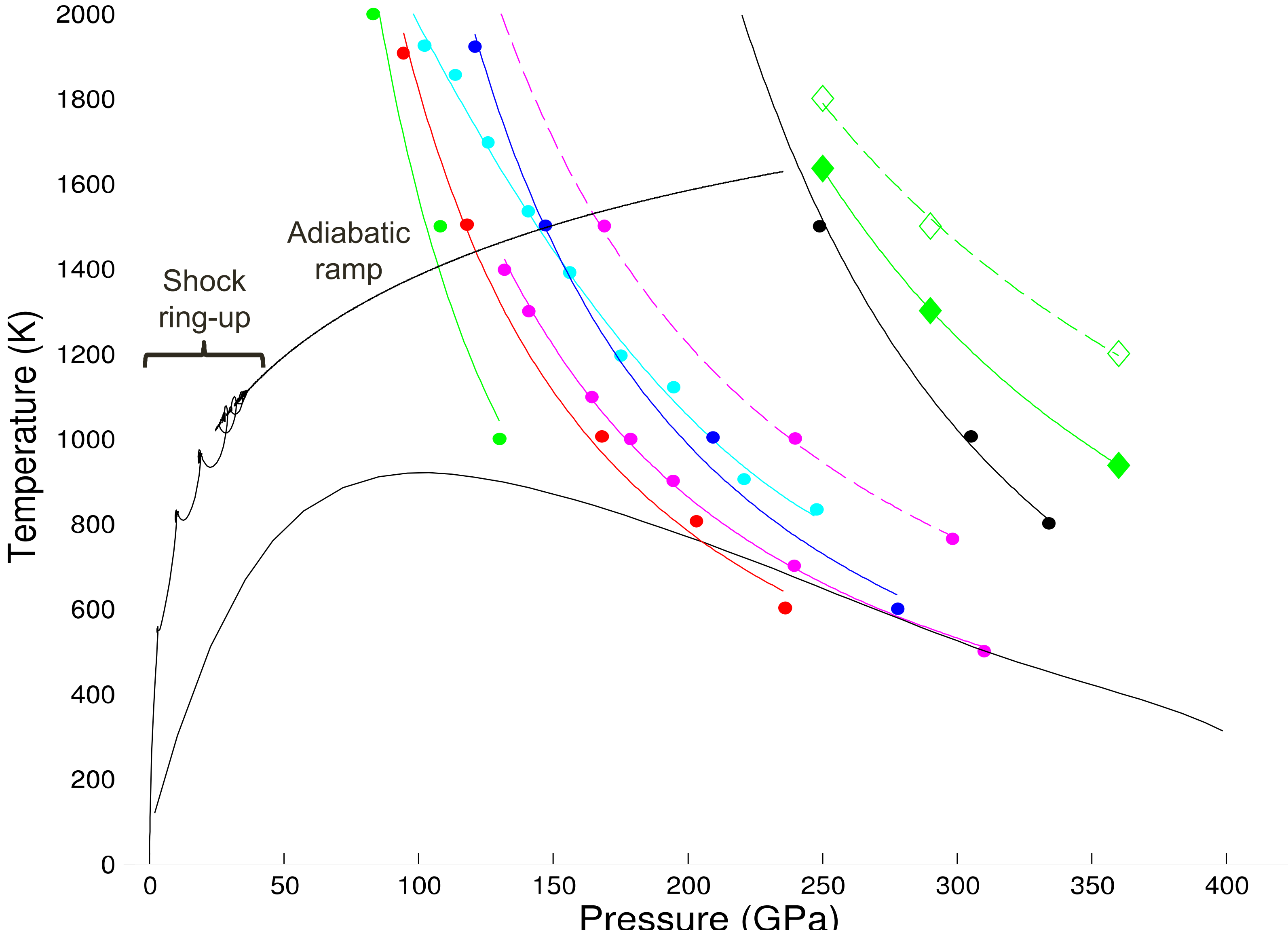


W. Lorenzen, B. Holst, and R. Redmer, Phys. Rev. B 84, 235109 (2011)

Recent predictions for LL-IMT in H

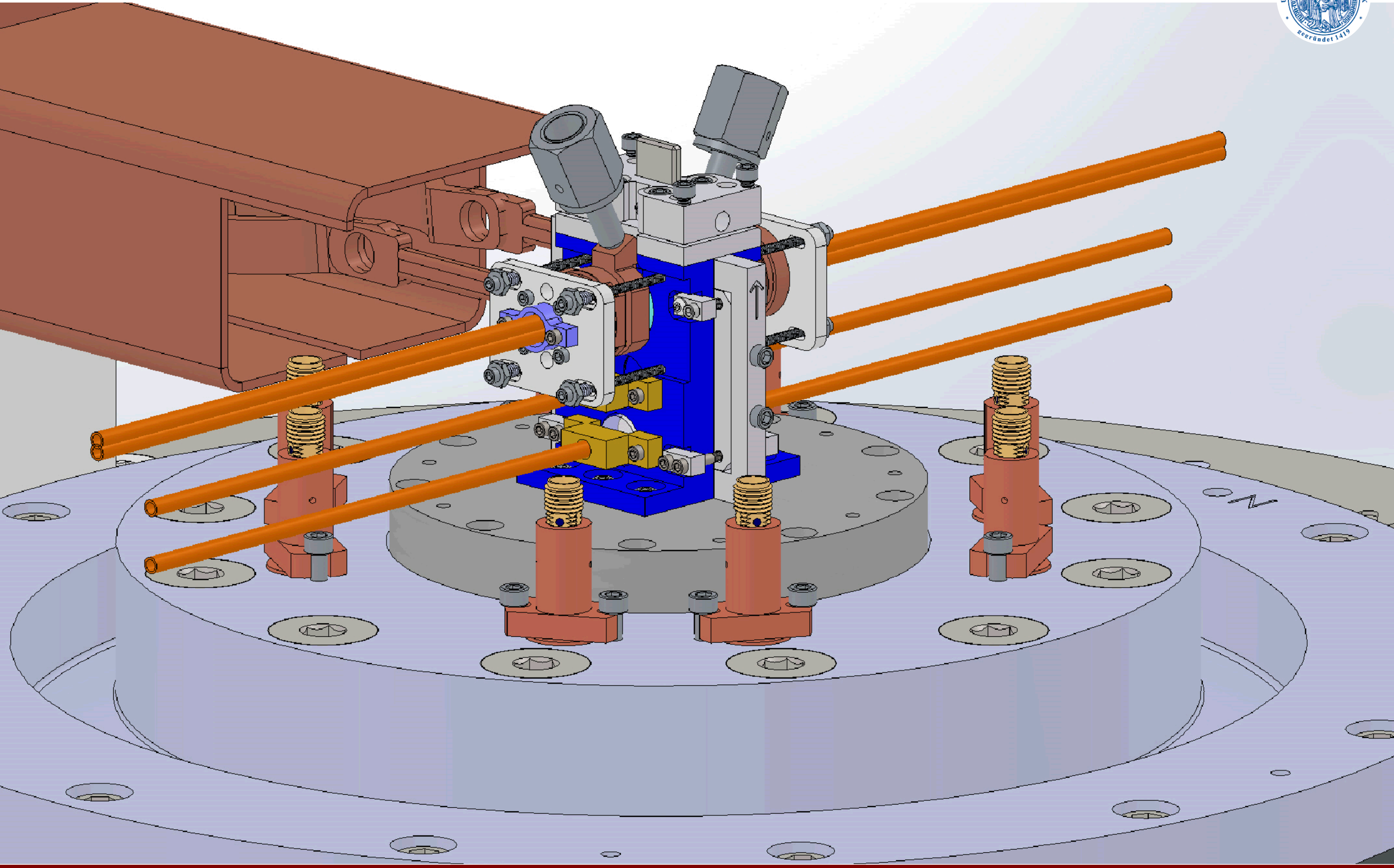


Proposed Experiment

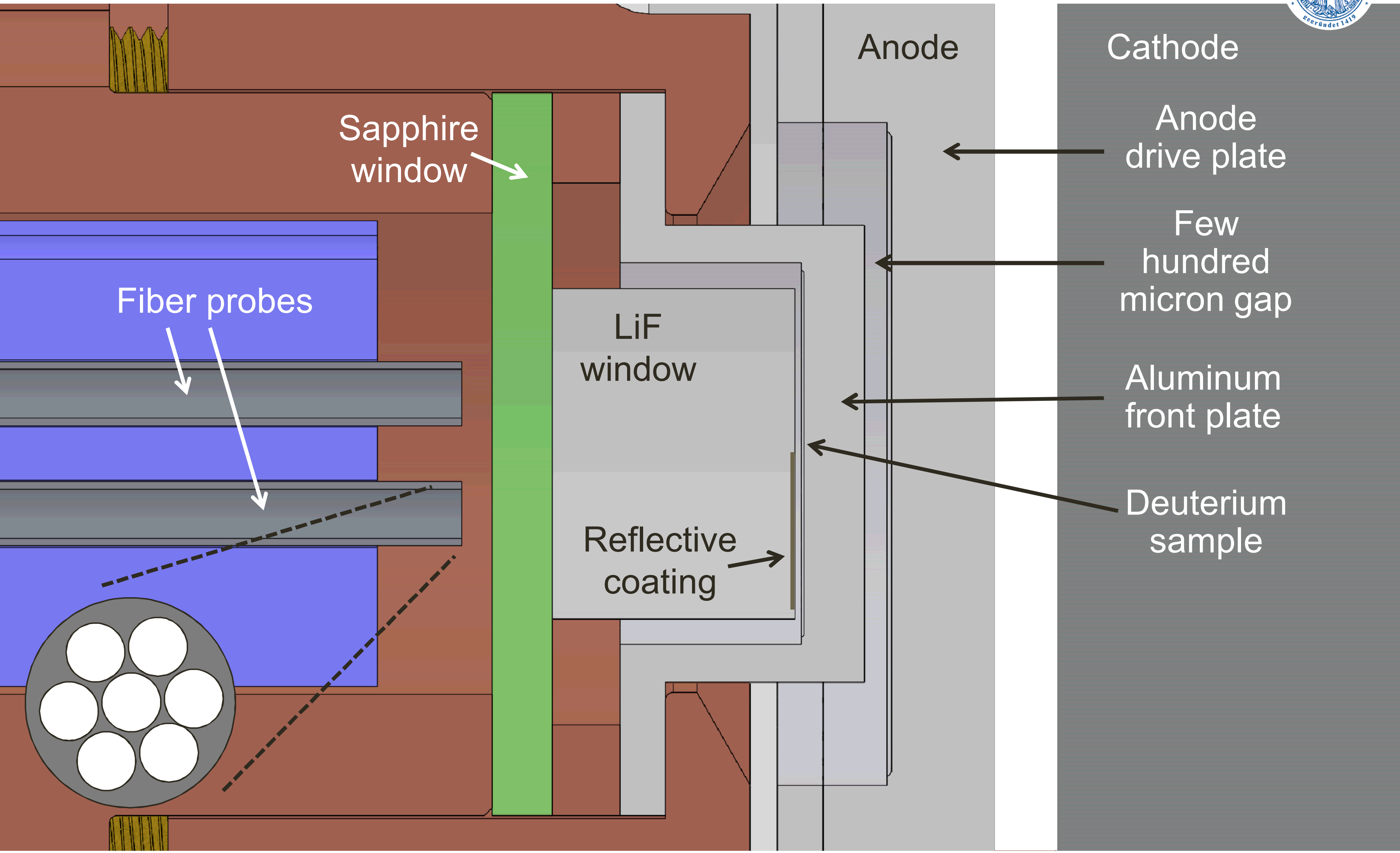


Coaxial experimental configuration

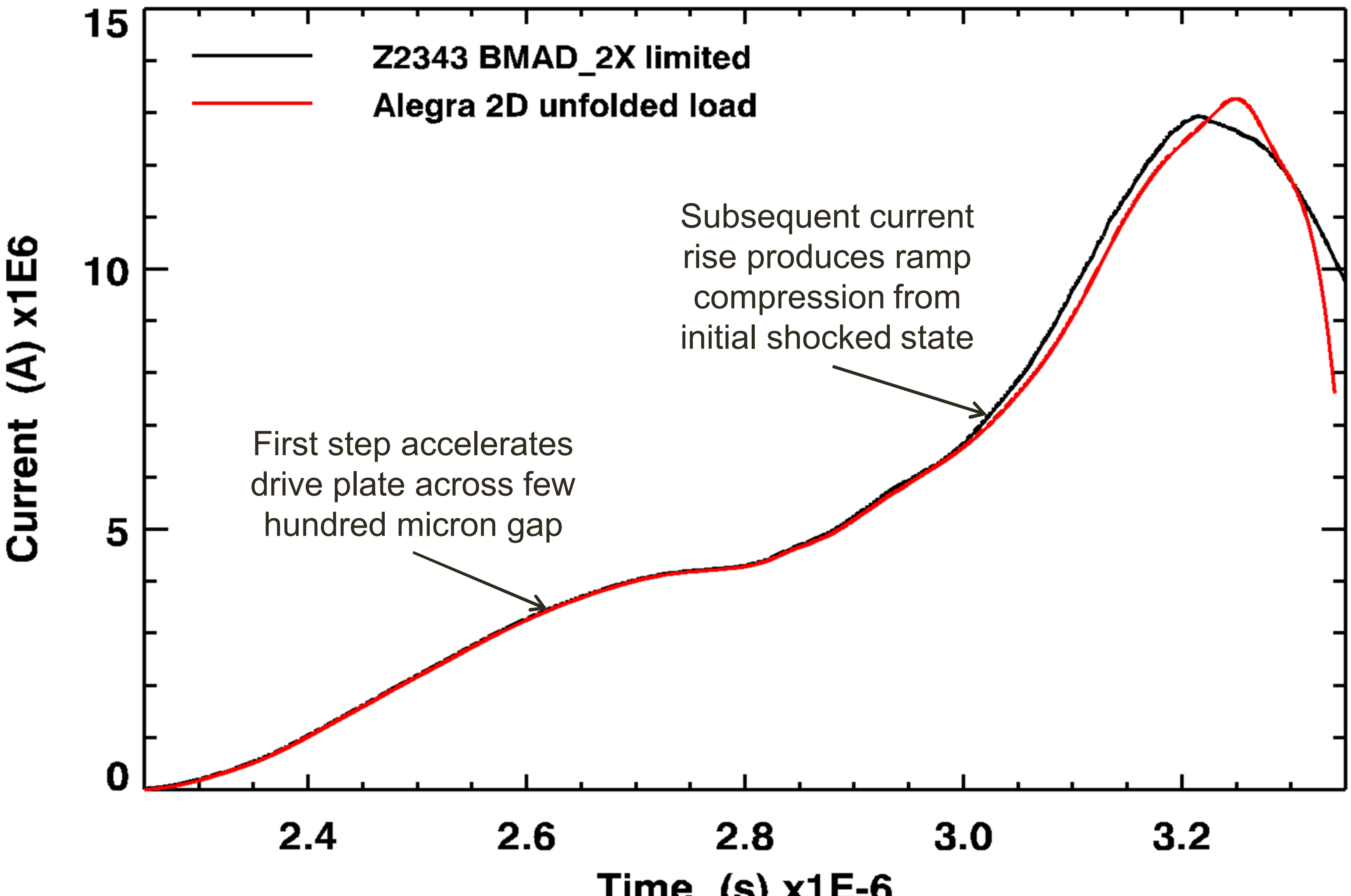
Sandia National Laboratories



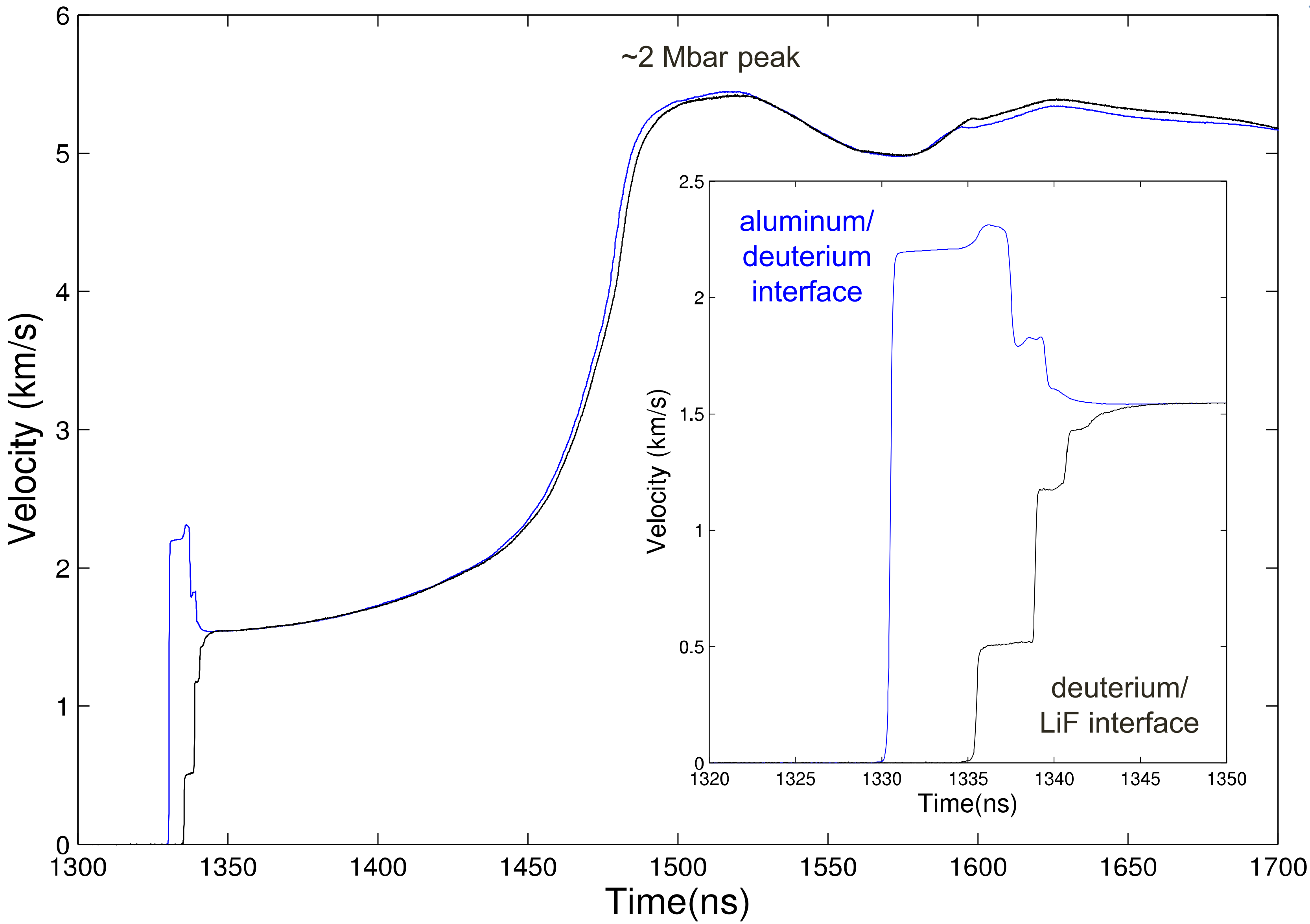
Experimental configuration



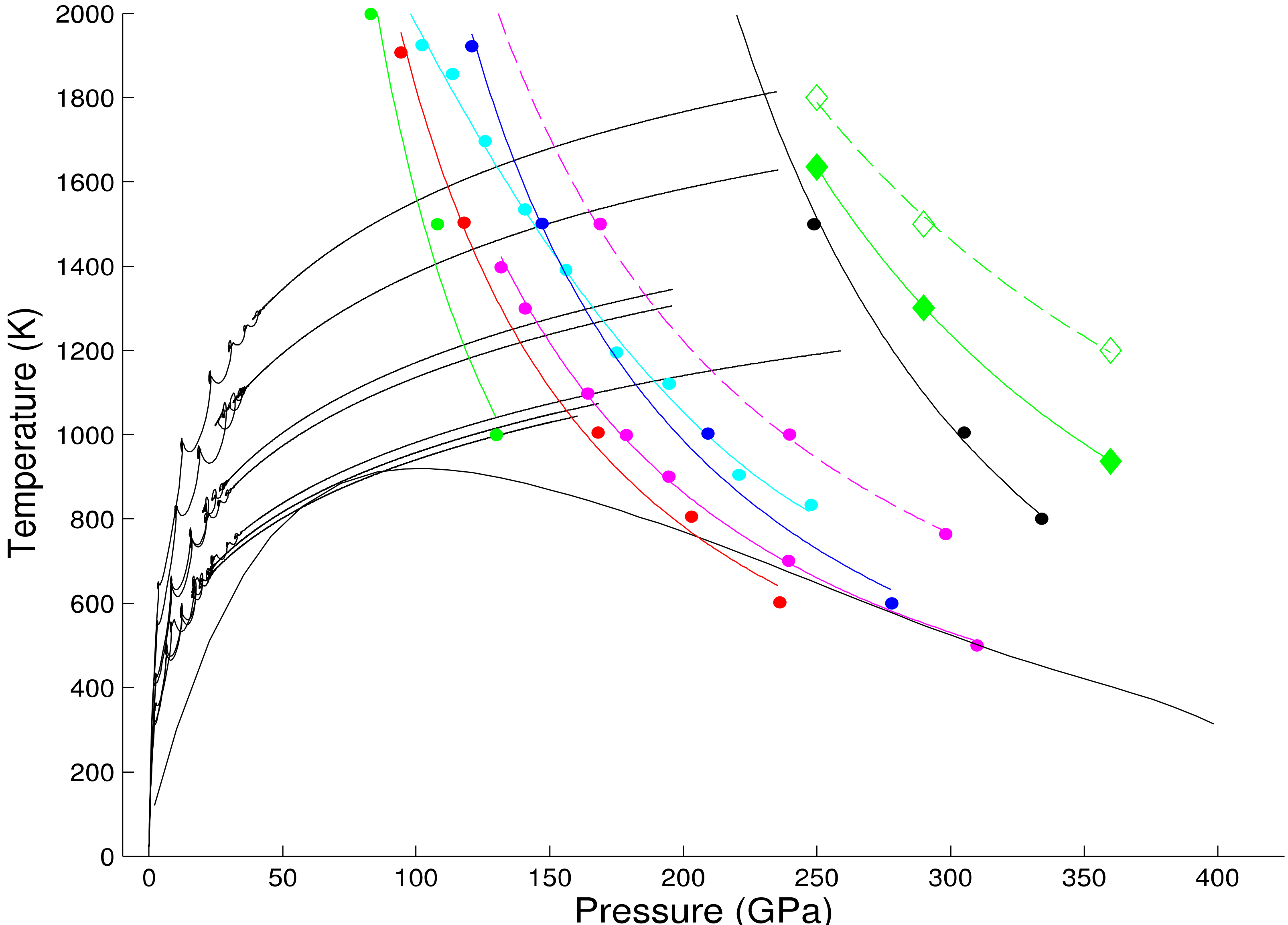
Two-step pulse shape provides shock-ramp profile



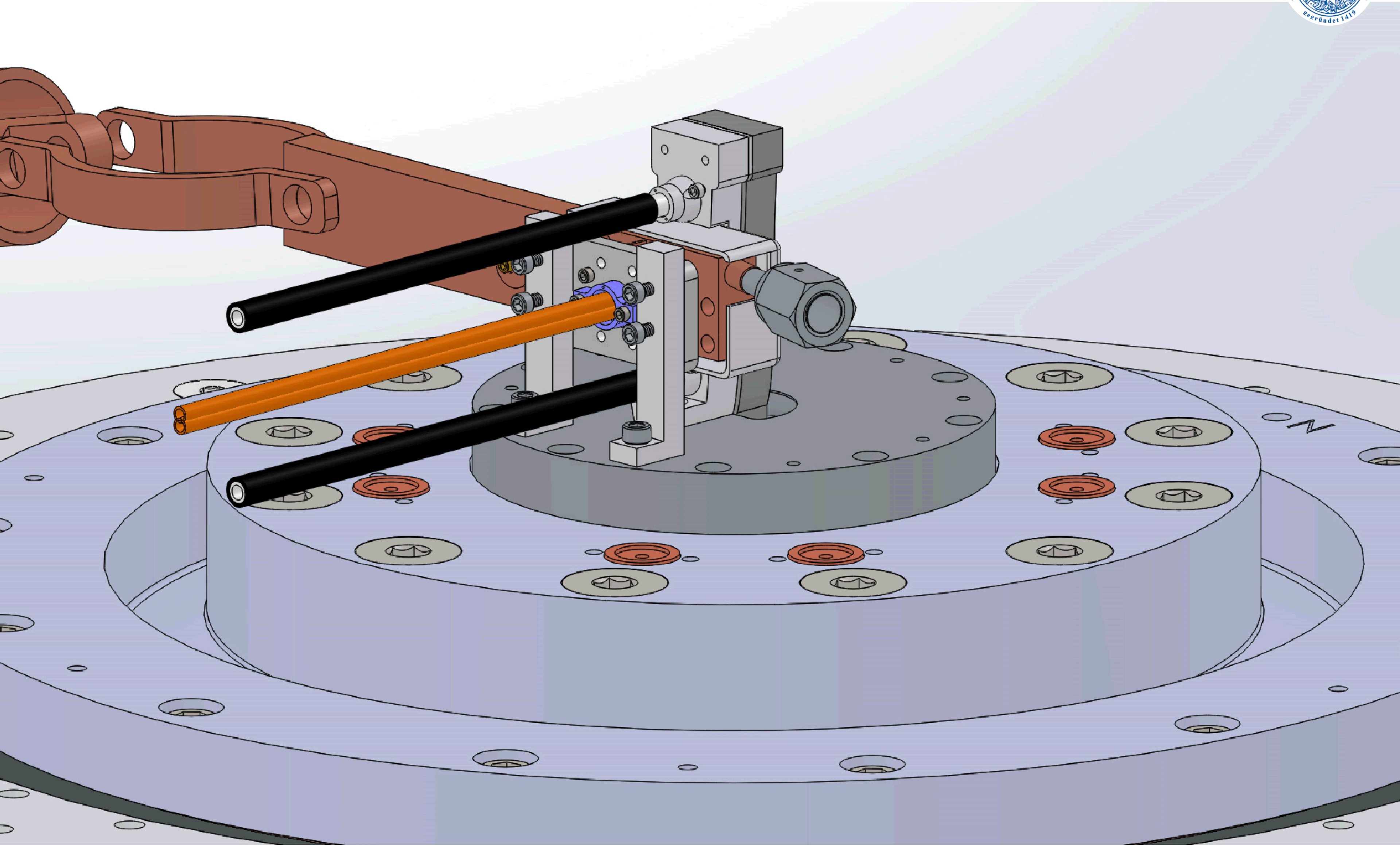
Coaxial experimental profiles



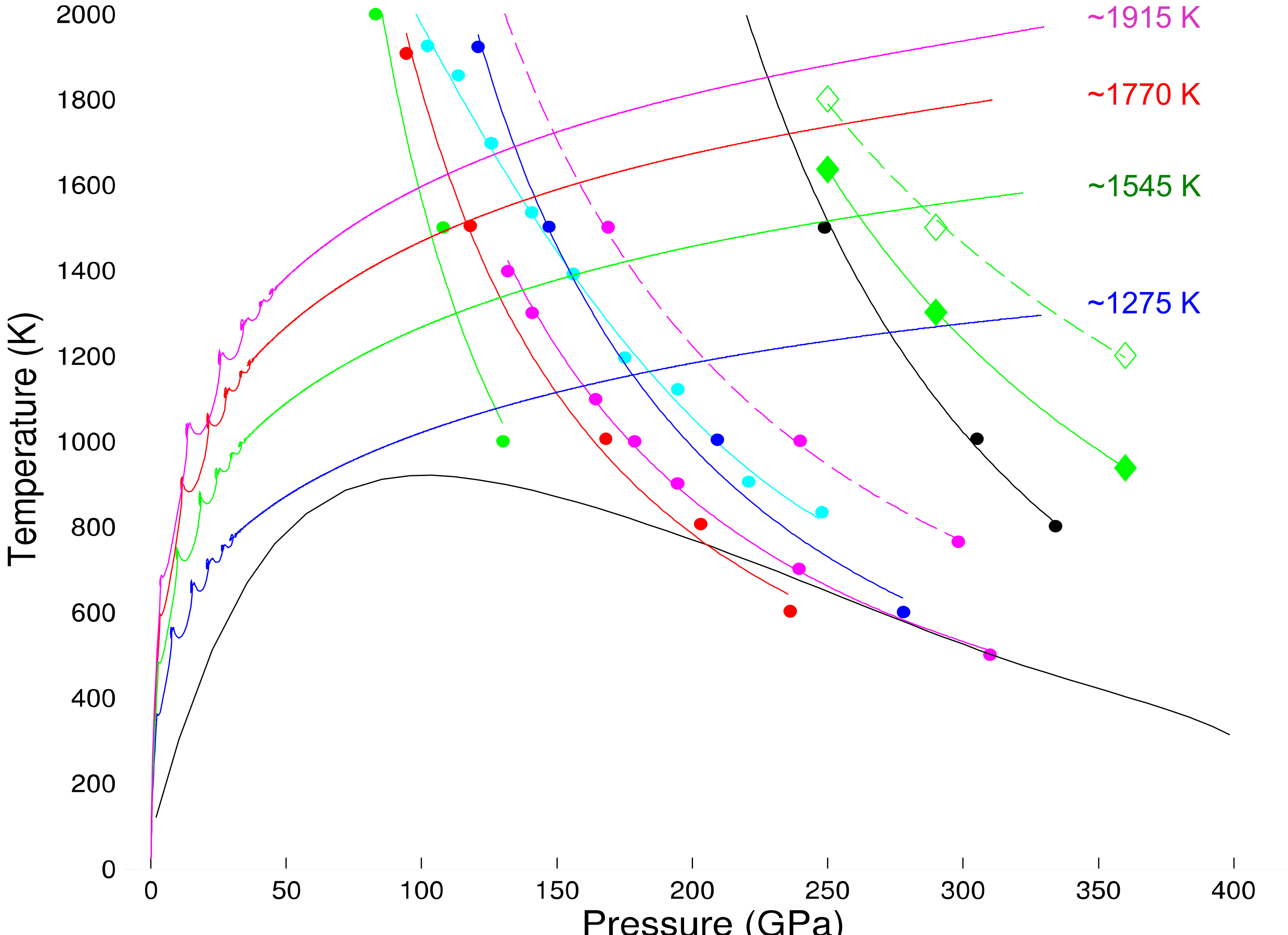
Coaxial experiment PT paths



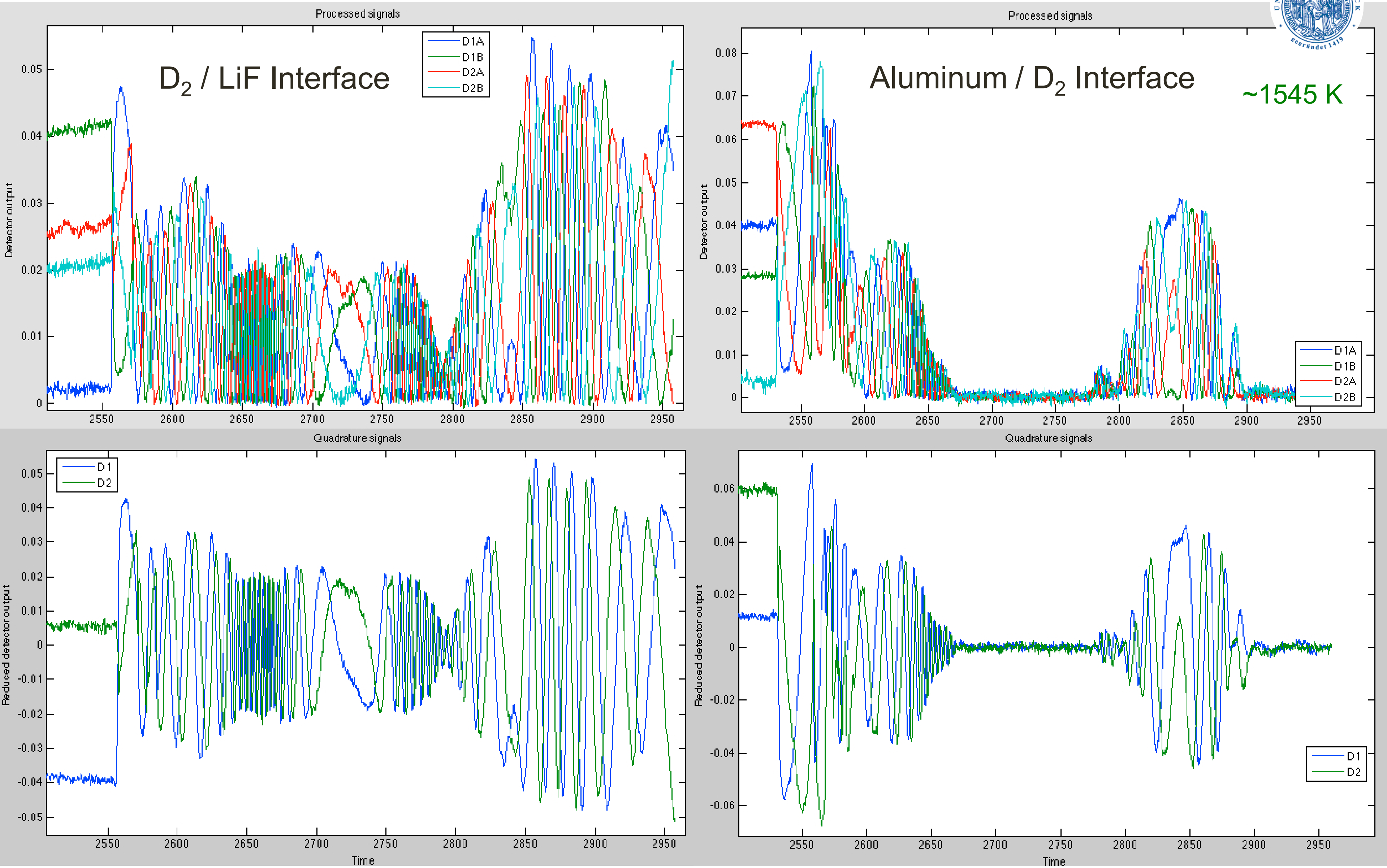
Stripline experimental configuration



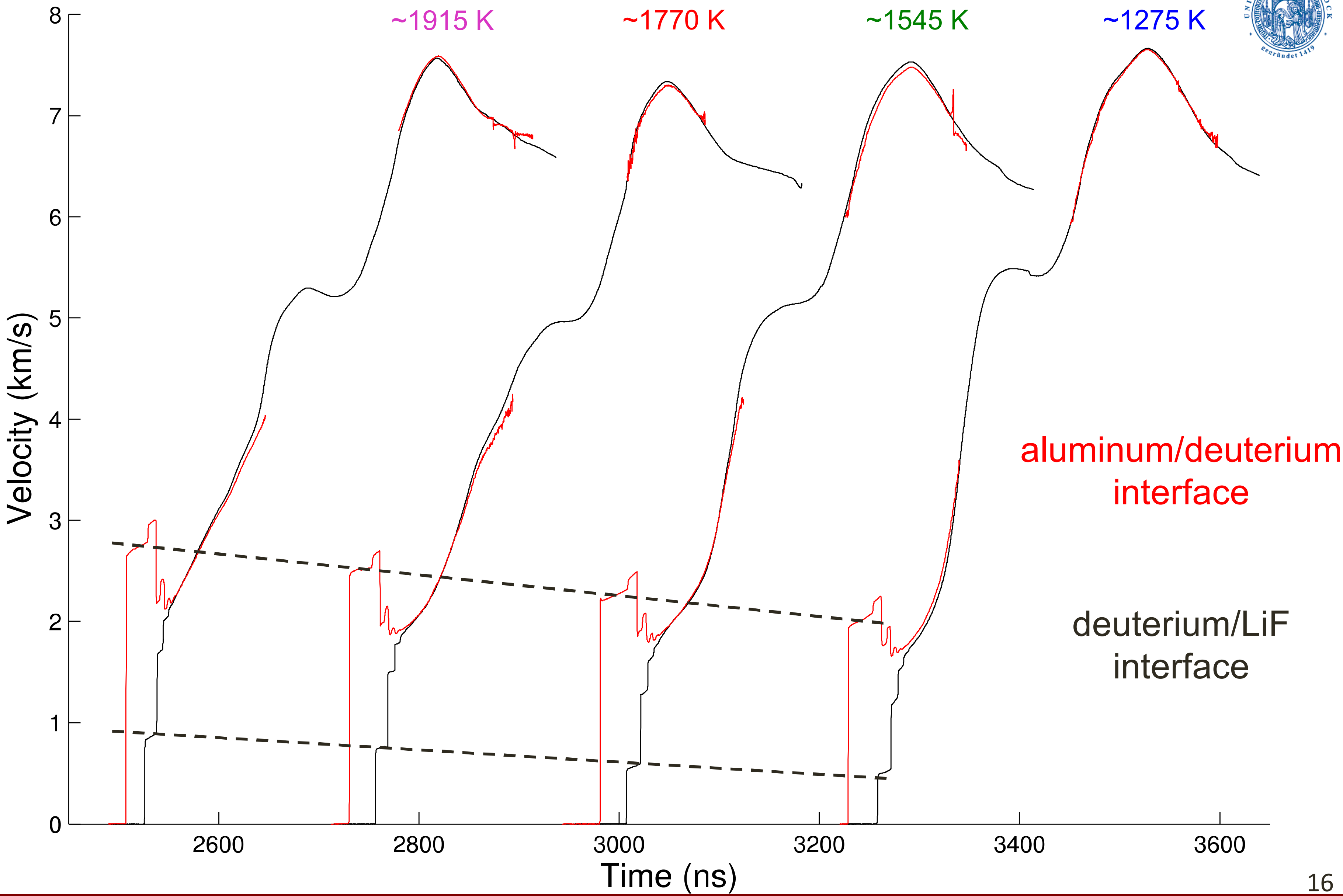
Stripline experiment PT paths



Processed VISAR signals

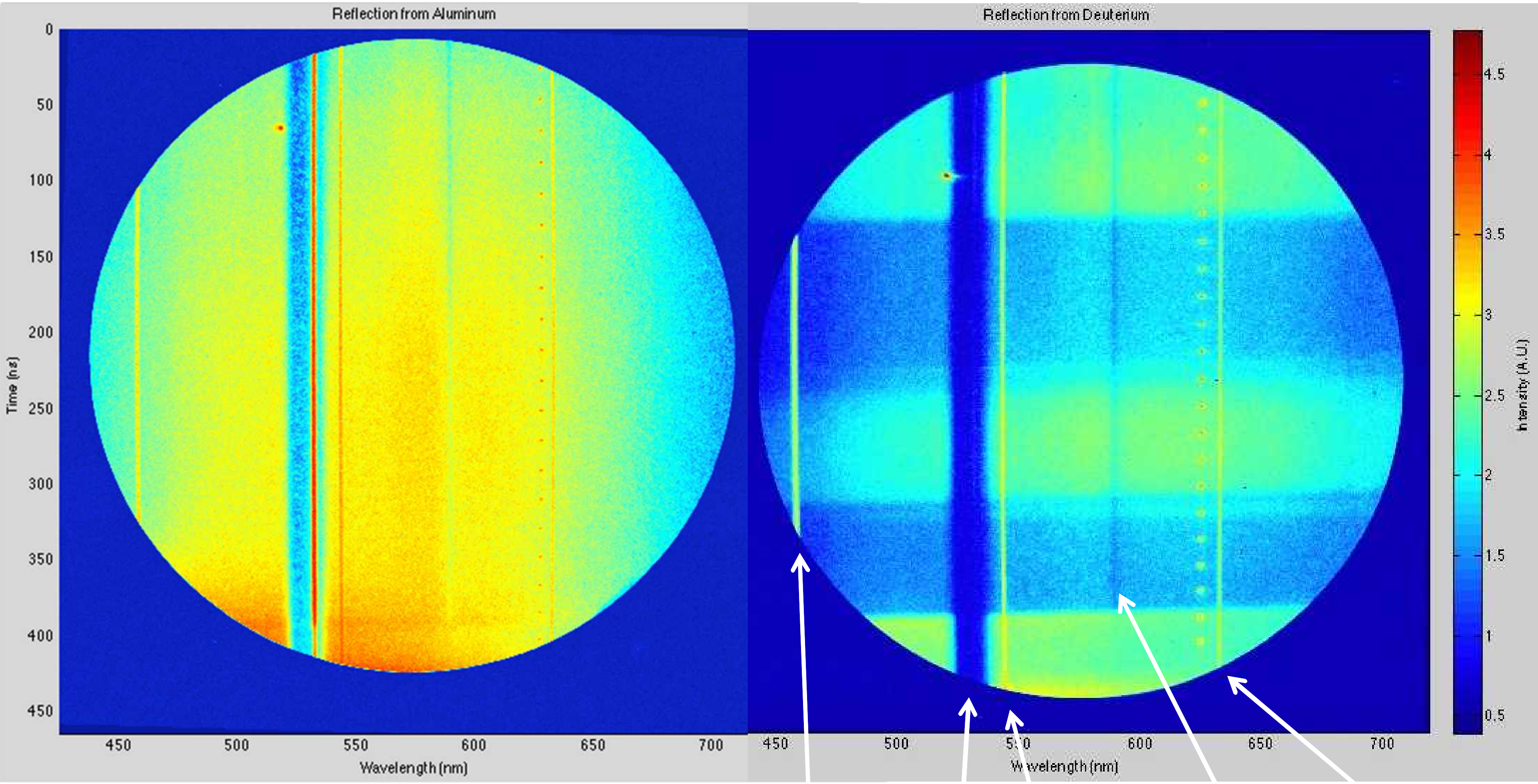


Stripline experimental profiles



SVS system provides data to infer reflectivity

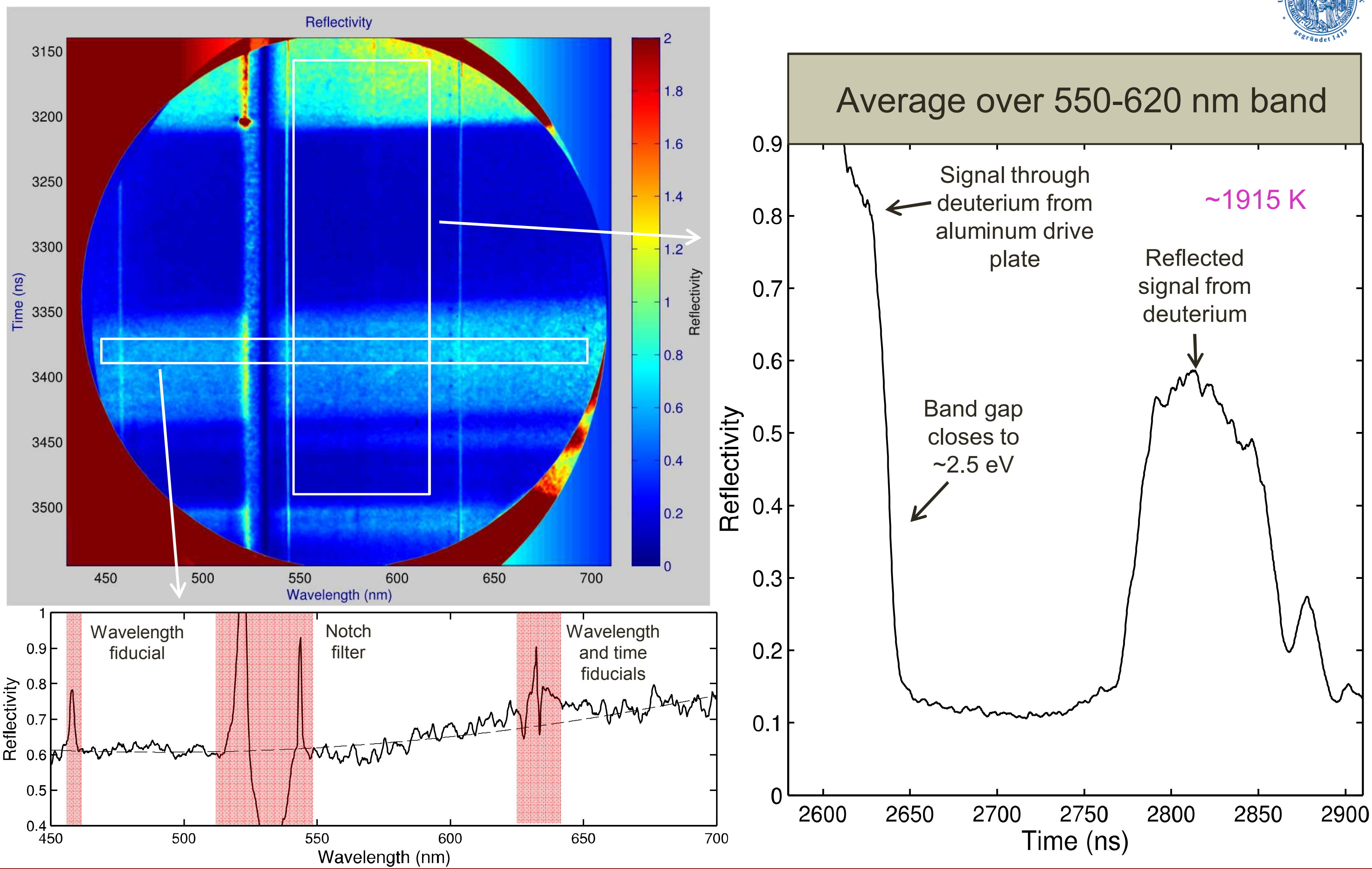
Reflection from aluminum coating | Reflection from deuterium



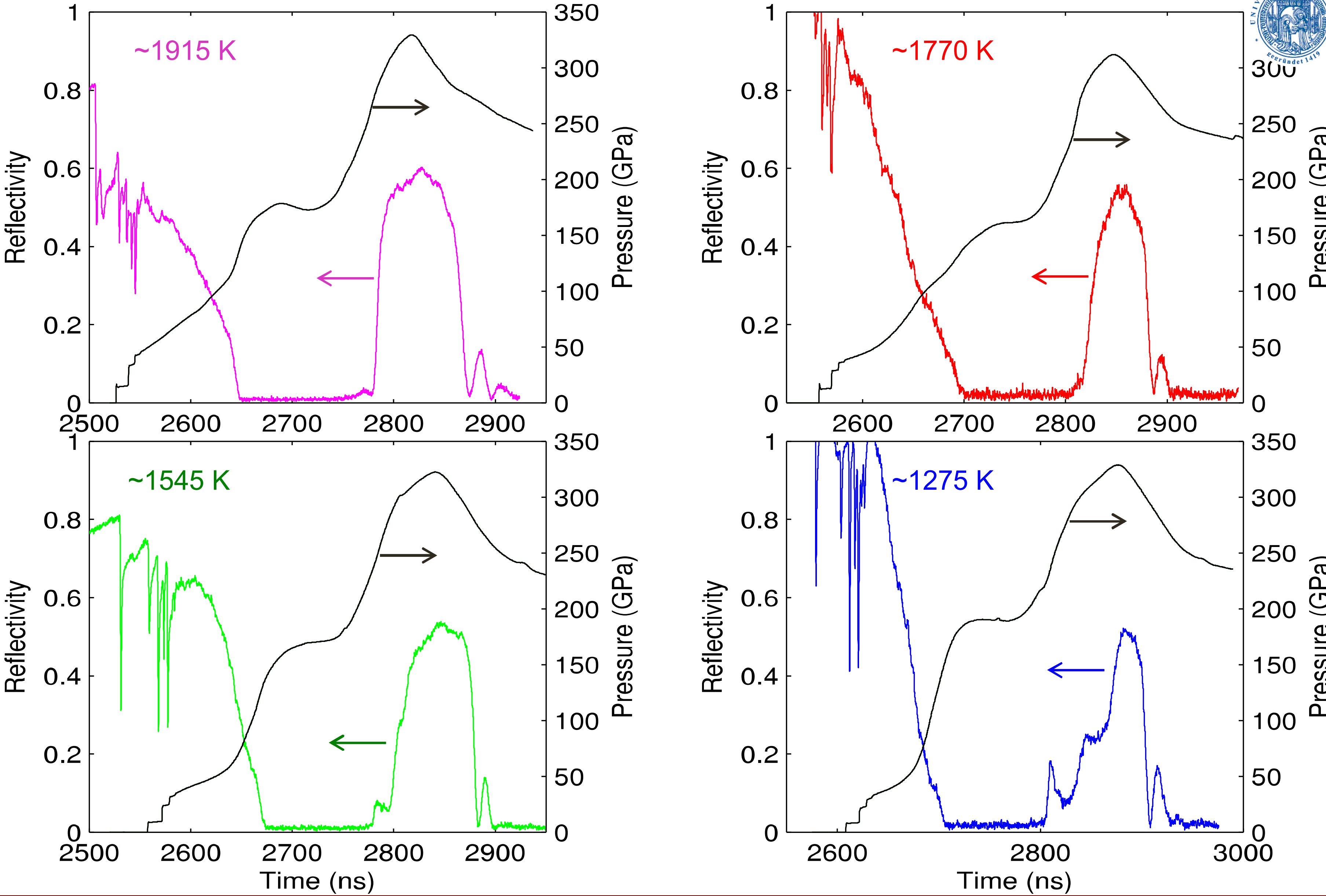
Wavelength range ~450-700 nm

457.9 nm | 532 / 543.5 nm | 589.3 nm | 633 nm

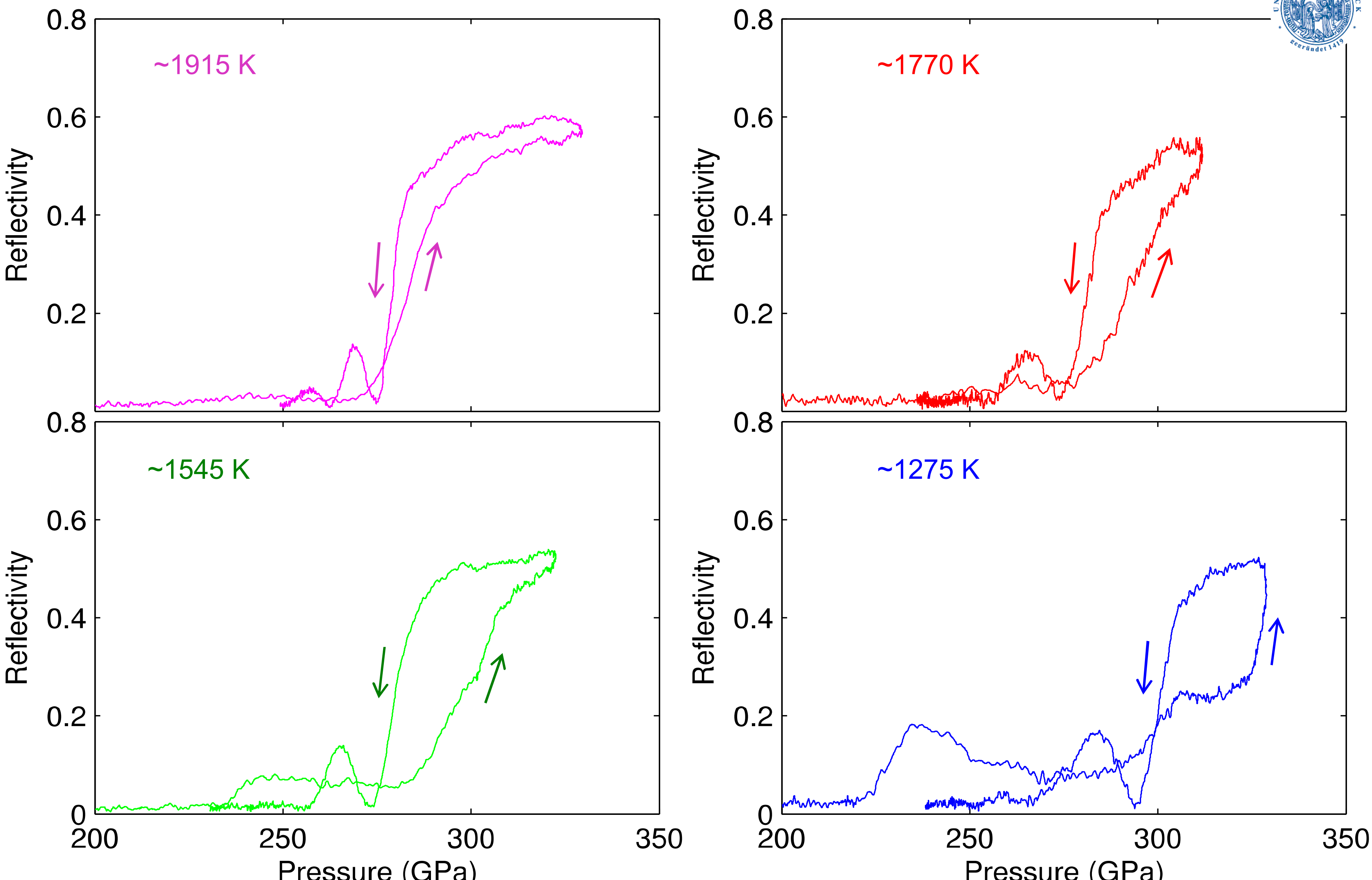
SVS system provides data to infer reflectivity



Reflectivity and pressure vs. time from VISAR

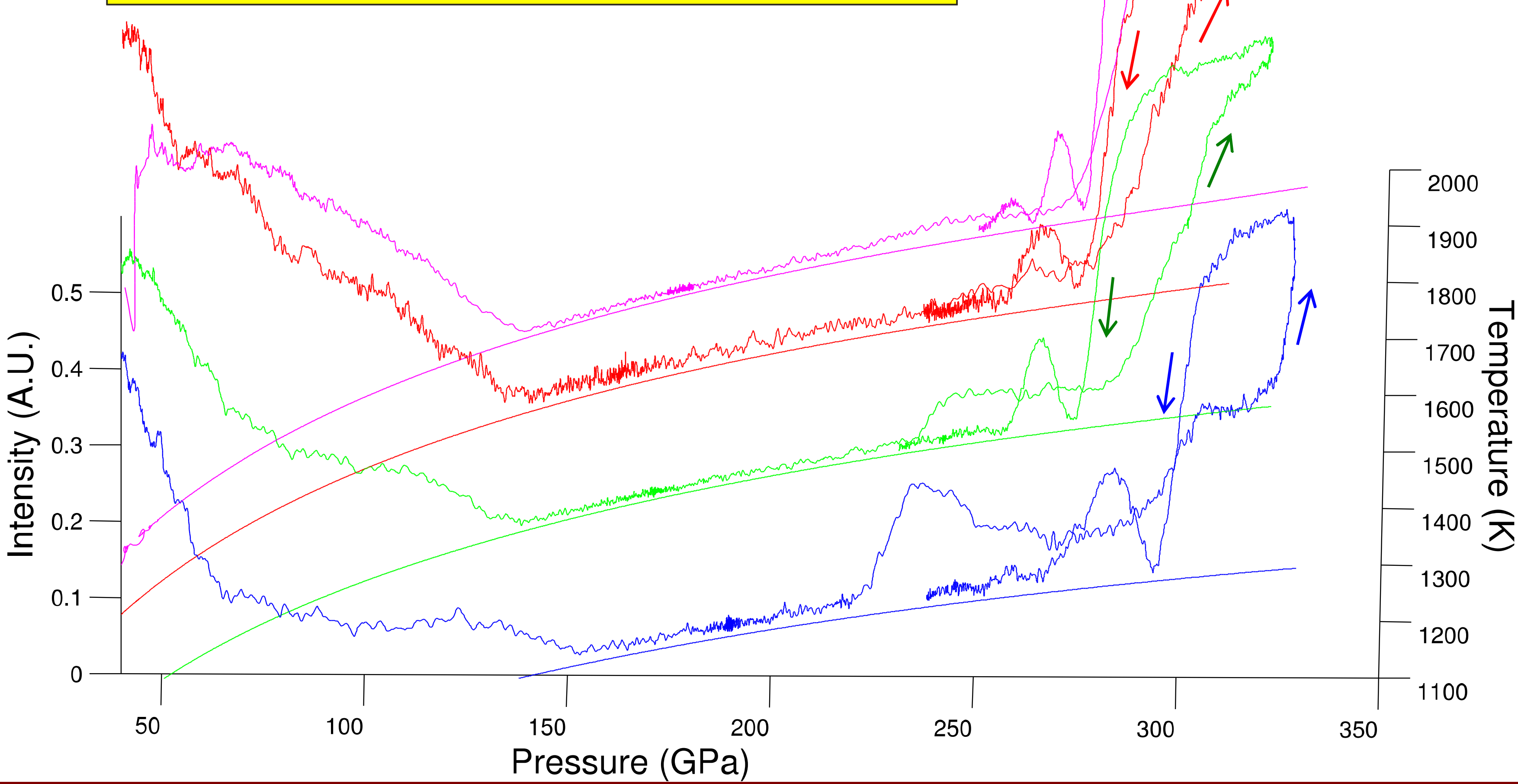


Reflectivity signals mapped to pressure

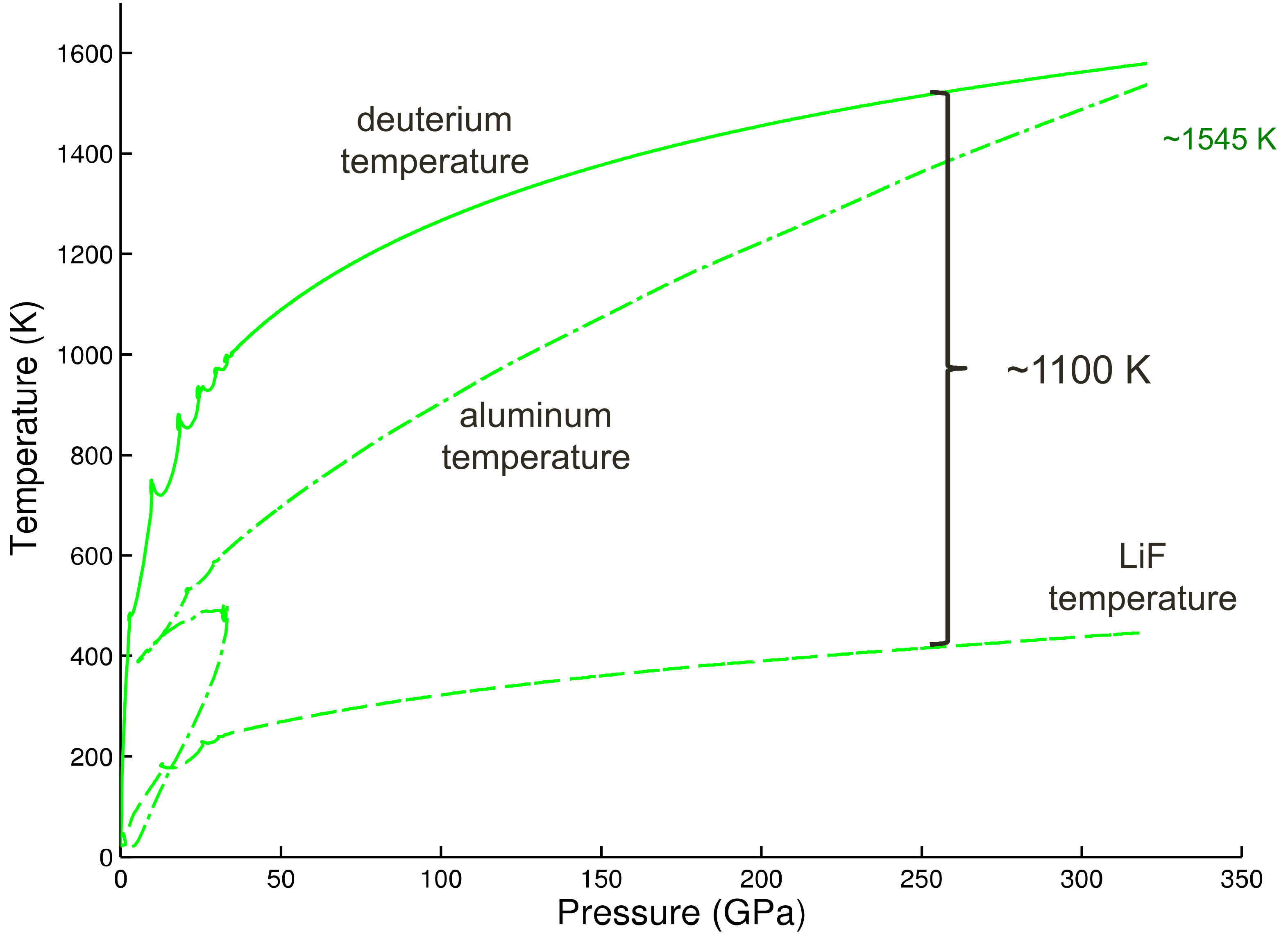


Deuterium reflectivity mapped to both pressure and temperature

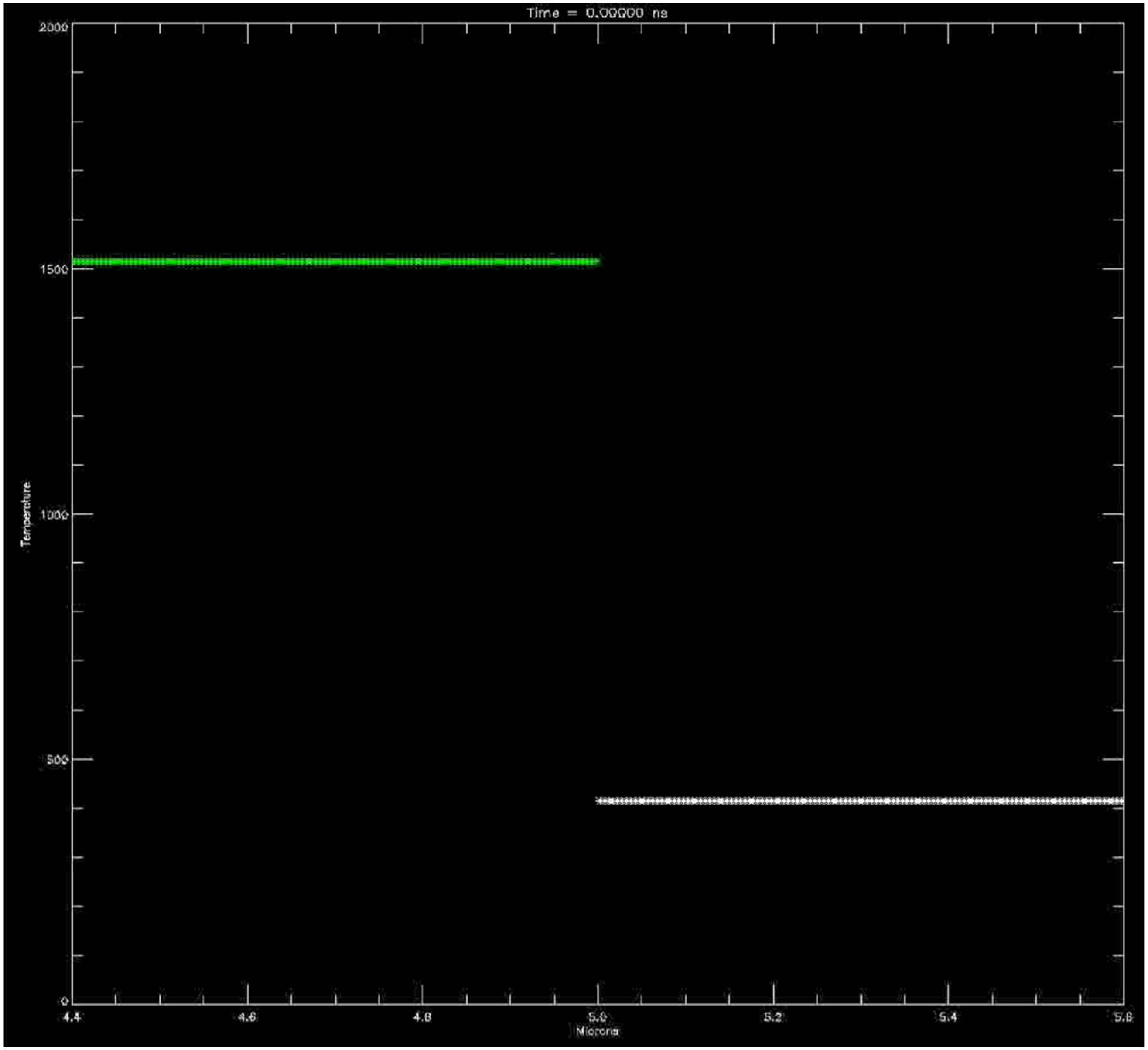
Asymmetry observed in the reflectivity is likely caused by time evolution of thermal gradients at the deuterium/LiF interface

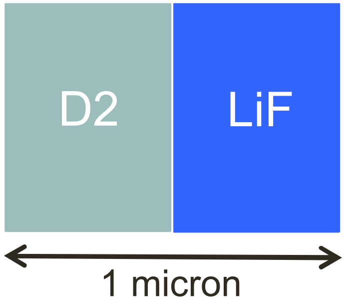


There is a significant temperature difference at the deuterium/LiF interface



Thermal conduction at D2/LiF interface





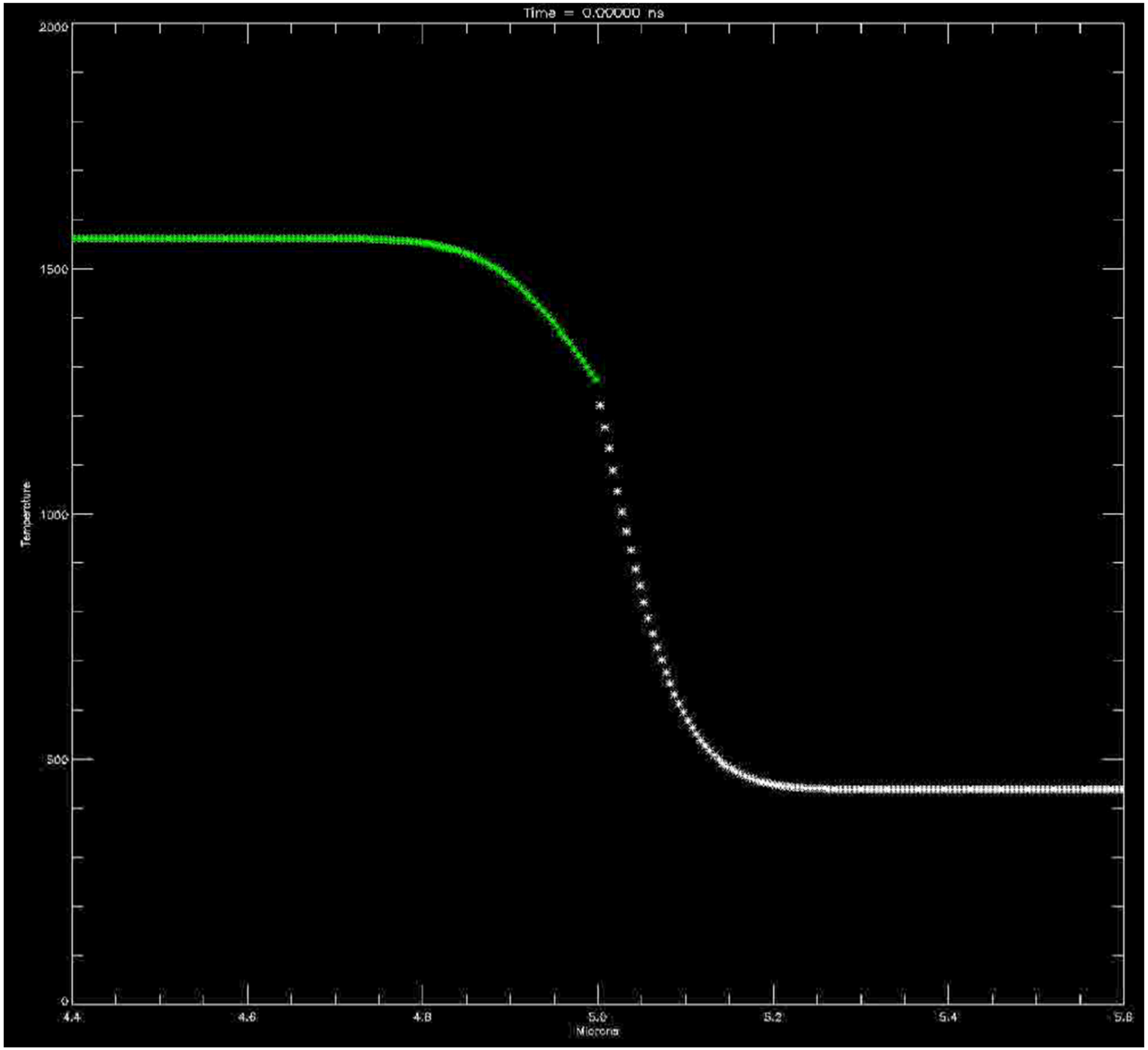
<u>deuterium</u>

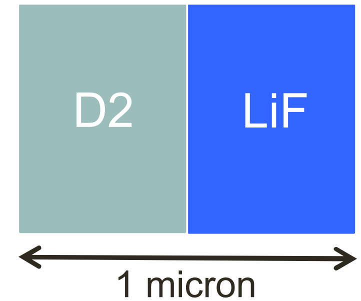
P_1 = 250 GPa
ρ_1 = 1.923 g/cc
T_{b1} = 1515 K
κ_1 = 0.36 W/mK

<u>LiF</u>

P_1 = 250 GPa
ρ_1 = 5.362 g/cc
T_{b1} = 415 K
κ_1 = 0.1 W/mK

Thermal conduction at D2/LiF interface





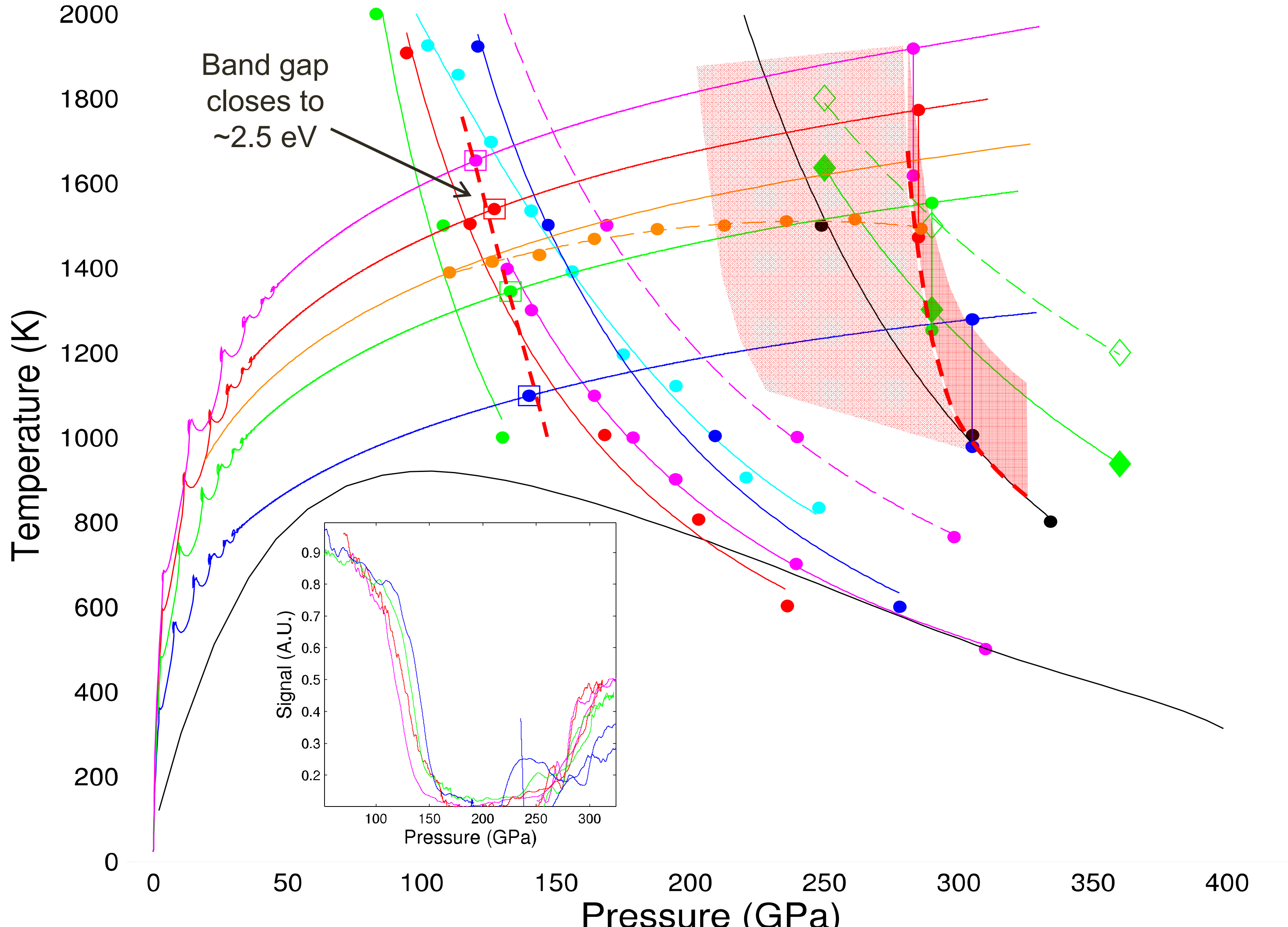
deuterium

P_2 = 300 GPa
ρ_2 = 2.080 g/cc
T_{b2} = 1562 K
κ_2 = 25 W/mK

LiF

P_2 = 300 GPa
ρ_2 = 5.547 g/cc
T_{b2} = 438 K
κ_2 = 0.1 W/mK

Possible location of the LL-IMT in deuterium



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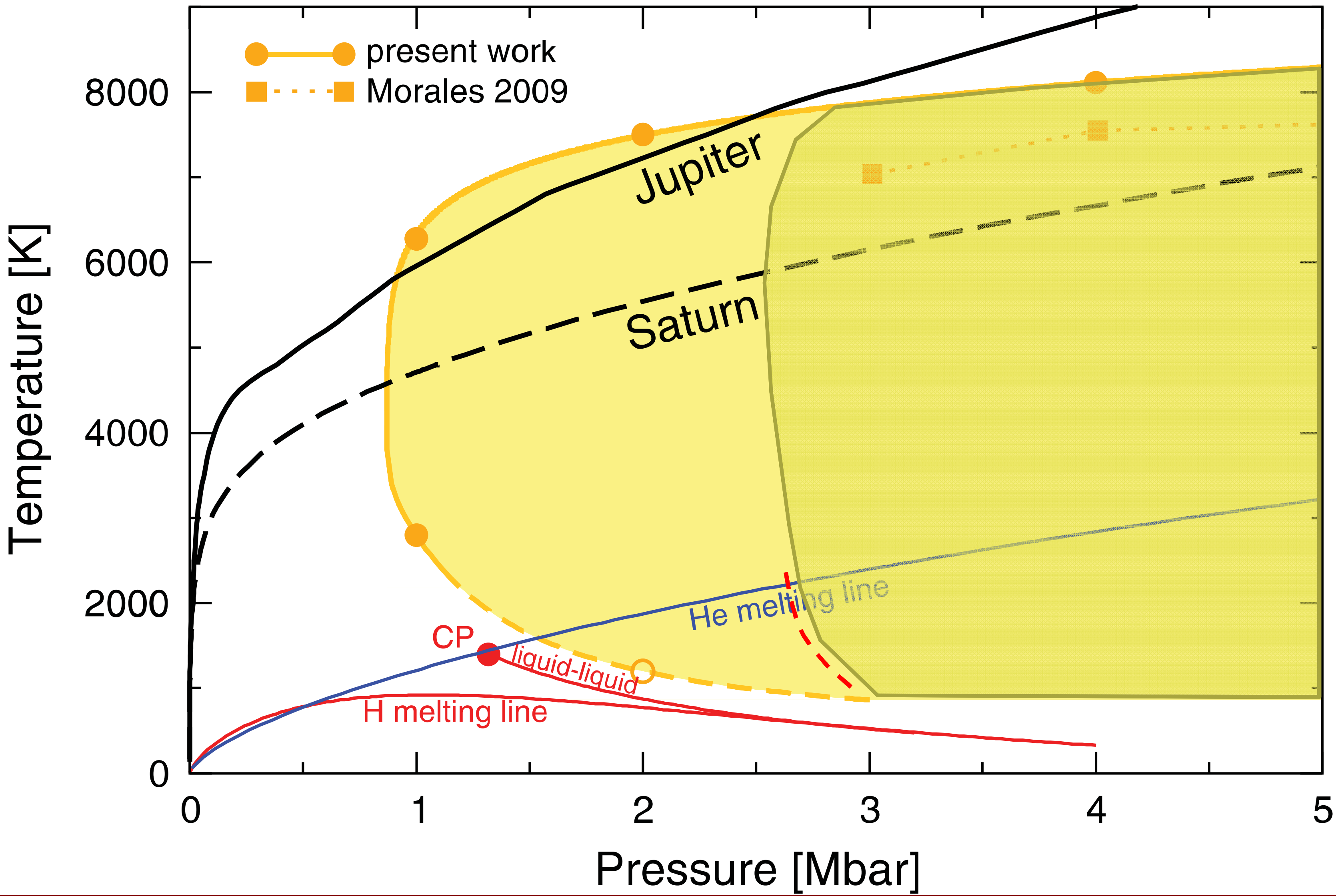

Conclusions

- 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 on state
- Experiments above ~250 GPa show clear evidence of metallization of deuterium
  - Very abrupt increase in reflectivity to ~50-60%
  - Pressure state well above numerous first principles predictions
  - Indications suggest that the transition is first order
- Interpretation of the experimental results is complicated
  - Thermal conduction likely very important at the deuterium / LiF interface

Future Directions

- Continued analysis of existing data
  - Evaluate effects of thermal conduction using QMD estimates for thermal conductivity of the molecular and atomic fluids
  - Detailed QMD calculations in the vicinity of the transition to estimate the temperature drop due to latent heat
  - Compare measured reflectivity with QMD predictions for optical properties of the atomic fluid
  - Compare observed band gap closure with QMD predictions for various functionals
- Attempt temperature measurements
  - Plan to use a novel reflectivity based temperature measurement to investigate the phase transition
  - Method is not yet calibrated, but could provide sign of dT/dP
- Experiments on hydrogen
  - Attempt to observe pressure difference for the transition due to zero-point energy effects

Acknowledgements

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Universität Rostock

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