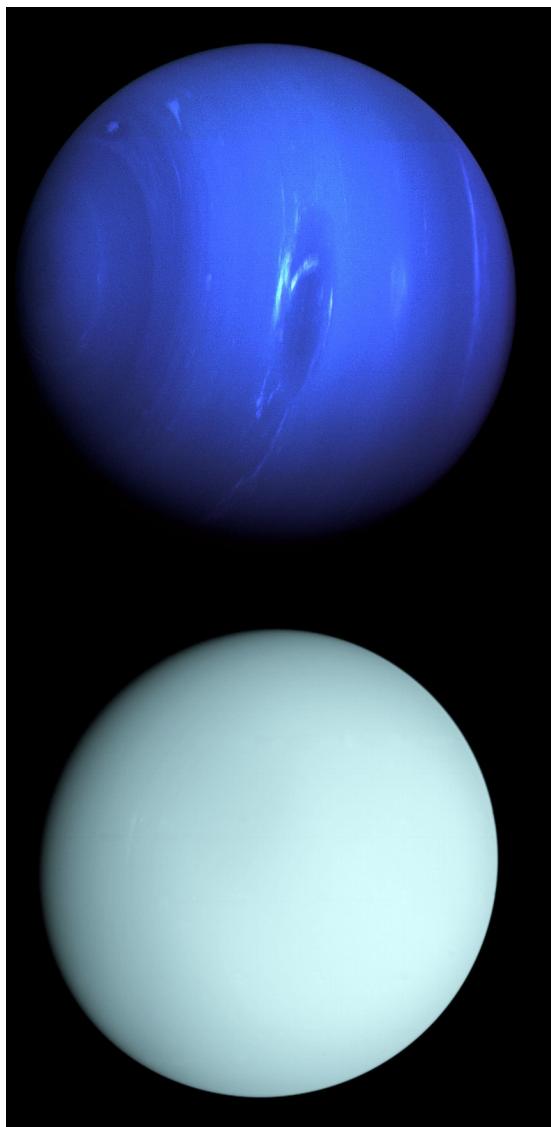




Equation of state and optical properties of shock-compressed C:H:N:O mixtures

Forum ILP



Île d'Oléron, June 10-15, 2018

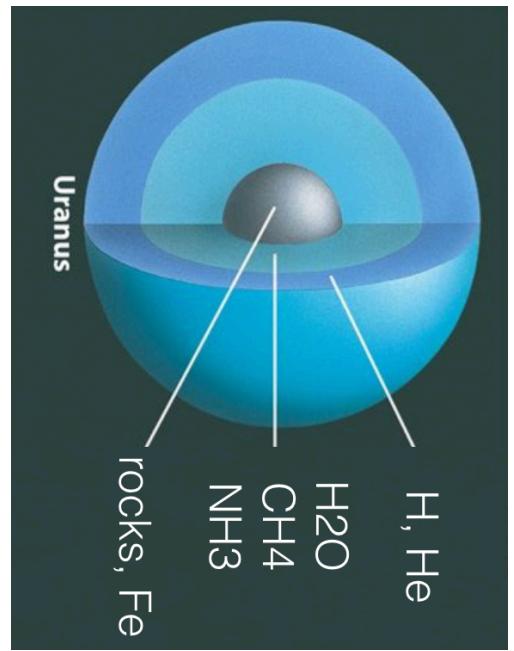
Marco Guarguaglini
Laboratoire LULI

École Polytechnique/CNRS/CEA/UPSay/Sorbonne Université

marco.guarguaglini@polytechnique.edu



Planetology in laboratory: Uranus & Neptune

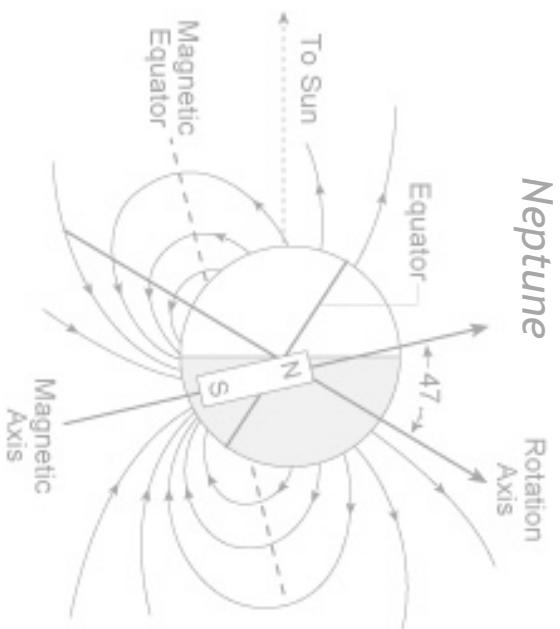


Planetary models:

- **origin**
- **evolution**
- **structure**

Need to characterize
warm dense matter:
 $P = 1 - 100 \text{ Mbar}$
 $T = 1\,000 - 10\,000 \text{ K}$

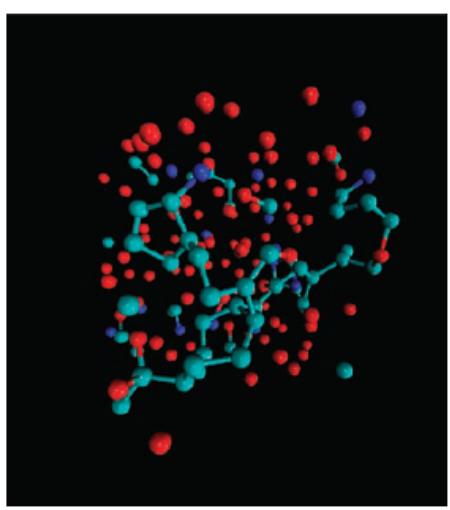
Puzzles to solve



P_{em}/P_{abs}
- Uranus in **equilibrium** with the Sun
- Neptune has internal **heat** source

↓
Different thermal histories?

www.nasa.gov/voyager

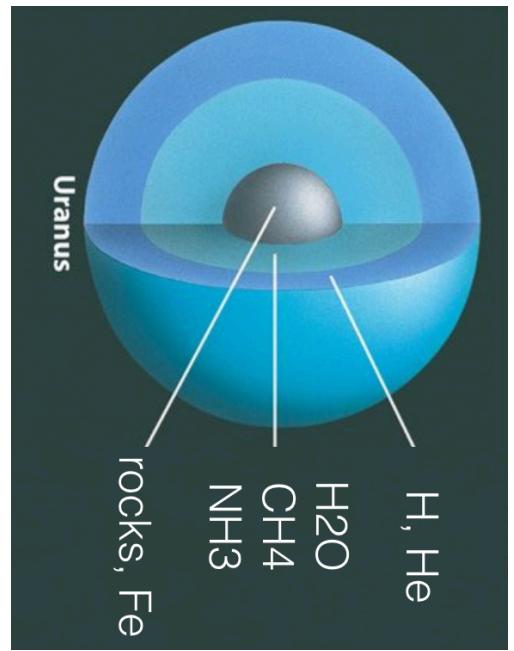


Chau et al. (2011), Nat. Comm.

↓
Peculiar geometry of the dynamo?



Planetology in laboratory: Uranus & Neptune



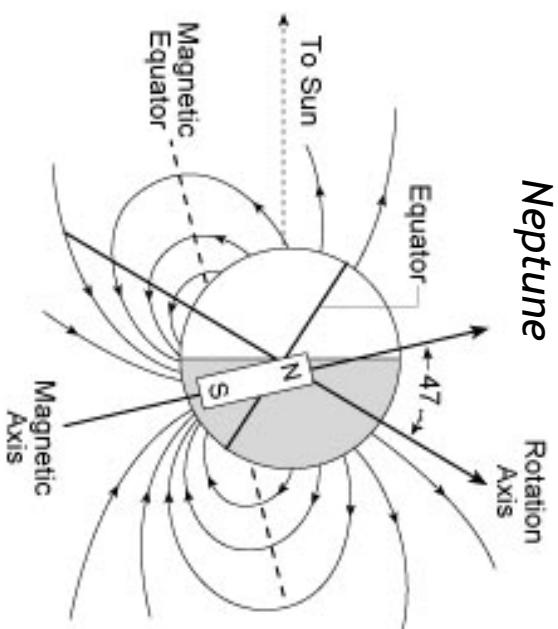
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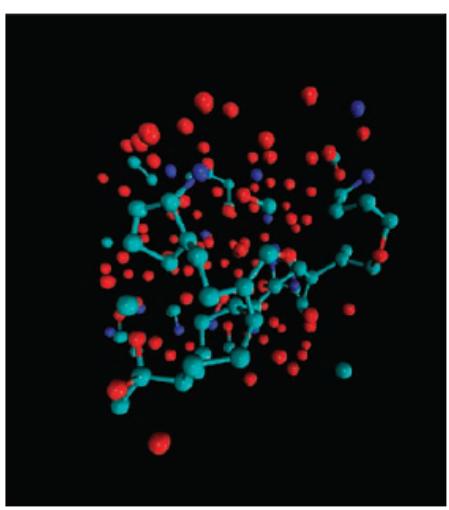
Puzzles to solve

P_{em}/P_{abs}	U	N
1.06	2.61	



Non-dipolar,
non-axisymmetric
magnetic fields

↓
**Peculiar geometry of the
dynamo?**



Chau et al. (2011), Nat. Comm.

Different thermal histories?

www.nasa.gov/voyager

- **Uranus in equilibrium** with the Sun
- **Neptune has internal heat** source





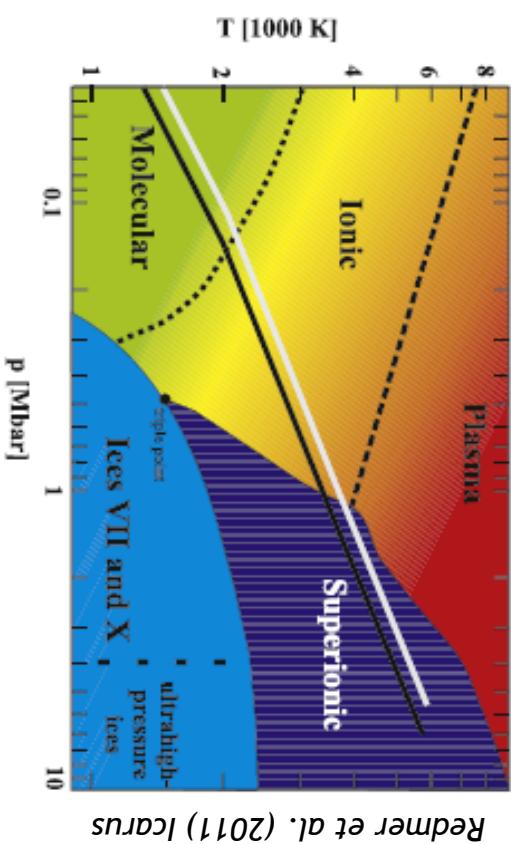
Planetology in laboratory: Uranus & Neptune

What to do?

Study:

- **equation of state** and **phase diagram**
- **conductivity** and **transport properties**
- of (pure and mixed) water, methane, ammonia

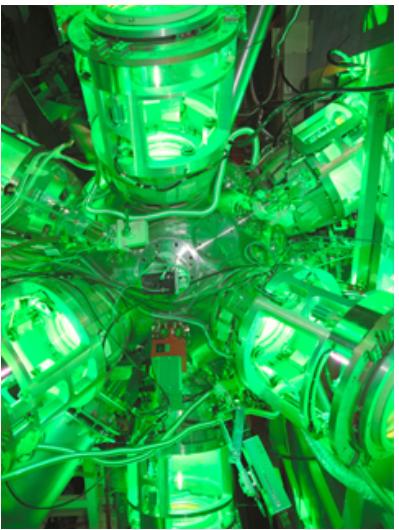
Water phase diagram



How?

Dynamic compression:
laser-driven shocks

> 1 **kJ** energy
~10 **ns** pulse duration



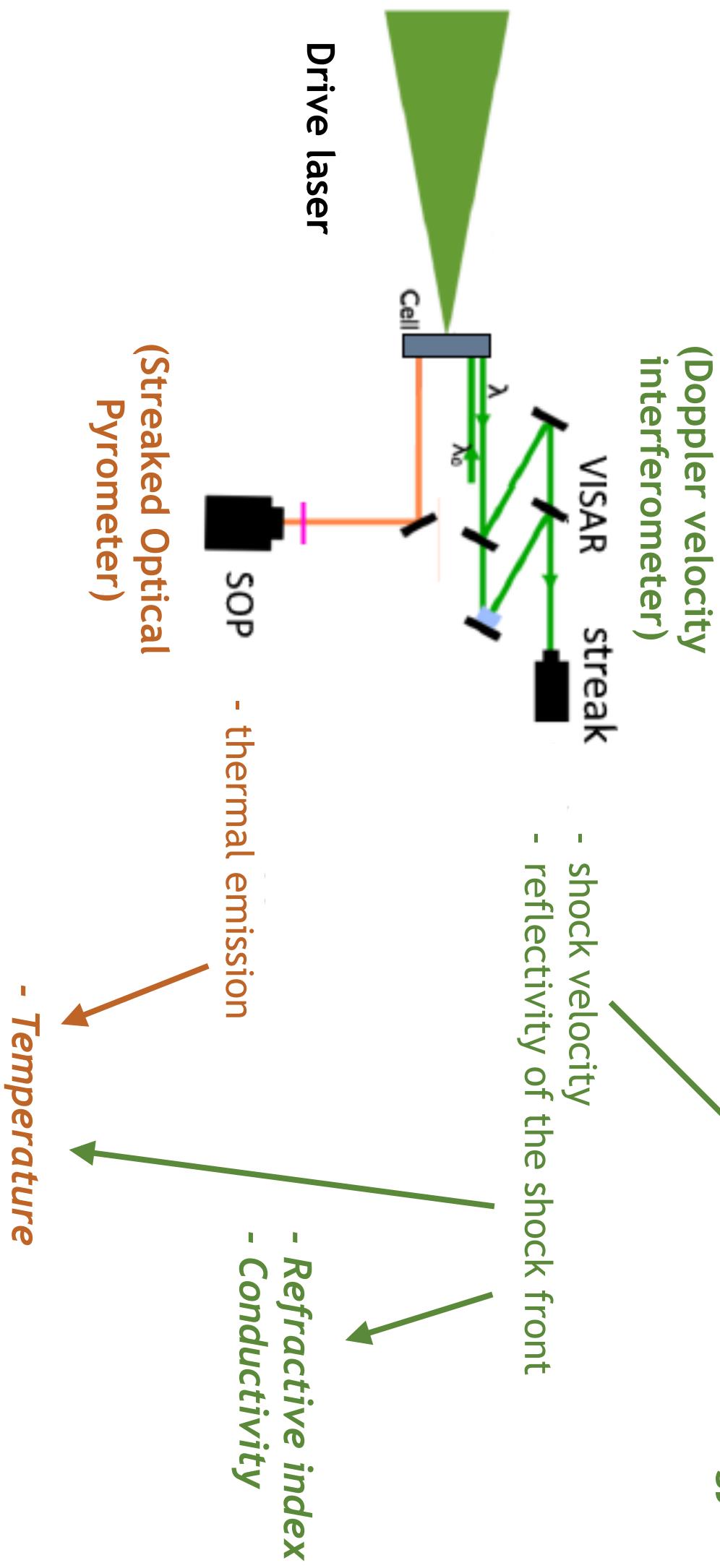
GEKKO XII interaction chamber
(Osaka, Japan)



JULI 2000 hall (Palaiseau, France)



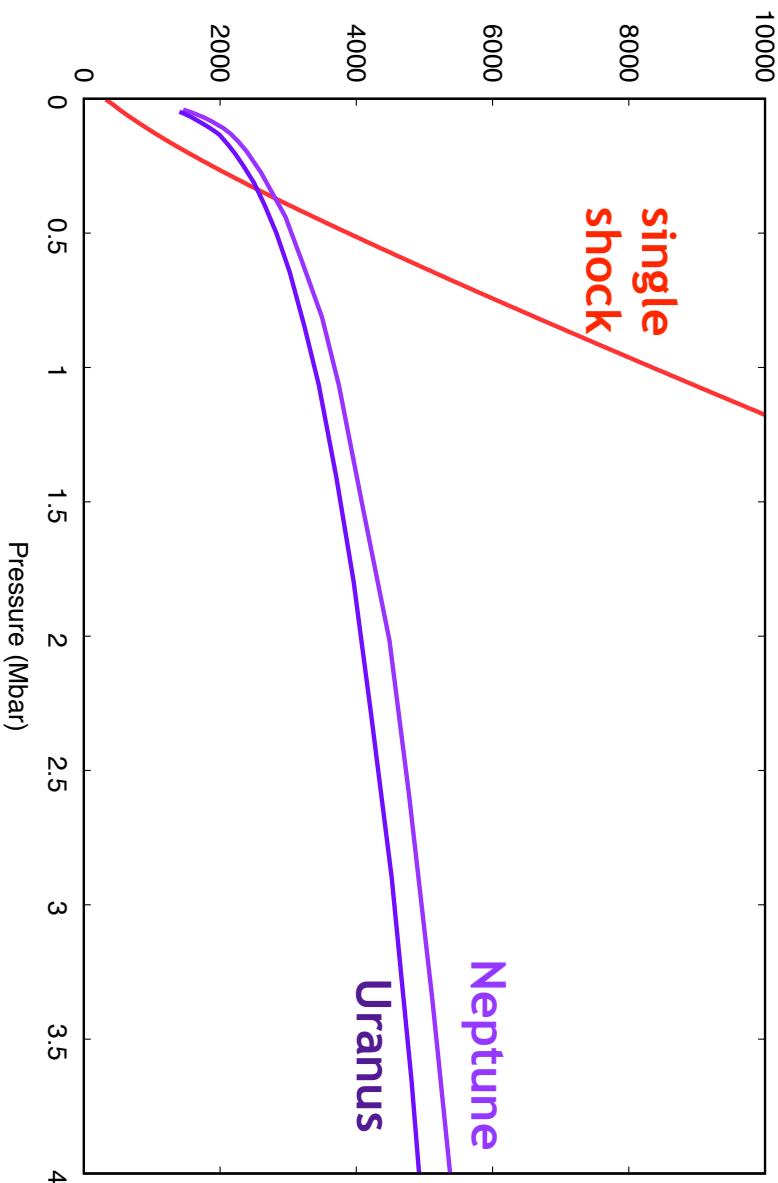
Optical diagnostics probe the shocked sample



Different techniques to vary P-T conditions



- Decaying shock: we explore a segment of the **main Hugoniot**

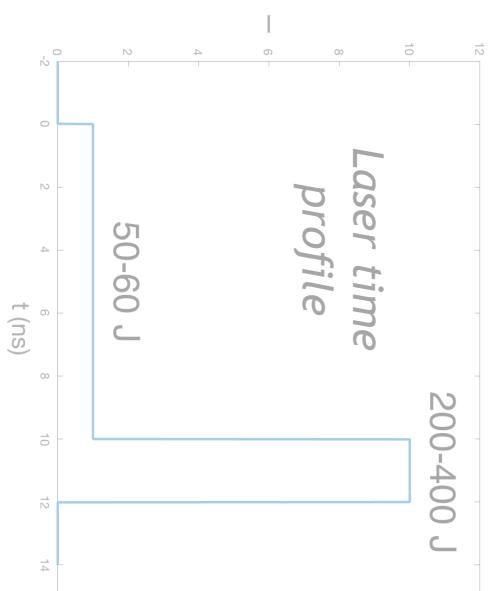


- A static pre-compression allows to explore a **colder Hugoniot path**



Diamond anvil cell (DAC)

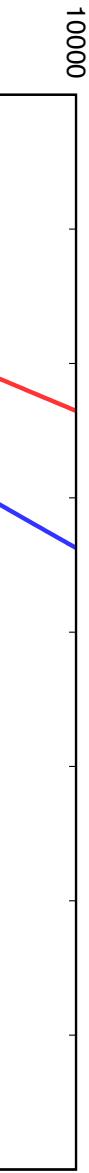
- The sample can be dynamically pre-compressed: **double shock**



Different techniques to vary P-T conditions



- Decaying shock: we explore a segment of the **main Hugoniot**



single
shock

DAC +
shock

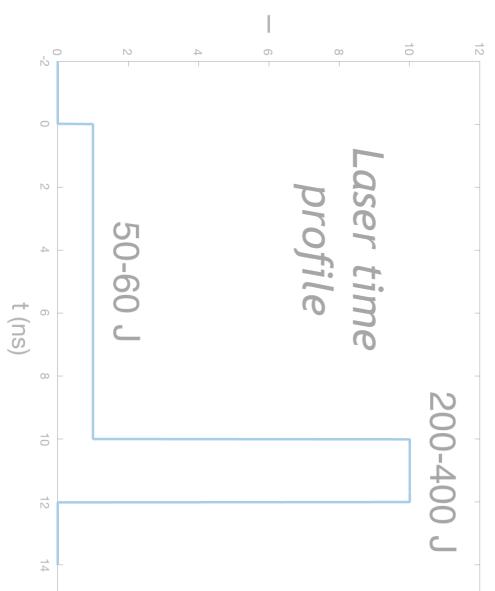
DAC +
laser heating

- The sample can be dynamically pre-compressed: **double shock**

Diamond anvil cell
(DAC)



- A static pre-compression allows to explore a **colder Hugoniot** path



Different techniques to vary P-T conditions

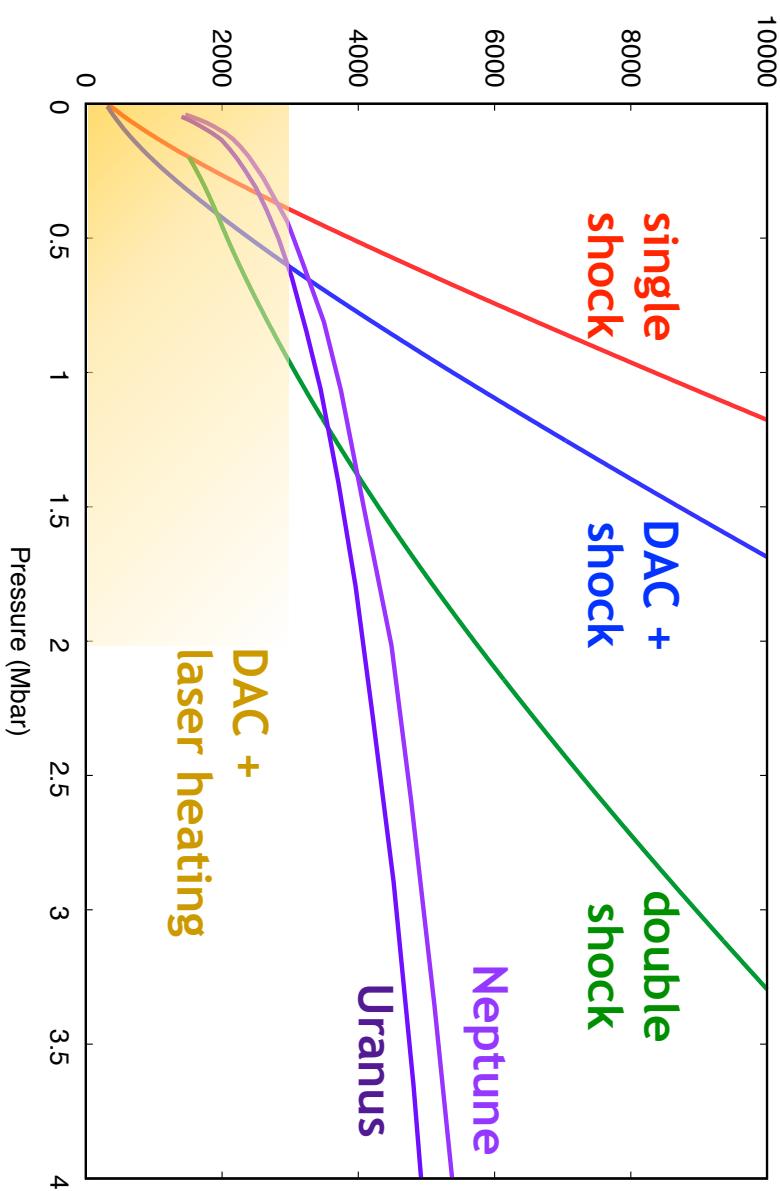


- Decaying shock: we explore a segment of the **main Hugoniot**

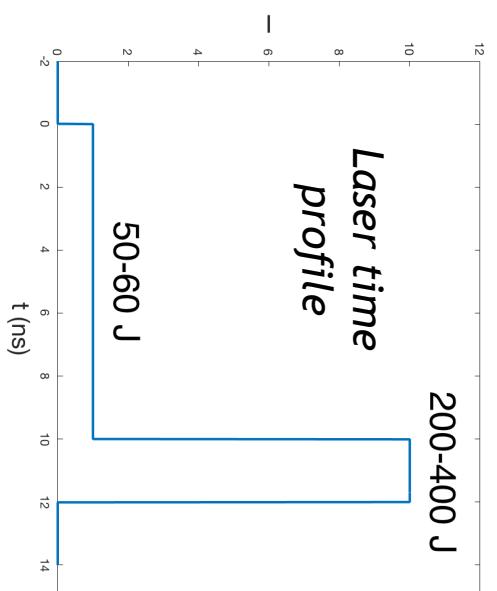
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*Diamond anvil cell
(DAC)*



- The sample can be dynamically pre-compressed: **double shock**





Projects

- Principal Hugoniot of planetary mixtures

Guarguaglini et al., arXiv:1804.06595,
submitted to Sci. Rep.

- Study of pure liquid ammonia

ongoing

- Development of a double shock technique

ongoing



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Principal Hugoniot of planetary mixtures



Different compositions:

- pure water
- a water / ethanol (C:H:O) mixture
- a water / ethanol / ammonia (C:H:N:O) mixture

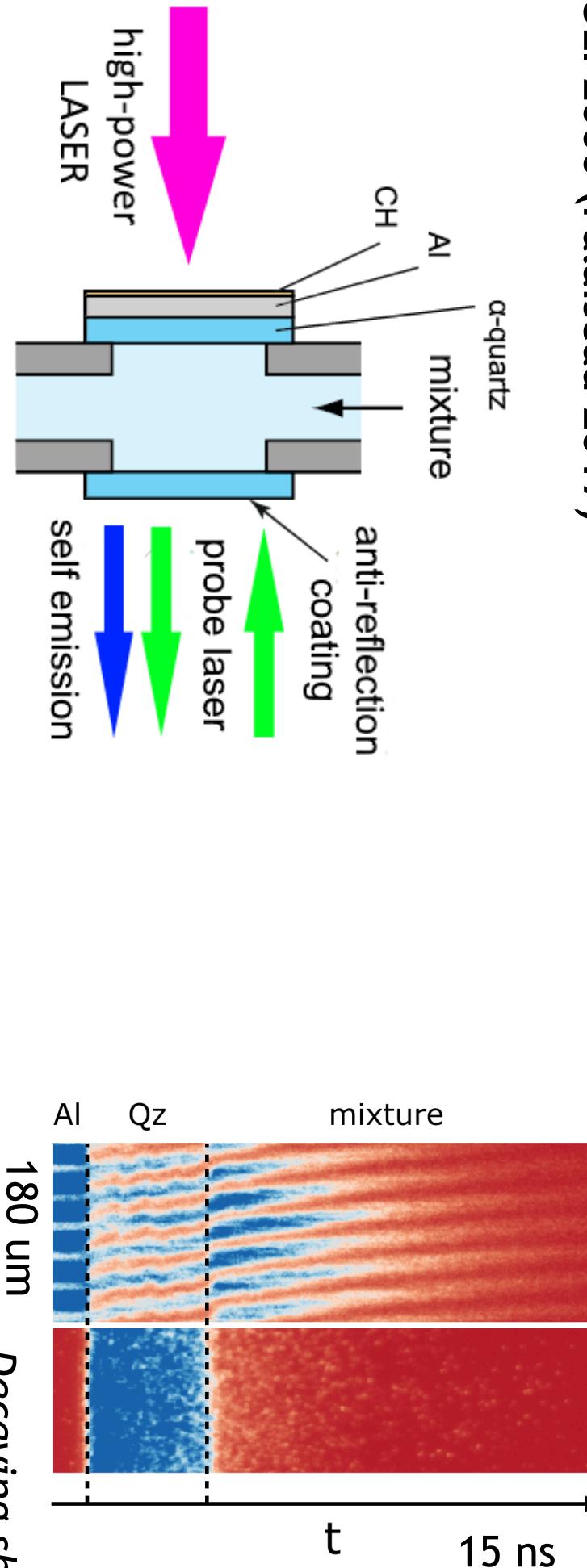
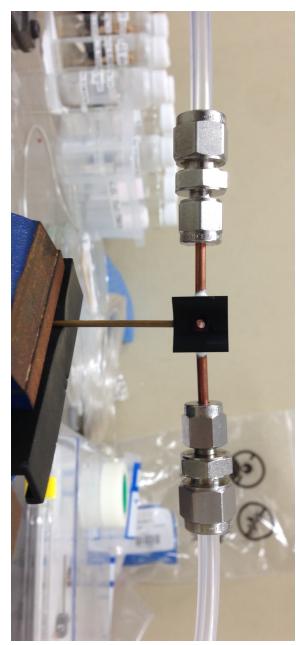
Target filling procedure

VISAR

SOP

“synthetic Uranus”

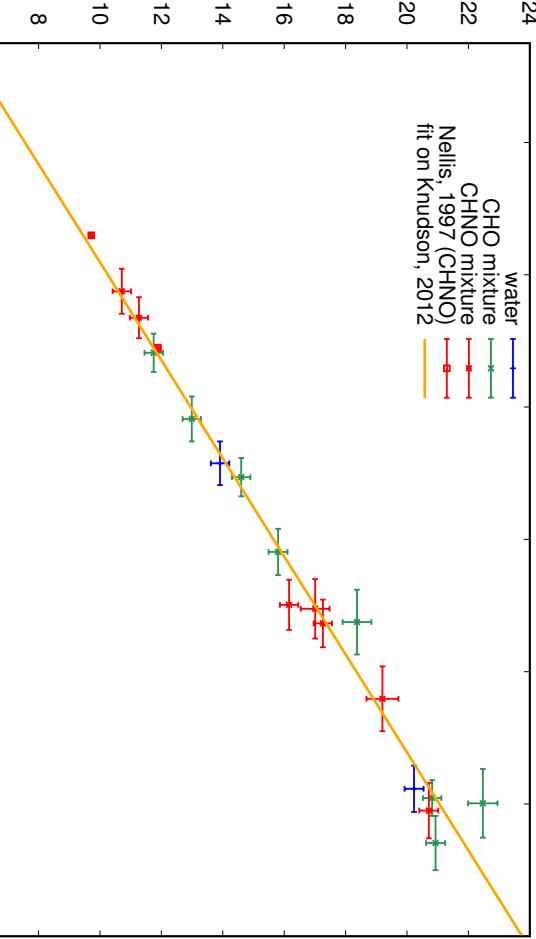
Experiments:
- GEKKO XII (Osaka 2016)
- LULI 2000 (Palaiseau 2017)



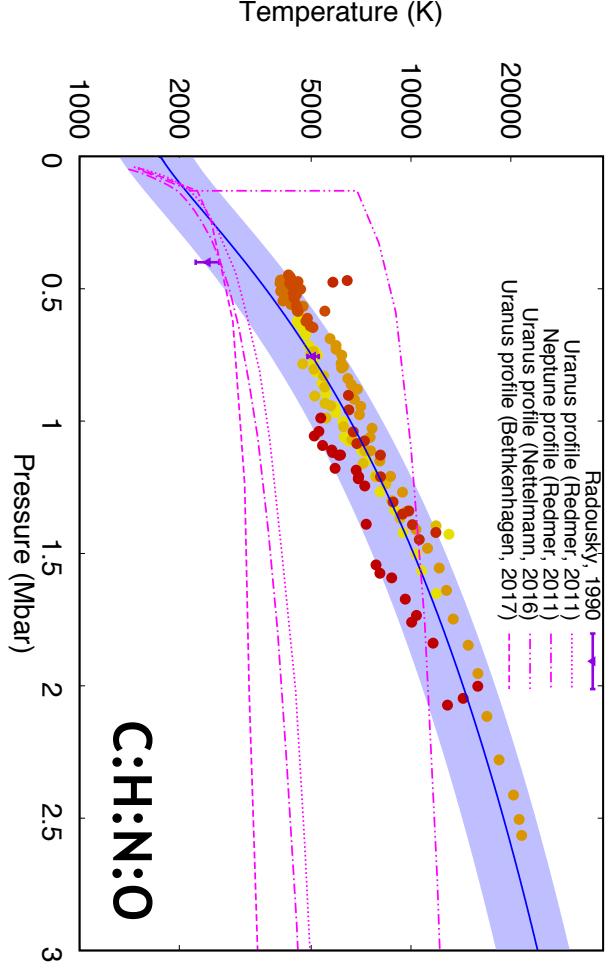
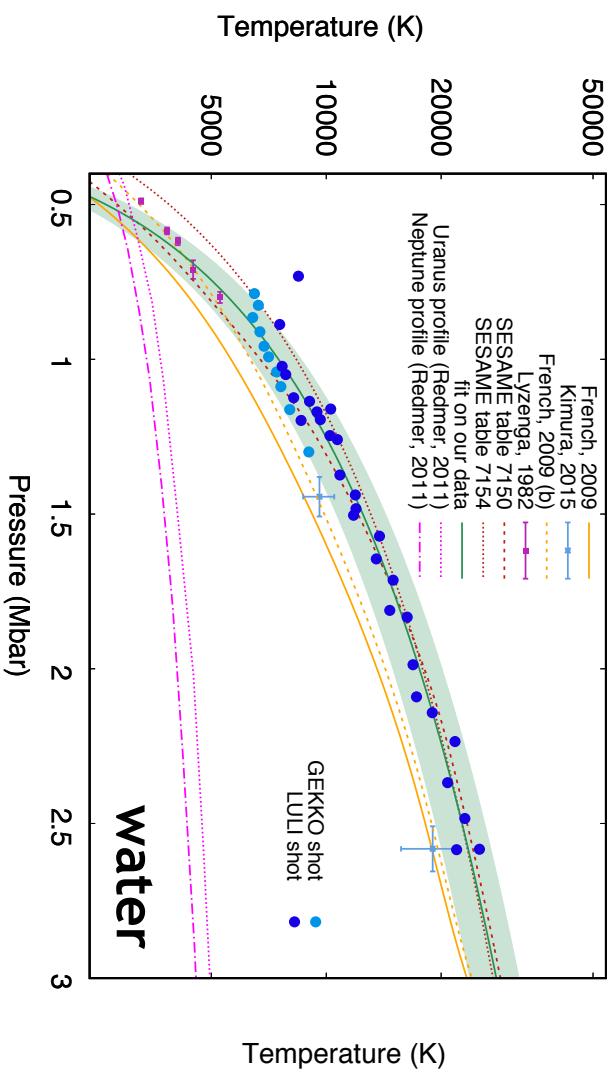
Water & C-H-(N)-O: same equation of state

No significant change in the U_s - U_p relation between water and mixtures

The only pressure-density difference is only due to initial density (1.00 vs. 0.88 g/cm³)

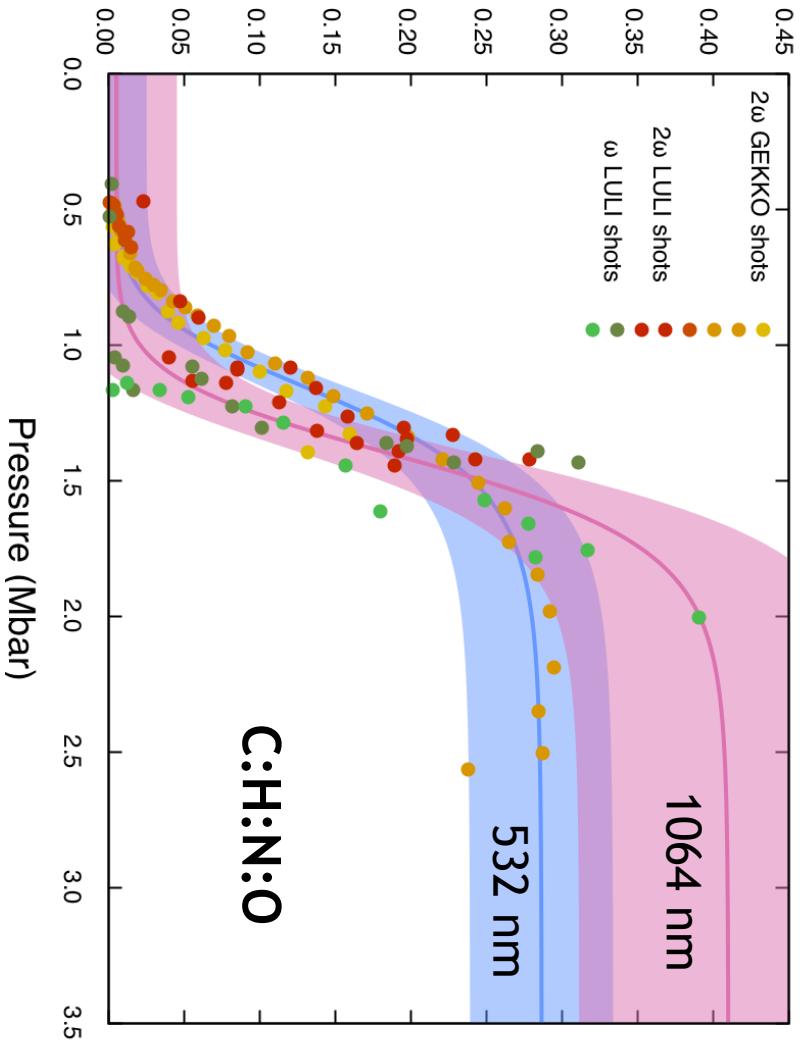
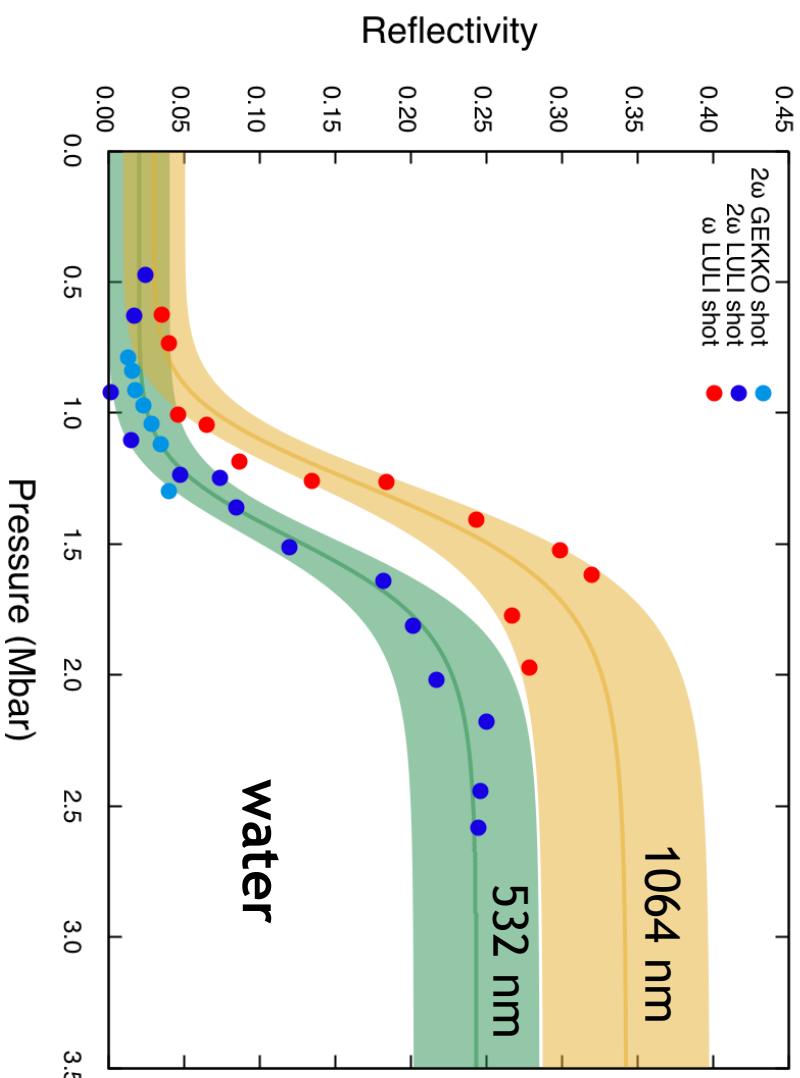


Temperature-pressure relations:
 - agreement with previous calc. and exp.
 - comparable between water and C:H:N:O





Discrepancies in the shock-front reflectivity



R measured
@ 2 frequencies
for 1st time

- Fresnel: refractive index
- Drude: conductivity

→ planetary dynamo models
(explain peculiar B fields)



Projects

- Principal Hugoniot of planetary mixtures

*Guarguaglini et al., arXiv:1804.06595,
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- **Study of pure liquid ammonia**

ongoing

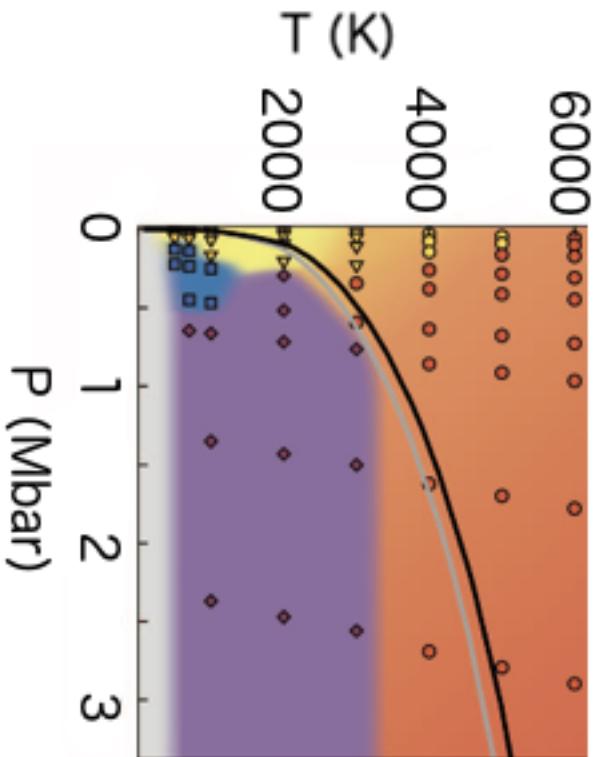
- Development of a double shock technique

ongoing

~~CCU~~ Study of pure liquid ammonia

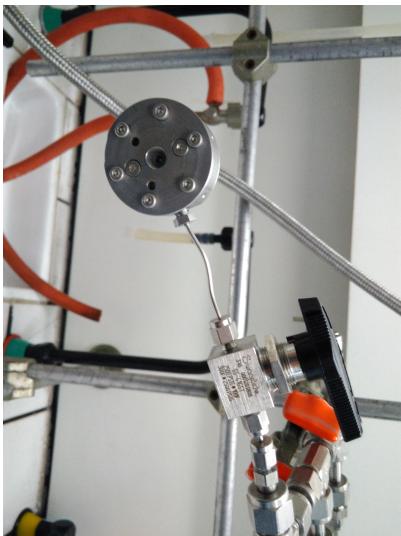


Bethkenhagen et al. (2013), JCP



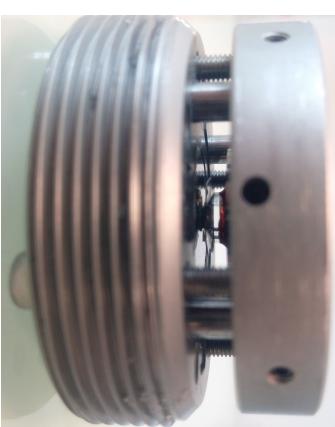
Issues

- Toxic
- Chemical reactions (no glue for target windows!)
- Gaseous at ambient pressure, but **liquid state is needed** for shock experiments



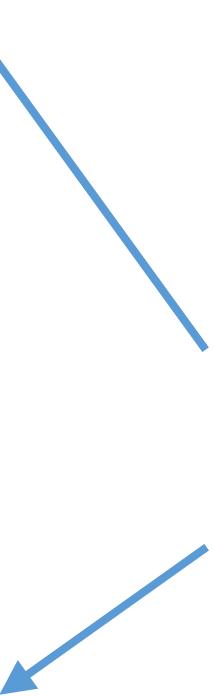
Cryostatic filling

1 bar, 25 °C



Diamond anvil cell

2 - 5 kbar

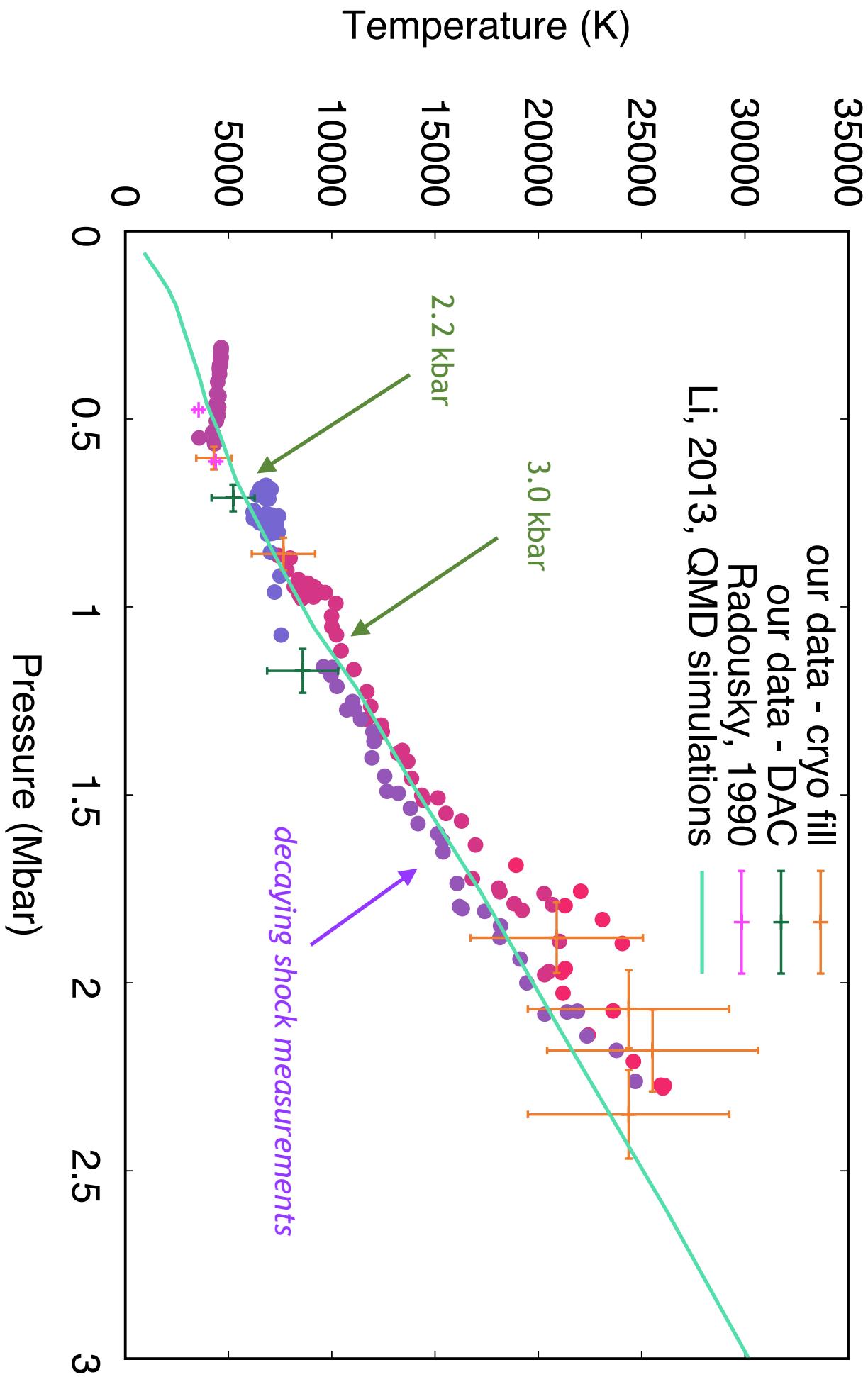


15 bar, 25 °C





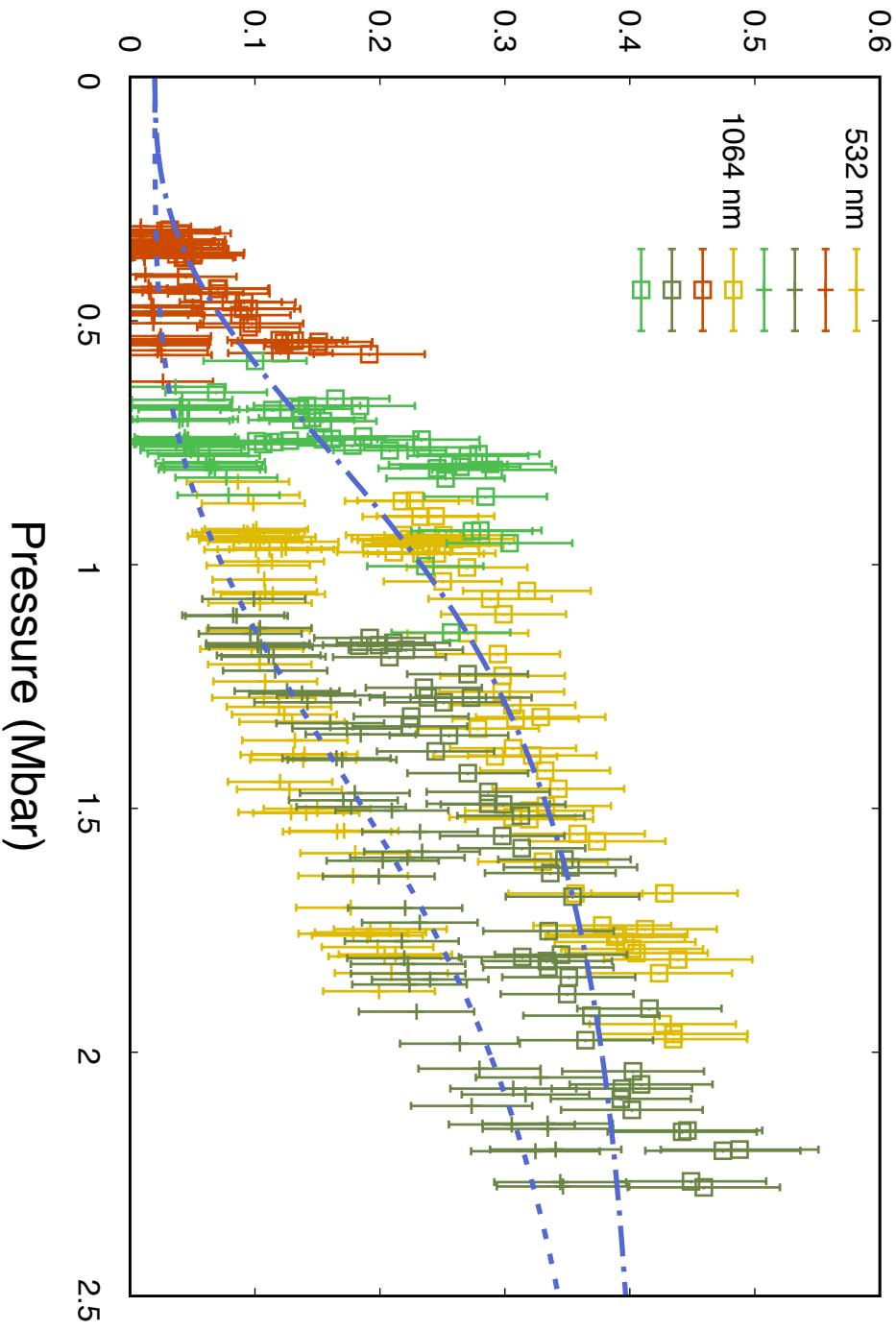
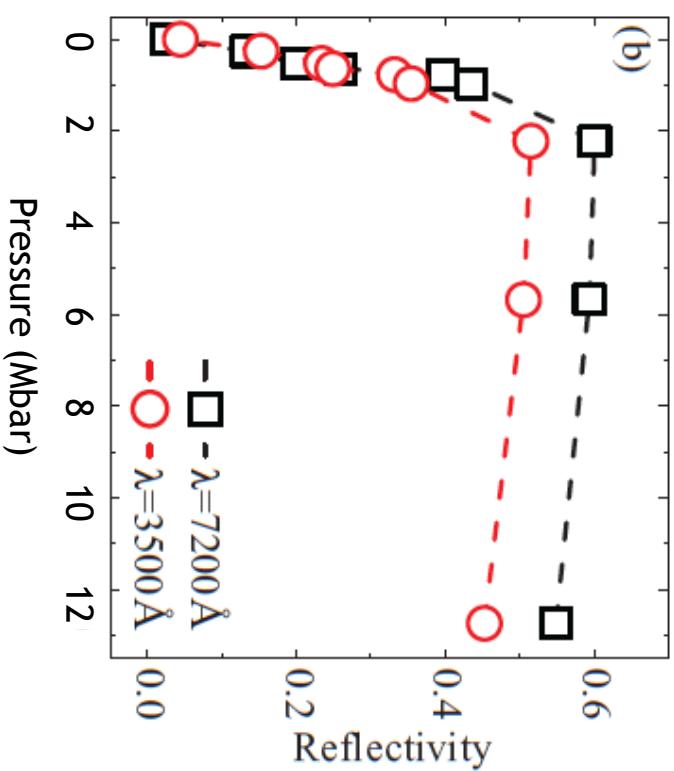
Temperature of shocked ammonia





Reflectivity of shocked ammonia

Li (2013), J.Chem.Phys.



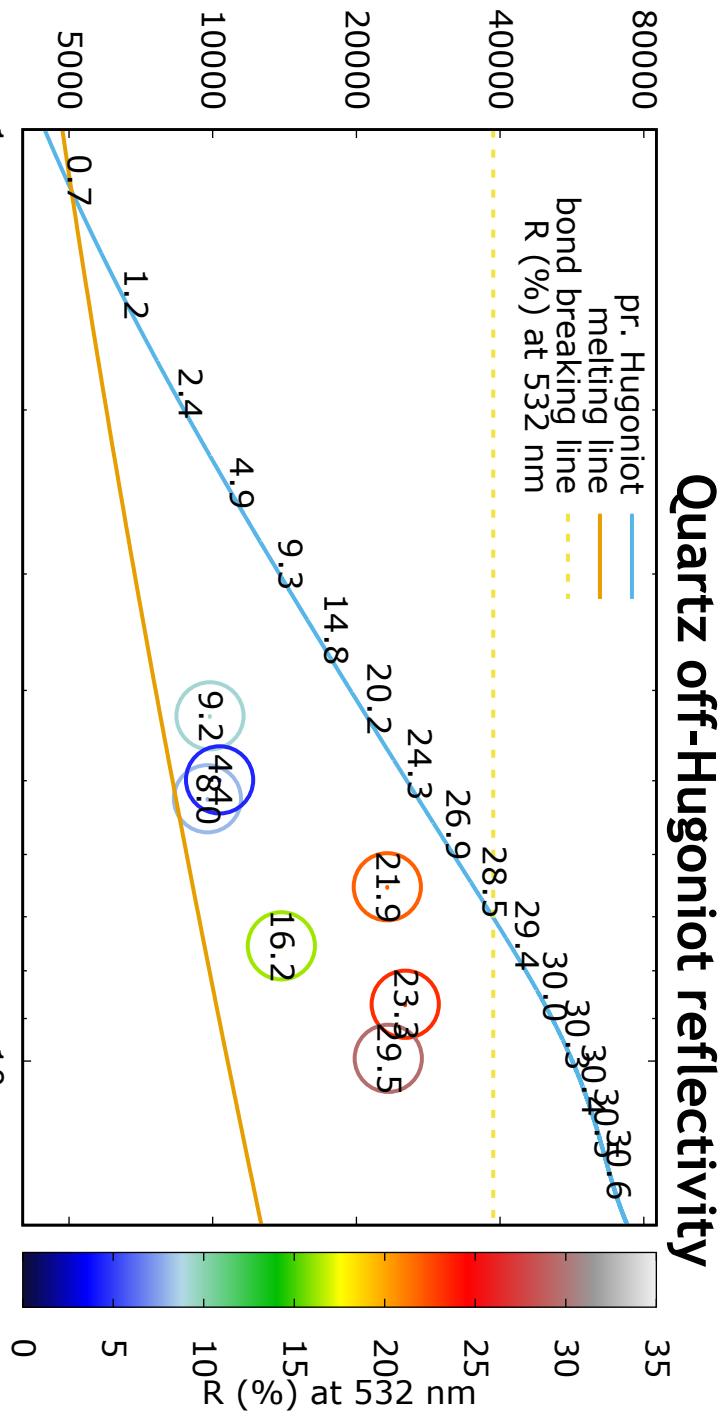
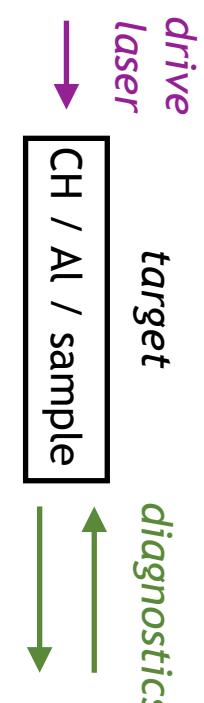
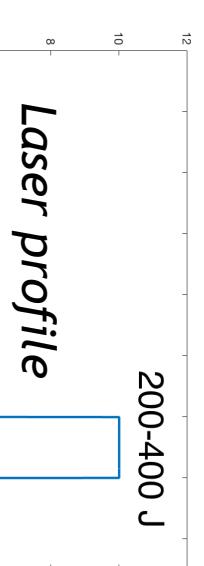
- Evidence of “metallization”
- Peak around 2 Mbar to be confirmed (more high-energy shots needed)
- Anomaly around 1 Mbar? Need to reproduct it



Projects

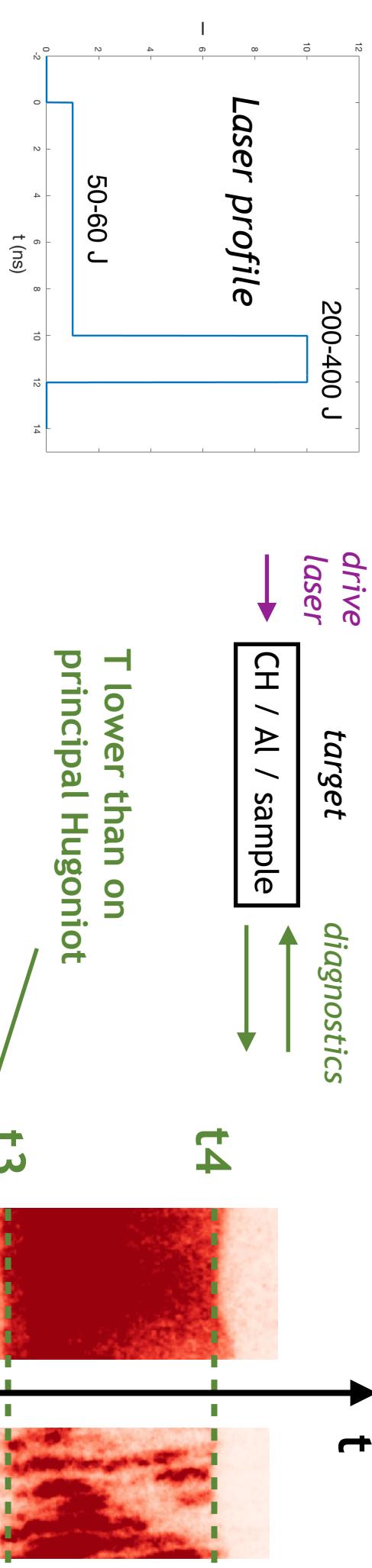
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ongoing
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ongoing

Development of a double shock technique



SOP

VISAR





Summary

- High power lasers to recreate planetary interiors in the laboratory
- Different compression techniques to explore (P, T) diagram

Hugoniot of water and C:H:N:O

- Same EoS (with density scaling)
→ planetary models 
- 1st R measure @ 2 freq.
→ planetary models 

Study of pure ammonia

- Development of cell + filling system
- First **high-pressure data: metallization**

Next steps...

- Complete liquid ammonia study
- Double shocks on mixtures & ammonia

Double shock technique

- Method development
- Explore phase diagrams
- @ low-T planetary conditions

Long term perspectives...

- Couple static & dynamic pre-compression
- Include X-ray diagnostics to probe microscopical structure

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Universität
Rostock



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