The Index of Refraction of Solid Hydrogen

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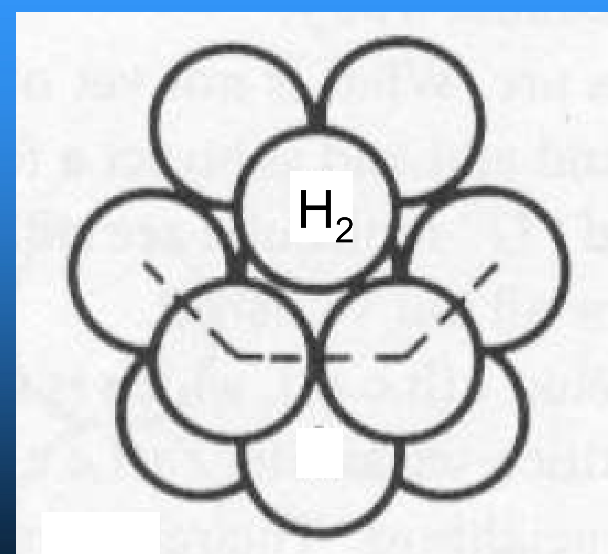
Overview

- Solid hydrogen background
- Why measure the index of refraction?
- Experiment
- Results
- Conclusions

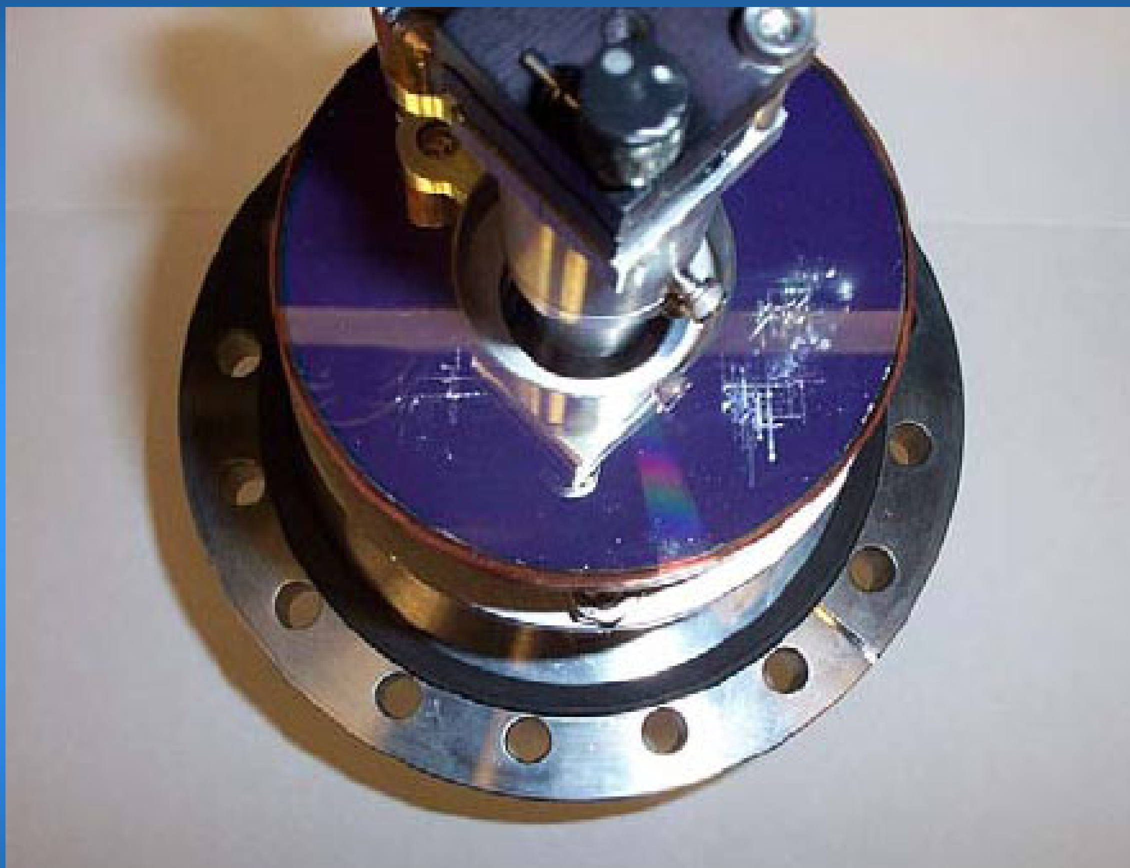
Solid Hydrogen Background

- Study of solid hydrogen is >70 years old
  - Quantum effects
  - Spin echo/relaxation NMR properties
  - Raman scattering
- Areas open for study
  - Mechanical properties
  - Index of refraction

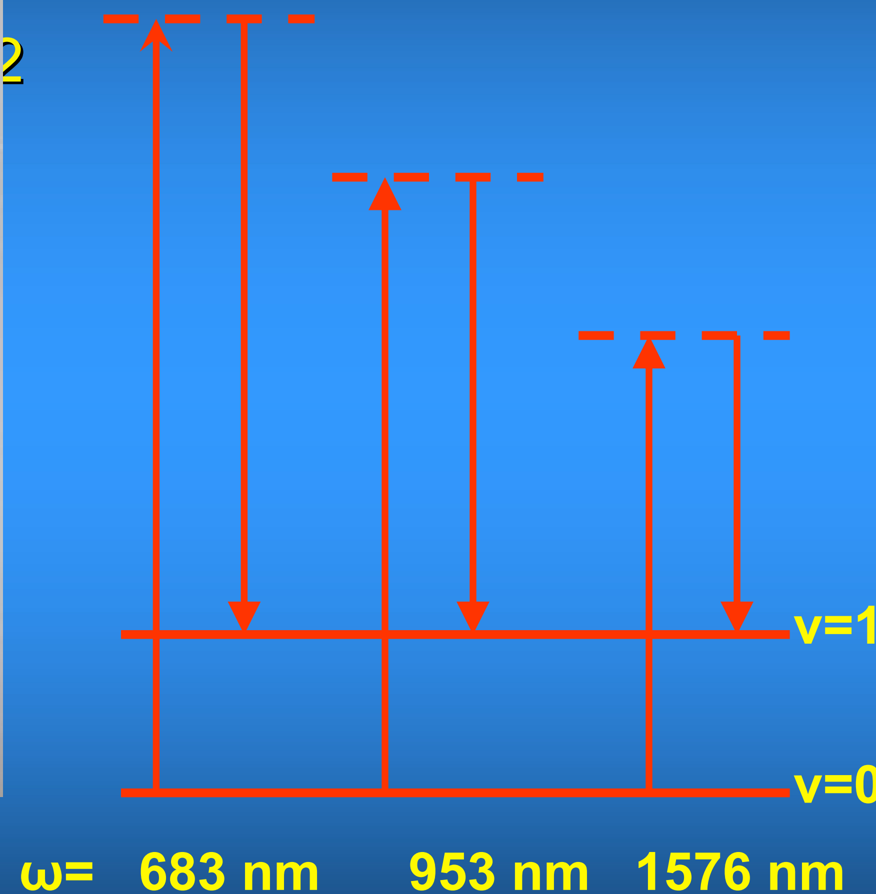


Van Kranendonk, Solid Hydrogen, Plenum Press, 1983.
Souers, Hydrogen Properties for Fusion Energy, U of Cal. Press, 75,1986.

Why measure the index?



threshold mirrors



Brasseur *et al.,* Optics Ltrs., **23**, 367, 1998.
Brasseur *et al.,* JOSA Comm., 1999.
McCall *et al.*, App. Phys. Ltrs., **82**, 2003.
McCall, OSU Conference Talk, 2003.

Why measure the index?

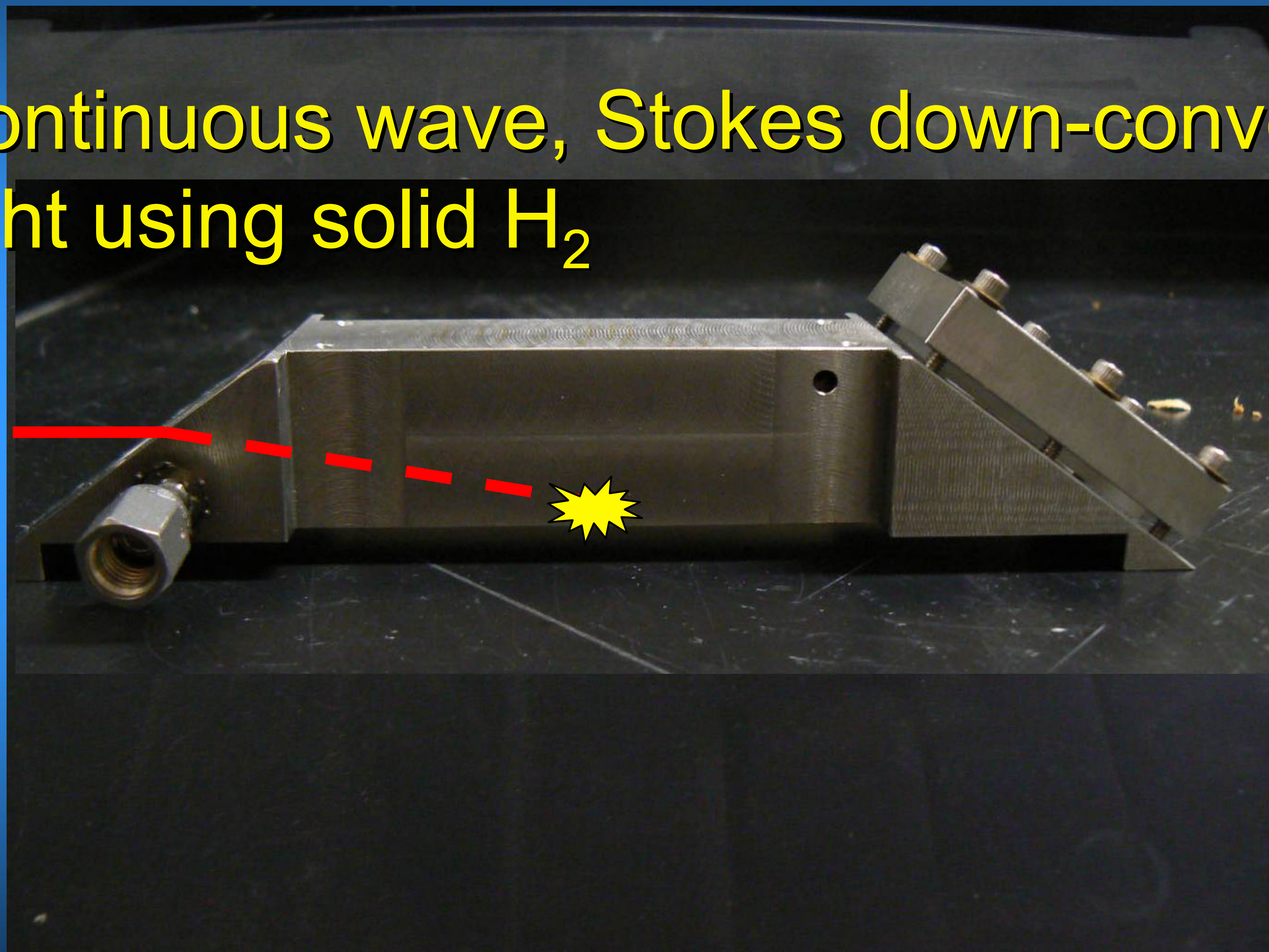
- Condensed phases are more efficient for Raman shift
  - 7000 x gain
  - Higher number density
  - Smaller line width
- Consistent with observations of Katsuragawa *et al*.

Phase	Number Density (cm^{-3}),n	Linewidth Γ	Gain
Gaseous H_2	3.1E21	28.4GHz	$\frac{n}{\Gamma}$
Liquid H_2	2.1E22	1.5 GHz	
Solid H_2	2.6E22	<7 MHz	

Souers, Hydrogen Properties for Fusion Energy, U of Cal. Press, 1986.
Uetake *et al.*, Phys. Rev. A., **61**, 1999.
Katsuragawa *et al.,* Optics Letters, **25**, 177, 2000.
McCall *et al.*, App. Phys. Ltrs., **82**, 2003.

Why Measure the Index?

- Continuous wave, Stokes down-converted light using solid H_2



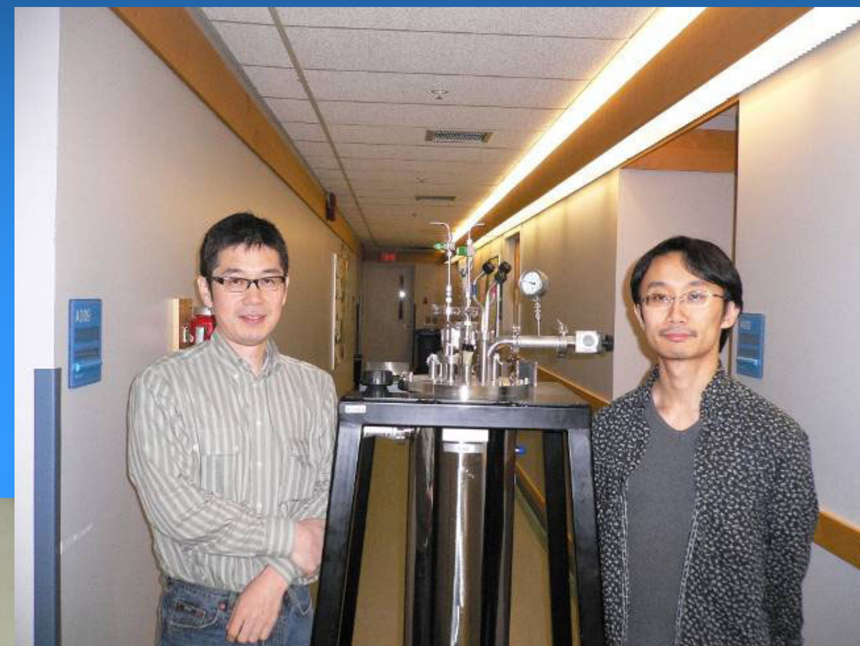
Experiment:
The art of making solid hydrogen

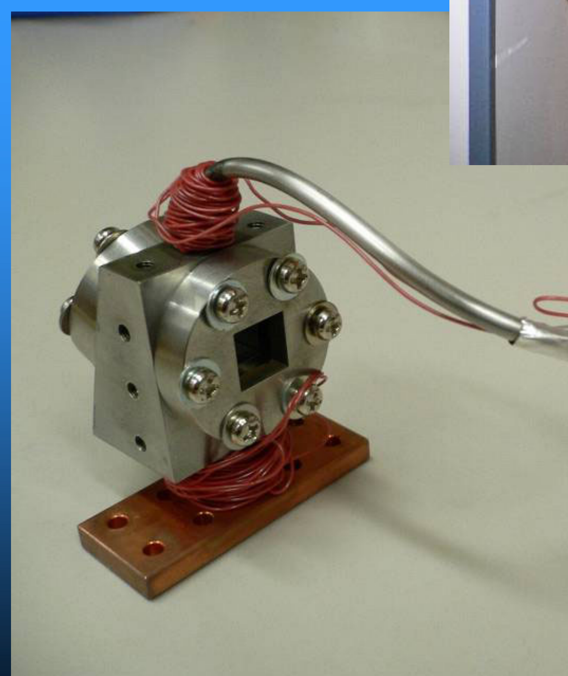
- >99.9% pure parahydrogen used in both Kyoto and Champaign-Urbana
- Two methods of crystal growth
  - Vapor Deposition
  - Crystallization from liquid

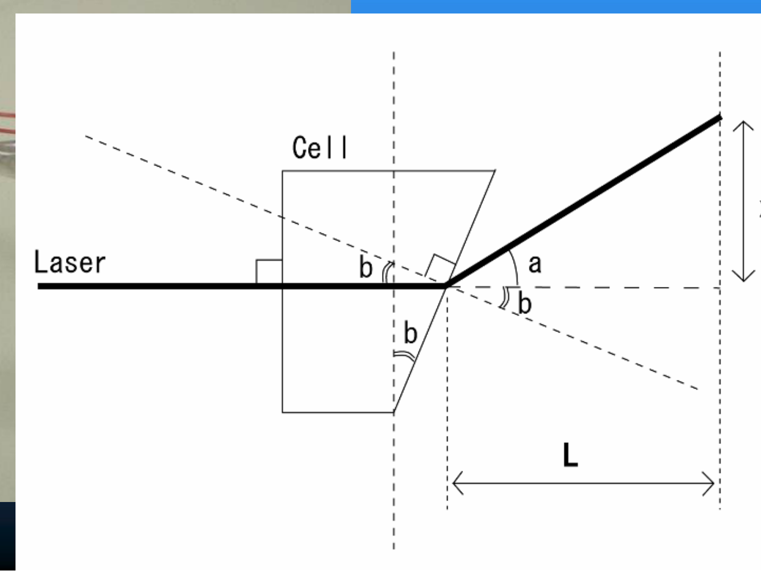
Souers, P., Hydrogen Properties for Fusion Energy, U of Cal., 1986.

Experiment: Kyoto

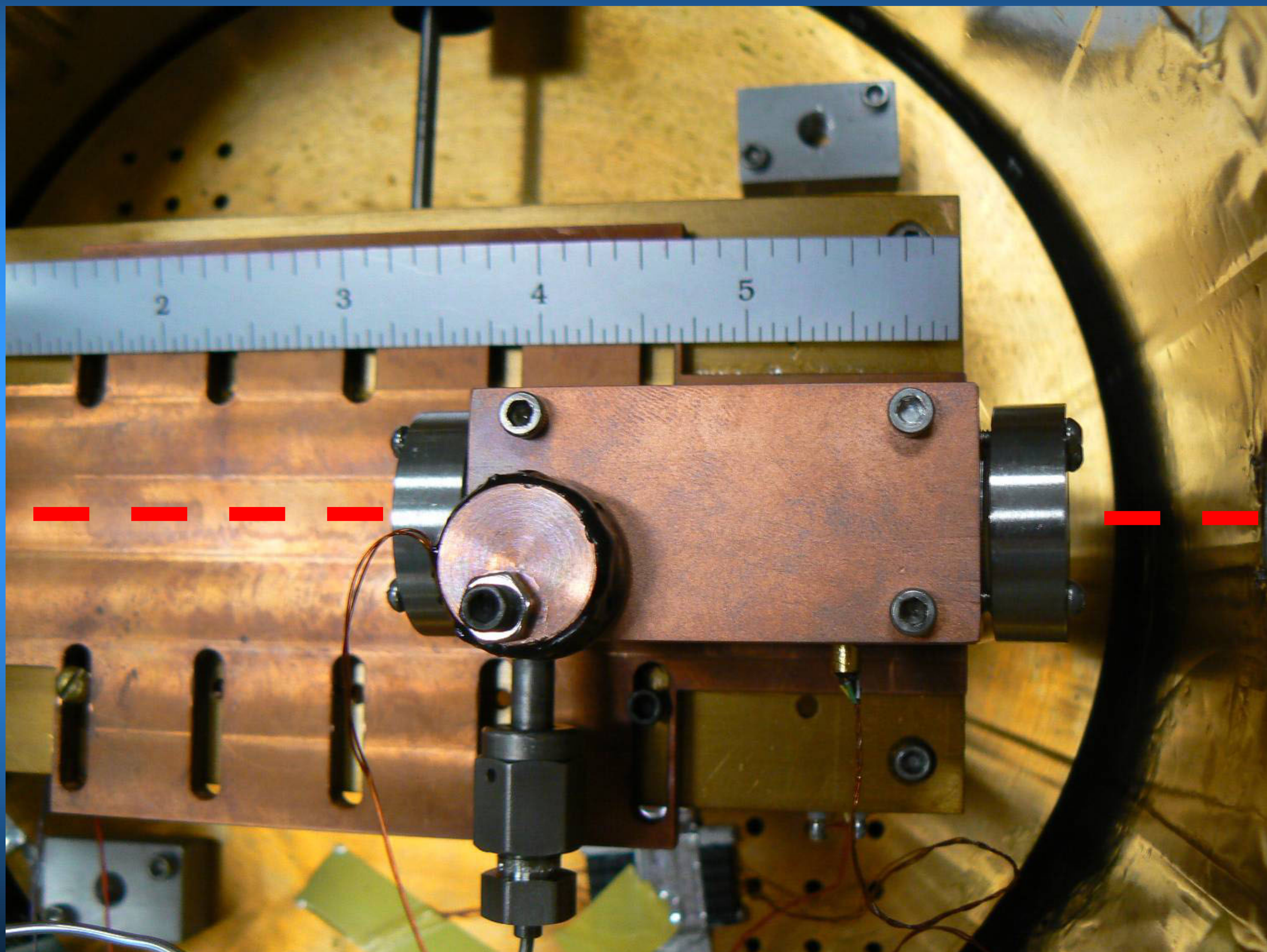
- 434.8 to 1111.1 nm
- Measured difference between vacuum and solid H_2
  - Measurement taken at 10 meters



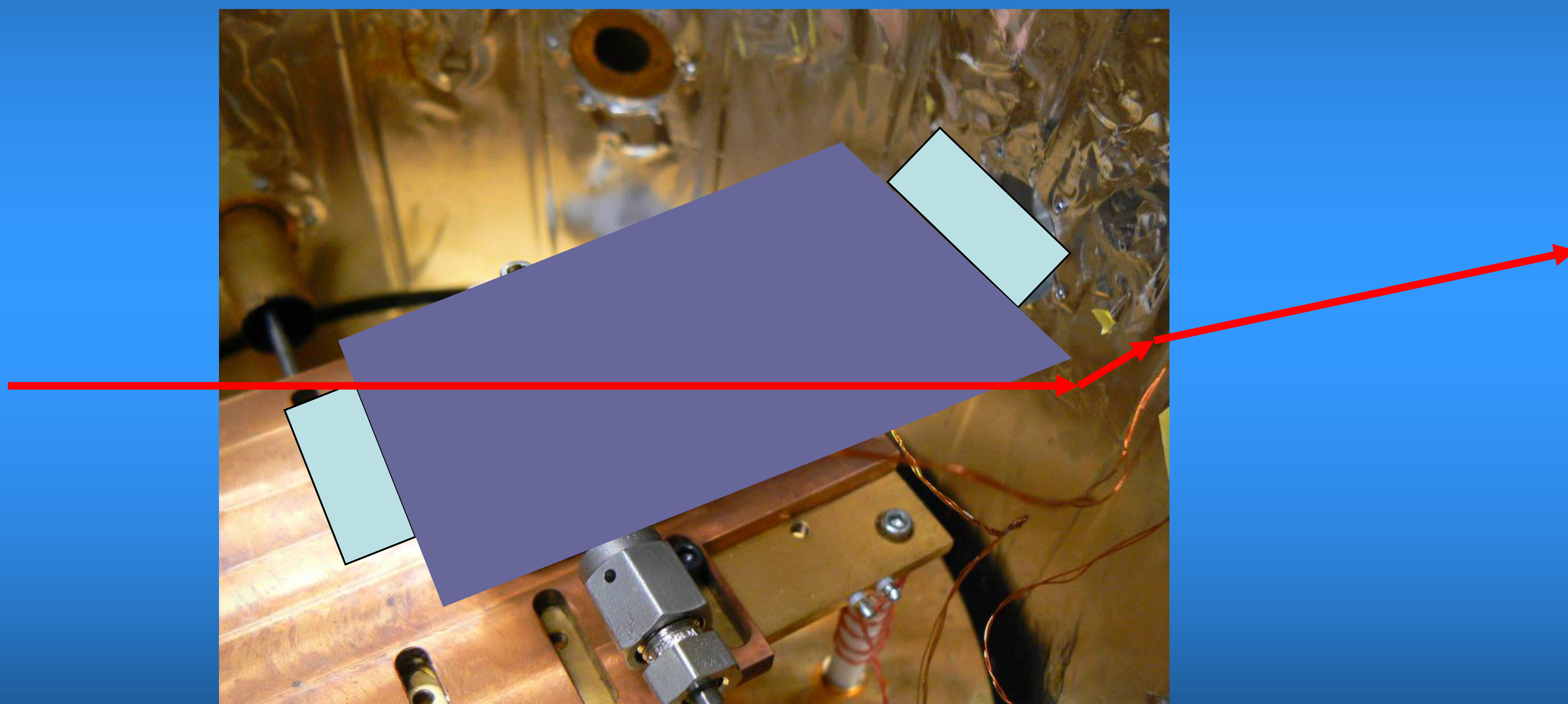




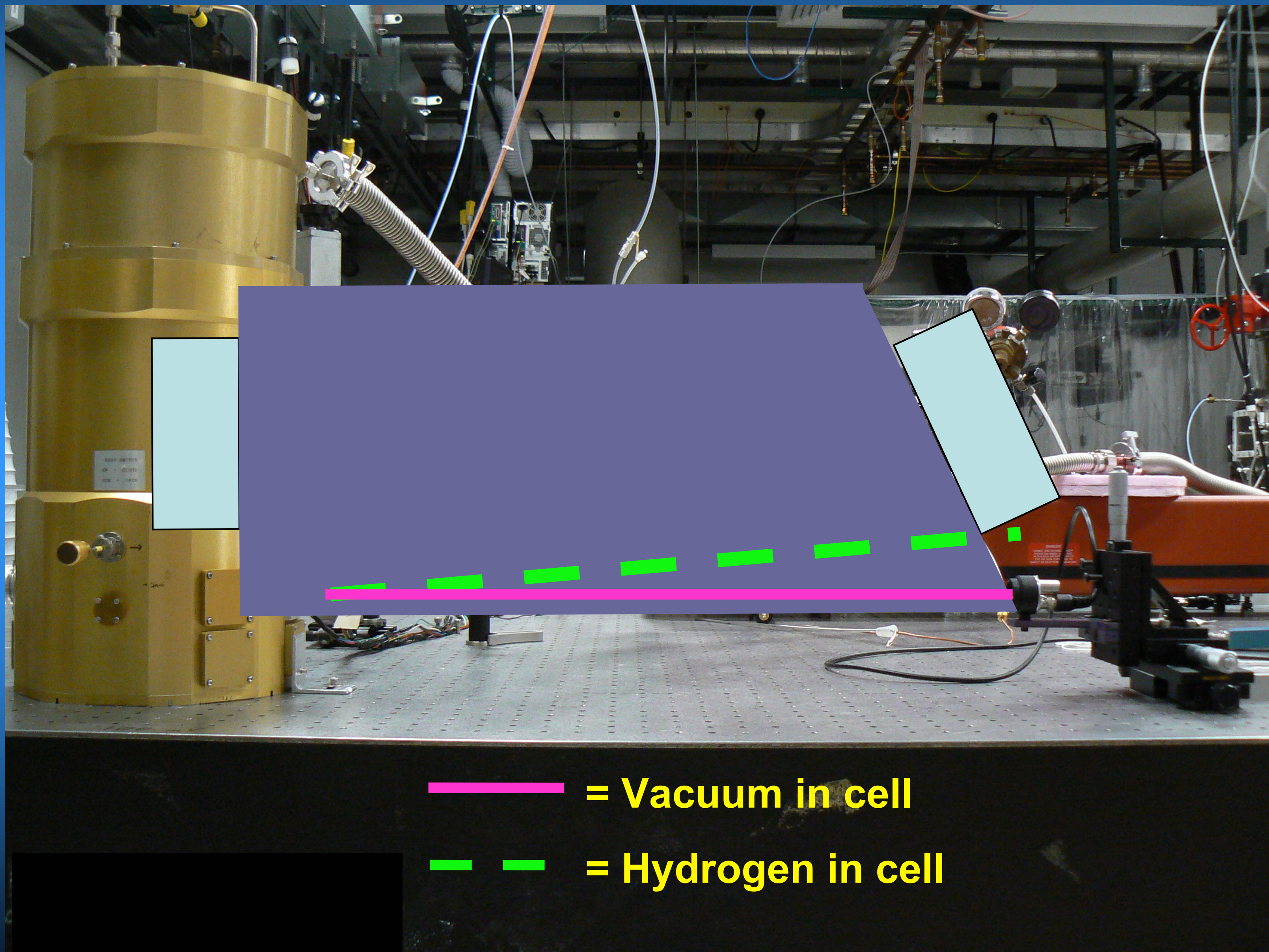
Experiment: Champaign-Urbana



Experiment: Champaign-Urbana



Experiment: Champaign-Urbana



Experiment: Champaign-Urbana

$$D = \frac{-S \cdot Sin\left[\theta_U - ArcSin\left(\frac{n_u}{n_s} Sin\theta_U\right)\right]}{Cos\left[ArcSin\left(\frac{n_U}{n_s} Sin\theta_U\right)\right]} + V \cdot Tan\left[ArcSin\left(\frac{n_U}{n_v} Sin\theta_U\right) - \theta_U\right] +$$

$$G \cdot Tan\left\{ArcSin\left[\frac{n_v}{n_s} Sin\left[ArcSin\left(\frac{n_U}{n_v} Sin\theta_U\right) - \theta_U\right]\right]\right\} +$$

$$A \cdot Tan\left\{ArcSin\left[\frac{n_v}{n_A} Sin\left[ArcSin\left(\frac{n_U}{n_v} Sin\theta_U\right) - \theta_U\right]\right]\right\}$$

Preliminary Results

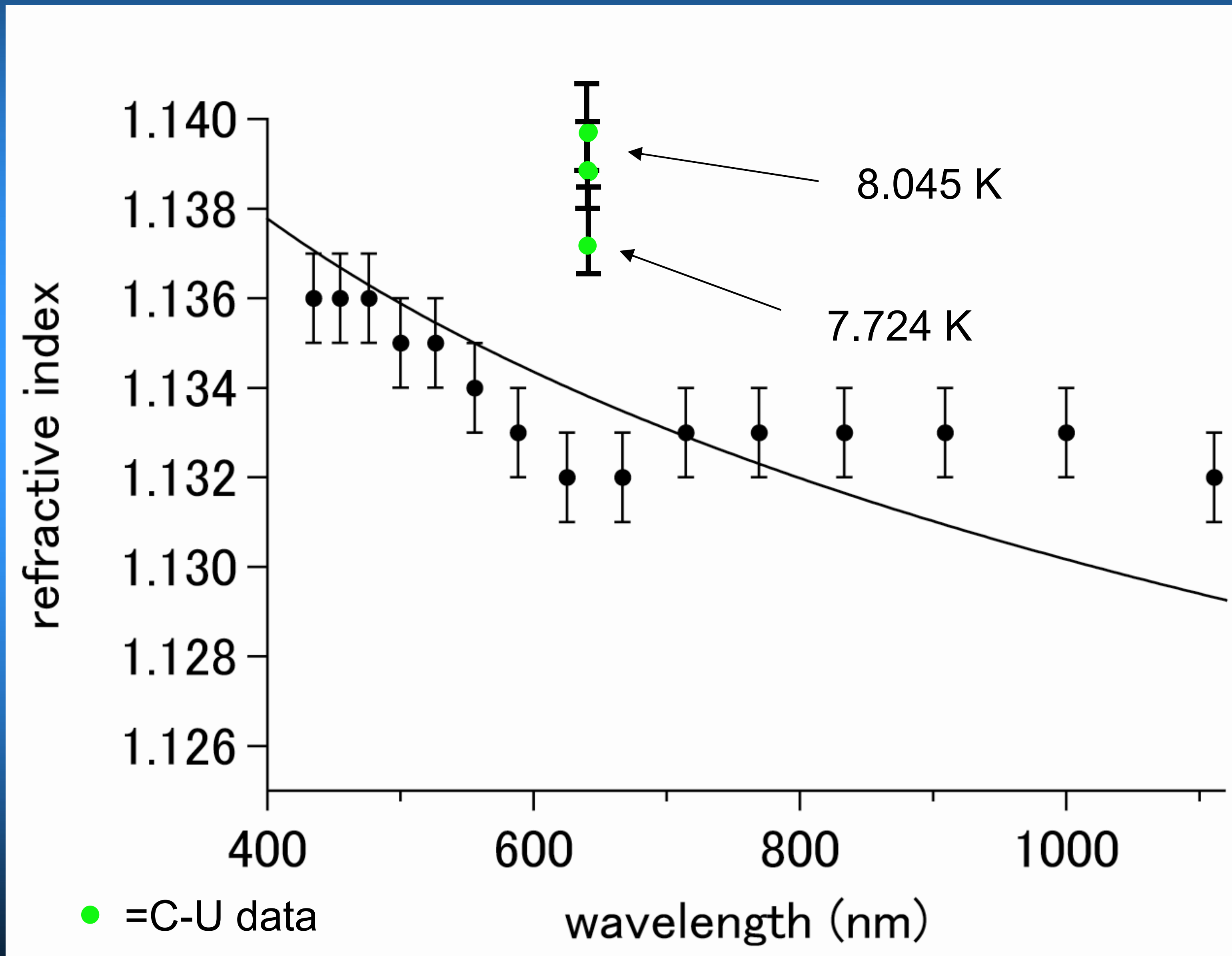
Wavelength (nm)	Index* ± 0.001 (Kyoto)	Index† ± 0.001 (C-U)
2000-5000		DFG
1111.1	1.132	
1000.0	1.133	Diode
909.1	1.133	Diode
[illegible]	[illegible]	
769.2	1.133	
[illegible]	1.133	
[illegible]	[illegible]	
632.8		1.1373-1.1395
625.0	1.132	
588.2	1.133	
555.6	1.134	
526.3	1.135	
500.0	1.135	Argon Ion
476.2	1.136	Argon Ion
454.5	1.136	
434.8	1.136	

*6 K

† 7.724-8.049 K

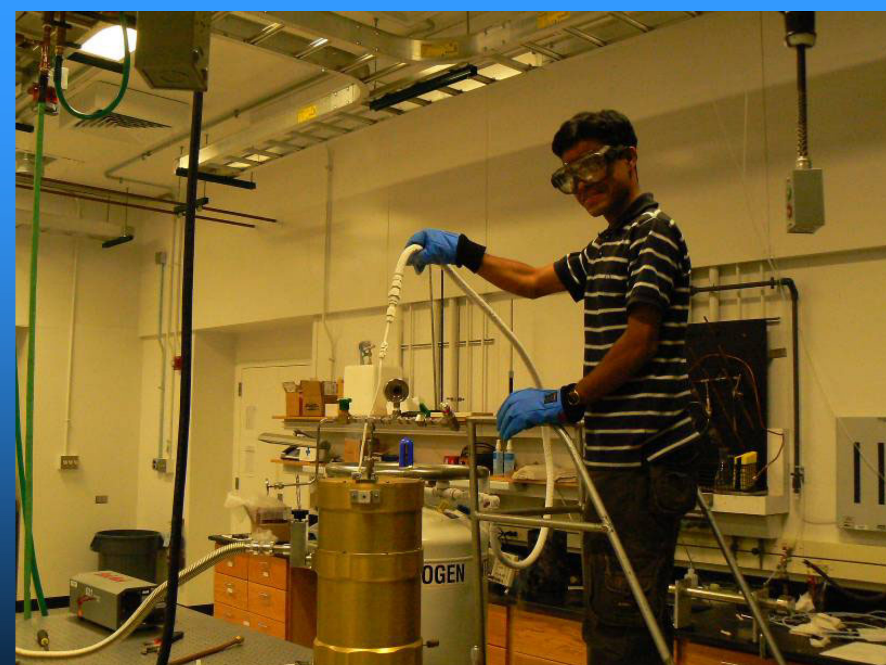
■ = C-U Target Wavelengths

Preliminary Results



Conclusions

- Solid hydrogen is an efficient tool for generating light for spectroscopy
- More measurements to come
- CW, Stokes-shifted light via solid H_2 is on the horizon



Acknowledgements

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