Laser stabilization via saturated absorption spectroscopy of iodine for applications in laser cooling and Bose-Einstein condensate creation

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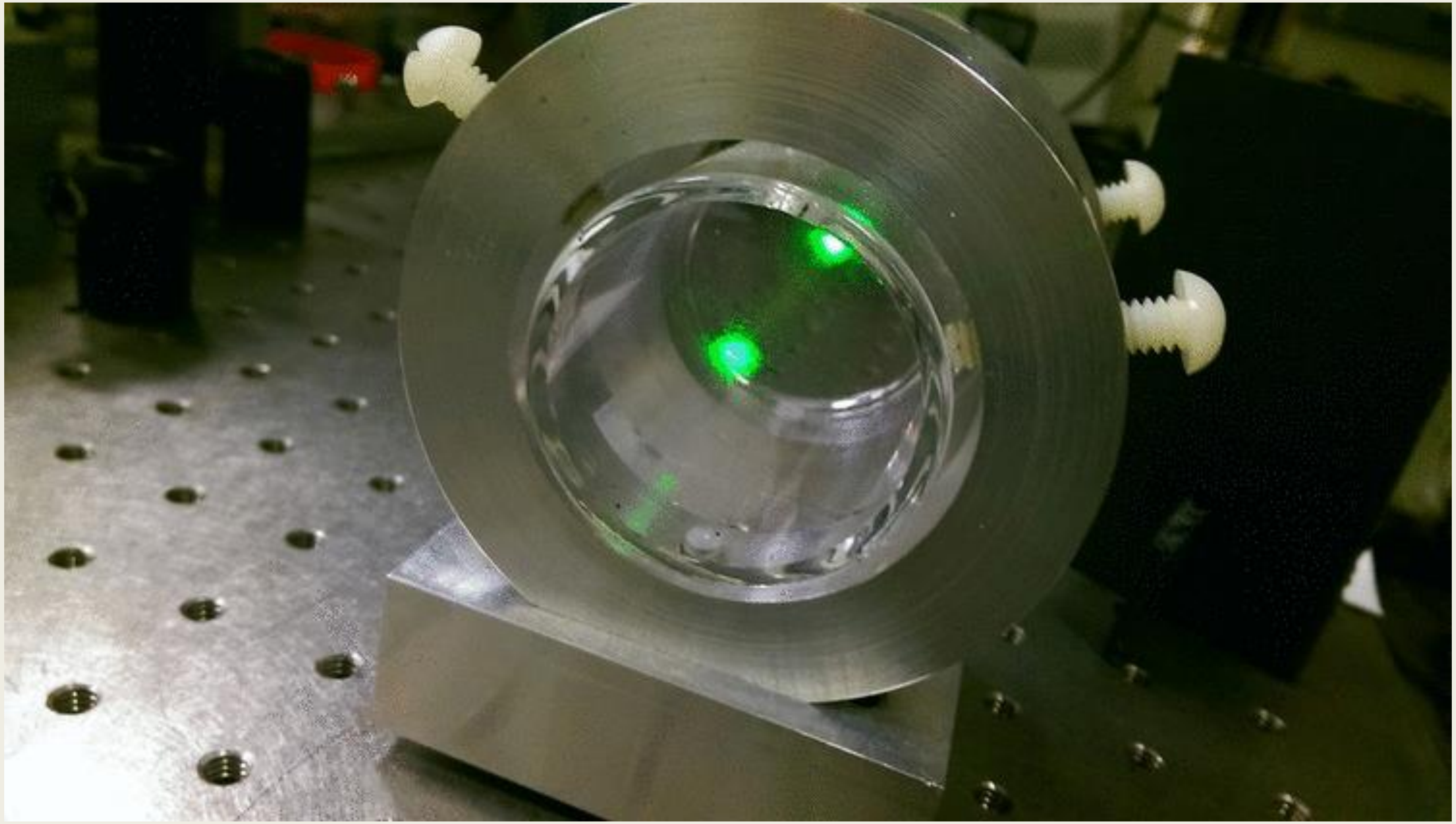
- Atomic and molecular transitions are nearly always constant, however
- A gas cell is used, and the laser wavelength varied around the target
- Absorption peaks when a transition is accessible by the laser

Visible fluorescence!



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- Doppler-broadened transitions are ~GHz, versus natural linewidths ~MHz

Doppler effects

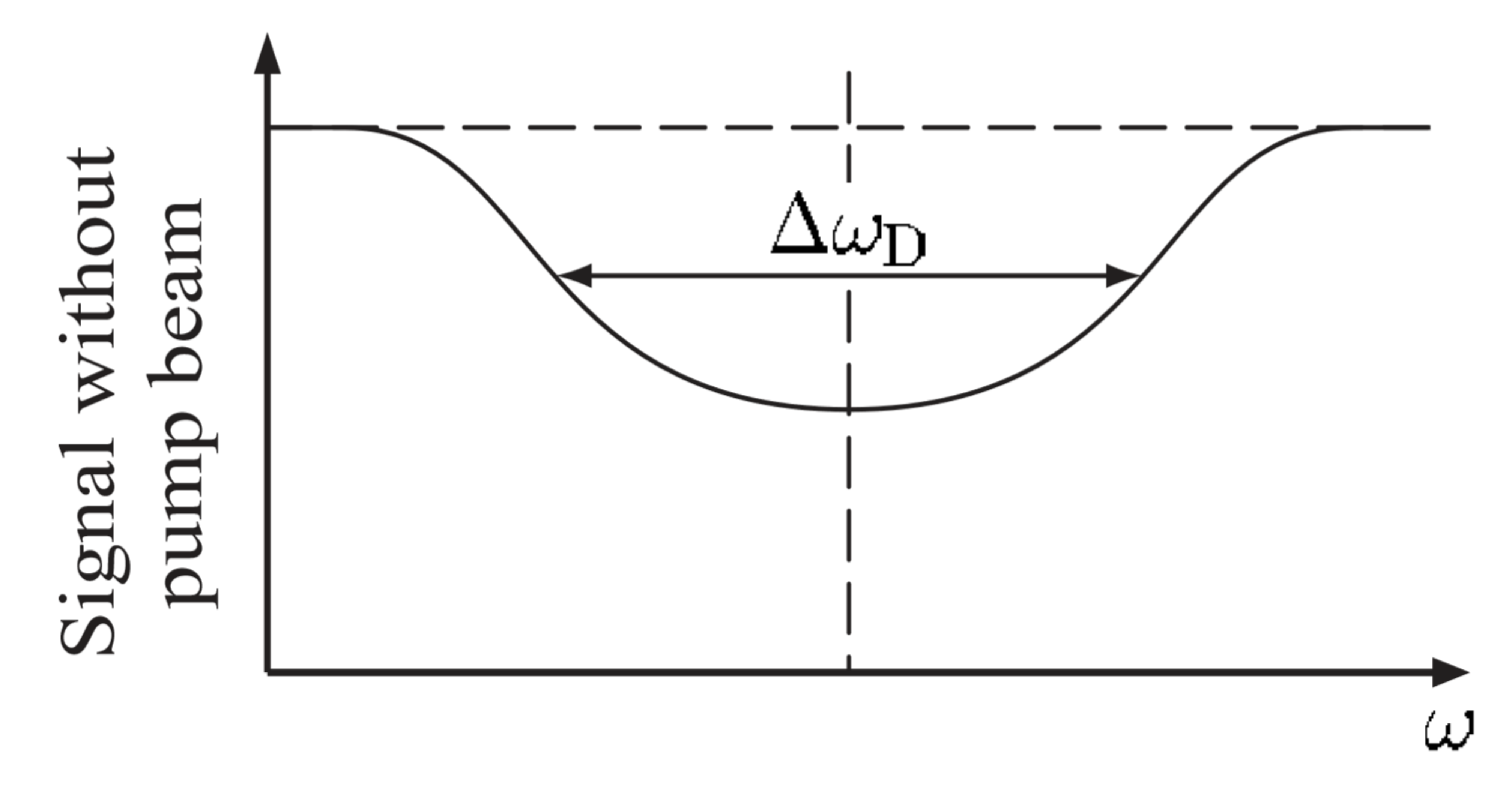
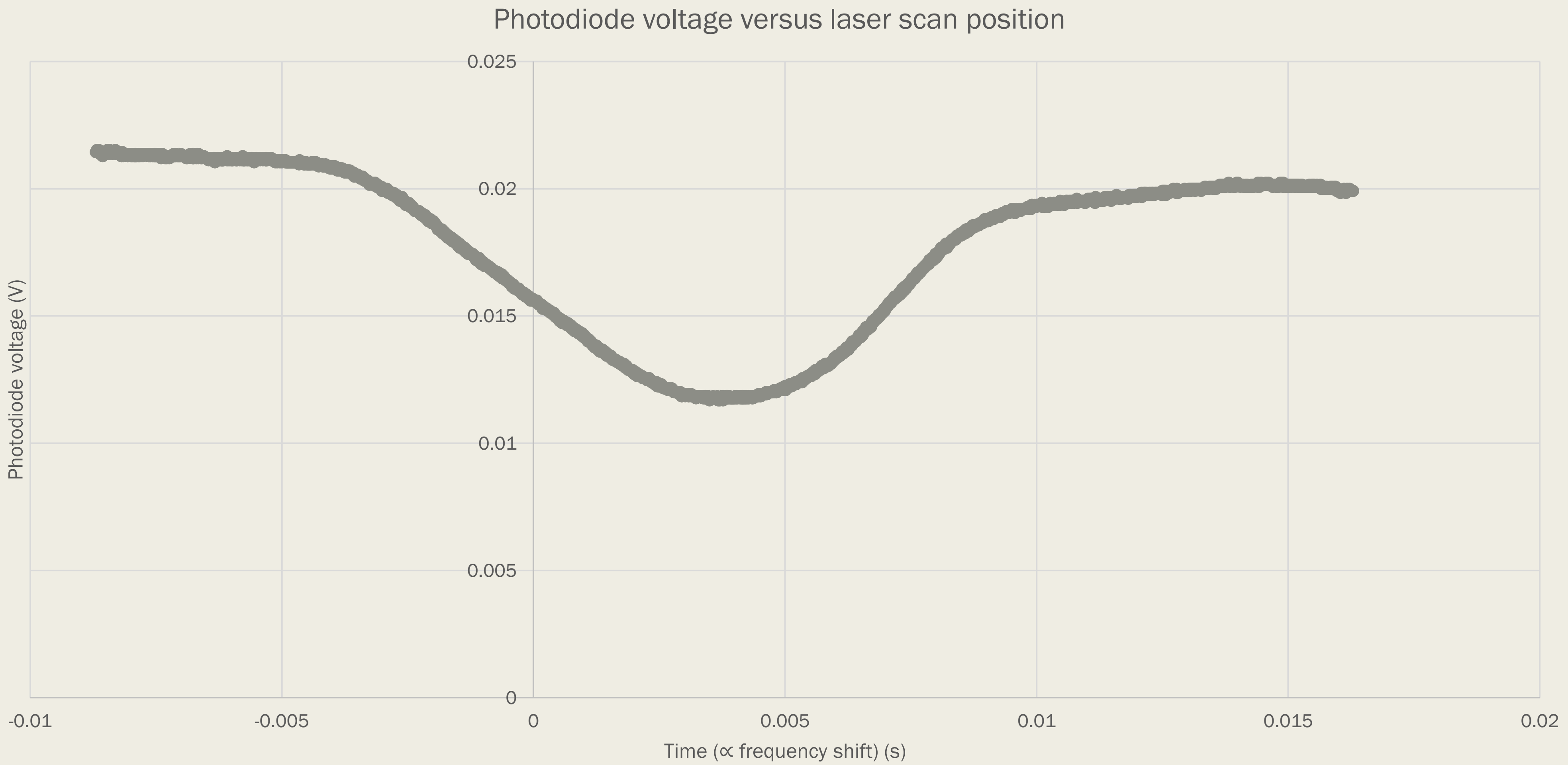


Image courtesy [2]

Sure enough:



Photodiode voltage versus laser scan position
0.025
0.02
0.015
0.01
0.005
0
Photodiode voltage (V)
-0.01
-0.005
0
0.005
0.01
0.015
0.02
Time (∝ frequency shift) (s)

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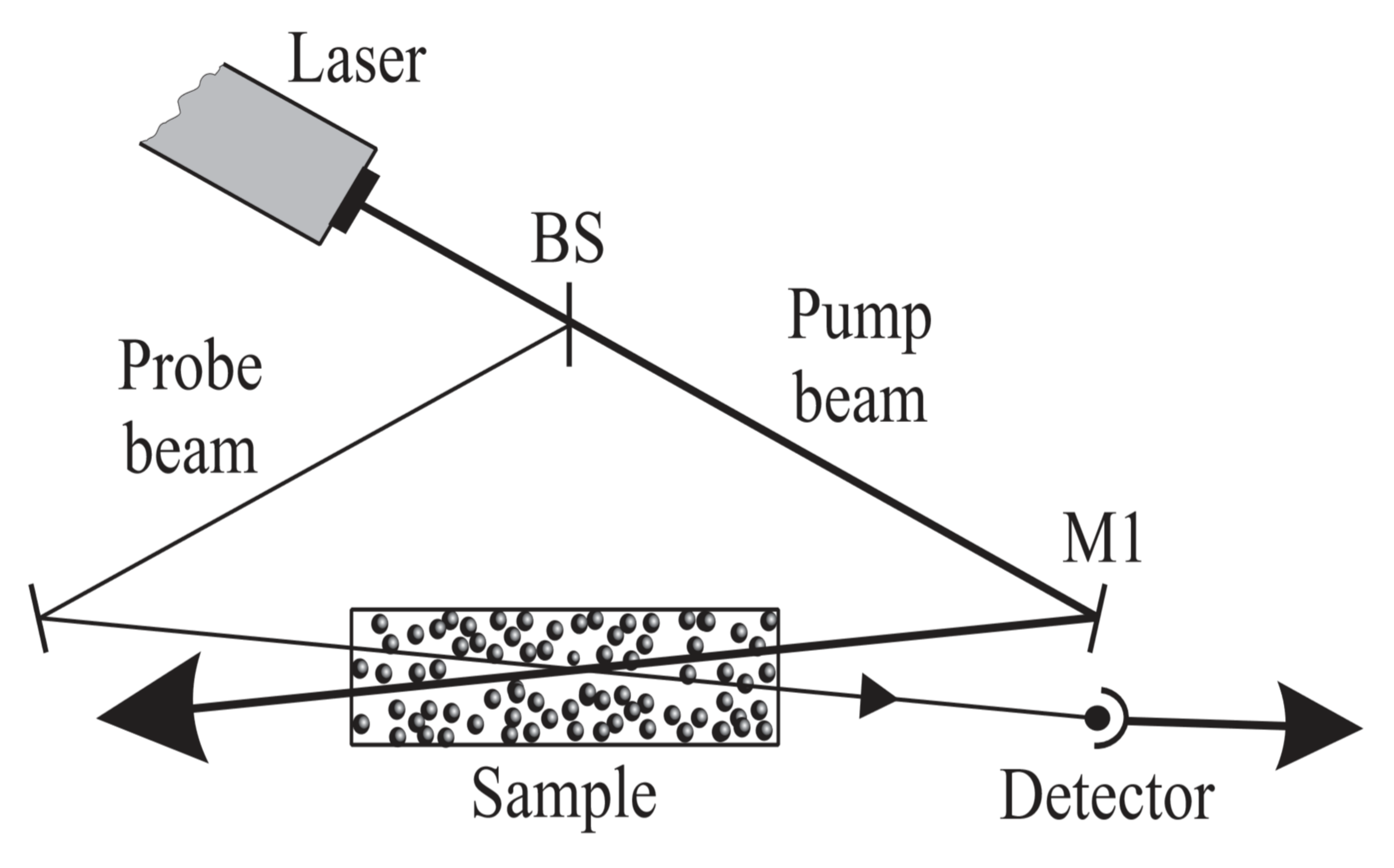
- Feedback is then arranged to constrain the laser wavelength to that of the transition

Saturated absorption spectroscopy



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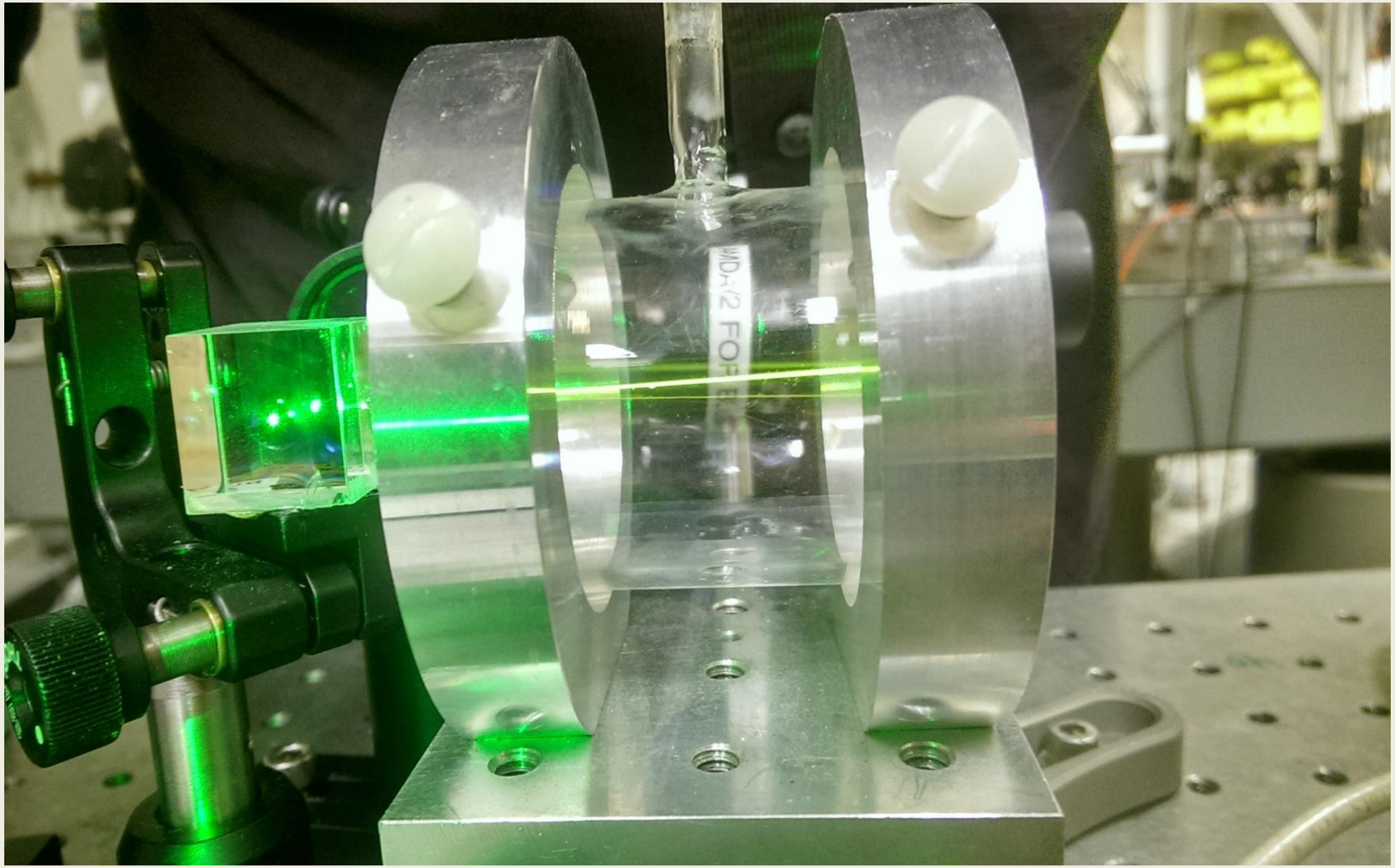

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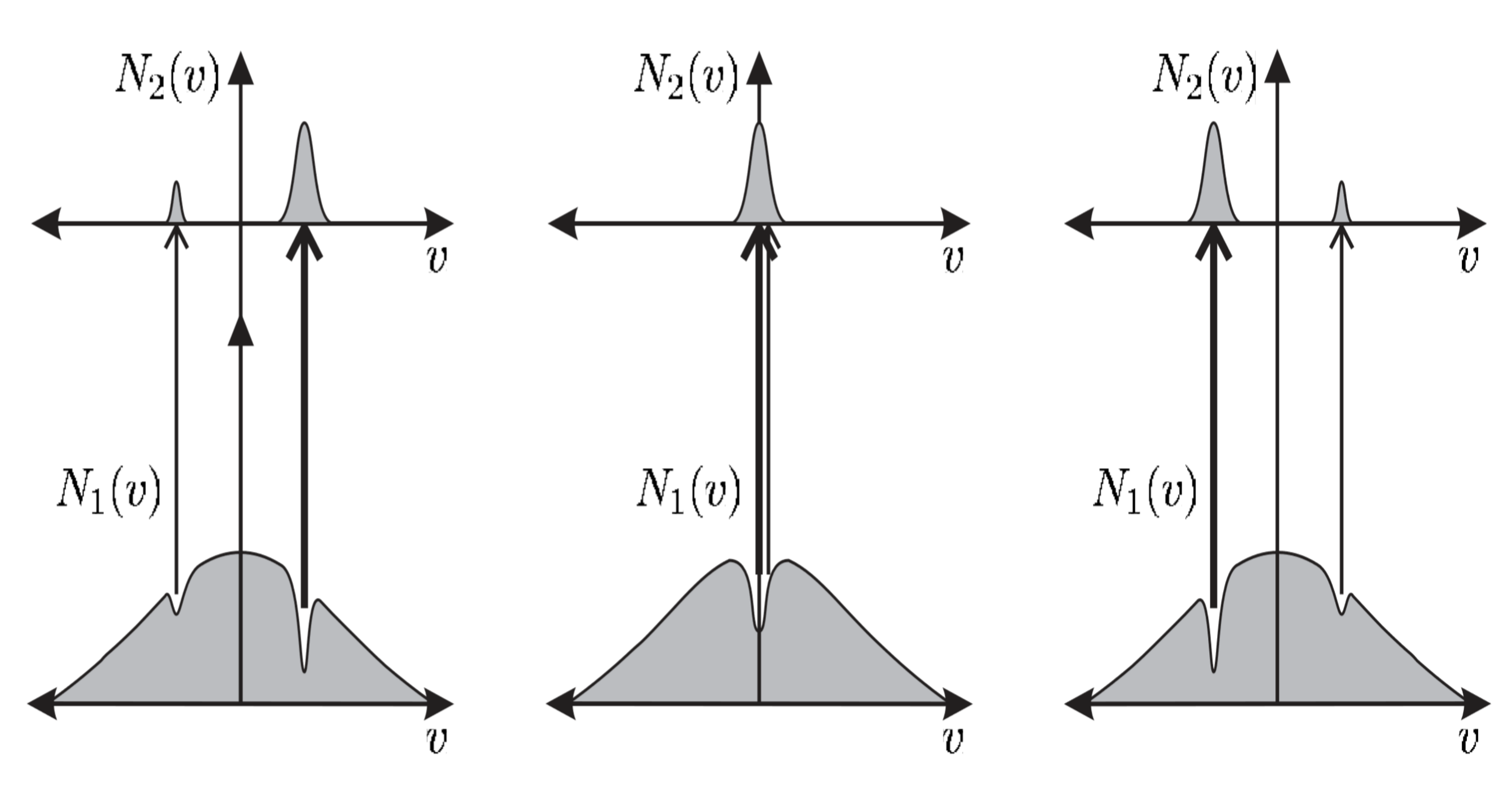

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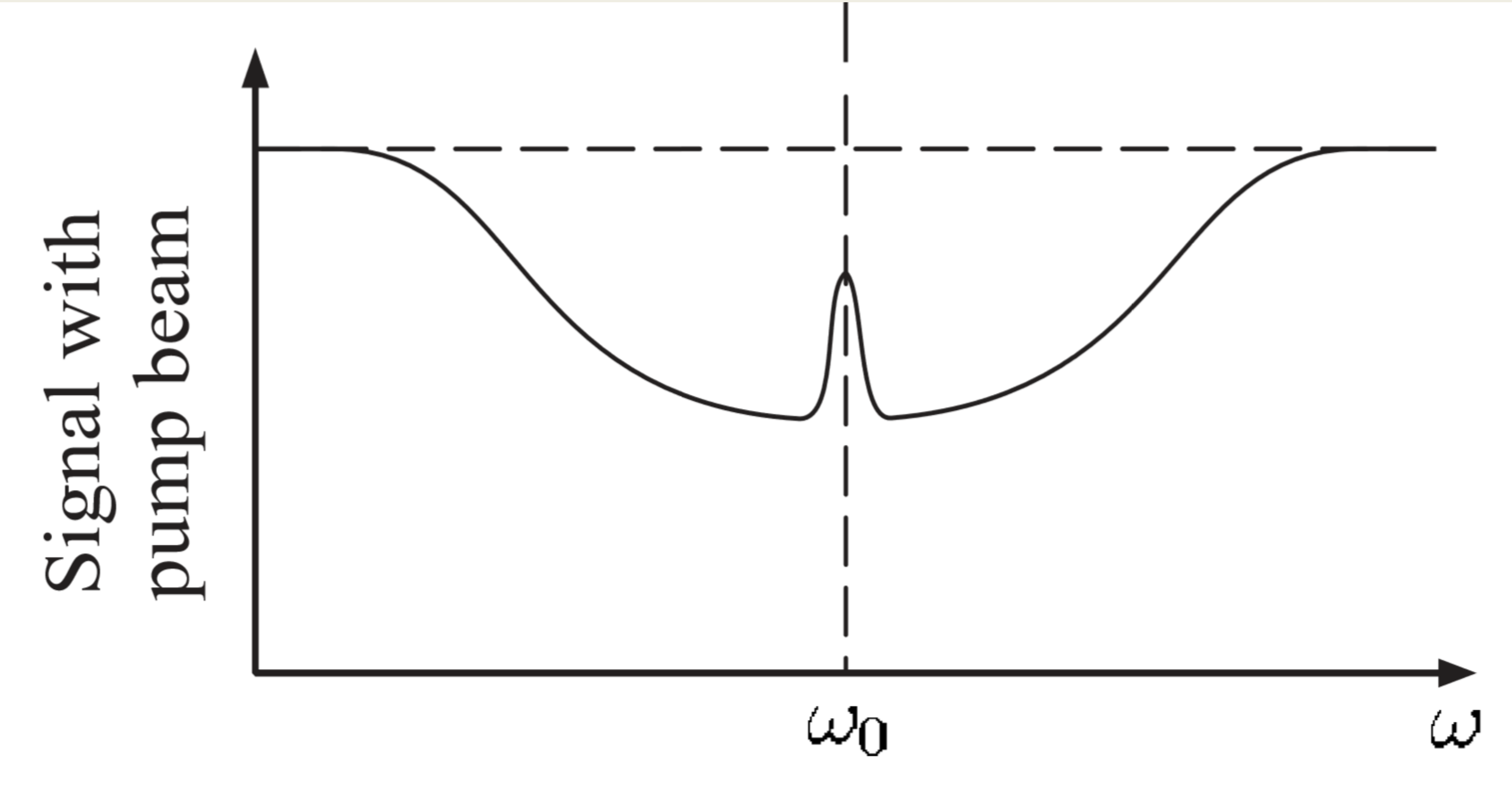

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- Easy to see visually

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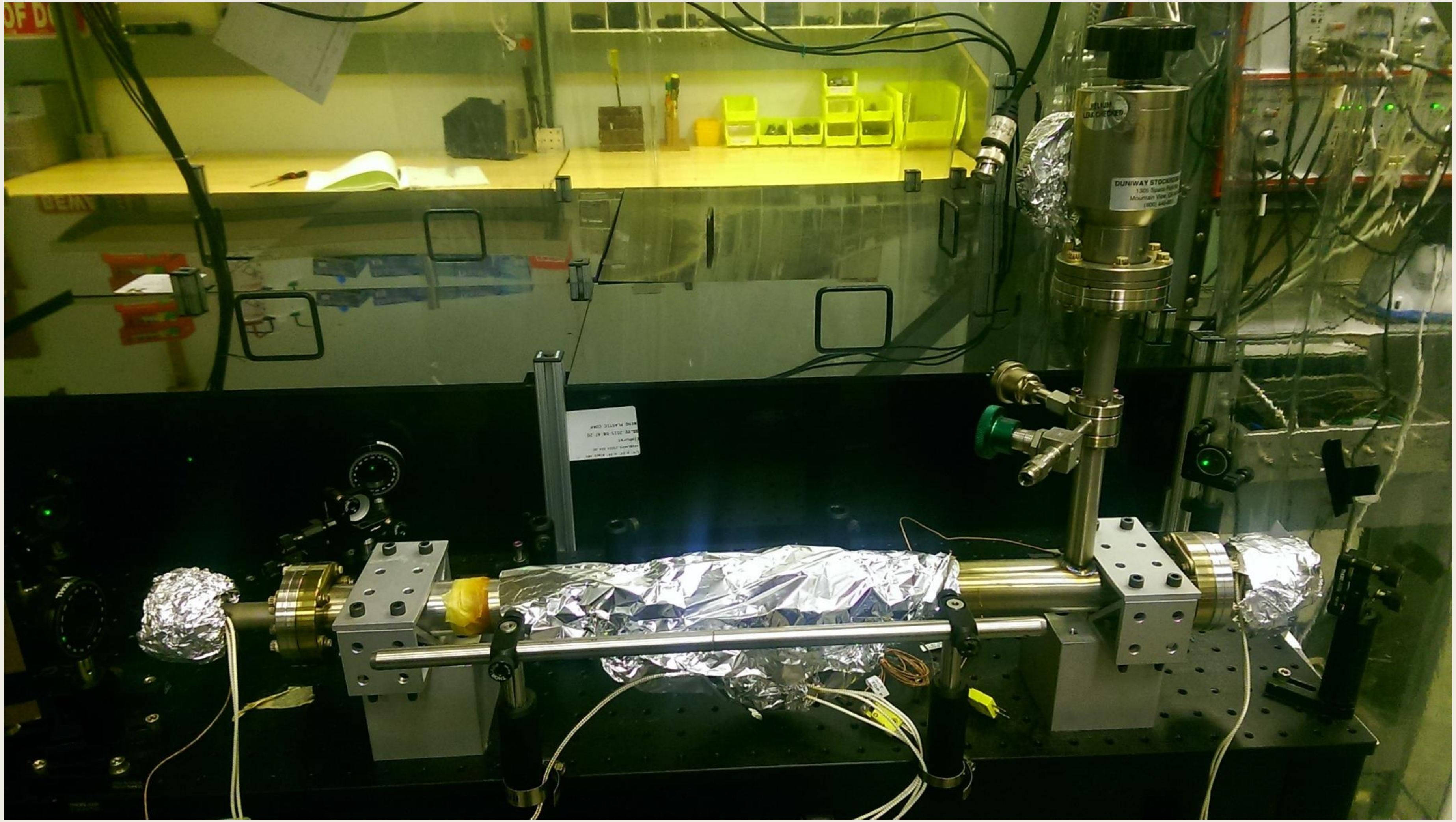

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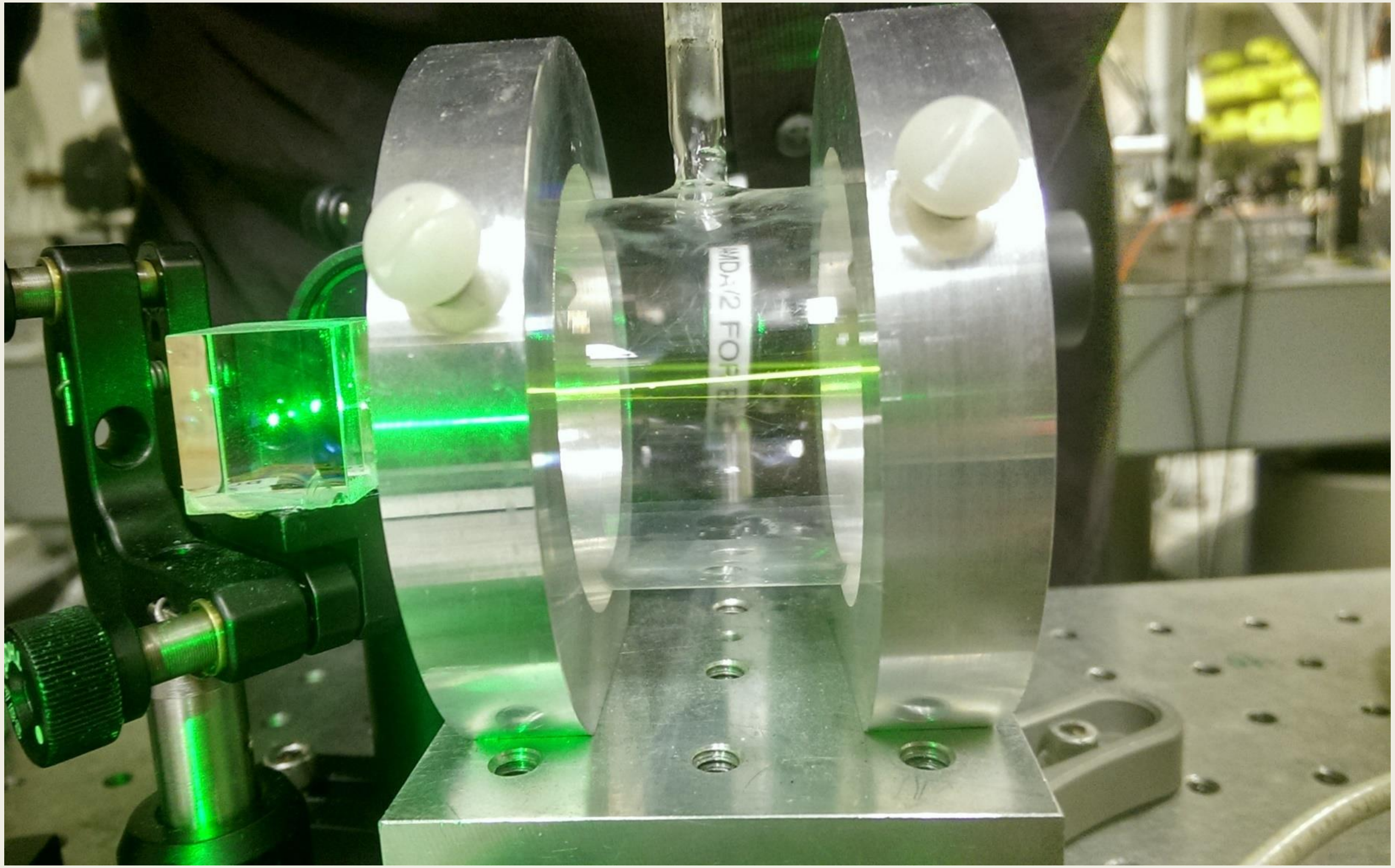

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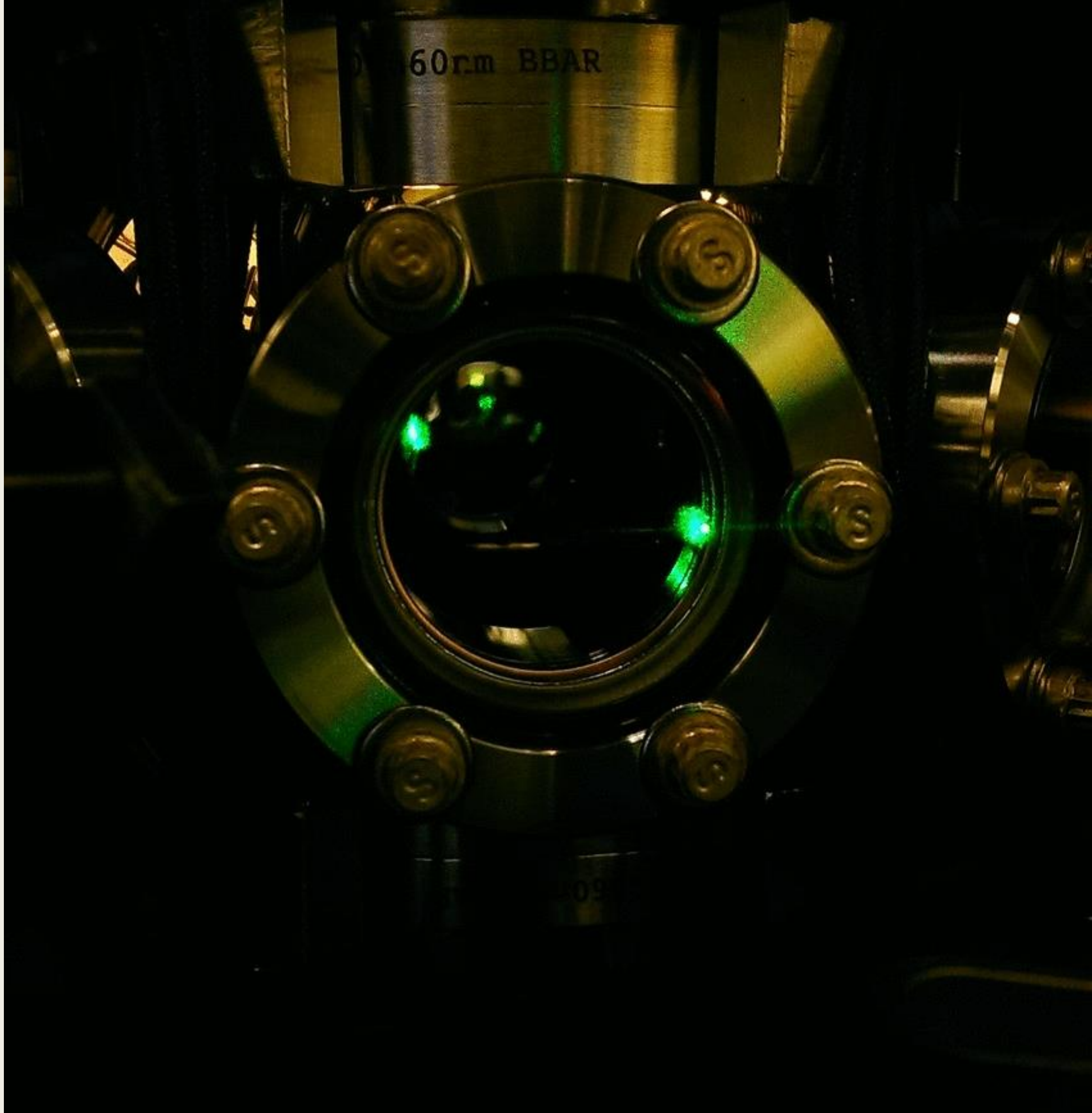
The MOT in action!



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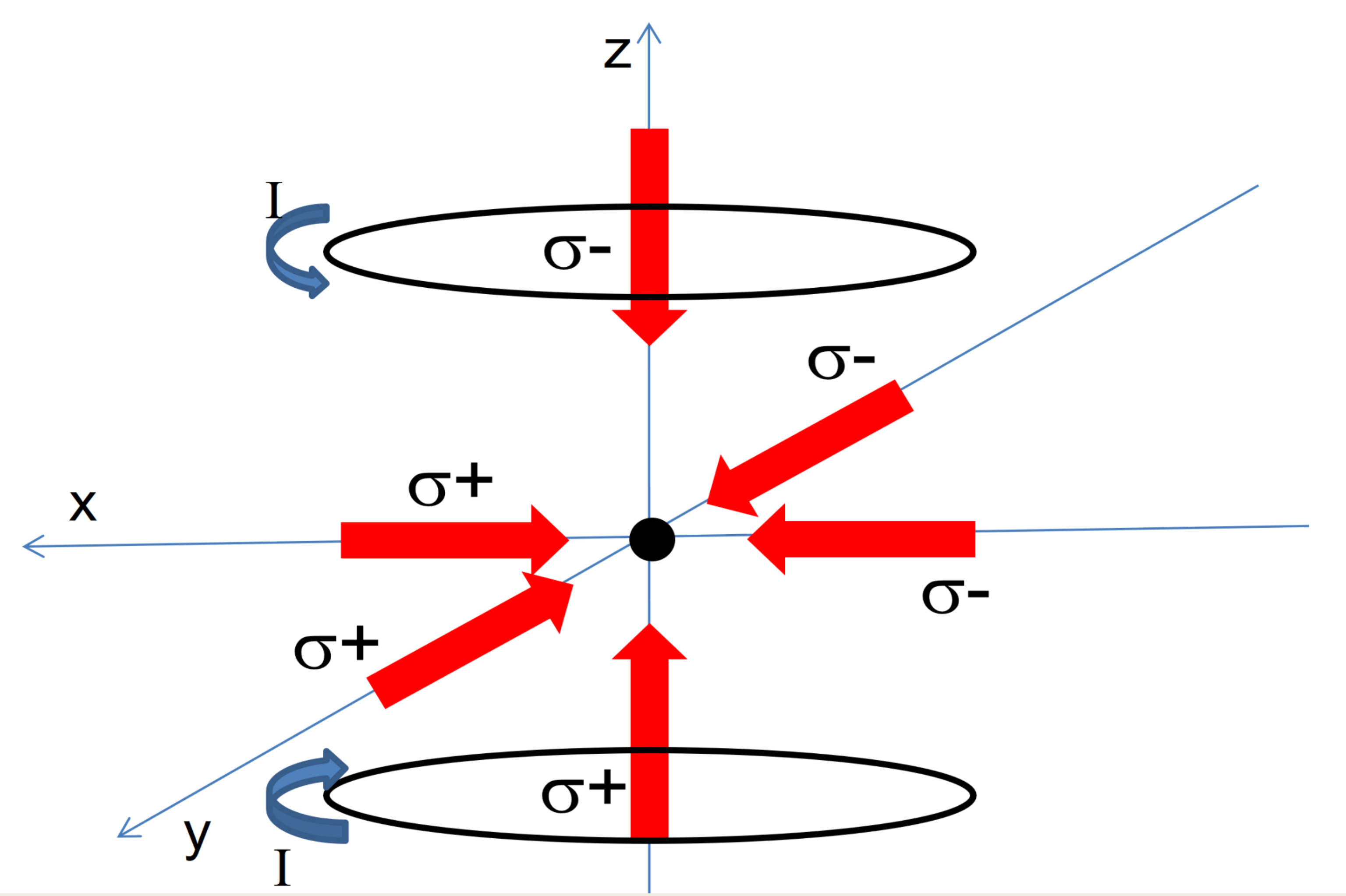

Image courtesy Deep Gupta

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Image courtesy [5]

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- Evaporative cooling allows high-energy atoms to exit

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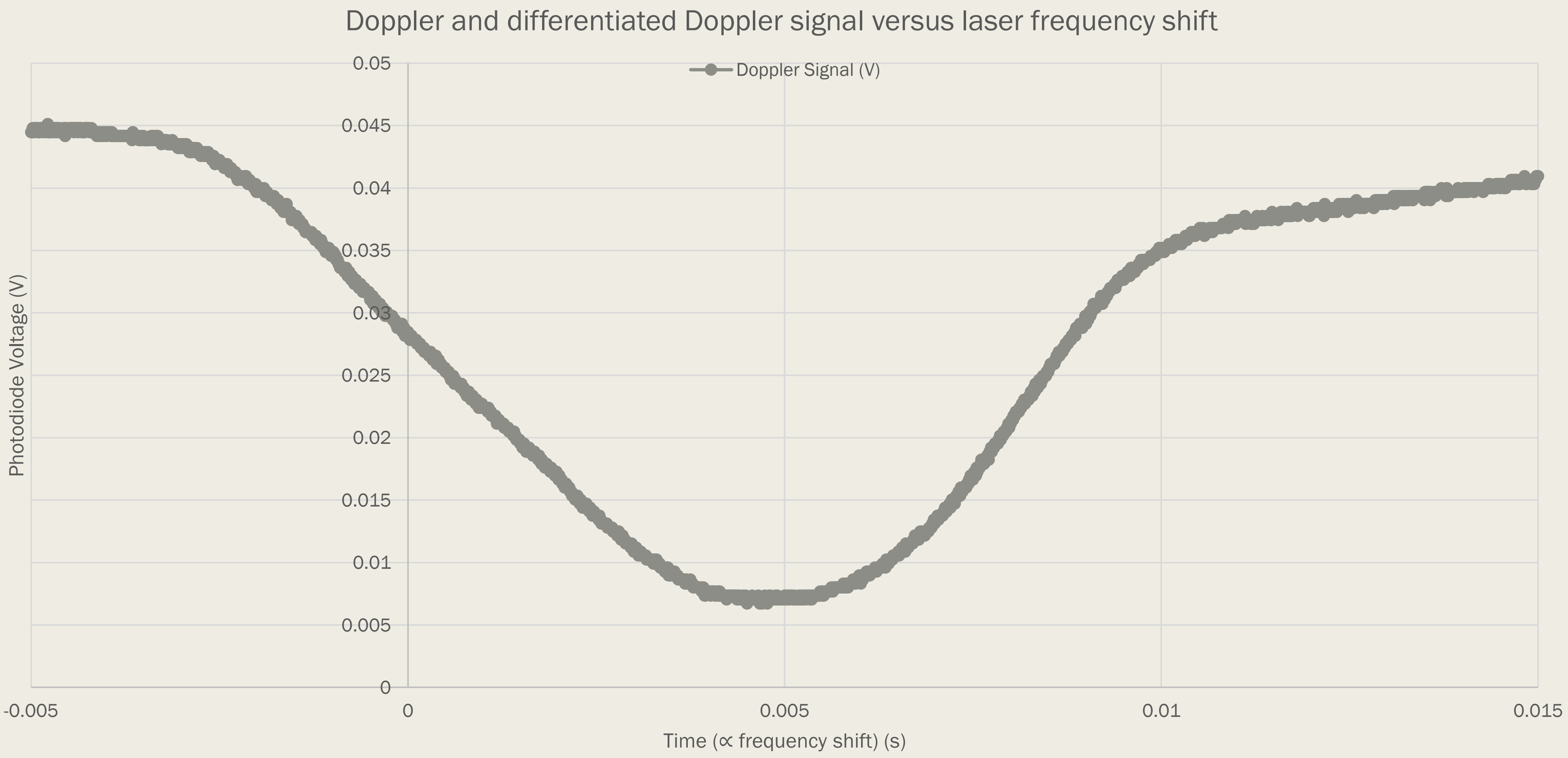
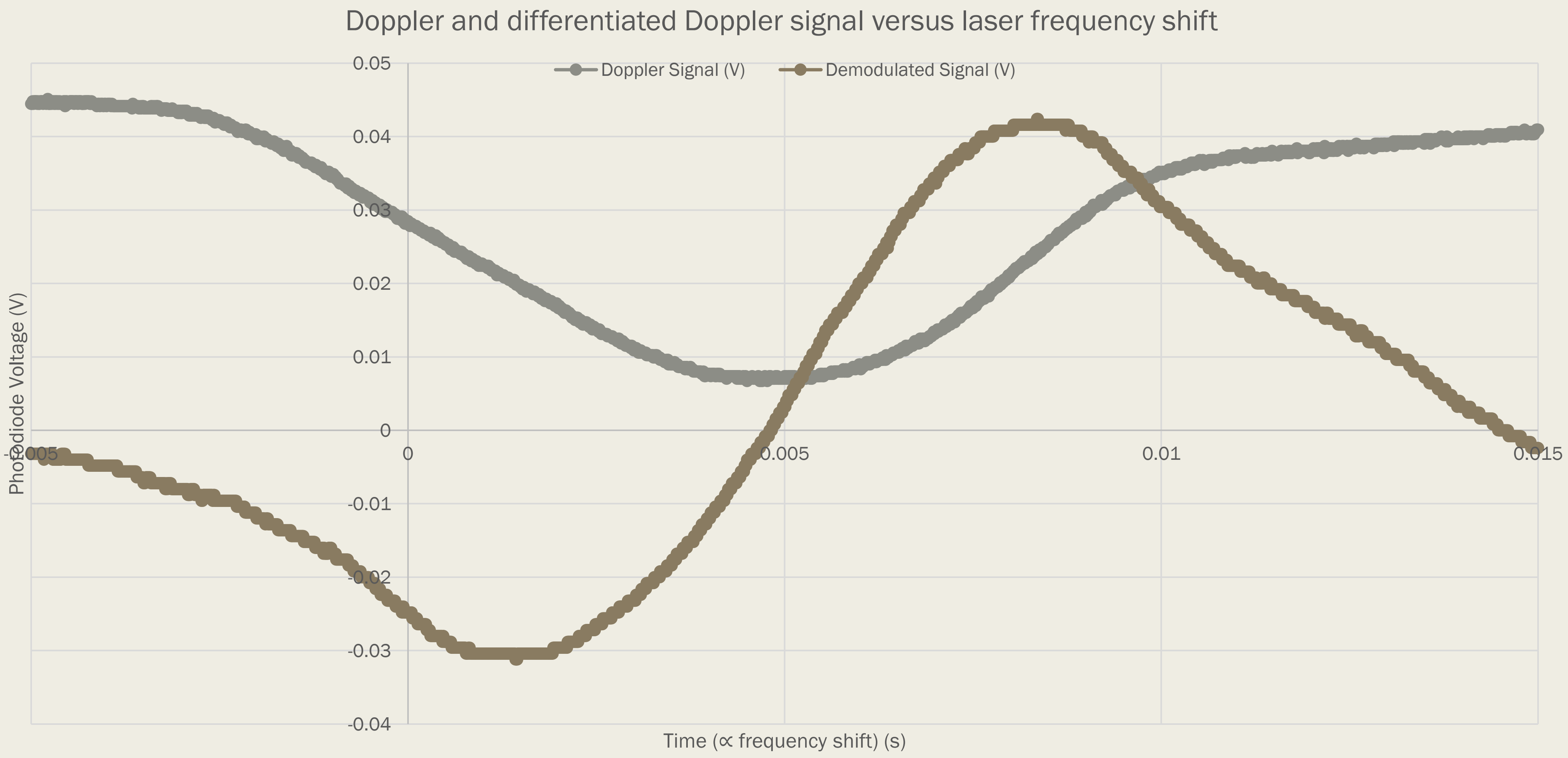
- Multi-species mixtures for observation of interactions and superfluid properties

Progress this summer

A strong Doppler profile



And its derivative



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- Filled in personal learning gaps
- Burned and shocked myself many times

Acknowledgements

- My lab mates Katie, Dan, and Ben, for putting up with my incessant questions and teaching me an incredible amount
- Those from B063 for also answering many, many questions, providing invaluable help, and allowing me to continually ~~steal~~ borrow supplies
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- Deep Gupta, Gray Rybka, and the INT REU program for continuing to facilitate these opportunities

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References

1. Jamison, Alan O. “Precision Interferometry with Bose-Einstein Condensates”. Ph.D. thesis, University of Washington - Seattle, 2014.
2. Foot, C. J. Atomic Physics. Oxford: Oxford UP, 2005. Print.
3. Gupta, S., Dieckmann, K., Hadzibabic, Z., Pritchard, D. E. 9/10/2002. Contrast Interferometry using Bose-Einstein Condensates to Measure h/m and α. *Physical Review Letters*. Vol. 89(14):1404-1-1404-4.
4. Jayakumar, Anupriya, Plotkin-Swing, Benjamin, Jamison, Alan O., Gupta, Subhadeep. 7/10/2015. Dual-axis vapor cell for simultaneous laser frequency stabilization on disparate optical transitions. *Review of Scientific Instruments*. Vol. 86(7):073115-1-073115-5.
5. http://newmansblogosphere.blogspot.com/2009/01/plainsboro-public-library-coin-vortex.html