Improving Laser Guide Stars through Magnetic Resonant Pulsing

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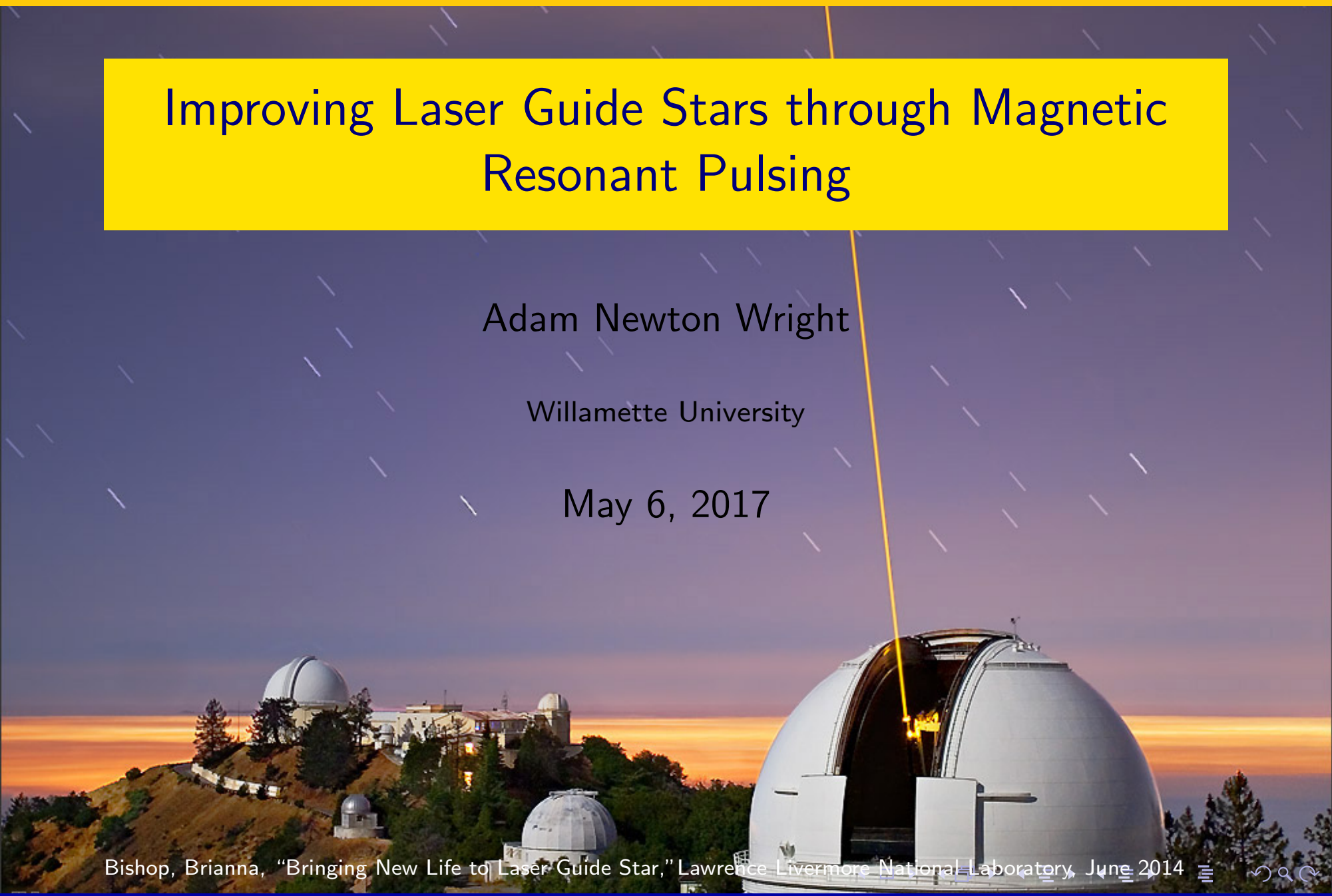


Bishop, Brianna, "Bringing New Life to Laser Guide Star," Lawrence Livermore National Laboratory, June 2014

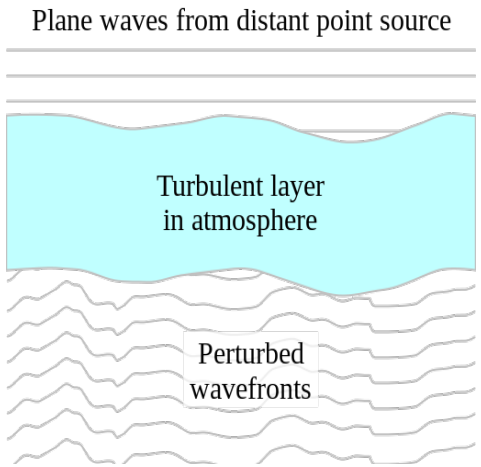
Overview

- Laser Guide Stars
  - What are Laser Guide Stars used for?
  - What is a Laser Guide Star?
- Optical Pumping
  - How it works
  - Geomagnetic Field Complications
  - Larmor Precession
  - How MRP can be a solution
- Our Experiment
  - Hypothesis
  - Dye Lasers
  - Lasing Frequency
  - Sodium Housing and Magnetic Field
  - Measurements and Comparison

Laser Guide Stars (LGS)

What are LGSs used for?

- Astronomers need clearer images; limited by atmosphere
- Employ adaptive optics (AO) systems[1]
- AO corrects distortions that occur as light enters atmosphere
- Need something bright the sky to measure these distortions
  - Use a star, but not always a bright star in all parts of the sky
  - Create an artificial star, i.e. LGS

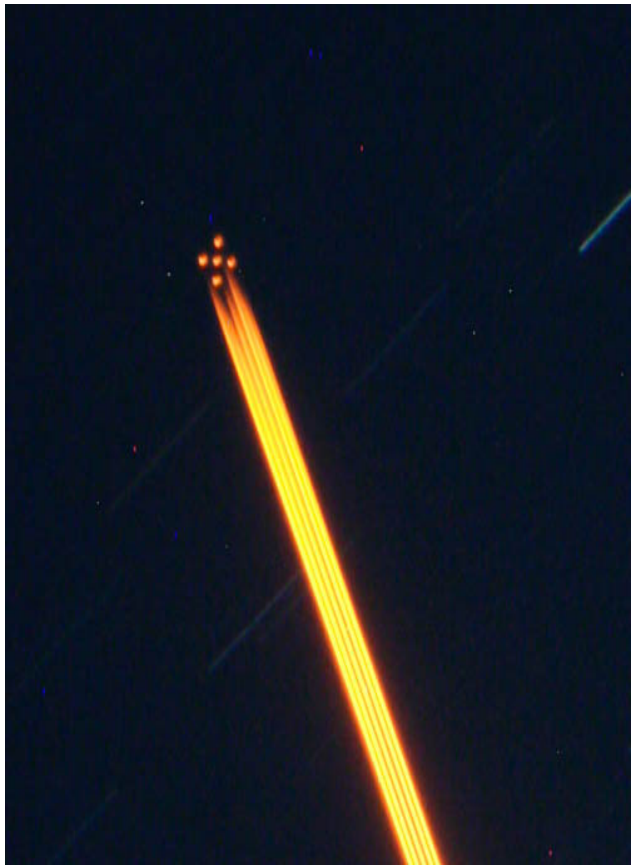


[1] Wizinowich, "The WM Keck Observatory laser guide star adaptive optics system: overview." Publications of the Astronomical Society of the Pacific118, no. 840 (2006): 297.

Laser Guide Stars (LGS)

What are they?

- Artificial star created by laser light
- Two Types:
  - Sodium beacon
  - Rayleigh Scattering
- Sodium LGS excites sodium in the mesosphere[2]
- Rayleigh scattering LGS scatters laser light in the lower atmosphere[2]



[2] "Laser Guide Star," RP Photonics, 2016

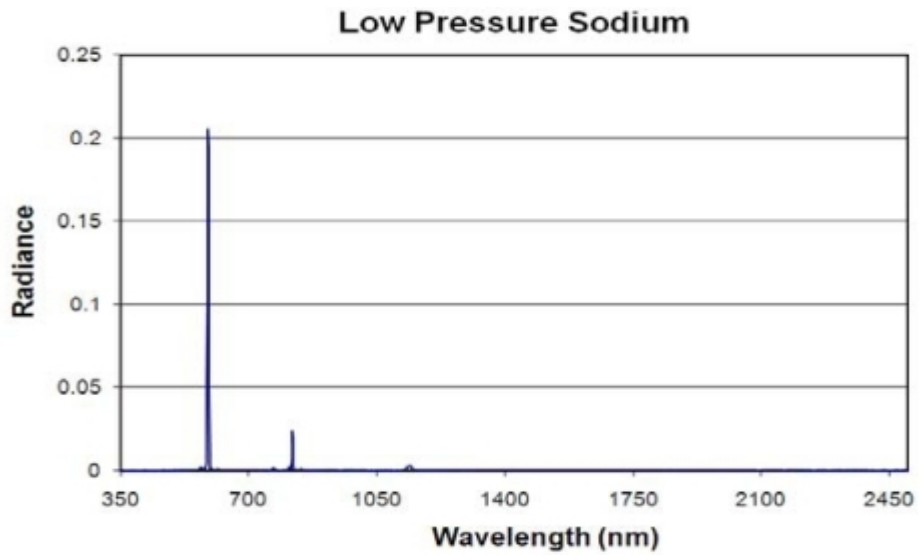
"Laser-Guide Star HD Videos and Imagesi," Gemini Observatory/AURA, gemini.edu, 2013

Laser Guide Stars (LGS)

Sodium LGS

Sodium Laser Guide Star System

- Mesospheric sodium layer: 10 km thick and 90 km in altitude
  - Created by the ablation of meteors
- Wavenlength $\lambda =$ 589.593 nm
- Intensity[3] $I \approx 10 Wm^{-2}$
- Circularly polarized light σ^+



[3]Schock, M., et al. "Performance analysis of polychromatic laser guide stars used for wavefront tilt sensing."

Monthly Notices of the Royal Astronomical Society 337.3 (2002)

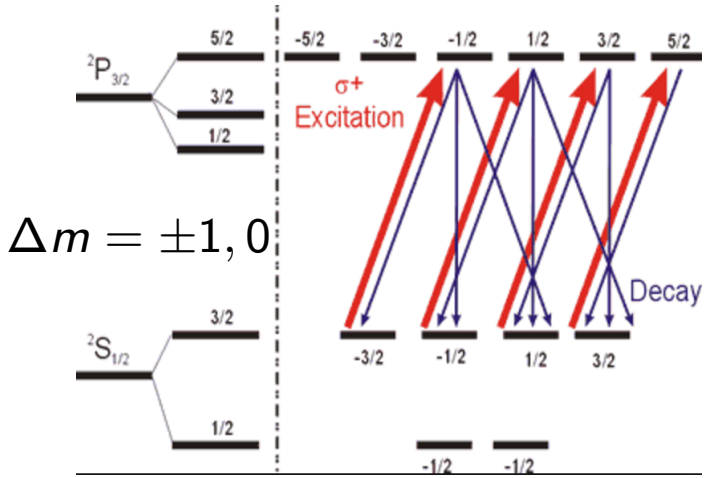
Elvidge CD et al, "Spectral identification of lighting type and character." Earth Observation Group

Optical Pumping

How it works

- Optical pumping uses circularly polarized light to exite atoms

- Atoms that scatter circularly polarized light move to different angular momentum state
- This angular momentum state has increases chance of backscattering photons (cycling)[4]



[4] Kane, "Pulsed laser architecture for enhancing backscatter from sodium." SPIE Astronomical Telescopes+ Instrumentation. International Society for Optics and Photonics, 2014.

"Spin polarization by optical pumping," Colinear Laser Spectroscopy, 2013

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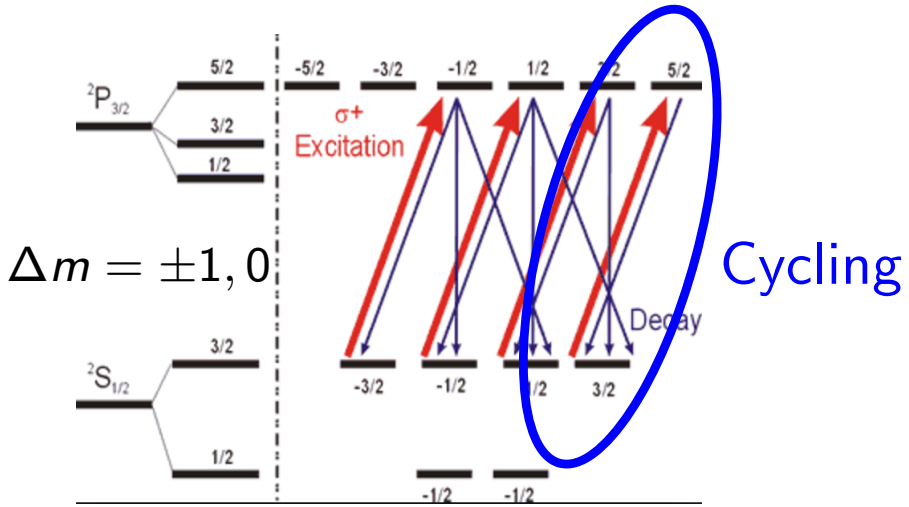

[4] Kane, "Pulsed laser architecture for enhancing backscatter from sodium." SPIE Astronomical Telescopes+ Instrumentation. International Society for Optics and Photonics, 2014.

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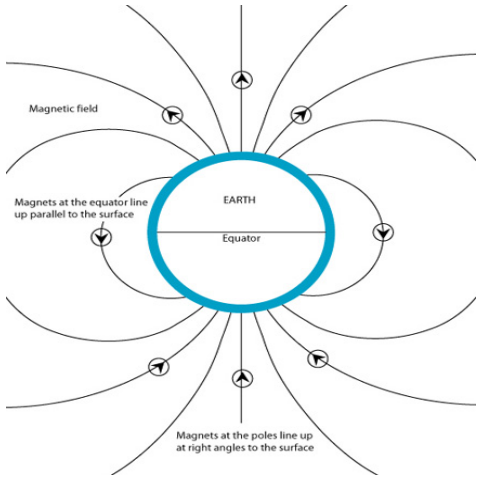
Optical Pumping

Geomagnetic Field Complications

- Optical pumping most efficient when $\vec{B} \parallel$ laser beam[5]
- When $\vec{B} \perp$ laser beam, benefits of optical pumping eliminated
- Most telescopes have are close to equator
  - Large $\perp \vec{B}$ component
- Want to find to way to keep optical pumping benefits at all magnetic orientations



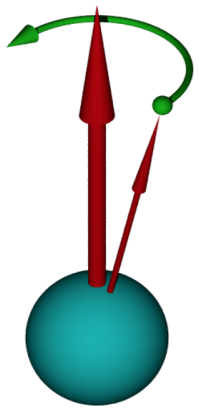
[5] Rampy, Rachel, Donald Gavel, Simon M. Rochester, and Ronald Holzlhner. "Toward optimization of pulsed sodium laser guide stars." JOSA B32, no. 12 (2015): 2425-2434.

Optical Pumping

Larmor Precession

- Larmor precession: precession of any magnetic moment in any magnetic field
- Sodium has a magnetic moment and thus precesses

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$
$$\omega = -\gamma B$$
$$\gamma = \frac{eg}{2m}$$



where τ is the torque exerted, μ is the magnetic dipole moment, B is the external magnetic field, ω is the angular frequency, and γ is the gyromagnetic ratio with e being the electric charge, g being the *g-factor*, and m being the mass of the object.

Optical Pumping

A Solution

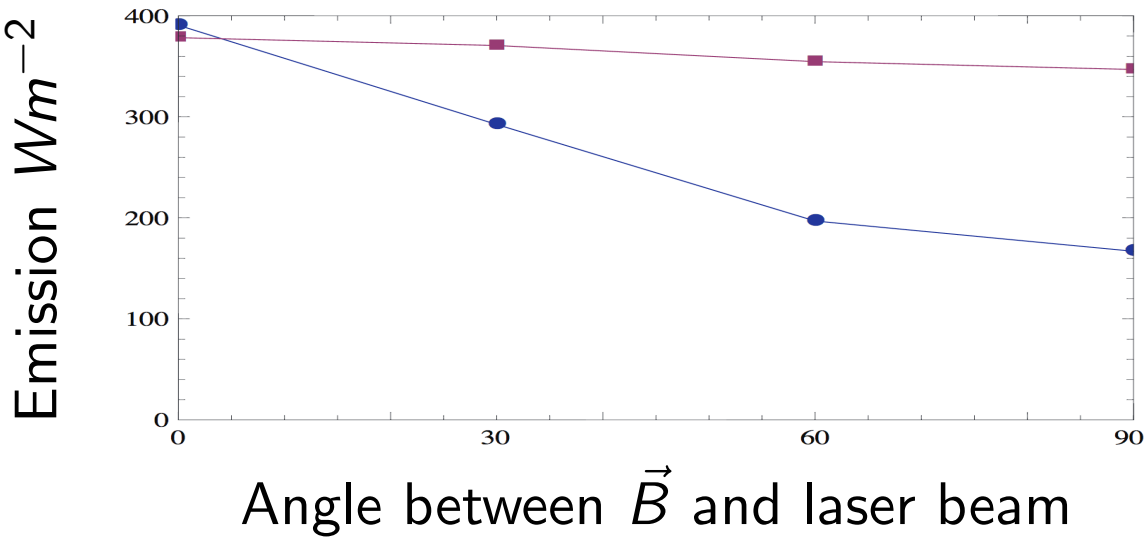
- Magnetic Resonant Pulsing (MRP):[6]
  - Laser is pulsed at a frequency corresponding to atom's Larmor frequency
  - Light only interacts with atom at one point in precession cycle
  - Atom can properly redistribute its angular momentum
- MRP has only been simulated, not experimented

[6] Kane, "Pulsed laser architecture for enhancing backscatter from sodium." SPIE Astronomical Telescopes+ Instrumentation. International Society for Optics and Photonics, 2014.

Our Experiment

Hypothesis

- Hypothesis: Magnetic resonant pulsing of sodium results in greater emission at all angles between beam and magnetic field than excition without MRP.
- Experimentally test the computer simulation of Kane et al.



Kane, "Pulsed laser architecture for enhancing backscatter from sodium." SPIE Astronomical Telescopes+

Our Experiment

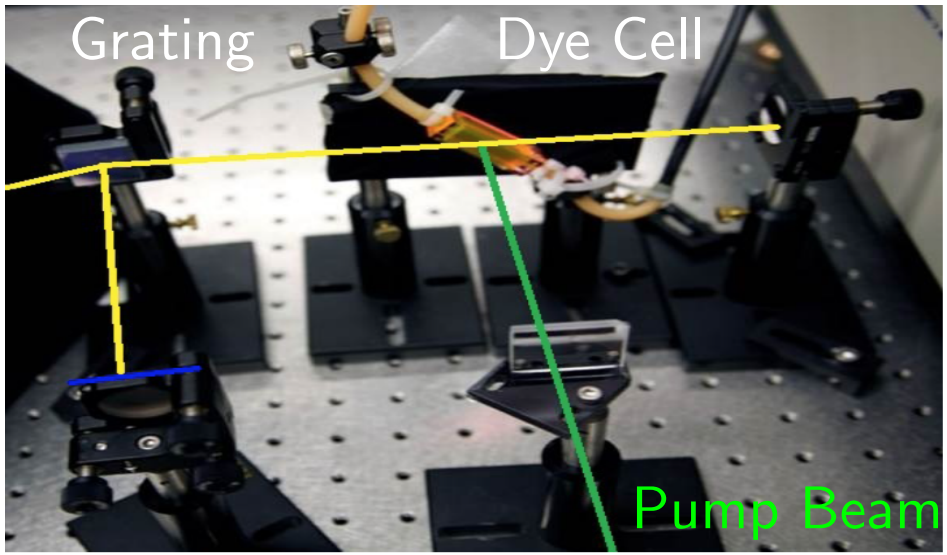
Outline

- Create MRP dye laser
- Sodium confinement and magnetic field
- Spectroscopy measurements

Our Experiment

Dye Lasers

- Excellent tunability over close to one hundred nanometers
- Lasing medium: organic fluid dye solution
- Pumping: Laser light excites dye solution
- Cavity: Two mirrors and a diffraction grating
- Diffraction grating allows wavelength to be selected



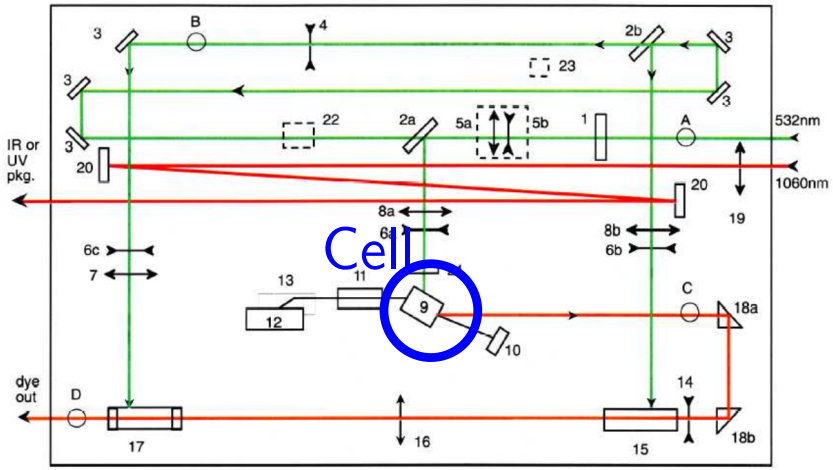
"Construction of a Dye Laser for Use in Detecting Ultracold RbCa," Hayley Whitson, Willamette University, 2012

Our Experiment

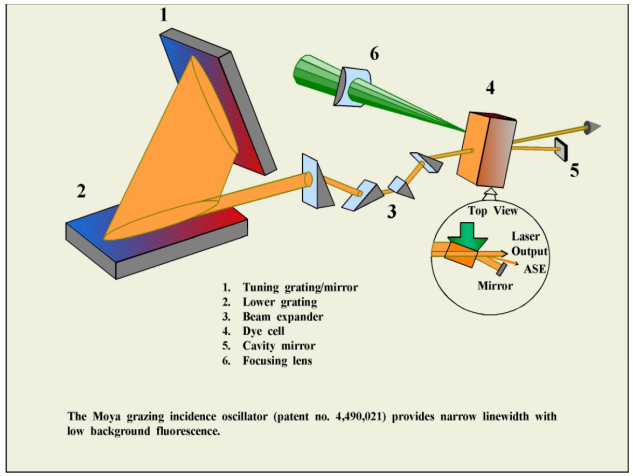
Our Dye Laser

- Moya cavity creates lasing and minimizes spontaneous emission
- Two amplification cells intensify output beam
- Pump with kilohertz, picosecond pump beam

Dye laser schematic



Moya cavity

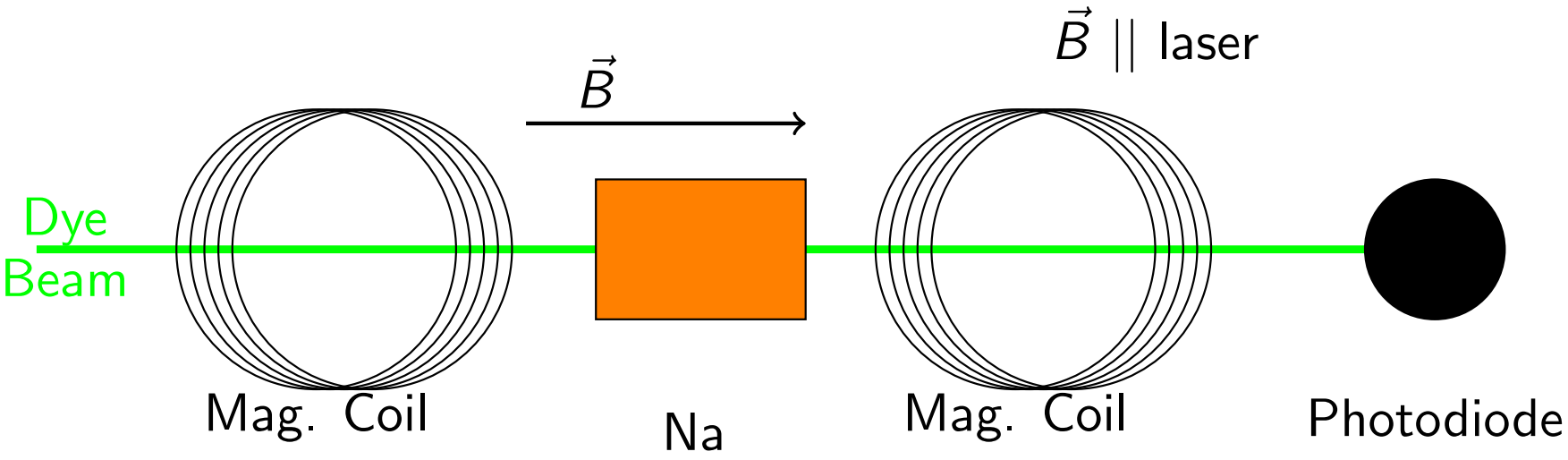


" ND6K User Manual," Contiuum Lasers, 1994

Our Experiment

Sodium Housing and Magnetic Field

- Sodium housed in a reference cell
- Magnetic coils on either side of reference frame
  - Rotate to change angle between laser and $\vec{B}$
- Dye laser shone into reference cell and collected by photodiode



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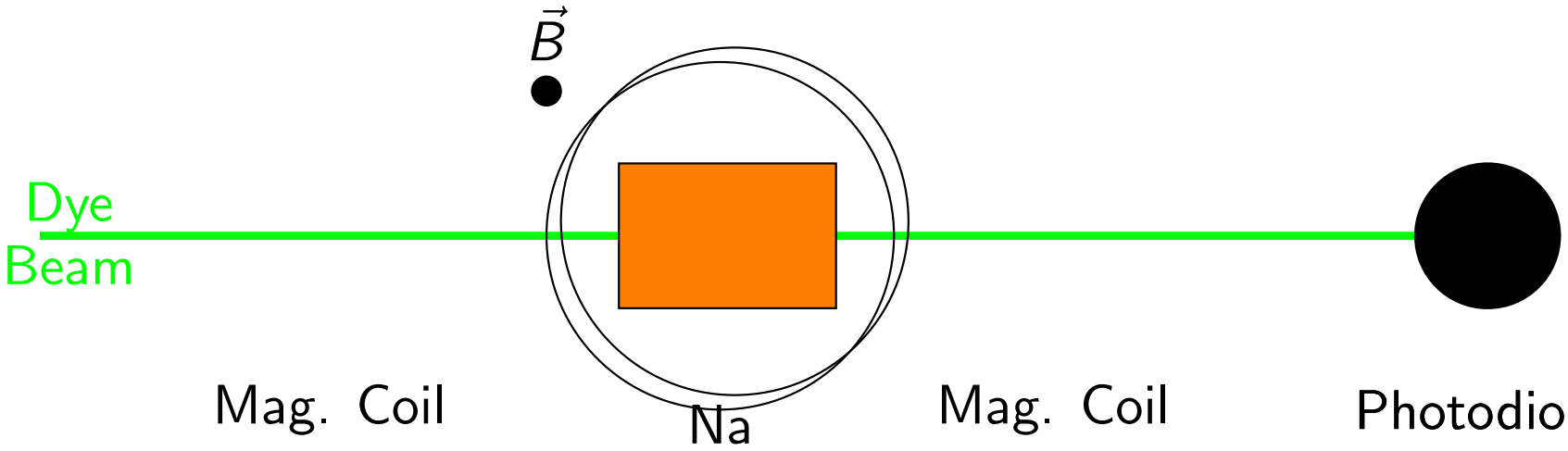
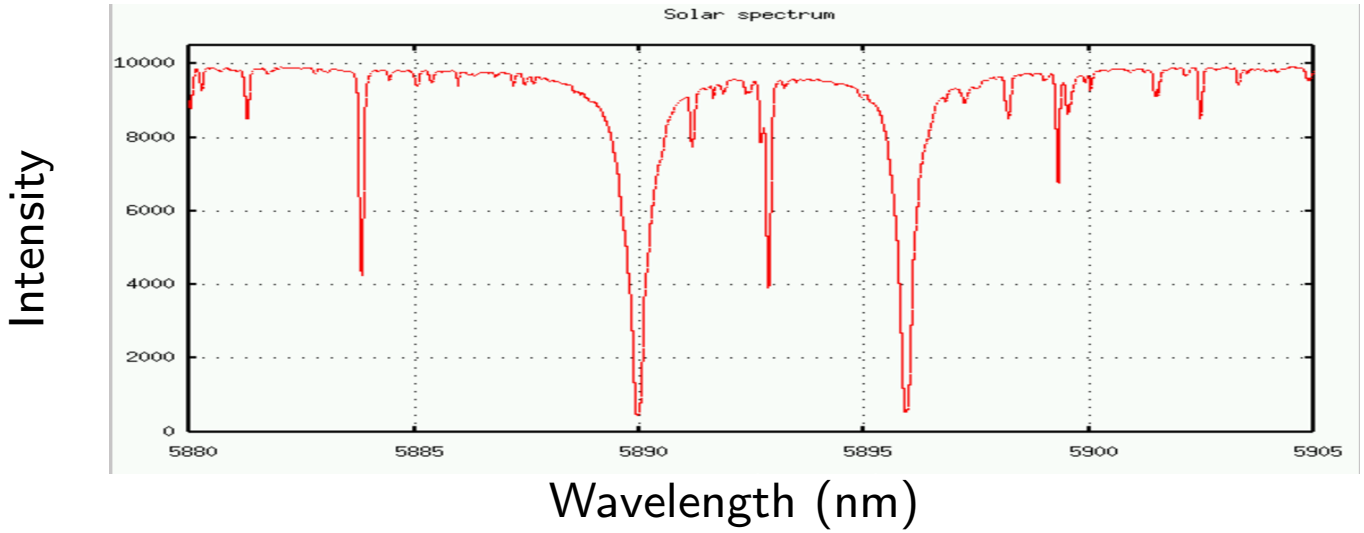


Our Experiment

Spectroscopy Measurements

- Take absorption spectroscopy measurements
  - $\vec{B}$ along one direction
  - Measure absorption as λ changes
  - Change direction of $\vec{B}$ and repeat



Michael Richmond, Rochester Institute of Technology, *spiff.rit.edu/classes/phys440/lectures/curve*

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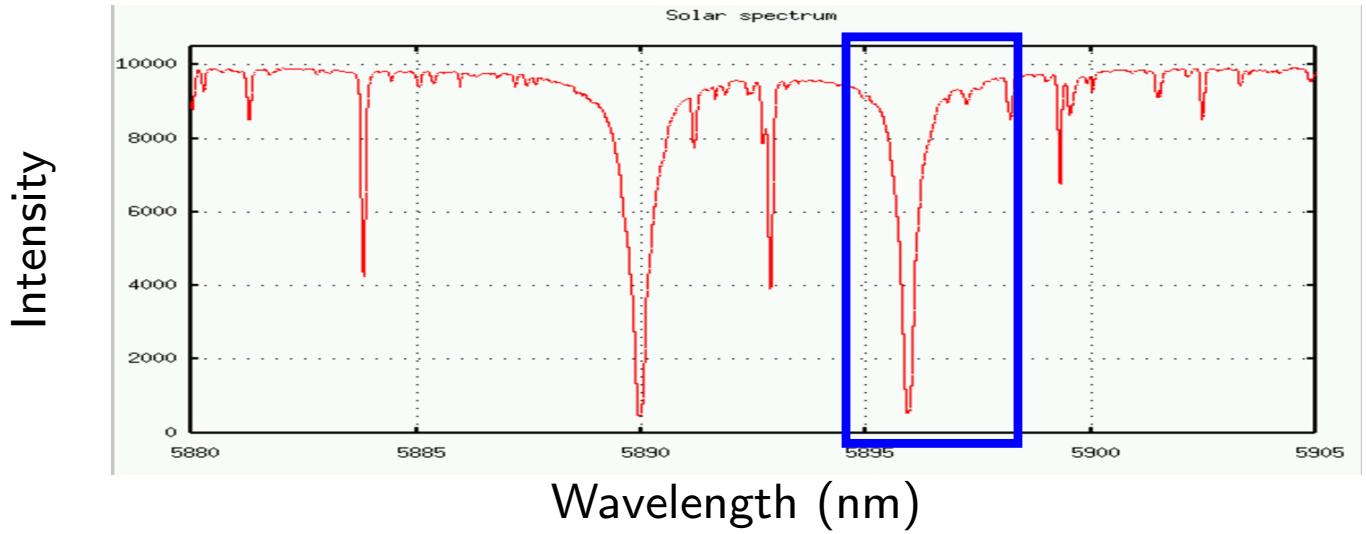
589.6 nm



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Our Experiment

Data Analysis

- Data will be taken with the laser pulsed at the Larmor frequency, and at a frequency not equal to the Larmor frequency
- These data will be compared by looking at the highest absorption of sodium

Conclusion

- Laser guide stars, and what they are used for
- Optical pumping and the geomagnetic field
- How MRP can solve this problem
- Our experiment to test MRP

Thank you all for wathcing my presentation!

Also, thank you

- Michaela Kleinert, for your endless help
- The Physics Department, for always being amazing
- Donald Swen, for all the hours we have struggled in lab together

Questions?

"Staight to the Milky Way's Heart," Scientific Computing, 2011