SENIOR YEAR RESEARCH PROPOSAL

(Please confine responses to this form only. Use Arial 11 point font.)

Proposer's Name: Adam Newton Wright

Phone: 619.540.9598

Department: Physics

Email: anwright@willamette.edu

Institution Name: Willamette University

Proposed starting date and duration:
August, 2017: 7 months

Institution Address:
900 State Street
Salem, OR, 97301

EDUCATION AND EXPERIENCE: *(Style: "YYYY – Current Institution, Department, City, State, Position" or "YYYY – YYYY Institution, Department, City, State, Degree, Mentor.")*

2014 – 2017, Willamette University, Salem, Oregon, Physics, Michaela Kleinert

TITLE OF PROPOSAL: *(Must fit on two lines and may not exceed 130 characters.)*

Absorption Spectroscopy of Sodium through Magnetic Resonant Pulsing

ABSTRACT: *(Provide a summary of your proposal plan. Maximum 200 words.)*

The newest generation of ground-based telescopes use adaptive optics (AO) systems in which an artificial star is created in the upper atmosphere, emitting light that is emitted and received by the telescope system and used to correct for atmospheric distortion. In earth's mesosphere exists a layer of sodium atoms that is used by astronomers to create a laser guide star (LGS), an artificial star created by the excitation of atoms through laser light. Many LGS systems use optical pumping in order to increase the emission of sodium. However, when the angle between the geomagnetic field and the laser beam approaches ninety degrees, many of the benefits of optical pumping can be eliminated. It has thus been suggested that a laser pulsed at the Larmor frequency of the subject sodium atoms can produce greater emission, a process known as *magnetic resonant pulsed* (MRP) lasing. We propose testing the MRP lasing of sodium atoms under various angles between the laser beam and the magnetic field. By creating an artificial magnetic field, and taking absorption spectroscopy with a MRP dye laser, we seek to experimentally test MRP lasing.

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Publications and Presentations: *(List all publications, presentations, or conference you attended that are relevant to this proposal. Explain briefly why/how they are relevant.)*

Advanced Techniques in Experimental Physics, Senior Proposal Presentations, Department of Physics, Willamette University, 2017.

Oral presentation to the Department of Physics at Willamette University justifying the legitimacy of my proposed senior project.

Student Scholarship Recognition Day, Senior Theses Presentations, Willamette University, 2017.

Oral presentation detailing the construction, calibration, and applicability of a rhodamine dye laser. This is the same laser that will be used in this proposed project, and knowledge of it will be invaluable in the success of this project.

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PROPOSED BUDGET: *(All amounts in US dollars. Attach copies of screenshots that show the cost. Listed items should be clearly <u>required</u> for the proposed research. Two semester requests should be itemized per semester.)*

Description:	Fall semester:		Spring semester:	
	Physics Department:	Match (e.g. scholarships):	Physics Department:	Match (e.g. scholarships):
Potassium Titanyl Phosphate – KTP Crystal - *EKSMA Optics*	$88	N/A		
Rhodamine 610 (1 gram) - Sigma Aldrich	$134.50	N/A		
Borosilicate Glass Reference Cells - Thorlabs	$478	N/A		
Silicon Heater Tape (600 C) - Jet.com	$126.50	N/A		
Tenma Amp Bench - *Newark Electronics*	$180.40	N/A		
Magnetic Coil Wires - *Powerwerx*	$7.92	N/A		
Methanol (3.8 L) - *Carolina Biological*	$24.20	N/A		
TOTALS:	**$1,039.52**	**$0**		

Total budget: **$1,039.52**

Less matching funds from scholarships: **$0**

Requested from Physics Department: **$1,039.52**

ADDITIONAL SUPPORT: *(List all scholarships received or requested for this or other research.)*

N/A

BUDGET RATIONALE: *(Include the source of other items [equipment/supplies] that are needed for this research beyond those requested from The Physics Department. Explain travel related to research and other budget items that require further clarification. List any items from the above proposed budget for which a match is being provided and give dollar amount of the match.)*

The crystal is a second harmonic generation crystal, which doubles the frequency of the light and halves its wavelength, which is necessary in order to properly excite Rhodamine 610. This crystal is necessary since the Duetto laser we will be using outputs 1064 nm light whereas Rhodamine needs 532 nm for excitation.

Rhodamine 610 and methanol are needed in order to create a solution that, after excited by the pump laser, emits a wavelength of light resonant with sodium.

The Borosilicate Glass Reference Cell is needed in order to properly contain the Sodium under high temperatures. The glass has a low coefficient of thermal expansion, making it ideal since we will be heating Sodium to high temperatures. The sodium needs to be heated in order to transition it out of solid phase, which is the rationale behind the heater tape.

Lastly, the magnetic coil wires and power supply are needed in order to create an electromagnet for measuring the spectroscopy of sodium in various magnetic fields.

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STATEMENT OF THE PROBLEM AND SCIENTIFIC SIGNIFICANCE OF THE PROPOSED RESEARCH: *(Provide a summary of your proposed research project. State succinctly the fundamental scientific problem that is to be addressed. Clearly outline the significance of the problem, the originality of the approach, the impact it may have on the field if successful and the hypothesis or primary idea that underpins the proposed work. Use Arial 11 point font. Do not use more than one page.)*

Fundamental Scientific Problem

LGS are artificial star images created for usage in adaptive optics (AO) systems in order to increase the resolution of ground-based telescope imaging. Sodium LGSs are produced by sending laser into the upper atmosphere at the resonant frequency of sodium; this laser light excites a layer of sodium that exists in the mesosphere (Rampy 2015), and is then emitted by these sodium atoms, creating a visible "star." The light from this LGS is then collected by a ground telescope and fed into an AO system where it is used to correct for atmospheric distortions that occur as light enters earth's atmosphere (Fugate, Wizinowich 2009). The AO system corrects for these distortions by measuring the amount of distortion that the LGS light undergoes, and adjusts a deformable mirror to correct for these distortions. It can then use these corrections to collect higher resolution images.

LGSs needs to be sufficiently bright in order for the AO system to collect enough light to correct for distortions (Watanabe 2004). Typical LGS lasers operate at an intensity of $I = 10\ Wm^{-2}$ (Kane 2014) and can be CW or pulsed. The LGS lasers are circularly polarized, which allows the atom, after being excited and emitting a photon, to move to an angular momentum state with increased probability of backscattering; this creates a pumping cycle which in beneficial for greater emission, a process known as optical pumping (Fan, Kane 2014). The fundamental problem, however, is that the benefits of optical pumping can be almost completely eliminated when the angle between the laser light and the magnetic field approaches ninety degrees (Kane 2014); this is due to the fact that the magnetic field reorients the atom before it can properly redistribute its angular momentum.

Significance of the Problem

Unfortunately, the majority of ground-based telescopes are relatively close to the equator, which corresponds to an angle close to ninety degrees when the laser is sent into the atmosphere. This in turn results in decreased emission of sodium atoms in the atmosphere, and a decreased efficiency of the LGS system. In order for AO systems to properly correct for atmospheric distortions, and in turn create higher resolution images, the LGS used must be sufficiently bright. By finding a way to reduce the negative effects of optical pumping at angles of ninety degrees between pump beam and the magnetic field, AO systems can not only function better, but will be much more efficient.

Originality of Approach

It has been suggested that by pulsing the LGS laser at the Larmor frequency of the sodium atom in what is called MRP results in greater emission of sodium at all angles between the laser light and the magnetic field. Sodium has a magnetic moment, and thus, when within a magnetic field, will precess about its magnet moment, in a process called Larmor precession (Rampy 2015). The frequency at which it precesses is known as the Larmor frequency. Furthermore, the Larmor frequency is equal to the energy between the states split by the Zeeman structure; thus, the Larmor frequency corresponds to the inverse of the lifetime an electron is in an excited Zeeman state. Hence, by pumping sodium at this frequency, as soon as an atom has absorbed and emitted a photon, it is excited by another photon, allowing it to stay in its angular momentum state and continue its pump cycle.

Kane et al. used simulation software developed by Rochester Scientific to test MRP lasing. His data show that MRP lasing creates greater emission of sodium for all angles between the magnetic field and the laser light. I in turn propose testing this in the laboratory. By studying these processes in the laboratory, I intend to understand better how light interacts with atoms within a magnetic field and how their Larmor precession plays a role in their absorption and emission of light. Furthermore, understanding these ideas more clearly has direct implications to improving the efficiency and functionality of LGS systems.

To the best of our knowledge, this will be the first experimental testing of the MRP lasing of sodium. This is thus novel not only in regards to understanding how light pulses interact with atoms under the Zeeman structure, but also to creating a more efficient and functional LGS systems.

Hypothesis

In this project I aim to show that the magnetic resonant pulsing (MRP) of sodium within a magnetic field produces greater emission for all angles between the magnetic field and the laser beam than pulsing at a frequency not equal to the magnetic resonant frequency.

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Plan of Procedure: *(Outline the experimental approach to the problem and its feasibility, providing details sufficient to support feasibility. Point out innovative features and relate them to previous work by including pertinent references. Indicate how this plan will contribute to the solution of the broad scientific problem being addressed. Preliminary results can buttress your case but are not required. Use Arial 11 point font. Do not use more than one page.)*

Month 1: We first need to test the feasibility of a MRP dye laser. The Larmor frequency of sodium is given by $w = -\gamma B$ where *B* is the magnetic field and γ is the gyromagnetic ration given by $\gamma = \frac{eg}{2m}$ with *e* being the electric charge, *g* being the g-factor, and *m* being the mass of the atom. For a sodium atom on earth, this corresponds to a frequency of $w = .281\ kHz$. During this first month, we will work on creating a tunable, pulsed dye laser (Sohl, 1997). This dye laser will consist of a dye cell filled will Rhodamine 610, which will enable the laser to emit light around the necessary 589.6 nm (Brackman 2000). Its cavity will consist of two mirrors and a diffraction grating, allowing us to select the corresponding wavelength of light.

Month 2: We need to configure our pump laser so that it will be able to pulse with the corresponding Larmor frequency and have a pulse width in the nanosecond regime; this can be accomplished by using a Duetto Nd:YAG laser. This laser is capable of pulsing on the order of kHz, sufficient for the sodium contained in our magnetic field. However, certain modification will need to be made to obtain this pulse frequency. Furthermore, the Duetto currently outputs 1064 nm laser light; 532 nm light is necessary in order to properly excite the Rhodamine dye and obtain the proper wavelength of light to excite sodium at its 589 nm peak line. We thus need to purchase and configure a second harmonic generation crystal on the Duetto in order to frequency double the light. A KTP crystal can be bought from EKSMA Optics and configured to the laser quite easily.

Month 3: We will next begin configuring our previously constructed dye laser with our MRP Duetto pump laser. The feasibility of this is described by Gale (Gale 1990), but we expect certain difficulties to arise. These difficulties may include the dye not being circulated quick enough, poor beam profile, or poor lasing (Gale 2012).

Month 4: If the previous projects are successful, we will continue with this project and construct a more advanced configuration. We will first use a dye laser capable of producing a cleaner and amplified beam. The dye laser is a Continuum ND6K, with dual amplification cells. This dye laser can be configured and tuned according to the Continuum ND6K User Manual (Continuum). It will also need to be made compatible with the MRP Duetto laser, an aspect which has not been tested on this dye system before.

Month 5: The dye laser output beam will need to be characterized with respect to wavelength, linewidth, and bandwidth in order to ensure it can properly excite sodium. It will also need to be able to produce an intensity of $I = 10\ Wm^{-2}$. Furthermore, the dye laser output beam will need to be circularly polarized (Kane 2012), which requires nothing more than a few quarter wave plates.

Month 6: Once the dye laser is properly established, the sodium reference cell and measurement system will need to be constructed. The reference cell will be a borosilicate glass reference cells available from Thorlabs. This ensures that maximum green light is transmitted, about 80%, and that the cell can withstand a temperature of 100 C, necessary to melt sodium. This cell will be mounted and wrapped in heating tape and filled with a small amount of Sodium. Lastly, a photodiode will be placed perpendicular to the length of the reference cell in order to collect transmitted light. We also will create a magnetic field around the reference cell. This can be done by created Helmholtz coils. We expect to create a magnetic field of $B = 10\ gauss$, which corresponds to a current of approximately $I = 2.1\ A$. We are able to 3D print a coil mount, and wrap this mount in wire and wire it to a power supply, which will need to be bought. The Helmholtz coils will need to be able to rotate around the reference cell, changing the angle between the magnetic field and the laser light.

Month 7: Data will finally be collected The laser light from the dye cell will be directed into the reference frame containing the sodium. The tunability of the dye laser is important, as we will measure the intensity of the light transmitted as a function of varying wavelength. At wavelengths close to 589 nm, the intensity of light should greatly decrease as sodium in absorbing this light and releasing it randomly. We then leave the dye laser at this wavelength and measure the intensity of transmitted light as the angle between the magnetic field and the dye beam is varied. We will then change the Duetto so that its pulse frequency is not at the Larmor frequency and repeat this process.

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LIST OF REFERENCES: *(Annotate the proposal with a list of <u>at least ten peer-reviewed</u> references from the primary literature. Use only one page for your references; size Arial 10 or 11 point font.* ***Include all authors and titles.****)*

Brackman, Ulrick, “Lambdachrome Laser Dyes,” Lambda Physik 3, 2000

Budker, Dmitry, and Romalis, Michael. “Optical Magnetometry.” Nature Physics 3, 2007.

Fan, Tingwei, Tianhua Zhou, and Yan Feng. "Improving sodium laser guide star brightness by polarization switching." Scientific reports 6 (2016).

Fugate, Robert Q., and D. L. Fried. "Measurement of atmospheric wavefront distortion using scattered light from a laser guide-star." Nature 353.6340 (1991): 144.

Gale, G. M., B. Pedersen, and P. Schanne. "Kilohertz picosecond distributed-feedback dye laser system." Optics Communications 76.2 (1990): 138-142.

Kane, Thomas J., Paul D. Hillman, and Craig A. Denman. "Pulsed laser architecture for enhancing backscatter from sodium." SPIE Astronomical Telescopes+ Instrumentation. International Society for Optics and Photonics, 2014.

Kibblewhite, Edward. "The physics of the sodium laser guide star: Predicting and enhancing the photon returns." In Advanced Maui Optical and Space Surveilance Technologies Conference. 2009.

Rampy, Rachel, Donald Gavel, Simon M. Rochester, and Ronald Holzlöhner. "Toward optimization of pulsed sodium laser guide stars." *JOSA B* 32, no. 12 (2015): 2425-2434.

Sohl, John E., and Stephen G. Payton. "A modular, reconfigurable-cavity, pulsed dye laser for the advanced undergraduate laboratory." American Journal of Physics 65.7 (1997): 640-652.

Watanabe, Makoto, et al. "Proceedings of SPIE-The International Society for Optical Engineering." Advancements in Adaptive Optics. 2004.

Wizinowich, Peter L., David Le Mignant, Antonin H. Bouchez, Randy D. Campbell, Jason CY Chin, Adam R. Contos, Marcos A. van Dam et al. "The WM Keck Observatory laser guide star adaptive optics system: overview." *Publications of the Astronomical Society of the Pacific* 118, no. 840 (2006): 297.

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LIST OF REVIEWERS: *(The reviewer list should include at least two "outsiders," individuals with whom you have had no substantive contact but who are experts in your area of research, and at least two "insiders," preferably former mentors. The best outside reviewers are frequently corresponding authors from the cited references who are not known to you. Do not hesitate to use a combination of reviewers from academia and non-academic laboratories; including scientists from abroad. Please include complete names (initials are not enough), current titles, mailing addresses, phone and fax numbers, and email addresses. Use size Arial 10 or 11 point font.* ***You must note briefly the nature and extent of your interactions, if any, with each of the outside reviewers. Examples: Met at a meeting, interviewed with, no interaction, never met, etc. Do not use more than one page.****)*

A. Insiders:

Michaela Kleinert
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B. Outsiders:

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edkoddjob.uchicago.edu
Never met

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ENDORSEMENT PAGE:

Conditions of Senior Year Research Experience Award:

The award is a contribution to the scientific and academic program of the institution and is to be used for support of work described in the application prepared by the principal investigator (you) and adopted by the institution (Willamette).

Since research by its very nature is unpredictable and may require adaptations in order to exploit promising leads, the principal investigator should feel free to make changes in the emphasis or direction of the work as it progresses. If major changes are contemplated, prior approval should be obtained.

Reallocation of awarded funds between budget categories requires prior approval.

A final polished thesis is due before the end of the spring of the principal investigator's senior year. A polished introductory section of said thesis is due by the end of the fall semester of the previous year. The Principal Investigator must also agree to present their research at least twice during their senior year to peers and faculty of Willamette and Linfield. Failure to provide a satisfactory preliminary thesis on time may result in suspension of the award and a request to return unspent funds.

The principal investigator is urged to publish the findings in the appropriate scientific journals.

Applicant Name: Adam Newton Wright

Project Title: Absorption Spectroscopy of Sodium through Magnetic Resonant Pulsing

Submitted by (institution): Willamette University

Name of institution adopting and assuming responsibility for the above project, believing the principal investigator is qualified to conduct the project, and accepting the Conditions of Award, if an award is approved.

Name and position of authorized financial officer: Michaela Kleinert, Associate Professor of Physics, Willamette University

Signature of financial officer: ______________________ Date: __________

Signature of Principal Investigator: ______________________ Date: __________