RESEARCH PERFORMANCE PROGRESS REPORT

National Nuclear Security Administration

DE-NA0003843

(Wootton) Center for Astrophysical Plasma Properties

Donald E. Winget, Professor
dew@astro.as.utexas.edu
512-471-3404

Elena Mota, Assistant Director, Office of Sponsored Projects
evmota@austin.utexas.edu, 512-232-1419

Submission Date: 12/06/2019

DUNS Number: 170230239

The University of Texas at Austin
Office of Sponsored Projects
3925 West Braker Lane
Building 156, Suite 3.340
Austin, TX 78759-5316

Project/Grant Period: 02/15/2018 to 02/14/2023

Reporting Period End Date: 02/14/2019, YR1

Report Term or Frequency: Annual

____

Elena Mota, Assistant Director

Signature of Submitting Official (electronic signatures (i.e., Adobe Acrobat) are acceptable)

1. ACCOMPLISHMENTS: Mandatory
What was done? What was learned?

WCAPP currently carries out ***four*** independent astrophysically-motivated experiments simultaneously on each shot in the following areas:

- White Dwarf stars
- Atomic kinetics, x-ray heating, and temperature of photoionized plasmas
- Accretion Powered Matter and Radiation
- Stellar interior opacity

o White Dwarf Stars

During the reporting period covering 02/15/18 - 02/14/2019, the team carried out 2 shot experiments at the Z Pulsed Power Facility for the white dwarf photosphere experiment (WDPE). These experiments involved hydrogen, helium, and carbon gases. Given that the plasma in our experiment evolved dynamically, we can probe a broad range of densities on each shot. We exploit this to make a more comprehensive test of competing line broadening theories than previously possible.

For the hydrogen experiments, we have reached significantly higher densities than the landmark studies of Wiese et al. (1972, PRA, 6, 1132), thereby putting competing line broadening theories to the test in a regime where their predictions strongly diverge. We deploy three lines of sight to simultaneously measure multiple lines in emission, absorption, and the backlighter continue in macroscopic plasmas on Z. This represents a significant advance relative to hydrogen line-profile experiments of the past. Our recent results have highlighted a measured difference in the width of a line when measured in absorption versus emission (Schaeuble et al., 2019, ApJ, 885, 86). We are also incorporating a new generation of hydrogen line calculations into model white dwarf atmospheres using hydrogen line models developed by Thomas Gomez (former UT-Austin graduate student and current Sandia postdoc).

We have also made experiments involving helium and have measured the pressure shift of the line centers over a range of densities, as well as measurements that constrain the neutral broadening of these lines. We find that the measured line widths due to neutral broadening are approximately six times larger than that predicted by theory. These line modeling tools, Xenomorph and Neomorph, advance the frontier of modern line shape calculations.

In exploring other compositions, we recently achieved carbon plasma conditions relevant to white dwarfs with carbon-dominated atmospheres. These stars are likely the result of mergers of two white dwarfs, and are potentially useful in understanding type Ia supernovae.

o Atomic kinetics, x-ray heating, and temperature of photoionized plasmas

The focus of this project is to study the ionization, x-ray heating, and electron temperature of plasmas driven by an intense flux of x-rays, i.e. photoionized plasmas; these are important for understanding a myriad of astrophysical systems including x-ray binaries, warm absorbers in active galactic nuclei, and the accreting disks formed around black holes. We have established a gas cell platform at Z to perform systematic experiments of single- or multi-element photoionized plasmas. Analysis of a transmission spectrum produces the CSD and electron temperature of the plasma independent of detailed atomic kinetic and heating modeling calculations. Systematic measurements performed in several series of Z experiments have produced ground breaking results about the heating and temperature of laboratory photoionized plasmas that impact physics models in astrophysical modeling codes.

- **Accretion Powered Matter and Radiation**

When matter accretes in a disk around a compact object such as a black hole or a neutron star, copious amounts of x-ray light is generated. These accretion-powered objects emit spectra that contain information about the accretion process and the nature of the accretor. For instance, the mass and spin of a black hole could be extracted thus enabling test of general relativity. The Z facility recreates the relevant state of x-ray photoionization of the radiation-dominated disk environment, and its spectral emission. One feature of the emission is the *radiative recombination continuum* (RRC), which is used as an important astrophysical diagnostic of disk temperature. In the last year, the first ever laboratory measurement of RRC was made on the Z machine, in an experiment on a photoionized silicon plasma, further testing a key feature of x-ray astronomy.

- **Stellar interior opacity**

Solar models presently disagree with helioseismology. This could be resolved if the true mean opacity is higher than calculated opacity used in the solar models by 10-30%. In past work, we successfully measured iron opacity at conditions similar to the solar-convection-zone base. The measurements, published in the journal *Nature*, were higher than predictions. If correct, the data accounts for approximately one half the opacity increase needed to resolve the solar problem. Research must continue until the opacity theory and measurements are reconciled. Last year, the opacity of chromium and nickel at similar conditions as iron was also measured. By studying how the model-data opacity disagreement changes as a function of atomic number, this restricts the hypotheses for the discrepancy. We have also developed time-resolved measurement capability. The opacity sample condition time history was measured and will help provide further constraints on the opacity problem.

a. **What are the major goals and objectives of this project?**

While our results are still preliminary, we find evidence of asymmetry in the Hβ and Hγ lines that the standard Vidal-Cooper-Smith theories and its derivatives are unable to fit; these asymmetries are also evident in WD spectra. From simultaneous fits to the strengths of multiple lines, we should also be able to constrain line quenching and the occupation probabilities (e.g., Hummer & Mihalas, ApJ, 331, 794) of higher-n states as they begin merging with the continuum/unbound states. We have also found evidence that the emission and absorption line shapes of Hγ do not agree, e.g., they have widths that differ by 20-30%. This is an extraordinary result and we are currently scrutinizing our experiment to make sure that this is not due to some artifact of our platform. Finally, we have made a large number of measurements of pressure shifts of helium lines. Our results agree with one previous set of measurements but spectacularly disagree with the most recent theoretical predictions. Our measurements also indicate that theoretical predictions of neutral helium broadening may underestimate the broadening by a factor of about 6 for the conditions of our experiments.

b. **What was accomplished under these goals?**
For this reporting period describe: 1) major activities; 2) specific objectives; 3) significant results or key outcomes, including major findings, developments, or conclusions (both positive and negative); and/or 4) other achievements. Include a discussion of stated goals not met. As the project progresses, the emphasis in reporting in this section should shift from reporting activities to reporting accomplishments.

c. **What opportunities for training and professional development has the project provided?**
Marc Schaeuble and Zach Vanderbosch, both graduate students at UT, have been trained on and learned to field experiments on the Z Machine at Sandia National Labs. They have also acted as mentors for the undergraduates who work in our group. Zach became a PhD candidate in Spring 2018, and Marc will defend his PhD in November of 2018. Finally, a new graduate student, Patty Cho, has joined our group. She is currently familiarizing herself with our experiment on Z.

In addition, numerous undergraduate students have participated in the research of our group, mainly through our involvement. In addition, numerous undergraduate students have participated in the research of our group, mainly through our involvement in the Freshman Research Initiative (FRI) at UT. They have learned the essentials of observing and data analysis and most have indicated an interest in graduate school in a scientific discipline. Since this program is in its 9th year, we have just begun to see our students graduate win awards. In addition to numerous smaller awards, our students have achieved the following:

1. Attending grad school at: 1) Harvard University (Astronomy), 2) University of Chicago (Astronomy), 3) University of Virginia (Astronomy), 4) University of Colorado (Physics), University of Texas (Physics), 5) Purdue University (Aerospace Engineering), 6) Southwestern Medical School at Dallas
2. Internships/REU programs at: 1) Sandia National Labs, 2) Greenbank Radio Observatory, 3) Microsoft Kinect Division, 4) Yahoo, 5) Yale (Astronomy REU), 6) Notre Dame (Physics REU), 7) SAO Astronomy Summer Intern (CFA), Space Astronomy Summer Program at STScI
3. Awards: 1) NSF 3-year Graduate Fellowship in Physics, 2) Grand Prize ($20,000) of George Mitchell Award for undergraduate research at UT-Austin, 3) First Place in Student Employee of the Year Award at UT-Austin, 4) Astronaut Scholarship
4. After graduating, one of our undergraduate students was recently hired as a telescope operator at the W. M. Keck Observatory.

d. **How have the results been disseminated to communities of interest?**
We publish papers in scientific journals and attend conferences in our field to disseminate our results. We also continue to be responsive to media requests aimed at the general public.

In July 2018, we hosted in Austin, Texas, the biennial “21st European White Dwarf Workshop”. We presented updates on our experiment at the Sandia Z Facility at a special session devoted to “Laboratory Astrophysics”.

e. **What do you plan to do during the next reporting period to accomplish the goals and objectives?**

- Experimental work: Continue He experiments, including scoping shots for C. Measure pressure shifts of He. Continue improvements to gas cell design inside blast shield. Compare observed dissolution of lines as a function of electron densities in the experiments with ab initio theoretical occupation probability calculations of He.
- Theoretical work: Include new profiles in model atmosphere codes. Begin new state-of-the-art model atmosphere calculations incorporating H line profile calculations. Continue work on line broadened profiles for He, and develop ab initio calculations of continuum lowering and occupation probabilities for He.
- Perform He and H mixture experiments to measure the effects of trace amounts of H (-1 < log(mH/mHe) < -4) on the temperature and density of the plasma derived from the broadening of He lines. The experimental results will help improve uncertainties in temperatures related to trace hydrogen in the atmospheres of helium dominated white dwarfs. These experiments will occur in tandem with time series photometric and spectroscopic observations from McDonald Observatory of candidates and known pulsating and non-pulsating helium atmosphere white dwarfs, providing a sample with which to apply and test the experimental results.

2. PRODUCTS: **Mandatory**

What has the project produced?

a. **Publications**

- M.-A. Schaeuble, T. Nagayama, J. E. Bailey, T. A. Gomez, M. H. Montgomery, and D. E. Winget, "Hß and Hγ Absorption-line Profile Inconsistencies in Laboratory Experiments Performed at White Dwarf Photosphere Conditions", *Astrophysical Journal*, vol. 885, 1, 2019.
- T. A. Gomez, T. Nagayama, D. P. Kilcrease, M. H. Montgomery, and D. E. Winget, "Density-matrix correlations in the relaxation theory of electron broadening", *Physical Review A*, vol. 98, 1, 2018.
- Thomas Gomez, Taisuke Nagayama, Chris Fontes, Dave Kilcrease, Stephanie Hansen, Mike Montgomery, and Don Winget, "Matrix Methods for Solving Hartree-Fock Equations in Atomic Structure Calculations and Line Broadening", *Atoms*, vol. 6, 2, 2018.

b. **Books or other non-periodical, one-time publications.**

Nothing to Report

c. **Other publications, conference papers and presentations**.

- "The UT Austin, UNR, Sandia Center of Excellence for Astrophysical Plasma Properties", Don Winget, University of Nevada Reno Physics Colloquium, Reno, NV, November 2019
- "Understanding spectra from white dwarf photospheres: benchmarking the atomic physics", Don Winget, IAU Symposium, Hilo, HI, October 2019
- "The White Dwarf Photosphere Experiment: Results for Neutral Helium Broadening", Mike Montgomery, APS DPP, Fort Lauderdale, FL, October 2019

- “Laboratory Measurements of Discrepancies between Hß and Hγ Absorption Line Profiles at the Conditions of White Dwarf Photospheres”, Marc-Andre Schaeuble, APS DPP, Fort Lauderdale, FL, October 2019
- “Revised Laboratory Measurements of Iron Opacity for Stellar Interiors”, Jim Bailey, APS DPP, Fort Lauderdale, FL, October 2019
- “Radiation Cooling of Laboratory Photoionized Plasmas”, Roberto Mancini, APS DPP, Fort Lauderdale, FL, October 2019
- “First Experimental Assessment of the Z Opacity Sample Evolution using Time-resolved Spectroscopy with a Gated Hybrid CMOS Detector”, Guillaume Loisel, APS DPP, Fort Lauderdale, FL, October 2019
- “Stellar Atmospheres in the Laboratory: A Testbed for Fundamental Atomic Processes”, Mike Montgomery, NASA-NSF PI Review meeting on Laboratory Astrophysics, Washington, DC, October 2019
- “Understanding spectra from white dwarf photospheres in the context of WCAPP”, Don Winget, IFSA, Osaka, Japan, September 2019
- “The Effect of a Variable Convection Zone on Coherence and Damping of Modes in Pulsating White Dwarfs”, Mike Montgomery, TASC5/KASC12 Workshop, Cambridge, MA, July 2019
- “White Dwarfs and McDonald Observatory”, Don Winget, Board of Visitors meeting, Fort Davis, TX, July 2019
- “The Wootton Center for Astrophysical Plasma Properties: First Results for Helium”, Mike Montgomery, IAU Symposium on Laboratory Astrophysics, Cambridge, UK, April 2019
- “The Wootton Center for Astrophysical Plasma Properties: At-Parameter Experimental Astrophysics”, Don Winget, Lakeway Men’s Breakfast Club”, Don Winget, Conopus, San Antonio, TX, April 2019
- “The Wootton Center for Astrophysical Plasma Properties: At-Parameter Experimental Astrophysics”, Don Winget, OLUG, Rochester, NY, April 2019

d. **Website(s) or other Internet site(s)**

https://wcapp.astronomy.utexas.edu

e. **Technologies or techniques**
Nothing to Report

f. **Inventions, patent applications, and/or licenses**
Nothing to Report

g. **Other products**
Nothing to Report

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS: Optional

Who has been involved?

a. **What individuals have worked on the project?**

1. Name: Donald E. Winget
   - Total Number of Months: 3
   - Project Role: PI
   - Researcher Identifier: orcid.org/0000-0003-0181-2521
   - Contribution to Project: PI Winget's role is to plan the overall scientific direction of the project, including the experiments, supplementary theoretical calculations, and to ready results for publication as appropriate.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: Yes
   - Country(ies) of foreign collaborator: Porto Alegre, BRAZIL
   - Travelled to foreign country: No
   - If traveled to foreign country(ies), duration of stay: NA

2. Name: Michael H. Montgomery
   - Total Number of Months: 6
   - Project Role: Co-I
   - Researcher Identifier: orcid.org/0000-0002-6748-1748
   - Contribution to Project: Co-I Montgomery's role is to assist in planning the overall scientific direction of the project, including the experiments, supplementary theoretical calculations, and to ready results for publication as appropriate.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

3. Name: John "Craig" Wheeler
   - Total Number of Months: 1
   - Project Role: Co-I
   - Researcher Identifier: orcid.org/0000-0003-1349-6538
   - Contribution to Project: Co-I Wheeler's expertise in High Energy Astrophysics, specializing in cosmic explosions of Type Ia supernovae and stellar astrophysics is beneficial to the project.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

4. Name: Keith A. Hawkins
   - Total Number of Months: 0.8
   - Project Role: Co-I
   - Researcher Identifier: orcid.org/0000-0002-1423-2174
   - Contribution to Project: Co-I Hawkins' work on stellar populations in large scale surveys is beneficial to the project.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

5. Name: Bart H. Dunlap
   - Total Number of Months: 12

- Project Role: Postdoctoral fellow
- Researcher Identifier: orcid.org/0000-0002-1086-8685
- Contribution to Project: Bart designs and fields experiments on the Z Machine at Sandia National Labs and reduces and analyzes the data from these shots.
- State, U.S. territory, and/or country of residence: New Mexico, U.S.A.
- Collaborated with individual in foreign country: No

6. Name: Zachary P. Vanderbosch
   - Total Number of Months: 7
   - Project Role: Graduate Student (research assistant)
   - Researcher Identifier: orcid.org/0000-0002-0853-3464
   - Contribution to Project: Zach fields experiments on the Z Machine at Sandia National Labs and reduces and analyzes the data from these shots. He also makes astronomical observations in support of these experiments.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

7. Name: Patricia B. Cho
   - Total Number of Months: 7
   - Project Role: Graduate Student (research assistant)
   - Researcher Identifier: orcid.org/0000-0002-9163-2905
   - Contribution to Project: Patty been trained on and learned to field experiments on the Z Machine at Sandia National Labs.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

8. Name: Theodore Lane
   - Total Number of Months: 3
   - Project Role: Graduate Student (research assistant)
   - Researcher Identifier:
   - Contribution to Project: Ted been trained on and learned to field experiments on the Z Machine at Sandia National Labs.
   - State, U.S. territory, and/or country of residence: West Virginia, U.S.A.
   - Collaborated with individual in foreign country: No

9. Name: Dolores E. Groves
   - Total Number of Months: 12
   - Project Role: Executive Assistant (Administration)
   - Researcher Identifier: NA
   - Contribution to Project: Provides administrative support to Director and Deputy Director with a large volume of complex administrative tasks while exercising a high degree of initiative and judgment. Coordinates center's activities with three major universities and three large laboratories.
   - State, U.S. territory, and/or country of residence: Texas, U.S.A.
   - Collaborated with individual in foreign country: No

b. **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**

- PI Don Winget
  1. Support: Current
     Project/Proposal Title: (Wootton) Center for Astrophysical Plasma Properties (WCAPP)
     Source of Support: DOE
     Total Award Amount: $7,000,000
     Total Award Period Covered: 02/15/2018 to 02/14/2023
     Location of Project: The University of Texas at Austin
     Person-Months Per Year Committed to the Project: 3 summer

  2. Support: Current
     Project/Proposal Title: Stellar Atmospheres in the Laboratory: A Testbed for Fundamental Atomic Processes
     Source of Support: NSF
     Total Award Amount: $450,000
     Total Award Period Covered: 09/01/2017 to 08/31/2020
     Location of Project: The University of Texas at Austin
     Person-Months Per Year Committed to the Project: 2 calendar

- Co-I Michael Montgomery
  1. Support: Current
     Project/Proposal Title: (Wootton) Center for Astrophysical Plasma Properties (WCAPP)
     Source of Support: DOE
     Total Award Amount: $7,000,000
     Total Award Period Covered: 02/15/2018 to 02/14/2023
     Location of Project: The University of Texas at Austin
     Person-Months Per Year Committed to the Project: 3 summer

  2. Support: Current
     Project/Proposal Title: Stellar Atmospheres in the Laboratory: A Testbed for Fundamental Atomic Processes
     Source of Support: NSF
     Total Award Amount: $450,000
     Total Award Period Covered: 09/01/2017 to 08/31/2020
     Location of Project: The University of Texas at Austin
     Person-Months Per Year Committed to the Project: 7 calendar

  3. Support: Current
     Project/Proposal Title: Mapping the distribution of the planetary debris accreted
     Source of Support: STScI
     Total Award Amount: $45,381
     Total Award Period Covered: 01/01/2020 to 12/31/2020
     Location of Project: The University of Texas at Austin
     Person-Months Per Year Committed to the Project: 1 calendar

  4. Support: Current
     Project/Proposal Title: Seismologically Mining White Dwarfs in the K2 Archive for their Rotation Rates, Convection Properties
     Source of Support: NASA

Total Award Amount: $334,513
Total Award Period Covered: 01/01/2020 to 12/31/2022
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project: 3 calendar

c. **What other organizations have been involved as partners?**

1. Organization Name: Sandia National Laboratories
   Location of Organization: Albuquerque, NM
   Partner's contribution to the project: Facilities - Provide the Z machine, gas cells, and other support for our experiments there.
   Collaborative research: Collaborators James E. Bailey, Thomas A. Gomez, Stephanie B. Hansen, Guillaume P. Loisel, Taisuke Nagayaman, and Gregory A. Rochau

d. **Have other collaborators or contacts been involved?**
Nothing to Report

4. IMPACT: Optional

What is the impact of the project? How has it contributed?

Benchmarking the physics of the atomic lines of H, He, C, and O will allow us to build more physically complete model atmospheres of white dwarf stars. In particular, we will be able to accurately determine the masses of WDs with pure H, pure He, and C/O surfaces. Knowing their masses allows them to be used as some of the most accurate Galactic chronometers, and it offers insight into different formation scenarios for the WDs with He and C/O surfaces.

a. **What was the impact on the development of the principal discipline(s) of the project?**
Describe how findings, results, and techniques that were developed or extended, or other products from the project made an impact or are likely to make an impact on the base of knowledge, theory, and research and/or pedagogical methods in the principal disciplinary field(s) of the project. Summarize using language that a lay audience can understand (*Scientific American* style). How the field or discipline is defined is not as important as covering the impact the work has had on knowledge and technique. Make the best distinction possible, for example, by using a "field" or "discipline", if appropriate, that corresponds with a single academic department (i.e., physics rather than nuclear physics).

b. **What was the impact on other disciplines?**
A better theoretical understanding of the H Balmer series will enable its use as a laboratory diagnostic of plasma conditions at a wider range of densities than is currently possible.

Making a grid of H Balmer line profiles available will allow their inclusion into WD atmosphere models. This will allow researchers to determine the masses of WDs from their spectra. WDs are used in many different contexts, for instance, as standard stars for various space missions.

c. **What was the impact on the development of human resources?**
Marc Schaeuble and Zach Vanderbosch, both graduate students at UT, have been trained on and learned to field experiments on the Z Machine at Sandia National Labs. They have also acted as mentors for the undergraduates who work in our group. Zach became a Ph.D. candidate in Spring 2018, and Marc defended his Ph.D. in December of 2018. Finally, a new graduate student, Patty Cho, has joined our group. She is currently familiarizing herself with our experiment on Z.

In addition, numerous undergraduate students have participated in the research of our group, mainly through our involvement in the Freshman Research Initiative (FRI) at UT. They have learned the essentials of observing and data analysis and most have indicated an interest in graduate school in a scientific discipline. Since this program is in its 9th year, we have just begun to see our students graduate win awards. In addition to numerous smaller awards, our students have achieved the following:

1. Attending grad school at: 1) Harvard University (Astronomy), 2) University of Chicago (Astronomy), 3) University of Virginia (Astronomy), 4) University of Colorado (Physics), University of Texas (Physics), 5) Purdue University (Aerospace Engineering), 6) Southwestern Medical School at Dallas
2. Internships/REU programs at: 1) Sandia National Labs, 2) Greenbank Radio Observatory, 3) Microsoft Kinect Division, 4) Yahoo, 5) Yale (Astronomy REU), 6) Notre Dame (Physics REU), 7) SAO Astronomy Summer Intern (CFA), Space Astronomy Summer Program at STScI
3. Awards: 1) NSF 3-year Graduate Fellowship in Physics, 2) Grand Prize ($20,000) of George Mitchell Award for undergraduate research at UT-Austin, 3) First Place in Student Employee of the Year Award at UT-Austin, 4) Astronaut Scholarship
4. After graduating, one of our undergraduate students was recently hired as a telescope operator at the W. M. Keck Observatory.

d. **What was the impact on teaching and educational experiences?**
Nothing to Report

e. **What was the impact on physical, institutional, and information resources that form infrastructure?**
Nothing to Report

f. **What was the impact on technology transfer?**
Nothing to Report

g. **What was the impact on society beyond science and technology?**
Nothing to Report

h. **What percentage of the award's budget was spent in foreign country(ies)?**
Nothing to Report

5. **CHANGES/PROBLEMS: Mandatory**
   a. **Changes in approach and reasons for change**
      Nothing to Report

   b. **Actual or anticipated problems or delays and actions or plans to resolve them**
      Nothing to Report

   c. **Changes that have a significant impact on expenditures**
      Nothing to Report

   d. **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents**
      Nothing to Report

   e. **Change of primary performance site location from that originally proposed**
      Nothing to Report

6. **SPECIAL REPORTING REQUIREMENTS: Mandatory**
   Nothing to Report

7. **BUDGETARY INFORMATION: Optional**
   Excel spreadsheet attached

8. **PROJECT OUTCOMES: Optional**

What were the outcomes of the award?
This information is used at the completion of the award to ascertain the cumulative outcomes or findings of a project. Describe project outcomes specifically for the public to provide insight into the outcomes of Federally-funded research, education, and other activities. Agencies may make this information available to the public in an electronic format.

Project Outcomes
The recipient is to provide information regarding the cumulative outcomes or findings of the project. For the final RPPR for the project, provide a concise summary of the outcomes or findings of the award (no more than 8,000 characters) that:
   a. is written for the general public (non-technical audiences) in clear, concise, and comprehensible language;
   b. is suitable for dissemination to the general public, as the information may be available electronically;
   c. does not include proprietary, confidential information or trade secrets; and
   d. includes up to six images (images are optional).