Wootton Center for Astrophysical Plasma Properties
Department of Astronomy and McDonald Observatory

2515 Speedway, C1400 • Austin, TX 78712-1205 • 512-471-3000 • FAX 512-471-6016
www.as.utexas.edu

Center Scientific Advisory Committee meeting for the Wootton Center for Astrophysical Plasma Properties

Meeting date: 25 February 2022

Location: Via Zoom

Members of Center Scientific Advisory Committee meeting (CSAC) for the Wootton Center for Astrophysical Plasma Properties (WCAPP) present:

Nancy Brickhouse, Harvard-Smithsonian Center for Astrophysics,
Chris Fontes, Los Alamos National Laboratory
Don Lamb, Department of Astronomy and Astrophysics, University of Chicago
Keith Matzen, Sandia National Laboratories, Albuquerque
Marilyn Schneider, Lawrence Livermore National Laboratory
Hugh Van Horn, Department of Physics and Astronomy, University of Rochester (retired)
Alan Wootton (retired)

David Kilcrease, Los Alamos National Laboratory was unable to attend (a prior commitment)

Contents

1. Summary

The Wootton Center for Astrophysical Plasma Properties (WCAPP) is engaged in an exciting research program. The focus remains unique: "At-parameter" experiments, with high-fidelity data, notably in the areas of atomic and radiation physics, and spectroscopy, resulting in publications with high impact for both astrophysical and DOE/NNSA interests. Efficient use of the Z Facility at Sandia National Laboratories (SNL) is assured by fielding multiple experiments (typically 4) on every shot. An experimental program at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) has been initiated, and first results obtained. The Center provides an education leading to a future source of young scientists in the important area of atomic and radiation physics of warm dense matter.

The committee meeting demonstrated that the team of experimental, theoretical, and computational scientists has made great progress in the past year. Three postdocs are located at SNL and involved in the studies of white-dwarf, solar-opacity, photoionized, and accretion-powered plasma projects. A postdoc also leads the WCAPP NIF involvement. Graduate-student recruitment is healthy.

Findings and Recommendations are given in individual sections, and also in the Final Summary.

2. Introduction

The Wootton Center for Astrophysical Plasma Properties (WCAPP) received funding in February 2018. It is focused on the atomic and radiation physics of matter over a wide range of temperatures and densities. Academics currently funded by the grant are from the University of Texas at Austin (UT) and the University of Nevada, Reno (UNR). The experiments undertaken have been performed at the Sandia National Laboratories (SNL) Z Facility and at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL). There is heavy involvement of national laboratory staff from SNL, LLNL and Los Alamos National Laboratory (LANL), as well as from the University of Arizona. While motivated by astrophysics, the Center also addresses problems of interest for stockpile stewardship, inertial confinement fusion (ICF) and high-energy-density (HED) physics. This document is a summary of the fourth meeting of the Center Scientific Advisory Committee (CSAC).

The panel met from 10:00 am to 5:00 pm CST on Friday February 25, 2022, using Zoom: The meeting agenda is listed in the Appendix. The discussions were structured around the areas where advice was requested:

a) Science in year 5 (the current year)
b) Personnel needed to achieve year 5 science goals
c) Longer-term science ideas that need ~1 year exploratory studies
d) Succession plans (Director and CSAC chair)
e) Renewal strategies (expansion of participants/institutions, budget, summer school)

3. Discussions, Findings and Recommendations

After presentations and a general discussion with WCAPP researchers (including students), the committee met alone for discussions in the areas noted above. We summarize those discussions below, including any Findings and Recommendations.

3.1 Science in year 5

The CSAC heard short presentations from senior graduate students Patty Cho (UT) and Kyle Swanson (UNR). In addition, we heard brief remarks from first-year UT graduate students Bryce Hobbs, Malia Kao, and Jackson White.

Patty Cho summarized her graduate work to date. In her first two years, she performed theoretical work with Thomas Gomez (SNL) in improving H-line-shape calculations for white dwarfs; this work has now been accepted for publication in the *Astrophysical Journal*. In her third year (2021), she was awarded a Laboratory Residency Graduate Fellowship (LRGF) at SNL, where she has been working with Guillaume Loisel on photoionized plasma experiments. Patty is now fully qualified to run this experiment and has since been doing so. A paper on Si line profiles is in preparation for the *Astrophysical Journal*, and work on the analysis of Fe lines is in progress, with data collection expected to be finished by 2023. Patty hopes to do a short residency at Caltech in summer 2022 working with Javier Garcia, and learning to run the XSPEC, XSTAR, and XILLVER codes. The core of her Ph.D. thesis will be focused on the Fe plasma platform at SNL and XSTAR, and she expects to have about three peer-reviewed publications by the time she receives her degree. This work could provide some of the supporting data that will be needed in a 3–5-year time frame for future space missions like *XRISM* and *Athena*.

Kyle Swanson described major advances that have been made in the fiber-based Photon Doppler Velocimetry (PDV) diagnostics with the 2 × 2 × 1 cm gas cell at SNL. By shielding the fiber-optic components from the intense radiation from Z, they have been able to reduce the noise in the measurements to the point where it is now negligible. Consequently, they are now able to record the time history of the electron density (n_e) to study the uniformity of the plasma, and they have made the first observations of preheating in the gas cell on the timescale of 50–60 ns. The measurements of n_e now are nominally "ideal," and they show that n_e rises at the front of the gas cell before it does so at the back. Whether or not these differences are significant is currently under study. The combination of measurements at Z and at Zebra (UNR) is thus able to address the impact of K- and L-shell atomic physics on the ionization of X-ray heated plasmas.

Bryce Hobbs received his bachelor's degree from UT in 2020, and he has been working with Thomas Gomez and Patty Cho to incorporate the lineshapes from the Xenomorph and Balrog codes into the astrophysical model atmosphere code TLUSTY. He is also analyzing the H-line data from the white-dwarf photosphere experiments at Z (see 3.1.1 below), and he plans to begin HYDRA simulations of the gas-cell experiments.

Malia Kao received her BS and MS from New Mexico Tech, and she held an internship at SNL working with Jim Bailey on the Fe opacity experiments. Their goal was to obtain "cold" Fe opacities with errors less than 10%. She found that the transmission of radiation through the thin Fe foil used in these experiments had errors less than about 1%, so her experiments at 1–2 keV thus resulted in Fe opacities accurate to about 1%. Malia and Jim are currently working on a paper describing this work. She is also excited about her second-year project at UT. At McDonald Observatory, she will be observing high-mass pulsating ZZ Ceti (H-atmosphere) white dwarfs in which core crystallization may have begun.

Jackson White graduated from Rice in 2021 with a thesis on the Carina Nebula. He has also worked on simulations using the FLASH code for shots at the Omega laser facility at the University of Rochester. He is currently studying the implications of the H-line shapes in white dwarf spectra. Photometric and spectroscopic observations of these stars give discordant values for the white-dwarf mass M and effective temperature T_{eff}, which motivated Thomas Gomez and Patty Cho to modify Xenomorph and Balrog. Jackson's goal is to determine whether the new lineshapes reduces this discrepancy. He is also getting involved in studies of quasi-molecular features in some H lines.

The CSAC also met the new post-Baccalaureate student Zethran Berbel, who is interested in WCAPP. He is currently looking at hydrogen in 2–3 megagauss fields.

In addition, Thomas Gomez (UT Ph.D. 2017, currently a postdoc at SNL) described his research for the CSAC. His lineshape code—created, as he emphasized, with contributions from many people—currently contains the most physics of any such code. The theory and applications to white dwarf lineshapes were published in *Physical Review Letters* in 2020 and 2021, but his new opacity results are not yet published. Together with several other investigators, he is currently starting work on the effect of plasma interactions on the oscillator strengths for lineshapes. Thomas is supported entirely by SNL, and he is an unfunded collaborator in WCAPP. In any new academic position, he would like to be included in WCAPP.

WCAPP is clearly doing a first-rate job in attracting new students, involving them in the wide range of multidisciplinary activities that are the WCAPP hallmark, and preparing them for careers in those areas.

3.1.1 White-dwarf photospheres

Bart Dunlap (UT postdoc) began the discussion of the white-dwarf experiments by noting that the reliability of line-profile measurements for white dwarfs has been improved by comparison with experiments at Z. However, the effects of gradients in the experimental measurements need to be investigated—especially for the C II lines that occur at higher temperatures in the hot DQ white dwarfs—and they need to add more lines of sight to measure those gradients in the experiments. They are currently performing benchmarking measurements for H lines, He II broadening, and the C II lines in DQs. He noted that fits to individual H lines in a given white dwarf atmosphere currently yield different results for the effective temperature T_{eff} and the logarithm of the surface gravity (log g). This results in different determinations of the stellar mass obtained from lines in the same spectrum, which in turn has implications for the use of the white dwarfs as "tools" for other astronomical investigations. Their current measurements at Z yield the continuum, emission spectrum, and absorption spectrum all at the same time. However, the electron densities obtained from Hβ and Hγ disagree by about 30%.

Mike Montgomery (UT, WCAPP Deputy Director) continued this discussion by sketching the work with the Xenomorph code—especially by Thomas Gomez and Patty Cho—which includes the first attempt to go beyond the occupation probability formalism. Both screening and the occupation probabilities have large effects on the line profiles. For screening, the code currently employs Debye shielding, and the investigators have found that they can actually use a modified Debye length to give the correct electric-field distribution around an atom in a plasma, which affects the atomic energy levels and thus the line shapes. Also, they have now used the occupation probabilities in a simulation code for the first time.

This is important work for two reasons. First, it is important to be able to determine white dwarf masses accurately from the spectra, as they affect the conclusions obtained in using white dwarfs, e.g., to determine the ages of stellar populations like those in the disk of the Milky Way Galaxy. Second, because the internal structure of an atom is influenced by the environment in which it is immersed (e.g., a plasma), the line transitions between atomic levels are affected. The ability to improve determinations of these effects is essential for interpreting the results of line-profile measurements both in laboratory spectra and in stellar spectra.

3.1.2 Stellar-interior opacity measurements

Taisuke "Tai" Nagayama (SNL) described the experiments being performed at Z to measure Fe absorption. For Fe, there is reasonable agreement at lower temperatures/densities [1], but there are significant disagreements at higher temperatures/densities. However, for both Cr and Ni, the experiments agree with the theory. This leads to three questions: (1) Is the Fe experiment wrong? (2) Is there some missing physics? (3) Are the O opacities—which provide the next largest contributions to the opacity at the base of the solar convection zone—accurate? To answer these questions, he is reanalyzing the Fe opacity experiments, and he needs more measurements of the O opacities.

Tai is currently performing time-resolved measurements using the SNL Ultrafast X-ray Imager (UXI). Whereas one would expect the electron density n_e to decrease with time as the plasma expands, these measurements showed that both the electron temperature T_e and n_e increased with time. This suggests that preheating is occurring. If so, then it will be possible to reach higher densities by blocking the preheating. Tai has accordingly taken steps to block preheating, and he finds that n_e now does decrease with time as the sample expands. He also finds that the temporal shape of the backlighting used to measure the absorption is reproducible. Thus, significant progress has been made in understanding the experiment, reaching the highest electron density achieved so far, and checking the Fe opacities. Tai also noted that Malia Kao had succeeded in measuring the "cold" Fe opacities with significantly improved accuracy.

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[1] The Z experiment is designed to increase both the temperature and density in such a way that the mean charge of the iron, etc. remains roughly constant.

Dan Mayes (Ph.D. in 2020 from UNR, now a UT postdoc stationed at SNL) took up the opacity story at this point. He noted that the O opacity is strongly affected by plasma-density effects. In some ways, this is a more tractable problem than the Fe opacity because only about 20 O lines are important in the plasma at the base of the solar convection zone, as opposed to ~10^9 lines for Fe. The O opacity also is important in white dwarfs. For the O experiments, Dan is using a SiO_2 sample at Z and an "Apollo" hohlraum at NIF. He emphasized that a major benefit of doing these experiments at both Z and NIF is that it allows cross-comparison of the experimental results. To date they have had six shots at Z, and more are expected in CY 2023–2024. Their first shot at NIF was in June 2021, and their next shots have just occurred (March 2022). The Z experiments provide high-resolution spectra of Si and O, which enables them to obtain the plasma conditions (temperature T_e from line ratios, density n_e from line widths) from the Si lines, and then obtain the O opacity with ±20% accuracy in the range from 11–15 Å. However, the data and three different opacity models do not agree. They have also carried out a first attempt to measure the O opacity at higher T_e and n_e and have reached $n_e \sim 2.5 \times 10^{22}$ cm^{-3}.

3.1.3 Photoionized plasmas

Roberto Mancini (UNR) next described the work being done through WCAPP by UNR personnel. He noted that Kyle Swanson began his Ph.D. work at UNR in 2020 and that Georges Jaar was hired as a UNR postdoc in 2021. His former Ph.D. student Dan Mayes performed the first measurements of the charge-state distribution over a full order-of-magnitude range. As Kyle already explained, his Ph.D. work involves the development of Photon Doppler Velocimetry (PDV) diagnostics, and Georges will be carrying out the first observations of multi-element Ne + H photoionized laboratory plasmas. Roberto emphasized that Kyle will be ready to "hit the ground running" at Z because he has already been well trained at the smaller Zebra facility at UNR.

Roberto emphasized four points: (1) The UNR investigators have developed a new method that is independent of kinetic modeling for extracting T_e for photoionized plasmas. (2) Boltzmann modeling has confirmed that the electron velocity distribution in the plasmas is Maxwellian, demonstrating that it has reached equilibrium. (3) Radiation–hydrodynamic codes provide good approximations for the plasma heating and temperature. (4) The driving of photoexcitation by a broadband X-ray flux produces large effects. In contrast, both Cloudy and XSTAR—two commonly used astrophysical codes—overestimate T_e by about a factor of two. In Roberto's opinion, they are on track to figure this out; he believes that it is due to transient effects because both Cloudy and XSTAR assume that the plasma is in a steady state, while the experimental conditions are not. However, he noted that time-dependent versions of both codes are currently being developed.

WCAPP's UNR group will be carrying out experiments at Z, Zebra, Omega, and NIF. The key element is the Gatling-Gun Cu X-ray source. They will also be working in three modeling areas: modeling the X-ray flux, Boltzmann modeling of the electron kinetics, and radiation hydrodynamics. They will be using several codes for the latter studies, including 2D FLASH simulations, principally to interpret the Omega results. They have already carried out the first observations of steady-state photoionized plasmas in the laboratory, and their first shot at NIF is scheduled for July.

Georges Jaar added that they are currently running simulations of mixed Ne + H plasmas. They find that Ne plays a significant role in determining the temperature of the combined plasma. They are also developing an extended PDV diagnostic (called "Fiber Direct") to probe more locations within the gas cell.

3.1.4 Black-hole accretion-disk radiation

Guillaume Loisel (SNL) discussed the use of experiments at Z to benchmark X-ray emission from black hole accretion disks. He pointed out that the geometry of such disks has a correspondence to a Z experiment: X-rays from the region near the black hole (or from Z) irradiate the disk (or the plasma from an experimental sample), with some radiation penetrating the disk (or plasma), where it affects the ionization and atomic kinetics, leading to emission from the plasma surface. The radiative recombination continuum (RRC) gives the electron temperature of the disk, while the broad Fe line provides information about radiative transfer, the structure of the disk, and general relativistic effects. The correspondence between the disk and a Z experiment enables the experimenters to build a laboratory analog of the disk, which has both advantages and challenges.

To date, the Z experiments have invalidated the Resonant Auger Destruction (RAD) hypothesis for black hole accretion disks, and the investigators have also found that current theoretical models—especially XSTAR—do not reproduce the Z data well. On the other hand, they also find that the Z experiments are highly reproducible over more than 10 experiments. In addition, they now have a new spectrometer that can measure the spectra all the way to the radiative recombination limit.

Guillaume then turned the discussion over to Patty Cho, who summarized five issues: (1) She is using Z data to benchmark and update atomic databases that are relevant to future space missions. Her measurements of the wavelengths of X-ray spectral lines are now very accurate, and a paper describing this work is in progress. She also noted that the relative intensities from XSTAR disagree with the Z measurements. (2) Consideration of the so-called "supersolar Fe abundances" will comprise the main part of her Ph.D. thesis. Current astrophysical models indicate that some black hole accretion disks appear to have very high Fe abundances. However, to date, the microphysics in these models is largely untested in the laboratory. So far, she has found that incorporating high-density effects into XSTAR reduces the Fe overabundance prediction, but not enough to resolve the whole problem. She is currently using Ca as a surrogate to test the microphysics. She noted that UT undergraduate Isaac Huegel is also involved in this work. (3) For active galactic nuclei (AGNs), the dynamical timescales may be shorter than the recombination timescales. If so, then equilibrium has not been achieved in these flows, so a time-dependent treatment of ionization is needed. (4) MONSTR is a new, time-gated emission spectrometer at Z that can be applied to their experiments. (5) Her work on the wavelengths of the Fe lines has made her wonder what other interesting data may already have been collected at Z that might have astrophysical implications.

Finding 1:

WCAPP investigators are continuing to perform world-class, at-parameter experiments at Z—broadened in the past year to include experiments at other leading facilities like Omega and NIF—as well as world-class theoretical work on problems of fundamental importance to plasma physics and astrophysics.

Recommendation 1:

For the reasons given below, all of the following investigations should be continued during Year 5:

a) *Work on the structure of lines in white dwarf spectra is essential for obtaining reliable spectroscopic masses for white dwarfs, which are necessary for utilizing them as "tools" for other astronomical investigations.*
b) *Investigations that go beyond the so-called "occupation probability" formalism for the radiation interactions of atoms immersed in dense plasmas are essential for obtaining accurate interpretations of spectra both for white dwarfs and for dense laboratory plasmas.*
c) *The Fe and O opacities at the base of the solar convection zone are critical for resolving the differences between solar models and helioseismology measurements. The O opacities at the convection-zone base in the white dwarfs also are critical for determinations of their cooling ages, which are key to their use for cosmochronology. The experimental work at Z on these topics is making important progress and must be continued.*
d) *The newly developed method for extracting the electron temperature of a photoionized plasma is an important advance. In addition, the recently begun investigations of multi-element photoionized plasmas have potentially important astrophysical applications. Further, the PDV diagnostics now being developed and refined will be important for investigating spatial variations in the laboratory plasmas. Also, the extension to time-dependent modeling of photoionized plasmas will be an important advance.*
e) *Accurate measurements of the Fe line wavelengths and intensities will be important for near-future space missions to study astrophysical X-ray sources. And discovering the reason for the "supersolar Fe abundances" inferred for some black hole accretion disks will constitute a very important astrophysical advance.*

3.2 Personnel needed for year 5

The various recruitment efforts undertaken by the Center over the past several years have been an unqualified success. Staffing levels at WCAPP have reached an optimum level, with three postdocs (Bart Dunlap, Georges Jaar and Dan Mayes), two senior graduate students (Patty Cho and Kyle Swanson) and three first-year graduate students (Bryce Hobbs, Malia Kao and Jackson White). The committee was impressed with the breadth of topics presented by this group of young researchers. A description of some of these efforts is provided in the previous section and a summary of responsibilities and achievements are provided here:

a) *Bart Dunlap* (UT postdoc) fields the white-dwarf photosphere experiments on-site at SNL, performing line-profile measurements for H, He and C.

b) *Dan Mayes* (UT postdoc) is working on-site at SNL with Jim Bailey and is analyzing oxygen opacity experiments at Z and NIF. Dan is also leading the NIF work. This active WCAPPP involvement with Jim and Tai is one of the most important scientific steps made over the past year.
c) *Georges Jaar* (UNR postdoc) is working with Roberto Mancini, on-site at SNL, investigating the importance of multi-element (H/Ne) mixtures in photoionization experiments at Z.
d) *Patty Cho* (UT graduate student; Laboratory Residency Graduate Fellow at SNL) is working on-site at SNL on photoionized plasma experiments with Guillaume Loisel. Patty's research includes Si line identification and the analysis of Fe emission spectra at conditions relevant to the super-solar abundance problem for black-hole accretion disks. She won a best poster award for the second consecutive year at the Stewardship Science Academic Programs (SSAP) Symposium.
e) *Kyle Swanson* (UNR graduate student) has taken over the UNR photoionization experiment, working with Georges Jaar and Roberto Mancini. Kyle has made significant progress in the development of the Photon Doppler Velocimetry (PDV) diagnostic for the gas cell. His efforts have garnered an invited talk at the upcoming HTPD Conference.
f) *Bryce Hobbs* (UT graduate student; 1st year) is working with Thomas Gomez and Patty Cho, using the Xenomorph and Balrog line-shape codes to analyze white-dwarf photosphere experiments at Z.
g) *Malia Kao* (UT graduate student; 1st year) completed a one-year internship at SNL, working with Jim Bailey on measuring "cold" Fe opacities. Her second-year project will be to observe ZZ Ceti white dwarfs at the McDonald Observatory.
h) *Jackson White* (UT graduate student; 1st year) is studying the implications of H line shapes in white-dwarf spectra. His goal is to determine whether new calculations reduce the discrepancy in temperatures that are inferred from photometric and spectroscopic fits.
i) *Zethran Berbel* (UT post-Baccalaureate student) is interested in WCAPP and is investigating hydrogen in the presence of 2-3 megagauss magnetic fields.
j) *Benjamin Thomas* (UT postdoc) is working with Craig Wheeler exploring neural network training on the HETDEX data.

The above personnel are actively engaged in the four experimental focus areas of the Center, as well as exploring new avenues of research. Their multidisciplinary (astrophysics, plasmas physics, HED physics) research activities are an integral part of the training that leads to a successful career in these fields, which is an important goal of the Center.

We note that Don Winget is currently intending to be temporarily stationed at SNL, starting late summer 2022.

Finding 2:

The present group of postdocs and graduate students is likely sufficient to cover the intended research efforts through year 5. However, there is a gap between the two senior graduate students and the three first-year graduate students, which could cause continuity problems in the future.

***Recommendation 2*:**

The Center should consider future hires that fill the gap between the senior and first-year graduate students, perhaps recruiting more advance students from the UT Physics Department.

3.3. Longer term science ideas that need ~1-year exploratory studies

An important and not well-understood effect on atomic structure in dense plasmas is continuum lowering, also called ionization-potential depression or occupation probability. This is the merging of high-*n* states with the continuum. Different occupation-probability models applied to white dwarf spectra produce different interpretations of plasma conditions. WCAPP scientists are in an excellent position to advance this field using their white dwarf photosphere experimental platform and their expertise in X-ray spectroscopy and lineshape modeling. They are strongly encouraged to do some exploratory studies of this during the coming year. See also section 3.1.1 and Finding 5c from 2021, reproduced in 3.5 below.

***Finding 3*:**

Exploratory studies for future research are important and should be chosen to minimize perturbing the ongoing programs and maximize the likelihood of success.

***Recommendation 3*:**

Continuum lowering, also called ionization-potential depression or occupation probability, is a good candidate.

3.4. Succession plans

The WCAPP Director is likely to step down sometime during the next five years. Under Don Winget's leadership the WCAPP has reached an exciting milestone, with unique "at-parameter" experiments, while also reaching out to the high energy astrophysical-spectroscopy community. The challenging nature of this interdisciplinary work cannot be overstated: not only is broad subject expertise required (e.g., plasma physics, atomic physics, astrophysics, solar physics, etc.), but the different programmatic approaches and infrastructure support of the national laboratories, university departments, and other funding agencies such as NASA must be well understood to maximize access to resources.

The program has recruited and retained a core group of students and postdocs in theory, experiment, and computation. One of the most important criteria in selecting the next Director is to maintain continuity so that the scientific programs can reach and sustain fruition. The Director needs to meet high academic standards for education and research, demonstrate strong communication skills, and possess the leadership qualities that will move the program forward.

The new Director will need to select a new Deputy Director and consider new candidates as Co-Investigators. New members of the leadership team will help maintain breadth and depth in the research program.

The current Chair of the CSAC has expressed interest in stepping down from that position but is willing to stay on as a committee member. The new Director should choose the new Chair, preferably with a record of obtaining grants from DOE and other funding sources, knowledge of the NNSA, and broad connections to the national laboratory community. The Chair in consultation with the Director should select Committee members with both national laboratory and astrophysics backgrounds.

Finding 4:

> *The WCAPP Director is likely to turn over within the next five years. The next Director will then select a new Chair for the CSAC. The new Chair in consultation with the Director should select new and returning committee members.*

Recommendation 4:

> *Continuity of leadership should be a strong consideration in the selection process for the next Director. The next Chair of the CSAC should have a deep understanding of the NNSA and the national laboratory programs. A newly constituted CSAC should represent the various disciplines contributing to the research program to help the WCAPP meet the challenges of its interdisciplinary goals.*

See also Finding 6 and Recommendation 6 below.

3.5 Renewal strategies (expansion of participants/institutions, budget, summer school)

Perhaps fortunately (from the perspective of continuity), the CSAC continues to stand behind the renewal strategy first articulated in the 2020 CSAC report:

> "A successful renewal proposal requires an exciting plan (research and personnel). Some limited and targeted evaluation of new opportunities is necessary, and limited exploratory studies are warranted. However, this must be done without jeopardizing the **Center's unique focus and reputation (world-class, high-fidelity atomic and radiation physics of warm- and high-energy-density plasmas, in particular "at parameter")**. Data analysis (both of existing Z data and presumed NIF data), and perhaps the NIF experiments themselves, will be a part of the renewal."

As a foundation for a renewal proposal, the CSAC also continues to support the Finding and Recommendation number 10 from the 2020 CSAC Report:

> **"Finding 10 (from 2020 CSAC Report)**:
> A successful renewal proposal requires a successful history, proven by metrics. These include not only research metrics (e.g., peer-reviewed papers), but also metrics that address the important objective of training graduate students and postdocs in the specialties of the Center, and exposing them to the capabilities of the NNSA national security laboratories.

Recommendation 10 (from 2020 CSAC Report):

a. WCAPP is strongly encouraged to highlight the people it is sending to SNL and other U.S. National Laboratories.

b. WCAPP is encouraged to highlight areas in which the Center's work has influenced other institutions and/or investigations."

The 2020 CSAC Report Recommendations were expanded upon in the 2021 CSAC Report, and we also stand behind those. They are reproduced below as ***Recommendation 5*** for 2022.

As noted in Sections 3.1 and 3.2 above, the CSAC was pleased to see great progress in the addition of postdocs, the addition of graduate students, continued progress in all four of the core research areas, and outreach to other academic, DOE laboratory, and government-funded institutions. We were also pleased to hear about the increasing interest in this "at-parameter" research within the astrophysics community. Lowering the barriers and increasing communication between research communities will lead to higher-impact research directions and the training of even more students for both the national laboratory and academic communities.

Finding 5:

The Recommendation number 10 from the 2020 CSAC Report and Recommendation number 5 from the 2021 CSAC Report, related to Renewal Strategies, are highly relevant for 2022. Recommendation number 5 from the 2021 CSAC Report is reproduced here.

Recommendation 5 (from 2021 CSAC Report):

a) *The renewal proposal should emphasize scientific success through peer-reviewed publications and influence on other institutions or investigations. Personnel education, development and training success should emphasize student and postdoc hires and their placements at US National Laboratories.*

b) *The proposed research should continue to emphasize exciting "at-parameter" experiments, with high-fidelity data that produce publications that have high impact for both astrophysical and DOE/NNSA interests, as well as education leading to a future source of young scientists in the important area of atomic and radiation physics of warm dense matter.*

c) *Including new scientific headline experiments would strengthen a renewal proposal. Some were presented and discussed; there appear to be many! For example, identifying debris in white dwarf spectra, the long-standing Fe XVII resonance-line problem, the O-line profile, and the occupation-probability formalism.*

d) *A strength of a renewal proposal would be to include collaborations with X-ray spectral-modeling group(s) that provide publicly available modeling tools and databases. This would help in obtaining recognition of the Center's relevant data and its inclusion into atomic-physics codes.*

The CSAC was also pleased to learn of the support and interest within the UT executive management (represented by UT Astronomy Chair, Volker Bromm) for WCAPP succession planning. We believe that clarity in this succession plan and action to ensure its implementation will be an important element in the renewal proposal (See Section 3.4). Therefore, in addition to Finding 4 and Recommendation 4, we include a specific Renewal-strategy-relevant Finding and Recommendation:

Finding 6:

Succession planning will be important for the future of WCAPP.

Recommendation 6:

A clear succession plan and action to ensure its implementation will be an important element in the renewal proposal.

As noted in Section 3.1, the CSAC was encouraged by the expansion of the historical strong collaboration with SNL to include growing efforts at both LLNL and the University of Rochester Laboratory for Laser Energetics (UR/LLE). As one looks to the future, it will be important to "right size" the experimental efforts at each of these institutions in a way that complements a small expansion of the program with additional academic collaborators.

Finding 7:

The current ~$2M-a-year research program is a standout for renewal. A small expansion would immediately allow additional high-impact research (See section 3.3).

Recommendation 7:

Consider a WCAPP expansion through additional collaborations that do not jeopardize the uniqueness of the independent entity that is WCAPP.

There was a short, specific discussion as to whether WCAPP should organize a summer school. The unique focus of WCAPP ("at-parameter" experiments, with high-fidelity data, notably in the areas of atomic and radiation physics and in spectroscopy) together with the direct link to astronomical observations (the WCAPP astronomers and access to the MacDonald Observatory) suggests that this possibility should be explored, including utilizing the Observatory.

Finding 8:

A summer school built around the Center's strengths would be valuable to the community of stockpile stewardship, ICF and HED physics, and a recruitment tool for the Center. It would include a mix of observational and "at parameter" laboratory astrophysics, with emphasis on radiation and atomic physics of warm dense matter.

Recommendation 8:

We suggest WCAPP include a summer school as part of the renewal proposal.

4. Other

As noted during the review, the CSAC has not been provided with the WCAPP annual progress reports submitted to NNSA (although they are available on the web page (https://sites.cns.utexas.edu/wcapp/reports). Therefore, we have not had the opportunity to review the metrics used to gauge the progress of the Center. In our advisory role, members of the CSAC would be happy to review these metrics as WCAPP continues to develop a renewal strategy.

4. Final Summary

Here we list the Findings and Recommendations.

Finding 1:

WCAPP investigators are continuing to perform world-class, at-parameter experiments at Z—broadened in the past year to include experiments at other leading facilities like Omega and NIF—as well as world-class theoretical work on problems of fundamental importance to plasma physics and astrophysics.

Recommendation 1:

For the reasons given below, all of the following investigations should be continued during Year 5:

a) *Work on the structure of lines in white dwarf spectra is essential for obtaining reliable spectroscopic masses for white dwarfs, which are necessary for utilizing them as "tools" for other astronomical investigations.*
b) *Investigations that go beyond the so-called "occupation probability" formalism for the radiation interactions of atoms immersed in dense plasmas are essential for obtaining accurate interpretations of spectra both for white dwarfs and for dense laboratory plasmas.*
c) *The Fe and O opacities at the base of the solar convection zone are critical for resolving the differences between solar models and helioseismology measurements. The O opacities at the convection-zone base in the white dwarfs also are critical for determinations of their cooling ages, which are key to their use for cosmochronology. The experimental work at Z on these topics is making important progress and must be continued.*
d) *The newly developed method for extracting the electron temperature of a photoioinized plasma is an important advance. In addition, the recently begun investigations of multi-element photoioinized plasmas have potentially important astrophysical applications. Further, the PDV diagnostics now being developed and refined will be important for investigating spatial variations in the laboratory plasmas. Also, the extension to time-dependent modeling of photoioinized plasmas will be an important advance.*
e) *Accurate measurements of the Fe line wavelengths and intensities will be important for near-future space missions to study astrophysical X-ray sources. And discovering the reason for the "supersolar Fe abundances" inferred for some black hole accretion disks will constitute a very important astrophysical advance.*

***Finding 2*:**

The present group of postdocs and graduate students is likely sufficient to cover the intended research efforts through year 5. However, there is a gap between the two senior graduate students and the three first-year graduate students, which could cause continuity problems in the future.

***Recommendation 2*:**

The Center should consider future hires that fill the gap between the senior and first-year graduate students, perhaps recruiting more advance students from the UT Physics Department.

***Finding 3*:**

Exploratory studies for future research are important, and should be chosen to minimize perturbing the ongoing programs and maximize the likelihood of success.

***Recommendation 3*:**

Continuum lowering, also called ionization-potential depression or occupation probability, is a good candidate.

***Finding 4*:**

The WCAPP Director is likely to turn over within the next five years. The next Director will then select a new Chair for the CSAC. The new Chair in consultation with the Director should select new and returning committee members.

***Recommendation 4*:**

Continuity of leadership should be a strong consideration in the selection process for the next Director. The next Chair of the CSAC should have a deep understanding of the NNSA and the national laboratory programs. A newly constituted CSAC should represent the various disciplines contributing to the research program to help the WCAPP meet the challenges of its interdisciplinary goals.

See also Finding 6 and Recommendation 6 below.

***Finding 5*:**

The Recommendation number 10 from the 2020 CSAC Report and Recommendation number 5 from the 2021 CSAC Report, related to Renewal Strategies, are highly relevant for 2022. Recommendation number 5 from the 2021 CSAC Report is reproduced here.

***Recommendation 5 (from 2021 CSAC Report)*:**

a) *The renewal proposal should emphasize scientific success through peer-reviewed publications and influence on other institutions or investigations. Personnel education, development and training success should emphasize student and postdoc hires and their placements at US National Laboratories.*
b) *The proposed research should continue to emphasize exciting "at-parameter" experiments, with high-fidelity data that produce publications that have high*

impact for both astrophysical and DOE/NNSA interests, as well as education leading to a future source of young scientists in the important area of atomic and radiation physics of warm dense matter.

c) *Including new scientific headline experiments would strengthen a renewal proposal. Some were presented and discussed; there appear to be many! For example, identifying debris in white dwarf spectra, the long-standing Fe XVII resonance-line problem, the O-line profile, and the occupation-probability formalism.*

d) *A strength of a renewal proposal would be to include collaborations with X-ray spectral-modeling group(s) that provide publicly available modeling tools and databases. This would help in obtaining recognition of the Center's relevant data and its inclusion into atomic-physics codes.*

Finding 6:

Succession planning will be important for the future of WCAPP.

Recommendation 6:

A clear succession plan and action to ensure its implementation will be an important element in the renewal proposal.

Finding 7:

The current ~$2M-a-year research program is a standout for renewal. A small expansion would immediately allow additional high-impact research (See section 3.3).

Recommendation 7:

Consider a WCAPP expansion through additional collaborations that do not jeopardize the uniqueness of the independent entity that is WCAPP.

Finding 8:

A summer school built around the Center strengths would be valuable to the community of stockpile stewardship, ICF and HED physics, and a recruitment tool for the Center. It would include a mix of observational and "at parameter" laboratory astrophysics, with emphasis on radiation and atomic physics of warm dense matter.

Recommendation 8:

We suggest WCAPP include a summer school as part of the renewal proposal.

Appendix. Meeting Agenda

Wootton Center for Astrophysical Plasma Properties
Department of Astronomy and McDonald Observatory

2515 Speedway, C1400 • Austin, TX 78712-1205 • 512-471-3000 • FAX 512-471-6016
www.as.utexas.edu

Wootton Center for Astrophysical Plasma Properties

DOE/NNSA

Stockpile Stewardship Academic Alliance Program

Center Scientific Advisory Committee (CSAC)

25 February 2022

Zoom link: https://us06web.zoom.us/j/81248406161

AGENDA

I. Welcome and introduction to Meeting by Chair of CSAC, Alan Wootton (10:00 – 10:10 am)

II. Introduction to WCAPP (Don Winget) (10:10 – 10:40 am)
   a. Finishing year 4. What has changed in the last year, particularly in response to the CSAC 2021 report?
   b. Four general areas where advice is requested from the committee: science in year 5, personnel needed to achieve these science goals, and longer-term science ideas that need exploratory studies on a 1-year time frame, and renewal strategies.

III. Evolving Relation of WCAPP to Sandia (Jim Bailey) (10:40 – 11:00 am)

IV. Highlights of current experiments and modeling finishing 4 years and leading to year 5: (11:00 am – 2:05 pm, with lunch break ~ 12:30 pm)
   a. Student introductions – Patty, Kyle, Bryce, Malia, and Jackson (50 minutes)
   b. *Lunch break (15 minutes to gather lunch and return)*
   c. Opacities in the Sun and related stars – Tai Nagayama (25 min.)
   d. Atomic physics and x-ray heating of photoionized plasmas – Roberto Mancini (25 min.)
   e. White dwarf photospheres and theoretical developments – Bart Dunlap and Mike Montgomery (25 min.)
   f. Black hole accretion disc radiation – Guillaume Loisel and Patty Cho (25 min.)
   g. Shot schedule for NIF (motivations and time-frames) – Don (10 min.)

Link to the Wootton Center for Astrophysical Plasma Properties:
https://sites.cns.utexas.edu/wcapp

Signature Page

Wootton Center for Astrophysical Plasma Properties
Center Scientific Advisory Committee

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