ASOS-10

Abstracts of Invited Talks

RADIATIVE POWER LOSSES IN FUSION PLASMAS

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Abstract

We present recent results on radiative power losses (RPL) in carbon and gold plasmas involved in fusion. Our approach is based on a detailed calculation where the atomic database is provided by the MCDF code [1]. Then a lineshape code (PPP) allowing for NLTE ionic populations was adapted to the calculation of RPL profiles. Because the calculation time is sometimes prohibitive an alternative approach based on statistical distributions is proposed [2]. This approach involves the first four moments of the integrated radiative power loss.

We have focused our attention on carbon and gold. The first element could be present in the walls of future TOKAMAK reactors such as ITER while the second is present in holraums and its X-ray emission contributes to the heating in inertial confinement fusion.

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Tungsten spectroscopy at the Livermore EBIT and SSPX facilities

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The utilization of tungsten spectroscopy for diagnostics of magnetically confined fusion plasmas requires the radiative properties of tungsten ions to be accurately known. At the Lawrence Livermore National Laboratory there has been an ongoing effort to gather spectroscopic data on tungsten with the purpose to study spectral signatures and identify candidate fusion diagnostics. Here, we give an overview of the recent Livermore tungsten spectroscopy program, which includes experimental investigations at the EBIT-I and SuperEBIT electron beam ion traps (EBITs) and measurements at the Sustained Spheromak Physics Experiment (SSPX) spheromak. In particular, the spectra of highly charged tungsten ions have been investigated at the Livermore EBIT facility. These studies include crystal spectrometer and x-ray calorimeter spectrometer measurements of the L-shell ions and soft x-ray measurement of n = 3 - n = 3, 4 transitions in several M-shell ions using grating, crystal, and x-ray calorimeter spectrometers. Lower tungsten charge states have been observed in the extreme ultraviolet, which is also the spectral interval studied at the SSPX spheromak. Injection of tungsten hexacarbonyl into the spheromak has been performed to simulate the tungsten emission from the ITER divertor. These measurements are complemented by calculations and spectral modeling using the Flexible Atomic Code (FAC).

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Determining Plasma Core Conditions in Magnetic Fusion Devices using X-ray Emission Spectroscopy of Highly Ionized Tungsten

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Measuring the core temperature, density and ionization conditions in ITER will be one of the challenges for diagnostics of burning magnetically-confined plasmas in the next ten years. Central core temperatures are predicted to be in the range of 10 – 40 keV on ITER and Bragg crystal x-ray spectroscopy is one of the few techniques able to diagnose the conditions. These high temperatures burn out the usual low Z K-shell diagnostic lines studied on smaller machines and so higher Z ions are required to address the new regime. Since tungsten tiles in the divertor region are expected to introduce and generate measurable quantities of highly ionized W^{64+} L-shell x-ray emission in the core, this working radiation will be an important spectroscopic tool. We report on the challenges of measuring L-shell tungsten and the atomic database development that will be required to correctly interpret the spectra. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Space-time variation of fundamental constants and accurate measurements of atomic spectra

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I present a review of recent works devoted to the variation of the fine structure constant $\alpha = e^2/\hbar c$, strong interaction and fundamental masses (Higgs vacuum). There are some hints for the variation in the quasar absorption spectra [1] and Big Bang nucleosynthesis data.

A change in α could be detected via shifts in the resonance transition frequencies in quasar absorption systems. We have developed a new approach which improves sensitivity of this method by 1-2 orders of magnitude [2]. The α dependence of transition frequencies appears due to the relativistic corrections which are proportional to α^2. We performed the calculations of the α dependence using modern many-body theory methods. Then the variation of α is obtained from the measurements of frequencies which have different dependence on α.

Atomic and molecular transitions in quasar absorptions spectra (optical and microwave) may also be used to study variation of the fundamental masses and strong interaction. We performed necessary calculations. Suggestions of new measurements (including new enhanced effects) and new results of measurements will be presented.

One can also search for the variation by studying atomic, molecular and nuclear transition frequencies in laboratory, both in optical and microwave transitions. We performed the calculations for a number of interesting cases and suggest new measurements.

To improve the measurements of the α variation we need new accurate measuements of the transtion frequencies and istopic shifts of ionic and atomic lines observed in the quasar absorpition spectra. Our “shopping list” is presented in [3].

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Visible Magnetic Dipole Emission from Ar X and Ar XIV in Alcator C-Mod Tokamak Plasmas

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A transmission grating spectrometer for visible light was used at the Alcator C-Mod tokamak. The purpose of the spectrometer was to make Doppler measurements of intrinsic impurities in a radial spatial region, which would bridge data from the x-ray based core Doppler spectrometer and that from the visible based edge charge exchange emission spectrometer. The idea is to use either the line emission from the $2s^2 2p$ j=1/2 → $2s^2 2p$ j=3/2 transition in B-like Ar XIV at 4412.4 Å or the $2s^2 2p^5$ j=3/2 → $2s^2 2p^5$ j=1/2 transition in F-like Ar X at 5533.4 Å, both of which have been recorded previously in lower density plasmas (10^9-10^{18} m^{-3}) produced in the LLNL and Heidelberg electron beam ion traps as well as in the Large Helical Device (LHD) [1-5]. For our purpose, argon is considered an intrinsic impurity because the core Doppler spectrometer depends upon its injection and in many cases it's presence is not perturbative. An extensive search for these emission lines proved fruitless. With support from Flexible Atomic Code (FAC) calculations it is determined that this emission line and others like it are not measureable in high density plasmas because they are overtaken by bremsstrahlung emission. Supporting data from the search will be shown as well as calculations from FAC. The use of neutral beam induced charge exchange emission from a n=14-13 transition in Li-like Ar XVI, as used before at DIIID [6], is suggested as an alternative approach.

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THE NEW SOLAR CHEMICAL COMPOSITION

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With Martin Asplund (Max Planck Institute for Astrophysics, Garching, Germany), Jacques Sauval (Observatoire Royal de Belgique, Brussels, Belgium) and Pat Scott (Stockholm University, Sweden) we have very recently re-determined the abundances of nearly all the available chemical elements in the solar photosphere, from Lithium to Thorium. The new data are compared with all the available data in a review that was recently published in Annual Review of Astronomy and Astrophysics(47, 481-522, 2009).

This new complete and homogeneous analysis results from:

* a very careful selection of spectral lines of all the indicators of the abundances present in the solar photospheric spectrum and discussion of the atomic and molecular data,
* an analysis of these lines based on a new 3D model of the solar outer layers taking non-LTE effects into account when possible.

We shall present these new results, compare them with other recent solar data as well as with recent results for the solar neighbourhood and discuss some of their most important implications as well as the atomic data we still urgently need.

Cross section enhancement in correlated resonant recombination processes

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Resonant mechanisms are highly efficient in either ionizing or recombining ions and hence the process of dielectronic recombination (DR) is of paramount importance for the physics of outer planetary atmospheres and interstellar clouds as well as an important radiative cooling mechanism in astrophysical and laboratory high-temperature plasmas.

In the simple DR process involving two interacting electrons, the kinetic energy of the recombined electron is transferred to a single bound electron by a radiationless excitation to an intermediate autoionizing state. Beyond this well-known scenario, two or even three bound electrons can be simultaneously excited by the resonantly captured electron in trielectronic or quadruelectronic recombination (TR and QR, respectively). We calculate cross sections for these processes in the framework of the multiconfiguration Dirac-Fock theory for a range of highly charged ions in Li- to N-like charge states, and find a good agreement with recent high-resolution electron beam ion trap observations [1]. For certain transitions in Ar and Fe ions, the resonance strength for TR is comparable to that of DR. Also, unambiguous signatures of QR has been found, in good agreement with our predictions.

Furthermore, in the presence of a neighboring atom, electron-ion recombination can proceed resonantly via excitation of an electron in the atom, with subsequent relaxation through radiative decay. It is shown that this two-center dielectronic process (2CDR) can largely dominate over single-center radiative recombination at internuclear distances as large as several nanometers. The relevance of the predicted process is demonstrated by using examples of warm dense matter such as some astrophysical objects and thermonuclear fusion plasmas.

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Relativistic multireference many-body perturbation theory for open-shell ions with multiple valence shell electrons*

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Accurate atomic structure and collision data are crucial to understanding astrophysical and laboratory plasmas. Recent efforts through the development and implementation of accurate many-body theoretical methods have greatly improved the accuracy of such data. We have recently developed a relativistic multireference many-body perturbation theory (MR-MBPT) for accurate predictions of term energies, spectroscopic transitions, and electron impact excitation cross sections in multielectron ions [1-6]. An important feature in the many-body algorithm is the highly correlated state-specific many-electron wavefunctions that accurately account for relativity and for static as well as dynamic correlation energy corrections arising from the effective electron-electron interaction - the instantaneous Coulomb and Breit interactions - in addition to the QED corrections. The multireference perturbation theory employs a general class of configuration-interaction wave functions as reference functions, and thus is applicable to multiple open valence shell systems with near degeneracy of a manifold of strongly interacting configurations.

The relativistic MR-MBPT is employed to construct the effective Hamiltonians for accurate representation of the N-electron target and (N+1)-electron scattering Hamiltonian matrices in relativistic R-matrix close-coupling theory. The effective many-body Hamiltonian R-matrix close-coupling calculations were successfully applied to the near-threshold electron impact excitation of electric dipole-allowed and spin-forbidden transitions in S^{4+}, Ar^{6+}, Fe^{14+}, and Kr^{6+} ions [1,2].

High-accuracy MR-MBPT calculations were carried out on the ground and excited levels of Fe VII - Fe XV in which the near degeneracy of a manifold of strongly interacting configurations mandates a multireference treatment [3-6]. Transition rates associated with E1/M1/E2/M2/E3 radiative decays and lifetimes of a number of excited levels were calculated and compared with laboratory measurements to critically evaluate recent experiments.

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Hyperfine Quenching: Review of Experiment and Theory

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Hyperfine quenching of low-lying metastable states of atoms and ions is reviewed with emphasis on theoretical methods. The seminal work of Garstang [1] on hyperfine quenching of the intercombination transitions $(6s6p)\,^3\mathrm{P}_{0,2}$ - $(6s)^2\,^1\mathrm{S}_0$ in Hg are discussed, in which the hyperfine interaction and the radiation field are both treated perturbatively. A more recent approach is described in which modifications of wave functions of fine-structure states by the hyperfine interaction are treated using CI (configuration interaction) theory while the radiation field is treated in lowest-order perturbation theory. In circumstances where radiative line widths are larger than relevant fine-structure intervals (e.g. heliumlike Ag), the perturbative treatment of the radiation field fails. In such cases, both hyperfine and radiation interactions are treated at the same level using the CI method. The radiation interaction in these cases is described using a generalization of the radiation damping Hamiltonian introduced by Robicheaux [2]. Theoretical and experimental results are presented for He, Be, Mg, and Ni isoelectronic sequences.

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X-ray spectropolarimetry at the Z-pinch generator at UNR: past and future

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The initial polarization-sensitive X-pinch experiments at UNR provided the experimental evidence for the existence of strong electron beams in Ti and Mo X-pinch plasmas and motivated the development of x-ray spectropolarimetry of Z-pinch plasmas [1]. X-pinches are an excellent source to develop spectropolarimetry because of the high density and temperature pinch plasmas that scale from a few μm to mm in size with a well-defined location. Such polarization-sensitive experiments on the 1 MA Zebra generator at UNR were based on the measurement of x-ray spectra recorded simultaneously by two spectrometers with different sensitivity to polarization and are then theoretically modelled. The values of polarization degree are calculated using the FAC code. The examples of applications to 1-2 transitions in K-shell and 2-3 transitions in L-shell spectra from mid-Z ions are considered and reviewed.

In addition, the results on the polarization of hard x-ray continuum radiation from implosions of various Z-pinch loads are presented. In particular, the hard x-ray polarimeter based on Compton scattering was used on the Zebra generator for electron beam studies by means of time-resolved hard x-ray spectropolarimetry. The values of polarization degree for different wire array and X-pinch loads were estimated and compared. Future directions of the development of Z-pinch plasma spectropolarimetry and needed atomic data are discussed.

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Recent progress in spectroscopy of tungsten

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This contribution reviews experimental and theoretical work on spectroscopy of tungsten published since the NIST critical compilation of 2008. Since then, nine new experimental papers were published containing new identifications and measured wavelengths of spectral lines of Li-like through Ca-like, Fe-like through Br-like, and Pm-like tungsten. Most of the measurements were made using electron-beam ion traps (EBITs). Two more papers contain new measurements of radiative lifetimes and transition probabilities of W II and W III. A few tens of theoretical papers on tungsten spectra were published since 2008. One of the most important of them contains a new theoretical interpretation of the odd-parity energy levels of neutral tungsten. This enabled a calculation of radiative transition rates. In another study, an extended calculation and collisional-radiative modeling of the spectra of Rh-like through Rb-like ions, W^{29+}–W^{37+} resulted in a revised interpretation of the observed spectra. A new high-precision calculation of the spectrum of Pm-like W^{13+} sheds some light on the complex electronic structure of this ion and identifies some experimentally observed transitions. A number of high-precision calculations of energy levels, transition wavelengths and radiative rates were reported for highly ionized spectra, such as Yb-like, Ag-like, Ga-like, Zn-like, Ni-like, Ca-like, Al-like, Mg-like, Na-like, Ne-like, B-like, and Be-like. These developments are briefly reviewed, and some problems are outlined.

Including All the Lines

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I present a progress report on including all the lines in the linelists, including all the lines in the opacities, including all the lines in the model atmosphere and spectrum synthesis calculations. I also report on producing high-resolution, high-signal-to-noise atlases for use in verifying the line data and spectrum calculations. All the data are available on my website kurucz.harvard.edu.

Slater-parameter Hamiltonians are determined from least-squares fits to observed energies using my versions of Cowan's atomic structure programs. Scaled Hartree-Fock starting values are used. My web site has the output files of the least-squares fits to the energy levels, energy level tables, with E, J, identification, strongest eigenvector components, lifetime, A sum, C_4, C_6, Landé g. The sums are complete up to the first (n = 10) energy level not included. Eigenvalues are replaced by measured energies so that lines connecting measured levels have correct wavelengths. Measured or estimated widths of autoionizing levels are included when available. Laboratory measurements of lifetimes are listed.

There are electric dipole, magnetic dipole, and electric quadrupole line lists. Radiative, Stark, and van der Waals damping constants, Landé g values, and branching fractions are automatically produced for each line. Hyperfine and isotopic splitting are included when laboratory data exist. Most of the lines have uncertain wavelengths because they connect predicted rather than measured levels. Laboratory measurements of gf values are included. When computations with the necessary information are available from other workers, I am happy to use those data instead of repeating the work.

My recent calculations include S I; Sc I, II, V; Ti I, II; V I: Cr I-III; Mn I, II; Fe I-VI; Co I, II; Ni I-VI; Cu I, II, IV; and Y I. Just these ions total 172 million E1 lines. I am producing about 7 times as many lines as in my previous iron group calculations in 1988 because I am including 3 times as many levels. Once the linelist for an ion or molecule is validated it will be incorporated into the wavelength sorted linelists on my website for computing opacities or detailed spectra.

Time-resolved Spectroscopy of the Electrode Region in a Fluorescent Lamp

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In the plasma inside a fluorescent lamp, the region most close to the electrodes is of high interest. The reason for this can be divided into two parts: 1) The wear of the electrodes due to their interaction with the plasma is one of the factors which limits the lifetime of the lamp; 2) Especially during the cathode phase, this region cannot be described by using local thermodynamic equilibrium approximations, making plasma modeling difficult. Thus, investigating the plasma close to the electrodes is interesting from an engineering point of view as well as for basic plasma physics purposes.

This talk will describe the experiments which are being in progress at Lund Observatory to look into these questions. The method which is being used is time resolved spectroscopy, where the temporal behavior of different spectral lines might give information about different population mechanisms taking place inside the atoms in the plasma. The results from these experiments are in the end planned being tested against an atomic excitation model of the electrode region; however, this is to some extent being hampered by the lack of data on for instance collisional cross sections and recombination rates.

Testing and improving the dielectronic recombination data used in fractional abundance calculations of tungsten

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We report of new dielectronic recombination calculations for W35+. For open d- and f-shell ion stages, the complexity of the atomic structure makes level-resolved DR calculations untenable on currently available computers. We investigate the use of the configuration-average distorted-wave (CADW) method to calculate DR rate coefficients for complex open d-shell systems. We compare against level-resolved distorted-wave and level-resolved Dirac R-matrix calculations for certain core excitations. We present results for CADW rate coefficients for both delta n = 0 and delta n = 1 excitations for W35+. This study indicates that it is now feasible to generate a much improved comprehensive set of DR data for the entire tungsten isonuclear sequence.

High Accuracy Radiative Data for Plasma Opacities

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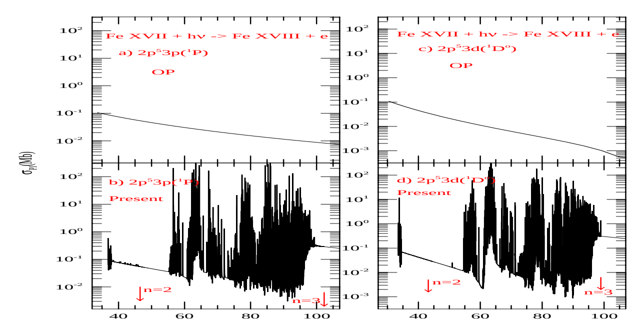
Abstract: Radiation transport in plasmas is determined by the opacity. The propagating radiation is absorbed and emitted by the constituent elements of the plasma resulting in the opacity effect. Higher or lower opacity indicates more or less attenuation of radiation. Hence opacity (κ) at a photon frequency ν, the monochromatic opacity, depends basically on two intrinsic atomic processes, photo-excitation in a bound-bound transition and photoionization in a bound-free transition. κ is calculated from oscillator strengths (f) and photoionization cross sections (σ_{PI}). However, total monochromatic opacity $\kappa(\nu)$ is obtained from summed contributions of all possible transitions from all ionization stages of all elements in the source. Calculation of accurate parameters for such a large number of transitions has been the main problem for obtaining accurate opacities. The opacity depends also on the physical conditions, such as temperature and density, elemental abundances and equation of state such in local thermodynaic equilibrium (LTE) of the plasmas. For plasmas under HED (high energy density) conditions, fluid dynamics may be considered for shock waves such as in a supernova explosion. The necessity for high precision calculations may be exemplified by some perplexing results for solar abundances. Recent determination of abundances of light elements carbon, nitrogen, oxygen etc are up to 30-40% lower than the standard values long supported by astrophysical models, helioseismology, and meteoritic measurements. Laboratories can now study radiation transport or opacity in fusion plasmas, such as created by high power lasers beams in National Ignition Facility or by a Z pinch machine, where the temperatures ($T > 10^6$ K) and density regimes ($N > 10^{20}$ cm^{-3}) are similar to those exist deep in stellar interiors. The measurements will enable calibration of the theoretical calculations of basic parameters that govern the opacity.

Under the Iron Project, we are able to calculate more accurate oscillator strengths for large number of transitions in relativistic Breit-Pauli R-matrix method. We also find existence of extensive and dominant resonant features in the high energy photoionization cross sections. such as illustrated for Fe XVII photoionization in the figure belwo.



The top panels show earlier Opacity Project data, and the bottom panels are from the recent R-matrix calculations for Fe XVII. Inclusion of these features and more accurate oscillator strengths should provide more accurate opacities which can be used to investigate the solar abundance problem.

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Testing the variation of fundamental constants with astrophysical and spectroscopic data

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In many theories of unified interactions, there are additional degrees of freedom which may allow for the variation of the fundamental constants of nature. I will review the motivation for and theoretical relations between such variations. I will then review the various astrophysical and experimental constraints on the variations of constants and their dependence on spectroscopic data.

Laboratory measurements of oscillator strengths and their astrophysical applications

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We present an overview of current needs for accurate laboratory atomic line f-values (oscillator strengths) for astrophysical applications, and examples of measurements. Data for f-values are particularly important for determination of elemental abundances in astrophysical objects. With new facilities, telescopes and spectrographs, access to underexplored regions (IR, vacuum UV,VUV), and new stellar atmosphere models (e.g. 3D, NLTE), astronomers are tackling problems ranging from determining elemental abundances in the Sun, studying Galactic evolution, to low mass stars and exoplanets. Such advances require improved accuracy and completeness of the atomic database for analyses of astrophysical spectra.

Our study of the astrophysically important neutral and singly ionised iron group element spectra continues, with applications to:

(i) improving the IR atomic database for use with new ground based and satellite borne telescopes with medium to high resolution IR spectrometers, e.g. Spitzer Space Telescope, and the Very Large Telescope (VLT) with CRIRES. Accurate IR f-values are needed, for example, for: the ESA Gaia mission aiming to determine the composition, formation and evolution of our Galaxy, the RAVE project, E-ELT with HARMONI and SIMPLE, and the APO Galactic Evolution Experiment (APOGEE), part of the SDSS-III (Sloan Digital sky survey);

(ii) modern elemental abundance studies using 3D hydrodynamical models/NLTE modelling of the Sun and stars [1], and

(iii) cool, low mass star studies requiring laboratory measured f-values for selected lines of atomic species in the IR, (see Blackwell-Whitehead et al, ASOS10) [2].

(iv) In addition, analyses of HST VUV spectra of sharp-lined early B main sequence stars in the Galaxy give information on the chemical evolution and metallicity gradient in our galaxy and allow checks of the validity of theoretical calculations of nucleosynthesis in stars. VUV f-values are particularly poorly known for transitions of the doubly ionised Fe group element spectra that dominate B star spectra.

We present measurements of oscillator strengths by high resolution Fourier transform spectrometry combined with time resolved LIF lifetime measurements. These measurements were carried out at Imperial College and Lund University, and also in collaboration with G. Nave at NIST (National Institute of Standards & Tech., USA).

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Tungsten Research at Alcator C-Mod and EBIT for Future Fusion Reactors

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Tungsten will be an important element in nearly all future fusion reactors because of its presence in plasma facing components. This makes tungsten a good candidate for a diagnostic element for T_i and v_φ measurement, and it makes an understanding of tungsten emissions important for tokamak power balance. Research on tungsten's effects on plasmas has been undergoing at Alcator C-Mod using VUV, bolometry, and soft X-ray spectroscopy. Tungsten was present in Alcator C-Mod as a plasma facing component and through laser blow off impurity injection. Continuum previously seen on ASDEX was identified and predicted spectra of Alcator's emission lines are shown. Further identification of candidate tungsten emission lines for future fusion devises are shown as well; research on them at the SuperEBIT electron beam ion trap is presented.

Astrophysical Transients Powered by the Decay of R-process Nuclei

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The merger of two neutron stars (NS) or a neutron star and a black hole (BH) occurs every 10-100 thousand years in a galaxy like the Milky Way. These events are the likely source of short-duration gamma-ray bursts, ~ 0.1 second flashes of gamma-rays detected from distant galaxies. Such mergers are also the most promising source of kHz gravitational waves for ground-based observatories such as Advanced LIGO and VIRGO. In this talk I will describe an additional type of electromagnetic transient coincident with NS-NS and/or NS-BH mergers: the decay of r-process nuclei in unbound neutron star debris generates a radioactively powered transient that peaks in the optical-infrared approximately 1 day after the merger. The detection of such a transient would provide significant constraints on the origin of the neutron-rich elements in nature and the physics of compact object mergers. I will highlight how uncertainties in the atomic transitions of rare neutron-rich elements currently limits our ability to predict the properties of these r-process powered transients.

SOFIA's Spectroscopic Capabilities

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) provides a near-space platform capable of carrying large instruments. From SOFIA's operational altitude of 12-14 km, it becomes possible to observe throughout most of the spectrum, with the most significant gains in the 30 to 1000 micron range. The initial suite of instruments for SOFIA will include three low to moderate spectral resolution instruments in the range 1 to 200 microns and three high spectral resolution instruments in the range 5 to 600 microns. I will discuss the capabilities of these instruments and attempt to put SOFIA into context relative to other astronomical observatories.

Atomic calculations for tests of fundamental physics

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I will give an overview of applications of atomic calculations for atomic physics tests of fundamental physics, including the study of parity violation, search for EDM, and search for variation of fundamental constants.

The present status of theory and need for further developments is discussed. In particular, I will report the progress on the development of a novel method for precision calculation of properties of atomic systems with a few valence electrons. This method combines the all-order approach currently used for monovalent atoms with the configuration-interaction approach that is applicable for many-electron systems. Preliminary results are reported.

Tests of fundamental symmetries and other applications not only require precise calculations of the atomic properties but also evaluation of the accuracy of the results. I will discuss possible approaches to evaluating the uncertainties of the theoretical values and present an example of such an evaluation. I will underline the importance of accurate measurements of oscillator strengths and related properties for benchmark tests of theoretical approaches.

Plasma polarization spectroscopy of atomic and molecular emission from magnetically confined plasmas

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In spectroscopic measurement of magnetically confined torus plasmas, the line-integrated emission along a viewing chord is usually observed. However, by utilizing dependence of the magnitude of the Zeeman splitting on the emission location, several localized emissions existing along the viewing chord can be separated. Detailed analysis of the Zeeman split spectral line shapes then enables us to evaluate the local values of the magnetic field strength, population density, temperature, and flow velocity. Applicability of this technique was originally verified in the Alcator C-Mod tokamak for the Dα emission generated locally in the edge region of the torus [1]. However, applicable region was limited to near the mid-plane because of the comparable magnitude of the Doppler broadening to the Zeeman splitting. In order to further improve the accuracy in separating the overlapped spectra, polarization resolved spectroscopy is available. We have observed the polarization resolved spectra of the Hα and HeI emissions on the multiple poloidal viewing chords, and succeeded to obtain the poloidal distributions of the emissions in the Large Helical Device [2] and TRIAM-1M tokamak [3]. The measured emission intensity and flow velocity have poloidal asymmetry which may be associated with the contribution of the local neutral recycling. In this paper, we summarize recent progress in this technique, and also introduce an attempt of extending the technique to measurement of light diatomic molecular emission spectra [4].

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Photoionization of Fe^{14+}: An EBIT measurement at a synchrotron radiation source

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Access to photoionization (PI) of ions in moderate to high charge states was demonstrated by coupling the transportable electron beam ion trap (EBIT) from MPI-K, Heidelberg, to the Berliner synchrotron BESSY II [1]. The main advantages of this novel technique is on the high target-ion areal density of typically 10^9 ions/cm^2, which is achieved by coaxial overlap of the cylindrical EBIT ion cloud with the photon beam. Observation of the PI process is enabled by analyzing the trap inventory upon extraction.

Measurements on Mg-like Fe^{14+} with an ionization potential of 456 eV from this threshold up to photon energies in the keV-range show good sensitivity and an excellent resolving power in the 10^4 range. Furthermore, the application of an EBIT offers good control over the photon-ion interaction time, which was successfully applied for the determination of an absolute oscillator strength [2].

No other experimental method has been capable of measuring PI of ions in such high charge states and the corresponding higher photon energies at the level of accuracy and control presented here [3]. In this energy range plasma simulations and the interpretation of astrophysical spectra often rely on input data from theory, which need to be benchmarked. A comparison to available and newer predictions based on different theoretical approaches will be drawn.

Further results, e.g., on N^{3+} [1], will be presented to illustrate the versatility of this technique. Here, the suppression of contributions from target-ions in metastable states and very good agreement with the well established merged beam method will be discussed.

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Mining for Rare Elements in Interstellar Spectra

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Rare elements are necessary probes for understanding the nucleosynthetic histories of galaxies. Specifically, r- and s-process elements can shed light on important contributors to metal enrichment such as supernovae and intermediate-mass stars. One location to study such elements is in the interstellar medium (ISM). The ISM has an advantage over stellar atmospheres in that abundance determinations are simple and model-independent. The disadvantage, however, is that some of the elements will be incorporated into dust, thereby preventing some of the abundance from being detected directly through absorption-line spectroscopy.

With currently available instruments, resonance lines of r- and s-process elements such as Ge, As, Cd, Sn, Xe, Os and Pb, whose dominant ions occur in the ultraviolet bandpass, can be explored in the Galactic ISM as well as in damped Lyman-a systems. Although oscillator strengths are reported for many of these elements [1], some have large uncertainties that affect interpretation of the abundances. For instance, interstellar tin abundances appear to be slightly supersolar in several measured sight lines [2]. This could be evidence of s-process enrichment of the ISM by low- to intermediate-mass asymptotic giant branch stars, or it could simply result from a small error in the reported transition oscillator strength.

In order to fully understand the nucleosynthetic history of a galaxy, one must be able to disentangle abundance contributions from each the r- and s-processes. Of the currently observable interstellar rare elements, As and Cd are formed through a mix of both processes, Ge, Sn and Pb are primarily formed through the s-process, and Xe and Os are basically r-process elements. Unfortunately, Xe and Os oscillator strengths for potentially observable interstellar transitions are not published, which hinders the interpretation of the nucleosynthetic efficiencies.

There are likely more rare element lines available for study in the ISM than we currently know about. High-resolution spectra produced by the Hubble Space Telescope reveal some weak absorption features that are currently unidentified. These are potential resources of information that remain untapped. Identification of these lines could lead to useful diagnostics in the future.

New Atomic Data for Trans-Iron Elements and Its Application to Abundance Determinations in Planetary Nebulae

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Investigations of the nucleosynthesis and chemical evolution of neutron(n)-capture elements (atomic number $Z > 30$) have largely been based on stellar spectroscopy. However, the recent detection of these elements in a large number of ionized nebulae (primarily planetary nebulae, or PNe) indicate that nebular spectroscopy is a promising new tool for such studies. In particular, n-capture element abundance determinations in PNe reveal important details of s-process nucleosynthesis and convective mixing in evolved low- and intermediate-mass stars, as well as the chemical evolution of elements that cannot be detected in stellar spectra. Due to their low cosmic abundances, only one or two ions of a given trans-iron element can typically be detected in individual PNe. Elemental abundance determinations thus require corrections for the abundances of unobserved ions. Such corrections rely on the availability of atomic data for processes that control the ionization structure of nebulae (e.g., photoionization cross-sections and rate coefficients for various recombination processes). Until recently, these data were unknown for virtually all n-capture element ions. For the first five ions of Se, Kr, and Xe – the three most widely detected n-capture elements in PNe — we have calculated photoionization cross-sections and radiative and dielectronic recombination rate coefficients using the multi-configuration Breit-Pauli atomic structure code AUTOSTRUCTURE. Charge transfer rate coefficients are being determined with a multichannel Landau-Zener code. To calibrate our computational results, we have measured experimental absolute photoionization cross-sections of several Se and Xe ions at the Advanced Light Source synchrotron radiation facility.

These atomic data can be incorporated into photoionization codes, which we will use to derive ionization corrections (and hence abundances) for Se, Kr, and Xe in ionized nebulae. Using Monte Carlo simulations, we will investigate the effects of atomic data uncertainties on the derived abundances, thereby illuminating the ionic systems and atomic processes that require further analysis. These results are critical for honing nebular spectroscopy into a more effective tool for investigating the production and chemical evolution of trans-iron elements in the Universe.

Verification and application of atomic polarization and spectral data for diagnostics of coronal plasma by their XUV spectra and spectral images

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Present report contains a short survey of the results concerning various issues of the method for diagnostics of so called “coronal plasmas“ based on simultaneously measured spectra and/or spectral images of their X-ray and EUV (XUV) emission. Accurate calculations of atomic polarization and spectral data and their verification in laboratory experiments is shown to be a crucial point for successful application of this method aimed at a study the structure and dynamics of coronal plasma in astrophysical and laboratory conditions.

Polarization degree of **w, x, y** and **z** lines due to, respectively, the resonance, magnetic quadrupole, intercombination and forbidden transitions of [He] argon ions excited by electron beams were obtained with account for radiative cascades from excited states in the framework of collisional-radiative model. An accuracy of corresponding atomic data for magnetic sublevels of [He] argon ions obtained by different methods of calculations is discussed. It was shown that the most important effect on polarization of **x** and **z** lines is due to cascade transitions from the levels with principal quantum numbers n=2 and 3. Polarization degree of **z** line, being not polarized by direct excitation of electron beam, is of 18% at the threshold and changes its sign at energies of about 1500 keV. The importance of the account for the effects of low energy cut-off in the energy spectrum of electron beams as well as a multi-temperature content of plasma sources for the modeling of their linear spectra is outlined. High-resolution spectra from the Ar XVII and Ar XVI ions measured at the TEXTOR tokamak (Julich, Germany) were used to verify the basic atomic data with 10% accuracy necessary for spectroscopic diagnostics of hot coronal plasma. It was shown that previously observed factor of 1.3–2 discrepancies between the measured and calculated values can be explained by the use of less accurate atomic data and simplified atomic kinetics model. The results of such verification of collisional characteristics of [He] and [Li] argon ions calculated by means of various code packages are discussed [1-4].

The Bayessian iterative method (BIM) in the framework of so called probabilistic approach, based on mathematical formalization of the inverse spectroscopic problem different to traditionally used “algebraic one”, have been proposed to derive the differential emission measure DEM(T) need for analysis of plasma temperature content. The results of the tests, including the analysis of the BIM level of confidence, made for applications to XUV spectral images of solar corona and tokamak plasmas are given. Some applications of the method developed for diagnostics of space-time dynamics of the temperature and density in hot plasma structures of solar corona are also demonstrated [5-7].

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Atomic data for stellar astrophysics from the UV to the IR

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Great progress has been made in creating the atomic data needed for stellar astrophysics in the past twenty years, the time since the launch of the Hubble Space Telescope (HST). In addition to requirements for the ultraviolet spectral region imposed by the HST, new instrumentation at ground-based and space observatories is producing high quality spectral data at optical and infrared wavelengths which also requires improvements to atomic data before fully realizing their discovery potential. In this presentation I review the progress that has been made in acquiring atomic data in recent years, and look to the future for satisfying additional atomic data needs for stellar astrophysics for UV to IR wavelengths.

Spitzer, Novae, Cross-Sections, and Reaction Rates

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Many facets of astrophysics are captured in classical novae (CNe) eruptions, making these systems unique laboratories in which several poorly understood processes (e.g., variable super-soft X-ray emission, mass transfer, thermonuclear runaway, molecule and grain formation) may be observed, many in real time. CNe are also thought to be related to the super-soft sources, the likely progenitors of SN Ia explosions. CNe spectra are remarkable for their changing elemental and ion content and the temporal development of line profiles are critical to understanding the dynamics of ejection. Low-energy permitted lines of CNO and Fe II give way to He II, as well as high ionization lines, e.g., [Fe VII] 6087 Angstrom, and ultimately to infrared (IR) "coronal" lines (few 100 eV transitions) as the ejecta evolve. The latter lines are sources for abundance information as a wide range of isoelectronic sequences and adjacent ionization states of metals are observable. Often, as the ejecta cool and evolve molecules (e.g., CO) and dust form; the spectrophotometric signature best revealed in the IR. CNe originating on CO White Dwarfs (WDs) are often dust-formers and, while C is a major grain component, silicates, PAHs, and SiC are often present, occasionally in the same nova. At higher energies, X-ray and UV emission in CNe comes from nuclear burning of residual accreted material on the WD surface after the initial outburst, directly probing processes powering the post outburst evolution and affecting ejecta grain growth and destruction.

However, from a theoretical standpoint interpretation of the emission line spectra, the derivation of metal abundances, and estimates of ejecta mass are vexed by limited and/or uncertain atomic and molecular data that is becoming increasingly acute as spectral resolution and wavelength coverage expands into heretofore new observational phase space. Here we highlight IR observations of select CNe studied with the NASA *Spitzer* telescope and contemporaneously with SWIFT, *Chandra*, and XMM-Newton discussing new paradigms derived from photoionization models and future challenges.

Interpretation of complex atomic spectra with the parametric method and Cowan codes

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Complex spectra of neutral to weakly ionized elements are of a steady interest for the diagnosis of laboratory plasmas (as is W I for operational tokomaks and ITER project) and for elemental abundances in astrophysical plasmas.

As a preliminary step to calculate radiative properties, the Racah-Slater (parametric) method, supported by *ab initio* (Hartree-Fock) determination of radial integrals, needs to be applied to large configurations. Semi-empirical regularities obtained through a systematic comparison of fitted parameters with *ab initio* (HFR) integrals are crucial to get appropriate sets of parameters, generating eigenvalues and Landé factors close to observed values. This helps to initiate the least squares optimisation of parameters even in intricate cases. The suite of codes by R.D. Cowan [1] applies well to all steps of this work. Examples of applications are given for Er II, Nd II, Nd IV, Tm II and some 5d-elements.

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Atomic Alignment- A New Diagnostics of Astrophysical MagneticField

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I would like to present a new technique of studying magnetic fields in interstellar and intergalactic gas/plasma we developed recently [1], [2], [3] [4]. This technique is based on the alignment (in terms of their angular momentum in the ground state) of atoms and ions with fine or hyperfine splitting of the ground state. A unique feature of this technique is that the properties of the polarized radiation (both absorption and emission) depend on the 3D geometry of the magnetic field as well as the direction and anisotropy of incident radiation. I shall outline the prospects of the technique and its possible application to studies magnetic fields within circumstellar regions, interplanetary medium, interstellar medium, intergalactic medium. Both spatial and temporal variations of turbulent magnetic field can be traced with this technique as well. In addition, I shall demonstrate that atomic alignment induced by anisotropic radiation can cause polarization of the radio/far-infrared magnetic dipole transitions within the ground state, thus providing a possible way to study magnetic fields, e.g. at the epoch of Universe reionization.

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