

ASOS 9



7-10 Aug 2007 Lund Sweden

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Program
List of participants



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The 9th International Colloquium on Atomic Spectra and Oscillator Strengths (ASOS) for Astrophysical and Laboratory Plasmas, is jointly organized by the Lund Observatory and Department of Physics at Lund University.

The ASOS 9 organizers gratefully acknowledge the support from:

- Royal Physiographical Society in Lund
- The Royal Swedish Academy of Sciences through its Nobel Institute for Physics
- Wenner-Gren Foundations
- Lund Laser Centre

Program

Tuesday, 7 August

18:00 - 21:00 Early registration and reception (at conference site)

Wednesday, 8 August

8:00 Registration (at conference site)

8:45 Welcome from the SOC and LOC - conference start

Session Wednesday 1: High Resolution Infrared Spectroscopy

Chairperson: Ruth Peterson

9:00 - 9:30 T1: Nils Ryde (Uppsala Observatory)

Near-IR spectroscopy of cool stars

9:30 - 10:00 T2: Hampus Nilsson (Lund Observatory)

Infrared Laboratory Spectroscopy with Astrophysical Applications

10:00 - 10:20 Coffee Break

Session Wednesday 2: Fusion and High Energy Spectroscopy - I

Chairperson: Wolfgang Wiese

10:20 - 10:50 T3: Charles H. Skinner (Princeton Plasma Physics Laboratory)

Atomic Physics in the quest for fusion energy and ITER

10:50 - 11:20 T4: Joseph Reader (NIST)

Spectral data for fusion energy: from W to W

11:20 - 11:40 Coffee Break

Session Wednesday 3: Topics in Astrophysics

Chairperson: Beatriz Barbuy

11:40 - 12:10 T5: Theodore Gull (NASA/GSFC) & Krister Nielsen (CUA and NASA/GSFC)

Eta Carinae: an astrophysical laboratory

12:10 - 12:40 T6: Manuel Bautista (Centro de Fisica-IVIC, Caracas)

Atomic processes in planetary nebulae and H II regions

12:40 - 14:15 Lunch

Session Wednesday 4: Plasma Spectroscopy: Data Needs & Tools

Chairperson: James Lawler

14:15 - 14:45 T7: Walter P. Lapatovich (Osram Sylvania)

Metal Halide Lamp Design: Atomic and Molecular Data Needed

14:45 - 15:15 T8: Lyudmila Mashonkina (Institute for Astronomy of the Russian Academy of Sciences)

Atomic data necessary for non-LTE analysis of stellar spectra

15:15 - 15:45 T9: Yuri Ralchenko (NIST)

Non-LTE spectroscopy for everyone: on-line tools and databases

Session Wednesday 5: Poster Viewing

Chairperson: Henrik Hartman

15:45 - 17:30 Poster session with coffee and refreshments

Bar with light dinner

20:00 Pub Rydberg, Physics Department

Thursday, 9 August

Session Thursday 1: Trapped Ions

Chairperson: Roger Hutton

9:00 - 9:30 T10: Peter Beiersdorfer (Lawrence Livermore National Laboratory)

Atomic spectroscopy with trapped ions

9:30 - 10:00 T11: Luis Gustavo Marcassa (University of Sao Paulo)

Measurement of Rydberg-state lifetimes using cold trapped atoms

10:00 - 10:20 Coffee Break

Session Thursday 2: Techniques of Oscillator Strength Determination

Chairperson: Donald Morton

10:20 - 10:50 T12: Edward B. Jenkins (Princeton University Observatory)

Relative f -values from interstellar absorption lines: advantages and pitfalls

10:50 - 11:20 T13: Richard Holt (University of Western Ontario)

Fast-ion-beam laser-fluorescence measurements of oscillator strengths in the lanthanides

11:20 - 11:40 Coffee Break

Session Thursday 3: The Spectrum of Fe II

Chairperson: David Leckrone

Ulf Litzén will give a short introduction to the work of Sveneric Johansson

11:40 - 12:10 T14: Sveneric Johansson (Lund Observatory)

A half-life with Fe II - tight bonds and loose ends

12:10 - 12:40 T15: Ekaterina Verner (CUA & NASA/GSFC)

Fe II emission spectra in active galactic nuclei: observations and theoretical interpretation

12:40 - 14:15 Lunch

Session Thursday 4: Theory of Oscillator Strengths

Chairperson: Alan Hibbert

14:15 - 14:45 T16: Charlotte Froese Fischer (Vanderbilt University & NIST)

So, how accurate are these theory results?

14:45 - 15:15 T17: Oleg Zatsarinny (Drake University)

Systematic calculations of oscillator strengths for noble gases in B-spline basis

15:15 - 15:45 T18: Martin Andersson (Lund University)

F-dependent lifetimes and intensity redistribution due to off-diagonal hyperfine interaction

15:45 Coffee Break & Poster Viewing

Conference Dinner

Dinner at 19:00 Grand Hotel, Lund. Prior to the dinner, drinks will be served to the music of Oscar Johansson Quartet.

Friday, 10 August

Session Friday 1: Precision Spectroscopy and Fundamental Constants

Chairperson: Sven Mannervik

9:00 - 9:30 T19: Ronald Holzwarth (Max Planck Institute)

One decade of femtosecond frequency combs: principles, applications and new ideas

9:30 - 10:00 T20: Olivier Dulieu (Laboratoire Aime Cotton, CNRS, Campus d'Orsay)

Hot prospects for cold molecules: new routes for high resolution molecular spectroscopy and measurements of fundamental constants

10:00 - 10:20 Coffee Break

Session Friday 2: Fusion and High Energy Spectroscopy - II

Chairperson: Joseph Reader

10:20 - 10:50 T21: Christoph Biedermann (Max-Planck Institute for Plasma Physics)

Spectroscopy of highly-charged tungsten ions relevant to fusion plasmas

10:50 - 11:20 T22: Eric le Bigot (Kastler Brossel Lab., Paris)

Towards high-precision X-ray standard lines (3 keV to 8 keV)

11:20 - 11:40 Coffee Break

Session Friday 3: Instrumentation for Spectroscopy

Chairperson: Steven Federman

11:40 - 12:10 T23: James Lawler (University of Wisconsin)

A broad-band, high resolution spatial heterodyne spectrometer

12:10 - 12:40 T24: Yaming Zou (Fudan University)

Progress at the Shanghai EBIT

12:40 - 14:15 Lunch

Session Friday 4: Spectrum Analysis and Applications

Chairperson: Gillian Nave

14:15 - 14:45 T25: Jorge Reyna Almandos (Centro de Investigaciones Opticas, La Plata)

Spectral analysis of ionized noble gases and implications to astronomy and laser studies

14:45 - 15:15 T26: Florian Kerber (ESO, Garching)

From laboratory to the sky - Th-Ar wavelength standards for CRIRES

15:15 - 15:45 T27: Maria Aldenius (Lund Observatory)

Laboratory wavelengths for cosmological constraints on varying fundamental constants

Session Friday 5: Discussion

15:45 - 16:30 Chairperson: Glenn Wahlgren

16:30 Closing Remarks

Coffee and snacks

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Abstracts for Talks

T1, Wed 9.00-9.30: Near-Infrared Spectroscopy of Cool Stars

Nils Ryde
Uppsala Observatory, Sweden

High-resolution spectroscopy of cool stars in the near-infrared is an emerging field due to the recent developments of near-IR spectrometers for use at large telescopes. I will discuss why we want to study cool stars spectroscopically in the near-IR, and discuss its advantages and drawbacks. I will also touch upon how we analyze astronomical spectra in general, and what is needed for a proper analysis. I will end by showing a few recent examples of work we have been performing with the new European near-IR spectrometer (CRIRES) at the Very Large Telescopes (VLT) in Chile. Partly I will talk about a large program in which we are studying the origin of the pivotal central region of the Milky Way (the Bulge), and partly about our work on the cosmic origin of sulphur.

T2, Wed 9.30-10.00: Infrared Laboratory Spectroscopy with Astrophysical Applications

Hampus Nilsson
Lund Observatory, Lund University, Lund, Sweden

With high spectral resolution instruments on modern telescopes it is today possible to study stellar objects in the infrared (IR) wavelength region. I will discuss the energy level structure of different atoms and ions, and give some example of atomic IR lines that one can expect to see in spectra of stellar objects.

With the new high resolution IR Fourier transform spectrometer at Lund Observatory, we can study atomic spectra from 2000 to 50 000 Å

T3, Wed 10.20-10.50: Atomic Physics in the Quest for Fusion Energy and ITER

Charles H. Skinner
Princeton Plasma Physics Laboratory, Princeton, NJ USA

The urgent quest for new energy sources has led developed countries, representing over half of today's world population, to collaborate on demonstrating the scientific and technological feasibility of magnetic fusion through the construction and operation of ITER. Data on high-Z ions will be important in this quest. Tungsten plasma facing components have the necessary low erosion rates and low tritium retention but the high radiative efficiency of tungsten ions leads to stringent restrictions on the influx and concentration of tungsten ions in the burning plasma. The influx of tungsten to the burning plasma will need to be diagnosed, understood and stringently controlled. Expanded knowledge of the atomic physics of neutral and ionized tungsten will be important to monitor impurity influxes and derive tungsten concentrations. Also, inert gases such as argon and xenon will be used to dissipate the heat flux flowing to the divertor. The talk will describe the spectroscopic diagnostics planned for ITER and outline areas where additional data is needed.

T4, Wed 10.50-11.20: Spectral Data for Fusion Energy: From W to W

Joseph Reader
NIST, Gaithersburg, MD 20899, USA

Because of its ability to withstand high temperatures and its low sputtering rate, tungsten has always been a material of interest for the development of tokamaks. Indeed, the early ST tokamak at Princeton contained a limiter of W. However, at that time it was thought that W would not be useful for more powerful machines

because, due to its high atomic number, it would radiate away too much of the energy. Thus its use was terminated. Nevertheless, interest in the spectral properties of W continued. In 1977 Cowan [1] calculated spectra of W^{37+} - W^{45+} with his semi-relativistic Hartree-Fock code. In this report he stressed the importance of resonance lines in isoelectronic sequences with simple ground configurations for diagnostics of tokamak plasmas. These lines would be few in number and easily detectable. Experimental work on W with spark sources and laser-produced plasmas led to the identification of the $4s\ 1/2$ - $4p\ 3/2$ and other $n=4$ - 4 transitions in Cu-like W^{45+} in 1980 [2]. Of great importance for these identifications were Cowan's predictions and the fully-relativistic Hartree-Fock calculations of Cheng and Kim [3]. Subsequent observations of W spectra improved the accuracy of these early measurements, and they are now known to a few thousandths of an Å [4]. With the advent of ITER, W took on new importance. Based on work at ASDEX Upgrade and JET, it was decided as early as 1991 that if W were used as a limiter or divertor material, its concentration in the hot core could be kept to manageable levels. Now it is planned to have W as the first wall of the divertor of ITER. This talk will trace the progress that has been made on the spectra of W over the years. Experiments with EBITs [4] and tokamaks [5] have become ever more sophisticated as have the related theoretical methods [6]. In particular, collisional-radiative modeling has facilitated line identifications and made it possible to carry out detailed interpretation of the plasmas. Recent results [7,8] for highly ionized W with the NIST EBIT will be described along with a new determination of the ionization energies for all W ions [9].

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[3] K.T. Cheng and Y.-K. Kim, At. Data and Nucl. Data Tables **22**, 547 (1978).

[4] S.B. Utter, P. Beiersdorfer, and E. Träbert, Can. J. Phys. **80**, 1503 (2002).

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[6] K.B. Fournier, At. Data and Nucl. Data Tables **68**, 1 (1998).

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[8] Yu. Ralchenko, J. Reader, J.M. Pomeroy, J.N. Tan, and J.D. Gillaspay, to be submitted to J. Phys. B.

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T5, Wed 11.40-12.10: Eta Carinae: an astrophysical laboratory

Theodore R. Gull and Krister Nielsen

Code 667, Goddard Space Flight Center, Greenbelt, MD 20771

Eta Carinae (η Car) provides a unique opportunity to investigate a massive star in a late evolutionary phase and how CNO processed material is ejected into the ISM. Investigation of the material surrounding η Car is reported to show similar characteristics as Gamma Ray Burst progenitors. Consequently, the η Car spectrum may provide clues about the nature of other extreme objects such as hypernovae and supernova impostors. In the 1840s, η Car underwent a massive ejection, repeated to a lesser extent in the 1890s. Today we see the Homunculus, a bipolar expanding neutral structure, and the Little Homunculus, an interior, spectroscopically time-variable, ionized structure. In line-of-sight, multiple narrow lines are observed, formed in environments with densities around 10^7 cm^{-3} and temperatures ranging from 100–7000 K. Thousands of neutral/singly ionized metal lines are identified, in addition to molecular transitions in species such as H_2 , CH, OH, NH. The system is ideal as a laboratory for absorption and emission line spectroscopy.

The input from the laboratory spectroscopy community has repeatedly helped the analysis of η Car. Future observations of η Car in the infrared through radio wavelength region with *Herschel*, *SOFIA* and *ALMA* will reveal new atomic and molecular transitions, most notably of hydrides and nitrides. We will demonstrate how experimentally derived atomic data have improved our spectral analysis, and illuminate where future work is needed.

T6, Wed 12.10-12.40: Atomic processes in Planetary Nebulae and HII Regions

Manuel Bautista
IVIC, Venezuela

Historically, Planetary Nebulae and HII regions research has been a ground for much development in atomic physics. In the last few years the combination of a generation of powerful observatories, the development of ever more sophisticated spectral modeling codes, and important efforts on mass production of high quality atomic data have led to important progress in our understanding of the astronomic atomic spectra. In this paper I review such progress, including identification of heavy species (beyond the iron peak elements), observations of hyperfine emission lines and analysis of isotopic abundances, fluorescent processes, and new techniques for diagnosing physical conditions based on recombination spectra. Also, I discuss the new trends on the research of atomic processes in PNe and HII regions and the current needs for atomic data.

T7, Wed 14.15-14.45: Metal Halide Lamp Design: Atomic and Molecular Data Needed

W. P. Lapatovich
OSRAM SYLVANIA, Beverly, MA 01915, USA

Metal-halide lamps are a subset of high intensity discharge (HID) lamps so named because of their high radiance. These lamps are low temperature ($\approx 0.5\text{eV}$), weakly ionized plasmas sustained in refractory but light transmissive envelopes by the passage of electric current through atomic and molecular vapors [1]. For commercial applications, the conversion of electric power to light must occur with good efficiency and with sufficient spectral content throughout the visible (380-780nm) to permit the light so generated to render colors comparable to natural sunlight. This is achieved by adding multiple metals to a basic mercury discharge. Because the vapor pressure of most metals is very much lower than mercury itself, metal-halide salts of the desired metals, and having higher vapor pressures, are used to introduce the material into the basic discharge [2]. The metal compounds are usually polyatomic iodides which vaporize and subsequently dissociate as they diffuse into the bulk plasma. Metals with multiple visible transitions are necessary to achieve high photometric efficiency (efficacy) and good color. Compounds of Sc, Dy, Ho, Tm, Ce, Pr, Yb and Nd are commonly used [3, 4]. The electrons, atoms and radicals are in equilibrium, under the approximation of local thermodynamic equilibrium (LTE), but not with the radiation field. Strong thermal (10^6K/m) and density gradients are sustained in the discharge. Atomic radiation produced in the high temperature core transits through colder gas regions where it interacts with cold atoms and undissociated molecules before exiting the lamp. Power balance and spectral output of the lamp are directly affected by the strength of atomic transitions. Attempts to simulate the radiative output of functional metal halide lamps have been successful only in very simple cases [5, 6]. More data (e.g. Ce I A_{ij} 's) [7] are necessary to improve lamp performance, to select appropriate radiators and in scaling the lamp geometry to various wattages for specific applications.

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[3] J. Geijtenbeek, et. al., *Intl. Patent Application WO 2005/088675 A1* (2005).

[4] H. Nohara, A. Utsubo, Y. Kanazawa, N. Nishiura and S. Ukegawa, Paper LL03, Proc. 11th Int. Conf. On Sci. and Tech. Of Light Sources, May 20-24th, Shanghai, China (2007)

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T8, Wed 14.45-15.15: Atomic data necessary for non-LTE analysis of stellar spectra

Lyudmila Mashonkina

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Analysis of stellar spectra based on non-local thermodynamic equilibrium (non-LTE) line formation has an advantage in deriving accurate stellar parameters and chemical abundances compared to the simple approach of using the Boltzmann-Saha equations for calculation of atomic level populations. A bulk of atomic data on energy levels, photoionization cross-sections, transition probabilities, collision ionization and excitation cross-sections is required to compute the statistical equilibrium (SE) of a given atom for specific physical conditions. A fairly extensive set of accurate data on photoionization cross-sections and oscillator strengths was recently calculated in the Opacity Project (OP). However, not all astrophysically important elements are covered by OP. For example, heavy elements beyond the iron group observed in AGB stars, Ap stars, and very metal-poor stars play a key role in studies of nucleosynthesis processes and understanding of the origin of chemical peculiarities. Rough theoretical approximations and hydrogenic formula, in most cases, are still used to compute photoionization cross-sections for these atoms. Accurate electron impact excitation and ionization cross-sections are available only for a few atoms and, in each atom, mainly for the transitions between low excitation terms. In most cases, approximate formulae are applied giving threshold values accurate to a factor of 2-3 at best. The question debated for decades is the role of inelastic collisions with hydrogen atoms in SE of atoms in cool stars. Only a few experimental and theoretical studies concern with this problem. Therefore the empirical approach based on analysis of the Sun's and reference star's spectra is widely used to constrain the efficiency of hydrogenic collisions. Based on test non-LTE calculations for Ca I/II, Nd II/III, and other atoms, we show here an importance of accurate photoionization cross-sections and collisional cross-sections for a determination of stellar parameters and chemical abundances.

T9, Wed 15.15-15.45: Non-LTE Spectroscopy for Everyone: On-Line Tools and Databases

Yuri Ralchenko

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Since most of laboratory and astrophysical plasmas are far from the local thermodynamic equilibrium (LTE), development of methods and tools for modeling of non-LTE plasmas remains an important and challenging task. This challenge is exacerbated by the fact that NLTE simulations generally require large sets of atomic data which are unavailable in the existing literature. In addition, there is no "hydrogen atom" problem for NLTE modeling that can serve as an exactly solvable benchmark case to test various models. I will describe the online NLTE databases and tools that are currently available at the National Institute of Standards and Technology (NIST). The recently developed SAHA and NLTE-4 databases contain benchmark results produced by the participants of the NLTE Code Comparison Workshops. The available data, which include mean ion charge, ionization distributions, effective ionization and radiative rates, and other numerous parameters, can serve as a testbed for plasma population kinetics codes. We developed an advanced data retrieval and visualization system that allows straightforward comparisons of results. In collaboration with the Lawrence Livermore National Laboratory (LLNL), an online version of the collisional-radiative code FLYCHK capable of performing collisional-radiative simulations for any element up to gold ($Z=79$) was created on the NIST website. The capabilities of FLYCHK will be discussed and examples of online calculations will be presented.

Supported in part by the US DOE Office of Fusion Energy Sciences.

T10, Thu 9.00-9.30: Atomic spectroscopy with trapped ions

Peter Beiersdorfer

Lawrence Livermore National Laboratory

Spectroscopy with electron beam ion traps has historically focused on the x-ray emission from highly charged ions interacting with the electron beam. But the operating modes of such devices have expanded to study radiation in almost all wavelength bands from the visible to the hard x-ray region; and in many cases the ions can be studied even in the absence of an electron beam. Photon emission by charge exchange or by laser excitation has been observed, and the work is no longer restricted to highly charged ions, but now includes any charge state including neutral atoms and molecules.

Here we give an overview of atomic spectroscopy performed on electron beam ion traps at various locations throughout the world for basic atomic physics, astrophysics, lithography, and studies of diagnostic lines in fusion plasmas. The focus of this work includes spectral surveys, radiative lifetime measurements, radiative power measurements, isotope effects, and tests of collisional-radiative models.

This work was performed by the University of California Lawrence Livermore National Laboratory under the auspices of the Department of Energy under contract W-7405-ENG-48 and supported in part by NASA's Astronomy and Physics Research and Analysis program.

T11, Thu 9.30-10.00: Measurement of Rydberg-state lifetimes using cold trapped atoms

L.G. Marcassa

Instituto de Física de São Carlos, Universidade de São Paulo

Accurate measurements of the lifetime of Rydberg states can provide powerful tests for theoretical calculations of dipole matrix elements, oscillator strengths, core polarizabilities, and influence of blackbody radiation on radiative lifetimes. Alkali atoms have been used both theoretically and experimentally as prototypes for the study of these problems. Although the alkali atoms are among the easiest to treat theoretically, the available predictions for the Rydberg state lifetimes present variations from 5% to 15%. The error bars of the experimental results are even worse, for $n > 15$ they can be larger than 25%. This large uncertainty comes mainly from the fact that most of the work done in this field have used conventional techniques to measure lifetimes, relying on the observation of atomic fluorescence decay of thermal atoms either in cells or in atomic beams. For levels which $n > 20$, superradiance occurs rapidly, making it impossible to perform a fair lifetime measurement. Another important effect present in these experiments is the blackbody radiation, which can appreciably alter the observed decay rates. At room temperature, the blackbody radiation can decrease the lifetime for as much as 40%. W. Spencer and co-workers (Phys. Rev. A 24, 2513 (1981)) were the first to eliminate this influence measuring the lifetime of sodium Rydberg states using an atomic sodium beam and a liquid helium cooled environment. They were able to measure lifetimes smaller than $25 \mu\text{s}$ at a temperature of 30K. However after this pioneer work, no more studies have been done in order to either eliminate or decrease the effect of collisions and superradiance on lifetime measurements using thermal atoms. Recently, we had demonstrated the possibility to obtain a high precision measurement of the lifetime of the Rb 27D Rydberg state by using pulsed field ionization on a sample of cold trapped atoms. In this work, we measured the lifetime of S, P and D states of Rb as a function of principal quantum number (n) using a sample of cold atoms. Due to the ultralow velocities of the atoms and the low collision rate, we were able to measure for the first time longer lifetimes ($> 100 \mu\text{sec}$). This talk will focus on the description of the experimental setup, followed by the results and the discussion, in which we present a comparison of our measurement with existing theory.

T12, Thu 10.20-10.50: Relative f-values from Interstellar Absorption Lines: Advantages and Pitfalls

Edward B. Jenkins

Princeton University Observatory, Princeton, NJ, USA

Interstellar absorption features seen in the UV and visible spectra of stars provide opportunities for comparing the strengths of different transitions out of the ground electronic states of atoms, ions, and simple molecules. In principle, such measurements are straightforward since the radiative transfer is manifested as a simple exponential absorption law at any given radial velocity. Complications arise when the velocity structures of the lines are not completely resolved, or when the lines are either very strongly saturated or too weak to observe. Dynamic range limitations can compromise the comparisons of two transitions that have very different absorption f-values, but they can be mitigated if there are examples with very different column densities and transitions of intermediate strength that can help to bridge the large gap in line strengths. Attempts to unravel the effects of saturation include the use of a curve of growth when only equivalent widths are available, or the measurements of the "apparent optical depth" when the line is mostly resolved by the instrument. Unfortunately, the application of the curve of growth for one constituent to that of another can sometimes create systematic errors, since the two may have different velocity structures. Likewise, unresolved fine velocity structures in features that have large optical depths can make the apparent optical depths misrepresent the smoothed versions of the true optical depths. One method to compare the strength of a very weak line to that of a very strong one is to measure the total absorption of the former and compare it with strength of the damping wings of the latter. However in many circumstances, small amounts of gas at velocities well displaced from the line center can masquerade as damping wings. For this reason, it is important to check that these wings have the proper shape.

T13, Thu 10.50-11.20: Fast-ion-beam laser-fluorescence measurements of oscillator strengths in the lanthanides

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Abundance measurements of the lanthanides are vital to nucleosynthesis studies, provide indirect information about stellar interiors, and serve as a reference in thorium cosmochronology. The many stable isotopes for each atomic number are an ideal "laboratory" for the study of the r-, s-, and p-processes because of the great variation of pathways by which they can be produced in neutron capture. As well, they can be overabundant by three orders of magnitude in CP photospheres. We have an established program of providing atomic data on lifetimes, branching fractions, oscillator strengths, as well as hyperfine structures and isotope shifts (which are needed to correct for desaturation). Our technique for oscillator-strength determinations makes use of the highly reliable approach of combining the data from separate lifetime and branching fraction measurements. In contrast to other research groups, we use a fast-ion-beam laser-fluorescence method for each. We have shown that this enables us to detect and correct errors in the literature that arise from misclassification of atomic transitions as well as those arising from spectral blends. [S. J. Rehse *et al.*, *Can. J. Phys.* **84**, 723 (2006)]. The extreme selectivity of laser excitation of a kinematically-compressed fast ion beam provides a unique identification of the upper level of each transition, sometimes down to an individual hyperfine level. I will present recent results in Pr II, in which we have measured 260 oscillator strengths for transitions over the wavelength range 250-850 nm, originating from 32 upper levels in the range 21 500 cm⁻¹ to 29 000 cm⁻¹. Of these transitions, 190 values have been derived for the first time using this modern method. The

uncertainties arose principally from systematics of the efficiency calibration of the optical detection system (7.1%), with smaller statistical contributions (1.5%). I will then discuss recent improvements to the technique, including the installation of a new ion source that allows highly refractory elements to be studied in various ionization states, plus the introduction of a completely new detector-efficiency calibration method. Finally, the latest results in Nd III will be discussed.

T14, Thu 11.40-12.10: A half-life with Fe II - tight bonds and loose ends

Sveneric Johansson

Lund Observatory, Lund University, Lund, Sweden

Even though the laboratory spectrum of singly ionized iron has been thoroughly studied over the last 30 years, with more than 1000 energy levels known, we could still expect that many unidentified stellar lines belong to Fe II. This statement is especially valid for the ultraviolet region, but we show that it is also true for the optical wavelength region.

In this review we show that the singly-excited system ($3d^6nl$) is quite well established, whereas the doubly-excited system ($3d^5snl$) is still poorly known. An extension of our knowledge of this energy level system requires high-resolution spectra in the vacuum-ultraviolet region, especially at 1000-1500 Å. We know that stellar HST spectra are not well analyzed in this wavelength region.

We will discuss particular transitions showing a strange behaviour in stellar emission line spectra - lines that are much stronger or much weaker than expected. Many lines are enhanced due to resonant photo-excitation by e.g. hydrogen, and some lines are enhanced due to stimulated emission.

We will give the first(?) example of how stellar spectra are used for extending the energy level system of an atom/ion). The atmosphere of the iron-rich star HR6000 is an ideal source for absorption spectroscopy of Fe II, and new levels have been established above the ionization limit from stellar lines not seen in the laboratory spectrum.

T15, Thu 12.10-12.40: Fe II Emission Spectra in Active Galactic Nuclei: Observations and Theoretical Interpretation

Katya Verner

Catholic University of America

The enrichment of Fe, relative to alpha-elements such as O and Mg, represents a potential means to measure the ages of QSOs and to probe nucleosynthesis in the galaxy formation epoch. QSOs exhibit prominent Fe II features and Mg II 2800Å resonance doublet emission in the UV. Although the Fe/Mg ratio in chemical evolutionary models are expected to decrease with redshift, measurements of Fe II(UV)/Mg II emission ratios show a large scatter from 1 to 20, with no redshift dependency up to $z \sim 6.4$. Before using Fe II emission as an abundance indicator, one must ascertain how Fe II emission varies with physical conditions. We have constructed an 830-level model atom for Fe II and used it in photoionization code to calculate Fe II emission. This model is more sophisticated than previous efforts: it uses the most recent laboratory atomic data and includes the numerous transitions that are sensitive to the strong radiation field in QSOs. Predicted Fe II(UV)/Mg II ratios and fluxes strongly depend on the non-abundance factors such as microturbulence, ionizing flux, and hydrogen density; all of them must be taken into account before any accurate abundance can be derived. The individual effects can be disentangled through multi-bandpass measurements of the Fe II emission spectrum. Specifically the Fe II(Optical) band is more sensitive to change in abundance, while the Fe II(UV) band is more sensitive to variations in microturbulence. Our calculations clearly demonstrate that Fe II is the dominant coolant at densities found in AGN Broad Line Regions. This is why, in spite of its complexity, analysis of the Fe II spectra must be included in photoionization modeling of AGN spectra. In our presentation here we use narrow Seyfert galaxy, I Zw 1 as a testbed for Fe II studies in the UV and

demonstrate how we applied our Fe II model to derive physical conditions for this object. Our close collaboration with spectroscopists, especially Prof. Johansson (Sweden) and his group (Lund Univ.), is beneficiary for further developments of our Fe II model, including new atomic data and transitions linking high energy levels in Fe II. In addition, such collaboration must improve our understanding of the AGN continua by accounting for the effects of the Fe II pseudo-continuum, which appears to blanket quasar spectra from 1000 to 10,000Å. The predicted Fe II emission spectra, suitable for BLRs in AGN, are available for public use at <http://iacs.cua.edu/people/verner/FeII>. We wish to acknowledge the support of the National Science Foundation through grant AST-0607465.

T16, Thu 14.15-14.45: So, how accurate are these theory results?

C. Froese Fischer

Vanderbilt University, Nashville, TN 37235, USA and National Institute of Standards, Gaithersburg, MD 20899-8422 USA

Comparison of theory with experiment for a few selected lines is a frequently used method for assessing the accuracy of transition data. But as computers become faster and large amounts of data are obtained through computation, independent methods are needed for theory. In this talk, the underlying principles related to accuracy and the effect of cancellation will be reviewed. For *ab initio* fine-structure results that include relativistic effects either in the Breit-Pauli (BP) or multiconfiguration Dirac-Hartree-Fock (MCDHF) theory, two indicators of accuracy are proposed, namely the accuracy of the transition energy and the agreement in length and velocity gauge of the line strength. With a database capable of comparing transition energies with those from the NIST Atomic Spectra Database, it will be shown that the more accurate of two sets of results can generally be identified by these indicators. The role of "fine-tuning", both as a means of improving and estimating accuracy, will be discussed as well as the discrepancy in length and velocity gauges for intercombination lines in the BP and MCDHF approximation. The usefulness of the Landé g_J factor for comparing theories will be illustrated.

T17, Thu 14.45-15.15: Systematic calculations of oscillator strengths for noble gases in B-spline basis.

Oleg Zatsarinny

Drake university, Des Moines, USA

The B-spline box-based close-coupling method [1,2,3] was applied for extensive calculations of the transition probabilities in the noble gases Ne, Ar, Kr and Xe for energy levels up to $n = 12$. Individually optimized, term-dependent sets of non-orthogonal one-electron radial functions were used to account for the strong term dependence in the valence orbitals. The core-valence correlation was introduced through multi-channel expansions, which include the ns^2np^5 , $nsnp^6$ and $ns^2np^4(n+1)l$ target states. The inner-core correlation was accounted for by employing multi-configuration target states. Energy levels and oscillator strengths for transitions from the np^6 ground-state configuration as well as transitions between excited states were computed in the Breit-Pauli approximation. The core-valence correlation was found to be very important for most of the transitions considered, whereas the inner-core correlation mainly affects the transitions from the ground states in Ar and Kr.

The present calculations provide the most systematic *ab initio* radiative data for noble gases: they include the lifetimes and oscillator strengths for 299 states and 11300 transitions in Ne, 359 states and 19000 transitions in Ar, 212 states and 6450 transitions in Kr, and 125 states and 2550 transitions in Xe. We obtained excellent agreement with existing experimental data in the case of Ne and overall very good agreement for Ar and Kr, except a few transitions to the closely spaced high-lying $(n+1)s/nd$ states. The overall good

agreement with other available calculations was obtained for transition from the ground states, whereas there is big discrepancies for transitions between excited states. In Xe, very close agreement with experiment was obtained for excitation of the lowest $6s$ and $6s'$ states. However, noticeable discrepancies for excitation of the nd states indicate the limitation of the Breit-Pauli approximation in this case.

Our results show that the B-spline method with non-orthogonal orbitals can be used for accurate calculations of oscillator strengths for states with intermediate n -values, i.e. exactly the region where it is difficult to apply standard MCHF methods.

We also present recent results for Xe, obtained with newly developed extension of the BSR complex [3] to the Dirac-Fock Hamiltonian. This extension considerably improves the accuracy of oscillator strength for transitions from the ground states.

[1] O. Zatsarinny and C. Froese Fischer, J. Phys. B **35**, 4669 (2002).

[2] O. Zatsarinny and K. Bartschat, J. Phys. B **39**, 2145 (2006).

[3] O. Zatsarinny, Comp.Phys.Comm. **174**, 273 (2006).

T18, Thu 15.15-15.45: F-dependent lifetimes and intensity redistribution due to off-diagonal hyperfine interaction

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Theoretical investigations of F -dependent lifetimes due to off-diagonal hyperfine interaction, and in particular the hyperfine levels of $3d^9 4s \ ^3D_3$ in Ni-like ions and $4s 4p \ ^3P_2$ in Zn-like ions are reported. A theoretical investigation of intensity redistribution among the hyperfine transitions $4s 4d \ ^3D_2 - 4s 4f \ ^3F_{2,3}$ in Ga II is also reported.

In Ni-like ions the $3s^9 4s \ ^3D_3$ level is the first excited state and it can only decay to the ground state through a magnetic octupole (M3) transition, but in the presence of a nuclear spin an electric quadrupole (E2) transition is induced by the hyperfine interaction with $3d^9 4s \ ^3D_2$ and the lifetime of the state becomes isotope and F dependent.

Extensive Multiconfiguration Dirac-Fock calculations were performed to calculate the $3d^{10} \ ^1S_0 - 3d^9 4s \ ^3D_3$ M3 transition element, the $3d^{10} \ ^1S_0 - 3d^9 4s \ ^3D_2$ E2 transition element and the hyperfine interaction matrix elements between 3D_3 and 3D_2 . First order perturbation calculation were used to calculate the hyperfine induced E2 transition element and the F -dependent lifetimes. [1] used a single exponential fit to experimentally determine the lifetime of the $3d^9 4s \ ^3D_3$ state in Ni-like Xe. It is shown that a single exponential could be fitted to a theoretical decay curve, where each lifetime was weighted according to a gas of natural mixing of isotopes, with good accuracy. Depending on which interval the single exponential was fitted to, different lifetimes was obtained.

The finestructure of $4s 4f \ ^3F$ in Ga II is small and the open $4s$ -shell makes the hyperfine interaction strong resulting in significant hyperfine mixings between the hyperfine levels of $4s 4f \ ^3F$. [2] investigated the hyperfine structure of 18 lines in Ga II. For 12 of the lines the observed pattern could be analyzed but the $4s 4d - 4s 4f$ transitions could not be explained.

Extensive Multiconfiguration Dirac-Fock calculations were performed to calculate the $4s 4d - 4s 4f$ transition elements and the hyperfine interaction matrix elements. Two different calculations, taking the hyperfine interaction into consideration were performed, the *diagonal* calculation where only the diagonal matrix elements were included (corresponds to the assumptions made by [2]) and the *complete* calculation where the hyperfine interactions between the $4s 4f$ hyperfine levels and the $4s 4d$ hyperfine levels were included as CI-calculations. It is shown that the *diagonal* calculation could not reproduce the experimental spectra whereas the *complete* calculation was in excellent agreement.

[1] E. Träbert, P. Beiersdorfer, G.V. Brown, K. Boyce, R.L. Kelley, C.A. Kilbourne, F.S. Porter and A. Szymkowiak, Phys. Rev. A **73**, 022508 (2006)

[2] H. Karlsson and U. Litzén, J. Phys. B. **33**, 2929 (2000)

T19, Fri 9.00-9.30: One decade of femtosecond frequency combs: principles, applications and new ideas

Ronald Holzwarth

Max-Planck-Institute for Quantum Optics and MenloSystems GmbH

T20, Fri 9.30-10.00: Hot prospects for cold molecules: new routes for high resolution molecular spectroscopy and measurements of fundamental constants

Olivier Dulieu

Laboratoire Aime Cotton, CNRS, Campus d'Orsay

The formation of ultracold molecules (ie with a translational energy equivalent to a temperature well below one millikelvin) generally results from the association of a pair of ultracold atoms using tunable laser light (photoassociation) or tunable magnetic fields (Feshbach association). In many cases such molecules are bound through induced dipole-dipole or polarisation interaction, and behave more like a pair of interacting atoms, than like a chemical bond. In other words, their binding energy is in most cases very small, corresponding to molecular levels close to the dissociation limit. In this talk, I will review the so-called "photoassociation" and "Feshbach" spectroscopy of such molecular levels, which provided measurements of atomic properties like long-range interaction, radiative lifetimes, and scattering lengths, with unprecedented accuracy. I will also discuss the current ideas for using strongly-bound cold molecules to determine fundamental constants like the electric dipole moment of the electron, or the time variation of the electron-to-proton mass ratio.

T21, Fri 10.20-10.50: Spectroscopy of highly-charged tungsten ions relevant to fusion plasmas

Christoph Biedermann

Lehrstuhl für Plasmaphysik am Institut für Physik der Humboldt-Universität zu Berlin and Max-Planck-Institut für Plasmaphysik, EURATOM Association

The Berlin EBIT has been established by the Max-Planck-Institut für Plasmaphysik to generate atomic physics data in support of research in the field of controlled nuclear fusion, by measuring the radiation from highly charged ions in the x-ray, extreme ultraviolet and visible spectral ranges and providing valuable diagnostics for high temperature plasmas. In future fusion devices, for example ITER, currently being constructed at Cadarache, France, the plasma facing components will be armored with high-Z materials, most likely tungsten, due to the favorable properties of this element. At the same time the tremendous radiation cooling of these high-Z materials impose a thread to fusion and oblique to carefully monitor the radiation. With EBIT a selected ensemble of ions in specific charge states can be produced, stored and excited for spectroscopic investigations. Employing this technique, we have for example resolved the wide structure observed around 5 nm at the ASDEX Upgrade tokamak as originating from E1-transitions into the open 4d shell of tungsten ions in charge states 25+ to 37+ producing a band-like emission pattern. Further these ions emit well separated M1 lines in the EUV range around 65nm suitable for plasma diagnostics. Kr-like to Cr-like tungsten ions (38+ to 50+) show strong soft-x-ray lines in the range 0.5 to 2 and 5 to 15 nm. Lines of even higher charged tungsten ions, up to Ne-like W(64+), abundant in the core plasma of present and future fusion test devices, have been investigated with high resolution Bragg-crystal spectroscopy at 0.13 nm.

T22, Fri 10.50-11.20: Towards high-precision X-ray standard lines (3 keV to 8 keV)

Eric le Bigot
Kastler Brossel Lab., Paris

The project that will be presented consists in identifying and measuring narrow X-ray lines in the 2.8 keV to 8 keV region. These lines can then be used as calibration lines for other measurements. Their energy can also fruitfully be compared to ab initio calculations.

Recent measurements of X-ray lines from highly-charged ions will thus be presented. The studied lines lie in the 3 keV region, and are produced by highly-charged ions (typically 1- to 4-electron sulfur, chlorine and argon). The ions were produced by an Electron-Cyclotron Resonance (ECR) Ion Trap at the Paul Scherrer Institute, Switzerland. Our goal is to reach the 3 ppm precision level.

Progress on the high-precision absolute spectrometer being built for the Paris ECR highly-charged ion source SIMPA will be reported.

T23, Fri 11.40-12.10: A Broad Band, High Resolution Spatial Heterodyne Spectrometer

J. E. Lawler¹, J. Harlander², F. L. Roesler¹, and Z. Labby¹

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Fourier Transform Spectrometers (FTS's) have well known advantages. Such instruments are important to Laboratory Astrophysics programs including the Univ. of Wisconsin effort on atomic transition probabilities. We are building a Spatial Heterodyne Spectrometer (SHS) to meet the needs of Laboratory Astrophysics in the VUV. The availability of large format, 2 dimensional detector arrays makes it possible to build high performance SHS's. In contrast to a traditional FTS where at least one mirror is moved to record an interferogram as a function of mirror position (or time) using a single channel detector, the SHS interferogram is spread out in space and is projected onto a detector array. The lack of moving parts in SHS instruments simplifies their design and construction and makes these instruments compatible with transient, low duty cycle sources. Furthermore, a SHS is somewhat more tolerant of optical imperfection and misalignment than a traditional FTS based on a Michelson interferometer. These advantages, and the prospects of building a broadband, very high resolution, all reflection SHS for the VUV motivated us. This paper is a progress report on our project. Our Mark 1 SHS is built around a CaF₂ beamsplitter, a matched pair of very coarse (23.2 groove/mm, 63 degree blaze) echelle diffraction gratings, and a Princeton Instruments 'Pixus' 2K by 2K VUV CCD camera. This instrument has VUV capability, but it is limited to wavelengths above the CaF₂ transmission cutoff. Order separation, scattered light, phase stability issues, and aberrations in broadband, high resolution SHS instruments are being addressed using our Mark 1 SHS. The echelle gratings of our Mark 1 instrument have ruled areas of 46 mm x 96 mm. This size grating yields a theoretical limit of resolution of 0.029 cm⁻¹ (the inverse of the maximum path difference of 4 x 9.6 cm x sin 63.5°) with a symmetric interferogram, but our 4 Mega pixel CCD supports a theoretical resolving power of 1,000,000. Test results on the Mark 1 SHS using a low pressure mercury discharge lamp to simultaneously record a broad band spectra between 1100 nm and 250 nm at a theoretical resolution of approximately 0.063 cm⁻¹ (the resolution is determined by the size of the gratings imaged on the CCD) indicate that the SHS is operating close to design goals with coverage exceeding a factor 4 in wavenumber. Full factor of 7 wavenumber coverage is anticipated once the system is in a vacuum tank. Temperature compensated mounts and a custom all-Invar breadboard have yielded very good (2 hour) phase stability in open lab air. Even better stability will be achieved in vacuum. Our Mark 2 SHS will be an all reflection SHS instrument that is not limited in wavelength range by the transmission cut off of refractive materials in the VUV. This instrument will use a diffraction grating as a beam splitter, combiner and dispersive element in a robust common path configuration that is extremely stable [1]. To meet

our requirements of high resolution with broad spectral coverage in the VUV a special coarse symmetrically blazed diffraction grating is needed. This will require a new master ruling, but Zeiss Optronics GmbH has a R&D plan for this grating.

Supported by NASA Grant NNG05GD48G.

[1] Harlander, J. & Roesler, F. L. 1990, in *Instrumentation in Astronomy VIII*, ed. D. L. Crawford (Proc. SPIE, 1235), 622.

T24, Fri 12.10-12.40: Progress at the Shanghai EBIT

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Electron Beam Ion Traps (EBIT), initially developed at LLNL, are sophisticated devices capable of acting both as highly charged ion (HCI) light sources and ion sources. As a HCI light source, they can basically provide light from emission states of any charge state of any element in the periodic table, hence almost unique for spectroscopic research. Furthermore, the emitting ions are almost at rest compared to those produced by heavy ion accelerators or storage rings, and hence much less bothered with Doppler shifts and line broadening. Because of the flexibility of EBITs in producing various ions, it is very good for studies along iso-electronic sequences, and along iso-nuclear charge sequences to reveal physical properties behind experimental phenomenon. To promote HCI relevant physics studies in China, the Shanghai Electron Beam Ion Trap, S-EBIT, project was launched in January of 2002, under a collaboration between Fudan University and the Shanghai Institute of Applied Physics. The design parameters of the S-EBIT put it well into the class of so-called super-EBITs, i.e. electron beam energies up to 200 keV at a current of 200-250 milliamps, compressed to a current density of around 5000 Å/cm² by a magnetic field up to 5 Tesla. The installation of the S-EBIT was completed by the end of 2004. Presently the S-EBIT can be operated at electron beam energies spanning from 0.9 keV to 130 keV. The electron current depends on the beam energy, however at 130 keV the current has reached 160 milliamps. A metal vapour vacuum ion source, MEVVA, and a gas injection system have been installed for metal and gas element (also gas compound) injection. To make the S-EBIT even more versatile in its ability to provide a variety of HCIs, a laser ion source and an atomic oven are under development. For spectroscopic studies of HCIs, we have set up three spectrometers covering the wavelength region of around 1 Å to above 10000 Å: a 1-meter normal incidence grating (McPherson 225) spectrometer for the wavelength region of 300 - 10000 Å, a flat-field grazing incidence grating spectrometer (home made) for the wavelength region of 30-300 Å, and a flat crystal spectrometer (home made) for 1-30 Å. A high purity Germanium detector is always attached to the S-EBIT for X-rays measurements and monitoring. Some preliminary experiments were done to test the S-EBIT and the diagnostic equipment. At the same time, a program was developed to simulate the time evolution of ion charge state distribution and ion temperature in the trap region of an EBIT, for guiding the future operation of the S-EBIT.

T25: Spectral Analysis of Ionized Noble Gases and Implications to Astronomy and Laser Studies

Jorge Reyna Almandos

Centro de Investigaciones Opticas, C. C. 124, (1900) La Plata, Argentina

Studies of emission spectra of noble gas ions have been carried out in La Plata for more than thirtyfive years, several of them in collaboration with other groups. Knowledge of the wavelengths, intensities and shapes of the lines of different species of neon, argon, krypton and xenon in intermediate and high degrees of ionization is important not only to study plasma conditions, but also to help in the understanding of laser emission mechanisms.

With the purpose of continuing this line of work we present an overview of some studies concerning the spectral analysis of several ions of noble gases with implications to astronomy and laser studies. The spectra were recorded in the V.U.V., UV, VIS, and IR regions, using pulsed discharges. In some cases temporal resolution was used. Earlier analysis for these ions were revised and extended. New energy levels, classified lines and oscillator strengths were established. The results of these analysis were supported by using relativistic Hartree-Fock calculations.

T26: From laboratory to the sky - Th-Ar wavelength standards for CRIRES

Florian Kerber

ESO

The Cryogenic High-Resolution IR Echelle Spectrograph (CRIRES) at the Very Large Telescope (La Silla Paranal Observatory, Chile) offers a resolving power of up to 100,000 and covers the wavelength range 950 nm to 5000 nm. In an effort to provide high quality wavelength calibration to this instrument the European Southern Observatory (ESO) is collaborating with the Atomic Spectroscopy Group at the US National Institute of Standards and Technology (NIST). Through laboratory measurements at NIST we have established more than 2500 lines as wavelength standards in the spectrum of a commercial low current Th-Ar hollow cathode lamp. The resulting line list is being used to drive the wavelength calibration of the science data reduction pipeline by means of a physical model description of the instrument. The instruments, its calibration unit and the pipeline are operational and scientific observations started in April 2007. ESO and NIST will make the Th-Ar wavelength standards available to the community in a form compliant with the standards of the Virtual Observatory providing easy access to all relevant data including meta-data describing the laboratory measurements. With this development wavelength calibration in the near IR will become very similar to the UV-visible region, and it will become possible to support high accuracy absolute wavelength calibration without having to rely on atmospheric features. I will briefly highlight the need for further such work in support of the instruments and the quantitative science envisaged for the European Extremely Large Telescope which is going to be most powerful in the near-IR range thanks to its adaptive optics capabilities.

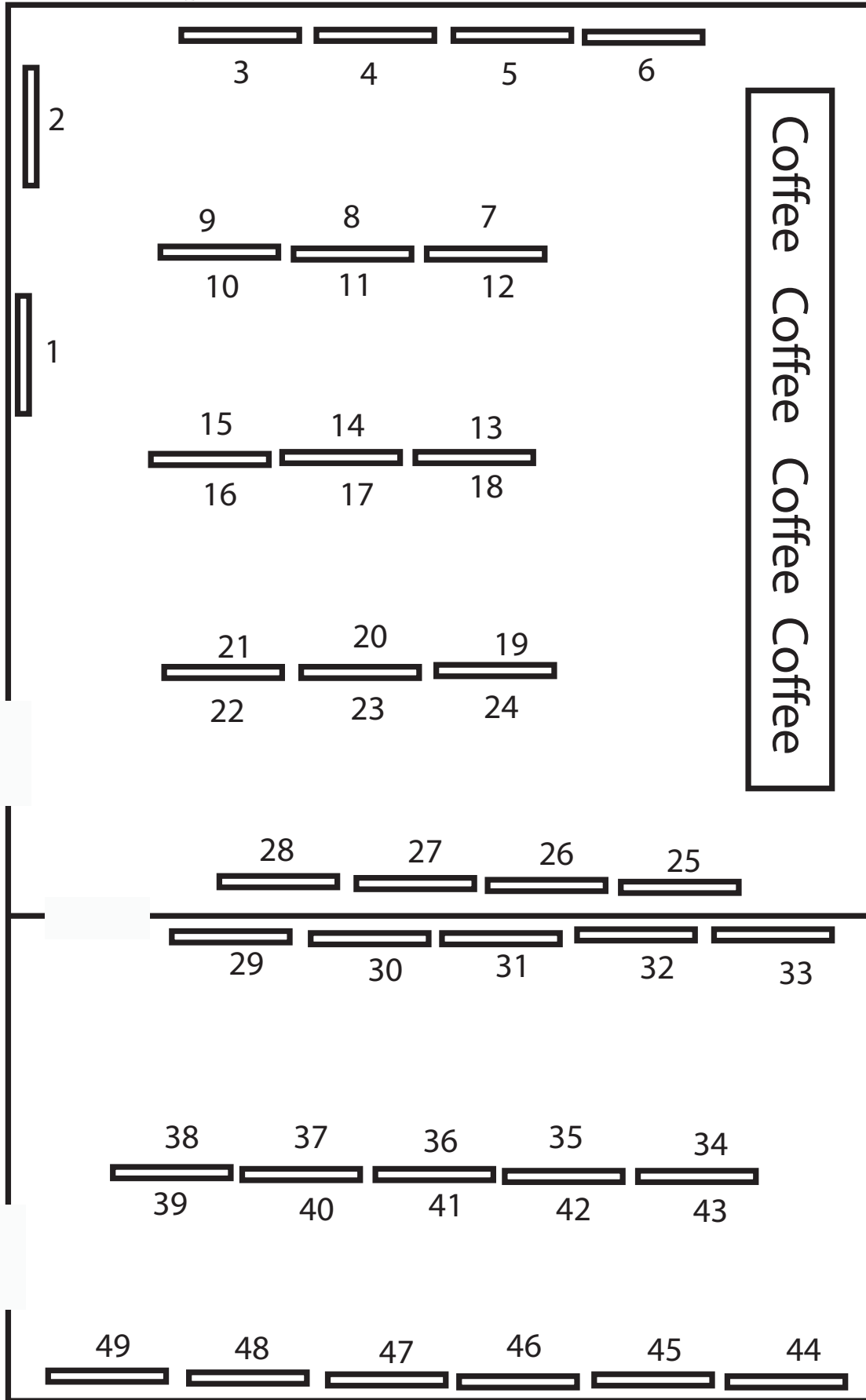
T27: Laboratory wavelengths for cosmological constraints on varying fundamental constants

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Cosmological investigations, using high-redshift QSO absorption spectra, of possible variations of the fine-structure constant (α) require very accurate laboratory wavelengths for a number of UV resonance transitions from several different species. Astrophysical spectra can now be obtained with such high precision that the accuracy of available laboratory data is getting more important for the analysis and interpretation. A cosmological change in α could be detected as a shift in wavelengths of atomic transitions in the QSO systems and to accurately determine the values of such shifts it is essential that the laboratory rest wavelengths are known with a high accuracy and precision. For this purpose laboratory wavelengths and wavenumbers of UV resonance lines from Mg I, Mg II, Ti II, Cr II, Mn II, Fe II and Zn II have been measured using the UV high-resolution Fourier Transform (FT) spectrometer in Lund. The high relative accuracy of the wavenumbers has been obtained by the use of a composite hollow cathode light source, which enables the spectra of the different species to be recorded simultaneously and thereby minimizing the effects from several steps of calibration. Much emphasis has been put on investigations of possible wavenumber shifts from line structure and self-absorption as well as pressure shifts and calibration effects. The absolute wavenumber accuracy depends both on the measurement precision of each spectral line and on the calibration accuracy, which is limited by that of the Ar II reference lines, by possible pressure shifts and by effects of illumination.

Poster map



Abstracts for Posters

P1: F-dependent lifetimes in Ni-like ions

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We report on a theoretical investigation of F-dependent lifetimes of the first excited $3d^9 4s \ ^3D_3$ hyperfine levels of Ni-like ions with nuclear spin. In a Ni-like ion without nuclear spin the $3d^9 4s \ ^3D_3$ level can only decay to the ground state $3d^{10} \ ^1S_0$ through a magnetic octupole (M3) transition, but in the presence of a nuclear spin an electric quadrupole (E2) transition channel is induced by the hyperfine interaction with $3d^9 4s \ ^3D_2$ and to some extent 1D_2 .

Extensive Multiconfiguration Dirac-Hartree-Fock calculations were performed to calculate the $3d^{10} \ ^1S_0 - 3d^9 4s \ ^3D_3$ M3 transition element, the $3d^{10} \ ^1S_0 - 3d^9 4s \ ^3D_2$ E2 transition element and the hyperfine interaction matrix elements between 3D_3 and 3D_2 . First order perturbation calculations were used to calculate the hyperfine induced E2 transition element and the F-dependent lifetimes. For some ions also the $3d^{10} \ ^1S_0 - 3d^9 4s \ ^1D_2$ E2 transition element and the hyperfine interaction matrix elements between 3D_3 and 1D_2 were calculated to investigate the importance of including the 1D_2 mixing.

Detailed published results [1,2] for Ni-like Xenon is presented. Xe consists of 9 different isotopes of which two have a nuclear spin ($I = 1/2$ and $I = 3/2$) resulting in 5 different lifetimes depending of isotope and F-value. Träbert et al. [3] used a single exponential fit to experimentally determine the lifetime of the $3d^9 4s \ ^3D_3$ state in Ni-like Xe. It is shown that a single exponential could be fitted to the theoretical multi-exponential decay curve, where each lifetime was weighted according to a gas of natural mixing of isotopes, with good accuracy. Depending on which interval the single exponential was fitted to, different lifetimes were obtained.

- [1] K. Yao, M. Andersson T. Brage, R. Hutton, P. Jönsson and Y. Zou, *Phys. Rev. Letter.* **97** 183001 (2006)
 [2] K. Yao, M. Andersson T. Brage, R. Hutton, P. Jönsson and Y. Zou, *Phys. Rev. Letter.* **98** 269903 (2006)
 [3] E. Träbert, P. Beiersdorfer, G.V. Brown, K. Boyce, R.L. Kelley, C.A. Kilbourne, F.S. Porter and A. Szymkowiak, *Phys. Rev. A* **73** 022508 (2006)

P2: Large-scale multiconfiguration Dirac-Hartree-Fock calculations of atomic properties

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Large-scale multiconfiguration Dirac-Hartree-Fock (MCDHF) calculations are commonly done in distributed, multiprocessor environments, which pushed the limits an order of magnitude or more, compared to single-node calculations, and opened new avenues to perform accurate calculations of the atomic properties. The paper will present an application of the MCDHF theory to the calculations of properties of neutral or nearly neutral heavy atoms. The variational schemes of evaluation of electron correlation effects, the leading correction to the independent-particle-model, will be discussed in detail. The examples will include calculations of hyperfine structures and transition rates in heavy atoms with one or two electrons outside closed shells. Experimental data on hyperfine shifts, together with *ab initio* determined magnetic and electric fields permit evaluation of nuclear electromagnetic moments. The calculations of the magnetic dipole and the electric quadrupole hyperfine constants of several heavy elements will be presented, together with *ab initio* determined nuclear quadrupole moments of several heavy elements.

Recent advances in trapping and spectroscopy of single atoms make them an ideal tool for searching for violations of discrete symmetries of physical laws in the low-energy sector. Parity and time reversal violation

effects in atoms are enhanced by various nuclear and atomic mechanisms, all of which are highly sensitive to the atomic number Z . In recent years several heavy atoms (as well as molecules) were considered as candidates for experimental searches. One of them is radium, which is currently the subject of two experiments. Calculation of the lifetimes of eight lowest excited states of radium will be presented, in connection with ongoing measurements. The interpretation of these experiments will require *ab initio* calculations of atomic enhancement factors, which are sensitive to the inner region of the electronic wavefunction, similarly to hyperfine interaction calculations. In the last part of the talk I will present an introduction to the calculations of the atomic enhancement factors, in particular the interaction of permanent electric dipole moments of elementary particles with an external electric field, within an atomic (or molecular) environment.

P3: Testing the validity of oscillator strengths by the use of 3D radiative hydrodynamical simulation of the solar surface. Application for the Gaia space mission.

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Observatoire de la Cote d'Azur

The Gaia satellite and its spectrometer (RVS) on board will collect millions of stellar spectra in the near IR (840-875 nm) during the mission (2011-2017). It will allow us to get the chemical abundances of millions of stars up to magnitude 15, which will be an unprecedented mapping of the stellar abundances through our Galaxy. To achieve this goal we must have the best up-to-date atomic data available. The correctness of oscillator strengths is often the Achilles heel of chemical abundance analysis of stars. We have therefore decided to test the validity of $\log gf$ of a selection of the most significant iron (FeI + FeII) and silicon (SiI) lines for Gaia/RVS. The method consists in fitting computed profiles obtained from 3D radiative time-dependent hydrodynamical simulations of the solar surface with the high resolution ($R > 500000$) spectroscopic data of the Sun.

The tested $\log gf$ were those of the VALD and NIST data bases. Our main conclusion is that the laboratory oscillator strengths agree well (<0.1 dex) with values derived from 3D simulations, whereas the semi-empirical values found in data bases like the Vienna Atomic Line Database are imprecise, with a disagreement that can be as large as 1 dex. We address this conclusion to laboratories to encourage new oscillator strength measurements in the infrared, especially in the Gaia region.

P4: Infrared atomic oscillator strengths for the study of brown dwarfs and extra solar planets

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The spectral opacity of cool dwarf stars, brown dwarfs and extra solar planets peak in the IR where their spectra is dominated by neutral atoms and molecules. The astrophysical importance of these Sub Solar Objects (SSOs) comes from the fields: galactic dynamics (how much mass is stored in faint SSO?), star formation (is there a lower mass limit below which no "stars" form?) and extra-solar planets (what distinguishes an extra-solar planet from a brown dwarf?). By determining their fundamental properties, such as their effective temperature, metallicity, and surface gravity, the parameters of SSOs can finally be derived, and their position and status within the HR diagram determined.

The spectra of SSOs are dominated by molecular absorption bands with relatively molecular spectra free window regions where atomic spectra are observed. SSO parameters are determined by comparing observed spectra to modelled spectra, but complex molecular spectra are exceedingly difficult to model to the accuracy required to determine the SSO classification. Instead one uses atomic spectra observed in the window regions to determine SSO parameters. However, observed SSO spectra can not be adequately analysed because the current IR atomic database completely lacks any oscillator strengths for the majority of atoms required for SSO analysis.

We present our laboratory measurements on specific atomic oscillator strengths using high resolution Fourier transform spectroscopy to determine accurate branching fractions, which combined with radiative lifetimes provide oscillator strengths. Our recent measurements of accurate laboratory line wavelengths and oscillator strengths for Ti I, and preliminary measurements for Y I will be discussed. The f-values are determined with an uncertainty of 10 to 15% and we report on the application to SSO analysis.

P5: Unidentified lines in spectra of two iron overabundant CP stars: are they Fe II lines ?

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The analysis of the high-resolution UVES spectra of the two CP stars HR 6000 and 46 Aql has revealed the presence of an impressive number of unidentified lines, mostly concentrated in the two regions 4404-4411 Å and 5100-5300 Å. Almost all the unidentified lines are the same in both stars which both have an iron abundance of the order of +0.7 dex over the solar value. The parameters of the two stars are $T_{\text{eff}}=12850$ K, $\log g=4.1$ and $T_{\text{eff}}=12750$ K, $\log g=3.8$. We show that some of the unknown lines can be identified as high-excitation (lower EP 13 eV) Fe II and that most of them appear as unclassified lines in laboratory iron spectra.

P6: Measurement of L-shell transition energies in F-like through Li-like Bi using SuperEBIT

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We have measured the x-ray emission from L-shell transitions in F-like Bi LXXV through Li-like Bi LXXXI. Our results include the identification of x-ray transitions in the 2 - 4 keV spectral band. The spectra were taken at the LLNL SuperEBIT electron beam ion trap using a cryogenic microcalorimeter array devised and built at GSFC [1]. The microcalorimeter is a high-resolution, energy-dispersive x-ray spectrometer with a resolving power of at 3 keV. The bismuth was injected into SuperEBIT using a Nd:YAG laser ablation system [2], which enabled repeated injection in order to maximize the filling of the trap. SuperEBIT was operated at an electron beam energy of 116 keV. For this experiment, bismuth ions of charge states 74+ through 80+ existed simultaneously. The transitions of our primary interest are the $2s_{1/2} - 2p_{3/2}$ transition near 2800 eV and the $2p_{1/2} - 2p_{3/2}$ transition near 2500 eV. We will present an overview of our results.

Work at University of California Lawrence Livermore National Laboratory was performed under the auspices of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

[1] F. S. Porter et al., Rev. Sci. Instrum. 75 (2004)

[2] A. M. Niles et al., Rev. Sci. Instrum. 77 (2006)

P7: Spheromak Spectroscopy for Fusion Research

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EUV plasma spectroscopy is one of the diagnostics used at the SSPX spheromak in Livermore. The spheromak is an alternative concept to the more conventional tokamak device in magnetic fusion research. A spheromak produces short pulses of high-density plasmas in a self-organized toroidal configuration; there are no external coils required to confine the plasma equilibrium. The simpler design of the machine offers several advantages over the tokamak scheme, however, the physics of spheromak plasmas is more complex. The SSPX spheromak, in operation since 1999, is the most successful one in achieving high temperature plasmas, and a core thermal diffusivity comparable to that achieved in tokamak L-mode discharges. The spheromak produces hydrogen plasmas of densities around 10^{14} cm⁻³ with peak electron temperatures from 10 eV up to 550 eV, thus covering a broad range of plasma conditions.

Plasma impurity ions represent a significant problem in fusion research since they effectively cool the plasma, making it more difficult to reach fusion ignition temperatures. By studying the amount and distribution of these fuel contaminants, care can be taken to minimize their abundances. Atomic spectroscopy offers a powerful and reliable diagnostic for investigating the plasma constituents.

Our diagnostic consists of an EUV grating spectrometer with a field of view overlooking a column at the mid-plane of the spheromak. It employs a spherical flat-field grating, covering the spectral region of 25 - 400 Å. The recording of spectra is done using a back-illuminated Photometrics CCD camera.

Several charge states of low-Z elements have been identified in the plasmas, notably B, C, N and O. Of the heavier elements, Cu and Ti are found in the machine, again in a variety of charge states. The copper originates from the walls of the device, and titanium is applied via vapor deposition to the plasma facing surfaces to getter, or pump, low-Z impurities and to reduce hydrogen recycling in order to control the plasma density. The experiment is ongoing; we are planning to inject into the spheromak metals of interest for fusion engineering, atomic theory and solar physics.

Work at University of California Lawrence Livermore National Laboratory was performed under the auspices of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

P8: The Second Spectrum of Rhenium and other Exotic Species in the Mercury Star HD 65949

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² *ESO*

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The Hg star HD 65949 was noted for its exceptionally strong line of Hg II 3984. We identified a number of unusual species at the ≤ 0.05 significance level, among them Re II, Os II, and Te II. The Re II spectrum is very well identified, including a number of unclassified lines. We elaborate on the announcement paper, A&A, 455, L21, stating the case for the marginal identifications, and giving more details on the Re II spectrum.

P9: Oscillator strengths for E1 transitions among Fe III levels belonging to lowest three configurations.

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Queen's University Belfast

We present a configuration interaction (CI) calculation for the fine-structure levels of Fe III belonging to $3d^6$, $3d^54s$ and $3d^54p$ configurations. All 136 LS states of these three configurations are considered. Using Hartree-Fock functions for 1s, 2s, 2p, 3s, 3p and 3d we have generated further radial functions for 4s, 4p, 4d, 4f, 5s, 5p, 5d, 5f and 6p orbitals. The 4s and 4p orbitals are taken as spectroscopic and remaining orbitals taken as either correction or correlation orbitals. Relativistic effects are accounted for through Mass correction and Darwin terms in addition to an approximate form of the two-body spin-orbit interaction term. Ab initio fine-structure levels are then fine-tuned to bring them in line with the available NIST values. We then calculate the oscillator strengths and transition probabilities for all possible E1 transitions. We present the first full scale CI calculation for all the fine-structure levels of lowest three configurations of Fe III which includes relativistic effects. The results are compared with the available calculations. While fair agreement is noticed among various theoretical calculations for strong transitions, large disagreements are found between present results and those of other calculations for less strong transitions.

P10: A Multiplet Table with Transition Rates for Neutral Helium ($^4\text{He I}$)

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We have combined the precise determination of the energy levels of $^4\text{He I}$ from calculations and experiments with theoretical transition probabilities to present multiplet tables for the fine structure of the helium atom. We have included all electric dipole transitions between levels with $n = 1$ to 10, $L = 0$ to 7 unless the wavenumber is less than 1 cm^{-1} . The tabulated transition rates, lifetimes, and oscillator strengths include singlet-triplet mixing and spin-orbit coupling, but not the higher-order relativistic terms nor the corrections for finite nuclear mass, though the latter are listed for future use. Our calculations should be accurate to about 0.2%. Comparisons with earlier calculations indicate very little difference for S - P and P - D transitions, but some lines of D - F and F - G have significant deviations from the LS coupling assumed by previous authors. Our results are consistent with almost all published laboratory lifetimes and oscillator strengths, but very few are accurate enough to be stringent tests.

P11: Oscillator Strengths for Ultraviolet Transitions in P II and Cu II

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Analysis of ultraviolet absorption from the dominant ions in interstellar clouds provides information on the mineralogy of the solid material in space and on the synthesis of elements in our Galaxy and beyond. For the most part, the spectra are acquired with spectrometers on the Hubble Space Telescope and the Far Ultraviolet Spectroscopic Explorer. In order to convert the amount of absorption into an accurate abundance, determinations of oscillator strengths of sufficiently high quality are needed. We present our most recent beam-foil measurements in this area. Lifetimes, branching fractions, and the resulting oscillator strengths for all transitions within the P II multiplet at 1154 \AA are compared with available results. The close agreement

between our laboratory measurements and theoretical and semi-empirical calculations suggests a means for calibrating fast-beam instruments in the far ultraviolet. As for Cu II, our results on the line at 1358 Å provide further evidence for a short lifetime for the upper state of interest.

This research was supported in part by NASA grants.

P12: IAU Commission 14: Atomic and Molecular Data

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P13: Manganese abundances and the importance of good hyperfine data.

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For a project studying stars in the disk of the Milky Way we wished to obtain Mn abundances for our stars from the stellar spectra. Mn is subject to hyperfine splitting of the lines. Some of these lines are also very sensitive to collisional broadening. In this poster we will show how the abundances we derive depend on these types of data and also high-light what data is currently missing as well as which data might benefit from further scrutiny. We end by showing how the application of the atomic data allows us to trace the origin of Mn.

P14: Multiconfiguration Dirac-Hartree-Fock calculations for the hyperfine-structure parameters and the scalar-pseudoscalar interaction constant of ¹³³Cs.

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The observation of static electric dipole moment (EDM) of a many-electron atom (which violates parity - P and time reversal - T symmetry) may be a very important step in searching for a new physics beyond the Standard model of elementary particles [1, 2]. One of the main possible sources of EDM in the paramagnetic atoms is the scalar pseudoscalar (*S - PS*) interaction between the electrons and the nucleus:

$$\hat{H}_{S-PS} = i \frac{1}{\sqrt{2}} G_F C_{S-PS} \sum_{i=1}^N \beta_i \gamma_i^5 \rho(r_i). \quad (1)$$

This interaction mixes parity of atomic states and also induces the EDM of an atom. In the multiconfiguration Dirac-Hartree-Fock method [3] atomic state function (ASF) with mixed parity:

$$\tilde{\Psi}(\gamma J M_J) = a \Psi(\gamma P J M_J) + \sum_{i=1}^m b_i \Psi(\alpha_i(-P) J M_J). \quad (2)$$

This function ($M_J = J$) can be used for the calculation of the EDM operator matrix elements. EDM operator (z projection) in the atomic units:

$$\hat{D}_Z = - \sum_{i=1}^N r_i C_0^{(1)}(\theta_i, \varphi_i). \quad (3)$$

Combining experimentally obtained limits of electric dipole moment with calculations the limit of scalar-pseudoscalar interaction constant can be found. For these calculations we extended GRASP2K [4] package of the relativistic atomic structure calculations. Due to the small values of obtained off-diagonal matrix elements

the computer algebra package MAPLE 10 for the final diagonalization of the full atomic Hamiltonian matrix were used.

Using extended GRASP2K package we calculated magnetic dipole constants A_J for the two atomic states $|6s, ^2S_{1/2}\rangle$ and $|6p, ^2P_{1/2}\rangle$ of ^{133}Cs and the scalar - pseudoscalar interaction constant ($m = 1$). For the MCDHF expansions of the even and odd atomic state functions we used several models. As an example we show the results of the calculations with two models. In the first model the configuration state functions include all single substitutions and core-valence double substitutions with full relaxation. CSFs of the second model additionally include core-core substitutions from $4d, 4f, 5s, 5p, 5d$ orbitals without relaxation. Calculated values of A_J (MHz) are presented in the table.

	$A_{6s}(1)$	$A_{6p}(1)$	$A_{6s}(2)$	$A_{6p}(2)$	$A_{6s}(Exp.)$	$A_{6p}(Exp.)$
n=7	1668	193	1722	296		
n=8	1672	199	1704	199		
n=9	1701	203	1725	200		
n=10	1702	208	1732	206		
n=11	1720	207	1750	205	2292	285

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P15: Energy dependance of Xe ion lines produced by beam-foil interaction

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Xe ions are present in some stars and in astrophysically interesting plasmas on the ground. Atomic spectrum of Xe ions induced by the beam-foil interaction have been recorded in the far UV region between 30-120 nm. From the relative intensities of Xe II to Xe IX lines, that appear in our spectra, we have deduced the first experimental charge state distribution of Xe ions at the exit of a carbon foil target. Our result suggests that Xe is two time more easy to ionize that what was predicted by existing models. This information is of interest for a correct modeling of the spectroscopic measurements in high temperature plasmas. Moreover, we have observed that some strong lines attributed to Xe IX did not appear in our spectra or that their behavior is not in agreement with the supposed ionization stage. This suggests that, for Xe IX, some problems exist in line classifications and/or energy level scheme.

P16: Seeking cosmic lasers with photon-correlation spectroscopy

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Natural laser emission may be produced whenever radiative mechanisms overpopulate suitable atomic energy levels. A well-studied case is the extremely luminous star Eta Carinae, in particular Fe II emission lines from its gas ejecta ('Weigelt blobs'), while other suggested optical laser sources include symbiotic stars such as RR Tel or V1016 Cyg, and hot Be stars in general.

However, the evidence for laser emission is indirect since the lines have not yet been spectrally resolved. Theoretically expected linewidths are on order 50 MHz ($< 1 \text{ m}\text{\AA}$), requiring spectral resolution around 100 million, far beyond any means of classical spectroscopy.

Such resolutions are feasible with high-speed photon-correlation spectroscopy, analyzing the autocorrelation function of photon arrival times. A 50 MHz wide emission line, say, is self-beating on a timescale equal to its coherence time (in this example, 20 ns), observable as a characteristic timescale in the autocorrelation function.

Numerically simulated observations estimate the fraction of laser emission within realistic spectral and spatial passbands for Eta Carinae and other sources, and how the signature of the expected emission components may appear in observable statistical functions.

The method is analogous to stellar intensity interferometry pioneered by Hanbury Brown et al., although this is temporal (not spatial) 'interferometry'. Also, the signal-to-noise ratios follow similar relations as in intensity interferometry: While generally expensive in terms of photon flux, sources of high brightness temperature (such as narrow emission-line components) are easier to measure. The method is thus most suitable for future extremely large telescopes, which thus may enable optical astronomical spectroscopy with resolutions of 100,000,000, and beyond.

P17: The Sulfur electron affinity: a good test case for theoretical isotope shift calculations

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Isotope shifts of atomic lines are of high interest in astrophysics, providing information on isotope distributions, themselves relevant for testing nucleosynthesis theories and diffusion models. The theoretical estimation of transition isotope shifts is often difficult. A renewed interest in the calculation of this property has arisen with the recent claims on a possible variation of the fine structure constant on a cosmological time scale [1]. The theoretical evaluation of isotope shifts on electron affinities is even more challenging [2]. On the experimental side, the photodetachment microscope technique allows to measure the electron affinity with an extreme accuracy, and a sensitivity high enough to allow the electron images to be recorded even for the rarest isotopes [3]. Such experiments have been performed on a beam of $^{32}\text{S}^-$ [4] and $^{34}\text{S}^-$ [5], opening the possibility of extracting the isotope shift $^{34,32}\text{S}$ on the electron affinity.

The theoretical calculation of the latter requires elaborate wave functions for estimating the expectation values of the mass polarization term [2] but the quality of the wave functions should be first assessed by monitoring the electron affinity itself. Ab initio calculations of this property from the total energies of the infinite-mass systems S^-/S are performed, adopting the numerical multiconfiguration Hartree-Fock (MCHF) approach using the ATSP2K package [6]. The differential correlation effects between the negative ion and the neutral atom are crucial. Various correlation models including in a systematic way valence, core-valence and core correlation, limiting the core to the $n=2$ shell are attempted to describe this delicate balance. The one-electron orbitals are optimized using a single- and double multi-reference expansion. The valence correlation result agrees with the non relativistic experimental value (2.093 eV) within 3%. Getting a reliable theoretical value by including additional core-valence and core correlation in an all-electron approach is definitely a hard task, the models being limited by the available computer facilities for approaching the total energy difference. Isotope shifts $^{34,32}\text{S}$ on the electron affinity are reported.

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P18: Laser Probing Measurements and Calculations of Lifetimes of the $5d^2D_{3/2}$ and $5d^2D_{5/2}$ Metastable Levels in Ba II

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The lifetimes of the metastable $5d^2D_{3/2}$ and $5d^2D_{5/2}$ levels in Ba II have been measured with a Laser Probing Technique [1] at the ion storage ring facility CRYRING located in the Manne Siegbahn Laboratory in Stockholm, Sweden. The lifetime of the $5d^2D_{3/2}$ level proved to be the longest lifetime ever measured with this technique utilizing fast ion beams, $\tau = 89.4 \pm 15.6$ s, and to the best of our knowledge it constitutes the longest lifetime ever measured in a storage ring. Also the $5d^2D_{5/2}$ level has a lifetime of the order of tens of seconds which was determined to be $\tau = 32.0 \pm 4.6$ s. These new measurements are supported by our new pseudo-relativistic Hartree-Fock calculations resulting in $\tau = 82.0$ s and $\tau = 31.6$ s respectively.

These lifetimes have been measured previously by several groups but the experimental lifetimes resulting from the different studies are inconsistent. For the $5d^2D_{3/2}$ level, the measurements of Schneider and Werth [2] and of Yu et al. [3] differ by a factor of four and, for the $5d^2D_{5/2}$ level, the results of Plumelle et al. [4] are larger than those of Nagourney et al. [5] and of Madej et al. [6] by about 50%. The value of the $5d^2D_{3/2}$ lifetime presented in this study shows good agreement with both the experimental result of Yu et al. [3] and also with several calculated values [7,8,9]. The measured lifetime of the $5d^2D_{5/2}$ level is also in agreement with several previous measurements [4,5,6] and calculations [4,5,7,8,9].

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P19: Atomic data for infrared lines in cool stars

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For present and upcoming astronomical studies using near infrared (NIR) high-resolution spectrometers, there is a need for experimental wavelengths and *gf*-values. In detailed abundance analyses using high-resolution instruments the accuracy of the atomic data is also important. The present status of atomic data in the NIR is scarce, but by using the new Fourier Transform Spectrometer (FTS), presently being installed at Lund Observatory, we will be able to improve the situation. Depending on the atomic structure of specific elements, resonance lines and high excitation lines can occur as NIR transitions. Various lines are expected to be observed in stellar spectra, and we discuss in general terms how *gf*-values for these can be measured. We present theoretical stellar spectra with atomic lines expected to be observed in spectra of cool stars, along with laboratory recordings.

P20: VUV oscillator strengths for iron lines of astrophysical importance

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In spectroscopic studies of astrophysical objects iron is an important tracer, and its high cosmic abundance and complex atomic structure result in many spectral lines. Iron is often used as a probe of metal abundance in distant objects, such as quasars and AGNs. Many stars and nebulae have temperatures of about 10 000 K, and for this temperature the favoured ionization stage is singly ionized iron, Fe⁺, whose spectrum is denoted FeII. The lines of FeII are thus of great importance in analyses of stars and nebulae not only to derive abundances, but also for diagnostics of the plasma conditions and derivation of physical properties such as temperature, electron density and radiation field. The FeII lines from the ground state are also important tracers of the interstellar medium (ISM), in which absorption from only the very lowest states are observed.

Some FeII lines have previously been measured by Lawler's group in Wisconsin [Wiese, L.M. et al., *ApJ* **569**, 1032 (2002)] using the same technique. We present a project to derive transition probabilities for specific 4s-5p lines at VUV wavelengths in FeII, important for many astrophysical applications, e.g. in objects where fluorescence is working and stars observed in the FUSE region. This will be done by combining absorption measurements of a FeII HC discharge illuminated by synchrotron radiation.

P21: The FERRUM project: Experimental and Theoretical Transition Rates of Forbidden [ScII] Lines and Radiative Lifetimes of Metastable ScII levels

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In many plasmas, long lived metastable levels are primarily depopulated by collisions. In low-density regions, however, radiative decays through forbidden transition channels will be more important and can be observed. If the atomic transition data is known, these lines are indicators of physical plasma conditions and can be used for abundance determination [2]. Transition probabilities can be derived by combining relative intensities between the decay channels, so called branching fractions (BFs), and the radiative lifetime of the common upper level [2]. We use this approach for forbidden [ScII] lines along with new calculations.

Neither BFs for forbidden lines nor lifetimes of metastable levels are easily measured in the laboratory. Therefore, astrophysical BFs measured in Space Telescope Imaging (STIS) spectra of the strontium filament of Eta Carinae are combined with lifetime measurements using a laser probing technique [3,4] on a stored ion beam at the CRYRING [5] facility in Stockholm, Sweden. These lifetimes are used to derive the absolute transition probabilities (A-values). New theoretical transition probabilities and lifetimes are calculated using the CIV3 code.

We report experimental lifetimes for the ScII levels $3d^2\ ^3P_{0,1,2}$ with lifetimes 1.28 ± 0.13 s, 1.42 ± 0.22 s and 1.15 ± 0.03 s respectively and transition probabilities for lines from these levels down to the ground state $3d4s\ a^3D$. New calculations for these forbidden [ScII] lines and metastable lifetimes are also presented.

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P22: A comparative analysis of transition probabilities of Fe-peak elements for a new release of VALD

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We carried out a comparative analysis of recent atomic data for Fe-peak elements (mainly Ti, Cr and Fe) for a new release of the Vienna Atomic Line Database (VALD-3). New data were compared with those available in VALD-2 and were checked using high-resolution high S/N stellar spectra. The observations include sharp-lined normal stars (21 Peg, HD 73666), a mild Am star (Sirius), and the zero-rotation extremely Cr and Fe-rich peculiar star HD 133792. The observed spectrum of the latter star allowed to compare theoretical

transition probability calculations based on the orthogonal operator technique and the Cowan code for Cr II and Fe II lines in a wide range of lower level excitation energies (2 – 11 eV) in the optical and near-IR region (3100 – 90000 Å).

In general, the agreement between the new experimental transition probabilities and those currently available in VALD-2 is fairly good, which supports the validity of the stellar abundance data derived with VALD-2 atomic parameters. But we found that for a few important Ti II and Fe II lines in the visible spectral region the new transition probabilities do not correspond to the quoted accuracy. New wavelengths for Ti II lines improved significantly the fit to the observations.

In a series of recent works on experimental f-values for Fe II it was shown that theoretical calculations based on the orthogonal operator technique agree much better with the experimental data than the Cowan code calculations and hence are to be preferred for stellar spectroscopy. On the other hand, our analysis of the Ap star HD 133792 spectrum clearly demonstrated that there are quite a number of high-excitation Cr II and Fe II lines which are fitted reasonably well using the transition probabilities calculated with the Cowan code.

P23: VALD

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VALD is a collection of atomic transition parameters and supporting extraction software. VALD services are available via e-mail (VALD-EMS) and a web interface. Different kinds of requests are useful for several needs like abundance analyses, radial velocity measurements, or line identification. Since 1994, the early days of VALD, the database was constantly improved and the release of VALD-3 - incorporating, e.g., molecular data and new line lists - is in preparation. With meanwhile about 200 requests per day, VALD has developed to a much appreciated tool.

P24: Electric dipole transitions among low lying levels of Fe IV

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Oscillator strengths and transition probabilities for dipole allowed and intercombination transitions among the levels of Fe IV belonging to $3d^5$, $3d^44s$ and $3d^44p$ configurations are calculated using a configuration interaction approach. To account for the important correlation effects, two electron promotions are allowed from $3p^63d^5$ to all $4l$ and $5l'$, with $l, l' \leq 2$ orbitals, for all 108 LS terms. After calculating LS energies with these configurations we delete those whose eigenvector strengths are less than 0.001. With this reduced set we further added $3s3p^63d^6$, $3p^63d^7$, $3s3p^63d^54s$, $3p^63d^64s$ configurations for the even levels and $3s3p^63d^54p$, $3p^63d^64p$ configurations for the odd levels to account for correlations involving the $3s$ subshell. Relativistic effects are then included through (a) the mass correction and Darwin terms and (b) a one-body operator approximating the spin-orbit and spin-other-orbit terms of the Breit-Pauli Hamiltonian. The calculated LSJ fine-structure energies are then fine-tuned to bring them into line with the measured values. This process effects a refinement of the CI mixing coefficients: this is important for the calculation of oscillator strengths. Results will be presented at the conference.

P25: Time-resolved spectroscopy of low-pressure discharges

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An important part of the understanding of processes in the vicinity of the electrodes in low-pressure plasma discharges, e.g. fluorescent tubes, is to establish the relative importance of the possible excitation/ionization channels. There are several observations supporting the view that a substantial part is due to multi-step processes. Ionization of vaporized alkali-metal emitter species is likely to be an important mechanism for recapturing, and hence reducing the mass-loss during the cathode phase of an AC-discharge. Quasi-resonant energy transfer between excited and/or ionized species is therefore believed to be of significant importance for understanding the factors determining the loss-rate of emitter material, and for the proper overall understanding of the behavior of the plasma.

One way to experimentally establish the excitation/ionization mechanisms is to explore the different time-scales of spontaneous decay, collisions and diffusion. This may be realized by a time-resolved recording of the optical and electrical signals after switching off the pulse-shaped electrical excitation.

A setup consisting of a computer-controlled pulse synthesizer, a wide-band power amplifier, a 1m Czerny-Turner grating spectrometer, equipped with a gated CCD-detector has been constructed for this purpose. The wavelength resolved output is sampled synchronously with the electrical parameters and stored for subsequent analysis.

This work is performed in cooperation with Auralight AB and is supported by the Swedish Energy Agency.

P26: Calculations of Zeeman Splittings, Hyperfine Structures, Isotope Shifts, and Oscillator Strengths using the grasp2K Relativistic Atomic Structure Package

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We report large scale calculations of spectroscopic properties such as energies, Zeeman splittings, hyperfine structures, isotope shifts, and oscillator strengths in different systems using the grasp2K relativistic atomic structure package. Different aspects of the computations such as accuracy and time consumption are discussed. Future perspectives on massive relativistic calculations of large portions of atomic spectra are given.

P27: Multireference relativistic configuration interaction calculations of lifetime of $2s^2 2p^2 P_{3/2}$ state in Ar^{+13}

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Fine structure separations and M1 and E2 transition probabilities for the lowest 2P doublet of Boron-like Argon have been calculated using multireference relativistic configuration interaction method based on the no-pair Dirac-Coulomb-Breit Hamiltonian. Analytic basis sets of Gaussian-type functions are employed to expand the upper and lower components of the Dirac four-spinors in the matrix Dirac-Fock self-consistent field and relativistic MR CI procedures. QED corrections were estimated by means hydrogenic and screened self energy model. Obtained result 9.572ms is in well agreement with the latest experimental value of A. Lapierre et al.: 9.573 ms(PRL 95, 183001 (2005))

P28: Predicted wavelengths of intercombination transitions in neutral boron and isoelectronic ions

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In 1969, Edlén et al. [*Solar Phys.* **9**, 432] made an isoelectronic extrapolation of the $2s^2 2p^2 \text{P}_{3/2}^{\circ} - 2s 2p^2 \text{P}_{5/2}^{\circ}$ interval based on the existing data for the sequence C II through F V. Since then, a number of experimental observations for Ne VI through Si X basically confirmed these predictions. However, no intercombination transitions have been observed in neutral boron so far. Here, we combined the new experimental data with recent extensive theoretical calculations on the boron-like sequence to refine these predictions by isoelectronic interpolation/extrapolation of differences between experimental and theoretical wavenumbers. It turned out that the probable location of the $2s^2 2p^2 \text{P}_{3/2}^{\circ} - 2s 2p^2 \text{P}_{5/2}^{\circ}$ transition in neutral boron is at $28643.1 \pm 1.8 \text{ cm}^{-1}$, which is 223 cm^{-1} below the value of Edlén et al.

P29: New Linelists for Fe I - VI

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Smithsonian Astrophysical Observatory

I am computing atomic line lists for generating stellar opacities, model atmospheres, and predicted spectra, and for interpreting observed spectra using my own versions of programs that I got from Robert Cowan. I compute the whole E1, M1, and E2 transition arrays for configurations up through $n = 9$ or higher. Hartree-Fock starting guesses are used for the Slater-parameter expansion of the Hamiltonians. Slater integrals are adjusted by least squares fitting the calculated eigenvalues to the observed energies. Once the least squares fits have converged, all the eigenvectors and eigenvalues are computed. The eigenvalues are replaced by the observed energies. The LS transition array is computed with Hartree-Fock transition integrals. Finally the LS transition array is transformed to the observed coupling using the eigenvector matrices. Here are numbers that indicate the scope of the calculations.

	config		levels		E1 lines	
	eve	odd	eve	odd	good wl	total
Fe I	61	50	18655	18850	93508	6029023
Fe II	46	39	19771	19652	85362	7615097
Fe III	49	41	19720	19820	33982	9770250
Fe IV	61	54	13767	14211	8408	14617228
Fe V	61	61	6560	7526	11417	7785320
Fe VI	61	61	2094	2496	3535	1386203

The calculations are compared with other calculations and with laboratory measurements. Comparisons are given with Iron Project calculations and with all the NIST compiled data for allowed and forbidden lines, and with other data.

I attempt to collect all other work from the literature and, in making the working line lists for interpreting spectra, I try to incorporate the best data available. I include data for measured isotopic and hyperfine splittings.

On my web site, <http://kurucz.harvard.edu/atoms>, are posted complete line lists, reduced linelists with only good wavelengths, energies, compositions, A-sums, C4, C6, Lande' g, lifetimes, branching fractions, partition functions, and programs for reading and reformatting the data.

P30: Fe VIII through Fe XVI Emission in the 170 - 250 Å Range

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The solar spectrum is dominated by emission lines from intermediate charge states of iron (Fe VIII - Fe XVI). This region is currently being observed in high resolution in the 180-204 Å and 250-290 Å range by the *EUV Imaging Spectrometer* on *Hinode (Astro-B)* and in the 90-270 Å range by the *Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)*. Correct interpretation of these spectra relies on complete and accurate plasma emission models, which are largely based on the CHIANTI database. To test this, we have performed a series of laboratory measurements of the 3-3 emission from M-shell iron ions with the Lawrence Livermore electron beam ion trap facility and the Large Helical Device at the National Institute for Fusion Science.

The EBIT measurements were made at a density of about 10^{11} cm⁻³ and covered the range 170-250 Å, while the LHD measurements were made at a density of about 10^{12} cm⁻³ and covered the range 190-250 Å. This allowed us to test density-sensitive line ratios of Fe XIII at their high-density limits (above 10^{10} cm⁻³). With a few exceptions, we found excellent agreement with CHIANTI predictions in both line position and intensity. We found some weak emission lines in both EBIT and LHD spectra, which we tentatively attribute to Fe XV, that are vanishingly small to nonexistent in CHIANTI. A comparison with the *CHIPS* spectrum of the sun is presented and the salient features are identified.

This work was supported in part by grant NNX07AH98G from NASA's Solar and Heliospheric Physics Supporting Research and Technology Program. Work at UC-LLNL was performed under the auspices of DOE under contract W-7405-ENG-48.

P31: SpectroWeb: An Online Astrophysical Spectral Database

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SpectroWeb is an online maintained interactive graphical database of digital spectral atlases of spectral standard stars at <http://spectra.freeshell.org>. It is an efficient and user-friendly research tool for accurate analyses of stellar spectra observed with large spectral resolution, including the solar spectrum. The web-interface displays observed and theoretical stellar spectra, and comprehensively provides detailed atomic and molecular line information via user interaction. It integrates interactive spectrum visualization tools for the analysis, management, and maintenance of large volumes of spectral line-identification, -transition, and -property data. SpectroWeb 1.0 currently offers optical (3300-6800 Å) flux normalized high-resolution spectra of Betelgeuse (M2), Arcturus (K1), The Sun (G2), Beta Aqr (G0), Procyon (F5), and Canopus (F0). The provided line identifications are based on state of the art spectrum synthesis calculations that utilize atomic data from publicly available resources, such as the VALD database. SpectroWeb is under permanent development as an online repository of identified (absorption) lines in spectral standard reference stars, covering a broad range of stellar spectral types.

P32: Experimental radiative lifetimes of highly excited states in Zr I.

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The determination of the abundance of zirconium in star atmospheres and in the solar photosphere requires a large number of accurately known radiative lifetimes and transition probabilities. In this poster we present radiative lifetimes of 17 highly excited states of Zr I, of which 14 are reported for the first time. The measurements were made using the time-resolved laser-induced fluorescence technique with single step excitation of atoms produced by laser ablation.

P33: Emission Spectra of Free Lanthanide Ions. Interpretation of Nd IV, V and Tm IV.

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Spectra of weakly charged free lanthanide ions are of great interest. The modelling of stellar atmospheres in chemically peculiar stars needs better knowledge of the third spectra, whereas the trivalent ions embedded in compounds have applications for lasers, for phosphors in the lighting industry and for quantum information optical devices. Finally, the most recent advances in the theory of 4fN configurations need experimental level energies for test of the effective parameters describing configuration interactions [1]. A major part of free ion IV spectra were missing in the unique critical compilation available [2].

Our interpretation of the Nd IV spectrum is based on sliding spark spectra recorded on the 10 meter normal incidence vuv spectrograph at the Meudon observatory, which supplemented spectrograms recorded at NBS (1980). The initial classification [3], i.e. 37 levels of the ground configuration $4f^3$ derived from 550 transitions $4f^3-4f^25d$, is now extended to include : 1) the missing upper terms 2G and 2F of $4f^3$, 2) the parametric study of all known levels using Cowan's codes[4]. In the odd parity, 108 levels of $4f^3+4f^26p+5p^54f^1$ are described by 23 free parameters with a rms deviation 91 cm^{-1} . In the even parity, 119 levels of $4f^25d+4f^26s$ ($70817 - 137456 \text{ cm}^{-1}$) lead to a rms deviation 37 cm^{-1} , provided that the core excited configuration $5p^54f^35d$ is added to the basis set.

Concerning the Tm IV spectrum, all the spectrograms were photographed at Meudon in the 700-2300 Å region. More than 750 lines are now classified as Tm IV transitions between 10 levels of the ground configuration $4f^{12}$, 157 levels of $4f^{11}5d$, 33 levels of $4f^{11}6p$ and 9 levels of $4f^{11}6s$. Similar to the case of Nd IV, the $5p^64f^{11}5d-5p^54f^{12}5d$ interaction has a significant quenching effect [5] on the calculated $4f^{12}-4f^{11}5d$ transition probabilities [6].

In parallel with the IV spectra, a breakthrough in the analysis of Nd V was achieved and all levels of $4f^2$, $4f5d$, $4f6s$ and $4f6p$ (except $4f^2 \ ^1S_0$) in Nd V have been derived from Meudon and NBS experimental data.

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P34: Dirac-Fock + core polarization' calculations of E1 transitions in francium isoelectronic sequence

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Some E1 transitions in francium isoelectronic sequence are computed in 'Dirac-Fock + core polarization' approximation where core-valence electron correlation is treated in semiclassical 'core polarization' picture. The obtained ionization energies and oscillator strengths are tested versus very accurate many body perturbation treatment (MBPT) theoretical results published recently as well as versus experimental data available. The role of core-valence correlation (core polarization) is carefully studied for both ionization energies and oscillator strengths along spectral series and isoelectronic sequence. Profound anomalies in oscillator strength fine structure components for principal series of neutral francium are predicted and await experimental confirmation.

P35: Atomic Oscillator Strengths in the Vacuum Ultraviolet

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Transitions in singly-ionized and doubly-ionized iron-group elements give rise to prominent emission lines from a wide variety of astrophysical objects. Many of these lines have been identified and analyzed by Sveneric Johansson and his co-workers and are important diagnostics of astrophysical plasmas. The database of experimental oscillator strengths of Fe II has also been greatly extended by the FERRUM project, which includes measurements made at Lund University, at Imperial College, London and other institutes around the world. However, few experimental oscillator strengths are available in the region below 1600 Å, where many levels that give rise to emission lines at longer wavelengths have their dominant decays.

The established way to measure accurate oscillator strengths for atomic lines combines the measurement of a lifetime of an upper energy level with a separate measurement of the branching fractions of all the lines emitted from that level. This technique relies on being able to observe all the spectral lines emitted by the upper level, which range down to Ly- α or below for many fluorescence lines. Methods of measuring branching fractions using Fourier transform spectroscopy are limited to wavelengths above about 1400 Å and cannot observe all the spectral lines required.

We have developed techniques to measure branching fractions in the vacuum ultraviolet using our 10.7-m normal incidence grating spectrograph. For this we use phosphor image plates as replacements for the photographic plates previously used on this instrument. Image plates are sensitive to wavelengths from the X-ray region to 2200 Å, and have a linear intensity response with a dynamic range of at least 10^4 . We have recorded spectra of iron-neon hollow cathode and Penning discharges, using a deuterium standard lamp for radiometric calibration. We will present the first measurements of oscillator strengths using this technique in the region below Ly- α . These measurements include experimental oscillator strengths of a set of unusual

doublet-sextet transitions in Fe II, studied in a 1995 paper by Johansson et al. (ApJ 446, 361), that appear in many astrophysical objects. We are also investigating methods of radiometric calibration below 1150 Å using hollow cathode standard lamps. This will enable us to measure branching ratios down to 800 Å or below – a region with many resonance lines of doubly-ionized spectra and critical for the analysis of data from the Far Ultraviolet Spectroscopic Explorer.

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P36: Breit-Pauli Oscillator Strengths for Transitions among the Fine-Structure Levels of Cl I

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We have undertaken an extensive calculation to obtain the oscillator strengths for all optically allowed and intercombination E1 transitions in Cl I between the fine-structure levels of the odd-parity configurations $3s^23p^5$, $3p^4(^1D)4p$, $3p^4(^3P)np$ ($4 \leq n \leq 5$) and the even-parity configurations $3s3p^6$, $3p^4(^3P, ^1D, ^1S)ns$ ($4 \leq n \leq 5$), $3p^4(^3P)6s$, $3p^4(^3P, ^1D)3d$, $3p^4(^3P)4d$, within the Breit-Pauli approximation, using the method of configuration interaction (CI) enveloped in the general atomic structure code CIV3 [1,2]. The CI wavefunctions have been constructed from a common orthogonal set of twenty-three one-electron functions (OEFs), which have been carefully selected to ensure that the LS -dependency of the orbitals and all important correlation effects have been accurately represented. In the LS -coupling regime, the configuration state functions (CSFs) included in the atomic wavefunction expansions were obtained from all single and double electron replacements to the OEFs for each symmetry from the orbitals in the set of dominant configurations $3s^23p^5$, $3s3p^6$, $3s^23p^4nl$. At the LSJ stage we retain only those CSFs with eigenvector components ≥ 0.0005 in magnitude. We then make a further *ad hoc* refinement to the calculation, whereby the diagonal Hamiltonian matrix elements are adjusted so that the theoretical energy differences coincide with the relevant experimental values. We observe excellent agreement in the length and velocity forms of the oscillator strengths, demonstrating a marked improvement over previous theoretical work by Ojha and Hibbert (1990) [3] and Singh *et al.* (2006) [4]. The present results also conform with the majority of the experimental data. Alternative energy level classifications to NIST [5] are proposed for a number of heavily mixed $J = 5/2$ and $J = 3/2$ levels based on our calculations, which are supported by the experimental measurements of Schectman *et al.* [6] for the $\lambda 1088, 1097\text{\AA}$ transitions, where we have reduced an inconsistency between theory and experiment by obtaining qualitative agreement with the relative strengths of the lines (*c.f.* Table 1).

Comparison of our length form oscillator strengths f_l for the lines at $\lambda 1088, 1097, 1095$ with other available theoretical and experimental work. The lower level of the transitions is $3s^23p^5\ ^2P_{3/2}^o$.

λ ()	This Work		Biémont <i>et al.</i> [7]		Ojha and Hibbert [3]		Expt. [6]
	Upper level	f_l	Upper level	f_l	Upper level	f_l	
1097	$(^3P)5s\ ^4P_{5/2}$	0.0022	$(^3P)3d\ ^2F_{5/2}$	0.0122	$(^3P)3d\ ^2D_{5/2}$	0.0423	0.0088
1088	$(^3P)3d\ ^2D_{5/2}$	0.0567	$(^3P)3d\ ^2D_{5/2}$	0.0688	$(^3P)3d\ ^2F_{5/2}$	0.0159	0.081
1095	$(^3P)3d\ ^2F_{5/2}$	0.0322			$(^3P)5s\ ^4P_{5/2}$	0.0011	

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P37: Inband Conversion Efficiency of Tin Based Laser Produced Plasmas for Extreme Ultraviolet Lithography at 13.5 nm

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The choice of wavelength for extreme ultraviolet lithography is based on the availability of Mo/Si multi-layer mirrors with $\approx 70\%$ reflectivity in a 2% band at 13.5 nm. A tin-based laser-produced plasma source has been proposed, since $4p^6 4d^n 4p^5 4d^{n+1} + 4d^{n-1} 4f + 4d^{n-1} 5p$ atomic transitions from adjacent Sn ions overlap to generate a broad unresolved transition array (UTA) with numerous strong lines superimposed within the required bandwidth. Because of opacity effects the profile and extent of this UTA is extremely sensitive to tin content in the target. The effect of target composition, with varying percentages of Sn present in the target and the laser pulse illumination conditions were studied experimentally using 15 ns FWHM Q-switched Nd:YAG laser pulses. It was found that a conversion efficiency (CE) of $\sim 3\%$ was attainable using targets containing 5% of Sn by number, while for pure tin targets, the CE could be improved by some 70% using subnanosecond pulse heating of an existing laser produced plasma. Comparisons were made between atomic and plasma theory and experimental results to explain these observations. Acknowledgement: This work was supported by Science Foundation Ireland under Investigator Grant 02/IN.1/199.

P38: The effects of low-lying excited states on 4d photoabsorption of La and Ce ions

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The photoabsorption spectrum of Xe-like La^{3+} and Ce^{4+} and I-like La^{4+} and Ce^{5+} have been obtained in the extreme ultraviolet (EUV) spectral region with the dual laser plasma (DLP) technique [1]. Photoexcitation from the 4d-subshell is the dominant process in the 80-160 eV energy range. Strong discrete structure, corresponding to 4d np, mf ($n > 6$, $m > 4$) transitions already identified by Köble et al [2] in La^{3+} appeared at lower laser power densities, but with increasing laser flux the discrete features were suppressed and replaced by broad features in the energy regions of the 4d-5p and 4d-4f transitions. This behaviour can be attributed to the presence of absorption from excited states containing open 5p and 4f subshells in La^{3+} and the onset of similar behaviour in La^{4+} . In Ce, where 4f wavefunction contraction effects are expected to be more significant [3], the effects of excited state absorption are even more pronounced and no strong discrete lines were observed though the spectrum contained evidence of regions of unresolved structure. The transitions responsible for these features were identified with the aid of Hartree-Fock with Configuration Interaction calculations using the Cowan suite of codes [4].

Acknowledgement: This work was supported by Science Foundation Ireland under Investigator Grant 02/IN.1/199.

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P39: Successes and Shortcomings of Modeling Spectra for A-K Stars

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We show the degree to which we are able to match high-resolution spectra observed for stars of a wide range of temperature and metallicity, using theoretical calculations based on Castelli model atmospheres, Kurucz codes, and laboratory line parameters adjusted and augmented to provide best fits across this range. These 1D, LTE spectral calculations generally provide a very good match, suitable for high-resolution abundance analysis except for the strongest-lined stars.

Successes:

Abundances of heavy elements can be more reliably deduced, thanks to improvements in laboratory gf-values and better appreciation of blends. This can now be done for A stars and for giants of near-solar metallicity, as well as for extremely metal-poor giants in which the heavy elements are enhanced.

The integrated-light spectra of globular clusters are matched well throughout the visible, and at low resolution in the near-UV.

Shortcomings:

Blends due to unidentified lines become formidable in the UV for stars of one-third solar metallicity and higher, and in the 4000Å – 4500Å region for solar-metallicity giants. The latter is partly due to the rapid growth of hydrides such as SiH.

SiH line strengths are reasonably well predicted but line positions are in error by 0.5Å or more.

Excited lines of CH, NH, and OH have gf-values dating from the 80's which dramatically overpredict line strengths at high J values.

P40: Atomic Oscillator Strengths for all Stages of Ionization of Chlorine

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We are compiling new tables of critically evaluated atomic transition probabilities for chlorine and its ions. These tables provide data of interest for astronomical as well as laboratory plasmas and represent a substantial improvement in both quantity and quality over the earlier tabulation [1] published almost four decades ago. Forbidden transitions are also being compiled. We usually consider transitions for which experimental energies are known for both the lower and upper level. Therefore first we have to compile experimental energy levels as well as wavelengths. Here we want to describe the evaluation procedure and outline some problems in the compilation process. In our work, we begin with consideration of all published results. Then we limit our considerations, by means of general assessment criteria, to references with the most accurate results. In general, we list transitions with line strengths having estimated uncertainties within 50% of experimental data are known for chlorine. Only a few of these are from emission experiments performed with wall-stabilized arcs, which produce the most reliable transition probabilities. Therefore, we mainly rely on theoretical values. We select results of recent sophisticated multiconfiguration calculations that include spin-orbit effects and other relativistic corrections. Supported in part by the Office of Fusion Energy Sciences of the U. S. Department of Energy.

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P41: The Spectrum of Singly Ionized Potassium, K II

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We investigated the spectrum of singly ionized potassium in the regions 495-612 Å and 1247-2150 Å using 10.7-m and 3-m normal-incidence vacuum ultraviolet spectrographs. More than 120 new K II lines were identified. The previous work [1,2] on this spectrum was revised and extended. In addition to the already known $3p^6$ ground state and $3p^53d$, $4s$, $4p$, and $4d$ configurations, all levels of the $3p^54f$ and $5f$ configurations as well as the levels of $3p^56f$ based on the $3p^5\ ^2P_{3/2}$ core state have now been located. Several new levels of $3p^53d$ were also located, bringing this configuration to completion. A unified list of 238 classified lines was compiled. The observed configurations were theoretically interpreted by means of Hartree-Fock calculations and least-squares fits of the energy parameters to the observed levels. The ionization limit was determined from the $3p^5nf\ 1.5[4.5]_5$ ($n=4-6$) series as $255072.8 \pm 1.5\ \text{cm}^{-1}$ ($31.6250 \pm 0.0002\ \text{eV}$). Our results have now been published in *Physica Scripta* [3].

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Work at NIST supported by the Office of Fusion Energy Sciences of the U. S. Dept. of Energy

P42: Extension of the Analysis of the Pt III Spectrum.

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The observation of the spectra of chemically peculiar stars Chi Lup and Kappa Cnc from the Goddard High Resolution Spectrograph (GHRS) on board of the Hubble Space Telescope (HST) have resulted in the first identification of the 11 Pt III lines in any stellar spectrum [1]. Spectrum of Chi Lup recorded in the region 1249 - 2688 Å is so rich of Pt III lines that transitions even from highly lying known levels of the $5d^76s$ are present [2]. Space observations of unprecedented accuracy available from HST require laboratory and theoretical data of a similar quality. The third spectrum of platinum has been newly investigated by using the low voltage triggered and sliding spark discharges and a 6.65-m normal incidence spectrograph. The number of classified lines for Pt III in the region 72.5 -210.5 nm was increased to 1007, 231 of them are new. Previous analysis of the $(5d^8 + 5d^76s) - 5d^76p$ transitions [3] was generally confirmed and new $5d^76s - 5d^66s6p$ transitions are identified leading to 54 new levels of the $5d^66s6p$ configuration. The observed configurations were theoretically interpreted by means of Hartree-Fock and MCDF calculations and least-squares fit of the parameters to the observed levels in the framework of the orthogonal parameter technique. From a comparison with observed lifetimes in the second and third spectra of the $5d$ - elements scaled theoretical transition probabilities have been calculated.

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P43: Spectral properties of atomic systems under external plasma

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Effect of plasma on the structural properties of hydrogen and helium like atomic systems have been investigated. Particular emphasis has been given for studying the behavior of oscillator strengths and transition probabilities under weakly as well as strongly coupled plasma environment. The plasma atom interaction modifies the potential energy function of a free atomic system and the atomic energy levels and other transition properties are evaluated under this altered potential function. Specifically, Debye screening model has been used for weakly coupled plasma and Ion Sphere (IS) model is chosen for the strong coupling case. Time dependent linear response theory under an external harmonic perturbation has been adopted for estimating the atomic transition properties. Systematic behavior of oscillator strengths and transition probabilities under different plasma coupling strength is noted. Consistent lowering of ionization potential with respect to increased plasma coupling strength is noted for all systems, which tend towards gradual instability. The spectral line positions of several ions have been found to be in good agreement with available data obtained from laser produced plasma experiment.

P44: Improved Laboratory Transition Probabilities for Neutral Chromium and Re-determination of the Chromium Abundance for the Sun and Three Stars

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Branching fraction measurements from Fourier transform spectra in conjunction with published radiative lifetimes are used to determine transition probabilities for 263 lines of neutral chromium. These laboratory values are employed to derive a new photospheric abundance for the Sun: $\log \epsilon(\text{Cr I})_{\odot} = 5.64 \pm 0.01$ ($\sigma = 0.07$). These Cr I solar abundances do not exhibit any trends with line strength nor with excitation energy and there were no obvious indications of departures from LTE. In addition, oscillator strengths for singly-ionized chromium recently reported by the FERRUM Project are used to determine: $\log \epsilon(\text{Cr II})_{\odot} = 5.77 \pm 0.03$ ($\sigma = 0.13$). Transition probability data are also applied to the spectra of three stars: HD 75732 (metal-rich dwarf), HD 140283 (metal-poor subgiant), and CS 22892-052 (metal-poor giant). In all of the selected stars, Cr I is found to be underabundant with respect to Cr II. The possible causes for this abundance discrepancy and apparent ionization imbalance are discussed.

P45: Stark Broadening of High-n Rydberg Transitions

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Calculations of line shapes of highly-excited Rydberg atoms and ions are important for various topics of plasma physics and astrophysics. Transitions involving high-n states are used for diagnostics of laboratory plasmas, e.g., in tokamak [1] and z-pinch [2] experiments. Such transitions are observed in the solar spectrum [3] and in the spectra of remote stars [4]. However, the Stark effect of the radiative transitions originating from high-n levels of hydrogen or hydrogen-like species is complex, making the detailed calculations of their spectral structure rather cumbersome. Even for weakly-coupled plasmas, a discrepancy between different

theoretical results is apparent [5]. Here, we suggest a simple analytical method for the calculation of such line shapes. Accurate computer simulations [6] are used to verify the validity of the method. Examples presented cover both low- and high-density plasma conditions.

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P46: Time-resolved observation of Xe ions in an electron beam ion trap

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Nickellike ions have a metastable level (3d⁹ 4s 3D₃) that decays exclusively by a magnetic octupole (M₃) transition. We recently have measured the lifetime of this level in isotopically pure Ni-like Xe ions and have shown how hyperfine interaction modifies the lifetime by mixing with a level that has an E₂ decay channel. We now demonstrate how this long-lived level enables multi-step ionization of Ni-like ions at much lower energies than the usual single-step ionization limit. Time-resolved and energy-varying observations of Xe XXVII (Ni-like) and Xe XXVIII (Co-like) in an electron beam ion trap indicate the notable influence of the metastable level on the charge balance in a plasma.

E. T. acknowledges support by the German Research Association (DFG). Work at UC LLNL was performed under the auspices of DoE under Contract No. W-7405-Eng-48.

P47: Electric-Dipole Forbidden Transition Rates in Fe XII Measured at the Heidelberg Heavy-Ion Storage Ring TSR

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Edlén's 1942 identification of prominent corona lines with electric-dipole forbidden transitions in the ground configurations of highly charged ions forced a revolution in the concepts of the solar environment. Such lines have since been observed in a wide variety of astrophysical objects. For many observations it would be useful to know the transition probability of the E₁-forbidden transitions, be they magnetic dipole (M₁), electric quadrupole (E₂), magnetic quadrupole (M₂), or even higher multipole order transitions, in order to interpret emission and absorption features and to quantify the environmental parameters of the emitter or absorber plasma. Fe X and Fe XIV are particularly intriguing because of their single, bright corona lines. The transition probabilities in these two cases have been determined to better than 1 heavy-ion storage ring TSR and at the electron beam ion traps at Livermore and Heidelberg.

In coronal Fe ions with a more complex structure, a variety of E₁-forbidden transitions with wavelengths in the UV, far UV, or VUV connect levels in the ground configuration (3p), and there also are a few 3d levels

that can decay only by higher-order multipole radiation, with wavelengths in the IR, UV, or EUV. All of these levels have typical level lifetimes of a few or many milliseconds, whereas levels with E1 decay branches have lifetimes in the picosecond to nanosecond range. Because the M1, E2, and M2 transition rates are comparable to the collision rates in the solar corona, specific line ratios (relative level populations) can be evaluated as density or temperature diagnostic tools.

The lifetimes of the ground configuration 3p levels of Fe XII have been measured at TSR by observing the level decays in the far UV, and the results have been corroborated by measurements on Co XIII. In Fe XII, the long-lived 3d levels have dominant E2 decay branches (in the EUV wavelength range) to the displaced terms, thereby affecting the line ratios of the latter levels decaying to ground. The density-sensitive line ratios thus range in wavelength from about 20 nm to about 357 nm.

Fe XII (P-like) has been particularly difficult to analyze on the basis of EUV spectra of the solar corona. However, after combining available spectral data with the results of calculations (by Biémont, Del Zanna, Storey, and others), we have been able to undertake specific lifetime measurements at TSR, so that now experimental lifetimes of all of the long-lived $n=3$ levels of Fe XII are available for collisional-radiative modeling.

E. T. acknowledges support by the German Research Association (DFG). Work at UC LLNL was performed under the auspices of DoE under Contract No. W-7405-Eng-48.

P48: Searching for the s -process in cool, luminous stars: A vital role for laboratory astrophysics

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We report on progress in determining the chemical composition of massive, cool supergiant photospheres for the purpose of investigating whether nuclear by-products from relatively recent nucleosynthesis have been brought up to the photosphere by convective processes. For evolved, massive stars, the post iron-group elements ($Z = 30 - 42$) are theorized to be created by slow neutron capture (the weak s -process) in their interiors.

For cool stars the infrared spectral region offers the benefits of higher stellar flux and a number of observing windows where the absorption from molecular species is reduced relative to that at optical wavelengths. However, the oscillator strengths needed for spectrum analysis at IR wavelengths carry high uncertainties and for many atoms and first ions of interest no oscillator strength data exists. Our initial work has therefore been focused on identifying atomic transitions at infrared wavelengths that are useful for stellar abundance work and gathering accurate atomic data for these transitions. The latter task includes the measurement of oscillator strengths, and represents a vital role for laboratory astrophysics in this project.

We use high-resolution optical and infrared spectra of the massive, cool star Betelgeuse (α Orionis) as a primary target for line identification and synthetic spectrum modeling. Abundances have been determined for a number of heavy elements, and our results illuminate the problems with the atomic data that must be overcome before we are able to derive chemical abundances with the accuracy required for a meaningful comparison with theoretical predictions from s -process nucleosynthesis.

One element of immediate interest is selenium, and we have obtained laboratory spectra of Se hollow-cathode lamps from 4000 Å to 1.2 μm using the NIST 2m FTS. Additional data will be collected below 4000 Å and above 1.2 μm to allow us to update wavelengths and energy levels and determine branching fractions for transitions in Se I and Se II. The branching fractions will be combined with atomic lifetimes to be recorded at the Lund Laser Center to determine oscillator strengths for lines of astrophysical importance.

P49: Precise Oscillator Strengths for Hydrogen, Helium, and Lithium

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We have completed a new tabulation of oscillator strengths for a large number of transitions of H, He, and Li. This compilation supersedes the NBS/NIST tabulation of 1966[1] and provides substantial improvements in the quantity as well as quality of the critically evaluated material. Most of the tabulated data are the results of two extensive very high precision calculations: For neutral helium and singly-ionized lithium, we have tabulated the results of sophisticated variational calculations by Drake.[2,3] Drake applied his computational approach to more than 2400 transitions of He I and about 500 transitions of helium-like Li II. For Li II, his calculations are non-relativistic, but for He I, he includes some relativistic effects. We estimate that the remaining higher order corrections and finite nuclear mass terms produce only very small changes, about 0.2% or less, so that for many practical purposes, his oscillator strength data can be considered as essentially exact. The other major set of transitions for this tabulation are fully relativistically calculated hydrogen data by Baker.[4] These are for the first four digits usually identical with the earlier NIST tabulation of non-relativistic values.[1] For Li I, we tabulated the results from several advanced, but smaller calculations. When there is overlap, the results agree normally within 0.1%. The only exceptions to this table of precision data are a few very weak transitions, where large differences among various authors occur, up to factors of two.

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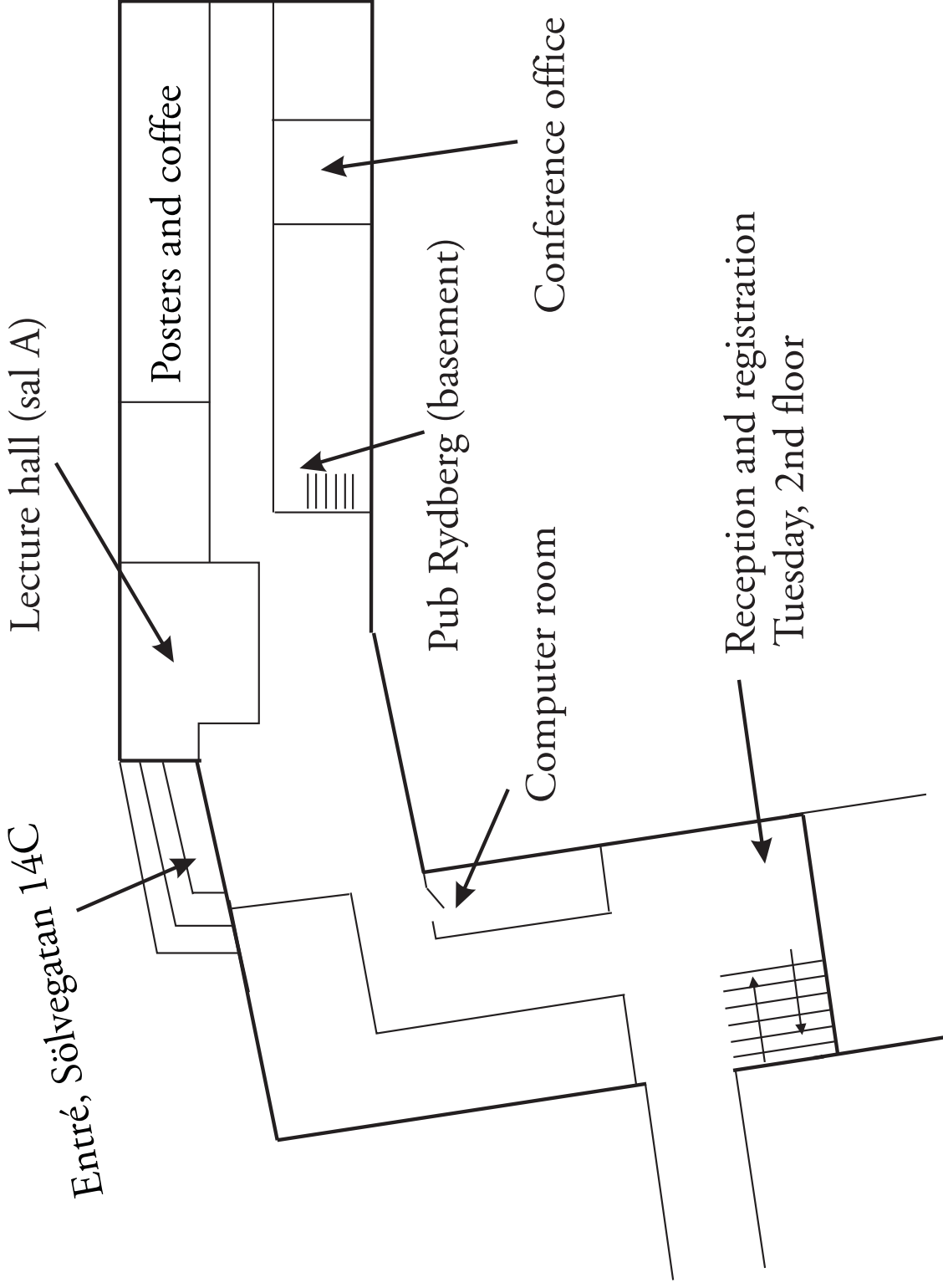
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Entré, Sölvegatan 14C

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Pub Rydberg (basement)

Computer room

Conference office

Reception and registration
Tuesday, 2nd floor