Workshop on Stellar Atmosphere Modeling

originally planned to be held at Tübingen, September 17 - 21, 2001.

This is the booklet of the submitted abstracts. We decided to distribute these because they may help to initiate new collaborations — with new results to be presented at the postponed Workshop Atmos200(1)2 in Spring 2002.

Opacities of Molecules and Dust

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As progressively lower temperatures are encountered in a stellar atmosphere, first molecules and finally dust grains become important sources of opacity. The abundance of important molecular and solid absorbers depends upon temperature, pressure, and the chemical composition in complex ways which require detailed equation of state calculations. Molecular spectra, which usually contain thousands or millions of spectral lines, are usually treated statistically in the opacity sampling method. Because of the size of modern line lists and the computation time required to process them, efficient computation of molecular opacity requires careful selection of the wavelengths and the relevant lines. We will discuss these procedures, and the results obtained for important absorbers such as H_2O and TiO.

For temperatures below about 1,800 K, some materials begin to precipitate out of the gas phase as small solid particles. Because these small grains are very efficient absorbers and scatterers of light, they dominate the opacity whenever they exist. The thermodynamic and optical properties of these materials will be explored. Recent results show that even grains with relatively low abundances, such as Al_2O_3 and $CaTiO_3$, can have a dramatic impact on the structure of stellar atmospheres. Most atmospheres with $T_{eff} < 3,000\ K$, both giant and dwarf, have grains in their outer layers in sufficient quantity to affect the emergent spectrum.

NLTE Line Formation in Late-Type Stellar Atmospheres

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We briefly describe an on-going project to calculate detailed NLTE fully-blanketed model atmospheres for late-type dwarfs. Present computers and state-of-the-art codes make it possible to calculate consistent NLTE atmospheric structures and spectra, including dozens of species, thousands of energy levels, and tens of thousands of transitions. We have initiated the gathering of a comprehensive and highly homogeneous library of model ions based on modern databases available on the net. We compare early test calculations against solar observations.

Formal Solvers: "Explicit Truth"

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The "Formal Solution to the Radiative Transfer Problem" is the calculation of the radiation field, given the time-, angle- and frequency-dependent emissivity, and opacity at all locations. The difficulty is that the emissivity cannot, in general, be specified until the radiation field is itself known. Modern approaches to Stellar Atmospheres, therefore, couple the formal solution for the details of the radiation field with efficient methods for correcting the estimated emissivity. In this paper we discuss (1) the *implicit* global coupling of the radiation throughout the entire medium, (2) techniques for solving the *explicit* transfer equations using estimates for the emissity, and (3) how the information from the formal solution may be used in Approximate Lambda Iteration or the Moment Equations to correct the estimated emissivity. The intimate connection between interpolation and the formal solution is stressed.

Limb-darkening and Angular Diameter Predictions from Spherically Extended and Expanding Model Atmospheres

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The interferometric measurement of stellar limb-darkening, the shape of the visibility curve at spatial frequencies beyond the first null, is presently only possible for a few stars. The vast majority of present day stellar diameter measurements require a theoretical limb-darkening correction to recover the "true" diameter and to interpret multi-wavelength uniform disk results. Compilations of theoretical wavelength dependent center-to-limb variations needed for such corrections are almost exclusively derived from plane-parallel model atmospheres and are generally inappropriate for giants and supergiants.

To model interferometric data, formally the Hankel transform of the stellar disk intensity distribution, it is necessary to predict the intensity as a function of angle on the sky. Using the `PHOENIX` code, static and expanding spherical atmosphere models have been constructed using a depth-impact parameter coordinate system where characteristic rays intersect nested shells. From these models wavelength dependent center-to-limb intensity variations have been extracted.

We compare the center-to-limb variations of hydrostatic and expanding model atmospheres and provide limb-darkening corrections to uniform disk angular diameter measurements obtained by optical interferometers. We present two cases: 1) a near-IR, broadband diameter measurement of Deneb, an A-type supergiant with a stellar wind, and 2) narrow band diameter measurements of M-type giants and supergiants at wavelengths inside and adjacent to a TiO band head. For Deneb we find that the expanding atmosphere limb profile is significantly extended relative to the hydrostatic case, leading to a correction of the uniform disk diameter which is less than unity. With our preliminary M-star models we are able reproduce the observed R-I color versus TiO diameter ratio for the giants, but not for the supergiants.

Influence of Mass Flows on the Energy Balance and Structure of the Solar Transition Region

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We have extended our previous modeling of energy balance in the chromosphere-corona transition region to include the effects of particle and mass flows. We consider quasi-steady cases satisfying the momentum and energy balance equations throughout the transition region and low corona. We include particle diffusion as well as flows in the non-LTE equations for H, HeI, and HeII. Mass flows substantially affect the ionization and radiative losses of H and He, thereby affecting the structure and extent of the transition region. We find that the H and He line profiles are greatly affected by flows, and that line shifts are much less important than the changes in line intensity and central reversal due to the effects of flows on atmospheric structure. The profiles we compute can generally explain the range of observed high spectral and spatial resolution Lyman alpha profies from the quiet Sun. A full account of this work appears in a paper by Fontenla, Avrett, and Loeser submitted to The Astrophysical Journal.

NLTE modeling of lines in expanding shells of LPV's

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The dynamics of the cool, shock penetrated, expanding atmospheres of Long Period Variables (LPVs) can be studied by spectral lines of various atoms or molecules. Especially the infrared molecular line profiles of the CO molecule are excellent diagnostic tools appropriate for the overall structure of the inner, expanding circumstellar layers. Due to the high abundance of CO as well as its formation and stability at high temperatures it is dominant in the circumstellar shells of LPVs. If one focuses on the detailed shock structures in atmospheric layers close to the photosphere for example, various optical atomic lines of neutral and ionized metals (e.g. Mg I, Fe I, Fe II) are suitable diagnostic tools (see Richter & Wood 2001, A&A 369, 1027).

To model the various atomic and molecular lines of interest, a radiative transfer code (static, spherical symmetric, co-moving frame, accelerated lambda iteration) has been developed to handle the especially awkward conditions of cool LPV's atmospheres. Here we present and discuss in detail results of the infrared CO-line calculations and give a brief outlook on work in progress for optical metal line calculations.

Numerical Multi-D Radiation (Magneto-) Hydrodynamics

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The problem of 3D Radiation Magneto-Hydrodynamics is too complex to solve numerically in the general case; approximations are needed to bring the numerical complexity to tractable levels. These approximations are problem dependent. We will use the case of the Solar chromosphere to illustrate these issues. The implementation of a 1D Radiation Hydrodynamics code with a rather detailed and realistic treatment of the coupling between radiation and matter is described. Scaling properties and parallelization issues are discussed. Various strategies and on-going work for the implementation of a 3D Radiation Magneto-Hydrodynamics code are described.

Dust Grains in the Photospheres of Red Giant Stars

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Model atmospheres for cool giants stars are usually computed with detailed equation of state and opacity calculations which include many molecular species. We show that models of oxygen-rich stars with effective temperatures below 3000 K also must include dust grains. The effects of dust condensation in the equation of state and on the opacity must be included to obtain accurate temperature structures and spectra.

PRD Redistribution Matrix in Polarized Radiative Transfer

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We present a polarized ALI method (PALI) which solves the polarized radiative transfer equation in a weak magnetic field. The PRD redistribution matrix employed accounts self-consistently for collisions. First we have a brief look at observations of scattering polarization in the solar spectrum to get an idea of possible applications. Then, we consider the physical problem which is solved, discuss the redistribution matrix, introduce the basic idea of the numerical method and compare the results with a previous, more simplified treatment of PRD.

NLTE line formation of the UV Be II doublet lines

Ana Elia García Pérez

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The UV Be II doublet lines at 313.0 and 313.1 nm are formed under NLTE conditions. The two main effects are over-ionization and over-excitation with respect to LTE. I have been studying them and how they are affected by changes in the collisions and radiation field in the UV wavelength range. Therefore, I will present several calculations showing the effects of such changes on them.

Hydrodynamic model atmospheres for hot stars

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The Kiel/Potsdam code for expanding atmospheres in non-LTE is extended by a consistent hydrodynamic treatment of radiatively accelerated atmospheres. The stationary momentum equation is solved under consideration of the radiation pressure from the non-LTE radiation transport. A hydrodynamic atmosphere model for the O-star ζ-Puppis is calculated under consideration of complex model atoms of H, He, C, N, O, Si and the iron group elements, and the influence of the stellar wind on "photospheric" line profiles is discussed.

Infrared radiative cooling / heating of the terrestrial mesosphere / lower thermosphere: Non-LTE analysis of the CRISTA limb radiance data

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The new model of radiative cooling/heating of the mesosphere and lower thermosphere (MLT) in the ro-vibrational bands of atmospheric gases (CO_2, O_3, H_2O, CO, NO, N_2O and others) accounts for vibrational and rotational non-LTE, line-overlapping, and absorption and transformation of the near-infrared solar radiation. The model utilizes ALI technique for the solution of the system of kinetic equations and the DFE radiative transfer algorithm. The contributions of various band to the total cooling/heating are analyzed. The model is applied to the calculation of the MLT cooling/heating for atmospheric data retrieved from the CRISTA limb radiance measurements. Implications for modeling of the MLT region are discussed.

Line-profile variations in eclipsing binaries

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The Fourier method of spectra disentangling generalized to the case of variable strength of lines (cf. Hadrava 1995, A&AS 114, 393 and 1997, A&AS 122, 581) applied to the spectra obtained during eclipses of a binary proved to be sensitive to the variations of limb-darkening across line-profiles. These variations reflect the vertical structure of the eclipsed atmosphere and, consequently, they yield, in addition to the frequency distribution of the radiative flux usually computed from the model atmospheres, another tool for the observational diagnostics of stellar atmospheres. Here we present the first examples of line-profile variations during an eclipse, which are calculated from the intensity distribution on the surface of model atmospheres (cf. Kubát 2001, A&A 366, 210). Consequences for the correct calculation of rotational broadening are also mentioned.

Atmospheres and Spectra of Magnetic Neutron Stars

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We construct atmosphere models for strongly magnetized neutron stars with surface fields $B \sim 10^{12} - 10^{15}$ G and effective temperatures $T_{\rm eff} \sim 10^6 - 10^7$ K. The atmospheres directly determine the characteristics of thermal emission from isolated neutron stars, including radio pulsars, soft gamma-ray repeaters, and anomalous X-ray pulsars. In our models, the atmosphere is composed of pure hydrogen or helium and is assumed to be fully ionized. The radiative opacities include free-free absorption and scattering by both electrons and ions computed for the two photon polarization modes in the magnetized electron-ion plasma. We describe a modified (due to the two photons modes) Unsöld-Lucy temperature correction method to establish radiative equilibrium and the resulting temperature profile. We also discuss the density-dependent, vacuum polarization resonance feature that is important at these strong magnetic field strengths.

Automated Spectral Classification and the Search for Variable White Dwarfs

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White dwarf stars exhibiting pulsational variability are one of the most important astrophysical tools for exploring the inner composition and atmospheric structure of degenerate stars. The variable DA, or ZZ Ceti stars, are also crucial in testing the models for convective energy transport in the atmospheres of cool hydrogen-rich white dwarfs. Only 31 of these pulsators are known to date.

We present results of an automated spectral classification of digitized photographic spectra from the Hamburg Quasar Survey. Parameters derived from fitting to a large grid of theoretical spectra are used to select hot stars with high gravity, in particular white dwarfs, and to estimate their effective temperature. These results can be used to identify cool DA white dwarfs close to the temperature range of the ZZ Ceti strip. Approximately 900 DA candidates with $10\,000\,\mathrm{K} < T_{\mathrm{eff}} < 14\,000\,\mathrm{K}$ have been found, most of them not previously known.

Additional follow-up spectroscopy at higher resolution and good S/N is required to confirm the white dwarf nature of these objects and get accurate determinations of their atmospheric parameters that will allow an efficient selection of variable DA. Our sample has the potential to at least double the number of known DAV and also improve the knowledge of their mass distribution and exact location of the ZZ Ceti stars in the $\log g - T_{\mathrm{eff}}$ plane.

Automated Spectral Analysis

C.S.Jeffery

Armagh Observatory

At Armagh Observatory we continue to make incremental improvements to our core model atmosphere and synthetic spectrum software, STERNE and SPECTRUM. These are employed in the analysis of low-, intermediate and high-dispersion dispersion multi-wavelength data for extreme helium stars and subdwarf B stars, including binaries. In order to make these analyses more objective, we tested a variety of χ^2-minimization procedures. These operate both with precomputed model grids and by recomputing synthetic spectra as required. As a consequence we have been able to analyse large datasets efficiently. Key results have led to the detection of secular contraction and the direct measurement of masses in extreme helium stars. This has been pivotal in identifying extreme helium stars as the product of mergers between CO and He white dwarfs. A time-resolved analysis of the short-period pulsator V652 Her involved the automatic measurement of effective temperatures and surface gravities from over 50 high-dispersion optical spectra. Semi-automatic techniques are even more important for the analysis of binary stars, including the discovery of a new hydrogen-deficient binary, BI Lyn. While our techniques have been developed using LTE models, it is likely that the efficiency gains could be even greater when extended to non-LTE models.

Computational Astrophysics Tools for the GRID

C.S.Jeffery

Armagh Observatory

The newest generation of telescopes and detectors and large scale astronomical databases are delivering vast volumes of astronomical data and creating increasing demands for their analysis and interpretation. Methods for such analyses rely heavily on computer-generated models of growing sophistication and realism. These pose two problems. First, simulations are carried out at increasingly high spatial and temporal resolution and physical dimension. Second, the dimensionality of parameter-search space continues to grow. Major computational problems include ensuring that parameter-space volumes to be searched are physically interesting and match observational data efficiently and without overloading the computational infrastructure.

For the analysis of highly-evolved hot stars, we have developed a toolkit for the modelling of stellar atmospheres and stellar spectra. We can automatically fit observed flux distributions and/or high-resolution spectra and solve for a wide range of atmospheric parameters for both single and binary stars. The software represents a prototype for generic toolkits that could facilitate data analysis within, for example, a Virtual Observatory.

We introduce a proposal to integrate a range of such toolkits within a heterogeneous network so as to facilitate data analysis. For example, data-mining functions will combine new observations with data from established archives. A goal-seeking algorithm will use this data to guide a sequence of theoretical calculations. These simulations may need to retrieve data from other sources, atomic data, pre-computed model atmospheres and so on. Such applications using widely distributed and heterogeneous resources will require the emerging technologies of computational grids.

V4334 Sgr (Sakurai's Object) - problems or a test for atmosphere modeling ?

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The central star V4334 Sgr (Sakurai's Object) of the planetary nebula PN G010.4+04.4 underwent in 1995-1996 the rare event of a very late helium flash. It represents only one out of two such events during the era of modern astronomy (the second event was V605 Aql = Nova Aql 1919, see Koller & Kimeswenger, 2001, ApJ, 559). All the other prominent objects of that type originate from events occurring several thousands of years ago (e.g. A30, A78). Hence, only snapshots can be modeled for those objects. These born-again objects, claimed to be possible progenitors for PG1159 class stars in general, all have unusual high carbon abundances. Thus it is of special interest for stellar evolution theory and theory of convection (Herwig, 2001, ApJL, 554, L71) to model the detailed observations obtained during the last four years. Models of the expanding shell depend essentially on basic stellar parameters of the illuminating source (effective temperature, surface gravity and stellar radius). Most of them depend strongly on the assumed distance to the object. Some models may give some constraints on this parameter, but most of them depend on the assumption as input parameter (see Kimeswenger 2001, Ap&SS in press, http://arxiv.org/abs/astro-ph/0105119). V4334 Sgr allows for the first time a dynamic consideration of this type of object from the very beginning.

The object showed us its stellar atmosphere only for about one year before hiding in its shell. I present here a model which is able to describe the complete photometric behavior of the object, including the fine structure dips of the optical light curve during the first two years of the mass loss and the dust formation. Those models depend only weakly on the details of the input from stellar models. Although assuming a distance and the effective temperature and thus the luminosity is needed as start point. This links to a set of questions, concerning the stellar atmosphere models obtained for the first year of its rapid evolution (Asplund et al. 1999, A&A, 343, 507; Pavlenko et al. 2000, 354, 229).

DFE Method in Moving Media

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We tested, if it's possible to solve the equation of radiative transfer in moving media effectively using the discontinuous finite element method. We show here a solution of this equation written in the comoving frame for two cases- with aberration and with its omission. We compare these results with a static case and with classical Feautrier method.

Modeling of multicomponent radiatively driven stellar winds using Newton-Raphson method

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We present a simple method for solution of onecomponent and multicomponent hydrodynamic equations based on the Newton-Raphson method. We show that this method can be used for the solution of stationary hydrodynamic equations. This method has been used for the calcuation of the low density stellar wind models for which the multicomponent nature of the wind influences the overall wind structure.

Calculation of temperature using a thermal balance of electrons

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Instead of the standard equation of radiative equilibrium the equation of thermal balance of the electron gas is used for the determination of the temperature structure of the stellar atmosphere. The thermal balance method is extremely useful in outer parts of stellar atmospheres with optically thick lines, where sometimes the common method based on radiative equilibrium fails to converge. On the other hand, thermal balance method sometimes fails at the inner parts of the atmosphere where collisions dominate.

A COMPUTER CODE FOR CALCULATION OF NLTE MODEL ATMOSPHERES USING ALI

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A code for calculation of NLTE model atmospheres in hydrostatic and radiative equilibrium in either spherically symmetric or plane parallel geometry is described. The method of accelerated lambda iteration is used for the treatment of radiative transfer. Other equations (hydrostatic equilibrium, radiative equilibrium, statistical equilibrium, optical depth) are solved using the Newton-Raphson method (linearization). In addition to the standard output of the model atmosphere (dependence of temperature, density, radius, and population numbers on column mass depth) the code enables optional additional outputs for better understanding of processes in the atmosphere. The code is able to calculate model atmospheres of plane-parallel and spherically symmetric semi-infinite atmospheres as well as models of plane parallel and spherical shells. There is also an option for solution of a restricted problem of a NLTE line formation (solution of radiative transfer and statistical equilibrium for a given model atmosphere). The overall scheme of the code is presented.

WANTED: BEST METHOD FOR SOLVING THE TRANSFER EQUATION IN MULTI-D HYDRODYNAMICAL MODEL ATMOSPHERES

Hans-Günter Ludwig

Lund Observatory, Sweden

My talk is intended to stimulate discussions about methods in radiative transfer for hydrodynamical model atmospheres of late-type stars. I will present a number a number of inherent problems, show how they are presently tackled (if so), and ask for ideas for more efficient approaches. The transperancies of my talk can be found in
http://www.astro.lu.se/~hgl/public_files/tuebingen2001.ps (4.3Mb)

On the treatment of line blanketing in O star atmospheres

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Inclusion of blanketing in non-LTE spherically expanding atmosphere models is crucial to improve our knowledge of massive stars. The treatment of numerous spectral lines and the velocity field renders this a difficult task requiring approximations (e.g. opacity sampling, super-levels).

In the present contribution we examine the importance of various effects that can influence the treatment of blanketing in a comoving frame code (CMFGEN, Hillier & Miller 1998): choice of the frequency grid to resolve each line, line broadening by microturbulence, etc. The influence of the atmospheric structure in the photosphere-wind transition region on the populations and the emergent spectrum are also discussed.

Last, but not least, the CMFGEN models are compared with results from CoStar (Schaerer & de Koter 1997), and other recent O star atmospheres.

Comparison of dissociation equilibrium constants

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AcDc - A new code to calculate the vertical structure of accretion disks

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We present a new code to calculate the vertical structure of accretion disks in cataclysmic variables. The disk is divided into concentric rings, each ring is treated like an independent plane-parallel radiating slab. We first calculate a gray LTE model and then a NLTE model of the ring. Finally we integrate over all ring spectra to get the spectrum of the full disk. The system of hydrostatic and radiative equilibrium, atomic level populations and particle conservation is solved consistently with the radiative transfer. This allows to calculate detailed theoretical spectra of accretion disks. Comparison with observations will allow to derive radial temperature distribution, mass accretion rate, viscosity and chemical composition. We also plan to compare our vertical structures to those of hydrodynamic simulations in order to estimate the influence of a detailed radiation transport on the stratification.

Solutions of polarized line transfer equations

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Recent developments in the NLTE polarized line formation theory in Astrophysics is discussed. Attention is focussed on pure theoretical aspects of the problem.

A conventional method of solving the line transfer equation is described briefly, in order to give a perspective to the modern Polarized Approximate Lambda Iteration (PALI) methods, which are developed only in recent years. Sample results computed using this old finite difference method for the polarized line transfer in planar and spherical media are presented. These examples include polarized resonance scattering in spherical media, polarized line formation in expanding atmospheres, the role of collisional frequency redistribution in polarized line scattering.

Further, the basic characteristics of a PALI method are described using a prototype resonance polarization problem, keeping the assumption of CRD. Directions are given about the manner in which the presence of an external weak magnetic field can be incorporated in a PALI method. This is basically, the well known problem of Hanle effect in weak magnetic fields. The PALI method for Hanle effect is described, first with CRD, and then with PRD scattering mechanism. Finally the generalization of PALI to the most difficult problem we have attempted until now, namely the study of partial frequency redistribution in the presence of collisions and an external weak magnetic field, is presented. Once again, sample results are shown to illustrate the essentials of PALI method, and the nature of solutions computed using this method, on sample theoretical problems. A comparison of the conventional and PALI approaches is made, whenever possible.

PRD RADIATIVE TRANSFER

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Partial redistribution in frequency (or PRD) provides a general description of the problem of photon correlation during the process of absorption/re-emission by a group of atoms. Since the 70's the effects of PRD have been successfully taken into account in the field of stellar modelling. The "basics" of PRD will be presented. Then, we shall review some of the most important astrophysical applications (e.g. the formation of solar chromospheric resonance lines, or the emission spectrum of solar prominences). We shall further discuss in some details the numerical implementation of so-called standard PRD effects in the non–LTE radiation transfer problem.

Model atmospheres and peculiar abundances.

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Procedure and results of computations of model atmospheres of hydrogen-deficient stars are discussed. Opacity sampling method was used to take into account absorption of atoms, ions and molecules. Spectral energy distributions (SED) are computed in wide wavelength regions (0.3 - 5 micron) for a grid of model atmospheres of Tef = 4000 - 8000 K, log g = 0 - 1. Theoretical spectra are fitted to the observed ones.

Temporary changes of SEDs of the ultra-fast evolved Sakurai's object are modeled.

Utrecht Radiative Transfer Courses

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The Utrecht course *"The Generation and Transport of Radiation"* teaches basic radiative transfer to second-year students. It is a much-expanded version of the first chapter of Rybicki & Lightman's *"Radiative Processes in Astrophysics"*. After this course, students understand why intensity is measured per steradian, have an Eddington-Barbier feel for optically thick line formation, and know that scattering upsets LTE. The text is a computer-aided translation by Ruth Peterson of my 1992 Dutch-language course. My aim is to rewrite this course in non-computer English and make it web-available at some time. In the meantime, copies of the Peterson translation are made yearly at Uppsala – ask them, not me. Eventually it should become a textbook.

The Utrecht course *"Radiative Transfer in Stellar Atmospheres"* is a 30-hour course for third-year students. It treats NLTE line formation in plane-parallel stellar atmospheres at a level intermediate between the books by Novotny and Boehm-Vitense, and Mihalas' *"Stellar Atmospheres"*. After this course, students appreciate that epsilon is small, that radiation can heat or cool, and that computers have changed the field. This course is web-available since 1995 and is regularly improved – but remains incomplete. Eventually it should become a textbook.

The three Utrecht exercise sets *"Stellar Spectra A: Basic Line Formation"*, *"Stellar Spectra B: LTE Line Formation"*, and *"Stellar Spectra C: NLTE Line Formation"* are IDL-based computer exercises for first-year, second-year, and third-year students, respectively. They treat spectral classification, Saha-Boltzmann population statistics, the curve of growth, the FAL-C solar atmosphere model, the role of H-minus in the solar continuum, LTE formation of Fraunhofer lines, inversion tactics, the Feautrier method, classical lambda iteration, and ALI computation. The first two sets are web-available since 1998; the third will follow.

Acknowledgement. Both courses owe much to previous Utrecht courses taught by the late Kees Zwaan. The third exercise set was developed by Phil Judge, Mandy Hagenaar, and Thijs Krijger.

Reverse acknowledgement. If you are a user of this free material you might refer to this summary and so boost my citation standing. Corrections are also welcome.

NLTE in a hot hydrogen star: the Auer & Mihalas 1969 papers revisited

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We pay tribute to two landmark papers published by Auer & Mihalas in 1969. They modeled hot-star NLTE-RE hydrogen-only atmospheres, using two simplified hydrogen atoms:

- ApJ 156, 157: H I levels 1, 2 and c, Lyman α the only line
- ApJ 156, 681: H I levels 1, 2, 3 and c, Balmer α the only line

and computed LTE and NLTE models with the single line turned on and off. The results were extensively analyzed in the two papers.

Any student of stellar line formation should take these beautiful papers to heart. The final exercise in Rutten's lecture notes *"Radiative Transfer in Stellar Atmospheres"* asks the student to work through five pages of questions concerning diagrams from the first paper alone! That exercise led to the present work in which we recompute the Auer-Mihalas hot-hydrogen-star models with TLUSTY, adding results from a complete hydrogen atom for comparison.

Our motivation for this Auer-Mihalas re-visitation is twofold:

- to add diagnostic diagrams to the ones published by Auer & Mihalas, in particular B_ν, J_ν, S_ν graphs to illustrate the role of the radiation field, and radiative heating & cooling graphs to illustrate the radiative energy budget,
- to see the effect of adding the rest of the hydrogen atom.

A new computer code SMART (Spectra from Model Atmospheres by Radiative Transfer) and its use for relaxation and correlation methods in NLTE problems

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A new computer code SMART for computing the stellar spectra forming in plane-parallel atmospheres has been compiled. It has been applied and extended to solution of several problems of processes in stellar atmospheres. An important goal was to elaborate a simple and compact code. Instead of linearization, which is mathematical method of recurrent approximations, a physical evolutionary change or relaxation of quantum state populations from LTE to NLTE has been proposed. Instead of the Λ-iteration procedure it has been proposed to use the physically changing emissivity (or the source function) which incorporates in itself correlations between different quantum state populations.

Testing hot star atmospheres with nebular modeling

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As the bulk of radiation in early type stars is emitted in the Lyman continuum and thus inaccessible to direct observations (except in extremely rare cases) it is crucial to find indirect tests to constrain this part of the spectrum, where the essential atmospheric conditions are settled. Nebular observations combined with detailed photoionization modeling can in principle provide such strongly needed constraints.

Here we present the current status of available constraints on the ionizing fluxes of O stars and first results from extensive photoionization model grids using recent non-LTE line blanketed model atmospheres including stellar winds and plane parallel models for O stars (CoStar: Schaerer & de Koter 1997, WMBASIC: Pauldrach et al. 2001, CMFGEN: Hillier & Miller 1998, TLUSTY: Hubeny & Lanz 2001).

The method and its dependence on nebular parameters (geometry etc.) are discussed. Our models are compared to a sample of HII regions observed with ISO providing a measure of the ionization degree through numerous IR fine structure lines. For stars with Teff $\leq$ 40000 K, all most recent atmosphere models show serious deficiencies in the wavelength range below $\sim$ 400 Angstrøm, predicting too weak fluxes. The possible causes for such a discrepancy are examined.

Modeling the dustosphere of AGB stars

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Dust formation is a common phenomenon in a variety of stellar environments. The formation of dust takes place very close or even inside the stellar atmosphere, triggered by stellar pulsation. The transition region between the stellar atmosphere and the ircumstellar envelope is not very well-defined. It is strongly influenced by the transport properties of newly formed dust grains, e.g. via radiation pressure or backwarming.

The intrinsic difficulties to put the dust generating region into the common nomenclature of stellar structure lead us to call this dynamic region the *dustosphere* (Greek: *Kornioktosphere*) of the star. Although we restrict ourselves in the following to the dustospheres of AGB stars, we expect this definition to be useful for a variety of other objects, too.

A reliable code is presented which has been designed for the numerical simulation of pulsationally levitated atmospheres of AGB stars. The code has been developed during the early 1990's by Fleischer (1994) and Gauger (1990) and since then served as a platform to implement more and more advanced descriptions of microphysics and to investigate their impact on the dustosphere of AGB stars.

Computation of element diffusion in non-LTE stellar atmosphere models

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The Tübingen model atmosphere program `PRO2` in its standard form approximates stellar atmospheres as plane parallel, chemically homogeneous atmospheres in radiative and hydrostatic equilibrium. Together with the solution of rate equations in full non-LTE for sophisticated atomic data this makes `PRO2` especially suitable for application to hot compact stars. Several extensions to this concept have recently been or are currently being implemented (see talks and posters by Werner, Nagel, Dreizler, Deetjen.) This poster presents the modifications made to correctly describe the chemically stratified atmospheres of hot white dwarfs and possibly sdB stars. In these stars, a large fraction of all heavy elements has disappeared from the outer layers due to gravitational sedimentation (Schatzman 1949). Traces of metals may however be sustained by radiative levitation provided the radiation field is intense enough to supply substantial momentum transfer. The radiative acceleration is excerted on trace elements by a non-LTE radiation field through the element's local opactity and therefore can vary strongly with depth. Balancing the radiative acceleration and the effective gravitational acceleration (including the effects of the electrical field that builds up through diffusion of electrons) yields an equilibrium condition for each atomic species (see e.g. Chayer et al. 1995). Its solutions yields equilibrium abundances, but as these also determine the opacity there exists a intimate coupling to the radiative acceleration. Therefore the whole system has to be solved self-consistently, which is done here by iteration (Dreizler 1999). Presented below are some results of such calculations which have been sucessfully used to reproduce the observed EUV spectra of a sample of hot DA white dwarfs (Dreizler & Wolff 1999; Schuh 2000; Schuh et al. 2001a,b,c).

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Using Superlevels to Calculate Molecular NLTE

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We present the method we use in the atmosphere code PHOENIX to calculate molecular NLTE. It is based on the concept of superlevels. Superlevels consist of many similar levels added together which are assumed to be populated by a relative LTE distribution. This reduces the size of the system of rate equations to be solved tremendously. However, we modified the classical superlevel method and combined it with our dynamical opacity sampling technique which allows us to treat millions of lines. Therefore, we can calculate the transitions with maximum accuracy. We demonstrate the qualities of this method with the examples of CO and TiO.

Opacities for protoplanetary disks

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The increase of computer power and the growing knowledge about dust and gas species in different astrophysical environments during the last decade allows the consideration of more complicated opacity models in a variety of hydrodynamical calculations. Unfortunately, there is a lack of studies which focus on calculations of the opacity due to both dust grains and gas species for temperatures between few and few thousands K, typical for protoplanetary disks, based on the best estimates on the dust composition and recent improvements in molecular line lists.

Our aim is to introduce such a model based on the unification of dust– and gas–dominated opacities. We show that the higher values of the Rosseland mean opacity, provided by this model, cause a hotter disk structure and a more extended, less dense and flared atmosphere. Evidently, the opacity model will affect the evolution of such disks dramatically.

Reflection Effect in Close Binaries

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The theoretical modeling of binary systems can be performed by considering realistic models which take into account the radiative transfer, hydrodynamics, reflection effect, temperature structure etc. Since the problem is complex, I have studied some of idealized models which will help us in understanding the important physical processes in close binaries. A method has been developed for obtaining radiation field along the spherical surface irradiated by an external point source, extended source of radiation as first step to understand the reflection effect in close binary systems. The method has been extended to the case of atmospheres distorted due to self rotation of the component and tidal effects due to the presence of its companion. We have computed the effects of irradiation on the line formation in the expanding atmospheres of the components of close binary systems.

We notice that the expansion of the medium produces P Cygni type profiles and the irradiation enhances the emission in the lines although the equivalent widths reduce considerably. In the case of distorted atmospheres, the self radiation produces the absorption line and the combination of self and irradiation from the secondary component produces the emission profile.

3D RADIATIVE TRANSFER FOR YOUNG STELLAR OBJECTS

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The general problem of performing 3D continuum radiative transfer in dust layers and accretion disks around young stellar objects is briefly reviewed. With emphasis on the technical aspects of the solution algorithm, we present direction grid nodes equally distributed on the unit sphere, obtained by applying a Metropolis algorithm. The influence of numerical diffusion on the solution using first-order finite differencing is discussed and a solution appropriate for 3D radiative transfer is given. A generator for grids used to solve the 3D radiative transfer equation with the finite differencing method is given. The grid is adaptive and optimized to minimize the first order discretization error. We show that for the calculated grid, the optical depth throughout every grid cell is below a given threshold and allows global error control for solutions of radiative transfer problems on the grid. The proposed grid generation algorithm is easy to implement and allows pre-calculation of the grids. Moreover, the grids can be stored in integer arrays making a fast solution of the radiative transfer equation possible. We suggest to use individual grids for each frequency to use the global error control of the grid generation method. It is shown that the use of one single grid for all frequencies can lead to large discretization errors. A first comparison to Monte-Carlo code results for a simple rotational symmetric accretion disk configuration is shown.

Multi-Grid Radiation Transfer Revisited

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Multi-grid radiation transfer is a highly efficient method for solving a large variety of radiation transfer problems. It is particularly efficient for problems of multiple spatial dimensions on scalar computers. This advantage is lost on massively parallel machines in which the computational grid can be directly mapped onto the processor array. Contrary to operator splitting methods, the convergence rate of the multi-grid method does not deteriorate with increasing spatial resolution of the computational grid. It is therefore particularly well suited for high resolution problems, while performance at low resolution is not better than the best operator splitting methods.

Since there is a considerable variety of different multi-grid algorithms, there is still ample room for improvements of the few multi-grid radiation-transfer calculations that have been carried out so far. This poster is available under http://www.kis.uni-freiburg.de/˜steiner/#sec6

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Optical Constants and Extinction Efficiency of Solid Materials

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The emergent spectrum of star is determined by the transfer of radiation through the matter in the outer layers of the star. Scattering and absorption of radiation by grains is very efficient. Calculation of extinction efficiency is very important application to the study of the formation and evolution of small stars and large planets, including Jupiter and Saturn in our solar system, the formation and structure of stellar winds, and the properties of the interstellar medium. Especially, when we consider about interstellar grains, extinction efficiency provides essential clues to understanding astrophysical phenomena.
We focused on the low temperature ($T_{\text{eff}} \approx 2000\,K$) extinction efficiency condensed absorbers over a wide range of temperatures, we searched the literature to obtain optical constants for as many materials as possible. As a result of the search, we compute the extinction efficiency of 27 different kinds of species with 37 different data sets. Likewise, the values of the optical constnats change with how scientsists measure (parallel or perpendicular), temperature, or a particle size. We examined how different values of the optical constnts affect to the extinction efficiency calculation.

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Multi-level Accelerated Lambda Iteration with PRD

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When parts of a spectral line form (i.e., have optical depth near unity) in a region of a stellar atmosphere where radiative excitation in the line dominates over collisional excitation, effects of coherent scattering have to be taken into account. In this paper we will discuss the problem coherent scattering poses for multi-level radiative transfer solutions and how this problem can be solved efficiently. Several examples will be discussed. Among them are a comparison of radiative cooling rates due to the calcium H and K lines computed with angle-dependent and angle-averaged redistribution, and complete redistribution, and a demonstration of the importance of cross-redistribution for the formation of the oxygen resonance triplet at 130 nm.

Analysis of B Supergiants revised: plane-parallel vs Unified models

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We compare B supergiants stellar parameters derived from analyses using plane-parallel and unified model astmospheres. Both codes are stationary, NLTE and un-blanketed, and the atomic data set is also the same for both of them. Plane-parallel model atmospheres are calculated with ALI using DETAIL/SURFACE for silicon level populations and for the emergent spectra. Unified models are calculated using the code by Santolaya-Rey, Puls and Herrero (1997).

Convection, Radiation, Shocks - All In One Box.

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Present hydrodynamic models show that the motions at the top of the solar convection zone generate acoustic waves which propagate upwards towards higher layers. Dissipation of these acoustic waves at chromospheric heights might release a sufficient amount of energy which could account for the observed chromospheric emission.

Our aim is to check this heating mechanism with detailed numerical simulations. With COBOLD, a radiation hydrodynamics code developed by B. Freytag and M. Steffen, we are able to compute 2-D and 3-D models which include the upper convection zone, photosphere and the chromosphere, thus describing generation, propagation and dissipation of acoustic waves in a self-consistent way in the same model.

We compare different model assumptions to investigate which details have the strongest influence on the results. Based on this first parameter study we recommend 3-D models with a frequency-dependent scheme for radiative transfer (adapted to chromospheric conditions) and opacities with molecular contributions.

2-dimensional non-LTE Radiative Transfer in Cartesian, cylindrical and spherical coordinates

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A new Radiative Transfer code that can calculate the non-LTE line transfer problem in a two-level atom formulation in Cartesian, cylindrical and spherical coordinate systems is presented. The transfer equation is solved using the ALI and the short characteristics methods, while allowing for an arbitrary 3-dimensional velocity field.
The code is modularised so that changing geometry can be accomplished by simply setting a switch, and parallelised for use on a networked PC cluster to increase computational speed. The spatial parallelization method is employed. It is found to be robust and efficient, while not relying heavily on fast communication. The internal accuracy of the code is tested extensively in all three geometries and is shown to be in good agreement with appropriate 1-D solutions.