

COMMISSION 36

THEORY OF STELLAR ATMOSPHERES

*THÉORIE DES ATMOSPÈRES
STELLAIRES*

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

Commission 36 covers the whole field of the physics of stellar atmospheres. The scientific activity in this large subject has been very intense during the last triennium and led to the publication of a large number of papers, which makes a complete report quite impractical. We have therefore decided to keep the format of the preceding report: first a list of areas of current research, then Web links for obtaining further information.

Many conferences and workshops have been held during the period covered by this report on topics related to the interests of Commission 36. Some of them were sponsored by IAU: IAU Symposium No. 231 *Astrochemistry throughout the Universe: Recent Successes & Current Challenges*; IAU Symposium No. 233 *Solar Activity and its Magnetic Origin*; IAU Symposium No. 239 *Convection in Astrophysics*; IAU Symposium No. 240 *Binary Stars as Critical Tools and Tests in Contemporary Astrophysics*; IAU Symposium No. 243 *Star-Disk Interaction in Young Stars*; IAU Symposium No. 247 *Waves and Oscillations in the Solar Atmosphere: Heating and Magneto-Seismology*; IAU Symposium No. 250 *Massive Stars as Cosmic Engines*; and IAU Symposium No. 252 *The Art of Modelling Stars in the 21st Century*. Our members also participated in many of the Joint Discussions and Special Sessions at the IAU XXVI General Assembly in Prague, August 2006.

Meetings not organised under the auspices of the IAU also attracted interest from our members. Among others, the following meetings were attended: *Mass loss from stars and the evolution of stellar clusters*, May 2006, Lunteren, Netherlands; *The Metal Rich Universe*, June 2006, La Palma, Spain; *14th Cambridge Workshop on Cool stars, stellar systems and the Sun*, 6-10 November 2006, Pasadena, USA; *International Workshop*

on *Corona of Stars and Accretion Disks*, 12-13 December 2006, Bonn, Germany; *International Workshop on Clumping in Hot-Star Winds*, June 2007, Potsdam, Germany; *Fifth Potsdam Thinkshop, Meridional flow, differential rotation, solar and stellar activity*, 24-29 June 2007, Potsdam, Germany; *CP#AP Workshop*, 10-14 September, Vienna, Austria; *Fifth Solar Polarisation Workshop*, September 2007, Ascona, Switzerland; and *Magnetic Fields in the Universe, II: From laboratory and stars to the primordial Universe*, 28 January - 1 February 2008, Cozumel, Mexico.

2. Primary research areas 2005 - 2008

2.1. Physical processes

General properties – Line-blanketed, unified NLTE models of massive star atmospheres (including winds) available to the community. Grids of synthetic fluxes and spectra. Calibrating parameterized models through physical modeling. Calibrating abundance determinations by filter photometry or low-resolution spectroscopy.

Stationary processes within stellar atmospheres – Convection (granulation) in surface layers, and its effects upon emergent spectra. Interplay between convection and non-radial pulsation. Scales of surface convection in stars in different stages of evolution. Hydrodynamic simulations of entire stellar volumes.

Transient processes – Shocks in pulsating stars. Radiative cooling of shocked gas. Emission lines as shock-wave diagnostics. Co-rotating interaction regions in radiation driven stellar winds. Particle acceleration during flares. Interaction of jets with interstellar medium. Episodic outflows and star-disk interaction.

Magnetic phenomena – Magnetic structures in single and binary stars. Dynamo generation of magnetic fields by convection. Generation of magnetic fields in massive stars. Discovery of strong magnetic fields in a few massive stars. X-ray line emission from magnetically confined winds. Interaction of magnetic fields and radiation-driven winds. Effects by magnetic fields on convective structures. Exploration of the turbulent nature of the general field of the Sun. Magnetic cycles at varying activity levels. Polarized radiation, gyrosynchrotron and X-ray emission. Deriving and interpreting Zeeman-Doppler images of stellar surfaces. Hanle effect diagnostics in stellar environments.

Radiative transfer and emergent stellar spectra – Effects on atmospheric structure by deviations from local thermodynamic equilibrium (non-LTE). Multidimensional radiative transfer. Radiative hydrodynamics. Origin and transfer of polarized light. Theory of scattering of polarized light by atoms and molecules, particularly for understanding the second solar spectrum. Numerical methods in radiative transfer. Scattering mechanisms in circumstellar disks.

Spectral lines and their formation – Line formation in convective atmospheres. Wavelength shifts as signatures of convection. Detection of strong broadening of metal lines in OB supergiants, and interpretation in terms of supersonic macroturbulence. Spectra of rapidly rotating stars viewed pole-on and equator-on. Non-LTE effects in permitted and forbidden lines. NLTE IR-diagnostics of massive hot stars, particularly those close to the Galactic Centre. Atomic and quantum processes affecting spectral lines. Databases for spectral lines. Atlases of synthetic spectra.

Forbidden lines and maser emission – Molecules in atmospheres of cool giant stars. Effects of fluorescence. Permitted and forbidden lines from shocked atmospheres of pulsating giants. Maser and laser emission from stellar envelopes.

Chemical abundances – Precise abundance measurements in BA supergiants. N abundances for massive stars as a function of rotation, which challenge present stellar evolution models. Abundance anomalies. Hydrodynamical models of metal-poor stars. Depletion of light elements through atmospheric motions. Pollution of atmospheres by interstellar dust. r- and s-process elements. Chemical stratification in stable atmospheres. Coronal versus photospheric abundances. Chemical inhomogeneities and pulsation.

Molecules – Theory of the molecular Paschen-Back effect, scattering and Hanle effect in molecular lines in the Paschen-Back regime.

2.2. *Stellar structure*

Structures across stellar disks – Doppler mapping of starspots. Radii and oblateness at different wavelengths for giant stars. Gravitational microlensing to test model atmospheres. Interaction between rotation and pulsation. Doppler tomography of stellar envelopes.

Stellar coronae – Coronal heating mechanisms (quiescent and flaring). Effects of age and chemical abundance. Multicomponent structure. Coronae in also low-mass stars and brown dwarfs. Diagnostics through X-ray spectroscopy and radio emission.

Stellar winds and mass loss – Dynamic outer atmospheres. Multi-component radiation- and dust-driven winds. Mass loss from pulsating giants. Effects of mass flows on the ionization structure. Coronal mass ejections. Instabilities in hot-star winds. X-ray emission.

Dust, grains, and shells – Formation of stellar dust shells. Grains in the atmospheres of red giants, and in T Tauri stars.

2.3. *Different classes of objects*

Stellar parameters of massive stars – significant downscaling of effective temperature scale of OB-stars, due to line-blanketing and mass-loss effects. Rotation rates for massive stars, as a function of metallicity. VLT-FLAMES survey of massive stars: 86 O-stars and 615 B-stars in 8 different clusters (Milky Way, LMC, SMC) observed and analyzed.

Stellar winds and mass-loss – Inhomogeneities in stellar winds suggest downscaling of mass-loss rates. Weak-winds from late O-/early B-dwarfs, which display significantly lower mass-loss rates than theoretically expected. Self-consistent models for winds from Wolf-Rayet stars. Empirical mass loss-metallicity relation for O-stars. X-ray line emission from line-driven winds. Stellar winds at very low abundances (First Stars). Continuum driven winds for super-Eddington stars. Wind-diagnostics by linear polarization variability.

Pulsating stars and asteroseismology – Classically variable stars, and 'ordinary' solar-type ones. Evidence for opacity-driven gravity-mode oscillations in periodically variable B-type supergiants. Inverting observed pressure-mode frequencies into atmospheric structure. Mass-loss mechanisms in pulsating stars. Effects of rapid rotation on pulsation.

Binary stars – Atmospheric structure and magnetic dynamos in common-envelope binaries. Role of binarity on mass loss. Tidal effects. Non-LTE effects by illumination from the component. Reflection effects in close binaries. Colliding stellar winds.

New classes of very cool stars – Dust, clouds, weather, and chemistry in brown dwarfs. Cloud clearings and hot-spots. Magnetic activity. The effective temperature scale. Molecular line and continuum opacities. Transition between extrasolar giant planets and ultracool brown dwarfs.

White dwarfs and neutron stars – Radiative transfer in magnetized white-dwarf atmospheres. Stokes-parameter imaging of white dwarfs. Molecular opacities in white dwarfs. Broad-band polarization in molecular bands in white dwarfs. Atmospheres and spectra of

neutron stars. Effects of vacuum polarization and accretion around magnetized neutron stars.

Special objects – Central stars of planetary nebulae. Population III stars of extremely low metallicity. Protostars. Accretion disks and coronal activity in young stars.

Interaction with exoplanets – Effects of planets on the atmospheres of evolved red giants. Characteristics of stars hosting exoplanets.

2.4. Development of techniques

Computational techniques – Parallel (super)computing to simulate convective surface regions, and throughout complete stars. 2- and 3-D NLTE unified models including winds. Neural networks and machine-learning algorithms. Analysis of stellar spectra using genetic algorithms. Preparing for the widely distributed network of computational tools and shared databases being developed for the forthcoming computing infrastructure GRID.

2.5. Applications of stellar atmospheres

Besides their study per se, stars are being used as probes for other astrophysical problems:

Exoplanets – Variable wavelength shifts in stellar spectra serve as diagnostics for radial-velocity variations induced by orbiting exoplanets. Atmospheric modeling can indicate which spectral features are suitable as such probes, and which should be avoided due to their sensitivity to intrinsic stellar activity.

Chemical evolution in the Galaxy – How accurately observations of stellar spectral features can be transformed into actual chemical abundances depends sensitively on the sophistication of the stellar model atmospheres.

Kinematics of the Galaxy – Planned space missions intend to measure radial velocities for huge numbers of stars. Model atmospheres are used to identify suitable spectral features for such measurements in different classes of stars.

Chemical evolution of Galaxies – Accurate measurements of metallicity gradients in various galaxies based on BA supergiants.

Evolution of First Stars – Effects from winds may be stronger than expected, due to fast rotation, continuum driving or self-enrichment. Strong mass-loss offers possibility to avoid Pair-Instability SNe.

Distance scales – Flux-weighted gravity-luminosity relationship as a tool to derive independent, precise extragalactic distances from A-supergiants.

Galaxies and cosmology – Stars are the main observable component of galaxies, and population synthesis for galaxies utilize model atmospheres to interpret observations. Cosmological origin of the lowest-metallicity stars.

3. Web links for further information

The following collection of links provides introductions and overviews of several significant subfields of the physics of stellar atmospheres.

3.1. Calculating atmospheric models and spectra

ATLAS, SYNTHÉ, and other model grids: <kurucz.harvard.edu>.

MARCS, model grids: <www.marcs.astro.uu.se>.

Tuebingen: Stellar atmospheres - grid of models:

<astro.uni-tuebingen.de/groups/stellar>.

CCP7 - Collaborative Computational Project: <ccp7.dur.ac.uk>.

CLOUDY - photoionization simulations: <www.pa.uky.edu/~gary/cloudy/>.
 MULTI - non-LTE radiative transfer: <www.astro.uio.no/~matsc/mul22>.
 PANDORA - atmospheric models and spectra:
 <www.cfa.harvard.edu/~avrett/pandora.lis.copy>.
 PHOENIX - stellar and planetary atmosphere code:
 <www.hs.uni-hamburg.de/EN/For/ThA/phoenix/>.
 STARLINK - theory and modeling resources:
 <www.astro.gla.ac.uk/users/norman/star/sc13/sc13.htx>.
 Synthetic spectra overview: <www.am.ub.es/~carrasco/models/synthetic.html>.
 TLUSTY - model atmospheres: <tlusty.gsfc.nasa.gov>.
 WM-Basic: unified hot star model atmospheres incl. consistent wind structure:
 <www.usm.uni-muenchen.de/people/adi/adi.html>.
 PoWR: The Potsdam Wolf-Rayet Models, grid of synthetic spectra:
 <www.astro.physik.uni-potsdam.de/~wrh/PoWR/powrgrid1.html>.

3.2. Useful links from research groups or individual researchers

Vienna: Stellar atmospheres and pulsating stars:
 <ams.astro.univie.ac.at/main.php>.
 Potsdam: Stellar convection:
 <www.aip.de/groups/sternphysik/stp/convect_neu.html>.
 R. F. Stein: Convection simulations & radiation hydrodynamics:
 <www.pa.msu.edu/~steinr/research.html#convection>.
 D. Dravins: Stellar surface structure:
 <www.astro.lu.se/~dainis/HTML/GRANUL.html>.
 A. Collier Cameron: Starspots and magnetic fields on cool stars:
 <star-www.st-and.ac.uk/~acc4/coolpages/imaging.html>.
 D. F. Gray: Stellar rotation, magnetic cycles, velocity fields:
 <astro.uwo.ca/~dfgray/>.
 J. F. Donati: Magnetic fields of non degenerate stars:
 <webast.ast.obs-mip.fr/users/donati/>.
 M. Jardine: Stellar coronal structure:
 <capella.st-and.ac.uk/~mmj/Welcome_research.html>.
 Munich: Hot stars: <www.usm.uni-muenchen.de/people/adi/adi.html>,
 <www.usm.uni-muenchen.de/people/adi/wind.html>.
 S. Jeffery: Stellar model grids, hot stars: <star.arm.ac.uk/~csj/>.
 P. Stee: Be-star atmospheres and circumstellar envelopes:
 <www.obs-nice.fr/stee/Bemodel.html>,
 <www.obs-nice.fr/stee/simugb.html>.
 N. Przybilla: NLTE atmospheres of massive stars, extragalactic stellar astronomy:
 <www.sternwarte.uni-erlangen.de/~przybilla/research.html>.
 S. Owocki: Theory of line-driven winds, hydrodynamics, rotation, magnetic fields:
 <www.bartol.udel.edu/~owocki/>.
 R. Townsend: Magnetically-Controlled Circumstellar Environments of Hot Stars:
 <zuserver2.star.ucl.ac.uk/~rhdt/research/magnetic/>.
 P. Crowther: Hot Luminous Star Research Group:
 <shef.ac.uk/physics/people/pacrowther/>.
 R. Kudritzki: Hot Stars and Winds, Extragalactic Stellar Astronomy:
 <www.ifa.hawaii.edu/~kud/kud.html>.
 J.L.Linsky: Cool stars, stellar chromospheres and coronae:
 <jilawww.colorado.edu/~jlinsky/>.

- G. Basri: Brown dwarfs: <astro.berkeley.edu/~basri/bdwarfs/>.
- D. Montes *et al.*: Libraries of stellar spectra:
<www.ucm.es/info/Astrof/spectra.html>.
- R. J. Rutten: Lecture notes: Radiative transfer in stellar atmospheres:
<www.fys.ruu.nl/~rutten/node20.html>.

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