ASTR 545 STELLAR ATMOSPHERES

Introduction

1. Outline
   - What is a stellar atmosphere?
   - Basic properties and morphology
   - Why study stellar atmospheres?
   - Stellar Atmospheres in the global astronomical and physical context
2. Observational Foundations
   - Spectral Classification
   - Colors, color-magnitude diagrams

Phenomenological Description of Radiation

3. Radiation
   - Specific intensity
   - Mean energy and energy density
   - Radiation flux and pressure tensor
   - Thermal radiation: Planck function
4. Interaction of radiation with matter
   - Absorption, emission, and scattering of radiation
   - Phenomenological absorption and emission coefficients
   - Stimulated emission
   - Emission by scattering
5. Radiative transfer equation
   - Derivation
   - Transport equation in various geometries
   - Moments of the transport equation
   - Optical depth and the source function

- Probabilistic interpretation
- Diffusion approximation

6. Approximate treatments of line formation
   - Eddington-Barbier relation
   - Classical Milne-Eddington and Schuster-Schwarzschild models
   - Optically thick and thin regimes
   - Escape probability
   - Flux-limited diffusion
   - Some astrophysical applications

Physics of Radiation-Matter Interaction

7. Kinetic equilibrium; LTE and NLTE
   - Fundamentals of statistical mechanics
   - Local Thermodynamic Equilibrium (LTE)
   - Microscopic requirements of LTE
   - Departures from LTE: non-LTE (or NLTE) effects
   - NLTE rate equations
8. Quantitative description of radiation-matter interactions
   - Semi-classical calculation of transition probabilities
   - Einstein relations for bound-bound transitions
   - Einstein-Milne relations for the continuum
   - Continuum absorption and scattering cross-sections
   - Thomson and Compton scattering
9. Spectral lines: broadening and redistribution
   - Overview of line broadening mechanisms
   - Natural damping
   - Collision (pressure) broadening
   - Frequency redistribution in lines
   - Redistribution functions

Radiation Transport

10. Formal solution of the transfer equation
    - Basic strategies; discretization
    - Integral methods: short characteristics
    - Finite elements methods; discontinuous finite element
    - Second-order differential methods: Feautrier algorithm
    - Comparison of methods
11. Radiative transfer with scattering
    - Nature of the problem
    - Lambda iteration and its failure
    - Direct algorithms
    - Iterative methods
12. Accelerated Lambda iteration
    - Aside on linear algebra: iterative solutions of large sparse linear systems
    - Astrophysical implementation
    - Construction of the approximate operator
13. NLTE line transfer
    - Two-level atom
    - Equivalent 2-level atom approach
    - Multi-level atom: coupling of many transitions and levels
    - Modern numerical approaches

Model Atmospheres and Spectral Analysis

14. Basic physics and equations of stellar atmospheres
    - Overview of Equations
    - Overview of approximations; basic types of models
    - Energy balance: radiative and convective equilibrium

15. Model stellar atmospheres: LTE-gray models
    - Formulation
    - Mean opacities
    - LTE-gray model: a key to understand the temperature structure of a stellar atmosphere
    - Generalizations of the gray model: two-step gray; multi-group
16. LTE model atmospheres
    - Temperature correction schemes
    - Treatment of convection: Mixing-length theory
    - Line blanketing
    - Treatment of molecules
    - Results: LTE temperature structure and emergent energy distribution
    - Existing grids of LTE model atmospheres: Kurucz models
17. NLTE stellar atmospheres: Methods
    - Early approximate models: Detailed radiative balance in lines
    - Complete Linearization
    - Modern numerical methods: application of ALI
    - NLTE line blanketing: superlevels and superlines
    - TLUSTY code
18. NLTE stellar atmospheres: Results; grids
    - NLTE temperature structure
    - Effects of NLTE line blanketing
    - NLTE emergent spectral energy distribution
    - Overview of existing computer programs and model grids
19. Use of model atmosphere for determining basic stellar parameters
    - Classical methods: curve of growth, abundances
    - Micro- and macro-turbulence, rotation
    - Detailed spectrum synthesis
    - Fit diagrams
    - NLTE abundance determination
    - Overview of spectrum synthesis codes

Beyond Classical Models

20. Radiative transfer in expanding atmospheres
    - Transfer equation in the observer's (Eulerian) frame
    - Transfer equation in the comoving (Lagrangian) frame
    - Sobolev approximation
    - Numerical methods
21. Stellar winds
    - Equations of radiation hydrodynamics
    - Radiation (line)-driven winds
    - Other types of stellar winds
    - Wind diagnostics
22. Atmospheres of substellar mass objects
    - Exatrasolar giant planets and brown dwarfs: Similarities and differences
    - Chemical equilibrium and departures from it
    - Grains and cloud formation
    - Models atmospheres of substellar mass objects
    - Theory precedes observations: models spectra of yet undiscovered Y dwarfs
    - Some applications
23. Accretion disks
    - Basic physics of accretion disks
    - Atmospheres and disks: similarities and differences
    - Accretion disk models
    - Applications: quasars and AGNs, X-ray binaries; cataclysmic variables
24. Advanced radiative transfer
    - Multi-dimensional transport
    - Time-dependent radiation transport
    - Neutrino transport; core-collapse supernovae
    - Radiation Hydrodynamics

Literature

- D.Mihalas and I. Hubeny, 2008: *Stellar Atmospheres*, 3rd Ed. (so far unpublished - draft version of selected chapters)
- I. Hubeny, 1997: *Stellar Atmospheres Theory: An Introduction*, in "Stellar Atmospheres: Theory and Observations", ed. by J.P. De Greve, R. Blomme, and H. Hensberge, Lecture Notes in Physics, Springer, Berlin Heidelberg (available electronically)
- D.Mihalas, 1978: *Stellar Atmospheres*, 2nd Ed., Freeman, San Francisco