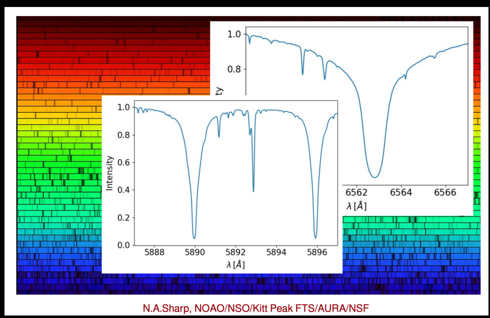
MASTER IN ASTROPHYSICS

Formation and Interpretation of Stellar Spectra (FISS)

SUMMARY.



Most of the information astronomers obtain from their telescopes is under the form of light spectra, i. e. the radiative energy emitted by the astrophysical objects as a function of the wavelength. More and more relevant physical information may be obtained by increasing the spatial and spectral resolutions. So, one of the most fundamental tool for astrophysicists is spectra modeling which allows to interpret the observations. To achieve this, one needs both to describe the physical phenomena taking place in the object and how the photons are created, absorbed or scattered and finally can escape the object and be detected by our instruments. In this METEOR, we shall focus on light emitted by stellar atmospheres, which restricts somehow the possible physical mechanisms at play. This training module aims at understanding how the physical conditions in a stellar atmosphere are imprinted in the shape of the light spectrum it emits. The students will focus on how to compute synthetic spectra from a given atmospheric model and on how to derive the fundamental stellar parameters from photometric data. We'll use one-dimensional models and spatially-averaged stellar spectra. Several practical applications will be performed using synthetic spectra and spectra obtained from ground and space-based instruments (VLT, Gaia/RVS, Hinode satellite...)

OBJECTIVES

We shall study how the atmosphere radiates and show that it emits a continuum spectrum quite close to a black body spectrum, allowing to define the so-called "effective temperature" of the star surface. Increasing the spectral resolution, we can observe absorption lines in the spectrum, i. e. a decrease of the radiative energy on narrow wavelength bands (a few hundredths of nanometers typically). These lines are due to the absorption of photons by chemical elements in the stellar atmosphere. One of the challenges of the interpretation of stellar spectra is to be able to explain both the wavelength positions and the shapes of the spectral lines (see the Figure). If we can achieve this, we get a wealth of information on the physics of the star, such as the abundances of the chemical elements, the acceleration of gravity at the surface, the effective temperature, rotational velocity, turbulence, convection, pulsations, etc ...

- Students will be able to understand how to apply basic physical laws to the modeling of an astrophysical object, to validate a model from observable quantities and to access the limitations of a model.
- They will learn how to derive and solve the radiative transfer equation in various media, and to implement numerical methods both in the case where the medium is in local thermodynamical equilibrium (LTE) and when it deviates from LTE.

PREREQUISITES

Basic computing skills
Fundamental courses:

- Stellar Physics (in particular: stellar atmospheres)
- General Astrophysics
- Statistical physics

THEORY

by Marianne Faurobert & Patrick de Laverny

- Stellar atmospheres (stationary and in radiative equilibrium) - Physical model and related equations - Stellar parameters - One-dimensional approximation - Formal solution and Eddington-Barbier approximation- Integral equation for the source function, the Lambda operator.

- Continuum spectrum emitted by a stellar atmosphere in LTE - Computation of the absorption coefficient.
- Continuum spectrum formed out of LTE in an atmosphere with scattering due to dust or molecules.
- Formation of spectral lines: Line absorption profiles -Opacity, emissivity and source function in a spectral line -LTE versus non-LTE. Formation of spectral lines under LTE and non-LTE conditions. Two-level atom and the integral equation for the source function.

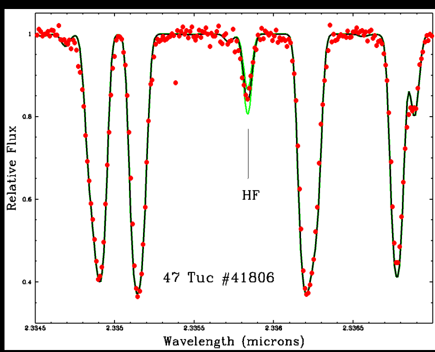
APPLICATIONS

by MARIANNE FAUROBERT

Interpretation of solar spectra obtained onboard the Hinode satellite.
Formation of the continuous solar radiation at 630 nm. Computation of continuum radiation from regions at different distances from the solar limb using a one-dimensional model of the solar atmosphere assuming LTE conditions. Comparison of the results with the center-to-limb variation of the continuum observed with Hinode.
Formation of the FeI 630.15 nm line observed at the center of the solar disk. Derivation of the line opacity (in LTE) and of the line absorption profile (Voigt profile). Numerical solution of the radiative transfer equation in the line. Comparison of the emergent line profile with the observed one. Discussion on the limitations of one-dimensional atmospheric models.
Additional study for students with good computing skills: Transmission and reflection coefficients of an atmosphere with scattering particles: a "simple" case of non-LTE radiative transfer. In that case the source function is not the Planck function but the mean intensity of the radiation field itself. The RT equation is an integro-differential equation that you will solve by iterative methods (called Lambda iteration and accelerated lambda iteration).

by PATRICK DE LAVERNY

Analysis of stellar spectra: As a practical application to observed stellar data, the students will learn how to estimate fundamental parameters such as stellar effective temperatures and surface gravities from broad-band photometry. Data from the ESA Gaia mission will be used. Then, they will be introduced to the numerical computation of 1D LTE synthetic spectra (Turbospectrum code) in order to be able to derive individual chemical abundances from observed spectra collected thanks to ESO and/or ESA Gaia spectrographs.



MAIN PROGRESSION STEPS

- First half of the period : with M. Faurobert. Theoretical courses in parallel with applications
- Second half of the period : with P. de Laverny. Bibliographical study and applications
- Last week : preparation of the final oral presentation.

EVALUATION

- Written exam on the theoretical aspects at the end of the first period (25%), report on the first applications (25%).
- Oral presentation of a published article (25%), report on the applications made in the second period (25%).
- The students' productions will be evaluated with respect to their ability in recovering standard theoretical results, in presenting clearly the context of a published work and the hypothesis, the results and their limitations. Reports are expected to be concise but stating clearly the objectives of the work, the method employed and comments on the results.

BIBLIOGRAPHY & RESSOURCES

Gaia data release article (DR2 & DR3)
The Observation and Analysis of Stellar Photospheres. Gray, Cambridge University Press, 2008.
Stellar atmospheres. Mihalas, Dover, 1978
http://www.staff.science.uu.nl/ rutte101/

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