Stellar Atmospheres: Literature

- Dimitri Mihalas
  - Stellar Atmospheres, W.H. Freeman, San Francisco
- Albrecht Unsöld
  - Physik der Sternatmosphären, Springer Verlag (in German)
- Rob Rutten
  - Lecture Notes Radiative Transfer in Stellar Atmospheres http://www.fys.ruu.nl/~rutten/node20.html

Why physics of stellar atmospheres?

Physics

Stellar atmospheres as laboratories

Plasma-, atomic-, and molecular physics, hydrodynamics, thermodynamics

Basic research

Technical application

Astronomy

Spectral analysis of stars

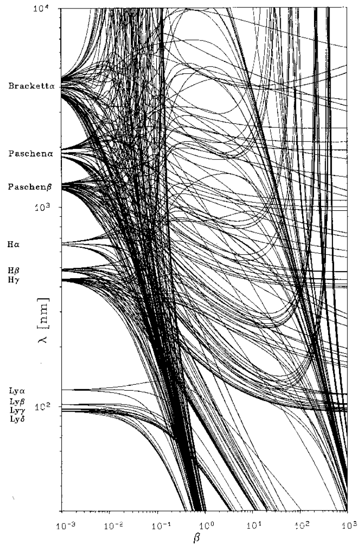
Structure and evolution of stars

Galaxy evolution

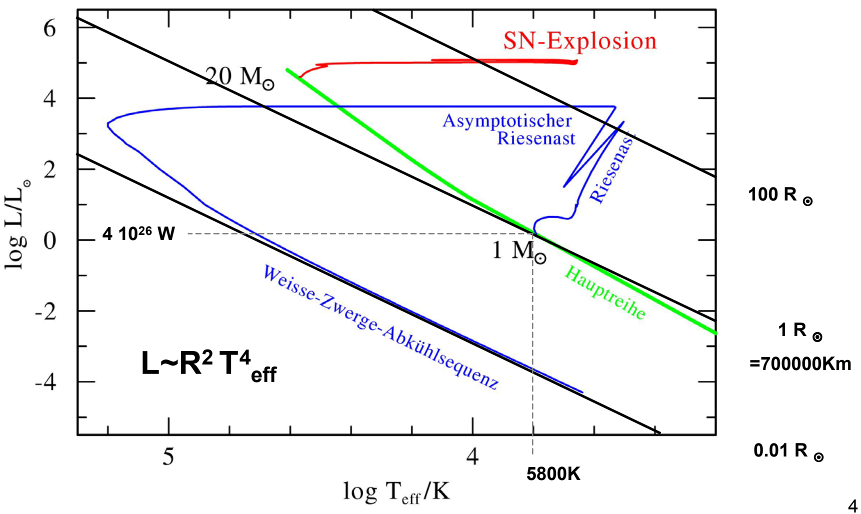
Evolution of the Universe

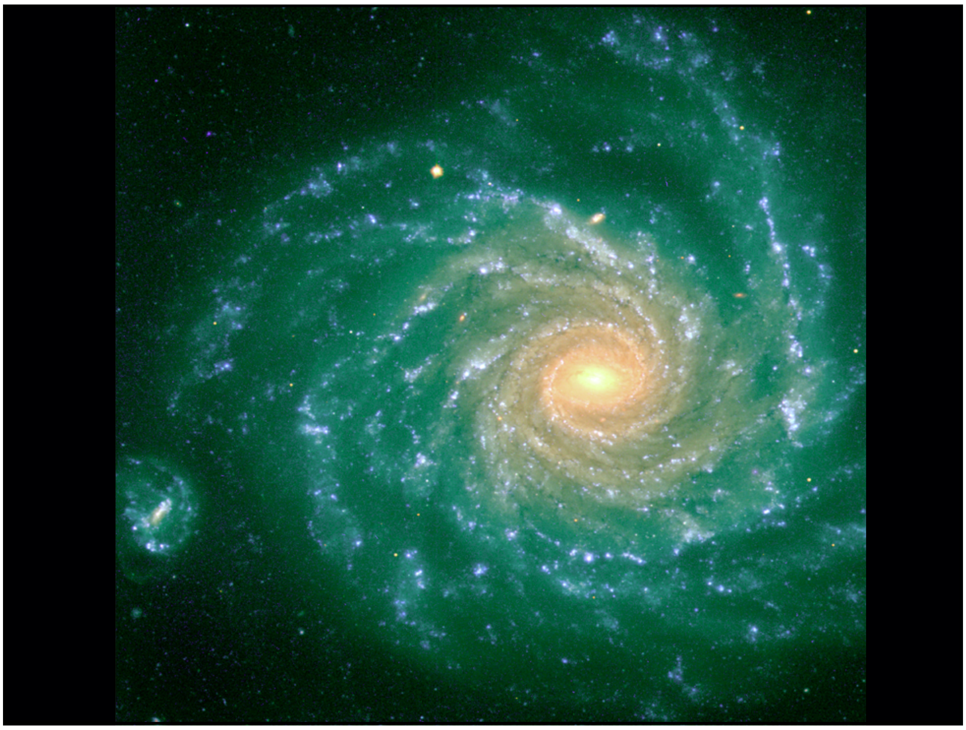
Magnetic fields in white dwarfs and neutron stars

Shift of spectral lines with increasing field strength

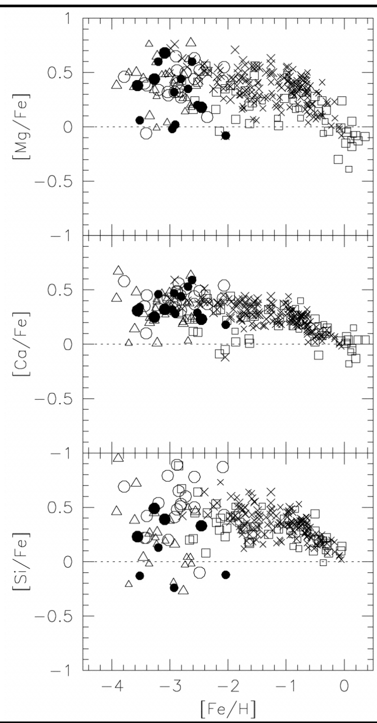


Hertzsprung Russell Diagram



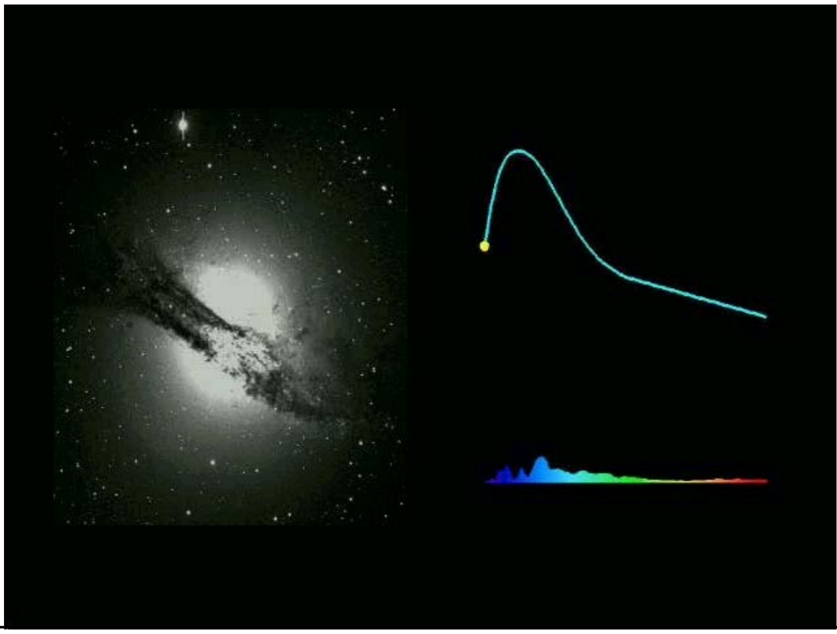


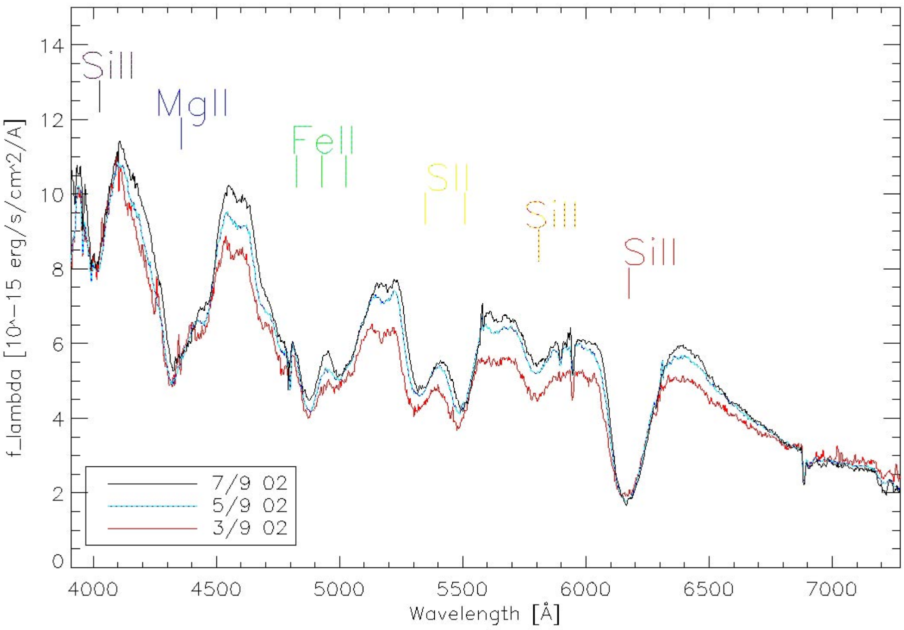
Chemical evolution of the Galaxy



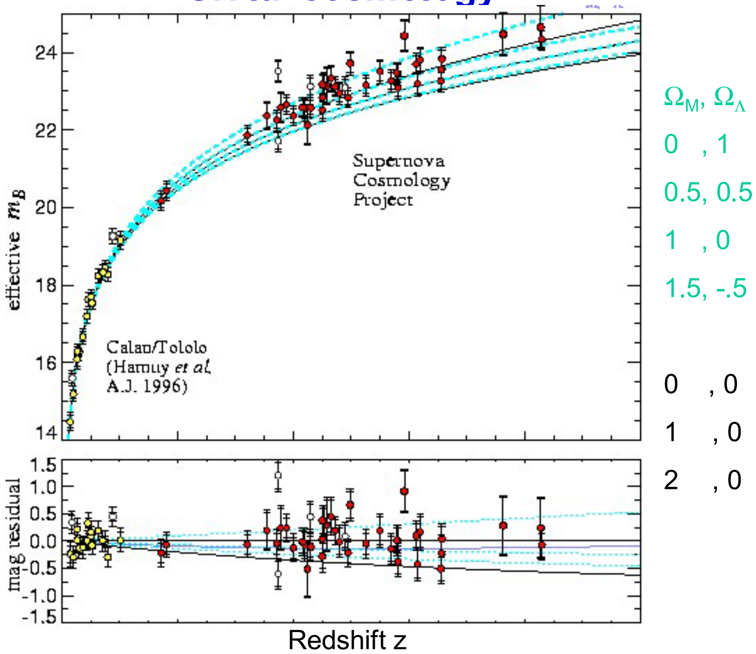
Carretta et al.
2002, AJ 124, 481

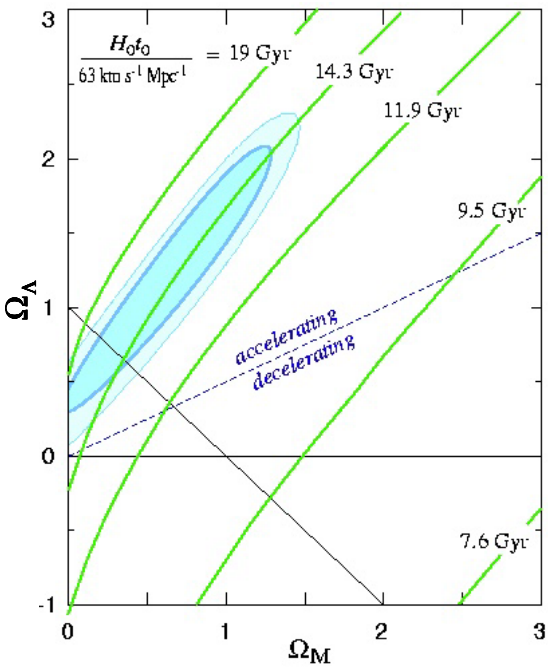
SN movie



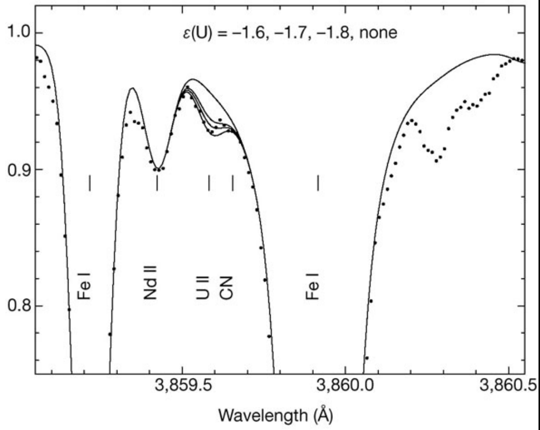

SiII
MgII
FeII
SII
SiII
SiII
7/9 02
5/9 02
3/9 02
f_lambda [10^-15 erg/s/cm^2/A]
Wavelength [Å]
0
2
4
6
8
10
12
14
4000
4500
5000
5500
6000
6500
7000

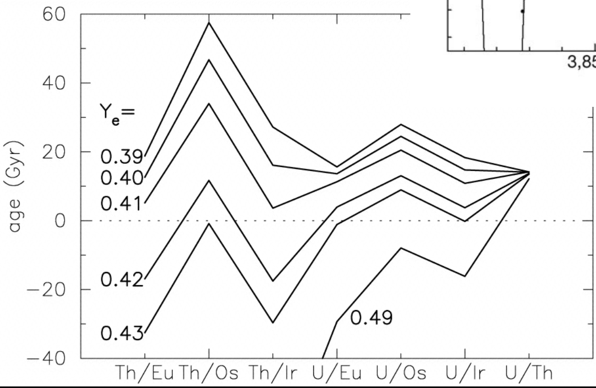
SN Ia cosmology





Uranium-Thorium clock





Stellar atmosphere – definition

- From outside visible, observable layers of the star
- Layers from which radiation can escape into space
  - Dimension

- Not stellar interior (optically thick)
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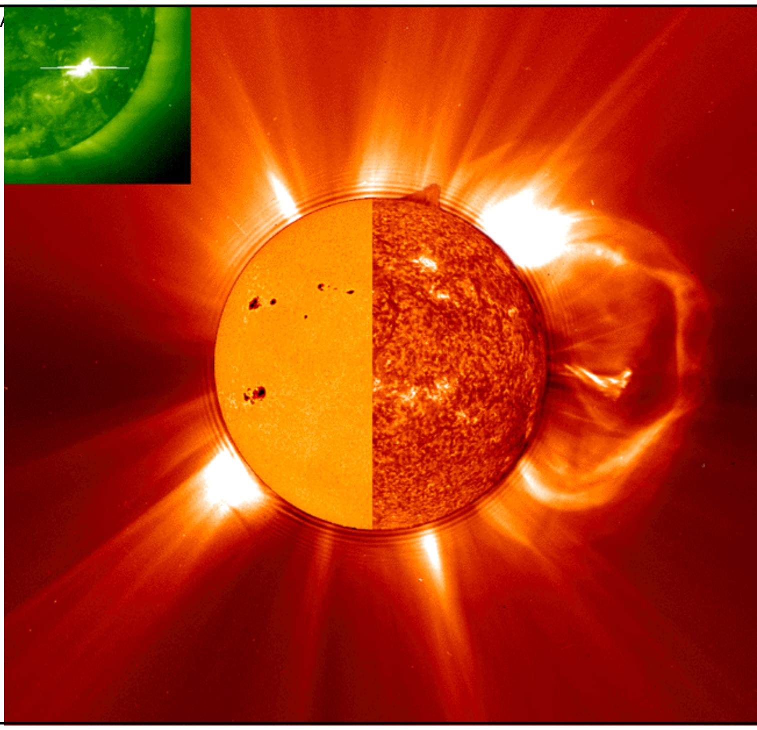
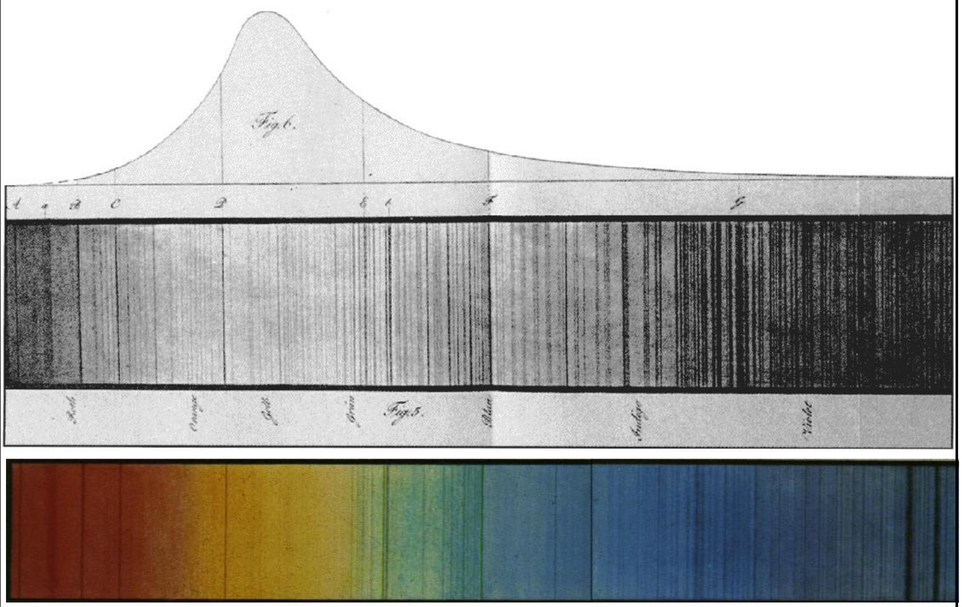
- But: chromospheres, coronae, stellar winds, accretion disks and planetary atmospheres are closely related topics

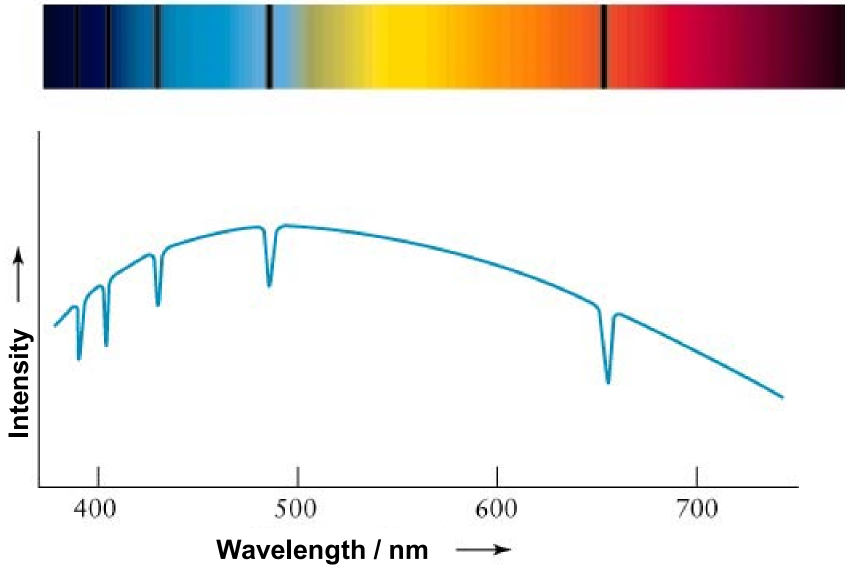


Fraunhofer lines



Stellar Atmospheres: Motivation

Spectrum - schematically



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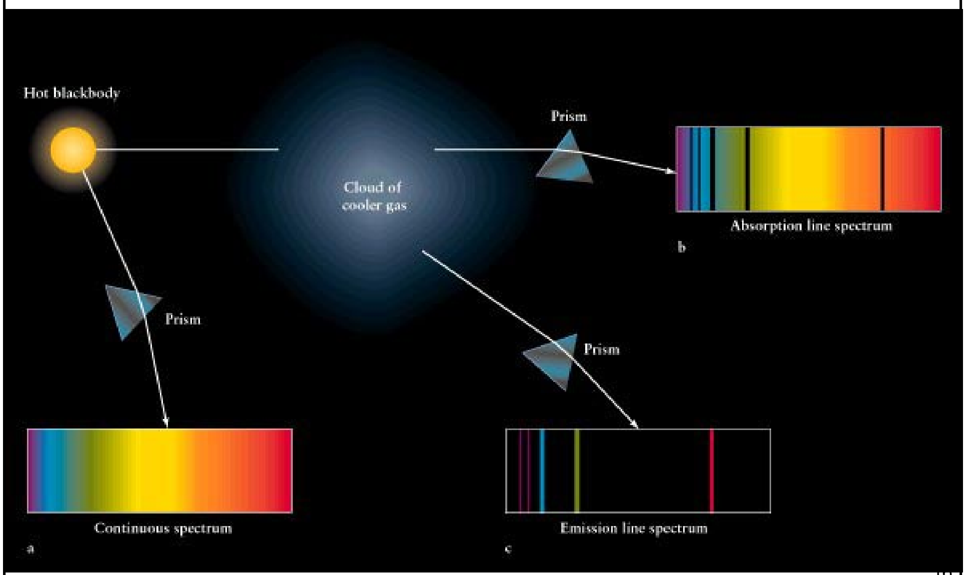
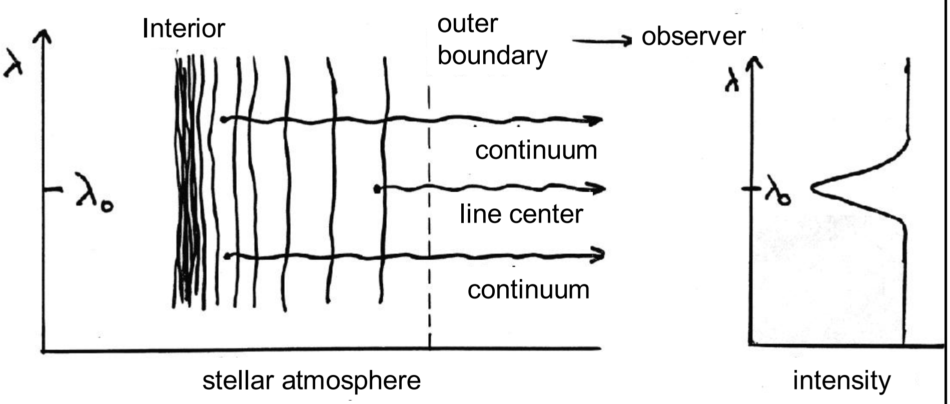
Stellar Atmospheres: Motivation

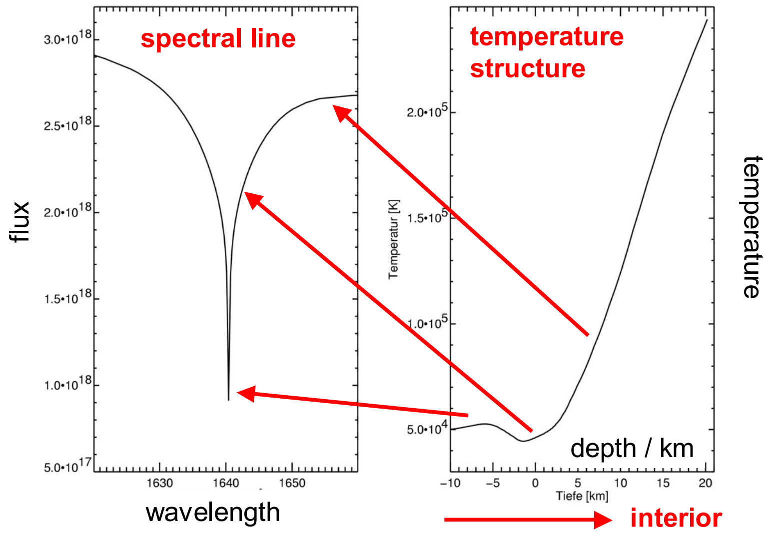
Spectrum formation

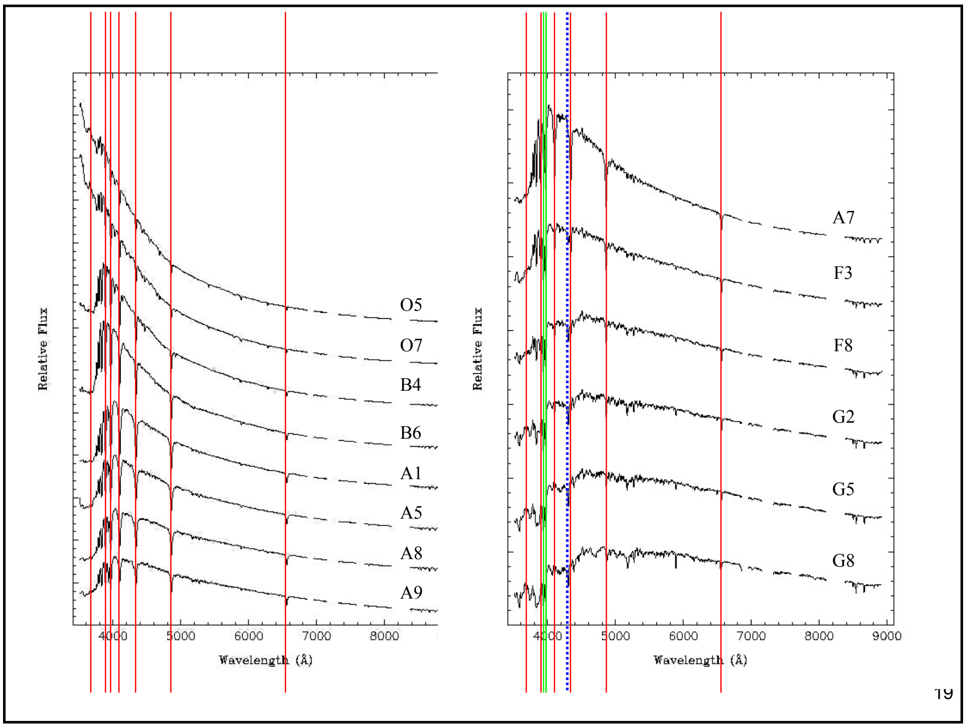


Formation of absorption lines



Line formation / stellar spectral types

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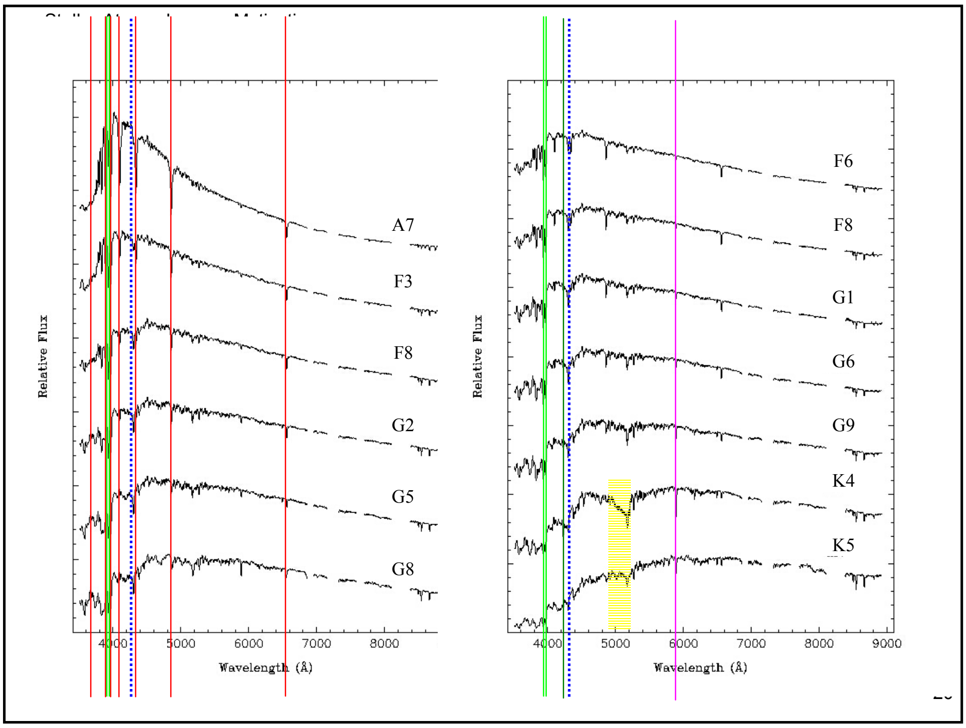
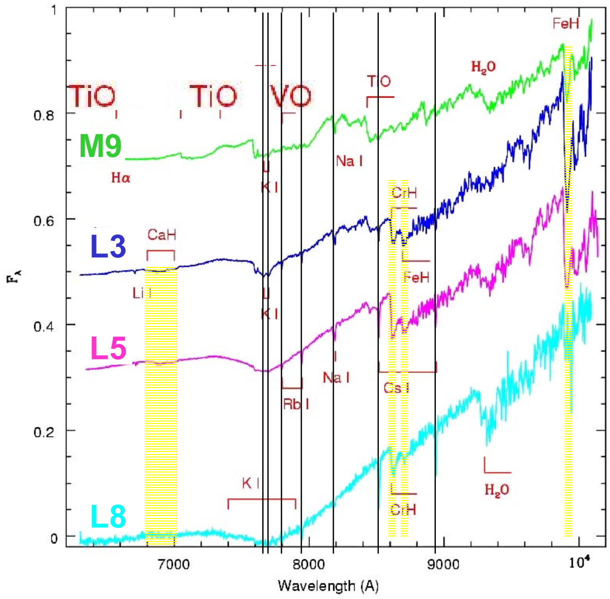
O5
O7
B4
B6
A1
A5
A8
A9
4000
5000
6000
7000
8000
Wavelength (Å)
Relative Flux
A7
F3
F8
G2
G5
G8
4000
5000
6000
7000
8000
9000
Wavelength (Å)
19


Relative Flux
A7
F3
F8
G2
G5
G8
4000
5000
6000
7000
8000
Wavelength (Å)
Relative Flux
F6
F8
G1
G6
G9
K4
K5
4000
5000
6000
7000
8000
9000
Wavelength (Å)

Stellar Atmospheres: Motivation



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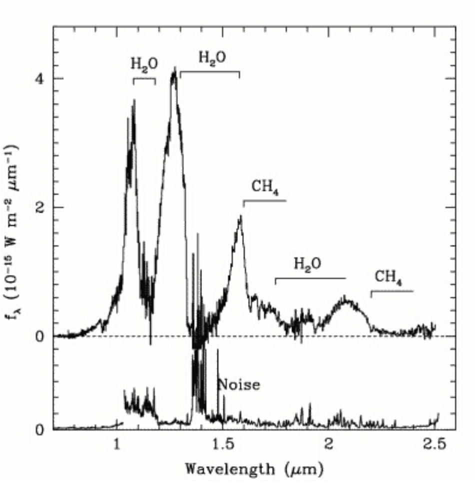
Stellar Atmospheres: Motivation

Classification scheme

T dwarfs



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Optical telescopes

Calar Alto (Spain)
3.5m telescope

Stellar Atmospheres: Motivation

Optical telescopes

ESO/VLT

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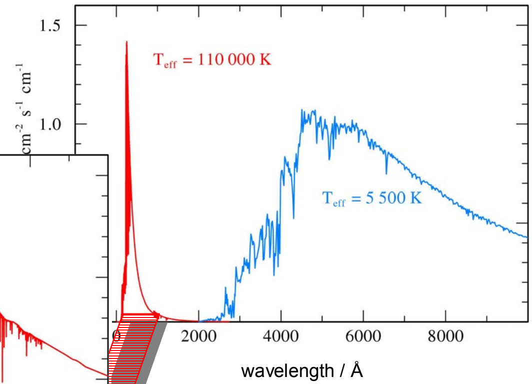
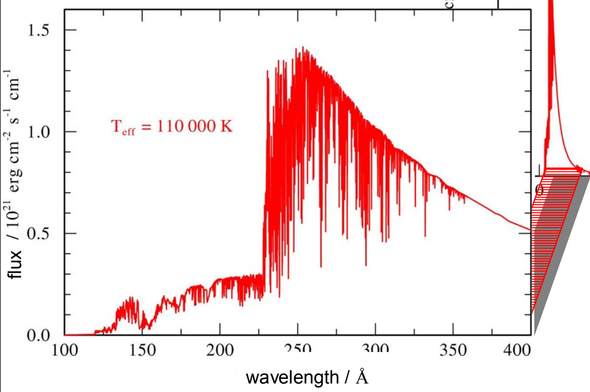
Stellar Atmospheres: Motivation

UV / EUV observations

Why is it important?





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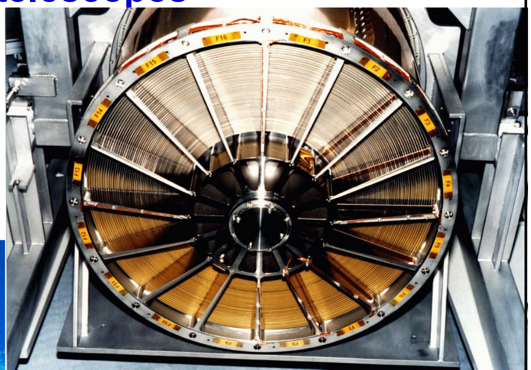
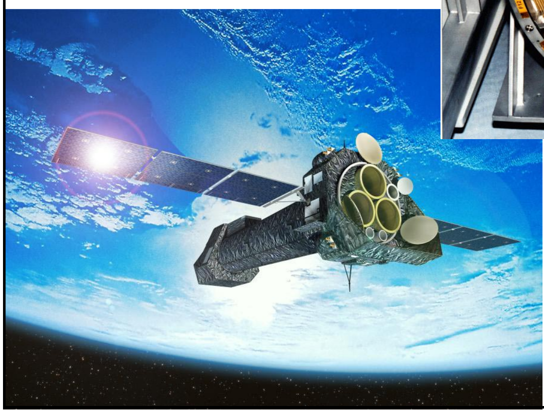
UV/optical telescopes

HST

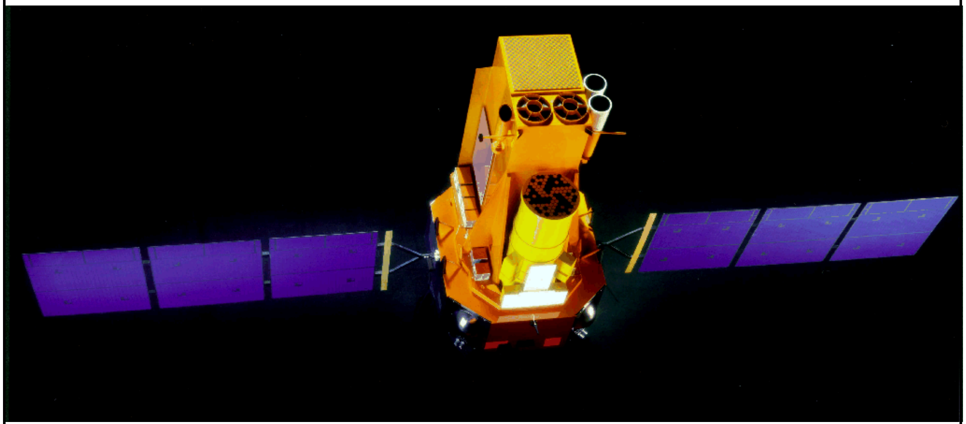
X-ray telescopes





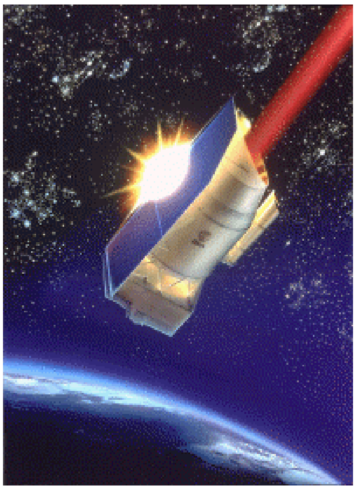
XMM

Gamma-ray telescopes



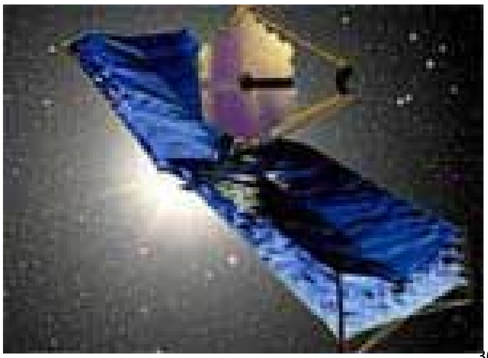
INTEGRAL

Infrared observatories

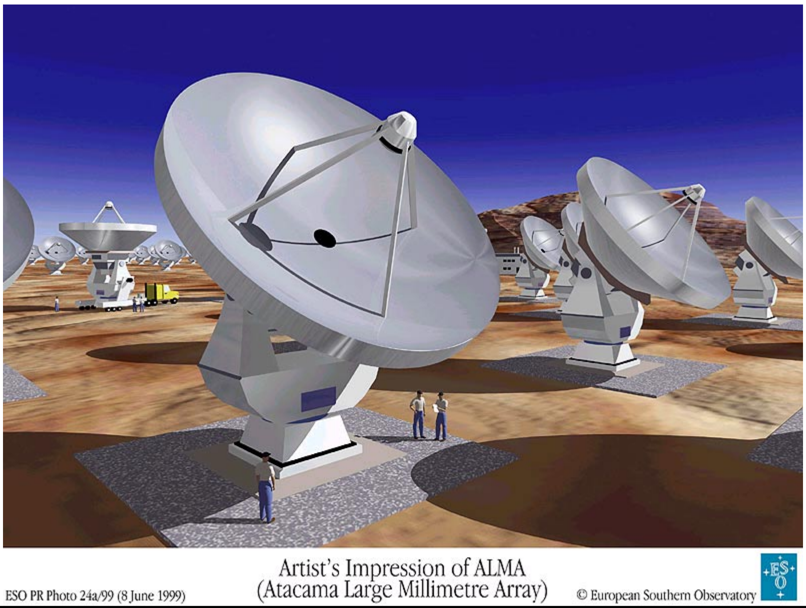


ISO

JWST



Sub-mm telescopes



Radio telescopes

100m dish at Effelsberg

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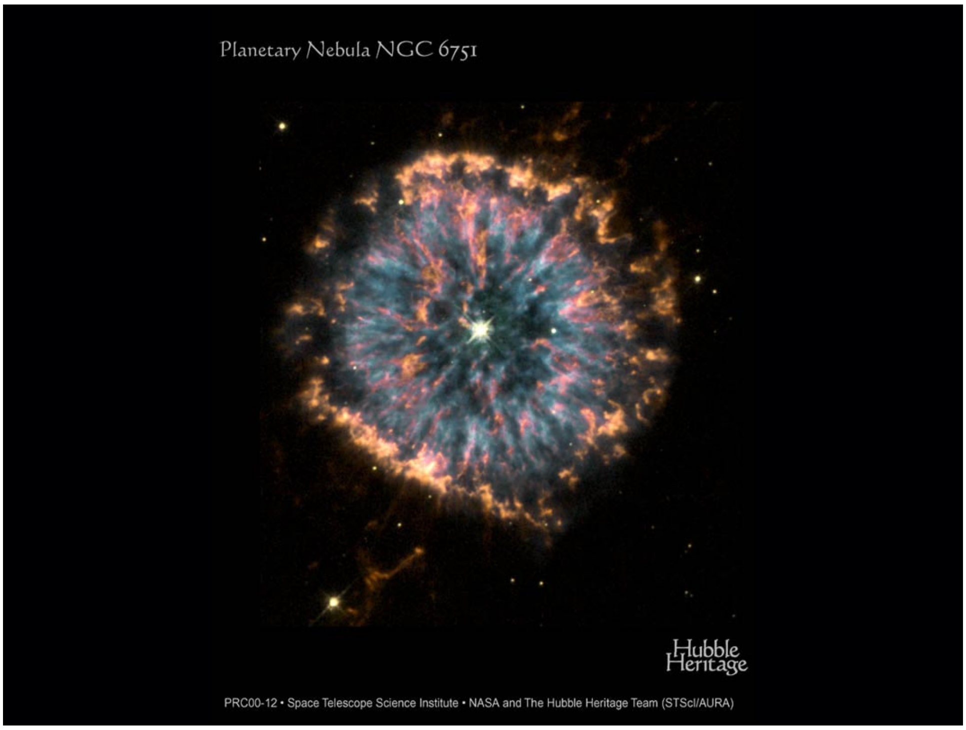
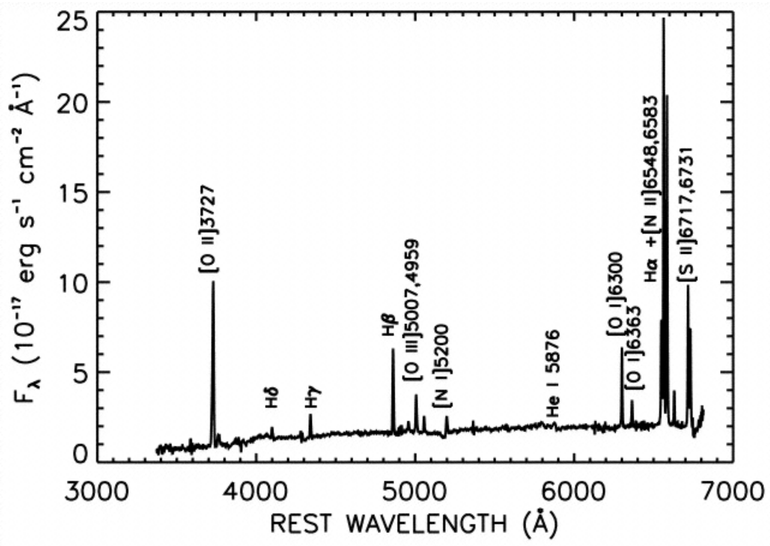
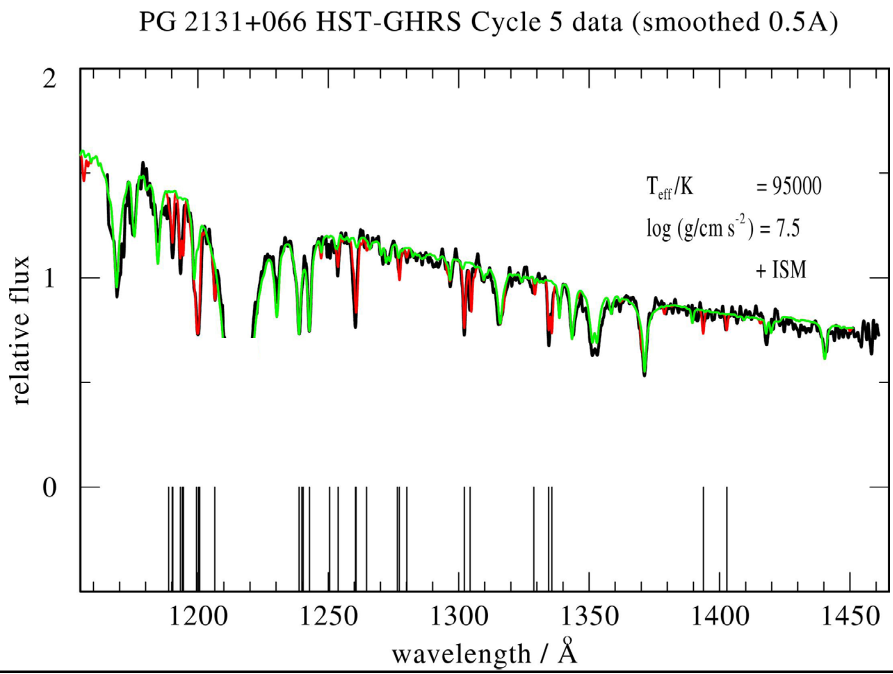
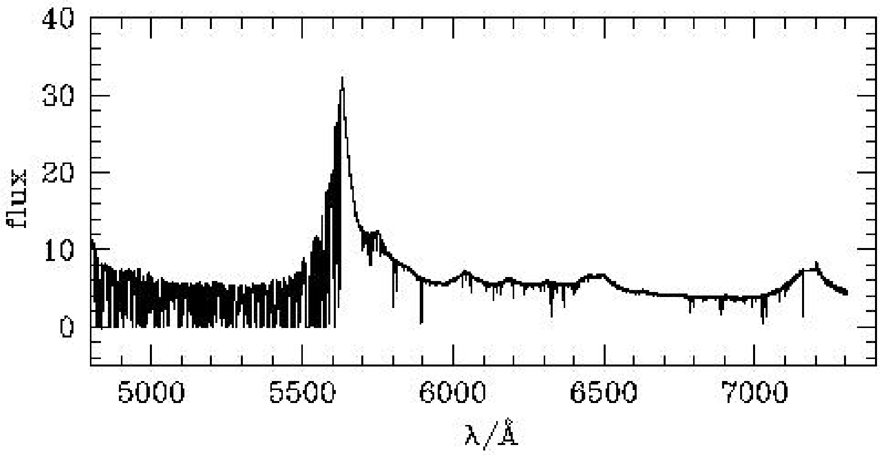


Planetary nebula spectrum





Quasar + IGM spectrum



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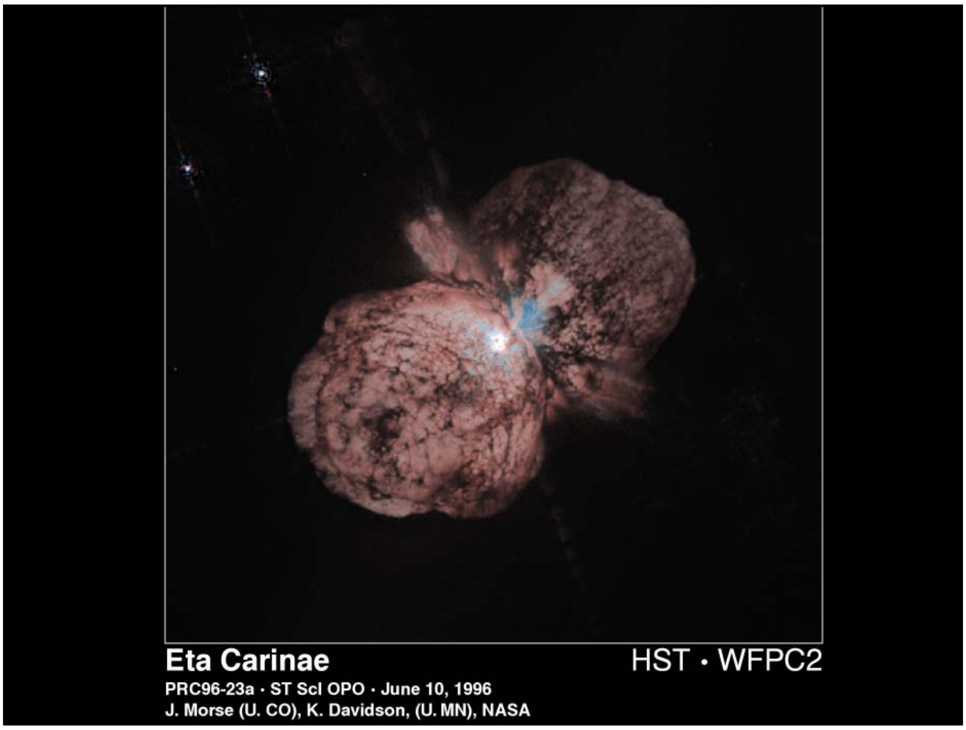
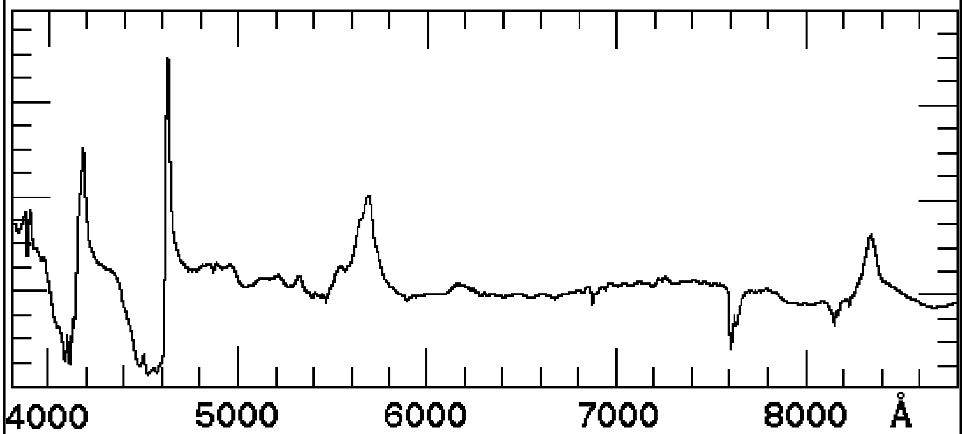
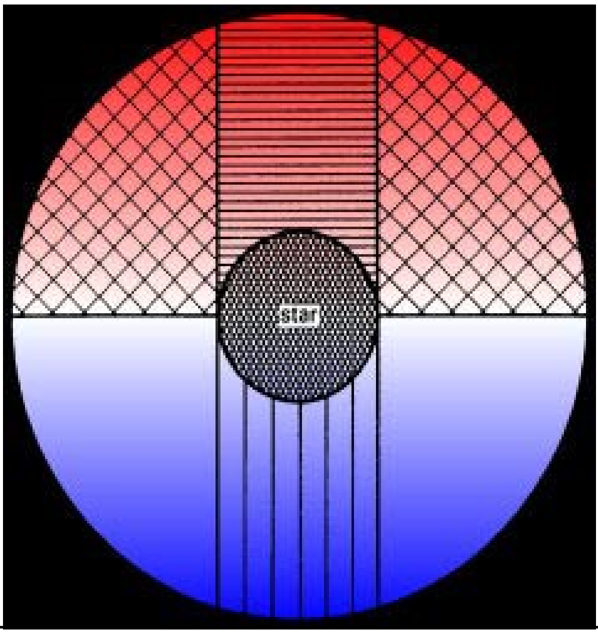


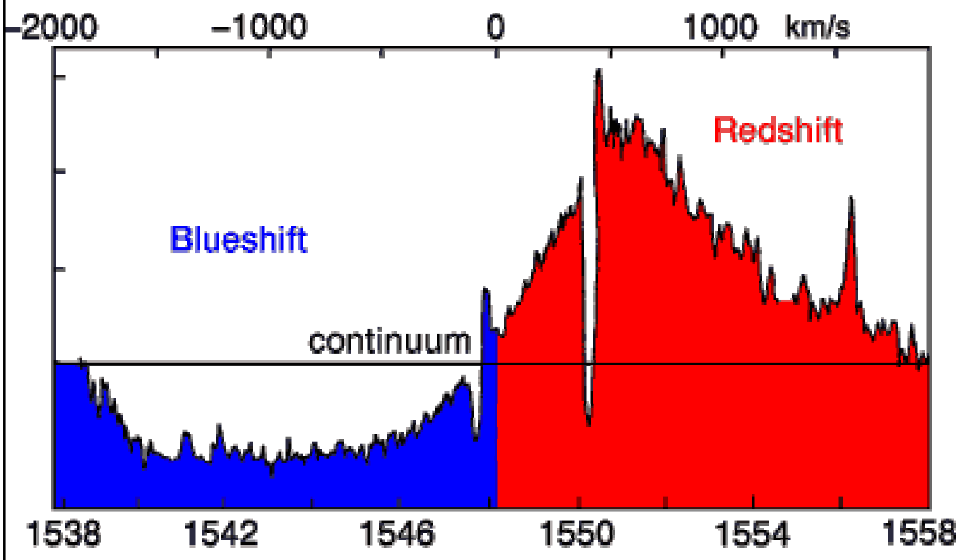
Stellar wind spectrum



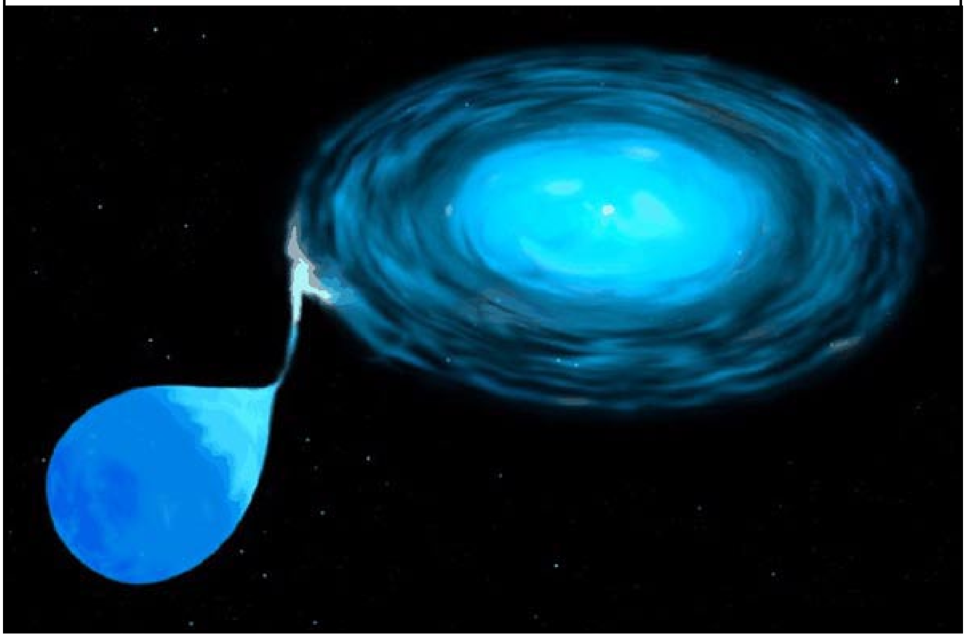
Formation of wind spectrum (P Cygni line profiles)



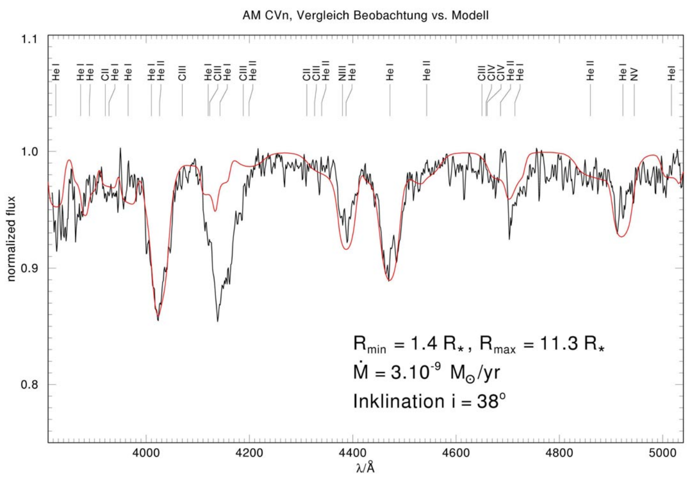
Stellar winds – P Cyg profiles



Accretion disks

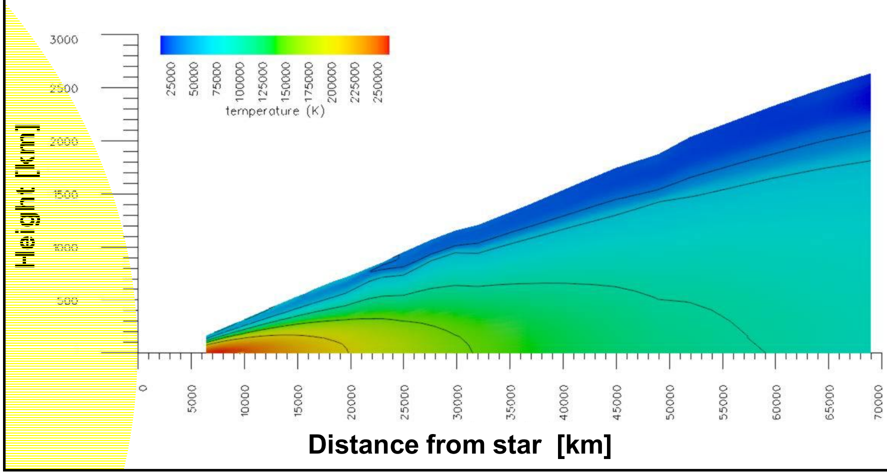


AM CVn disk spectrum

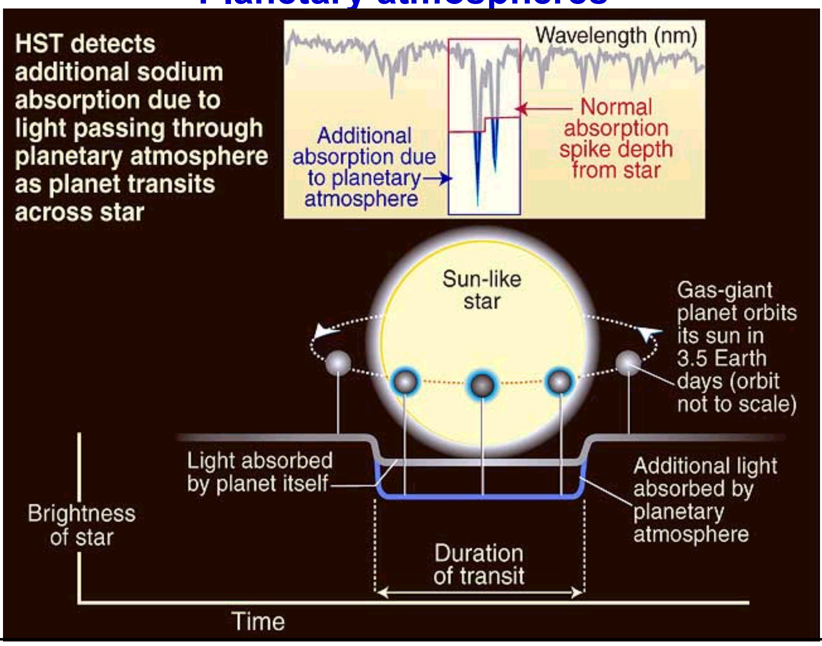


models

Temperature structure of an accretion disk



Planetary atmospheres



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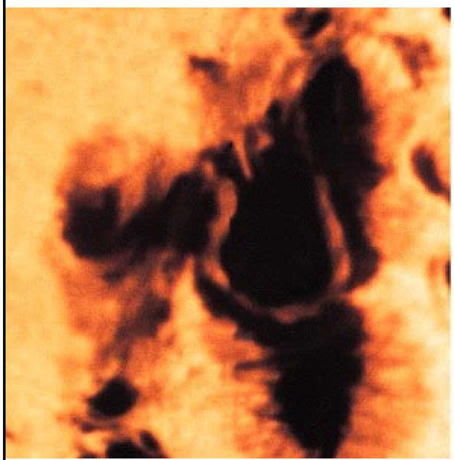
Quantitative spectral analyses – what can we learn?

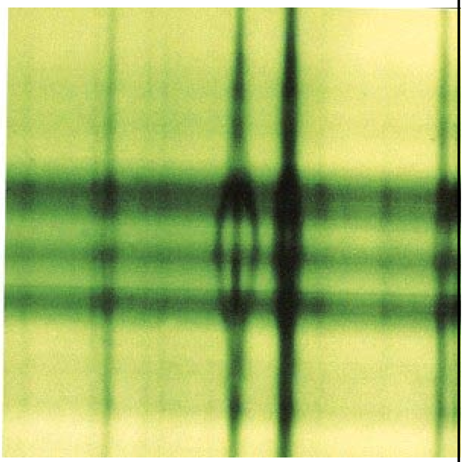
Shape of line profile:
- Temperature Film
- Density Film
- Abundance Film
- Rotation
- Turbulence
- Magnetic field

Line position:
- Chemical composition
- Velocities
- Redshift

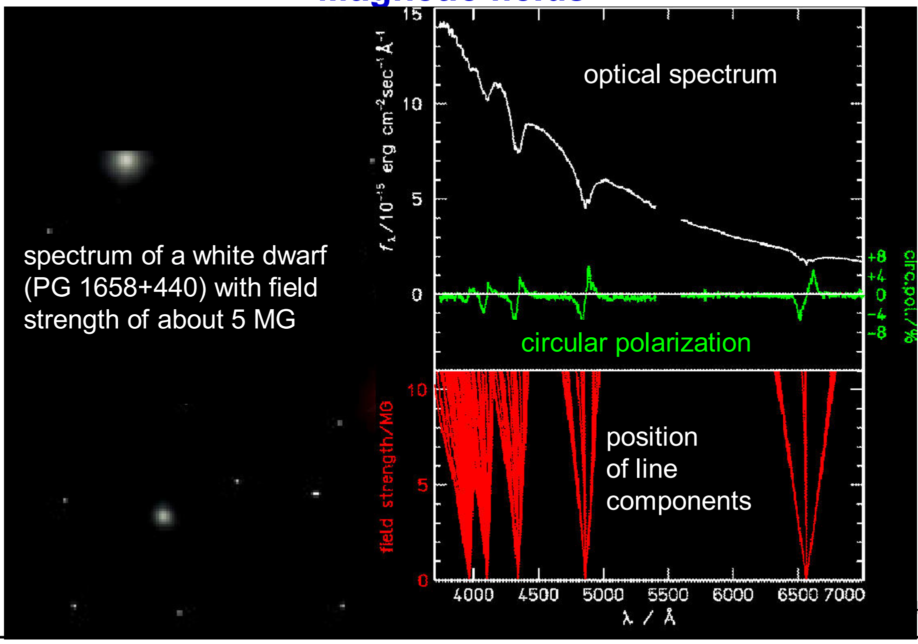
Temporal variation:
- Companion
- Surface structure
  - Spots
  - Pulsation

Zeeman effect

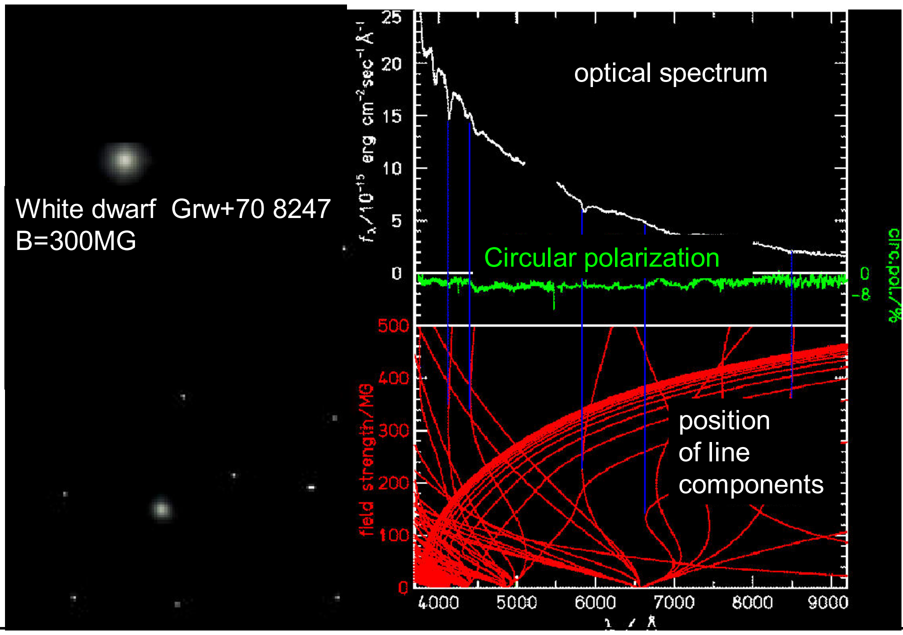




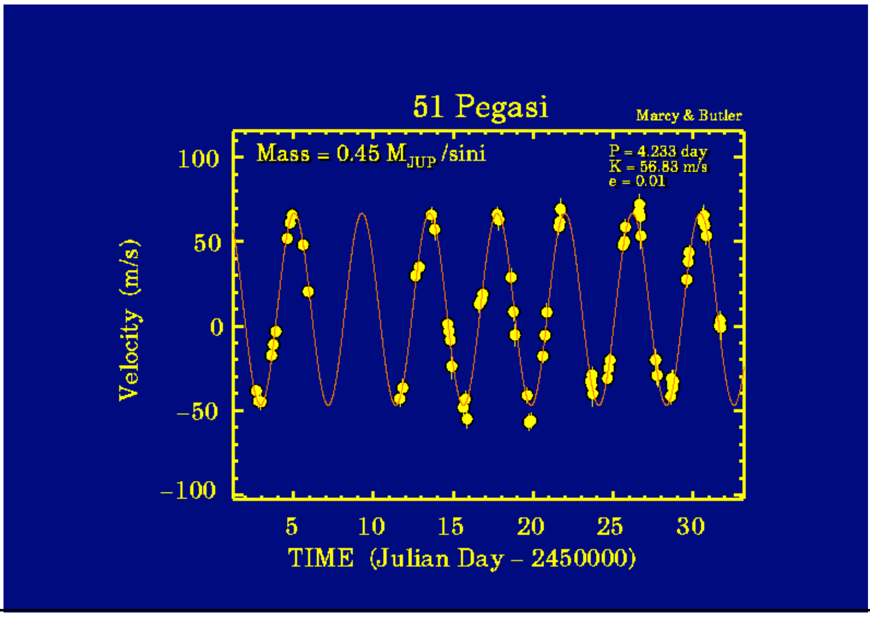
Magnetic fields

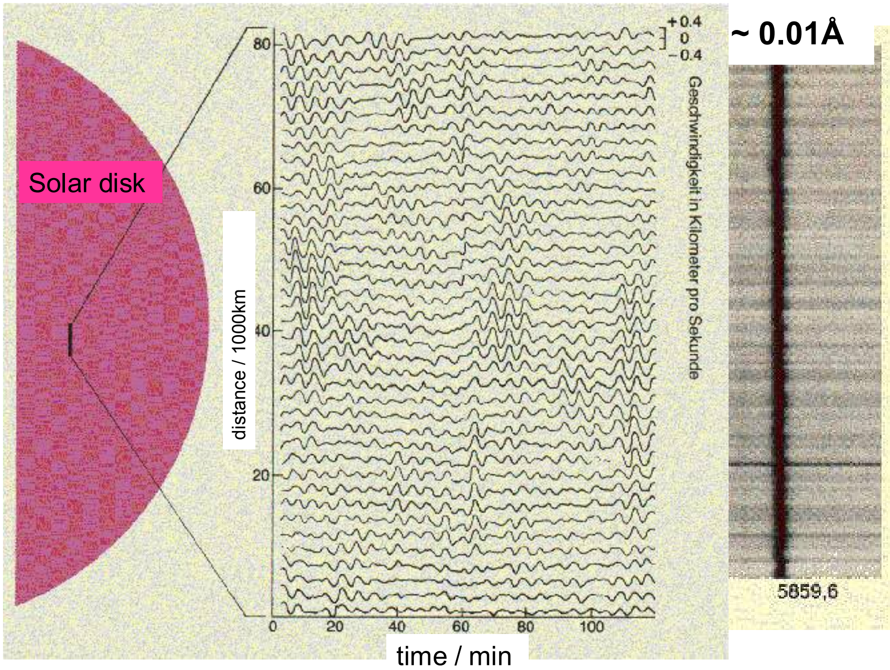


Magnetic fields

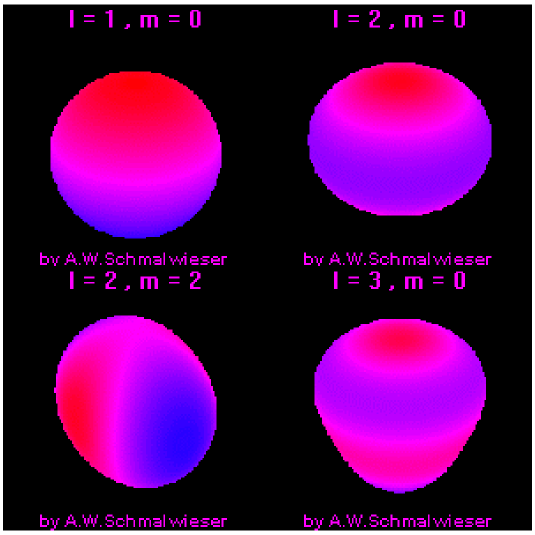


Extrasolar planets

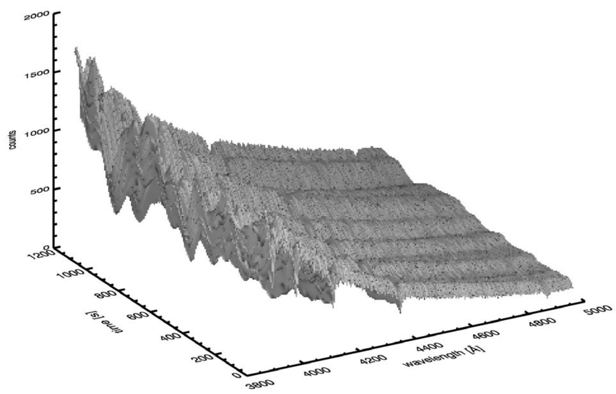




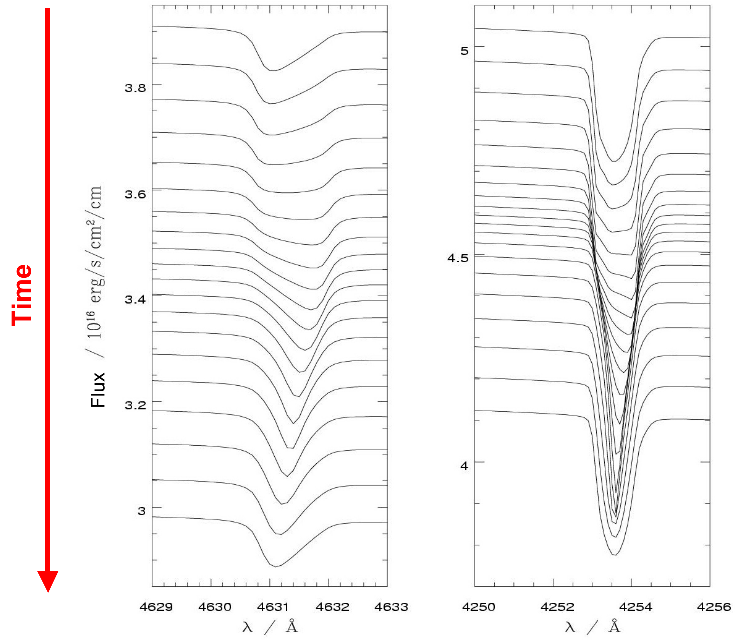
Non-radial pulsation modes



Time resolved spectroscopy

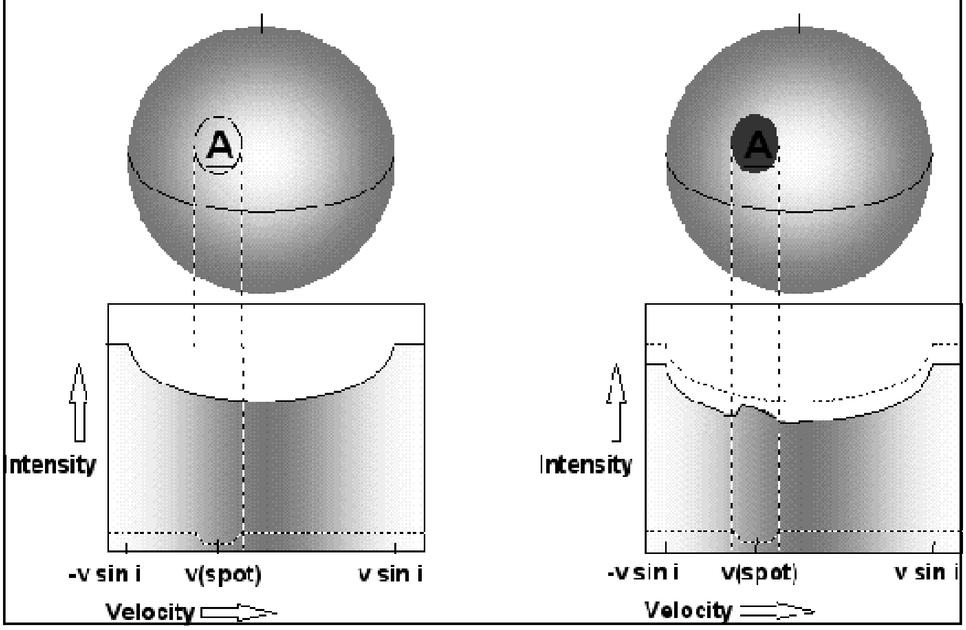


Stellar Atmospheres: Motivation



Stellar Atmospheres: Motivation

Doppler tomography



Summary – stellar atmospheres theory

The atmosphere of a star contains less than one billionth of its total mass, so, **why do we care at all?**

- The atmosphere of a star is that what we can **see**, measure, and analyze.
- The stellar atmosphere is therefore the source of information in order to put a star from the color-magnitude diagram (e.g. B-V,m_v) of the observer into the HRD (L,T_{eff}) of the theoretician and, hence, to drive the **theory of stellar evolution**.
- Atmosphere analyses reveal element abundances and show us results of **cosmo-chemistry**, starting from the earliest moments of the formation of the Universe.
- Hence, working with stellar atmospheres enables a test for **big-bang theory**.
- Stars are the **building blocks of galaxies**. Our understanding of the most distant (hence most early emerged) galaxies, which cannot be resolved in single stars, is not possible without knowledge of processes in atmospheres of single stars.
- Work on stellar atmospheres is a big challenge. The atmosphere is that region, where the transition between the thermodynamic equilibrium of the stellar interior into the empty blackness of space occurs. It is a region of extreme **non-equilibrium states**.

Summary – stellar atmospheres theory

Important source of information for many disciplines in astrophysics

- research for pure knowledge, contribution to our culture
- ambivalent applications (e.g. nuclear weapons)

Application of diverse disciplines

- physics
- numerical methods

Still a very active field of research, many unsolved problems

- e.g. dynamical processes