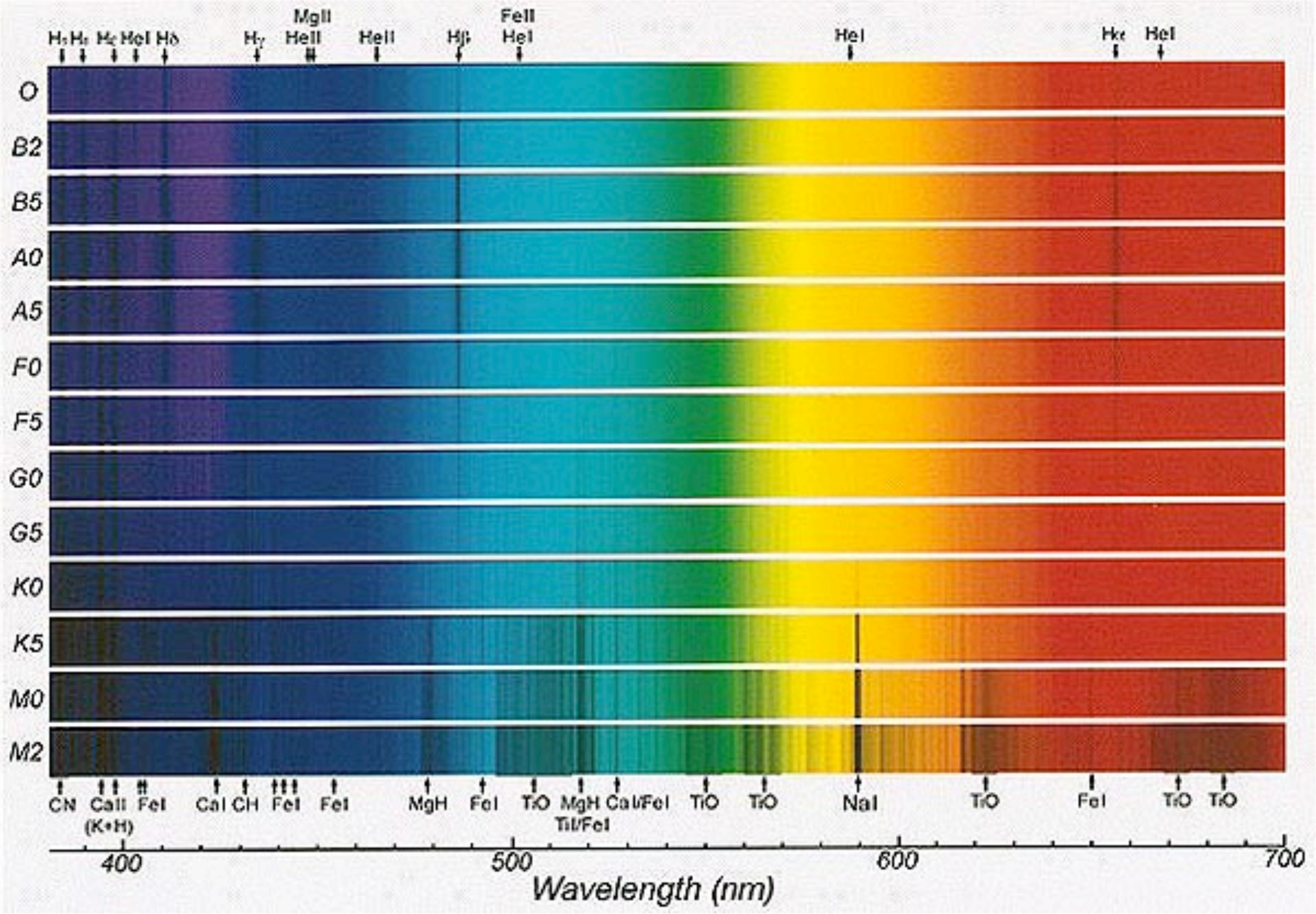
Spectroscopy

XIII. Classification and more

Stellar Classification

Gray & Corbally, *Stellar Spectral Classification*, 2009

An important aspect of spectroscopy is classification of objects. This has been very critical in the classification of stellar spectra and lead to our understanding of stellar evolution.



Images from
odin.physastro.mnsu.edu

Early Timeline

- 1814: First spectra of the sun by J. Fraunhofer
- 1863: First classification scheme proposed by Angelo Secchi (Vatican Observatory) after observing 4000 stellar spectra
- 1870: H. Vogel classification scheme revised Secchi's scheme
- 1890: N. Lockyer based a classification scheme off theoretical ideas
- 1897: F. Mclean based on observations from Cape Town. Classification scheme did correspond to the familiar OBAFGKM scheme

The Harvard System

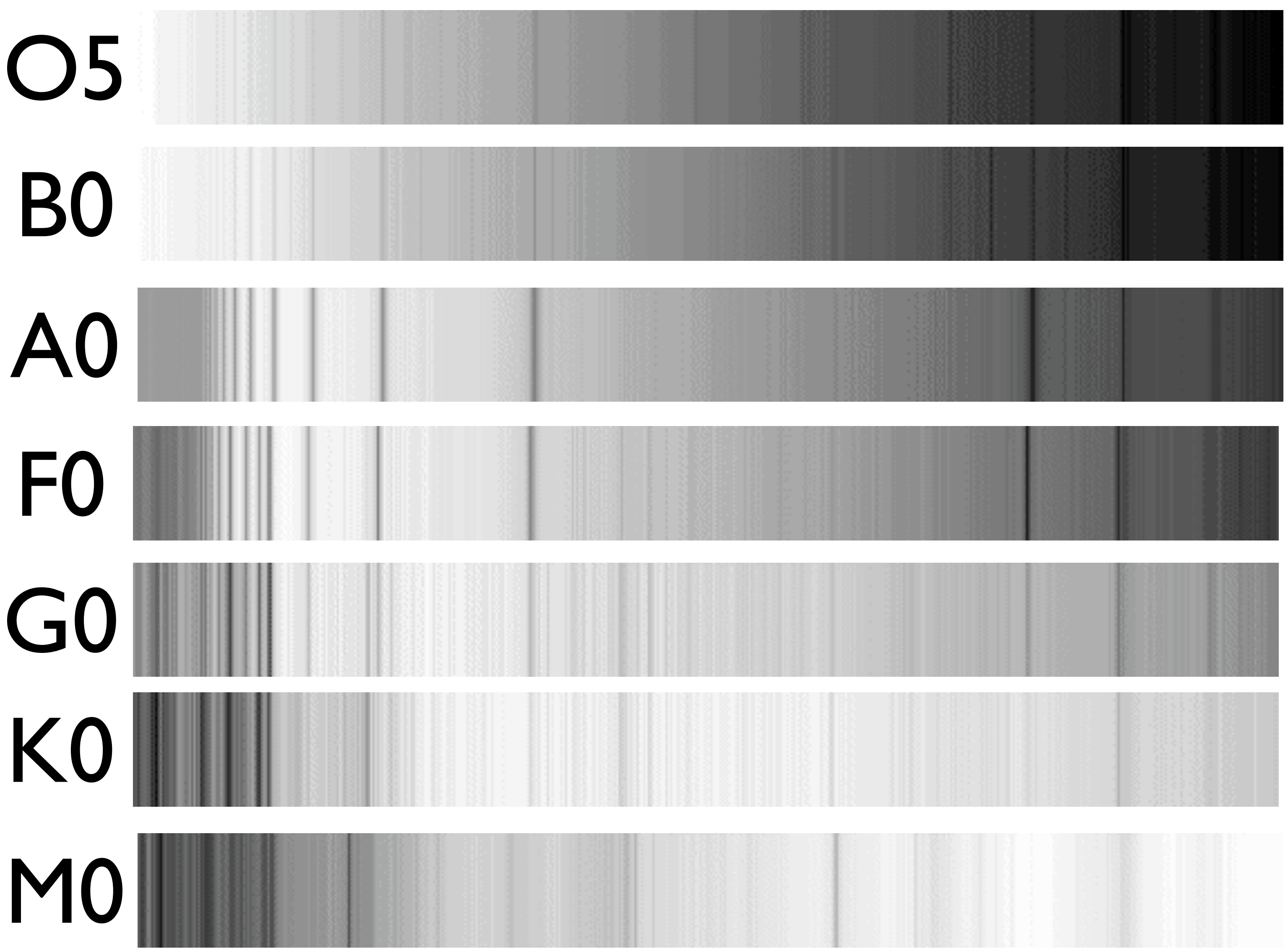
Starting around 1890, a group of women were employed by Harvard to classify stars in the Henry Draper catalog. These women also known as 'computers' were critical to our understanding of stars.

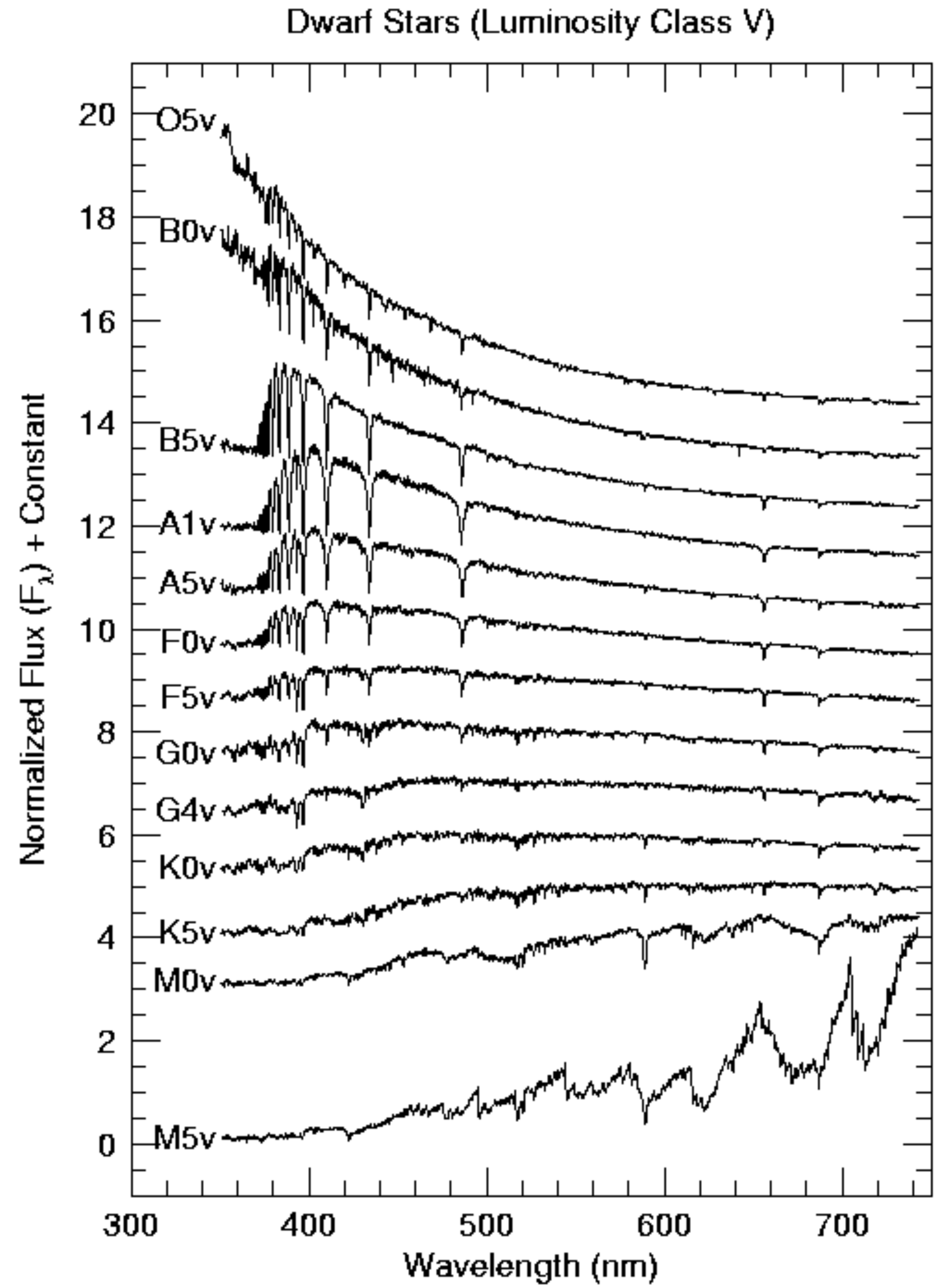
They developed a number of different classification schemes and the one developed by Annie Jump Cannon is still used today.

Harvard College Observatory

By her death in 1941, Annie Jump Cannon classified close to 395,000 stars by hand

Examples





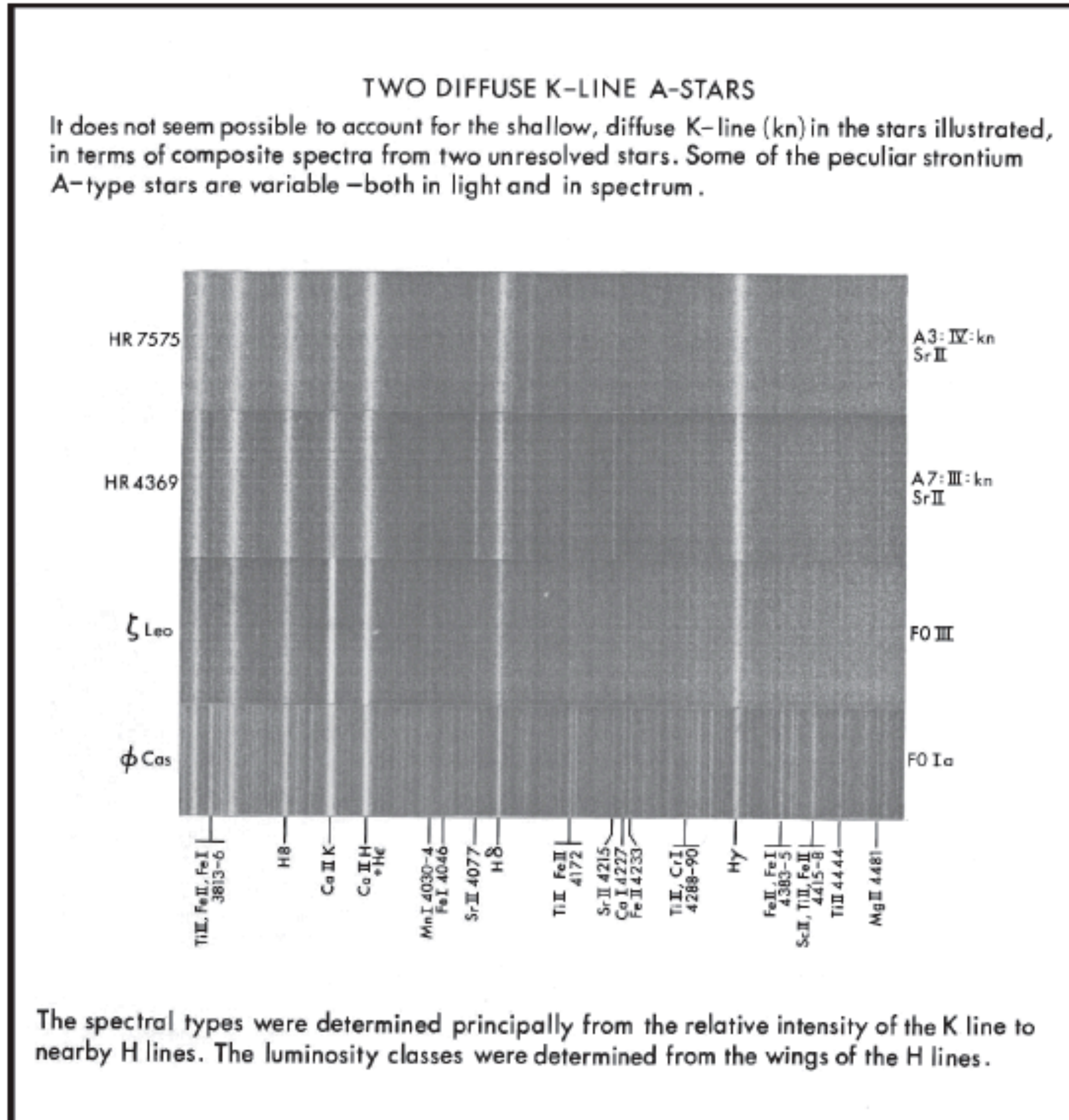
Pogge 2006

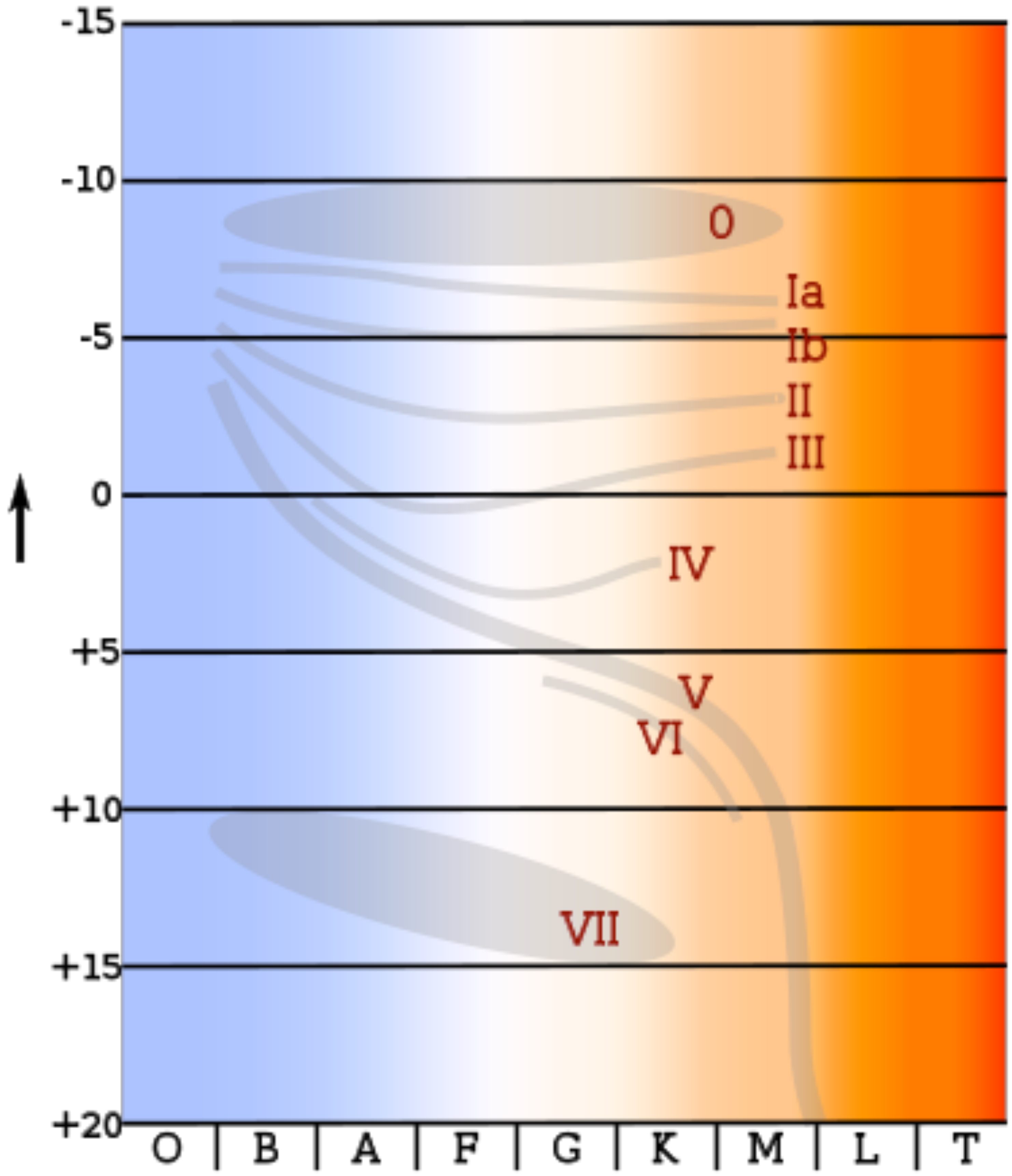
Spectral Class	Intrinsic Color	Temperature (K)	Prominent Absorption Lines
O	Blue	41,000	He+, O++, N++, Si++, He, H
B	Blue	31,000	He, H, O+, C+, N+, Si+
A	Blue-white	9,500	H(strongest), Ca+, Mg+, Fe+
F	White	7,240	H(weaker), Ca+, ionized metals
G	Yellow-white	5,920	H(weaker), Ca+, ionized & neutral metal
K	Orange	5,300	Ca+(strongest), neutral metals strong, H(weak)
M	Red	3,850	Strong neutral atoms, TiO

MK Classification

The standard classification system that is now used is the MK Classification which is based on work by Morgan & Keenan (1943). They realized that stars could be further grouped by their surface gravity g. This is where giants (I) and dwarfs (V) gained their classification.

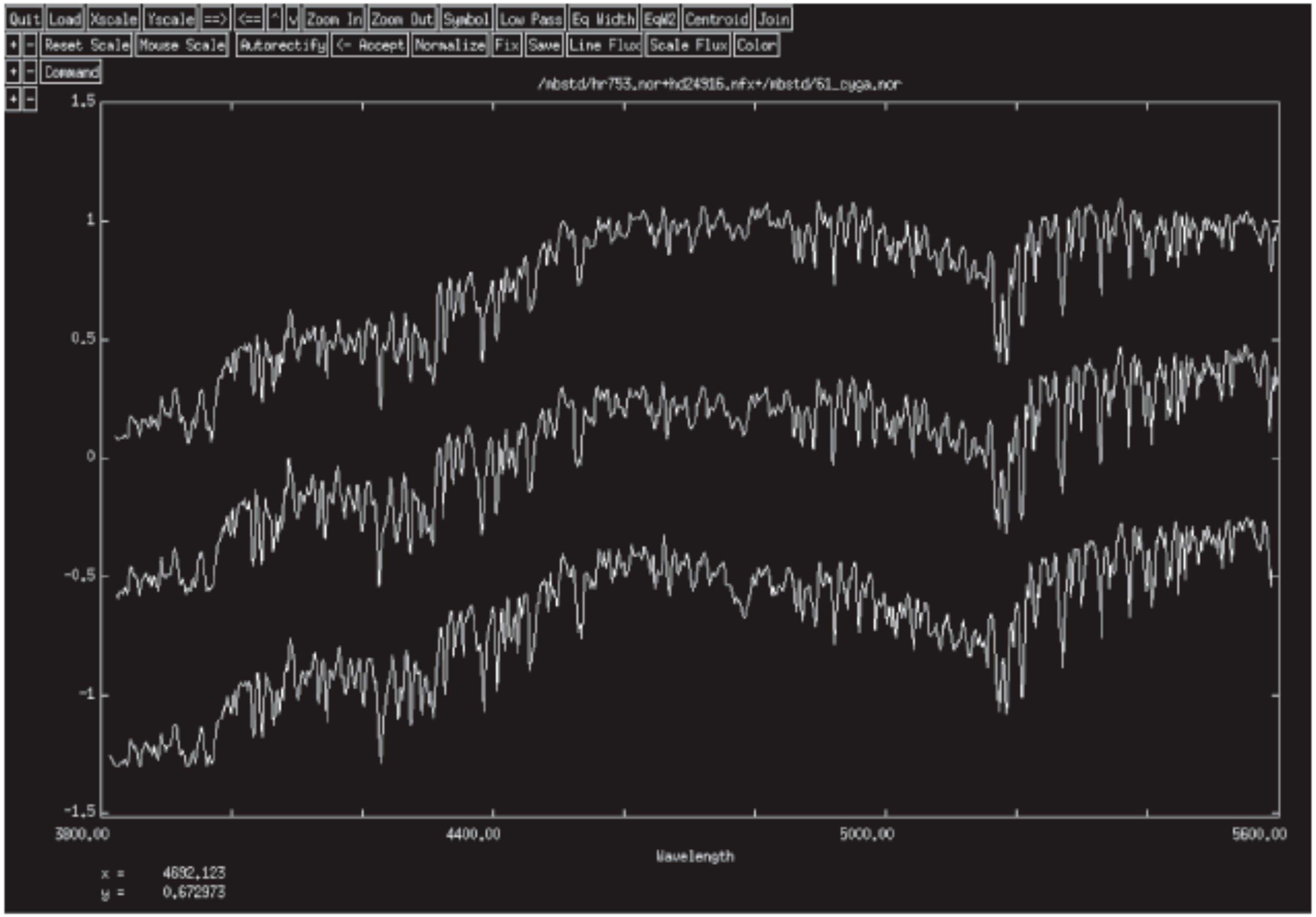
The system is based on comparing an observed spectra to a series of standard spectra.





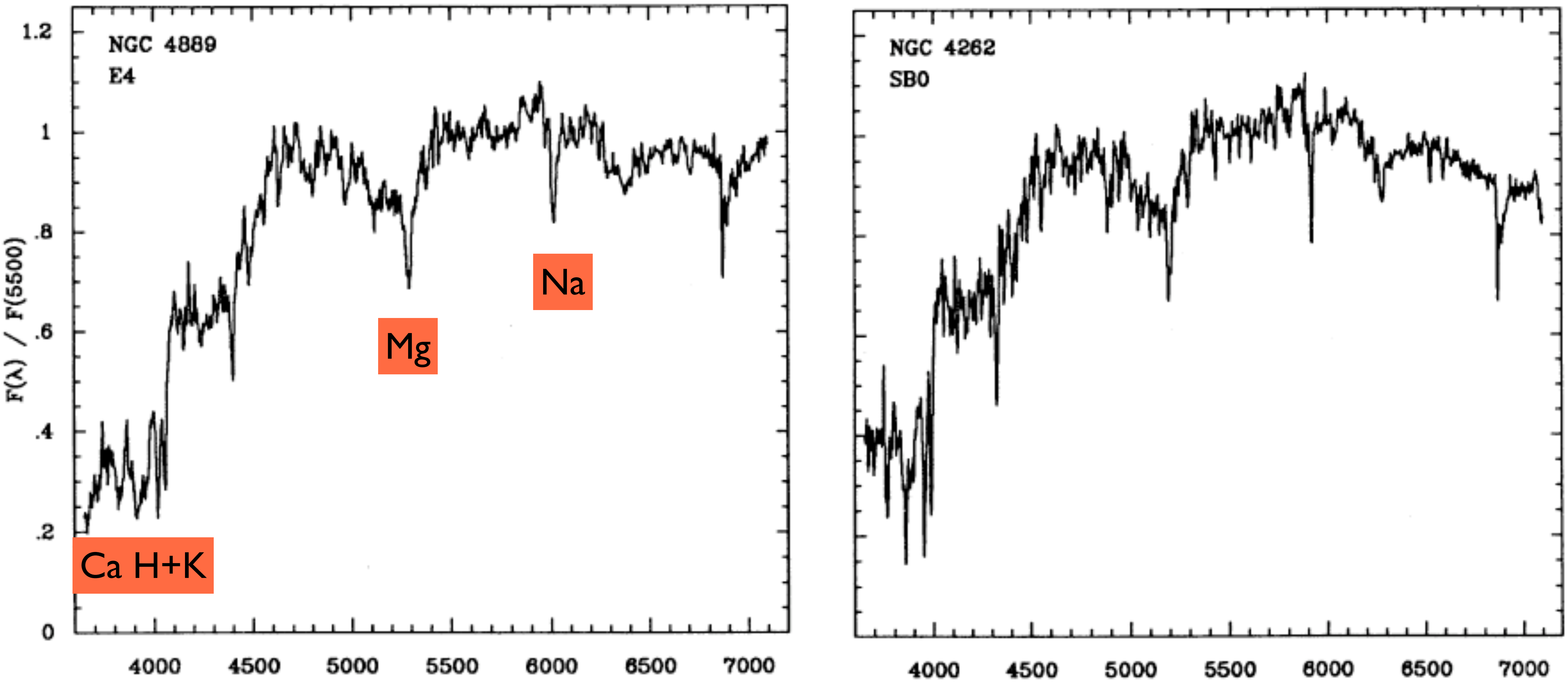
-15
-10
-5
0
+5
+10
+15
+20
0
Ia
Ib
II
III
IV
V
VI
VII
O
B
A
F
G
K
M
L
T

Automatic Classification



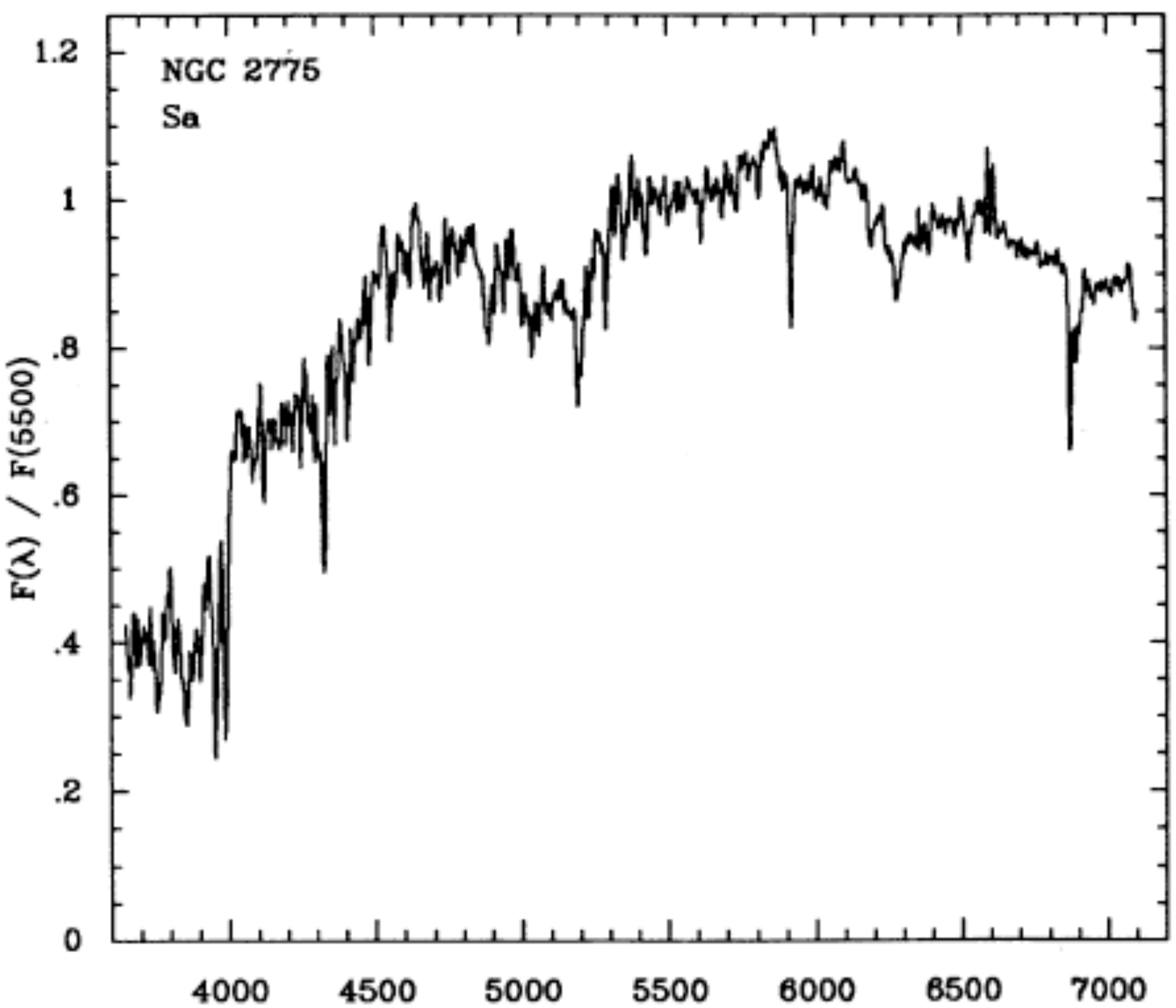
Galaxy Classification

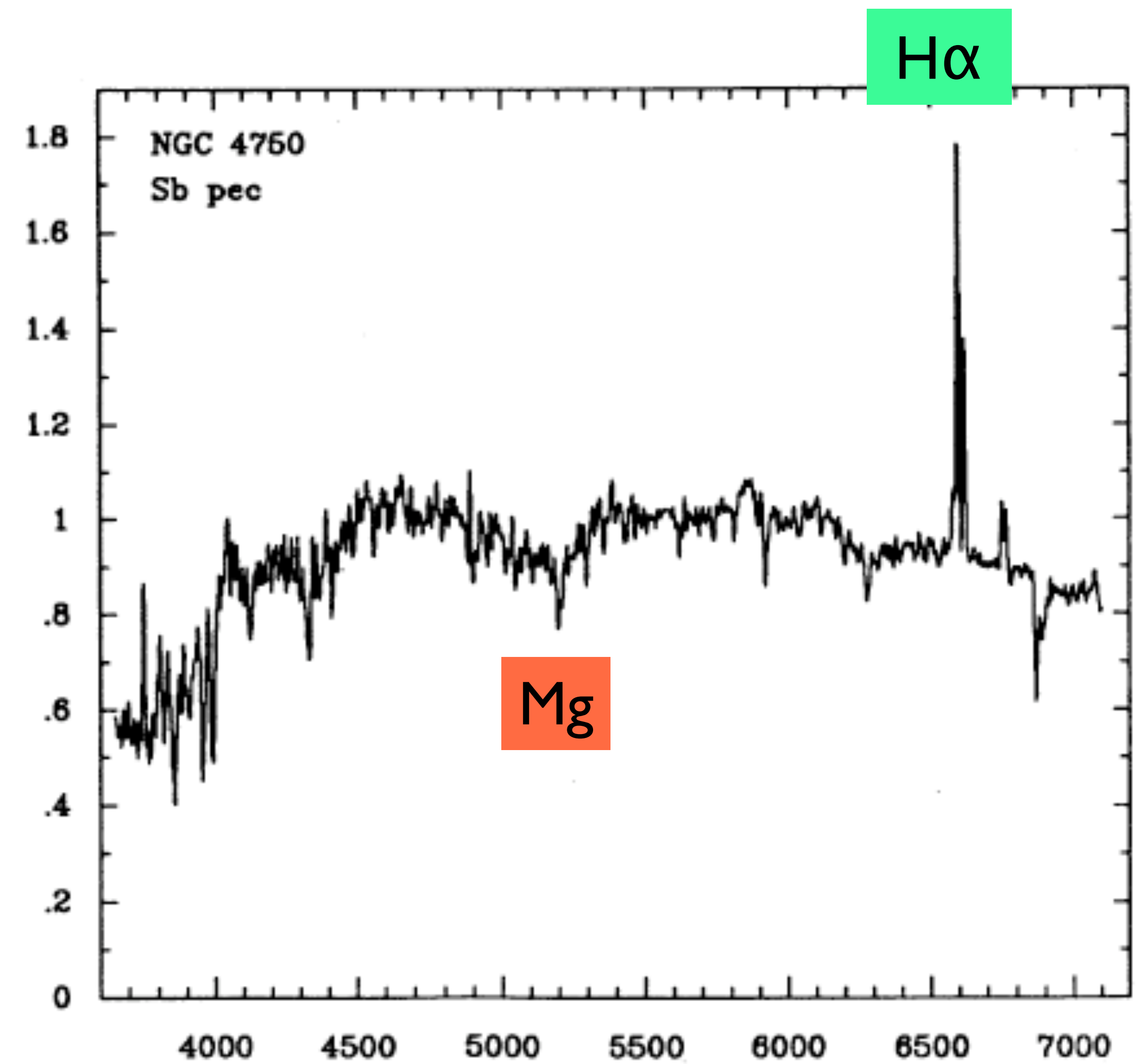
Early-Type Galaxies



R. Kennicutt 1992

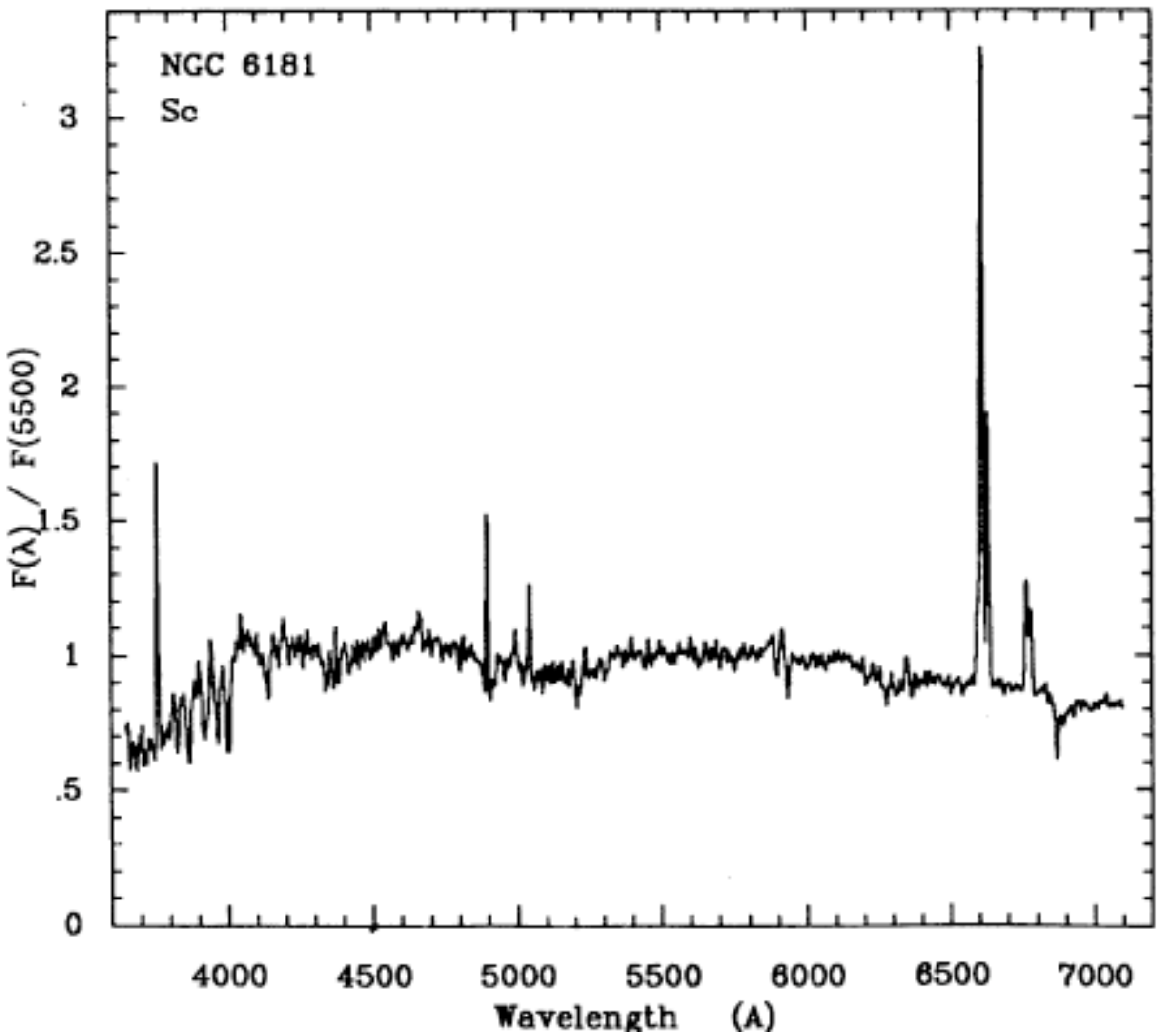
Late-Type Galaxies

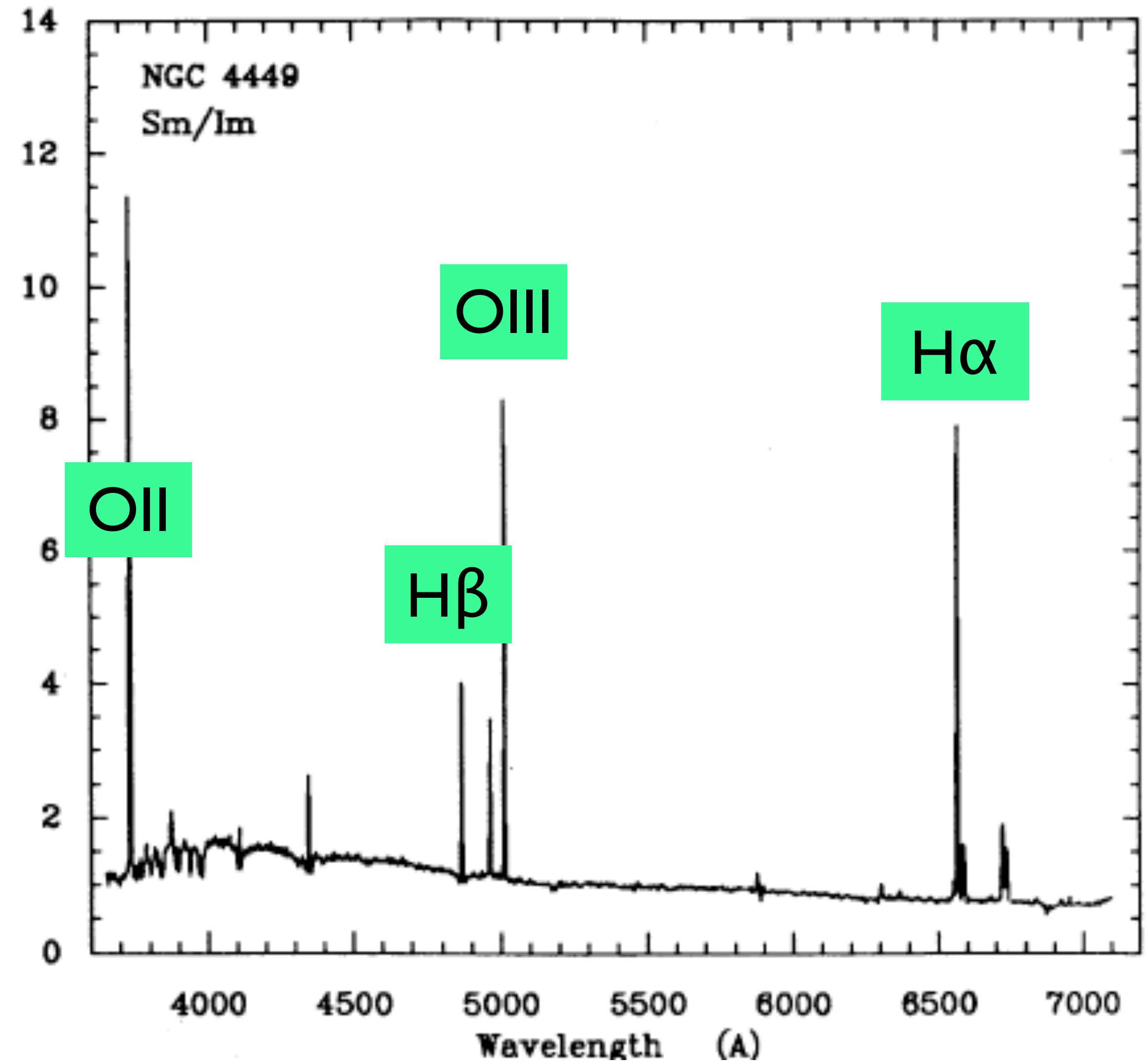




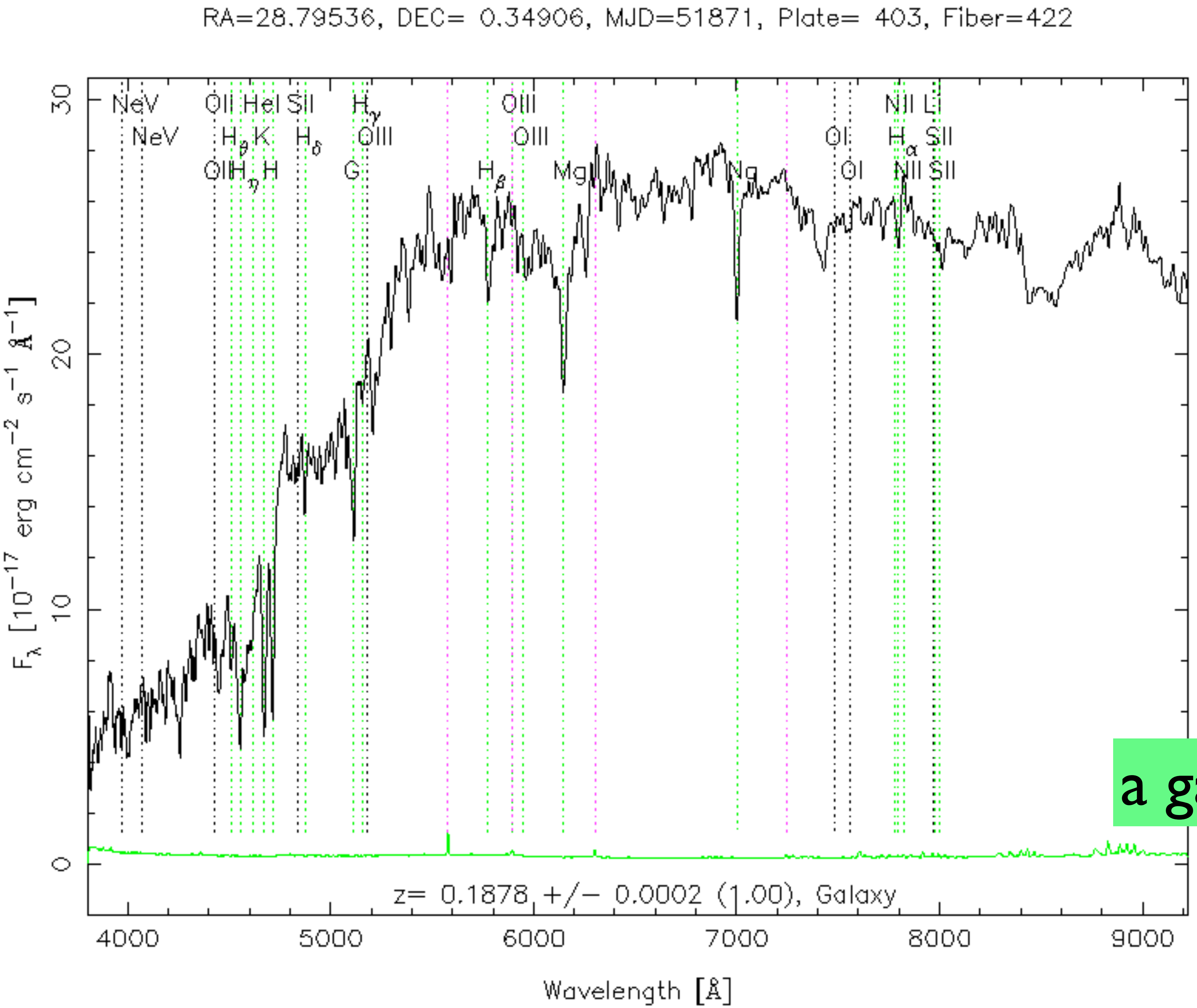
R. Kennicutt 1992

Emission Line

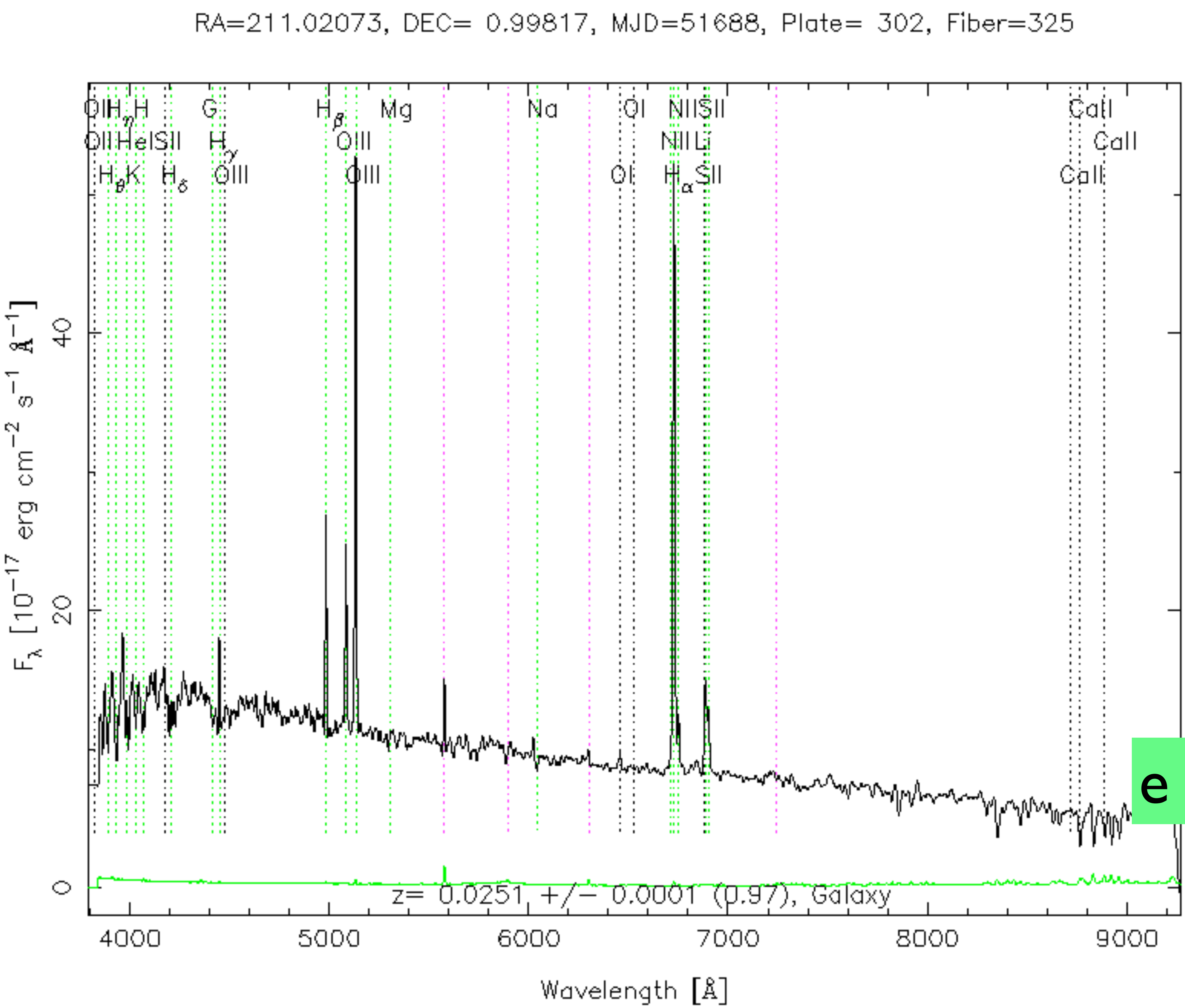




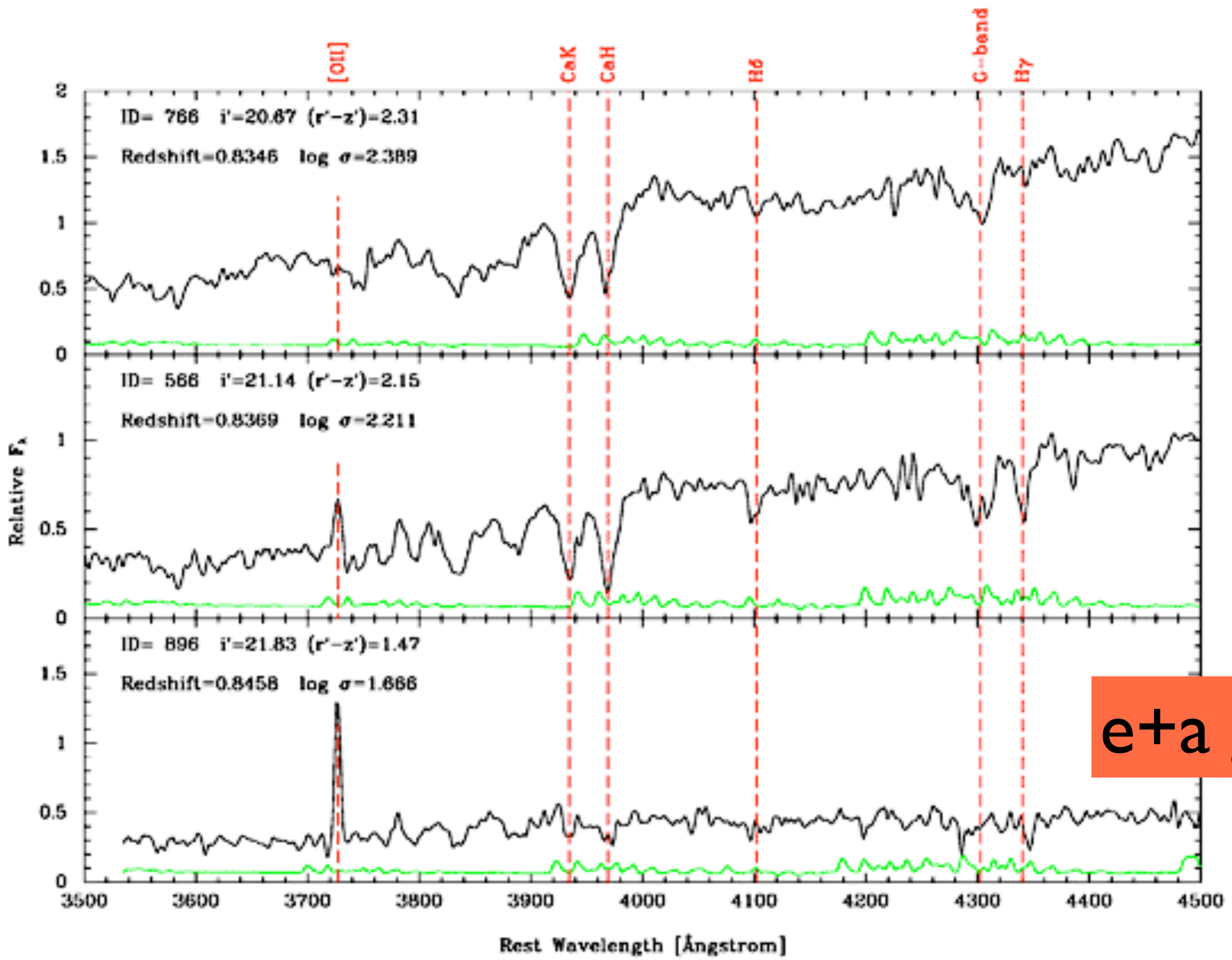
R. Kennicutt 1992


RA=28.79536, DEC= 0.34906, MJD=51871, Plate= 403, Fiber=422
NeV
NeV
OII
OII
HeI
K
H
SII
G
OIII
OIII
Mg
Na
OI
OI
NII
NII
Li
SII
SII
z= 0.1878 +/- 0.0002 (1.00), Galaxy
4000
5000
6000
7000
8000
9000
0
10
20
30
Wavelength [Å]

a galaxy


RA=211.02073, DEC= 0.99817, MJD=51688, Plate= 302, Fiber=325
OII Hη H
OII HeI SII
Hθ K
Hδ
G
Hγ
OIII
Hβ
OIII
OIII
Mg
Na
OI
OI
NII SII
NII Li
Hα SII
CaII
CaII
CaII
z= 0.0251 +/- 0.0001 (0.97), Galaxy
Fλ [10^-17 erg cm^-2 s^-1 Å^-1]
Wavelength [Å]
0
20
40
4000
5000
6000
7000
8000
9000

e galaxy



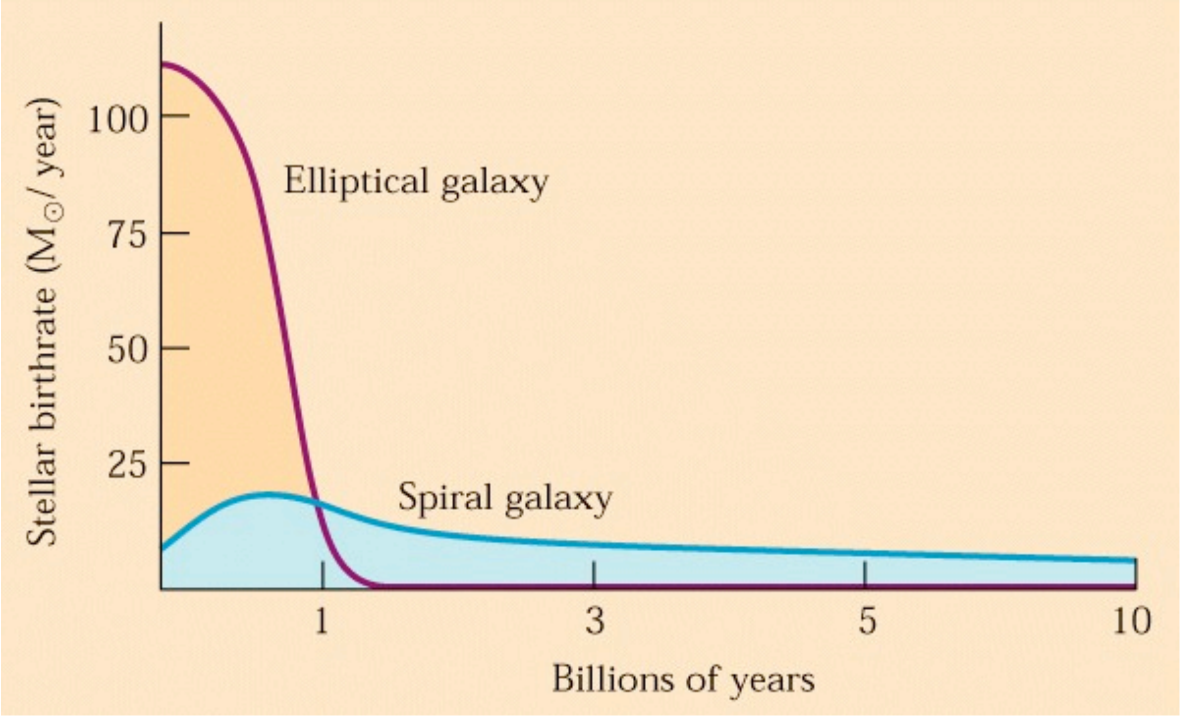
[OII]
CaK
CaH
Hδ
G-band
Hγ
ID= 766 i'=20.67 (r'-z')=2.31
Redshift=0.8346 log σ=2.389
ID= 566 i'=21.14 (r'-z')=2.15
Redshift=0.8369 log σ=2.211
ID= 896 i'=21.83 (r'-z')=1.47
Redshift=0.8458 log σ=1.666
Relative F_λ
Rest Wavelength [Ångstrom]

e+a galaxy

Star Formation Histories

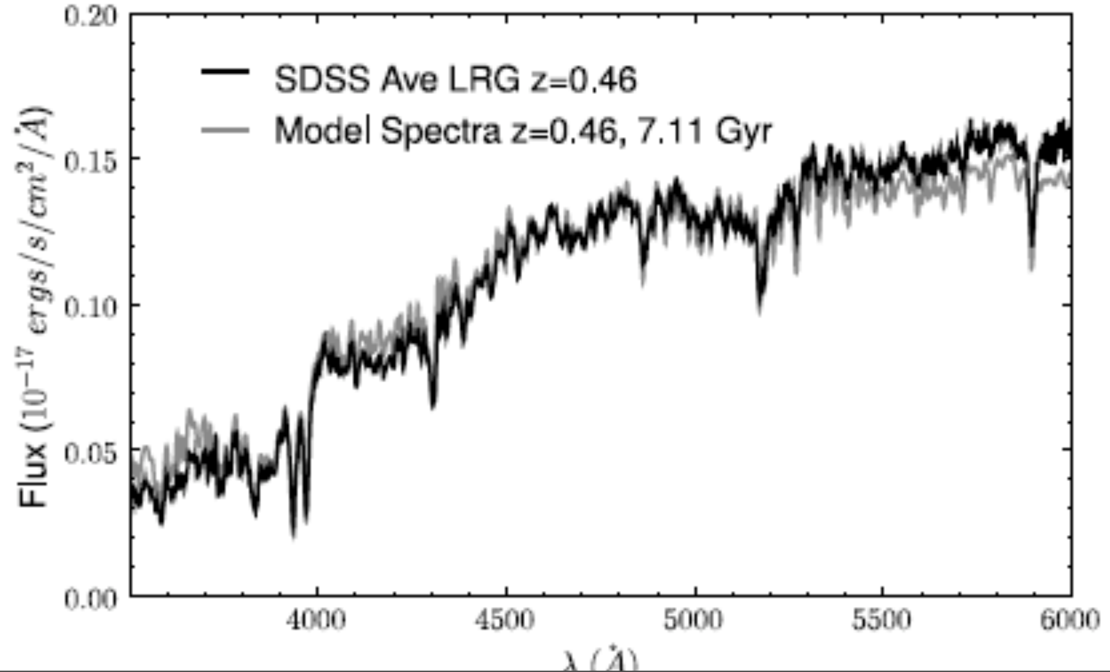
A galaxy spectra is primarily just the summation of the stars which compose it:

$$F(\lambda) = \int_0^{t_{form}} S(t) F_{SSP}(\lambda, t, Z(t)) dt$$

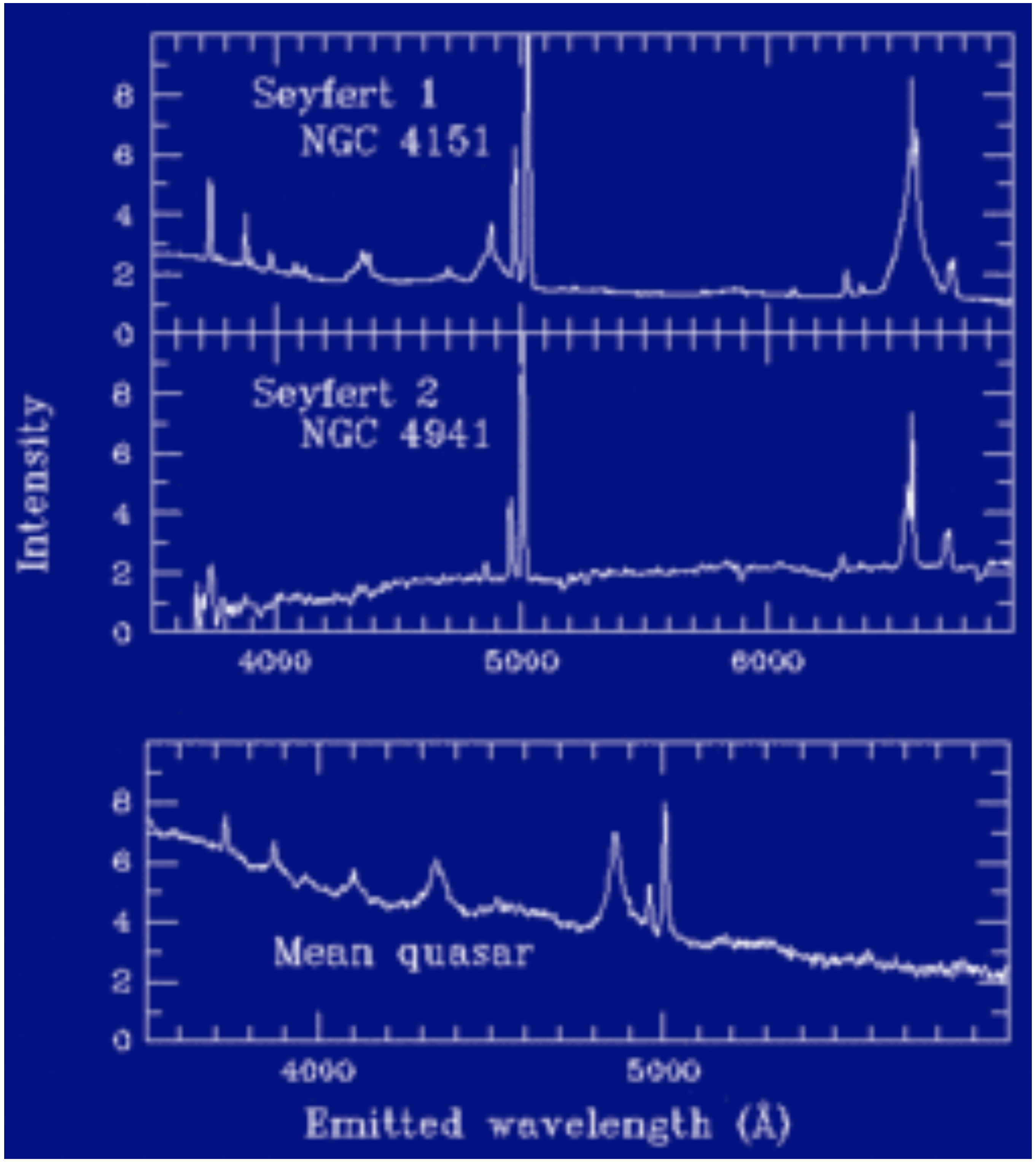


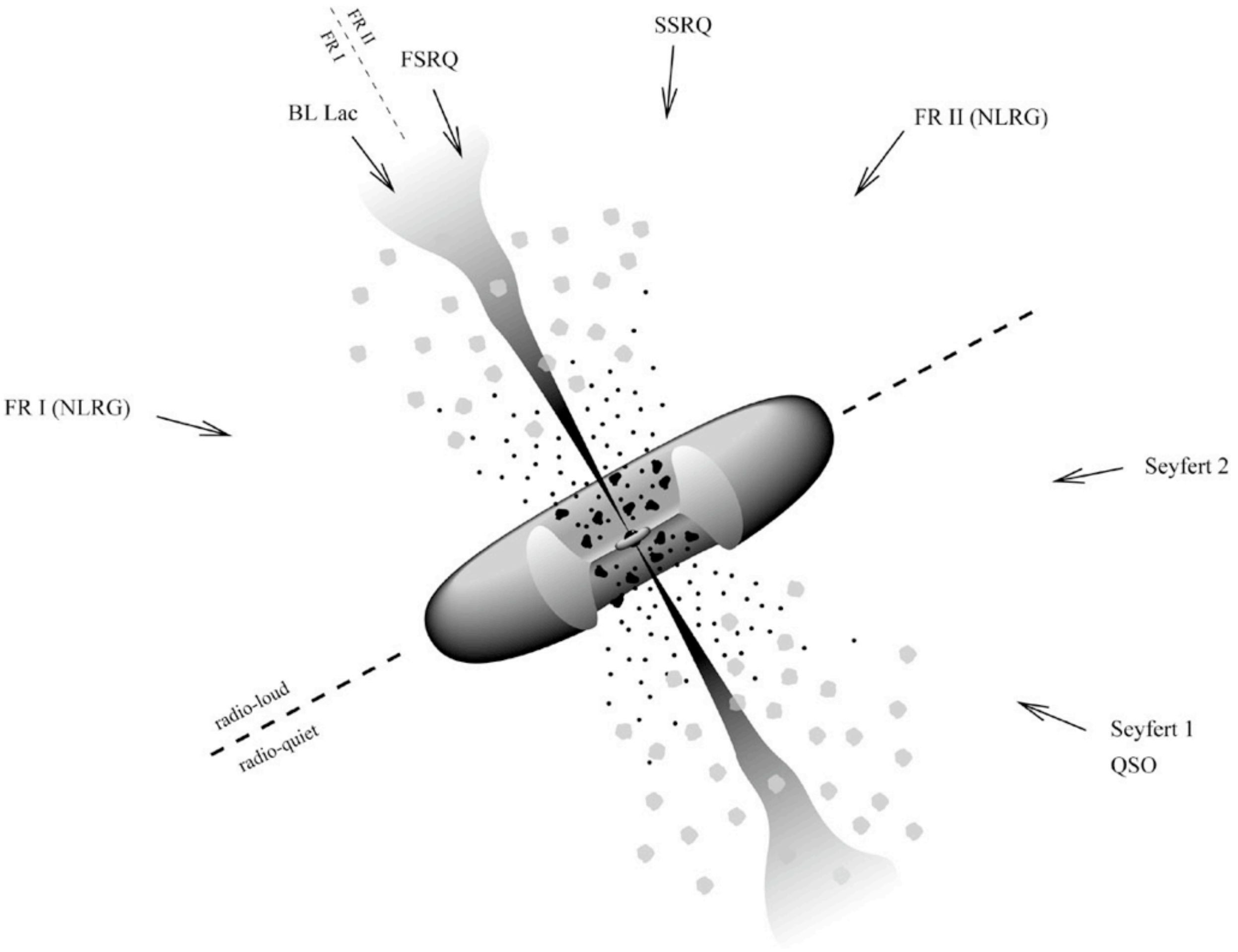
This will be further modulated by any extinction in the galaxy, nebular emission, or nuclear emission (AGN).

A number of different groups work on modeling and fitting stellar populations. The most popular program for doing stellar populations is Bruzual & Charlot 2003. However this is a very active area of research currently.



AGN

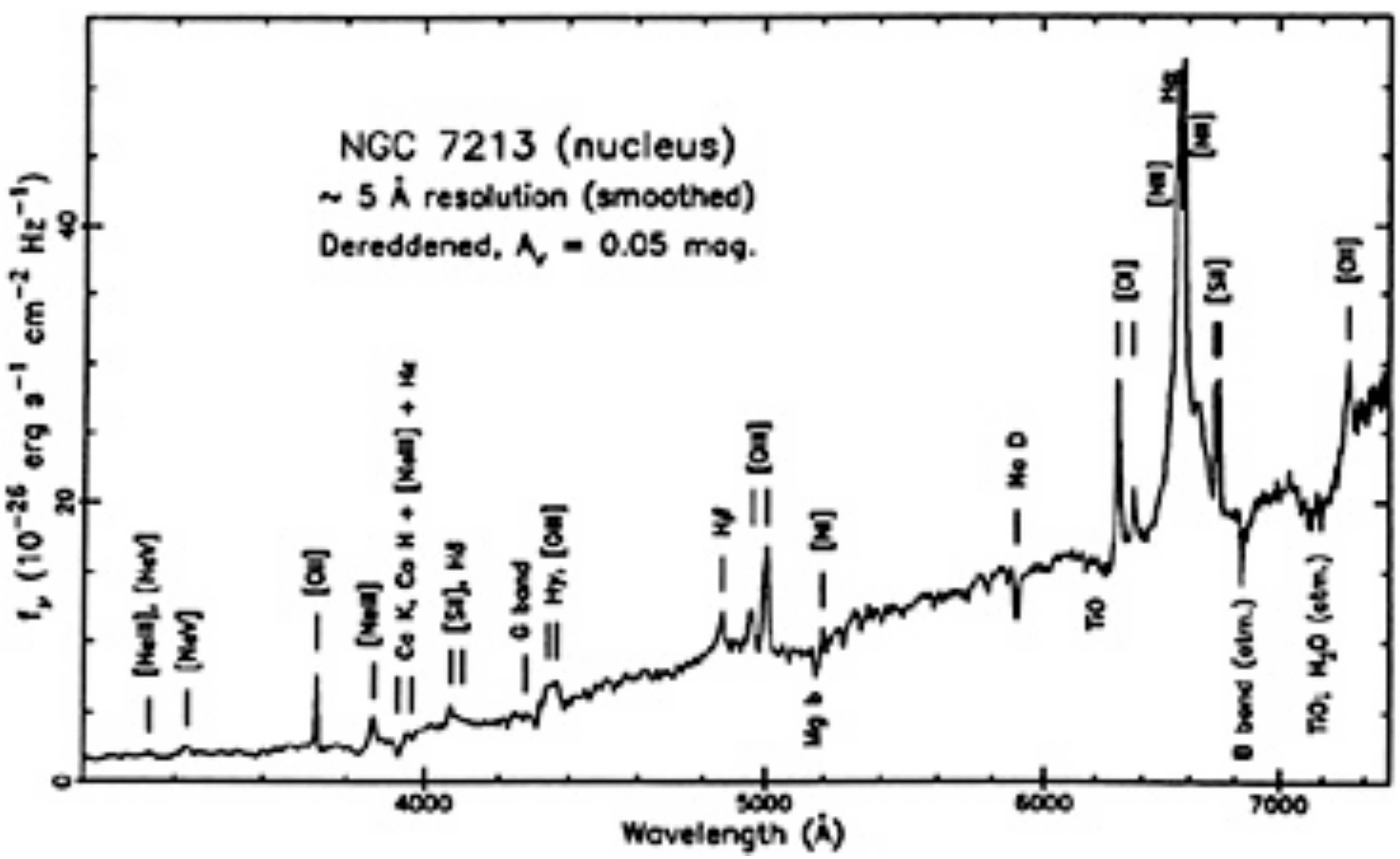




Torres & Anchordoqui 2004

Narrow-Line AGN

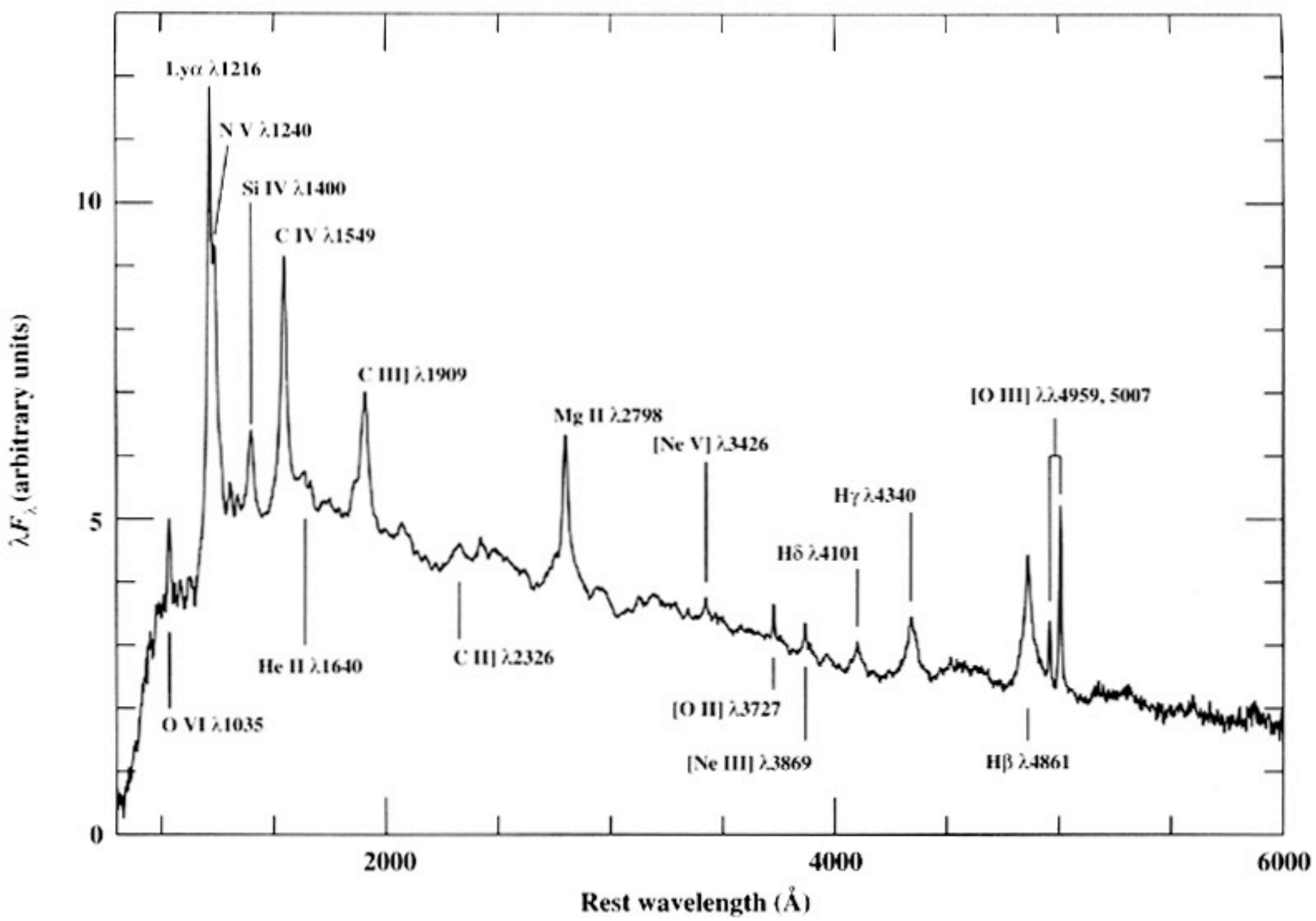
Narrow-line AGN are expected when viewing AGN at a fairly high angle. The line of site is sampling the lower density regions. The lines are expected to be produced from strong photo-ionization source with a very hard spectrum.



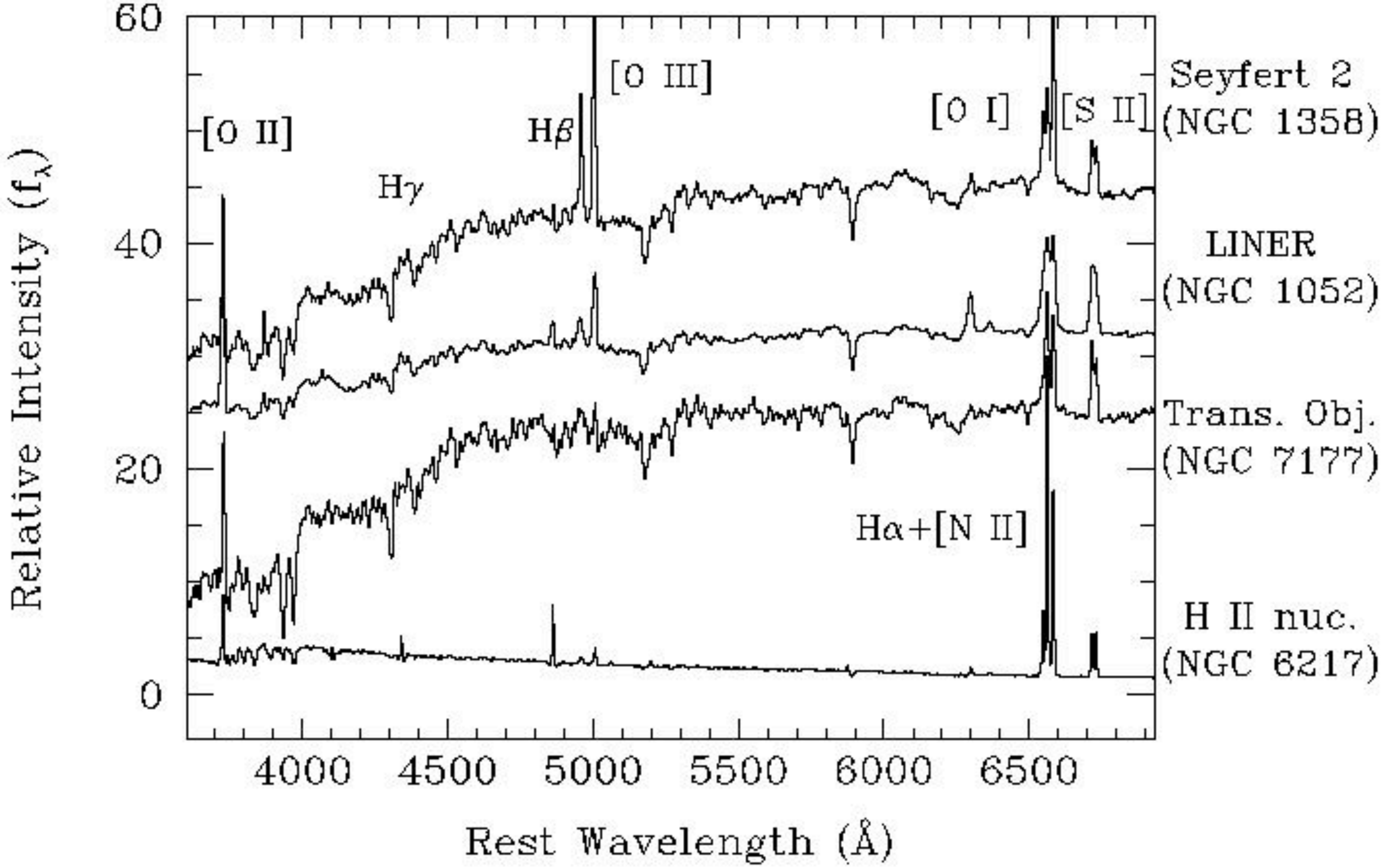
Filippenko and Halpern 1986

Broad-Line AGN

Broad lines in AGN are expected to come from very high density regions. Only allowed transitions are seen in broad line regions meaning the density is higher than the critical density (10^9 cm^{-3}) . These regions are typically expected to be very small (0.1 pc). Narrow forbidden lines for lower density regions are also usually seen.

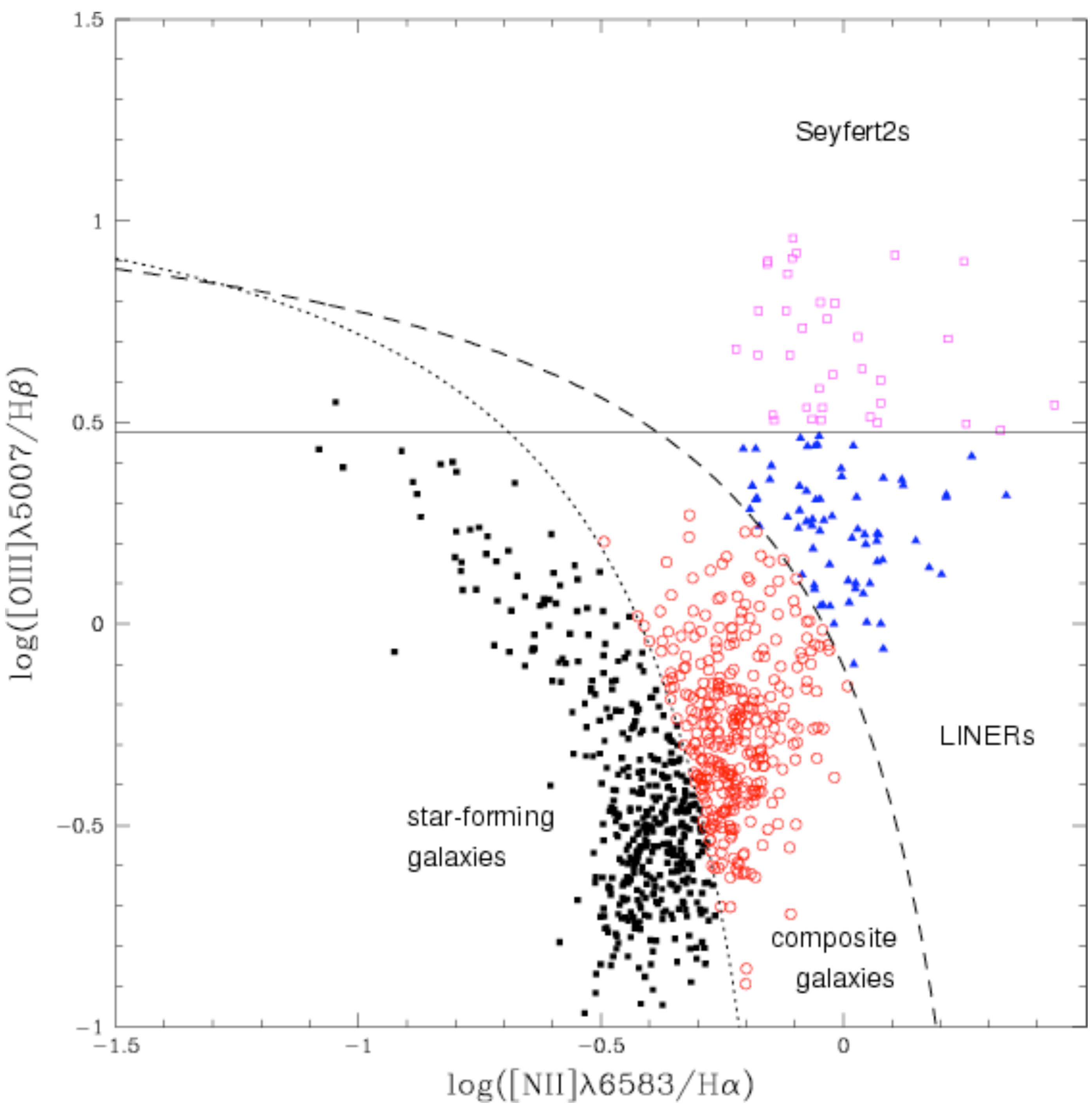


AGN vs SF



Ho 1996

Line diagnostics

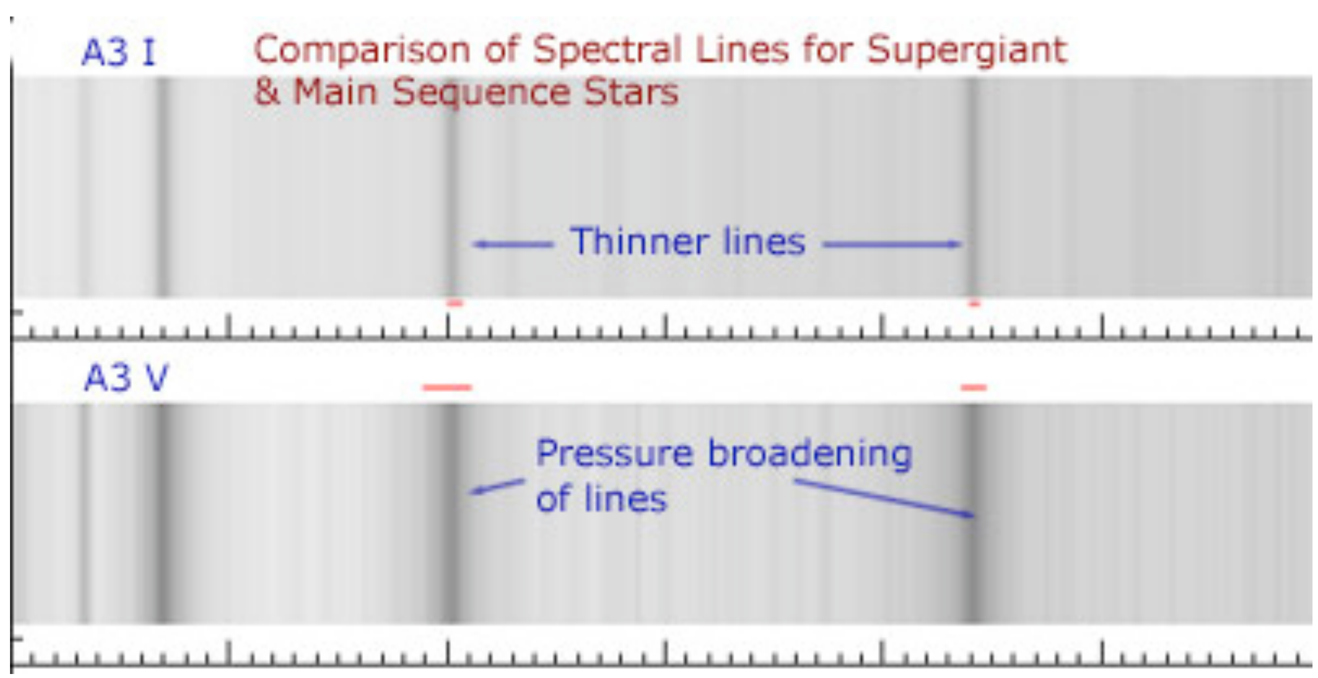


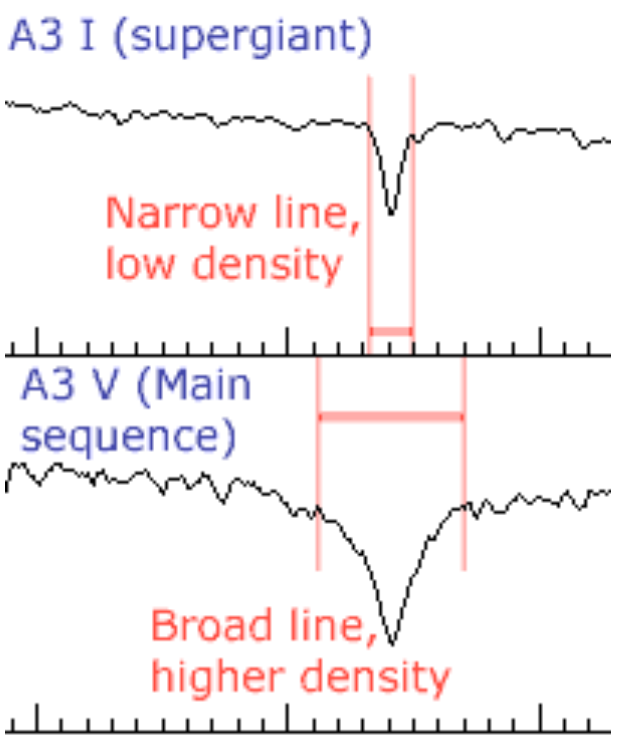
Pressure

Broad Lines in Dwarf Stars

More Information: Gray Ch 11

Why are broader lines seen in dwarf stars?





Pressure Broadening

Energy levels in atoms are interfered with by interactions with other particles. This may result in no effect, a shift, a asymmetry, or broadening of the lines. Broadening of lines is most applicable for stellar atmospheres. The degree of interaction increases with the density such that:.

$$\Delta E \propto R^{-n}$$

As the density of material increases, energy levels in atoms are interfered with by interactions with other particles to a greater effect. The value of n can vary for what type of interaction is occurring. It will range between n=2-6.

At the surface of a star, the pressure is related to the surface gravity. Hence the correlation between g and line widths.

Pressure Broadening

Common types of pressure broadening in stars:

Type	Lines Affected	Perturber
Linear Stark	Hydrogen	Protons,electrons
Quadratic Stark	Most lines, esp, in hot stars	electrons
Van der Waals	Most lines, esp. in cool stars	Neutral Hydrogen

Abundances

Another critical question that spectroscopy can answer is what are the abundances of stars? This requires several steps in order to determine the appropriate abundances for the measurement of different elements.

The ratio of the abundance between two species (the ionization state of different elements).

$$\frac{n(a_i)}{n(b_j)} = \frac{I(a_i)F(b_j, T, n)}{I(b_j)F(a_i, T, n)}$$

Metallicities

Metallicities

$$[\frac{a}{b}] = log\frac{N(a_i)}{N(b_j)} + log\frac{f(b_j)}{f(a_i)} + log\frac{a_\odot}{b_\odot}$$

Metallicities

$$[\frac{a}{b}] = log\boxed{\frac{N(a_i)}{N(b_j)}} + log\frac{f(b_j)}{f(a_i)} + log\frac{a_\odot}{b_\odot}$$

Column Density
Can be determine from
the curve of growth

Metallicities

$$[\frac{a}{b}] = log\boxed{\frac{N(a_i)}{N(b_j)}} + log\boxed{\frac{f(b_j)}{f(a_i)}} + log\frac{a_\odot}{b_\odot}$$

Column Density
Can be determine from the curve of growth

Ionization Correction
Needs to be determined from T, n.
Saha Equation/ Boltzman Equation.
Calculated Numerically.

Metallicities

Solar Abundances

$$[\frac{a}{b}] = log\frac{N(a_i)}{N(b_j)} + log\frac{f(b_j)}{f(a_i)} - log\frac{a_{\odot}}{b_{\odot}}$$

Column Density
Can be determine from the curve of growth

Ionization Correction
Needs to be determined from T, n.
Saha Equation/ Boltzman Equation.
Calculated Numerically.

Galactic Structure

By knowing the chemical structure of stars, we can plot out what the galactic structure is. We can trace stars back to where they were born. For example, this gives us a picture of where stars in streams in the galactic halo came from: