# The Spectra of Galaxies

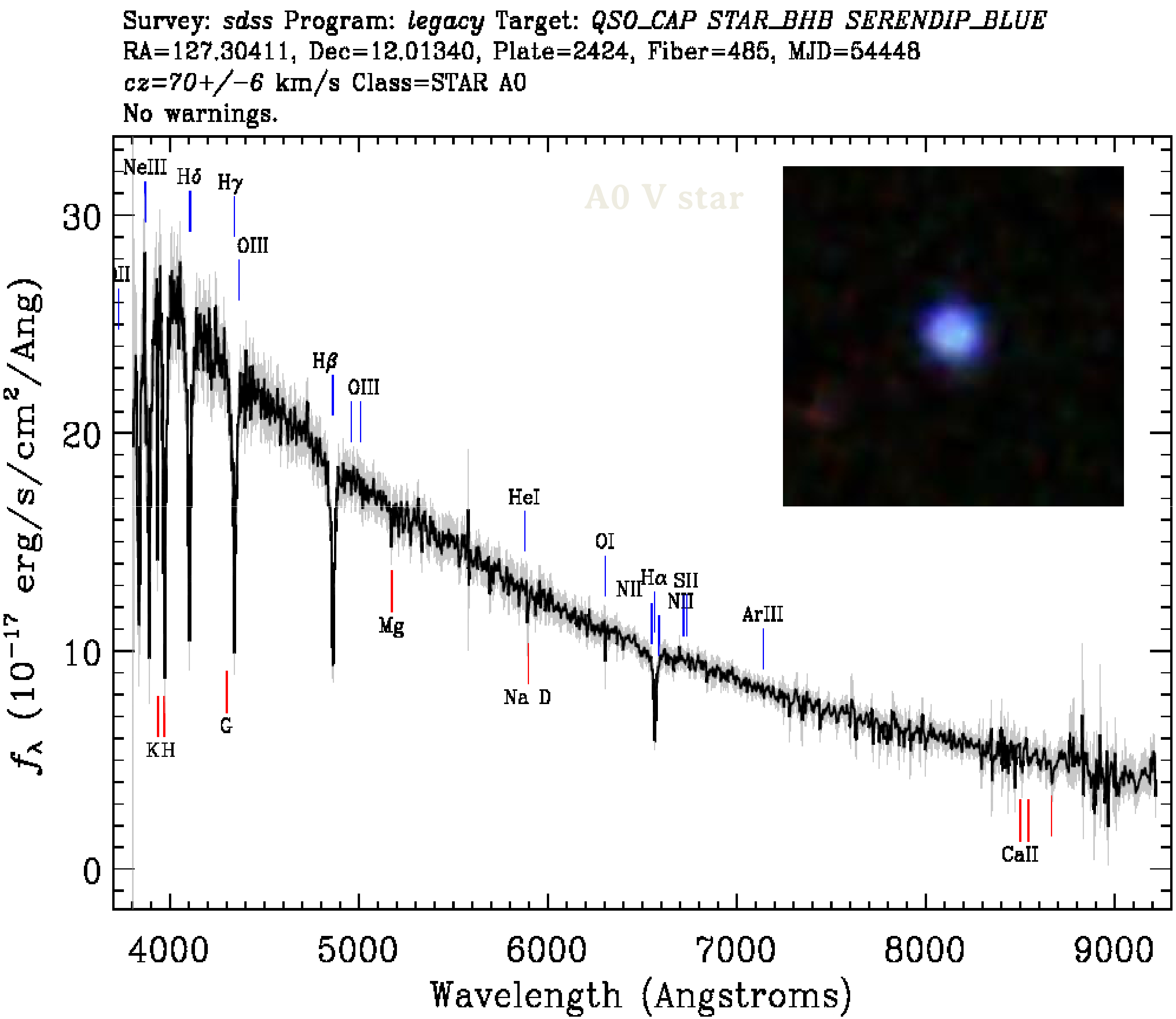
*The light from galaxies =*

*Stars + Nebulae + Dust*
*+ Galactic Center*

# The Formation of Spectral Lines

*The next several slides show sample optical spectra of main-sequence stars of various spectral type. Pay attention to how some of the prominent absorption lines in the optical wavelength range, like the Balmer series of Hydrogen, Ca II H & K lines etc, change with spectral type (temperature).*

You will find that star of a given spectral type has a set of signature absorption lines of a certain relative strength between them.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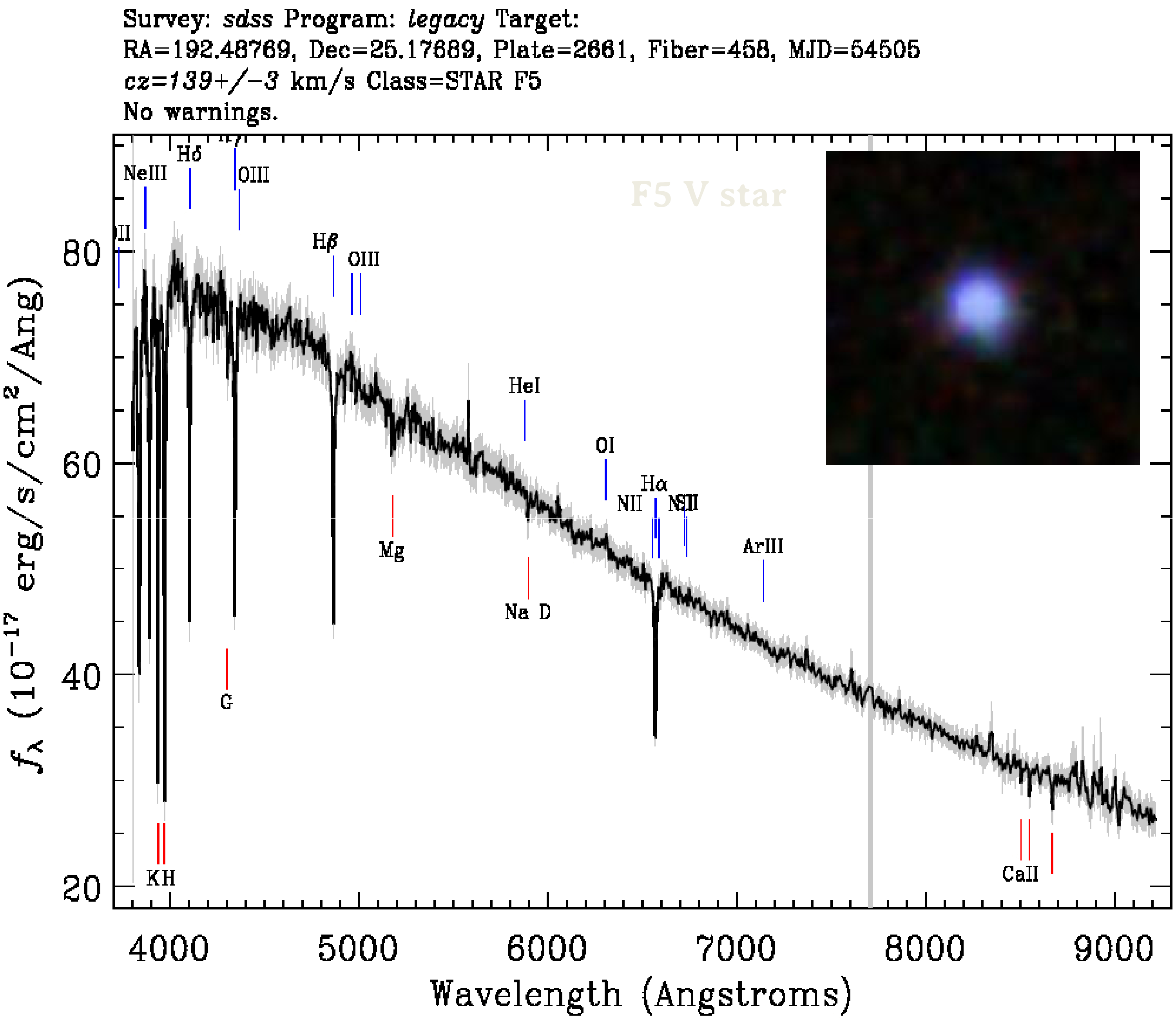
No warnings.
A0 V star
NeIII
Hδ
Hγ
OIII
Hβ
OIII
HeI
OI
NII
Hα
SII
NII
ArIII
KH
G
Mg
Na D
CaII
0
10
20
30
4000
5000
6000
7000
8000
9000
$f_\lambda$ ($10^{-17}$ erg/s/cm$^2$/Ang)
Wavelength (Angstroms)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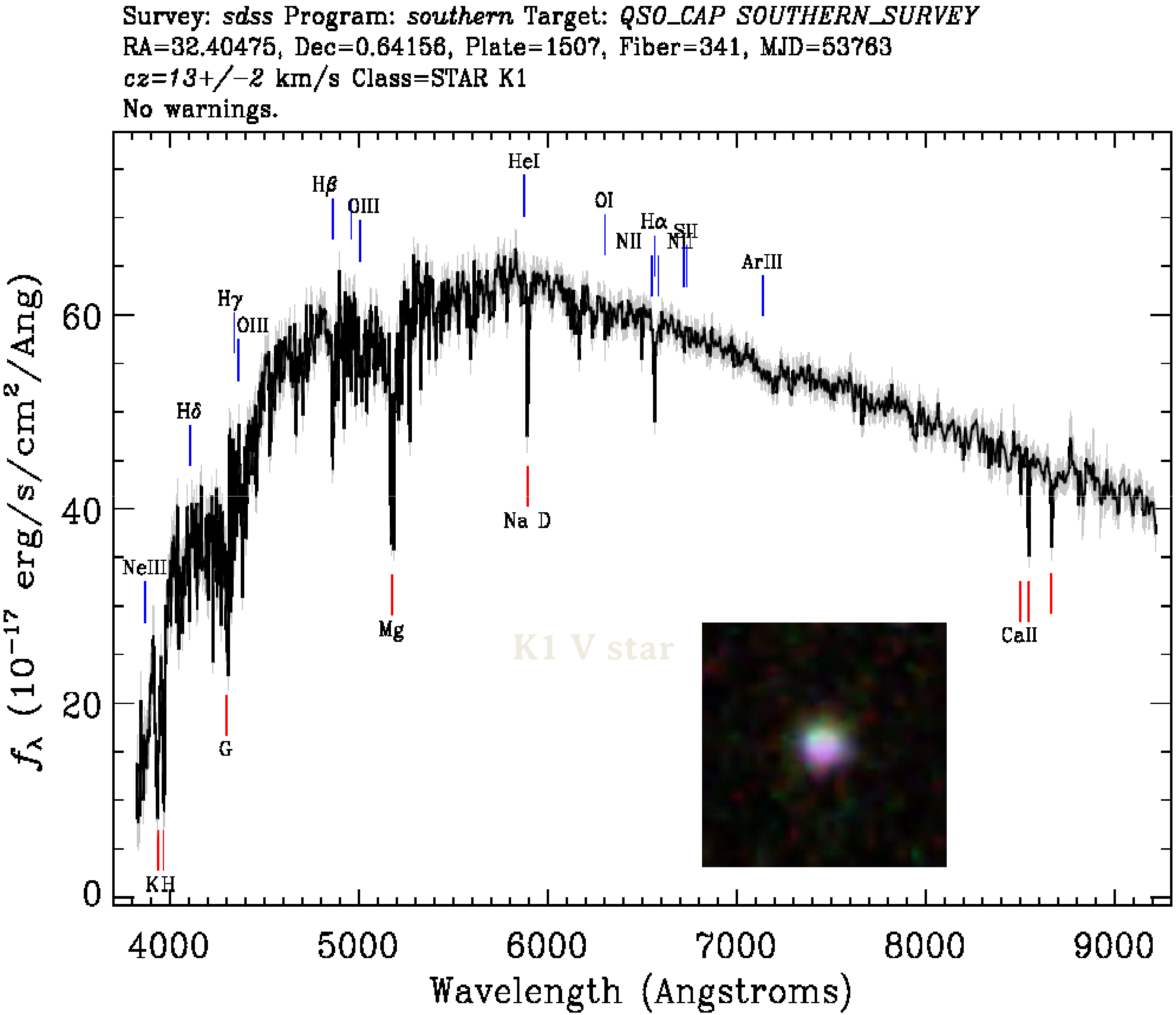
No warnings.
F5 V star
NeIII
Hδ
OIII
Hβ
OIII
HeI
OI
Hα
NII
SII
ArIII
Mg
Na D
G
KH
CaII
80
60
40
20
4000
5000
6000
7000
8000
9000
Wavelength (Angstroms)
$f_\lambda$ ($10^{-17}$ erg/s/cm$^2$/Ang)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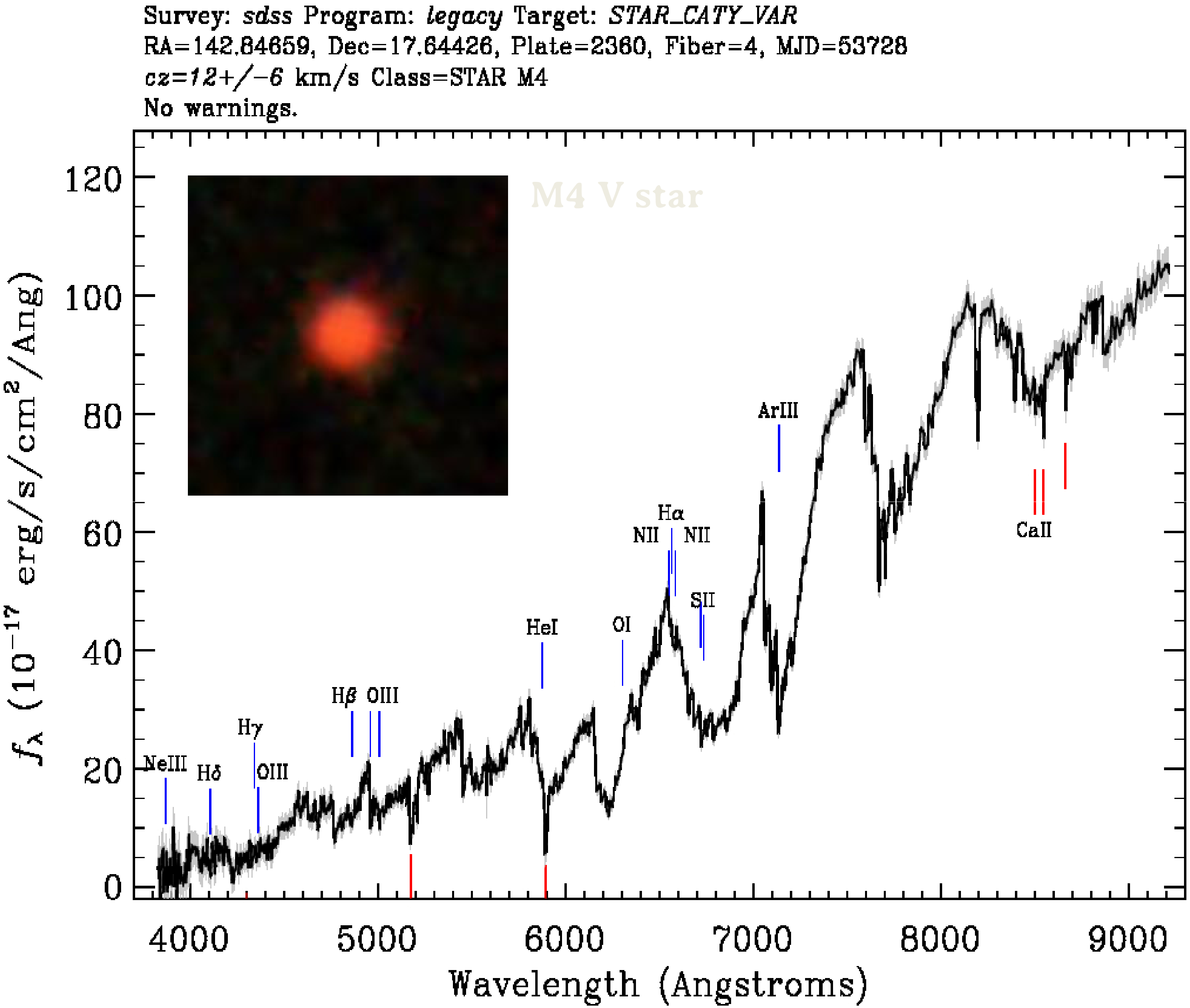
cz=13+/−2 km/s Class=STAR K1
No warnings.
$f_\lambda$ ($10^{-17}$ erg/s/cm$^2$/Ang)
0
20
40
60
4000
5000
6000
7000
8000
9000
Wavelength (Angstroms)
HeI
Hβ
OIII
OI
Hα
NII
SII
NII
ArIII
Hγ
OIII
Hδ
NeIII
KH
G
Mg
Na D
CaII
K1 V star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cz=12+/-6 km/s Class=STAR M4
No warnings.
M4 V star
NeIII
Hδ
Hγ
OIII
Hβ
OIII
HeI
OI
NII
Hα
NII
SII
ArIII
CaII
$f_\lambda$ ($10^{-17}$ erg/s/cm$^2$/Ang)
Wavelength (Angstroms)
0
20
40
60
80
100
120
4000
5000
6000
7000
8000
9000

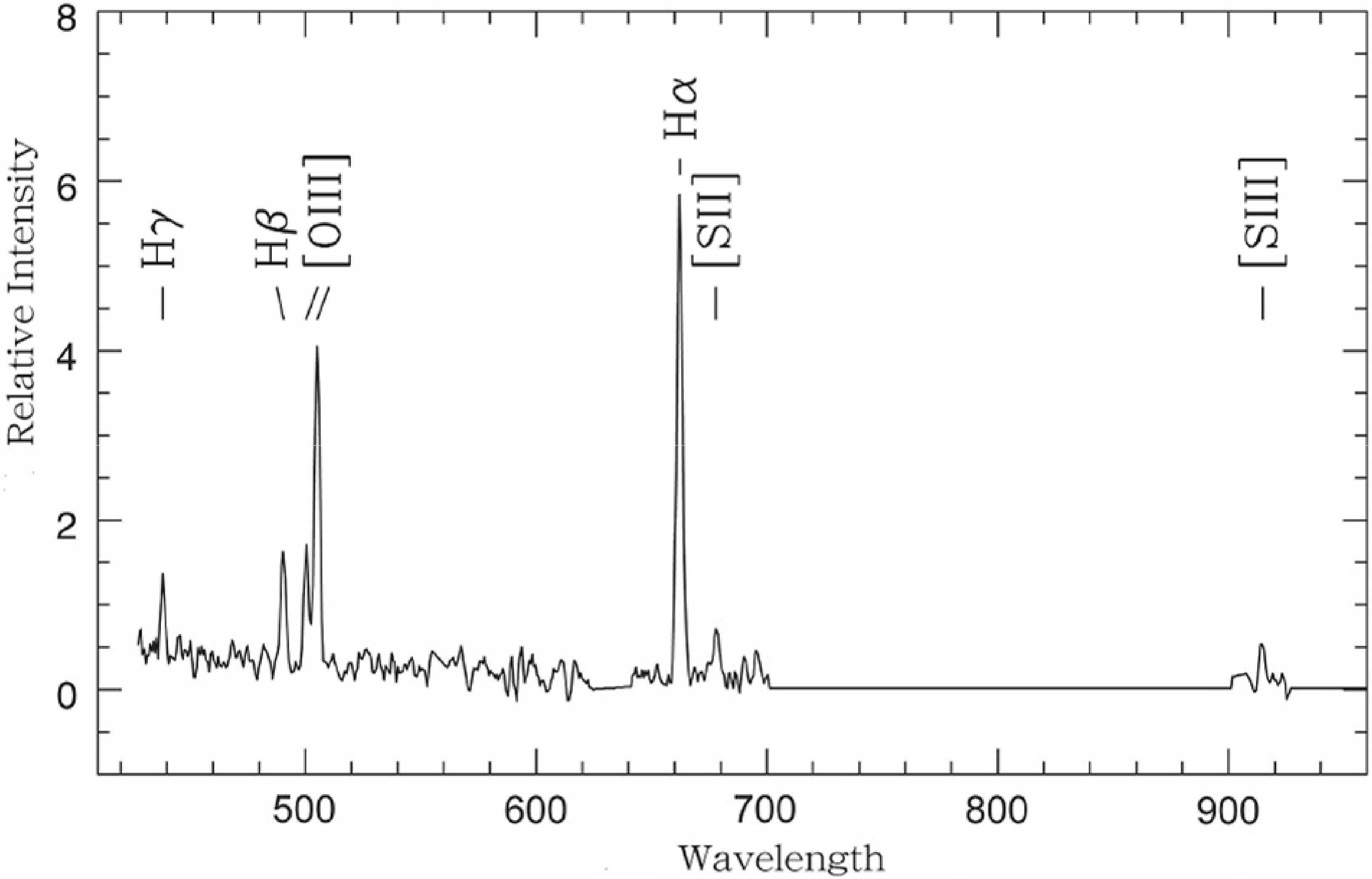
The spectrum of a galaxy in the optical and infrared is a combination of the light output from stars, the ISM and dust.

*The next two slides show the optical spectrum of H II regions, supernova remnants (SNR) and planetary nebulae (PNe) which are all components of the ISM.*

The light from H II regions, SNR and PNe is from emission lines due to ion – electron recombinations happening in those regions. The spectra of these astrophysical sources are indicative of this. There is very little continuum flux. Most of the flux comes at specific wavelengths.

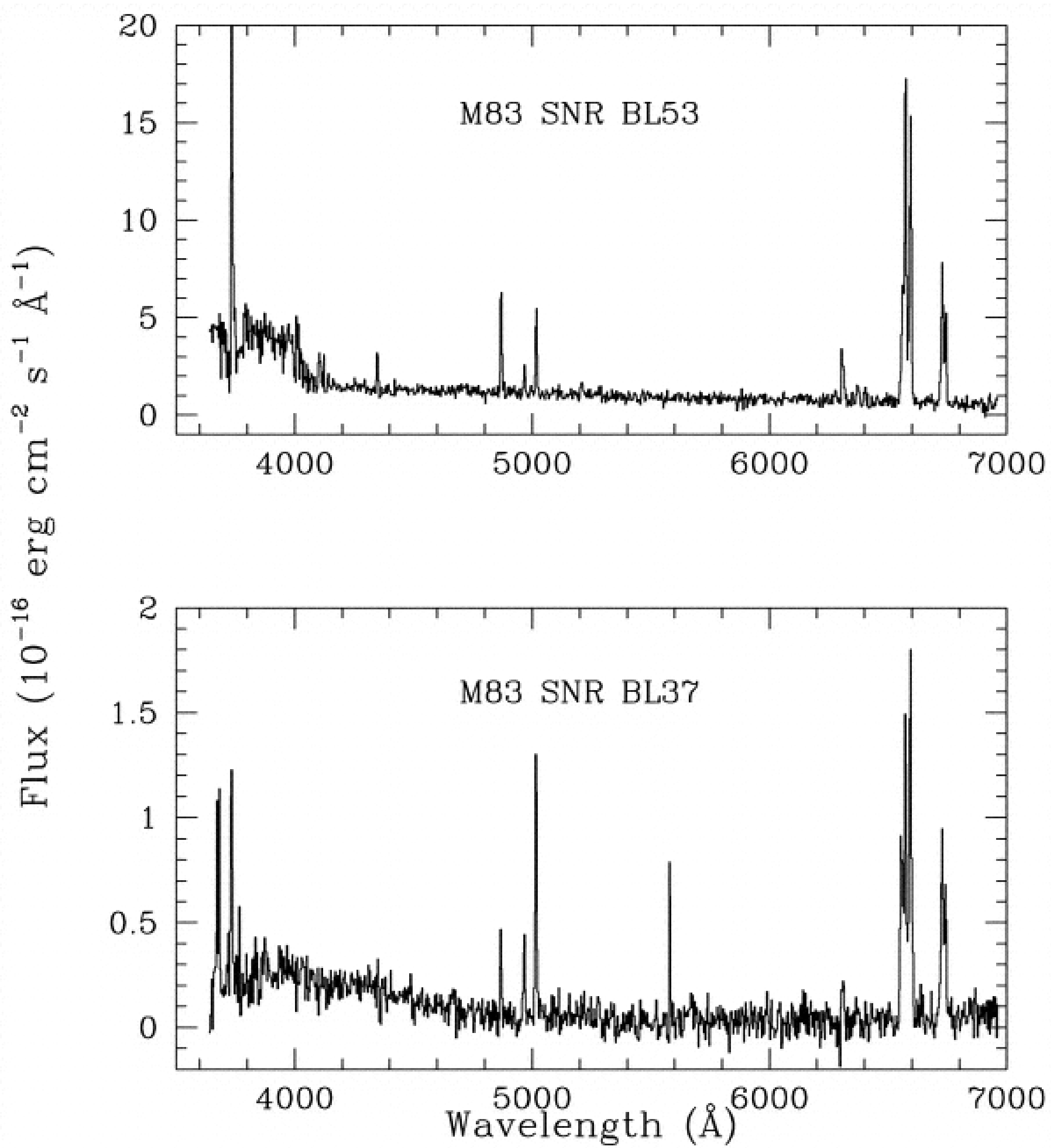
# The Glow of H II Regions

## Optical Spectrum of a H II Region

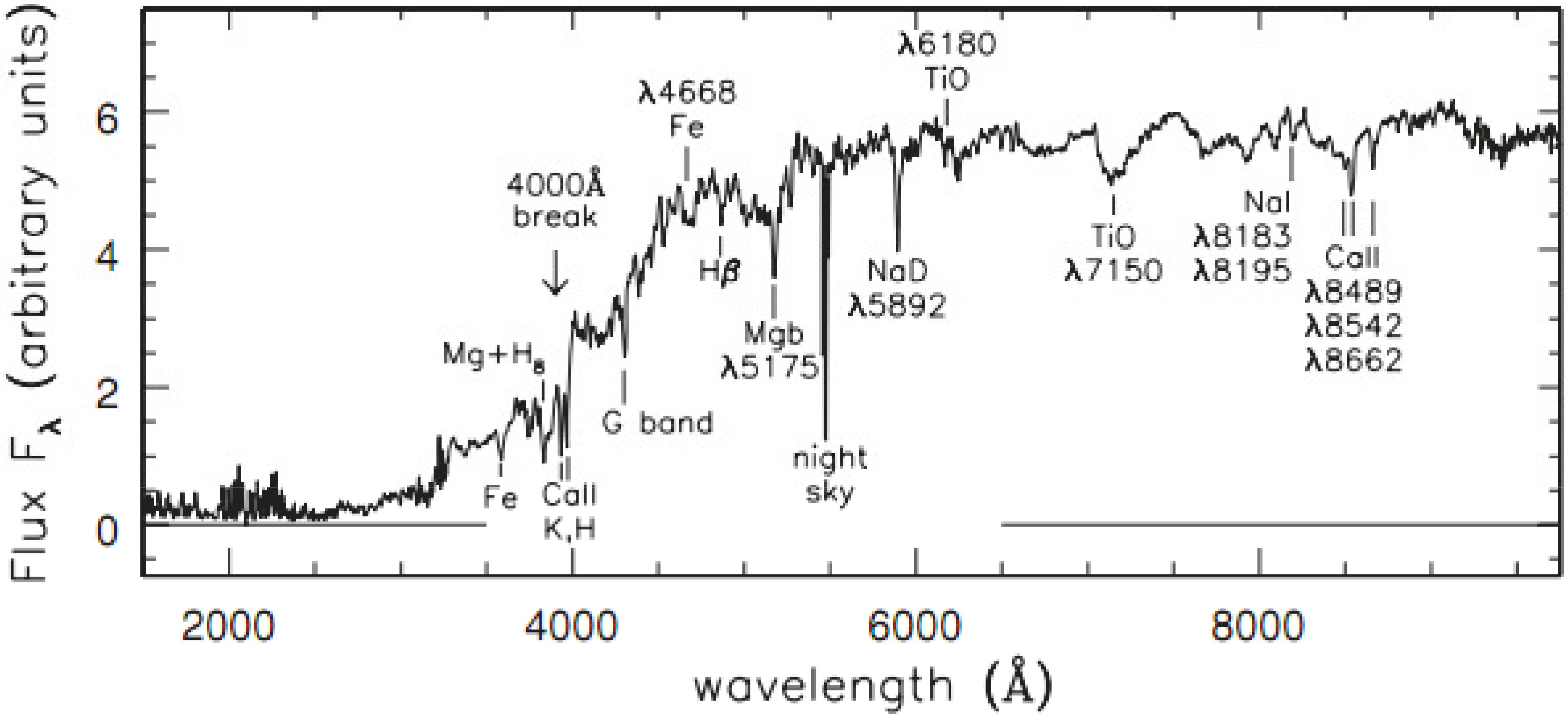



FORS2, VLT YEPUN

# The Glow of SNRs

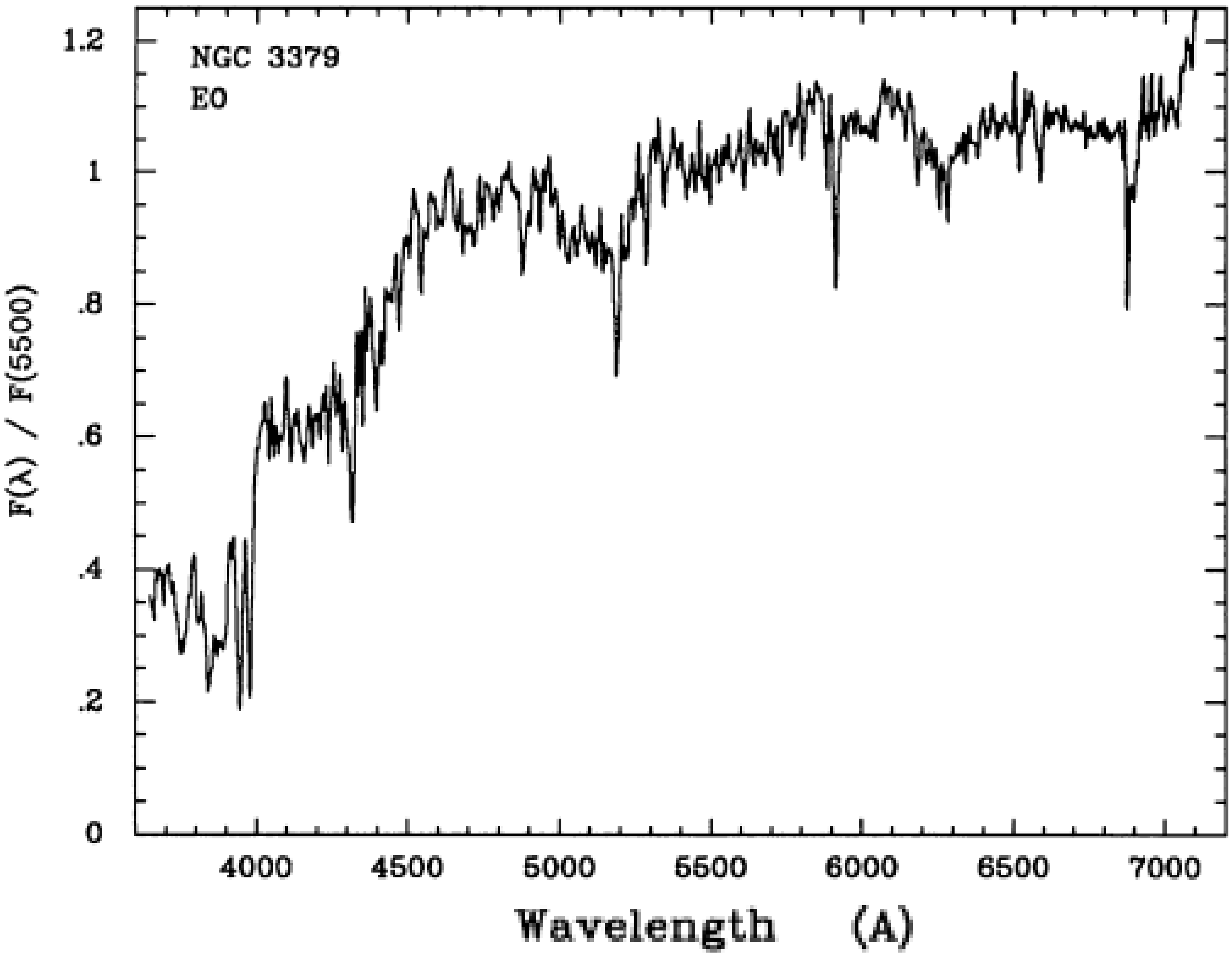


# Spectrum of a Typical Elliptical Galaxy

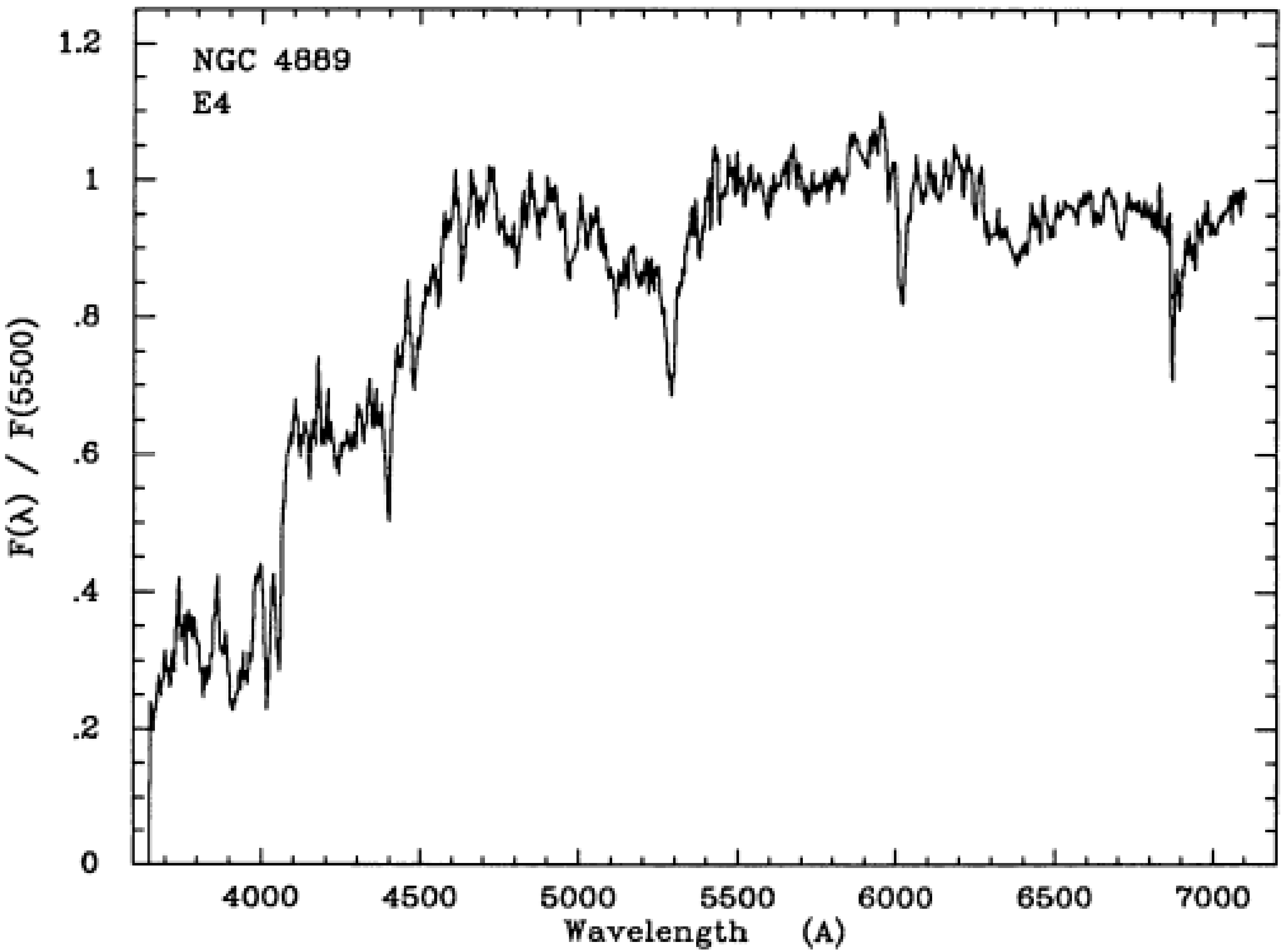



The spectrum of elliptical galaxies show strong absorption lines of heavy elements such as Na, Ca, Mg, similar to the K-star spectrum There is little light below 3500 Å, showing that the elliptical galaxies have made very few new stars in the last 1–2Gyr. So the galaxy's light comes mainly from red giants. The sharp break in the spectrum at 4000 Å comes from absorption by metals (heavier elements that have many energy levels), which suggests that the metallicity of the stars are NOT fairly low.

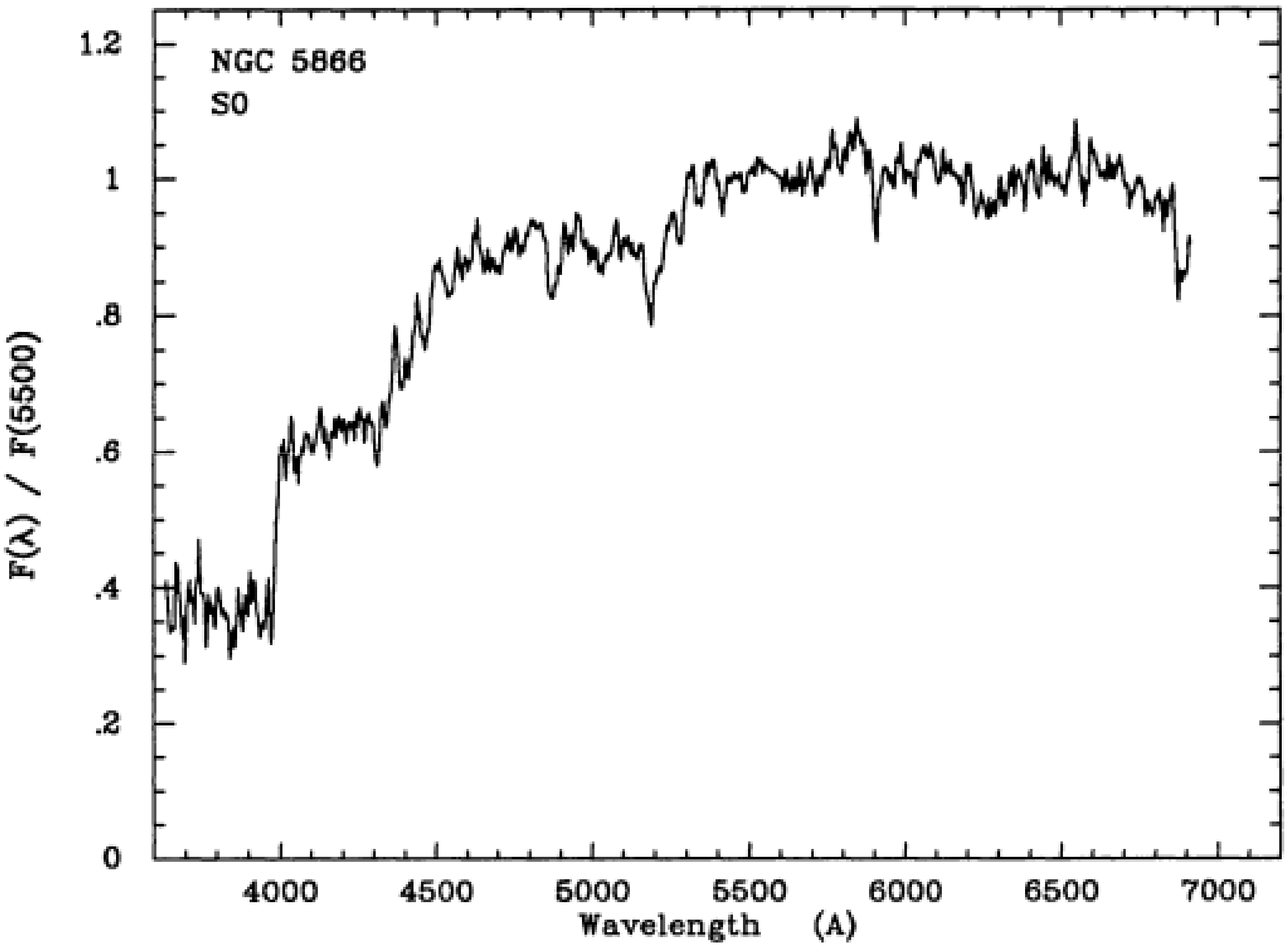
# Examples of Galaxy Spectra



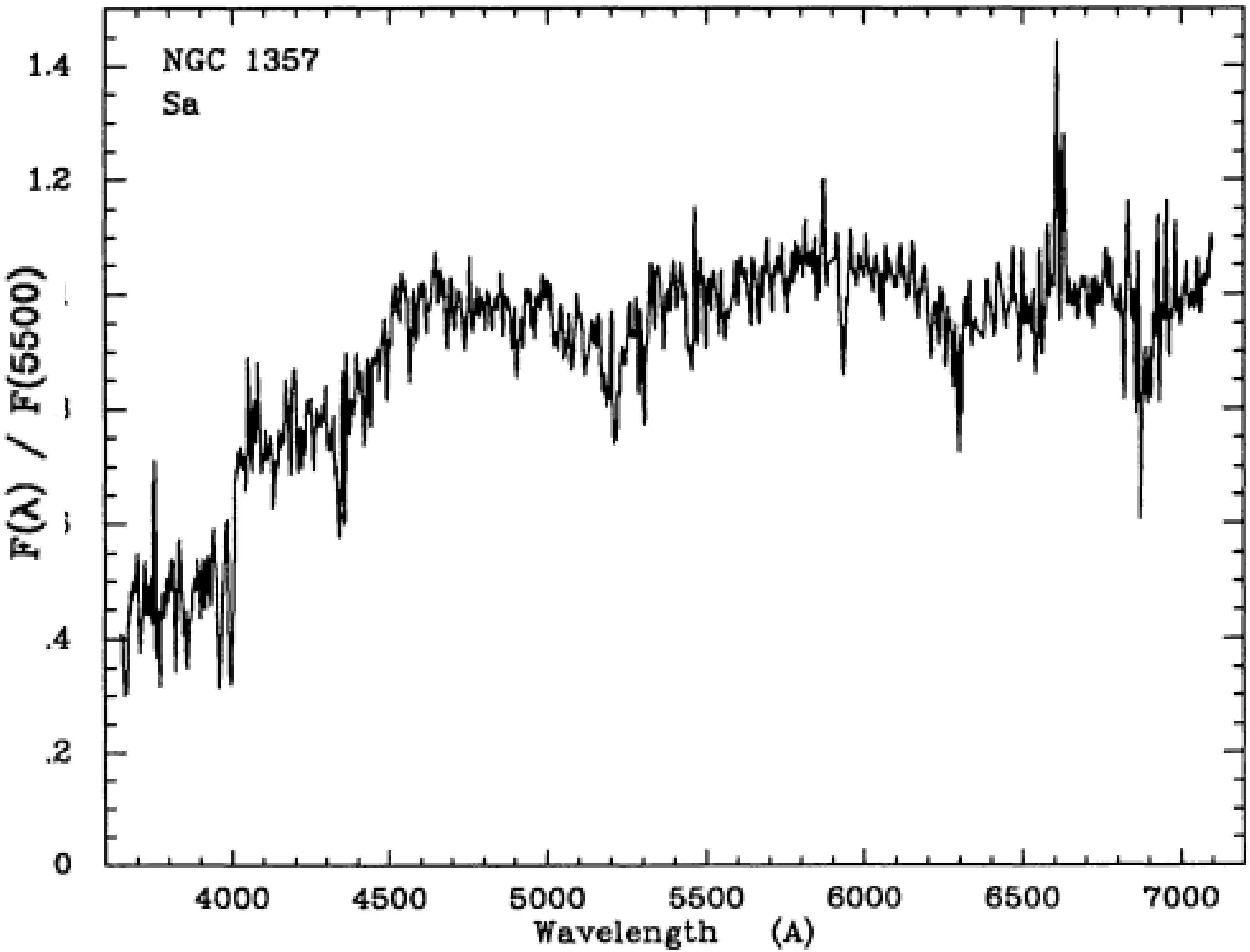
# Examples of Galaxy Spectra



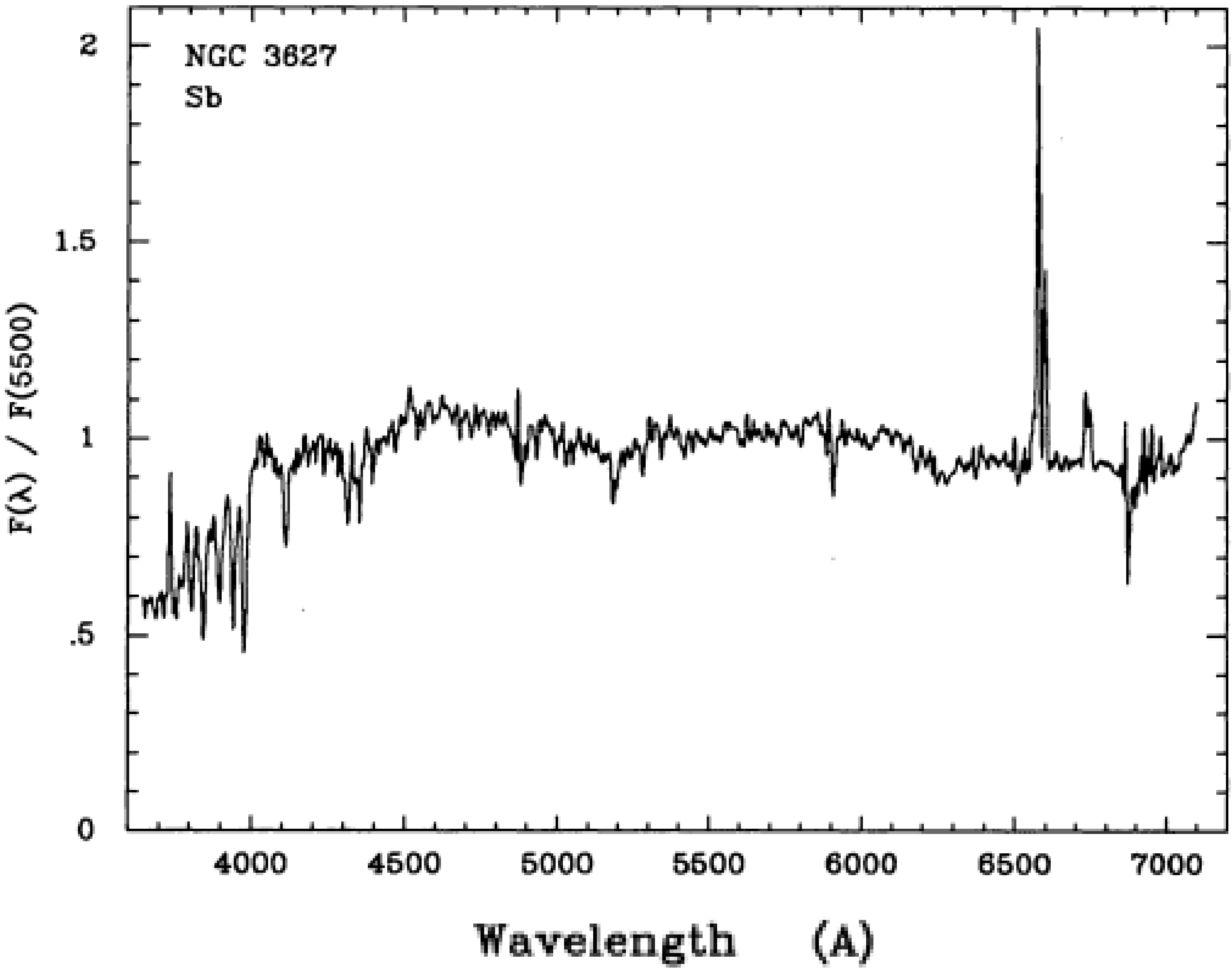
# Examples of Galaxy Spectra



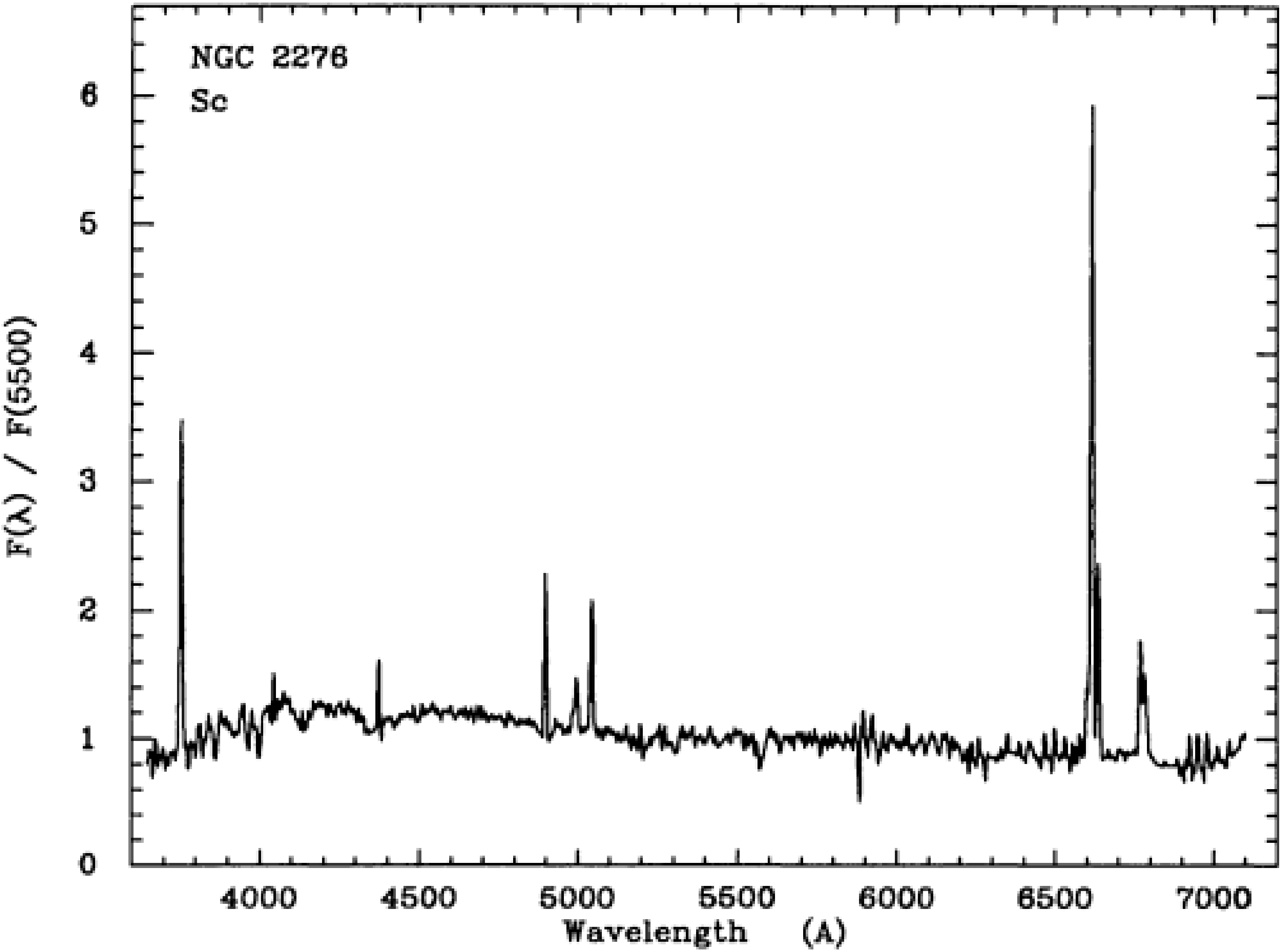
# Examples of Galaxy Spectra



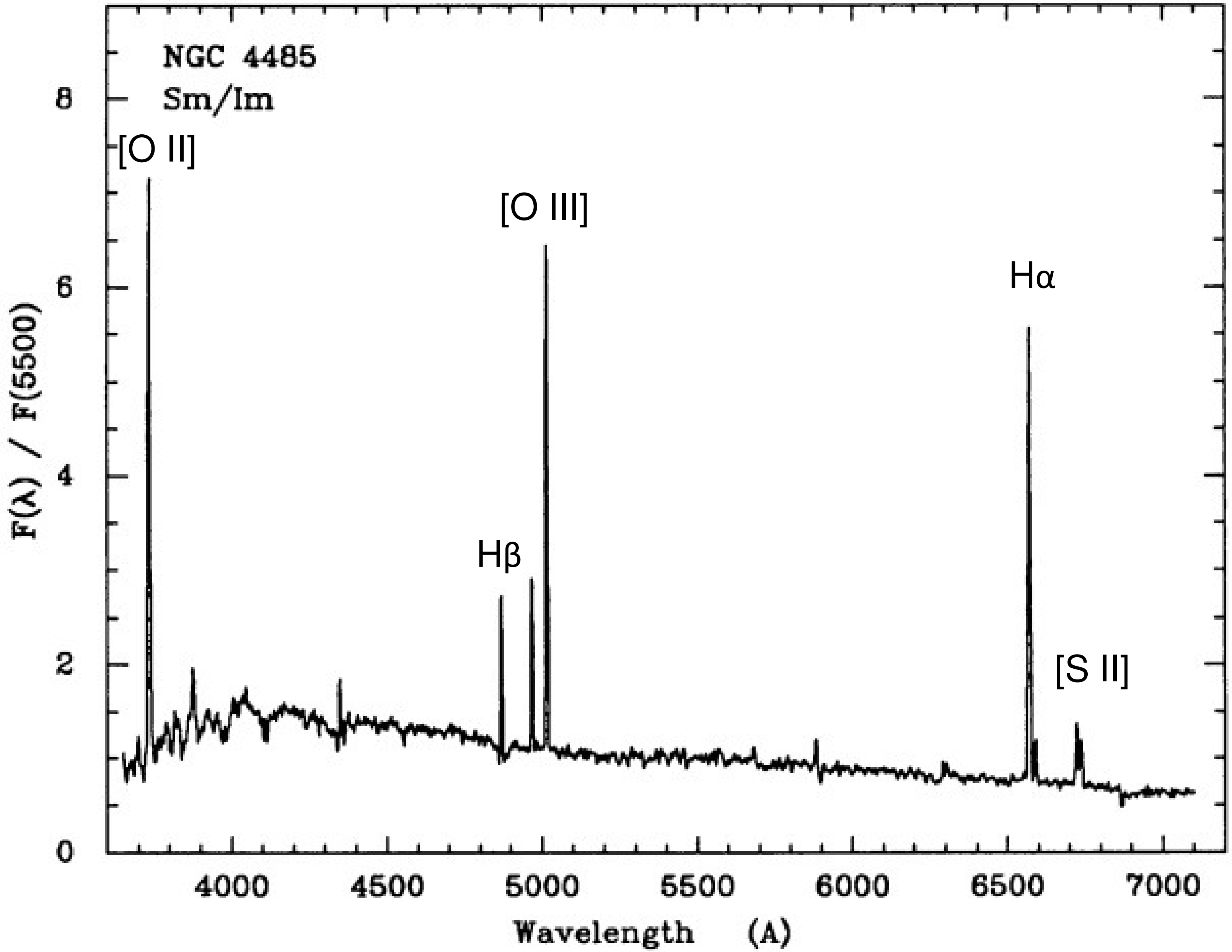
# Examples of Galaxy Spectra



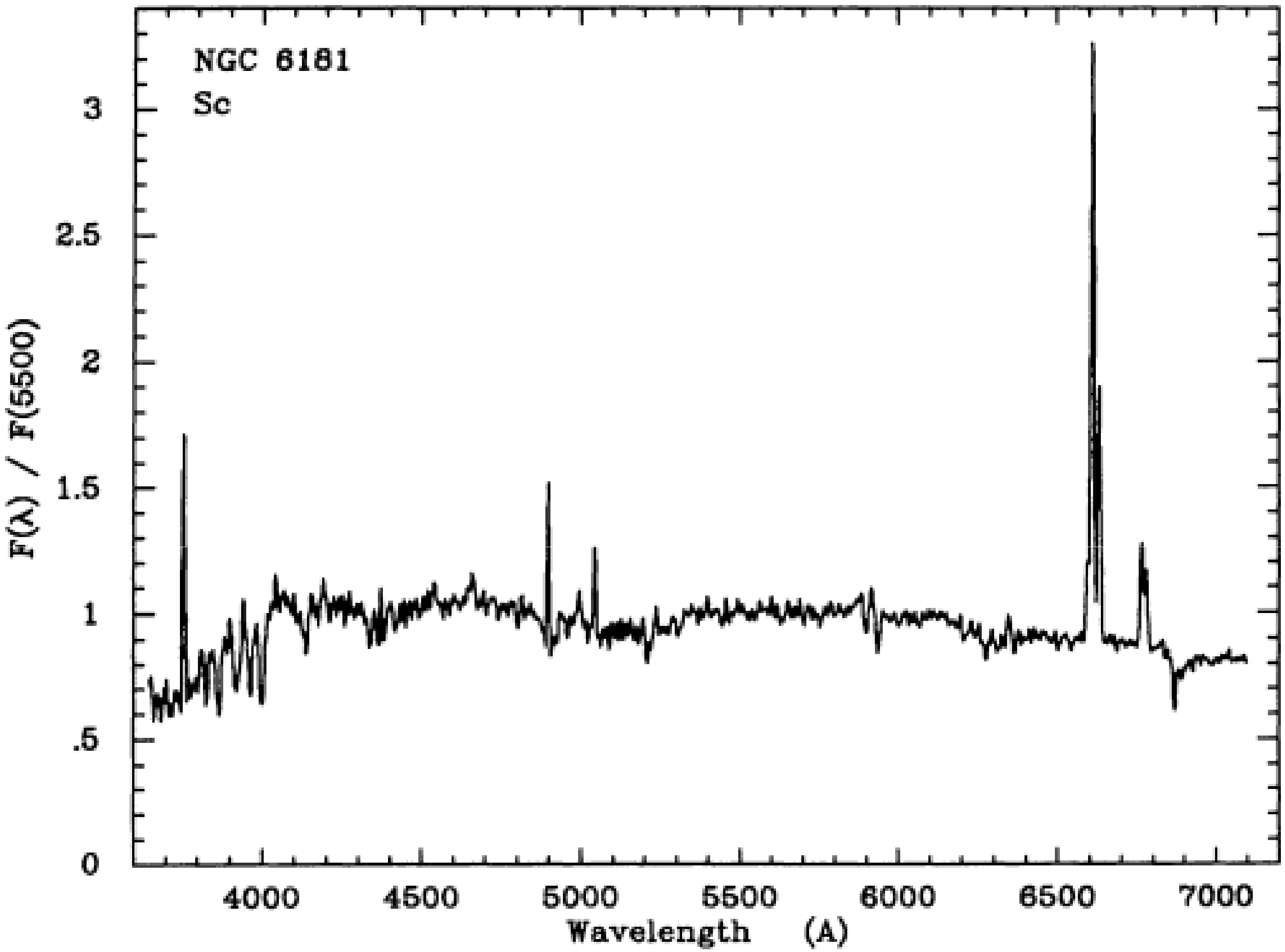
# Examples of Galaxy Spectra



# Examples of Galaxy Spectra



# Spectrum of a Typical Spiral (Sc / Sd) Galaxy




- The spectrum of spiral galaxies are usually emission line dominated (from H II regions, SNRs etc) indicating an underlying young stellar population, and possibly ongoing star formation.

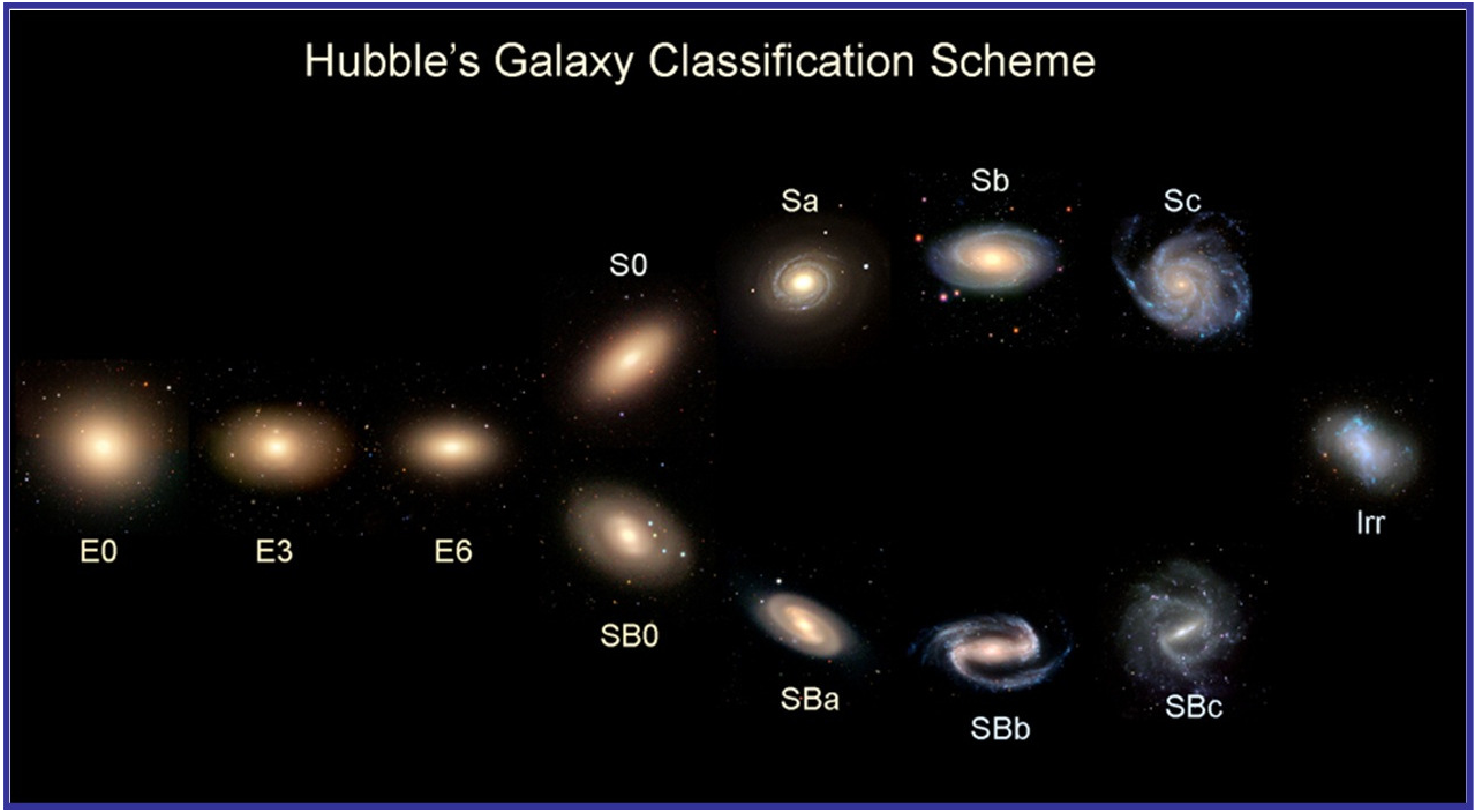
# The Hubble Sequence of Galaxies

This variation in spectral energy distribution (SED) and spectral properties signifies a difference in stellar content from ellipticals to spirals and irregulars. This difference in stellar content was the basis for Edwin Hubble's classification of galaxies in a manner which is now known to us as the ***Hubble Sequence***.

Hubble introduced this scheme to categorize galaxies based on their stellar content in his 1926 paper and 1936 book. Its concepts are still in use. In its simplest form, three basic types are recognized: ellipticals, spirals, and irregulars. Hubble could trace some trends in the sequence of arranging galaxies that fall under these three morphologies.

Remember that it is not possible to resolve individual stars directly in galaxies that are farther away that ~ 10 Mpc or so, with the current observing capabilities. Investigations of the spectral properties is therefore the only way to get a clue of the underlying stellar population in galaxies.

# Hubble's Tuning Fork



# Hubble’s Tuning Fork

Based on the observed morphologies, Edwin Hubble set out to place the galaxies in some sequential order which resulted in what is now famously known as *Hubble's tuning fork*.

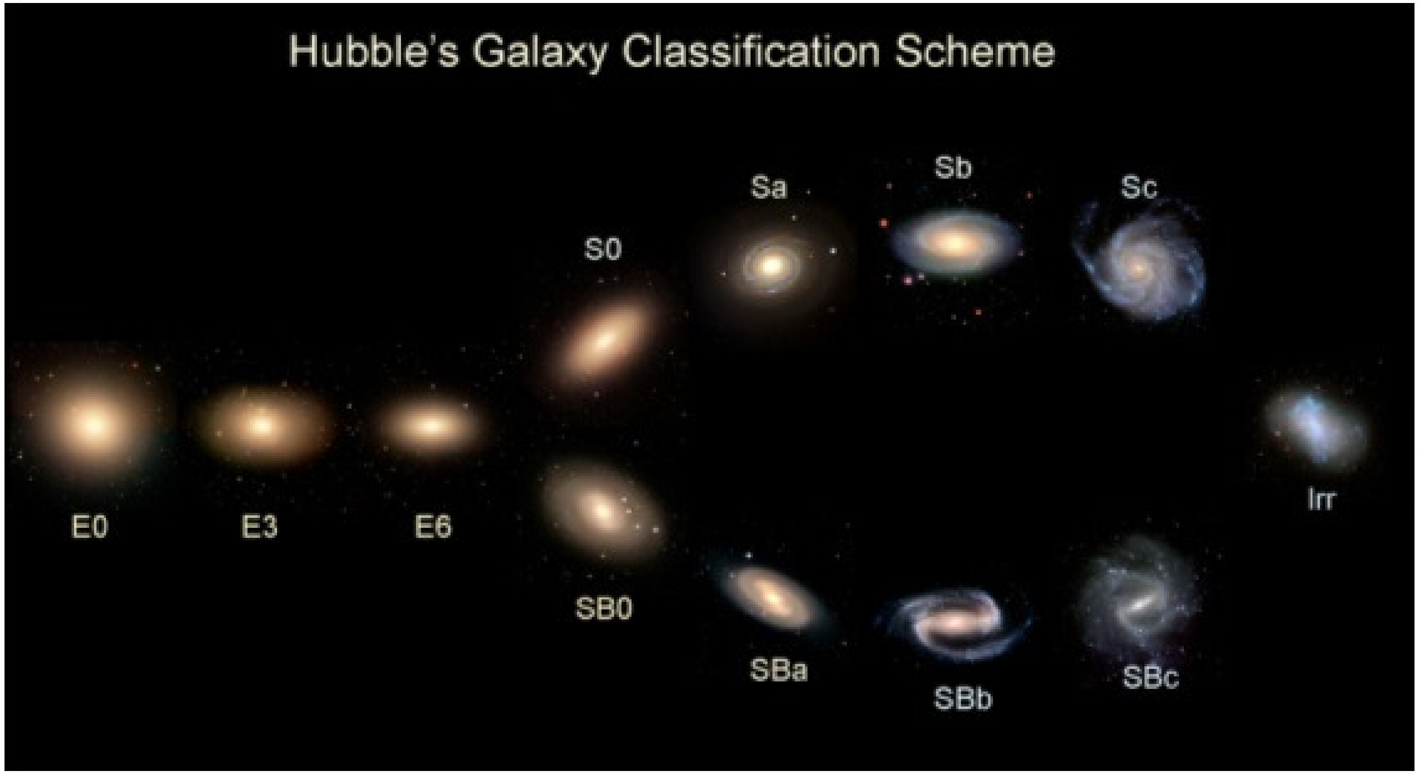
Hubble believed that galaxies started at the left end of the diagram and evolved to the right. This lead to the hypothesis that newly formed galaxies were ellipticals and they flattened and developed into spirals with the passage of time. Based on this, Hubble called the ellipticals ***early type galaxies*** and spirals as ***late type galaxies***. The basis of the classification involved the colour of the galaxies as well. Ellipticals are predominantly red in colour, whereas in spirals, the sprial arms are blue in colour. Almost all irregular galaxies are blue. Hubble inferred (correctly) this to be due to a predominantly older stellar population in ellipticals and a younger stellar population in spirals. But from there he came to the (incorrect) conclusion that ellipticals are older galaxies that formed early in the history of the universe and spiral galaxies formed much later and therefore are younger.

# Hubble's Tuning Fork

Hubble used the tuning fork diagram to put forth the idea that galaxies start at the left end of the diagram and over time evolve to the right end. This notion that the Hubble sequence is an evolutionary sequence is now completely rejected. We know this because spiral galaxies have systematic rotation, while elliptical galaxies have only random motion (not known to Hubble). It would be very rare for an elliptical galaxy to spontaneously begin rotating. The current understanding is that the morphologies of galaxies are primarily dictated by the environment in which they form. Galaxies do evolve after they form, but that evolution is not along the Hubble sequence.

Although Hubble was wrong about his theory on galaxy evolution, his diagram provides a convenient way of classifying galaxies based on their observed morphology. Astronomers still classify galaxies based on his terminology: elliptical galaxies are still referred to as "early galaxies" and spirals as "late galaxies." Despite the lack of an evolutionary trend, Hubble classification of galaxies do show some trends in certain important galaxy properties (*see next slide*).

# Trends in the Hubble Sequence




**Color :** RED ⟶ BLUE

**Stellar Population :** Old — Old + Intermediate — Intermediate + Young — Young

**SFR :** ⟶

**H I gas :** ⟶

**Dust :** Low / Zero ⟶ Highest — Low