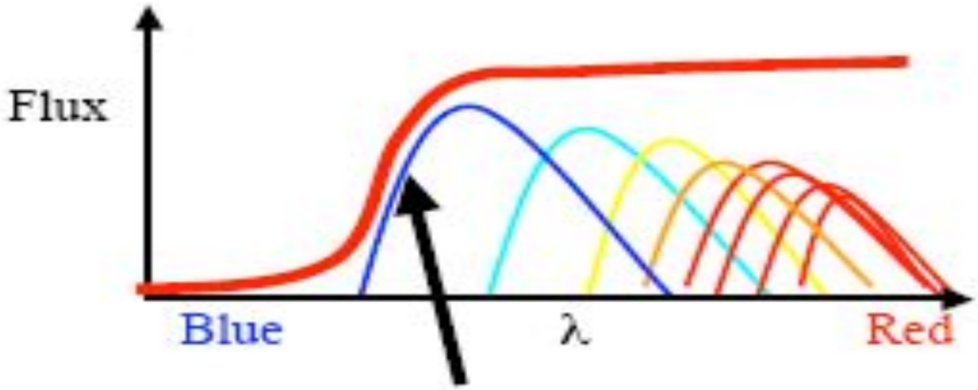
Galaxy Spectra

- The combination of ~50 billion **stars** plus many **molecular clouds** and **star-forming regions**.
- The spectra tell us:
  - The galaxy's relative **velocity**
  - The **star-formation rate**
  - The average **age** of the stellar population
- 3 Aspects:
  - **Continuum**
  - **Absorption Lines**
  - **Emission Lines**

Continuum

- The combination of many Black-Body spectra spanning a range in temperatures
- This produces a fairly flat overall spectrum



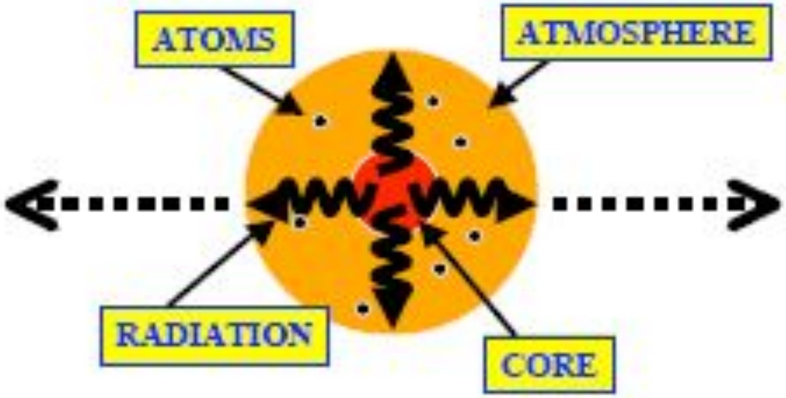
- The main feature is the 4000A-break

The 4000A-break

- Caused by:
  - **absorption** of high energy radiation by **metals** in the stellar atmospheres
  - the **lack of hot blue stars**
- Hence:
  - Ellipticals => A strong 4000A-Break
  - Spirals => A weak 4000A-Break
  - Irregulars => No 4000A-Break

Absorption Lines

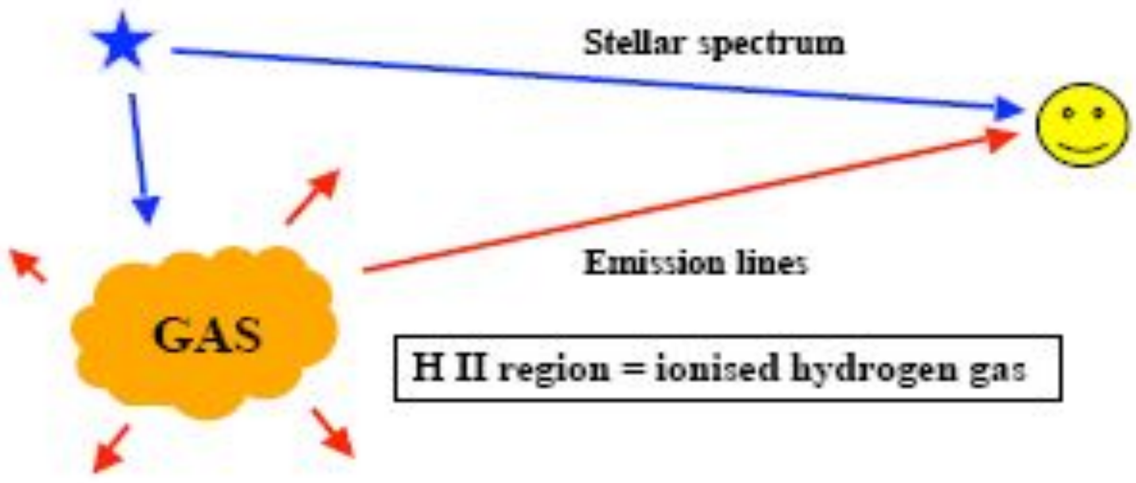
- Atoms/Molecules in a star's atmosphere absorb light at specific wavelengths



- Cold gas in the interstellar medium (ISM) also absorbs specific wavelengths from the passing radiation: Extinction in Galaxy course.

Emission Lines

- Young stars are initially embedded in gas.
- Hot (high-mass) young stars ionise nearby gas.
- Gas emits at specific wavelengths as the free electrons recombine.



Absorption / Emission Lines

- Absorption Lines
  - Need metals in stellar atmospheres or cold gas in the interstellar medium
- Implies
  - Old stellar population = old galaxy
- From
  - Ellipticals
  - Spiral Bulges

- Emission Lines
  - Need gas heated by nearby O and B type stars
- Implies
  - Newly formed stars = star-forming/young galaxy
- From
  - Spiral Disks
  - Irregulars

Typical Spectral features

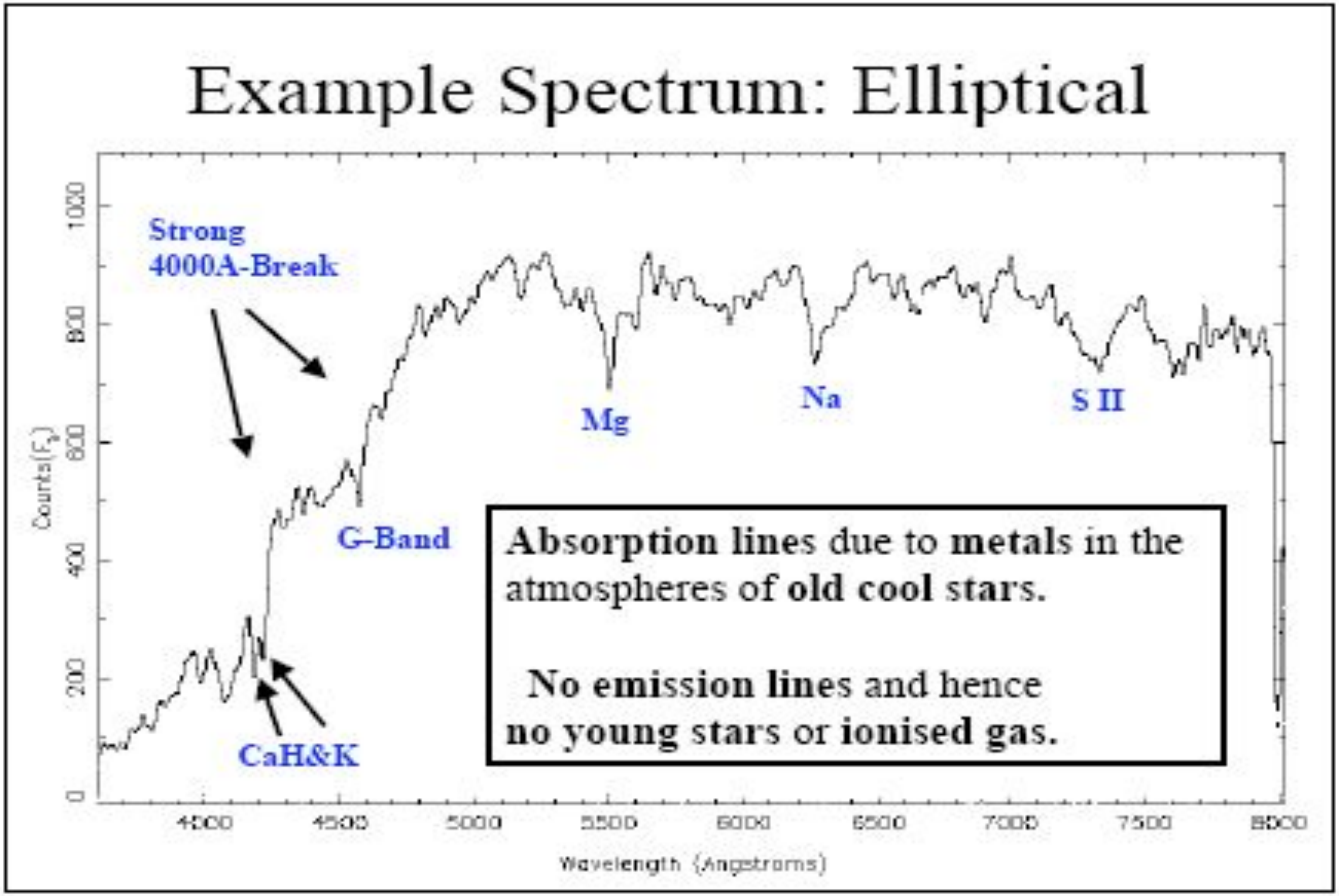
- Absorption
  - Ca(H) = 3933.7A
  - Ca(K) = 3968.5A
  - G-band = 4304.4A
  - Mg = 5175.3A
  - Na = 5894.0 A
- Emission
  - O[II] = 3727.3A
  - Hδ = 4102.8A
  - Hγ = 4340.0A
  - Hβ = 4861.3A
  - O[III] = 4959.0A
  - O[III] = 5006.8A
  - Hα = 6562.8A
  - S II = 6716.0A

1 Angstrom = 0.1 nm = 10^{-10} m

Brackets (e.g. O[III]) mean "forbidden lines", emitted only at very low gas densities.

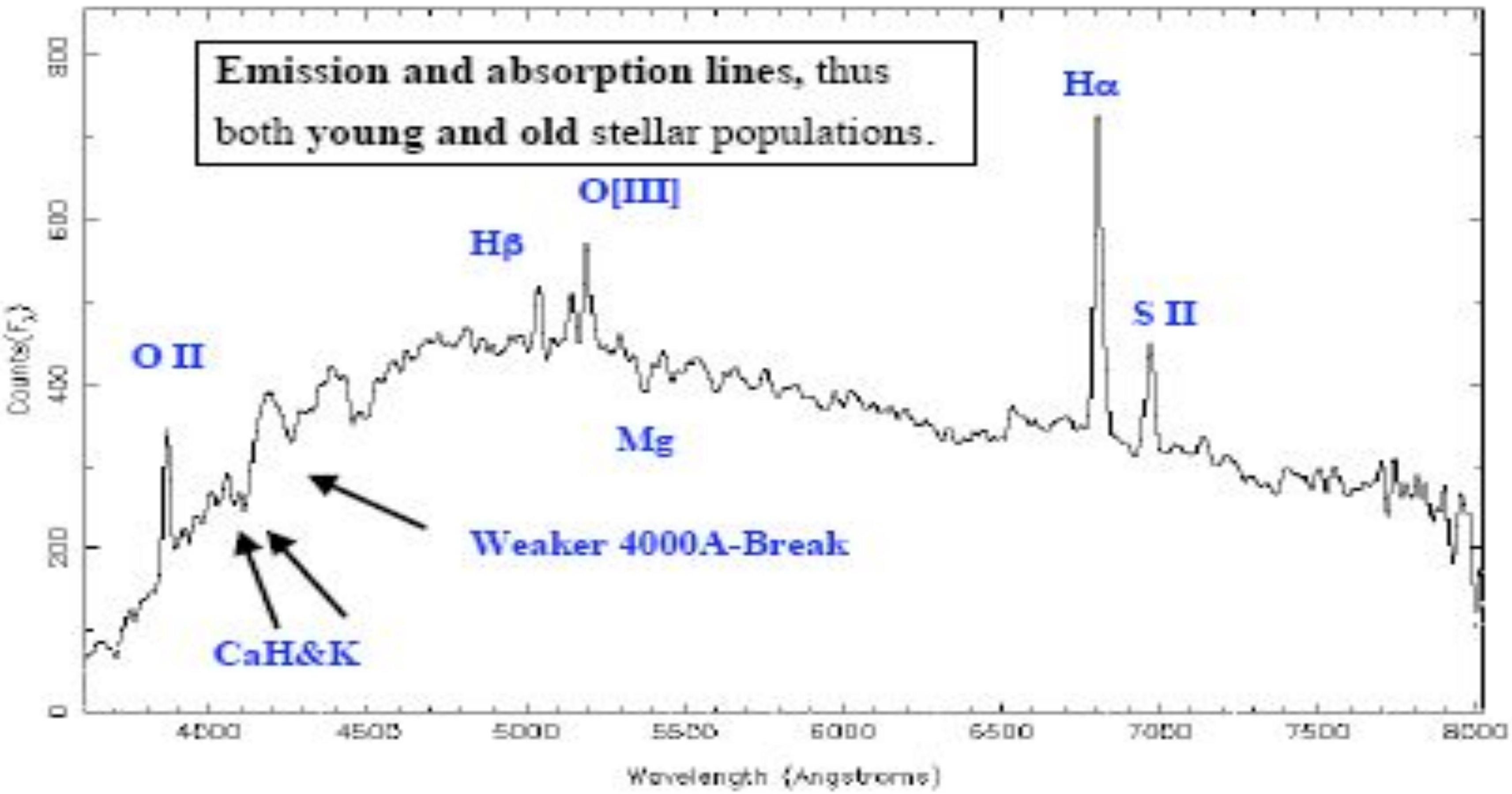
- Cuando n2 = 2, las energías de los fotones son tales que las longitudes de onda asociadas pertenecen a la serie de Balmer, y son designadas de la siguiente manera:
- n = 3 a n = 2 se llama H-alfa, o Hα
- n = 4 a n = 2 se llama H-beta, o Hβ
- n = 5 a n = 2 se llama H-gamma, o Hγ, etc.

- Ca(H): A spectral line of singly ionized calcium.
- Ca(K): Two spectral lines of singly ionized calcium.

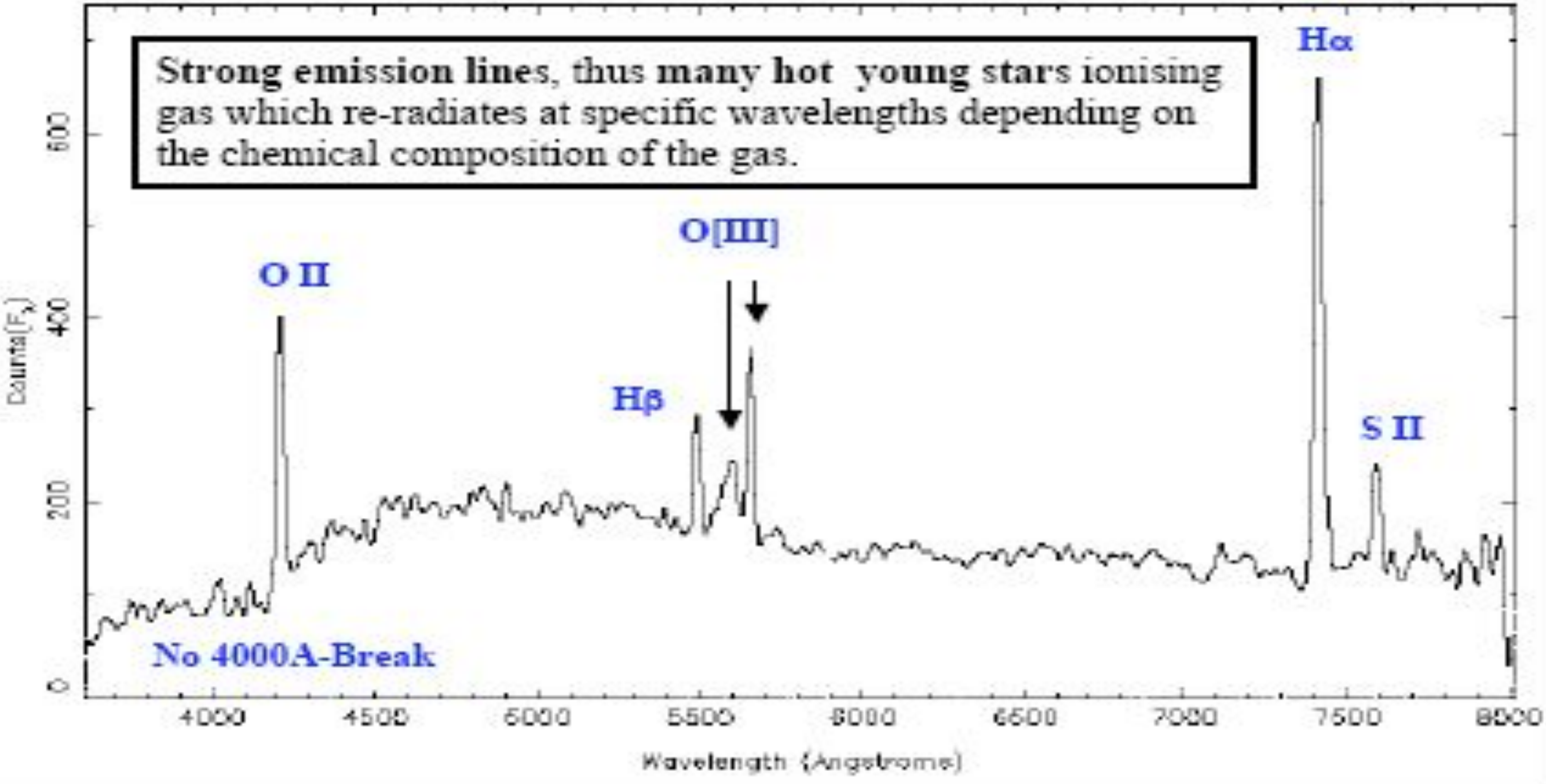


Example Spectrum: Elliptical
Strong
4000A-Break
CaH&K
G-Band
Mg
Na
S II
Absorption lines due to metals in the atmospheres of old cool stars.
No emission lines and hence no young stars or ionised gas.
Counts(F_λ)
Wavelength (Angstroms)
0
200
400
600
800
1000
4000
4500
5000
5500
6000
6500
7000
7500
8000

Example Spectrum: Spiral

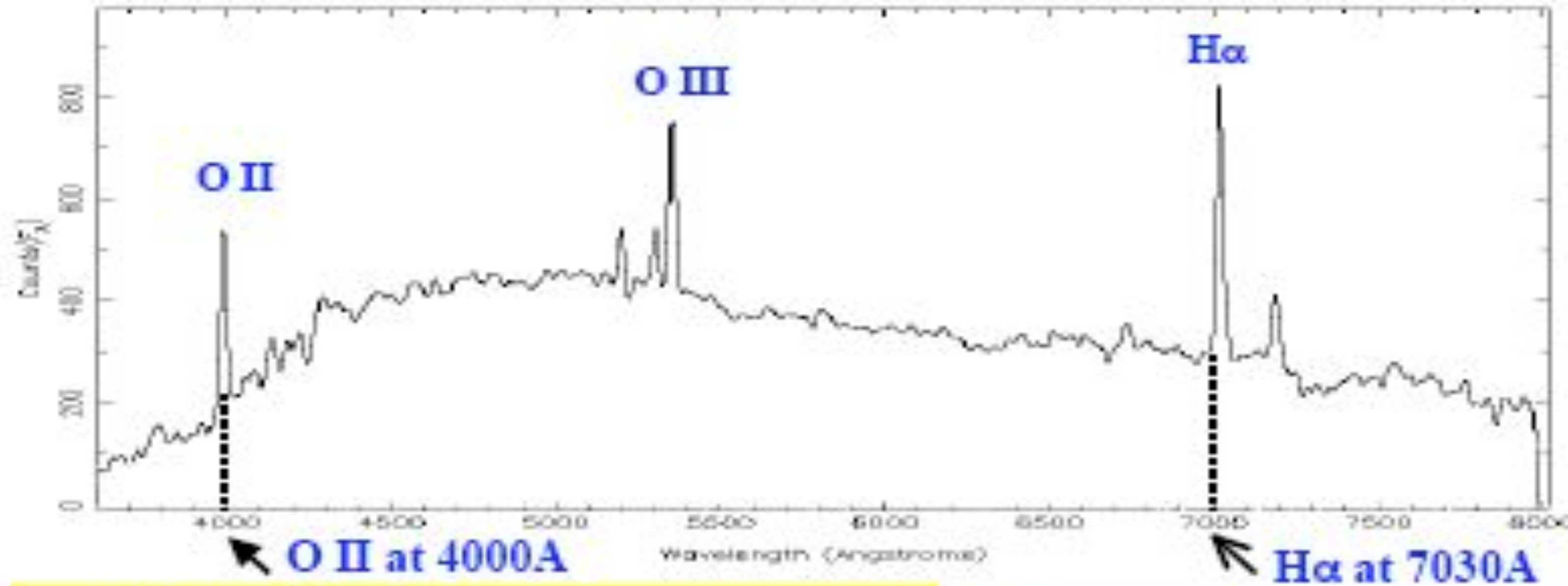


Example Spectrum: Irregular



- G in the spectra of stars and galaxies doesn't denote a specific element, but a specific spectral feature. In this case it comes from many weaker things blended together - the CH molecule, Fe lines, and more.
- The name goes back to the time of Joseph Fraunhofer, who saw absorption features in the spectrum of sunlight and named some of the stronger ones from red to blue. C is what we now call H-alpha, D is a pair of sodium lines near 5893 A, and H and K are the violet lines of Ca II at 3933/3968 A.
- The so-called G band is strong in the spectra of stars sort of like the Sun, making it correspondingly strong in the spectra of elliptical galaxies and spirals with lost of old stars in the central bulge.

Example Radial Velocity



$$v = c\left(\frac{\lambda_{OBS}-\lambda_{LAB}}{\lambda_{LAB}}\right)$$

$$= \left(3\times10^{5}\ \text{km/s}\right)\left(\frac{4000-3727}{3727}\right) = 21{,}974\ \text{km/s}$$

$$v = c\left(\frac{467}{6563}\right) = 21{,}500\ \text{km/s}$$

GALAXY IS MOVING AWAY AT ABOUT 21,750 km/s

- Spectral synthesis is the decomposition of an observed spectrum in terms of a superposition of a base of simple stellar populations of various ages and metallicities, producing astrophysically interesting output such as the star-formation and chemical enrichment histories of a galaxy, its extinction and velocity dispersion.

- GALAXEV is a library of evolutionary stellar population synthesis models computed using the isochrone synthesis code of Bruzual & Charlot (2003).
- This code allows one to computes the spectral evolution of stellar populations in wide ranges of ages and metallicities at a resolution of 3 Å across the whole wavelength range from 3200 Å to 9500 Å, and at lower resolution outside this range.

Correlación morfología-Espectro (Madgwick, astro-ph/0209051):

- Espectros del 2dFGRS vs. morfología en el APM.
- Rango espectral: 3700-8000A
- Espectro típicos:

Espectro Promedio

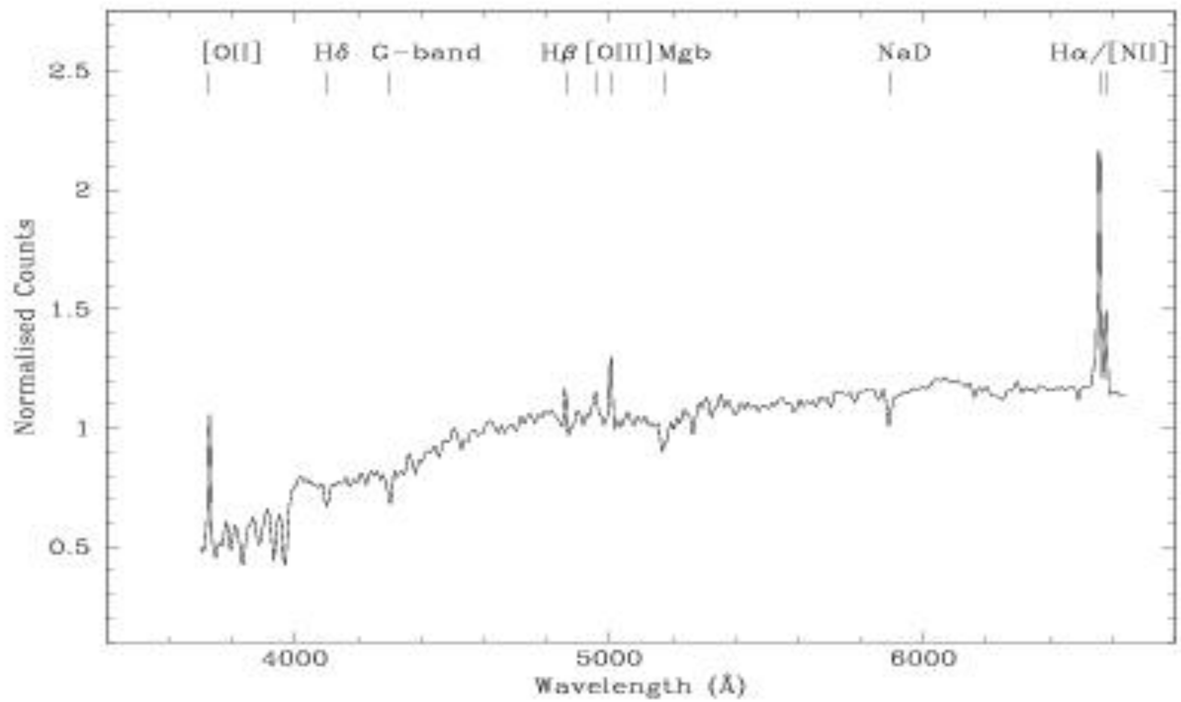


Figure 3. The average spectrum of an $M_{b_J} - 5\log_{10}(h) > -18$ volume-limited sample of galaxies drawn from the 2dF Galaxy Redshift Survey. The main spectral features present are labelled.

be measured in a given period of time, compromises have had to be made with respect to the spectral quality of the observations. Therefore if one wishes to characterise the observed galaxy population in terms of their spectral properties care must be taken in order to ensure that these properties are robust to the instrumental uncertainties.

is to separate those galaxies with $\eta < -1.4$ from those with $\eta \geqslant -1.4$, referred to as *relatively* quiescent and star-forming galaxies respectively.

4 FISHER'S LINEAR DISCRIMINANT

Espectro típicos:

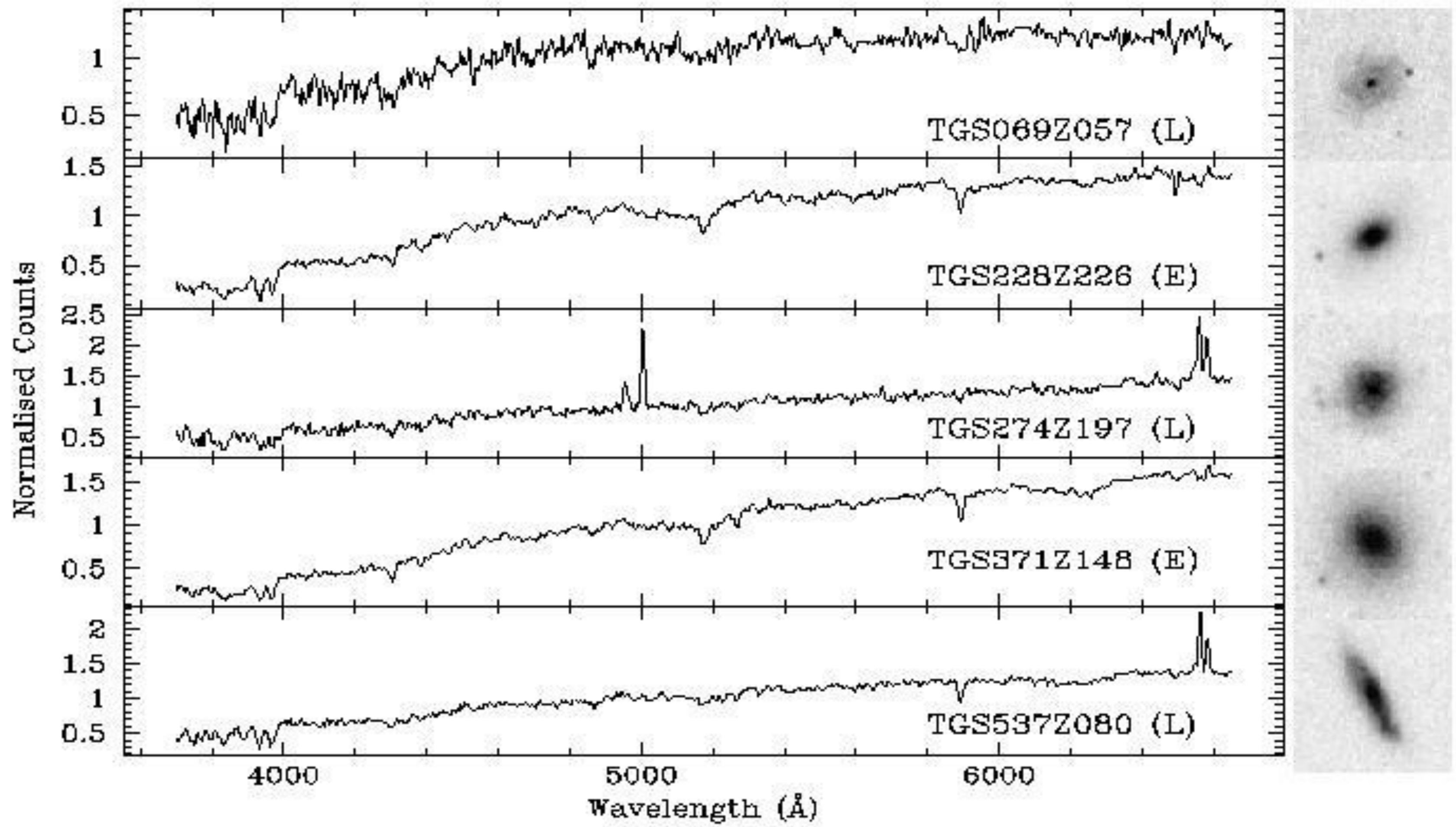


Figure 1. A selection of example galaxy spectra and images are shown. The spectra have been taken from the 2dF Galaxy Redshift Survey and are in units of counts/bin with arbitrary normalisation. The images shown are **1 × 1** arcmin postage stamps, in the standard astronomical orientation, taken from the SuperCOSMOS Sky Survey (Hambly et al. 2001). For each spectrum the 2dFGRS object name is given and the labels (L) and (E) refer to Late-type and Early-type morphologies respectively.

- Para hacer más fácil el problema se recurre al análisis de las componentes principales.
- La idea es crear un set de componentes (autoespectros) ortogonales, PC1, PC2, etc. que cubran todo el rango de longitudes de onda.
- La idea es que la mayor cantidad posible de información sea contenida en la primera componente y así sucesivamente.

- Notar que es una cuestión estadística y no implica una vinculación física.
- Se enmascaró una seccion del espectro (5850-6200) por problemas con líneas de cielo.
- En general se encuentra que la mayoría de los espectros pueden ser reproducidos con 4 o 5 autoespectros. No obstante trabajan con un set de 9.

Correlación de cada PC con la morfología

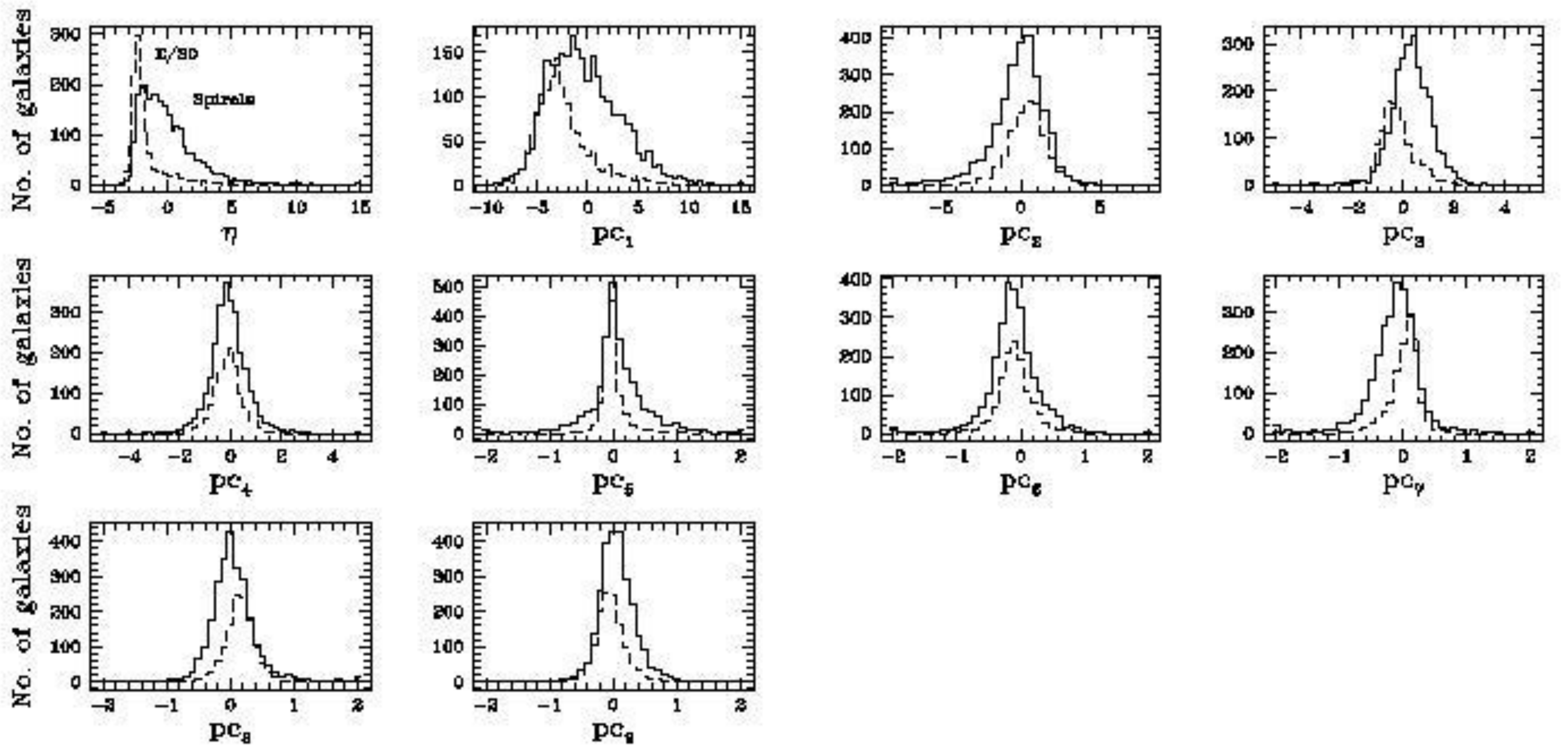


Figure 4. The distribution of η for E/S0 (dotted line) and Spiral galaxies (solid line) is shown in the top left panel. The other panels show these distributions for the first 9 principal components.

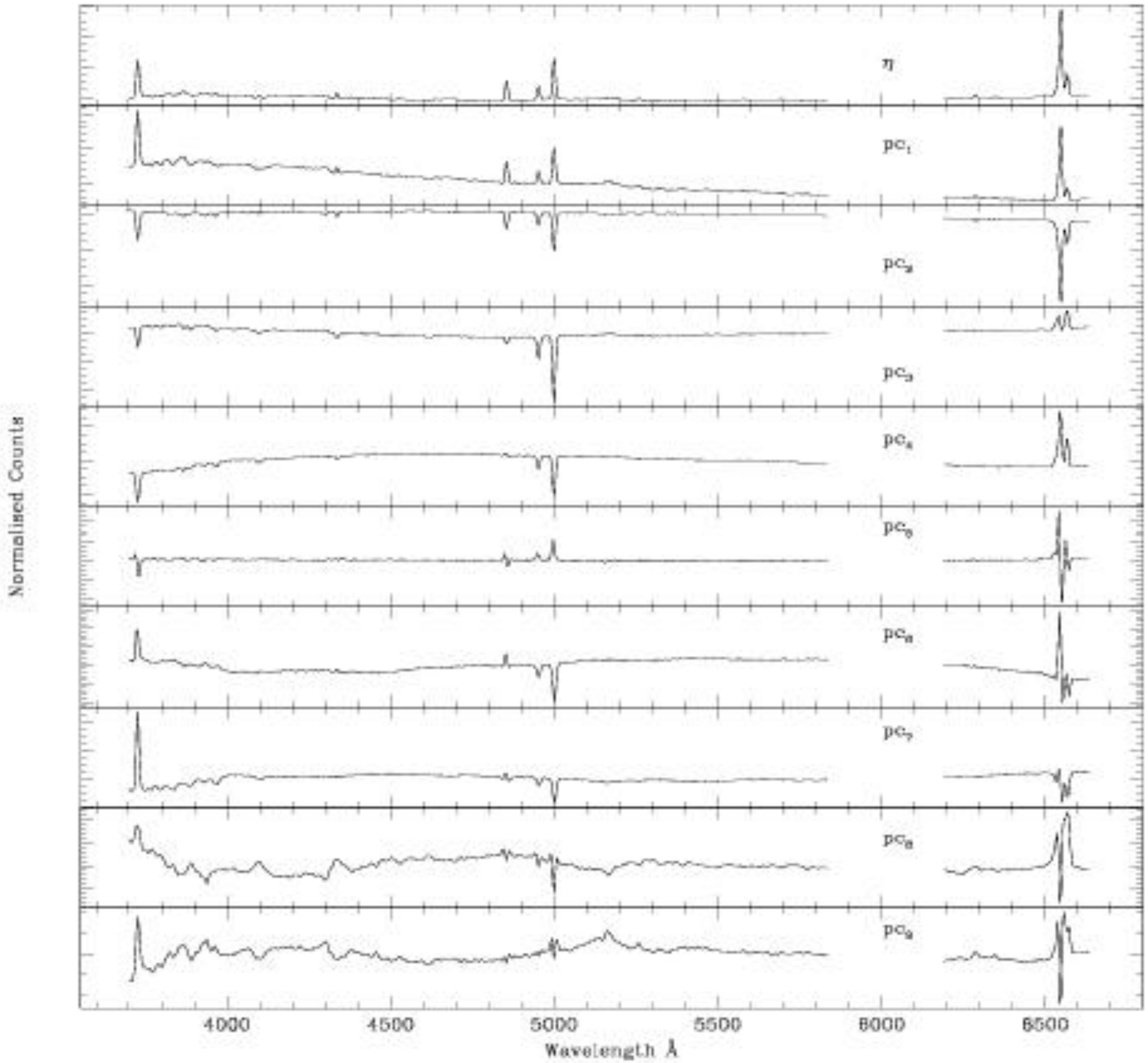


Figure 5. The first 9 principal components. Also shown is the spectrum of the η component (top panel), used to classify the 2dFGRS.

is the total *within-class* covariance matrix. Equation 7 only yields the direction of the weight vector, not its magnitude. Convention-

Figure 7 shows the resulting Fisher projections using these weights for both the known Early and Late type galaxies in the 2dFGRS. It

- Notar que se agrega el comportamiento de $\eta=0.5pc1-pc2$ que es la que se usa en el 2dF.
- La división $\eta < -1.4$ y $\eta >= -1.4$ "separa” galaxias tranquilas de las que forman estrellas.

- La idea es ver si con análisis como los de Artificial Neural Networks se pueden lograr combinaciones más sofisticadas que den una mejor correlación con los tipos morfologicos.
- Dos Técnicas:

Técnica de pesos de Fisher (método que trata de maximizar la diferencia entre dos clases).

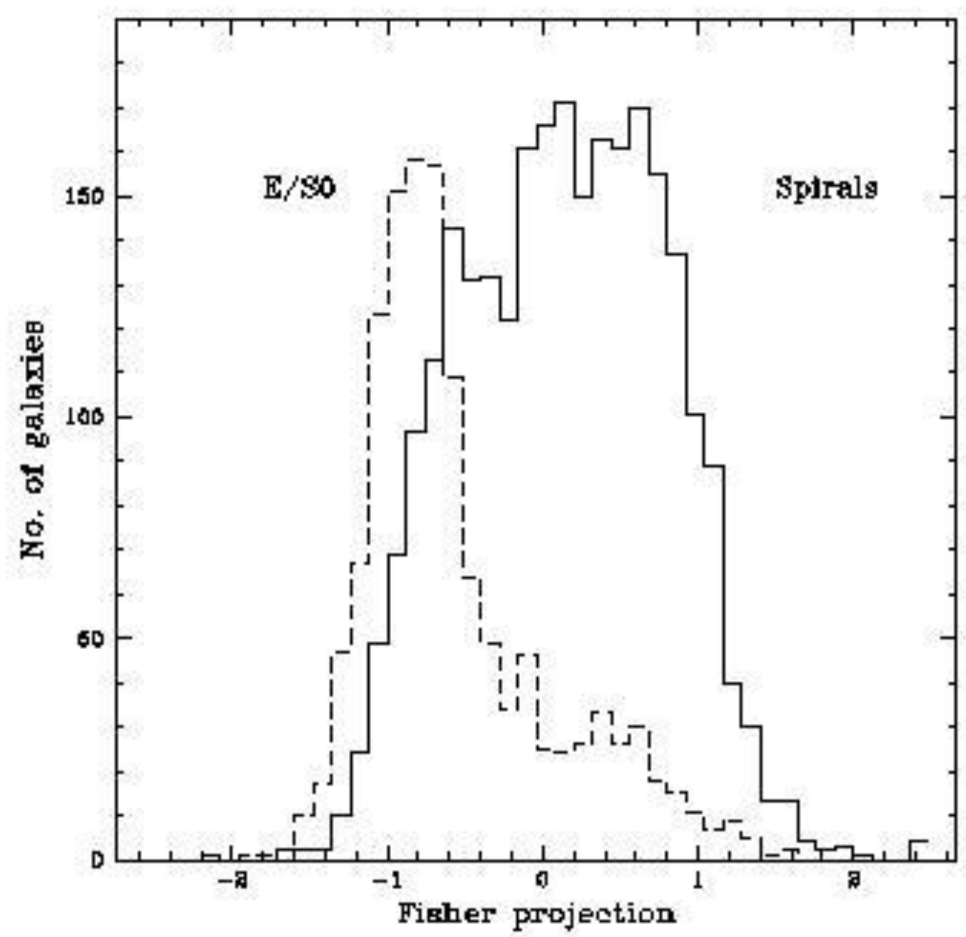


Figure 7. Fisher's linear discriminant, as calculated from the first nine principal components with the aim of discerning the galaxy morphology. It is clear a significant degree of overlap between the morphological types still exists.

No muestran separación de tipos mucho mejor que el eta.

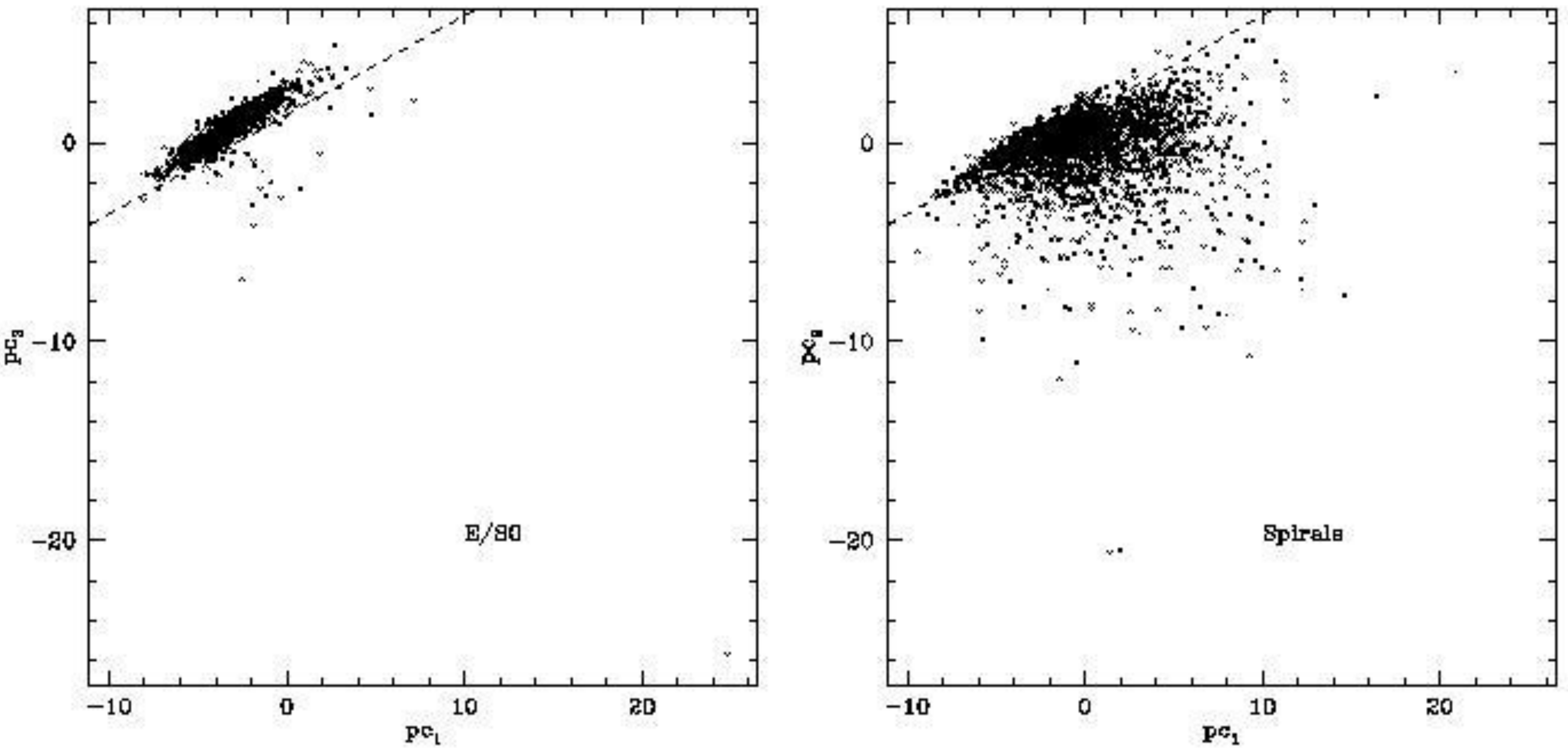


Figure 8. The pc1 and pc2 projections of the morphologically classified 2dFGRS galaxies are shown. Here the morphologies have been derived using Fisher's method with 9 principal components. It is remarkable that all the information in these 9 components is essentially contained in these first two projections. The Fisher discriminant has been cut at -0.55.

ANN

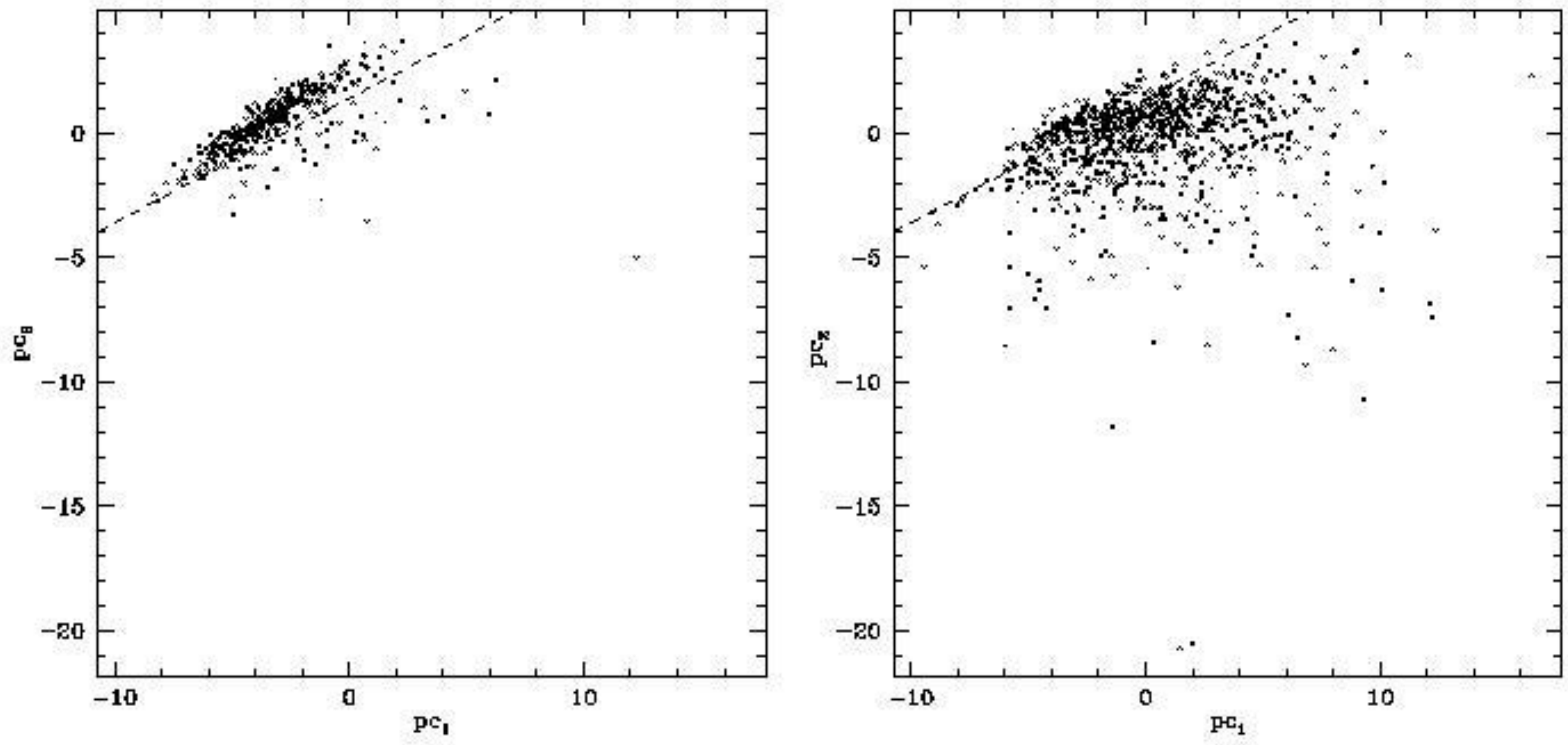


Figure 10. The $\mathbf{pc_1}$ and $\mathbf{pc_2}$ projections of the morphologically classified 2dFGRS galaxies are shown. Here the morphologies have been derived using an Artificial Neural Network with 9 principal components as inputs (9:9:2). Again we can see that all the information in these 9 components is essentially contained in just these first two projections.

Comparación entre los tres métodos: eta, Fisher y ANN:

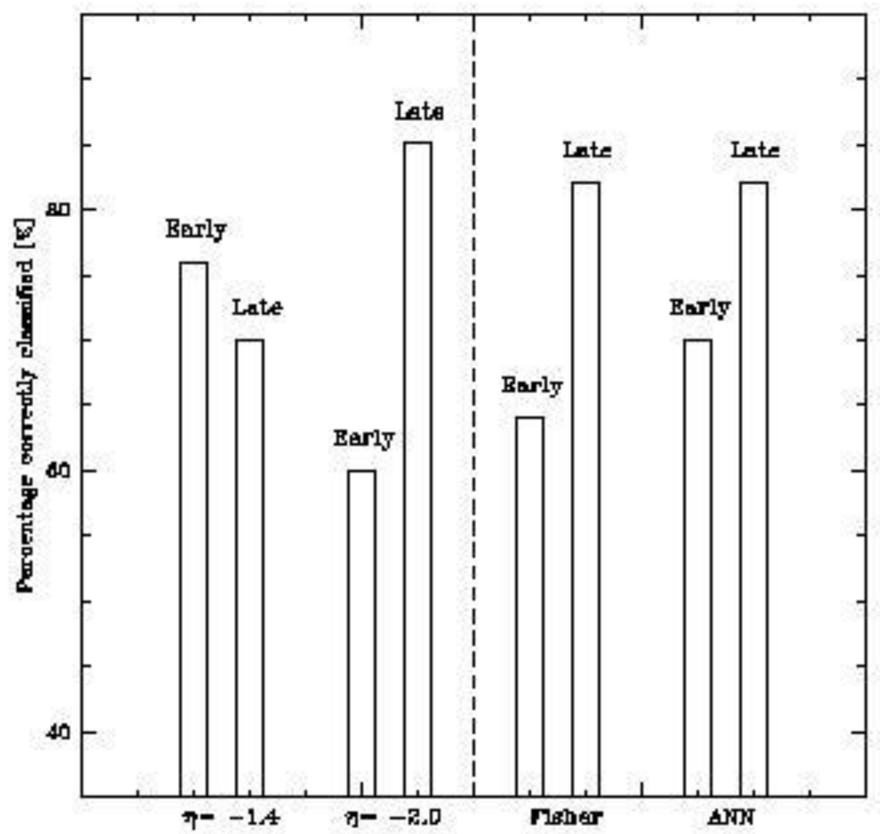


Figure 11. Comparison between the success rates of different classification methods. The first two sets of histograms show the success rates that can be achieved simply by using the (PCA based) η spectral classification adopted in the 2dFGRS. The second two histograms show the success rates for the more advanced statistical methods: Fisher's linear discriminant and the ANN. It can be seen that the results are generally comparable, although the ANN gives the best results.

- El ANN sería el más poderoso.
- No obstante, si uno cambia el modelo de ANN, los resultados pueden variar.
- En términos generales no hay grandes diferencias.