Jacopo Fritz, IRyA - UNAM

DataCubes in Astrophysics

Lesson 8

M51 ISM properties

- See paper from M. Hitschfeld et al. (A&A, 495, 795, 2009): *"A complete 12CO 2-1 map of M 51 with HERA. II. Total gas surface densities and gravitational stability"*;
- the analysis of this paper is very careful;
- see also Nakai & Kuno (PASJ, 47, 761 1995) for the X-factor.

The radially averaged gas-to-dust mass ratio of the surface densities of the exponential disk is shown in the lower box of Figure 7. The gas-to-dust mass ratio is nearly constant with galacto-centric radius, reflecting the similar scale lengths. Values vary only between 23 and 26, which is about a quarter of the canonical Galactic gas-to-dust mass ratio of 100. This constancy is in contrast for example to the strong radial variation of the H_2/H I surface density ratio by more than a factor of 100.

Star Formation Rate

- In general: quantifies the mass of newly formed stars within a given period;
- More specifically: it refers to recently formed stars;
- Measured in $M_\odot$/yr;
- Traced by massive stars. $\Rightarrow$ Extrapolated to lower masses;
- Typical values range from fractions of $M_\odot$ to several hundreds (or even thousands);

	M31: ~ 0.2	$M_\odot$/yr
Nearby examples:	MW: ~ 2	$M_\odot$/yr
	M82: ~ 10	$M_\odot$/yr

How to calculate it

- We focus on the “recent” (about 10^7 years) SFR;
- what are the main characteristics of a young stellar population with respect to older stars?
- how can we use these characteristics?
- what are the models, prescriptions and assumptions that we have to make and use?

How to calculate it

- Stellar emission is, in a rough approximation, very similar to a black body;
- the youngest and most massive stars are the most luminous (at all frequencies);
- despite being the less numerous, they can dominate the emitted spectrum;
- they (basically) are the only UV photons emitters.

SFR indicators

- X-ray
- UV
- forbidden lines
- recombination lines
- Mid-Infrared
- Far-Infrared
- Radio

A must-read: The review by R. Kennicutt, 1998

SFR estimators

- UV $$SFR(UV) = 1.4 \times 10^{-28} L_\nu \; [erg/s/Hz]$$
- forbidden lines $$SFR([O\,\textsc{ii}]) = 1.4 \times 10^{-41} L([O\,\textsc{ii}]) \; [erg/s]$$
- recombination lines $$SFR(H\alpha) = 7.9 \times 10^{-42} L(H\alpha) \; [erg/s]$$
- Mid-Infrared $$SFR(MIR) = 2.04 \times 10^{-43} L(MIR) \; [erg/s]$$
- Far-Infrared $$SFR(FIR) = 4.5 \times 10^{-44} L(FIR) \; [erg/s]$$
- Radio $$SFR(1.4GHz) = 1.2 \times 10^{-28} L_{1.4\mathrm{GHz}} \; [erg/s/Hz]$$

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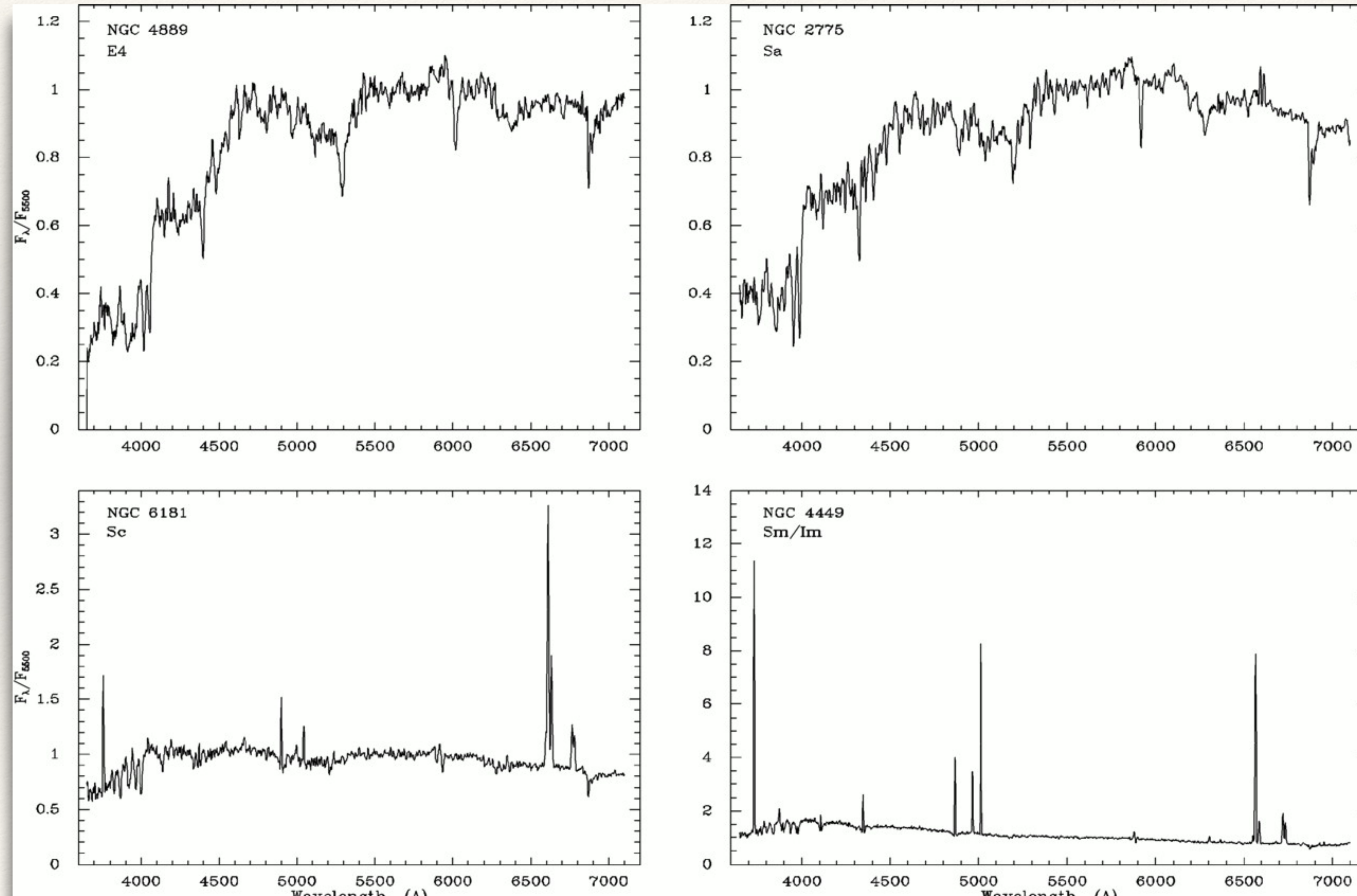
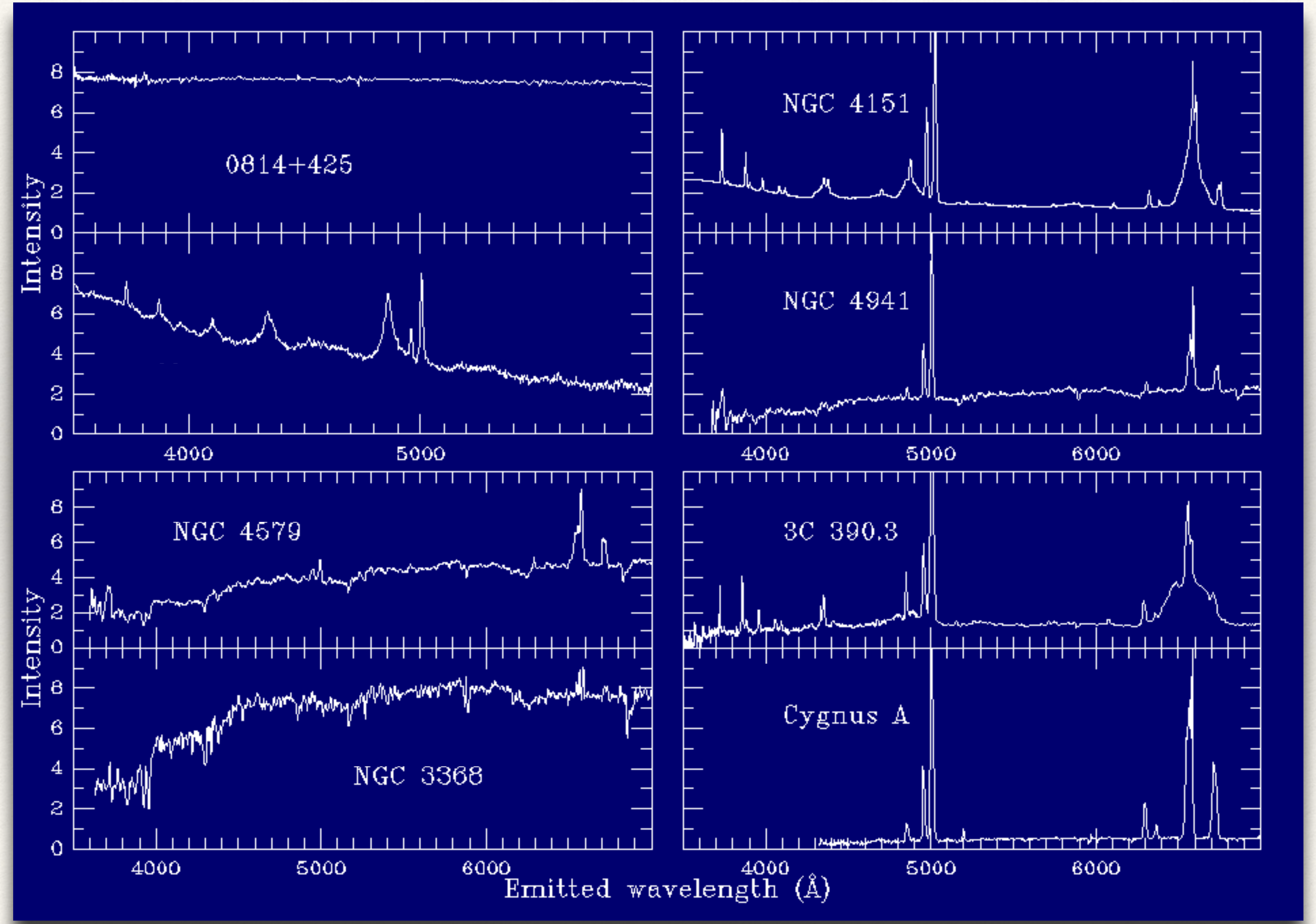
- assume a constant SFR over the same period;
- calculate the relative luminosities.

Spectra of Galaxies



Spectra of Galaxies: some weird ones



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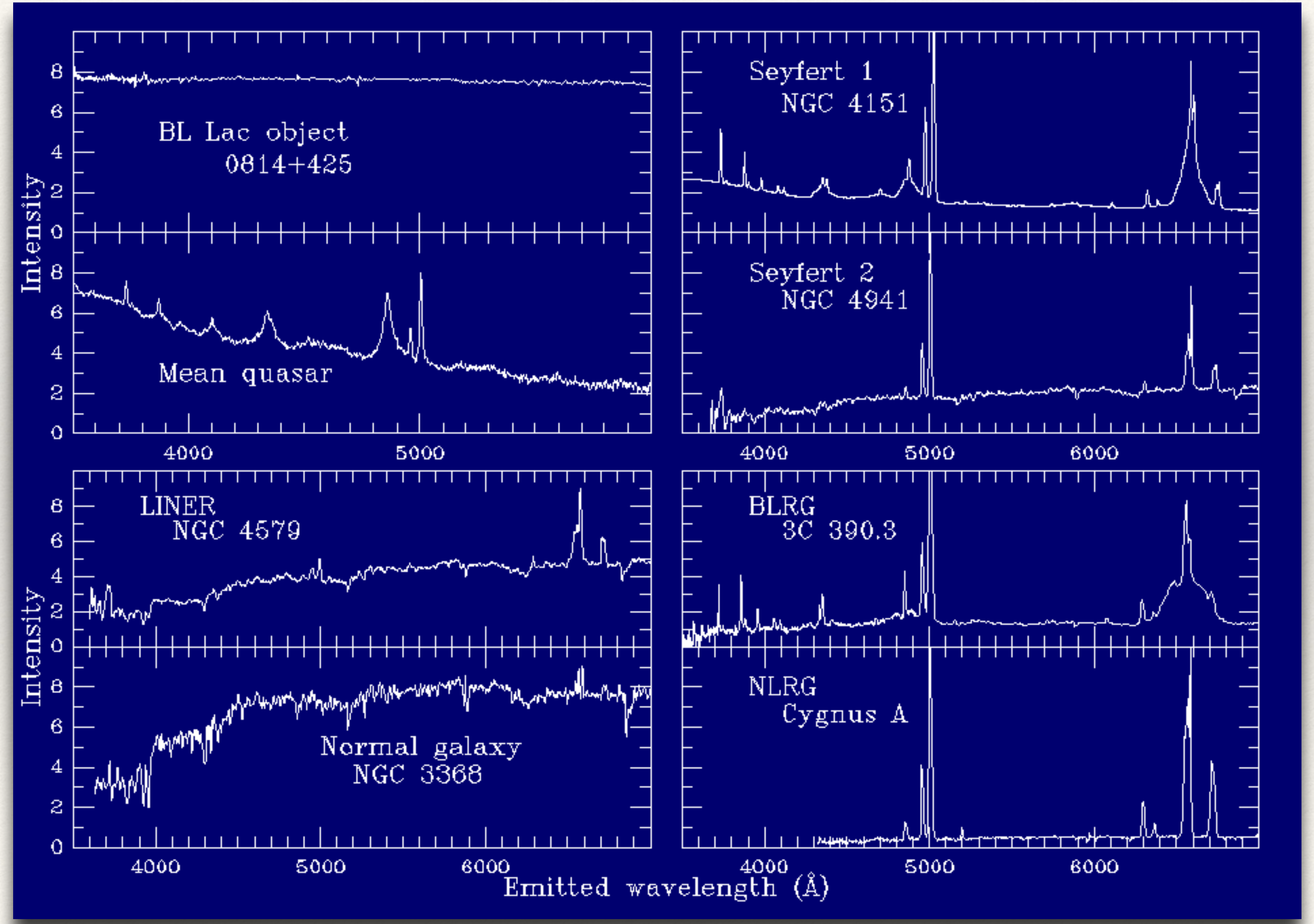
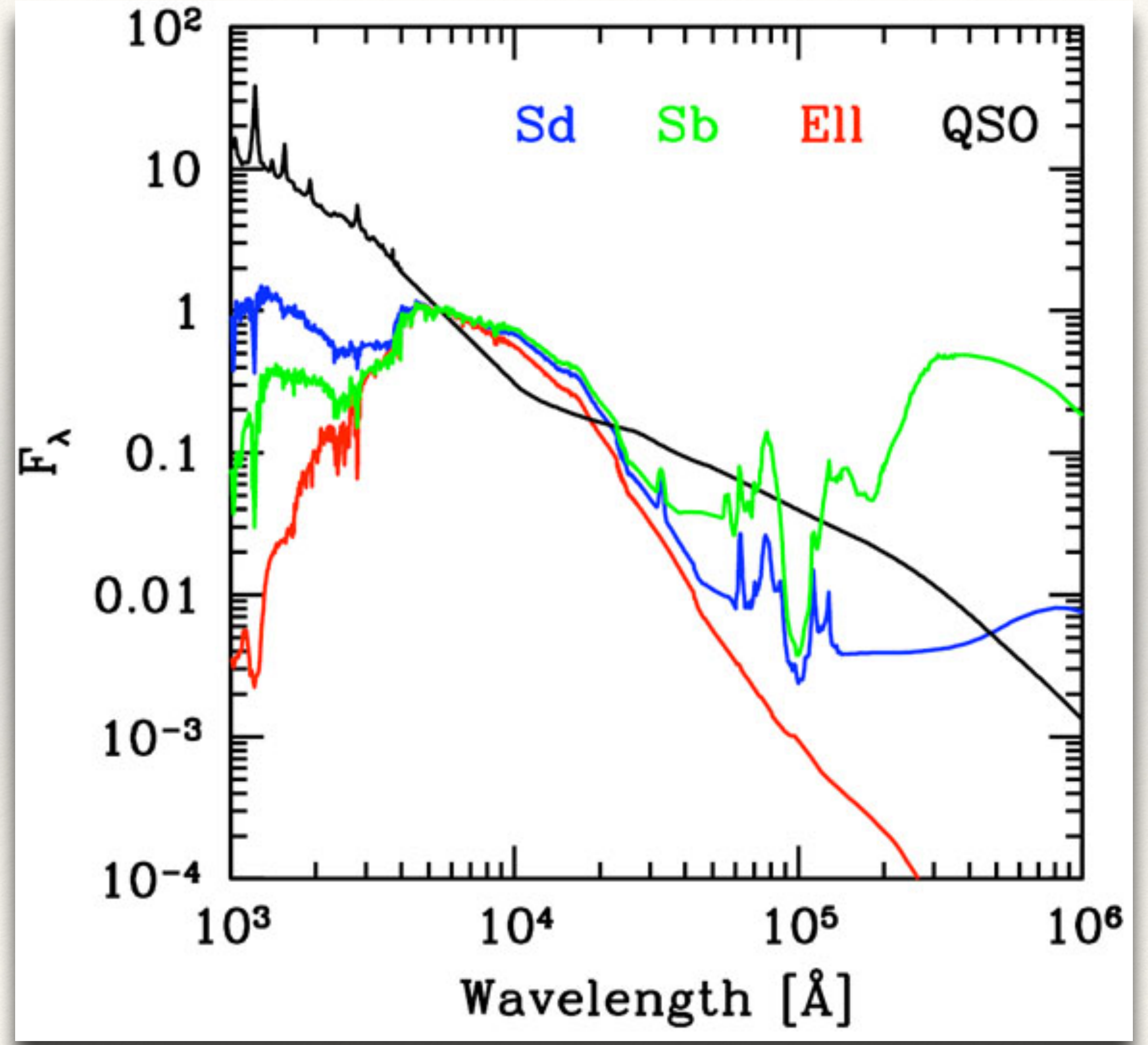


Photometry (broad-band SED) of galaxies



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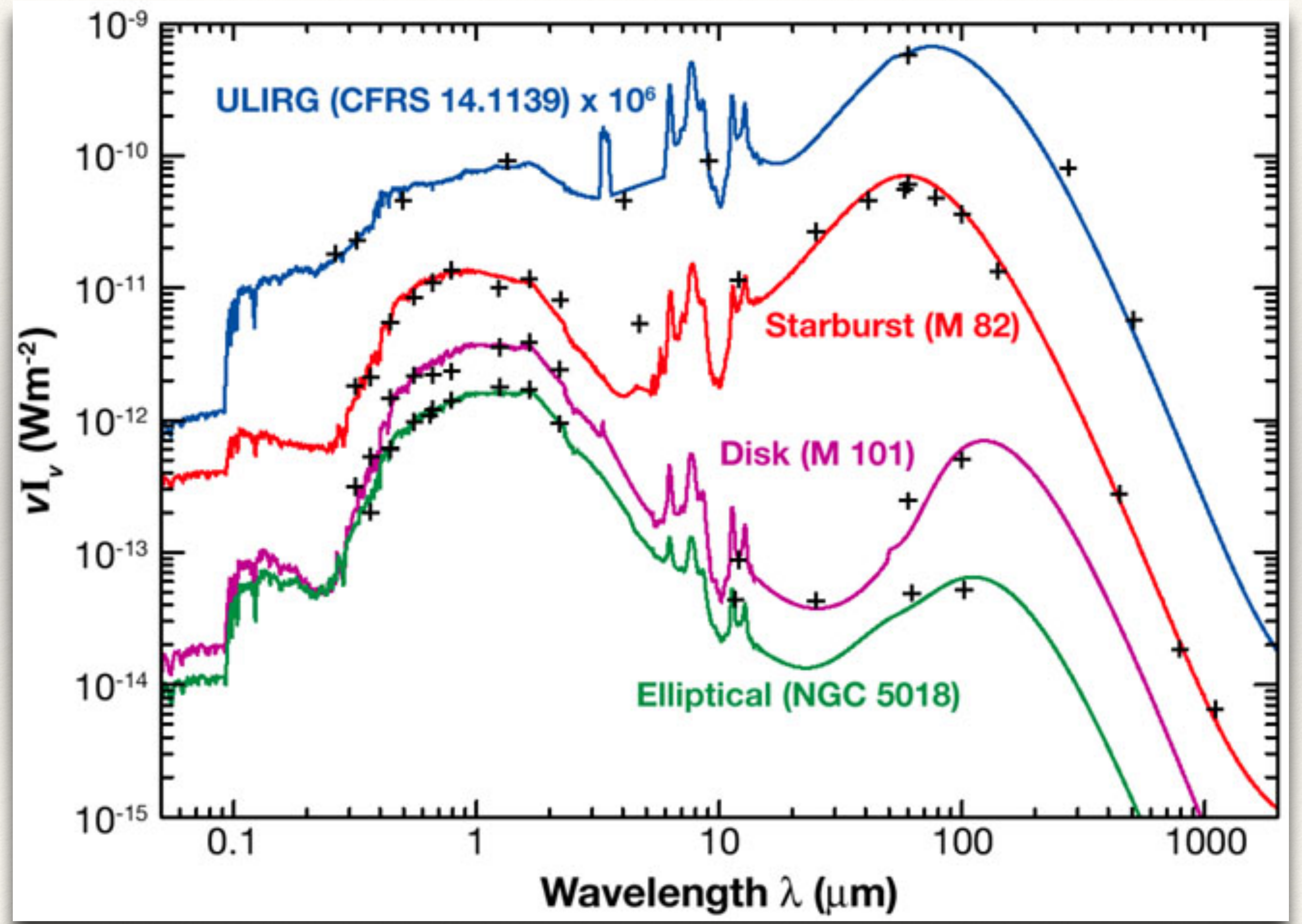

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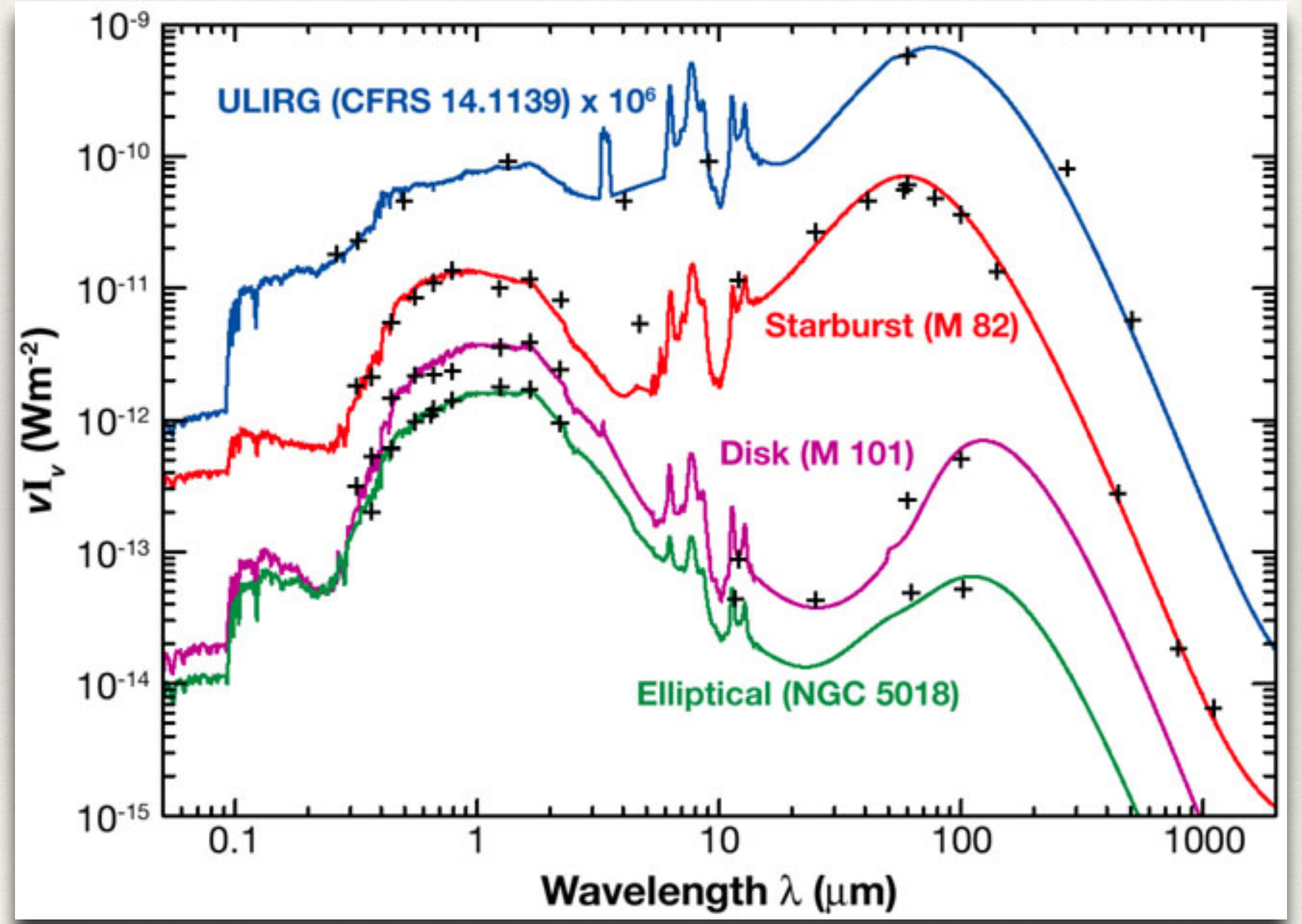

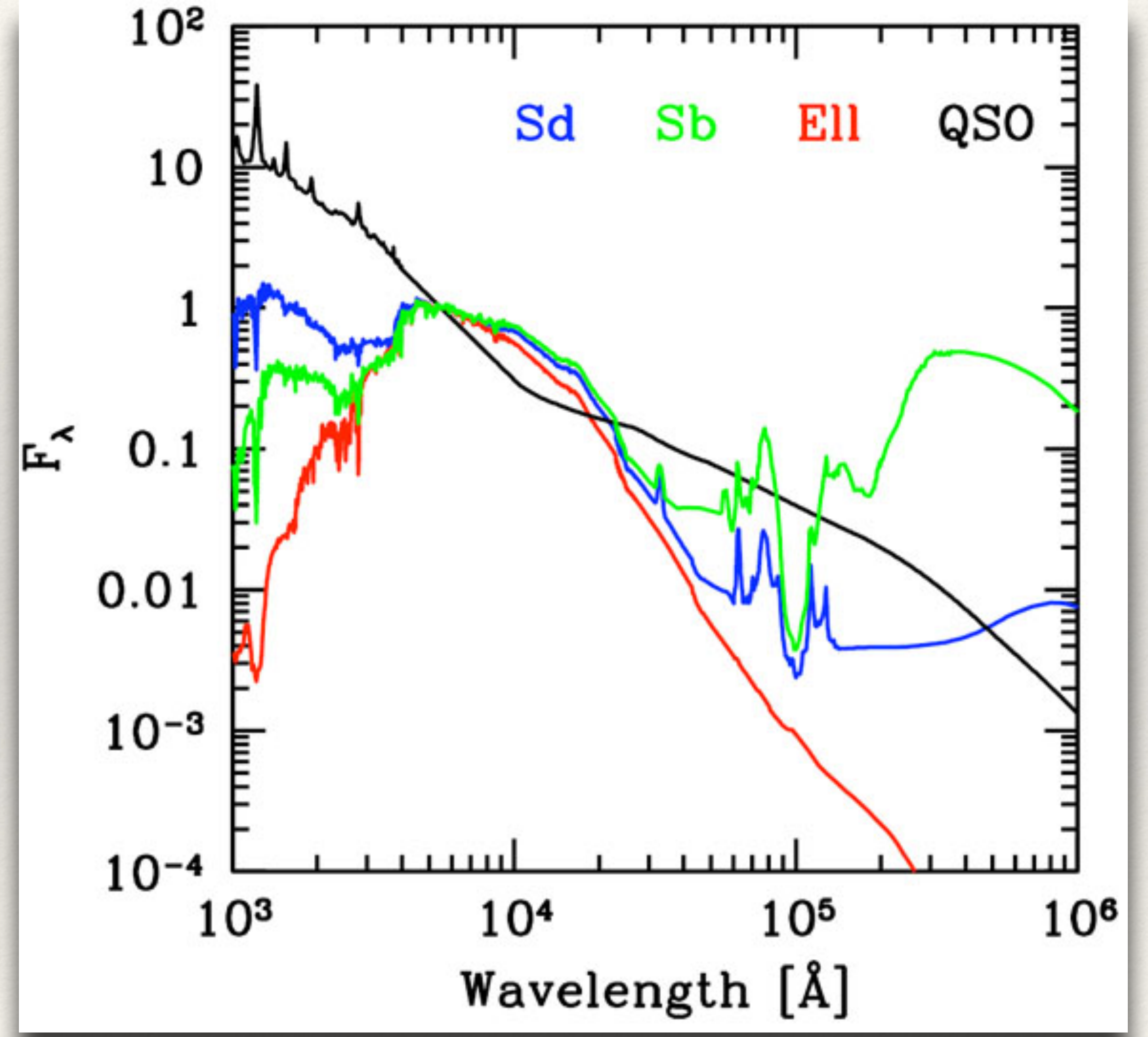

Understanding galaxies

OBSERVATIONAL FACTS:

- We observe galaxies with different morphologies;
- we observe galaxies with different spectra (or, more in general, SED);
- galaxies living in different environments are in general different;
- the galaxy population is different at different cosmic epochs.

Understanding galaxies

WHAT WE WANT TO UNDERSTAND:

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WHAT WE WANT TO UNDERSTAND:

- What determines a galaxy morphology?
- why is the content of galaxy different from galaxy to galaxy, and what does it depend on?
- what is the role of environment on the physical properties of galaxies?
- how were galaxies born, how do they evolve, and what are the main mechanisms driving their evolution?

Stellar Population Synthesis

Interpretation of galaxies' spectra by means of a superposition of Simple Stellar Population (SSP) spectra.

We must take into account some facts:

- Stellar properties are a function of:
  - mass
  - time (stellar age);
  - metallicity;
- A galaxy's SED depends on its SFH (SFR[t]);
- Dust dramatically changes galaxies' SED.

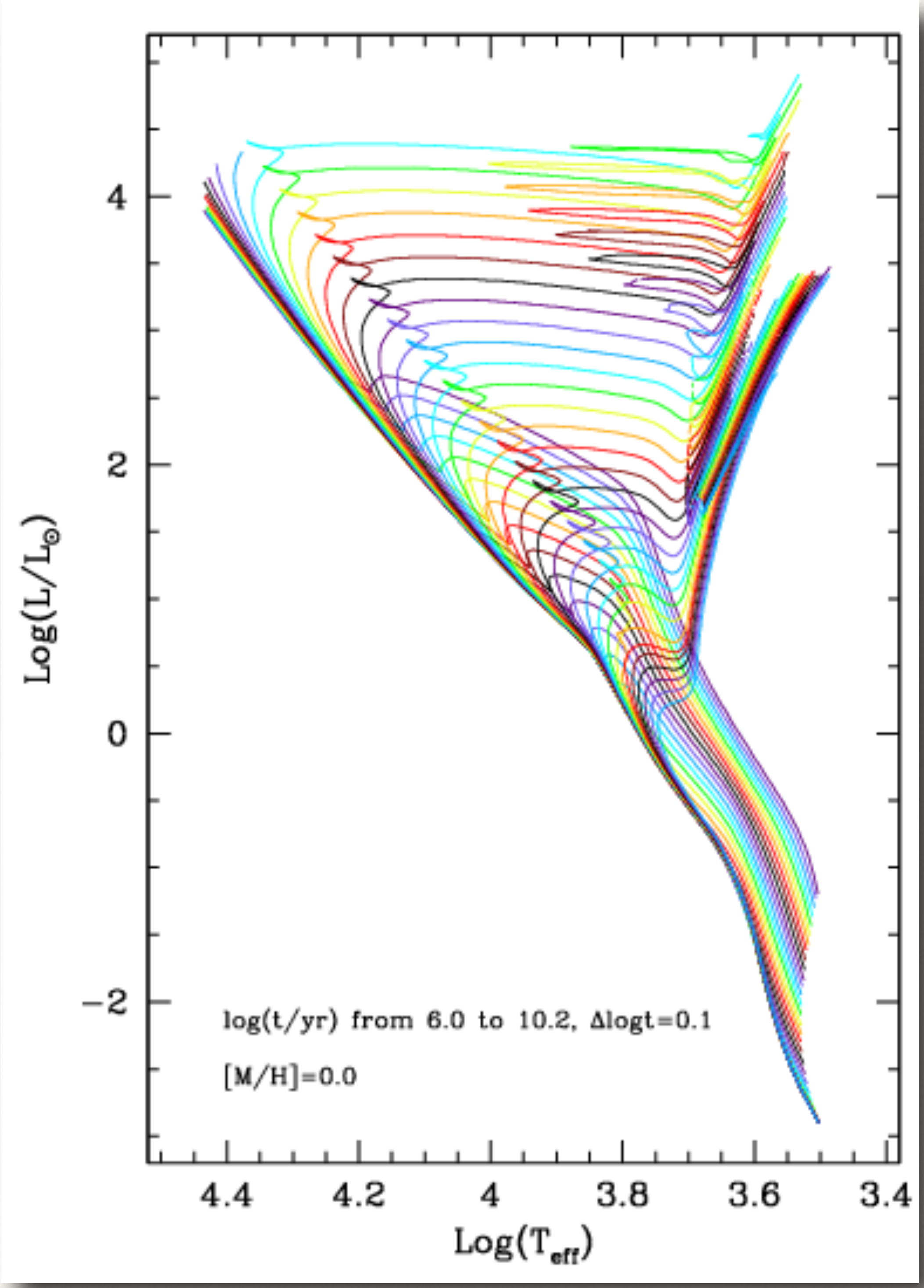
How to get a model spectrum

The Ingredients
(or: assumptions!)

- Theoretical set of isochrones (various ages and metallicities);
- Model or observed stellar atmospheres;
- Initial Mass Function (IMF);
- Star Formation Rate as a function of time: $\psi(t)$ ($\Rightarrow$ SFH);
- a dust model.

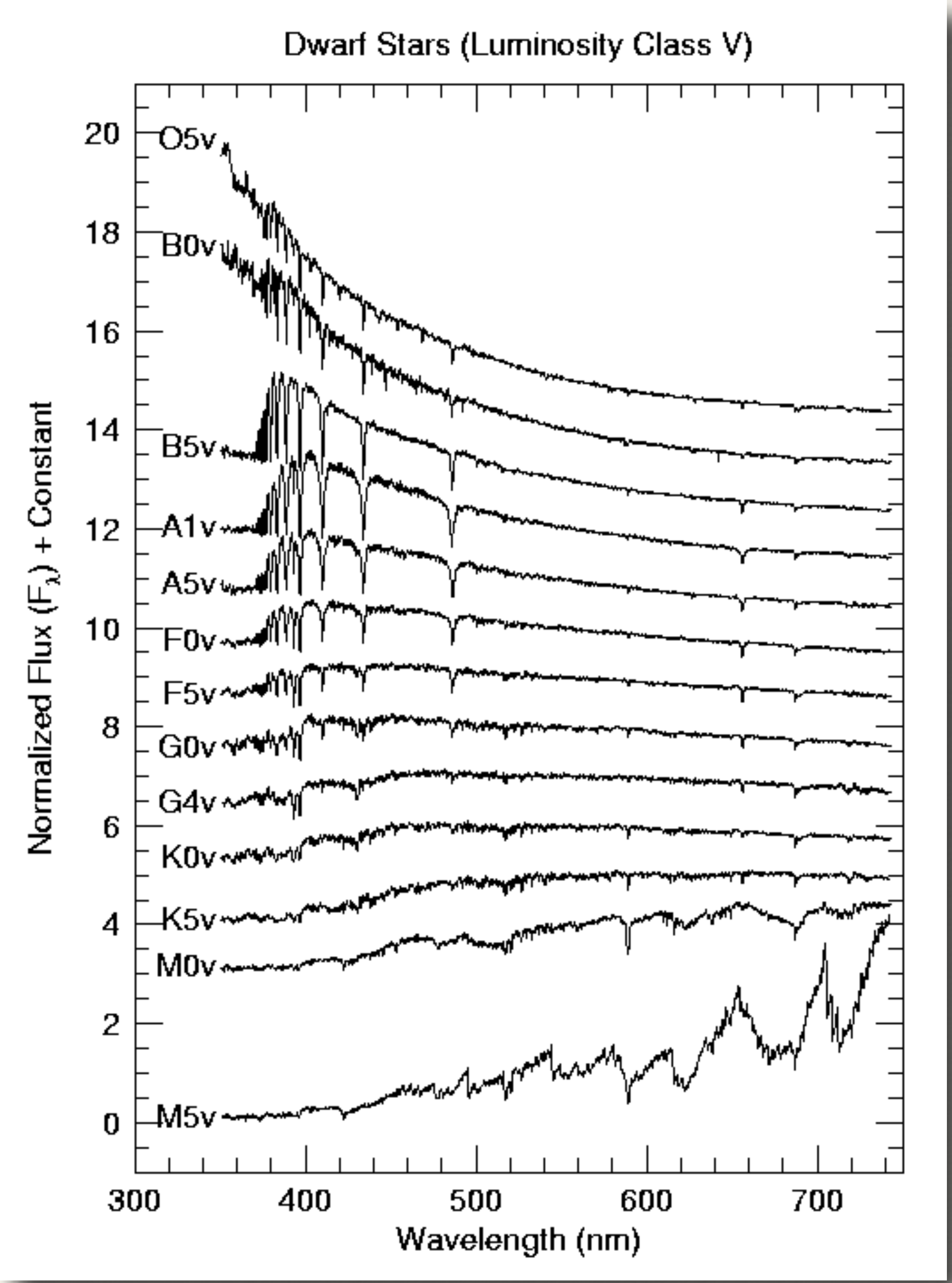
Isochrones

What do we learn from this?
Or:
What are the characteristics of stars in the various points of the diagram?

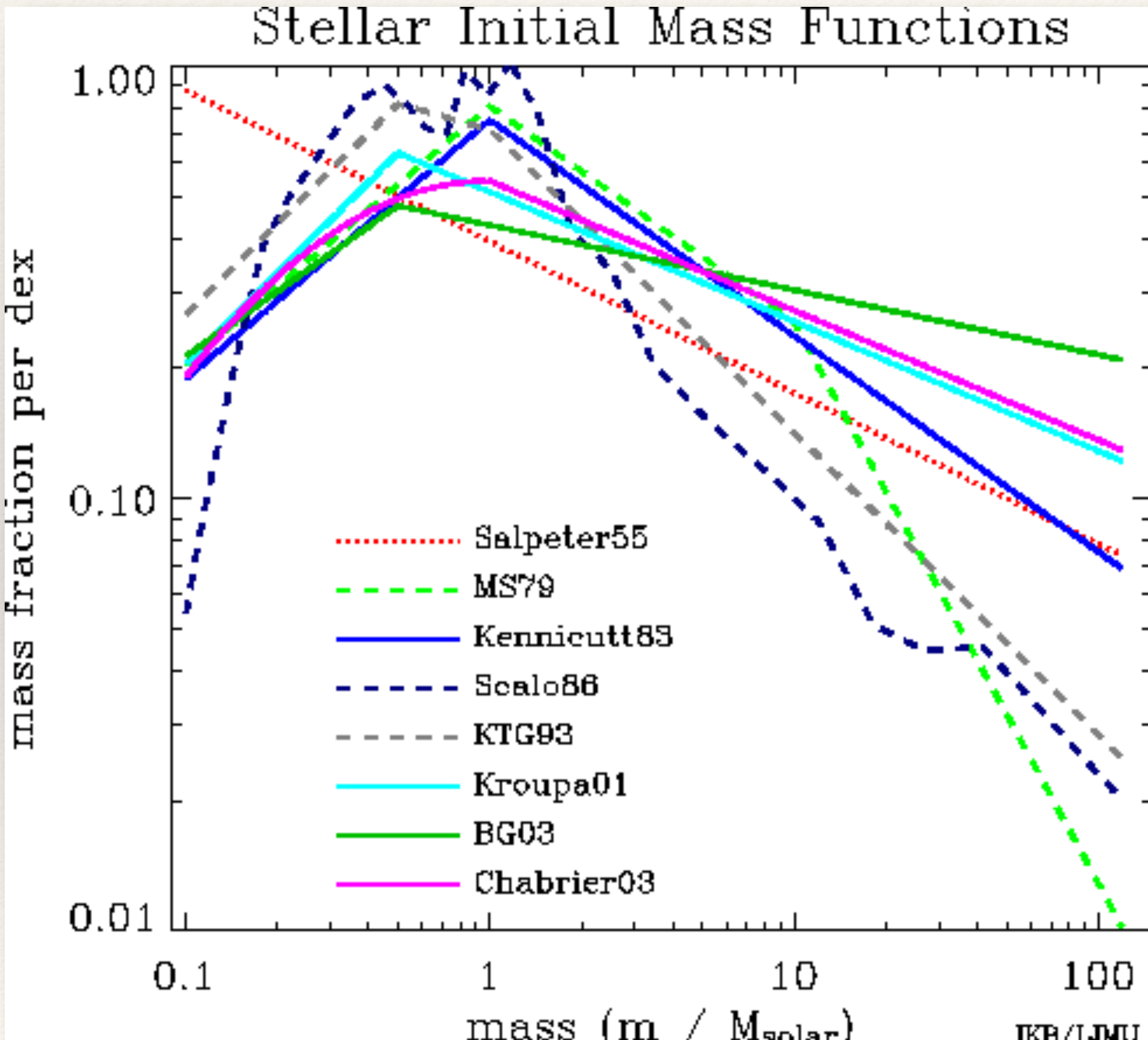


PARSEC libraries (Bressan et al. 2012)

Stellar Atmospheres



Initial Mass Function



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$$\phi(m) \propto m^{-2.35}$$ Salpeter (1956)

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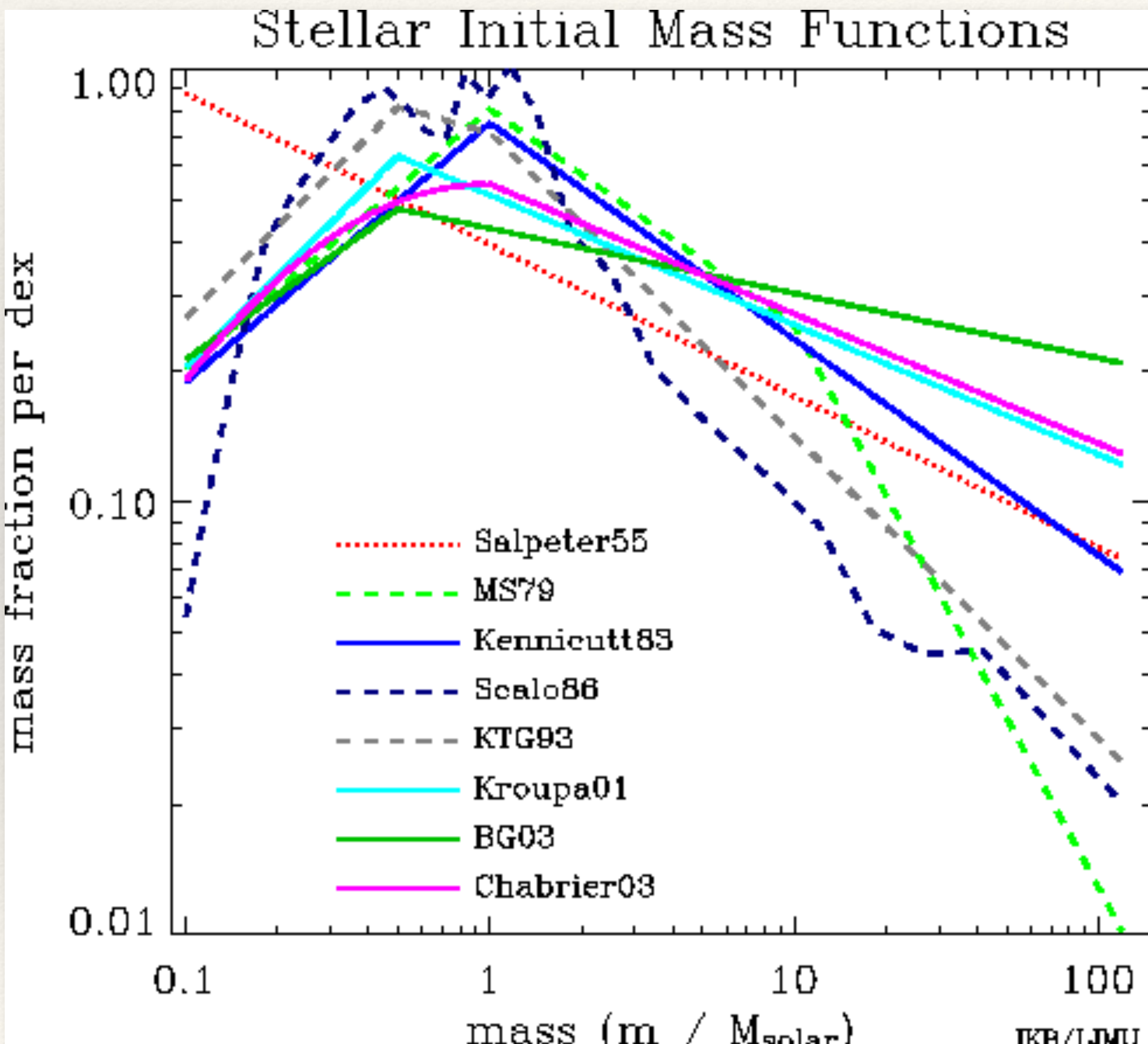

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Many uncertainties:

- What are the lower and upper limits?
- What is the shape?
- Does it change as a function of the galaxy properties?
- <u>Is it "universal"</u>?

The Star Formation Rate

Is the mass of gas converted into stars:

$$\psi(t) = -\frac{dM_{gas}}{dt}$$

- how many stars are formed in a given epoch?
- is there any relation between the SFR at different epochs?
- are all galaxies similar in this respect (bursting and quenching);

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Metallicity is NOT constant, but is instead a function of time and depends on various factors (e.g.: SFH, stellar mass,…)

A galaxy's spectrum

$$F_\lambda(\lambda, t) = \int_0^t \psi(t - t') S_{\lambda, Z(t-t')}(\lambda, t') dt'$$

- $S_{\lambda,Z}(t')$: energy emitted per unit λ per time interval of 1 $M_\odot$ of stars with metallicity Z and age t';
- $S_{\lambda,Z(t-t')}(t')$ is the emission at each cosmic epoch t, and accounts for the initial metallicity of the stars;
- this changes with time and is related to the chemical evolution of the ISM.

...and Dust!

$$F_\lambda(\lambda, t) = \int_0^t \psi(t - t') S_{\lambda, Z(t-t')}(\lambda, t') \times 10^{-0.4 A_\lambda (t')} dt'$$

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- emission lines: Hα, Hβ, [OIII], [OII]…
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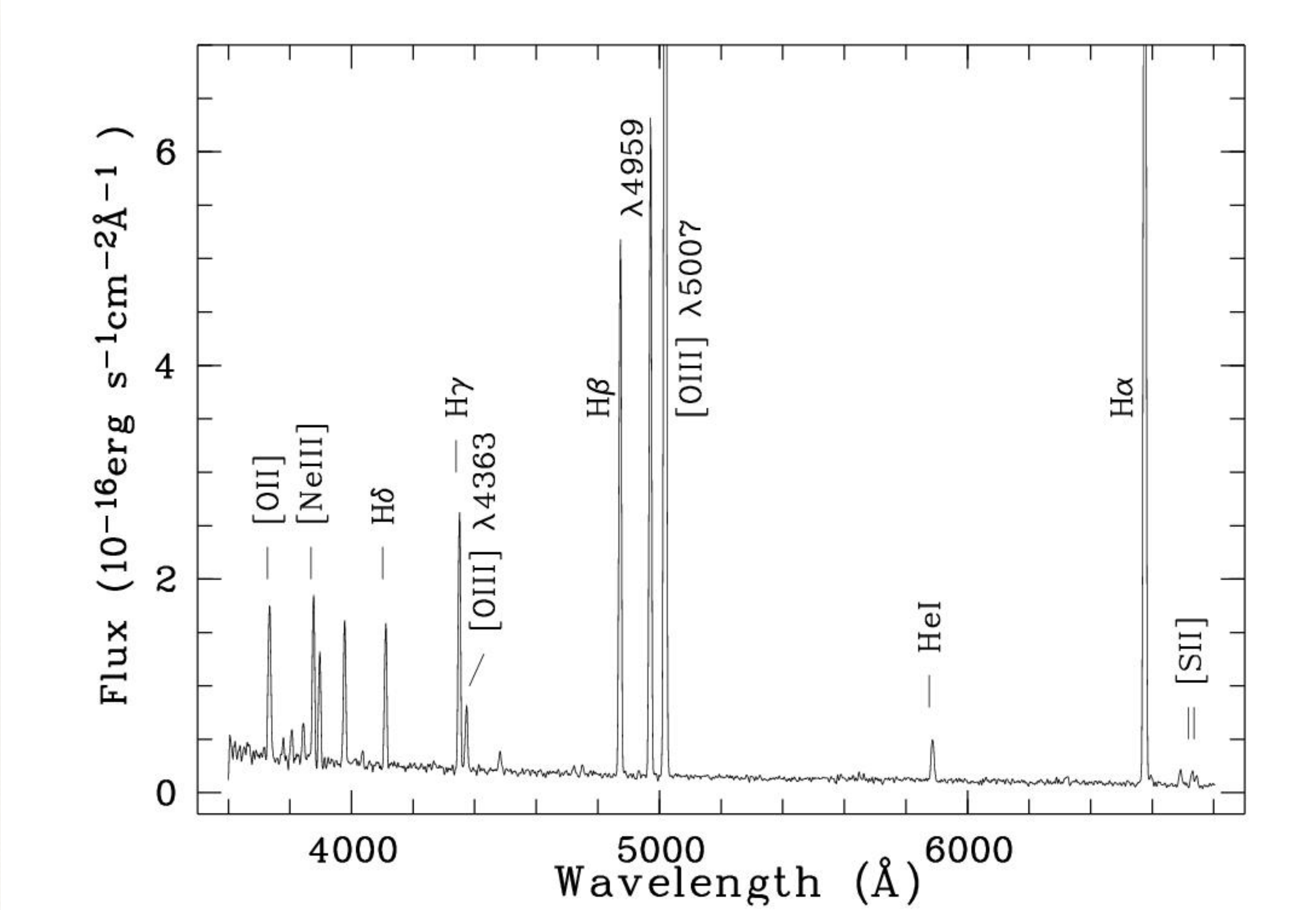

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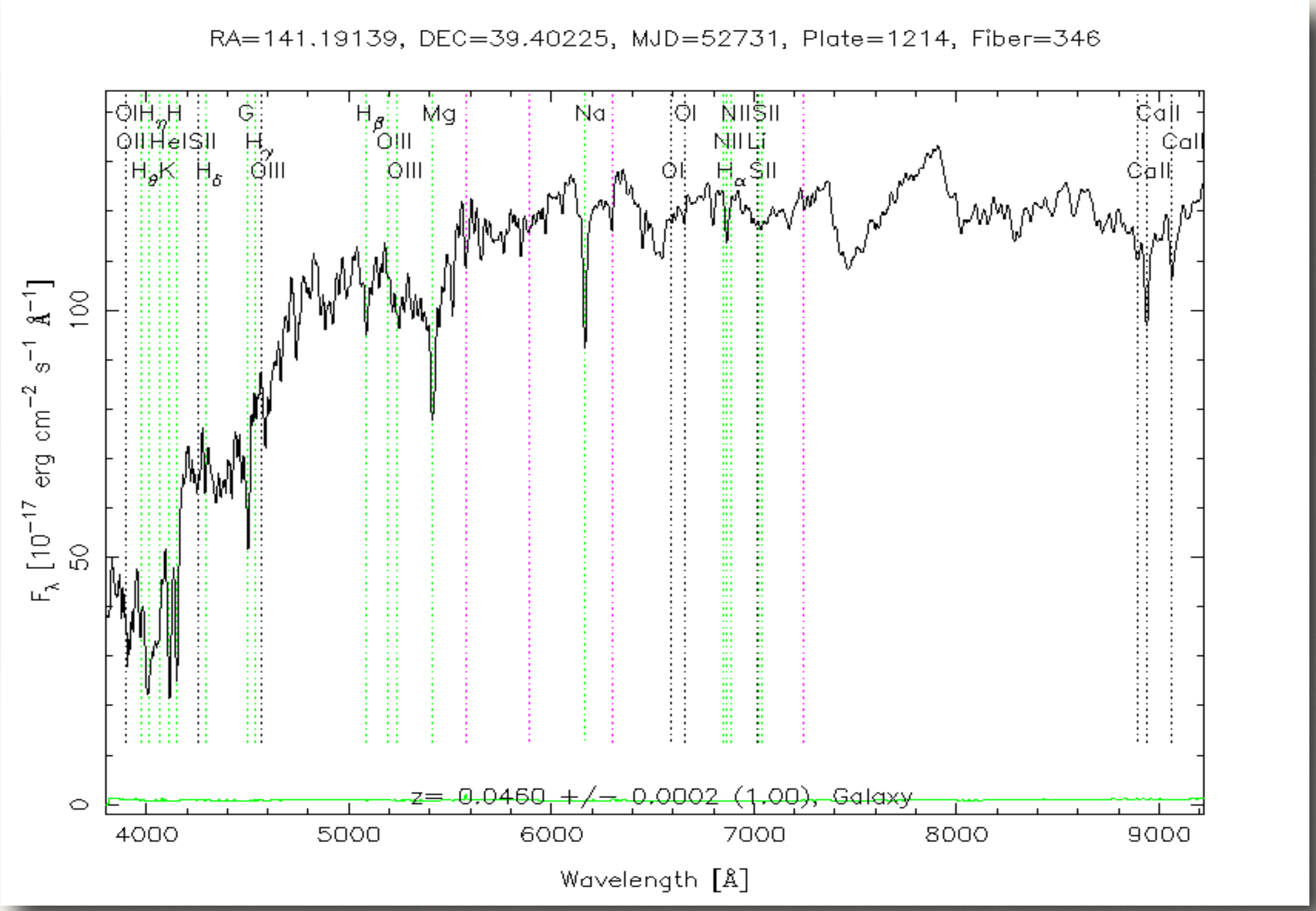

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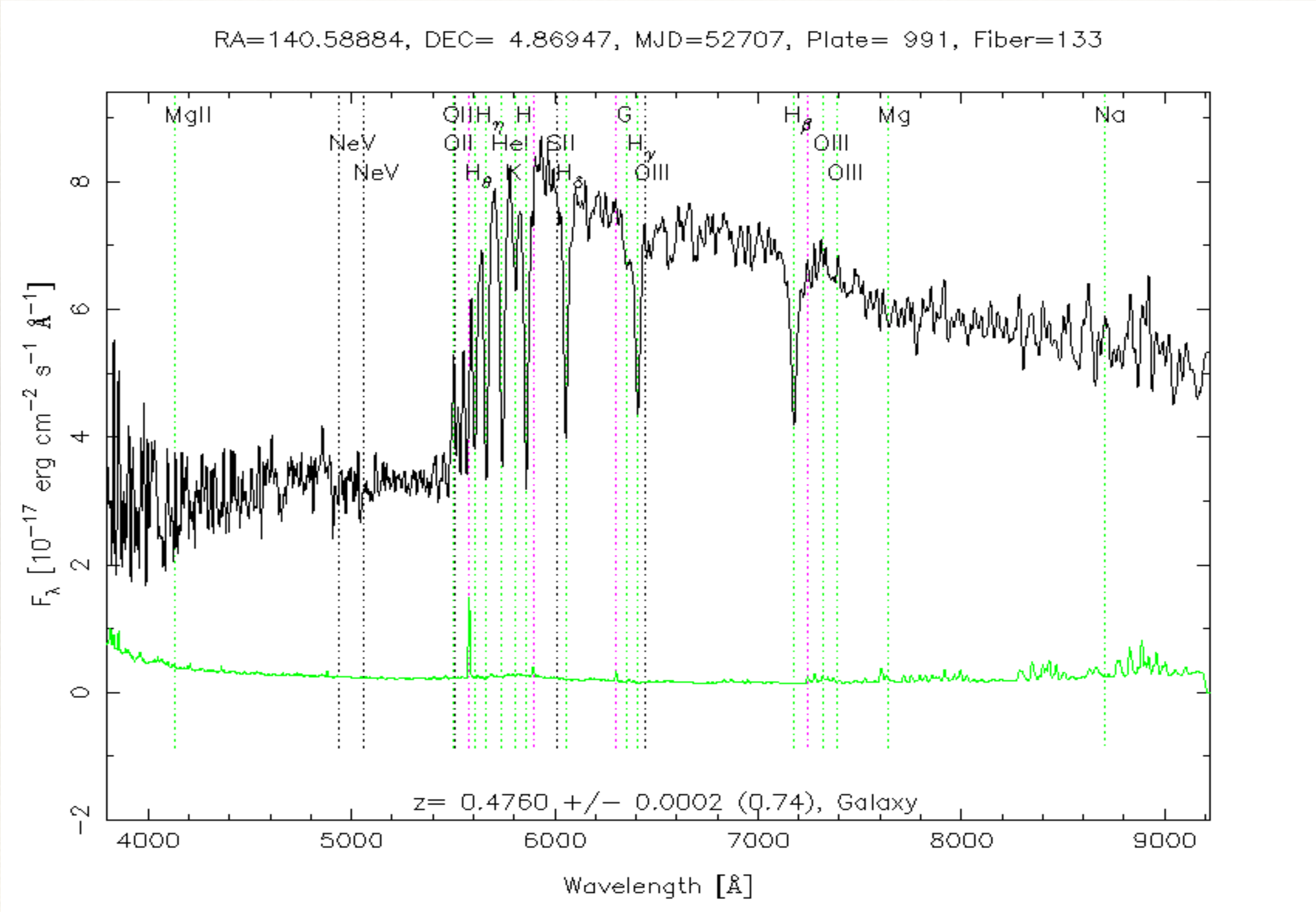

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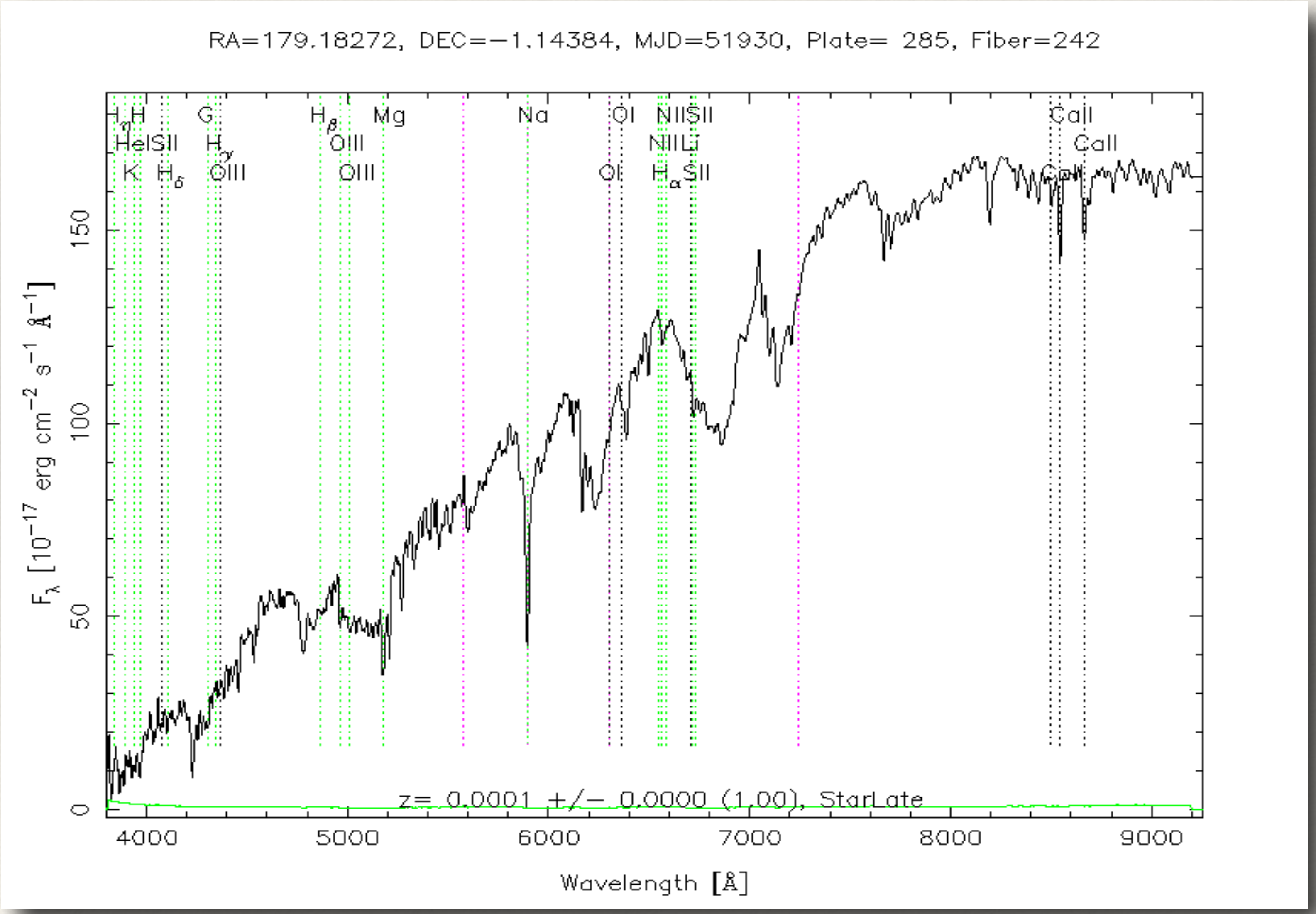
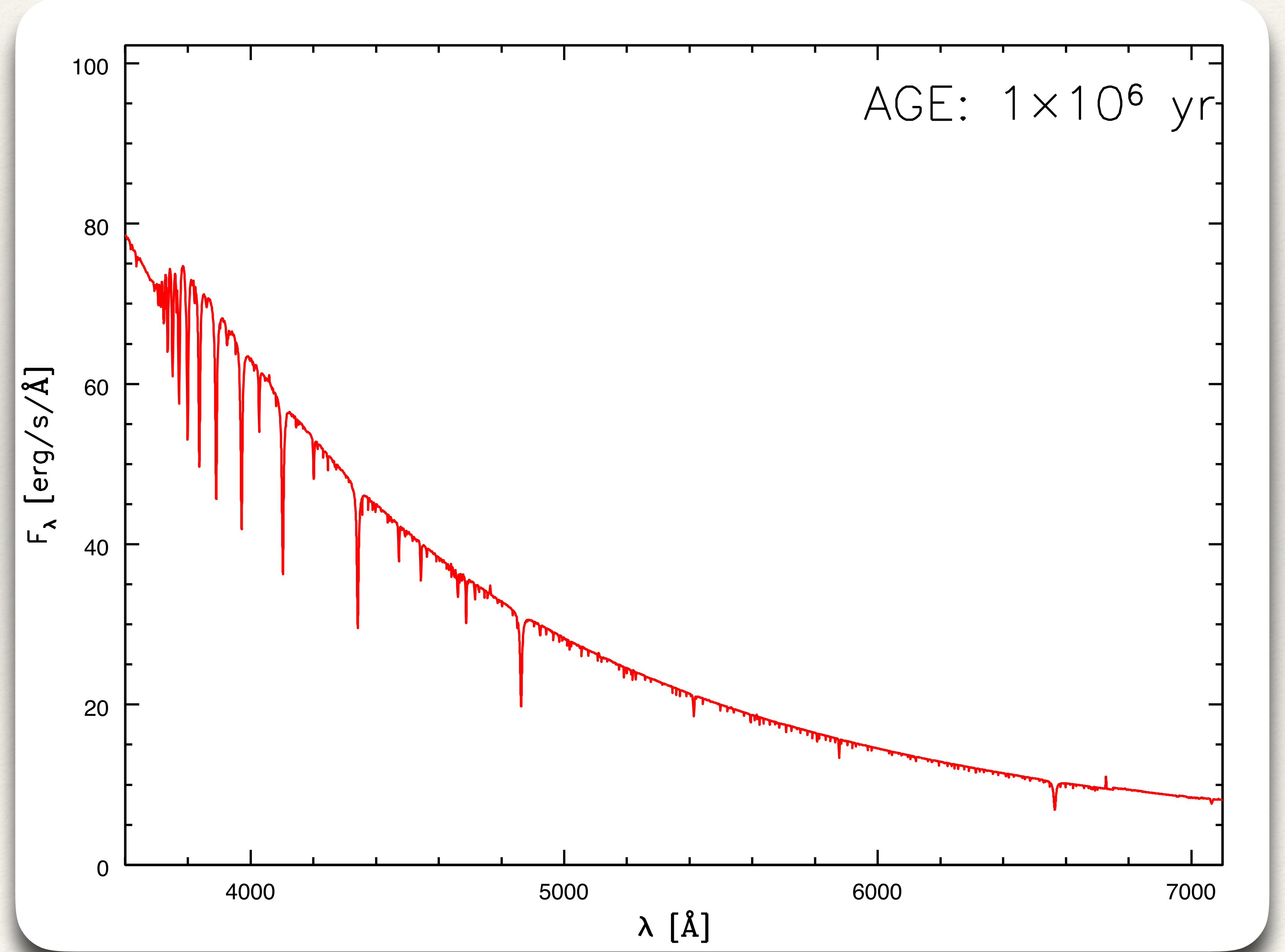


Simple Stellar Population Spectra

…as a function of age.



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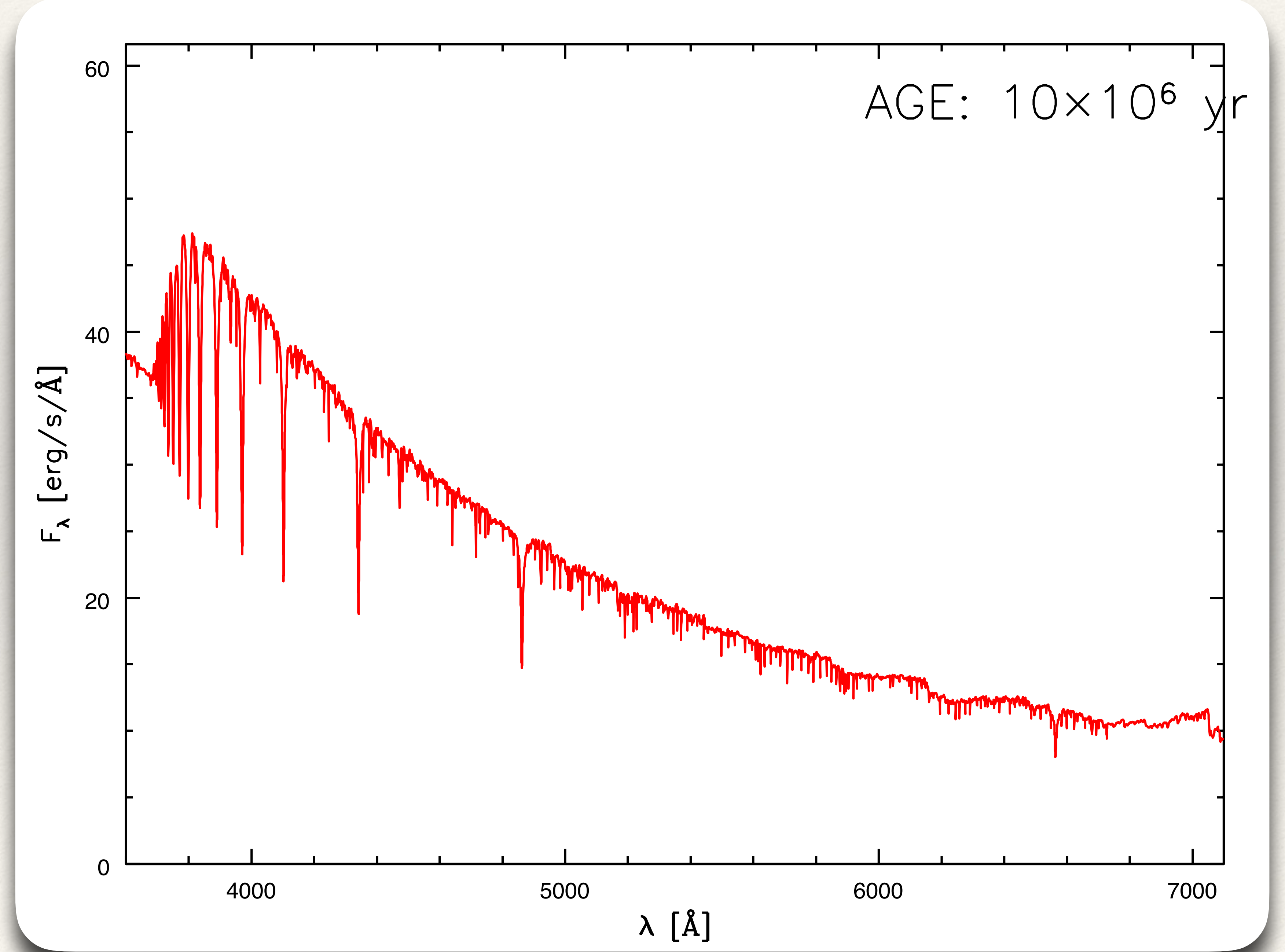

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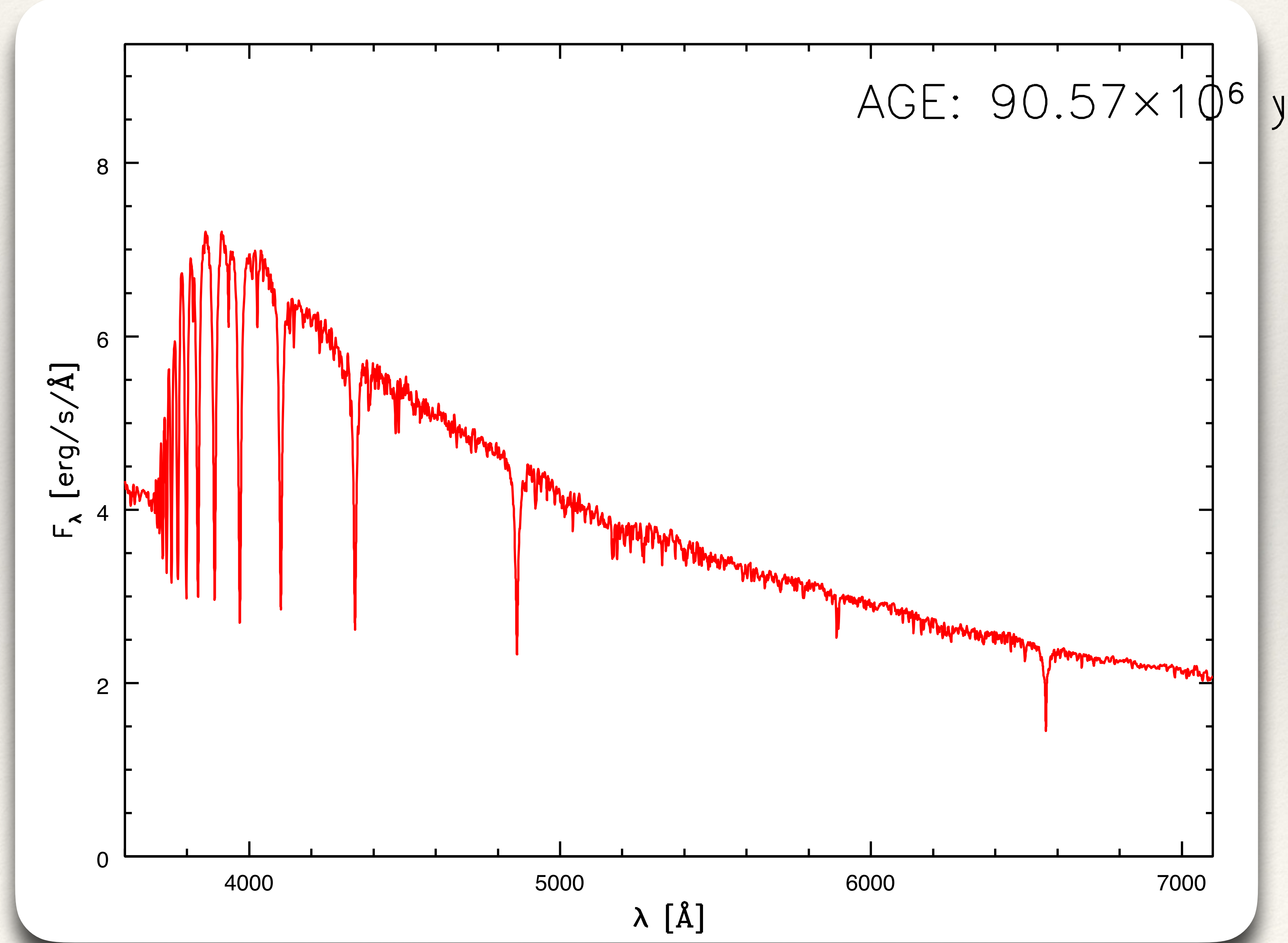

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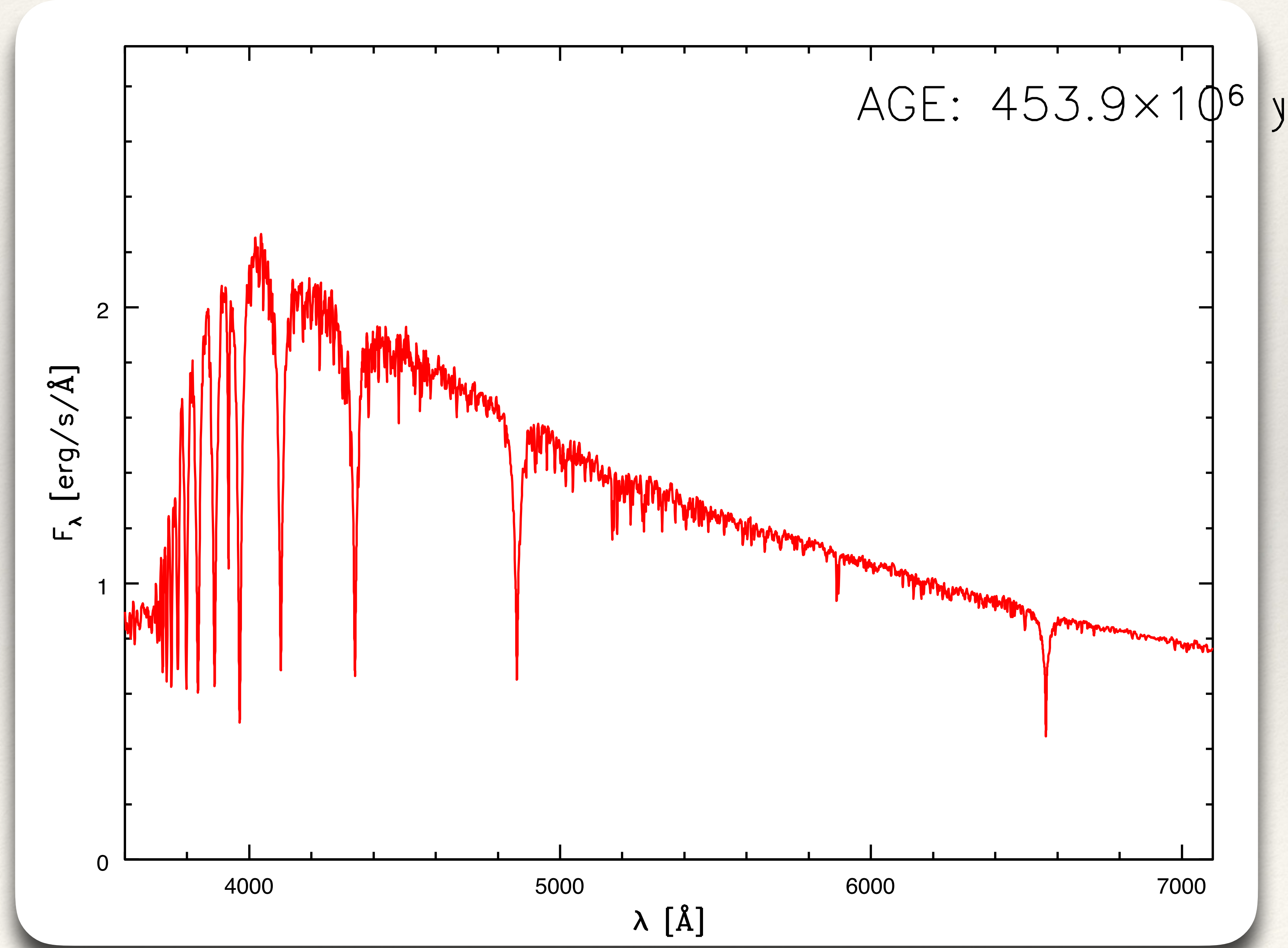

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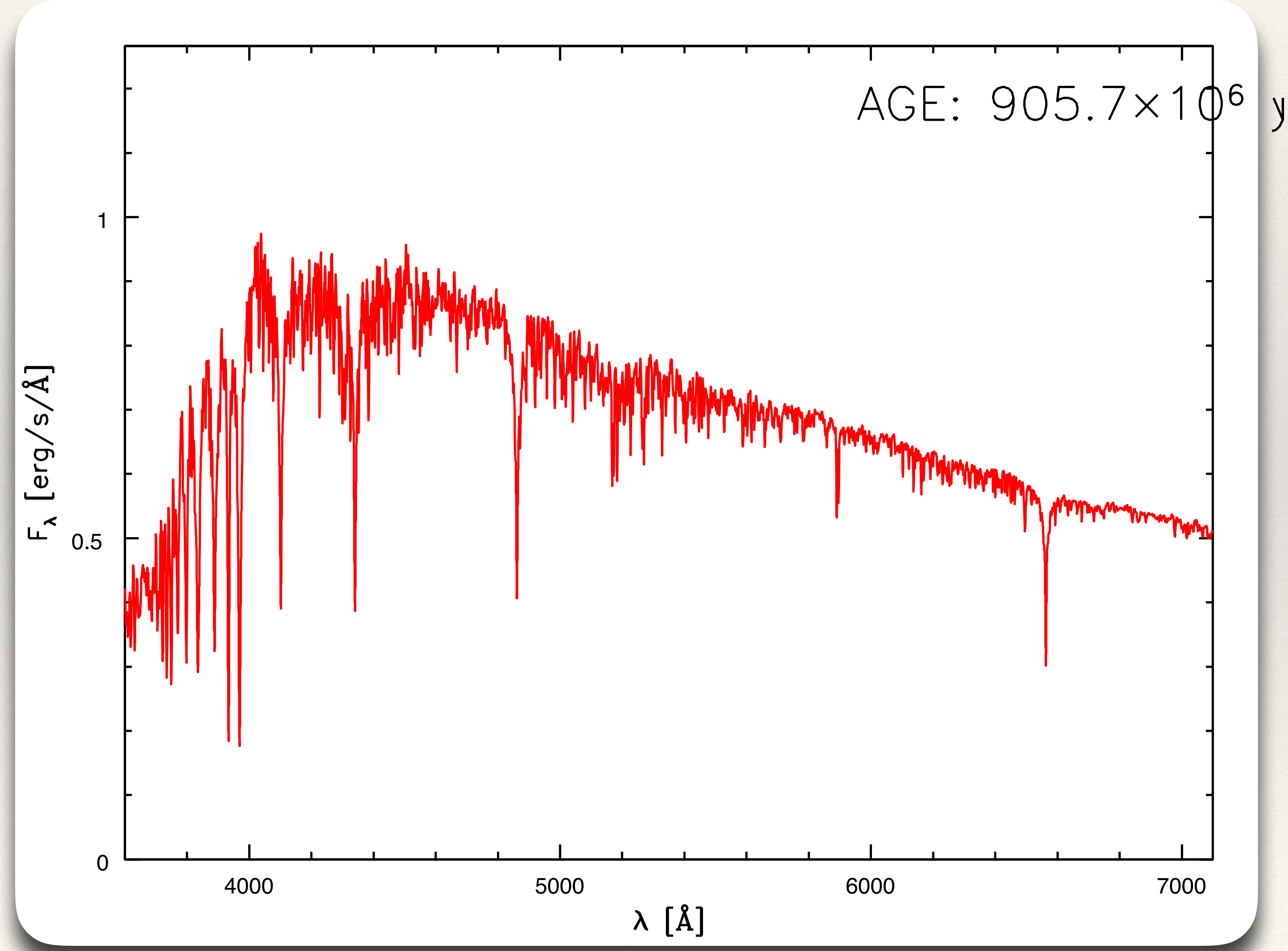

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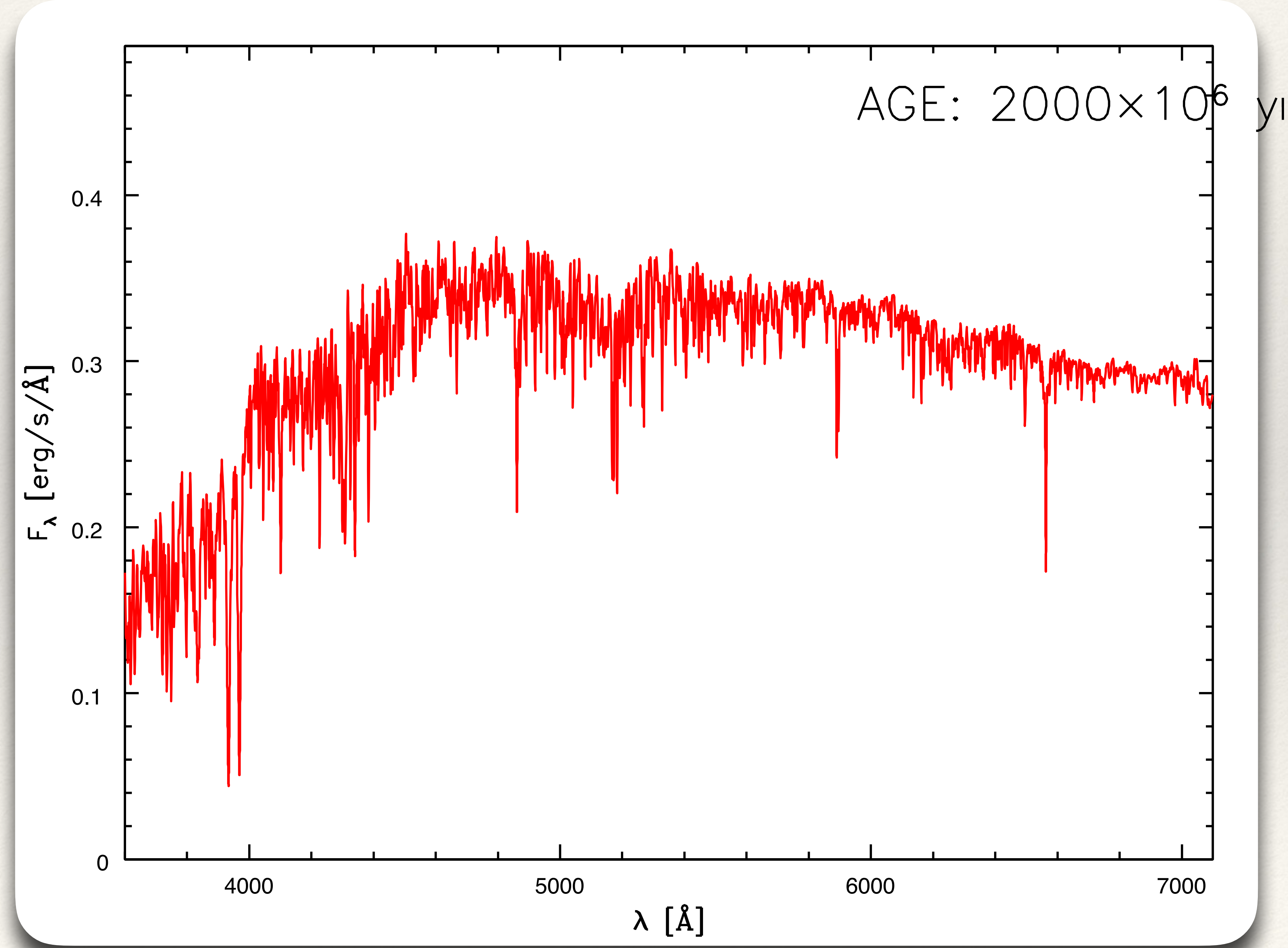

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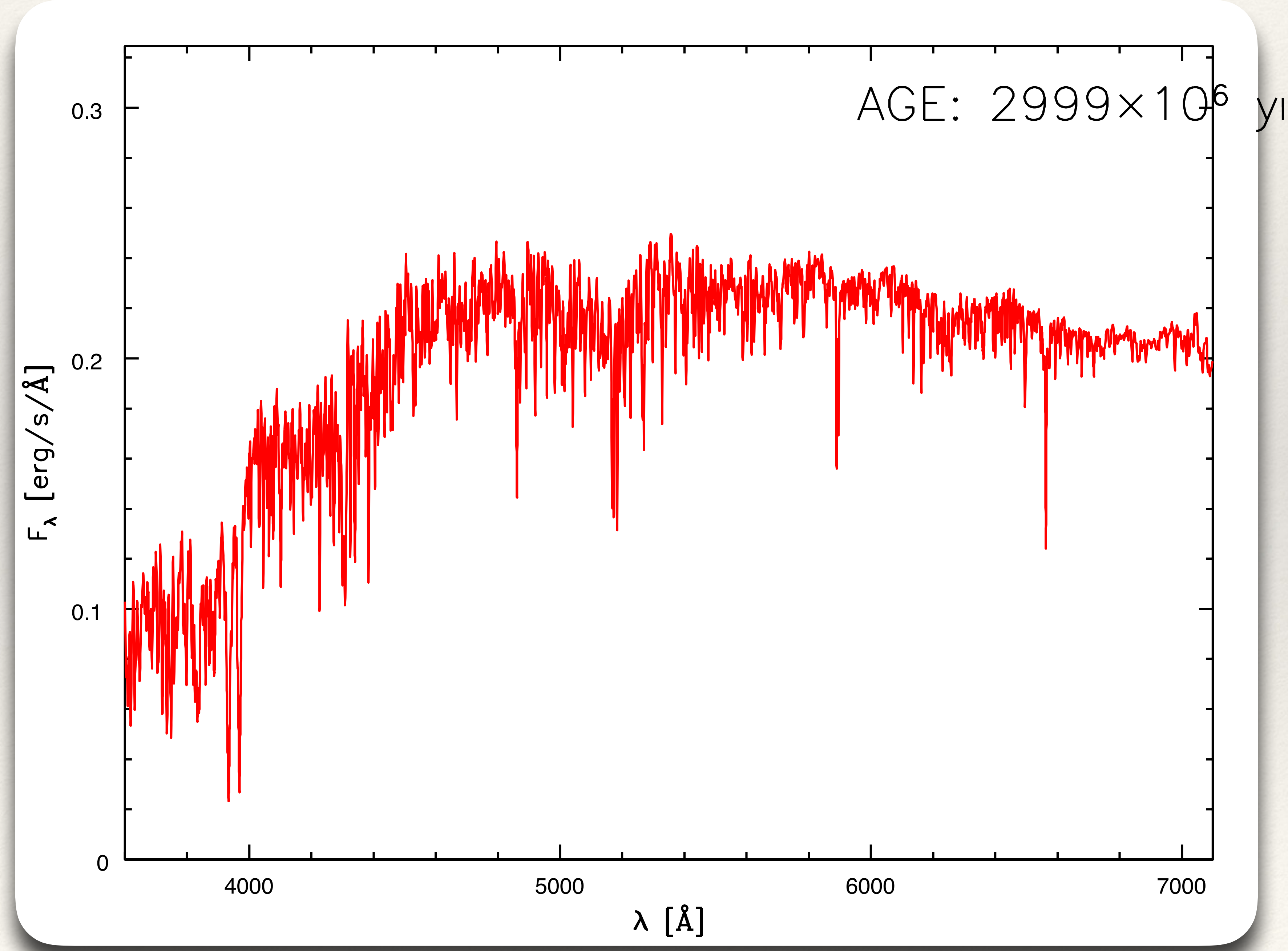

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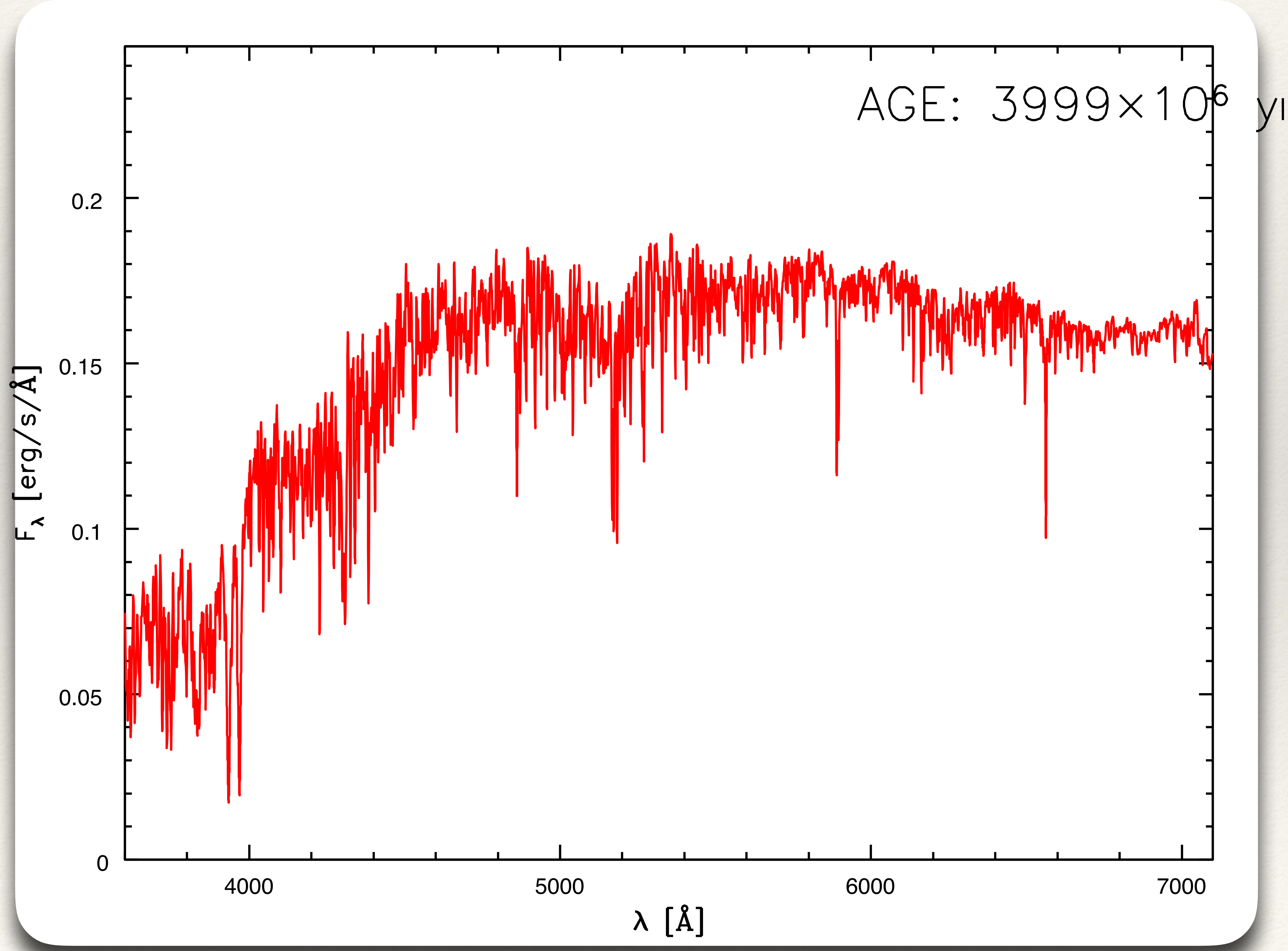

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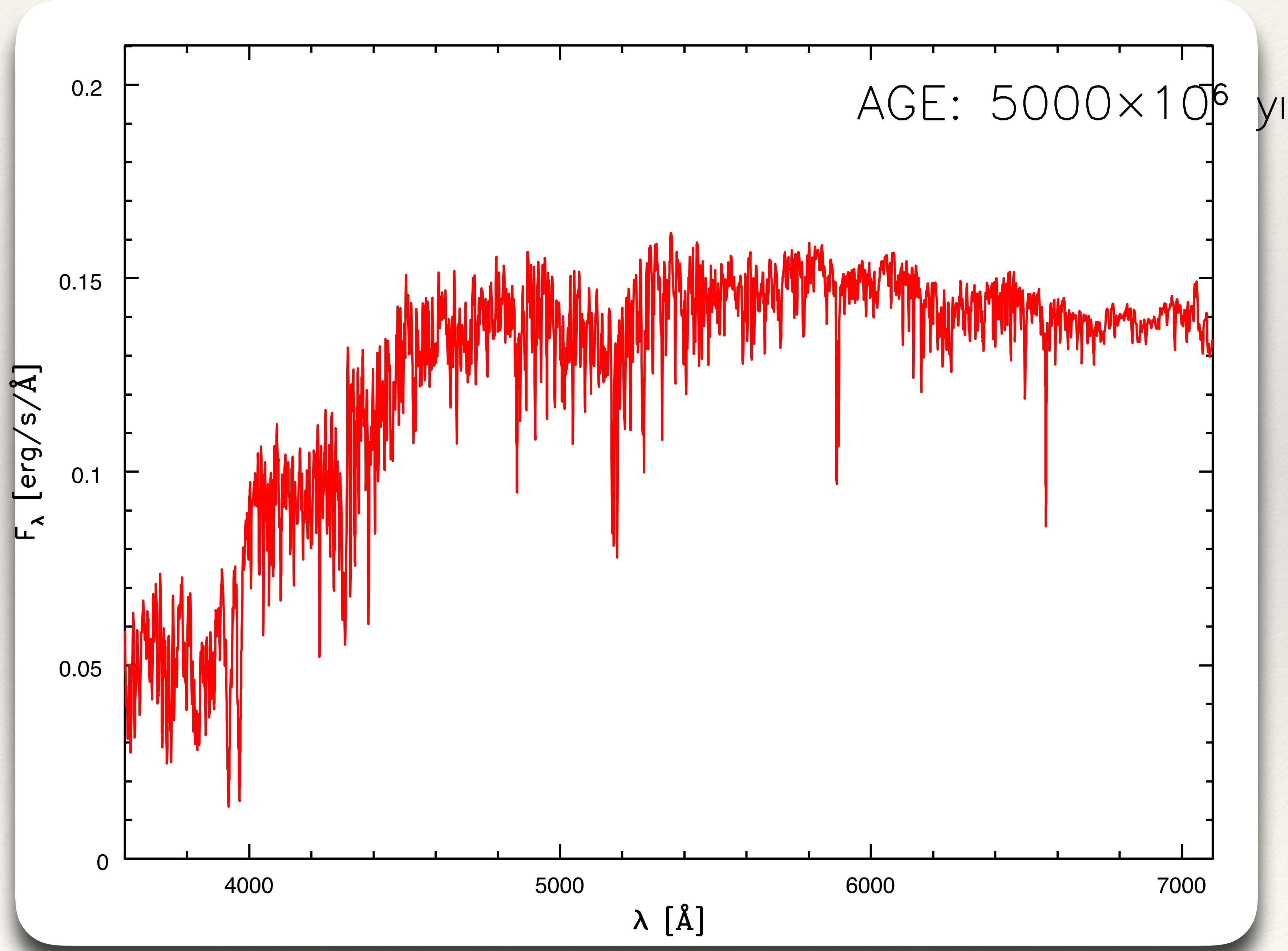

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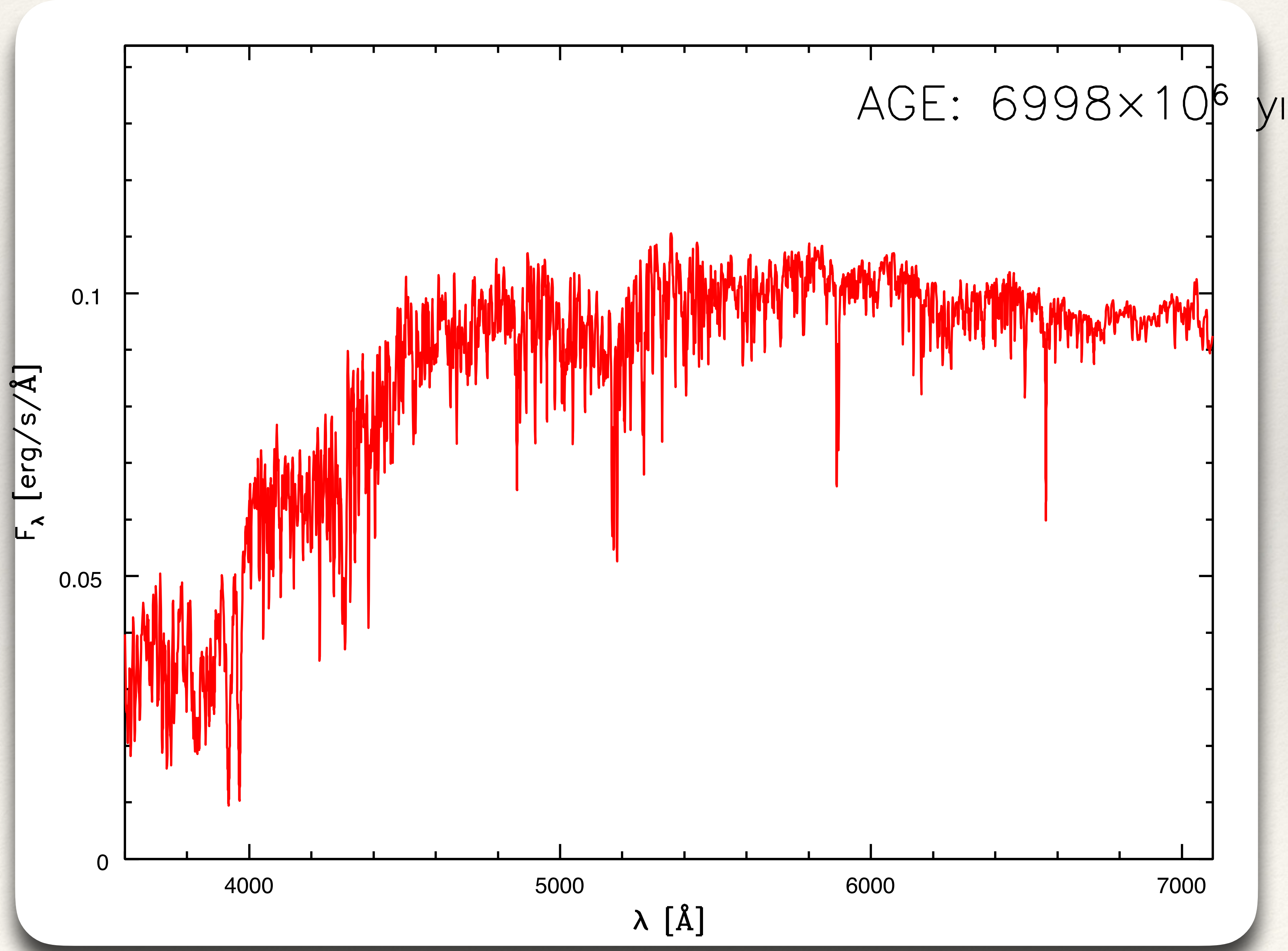

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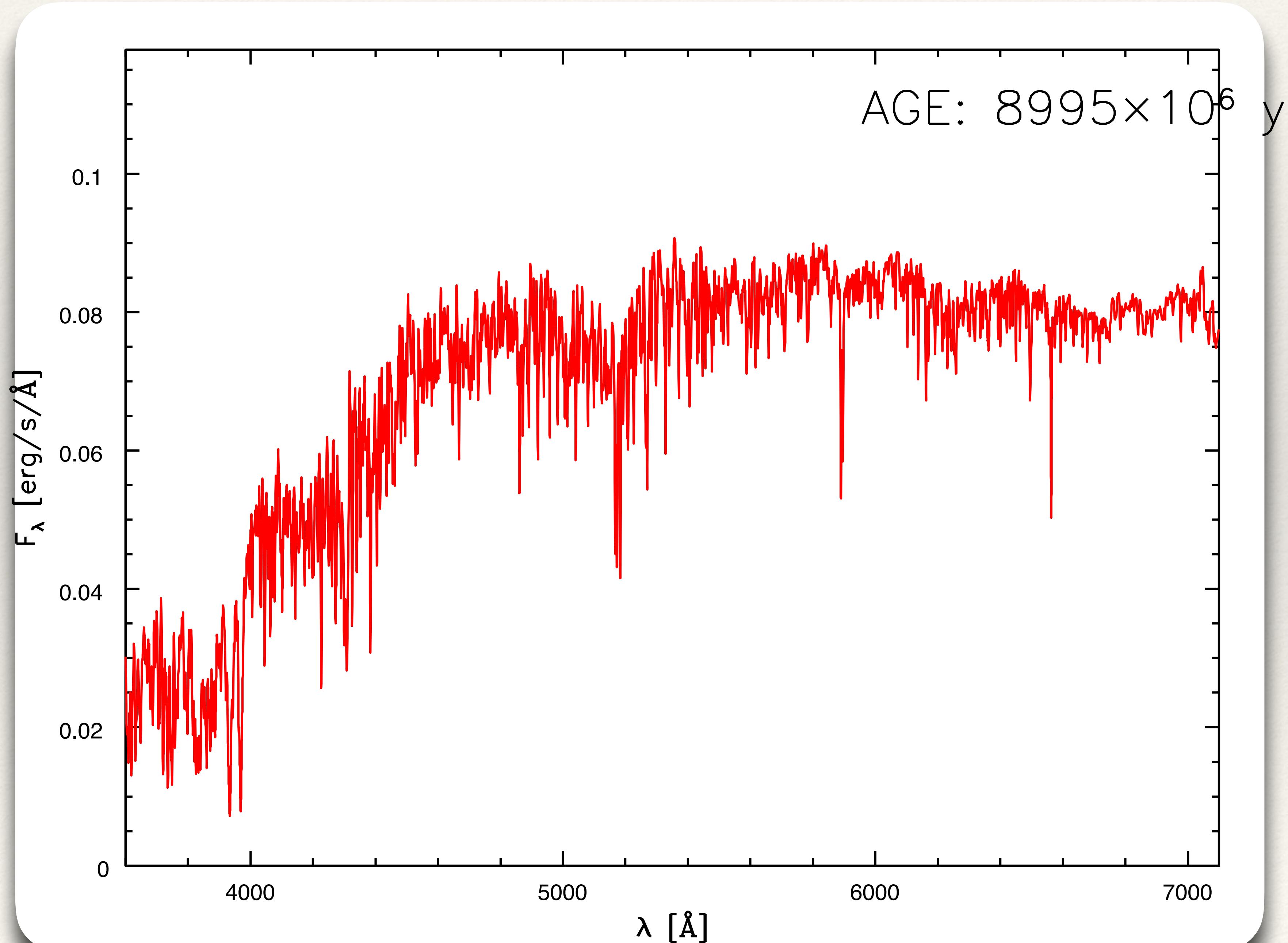

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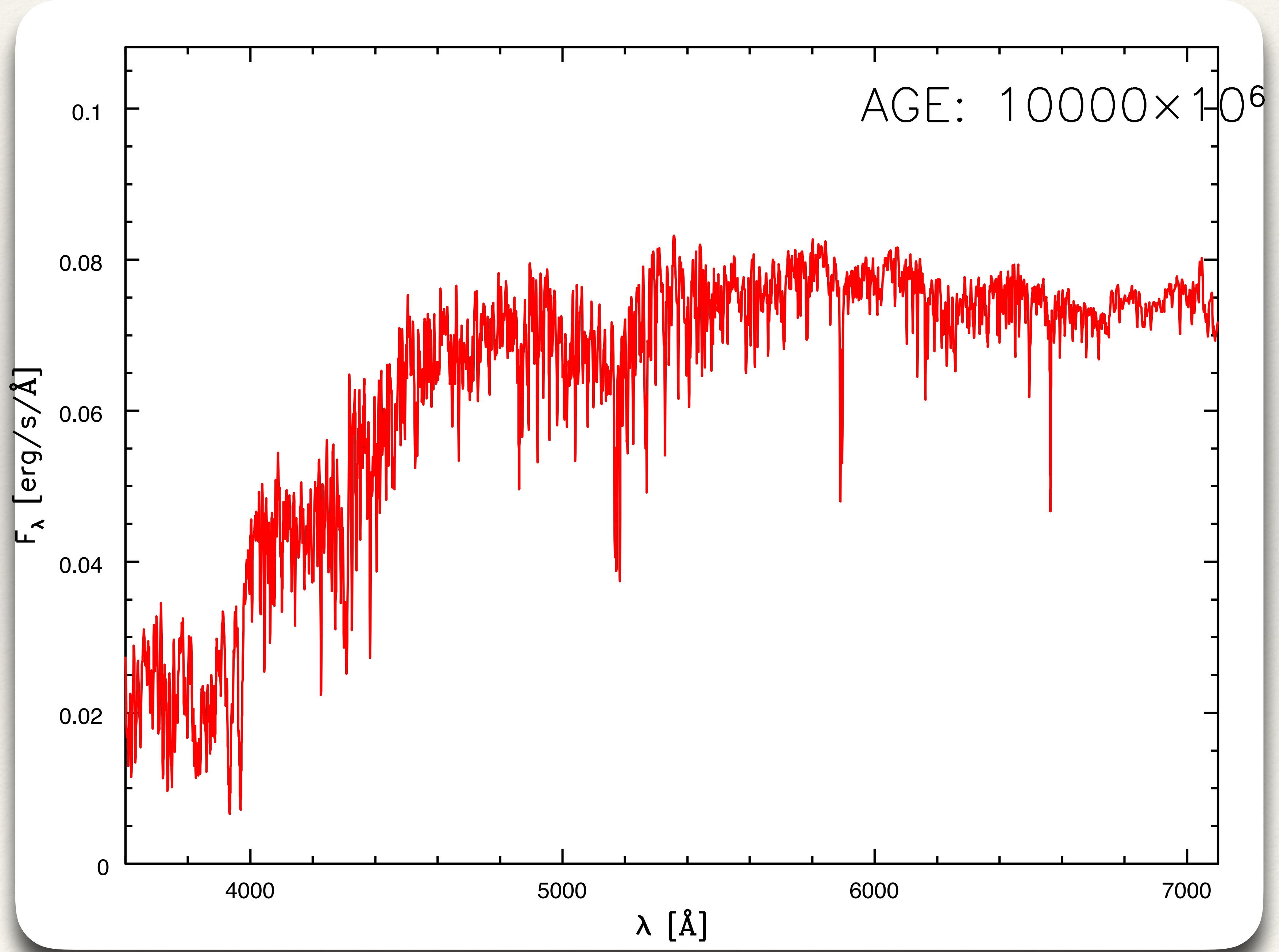

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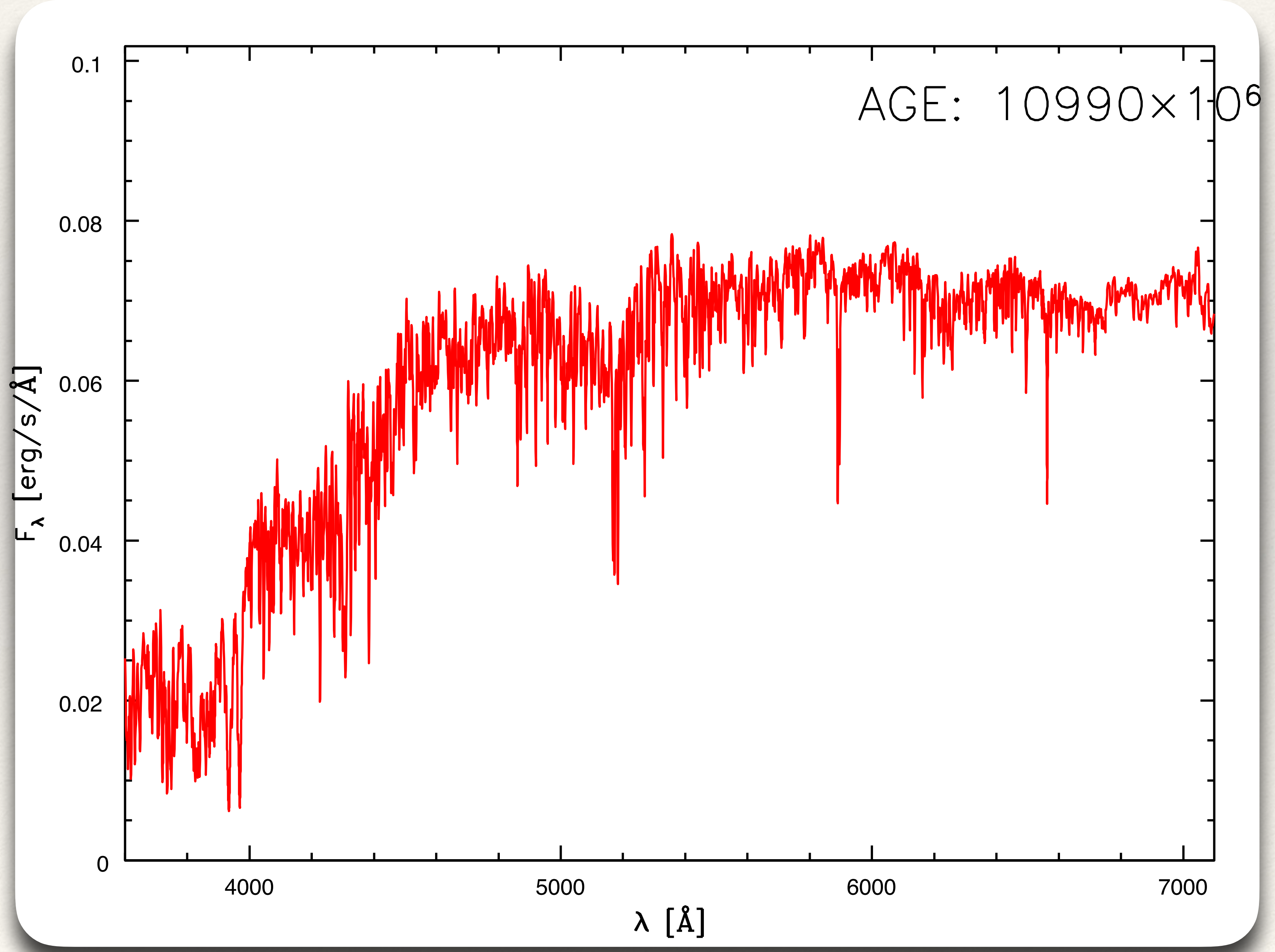

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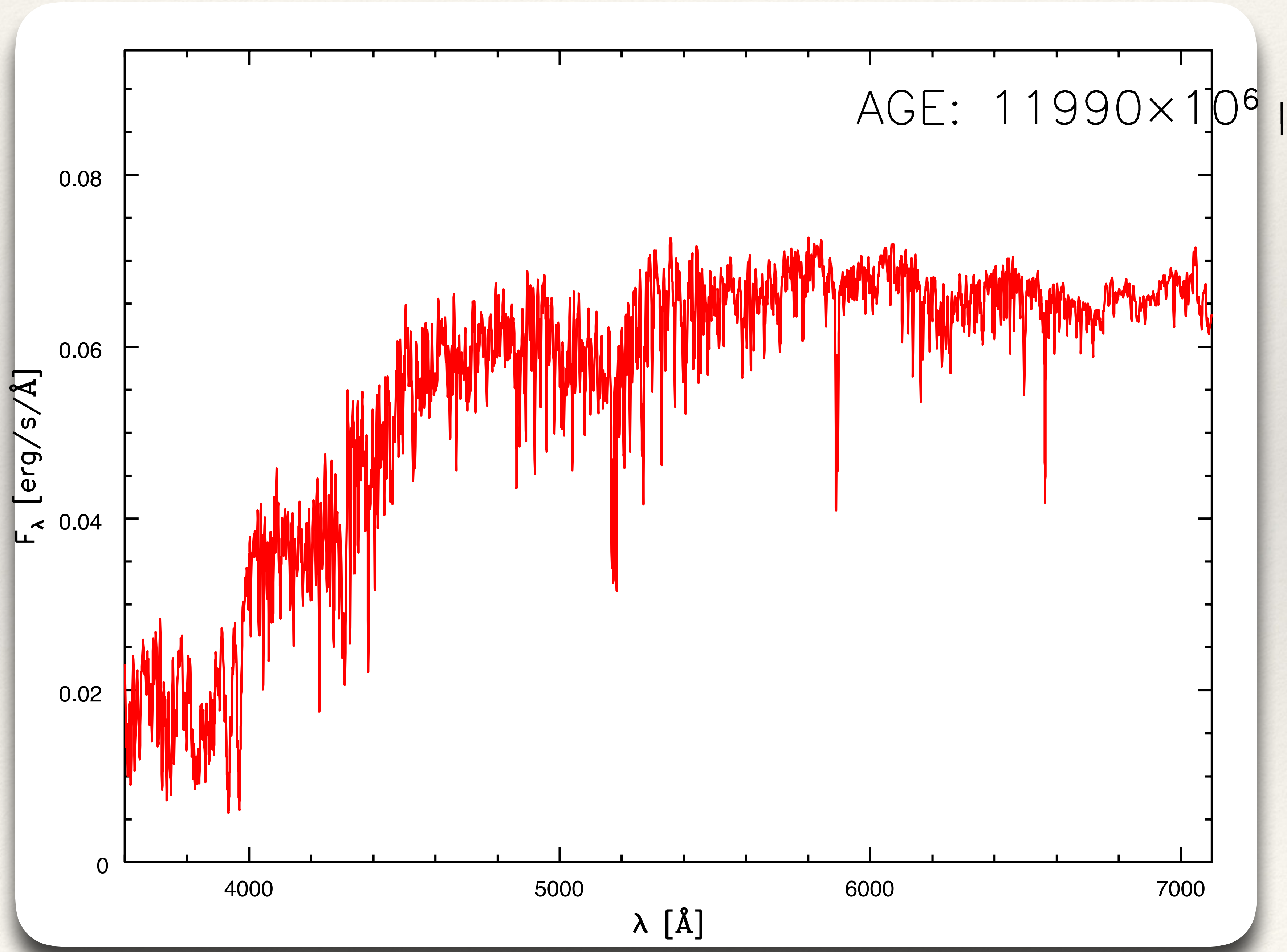

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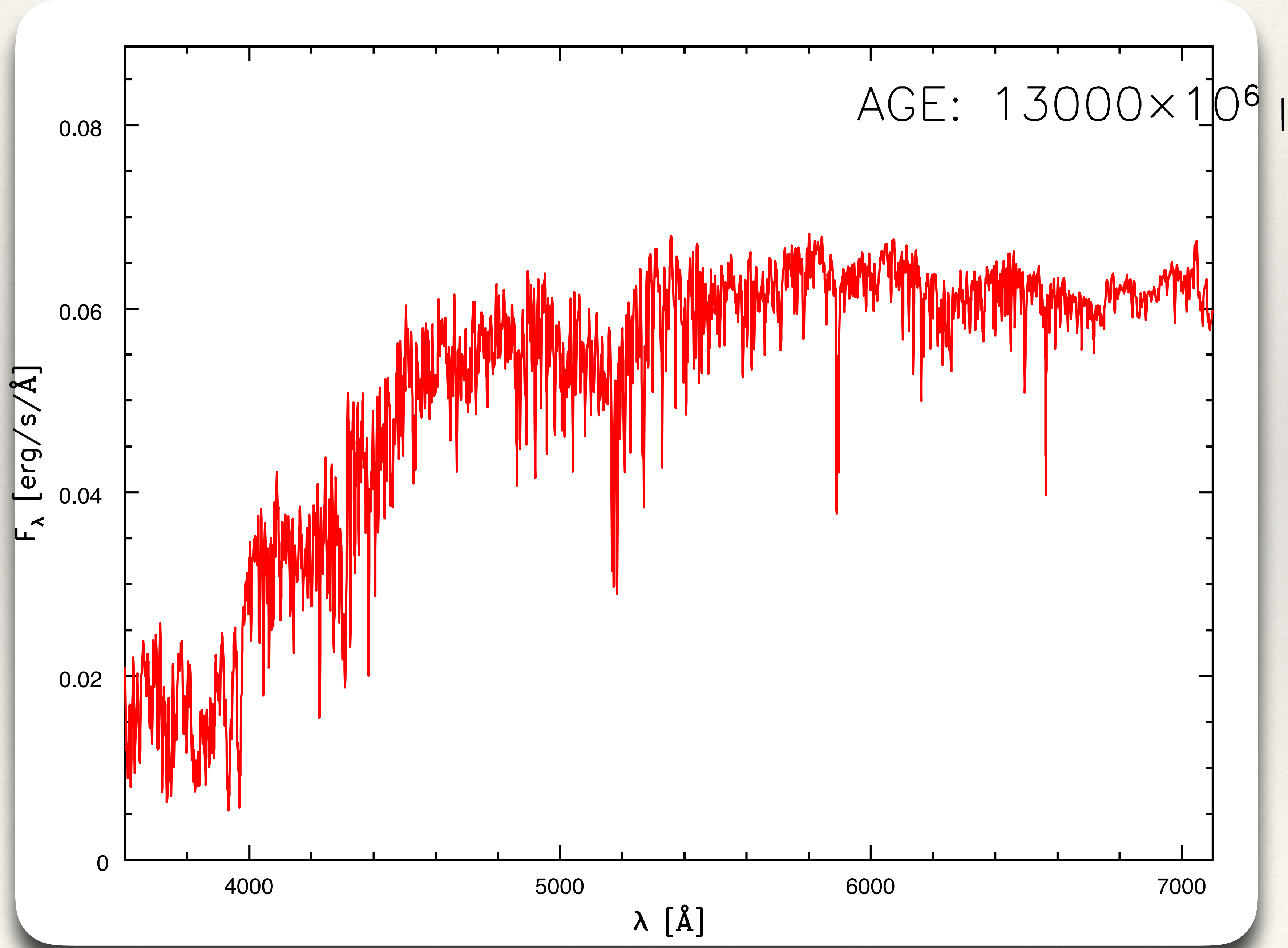

Simple Stellar Population Spectra

- The luminosity (per unit mass) decreases with increasing age;
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+

- Metallicity makes a spectra at similar age redder;
- dust has a similar effect.

Stellar Population Synthesis

- To analyze and understand the spectrum of a galaxy, we will work in the hypothesis that it is well represented by a combination of SSP spectra of different age;
- we will use the distinctive, characteristic spectral features to try and recognize which are the SP that dominate un a galaxy;
- plus, we will include dust extinction as a function of age.

Summary

- SFR definition and calculation;
- galaxies' spectra: main features, broad-band SED;
- Stellar Population Synthesis: isochrones, IMF, SFH, metallicity;
- theoretically building a galaxy spectrum;
- Simple Stellar Population spectra: characteristics as a function of age.