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DataCubes in Astrophysics

Lesson 9

SINOPSIS

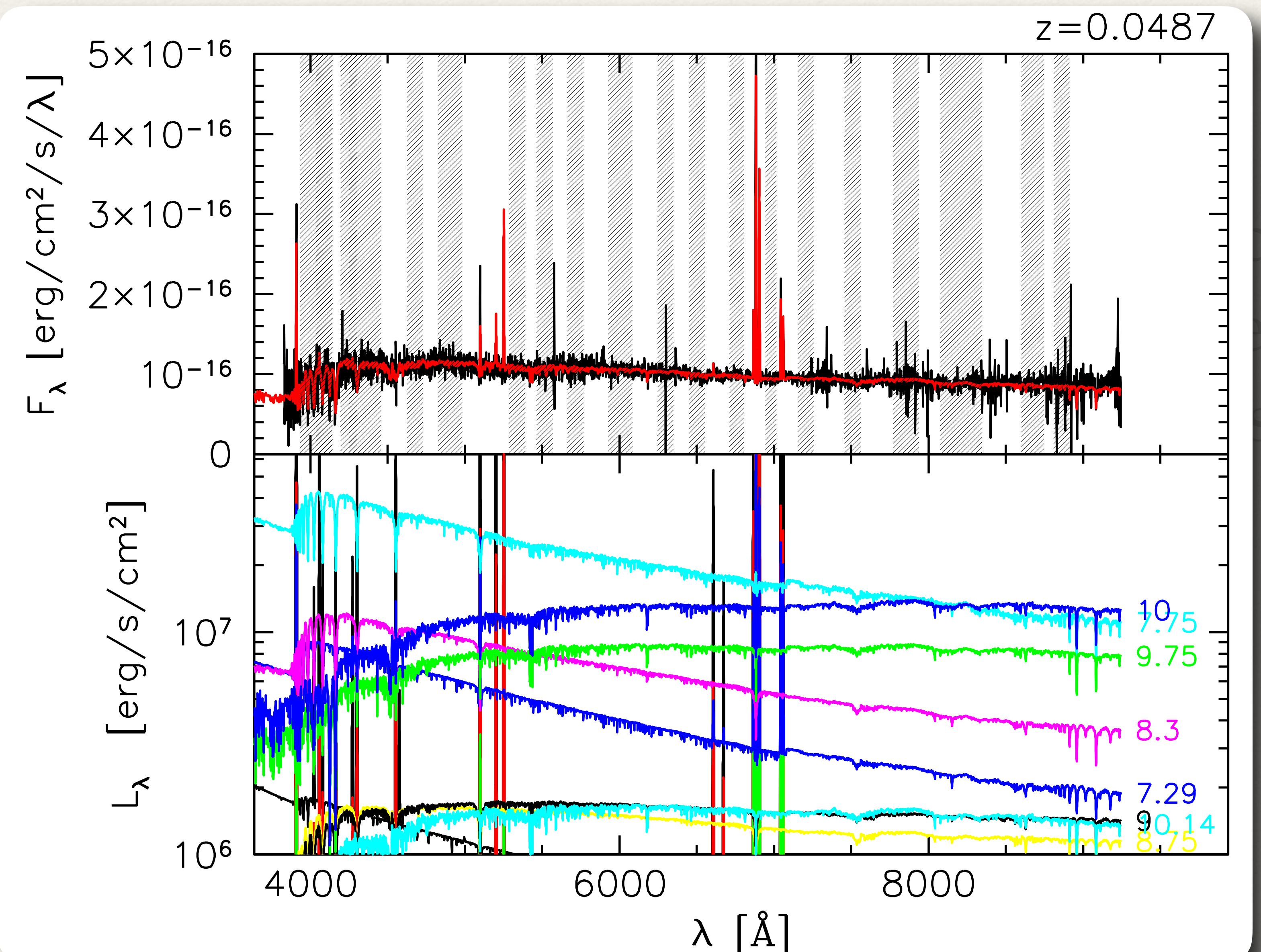
SImulatiNg OPtical Spectra wIth population Synthesis models

Is a spectrophotometric fitting code that, by reproducing the main features in an optical spectrum of a galaxies, derives its stellar population and dust extinction properties.

SINOPSIS

SImulatiNg OPtical Spectra wIth population Synthesis models

Is a spectro… …ing the main features i… …s its stellar …s.



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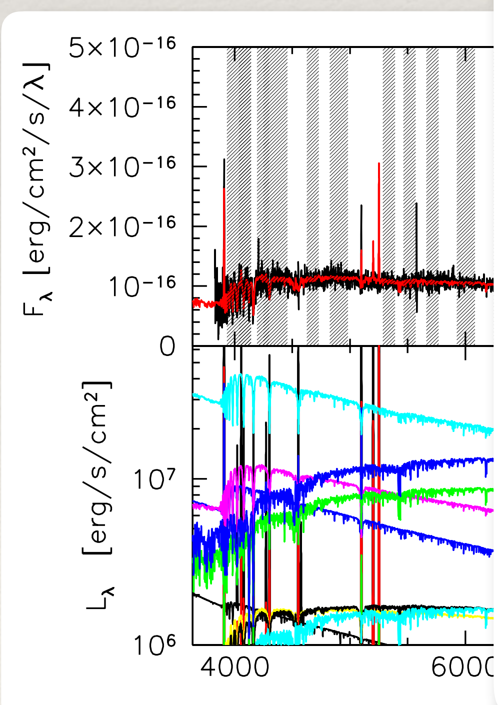

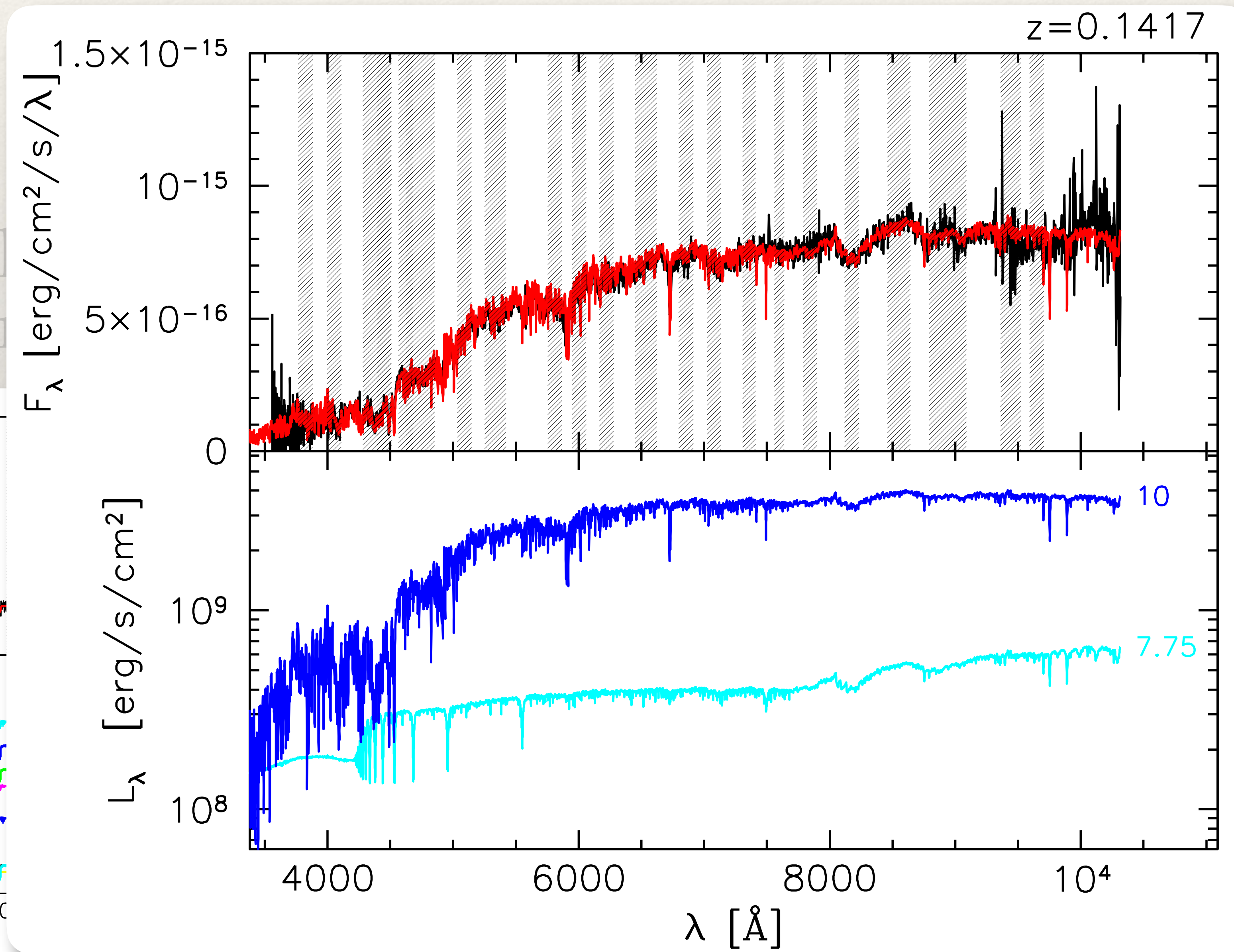

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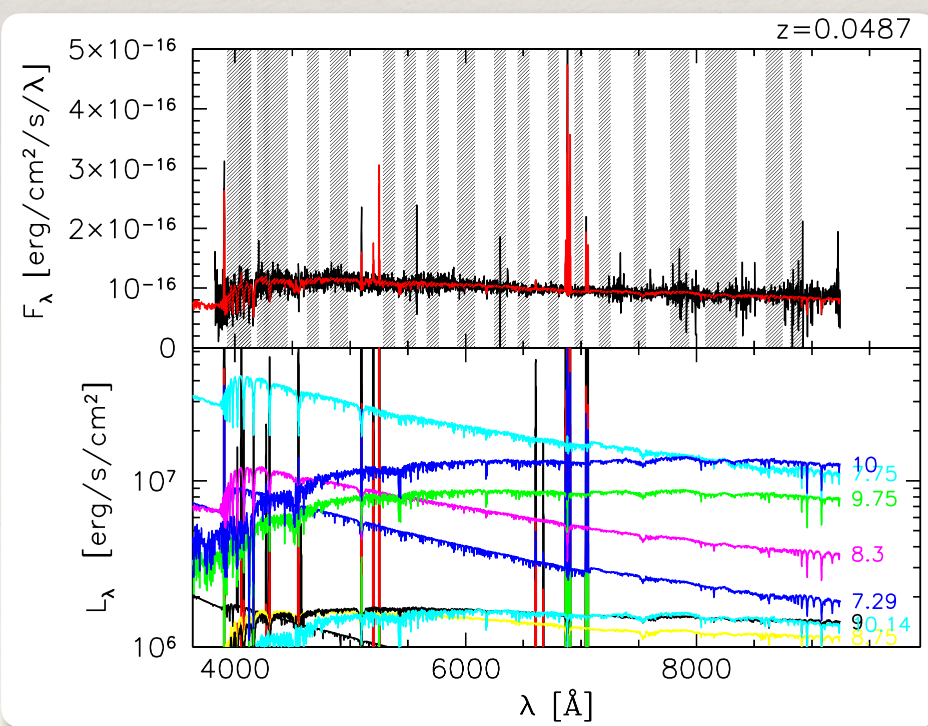
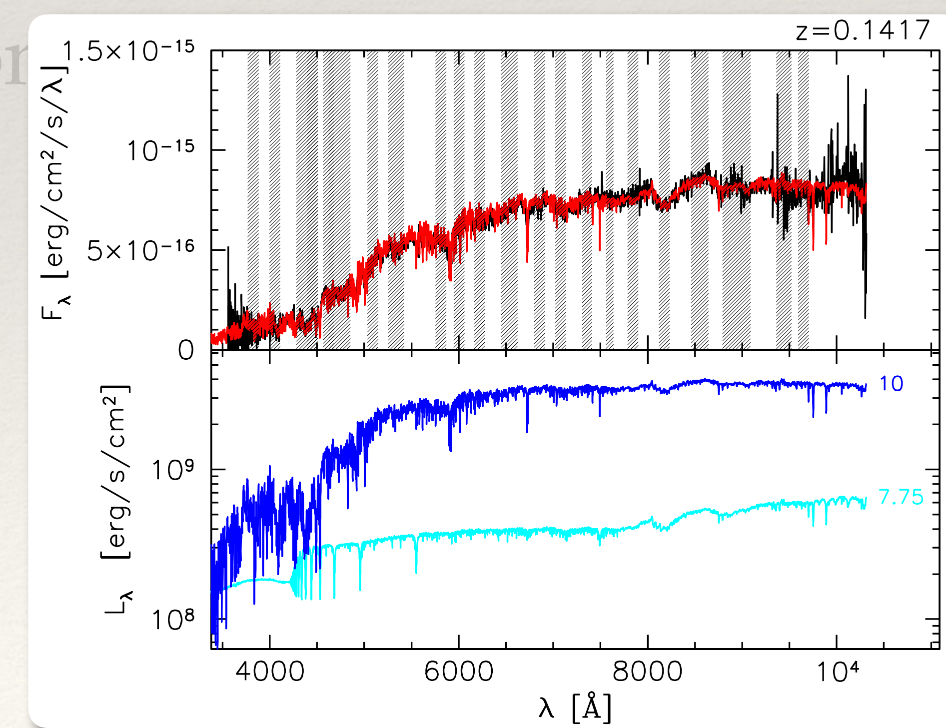




SINOPSIS

Model construction

$$L_{\lambda}^{mod}(\lambda) = \sum_{i=1}^{N_{SSP}} \left[L_i(\lambda) \times M_i \times 10^{-0.4 \cdot R_V \cdot E(B-V)_i \cdot A_\lambda / A_V} \right]$$

SINOPSIS

Model construction

Final model spectrum

Number of SSP of different ages

Dust extinction (as a function of age)

$$L_\lambda^{mod}(\lambda) = \sum_{i=1}^{N_{SSP}} \left[L_i(\lambda) \times M_i \times 10^{-0.4 \cdot R_V \cdot E(B-V)_i \cdot A_\lambda / A_V} \right]$$

Age index

SSP models (as a function of age)

Stellar mass (as a function of age)

Extinction curve

SINOPSIS

Comparison with observed spectrum

- Continuum bands chosen for being devoid of spectral lines;
- equivalent width of most significant spectral lines.
    - The "best fit" parameters are derived by minimizing the differences between model and observed.

From this, we find a best fit model, that is a model for which the differences between the observed features and the corresponding ones in the model is MINIMAL

SINOPSIS on CUBES

- To run SINOPSIS on a data cube you need:
    1. the data cube
    2. a “catalog” file’
    3. the `config.sin` file;
    4. a redshift mask (fits format: 2 masks can be used as well, one for the stellar redshift, the other for the gas).

SINOPSIS: file preparation

1. Configuration file "`config.sin`": contains information on the kind of data to analyze, and on the details of data treatment and output (see sample in the directory `example/`);
2. "catalog" file: contains information on the files with the data and on some characteristics (redshift, magnitudes, etc…; see sample `input_cat_case5.dat` in the `example/` directory).

SINOPSIS: the `config` file (1)

Type of catalog to be used

```
################################################################################
###                    Configuration file for SINOPSIS                      ###
###                             version 1.6.4                               ###
###              If a keyword is not defined here, a default value          ###
####                     will be assumed, when possible.                    ###
################################################################################
################################################################################
#######                #######
###     INPUT CATALOG
Name of the input catalog := inputcatalog.dat
# Allowed keywords: basic, advanced, eqw.
Type of input catalog := basic
################################################################################
```

SINOPSIS: the `config` file (2)

Input spectra dealing

```
################################################################################
###     OBSERVED SPECTRA CHARACTERISTICS and OPTIONS
# Allowed keywords: ascii, fits, mfits, cube
Format of the observed spectrum or spectra:= ascii
Spectral resolution of the data (FWHM in Angstroem) := 9.0
# Allowed keywords: linear, logarithmic
Wavelength array in linear or logarithmic units := linear
# Allowed keywords:  linear, logarithmic
Flux array in linear or logarithmic units := linear
Number of lines to be skipped in the observed spectra (ascii format only) := 0
Cut the observed spectra in the blue part by this amount (in Angstroem) := 200
Cut the observed spectra in the red part by this amount (in Angstroem) := 300
Smooth the observed spectra resolution to match the SSP resolution := no
Smooth the observed spectra to a custom resolution := no
Resolution of the smoothed observed spectra (FWHM in Angstroem) := 6.0
Write the smoothed observed spectra := yes
################################################################################
```

SINOPSIS: the `config` file (3)

Normalization and constraints

```
################################################################################
#######                                                                  #######
###    NORMALIZATION OF THE MODEL SPECTRUM & OBSERVED CONSTRAINTS (CONTINUUM)
# Allowed keywords: phot, spec, none, norm
Normalize the model spectrum to := spec
Normalisation factor := 1.0e-17
# Allowed keywords: file, custom
Continuum bands definition := file
File with the definition of the continuum bands used as constraints :=
default_cont_bands.dat
################################################################################
```

SINOPSIS: the `config` file (4)

Dust extinction law

```
###############################################################################
#######            #######
###    EXTINCTION
# Allowed keywords: MW, SMC, CAL, 2.5, 4.0, 5.0
Extinction curve to be adopted := MW
###############################################################################
```

SINOPSIS: the `config` file (5)

SSPs models and dealing

```
################################################################################
#######                                               #######
###     CHARACTERISTICS OF THE MODELLING
# Allowed keywords: jm, cb16
SSP set := jm
# Allowed keywords: ff, dexp, logn
Star formation history pattern := ff
Number of different metallicity values := 3
Metallicity values to be used := 0.004 0.02 0.05
Smooth SSP spectra to the observed spectra resolution := yes
################################################################################
```

SINOPSIS: the `config` file (6)

Calculation of uncertainties

```
################################################################################
#######                             #######
###     UNCERTAINTIES DETERMINATION
Number of separate runs for each metallicity value := 11
Chi2 threshold value to calculate uncertainties := 3.0
################################################################################
```

SINOPSIS: the `config` file (7)

Outputs and other settings

```
#################################################################################
#######         #######
###    VARIOUS
Create a model magnitudes catalog := yes
# Allowed keywords: Jon, AB
Magnitudes type for the model catalog := Jon
Catalog of redshift-independent distances to be used := mydistances.dat
File with cosmological parameters := cosmology.dat
Redshift value below which a redshift-independent distance is used := 0.00
Measure the equivalent width of Hbeta using fixed bandwidth := no
Output all the best fits for all runs and metallicities := no
Write output file for each reference model := yes
Write out the model spectra without emission lines := yes
Write out the flag mask of fitted pixels in a cube dataset := yes
Write out the contribution to the continuum flux from the SSPs := yes
Minimize memory usage := n
#################################################################################
```

Other catalog options

- Observed spectra are in separate files:
    1. no photometric data; normalisation on the spectrum itself;
    2. photometry added; normalisation on the spectrum itself;
    3. normalisation based on magnitude value (plus case 1 or 2);
- Observed spectra are in a 2D file;
- Observed spectra are in a datacube.

Other configuration options

- Cosmology;
- continuum bands to be reproduced;
- star formation history parameters;
- equivalent widths (<u>hardcoded</u>!!!).

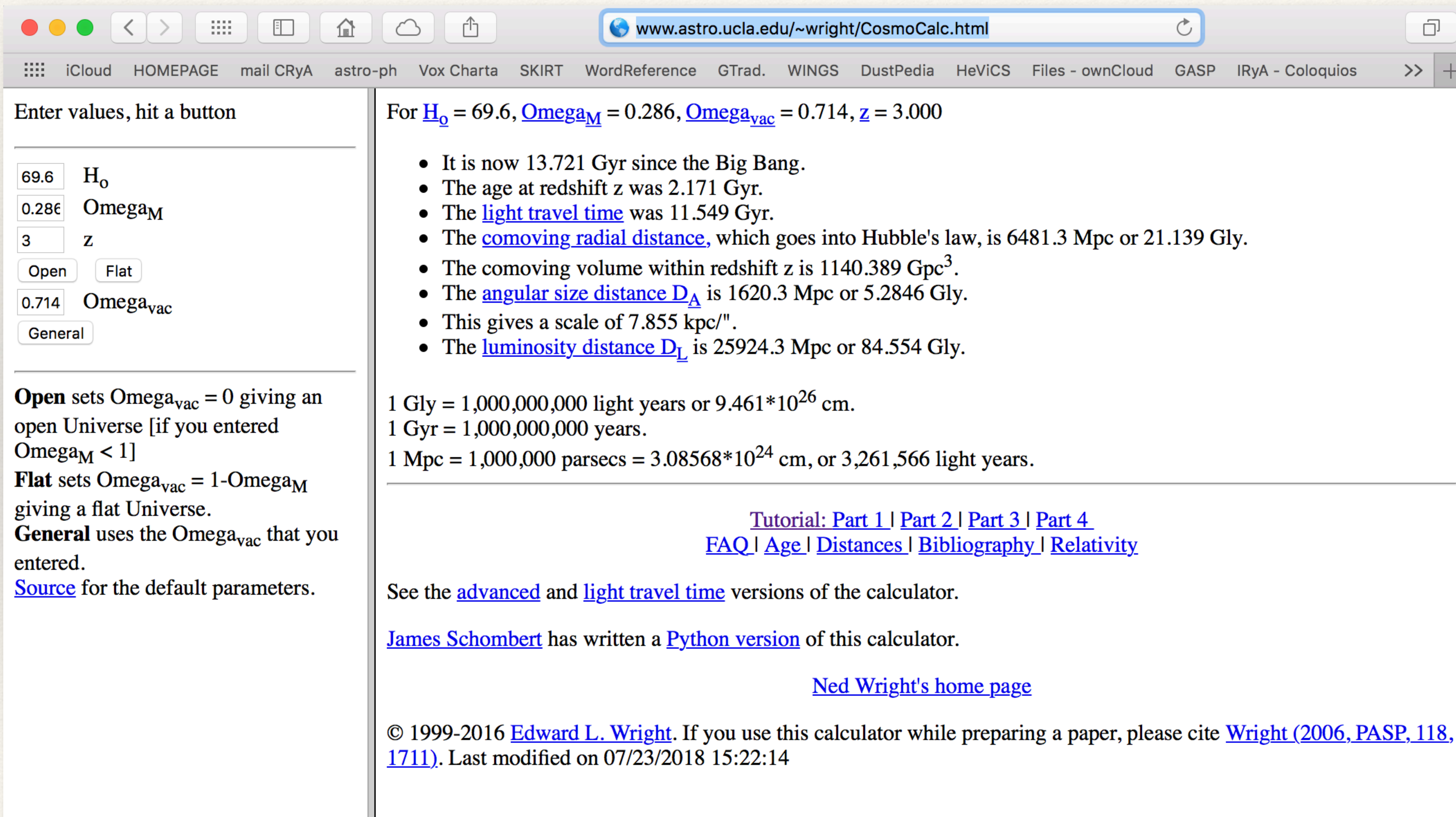
Note on the distance

- The distance is calculated from the redshift value;
- a cosmology needs to be assumed (i.e.: H_0, Ω_m, and Ω_Λ);
- if the redshift is too small (i.e.: < 0.01, for example), you might want to provide your own value of the distance (taken from a redshift-independent measure);
- the observed spectrum still might need to be redshift-corrected.

Distance calculator:

http://www.astro.ucla.edu/~wright/CosmoCalc.html

Note on the distance



Enter values, hit a button

69.6	H_o
0.286	$Omega_M$
3	z
Open	Flat
0.714	$Omega_{vac}$
General	

Open sets $Omega_{vac} = 0$ giving an open Universe [if you entered $Omega_M < 1$]
Flat sets $Omega_{vac} = 1-Omega_M$ giving a flat Universe.
General uses the $Omega_{vac}$ that you entered.
Source for the default parameters.

For $H_o = 69.6$, $Omega_M = 0.286$, $Omega_{vac} = 0.714$, $z = 3.000$

- It is now 13.721 Gyr since the Big Bang.
- The age at redshift z was 2.171 Gyr.
- The light travel time was 11.549 Gyr.
- The comoving radial distance, which goes into Hubble's law, is 6481.3 Mpc or 21.139 Gly.
- The comoving volume within redshift z is 1140.389 Gpc^3.
- The angular size distance D_A is 1620.3 Mpc or 5.2846 Gly.
- This gives a scale of 7.855 kpc/".
- The luminosity distance D_L is 25924.3 Mpc or 84.554 Gly.

1 Gly = 1,000,000,000 light years or $9.461*10^{26}$ cm.
1 Gyr = 1,000,000,000 years.
1 Mpc = 1,000,000 parsecs = $3.08568*10^{24}$ cm, or 3,261,566 light years.

Tutorial: Part 1 | Part 2 | Part 3 | Part 4
FAQ | Age | Distances | Bibliography | Relativity

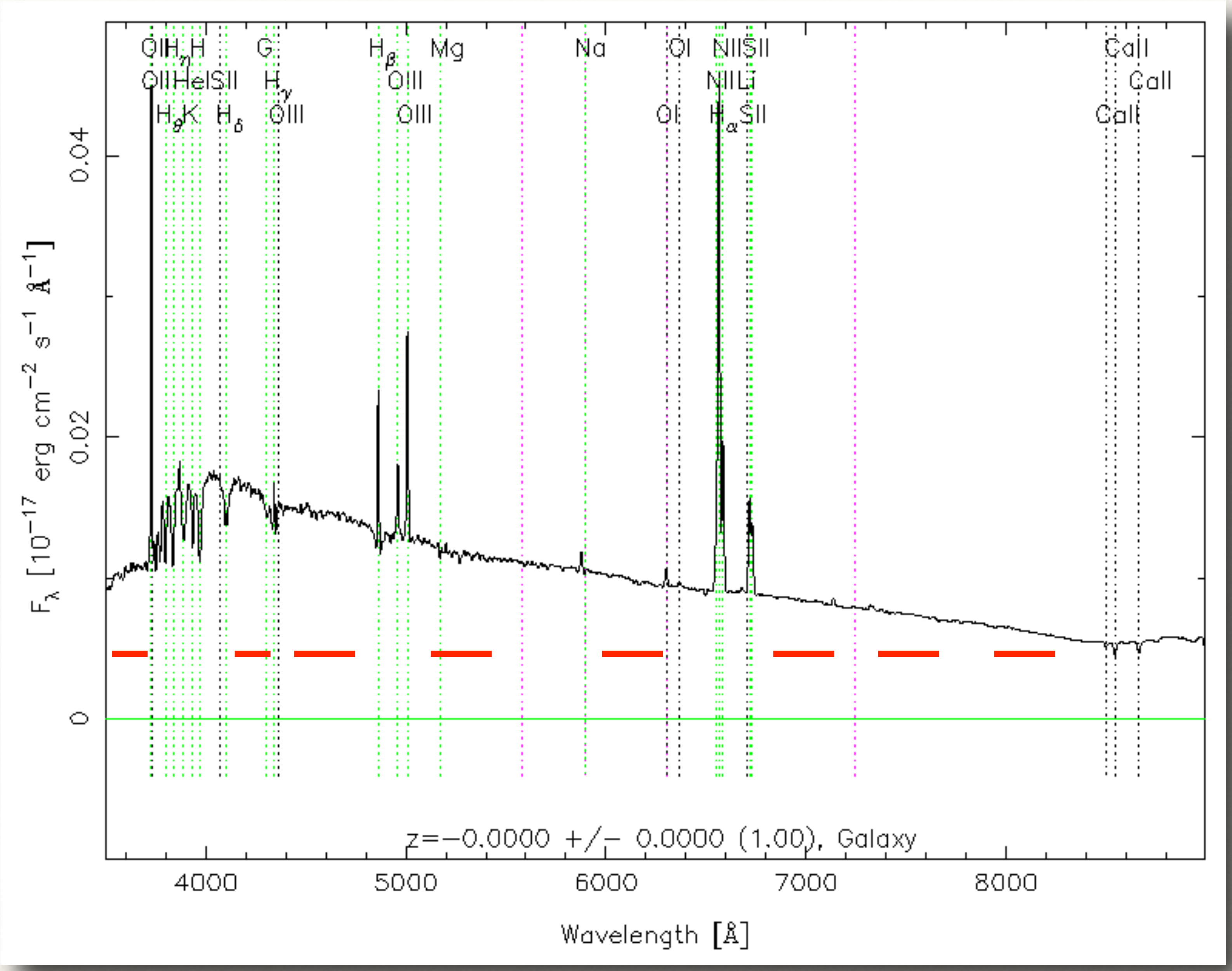
See the advanced and light travel time versions of the calculator.

James Schombert has written a Python version of this calculator.

Ned Wright's home page

How does it work?

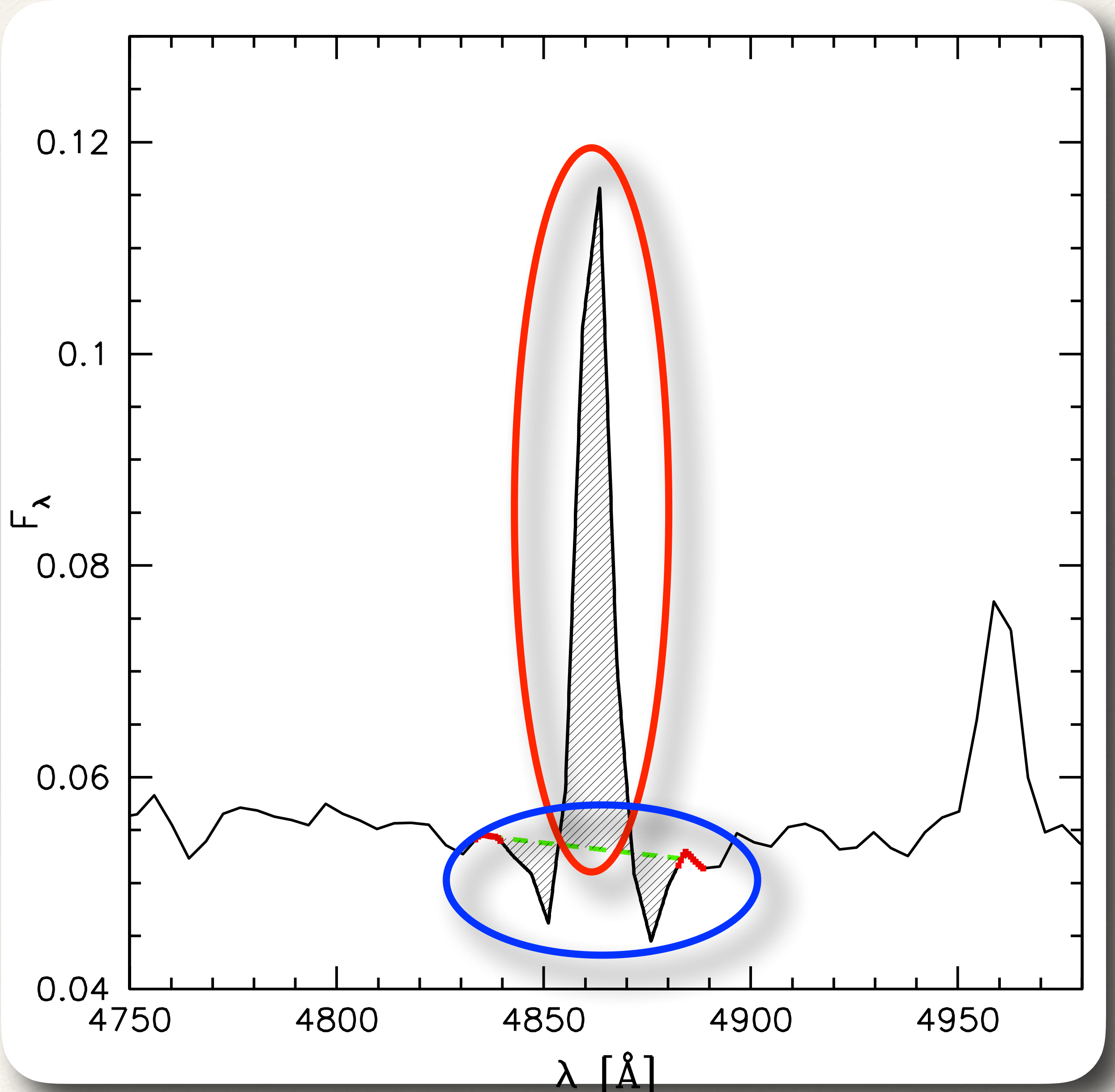
1. measure continuum flux and equivalent widths of lines



How does it work?

1. measure continuum flux and equivalent widths of lines

It includes both emission and absorption lines, or lines with both components at the same time



How does it work?

2. creates models with randomly-chosen parameters

N_{SSP} values of stellar mass

$$L_\lambda^{mod}(\lambda) = \sum_{i=1}^{N_{SSP}} \left[L_i(\lambda) \times M_i \times 10^{-0.4 \cdot E(B-V)_i \cdot A_\lambda / A_V} \right]$$

SSP spectra at
different ages

N_{SSP} values of extinction

How does it work?

3. measure and compare to observed

The same continuum bands and equivalent widths measured on the observed spectra are measured on the model spectrum

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{M_i - O_i}{\sigma} \right)^2$$

1., 2., and 3. are repeated until a good fit is achieved.

Outputs

- Model spectrum;
- model magnitudes in various bands (observed and absolute);
- model parameters (in various form): “`out`” file;
- measured equivalent widths of the main spectral lines.

The main output file (1)

1. Luminosity distance;
2. redshift;
3. reduced chi square;
4. best fit stellar metallicity;
5. best fit run;
6. number of lines used to constrain the model;
7. extinction value of the youngest stellar population;
8. minimum value of extinction from young stars;
9. maximum value of extinction from young stars;

The main output file (2)

10. extinction value averaged over all age stars;
11. minimum extinction value averaged over all age stars;
12. maximum extinction value averaged over all age stars;
13. star formation rate - age bin 1;
14. minimum value of the star formation rate - age bin 1;
15. maximum value of the star formation rate - age bin 1;
16. star formation rate - age bin 2;
17. minimum value of the star formation rate - age bin 2;
18. maximum value of the star formation rate - age bin 2;

The main output file (3)

19. star formation rate - age bin 3;
20. minimum value of the star formation rate - age bin 3;
21. maximum value of the star formation rate - age bin 3;
22. star formation rate - age bin 4;
23. minimum value of the star formation rate - age bin 4;
24. maximum value of the star formation rate - age bin 4;

…

…

The main output file (4)

49. stellar mass value (in $M_\odot$) within an aperture;

50. minimum value of the stellar mass within the aperture;

51. maximum value of the stellar mass within the aperture;

52. total stellar mass value (in $M_\odot$);

57. luminosity-weighted age (in log(yr));

63. mass-weighted age

The main output file (4)

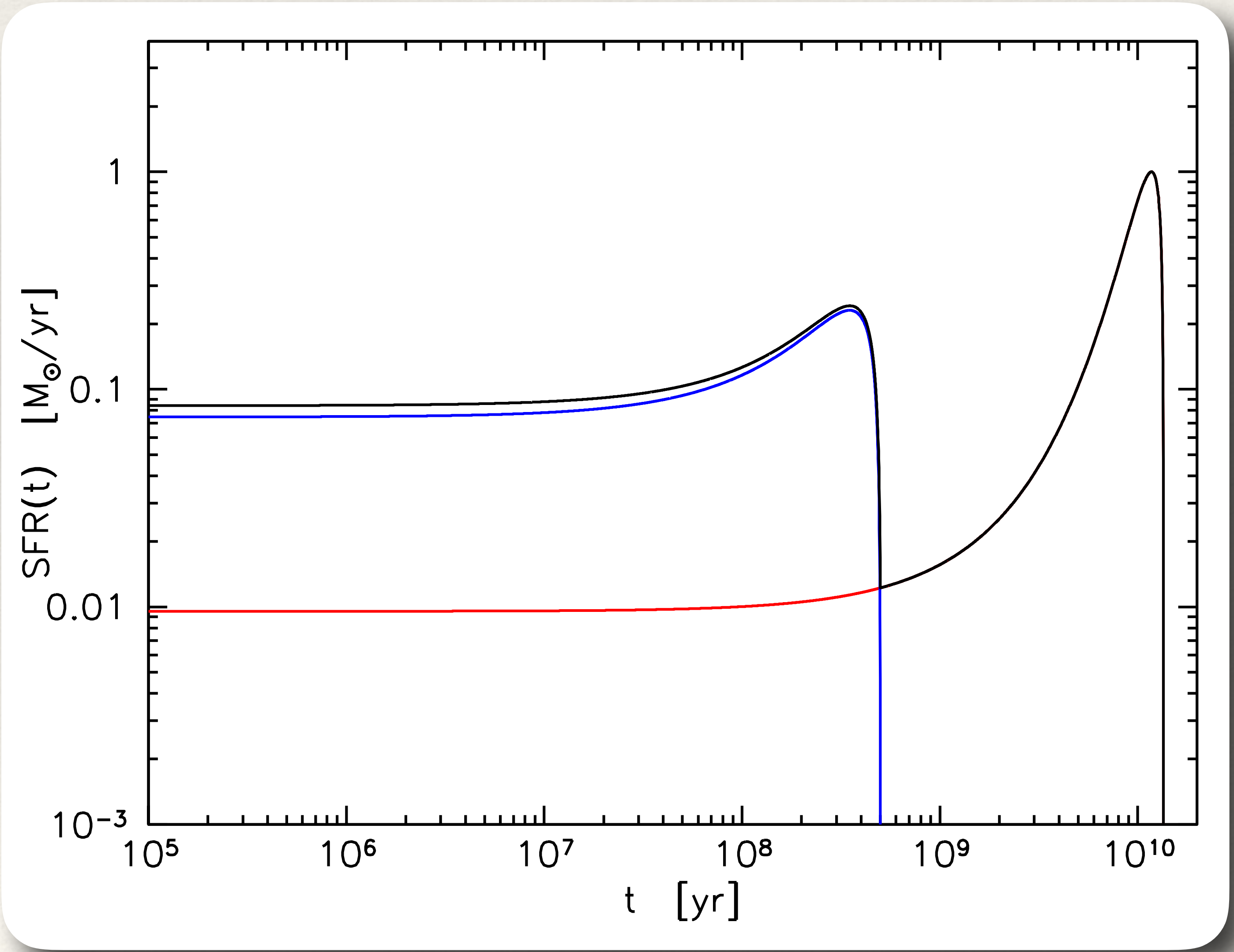
- 64 → 75: star formation rates of the SSPs used in the minimization;
- (or, alternatively) values of the SFH law parameters.

SFH prescriptions

- Free-Form (FF): the SFR of a predefined number of SSP at different age is let free to vary independently (and so is extinction);
- double exponential (dexp): the SFR(t) is represented as an analytical function in the form of a double decaying exponential;
- log-normal (logn): the SFR(t) is represented as an analytical function in the form of a log-normal curve.

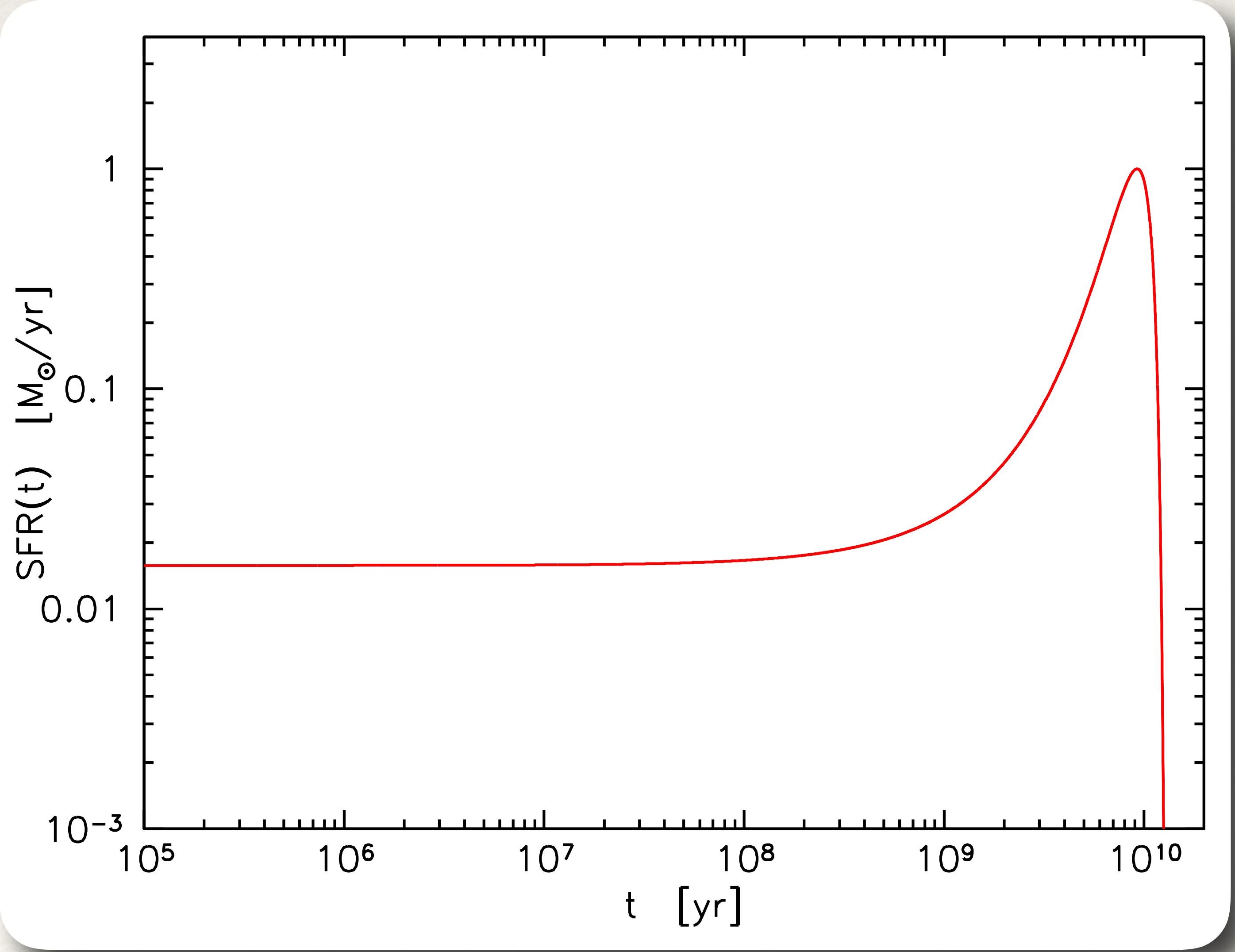
Double Exponential

$$SFR(t) = \left(\frac{T_U - t}{T_U}\right)^{n_1} \cdot \exp\left(-\frac{T_U - t}{\tau_i T_U}\right) + M_B \cdot \left(\frac{T_B - t}{T_B}\right)^{n_2} \cdot \exp\left(-\frac{T_B - t}{\tau_B T_B}\right)$$



Log-normal

$$SFR(t) = \frac{1}{(T_U - t) \times \sqrt{2\pi\tau_i^2}} \cdot \exp\left(-\frac{[\ln(T_U - t) - T_0]^2}{2\tau_i^2} \right)$$



Now start analysis

- Change the `config.sin` file according to your needs;
- create the “catalog” file;
- run SINOPSIS;
- running requieres several hours so, as an option, SINOPSIS can be run on a rectangular sub-region of the data;
- this is done by providing SINOPSIS with the pixel coordinates of the two extreme corners, e.g.: SINOPSIS 80 90 160 200.

$x_1,\ y_1,\ x_2,\ y_2$

Summary

- Brief review of SINOPSIS;
- star formation history prescription;
- the output provided by SINOPSIS;
- how to set-up a fitting.