“Towards an improved semi-empirical library for UGC. Construction of galactic spectra using the *PÉGASE.3* code and comparison with SDSS.”

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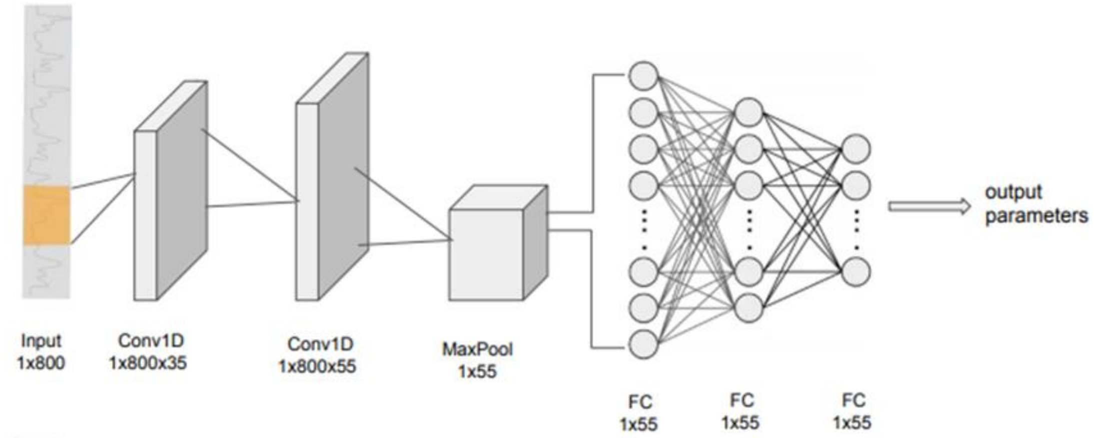
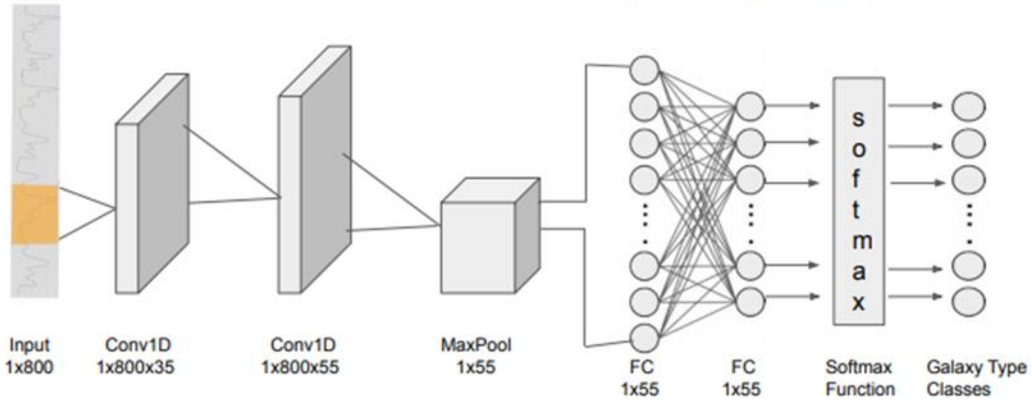
Unresolved Galaxy Classifier (UGC)

- At the moment:
  Successful estimation of **redshift.**

- For future releases:
  Provide **taxonomic classification** and **specific parameters estimation** as initially planned.





Unresolved Galaxy Classifier (UGC):
Libraries of galaxy spectra for testing-training process

1st step

Synthetic Library

- Synthetic spectra are created using ***PÉGASE.3*** *galaxy* evolution code.
- Compare synthetic spectra with observed (SDSS) using color-color diagrams.

2nd step

Semi-empirical Library

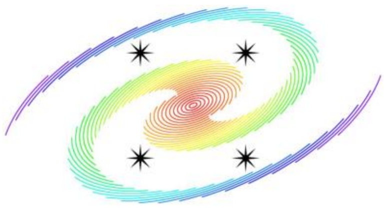
- **Fitting** between the **synthetic** and **observed** (SDSS) spectra, to produce a **semi-empirical** library of **labelled** (redshift, galaxy type, star-forming parameters, etc) observed spectra.
- Library will be simulated with the most up-to-date *Gaia* BP/RP instrument model.
- Used to **train, test** and **validate** the UGC module.

We <u>focus</u> on the 1st step i.e. <u>the construction of a synthetic library</u> of galactic spectra that will optimally describe the observed ones.

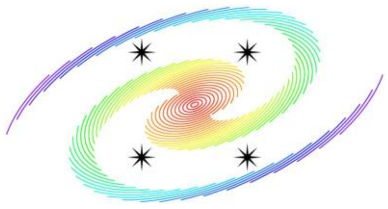
Construction of synthetic library

galaxy evolution model

PÉGASE.2



(Fioc & Rocca-Volmerange, 1997, 1999;
Le Borgne & Rocca-Volmerange, 2002).



Input

SFR law, Age,

Infalling gas,

Stellar winds,

metallicity of the gas, e.t.c.

Output

Spectrum,

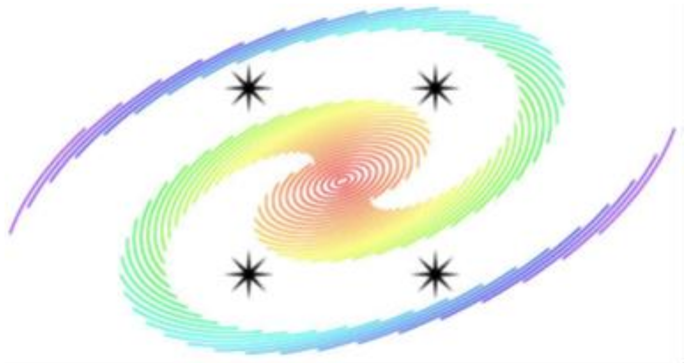
Mass in stars,

Mass of gas,

M/L, e.t.c.

Improving the semi-empirical library: PÉGASE.3 - What’s different?

- Main innovation (compared to *PÉGASE.2*): modeling of **dust emission** and its evolution.
- **Extended wavelength** range through the mid- and far-infrared up to the submillimetric domain.
- Computation of **nebular emission** entirely upgraded to take into account metallicity effects and infrared lines.

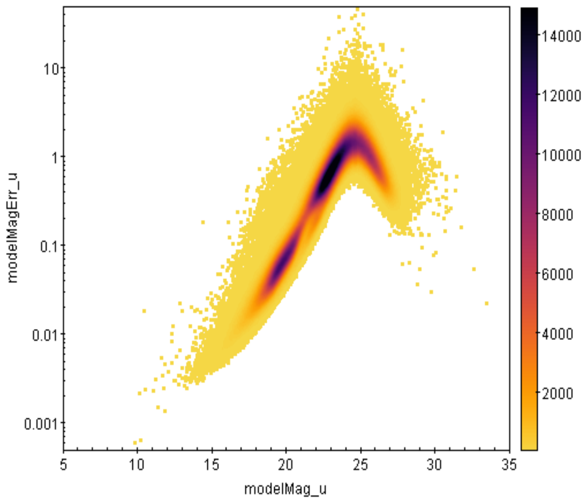


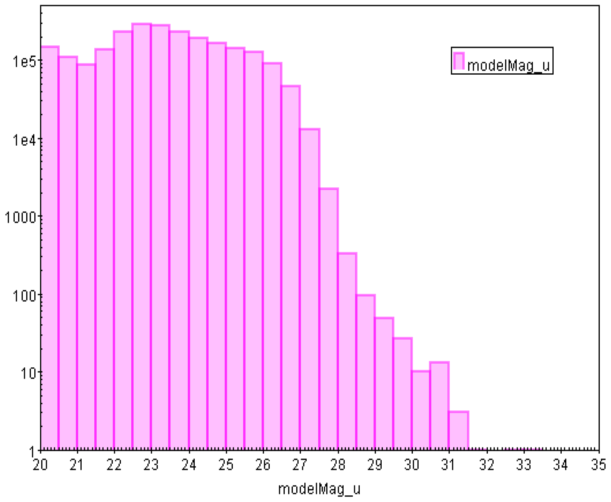
Michel Fioc & Brigitte Rocca-Volmerange , 2019

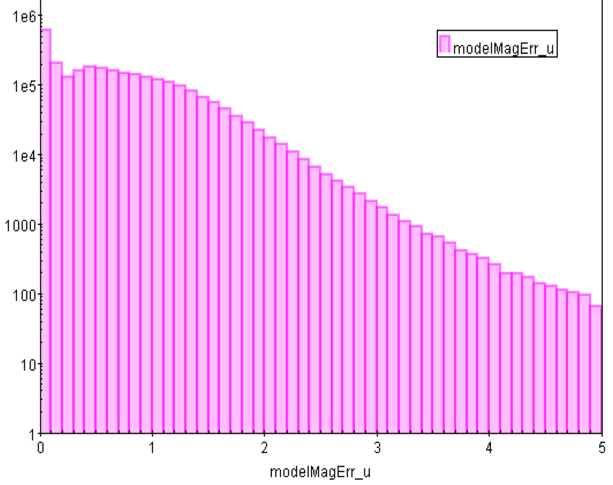
These optimizations lead to a more realistic construction of synthetic galactic spectra, thus improving the UGC.

SDSS dataset

1. Filter Data: Clearing Errors - Photometry limits







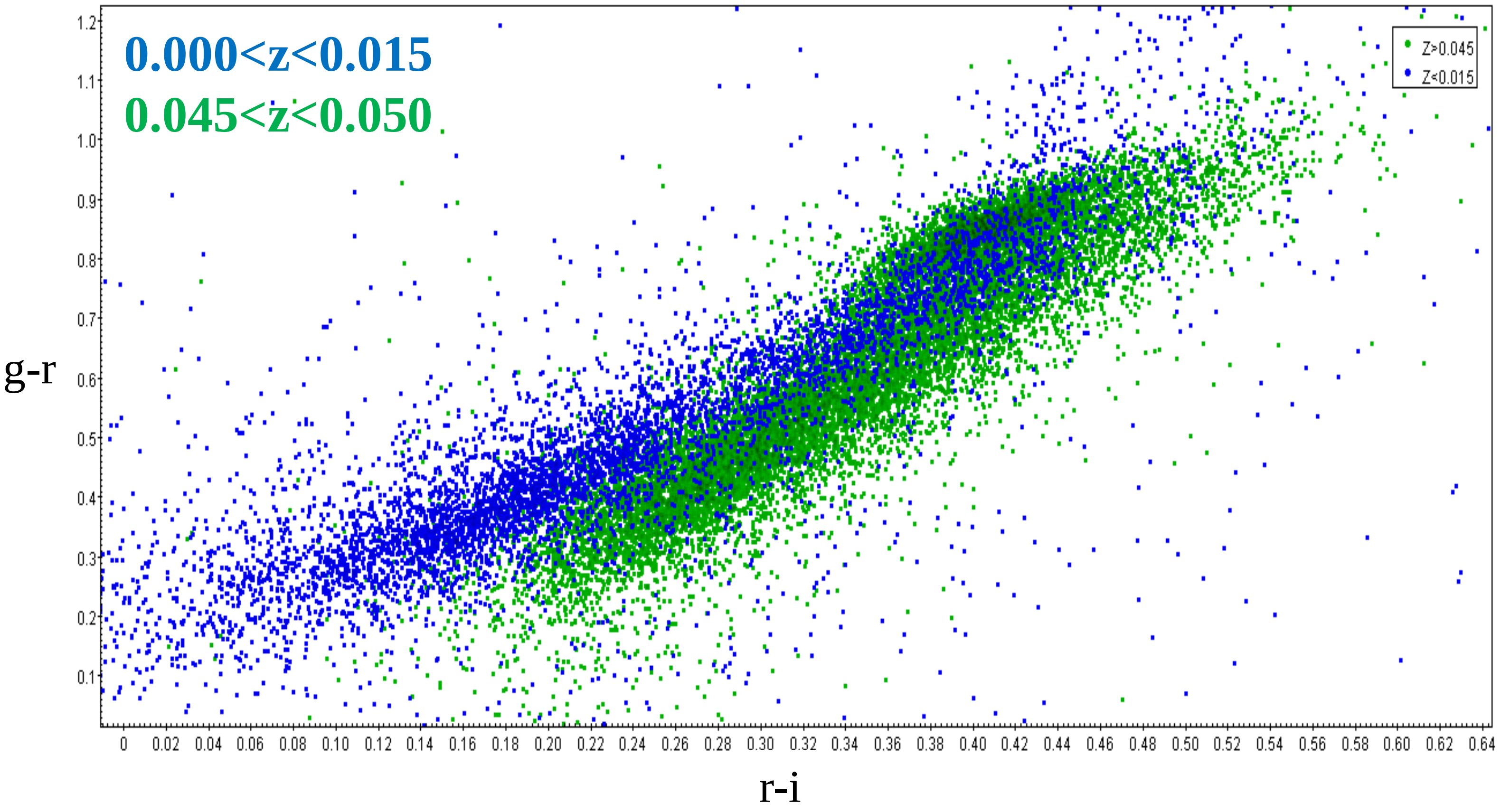
Parameter	Limit (mag)
ModelMagErr_u	3.0
ModelMagErr_g	2.0
ModelMagErr_r	0.5
ModelMagErr_i	1.0
ModelMagErr_z	2.0

Parameter	Limit (mag)
ModelMag_u	27
ModelMag_g	26
ModelMag_r	24
ModelMag_i	25
ModelMag_z	25

- Database of real spectra needed, to **compare** (using color-color diagrams) with the synthetic spectra.
- SDSS offers the largest database of galaxies in the optical window (u, g, r, i, z filters).
  (similar range with Gaia BP/RP instrument)
- Photometry limits on the models of u, g, r, i ,z filters and their errors, based on the work of I. Bellas-Velidis
- Clearing error values

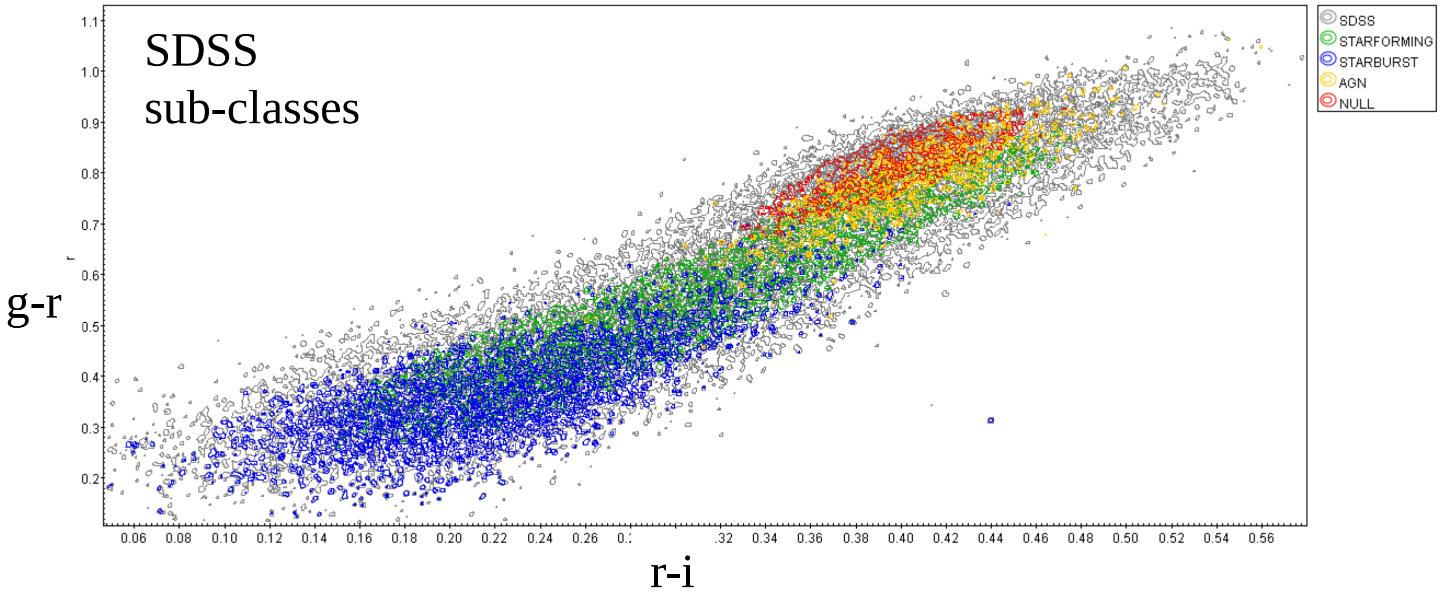
SDSS dataset

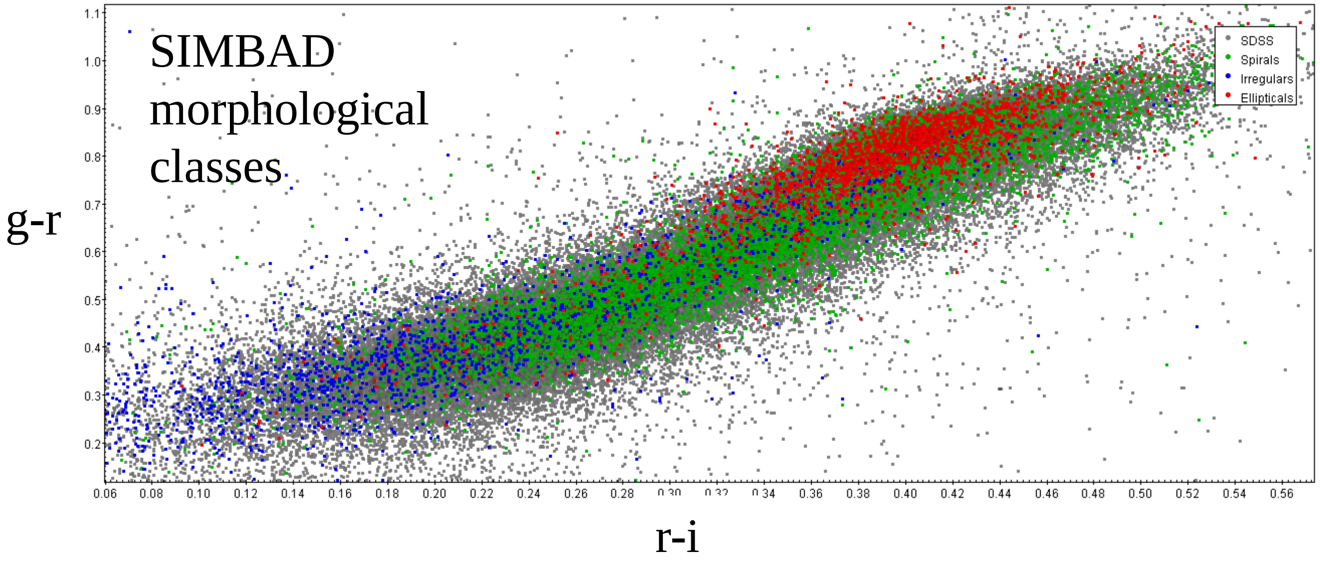
2. Redshift selection criterion



- *PÉGASE.3* code produces spectra with **zero redshift**. We choose data with very low values of redshift ($z < 0.05$) for better comparison.
- Spectra with lower values of redshift are shifted to more “blue” colors.
- Redshift **crucial** parameter

Galaxy types





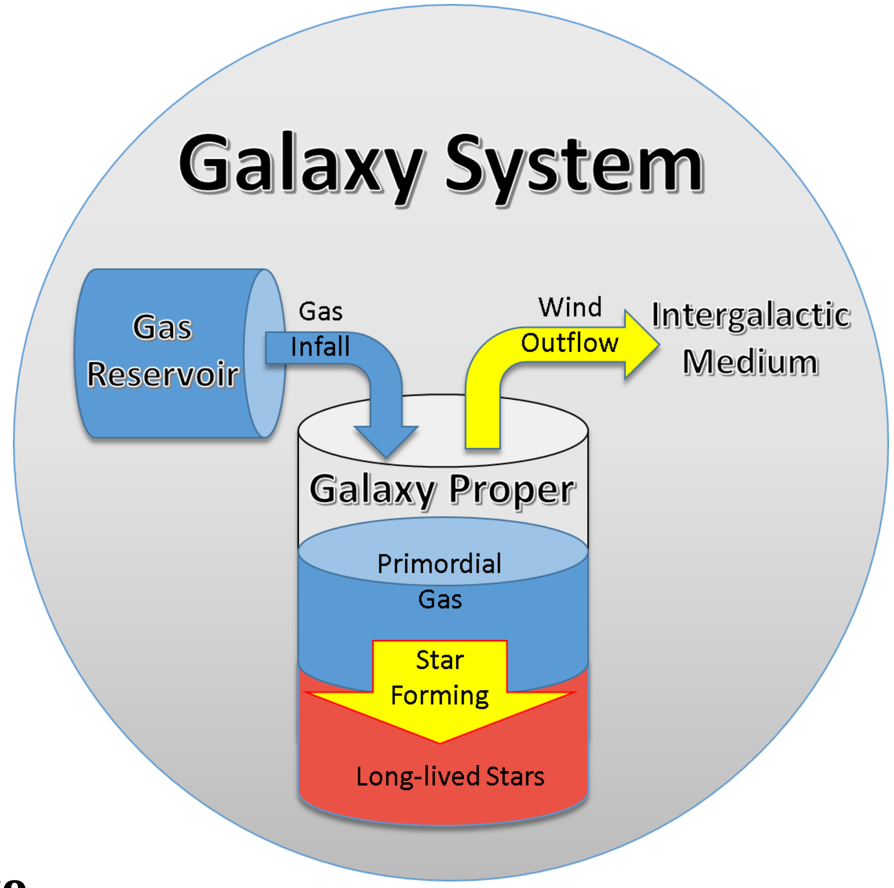
- Construction of 3 basic galaxy classes (based on Star Formation Law):
  - **Early type** (most gas consumed early, less gas at the end, low SF)
  - **Starforming** (lower consumption of gas in early stages, SF lasts longer)
  - **Starburst** (low consumption of gas in early stages, enhanced SF in the late period of galaxy life)

(based on the previous work of Tsalmantza et al., 2007, 2009)

PÉGASE.3 : Modelling of a galaxy

The **system** consists of three distinct zones:

- the ***galaxy proper***, from where all the light comes. Initially, contains only primordial gas (no stars).
- zero, one or more ***reservoirs***. These contain only gas, which may fall onto the galaxy via **infall**.
- the part of the ***intergalactic medium*** (IGM) produced by **outflows** (= galactic winds) of interstellar matter (gas and dust) from the galaxy.



We use a range of values for general and special parameters to model different types of galaxies.

Creating synthetic spectra with *PÉGASE.3*

Early Type

```
SSPs_set = "Kroupa_SSPs.txt"
infall_type=none
outflow_type = none
nebular_emission = .true.
extinction=.true.
dust_emission = .true.
dust_evolution=basic
geometry=spheroidal
M_sys_spher=2.79E+11
core_radius=192
cluster_stel_mass =10000
cloud_duration=100
cloud_power=1
cloud_init_frac=1
cluster_stel_mass = 10000
SF_type=exponential
SF_Z_type=consistent
SF_expo_timescale = 50
SF_expo_mass = 0.2
spectra_file = early_type.txt
return
```

Starforming

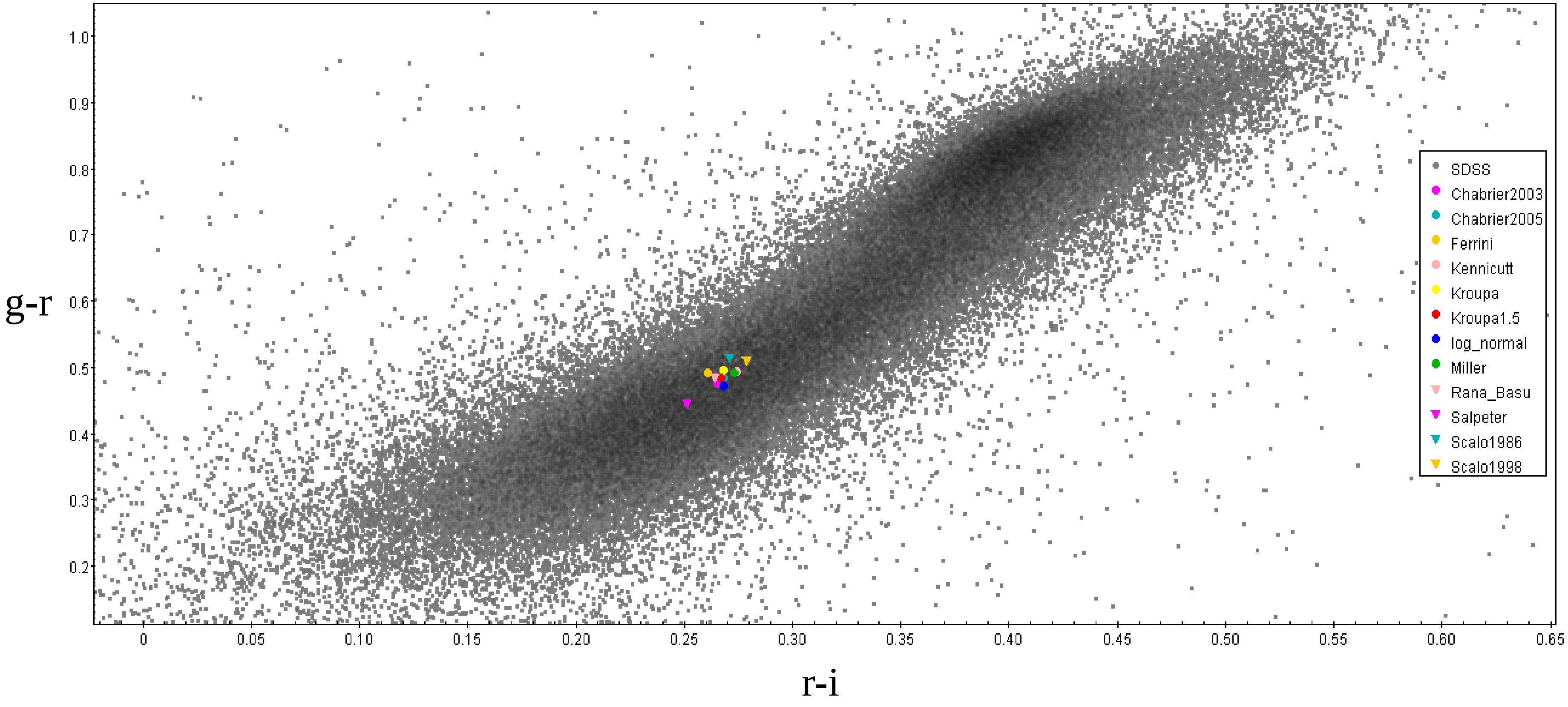
```
SSPs_set = "Kroupa_SSPs.txt"
nebular_emission = .true.
extinction=.true.
dust_emission = .true.
dust_evolution=basic
geometry=spiral
inclin_averaged = .true.
reserv_init_mass=1
infall_type=exponential
infall_expo_timescale = 3000
outflow_type=none
SF_type=ISM_mass
SF_ISM_timescale = 13000
SF_ISM_power=4.2
SF_ISM_threshold=0
cloud_duration=100
cloud_power=1
cloud_init_frac=1
cluster_stel_mass = 10000
spectra_file = spiral.txt
return
```

Starburst

```
SSPs_set = "Kroupa_SSPs.txt"
SF_Z_type=consistent
outflow_type = none
stoch_heating=.true.
self_abs_power=0
form_redshift=10
nebular_emission = .true.
extinction=.true.
dust_emission = .true.
dust_evolution=basic
geometry=spiral
inclin_averaged = .true.
cloud_duration=100
cloud_power=1
cloud_init_frac=1
cluster_stel_mass =  10000
SF_type = "constant"
SF_const_mass = 1.e-1
SF_begin_time = 10500
SF_end_time = 11000
spectra_file = starburst.txt
return
```

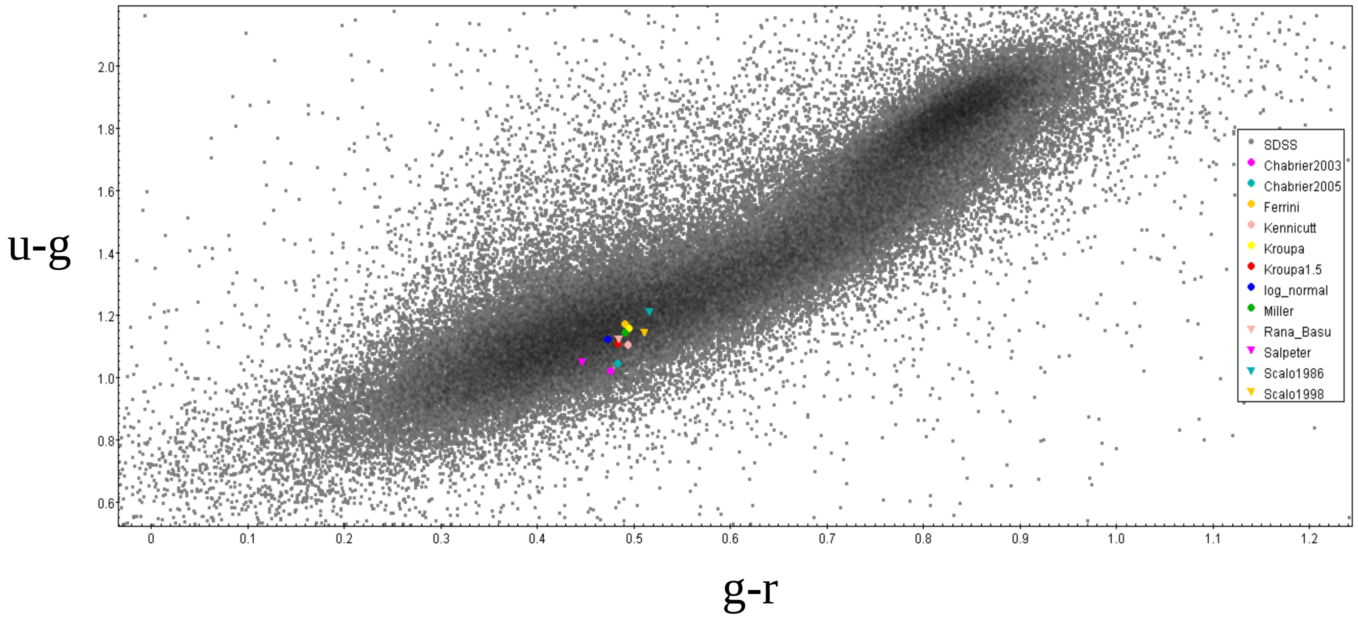
- Examples of **scenarios** in *PEGASE. 3*
- Parameter Types:
  - Infall
  - Geometrical/ Dust
  - Cloud
  - Star Formation

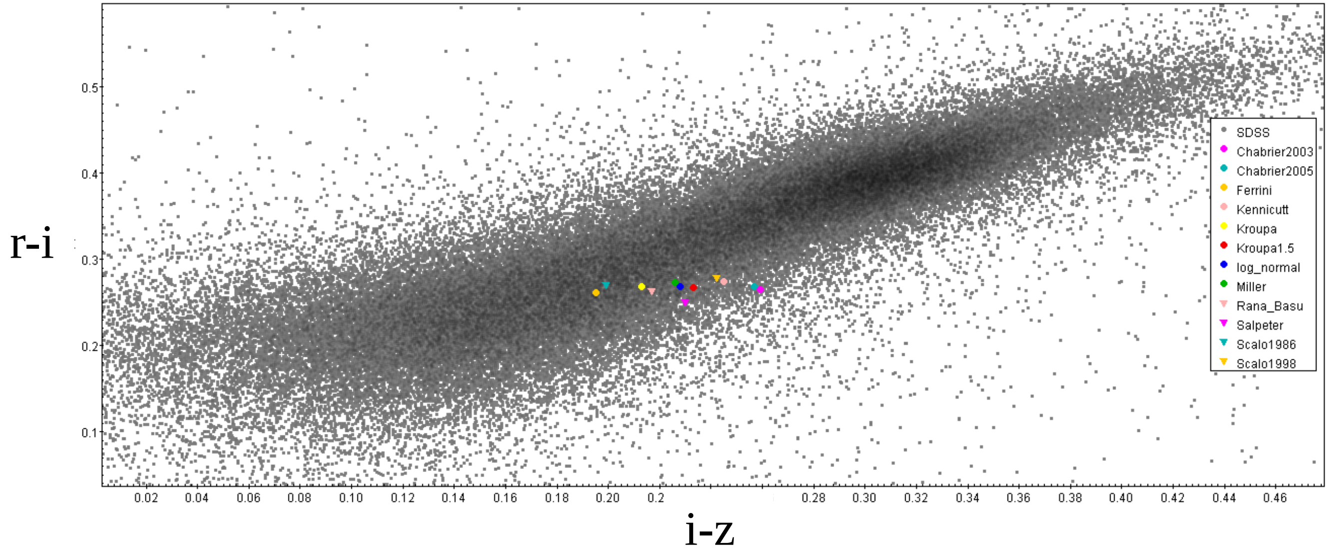
Construction of galactic spectra:
General Parameters: Initial Mass Function (IMF)



- IMF: An empirical function that describes the initial distribution of masses for a population of stars.
- Tested the same scenario of a starforming galaxy using all available IMFs.
- **Kroupa IMF** (yellow dot) seems to respond better for all 3 color-color diagrams

Construction of galactic spectra:
General Parameters: Initial Mass Function (IMF)



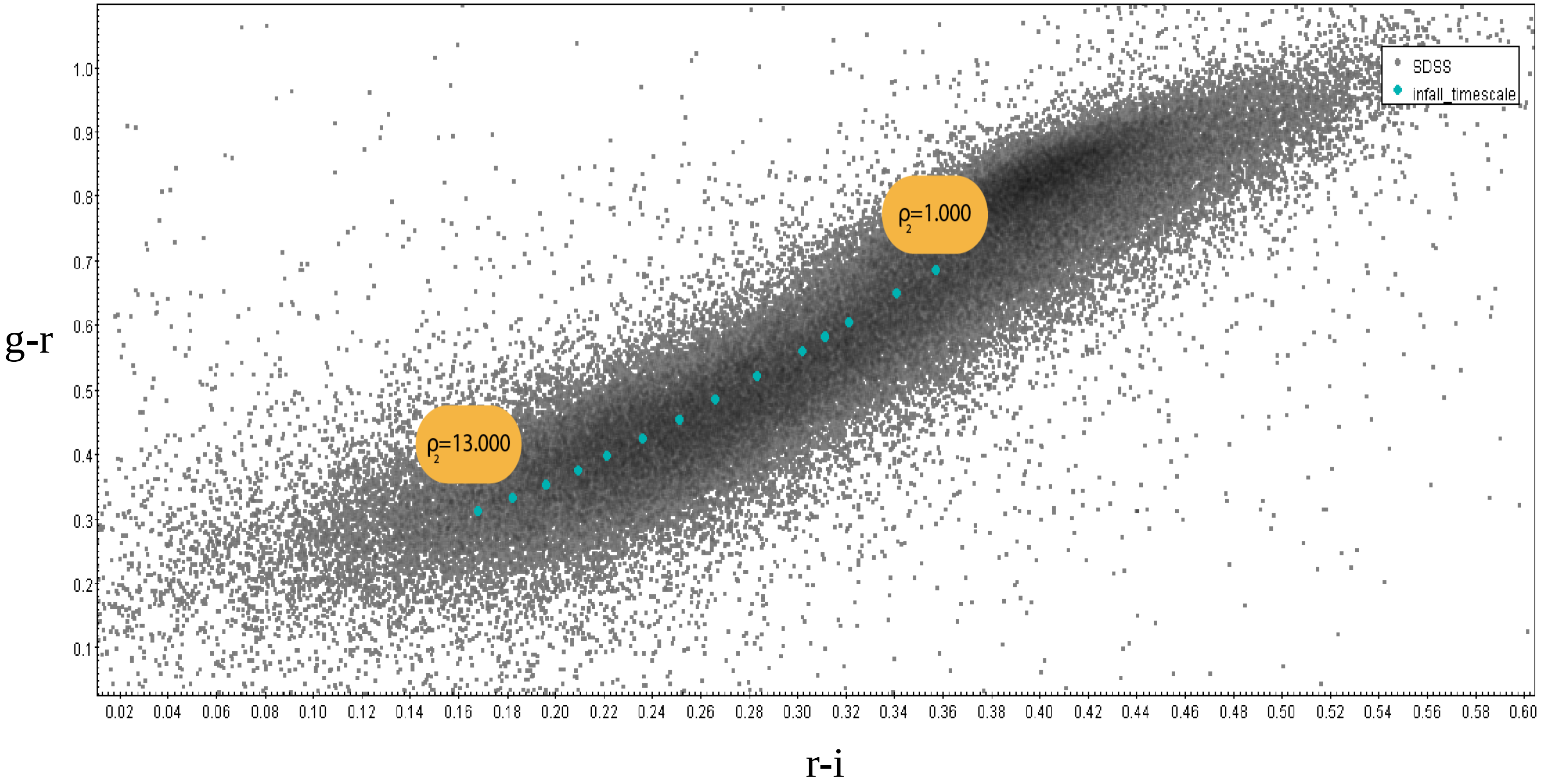


Main Special Parameters

Class	infall_type		ρ_1	ρ_2
Early type	none	-	-	-
Starforming	exponential	$\dot{M}_{in}(t) = \frac{\rho_1}{\lvert\rho_2\rvert} e^{-t/\rho_2}$	infall_expo_mass	infall_expo_timescale
Starburst	none	-	-	-

Class	SF_type		p_1	p_2
Early type	exponential	$SFR(t) = \frac{p_2}{p_1} \cdot e^{-\frac{t}{p_1}}$	SF_expo_timescale	SF_expo_mass
Starforming	ISM_mass	$SFR(t) = \frac{1}{p_2} \cdot M_{gas}(t)^{p_1}$	SF_ISM_power	SF_ISM_timescale
Starburst	constant	$SFR(t) = \frac{M_{const}}{p_2 - p_1}$	SF_begin_time	SF_end_time

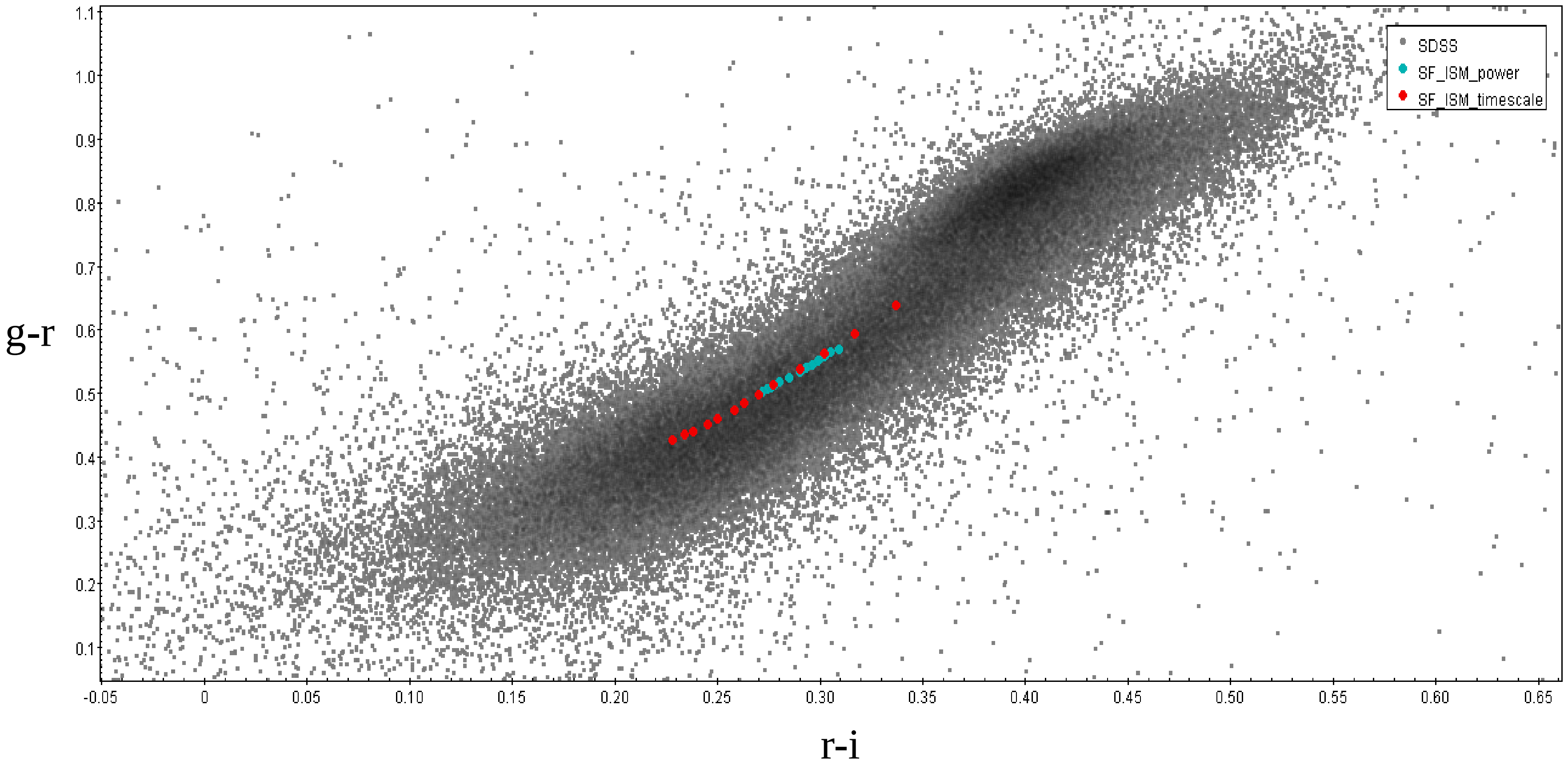
Starforming galaxies: infall rate ($\dot{M}_{in}$)



- $\dot{M}_{in}(t) = \frac{\rho_1}{|\rho_2|} e^{-t/\rho_2}$
- Determines the rate of gas flow from the *reservoir* into the *galaxy proper*
- Crucial parameter for the position on the color-color digrams

Slow infall ↓ More young stars	Fast infall ↓ More old stars

Starforming galaxies: Star Formation Rate (SFR)

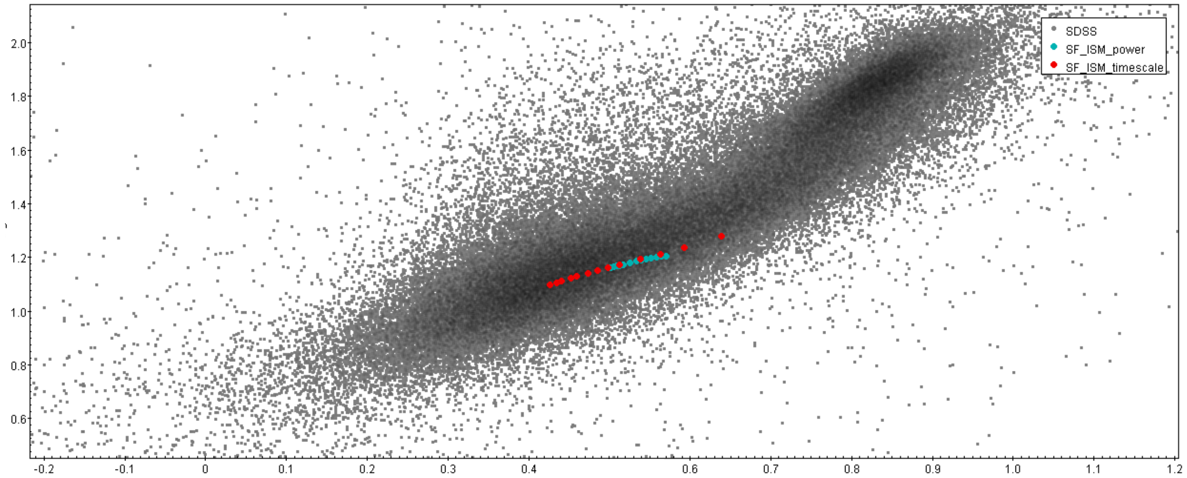


- $SFR(t) = \frac{1}{p_2} \cdot M_{gas}(t)^{p_1}$
- Success in producing good results in all color-color diagrams

High SFR	Low SFR
↓	↓
Fast Gas Consumption	Slow Gas Consumption
↓	↓
More old stars	More young stars

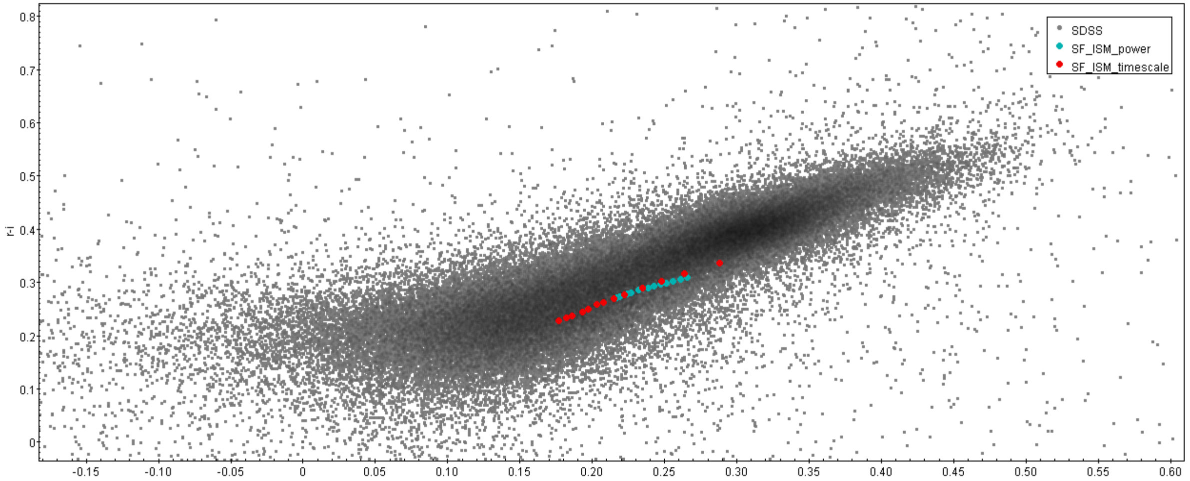
Starforming galaxies: Star Formation Rate (SFR)

u-g



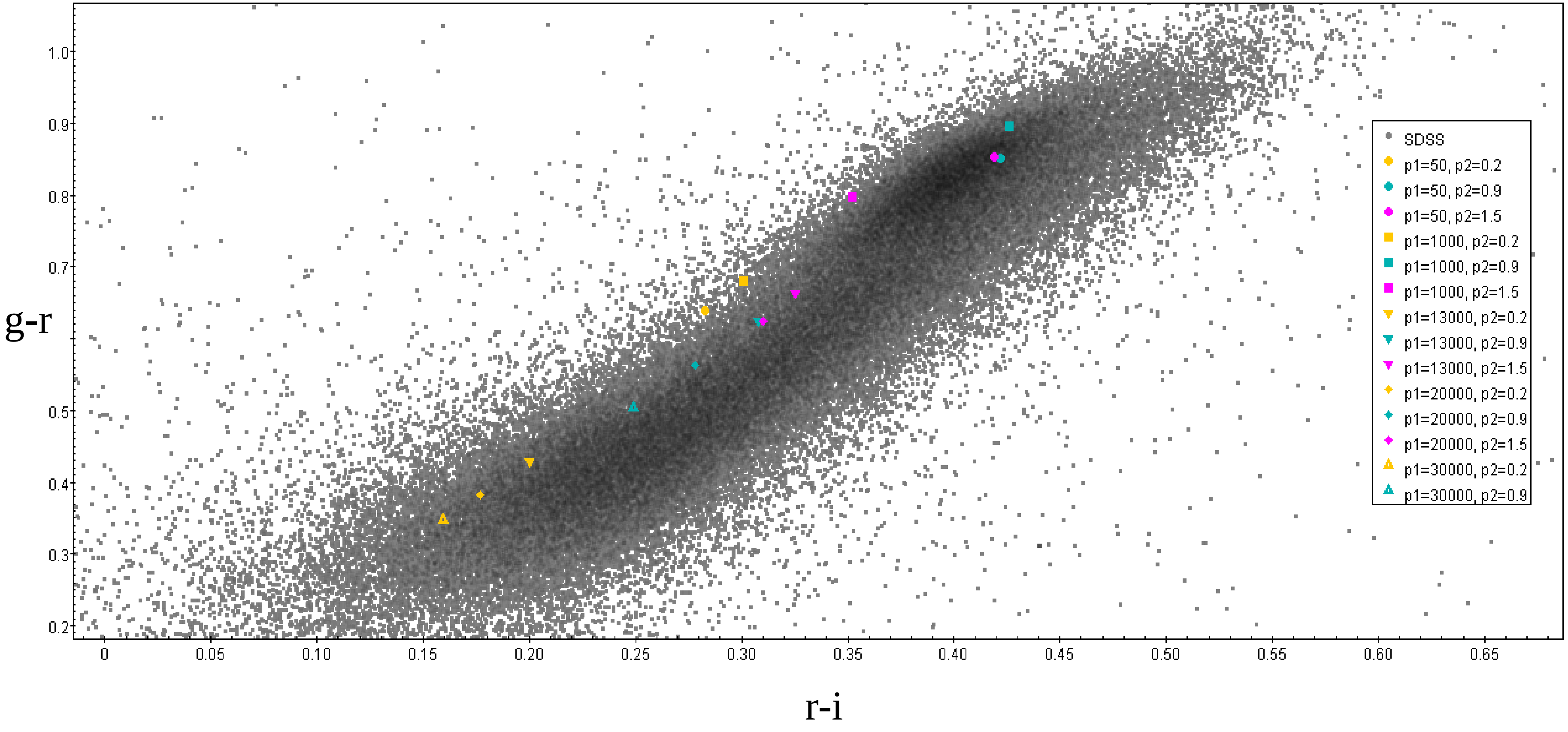
g-r

r-i



i-z

Early type galaxies: Star Formation Rate (SFR)

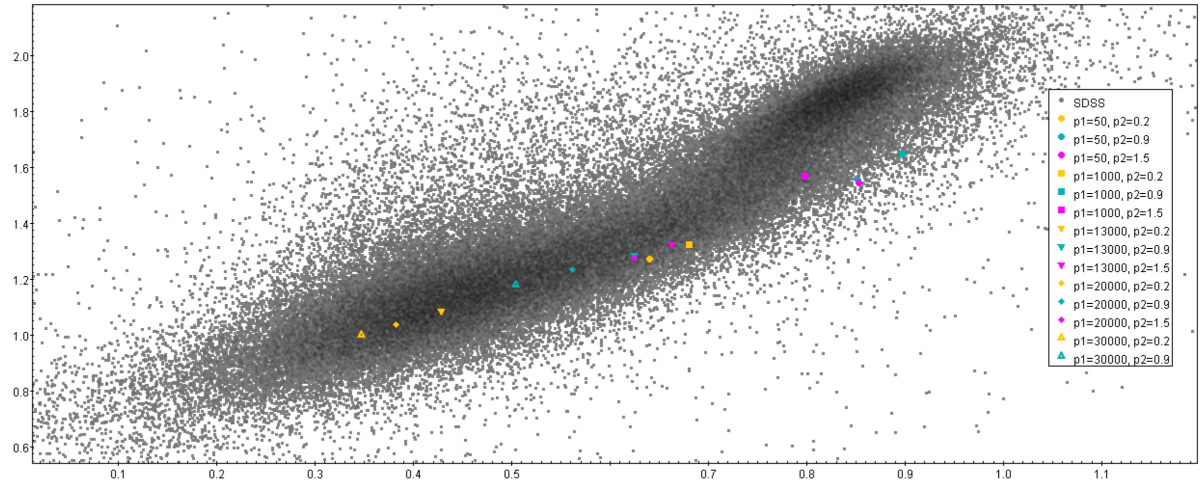


- $SFR(t) = \frac{p_2}{p_1} \cdot e^{-\frac{t}{p_1}}$
- Achieved adequate results for (i-z, r-i) color-color diagram.
- Re-testing the range of values is needed.
- Lower values of p_1, p_2 produce better results.

(early type galaxies expected in the red colors)

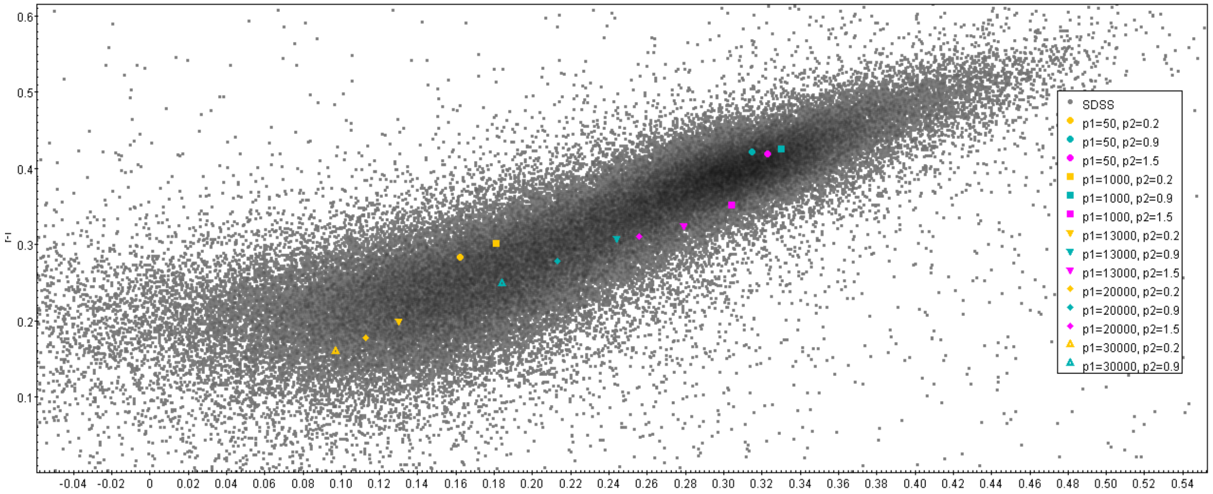
Early type galaxies: Star Formation Rate (SFR)

u-g



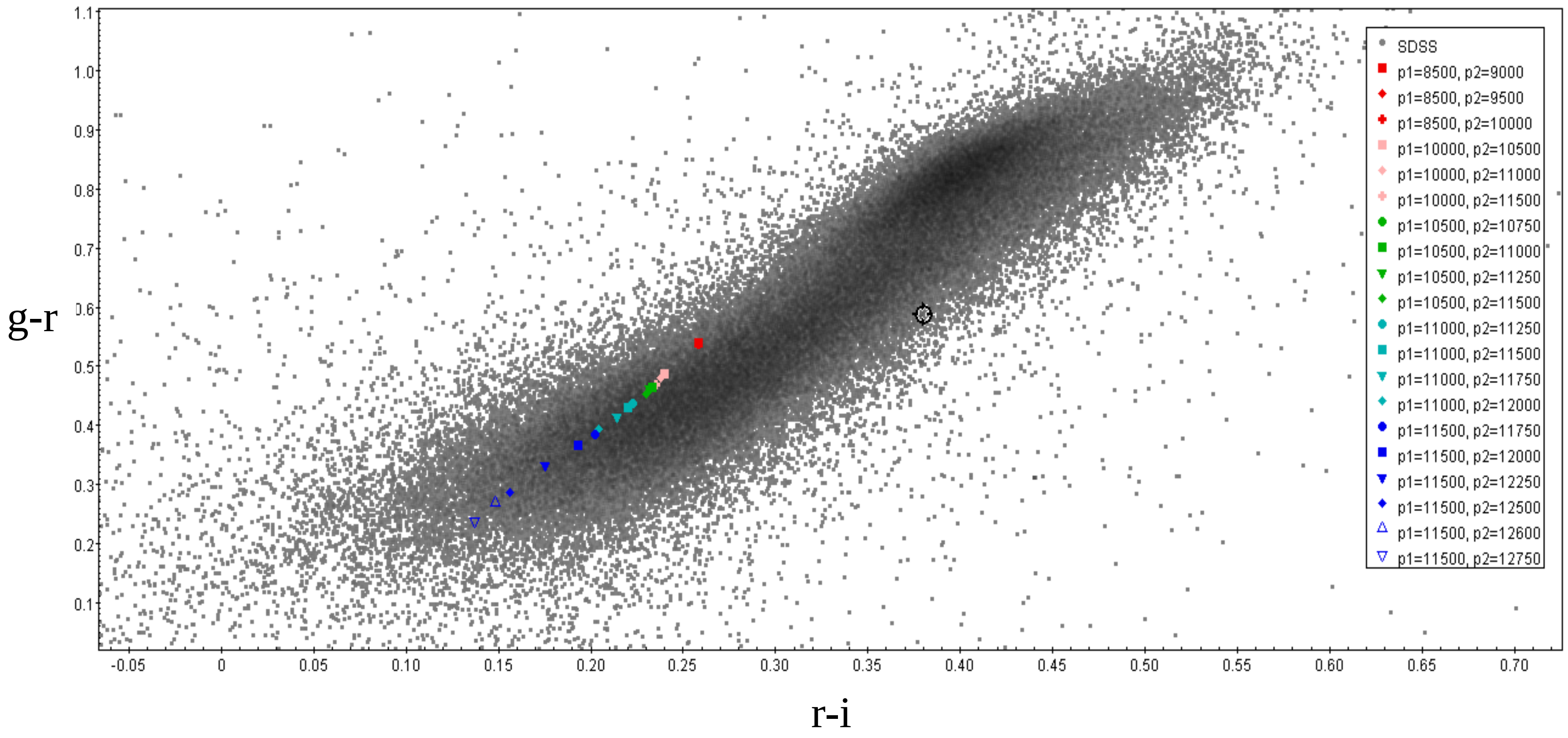
g-r

r-i



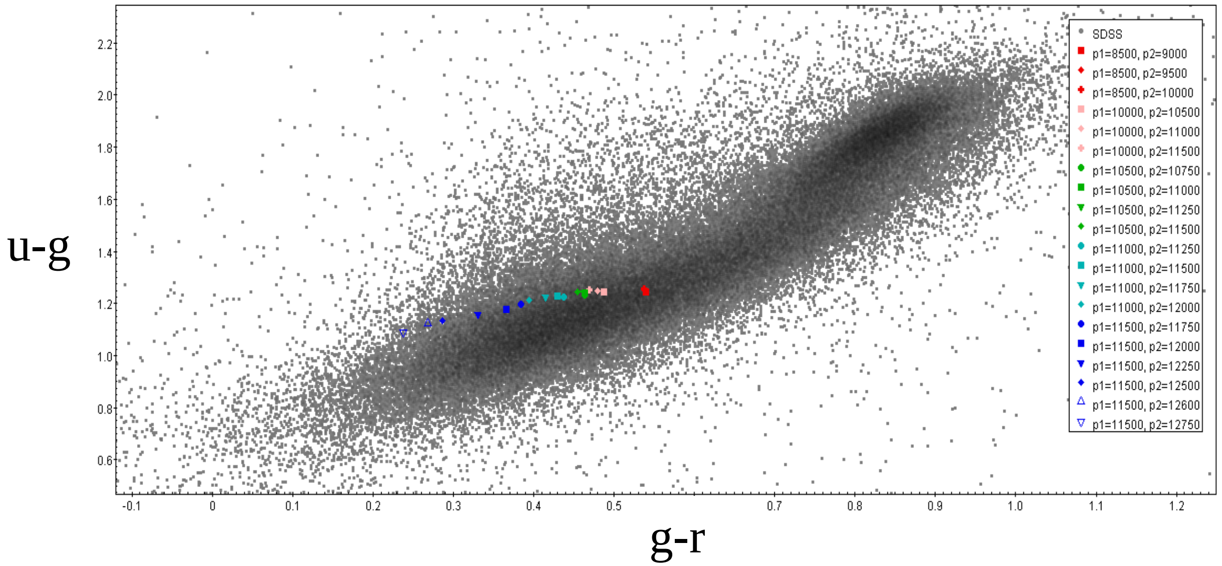
i-z

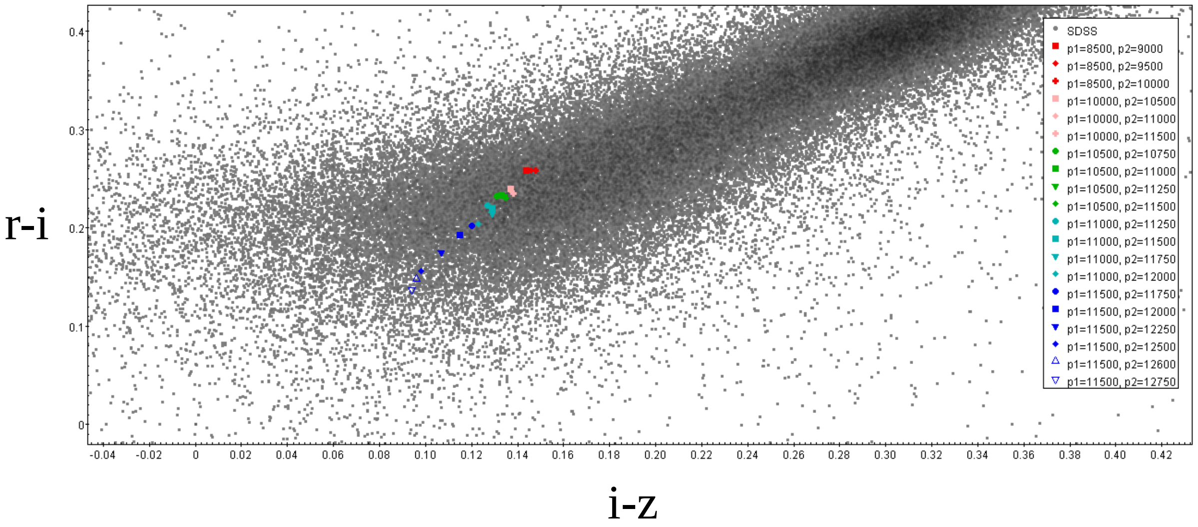
Starburst galaxies: Star Formation Rate (SFR)



- $SFR(t) = \frac{M_{const}}{p_2 - p_1}$
- Not successful to capture the high density regions for all color-color diagrams

Starburst galaxies: Star Formation Rate (SFR)





Conclusions

- Examined the **significance** of basic parameters (IMF, SFR, infall rate) in a given scenario and their **effect** in the position on the color-color diagrams.
- Updated the range of values for the tested parameters using *PEGASE.3*.
- Achieved **more realistic** synthetic spectra using color-color diagrams, compared to previous attempts and taking advantage of the new version of *PEGASE* code.
- Future steps:
  - Next step is the link of synthetic spectra with observed data.
  - Further investigation needed in *Starburst* galaxies.

Thank you for your attention!