A library of synthetic galaxy spectra for GAIA Comparison with SDSS

P. Tsalmantza [(1)], M. Kontizas [(1)], R. Korakitis[(2)], B. Rocca-Volmerange[(3,4)], E. Kontizas[(5)], E. Livanou[(1)], A. Dapergolas[(5)], I. Bellas-Velidis[(5)], C. A. L. Bailer-Jones[(6)], A. Vallenari[(7)], M. Fioc[(3),(8)]

(1) Department of Astrophysics, Astronomy & Mechanics, Faculty of Physics, University of Athens, 15783 Athens, Greece
(2) Dionysos Satellite Observatory, National Technical University of Athens, 15780 Athens, Greece
(3) Institut d'Astrophysique de Paris, 98bis Bd Arago, 75014 Paris, France
(4) Université de Paris-Sud XI, I.A.S., 91405 Orsay Cedex, France
(5) Institute of Astronomy and Astrophysics, National Observatory of Athens, PO Box 20048, 118 10 Athens, Greece
(6) Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
(7) INAF, Padova Observatory, Vicolo dell'Osservatorio 5, 35122 Padova, Italy
(8) Université Pierre at Marie Curie-Paris6, Paris, F-75005, France

contact e-mail: vivitsal@phys.uoa.gr

Abstract

Introduction: The ESA cornerstone mission GAIA will acquire observations for a large number of unresolved galaxies. In this project we provide synthetic data required to identify and classify these objects with GAIA.
Methods: An extended grid of synthetic galaxy spectra has been created, using the code PÉGASE.2, which is based on models of galaxy evolutionary synthesis and the BaSeL library of stellar spectra.
Results: The library contains about 4000 spectra at redshift zero, in the wavelength range 250 to 1050 nm and at one nm or less resolution, and covers the main Hubble types of galaxies. It is computed on a regular grid of four key astrophysical parameters for each type and for intermediate random values of the same parameters. In addition, the library is produced for various redshifts.
Discussion: This synthetic library has been compared with real spectra obtained from SDSS. We have produced two-color diagrams computed from both the synthetic PÉGASE.2 and the real SDSS spectra. The agreement is very good on the full range of galaxy types.

Introduction

The main task of the Working Group of "Unresolved galaxy classifier" is the classification and determination of the astrophysical parameters of the unresolved galaxies which are expected to be observed by GAIA. In order to proceed with this task it is necessary to obtain a reliable library of galaxy spectra in the wavelength range that GAIA will observe. Such a library needs observational and synthetic data based on the theoretical Astrophysical Parameters (APs). The lack of coverage of the GAIA wavelength range by the existing telescopes is a constrain. Synthetic spectra can provide us with a homogeneous set of APs, which is not always the case for the observed spectra. However, the rare existing libraries of synthetic spectra of galaxies include too few spectra, they are based on a large number of free parameters and, therefore, are not appropriate for our classification and parametrization project. Thus, the creation of a new synthetic library of galaxy spectra is required. For the production of the synthetic spectra we used the galaxy evolution model PÉGASE.2 (Fioc M. & Rocca-Volmerange B., 1997). The PÉGASE.2 code is principally aimed at modeling the spectral evolution of galaxies.
Synthetic spectra for eight standard types of Hubble sequence galaxies (E, S0, Sa, Sb, Sbc, Sc, Sd and Im) have been produced with PÉGASE.2 and were compared with observations (Le Borgne & Rocca-Volmerange 2002 and Fioc M. & Rocca-Volmerange B, 1999). Now that SDSS is available, we used these data to fit our synthetic data and produce a large grid of realistic APs for our library. The comparison was made using simulated photometry and, more specifically, color-color diagrams.

Comparison of the PÉGASE.2 synthetic spectra with the SDSS spectra

Simulated photometry, based on the SDSS galaxy spectra and on PÉGASE synthetic spectra was used in order to treat both sets of data homogeneously. The simulated photometry was produced by the appropriate module of the PEGASE.2 code.

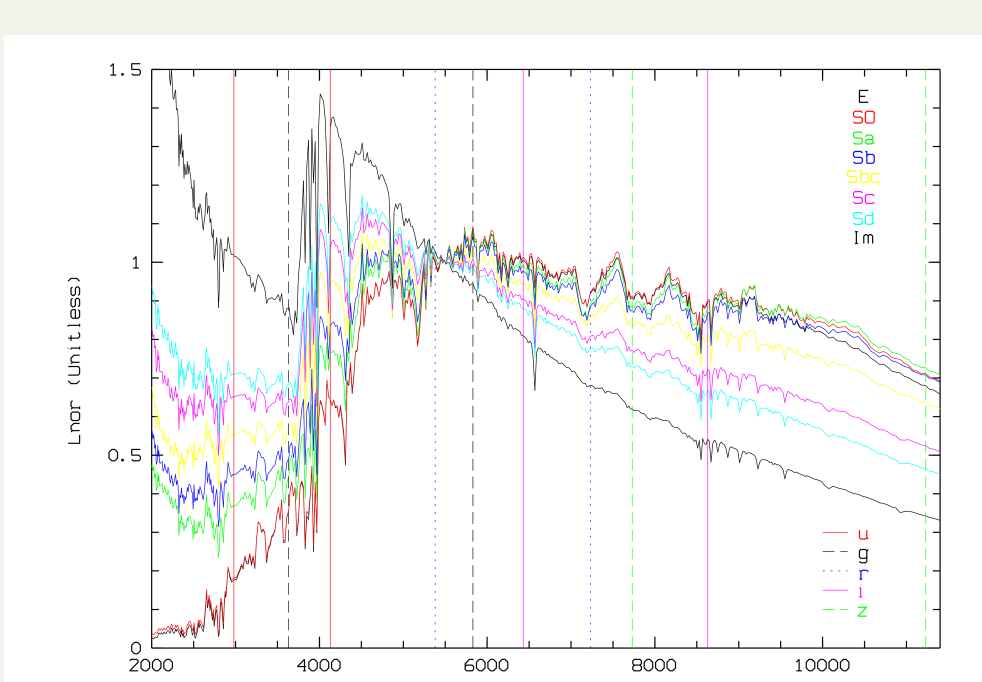

Figure 1: Position of the SDSS filters on the spectra of the 8 standard types of galaxies produced by PÉGASE.2. On the right side of the plot the color code corresponding to each type of galaxy (up) and to each SDSS filter (down) is shown. The spectra produced by PÉGASE.2 have been normalized to the flux in a 50A wavelength interval centered on 5500A.

Since the wavelength range of SDSS spectra does not allow us to use all the SDSS filters we decided to base the comparison of the SDSS and PÉGASE.2 data on the g, r, i filters only. For the simulated photometry, the g filter had to be cut-off at the blue end and a new g* filter was created. In figure 2 it can be seen that the change in the g filter is very small. In this way we could now simulate the magnitude in the g* filter and create the g*-r vs r-i color-color diagram.

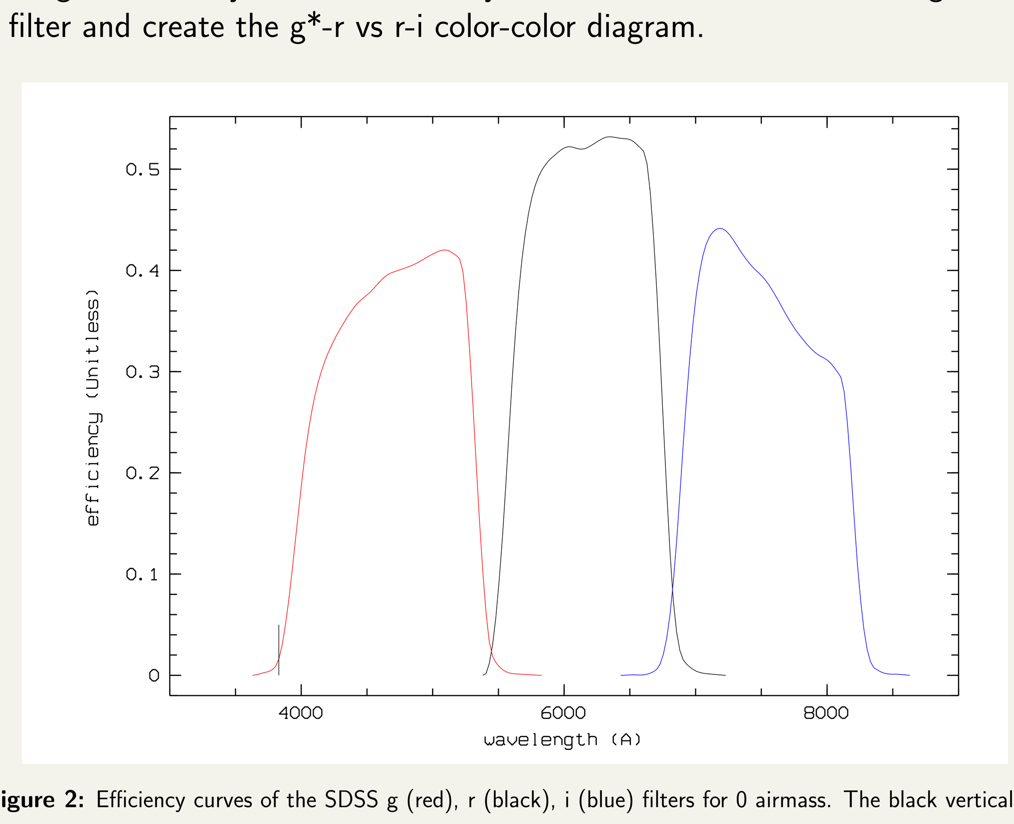

Figure 2: Efficiency curves of the SDSS g (red), r (black), i (blue) filters for 0 airmass. The black vertical line at the blue end of the g filter shows where the filter was cut and the new filter g* was produced.

To obtain the observed spectra of galaxies that SDSS has observed we used the Data Release 4 (DR4). We downloaded 1d spectra for galaxies fullfiling the following criteria: the galaxies should not be near a CCD edge nor saturated and their errors should be small. Their redshifts should be less than 0.01, since the synthetic spectra of PÉGASE.2 were produced for zero redshift. These restrictions led us to a sample of 1292 galaxies. We then proceeded to simulate their photometry in the same way as in the synthetic data and compared the two sets. The result is shown in figure 3.

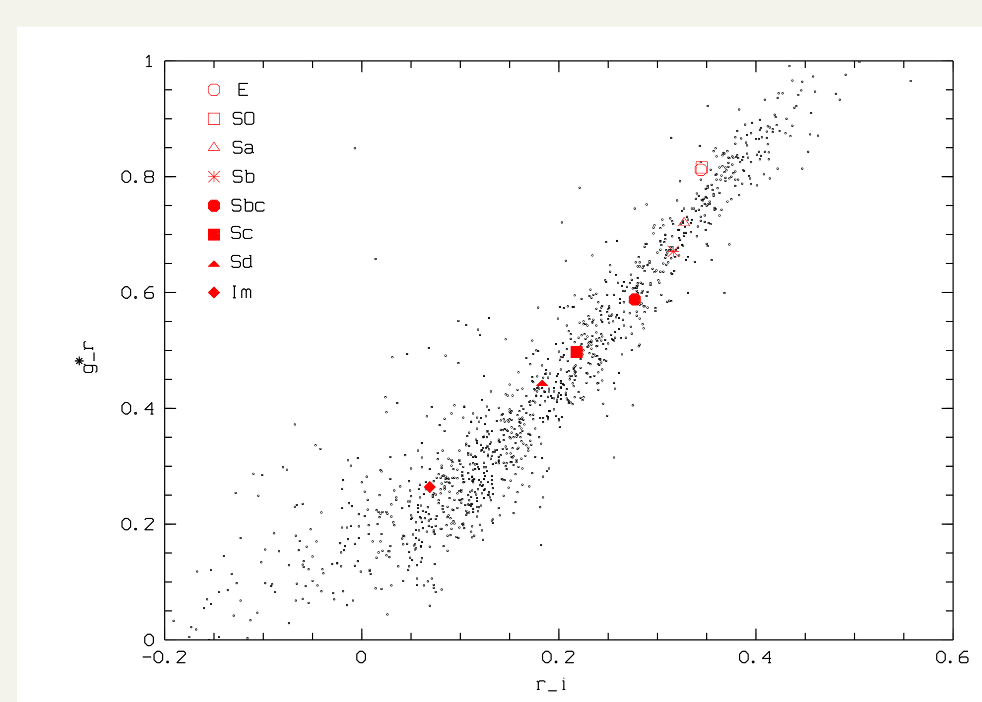

Figure 3: Color-color diagram (g*-r vs r-i) of simulated photometry of SDSS galaxy spectra (black) and of the synthetic data of PÉGASE.2 (red).

The synthetic library of spectra

The eight standard models used to create the synthetic spectra of PÉGASE.2 differ in four parameters, which are the most significant among the seventeen input parameters of PÉGASE.2. These are: the parameters p1 and p2 of the star formation scenario ($(Mgas^{p1})/p2$), the infall timescale and the age of the galactic winds. The last one has a nonzero value only in the case of E and S0 galaxies.
By varying these four parameters (over a regular grid of values) and using all their combinations in each of the eight standard models we managed to cover most of the space of the SDSS data in the color-color diagram. To avoid degeneracies we decided to keep in the library only the models that, in the color-color diagram, were positioned inside a circle, centered on the standard model and with radius equal to half the distance to its closest neighboring standard model. In this way, upper and lower limits of the values of the parameters were established for each type.
Applying the above procedures, we produced a library of 888 synthetic spectra of seven types because we considered the E and S0 as a single type.
The limits of the four parameters of each type are given in table 1, while the values of the other input parameters of PEGASE.2 (kept constant in all models) are given in table 2.

Type	p1	p2 (Myr/Msol)	infall (Myr)	galactic winds (Gyr)	N
E-S0	0.6-1.5	100-1500	100-2500	0.1-7.5	327
Sa	0.8-1.5	500-2500	2500-3500	none	10
Sb	0.6-1.5	1500-6000	2000-4500	none	25
Sbc	0.4-1.5	2000-10000	4000-7000	none	148
Sc	0.6-1.5	6000-14000	7000-10000	none	68
Sd	0.4-1.5	10000-18000	7000-10000	none	65
Im	1.0-2.0	14000-20000	7000-10000	none	245

Table 1: The ranges of the four parameters of the models of each type in the first library of synthetic spectra. The last column (N) gives the number of spectra for each type.

Parameters	Values
SNII Ejecta of massive stars	model B of Woosley & Weaver (1995)
Stellar winds	yes
Initial mass function	Rana & Basu (1992)
Lower mass	0.09 solar masses
Upper mass	120.00 solar masses
Fraction of close binary systems	0.05
Initial metallicity	0.00
Metallicity of the infalling gas	0.00
Consistent evolution of the stellar metallicity	yes
Mass fraction of substellar objects	0.00
Nebular emission	yes
Extinction	disk geometry: inclination-averaged for Sa, Sb, Sbc, Sc, Sd and Im spheroidal geometry for E-S0
Age	13 Gyr for E-S0,Sa, Sb, Sbc, Sc & Sd 9 Gyr for Im

Table 2: The values of the parameters of the models which are kept constant in the first library of synthetic spectra of galaxies (Fioc & Rocca-Volmerange,1997).

This first set of 888 synthetic spectra was provided for five values of redshift: 0, 0.05, 0.1, 0.15, 0.2 (a total of 4440 spectra). After producing this set, corresponding to a regular grid (table 1), we proceeded to produce synthetic spectra of galaxies with random values of parameters, in order to achieve a more continuous coverage in color space. By the term random we mean that, instead of using regularly varying values of the four parameters, we randomly chose the values of each parameter within the range shown in table 2. In this way we created 2709 synthetic spectra.

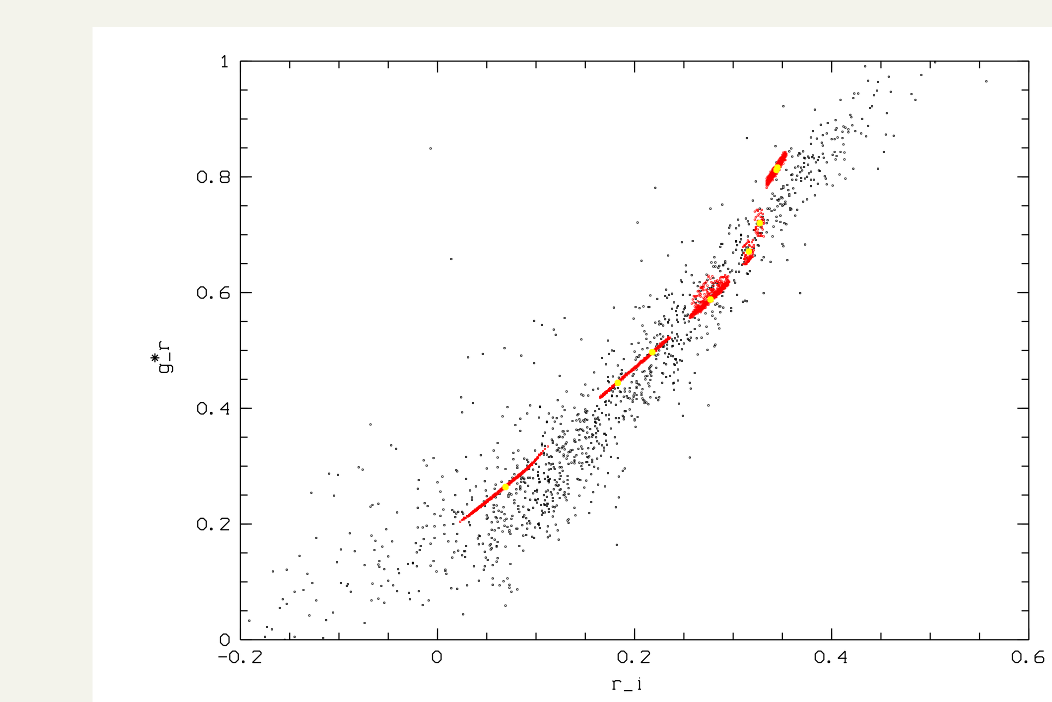

Figure 4: Color-color (g*-r vs r-i) diagram of simulated photometry of SDSS galaxy spectra (black) and of synthetic PEGASE spectra of the 8 standard models of PÉGASE.2 (yellow). Moving from the lower left to the upper right part of the diagram we encounter types from Im to E. The red points around the standard models represent the spectra of both the regular and random library.

The comparison of the simulated colors of the synthetic spectra (888 regular grid plus 2709 random grid at redshift zero) with the colors of SDSS spectra is shown in figure 4. One sees that the new set of spectra is in very good agreement with the SDSS data, except for the small differences in the E and S0 galaxies.
This library was created with PÉGASE.2 using the BaSeL 2.2 stellar library, the spectral resolution of which is below the requirements for GAIA simulations. Therefore, we linearly interpolated our spectra in order to obtain a resolution of 1nm or less on the whole wavelength range of 250-1050 nm.

Conclusions

The observational data of SDSS and the code of galaxy evolution PÉGASE.2 allowed us to create an extended grid of synthetic galaxy spectra (7149 in total).
We adopted a grid of APs based on the comparison of simulated colors in a color-color diagram, derived from both sets of synthetic and observational spectra. The filters used were selected to be within the spectral range of SDSS spectra.
A small deviation between the two sets towards the red end, where ellipticals are found, might be due to the fact that SDSS spectra are obtained in a small aperture while PÉGASE spectra are representative of the whole galaxy.
We continue to investigate the effects of the other parameters used in the PEGASE.2 code, which were kept constant in this first release of the library. We also plan to include starburst galaxies in future releases.

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