Library of typical synthetic galaxy spectra for the Gaia Universe model simulator

M. Kontizas[(1)], E. Livanou[(1)], A. Karampelas[(1)], E. Kontizas[(2)], P. Tsalmantza[(3)], B. Rocca - Volmerange[(4,5)], I. Bellas - Velidis[(2)] and A. Dapergolas[(2)]

1. *Department of Astrophysics Astronomy & Mechanics, Faculty of Physics, University of Athens, Greece*
2. *IAA, National Observatory of Athens, Greece*
3. *Max-Planck-Institut f ̈ur Astronomie, Heidelberg, Germany*
4. *Institut d'Astrophysique de Paris, Paris, France*
5. *Universit ́e de Paris-Sud XI, I.A.S., Orsay Cedex, France*

Abstract

During its mission Gaia will observe several million unresolved galaxies all over the whole sky. The Universe Model developed for the simulation of the Gaia mission is a set of algorithms for computing the positions at any time, and observational properties of any observable object. The galaxy simulator generates a catalog of galaxies with a 2D uniform distribution for each selected Hubble–spectral type. The corresponding spectrum will be obtained through a link to the Gaia Spectral Library. In order to cover this need we produce a sufficient set of 407 typical synthetic galaxy spectra that will be included to the Gaia Spectral Library. We provide a grid of 9 different selected Hubble–spectral types, with 11 different values of z and 5 different values of inclination in the cases where disk geometry has been selected to describe the galaxy.

1. Introduction

The Universe Model developed for the simulation of the Gaia mission is a set of algorithms for computing the positions at any time, and observational properties of any objects expected to be observed by the instruments. The distributions of these objects and the statistics of observable sources should be as realistic as possible for simulations to be usable for estimating telemetry, testing software, simulating images, etc. The algorithms have to be optimised in order that the simulations can be performed in reasonable time and can be redone when necessary. The complexity of the model is expected to increase during the preparation of Gaia. Objects which will be, in fine, simulated are: solar system objects (planets, satellites, asteroids, comets), galactic objects (stars, nebulae, stellar clusters, diffuse light), extragalactic objects (galaxies resolved in stars, unresolved but extended galaxies, quasars and active galactic nuclei, supernovae). For each of these simulated objects one needs to have their full 3D spatial distribution together with their spectral characteristics (to be able to compute photometry and spectroscopy, stable or variable in time), and their motions (for astrometric computations and for spectral corrections). Gravitational lensing for stars and galaxies are also to be simulated (Robin et al., 2009).

Extragalactic objects are generated using the Stuff (catalogue generation) and Skymaker (shape/image simulation) codes from E. Bertin, adapted to Gaia by C. Dollet. The galaxy simulator generates a mock catalog of galaxies with a 2D uniform distribution and a distribution in each selected Hubble–spectral type sampled from Schechter's luminosity function. Each galaxy is assembled as a sum of a disc and a spheroid, internal extinction is computed using the LMC extinction curve. Each galaxy is put at its redshift and luminosity and K corrections are applied. The algorithm returns for each galaxy its position, magnitude, B/T relation, disk size, bulge size, bulge flatness, redshift, position angles, and V-I. In the next development step, the spectrum will be obtained through a link to the Gaia Spectral Library.

We have created a set of typical synthetic galaxy spectra in accordance with Universe Model requirements that have been included to the Gaia Spectral Library in order to provide each simulated galaxy image with the corresponding synthetic spectrum. In this paper we describe the production of this library (Section 2) and we investigate the photometric properties of these galaxies comparing with observational data from SDSS (Section 3). Finally in Section 4 we sum up our conclusions.

2. The P´EGASE.2 code

We use the galaxy evolution model P´EGASE (Projet d' Etude des Galaxies par Synthese Evolutive) (Fioc & Rocca-Volmerange 1997, 1999), to synthesize galaxy spectra. The P´EGASE.2 code is aimed principally at modeling the spectral evolution of galaxies by types: the active and passive evolution of stellar populations as well as interstellar gas and dust are coherently evolved in time. No galaxy number density evolution is considered, although the results of our models are compatible with occasional rare galaxy merging. The code is based on the stellar evolutionary tracks from the Padova group, extended to the thermally pulsating asymptotic giant branch (AGB) and post-AGB phases (Groenewegen & de Jong 1993). These tracks cover all the masses, metalicities and phases of interest for galaxy spectral synthesis. P´EGASE.2 uses the BaSeL 2.2 library of stellar spectra and can synthesize low resolution (R=200) ultraviolet to near-infrared spectra of selected Hubble–spectral sequence galaxies, as well as of starbursts. For a given evolutionary sce-

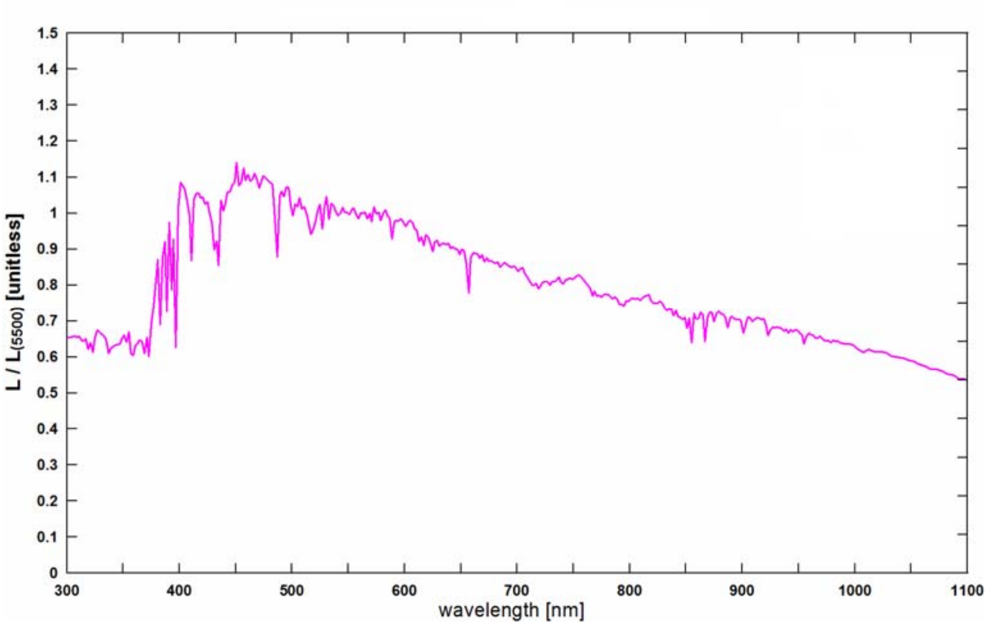

Figure 1. Synthetic spectra for typical galaxy type Sc from P´EGASE.2.

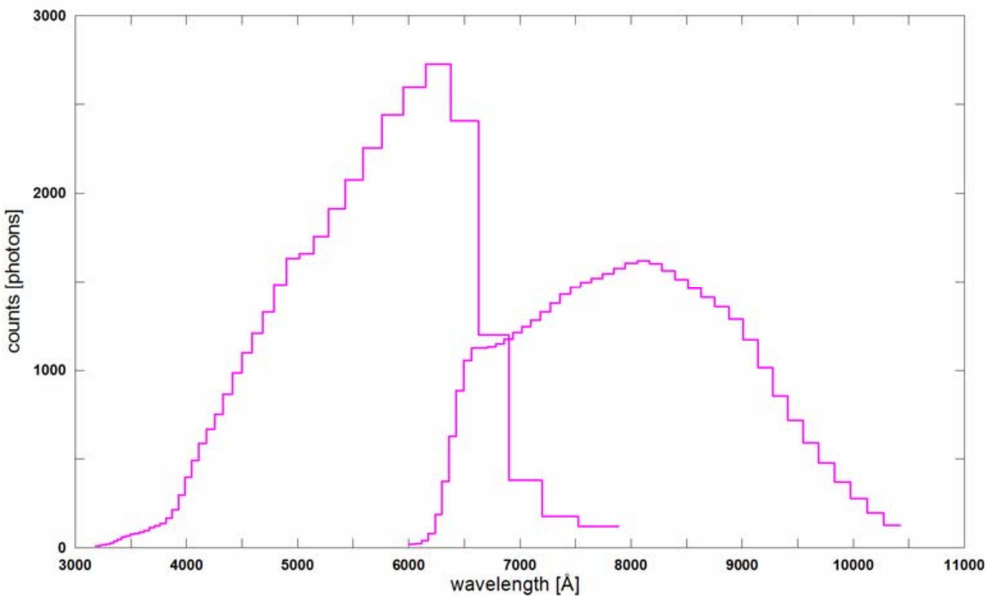

Figure 2. Simulated synthetic spectra of Fig1.

nario (typically characterized by a star formation law, an initial mass function and, possibly, infall or galactic winds), the code consistently gives the spectral energy distribution (SED) and computes the star formation rate and the metallicity at any time. The nebular component (continuum and lines) due to HII regions is calculated and added to the stellar component. Depending on the geometry of the galaxy (disk or spheroidal), the attenuation of the spectrum by dust is then computed using a radiative transfer code which takes account of the scattering (Tsalmantza et al. 2007).

P´EGASE.2 has already been used for producing 2 libraries of synthetic galaxy spectra for Gaia. (Tsalmantza et al. 2007, Tsalmantza et al. 2009). The libraries have been simulated and been used for various Gaia purposes. In Figure1 we see a typical (Sc) synthetic spectrum, while in Figure 2 the same spectrum simulated for Gaia is demonstrated.

Each spectrum in our library is uniquely defined by a set of 17 astrophysical parameters, that are given as input to PEGASE.2 code. For this library the most significant parameters are: the star formation scenario, the infall timescale, the age of the galactic winds and the extinction when disc geometry is adopted. The age of

Table 1. *The values of the parameters of the P´EGASE models which are kept constant in the library.*

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
Galactic Winds	5 Gyr only for E-S0, none for all the rest
Age	13 Gyr for E2,E-S0,Sa, Sb, Sbc, Sc & Sd 9 Gyr for Im and QSFG

the galactic winds is non-zero only for E2 and E-S0 galaxies. The values of the parameters we keep constant can be seen on Table1 while the values of the once changed can be seen in Table 2.

Table 2. *The astrophysical parameter in the library of P´EGASE synthetic spectra. The morphological type can be considered as an additional (but non-independent) parameter, required to fully explain the variance in the library*

Type	SFR scenario	p1 (Myr)	p2 (Myr/Msol)	p3 (Myr)	infall (Gyr)	extinction
E2	$p2\times\frac{\exp\left(-\frac{t}{p1}\right)}{p1}$	89.17	1.18680	–	–	spheroidal geometry
E-S0	$\frac{Mgas^{p1}}{p2}$	1.0	500.00	–	500	
Sa		1.0	1409.00	–	2800	Disk geometry: specific inclination: 0.0, 22.5, 45.0, 67.5, and 90.0 degrees
Sb		1.0	2500.00	–	3500	
Sbc		1.0	5714.00	–	6000	
Sc		1.0	10000.00	–	8000	
Sd		1.0	14290.00	–	8000	
Im		1.5	15390.00	–	8000	
QSFG	$\frac{Mgas^{P1}}{p2}, \quad t<9Gyr-p3$; $0, \quad t>9Gyr-p3$	2.6127	0.55642	74.14	10560	

We thus have 9 galaxy types with 7 of them produced for 5 values of disk inclination providing $2+5\times7=37$ spectra for $z=0$. Each one of these spectra is then calculated for 10 more z values (0.02 to 0.20 with step of 0.02) leading to a set of $37\times11=407$ spectra

3. Comparison with SDSS

In order to correlate the synthetic spectra with observed galaxy sources we compaire between the SDSS and P´EGASE.2 data using the g*, r, i filters only (Tsalmantza et al. 2007) and, more specifically, the g*–r and r–i colours. The observed galaxies that have been selected for comparison meet the following criteria: the galaxies should not be near a CCD edge nor saturated, and they should not be very low SNR (the photometric error in all bands should be less than 0.1 mag).

Only spectra with redshifts below 0.20 are retained, since the synthetic spectra of P´EGASE.2 were produced have range of z 0.0 to 0.20 redshift. These criteria resulted in a sample of about 650000 galaxies. On the CCD we plot only the 1/100 selecting them in random order (Tsalmantza et al. 2007).

Their synthesized photometry plus that for the typical galaxy types from P´EGASE.2 for $z = 0.0$ and for inclination 45.0 degrees are shown in Figure 3. Inclination 45.0 degrees is comparable with results of the selection of inclination averaged that has been used in the former libraries.

The SDSS photometry is plotted with our library spectra for the different z values again on constant inclination 45.0 degrees in Figure 4. Finally in Figure 5 we show the photometry of all the spectra produced for the needs of the Gaia Universe Model.

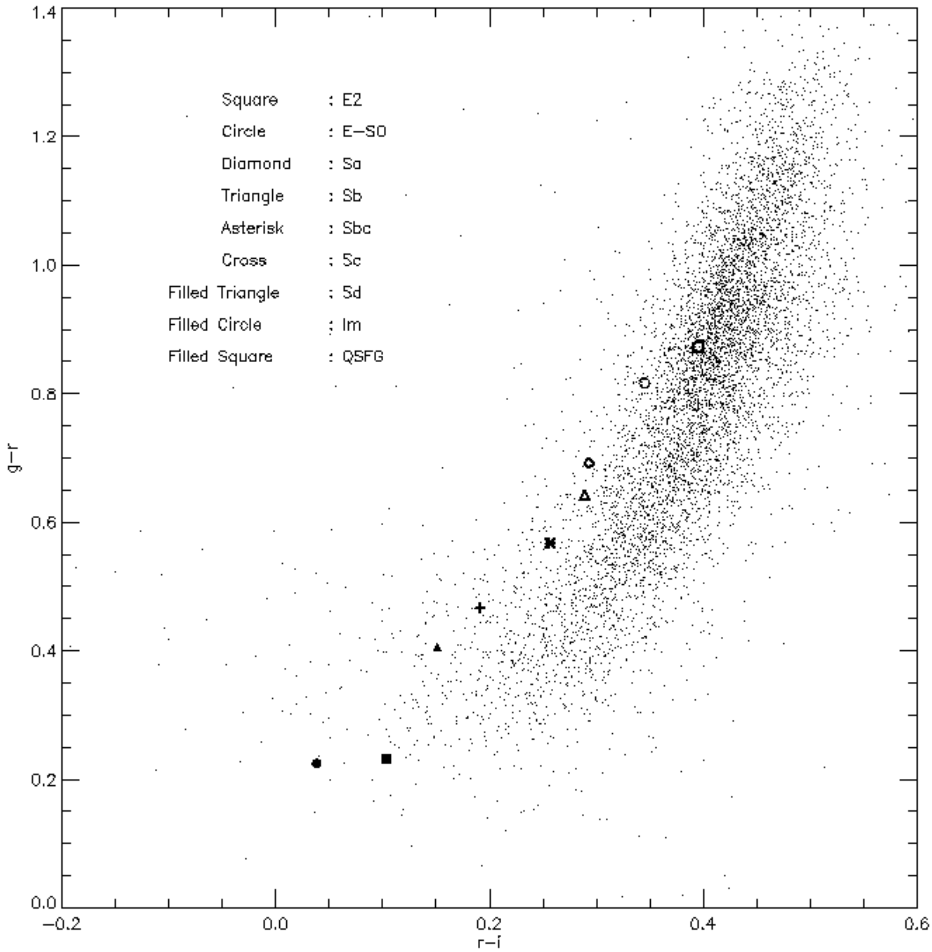

Figure 3. *Synthetic typical galaxy types from P´EGASE.2 for the $z=0.0$ and for inclination=45.0 degrees plotted over SDSS galaxies with $z \leq 0.20$.*

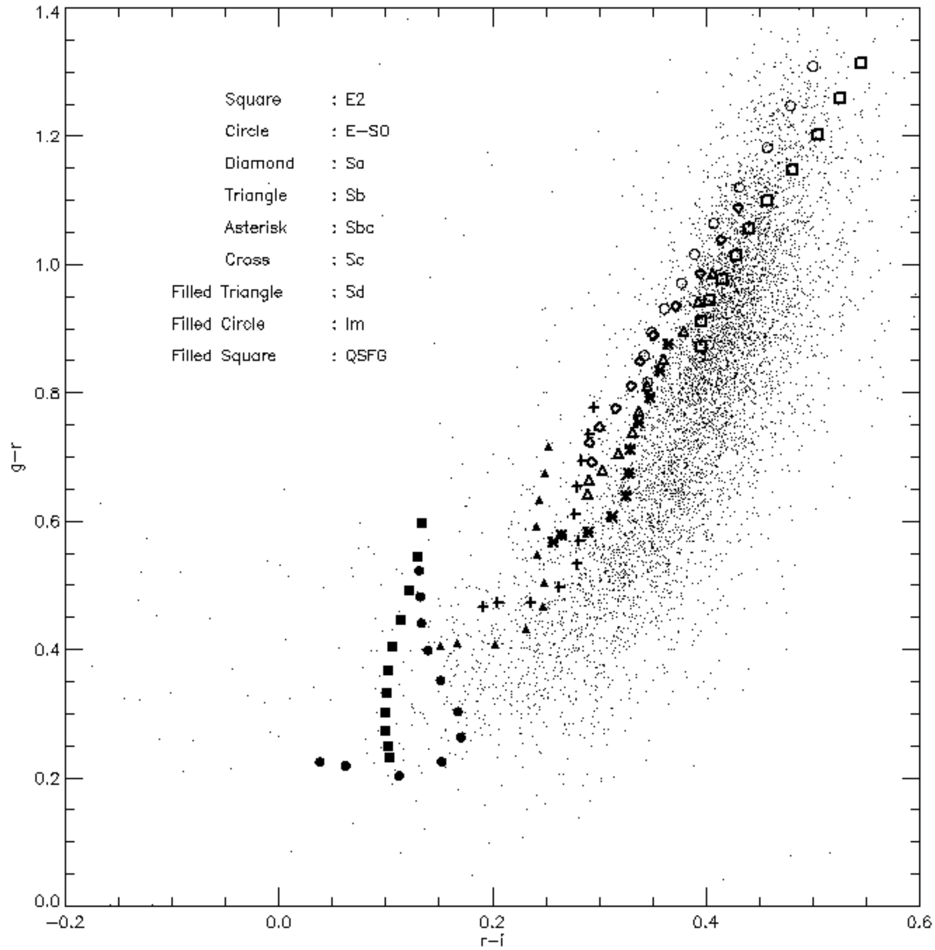

Figure 4. *Synthetic typical galaxy types from P´EGASE.2 for the different z values between 0.00 and 0.20 plotted over SDSS galaxies of the same z range. Inclination is set to 45.0 deg again.*

4. Conclusions

A grid of 407 typical synthetic galaxy spectra was produced (using the P´EGASE.2 code) that will be included to the Gaia Spectral Library. The aim of this investigation is to create a suitable set of galaxy spectra with a variety of parameters, covering the observed galaxy types at different redshifts. We provide a grid of 9 selected Hubble–spectral types, with 11 different values of z and 5 different values of inclination in the cases where disk geometry has been selected to describe the galaxy. The photometry of the synthetic spectra, compared with the photometry of observed galaxy sources (SDSS), was found to cover the observed colour-colour diagram in a very realistic way.

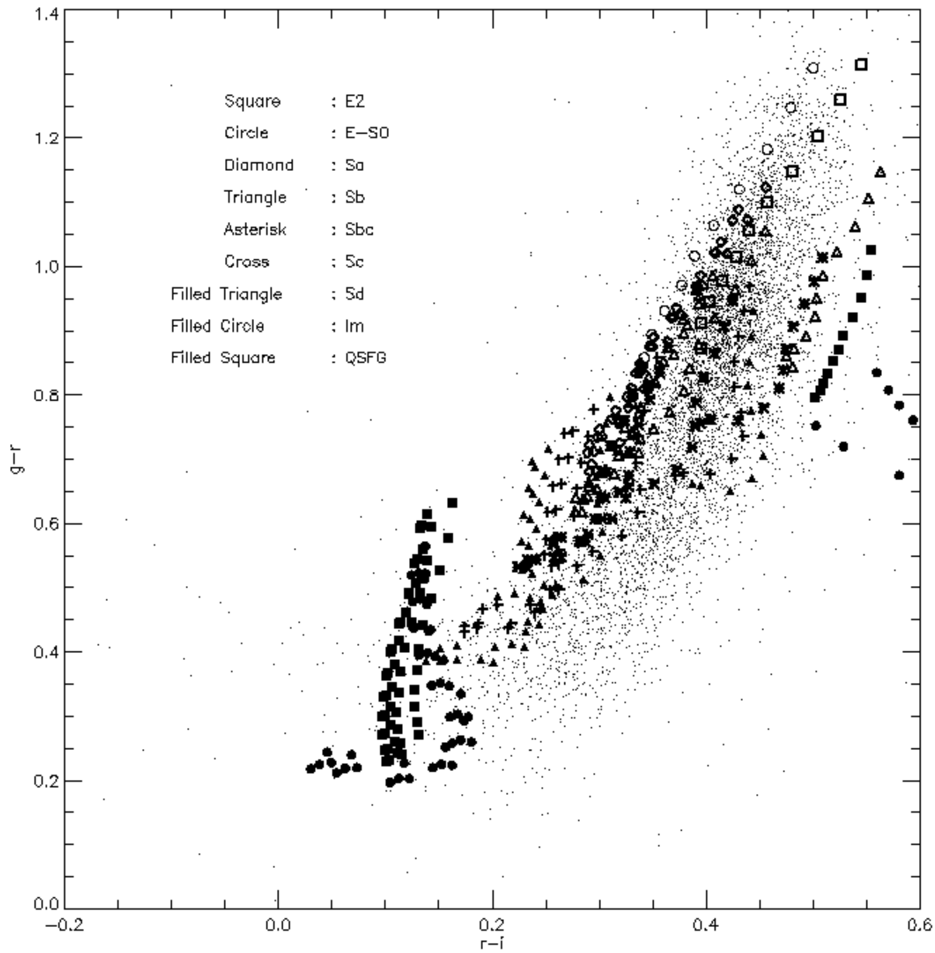

Figure 5. *Synthetic typical galaxy types from P´EGASE.2 for the different z and inclination values plotted over the SDSS galaxies.*

5. Acknowledgments

E. Livanou would like to thank the State Scholarships Foundation (I.K.Y) for financial support.

Funding for the Sloan Digital Sky Survey (SDSS) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Insti-

tutions are The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Korean Scientist Group, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

References

Fioc, M. & Rocca-Volmerange, B.: PEGASE: a UV to NIR spectral evolution model of galaxies. Application to the calibration of bright galaxy counts, A&A, 326, 950-962, 1997

Fioc, M. & Rocca-Volmerange, B.: Star Formation Histories From Faint Galaxy Counts, Ap&SS, 265, 507-511, 1999.

Groenewegen, M. A. T. & de Jong, T.: Synthetic AGB evolution. I - A new model, A&A, 267, 410-432, 1993

Le Borgne, D. & Rocca-Volmerange, B.: Photometric redshifts from evolutionary synthesis with PÉGASE: The code Z-PEG and the z=0 age constraint, A&A, 386, 446-455, 2002

Robin, A.C., Reyle, C., Arenou, F., et al.: Universe Model 6.0 overview, GAIA-C2-TN-LAOB-AR-004-6, 2009

Tsalmantza, P.; Kontizas, M.; Bailer-Jones, C. A. L.: Towards a library of synthetic galaxy spectra and preliminary results of classification and parametrization of unresolved galaxies for Gaia, A&A, 470, 761-770, 2007

Tsalmantza, P.; Kontizas, M.; Rocca-Volmerange, B. et al.: Towards a library of synthetic galaxy spectra and preliminary results of classification and parametrization of unresolved galaxies for Gaia – II, arXiv0907.1671T, 2009