Modelling the Extinction Properties of Galaxies

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**Abstract.** Recently (Granato, Lacey, Silva et al. 2000, astro-ph/0001308) we have combined our spectrophotometric galaxy evolution code which includes dust reprocessing (GRASIL, Silva et al. 1998) with semi-analytical galaxy formation models (GALFORM, Cole et al. 1999). One of the most characteristic features of the former is that the dust is divided in two main phases: molecular cloud complexes, where stars are assumed to be born, and the diffuse interstellar medium. As a consequence, stellar populations of different ages have different geometrical relationships with the two phases, which is essential in understanding several observed properties of galaxies, in particular those undergoing major episodes of star formation at any redshift. Indeed, our merged GRASIL+GALFORM model reproduces fairly well the SEDs of normal spirals and starbursts from the far-UV to the sub-mm and their internal extinction properties. In particular in the model the observed starburst attenuation law (Calzetti 1999) is accounted for as an effect of geometry of stars and dust, and has nothing to do with the optical properties of dust grains.

1. Introduction

Semi–analytical models are the key technique to predict galaxy properties in the framework of hierarchical structure formation. Simplified analytical descriptions of gas cooling and collapse, star formation, supernovae feedback and galaxy merging are applied to a Monte Carlo description of the formation and merging of DM halos. However, semi-analytical models have so far ignored or treated poorly dust reprocessing.  

To cope with this point, which according to several pieces of evidence appears to be crucial to understand high-z observations, we combined the semi–analytical galaxy formation model of Cole et al (1999, GALFORM) with the stellar population + dust model of Silva et al (1998, GRASIL). Both models are state–of–the–art.

We refer the reader to Granato et al. (2000) for the details. Here we remind only the basic features of our modelling. GALFORM includes: 
(1) formation of DM halos through merging; (2) cooling and collapse
of gas in halos to form disks; (3) star formation in disk regulated by supernovae feedback; (4) merging of disk galaxies to form ellipticals and bulges; (5) bursts of star formation triggered by these mergers; (6) predictions of the radii of disks and spheroids; (7) star formation and chemical enrichment histories of stars and gas.

GRASIL (http://grana.pd.astro.it, Silva, Granato, Bressan & Danese 1998) includes: (1) a realistic 3D geometry (disk + bulge) with a two phase ISM (cirrus + Molecular Clouds MCs); (2) birth and early evolution of stars in MCs; (3) clumpiness of both ISM and stars spatial distributions, with age dependence; (4) radiative transfer whenever required; (5) dust grain model including PAHs and quantum heating of small grains, calibrated to fit the MW extinction law; (6) self consistent computation of thermal status of grains in each point; (7) effects of AGB dusty envelopes.

The purpose of our first paper is to study the effects of including dust in a fixed galaxy formation model, chosen previously by Cole et al (1999) to fit the properties of local galaxies in the optical-NIR. GALFORM provides the star formation and chemical enrichment histories, the gas mass and various geometrical parameters of mock catalogs of galaxies at various redshifts. GRASIL uses these information to predict synthetic SEDs. In this way, now semi-analytical models can be effectively compared with IR and sub-mm data, essential to understand the high-z SF history.

We test our models against the observed spectro-photometric properties of galaxies in the local Universe, assuming a CDM cosmology with $\Omega_0 = 0.3$ and $\Lambda_0 = 0.7$. In this contribution we focus our attention on one particular result, namely our interpretation of the observed starburst attenuation law. Before doing this, we summarize very briefly our other findings.

The models reproduce fairly well the SEDs of normal spirals and starbursts from the far-UV to the sub-mm, and their internal extinction properties. The starbursts follow the observed relationship between the FIR to UV luminosity ratio and the slope of the UV continuum. We compute galaxy luminosity functions over a wide range of wavelengths, which turn out to be in good agreement with observational data in the UV (2000Å), in the B and K bands, and in the IR (12−100µm). Finally, we investigate the reliability of some star formation indicators which are based on the properties of the continuum SEDs of galaxies. The UV continuum turns out to be a poor star formation indicator for our models, whilst the infrared luminosity is much more reliable.
2. Interpretation of the observed starburst attenuation law

An important problem in the study of star-forming galaxies is to determine the amount of attenuation of starlight by dust, especially in the UV. This bears directly on the determination of star formation rates in galaxies from their UV luminosities. The differences found between the shapes of the extinction curves of the Galaxy, the LMC and the SMC below $\lambda \lesssim 2600\text{Å}$ are often ascribed to the different metallicities in these systems.

From the optical and UV spectra of a sample of UV-bright starbursts, Calzetti et al. (1994) derived an average attenuation law characterized by a shallower far-UV slope than that of the Milky Way extinction law, and by the absence of the 2175 Å feature. This is at first sight quite surprising, because the metallicities of these galaxies are mostly similar to that of the Milky Way, and so they might be expected to have similar dust properties. The question is then to what degree the differences between the starburst attenuation law and the Milky Way extinction law are due to the geometry of the stars and dust, and to what degree they can only be explained by differences in dust properties.

Figure 1. The average dust attenuation curves for starlight in different classes of galaxies (normal and starburst, SB) in the model compared with the average Milky Way extinction law (solid line) and with the Calzetti “attenuation law” (filled circles, with $R_V = 4.05$). The error bars show the dispersion of the models around the mean attenuation curve.

Figure 1 compares the average attenuation curves for galaxies from our model with the empirical “attenuation law” obtained for starbursts
by Calzetti (1999). As already remarked, the dust properties we adopt imply an extinction law characterized by a distinct 2175 Å feature produced by graphite grains, and well matching the average Milky Way extinction curve. The model extinction law (solid line in Fig. 1) is the attenuation law that would be measured if all the dust were in a foreground screen in front of the stars and no scattered light reached the observer. This geometry is clearly not realistic as applied to the integrated light from galaxies. In our models, we have instead a complex and wavelength dependent geometry, where the UV emitting stars are heavily embedded inside molecular clouds, while the older stars, mainly emitting in the optical and near infrared, are well mixed with the diffuse interstellar medium.

All the 3 classes of models in Figure 1 show a weak or completely absent 2175 Å feature. In particular, the predicted attenuation curve for the lower luminosity starbursts is remarkably close to the empirical “Calzetti law”. This result is an entirely geometrical effect, and did not require us to assume for starbursts dust properties different from those of the Galaxy, but rather follows naturally from the assumption that stars are born inside optically thick dust clouds and gradually escape.

Indeed, in the far-UV, including the spectral region around the 2175 Å feature, the global attenuation in the models is strongly contributed, or even dominated, by the MCs. The shape of the attenuation curve there has little to do with the optical properties of grains, because our MCs usually have such large optical depths that the UV light from stars inside the clouds is completely absorbed. The wavelength dependence of the attenuation law of the MC component instead arises from the fact that the fraction of the light produced by very young stars increases with decreasing wavelength, and at the same time, the fraction of stars which are inside clouds increases with decreasing age. The additional attenuation arising in the cirrus component can sometimes imprint a weak 2175 Å feature, but this is not the case for the starbursts.

References

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