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Dust in Spectral Galaxy Evolution Models

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Abstract. To analyse the effects of dust on the UV emission in various galaxy types we present our evolutionary synthesis models which includes dust absorption in a chemically consistent way. We show how the time evolution of the extinction is based on the evolution of both the gas content and the metallicity. We analyse the differences among various spectral types depending on the characteristic timescales of star formation and show the influence of the IMF. Our model SEDs are in very good agreement with templates from Kennicutt's and Kinney et al.'s atlases. With this comparion we point out the importance of aperture effects. Combined with a cosmological model we are able to predict the UV fluxes for different galaxy types from nearby to very high redshifts.

1. Introduction

The data on high and very high redshift galaxies is rapidly increasing these days. Many Lyman break galaxies with photometric redshift estimates are known, more than 750 have confirmed redshifts in the range $2 \leq z \leq 5$ (Steidel et al. 1998). Many more will be detected in ground-based large and deep field projects (e.g. FORS – Deep Field on VLT). Deep surveys are conducted at all wavelengths from UV through IR and far into the submm range (SCUBA on JCMT). These brilliant data require mature galaxy evolution models for adequate interpretation. Ideally, these models should cover the wavelength range from UV through FIR and submm and describe the evolution of as many observable quantities as possible (spectrum, luminosities, colours, emission and absorption features for the stellar population, the gas content and a large number of element abundances for the ISM) and, at the same time, be as simple as possible, involving the smallest possible number of free parameters. A realistic galaxy evolution model should consistently take into account both the age and metallicity distributions of the stellar populations that enevitably result from any extended SF history. This is what we attempt with our chemically consistent spectrophotometric, chemical and cosmological evolutionary synthesis model. The chemical evolution aspects of this model are presented in Lindner et al. (1999) in comparison with and interpretation of the observed redshift evolution of damped Lyα (DLA) abundances.

In recent years it has also become increasingly clear that dust in galaxies plays a non-negligible role determining their appearance and their observed spectral energy distributions in both for nearby and high redshift galaxies. E.g., UV dust obscuration of a factor of a few has been inferred in the spectral energy distributions of young galaxies at redshift z $\geq$ 1 (Adelberger & Steidel et al. 2000, Glazebrook et al. 1999).

2. Extinction in different spectral types

Here we present the extended spectrophotometric model which includes the effects of dust in a chemically consistent manner, with the amount of dust tied to the amount and metallicity of gas as they evolve with time for various galaxy types.

Combining the spectrophotometric time evolution with a cosmological model and some assumed redshift of galaxy formation we calculate the evolutionary and cosmological corrections as well as the evolution of apparent magnitudes from optical to NIR for various spectral types and cosmological parameters taking into account the attenuation by intervening HI as described by Madau (1995).

In Figure 1 we show for various galaxy models the time evolution of ISM metallicity, gas content and extinction. In the following we classify the various spectral types from E, S0,..., Sd with their characteristic timescales. After a Hubble time, our models not only have the observed colours and spectral energy distributions of the respective nearby galaxy types (see comparison with Kennicutt templates in Möller et al. 2000), but also the observed average ISM abundances at $\sim 1R_e$, gas content and E(B-V) of nearby galaxies. To represent the wide range of observed properties for ellipticals and S0's we calculate two different models varying t_* from 1 (a) to 1.5 (b) Gyr which has no remarkable effect on the spectral energy distribution except for the resulting extinction E(B-V) over the entire time evolution. After a Hubble time both E/S0 models have the same ISM metallicity of about $Z \sim Z_\odot$. While in model a) SF stops after 2 Gyr and the amount of gas thereafter increases to a few percent due to the stellar yields, the star formation in model b) continues until the gas content is negligible. Therefore the extinction in both models varies between E(B-V) = 0 and 0.1 after a Hubble time. These values are in good agreement with observations of field ellipticals (Goufrooij et al. 1994), for which E(B-V) can go up to 0.2. The influence of the IMF is seen in the comparison of the two Sa models with Salpeter IMF (c) and Scalo IMF (d). All other models are calculated with Salpeter IMF. The model with Salpeter IMF produces more metals and therefore results in a higher metallicity but also consumes more gas for the same SFR and gives a lower extinction after a Hubble time. The model with $t_* = 8$ Gyr (e) shows the highest present day extinction of about 0.3 to 0.4 mag in agreement with observations of Gonzalez et al. (1998). Because of the increasing abundances and decreasing gas content the chemically consistent model with constant SF also shows an evolutionary effect - not only in the time evolution of its SED but also due to its increasing extinction.

In all models, except for the constant SFR, we see that the evolution of the extinction over redshift shows a maximum at earlier times (higher z), which is

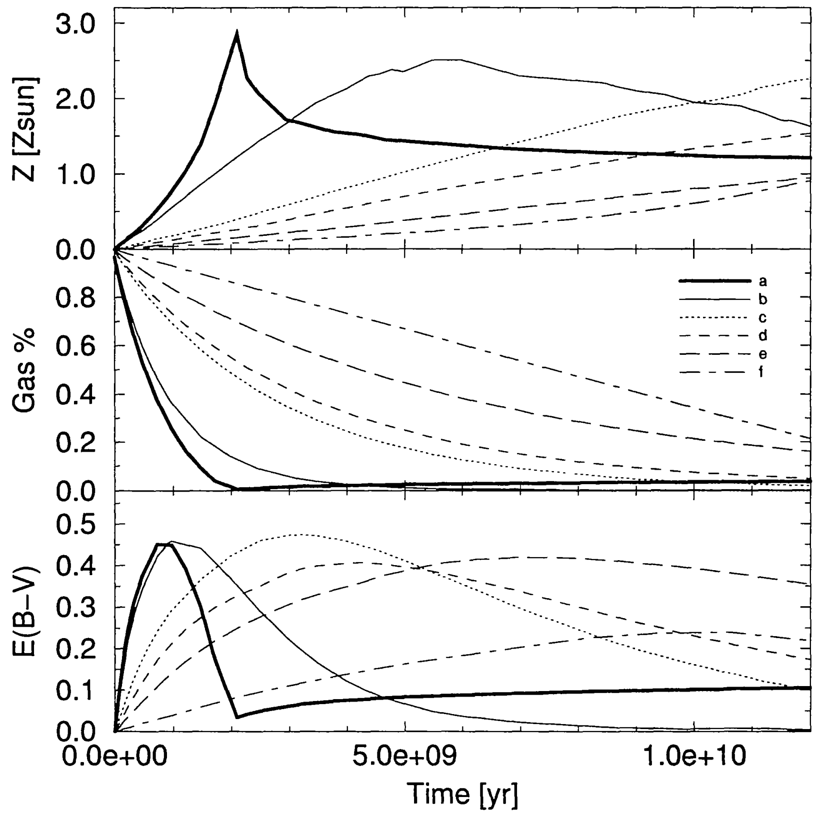

Figure 1. Time evolution of ISM metallicity (top), gas content (middle) and extinction (bottom) for galaxy models E/S0 (a) and (b), Sa (c) and (d), Sb (e), Sd (f)

different for the various spectral types, and then decreases again to very high z due to the low metallicity.

Our model describes the entire spectrophotometric evolution of field galaxies, e.g. metallicities and colours measured at 1 R_{eff}. In particular our E model represents a L^* elliptical galaxy. We have shown that our model well describes the stellar metallicity observed by absorption indices (Möller et al. 1997) and the chemical evolution of nearby and high redshift spiral galaxies (Lindner et al. 1999). Our model SEDs for various types E, Sa,..., Sd show very good agreement with the templates NGC 3379, NGC 3368, ..., NGC 4449 from Kennicutt's atlas in the wavelength range (3600 - 6800) Å.

The S0 galaxy NGC 1553 (Kinney et al. 1996) is best reproduced by a $t_* = 1$ Gyr model with an $\sim$ 11 Gyr old stellar population, a mean ISM metallicity of Z= 1.2 $Z_\odot$ and E(B-V) = 0.1.

The comparision of the UV and optical spectrum of NGC 210, a template Sb galaxy from Kinney et al.'s atlas, with our model spectra shows that our Sb (t_* = 8 Gyr) model with or without dust only gives a very poor match. Instead, we find good agreement over the entire wavelength range (912 - 10000 Å) with our $t_* = 1$ Gyr model at an age of the stellar population of $\sim$ 9 Gyr, $Z = 1.3 Z_\odot$ and

E(B-V)=0.1. This is due to the fact that for nearby galaxies the IUE Aperture of 10"x20" only covers the central 300 - 500 pc which are dominated by the bulge component. The optical aperture in this case matches the one in the UV so that the agreement with our $t_* = 1$ Gyr model, which is appropriate for speroidals and bulge components, is a result of this small aperture effect: while the integrated spectrum of the Sb template NGC 210 should be well described by our $t_* =$ 7-8 Gyr model as is e.g. the case for Kennicutt's integrated Sb template spectrum of NGC 3147, its bulge spectrum clearly requires a short SF timescale $t_* = 1$ Gyr.

3. Conclusion

We have extended our spectrophotometric and chemical evolutionary synthesis model in a chemically consistent way. We present the time and redshift evolution of the extinction in various galaxy types resulting from the evolution of their gas contents and metallicities. Comparing our model SEDs with templates from Kennicutt's and Kinney et al.'s atlas we show the detailed agreement of our model spectra with integrated spectra of galaxies and point out the importance of aperture effects on the example of an Sb galaxy. It would be necessary to observe the UV flux over a wider area. So far our models give predictions for the extinction and the metallicity, and it should be possible to disentangle extinction and metallicity with a wide wavelength basis from UV to opt. or NIR bands.

We have compiled a large grid of evolutionary and cosmological corrections from UV to IR and compare the models using only solar metallicity with the chemically consistent models. A detailed description and comparison of model results w/o dust with observations of colors and luminosities of high redshift galaxies will be presented in Möller et al. (2000).

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