

MAGPHYS: a publicly available tool to interpret observed galaxy SEDs

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Abstract. We present a simple, physically-motivated model to interpret consistently the emission from galaxies at ultraviolet, optical and infrared wavelengths. We combine this model with a Bayesian method to obtain robust statistical constraints on key parameters describing the stellar content, star formation activity and dust content of galaxies. Our model is now publicly available via a user-friendly code package, MAGPHYS at www.iap.fr/magphys. We present an application of this model to interpret a sample of ~ 1400 local ($z < 0.5$) galaxies from the H-ATLAS survey. We find that, for these galaxies, the diffuse interstellar medium, powered mainly by stars older than 10 Myr, accounts for about half the total infrared luminosity. We discuss the implications of this result to the use of star formation rate indicators based on total infrared luminosity.

Keywords. dust, extinction galaxies: ISM galaxies: stellar content galaxies: statistics.

1. A simple model to interpret galaxy SEDs

Multi-wavelength surveys of large samples of galaxies both in the local and high-redshift Universe have become widely available in recent years. To understand these observations in the framework of galaxy formation and evolution, we must be able to extract key physical parameters from their observed spectral energy distributions (SEDs). In da Cunha, Charlot & Elbaz (2008), we have developed a simple model to interpret consistently the ultraviolet, optical and infrared emission from galaxies in terms of their star formation histories and dust content.

1.1. Description of the model

We compute the spectral evolution of stellar populations in galaxies using the state-of-the-art population synthesis model of Bruzual & Charlot (2003). This model is based on the property that stellar populations with any star formation history can be expanded in a series of instantaneous bursts, simple stellar populations (SSPs). The spectral energy distribution of a galaxy is then computed by adding the individual spectra of all SSPs weighted by the star formation rate over time since the galaxy was formed.

The spectra of galaxies also contain valuable information about the interaction of starlight with interstellar gas and dust, and the physical properties of the interstellar medium (ISM), such as dust content. Following Charlot & Fall (2000), we describe the

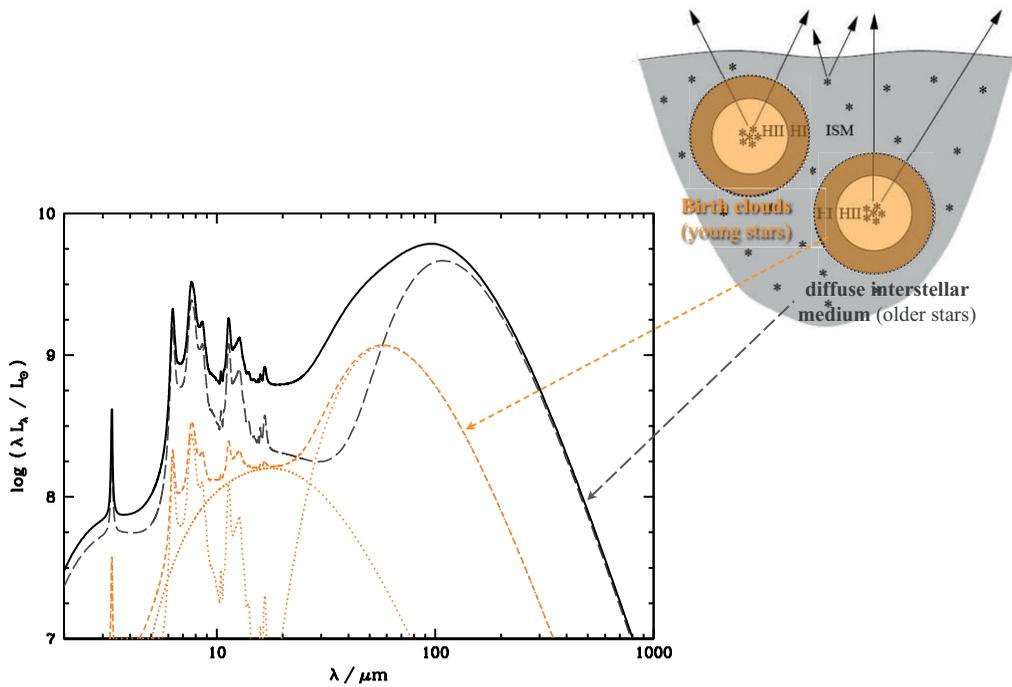


Figure 1. Schematic view of the two-component ISM by Charlot & Fall (2000) (top-right): stars are born in dense molecular clouds – birth clouds – and later (after 10^7 yr) migrate to the ambient diffuse ISM. The left-bottom plot shows an example total dust emission SED (solid line) in the infrared range, constructed using the emission components described in da Cunha, Charlot & Elbaz (2008). The contributions by the birth clouds and the ambient ISM are plotted with short-dashed and long-dashed lines, respectively.

ISM of galaxies in our model using two main components: the ambient (diffuse) interstellar medium and the star-forming regions (birth clouds). Stars are born in dense molecular clouds which dissipate typically on a time-scale of 10^7 years. As a result, the non-ionizing continuum emission from young OB stars and line emission from their surrounding HII regions may be absorbed by dust in these birth clouds and then in the ambient ISM, while the light emitted by stars older than 10^7 yr propagates only through the diffuse ISM. This simple model successfully accounts for the different attenuation of line and continuum emission in star-forming galaxies. We use this prescription to compute the total energy absorbed by dust in the birth clouds and in the ambient ISM. We define the total dust luminosity re-radiated by dust in the birth clouds and in the ambient ISM as L_d^{BC} and L_d^{ISM} , respectively. The total luminosity emitted by dust in the galaxy is $L_d^{tot} = L_d^{BC} + L_d^{ISM}$. We distribute L_d^{BC} and L_d^{ISM} in wavelength over the range from 3 to 1000 μm using four main dust components: (i) the emission from polycyclic aromatic hydrocarbons (PAHs); (ii) the mid-IR continuum from hot dust; (iii) the emission from warm dust (30–60 K) in thermal equilibrium; (iv) the emission from cold dust (15–25 K) in thermal equilibrium. In stellar birth clouds, the relative contributions to L_d^{BC} by PAHs, the hot mid-infrared continuum and warm dust are kept as adjustable parameters. These clouds are assumed not to contain any cold dust. In the ambient ISM, the contribution to L_d^{ISM} by cold dust is kept as an adjustable parameter. The relative proportions of the other 3 components are fixed to the values reproducing the mid-infrared cirrus emission of the Milky Way. We find that this minimum number of components is required to

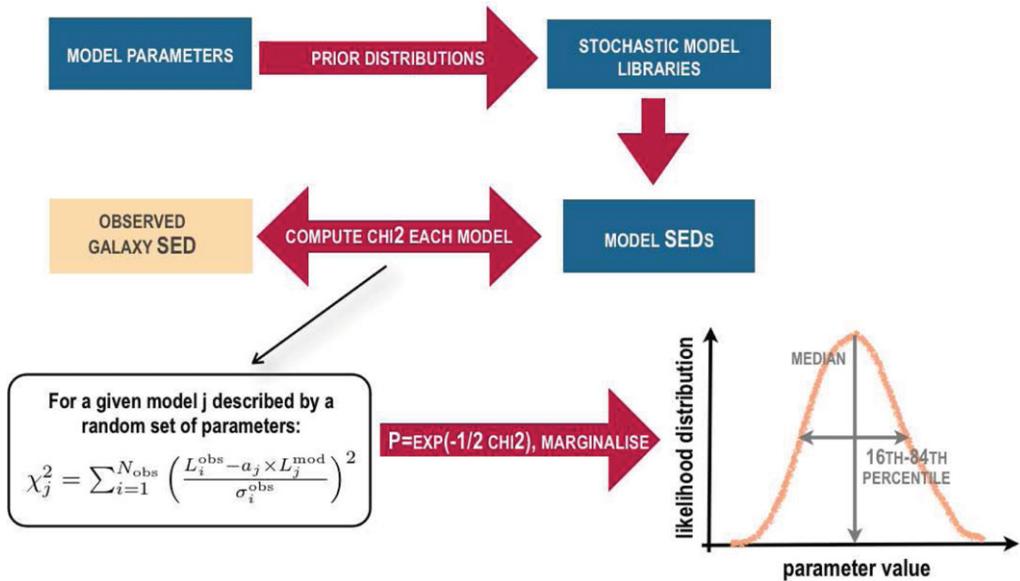


Figure 2. Summary of the Bayesian approach we use to compare observed galaxy SEDs with our model and derive statistical constraints on the physical parameters of observed galaxies (see da Cunha *et al.* 2008 for details).

account for the infrared SEDs of galaxies in a wide range of star formation histories (see da Cunha *et al.* 2008 for details). An example model SED is shown in Fig. 1.

1.2. Statistical constraints of physical parameters

Our model is optimized to derive statistical constraints of fundamental parameters related to star formation activity and dust content (e.g. star formation rate, stellar mass, dust attenuation, dust temperatures) of large samples of galaxies using a wide range of multi-wavelength observations (e.g. da Cunha *et al.* 2008, 2010). We use a Bayesian approach, summarized in Fig. 2, to interpret the SEDs all the way from the ultraviolet/optical to the far-infrared. A similar approach has been previously used mostly to interpret optical galaxy spectra from the ultraviolet to the near-infrared, i.e. not including the dust emission. This approach allows us to understand in detail our parameter constraints by identifying degeneracies and exploring what observations are required to constrain each parameter.

2. The MAGPHYS package

The da Cunha, Charlot & Elbaz (2008) model is **publicly available as the MAGPHYS package** at www.iap.fr/magphys. MAGPHYS - *Multi-wavelength Analysis of Galaxy Physical Properties* - is a self-contained, user-friendly model package to interpret observed spectral energy distributions of galaxies in terms of galaxy-wide physical parameters pertaining to the stars and the interstellar medium. The analysis of the spectral energy distribution of an observed galaxy with MAGPHYS is done in two steps: (i) The assembly of a comprehensive library of model SEDs at the same redshift and in the same photometric bands as the observed galaxy, for wide ranges of plausible physical parameters pertaining to the stars and ISM. (ii) The build-up of the marginalised likelihood distribution of each physical parameter of the observed galaxy, through the comparison of the observed SED with all the models in the library (Fig. 2).

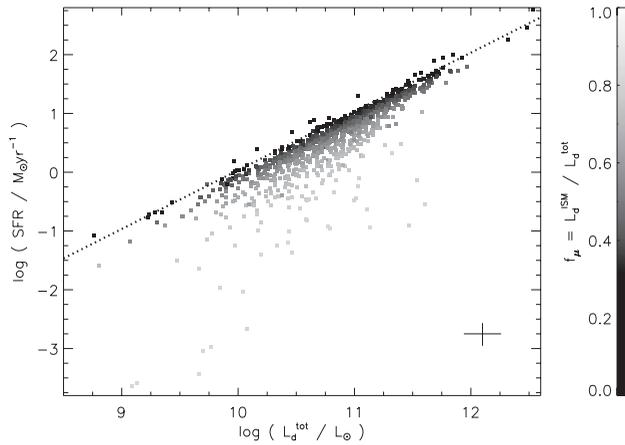


Figure 3. Star formation rate, SFR, plotted against total dust luminosity, L_d^{tot} , for 1404 galaxies from the H-ATLAS survey (da Cunha *et al.*, in prep.). Each galaxy is colour-coded (on a grey-scale) according to the fraction of total infrared luminosity contributed by the diffuse ISM, f_μ . The dotted line shows, for reference, the conversion between total IR luminosity and SFR from Kennicutt (1998).

3. Dust heating by stars older than 10 Myr in H-ATLAS galaxies

The H-ATLAS survey is detecting thousands of galaxies in the Herschel/SPIRE bands over a large area of the sky. Thanks to the overlap with other multi-wavelength surveys, complete UV-to-IR SEDs are available for large samples of galaxies (Eales *et al.* 2010). We have used MAGPHYS to extract statistical constraints on star formation rates (SFRs), stellar masses, dust luminosities and dust masses of a sample of 250- μm detected galaxies at $z < 0.5$ from their observed SEDs (Smith *et al.*, submitted). We are investigating the use of the IR luminosity as a SFR indicator in these galaxies. The total IR is often used as a SFR tracer but observational evidence shows that dust in galaxies is not exclusively heated by newly-formed stars (e.g. Bendo *et al.* 2010). We find that the SFR derived from fits to the total SED with our model, which includes heating by stars older than 10^7 yr in the diffuse ISM, is not exactly traced by the dust luminosity (as, for example, when using the Kennicutt 1998 IR to SFR conversion; see Fig. 3). A significant fraction (typically 50%) of L_d^{tot} in H-ATLAS galaxies comes from the diffuse ISM, mainly powered by stars older than 10 Myr. This implies that using the total IR as a SFR tracer may lead to overestimating the SFR unless the contribution by the diffuse ISM to the total IR is properly taken into account (see also e.g. Kennicutt 2009).

Acknowledgements

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Discussion

MADDEN: Could you describe further the parameters of the dust components in your model? For example for the modified black bodies you use for the FIR-submm, are the beta parameter and temperature fixed? Do you solve for PAHs, or do you use fixed templates from models/observations?

DA CUNHA: The emission by dust in thermal equilibrium in our model is described by a set of modified black bodies. In the stellar birth clouds, we adopt an emissivity index of $\beta = 1.5$ to describe the emission by warm dust; the temperature of this dust can vary between 30 and 60 K. Cold dust in the diffuse ISM is described by $\beta = 2$ and the equilibrium temperature can vary between 15 and 25 K. The emissivity index is fixed for simplicity, to keep the number of adjustable parameters of the model minimal. The PAH emission is described by an empirical template for simplicity: we use the mid-IR spectrum of the M17 PDR. The contribution of PAHs to the total IR of the diffuse ISM is fixed according to the observed SED of the Milky Way cirrus emission. In the birth clouds the contribution of PAHs to the total IR is allowed to vary (more details are given in da Cunha, Charlot & Elbaz 2008).

BENDO: Did you test your model fitting code on model spectra without some SED data points (similar to the tests performed with observational data)?

DA CUNHA: Yes, we did such tests in da Cunha, Charlot & Elbaz (2008), to test how well we can recover known model parameters from a set of photometric observations. We have not done this in the context of higher redshift galaxies ($z \sim 2$) and two-dimensional pdfs as I showed in this talk, but this is definitely a test we plan to do in the near future.

SCHAERER: I have a comment regarding the contribution from "old" stars to the IR emission. One has to be careful: I suppose that by "old" you mean younger than ~ 10 Myr? Remember that stars older than this still contribute to the UV. That may explain the very large contribution of "old" stars you find.

DA CUNHA: Indeed that is a good point. By "old stars" I mean stars older than 10 Myr, which have migrated from the stellar birth clouds into the diffuse ISM component. These stars still radiate a large amount of non-ionizing UV radiation which heats the dust. But even stars with little UV emission (typically older than 100 Myr) still contribute to the dust heating in a significant way. But I agree that if we considered a large time-scale, the fraction contributed to the IR luminosity might be smaller. The main point of the plot I showed was to emphasize that a non-negligible fraction of the total IR is not powered by recent star formation, and this should be taken into account when deriving SFR from the observed IR luminosity.