Dust and Nebular Emission in Star Forming Galaxies

Pasquale Panuzzo (panuzzo@sissa.it)
S.I.S.S.A., Via Beirut 4, I-34014 Trieste, Italy

Alessandro Bressan and Gian Luigi Granato
Osservatorio Astronomico, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy

Laura Silva
Osservatorio Astronomico, Via G. B. Tiepolo 11, I-34131 Trieste, Italy

Luigi Danese
S.I.S.S.A., Via Beirut 4, I-34014 Trieste, Italy

Abstract. Star forming galaxies exhibit a variety of physical conditions, from quiescent normal spirals to the most powerful dusty starbursts. In order to study these complex systems, we need a suitable tool to analyze the information coming from observations at all wavelengths. We present a new spectro-photometric model which considers in a consistent way starlight as reprocessed by gas and dust. We discuss preliminary results to interpret some observed properties of VLIRGs.

1. Introduction: why we care about nebular emission

A common property of star forming galaxies is the presence of emission lines in the spectrum. Emission lines are produced by gas that is ionized by UV radiation emitted from young massive stars. Star-forming regions are the sites where the nebular emission is produced, but these regions are also dusty environments. It seems a natural goal for a model of star-forming galaxies to treat contextually the nebular emission and dust processing.

We present the implementation of nebular emission calculation in the spectrophotometric code GRASIL (Silva et al., 1998). GRASIL is a code built to simulate the SED of galaxies including a careful treatment of starlight dust reprocessing.

The study of emission lines with GRASIL will give us many further constraints about:

- The dust obscuration: the optical thickness of star-forming regions can be derived from line ratio while it is very difficult to constrain optical thickness of ISM only from continuum.

- The star formation rate: emission lines are believed to be powerful SFR estimators. We can now compare SFR derived from nebular lines with the results from FIR, UV etc.
2. The model

In our model, the galaxy is composed by two main components: the bulge and the disk. Dust within the disk is divided in: i) molecular clouds (MCs), where the star formation is active, ii) diffuse medium (or cirrus).

Young stars are supposed to be born into the MCs, and leave them progressively as their age increases. This is modelled by considering that a suitable fraction of the light of SSP is radiated inside the MCs. This fraction is a function of age, parametrized by an escaping time.

So we have two populations: A) young stars inside MCs, B) older stars outside MCs.

A molecular cloud is modelled as a thick spherical shell of dense gas (and dust) around a central point source representing all the star content of the cloud. The MCs, as well as old stars, are embedded in the diffuse medium. For more details on energy transport, refer to Silva et al. 1998 or Silva et al., this conference.

To calculate emission lines we used the photoionization code CLOUDY 94 (Ferland, 1996).

We built a library of HII regions in order to avoid the computation of entire nebular emission via CLOUDY at every run of the code GRASIL.

The HII regions of the library are calculated for different density, metallicity and radii. The SEDs of ionizing sources of HII regions are obtained by integrating the light of each of the two populations for several assumption of escaping time and IMF.

The SEDs of ionizing sources are parametrized by the number of ionizing photons for HI, HeI and OII (Q(H), Q(He), and Q(O)). Q(H) gives the mass of ionized gas, while the ratios Q(He)/Q(H) and Q(O)/Q(H) are related to the hardness of ionizing flux and to the degree of ionization. In table I it is reported the list of computed lines.

GRASIL calculates the Qs of each population (inside and outside the MC), interpolates on the library of HII regions, and computes the nebular emission for each population. Then, the nebular emission is extincted in the same way as the population that produced it.

3. An application to Very Luminous InfraRed Galaxies

VLIRGs ($L_{IR} \geq 10^{11.5} L_\odot$) are the most powerful star forming galaxies at low redshift. Recent results show that: VLIRGs do not follow the Meurer's relation $L_{FIR}/L_{FUV}$ versus UV spectral index $\beta$ (Meurer et al., 1999; Meurer et al., 2000); SFR computed from H$\alpha$, even corrected for extinction, is always lower than SFR derived from FIR (Poggianti...
Table I. Computed lines: Hydrogen recombination lines (upper pannel), Helium and metal lines (lower pannel)

| Line       | Wavelength (Å) |
|------------|----------------|
| Lyα        | 1216           |
| Lyβ        | 1025           |
| Lyγ        | 972            |
| Lyδ        | 949            |
| Ly937      | 937            |
| Ly930      | 930            |
| Hα         | 6563           |
| Hβ         | 4861           |
| Hγ         | 4340           |
| Hδ         | 4102           |
| Paα        | 18752          |
| Paβ        | 12819          |
| Paγ        | 10939          |
| Paδ        | 9546           |
| Brα        | 40515          |
| Brβ        | 26254          |
| Brγ        | 21657          |
| Brδ        | 19447          |
| Pfα        | 3970           |
| Pfβ        | 3889           |
| Pfγ        | 3835           |
| Pfδ        | 3798           |
| HeII 1640  | 1640           |
| HeII 1217  | 1217           |
| HeII 1085  | 1085           |
| HeII 9686  | 9686           |
| HeII 3203  | 3203           |
| HeII 2733  | 2733           |
| [CI]609µm  | 609            |
| [CI]5199   | 5199           |
| [NI]10400  | 10400          |
| [Ni]5755   | 5755           |
| [NiII]122µm| 122            |
| [NiII]265µm| 265            |
| [NiII]2141 | 2141           |
| [OH]13µm   | 13             |
| [OH]1663   | 1663           |
| [OII]5577  | 5577           |
| [OIII]15µm | 15             |
| [OIII]2471 | 2471           |
| [OIV]26µm  | 26             |
| [NeII]15µm | 15             |
| [NeII]4671 | 4671           |
| [NeII]3636 | 3636           |
| [NeII]9686 | 9686           |
| [NeII]3343 | 3343           |
| [MgII]1815 | 1815           |
| [MgII]1280 | 1280           |
| [SII]10330 | 10330          |
| [SII]6731  | 6731           |
| [SII]3727  | 3727           |
| [SIII]952 | 952            |
| [ArIII]7135| 7135           |

& Wu, 2000). Can the above problems be solved with a correct picture of the obscuration?

We have simulated with our code a starburst galaxy (barionic mass of $5 \times 10^{10} M_\odot$) with a quiescent star formation lasting all its history, plus a final (analytical) burst. We supposed that, as the burst begins, half of total ($1.2 \times 10^{10} M_\odot$) gas is under molecular form, and a fraction (from 70% to 99%) of it is converted in stars during the burst. As the molecular gas is consumed during the burst, the MCs become more and more transparent. This is to mimic the consumption of the gas and the feedback of SNe. The initial optical thickness of MC is chosen to reproduce observed eq. width of Hα+[NII] and Hβ (-62.5 Å and 0.7 Å) and the ratio $L_{FIR}/L_V$ (88, Poggianti et al., 2001). The time evolution of the model is shown in figure 1.

The temporal evolution in the $\beta$-FIR/FUV plane can be described in three phases:

1) VLIRG phase: the burst is very obscured; IR emission comes from the burst while UV comes from the disk. There is no correlation between UV and IR because they come from different component of the galaxy.

2) UV-bright phase: the burst has almost consumed the gas and the MCs become transparent; the model moves towards Meurer’s relation.

3) Final phase: the burst is aging and the model departs from the relation. The galaxy can not be observationally selected as a starburst any longer.
Figure 1. Left: The time evolution of the model in $\beta$-FIR/FUV plane. Observed data are ULIRG observations (filled squares, Meurer et al. 2000) and UV-selected starburst (open circles, Meurer et al. 2000). Different paths correspond to different fraction of gas converted in stars. Right: SFR derived from H$\alpha$ corrected for extinction with Balmer decrement versus SFR from FIR.

In initial VLIRG phase, H$\alpha$ corrected for extinction from Balmer decrement H$\alpha$/H$\beta$ can be a wrong estimate of the “true” H$\alpha$ (and then of the SFR, see fig. 1 right). In fact in this phase H$\beta$ can be dominated by the population outside MCs affected by a low extinction; then, the Balmer decrement is altered because of the selective extinction. This effect can explain the low $L_{H\alpha}/L_{bol}$ observed in VLIRGs (Meurer & Seibert, 2001). Concluding, we are able to interpret different UV, optical, IR properties of obscured galaxies within a unique star formation selective (in age) extinction scenario. We found that the relation $\beta$ – FIR/FUV is not unique in the obscured phase. For the same reason, the correction of H$\alpha$ from balmer decrement can be wrong in this phase.

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