THE SPECTRAL ENERGY DISTRIBUTION OF SPIRAL GALAXIES

H. R. Schmitt

1 Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD21218, USA

Abstract

Spectral energy distributions (SEDs) are some of the most important sources of
information for galaxies, especially for high redshift ones. Here we review recent work on
the subject. We discuss the integrated spectra of galaxies of different morphological and
activity type, their application to derive K-corrections and classification of high redshift
objects. We also discuss the radio to X-rays SEDs of Seyfert 2’s, Starbursts and normal
galaxies, their behavior as a function of the waveband, their bolometric fluxes and the
wavebands that contribute most to it.

1 Introduction

With the increasing number of surveys of high redshift galaxies, it is necessary to have a good
knowledge of the integrated properties and the stellar population of local galaxies, since this
is virtually the only information available for distant objects [5],[7],[8]. Integrated spectra of
local galaxies can be used for the spectroscopic classification of galaxies discovered through
radio, X-rays and infrared surveys, to compute K-corrections, galaxy number counts, and to
determine the redshifts or morphological types of distant objects based on their colors.

Similarly, the knowledge of the continuum energy output of galaxies over a broad wavelength
range is important for the understanding of the physical processes responsible for the emission
at different wavebands. It is also a means to distinguish between objects of different activity
class, and for the determination of accurate bolometric fluxes.

2 Integrated Spectra of Galaxies

Some of the first and most used integrated spectra of galaxies and K-corrections were the ones
compiled by Pence (1976) and Coleman et al. (1980) [3],[2]. These were the best template
spectra available for several years. However, they were based on inhomogeneous samples of
ultraviolet and optical spectra of galaxies, and, in some cases, were made combining spectra of
galaxies and stars.

Nowadays, the best set of spatially integrated template spectra of galaxies available in the
literature is that of Kennicutt (1992) [2]. It includes 55 galaxies of different morphological
and activity types, observed from the ground with apertures of \( \approx 90'' \times 90'' \), which in most
cases includes the entire galaxy. The only problem with these spectra is that they span only a
Figure 1: Comparison between Kennicutt (1992) and Kinney et al. (1996) Sb (top) and S0 (bottom) templates. The templates were normalized to the flux at $\lambda 5500\text{Å}$ and displaced by a constant for clarity.

short wavelength range $\lambda 3650-7000\text{Å}$, and cannot be used for the optical study of high redshift galaxies ($z > 1$).

The other set of template spectra available in the literature is that of Kinney et al. (1996) [14], which includes both ground based and satellite ultraviolet (IUE) data of 69 galaxies (quiescent and starburst galaxies), observed with matched apertures ($10'' \times 20''$). Although these spectra were observed with an aperture much smaller than that used by [12], they cover the wavelength range 1200-10000 Å and can be used in the study of higher redshift galaxies (up to $z \approx 2$ in the B band and even higher for redder wavebands).

In Figure 1 we show the Kinney and Kennicutt S0 (bottom) and Sb (top) templates. The comparison between the equivalent widths of metal and HI lines, as well as continuum shapes, indicates that both sets of S0 templates are very similar and the Kinney templates do not suffer from aperture effects. In the case of Sb galaxies, the comparison shows that the Kinney template has an older stellar population and redder continuum, indicating that the use of smaller apertures probably included most of the bulge emission and missed part of the emission from young stellar populations in the disk.

Figure 1 also illustrates the evolution of the templates characteristics as a function of the morphological type. Early type galaxies (ellipticals, S0’s and Sa’s) are characterized by strong metal absorption lines (e.g. Ca H and K around $\lambda 3900\text{Å}$ and the Mg lines around $\lambda 5200\text{Å}$) and a large amplitude 4000Å break, typical of old stellar populations. As we move to late type galaxies (Sb’s, Sc’s, Sd’s and irregulars), the intensity of the metal absorption lines decreases, we start to see strong high order HI lines in absorption (around 4000Å), typical of young stars, the amplitude of the 4000Å break decreases, and emission lines appear (e.g. Hα, [NII] and
Figure 2: U-I color versus redshift, predicted using the Kinney templates \[14\] and assuming no evolution.

Figure 2 shows the predicted colors of galaxies of different morphological type (in the case of quiescent galaxies) and reddening (in the case of starburst galaxies), created by redshifting the templates, with no evolution, and measuring their colors. These kinds of plots can be used to determine the morphological type of galaxies, once their redshifts and colors are known. In the case where the morphological types and colors are known, it can be used to determine the redshifts.

For other applications of these templates, like K corrections, number counts of galaxies, determination of redshifts based on colors and star formation properties of galaxies, we suggest the following references \[4\], \[7\], \[12\], \[13\], \[14\].

3 Spectral Energy Distributions

Most of the previous works in this area (e.g. \[6\], \[9\], \[19\], \[23\]) were concentrated on the study of the nuclear emission of high luminosity objects, like Quasars and Seyfert 1 galaxies, objects for which it is relatively easy to find large quantities of data on several wavebands, and where the nuclear emission dominates over the host galaxy flux, so aperture effects are not a problem for the analysis.

Until recently, very little had been done on the SEDs of Starbursts, Seyfert 2’s, LINER’s and Normal galaxies, to study of the properties of the entire galaxy and not only the emission from the nuclear region, like in high luminosity AGN’s. Some works like \[15\], \[16\], \[21\] presented radio to X-ray multiwavelength analysis of Seyfert 1’s, Seyfert 2’s, Starbursts, Quasars and normal galaxies. Although some of these works dealt with large samples, they only used relatively sparse data points to cover the entire frequency range. Also, in the case of \[21\], the authors applied corrections to include the flux of the entire galaxy in the analysis, which is uncertain, and did not distinguish between normal and Starburst galaxies.

Here we discuss the SEDs of normal, active and Starburst galaxies presented by Schmitt et al. (1997) \[20\]. These SEDs were created using measurements collected from large databases.
Figure 3: SEDs of normal spiral galaxies, normalized to the flux at $\lambda 7000\text{Å}$. The figure also shows the division between different wavebands: radio ($\log \nu < 10$), mid/far-IR ($11 < \log \nu < 13.5$), near-IR ($13.5 < \log \nu < 14.5$), optical/ultraviolet ($14.5 < \log \nu < 15.5$), X-rays ($\log \nu > 15.5$).

of X-rays, ultraviolet, infrared and optical, spanning over 10 decades in frequency ($10^8$—$10^{18}$ Hz).

3.1 Data and Aperture Effects

In Figure 3 we show the individual SED’s of spiral galaxies, normalized to the flux at $\lambda 7000\text{Å}$, which will be used to illustrate the sources from which the data were obtained. This Figure will also be used to explain possible aperture effects and the processes responsible for the emission at different wavebands.

The data used in the construction of these SEDs is described in [20]. It consists of ultraviolet IUE and ground-based spectra for 59 galaxies, obtained with similar apertures ($10'' \times 20''$) by [14], [17], [22], and literature near-IR data (J,H,K and L band photometry) also obtained with similar apertures. For the X-ray data we used Einstein observations (0.2-4Kev) from the literature, and the mid/far-IR data was obtained from the IRAS catalog, both of which include emission from the entire galaxy. The radio data were obtained from the literature, and in some cases only data observed with large apertures could be found. One gap in these SEDs is data in the millimeter waveband, which was available only for 3 Seyfert 2 galaxies in our sample.

The emission in the different wavebands originates from different processes in different types of galaxies. The X-ray originates from thermal emission from gas heated by supernovae remnants in the case of normal spirals and Starbursts, and mostly from cooling flows in normal ellipticals. In Seyfert 2’s, and, possibly in LINER’s, it originates from the accretion disk. The ultraviolet emission is dominated by young stars, can have some contribution from the AGN in the case of Seyfert 2’s and LINER’s, but has very little contribution from old stars. The visual and near-IR parts of the SEDs are dominated by the old stellar population. The mid/far-IR
emission comes from ultraviolet and visual radiation absorbed by dust and reradiated in this waveband. The radio emission originates from free-free emission in HII regions and supernova remnants in normal spirals and Starbursts, is mostly synchrotron emission from the active nucleus in Seyfert 2’s and LINER’s, while in ellipticals it can originate from free-free emission in a cooling flow or also synchrotron emission from an active nucleus.

As said above, we tried as much as possible to use measurements obtained with apertures similar to that of the IUE (10” × 20”), which were relatively easy to obtain for the ultraviolet, visual and near-IR wavebands. However, in the case of X-rays, mid/far-IR, and for some of the galaxies in radio, we had to use measurements that included the entire galaxy. We estimate that the use of such large aperture data does not influence the results significantly in the case of Seyfert 2’s and Starbursts, because most of the light in these objects is concentrated in the nuclear region, but it may present some problem in the case of the lower luminosity objects (LINER’s and normal galaxies).

Figure 3 demonstrate some of the effects caused by the use of data with large apertures to construct the SEDs of normal spirals. For X-rays, only data for 2 normal spirals were available. The object with the strongest emission is NGC598, which is a nearby late type spiral galaxy. The emission in this waveband is strongly influenced by the emission from HII regions and supernova remnants along the galaxy disk, which makes this portion of the SED look much stronger than it actually would be if observed with an aperture similar to that of IUE. In the case of elliptical galaxies, the X-ray emission can be influenced by cooling flows. A similar problem also happens in the radio waveband, where large aperture data can include emission from HII regions and supernova remnants in the disk of spirals, while in ellipticals it can be strongly influenced if the galaxy contains a radio loud nucleus, or if it is in the middle of a cooling flow. The mid/far-IR waveband can be affected by two different effects, the amount of dust in the galaxy and the dust temperature. Since dust absorption is more effective at shorter wavelengths, galaxies with stronger ultraviolet emission have stronger mid/far-IR emission (hotter temperatures) than galaxies with similar dust content, but redder stellar population.

### 3.2 X-ray to Radio SEDs

The galaxies were separated in six groups, according to the morphological and activity type: normal spirals (6 galaxies), normal ellipticals (7 galaxies), LINER’s (5 galaxies), Seyfert 2’s (15 galaxies), Starbursts of low reddening (11 galaxies) and Starbursts of high reddening (15 galaxies). The last two groups will be called SBL and SBH, respectively, hereafter. The SBL group comprises those Starbursts with E(B-V)<0.4, while the SBH’s are those with E(B-V)>0.4 (assuming the values given by [1]).

In Figure 4 we show the average SED’s of these six groups of galaxies, where the errorbars represent the standard deviations and can be used as a guide of how similar, or different the individual SED’s are in different waveband. It can be noticed that the SEDs of normal spirals show a considerable spread in the ultraviolet to near-IR, probably due to their different morphological type, where some of them have HII regions close to the nucleus, which increases the ultraviolet flux. As discussed above, there were X-ray data available only for two of these galaxies and one of them is a large nearby object, which makes the X-ray SEDs very different between the two. The emission in the mid/far-IR has a large spread, which can be attributed to both aperture effects and the amount of dust in the galaxies. Finally, the SEDs are very similar in the radio waveband, with the exception of NGC598, discussed above, which was observed with a large aperture.

The SEDs of elliptical galaxies unlike the spirals, are very similar in the ultraviolet to near-
IR range, consistent with an old, red stellar population, and the presence of the UV turn-up. The situation changes when we go to the mid/far IR and radio wavebands, where there is a large difference between individual SEDs. The large spread in mid/far-IR properties can be attributed to different amounts of dust [11], while in the radio, it can be due to cooling flows or the existence of a radio loud nucleus. In part, the differences in the radio emission could also be due to the different apertures through which the observations were taken. The X-ray fluxes of these galaxies also show some differences, which are due to the large aperture through which they were observed, including the contribution from sources like X-ray binaries and the hot gaseous halo [11], which extend for much more than 10″ × 20″.

Seyfert 2 galaxies have similar SEDs in the near-IR to radio wavelengths. However, when we move to the visual and ultraviolet range, the SEDs start to show a considerable variation from object to object, being as red as a normal galaxy or as blue as a Starburst. This increasing blueness can be due to an increasing contribution from the AGN continuum to the spectrum,
Figure 5: Comparison between the average SED of Seyfert 2, high and low reddening Starbursts (top left); LINER’s, high and low reddening Starbursts (top right); normal spirals, LINER’s and Seyfert 2’s (bottom left); and normal spirals, high and low reddening Starbursts (bottom right).

or to the presence of circumnuclear HII regions. Figure 4 also shows that there is a steep drop in the emission from far-IR to the millimeter waveband ($\log \nu \approx 11.5$), which represents the end of the thermal emission from radiation reprocessed by the circumnuclear torus, and maybe HII regions in the galaxy disk, and the beginning of the non-thermal, synchrotron radio emission.

The LINER SEDs are similar in the radio and visual part of the spectrum, but have some spread in mid/far IR and ultraviolet wavebands. The mid/far IR spread can be explained using the same arguments used above for normal galaxies, while the difference in the ultraviolet band can be due to an increasing contribution from a population of young stars, or the active nucleus. The emission in the X-ray has some spread due to the large aperture.

The SBL’s and SBH’s have similar SEDs over the entire energy spectrum. The SBL’s have a small spread in the ultraviolet, while for SBH’s the most noticeable spread is in the radio and far IR bands. The X-ray emission, contrary to what is observed for the rest of the galaxies, drops abruptly relative to the ultraviolet emission in both types of Starburst galaxies. The emission in the X-ray comes mostly from SNR, concentrated in the Starburst region. When comparing the SEDs of SBL’s and SBH’s (see also Figure 5), we notice that SBL’s have stronger ultraviolet emission than SBH’s, while in the far-IR the opposite happens. This difference is due to the fact that the ultraviolet and visual radiation absorbed by dust in SBH’s is reradiated in the far-IR.

In Figure 5 we compare the SED’s of galaxies with different activity class. On the top left panel we plot the Seyfert 2’s, SBL’s, and SBH’s, which have similar SEDs in the radio to near-IR waveband, but start to diverge in the visual and ultraviolet parts of the spectrum.
In this waveband the Seyfert 2’s are mostly dominated by the old stellar population and have the reddest energy distribution, probably due to the obscuration of the AGN continuum by the torus. On the other hand, SBH’s and SBL’s are increasingly bluer, and dominated by the young stellar population. These SEDs also differ in the X-ray waveband where Seyfert 2’s are brighter. The comparison between the SEDs of LINER’s, SBH’s and SBL’s is made on the top right panel of Figure 5. The only waveband region where these SEDs are similar is from the visual to the near-IR, where they are normalized. The LINER’s SED is systematically fainter at all other bands.

The SEDs of LINER’s, Seyfert 2’s, and spirals are compared on the bottom left panel of Figure 5. LINER’s and spirals have very similar SEDs, only differing in the mid/far-IR and ultraviolet, where the spirals are fainter, and in the far-IR where LINER’s are brighter. The similarity between these two SEDs is due to the fact that the nuclear luminosity of LINER’s is low, so their SED are dominated by emission from the host galaxy. Seyfert 2’s and spirals SEDs are similar only in the near-IR to visual waveband, where they are dominated by the old stellar population, with the Seyfert 2’s being much brighter than the spirals in the IR and ultraviolet. The SEDs of spirals, SBL’s and SBH’s are compared on the bottom right panel of Figure 5. In this panel we can see the difference between SEDs dominated by old (spirals) and young stellar populations (SBH’s and SBL’s). The only wavelength region where these SEDs can be considered similar is in the visual to near-IR, again the region where they are normalized (Starbursts have some contribution from old stars in this region). The spirals are fainter in any other waveband.

3.3 Bolometric Fluxes

Another important point in the study of the SEDs of galaxies is their use in the measurement of bolometric fluxes, which was done by integrating the SEDs over the entire wavelength range. Some of the results are presented in Figure 6, and we direct the reader to Section 8 of [21] for a better description of the results. In this Figure we compare the bolometric flux with the flux density at 25μm (left) and 7000Å (right). The bolometric flux of both Seyferts and Starbursts show a good correlation with the flux density at 25μm, while LINER’s and normal galaxies have
a large spread. We also notice that the bolometric flux of Seyferts and Starbursts have a large contribution from emission in this waveband, as well as from other infrared bands, indicating that the bolometric flux of these objects is dominated by reradiation of visual and ultraviolet emission absorbed by dust.

On the other hand, when we compare the bolometric flux with the flux density at 7000 Å, we see that all galaxies present a good correlation, but there is a clear separation between the normal galaxies and the active ones (Seyfert 2’s and Starbursts). The flux in this waveband is the most important contributor to the bolometric flux of normal galaxies, which are dominated by emission from the old stellar population, but does not contribute significantly to the bolometric flux of the more active objects.

4 Summary

In this contribution we reviewed some of the works on the spatially integrated Spectral Energy Distributions of nearby galaxies. This data have several applications for the study of nearby and distant galaxies, like their stellar population, bolometric luminosities, classification of distant objects and K-corrections, among others.

Some of the important points to be summarized here are that galaxies of similar morphological, or activity class have similar SEDs. When comparing the SEDs of Seyfert 2’s with those of Starbursts, we see that Seyfert 2’s are redder in the optical and ultraviolet, but stronger in the X-rays. The mid/far-IR emission of Seyfert 2’s and Starbursts is stronger than that of normal galaxies and LINER’s. This fact has a strong influence in the galaxies bolometric flux. Seyfert 2’s and Starbursts bolometric flux is dominated by infrared emission from dust reradiation, while in normal galaxies the bolometric flux is dominated by the emission from the old stellar population.

Acknowledgements. We would like to thank D. Calzetti for comments. This work was supported by NASA grants NAGW-3757, and AR-06389.01-94A.

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