Chapter 4

Extragalactic Survey using
GALEX-Spitzer Matching fields

4.1 Introduction

We further extend the work by introducing a new approach to refine the estimate of
number counts of galaxies by using multiwavelength analysis to find more number of
sources at fainter side. The European Large Array ISO (Infrared Space Observatory)
Survey (ELAIS) fields were chosen specifically to analyse extragalactic sources in a
location where the Galactic cirrus emission is exceptionally low (Oliver et al. 2000)
[54]. Of these, the N1 field (ELAIS-N1) has been intensively observed by a wide range
of instruments over different wavelengths with optical associations of ELAIS sources in
N1 region by the Isaac Newton Telescope (INT) Wide Field Survey (Gonzalez et al.
2005) [26]. J and K surveys were made by the STELIRCam instrument (Vaisanen et al.
2002; Rowan et al. 2004) [73, 58] with additional observations including a deep Hubble
Space Telescope Advanced Camera for Surveys (HSTACS); a Very Large Array (VLA)
radio survey at 20 cm (Ciliegi et al. 1999) [14]; Chandra observations of the central
region of N1 (Manners et al. 2003) [42]; and partial coverage by the Sloan Digital Sky Survey (Adelman, 2008) [1].

The N1 field is a northern ELAIS field centered at $16^h10^m01^s, +54^\circ30'36''$. This field is also covered by Spitzer Space Infrared Telescope SWIRE survey. Observations from Spitzer (Werner, 2004) [76] detected a total of 114,658 objects in this field (Mauduit et al. 2012) [46], most of which are galaxies.

The ELAIS-N1 field was also observed in two ultraviolet (UV) bands (FUV:1350 - 1800 Å and NUV:1800 - 2000 Å) by the Galaxy Evolution Explorer (GALEX). We have examined the positions of the Spitzer-detected galaxies, in order to understand their distribution with magnitude as well as to find out the contribution of these galaxies to the extragalactic background in the UV.

4.2 Observations of GALEX and Spitzer

The ELAIS is a key project of the ISO mission and covered about 12 square degrees divided into several different fields. One of these fields Spitzer observed was the N1 field centered at $16^h10^m01^s, +54^\circ30'36''$ as part of the Spitzer Extragalactic Representative Volume Survey (SERVS) with an average of 1400 s observation time per pixel ($\sim2''$ resolution). Point sources in the IRAC 3.6µm and 4.5µm (Infrared Array Camera: Mauduit et al. 2012) [46] observations of the region have been extracted into a merged catalog (available from the Spitzer archive\footnote{http://sha.ipac.caltech.edu/applications/Spitzer/SHA/}) containing 114,658 objects. We identified and removed stars from the source catalog using the prescription of Groe-
Table 4.1: GALEX Observation Log

<table>
<thead>
<tr>
<th>Title Name</th>
<th>R.A (deg)</th>
<th>Dec (deg)</th>
<th>NUV exposure time(s)</th>
<th>FUV exposure time(s)</th>
<th>Observation period (yy/dd/mm)</th>
<th>NUV visits</th>
<th>FUV visits</th>
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<td>ELAISN1_00</td>
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<td>54.9</td>
<td>26877</td>
<td>28704</td>
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<td>26</td>
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<td>20762</td>
<td>6088</td>
<td>07/06/04</td>
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<td>06</td>
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<td>53.8</td>
<td>17790</td>
<td>3222</td>
<td>07/06/04</td>
<td>17</td>
<td>06</td>
</tr>
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<td>55.0</td>
<td>18242</td>
<td>5412</td>
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</tbody>
</table>

newegen et al. (2002) [27] and Fadda et al. (2004) [22] based on the stellarity index value (CLASS_STAR is 0 for a galaxy-like object), leaving 87,625 galaxies in the field.

GALEX took 9 deep observations of the ELAIS-N1 region with a minimum exposure of 17000 s in the NUV band and 3000 s for FUV band (Table 1.1). Both the GALEX and Spitzer observations are marked on a 100 µm image from the Infrared Astronomical Satellite (IRAS) mission in Figure 4.1. The E(B-V) variation in the field is 0.01 - 0.05 magnitude (Schlegel et al. 1998) [62], which corresponds to an optical depth of 0.08 -
Figure 4.1: IRAS 100µm map of the region in equatorial coordinates. The GALEX fields are marked as circles having radius 0.55° (yellow) and Spitzer IRAC field is marked as box (green)

0.40 in the UV. The standard GALEX pipeline (Morrissey et al. 2005) [55] provides a catalog of UV sources based on the detection and flux measurements with SExtractor (Bertin et al. 1996) [8] for each flux calibrated image. But, given the GALEX point spread function of about 5″, limits resolution of source identification of the star/galaxy in deep fields (Xu et al. 2005; Hammer et al. 2010) [78, 29]. A new separate catalog was produced for each of the GALEX observations and we then consolidated the individual catalogs. If two sources were within the GALEX spatial resolution (5″), we recognised them as duplicates and averaged the fluxes after weighting each by its exposure time. Note that there were no cases where the sources had very large discrepancies in fluxes, indicating them to be different sources. This left a total of 58, 245 sources of which
Figure 4.2: Percentage of IR sources detected by GALEX versus IR flux at 4.5µm in N1 field. Only 40.7% of the Spitzer sources have NUV counterparts and 33.6% have FUV in GALEX source catalog.

37,548 were identified as galaxies based on the STAR_CLASS parameter (<0.85) as defined by the SExtractor pipeline.

We have compared GALEX source catalog with high resolution Spitzer catalog in N1-field and found that almost all of the GALEX cataloged sources have Spitzer analogs (98.7% in the FUV; 98.4% in the NUV) but the converse is not quite true. Only 40.7% of the Spitzer sources have NUV counterparts and 33.6% have FUV in GALEX source catalog. The percentage of the IR galaxies at 4.5 µm detected by GALEX is a strong function of the brightness and there is a sharp dropoff in the number of sources detected, fainter than 1 microjansky (Figure 4.2). However, the high source density in deep images and the relatively large GALEX PSF result in a non-negligible fraction of object blends in the pipeline catalogs, i.e., two or more objects in close proximity.
Figure 4.3: FUV and NUV number counts of galaxies in 9 GALEX DIS observations in ELAIS-N1. '+' and '*' represents NUV and FUV number counts of galaxies. In this work, have extended the limit of source identification down to about 27th magnitude in both the FUV and the NUV bands.

Figure 4.4: The results are compared with previous NUV number counts. The number counts are consistent with Xu et al (2005) & Hammer et al (2010) at brighter end and is higher than Gardner et al (2000) at fainter side.
on the sky are considered to be a single source (Hammer et al. 2010) [29]. We found that about 25% of the Spitzer galaxies were affected by this mix-up. The sources in the catalog may also be reported as systematically fainter due to overestimating the background level (Bianchi et al. 2007) [9].

We identified the Spitzer sources having UV flux greater than their local background flux. We have therefore used the DAOPHOTII package (Stetson, 1987) [69] to perform aperture photometry on the GALEX images with the expectation that we might stretch the GALEX source detections to fainter magnitudes. Each aperture was centered as per the Spitzer source coordinates with an inner and outer sky annulus of 5 pixels (7.5") and 7 pixels (10.5"), respectively and the source flux was calculated from the difference between the two rings. We have cross-checked it on a random set of samples from the GALEX catalog finding agreements better than 0.04 magnitude in most of the sources.
To test the robustness and reliability of the above technique, we created two simulated images, one without any sources and other with artificially introduced sources using Poisson probability function with mean and standard deviation comparable to that of the *GALEX* background image in the region. That is, artificial sources of different magnitudes were inserted at random positions in one of the simulated images. We then ran both SExtractor (with same parameters of *GALEX* pipeline) and Aperture photometry on those two images and extracted the number counts of UV sources. We did not detect any sources in the first simulated image whereas in the simulated image with fake sources, we detected same number counts in the brighter region as expected from both the methods. Consistent results obtained from repeated simulation tests by varying the noise level and source positions validated this technique.

For high Galactic latitude fields, N1-field, typical background count rates are $10^{-4}$ cts/sec/arcsec$^2$ in the FUV and $10^{-3}$ cts/sec/arcsec$^2$ in the NUV. These count rates correspond to surface brightnesses in AB mag/arcsec$^2$ of 28.8 and 27.6 in the FUV and NUV, respectively. Sources which have fluxes less than these background count rates are rejected as dubious.

To further test the sensitivity of number counts, a total of 1,62000 sources from the magnitude range 12 to 28 (900 sources per 0.1 mag) were artificially inserted on simulated images at random positions above the background level that varies between 27.7 and 28.4 mag. While extracting the sources, we observed that the SExtractor could detect the sources only up to 24.2 magnitudes, whereas the aperture photometric technique could extract the sources even at higher magnitudes up to 27.6 magnitudes,
Figure 4.6: Comparing NUV number counts with the luminosity evolution model (SB4/Lyα-flat SED model) from Xu et al. 2005 [78] and the semi-analytical model (SAM), developed by Somerville and collaborators (Somerville et al. 2012) [64]. It shows that our NUV data are consistent with existing models.

Figure 4.7: FUV number counts of field galaxies compared with existing models. The FUV data are consistent over the entire magnitude range from 20th to 27th.
beyond which a rapid decline was seen in the detection of sources as the magnitudes become comparable that of the sky background. From these simulation tests, we find that the magnitude of the sky background in any region limits the source detection by the aperture photometry whereas the inaccurate background subtraction limits the source detection by SExtractor technique.

Using aperture photometry, we have been able to determine the UV fluxes for a significant fraction of the fainter Spitzer galaxies (Figure 4.2) and have extended the limit of source identification down to about 27th magnitude in both the FUV and the NUV bands (Figure 4.3). There have been relatively fewer studies of the number counts of galaxies in the UV (Table 4.1) but our results are in good agreement with previous measurements in the respective magnitude ranges of overlap (Figure 4.4 & 4.5).

SExtractor can detect brighter end without any difficulty, but for magnitudes greater than +24.3, correction to the magnitudes are to be made because, the computations are performed on background-subtracted image. Also the background is estimated using the mean and counts using full poisson distribution rather than Gaussian.

4.3 Comparison with Number Count Models

We have compared our UV number counts with the luminosity evolution model (SB4/Lyα-flat SED model) from Xu et al. 2005 [78], which, in turn, was derived from the high redshift UV luminosity function of Arnouts et al. 2005 [4] and K-corrections from Kinney et al. 1996 [35]. We have also compared our data with the semi-analytical model (SAM), developed by Somerville and collaborators(Somerville et al. 2012) [64]. The
latter model accounts for a variety of astrophysical processes in the galaxies to yield an age-dependent attenuation function for internal dust in the galaxy and gives a better agreement with the UV-optical colors of galaxies than previous models which used a fixed attenuation curve. This is especially relevant in UV number counts which are sensitive to the dust extinction. Both sets of models yield similar predictions for the number counts of the galaxies and our results are consistent with either (Figure 4.6 & 4.7). The FUV data are consistent over the entire magnitude range from 20th to 27th but the NUV data are flatter at magnitudes greater than about 23rd, perhaps reflecting incompleteness in the data. The plotted error bar had been computed by changing the aperture radius of ±1.5 arcsec (1 pixel) for both FUV and NUV (Figure 4.5, 4.4).

We predict a total of 41 photons cm⁻²sr⁻¹s⁻¹Å⁻¹ for FUV at 1521 Å and 42 photons cm⁻²sr⁻¹s⁻¹Å⁻¹ for NUV at 2361 Å as the contribution of GALEX detected galaxies to the UV background in the magnitude range 17 - 27. Extrapolating the number counts of galaxies in UV using the luminosity evolution model (SB4/Lya-flat SED Model) and integrating down to a flux of zero, Xu et al. (2005) [78] estimated the total extragalactic UV background as 52 ± 7 photons cm⁻²sr⁻¹s⁻¹Å⁻¹ in FUV and 110 ± 14 photons cm⁻²sr⁻¹s⁻¹Å⁻¹ in NUV. Our predictions are also within the range of 40 - 140 photons cm⁻²sr⁻¹s⁻¹Å⁻¹ as derived by Armand et al. (1994) [3] at 2000 Å in the magnitude range of 15.0 - 18.5, which would have also factored the detection of galaxies in the brighter end.
4.4 Conclusions

We have shown that we can circumvent the sensitivity limit of *GALEX* in both the FUV and NUV bands if we have prior information about the sources. In this case, we use deep *Spitzer* observations of galaxies in the ELAIS fields to compute the UV fluxes of the same galaxies. The number counts that we obtained in the FUV and NUV are consistent with standard models of galaxy evolution up to 27\textsuperscript{th} magnitude adding further credence to our method. We have also found that the extragalactic contribution from these galaxies in the range 17 to 27 magnitude is about 40 photons cm\(^{-2}\)sr\(^{-1}\)s\(^{-1}\)\(\text{Å}^{-1}\) in both bands. We further carried out our investigation to other areas of the sky using the same techniques pushing the limits of extraction of the UV galaxies to fainter magnitudes.

In our sample of *Spitzer* galaxies, the red shifts range from 1.0 - 3.0 where the dust attenuation is low (Schlegel et al. 1998) [62]. Present studies of IR and UV samples shows that dust attenuation decreases at higher redshift, hence we get an increase in the number count of UV/IR sources enabling to detect larger numbers at the fainter side.