Exploring the Multi-Wavelength, Low Surface Brightness Universe

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Abstract.
Our current understanding of the low surface brightness universe is quite incomplete, not only in the optical, but also in other wavelength regimes. As a demonstration of the type of science which is facilitated by a virtual observatory, we have undertaken a project utilizing both images and catalogs to explore the multi-wavelength, low surface brightness universe. Here, we present some initial results of this project. Our techniques are complimentary to normal data reduction pipeline techniques in that we focus on the diffuse emission that is ignored or removed by more traditional algorithms. This requires a spatial filtering which must account for objects of interest, in addition to observational artifacts (e.g., bright stellar halos). With this work we are exploring the intersection of the catalog and image domains in order to maximize the scientific information we can extract from the federation of large survey data.

1. Introduction

Looking at large scale images (i.e., several degrees or more), one is immediately drawn to the high density of small galaxies, especially at high Galactic latitude, which are often strongly clustered. Interestingly enough, the vast majority of these galaxies have optical surface brightness distributions that are nearly identical to the terrestrial sky (Freeman 1970, Disney 1976). This interesting point, unless it is the manifestation of a cosmic coincidence, is most easily explained by accepting that current surveys suffer from an implicit surface brightness selection effect (see Disney 1998 for a stimulating discussion). As a result, untold numbers of galaxies remain uncatalogued with many important consequences.
For example, while the theoretical predictions of models of hierarchical structure formation have been successful in predicting the observed properties of the high redshift universe, they tend to over-predict the number of observed local group galaxies (Klypin et al. 1999). This situation can be viewed as either a failure of the models, or a failure of the observations, possibly due to selection effects. In addition, galaxies which have low surface brightness (LSB) distributions have enormous cosmological implications (e.g., Impey & Bothun 1997), yet, they are relatively unexplored, primarily due to the intrinsic selection effects in finding them. For example, LSB galaxies constitute an unknown fraction of mass (both baryonic and dark matter) which must be accounted for when determining \( \Omega \) or \( \Lambda \).

In order to address these questions, we have initiated a project to reprocess the Digitized Palomar Observatory Sky Survey (DPOSS, Djorgovski et al. 1998) optical photographic plate data in effort to find previously unknown, low surface brightness objects (Brunner et al. 2001). Our techniques are complimentary to normal data reduction pipeline techniques in that we focus on the diffuse emission that is ignored or removed by more traditional algorithms (see also, Armandroff et al. 1998). This requires a spatial filtering which must account for objects of interest, in addition to observational artifacts (e.g., bright stellar halos). As part of this project, we have developed a novel background enhancement technique to look for new low surface brightness sources (see Figure 1 for a demonstration). Additional aspects affecting low surface brightness galaxy research in the context of a virtual observatory are addressed elsewhere (see, e.g., Schombert, J. in this volume).

Figure 1. The left image is an approximately 17 arcminute square cutout of the DPOSS F plate image containing the dwarf Spheroidal Andromeda III. The image on the right is the background enhanced image generated by our software pipeline. The elongated object in the background image, which is Andromeda III, is clearly detected via this technique.
2. The Technique

Overall, the software pipeline we developed utilizes publicly available software tools, such as SExtractor (Bertin & Arnouts 1996), to generate our final candidate lists. With this technique, we can easily apply the same process to additional datasets, either individually or jointly, in a full multi-wavelength exploration of parameter space.

Briefly, our software pipeline performs the following steps.

- Pull raw DPOSS $F$ and $J$ plate scan footprints off on-line storage.
- Mosaic full plate images.
- Apply Vignetting correction to full plate mosaics.
- Process the full plates to produce a background map, an object map, and a bright star catalog.
- Process the background map using optimized convolution kernel, using the object map as a pixel mask, to detect background variations.
- Eliminate bright stellar halos using the bright star catalog.
- Combine candidate lists from J and F plates to remove candidates that arise from individual plate defects.
- Visually classify candidates according to assigned classes (e.g., planetary nebula, dwarf spheroidal galaxy, low surface brightness galaxy, etc.)

In the past, non local group LSB galaxies were identified by visually inspecting POSS-I or POSS-II sky survey plates (e.g., Schombert et al. 1995). Previously, this process, particularly automated approaches, was hampered by the unknown vignetting corrections, the plate mosaicing process, as well as the sheer amount of data that needs to be explored. As part of the Digital Sky project, a technology demonstrator for a future National Virtual Observatory, these types of problems are being tackled, and algorithmic solutions are close to being implemented. We, therefore, plan to extend the automated low surface brightness survey to target the unexplored population of low surface brightness disk galaxies (see Figure 2 for a demonstration).

The technique we have developed can be easily applied to other large imaging surveys, e.g., the SDSS and 2MASS surveys, in an effort to further explore the low surface brightness universe. In addition, this work can be naturally extended to include additional wavelength information from supplemental surveys in order to improve the source classification (see, e.g., Brunner, R. this volume) since Astronomical objects have different source characteristics, including surface brightness and morphology, at different
wavelengths. Other, complimentary projects are also being applied to the DPOSS data in order to extract the maximal amount of information from this photographic plate data (see, e.g., Sabatini et al. 2000).

Figure 2. Cutouts of low surface brightness galaxies first detected visually from POSS-II plates by J. Schombert, and later detected in HI at Arecibo.

3. Contaminants

Sometimes the background enhancement procedure picks up objects which, while interesting in their own right, are not the objects of primary interest. Primarily these objects are either planetary nebulae, stellar clusters, interacting galaxies, or galaxy clusters (see Figure 3 for a montage). All of these candidates are flagged due to the presence of low surface brightness features: the nebula itself, the combined stellar halos, the tidal interactions, and the cD envelope, respectively.

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Figure 3. Examples of some diverse types of contaminants generated by the LSB software pipeline. The upper left figure is a Planetary Nebula, the upper right figure is an open cluster. The figure on the lower left is a pair of interacting galaxies, while the figure on the lower right is a galaxy cluster.

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