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Going wider and deeper: the low surface brightness perspective

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Abstract

The low surface brightness Universe ($\mu_r \sim 28.5 - 29$ mag arcsec^{-2}) remains almost unexplored. Its analysis is a technical challenge from the observational point of view but also requires a very sophisticated data treatment. The incoming deep and wide surveys as the LSST or Euclid, will allow us to explore low surface brightness objects such as stellar haloes of galaxies, intra-cluster light or Galactic cirrus. Thus, it is necessary to develop new techniques and software procedures that improve the reduction of huge amounts of astronomical images and prevent the removal of large and diffuse astrophysical structures.

Keywords: astronomy, astronomical data analysis, sky survey, low surface brightness

1. Introduction

In the last several years there have been significant advances in detector technology, observational strategies, and data reduction techniques in order to fulfil the requirements of new ultra-deep imaging science.

Although these improvements allow astrophysicists to reach surface brightnesses fainter than 28 mag arcsec^{-2} in r-band, this is actually not significantly deeper than those reached using very long photographic integrations four decades ago (e.g., Kormendy and Bahcall, 1974). Such depths have been achieved on many scales, from large imaging surveys to small galaxy samples, or even the study of individual objects. These observational depths may be achieved either via very long exposure times on small telescopes, or by using shorter times on the largest telescopes.

Nevertheless, going beyond the $\mu_r = 30$ mag arcsec^{-2} frontier, which is equivalent to a surface brightness ~1500 times fainter than the darkest sky on Earth, is a difficult task. Only a few deep surveys have reached surface brightness structures at $\sim 29-30$ mag arcsec^{-2} (3σ, 10×10 arcsec boxes; e.g., Martínez-Delgado et al., 2010; Ferrarese et al., 2012; Merritt et al., 2014; Duc et al., 2014; Koda et al., 2015; Capaccioli et al., 2015) and even fewer studies have achieved a limit fainter $\mu_r = 30$ mag arcsec^{-2} (3σ, 10×10 arcsec boxes; e.g., Trujillo and Fliri, 2016). In this sense, we are now starting to scratch the surface of all the interesting phenomena that are observable when the Universe is explored at such depths.

Further progress in the field of low surface brightness science is difficult not because of the collection capability of the telescopes and their detectors which provide deep imaging and good photons statistics, but rather because of systematic errors. Thus, it is crucial to perform very careful data reduction and treatment of both sky and object images (for a more detailed description see the review by Knapen and Trujillo, 2017).

In this talk we are going to evaluate what do we need in order to make the best of the huge amount of data from the incoming large and deep surveys, in terms of the low surface brightness technical issues.

2. Technical challenges

The development of the low surface brightness science is held back mainly by systematic errors. It is necessary to develop new techniques and software procedures that improve the reduction of astronomical images and prevent the removal of large and diffuse astrophysical structures. This becomes crucial when dealing with massive telescopic surveys as a manual inspection of the data is not possible.

In particular, the arrival of Large Synoptic Survey Telescope (LSST, Ivezić et al., 2008) will allow us to explore low surface brightness structures in unprecedented detail ($\mu_r >$ 30 mag arcsec^{-2}). The LSST is a deep-wide-fast survey which will uniformly observe a 18000 deg^2 region about 1000 times (summed over all six bands). This means $\sim 30\,$TB of data per night or $\sim 100\,$PB in its whole lifetime. To manage all that data, it is mandatory to build automatic routines.

The first step in the process is to perform a very careful data reduction (bias and flat field). To do this properly, it is necessary to take into account any effect over the detector and/or the optical system. By subtracting of bias and overscan, we can remove the read noise contribution from the CCD and set the zero level of the camera independently of the pixel position and the observing time. Then, obtaining the so-called auto-flats from the science images rather than the common sky or dome flat fields, it is possible to remove the non-uniform response of the pixels in the camera such as those due to the vignetting and camera rotations.

The next key step is to make the sky background correction. The aim is to not confuse the light coming from the faintest extended galaxy structures with the background and, consequently, oversubtract the image. It is important to point out that a sky handling optimised for very faint point sources (i.e., that typically used in deep surveys whose aim is the detection of high-z galaxies) is inappropriate as, for instance, it could cause holes (i.e., oversubtraction) around the extended objects as a result of very aggressive sky subtraction. This is the case in some deep surveys such as the Canada-France-Hawaii Legacy Survey (CFHTLS, Goranova et al., 2009) or the HST eXtreme Deep Field (Illingworth et al., 2013). Another aim of careful sky subtraction is to produce a proper mask over the field of view in order to avoid any undesirable light over the target (and the sky) from foreground objects. There are a variety of systematic problems that significantly affect the background level of the images depending on the required imaging depth, such as fringing, ghosts, flat fielding residuals, gain differences between chip amplifiers, Galactic cirrus, etc.

Another main issue in low surface brightness data is the light scattered in the atmosphere and in the telescope. The importance of correcting for light scattering is well documented (e.g., Sandin, 2014, 2015; Trujillo and Fliri, 2016) but the correction process is challenging. We need to accurately characterise the point spread function (PSF) of the images over an extension as large as possible to remove the scattered light produced by stars and galaxies in the field. This can be done combining very bright (saturated) and fainter stars in different filters in order to obtain a specific extended PSF for each field and in each band. Hence, every PSF image has the angle, field, and wavelength dependence built into its form.

When building a PSF, two additional factors may play an important role: the assumed sky background level, and the scattered light from surrounding objects. Scattered light also affects the sky background, so a correct PSF deconvolution of an extended object like a galaxy is crucial in order not to consider background and scattered light emission as a part of its internal (as a halo or a thick disc) or external (as a tail or a stream) structure.

The variety of systematic problems in low surface brightness data requires the use of robust statistical tools for the study of the outskirts of galaxies (see more details in Borlaff et al., 2018).

Finally, important to point out that in huge amounts of data, all these steps should be carried on very carefully as a small error of anything tag is taken (or not taken) into account in the process could be spread over the consecutive steps of the data reduction or the analysis, so it might become a large source of uncertainties or in a wrong analysis.

3. Current developments

In the recent years, there have been a few groups leading the advances in data reduction techniques in low surface brightness data. In particular at the IAC team has developed many integrated light studies by using both ground based and space telescopes (e.g., Fliri and Trujillo, 2016; Trujillo and Fliri, 2016; Román and Trujillo, 2017; Martínez-Lombilla et al., 2019; Borlaff et al., 2018). These studies paid special attention to the data reduction process, the background subtraction, and the scatter light contamination and how to reduce it by an exquisite treatment of the Point Spread Function (PSF). The transformation of the procedures showed in these studies into automatic, fast, and reproducible algorithms that produce data easy to access and visualise, is the next step to successfully face the Big Data era.

4. Concluding remarks

The incoming all sky surveys point towards a new generation researchers who should be educated with details of computer algorithms and software engineering. They need a good understanding of the algorithms and software engineering that has gone inside the tools to customise their data. Otherwise, wrong interpretations of the numbers/results will get from it. Thus, since the data is “Big”, small misunderstandings can easily go off track very fast.

At the same time it is very important to start promoting interdisciplinary networks or teams (e.g., COST, SUNDIAL, ...) with the aim of joint efforts to design and develop innovative Big Data tools. Interdisciplinary workshops and schools play also a key role in the formation of both young and senior scientists (e.g. XXX Canary Islands Winter School of Astrophysics on Big Data Analysis in Astronomy, EWASS 2019 Special Session SS34).

In the particular case of the low surface brightness science, an extra effort is needed in terms of developing automatic algorithms for handle big data sets due to the wide variety of systematic effects over the images.

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