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Extended Faint Source Detection in Astronomical Hyperspectral Images

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Abstract

The circum-galactic medium consists in gas orbiting around galaxies, whose faintness prevents any complete and easy detection. A powerful tool to detect such pattern can be found in using hyperspectral imaging. Nevertheless, detection in hyperspectral datacubes faces various problems, including well-fitted signal and noise descriptions to ensure further discrimination. A specificity of astronomical images resides in dealing with faint and very noisy signals. In this paper, we introduce a new constrained generalized likelihood ratio test adapted to the problem and a compound test to exploit most of the available information. We also investigate the use of both spatial information and multiple observations on a single scene, to enhance robustness. Numerical experiments on synthetic data are performed to quantify the gain of the different approaches. Finally, results on real hyperspectral astronomical data are presented, which may map for the first time observation of the circum-galactic medium around faint and distant galaxies.

Keywords: Hyperspectral Images, Hypothesis Testing, Generalized Likelihood Ratio, Spatial Enhancement, Multiple Observations, Astronomical Images

1. Introduction

1.1. Problem Formulation

Galaxies evolve by interaction with their environment through different mechanisms. Their immediate environment, known as the Circum-Galactic Medium (CGM), is the place to study these mechanisms. The surrounding neutral gas can be ionized and then be detectable through the Lyman-alpha emission line. This emission line is generally strong in young star-forming galaxies known as Lyman-Alpha Emitters (LAE). However, the CGM emission is extended, its morphology is unknown and its brightness is much fainter than the emission of the galaxy itself. Until recently [1] it has escaped direct detection, but with the advent of new hyperspectral imagers, it is now possible to detect the CGM at high redshift, at a time where we expect that most interaction should take place. Making progress towards an unbiased and robust detection of the CGM is then of considerable interest for upcoming astrophysical studies.

We propose in this paper a general unsupervised detection strategy for faint extended sources in Hyperspectral Images (HSI or datacube) based on hypothesis testing. This formulation is widespread and often takes the form of two hypotheses describing the presence/absence of the signal. A test is then set to choose between the two alternatives, by the mean of a *test statistic* thresholding. In the HSI, the tests are applied on spectra, so that the statistic yields a detection map. One might see the test as a *contrast function*: an image well contrasted between signal and noise implies that the test statistic is more relevant.

Furthermore, astronomical HSI present several peculiarities, including:

– They have a non-negligible degree of sparsity, and spectra mostly consist in emission or absorption lines plus an eventual smooth continuum component. This spectral sparsity is well exploited in the context of restoration [2] and source separation [3].
– Long exposure times are needed when probing faint, distant objects. The total exposure time can sum up to several hours, and generally cannot be obtained at once because of cosmic rays, saturation or night duration. Therefore, the observation is actually an average of several observations. Nevertheless, we also have acess to the individual (stacked) observations.

Keeping in mind these specificities, we now describe previous work on detection in HSI.

1.2. Previous Works in HSI Detection

When considering the detection of target spectra in hyperspectral imagery, one can select non-parametric or parametric methods. The non-parametric methods do not rely on the knowledge or estimation of the background distribution and its parameter. Some of these methods are related to order statistics, such as the FDR control [4][5], which are robust to changes in noise level but not to outliers. This makes it delicate to choose in the eventuality of a spatially wide target. Other methods from this family, specifically designed to handle outliers, rely on extreme value theory [6]. This kind of method is useful when the noise distribution is hard to estimate from the observation, and when the target is seldom encountered in the image. In our application, the target is weak, so its impact on the estimation will

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