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Improving Galaxy Cluster Photometric Redshifts

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DARK ENERGY SURVEY

Abstract

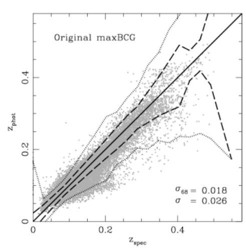
The measurement of accurate photometric redshifts (photo-z's) is an important ingredient in enabling optimal scientific analysis of the photometric galaxy cluster samples found in large optical imaging surveys like the Sloan Digital Sky Survey (SDSS) and the proposed Dark Energy Survey (DES). Here we use real SDSS cluster catalogs (taken from both SDSS single-pass and coadded imaging data) and simulated DES cluster samples to examine the accuracy of different photometric redshift estimators. In particular, we show how we can significantly improve upon the original photo-z estimates provided by the maxBCG cluster finding algorithm, by the use of empirical photo-z techniques such as neural network and "nearest-neighbor polynomial", which have been trained on cluster galaxies with spectroscopic redshifts. In addition, we examine the further improvements made possible by stacking the individual photo-z estimates of all the member galaxies of each cluster, and we measure the scaling of the resulting photo-z error with cluster richness, as well as explore the limitations in this method due to systematic errors. Finally, we present estimates of the uncertainties in cluster photometric redshifts for the proposed DES, a 5000 deg^2 survey which will use a large sample of galaxy clusters out to redshifts z > 1 to help constrain dark energy and cosmological parameters.

Improving Cluster Galaxy Photo-z's with Training Set Methods

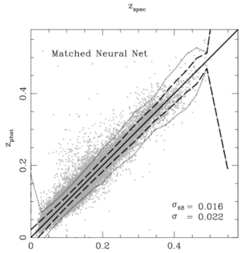
Here we use a large sample of SDSS cluster galaxies and show that we can significantly improve upon the original maxBCG cluster finder photo-z's, using training-set-based photo-z methods which are trained specifically on the cluster galaxy sample.

- **SDSS maxBCG Cluster Galaxies**
  - Clusters found from single-epoch SDSS imaging data using maxBCG method (e.g., see Koester et al. 2007, Hansen et al. 2005), which identifies brightest cluster galaxies (BCGs) and cluster member galaxies using a red sequence finding technique
  - Use sample of 75599 maxBCG cluster galaxies which also have spectroscopic redshifts to test photo-z methods
- **Comparison of Photo-z Methods**
  - Original photo-z estimate from maxBCG cluster finder itself
  - Training set methods, trained on a subset of the maxBCG cluster galaxy sample
    - Neural network: trained neural network outputs photo-z's from the input ugriz magnitudes (e.g., Collister & Lahav 2004)
    - Nearest neighbor polynomial: photo-z's from polynomial fits (in ugriz magnitudes) derived using a given object's nearest neighbors in the spectro-z training set (cf. Connolly et al. 1995)
  - Both training set methods provide significantly improved photo-z's

Cluster Galaxy Photo-z Comparison

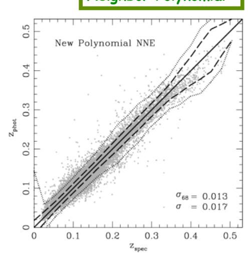


Good: original maxBCG



Better: Neural Network

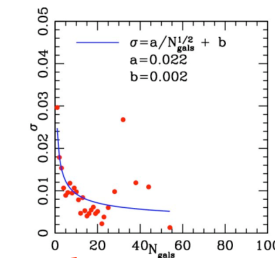
Best: Nearest Neighbor Polynomial

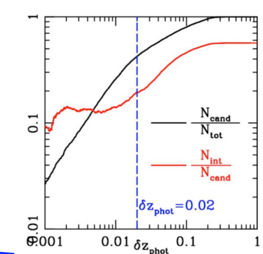


Improving Cluster Photo-z's by Stacking Members and Removing Interlopers

Here we use a preliminary cluster catalog obtained from deeper, coadded multi-epoch SDSS imaging data to illustrate how we can stack, or combine, the individual photo-z's of the cluster member galaxies to obtain an improved photo-z for the cluster as a whole. We also show how we can use solely photo-z information to reduce the systematic errors caused by including contaminating interlopers in the whole-cluster photo-z estimates.

- **SDSS (Preliminary) Coadd Cluster Sample**
  - SDSS clusters found using a modified maxBCG method (J. Hao) using the deeper, coadded 5-epoch imaging data from SDSS "Stripe 82"
  - Extends out to redshift z~0.6 (cf. z~0.3 for clusters in single-pass SDSS data)
  - 5453 clusters used which have a spectroscopic redshift for the brightest cluster galaxy (BCG)
  - Another 8764 member galaxies used which also have spectroscopic redshifts
- **Stacking Cluster Member Photo-z's**
  - Nearest neighbor polynomial (NNP) photo-z's trained using a subset of the cluster galaxy sample
  - Average the photo-z's of cluster member galaxies, after interloper removal procedure (below)
  - Adopt BCG spectroscopic redshift as true cluster redshift
  - Photo-z errors σ scale approximately as sqrt(number of member photo-z's), and σ < 0.01 per cluster readily achieved for > 5 cluster member photo-z's
- **Removing Interlopers**
  - There is a significant interloper fraction, defined by candidate cluster members whose spectro-z differs by more than 3000 km/s from the BCG spectro-z
  - Interloper fraction can be significantly reduced by a simple cut on δz_{phot}, the difference in photo-z between the BCG and the candidate cluster member
  - Cluster photo-z errors significantly improved after the interloper reduction procedure
  - Photo-z's will be integrated more directly into future maxBCG-like cluster finders applied to SDSS and DES data, in order to improve redshift estimates and reduce interloper contamination

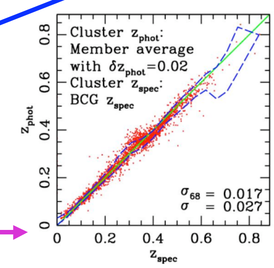




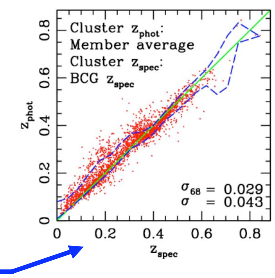
Black: cumulative candidate member fraction vs. δz_{phot} = |(member photoz)-(BCG photoz)|

Red: cumulative interloper fraction vs. |(member photoz)-(BCG photoz)|

Interlopers reduced



Original



DES Galaxy Cluster Photo-z Forecasts

One of the 4 Dark Energy Survey (DES) science key projects is to constrain dark energy cosmological parameters, using a sample of a few x 10^4 DES galaxy clusters, taking special advantage of 4000 deg^2 of overlap with the Sunyaev-Zel'dovich effect (SZE) cluster survey to be carried out by the South Pole Telescope (SPT). Below we outline DES galaxy cluster photo-z simulations, which demonstrate that the DES will provide robust photometric redshifts for typical (10^{14} solar mass) DES+SPT detected galaxy clusters, for redshifts z < 1.3, with typical photo-z errors < 0.02.

- **DES Galaxy Cluster Mock Catalogs**
  - Local cluster luminosity function (LF), luminosity-mass, and number-mass relations (within R_{200} virial region) from Lin, Mohr, & Stanford (2004)
  - Passively-evolving Pegase-2 elliptical galaxy model (from J. Annis) determines the redshift evolution of the cluster LF characteristic magnitude M* and of cluster galaxy colors
  - Cluster LF faint-end slope fixed at α = -1
  - Halo occupation number evolves with redshift as $(1+z)^\gamma$, where γ = 1
  - Flat Ω_M=0.3, Ω_Λ=0.7, h=0.7 cosmology
  - 10σ galaxy magnitude limits griz = 24.6, 24.1, 24.0, 23.65, plus 2% photometric calibration error in quadrature
- **DES Cluster Photo-z Results**
  - Sets of 20,000 mock clusters (uniformly distributed over redshifts z=0-2) with 1.0 x 10^{14} or 2.5 x 10^{14} solar masses each
  - Template-based photo-z fits, using original Pegase-2 SED
  - **Robust photo-z's for clusters to redshifts of about 1.3: 68% photo-z scatter is 0.02 or less, and tails are generally less than about 0.05 in redshift**
  - **Photo-z errors show tails at higher redshifts, though 68% photo-z scatter is generally < 0.1 out to a redshift of 2**