Photometric Redshifts for Public Data Release 1

The Photo-z Working Group

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1 Overview

J. Coupon, B.C. Hsieh, S. Mineo, A. Nishizawa, J. Speagle, and M. Tanaka participate in the photo-z production run and independently compute photo-z's. Our catalog products are available from the database and PDFs from the photo-z release page on the data release site.

- **Please carefully read the data release paper first. Problems in the photometry propagates to photo-z's.**
- **We have defined a set of common outputs from our codes (see Section 3). We also (mostly) homogenized the format of our P(z) files.**
- **We have two new quantities in the common outputs: 'best' point estimate and photo-z 'risk' (see brief note in Section 3 and photo-z release paper (in prep) for more details). `photoz_best` is likely better than the commonly used median estimates and `photoz_risk` is also better indicate of photo-z reliability than `photoz_conf`.**

2 Catalog construction and how the photo-z's are computed

1. JS collected spectroscopic, grism, and high accuracy photometric redshifts from the literature and cross-matched with HSC objects. He then computed weights to reproduce multi-color-magnitude distributions of the target galaxies from the Wide layer. Refer to Appendix for details of this procedure.
2. The catalog is used for training/validation/test. JS performs cross-validation to train and validate his model. The other people use the hold-out validation technique using 4/5 of the sample. The remaining 1/5 is not used for training and validation. It is used for test.
3. A set of QA plots on are generated using photo-z's for the test sample (not currently available on the photo-z release page). The training sample is matched to the COSMOS wide-depth best/median/worst data and photo-z's are run on these catalogs as well and QA plots to evaluate the seeing dependence are generated. The median seeing stack is used for the plots available from the data release site.
4. Once the calibrations are done, the photo-z codes are run on the full UD, D, and Wide catalogs prepared by AN. The photo-z's and other products are ingested into the database and made available to the users.

3 Photo-z products

Our products are not limited to photo-z, but some codes deliver ancillary information such as stellar mass, rest-frame magnitudes, etc. For the available products in this release, please refer to the schema browser. We are aware that some hardcore users would like to use the full $P(z)$ information. Full $P(z)$ tables is available at the photo-z release page.

In this release, the photo-z team defined a set of common outputs for all the codes:

- ID : object ID. This should be used to join tables.
- several photo-z point estimates: $z_{mean} = \int zP(z)dz$, z_{mode} is mode of P(z), z_{median} is defined as $\int_{z=0}^{z_{median}} P(z)dz = 0.5$, z_{mc} is a Monte-Carlo draw from $P(z)$. z_{best} is a new point estimate and is defined as a optimal estimate to minimize a loss function in the form:

$$loss(z, z_{true}) = 1 - \frac{1}{1 + (\frac{\Delta z}{\sigma})^2}, \tag{1}$$

  where $\Delta z = \frac{z - z_{true}}{1 + z_{true}}$ and $\sigma = 0.15$. For further details, please refer to the photo-z release page.
- photo-z confidence intervals: z_{low95} is defined as $\int_{z=0}^{z_{low95}} P(z)dz = 0.025$. z_{low68}, z_{hi68}, and z_{hi95} are defined in a similar manner.
- photo-z rms around each point estimate: $\sqrt{\int P(z)(z - z_{pt})^2 dz}$, where z_{pt} is a point estimate.
- Redshift confidence for each point estimate: $\int_{z_{pt}-0.03(1+z_{pt})}^{z_{pt}+0.03(1+z_{pt})} P(z)dz$
- photo-z risk, which can be used to identify likely bad photo-z objects. It is defined as the integrated probability of P(z) convolved with the loss function.

4 Statistics

A set of plots to characterize the photo-z accuracy is provided for each code on the data release site. Before you look at these plots, please be aware of the following important points/caveats.

1. **In all the plots, we consider objects down to $i_{cmodel} = 25$.** We impose this cut because the 'true' redshifts at faint mags are mostly from COSMOS 30-band photo-z's and they are not reliable for very faint objects.
2. We assume that the high accuracy photo-z's based on the 30-band photometry, which comprise a large fraction of our sample, are the truth table and we compare our 5-band photo-z's against them. However, some of the 30-band photo-z's will be incorrect and the absolute numbers here should be taken with caution.
3. We used to include stars in the statistics, but they are not included this time.
4. No object clipping is applied. However, some users may want to apply clipping in order to reduce outliers. Redshift risk is a useful indicator of the reliability of a photo-z.

We use the 'standard' metrics to characterize photo-z accuracy; bias, dispersion, and outlier rate. The definitions adopted in the literature are not always the same and we explicitly define them here. In what follows, we denote the true redshifts as z_{ref}.

- **Bias:** Photo-z's may systematically be off from spectroscopic redshifts and we call this systematic offset bias. We compute a systematic bias in $(z_{\rm phot} - z_{\rm spec})/(1 + z_{\rm spec})$ by applying the biweight statistics (Beers et al. 1990). We iteratively apply 3σ clipping for 3 times to reduce outliers.

- **Dispersion:** In the literature, dispersion is often computed as

$$\sigma_{\rm conv} = 1.48 \times {\rm MAD}\left(\frac{z_{\rm phot} - z_{\rm spec}}{1 + z_{\rm spec}}\right), \tag{2}$$

  where MAD is the median absolute deviation. Note that this definition does not account for the systematic bias. In addition to this conventional definition, we also measure the dispersion by accounting for the bias using the biweight statistics. We iteratively apply a 3σ clipping as done for bias to measure the dispersion around the central value. We denote the conventional dispersion and the biweight dispersion as $\sigma_{\rm conv}$ and σ, respectively.

- **Outlier rate:** The conventional definition is

$$f_{\rm outlier,conv} = \frac{N\left(\frac{|z_{\rm phot} - z_{\rm spec}|}{1 + z_{\rm spec}} > 0.15\right)}{N_{\rm total}}, \tag{3}$$

  where outliers are defined as $|z_{\rm phot} - z_{\rm spec}|/(1 + z_{\rm spec}) > 0.15$. Again, this definition does not account for the systematic bias. The threshold of 0.15 is an arbitrary value but is probably fine for photo-z's with several bands. It is clearly too large for those with many bands. Together with this conventional one, we also define outliers as those 2σ away from the central value (these σ and center are from biweight; see above). This 2σ is an arbitrary choice, but it is motivated to match reasonably well with the conventional one for several band photo-z's. We will denote the σ-based outlier fraction as $f_{\rm outlier}$ and the conventional one as $f_{\rm outlier,conv}$.

In addition to these standard metrics, we include the *loss* defined in Section 3.

Now, we explain each plot –

page A1: The HSC 5-band photo-z plotted against z_{ref} (they are actually high accuracy spec/grism/photometric redshifts from various surveys). A set of basic statistics has been computed and are shown in the plot. The solid line is $z_{phot} = z_{ref}$ and the dashed lines are $z_{phot} = z_{ref} + 0.15(1 + z_{ref})$. Objects outside of the dashed lines are regarded as outliers in the conventional definition ($f_{\rm outlier,conv}$).

page A2: Dispersion and outlier rate (both conventional ones), and loss plotted against i-band magnitude. It should be straightforward to read this figure.

page A3: Bias, dispersion, and outlier rate computed with the biweight method are plotted against i-band magnitude. The horizontal dashed lines show ± 0.01 and they might be useful to read the amount of bias off the figure.

page A4: Conventional dispersion and outlier rate, and loss plotted against redshift.

page A5: Same as page A4, but for bias, dispersion, and outlier rate with biweight. The horizontal dashed lines show ± 0.01.

page A6: Fraction of objects that are consistent with z_{ref} within the 68% (red) and 95% (blue) intervals. This plot shows the accuracy of photo-z uncertainties. If the uncertainties are correctly estimated, the fractions should be 68% and 95%.

page A7-A9: Redshift distribution of the photo-z selected objects. The panels are for different redshift bins. On the right of each panel, mean photo-z, mean of the true redshifts, and fractions of foreground and background objects are shown. Note that the mean is straight mean and is strongly affected by outliers.

A: training sample construction by J. Speagle

Catalog quantities:

- Identifiers for each object include ID, (ra,dec), and (tract,patch) coordinates.
- Fluxes include psf fluxes, cmodel fluxes, cmodel_exp fluxes, and cmodel_dev fluxes. In addition, I've included 1.5-arcsec aperture photometry with target PSF=1.1 arcsec taken from the afterburner run, with associated uncertainties taken from 1.5-arcsec aperture photometry without PSF matching.
- Shapes are measured using the sdss_shape parameters.
- Merge measurement flags, attenuation data, and extendedness are also included.
- Redshift and 1-sigma error.
- Parent survey, where: SDSS=1, DEEP2/DEEP3=2, PRIMUS-3, VIPERS=4, VVDS=5, GAMA=6, WIGGLEZ=7, COSMOS=8, UDSZ=9, 3DHST=10, FMOS-COSMOS=11
- Redshift type: spec-z=1, grism/prism-z=2, photo-z=3.
- Depth: udeep=1, deep=2, wide=3
- Emulated errors, which are indicated by the "_wide" suffix.
- k=5 shuffled cross-validation folds, which are labeled in the 'crossval_sample' field.
- Color/mag weights ('crossval_weights') to forecast performance to a generic wide-selected sample. (These might be zero.)

Database selection criteria:
Photometry for the parent catalogs was selected from the database using the following cuts:

- detect_is_primary
- NOT [grizy]centroid_sdss_flags
- NOT [grizy]cmodel_flux_lags
- NOT [grizy]flags_pixel_edge
- NOT [grizy]flags_pixel_interpolated_center
- NOT [grizy]flags_pixel_saturated_center
- NOT [grizy]flags_pixel_cr_center
- NOT [grizy]flags_pixel_bad

Spec-z quality requirements:
I include objects according to the following criteria:

Public spec-z/prism-z data:

- z>0.01 (confirm star removal) and z<9 (no quasars)
- sigma_z<0.005(1+z)
- SDSS/BOSS: zWarning=0 (no apparent issues), z<1.2
- DEEP2: qFlag=3-4 (>95% confidence)
- PRIMUS: qFlag=4 (highest quality)
- VIPERS: qFlag=3-4 (>95% confidence)
- VVDS: qFlag=3-4 (>95% confidence)
- GAMA: qFlag>=4 (very confident)
- WIGGLEZ: qFlag>=4 (very confident)
- UDSZ: qFlag=all (provisional catalog only includes >95% confidence redshifts)
- FMOS-COSMOS: qFlag=3-4 (>95% confidence), z>0.01, flag_star=False.

3DHST data:

- Flag_star=False
- 0<z<9 (no stars, quasars, or failed redshifts)
- For grism-zs/photo-zs:
  sigma_z68<0.05(1+z), sigma_z68=max(zh68zmed,zmed-zl68)
  sigma_z95<0.1(1+z), sigma_z95=max(zh95zmed,zmed-zl68)

COSMOS data:
Spec-z:

- 3 <= qFlag < 6 (>99% confidence redshifts)
- 0 < z < 9.9
- For objects with repeat observations, sigma_z<0.005(1+<z>)

photo-z:

- No bad photometry (flag_capak)
- Type=0 (galaxies only)
- chi2(gal)<chi2(star), chi2_reduced(gal)<5 (reasonable fits)
- No secondary peaks (z_secondary)
- Mstar>7.5 (stellar mass successful)

- 0<z<9 (no stars, quasars, or failed redshifts)
- sigma_z<0.05(1+z), sigma_z=max(zh68-zmed,zmed-zl68)

I find this selects a set of spec-z's that do not differ substantially from those selected Masayuki's "homogeneous" quality flags.

Photometry Quality Cuts:

I have limited the catalog to only include objects with (all) fluxes properly measured in all 5 bands. This removes $\sim 1\%$ ($\sim$4000 objects) from the parent sample, mostly from failed measurements in the afterburner photometry. I have confirmed this cut is (to first order) unbiased in color/mag and redshift. Note that this means I include objects with poorly measured/undefined shapes. I found that cut removed a much larger ($\sim$7%) portion of the sample, and substantially biased the sample at higher redshifts.

Cross-Matching Procedure:

All spec/grism/prism/photo-z data are (uniquely) matched successively to the udeep>deep>wide data to within 1" (the closest object is selected if duplicate matches occur), where I've supplemented the objects matched in the database with 3DHST/COSMOS high quality photo-z's and private COSMOS spec-z's. Note that the DEEP3 redshifts are not included in this version due to some technical issues. I hope to include them in future releases.

Error Emulation:

Since objects in the catalog are from a variety of depths, I emulate wide-depth photometric errors by matching photometric noise-to-signal ratio (N/S) to a target dataset of $\sim$500k objects from the wide field (selected with the same database selection criteria) using k-d trees. I find that just selecting the closest neighbor in 5-band flux space (per flux type) or 3-parameter shape space (per band) reproduces the general distribution (both mean error and variance among S/N measured for similar 5-band SEDs) quite well.

Color/Mag Weights:

Finally, I've included a series of color/mag weights under that should be used to ensure appropriate weighting when forecasting results to the wide data. I computed these using an improvement of the kNN approach used in, e.g., SDSS, where I've actually gone through the trouble to compute numerical approximations to the Bayesian evidence among a group of $\sim$100 "neighbors" in color/mag space (selected across multiple Monte Carlo runs). I've confirmed this successfully matches across basic magnitude/color distributions.