NEXT GENERATION

NGST

SPACE TELESCOPE

Using a Multi Object Spectrograph (MOS) with a Low Resolution Prism on NGST to Determine Redshifts

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Introduction

NGST deep fields will use spectral energy distribution (SED) fitting for redshift estimation, "photometric redshifts", to study objects either too numerous or too faint to be followed-up spectroscopically (see Madau et. al. 1999, Connolly et. al. 1997, Lanzetta et. al. 1996). Traditional photometric redshifts have used serial observations in several filters with an imager to obtain very low resolution SEDs from which redshifts are inferred. We suggest the use of a prism as a more efficient means to obtain the SEDs of galaxies in deep NGST observations.

Prism observations have one intuitively appreciated advantage; their simultaneous observation of the SED at all wavelengths. Indeed, near-IR prisms are already planned for ground based instrumentation (e.g. Oliva et. al. 1999). However, R < 100 prism spectra with NGST would need to be taken through an entrance mask of some kind. Two kinds of multi-object spectrographs (MOS) masks have been suggested for NGST; micro-shutters (Moseley et. al. 1999) and micro-mirrors (MacKenty et. al. 1999). MOS observations lead to a number of limitations. Unlike filter observations, prism spectra:

a) contain little or no spatial information;
b) are limited to some fraction of the objects in a given field;
c) suffer additional throughput losses from the mask;
d) may need to be taken with a coarser plate scale.

Nevertheless, we will show that prism spectra enjoy a significant advantage over serial filter observation for the study of the faintest galaxies with NGST.

In this paper we explore the utility of prism spectroscopy as a primary mode for NGST observations. We have carried out extensive Monte-Carlo simulations to examine the trade offs involved in choosing a prism as the primary "photometric redshift machine" for NGST instead of relying on the imager for this purpose. We conclude that prism observations are more successful in recovering object redshifts and reaching fainter magnitudes than serial filter observations in equal observing time.

We begin by reviewing the details of our simulations. We next define the figure of merit by which we judge the photometric redshifts. Our simulations include a number of assumptions about the imager and spectrograph properties; we show the effect of varying each of these assumptions in turn, to check that our conclusion is robust to the many unknowns of an instrument that may be half a decade away.

Monte-Carlo Simulations

We generated a suite of 25,000 model galaxies having the properties of redshift (sampled from the redshift distribution of the Hubble Deep Field North), K-band magnitude (sampled from the number-magnitude relation of the STIS HDF-South observations), and spectra (sampled from a suite of 10 galaxy ages ranging from 0.8 Gyr to 11 Gyr selected from a Bruzual & Charlot spectral synthesis model, solar metallicity, and a 1 Gyr burst).

The "observed" SEDs of the simulated galaxies were constructed by redshifting their spectra, scaling the flux, and decrementing for intervening Lyman alpha, beta and continuum absorption. Each spectrum was then sampled by the relevant spectral elements (prism or filters) and noise was added appropriate to the instrument (MOS or imager). Camera specifications consistent with the ISIM Yardstick camera were taken from Greenhouse et. al. (1999), while MOS specifications were taken from Moseley et. al. (1999; the micro-shutter study). The major source of noise (for faint galaxies) for both the MOS and the imager is background zodiacal light. Noise was determined from the galaxy flux, sky flux, detector read and dark noise for each resolution element of the prism and each band for serial filters. The total exposure time was assumed to be 100,000 seconds for both the prism and the filters, but for the filters the total exposure time was evenly divided between the bands with no overhead. The filter profiles were Gaussians spaced evenly in log wavelength space.

Template SEDs for a suite of 10 different ages (SED types) at redshifts out to z=15 were constructed in the same way. The "measured" redshifts were obtained by comparing the "observed" SEDs to the suite of templates and minimizing chi-square.

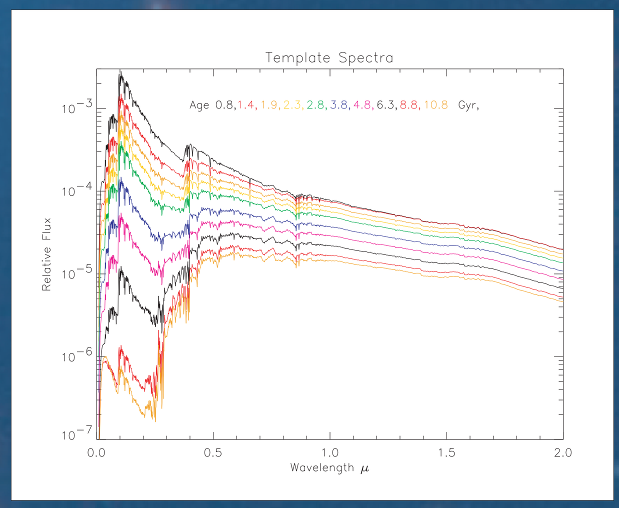

Figure 1: We used a solar metallicity, 1 Gyr burst, Bruzual & Charlot (1993) spectral synthesis model for the template spectra. The 10 spectra covering the age range from 0.8 to 11 Gyr, used for the suite of templates is shown. For most of the simulations, 10 different spectra at intermediate ages were used to make the model redshifted galaxies.

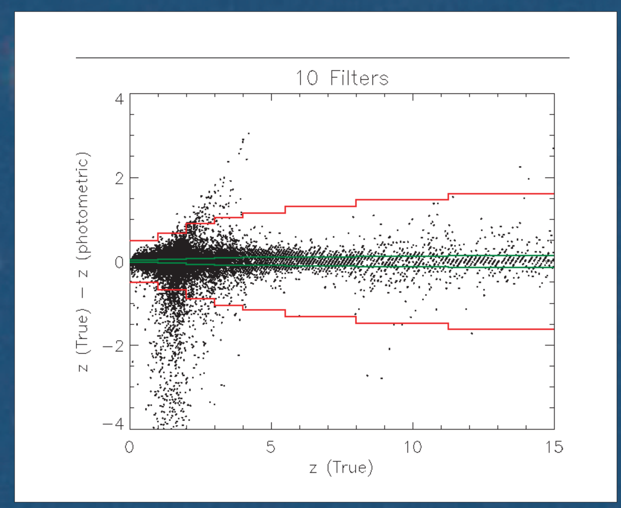

Figure 2: The results of one simulation is shown. In this simulation 10 filters were used to sample the simulated galaxy spectra and the templates. The green line represents the criteria for an excellent result, "hitting the bulls-eye" (lZtrue-Zphotl < 0.03 + 0.1 log(z)). The red line represents the criteria for an unacceptable result, "missing the dart board" (lZtrue-Zphotl > 0.5 + 1.0 log(z)).

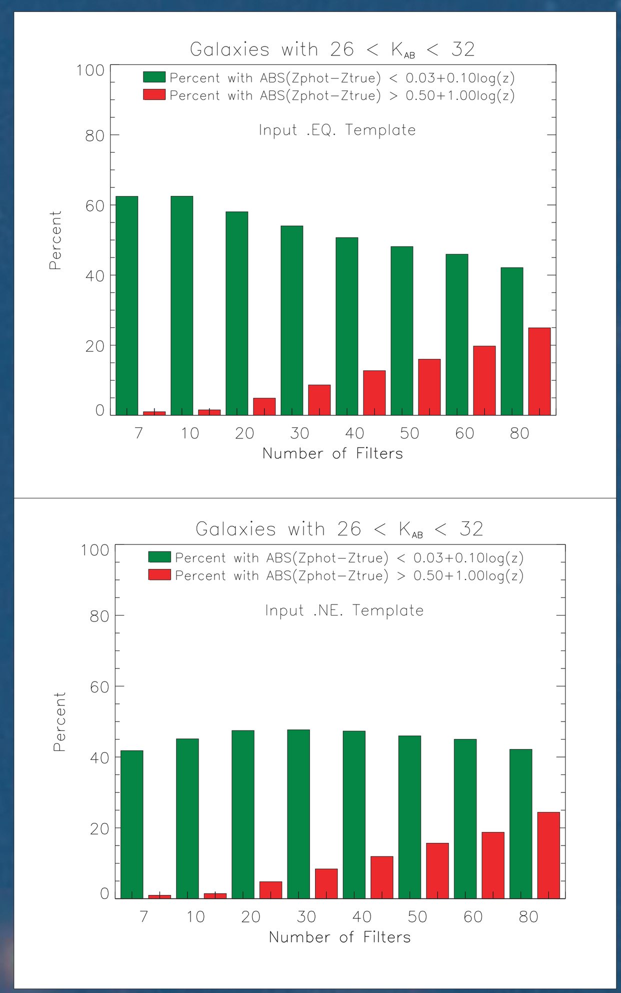

Figure 3: The effect of having model galaxies exactly the same as the template galaxies is shown in these bar graphs. a) the models are exactly the same as the templates and b) the models are from ages in between the templates. The green bars show the percentage of galaxies which hit the bulls-eye (the green line in figure 2). The red line show the percentage of galaxies which miss the dart board (the red line in figure 2). These percentages are shown for number of filters 7, 10, 20, 30, 40, 50, 60, and 80. The total exposure time is the same (100,000 sec) for each simulation, thus the time per filter is much lower for the larger number of filters and, therefore, so is the signal to noise. That explains why the percentage of bulls-eyes decreases with larger number of filters. The main difference between the model equals template case and the model not equal template case is in the lower number of filters. When the template is exactly the same as the model the lower resolution does much better than it should. We use the model not equal to the template case for all of the remaining simulations.

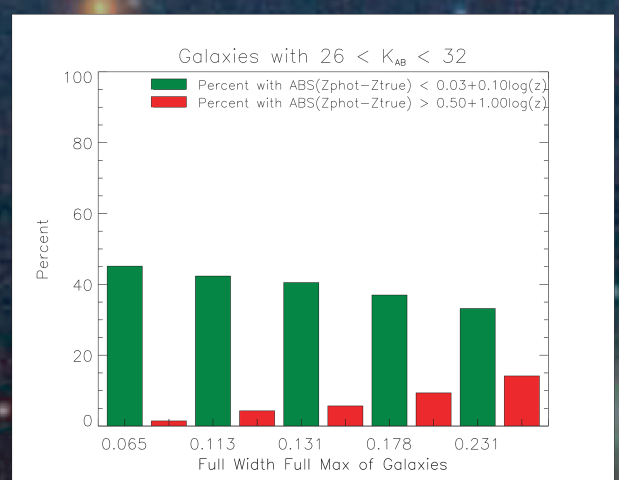

Figure 4: The actual size of the galaxies of interest is very important as illustrated by this bar graph. When using a prism and the MOS, the sky background is fixed by the size of the micro-shutters (0.186x0.279 arcsec area for this study). An imager with smaller pixels can take advantage of decreasing the size of an aperture to match the size of a galaxy, getting much less sky noise, provided that the galaxy is smaller than the MOS aperture. This bar graph shows the results for the 10 filter case using successively larger apertures. In this study we compare the MOS+prism to filter apertures of FWFM=0.113, comparable to Gardner & Satyapal (2000) best estimate of the size of high redshift galaxies at K(AB)=29.

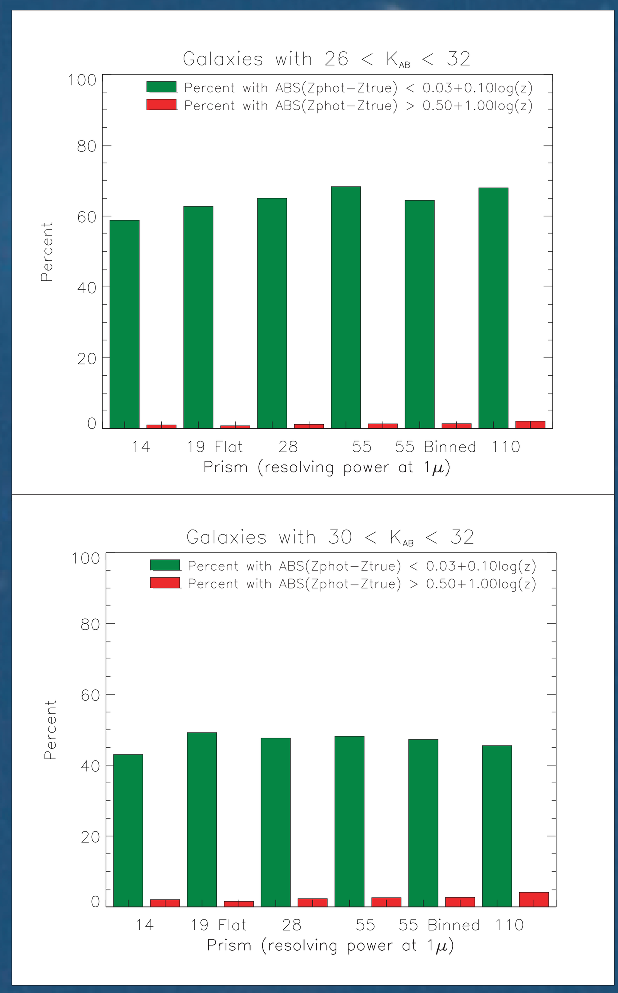

Figure 5: The effect of varying prism resolution is shown for a) all galaxies and b) those galaxies in the faintest 2 magnitudes. Since for a prism each resolution element is exposed for the full time the total signal to noise is the same for each prism. There is a slight fall off for low resolution, otherwise the results do not vary much with prism resolution. For the sake of comparison with the filters we use the R=55 (at 1 micron) prism as our nominal prism.

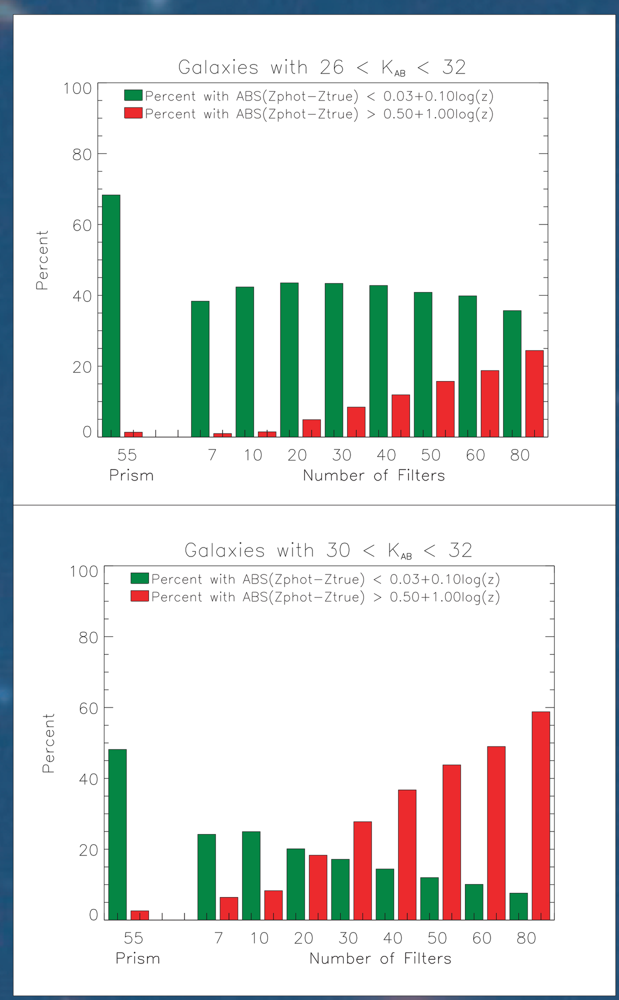

Figure 6: The nominal prism is compared to the results for 7, 10,20, 30, 40, 50, 60, and 80 filters for a) all galaxies and b) the galaxies with the faintest 2 magnitudes (roughly 1/2 of all of the galaxies). Notice that the percentage of galaxies for which the redshifts are poor (red bars) increases dramatically with number of filters, especially for the fainter galaxies. This is strictly a signal to noise effect. The larger number of filters gives a diminishing return on both accuracy and reliability of the measured redshifts. The prism improves both the accuracy and reliability of the measured redshifts compared to any number of filters. Note that these results are assuming that the galaxies have a FWFM=0.113 arcsec. If the galaxies are larger the prism wins by a larger amount, while if the galaxies are smaller the prism still wins, but by a smaller amount.

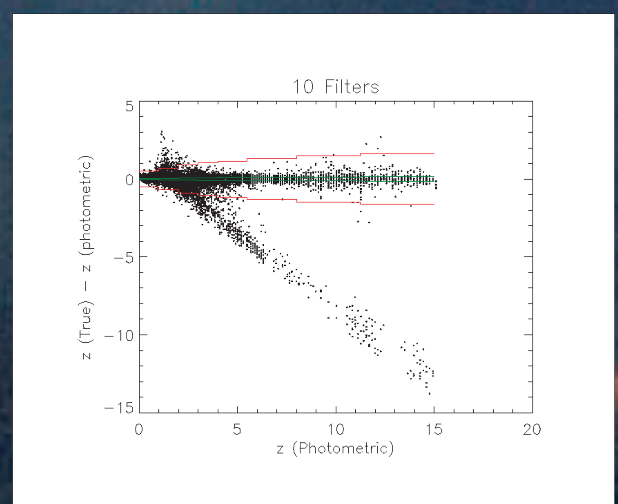

Figure 7: The difference between the true and measured redshifts vs. the measured redshift for the 10 filter case. The tail of galaxies running from the upper left to the lower right is caused by the galaxies with true redshift between z=1 and z=3, which have a spectral break that is misidentified as the Lyman break. At the higher redshifts these galaxies are a significant contamination.

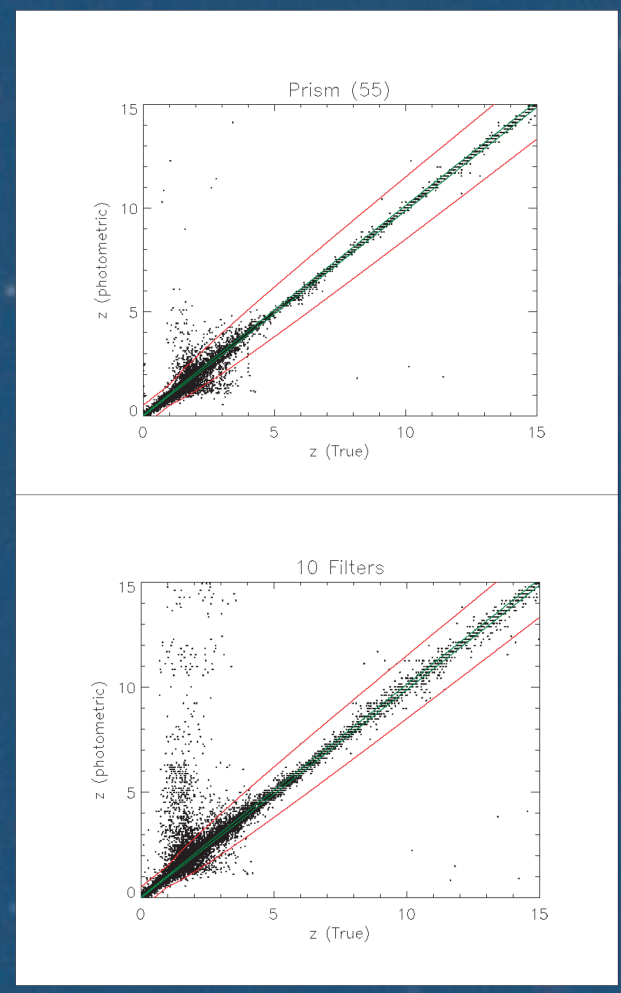

Figure 8: The results for a) the nominal prism and b) the nominal filter (10 filters) case are shown as measured redshift (Zphot) vs. true redshift (Ztrue). The bulls-eye and dart board criteria are shown as the green and red lines. Notice that the prism does much better in the difficult z=1 to z=3 range. The relation between measured redshifts and true redshifts is good for both the prism and the filters above z=5, but the prism has a tighter relation.

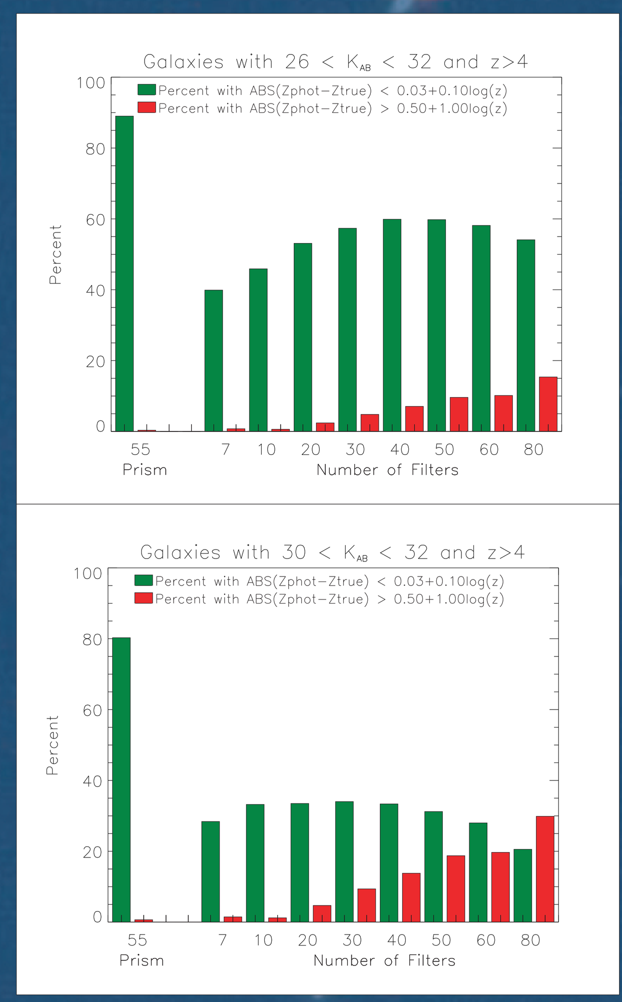

Figure 9: The same as figure 6 except limited to galaxies with true redshift greater than z=4 (the key discovery space for NGST). For these galaxies the Lyman break is the strongest feature and thus the accuracy and reliability of the redshifts is better for both the filters and the prisms. The prism, however, still has a decided advantage over the filters, getting an excellent answer (hitting the bulls-eye) 80% of the time, as opposed to under 40% of the time for 10 filters in the faintest 2 magnitudes.

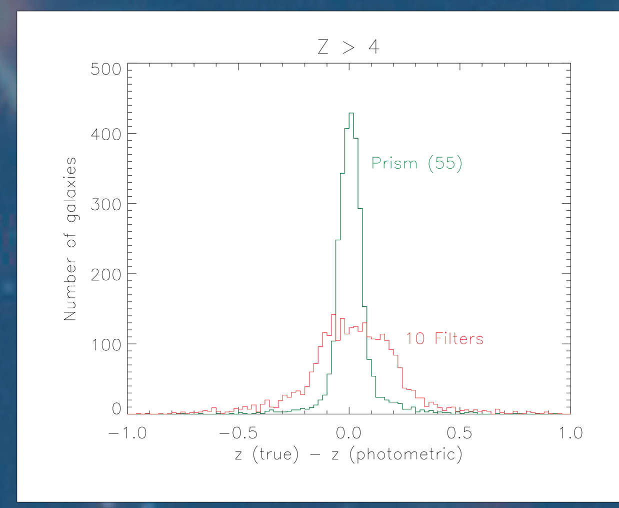

Figure 10: Histogram of the difference between the measured and true redshift for the nominal prism (green line) and the nominal 10 filters (red line). The prism has a much smaller scatter showing that the accuracy of the measured redshifts is indeed much better for the prism. This increased accuracy will be crucial for programs where it is not possible to have follow-up spectroscopy, such as objects with K(AB) > 30.

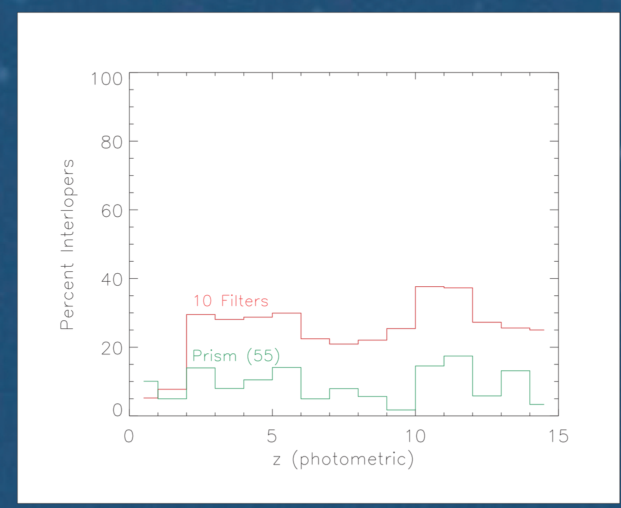

Figure 11: The percent of measured redshifts which fall into the wrong unit z bin (interlopers) is shown for the prism (green line) and for 10 filters (red line). Most of the interlopers at high redshift (z > 5) come from galaxies with redshifts between z=1 and z=3 (see figure 8). Here the prism does much better having about 20% interlopers, as opposed to about 40% interlopers for z > 10.

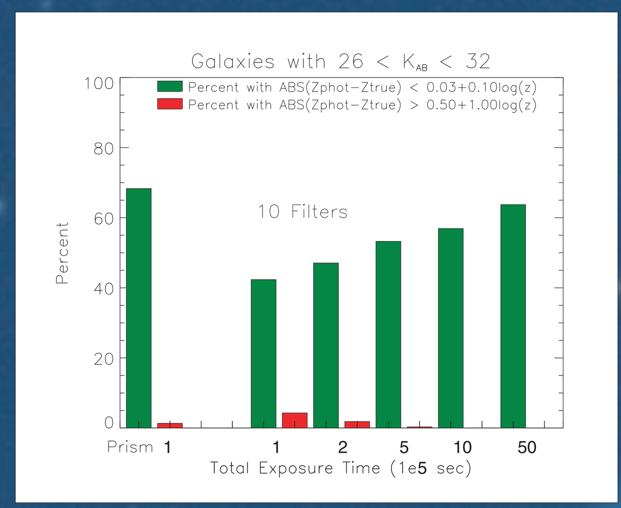

Figure 12: The effects of increasing the total exposure time for the filters is shown. In any real MOS observation it will not be possible to observe all of the objects in a deep field at the same time. In some real fields it may take 2 or 3 exposures to measure redshifts for all (or nearly all) of the galaxies in the field. Therefore, the total exposure time available to an imager to measure the redshifts of the same galaxies may be 2 to 3 times longer than assumed here. We note that many, if not most, science applications will not require spectra of every object, so one MOS exposure may be sufficient. This plot shows the effect of lengthening the total exposure time for the nominal 10 filter case by factors of 2, 5, 10 and 50. It is only when the filters have 10 to 50 times the exposure time that the accuracy approaches that of the prism.

Conclusions

We have run numerous Monte-Carlo simulations to asses the utility of using a low resolution prism with a MOS on NGST to measure large numbers of galaxy redshifts. Each simulation consisted of 25,000 galaxies ranging in redshift from z=0 to z=15, K(AB)=26 to K(AB)=32. Simulations were run for a prism in the micro-shutter MOS and the Yardstick imager. We varied the prism resolution (and shape); the number of filters; the size of the galaxies and the total exposure time (for the filters); and how well the SED templates matched the simulated SEDs. We reached the following conclusions.

1) ***In all cases the prism+MOS gives a superior result. The percentage of excellent "measured" redshifts is a factor of 2-3 times higher than obtained with filters. The percentage of interlopers which would contaminate high redshift samples is about a factor of 2 lower with the prism.***

2) ***In the regime where much of the primary NGST science will be done (very faint, very high redshift galaxies) the prism gives much more accurate and reliable redshifts. In this most important regime spectroscopic follow-up would be difficult or impossible.***

3) The accuracy and reliability of the prism in determining redshifts does not vary much with prism resolution, except for very low resolution.

4) The results for large numbers of filters are very poor. The increased resolution does not make up for the decrease in the signal to noise ratio caused by having to split the total exposure time between many filters. Therefore, the imager cannot achieve the resolution of the prism in a reasonable amount of time.