Photometric redshift plans for Roman

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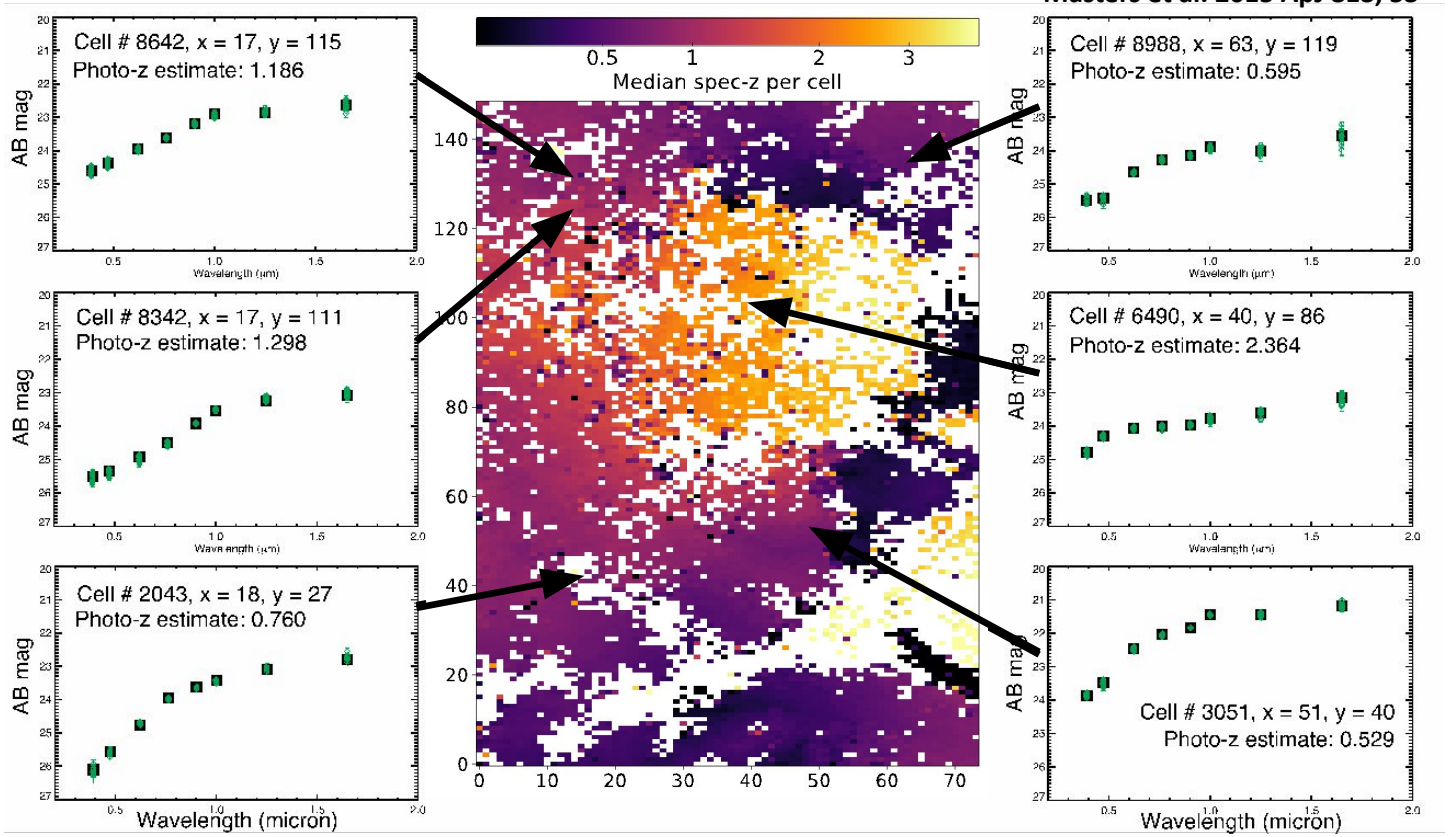
Mapping the link between colors and redshift

- Obtaining the accurates redshifts for ~10^9 galaxies is a major challenge for Roman
- The Roman+Rubin filters (e.g., *ugrizYJHK*) to a given depth define a galaxy color *manifold*, which can be mapped using unsupervised learning
- Spectroscopic redshifts in that manifold are empirical measures of the color-redshift relation for those filters
- Assumptions: relation is smooth and (mostly) non-degenerate
- We are working to map that relation

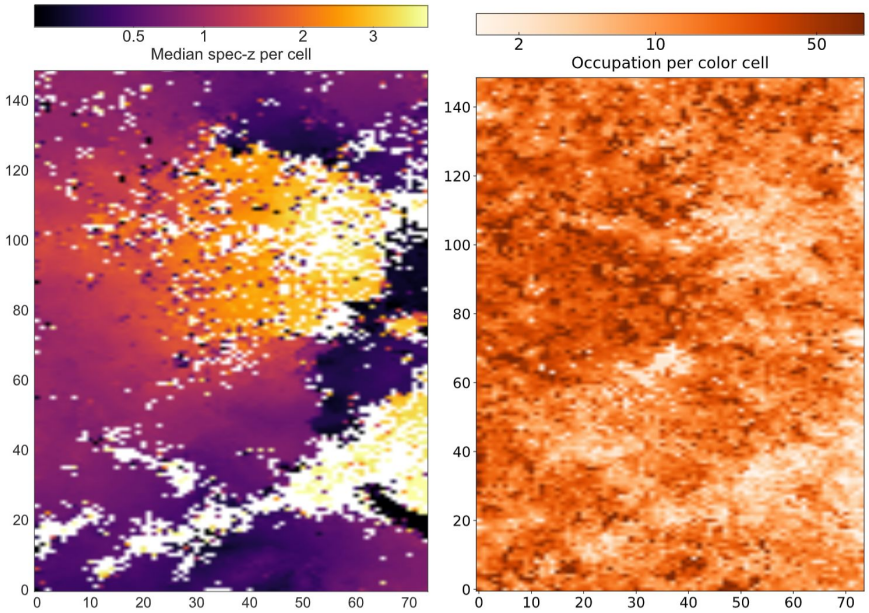
The 8-color SOM

Masters et al. 2015 ApJ 813, 53



Basic idea of direct calibration

- Associate to each cell built on deep/calibration field data a redshift from spectroscopy
- For a given selection of SOM cells, the mean redshift estimate of the galaxies in the cells is the occupation-weighted average of the mean redshifts of the cells
- Alternatively, build a dN/dz distribution from individual galaxies compared with the calibrated SOM



C3R2 DR3, Stanford et al. 2021

C3R2 = Complete Calibration of the Color-Redshift Relation

A large Keck Program to prepare for Stage IV Dark Energy Experiments

Judith Cohen (Caltech) - PI of Caltech Keck C3R2 allocation
16 nights (DEIMOS + LRIS + MOSFIRE)
Daniel Stern (JPL) - PI of NASA Keck C3R2 allocation
10 nights (all DEIMOS; "Key Strategic Mission Support")
Daniel Masters (JPL) – PI of NASA Keck C3R2 allocation 2018A/B, 2019B, 2020A
16 nights (8 each LRIS/MOSFIRE; "Key Strategic Mission Support")
Dave Sanders (IfA) - PI of Univ. of Hawaii Keck C3R2 allocation
6 nights (all DEIMOS) + H20
Bahram Mobasher (UC-Riverside) - PI of UC Keck C3R2 allocation
2.5 nights (all DEIMOS)

+ time allocations on VLT (PI F. Castander), MMT (PI D. Eisenstein), and GTC (PI C. Guitierrez)
-Coordinating closely with these collaborators for these observations
-Sample drawn from 6 fields totaling ~6 deg^2

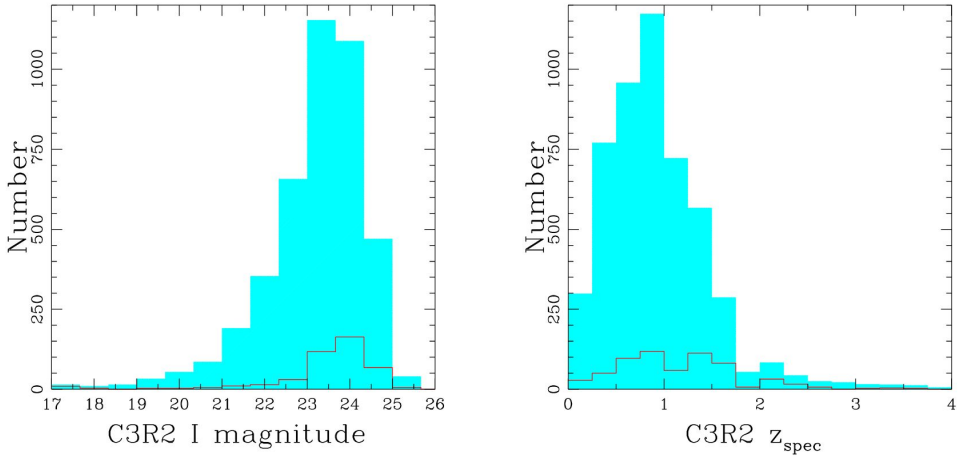
Additional Collaborators: Peter Capak, S. Adam Stanford, Nina Hernitschek, Francisco Castander, Sotiria Fotopoulou, Audrey Galametz, Iary Davidzon, Stephane Paltani, Jason Rhodes, Alessandro Rettura, Istvan Szapudi, and the Euclid Organization Unit – Photometric Redshifts (OU-PHZ) team

C3R2: Mapping the color-redshift relation with Keck

- Designed to "fill the gaps" in our knowledge of the color-redshift relation to Euclid depth (i~24.5)
  - Multiplexed spectroscopy with a combination of Keck DEIMOS, LRIS, and MOSFIRE and VLT FORS2/KMOS targeting VVDS, SXDS, COSMOS, and EGS
  - DR1 (Masters, Stern, Capak et al. 2017) comprised 1283 redshifts, DR2 (Masters, Stern, Cohen, et al. 2019) brought total to 4454 redshifts, observations in 2017B to be published in Stanford et al. 2021 (submitted), bringing total to 5090 redshifts
  - Survey website (**https://sites.google.com/view/c3r2-survey/home**) provides links to spectroscopic catalog and reduced spectra hosted by Keck Observatory Archive (KOA)
- A total of 50 Keck nights awarded
  - ~11 nights lost to weather
- >200h of VLT time used to obtain additional ~500 redshifts

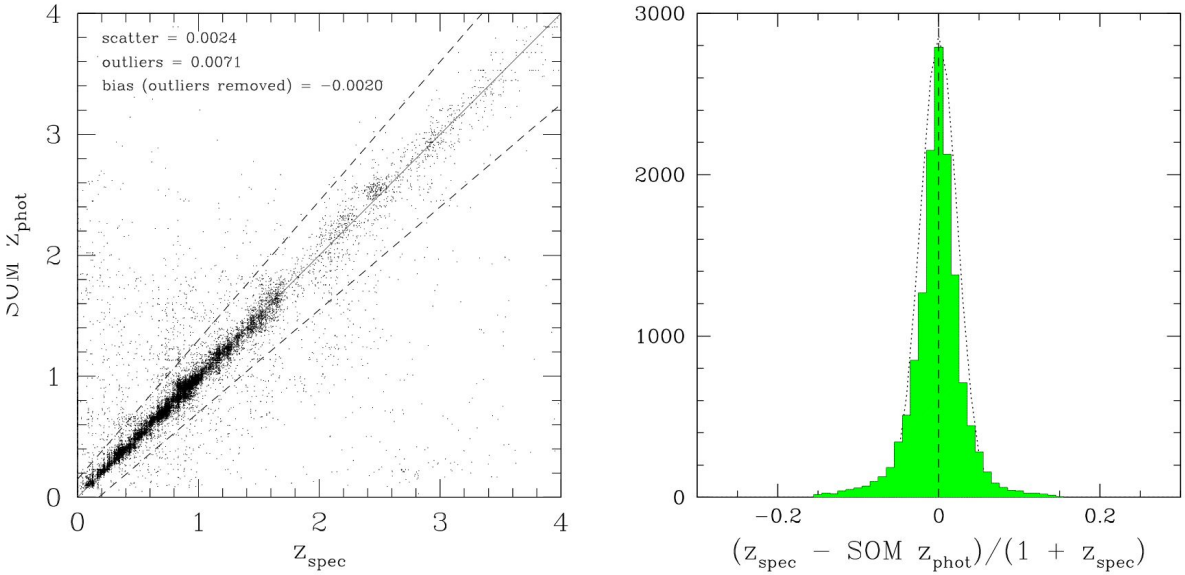
C3R2 survey results

- Sources in undersampled parts of the galaxy color space preferentially targeted
- All spectra examined by at least two human experts (low S/N spectra require this)
- >5000 spectra published with quality flag 3-4 (high confidence redshifts)
- Another proposal submitted this year to push deeper, approaching Roman depth



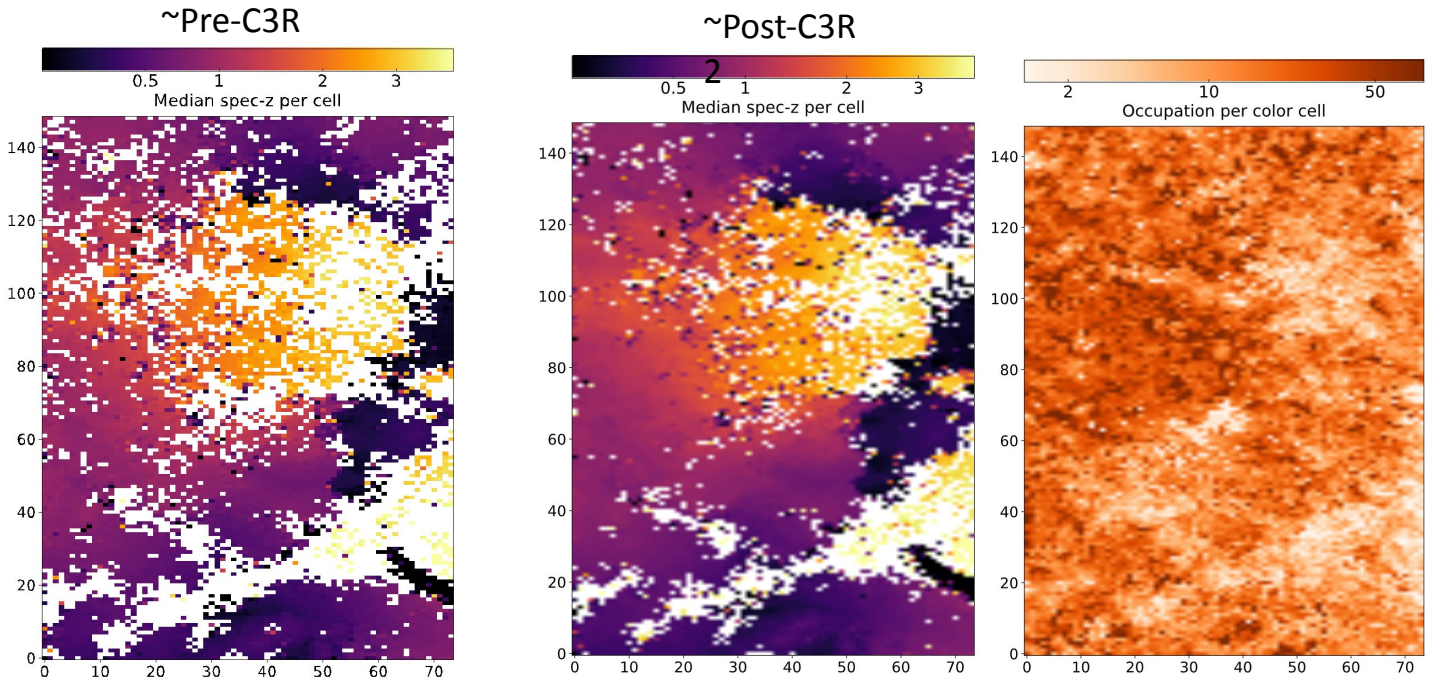
Stanford, Masters, Darvish, Stern, et al. 2021 (ApJ, 256, 9)

SOM-based photo-z



Stanford, Masters, Darvish, Stern, et al. 2021 (ApJ, 256, 9)

Color space coverage



To Roman depth

Hemmati et al. 2019 comparing the colorspace of Roman to shallower Euclid using CANDELS depth to simulate Rubin+Roman:

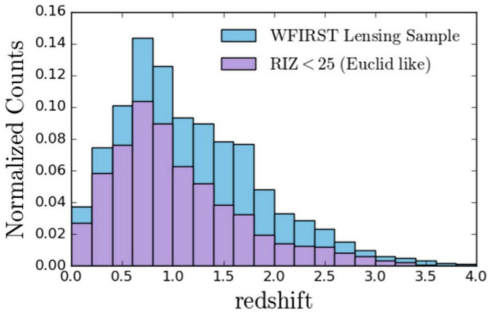
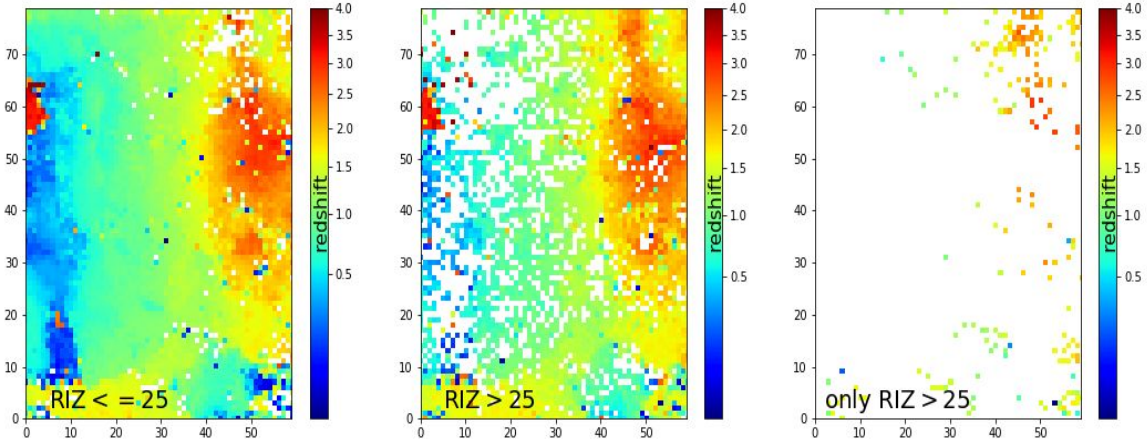
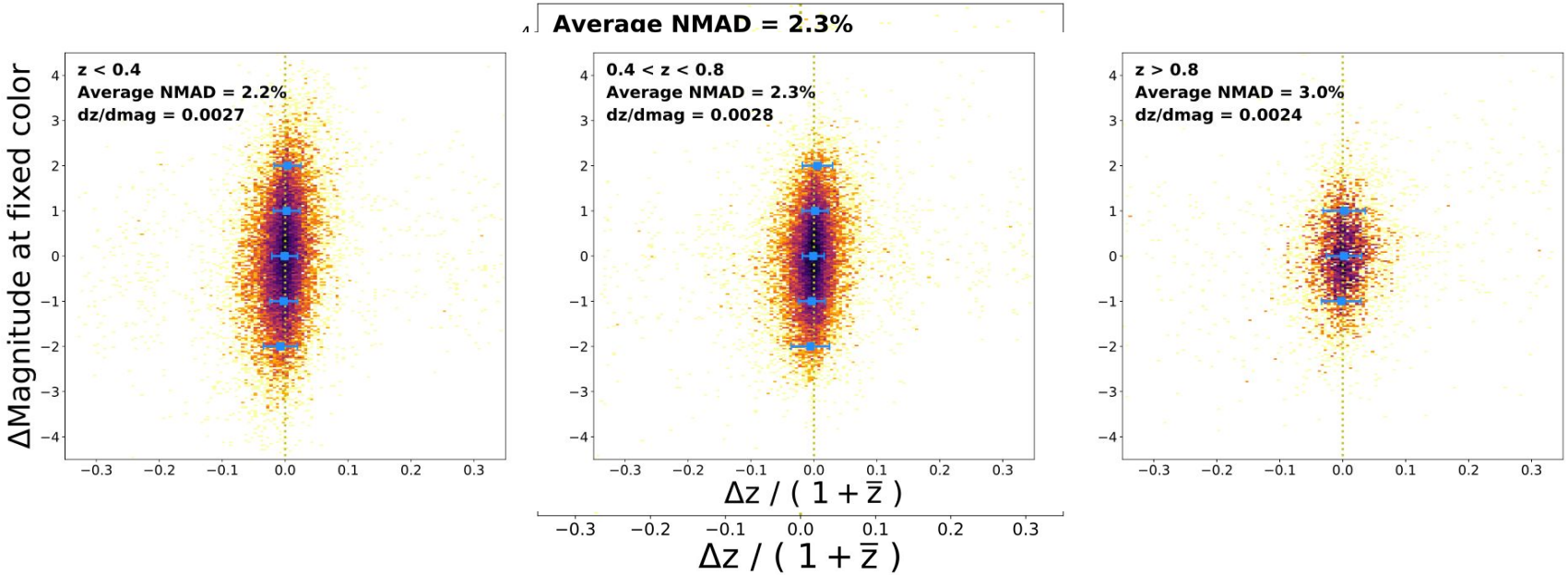


Figure 15. *WFIRST* will significantly increase the lensing sample size. The normalized redshift distribution of galaxies in the LSST+*WFIRST* analog sample is shown as the blue histogram, and the fraction of galaxies with riz < 25 as would be found by *Euclid* is overplotted in purple.



- 26% of Roman sample is fainter than Euclid
- 91% of which live in cells containing a bright source as well.
- 4% of the SOM cells have no bright galaxy counterpart

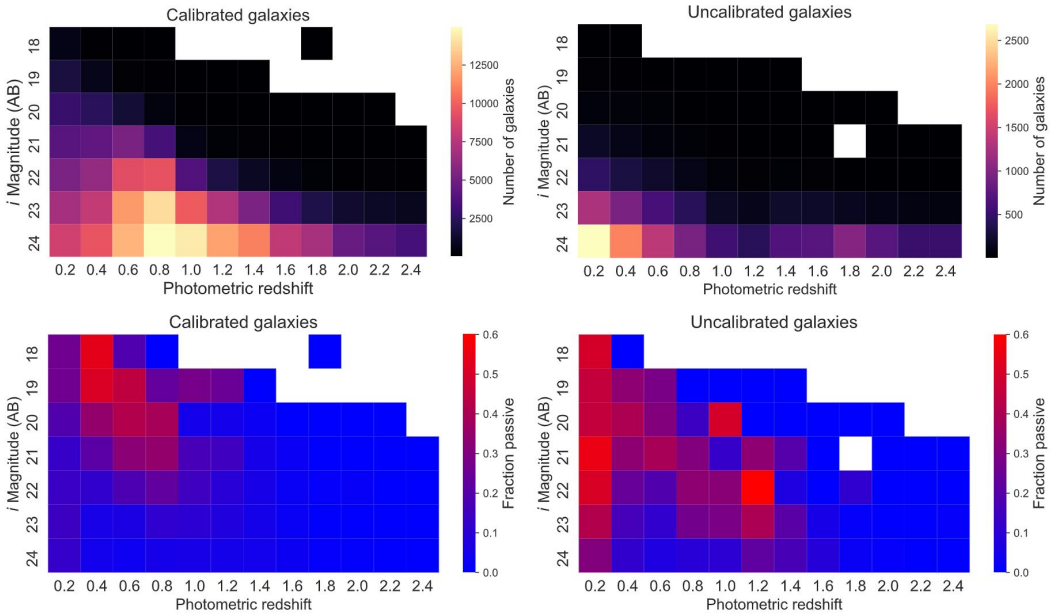
Impact of galaxy magnitude at fixed color



All unique pairs of spec-z galaxies with matching positions on SOM are shown, illustrating the relation of magnitude and redshift at fixed color
Good news for Roman!

What’s still missing?

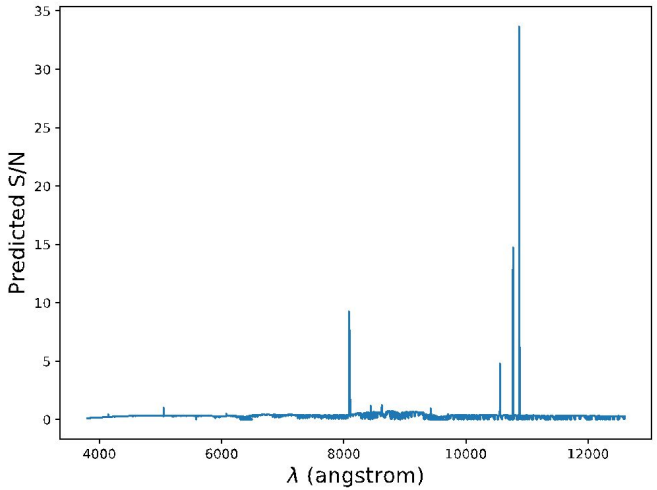
“Calibrated” = lives in color cell with at least one redshift, “Uncalibrated” = lives in color cell with no redshifts



Stanford, Masters, Darvish, Stern, et al. 2021 (ApJ 256, 9)

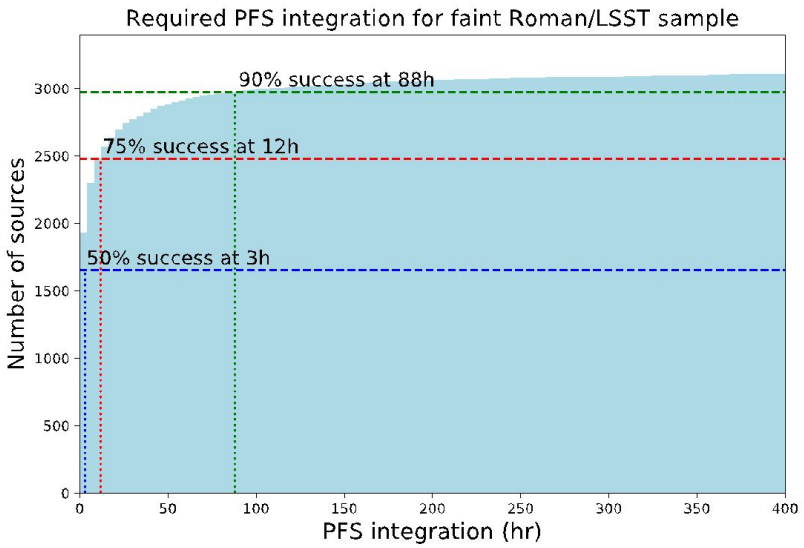
PFS: Integration time for secure redshift

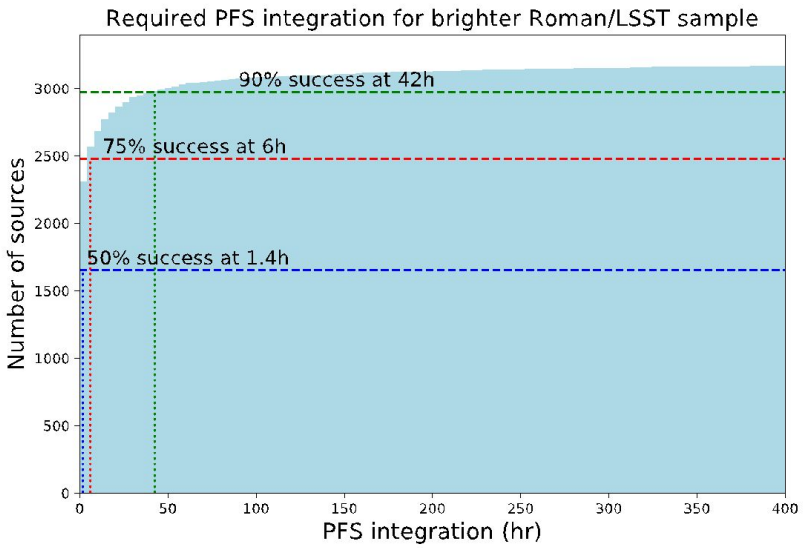
- We break galaxies into star-forming/passive according to their designation in the COSMOS2015 catalog
- For star-forming galaxies, assumed a secure redshift is obtained if either of the following conditions are met:
  - Two emission lines are both detected at >4σ
  - Lyα or [OII] is detected at >10σ
- For passive galaxies, assume the continuum around two prominent absorption features would need to be detected at >5σ
- Assume the S/N scales as $\sqrt{t}$



Example PFS ETC result for one galaxy in the sample, z=1.278

Getting to Roman depth



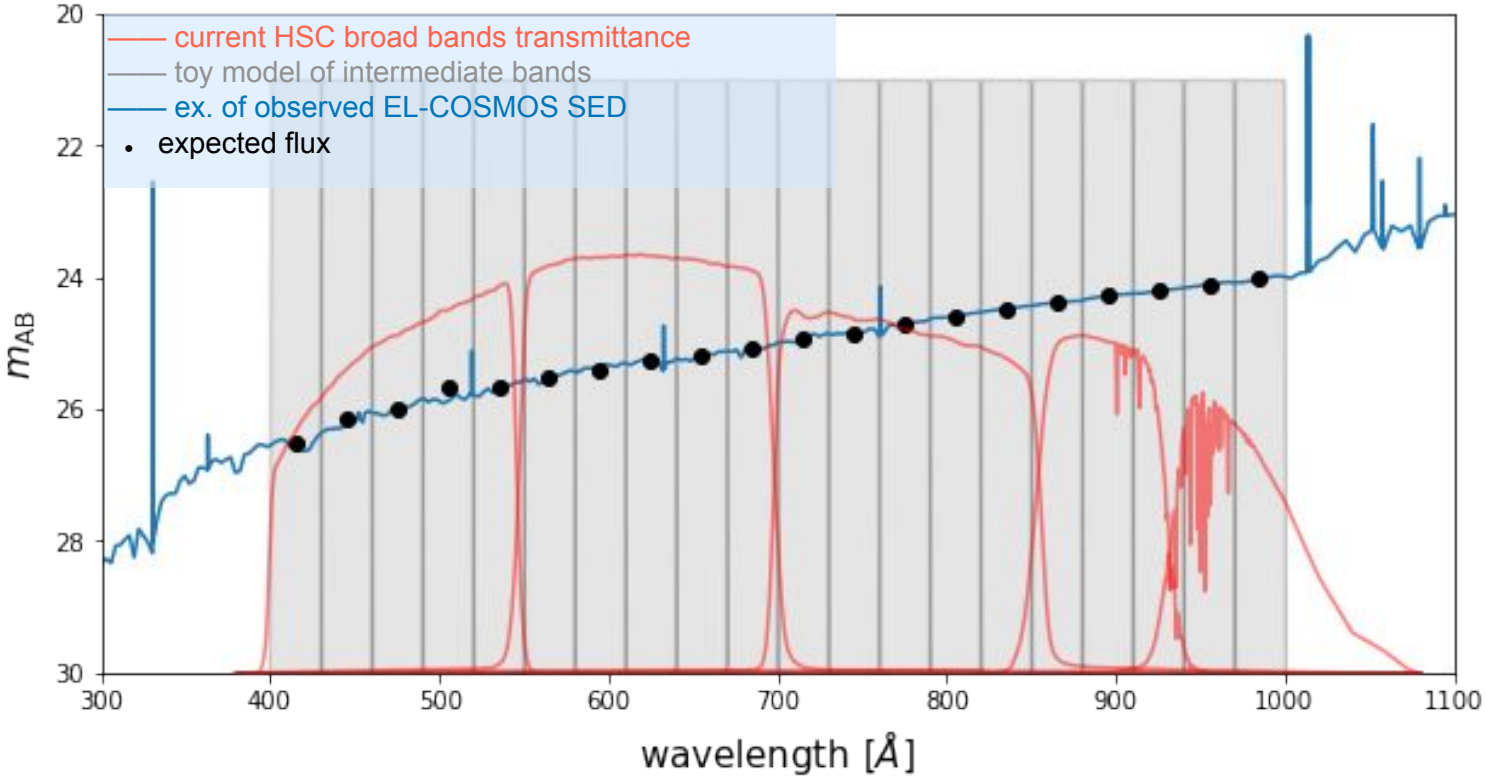


- From these simulated spectroscopic results, getting to Rubin/Roman depth is challenging even with high multiplex on an 8m telescope
- While partial success is attainable, the most difficult 10% of sources are predicted to required >100h integrations
- Solution for such sources could be to (1) exclude them from cosmology samples, (2) calibrate them with spatial clustering, or (3) extrapolate the color-redshift relation from brighter sources with similar colors, if possible

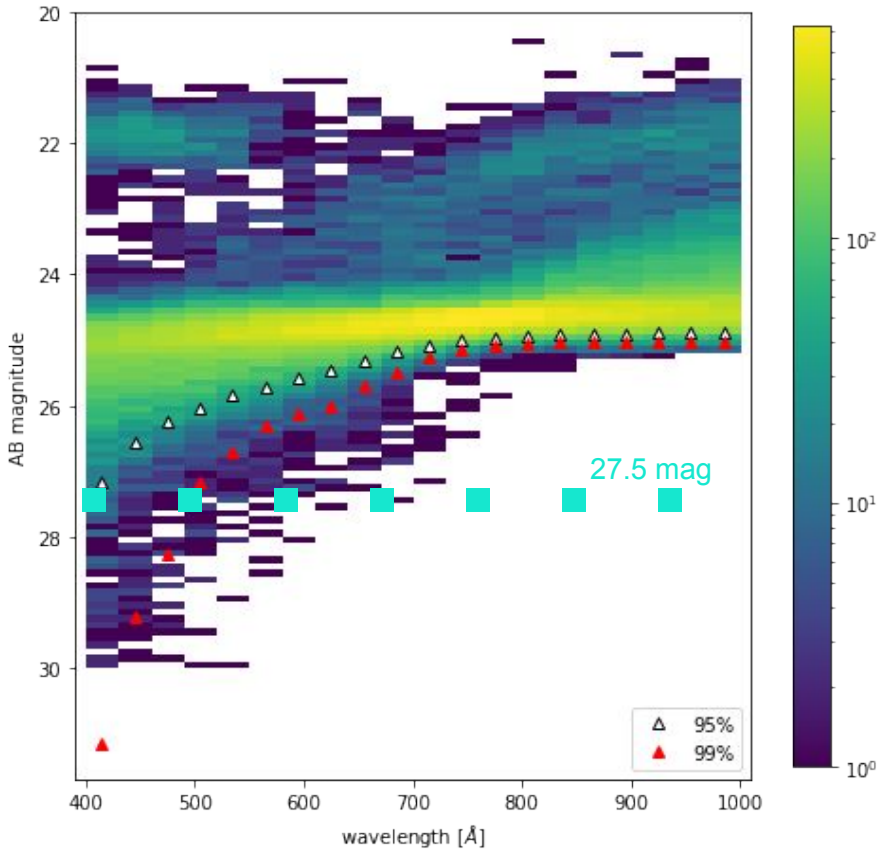
Conclusions

- A dedicated deep-drilling program with PFS would give good constraints on the faintest Roman sources of interest
- A larger program with more independent fields would be preferred, to establish statistics and account for possible environmental dependence in color-redshift relationship
- However, a ~20-40 night program with extremely deep observations would be beneficial:
  - Meaure color-redshift relation for ~75-90% of faintest Roman sources
  - Far more than 3k galaxies could potentially be observed in such a program if fibers could be dynamically reallocated
  - Presumably observational challenges associated with ~100h combined integrations

Intermediate bands



Expected time for EL-COSMOS sample

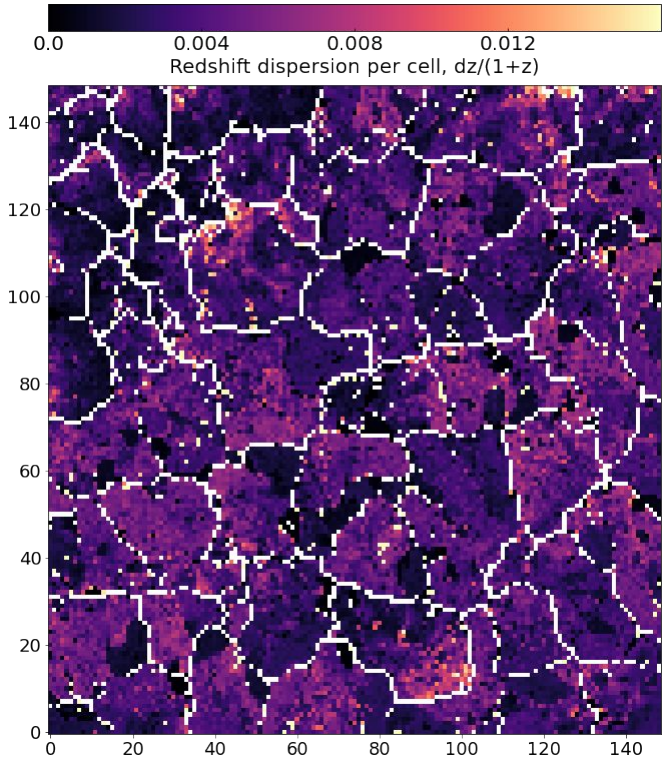


- EL-COSMOS (faint) sample
- Observed SED is converted to the expected flux at each IB filters
- How much fraction of objects we need to observe?
- (*) cut at 27.5 mag at bluer bands
- (**) assume 7 hours / night

nights(**)	95%	99%(*)
/FoV	2.3	4.4
/5 deg2	7.7	14.7
/25 deg2	38.3	73.3

number of nights required

Ability of SOM to classify the redshifts

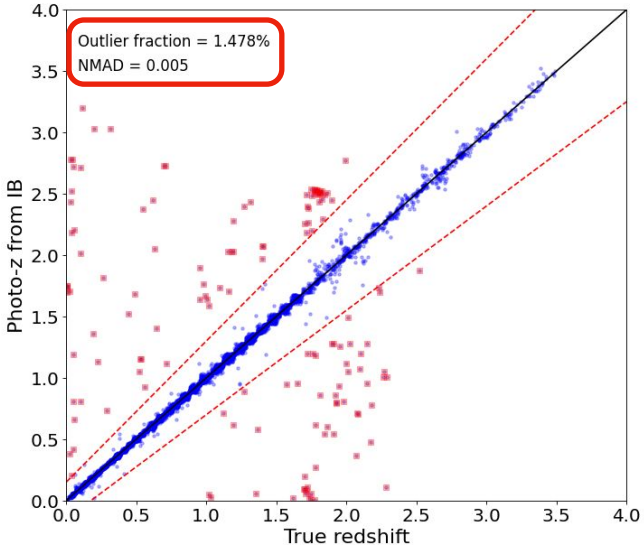


c. Dan Masters

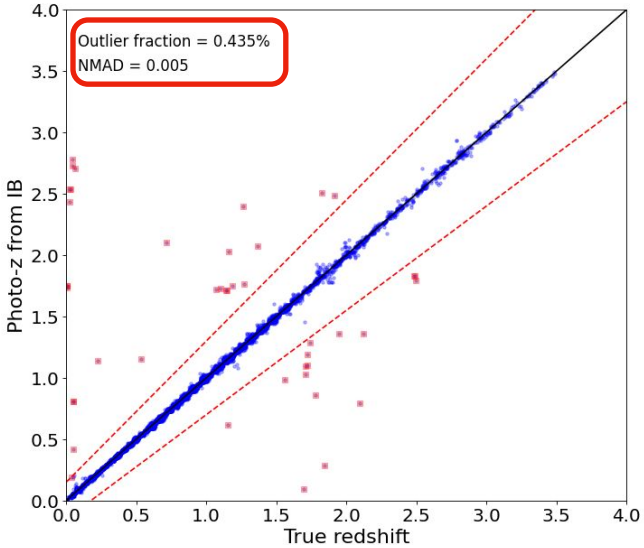
- Self Organizing Map (SOM) is used to characterize the colors in the 20 IBs
- Each cell has the vector value of color (flux).
- galaxies are classified into SOM cell where the color of the galaxy is closest those of the SOM cell.
- Each SOM cell has then median (or any other summary statistics) of redshift: zSOM_i
- Now the redshift of the z-unknown galaxy is given by the zSOM_i of the cell which has the closest color of that galaxy.
- <1.5% dispersion within a cell

IB band photo-z expected performance

10 sigma sample w/ shallow Texp. (2.3nights/FoV)



same sample but deep Texp. (4.4 nights/FoV)



- Add photometric noise corresponding to the exposure time
- find the nearest SOM cell trained with the spec-z sample (10 sigma detection in all 20 IBs)
- pretty good performance of intermediate photo-z
- still need to discuss how the outlier number (a few percent) spoils the calibration?

Photo-z DOE/NASA RFI response

- Photo-z's for billions of galaxies is a challenge shared by Roman/Rubin/Euclid
- At Roman+Rubin depths (i~25.3), spectroscopy is lacking
- Photo-z precision & accuracy key for maximally exploiting these datasets for cosmology
  - Improvement here also brings great benefits to galaxy evolution and other science
- Coordination between DOE+NASA on solving the photo-z problem, particularly for Roman+Rubin, potentially very important

Summary

- Progress is being made on calibrating the color-redshift relation in order to measure accurate photo-z's essential for cosmology with Roman
- Calibrating the faintest sources may require deep integrations with, e.g., PFS, or a dedicated deep field in IB filters
- Cluster-z (not discussed here) is another possibility for redshift validation and calibration that is being explored in more detail

Photo-z challenges identified in RFI response

- Need for ultradeep, high-multiplex spectroscopy
  - Most ambitious goal, could entail funding of new instruments such as FOBOS on Keck, MSE, MegaMapper, etc.
- Developing large-scale, realistic simulations for photo-z
- Creation of a centralized deep-sky spectroscopic database
  - Could be hosted by an established center like NED
  - A key problem and difficult to get funding/effort for
- Joint definition of a “fiber clearinghouse” list of most-wanted targets that can be used as fillers for current and upcoming fiber spectrographs
- Funding for direct collaboration between DOE and NASA-funded scientists working on photo-z, e.g., annual workshops