The C3R2 Survey: Keck Enabling Weak Lensing Cosmology with Euclid and WFIRST

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Keck Science Meeting

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Jet Propulsion Laboratory
California Institute of Technology

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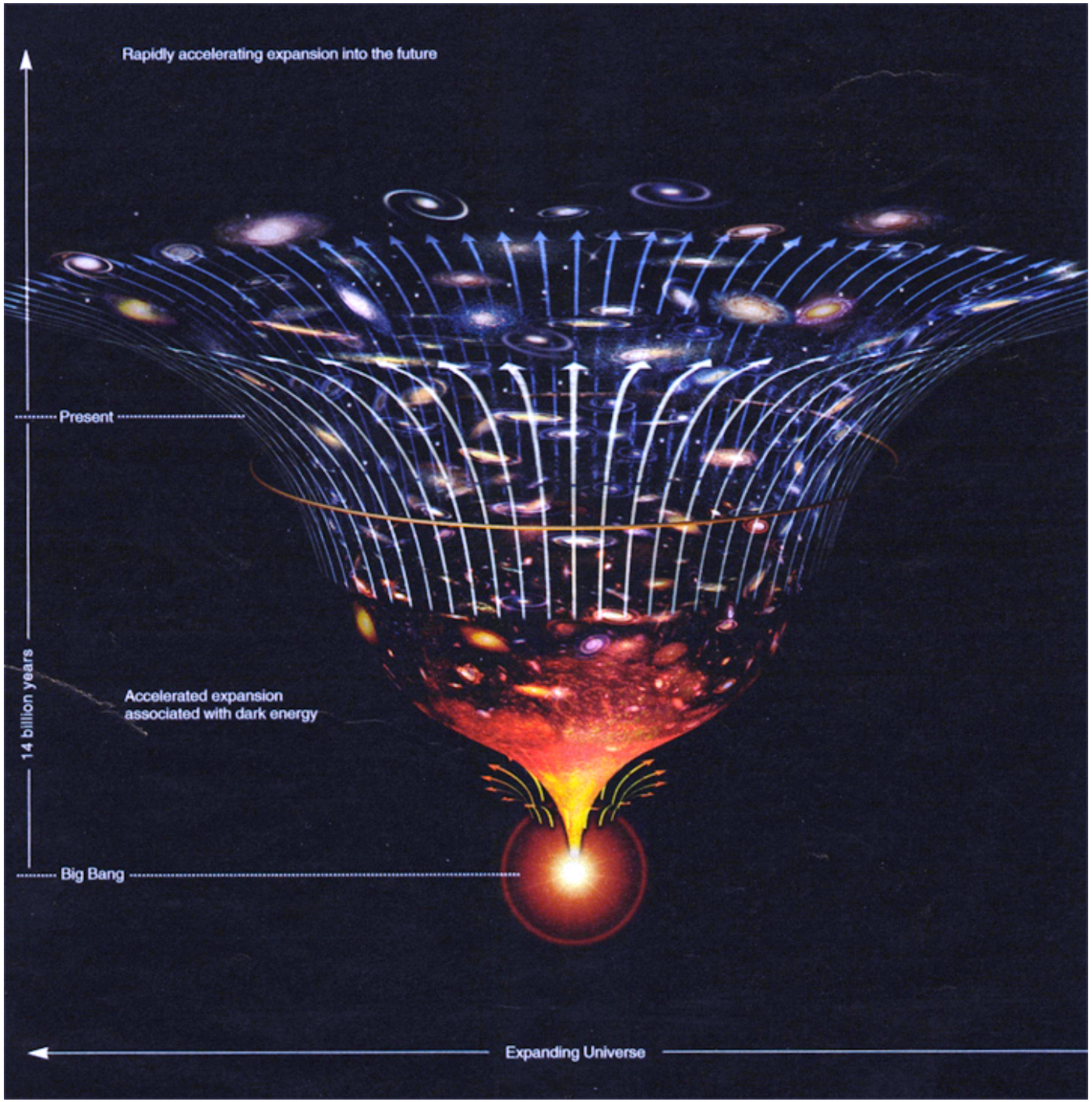


Breakthrough from the 1990s:
Accelerating cosmic expansion

2011 Nobel Prize in Physics

Λ?

Consequences of Dark Energy

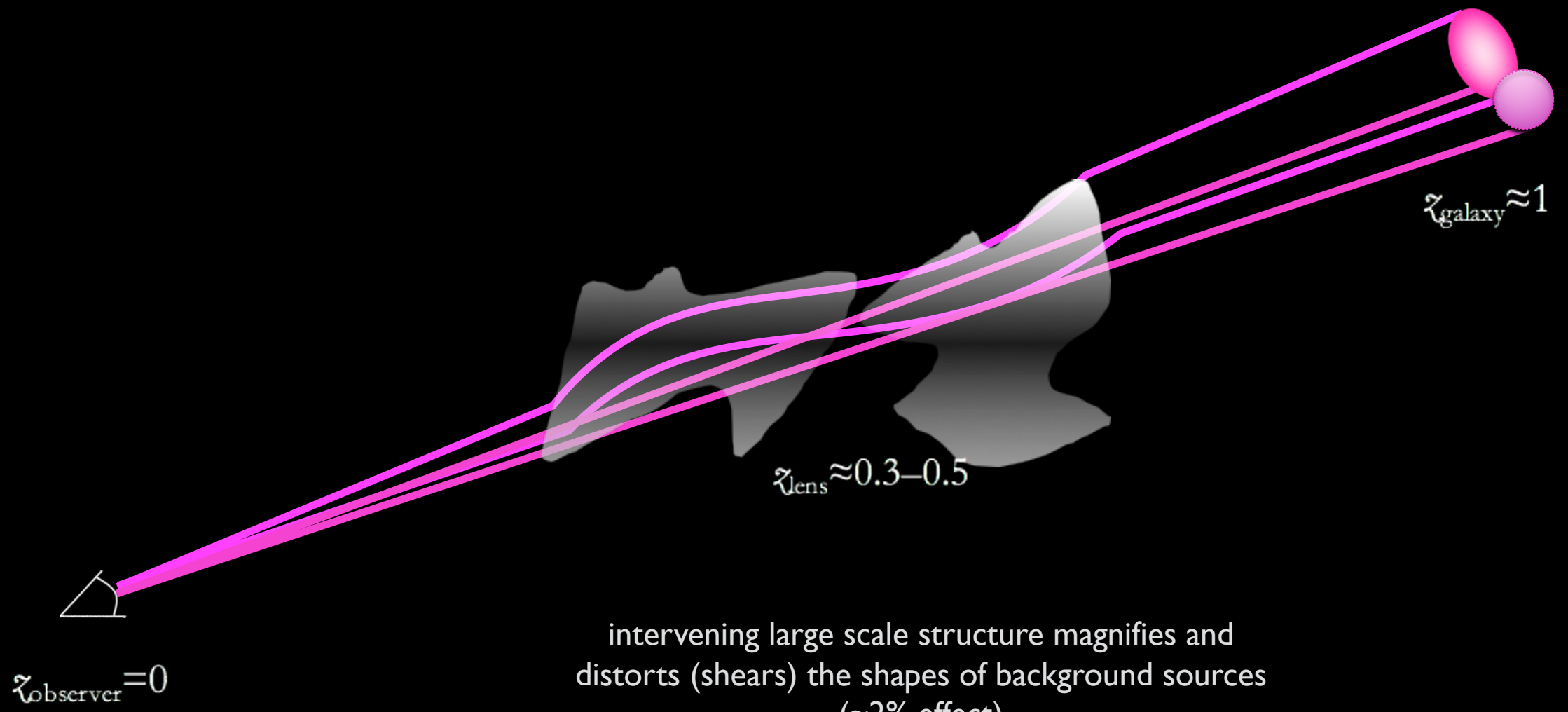
1. Expansion history of the Universe (distance-redshift relation)
2. Growth of Structure
   - How do structures (mainly dark matter) evolve and grow over cosmic time?
   - Attraction of gravity competes with repulsion of dark energy

Alternatively, if General Relativity is wrong on large scales, modified gravity theories could explain the accelerating expansion, but with *different* implications for the growth of structure

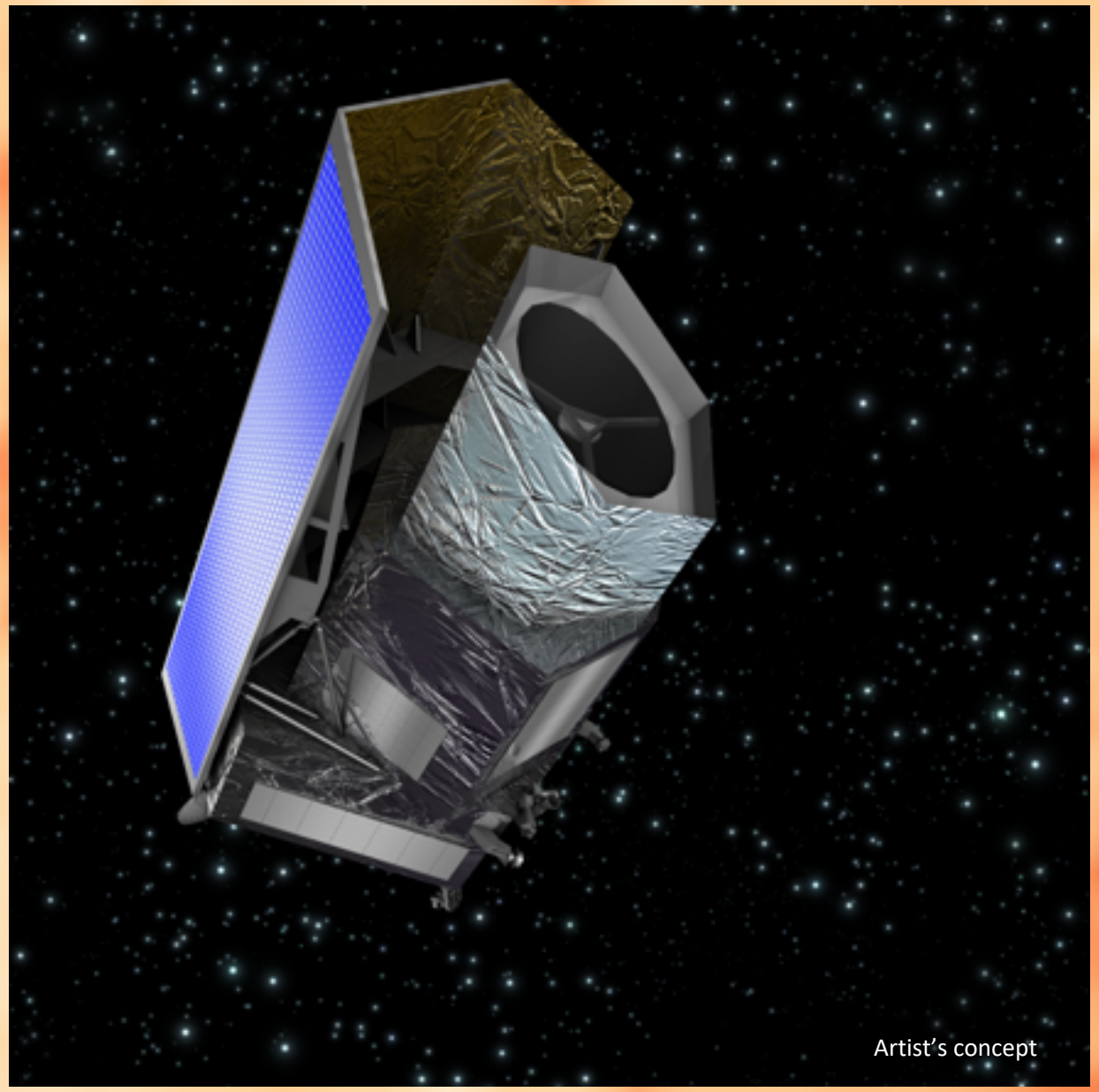
→ **MEASURE BOTH**

Image credit: Volker Springel/MPA

Probes of the Structure Formation: Weak Gravitational Lensing



intervening large scale structure magnifies and distorts (shears) the shapes of background sources (~2% effect)



Euclid:

- ESA M-Class Mission (~probe-class)
- significant NASA participation
- launch date: **2022**

- 1.2-meter mirror (TMA = three-mirror anastigmat)
- two instruments: **VIS** & **NISP**
- wide-field optical imaging survey (**VIS**)
  - single broad band (riz)
- wide-field near-IR imaging survey (**NISP**)
  - three band (approx. Y, J and H)
- wide-field near-IR spectroscopy survey (**NISP**)

- primary science: cosmology (multiple probes)
- significant legacy science, ranging from resolved stellar populations within ~5 Mpc to most distant quasars

- 6-yr. survey, mapping 15,000 deg^2 from L2

WFIRST:

- NASA Flagship mission
- launch date: **~mid-2020s**

- 2.4-meter primary mirror (like Hubble)
- **Coronograph + Wide Field Imager / Slitless Spectrograph (0.28 deg^2 FOV)**
- Wide-field imaging / low-res spectroscopy from 0.7-2 μm

- Primary science: cosmology and exoplanets
- Significant legacy science, including early universe galaxies, galactic streams, "extreme" galaxies and quasars, clusters, etc.

- Plan to map ~2,000 deg^2 from L2 for weak lensing cosmology

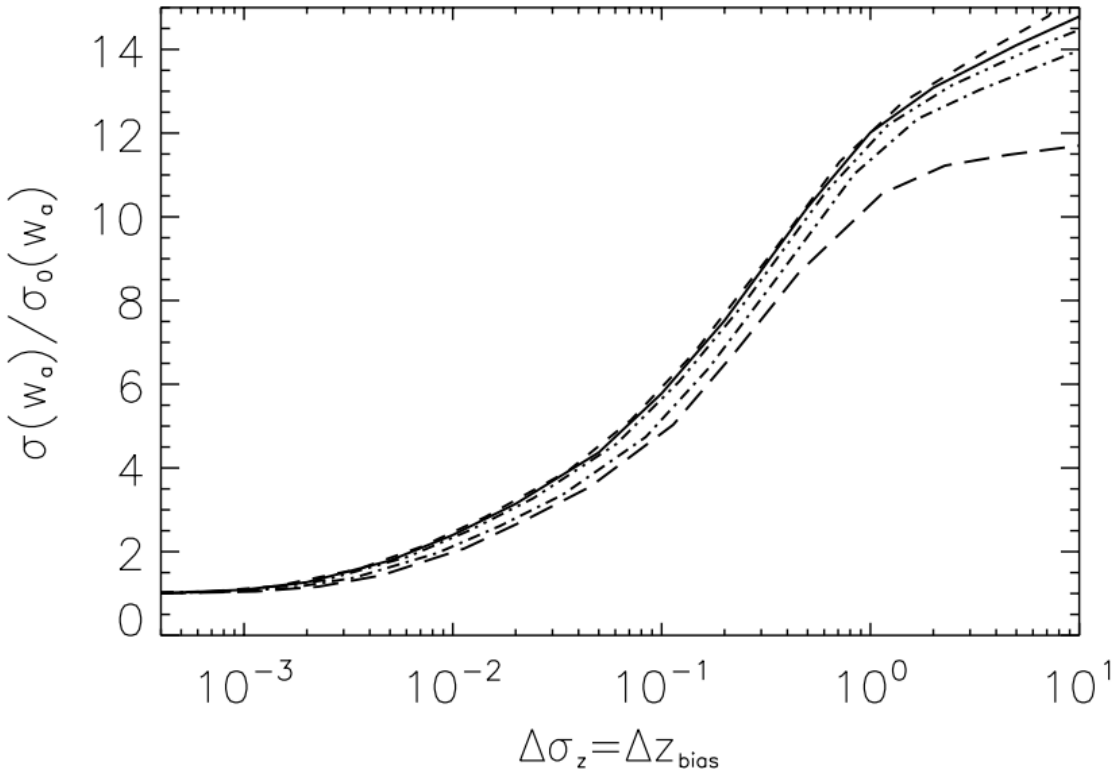
The Redshift Measurement Problem

- Billions of galaxies will be imaged by the Stage IV cosmology surveys
- Only possible to get spectroscopic redshifts for a small fraction
- Weak lensing cosmology requires that the redshift distributions of galaxies in ~10-20 redshifts bins be known with **high accuracy**

→Photometric redshifts will necessarily be crucial for weak lensing cosmology with these missions

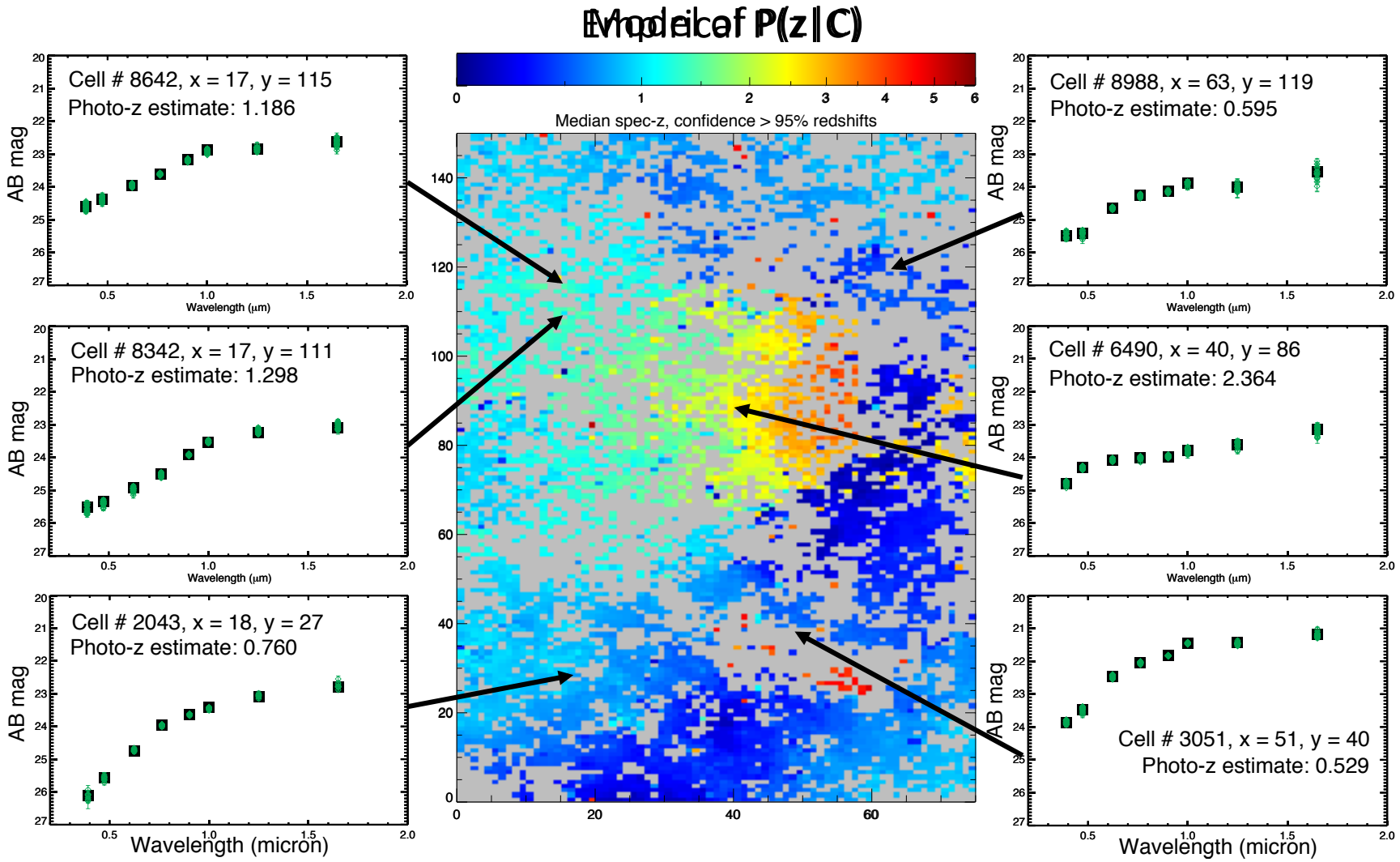
Requirement for weak lensing cosmology

- Weak lensing probes the growth of structure with redshift
- Need to split shear sample up into well-defined redshift bins, and know the redshift distributions *N*(z) of the galaxies in those bins with high accuracy
- ➢ $\Delta\langle z\rangle < 0.002\ (1+\langle z\rangle)$ for the redshift bins – i.e., the mean redshift in ~10-20 shear bins must be known to better than 0.2%
- Not possible with existing photo-z methods



Degradation of cosmological constraint with increasing photo-z bias (Ma et al. 2006)

Self-organized map of galaxy colors to Euclid depth



Masters et al. 2015, ApJ, 813, 53

C3R2 = Complete Calibration of the Color-Redshift Relation

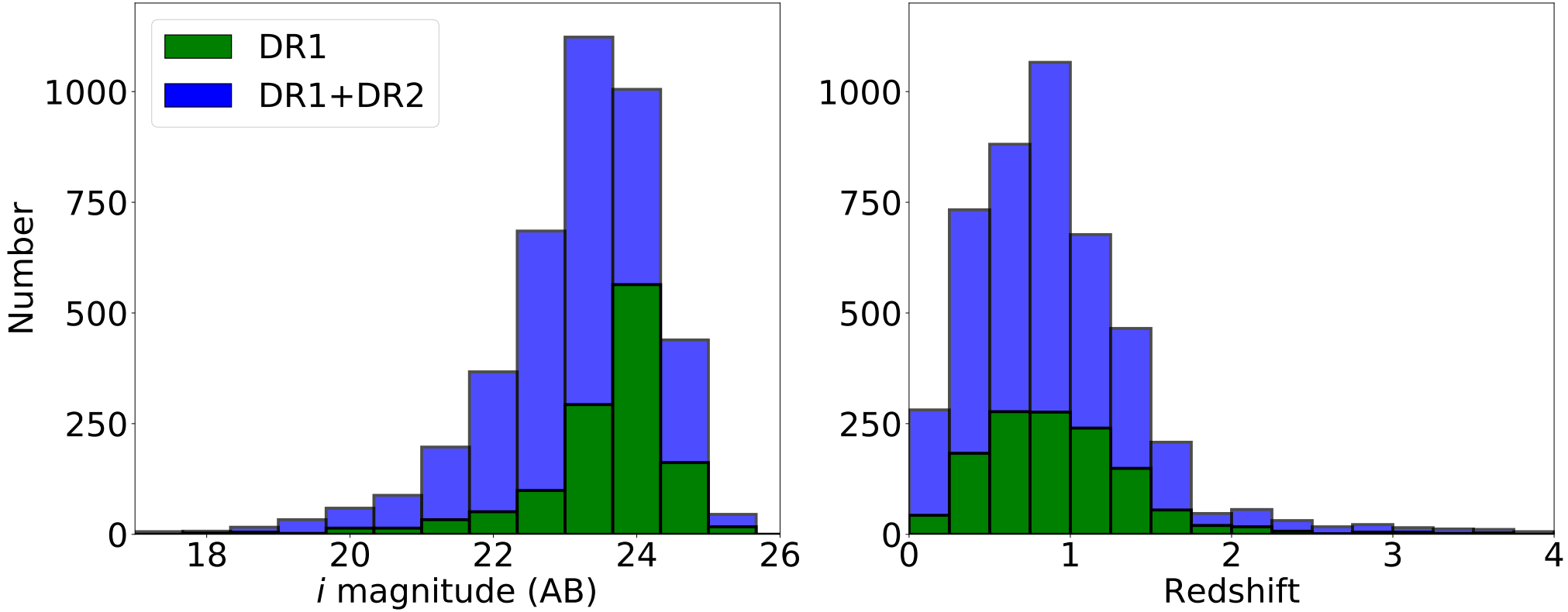
Judith Cohen (Caltech) - PI of Caltech Keck C3R2 allocation
16 nights (DEIMOS + LRIS + MOSFIRE, kicked off program in 2016A)
Daniel Stern (JPL) - PI of NASA Keck C3R2 allocation
10 nights (all DEIMOS; "Key Strategic Mission Support")
Daniel Masters (JPL) – PI of NASA Keck C3R2 allocation 2018A/B
10 nights (5 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

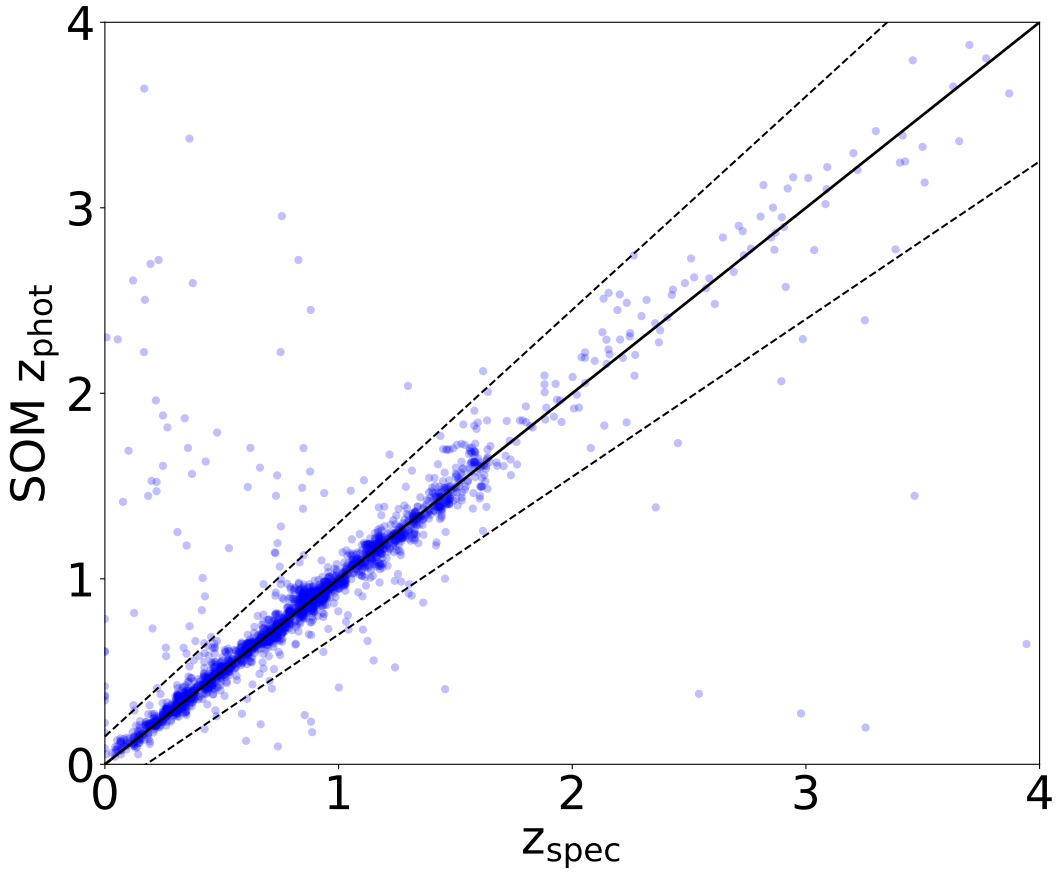
Additional Collaborators: Peter Capak, S. Adam Stanford, Nina Hernitschek, Francisco Castander, Sotiria Fotopoulou, Audrey Galametz, Iary Davidzon, Stephane Paltani, Jason Rhodes, Alessandro Rettura, Istvan Szapudi, and the Euclid Organization Unit – Photometric Redshifts (OU-PHZ) team

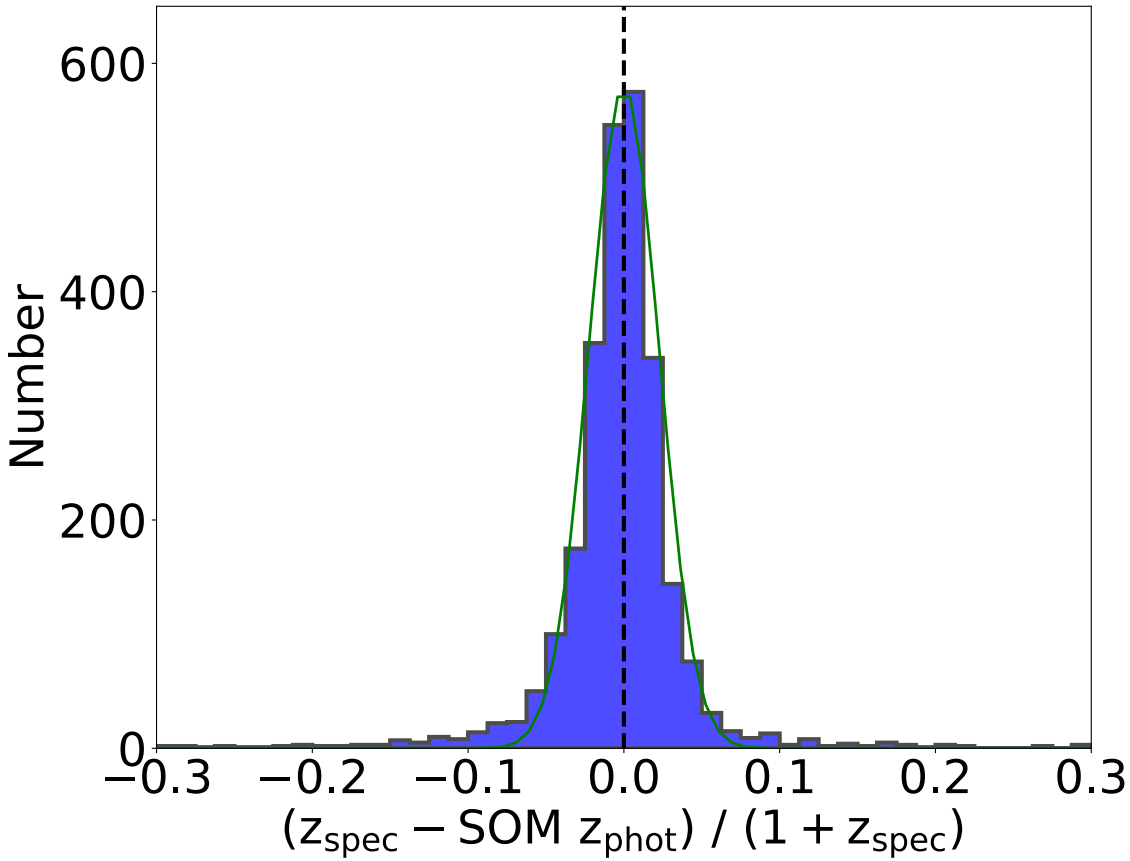
C3R2 stats through DR2 (2016A-2017A)

- 29 nights, ~19 good weather
  - 22 DEIMOS, 5 LRIS, 2 MOSFIRE
- 6696 spectra: 4534 Q >= 3 (high quality), 3971 Q = 4 (certain)



C3R2 – SOM-based photo-z



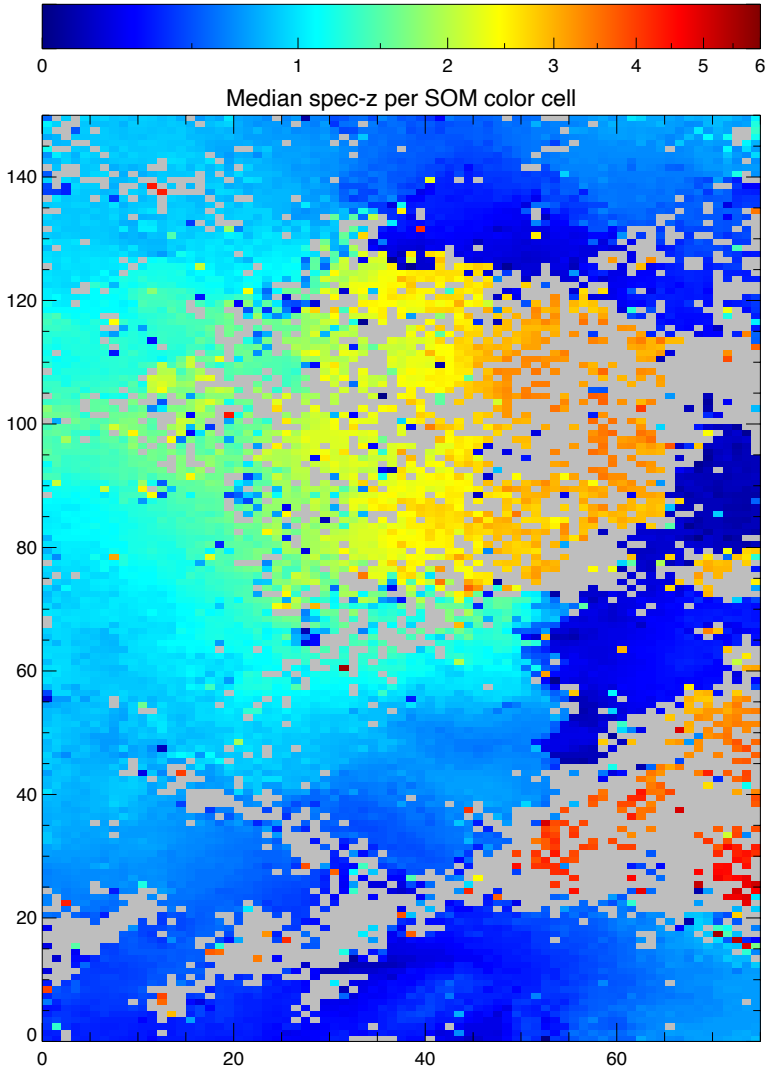


Outlier fraction 4.7%, scatter < 3%, bias of 0.18%

Method achieving unbiased performance!

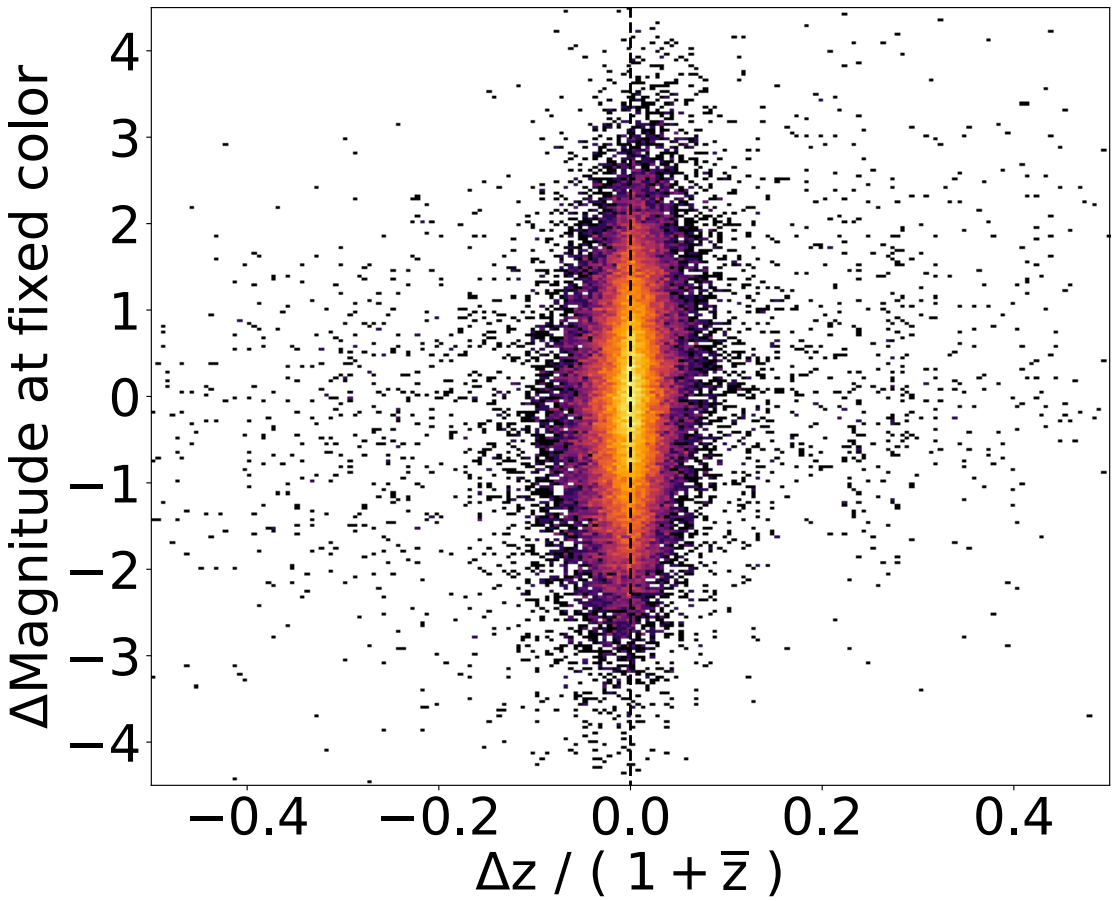
Color coverage to Euclid depth

- Much of the galaxy color space explored to significant depth (>85% of galaxies in cell with at least 1 specz)
- Small fields (~1-2 deg^2) means cosmic variance an issue
  - ➢ Is P(z|C) relation we derive fully applicable to wider fields?
  - ➢ Are we missing relevant parts of the galaxy color space?



Magnitude (in)dependence

- Compare spec-zs of unique pairs of galaxies at fixed color (SOM position)
- Illustrates very weak secondary dependence of redshift on magnitude at fixed color in the LSST+Euclid color space



Summary

- C3R2 survey is a major initiative with the Keck telescopes to enable cosmology in the 2020s
- Survey has obtained >4500 secure redshifts of faint galaxies to calibrate P(z|C) relation
- Initial tests of the method are very promising.
- DR1 published; DR2 soon to be submitted