4MOST complete calibration of the color-redshift relation: 4C3R2

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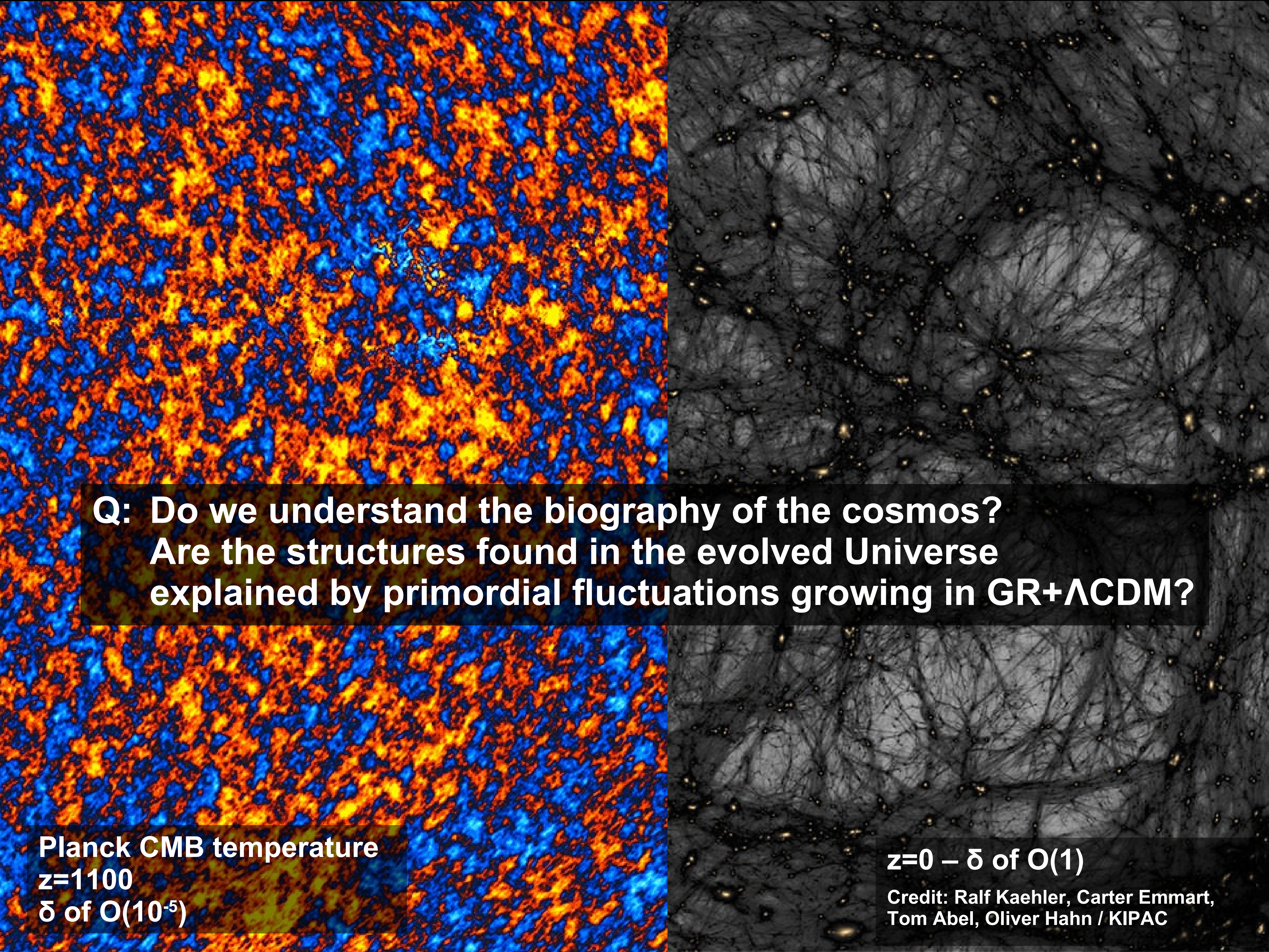
4MOST Community Workshop, virtually, June 13 2020

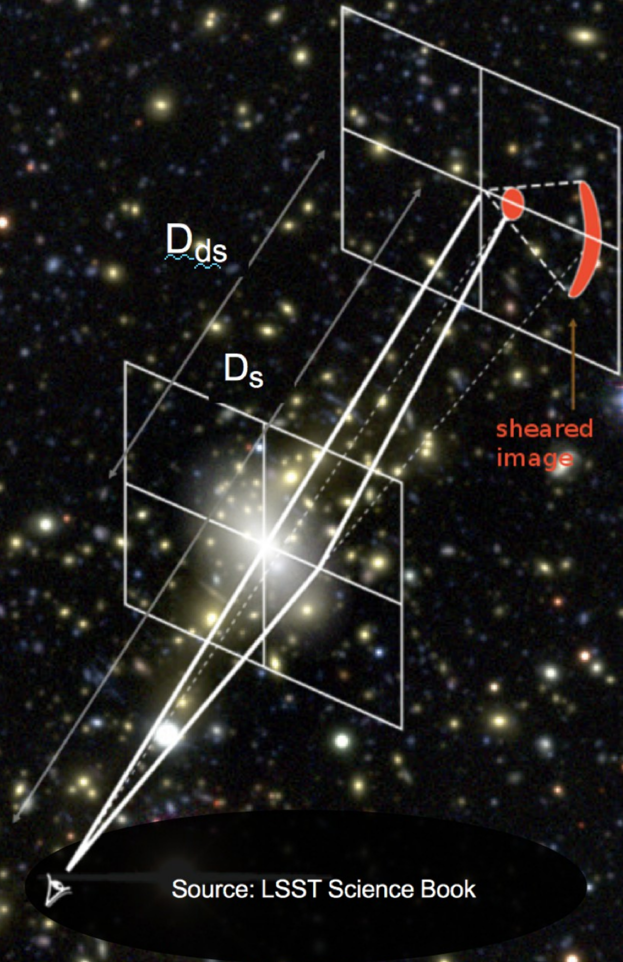
Agenda

- Introduction: Why the color-redshift relation of galaxies needs spectroscopic calibration

- What is 4C3R2? A participating survey that extends WAVES to fainter magnitudes and higher redshift to cover ugrizYJHK_s color space

- Who we are - 4C3R2 and some first ideas for collaboration within the Science Team


Q: Do we understand the biography of the cosmos?
Are the structures found in the evolved Universe
explained by primordial fluctuations growing in GR+ΛCDM?
Planck CMB temperature
z=1100
δ of O(10-5)
z=0 – δ of O(1)
Credit: Ralf Kaehler, Carter Emmart,
Tom Abel, Oliver Hahn / KIPAC



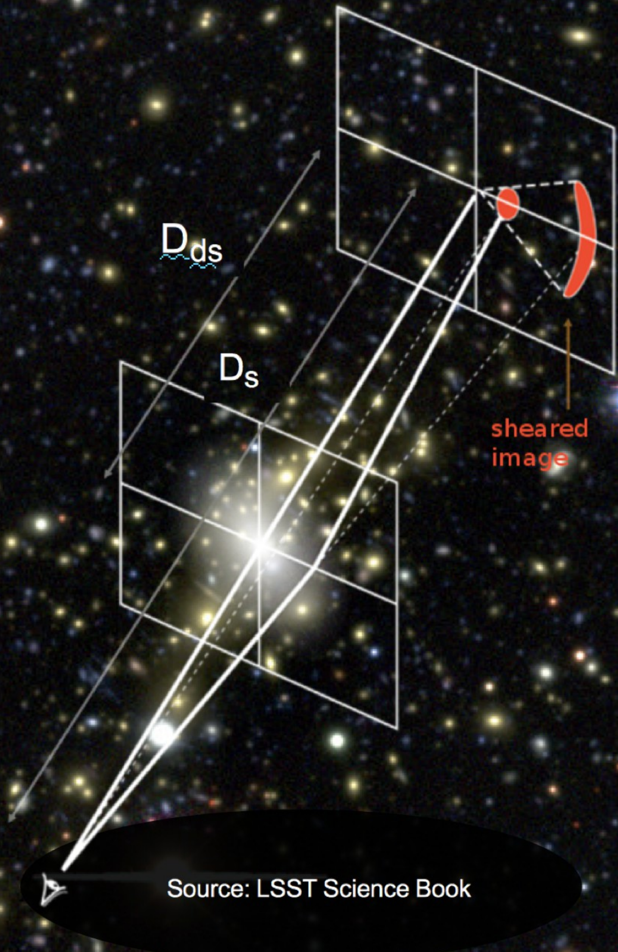
DES deep field

Gravitational lensing

- Weak lensing connects observed galaxy images to the underlying matter density field.
- Need to estimate **shapes** and distances (**redshifts**) of galaxies.

$$\gamma_t(\theta) = \langle \kappa(\theta') \rangle_{\theta' < \theta} - \kappa(\theta)$$
$$\kappa = \Sigma / \left[\frac{c^2}{4\pi G} \frac{D_\mathrm{s}}{D_\mathrm{d} D_\mathrm{ds}} \right]$$

- As data sets increase, **bias** in shapes/redshifts is key issue.



Shapes: Done by DES, KiDS, Euclid, LSST for $10^{8...9}$ galaxies to ~better than 1%

Redshifts: Elephant in the room

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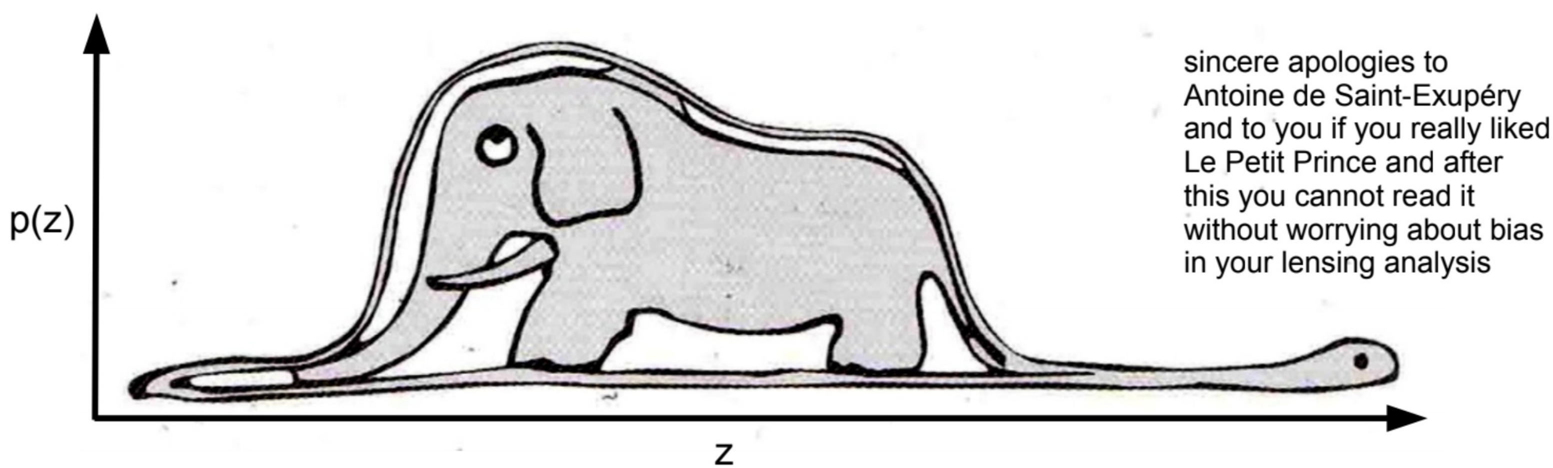
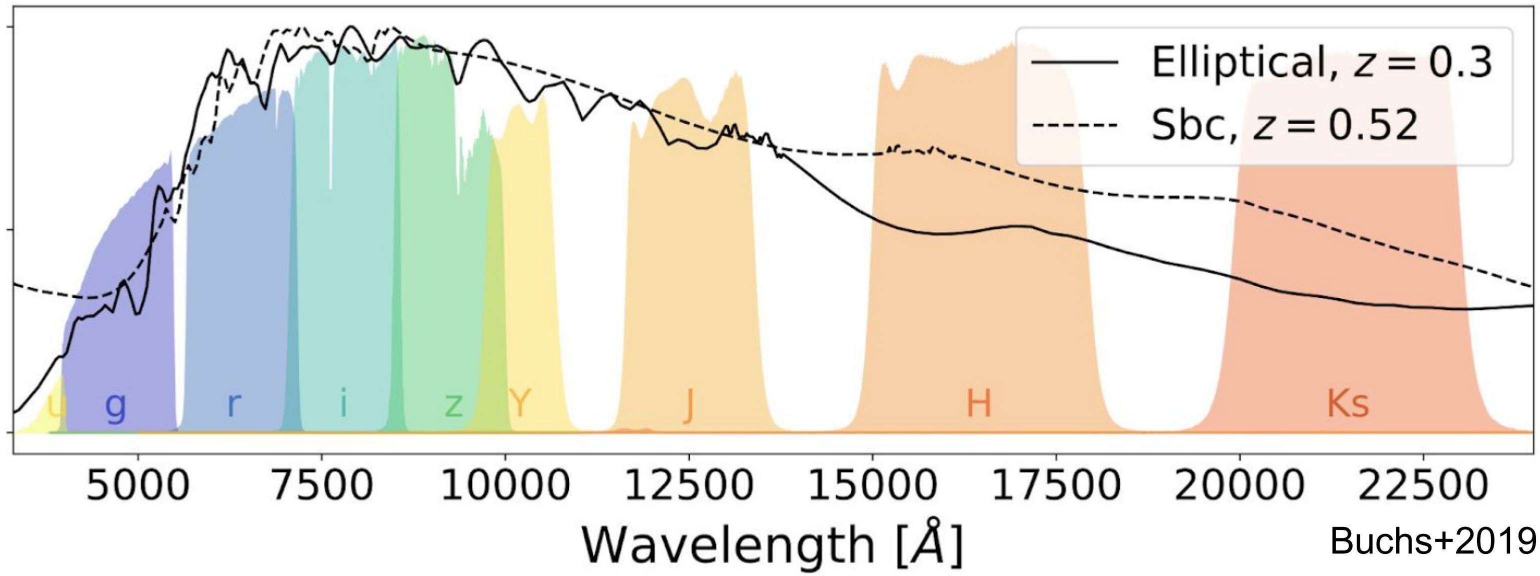
Photometric redshift calibration is the elephant in the room

- The relation of color-magnitude to redshift is not simple – every galaxy is different
- Uncertainty of the p(z) of galaxy samples is already today (DES, KiDS) the bottleneck of lensing surveys
- With Euclid and LSST, things will be much worse: smaller statistical errors, fainter galaxies. Need <z> to 0.002 ...
- There is no magic cure. We need (the right kind of) data.



Why? Type-redshift degeneracy

p(redshift | observed fluxes in few bands)



Buchs+2019

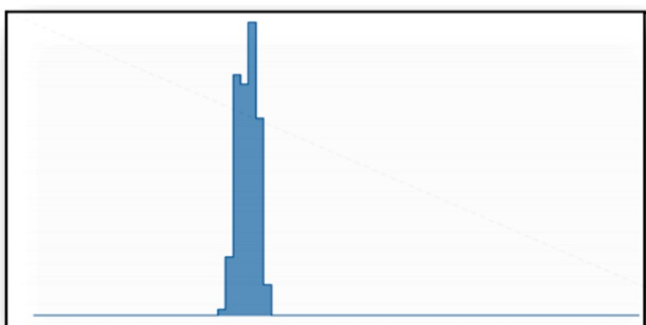
Difficulties in the common case of type-redshift degeneracy:

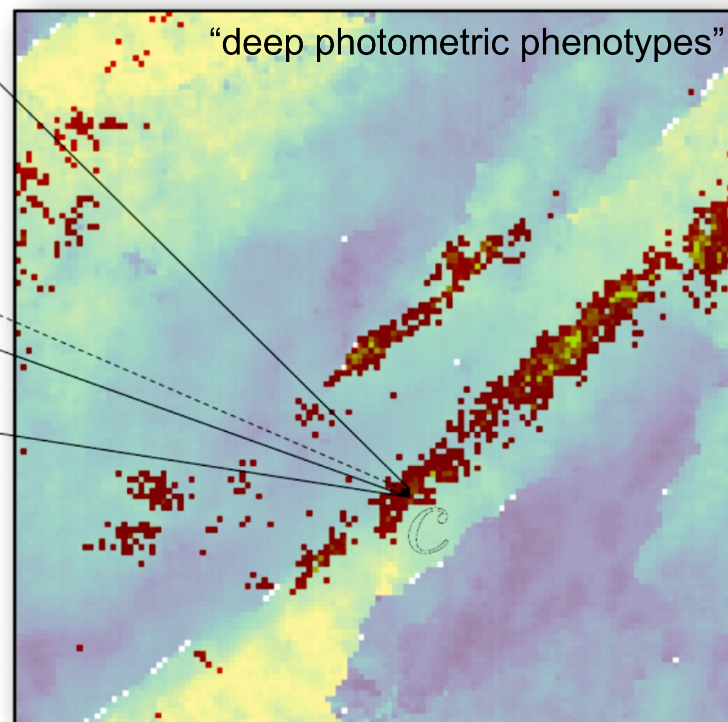
- Templates / “implicit” priors determine the mix of types/redshifts — Schmidt+2020
- Spectroscopic selection effects matter distort the mix of types/redshifts — Gruen+2016; Hartley+2020; Joudaki+2020
- Bias evolution of mixed-bag samples is limiting clustering redshifts — Gatti+2017

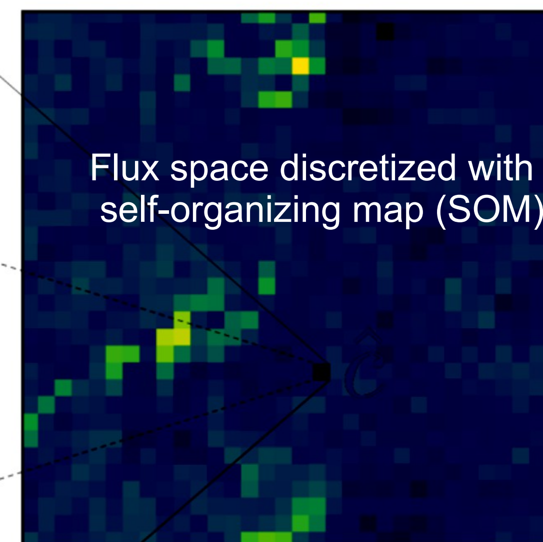
Complete calibration of color-redshift relation in ugrizYJHK_s

p(redshift | observed fluxes in few bands) ~

p(redshift | ugrizYJHK_s color) x p(ugrizYJHK_s color | observed fluxes in few bands)







Buchs+2019

This part needs data: spectroscopic redshifts at each point in ugrizYJHK_s!

C3R2: VLT/Keck/LBT hunt for faint galaxy redshifts

4C3R2: wide, brighter, high-multiplicity complement

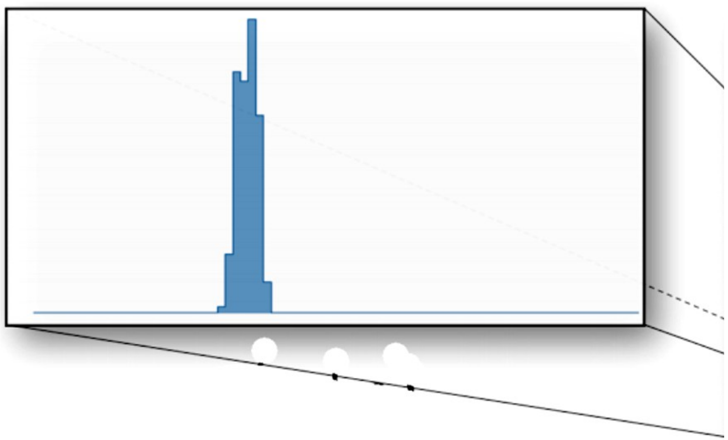
This part comes from wide survey observations and ugrizYJHK_s deep fields

SOM-based redshifts: Now main method of DES (Buchs+2019; Myles+in prep.), KiDS (Wright+2020), Euclid (Masters+2015,17,19), possibly LSST (McCullough+in prep.)

Complete calibration of color-redshift relation in $ugrizYJHK_s$

p(redshift | observed fluxes in few bands) ~

p(redshift | $ugrizYJHK_s$ color) x p($ugrizYJHK_s$ color | observed fluxes in few bands)



This part needs data: spectroscopic redshifts at each point in $ugrizYJHK_s$!

C3R2: VLT/Keck/LBT hunt for faint galaxy redshifts

4C3R2: wide, brighter, high-multiplicity complement

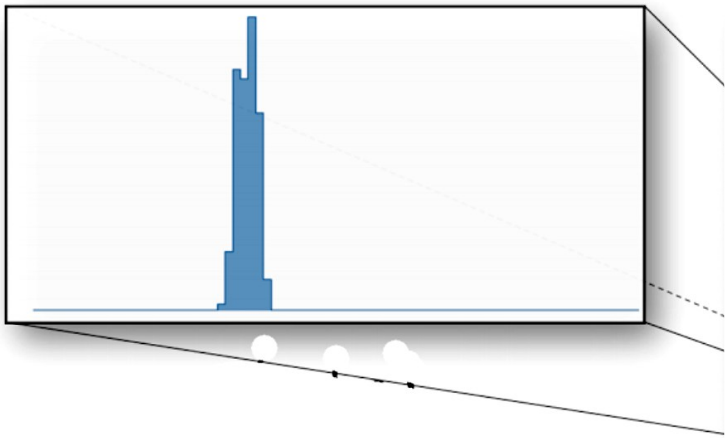
Benefits:

- p(redshift | $ugrizYJHK_s$ color) is narrow
  - few redshifts per color cell suffice
  - best to spread out over large area
  - selection effects matter less
- p(redshift | $ugrizYJHK_s$) is nearly magnitude independent
  - get the brightest galaxies if you can!

Complete calibration of color-redshift relation in $ugrizYJHK_s$

p(redshift | observed fluxes in few bands) ~

p(redshift | $ugrizYJHK_s$ color) x p($ugrizYJHK_s$ color | observed fluxes in few bands)



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C3R2: VLT/Keck/LBT hunt for faint galaxy redshifts

4C3R2: wide, brighter, high-multiplicity complement

Challenges:

- Need to reject outliers confidently – need ~30 per cell - multiplicity is key!
- Need to calibrate $O(10^4)$ color cells – multiplicity is key!

4C3R2 sample selection

	WAVES-Deep	**4C3R2-Deep**	WAVES-Wide	**4C3R2-Wide**
Survey regions	GAMA23 + Deep Drilling	**GAMA23 + Deep Drilling [66 sq. deg.]**	WWS + WWN	**WWS + WWN [1170 sq. deg.]**
Target mag cut	Z<21.25	**Z<22**	Z<21.1	**Z<21.1**
Photo-z cut	z<0.8	**0.8<z<1.55**	z<0.2	**0.2<z<1.55**
Target density	11000 / sq. deg.	**300 per sq. deg., sampling from 1500 / sq. deg.**	750 / sq. deg.	**100 per sq. deg., sampling from 2000 / sq. deg.**

- Maximally complementary to WAVES: inverted WAVES photo-z cut
  - Better yet: both selections could be defined as sets of SOM cells
- Arbitrary subset of targets (Wide, 5%; Deep, 20%) yields sufficient sample for outlier rejection (30 / 10 per SOM cell in wide / deep)
- Exposure time matched to WAVES requirements (1.1h / 2.5h average for wide/deep)

Basic requirements: LRS, redshift only, SNR per resolution element ~3,
use photometric information when redshift is uncertain (single emission line)

Level 2: as WAVES (physical parameters derived from spectra),
Level 3: photometry+spectroscopy, including of non-observed or unsuccessful targets,
and SOM-level information (cell assignment, redshift distributions, stacked line diagnostics)

4C3R2 sample selection

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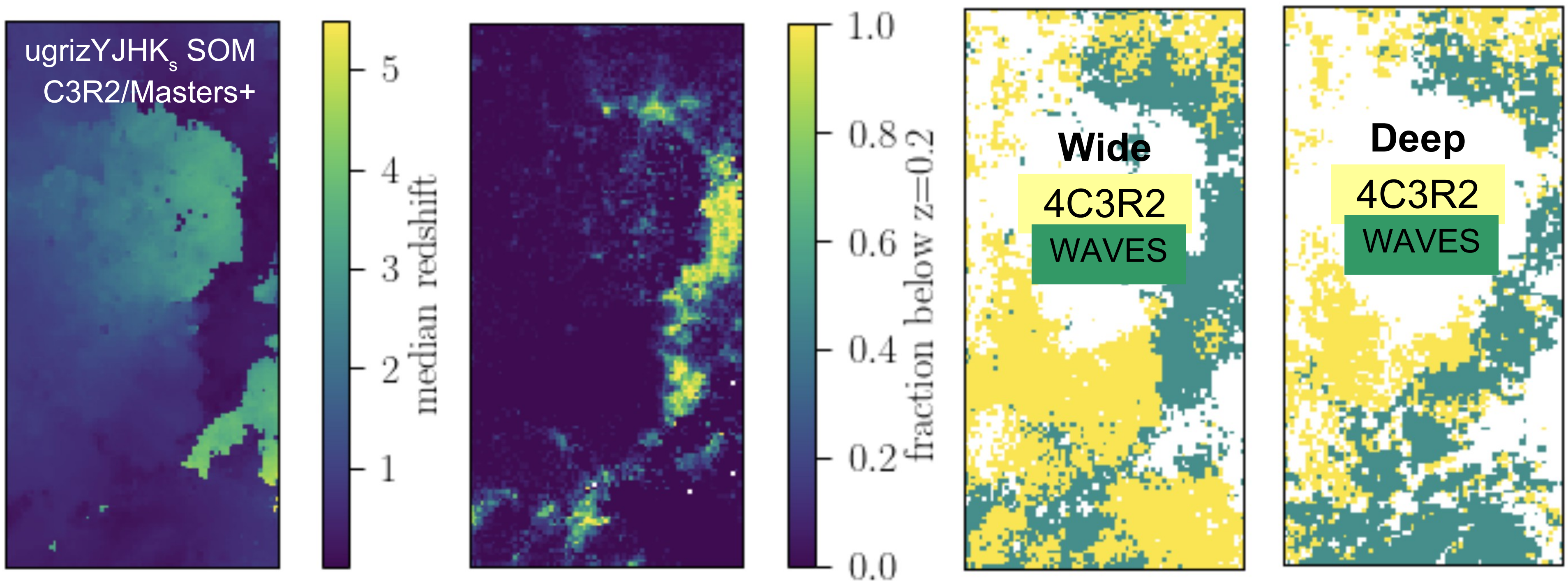
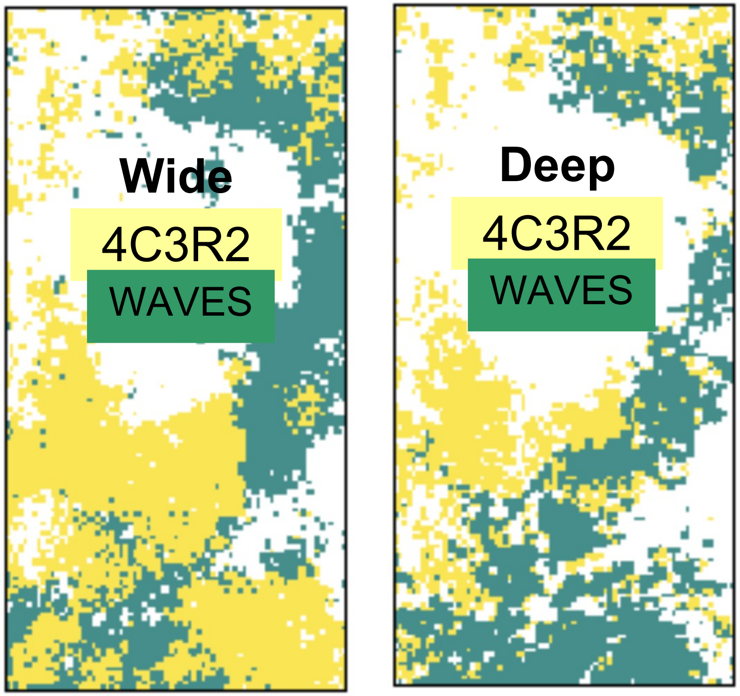


4C3R2 deliverables

WAVES + 4C3R2 cover, with sufficient count, the ugrizYJHK color space of ~60% of the galaxies that Euclid and LSST will use for cosmology.

Together, they form the three bottom layers of a wedding-cake strategy for color-redshift calibration.

4C3R2 (unlike WAVES) only observes a subset of these galaxies. Utilizing photometric catalogs, that still allows some of the WAVES science, to higher redshift / lower mass.



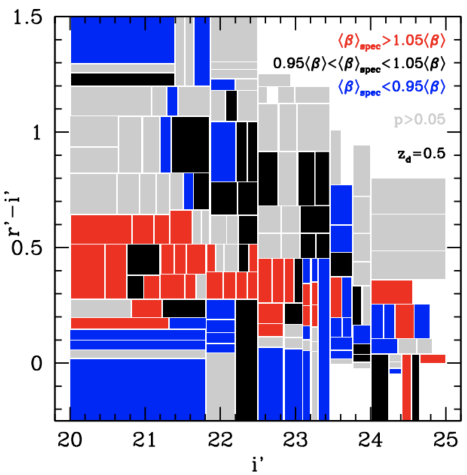
4C3R2 team has expertise on...

- deep multi-band photometry
  [Amon, Bernstein, Hartley (DES+NIR deep fields); Hildebrandt, Kuijken, Wright (KiDS+VIKING)]
- SOM methodology [Masters (C3R2); Amon, Bernstein, Gruen, McCullough, Pocino, Roodman (DES); Wright, van den Busch (KiDS)]
- redshift calibration
  [Amon, Bernstein, Gruen, Hartley, Hildebrandt, Miquel, McCullough, Roodman, Seitz, Wright]
- spectroscopic surveys
  [C3R2: Masters (Keck PI), Castander (VLT PI), Guglielmo, Saglia, Seitz (LBT), Liske (WAVES), Canning]
- wide-field photometric surveys [DES / KiDS / LSST / Euclid leadership, including by Amon, Bernstein, Castander, Gruen, Hartley, Hildebrandt, Roodman, Saglia]

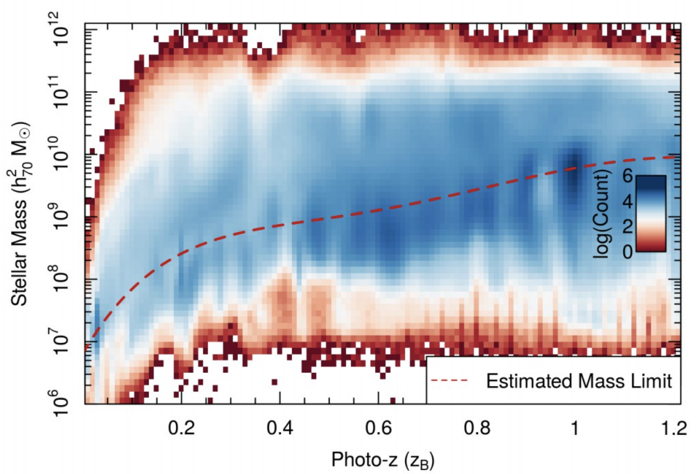
4C3R2 team is keen to collaborate on...

- Extracting and interpreting multi-band photometry
- Predicting distributions / purity / completeness of galaxy samples selected by photometry
- Using photometry to inform single-line spectra
- Linking 4MOST with DES/KiDS/LSST/Euclid
- Making lensing measurements to study the galaxy-matter connection and cosmology
- Modeling the galaxy population, stellar populations, AGN, across time

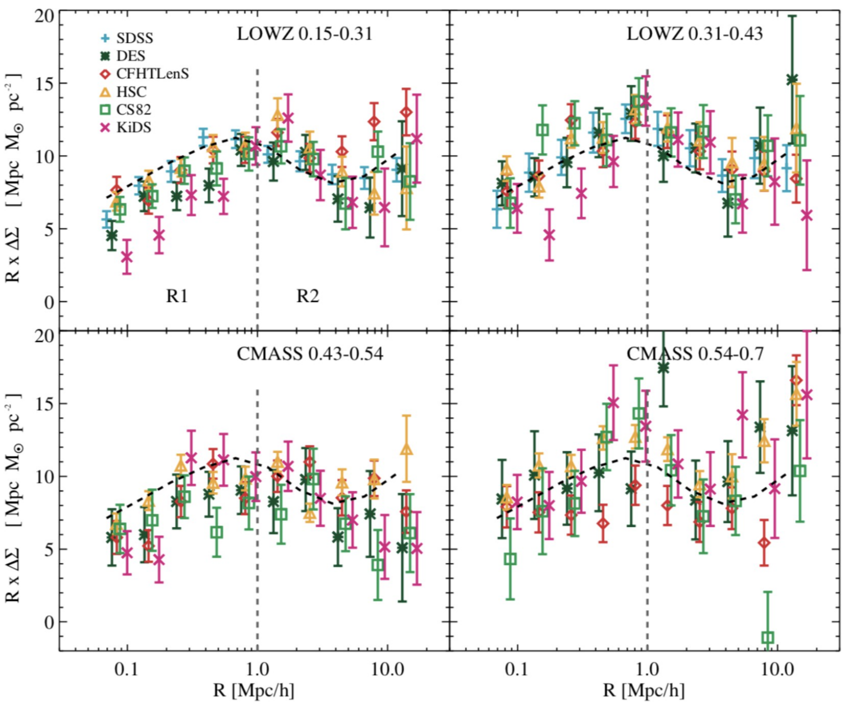
Coordination with WAVES is key!



Spec-z selection bias: Gruen+2016



KiDS-VIKING catalog: Wright+2019



Lensing without Borders: Leauthaud&Amon+, including Gruen, Hildebrandt, in prep.

Take-aways on 4C3R2

- 4C3R2 targets a systematically selected, small subsample of galaxies at higher redshift and fainter magnitude than WAVES
- This way, we collect representative spectra over parts of ugrizYJHK$_s$ color space that ~60% of the faint galaxies of photometric surveys live in
- Together with WAVES, 8m-class C3R2, and photometric surveys, this is key to accurate, reliable insights into cosmology and galaxy evolution with gravitational lensing

Le Petit Prince, Chapter 13

Taking stock of 60% of the photometric galaxies of the next decade!