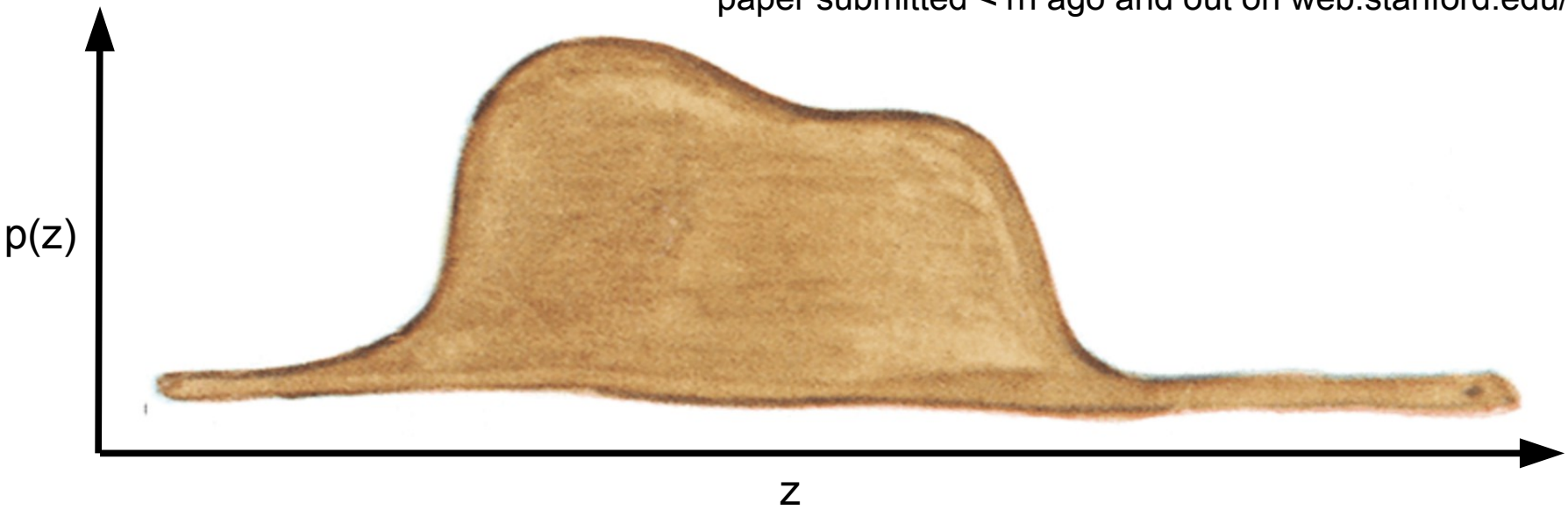
Accurate lensing in the era of
precision Cosmology
Berkeley, 01-15-2019

Breaking the type/redshift degeneracy with deep, many-band galaxy phenotypes

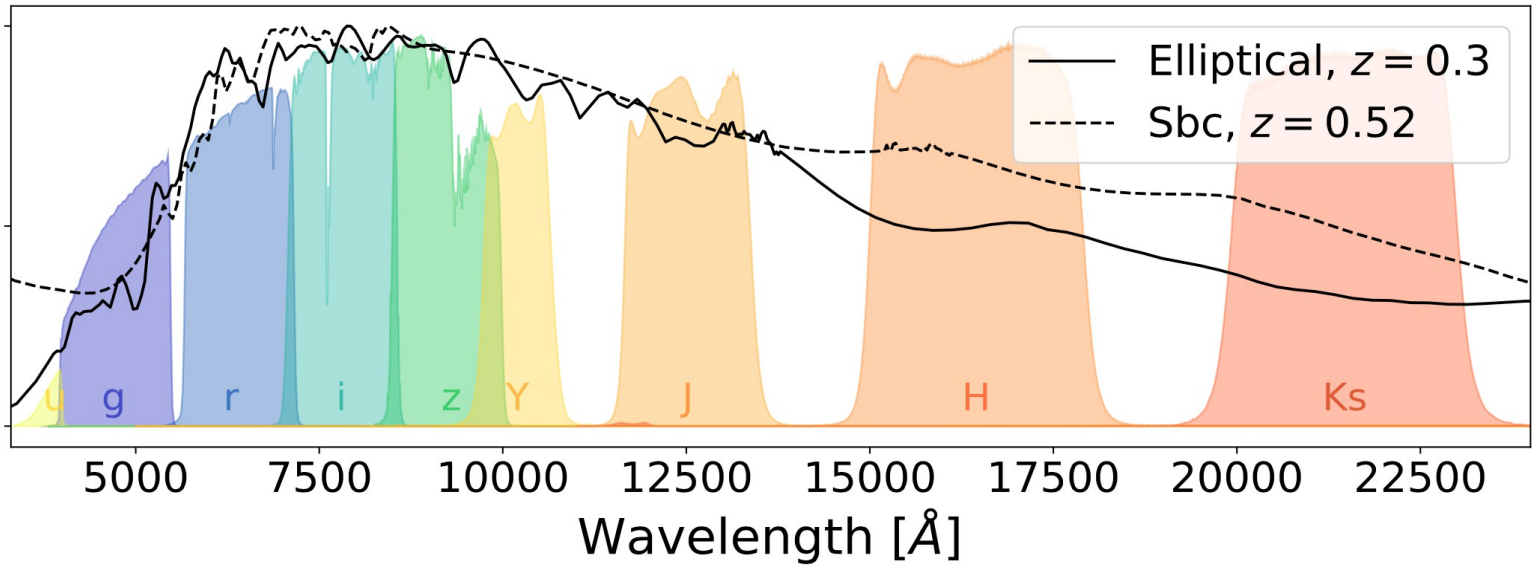
Daniel Gruen, Stanford

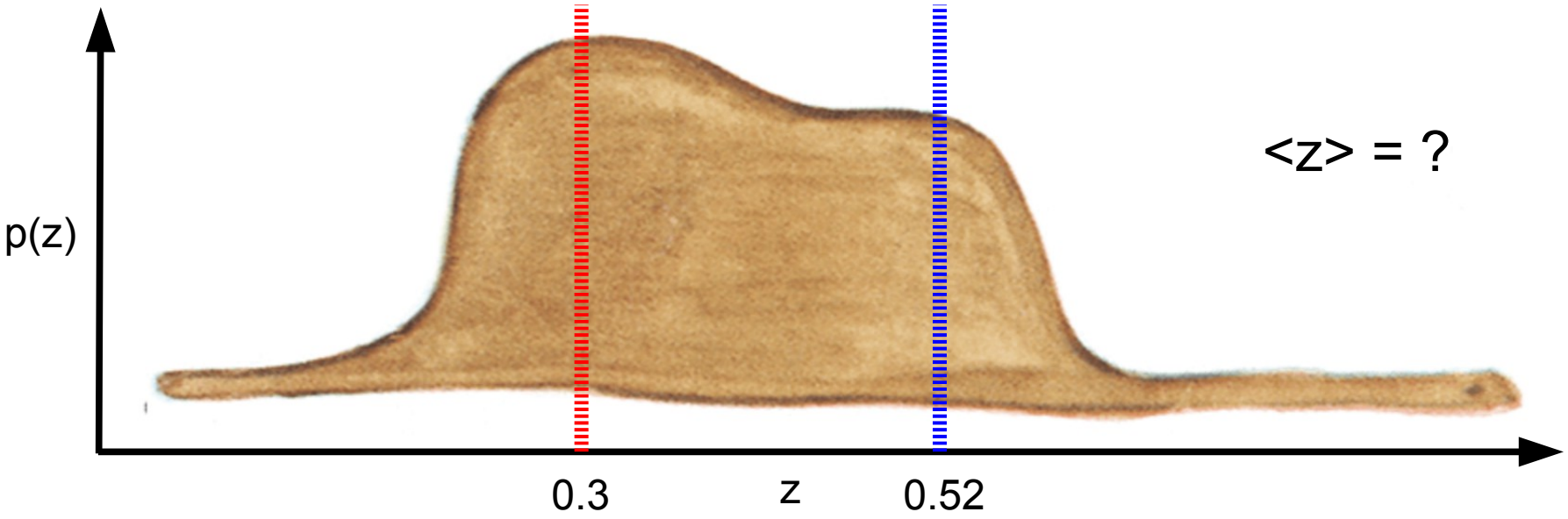
with Romain Buchs, Chris Davis, and the DES collaboration

paper submitted <1h ago and out on web.stanford.edu/~dgruen



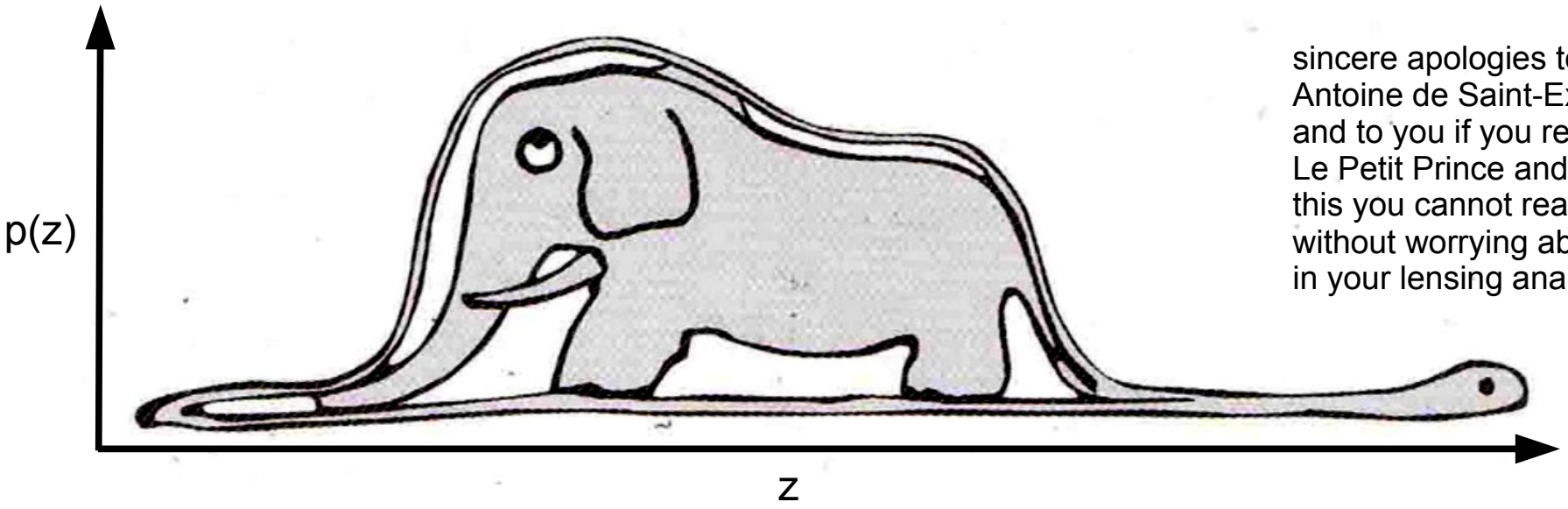
Type/redshift degeneracy is unavoidable in wide-field surveys





Type/redshift degeneracy is the elephant in the room

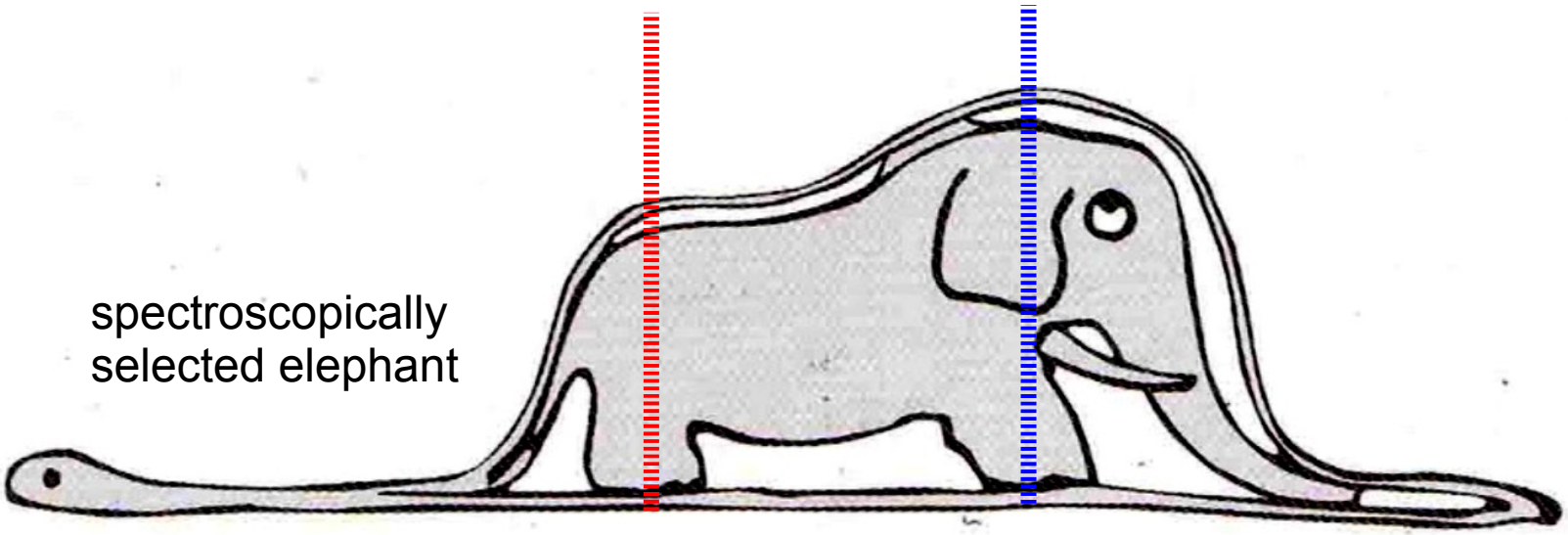
Empirical methods	Template fitting	Bayesian hierarchical analysis	Clustering redshifts	Cosmic variance



sincere apologies to Antoine de Saint-Exupéry and to you if you really liked Le Petit Prince and after this you cannot read it without worrying about bias in your lensing analysis

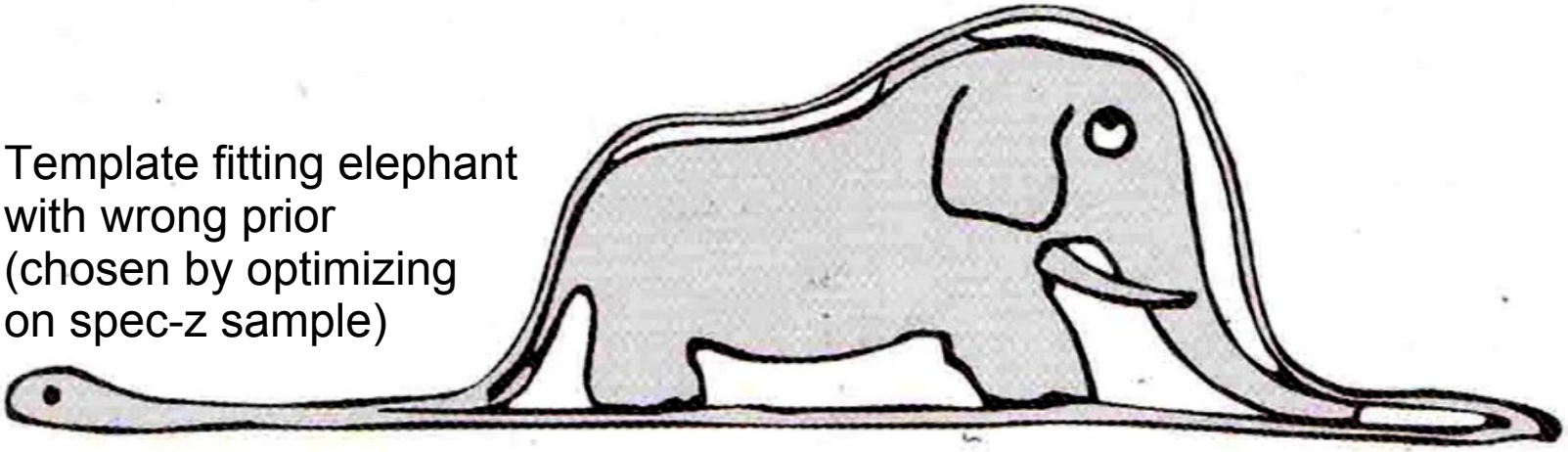
Type/redshift degeneracy causes selection bias in empirical methods

- Empirical methods == some way of re-weighting spec-z galaxies
- What is essential is invisible to the wide-field survey:
  all deep spec-z are **selected** by redshift / type / unobserved colors
- No way to correct this by re-weighting as a function of observed colors
  - perhaps KV450 is a sole exception due to u...Ks coverage
- Biases at O(few %) [Bonnett+2016, DG+2017]



Type/redshift degeneracy causes bias in template fitting

- Template fitting == Bayesian p(z, template | photometry)
- Depends on prior p(z, template)
- Data does not inform ratio of degenerate $p(z_1, \text{template}_1)/p(z_2, \text{template}_2)$
- A generative model or complete understanding of galaxy evolution helps, but it will not come from few-band photometry

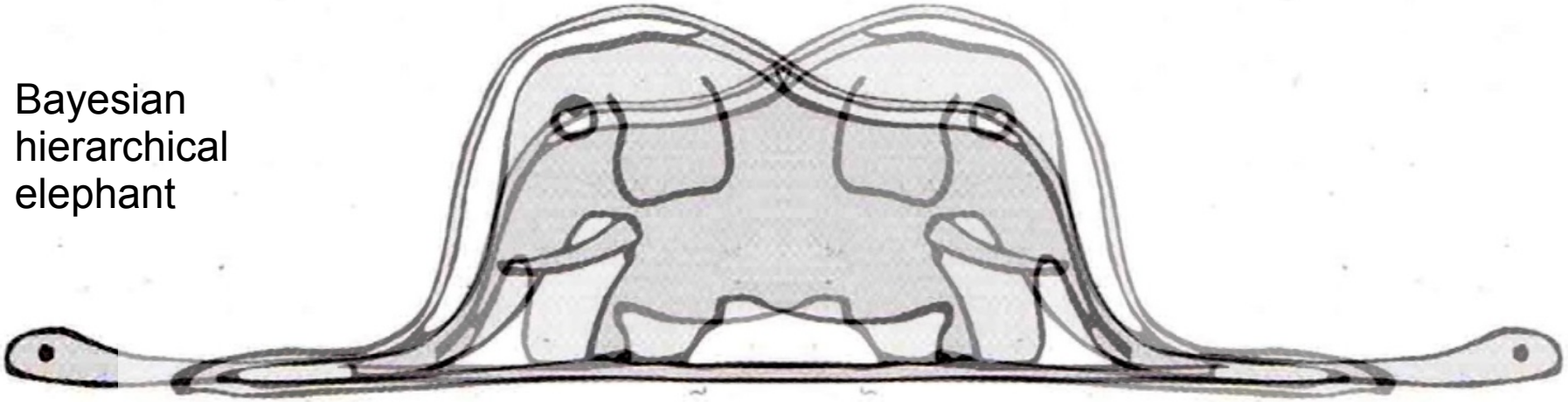


Template fitting elephant with wrong prior (chosen by optimizing on spec-z sample)

Type/redshift degeneracy causes irreducible uncertainty in BH analysis

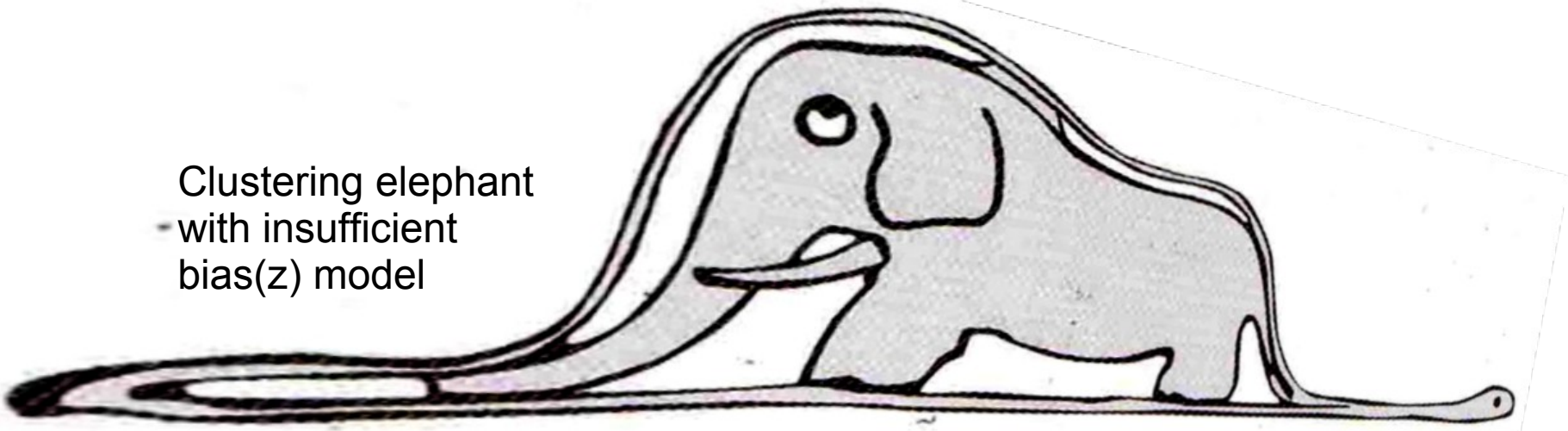
- Bayesian hierarchical analysis == Bayesian p(z, template | photometry)
- Prior p(z, template) constrained by the data
- Data does not inform ratio of degenerate $p(z_1, \text{template}_1)/p(z_2, \text{template}_2)$
- A generative model or complete understanding of galaxy evolution helps, but it will not come from few-band photometry
- Additional data that breaks type/redshift degeneracy helps

Bayesian hierarchical elephant



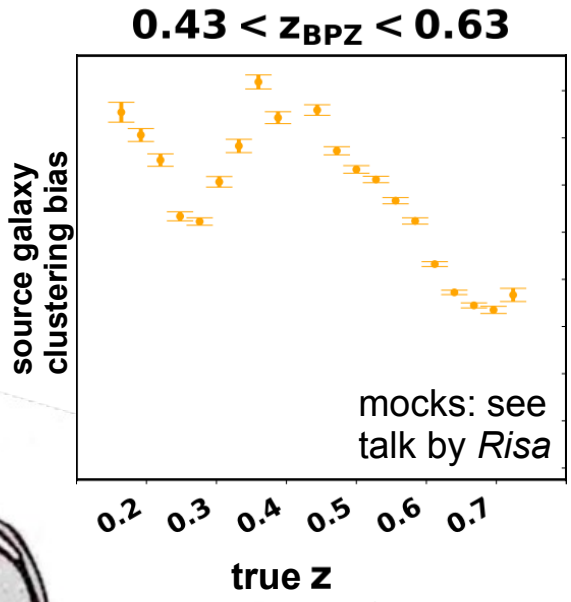
Type/redshift degeneracy causes complex bias(z) in clustering redshifts

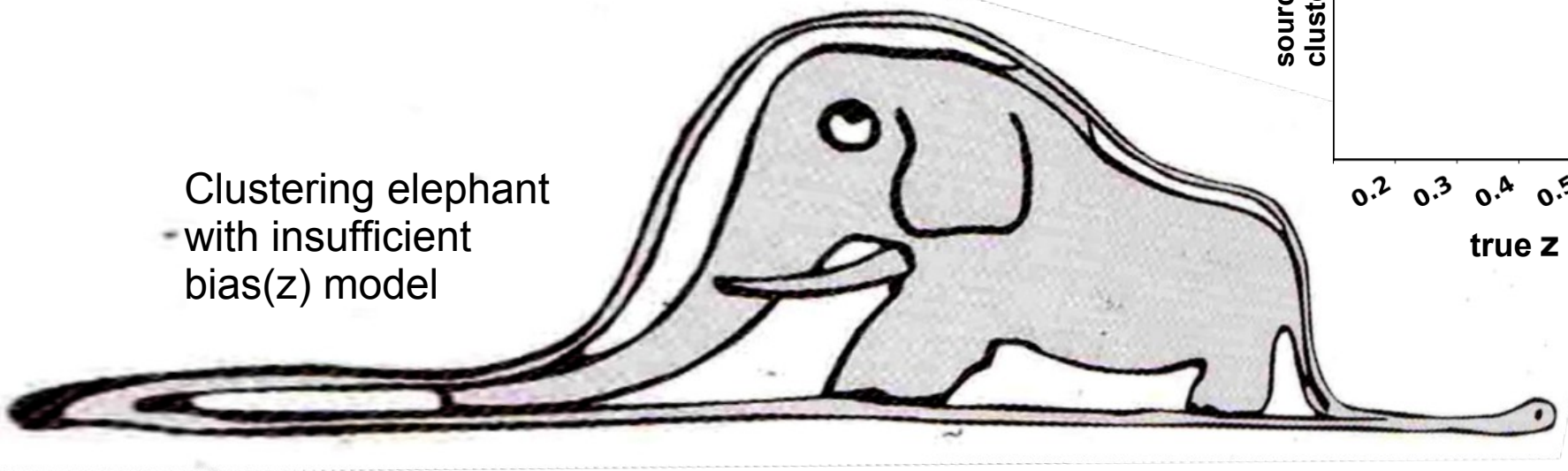
- Clustering signal ~ product of bias and abundance at given redshift
- Photometrically selected source galaxy sample will be different types at different redshifts, with different bias
- Unknown bias(z), not linear
- dominant uncertainty in DES Y1 [Gatti, Vielzeuf+2018]



Type/redshift degeneracy causes complex bias(z) in clustering redshifts

- Clustering signal ~ product of bias and abundance at given redshift
- Photometrically selected source galaxy sample will be different types at different redshifts, with different bias
- Unknown bias(z), not linear
- dominant uncertainty in DES Y1 [Gatti, Vielzeuf+2018]





Type/redshift degeneracy causes cosmic variance / shot noise

- Redshift calibration == you go to some field where you know redshifts
- You re-weight redshift sample to match survey color/mag distribution
- You take the weighted histogram of z as your survey redshift distribution
- At given survey color/magnitude, the mix of $type_1$,z_1 and $type_2$,z_2 depends on the large-scale density of your redshift field at z_1 and z_2
- and also on shot noise in $template_1$ and $template_2$ count if you look at a small volume in color/mag space

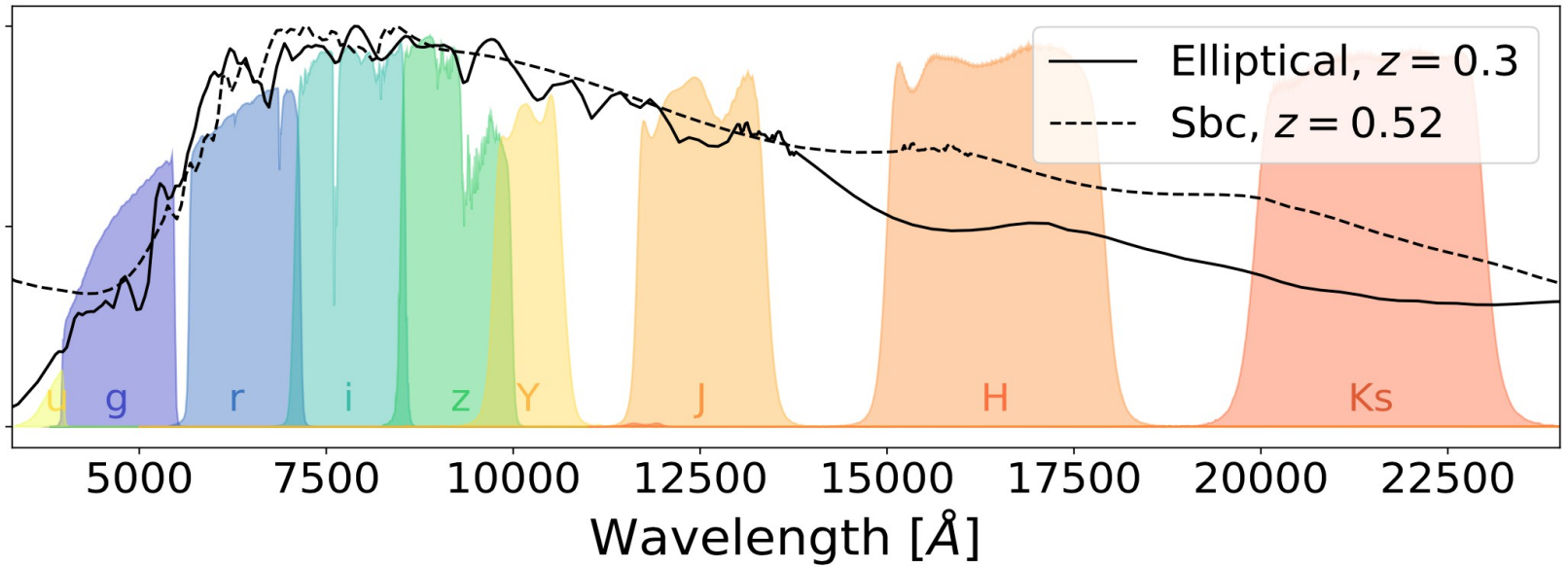
Shot (noise) elephant

Choose your field wisely

- Type/redshift degeneracy in wide-field data causes irreducible problems
- We cannot get wide-field data that is better at distinguishing type/redshift

Choose your deep fields wisely to break type/redshift degeneracy

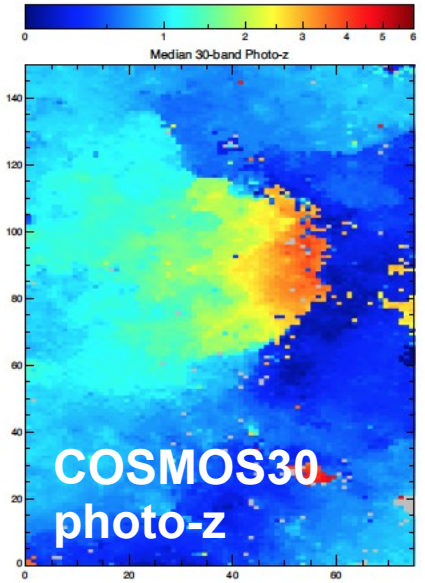
- Type/redshift degeneracy in wide-field data causes irreducible problems
- We cannot get wide-field data that is better at distinguishing type/redshift
- But we could collect additional photometric bands that break type/redshift degeneracy over a large enough deep field area to know well enough what's the mix of $type_1$ / $type_2$ at given wide-field photometry

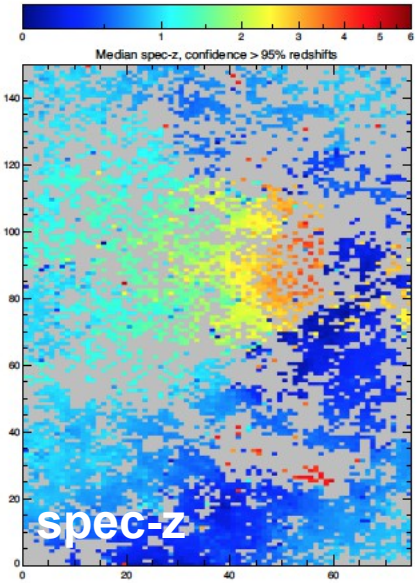


Choose your deep fields wisely to break type/redshift degeneracy

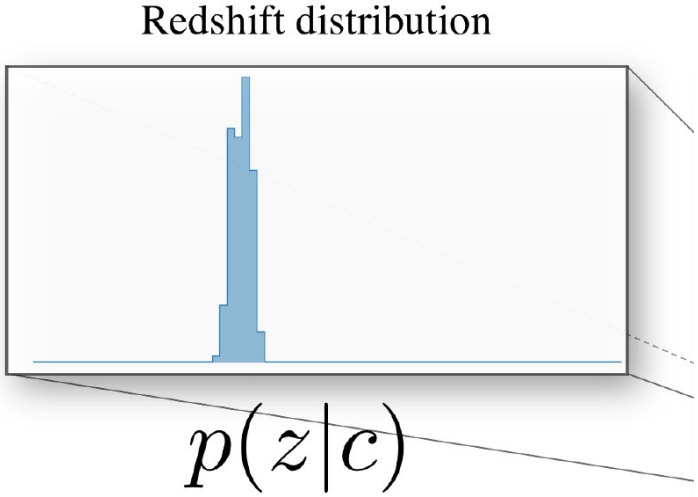
- Type/redshift degeneracy in wide-field data causes irreducible problems
- We cannot get wide-field data that is better at distinguishing type/redshift
- But we could collect additional photometric bands that break type/redshift degeneracy over a large enough deep field area to know well enough what's the mix of $type_1$ / $type_2$ at given wide-field photometry
- If you reduce dimensionality, spectroscopic calibration is feasible (Masters+, C3R2)

8D color space →
2D self-organizing map
Masters+2017





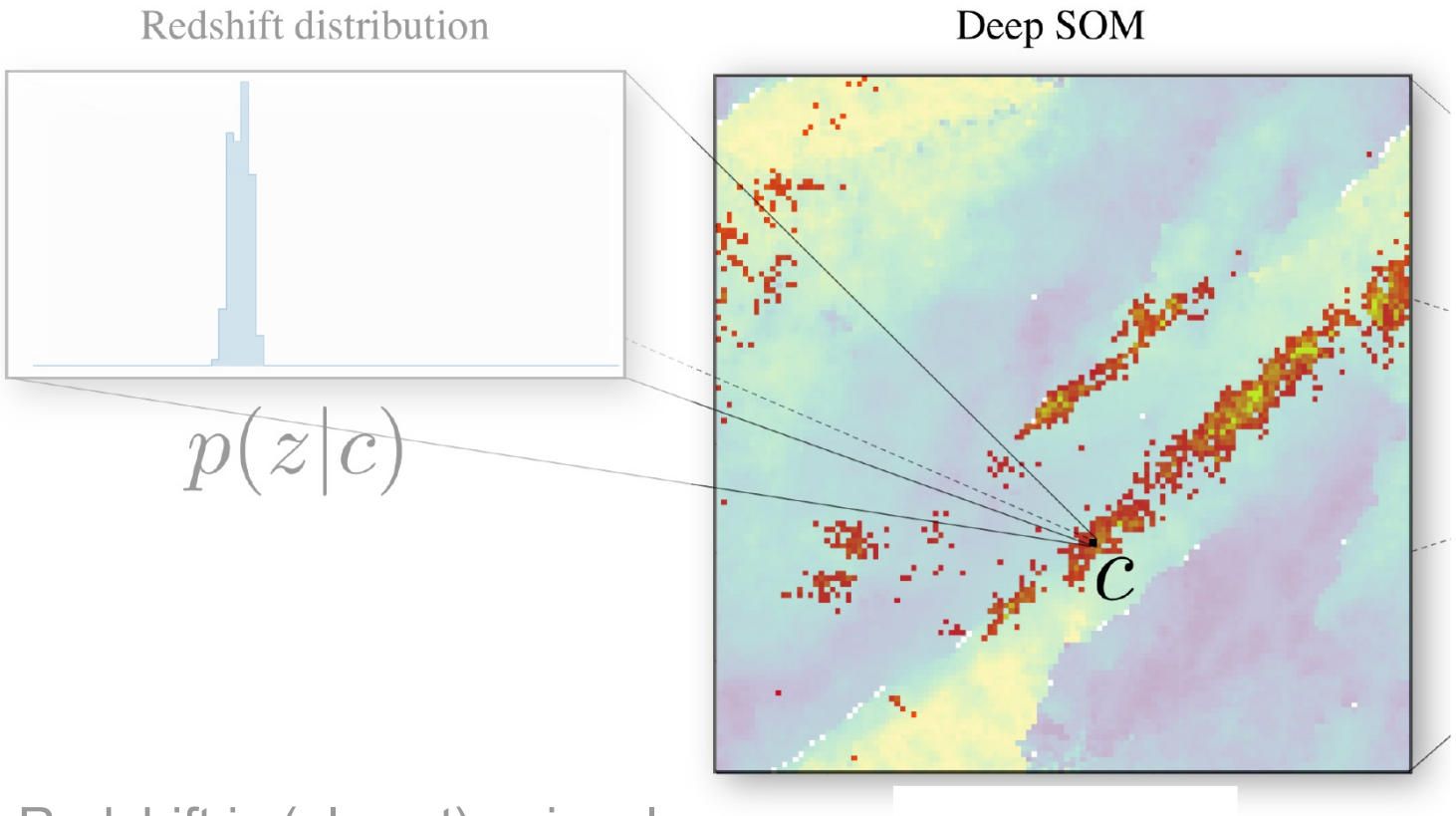
Using, wide, deep, and redshift fields for Photometric redshift calibration



Buchs&Davis, DG+ submitted

Redshift is (almost) uniquely determined at given ugrizYJHKs, reducing selection bias and cosmic variance from redshift sample

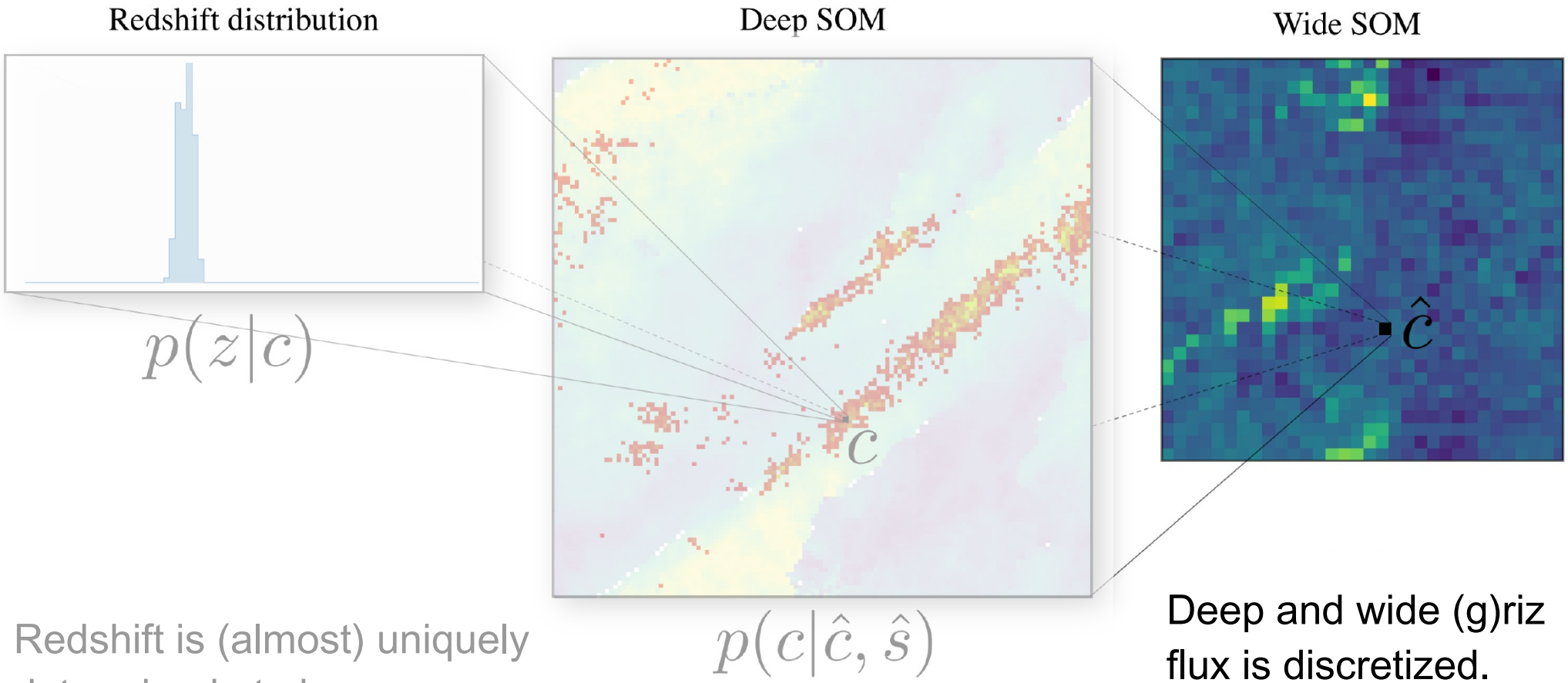
Using, wide, deep, and redshift fields for Photometric redshift calibration



Redshift is (almost) uniquely determined at given ugrizYJHKs, reducing selection bias and cosmic variance from redshift sample

Self-organizing map on ugrizYJHKs colors defines observable galaxy *phenotypes*. Large deep sample constrains their abundance.

Using, wide, deep, and redshift fields for Photometric redshift calibration



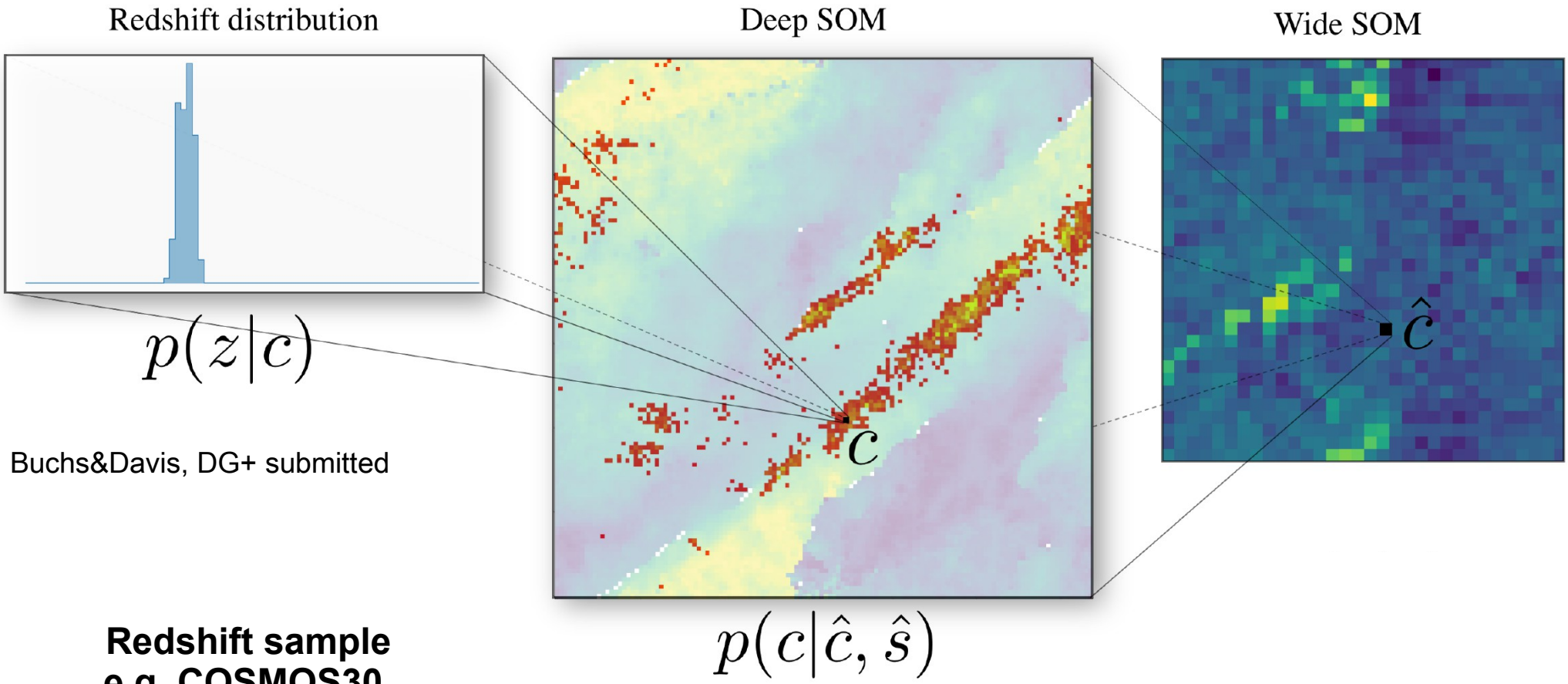
Redshift is (almost) uniquely determined at given ugrizYJHKs, reducing selection bias and cosmic variance from redshift sample

Self-organizing map on ugrizYJHKs colors defines observable galaxy *phenotypes*. Large deep sample constrains their abundance.

Deep and wide (g)riz flux is discretized.

Painting deep galaxies into wide field determines transfer and selection function.

Using, wide, deep, and redshift fields for Photometric redshift calibration



Buchs&Davis, DG+ submitted

Redshift sample e.g. COSMOS30, PAU, spec-z with ugrizYJHKs

Deep *photometric* sample with ugrizYJHKs

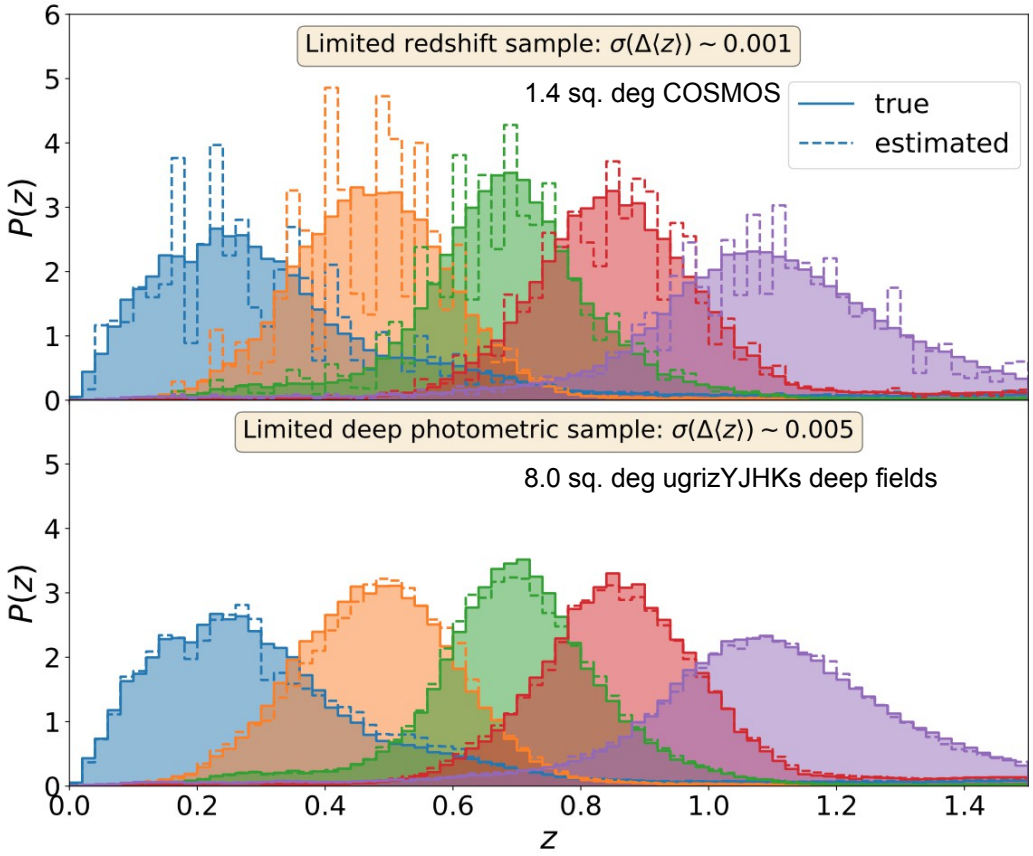
Wide sample with few bands

redshift distribution of a galaxy sample with wide fluxes and selection $\hat{c},\hat{s}$

$$p(z|\hat{c},\hat{s}) = \sum_c p(z|c)\ p(c|\hat{c},\hat{s})$$

Source of uncertainty in phenotypic redshifts for a DES-like survey

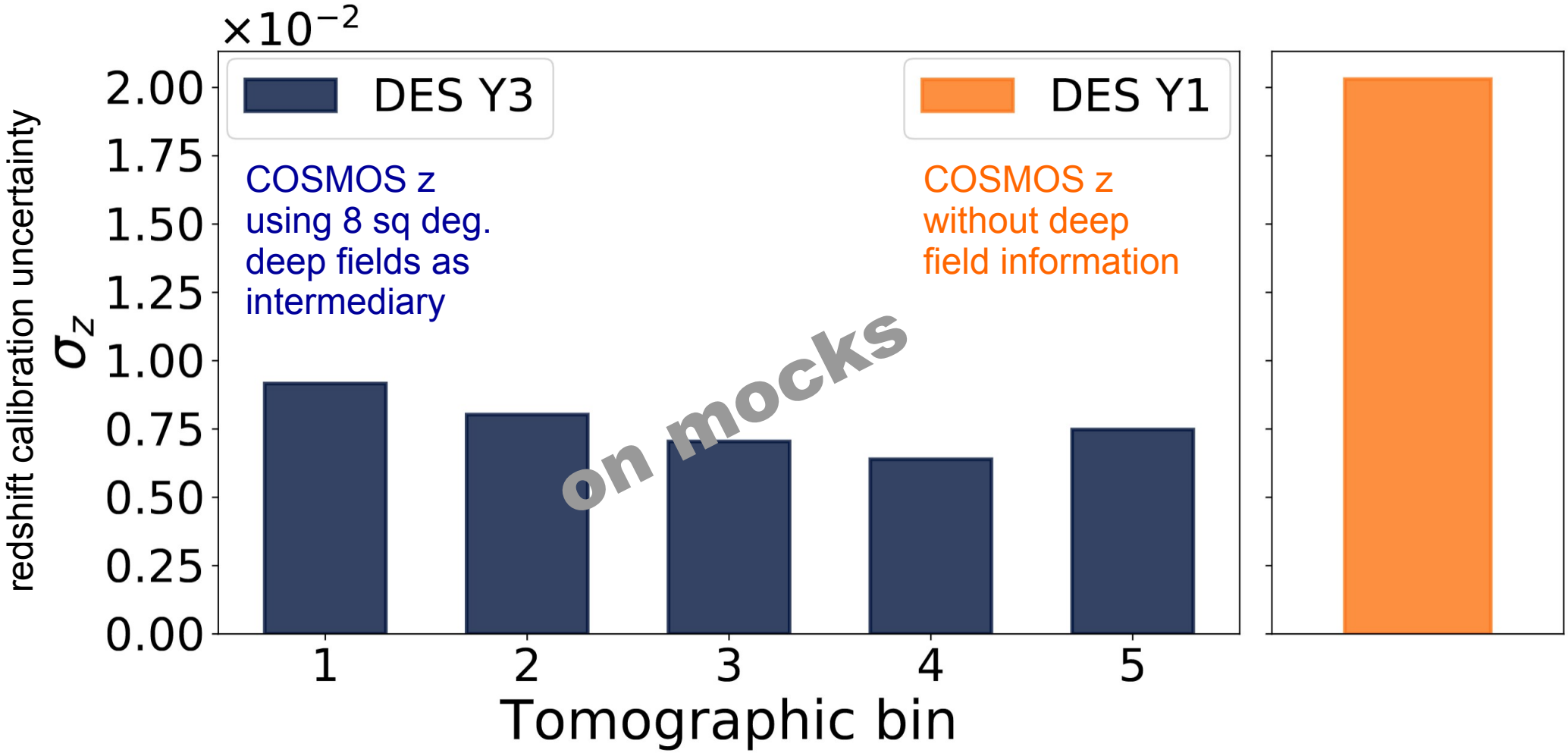
- Statistical uncertainty is dominated by deep sample (not redshift sample!)
- Cosmic variance is largely removed from spec-z
- Present scarcity of spec-z causes resolution-based bias of similar amplitude (~0.005 in mean z)



→ **increase of deep optical/NIR fields**
+ targeted spec-z to cover multi-color space is way forward!

Clustering, especially in deep fields, would be useful [Sanchez & Bernstein 2018]

Performance of redshift calibration



Summary

- Type/redshift degeneracy at observed wide-field flux is the source of (almost) all evil

  → sandwich wide-field data and redshifts with galaxy phenotypes, counted in deep fields

Le Petit Prince, Chapter 13

- Work to do:
  - Application of method to DES Y3 [Myles, DG+ in prep]
  - Data collection (deep fields + redshifts)
  - Inclusion of clustering and wide field data in a full likelihood [Sanchez & Bernstein 2018]

Paper out: see arXiv tomorrow and web.stanford.edu/~dgruen