Constraints on intrinsic alignments of elongated low-mass galaxies out to z~2.5

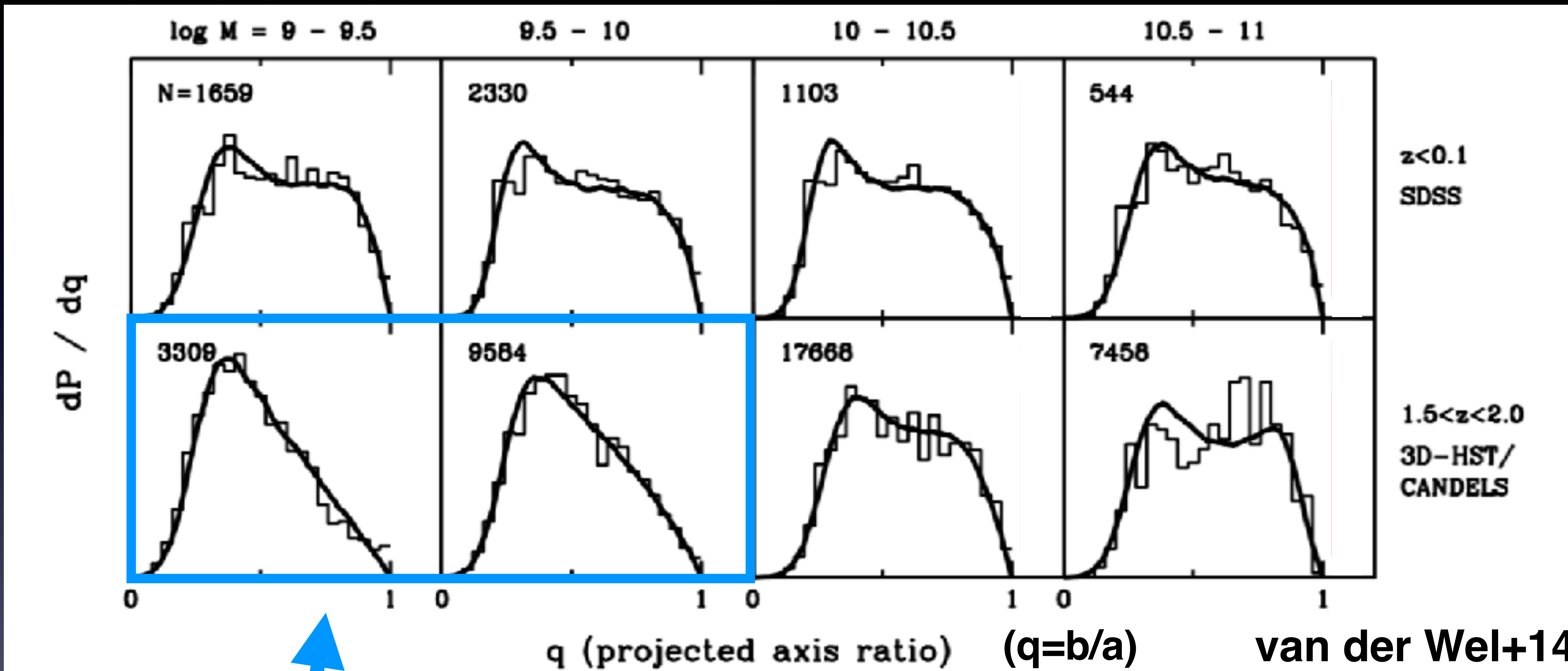
Viraj Pandya
UC Santa Cruz

with Joel Primack, Peter Behroozi, Avishai Dekel, Haowen Zhang, Elliot Eckholm, Sandy Faber, Henry C. Ferguson, Mauro Giavalisco, Yicheng Guo, Nimish Hathi, Dritan Kodra, Anton Koekemoer, David Koo, Jeff Newman, Arjen van der Wel and Patrick Ward

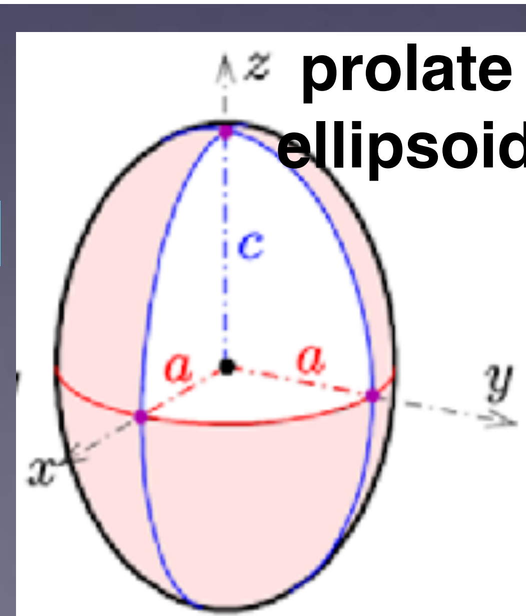
Kavli IPMU Seminar
May 13, 2020

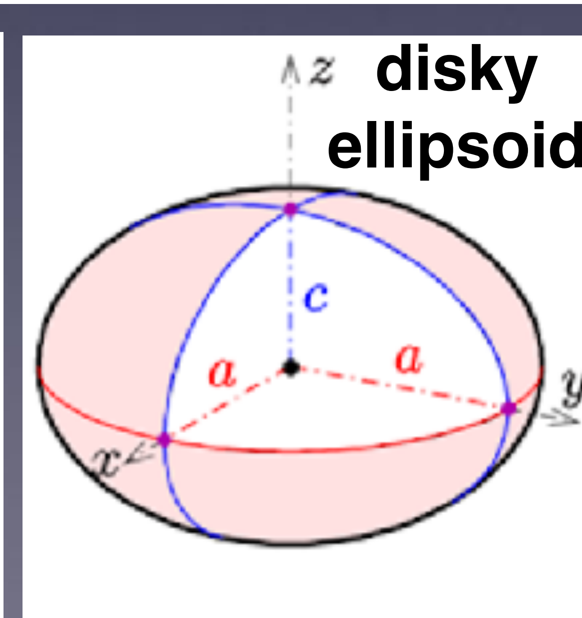
Viraj Pandya (UC Santa Cruz)

CANDELS observations: galaxies start out elongated



Prolate ellipsoids will preferentially have low b/a in projection





Projected disks should have ~uniform b/a

Viraj Pandya (UC Santa Cruz)

CANDELS observations: galaxies start out elongated

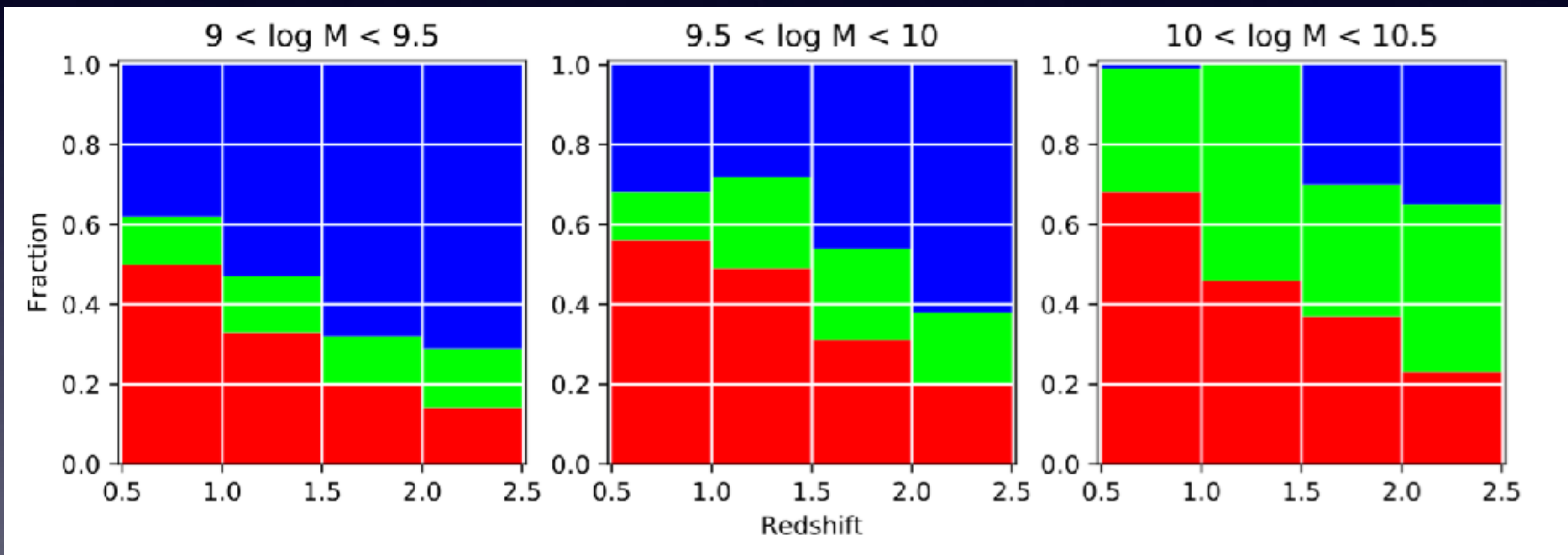
Zhang, Primack, Faber, Koo et al. (2019); van der Wel et al. 2014

Blue = elongated

Green = Spheroidal

Red = disky

Statistically inferred from observed distributions of b/a and a by comparing to random projections of toy triaxial ellipsoids



Four stellar mass—redshift bins where >50% galaxies are likely elongated:

$1.0 < z < 1.5, 9.0 < \log M_* < 9.5$

$2.0 < z < 2.5, 9.0 < \log M_* < 9.5$

$1.5 < z < 2.0, 9.0 < \log M_* < 9.5$

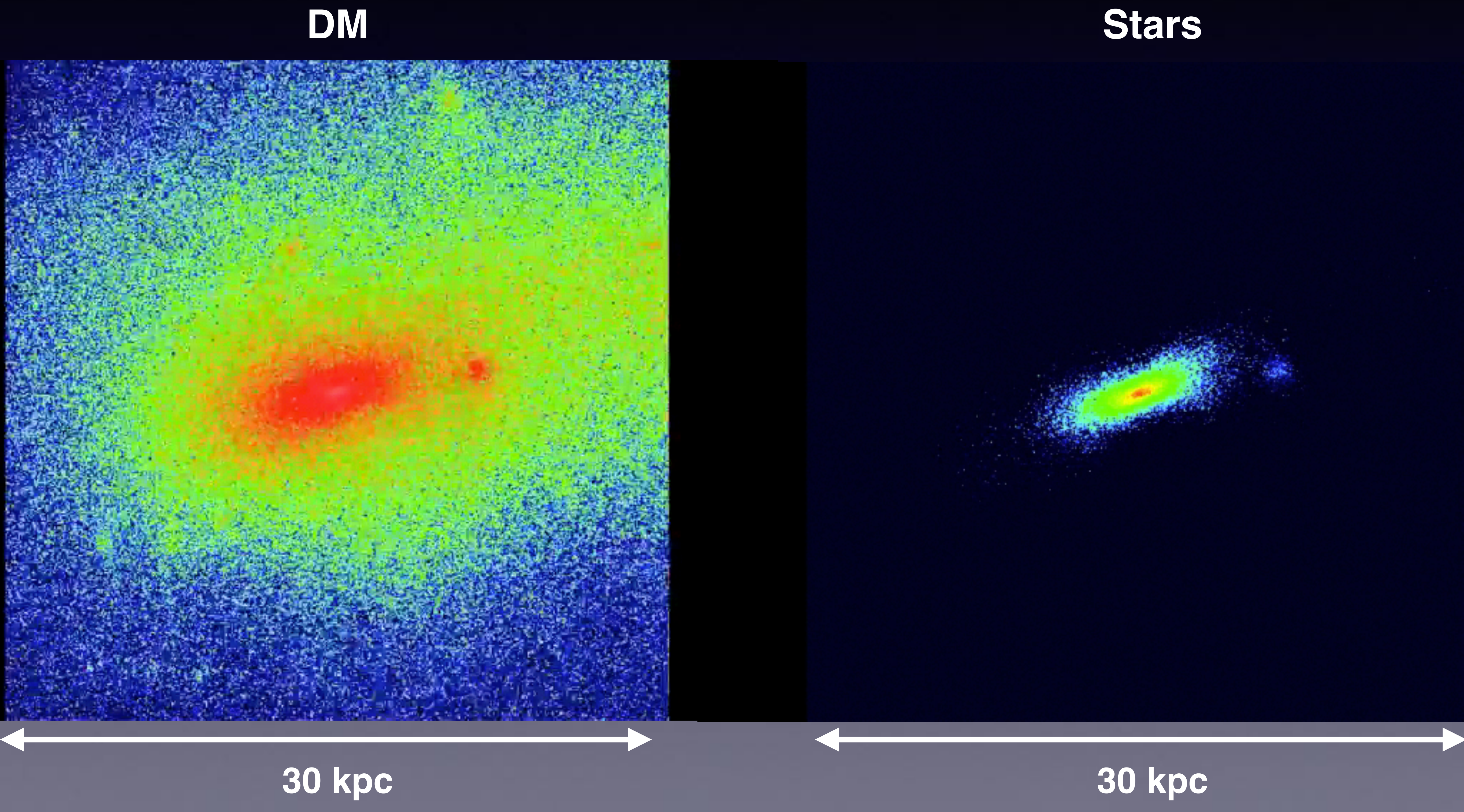
$2.0 < z < 2.5, 9.5 < \log M_* < 10.0$

Viraj Pandya (UC Santa Cruz)

Simulations: galaxies *also* start out elongated

Ceverino, Primack & Dekel 2015

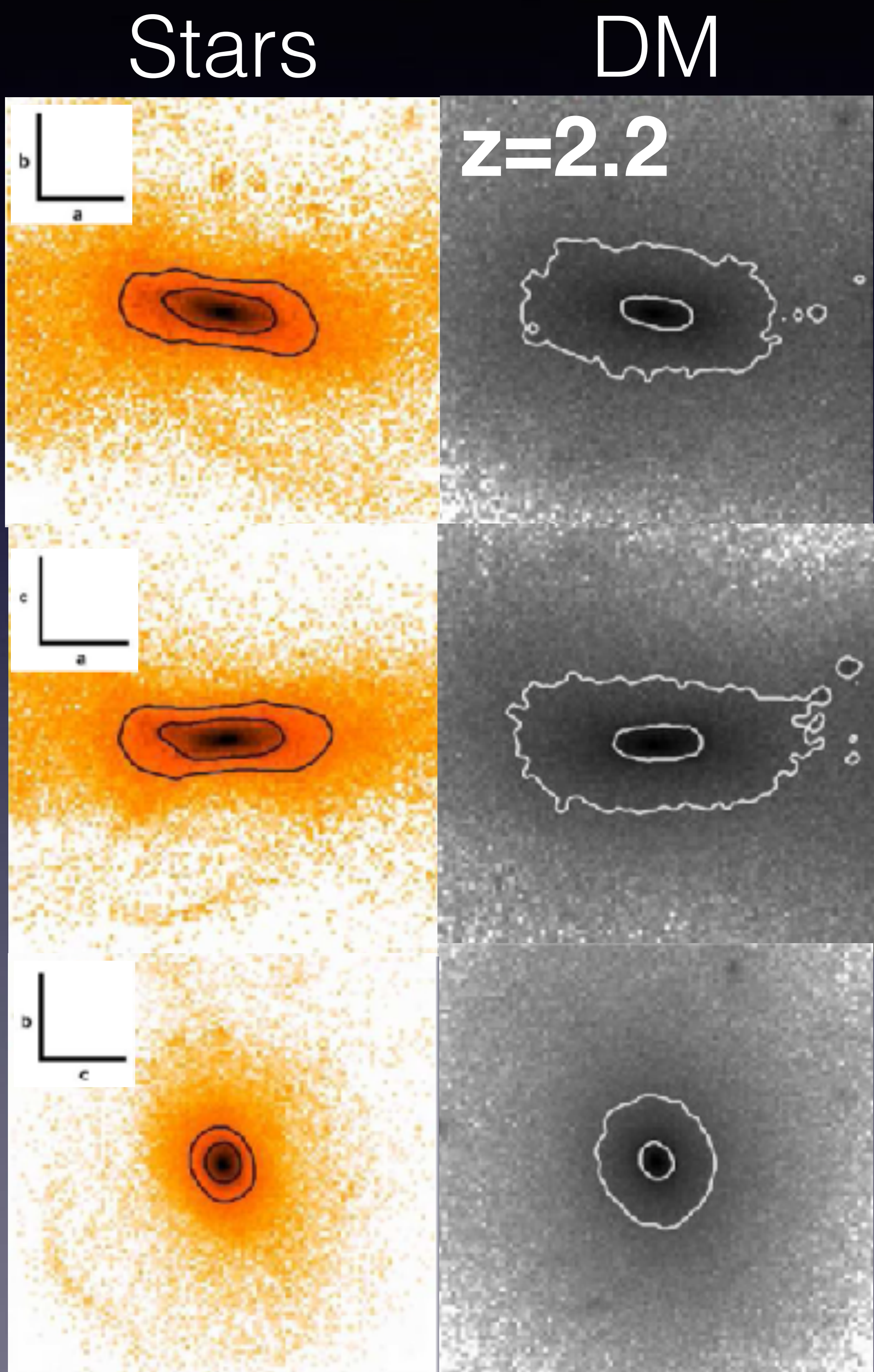
- Elongated low-mass galaxies live in elongated low-mass dark matter halos
- The halos are accreting matter preferentially along direction of host filament

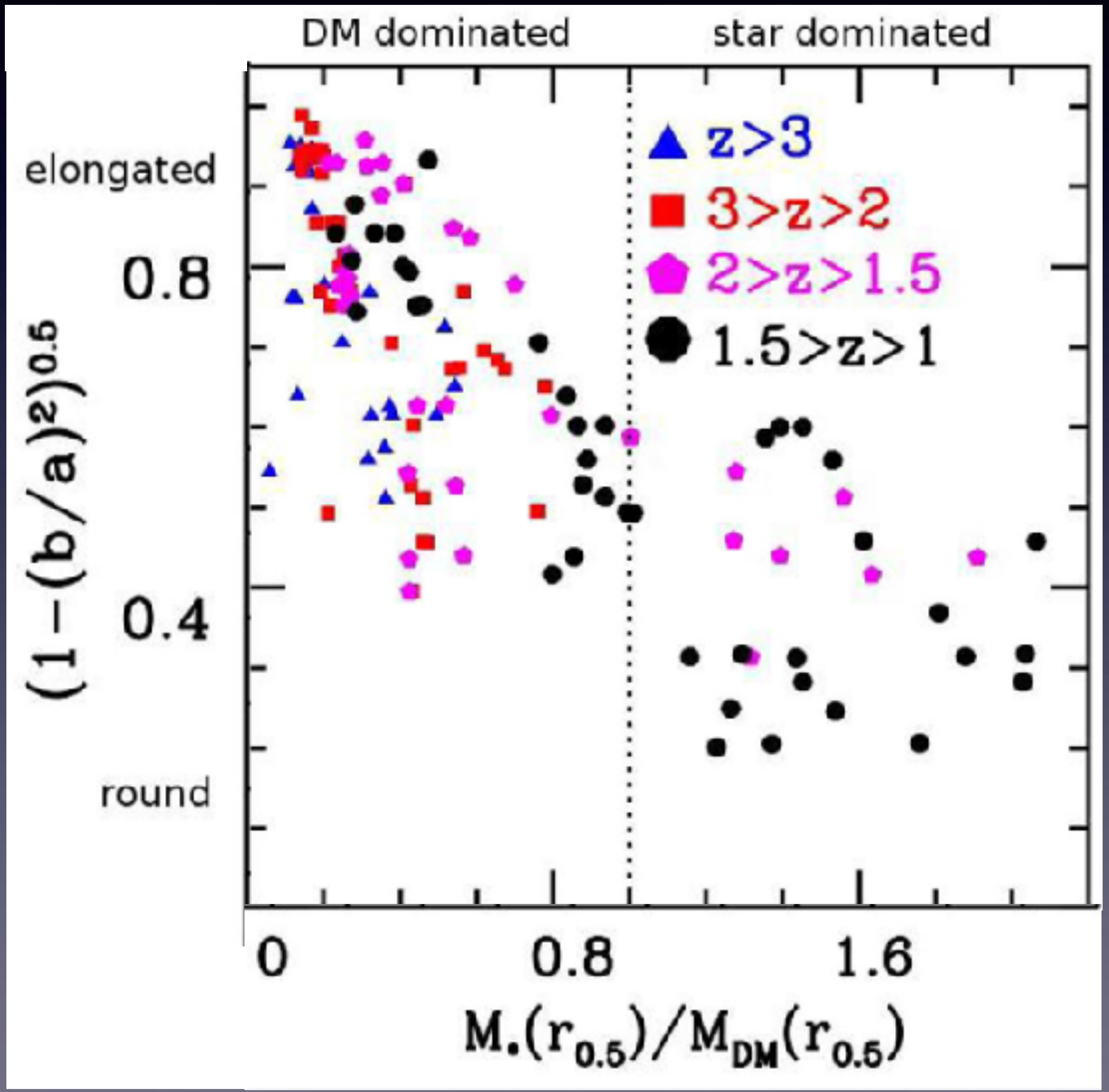


Viraj Pandya (UC Santa Cruz)

Simulations: elongated galaxies are centrally DM-dominated

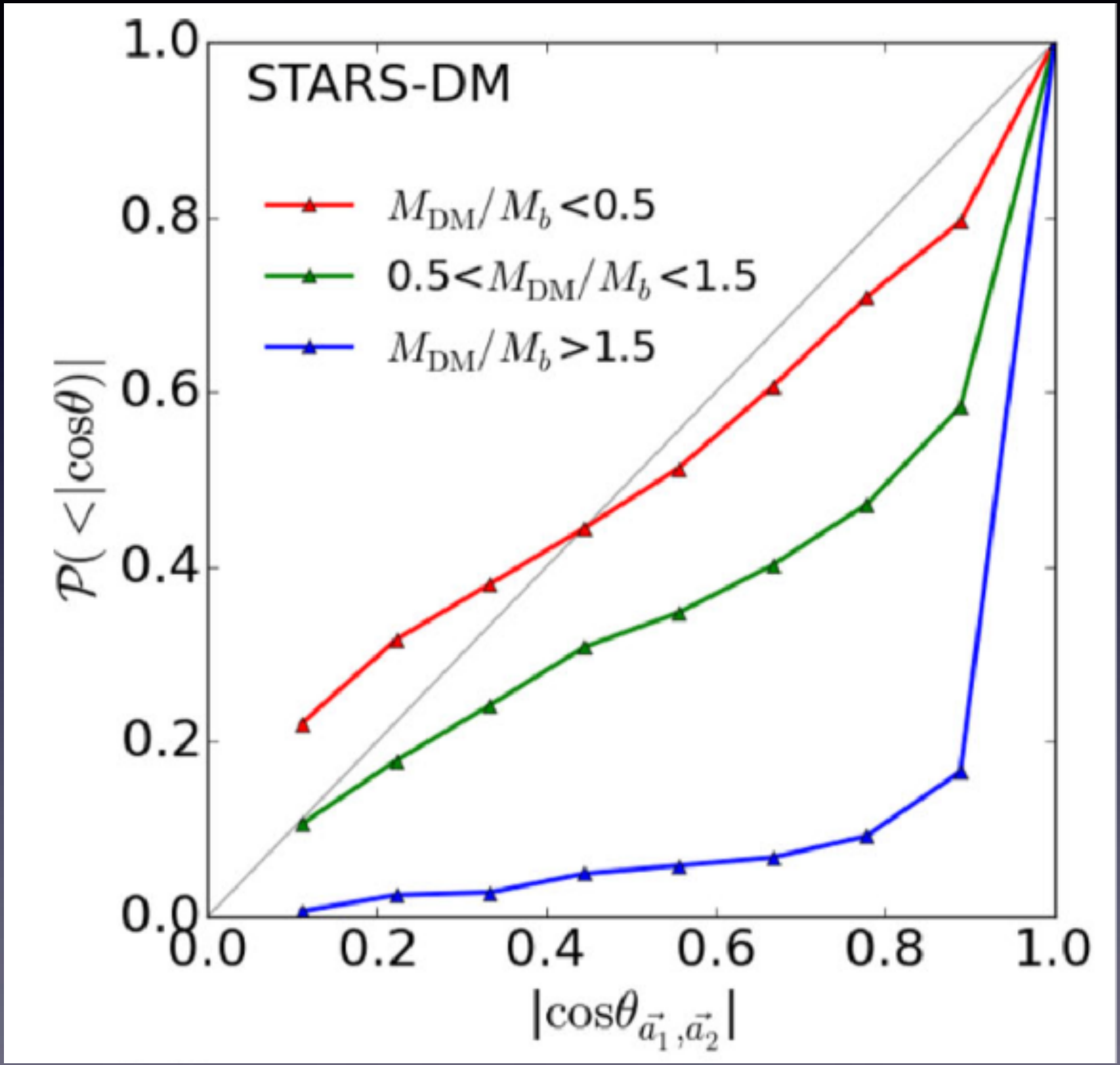
Ceverino, Primack & Dekel 2015





Simulations: elongated galaxies are aligned with their halos

Tomassetti+16



Blue curve: < 20% of VELA galaxies in elongated phase have cos θ < 0.9

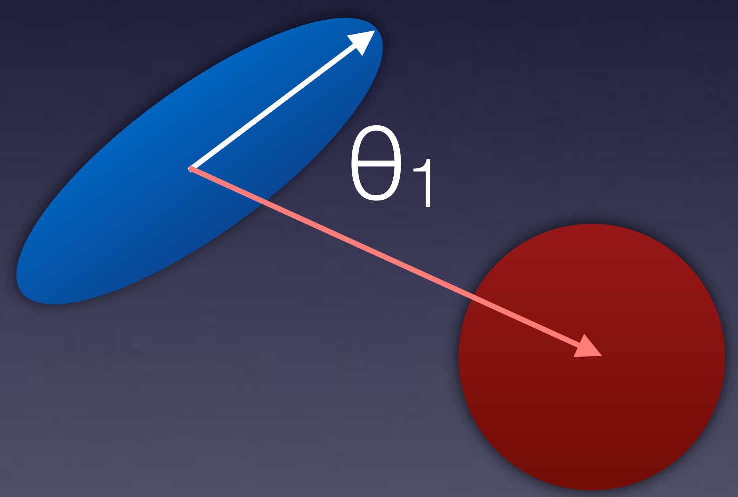
CDF of alignment between longest axis of DM and stars for all 34 simulated VELA galaxies

Could low-mass elongated galaxies be clean tracers of the high-redshift cosmic web via their intrinsic alignments?

Pandya et al. (2019)

Two kinds of alignments

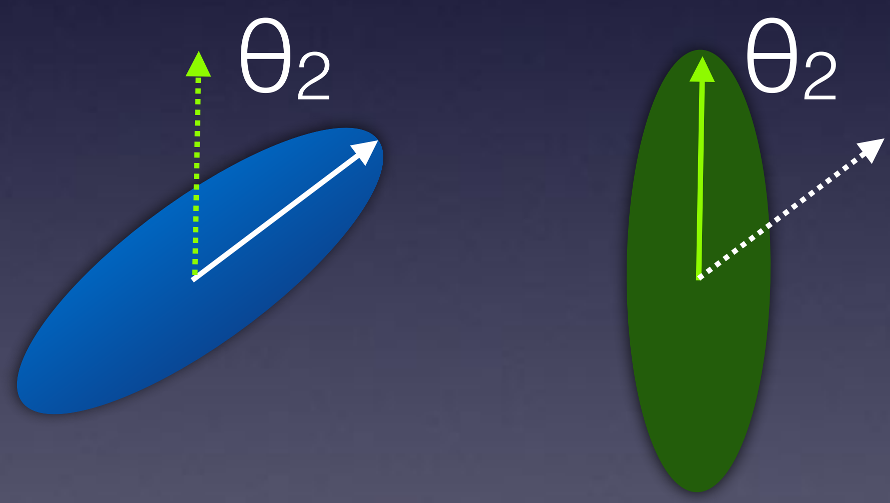
"Shape—position"



Primary galaxy must be low-mass & elongated

Neighbor can be of any mass/shape

"Shape—shape"



Both galaxies must be low-mass prolate candidates

Could low-mass elongated galaxies be clean tracers of the high-redshift cosmic web via their intrinsic alignments?

Long history of intrinsic alignment studies…

See reviews by Kiessling+15 and Kirk+15

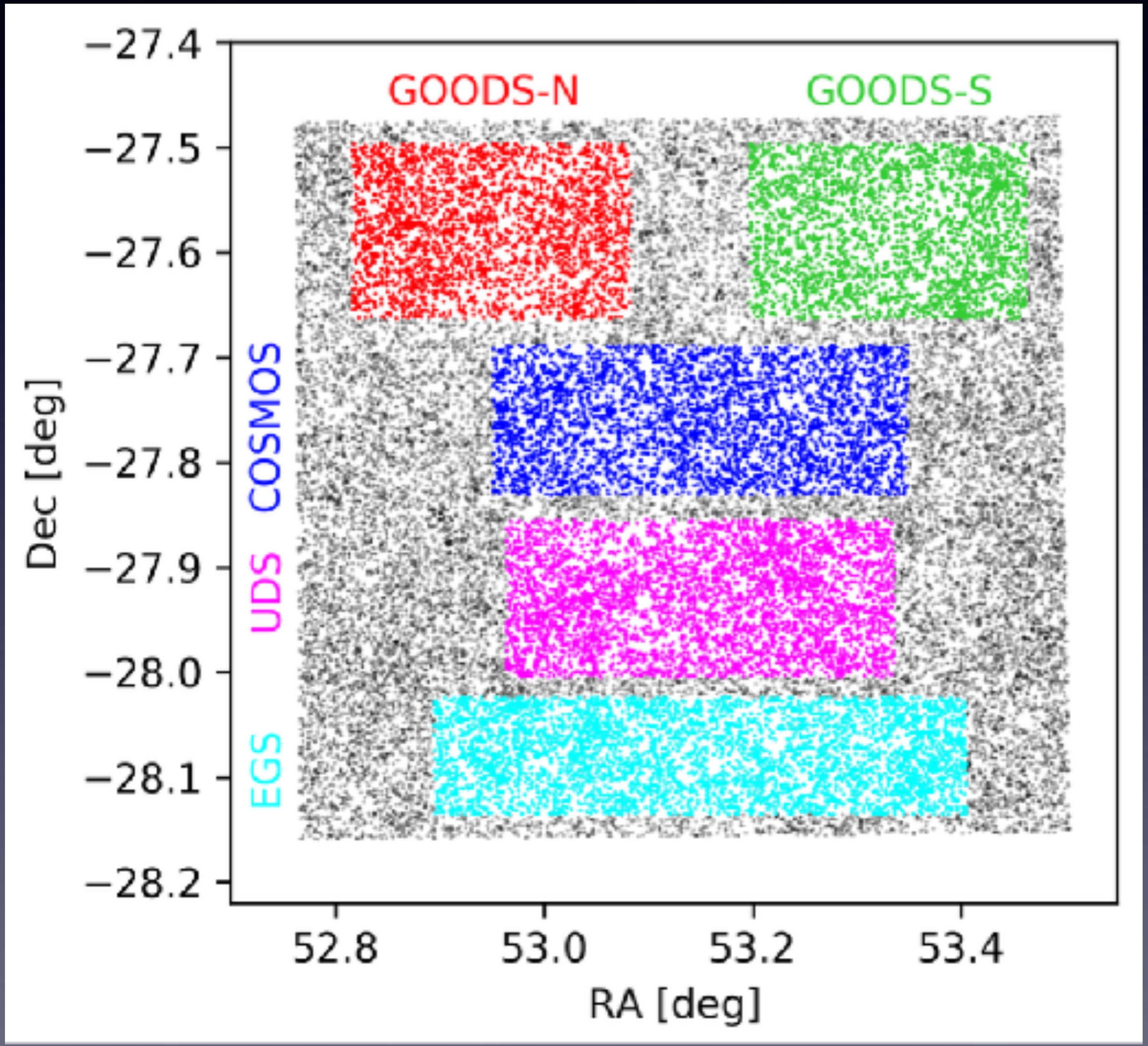
- Red elliptical galaxies: detections out to z~1
  - e.g., Mandelbaum+06, Hirata+07, Joachimi+11, Samuroff+18, …
- Blue disky galaxies: non-detections out to z~1.4
  - e.g., Mandelbaum+11, Tonegawa+18
- Our work extends beyond previous studies in 3 ways:
  - Much higher redshifts (z=1.0-2.5)
  - Lower stellar masses ($M_{star}=10^9$-$10^{10}M_{sun}$)
  - Focusing on elongated objects, not disks/spheroids

CANDELS Observations

- All 5 CANDELS fields (~0.25 deg^2 total)
- Only use galaxies in prolate-dominated M_{star}–redshift bins
  - effectively log M_{star} = 9–10 and z=1.0–2.5 (Zhang+19)
- Require well-measured b/a, a and PA using GALFIT (F160W)
- Require spectroscopic or grism redshifts (Kodra, Newman+19)
- Pair selection: 3D comoving separations < 10 cMpc
- ~8000 unique pairs where at least 1 galaxy is elongated
  - In ~2000 of these pairs, the neighbor is also elongated

CANDELS Mock Lightcones

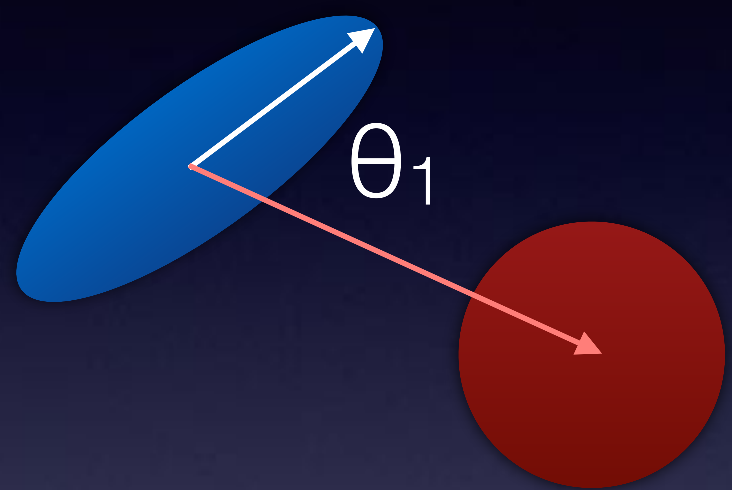
- Based on the Bolshoi-Planck DM-only simulation
  - Extract CANDELS-sized fields
- Fill DM halos with galaxies using abundance matching (Behroozi+19)
- Same M_{star}—z cuts as observations
- Assume prolate galaxies hosted by prolate halos
- Following Tomassetti+16, make extreme assumption that prolate galaxies would point in same direction as their host prolate halos



One example mock lightcone w/ 5 CANDELS subfields

Alignments in mocks vs. observations

"Shape—position"



Neighbor can be
of any mass/shape

"Shape—shape"

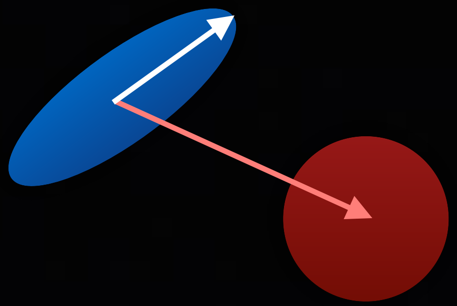
Both galaxies must be
prolate candidates

Predict signal in 3D real space
Then degrade to 3D redshift space
Then degrade to 2D projected redshift space (like observations)

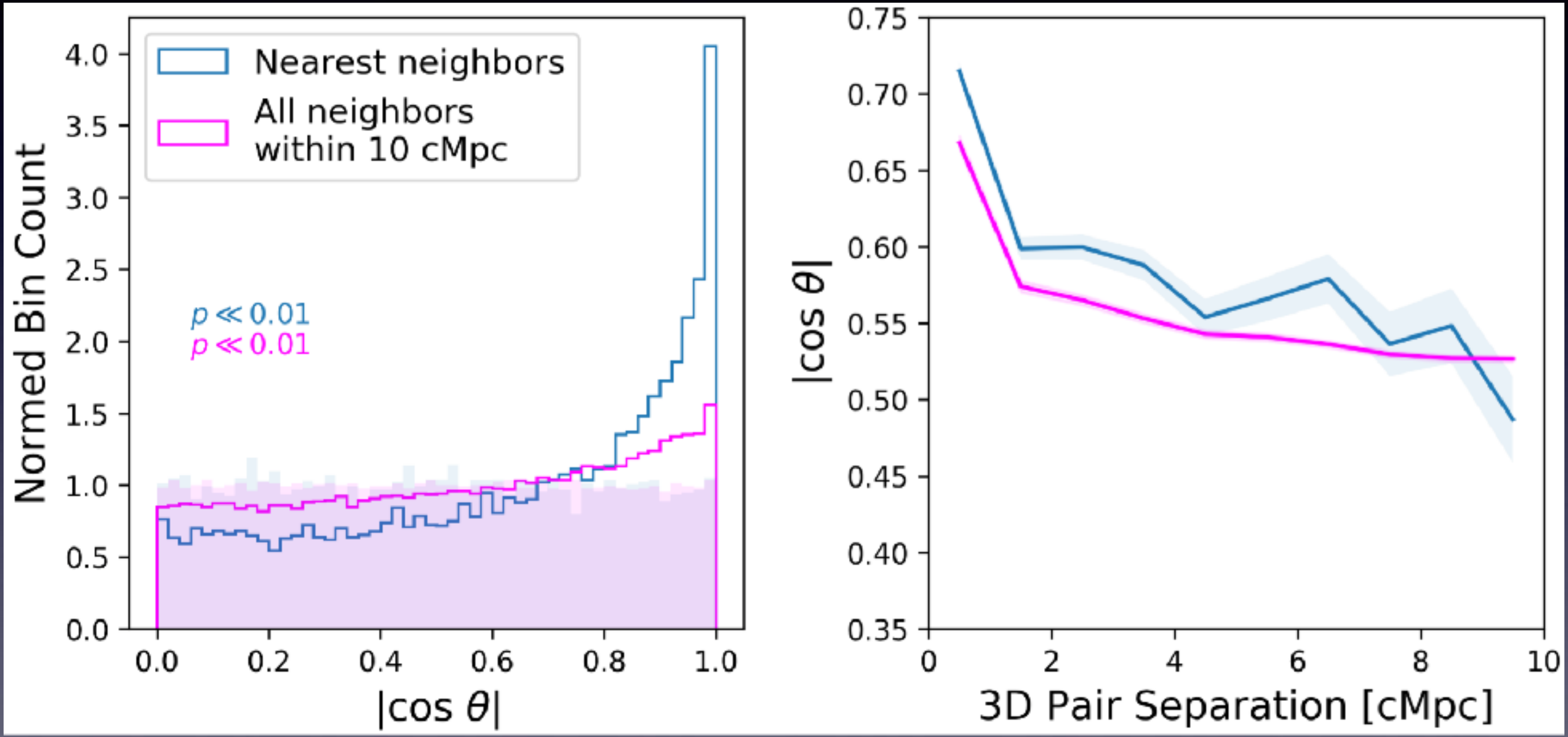
Pairs selected to have 3D comoving separations < 10 cMpc

Viraj Pandya (UC Santa Cruz)

Results: shape—position alignments

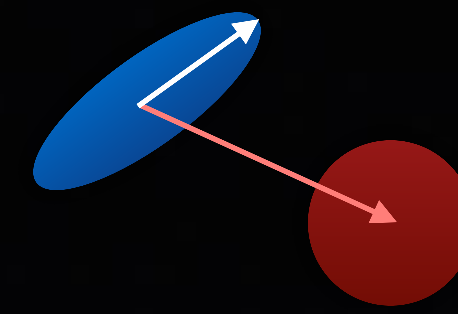


Mocks: 3D real space

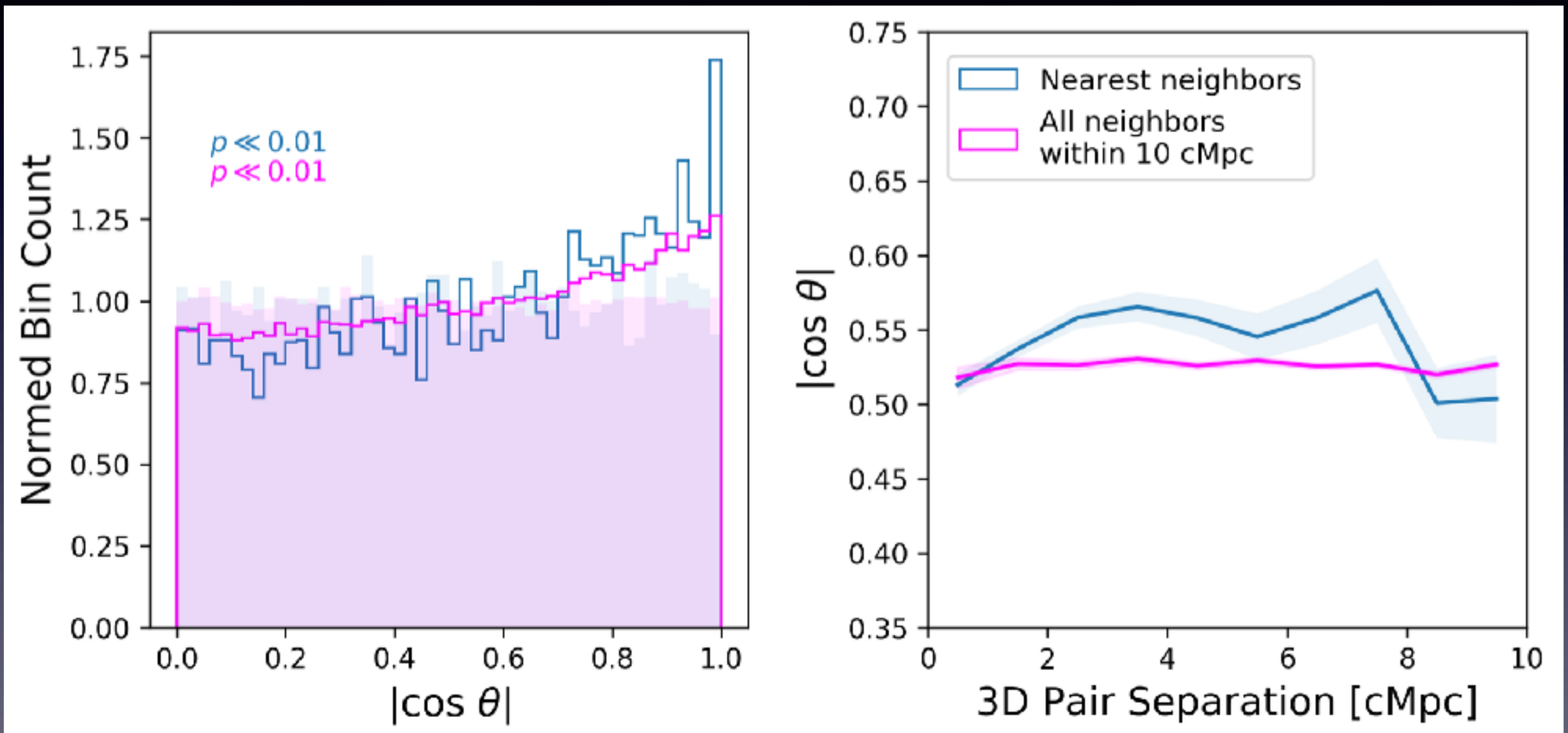


Viraj Pandya (UC Santa Cruz)

Results: shape—position alignments

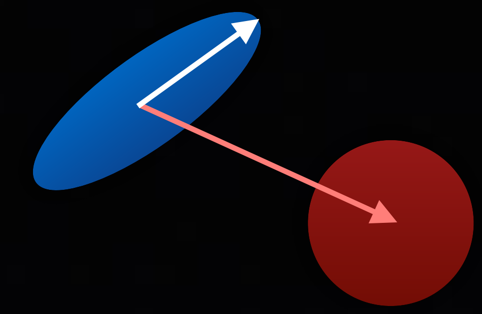


Mocks: 3D redshift space

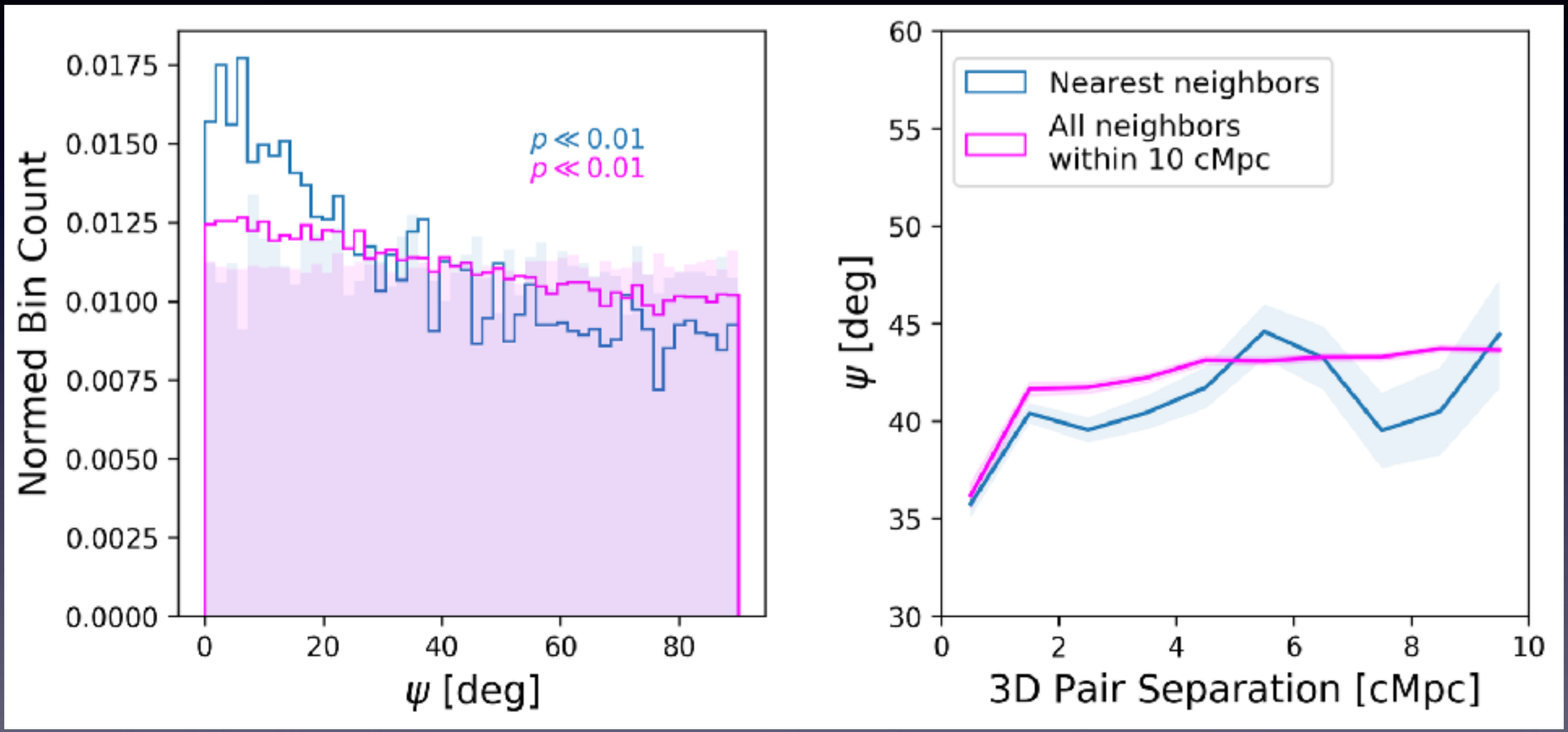


Viraj Pandya (UC Santa Cruz)

Results: shape—position alignments

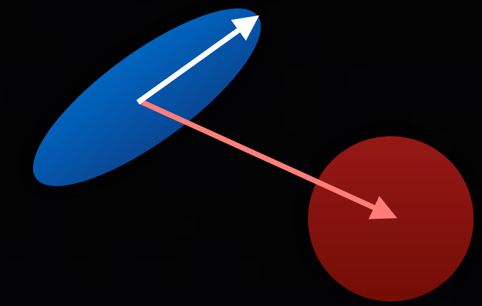


Mocks: 2D projected redshift space

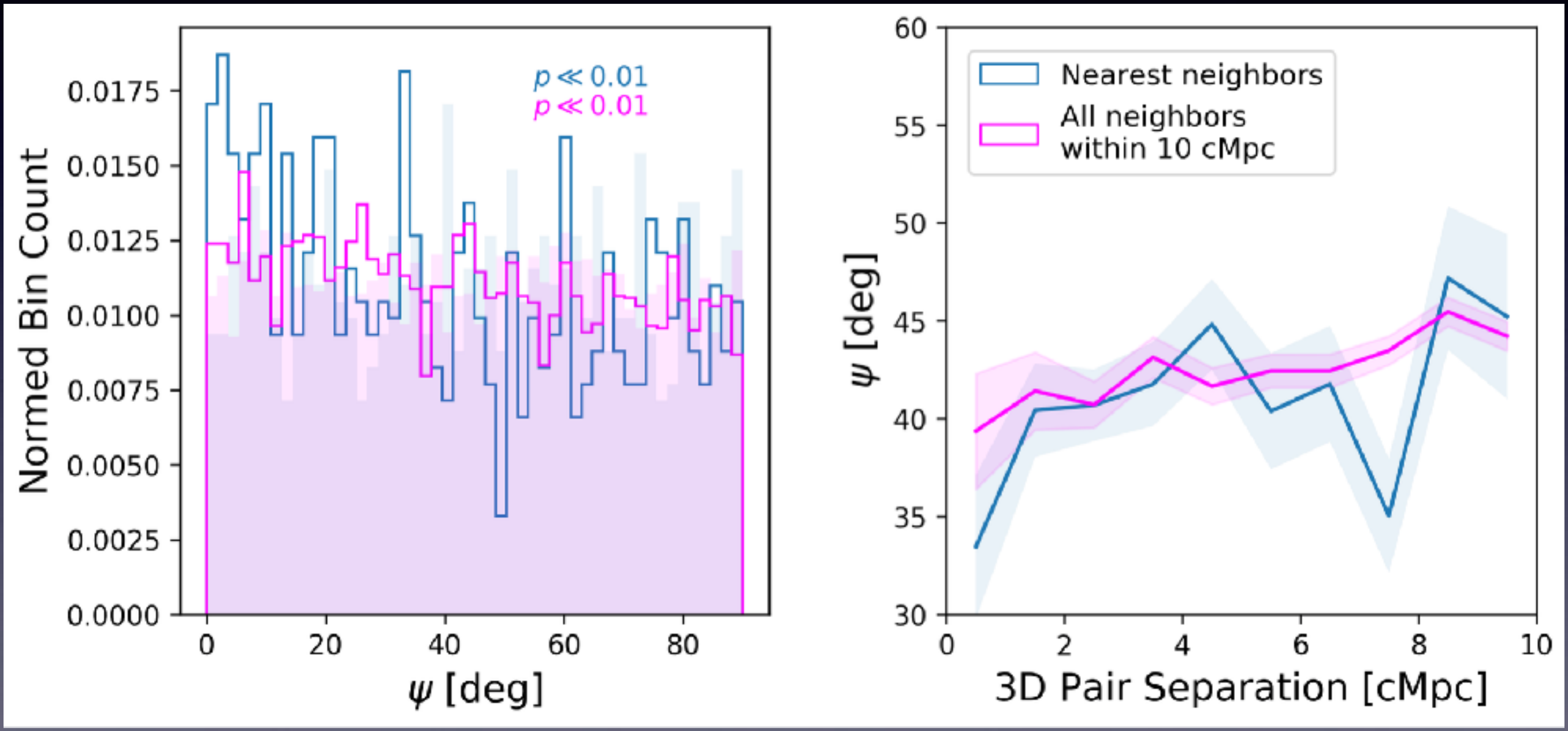


Viraj Pandya (UC Santa Cruz)

Results: shape—position alignments



Mocks: 2D projected redshift space with spectroscopic incompleteness & z_{grism} errors

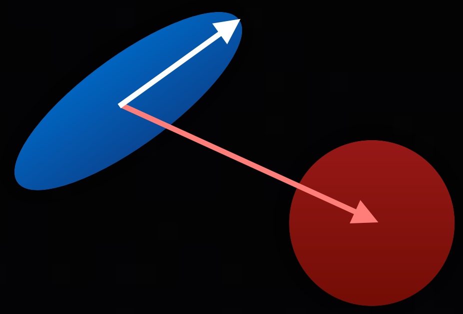


One example realization out of 1000

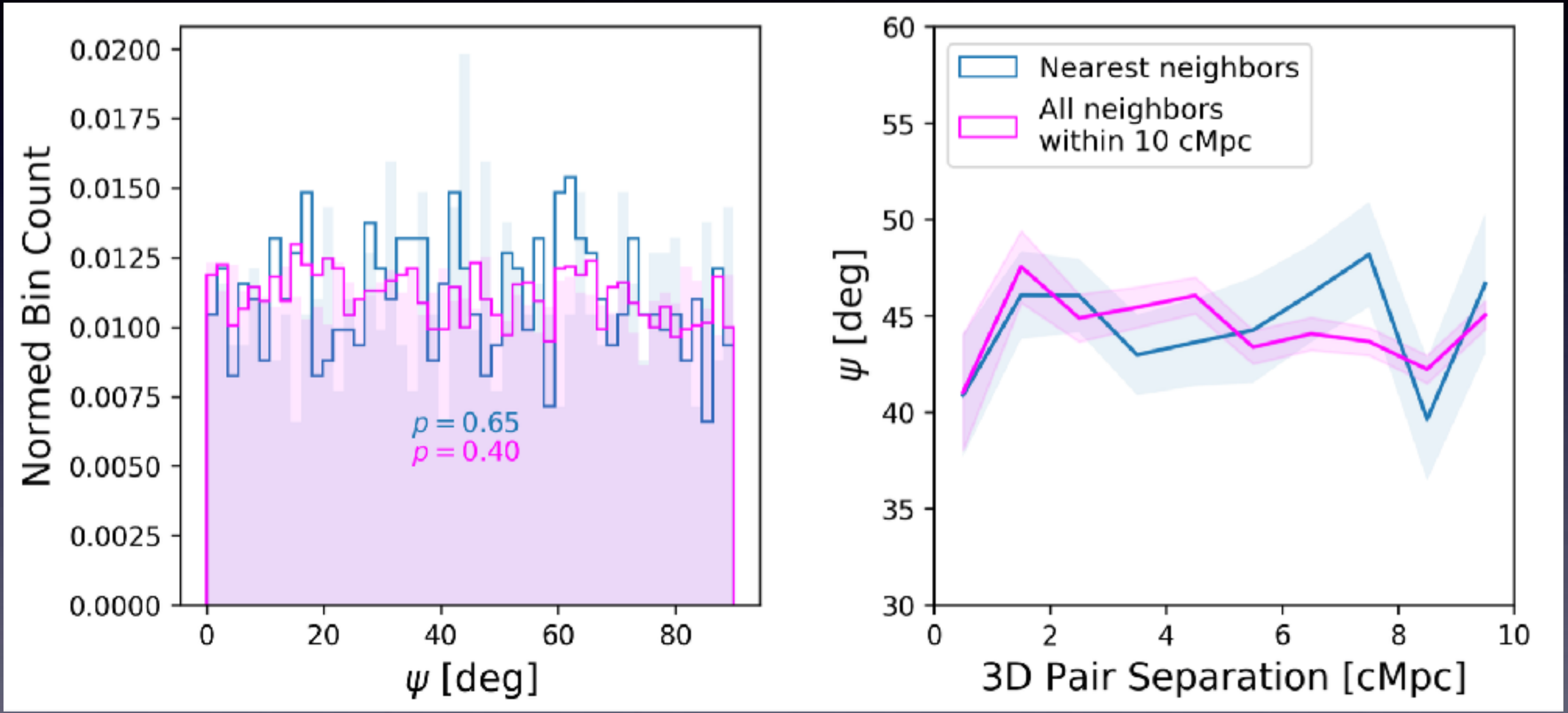
Only ~54% of realizations show significant signal

Viraj Pandya (UC Santa Cruz)

Results: shape—position alignments



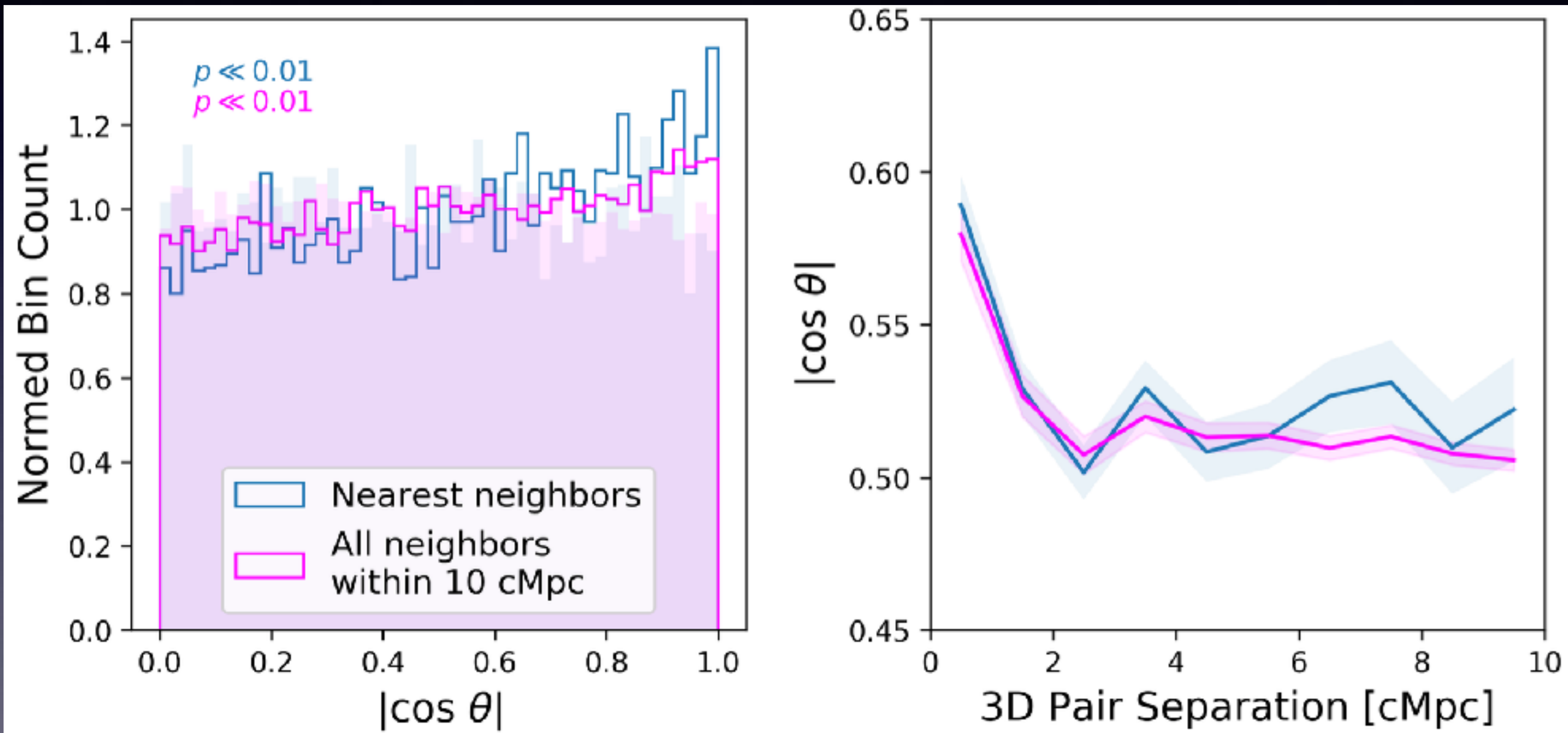
CANDELS Observations



Viraj Pandya (UC Santa Cruz)

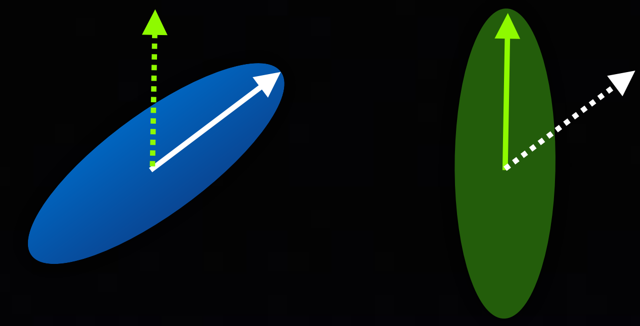
Results: shape—shape alignments

Mocks: 3D real space

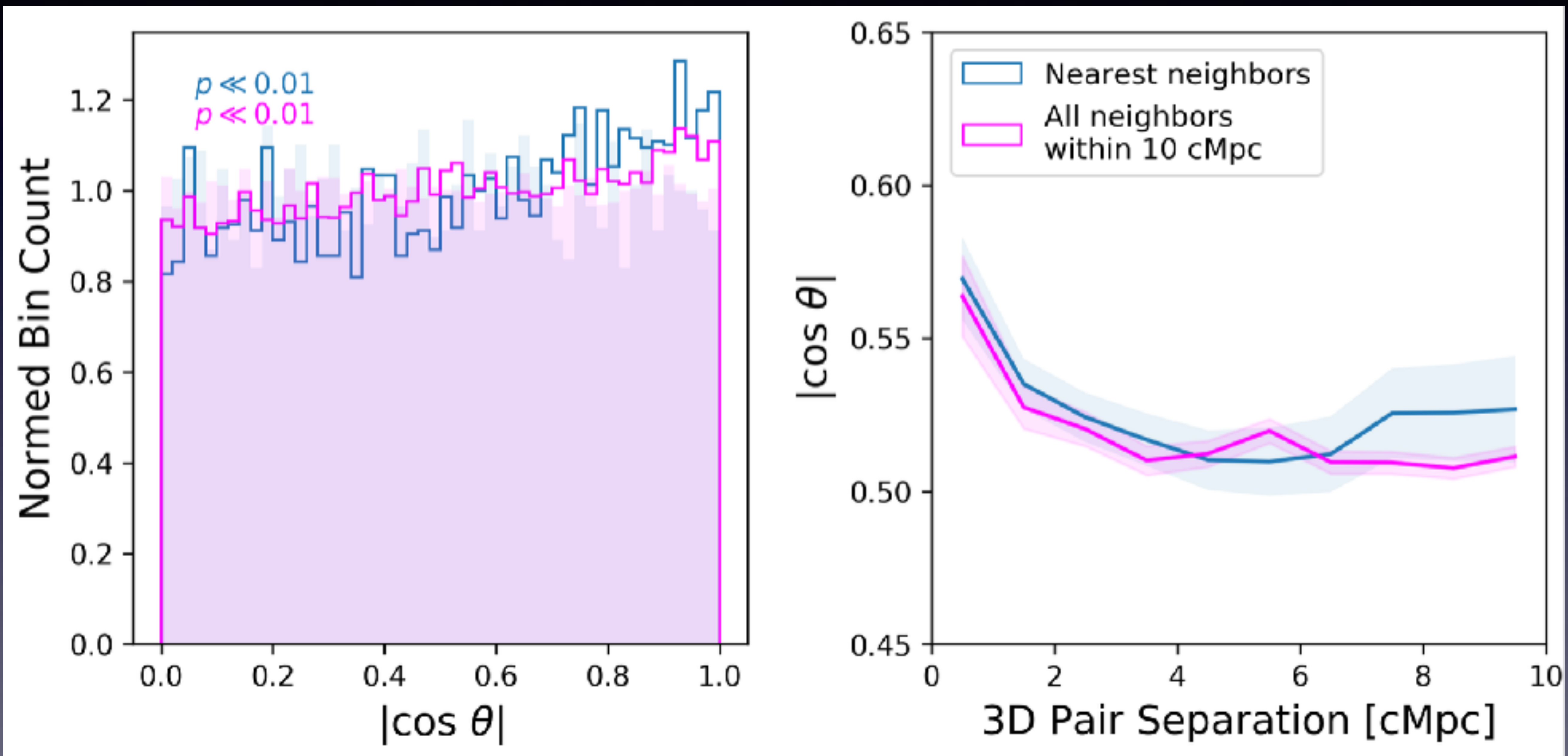


Viraj Pandya (UC Santa Cruz)

Results: shape—shape alignments

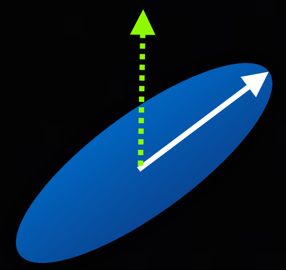


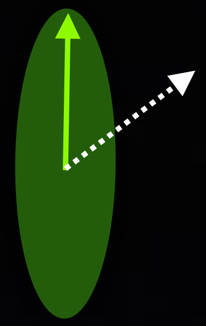
Mocks: 3D redshift space

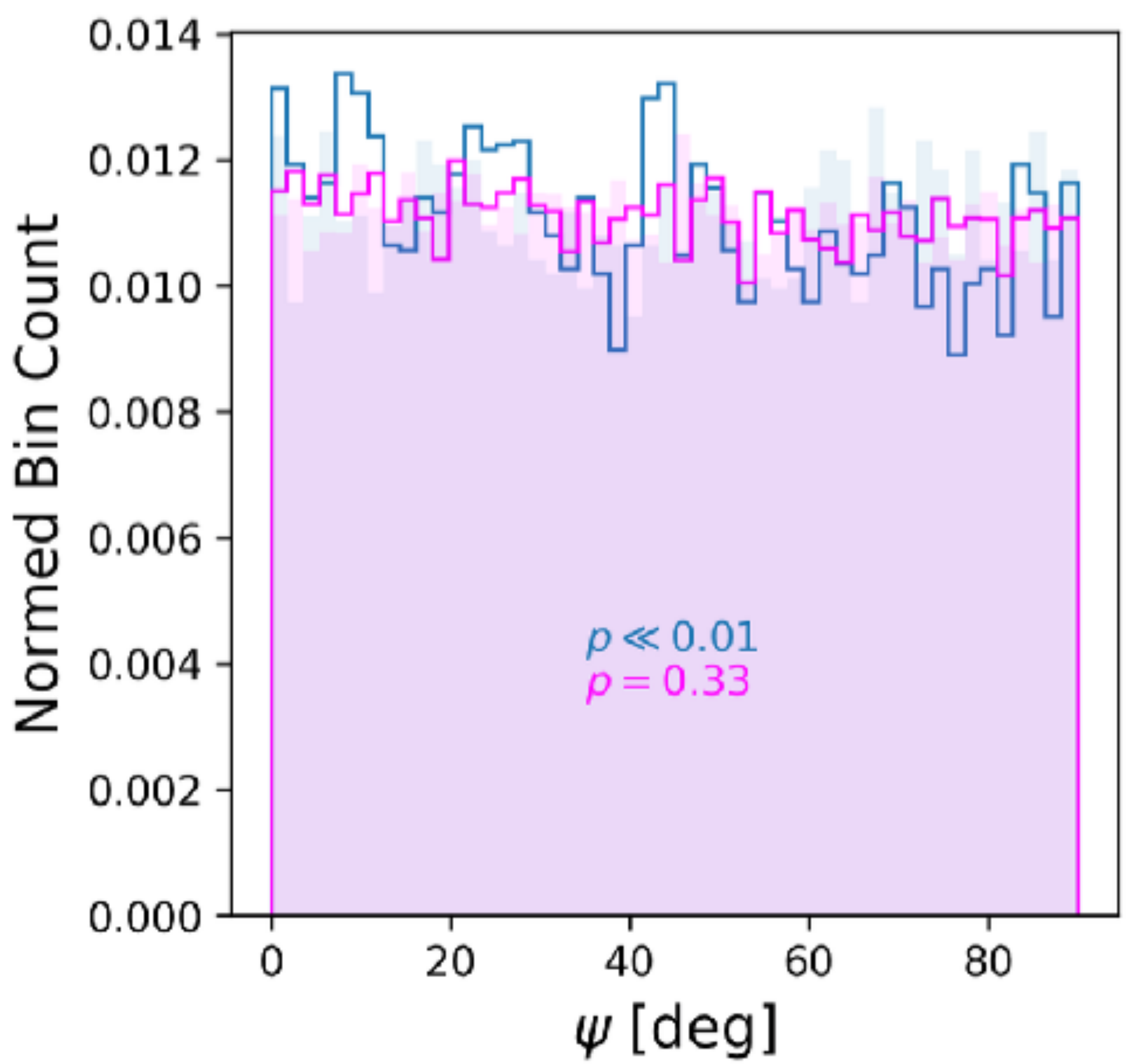


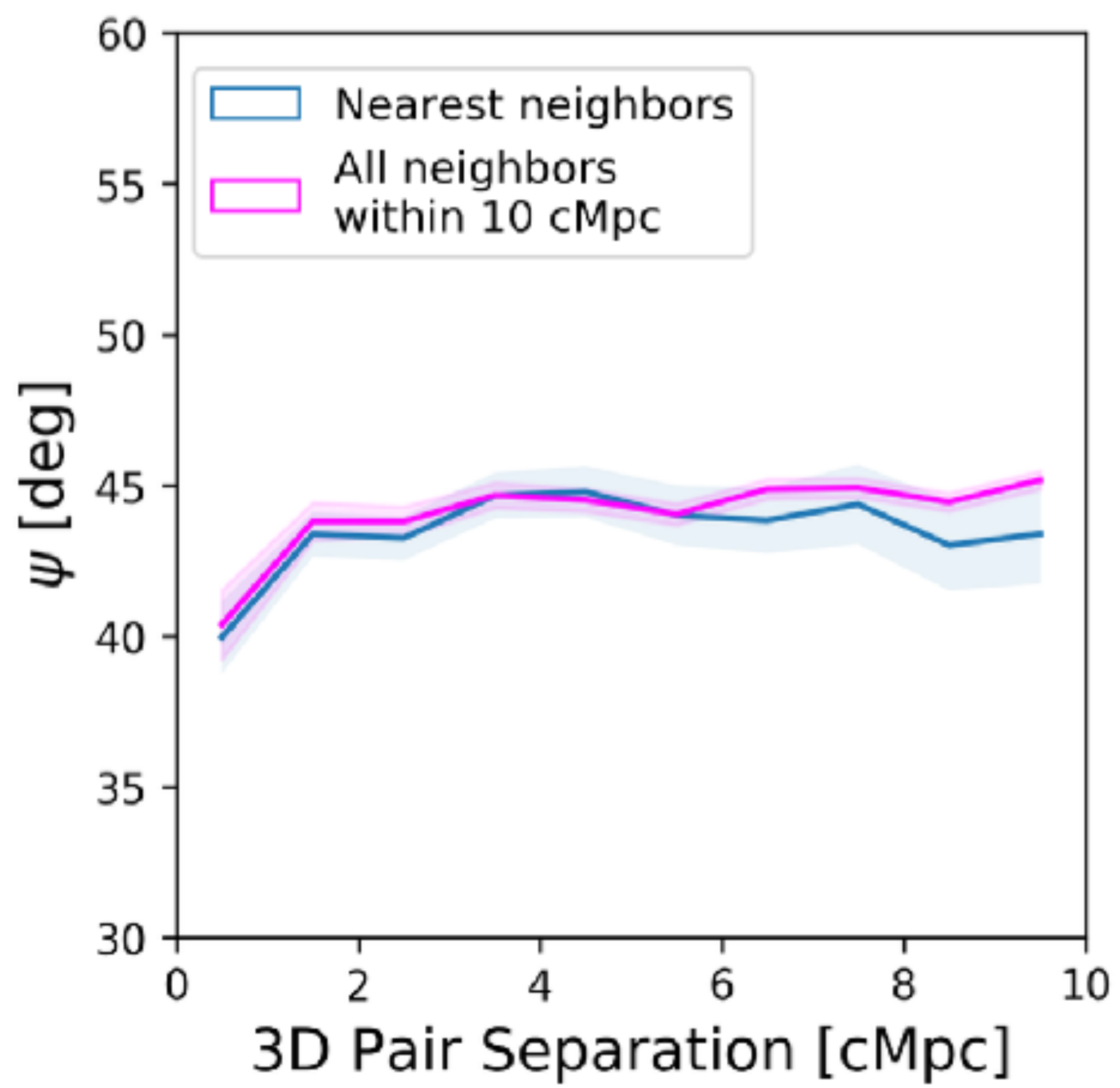
Results: shape—shape alignments

Mocks: 2D projected redshift space



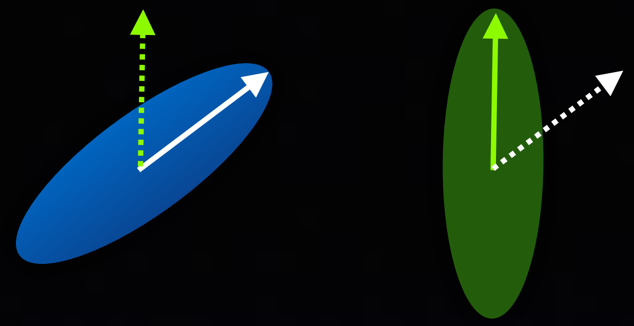




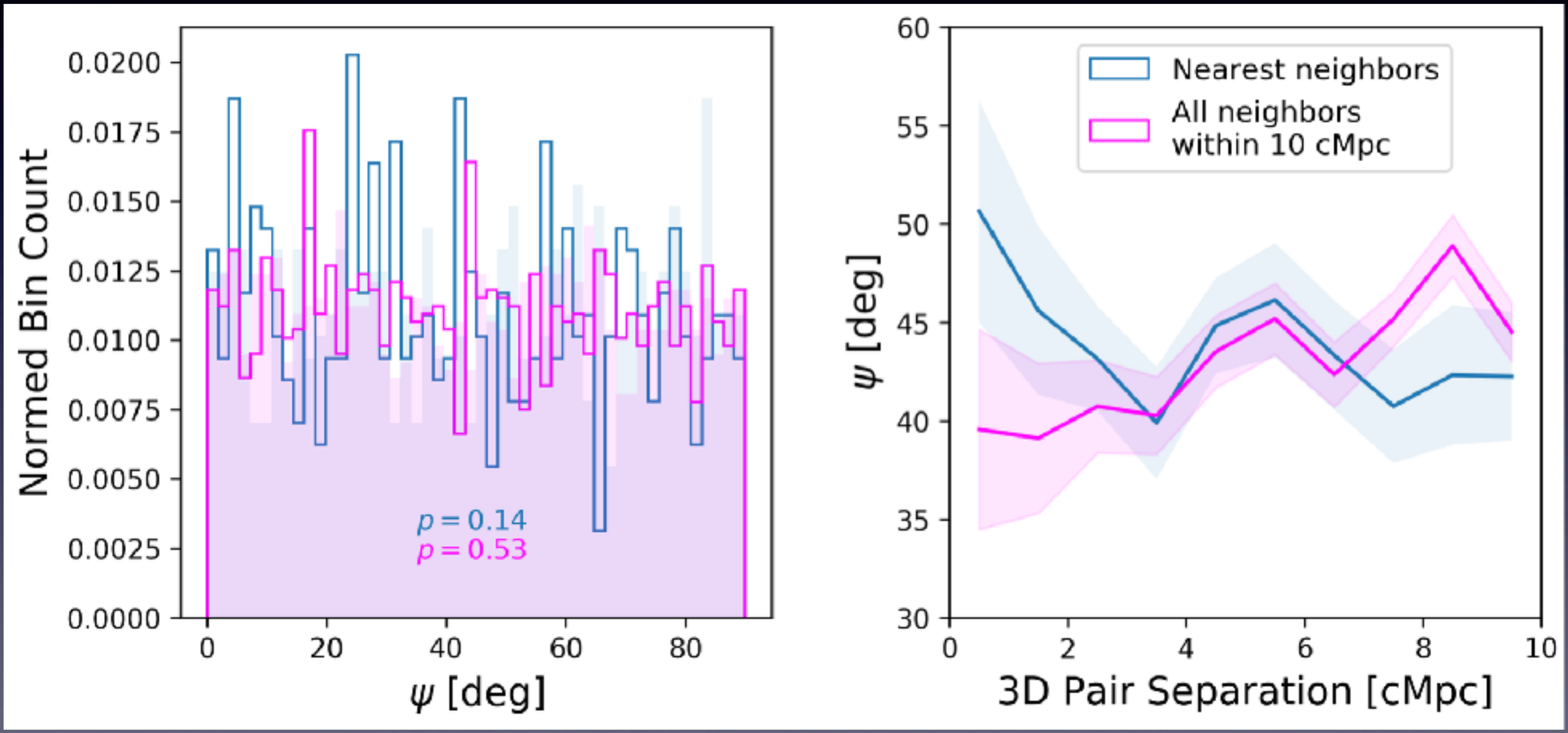


Viraj Pandya (UC Santa Cruz)

Results: shape—shape alignments



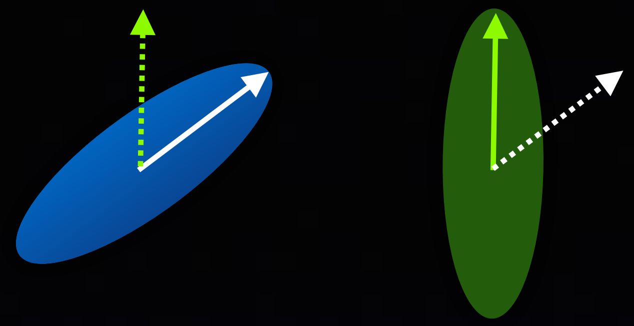
Mocks: 2D projected redshift space
with spectroscopic incompleteness & z_{grism} errors



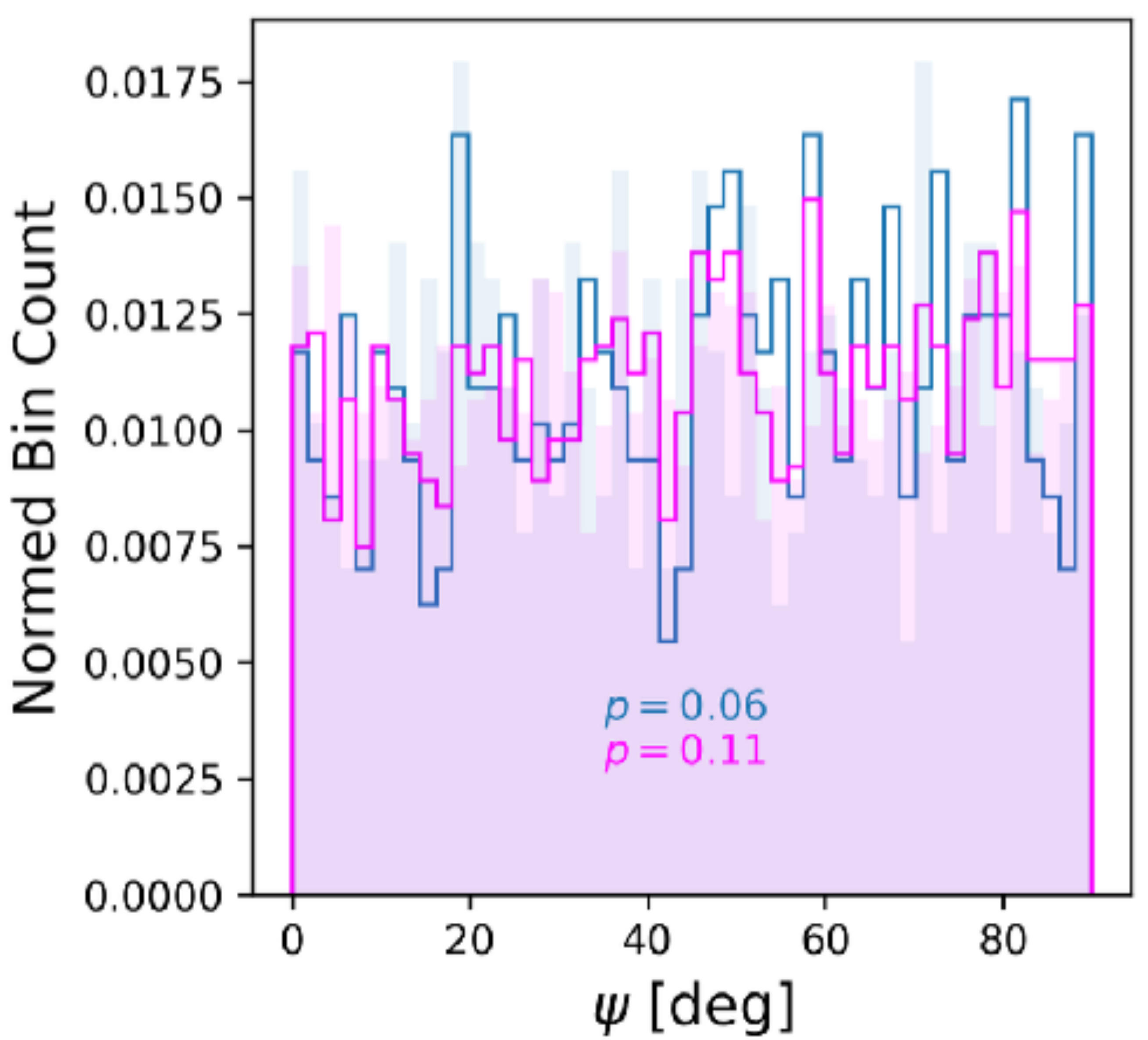
One example realization out of 1000
Only ~2% of realizations show significant signal

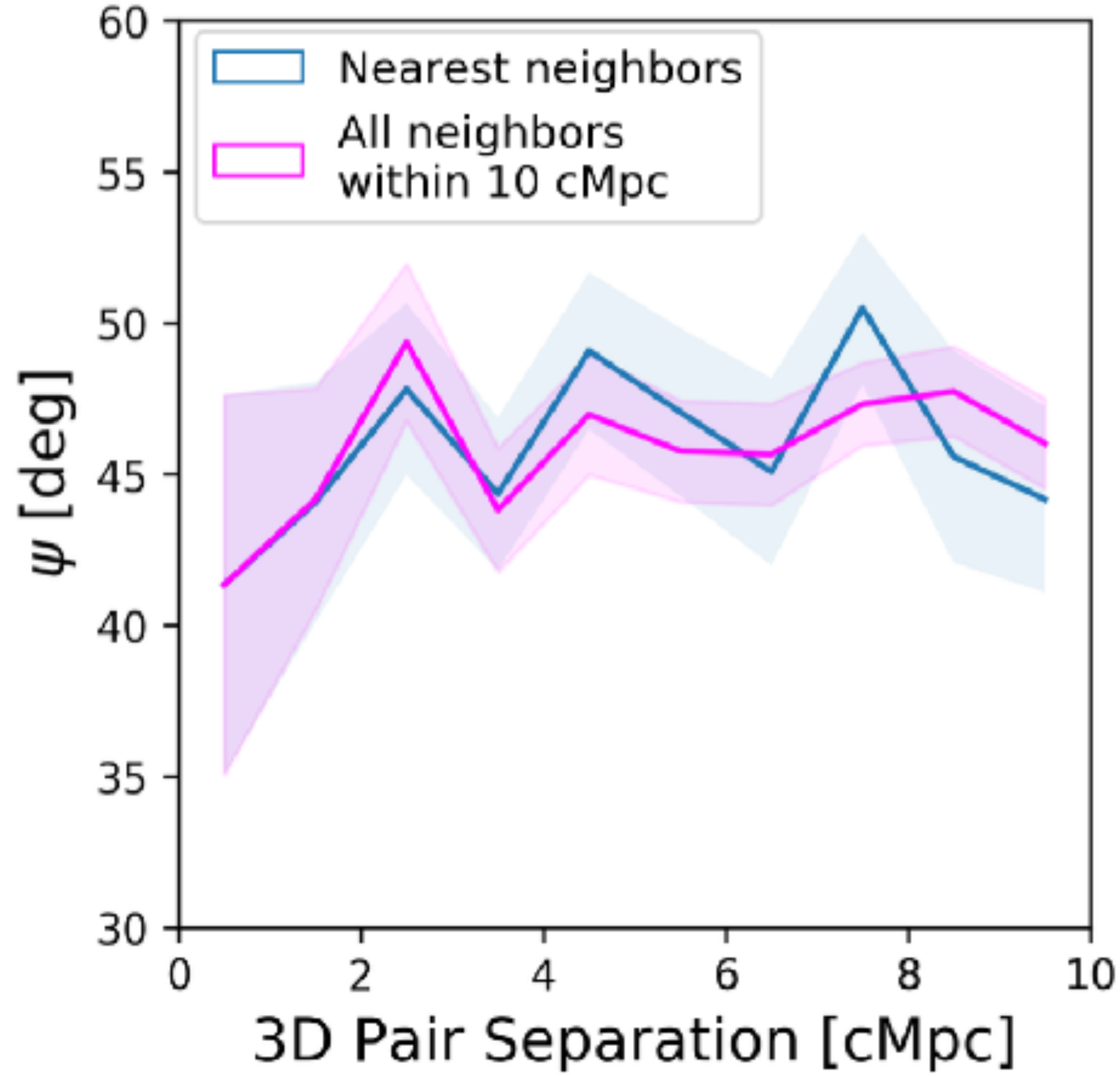
Viraj Pandya (UC Santa Cruz)

Results: shape—shape alignments



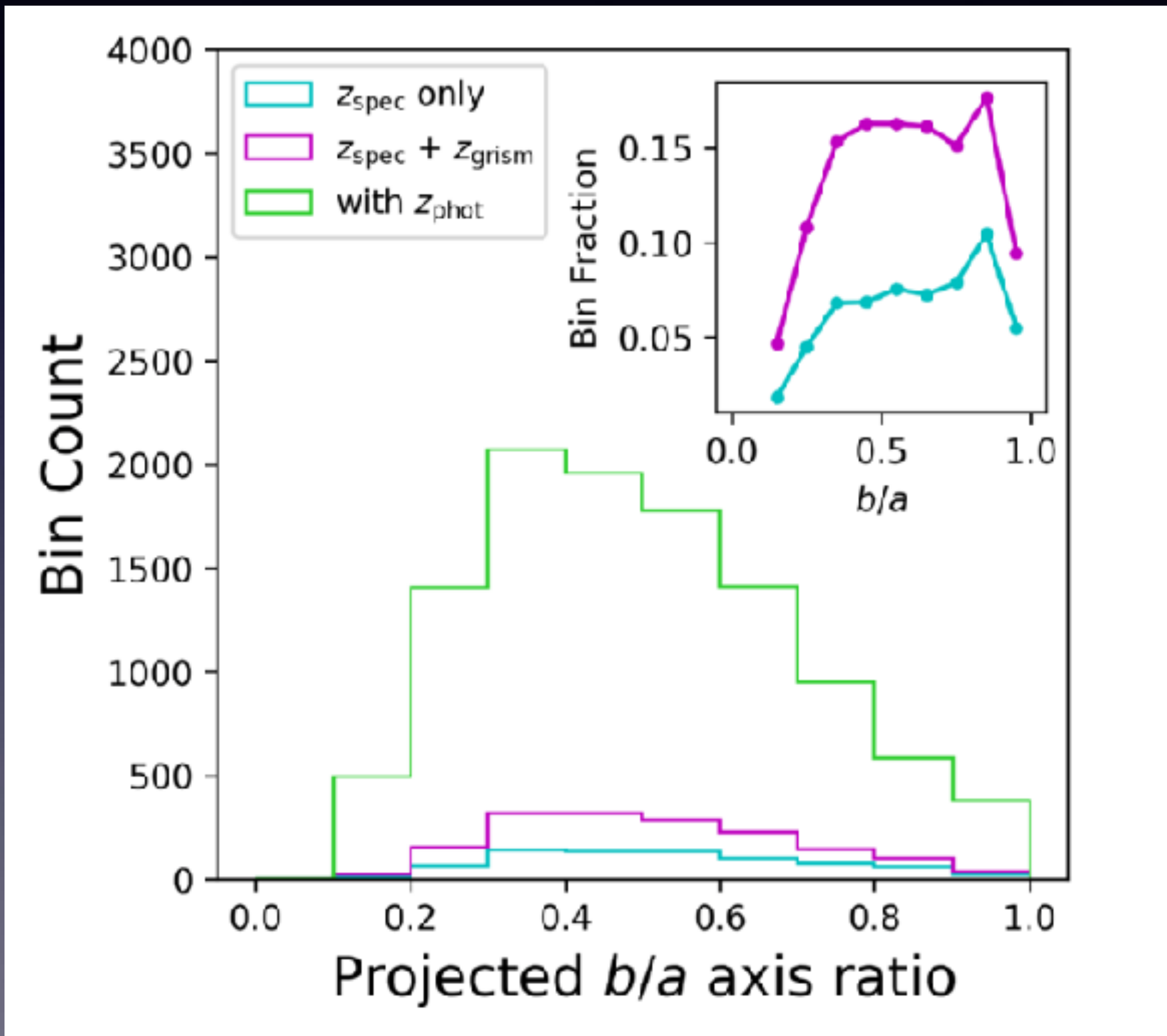
CANDELS Observations





Viraj Pandya (UC Santa Cruz)

Lack of expected signal due to spectroscopic incompleteness/bias?



- The spectroscopic/grism fraction is preferentially low for galaxies with small b/a
- Possibly due to bias in spectroscopic selection criteria and/or too faint
- Observing ~1200 more pairs would help detect or firmly rule out expected shape-position signal (UCSC senior thesis: Patrick Ward)

Other possible explanations for no observed signal?

- Misalignment between prolate galaxy & host halo orientation
- Halo orientation itself changes as a function of radius
- Contamination from misaligned edge-on disks
- Crude observed galaxy shape measurements (GALFIT)

Future prospects

- Analyze full photometric CANDELS catalog for on-sky alignments in broad redshift bins (Patrick Ward's senior thesis)
- Use mocks to devise optimal spec-z targeting campaign
- Look for other alignments (e.g., shape-filament in COSMOS)
- More detailed shape analysis as used in weak lensing studies
- Make predictions using large-volume sufficient-resolution hydro simulations (IllustrisTNG 50 Mpc box; Haowen Zhang+)

Main Takeaways

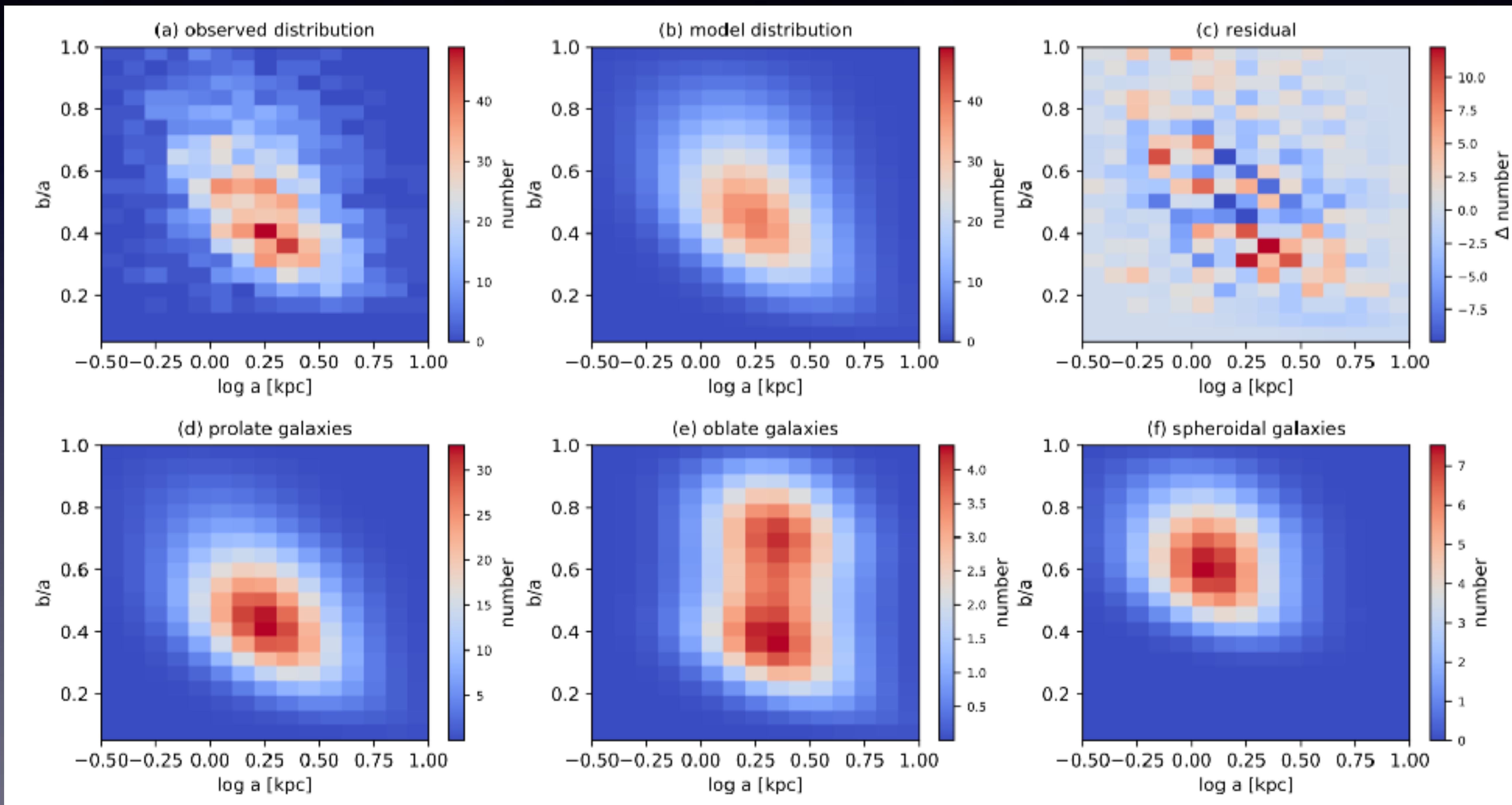
- Observations and simulations show that most low-mass ($M_{star}=10^9$-$10^{10}M_{sun}$) galaxies at z>1 are elongated
- In simulations, elongation is due to accretion along cosmic filament
- Could these low-mass elongated galaxies be clean tracers of the high-redshift cosmic web via their intrinsic alignments?
- Our mock lightcones predict that these elongated galaxies should show strong net alignments with other nearby galaxies
- But the expected signal is not detected in CANDELS observations
- Spectroscopic incompleteness may partly explain the discrepancy

Bonus slides

Prolateness probabilities

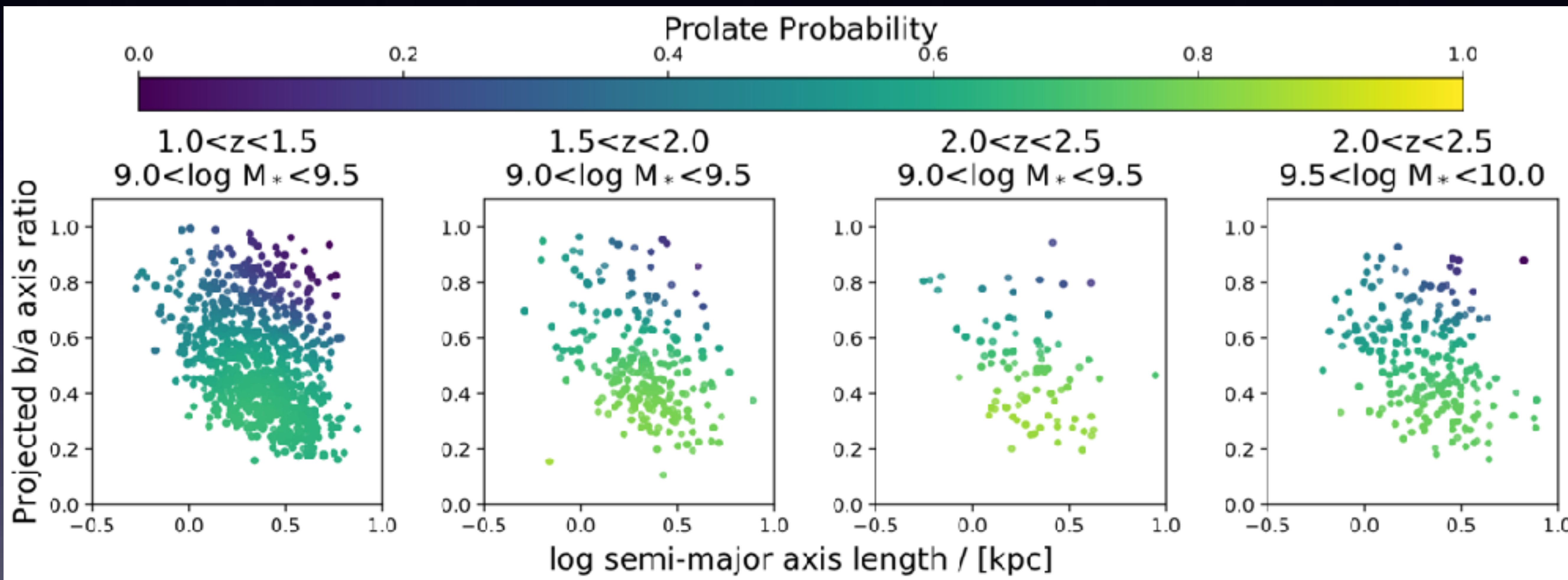
Haowen Zhang+18

Low-mass ($M_{star}=10^{9}$-$10^{9.5}M_{sun}$), high-redshift ($z=2.0$-2.5) CANDELS bin

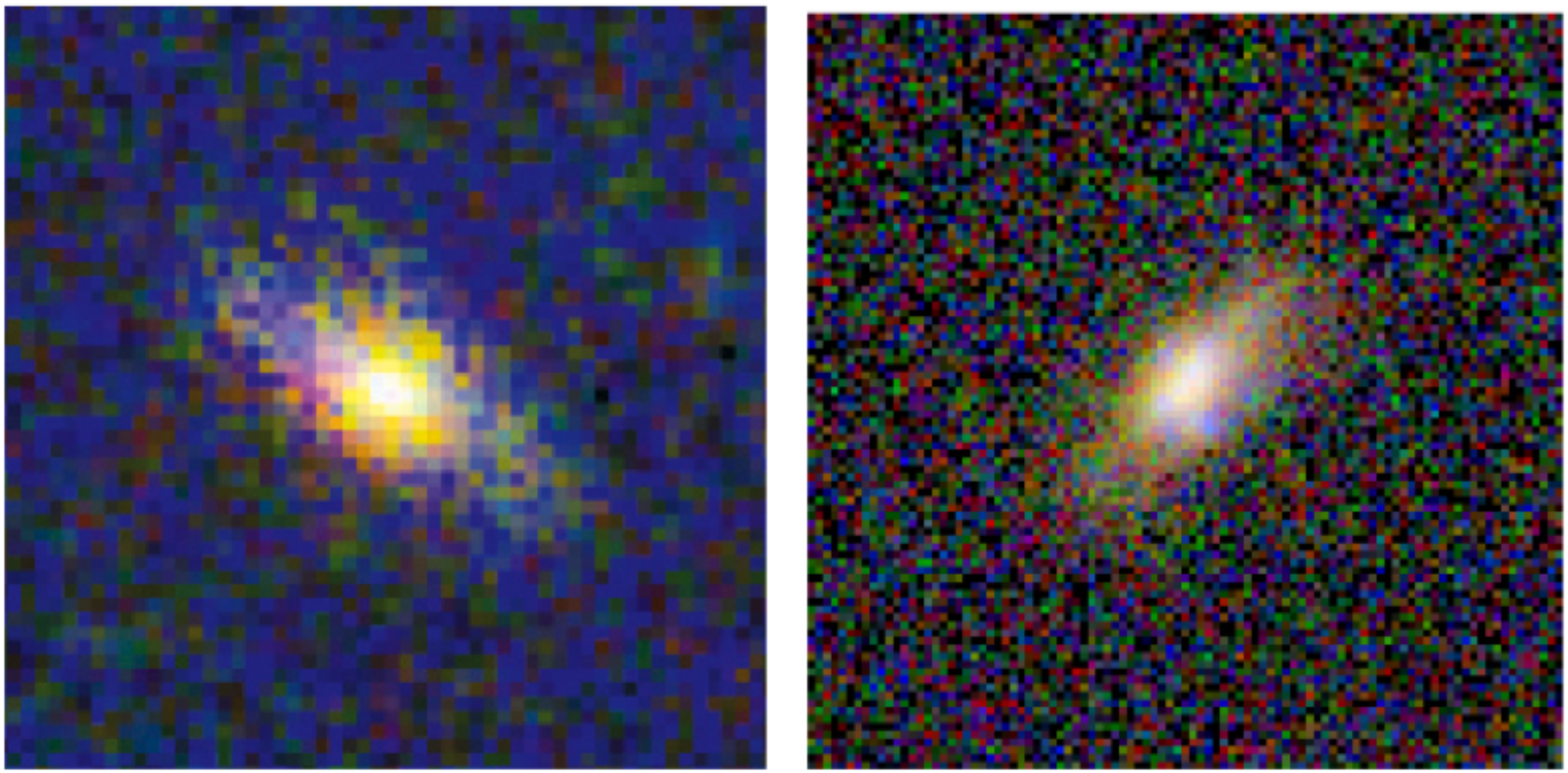


Elongated **Disky** **Spheroidal**

Prolateness probabilities



CANDELS: galaxies start out elongated



(a) CANDELS galaxy (b) VELA galaxy

Zhang, Primack, Faber, Koo, et al. 2019

Spectroscopic incompleteness and grism redshift errors