# Cosmological simulations in preparation for future galaxy surveys

Albert Izard (UC Riverside / Jet Propulsion Laboratory / Caltech)

Alina Kiessling[1], Bahram Mobasher[2], Peter Capak[3], Eric Huff[1], Jason Rhodes[1]

[1]Jet Propulsion Laboratory / Caltech

[2]Department of Physics and Astronomy, UC Riverside

[3]Spitzer Science Center, Caltech

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Jet Propulsion Laboratory
California Institute of Technology

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# Outline

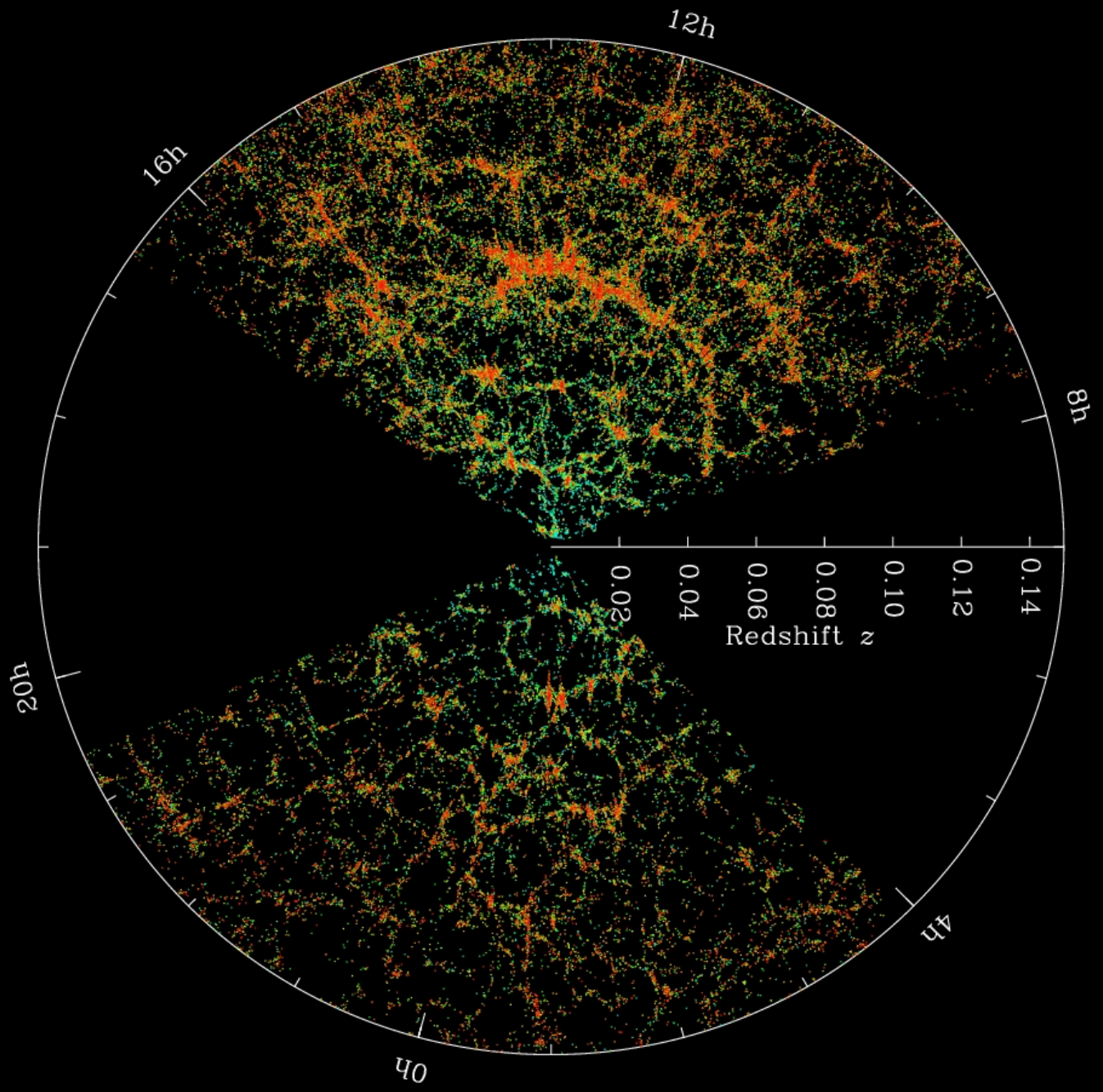
- Space-based dark energy missions in the 2020s
- End-to-end simulation pipeline
- Neighbor bias
- Grants & publications

# The ΛCDM model

- Successfully explains:
  - Homogeneity
  - Expansion
  - Structure formation

- Challenges:
  - Dark matter
  - Dark energy

What is the 96% of the content of the Universe?



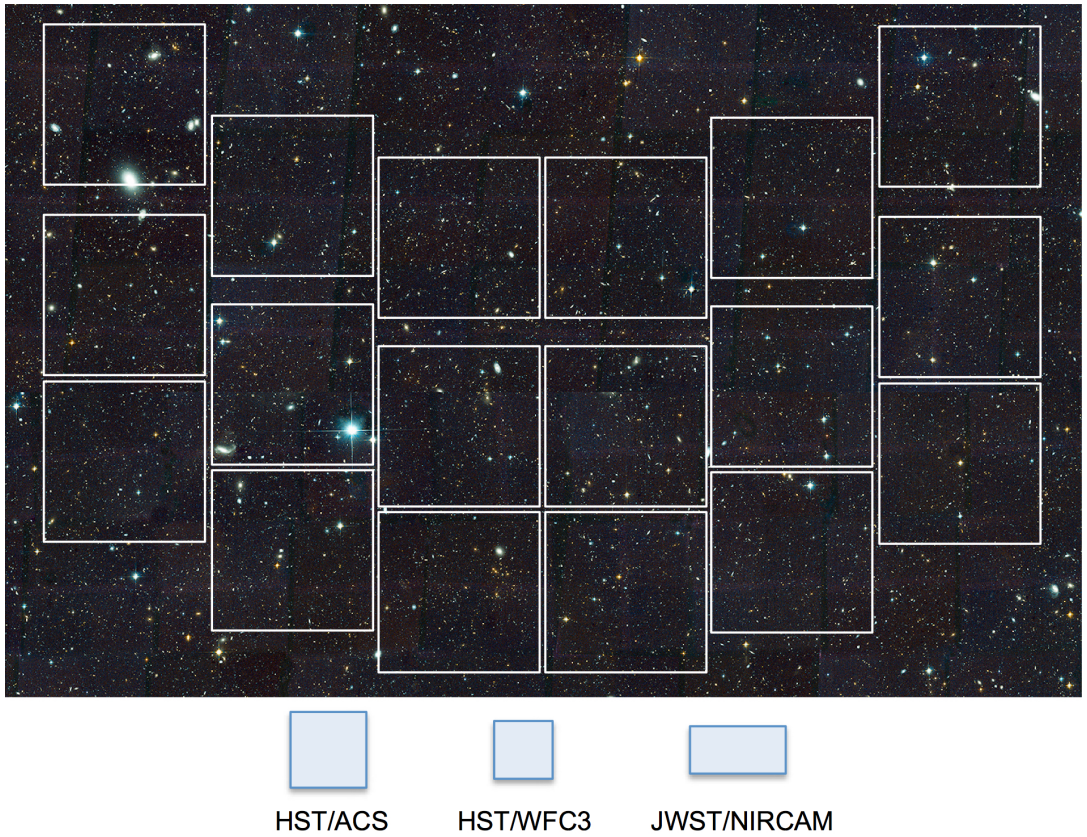

Credit: M. Blanton and SDSS (Blanton et al. 2003)

# 2020s space-based dark energy missions

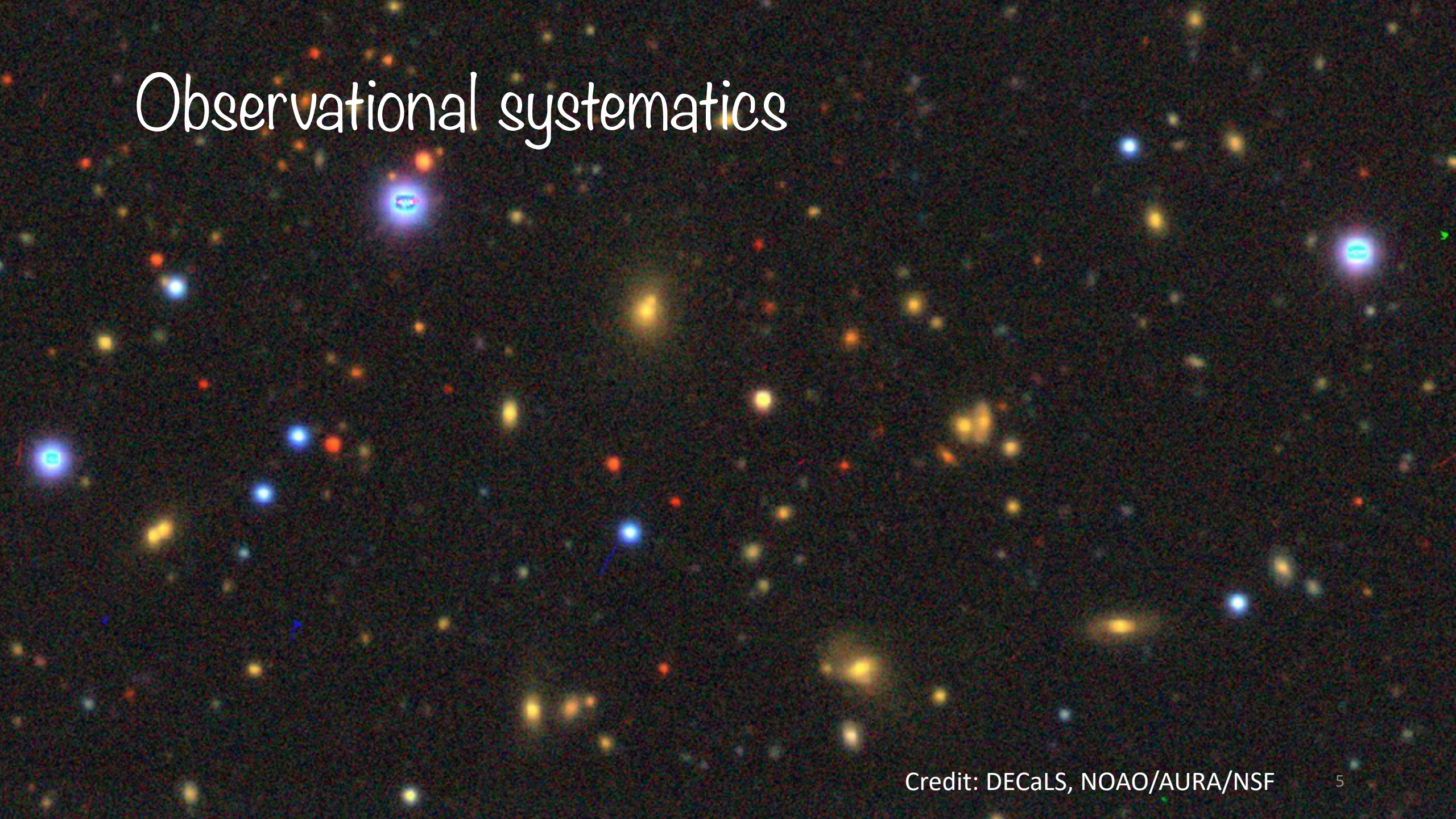
- Field of view: 0.54 $deg^2$
- 15.000 $deg^2$ (37.5% of the sky)
- 1.2B galaxies

- Field of view: 0.28 $deg^2$
- ~2000 $deg^2$
- 380M galaxies

Credit: https://wfirst.gsfc.nasa.gov



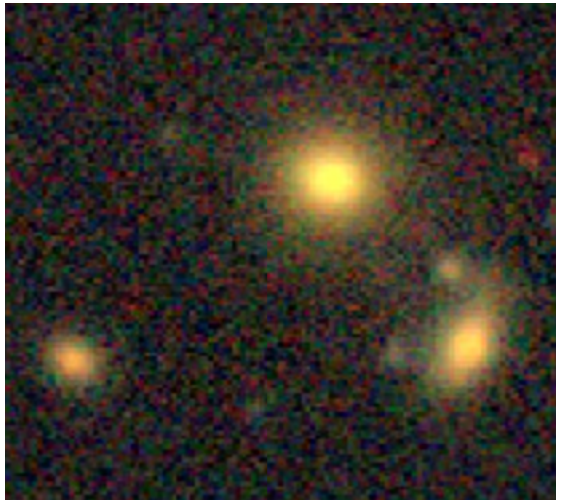
# Observational systematics



Credit: DECaLS, NOAO/AURA/NSF

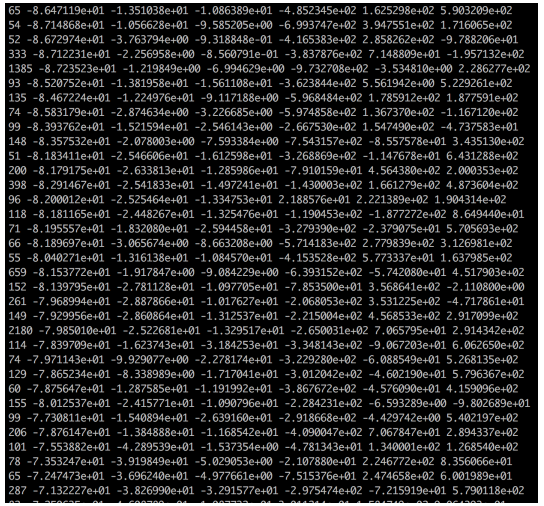
# The data flow in a galaxy survey

Images



Credit: DECaLS, NOAO/AURA/NSF

Catalogs



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| 54 | -8.714868e+01 | -1.056628e+01 | -9.585205e+00 | -6.993747e+02 | 3.947551e+02 | 1.716065e+02 |
| 52 | -8.672974e+01 | -3.763794e+00 | -9.318848e-01 | -4.165383e+02 | 2.858262e+02 | -9.788206e+01 |
| 333 | -8.712231e+01 | -2.256958e+00 | -8.560791e-01 | -3.837876e+02 | 7.148809e+01 | -1.957132e+02 |
| 1385 | -8.723523e+01 | -1.219849e+00 | -6.994629e+00 | -9.732708e+02 | -3.534810e+00 | 2.286277e+02 |
| 93 | -8.520752e+01 | -1.381958e+01 | -1.561108e+01 | -3.623844e+02 | 5.561942e+00 | 5.229261e+02 |
| 135 | -8.467224e+01 | -1.224976e+01 | -9.117188e+00 | -5.968484e+02 | 1.785912e+02 | 1.877591e+02 |
| 74 | -8.583179e+01 | -2.874634e+00 | -3.226685e+00 | -5.974858e+02 | 1.367370e+02 | -1.167120e+02 |
| 99 | -8.393762e+01 | -1.521594e+01 | -2.546143e+00 | -2.667530e+02 | 1.547490e+02 | -4.737583e+01 |
| 148 | -8.357532e+01 | -2.078003e+00 | -7.593384e+00 | -7.543157e+02 | -8.557578e+01 | 3.435130e+02 |
| 51 | -8.183411e+01 | -2.546606e+01 | -1.612598e+01 | -3.268869e+02 | -1.147678e+01 | 6.431288e+02 |
| 200 | -8.179175e+01 | -2.633813e+01 | -1.285986e+01 | -7.910159e+01 | 4.564380e+02 | 2.000353e+02 |
| 398 | -8.291467e+01 | -2.541833e+01 | -1.497241e+01 | -1.430003e+02 | 1.661279e+02 | 4.873604e+02 |
| 96 | -8.200012e+01 | -2.525464e+01 | -1.334753e+01 | 2.188576e+01 | 2.221389e+02 | 1.904314e+02 |
| 118 | -8.181165e+01 | -2.448267e+01 | -1.325476e+01 | -1.190453e+02 | -1.877272e+02 | 8.649440e+01 |
| 71 | -8.195557e+01 | -1.832080e+01 | -2.594458e+01 | -3.279390e+02 | -2.379075e+01 | 5.705693e+02 |
| 66 | -8.189697e+01 | -3.065674e+00 | -8.663208e+00 | -5.714183e+02 | 2.779839e+02 | 3.126981e+02 |
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| 659 | -8.153772e+01 | -1.917847e+00 | -9.084229e+00 | -6.393152e+02 | -5.742080e+01 | 4.517903e+02 |
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| 261 | -7.968994e+01 | -2.887866e+01 | -1.017627e+01 | -2.068053e+02 | 3.531225e+02 | -4.717861e+01 |
| 149 | -7.929956e+01 | -2.860864e+01 | -1.312537e+01 | -2.215004e+02 | 4.568533e+02 | 2.917099e+02 |
| 2180 | -7.985010e+01 | -2.522681e+01 | -1.329517e+01 | -2.650031e+02 | 7.065795e+01 | 2.914342e+02 |
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| 74 | -7.971143e+01 | -9.929077e+00 | -2.278174e+01 | -3.229280e+02 | -6.088549e+01 | 5.268135e+02 |
| 129 | -7.865234e+01 | -8.338989e+00 | -1.717041e+01 | -3.012042e+02 | -4.602190e+01 | 5.796367e+02 |
| 60 | -7.875647e+01 | -1.287585e+01 | -1.191992e+01 | -3.867672e+02 | -4.576090e+01 | 4.159096e+02 |
| 155 | -8.012537e+01 | -2.415771e+01 | -1.090796e+01 | -2.284231e+02 | -6.593289e+00 | -9.802689e+01 |
| 99 | -7.730811e+01 | -1.540894e+01 | -2.639160e+01 | -2.918668e+02 | -4.429742e+00 | 5.402197e+02 |
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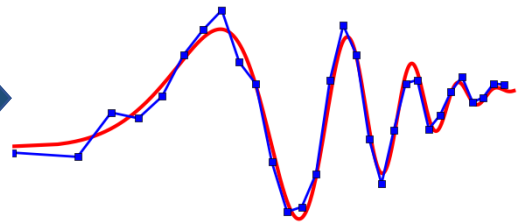
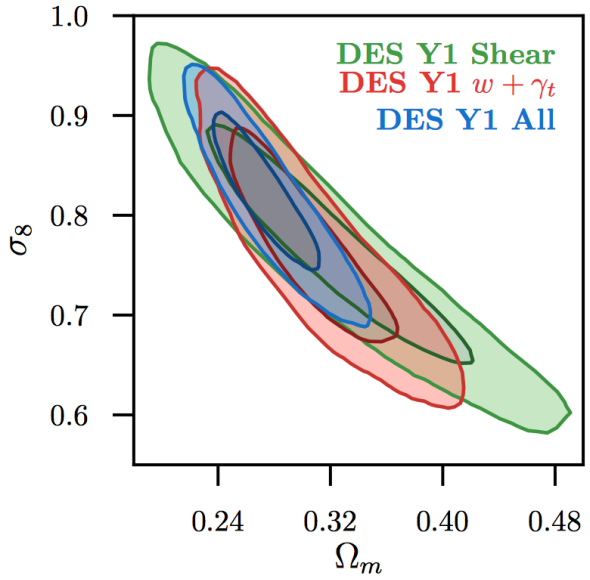
| 287 | -7.132227e+01 | -3.826990e+01 | -3.291577e+01 | -2.975474e+02 | -7.215919e+01 | 5.790118e+02 |

Observables



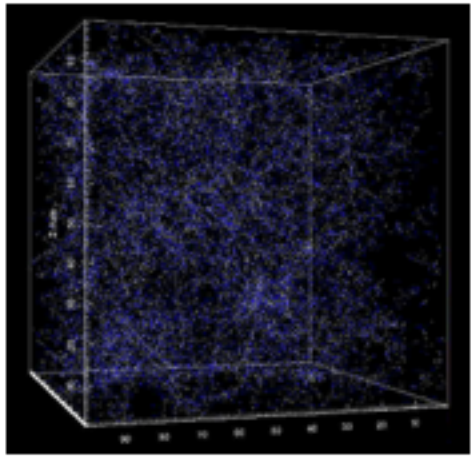
Constraints on cosmological parameters/models

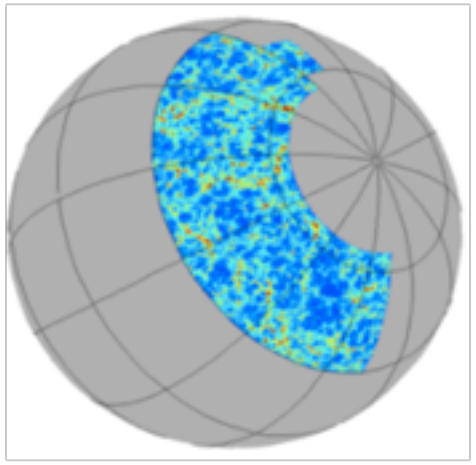


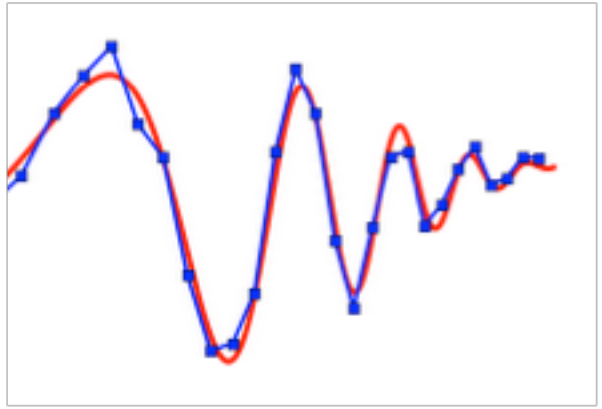

The Dark Energy Survey Collaboration, Troxel et al. 2017

# End-to-end simulation pipeline

**N-body simulation** → **Realistic catalogues** → **Modelling observables**







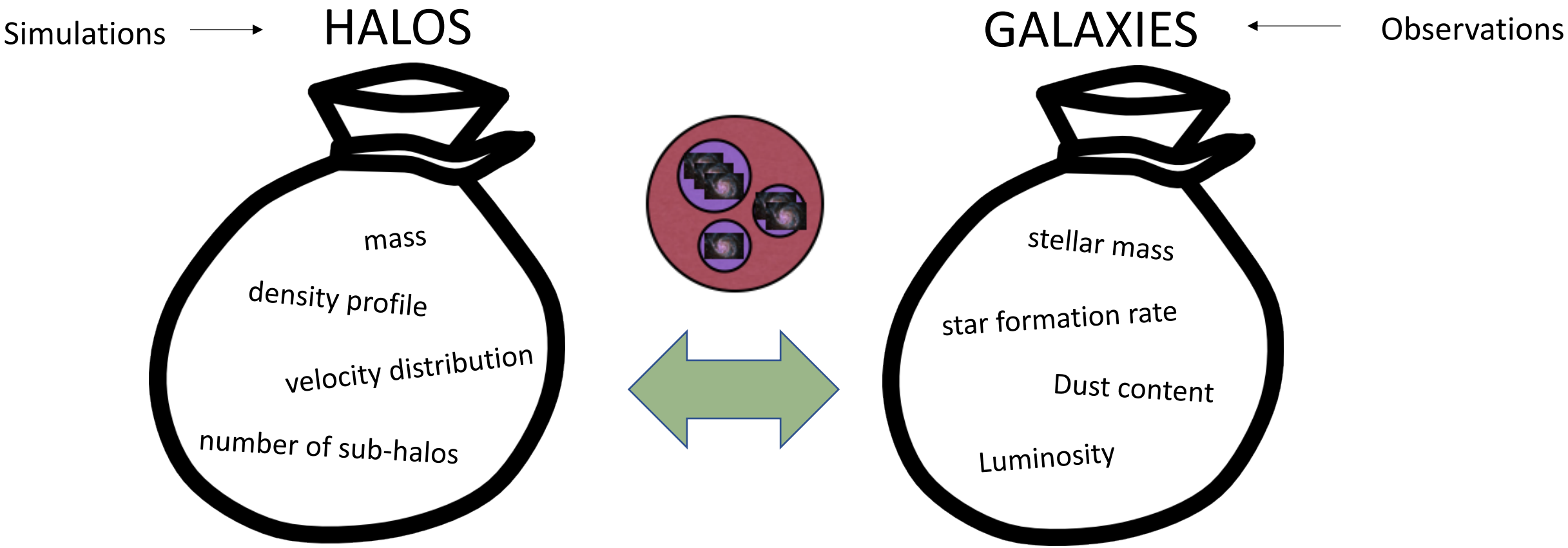
Fast cosmological simulations:

- Dark matter halo catalogs
- Weak lensing maps

Galaxy formation model

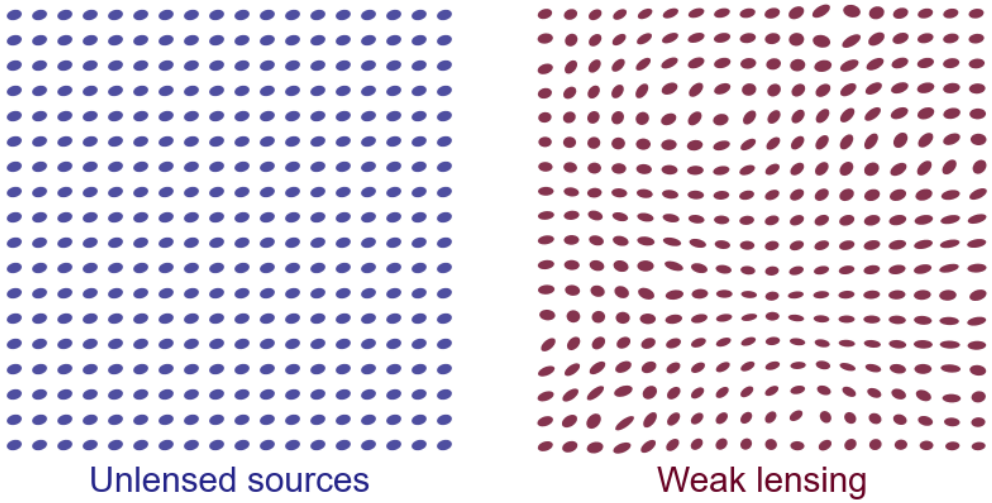
Systematic effects

# From halos to galaxies

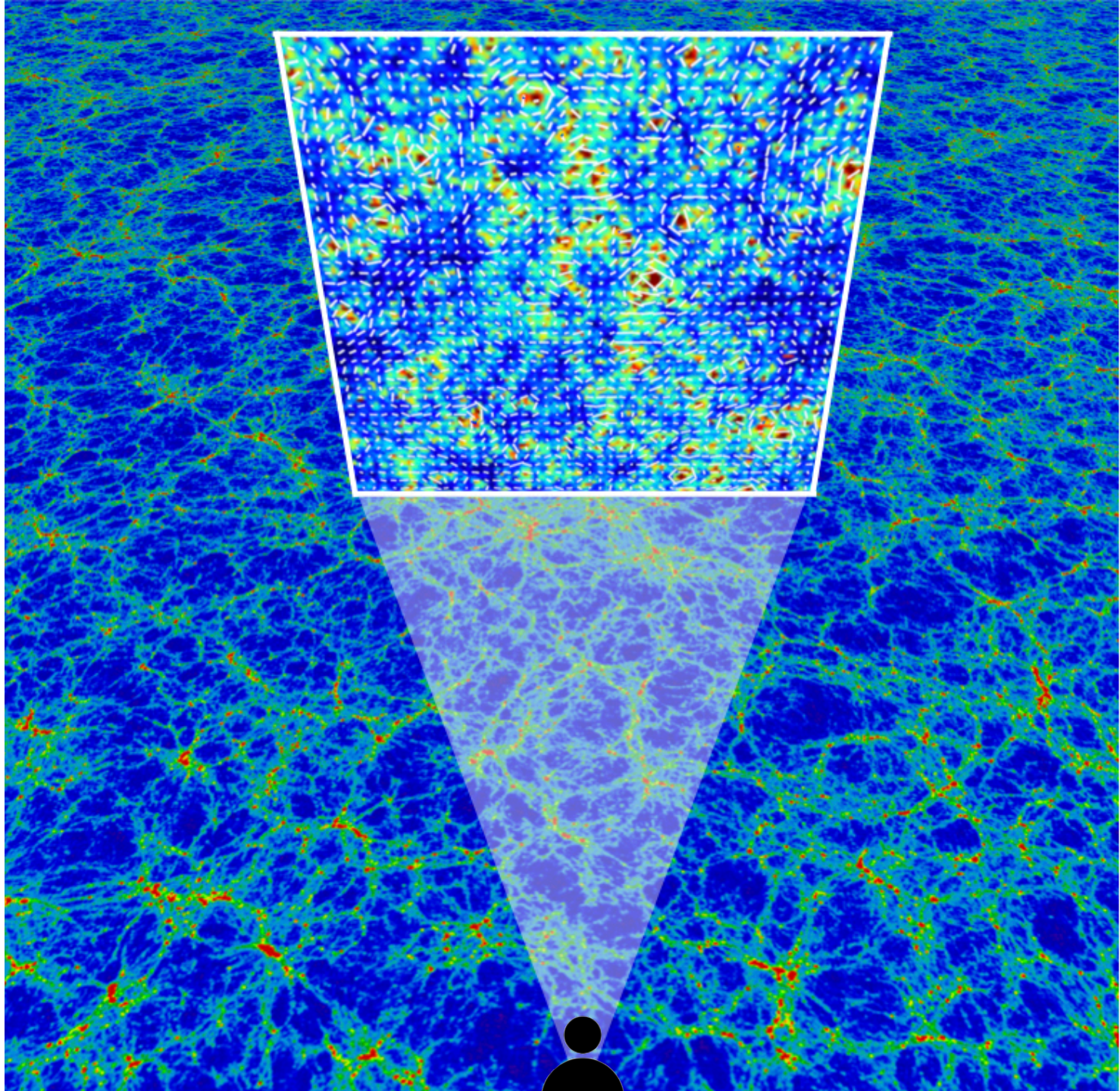



Ghost software (Bull 2017, MNRAS, 471, 12):
Enables a fast modeling of galaxy properties

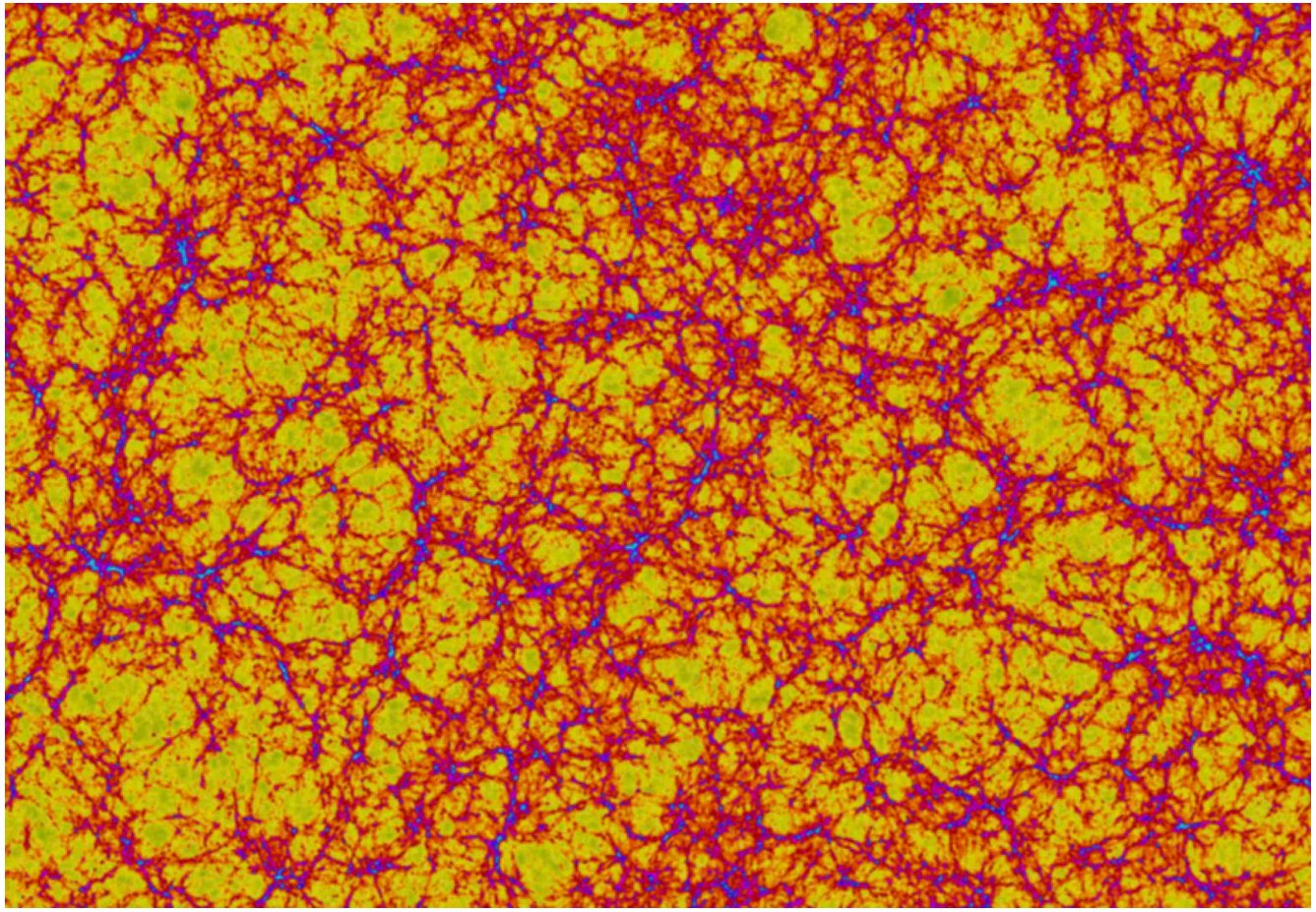
# Weak gravitational lensing maps

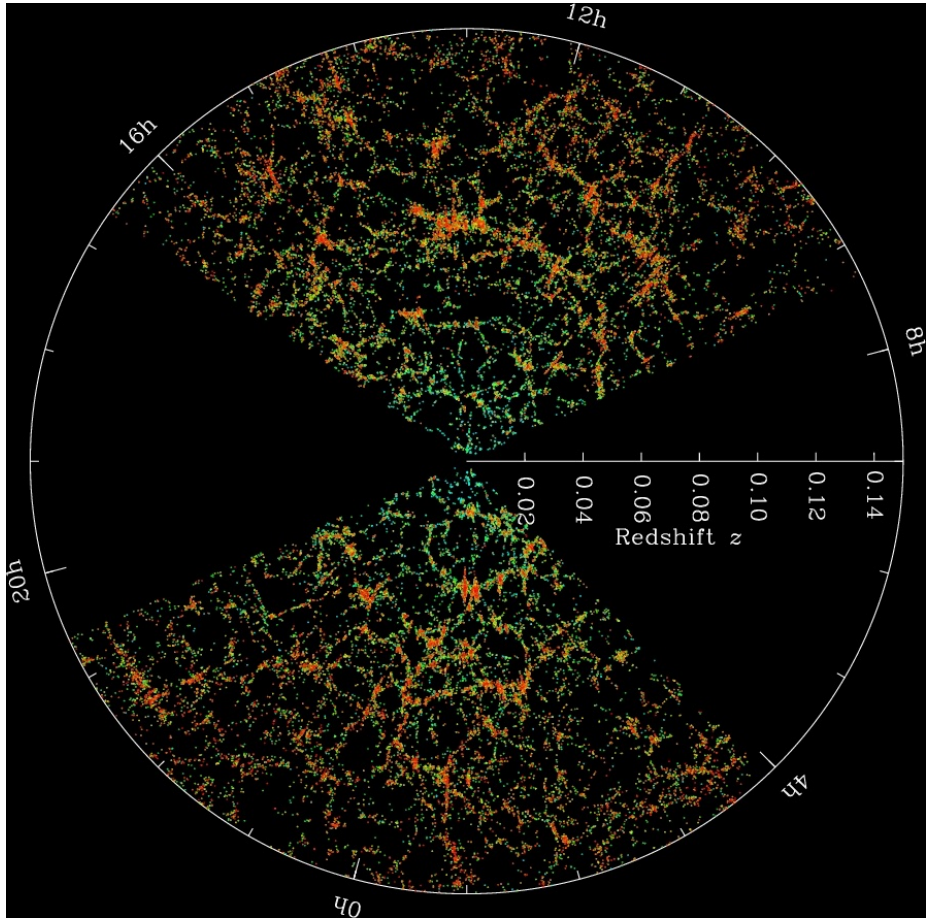



Credit: Chieh-An Lin



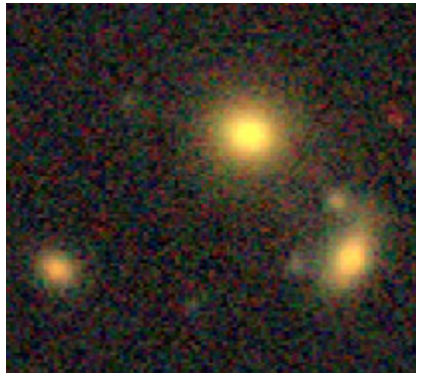
# Simulations vs observations

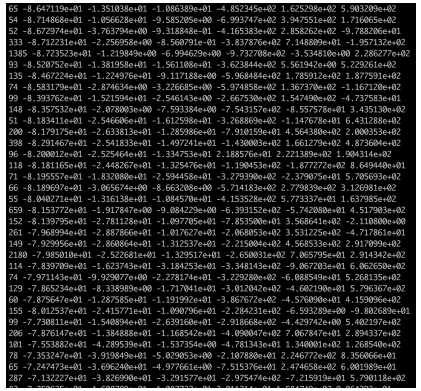





Credit: M. Blanton and SDSS (Blanton et al. 2003)

# Observational systematics: neighbor bias





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|---|---|---|---|---|---|---|
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| 52 | -8.672974e+01 | -3.763794e+00 | -9.318848e-01 | -4.165383e+02 | 2.858262e+02 | -9.788206e+01 |
| 333 | -8.712231e+01 | -2.256958e+00 | -8.560791e-01 | -3.837876e+02 | 7.148809e+01 | -1.957132e+02 |
| 1385 | -8.723523e+01 | -1.219849e+00 | -6.994629e+00 | -9.732708e+02 | -3.534810e+00 | 2.286277e+02 |
| 93 | -8.520752e+01 | -1.381958e+01 | -1.561108e+01 | -3.623844e+02 | 5.561942e+00 | 5.229261e+02 |
| 135 | -8.407224e+01 | -1.224976e+01 | -9.117188e+00 | -5.964484e+02 | 1.785912e+02 | 1.877591e+02 |
| 74 | -8.583179e+01 | -2.874634e+00 | -3.226685e+00 | -5.974858e+02 | 1.367370e+02 | -1.167120e+02 |
| 99 | -8.393762e+01 | -1.521594e+01 | -2.546143e+00 | -2.667530e+02 | 1.547490e+02 | -4.737583e+01 |
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| 200 | -8.179175e+01 | -2.633813e+01 | -1.285986e+01 | -7.910159e+01 | 4.564380e+02 | 2.800353e+02 |
| 398 | -8.291467e+01 | -2.541833e+01 | -1.407241e+01 | -1.430003e+02 | 1.661279e+02 | 4.873604e+02 |
| 96 | -8.200012e+01 | -2.525464e+01 | -1.334753e+01 | 2.188576e+01 | 2.221389e+02 | 1.904314e+02 |
| 118 | -8.181165e+01 | -2.448267e+01 | -1.325476e+01 | -1.190453e+02 | -1.877272e+02 | 8.649440e+01 |
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| 66 | -8.189697e+01 | -3.065674e+00 | -8.663208e+00 | -5.714183e+02 | 2.779839e+02 | 3.126981e+02 |
| 55 | -8.040271e+01 | -1.316138e+01 | -1.084570e+01 | -4.153528e+02 | 5.773337e+01 | 1.637985e+02 |
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| 149 | -7.929956e+01 | -2.860864e+01 | -1.312537e+01 | -2.215004e+02 | 4.568533e+02 | 2.917099e+02 |
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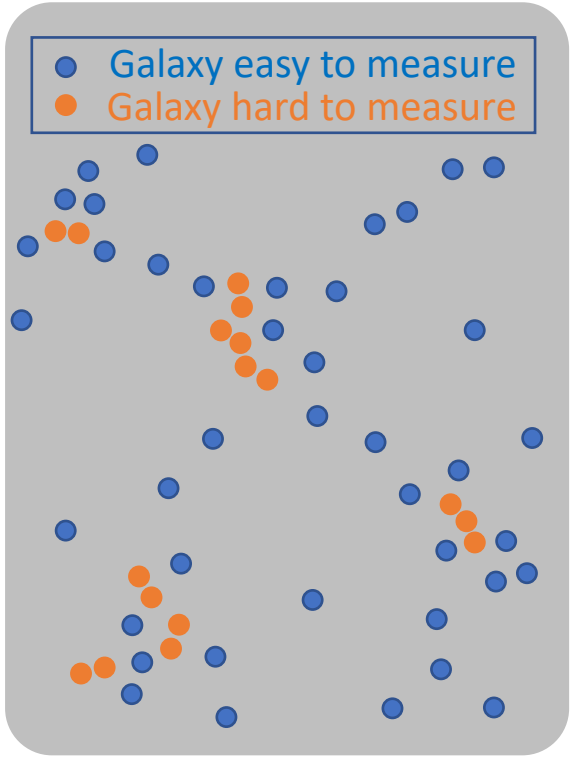
| 287 | -7.132227e+01 | -3.826990e+01 | -3.291577e+01 | -2.975474e+02 | -7.215919e+01 | 5.790118e+02 |

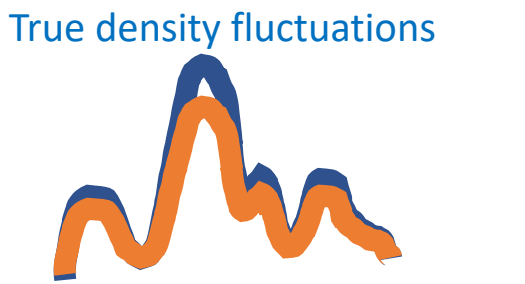
Channels for neighbor bias:

- Flux contamination
- Indistinguishability of overlapping galaxies
- Undetected galaxies
- Varying noise background

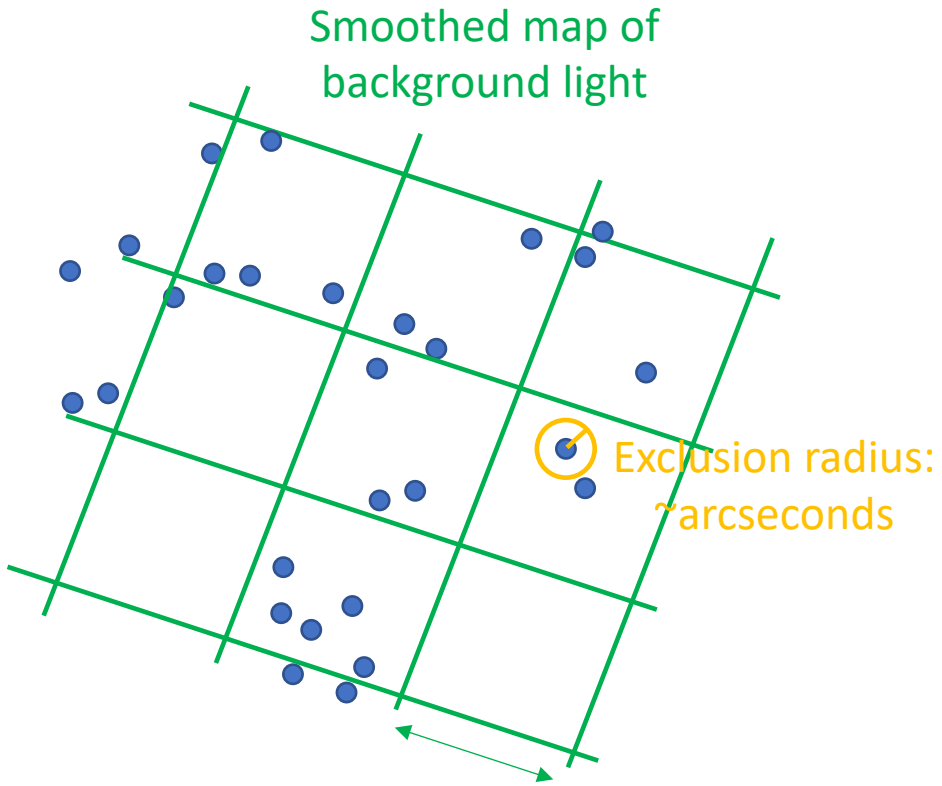
Impact on:

- Detection probability
- Measured galaxy properties



# Modeling the neighbor bias: simulations



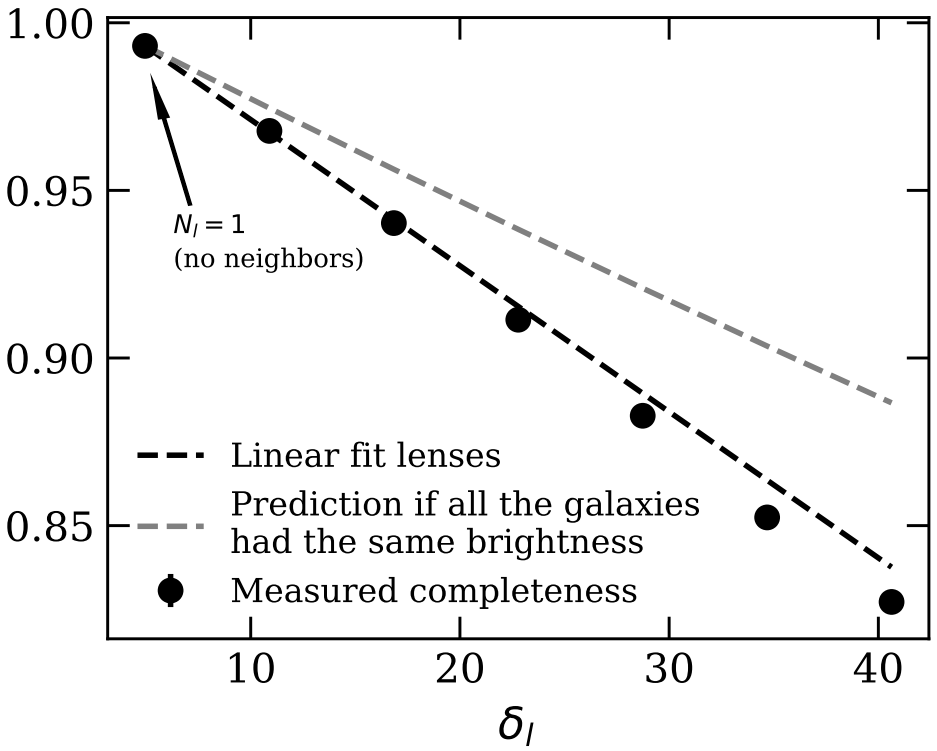

Light distribution at small scales (exclusion radius)

Intermediate smoothing scale

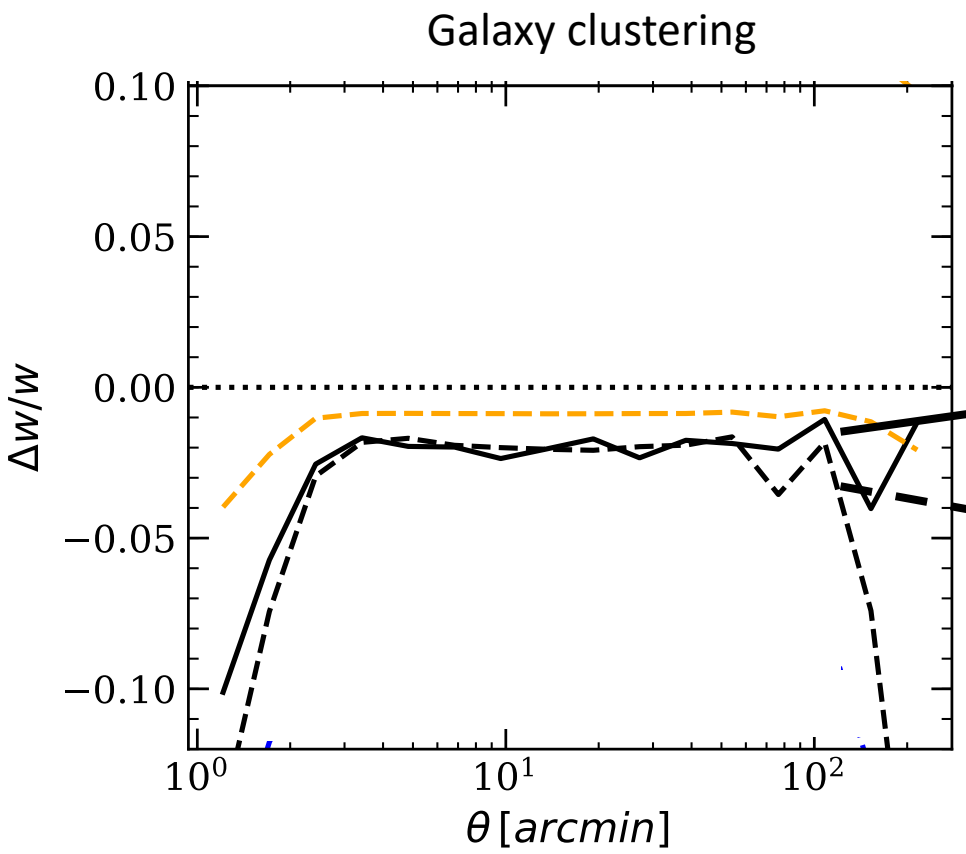
Observables at large scales

# Coupling between the neighbor bias and the density field

Probability of detecting a galaxy

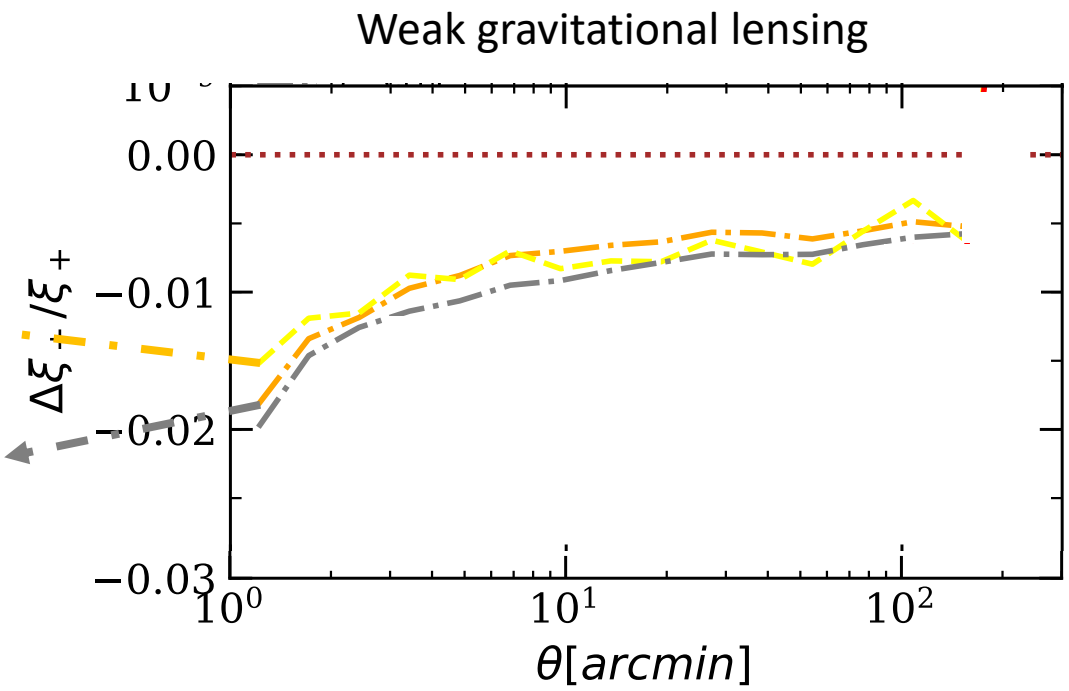


# Impact on cosmological observables




Measurements from mocks

Prediction from the analytical model



Amazon Web Services (AWS) - Cloud Computing Services

https://aws.amazon.com/

**Amazon Web Services** offers reliable, scalable, and inexpensive cloud computing services. Free to join, pay only for what you use.

Congratulations Albert Izard Alberich!

Your AWS promotional credits of $83,300 have now been added to your account

- I am the PI of the proposal *Simulating 1000 Universes*:
  - 2x1000 simulations of weak gravitational lensing
  - Total number of particles simulated: > 1 trillion!
  - 1Tb of final data products
  - State-of-the art in simulations for weak lensing covariance matrices.
  - Data sets publicly available.
  - Collaborations that will benefit from this: Euclid, WFIRST, LSST.

# Publications

- Co-author of:
  - Lippich M., et. al. (including **Izard A.**), *Comparing approximate methods for mock catalogues and covariance matrices I: correlation function*, 2018, MNRAS, 482, 1786-1806.
  - Blot L., et. al. (including **Izard A.**), *Comparing approximate methods for mock catalogues and covariance matrices II: Power spectrum multipoles*, 2018, MNRAS accepted, ArXiv: 1806.09497.
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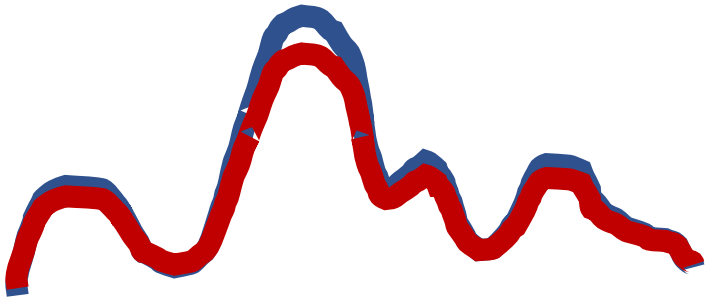
# Summary

- Euclid and WFIRST will be systematics limited
- I developed an efficient end-to-end pipeline for cosmological simulations
  - I developed a model for the neighbor bias.
  - Future missions will need to account for it.
  - Proposed solution: add a new parameter to describe its impact on cosmological observables.
- Simulating 1000 Universes in AWS: unique simulation suite of its kind