Systematic Biases in Weak Lensing Cosmology with the Dark Energy Survey

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Part 1: Preamble & Theory

Background: The Dark Energy Survey

- DES, KiDS & HSC represent the forefront of late-time observational cosmology
- Current generation (Stage-III) lensing surveys seek to constrain large-scale properties of dark energy and dark matter
- Forecast to bring a factor of 4 (or more) improvement in DE FOM

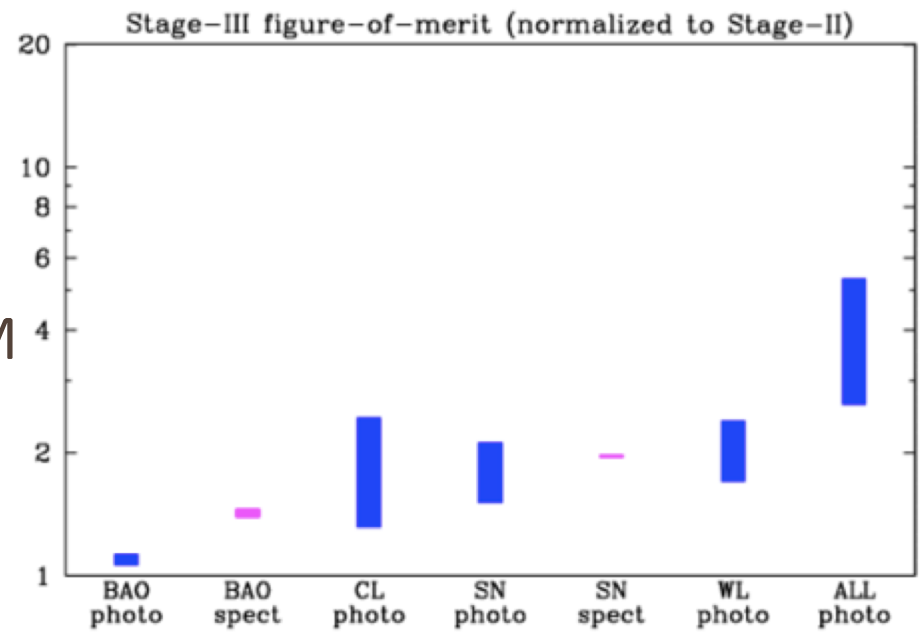
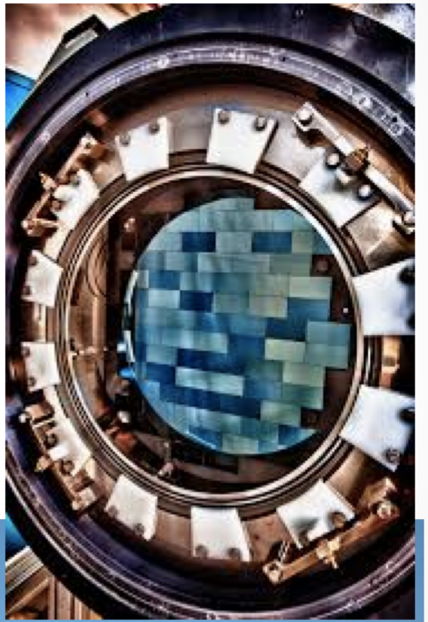


Figure credit: Albrecht et al 2006

The Dark Energy Survey in Numbers

- 4m Blanco Telescope at the Cerro Tololo Inter-American Observatory, Chile
- 5 photometric bands *grizY*
- 5 year observing period + 1 year of Science Verification (SV)
- 570 Mpix camera mounted on 5000 square deg. of the southern sky to r~24.1 mag, n_{gal}~10 arcmin^{-2}
- Approx. 3 sq. deg. field
- Partial overlap with COSMOS, SDSS, VVDS & VIMOS spectroscopic fields



Current Status of The Dark Energy Survey

- Data is now collected for all 5+1 years of observations, across 5000 square degree footprint
- The first set of Y1 analysis papers were submitted in August 2017 (~1300 sq. deg.)
- Work towards cosmology analysis from Y3 data currently ongoing

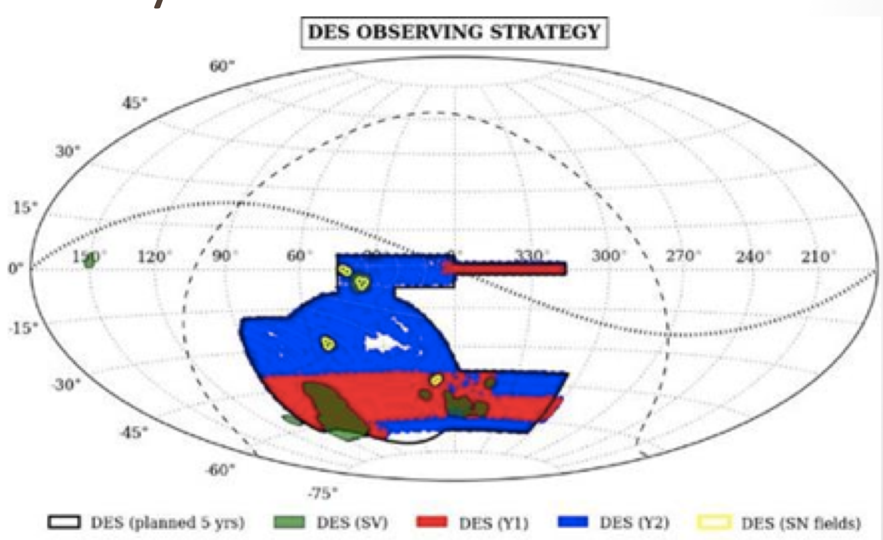
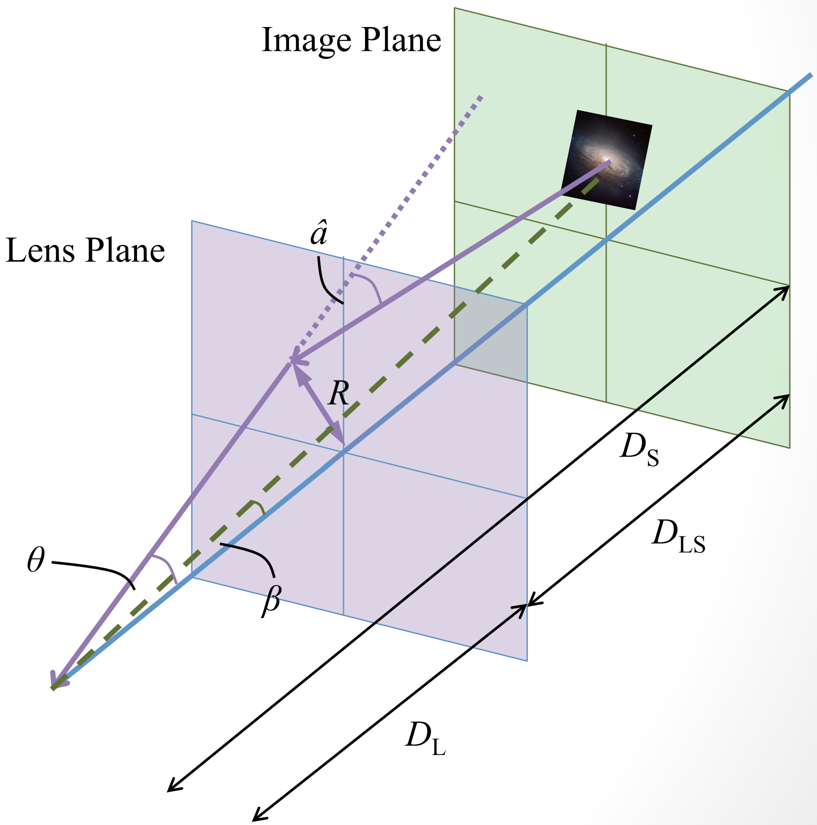


Figure credit: DES Collaboration 2016

Background: Weak Lensing as a Cosmological Probe

- Lensing has long been recognized as a 'clean' cosmological probe
- Toy model: rays from background galaxy deflected by a foreground lens plane

→ Sensitive to lens-source configuration (and thus the background geometry of the Universe)



Background: Weak Lensing as a Cosmological Probe

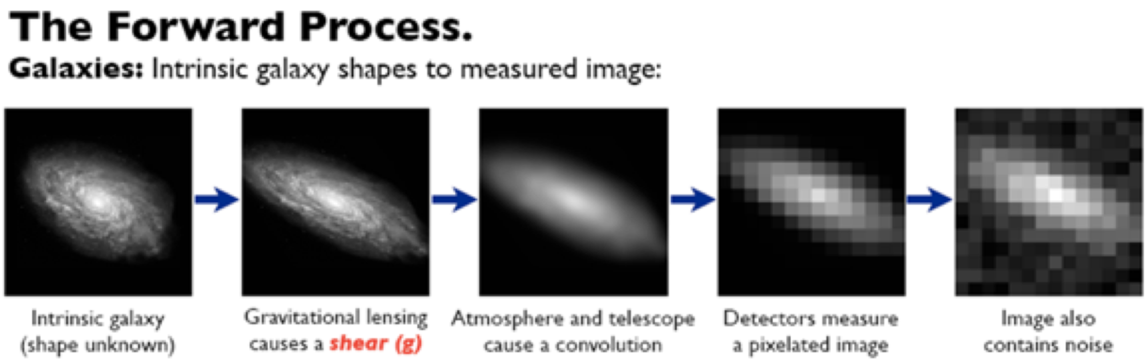
- One observes the Universe not through one lens, but many

→lensing occurs continuously along the line-of-sight as light travels from distant galaxies

→An effect known as "cosmic shear"

- Continuous cosmological lensing sensitive to the background properties of the Universe (e.g. the total mass density and level of structure at a given epoch)

Background: Weak Lensing as a Cosmological Probe



- Unfortunately the picture is more complicated!
- What we see as "galaxies" include the cumulative impact of

1. Pixelization
2. Atmospheric blurring
3. Pixel noise
4. + a tiny cosmological shear

→ Mapping measured galaxy shapes back to gravitational shear is a highly non-trivial observational task

Part 2: A Route to Cosmology - Accurate Shear Measurements from DES Y1

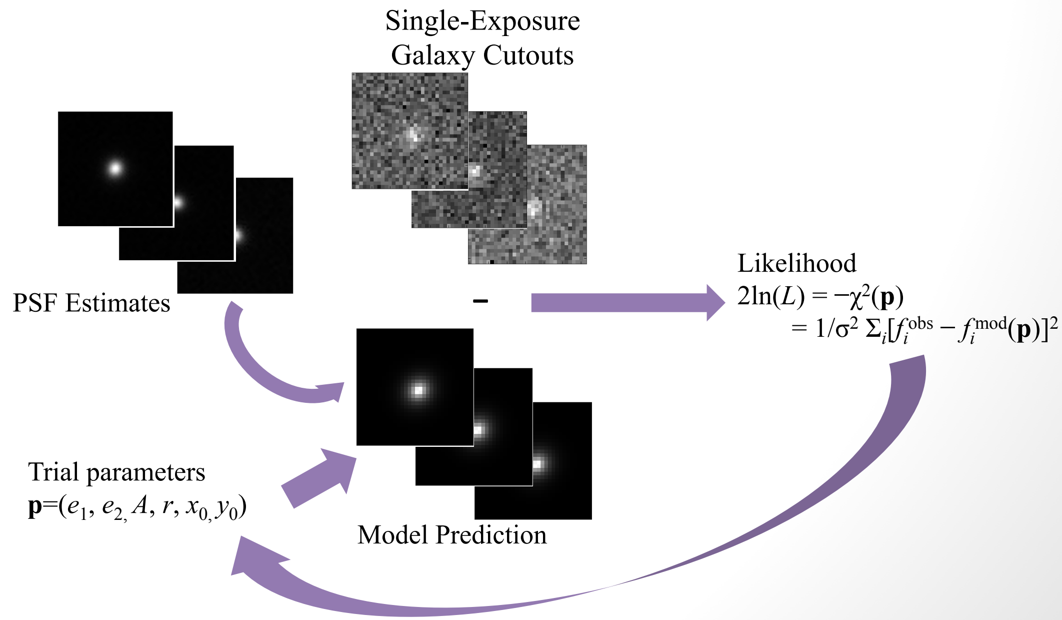
Zuntz, Sheldon, Samuroff et al 2017, arxiv.org/pdf/1708.01533.pdf

Measuring Galaxy Shapes with *im3shape*

Simple forward modeling approach to estimating a galaxy's shape:

1. Choose a set of trial values for galaxy params
2. Generate a model galaxy profile, convolve with measured PSF
3. Compare model with multi-epoch pixel data → Likelihood
4. Repeat until the likelihood converges

The maximum likelihood then gives a point estimate for the galaxy properties.

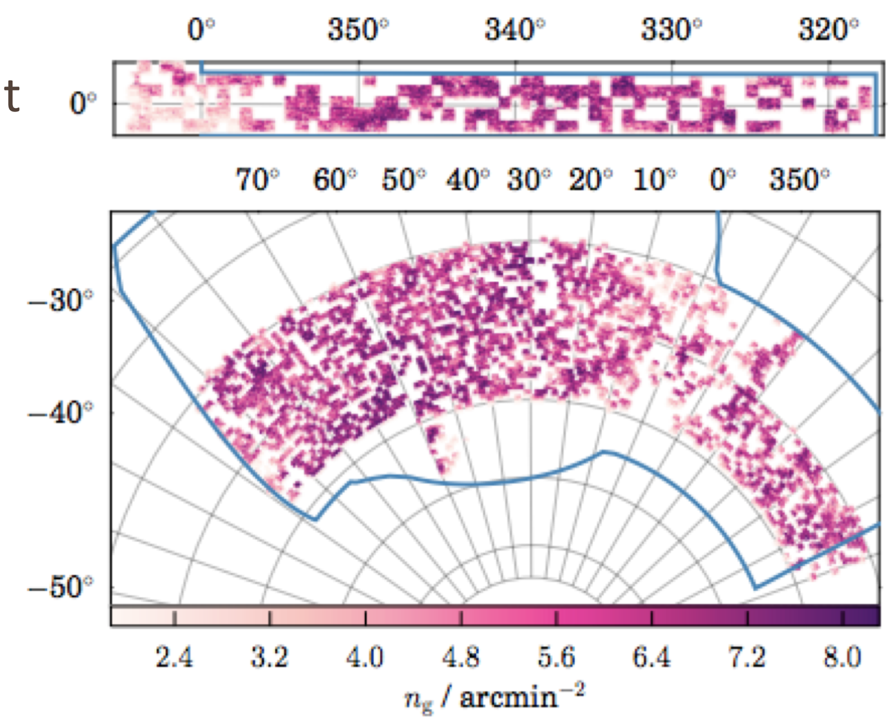


Simulating DES Y1: Method

Matched simulations built as follows:

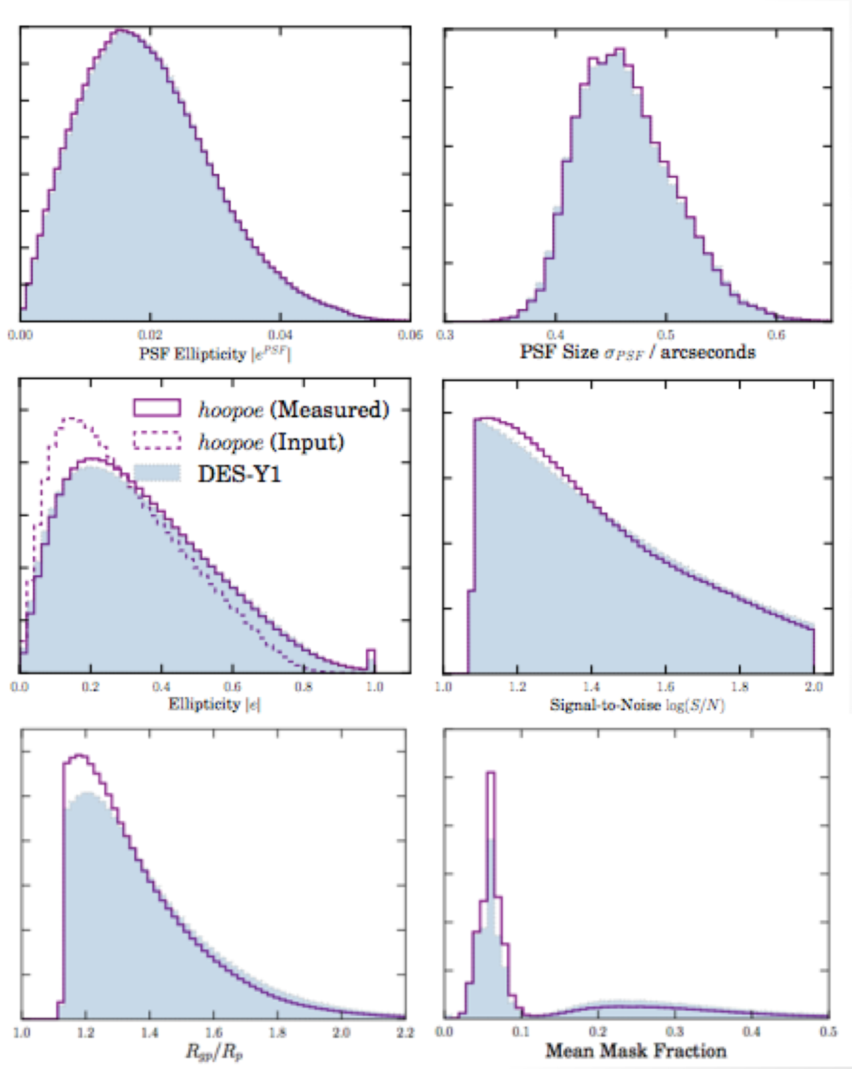
- Start with real survey images, create a set of blank mocks with the same masking, bad pixels etc.
- For every real galaxy detection, paste a synthetic galaxy profile into the mock images
- Add a random scatter of faint "sub-detection" objects
- Add Gaussian pixel noise

Rerun much of the image processing pipeline on the simulated images (from source detection to shape measurement)



Simulating DES Y1: Is it Right?

- First level of validation – compare observables with the real data
- Good match in most cases
- Small discrepancy in size vs. the data → tested by reweighting and shown to be inconsequential

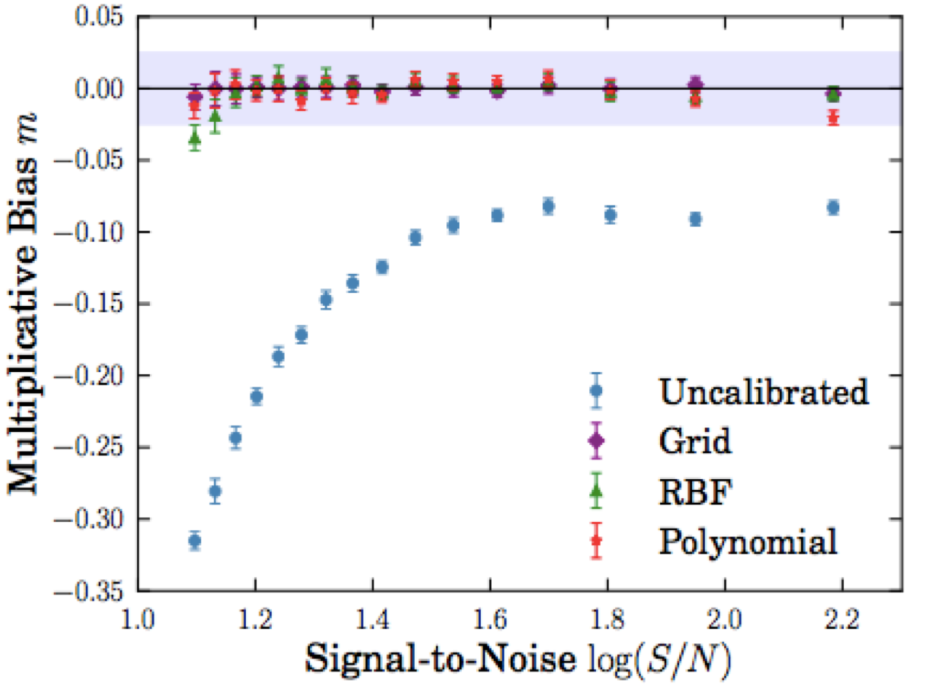


Calibrating DES Y1

- Bias is defined at the ensemble level in terms of additive and multiplicative terms: $\langle g \rangle = (1+m) \langle g^{tr} \rangle + c$
- Simulations used to build a map of bias as a function of measurement parameters (*S*/*N*, size)
- Used to devise a correction for each galaxy in DES

Testing the Calibration

- Split simulated catalogue randomly
- Derive calibration from one half and apply it to the other half
- Tests indicate catalogues are free from residual bias to within requirements for Y1 cosmology

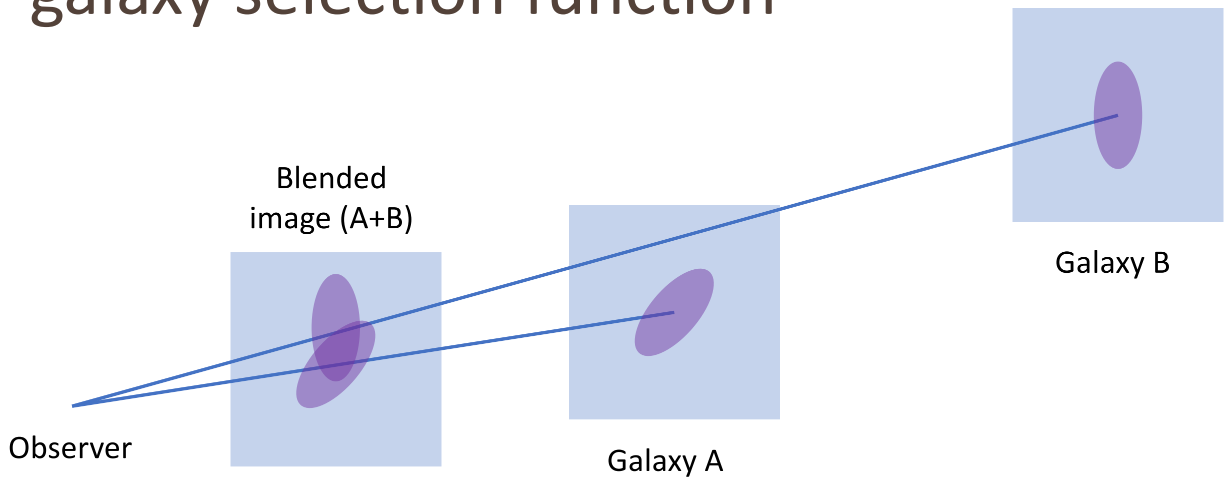


Part 3: The Impact of Neighbor Bias in DES Y1

Samuroff et al 2017 arxiv.org/abs/1708.01534

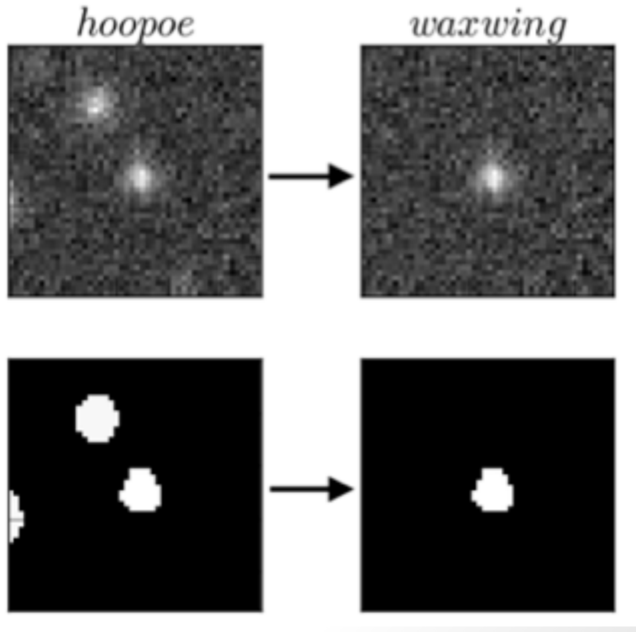
Basic Concept: Neighbor Bias

- Part of the shear bias is known to come from this effect
- Exact impact is heavily dependent on the details of the shape measurement and the galaxy selection function



Testing Neighbor Bias

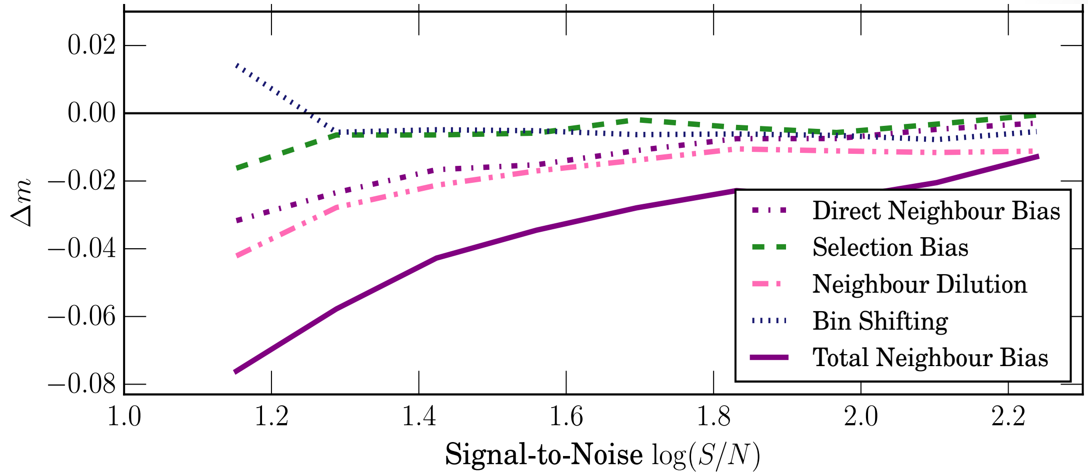
- We devised a set of spin-off simulations tailored to this question, "*Waxwing*"
- For each galaxy cutout from the main simulation, explicitly subtract off the light of neighboring galaxies
- Correct the masking
- Rerun shape measurement on the modified images



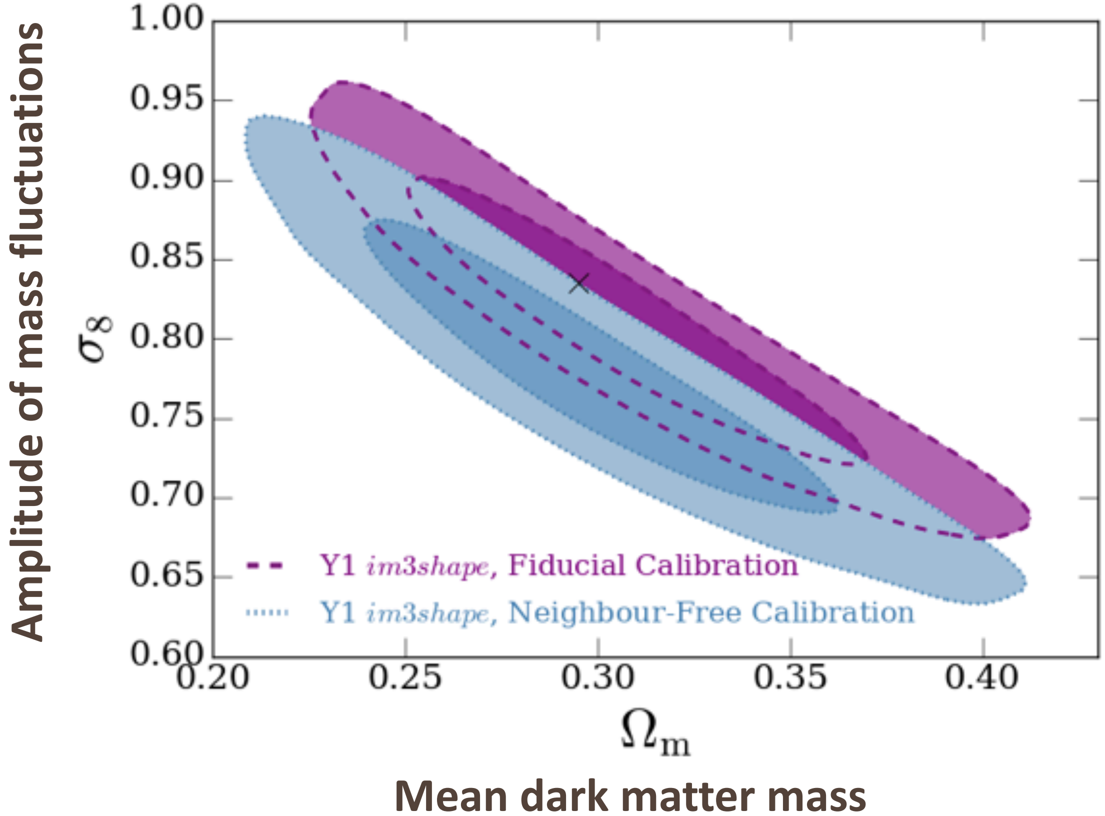
Understanding Neighbor Bias

Many competing mechanisms at work due to neighbors. Most notably:

1. **Direct bias**: the impact of contaminating light from nearby galaxies on the model fit
2. **Selection bias**: blending changes the galaxy selection function
3. **Neighbor dilution**: superimposing a close blend completely overrides a galaxy's shape
4. **Bin shifting**: galaxies are shifted in S/N and size by the influence of a neighbor.



The Cosmological Impact of Neighbor Bias



Blending is a highly non-trivial challenge for shear cosmology!

Conclusions

- Doing cosmic shear correctly is difficult, but not impossible!
- Shear biases of the level of <1% can corrected for, provided sufficient care is taken in simulating the data
- Blending is still a significant and complex challenge - the focus of much ongoing work
- Exciting time for lensing cosmology – new datasets will provide a significant test for methods developed for Stage III

Thank You