THE DARK ENERGY SURVEY

Carnegie Mellon University

# Intrinsic Alignments: Observational Constraints and Model Testing with the Dark Energy Survey

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# Background

# Intrinsic Alignments: Basics

$$\tilde{\gamma}^i = \gamma^i + \gamma_I^i$$

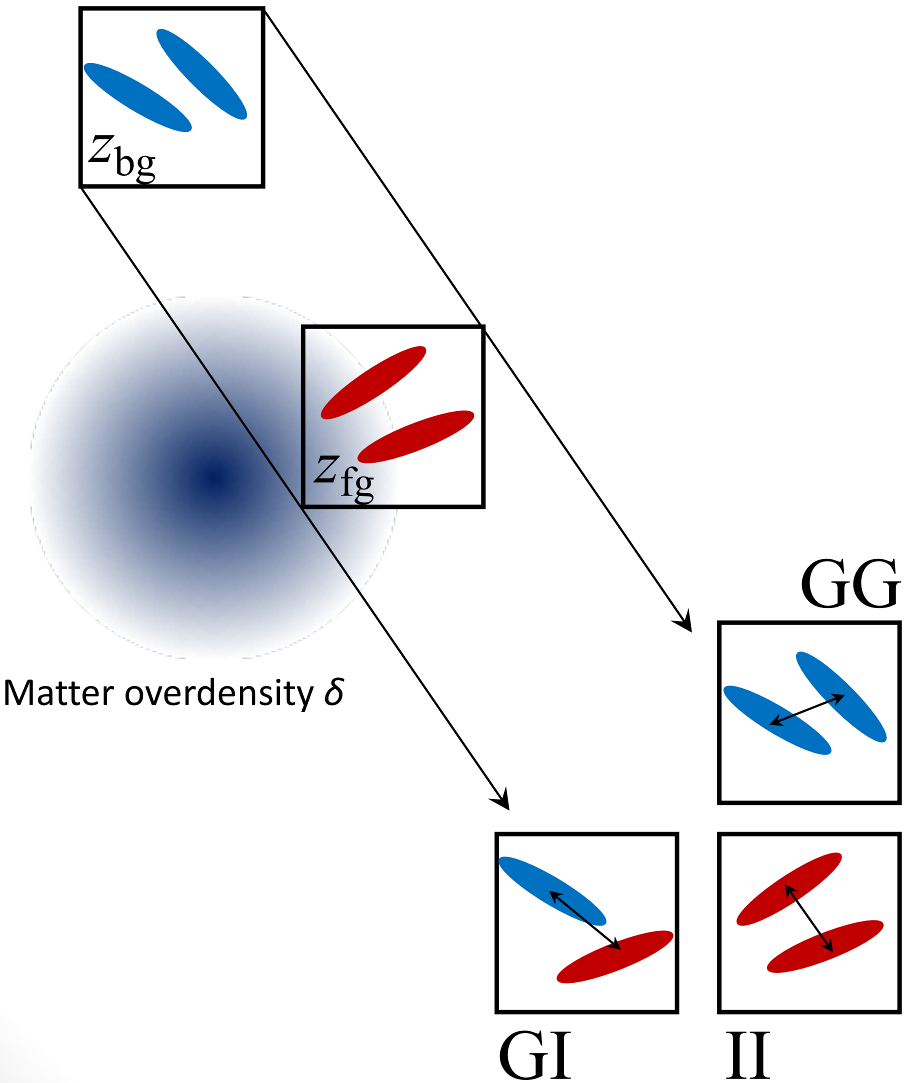
$$\left\langle \tilde{\gamma}^i \tilde{\gamma}^j \right\rangle = \left\langle \gamma^i \gamma^j \right\rangle + \left\langle \gamma_I^i \gamma^j \right\rangle + \left\langle \gamma^i \gamma_I^j \right\rangle + \left\langle \gamma_I^i \gamma_I^j \right\rangle$$

GG
(aka cosmic shear)

GI

II

# Intrinsic Alignments: Basics

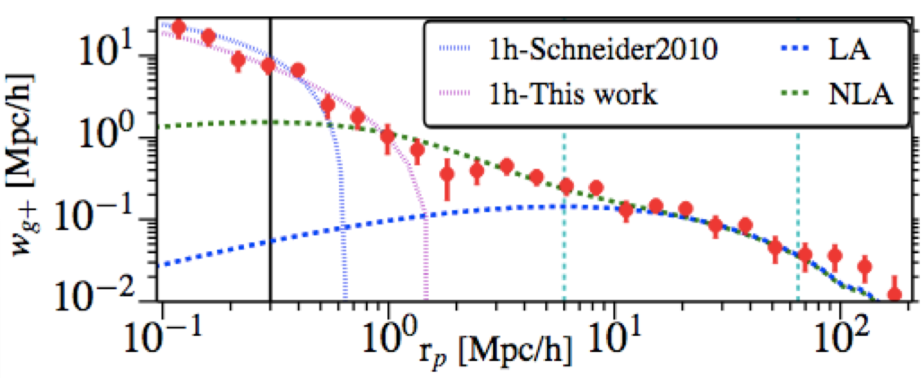



**Simple physical picture**:

- Background galaxies on the same line of sight lensed by the same (or correlated) foreground matter
  → GG correlations
- Foreground galaxies' shapes become correlated with the common background tidal field
  → II correlations
- Background galaxies lensed and foreground galaxies locally interact with matter overdensities
  → GI correlations

# The Current State of the Field

- Commonly used model based on linear galaxy alignments
- Observations show it works well on large scales and in low redshift, bright, red populations
- Small scale IAs relatively poorly understood
- Evidence to support extending to blue/faint/right redshift galaxies much weaker



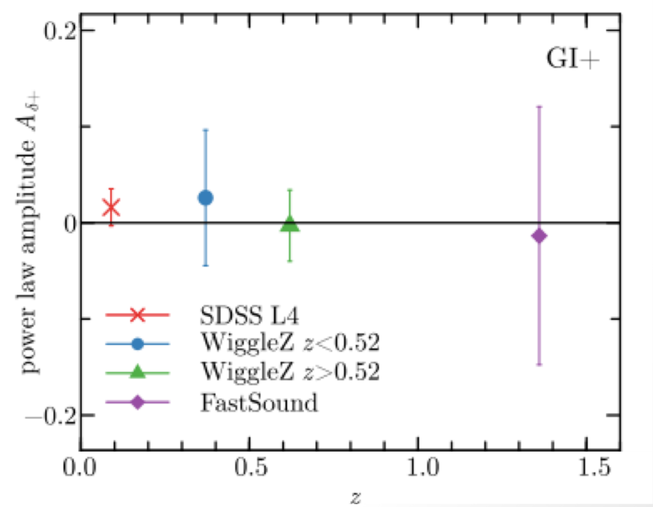




Figure credits: *Singh et al 2016* (left) & *Tonegawa et al 2016* (right)

# The Current State of the Field

- Modern studies of cosmic shear (including combined probes) MUST mitigate intrinsic alignments → ignoring them isn't an option (see figure below)
- Several different methods have been proposed for mitigating IAs directly (see e.g. *Joachimi & Schneider* 2010, *Yao* et al 2018)
- Standard approach to model & marginalize - most commonly NLA (sometimes with redshift or luminosity power law)

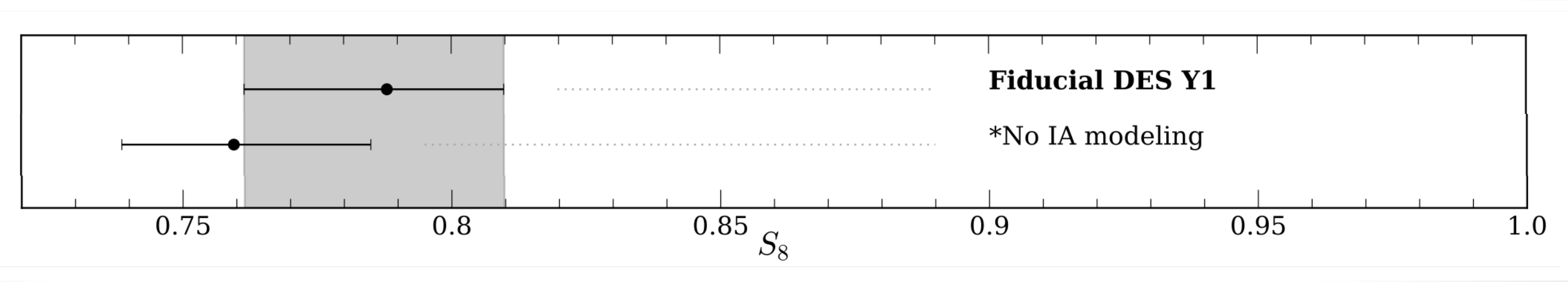



Figure credit: *Troxel et al 2017*

# Results

# Setup

- Set out to test/constrain our current best IA modelling using DES Y1 data
  → colour-split reanalysis of Y1 aimed at studying differences in intrinsic alignments (see *SS et al* https://arxiv.org/abs/1811.06989)
- Take main 3x2pt analysis (*DES Collab. 2017, Krause et al 2017*) as baseline for analysis choices
- All results based on the Y1 *Metacalibration* cosmology sample (~26 M galaxies over 1321 sq. degrees at ~5 gal/arcmin$^2$)

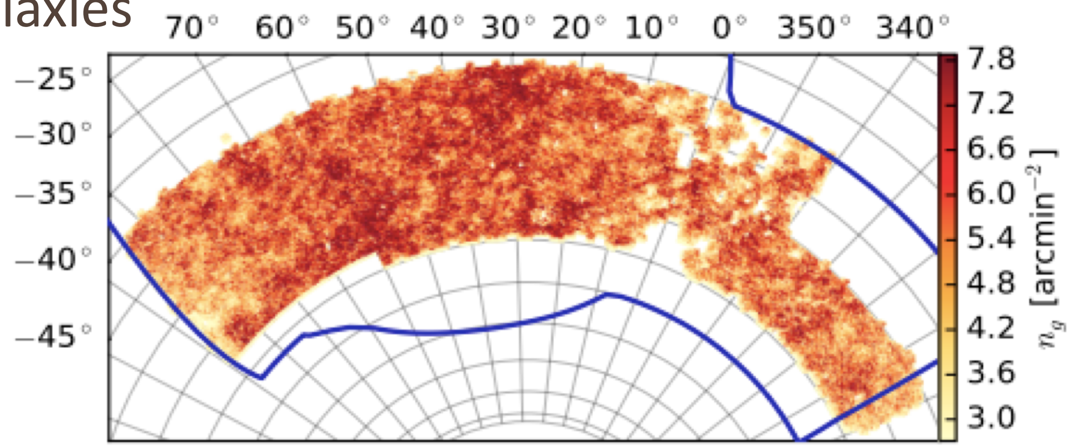
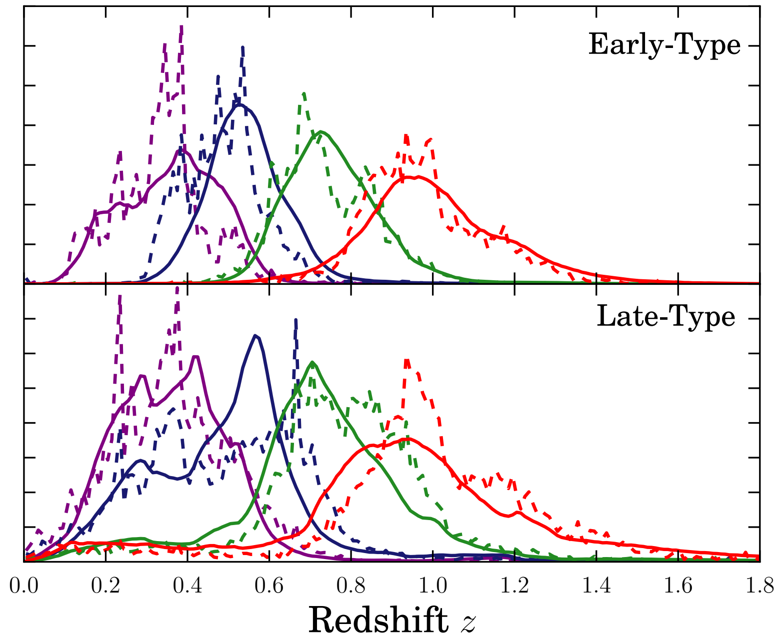



Figure credit: *Troxel et al 2017*

# Defining 'Red' & 'Blue'

- Catalogue-level split applied to source sample (lenses unsplit see *Elvin-Poole et al 2017*)
- Fiducial split based on best fitting SED type from BPZ (c.f. *Heymans et al 2013*)
- Global red fraction $f_R$~0.18, declining at higher $z$



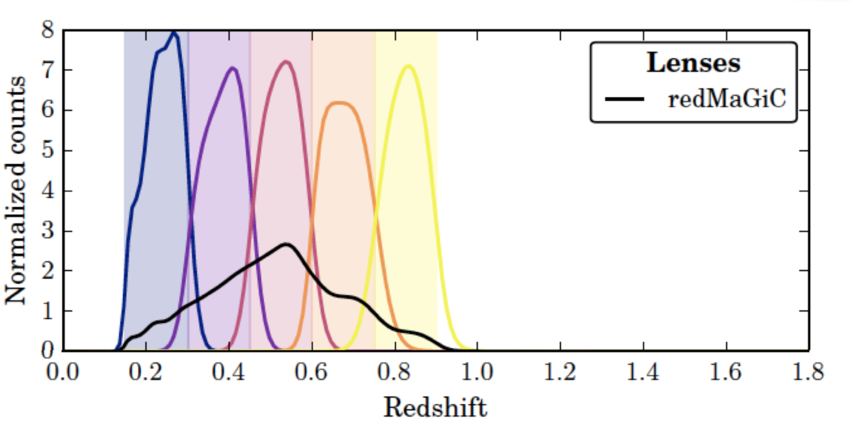
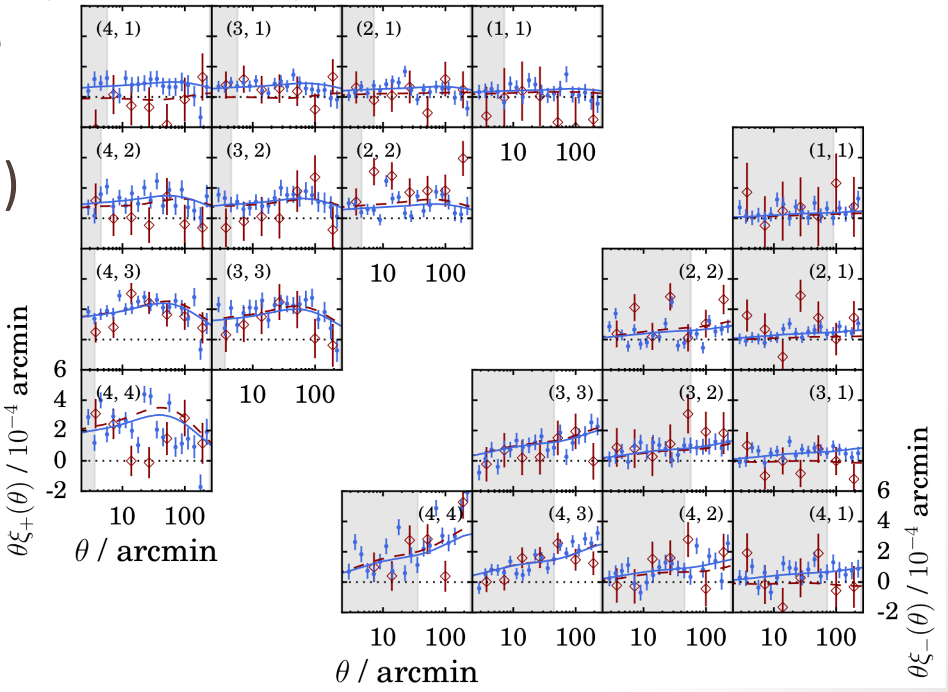




Figure credit: *Elvin-Poole et al 2017* (right)

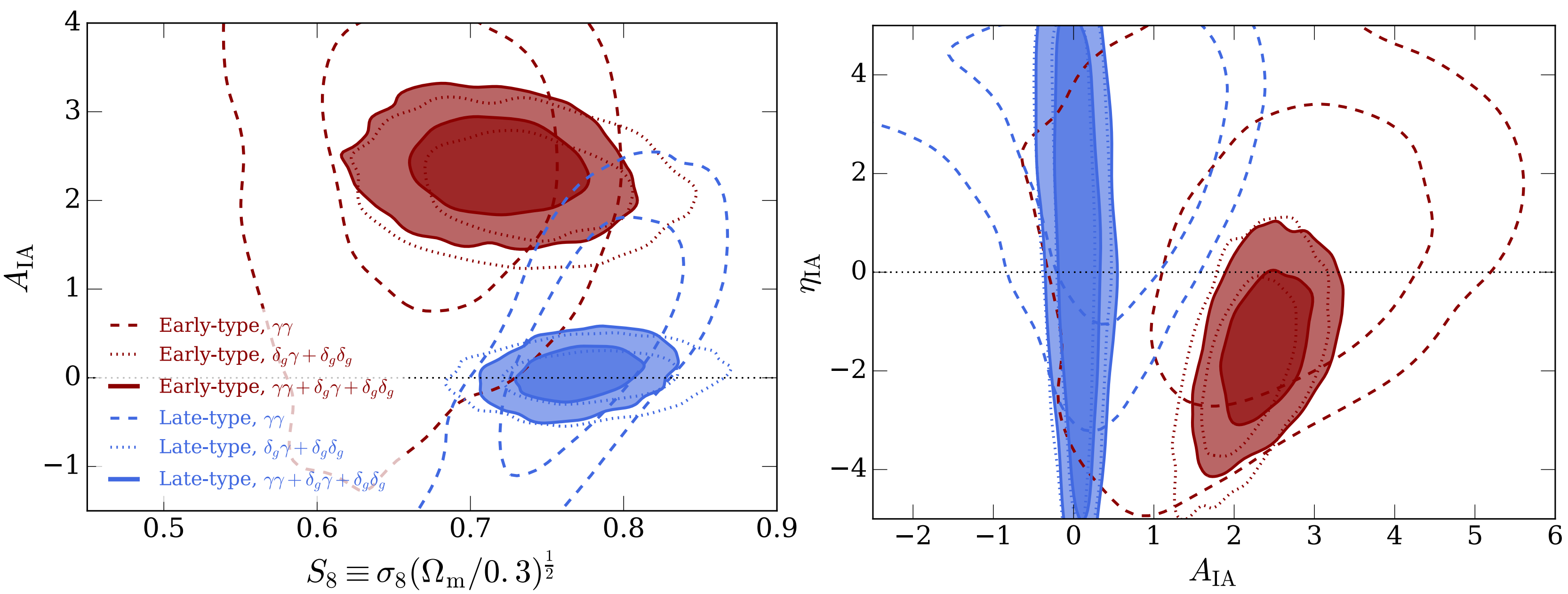
# Measurements

- Measure red/blue shear & galaxy-galaxy lensing correlations
- Re-stack redshift distributions and recalibrate using COSMOS
- Recalibrate red/blue shapes after split
- Recompute covariance matrix (including non Gaussian contributions) using new $n(z)$ and no. densities



# Fitting the NLA Model

- For baseline analysis use NLA + $z$ power law (c.f. *Troxel et al 2017, DES Collab. 2017*)
- Blue galaxies consistent with zero alignments
- Red galaxies positively aligned at ~5$\sigma$
- Tentative evidence of $z$ dependence in red galaxies

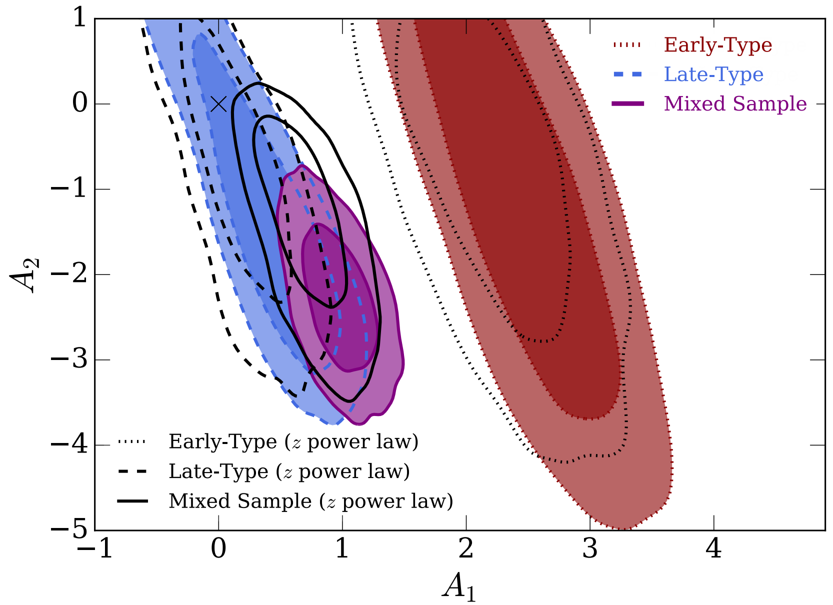


# Fitting the TATT Model

- Fit a more complex model, based on perturbation theory (*see Blazek et al 2017*)
- TATT model includes linear (tidal alignment) and quadratic (tidal torque) terms

$$\gamma_{ij}^{I} = C_1 s_{ij} + C_2 \left( s_{ik} s_{kj} - \frac{1}{3} s^2 \right) + C_{1\delta} \left( \delta s_{ij} \right) + \cdots$$

- Negative $A_2$ consistent with *Troxel et al 2017*



# Including Cross Correlations

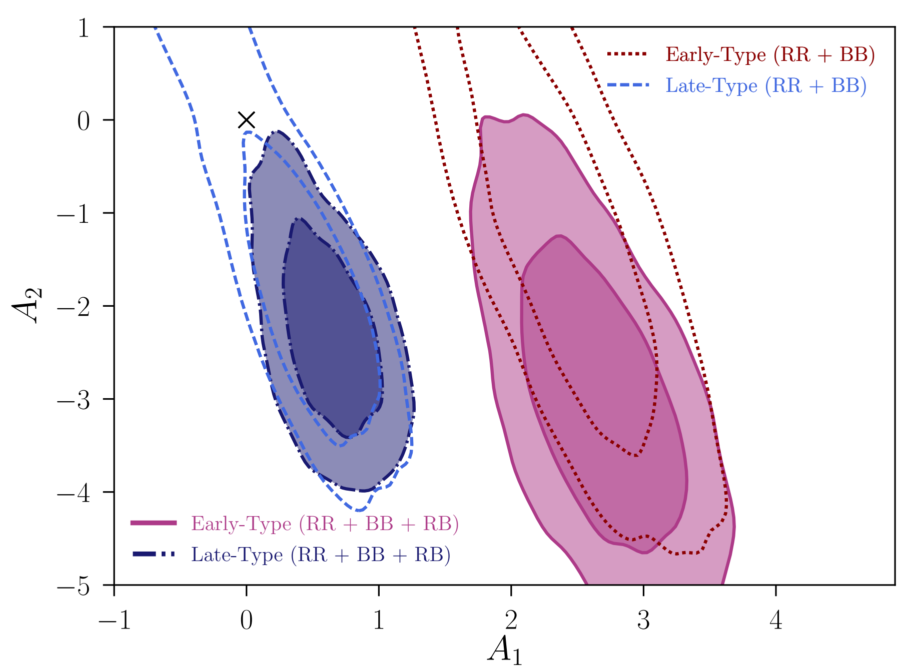
With two colour samples (plus a lens catalogue) we can form six possible two-point correlations:

$$\gamma\gamma \quad \gamma\gamma \quad \gamma\gamma \quad \delta_g\gamma \quad \delta_g\gamma \quad \delta_g\delta_g$$

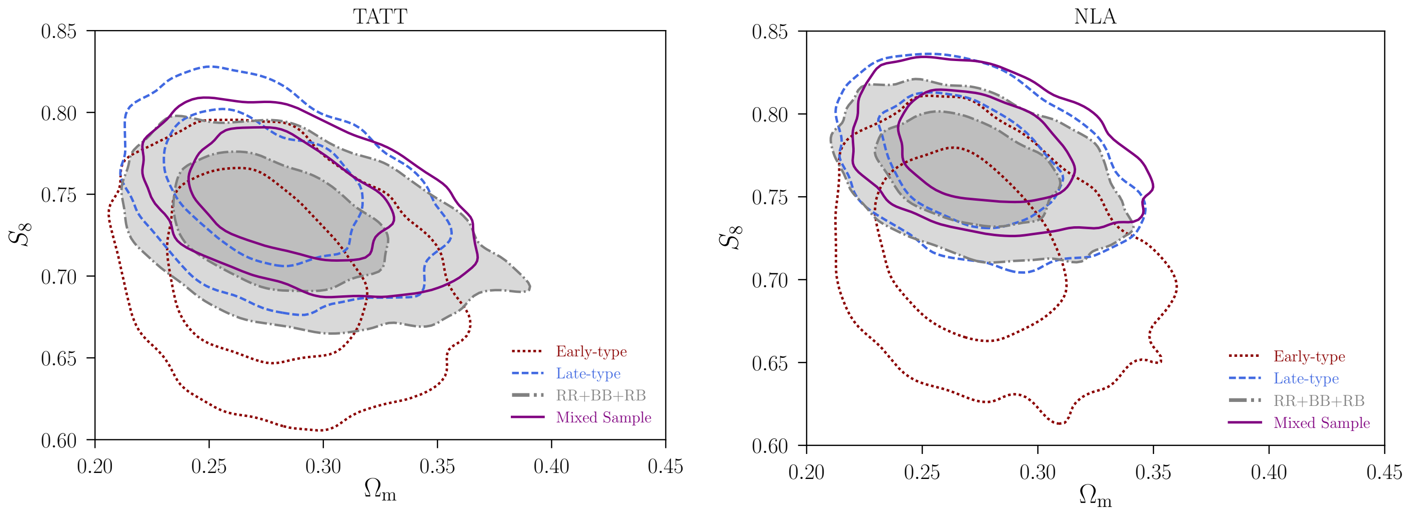
- Red-red and blue-blue correlations analysed (separately) in exclusive split chains
- Now we also include the red-blue shear-shear correlations $\xi_{+/-}$
- Recompute covariance matrix for multicolour data

# A Simultaneous Red/Blue Analysis

- Significant additional information on quadratic alignment amplitude in red-blue cross correlations
- Combined analysis suggests significant non-zero IA amplitudes in blue sample:
    - Negative $A_2$ (implies tangential alignment relative to matter overdensities)
    - Mild positive $A_1$



# Impact on Cosmology




- Switching NLA → TATT shifts $S_8$ down in blue and unsplit samples
- For both IA modelling scenarios, switching from unsplit → simultaneous multicolour shifts $S_8$ down by a similar increment

# Conclusions

- Presented a colour split analysis of DES Y1, in which we fit cosmology + IAs simultaneously on “red” and “blue” 3x2pt samples
- Cosmological results consistent with fiducial unsplit analysis (though we did see sub-sigma shifts)
- NLA fits suggest $A_{IA}$=2.5 in red galaxies, consistent with zero in blue sample
- New constraints on extended IA model, with the first marginal detection of non-zero alignments in a sample of blue galaxies


Thank You!

# Splitting the DES Y1 Metacal Catalogue

- Selection effects handled naturally in fiducial shear catalogue
- *Metacalibration* works by remeasuring ellipticity on sheared copies of each galaxy (see *Huff & Mandelbaum 2017, Sheldon & Huff 2017*)
- Each galaxy has an (albeit noisy) response component, due *only* to selection:

$$\langle \boldsymbol{R_S} \rangle_{i,j} \approx \frac{\langle e_i \rangle^{S+} - \langle e_i \rangle^{S-}}{\Delta \gamma_j},$$

→ Bias due to an additional selection (e.g. on colour) can be corrected *if* the selection can repeated on the sheared images

# Analysis Choices

- Always vary 6 cosmological parameters + nuisance parameters
- Baseline priors unchanged relative to *Krause et al 2017*

| Parameter | Prior |
|---|---|
| **Cosmology** | |
| $\Omega_m$ | flat (0.1, 0.9) |
| $A_s$ | flat $(5\times10^{-10}, 5\times10^{-9})$ |
| $n_s$ | flat (0.87, 1.07) |
| $\Omega_b$ | flat (0.03, 0.07) |
| $h$ | flat (0.55, 0.91) |
| $\Omega_\nu h^2$ | flat$(5\times10^{-4}, 10^{-2})$ |
| $w$ | flat $(-2, -0.33)$ |
| **Lens Galaxy Bias** | |
| $b_i(i=1,5)$ | flat (0.8, 3.0) |
| **Intrinsic Alignment** | |
| $A_{\rm IA}(z) = A_{\rm IA}[(1+z)/1.62]^{\eta_{\rm IA}}$ | |
| $A_{\rm IA}$ | flat $(-5, 5)$ |
| $\eta_{\rm IA}$ | flat $(-5, 5)$ |
| **Lens photo-$z$ shift (red sequence)** | |
| $\Delta z_l^1$ | Gauss (0.001, 0.008) |
| $\Delta z_l^2$ | Gauss (0.002, 0.007) |
| $\Delta z_l^3$ | Gauss (0.001, 0.007) |
| $\Delta z_l^4$ | Gauss (0.003, 0.01) |
| $\Delta z_l^5$ | Gauss (0.0, 0.01) |
| **Shear calibration** | |
| $m^i_{\rm METACALIBRATION}(i=1,4)$ | Gauss (0.012, 0.023) |

| Selection | $\delta z^{(1)}$ | $\delta z^{(2)}$ | $\delta z^{(3)}$ | $\delta z^{(4)}$ |
|---|---|---|---|---|
| All Galaxies | $-0.006 \pm 0.018$ | $-0.014 \pm 0.018$ | $0.018 \pm 0.017$ | $-0.018 \pm 0.018$ |
| Early-Type | $-0.022 \pm 0.020$ | $-0.040 \pm 0.012$ | $-0.008 \pm 0.012$ | $-0.044 \pm 0.014$ |
| Late-Type | $-0.003 \pm 0.020$ | $-0.007 \pm 0.023$ | $0.030 \pm 0.020$ | $-0.010 \pm 0.023$ |