# Combining Probes
# to Detect and Correct Systematics

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Cosmic Frontiers Workshop, SLAC, 3/6/13

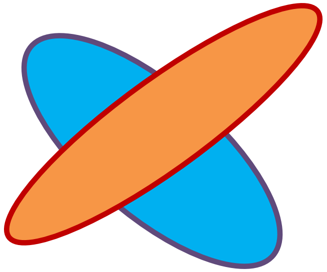
# Systematic error detection

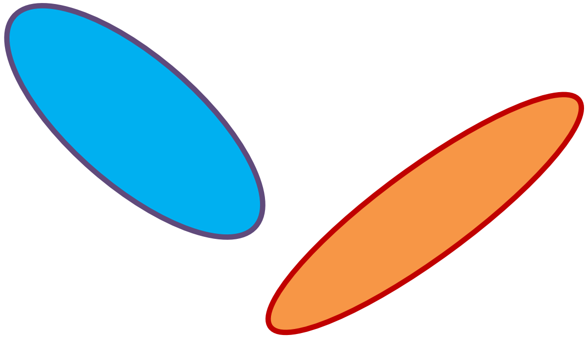
Simple, commonly-used test of systematics or new physics:

Estimate parameters separately for each probe,
then check whether they agree.

Can be difficult to interpret results:

**overlapping contours:**
- could be cancellation between multiple systematics and/or model extensions
- might result from projection to 1D/2D (e.g. Shapiro et al. 2010)

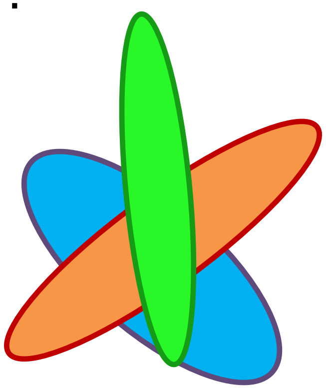




**tension between probes:**
- cause of tension may be unclear
- need high significance to be convinced that there actually is a problem

More information can help resolve ambiguity:

Cross-checks with additional probes

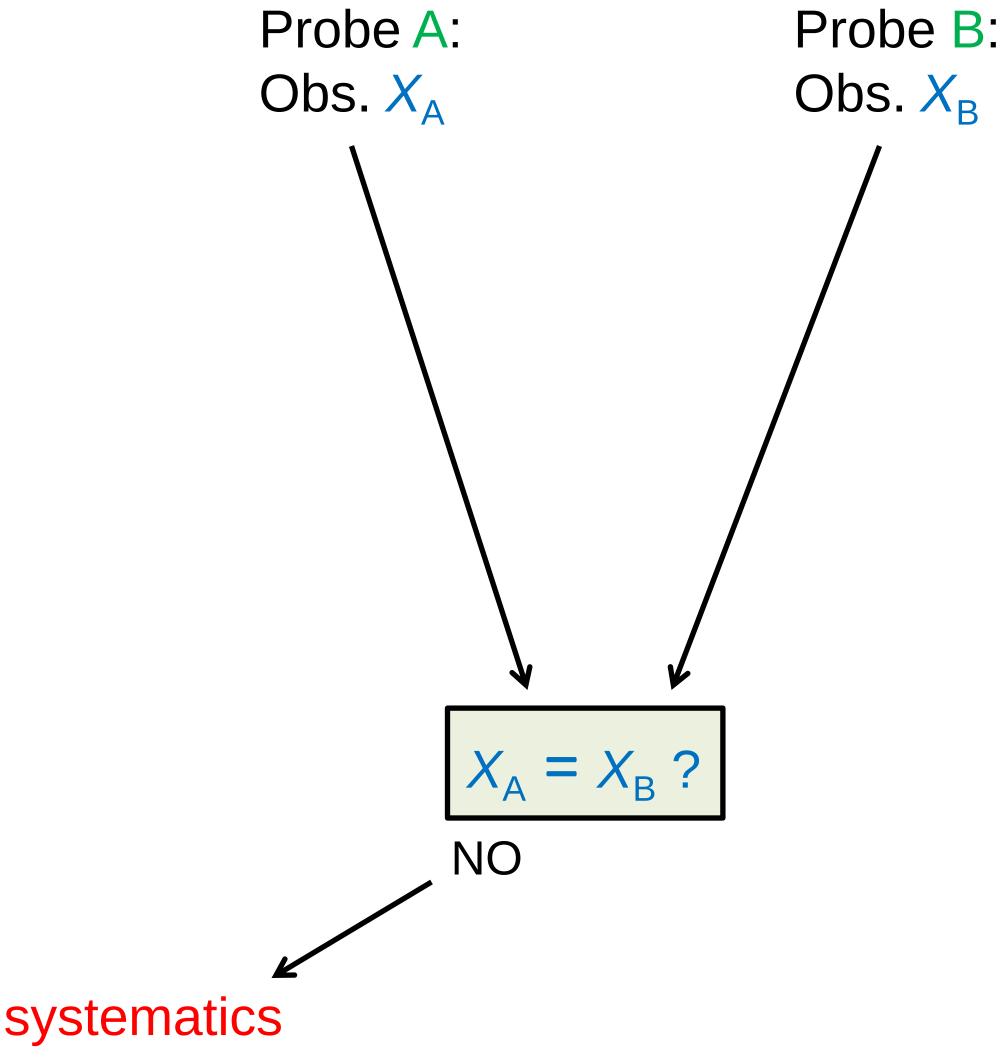


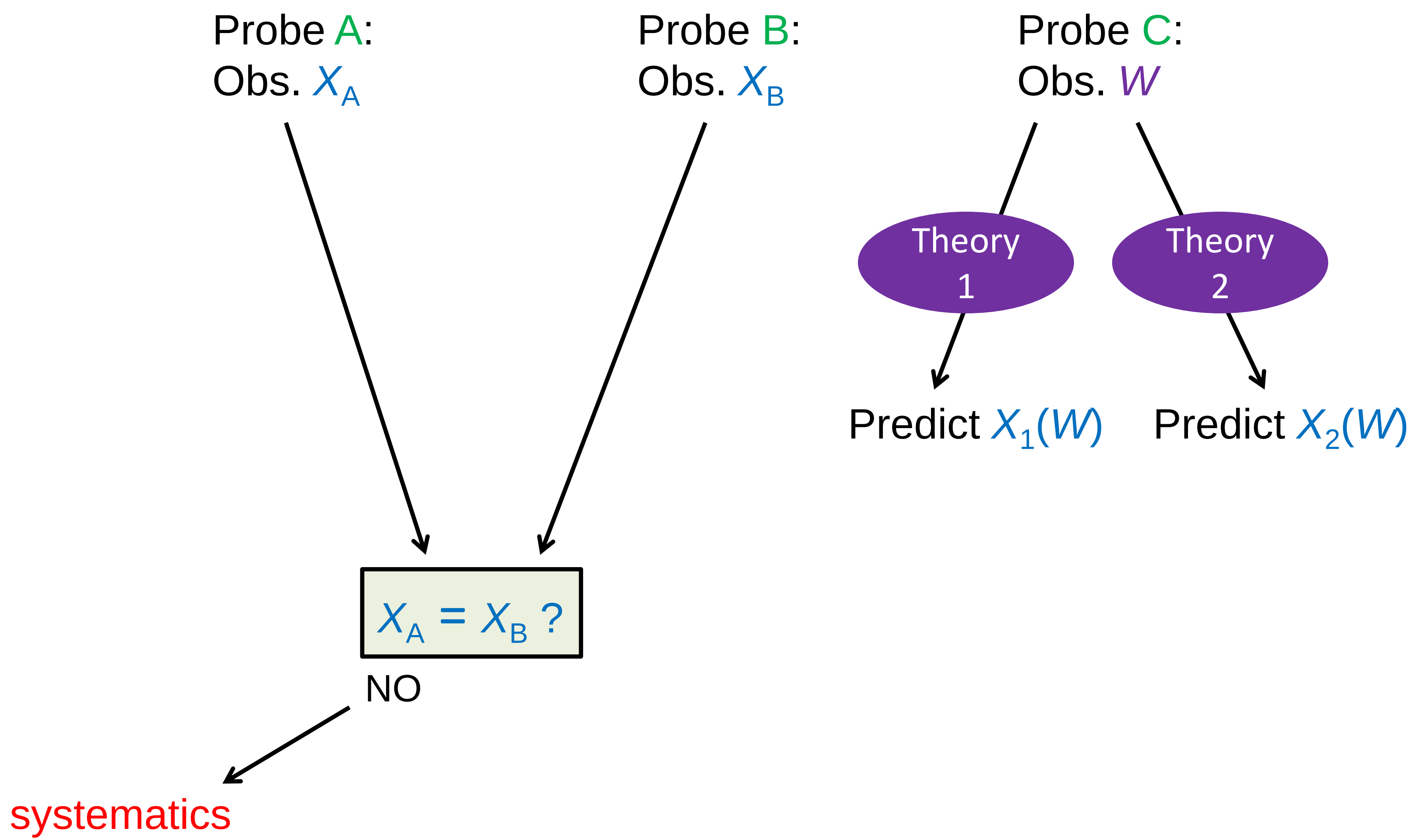
Split samples in “bins” of some quantity, and check for consistency bin-by-bin

e.g., look at dependence on redshift, angular or physical scale, mass, luminosity, color, etc.

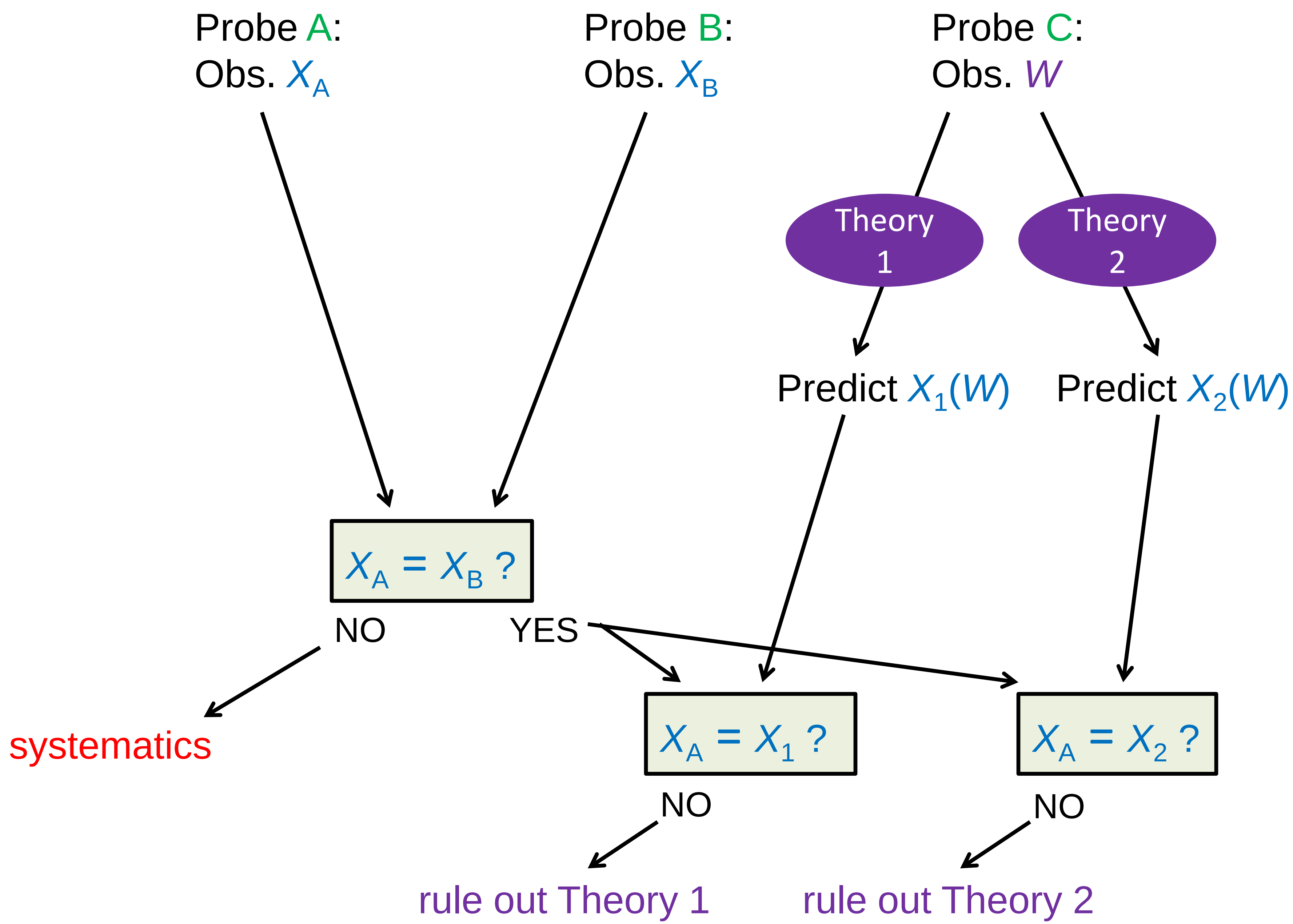
To test theories and systematics at the same time, it’s helpful to use a model-independent quantity for comparisons between probes.

e.g., distance vs. redshift, growth function/rate, ...


Probe A:
Obs. $X_A$
Probe B:
Obs. $X_B$
$X_A = X_B$ ?
NO
systematics



Probe A:
Obs. $X_A$
Probe B:
Obs. $X_B$
Probe C:
Obs. $W$
Theory 1
Theory 2
Predict $X_1(W)$
Predict $X_2(W)$
$X_A = X_B$ ?
NO
systematics



Probe A:
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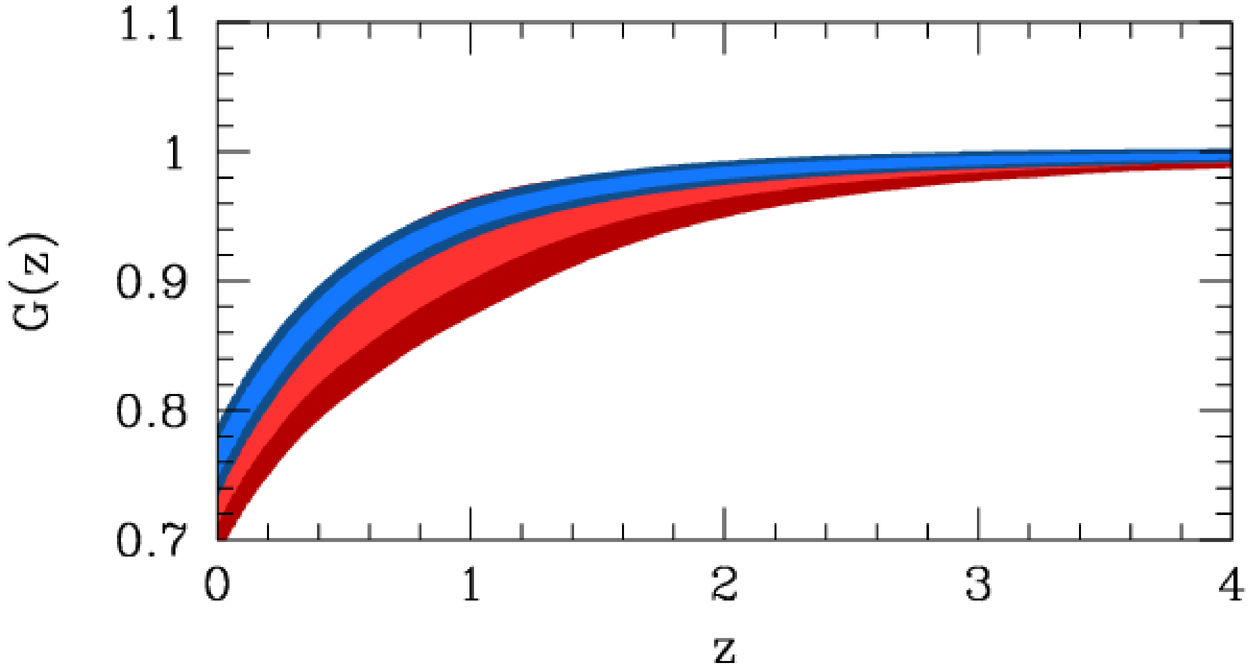
Probe B:
Obs. $X_B$
Probe C:
Obs. $W$
Theory 1
Theory 2
Predict $X_1(W)$
Predict $X_2(W)$
$X_A = X_B$ ?
NO
YES
systematics
$X_A = X_1$ ?
$X_A = X_2$ ?
NO
NO
rule out Theory 1
rule out Theory 2

# Example: Growth predicted by BAO+SN+CMB




ΛCDM

quintessence

(68 / 95% CL)

Mortonson et al. (2009, 2010)
cluster predictions: Mortonson et al. (2011)
WL predictions: Vanderveld et al. (2012)

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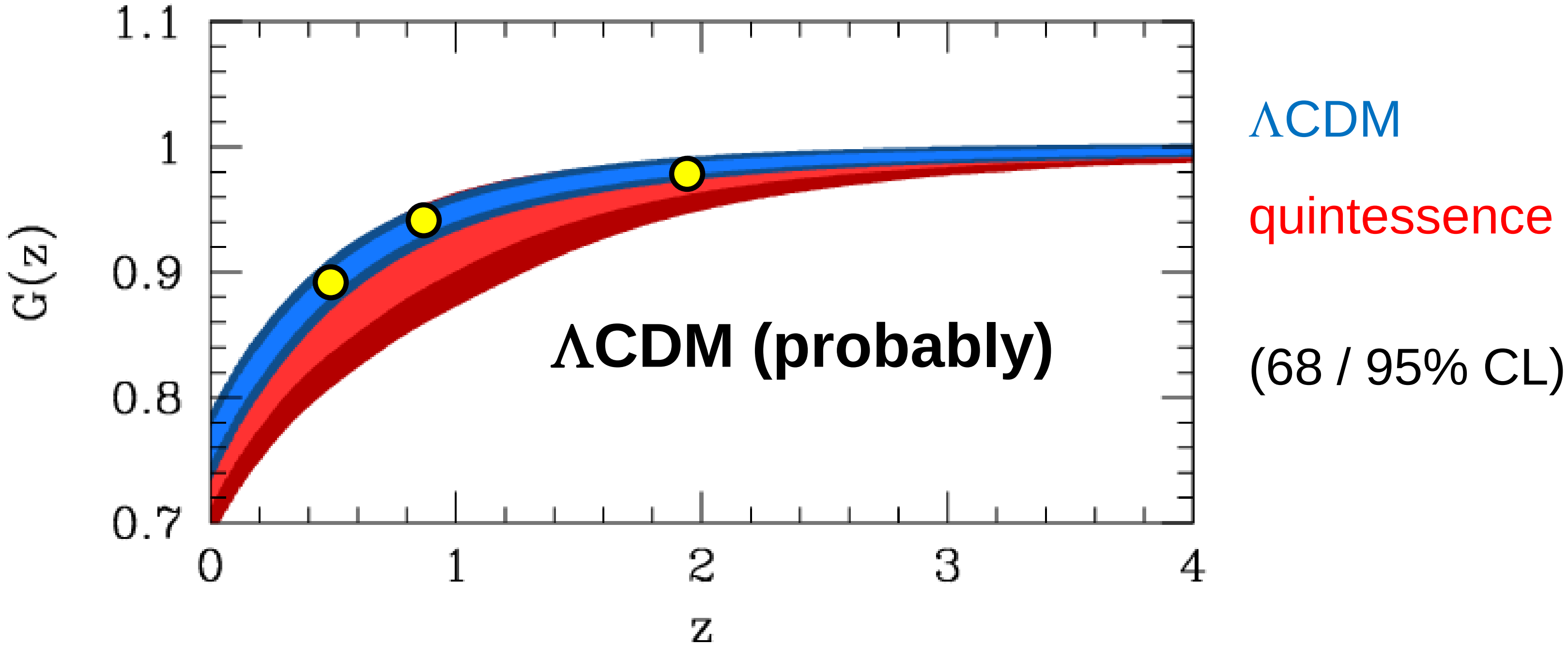


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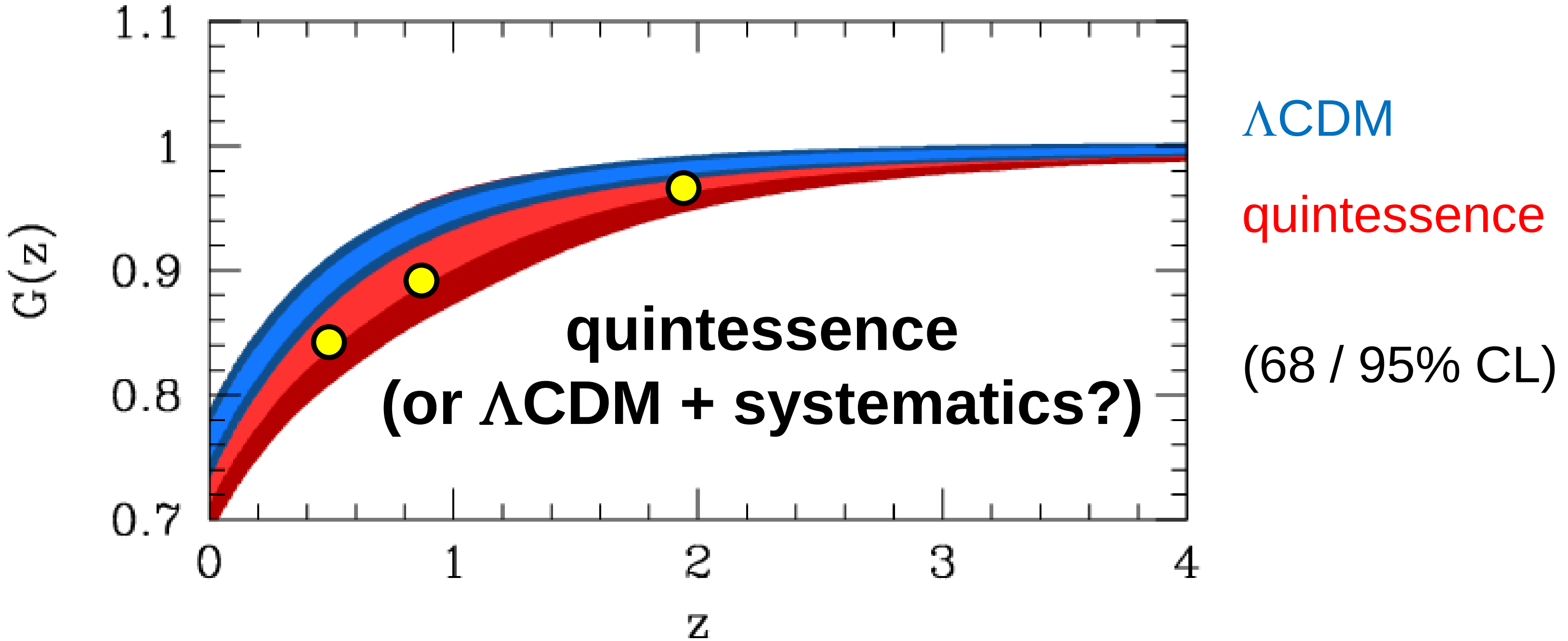


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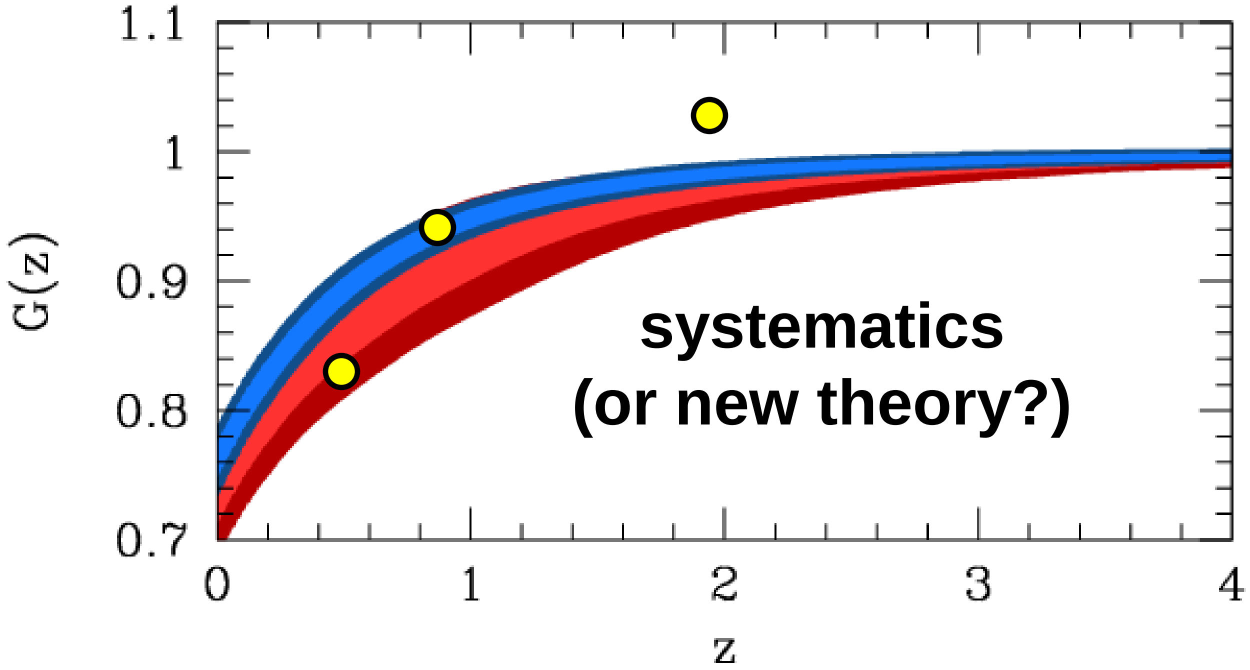


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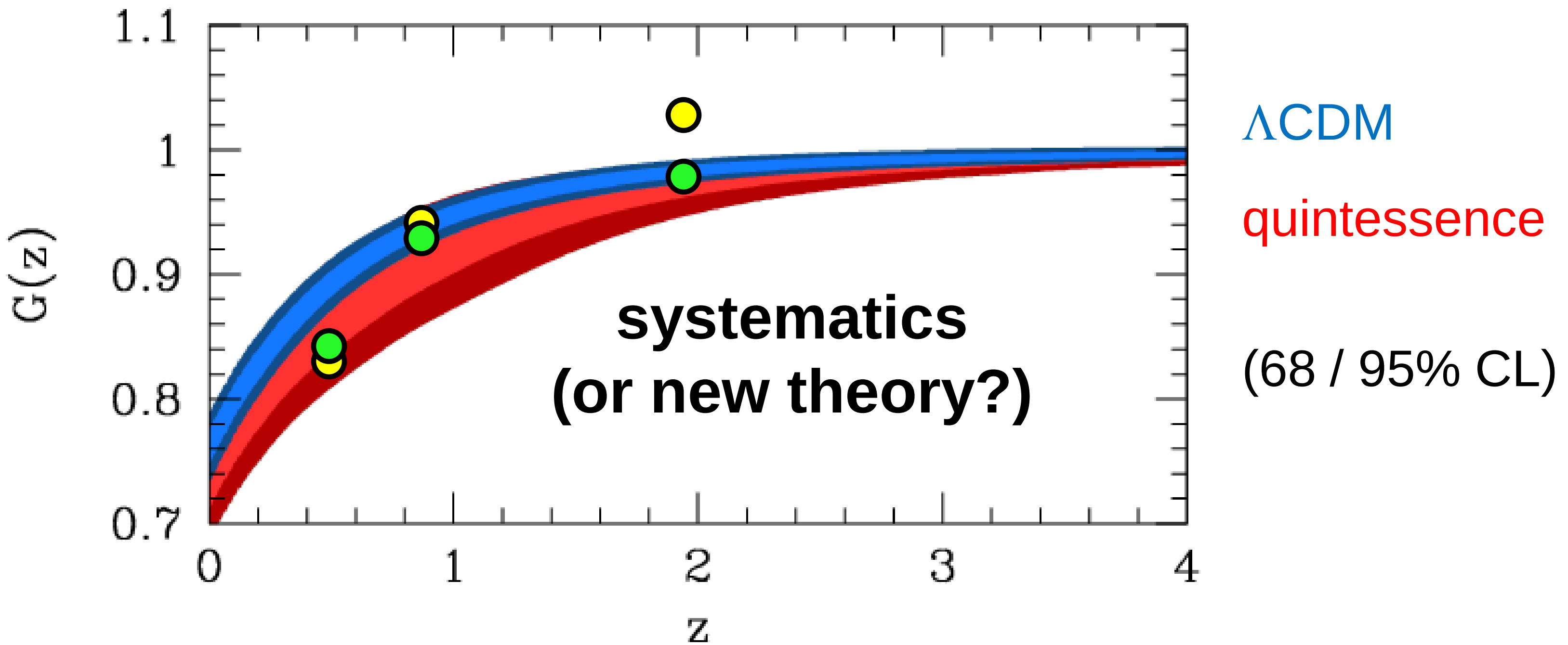


Mortonson et al. (2009, 2010)
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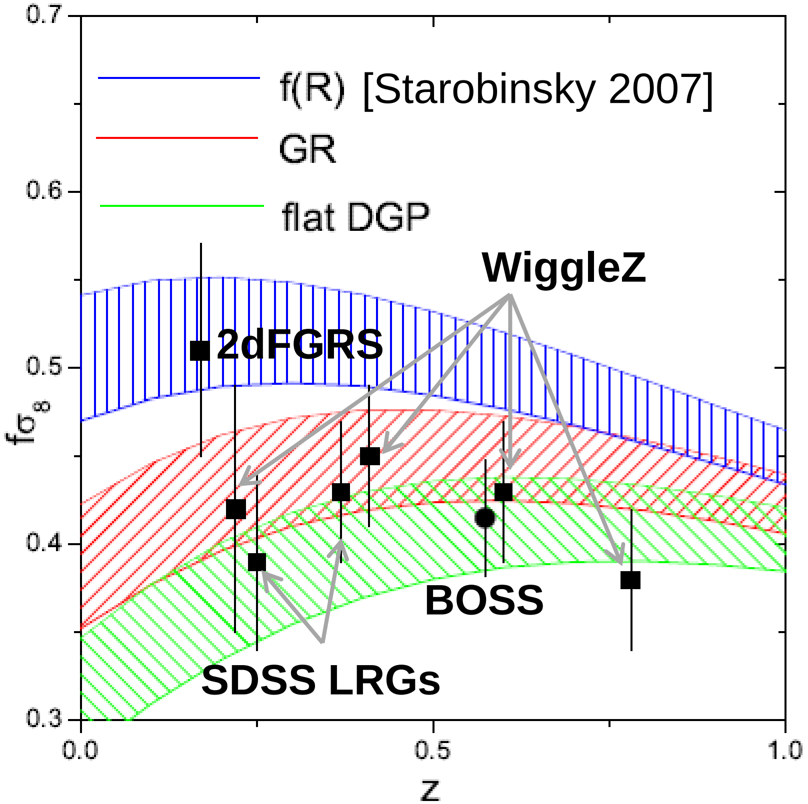
# Example: Tests of GR with RSD




WMAP7 predictions (68% CL)

Samushia et al. (2012)

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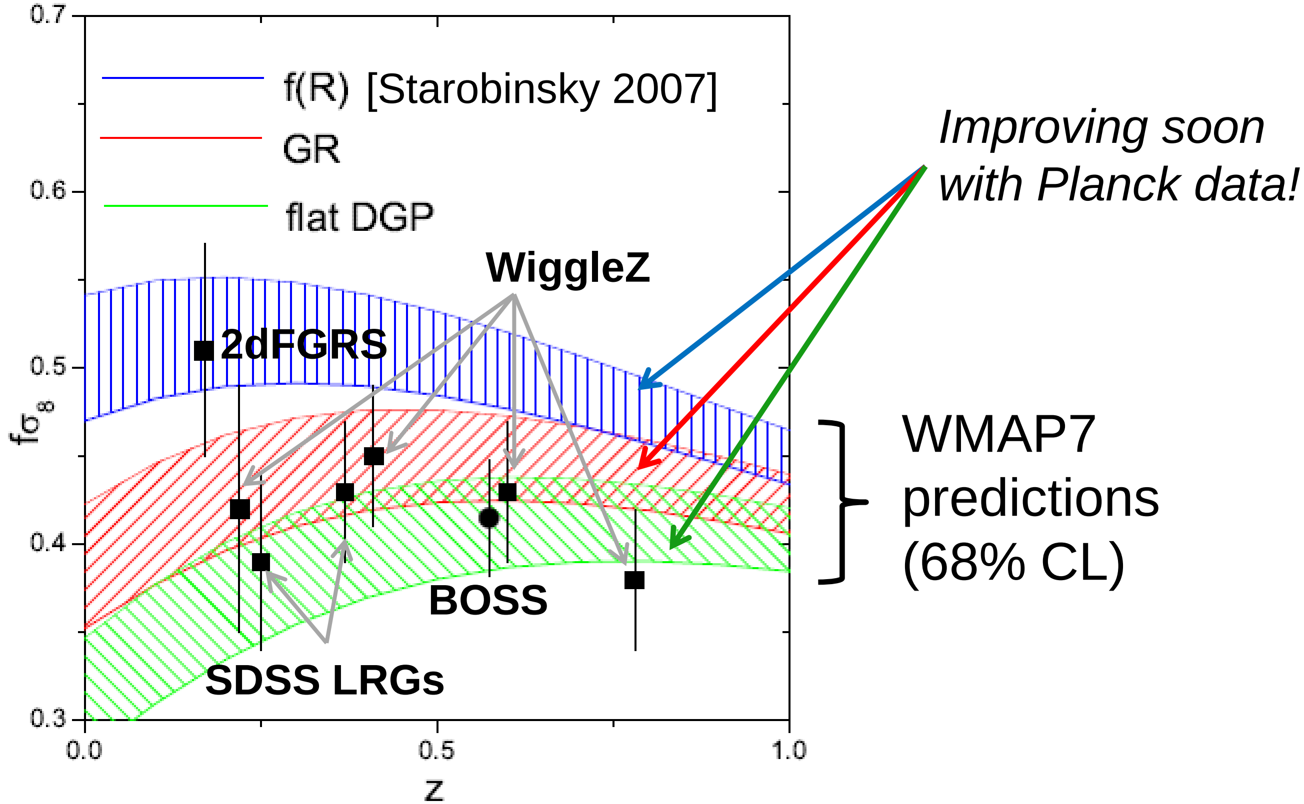


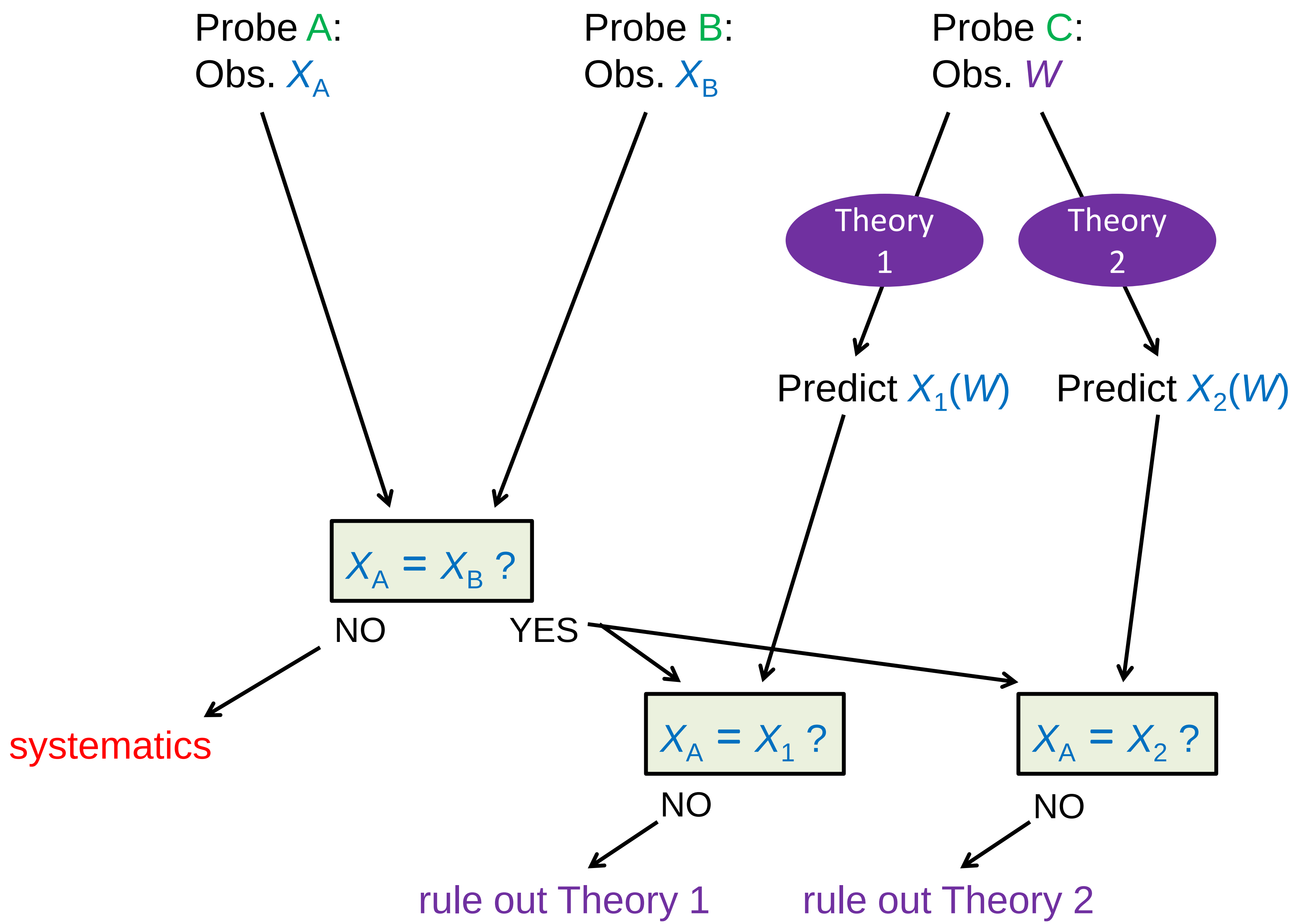

Samushia et al. (2012)

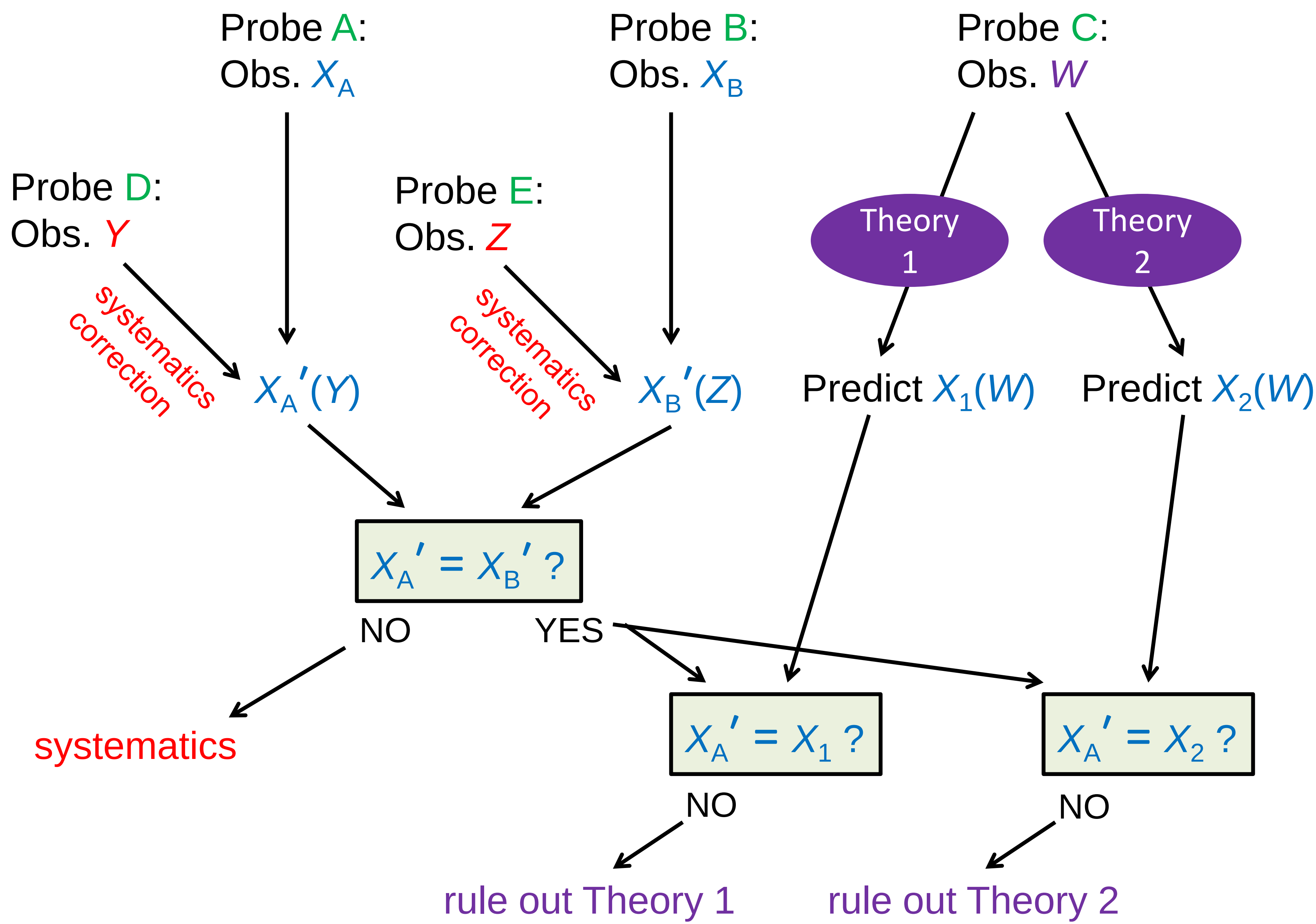
# Systematic error correction and marginalization

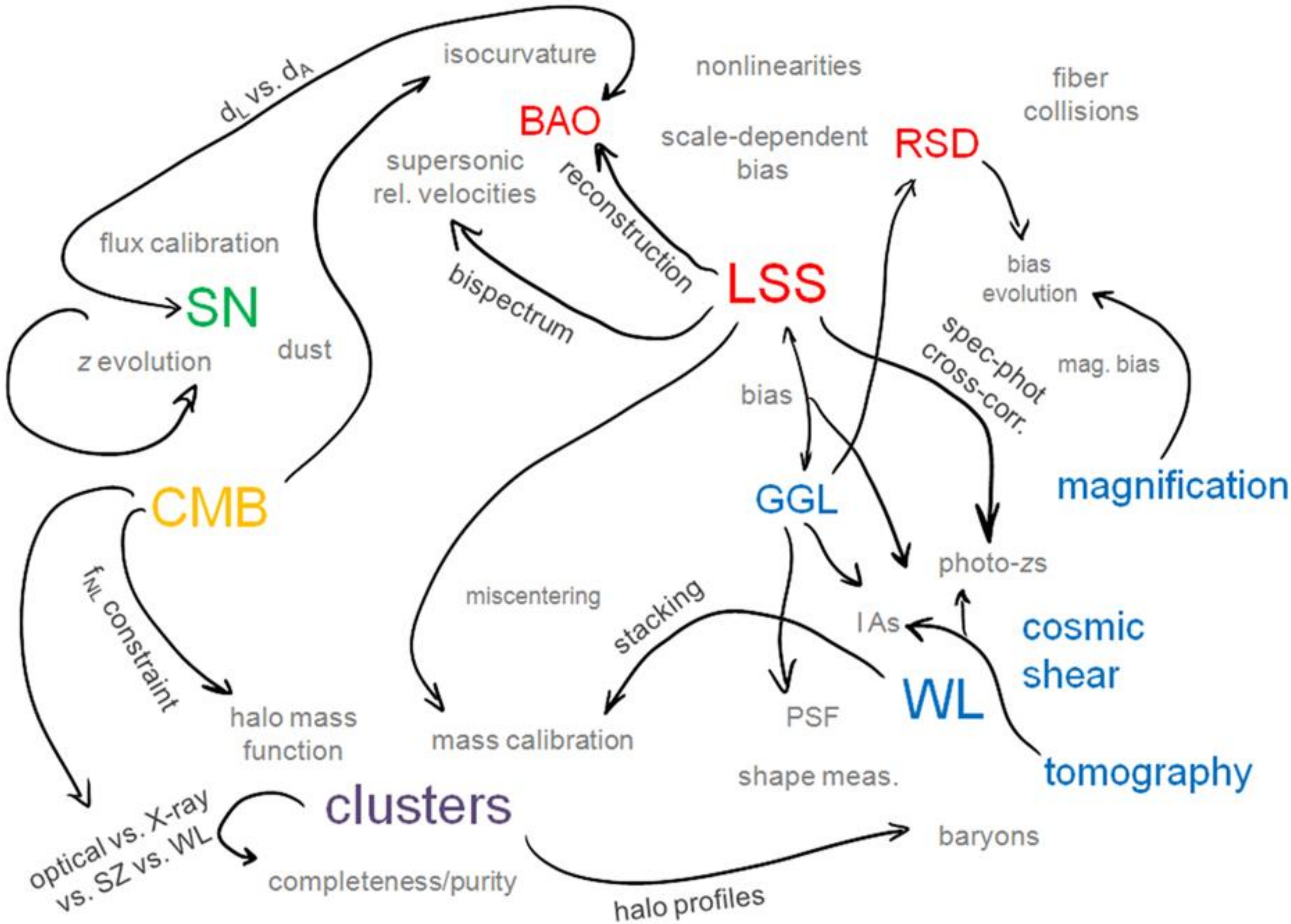
- **measurement** systematics:
  - use multiple probes as cross-checks or for calibration

- **astrophysical** systematics:
  - often difficult to model, but additional probes may provide
  an empirical description and/or priors on nuisance parameters

- **cosmological** systematics (i.e. new physics):
  - include additional parameters and marginalize,
  using priors from other probes


Probe A:
Obs. $X_A$
Probe B:
Obs. $X_B$
Probe C:
Obs. $W$
Theory 1
Theory 2
Predict $X_1(W)$
Predict $X_2(W)$
$X_A = X_B$ ?
NO
YES
systematics
$X_A = X_1$ ?
$X_A = X_2$ ?
NO
NO
rule out Theory 1
rule out Theory 2


Probe A:
Obs. $X_A$
Probe B:
Obs. $X_B$
Probe C:
Obs. $W$
Probe D:
Obs. $Y$
Probe E:
Obs. $Z$
systematics correction
systematics correction
Theory 1
Theory 2
$X_A'(Y)$
$X_B'(Z)$
Predict $X_1(W)$
Predict $X_2(W)$
$X_A' = X_B'$ ?
NO
YES
systematics
$X_A' = X_1$ ?
$X_A' = X_2$ ?
NO
NO
rule out Theory 1
rule out Theory 2



isocurvature
nonlinearities
fiber collisions
$d_L$ vs. $d_A$
BAO
scale-dependent bias
RSD
supersonic rel. velocities
reconstruction
flux calibration
bias evolution
bispectrum
LSS
SN
z evolution
dust
spec-phot cross-corr.
mag. bias
bias
magnification
CMB
GGL
photo-zs
miscentering
$f_{NL}$ constraint
stacking
IAs
cosmic shear
WL
halo mass function
mass calibration
PSF
tomography
shape meas.
clusters
optical vs. X-ray vs. SZ vs. WL
baryons
completeness/purity
halo profiles

## galaxy-galaxy lensing (GGL):

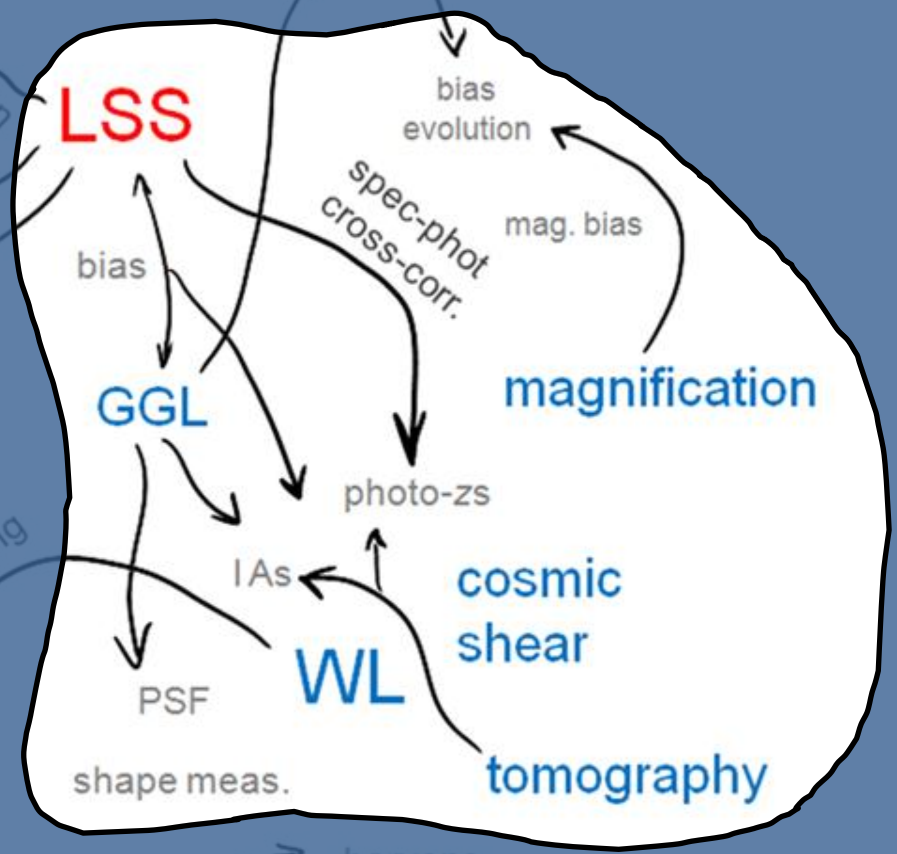
many WL systematics cancel in cross-correlation
[Bernstein & Jain 2004, Hu & Jain 2004]

- no additive shear bias (e.g. from PSF anisotropy)
- reduced intrinsic alignments (none if source and lens redshift ranges are well separated)

GGL+galaxy clustering statistical errors competitive with cosmic shear
[Mandelbaum et al. 2012, Yoo & Seljak 2012]

## magnification:

cross-check constraints from shear
[e.g. Eifler et al. 2013]




## overlapping WL + spec. survey:

use cross correlation to calibrate source galaxy photo-z distribution
[e.g. Newman 2008, McQuinn & White 2013]

obstacles include uncertainties in redshift evolution of bias, effects of lensing magnification

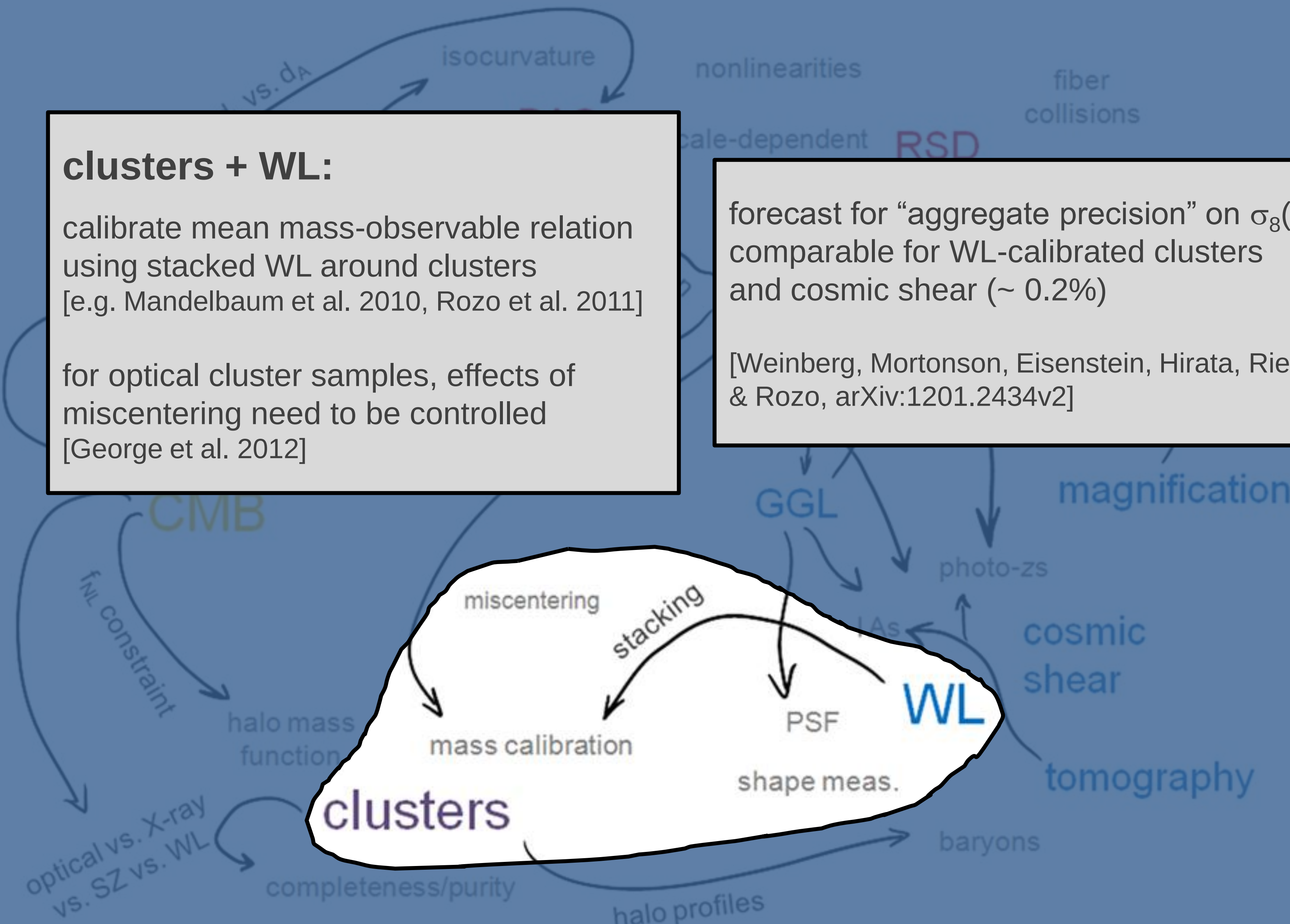
## clusters + WL:

calibrate mean mass-observable relation using stacked WL around clusters
[e.g. Mandelbaum et al. 2010, Rozo et al. 2011]

for optical cluster samples, effects of miscentering need to be controlled
[George et al. 2012]

forecast for “aggregate precision” on $\sigma_8(z)$ comparable for WL-calibrated clusters and cosmic shear (~ 0.2%)

[Weinberg, Mortonson, Eisenstein, Hirata, Riess, & Rozo, arXiv:1201.2434v2]



# Summary

To get believable results, we need to combine multiple high-precision probes.

Splitting observations into bins (if possible without sacrificing precision) can help distinguish among different types of systematic errors and new physics.

Many systematics have already been identified. Improving modeling of those effects and finding new ways to constrain them empirically could help increase the leverage of combined probes.