WFIRST + LSST

Science Opportunities

AND

Systematics Control

Outline

1. Synergistic opportunities with WFIRST + LSST
   a. Extra information due to combination of probes
   b. Breaking Degeneracies
   c. Consistency checks
   d. Systematic opportunities
2. Ongoing Projects
   a. LSST multi-probe science and systematics mitigation
   b. WFIRST multi-probe forecasts
3. Target Science
   a. What are the interesting science in mid-2020s?
   b. What can we try to measure?
   c. Opportunities?
   d. WFIRST options as a function of time and discoveries (in eg. Stage 3 and beyond)

What can WFIRST bring to the LSST party?

- **Spectroscopy:** 2×10^7 spectro-z's at z ~ 1.1 - 2.8
- **NIR imaging:** YJH,F184 complements LSST ugrizy
- **Depth:** LSST r_{AB}~27.1 mag (wide) and ~28.6 mag (deep); WFIRST J_{AB} ~ 26.7 mag (wide) and ~29 mag (deep)
- **Area:** ~2,200 deg^2 vs. LSST's ~18,000 deg^2; full overlap?
- **Resolution:** Space-based, ~0.11" vs. LSST seeing-limited ~0.7"
- **Cadence:** Flexible survey strategy; time-domain applications?

Synergies

Synergies

Possible synergies:

- Multi-probe methods
    - Extra info from cross-correlations
    - Breaking degeneracies
- Consistency checks
    - Agreement between independent measurements?
- Systematics and calibration
    - Training
    - Cross-correlation

Synergies

Cross-correlations: New information

- Multi-tracer: cancel sample variance (e.g. RSDs, relativistic effects, f_{NL});
  Needs multiple high number density populations with different bias
- Extra info in “off-diagonal” elements of (z, z’) covariance matrix
- Extract small signals, e.g. ISW

Intrinsically multi-probe methods

- Beyond 2-pt statistics: combine photo+spectro-z for void statistics, filaments
- De-lensing the CMB; velocity field reconstruction x-corr; kSZ + tSZ; clusters
- Testing GR with E_G: lensing (photo-z) + RSD (spectro-z)

Synergies

Breaking degeneracies

- CMB degeneracies (geometric; τ - n_s; neutrino mass/N_eff)
- H_0, Omega_M (geometric vs. growth probes)
- Bias, growth, sigma_8 (RSDs vs lensing)
- Info at new redshifts: better “lever arm” on certain parameters

Consistency checks

- What’s the deal with σ_8?
- Lensing amplitude - including (nearly) shape-noise-free, photo-z free test of shear calibration
- w(z), f(z) from different probes
- H_0 (local vs. derived)

Synergies (also with CMB-S4)

Calibration

- Redshift training for photo-z’s
- Intrinsic alignment model
- De-blending / identifying blends

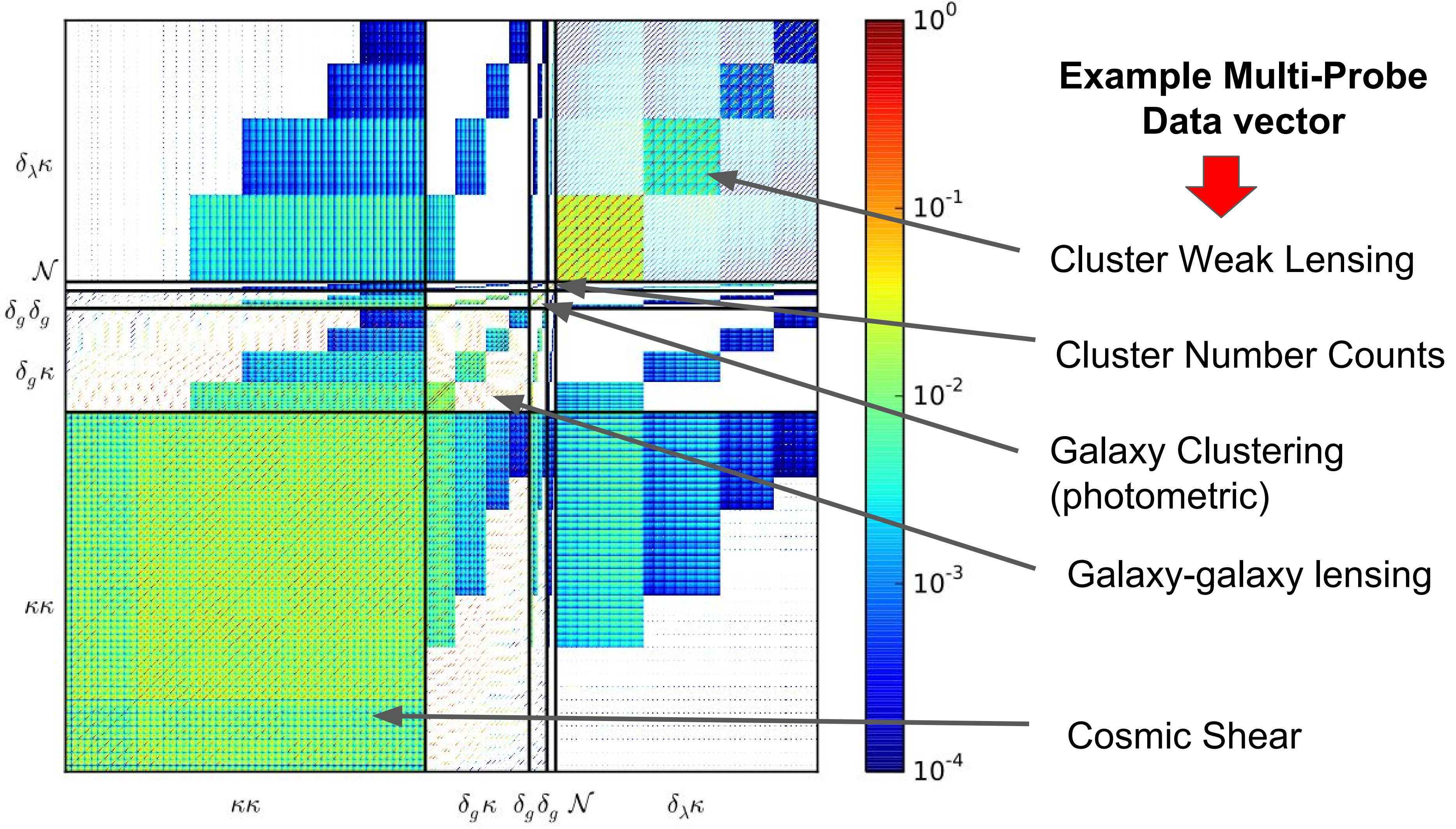
Cross-correlations: Systematics

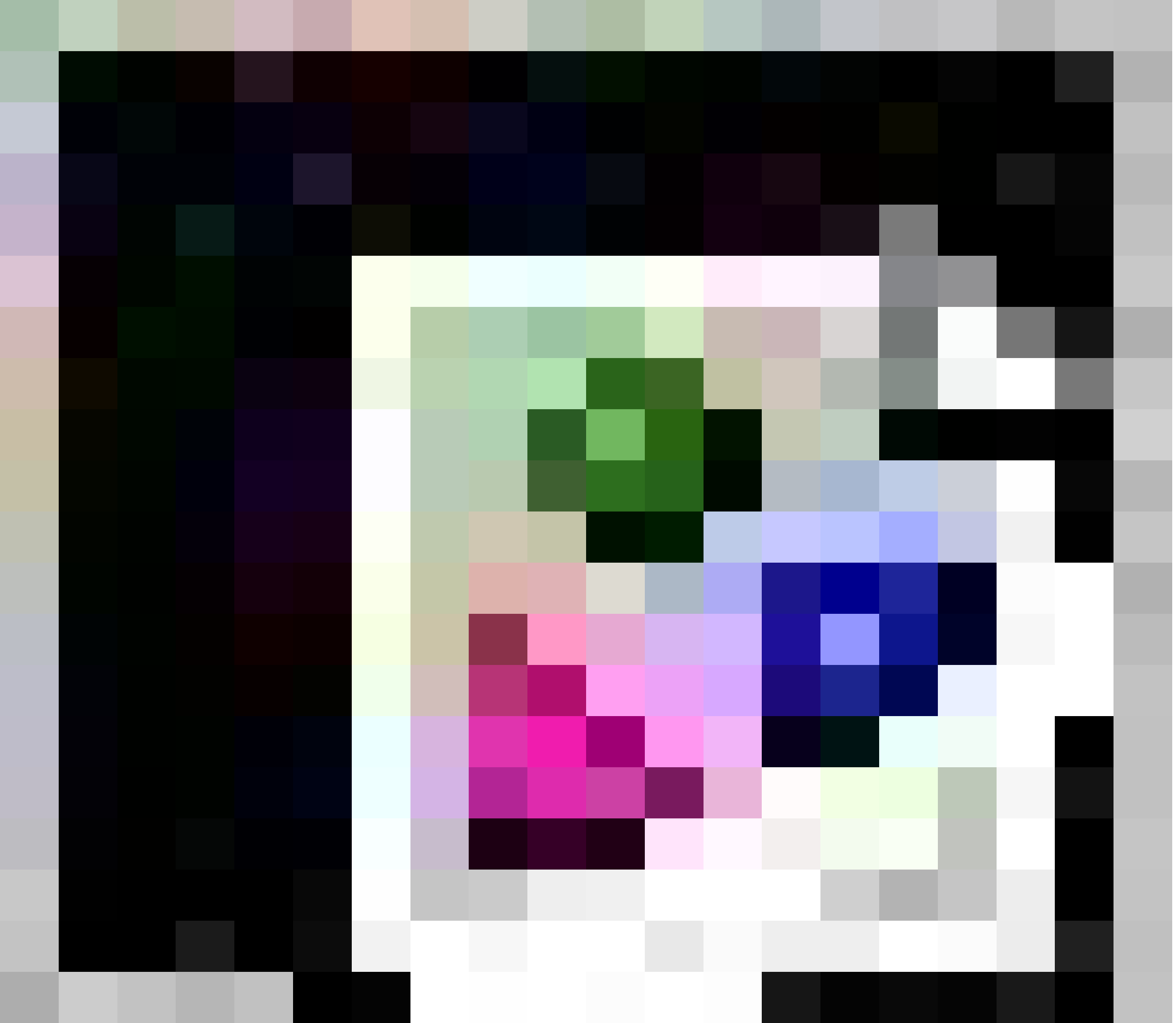
- Cancel uncorrelated systematics (e.g. CMB foregrounds, PSF effects)
- Identify contaminants (stars, other interlopers)
- Lensing x CMB lensing; remove/reduce shear calibration uncertainties

Ongoing Projects

Exploring science ideas and systematics studies

1) Whatever your science case/synergy to explore you probably need multi-probes forecasting capability, systematics models, covariances, and sampling
2) Given this capability one can:
    a) Explore science cases, optimal combination of probes
    b) Explore survey strategies/trade studies
    c) Rank systematics, explore impact of uncertainties in combination
    d) Explore systematics mitigation strategies (also with external probes)
3) Let’s look at some cosmic acceleration and MG studies

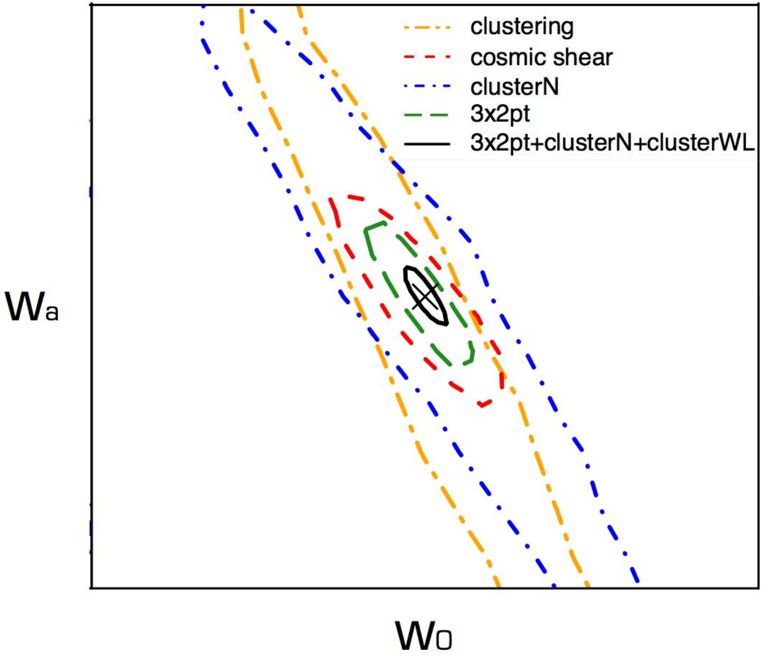

Example Multi-Probe Data vector
Cluster Weak Lensing
Cluster Number Counts
Galaxy Clustering (photometric)
Galaxy-galaxy lensing
Cosmic Shear
$\delta_\lambda\kappa$
$\mathcal{N}$
$\delta_g\delta_g$
$\delta_g\kappa$
$\kappa\kappa$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}



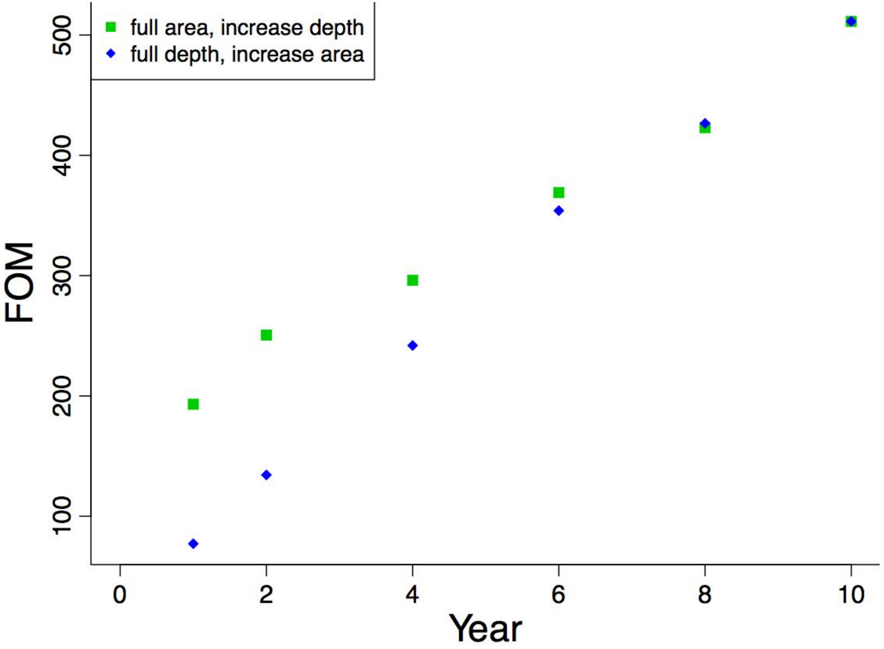
Working Example - LSST multi-probe analysis with "realistic" systematics.

See Krause & Eifler '16 for details

LSST individual vs multi-probes

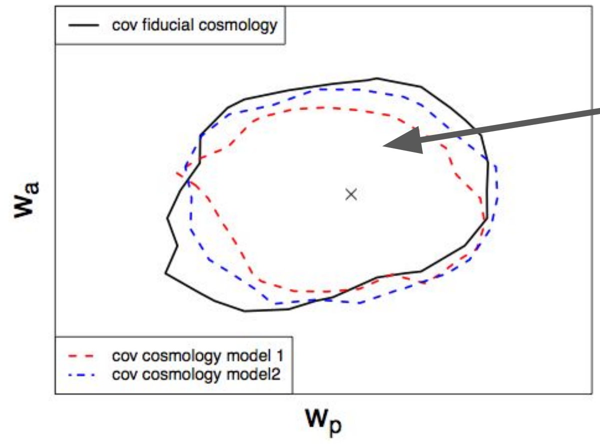


Cosmic Acceleration constraints from multi-probe LSST Y10

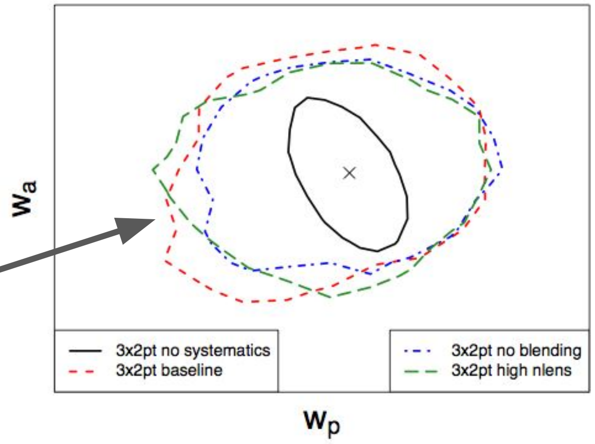


LSST (statistical) constraining power as a function of time for different survey strategies

LSST Systematics studies

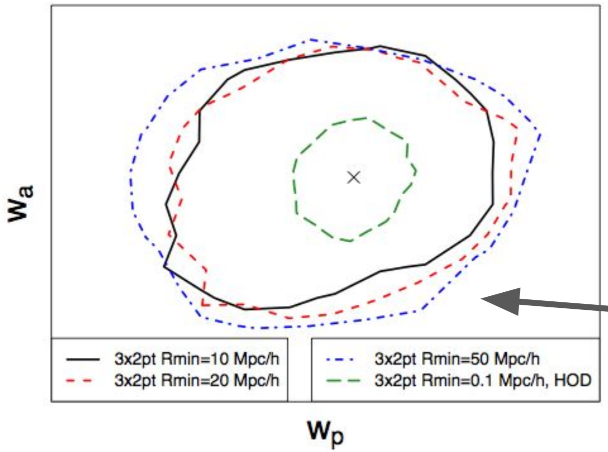


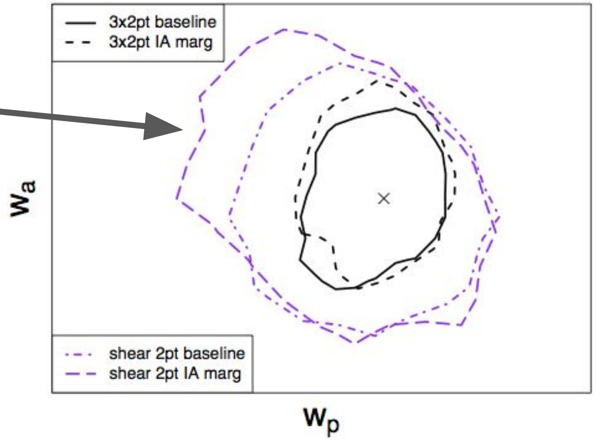
Covariance model dependence



Blending (if identifiable and removable)

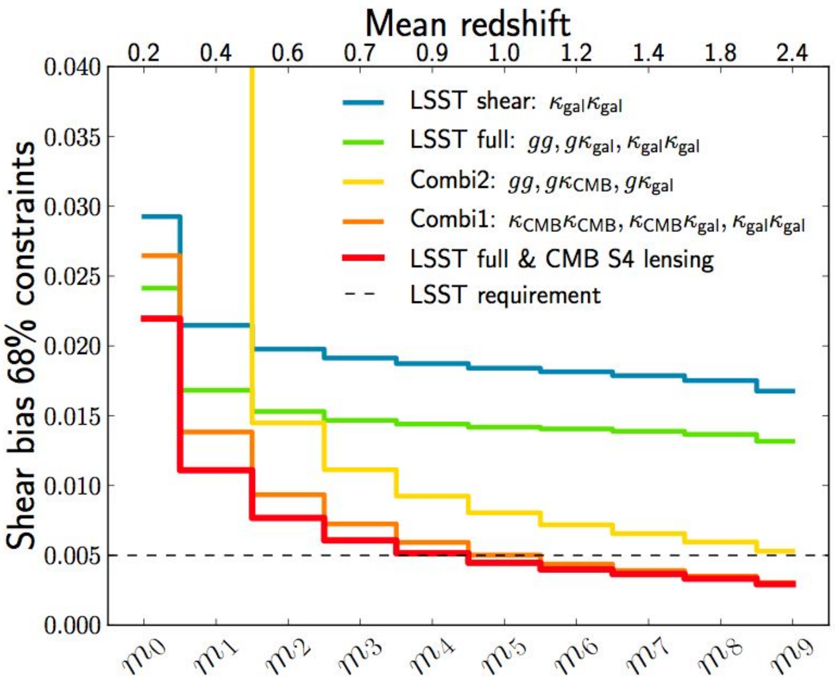
Intrinsic Alignment Mitigation (single vs multi-probe if imperfect IA model)

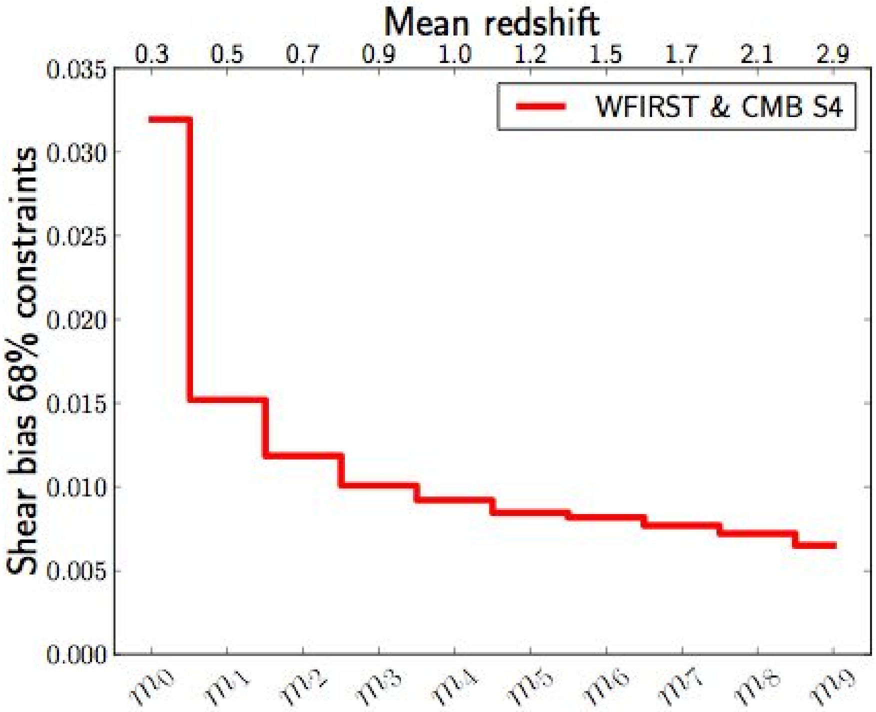




Small Scale information (HOD or clusters)

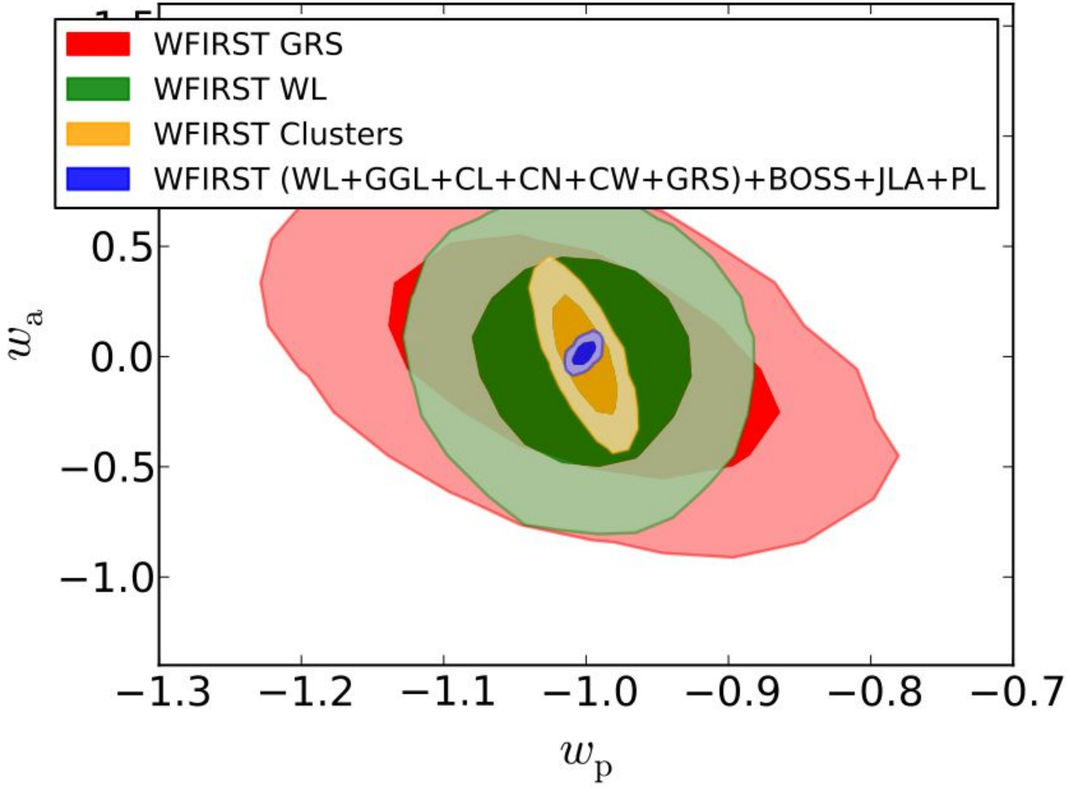
Multiplicative shear bias control through CMB-lensing (CMB-S4)





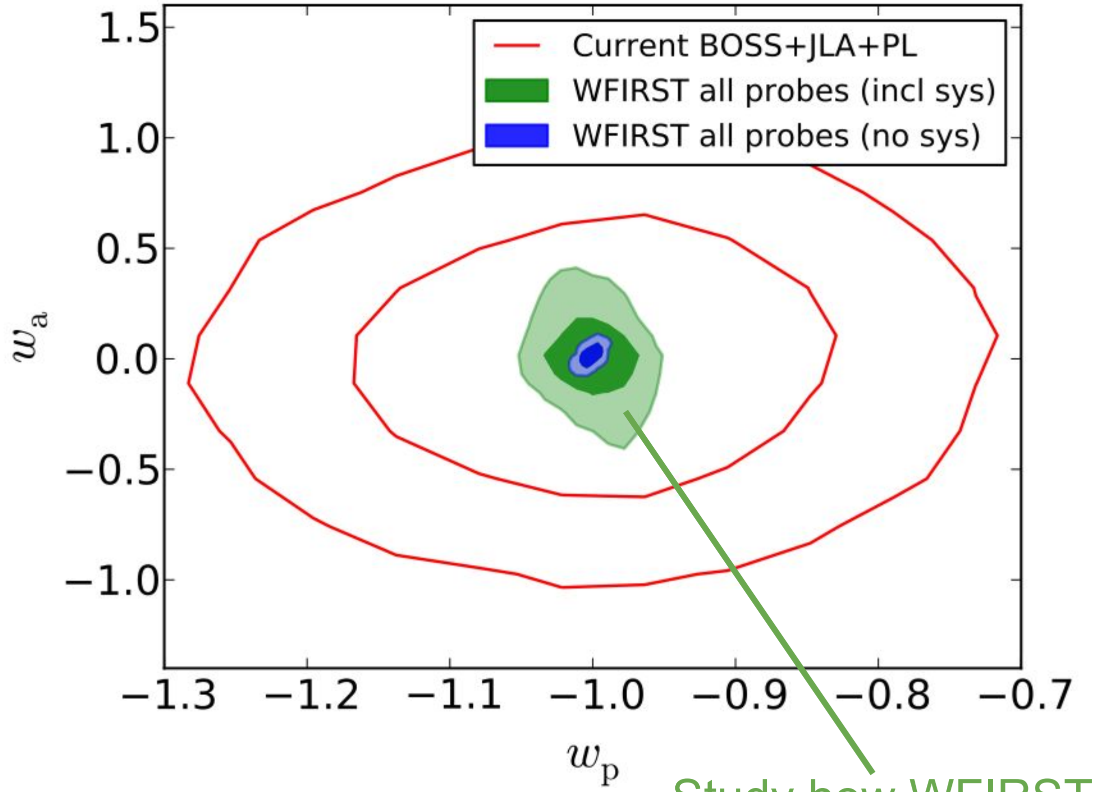
see Schaan et al ‘16 for details

WFIRST individual vs multi-probes



Including cross-correlations and external data sets adds substantial information

WFIRST systematics studies

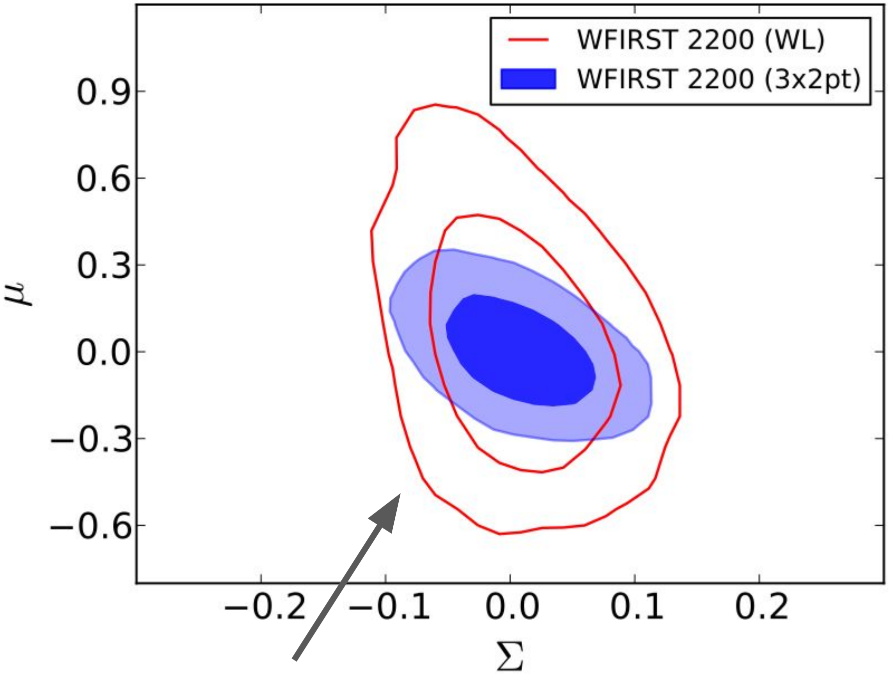


Multi-probe analyses set different requirements on systematics compared to individual systematics…

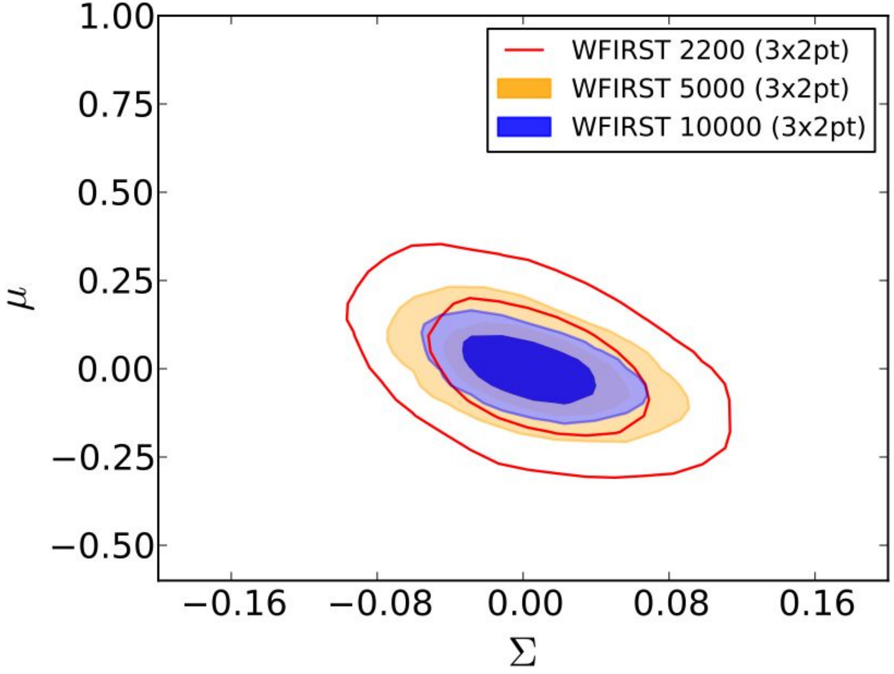
Check your systematics with multi-probe constraining power

Study how WFIRST+LSST can help here

WFIRST modified gravity startup project



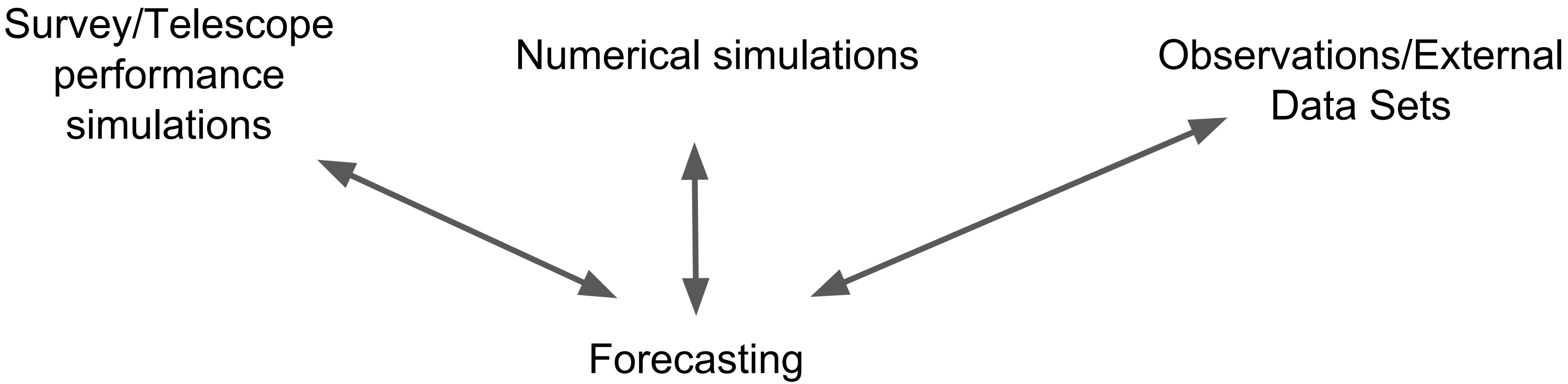
Clustering included is photometric only, RSD will give additional boost
Credit: Hironao Miyatake



Prospects of an extended WFIRST survey

(Good) forecasts don’t exist in isolation

Concrete and meaningful exploration of science ideas, trade-studies, systematics mitigation concepts needs Interfaces to experts



Target Science

Target science

What should we be trying to measure/discover?
(ΛCDM parameter estimation will be *super*-boring by the mid-2020's)

- **Dark energy, in any way possible!**
  w(z) not necessarily the most informative
  (deviations from ΛCDM expansion may be small; look at growth etc.)
- **Modified gravity, in any way possible!**
  MG = extra fields and couplings. DE is a subclass: just an extra field.
  Environment-dep. *screening effects* must suppress MG on small scales
- **Massive neutrinos** and other light species (e.g. axions, sterile neutrinos)
  Cosmology has a good chance of beating particle physicists to a detection!
- **Dark matter**
  Deviations from simple CDM; interactions; non-WIMP signatures

Target science

What should we be trying to measure/discover?

- **Early universe**: any new info we can get!
  Scale-dependent bias, non-Gaussianity/n-point functions,
  spatial curvature (Omega_K), preferred directions
- **Effects predicted by ΛCDM**
  e.g. secondary CMB anisotropies (kSZ, ISW), baryon-CDM relative velocity,
  relativistic effects on ultra-large scales
- **Anything *not* predicted by ΛCDM**
  Anomalies, unexpected features/scalings
- **Nuances of structure formation**
  e.g. assembly bias, advection, feedback, small-scale clustering, cosmic web

New opportunities

- 2200 deg^2 survey is small *if we only care about mode-counting* observables.
  Think beyond 2-pt statistics: multi-tracer effect, halo profile shapes
- A lot more cosmological info is available *if we can also model astrophysics.*
  Reliable models for galaxy emission/morphology → new distance measures
  Understand small-scale clustering/bias → use non-linear modes for RSDs

WFIRST options as a function of time and discoveries

WFIRST options as a function of Stage3 discoveries

Pre-WFIRST ground-based results are important:

- Do we change our strategy if sigma_8 is low by several sigma after DES/KIDS/HSC?
- What if the Lyman alpha forest BAO scale is still weird after the initial DESI results?
- What if still more anomalies appear? What if they all go away?

WFIRST options as a function of LSST discoveries

- We can think about changing the WFIRST strategy based on LSST **on-sky performance**, but doing so based on DE **science results** might be hard
- What is LSST constraining power as a function of time?
- When is start of WFIRST HLS survey, and how much flexibility is there in terms of observing strategy?
- Prioritize forecasts for these multi-probe/data set studies

Contemporary surveys

Spectroscopy: BOSS, DESI, 4MOST, HETDEX , PSF, …

Imaging: SDSS, DES, HSC...

Other wavelength regimes:

- AdvACT, SPT-3G, Simons Array, CMB-S4... (CMB/microwave)
- ASKAP, MeerKAT, SKA (general radio); CHIME, HIRAX, Tianlai (21cm)
- JWST, ALMA, SPHEREx (IR/sub-mm)
- eRosita (X-ray)
- Gamma rays, neutrinos, cosmic rays, GWs? (e.g. CTA, LIGO)