Cosmology with the Roman Space Telescope: Weak Lensing and Beyond

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On behalf of the SIT on Cosmology with the High Latitude Survey

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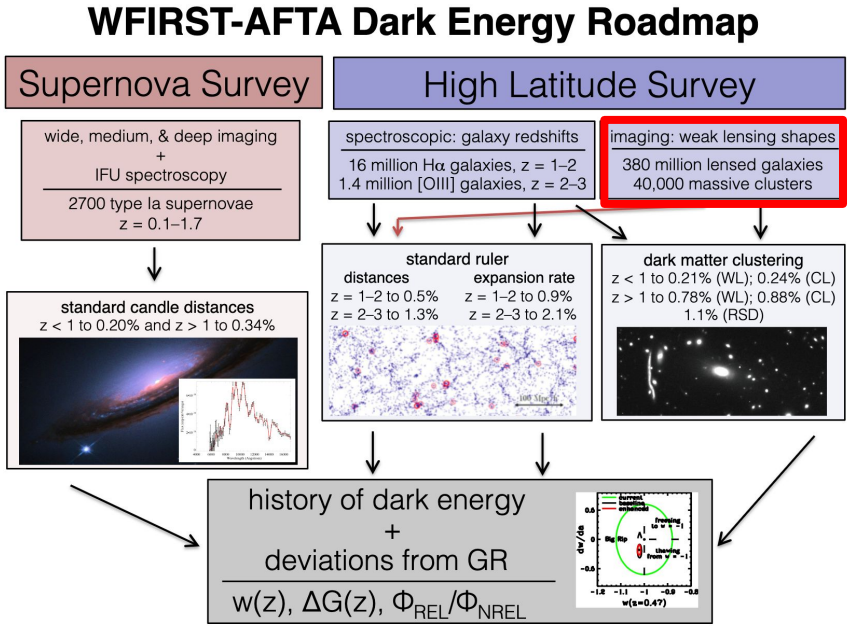
Image credit: NASA

Science Goals

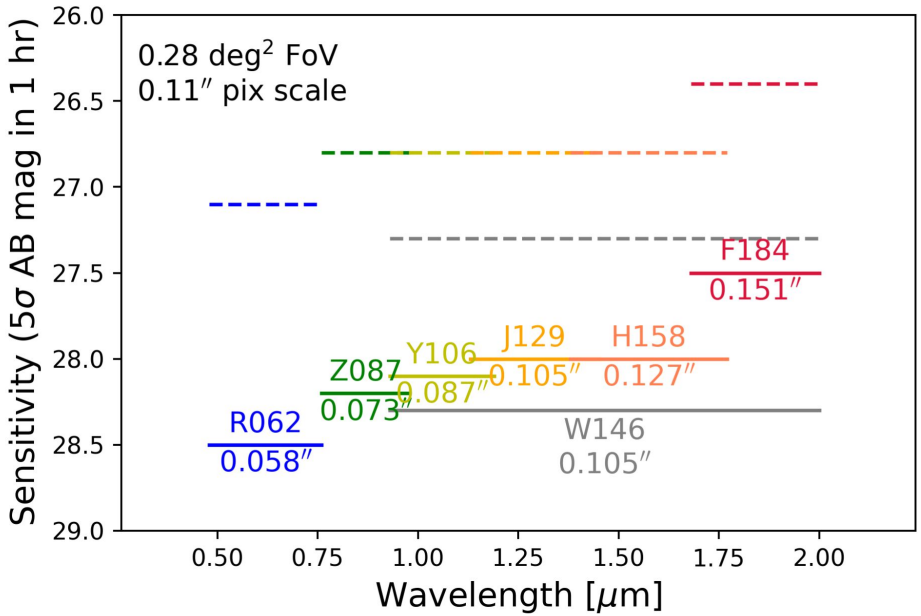
- Exploring the nature of cosmic acceleration:
  - Dark energy or modified gravity?
  - If dark energy, how does it evolve?
- Cosmological Phenomenology of DE/MG
  - Expansion history/geometry: e.g. wCDM v.s. LCDM
  - Growth history/clustering: e.g. f(R) gravity v.s. GR
- HLS survey has two components:
  - HLSS spectroscopic galaxy redshift survey
  - HLIS multi-probe analysis from imaging data (WL, GGL, 2D clustering, galaxy clusters), which is the focus of this talk



Spergel et al. (2015)

Reference High Latitude Imaging Survey

Instrument Capabilities



HLIS reference survey design

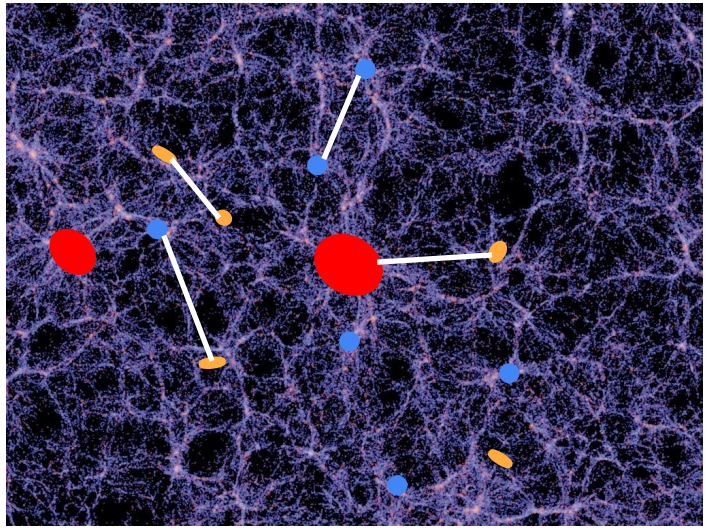
- Survey area: 2,000 sq deg
- Bandpasses: Y, J, H and F184
- Survey depth: 26.7 (5σ point source in J-band)

Cosmological Probes

- What can be measured from imaging
  - Galaxy shapes -> WL
  - Galaxy position -> 2D clustering
  - Galaxy clusters
  - Cross-correlations thereof (GGL, cluster WL)

- Observables that enter into forecasted imaging based multi-probe analysis (Eifler et al. 2021b)
  - Shear-shear auto-correlation
  - Shear-galaxy cross-correlation
  - Galaxy-galaxy auto-correlation
  - Cluster number counts
  - Cluster-shear cross-correlation

- Other probes that can be included are, e.g. peak statistics, magnification, cluster clustering, voids, higher order stats, etc



Galaxy Sample Definition (based on CANDELS catalog)

Source galaxy (used for WL)

- J+H band combined $S/N > 18$
- Ellipticity error $\sigma_e < 0.2$
- Resolution factor $R > 0.4$

$$n_{src} = \frac{51}{\mathrm{arcmin}^2}$$
$$\sigma_\epsilon = 0.37$$

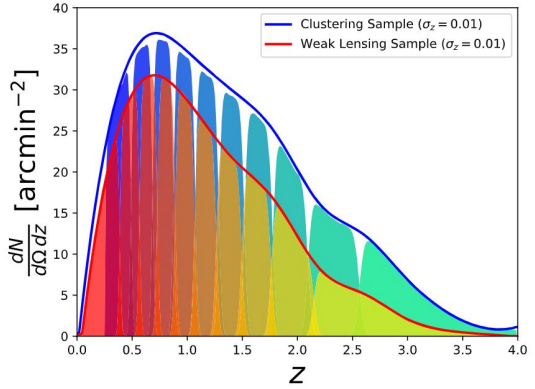
Lens galaxy (used for 2D clustering)

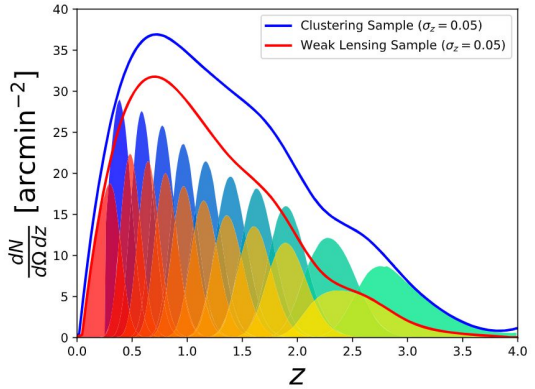
- S/N >10 in Y, J, H, F184
- S/N > 5 in each LSST band expect u

$$n_{lens} = \frac{66}{\mathrm{arcmin}^2}$$

Galaxy clusters

- Optical-selected clusters (e.g. Rykoff et al. 2014)
- Falls in redshift range [0.4, 1.2] and optical richness range [40, 220]





Eifler et al. (2021b)

Systematics considered

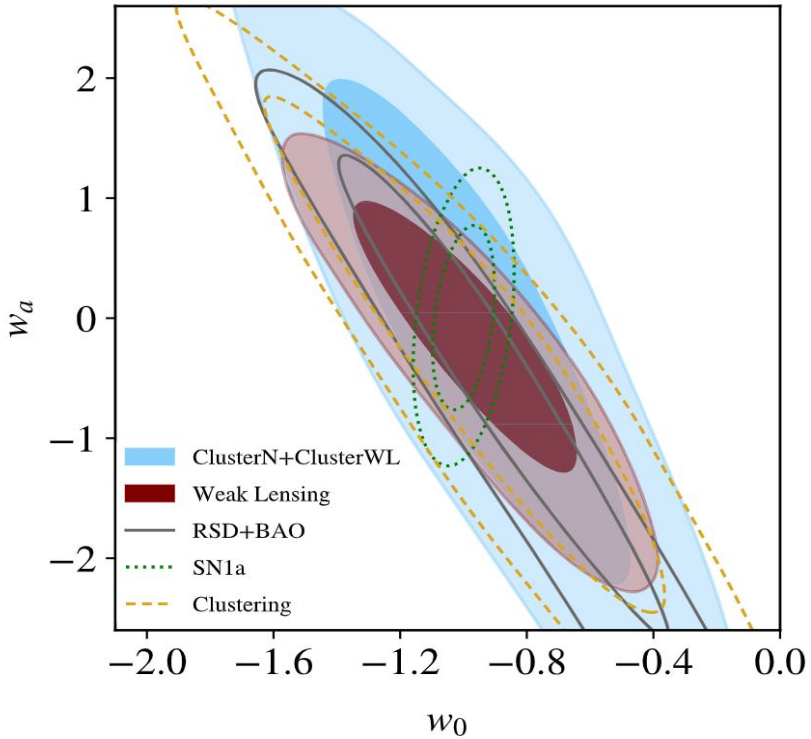
- Photo-z uncertainties: percent-level precision can be reached with self-organizing map (Hemmati et al. 2019)
- Shear calibration bias: recent detector and image simulations (Troxel et al. 2021, Givans et al. 2021, Lin et al. 2021) show the shear calibration bias generally falls between the optimistic and pessimistic cases
- Cluster mass-observable relation: From Murata et al. (2018), the mass-observable relation has a scatter around 0.46 dex
- For intrinsic alignment, baryonic physics and linear galaxy bias, we choose non-informative flat priors

	Lens photo-z (optimistic)	
$\Delta^i_{\mathrm{z,lens}}$	0.0	Gauss (0.0, 0.002)
$\sigma_{\mathrm{z,\ lens}}$	0.01	Gauss (0.01, 0.002)
	Lens photo-z (pessimistic)	
$\Delta^i_{\mathrm{z,lens}}$	0.0	Gauss (0.0, 0.02)
$\sigma_{\mathrm{z,\ lens}}$	0.05	Gauss (0.05, 0.02)
	Source photo-z (optimistic)	
$\Delta^i_{\mathrm{z,source}}$	0.0	Gauss (0.0, 0.002)
$\sigma_{\mathrm{z,\ source}}$	0.01	Gauss (0.01, 0.002)
	Source photo-z (pessimistic)	
$\Delta^i_{\mathrm{z,source}}$	0.0	Gauss (0.0, 0.02)
$\sigma_{\mathrm{z,\ source}}$	0.05	Gauss (0.05, 0.02)
	Shear calibration (optimistic)	
m_i	0.0	Gauss (0.0, 0.002)
	Shear calibration (pessimistic)	
m_i	0.0	Gauss (0.0, 0.01)
	Intrinsic alignment	
A_{IA}	5.95	Flat (0.0, 10)
β_{IA}	1.1	Flat (–4.0, 6.0)
η_{IA}	0.49	Flat (–10.0, 10.0)
$\eta_{\mathrm{IA}}^{\mathrm{high-z}}$	0.0	Flat (–1.0, 1.0)
	Baryonic physics	
Q_1	0.0	Gauss (0.0, 16.0)
Q_2	0.0	Gauss (0.0, 5.0)
Q_3	0.0	Gauss (0.0, 0.8)
	Galaxy bias (tomographic bins)	
b^i_{g}	$1.3\ + i \times 0.1$	Flat (0.8, 3.0)

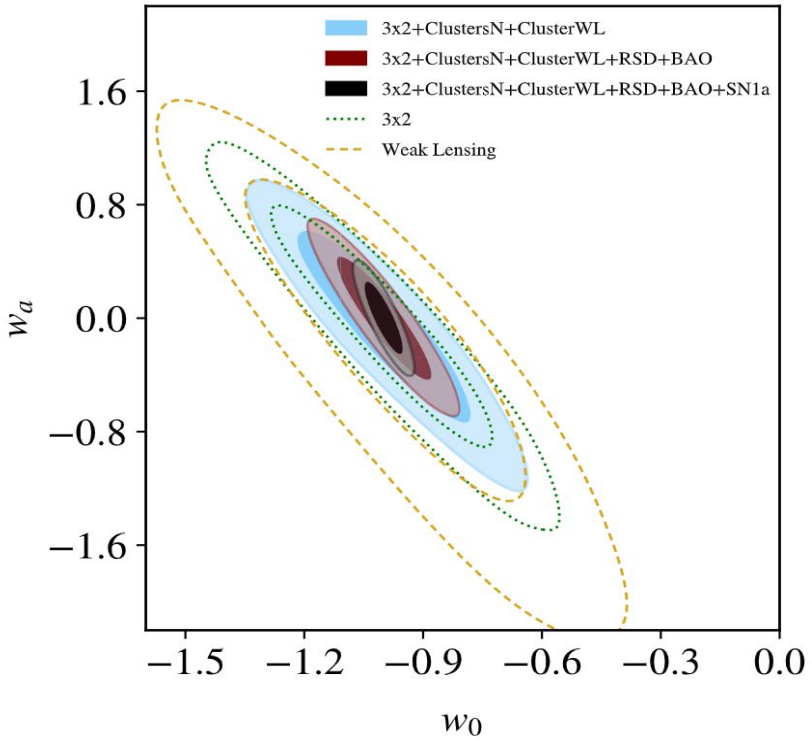
Eifler et al. (2021a,b)

Roman Reference Survey: Multi-probe from Imaging

Eifler, Miyatake, Krause, Heinrich, Miranda, Hirata, Xu, **many others** 2021



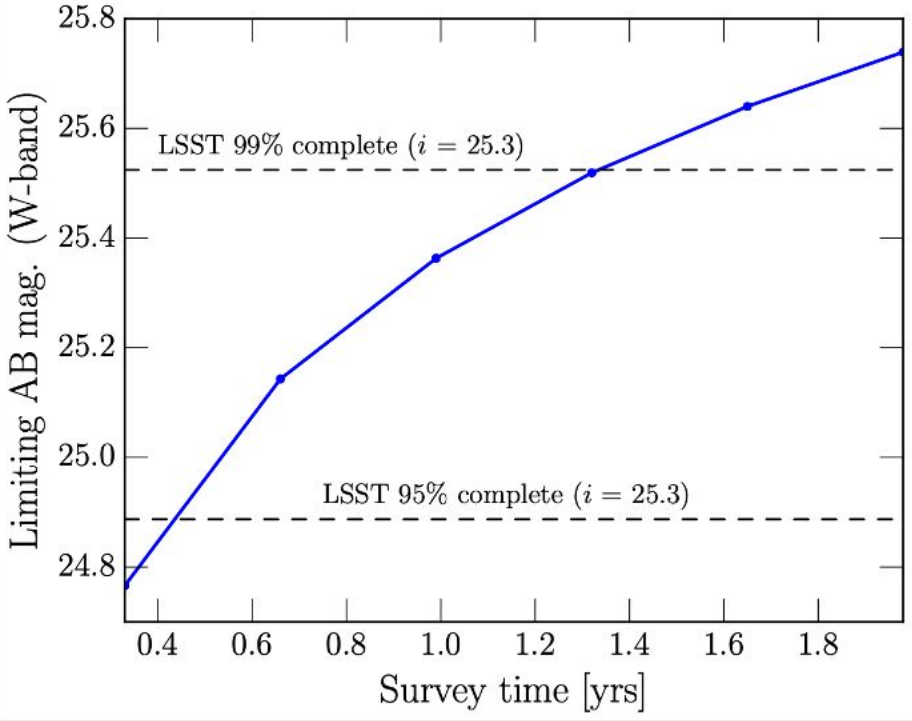
Individual probes - constraining power on dark energy



Multi-Probe Analysis

Roman wide survey idea: Synergies with the Rubin Observatory

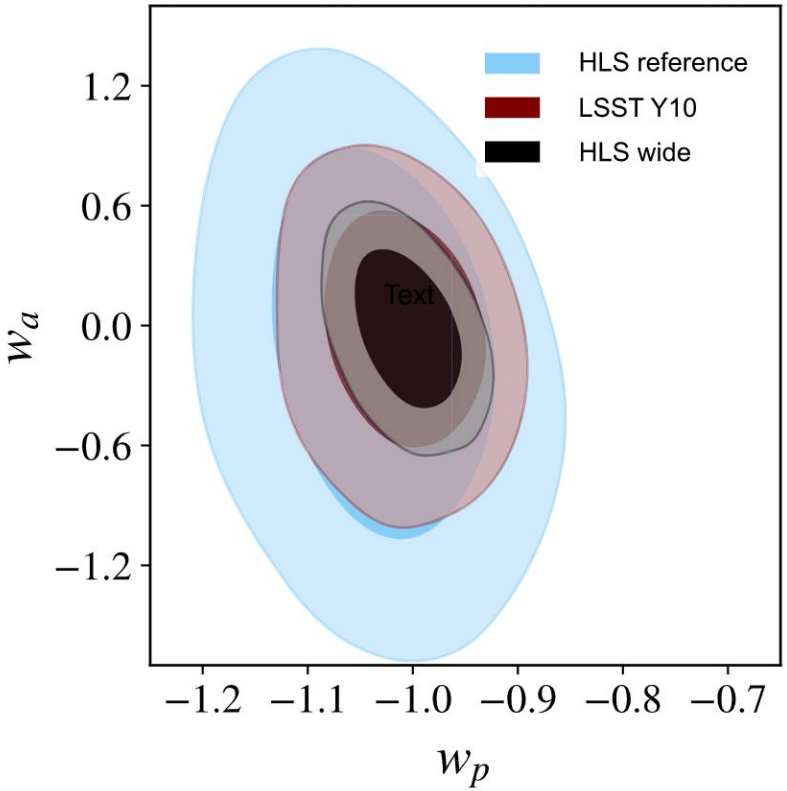
see Eifler, Simet, Krause, Heinrich, Hirata, Huang, Fang, Miranda, Mandelbaum, Doux, **many others** 2021



- Idea 1: Use W-band of Roman to cover LSST area (or more? … one can dream…)
  5 months: Roman W-band can cover all of LSST's area and obtain space quality shape measurements for 95% of the LSST Y10 gold sample.
  Interesting for many science cases beyond DE
  Disclaimer: W-band only survey is more easily affected by systematics
- Idea 2: Combine wide W-band survey with smaller multi-band photometry as in the reference survey to calibrate W-band data

Roman wide survey idea: Synergies with the Rubin Observatory

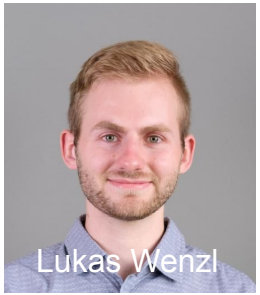
- 3x2pt analysis: Weak lensing and Galaxy Clustering (photo-z) only, no clusters, spec-z, SN, CMB
- Includes 56 dims of systematics modeling (shear calibration, galaxy bias, photo-z, IA, Baryons)
- FoM (Roman wide + Rubin)=2.4 x FoM (LSST only)
  FoM (Roman wide + Rubin) = 5.5 x FoM (Roman Reference survey)
  Disclaimer: The usual caveats to the FoM metric apply

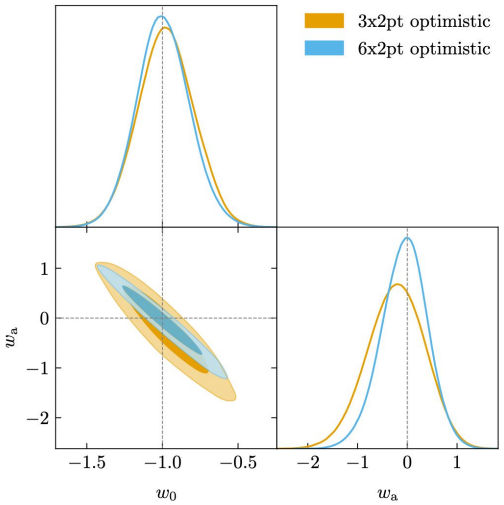


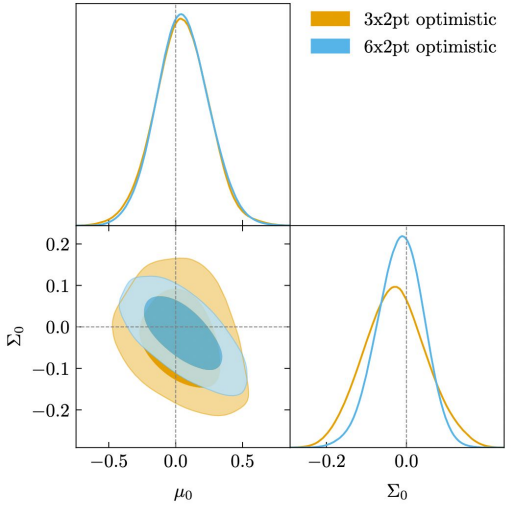
Synergies between Roman HLS and CMB Lensing from Simons Observatory

- 6x2pt analysis: auto- and cross-correlation among $\{\delta_g,\ \gamma,\ \kappa_{\rm CMB}\}$
- Realistic systematics: galaxy bias, IA, baryonic effects, shear calibration bias, photo-z
- Adding CMB lensing improves $\mathrm{FoM}_{w_0 w_a}$ by a factor of 2.4 and $\mathrm{FoM}_{\mu_0 \Sigma_0}$ by 64%
- Adding CMB lensing also helps in galaxy bias self-calibration and constraining modified gravity significantly. A wide HLS idea is also compelling in the context of 6x2pt strategy

Wenzl et al. (2021)
arXiv:
2112.07681

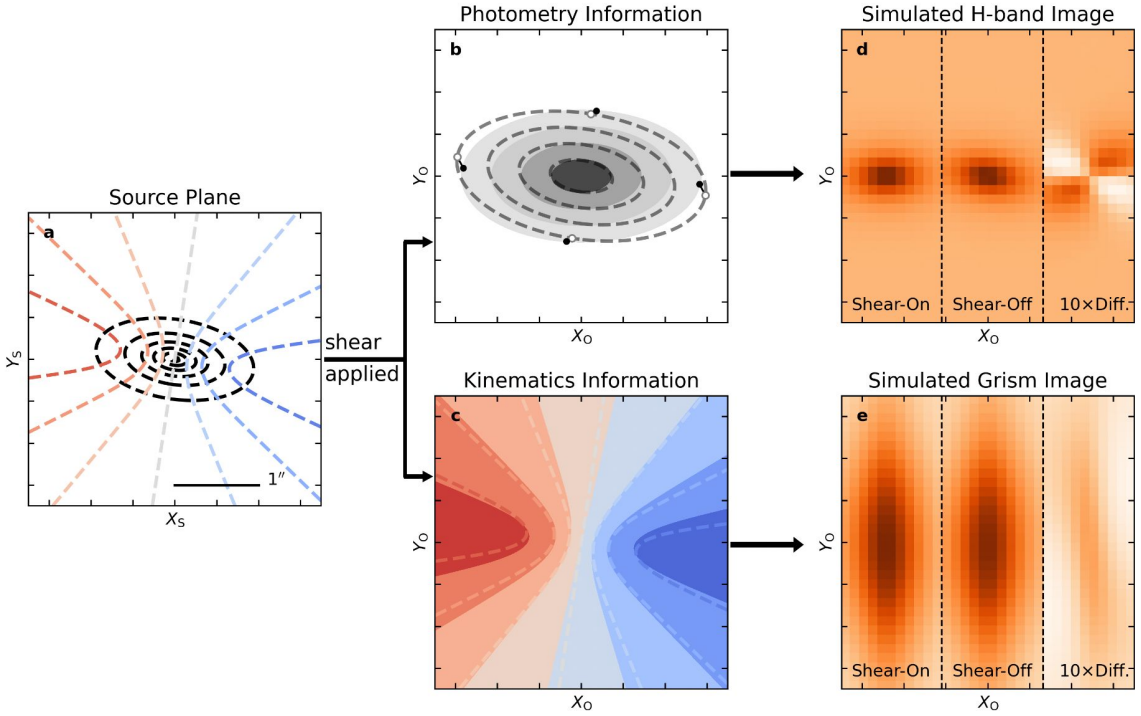






Kinematic Lensing with Roman HLS

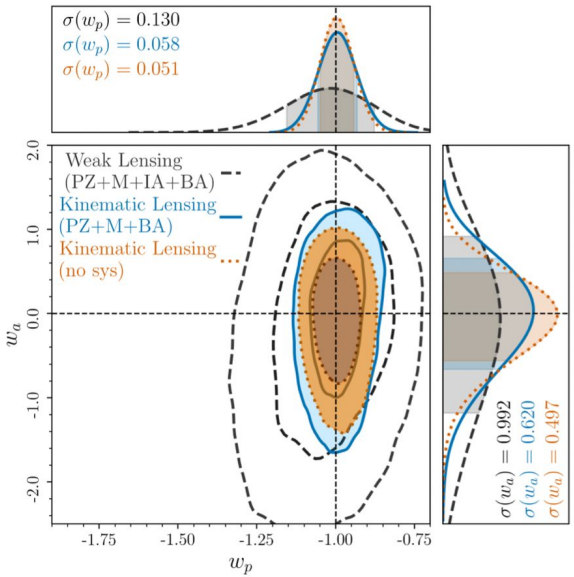
- Kinematic lensing (Huff et al. 2013) is a novel weak lensing technique combining imaging and spectrum to estimate shear distortion
- Shear distorts the photometry image and the spectrum of galaxies differently. Combining both helps breaking the degeneracy between intrinsic shape and shear, suppress shape noise by a order of magnitude
- KL is a fantastic science case that combines the capabilities of the spectroscopic and imaging component of Roman HLS

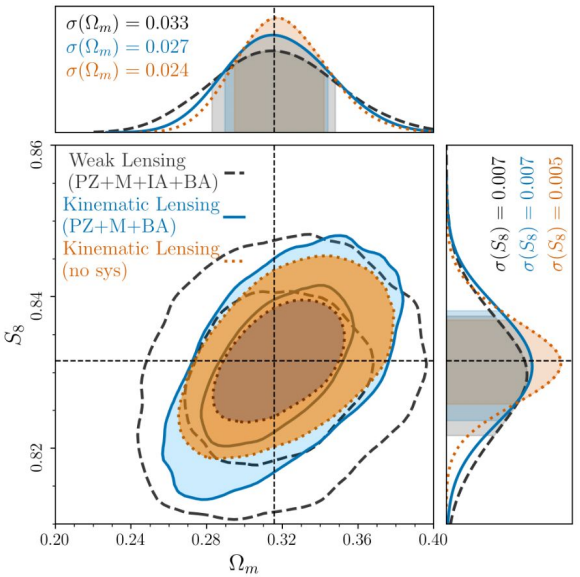


Xu et al. (2021) arXiv: 2201.00739

Kinematic Lensing with Roman HLS

- Shear-shear autocorrelation only
- KL sample defined by overlap of HLS Imaging and Spectroscopy samples, has a shape noise of 0.035 and a number density of 4 per sq arcmin. Other systematics, like photo-z uncertainties, shear calibration bias and intrinsic alignment are also better controlled
- Compared to traditional WL, KL improves $\mathrm{FoM}_{w_0 w_p}$ by a factor of 2.65, and $\mathrm{FoM}_{\Omega_m S_8}$ by 70%
- Future works include multiprobe extensions and exploring the wide survey strategy



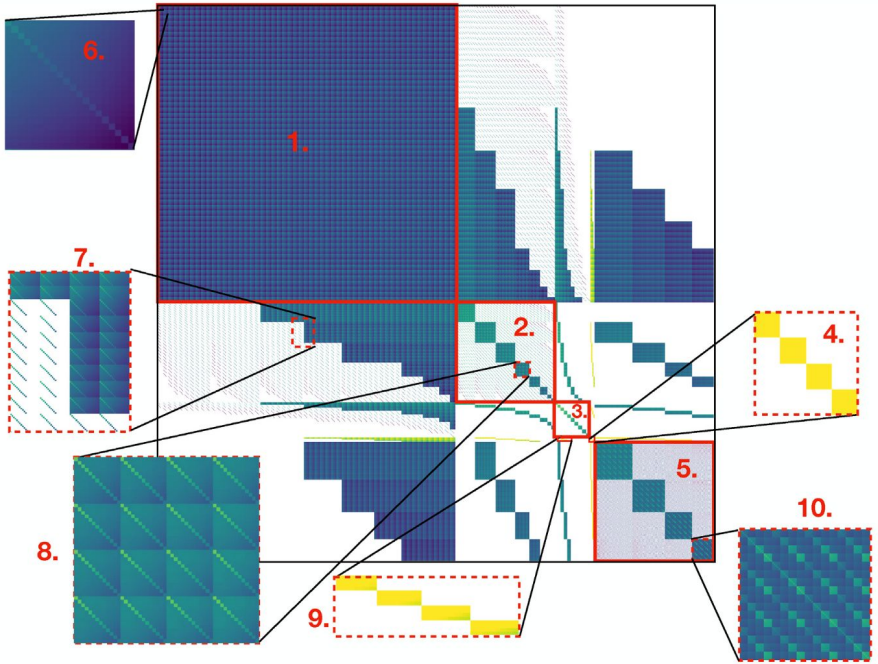


[Xu et al. (2021) arXiv: 2201.00739]

Summary

- A multi-probe analysis combining cosmic shear, photometric clustering, photometric galaxy-galaxy lensing, galaxy cluster number counts, galaxy cluster lensing and 3D BAO/RSD has shown that Roman HLS along can reach a standard DE FoM > 300, although more works are needed to increase the realism.
- A wide Roman HLS survey, e.g. use 5-months to cover LSST footprint in W-band, can generate space quality shape measurements for 95% of the LSST Y10 gold sample and has 4.5 times higher standard DE FoM than the reference HLS design, at the cost of systematic controls gain from multiband imaging.
- Synergy between Roman HLS and Simon Observatory CMB lensing can improve the constraining power on DE/MG models significantly. Meanwhile, systematics like galaxy bias and shear calibration bias can also get self-calibrated.
- The capabilities of Roman HLS enable a self-contained kinematic lensing survey, which is a novel weak lensing technique integrating image and spectrum dataset to estimate shear with high S/N. The reference HLS can gain huge constraining power on DE equation of state for free with the new KL technique applied.
- Note that the survey strategy of Roman is open for modification to maximize the science output given any new analysis technique/datasets are available.

Roman Multiprobe

Probe	Multiprobe FoM summary Individual	Cumulative
Cosmic shear	9.8	9.8
3×2	23.46	23.46
Clusters	3.86	31.56
RSD + BAO	8.19	89.54
SN Ia	24.62	300.11

Notes. Note that 3×2 includes cosmic shear. All FoMs assume a flat universe.