Roman Core Community Survey White Papers

Optimizing the Roman HLWAS

Roman Core Community Survey: High Latitude Wide Area Survey (Imaging)

Scientific Categories: Large scale structure of the universe

Submitting Authors: Tim Eifler (UArizona, timeifler@arizona.edu), Christopher Hirata (Ohio State University, hirata.10@osu.edu)

Co-authors/Endorsers: Rachel Bean (Cornell University), Jayashree Behera (Kansas State University), Karim Benabed (Institut d'astrophysique de Paris), Jonathan Blazek (Northeastern University), Jamie Bock (Caltech/JPL), Ami Choi (NASA GSFC), Brendan Crill (JPL), Olivier Doré (JPL/Caltech), Cyrille Doux (CNRS/IN2P3), Eric Gawiser (Rutgers University), Sven Heydenreich (UC Santa Cruz), Eric Huff (JPL), Shirley Ho (CCA, Flatiron Institute), Bhuvnesh Jain (UPenn), Buell T. Jannuzi (UArizona), Arun Kannawadi (Princeton University), Elisabeth Krause (UArizona), Anja von der Linden (Stony Brook University), Jia Liu (Kavli IPMU), Vivian Miranda (Stony Brook University), Hironao Miyatake (Nagoya University), Satoshi Miyazaki (Subaru, NAOJ), Paulo Montero-Camacho (Tsinghua U/PCL), Catalina Morales-Gutierrez (University of Costa Rica), Andrés A. Plazas Malagón (SLAC/ KIPAC), Anna Porredon (University of Edinburgh), Brant Robertson (UC Santa Cruz), Lado Samushia (Kansas State University), Robyn E Sanderson (UPenn), Tomomi Sunayama (UArizona), Masahiro Takada (Kavli IPMU), Ting Tan (LPNHE/CNRS), David Weinberg (Ohio State University)

Abstract:
We outline possible survey strategies for the imaging component of the Nancy Grace Roman Space Telescope (Roman) High Latitude Wide Area Survey (HLWAS) that consider synergies with ground-based experiments, most prominently Rubin Observatory's Legacy Survey of Space and Time (LSST).

The *reference design* for the Roman HLWAS ensures excellent systematics control by covering 2000 deg^2 in 4 bands (and the grism). Alternatively, Roman could cover the LSST area of 18,000 deg^2 in the W-band (i.e. the F146 filter spanning 0.93-2.00μm). While the latter strategy significantly boosts the statistical constraining power of Roman, it is also more susceptible to systematic effects, e.g., shear calibration and photo-z estimation.

The most promising way to increase statistical constraining power while retaining systematics control is a two-tier HLWAS: to split the time between a "medium" tier, which resembles the reference survey but with a reduced area, and a "wide" tier in a single filter. We outline several options for the wide tier option that cover the trade space of systematics control vs statistical information content.

If Vera Rubin and Nancy Grace Roman worked together…

Tim Eifler
Arizona Cosmology Lab
Steward Observatory / University of Arizona

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NANCY:
Next-generation All-sky Near-infrared Community surveY

Roman Core Community Survey Category: High Latitude Wide Area Survey

Scientific Categories: *Solar system astronomy; stellar physics and stellar types; stellar populations and the interstellar medium; galaxies; the intergalactic medium and the circumgalactic medium, supermassive black holes and active galaxies; large scale structure of the universe*

Submitting Authors: Jesse Han <jesse.han@cfa.harvard.edu>, Arjun Dey <arjun.dey@noirlab.edu>

Affiliation: Harvard-Smithsonian Center for Astrophysics, NOIRLab

https://asd.gsfc.nasa.gov/roman_wp_2023/

Roman Core Community Surveys will be designed in the coming 2 years

Notional Survey	Target region	Primary spectral elements	On-sky time in notional survey plan
High Latitude Wide Area Survey (core community survey)	Extragalactic sky, ~ 2000 deg^2	Y106, J129, H158, F184, and Grism	~ 24 months
High Latitude Time Domain (core community survey)	5-20 deg^2 in the continuous field of regard,.	TBD filters + Prism	~ 6 months
Galactic Bulge Time Domain (core community survey)	2 deg^2 in a low-extinction area near Galactic center	W149 filter (occasional use of other filters)	~ 13 months
General Astrophysics Surveys	Full sky is available	All WFI elements	~ 15 months
Coronagraph Instrument Tech Demo Observations	Selected nearby stars	Coronagraph Instrument	~ 3 months

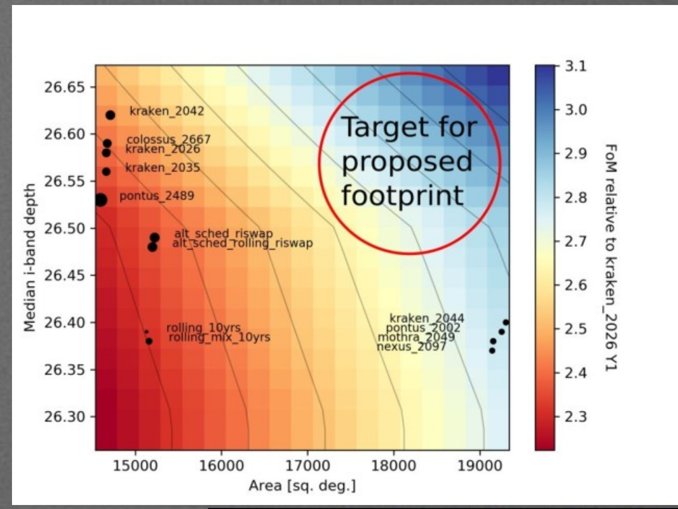
How do we optimize the Roman survey?

How do we explore synergies with other surveys, e.g. LSST?

We need simulated likelihood analyses…
many of them…

Multi-Probe Forecasts Roman+LSST

LSST survey scenario + Exposure Time Calculator *(Hirata ++ 2012)*
Creates realistic survey area, depth combination



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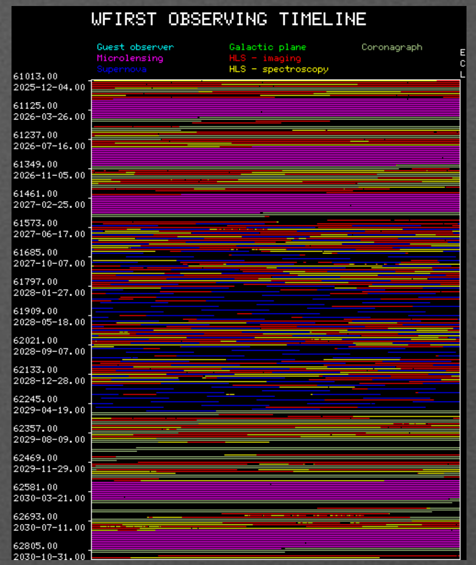
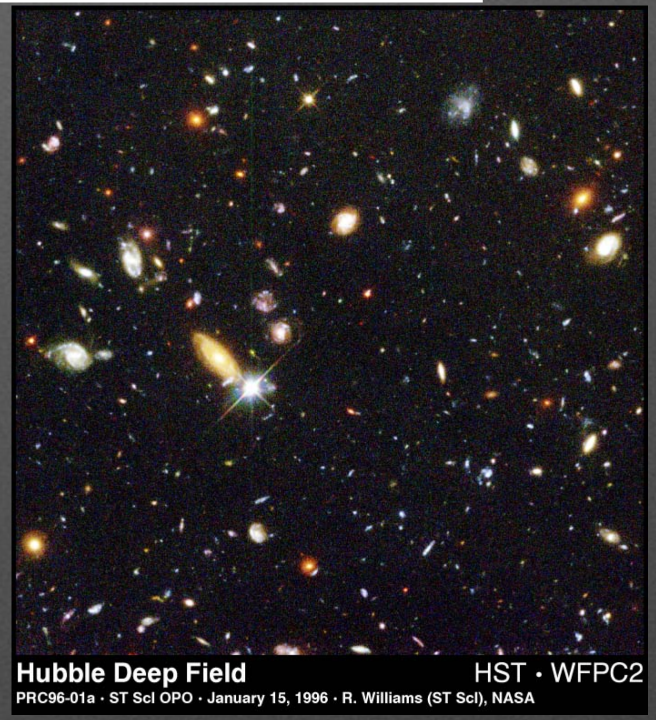
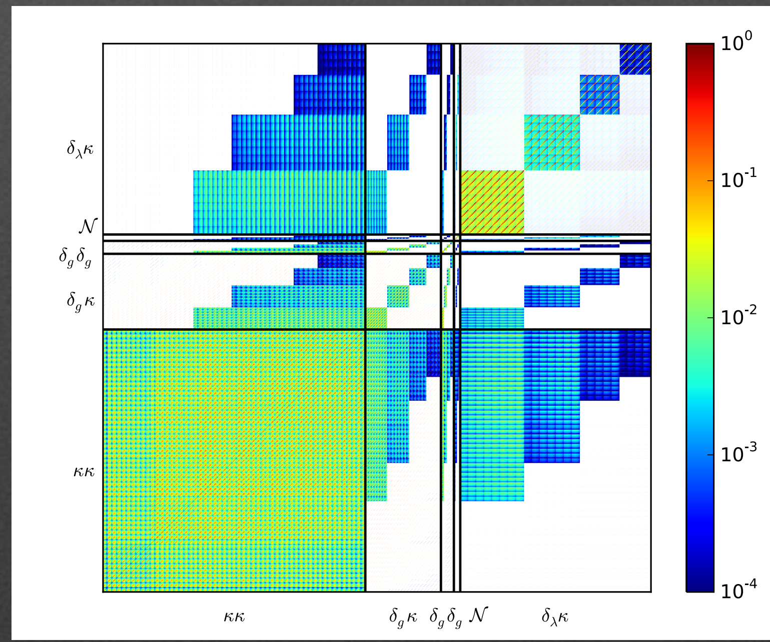


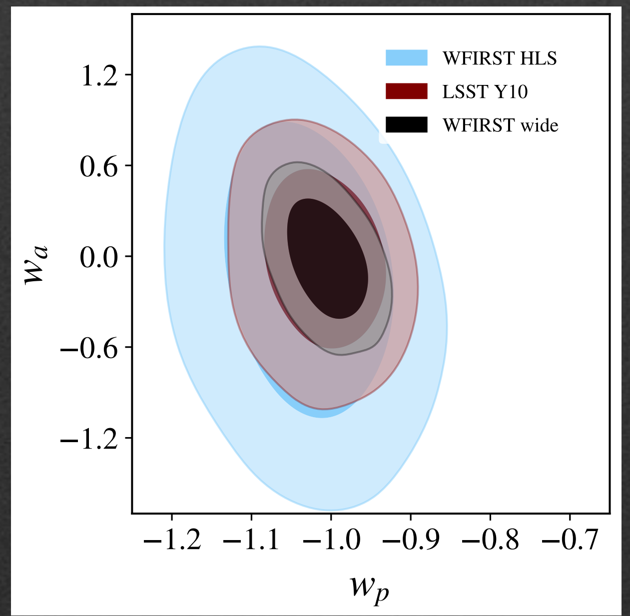
CANDELS Roman catalog *(Hemmati et al 2018)*
Extract “realistic” redshift distribution for lensing and clustering sample (also for galaxy clusters)



CosmoLike Multi-Probe Covariance
Krause & Eifler (2017)



CosmoLike Likelihood Analysis
Eifler, Miyatake, Krause et al (2021)
Eifler, Simet, Krause et al (2021)



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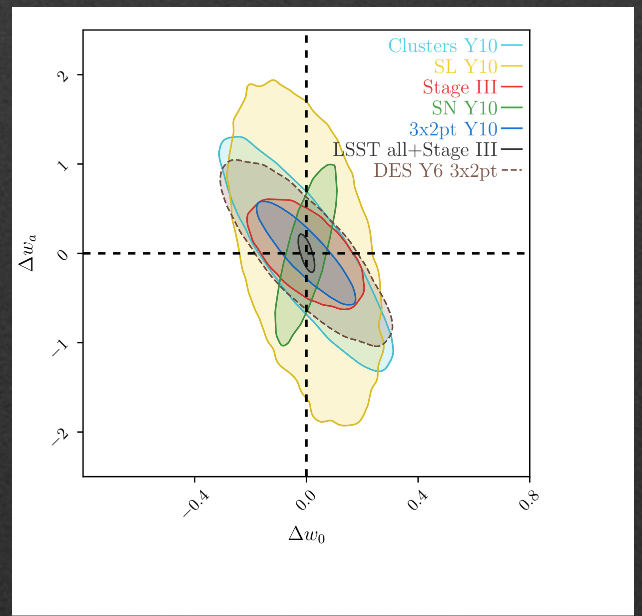
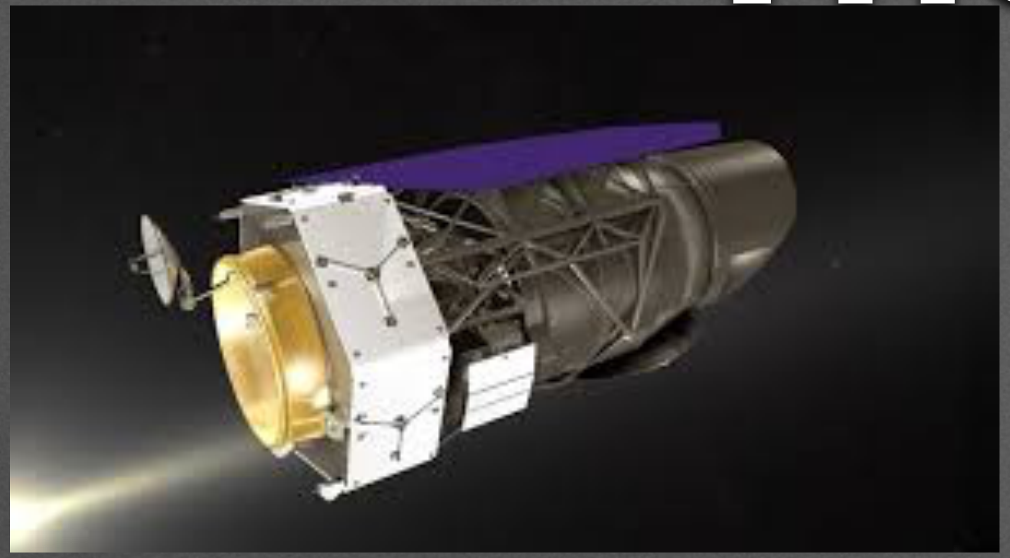


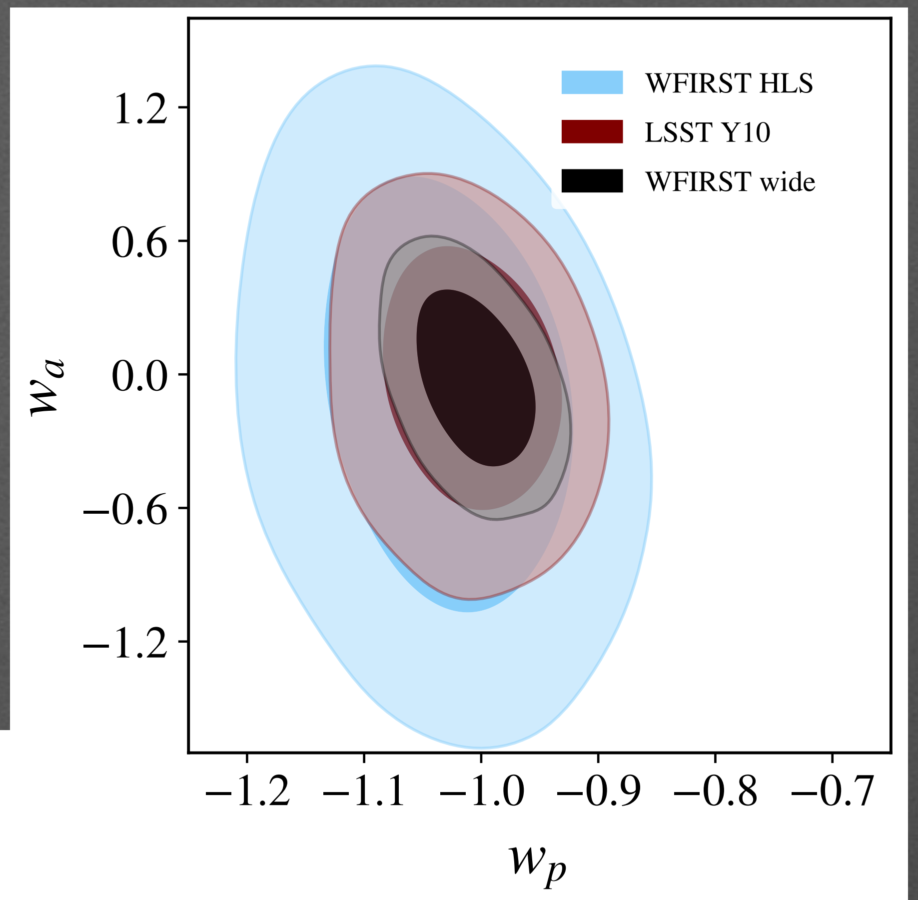
Same code used in the LSST-DESC SRD:
DESC, Mandelbaum, Eifler et al 2019

The challenge of forecasting



reduced data and catalogs → summary statistics →

→



Independent probes
e.g., SN1a as priors

Large model vector (CMB+LSS)
Self-consistent modeling of all observables as a function of
1) cosmological parameters (~10)
2) nuisance parameters (XXX)

large data vector

posterior probability

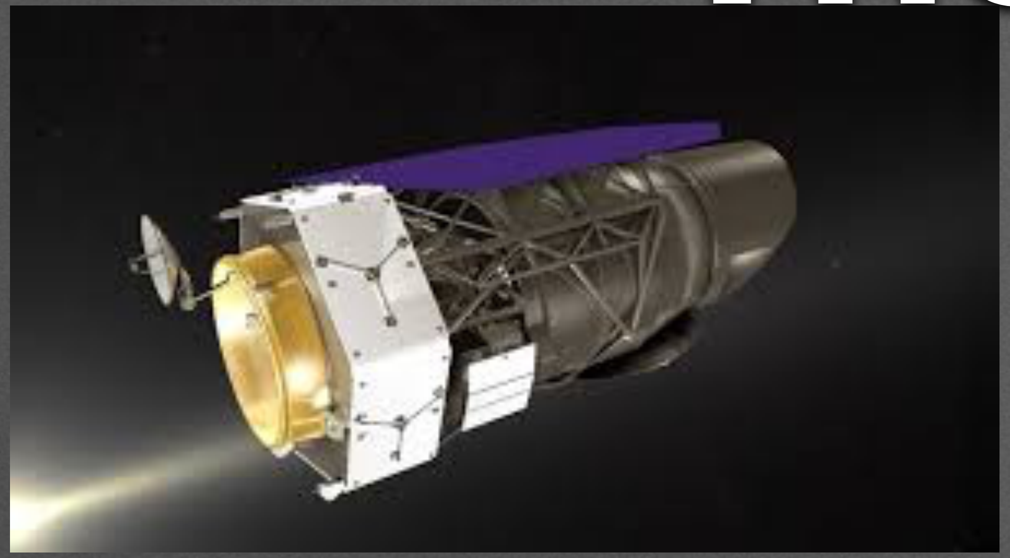
$$p\left(\boldsymbol{\pi}|\hat{\mathbf{d}}\right) \propto p\left(\boldsymbol{\pi}\right)\mathcal{L}\left(\hat{\mathbf{d}}|\mathbf{m}\left(\boldsymbol{\pi}\right), C\right)$$

Enhanced modeling via
- Observations
- Simulations
- Theory

Statistics I - Likelihood function
- Multivariate Gaussian vs other parameterizations
- Non-parametric forms
- Approximate Bayesian Computation

Statistics II - Covariances
- cosmology dependent Signal + constant Noise
- large and complicated, non-(block) diagonal
- different methods for derivation

The Challenge of forecasting



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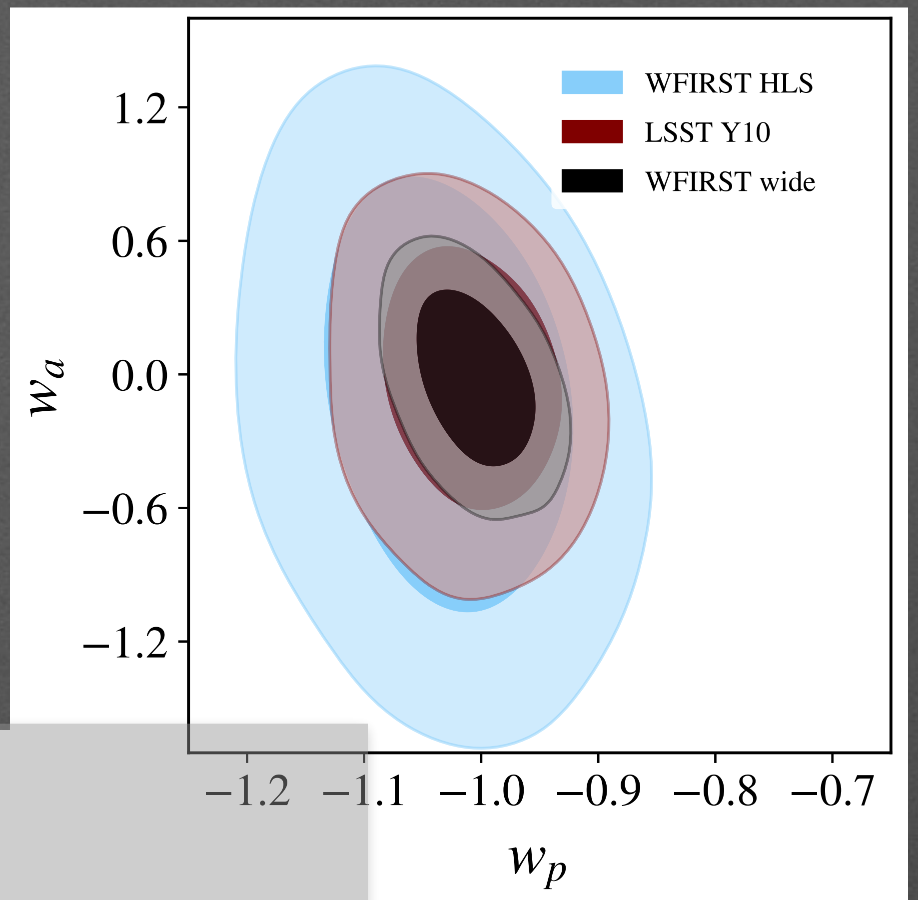

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Simulated Multi-Probe Analysis

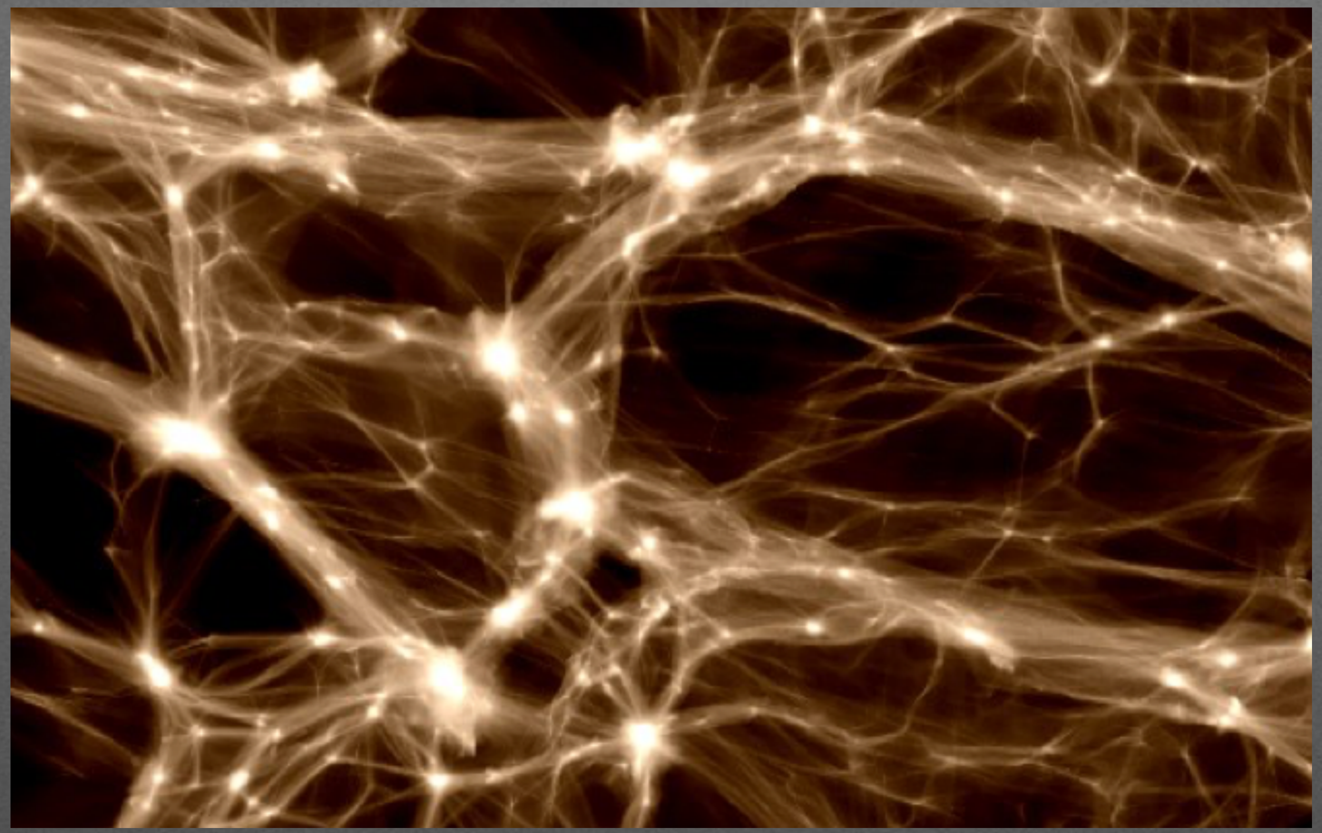
- Cosmic shear
- Galaxy-Galaxy Lensing
- Galaxy Clustering

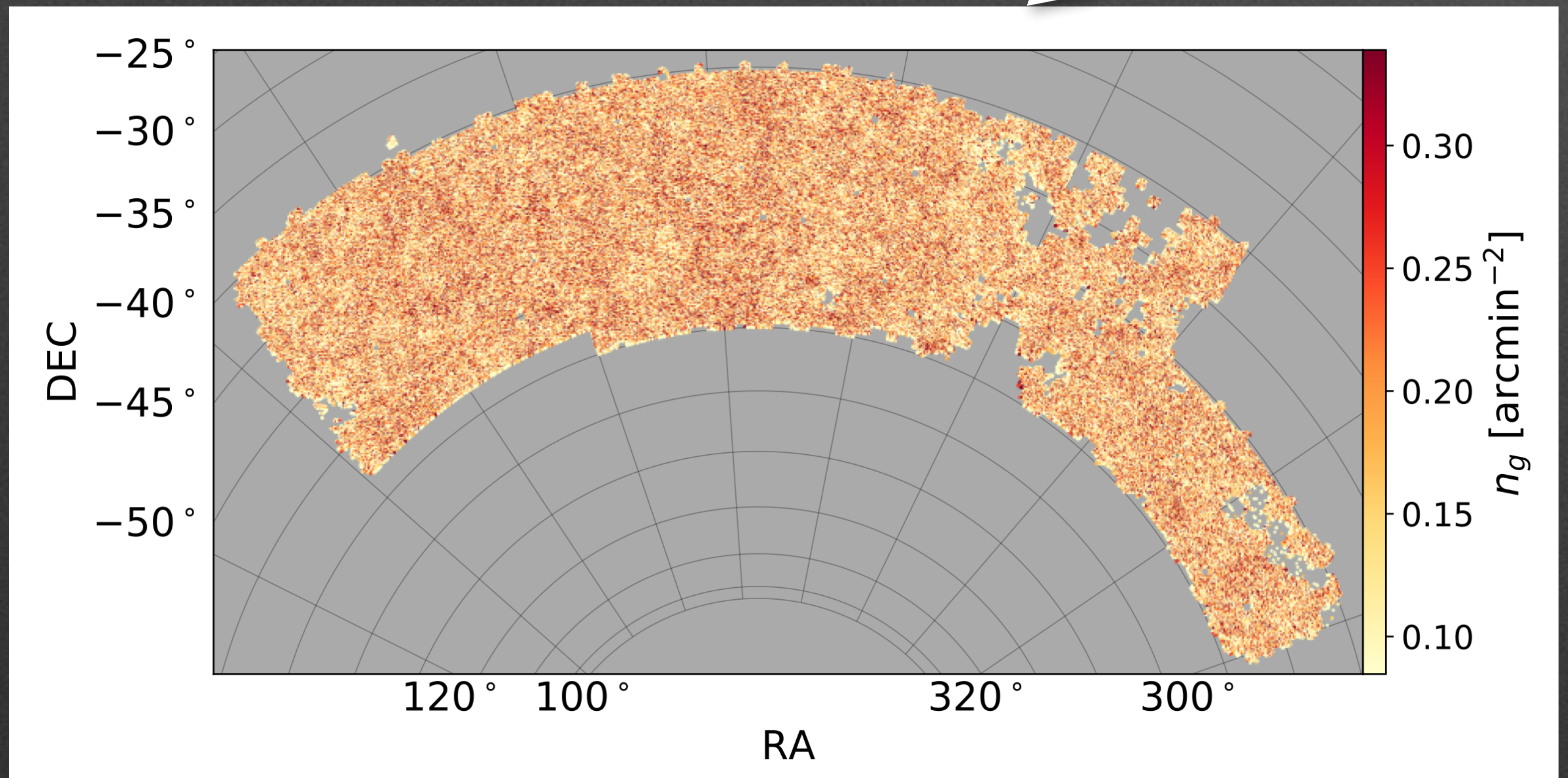
We use these

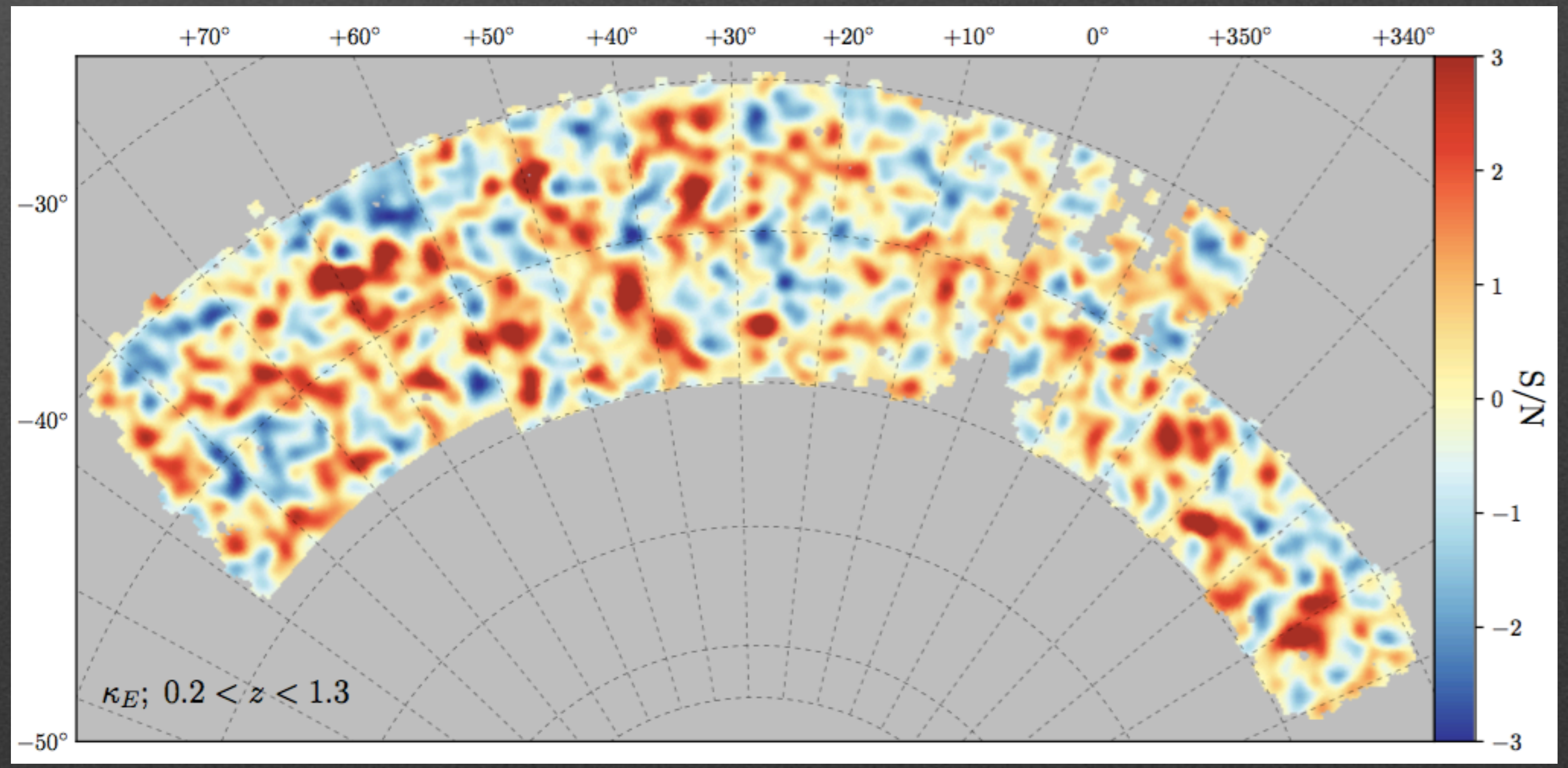
- Cluster Clustering
- Peak Statistics
- Voids
- Magnification
- Higher-order statistics (many position, shape, magnification combinations are possible)
- Cluster Number Counts
- Cluster Weak Lensing
- Galaxy Clustering (Spectro)
- SN1a
- Many correlations with CMB possible

We ignore these (in this particular analysis)

Joint clustering and weak lensing (3x2pt)







galaxies x galaxies:
angular clustering

galaxies x lensing:
galaxy-galaxy lensing

lensing x lensing:
cosmic shear

Problem 1: Probes have systematics

- Weak Lensing (cosmic shear)
  - 10 tomography bins
  - 25 l bins, 30 < l < 4000
- Galaxy clustering (photometric)
  - 10 tomography bins (different from sources, higher number density)
- Galaxy-galaxy lensing
  - galaxies from clustering (as lenses) with shear sources

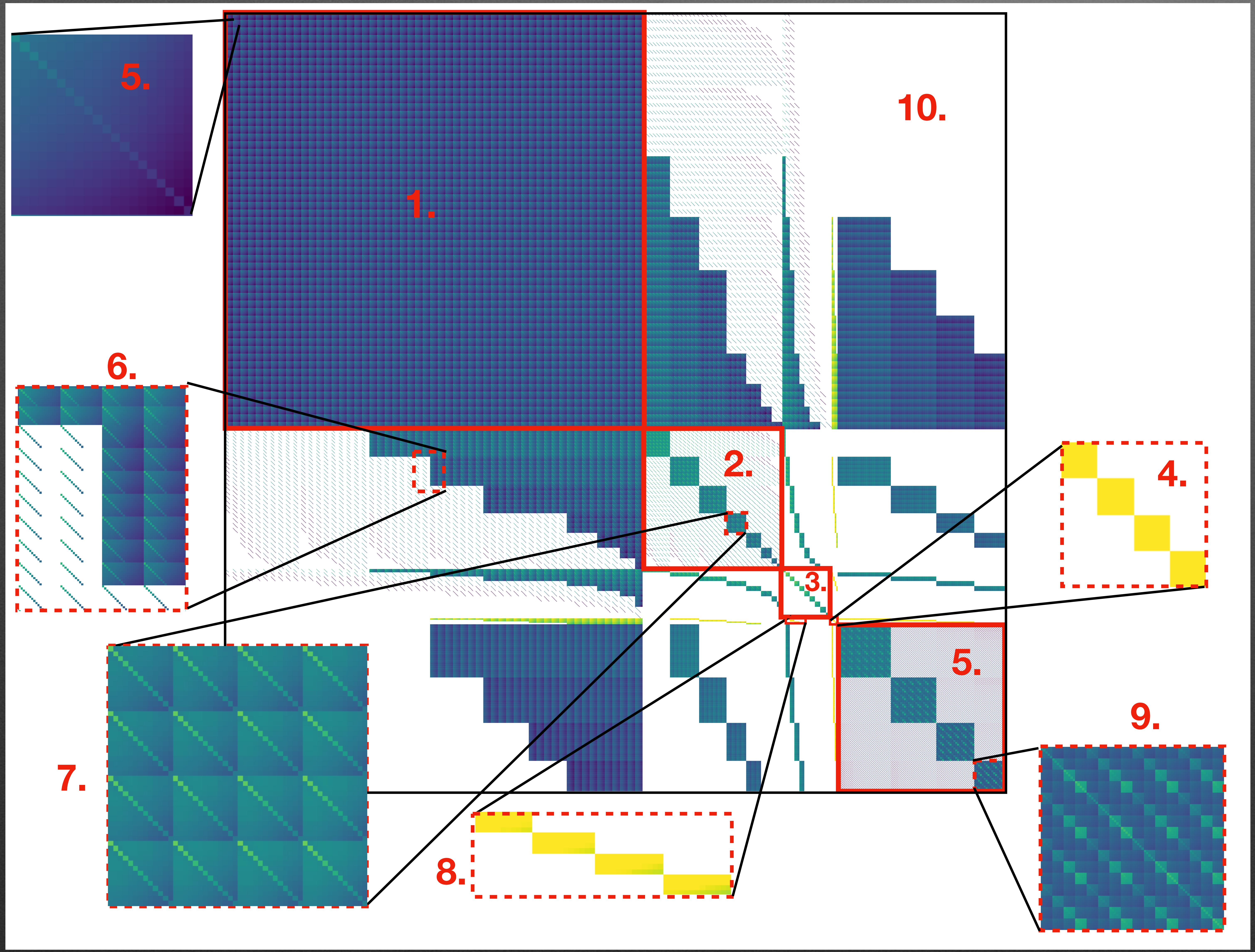
Shear calibration
Photo-z (sources)
Intrinsic alignment
Baryons

Photo-z (lenses)
Galaxy bias

Many analysis choices are necessary beyond "choosing probes": (e.g. scales, redshifts, binning, galaxy samples, etc) that depend on:

- data quality
- **modeling precision/accuracy of physics, systematics, statistical errors <u>in finite time</u>**

Problem 2: Probes are correlated



1. Cosmic Shear

2. Galaxy-Galaxy Lensing

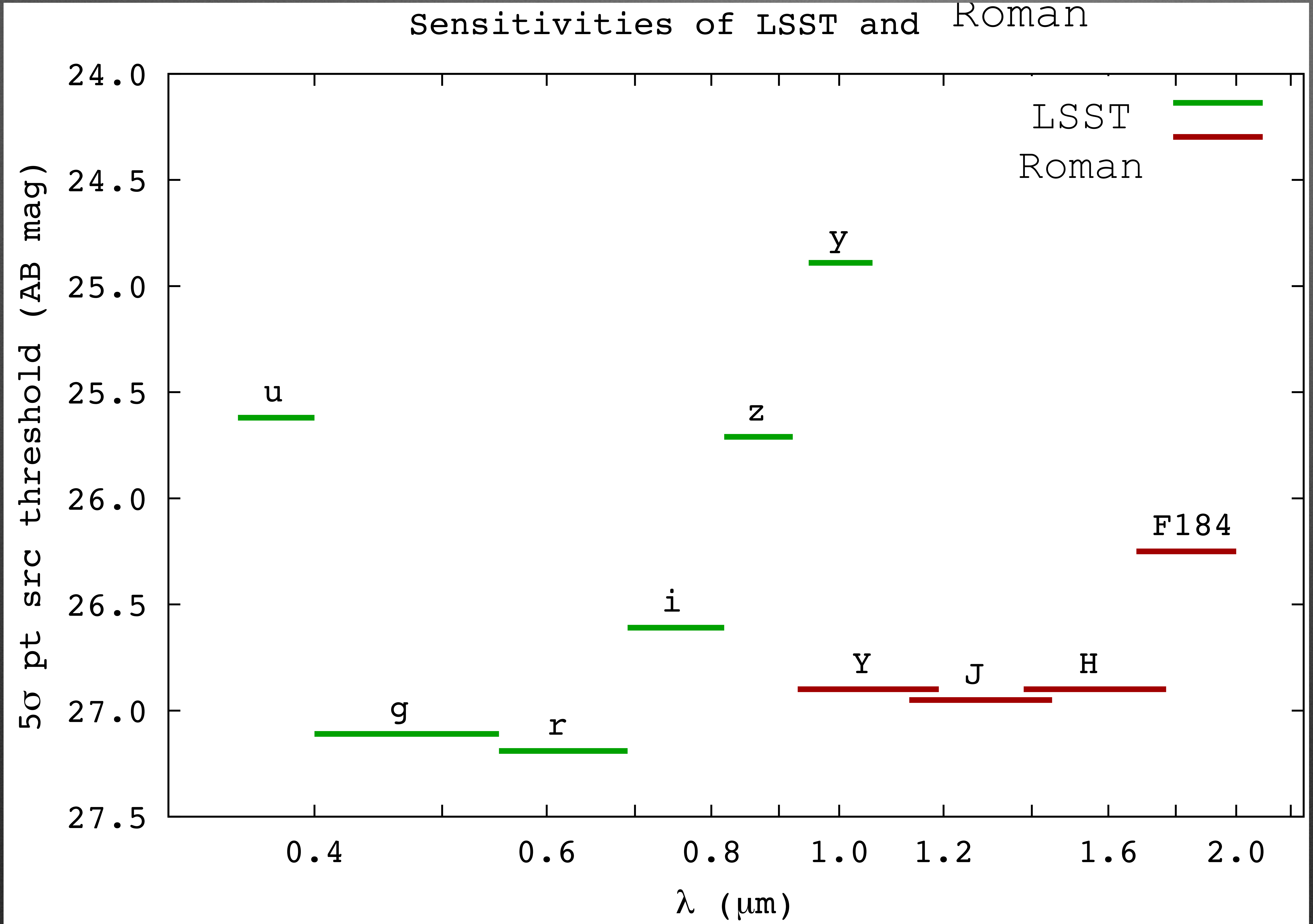
3. Galaxy Clustering

4. Cluster Number Counts

5. Cluster Lensing

Let’s explore synergies of Roman and LSST…

Roman+LSST overlap in wavelength



Credit: Chris Hirata

Roman Space Telescope Imaging Capabilities			
Telescope Aperture (2.4 meter)	**Field of View** (45′x23′; 0.28 sq deg)	**Pixel Scale** (0.11 arcsec)	**Wavelength Range** (0.5-2.3 μm)

Filters	**F062**	**F087**	**F106**	**F129**	**F146**	**F158**	**F184**	**F213**
Wavelength (μm)	0.48-0.76	0.76-0.98	0.93-1.19	1.13-1.45	0.93-2.00	1.38-1.77	1.68-2.00	1.95-2.30
Sensitivity (5σ AB mag in 1 hr)	28.5	28.2	28.1	28.0	28.3	28.0	27.5	26.2

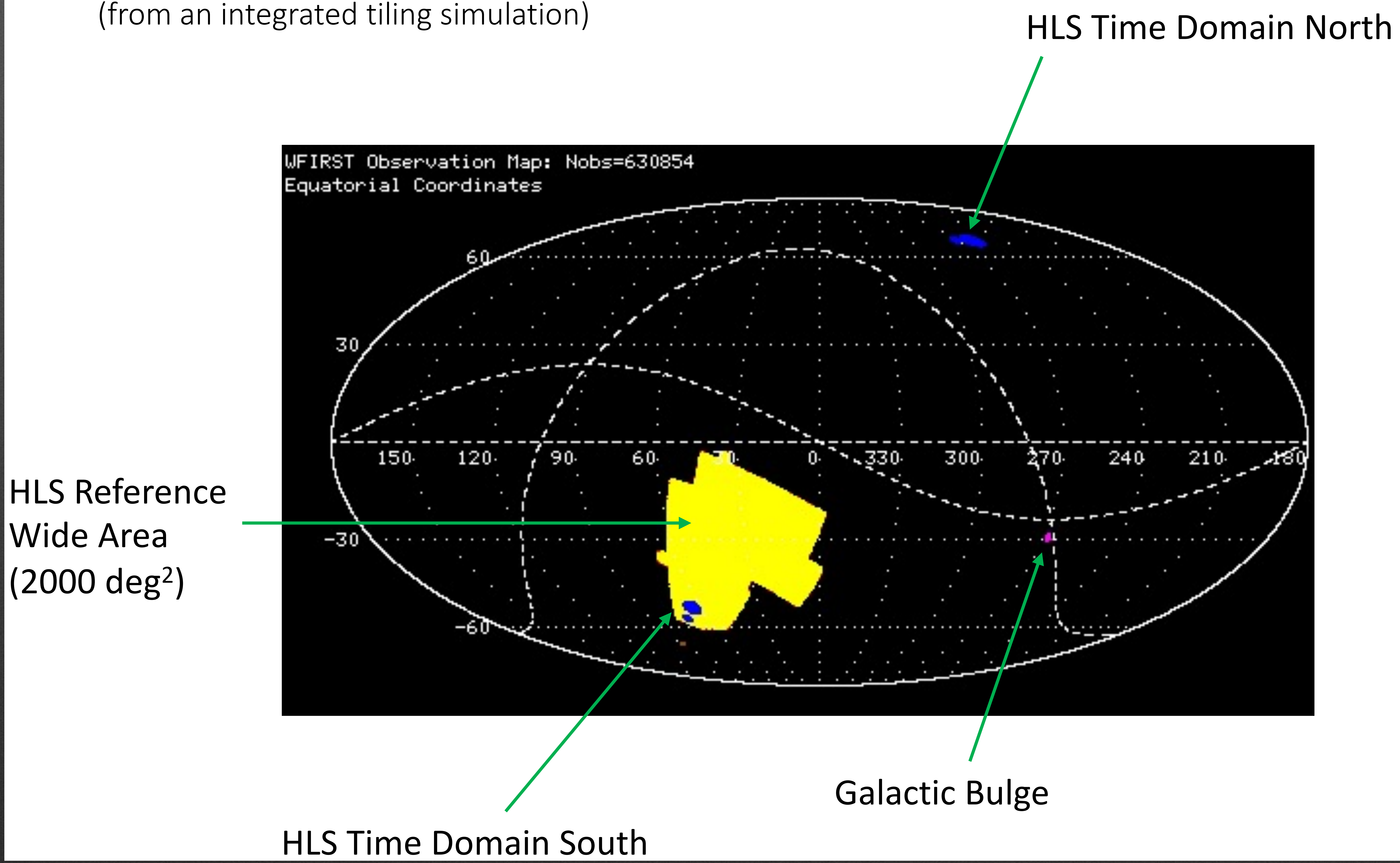
Roman Space Telescope Spectroscopic Capabilities				
	Field of View (sq deg)	**Wavelength (μm)**	**Resolution**	**Sensitivity (AB mag) (10σ per pixel in 1hr)**
Grism	0.28 sq deg	1.00-1.93	461	20.5 at 1.5 μm
Prism	0.28 sq deg	0.75-1.80	80-180	23.5 at 1.5 μm

Roman Space Telescope Coronagraphic Capabilities					
	Wavelength (μm)	**Inner Working Angle (arcsec)**	**Outer Working Angle (arcsec)**	**Detection Limit***	**Spectral Resolution**
Imaging	0.5-0.8	0.15 (exoplanets) 0.48 (disks)	0.66 (exoplanets) 1.46 (disks)	10^{-9} contrast (after post-processing)	47-75
Spectroscopy	0.675-0.785				

https://roman.gsfc.nasa.gov/science/Roman_Reference_Information.html

Roman reference design survey

(from an integrated tiling simulation)



Are there alternatives relying on ground based data?

Let's explore Roman strategies based on synergies with LSST

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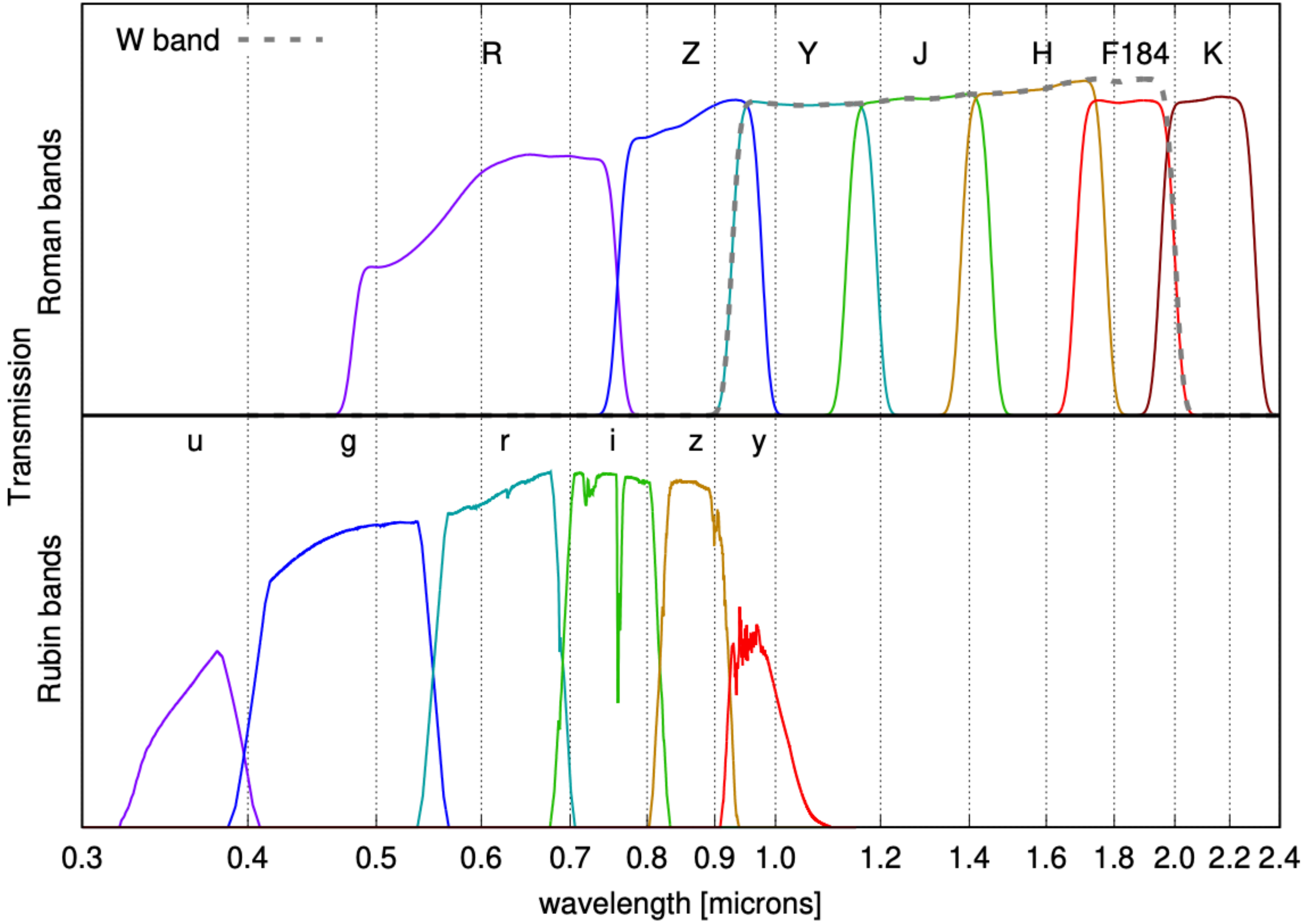
Roman “wide survey” idea - Synergies with Rubin



This concept combines the Roman W-band with the 6 LSST bands

The LSST Dark Energy Science Collaboration (DESC) Science Requirements Document

The LSST Dark Energy Science Collaboration, Rachel Mandelbaum, Tim Eifler, Renée Hložek, Thomas Collett, Eric Gawiser, Daniel Scolnic, David Alonso, Humna Awan, Rahul Biswas, Jonathan Blazek, Patricia Burchat, Nora Elisa Chisari, Ian Dell'Antonio, Seth Digel, Josh Frieman, Daniel A. Goldstein, Isobel Hook, Željko Ivezić, Steven M. Kahn, Sowmya Kamath, David Kirkby, Thomas Kitching, Elisabeth Krause, Pierre-François Leget, Philip J. Marshall, Joshua Meyers, Hironao Miyatake, Jeffrey A. Newman, Robert Nichol, Eli Rykoff, F. Javier Sanchez, Anže Slosar, Mark Sullivan, M. A. Troxel

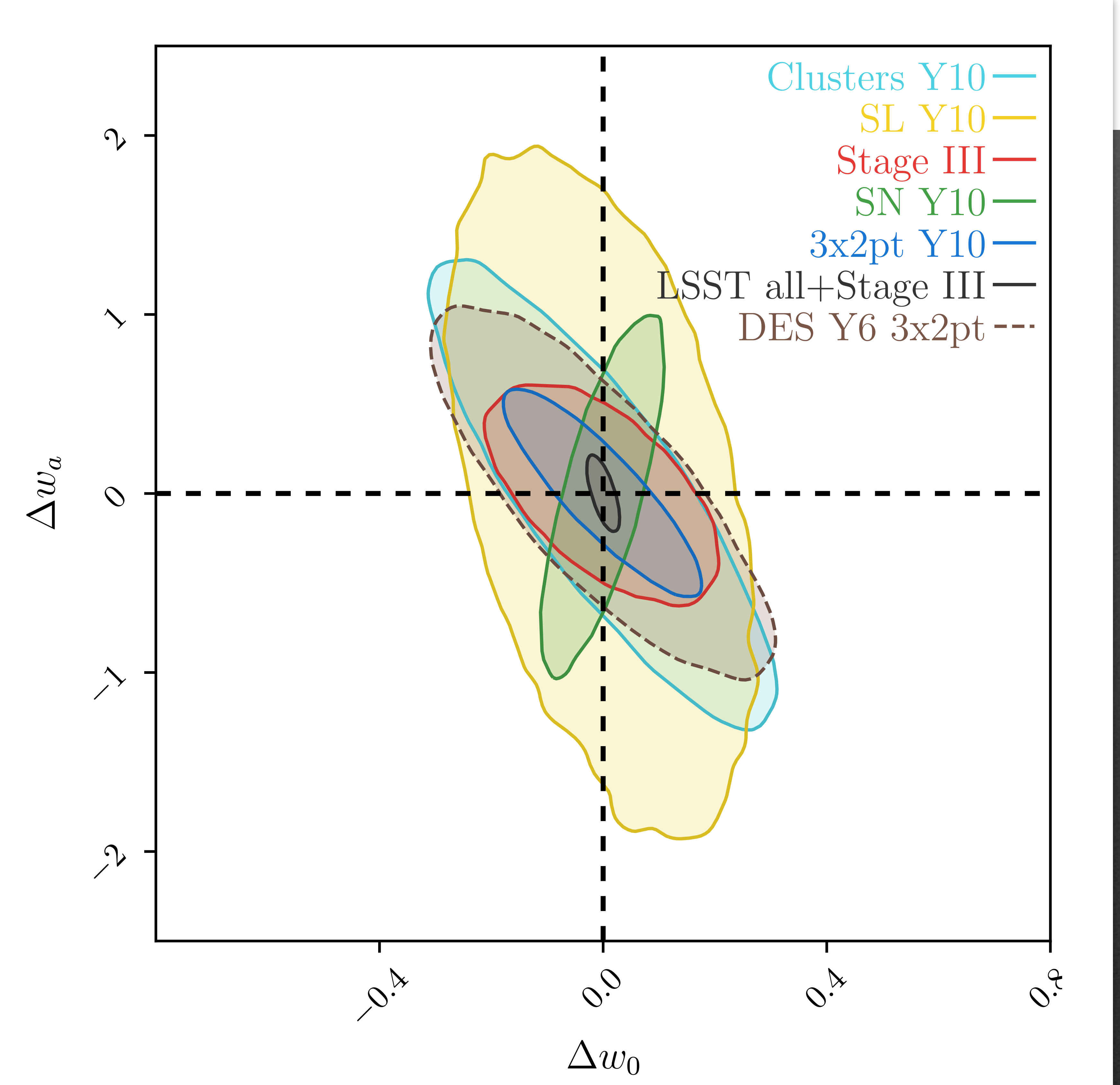
(Submitted on 5 Sep 2018)

The Large Synoptic Survey Telescope (LSST) Dark Energy Science Collaboration (DESC) will use five cosmological probes: galaxy clusters, large scale structure, supernovae, strong lensing, and weak lensing. This Science Requirements Document (SRD) quantifies the expected dark energy constraining power of these probes individually and together, with conservative assumptions about analysis methodology and follow-up observational resources based on our current understanding and the expected evolution within the field in the coming years. We then define requirements on analysis pipelines that will enable us to achieve our goal of carrying out a dark energy analysis consistent with the Dark Energy Task Force definition of a Stage IV dark energy experiment. This is achieved through a forecasting process that incorporates the flowdown to detailed requirements on multiple sources of systematic uncertainty. Future versions of this document will include evolution in our software capabilities and analysis plans along with updates to the LSST survey strategy.

Comments: 32 pages + 60 pages of appendices. This is v1 of the DESC SRD, an internal collaboration document that is being made public and is not planned for submission to a journal. Data products for reproducing key plots are available at the LSST DESC Zenodo community, this https URL; see "Executive Summary and User Guide" for instructions on how to use and cite those products

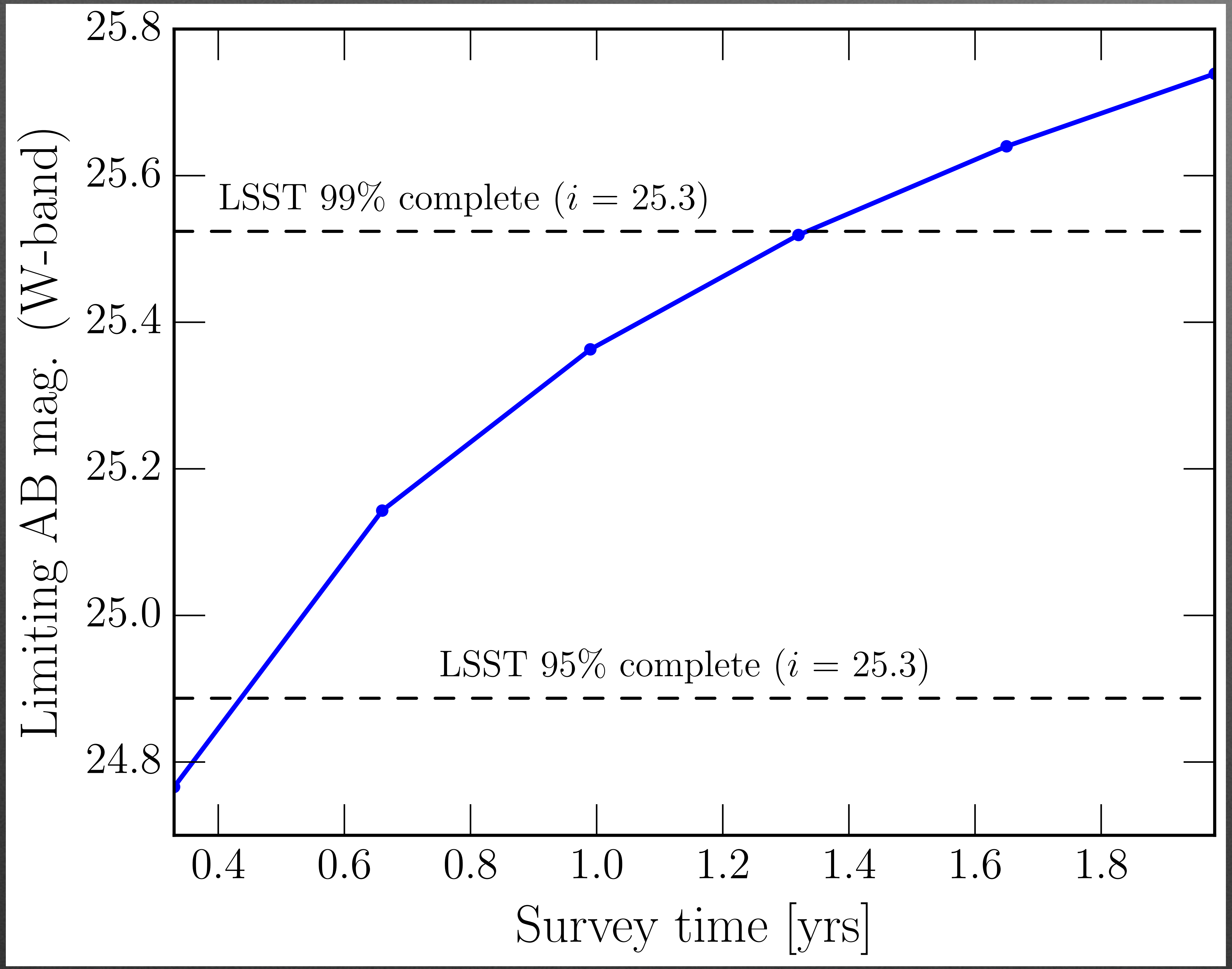
Subjects:

Cite as:

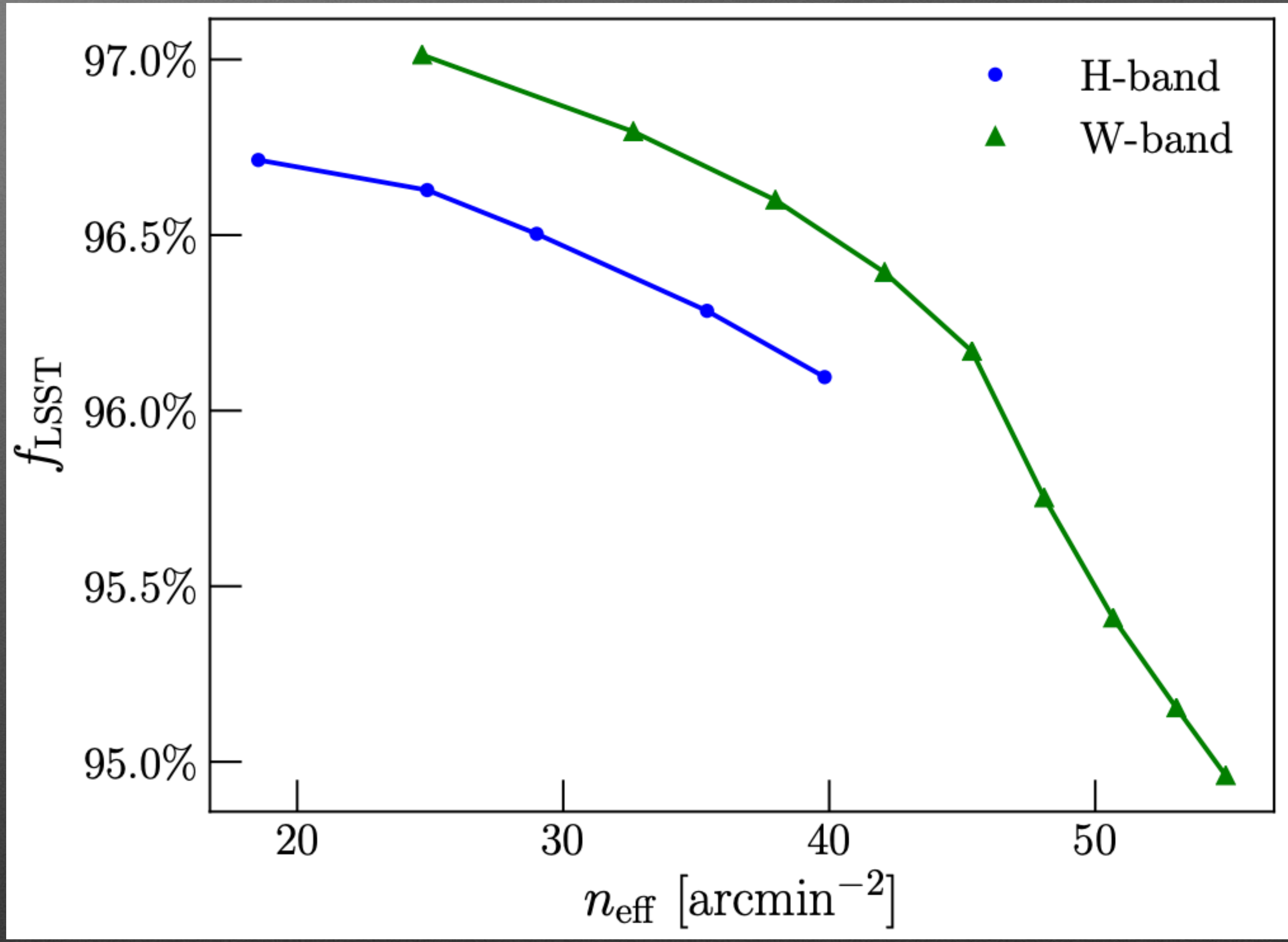


- Many code aspects have improved since the DESC SRD, e.g. the below includes:
  - baryonic physics uncertainty models
  - 10 tomo bins for lenses and sources
  - Full MCMC analysis
  - More complex IA model
  - Different galaxy lens samples
  - Train NNs to run 1000s of simulated analyses in short time

Explore Roman W-band Wide Survey, 18000 deg^2

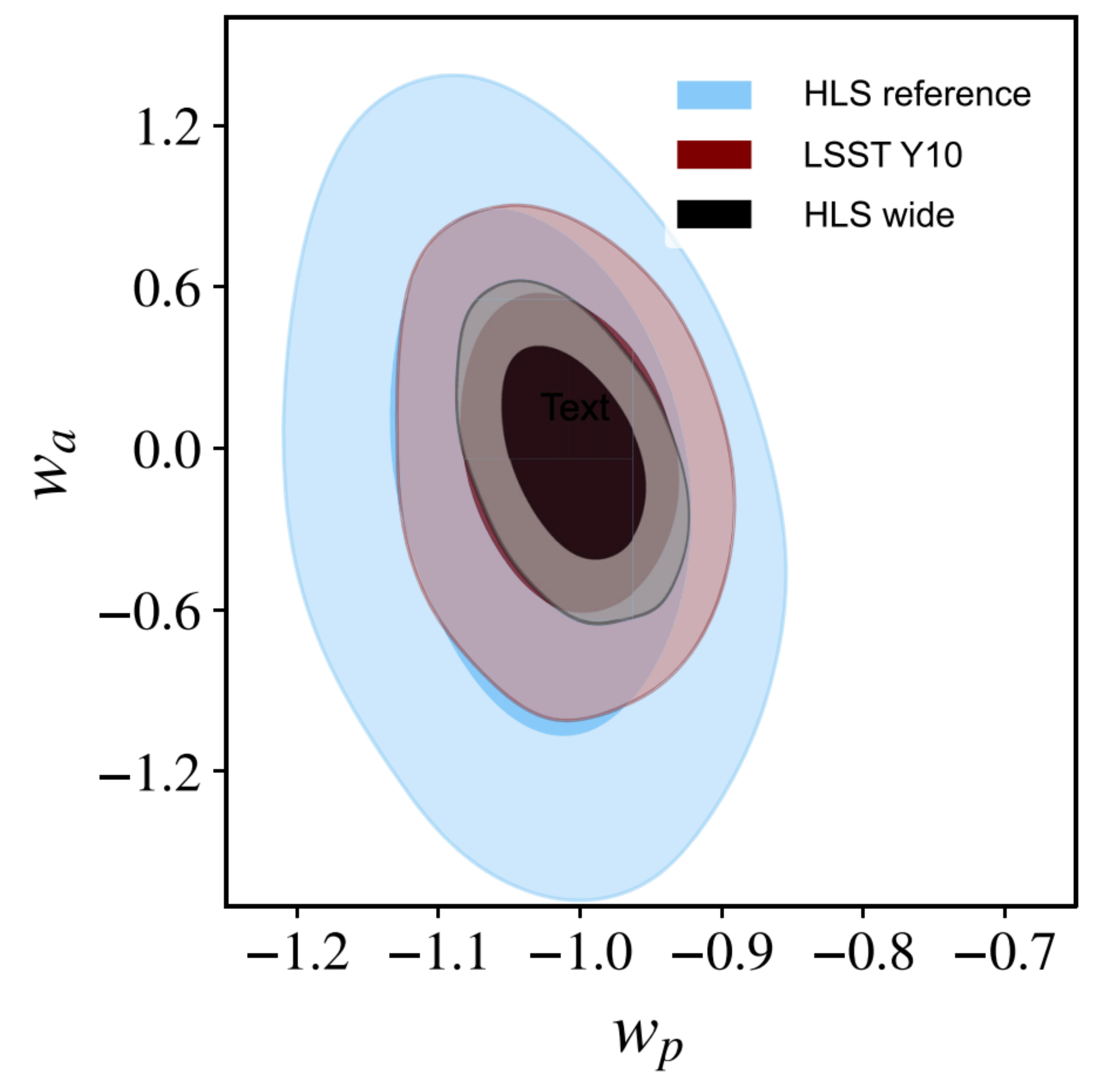


In 5 months Roman can cover LSST area in the W-band with 95% LSST completeness



Fraction of LSST galaxies with good multi-band photometry as a function of n_gal of a HLS WL sample, based on the CANDELS catalog.

Multi-probe Roman+LSST



1.5 year Roman W-band survey+LSST
Analysis is 3x2pt only, (no clusters, spec-z, SN)

Includes 49 dims of systematics modeling:

- Shear calibration (10 params)
- Galaxy bias (10 params)
- Photo-z (22 params)
- Intrinsic Alignment (4 params)
- Baryons (3 params)

Roman wide + LSST analysis assumes worse systematics than reference survey

FoM (Roman wide + LSST) = 2.4 x FoM (LSST only)

FoM (Roman wide + LSST) = 5.5 x FoM (Roman Reference survey)

Two-tier survey idea

- **Goal:** Get the best of both worlds (systematics control and statistical power)
- **Medium tier:** A reduced size reference survey (~1000 deg^2) that serves as an anchor for systematics control, preserving multi-band photometry, grism overlap, dithering strategy.
- **Wide tier:** This should overlap with LSST to obtain photo-z’s and still allow for exquisite shape measurements. Various options exist:

Two-tier survey idea

Option 1: A wide layer done in the H band with the 2-pass Reference survey strategy. The H band would be chosen because it avoids the thermal background of F184, but has better sampling properties than Y and J. This choice is relatively conservative, in that it recovers full sampling using IMCOM [24] and enables übercalibration using the cross-linked survey strategy. It can use the same data processing tools with similar settings as the medium-tier survey, and would serve as 1 of the 4 bands if the decision were made to increase the area of the medium tier in an extended mission. There will be enhanced photo-z scatter due to the 1.06–1.38 μm gap in photometric coverage; the source redshift distributions in the wide layer would have to be calibrated from the medium layer using the mapping from the full color space to the lower-dimensionality $ugrizyH$. The principal disadvantage is that the 1-band survey speed is only $\sim 4\times$ faster than the medium tier 4-band survey speed.

Option 2: A variant is to do the wide layer in the H band with reduced dithers (one full pass, and only a sparse second pass for cross-linking) to save time. The disadvantage is that full sampling is not recovered, so in addition to calibrating the effect on photo-zs of having only some of the bands, we would also have to calibrate the undersampling effects.

Option 3: The fastest weak lensing survey possible with Roman is to use the W filter with shorter exposures. This opens the exciting possibility of observing the full extragalactic LSST footprint. However it also poses the greatest challenge for systematics: in addition to needing to calibrate $ugrizyW$ photo-zs and undersampling effects from the 4-band layer, we would need to calibrate the chromatic astrometric + PSF effects over the 0.93–2.00 μm bandpass.

Two-tier survey idea

Case	band	Zodi brightness [pole=1]	source n_{eff} [arcmin^{-2}]	z_{med}	5σ pt src depth [mag AB]
Reference Survey (2000 deg^2/yr)	F184	1.5	25	0.9	26.1
	H	1.5	36	1.0	26.7
	J	1.5	35	1.0	26.8
	Y	1.5	(28)	(0.8)	26.7
	J+H	1.5	46	1.0	27.1
Wide tier, Option 1 (8000 deg^2/yr)	H	1.5	36	1.0	26.7
	H	2.5	32	1.0	26.5
Wide tier, Option 2 (13000 deg^2/yr)	H	1.5	(29)	(0.9)	26.4
	H	2.5	(26)	(0.9)	26.2
Wide tier, Option 3 (13000 deg^2/yr)	W	1.5	(44)	(1.0)	27.1
	W	2.5	(38)	(1.0)	26.9

Summary

- HLWAS reference survey (2000 deg^2) is designed for exquisite systematics control

- 1.5 year Roman W-band + LSST coverage can increase FoM by a factor of 5.5 over reference survey (even with degraded systematics)

- Wide Roman covering LSST area to LSST Y10 WL depth (95%) can be done in 4-5 months with the W-Band

- Proposed idea is a Two-Tier Roman HLWAS survey:
  1) medium tier: similar to reference survey (anchor for systematics)
  2) wide tier: several options from 5000-13000 deg^2 that need to be explored further