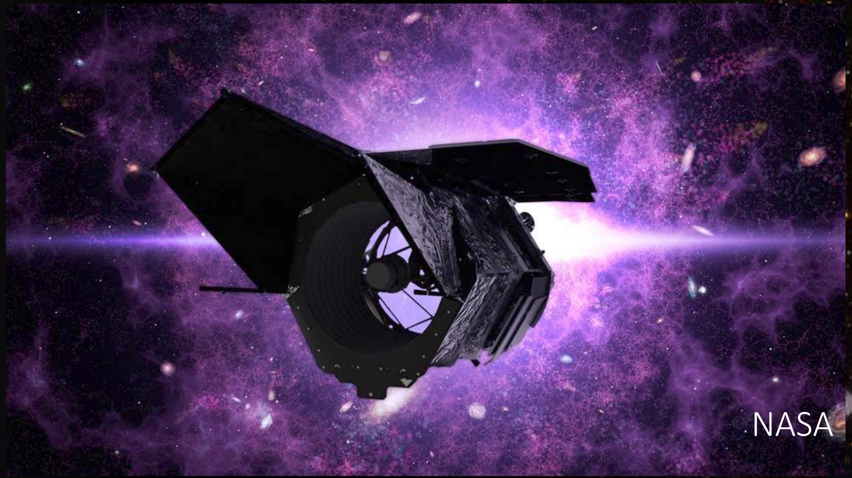
Cosmology with the Nancy Grace Roman High Latitude Wide Area Survey



Ami Choi

Caltech

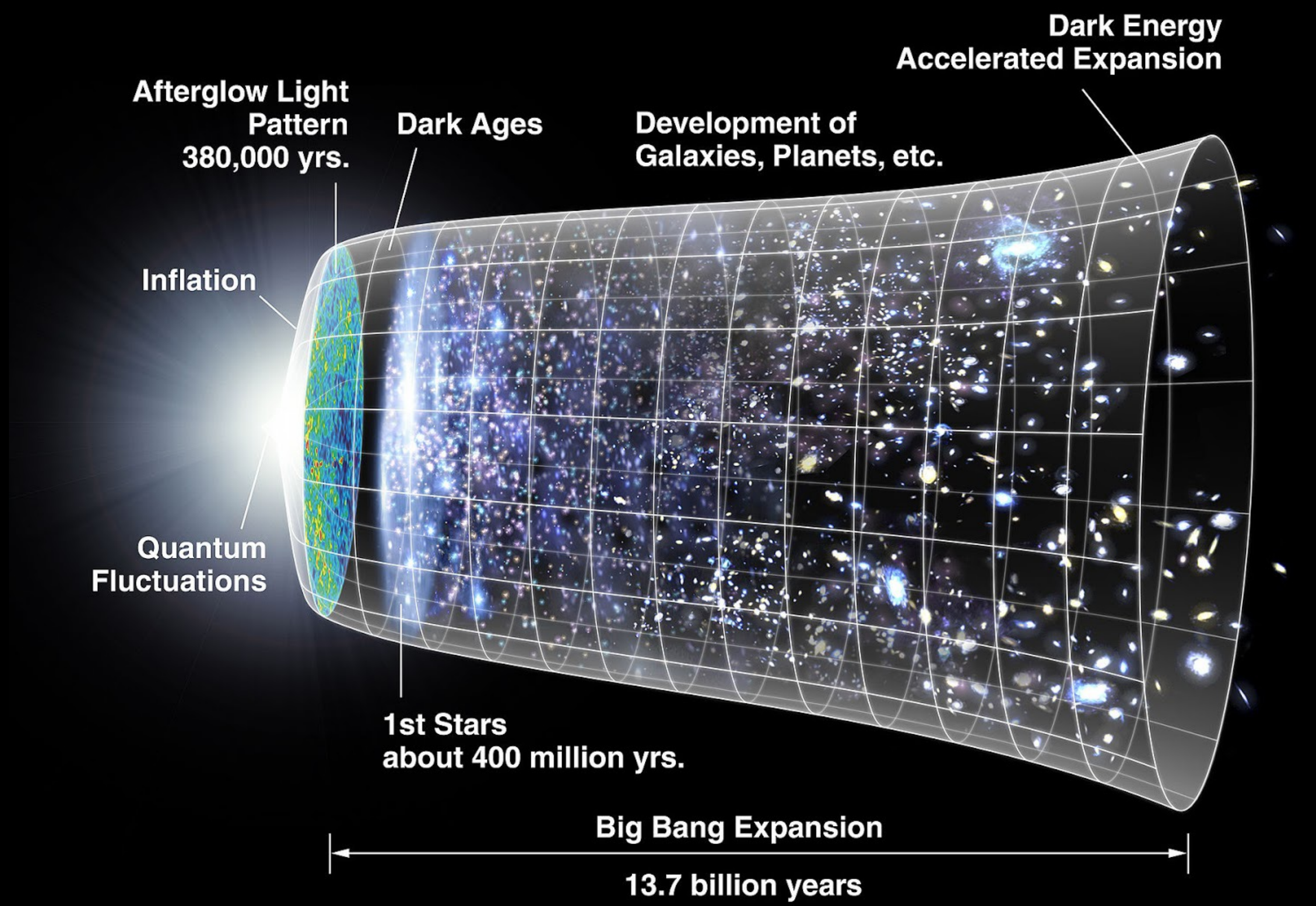
on behalf of the Cosmology Science Investigation Team++

Roman Cosmology Virtual Seminar

January 27, 2022

Simulated image: M. Troxel

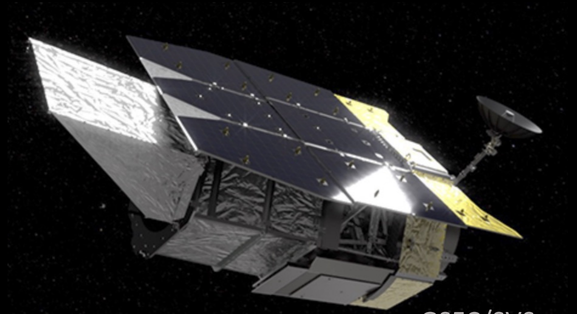
What drives the accelerated expansion of the Universe?



NASA/WMAP

Cosmological constant?

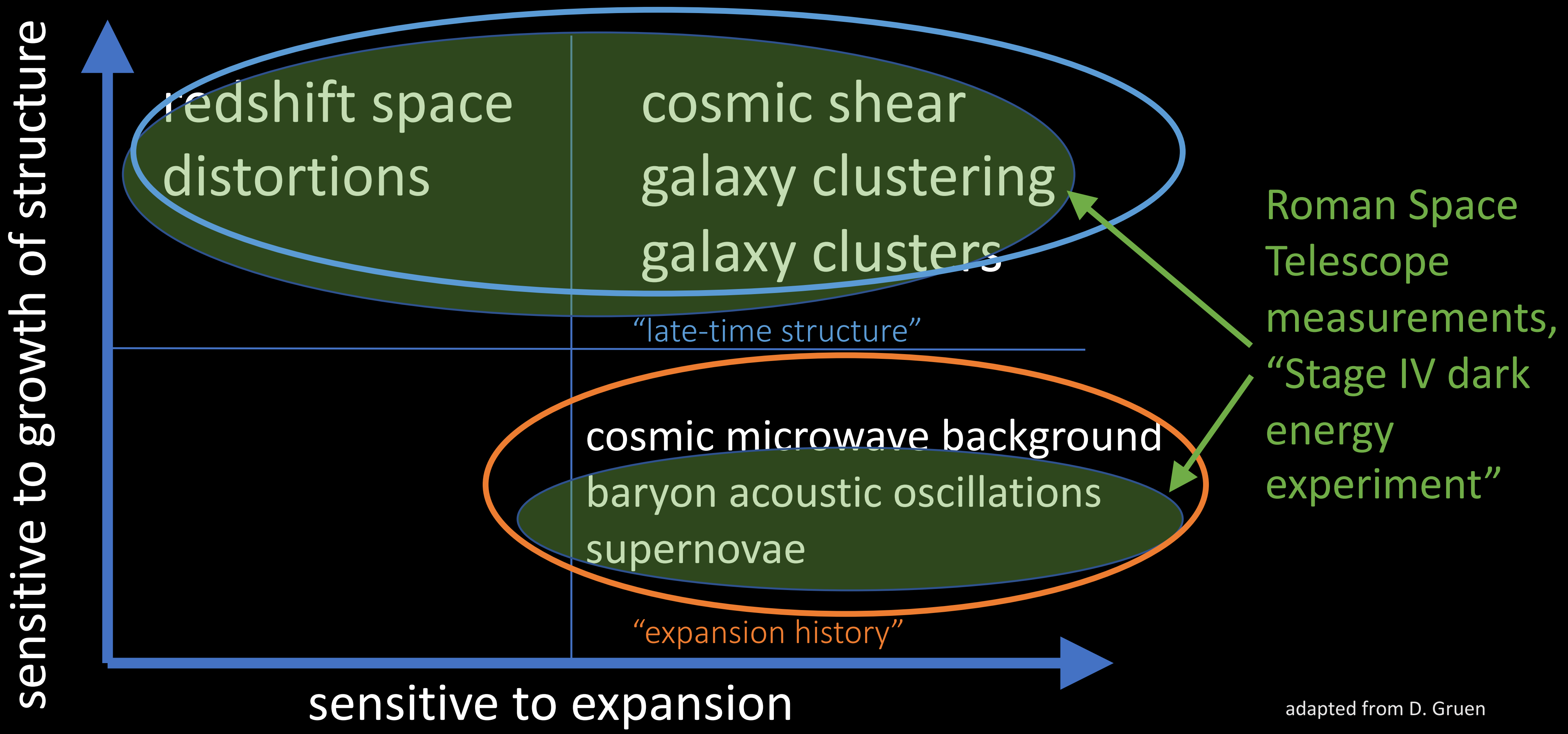
Time-varying equation of state parameter?



GSFC/SVS

Departure from General Relativity on cosmological scales?

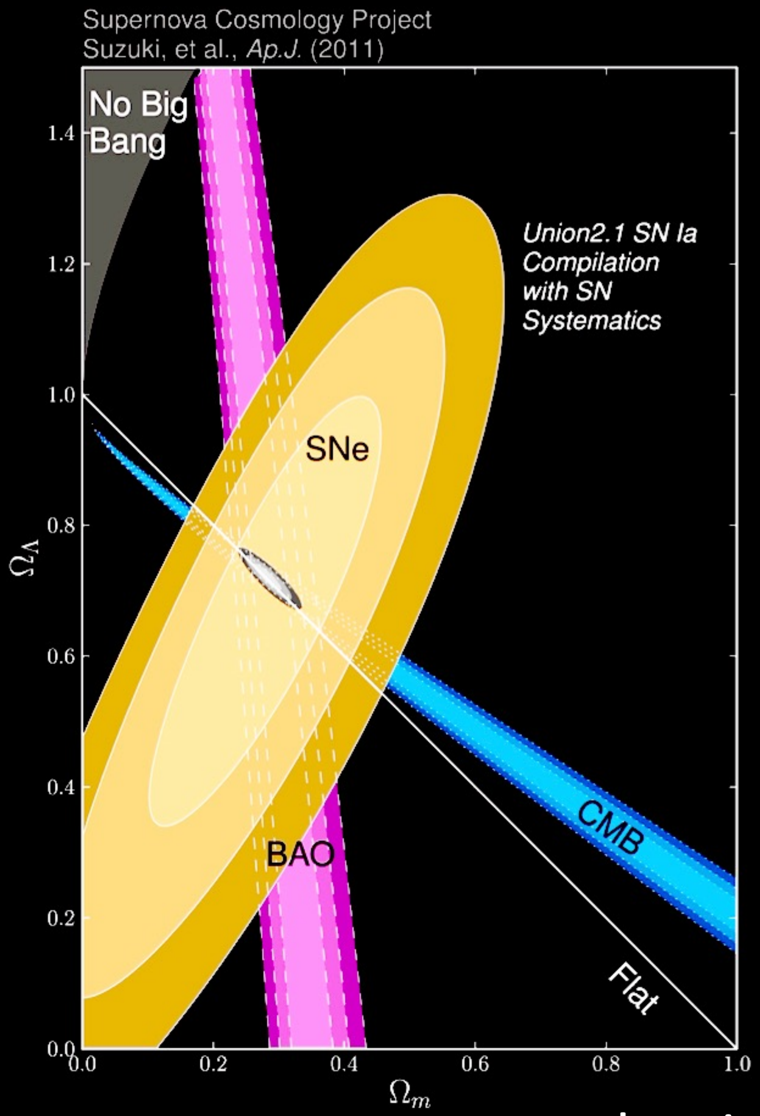
Complementary Measurements of Dark Energy and Dark Matter



adapted from D. Gruen

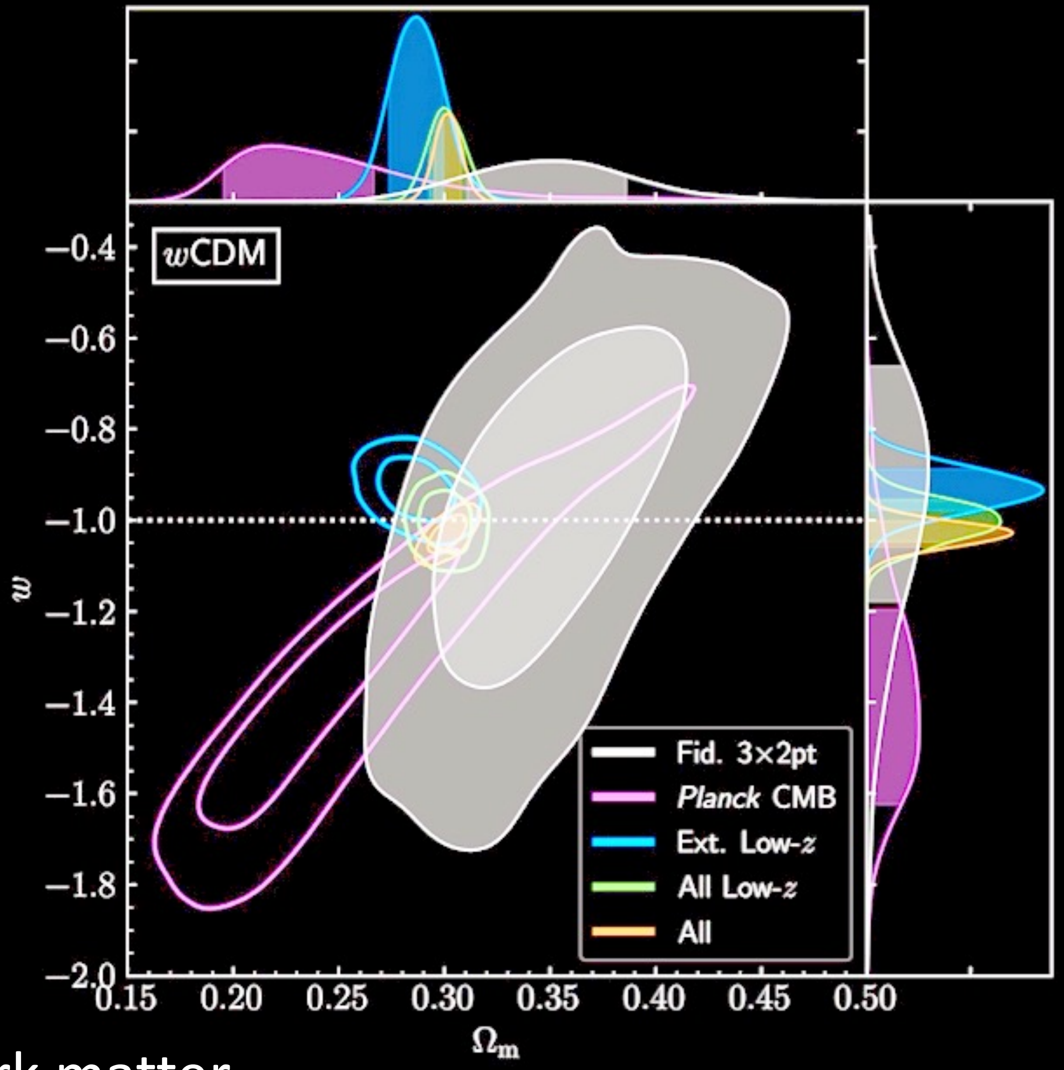
Complementary Constraints on Dark Energy and Dark Matter

density of dark energy



equation of state parameter

DES Collaboration 2021 (Stage III DE Experiment)

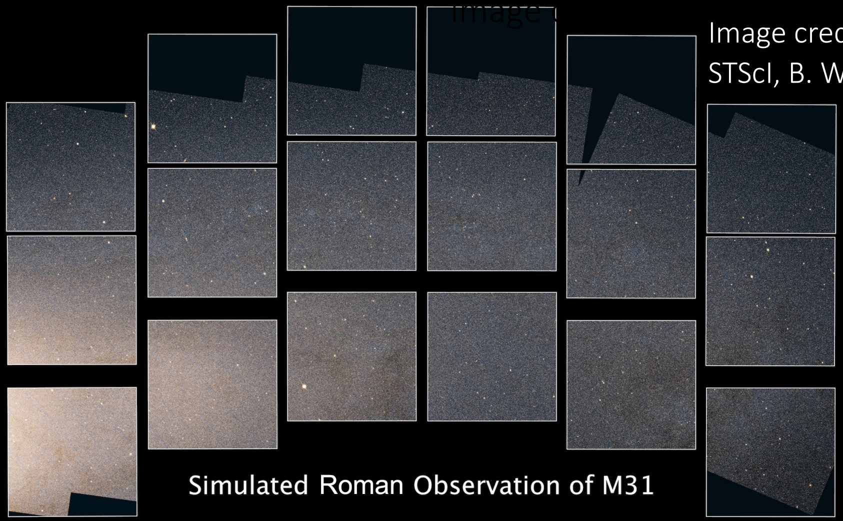


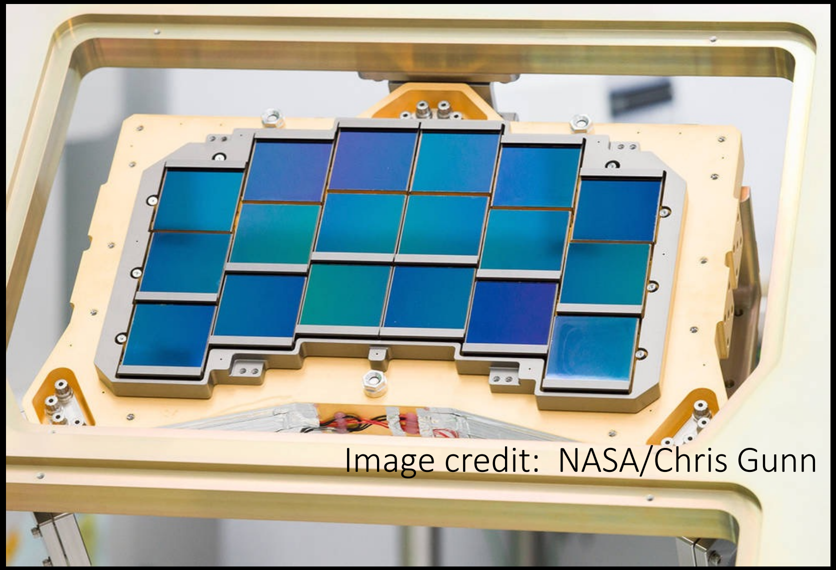
density of dark matter

The Nancy Grace Roman Space Telescope

- Hubble-sized telescope, power, and resolution, Wide Field Instrument (WFI) has 100x field of view (0.28 sq. deg.)
- 18 H4RG-10 infrared detectors (4k x 4k, ~300Mpix); 0.11 arcsec/pixel
- Filters cover 0.48—2.3 μm
- Grism: wavelength range 1.00—1.93 μm, R=435−865
- Prism, 0.75—1.80 μm for low-dispersion multi-object spectroscopy

Image credit: NASA, STScI, B. Williams





Roman's Dark Energy Roadmap

~6 mo. over 2 years

~1.6 years

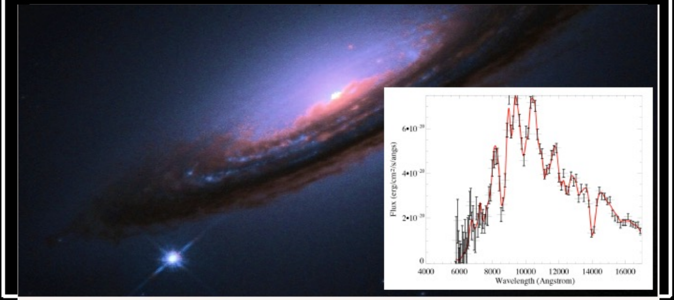
Supernova Survey

wide, medium, & deep imaging + slitless spectroscopy

12k type Ia Sne (imaging), 1.5k (spec)
$z = 0.5 < z < 2.0$

See talks by Phil Macias and Helen Qu!

standard candle distances
$z < 1$ to 0.20% and $z > 1$ to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

10 million Hα galaxies, $z = 1$–2
2 million [OIII] galaxies, $z = 2$–3

imaging: weak lensing shapes

380 million lensed galaxies
20,000 massive clusters

standard ruler

distances	expansion rate
$z = 1$–2 to 0.5%	$z = 1$–2 to 0.9%
$z = 2$–3 to 1.3%	$z = 2$–3 to 2.1%

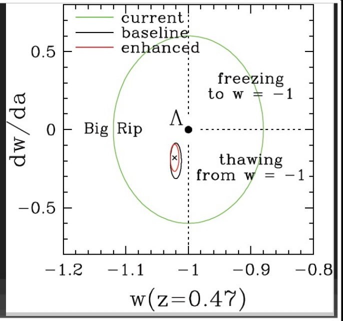
Talk by Lado Samushia!

dark matter clustering
$z < 1$ to 0.21% (WL); 0.24% (CL)
$z > 1$ to 0.78% (WL); 0.88% (CL)
1.1% (RSD)

Talk by Jiachuan Xu!

history of dark energy + deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



adapted from Spergel+2015 SDT Report

Roman High Latitude Survey Cosmology Team

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- Rachel Bean (Cornell)
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- Ami Choi (OSU)
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- Cyrille Doux (Penn)
- Tim Eifler (U. Arizona)
- Xiao Fang (U. Arizona)
- Henry Gebhardt (JPL)
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- Shoubaneh Hemmati (Caltech/IPAC)
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- Shirley Ho (CCA, Flatiron Institute)
- Bhuvnesh Jain (Penn)
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- Peter Taylor (JPL)
- Harry Teplitz (Caltech/IPAC)
- Michael Troxel (Duke)
- Francisco Antonio Villaescusa-Navarro (Princeton)
- Anja von der Linden (Stony Brook University)
- Yun Wang (Caltech/IPAC, Galaxy redshift survey lead)
- David Weinberg (OSU, Galaxy clusters lead)
- Lukas Wenzl (Cornell)
- Hao-Yi Wu (Boise State)
- Zhongxu Zhai (Caltech/IPAC)

Wide and Deep Galaxy Surveys for Dark Energy

need for systematics control, size of team increasing

statistical error decreasing →

2000 · 2005 · 2020 · 2024 · 2027

First detections of cosmic shear

2dFGRS and SDSS detect BAO

Many other large-scale structure surveys in these intervening years

Extended Baryon Oscillation Spectroscopic Survey (eBOSS) 2014-2019

Hyper-Suprime Camera (HSC) 2014-2021 →

The Dark Energy Survey (DES) 2013-2019 →

Kilo-Degree Survey (KiDS) 2011-2019 →

Dark Energy Spectroscopic Instrument (DESI) first light 2019 + survey 2021-2026

Vera C. Rubin Observatory first light

Rubin Legacy Survey of Space and Time (LSST) 2024-2034

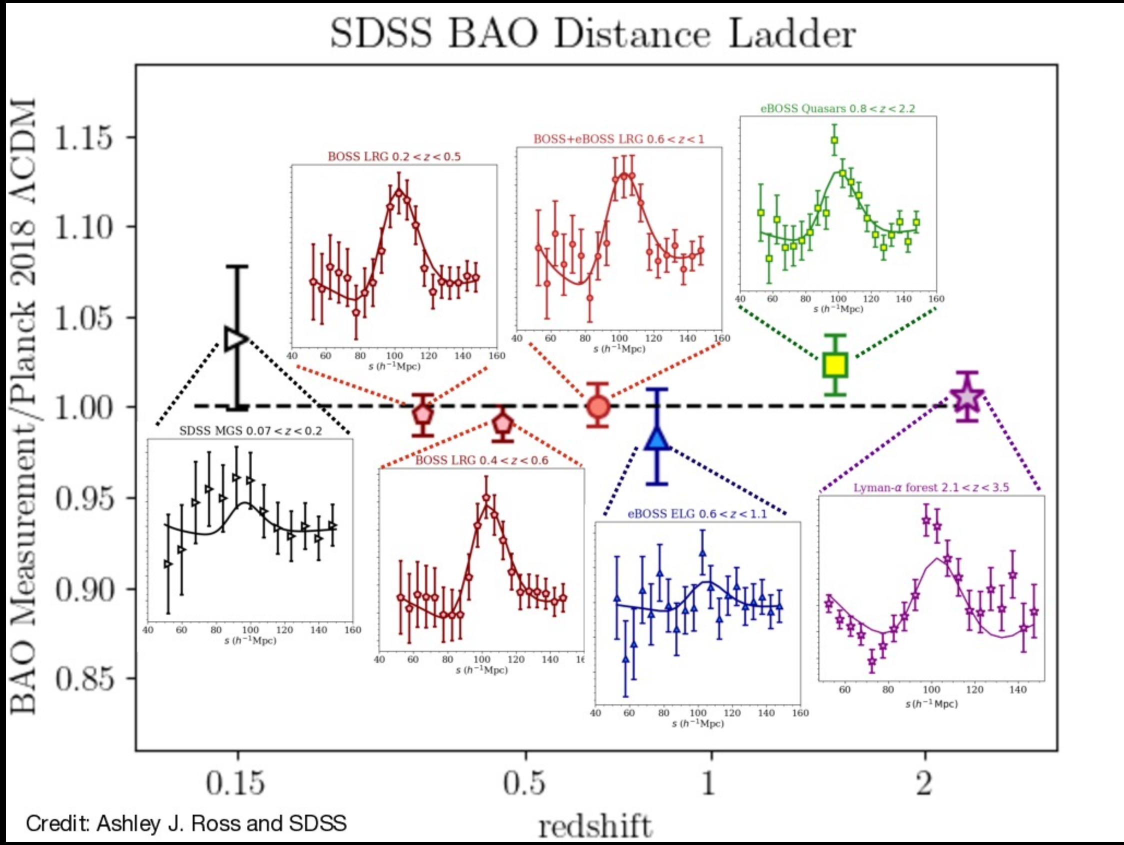
Nancy G. Roman Space Telescope launches

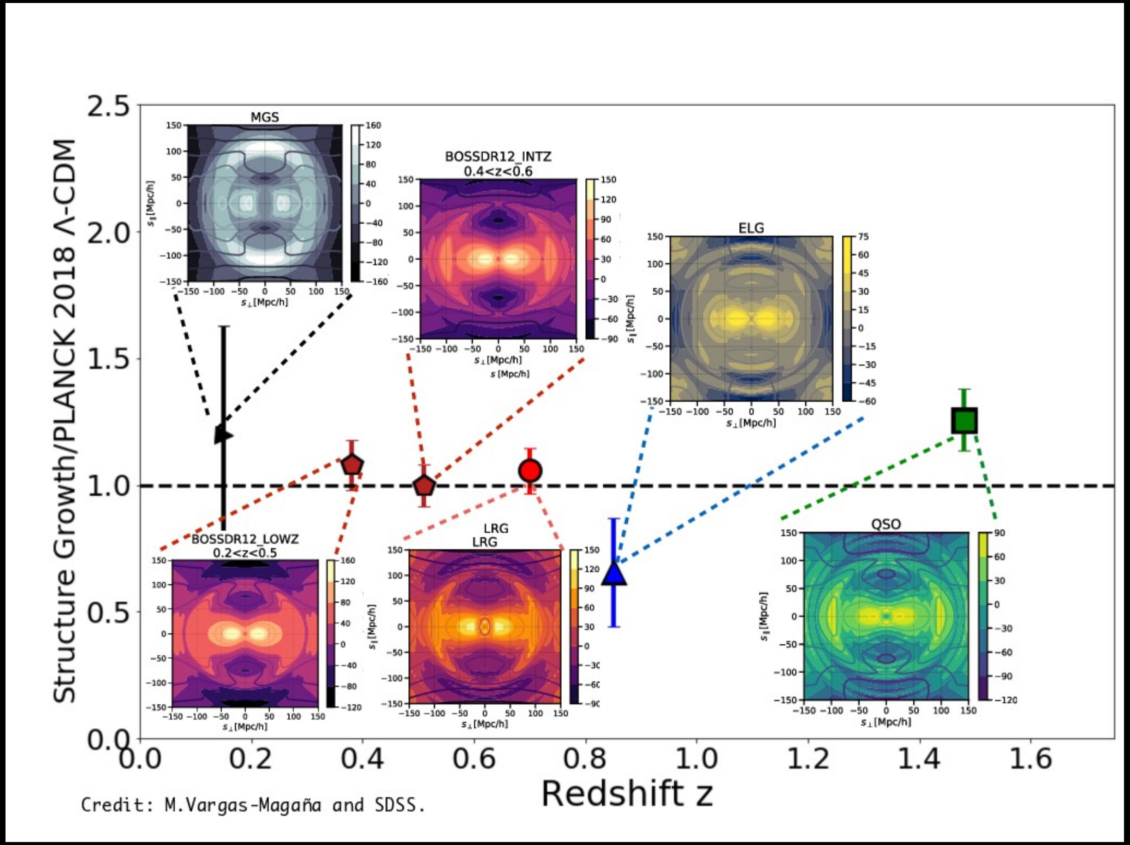
Euclid launches, nominal 6y mission

High Latitude Spectroscopic Survey (HLSS) Probes

- Baryon acoustic oscillations (BAO)
  - Fluctuations in density of visible matter
- Redshift space distortions (RSD)
  - Spatial position appears squashed as function of z vs distance

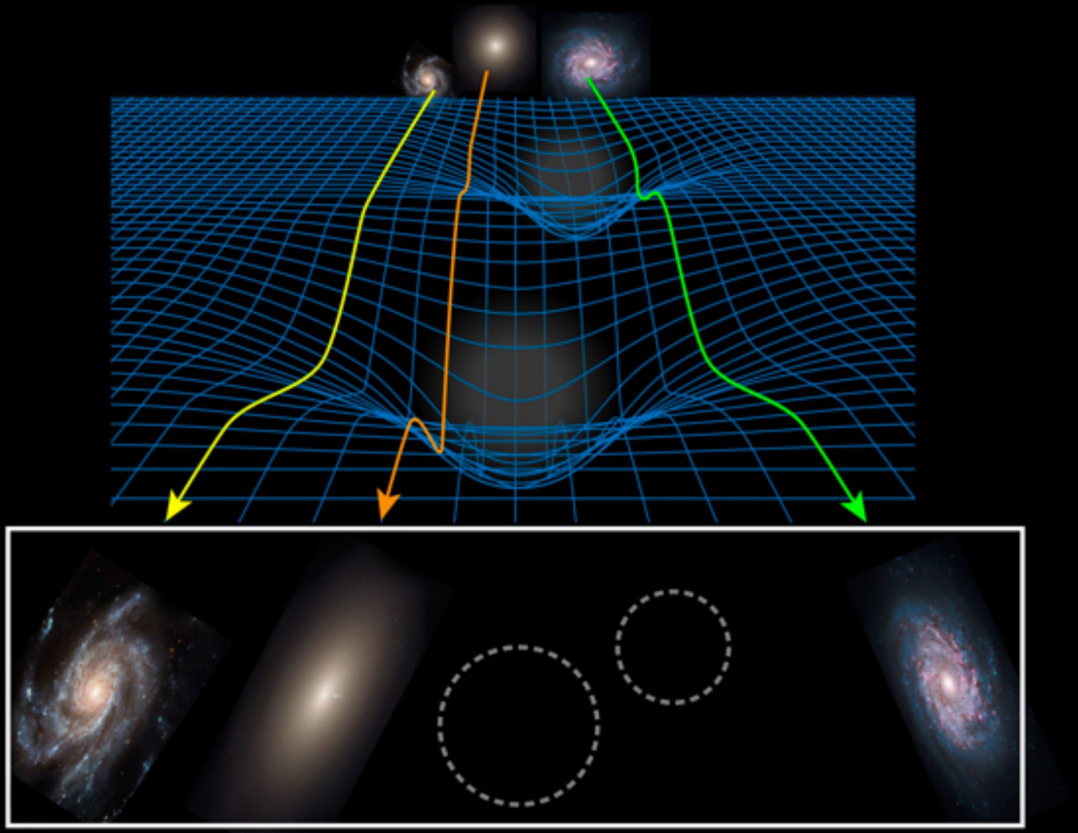
- Large-scale anisotropy (Alcock-Paczynzki)
- Galaxy clustering/power spectrum shape
- Beyond 2-point statistics of the galaxy field: higher-order stats, small-scale clustering, voids





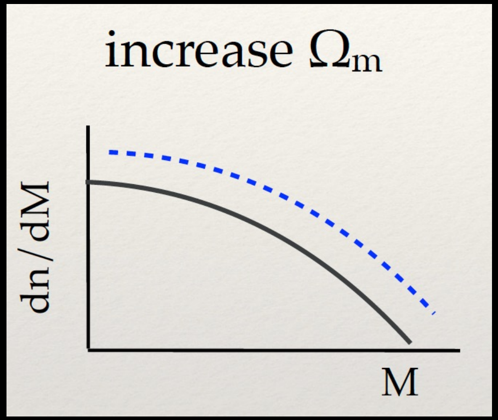
High Latitude Imaging Survey (HLIS) Probes

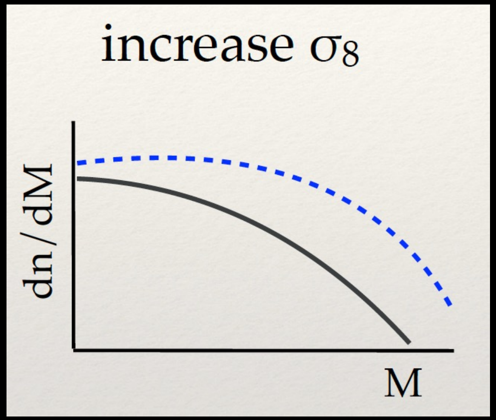
- Weak lensing
  - Light path from distant galaxies is distorted by intervening mass structures, sensitive to matter density and amplitude of structure fluctuations



APS/Stonebraker

- Cluster counts
  - Number counts as function of mass also sensitive to matter density and amplitude of structure fluctuations





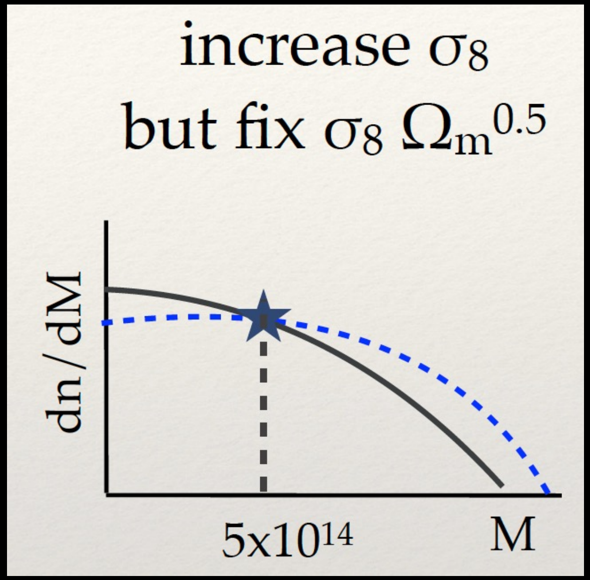


image credits: Heidi Wu

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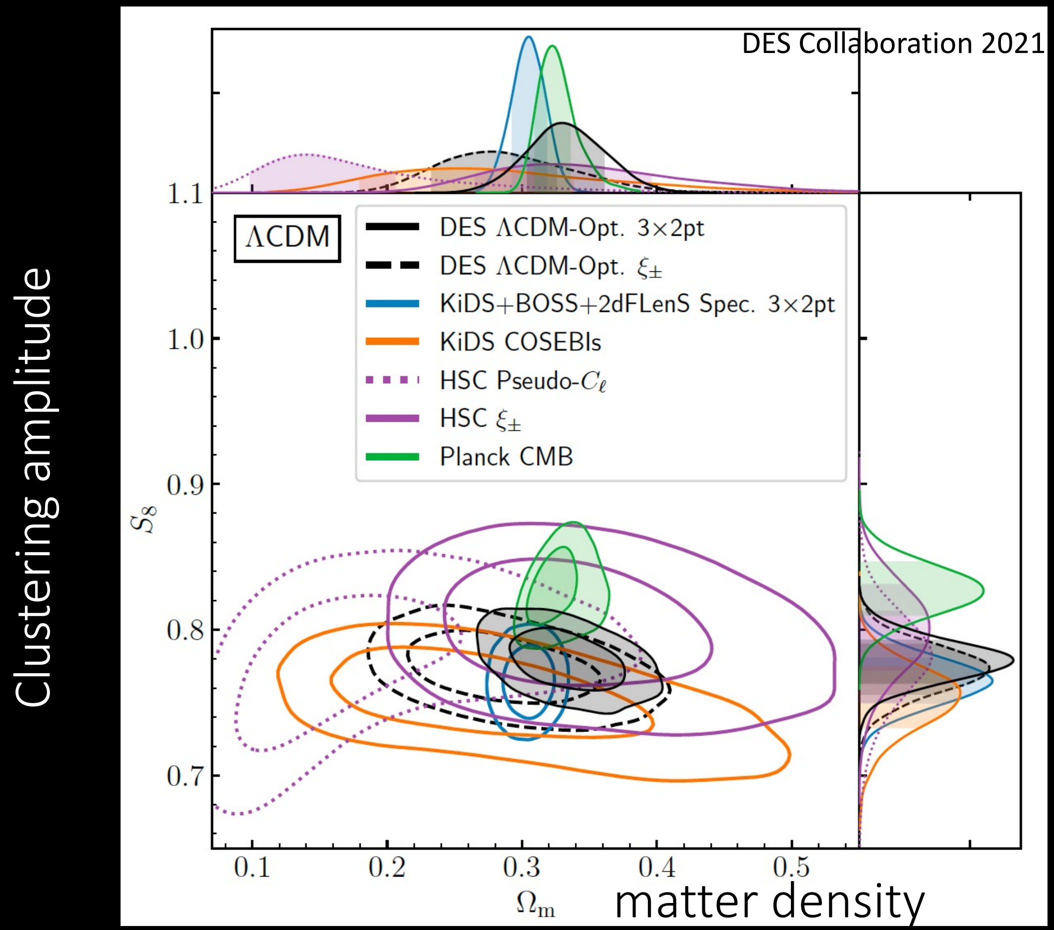

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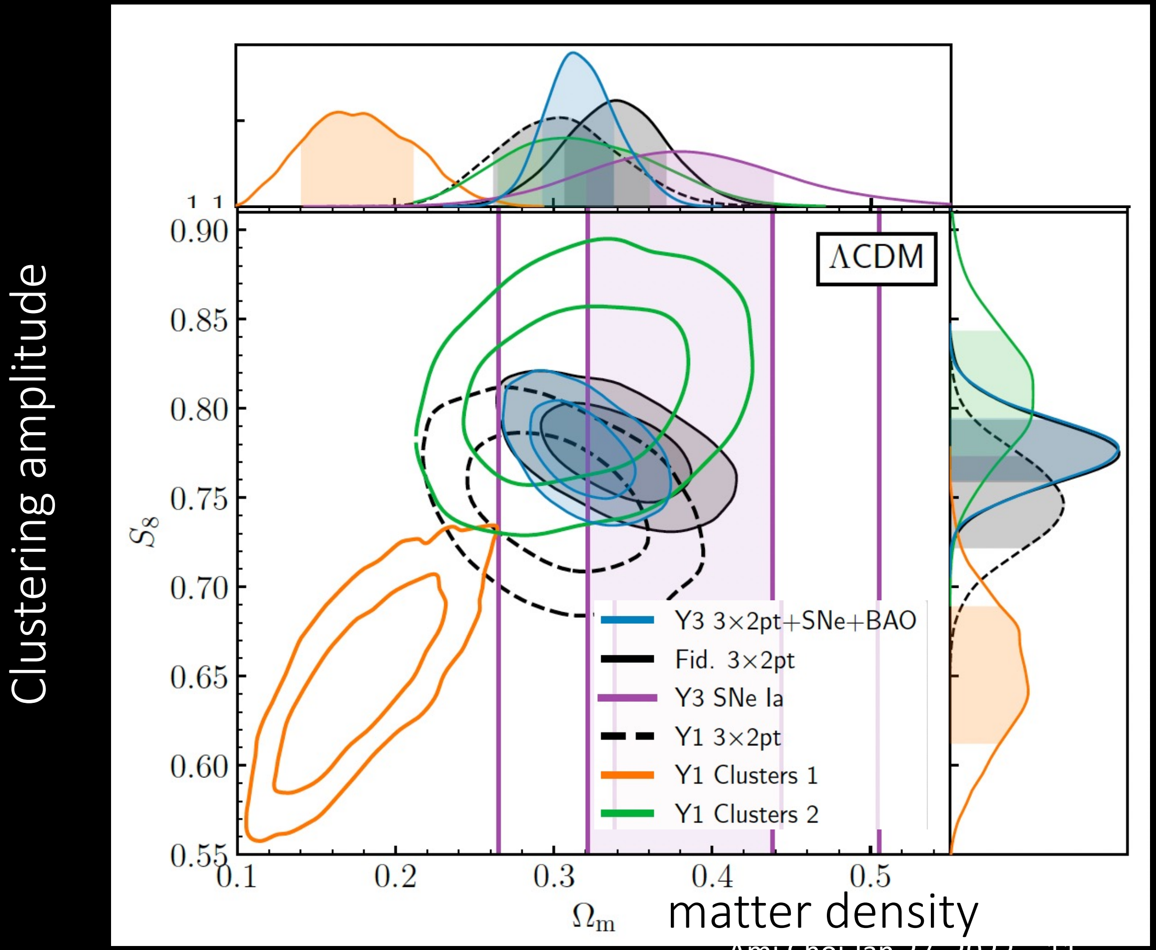
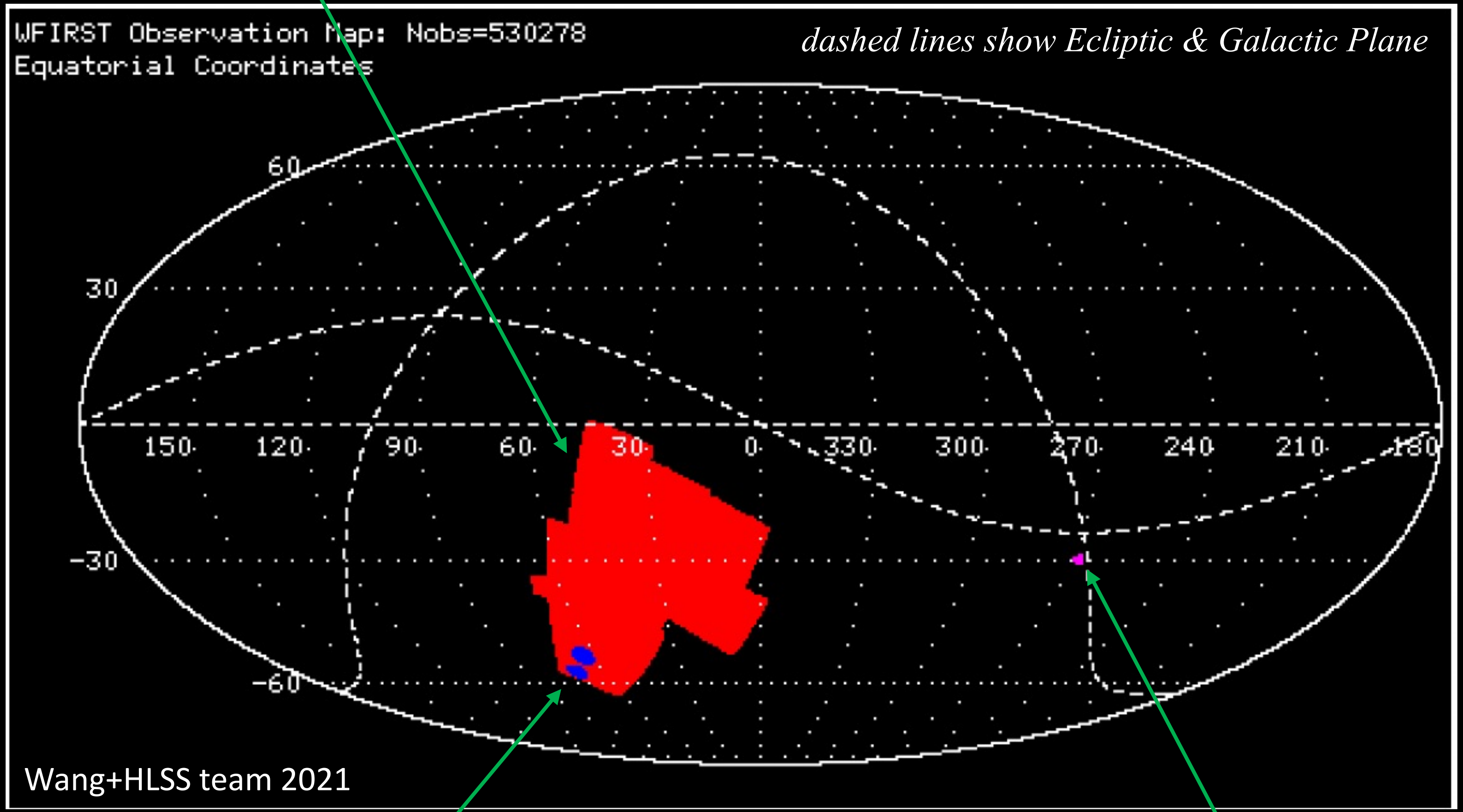


HLSS Reference Survey

HLS Reference Wide Area ($2000\ deg^2$)

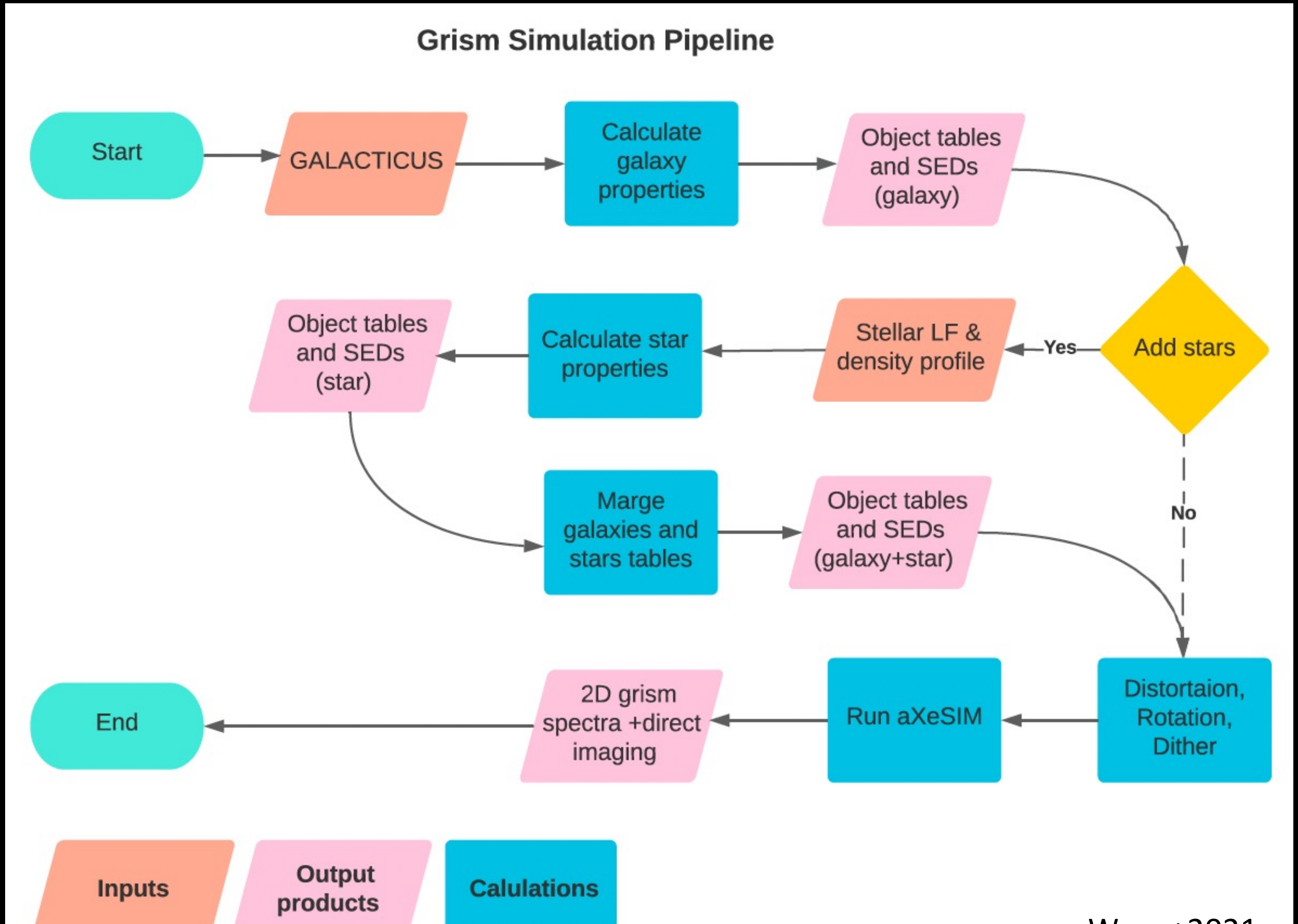


Galactic Bulge

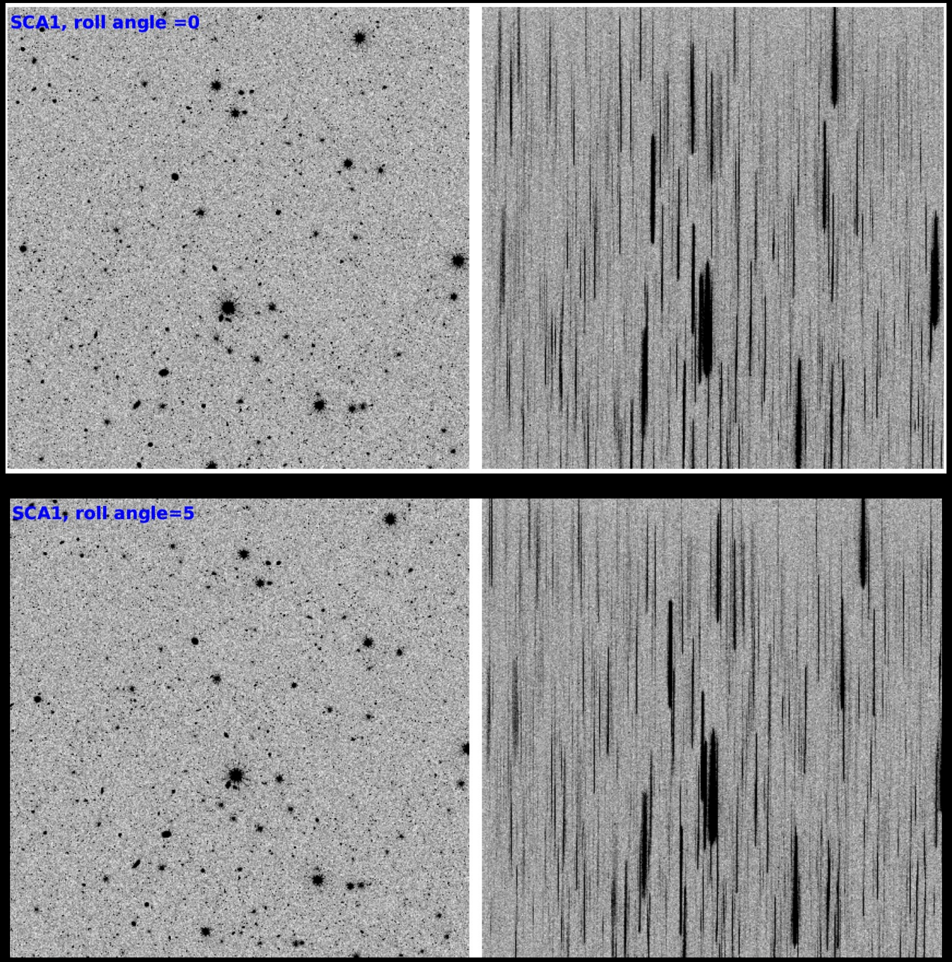
HLS Time Domain South

- Wang+2021 present a $2000\ deg^2$ reference survey with emission line flux limit of $10^{-16}\ erg/s/cm^2$ at 6.5σ, requiring ~0.6 yrs of observing time.
- Development of simulation framework including galaxy mocks and grism simulation
    - Galacticus semi-analytic model (Benson 2012) tuned to high-z observations
    - Grism sims adapted from HST slitless spectroscopy tools
- Enables optimization of survey strategy, validation, predictions, forecasts including how systematics propagate to cosmology constraints

HLSS Reference Survey Simulation Tools

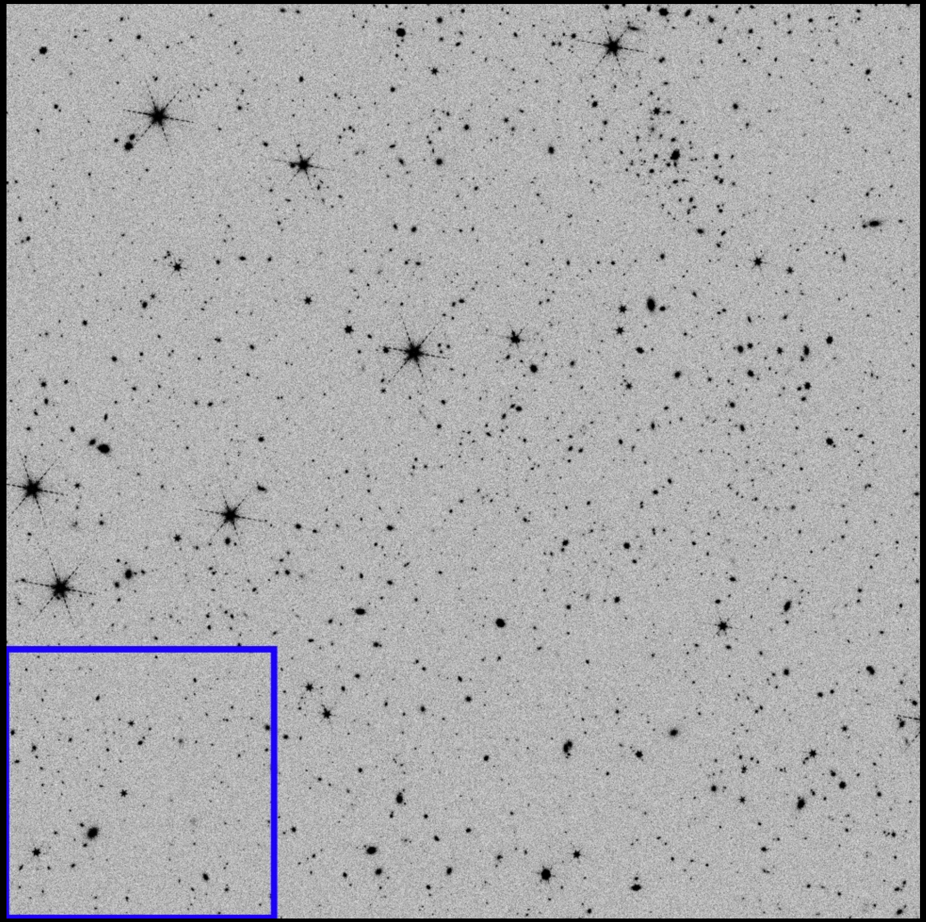


Wang+2021



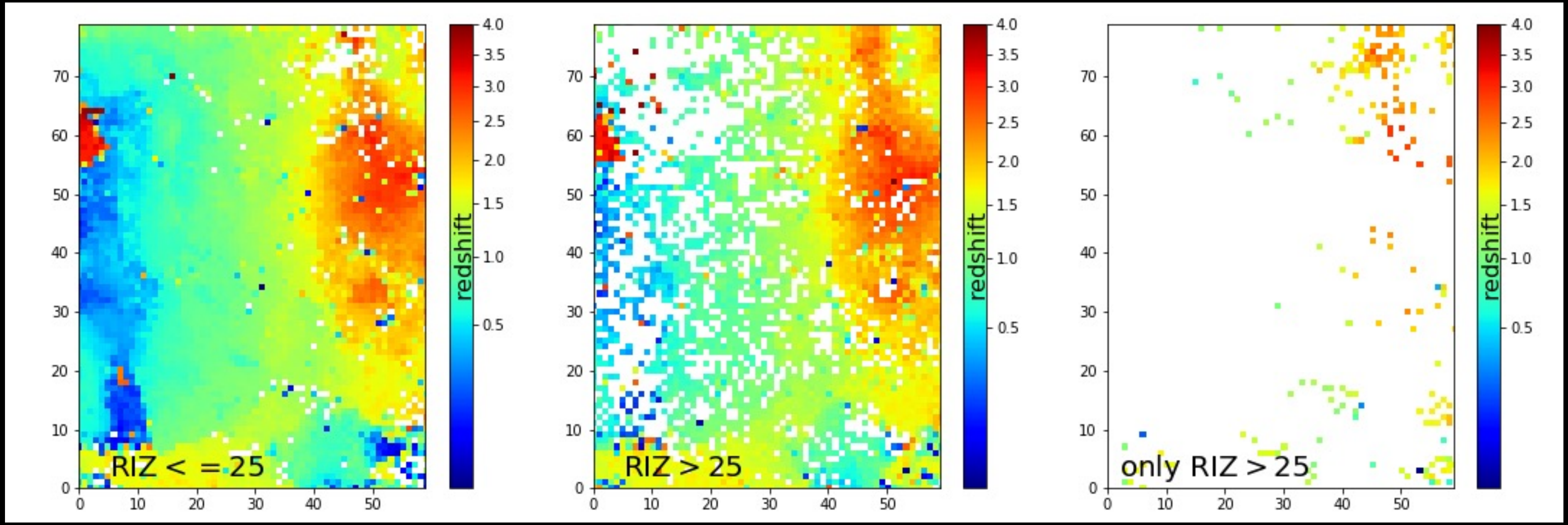
HLIS Reference Survey and Simulation Tools

- Weak lensing is primary driver
- Shape measurement with J & H (primary) + F184 (redder of 2μm, background gets high)
  - Y band is most challenging for shapes due to sampling & wavefront
- Depth vs area trade depends on sky tiling
- **Shapes n_{eff} = 50 galaxies/arcmin^2 (35 in H-band only)**
- Realistic image simulation tools enable optimization of survey strategy, validation, calibration, ++
- Paper describing updated sims + HLIS ref survey in prep



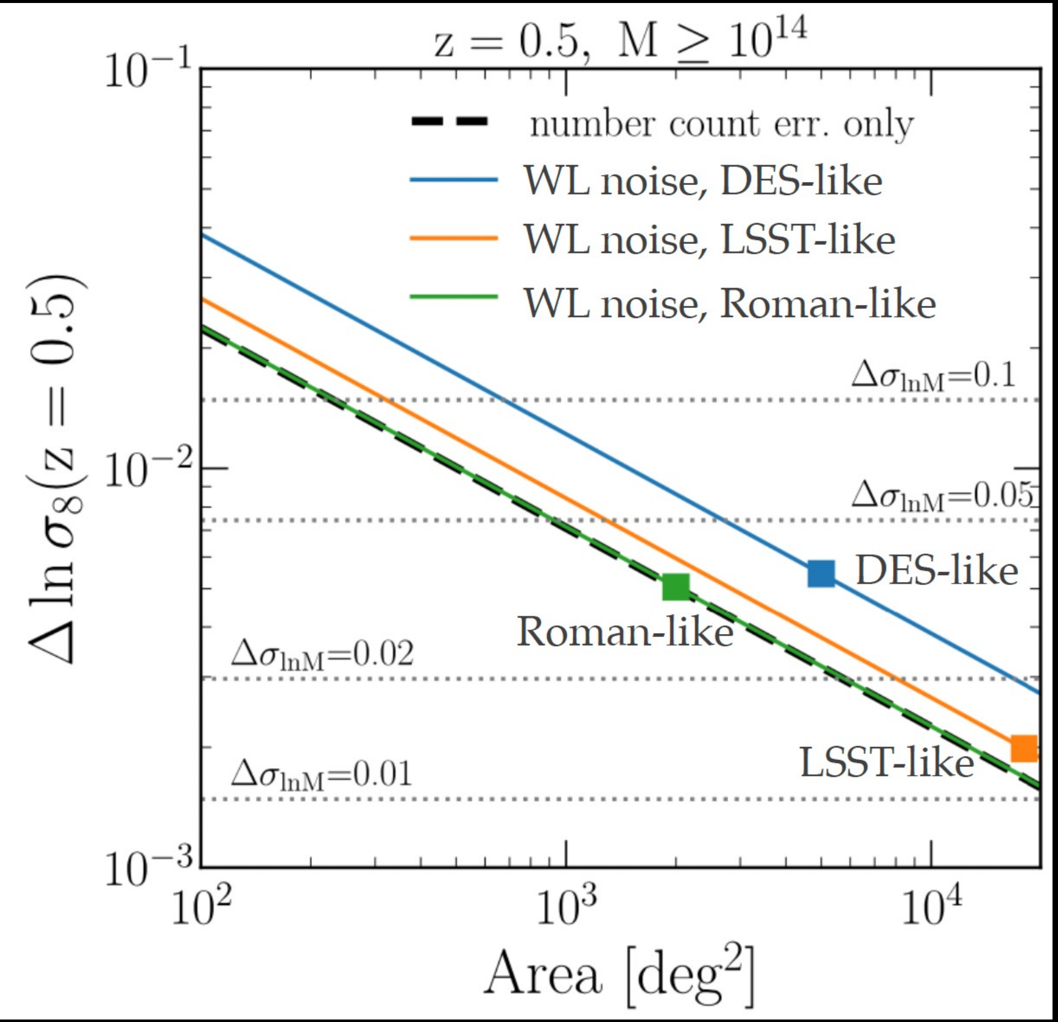
Troxel, Long+2021

HLIS Simulation Tools



- Hemmati+2019 created a synthetic Roman analog sample based on CANDELS and used self-organizing maps (SOMs) to investigate necessary spectroscopic calibration sample
  - 26% of Roman sample is fainter than Euclid
  - 91% of which live in cells containing a bright source as well
  - 4% of the SOM cells have no bright galaxy counterpart
- Complete Calibration of the Color-Redshift Relation (C3R2) collecting spectra (e.g., Masters+2019, Stanford+2021)

Cluster Forecasting Tools for HLIS



Wu+2021

- Approach combines mean number counts and the mean weak lensing profile of clusters above a mass proxy threshold
- logarithmic scatter $\sigma_{\ln M}$ between the mass proxy and true mass near the threshold is primary nuisance parameter
- number count and weak lensing errors contribute almost equally to the σ_8 uncertainty for a Roman-like survey
- constraining power scales with area

Summary & References

- In addition to systematics control, forecasts for the main probes, we have also explored higher-order statistics, how voids can constrain massive neutrinos, small scales, dwarf galaxy samples, modified gravity scenarios, and more (for a list, see https://www.roman-hls-cosmology.space/publications/)
- Reference survey designs for 2000 deg^2 High Latitude Wide Area Survey (spec: Wang+2021, arXiv:2110.01829; imaging paper in prep)
  - uses simulation tools noted earlier
  - illustrate strategy choice that meet scientific requirements
  - not necessarily what we will execute, there is flexibility
- Continued forecasting, theory/measurement pipeline development
  - synergies with cosmic microwave background (e.g., Simons Observatory), Euclid, Rubin LSST, SPHEREx, eRosita, and more
  - leverage these to design pilot studies and Roman time later in the mission, plenty of trade space (depth vs area, spectroscopy vs imaging, number of filters vs area)
- Other useful refs:
  - Hirata+2012 (arxiv:1204.5151) Exposure Time Calculator https://wfirst.ipac.caltech.edu/sims/tools/wfDepc/wfDepc.html
  - 2015 Science Definition Team Report https://roman.gsfc.nasa.gov/science/sdt_public/WFIRST-AFTA_SDT_Report_150310_Final.pdf
  - 2017 Annual Report for the cosmology SIT (arxiv:1804.03628)
  - Astro2020 Science White Paper (arxiv:1904.01174)

Panel discussion will touch on more cosmology topics! Lado and Jiachuan will expand on some of these!