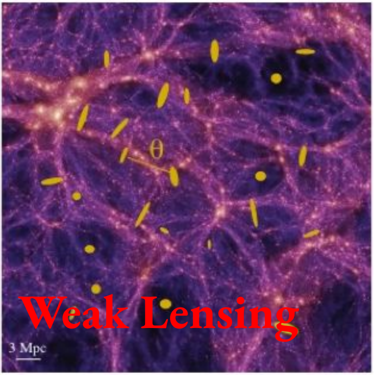
BAO science with the Roman Space Telescope

Lado Samushia
Kansas State University
AAS 239: Roman Cosmology Virtual Seminar

Sponsors:
NASA ROSES grants 12-EUCLID12-0004 and 15-WFIRST15-0008
US Department of Energy grants DE-SC0021165 and DE-SC0011840
Shota Rustaveli national science foundation of Georgia grant FR 19-498

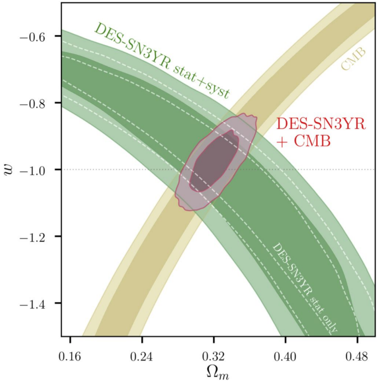
Cosmology with Roman



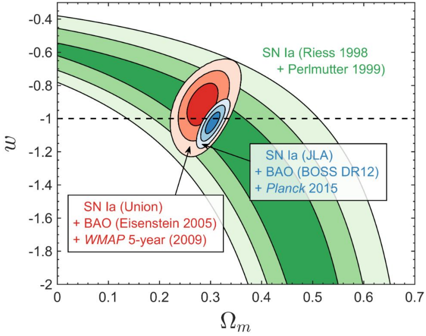
Clustering/Weak Lensing/Supernovae -> Dark Energy

Clustering patterns:

- BAO - a special scale (~100 Mpc) created in the early Universe. Sensitive to the expansion history.
- RSD - anisotropy in clustering between across and along the line of sight created by gravitational infall. Sensitive to expansion history and gravity.
- Other patterns - Voids, Small Scales, ...

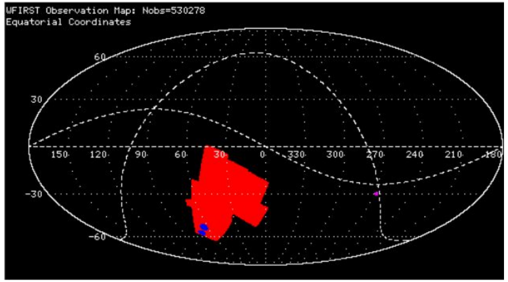


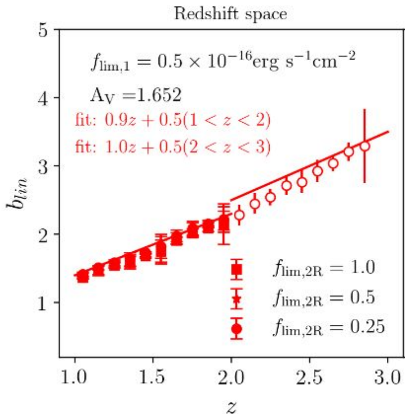
Abbott et al. 2019



Huterer & Shafer 2018

Roman: High Latitude Spectroscopic Survey





Near-IR grism (1-1.93 μm, R = 435-865)

0.28 deg^2 wide field camera

0.6 years (including calibration)

2,000 square degrees

11 deg^2 of deep survey (near 100% completeness, 4x10 nominal observations)

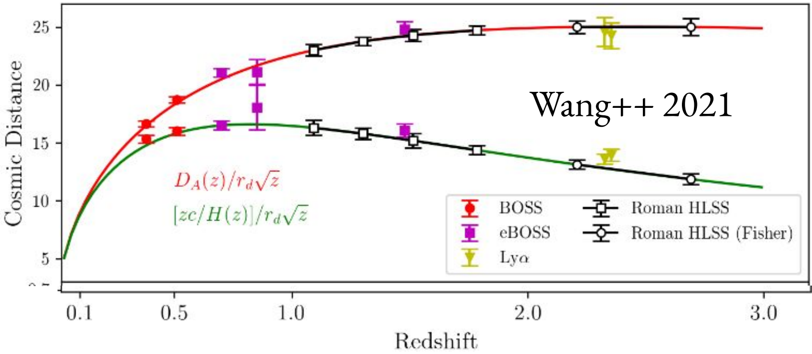
emission line flux limit of 10^{-16} erg/s/cm^2 at 6.5σ

10 million Hα galaxies ($1 < z < 2$, $7h^{-3}$ Gpc^3 of volume)

2 million OIII galaxies ($2 < z < 3$)

Wang++ 2021
Zhai++ 2021a,b,c

BAO

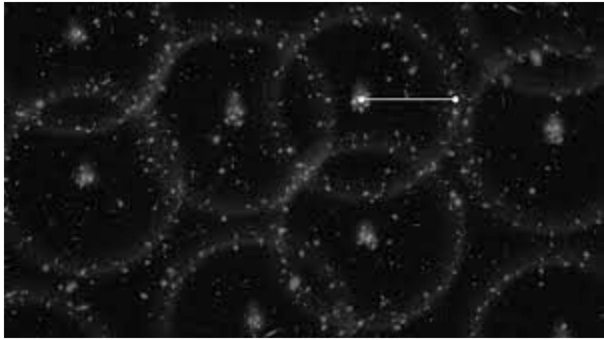


An excess probability at ~100 Mpc.

Largely insensitive to galaxy physics. A robust and safe feature.

Highly sensitive to Dark Energy.

BOSS obtained first sub-1% level measurements at z < 0.7.

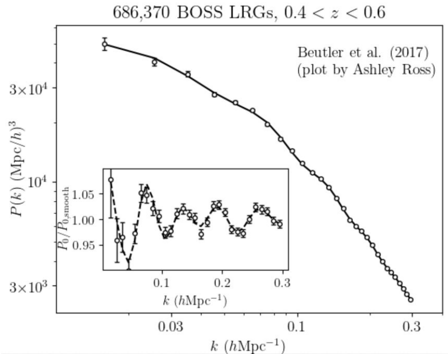


DESI will obtain a cumulative 0.25% level measurement at 0.6 < z < 1.6 (based on analytic forecasts).

Euclid will obtain a cumulative 0.4% level measurement at 1 < z < 2 (based on analytic forecasts).

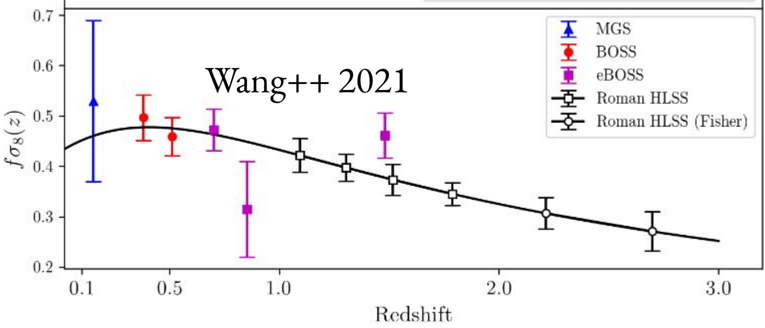
Roman forecasts (based on the analysis of Roman mocks):

- Cumulative σD_A and σH~ 1% at 1 < z < 2.
- Cumulative σD_A and σH~ 1.7% and 2.4% at 2 < z < 3.



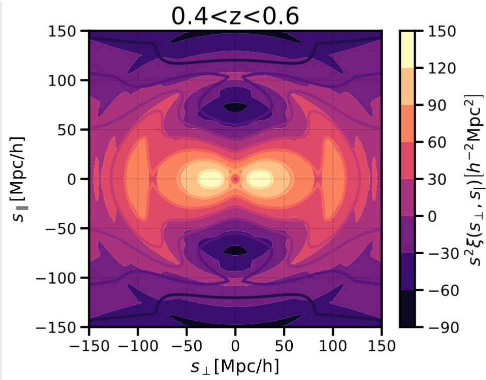
Note: These are order of magnitude estimates. Exercise caution when directly comparing these numbers. They are derived using different methods and assumptions the resulting differences could be as large as a factor of few.

RSD



Anisotropy in clustering.

Sensitive to smaller scales. More sensitive to galaxy physics (and small scales in general) than the BAO, but by now considered to be equally robust. Highly sensitive to both Dark Energy and Gravity.



BOSS collaboration (MNRAS 470, 2617; 2017)
(plot by Jiamin Hou, MPE)

BOSS obtained < 10% level measurements below z < 0.7

DESI will obtain a cumulative 0.4% measurement in 0.6 < z < 1.6 (analytic predictions)

Euclid will obtain a cumulative 0.5% measurement in 1 < z < 2 (analytic predictions)

Roman forecasts (based on the analysis of Roman mocks):

- a cumulative constraint of < 2% at 1 < z < 2
- a cumulative constraint of 8% at 2 < z < 3

Note: These are order of magnitude estimates. Exercise caution when directly comparing these numbers. They are derived using different methods and assumptions the resulting differences could be as large as a factor of few.

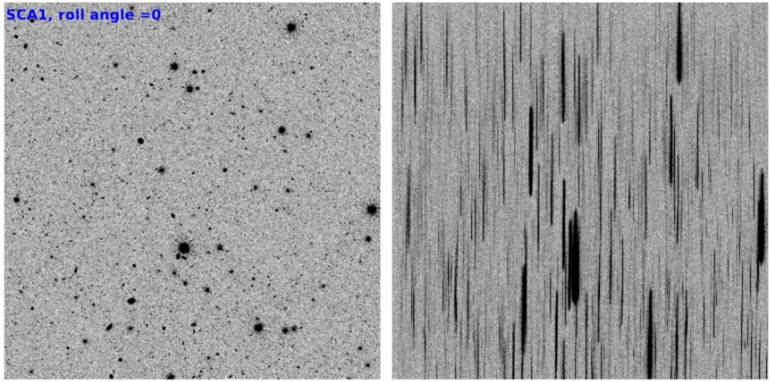
Possible Systematics

BAO and RSD can be considered to be “safe science”. Other surveys will have to perform these measurements at higher absolute precision. The methodology is well tested, documented, and converged.

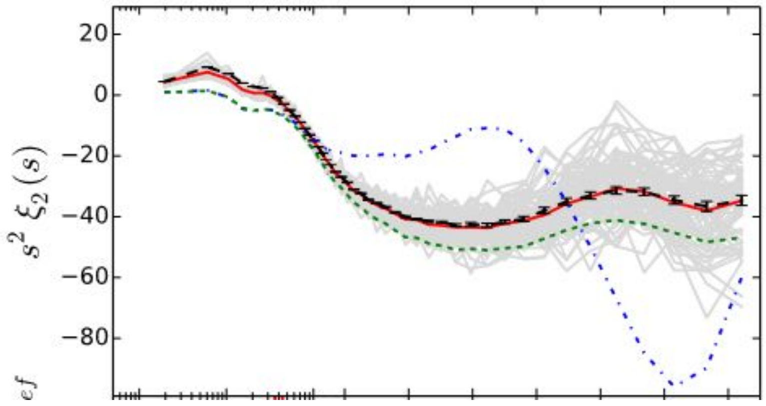
Roman will be free of many observational systematics present in ground based surveys.

Possible systematic effect that has not been sufficiently studied: Effects of slitless spectroscopy on large-scale clustering patterns.

Because of the slitless spectroscopy spectra in overdense areas will be noisier. Density dependent incompletnesses can sometimes lead to larger than anticipated effects (e.g. fiber assignment incompleteness in DESI survey)

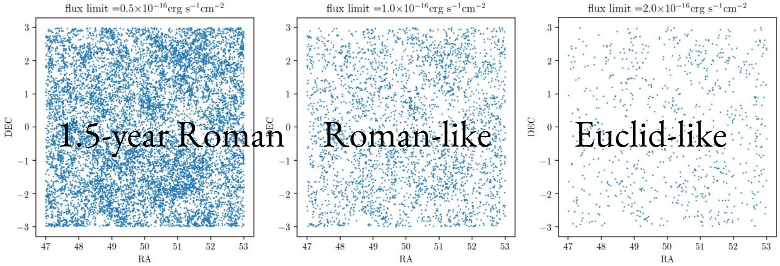


Wang++ 2021

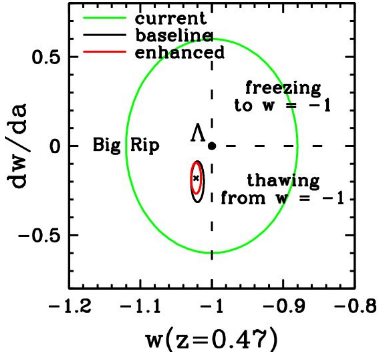


Bianchi++ 2018

Figures of Merit and Unique Capabilities



BAO/RSD from Roman will require a lot of hard and competent work but can be considered safe. As a researcher I am interested in pushing the cosmology analyses to not so well explored territories.

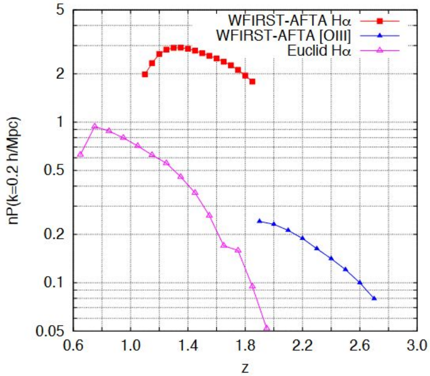


WFIRST-AFTA 2015 report Figures of Merit

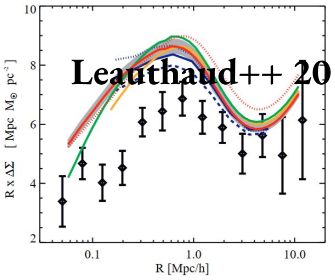
Figures of Merit assume the model is known and the only thing to do is to measure parameters with ever increasing precision. They don’t always capture well the discovery potential of an experiment.

A unique feature of Roman is its relatively high sampling density that allows for:

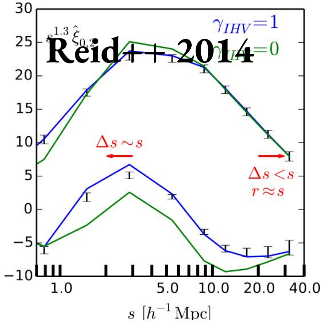
- A better sampling of smaller scales
- A better sampling of higher order patterns
- A better view of cosmic web



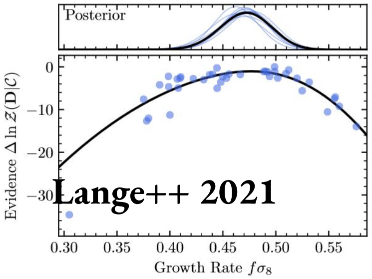
Small Scale Patterns



Leauthaud++ 2016 small scale lensing signal



Reid++ 2014 2.5% growth from CMASS



Lange++ 2021 5% growth from LOWZ

A lot of cosmological information is potentially extractable from smaller scale clustering.

Because of highly nonlinear evolution these signals are difficult to model.

Galaxy physics plays a very important role and needs to be carefully studied.

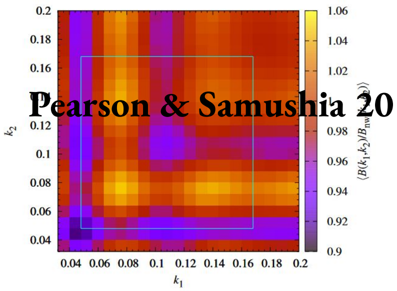
Many interesting papers/approaches have been put forward in the last 10 years.

The methodology is not settled.

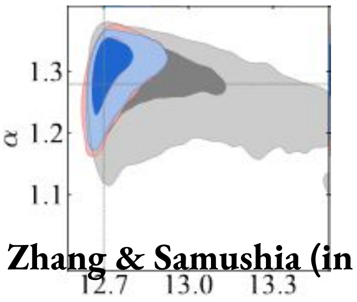
Forecasts are difficult to make (because of complicated nonlinear evolution and galaxy physics).

All current approaches are simulation based.

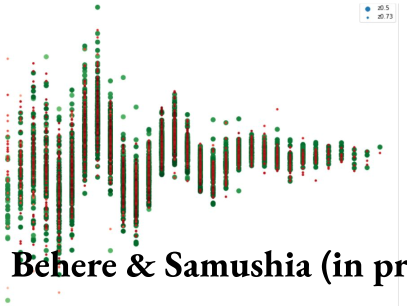
Higher Order Patterns



Pearson & Samushia 2017



Zhang & Samushia (in prep)



Behere & Samushia (in prep)

Reasonable improvements can be obtained from looking at higher order statistics at both large and small scales (e.g. 10-20% on the BAO scale from the large scale bispectrum [Behere & Samushia], factor of 2 improvement on the HOD [Zheng & Samushia]).

Observables and their covariances are more difficult to model even on large scales.

On large scales galaxy physics can be accounted for in perturbation theory as bias parameters, on small scales galaxy physics remains important.

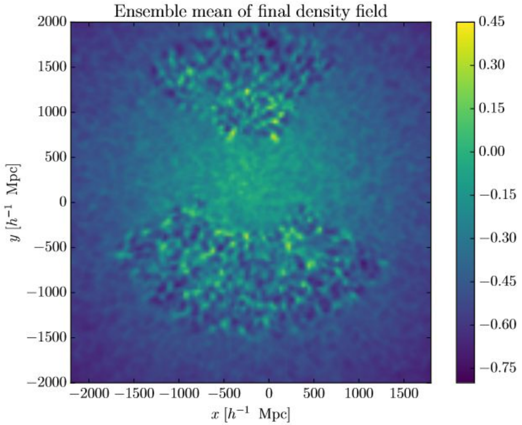
Many interesting papers/approaches have been put forward in the last 10 years.

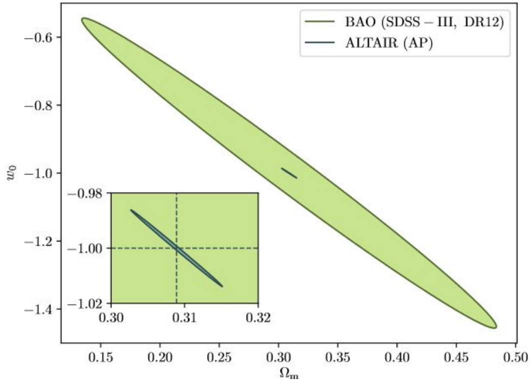
The methodology is not settled.

Forecasts are difficult to make (theory is more complicated at higher orders).

On large scales, perturbation theory based approaches are possible, even there input from simulations is necessary

Cosmic Web





Ramanah++ 2018

Entire cosmic web can in principle be used for cosmology.

Generate IC -> Evolve -> Model Galaxy Formation -> Impose observational constraints (mask, instrument inefficiency, etc.) -> Compare to the observations.

Pros:

- All of the information is analysed and utilized at once
- Fits nicely into Baysian framework/philosophy

Cons:

- Requires lots of CPU resources
- Need to understand all processes (nonlinear evolution, galaxy formation, observational effects, ...)
- Many parts of analysis are purely simulation based (are any simulations good enough at this precision level?)
- Many parts of analysis have often a “black box” nature (unclear where the information comes from)

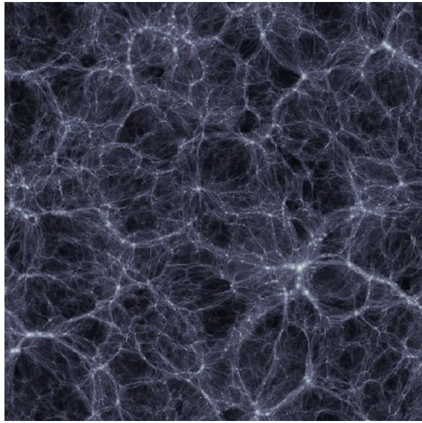
Challenges

Lots of very promising non-standard (non-BAO/RSD) science cases currently in development. Will they be ready by the time we have Roman data?

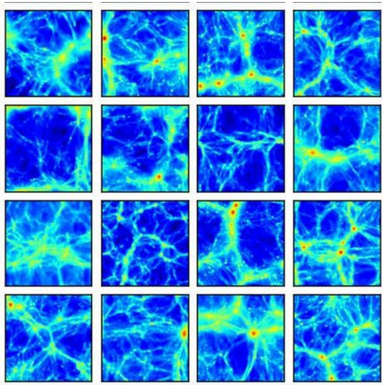
All rely on the availability of high quality simulations.

Wish list:

- Large cumulative volume
- Multiple cosmological models
- Good mass resolution for lighter dark matter halos
- Baryonic physics
- Extremely stringent tests to ensure that the systematics in the simulations (finite volume, step size, sampling, etc.) are subdominant to the statistical errors (sometimes below 0.1%!)



Hahn 2014



Villaescusa-Navarro++ 2022

Summary

- Roman HLSS is a great survey for cosmology
- Expected to deliver competitive measurements for the standard analysis (BAO/RSD)
    - Highly complementary measurements in $1 < z < 2$
    - unique measurements in $2 < z < 3$
- Roman will enable lots of currently non-standard cosmology analysis that have a potential to go significantly beyond BAO/RSD
    - small scale clustering
    - higher order statistics
    - voids
    - cosmic web
- Access to high quality simulations will be the key