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

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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 0.93-2.00 µm). 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.
Abstract: We outline possible survey strategies for the imaging component of the NANCY Grace Roman Core Community Survey (HLWAS) that considers synergies with existing imaging surveys such as Roman Core Community Survey and the Large Synoptic Survey Telescope (LSST). We envision a two-tiered wide area survey, with a "narrow" tier that covers the whole sky in 0.3-2.0 μm, and an "intermediate" tier that covers a reduced area, and a "wide" tier in a single filter. The most promising Roman Core Community Survey (HLWAS) that considers synergies with ground-based experiments is the High Latitude Wide Area Survey (HLWAS) that considers synergies with ground-based experiments, e.g., shear calibration and photometric estimation.

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 the trade space of systematics control vs statistical information content.

If Vera Rubin and Nancy Grace Rom...
Roman Core Community Surveys will be designed in the coming 2 years

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

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)

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)

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

- reduced data and catalogs
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**Statistics I - Likelihood function**
- Multivariate Gaussian vs other parameterizations
- Non-parametric forms
- Approximate Bayesian Computation

**Independent probes**
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**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

**Enhanced modeling via**
- Observations
- Simulations
- Theory

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

- **Figure 6.**
  - We show results for the 18,000 deg² WFIRST wide scenario compared to the LSST Y10 scenario
  - The 'Gain in . . . ' implies a quantitative comparison, but I think that here and elsewhere in the section you mean a multiplicative factor, as stated in the abstract? Perhaps indicate this difference.

- **RM: I have a silly question: I may be misreading the figure, but I see the (inner) black and red contours differ.**

- **RM: The 'Gain in . . . ' implies a quantitative comparison, but I consider by maybe 40% and the FoM goes like sqrt(determinant), so that if the area goes up by a factor of 1.4 then the determinant goes up by a factor of 1.4 and the FoM goes like sqrt(determinant), so how is the FoM different?**
Simulated Multi-Probe Analysis

- Cosmic shear
- Galaxy-Galaxy Lensing
- Galaxy Clustering

- 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 use these

We ignore these (in this particular analysis)
Joint clustering and weak lensing (3x2pt)

- **galaxies x galaxies:** angular clustering
- **lensing x lensing:** cosmic shear
- **galaxies x lensing:** galaxy-galaxy lensing
Problem 1: Probes have systematics

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

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 in finite time
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

- Choose bands from Y band (Rubin coverage) to 2 µm (beyond which background would increase dramatically).
- Reference Survey did not plan to use the visible filters for the wide survey as Rubin/LSST is providing the necessary depth.
- This predates the $K_s$ filter.
- Shape measurement with J & H (primary) + F184.
- Y band is most challenging for shapes due to sampling & wavefront. We intend to do shapes in Y on a best-effort basis, requirements are set for J & longer.
- F184 is 0.7 mag shallower than H.
- Depth vs. area trade depends on how you tile the sky.

Credit: Chris Hirata

### Sensitivities of LSST and Roman

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>LSST</th>
<th>Roman</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>27.0</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>26.0</td>
<td></td>
</tr>
<tr>
<td>z</td>
<td>25.2</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>24.5</td>
<td>24.8</td>
</tr>
<tr>
<td>J</td>
<td>25.0</td>
<td>25.3</td>
</tr>
<tr>
<td>H</td>
<td>25.5</td>
<td>25.8</td>
</tr>
<tr>
<td>F184</td>
<td>26.0</td>
<td>26.3</td>
</tr>
</tbody>
</table>

Credit: Chris Hirata
Continuing the Legacy of NASA's Great Observatories

The Nancy Grace Roman Space Telescope

**Roman Space Telescope Spectroscopic Capabilities**

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

*Based on current best estimates of performance.

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

**November 2021**

**Roman Space Telescope Imaging Capabilities**

<table>
<thead>
<tr>
<th>Telescope Aperture</th>
<th>Field of View (45’x23’; 0.28 sq deg)</th>
<th>Pixel Scale (0.11 arcsec)</th>
<th>Wavelength Range (0.5-2.3 µm)</th>
</tr>
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<tr>
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**Roman Space Telescope Coronagraphic Capabilities**

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<thead>
<tr>
<th>Imaging</th>
<th>Wavelength (µm)</th>
<th>Inner Working Angle (arcsec)</th>
<th>Outer Working Angle (arcsec)</th>
<th>Detection Limit*</th>
<th>Spectral Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5-0.8</td>
<td>0.15 (exoplanets) 0.48 (disks)</td>
<td>0.66 (exoplanets) 1.46 (disks)</td>
<td>10⁻⁹ contrast (after post-processing)</td>
<td>47-75</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>0.675-0.785</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
Roman reference design survey

Are there alternatives relying on ground based data?

Let’s explore Roman strategies based on synergies with LSST
### Roman Space Telescope Imaging Capabilities

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<td>27.5</td>
<td>26.2</td>
</tr>
</tbody>
</table>

### Roman Space Telescope Spectroscopic Capabilities

<table>
<thead>
<tr>
<th>Field of View (sq deg)</th>
<th>Wavelength (µm)</th>
<th>Resolution</th>
<th>Sensitivity (AB mag) (10σ per pixel in 1hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grism</td>
<td>0.28 sq deg</td>
<td>1.00-1.93</td>
<td>461</td>
</tr>
<tr>
<td>Prism</td>
<td>0.28 sq deg</td>
<td>0.75-1.80</td>
<td>80-180</td>
</tr>
</tbody>
</table>

### Roman Space Telescope Coronagraphic Capabilities

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[https://roman.gsfc.nasa.gov/science/Roman_Reference_Information.html](https://roman.gsfc.nasa.gov/science/Roman_Reference_Information.html)
Roman “wide survey” idea - Synergies with Rubin

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

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