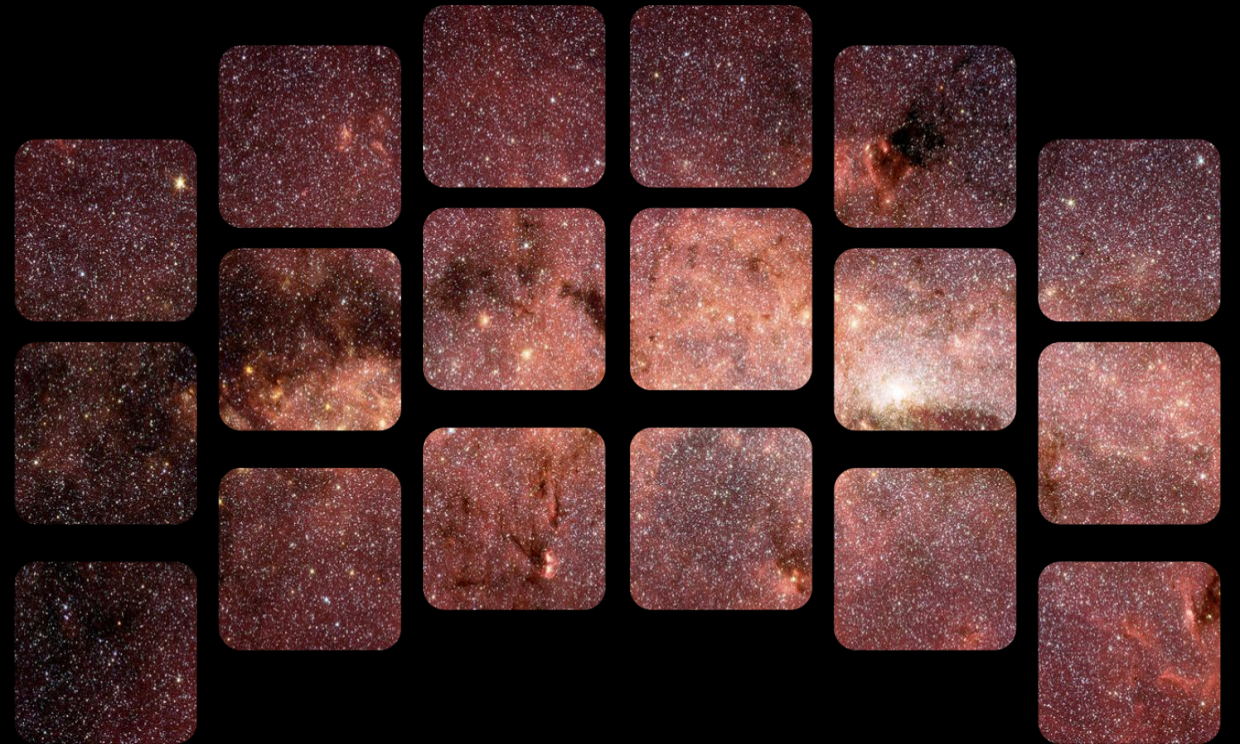


# Roman Observations and Design Reference Mission

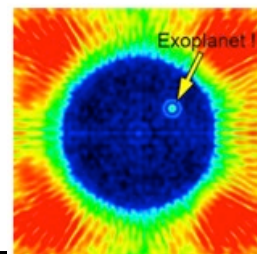
# R.ÖMAN



# SPACE TELESCOPE

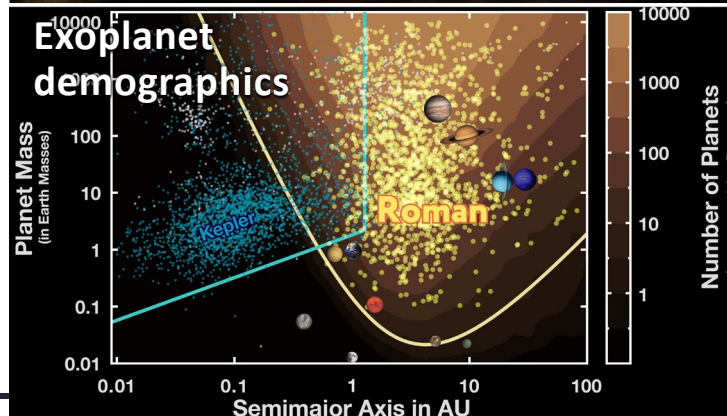
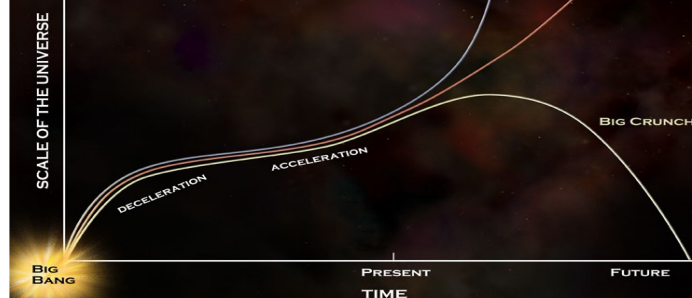
# Roman Mission Objectives

- **Wide Field Infrared Survey**
  - Imaging and spectroscopy to  $>26.5$  AB mag
- **Expansion history of the Universe**
  - Using supernova, weak lensing and galaxy redshift survey techniques
- **Growth of Structure in the Universe**
  - Weak lensing, redshift space distortions and galaxy cluster techniques
- **Exoplanet Census**
  - Statistical census of exoplanets from outer habitable zone to free floating planets via microlensing technique
- **General Astrophysics Surveys**
  - Devote substantial fraction of mission lifetime to peer-reviewed program
- **Coronagraph technology demonstration**
  - Demonstrate exoplanet coronagraphy with active wavefront control



## Wide-Field Infrared Surveys of the Universe

## Dark Energy and the Fate of the Universe



# The Long and Winding Road...from Objectives to Requirement



- **Top-level science requirements were included in the RFI submissions to Astro-2010**
- **The first Science Definition Team (SDT) and Project Office began defining Objectives and resulting science requirements based on the Astro-2010 recommendations**
  - Based on the 1.5m concept for WFIRST
  - SDT #1 report: arXiv:1208.4012
- **When the 2.4m telescope elements became available, a second SDT was established to explore a mission concept based on this telescope.**
  - The first drafts of the Science Requirements Document were developed by this group
  - SDT #2 report: arXiv:1503.03757
  - The Mission Concept Review held Dec. 2015 was based on the work of this SDT with the Project Office
  - This review was the basis for formally entering Phase A in February 2016
- **The Formulation Science Working Group began work February 2016**
  - This group developed the Science Requirements Document we have today
  - The essential aspects of the SRD have been stable since SDT #2, though substantial work has gone into understanding margins and refining observing strategies
- **The science requirements and resulting flowdown to mission requirements was reviewed by several external groups**
  - National Academy Reviews: Harrison review (2014), Astro2010 mid-decadal review (2016)
  - NASA Reviews: WFIRST Independent External Technical, Cost, Management Review - WIETR (2017), APAC (2018), WFIRST Science Assessment Team (2019)

- **Three Core Community Surveys address the 2010 Decadal Survey science goals while providing broad scientific power**
  - **High Latitude Wide Area Survey**
    - Wide area multiband survey with slitless spectroscopy
    - Enables weak lensing and galaxy redshift cosmology mission objectives
  - **High Latitude Time Domain Survey**
    - Tiered, multiband time domain observations of 10s deg<sup>2</sup> at high latitudes
    - Enables Type Ia supernova cosmology mission objectives
  - **Galactic Time Domain Survey**
    - ~<15 min cadence observations over few deg<sup>2</sup> towards galactic bulge
    - Enables exoplanet microlensing mission objectives
- **Minimum 25% time allocated to General Astrophysics Surveys**
- **90 days for Coronagraph technology demonstration within first 18 months of mission**

# *Core Community Surveys are for Everyone*

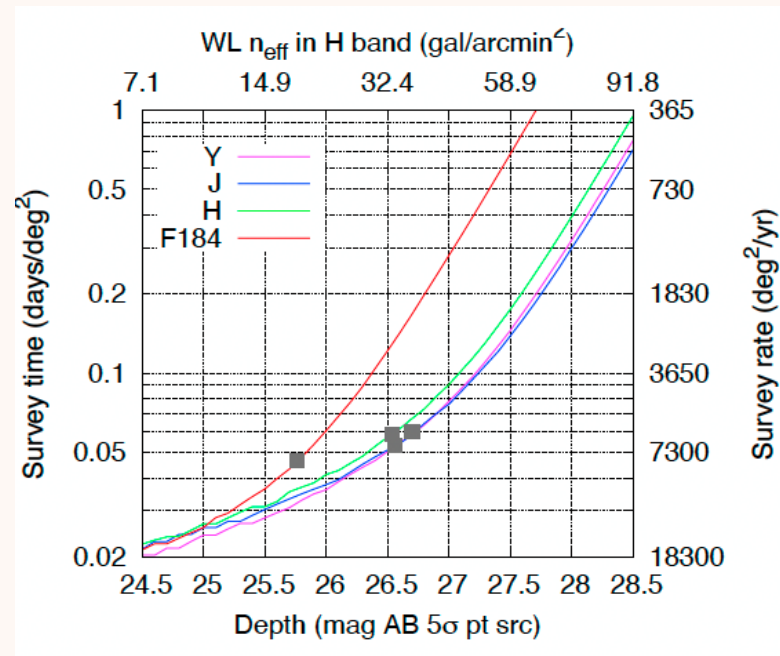


- **Core Community Surveys:** a significant fraction of the prime mission used for revolutionary surveys of unprecedented scale.

**Core Community Surveys definition will be via an open process, maximizing the overall science return while meeting the cosmology and exoplanet science requirements**

- The Design Reference Mission is a notional observing plan that is used to demonstrate that Roman can execute a science program that will meet the mission objectives within the prime phase of the mission
- **It is NOT the observing plan** but gives a flavor for that nature of surveys that address the science objectives and the degree of flexibility to optimize the observing program for a broad range of science
  - **High Latitude Wide Area Survey**
    - 1700 deg<sup>2</sup> (wide), 20 deg<sup>2</sup> (deep), 4 filters (Y, J, H, F) for wide and deep fields and grism spectroscopy
  - **High Latitude Time Domain Survey**
    - 19 deg<sup>2</sup>, (wide), 4.2 deg<sup>2</sup> (deep), 4 filters (R, Z, Y, J – wide) / (Z, Y, J, H – deep), 5 day cadence, and prism spectroscopy.
  - **Galactic Time Domain Survey**
    - 2 deg<sup>2</sup>, 15 min cadence with W filter, 12 hour cadence for R or Z and Y or J for 60 – 72 day seasons; 6 seasons

- **1700 sq deg area to measure  $\sim >10^8$  galaxy shapes and  $\sim >10^7$  galaxy spectroscopic redshifts**
  - Imaging
    - Two passes in 4 NIR bands (F106, F129, F158, F184) spanning the range from 0.93-2.00  $\mu\text{m}$  to magnitudes 25.8-26.7 AB (band-dependent) and reaching the diffraction limit in F129 and redder bands
    - 4 dithers on each pass (to enable shape measurements and diagnose systematics)
    - 140 s for each exposure
  - Spectroscopy
    - Four passes
    - Two dithers per pass
    - 298 s per exposure
  - 20 sq deg deep field
    - 10% of time allocated to imaging+spectroscopic survey.



# HLWA Survey - Additional Possible Primary Science

- Tens of thousands of Galaxy Clusters
- Huge sample of galaxies enable studies of galaxy formation and evolution
  - thousands of galaxies at redshift 10-15
  - Rare objects
- Stellar streams and dwarfs around nearby galaxies
- brown dwarf census and luminosity function through large volume of Milky Way
- white dwarf luminosity function down to tip of cooling curve, to much greater distances than present surveys - provides chronometer for age of MW, or equivalent for different stellar populations

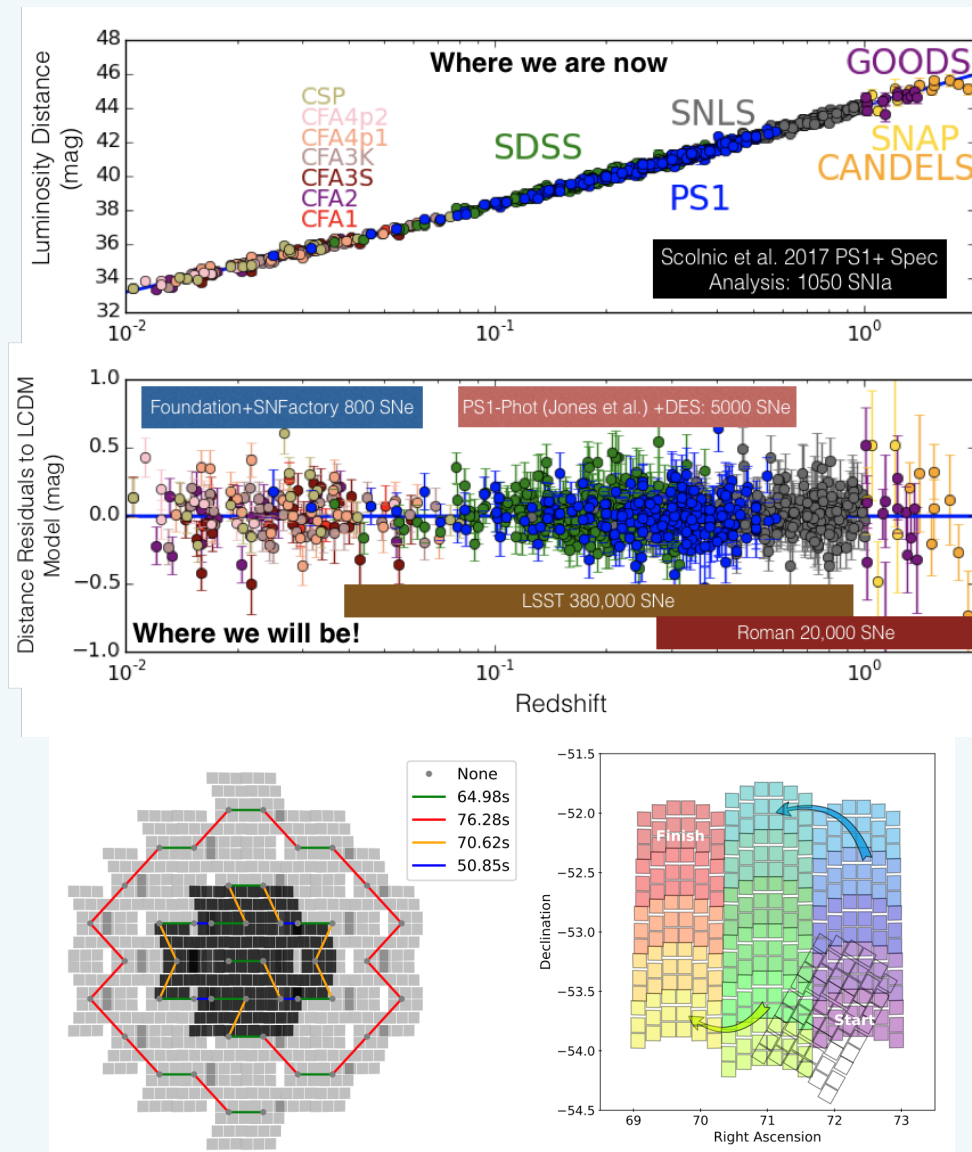
# HLWA Survey – Possible trades, modifications and extensions

- Location of survey footprint
- Depth vs area
- Add additional filters to all or part of the survey footprint
- Increase the survey footprint
- Place part of HLWAS, esp. part of the deep field, accessible to the Subaru PFS for spectroscopic calibration of photometric redshifts
- Extend time baseline of deep field portion of the HLWAS
- Add the F213 filter to these datasets, [especially with sufficient observing time, would enable detection of transients at high redshifts]
- Adding long time baselines will have interesting astrometric application
  - Stellar kinematics in distant halo to measure MW mass

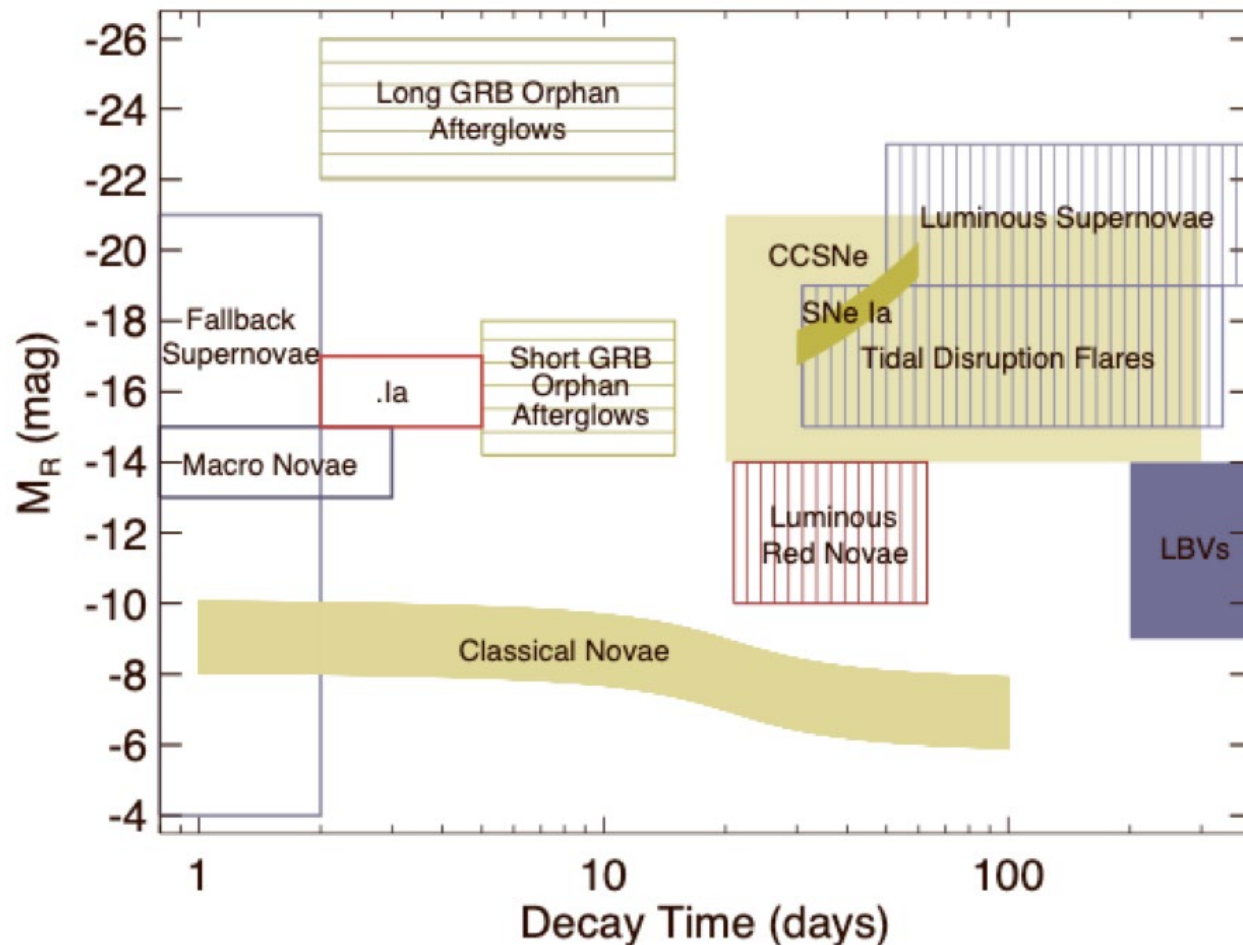
## Enables Type Ia Supernova Cosmology

- **6 months over 2 yrs**
  - 5-day cadence
- **2 tier survey:**
  - Wide:  $z < 1$
  - Deep:  $z < 1.5$ , and to characterize SN
- **4 filters per tier:**
  - Wide: RZYJ
  - Deep: YJHF
- **~30 hr visits**
  - Some fraction of imaging and prism spectroscopy
  - Imaging exposures based on achieving a S/N  $\sim 10$  for each filter at peak.
  - Prism exposures based on achieving a S/N  $\sim 25$  in rest frame

Images: Top – Current observations of SN Ia and how Roman will increase the number observed at higher redshifts.  
Bottom – Possible slewing strategies.



- Reverberation mapping to measure black hole masses of high redshift quasars
- Blind searches for Kilonovae
- Tidal Disruption events
- AGN variability studies
- Long and short GRB studies
- Cataclysmic variables
- Other kinds of supernovae
  - Core collapse
  - Luminous
  - .Ia

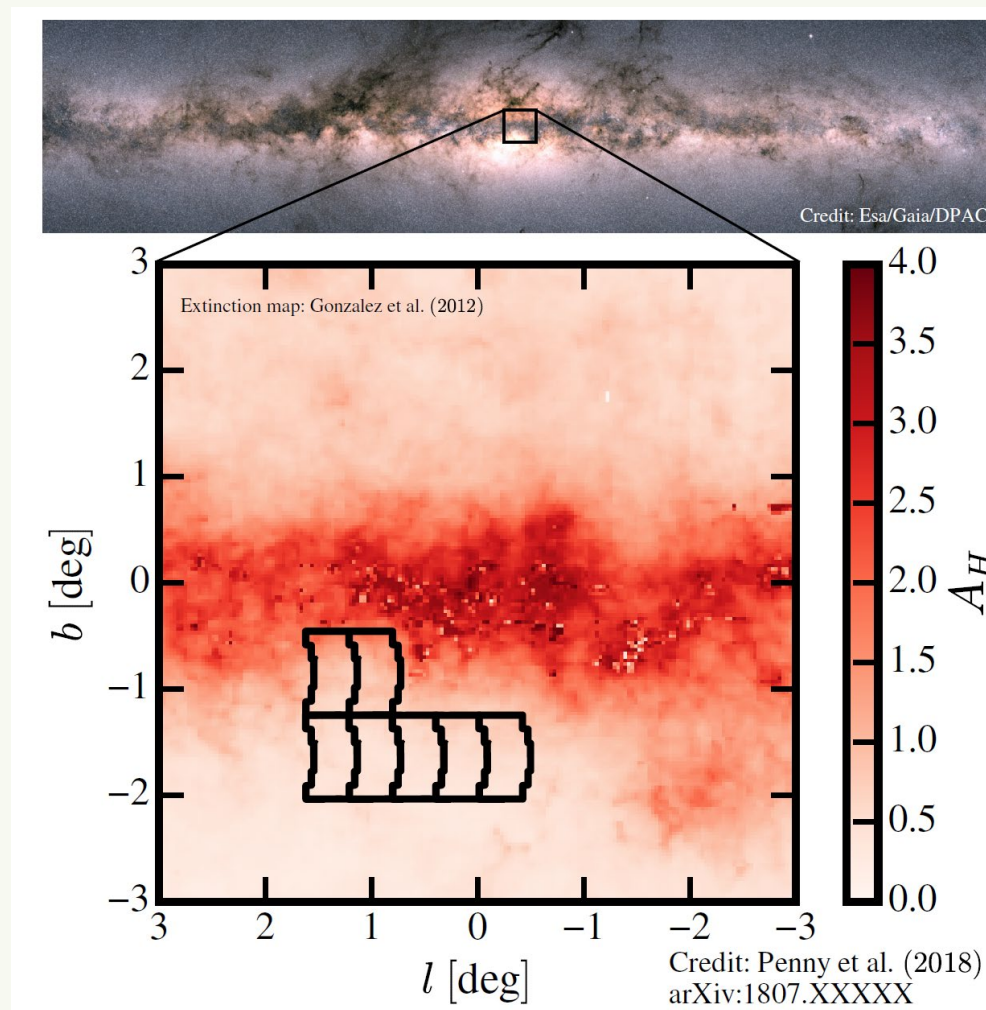


R-band peak magnitude as a function of decay time. Taken from Rau et. al., 2009

- **Location of survey footprint**
- **Increase cadence for some period**
  - Enable timely identification of kilonova
- **Add F213 filter observation**
- **Add periodic Grism observations**
- **Extend baseline of survey beyond 2 years**

# Galactic Bulge Time Domain Survey – Design Reference Mission

- 7 fields for a total of  $\sim 2 \text{ deg}^2$
- Wide F146<sub>AB</sub> (0.93-2  $\mu\text{m}$ ) filter\*\*.
- 15-minute cadence.
- Observations every at 6 hours in alternating filters (e.g., F087,F219), 2 x 450 total obs
- 6 x 72-day seasons.
- $\sim 41,000$  exposures in W149<sub>AB</sub>
- $\sim 432$  total days spread over 5-year mission



## GBTD Survey – Additional possible primary science

- Measurement of the Compact Object Mass Function over 10 Orders of Magnitude.
- Detection of  $\sim 10^5$  Transiting Planets.
- Astroseismology of  $\sim 10^6$  Bulge Giants.
- Resolved Stellar Populations and Galactic Structure.
- Detection of  $\sim 5 \times 10^3$  Trans-Neptunian Objects.
- Parallaxes and Proper Motions of  $\sim 6 \times 10^6$  Bulge and Disk Stars.

- **Modifications**

- Periodic observations of the GC.
- Periodic observations of the survey fields in all filters.
- Periodic observations of a much larger survey area

- **Extensions**

- Extending the survey for additional seasons
- Very high cadence observations of a smaller area
- Lower-cadence observations of a larger area
- High-cadence observations in alternate filters
- Surveying Northern Galactic fields
- High cadence observations of the GC

# Evaluation of Design Reference Mission against high level requirements

| Survey – type of FOM                      | Requirement | Projected Performance with DRM |
|-------------------------------------------|-------------|--------------------------------|
| HLWA – Weak Lensing (WL)                  | 327,400     | 506,000 <sup>†</sup>           |
| HLWA – Baryon Acoustic Oscillations (BAO) | 7,533       | 11,300 <sup>†</sup>            |
| HLWA – Redshift Space Distortions (RSD)   | 4,047       | 5,750 <sup>†</sup>             |
| HLTD – Dark Energy Task Force (SNIa)      | 325         | 443-602 <sup>*</sup>           |
| GBTD - # planets                          | 1179        | 1400                           |

*N.B. These FoM are different metrics appropriate to each study, so are not intercomparable*

FoM definitions:

WL:  $1/\sigma(F_W)^2$  where  $F_W$  is scaling of  $\sigma_m(z)$  (amplitude of mass clustering) wrt  $\Lambda_{\text{CDM}}$

BAO:  $1/\sigma(F_D)\sigma(F_H)$ , where  $F_D$ ,  $F_H$  are scaling of  $D_A(z)$ ,  $H(z)$  wrt  $\Lambda_{\text{CDM}}$

RSD:  $1/\sigma(F_G)^2$  where  $F_G$  is scaling of  $\sigma_m(z)f(z)$  wrt  $\Lambda_{\text{CDM}}$ ,  $f(z)=d\sigma_m(z)/d\ln a$

SNIa:  $1/\det(\text{Cov}(w_0, w_a))$

References:

HLIS, HLSS: <sup>†</sup>1700 deg<sup>2</sup> - C. Hirata memo dated Aug 25, 2021; Troxel et al 2021, Eifler et al 2021

SN: <sup>\*</sup>systematics-limited, statistics limited; SN teams joint report, 9/1/2021

EML: Penny et al 2019 APJS 241:3, Johnson et al 2020

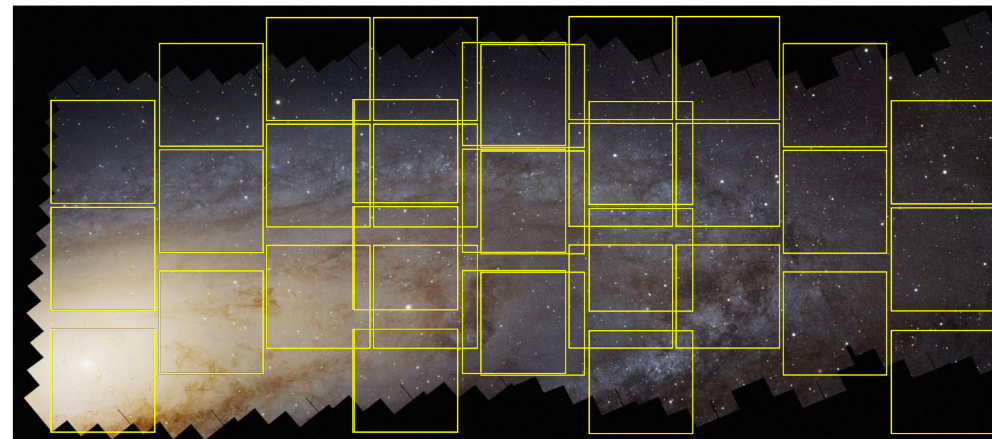
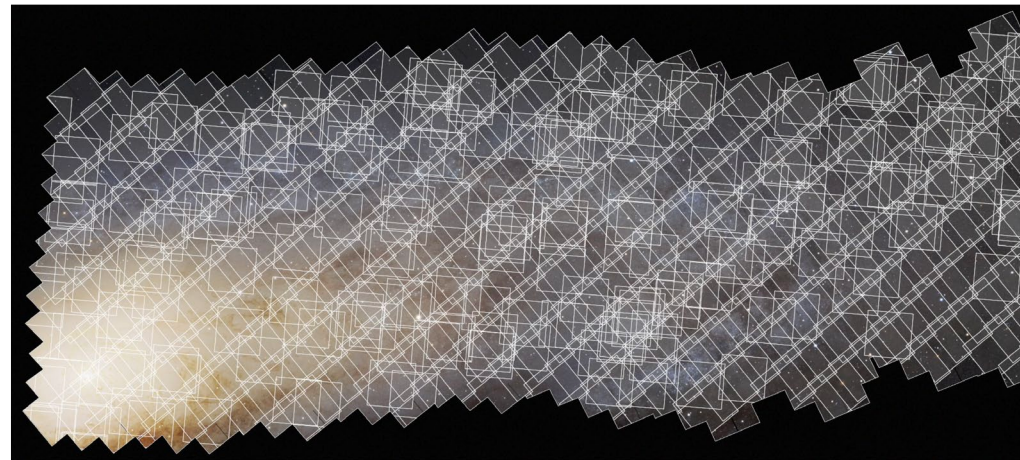
SN FOM Range reflects impact of astrophysical uncertainties; the upper end of the range matches the assumptions used in the SRD FOM requirement.

# Time Allocations in Design Reference Mission

|                                                                           | Durations (days) |
|---------------------------------------------------------------------------|------------------|
| High Latitude Wide Area Survey (HLWA Survey) – Imaging                    | 283.6            |
| High Latitude Wide Area Survey (HLWA Survey) - Spectroscopy               | 169.4            |
| High Latitude Wide Area Survey (HLWA Survey) – Deep field                 | 51.6             |
| High Latitude Time Domain Survey (HLTD Survey) – Imaging and Spectroscopy | 189.3            |
| Galactic Bulge Time Domain (GBTD Survey)                                  | 372.1            |
| General Astrophysics Surveys                                              | 412.6            |
| Coronagraph Technology Demonstration                                      | 90               |
| WFI Calibration                                                           | 113.8            |
| Mission operations overheads                                              | 62.6             |
| <b>Total</b>                                                              | <b>1744.9</b>    |
| <b>Margin</b>                                                             | <b>81.1</b>      |

- **Considerable flexibility because current design reference mission demonstrates that we can meet science requirements with margin**
  
- **Three Areas of Margin**
  - Margin between predicted performance and science requirements/FoM
  - Explicit margin
    - Days not currently assigned to anything (could be added to GA surveys or used to enhance core community surveys)
  - Implicit margin (e.g. slew rates assume 5 reaction wheels)
  
  - Real opportunities for the planned community process to result in enhancements to the core community surveys for broader astrophysics return and/or increase the time allocated to General Astrophysics Surveys above 25%

- The power of Roman is not *just* the large field of view:
  - Very efficient observations
    - Rapid slew & settle
    - No Earth occultations
    - No South Atlantic Anomaly
  - Well understood and stable PSF
    - Stable thermal environment (L2 orbit, thermal control of all parts of the optical system)
    - Rigid optical structure with vibration isolation from the spacecraft
    - Stable attitude control
  - Excellent flux calibration
    - The onboard Relative Calibration System enables 0.3% photometric accuracy



- **The DRM shows that it is possible to meet the science objectives, ensure the minimum 25% of time for General Astrophysics, and still have some margin.**
- **There is real scope for the future open community process to optimize the Core Community Surveys for broad and deep astrophysics return and also have the option of reallocating time back to the General Astrophysics survey pool.**

**Is this the right amount of flexibility?**

**Should we constrain things further now and provide less flexibility in the future Core Community Survey definition, in order to ring-fence a larger allocation for General Astrophysics Surveys? Or reduce the ring-fence to allow more community optimization?**

# Backup