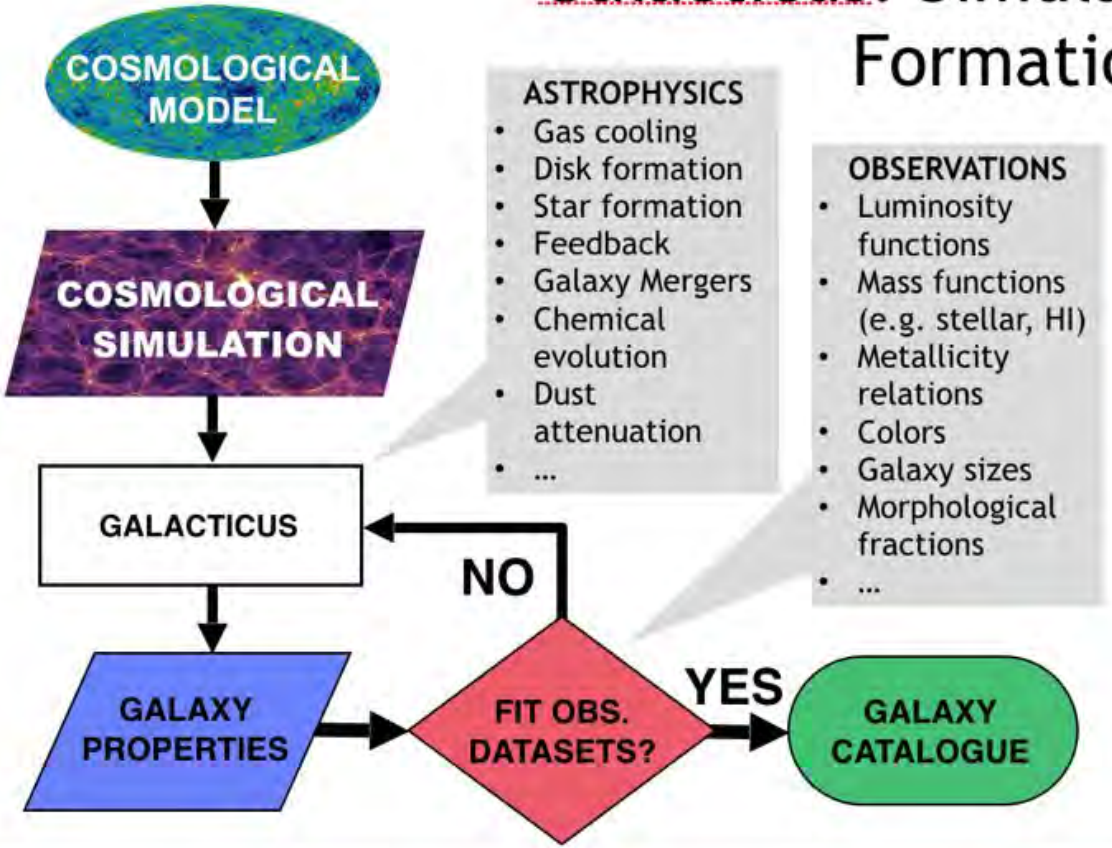
Roman High Latitude Spectroscopic Survey: Galaxy and Grism simulations

Speakers: Zhongxu Zhai (Waterloo), Anahita Alavi (IPAC/Caltech), James Colbert (IPAC/Caltech)
On behalf of Yun Wang, Olivier Dore, Harry Teplitz, and High Latitude Survey Science Investigation Team

Galacticus: Simulating Galaxy Formation



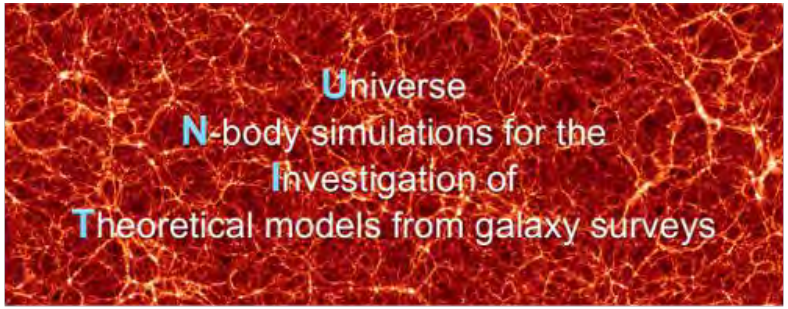
Andrew Benson (Carnegie Observatories)

bitbucket.org/galacticusdev/galacticus

- **Simulating galaxy formation is a complex process.**
- "Semi-analytical model": solves coupled sets of differential equations governing astrophysical processes.
- OpenMP/MPI parallelized.
- Open source.

credit: Alex Merson

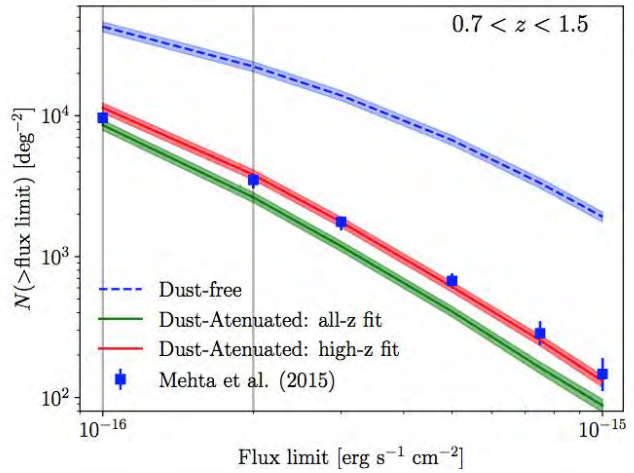
UNIT simulation: dark matter halos & merger trees

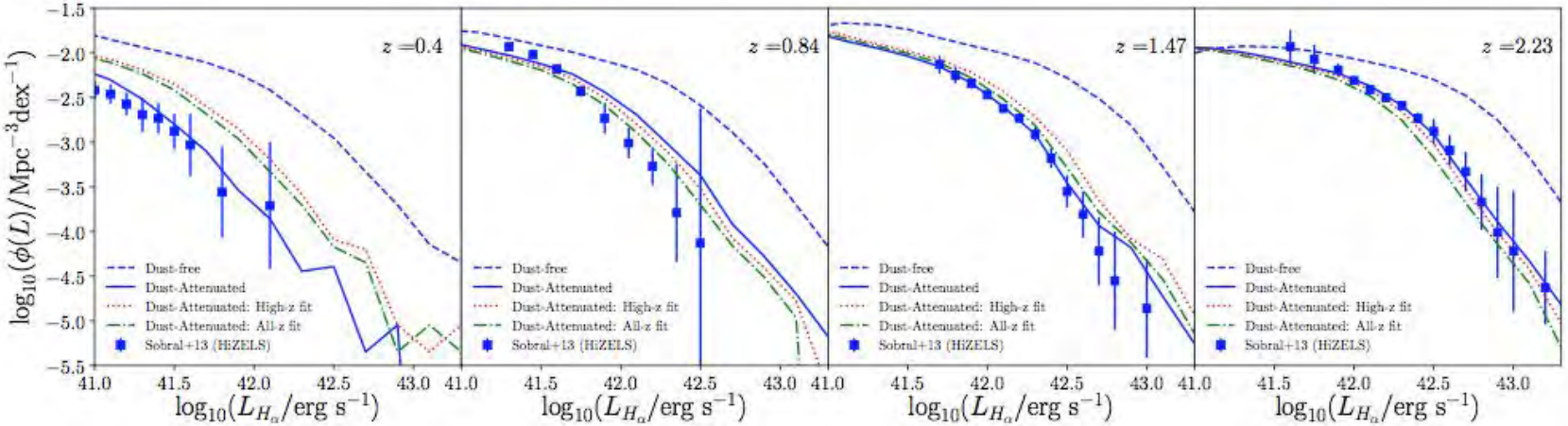


simulation code	amplitude	phases	box side length	number of particles	particle M $[h^{-1}\,M_\odot]$	force resolution	number of boxes
Gadget G	fixed	regular	1 h^{-1}Gpc	4096^3	1.2×10^9	6 h^{-1}kpc	2
Gadget $\overline{\text{G}}$	fixed	inverse-phase of G	1 h^{-1}Gpc	4096^3	1.2×10^9	6 h^{-1}kpc	2
FastPM A	non-fixed	regular-reference LR	1 h^{-1}Gpc	1024^3	7.68×10^{10}	1.46 h^{-1}Mpc	100
FastPM $\overline{\text{A}}$	non-fixed	inverse-phase of A	1 h^{-1}Gpc	1024^3	7.68×10^{10}	1.46 h^{-1}Mpc	100
FastPM B	fixed	regular	1 h^{-1}Gpc	1024^3	7.68×10^{10}	1.46 h^{-1}Mpc	100
FastPM $\overline{\text{B}}$	fixed	inverse-phase of B	1 h^{-1}Gpc	1024^3	7.68×10^{10}	1.46 h^{-1}Mpc	100
FastPM C	non-fixed	regular-reference HR	250 h^{-1}Mpc	1024^3	1.2×10^9	0.36 h^{-1}Mpc	100
FastPM $\overline{\text{C}}$	non-fixed	inverse-phase of C	250 h^{-1}Mpc	1024^3	1.2×10^9	0.36 h^{-1}Mpc	100
FastPM D	fixed	regular	250 h^{-1}Mpc	1024^3	1.2×10^9	0.36 h^{-1}Mpc	100
FastPM $\overline{\text{D}}$	fixed	inverse-phase of D	250 h^{-1}Mpc	1024^3	1.2×10^9	0.36 h^{-1}Mpc	100

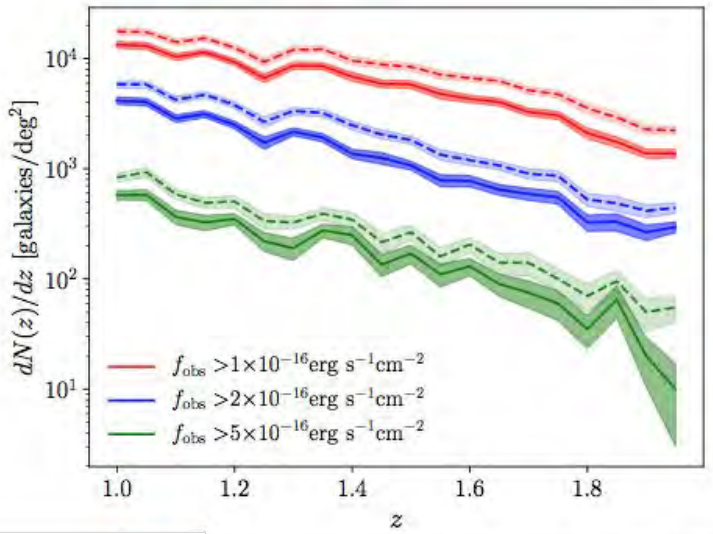
Calibration

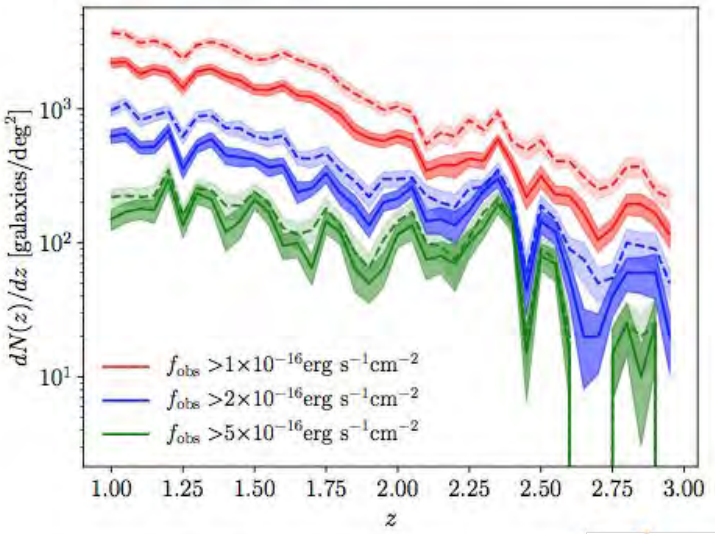
Find the parameter set of the SAM to make reasonable galaxy statistics.
Astrophysical processes include gas cooling, star formation, SNe feedback, dust attenuation etc.





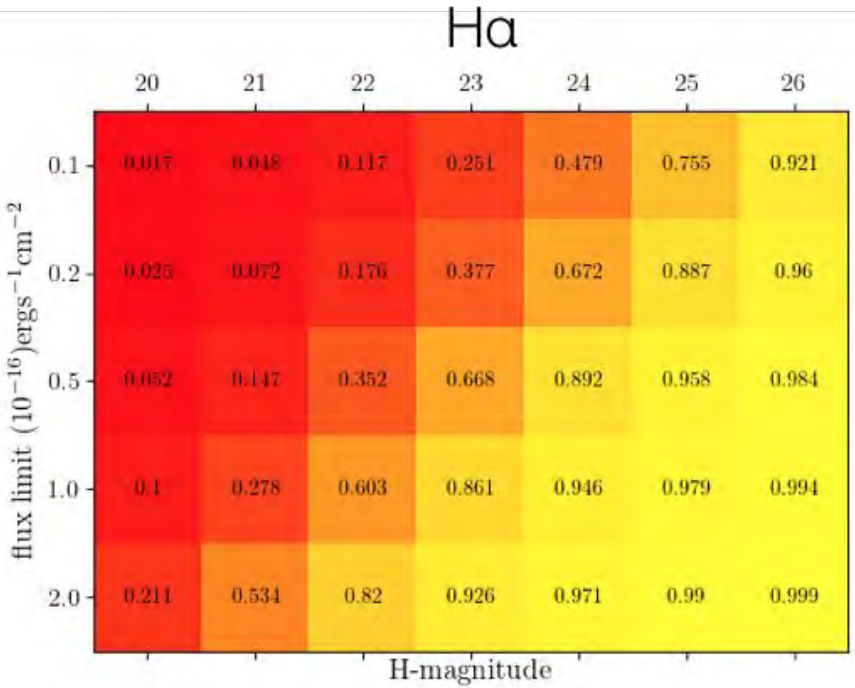
ELG number density

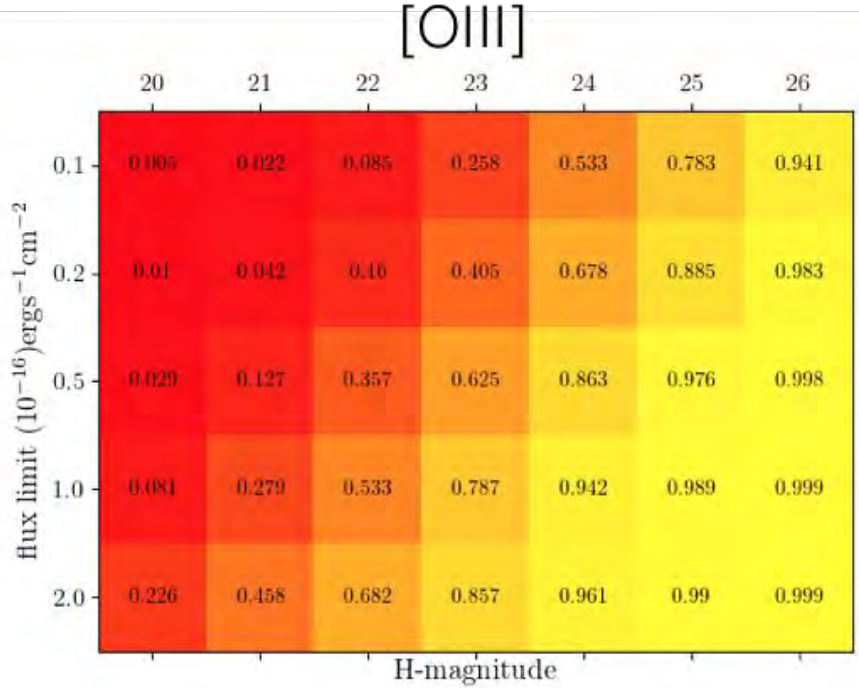




		Dust model fit at all redshifts			Dust model fit at high redshifts		
Redshift		Flux limit [erg s^{-1}cm^{-2}]			Flux limit [erg s^{-1}cm^{-2}]		
From	To	(5×10^{-17})	(1×10^{-16})	(2×10^{-16})	(5×10^{-17})	(1×10^{-16})	(2×10^{-16})
1.0	2.0	18155 ± 924	5958 ± 303	1426 ± 75	23659 ± 1201	8480 ± 432	2203 ± 114
0.5	2.0	22270 ± 1125	9061 ± 461	2967 ± 156	27809 ± 1404	11993 ± 610	4166 ± 217
1.0	2.0	5185 ± 258	1433 ± 72	393 ± 20	8110 ± 406	2399 ± 121	627 ± 32
2.0	3.0	1364 ± 74	297 ± 18	119 ± 7	2408 ± 127	517 ± 30	160 ± 10

Prediction of the photometric completeness





Motivation behind the grism simulation

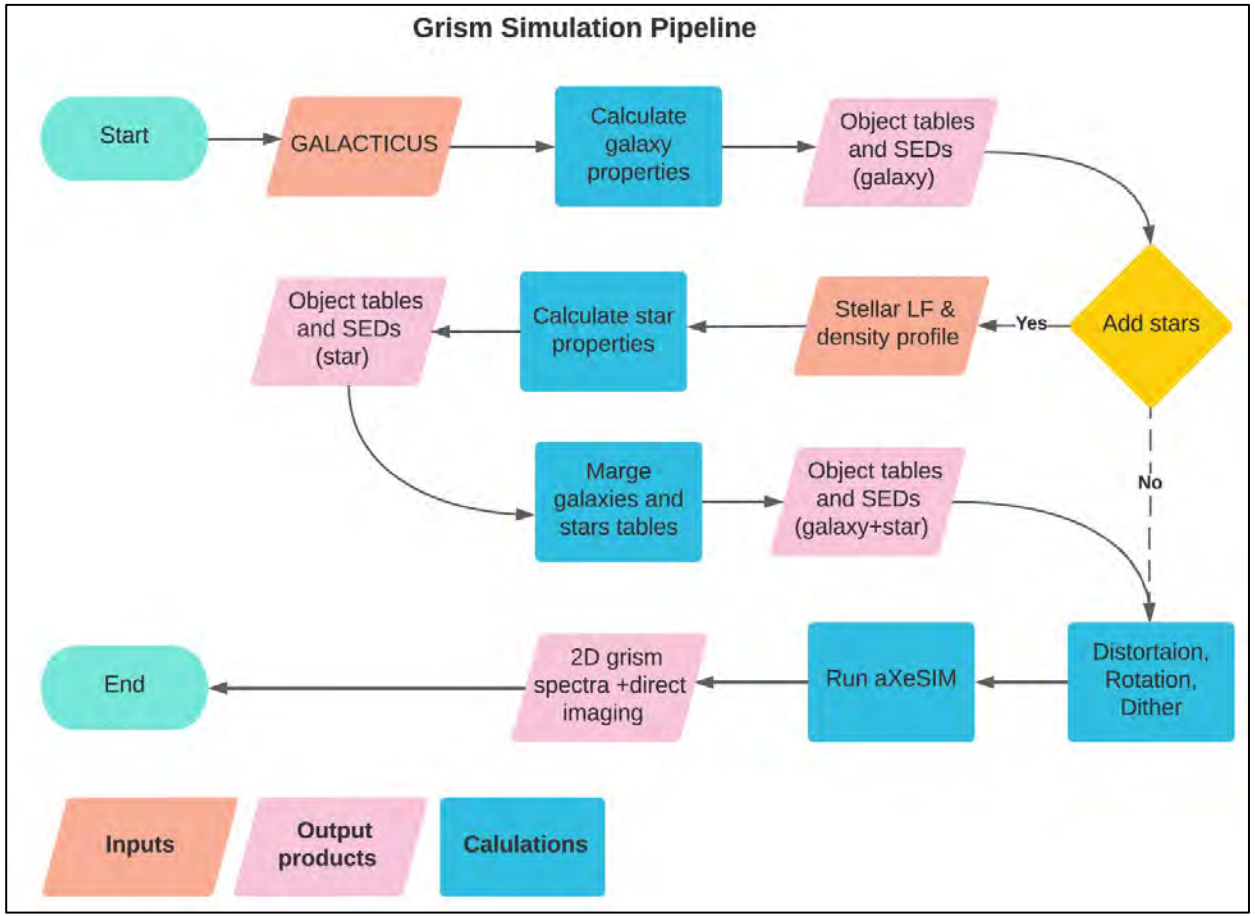
Slitless grism spectroscopic surveys, including HLSS, can suffer from:

- Incompleteness
  - Sources that we fail to detect because their fluxes are close to the detection limit
  - sources may be missed due to their flux and/or emission lines blending with those of nearby objects
- low purity:
  - the fraction of sources with correctly identified emission lines

We have designed the mock slitless spectroscopy observations to measure the completeness and purity for the Roman HLSS

Simulation overview

- A pipeline to simulate grism observations for the Roman HLSS
- simulations cover an area of 4 deg^2 over the redshift range of 0 < z < 3 (~10 million galaxies)



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Simulation overview

➢ Running aXeSIM (Kuemmel+2007) to generate a synthetic grism spectra

INPUTS

Galaxies: From the Roman HLSS 4 deg2 galaxy mock catalog (GALACTICUS)

- Coordinates
- Redshift
- Size , A- & B-major axis,two-dimensional Gaussian profiles as image templates
- Brightness
- Inclination angle (random)
- SED

Stars: For a realistic sky scene, we also incorporate stars in our simulation.

- Star's number density, Chang+2010
- Stellar luminosity Function, Just+2015
- PSF as image template

Instrument characteristic

- Configuration file (trace and dispersion solutions)
- Sensitivity files
- Filter , H158

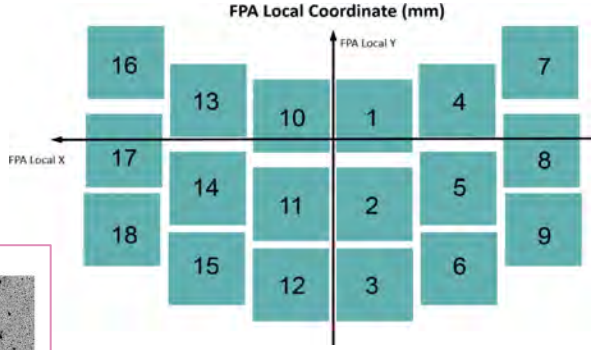
Survey parameters

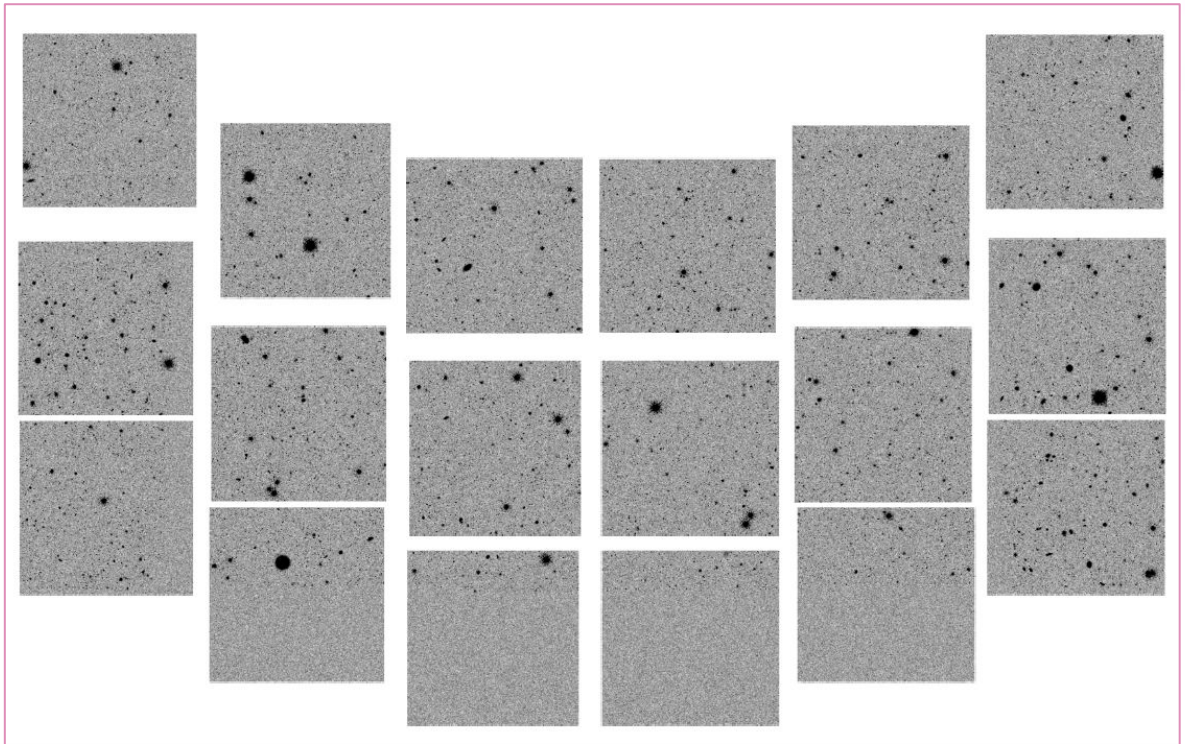
- Exposure time (141s for direct, 301 for grism)
- magnitude cut (i.e., m_H=28)
- Background (i.e., 0.25 for direct, 0.57 e/pix/sec for grism)
- 4 Roll angles * 2 dithered positions (0,5,170 & 175 deg and ¼ SCA_size dithering)

Simulation products

OUTPUTS

- 4 deg^2 area (~15 full Roman FOV): simulated direct images and simulated 2D slitless dispersed images (i.e., grism spectra) for all WFI 18 detectors in their proper configurations.

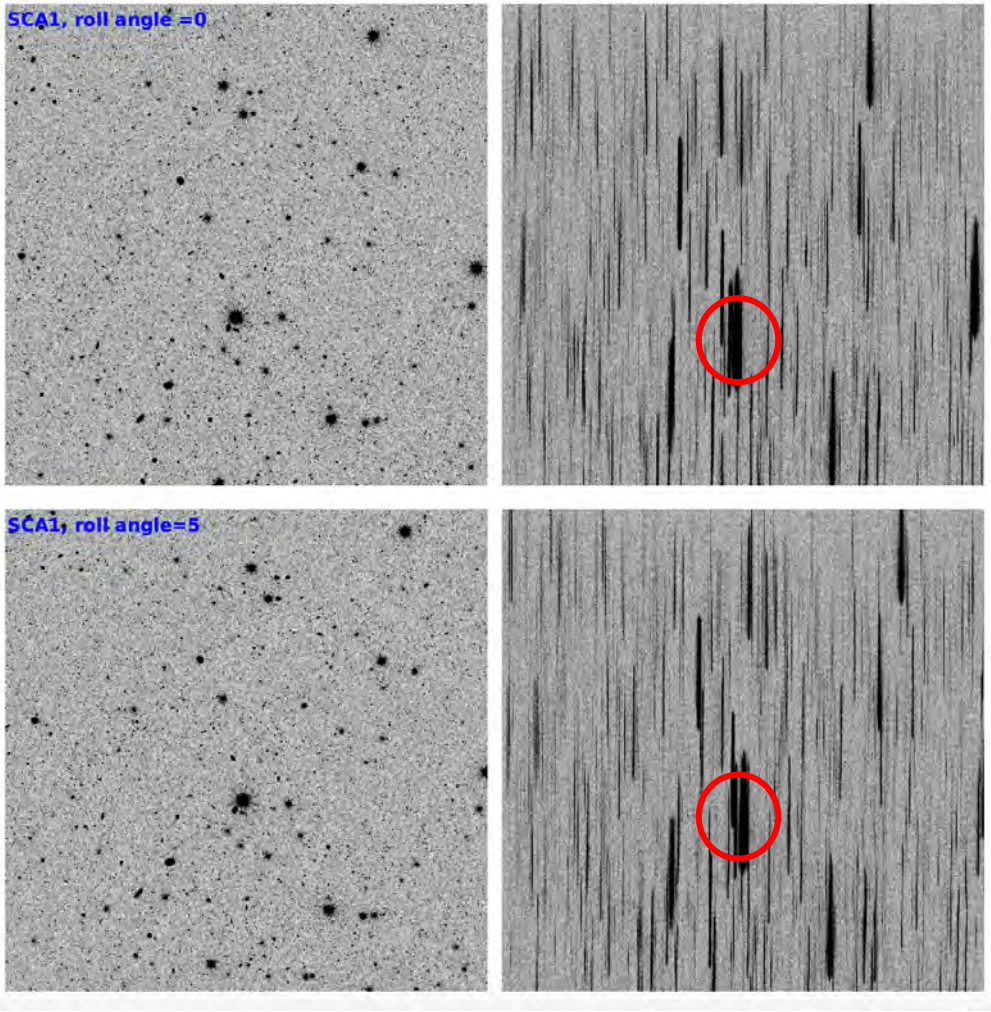




An example of a simulated direct image for one full Roman FOV

Simulation products

- This example displays a direct image on the left and a 2D slitless dispersed image on the right for detector number 1. The images are shown for two roll angles of 0 and 5 degree.



- Our final products are ready and soon will be publicly released on the IPAC website (https://roman.ipac.caltech.edu/)

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Wavelength Uncertainties

Redshift uncertainties are wavelength uncertainties which are fundamentally the accuracy to which we know at what wavelength the emission lines are located.

Statistical Errors

Line centroiding

- Primary source of error.
- Well represented in present simulations
- 0.5" galaxy, 1 line, 6.5σ + additional 4σ line: 0.07% error

Reference galaxy position

- Could measure positions independently from direct images, however direct images do not include complexity of true universe. Gaussian ellipticals will produce lower errors.
- Small component: H=25, 0.5” galaxy ~0.015% error

Measurement of zero point location

- Every image must be registered to sky-to-pixel solution using bright stars
- Contains uncertainty in edge measurement + uncertainty in SED knowledge used to fit edge
- Expected to be around 0.03% error

Random Pixel Level Uncertainties

- Variety of pixel effects expected to be essentially random: Errors in flat field, dark current, cross talk, PSF asymmetries, etc.
- Altogether expected to be small effect: ~0.015%

Statistical errors not accounted for in simulation could just be added to final redshift measurements. None should be a source of systematic redshift distortions.

Systematic Uncertainties

- There are limits to how finely the entire system can be calibrated. In this case the uncertainties will be consistently in the same direction.
- Total EXPECTED systematic errors are presently predicted to be ~ 0.03%
- To account for these in simulations there is no need to change the flux in pixels – Just need to add error into the headers and/or configuration files one uses to extract the data.
- Future simulations COULD do this for the user, i.e. provide sims with a pair of configuration files: true and with systematics
- But probably best left to user depending on what they wish to investigate
  - Might want to test effect of larger than expected in systematic error in particular area

Systematic Uncertainty	Error
Optical distortions in image data	**0.01%**
Optical distortions in grism data	**0.01%**
Spectral dispersion	**0.015%**
Filter bandpass	**0.01%**
Mean plate scale	**0.005%**
Knowledge of model LSF	**0.02%**

Future Simulations

- Clearly great improvements are being made and will continue to be pursued in simulating the universe side, but for this brief discussion I am focusing more on the sky-to-pixel simulations.
- Need to be some general coordination of simulations
  - There are different interest groups with different simulation needs
    - Pipeline development, requirement testing, completeness and purity testing, etc.
  - Should try and learn from Euclid, for which simulation availability has been a bottleneck
  - Want to ensure we have allocated enough resources/planned far enough ahead
  - Should avoid a centralized, simulations designed for all model, which will work even worse for Roman than Euclid (more diverse science goals)
  - This should be a major component of future SIT proposals

Improved Simulation Engines

- We are reaching the limits of what aXeSIM can provide
  - A lot of development involves writing complicated wrappers around the aXeSIM core. This can be very inefficient, pushing the same object through multiple times to achieve certain detector effects (offset emission, different PSFs for different orders, etc.)
- Need a wavelength dependent PSF
- Need different PSFs for different orders
- There is some evidence of different groups working on grism simulation software
  - We should identify interested parties and gather them together, maybe in a small virtual workshop of some sort
  - We can then evaluate where we are, do we need to start from scratch, and if there are more than one tool in development whether we should focus on it, or if we need multiple tools for multiple end goals

Personal Future Sim Wish List

- Must have 0 and 2nd orders
  - Will not be able to properly evaluate confusion without
  - Much different PSFs than 1st order. Must find a way to deal with.
- Realistic distribution of stars
  - Sims we present have correct mag distribution, but not SED distribution
  - To evaluate blue edge measurement error (significant statistical uncertainty), need to see changing cut-off with stellar type.
- Wavelength dependent PSF
  - With a wavelength range of 1-1.9um, more significant effect than in WFC3 (G141 is roughly half that range)