

The Need for Robust WFIRST Wide Field Imager Data Simulator

Molly S. Peebles, Scott Gaudi, Michael Jarvis, Rebekah Hounsell, Rubab Khan,
Sangeeta Malhotra, Joshua E. G. Peek, Matthew Penny, Gregory F. Snyder,
Rachel Street, Harry Teplitz, Ben Williams, Jennifer Yee
March 8, 2017

As astronomy's first high-resolution wide-field instrument, simulated data will play a vital role in the planning for and analysis of the data from WFIRST's WFI (Wide Field Imager) instrument. Part of the key to WFIRST's scientific success lies in our ability to push the systematics limit, but in order to do so, the WFI pipeline will need to be able to measure and take out said systematics. The efficacy of this pipeline can *only* be verified with large suites of synthetic data; these data must include both the range of astrophysical sky scenes (from crowded starfields to high-latitude grism data observations) and the systematics from the detector and telescope optics the WFI pipeline aims to mitigate. In the near future, a definitive WFI Data Simulator (WFIDS) will save redundant efforts across the SITs: these teams have limited resources, and it makes sense for the development of the WFIDS to be closely-coupled with instrumentation updates, rather than distributed amongst the SITs. In the longer term, these tools will maximize the science return of the mission. In particular, we stress the integrated nature of the WFIRST surveys: if the Microlensing Survey (MLS) is to be used to calibrate the other WFI observations, then it is likewise critical that the data simulator used to prepare for the MLS is the same as that used to prepare for the High Latitude Survey (HLS) and GO observations. In short, the least risky and most efficient course is to have all effects carefully vetted for one simulator, instead of separately by many teams with disparate goals. We outline here the need for a robust WFIDS, a survey simulator, and suites of synthetic WFI data.

I. Ground system risk mitigation

An increasingly realistic data simulator for WFIRST would be a major risk mitigator for SSOC (and perhaps ISOC and GSOC) data management. As experience with JWST has shown, science-free engineering data from the flight hardware is not enough to prime and test the pipelines effectively. To help us run our pipelines well, we need actual science data so we can verify our end-to-end testing is providing data products of the quality needed to accomplish the science requirements. Further, the WFIDS as imagined, which takes inputs from an APT-like tool to point the simulated telescope at the simulated sky (i.e., a survey simulator), would also provide a critical stream to the Proposal and Planning Subsystem, which further feeds Data Management. Since WFIRST's core science is **systematics-limited**, later development of a data simulator tool must include telemetric engineering data (e.g., the temperature of the telescope may impact the PSF, and thus the telemetric temperature information will be needed in weak lensing regression) and this telemetric engineering feed will be an essential input for priming the pipeline and as a major additional risk mitigator for data management across the mission.

II. Maximizing the science return of WFIRST

The Microlensing Survey: The WFIRST microlensing survey must achieve high photometric quality and fidelity, but in order to do so it is critical that WFIRST's pipeline can characterize and remove the form and magnitude of systematic errors, and in particular detector-specific systematic errors (non-linearity, persistence, non-reciprocity failure, brighter-fatter, etc.). Robustly identifying microlensing events from the hundreds of millions of light curves tracked in these crowded fields will only be feasible with such a robust pipeline—and such a pipeline must first be trained on synthetic data. In particular, we need to understand what systematics will be imprinted on photometric and astrometric curves by the detector, and what detrending will be needed to be included

in the microlensing analysis pipeline to mitigate them. A survey simulator that includes both the MLS footprint and observing cadence (affected by, e.g., slew-and-settle times) coupled with simulated photometric and astrometric curves will be required to maximize the number of detectable microlensed planets, and thus maximize one crucial component of the science yield. Moreover, WFIDS can help us understand how well WFIRST can characterize those planets, e.g., by measuring the light of the host star as it separates from the source, which depends on measuring color-dependent effects over fractions of a pixel. Estimating the performance of WFIRST for these challenging measurements can only be done effectively with synthetic WFIRST data, as the WFIRST dataset will have different properties than any existing dataset. Effective testing of the event detection and classification algorithms being developed require simulated data, as the WFIRST dataset will have different properties than any existing dataset (which are predominately ground-based). A WFIDS that can generate both the crowded bulge fields of the MLS and also, e.g., synthetic images of the HLS, will enable both day-one identification and analysis of microlensing events *and* a pre-launch construction of a WFI pipeline that not only enables the microlensing survey to achieve its science requirements, but delivers the quantification and calibration of the detector effects that are needed in order for the HLS and other surveys to achieve their science requirements.

The High-Latitude Survey: Over the last decade, image simulations have become industry standard for observational cosmology: modern precision cosmology *requires* that the systematics introduced by the detector and telescope optics are understood, and corrected for, at a higher level than the observations being made.

Weak lensing: A WFIDS is critical to testing the weak lensing pipeline and measurement methods, including the validation of shear calibration algorithms. It is only with simulated data that we can quantify biases, the effects of detector characteristics, the effects of dithering, and how imperfect knowledge of the detector affects measured galaxy shapes (and thus weak lensing signal).

Galaxy clustering and the BAO survey: Galaxy clustering surveys require accurate redshifts, which for WFIRST will come from the grism. As such, WFIRST grism pipelines will have to be *fully* automated, unlike current Hubble-based ones, which require significant human intervention. Realistic simulated data are crucial to constructing such an automated pipeline; the most robust way to generate such data is via a single WFIDS that includes the same systematics from telescope optics and detector effects to generate both the broad-band pre-imaging and the slitless spectra.

The Supernova Survey: With a WFIDS, it will be possible to quantify the effects of various sources of noise on the ability to detect and characterize supernovae. A robust survey simulator is crucial to creating and testing observing strategies to maximize the number of detected supernovae at the desired redshift distributions—and how difficult any given strategy would be to schedule.

Guest Observer and Guest Investigator Science: Many science cases, such as the ability to recover structures in the stellar halos of galaxies, will require an optimized star-galaxy separation. The ability to do this will depend critically on how well a well-sampled PSF can be recovered through dithering. As for the HLS, Guest Observers will thus need to be able to reliably simulate stars and background galaxies over the full field of view at sub-pixel dither positions. A basic data simulator that merely pixelates synthetic stars and galaxies without also including WFIRST-specific effects such as the field-dependent PSF, detector characteristics and artifacts, and so on, will not be enough to optimize the observing strategies and analysis techniques needed to maximize the science return of such observations. A well-developed WFIDS would also allow proposals to include detailed mockups of their proposed observations and results, helping the TAC better select the best possible science for WFIRST.

The grism: While slitless spectroscopy coupled with the WFI's large field of view will revolutionize multi-object spectroscopy, maximizing the science return of grism data has its own specific set of needs. With respect to high- z galaxy surveys, for example, the recovery rate of emission lines as a

function of line flux, size of the galaxy/HII regions, and the density of sources will need to be modeled in order to determine completeness for a given set of observations. Likewise, grism simulations are critical to determining redshift accuracies in the face chip gaps, distortions, and astrometric uncertainties. These simulations must also be robust enough to account for astrophysical sources of redshift uncertainty from slitless spectroscopy, such as field crowding or cases in which a galaxy's emission line region and starlight being physically offset. It is only with such synthetic data that algorithms for identifying and recovering emission line galaxies and constructing accurate field-to-field calibrations will be able to be done.

Broader GO/GI cases: Moreover, with a survey simulator, guest investigators will be able to interface their astrophysical simulations directly to WFIRST datasets as soon as science observations begin. GO/GI cases for a WFIDS include:

- Using simulations of the Local Group, how many Milky Way satellite galaxies do they expect to find in the HLS? For a given model of Milky Way structure, how many RR Lyrae stars will be detected in the MLS?
- Which theories of galaxy formation reproduce the HLS galaxy properties on kiloparsec to megaparsec scales? How do AGN affect the observed host galaxies and vice-versa?
- Are large samples of reionization sources resolved or not in WFI imaging? What surveys will best map the patchiness of reionization and constrain different reionization models?

By packaging the steps necessary for modeling GO/GI data, a WFIDS would eliminate redundant activities across the field. This would expand the pool of community labor available to produce WFIRST science, accelerate the growth in archival value of the WFIRST dataset, and enable new projects not yet envisioned.