



The Hourglass Simulation: A Catalog for the Roman High-latitude Time-domain Core Community Survey

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Abstract

We present a simulation of the time-domain catalog for the Nancy Grace Roman Space Telescope's High-Latitude Time-Domain Core Community Survey. This simulation, called the Hourglass simulation, uses the most up-to-date spectral energy distribution models and rate measurements for 10 extragalactic time-domain sources. We simulate these models through the design reference Roman Space Telescope survey: four filters per tier, a five-day cadence, over 2 yr, a wide tier of 19 deg², and a deep tier of 4.2 deg², with ~20% of those areas also covered with prism observations. We find that a science-independent Roman time-domain catalog, assuming a signal-to-noise ratio at a max of >5, would have approximately 21,000 Type Ia supernovae, 40,000 core-collapse supernovae, around 70 superluminous supernovae, ~35 tidal disruption events, three kilonovae, and possibly pair-instability supernovae. In total, Hourglass has over 64,000 transient objects, 11,000,000 photometric observations, and 500,000 spectra. Additionally, Hourglass is a useful data set to train machine learning classification algorithms. We show that SCONE is able to photometrically classify Type Ia supernovae with high precision (~95%) to a $z > 2$. Finally, we present the first realistic simulations of non-Type Ia supernovae spectral time series data from Roman's prism.

Unified Astronomy Thesaurus concepts: [Surveys \(1671\)](#); [Catalogs \(205\)](#); [Time domain astronomy \(2109\)](#); [Space telescopes \(1547\)](#); [Astronomical simulations \(1857\)](#)

1. Introduction

The Nancy Grace Roman Space Telescope is NASA's next flagship mission, with a design focused on answering questions in cosmology, measuring exoplanet demographics, and conducting near-infrared astrophysics surveys (D. Spergel et al. 2015). It has a 2.4 m primary mirror and will be located at the Earth–Sun L2 point. Roman's primary instrument is the Wide Field Instrument (WFI), which has 18 near-infrared detectors (0.48–2.3 μm and 0.''11 pix^{-1}) that create a field of view of 0.281 deg², an expansive 200 \times the field of view of the Hubble Space Telescope's Wide Field Camera 3 infrared channel.¹⁵ NASA has committed to launch the Roman Space Telescope no later than 2027 May.

Up to 75% of the first 5 yr of Roman Space Telescope observations will be dedicated to large core surveys. The data

set from the Roman High-Latitude Time-Domain Core Community Survey will provide the majority of the extragalactic transient data from this mission. The observing strategy for this survey is not finalized; however, an initial reference survey has been developed (B. M. Rose et al. 2021; R. Hounsell et al. 2023).¹⁶ This reference survey is not a fully optimized design, but rather an example to show that the science goals of Roman are achievable. It is also an excellent baseline for simulations of ancillary science, such as a generic time-domain catalog.

The most recent High-Latitude Time-Domain reference survey (B. M. Rose et al. 2021; R. Hounsell et al. 2023) will observe one or two discrete locations in the Roman continuous-viewing zone—within 36° of either the north or south ecliptic pole—every 5 days over the course of 2 yr. The reference survey includes two filter-depth combinations, referred to as tiers: one tier with ~19 deg² of *RZYZ* (0.48–1.454 μm) at 25.5 mag depth per visit and another ~5 deg² field with *YJHF* (0.927–2.00 μm) at 26.6 mag depth. Additionally, there are slitless spectroscopy observations of

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¹⁵ https://roman.gsfc.nasa.gov/science/WFI_technical.html

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¹⁶ During the time this paper was written, the Core Community Survey Definition Committees met and provided proposed survey definitions. The Roman Time Allocation Committee is currently meeting to finalize the survey.

Table 1
Summary of Transient Input Values

Transient	SED Model	SED Wavelengths (Å)	Simulated Redshifts	Simulated Phase
SN Ia	J. D. R. Pierel et al. (2022) ^a	2800–20,000	0.03–2.9	–40–90
SNIa-91bg	S. González-Gaitán et al. (2014) ^a	1000–12,000	0.03–2.9	–40–90
SN Iax	Jha & Dai ^b	1000–25,000	0.03–2.9	–40–90
CCSN	M. Vincenzi et al. (2019) ^a	1605–11,000	0.03–2.9	–40–90
SLSN-I	MOSFiT slsn	1000–11,000	0.03–2.9	–50–150
TDE	MOSFiT tde	1000–11,000	0.03–2.0	–40–90
ILOT	MOSFiT csm	1100–11,000	0.03–1.0	–20–25
KN	M. Bulla (2019)	100–99,900	0.03–1.5	–2–20
PISN	MOSFiT default	1000–11,000	0.03–2.9	–50–150
AGN	ELAsTiCC (2025, in preparation)	100–20,000	0.03–2.9	–40–90

^a These models have been updated since PLAsTiCC to extend their wavelengths into the rest-frame near-infrared.

^b Available at <https://github.com/RutgersSN/SNIax-PLAsTiCC>.

Notes. AGN: active galactic nuclei; CCSN: core-collapse supernovae; ILOT: intermediate luminosity optical transients; KN: kilonovae; PISN: pair instability supernovae; SLSN-I: superluminous supernovae Type I; SN Ia: Type Ia supernovae; SN Iax: Type Iax supernovae; SNIa-91bg: SN 1991bg-like supernovae; TDE: tidal disruption events.

about one-tenth of the total area (B. M. Rose et al. 2021; D. Rubin et al. 2022; K. X. Wang et al. 2023) using an $R \sim 100$ prism (0.75–1.80 μm).

The reference survey is used to demonstrate that Roman can achieve its science goal of understanding dark energy. As such, there is a need to investigate the expected time-domain data set. It is important for the community to understand the capabilities of the Roman Space Telescope as NASA starts the public process of defining the core community surveys.¹⁷ It is valuable to not only release a simulated data set, but also the simulation input files, as these can be used for studying contaminated cosmological samples, and have been requested by the community.¹⁸

Simulating a wide range of time-domain sources has previously been done for the Vera C. Rubin Legacy Survey of Space and Time (LSST). Both the Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC; The PLAsTiCC team et al. 2018; R. Kessler et al. 2019) and the Extended LSST Astronomical Time-series Classification Challenge¹⁹ (ELAsTiCC) have produced large simulated data sets for community analysis. These two programs were designed for improving photometric-classification and data-broker pipelines, respectively.

In this work, we present the Hourglass simulation: a suite of simulated light curves and spectral time series data for 10 extragalactic transient types. Hourglass will allow the community to evaluate the science that is possible with the current Roman High-Latitude Time-Domain Core Community Survey, and assist in the ability to optimize this survey. In Section 2, we present the assumptions and methods of our simulations. In Section 3, we present results of our simulations. Finally, in Section 4, we discuss what might be possible in future simulations.

2. Simulations

For this work, we use the simulation components of the SuperNova ANalysis Software (SNANA; R. Kessler et al.

2009a) with the PIPPIN (S. Hinton & D. Brout 2020) pipeline manager. A brief overview of the simulation is as follows:

1. Fluxes are generated from an astronomical source spectral-temporal model that starts from a rest-frame spectral model for each epoch. The model is then subject to astrophysical and observational effects such as redshifting.
2. The source’s spectra are integrated for each filter (or spectral resolution element) to obtain broadband fluxes.
3. Finally, survey and follow-up logic is applied.

The details of our simulations are explained in the following sections, first looking at the sources (Section 2.1), then summarizing the survey design, selection criteria and other astrophysical parameters (Section 2.2), and describing the noise and instrument characteristics (Section 2.3).

The full set of simulation input files used can be found at https://github.com/Roman-Supernova-PIT/hourglass_snana_sims and in the data release (on Zenodo doi: [10.5281/zenodo.14262943](https://zenodo.org/record/14262943)).

2.1. Transients

In total, we simulate 10 transient types as our source models. A list of transient types and their associated parameters can be found in Table 1. We take the spectral energy distributions (SEDs), absolute magnitudes, and rates from various sources in the literature. For our simulations, we predominately use the publicly released models developed for PLAsTiCC²⁰ (R. Kessler et al. 2019; PLAsTiCC Modelers 2022), though we use several models that have been updated since then. We use the SED, luminosity functions, and luminosity scatter models that come with each model, unless noted otherwise.

We note that our simulations do not use the library of near-infrared-extended SED models developed for the recently published OpenUniverse2024 (OpenUniverse et al. 2025). This is because the diversity of transient types included in the OpenUniverse2024 transients’ template library is significantly

¹⁷ https://roman.gsfc.nasa.gov/science/ccs_community_input.html

¹⁸ https://pcos.gsfc.nasa.gov/TDAMM/docs/TDAMM_Report.pdf

¹⁹ https://portal.nersc.gov/cfs/lsst/DESC_TD_PUBLIC/ELASTICC/

²⁰ See on Zenodo: <https://zenodo.org/record/6672739>.

reduced compared to the PLAsTiCC transient library. Leaving out the near-infrared extensions is only apparent in one or two bands of the lowest redshift objects.

2.1.1. Type Ia Supernovae

For the simulation of Type Ia supernovae (SNe Ia), we use the generative SALT3-NIR model for the SED (J. D. R. Pierel et al. 2022). We use the well-tested intrinsic scatter model presented in J. Guy et al. (2010) along with the population parameters defined in R. Kessler & D. Scolnic (2017). The differences between scatter models (i.e., J. Guy et al. 2010; N. Chotard et al. 2011; B. Popovic et al. 2021a) are negligible (<0.1 mag) when not focusing on precise cosmological distances. SALT3-NIR is defined from 2800 to 20000 Å.

We use the volumetric rate of

$$R(z) = \begin{cases} 2.4 \times 10^{-5} \times (1+z)^{1.55} \text{ yr}^{-1} \text{ Mpc}^{-3} & \text{if } z < 1.0 \\ 7.5 \times 10^{-5} \times (1+z)^{-0.1} \text{ yr}^{-1} \text{ Mpc}^{-3} & \text{if } z \geq 1.0 \end{cases} \quad (1)$$

as measured in L.-G. Strolger et al. (2020), thus updating the volumetric rate assumptions used in previous Roman simulations (R. Hounsell et al. 2018; B. M. Rose et al. 2021). For this simulation, we assume that the measured redshift dependence of the rate from $1 < z < 2$ can be extrapolated out to $z = 3$, as there are no available measurements of SN Ia rates above redshift 2.

For each simulated SNIa, the host galaxy is assigned following the SN rates as a function of host-galaxy properties published by P. Wiseman et al. (2021), similar to the method presented in M. Vincenzi et al. (2021). Host galaxies are selected from the 3DHST program (A. Van Der Wel et al. 2014). Correlations between SN properties and host-galaxy properties are modeled following the approach presented by B. Popovic et al. (2021b).

2.1.2. SN 1991bg-like Supernovae

SN 1991bg-like SNe (SNIa-91bg) represent the faintest end of the thermonuclear SN Ia population (A. V. Filippenko et al. 1992). These objects represent about 15%–20% of the SN Ia class (W. Li et al. 2011b; O. Graur et al. 2018). For these simulations, we use an SNIa-91bg model derived in S. González-Gaitán et al. (2014), which contains 35 templates over a wavelength range of 1000–12000 Å.

We simulate SNIa-91bg at 15% of the rate of SNe Ia (see Equation (1)). The high-redshift rate of SNIa-91bg is uncertain since they are preferentially found in more passive and massive galaxies (S. González-Gaitán et al. 2011), and a stronger decline in rate at higher redshift is expected. We keep the rate of SNIa-91bg at 15% of Equation (1), and use the SNIa-91bg–host galaxy correlations assumed in the Dark Energy Survey SN simulations (M. Vincenzi et al. 2021).

2.1.3. Type Iax Supernovae

Type Iax SNe (or O2cx-like SNe; W. Li et al. 2003; hereafter SNe Iax) are thought to be failed thermonuclear runaways (R. J. Foley et al. 2013; S. W. Jha 2017). For this simulation, we use templates created by S. Jha and M. Dai²¹ that are based on observations of SN 2005hk and are adapted to match the

luminosity function and light-curve parameters for SNe Iax. The 1000 SNe Iax templates have a rest-frame wavelength range of 1000–25,000 Å and include A_V variations (M. Vincenzi et al. 2021).

The volumetric rate for SNe Iax is set by local measurements relative to the SNe Ia rate (30%; R. J. Foley et al. 2013; A. A. Miller et al. 2018). With this information, we simulate SNe Iax at 30% of the SN Ia volumetric rate (see Equation (1)), and use the transient–host galaxy correlations assumed in the Dark Energy Survey SN simulations (M. Vincenzi et al. 2024).

2.1.4. Core-collapse Supernovae

For core-collapse SNe (Type Ib/c and Type II, hereafter referred to as CCSNe), we use 65 spectral models from M. Vincenzi et al. (2019), including the CCSN–host galaxy property correlations. We use the rates derived from the GOODS, CANDELS, and CLASH surveys (L.-G. Strolger et al. 2015). This rate is

$$R(z) = 0.015 \frac{(1+z)^5}{((1+z)/1.5)^{6.1} + 1} \text{ yr}^{-1} \text{ Mpc}^{-3}. \quad (2)$$

This rate was only measured out to $z \sim 2.5$; therefore, we make the assumption that it is valid to $z = 3$. Additionally, each parameter in this equation has an uncertainty of $\sim 10\%$.

2.1.5. Superluminous Supernovae

Superluminous SNe Type I (SLSNe-I) are some of the most luminous transients, with a peak absolute magnitude of $\lesssim -21$ mag. They are fairly rare and only recently discovered (L. Chomiuk et al. 2011; R. M. Quimby et al. 2011). For this simulation, we use the Modular Open-Source Fitter for Transients (MOSFiT; J. Guillochon et al. 2018) generated spectral-temporal SEDs using the MOSFiT slsn model that assumes a magnetar engine and a blackbody SED (D. Kasen & L. Bildsten 2010; M. Nicholl et al. 2017). This model is defined from 1000 to 11,000 Å and resulted in 960 templates.

We use the SLSN rate from S. Prajs et al. (2017):

$$R(z) = 2.0 \times 10^{-8} \times R_{\text{MD14}}(z), \quad (3)$$

where $R_{\text{MD14}}(z)$ is the redshift-dependent component of the cosmic star formation rate defined in P. Madau & M. Dickinson (2014) and repeated here:

$$R_{\text{MD14}}(z) = \frac{(1+z)^{2.7}}{((1+z)/2.9)^{5.6} + 1} \text{ yr}^{-1} \text{ Mpc}^{-3}. \quad (4)$$

This rate is a slight variation to what was reported in P. Madau & M. Dickinson (2014). We do not use the multiplicative scaling of 0.015 that is seen in Equation (15) of P. Madau & M. Dickinson (2014) since we want to normalize each astrophysical object to its own $z = 0$ rate. This SLSNe rate is within the current uncertainty presented in the literature (R. M. Quimby et al. 2013; M. McCrum et al. 2015; S. Prajs et al. 2017), and reflects the fact that the SLSNe rate appears to follow the cosmic star formation rate (S. Prajs et al. 2017). For the SLSN, we use the transient–host galaxy correlations derived for the OpenUniverse2024 simulations (OpenUniverse et al. 2025). These are built off of the work of the Simulated Catalog of Optical Transients and Correlated Hosts (SCOTCH;

²¹ <https://github.com/RutgersSN/SNIax-PLAsTiCC>

M. Lokken et al. 2023), but extended into the Roman wavelength range.

2.1.6. Tidal Disruption Events

Tidal disruption events (TDEs) occur when stellar objects are tidally ripped apart as they fall into a black hole. Typically, this takes place near supermassive black holes due to the required orbital-to-stellar radius ratio (M. J. Rees 1988; B. Mockler et al. 2019). We use SEDs generated from the MOSFiT tde model and transient–host galaxy property correlations derived for the SCOTCH and OpenUniverse2024 simulations (M. Lokken et al. 2023; OpenUniverse et al. 2025, respectively).

We use the TDE rate from C. S. Kochanek (2016) and S. van Velzen (2018):

$$R(z) = 10^{-6} \times 10^{-5z/6} \text{ yr}^{-1} \text{ Mpc}^{-3}. \quad (5)$$

We assume this rate holds throughout cosmic time; however, C. S. Kochanek (2016) argues that the rate of TDEs sharply drops off at $z = 1$. This claim is something the Roman Space Telescope can test.

2.1.7. Intermediate Luminosity Optical Transients

Intermediate luminosity optical transients (ILOTs) have peak luminosities between classical novae and SNe and display signs of interaction with a dense circumstellar material, similar to SNe IIn. The 385 templates we use were generated using the MOSFiT csm model following parameter ranges described in V. A. Villar et al. (2017) and E. Chatzopoulos et al. (2012) with a rest-frame wavelength range of 1000–11000 Å. We assume a volumetric rate that is 6% that of the CCSN rate defined in Equation (2), and use the CCSN–host galaxy correlations from the Dark Energy Survey. This rate is from W. Li et al. (2011a) following the assumption that ILOTs have a similar progenitor as Type IIn SNe.

2.1.8. Kilonovae

Kilonovae (KNe) are the merger of two compact objects, typically neutron stars (D. Kasen et al. 2017). We use the SED model defined in M. Bulla (2019). Our model has 550 templates with a rest-frame wavelength range of 100–99900 Å. We use the volumetric rate of

$$R(z) = 3.2 \times 10^{-7} \text{ yr}^{-1} \text{ Mpc}^{-3} \quad (6)$$

from a recent estimate of binary neutron stars (R. Abbott et al. 2021). However, this rate is very uncertain, and the total number of KN observed by the Roman Space Telescope could be over- or underestimated by a factor of ~ 3 (R. Abbott et al. 2021). Additionally, to reduce Poisson noise in the detection rate, we scale up these simulations by using a rate 5 times that of Equation (6) to ensure the total detected objects is > 10 .

2.1.9. Pair-instability Supernovae

Pair-instability SNe (PISNe) are proposed to arise when low-metallicity Population III stars, with $M_* \sim 140\text{--}260 M_\odot$, reach sufficiently high core temperatures that γ -rays produce electron–positron pairs (Z. Barkat et al. 1967; D. Kasen et al. 2011). PISN are extremely high-redshift transients, and therefore only a few possible PISN have been reported

Table 2
Summary of Observing Strategy from B. M. Rose et al. (2021)

Filters	Exp. Time (s)	No. of Pointings	Area (deg ²)
Wide tier			
RZYJ	160;100;100;100	68	19.04
Prism	900	12	3.36
Deep tier			
YJHF	300;300;300;900	15	4.20
Prism	3600	4	1.12

(A. Gal-Yam & D. C. Leonard 2009; J. Cooke et al. 2012; A. Kozyreva et al. 2018; S. Gomez et al. 2019; A. Aamer et al. 2024; S. Schulze et al. 2024). We use the MOSFiT default model with PISN parameters as described in V. A. Villar et al. (2017). We use 1000 SED time series templates that have a rest-frame wavelength range of 1000–11000 Å.

A volumetric rate for PISN is presented in M. M. Briel et al. (2022). We fit a polynomial to the data presented and obtain a volumetric rate of

$$R_{B22}(z) = [-4.08 + 30.56z - 19.91z^2 + 16.82z^3 - 3.00z^4] \text{ yr}^{-1} \text{ Gpc}^{-3}. \quad (7)$$

At $z = 1$, it is nearly twice the PISN rate (T. Pan et al. 2012) used in previous simulation efforts. Since PISN are from extremely massive stars, we use the CCSN–host galaxy correlations derived from the Dark Energy Survey.

2.1.10. Active Galactic Nuclei

We simulate 500 active galactic nuclei (AGN) that have a constant volumetric rate ($1.0^{-3} \text{ Mpc}^{-3}$) for the redshift range $0.03 < z < 3$. We use the analytical model that has been generated for the ELAsTiCc simulations. It is a damped random walk model that includes the possibility of changing look behavior. The simulation varies the black hole mass, Eddington ratio (A. K. Weigel et al. 2017; L. F. Sartori et al. 2019), and i -band absolute magnitude (Y. Shen 2013) for each object. This model will be described in further detail in the ELAsTiCc paper (2025, in preparation).

2.1.11. Nonvariable Sources

To allow for the widest range of tests, we include “fixed magnitude sources.” These are objects that have the same magnitude at all epochs, but a different random magnitude is chosen for each event. We simulate 1000 events that range in apparent magnitude from 18 to 30 mag.

2.2. Survey Design and Detection

We follow the “25% spectroscopic time” survey strategy laid out in B. M. Rose et al. (2021), where the wide tier is observed with the F062, F087, F106, and F129 filters (colloquially R, Z, Y, J) and covers 19.04 deg^2 . The deep tier is observed with the F106, F129, F158, and F184 filters (Y, J, H, F) and covers 4.20 deg^2 . These exposure times and areas were determined when the average slew and settle time would have been ~ 70 s. This has since been reduced, and the expectation is that the actual survey should have more “open-

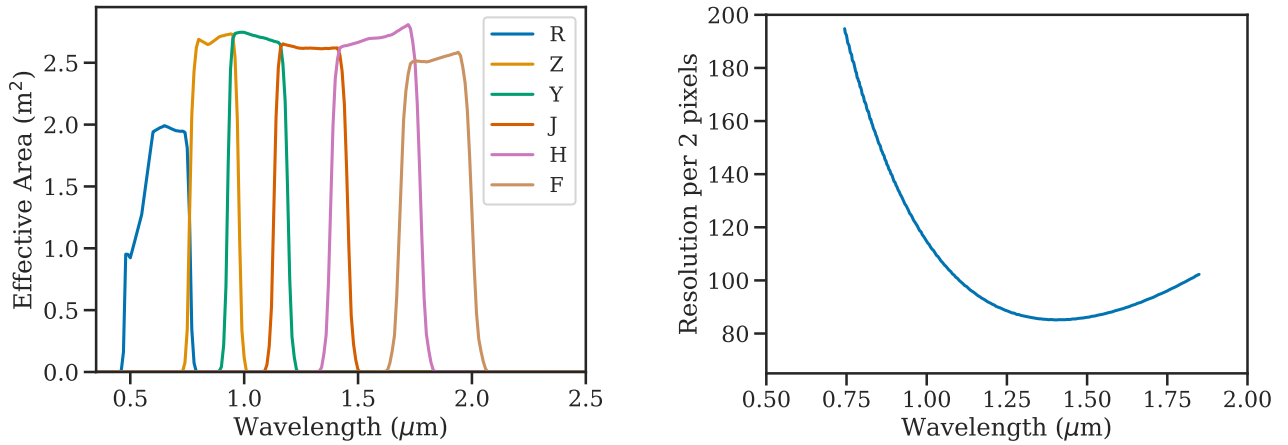


Figure 1. Left: the filter transmission and detector response functions used for these simulations. Curves are taken from the Roman project technical resources. Right: the prism’s resolution (per two pixels) as a function of wavelength. The prism is transmissive from 7500 to 18000 Å. The minimum two-pixel dispersion is ~ 80 around 14000 Å. Except for the blue edge, most of the wavelengths have an $R \leq 100$.

Table 3
Roman WFI Characteristics Used in Simulations

Filters	PSF _{NEA} (pix)	σ_{read} (e ⁻ pix ⁻¹)	$\sigma_{\text{thermal}}^2$ (e ⁻ s ⁻¹ pix ⁻¹)	σ_{zodi}^2 (e ⁻ s ⁻¹ pix ⁻¹)	σ_{sky} (ADU pix ⁻¹)	ZP _{AVG} (mag)
Wide tier						
<i>R</i>	5.575	9.011	0.003	0.315	7.133	32.129
<i>Z</i>	6.695	10.624	0.003	0.316	5.648	31.303
<i>Y</i>	7.895	10.624	0.003	0.357	6.000	31.356
<i>J</i>	9.210	10.624	0.003	0.359	6.017	31.354
Deep tier						
<i>Y</i>	7.895	7.450	0.003	0.357	10.392	32.549
<i>J</i>	9.210	7.450	0.003	0.359	10.421	32.547
<i>H</i>	11.140	7.450	0.048	0.339	10.775	32.570
<i>F</i>	16.335	5.942	0.155	0.194	17.723	33.299

Note. N_{read} , N_{sky} , and ZP_{AVG} assume the exposure times listed in Table 2. PSF: point-spread function; NEA: noise-equivalent areas.

shutter” time. For these simulations, we keep the 70 s slew and settle time assumption. With many of the SED models only extending redward to 11000 Å, the simulations for these events only have *R*, *Z*, and *Y* until $z > 0.175$ where there is full coverage of the *J* band. We locate the two tiers such that they do not overlap and are located near Euclid’s Deep Field South, roughly (R.A., decl.) = (04:04:58, -48:25:23). We also simulate the slitless prism with 12 wide-tier and four deep-tier pointings (3.36 and 1.12 deg², respectively). All exposure times and numbers of pointings per tier are taken from B. M. Rose et al. (2021) and are summarized in Table 2. We have designed these simulations so that they can be updated once an observational strategy has been selected by the Roman scientific community. The Roman Time Allocation Committee (ROTAC) recently released recommendations for the Core Community Surveys (Roman Observations Time Allocation Committee & Core Community Survey Definition Committees 2025). This is similar to the design reference mission but increases the area of the deep tier (from 15 to 23 pointings) and adds additional filters at the cost of using an interleaving cadence (rotating sets of filters so an observation is still taken every 5 days but the filter to same filter cadence is 10 days). As a result, the expected number of objects increases by approximately 25%–30%. Additionally, they recommended a pilot and extended surveys outside the core, two-year survey.

We plan on updating these simulations when a stable version of the ROTAC recommendations are implemented, likely fall 2025.

Additionally, these simulations do not account for dithering, roll angles, or field-edge effects. Some ramifications of these effects have been discussed previously in B. M. Rose et al. (2021) and R. Hounsell et al. (2023). For current approximations of these effects, one can discard one of every eight photometric observations, representing the Roman Space Telescope’s approximately seven-eighths focal plane fill factor.

Regarding detection, we impose a threshold of two observations with a signal-to-noise ratio (S/N) > 5 .²² This is a loose quality cut that only removes the lowest signal-to-noise simulated events. It is also a fairly standard cut applied to real data in order to remove subtraction artifacts (which are not included in our simulations). This approach of only applying a loose cut in our simulations will allow users to implement their own quality cuts. We do not apply any selection effects from spectroscopic follow-up.

We use host-galaxy characteristics from the 3DHST program (A. Van Der Wel et al. 2014). Our sample contains 110,798 entries with galaxy properties derived from real

²² This cut is on single epoch images. Presumably, one can stack epochs and increase the total detections for slow transients, such as PISN and SLSN.

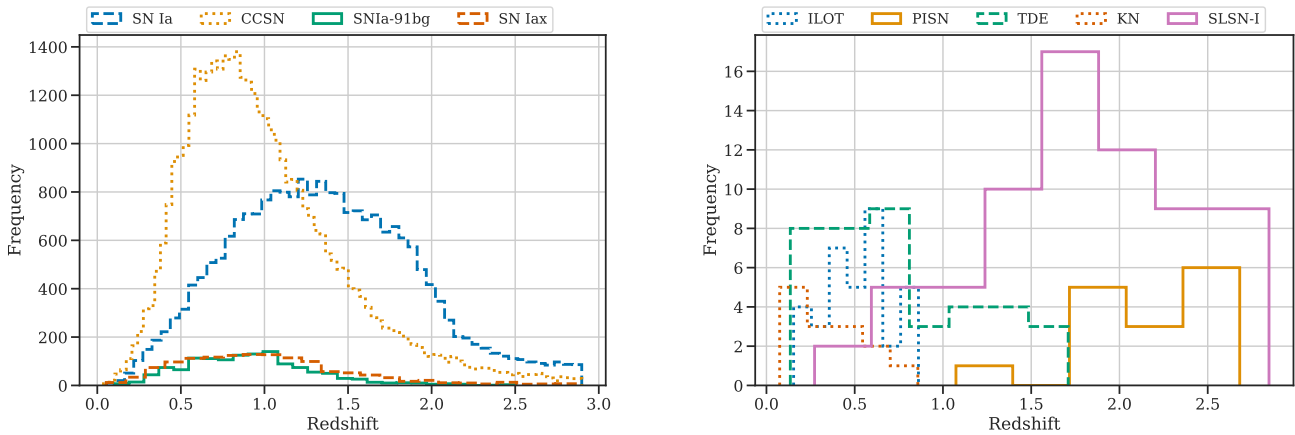


Figure 2. Redshift distribution of recovered transients. Left: the redshift distributions for high-volume transients such as CCSNe and SNe Ia, as well as for the fainter SN Ia-like objects (SNe Iax and SNIa-91bg). Right: the redshift distribution of rarer transient events, including SLSNe, TDEs, ILOTs, KNe, and PISNe. These distributions are more uncertain due to the limited data used in rate models, particularly at redshifts that will be probed by Roman. We do not present the redshift distributions for the AGN in this figure since we generated a fixed number of events rather than use a redshift-dependent volumetric rate. The light curves and spectra are still in the data release.

Table 4
Hourglass Catalog Summary

Transient	Total Detected	Median S/N at Maximum	Median Redshift
SN Ia	21,700	13.5	1.32
SNIa-91bg	1300	10.6	0.84
SN Iax	1300	8.5	0.95
CCSN	39,000	8.8	0.90
SLSN-I	70 ^a	32.4	1.82
TDE	39	13.5	0.65
ILOT	35	6.7	0.49
KN ^b	14	7.9	0.35
PISN	15 ^a	8.2	2.23
AGN	139	13.6	1.78

Notes. Detected values are rounded according to the expected counting statistics uncertainty. The ROTAC recommend survey should increase these numbers by 25%–30% for the core survey. Including the pilot and extended surveys, we expect over 100,000 transients.

^a One could use multiepoch stacked images and increase the total detections for slow transients.

^b This simulated KN rate is 5 times that of R. Abbott et al. (2021) to overcome Poisson noise, which has stated uncertainty up to a factor of 4.

data.²³ This set of host galaxies was used in the pixel simulations found in K. X. Wang et al. (2023). However, this choice limits our simulations to a redshift maximum of 3. This upper limit does not affect the majority of transients included in the simulations, except for SLSNe and PISN, which in principle could be detected far beyond this redshift with Roman. In the future, we plan to update the host-galaxy catalogs used for our simulations using N -body simulations such as the Deep Realistic Extragalactic Model Galaxy Catalog (N. E. Drakos et al. 2022).

For host-galaxy dust, we use an exponential plus Gaussian “galactic line-of-sight” model for A_V presented in W. M. Wood-Vasey et al. (2007, Equation (2)). The Gaussian

core has a standard deviation of $\sigma = 0.6$ mag, and the exponential tail has a rate parameter $\tau = 1.7$ mag. These values are taken from M. Vincenzi et al. (2021). For R_V , we simulate a range of values, 3.0–3.2, peaking at 3.1. For SNe Ia, the host-galaxy dust is already a part of the SALT2 and population models; therefore, we do not include more.

We use the Milky Way color law from E. L. Fitzpatrick (1999), assuming an $R_V = 3.1$ and a dust map from E. F. Schlafly & D. P. Finkbeiner (2011). In this simulation, we assume a flat Λ CDM cosmology with $\Omega_M = 0.3$ and $h = 0.7$.

2.3. Roman WFI Characteristics

The latest hardware characteristics for the Roman Space Telescope’s WFI can be found at https://roman.gsfc.nasa.gov/science/WFI_technical.html. This URL contains the current estimates for the filter transmission, detector efficiency, prism two-pixel dispersion, and filter throughput. These parameters are incorporated into the simulation’s noise model by the creation of appropriate definitions of filter and prism zero points and point-spread functions. Figure 1 (left) shows the filter transmission functions used, and Figure 1 (right) shows the prism’s wavelength-dependent two-pixel dispersion.

For the SNANA simulations, the noise values (thermal, sky, and read noises) are calculated to include exposure times. Thus, we have different noise and zero points per filter and per tier. Our values are presented in Table 3 and are updated from those assumed in the simulations presented by R. Hounsell et al. (2018). Since these simulations are based on the current reference survey design (B. M. Rose et al. 2021), we use the same exposure times (see Table 2) and average slew and settle time (70 s). However, other instrument properties have been updated since then. They are available in G. Mosby et al. (2020) or on the WFI technical specifications website, https://roman.gsfc.nasa.gov/science/WFI_technical.html. WFI underwent thermal-vacuum testing in the first half of 2024. We have set up our simulations such that we can update them with post-thermal-vacuum values when they become available.

2.3.1. Point-spread Function

We take the point-spread function (PSF) from the Roman WFI technical website mentioned above. The PSF has a large

²³ <https://github.com/srodney/romansims/blob/main/romansims/catalogs.py>

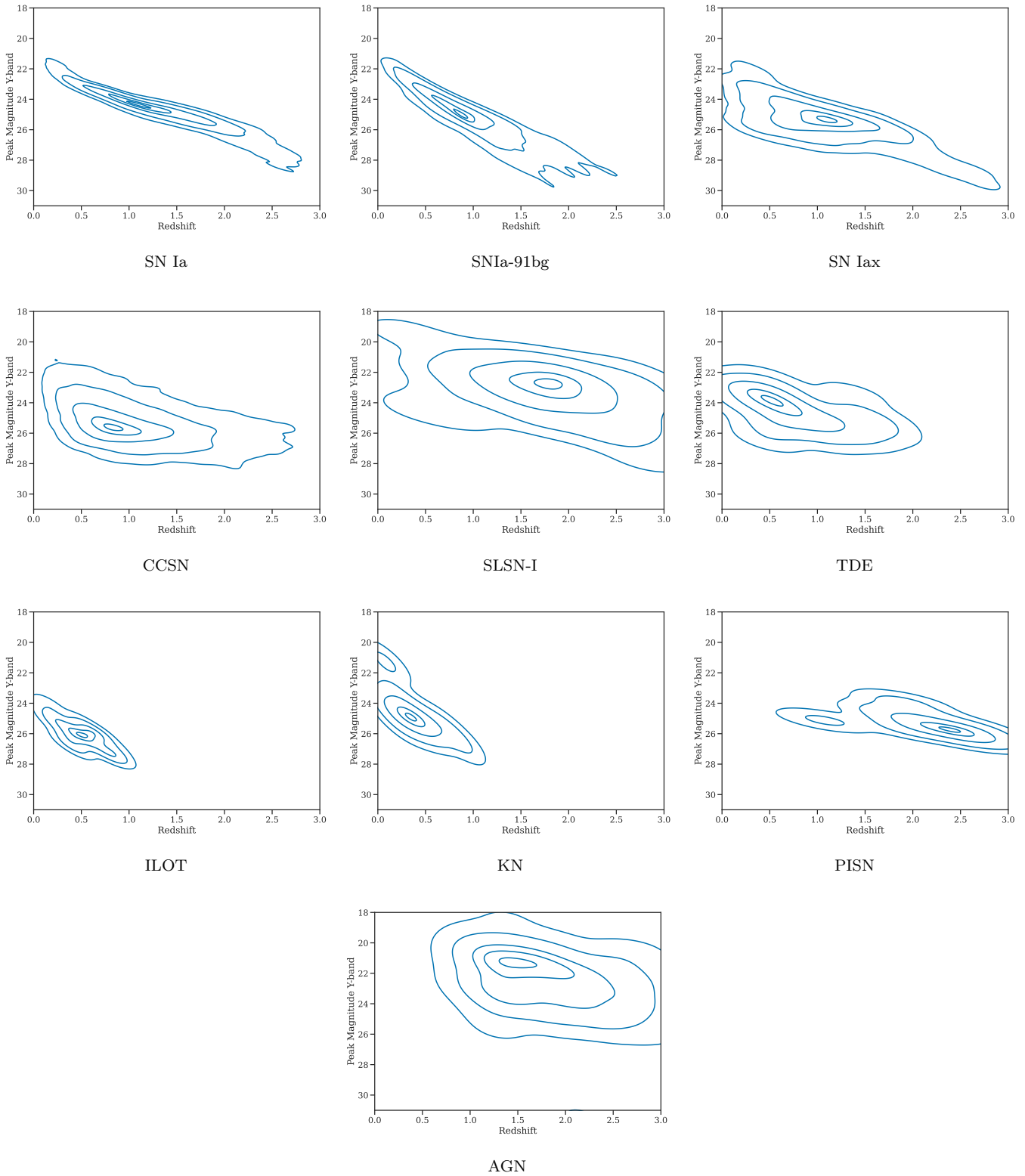


Figure 3. Peak AB magnitude (in Roman *Y* band) vs. redshift for all 10 time-domain classes. Contours are at 2.75, 15.87, 50, 84.13, and 97.25 percentiles. The standard-candle nature of SN Ia can be seen in the first figure. Additionally, the extreme brightness of SLSN-I is visible in the middle frame. From this plot, it is clear that SLSN-I will be visible at redshifts of $z > 3$. There is an artificial cutoff at $z = 0.08$ for models with a red edge of 11000 \AA since they will not have a defined *Y*-band magnitude.

variation across the field of view; therefore, we use the median of the best and worst noise-equivalent areas (NEA). The values are presented in Table 3. Though we only have one area per

filter, we account for the significant NEA change across the field of view through the variation of the zero point. This does not fully match the effects of a changing PSF (e.g., it has no

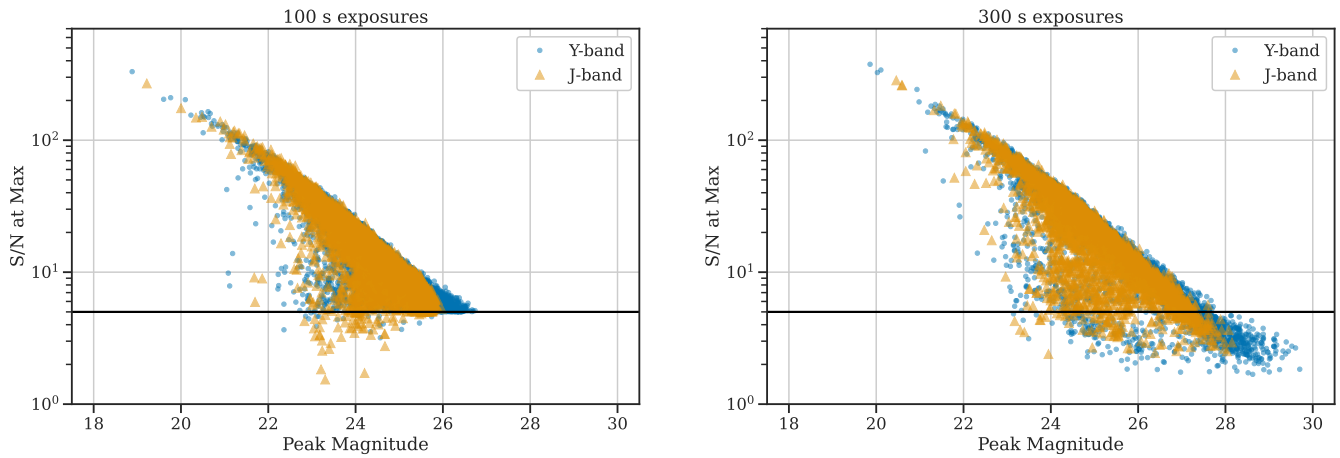


Figure 4. S/N vs. AB magnitude at peak luminosity for SNe Ia in both *Y* and *J* bands. S/N = 5 is marked with a horizontal line. The left panel shows values taken from the wide tier where the *Y* and *J* band each have 100 s exposures. The right panel shows data taken from the deep tier where each band has 300 s exposures. With this exposure time, we calculate a S/N ≈ 20 for an SN Ia of peak magnitude ~ 25 mag.

dependence on source color), but it does approximate the changes in signal to noise as a point source gets spread over different areas.

2.3.2. Zero-point Values

The simulations use an exposure time-dependent zero point defined as

$$ZP_{AVG} = ZP + 2.5 \log_{10}(t), \quad (8)$$

with ZP being the magnitude that results in one count per second and t being the total exposure time. ZP was calculated by using the filter-effective area curves provided, available at the WFI technical specifications website, and integrating a flat AB spectrum. There is a significant scatter in the zero point and PSF across the field of view. To approximate these effects, we include a zero-point scatter with a standard deviation of 0.15 mag. This is a stochastic effect that depends on where a source lands on the field of view.

2.3.3. Read Noise

The simulation uses the read noise as a function of exposure time. Since near-infrared detectors use nondestructive reads, and Roman will not download every resultant that is read (S. Casertano 2022; S. Gomez 2023), the total read noise as a function of exposure time can be defined as

$$\sigma_{\text{read}} = \sqrt{\sigma_{\text{floor}}^2 + \sigma^2 \frac{(n-1)}{n(n+1)}}, \quad (9)$$

where $n = t_{\text{exp}}/3.04$ s or number of reads for a given exposure (t_{exp}). We use $\sigma_{\text{floor}}^2 = 25$ and $\sigma^2 = 12 \cdot 16^2 = 3072$, as defined by measurements reported by the project in 2021.²⁴ These values are given from the project on the WFI technical specifications website. This is the same equation for read noise as used in R. Hounsell et al. (2018), but the final numbers are reduced slightly. The final read noise per filter for our given exposure times can be seen in Table 3.

2.3.4. Sky Noise

The simulation combines all sky noise together—zodiacal and thermal—for a given exposure length. The sky noise is reported as a standard deviation in ADU per pixel. This can be calculated with the following equation:

$$\sigma_{\text{sky}} = \sqrt{t_{\text{exp}}(\sigma_{\text{zodi}}^2 + \sigma_{\text{thermal}}^2)}, \quad (10)$$

where t is exposure time, and σ_{zodi}^2 and $\sigma_{\text{thermal}}^2$ are given by the project. The dark current is sufficiently small to be ignored in this simulation. These values have reduced since R. Hounsell et al. (2018).

3. Light Curves and Spectral Time Series

We provide a summary of the Hourglass simulation in Table 4. We give the median redshift for each type and find it varies as expected depending on the intrinsic magnitude. We show redshift histograms for the different types of transients in Figure 2. Along with this paper, we release the photometry, spectroscopy, and object characterization data as parquet files on Zenodo doi:10.5281/zenodo.14262943. Details on this data release are described in the Appendix.

We find that SNe Ia, PISN, and SLSN can be discovered up to the redshift limit of our simulations at $z = 3$. In particular, significantly higher redshift PISN and SLSN will be visible, but this simulation artificially cuts off at $z = 3$. T. J. Moriya et al. (2022) estimated around 100 PISN at $z > 5$ and about a dozen SLSN at the same redshift range. Due to our redshift range, our simulations are not directly comparable, but these values are not inconsistent since Hourglass is only seeing the “low- z ” tail of the PISN and SLSN distributions.

For each class of transient, we see the expected drop-off in number due to selection effects (Figure 2). This effect is most obvious in SNe Ia and CCSNe. Additionally, we agree with K. Inayoshi et al. (2024) that Roman will observe 10–60 TDEs, though our number suggests the higher side of that range.

To better understand the redshift histograms, we show the peak AB magnitude in the *Y* band of each object type versus redshift in Figure 3. The precision of SNe Ia as standard candles is immediately obvious, as they have the tightest scatter in magnitude versus redshift space. We can also see that the magnitude limits are around the 28th mag.

²⁴ https://roman.gsfc.nasa.gov/science/RRI/Roman_WFI_Reference_Information_20210125.pdf

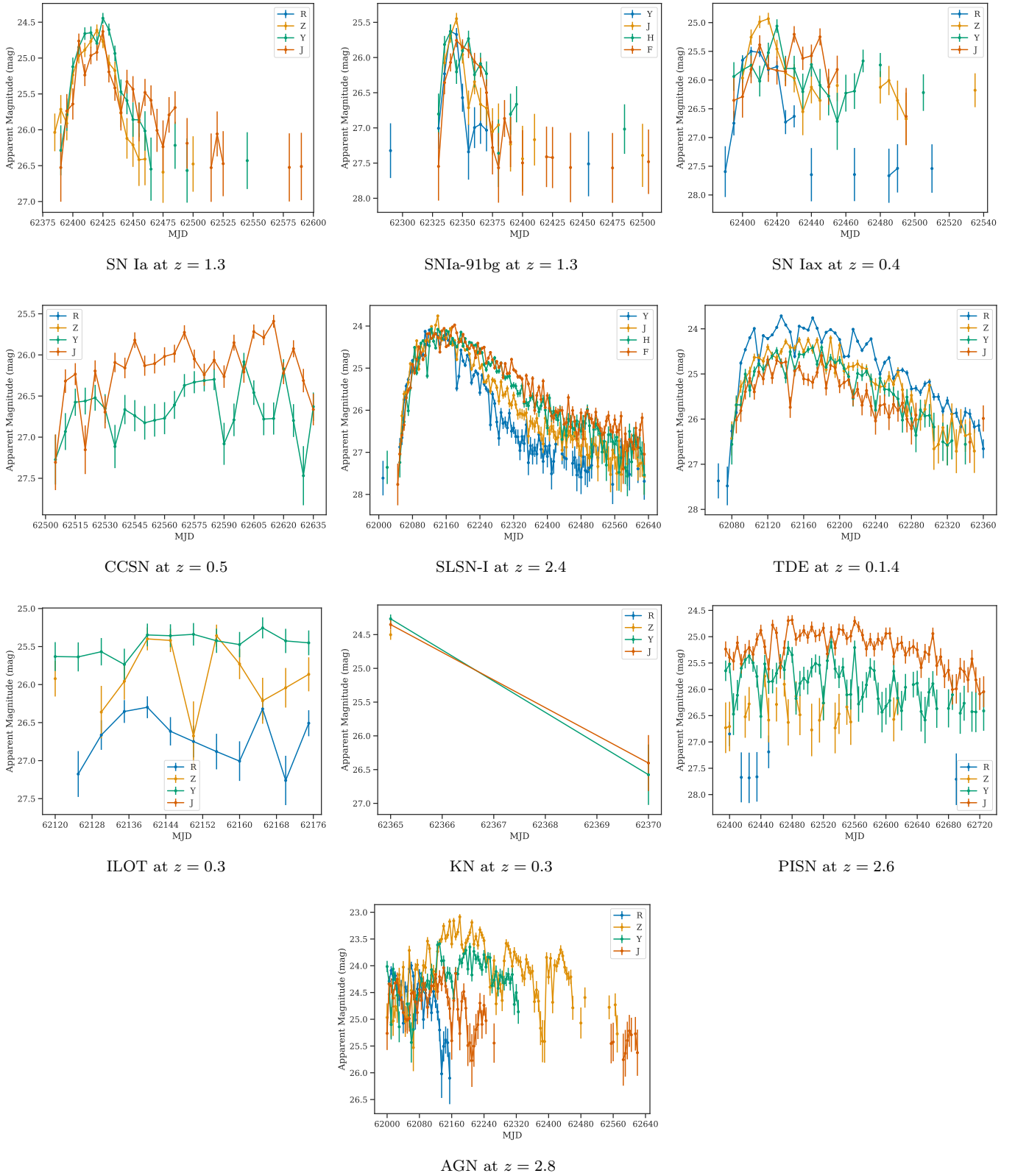


Figure 5. Light curves of the median S/N events per type. The long-lived transients, SLSNe and PISNe, have very well-sampled light curves. Fast transients are also well sampled; however, the KN detections have measurements around the peak, but very little light-curve information. We needed to go to the 75% percentile S/N at peak in order to get an observation at a second epoch.

To demonstrate the detection limits per tier, we show the relation between the S/N and peak magnitude in Figure 4. We find detection limits of a S/N of 5 for magnitudes of ~ 27.5 th and ~ 26.5 th mag for *Y* and *J* for deep and shallow,

respectively. We are therefore able to translate the relation seen in Figure 3 to the redshift limits in Table 4.

All of these results are highly dependent on the assumed rates. For the most rare transients the rates can have an

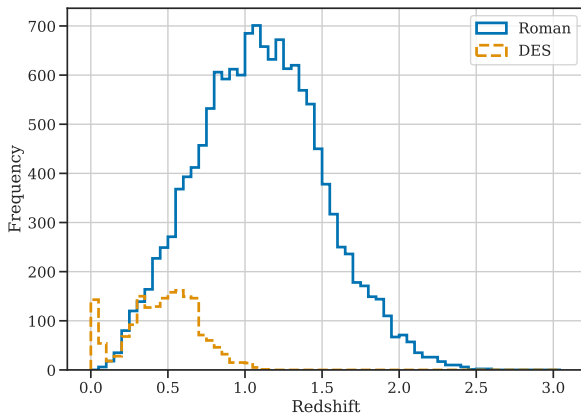


Figure 6. The Roman SN Ia sample compared to the recent cosmological sample of the DES. DES has over 1500 SNe in its cosmological sample with very few at $z > 1$. However, we expect Roman to have nearly 19,000 SN Ia, with the majority above $z > 1$. For this paper, we define “cosmologically useful” as having a S/N at max of greater than 10. This is an overly simple assumption, but still reasonable.

uncertainty range of a factor of 2 (for PISNe, T. Pan et al. 2012; M. M. Briel et al. 2022) or 3 (for KNe, R. Abbott et al. 2021). Additionally, rates are poorly defined at higher redshifts. For example, the SN Ia rates have only been measured to $z \sim 2$, and above $z > 1$ the uncertainty is significant (L.-G. Strolger et al. 2020). Yet for this work, we assume these rates are valid to $z = 3$. The Roman Space Telescope’s field of view, survey length, and depth will allow it to probe parameter space that has never previously been explored. Though high-redshift transients have been discovered with JWST (e.g., J. D. R. Pierel et al. 2024, 2025; C. DeCoursey et al. 2025), these are not sufficiently large enough samples to improve our rate estimates.

We showcase example light curves of the median S/N at max for each time-domain class in Figure 5. The five-day observer frame cadence will allow for very high sampling, particularly for the longer-lasting transients like SLSNe, TDEs, and PISNe. For KNe, this cadence is closer to the decay rate of the explosions and thus limits their detectability.

3.1. Comparison with Current Samples

For SNe Ia, the Roman Space Telescope will provide an order of magnitude more and reach a redshift of more than twice that of previous cosmological data sets (e.g., D. Scolnic et al. 2021; D. Rubin et al. 2023; B. O. Sánchez et al. 2024). In Figure 6, we compare the redshift distribution of the Roman SN Ia sample with the Dark Energy Survey Year 5 data release (DES; B. O. Sánchez et al. 2024). This is the most recent, photometrically classified sample, and represents the current state of the art for SN cosmology. However, their sample of approximately 1500 SN Ia has very few objects above $z > 1$. Comparably, Roman is expecting a cosmological sample of over 10,000 SN Ia. In this simulation, we do not perform a full cosmological analysis, so we use a S/N at max of greater than 10 as a proxy for “cosmologically useful.” With this definition, we have over 19,000 Type Ia SNe with the majority being above a redshift of 1.

3.2. Spectra

In addition to the photometry, we simulate the prism spectral time series for all 10 time-domain classes. As an

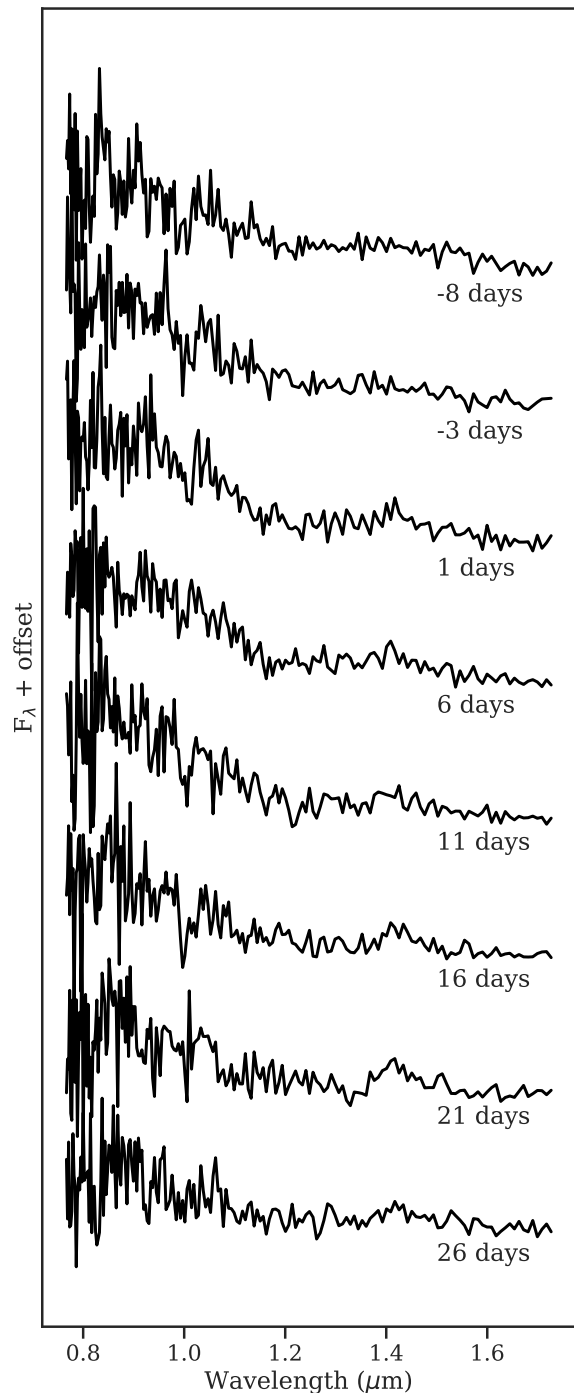


Figure 7. A spectral time series from the Roman WFI prism, presented in the observer’s frame. This is a $z = 0.636$ SN Ia observed in the wide tier (900 s exposures). This results in nine observations from phase -8 to 26 days.

example, we present one SN Ia as observed with the wide-tier exposures, 900 s, in Figure 7. We show eight phases, from phase -9 to 30–6 to 28 days. Additional late time spectra will be observed with Roman Space Telescope, but our SN Ia model stops at a phase of 40 days.

3.3. Photometric Classification of Type Ia SNe

For a first test on these simulations, we train and test the binary classification of SCONE (H. Qu et al. 2021). SCONE is a convolutional neural network that was used in the DES SN

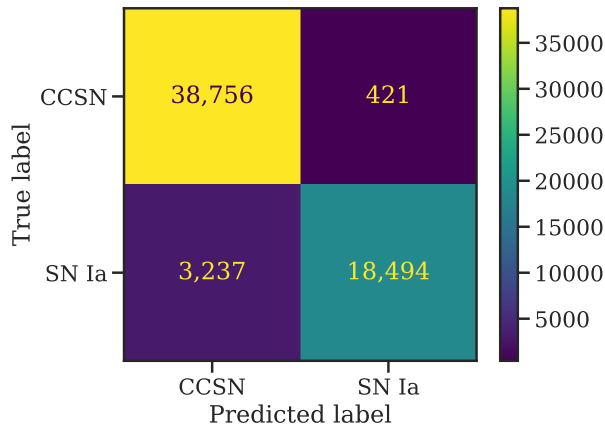


Figure 8. Confusion matrix for the photometric classifier SCONE. We train the binary classification to distinguish between cosmologically useful SNe Ia and contaminants. Contaminates are labeled as CCSN but also contain SNIa-91bg and SNIax objects. SCONE gets a high recall (85%, i.e., incorrectly classifying a small fraction of the SNe Ia). More importantly, we obtain a high precision (98%), meaning that the predicted SNe Ia label has a low level of contamination.

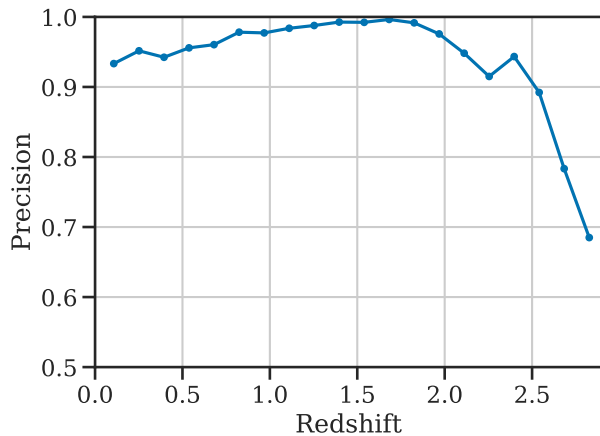


Figure 9. SCONE’s precision is around 99% and peaks near a redshift of 1.7. However, it has a significant drop-off at high redshifts. The slightly worse performance at low- z is unexpected. We are unsure if this is an issue with low statistics or the fact that the rest-frame near-infrared features of the transients are different.

cosmological analysis. For training, we use a unique set of only 8600 SN Ia and 8600 “contamination” objects (CCSN, SNIax, SNIa-91bg). This simulation uses the same properties as the main Hourglass simulations. The resulting SCONE model can be found at https://github.com/Roman-Supernova-PIT/hourglass_snana_sims/tree/main/3_clas/models/scone.

SCONE requires more than just a single detection; therefore, we add a requirement that there are a minimum of five epochs per transient. This results in 21,731 SNe Ia and 39,177 combined CCSNe, SNIax, and SNIa-91bg objects. The confusion matrix can be seen in Figure 8. We obtain an accuracy of 94% (number of correct predictions over all predictions), along with a precision of 98% (correctly classified SN Ia over everything classified as an SN Ia), and a recall of 85% (correctly classified SN Ia over everything that is an SN Ia).

We investigate SCONE’s performance as a function of redshift. We present SCONE’s precision, the fraction of correctly labeled SNe Ia over of all events labeled SNe Ia, as a function of redshift in Figure 9. SCONE predominately performs at $>95\%$ but has a significant drop-off at high redshifts ($z > 2.5$).

4. Conclusions

In this work, we present and release the Hourglass simulation, a catalog for the Nancy Grace Roman Space Telescope High-Latitude Time-Domain Core Community Survey. This simulation includes 10 extragalactic time-domain classes. We run this through the current baseline Roman survey: four filters per tier, a five-day cadence, a wide tier of 19 deg^2 , and a deep tier of 4.2 deg^2 , with about $\sim 20\%$ of the area also covered by prism observations.

With a detection threshold of a $S/N > 5$ in two filters, we find that a Roman time-domain catalog would have approximately 21,700 SNe Ia and 39,000 CCSNe. There would also be around 70 SLSN, 40 TDEs, over 10 PISNe, and possibly three KN. We demonstrate that the data set is not purely low S/N observations: most transient classes have a median S/N at maximum luminosity of ~ 10 , and long-lived events have individual light curves with 200 to 500 observations. Additionally, we present the first examples of the expected spectral time series data from Roman’s prism and the SCONE photometric classifier on Roman data. The simulated data can be found on Zenodo doi: [10.5281/zenodo.14262943](https://doi.org/10.5281/zenodo.14262943).

Though this simulation surpasses what has come before—in terms of breadth of transient types and the inclusion of the spectral time series data—it is still insufficient for the community’s preparation for the Roman Space Telescope. Future simulations need to take into account the hardware knowledge gained from thermal-vacuum testing, test the observation strategy recommended by the ROTAC, and continue to add time-domain sources such as variable stars. Currently, we do not expect these changes to have a significant effect on what the Roman High-Latitude Time-Domain Core Community Survey catalog looks like, other than increasing the number of transients detected, but we have set up the Hourglass simulation in such a way that we can update it when new input parameters are available.

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B.M.R. led the project, ran the simulations, and wrote the first draft of the paper. M.V. assisted in running and analyzing the non-SN Ia simulations. R.H. provided guidance and help in ensuring the Roman-specific components were accurately simulated and provided details from the first set of Roman

simulations using SNANA. H.Q. supported the development and use of the photometric classifier SCONE. L.A. helped validate the data release files. D.S. advised and worked on the figures. R.K. supported the development and debugging of SNANA. P.M. helped get the project started with insight from previous Roman simulations using SNANA. D.B. provided a technical review of the paper. All authors provided editing and discussions around the paper and the data release.

Software: Matplotlib (J. D. Hunter 2007), Numpy (C. R. Harris et al. 2020), Pandas (W. McKinney 2010), PIPPIN (S. Hinton & D. Brout 2020), Python, SciPy (E. Jones et al. 2001), SCONE (H. Qu et al. 2021), Seaborn (M. Waskom et al. 2020), SNANA (R. Kessler et al. 2009b; R. Kessler & D. Scolnic 2017).

Appendix Data Release

The data are available on Zenodo doi:[10.5281/zenodo.14262943](https://doi.org/10.5281/zenodo.14262943). The data come in three parquet files: `hourglass_objects.parquet`, `hourglass_photometry.parquet`, and `hourglass_spectra.parquet`. In python, these files can be read with Pandas via the `.read_parquet()` method.

PyArrow also has a `.read_parquet()` method. PyArrow’s method allows for the inspection of the file prior to importing the whole thing into memory. One useful thing is to inspect the metadata with `pq.ParquetFile("hourglass_objects.parquet").metadata.metadata`. This provides information like the version of the data set and the date it was produced.

The object file is one row per object. It has all the “object-level” information like R.A., decl., redshift, S/N at maximum, and other information. The full list of columns for this file can be seen in Table 5. For operations, we expect these data releases to be richer. We release this set of simulations to engage the community to determine what light-curve features are most useful to include.

The next file is the photometry file. It has one row per flux measurement. Each row has the candidate ID (CID), for joining with the CID column in the object file. Each row also has the flux, band, PSF, sky noise, and other photometry measurements. The full list can be seen in Table 6.

Finally, we provide the spectroscopic data. This file is one row per object per epoch. Each row has a CID for joining with the object table. The full list of columns in this table can be found in Table 7.

Table 5
Description of `hourglass_objects.parquet`

Column Name	Description Name	Units	Type
<code>cid</code>	Candidate ID	...	integer
<code>field</code>	Field name	...	string
<code>class</code>	Object classification name	...	string
<code>sub_class</code>	Name of subclass, such as “IIP” or “Ic”	...	string
<code>z_cmb</code>	Redshift in CMB frame	...	float
<code>ra</code>	Right Ascension	degrees	float
<code>dec</code>	Declination	degrees	float
<code>mw_ebv</code>	Milky Way $E(B - V)$ along line of sight	AB mag	float
<code>peak_mjd</code>	Modified Julian date of maximum	...	float
<code>snr_max_Y</code>	Simulated peak S/N in Y band	...	float
<code>snr_max_J</code>	Simulated S/N magnitude in J band	...	float
<code>peak_mag_Y</code>	Simulated peak magnitude in Y band	AB mag	float
<code>peak_mag_J</code>	Simulated peak magnitude in J band	AB mag	float
<code>n_obs</code>	Number of total observations	...	integer
<code>t_rest_min</code>	Phase of first observation	days	float
<code>t_rest_max</code>	Phase of last observation	days	float
<code>scone_prob_Ia</code>	Probability of being an SN Ia via SCONE	...	float

Note. Ic, IIP: CCSNe subtypes; CMB: Cosmic Microwave Background.
















Table 6
Description of `hourglass_photometry.parquet`

Column Name	Description Name	Units	Type
<code>cid</code>	Candidate ID	...	integer
<code>mjd</code>	Modified Julian date of observation	...	float
<code>band</code>	Photometric band, one of <i>R</i> , <i>Z</i> , <i>Y</i> , <i>J</i> , <i>H</i> , or <i>F</i>	...	string
<code>phot_flag</code>	Photometric flag, 0 is pass	...	integer
<code>fluxcal</code>	Calibrated flux, $\text{mag} = 27.5 - 2.5 \log_{10}(\text{“fluxcal”})$...	float
<code>fluxcal_err</code>	Poisson uncertainty on “fluxcal,” sky +galaxy+source	...	float
<code>psf_nea</code>	PSF NEA	pixels	float
<code>sky_sig</code>	Sky noise	ADU/pixel	float
<code>read_noise</code>	Read noise	ADU/pixel	float
<code>zp</code>	Zero point	AB mag	float
<code>zp_err</code>	Error on zero point	AB mag	float
<code>sim_mag_obs</code>	Input model mag	AB mag	float

Table 7
Description of `hourglass_spectra.parquet`

Column Name	Description Name	Units	Type
<code>cid</code>	Candidate ID	...	int
<code>mjd</code>	Modified Julian date of observation	...	float
<code>t_expose</code>	Exposure time	s	float
<code>n_bin_lam</code>	Number of wavelength bins	...	int
<code>lam_min</code>	Low-wavelength edge of spectral bin	angstroms	list of floats
<code>lam_max</code>	High-wavelength edge of spectral bin	angstroms	list of floats
<code>flam</code>	Flux per wavelength bin	$\text{erg}^{-1} \text{s}^{-1} \text{\AA}^{-1} \text{cm}^{-2}$	list of floats
<code>flam_err</code>	Error on “flam”	$\text{erg}^{-1} \text{s}^{-1} \text{\AA}^{-1} \text{cm}^{-2}$	list of floats
<code>sim_flam</code>	Input or true flux	$\text{erg}^{-1} \text{s}^{-1} \text{\AA}^{-1} \text{cm}^{-2}$	list of floats

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