The Target-selection Pipeline for the Dark Energy Spectroscopic Instrument

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Abstract

In 2021 May, the Dark Energy Spectroscopic Instrument (DESI) began a 5 yr survey of approximately 50 million total extragalactic and Galactic targets. The primary DESI dark-time targets are emission line galaxies (ELGs), luminous red galaxies (LRGs) and quasars (QSOs). In bright time, DESI will focus on two surveys known as the Bright Galaxy Survey (BGS) and the Milky Way Survey (MWS). DESI also observes a selection of “secondary” targets for bespoke science goals. This paper gives an overview of the publicly available pipeline (desitarget) used to process targets for DESI observations. Highlights include details of the different DESI survey targeting phases, the targeting ID (TARGETID) used to define unique targets, the bitmasks used to indicate a particular type of target, the data model and structure of DESI targeting files, and examples of how to access and use the desitarget code base. This paper will also describe “supporting” DESI target classes, such as standard stars, sky locations, and random catalogs that mimic the angular selection function of DESI targets. The DESI target-selection pipeline is complex and sizable; this paper attempts to summarize the most salient information required to understand and work with DESI targeting data.

Keywords: catalogs; cosmology: observations; galaxies: distances and redshifts; galaxies: photometry; methods: data analysis; quasars: general; Astrophysics - Cosmology and Nongalactic Astrophysics; Astrophysics - Astrophysics of Galaxies

1. INTRODUCTION

As sky surveys have expanded in size and sophistication, the accompanying software has also become increasingly complex. Improvements in software pipelines are typically driven by, and proceed hand-in-hand with, augmentations in instrumentation and more ambitious scientific goals. Some examples of these algorithmic leaps include the development of techniques to perform spectroscopic reductions in near real-time to improve the completeness of redshift surveys (e.g. Tonry & Davis 1979), and the automated cataloging of galaxies using scanning machines in order to better sample and characterize large-scale-structure (e.g. Loveday et al. 1992).

With the advent of multi-object spectrographs (e.g. Bagnuolo et al. 1990; Lewis et al. 2002; Smee et al. 2013), spectroscopic surveys have greatly expanded in scope. This has facilitated larger campaigns with objectives that required greater accuracy and precision. Surveys with lower shot-noise are more prone to being affected by subtly heterogeneous source catalogs, and survey pipelines have had to become increasingly elaborate to mitigate inhomogeneity. Targeting for the 2dF Surveys, for example, incorporated color equations to account for different emulsions on glass plates versus films, and the survey pipeline generated masks to mitigate density fluctuations caused by bright stars, varying flux limits, satellite tracks and plate defects (e.g. Colless et al. 2001, 2003; Croom et al. 2004; Smith et al. 2005).

The Sloan Digital Sky Survey (SDSS; York et al. 2000), in particular, greatly advanced the frontiers of software development for large sky surveys. Specialist pipelines were developed for imaging reductions (Lupton et al. 2001; Blanton et al. 2011), spectroscopic reductions, source classifications and redshift-fitting (SubbaRao et al. 2002; Bolton et al. 2012), and tiling and fiber assignment (Blanton et al. 2003), among other goals. Crucially, the source code for these pipelines was made public, and the associated algorithms and data model were extensively documented (e.g. Stoughton et al. 2002).

Targeting pipelines also advanced with later iterations of the SDSS, such as the SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013) and the SDSS-IV extended Baryon Oscillation Spectroscopic Survey (eBOSS; Dawson et al. 2016). The BOSS and eBOSS quasar targeting pipelines (Ross et al. 2012; Myers et al. 2015), for instance, not only incorporated long-established approaches such as color cuts and cross-matches to multi-wavelength catalogs, but also implemented targeting techniques based on variability in multi-epoch data (Palanque-Delabrouille et al. 2011, 2016), forced photometry (Lang et al. 2016), ma-
chinese learning methods (Yèche et al. 2010), and rigorous Bayesian approaches (Kirkpatrick et al. 2011; Bovy et al. 2011, 2012).

The Dark Energy Spectroscopic Instrument (DESI) is a robotic, fiber-fed, highly multiplexed spectroscopic surveyor that operates on the Mayall 4-meter telescope at Kitt Peak National Observatory (DESI Collaboration et al. 2016a, 2022). DESI, which can obtain simultaneous spectra of almost 5000 objects over a ∼3° field (DESI Collaboration et al. 2016a; Silber et al. 2022, T. Miller et al. 2023, in preparation), is currently conducting a five-year survey of about a third of the sky. This campaign will obtain spectra for approximately 40 million galaxies and quasars (Levi et al. 2013; DESI Collaboration et al. 2016b), which will produce about an order-of-magnitude more extragalactic redshifts than measured by BOSS and eBOSS combined (see Alhumada et al. 2020, for BOSS and eBOSS source statistics). DESI spectra span wavelengths of ∼3600–9800 ˚A with a blue-end resolution of ∼2000 growing to ∼5000 at the red-end. Effective exposure times are ∼1000 seconds for dark-time targets and ∼180 seconds in bright time (see §4 of Guy et al. 2022). Quasar targets that DESI measures to be at redshifts of z ≥ 2.1 are observed multiple times to improve signal-to-noise in the Lyman-α Forest, and can ultimately amass ∼4000 seconds of exposure time (see §4 of E. Schlafly et al. 2023, in preparation).

The sheer scale of the DESI experiment necessitates multiple supporting software pipelines and products. These include significant imaging from the DESI Legacy Imaging Surveys (Zou et al. 2017; Dey et al. 2019, D. Schlegel et al. 2023, in preparation), an extensive spectroscopic reduction pipeline (Guy et al. 2022), a template-fitting pipeline to derive classifications and redshifts for each targeted source (Redrock; S. Bailey et al. 2023, in preparation), a pipeline to assign fibers to targets (A. Raichoor et al. 2023, in preparation), a pipeline to tile the survey and to plan and optimize observations as the campaign progresses (E. Schlafly et al. 2023, in preparation), and a pipeline to select targets for spectroscopic follow-up (desitarget; this paper).

Target selection approaches for DESI are, themselves, varied and extensive. Other publications that accompany this work include a paper describing the DESI Survey Validation (SV) phase (DESI Collaboration et al. 2023, in preparation), two papers describing how visual inspection of spectra of targets acquired during SV produced truth tables to inform target selection for the DESI Main Survey (Alexander et al. 2022; Lan et al. 2022), and a series of five papers detailing the selection of DESI bright-time and dark-time science targets (Chaussidon et al. 2022a; Zhou et al. 2022; Raichoor et al. 2022; Cooper et al. 2022; Hahn et al. 2022, see also §4.1.1).

In this paper, we detail the DESI target selection pipeline, which we refer to throughout as desitarget. In §2 we give an overview of how DESI uses bitmasks to record which targets were selected by each classification algorithm. In §3 we detail the unique identification number (TARGETID) that DESI adopts to track targets. In §4 we give a technical overview of the main DESI target classes. In §5 we highlight some important known issues and caveats that should be considered when working with DESI targets. Finally, we present some closing thoughts in §6. Throughout this paper, code examples are given in the Python programming language and HEALPix1 nside numbers (Górski et al. 2005; Zonca et al. 2019) are always expressed in the NESTED scheme. The desitarget codebase, and the entire history of its development, is publicly accessible2. Much of the data model for files produced by desitarget, including definitions of quantities in these files, is also available online3.

2. BITS AND BITMASKS

The chief purpose of the desitarget pipeline is to determine which sources selected by a variety of algorithms will be targeted for follow-up spectroscopy by DESI. To record that a specific source has been selected by a particular targeting algorithm, desitarget uses a number of bitmasks. A tutorial to further help elucidate DESI bitmasks is available on GitHub4.

The full set of targeting bitmasks assigned by desitarget will be tabulated in forthcoming DESI Data Release papers (e.g., DESI Collaboration et al. 2023, in preparation). Here, though, we will introduce (and refer to) some of the principal DESI targeting bitmasks to help illustrate the functionality of the desitarget pipeline.

2.1. An Overview of DESI Target Classes

The primary dark-time target classes observed by DESI (DESI Collaboration et al. 2016b) are emission line galaxies (ELGs; Raichoor et al. 2020, 2022), luminous red galaxies (LRGs; Zhou et al. 2020, 2022) and quasi-stellar objects (QSOs, also known as quasars; Yèche et al. 2020; Chaussidon et al. 2022a). During survey bright-time, DESI also targets galaxies as part of

1 https://healpix.sourceforge.net/.
2 https://github.com/desihub/desitarget.
3 https://desidatamodel.readthedocs.io.
4 https://github.com/desihub/desitarget/blob/2.5.0/doc/nb/target-selection-bits-and-bitmasks.ipynb, in Jupyter Notebook format.
a dedicated Bright Galaxy Survey (BGS; Ruiz-Macias et al. 2020; Hahn et al. 2022), and a variety of Galactic sources as part of a Milky Way Survey (MWS; Allende Prieto et al. 2020; Cooper et al. 2022). Finally, to calibrate the output from its spectroscopic pipeline, DESI also targets calibration sources such as standard stars and blank sky locations. These target classes will be described in more detail in §4.

The DESI survey also incorporates a plethora of programs that are not driven by the main cosmological goals of the primary campaign. These are referred to as “secondary” programs, and include, for example, studies of high-proper-motion stars in our Galaxy, a campaign to target M31 (Dey et al. 2022), studies of peculiar velocities in local galaxies, broad censuses of extragalactic sources, follow-up of gravitational lenses, and identification of quasars at redshifts of $z \gtrsim 5$ (J. Yang et al. 2023, in preparation). These target classes will be detailed in forthcoming DESI Data Release papers (e.g., DESI Collaboration et al. 2023, in preparation) — but we include some technical details about DESI secondary targets in §3.2 and §4.6.

All DESI primary targets, and the vast majority of secondary classes, are selected using properties from imaging. Based on algorithms applied to these photometric quantities, a bitmask (see §2.2) is constructed to designate a source as being a member of a particular target class or classes. Note that as the bits corresponding to “QSO,” “ELG,” “LRG,” etc. are assigned using only imaging quantities, subsequent DESI spectroscopy will reveal that some sources are inconsistent with their target class or classes, i.e., not all QSO targets will have quasar-like spectra.

### 2.2. A Brief Introduction to Bitmasks

As an example of how a bitmask is constructed, consider two types of source that DESI will target: LRGs and ELGs. Let’s assume that LRGs are designated by bit 0 and ELGs by bit 1, and that the name of the variable used to store the targeting bitmask is DESI_TARGET. Then, $\text{DESI\_TARGET} = 1$ ($\equiv 2^0$) would signify a source selected by the LRG targeting algorithm, $\text{DESI\_TARGET} = 2$ ($\equiv 2^1$) would signify a source selected by the ELG targeting algorithm and $\text{DESI\_TARGET} = 3$ ($\equiv 2^1 + 2^0$) would signify a source selected by both of the LRG and ELG targeting algorithms. The desitarget pipeline uses 64-bit signed integers to represent bitmasks. But the desitarget bit-values that are used to distinguish target classes are never negative numbers, so each of the bitmasks can register up to 63 distinct selections (bit 0 to bit 62).

A more realistic example of a DESI bitmask would be $1152921504606849827$, which equals $2^{60} + 2^{11} + 2^9 + 2^8 + 2^5 + 2^4 + 2^3$. For the DESI Main Survey (see §2.3), a bitmask of $1152921504606849827$ would signify that a target was part of the DESI Bright Galaxy Survey ($2^{60}$) as well as being selected by the LRG ($2^9$) and ELG ($2^1$) targeting algorithms—specifically, by the ELG “low-priority” targeting algorithm ($2^3$). The remaining bits ($2^{11} + 2^8 + 2^5$) are informational, and indicate that the method used to target ELGs and LRGs corresponded to the northern target selection algorithm (see §4.1.3).

### 2.3. Commissioning, Survey Validation, and the Main Survey

The DESI survey has progressed through a number of targeting phases:

- First, DESI underwent commissioning (e.g. Bessner et al. 2020; Meisner et al. 2020; Perruchot et al. 2020; Poppett et al. 2020; Shourt et al. 2020). During this phase, a number of target classes were defined to calibrate the instrument, such as dither stars to test pointing models, standard stars to test throughput, and “first light” science targets. The commissioning phase of DESI is typically abbreviated as CMX by the desitarget pipeline. Although a general reader is unlikely to encounter commissioning targets, it should be noted that:
  - CMX observations were highly preliminary and, for expediency, were not carefully tracked and documented by desitarget. From a targeting perspective, CMX observations therefore should not be used for general scientific analyses. Nevertheless, broadly, commissioning bitmasks can be handled by replacing occurrences of SV1 or sv1 (see below) with cmx or CMX and occurrences of desi_mask with cmx_mask.
  - The CMX data a general reader is most likely to encounter is a tile of observations of M33 with TILEID = 80615.

- Prior to commencing its main 5 yr mission, DESI underwent a period of Survey Validation (see DESI

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5 The sign was reserved in case especial cases arose, see, e.g., §3.3.2.
6 Note that there were no specific MWS, BGS or secondary targets for CMX, so there are no bitmasks for these program types.
7 See, e.g., E. Schlafly et al. 2023 (in preparation) for a description of DESI TILEIDs.
The major objectives of this phase were to validate the end-to-end DESI systems, to provide observations to refine the purity and completeness of the targeting algorithms that would be used for the main DESI survey, and to stress-test the procedures that would be needed for day-to-day DESI operations. Survey Validation is typically abbreviated as SV by the desitarget pipeline, and SV itself was divided into three distinct stages:

- **SV1**: The first iteration of SV ran, mainly from the night of 20201214 to the night of 20210402, and encompassed DESI tiles with TILEID numbers in the interval 80605–80975. A total of 189 tiles were targeted in the context of SV1. These tiles were spread widely across the sky and were observed over multiple months in order to sample a wide range of observational conditions. The main goals of SV1, from a data pipeline perspective, were to collect sufficient spectra of different target classes to train target selection algorithms and to refine the spectroscopic pipeline (see also Guy et al. 2022). The targeting algorithms deployed during SV1 were deliberately loosened to allow targeting to be refined.

- **SV2**: The second phase of SV (also referred to as “the 0.1% Survey”) ran from the night of 20210324 to the night of 20210511, covering DESI tiles in the interval 81000–81099. During SV2, 39 tiles were observed. The purpose of SV2 was to test critical end-to-end operational procedures, such as establishing the processing of “Merged Target Ledgers” (MTLs; see E. Schlafly et al. 2023, in preparation), in which spectroscopic classifications and redshifts are used to decide whether a target requires additional observations.

- **SV3**: The final stage of SV (also known as “the One-Percent Survey,” but typically referred to as SV3 in this paper) ran from the night of 20210405 to the night of 20210610, although it was mostly completed by the end of the night of 20210513. SV3 covered DESI tiles with IDs in the interval 1–596. During SV3, 488 tiles were observed, 239 in dark time, 214 in bright time, and 35 as part of a “backup” program (see §2.5 and §4.1.2). Observations were conducted in 20 separate “rosette” patterns consisting of 11 overlapping pointings arranged in a circle comprising a little more than 7 deg² of total area. A few additional passes were made in some rosettes to further increase completeness. The main goals of SV3 were to conduct DESI observations in a mode that mimicked main-survey observations, and to sample main-survey target classes at high completeness.

The DESI collaboration typically refers to SV1 as “Survey Validation” and SV3 as “the One-Percent Survey” (again, see DESI Collaboration et al. 2023, in preparation). But, this paper will refer to the entire period encompassing SV1, SV2 and SV3 as “Survey Validation,” as such terminology better matches the nomenclature embedded in the desitarget data model.

- Finally, DESI embarked upon its five-year Main Survey, which is typically denoted main by the desitarget pipeline. First observations for the Main Survey began on 20210514. The target classes that had been refined using spectra from SV1 and observed at high completeness during SV3 then began to be observed in earnest. Observations were conducted using procedures that were introduced during SV2 and finalized near the end of SV3.

2.4. **DESI Bitmask Denominations, Values and Access**

The DESI bit-names and bit-values are available on GitHub for SV1, SV2, SV3 and the Main Survey. Note that, although the vast majority of targets for SV1 used version 0.51.0 of the desitarget code, some SV1 targets...
Table 1. Commands for importing DESI targeting bitmasks

| Phase | Import command |
|-------|----------------|
| SV1   | `from desitarget.sv1.sv1_targetmask import desi_mask, bgs_mask, mws_mask, scnd_mask` |
| SV2   | `from desitarget.sv2.sv2_targetmask import desi_mask, bgs_mask, mws_mask, scnd_mask` |
| SV3   | `from desitarget.sv3.sv3_targetmask import desi_mask, bgs_mask, mws_mask, scnd_mask` |
| main  | `from desitarget.targetmask import desi_mask, bgs_mask, mws_mask, scnd_mask` |

*a* `desi_mask`, `bgs_mask`, `mws_mask` and `scnd_mask`, here, correspond to the different target type columns listed in Table 2. Any of the individual masks can be omitted from the command.

Table 2. Relevant column names for DESI targeting bitmasks

| Survey Phase | Primary Targets | Secondary Targets |
|--------------|----------------|-------------------|
| SV1          | DESI_TARGET    | SV1_DESI_TARGET   |
| SV2          | BGS_TARGET     | SV1_BGS_TARGET    |
| SV3          | MWS_TARGET     | SV1_MWS_TARGET    |
| main         | SCND_TARGET    | SV1_SCND_TARGET   |

*a* Dark-time targets include LRGs, ELGs and QSOs.

Secondary programs were updated to use version 0.52.0 of the code (see the Appendix of DESI Collaboration et al. 2023, in preparation, for more details). Further, for secondary targets from SV1, it is important to use the appropriate version of the `desitarget` code for the corresponding survey files (e.g. use version 0.51.0 of `desitarget` when working with bit-masks from files in the 0.51.0/targets/sv1 directory), as some SV1 secondary targeting bits were deprecated. For all primary targets (and throughout SV2, SV3 and the Main Survey), it is acceptable to use the corresponding version of the code or a *later* version as bitmasks were only added during software development. The bitmasks can be accessed directly in Python using the `targetmask` module in the `desitarget` code. For example, if a user is interested in the primary dark-time target classes (ELGs, LRGs, QSOs, etc.) the relevant bitmask can be accessed via the command `from desitarget.targetmask import desi_mask`. The specific commands needed to retrieve each bitmask for different combinations of survey phase and target type are listed in Table 1. The bits that correspond to the different bitmasks are stored in different columns depending on the type of target. For instance, the primary dark-time classes are stored in DESI data files in a column called DESI_TARGET for the Main Survey and SVX_DESI_TARGET for SV for $x \in 1, 2, 3$.

The specific column names used to store each target type for each survey phase are listed in Table 2.

It may be helpful to illustrate the use of DESI targeting bitmasks with a short example. Say we wish to know if a target has been selected by (at least) the quasar targeting algorithm in the Main Survey. Further, let’s assume that the appropriate data file has been read into a structure called `targs`, then the necessary commands to determine which indexes in `targs` correspond to quasar targets would be:

```python
from desitarget.targetmask import desi_mask as Mx
is_QSO = (targs["DESI_TARGET"] & Mx["QSO"]) != 0.
```

Much additional functionality exists for working with DESI targeting bitmasks. Two utility functions, in particular, are worth mentioning. First, any integer ($i$) can be converted to the corresponding bitnames using the `mask.names(i)` function. For example, `desi_mask.names(7)` will return the list ['LRG', 'ELG', 'QSO']. Second, the function `main_cmx_or_sv` can be used to directly extract the relevant bitmasks, column names, and survey phase (detailed in Table 1 and 2) from a DESI data file. For example:
from desitarget.targets import main_cmz_or_sv
column_names, masks, survey = main_cmz_or_sv(targs)

2.5. Observing Conditions and Programs

Depending on the quality of the observing conditions at Kitt Peak, DESI pursues one of three different observing programs, corresponding to three different sets of targets (see, e.g., E. Schlaufly et al. 2023, in preparation, for more details). During DARK time, DESI observes ELG, LRG and QSO targets; the bits for such targets are stored in columns with names that resemble DESI_TARGET (see Table 2) and are described in the desi_mask mask (see Table 1). During BRIGHT time, DESI observes BGS targets, stored in columns like BGS_TARGET and recorded in the bgs_mask mask, and MWS targets, stored in columns like MWS_TARGET and recorded in the mws_mask mask. Finally, during more marginal observing conditions, DESI pursues a BACKUP program (see §4.1.2); the bits that indicate targets that are part of the backup program are also stored in columns like MWS_TARGET and are recorded in the mws_mask mask.

Because the same target can be selected to be observed in both, e.g., bright and dark time, it is useful to record the specific programs associated with each target. In DESI targeting files, such information is stored in a column called OBSCONDITIONS and the corresponding bit-names and bit-values are accessible in the obconditions mask, which can be accessed using a similar command to those listed in Table 1:

from desitarget.targetmask import obconditions.

Note that there are some placeholder bits included in the obconditions mask (e.g., GRAY) that were deprecated for the DESI Main Survey or that were never adopted for DESI operations.

3. TARGETID - A UNIQUE IDENTIFIER FOR DESI TARGETS

DESI utilizes a unique ID, similar to the objID used by the SDSS (e.g. Stoughton et al. 2002), to track targeted objects through the end-to-end pipeline. In DESI, this unique targeting ID is denoted TARGETID. It is critical for DESI operations that each TARGETID is associated with only one object. However, it is less crucial that each object is associated with only one TARGETID, particularly for targets that will not be used in the key DESI large-scale-structure analyses. So, it is important to note that (for most cases) TARGETID does not have coordinate-based provenance—and targets at the same coordinates can therefore have a different TARGETID. Instead TARGETID is constructed using information from the imaging survey used to select a target.

An illustrative example in DESI might be a target selected from the Legacy Imaging Surveys versus a target selected using only information from Gaia (e.g. Gaia Collaboration et al. 2018a). Although an object might share a location on the sky in Gaia and the Legacy Surveys, desitarget does not perform an exhaustive coordinate-match across all possible input surveys. Therefore, such a target can have a TARGETID derived from Legacy Surveys information (see §3.1) and a TARGETID derived from Gaia information (see §3.1.5).

An exception to the rule that the DESI TARGETID is not coordinate-based is negative values of TARGETID. Negative TARGETID, which are described in §3.3.2, are used to distinguish sky locations that need to be rapidly assigned during survey operations.

3.1. Primary Targets

Figure 1 depicts the bitmask that defines the DESI TARGETID. In the rest of this subsection, we will detail the bits that comprise a “primary” TARGETID, by which we mean the unique identifier for a source that is part of one of the primary DESI subprograms, i.e., LRGs, ELGs, QSOs, the BGS or the MWS, rather than being part of a secondary program (see, e.g., Table 2).

3.1.1. The OBJID and BRICKID Bits

Imaging from the Legacy Surveys (Dey et al. 2019, D. Schlegel et al. 2023, in preparation), on which DESI targeting draws, is processed through the legacypipe pipeline to produce catalogs of sources. The legacypipe code extracts these sources in individual regions of the sky denoted bricks. The bricks cover an area of roughly \(0.25^\circ \times 0.25^\circ\) on the sky, and each brick is assigned a unique integer from 1 to 662,174. Each extracted source in each brick is assigned an integer from 0 to \(N - 1\), where \(N\) is the total number of sources extracted by legacypipe in the brick. The unique brick number is called BRICKID and the unique source number is called OBJID.

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15 https://github.com/desihub/desitarget/blob/1.1.1/py/desitarget/data/targetmask.yaml#L184-L187.
16 See also https://github.com/desiHub/desitarget/blob/1.1.1/py/desitarget/data/targetmask.yaml#L214-L221.
17 https://github.com/legacysurvey/legacypipe.
18 See, e.g., https://www.legacysurvey.org/dr9/catalogs/.
Together, OBJID and BRICKID encode a unique legacyPipe-extracted source. TARGETID inherits these two numbers as a method to track unique sources, and they occupy the two least significant sets of bits in TARGETID (see Figure 1).

3.1.2. The RELEASE Bits

OBJID and BRICKID encode a unique source, but not the imaging reductions from which that source was extracted. To track this, starting with Data Release 4 (DR4), the Legacy Surveys included a column RELEASE that records image-processing information\(^\text{19}\). RELEASE is an integer in the 1000s, with the first digit denoting the Data Release and subsequent digits representing the photometric system.

The Legacy Imaging Surveys commenced with Data Release 1, which means RELEASE numbers < 1000 have no pre-defined meaning. As we will discuss more in subsequent sections, we take advantage of this extra bit-space by using integers with RELEASE < 1000 to indicate a target that (potentially) was selected using information from beyond the Legacy Surveys.

3.1.3. The MOCK Bit and TARGETIDs for Random Catalogs

In preparation for going on-sky, the DESI collaboration produced multiple catalogs of ersatz targets to stress test the end-to-end software pipelines and to model survey outcomes. The MOCK bit is a single bit (again see Figure 1) that encodes whether or not a source is derived from such “mock” data. In addition, the desitarget pipeline includes a randoms module that can be used to produce catalogs of points that mimic the selection function of sources in the Legacy Imaging Surveys (see §4.5.1). A value of “1” for the MOCK bit indicates that a target was generated as part of either a “mock” data run or a random catalog.

\(^\text{19}\) See, e.g., https://www.legacysurvey.org/release/.

Information at locations created in desitarget random catalogs is derived at the pixel-level using images from the Legacy Surveys (again see §4.5.1). As such, RELEASE and BRICKID are inherited directly from the Legacy Surveys for points in random catalogs. Within a brick, desitarget assigns an OBJID integer for random points sequentially in order of Right Ascension (henceforth RA), such that the object with the smallest RA is assigned OBJID=0. Ordering by RA in this manner guarantees that random points in northern and southern portions of the Legacy Surveys (see §4.1.3) have the same OBJID. Note that even though [RELEASE, BRICKID, OBJID] for random points can resemble similar combinations for real sources from the Legacy Surveys, random points will always have a distinct TARGETID because the MOCK bit will be set.

3.1.4. The SKY Bit and TARGETIDs for Blank Skies

The desitarget pipeline also generates blank sky positions to facilitate spectral calibration (see §4.4.1). The SKY bit is a single bit (again see Figure 1), which, if set, indicates that a target corresponds to a sky position. The majority of blank sky locations in the DESI footprint are assigned at the pixel-level using blobmaps from the Legacy Surveys imaging (again see §4.4.1). For these sky locations, RELEASE and BRICKID are therefore inherited directly from the Legacy Surveys. Within each brick, the desitarget code assigns sequential integers for OBJID. This schema is guaranteed to produce unique values of TARGETID as setting the SKY bit distinguishes combinations of [RELEASE, BRICKID, OBJID] from any target derived from the Legacy Surveys source catalogs.

DESI also creates files of “supplemental” sky targets to cover areas outside of the Legacy Imaging Surveys (see §4.4.2), which are assigned by using a catalog-level match to avoid bright sources in Gaia. If these supplemental skies are near a bright object in Gaia, they are retained but are designated to be BAD_SKY (see §4.4.2 for more details). For BAD_SKY supplemental sky targets, RELEASE is set to 0 and the GAIADR indicative bits (see

Figure 1. The bits that comprise a positive DESI TARGETID. The least significant bit (i.e. \(2^0\)) is depicted to the right of this diagram. The 58 least significant bits (\(2^{56}–2^{29}\)) record information from the Legacy Imaging Surveys. The next two most significant bits are Boolean flags that indicate whether a target is drawn from a mock or random catalog (\(2^{28}\)) and whether a target is a blank sky location (\(2^{29}\)). The remaining two populated bits (GAIAIDR), which are used to indicated targets that are selected solely using Gaia information, store the Gaia Data Release number. (\(2^{60}–2^{61}\)). Bit 62 is not used. Note that DESI also uses a differently structured negative TARGETID to distinguish some sky locations (see §3.3.2).
§3.1.5) are set to the Gaia Data Release integer used to assign supplemental skies (typically ‘2’ to indicate Gaia DR2). For other supplemental skies, both the RELEASE and GAIADR bits are populated with the Gaia DR integer. BRICKID is set to the nsid = 256 HEALPix integer of each supplemental sky location, and OBJID is a sequential integer generated within each HEALPix. The SKY bit, of course, is also always set. Note that setting RELEASE < 1000 guarantees that the TARGETID for supplemental skies will always differ from the TARGETID for pixel-level skies, as there were no Legacy Surveys Data Releases prior to DR1.

3.1.5. The GAIADR bits and Gaia-based TARGETID

A substantial set of DESI targets are derived solely using information from Gaia. These targets generally lie outside of the Legacy Imaging Surveys footprint and are intended for BACKUP observations (see §2.5). Objects that are targeted purely using Gaia have the GAIADR bits (depicted in Figure 1) set to the Gaia Data Release used to select the target (i.e ‘2’ for Gaia DR2)\textsuperscript{20}. For targets that are selected solely using Gaia, BRICKID is populated with the integer of the nsid = 32 HEALPix that contains the target, and OBJID is set to a sequential integer generated within each HEALPix. Note that this schema differs slightly from the one described for supplemental skies in §3.1.4 (for which nsid = 256 is adopted when populating BRICKID).

3.2. Secondary Targets

In addition to “primary” target classes, DESI observes a number of secondary programs (see also §4.6) proposed by the wider DESI collaboration to address specific science goals. In many cases, proposers specified that targets should not share the observing characteristics of a DESI primary target. For example, a supernova in a galaxy that is part of the BGS sample should not be considered to be the same target as the galaxy itself. Such a supernova might not be at exactly the same location as the galactic center, and may, for instance, need to be scheduled for dark-time observations rather than during bright time. The end-to-end DESI pipeline uses TARGETID to ensure correspondence between a target, an allocated fiber, and the resulting spectrum. Therefore, secondary targets that cannot be merged with a corresponding primary target (see §4.6) must, by definition, have a different TARGETID. In some instances, there is an unused primary TARGETID, because a secondary target that is also a source from the Legacy Surveys is not part of the primary DESI campaign. In those instances, a secondary target is simply assigned the primary TARGETID detailed in §3.1. Still, there are cases where a secondary target does not have a corresponding source in the Legacy Surveys or a secondary target is prevented from being merged with a primary target that is already using the primary TARGETID. In those cases, the desitarget pipeline constructs a “secondary” TARGETID that is guaranteed to always be unique, as well as distinct from the TARGETID of any primary target.

3.2.1. The General TARGETID for Secondary Targets

The secondary TARGETID is structured similarly to the schema displayed in Figure 1. BRICKID has the same definition for secondary and primary targets—it is the number of the brick from the Legacy Surveys on which the secondary target lies—but OBJID and RELEASE have different meanings. OBJID, for secondary targets, records the row that a target was listed in a file of secondary targets prepared by a proposer to pass to the desitarget pipeline, after first partitioning by BRICKID. RELEASE, for secondary targets, corresponds to:

\[
100[X - 1] + \log_2(S),
\]

where \(X\) is the iteration of SVX during which the target was observed (see, e.g., Table 2); with \([X - 1] = 5\) used to denote the DESI main survey\textsuperscript{21}. Here, \(S\) is the bit-value from the scnd_mask (see, e.g., Table 1). For example, pseudo-RELEASE = 245 would denote secondary targeting bit 45 from the SV3 campaign and pseudo-RELEASE = 534 would denote secondary targeting bit 34 from the main observing campaign. Note that secondary targets that have not adopted the primary TARGETID can always be identified by virtue of having RELEASE < 1000. TARGETID bits other than OBJID, BRICKID and RELEASE are set to zero for secondary targets.

3.2.2. The TARGETID for Targets of Opportunity

When merited, the DESI survey can occasionally be suspended to pursue rapidly designed, dedicated tiles that place fibers on Targets of Opportunity (ToOs). An example science case might be to follow-up potential host galaxies of gravitational waves or neutrino events (e.g., Palmese et al. 2021). DESI targeting also facilitates an observing mode where some ToOs are added to the existing pool of science targets. As with any DESI target class, ToOs must have a unique TARGETID so that they can be tracked by the end-to-end pipeline. ToOs

\textsuperscript{20} Gaia DR1 was never used for DESI targeting. GAIADR=1 instead denotes a “first light” target observed during commissioning.

\textsuperscript{21} New or updated sets of secondary targets assigned during the Main Survey will progressively use higher (integer values) of \(X\).
have a TARGETID that follows the model of Figure 1, and BRICKID has the same meaning as for general primary and secondary targets. The list of all DESI ToOs is maintained in a single ledger, to which new targets can be added but not removed\(^{22}\), and the OBJID for ToOs is simply the row number of the corresponding target in that ledger. For ToOs, RELEASE is always set to 9999, which is distinct from any other RELEASE value used to encode a TARGETID. The other possible TARGETID bits are set to zero for ToOs.

3.2.3. Tertiary Targets

Occasionally, special tiles need to be rapidly scheduled for a scientific purpose that doesn’t comport with the desitarget scheme for Targets of Opportunity. To facilitate prompt observation of such tiles, desitarget reserves RELEASE bits equivalent to 8888 to denote targets that were “directly” assigned fibers. Targets that have a TARGETID with a RELEASE of 8888 were not processed by the desitarget pipeline and are instead maintained and handled by the DESI fiberassign code (A. Raichoor et al. 2023, in preparation). Such programs are sometimes referred to as “tertiary” programs.

3.3. Encoding and Decoding TARGETID

The desitarget codebase includes utility functions for extracting the bits depicted in Figure 1 from a TARGETID and for constructing a TARGETID from its constituent bits. These functions will work for all positively valued TARGETID integers.

3.3.1. desitarget Functionality

The specific functions in desitarget for encoding and decoding TARGETID can be called as follows:

```python
from desitarget.targets import decode_targetid, encode_targetid
objid, brickid, release, mock, sky, gaiadr = decode_targetid(targetid)
targetid = encode_targetid(objid, brickid, release, mock, sky, gaiadr).
```

Both of the encode_targetid and decode_targetid functions are written with a high degree of flexibility. For example, targetid can be passed to decode_targetid as a single integer or as an array. Similarly, encode_targetid can be passed a mix of arrays and integers. Additionally, none of the inputs must be passed. This makes it straightforward to encode a TARGETID that is composed of, say, arrays of BRICKIDs and OBJIDs but only a single RELEASE number.

3.3.2. Negative TARGETIDs

Some TARGETID integers in DESI files have negative values. Typically, these correspond to stuck fibers that could not be used by DESI to observe a science target, so were assigned to sky locations on-the-fly (see, e.g., E. Schlafly et al. 2023, in preparation). Assigning stuck fibers to sky locations frees up fibers to be assigned to science targets elsewhere in the focal plane. The least-significant 29 bits encoded in a negative TARGETID correspond to Declination, partitioning in equal bins in a northerly direction with the Dec = -90° bin corresponding to bit 0. The next-most-significant 30 bits correspond to RA, partitioned in equal bins with the RA = 0° bin corresponding to the least significant bit. The remaining four bits allow flexibility to record up to 16 different groups of distinct negative TARGETIDs.

The resulting schema allows unique TARGETIDs to be assigned by location at a resolution of \(\sim1.2\) millarcseconds. Negative TARGETIDs can be created and decoded using desitarget routines as follows:

```python
from desitarget.targets import decode_negative_targetid, encode_negative_targetid
ra, dec, group = decode_negative_targetid(targetid)
targetid = encode_negative_targetid(ra, dec, group=group).
```

Here, decode_negative_targetid(targetid) will return the lowest-valued bin edge in RA and Dec (i.e. the “left-hand” and “bottom” edges of the bin). A full description of how negative TARGETIDs are handled by the DESI fiber assignment code is provided in A. Raichoor et al. (2023, in preparation).

4. DESI TARGET CLASSES

In this section, we detail each of the main DESI target classes and the location and structure of the files in which they are stored. We will frequently refer to columns in these files being populated by certain “target selection bits,” which are detailed in §2.

4.1. Primary Science Targets

The selection and optimization of DESI science targets for SV3 and the Main Survey are described in a series of papers, listed in Table 3.

4.1.1. Bright-time and Dark-time Targets

\(^{22}\) See E. Schlafly et al. 2023 (in preparation) for a full description of the ToO ledger.
Table 3. Publications that describe specific DESI science target classes

| Target selection class       | Main Survey bit names<sup>a</sup> | Brief description                                      | Selection detailed in                        |
|------------------------------|----------------------------------|--------------------------------------------------------|----------------------------------------------|
| **Dark-time targets**        |                                  |                                                        |                                              |
| Luminous Red Galaxies        | LRG                              | LRG target                                             | Zhou et al. (2022)                           |
| Emission Line Galaxies       | ELG                              | ELG target                                             | Raichoor et al. (2022)                       |
|                              | ELG.LOP                          | ELG at standard priority                               |                                              |
|                              | ELG.HIP                          | ELG observed at the priority of an LRG<sup>b</sup>     |                                              |
|                              | ELG.VLO                          | Very-low-priority “filler” ELG                        |                                              |
| Quasars                      | QSO                              | Quasar target                                          | Chaussidon et al. (2022a)                    |
| **Bright-time targets**      |                                  |                                                        |                                              |
| Bright Galaxy Survey         | BGS.ANY                          | Any BGS bit is set                                     | Hahn et al. (2022)                           |
|                              | BGS.FAINT<sup>c</sup>            | Faint BGS target                                       |                                              |
|                              | BGS.BRIGHT                       | Bright BGS target                                      |                                              |
|                              | BGS.WISE                         | AGN-like BGS target                                    |                                              |
|                              | BGS.FAINT.HIP                    | Faint BGS target prioritized like a bright BGS target<sup>b</sup> |                                              |
| Milky Way Survey             | MWS.ANY                          | Any MWS bit is set                                     | Cooper et al. (2022)                         |
|                              | MWS.BROAD<sup>d</sup>            | Magnitude-limited bulk sample                         |                                              |
|                              | MWS.WD                           | White dwarf                                            |                                              |
|                              | MWS.NEARBY                       | Volume-limited ~100 pc sample                          |                                              |
|                              | MWS.BHB                          | Blue Horizontal Branch target                          |                                              |
|                              | MWS.MAIN.BLUE                    | Magnitude-limited blue sample                         |                                              |
|                              | MWS.MAIN.RED                     | Magnitude-limited red sample                          |                                              |
| **Backup targets**           |                                  |                                                        |                                              |
| Part of the Milky Way Survey | BACKUP.GIANT.LOP<sup>e</sup>     | Candidate Giant Star observed at lower priority        | MWS et al. 2023 (in preparation)             |
|                              | BACKUP.GIANT                     | Candidate Giant Star                                   |                                              |
|                              | BACKUP.BRIGHT                    | Brighter backup target                                 |                                              |
|                              | BACKUP.FAINT                     | Fainter backup target                                  |                                              |
|                              | BACKUP.VERY.FAINT                | Even fainter backup target                             |                                              |

<sup>a</sup> Stored as bit-values in the DESI_TARGET, BGS_TARGET and MWS_TARGET columns. Bit-names can be converted to bit-values using the desi_mask, bgs_mask and mws_mask bitmasks (see §2.4).

<sup>b</sup> Some targets with low observational priority are observed at higher priority to help characterize the survey selection function.

<sup>c</sup> BGS bits other than BGS.ANY are stored in the BGS_TARGET column and bgs_mask bitmask.

<sup>d</sup> MWS bits other than MWS.ANY are stored in the MWS_TARGET column and mws_mask bitmask.

<sup>e</sup> BACKUP bits are stored in the MWS_TARGET column and mws_mask bitmask.
Bright-time and dark-time science targets are publicly available online for SV1\textsuperscript{23}, SV2\textsuperscript{24}, SV3\textsuperscript{25} and the Main Survey\textsuperscript{26}. Each url links to bright and dark sub-directories which contain bright-time (MWS, BGS) and dark-time (ELG, LRG, QSO) targets, respectively. Note that operational procedures were in flux during SV1, meaning that a (very small) subset of SV1 targets can only be found in earlier versions of the target files than 0.51.0. Similarly, a few hundred targets from the DESI Main Survey are only available in the 1.0.0 version of the target files (see §5.1). The bright/dark sub-directories host files containing targets that are only selected by bright-time/dark-time target selection algorithms. But, every target in each sub-directory has all of the appropriate targeting bits populated. Consider, for instance, a QSO target that is also targeted by the MWS survey. Such a target will appear in the appropriate file in both of the bright/dark sub-directories with the same bits set in the DESI_TARGET and MWS_TARGET columns. However, a QSO target that is not also targeted by a bright-time survey will only appear in the appropriate file in the bright sub-directory.

In Table 5 and Table 6 we show the densities of the principal DESI Main Survey bright-time and dark-time target classes. We also show how the densities of these target classes overlap (i.e. whether a target is included in both of two target classes). For example, Table 6 demonstrates that ~0.4% (7.6/1910.5) of MWS targets are also quasar targets. This overlap is driven by the MWS\textsubscript{MAIN-BLUE} sample described in §4.1 of Cooper et al. (2022), which contains blue point sources that resemble quasars in imaging. Densities in these

\begin{table}[h]
\centering
\caption{Columns added to target files by the \texttt{desitarget} pipeline}
\begin{tabular}{lll}
\hline
\textbf{Column Name} & \textbf{Python Format} & \textbf{Description} \\
\hline
\texttt{BRICK\_OBJID} & i4 & OBJID from the Legacy Surveys sweep catalogs. \\
\texttt{MORPHTYPE} & U4 & TYPE from the Legacy Surveys sweep catalogs. \\
\texttt{PHOTSYS} & U1 & ‘N’ for \textit{MzLS}/\textit{BASS} photometric system, ‘S’ for \textit{DECaLS}.\textsuperscript{a} \\
\texttt{TARGETID} & i8 & Column name differs for SV; see §2.4. \\
\texttt{DESI\_TARGET} & i8 & Column name differs for SV; see §2.4. \\
\texttt{BGS\_TARGET} & i8 & Column name differs for SV; see §2.4. \\
\texttt{MWS\_TARGET} & i8 & Column name differs for SV; see §2.4. \\
\texttt{SCND\_TARGET} & i8 & Column name differs for SV; see §2.4. \\
\texttt{SUBPRIORITY} & f8 & Random number (0–1) used to break fiber-assignment ties. \\
\texttt{OBSCONDITIONS} & i8 & See §2.5. \\
\texttt{PRIORITY\_INIT} & i8 & See E. Schlafly et al. 2023 (in preparation). \\
\texttt{NUMOBS\_INIT} & i8 & See E. Schlafly et al. 2023 (in preparation). \\
\texttt{HPXPIXEL} & i8 & The \texttt{nside} = 64 HEALPixel of the target.\textsuperscript{b} \\
\hline
\end{tabular}
\end{table}

\begin{itemize}
\item \textsuperscript{a} \textit{BASS}, \textit{MzLS} and \textit{DECaLS} are the individual surveys that comprise the DESI Legacy Imaging Surveys (e.g. Dey et al. 2019). The photometric system (\texttt{bok} for \textit{BASS}, \texttt{mosaic} for \textit{MzLS} and \texttt{decam} for \textit{DECaLS}) can be derived from the \texttt{RELEASE} number according to \url{https://www.legacysurvey.org/release/}.
\item \textsuperscript{b} This \texttt{nside} is stored in the file header as \texttt{HPXNSIDE}.
\end{itemize}

\textsuperscript{23} \url{https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.51.0/targets/sv1/resolve/}
\textsuperscript{24} \url{https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.53.0/targets/sv2/resolve/}
\textsuperscript{25} \url{https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.57.0/targets/sv3/resolve/}
\textsuperscript{26} \url{https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/1.1.1/targets/main/resolve/}
\textsuperscript{27} \url{https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/files/#sweep-catalogs-region-sweep.}
\textsuperscript{28} \url{https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.}
Table 5. Densities (deg$^{-2}$) of principal Main Survey target classes in dark time

| Bit name   | BGS ANY | ELG   | LRG   | MWS_ANY | QSO | STD_BRIGHT$^a$ | STD_FAINT$^a$ |
|------------|---------|-------|-------|---------|-----|----------------|---------------|
| BGS_ANY    | 79.8$^b$| 1.0$^c$| 78.4  | 0.5     | 0.9 | 0.0            | 0.0           |
| ELG        | 2394.3  | 2.3   | 0.0   | 108.5   | 0.0 | 0.0            | 0.0           |
| LRG        | 625.7   | 0.4   | 4.0   | 0.0     | 0.0 | 0.0            | 0.0           |
| MWS_ANY    | 119.0   | 7.6   | 51.9  | 104.2   | 0.0 | 0.0            | 0.0           |
| QSO        | 319.8   | 0.0   | 0.0   | 0.0     | 0.0 | 0.0            | 0.0           |
| STD_BRIGHT | 54.9    | 54.9  | 54.9  | 54.9    | 54.9| 54.9           | 54.9          |
| STD_FAINT  | 107.2   | 107.2 | 107.2 | 107.2   | 107.2| 107.2          | 107.2         |

$^a$STD_BRIGHT and STD_FAINT are the main standard star classes intended for use in bright time and dark time, respectively (see §4.2).

$^b$On-diagonal elements represent the density for a target class, with areas derived using the desitarget weight maps (see §4.5.2).

$^c$Off-diagonal elements represent the overlap in density between two target classes.

Table 6. Densities (deg$^{-2}$) of principal Main Survey target classes in bright time

| Bit name   | BGS_ANY | ELG   | LRG   | MWS_ANY | QSO | STD_BRIGHT$^a$ | STD_FAINT$^a$ |
|------------|---------|-------|-------|---------|-----|----------------|---------------|
| BGS_ANY    | 1389.7$^b$| 1.0$^c$| 78.4  | 0.6     | 0.9 | 0.0            | 0.0           |
| ELG        | 1.0      | 0.4   | 0.0   | 0.0     | 0.0 | 0.0            | 0.0           |
| LRG        | 78.8     | 0.4   | 0.3   | 0.0     | 0.0 | 0.0            | 0.0           |
| MWS_ANY    | 1910.5   | 7.6   | 51.9  | 104.2   | 0.0 | 0.0            | 0.0           |
| QSO        | 8.0      | 0.0   | 0.0   | 0.0     | 0.0 | 0.0            | 0.0           |
| STD_BRIGHT | 54.9    | 54.9  | 54.9  | 54.9    | 54.9| 54.9           | 54.9          |
| STD_FAINT  | 107.2   | 107.2 | 107.2 | 107.2   | 107.2| 107.2          | 107.2         |

$^a$STD_BRIGHT (STD_FAINT) is the principal standard star class (see §4.2) intended for use in bright time (dark time).

$^b$On-diagonal elements represent the density for a target class, with areas derived using the desitarget weight maps (see §4.5.2).

$^c$Off-diagonal elements represent the overlap in density between two target classes.

tables are derived from the target files discussed in this section, with areal weights derived using the desitarget pixelized weight maps detailed in §4.5.2. The resulting matrices of densities can also be seen on the front page of the Quality Assurance (QA) web pages described in §4.5.3.

4.1.2. Backup Targets

In addition to other campaigns, DESI pursues a program of “backup” targets when observing conditions are of insufficient quality to collect signal on bright-time or dark-time science targets (see also §2.5). The principal backup targets are listed in the final part of Table 3 and will be detailed in a forthcoming paper (see MWS et al. 2023, in preparation). Backup targets differ from other science targets in that they are selected solely using Gaia information rather than imaging from the Legacy Surveys. As such, the directory structure for the files that contain backup targets differs slightly from that of other science targets, having gaiadr2 in the directory construction instead of dr9$^{29}$. For versions of desitarget starting with 0.52.0, backup targets are stored in a backup sub-directory but prior to 0.52.0, this sub-directory was instead called supp (for “supplemental”). Backup targets used for the DESI Main Survey are derived from a slightly later release of the desitarget code than for other target classes.$^{30}$

4.1.3. Overlapping Imaging: The North/South “Resolve”

$^{29}$For instance, SV3 backup targets are at https://data.desi.lbl.gov/public/ets/target/catalogs/gaiadr2/0.57.0/targets/sv3/resolve/.

$^{30}$https://data.desi.lbl.gov/public/ets/target/catalogs/gaiadr2/2.2.0/targets/main/resolve/.
Table 7. Columns that use Gaia EDR3 instead of DR2 when GAIA_SUB is set in a file header. Columns are as for the Legacy Surveys sweep files.

| Column name                        |
|------------------------------------|
| PARALLAX                           |
| PARALLAX_IVAR                      |
| PMRA                               |
| PMRA_IVAR                          |
| PMDEC                              |
| PMDEC_IVAR                         |
| GAIA_DUPlicated_SOURCE             |
| GAIA_ASTROMETRIC_PARAMS_SOLVED     |
| GAIA_ASTROMETRIC_SIGMA50_MAX       |
| GAIA_ASTROMETRIC_EXCESS_NOISE      |

The majority of DESI targets are selected from the Legacy Surveys, which comprises three individual imaging campaigns called BASS, MzLS and DECaLS. Because these surveys overlap (see, e.g., Figure 1 of Dey et al. 2019), it is crucial to decide which imaging to use in each area of the sky. To help decide this, the desitarget pipeline adds a PHOTSYS column to targeting files (see Table 4), which is set to ‘N’ for targets derived using imaging from the “northern” Legacy Surveys (BASS and MzLS) and ‘S’ for targets derived using DECaLS imaging. A function called targets.resolve in the desitarget pipeline then uses PHOTSYS to determine (or “resolve”) which imaging to adopt in a given area of the DESI footprint.

The desitarget resolve function first defines the “northern” sky to comprise areas that are both north of the Galactic plane (in Galactic coordinates) and north of Dec $\geq 32.375^\circ$ (in equatorial coordinates). Any area that does not meet both of these criteria is considered to be “southern” area (again, Figure 1 of Dey et al. 2019, may be helpful to visualize these areas). The desitarget resolve function then ensures unique imaging by only retaining targets that are in the northern sky area and that have PHOTSYS == ‘N’ set, or that are in the southern sky area and have PHOTSYS == ‘S’ set. Note that no resolve is necessary for targets—such as backup targets—that are selected purely from Gaia data.

The urls from which to retrieve targets that are provided in §4.1.1 all terminate with a resolve directory, indicating that they have been resolved by desitarget into unique targets in areas where the individual Legacy Surveys overlap. It is possible to use the desitarget pipeline to generate all targets in overlapping imaging areas rather than resolving them, and some (very early) versions of DESI targeting files were processed with this option. Such targets end up in a directory structure that includes noresolve instead of resolve.

4.1.4. Gaia DR2 or Gaia EDR3?

Version 0.58.0 of the desitarget code introduced the option of partially using Gaia Early Data Release 3 (EDR3; Gaia Collaboration et al. 2021) for target selection, with a view to optimizing astrometry-based selection of MWS targets without changing Gaia information for selections used by other target classes. Target files processed with this option have a GAIA_SUB value in the FITS header that is set to True. EDR3 values are obtained by coordinate-matching the Legacy Surveys sweep catalogs used for target selection (see §4.1.1) and EDR3 at 0.2″, after first accounting for EDR3 proper motions. The EDR3 columns that are substituted for Gaia in such target files are listed in Table 7.

So, broadly, SV targets were selected using Gaia DR2 and Main Survey targets were selected using imaging quantities from Gaia DR2 and astrometric quantities from Gaia EDR3. An important caveat to this statement is that, as of the time of writing—corresponding to version 2.5.0 of desitarget—backup targets (§4.1.2) still always use Gaia DR2 for all quantities. This is due to a bug where the Gaia EDR3 quantities are not substituted for backup targets even though the GAIA_SUB keyword is set to True.

4.2. Standard Stars

The DESI survey requires flux standards for spectrophotometric calibration. To achieve this goal, desitarget defines three principal standard star classes to be used inside of the footprint of the Legacy Surveys imaging, with bit-names STD_BRIGHT, STD_FAINT (see also Table 5 and Table 6) and STD_WD31, and three classes for use outside of the Legacy Surveys imaging footprint, GAIA_STD_BRIGHT, GAIA_STD_FAINT and GAIA_STD_WD. The Gaia standard star selections are designed to approximate the principal standard star classes but using imaging from Gaia in place of Legacy Surveys quantities. The STD_WD and GAIA_STD_WD classes are identical to each other—as well as to the $\text{MWS}\_\text{WD}$ class described in Cooper et al. (2022)—so won’t be further detailed here.

The STD_BRIGHT and STD_FAINT target classes are designed to select Main Sequence F-stars in a similar fashion to the BOSS selection of spectrophotometric standards32. Color constraints differ somewhat from those applied in BOSS, though, both because DR9 of the Legacy Surveys does not include deep u- and i-band imaging (unlike the SDSS) and to ensure sufficient flux standards across the DESI focal plane. The overall approach introduces a small fraction of A-type stars, while retaining sufficiently precise flux calibration to measure signal in the Lyman-$\alpha$ Forest. Broadly, the STD_BRIGHT target class is intended to be used for calibration during bright-time programs and the STD_FAINT target class is intended for use during dark time.

The STD_BRIGHT flux standards are selected as detailed in Table 8. The only difference between STD_BRIGHT and

31 “WD” denotes a white dwarf.
32 https://www.sdss.org/dr12/algorithms/boss_std_ts/
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Table 8. Target Selection for the STD_BRIGHT and STD_FAINT target classes

| Reason for Selection                  | How Selection is Applied                                                                 |
|---------------------------------------|-------------------------------------------------------------------------------------------|
| Not masked                            | MASKBITS\(^a,b\) is not BRIGHT or GALAXY                                                   |
| Point-like                            | TYPE == "PSF"                                                                             |
| Isolated                              | FRAFLUX.X\(^c\) < 0.01                                                                    |
| Measured flux                         | FLUX_IVAR.X > 0                                                                           |
| Observed                              | NOBS.X > 0                                                                                |
| Low fraction of masked pixels         | FRACMASKED.X < 0.6                                                                        |
| Color of halo turnoff or bluer\(^d\)  | (r − z) < 0.2 AND 0.0 < (g − r) < 0.35                                                   |
| Reasonably bright in Gaia\(^e\)       | 16 ≤ PHOT.G_MEAN_MAG < 18                                                                 |
| Bp − Rp color is measured             | GAIA_PHOT_BP_MEAN_MAG − GAIA_PHOT_RP_MEAN_MAG is not NaN                                   |
| No astrometry issues                  | GAIA_ASTROMETRIC_EXCESS_NOISE < 1 AND                                                     |
|                                       | GAIA_ASTROMETRIC_PARAMS_SOLVED == 31                                                      |
| Proper motions are finite              | Neither PMRA or PMDEC is NaN                                                              |
| Parallax smaller than 1 mas           | PARALLAX < 1                                                                             |
| Proper motion larger than 2 mas yr\(^{-1}\) | \(\sqrt{PMRA^2 + PMDEC^2} > 2\)                                                           |
| Unique source in Gaia                 | GAIA_DUPlicated_SOURCE == 0                                                               |

\(^a\)Parameters that appear in this table are derived from the Legacy Surveys sweep files at https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.

\(^b\)The Legacy Surveys MASKBITS mask is described at https://www.legacysurvey.org/dr9/bitmasks/.

\(^c\)In this table, X denotes that the criterion is applied for all bands from the Legacy Surveys (g, r and z).

\(^d\)g, r, z denote FLUX.G, FLUX.R, FLUX.Z converted to magnitudes and corrected for Galactic extinction.

\(^e\)The only difference between the STD_BRIGHT and STD_FAINT target classes is that STD_FAINT extends across 16 ≤ PHOT.G_MEAN_MAG < 19.

STD_FAINT targets is that STD_FAINT targets extend over the magnitude range 16 ≤ G < 19 instead of 16 ≤ G < 18 (in Gaia G-band)\(^33\). The selection of the GAIA_STD_BRIGHT and GAIA_STD_FAINT flux standards is detailed in Table 9. Again, GAIA_STD_BRIGHT and GAIA_STD_FAINT targets only differ because GAIA_STD_FAINT standards extend over the magnitude range 16 ≤ G < 19. The proper motion cuts listed in Tables 8 and 9 are included to help avoid stars in the thick disk of the Milky Way in favor of a more metal-poor halo turn-off population. Thick disk stars are more numerous at distances of a few kiloparsecs from the Sun—but the halo is hotter. Halo stars therefore typically have larger proper motions than thick disk stars at intermediate distances.

The algorithms used to select standard stars remained the same throughout DESI SV and the Main Survey. Gaia-only standards (GAIA_STD_BRIGHT, etc.) weren’t introduced until version 0.48.0 of desitarget—and weren’t actually finalized until version 0.50.0—meaning that these standards do not appear in target files that pre-date SV1. As with other target classes (see §4.1.4) the option to substitute Gaia EDR3 astrometric data became available in version 0.58.0 of the desitarget code, and this option was used to produce targeting files for the DESI Main Survey.

Because the Gaia-only standards were designed for observations outside of the Legacy Surveys imaging footprint, the data model for these targets is slightly different to that of the principal flux standards. First, the Gaia-only bits (GAIA_STD_BRIGHT, etc.) can be accessed via the mws_mask bitmask and are stored in the MWS_TARGET column (see Tables 1 and 2), whereas the principal standards (STANDARD, etc.) can be accessed via the desi_mask bitmask and are stored in the DESI_TARGET column. Second, the Gaia-only standards, as is the case for all Gaia-only targets, reside in the backup files outlined in §4.1.2 rather than the bright-time and dark-time targeting files outlined in §4.1.1.

4.3. Guiding, Focusing and Alignment (GFA) targets

The DESI instrument requires samples of stars to use for guiding, focusing and alignment. Collectively, we will refer to these as GFA targets, or just “GFAs.” The desitarget pipeline includes a module called gfa specifically for assembling these targets. GFAs are publicly available online in directories accompanying those described in §4.1.1, where the

\(^33\) Standards appropriate for bright-time were also intended to be used in dark-time, but not vice-versa, meaning that the STD_FAINT class is a “fainter” extension of the STD_BRIGHT selection. Hence the name “STD_FAINT” rather than, say, “STD_DARK.”
Table 9. Target Selection for the GAIA_STD_BRIGHT and GAIA_STD_FAINT target classes

| Reason for Selection | How Selection is Applied |
|----------------------|--------------------------|
| Point-like           | GAIA_ASTROMETRIC_EXCESS_NOISE < 10⁻⁹.⁵ |
| Isolated             | No other Gaia source within 3.5″ |
| Color of halo turnoff or bluer⁶ | 0.2 < (Bp − Rp) < 0.9 AND |
|                      | (G − Bp) > −0.5(Bp − Rp) AND |
|                      | (G − Bp) < 0.3 − 0.5(Bp − Rp) |
| Reasonably bright in Gaia⁵ | 16 ≤ PHOT_G_MEAN_MAG < 18 |
| Bp − Rp color is measured | GAIA_PHOT_BP_MEAN_MAG − GAIA_PHOT_RP_MEAN_MAG is not NaN |
| No astrometry issues | GAIA_ASTROMETRIC_EXCESS_NOISE < 1 AND |
|                      | GAIA_ASTROMETRIC_PARAMS_SOLVED == 31 |
| Proper motions are finite | Neither PMRA or PMDEC is NaN |
| Parallax smaller than 1 mas | PARALLAX < 1 |
| Proper motion larger than 2 mas yr⁻¹ | √PMRA² + PMDEC² > 2 |
| Unique source in Gaia | GAIA_DUPLICATED_SOURCE == 0 |

⁶In this table, Bp, G, Rp denote versions of GAIA_PHOT_BP_MEAN_MAG, GAIA_PHOT_G_MEAN_MAG, GAIA_PHOT_RP_MEAN_MAG that have been corrected for Galactic extinction using the prescription in Table 1 of Gaia Collaboration et al. (2018b).

⁵The only difference between the GAIA_STD_BRIGHT and GAIA_STD_FAINT target classes is that GAIA_STD_FAINT extends across 16 ≤ PHOT_G_MEAN_MAG < 19.

directory names terminate with gfas instead of targets.⁴⁴ Within a gfas directory, files have names of the form gfas-hp-HPX.fits. Here, HPX refers to the nside = 8 integer of the HEALPixel that contains the GFAs.⁴⁵

The selection of GFAs did not significantly change between iterations of SV and the DESI Main Survey. GFA targets essentially comprise all sources in Gaia limited to G < 21 in the Gaia G-band. We include extra imaging information for Gaia sources that are also in the Legacy Surveys sweep catalogs (i.e. that have REF_ID > 0) and that are not part of the 2020 Siena Galaxy Atlas (J. Moustakas et al. 2023, in preparation). This ensures that high-precision fluxes and morphologies are retained for GFAs in the primary DESI targeting footprint to make quality cuts downstream of desitarget, if needed.

Between the SV and Main Survey phases of DESI the desitarget.gfa code was updated to include the option of substituting Gaia-based values from Gaia EDR3 in place of values from Gaia DR2 (see also §4.1.4). GFA targets for the DESI Main Survey included this substitution. In general, files of GFAs that were run with Gaia EDR3 have a GAIAEDR value in the FITS header that is set to “edr3”. For GFAs that have a match in the Legacy Surveys sweep catalogs, only the columns in Table 7 are ever updated from Gaia DR2 to Gaia EDR3. For GFAs that do not match a Legacy Surveys source (i.e. typically objects outside of the Legacy Surveys imaging footprint) all Gaia-derived quantities are updated to EDR3.

Some sources that appear in Gaia—particularly in DR2—do not have measured proper motions. As astrometric information is essential for DESI guiding, the GFAs incorporate proper motions from the First U.S. Naval Observatory Robotic Astrometric Telescope Catalog (URAT; Zacharias et al. 2015) where Gaia proper motions are missing. Only proper motions for URAT sources that match a Gaia source within 0.5″ are substituted for missing Gaia values. The desitarget code has the option of turning off this URAT-substitution mechanism. GFA targets that did include substitution of URAT proper motions in place of missing Gaia values can be identified by having NOURAT set to False in the FITS header of the GFA file.

All of the columns in the desitarget GFA files are derived from the Legacy Surveys sweep catalogs or are provided in Table 4, with the exception of URAT_ID, URAT_SEP and GAIA_PHOT_G_N_OBS. The URAT_ID column records the recommended identifier for URAT1 sources (see http://cdsarc.u-strasbg.fr/ftp/1/329/ReadMe), URAT_SEP is the separation (in arcseconds) between a URAT source and a GFA target, and GAIA_PHOT_G_N_OBS records the number of observations in G band from Gaia (which is useful for characterizing variable sources downstream of desitarget).

⁴⁴ For example, for the Main Survey the appropriate url is https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/1.1.1/gfas/

⁴⁵ As for science targets, this nside is stored in the file header as NIDE.

³⁶ https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.

³⁷ https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.
In addition, the MORPHTYPE column described in Table 4 has a different provenance for GFA targets that do not have a match in the Legacy Surveys. For such Gaia-only GFAs, a source is recorded as point-like if

\[
\begin{align*}
G \leq 19. & \text{ AND } AEN < 10^{4.0+0.2(G-19)} \\
G \geq 19. & \text{ AND } AEN < 10^{4.0+0.2(G-19)}
\end{align*}
\]

where \(G\) denotes Gaia \(G\)-band magnitude (without any correction for Galactic extinction; \texttt{GAIA_PHOT\_G\_MEAN\_MAG}), \(AEN\) denotes \texttt{GAIA\_ASTROMETRIC\_EXCESS\_NOISE}, and \(A\) is 0.5 for Gaia DR2 or 0.3 for EDR3. Sources which do (do not) meet the criterion in Eqn. 2 are designated \texttt{GSPF} (\texttt{GGAL}) in the MORPHTYPE column.

### 4.4. Blank-sky Locations

The DESI fiber allocation software (A. Raichoor et al. 2023, in preparation) assigns fibers to empty or “blank” locations that the DESI spectroscopic pipeline (Guy et al. 2022) uses to perform sky subtraction. To assign these fibers, DESI operations utilizes pre-calculated lists of sky locations that are expected to include minimal flux from astronomical sources when integrated over a DESI fiber. The desitarget pipeline\(^{38}\) assembles such lists of blank sky locations using two different techniques, a pixel-level approach and a Gaia-avoidance approach, which we describe in this section.

In addition, as of the Main Survey, DESI operations software determines, on-the-fly, whether stuck fibers in the DESI focal plane would collect significant flux during survey observations. Where possible, these stuck fibers then become part of the sky budget, which releases other fibers that can then be used to observe science targets (see §3.3.2). Reassigning sky locations on-the-fly is detailed in A. Raichoor et al. (2023, in preparation) and E. Schlafly et al. (2023, in preparation).

#### 4.4.1. Pixel-based Sky Locations

The legacypipe software used by the Legacy Surveys to extract sources from astronomical images operates on areas, called “blobs,” in which pixels have signal that exceeds a certain detection threshold. The legacypipe code builds maps where pixels that lie in a particular blob are set to a positive integer that encodes that blob and pixels that aren’t in any blob are set to -1. These “blob maps” are created for each brick of the Legacy Surveys and are available in the metrics sub-directory of the DR9 Legacy Surveys release (D. Schlegel et al. 2023, in preparation), with names resembling metrics/000/blobs-0003m015.fits.gz\(^ {39}\). The desitarget code adapts these blob maps by setting all pixels that do (do not) have a value of -1 to \texttt{True} (\texttt{False}), essentially building a pixel-map that stores values of \texttt{True} where no sources are detected. The resulting source-detection-maps share the Legacy Surveys native resolution for a brick of 3600 \(\times\) 3600 pixels, at 0.262\arcsec\ pixel\(^{-1}\). So, each map contains 12.96M pixels spread across the approximately 0.0623 deg\(^2\) unique area of a brick.

The desitarget pipeline produces catalogs of pixel-level blank locations at a user-specified density of sky positions. The density used for the Main Survey, for instance, was 18,000 sky locations per square degree, which is easily sufficient to fill the DESI focal plane\(^ {40}\). The desitarget code then performs a binary erosion on the source-detection-maps (in each unique brick) to achieve the required density. For example, if 18,000 deg\(^{-2}\) sky locations are desired in a 0.0623 deg\(^2\) brick, then a total of about 1120 locations are needed—meaning a brick needs to be eroded until it has dimensions of approximately 34 \(\times\) 34. In each step of the erosion, in a given grid cell, desitarget calculates the distance (in pixels) of the pixel that is farthest from a detected source; we will refer to this quantity as \texttt{BLOBDIST}. At the conclusion of the erosion procedure, a blank sky target is placed in each grid cell at the location with the maximum value of \texttt{BLOBDIST}. If a grid cell completely overlaps pixels that include source detections, then \texttt{BLOBDIST} will be equal to 0, meaning that there are no completely blank sky locations in that grid.

The desitarget pipeline then uses the photutils (Bradley et al. 2019) routines \texttt{CircularAperture} and \texttt{aperture_photometry} to photometer flux at each calculated sky location. Fluxes are measured in the per-filter image and \texttt{invvar} stacks provided by the Legacy Surveys\(^ {41}\). The measured fluxes, and their associated inverse variances, are then stored as quantities called \texttt{FIBERFLUX} and \texttt{FIBERFLUX\_INVVAR}, where \(X\) refers to each of the Legacy Surveys optical bands (\(g\), \(r\) and \(z\)). The measured flux quantities can have multiple values if apertures of different radii are specified when running desitarget\(^ {42}\), though processing for the DESI SV and Main Survey files exclusively adopted a 0.75\arcsec\ aperture, corresponding to the radius of a DESI fiber. Given the high density of sky locations required by DESI, it is inevitable that apertures placed at certain positions will not be empty. The desitarget pipeline therefore labels two distinct types of sky locations: particularly good positions and more dubious ones. Sky locations that have any of \texttt{FIBERFLUX} \(\geq 0\) or \texttt{FIBERFLUX\_INVVAR} \(\geq 0\) or \texttt{FIBERFLUX\_R} \(\geq 0\) or \texttt{FIBERFLUX\_INVVAR\_R} \(\geq 0\) or \texttt{BLOBDIST} \(\geq 0\) are referred to as “bad” skies, and are assigned the bit-name \texttt{BAD\_SKY}\(^ {43}\). Sky locations that do not meet these criterion are referred to just as “skies” and are assigned the bit-name \texttt{SKY}.

The logic behind the criteria that determine whether a sky location is bad is that locations with zero flux or infinite flux variance in the \(g\) or \(r\) bands are typi-
cally missing entirely from the Legacy Surveys—rather than genuinely having flux of exactly zero—and that sky locations with BLOBDIST $\ll 0$ certainly intersect a source, as described above.

Pixel-level sky locations are derived within Legacy Surveys bricks. It is important to note that this generally contrasts with other files produced by desitarget, which are stored within HEALPixels. Therefore, before using the desitarget pipeline to make supplemental sky locations by avoiding bright stars in Gaia—which is discussed in the next section of this manuscript—it is important to recast the derived sky locations from a brick-based scheme to a HEALPixel-based scheme. The desitarget function that can be used to achieve this is called skyfibers.repartition_skies, and how this function is applied is detailed in the tutorial linked to in §4.7.

4.4.2. Supplemental Sky Locations

To account for the fact that certain areas of the sky covered by DESI might be outside of—or missing in—the Legacy Surveys, the desitarget pipeline generates an additional catalog of sky positions using Gaia. These “supplemental” sky locations are produced at random positions across the sky within HEALPixels at a user-specified density. For SV and Main Survey files, this density was chosen to be 18,000 deg$^{-2}$ to match the density at which pixel-based sky locations were generated. Supplemental sky locations are then removed if they are within a radius of 2′ of any source in Gaia DR2. Finally, to limit the total density of sky locations that could be used by the DESI fiber assignment software, supplemental skies are removed if they share a HEALPixel with a pixel-based sky location at $\text{nside} = 4096$, which corresponds to a resolution of approximately 18,000 deg$^{-2}$.

Quantities generated for pixel-based sky locations are also “mocked up” for supplemental sky locations. The BLOBDIST value is set to be the (2′) radius for avoiding Gaia sources, divided by the 0.262′ pixel-scale of the Legacy Surveys imaging. All FIBERFLUX_X and FIBERFLUX_IVAR_X quantities (see §4.1.1) are set to -1. Finally, supplemental skies are assigned the bit-name SUPP_SKY; as with other sky locations, this bit is set in the DESI_TARGET column and can be extracted using the desis_mask bitmask (see §2).

4.4.3. The Data Model for Sky Locations

Files of sky locations derived by desitarget at the pixel-level (see §4.1.1) are available online in the dr9 directory in a similar way to the target files detailed in §4.1.1, with directory names that terminate with skies rather than targets. Files of supplemental sky locations derived by avoiding bright sources in Gaia (see §4.4.2) are available in gaiadr2 directories in a similar manner to what is outlined in §4.1.2. Directory names for supplemental skies, however, terminate in skies-supp instead of in skies or targets.

Within the skies (skies-supp) directory, files have names of the form skies-hp-HPX.fits (skies-supp-hp-HPX.fits). Here, HPX refers to the $\text{nside} = 8$ integer of the HEALPixel that contains the sky locations. As is the case for other desitarget products, the adopted $\text{nside}$ is stored in the file header as FILENSID. The skies directory also contains an unpartitioned sub-directory. This stores the original sky locations generated by desitarget before applying the repartitioning code discussed in §4.1.1, i.e., unpartitioned contains files assembled according to which bricks occupy each HEALPixel rather than by which sky locations occupy each HEALPixel. Columns in the skies and supp-skies files are either inherited from the Legacy Surveys sweep catalogs, are provided in Table 4, or were introduced in 4.4.1.

4.4.4. Masking and “Safe” Locations

Locations assigned near very bright stars are potentially unusable for sky subtraction by the DESI spectroscopic pipeline. To help characterize such locations for SV and the Main Survey, the desitarget code was used to compile in §4.4.4.

46 As with other sky locations, this quantity is stored as NPERSDDEG in the header of files produced by desitarget.

47 For example, the appropriate url for the Main Survey is https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/1.1.1/skies/.
a “bright star” catalog using all *Gaia* DR2 sources, supplemented with sources from the Tycho 2 (*Hog et al. 2000*) catalog. Any matches between *Gaia* and Tycho 2 within a radius of 10″ are first removed from the Tycho 2 catalog to prevent duplication of sources. Then, *Gaia*-Tycho coordinate matches are performed, after first shifting the location of *Gaia* sources to the Tycho epoch using *Gaia* astrometric parameters. *Gaia* sources with missing proper motions are assigned information from URAT using the same routine as detailed for GFAs (see §4.3). This catalog is then limited to only sources with a magnitude < 12, where the magnitude that is used is *Gaia* *G*, Tycho *VT*, Tycho *HP* and Tycho *BT*, in that order of preference—because *G* is not measured for Tycho-only sources, *VT* isn’t measured for every Tycho source, etc.

A “bright star mask” is then constructed around all sources in this bright star catalog by shifting sources to an epoch of 2023.0 to roughly match the expected central time of the DESI survey. Any sky locations within 5″ of this (circa 2023) bright star mask are assigned the bit `IN_BRIGHT_OBJECT` from the `desi_mask` bitmask in the `DESI_TARGET` column (see §2). Similarly, any sky locations within 10″ of a bright star are assigned the `NEAR_BRIGHT_OBJECT` bit.

Given the extensive sky coverage of the DESI survey, it is impossible to completely avoid placing fibers near bright stars. So, to assist with finding reasonable locations for sky subtraction in regions near bright stars, both the pixel-based and supplemental skies are augmented by additional “safe” locations. Any sky location that has `IN_BRIGHT_OBJECT` set is supplemented with six additional, symmetrically placed locations (see Figure 2) around the periphery of the circular mask for any individual star. This placement pattern corresponds to approximately 1 safe location per radius of the mask (with a margin of one extra location), which should be sufficient to ensure a safe location for the vast majority of fibers in the DESI focal plane. These safe locations all have the `BAD_SKY` bit set. They are also assigned the bits `IN_BRIGHT_OBJECT` and `NEAR_BRIGHT_OBJECT` using the bright star mask (as for any other sky location).

Finally, any pixel-based or supplemental sky locations that have both `IN_BRIGHT_OBJECT` and `BAD_SKY` set (including “safe” locations) are removed completely from their respective `desitarget` output files. This step ensures that any freshly generated safe locations aren’t, themselves, inside the boundary of a bright star (again see Figure 2). Sky locations with other combinations of the sky and bright object bits set are retained, but with all of the bits set in the `DESI_TARGET` column to help downstream code identify potentially problematic positions.

### 4.5. Monte Carlo Sampling of the Target-selection Footprint

To help facilitate large-scale structure analyses with DESI, the `desitarget` pipeline produces Monte Carlo samples that attempt to recreate the angular selection function of the Legacy Surveys imaging that was used to select DESI targets. These “random catalogs,” and related products, are detailed in this section.

#### 4.5.1. Random Catalogs

The main `desitarget` module used to create random catalogs is called `desitarget.randoms` and the main worker function is `randoms.quantities_at_positions_in_a_brick()`. Initially, a desired density of random points (deg⁻²) is specified⁴⁹. Then, for each brick in the Legacy Surveys, the desired density is multiplied by the (∼0.0623 deg⁻²) brick area, with the resulting number being modified by a (random) draw from the Poisson distribution to produce a final number of points to be sampled in a given brick. Locations (in RA and Declination) are then generated in the brick according to that final number of points.

The `desitarget` pipeline then queries the Legacy Surveys imaging at the pixel-level, by directly sampling information from the CCDs used to produce the Legacy Surveys. In general, the files used as inputs to `desitarget` in this context are.

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⁴⁸ https://heasarc.gsfc.nasa.gov/W3Browse/all/tycho2.html

⁴⁹ This density appears in the header of output random catalogs as `DENSITY`. 

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Table 10. Columns in the pixweight files

| Column Name     | Python Format | Description                                                                 |
|-----------------|---------------|-----------------------------------------------------------------------------|
| HPXPIXEL        | i4            | HEALPixel integers at an input nside (typically nside=256).                  |
| FRACAREA        | f4            | Fraction of the HEALPixel with ≥ 1 observation in any band.                  |
| STARDENS        | f4            | Density (deg⁻²) of stars in the HEALPixel from Gaia DR2 (see §4.5.2).        |
| EBV             | f4            | Galactic dust extinction (E[B-V]). b                                        |
| PSFDEPTH_X      | f4            | √ gives the 5σ flux-detection-limit in nanomaggies for a point source. b, c |
| GALDEPTH_X      | f4            | As for PSFDEPTH_X but for a round, exponential galaxy of effective radius 0.45″ b, c |
| PSFSIZE_X       | f4            | Weighted average PSF FWHM, in arcseconds. b, d                               |
| FRACAREA_X      | f4            | Fraction of HEALPixel with ≥ 1 observation in any band with MASKBITS=X. e   |
| target name     | f4            | Target density in the HEALPixel for each target class bitname (see Table 3).|

a Derived from the NOBS_G, NOBS_R, NOBS_Z quantities in the random catalog.
b This quantity is the median in the HEALPixel from the passed random catalog.
c One each for optical and WISE bands (i.e. X = G, R, Z, W1, W2) where the WISE values are AB, not Vega.
d One for each optical band (i.e. X = G, R, Z).
e This is a bitwise OR, so, e.g., if X=7 then it’s the fraction for 2⁰ | 2¹ | 2². MASKBITS is described in the Legacy Surveys documentation at https://www.legacysurvey.org/dr9/bitmasks/.

from the Legacy Surveys coadded stack files. Each random location is converted to a pixel using the World Coordinate System information for a given brick-based stack. The quantities produced for the DESI random catalogs are described in the documentation for the Legacy Surveys. Flux-related columns are derived by integrating over an aperture of a specified radius, as described in §4.4.1. The chosen aperture radius is recorded as APRAD in the header of an output random catalog, and is likely to always be 0.75″, corresponding to the radius of a DESI fiber.

In addition to the random catalogs described above, the desitarget pipeline can produce random catalogs in bricks that lie outside of the Legacy Surveys footprint. Such catalogs only include a limited number of columns, as most of the informative quantities are not defined where imaging does not exist. The “inside” and “outside” catalogs can also be combined by desitarget to produce all-sky catalogs, which are particularly useful for determining, e.g., the areal coverage of the Legacy Surveys (see Figure 3). Again, columns present in these additional catalogs are detailed in the Legacy Surveys documentation.

As for other files produced by desitarget, random catalogs are available online at the urls specified in §4.1.1. For random catalogs, the directory names terminate with randoms (instead of, e.g., targets) and the most recent desitarget version number used to run a substantial set of random catalogs is 0.49.0. Versions of the random catalogs that have and have not been resolved according to the criteria in §4.1.3 are available in the resolve and noresolve sub-directories. A randomsall sub-directory may also exist, which contains a larger file created by concatenating multiple smaller random catalogs to increase sampling density, as outlined in an accompanying README file.

Within the randoms/resolve directory, the inside-the-Legacy-Surveys random catalogs have the form randoms-ISEED-ISPLIT.fits, the outside-the-Legacy-Surveys random catalogs have the form randoms-outside-ISEED-ISPLIT.fits and the combined random catalogs have the form randomsallsky-ISEED-ISPLIT.fits. Here, ISEED refers to the random seed used to produce the catalog and ISPLIT is an integer specifying a particular subset of randoms; the catalogs are split into smaller files from a larger parent set (which is itself randomized) during processing to make them more manageable. The specific integer seed (ISEED) used to produce a given file is stored in the file header as SEED.

4.5.2. Pixelized Weight Maps

The desitarget pipeline—specifically the desitarget.randoms.pixmap() function—can be used to combine files of DESI targets with random catalogs in a convenient HEALPix-based format to produce maps of important quantities derived from the Legacy Surveys imaging. The resulting “pixweight” files have been made publicly

50 The stacks are documented at https://www.legacysurvey.org/dr9/files/#image-stacks-region-coadd.
51 Specifically, under “random catalogs” at https://www.legacysurvey.org/dr9/files/#random-catalogs-randoms.
52 i.e. the catalogs are at https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.49.0/randoms/.
available for both SV3\textsuperscript{53} and the Main Survey\textsuperscript{54}. Maps of
dark-time and bright-time targets are created separately,
and so each release directory contains dark and bright sub-
directories. The HEALPixel resolution of each pixweight file is $nside=256$, which is stored in the header of the file
as \texttt{HPXNSIDE}. This resolution corresponds to a pixel area of $\sim 0.0525$ deg$^2$, which approximates the size of a Legacy
Surveys brick.

The pixweight maps contain the quantities detailed in Table
10, which are all easily derived from the random catalogs
discussed in \S4.5.1 (typically from the file in the \texttt{randomsall}
sub-directory) and the bright- and dark-time target files de-
scribed in \S4.1.1. One column that appears in Table 10 that
we have not previously described is \texttt{STARDENS}, which con-
tains a measure of the stellar density in a given HEALPixel.
The \texttt{STARDENS} quantity is derived from a count of sources in
\textit{Gaia} DR2 that have a \textit{Gaia} $G$-band magnitude in the range
$12 \leq G < 17$ and that are point-like. Point-like, here, is
defined using \textit{Gaia} quantities via:

\begin{equation}
AEN = 0. \text{ OR } \log_{10}(AEN) < 0.3G - 5.3
\end{equation}

where $AEN$ is the \textit{Gaia} quantity \texttt{ASTROMETRIC_EXCESS_NOISE}
and $G$ is the \textit{Gaia} $G$-band magnitude (i.e. \texttt{PHOT\_G\_MEAN\_MAG}).

4.5.3. Quality Assurance Web Pages

The “pixweight” files described in \S4.5.2 can be used to
derive useful plots of sky coverage for targets. In particular,
the \texttt{FRACAREA} quantity allows target densities to be correctly
weighted by the actual areal coverage of the Legacy Surveys
imaging. In addition, as the “pixweight” files collate
information about observational properties of the imaging
surveys, such as depth and local stellar density, they can be
used to determine how target densities correlate with sys-
tematic effects (see, e.g., Chaussidon et al. 2022b).

The \texttt{desitarget.QA} module can be used to combine the
“pixweight” files from \S1.5.2 with the target files detailed
in \S4.1.1 to create web pages of diagnostic plots for DESI
targeting. The gateway to these web pages also includes a
version of the target density matrices provided in Tables 5
and 6, which are trivial to derive from the “pixweight” files.

These QA web pages have been made publicly available by
the DESI collaboration for SV3\textsuperscript{55} and the Main Survey\textsuperscript{56}.
At each url, there are individual sub-directories for bright-time
and dark-time targets. Clicking on a sub-directory launches a
page that includes target density matrices, plots of observa-
tional systematics, and a list of targeting bit-names (see, e.g.,
Table 3). Clicking on any bit-name produces a page with a
number of diagnostic plots for that target class, including sky
maps, color-color plots and trends in target density with ob-
ervational systematics. Some examples of these diagnostic
plots are included in Figure 4.

4.6. Secondary Target Classes

In addition to the dark-time targets, bright-time targets,
backup targets, calibration targets, and random catalogs
discussed elsewhere in this section, the DESI survey incor-
porates additional targets to pursue science efforts beyond
the primary DESI goals. These targets, which we refer to as
“secondary” targets, are either conducted as dedicated
campaigns or as “filler” programs to mop up spare fibers
where no primary DESI targets are available. The dedicated
campaigns include tertiary programs (c.f. \S3.2.3) and some
large Targets of Opportunity campaigns (see \S3.2.2 and, e.g.,
Palmese et al. 2021).

4.6.1. An Overview of Secondary Targets

In \S2 we discussed how secondary targets can be re-
trieved from the DESI target files (\S4.1.1) by applying the
\texttt{scnd\_mask} bit-names to bit-values in columns that resemble
\texttt{SCND\_TARGET}. In \S3.2 we detailed the specific, unique
\texttt{TARGETID} that \texttt{desitarget} assigns to secondary targets.
But, a full description of all of the scientific goals that un-
derlie the DESI secondary target programs is beyond the
scope of this paper and will be reserved for forthcoming DESI
Data Release papers (e.g., DESI Collaboration et al. 2023, in
preparation). We will, however, provide an overview of the
process for selecting secondary targets here.

Every secondary program provides lists of targets which
are preserved for posterity in a specific directory\textsuperscript{57}. This
“secondary directory” contains sub-directories for SV1, SV3,
the Main Survey and some bespoke programs (sv1, sv3,
main, bespoke; no secondary targets were assigned during
SV2). Secondary targets added after the Main Survey may
also be present in additional directories named main2, main3,
etc. Each of these sub-directories includes; a file of notes
about each secondary target class; a \texttt{docs} directory of text
files or Jupyter notebooks documenting a particular sec-
dondary program; an \texttt{indata} directory of the targets supplied
by a secondary program to be processed by \texttt{desitarget}; and a
\texttt{outdata} directory containing files for bright-time
(bright) and dark-time (dark) secondary targets that in-
clude the \texttt{TARGETID}, \texttt{DESI\_TARGET} and \texttt{SCND\_TARGET}
assigned by \texttt{desitarget} (again see \S2 and \S3.2). The \texttt{outdata}
directory contains one or more sub-directories, which corre-
spond to the different versions of the \texttt{desitarget} pipeline
that were run to produce secondary targets. Each secondary
targeting file is named \$\texttt{bit\_name}\.fits, \$\texttt{bit\_name}\.txt or
\$\texttt{bit\_name}\_ipynb where \$\texttt{bit\_name}\ is the specific bit-name
assigned to a secondary program in the \texttt{scnd\_mask} (see \S2).

Files of targets provided by a secondary program were
required to include the columns RA, DEC, PMRA, PMDEC,
\texttt{REF\_Epoch}, and \texttt{OVERRIDE}. The first five of these columns
have the same meaning as for the Legacy Surveys sweep

\textsuperscript{53} e.g., https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.57.0/pixweight/sv3/resolve/bright/sv3pixweight-1-bright.fits
\textsuperscript{54} e.g., https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/1.1.1/pixweight/main/resolve/dark/pixweight-1-dark.fits
\textsuperscript{55} https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/0.57.0/QA/sv3/.
\textsuperscript{56} https://data.desi.lbl.gov/public/ets/target/catalogs/dr9/1.1.1/QA/main/.
\textsuperscript{57} Which is publicly available at https://data.desi.lbl.gov/public/ets/target/secondary.
catalogs\textsuperscript{58}. The OVERRIDE column, which was required to be set to True or False for each secondary target for each program, is used by desitarget to determine whether a secondary target should be merged with a primary target. When a secondary target is merged with a primary target by desitarget (corresponding to OVERRIDE==False), it inherits all of the properties of that primary target (such as the target’s coordinates, observational priority, whether it will be observed in bright-time or dark-time, the primary TARGETID, etc.). If, on the other hand, OVERRIDE is set to True for a target, then the target is free to be observed as defined by the secondary program but a new TARGETID is generated for the secondary target (see §3.2). Secondary and primary targets are merged by performing a coordinate match with a 1″ separation\textsuperscript{59}.

One benefit to a secondary program of specifying OVERRIDE==False for a secondary target that matches a primary target is that such targets are easier to track, because the same TARGETID will be assigned for the secondary and primary target throughout the DESI program. This choice also guarantees standard processing for a secondary target (such as being automatically coadded by the spectroscopic pipeline in the same manner as for primary targets). But, a major drawback of providing targets with OVERRIDE==False is that the target exactly resembles any matching DESI primary target, meaning that bespoke observational strategies—such as observing a target twenty times, or observing a match to a bright-time primary target in dark-time—cannot be adopted.

Secondary targets that specified OVERRIDE==False are present in the standard dark-time and bright-time files detailed in §4.1.1. Whether a target is both a secondary and a primary target can be determined by checking if the SCND\_ANY bit from the desi\_mask is set in the DESI\_TARGET column (see §2). Secondary targets that specified OVERRIDE==True\textsuperscript{60} are written to their own monolithic files. These files are in the same root directory as detailed in §4.1.1 for primary targets, except that instead of being stored in the resolve directory they are in the secondary directory. Bright-time standalone secondary targets are compiled in the secondary/bright/targets-bright-secondary.fits file and dark-time standalone secondary targets are in the secondary/dark/targets-dark-secondary.fits file.

Secondary targets that have OVERRIDE set to False aren’t necessarily as carefully vetted as primary targets. So, the desitarget code takes several precautions to ensure that DESI fibers aren’t placed on very-bright OVERRIDE targets that could contaminate the spectra of primary targets. First, any OVERRIDE targets that lie inside of the bright star mask discussed in §4.4.4 are removed completely from the output files of secondary targets. Second, when secondary targets are matched to primary targets (see above), they are also matched to the Legacy Surveys sweep catalogs\textsuperscript{61}. During this match, information from Gaia and the Legacy Surveys is added to the secondary targeting file, including flux and magnitude quantities (\texttt{FLUX\_G}, \texttt{FLUX\_R}, \texttt{FLUX\_Z}, \texttt{GAIA\_PHOT\_G\_MEAN\_MAG}, \texttt{GAIA\_PHOT\_BP\_MEAN\_MAG}, \texttt{GAIA\_PHOT\_RP\_MEAN\_MAG}). If an OVERRIDE target is brighter than 16th magnitude in any of these Gaia or Legacy Surveys bands, it is removed completely from all of the output files of secondary targets.

4.6.2. Is This Target Primary?

\textsuperscript{58} https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.
\textsuperscript{59} This separation is recorded in output desitarget secondary files as SEP.
\textsuperscript{60} These targets are sometimes referred to as “standalone” secondaries in DESI parlance.
\textsuperscript{61} https://www.legacysurvey.org/dr9/files/#sweep-catalogs-region-sweep.
The introduction of secondary programs and Targets of Opportunity somewhat complicate the provenance of a given target—particularly as secondary programs were allowed to be merged with primary programs if OVERRIDE was set to False. So, it is useful to provide a simple recipe for applying the information in §2 and §3 to determine whether a target is part of the primary DESI campaign or is more exotic. One possible recipe is:

- Check the DESI_TARGET column for a target, or the equivalent SVX_DESI_TARGET column (see §2).
- If DESI_TARGET only has the bit SCND ANY set (i.e. if it is equal to $2^{62}$), then the target is either a secondary or tertiary target, or a ToO.
  - Otherwise the target is primary (consult §4).
- Use the decode_targetid() utility (see §3.3) to determine release for the target.
  - If release < 1000 then the target is a general secondary target (see Eqn.1 for the different meanings of release and DESI Collaboration et al. 2023, in preparation, for a description of the secondary programs).
  - If release == 8888 then the target is a tertiary target (consult §3.2.3 and A. Raichoor et al. 2023, in preparation).
  - If release == 9999 then the target is a ToO (consult §3.2.2 and E. Schlafly et al. 2023, in preparation).

4.7. How to Run the desitarget Pipeline

Researchers may wish to fully recreate a suite of desitarget output files in order to conduct large-scale-structure studies in the context of DESI or to inform target selection for future sky surveys. To help facilitate such endeavors, we have provided a tutorial on GitHub, in the form of a Jupyter Notebook, that includes a detailed overview of how each of the data products outlined in this section were produced for the DESI Main Survey using the desitarget pipeline.

5. DISCUSSION: IMPORTANT KNOWN ISSUES

As with any evolving software, desitarget underwent several bug-fixes during catalog-creation. In this section, we try to detail some of the most prominent issues and discrepancies that users of the DESI targeting files might encounter.

5.1. Target Reproducibility

Perhaps the most important known issue is that output from the desitarget code was not wholly reproducible throughout the Main Survey. This was due to the fact that although primary targets typically supersede secondary targets (see §4.6) the desitarget code was written to allow Milky Way Survey targets to bump each other, regardless of whether they were primary or secondary. Unfortunately, because some MWS targets have similar colors to primary targets—for instance, white dwarfs resemble some QSOs—and because MWS white dwarf targets had a relatively high observational priority, the desitarget pipeline fostered occasional glitches where an MWS target could bump a primary target intended for large-scale structure analyses. Notably, in situations where multiple MWS targets matched a primary target during primary-secondary merging (§4.6), which MWS target was chosen as the match was not ordered. So, on repeated execution of the desitarget code a different MWS target could end up being merged with a particular primary target. The upshot of this bug was that, prior to version 1.1.1 of desitarget, a small subset of bright-time targets, and very occasional dark-time targets, were selected differently each time desitarget was run.

This MWS-prioritizing issue was noticed because a new, high-density, target class (called MWS_FAIN(T) was designed to be introduced for the first iteration of Main Survey targets, which were processed with version 1.0.0 of desitarget. Due to an oversight, these MWS_FAIN targets were not included in the 1.0.0 target catalogs. When this oversight was corrected, and the target catalogs were updated, it became clear that a slightly different subset of targets had been selected, even when the MWS_FAIN targets were redacted. Any reproducibility bugs were subsequently fixed and new targets were processed with the MWS_FAIN selection once more omitted—resulting in the version 1.1.1 targets discussed throughout this paper.

While this bug-fix was being addressed, 157 Main Survey tiles were observed with version 1.0.0 targets before updating to version 1.1.1 of desitarget and producing the bright-time and dark-time targets that will be used throughout the remainder of the DESI survey. Fortunately, the scope of the differences between which 1.0.0 targets were scheduled to be observed and which 1.1.1 targets would have been scheduled to be observed is minor. Across the 157 initial tiles, a total of 270 bright-time targets differed in a manner that could have produced discrepancies in fiber placement in the DESI focal plane. Only four dark-time targets differed in such a way. Given that there were $\sim$785k fibers that could have been assigned fibers across 157 tiles, any reproducibility issues moving from version 1.0.0 to 1.1.1 targets near the start of the DESI Main Survey should have a negligible effect on large-scale-structure analyses.

5.2. SUBPRIORITY Reproducibility

Assigning fibers to targets during early DESI Main Survey observations revealed an additional issue that could affect the overall reproducibility of the DESI survey. As noted in Table 4, desitarget adds a SUBPRIORITY column to target files that is used to break ties in the event that the DESI

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62 See https://github.com/desihub/desitarget/blob/2.5.0/doc/nb/how-to-run-target-selection-main-survey.ipynb.

63 Note that the crucial point is not that 270 different targets were observed, merely that a maximum of 270 different targets could have been observed, potentially impacting the survey selection function for large-scale structure studies.
fiber-assignment code has to choose between two targets that are otherwise equivalent in observational priority. A similar SUBPRIORITY column is added by desitarget to the pixel-based and supplemental sky locations discussed in §4.4. As of version 1.0.0 of the desitarget pipeline, SUBPRIORITY values were added as part of the function that writes files to disk. This meant that if an external routine read a target (or sky) file produced by desitarget and then wrote it back out using the desitarget writing utilities then each SUBPRIORITY would be overwritten with a new value.

Rewriting SUBPRIORITY using the approach of version 1.0.0 of the desitarget pipeline was not a bug, per se, but it proved problematic downstream of desitarget. In particular, the software that assigns fibers to DESI targets (A. Raichoor et al. 2023, in preparation) uses the desitarget writing routines to produce its own output data files. To guard against accidentally overwriting SUBPRIORITY values throughout the Main Survey, the desitarget pipeline was updated to only overwrite zero-valued SUBPRIORITY entries—meaning that no values are accidentally overwritten when the DESI fiber assignment pipeline (or any other software) uses the desitarget writing functions. Although this issue with SUBPRIORITY was fixed before the Main Survey proceeded with version 1.1.1 targets, differences would persist in how fibers were assigned on the 157 Main Survey tiles that used targets compiled with version 1.0.0 of the desitarget pipeline. To ameliorate any discrepancies, files were constructed that contained the mapping between SUBPRIORITY and TARGETID for the SUBPRIORITY values that were initially assigned to version 1.0.0 Main Survey targets. Versions of the desitarget pipeline subsequent to 1.1.0 incorporate a command-line option that can use these mappings to enforce the values of SUBPRIORITY used on the 157 Main Survey tiles that proceeded with version 1.0.0 targets.

5.3. Targets with RELEASE of 9010 in SV1

Early Survey Validation (i.e. SV1) took input information from the DR9 Legacy Surveys sweep catalogs before they were patched due to a data processing issue that altered the imaging properties of some sources. The desitarget pipeline switched to using the “patched” DR9 sweeps as of version 0.49.0 of the desitarget code. Targets that might have different source properties because of this patching bug can be identified because they will have a RELEASE of 9010 in files produced by versions of desitarget prior to 0.49.0 but a RELEASE of 9012 in later target files. Such targets will have similar coordinates but a different TARGETID, both because the RELEASE number changed for all such sources in the patched sweep catalogs and because the OBJID changed for some such sources (see, e.g., Figure 1).

6. SUMMARY

In this paper, we have provided a detailed overview of the DESI target selection pipeline. The exact algorithms used to classify specific subsets of DESI bright-time and dark-time targets are detailed in other papers (Raichoor et al. 2022; Zhou et al. 2022; Chaussidon et al. 2022a; Cooper et al. 2022; Hahn et al. 2022) but aspects of how these targeting algorithms are implemented are crucial to understanding how to work with DESI data. This paper also details the approaches used to classify targets to help calibrate DESI spectroscopy, such as GFA targets and blank sky locations.

The DESI target selection pipeline, which is known as desitarget, is publicly available on GitHub. As with any software product, some documentation of the desitarget code and the resulting products will be described online, and in other papers related to the DESI end-to-end pipeline (E. Schlafly et al. 2023, in preparation; A. Raichoor et al. 2023, in preparation; Guy et al. 2022, S. Bailey et al. 2023, in preparation). So, here, we have tried to focus on an overview of the most important concepts related to the technical aspects of DESI target selection.

The desitarget pipeline sets bit-values in output data files in a number of different columns, which indicate whether a particular target meets specific selection criteria. The names of these columns resemble DESI_TARGET (for dark-time DESI targets), BGS_TARGET (for bright-time galaxies), MWS_TARGET (for Milky Way targets) and SCND_TARGET (for targets beyond the primary DESI campaigns). Values in these columns can be interpreted using bitmasks with names like desi_mask, bgs_mask, mws_mask and scnd_mask.

Another important output of the desitarget pipeline is a unique TARGETID that allows each target to be tracked throughout the DESI survey. This TARGETID encodes additional, useful information about each DESI target, such as whether a target is selected from Legacy Surveys imaging or from Gaia, whether a target is a sky location or part of a random catalog, and whether a target is part of a secondary program or is a target-of-opportunity.

It is important to note that different versions of the desitarget pipeline were used for different phases of the DESI survey, such as the Survey Validation phase—including the DESI One-Percent Survey—and the Main Survey phase. The evolving nature of desitarget spawned multiple complexities in target selection that we have attempted to document in this paper. Examples of such technical details include (but are not limited to):

- That sometimes Gaia EDR3 data, instead of Gaia DR2 data, is incorporated by desitarget when processing certain target selection classes.
- That the URAT survey is used to help select GFA targets for sources that are missing astrometric information in Gaia DR2.
- That a bright-star-mask based on Tycho and Gaia is applied to all sky locations and secondary targets, and that secondary targets are further removed from any DESI program if they are too bright in Gaia or Legacy Surveys imaging.

64 These files are publicly available in the https://data.desi.lbl.gov/public/ets/target/catalogs/subpriority/fba-version-4.0.0/ directory.
65 As detailed at https://github.com/desihub/desitarget/blob/2.5.0/doc/nb/how-to-run-target-selection-main-survey.ipynb in a Jupyter Notebook tutorial.
66 see https://www.legacysurvey.org/dr9/issues/#bricks-that-were-processed-using-the-burst-buffer-at-nersc.
That targets processed using version 1.0.0 of the desitarget pipeline were observed for the earliest part of the DESI Main Survey but that, for reproducibility reasons, DESI rapidly updated to observing targets processed with version 1.1.1 of the desitarget pipeline.

The desitarget codebase is now mostly stable as regards producing the static files used for DESI target selection. Further modifications to desitarget might be expected in modules related to producing random catalogs for large-scale-structure analyses, and to converting static files to the dynamic files used to monitor the state of a DESI target as it is observed (see also E. Schlafly et al. 2023, in preparation). Any updates will be documented in later works as the DESI survey progresses.

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The DESI Legacy Imaging Surveys consist of three individual and complementary projects: the Dark Energy Camera Legacy Survey (DECaLS), the Beijing-Arizona Sky Survey (BASS), and the Mayall z-band Legacy Survey (MzLS). DECaLS, BASS and MzLS together include data obtained, respectively, at the Blanco telescope, Cerro Tololo Inter-American Observatory, NSF’s NOIRLab; the Bok telescope, Steward Observatory, University of Arizona; and the Mayall telescope, Kitt Peak National Observatory, NOIRLab. NOIRLab is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation. Pipeline processing and analyses of the data were supported by NOIRLab and the Lawrence Berkeley National Laboratory. Legacy Surveys also uses data products from the Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE), a project of the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. Legacy Surveys was supported by: the Director, Office of Science, Office of High Energy Physics of the U.S. Department of Energy; the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility; the U.S. National Science Foundation, Division of Astronomical Sciences; the National Astronomical Observatories of China, the Chinese Academy of Sciences and the Chinese National Natural Science Foundation. LBNL is managed by the Regents of the University of California under contract to the U.S. Department of Energy. The complete acknowledgments can be found at https://www.legacysurvey.org/acknowledgment/.

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This research made use of Photutils, an Astropy package for detection and photometry of astronomical sources (Bradley et al. 2019). Some of the results in this paper have been derived using the healpy and HEALPix packages.

DATA AVAILABILITY

Data generated or analyzed as part this work are publicly available at URLs included in the text of the paper. Data points and code to produce the figures from this paper are at https://zenodo.org/record/7015786.

Facilities: Blanco (DECam), Bok (90Prime), Gaia, Mayall (DESI, Mosaic-3), NEOWISE, WISE

Software: astropy (Astropy Collaboration et al. 2013, 2018), fitsio (https://github.com/esheldon/fitsio), healpy (Zonca et al. 2019), matplotlib (Caswell et al. 2021), numpy (Harris et al. 2020), photutils (Bradley et al. 2019), pycam (https://pyyaml.org/), scipy (Gommers et al. 2021).

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