DESI Early Data Release Milky Way Survey value-added catalogue

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ABSTRACT

We present the stellar value-added catalogue based on the Dark Energy Spectroscopic Instrument (DESI) Early Data Release. The catalogue contains radial velocity and stellar parameter measurements for $\simeq 400\,000$ unique stars observed during commissioning and survey validation by DESI. These observations were made under conditions similar to the Milky Way Survey (MWS) currently carried out by DESI but also include multiple specially targeted fields, such as those containing well-studied dwarf galaxies and stellar streams. The majority of observed stars have 16 < r < 20 with a median signal-to-noise ratio in the spectra of ~ 20 . In the paper, we describe the structure of the catalogue, give an overview of different target classes observed, as well as provide recipes for selecting clean stellar samples. We validate the catalogue using external high-resolution measurements and show that radial velocities, surface gravities, and iron abundances determined by DESI are accurate to 1 km s^{-1} , 0.3 dex, and ~ 0.15 dex respectively. We also demonstrate possible uses of the catalogue for chemo-dynamical studies of the Milky Way stellar halo and Draco dwarf spheroidal. The value-added catalogue described in this paper is the very first DESI MWS catalogue. The next DESI data release, expected in less than a year, will add the data from the first year of DESI survey operations and will contain approximately 4 million stars, along with significant processing improvements.

Key words: catalogues – surveys – stars: abundances – Galaxy: general – Galaxy: kinematics and dynamics.

1 INTRODUCTION

In the last 20 yr, major progress in stellar astrophysics, Galactic dynamics and Galactic archaeology has been driven to a large degree by the arrival of massive digital surveys. The first surveys were mainly photometric, such as 2MASS (Skrutskie et al. 2006), SDSS-I (York et al. 2000) and PanSTARRS (Chambers et al. 2016). More recently, these data sets have been complemented by unprecedented astrometric measurements from Gaia, which provided high-quality proper motions and parallaxes (Gaia Collaboration 2021). Over the last 10 yr or so, an increasingly large number of surveys such as SEGUE (Yanny et al. 2009; Rockosi et al. 2022), LAMOST (Zhao et al. 2012), GALAH (De Silva et al. 2015), APOGEE (Majewski et al. 2017), Gaia-ESO (Gilmore et al. 2022) and Gaia itself (Katz et al. 2023) have provided spectroscopic data for hundreds of thousands, and in some cases millions, of stars. These surveys have made particularly valuable contributions to our understanding of the Galaxy and its constituent stellar populations. The combination of

In this contribution, we describe the first catalogue of measurements from the stellar part of the Dark Energy Spectroscopic Instrument (DESI) Survey's Early Data Release (EDR; DESI Collaboration 2024b). DESI is a 5020-fiber, 3.2°-diameter field-of-view, moderate-

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radial velocities with proper motions provides full 6D coordinates that enable, for example, the discovery of ancient substructure in 'integral of motion' spaces (Myeong et al. 2018; Koppelman et al. 2019; Naidu et al. 2020) and measurements of the distribution of mass in the Milky Way (Deason et al. 2021; Bird et al. 2022; Koposov et al. 2023). The measurement and interpretation of chemical abundances on the scale of these surveys is a rapidly developing field that has already provided significant insight into the formation and assembly of the Milky Way (Hayden et al. 2015; Mackereth et al. 2019; Horta et al. 2021; Belokurov & Kravtsov 2022). Finally, the large numbers of stars in these surveys allow for many serendipitous discoveries, including extremely metal-poor stars (Caffau et al. 2011; Allende Prieto et al. 2023) and hyper-velocity stars (Koposov et al. 2020). These successes have motivated a new generation of even more ambitious stellar spectroscopic surveys such as DESI, 4MOST, SDSS-V and WEAVE (Kollmeier et al. 2017; de Jong et al. 2019; Cooper et al. 2023; Jin et al. 2024).

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resolution spectrograph (2000 < $\lambda/\Delta\lambda$ < 5000 for 3600 Å < λ < 9800 Å spread across three arms) mounted at the prime focus of the Mayall 4-m telescope at the Kitt Peak National Observatory (DESI Collaboration 2016; Abareshi et al. 2022). While DESI's primary mission is to provide sub- per cent cosmological measurements of the expansion history of the universe, the instrument is also being used for a Milky Way Survey (DESI-MWS; Cooper et al. 2023) of \approx 7 million stars with $r \leq$ 19 mag, focused on the thick disc and stellar halo of our Galaxy. DESI-MWS will also create the largest spectroscopic catalogue to date of white dwarfs, stars within 100 pc of the Sun, RR Lyrae, and BHB stars up to distances of 100 kpc. Serendipitous discoveries have already been made using DESI-MWS data, with the identification of metal-poor stars and rare magnetic white dwarfs exhibiting emission features (Allende Prieto et al. 2023; Manser et al. 2023)

Following the first light with the instrument in 2020 October and the initial period of commissioning, DESI moved into a survey validation (SV) phase (DESI Collaboration 2024a). During this period (approximately 2020 December to 2021 June), the DESI Collaboration observed specific areas of sky (referred to as tiles) with a variety of instrument configurations and target selection schemes to validate observing and data reduction procedures and to optimize the definition of the primary survey target classes (i.e. Milky Way Stars and white dwarfs; Allende Prieto et al. 2020; Cooper et al. 2023; Bright Galaxies, Ruiz-Macias et al. 2020; Hahn et al. 2023; Luminous Red Galaxies, Zhou et al. 2020, 2023; Emission-Line Galaxies, Raichoor et al. 2020, 2023; and OSOs, Yèche et al. 2020; Chaussidon et al. 2023). The final definitions of all the DESI target classes are summarized in Myers et al. (2023). The SV phase was split into three campaigns: the first two took an iterative approach to optimize the target selection and survey strategy. During the third campaign, DESI conducted a 'One-Percent Survey', covering approximately 140 deg² of sky (i.e. 1 per cent of the overall DESI footprint) using the same target selection as the main DESI survey but with much higher completeness across different target classes. After completing the SV phase, DESI began its main 5-yr survey program in 2021 May.

In this paper, we describe the observation and analysis of stellar spectra taken during the DESI commissioning and SV campaigns, supplementing and updating the description given in Cooper et al. (2023), and provide a guide to the Milky Way Survey Value-Added Catalogue¹ (MWS VAC) constructed from stellar spectra in the DESI EDR. In Section 2, we give an overview of the target selections used in each campaign. Section 3 describes the MWS-specific data analysis pipelines that measure stellar radial velocities and atmospheric parameters. Section 4 presents the individual data products provided in the MWS VAC. In Section 4.3, we describe the combined catalogue of measurements, which we expect to be the most convenient data product for general use. Section 5 presents several use cases that exemplify scientific applications of the EDR data, and Section 6 describes known limitations of the MWS VAC.

2 DATA SET

The DESI EDR comprises observations obtained during commissioning and SV, which began in 2020 December and ended in 2021 June. As described in DESI Collaboration (2024b), the data are organized by survey and program. Table 1 provides the list of survey

 Table 1. Different DESI survey and program combinations that are in the EDR data release, together with the number of objects included in the MWS VAC.

Survey	Program	Number of stars
СМХ	Other	728
SPECIAL	Dark	2457
SV1	Backup	60 959
SV1	Bright	45 738
SV1	Dark	41 984
SV1	Other	82 247
SV2	Backup	2953
SV2	Bright	7217
SV2	Dark	3956
SV3	Backup	83 976
SV3	Bright	236 448
SV3	Dark	57 025
Total		625 688

and programme combinations with the number of stars in the MWS VAC for each combination.

The surveys, CMX, SV1, SV2, and SV3, correspond to commissioning (CMX) and several stages of SV (SV1, SV2, and SV3), respectively. The SV3 data are the closest in target selection to those in the main DESI survey.

The programs, such as 'dark', 'bright', and 'backup', correspond to the observational conditions. During a given survey, DESI conducts observations in different programs based on a metric referred to as survey speed (Schlafly et al. 2023). The SV1 program called 'other' is a special category comprising observations dedicated to specific validation tasks. The main MWS survey is carried out exclusively in the 'bright' program. However, during SV, a large number of targets in specific fields and special classes of stellar targets outside the main MWS selection function were observed in 'dark' and 'other' programs.

The target selection evolved as DESI progressed from commissioning and SV up to the start of the main survey. Additionally, new target classes and customized target selection criteria were introduced for specific fields during the SV programs. In the following sections, we briefly summarize different target classes relevant to Milky Way science.

2.1 Targets

Details of the DESI target selection and different target classes are given in Cooper et al. (2023), Myers et al. (2023), and DESI Collaboration (2024a, b). Here, we provide a summary relevant to Milky Way science and necessary for the interpretation of the valueadded catalogue.

During commissioning, targeting information was not carefully tracked. Since the total number of spectra from commissioning included in the DESI EDR is very small, we do not discuss them here. After commissioning, each of the SV1, SV2, and SV3 surveys used distinct target selection strategies in which new target classes were introduced, and some selections were modified or renamed.

The majority of stellar spectra in the EDR were observed as MWS targets, flux calibration standards, or one of several classes of 'secondary' targets. Secondary program targets include those in several specific fields [for example, the M31 observations described by Dey et al. (2023)] and spare fibre programs used in multiple SV fields.

 Table 2. The name of the columns that contain selection bit masks for SV1,

 SV2, and SV3 surveys.

Targeting column names	
SV1_DESI_TARGET	
SV1_MWS_TARGET	
SV1_SCND_TARGET	
SV2_DESI_TARGET	
SV2_MWS_TARGET	
SV2_SCND_TARGET	
SV3_DESI_TARGET	
SV3_MWS_TARGET	
SV3_SCND_TARGET	

 Table 3. DESI_TARGET bits for target classes relevant for MWS (the bits are identical for SV1, SV2, and SV3).

Bit name	Bit index	Description	
STD_FAINT	33	Standard stars for dark/grey conditions	
STD_WD	34	White dwarf standard stars	
STD_BRIGHT	35	Standard stars for bright conditions	
MWS_ANY	61	Any MWS bit is set	
SCND_ANY	62	Any secondary bit is set	

In the MWS VAC, as in other DESI data products, information about why a given source was targeted is encoded in the integer columns (bitmasks) DESI_TARGET, MWS_TARGET and SCND_TARGET. The DESI_TARGET bitmask provides high-level separation between the different components of the DESI survey, distinguishing between targets associated with the primary extragalactic and stellar programs, the secondary programs, standard stars, and sky fibres; MWS_TARGET is a detailed bitmask for the MWS, separating different classes of Milky Way target; likewise, SCND_TARGET bitmask separates different classes of secondary targets (both stellar and extra-galactic). In the SV programs, many secondary classes correspond to subsets of the main MWS survey target selection that were given higher priority to increase the number of representative spectra for particular types of stars.

Since the SV1, SV2, and SV3 surveys used different target selections, the MWS VAC has three distinctly named target bitmasks for each survey; for example, SV1_DESI_TARGET, SV1_MWS_TARGET and SV1_SCND_TARGET are the bitmasks for the SV1 survey. Table 2 specifically lists the bitmask names for SV1, SV2, and SV3. Stars observed in a given SV program should be selected using the corresponding set of target bitmasks.

2.2 High-level DESI target types

The DESI_TARGET bitmask encodes the overall DESI survey component for which each source was observed and also separates science targets from flux calibration standard stars and sky fibres. Table 3 lists the subset of DESI_TARGET bits corresponding to standard stars, MWS targets and secondary targets. These bits have the same meaning for SV1, SV2, and SV3, although the actual selections did change somewhat.² The DESI_TARGET bitmask for a given SV stage is nonzero only for stars observed in that stage. For example, only stars observed in SV1 have a non-zero value of SV1_DES1_TARGET.³

2.3 MWS survey targets

The criteria used to select stars for the MWS (i.e. those with the MWS_ANY bit set in the DESI_TARGET bitmask) were different in SV1 and SV2. The SV3 observations used the same target classes and selections as SV2. The MWS target classes defined for SV1 are given in Table 4, while the new or modified SV2 target classes are given in Table 5. The exact criteria that define these classes in the main DESI survey are provided in Cooper et al. (2023) and Myers et al. (2023). Note that the criteria used to define a given class with the same name, although in most cases, they are very similar. To make it easier to interpret the catalogues we also summarize the selection criteria for the main (most numerous) MWS classes for the SV3 data in the appendix. Briefly, these classes are as follows.

(i) MWS_MAIN_BROAD class correspond to a magnitude limited selection in the range 16 < r < 19 without kinematic or colour cuts, supplemented by basic photometric quality requirements and was used in SV1 only.⁴

(ii) MWS_MAIN_FAINT corresponds to faint stellar targets with 19 < r < 20 observed during SV1 only. We note however that in the main survey this target category is observed as a secondary target, rather than the main survey target.

(iii) MWS_MAIN_BLUE comprises stars with g - r < 0.7. This class has no proper motion or parallax selection and was used starting from SV2.

(iv) MWS_MAIN_RED comprises stars selected using proper motion and parallax with g - r > 0.7, intended to favour the selection of distant giants. This category was used starting from SV2.

(v) MWS_BROAD class correspond to a magnitude limited selection in the range 16 < r < 19 with g - r > 0.7, but not satisfying astrometric cuts of MWS_MAIN_RED and was used starting from SV2.

(vi) MWS_NEARBY selects stars in a volume-limited sample within 100 pc, using *Gaia* parallaxes, and was used starting from SV1.

(vii) MWS_WD corresponds to white dwarfs and was used starting from $SV1.^5$

(viii) MWS_BHB comprises blue horizontal branch stars selected using the DESI Legacy Survey photometry and was used from SV1. We note that this category, which is described in (Cooper et al. 2023), is distinct from the BHB secondary target category defined for observations of more distant BHB candidates in the dark time (see below).

(ix) GAIA_STD_WD, GAIA_STD_FAINT, GAIA_STD_BRIGHT are flux calibration standards selected based on *Gaia* data alone.

³The VAC also has a small number (759) of rows with zero SV1_DESI_TARGET, SV2_DESI_TARGET and SV3_DESI_TARGET, but non-zero DESI_TARGET. These are fibres targeted as sky but having significant flux in them.

⁴Several target classes (e.g. MWS_BROAD) have NORTH and SOUTH subcategories (e.g. MWS_BROAD_NORTH and MWS_BROAD_SOUTH). Sources selected using Bock/Mosaic photometry in the northern section of the DESI survey footprint have the NORTH bit set, while those selected using DECam photometry in the southern section of the footprint have the SOUTH bit set. Since the MWS selection criteria were identical for the northern and southern parts of the footprint, these subclasses only indicate the origin of the input photometry.

⁵Different selections were used in different SVs and will be described in the dedicated paper.

²The magnitude range for STD_BRIGHT was changed from $15 \le G < 18$ in SV1 to $16 \le G < 18$ in SV2 and SV3. The colour criteria and the magnitude range of STD_FAINT were the same in SV1, SV2, and SV3.

Table 4.	MWS	targeting	bits	for	the SV1	
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Bit name	Bit index	Description		
MWS_MAIN_BROAD	0	MWS magnitude-limited bulk sample		
MWS_WD	1	MWS White Dwarf target		
MWS_NEARBY	2	MWS volume-complete (~100 pc) sample		
MWS_MAIN_BROAD_NORTH	4	MWS targets from Bok/Mosaic		
MWS_MAIN_BROAD_SOUTH	5	MWS targets from DECam		
MWS_BHB	6	MWS Blue Horizontal Branch targets		
MWS_MAIN_FAINT	14	MWS magnitude-limited sample		
MWS_MAIN_FAINT_NORTH	15	MWS magnitude-limited sample from Bok/Mosaic		
MWS_MAIN_FAINT_SOUTH	16	MWS magnitude-limited sample from DECam		
GAIA_STD_FAINT	33	Gaia-based standard stars for dark/grey conditions		
GAIA_STD_WD	34	Gaia-based White Dwarf stars for use as standards		
GAIA_STD_BRIGHT	35	Gaia-based standard stars for bright conditions		
BACKUP_GIANT_LOP	58	Gaia-based possible giant stars for backup survey		
BACKUP_GIANT	59	Gaia-based selection of giant stars for backup survey		
BACKUP_BRIGHT	60	Bright backup Gaia targets		
BACKUP_FAINT	61	Fainter backup Gaia targets		
BACKUP_VERY_FAINT	62	Even fainter backup Gaia targets		

Table 5. Additional and updated names and targeting bits for the MWS used during SV2.

Bit name	Bit index	Description
MWS_BROAD	0	MWS magnitude-limited bulk sample
MWS_BROAD_NORTH	4	MWS cuts in Bok/Mosaic imaging footprint
MWS_BROAD_SOUTH	5	MWS cuts in DECam imaging footprint
MWS_MAIN_BLUE	8	MWS magnitude-limited blue sample
MWS_MAIN_BLUE_NORTH	9	MWS magnitude-limited blue sample in Bok/Mosaic imaging footprint
MWS_MAIN_BLUE_SOUTH	10	MWS magnitude-limited blue sample in DECam imaging footprint
MWS_MAIN_RED	11	MWS magnitude-limited red sample
MWS_MAIN_RED_NORTH	12	MWS magnitude-limited red sample in Bok/Mosaic imaging footprint
MWS_MAIN_RED_SOUTH	13	MWS magnitude-limited red sample in DECam imaging footprint

These are used in areas without the DECaLS photometry to select regular DESI standards. They were included starting from SV1.

(x) BACKUP_BRIGHT, BACKUP_FAINT, BACKUP_VERY_FAINT, BACKUP_GIANT, BACKUP_GIANT_LOP are targets that were observed when conditions were too poor for the bright or dark SV programs. The exact definition of the backup survey and its target classes will be described in a follow-up paper. Backup targets were included starting from SV1.

For all the target classes listed above in Tables 6, 7, and 8 we provide the number of objects in these classes observed in different surveys and programmes included in this VAC. Note that the same object may have more than one target class and may have been observed in multiple surveys.

In this paper we do not describe the selection function of the survey in detail, partially because this VAC is based on the early data release which is a combination of commissioning and science verification surveys and the target selection was changing throughout. However, for each survey and programme the information needed to reproduce the selection function or replay the target selection is available as part of the DESI EDR. Specifically:

(i) The details of the target selection for different classes are given in Myers et al. (2023)

(ii) The code used for target selection in SV1, SV2, SV3 and main survey is publicly available https://desitarget.readthedocs.io/ en/latest/ and is based on public Legacy Survey photometry data.

(iii) The list of all potential survey targets selected by the DESI targeting code is available as part of the DESI EDR. I.e.

the list of all the potential targets of different classes for SV3 is available here https://data.desi.lbl.gov/public/edr/target/catalogs/ dr9/0.57.0/targets/sv3/resolve/. These are all the objects that DESI considered targeting, before the fiber assignment on individual DESI tiles was run.

To give an idea of how this can be used, Table 9 provides the fraction of objects of different MWS target types in the SV3 footprint that ended up being observed in SV3 in bright programme and are in this VAC. These numbers were obtained by taking the ratio of number of objects in different target categories in the VAC divided by the number of objects in the same target class in the SV3 footprint in the input catalogues. The reason why those fractions are not 100 per cent is primarily because of the fiber allocation, as the number of potential targets can be larger than the number of fibers and because there is competition between fiber allocation to sky, standard stars, BGS program targets and MWS targets. The table shows that for the main MWS classes in SV3 survey the completeness of observations was above 70 per cent.

2.4 Secondary targets

Alongside the main survey target classes, a variety of sources were observed as secondary targets. Some of these were defined to fill spare fibres, while others correspond to targets of particular interest on specific tiles observed during SV.

Table 10 lists the different secondary stellar target categories and the corresponding SCND_TARGET bit values. The table also gives the number of objects of each type included in the VAC. Note that

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 Table 6. The number of objects in different MWS target categories observed in SV1 and included in the VAC.

Program: dark 15 638 MWS_MAIN_BROAD 15 638 MWS_WD 652 MWS_NEARBY 71 MWS_BHB 22 MWS_MAIN_FAINT 34611 GAIA_STD_FAINT 4 GAIA_STD_WD 6 BACKUP_BRIGHT 1 BACKUP_FAINT 18 BACKUP_FAINT 14 Program: bright 24 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 MWS_NEARBY 112 MWS_BHB 3 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 123 BACKUP_FAINT 124	Target class	Number
MWS_MAIN_BROAD 15 638 MWS_WD 652 MWS_WD 652 MWS_MAIN_FAINT 3461 GAIA_STD_FAINT 3461 GAIA_STD_FAINT 4 GAIA_STD_FAINT 4 GAIA_STD_WD 6 BACKUP_BRIGHT 1 BACKUP_FAINT 18 BACKUP_VERY_FAINT 14 Program: bright 70 MWS_MAIN_BROAD 32 507 MWS_MAIN_BROAD 32 507 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_FAINT 123 BACKUP_BRIGHT 170 BACKUP_BRIGHT 123 BACKUP_VERY_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 16 MWS_MAIN_BROAD 242 MWS_MAIN_BROAD 242 MWS_WD 212 MWS_MAIN_BROAD 44 504 MWS_WD 222 GAIA_STD_FAINT 58 MWS_MA	Program: dark	
MWS_WD 652 MWS_NEARBY 71 MWS_BHB 22 MWS_MAIN_FAINT 3461 GAIA_STD_FAINT 4 GAIA_STD_FAINT 1 BACKUP_BRIGHT 1 BACKUP_VERY_FAINT 14 Program: bright 1 MWS_MAIN_BROAD 32 507 MWS_MAIN_BROAD 24 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_FAINT 24 GAIA_STD_FAINT 24 GAIA_STD_FAINT 23 BACKUP_VERY_FAINT 123 BACKUP_VERY_FAINT 123 BACKUP_VERY_FAINT 123 BACKUP_VERY_FAINT 272 MWS_MAIN_BROAD 44 504 MWS_MAIN_BROAD 272 MWS_NAIN_BROAD 272 MWS_NAIN_BROAD 272 MWS_NEARBY 158 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 166 MWS_MAIN_FAINT 2868	MWS_MAIN_BROAD	15 638
MWS_NEARBY71MWS_BHB22MWS_MAIN_FAINT3461GAIA_STD_FAINT4GAIA_STD_WD6BACKUP_BRIGHT1BACKUP_FAINT18BACKUP_VERY_FAINT14Program: bright1MWS_MAIN_BROAD32507MWS_WD24MWS_NEARBY112MWS_BHB3MWS_MAIN_BROAD22507MWS_MAIN_BROAD32507MWS_MD24MWS_NEARBY112MWS_BHB3MWS_MAIN_FAINT4893GAIA_STD_FAINT24GAIA_STD_FAINT170BACKUP_FAINT123BACKUP_VERY_FAINT8Program: other272MWS_MAIN_BROAD44504MWS_MAIN_BROAD44504MWS_MAIN_BROAD272MWS_NAIN_BROAD44504MWS_MAIN_BROAD22GAIA_STD_FAINT8028GAIA_STD_FAINT2808BACKUP_AINT158MWS_BHB116MWS_MAIN_FAINT2868BACKUP_FAINT159Program: backup48MWS_MAIN_FAINT289GAIA_STD_FAINT289GAIA_STD_FAINT289GAIA_STD_FAINT33GAIA_STD_FAINT34GAIA_STD_MD34GAIA_STD_MD34GAIA_STD_MD34GAIA_STD_FAINT1136	MWS_WD	652
MWS.BHB22MWS.MAIN.FAINT3461GAIA.STD_FAINT4GAIA.STD_FAINT1BACKUP.BRIGHT1BACKUP.FAINT18BACKUP.VERY_FAINT14Program: bright1MWS.MAIN.BROAD32 507MWS.MAIN.BROAD32 507MWS.MAIN.BROAD24MWS.NEARBY112MWS_BHB3MWS_MAIN.FAINT4893GAIA.STD_FAINT24GAIA.STD_FAINT24GAIA.STD_BRIGHT170BACKUP.VERY_FAINT23BACKUP.FAINT123BACKUP.VERY_FAINT8Program: other116MWS_MAIN.BROAD44 504MWS_WD272MWS_MAIN.BROAD44 504MWS_MAIN.BROAD44 504MWS_MAIN.BROAD44 504MWS_MAIN.BROAD222GAIA.STD_FAINT657GAIA.STD_FAINT59SO28GAIA.STD_FAINTBACKUP.VERY_FAINT159Program: backup1045BACKUP.VERY_FAINT159Program: backup48MWS_MAIN.BROAD59 456MWS_MAIN.BROAD59 456MWS_MAIN.BROAD48MWS_NEARBY180MWS_NEARBY133GAIA.STD_FAINT289GAIA.STD_FAINT289GAIA.STD_BRIGHT131BACKUP_FAINT131BACKUP_FAINT135	MWS_NEARBY	71
MWS_MAIN_FAINT3461GAIA_STD_FAINT4GAIA_STD_WD6BACKUP_BRIGHT1BACKUP_VERY_FAINT14Program: bright14MWS_MAIN_BROAD32 507MWS_MAIN_BROAD32 507MWS_MAIN_BROAD24MWS_MAIN_BROAD32MWS_MAIN_BROAD3MWS_MAIN_FAINT4893GAIA_STD_FAINT24GAIA_STD_FAINT24GAIA_STD_BRIGHT170BACKUP_BRIGHT490BACKUP_FAINT123BACKUP_VERY_FAINT8Program: other116MWS_MAIN_BROAD44 504MWS_WD272MWS_MAIN_BROAD44 504MWS_MAIN_BROAD44 504MWS_MAIN_BROAD22GAIA_STD_FAINT8028GAIA_STD_FAINT657GAIA_STD_FAINT657GAIA_STD_FAINT1540BACKUP_FAINT1540BACKUP_FAINT1540BACKUP_VERY_FAINT159Program: backup180MWS_MAIN_BROAD59 456MWS_WD494MWS_MAIN_FAINT289GAIA_STD_FAINT133GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_MD34GAIA_STD_MD34GAIA_STD_MD34GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_WD34GAIA_STD_WD <td>MWS_BHB</td> <td>22</td>	MWS_BHB	22
GAIA_STD_FAINT4GAIA_STD_WD6BACKUP_BRIGHT1BACKUP_FAINT18BACKUP_VERY_FAINT14Program: bright112MWS_MAIN_BROAD32 507MWS_WD24MWS_NEARBY112MWS_BHB3MWS_DAIN_FAINT4893GAIA_STD_FAINT24GAIA_STD_FAINT24GAIA_STD_FAINT170BACKUP_BRIGHT490BACKUP_FAINT123BACKUP_VERY_FAINT8Program: other116MWS_MAIN_BROAD44 504MWS_WD272MWS_MAIN_BROAD44 504MWS_WD272GAIA_STD_FAINT8028GAIA_STD_FAINT657GAIA_STD_FAINT657GAIA_STD_FAINT657GAIA_STD_FAINT1540BACKUP_VERY_FAINT1540BACKUP_FAINT2868BACKUP_FAINT1540BACKUP_FAINT1540BACKUP_FAINT1540BACKUP_FAINT286MWS_MAIN_BROAD59 456MWS_MAIN_BROAD59 456MWS_MAIN_BROAD59 456MWS_MAIN_FAINT289GAIA_STD_FAINT133GAIA_STD_FAINT131BACKUP_FAINT131BACKUP_FAINT131BACKUP_FAINT131	MWS_MAIN_FAINT	3461
GAIA_STD_WD6BACKUP_BRIGHT1BACKUP_FAINT18BACKUP_VERY_FAINT14Program: bright112MWS_MAIN_BROAD32 507MWS_WD24MWS_NEARBY112MWS_BHB3MWS_MAIN_FAINT4893GAIA_STD_FAINT24GAIA_STD_BRIGHT170BACKUP_BRIGHT170BACKUP_FAINT123BACKUP_VERY_FAINT8Program: other116MWS_MAIN_BROAD44 504MWS_WD272MWS_NAIN_BROAD44 504MWS_WD272MWS_MAIN_BROAD44 504MWS_WD272MWS_MAIN_BROAD44 504MWS_WD272MWS_ND272MWS_NEARBY158MWS_DD22GAIA_STD_FAINT657GAIA_STD_FAINT159Program: backup1045BACKUP_FAINT159Program: backup48MWS_MAIN_BROAD59 456MWS_WD494MWS_MAIN_BROAD59 456MWS_MAIN_BROAD59 456MWS_MAIN_BROAD59 456MWS_MAIN_FAINT289GAIA_STD_FAINT131BACKUP_FAINT131BACKUP_FAINT131BACKUP_FAINT131BACKUP_FAINT131	GAIA_STD_FAINT	4
BACKUP_BRIGHT 1 BACKUP_VERY_FAINT 18 BACKUP_VERY_FAINT 14 Program: bright 1 MWS_MAIN_BROAD 32 507 MWS_NEARBY 112 MWS_NEARBY 112 MWS_BHB 3 GAIA_STD_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 490 BACKUP_BRIGHT 490 BACKUP_VERY_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_NAIN_BROAD 272 MWS_NAIN_FAINT 8028 GAIA_STD_FAINT 57 GAIA_STD_BRIGHT 1045 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NEARBY 180	GAIA_STD_WD	6
BACKUP_FAINT 18 BACKUP_VERY_FAINT 14 Program: bright 14 MWS_MAIN_BROAD 32 507 MWS_WD 24 MWS_WD 24 MWS_NEARBY 112 MWS_BHB 3 MWS_BHB 3 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_DAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 222 GAIA_STD_BRIGHT 1045 BACKUP_VERY_FAINT 159 Program: backup 48 MWS_MAIN_FAINT 286	BACKUP_BRIGHT	1
BACKUP_VERY_FAINT 14 Program: bright 32 507 MWS_MAIN_BROAD 32 507 MWS_WD 24 MWS_WD 24 MWS_NEARBY 112 MWS_BHB 3 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_FAINT 8028 GAIA_STD_FAINT 58 MWS_BHB 116 MWS_MAIN_FAINT 22 GAIA_STD_BRIGHT 1045 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_MAIN_BROAD 59 456 MWS_MAIN_FAINT	BACKUP_FAINT	18
Program: bright 32 507 MWS_MAIN_BROAD 32 507 MWS_WD 24 MWS_ND 24 MWS_NEARBY 112 MWS_BHB 3 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_JRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_WD 272 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_WD 272 MWS_NAIN_BROAD 44 504 MWS_MAIN_BROAD 272 MWS_NAIN_FAINT 8028 GAIA_STD_FAINT 58 MWS_MAIN_FAINT 22 GAIA_STD_FAINT 1540 BACKUP_FAINT 1540 BACKUP_FAINT 2868 BACKUP_FAINT 59 456 <t< td=""><td>BACKUP_VERY_FAINT</td><td>14</td></t<>	BACKUP_VERY_FAINT	14
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MWS_BHB 3 MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1045 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 48 MWS_MAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NEARBY 180 MWS_SBHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 131 BACKUP_FAINT 131	MWS_NEARBY	112
MWS_MAIN_FAINT 4893 GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1045 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_FAINT 159 Program: backup 48 MWS_NAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NEARBY 180 MWS_NEARBY 133 GAIA_STD_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 131	MWS_BHB	3
GAIA_STD_FAINT 24 GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 123 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_NAIN_BROAD 59 456 MWS_NAIN_BROAD 59 456 MWS_NEARBY 180 MWS_NEARBY 133 GAIA_STD_FAINT 289 GAIA_STD_FAINT 289 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 133	MWS_MAIN_FAINT	4893
GAIA_STD_BRIGHT 170 BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_MAIN_BROAD 59 456 MWS_MAIN_BROAD 59 456 MWS_MAIN_BROAD 59 456 MWS_MAIN_BROAD 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 133	GAIA_STD_FAINT	24
BACKUP_BRIGHT 490 BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_MAIN_BROAD 59 456 MWS_MAIN_BROAD 59 456 MWS_ND 494 MWS_NEARBY 180 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 131	GAIA_STD_BRIGHT	170
BACKUP_FAINT 123 BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_NAIN_BROAD 59 456 MWS_NEARBY 180 MWS_NEARBY 180 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 133 GAIA_STD_FAINT 131 BACKUP_FAINT 131	BACKUP_BRIGHT	490
BACKUP_VERY_FAINT 8 Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_NEARBY 180 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 131 BACKUP_FAINT 131	BACKUP_FAINT	123
Program: other 44 504 MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 494 MWS_NEARBY 180 MWS_NEARBY 180 MWS_NEARBY 133 GAIA_STD_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 131 BACKUP_FAINT 131	BACKUP_VERY_FAINT	8
MWS_MAIN_BROAD 44 504 MWS_WD 272 MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 657 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_NEARBY 183 GAIA_STD_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 131 BACKUP_FAINT 1136	Program: other	
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MWS_NEARBY 158 MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 22 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 131	MWS_WD	272
MWS_BHB 116 MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 22 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 131	MWS_NEARBY	158
MWS_MAIN_FAINT 8028 GAIA_STD_FAINT 657 GAIA_STD_FAINT 22 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_BHB	116
GAIA_STD_FAINT 657 GAIA_STD_WD 22 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 136	MWS_MAIN_FAINT	8028
GAIA_STD_WD 22 GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	GAIA_STD_FAINT	657
GAIA_STD_BRIGHT 1540 BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_BRIGHT 131 BACKUP_FAINT 136	GAIA_STD_WD	22
BACKUP_BRIGHT 1045 BACKUP_FAINT 2868 BACKUP_VERY_FAINT 159 Program: backup MWS_MAIN_BROAD 59456 MWS_WD 494 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	GAIA_STD_BRIGHT	1540
BACKUP_FAINT2868BACKUP_VERY_FAINT159Program: backup59 456MWS_MAIN_BROAD59 456MWS_WD494MWS_NEARBY180MWS_BHB48MWS_MAIN_FAINT289GAIA_STD_FAINT133GAIA_STD_BRIGHT131BACKUP_FAINT1136	BACKUP_BRIGHT	1045
BACKUP_VERY_FAINT159Program: backup59 456MWS_MAIN_BROAD59 456MWS_WD494MWS_NEARBY180MWS_BHB48MWS_MAIN_FAINT289GAIA_STD_FAINT133GAIA_STD_BRIGHT131BACKUP_FAINT1136	BACKUP_FAINT	2868
Program: backup 59 456 MWS_MAIN_BROAD 59 456 MWS_WD 494 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	BACKUP_VERY_FAINT	159
MWS_MAIN_BROAD 59 456 MWS_WD 494 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	Program: backup	
MWS_WD 494 MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_MAIN_BROAD	59 456
MWS_NEARBY 180 MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_WD	494
MWS_BHB 48 MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_WD 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_NEARBY	180
MWS_MAIN_FAINT 289 GAIA_STD_FAINT 133 GAIA_STD_FAINT 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_BHB	48
GAIA_STD_FAINT 133 GAIA_STD_WD 34 GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	MWS_MAIN_FAINT	289
GAIA_STD_WD34GAIA_STD_BRIGHT131BACKUP_FAINT1136	GAIA_STD_FAINT	133
GAIA_STD_BRIGHT 131 BACKUP_FAINT 1136	GAIA_STD_WD	34
BACKUP_FAINT 1136	GAIA_STD_BRIGHT	131
	BACKUP_FAINT	1136

many of these object categories may have been observed as regular survey targets. We briefly summarize these secondary classes here; more detailed descriptions are given in Cooper et al. (2023), Dey et al. (2023), Myers et al. (2023), and DESI Collaboration (2024a).

(i) WD_BINARIES_DARK, and WD_BINARIES_BRIGHT select white dwarf binary candidates using *Gaia* and GALEX photometry to assemble an unbiased, homogeneous sample for studying the evolution of close white dwarf binaries.

(ii) M31_QSO, M31_STAR and M31_KNOWN are targets selected for the dedicated M31 observations described in detail by Dey et al. (2023).

(iii) MWS_DDOGIANTS was originally intended for selecting highly probable halo giants using DDO photometry; however, this bit was not used for any DESI observations.
 Table 7. The number of objects in different MWS target categories observed in SV2 and included in the VAC.

Program: dark	
MWS_BROAD	2
MWS_WD	270
MWS_NEARBY	30
MWS_MAIN_BLUE	3315
MWS_MAIN_RED	12
Program: bright	
MWS_BROAD	1381
MWS_WD	255
MWS_NEARBY	53
MWS_BHB	7
MWS_MAIN_BLUE	4727
MWS_MAIN_RED	724
Program: backup	
GAIA_STD_FAINT	329
GAIA_STD_BRIGHT	217
BACKUP_BRIGHT	1261
BACKUP_FAINT	1114
BACKUP_VERY_FAINT	578

 Table 8.
 The number of objects in different MWS target categories observed in SV3 and included in the VAC.

Target class	Number
Program: dark	
MWS_BROAD	10
MWS_WD	662
MWS_NEARBY	40
MWS_BHB	321
MWS_MAIN_BLUE	10 928
MWS_MAIN_RED	26
Program: bright	
MWS_BROAD	87 772
MWS_WD	840
MWS_NEARBY	355
MWS_BHB	439
MWS_MAIN_BLUE	99 448
MWS_MAIN_RED	25 330
Program: backup	
GAIA_STD_FAINT	19 476
GAIA_STD_BRIGHT	14 633
BACKUP_FAINT	56 663
BACKUP_VERY_FAINT	27 185

Table 9. Fraction of the targets in the input catalogue within the SV3/bright footprint that were observed in SV3 in bright program and have a measurement in the EDR VAC.

Target class	Fraction
MWS_BROAD	0.77
MWS_WD	0.95
MWS_NEARBY	0.87
MWS_BHB	0.84
MWS_MAIN_BLUE	0.83
MWS_MAIN_RED	0.83

 Table 10.
 Secondary targeting bits relevant to MWS and the number of objects with those bits in the catalogue.

Bit-name	Bit index	Number of objects
M31_KNOWN	6	25
M31_QSO	7	15
M31_STAR	8	827
MWS_DDOGIANTS	9	0
MWS_CLUS_GAL_DEEP	10	4405
FAINT_HPM	12	371
BHB	18	249
HPM_SOUM	27	31
MWS_CALIB	36	2515
BACKUP_CALIB	37	2540
MWS_MAIN_CLUSTER_SV	38	4669
MWS_RRLYR	39	332
BRIGHT_HPM	40	5
WD_BINARIES_BRIGHT	41	71
WD_BINARIES_DARK	42	88

Detailed descriptions of these target classes are given in the text.

(iv) BHB targets were selected as faint candidate horizontal branch stars, potentially up to distances of 150 kpc from the Galactic Centre. This class has a fainter magnitude limit than the regular survey MWS_BHB targets (see above) and was observed in dark conditions only. The targets were selected using Legacy survey g - r, r - z colours selection analogous to equation (6) in Li et al. (2019) and include faint RR Lyrae from *Gaia* DR2 (Clementini et al. 2019) and Sesar et al. (2017).

(v) FAINT_HPM, BRIGHT_HPM and HPM_SOUM targets were selected to identify fast-moving stars in the Milky Way based on parallax and proper motion. The goal of this selection was to identify rare populations of hypervelocity stars and SNIa remnants.

(vi) MWS_CLUS_GAL_DEEP is a target bit for a secondary program observing Milky Way star clusters and dwarf galaxies. During SV, dedicated observations were taken of the Draco and Ursa Major II dwarf spheroidal galaxies, the open cluster M44 (Beehive/Praesepe) and the globular cluster pair M53 and NGC 5053. Different combinations of colour and magnitude from Legacy Survey DR9 and parallax and proper motion from *Gaia* EDR3 were used in each case to select candidate members of these objects. These targets were only included in dedicated tiles observed in dark time and were given higher priority than all other MWS targets on those tiles, except white dwarfs. Note that additional tiles in the same areas were also observed under regular bright-time conditions (see MWS_MAIN_CLUSTER_SV below).

(vii) MWS_MAIN_CLUSTER_SV has a similar purpose to the MWS_MAIN_CLUS_GAL_DEEP class. It was used in a series of dedicated fields observed in SV1 to prioritize likely member stars of clusters and dwarf galaxies. These targets are, on average, brighter than those selected in MWS_MAIN_CLUS_GAL_DEEP, and the selection was based on *Gaia* DR2. They were observed under both bright and dark conditions. In addition to the fields listed for MWS_MAIN_CLUS_GAL_DEEP, this class was used to target stars in the globular clusters M5, M13, M92, and NGC 2419. A handful of these targets also appear in the outskirts of one SV3 field near M13.

(viii) MWS_RRLYR⁶ are RR Lyrae variables that were selected from the *Gaia* DR2 RRL catalogue (Clementini et al. 2019). Note

⁶Note that the main survey uses a different bit and different name for the RR Lyrae selection (bit 37 of the secondary targeting mask with the name MWS_RR_LYRAE).

Table 11. Dedicated observations in SV1 relevant to the MWS.

Object	RA [°]	Dec [°]	$T_{\exp}(s)$	Tile number
NGC 2419	114.221	38.469	9779.6	80618
NGC 2419	114.54	39.38	2986.9	80721
NGC 5053/M53	199.1	18.3	5245.3	80733
NGC 5053/M53	198.3	17.5	7200.4	80863
M 5	229.64	2.58	10112.7	80734
M 13	250.42	36.96	7242.2	80735
M 44	130.1166	19.4692	1200.1	80719
M 92	259.28	43.64	11076.0	80736
GD 1	128.5	0.8	4225.2	80722
GD 1	132.7	9.93	655.9	80724
GD 1	132.7	9.93	2400.2	80648
GD 1	163.736	47.858	8488.8	80658
GD 1	163.74	47.86	9754.7	80729
GD 1	173.55	52.86	7153.1	80730
Orphan	159.08	7.5	2576.3	80727
Ursa Major 2	132.87	63.73	4239.3	80726
Ursa Major 2	132.87	63.73	1200.1	80720
Sextans 1	154.1	-1.375	1431.2	80614
Sextans 1	153.26	-1.11	3600.1	80737
Draco 1	260.07	58.42	7720.7	80738
Draco 1	260.07	57.42	6100.3	80862
M31	10.17	41.38	2700.1	80715
M33	24.027	31.39	3600.1	80615
Blank	98.0063	-4.8356^{7}	1800.3	80718
Blank	192.86	27.13	6663.5	80731
Blank	198.04	0.0	5914.9	80732

From left to right, columns give the name of the object, the central coordinates of the field, the total exposure time, and the DESI tile number. The field was designed to point at the Rosette Nebula, but was mistakenly centred at a negative declination of $\delta = -4.8$ instead of $\delta = 4.8$.

that there is some overlap with the RRL targeted with the BHB class. In the EDR, 42 stars out of 332 MWS_RRLYR targets are also BHB targets.

(ix) MWS_CALIB and BACKUP_CALIB are classes used during SV only to prioritize stars with data from one or more previous surveys, including APOGEE (Abdurro'uf et al. 2022), BOSS (Dawson et al. 2013), GALAH (De Silva et al. 2015) and Gaia-ESO (Gilmore et al. 2022). The MWS_CALIB stars have *Gaia G*-band magnitudes 16 < G < 19 while the BACKUP_CALIB stars have G < 16.

2.5 Dedicated fields

The DESI SV program observations used either a generic target selection (preliminary versions of the target selection for the main survey) or field-specific selections when observing various objects of particular value to validate the DESI data reduction pipelines.

In Table 11, we provide a list of the SV fields that are of most interest for the MWS. These include the fields designed for tests of the MWS strategy and pipelines listed in Cooper et al. (2023) and several other fields of interest, such as a field centred on M31 (Dey et al. 2023) and additional observations of streams, clusters and dwarf galaxies. As mentioned above, the target selection in these fields was customized by adding additional secondary target classes with high priority for fibre assignment (see Section 2.4). Most of these dedicated fields were observed in SV1, under the program 'other'. Many of these fields are centred on stellar streams and dwarf

⁷The field was designed to point at the Rosette Nebula, but was mistakenly centred at a negative declination of $\delta = -4.8$ instead of $\delta = 4.8$.

galaxies and contain tens to hundreds of stars associated with those objects. These data will be described in upcoming publications. The data obtained from SV fields covering the Draco dwarf spheroidal are demonstrated in Section 5.6.

3 MWS PROCESSING

3.1 DESI data

The MWS VAC described in this paper is based on the processing of coadded spectra of DESI targets grouped by sky area (HEALPIX pixels with nside = 64; Górski et al. 2005), survey and program. This VAC does not include the processing of spectra from individual exposures or spectra coadded across surveys and programs. Importantly, within a given survey and program, if an object was observed multiple times on different nights or within a different pointing, all the spectra of that object were coadded. This means that, even within one HEALPIX pixel, it is possible to have targets with very different total exposure times and numbers of exposures. The details of the coaddition process are provided in section 4.1.1 of Guy et al. (2023).

The processing steps described below are all executed after the data reduction and flux calibration by the main DESI pipeline (Guy et al. 2023), as well as spectral classification and redshift determination by Redrock (Bailey et al., in preparation).

3.2 Stellar subset

The MWS pipelines are run on a subset of the targets observed in DESI to avoid fitting stellar models to spectra of quasars or galaxies, which are much more numerous among DESI targets. This VAC release is based on the subset of DESI spectra that satisfy at least one of the following criteria:

(i) The object was targeted as an MWS object (i.e. has the MWS_ANY bit set in the DESI_TARGET).

(ii) The object was targeted as a secondary target (i.e. has the SCND_ANY bit set in DESI_TARGET).

(iii) The object was targeted as a standard star (i.e. it has one of the STD_ bits set in DESI_TARGET).

(iv) The object was classified by Redrock as a star.

(v) The object has a Redrock redshift between -1500 km s⁻¹ and 1500 km s⁻¹ (irrespective of spectral type).⁸

These criteria likely include the vast majority of stars observed by DESI, only potentially missing stars targeted through one of the cosmological DESI surveys and incorrectly classified by RedRock as something other than a star. We also require that the object's spectrum has a median (across all the pixels) signal-to-noise ratio per pixel of at least two in one of the B, R, and Z arms and that the object has a good quality spectrum according to the pipeline flag COADD_FIBERSTATUS = 0.

3.3 RVS pipeline

The first stellar pipeline that DESI MWS runs is the RVSPECFIT code,⁹ or RVS, which performs the simultaneous least-squares modelling of the blue, red, and infrared parts of the DESI spectra by interpolating templates from PHOENIX spectral library. The code is based on the

⁸This selection is expected to bring significant number of non-stellar objects, but ensures that we do not miss possible stars with high velocities. ⁹https://github.com/segasai/rvspecfit approach presented in Koposov et al. (2011) and Li et al. (2019) and is described in more detail in Cooper et al. (2023). RVS provides maximum likelihood estimates of stellar parameters surface gravity log g, effective temperature $T_{\rm eff}$, metallicity [Fe/H], α -abundance [α /Fe], radial velocity, and stellar rotation velocity ($v \sin i$). The uncertainties for the stellar parameters come from the Hessian matrix of the log-likelihood function, and the radial velocity uncertainties are determined from its 1D posterior. The RVS modelling only relies on DESI spectral information; no priors from photometry or *Gaia* astrometry are used.

3.4 SP pipeline

The second stellar pipeline for MWS is the SP¹⁰ pipeline, which uses the FERRE code¹¹ to process the same set of stars as RVS. SP works with spectra that are shifted to zero velocity, according to the velocity measurement obtained from RVS, and are continuum-normalized by dividing the observed spectra by a running mean filter with a width of 500 pixels.

The SP processing consists of two steps. In the first step, the code minimizes the χ -square between the model and observations in the entire DESI spectral range to find the main atmospheric parameters: $T_{\rm eff}$, log g, microturbulence ξ , metallicity [Fe/H], and α -element abundance $[\alpha/Fe]$.¹² In the second step, the code holds the atmospheric parameters fixed and infers individual elemental abundances for C, Mg, Ca, and Fe¹³ by evaluating the χ -square in regions dominated by atomic and molecular transitions associated with each element. This methodology is similar to that used in the APOGEE survey García Pérez et al. (2016). FERRE was first used in Allende Prieto et al. (2006) and more details are given in Cooper et al. (2023).

4 DATA PRODUCTS

Here we describe the data products included in this publicly available VAC.¹⁴ These include:

(i) The outputs of the RVS pipeline fitted to coadded spectra grouped by HEALPIX pixels on the sky, survey, and program (3944 individual pixel, survey, program combinations).

(ii) The outputs of the SP pipeline fitted to the same data.

For ease of use, we also combine the tables produced by RVS and SP pipeline across HEALPIX pixels, making 12 distinct SP and RVS catalogues corresponding to different survey and program combinations listed in Table 1. Finally, we also provide the main combined catalogue, which includes RVS and SP measurements for all stars observed across all different surveys and programs. This is the data product that will be of most interest to users.

We add that the original spectra that were used for the fits with all the associated information are available as part of the main DESI EDR data release.

¹¹http://github.com/callendeprieto/ferre; see also http://github.com/ callendeprieto/piferre for DESI-specific supporting code.

¹⁰An abbreviation of Stellar Parameters.

¹²For white dwarfs, only $T_{\rm eff}$ and log g are measured

¹³When the abundances of C and Fe are determined, the [Fe/H] of the model is allowed to change. When the abundances of Mg and Ca are determined, the $[\alpha/Fe]$ of the model is allowed to change.

¹⁴ https://data.desi.lbl.gov/doc/releases/edr/vac/mws/

The data model of all the products in this release is available at https://desi-mws-edr-datamodel.readthedocs.io/. The following is a brief overview.

4.1 RVS data products

We start by describing the individual RVS outputs of fitting results on coadded DESI spectra. The output of RVS (for a given survey, program and HEALPIX pixel) consists of two files: an rvtab file that tabulates measurements by RVSPECFIT and a rvmod file that contains the best-fitting model for each spectrum.

The rvtab file is a FITS table with several extensions: RVTAB, FIBERMAP, SCORES, EXP_FIBERMAP. The RVTAB extension contains the main measurements made by RVSPECFIT and basic quantities that identify the source. All other extensions are copied directly from DESI data products described in Guy et al. (2023).¹⁵ The full list of columns in the RVTAB extension is given in Table A1. The data in these columns are as follows:

(i) VRAD, VRAD_ERR, VRAD_SKEW, VRAD_KURT contain radial velocity measurements in the heliocentric frame, together with the estimate of the uncertainty, skewness, and kurtosis of the radial velocity posterior.

(ii) VSINI the stellar rotation velocity $v \sin i$. In this release, the rotation velocity measurements have been affected by a software bug and should not be used.

(iii) LOGG, TEFF, ALPHAFE, FEH, LOGG_ERR, TEFF_ERR, ALPHAFE_ERR, FEH_ERR are stellar parameters (surface gravity, effective temperature, $[\alpha/Fe]$, [Fe/H]) and their uncertainty estimates from Hessian matrices of the likelihood function.

(iv) NEXP is a deprecated column for the number of individual spectra used in the fit.

(v) CHISQ_B, CHISQ_R, CHISQ_Z, CHISQ_TOT are the χ^2 of the best-fitting models in the blue, red, infrared arms and combined across all the arms, respectively. Note that these χ^2 are not divided by the number of degrees of freedom.

(vi) CHISQ_C_B, CHISQ_C_R, CHISQ_C_Z, CHISQ_C_TOT are the χ^2 of the best-fitting continuum-only model, i.e. model using a smooth featureless stellar spectrum template.

(vii) RVS_WARN is an integer bitmask set to zero if there are no warnings during the RVS fit. The first bit (or a bit number zero) of the bitmask is set if the CHISQ_TOT—CHISQ_C_TOT < 50, which means that the stellar fit provides only a small improvement over the continuum-only fit. The second bit of RVS_WARN is set to one if the best-fitting velocity is within 5 km s⁻¹ of the radial velocity grid edges ($\pm 1500 \text{ km s}^{-1}$); the third bit is set to one if the radial velocity error value is larger than 100 km s⁻¹. The remaining bits of the bitmask are unused in this VAC.

(viii) REF_CAT and REF_ID are the external catalogue name and the source identifier if a catalogue other than the DESI Legacy Imaging Survey was used for targeting. REF_CAT can be T2 for Tycho-2, G2 for *Gaia* DR2, L3 for the Siena Galaxy Atlas (SGA) 2020 (Moustakas et al. 2023)¹⁶, or F1 (for sources prepared for DESI first light observations). For most *Gaia* sources, the REF_ID is the *Gaia* DR2 source_id and REF_CAT is G2.¹⁷

¹⁷We do not recommend using the REF_ID from this table, but instead recommend using the cross-match with *Gaia* DR3 provided in the combined

(ix) TARGET_RA, TARGET_DEC are the coordinates of objects.

(x) TARGETID is the unique DESI target identifier.¹⁸

(xi) SN_B, SN_R, SN_Z are the median signal-to-noise ratios in the blue, red, and infrared arms of the spectrum of the object.

(xii) SUCCESS is a boolean flag that is set to true when the spectrum has no warnings from RVSPECFIT (i.e. $RVS_WARN = 0$).

The rvmod FITS files contain the best-fitting stellar model spectra corresponding to the individual objects in the rvtab file. The files contain three B_MODEL, R_MODEL, Z_MODEL extensions for the best-fitting model in each wavelength arm. The rvmod files also include B_WAVELENGTH, R_WAVELENGTH and Z_WAVELENGTH extensions with the wavelength arrays for the different arms (copied from the original DESI data products).

For each combination of survey and program, in addition to catalogues of parameters measured from spectra grouped by HEALPIX pixels on the sky, we also provide a combined catalogue of all objects observed that given survey and program. For example, rvpix-sv2-backup.fits includes one row for every target in the 'backup' program of the SV2 survey. These catalogues are concatenated rvtab files from different HEALPIX pixels and thus have the same structure as the individual rvtab tables.

4.2 SP data products

As for RVS, the SP output consists of two files per input spectral file with coadded DESI spectra. One output is the sptab file, which is the table of measurements from FERRE, and the other is the spmod file, which contains the best-fitting model for each spectrum. The spmod files, unlike the RVS outputs, provide continuum-normalized observed spectra, along with their uncertainties, the continuumnormalized best-fitting models, and the model absolute fluxes.

The sptab file is a FITS table with four extensions: SPTAB, FIBERMAP, SCORES, and AUX. The SPTAB extension contains the main measurements from FERRE and several additional quantities helpful for cross-matching with other data products. The FIBERMAP and SCORES extensions are copied directly from the main DESI data products – they are identical to the extensions with the same names in the rvtab files. Table A2 gives a complete description of all the fields included in the SPTAB extension, but we provide a summary of the most relevant ones below:

(i) FEH, ALPHAFE, LOG10MICRO, TEFF, and LOGG are the main atmospheric parameters: [Fe/H], [α /Fe], micro-turbulence, effective temperature, and surface gravity. These values are also stored, in this order, in the array PARAM (see below), and their covariance matrix is provided in COVAR.

(ii) ELEM and ELEM_ERR are arrays with the Fe, Ca, C, and Mg abundances and their estimated uncertainties, respectively. See Section 6 for caveats on the Ca, C, and Mg abundances.

(iii) CHISQ_TOT is the reduced χ^2 of the best-fitting model for the entire (continuum-normalized) spectrum.

(iv) REF_CAT and REF_ID are the source catalogue names and the corresponding identifiers in those catalogues used for targeting – the same as in the RVTAB extension.

(v) TARGET_RA, TARGET_DEC are the coordinates of the object.

main MWS catalogue (Section 4.3). This is because REF_ID is incorrect for some secondary targets due to a software bug with the fibre assignment code. ¹⁸We remark that different objects observed by DESI are guaranteed to have different TARGETID, but it is possible for the same source to have more than one TARGETID.

¹⁵The FIBERMAP extension contains the targeting information, including DESI Legacy Imaging Survey fluxes, *Gaia* DR2 parameters and targeting bitmasks. The SCORES extension contains quality statistics for the spectra. ¹⁶https://www.legacysurvey.org/sga/sga2020/

(vi) TARGETID is the DESI target identifier.

(vii) SNR_MED gives the median signal-to-noise of the spectrum across B, R, and Z arms.

(viii) PARAM is the vector of atmospheric parameters ([Fe/H], $[\alpha/Fe]$, \log_{10} of microturbulence velocity, $T_{\rm eff}$, $\log g$).

(ix) COVAR Covariance matrix for the parameter vector given in PARAM column.

 (\boldsymbol{x}) SRCFILE is the file name with the DESI spectrum that was fitted.

(xi) BESTGRID is the stellar model grid that provided the best fit to the spectrum. Possible values are'm_rdesi1' to'm_rdesi5' for Kurucz models,'m_rdesi6' to'm_rdesi9' for Koester white-dwarf models, or's_rdesi1' for PHOENIX models.

(xii) RV_ADOP, RV_ERR are the radial velocity and its uncertainty (adopted from the RVS fits) when shifting the spectrum to the rest frame.

The AUX extension of the sptab files includes two string arrays: the p array gives the names of the parameters in the order included in the PARAM array and the COVAR matrix, and the e array gives the names of the chemical elements included in the ELEM and ELEM_ERR arrays.

The model spmod files are FITS files with nine extensions: B_WAVELENGTH, R_WAVELENGTH and Z_WAVELENGTH, which store the wavelengths arrays, the B_MODEL, R_MODEL, Z_MODEL, which hold the model spectra and related quantities, the FIBERMAP and SCORES extensions, already mentioned in the description of the sptab files, and a FILTER extension, which contains the concatenated arrays of weights for the B, R, and Z channels used for determining elemental abundances.

The model extensions (B_MODEL, R_MODEL, and Z_MODEL) contain multiple columns:

(i) The OBS column in the tables gives the continuum-normalized observed spectrum resampled to rest-frame.

(ii) The ERR column stores the uncertainties on the continuum normalized resampled spectrum.

(iii) The FIT column contains the best-fitting continuumnormalized stellar model obtained from the first step described in Section 3.4, corresponding to the determination of the stellar parameters.

(iv) The ABU column is similar to the FIT column, but for the fitting obtained in the second step (abundances determination). There is only one ABU array but multiple elements, so the data are overwritten in the order given in the ELEM array, chosen to ensure that values corresponding to elements with fewer spectral lines are written last. The FLX column stores the un-normalized absolute flux model corresponding to the best-fitting parameters of the star.

Similar to the RVS outputs, we provide combined catalogues of objects observed in a given survey and program, for example sppix-sv2-dark.fits. These are constructed by concatenating sptab files and thus have a similar structure as the individual sptab files, but without the AUX extension.

4.3 Main combined catalogue

In addition to the catalogues of measurements for targets grouped by DESI survey/program and HEALPIX pixel, we also provide a combined catalogue of measurements from RVS and SP pipelines, including all the surveys and programs that are part of the DESI EDR. This main catalogue is a FITS table named mwsall-pixfuji.fits. The main catalogue also includes additional *Gaia* DR3 cross-match information. We expect the main combined catalogue to be the most frequently used data product in the DESI MWS VAC. The catalogue contains 625 588 rows.

The combined table contains the following extensions: RVTAB, SPTAB, FIBERMAP, SCORES, and GAIA. The RVTAB extension includes all the columns listed in Section 4.1, as well as a few additional columns:

(i) PROGRAM identifies the program from which the star came from (i.e. dark, bright, backup, or other).

(ii) SURVEY identifies the survey from which the star came from (i.e. SV1, SV2, SV3, or CMX).

(iii) HEALPIX is the HEALPIX pixel (at nside = 64) of the star. (iv) PRIMARY is the flag that is set to true if this specific measurement was labelled as primary (because the same star could have been observed in different surveys and programs). The observation with the largest signal-to-noise in the R arm is selected as primary.

(v) ${\tt RR}_{-}{\tt Z}$ is the redshift from Redrock.

(vi) RR_SPECTYPE is the spectroscopic type of the object, such as STAR, QSO, GALAXY as provided by Redrock.

The SPTAB extension in the catalogue contains measurements from the SP pipeline as described in Section 4.2. The FIBERMAP and SCORES extensions store information relevant to targeting and spectral quality, respectively (see Guy et al. 2023). Finally, the GAIA extension in the file contains *Gaia* DR3 measurements for each source in the catalogue (we provide all the columns from the gaia_source table). *Gaia* sources have been associated with DESI targets by on-sky position (using a radius of one arcsecond).

5 CATALOGUE OVERVIEW

In this section, we provide an overview of the contents of the MWS VAC catalogue, demonstrate how it could be used for science, and discuss some of its limitations.

5.1 Selecting clean stellar samples

Because the list of criteria used to identify potential objects for fitting by the stellar pipeline (described in Section 3) is deliberately broad and designed not to miss any stellar targets, the MWS catalogue contains a significant number of sources that are not stars.

In this section, we provide several methods to identify mostly clean samples of stars using values provided in the VAC tables. These criteria are not meant to be exhaustive or optimal because different science cases may have different requirements for purity and completeness.

(i) $RVS_WARN = 0$ selects objects for which RVSPECFIT obtained a satisfactory fit to the DESI spectrum. This selects most stellar spectra, but this is not a particularly pure selection because it accepts a fraction of QSOs and galaxies.

(ii) RR_SPECTYPE = STAR selects on the Redrock classification of an object as a star. This is a robust classification, but it is limited by the condition imposed by Redrock that stars have radial velocities between -600 and 600 km s⁻¹.

(iii) (DESI_TARGET & MWS_ANY)> 0^{19} selects objects with the MWS_ANY targeting bit set, which means that the source was targeted for the MWS. This removes a large number of non-stellar objects but also retains a significant number of QSOs that fall in the MWS MAIN-BLUE and BROAD selections.

¹⁹Where MWS_ANY = 2^{61} as specified in Table 3.

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RR_SPECTYPE	$RVS_WARN = 0$	Number
STAR	True	511 809
STAR	False	4454
GALAXY	True	13911
GALAXY	False	61 677
QSO	True	10336
QSO	False	23 401



Figure 1. The distribution of line of sight velocities for different subsamples in the VAC. The distributions highlight alternative ways of selecting stellar objects from the catalogue. The black line shows the distribution of objects with RVS_WARN = 0. These comprise mostly stars, with a few per cent contamination by non-stellar sources that produce flat tails in the distribution out to $\pm 1500 \text{ km s}^{-1}$. The red line shows the distribution of objects with RVS_WARN $\neq 0$. These are almost uniformly distributed in velocity, confirming that they are not stars. The pink curve shows the distribution for objects with RVS_WARN = 0 that were targeted for the MWS survey; the green curve shows the distribution for objects with RVS_WARN = 0 that were classified as star by Redrock (i.e. RR_SPECTYPE = STAR). The latter sample has the least contamination; these criteria should be used to select stars in the MWS VAC unless stars with $|V_{\text{los}}| > 600 \text{ km s}^{-1}$ are of interest.

In Table 12, we provide the number of objects in the catalogue with different spectroscopic classifications from Redrock, depending on whether RVS_WARN = 0 is true or not. The table shows that the number of non-stellar objects in the MWS VAC EDR catalogue is \sim 20 per cent.

Fig. 1 shows the distribution of radial velocities as measured by RVS and reported in the MWS VAC. We show separately the distributions for objects with RVS_WARN = 0 and RVS_WARN $\neq 0$ (black and red lines, respectively), illustrating that objects with RVS_WARN $\neq 0$ do not concentrate at $V_{\rm los} = 0 \,\rm km \, s^{-1}$. This indicates that objects with RVS_WARN $\neq 0$ are either not stars or unlikely cases of a bad fit by the RVS pipeline. The figure also shows that an additional constraint on the spectroscopic type from Redrock (green line) or on selection as an MWS target (pink line) results in a velocity distribution concentrated mostly within $|V_{\rm los}| < 600 \,\rm km \, s^{-1}$, implying a cleaner stellar selection.

For the rest of this paper, we will use the $RVS_WARN = 0$ and $RR_SPECTYPE = STAR$ selection to identify stellar targets as well as the PRIMARY = True flag to exclude duplicate observations.



Figure 2. The density on the sky of stellar targets in the value-added catalogue. The density is shown in units of stars per square degree. The dashed line shows the Galactic plane. Individual DESI pointings are easily discernible on the map as 3-degree diameter circles.

This leaves 421 403 individual sources out of 625 588 in the combined catalogue. Additional cuts will be noted where relevant.

A few further selection cuts are recommended for restricting the sample to the highest-quality measurements. These are described in Appendix A for SP and in Appendix B for RVS.

5.2 Spatial and colour-magnitude distribution

The distribution of VAC stars on the sky is shown in Fig. 2. The colour on this map shows the density of observed targets, which varies from a few hundred to a few thousand per square degree, depending on which surveys (SV1, SV2, or SV3) and programs covered a particular area. The density is highest in dedicated MWS fields (described in Section 2.5) and SV3 areas, which have high completeness for all target classes. In areas of the sky that were not observed by the bright SV programs, the target density is typically small. Stars in these fields were only observed as flux standards or secondary targets or as contaminants to other DESI target selections.

The colour-magnitude diagram of stars from all the surveys and programs included in the VAC is shown in Fig. 3. This figure highlights several aspects of target selection discussed in Section 2. A common feature of all these colour-magnitude distributions is the area populated by DESI flux calibration standard stars, with $g - r \sim 0.4$ and $15 \leq r \leq 19$. These targets are included in both dark and bright observations. In the bright program observations, the colour-magnitude distribution shows the main MWS selection in the magnitude range 16 < r < 19 and fainter extensions to r < 20 explored during SV.

Fig. 4 illustrates the distribution of stars from the VAC in Galactocentric coordinates using photo-geometric distance estimates from Bailer-Jones et al. (2021).²⁰ The top two panels show the 2D number density of stars in Galactocentric *x* versus *y* and *x* versus *z*. The distribution shown in this figure is only valid within ~ 10 kpc of the Sun because the distances from Bailer-Jones et al. (2021) are not robust enough for more distant targets. The bottom row of the figure shows the distribution of stars in the same coordinates, but

²⁰We assume the distance to the Galactic centre $R_0 = 8.277$ kpc (GRAVITY Collaboration 2022), and the solar height with respect to the Galactic plane $z_0 = 20.8$ pc (Bennett & Bovy 2019).



Figure 3. Hess diagrams of stellar targets in the VAC observed in different surveys and programs. The bright stars with $g - r \sim 0.4$ are those used by the DESI survey as flux calibration standards. As the main MWS survey targets are only observed in bright time, the main 16 < r < 19 selection is only seen in the bright SV programs (as well as in SV1/other, which was used for some dedicated MWS tiles). In the dark program, stellar targets are observed either as standards, secondary targets or stellar contaminants from other cosmological target selections.



Figure 4. Spatial distribution of stars from the DESI EDR value-added catalogue in Galactocentric coordinates x - y (left) and x - z (right), in 200 × 200 bins. The panels are colour-coded by the numbers of stars per bin (top) and mean [Fe/H] (bottom) from the RVS pipeline. The solid contours show iso-potentials of the barred Milky Way model of Hunter et al. (2023; in preparation). The distribution is based on distances from Bailer-Jones et al. (2021) and thus shows only the nearby part of the DESI sample.

now colour-coded by mean [Fe/H] from the RVS pipeline. The solid contours show the iso-potentials of the barred Milky Way model of Hunt et al. (in preparation), built with the Agama library (see Vasiliev 2019) – see also Sormani et al. (2022). The figure illustrates the Galactic volume probed by the majority of the DESI EDR stellar sample, with most stars at high galactic latitudes. Although a significant part of the DESI EDR sample shown in the figure is within a Galactocentric distance of ~ 15 kpc, a large number of stellar targets in the VAC sample of the Milky Way stellar halo out to distances of ~ 100 kpc. This is not visible in the figure due to



Figure 5. The distribution of surface gravity and effective temperatures for stars in the MWS VAC as determined by the RVS and SP pipelines. The parameter range shown here is smaller than the actual range of measured parameters; the RVS maximum temperature extends to $15\,000$ K and SP to $40\,000$ K. The SP pipeline also models white dwarfs, which can have log g up to 9.5 and are not shown here.

the distance estimator used (better distance estimators are currently being developed). The bottom panels of the figure also illustrate that we recover the expected decrease in mean [Fe/H] further from the disc mid-plane (|z|), with high-|z| halo stars typically having [Fe/H] $\lesssim -1$.

5.3 Stellar parameter distribution

All of the stars in the MWS VAC have stellar parameter measurements from both the SP and RVS pipelines. We provide measurements of log g, $T_{\rm eff}$ and [Fe/H] (as well as other parameters described in Sections 4.1 and 4.2).

In Fig. 5, we show the distributions of surface gravity and effective temperature (Kiel diagrams) for stars in the VAC, as measured by the RVS (left) and SP pipelines (right). The distributions are similar



Figure 6. The distribution of iron abundances for stars in the MWS VAC as determined by the RVS and SP pipelines. The distribution shows the peak associated with thick disc stars at [Fe/H] = -0.5, the peak associated with GSE at [Fe/H] = -1.2 and metal-poor stellar halo at lower metallicities. The distributions are shown with the bin size of 0.1 dex. Due to gridding issue associated with the RVS measurements, would the plot be made with much smaller bins (i.e. 0.01 dex), we would see peaks at location of template grid with the step of 0.25 dex.

and show features that are expected, such as the red giant branch (extending from log g = 4, $T_{\text{eff}} = 5500$ K to log g = 1, $T_{\text{eff}} = 4000$ K), the blue horizontal branch (log $g \sim 3$, $T_{\text{eff}} > 6$, 500 K) and the main sequence (log g < 4, $T_{\text{eff}} < 6000$ K). The shape of the main sequence below the turn-off, however, is not very realistic and is likely dominated by systematic effects from the stellar atmospheric grids used in our pipelines. Both pipelines show clustering around grid points in log g and T_{eff} . In addition, the SP pipeline also shows problematic clustering at $T_{\text{eff}} = 5000$ K and log g = 5. Some of these SP artefacts mostly disappear when using stricter selections described in Appendix A.

In Fig. 6 we show the distribution of iron abundances for all the unique DESI stars. We display the distribution for abundances from both RVS and SP pipelines. The metallicity distribution function (MDF) shows that the majority of stars is in the thick disc with [Fe/H] ≈ -0.5 , but with about 25 per cent of stars having metallicities below -1. The metallicity distribution for metal-poor stars shows the peak at [Fe/H] ≈ -1.2 which would be the Gaia-Sausage-Encelladus (GSE) structure (Belokurov et al. 2018; Helmi et al. 2018). At low metallicities the MDF extends like a power-law down to [Fe/H] = -3.5 as expected for the Milky Way stellar halo (Youakim et al. 2020). The metallicity distributions from RVS and SP do agree, although due to issues highlighted earlier, we see some discrepancies for very metal-rich stars, as well as accumulation at the edges near [Fe/H] = -4 for RVS and [Fe/H] = -3.5 for SP.

5.4 Parameter validation with APOGEE

Here, we compare our stellar parameter measurements with the parameters from the APOGEE survey in more detail than Cooper et al. (2023). The APOGEE results are of high quality (high-resolution and high signal-to-noise) and based on H-band spectroscopy. Jönsson et al. (2018) has shown good agreement between the APOGEE results and high-resolution optical studies in the literature, although systematic differences are apparent for some elements. We specifically take the APOGEE DR17 measurements from Abdurro'uf et al. (2022) and cross-match them with the MWS



Figure 7. Comparison of RVS and SP parameters to APOGEE measurements is shown as a function of APOGEE effective temperature. Each panel shows in greyscale shows the 2D histograms of $\delta X = X_{\text{DESI}} - X_{\text{APOGEE}}$ (where X is [Fe/H] for the top panel, log *g* for the second panel, T_{eff} for the third panel and [α /Fe] for the bottom panel) versus effective temperature. Solid curves show the median residual with respect to APOGEE, and dashed curves show the 16th and 84th percentiles of the distribution. Inset boxes report the median value of the offset with respect to APOGEE for the whole sample.

VAC. In the APOGEE catalogue, we exclude measurements with the STAR_BAD flag set. In the MWS VAC, we use the selection given in Section 5.1. After these cuts, we have 507 stars in common between APOGEE and the MWS VAC.

Fig. 7 shows the residuals between RVS and SP measurements of log g, $T_{\rm eff}$, $[\alpha/Fe]$ and [Fe/H] and the corresponding measurements from APOGEE. The residuals are plotted as a function of the effective temperature from APOGEE. We also show the median (solid line) and the 16/84 percentiles of the residuals (dashed lines). The annotation in each panel gives the median and 16/84 percentiles of the residuals for the whole DESI×APOGEE data set.

The figure shows that, for both RVS and SP, the typical scatter in [Fe/H] with respect to the high-resolution APOGEE measurements is ~ 0.15–0.2 dex with a small bias. There are no significant trends of [Fe/H] with temperature, but the metallicities seem more robust for warmer stars with $T_{\rm eff}$ > 4800 K. The surface gravity measurements show strong systematic trends with temperature. At $T_{\rm eff}$ ~ 4500 K the RVS log g deviation reaches –0.5, and at a similar temperature, the SP systematics in log g switch from positive to negative bias

with respect to APOGEE. The effective temperatures for RVS and SP show good agreement with APOGEE for cool stars but show ~ 200 K bias for hotter stars. With $[\alpha/Fe]$ the typical agreement with APOGEE for both RVS and SP is around 0.1 dex, although the dynamic range of $[\alpha/Fe]$ in the DESI/APOGEE overlap sample is quite small (~ 0.4 dex). The $[\alpha/Fe]$ measurements from RVS seem more biased than SP and there is a subset of stars with large $[\alpha/Fe]$ deviation at $T_{\rm eff} = 4000$ K.²¹

Although Fig. 7 shows systematic trends with temperature, the trends with surface gravity are also important. For example, there is an indication that PHOENIX-based measurements are biased for log g < 2. However, since the EDR data set does not overlap enough with high-resolution surveys like APOGEE to investigate systematics as a function of multiple variables, we postpone a more detailed analysis of these systematics to future data releases.

The comparison of abundance and stellar parameter measurements in APOGEE presented here is mostly demonstrating the systematic offsets of DESI measured parameters as opposed to random errors. As shown in Cooper et al. (2023; fig. 14) the [Fe/H] uncertainty is a strong function of magnitude and colour, reaching values of ~ 0.3 dex for blue stars at the faint r = 19 limit.

5.4.1 Radial velocity comparison with APOGEE

In the overview paper, we analysed the overall quality of radial velocities and radial velocity errors (fig. 11 in Cooper et al. 2023). The analysis of repeated observations showed that the velocity errors provided by RVSPECFIT correctly characterise the velocity uncertainties if we take into account the systematic error floor of 0.9 km s⁻¹. We do not repeat this analysis here because it should also apply to the data in the EDR. However, it is worthwhile to check for any systematic velocity offset with respect to other data sets.

In Fig. 8, we compare the distribution of radial velocity differences against APOGEE using the same sample as our investigation of the stellar parameters above. This shows that DESI radial velocities have a small bias of 0.93 km s⁻¹ (i.e. DESI radial velocities are larger than APOGEE velocities by 0.93 km s⁻¹). We do not apply this correction in the VAC, so users should consider subtracting 0.93 km s⁻¹ from DESI velocities to bring them to the same frame as APOGEE.

5.5 Chemo-dynamic studies with DESI stars

Here, we look at the spectroscopic abundance measurements in combination with the orbital properties of stars to demonstrate the power of data included in the MWS VAC for chemical analyses of the Milky Way disc and stellar halo (similar to e.g. Mackereth et al. 2019). Fig. 9 shows the [Fe/H] versus $[\alpha/Fe]$ distributions for stars in the VAC. The top panels show the density of stars in [Fe/H] versus $[\alpha/Fe]$ space, while in the bottom panels, we colour each pixel by the average orbital eccentricity of stars in those pixels. The left and right panels show measurements from the RVS and SP pipelines, respectively.

Looking at the distribution of abundances in the top left panel of the figure, we notice very clear gridding effects in RVS param-



Figure 8. The histogram of differences between DESI RVS and APOGEE radial velocity measurements. The distribution shows a small bias, such that velocities from DESI are ~ 0.93 km s⁻¹ larger than those from APOGEE.



Figure 9. Chemical map ([Fe/H]-[α /Fe]) from the RVS (left) and SP (right) pipelines, in 150 × 150 bins. The panels are colour-coded by the number of stars per bin (top) and by the eccentricity (bottom) $(r_{apo} - r_{per})/(r_{apo} + r_{per})$, where r_{apo} and r_{per} are the apo- and pericenter radii. Orbits were integrated for 10 Gyr in the potential model of McMillan (2017), using photo-geometric distances from Bailer-Jones et al. (2021).

eters, with steps of 0.25 dex in [Fe/H] and 0.2 dex in $[\alpha/Fe]^{22}$ Despite this gridding, the overall distribution closely resembles that obtained by higher resolution spectroscopic surveys (e.g. APOGEE – see Abdurro'uf et al. 2022), with the region [Fe/H] < -1 being typically populated by halo stars and the region [Fe/H] > -1 being typically split into an $[\alpha/Fe]$ -rich track ($[\alpha/Fe] \gtrsim 0.2$) and an $[\alpha/Fe]$ -poor track ($[\alpha/Fe] \lesssim 0.2$). The $[\alpha/Fe]$ -poor and $[\alpha/Fe]$ rich sequences can be seen in the figure separated at $[\alpha/Fe]$ of 0.15

²¹This particular feature was caused by a few problematic stellar atmospheres in the PHOENIX grid. Those stellar atmospheres have since been removed, and the problematic feature disappears in more recent reductions of the DESI data.

²²The gridding in measured parameters is caused by the use of multilinear interpolation over a rectangular grid in the space of parameters. This interpolation is continuous but does not produce continuous first derivatives, leading to clumping at the edges of interpolation grid cells. This will be addressed in future DESI MWS data releases.



Figure 10. The distribution of stars in the MWS VAC around Draco dSph in [Fe/H] and line of sight velocity. Here, we use only stars with membership probabilities based on *Gaia* data, computed by Pace, Erkal & Li (2022). Greyscale shows the 2D histogram of all the stars with membership measurement from Pace et al. (2022). The stars with high membership probability P > 0.5 are shown in red. The total number of likely Draco members is ~ 260 stars.

at [Fe/H] = -0.5. The halo stars are seen as less dense part of the distribution at [Fe/H] < -1 and $[\alpha/Fe] \sim 0.5$. The distribution of SP abundances (top right panel) does not show gridding effects but resembles less closely the halo/ $[\alpha/Fe]$ -rich/ $[\alpha/Fe]$ -poor distribution of APOGEE. We also note a clustering of stars at [Fe/H] = 0 and $[\alpha/Fe] \sim 0$ that is not physical.

The bottom panels of Fig. 9 show the same distribution as the top panels but are colour-coded by the average eccentricity of orbits for these stars. To compute orbits, we use *Gaia* DR3 astrometry and the photo-geometric distances from Bailer-Jones et al. (2021) (without applying any quality cuts on the distances). Orbits were integrated for 10 Gyr in the Milky Way potential of McMillan (2017) with the same parameters for the position of the Sun in the Galaxy as in Section 5.2 and assuming $U_{\odot} = 9.3 \text{ km s}^{-1}$, $V_{\odot} + V_c(R_0) = 251.5 \text{ km s}^{-1}$, and $W_{\odot} = 8.59 \text{ km s}^{-1}$, from (Reid & Brunthaler 2020; GRAVITY Collaboration 2022).

Overall, both the RVS and SP chemical maps show the same chemo-dynamical correlations observed in other spectroscopic surveys in combination with *Gaia*: intermediate metallicity halo stars dominated by the Gaia-Enceladus-Sausage merger (Belokurov et al. 2018; Helmi et al. 2018) typically have eccentricities ≥ 0.8 , while the $[\alpha/Fe]$ -rich ($[\alpha/Fe]$ -poor) stars have intermediate (low) eccentricities, in close connection to the thick and thin disc, respectively – see Fig. 4. While in this data we may also expect to see separation of the GSE from other parts of the accreted halo (Feuillet et al. 2021; Hasselquist et al. 2021), given the current quality of $[\alpha/Fe]$ measurements we can not make such a separation. We also note that in our analysis did not take into account the survey selection function which can affect Fig. 9. One reason it may play a role is because the MWS_MAIN_BLUE sample, which constitutes a substantial fraction of the catalogue is colour selected (hence is biased towards more metal-

poor stars), but has no astrometric selection. The complementary red MWS_MAIN_RED sample is selected using colour, but also uses astrometry to exclude more nearby stars. This will affect significantly the distribution shown on the figure by down-weighting the metalrich disc population.

5.6 Draco dwarf galaxy dedicated fields

As mentioned in Section 2 and shown in Table 11, this VAC includes not only observations that follow the regular DESI MWS strategy but also multiple dedicated fields placed on stellar streams, star clusters and dwarf galaxies. While a detailed exploration of the data from these observations is beyond the scope of this paper, here we provide a demonstration of measurements from fields centred on the Draco dwarf spheroidal galaxy.

Fig. 10 shows the distribution of stars in the MWS VAC in [Fe/H] and radial velocity space in the vicinity of Draco. We only plot stars with Draco membership probability estimates from Pace et al. (2022), which were computed based on *Gaia* DR3 astrometry. The total number of stars in common with the membership catalogue is ~ 950. The greyscale in the figure shows the 2D distribution of velocity and metallicity for these potential member stars. There is a broad distribution from halo contaminants and a peak associated with Draco stars near $V_{\rm los} \sim -290 \,\rm km \, s^{-1}$ and [Fe/H] ~ -2 . Red points in the figure show stars with a membership probability from Pace et al. (2022) $P_{\rm mem,fixed_complete} > 0.5$. Almost all high-probability member stars are clustered around Draco's radial velocity and metallicity, indicating that they are very likely Draco members.

By looking at the metallicity distribution of Draco member stars in DESI, we find a median metallicity of $[Fe/H] \approx -2.25 \pm 0.03$, which at face value seems to differ significantly (by ~ 0.3 dex) from the median metallicity of -1.93 ± 0.01 reported by Kirby et al. (2011). However, Kirby et al. (2011) measured a significant metallicity gradient in Draco of ≈ -0.73 dex deg⁻¹. The median angular distance of the member stars in the DESI sample from the centre of Draco is ~ 0.25 degrees, as opposed to ~ 0.1 degrees for the literature sample, owing to the large field of view of DESI. This metallicity gradient can, therefore, explain at least ~ 0.1 dex of the discrepancy between Kirby et al. (2011) and the DESI measurement. In fact, the median metallicity of the DESI members within 0.1 degrees is -1.97 dex perfectly consistent with previous measurements.

The total number of Draco members detected in DESI is ~ 260 , which is comparable in size to the existing literature data sets on Draco (see e.g. Kirby et al. 2010; Walker, Olszewski & Mateo 2015). However, our sample extends much further in radius, highlighting the power of the DESI survey for observations of the outskirts of dwarf galaxies.

5.7 Wide binaries

A final demonstration of the catalogue utilizes an astrometrically selected set of wide binaries.

Since wide binaries are expected to share almost the same chemical compositions (Duchêne & Kraus 2013) and have similar kinematics, these pairs should provide an additional internal consistency check on our stellar parameter measurements. To perform this test, we cross-match a subset of EDR VAC stars, selected to have good-quality measurements in radial velocities and metallicities, to the wide binary catalogue from *Gaia* EDR3 by El-Badry et al. (2021). In addition to the selection criteria introduced in Section 5.1, we impose the following requirements:



Figure 11. Comparison of stellar parameters from the RVS and SP pipelines between the primary and secondary star for 477 wide-binary pairs from El-Badry, Rix & Heintz (2021) with high confidence of being physical binaries ($R_{chance.align} < 0.1$). The panels show the distribution of differences in the radial velocities (a), the distribution of differences in metallicity measurements (b), and scatter plots (c and d) displaying metallicities colour-coded by temperature differences. Note that SP metallicities are available for 453 pairs.

 $\begin{array}{l} (i) \ \text{CHISQ_TOT} < 5 \\ (ii) \ \text{SNR_MED} > 5 \\ (iii) \ \sigma(V_{rad}) < 20 \ \text{km s}^{-1} \\ (iv) \ [\text{Fe}/\text{H}]_{\text{RVS}} > -3.9 \ \text{dex} \\ (v) \ [\text{Fe}/\text{H}]_{\text{SP}} > -4.9 \ \text{dex} \\ (vi) \ R_{\text{chance_align}} < 0.1. \end{array}$

These criteria select 477 high-confidence wide-binary pairs. We take the definition of 'primary' (P) and 'secondary' (S) from El-Badry et al. (2021), which designate the brighter and fainter member in each pair, respectively, in the *Gaia G* band. In a majority of pairs, both primary and secondary stars are on the main sequence and are K or M dwarfs. In the MWS VAC, all of these pairs have radial velocity and metallicity measurements from RVS, while metallicities measured from the SP pipeline are available for 453 pairs.

Fig. 11 presents a comparison of stellar parameters from the RVS and SP pipelines. Panel (a) shows the distribution of $\Delta V_{\text{rad}} = V_{\text{rad, S}} - V_{\text{rad, P}}$, the velocity difference between secondary and primary. Panel (b) presents the distribution of the metallicity difference, Δ [Fe/H] = [Fe/H]_S - [Fe/H]_P, while panels (c) and (d) are scatter plots of individual metallicity measurements, colour-coded by the differences in effective temperatures, i.e. $\Delta T_{\text{eff, S}} - T_{\text{eff, P}}$.

The figure shows no significant difference between the radial velocity measurements of primary and secondary stars, with a small standard deviation of 1.84 km s^{-1} (measured from the 16th to 84th percentile range of the distribution). Some of that dispersion can be attributed to orbital motions and some to the individual radial velocity uncertainties, which are $\sim 2 \text{ km s}^{-1}$ for this sample.

Fig. 11(b)–(d) show that the distributions of Δ [Fe/H] in both the RVS and SP pipelines have noticeable scatter between the measurements for primary and secondary stars. Notably, however, the Δ [Fe/H] values measured from the RVS pipeline have a standard deviation of 0.16 dex. This is comparable with the spread we obtained when comparing DESI measurements to APOGEE measurements. The distribution of Δ [Fe/H] from the SP pipeline, however, shows a significantly wider spread with a dispersion of 0.31 dex. A similar picture can be seen in panels (c) and (d), where we plot the metallicity of the primary against the metallicity of the secondary for RVS and SP measurements. Here, larger scatter in SP metallicities is mostly caused by issues associated with cool stars, discussed in Section 5.3 and the next section.

6 KNOWN LIMITATIONS

In previous sections, we have described the contents of the MWS VAC, demonstrated the quality of DESI measurements and provided examples of scientific applications of the data. This section focuses on known issues and limitations in the catalogue that users should know.

(i) The distribution of parameters measured by RVSPECFIT shows concentrations at the edges and nodes of the underlying grid of stellar atmospheres. Since the code relies on multi-linear interpolation of the over-sampled PHOENIX grid, the [Fe/H] grid step of 0.25 dex leads to concentrations of measurements at [Fe/H] = -4, -3.75 and so forth. Concentration at the grid points is more likely for bright stars. Despite this gridding, the overall accuracy of the [Fe/H] abundances is $\sim 0.1 - 0.2$ dex, as demonstrated in Section 5.4. The concentration of measurements around grid points is also observed for log *g*, *T*_{eff} and [α /Fe]. Because of this, we believe that the uncertainties on stellar parameters in the RVS catalogue are likely underestimated and not well described by a Gaussian.

(ii) Both RVS and SP metallicities display an excess of objects at the lower limit of their metallicity grids, [Fe/H] = -4 and -5, respectively. At least some of these measurements are caused by the spectra that cannot be fit by regular spectral models (i.e. they are non-stellar or otherwise unusual).

(iii) The SP parameter distributions exhibit artificial concentrations at the boundary of the PHOENIX grid used for cool stars (see Fig. 9). For this reason, we recommend avoiding using the SP parameters for stars analysed with that grid, as described in Appendix A.

(iv) The [α /Fe] abundances for dwarfs cooler than about 4000 K as measured by SP show concentration at values in the range $-0.1 < [\alpha/Fe] < 0.0$ and -0.6 < [Fe/H] < -0.3. We believe this is an artefact and discourage using the SP results for those stars, as described in Appendix A.

(v) The carbon and magnesium abundances reported by the SP pipeline are unreliable. The reason carbon abundances are not trustworthy is because of an issue with the coating of the DESI blue collimators, which creates a throughput artefact in many spectra around 4300 Å (see e.g. fig. 26 in DESI Collaboration 2022). This is the region of the CH absorption band, which is the most important indicator of carbon abundance in late-type stars at the resolution of DESI. While the abundances of iron and calcium

show a good correlation with the [Fe/H] and $[\alpha/Fe]$ parameters derived by the same pipeline, that is not the case for magnesium. We, therefore, recommend not using the abundance of carbon or magnesium included in the EDR MWS VAC.

(vi) When looking for high-velocity stars, the spectral classification by Redrock cannot be used because Redrock assumes stars have velocities $|V_{\rm los}| < 600 \,\rm km \, s^{-1}$. That means that other criteria described in Section 5.1 should be used instead. However, these selections are more contaminated by non-stellar sources (QSOs and galaxies) than the criteria we recommend for general use.

(vii) $v \sin i$ measurements of stellar rotation velocity provided by RVSPECFIT are problematic in this release. The rotational broadening measurement sometimes compensates for the inability of the model to fit some objects. For example, measurements of white dwarfs by the RVSPECFIT tend to have high inferred $v \sin i$. In addition, due to a software bug in the processing discovered during the preparation of this manuscript, $v \sin i$ measurements are biased to higher values for stars with higher line of sight velocities, $V_{\rm los} > 50 \, {\rm km \, s^{-1}}$ especially at low signal to noise. Thus, we recommend not to use $v \sin i$ values in this release.

(viii) Although the SP and RVS pipelines fit spectra of white dwarfs, these pipelines are not fully optimized for that purpose. SP uses both hydrogen-rich atmosphere (DA) and helium-rich atmosphere (DB) white dwarf model grids provided by Koester (2010), whereas RVS does not have dedicated white dwarf models and instead uses regular stellar models and compensates for the pressure-broadened absorption features by increasing $v \sin i$ as noted above. While the majority of white dwarfs tend to have pure hydrogen DA-type spectra, many have more complex spectral features such as metal pollution, strong magnetic fields or molecular carbon from core dredge-up (see fig. 2 of Cooper et al. 2023). Dealing with these complications is beyond the scope of the SP and RVS pipelines. The DESI EDR white dwarf systems will be described separately in a future paper Manser et al. (2024).

7 CONCLUSIONS

This paper presents the first value-added catalogue of stellar measurements based on the DESI Early Data Release, published in 2023 June. The MWS VAC data set includes over half a million spectra for more than 420 000 unique stars with a typical brightness $16 \leq r \leq 20$. We have described the different target types for the main DESI stellar survey and reviewed additional targets and special fields that were observed during SV and included in the EDR data set.

As described in Cooper et al. (2023), two stellar analysis pipelines have been developed for the DESI MWS. These pipelines were run on the EDR data set to obtain the radial velocities, chemical abundances and stellar parameters included in the MWS VAC. By comparing these measurements with earlier high-quality reference catalogues, we conclude that our reported radial velocities are accurate to approximately 1 km s⁻¹, metallicities to 0.15 dex, effective temperatures to 200 K, surface gravities to about 0.3 dex, and [α /Fe] to about 0.1 dex.

We have identified a number of limitations in this release of the MWS VAC, and provided a recommended set of criteria that can be used to select a high-quality subset of the data. At this point, the quality of the parameters measured by the RVS and SP pipelines is similar, each having its own benefits and drawbacks. We, therefore, do not provide a definite recommendation to use either set of parameters beyond the caveats listed in Section 6.

Despite some limitations in the value-added catalogue, it can already be used in many studies, including chemo-dynamical studies of the Milky Way halo and analyses of stellar streams and dwarf galaxies within the DESI EDR footprint.

As of the writing of this paper, DESI is progressing into its third year of observations, with regular data releases planned over the coming years. The stellar data included in the DESI EDR is a very small fraction of the total expected data set. Future data releases will include spectra and results for several million stars. Ongoing development of the analysis pipelines is expected to address the issues described in this paper, although few changes are expected in the data model and the target selection criteria. Therefore, we believe this value-added catalogue based on the EDR data set should be useful for the community, in particular to prepare for the scientific exploration of the full DESI MWS.

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Software: ASTROPY (Astropy Collaboration 2013, 2018, 2022).

DATA AVAILABILITY

All the data shown in the published graphs or necessary to reproduce them are available in a machine-readable form on Zenodo https://do i.org/10.5281/zenodo.10498911. The value-added catalogue itself is available at https://data.desi.lbl.gov/doc/releases/edr/vac/mws/.

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APPENDIX A: SELECTION CRITERIA OF THE MAIN MWS TARGETS IN SV3

In this appendix we provide the selection criteria for the SV3 targets. The selection code is also available at https://desitarget.readthedocs .io/en/latest/_modules/desitarget/sv3/sv3_cuts.html. We remark that the EDR covers DESI observations prior to the main survey. These targets were selected using *Gaia* DR2 photometry and astrometry, while the main survey selection uses *Gaia* DR3 astrometry. These selection criteria are slightly different from the main survey selection criteria described in Cooper et al. (2023).

All the columns used for selection of each target are available for each source in the VAC in the FIBERMAP file extension (see Section 4). In the following selections g, r refer to extinction corrected magnitudes obtained from Legacy Survey fluxes, r_{obs} is the r magnitude not corrected for extinction. Other variables are columns in the Legacy Survey table. π, σ_{π}, μ are *Gaia* parallax, parallax uncertainty and proper motion respectively. All the main DESI

Table A1. The list of columns in the RVTAB extension with measurements from RVSPECFIT.

Name	Units	Description
VRAD	$\mathrm{km}\mathrm{s}^{-1}$	Radial velocity
VRAD_ERR	$\mathrm{km}\mathrm{s}^{-1}$	Radial velocity error
VRAD_SKEW		Radial velocity posterior skewness
VRAD_KURT		Radial velocity posterior kurtosis
LOGG		Logarithm of surface gravity
TEFF	К	Effective temperature
ALPHAFE		$[\alpha/\text{Fe}]$ from template fitting
FEH		[Fe/H] from template fitting
LOGG_ERR		Log of surface gravity uncertainty
TEFF_ERR	К	Effective temperature uncertainty
ALPHAFE_ERR		$[\alpha/\text{Fe}]$ uncertainty from template fitting
FEH_ERR		[Fe/H] uncertainty from template fitting
VSINI	$\mathrm{km}\mathrm{s}^{-1}$	Stellar rotation velocity
NEXP		Number of exposures (unused)
CHISQ_TOT		Total chi-square for all arms
CHISQ_C_TOT		Total chi-square for all arms for polynomial only fit
CHISQ_B		Chi-square in the B arm
CHISQ_C_B		Chi-square in the B arm after fitting continuum only
CHISQ_R		Chi-square in the R arm
CHISQ_C_R		Chi-square in the R arm after fitting continuum only
CHISQ_Z		Chi-square in the Z arm
CHISQ_C_Z		Chi-square in the Z arm after fitting continuum only
RVS_WARN		RVSPECFIT warning flag
REF_ID		Tyc1*1000 000+Tyc2*10 + Tyc3 for Tycho-2; source_id for Gaia DR2
REF_CAT		Reference catalog source for star: T2 for Tycho-2
		G2 for Gaia DR2, L2 for the SGA, empty otherwise
TARGET_RA	deg	Target right ascension
TARGET_DEC	deg	Target declination
TARGETID		Unique DESI target ID
SN_B		Median S/N in the B arm
SN_R		Median S/N in the R arm
SN_Z		Median S/N in the Z arm
SUCCESS		Did RVSPECFIT succeed (RVS_WARN = 0) or fail

Table A2. The list of columns in the SPTAB extension with measurements from FERRE.

Name	Units	Description	
SUCCESS		Boolean flag indicating whether the code has likely produced useful results	
TARGETID		Unique DESI target ID	
TARGET_RA	deg	Target right ascension	
TARGET_DEC	deg	Target declination	
REF_ID		Tyc1*1000000+Tyc2*10 + Tyc3 for Tycho-2; source ID for Gaia DR2	
REF_CAT		Reference catalog source for star: T2 for Tycho-2	
		G2 for Gaia DR2, L2 for the SGA, empty otherwise	
SRCFILE		DESI data file	
BESTGRID		Model grid that produced the best fit	
TEFF	K	Effective temperature	
LOGG		Logarithm of surface gravity in cm s ^{-2}	
FEH		Metallicity [Fe/H]	
ALPHAFE		α -to-iron ratio [α /Fe]	
LOG10MICRO		Log10 of microturbulence (km s^{-1})	
PARAM		Array of atmospheric parameters ([Fe/H], $[\alpha/Fe]$, log10micro, T_{eff} , log g)	
COVAR		Covariance matrix for ([Fe/H], $[\alpha/Fe]$, log10micro, T_{eff} , log g)	
ELEM		Elemental abundance ratios to hydrogen [elem/H]	
ELEM_ERR		Uncertainties in the elemental abundance ratios	
CHISQ_TOT		Total χ^2	
SNR_MED		Median signal-to-ratio	
RV_ADOP	$\mathrm{km}\mathrm{s}^{-1}$	Adopted radial velocity	
RV_ERR	$\mathrm{km}\mathrm{s}^{-1}$	Uncertainty in the adopted Radial Velocity	
HEALPIX		HEALPIX pixel containing this location at $NSIDE = 64$ in the NESTED scheme	

classes, such as MWS_MAIN_BLUE, MWS_MAIN_RED, MWS_BROAD are selected using this common set of criteria:

(i) 16 < r < 19(ii) $r_{obs} < 20$ (iii) type = PSF (iv) gaia_astrometric_excess_noise < 3 (v) gaia_duplicated_source = False (vi) brick_primary = True (vii) nobs_g, r > 0(viii) g,r_flux > 0 (ix) fracmasked_g, r < 0.5

Definition of MWS_MAIN_BLUE:

(i) g - r < 0.7(ii) astrometric_params_solved = 31

Definition of MWS_MAIN_RED:

(i) g - r >= 0.7(ii) astrometric_params_solved = 31 (iii) $\pi < max(3\sigma_{\pi}, 1)$ (iv) $|\mu| < 7$

Definition of MWS_BROAD:

(i) $g - r \ge 0.7$ (ii) astrometric_params_solved< 31 or $\pi > max(3\sigma_{\pi}, 1)$ or $|\mu| > 7$

APPENDIX A: RECOMMENDED SELECTION FOR THE SP PARAMETERS

In the case of the results of the SP pipeline, included in the SPTAB extensions of various files, we recommend the following cuts to obtain a science-grade sample:

(i) SNR_MED > 5, a minimum median signal-to-noise ratio of 5,

(ii) CHISQR_TOT < 5, a reduced χ^2 smaller than 5,

(iii) TEFF > 4000 K, to avoid M-type stars,

(iv) FEH > -4.9, avoiding the stars that accumulate the edge of the grids, and

(v) $\text{BESTGRID} \neq \text{s_rdesil}$, avoiding the stars that were fitted with the PHOENIX grid.

The use of the PHOENIX grid for stars with effective temperatures between 2300 and 5000 K was adopted to supplement the Kurucz (2005) grids since the latter only cover $T_{\text{eff}} \ge 3500$ K. For stars in the overlapping range of temperatures between two grids the results with the lowest χ^2 were adopted. We find that this led to spurious results when the PHOENIX grid was used. One such example is the accumulation of stars near the grid edge at 5000 K illustrated in Fig. 5, the presence of systematic errors in the surface gravity of cool dwarfs, or large scatter in the abundances for cool dwarfs seen in Fig. 11.

APPENDIX B: RECOMMENDED SELECTION FOR THE RVS PARAMETERS

On top of the selection listed in Section 5.1, for a more reliable subset of RVS parameters, we recommend applying the following cuts.

(i) FEH>-3.9 removes objects clumped at the bottom edge of the metallicity grid.

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