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Preliminary Target Selection for the DESI Milky Way Survey (MWS)

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ABSTRACT

The DESI Milky Way Survey (MWS) will observe ≥8 million stars between $16 < r < 19$ mag, supplemented by observations of brighter targets under poor observing conditions. The survey will permit an accurate determination of stellar kinematics and population gradients, characterize diffuse substructure in the thick disk and stellar halo, enable the discovery of extremely metal-poor stars and other rare stellar types, and improve constraints on the Galaxy's 3D dark matter distribution from halo star kinematics. MWS will also enable a detailed characterization of the stellar populations

within 100 pc of the Sun, including a complete census of white dwarfs. The target catalog from the preliminary selection described here is public[a)].

Keywords: Milky Way Galaxy, Radial velocity, Stellar abundances, White dwarf stars

Although DESI is conceived primarily as a cosmological experiment, in bright time the survey will obtain spectra of Milky Way stars within the DESI footprint selected from the *Gaia* DR2 catalog (Gaia Collaboration et al. 2018) and the DESI Legacy Imaging Surveys (LS; Dey et al. 2019). This Milky Way Survey (MWS) at Galactic latitudes $|b| > 22°$ will share the DESI focal plane with the Bright Galaxy Survey (BGS; Ruiz-Macias et al. 2020), using approximately half of the DESI fibers available during bright time. In addition, bright stars across the entire sky (including Galactic plane sources) will be observed in twilight and poor weather conditions.

The MWS target selection is designed to be simple, inclusive, and amenable to forward modeling. It will yield an essentially magnitude-limited random sample of stars over a significant fraction of the sky that can be compared to theoretical predictions, a philosophy similar to that of the SDSS main galaxy sample. Comprised of ∼8 million sources with *Gaia* parallaxes and proper motions but fainter than the $G = 16$ limit of *Gaia*'s radial velocity spectrograph, MWS will more completely sample stellar kinematics far from the Galactic center.

MWS Main Sample

The MWS Main sample will target all stars (i.e., sources of type "PSF" from LS with *Gaia* DR2 ASTROMETRIC_EXCESS_NOISE < 3 mas) in the range $16 < r < 19$ mag, where r is the LS apparent r-band magnitude corrected for Galactic extinction. A small number of stars with uncorrected magnitude $r_{\rm obs} < 20$ will be excluded to ensure spectra of sufficient signal-to-noise (the DESI bright-time survey footprint is mostly at high latitude, hence low extinction). Stars will be assigned to one of following three target classes based on their color and *Gaia* DR2 astrometry (Fig. 1).

- **MWS Main Blue**: **all** stars with $g - r < 0.7$ mag.
- **MWS Main Red**: stars with $g - r \geq 0.7$ mag; good parallaxes (Gaia ASTROMETRIC_PARAMS_SOLVED $= 31$, parallax $\pi < \max(3\sigma_\pi, 1)$ mas); and very small proper motion ($|\mu| < 7$ mas/yr).
- **MWS Main Broad**: stars with $g - r \geq 0.7$ not included in MWS Main Red.

For $g - r < 0.7$, the selection is a magnitude-limited random sampling, valuable for high-resolution kinematic studies of the thick disc and nearby halo using turn-off stars. For $g - r \geq 0.7$, the Main Red astrometric criteria exclude a significant fraction of nearby dwarfs and hence increase the probability of targeting more distant halo giants, useful for studies of kinematic and stellar population gradients to ~ 100 kpc. The Main Blue and Main Red selections are weighted equally in fiber assignment. The remaining stars are included in the Main Broad sample and assigned fibers at lower priority. The completeness and purity of the Main Red sample will be evaluated during the DESI Survey Validation (SV) phase (a precursor to the DESI 'main' science survey). The magnitude, color, proper motion, and parallax limits will be adjusted, if necessary, before the survey commences. We will prioritize all known *Gaia* RR Lyrae with $14 < G < 19$ (Clementini et al. 2019), and evaluate a blue horizontal branch (BHB) star selection based on *Gaia* and LS in this range.

The Backup Survey

During poor weather and twilight conditions, when the MWS Main and BGS observations are not possible, DESI will observe an "unbiased" bright star sample ($10.5 < G < 16$ mag) at declination $\delta \geq -30°$. This Backup Survey is expected to yield spectroscopic parameters, abundances, and kinematics for several million stars, creating a rich resource for studies of disk stellar populations, stellar evolution, and Galactic structure.

[a)] Available at https://data.desi.lbl.gov/public/ets/target/catalogs/ and detailed at https://desidatamodel.readthedocs.io

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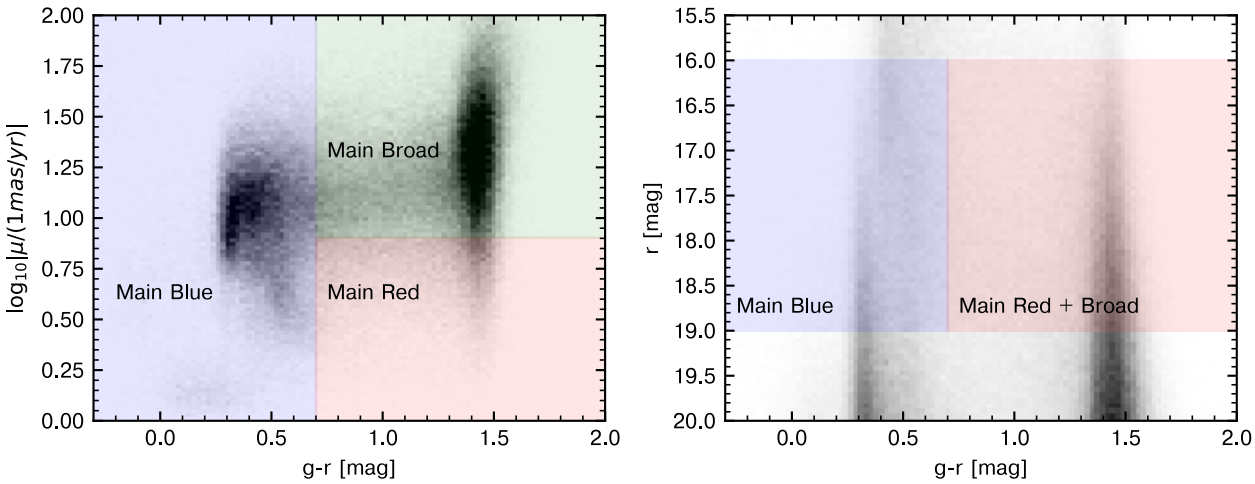

Figure 1. *Left:* Source density as a function of $g - r$ color and proper motion for stars in the magnitude range $16 < r < 19$ near the North Galactic Pole. Redward of $g - r = 0.7$, cuts in parallax ($\pi < 3\sigma_\pi + 1$) and proper motion exclude fast-moving nearby dwarfs. Main Red and Main Blue targets are observed at equal priority and constitute the bulk of the MWS main survey sample; Main Broad targets are observed at lower priority. *Right:* Selection in color–magnitude space, illustrating that Main Blue targets are halo/disk main sequence turn-off (MSTO) and BHB stars, while Red/Broad targets are MW giants/dwarfs.

Sparse high-value targets

MWS will also include sparse (< 10 deg^{-2}) samples of high-value targets. These will be given higher priority for fiber assignment but will not perturb the main sample selection function significantly.

White Dwarfs—White dwarf (WD) stars can constrain the local star formation history, the nature of SN Ia progenitors, and the composition of exo-planetesimals. Selected following Gentile Fusillo et al. (2019), their priority will be the highest of all bright-time targets.

Stars within 100 pc—*Gaia* is complete for stars within 100 pc, and DESI will provide a comprehensive stellar population census of the solar neighborhood. This will establish strong constraints on the initial mass function and local chemical evolution. Target selection: $16 \leq G \leq 20$, $\pi + \sigma_\pi \geq 10$ mas. Stars with $G < 16$ are in the Backup Survey.

MWS may include these additional high-value targets:

Distant halo tracers—RR Lyrae, BHB and giant stars are excellent tracers of halo structure because reliable distances can be determined for them. We will target faint ($G > 19$) *Gaia* RR Lyrae and color-selected BHBs, and use DDO51 photometry over 10,000 deg^2 (Slater et al. 2016) to select a sparse sample of giants.

Close white dwarf binaries—Understanding the evolution of WD binaries, which include SN Ia progenitors and low-frequency gravitational wave sources, requires robust observational constraints (Toloza et al. 2019). These targets will be selected using *Gaia/GALEX* data as follows: $\pi/\sigma_\pi > 5$, $16 \leq G \leq 20$, $FUV + 5\log 10(\pi[''\,]) + 5 > 1.5 + 1.28 \times (FUV - G)$.

Cluster members—We will use proper motion to select likely members of a few bright dwarf galaxies and globular clusters out to ~ 10 times their half-light radius. DESI is ideal for surveying the environs of such objects for signs of tidal interactions and extended halos.

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