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DISCO: PRECISION CHEMISTRY THROUGHOUT THE DISK

JONATHAN C. BIRD [1], MELISSA NESS[2], GAIL ZASOWSKI[3], JAN RYBIZKI[2], HANS-WALTER RIX[2], DAVID W. HOGG[2,5,6], LAURA INNO[2], BRANIMIR SESAR[2], ANDREW CASEY[4], JON HOLTZMAN[7], JENNIFER SOBECK[8]

1. OVERVIEW

We propose Disco, a groundbreaking magnitude-limited survey of the Galactic disk that will collect high-resolution NIR spectra of $N = 4$ million stars, across a contiguous 3000 square degree area. Using our proven new data-driven methods, we will deliver chemical abundances with better than 0.05 dex precision for more than 20 elements, spanning five nucleosynthetic families. These attributes make Disco compelling and unique; even in the early 2020s, it is the only program compatible with "chemical tagging" studies that will comprehensively cover stars in the extincted regions of the Milky Way, including the only expansive study of the far side of our Galaxy. Disco augments the existing APOGEE surveys in three key ways to obtain a $>$10-fold increase in survey targets with a dense, contiguous angular sampling, crucial to our science objectives: (i) introducing a simple selection function to favor relatively-bright, heavily-extincted stars throughout the Galaxy (ii) reducing the required SNR from 100 to ≤ 75, and (iii) achieving a huge efficiency gain with the addition of a robotic fiber positioner. Disco is designed to both maximize our investment in existing APOGEE infrastructure and exploit synergies with current and future surveys such as *Gaia*. We will also obtain a large set of calibration objects observed at high SNR that will be used to place all major spectroscopic surveys on the same abundance scale. Within this framework, we expect SDSS to emerge as the natural leader in Galactic Cosmology studies for the coming decade.

2. SCIENTIFIC OBJECTIVES

The Milky Way (MW) offers a unique opportunity to study galaxy evolution — structural, dynamical, and chemical — in exquisite detail and on all scales. Disco's objective is to characterize the processes driving the chemical and dynamical evolution of the MW. The current snapshot in time in which we can examine our Galaxy is the end product of a roughly 13 billion year mass assembly history including galaxy mergers, gas accretion and expulsion, star formation, and chemodynamical evolution. We can study the imprint of this myriad of processes through the stellar archaeological record. As we are learning through surveys like APOGEE, a single star is information rich. Its chemistry reflects the physical conditions and time of its birth, while its dynamics can reveal where it formed and/or where it is going. This set of observables exists for all 10 billion MW stars; the total information content available to us in the MW is arguably larger than any extragalactic survey. The next revolution in Galaxy Formation will be predictive, quantitative models of the often non-linear integration of stellar astrophysics and sub-galactic scale physical processes. It is clear that such an ambitious undertaking can only be successful through aggressive pursuit of large samples of precise stellar chemo-dynamics. This is the promise of Disco.

In addition to the science drivers of APOGEE, Disco is uniquely suited to address the following: • Where and when did stars form, and in how many groups? This requires the application of chemical tagging (e.g., Freeman & Bland-Hawthorn 2002), which drives our abundance precision requirements (§5). The kinematics of identified stellar birth groups provide direct constraints on important dynamical processes affecting stars after their birth (e.g., radial migration, Roškar 2008). The number of stellar birth twins, found by means of chemical tagging, increases as N_{sample}^2: hardly any other surveys have such a scaling of their figure of merit! This drives us to the largest possible sample. • What is the dimensionality of chemical abundance space? To progress towards predictive chemical evolution models, we must determine the principal nucleosynthetic yields beyond the basic distinction between SNIa and SNII. This goal partially drives our requirements on precision, number, and type of elemental abundances. • The MW is truly all-sky; important dynamical features such as spiral arms, stellar streams such as Monoceros, and other azimuthal asymmetries are relatively "narrow" phase space features that can only be characterized by a spatially contiguous survey. • What can the MW disk tell us about hierarchical structure formation? Did the MW have a quiet history, or were there many early mergers, as expected under ΛCDM models? How has internal, secular evolution shaped the Galaxy? The bulge is a key signature of formation in these scenarios, and the oldest stars, which our survey will obtain in vast number in the dust-extincted bulge, will be key in answering this question. Chemical identification of disrupted globular clusters and other coherent groups (streams, etc) will also help characterize our Galaxy's assembly history . • We will use the measured [X/Fe] patterns and densities as tools to characterize both broad star formation history and chemically peculiar stars. • What are the abundance differences between planet and non-planet hosting stars, and what are the abundance variations versus planetary mass and period? These aims tie into TESS, *Gaia*, the ATLaS LOI, and others.

3. SURVEY DESIGN AND TECHNICAL CONSIDERATIONS

Main Survey Observations The main survey selection function is simple: we target all stars that are both (1) relatively bright ($m_H < 11$) and (2) in the heavily dust obscured regions (A_V exceeds 2 mag). The resulting parent sample contains > 4 million stars throughout the Galaxy (Figure 1). Nominally, we will employ 30-minute exposures to obtain a SNR of ≥ 75, which will enable radial velocities precise to <200 ms^{-1} and abundance measurements precise to <0.05 dex for more than 20 elements from five nucleosynthetic families (see Figure 2 for some examples). Even with a magnitude limit of $m_H < 11$, we will be able to target giants throughout a significant volume of the MW, including tip of the RGB stars *in* and *beyond* the bulge (Figure 3).

Calibration Sample and High Impact Targets We will also build a comprehensive set of calibration targets, which will not only provide a robust training set for our *Cannon* style abundances, but will also create a new set of calibration standards for other surveys. This will comprise both bright and faint stars; faint stars will be visited multiple times to obtain the required SNR and include target classes with precise distances and reliable age determinations (e.g., RR Lyrae, Cepheids, and RC stars).

Survey Requirements and Flexibility Assuming 30 minute exposures, APOGEE's current specified efficiency, and 300 targets per plate, Disco would require $\sim$ 6700 telescope hours of exposure time to observe *each and every* MW star meeting our selection criteria. Five years of bright time at APO equates to $\sim$ 7370 hours, or $\sim$ 3600 hours for 50% bad weather. APOGEE-2S has $\sim$ 75 nights per year at LCO, and a similar commitment would greatly increase the number of available visits, especially in the inner Galaxy where target densities are highest. A preliminary LST analysis reveals sufficient target densities throughout the year at APO. Advances in observing efficiency and robotic fiber positioning make our ambitious survey plan possible, and Disco's survey design is well-suited to maximize its science return under a wide range of observational commitments. At the proposal stage, we will conduct a formal study to optimize trade-offs between SNR, element abundance recovery, and sampling strategy.

Hardware Requirement. To obtain millions of H-band stellar spectra, Disco requires a robotic fiber positioner (estimated cost of $\sim$ \$1M USD). A robotic positioner would likely be based on the two-plate design currently deployed with 2dF, but with new advances that reduce the reconfiguration time to minutes.

Sparse Targeting Programs / Shared Fibers. Disco will be one of the most efficient multi-object spectroscopy surveys in the AS-4 era, making it extremely "nimble" and an ideal umbrella survey for other Galactic science within the greater SDSS collaboration. Disco is immediately compatible with all sparse targeting programs within its survey geometry. The planned high SNR sample is just one example of such a program. Disco's flexibility also makes it an ideal platform for shared and ancillary programs.

Survey Capacity. Disco's specific capabilities are still contingent on hardware development, efficiency characterization, observation time commitment, and intra-SDSS survey synergy. Disco would prioritize its large-scale, contiguous sky-coverage within which our selection function performs a simple random sample of bright stars. Less exposure time simply equates to a smaller sample, resulting in fewer chemical twins. The remaining Disco science would still be affected, but to a lesser degree.

Efficiency Metrics APOGEE-2 N+S will observe $70,000$ disk stars at $\sim$ 50 stars/visit. $H < 11 \rightarrow$ 5x efficiency (> 250 stars/visit). SNR$\sim$ 75 and current observing efficiency gains over APOGEE specifications $\rightarrow$ 2x efficiency (1/2 the exposure time). In a pessimistic sans-robot scenario, our nominal sample would still likely be $\sim$ 1 million stars. On the other hand, a robotic positioner with short reconfiguration time, and a mildly optimistic reduction of our SNR requirements – thus obtaining a subset of stars distributed down to lower SNR – could yield 10 million stars.

4. SURVEY SYNERGY

Disco directly builds upon the successful APOGEE-APO (and future APOGEE-LCO) infrastructure and investment. Optical surveys, such as Galah, must avoid the mid-plane or rapidly become inefficient, while competing multi-object IR surveys, such as MOONS, are installed at significantly larger telescopes and are therefore limited to a fainter target magnitude range and very small field of view. We stress that *no other survey in the AS-4 era will have a competitive combination of sample size, abundance precision, and midplane coverage*. In the AS-4 era, we will use distances from *Gaia* to select for the distant bright giants, enabling observations of stars across an expansive region of the disk beyond the bulge and to the far disk. Given Disco's proposed magnitude distribution, *Gaia* will also measure proper motions and precise parallaxes with $7\mu''$ uncertainty for every star in the main sample. A dominant fraction of Disco's main survey sample will therefor have full phase-space information. We note that this dataset will also be extremely useful for studies of the obscuring ISM itself, as described in the Galactic Dust LOI.

5. SURVEY PERFORMANCE AND DELIVERABLES

The H-band region is information rich and our significant precision gains (e.g., Ness et al. 2015; Casey et al. 2016) are critical to achieving our scientific goals. In addition, the information content of the spectra is key (e.g., Ting et al. 2012). We can deliver a prediction for more elements than previously – namely, the critical neutron capture elements in the H-band region (see the s-process element barium in Figure 2). The neutron capture elements offer strong constraints on star formation and chemical evolution history and significantly raise the scientific capability of our program with respect to chemical tagging. Derivation of ages from spectroscopy (Martig et al. 2016, Ness et al. 2016) for this number of stars will be revolutionary. We are building on the legacy built by APOGEE, with significant gains in scientific potential via (1) numbers of stars and spatial coverage, (2) abundance precision and the delivering of new elements not previously measured in the H-band region, (3) delivering stellar ages for giants, and (4) utilizing the data that will be available from Gaia, all in a high efficiency strategy enabled by the robotic fiber positioner.

AUTHOR AFFILIATIONS Email contact: jonathan.bird@vanderbilt.edu; ness@mpia-hd.mpg.de . [1] Vanderbilt University, [2] Max-Planck-Institut für Astronomie, [3] Johns Hopkins University, [4] University of Cambridge, [5] CCAPP, New York University [6] CDS, New York University, [7] New Mexico State University, [8] University of Virginia.

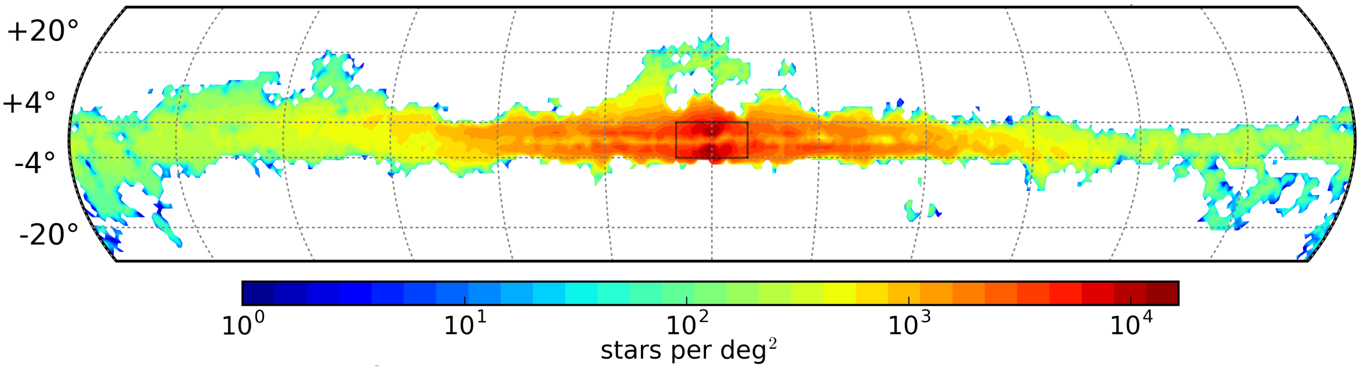

Figure 1. Simulated density of stellar sources across the Galactic plane for a magnitude limited ($m_H < 11$ mag) and high extinction ($A_V > 2$ mag) Disco sample. The synthetic stellar catalog was generated with *Galaxia* (Sharma et al. 2011) using a Besançon-like Galaxy model (Robin et al. 2003) together with a simple 3-D dust model reproducing the SFD (1998) maps at infinity. Overall, 4×10^6 stars are visible, 3×10^6 in the $b = \pm4^\circ$ stripe and 8.6×10^5 in the grey $l \pm 10^\circ$ box around the Galactic Center. Within that box, 1500 stars have a metallicity below -2 dex.

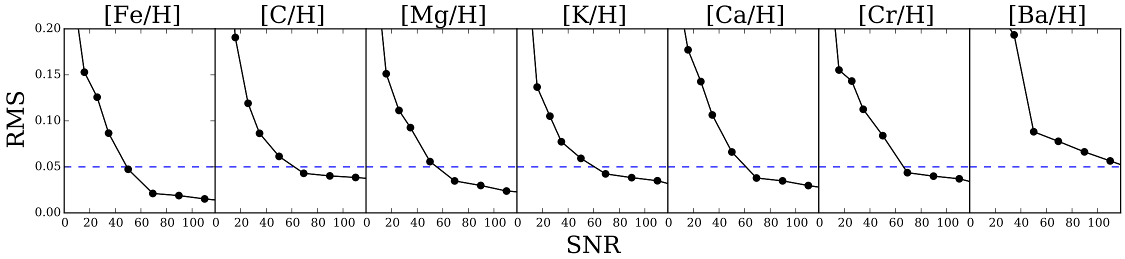

Figure 2. *The Cannon's* derived abundance precision for seven elements, representative of the full sample of ~20 elements (light, alpha, iron peak, and neutron-capture) that will be measured in APOGEE and Disco. The horizontal dashed line indicates the target 0.05 dex precision.

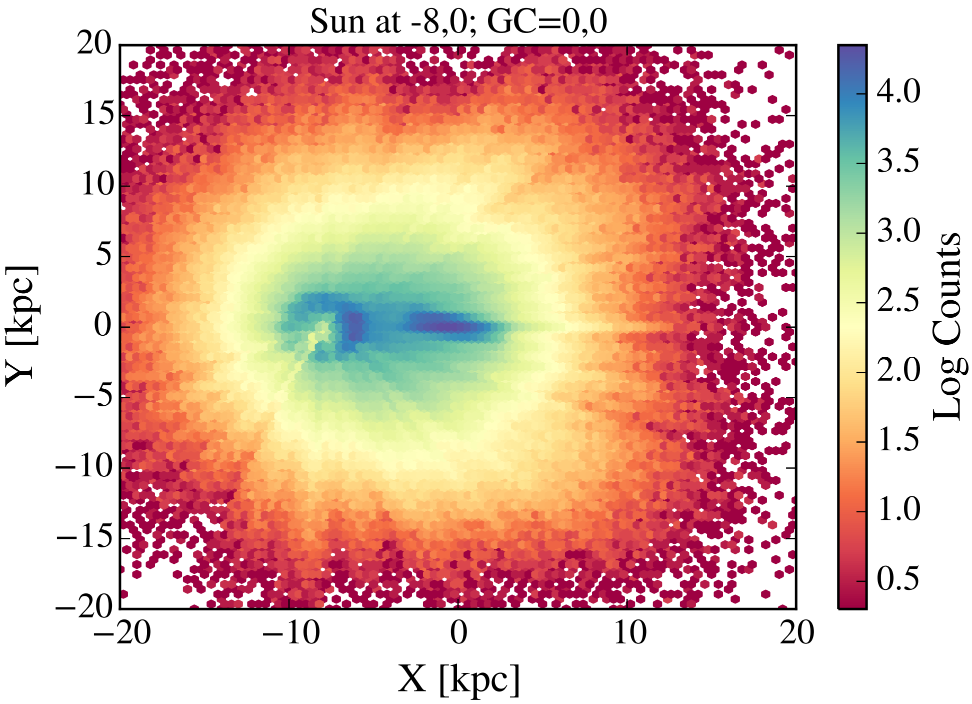

Figure 3. Face-on projection of the stars in the magnitude limited ($m_H < 11$ mag) and high extinction ($A_V > 2$ mag) Disco sample from Figure 1. Though the magnitude limit is bright relative to other AS-4 surveys, Disco surveys an enormous volume of the Milky Way, including the bulge and far side of the disk. In this projection, the Sun is located at (-8,0), while the Galactic center is at the origin.