APOGEE-2 Ancillary Proposal: The Far Disk in APOGEE-2 using Low-extinction Windows

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Co.I.s with a † are External Collaborators (see below).

2. External Collaborator Request for Finkbeiner and Green

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Dear CoCo,

We are writing to request External Collaborator Status for Gregory
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Green and Douglas Finkbeiner (both CfA) to participate in the approved APOGEE_2 ancillary program ‘‘The Far Disk in APOGEE-2 using Low-extinction Windows’’. The project will proceed according to SDSS-IV rules.

The goal of this ancillary program is to target stars in the Milky Way disk at very large distances from the Sun, by employing three-dimensional dust maps to identify regions of low extinction in the inner Milky Way where we can reach large distances at relatively bright magnitudes. Green and Finkbeiner are experts on mapping the distribution of dust in three dimensions, having in particular produced the largest three-dimensional extinction map from Pan-STARRS+2MASS data that covers the 3pi Pan-STARRS footprint, which contains almost all APOGEE-2N fields. Their maps and general expertise on the relative merits of different extinction maps have been essential in designing the target selection for this ancillary program.

Sincerely,

Jo Bovy

3. Type of Request

We are requesting targets in two existing fields as well as a single new field. Therefore, the type is a combination of 2 and 3.

Special request: We are proposing new targets in the existing $l = 34°$ and $l = 64°$ fields. All of the designs for these fields have already been drilled and two (for $l = 34°$) and three (for $l = 64°$) have already been started. We are requesting that some of these are re-designed and re-drilled to allow for our new targets and that further observations of these fields are postponed until after the decision about the ancillary proposals.

4. Scientific Justification

One of APOGEE-2's main scientific objectives is a comprehensive study of the chemo-dynamical structure of a large volume of the Milky Way's disk. In particular, the color selection in the main "Disk" sub-sample is tuned to produce a larger number of distant stars (defined as $D \gtrsim 6$ kpc in the Disk Working Group White Paper) to extend APOGEE-1's already extensive study of the "local" disk ($D \lesssim 6$ kpc). However, while the main "Disk" target-selection will produce a large sample of stars at distances between 6 and ≈ 9 kpc, the expected number of stars at these large distances in the mid-plane will only be a few dozen, primarily because of the large extinction.

With the availability of three-dimensional dust maps covering a large fraction of the sky and a large range of extinctions (e.g., Marshall et al. 2006; Green et al. 2015), it is now possible to identify low-extinction windows in the inner Milky Way where stars at large distances can be observed at relatively bright optical and infrared magnitudes. While the dust is highly filamentary on small scales such that most of the area of a typical APOGEE pointing in the mid-plane suffers from high extinction, substantial fractions of a pointing can cover low extinction regions. **We propose here to take advantage of these windows in already existing APOGEE-2 disk pointings ($l = 34°$ and $64°$ as well as in a new pointing centered on $l = 27°$) combined with a red color cut ($[J - K_s]_0 > 0.8$) to create a sample of ≈ 700 luminous giants at $D \gtrsim 6$ kpc in the mid-plane. About 250 of these will have $D \gtrsim 15$ kpc and thus sample the disk at very large distances.** A major motivation of this proposal is that if this selection is successful, it could be used in a post-Gaia target selection for APOGEE-2 and future surveys. Using an infrared spectrograph still remains essential in these low-extinction windows, because the optical extinction will be a factor $\gtrsim 5$ larger.

A sample of only a few hundred of stars in low-extinction windows probing distances as far as 16 kpc a few magnitudes below the tip of the red-giant branch would significantly improve APOGEE-2's investigation of the large-scale dynamics and metallicity structure of the disk. Because of the low extinction, such stars would have highly precise proper motions from Gaia (at large distances proper motions due to Galactic rotation are a few mas yr^{-1}) that combined with APOGEE's precise radial velocities allow the study of large-scale lopsided modes in the disk and therefore more direct constraints on the axisymmetric rotation (the rotation curve) than will be possible from Gaia data alone. Similarly, a few hundred stars would allow the mean metallicity at otherwise inaccessible regions of the Disk to be mapped leading to much stronger constraints on the azimuthal chemical homogeneity of the disk. The $l = 64°$ field would also sample the outer disk in a region that is much less affected by the warp than that at $l = 180°$, allowing for a cleaner study of the outer disk in

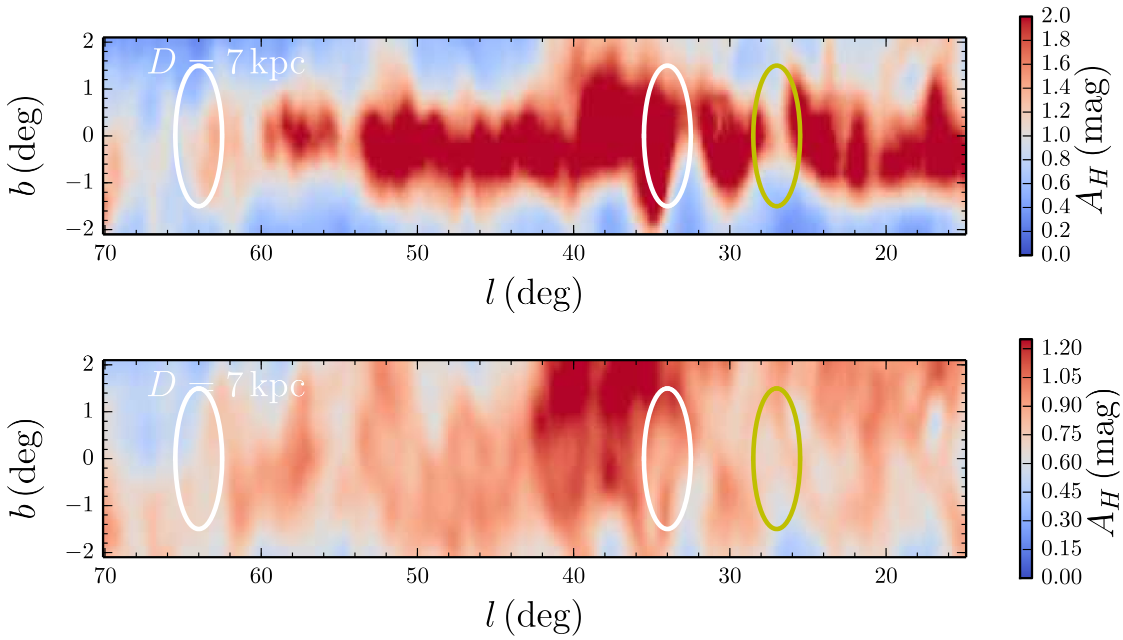

Fig. 1.— Extinction to $D = 7$ kpc from the extinction map of Marshall et al. (2006) (*top panel*) and that of Green et al. (2015) (*bottom panel*). This map shows the average extinction in regions with a radius of 0.5°. The white contours display the existing $l = 34°$ and $l = 64°$ APOGEE-2 fields, the yellow contour shows the newly proposed $l = 27°$ field that lies in a region of particularly low extinction. While the Marshall et al. (2006) and Green et al. (2015) map do not agree well on the extinction in the mid-plane—the Green et al. (2015) map is limited to $D \lesssim 5$ kpc in regions of high extinction in the mid-plane because it relies mainly on main-sequence stars—they both demonstrate that these fields have low extinction compared to the rest of the inner Galactic plane.

that region and for stronger constraints on the warp and flaring of the disk by comparison with the $l = 180°$ study.

5. Feasibility Assessment

We select fields in low extinction regions by considering the H-band extinction to $D = 7$ kpc from the Marshall et al. (2006) and Green et al. (2015) extinction maps (see Figure 1). Because placing new targets in existing fields allows for a more efficient use of the limited resources available in this ancillary call, we prefer to use fields that are already part of APOGEE-2. The $l = 34°$ and $l = 64°$ disk fields both each still have 6 remaining visits and from inspection of the extinction maps in Figure 1 they contain low extinction regions.

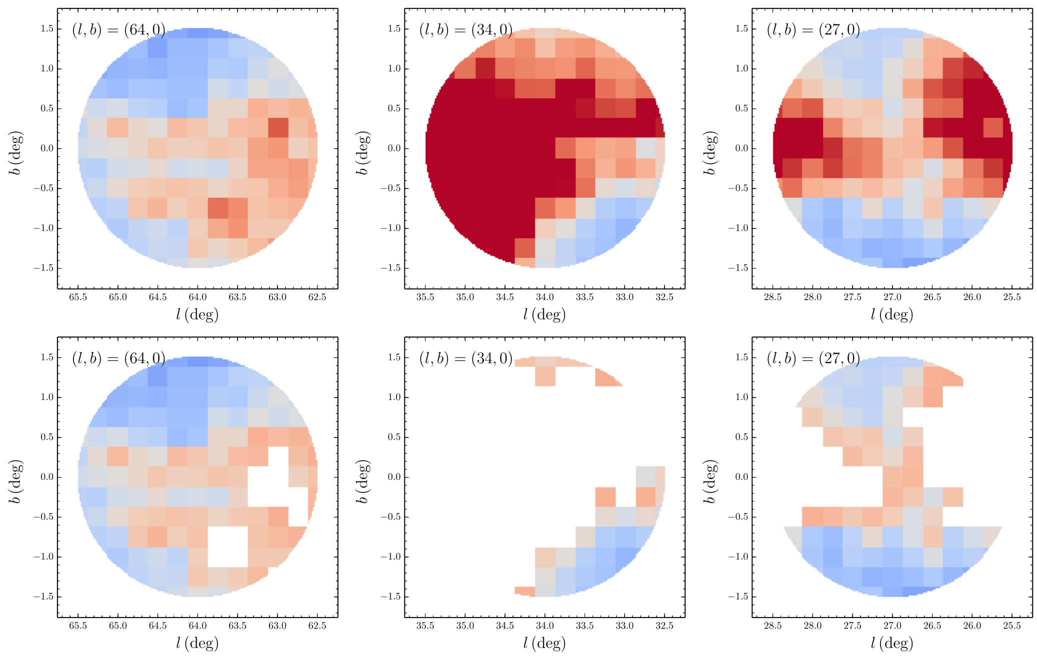

Fig. 2.— Top row: Extinction to $D = 7\,\mathrm{kpc}$ in the $l = 64°$ (*left*), $l = 34°$ (*middle*), and $l = 27°$ (*right*) fields from the extinction map of Marshall et al. (2006). Bottom row: The same as the top row, but removing parts of the field with $A_H(D = 7\,\mathrm{kpc}) > 1.4$, the cut that defines our target area. The color-scale is the same as that of the Marshall map in Figure 1.

We do not consider the $l = 49°$ field, because all of the planned designs have already been started to be observed and because the mid-plane in this field is entirely obscured by dust. Figure 1 also demonstrates that the region around $l = 27°$ is remarkably free of extinction out to 7 kpc from the Sun. Therefore, we propose to add a single-visit field centered on $(l, b) = (27°, 0°)$.

The extinction to 7 kpc within each of these three fields is displayed in Figure 2. As a compromise between covering a large area of each field with targets and selecting regions of low extinction, we only target in regions with $A_H(D = 7\,\mathrm{kpc}) \leq 1.4$, using the $15' \times 15'$ grid in (l, b) from Marshall et al. (2006). The regions of each field passing this cut are shown in the bottom panels of Figure 2.

In detail, we request single-visit observations for 207 stars in the `034+00` field, 207 stars in the `064+00` field, and 300 stars in a new `027+00` field (the latter including sky and telluric fibers). **Therefore, the total number of requested fiber-hours is 714.** Targets are selected using $(J - K_s)_0 > 0.8$ and $12 < H < 13$, which will return a S/N of 50 to 25 in a single visit for stars at $7 \lesssim D \lesssim 16$ kpc. Such S/N is sufficient to determine the line-of-sight velocity to $\lesssim 1\,\mathrm{km\,s^{-1}}$ and to determine the metallicity and high-priority APOGEE elements to $\lesssim 0.3$ dex (using, e.g., *The Cannon*; Ness et al. 2015).

6. Data Reduction

We request that our targets be run through the standard APOGEE reduction and ASPCAP pipelines and any dedicated analysis using, e.g., the Cannon can be run using the standard data products. The P.I. further has complete versions of the Cannon, ASPCAP, and a MOOG-based custom pipeline that can be used to analyze these low-S/N stars. Selected stars that were already selected using APOGEE-2's Disk target selection will be removed and their higher S/N spectra will allow a cross-check of the spectral analysis of the lower S/N stars. For the analysis to be scientifically interesting at a minimum the targets in two of the fields need to be observed.

7. Summary of results from previous SDSS ancillary science programs

None.

8. Target Information

We request:

- Single-visit observations of 207 targets with $(J - K_s)_0 > 0.8$ and $12 < H < 13$ in the `034+00` field. These should be selected from the regions of the field that have A_H at 7 kpc from Marshall et al. (2006) ≤ 1.4.
- Single-visit observations of 207 targets with $(J - K_s)_0 > 0.8$ and $12 < H < 13$ in the `064+00` field. These should be selected from the regions of the field that have A_H at 7 kpc from Marshall et al. (2006) ≤ 1.4.
- Single-visit observations of 230 science targets with $(J - K_s)_0 > 0.8$ and $12 < H < 13$ in a new `027+00` field centered on $(l, b) = (27^\circ, 0^\circ)$. These should be selected from the regions of the field that have A_H at 7 kpc from Marshall et al. (2006) ≤ 1.4. Tellurics and sky fibers should be assigned using the standard APOGEE procedure.

We demonstrate the target selection by applying it to the `034+00` and `064+00` fields, based on standard APOGEE target-selection products. Target selection for the new field `027+00` would proceed in the same manner.

The `Python` routine in Figure 3 selects all potential targets; a random sub-sample (the first N) of those should be observed. For the `034+00` and `064+00` fields there are 3,087 and 4,521 potential targets respectively.

REFERENCES

Green, G., Schlafly, E., Finkbeiner, D., et al. 2015, ApJ, submitted

Marshall, D. J., Robin, A. C., Reylé, C., Schultheis, M., & Picaud, S. 2006, A&A, 453, 635

Ness, M., Hogg, D. W., Rix, H.-W., et al. 2015, ApJ, submitted

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This preprint was prepared with the AAS LaTeX macros v5.2.

```python
import sys
import numpy
import fitsio
from galpy.util import bovy_coords
import mwdust
def select_targets(outfile,location):
    numpy.random.seed(location)
    datafilename= '../target_info/SecQuanObj_%03i+00.fits' % location
    data= fitsio.read(datafilename)
    # De-redden
    ak= data['AK']
    aj= ak*2.5
    j0= data['J_M']-aj
    k0= data['K_M']-ak
    # Cut on jk0,h
    indx= ((j0-k0) > 0.8)*(data['H_M'] > 12.)*(data['H_M'] < 13.)
    data= data[indx]
    # setup dust map
    dmap= mwdust.Marshall06(filter='2MASS H')
    # Calculate A_H(7 kpc) according to Marshall et al. (2006)
    ahdmap= numpy.zeros(len(data))
    lb= bovy_coords.radec_to_lb(data['RA'],data['DEC'],degree=True)
    for ii in range(len(data)):
        ahdmap[ii]= dmap(lb[ii,0],lb[ii,1],7.)
    # Cut on AH <= 1.4
    indx= ahdmap <= 1.4
    data= data[indx]
    # Write to file
    fitsio.write(outfile,data[numpy.random.permutation(len(data))])
    return None

if __name__ == '__main__':
    select_targets(sys.argv[1],int(sys.argv[2]))
```

Fig. 3.— Selecting targets in a particular location; run as `python select_targets.py targets.fits $location`.