TECHNICAL REPORT

Title: WFIRST-AFTA Guide Stars and the 2MASS Point Source Catalog		Doc #: WFIRST-STScI-TR1501 Date: Rev: A
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Abstract

We developed the means to evaluate the suitability of the 2MASS point source catalog to serve as the guide star catalog for the WFIRST-AFTA mission. For any given telescope pointing we can compute the probability of having guide stars available, subject to constraints of bright & faint limiting infrared magnitudes, and isolation from neighboring stars within several magnitudes of the guide star. The WFIRST operations concept calls for having up to all 18 WFI detectors simultaneously executing the guide function, each observing a guide star. In anticipation of some future constraints that may limit the number of detectors available for the guide function, we compute guide star availability for any number of detectors, and for specific detectors if a subset of the 18 are set aside as dedicated guide fields. If the WFIRST attitude control system absolute coarse pointing error exceeds ~2”, a two-step guide star acquisition process will be needed. For extremely crowded fields, we find it necessary for the coarse pointing error to be less than ~10” to assure that the correct guide stars are acquired without needing to implement a guide star identification function. In support of this study we developed a tool hosted within MAST at STScI that is used to visualize the WFIRST apertures on the sky and the 2MASS and GSC2.3 catalogs. We identify future work that will likely be needed to support the development of the WFIRST operations concept for the guide function.

1. Introduction

The Wide-Field Infrared Survey Telescope-Astronomically Focused Telescope Assets (WFIRST-AFTA) mission contains a wide field imager (WFI) instrument along with coronagraphs and an integral field spectrograph (IFS). The WFI contains eighteen 4Kx4K pixel detectors with a 0.11” pixel scale illuminated by astronomical sources through broad band filters covering a total bandpass from ~0.7μm to 2.0μm. The WFIRST pointing requirements (Spergel et al., 2015) call for the attitude control system (ACS) to stabilize the telescope line-of-sight pointing to better than 0.014” and provide absolute pointing accuracy of 0.1”. This requires WFIRST-AFTA to implement a fine guidance sensor (FGS) function that uses guide stars to provide the ACS with the means to determine the line of sight attitude knowledge.

The FGS function calls for each of the WFI detectors to be capable of supporting the operation of a pre-selected, visit specific, guide window (GW) sub array that observes a guide star (GS) selected by the ground system. Following a slew to the target field, the initial GW will be a 64 x 64 pixel sub array (7"x7"). Observations of the guide star positions within these GWs will be used to update and correct the spacecraft attitude, after which each GW will be reduced in size to a 16 x 16 pixel sub array (1.76"x1.76") for the subsequent science exposures. The GW readout is to be interleaved with the uninterrupted readout of the science data in the full frame detector. This results in a GW update rate of ~5.86 Hz. This in turn determines the WFIRST-AFTA guide star magnitude range for broad band imaging, which is anticipated to be $13 < H_{AB} < 17$ (Kruk 2015, priv. communication).

Not all of the 18 detectors are required to simultaneously participate in the FGS function, but at least 4 of the 18 are expected to be needed for the ACS to meet its pointing requirements (Spergel et al. 2015). Bright ($9 < H_{AB} < 12$) guide stars may be needed for grism spectroscopy (GRS) observations since the guide star's point spread function (PSF) will be replaced by a line spread function (LSF) with no zero-order image, and the FGS function may need to sense this dispersed image. Alternatively, there may be two or three apertures dedicated to the FGS function if it is found that the position of a guide star can not be determined with sufficient accuracy from the GRS LSF (Kruk 2015, priv. communication).

The Two Micron All Sky Survey Catalog of Point Sources (2MASS), with an H_{AB} limit of ~ 17.5, is expected to be well suited as the guide star catalog for WFIRST-AFTA since it is generally complete down to and beyond the anticipated faint limit of the FGS function. This report documents the results of a study carried out by the Space Telescope Science Institute (STScI) to evaluate the suitability of 2MASS as the guide star catalog for the WFIRST-AFTA mission, and conversely, the robustness of the WFIRST-AFTA FGS concept.

2. Evaluating Guide Star Statistics

To assess guide star availability for WFIRST-AFTA using the 2MASS point source catalog, we extracted cones of up to 5 degrees in radius from the catalog for four different pointings on the sky. This includes two fields of particular interest for WFIRST-AFTA; the fields associated with the High Latitude Survey (HLS) and the Micro Lensing Survey (MLS, centered on OGLE 2003-BLG-235Lb). In addition, we explored two other fields, the north galactic pole (NGP), and an intermediate high galactic field (HGF) at (l,b) = (180,-60), which similar studies by STScI (Nelan, 2004) in support of the JWST guide function, showed them to be representative of the sparsest places on the sky for guide star candidates. These four fields represent the full dynamic range in the areal density of star fields that will confront the WFIRST-AFTA FGS function.

For each pointing we specified a bright limiting magnitude for the guide star candidates, using $H_{AB} = 13$ when guiding on the nominal PFS, and the faint limiting magnitude ranging from $H_{AB} = 14$ to 17. For guiding on a dispersed LSF (GRS visits) we studied the

Table 1 Target fields

Target Field	RA	Dec	l	b
High Galactic Latitude Survey (HLS)	314.897	-45.01	355.21	-41.02
Exo-Planet Micro Lensing Survey (MLS)	271.318	-28.89	02.20	-03.69
Northern Galactic Pole (NGP)	192.859	+27.13	213.22	+90.0
High Galactic Field (HGF)	37.99	-08.80	180.0	-60.06

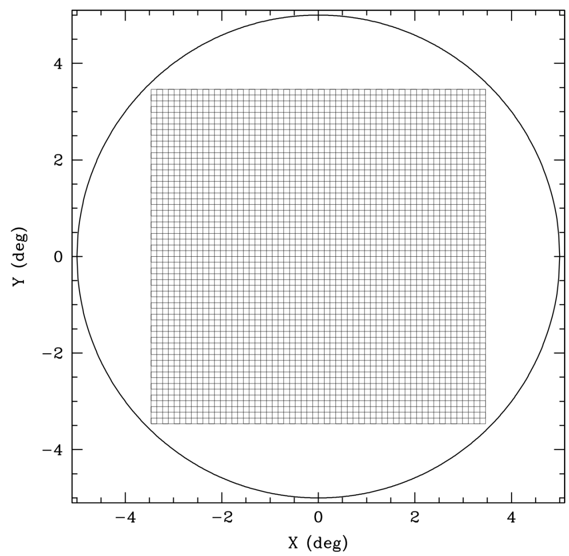

Figure 1. For cones of 5 degrees, we used the 58x58 grid of 440"x440" detectors to sample the 2MASS catalog for computing guide star candidate statistics. For the MLS field we used a cone of 2 degrees and a grid of 22x22 detectors (to contain data processing time).

availability of guide stars with $9 < H_{AB} < 12$. We compute, for each candidate, the distance to its nearest neighbor that is up to several magnitudes fainter. Stars with such neighbors closer than 10" are disqualified as guide star candidates since both stars might appear in the initial 64x64 pixel (7"x7") GW.

After applying this no-neighbor filter, we place an NxN grid of "detectors" (Fig 1), each being 440"x440", on the field (where N = 58, resulting in 3364 detectors). We compute the number of guide star candidates in each detector, and the average number of GS candidates per detector for the field. We verified that the distribution of star counts in the sample approximates a Poisson distribution (Fig 2) over the locally extracted catalog.

The Poisson distribution, with an average number *m* of candidate guide stars per WFI detector, yields the probability *Pr(k)* that *k* guide stars will be found in a given WFI, where

$$Pr(k) = e^{-m} m^k / k!$$

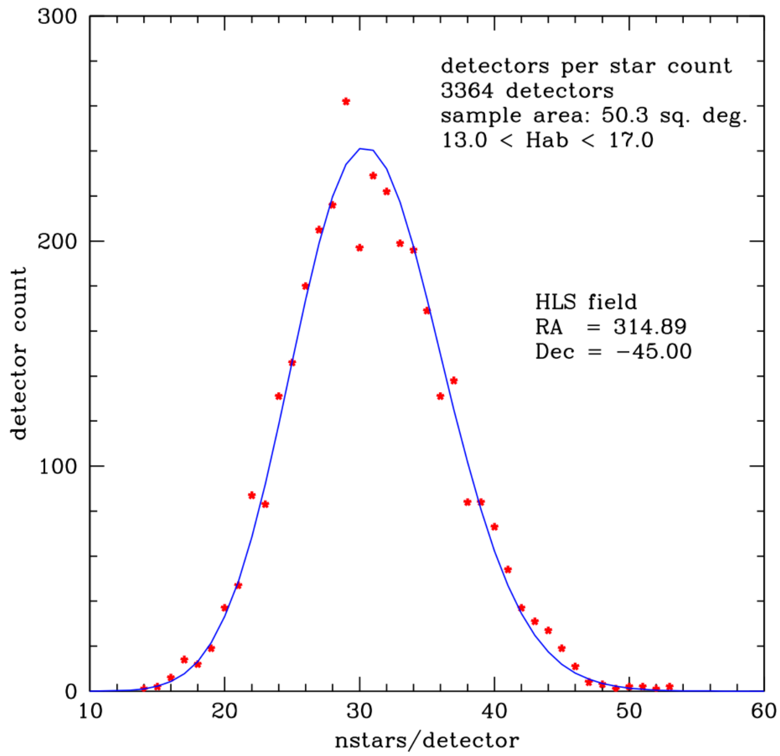

Figure 2: The distribution of star counts within the 3364 "detectors" used to analyze the HLS field (red dots). The blue line is a Poisson distribution of the expected number of detectors containing N stars, based upon the observed average number of stars/detector = 30.9 stars.

Thus, the probability that a given detector will have at *least* one guide star candidate is

$$P_d = 1 - Pr(0).$$

The probability that M of N detectors will contain at *least* one guide star candidate is given by

$$P(M) = N!/((N\text{-}M)! * M!) * P_d * *(M) * (1 - Pd)**(N\text{-}M).$$

Likewise, the probability that at *least i* detectors will contain at least one guide star candidate is given by $P_i = P(i) + P(i+1) + P(i+2) \ldots + P(N)$, or equivalently,

$$P_i = 1 - \Sigma(P(k)),\ \text{where the sum k = 0, to (i-1).}$$

For each field we ran a series of tests with the guide star bright limiting magnitude set to H_{AB} = 13, as might be appropriate for WFI visits, and the faint limiting magnitude ranging over H_{AB} = (14,15,16,17). In the event that the FGS function will need much brighter guide stars for GRS visits, we also evaluated the guide star availability with the bright limit set at H_{AB}=9, with the faint limit ranging over H_{AB} = (10,11,12,13). For each test we compute the probability that:

- any given WFI detector will contain at least one guide star candidate
- 1 of 18 detectors will have at least one guide star candidate
- 2 of 18 detectors will have at least one guide star candidate
- 4 of 18 detectors will have at least one guide star candidate
- 10 of 18 detectors will have at least one guide star candidate
- 18 of 18 detectors will have at least one guide star candidate

In the event that GRS visits may call for the use of 2 or 3 dedicated detectors to support the FGS function (using normal PSF guide star images), we compute the probability that:

- 1 of 2 detectors will have at least one guide star candidate
- 2 of 2 detectors will have at least one guide star candidate
- 2 of 3 detectors will have at least one guide star candidate

3. Results

We report the candidate guide star statistics for the four selected fields using the 2MASS catalog of point sources. In all cases the 10” no-neighbor isolation criterion was applied. Separate tests with a 15” and 20” isolation criterion were also conducted, and this was found to only affect the results for the crowded MLS field, to be discussed below.

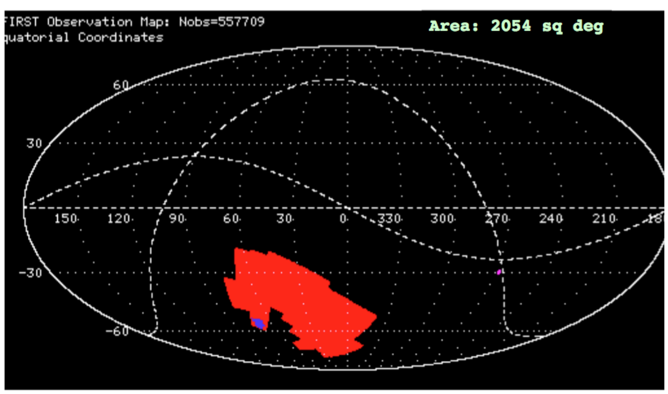

Figure 3. A representative LSST field from Hirata (2014), which is expected to be representative of the WFIRST-AFTA HLS field. For this study we chose a cone of 5^{o} radius centered on ecliptic coordinates (+45^{o}, -45^{o}).

3.1 High Latitude Survey

The WFIRST-AFTA high latitude survey (HLS) field is expected to overlap with the fields chosen for the Large Synoptic Survey Telescope and the Euclid mission. The HLS field chosen for this study is based upon Hirata (2014), as shown in figure 3, from which a cone of 5^{o} radius was extracted from the 2MASS point source catalog. Figure 4 shows an overlay of the 2MASS catalog and the WFI apertures on a region within the HLS field, generated by use of the WFIRST aperture tool developed by STScI for the Mikulski Archive for Space Telescopes (MAST). Refer to section 5 for more information about this tool.

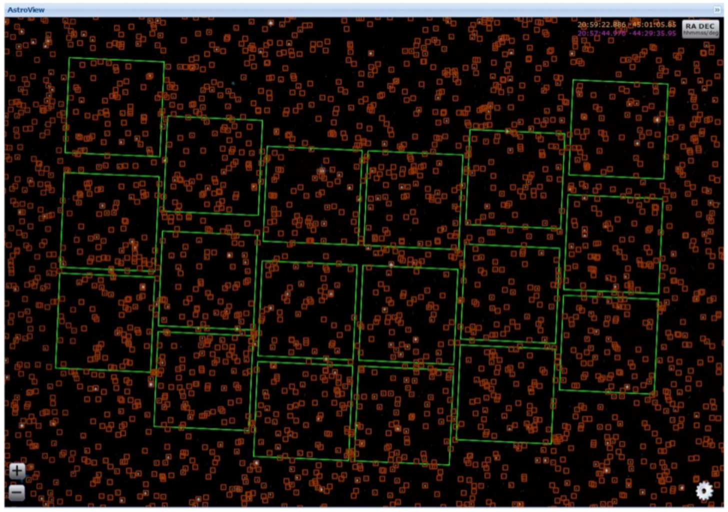

Figure 4. The WFI apertures projected on the 2MASS catalog for the HLS field chosen for this study. This image was generated using the STScI MAST tool for WFIRST-AFTA.

Table 2a shows the statistics for the availability of guide star (GS) candidates from the 2MASS catalog as a function of faint limiting magnitude in H_{AB}. For each faint limiting magnitude, the following entries are shown:

m	the average number of stars per WFI detector
$\mathbf{P_d}$	the probability that any given WFI detector will contain at least one GS candidate
$\mathbf{P_4}$	the probability that 4 of the 18 WFI detectors will have GS candidates
$\mathbf{P_{10}}$	the probability that 10 of the 18 WFI detectors will have GS candidates
$\mathbf{P_{18}}$	the probability that all 18 WFI detectors will have GS candidates.

In the event that two or three apertures of similar size as the WFI detectors are dedicated to the FGS function, we show the resultant guide star statistics, assuming the same magnitude limits.

$\mathbf{P_{1,2}}$	the probability that one of two specific WFI detectors will have GS candidates
$\mathbf{P_{2,2}}$	the probability that two of two specific WFI detectors will have GS candidates
$\mathbf{P_{2,3}}$	the probability that two of three specific WFI detectors will have GS candidates

Table 2b shows the availability of guide star candidates with an assumed bright limit of $H_{AB} = 9$, which may be required when the stars are dispersed by the grism.

Table 2a. Guide Star statistics for the HLS field, with bright limit $H_{AB} = 13.0$ (WFI)

faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
14	2.2	0.886	1.000	1.000	0.114	0.987	0.785	0.964
15	6.4	0.998	1.000	1.000	0.971	1.000	0.996	1.000
16	14.7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	30.9	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 2b. Guide Star statistics for the HLS field, with bright limit H_{AB} = 9.0 (GRS)

faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
10	0.1	0.081	0.053	0.000	0.000	0.156	0.007	0.019
11	0.3	0.243	0.670	0.004	0.000	0.427	0.059	0.148
12	0.7	0.518	0.998	0.467	0.000	0.767	0.268	0.526
13	1.8	0.833	1.000	1.000	0.037	0.972	0.694	0.926

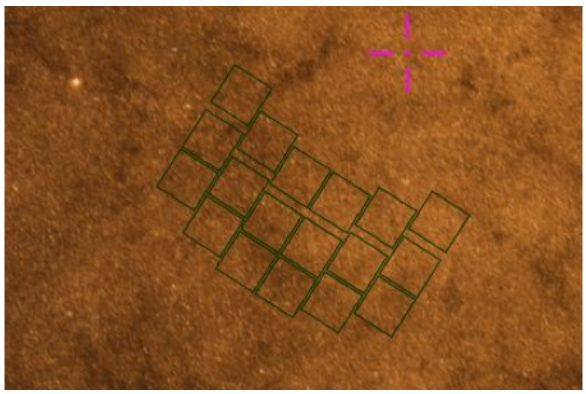

Figure 5. The WFI apertures and the DSS image at the MLS field.

3.2 Exo-Planet Micro Lensing Survey

The MLS field is an extremely crowded field. Figure 5 shows the WFI apertures overlaid on an image from the Digitized Sky Survey (DSS). The 2MASS point source catalog lists over 110,000 stars per square degree, but the catalog is complete only down to a faint limit of about H_{AB} ~15, as shown in figure 6. Application of the 10” isolation criteria yields over 5500 candidate guide stars/deg^2. However, given the shallow depth of 2MASS in this region, it is likely that a significant fraction of these candidates actually have a neighbor only slightly fainter, but below the depth of the catalog. Therefore a deeper catalog is needed to verify that these stars satisfy the isolation criteria. Unfortunately GSC2.3 is also shallow in this field (by about 5 magnitudes relative to its nominal depth) and thus can provide little if any additional support to evaluating a star’s isolation. This crowded region underscores the need to determine how much fainter a neighboring star must be for it to not interfere with the acquisition of the guide star. Table 3 summarizes the guide star statistics for the MLS field, using only 2MASS. We do not include an analysis of guide star availability for GRS dispersed images since grism spectroscopy in this field is not expected to be feasible.

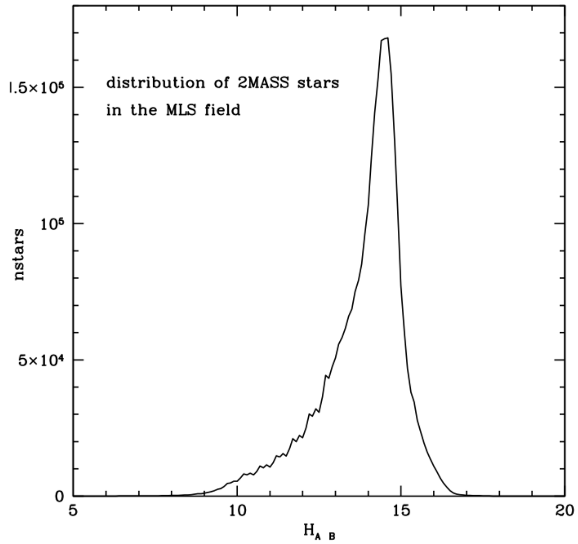

Figure 5. The distribution of stars in the MLS field as a function of H_{AB} magnitude over an area of 28.3 square degrees.

Table 3. Guide Star statistics for the MLS field, with bright limit H_{AB} = 13.0

faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
14	23.2	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	76.1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
16	88.7	1.000	1.000	1.000	1.000	1.000	1.000	1.000

3.3 Northern Galactic Pole

The region of sky near the north galactic pole is representative of sparse fields with a near minimum density of guide star candidates. Table 4 summaries the statistics for guide star candidates in this region. For sparse fields it will be necessary to use guide stars down to $H_{AB} < \sim 15$ to exceed a 95% probability of access to guide stars in the event that the FGS function employs two or three dedicated apertures for the guide function (table 4a). If guiding for the GRS mode uses the dispersed LSF, table 4b indicates that the FGS function will need to reach $H_{AB} \sim 13$ to assure that at least 4 detectors will have GS candidates.

Table 4a. Guide Star statistics for the NGP, with bright limit H_{AB} = 13.0 (WFI)

faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
14	0.8	0.571	1.000	0.648	0.000	0.816	0.326	0.606
15	2.8	0.939	1.000	1.000	0.321	0.996	0.882	0.989
16	5.5	0.996	1.000	1.000	0.926	1.000	0.992	1.000
17	10.6	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4b. Guide Star statistics for NGP, with bright limit HAB = 9.0 (GRS)

faint lim H_{AB}	m	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
10	0.04	0.035	0.003	0.000	0.000	0.069	0.001	0.004
11	0.122	0.115	0.145	0.000	0.000	0.217	0.013	0.037
12	0.320	0.275	0.771	0.011	0.000	0.474	0.075	0.185
13	0.731	0.519	0.998	0.470	0.000	0.768	0.266	0.528

3.4 Intermediate High Galactic Latitude

We include an additional field at (l,b) = (180, -60) since, in GSC2.3, this field is even more sparse than the north galactic pole. However, we find this field to have similar star densities as the north galactic pole down to the limit of the 2MASS catalog (most likely the photographic plates upon which GSC2.3 is based did not go as deep as usual in this particular field). As with all these fields, using only 2MASS to search for near neighbors effectively reduces the magnitude difference of known neighbors as the faint end of the catalog is approached. Fortunately there is a sufficient number of guide star candidates with $H_{AB} < 15$, so setting this as the operational faint limit assures that no neighbors down to H_{AB} ~17.5 are within 10" of the guide star candidates.

Table 5a. Guide Star statistics for HGF, with bright limit H_{AB} = 13.0 (WFI).

Faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
14	1.0	0.633	1.000	0.824	0.000	0.865	0.401	0.695
15	2.9	0.942	1.000	1.000	0.346	0.997	0.887	0.990
16	6.1	0.998	1.000	1.000	0.960	1.000	0.996	1.000
17	11.9	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 5b. Guide Star statistics for HGF, with bright limit HAB = 9.0 (GRS).

faint lim H_{AB}	*m*	P_d	P_4	P_{10}	P_{18}	$P_{1,2}$	$P_{2,2}$	$P_{2,3}$
10	0.054	0.052	0.013	0.000	0.000	0.102	0.003	0.008
11	0.165	0.152	0.290	0.000	0.000	0.281	0.023	0.063
12	0.368	0.308	0.852	0.025	0.000	0.521	0.095	0.226
13	0.919	0.601	1.000	0.740	0.000	0.841	0.361	0.650

4. Isolation Criterion and Coarse Pointing Performance

The adopted guide star isolation criterion of 10" is based upon the size of the initial guide window (GW), being a 64x64 pixel (7"x7") subarray (Spergel et al. 2015). To guarantee that a particular guide star will be within this GW, the attitude control system must be able to achieve an absolute pointing of ~1.2" 1-σ/axis, without making use of data from the FGS function. If actual ACS performance requires a larger initial GW, it follows that a larger isolation criterion must be applied when selecting guide stars. For the three sparse fields (HLS, NGP, HGL) included in this study we find no significant change in the statistics of guide star availability for isolation criterion as large as 20”. However, the access to guide stars in the crowded MLS field is very sensitive to the imposed isolation requirement beyond 15”. Table 6 shows the average minimum separation between stars in the 2MASS catalog for these four fields, along with the standard deviation about these separations. Clearly for all but the MLS field, the average distance to a neighboring cataloged star is significantly greater than the 10” isolation criterion we applied in this study. For the MLS field however, the average distance to the nearest neighbor, at 6.5”, is already well under the 10” limit. Application of a δmag >1 constraint to allow fainter neighbors to be present (the results in section 3.2 effectively precluded neighbors of any brightness) does not mitigate the issue since the dynamic range of 2MASS in this field is little more than ~1 magnitude (fig. 5). Table 7 shows the statistics for the MLS field for guide stars with $13<H_{AB}<16$ and a δmag>1 constraint on acceptable neighbors within 10”, 15”, and 20”. The columns have the same meaning as in tables 2 through 5. The new entries $\mathbf{P_1}$ and $\mathbf{P_2}$ are the probabilities that at least one or two of the 18 WFI detectors will have a guide star candidate, respectively.

Table 6. Average distance and standard deviation (arcseconds) to nearest neighbors.

Field	d	d_σ
HLS	28.7	15.2
NGP	49.6	27.8
HGF	46.0	25.4
MLS	6.2	2.2

Table 7. Guide star statistics for MLS field, isolation criteria on neighbors with δmag>1

isolation (arcsec)	***m***	$\mathbf{P_d}$	$\mathbf{P_1}$	$\mathbf{P_2}$	$\mathbf{P_4}$	$\mathbf{P_{1,2}}$	$\mathbf{P_{2,2}}$	$\mathbf{P_{2,3}}$
10	101.3	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	3.22	0.960	1.000	1.000	1.000	0.998	0.922	0.995
20	0.213	0.192	0.985	0.914	0.534	0.347	0.037	0.096

If the ACS absolute coarse pointing performance achieves an accuracy no better than about 3.3” 1σ/axis, the guide star acquisition function will require an initial GW of 128x128 pixels (14”x14”), and an isolation criterion of ~20” for guide star candidates. Table 7 shows that access to guide star candidates for at least 4 WFI detectors (P_4) in the MLS field would be difficult. However, even for an isolation requirement of 20” there is still a very high probability ($\mathbf{P_1}$) that such a star can be found in at *least one* of the WFI detectors. The ACS could first acquire this guide star with a sufficiently large initial GW, use its observed position to update knowledge of the spacecraft’s attitude, and then execute a corrective maneuver to allow for the use of the 64x64 pixel subarrays to acquire the other guide stars. These “second to acquire guide stars” only need an isolation criterion applicable for the small, 16x16 pixel subarray (1.7”x1.7”) fine guide GW, which is easily accommodated using 2MASS.

5. Future Work

The scope of this study is limited to the computation of guide star availability statistics using 2MASS as the WFIRST-AFTA guide star catalog over just four selected areas on the sky. We are informed by the operations concept for the FGS function outlined in Spergel et al. (2015), supplemented by Kruk (2015, priv. communications). This study considered guide stars only for wide field imaging and grism spectroscopy. We did not address guiding for the coronagraphs or the integral field spectrographs. We have identified areas associated with the WFIRST guide function that may warrant further studies.

5.1 Grism Spectroscopy

The operations concept for the FGS function for the GRS may introduce additional requirements on the guide star selection system, such as position angle constraints to avoid overlapping LSFs of the guide stars and its neighbors. If particular features of the LSF are to be used by the FGS function, the available area on a WFI detector that can be used for the guide function may be reduced, which in turn would reduce the guide star availability. A study to better define the FGS function using the LSF may be warranted.

5.2 Dedicated FGS fields

It may be concluded that the WFIRST-AFTA science program is optimized by using apertures dedicated to the FGS function, as may be the case if guiding on GRS LSFs results in high line of sight jitter, or if the WFI is to include narrow band filters. The guide star availability for these apertures will depend upon the passband, angular extent, sensitivity of the detectors, and the throughput of the optical train. This may require the use of a different guide star catalog, such as GSC2.3 rather than 2MASS.

5.3 Improving Reliability of Isolation Constraint for Crowded Fields

This study showed the need to apply an isolation constraint on guide star candidates in the Exo-planet Micro Lensing Field, as well as the difficulty of doing so using only 2MASS as the guide star catalog due to its shallow depth and hence small dynamic range in star brightness. Further studies are warranted to determine what the required δmag is for stars in the vicinity of the guide star. This is turn will better inform the selection of guide stars in fields similar to the MLS.

5.4 Guide Star Availability in M31

It is very likely that WFIRST-AFTA will observe and mosaic the Andromeda Galaxy, the LMC, the SMC, M51, e.g., with the WFI. These fields may present unique challenges to the guide star selection system. It is worth exploring access to guide stars using 2MASS and if needed, GSC2.3. Note: in support of JWST, STScI has developed the means to transform the three GSC2.3 optical magnitudes to the NIR (Chayer & Nelan, 2008).

5.5 Future Catalogs

The 2MASS catalog contains only positions and NIR magnitudes. It does not include proper motions. By the time WFIRST-AFTA becomes operational in approximately 2024 (Spergel et al., 2015), the 2MASS star positions will be based upon observations made ~24 years in the past, so considerable positional errors will be present due to unaccounted for proper motions. All-sky catalogs with proper motions, most notably PPMXL (Roeser et al., 2010) and UCAC4 (Zacharias et al., 2013) are available, but the errors of the proper motions are fairly large and, moreover these catalogs are not as deep as 2MASS and hence do not provide a clear benefit to WFIRST-AFTA. However, the GAIA mission will have completed its observations and released it final catalog in ~2023 (Eyer et al., 2013). It will have a depth of V < ~20 (which is $H_{AB} < 17.9$ for the M0 spectral type, but significantly deeper than 2MASS for earlier type stars). GAIA will provide positions and parallaxes for (even faint) stars with sub-milliarcsecond accuracy, along with proper motions with errors less than several micro-arcseconds/year, with an epoch of ~2020. Given the results of the study reported in this document, it is likely that 2MASS will suffice as the source of near infrared guide stars WFIRST-AFTA, but it should be updated with the astrometric results from the GAIA mission so that errors of the guide star positions contribute only insignificant errors to the WFIRST-AFTA astrometry. (STScI plans to utilize the intermediate GAIA releases to update the astrometry of GSC2 in support of the JWST mission.)

5.6 Improving support of WFIRST-AFTA in MAST

The Mikulski Archive for Space Telescopes (MAST) at STScI now supports the means to display the WFI apertures at any RA,Dec & orientation, overlaid with images from the digitized sky survey (DSS), SDSS, or Galex, and objects from 2MASS and GSC2.3 (e.g., refer to figures 4 & 6 of this document). The tool currently supports displaying catalog entries filtered by both a bright and faint limit. We plan to continue development of this tool to support the WFIRST coronagraphs and integral field spectrographs. The tool can be used to explicitly verify the statistical results documented in this report (this was done, as a spot check for a few locations in each field). The tool can be developed to support the WFIRST guide star selection system. The current version of the tool can be accessed at:

www.gsss.stsci/webservices/footprints/webform.aspx

5. Conclusions

The Two Micron All Sky Survey point source catalog is well suited to serve as the guide star catalog for WFIRST-AFTA with the current operations concept for the FGS function. Only the Expo-planet Micro Lensing Survey field presents a challenge to the FGS function because of the crowded star field and the shallow depth (small dynamic range) of the 2MASS catalog for application of a reliable isolation criterion for selecting guide star candidates. If the WFIRST ACS can provide an absolute line of sight coarse pointing accurate enough for the FGS function to use the 7.0”x7.0” guide star acquisition window then a guide star identification function, such as a pattern match of an observed star field to an uplinked predicted scene, can be avoided entirely, even in the extreme MLS field. If the FGS function can tolerate stars as bright as one magnitude fainter than the guide star in the GW, no catalogs deeper than 2MASS are needed for the MLS type fields.

6. Acknowledgements

This work was carried out under contract with the WFIRST Study Office at NASA Goddard Space Flight Center (GSFC), as part of the joint preformulation science center studies by the Space Telescope Science Institute (STScI) and the Infrared Processing and Analysis Center (IPAC). The authors acknowledge the use of a 2MASS catalog extraction tool developed by Jay Anderson at STScI.

7. References

Chayer, P., & Nelan, E., 2008, *"Algorithms for Transforming GSC-II Magnitudes into the NIR"*, JWST-STScI-001410

Kruk, J., 2015, private communication

Hirata, C, 2014, *"WFIRST high latitude survey"*, Wide Field InfraRed Surveys: Science and Techniques, Pasadena, Ca.

Nelan, E, 2004, "*The Density of Stars in GSC2 at High Galactic Latitudes"*, JWST-STScI-000379

Roesser et; al., 2010, *"The PPMXL Catalog if Positions and Proper Motions on the ICRS, Combining USNO-B1.0 and the Two Micron All Sky Survey (2MASS)"*, AJ 139, 6

Spergel, D., et al., 2015, *Wide-Field InfraRed Survey Telescope – Astrophysics Focused Telescope Assets, WFIRST-AFA 2015 Report by the Science Definition Team and WFIRST Study Office.*

Zacharias, N., et al., 2013, *"The Fourth US Naval Observatory CCD Astrograph Catalog (UCAC4)"*, AJ 145, 44Z

8. Acronyms

ACS	attitude control system
FGS	fine guidance sensor
GS	guide star
GSC2.3	guide star catalog, 2.3
GW	guide window
GRS	grism spectroscopy
HGL	high galactic latitude
HLS	High Latitude Survey
IFS	integral field spectrograph
LSF	line spread function
MAST	Mikulski Archive for Space Telescopes
MLS	Micro Lensing Survey
NGP	north galactic pole
PSF	point spread function

2MASS	two micron all sky survey
WFI	wide field imager