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Zero-Parallax Galactic Stars

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ABSTRACT

Zero parallax sources are required to reduce parallax zonal errors in the final JMAPS global block-adjustment solution. For most of the sky, ICRF quasars provide stable, zero parallax anchors for astrometry. However, quasars that fulfill JMAPS requirements on magnitude and stability cannot be seen along the galactic plane because of extinction. As a result, parallax zonal errors are larger than desirable along the galactic plane region. We look to possible alternative near-zero parallax sources that could be used in lieu of quasars to suppress zonal parallax errors along the galactic plane. We examine O-stars, Wolf-Rayet stars, and K-giants as potential candidates for JMAPS zero parallax galactic stars. We find that O-stars are not viable as zero parallax reference stars because of close proximity. We identify 249 K-giant and 2 Wolf-Rayet star candidates and simulate the effects of their inclusion on the final block-adjustment parallax solution.

1. Introduction

For a global astrometric project depending on many stars and a large fraction of the sky, zonal error is one of the crucial parameters. Zonal error, defined as positionally correlated residuals, can have either a systematic cause, resulting from instrument problems or astrometric method errors, or a random cause, resulting from photon noise for example, or both. Because JMAPS observations in small fields are differential, and because JMAPS will obtain precise relative parallaxes directly, zero or near zero parallax objects are required to minimize zonal errors and make JMAPS positions, parallaxes, and proper motions as accurate as possible.

As documented in TM 08-25, one of the three requirements of the reference frame program is orientation or link to the ICRF. The JMAPS reference frame will use about 100 zero parallax extragalactic sources, quasars, and will use optical observations of about 50 ICRF quasars to to link the JMAPS system to the ICRS. However, because ICRF targets can be very faint and require excessive JMAPS observing time, or are nearby and have arcsecond scale structure, and because these quasars cannot be found along the galactic plane, alternative zero parallax objects are required along the galactic plane to reduce JMAPS zonal errors. In TM 08-25, Zacharias suggests three viable candidates for zero-parallax stars, luminous O-stars, Wolf-Rayet Stars, and along with Frink et al. 1999, K-giants.

2. O-Stars

The group of O-stars considered was the most comprehensive available catalog, the Maiz-Apalleniz et al. (2004) catalog of bright galactic O-stars complete to a V-band magnitude ≤ 8 that also includes many fainter stars. Among other data, the catalog include Hipparcos distances to many of the stars. While a few of the entries had listed distances greater than 5 kpc, the errors on the parallax were large enough to render the data useless. Next, a simple photometric parallax was calculated for each entry. The observed B and V banded data is used along with color excess data from the Schlegel et al. (1998) reddening map as a function of position to determine the the intrinsic B-V color index.

$$(B-V)_{intrinsic} = (B-V)_{observed} - E_{B-V} \tag{1}$$

This intrinsic color index is then used in a 6^{th} order polynomial interpolation from Mermilliod et al. (1981) to determine the absolute V-band magnitude of the entry.

$$M_v = a(B-V)^6 + b(B-V)^5 + c(B-V)^4 + d(B-V)^3 + e(B-V)^2 + f(B-V) + g \tag{2}$$

The error for the (B-V) color index is calculated by adding the apparent B and V-band magnitudes in quadrature:

$$\sigma(B-V) = \sqrt{\sigma(B)^2 + \sigma(V)^2} \tag{3}$$

The $\sigma(B-V)$ is then propagated through the Mermilliod et al. interpolation to calculate the error in absolute magnitude. This error is then included with the listed V-band error to calculate the shortest distance from photometric parallax:

$$d = 10^{\frac{(m_v - \sigma(m_v) - M_v - \sigma(M_v) + 5)}{5}} \tag{4}$$

Unfortunately, none of the calculated distances were farther than the required 5kpc.

3. Wolf-Rayet Stars

The analyzed sample of Wolf-Rayet (WR) Stars was the 7^{th} Catalog of Galactic Wolf-Rayet Stars (van der Hucht, 2001), which documents a collection of 227 luminous and distant stars. Because of the nature of the stars in this catalog, extra criteria are implemented when searching for zero parallax stars. First, because many of the listed stars were binaries, extra checks to avoid these binaries are used. Second, the only distance determinations from van der Hucht 2001 accurate enough for this search are calculated by determining that the WR star belongs to an open cluster or OB association and using the distance to the cluster or association. Only distances identified through this method are accepted. Implementing these extra criteria, 4 candidates are viable. Because two of these are all in the same cluster, they provide little more than a single zero parallax star to tie down zonal errors in the vicinity.

Candidate Wolf-Rayet Stars

WR	SpType	v	b-v	$(b\text{-}v)_0$	E_{b-v}	A_v	v_0	Mv(WR)	v_0-M_v	d	Cl/OB
20a	WN7:h/WC	14.14	1.38	-0.27	1.68	6.76	7.38	-6.42	13.80	5.75	Westerlund 2
38a	WN5	16.21	0.83	-0.49	1.32	5.41	10.80	-4.70	15.50	12.10	C 1104-610a
43b	WN6ha	11.97	0.74	-0.28	1.02	4.17	7.80	-7.23	15.03	10.10	NGC 3603
43c	WN6ha	12.37	0.74	-0.28	1.02	4.17	8.20	-6.83	15.03	10.10	NGC 3603

Note: WR stands for the van der Hucht 2001 catalog number, and Cl/OB stands for the cluster or OB association of the WR candidate.

Unfortunately, because of the distance identification method van der Hucht et al. used, distance errors cannot be determined. Either the WR stars are part of the open cluster or OB associating, in which case the determined distances are accurate, or the WR stars are not part of the cluster or association, in which case no errors can be calculated. At this time, we are provisionally including 38a and 43b. More research will be done on these stars, but their inclusion will likely make only a small impact because there are only two and because they are close to other zero parallax candidates.

4. K-Giants

K-giants are viable candidates because they are numerous, they can be found all over the sky, and their radial velocities can be measured with good precision. K-giants have fewer characteristics that may potentially cause problems for zero parallax astrometry. The first of those problems is variability, which effects M-giants. Because luminous O and B stars are young, they are more often found in spiral arms, which can cause reddening and identification issues. Furthermore, precise radial velocity measurements of early-type stars are not easily obtained, making critical identification of spectroscopic binaries more difficult. However, K-giants may have exoplanet companions or chromospheric activity, both of which can hamper accurate astrometric measurement. But, if the stars in question are far enough away, these issues will become negligible.

We search through a subset of the Space Interferometry Mission (SIM) K-giant Grid Stars, courtesy of Ricky Patterson (UVA). We require that each candidate has only one UCAC3 entry, then use UCAC3 and included 2MASS data to further constrain the sample. We use the Schegel 1998 reddening map and 2MASS photometric data and associated errors to strictly constrain all color indices to those set forth in Allen's Astrophysical Quantities. With these criteria, we narrow the original subset down to 1700 viable candidates. However, we also require an I-band magnitude of 12.5 or brighter to observe at 5 milliarcsecond (mas) single measurement precision (SMP) routinely during the mission without using additional mission time, which further reduces the number of viable candidates to 253.

To further justify the sample set, we analyze galactic geometry to ensure distance accuracy. Candidates close the galactic anti-center, the shortest distance to the edge of the galaxy, may have an upper limit to how distant they can be. Because the upper limit to estimates on the diameter of the Milky Way is around 50 kpc (Modern Astrophysics 1996), and because the consensus on the distance to the galactic center is around 8.0 +/- 0.5 kpc (Modern Astrophysics 1996), an upper limit of about 17 kpc may placed on the distance of K-giants in the direction of the galactic anti-center. We use the law of cosines to validate the distances of candidates +/- 30° from the galactic anti-center. If the cosine calculation produces a distance less than 25% as far as the photometric parallax calculation, the candidate is discarded. Furthermore, to ensure accurate data, any candidate within 2° of the galactic bulge, which has a diameter of about 2 kpc (Modern Astrophysics 1996), will be discarded to reduce the risk interstellar reddening and extinction pose to K-giant identification or distance calculation. These galactic contraints reduce the number of viable candidates to 249.

Table 1 shows the number of candidates as a function of I-band magnitude and cummulative I-band magnitude, as provided by SuperCOSMOS, while Table 2 provides the number of candidates as a function of distance. Figures 1a and b display non-cumulative and cumulative histograms of K-giant candidates as a function of I-band magnitude, while Figures 2a and b show non-cumulative and cumulative histograms of K-giant candidates as a function of distance. Figure 3 displays the K-giant candidate locations and distances, and Figure 4a-d shows candidate locations for four separate distance bins, 10-12 kpc, 12-14 kpc, 14-16 kpc, and >16 kpc, respectively.

Table 1: Non-Cummulative and Cummulative
K-Giant Counts by I-band Magnitude

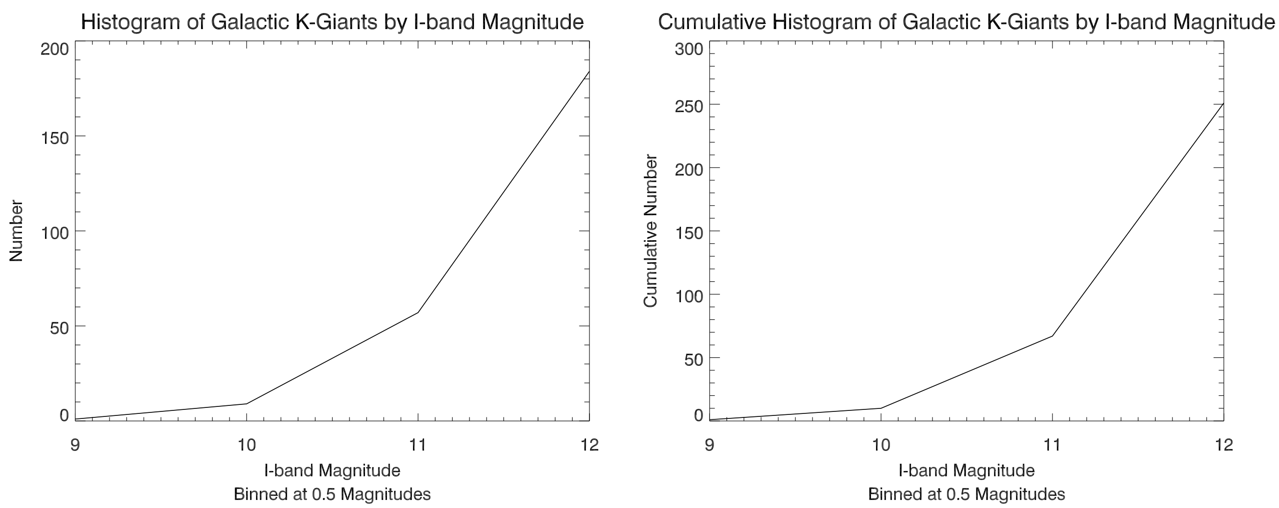
I-band Magnitude	Non-cummulative Counts	Cummulative Counts
9	1	1
10	9	10
11	57	67
12	184	251

Table 2: Non-Cummulative and Cummulative
K-Giant Counts by Distance

Distance (kpc)	Non-cummulative Counts	Cummulative Counts
5	4	4
6	6	10
7	0	10
8	0	10
9	0	10
10	47	57
11	59	116
12	42	158
13	19	177
14	14	191
15	20	211
16	8	219
17	4	223
18	5	228
19	23	251

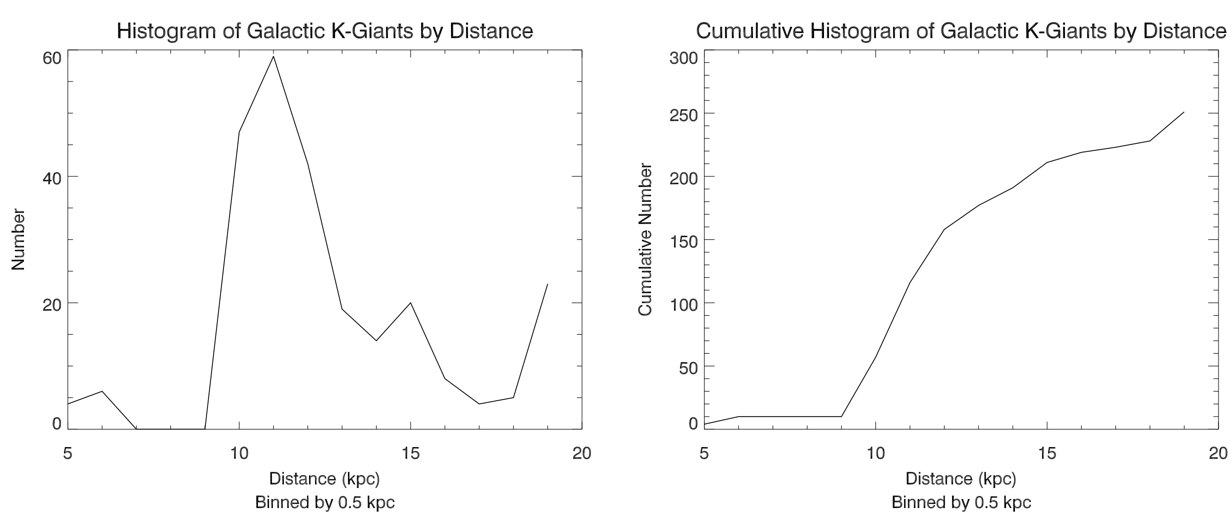
5. Zonal Error Simulations

Zonal errors have characteristically continuous variation over the entire sky, and as such form a scalar field that ordinary spherical harmonics can represent successfully (Makarov TM 08-17). Using the MATLAB simulation documented in TM 08-17, we simulate zonal errors with and without the K-giant and WR candidates. Figures 5, 6, and 7 show the zonal



(a) (b)

Figure 1: Histogram and Cumulative Histogram of K-giants by I-band Magnitude



(a) (b)

Figure 2: Histogram and Cumulative Histogram of K-giants by Distance

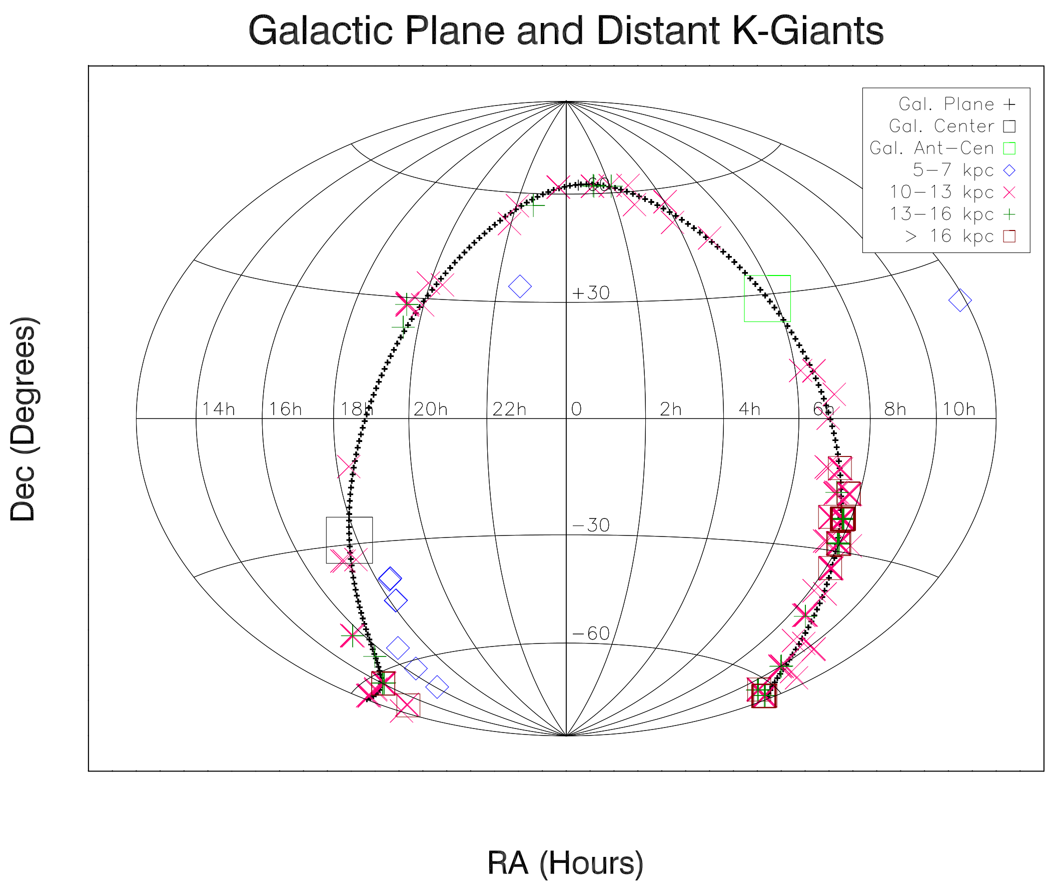


Figure 3: K-Giant Candidate Locations and Distances

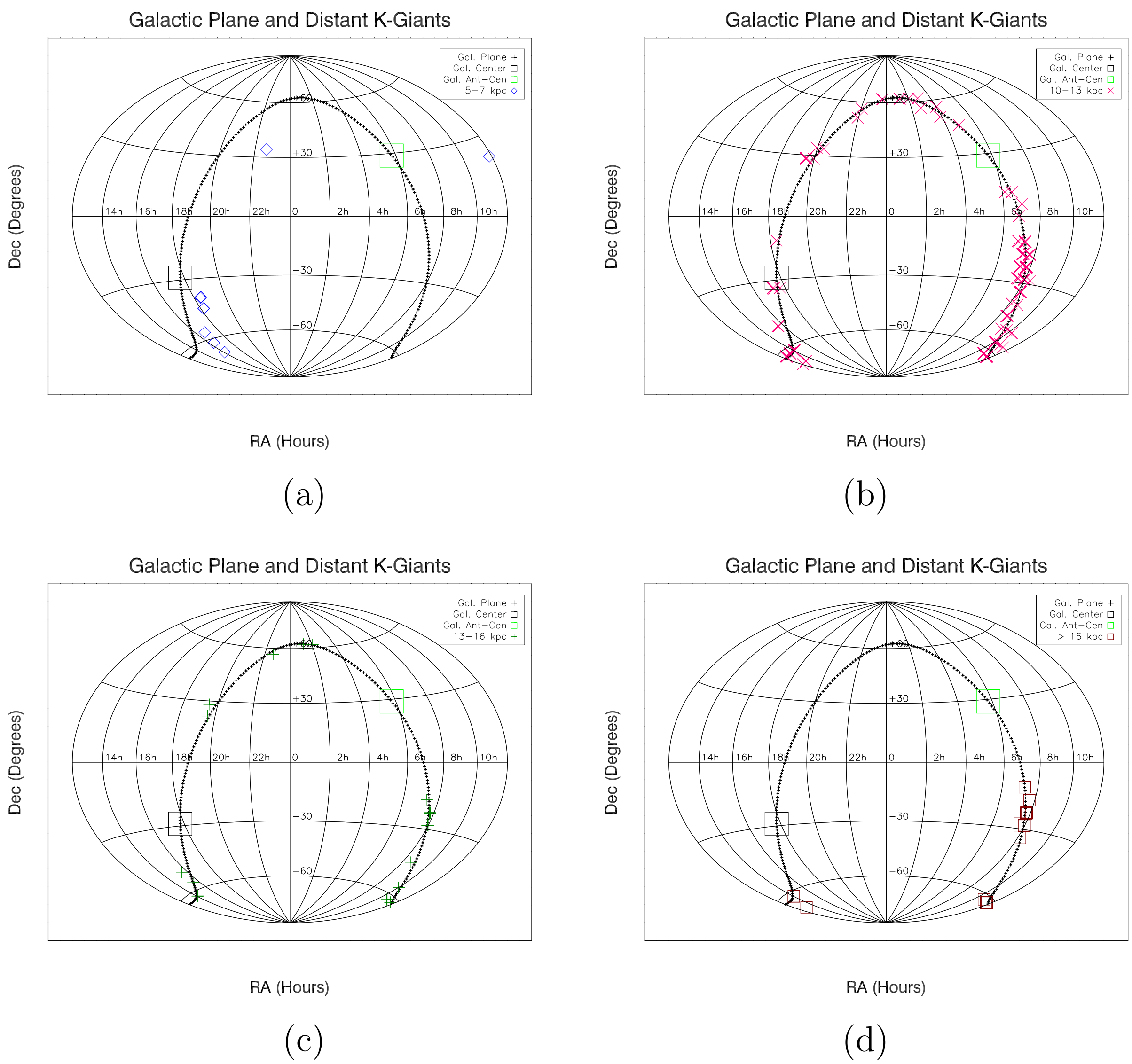


Figure 4: K-Giant Locations for Distances 10-12 kpc, 12-14, kpc, 14-16 kpc, and >16 kpc, respectively.

error simulation results without the K-giants or WR stars, with the K-giants and without the WR stars, and with both the K-giants and the WR stars, respectively.

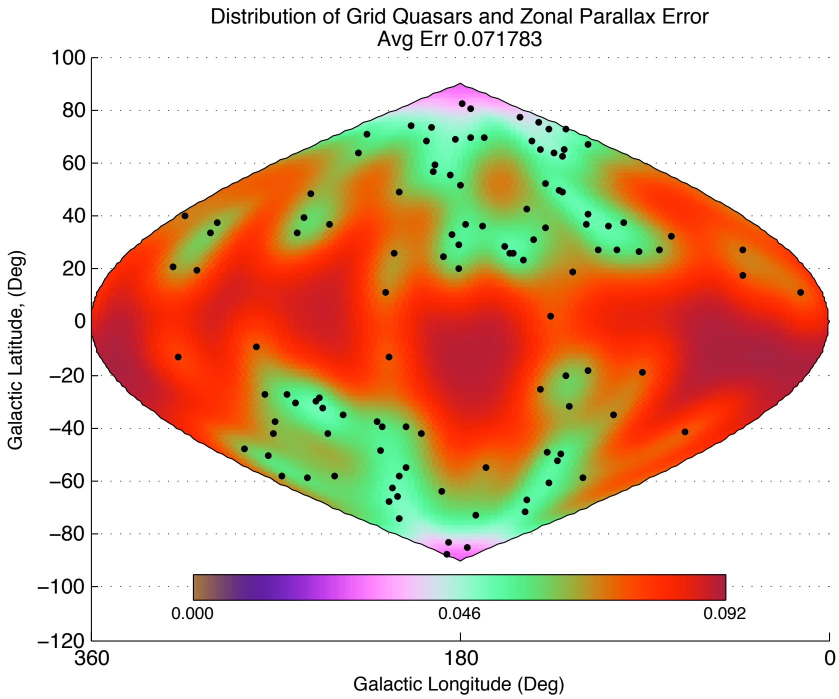


Figure 5: Zonal Error Simulation without K-giants and without WR Stars

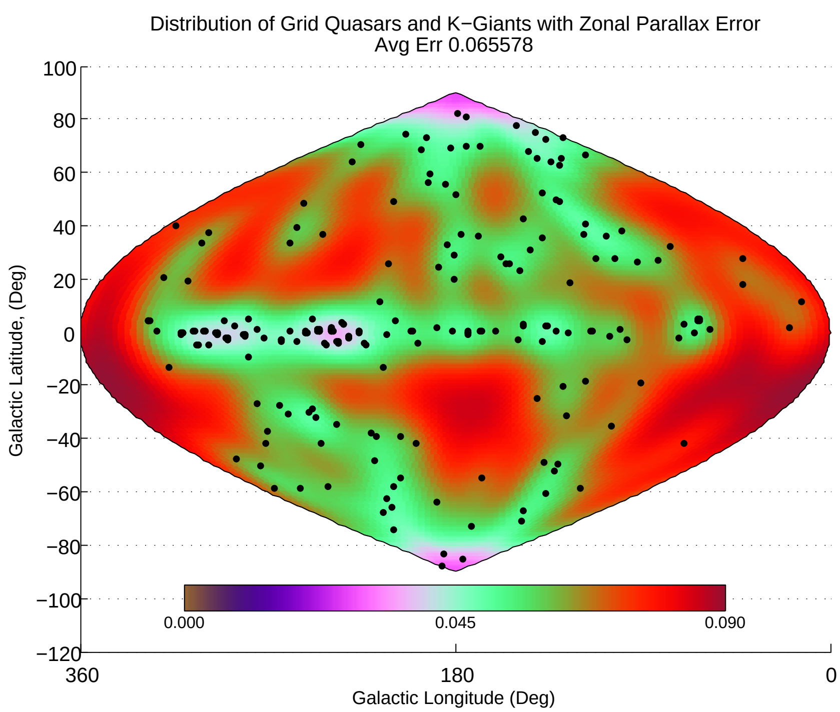


Figure 6: Zonal Error Simulation with K-giants and without WR Stars

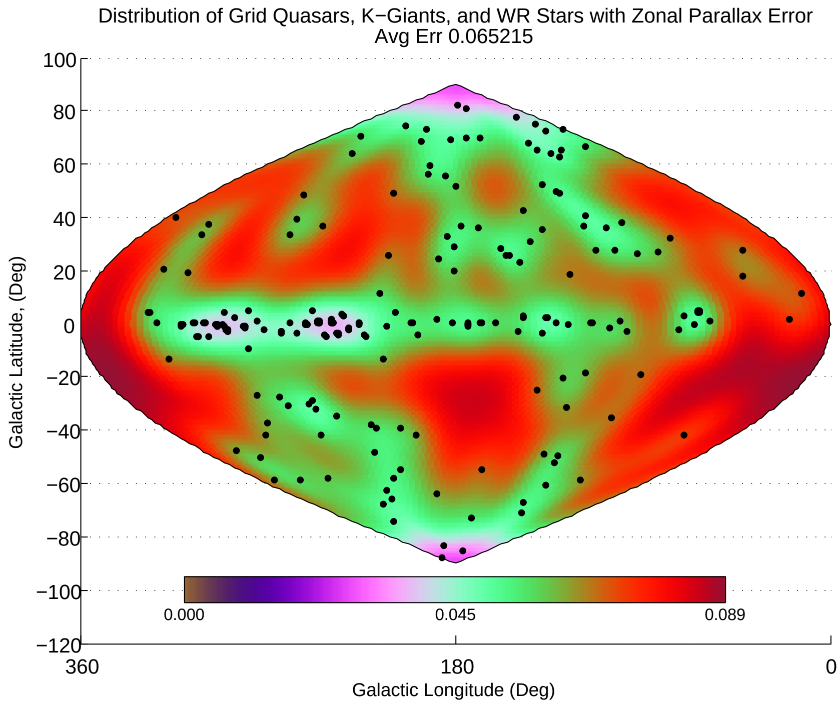


Figure 7: Zonal Error Simulation with K-giants and with WR Stars

The average error in mas is given by multiplying the "average error" coefficient by the SMP of the ICRF quasars. Assuming an SMP of 5 mas, we get $0.071783 \times 5\text{mas} = 0.360\text{mas}$ without the K-giants and $0.065578 \times 5\text{mas} = 0.328$ mas with the K-giants, a reduction of approximately 8.9%. Including the WR stars, the average error becomes $0.065215 \times 5\text{mas} = 0.326$ mas, a continued reduction of 0.6% from the simulation only including the K-giants. Perhaps more importantly, errors are significantly reduced in along the galactic plane region where the majority of JMAPS stars will be. Figures 5, 6, and 7 clearly show how the 249 K-giant and 2 WR Stars candidates tie down zonal errors along the galactic plane, which is where zonal errors were previously at their highest. We note that the addition of the 2 WR stars does not significantly help the error reduction after the inclusion of the K-giants. UCAC3 data on all 251 candidates can be found online at the JMAPS Docushare website.

6. Conclusions

O-Stars cannot serve as JMAPS zero-parallax reference objects because they are too close. We find 249 K-giant and 2 WR Star near-zero parallax galactic candidates to reduce zonal errors along the galactic plane. Errors on the candidates' available data have been analyzed, and the candidates remain viable. Both K-giants and WR stars off the galactic plane may also be used to reduce JMAPS zonal errors in the future.

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