COMPUTATION OF COMPILATION CATALOGS

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Abstract: Currently the computation of mean positions and proper motions for the International Reference Stars (IRS) is hampered by large variations in the observational histories of the stars and lack of overlap between the magnitudes of the IRS and of the FK4. The poorest IRS observational histories are +60° to +80° in the north and -40° to -80° in the south. The much-needed extension of the fundamental system to the ninth magnitude will be made in the FK5. The Faint Fundamental Extension is currently being selected at the U. S. Naval Observatory. A proposed list of 1030 Faint Fundamental stars has been prepared for the Northern Hemisphere, and work has begun on the selection in the Southern Hemisphere.

Compiled catalogs of stellar positions and motions are usually produced by combining a number of catalogs of observed stellar positions. The reasons for doing this are to average out the systematic errors of the individual catalogs to give the best possible mean positions and to determine as accurately as possible the proper motions by combining observations made over a range of epochs. The fundamental catalogs have been examples of this.

In order to combine catalogs it is necessary to do two things. First the catalogs must be brought to some common system. The system may either be an existing one, such as the FK4, or one that is defined by a subset of catalogs to be combined, such as the GC. Second, the catalogs must be brought to a common equinox.

In reducing a catalog to a given system, FK4 for example, it is necessary that there be a number of stars in common between the catalog and the FK4. If this is the case, then some interpolating procedure must be applied in order to determine the systematic differences at points in the sky where there are no stars in common and in order to smooth out the individual fluctuations about the mean. In recent years two methods have generally been used to acomplish this goal: a cellular method, Brosche et al. (1964), modified by Corbin

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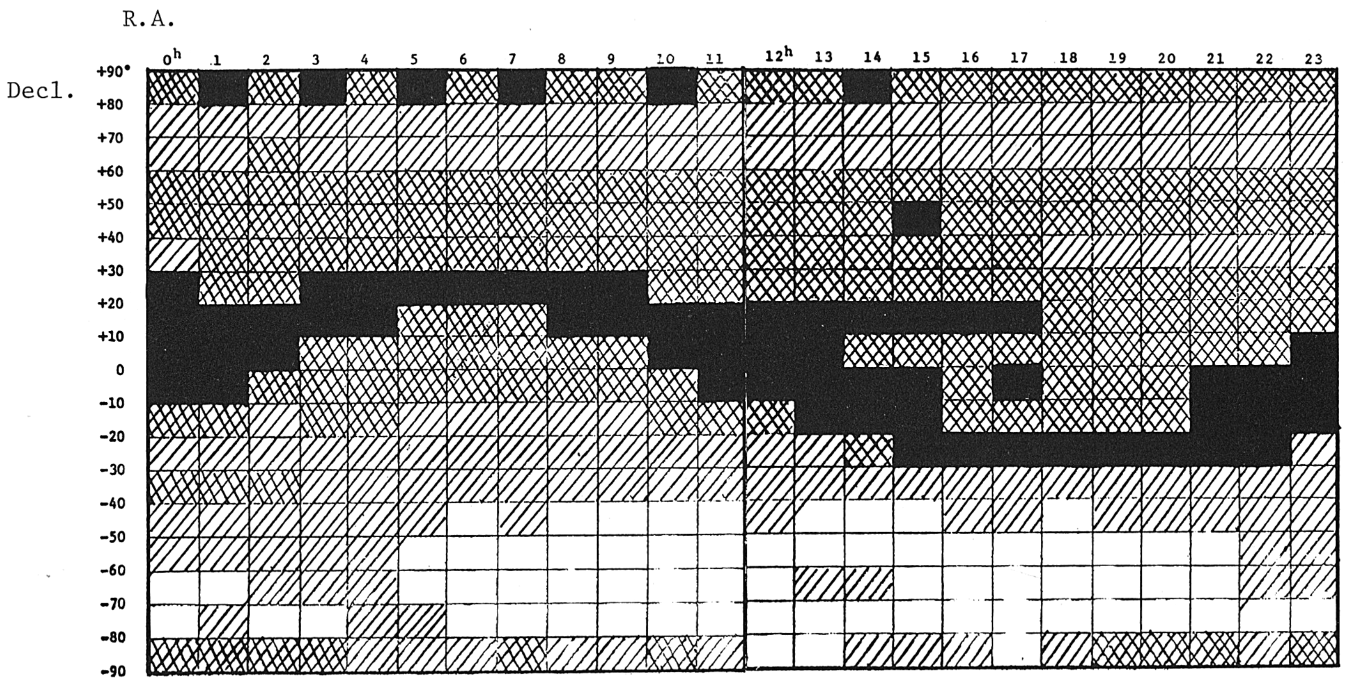
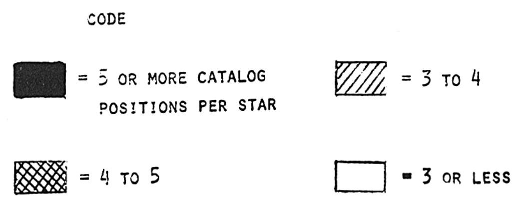


Figure 1. The observational histories of the International Reference Stars. The averages are for blocks of 1^h in right ascension by 10° in declination.



(1977) and an analytical method developed by Bien et al. (1978). Both methods give good results, and comparisons of reductions to the FK4 made with each method show that the two agree to within the internal errors of the catalog systems themselves.

For some time there has been a need for an improved catalog of positions and motions of reference stars in the seventh to ninth magnitude range. Such a catalog was proposed by Scott (1962). A combination of the SRS and AGK3R would give the desired result of about one star per square degree in the required magnitude range. It was therefore decided to produce a compiled Catalog of International Reference Stars (IRS) by incorporating the results of the AGK3R and SRS observing programs with earlier catalog positions. In addition to the considerations just mentioned this project has presented two problems that have not yet been fully solved. The first problem is that of observational history. Unlike the Albany GC the IRS list was selected on the basis of an even distribution over the whole sky. Whenever possible, stars with good observational histories were selected, but there are whole regions, especially in the Southern Hemisphere, where the histories are poor. Figure 1 summarizes the situation. Two features stand out: 1. The Zodiacal region has been observed much more heavily than the rest of the sky. 2. The stars between declinations -40° and -80° have very poor histories, and in the band from +60° to +80° the histories are below average. The second problem can be seen in Figure 2. Since the IRS positions are to be on the system of the FK4, catalog reductions become difficult in those cases where bright stars were not included in the observing program or where there is reason to believe that the observed positions are affected by magnitude equation. As Figure 2 shows, there is practically no overlap in the magnitude ranges of the FK4 and the IRS. Therefore, catalogs that either have no bright stars or have magnitude equation in the positions cannot be reduced to the FK4 system by direct comparison.

The solution to the first problem can only be found in additional observations. Global programs such as the upcoming Hipparcos and Naval Observatory programs will be especially valuable for improving the positions and motions of the whole of the IRS. Smaller programs are also needed. An example is the recent Washington Six-Inch program. During this program 1600 northern IRS stars with the poorest histories were added to the list.

The solution to the second problem lies in the composition of the next fundamental catalog (FK5). No matter which interpolating scheme is used for the systematic differences, an extrapolation of several magnitudes is required to bring observations of the IRS list to the FK4 system. In the case of the northern IRS we were able to combine catalogs that had been observed with instruments equipped with screens and form a Base System of 5590 IRS stars. This Base System was then used to make systematic reductions of those catalogs that either have no FK4 stars or are likely to have magnitude equation in their

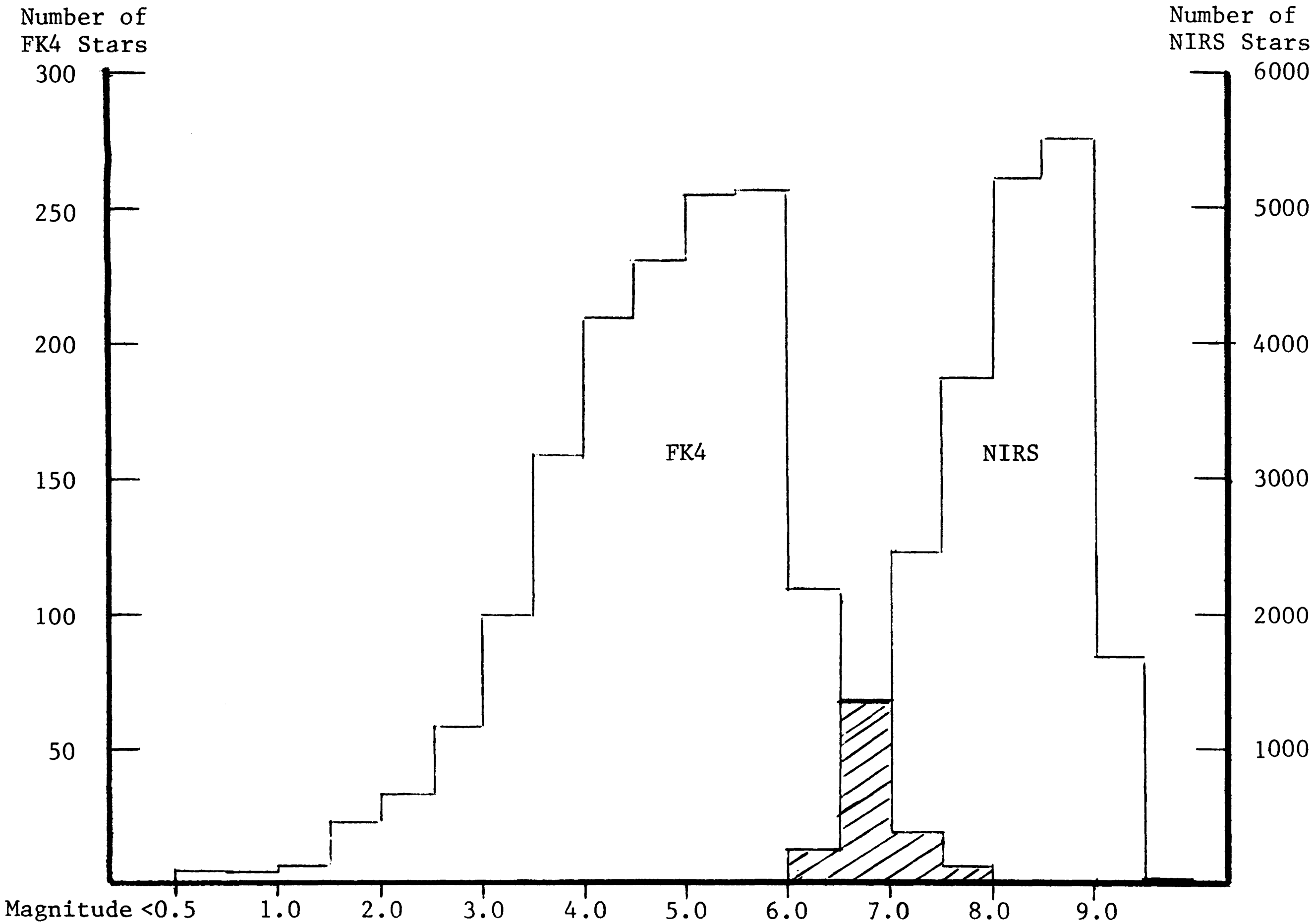


Figure 2 - Comparison of the distributions of magnitudes in the FK4 and the northern International Reference Stars (NIRS). The shaded area shows the small overlap in magnitude between the two catalogs.

results. Thus in this case the extrapolation from the bright to the faint stars has been made directly through the instruments that observed the Base System catalogs. Such a direct approach is not possible for the southern IRS work. We have constructed a preliminary Southern Base System and find that 61% of the stars fall north of −30°, 30% are between −20° and −50° and only 9% are south of −50° . The density of these stars south of −30° is too low to permit their use in making systematic reductions. It will therefore be necessary to take those catalogs that cover a wide range of southern declinations and determine magnitude equations north of −30° . These will be studied for variation with declination, and for those catalogs whose magnitude equations appear to be constant with declination, the magnitude equations will be applied to the systematic differences determined by the bright stars south of −30° . Thus in the south the reduction of the IRS positions in the catalogs to the FK4 system will of necessity be a less reliable extrapolation than that made in the north. Direct and reliable systematic reductions can only be made if the fundamental catalog contains stars down to the 9th magnitude.

Kopff (1954) published the "Supplement-Katalog des FK3 (FK3Supp)" and later Fricke (1963) gave the positions of these same stars on the FK4 system (FK4 Sup) with the intention that these stars would be included as much as possible in programs and could be used to expand future fundamental catalogs. However, while the Sup list would increase the density of the fundamental stars, it would not extend the magnitude range very much. Table 1 shows the distributions of the magnitudes of the FK4 Sup stars and of a combined FK4 & FK4 Sup list. It is clear from this table that a combined list would not be a significant improvement over the FK4 for the purpose of systematic

Table 1

Distribution of Magnitudes

Magnitude	FK4 Sup		FK4 & FK4 Sup	
< 1.0	0 stars	0.0%	12 stars	0.3%
1.0 - 1.5	0	0.0	7	0.2
1.5 - 2.0	0	0.0	21	0.6
2.0 - 2.5	0	0.0	33	0.9
2.5 - 3.0	0	0.0	57	1.6
3.0 - 3.5	0	0.0	99	2.8
3.5 - 4.0	3	0.2	161	4.6
4.0 - 4.5	34	1.7	243	6.9
4.5 - 5.0	139	7.0	368	10.4
5.0 - 5.5	300	15.1	554	15.7
5.5 - 6.0	514	25.9	769	21.8
6.0 - 6.5	572	28.8	682	19.4
6.5 - 7.0	322	16.2	388	11.0
7.0 - 7.5	97	4.9	115	3.3
7.5 - 8.0	6	0.3	12	0.3
< 8.0	0	0.0	1	0.0

reductions of observed positions of the IRS list. Fricke (1963) realized that there must be additional fundamental stars that would extend the next fundamental catalog to the ninth magnitude. This concept is now referred to as the Faint Fundamental Extension (FFE).

In order to assist with the effort to complete the FK5 catalog the U. S. Naval Observatory agreed several months ago to begin the selection of the FFE. Since the work on the northern IRS has been completed (Corbin, 1978),the required data are available for selection of the FFE in that part of the sky. Discussions with our colleagues at the Astronomisches Rechen-Institut have shown that there should be a total of about 2,000 FFE stars. Using this number as a guide, we have adopted the following process to select a proposed list of FFE stars in the Northern Hemisphere:

1. A list of candidate stars was prepared by choosing all northern IRS stars that had observational histories of seven or more catalog positions and that had a sum of weights of 2.5 resulting from the proper motion solution (where the average AGK3R catalog position defined unit weight). This gave a list of 2940 candidate stars.

2. Those candidates within one degree of an FK4 star were excluded. Exceptions were made for 18 of these stars that have very good histories (generally 12 or more catalog positions) and that are at least 2500 arcsec from the neighboring FK4. This process reduced the number of candidates to 2654 stars.

3. The northern sky was divided into blocks that were 4° in declination by 5.5^h in right ascension. The number of candidates in each block was exhibited. As Figure 1 indicates, the numbers of stars in the blocks varied greatly. Some of the blocks in the Zodiacal region showed as many as eleven candidates, and other blocks in poorer regions of the sky showed none.

4. Since it is desirable to have an FFE list that not only gives the fundamental list a good distribution in magnitude down to the ninth magnitude, but also is well distributed in spectral type, it was necessary to consider these factors while at the same time selecting the stars that have the best possible observational histories. Table 2 shows that the northern IRS does not have an even distribution in either magnitude from seventh to ninth magnitude or spectral type. The distribution of the candidates is better in magnitude than the parent list and about the same in spectral type.

5. The list was divided into 10° zones. In each zone the blocks with the lowest numbers of candidates were considered first. For each block a listing was made which itemized for each candidate star the magnitude, spectral type, number of catalog positions used in the IRS work and the dispersion of their epochs, mean epochs of the mean positions, mean errors of the proper motions and sum of the weights from the proper motion solution. Information was also listed for the candidates and FFE stars selected in the surrounding blocks. In addition plots of the block and surrounding blocks were made so that relative positions of the stars could be taken into account.

6. As selection progressed in each 10° zone, updated summaries of the distributions of magnitudes and spectral types of selected stars

in the zone were made. Since the poorest blocks were done first, these summaries made it possible to adjust the distributions of these quantities as selections were made in the more densely populated blocks.

7. After these steps had been taken, a program that had been developed by C. Smith, USNO, for the identification of holes in the distribution of stars in the IRS list was modified to check the distribution of the stars that had been selected. All areas of 30 or more square degrees without any selected stars were identified and exhibited (see step 5). Additional stars were selected to fill in these areas. Next, fourteen extra stars were added to the zone +80° to +90° to give the polar region a higher density than the average zone. This was done because many applications of fundamental catalogs require a certain number of stars per hour of right ascension rather than per square degree.

Table 2

Distributions in Magnitude and Spectral Type

	Northern IRS	Faint Fundamental Candidates
Magnitude		
< 6.5	1.4 %	4.2 %
6.5 - 7.0	6.4	14.8
7.0 - 7.5	12.1	20.4
7.5 - 8.0	18.5	20.3
8.0 - 8.5	25.8	20.0
8.5 - 9.0	27.3	16.4
> 9.0	8.5	3.9
Total Number of Stars	20,194	2,654
Spectral Type		
O & B	3.5 %	4.0 %
A	16.8	15.4
F	16.9	17.8
G	16.7	18.0
K	43.0	40.7
M & other late types	3.1	4.1

8. The resulting list of proposed FFE stars for the Northern Hemisphere contains 1030 stars. The basic characteristics of the list are in Tables 3 and 4, in which the magnitudes and spectral types in AGK3R and the northern IRS mean errors of the proper motions are used. The values shown in Table 3 illustrate the fact that it was possible to get a better balance among the spectral types than exists in the

candidate list. There is also a better distribution in magnitude in that the percentage of stars fainter than 8.5 has been increased and the percentage brighter than 7.0 has been decreased. The reason for the decrease in the brighter stars is that it is in the 6.0 to 7.0 magnitude range where the Faint Fundamentals must interface with the combined FK4 and FK4 Sup list. It is anticipated that there will be about 1200 FK4 Sup stars in the FK5. Using this as a guide, Figure 3 has been drawn to show the projected distribution of magnitudes in the Northern Hemisphere that will result from combining the FK4, 600 FK4 Sup stars and the northern Faint Fundamentals. It is clear that the FK5 will be capable of meeting a much greater variety of requirements than the FK4. This will be due to both the increase in number of stars and the uniform distribution in magnitude from the fifth to ninth magnitudes.

Table 3

Distributions by Magnitude and Spectral Type of Stars Selected for the Northern Faint Fundamental Extension

Magnitude		Spectral Type	
< 6.5	1.0 %	B & O	7.6 %
6.5 - 7.0	11.2	A	19.8
7.0 - 7.5	20.2	F	18.6
7.5 - 8.0	19.7	G	19.6
8.0 - 8.5	20.3	K	28.4
8.5 - 9.0	20.0	M & other late types	5.9
9.0 - 9.5	7.7		

Table 4

Distribution of the Mean Errors of the Proper Motions of the Stars Selected for the Northern Faint Fundamental Extension (Data from the Northern IRS Proper Motions)

Number of Catalog Positions	Number of Stars	Average $\varepsilon(\mu_\alpha)$	Average $\varepsilon(\mu_\delta)$
5	40	0".34/century	0".36/century
6	155	.32	.33
7	232	.31	.34
8	187	.30	.35
9	95	.31	.34
10	105	.27	.31
11	80	.29	.31
12	50	.28	.30
13	23	.27	.30
14	17	.26	.29
15	19	.25	.29
> 15	27	.24	.28

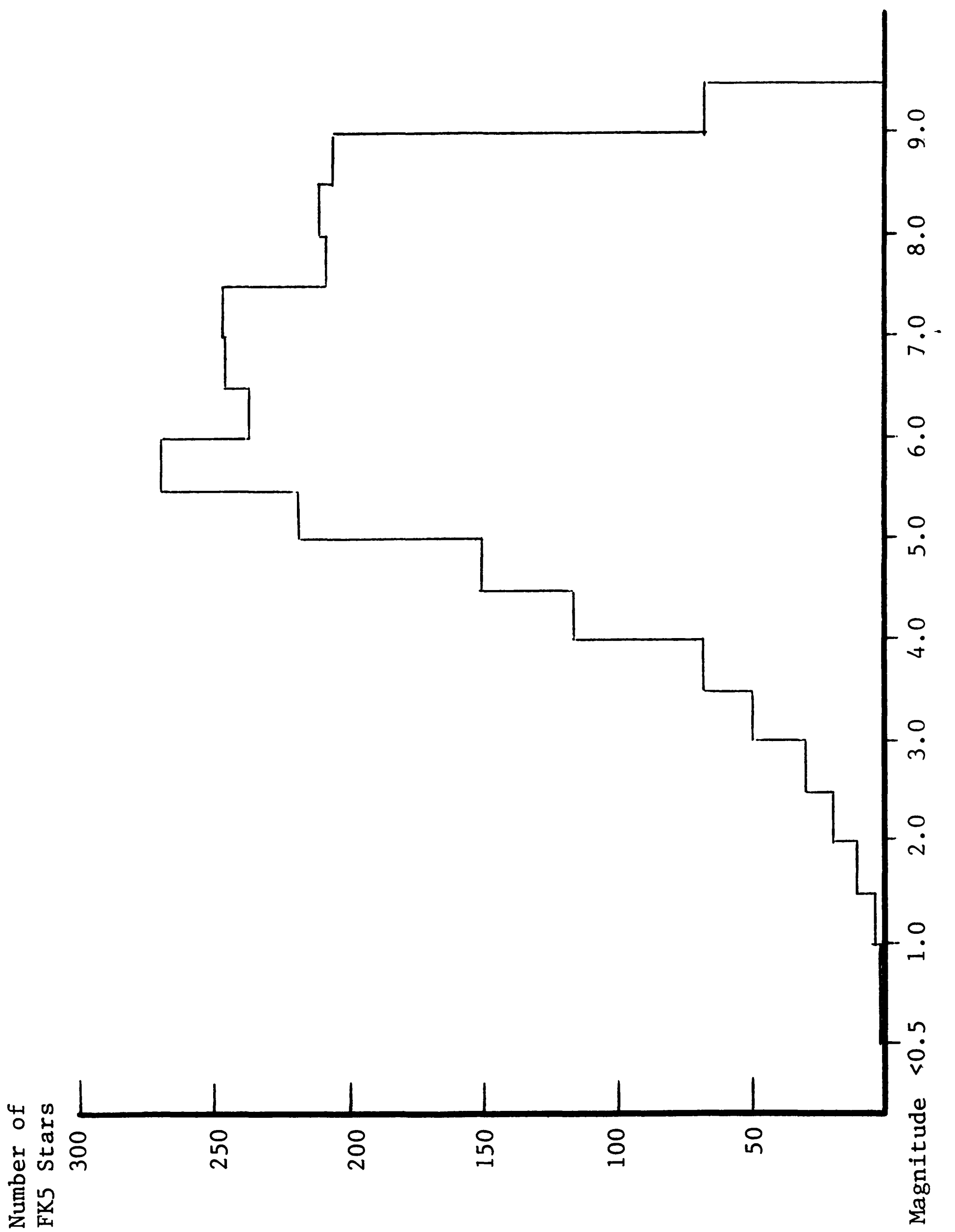


Figure 3 - Distribution of magnitudes of combined FK4, FK4 Sup and Faint Fundamentals in the Northern Hemisphere.

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One other aspect of the proposed Faint Fundamental list should be mentioned here. Table 4 shows that there are 195 stars with observational histories of fewer than seven catalog positions. This is a result of meeting all of the requirements of selection that have just been discussed. Indeed, most of these 195 stars are from blocks in which there were no stars with better histories.

Work has begun on the southern Faint Fundamentals. Since the SRS is not available, it is necessary to compute provisional proper motions in order to generate the weights, mean errors, dispersions of epochs and numbers of catalog positions needed to make the selections. While there were regions in the north where selection was difficult, Figure 1 shows that the situation in the south is considerably worse. It is already clear that the basic list of southern Faint Fundamental candidates must be compiled from those stars with histories of five or more catalog positions if there is to be any choice at all in the zone $-40°$ to $-80°$. Even then only 25% of the southern candidates are south of $-30°$ (1747 stars out of 7055). An additional difficulty is seen in Table 5. The southern Faint Fundamental candidate list has a good distribution in magnitude but has a poorer distribution of spectral types than the northern list. However, the data for the candidates south of $-30°$ show that the list is poorly distributed in magnitude and very poorly distributed in spectral type. This combined with the weak observational histories of these stars will make selection of the Faint Fundamentals in the Southern Hemisphere very difficult.

Table 5

Distribution of Magnitudes and Spectral Types in the List of Southern Faint Fundamental Candidates

Magnitude	Southern Candidates (7055 stars)	Southern Candidates (south of -30° 1747 stars)
< 6.5	1.0 %	0.3 %
6.5 - 7.0	4.9	1.7
7.0 - 7.5	15.6	17.6
7.5 - 8.0	22.9	33.2
8.0 - 8.5	28.2	30.3
8.5 - 9.0	23.8	12.6
> 9.0	3.6	4.4
Spectral Type		
O & B	3.2 %	0.6 %
A	13.7	5.0
F	15.5	10.7
G	16.8	18.6
K	47.7	60.2
M & other late types	3.2	4.8

As C. Smith reports elsewhere in these proceedings, supplementary stars will be added to the IRS list. In the zone −30° to −90° the IRS Sup will increase the percentage of early spectral types. In order to achieve a reasonable balance in the spectral types of the Faint Fundamentals south of −30° it may even be necessary to select some IRS Sup stars.

There is one final point that we must discuss here. After the selection process had been completed for the northern Faint Fundamentals, the list was compared with the Washington Double Star Catalog. The result of this comparison is shown in Table 6. For purposes of our observing program stars in the 1" to 10" range should be deleted, unless the magnitude difference is very large, six magnitudes or more. This restriction is due to the nature of the detector on the 7" Transit Circle. What I must now learn from those of you attending this meeting is what other limits we should place on the double stars in the Faint Fundamental Extension. Certainly we should observe the convention adopted by the IAU for eliminating double stars that will be used for astrographic purposes: that is when

$$m2 - m1 < 4.0$$

and the separation is

$$2'' < d < \{54'' - 2(m1 + m2)\}$$

the star should not be included in the list. In addition to this, however, the detectors on instruments other than the 7" Transit Circle may require that additional restrictions be applied.

Table 6

Double Stars in the Northern Faint Fundamental List

Separation	Difference in Magnitude	Number of Stars
1" to 10"		18
< 1"	$\Delta m < 4$	3
< 1"	$\Delta m > 4$	1
10" to 50"	$\Delta m < 4$	22
10" to 50"	$\Delta m > 4$	7
> 50"		12

Acknowledgements: The author wishes to thank Dr. J. Hughes, USNO, who is reviewing the Faint Fundamental list and especially give recognition to Prof. W. Fricke who suggested that this work be undertaken as a contribution to the compilation of the FK5.

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Discussion:

MURRAY: I hope you have been able to include a satisfactory representative sample of stars from each PZT zone. I feel that these particular stars provide valuable information on periodic errors.

CORBIN: This was done.

KOVALEVSKY: For HIPPARCOS observations, double stars with separations between 10" and 30" and $\Delta m < 3^m$ or $3^m.5$ are a great nuisance. There is a risk of large errors. These stars should therefore be avoided on a reference list.

MORRISON: Regarding the exclusion of double stars, we would prefer for the Carlsberg Automatic Transist Circle not to have stars closer than 13 arcsec if the magnitude difference is less than $3^m.5$.

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