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A Hierarchy of Standards for the MK Process

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Abstract. "An Atlas of Stellar Spectra" was produced fifty years ago at the Yerkes Observatory, University of Chicago, by W.W. Morgan, P.C. Keenan, and E. Kellman. A brief review is presented, stressing that the MK Process, with its emphasis on standards, is the main reason for the long-term success of the MK System. Sets of standard stars are analyzed and a hierarchy is proposed.

1. Introduction

Fifty years ago, in 1943, "An Atlas of Stellar Spectra" was produced at the Yerkes Observatory, University of Chicago, by W.W. Morgan, with the aid of P.C. Keenan, and E. Kellman. The original ("MKK") atlas represented a new approach to the classification of stars, one that depends on a set of standard "specimens." The System was refined by Morgan in 1953 (Johnson and Morgan 1953, referred to as "MK"), and again in 1973 by Morgan and Keenan (referred to as the "revised MK"). New atlases appeared in 1976 (Keenan, for the stars cooler than the Sun) and in 1978 (Morgan, for the stars hotter than the Sun).

In 1983, at a workshop held in Toronto, the philosophical underpinnings of the MK System were generalized to include extensions to the MK System as well as other areas of classification, not just those in stellar spectroscopy or even in astronomy. The MK Process (Mihalas 1984, Morgan 1984) is a methodology which uses the objects themselves as standards. This approach gives the MK System a richness and depth which cannot be achieved by any mere description in words or numbers (e.g. temperature, surface gravity, abundance, etc.). A star is given a certain MK type because it is "like" the standard specimen. A detailed discussion of "The Use and Abuse of Standard Stars" is given in Garrison (1985). The MK Process, with its emphasis on standards and specimens, is one of the main reasons for the long-term success of the MK System.

Another key to the success of the MK System and to its continuing usefulness into the future is that the classifications are independent of the calibration, which can be given in a separate table. Thus, as the temperature and luminosity calibrations change from year to year, observer to observer, instrumentation to instrumentation, reduction to reduction, and theory to theory, the more fundamental MK classification remains the same. A normal star which was "like" the Sun at MK resolution (1-3 Angstroms) twenty years ago will still be "like" the Sun at the same resolution now and in another twenty years, whereas the calibration of the type in terms of temperature, luminosity or chemical composition will almost certainly have changed. Without this advantage, the MK System would have gone the way of the dinosaurs long ago.

In this first paper of the conference, I want to talk about standards, because they not only represent the MK System, they *are* the MK System.

2. The Hierarchy

As mentioned above, the MK System has been refined since 1943, and several lists of standards have been produced by Morgan and/or Keenan. The types of some of the original standard stars have been modified slightly and other types refined, for a variety of reasons, but mostly because of the availability of better data. For those observers not familiar with the stars or with the MK System, this can be confusing.

In order to reduce the level of confusion about standards, a new hierarchy is being introduced herein. "Anchor Points" is a set of standards which have survived through the years without change, and which represent the most stable points in the system. There is no attempt, with the Anchor Points, to cover the complete grid of possible classifications.

"Primary Standards" are those which have been thoroughly tested over many years and which best represent the types, but which may not have such a long and consistent history. The set of Primary Standards include the Anchor Points and they do cover a complete grid of classification boxes.

"Secondary Standards" are those which are used as surrogates when the Primary Standards cannot be observed, by reason of position or brightness. For example, there is a need for standards fainter than tenth magnitude, because some of the modern electronic detectors on large telescopes cannot be used to observe the bright standards.

There are some stars which have good data and good classifications by Morgan, Keenan or one of their close associates, but which do not have the status of standards. In some situations where high precision is not required, these can be used to obtain approximate types, but this is not recommended as a general practice. It is better to return to the standards. The list of good classifications by Keenan and McNeil (1989), which also includes most of the standard stars cooler than the Sun, is an example of this category.

Finally, there are some very peculiar stars, which don't fit into the standard star scheme, and which do not form a large enough or stable enough group to become standards. Individual members of this group can be used as prime examples of a given peculiarity (for example, the metallic-line or magnetic-A stars). Stars like P Cygni (a very luminous early-B type supergiant with very peculiar hydrogen-line profiles) have become prototypes for their peculiarities. Such stars are considered to be good specimens of the peculiarity and can be used as guides, but are not considered to be standards.

3. Anchor Points

As an example of one layer of the hierarchy, the Anchor Points are presented in Table 1, selected from a complete list of all standards. The table is a list of the stars whose classifications have not changed since 1943. These stars can be thought of as the "Anchor Points" of the MK System. Additional criteria applied to this list of stars are that they must also have a reliable modern published type (by Morgan, Keenan, Richard Gray for A stars, Nolan Walborn for O stars, and/or myself) and that the types also must be consistent with my own classifications of new spectra. Thus these stars represent the MK System as it was then and is now. The stability and consistency of the MK System, as represented by the Anchor Points, is one of its greatest advantages.

The first three columns of Table I are self explanatory. Column four is a list of classifications from the tables in the introductory booklet of the MKK Atlas (1943). In parentheses are listed types from the Atlas which were not listed in the tables (only one star in the final list: HR 617, K2 III), or which differed slightly from the types in the tables (only one star in the final list: HR 5191, B3 V, to which an "n" was added in the Atlas).

Column five is a list of classifications from Morgan's table of MK standard stars given in the UBV definition paper by Johnson and Morgan (1953). This revision of types is usually referred to in the literature as the definition of "MK" standards (rather than "MKK", which refers to the 1943 Atlas). Only the latest O stars are listed in the 1953 paper; the best source for O-star types from that era is Michigan Publications No.X (1951), which contains a list of OB-star types. These additional types are in parentheses and are identical for stars in the final list, except that S Mon is not listed in the 1953 paper.

Column six is a list of types from the Annual Reviews article by Morgan and Keenan (1973). In their table 1, Morgan gives the best standards for stars earlier than the Sun, all marked with "daggers"; in their table 2, Keenan gives a list of his best classifications, with "daggers" to indicate the ones with the most reliable standard types. The types from these two tables have become known as "dagger types." Also included parenthetically in column six are types from the atlases produced in the late 1970's by Morgan (1978) and Keenan (1976).

The types listed on the second page are taken from several modern lists to make sure that the MKK and MK types are still considered valid. The second and third columns include types for stars cooler than the Sun from various publications by Keenan and his associates (Keenan and Pitts 1980, Keenan and Yorka 1985, Keenan and Yorka 1988, Keenan and McNeil 1989). Morgan (circa 1986, unpublished) gave me a list of what he called "strong stars," which he reclassified from a series of new plates taken by Helmut Abt. (These are not to be confused with strong-lined stars, so I have left out the word strong in the column heading.) He considered them to be the most reliable standard types for the GK stars; hence I have included those classifications here in column four. Also included in column four are lists of new types by Walborn (1973) for the O stars and Gray (Gray 1986; Gray and Garrison 1987, 1989a,b; Garrison and Gray 1994) for the B8-F2 stars.

Finally, I have my own spectra of all of the listed standard stars, taken at both 1.2 A and 2.4 A resolutions. I have checked these for consistency with the listed type, and personally have confirmed all of them independently.

Thus, these stars represent the MK System as it was in 1943, as it was in 1953, 1973, 1978, 1989, and as it is now. The Anchor Points are the *de facto* standards, though they may not be the best ones or the ones we wish were standards. However, because of its long history, the MK System now has a life of its own. Instead of trying to manipulate it and distort it, we must listen to it.

4. Primary Standards

In the case of the Anchor Points no attempt has been made to fill in the grid of standard stars. A set of Primary Standards, equally reliable and representing the best known specimen of each spectral type and luminosity class, is needed to fill in the gaps. The set of Primary Standards includes the set of Anchor Points. Work on this set is not yet complete and will be published separately.

5. Secondary Standards

The Anchor Points and Primary Standards are distributed randomly over the sky, with most located north of the equator. Thus, in some cases, a primary standard cannot be observed, by virtue of its position relative to the observer. For those types whose Primary Standards are unobservable from some key locations, we are in the process of setting up Secondary Standards located near the equator, so that observers in both hemispheres easily can use the same standards. Ideally, these all would be within 10 degrees of the equator, but we find that for some of the rarer types it is necessary to extend the limit to 20 degrees.

In case the Sun is located too near one of the standard stars, it is essential to have more than one Secondary Standard for each type. Ideally, these would be placed 12 hours apart, but in practice at least 6-8 hours apart, so one of them always can be reached when the Sun is too near the other.

Another problem is the brightness of the standards. Most of the Primary Standards are brighter than fifth magnitude and some are among the brightest stars in the sky. Modern detectors are very efficient and most spectrographs, especially those on large telescopes, are being built to observe the faintest stars. In some cases, there is no provision for a neutral density filter or fine mesh screen to decrease the light for standards, so stars brighter than tenth magnitude cannot be observed. Thus we need at least a skeletal grid of Secondary Standards at tenth and fifteenth magnitudes to tie the observations with large telescopes to the standard system.

This is not an easy task! There is no problem with the lower main-sequence stars and the common red giant stars, but the rarer and more luminous the type, the more difficult it is to find a relatively unreddened specimen at faint magnitudes. For example, how many blue supergiants with small reddening can we expect to find at fifteenth magnitude? There are ways around the problem, but most are not very easy or practical.

For example, we could use the same spectrograph with a small telescope of the same f/ratio. Or we could diaphragm down the large telescope to build a library of digital electronic spectra which can be used by any observer for a given spectrograph. In practice, we may even have to use spectra taken with another telescope and spectrograph, even though the scattering properties of the two spectrographs may differ slightly.

However, these are problems we need to think about and worry about. Otherwise, work done with the brightest stars in other galaxies may not be well calibrated against stars in our own galaxy, and much subtle information will be lost or misinterpreted.

As an interim measure, we may publish faint Secondary Standards for the more common and less luminous stars, leaving the larger problem of the rare, luminous stars until later.

6. Peculiar Stars

Even though peculiar stars, by definition, lie outside the system, it is useful to have specimens of them to show the classifier what to expect. Examples are the Ap stars, the Am stars, and the red giants.

Some peculiar stars are so numerous and well understood that they eventually work their way into the standard system, one way or another, and the system is expanded to include them. An example of these is the class of rapidly rotating stars, which were incorporated into the MKK (1943) system using the n or nn notation (meaning rapidly rotating and very rapidly rotating). However there were many gaps in the set of standards for rapidly rotating stars, and the differences in line ratios introduced by rapid rotation made it necessary to be very careful in classifying rapid rotators, and especially in setting up standards. Richard Gray (1986), in his thesis at the University of Toronto, carefully studied the problem, set up additional high and low rotation standards for the A-type stars, based on Morgan's Primary Standards, and used them to classify over a thousand stars with high precision. His work was very successful and resulted in an increase in the understanding of a number of astrophysical problems, such as the λ Bootis stars and the rotation of Vega.

For most of the peculiar stars, it is good to have a specimen of the peculiarity, a prototype to show how the peculiarity manifests itself. In this case, we don't expect the star being classified to be exactly "like" the specimen, but only to exhibit the same peculiarity.

An example might be the Ap(Si) stars. They have a range of spectral types, luminosity classes, and silicon-line strengths, but they share the characteristic of having silicon lines stronger than in any of the normal stars. In modern classification, they are given a type which is the best match to a standard along with the silicon designation to characterize the type of peculiarity, say B9 IVp (Si). A logical extension of this system would be to add a silicon-line strength indicator on a scale of 1-5. The problem with this is that the strength of silicon in normal stars varies with temperature and luminosity, so a silicon star with a certain strength at B8 V might be peculiar, while the same silicon strength might be observed in an A2 II star and be perfectly normal. Besides this, while the temperature and luminosity of a silicon star are reasonably stable, the silicon-line strength for a given star is often variable on a scale of days (rotation) or decades (spot evolution). Therefore, it is better to leave the classification more general, signaling the user that this star is among those with peculiar and variable silicon-line strength. Similar arguements apply to the class of Be stars and others. Nevertheless, it is useful to have specimens or prototypes of the particular kind of peculiarity.

In the case of the metallic-line (Am) stars, the range of metals strengths is greater than that in normal stars, and normal criteria are markedly inconsistent.

An Am star may have a Ca II K line similar to that of an A2 star, hydrogen lines similar to those in an A5 star, and metal lines similar in strength to those in an A7 star. In this case, it is useful to give estimates of the extent of these discrepancies. Thus, in the example, we might classify a star as kA2hA5mA7 V:, which signals the user that it is an Am star and gives an indication of how extreme it is.

For metal-weak or metal-strong stars, Keenan has developed a very workable system for estimating the degree of peculiarity. He gives the best match with standards for temperature-dependent, but abundance-independent, lines and features, then gives an estimate of the excess or deficiency. In most cases, when iron is weak or strong, so are chromium, titanium, vanadium, CN, and CH, so a classification "K0 III Fe-1" indicates that the pattern matches K0 III except that all the line strengths are weakened with respect to the K0 III standards. A classification of "K0 III Fe-1, CN+1" indicates that while the iron is weak, the CN is strong, making the spectrum unusually peculiar. This nomenclature is so useful that it eventually will become part of the standard system.

Other peculiar stars are sufficiently unique or variable that the most we can do is offer a description of how they *don't* fit into the system.

7. Other Dimensions and Other Wavelength Regions

There will be much discussion of these extensions during this workshop, so I will be brief. There is no "third dimension," involving abundance or age, which will apply all over the HR diagram. Rather, there are as many other dimensions as there are chemical elements. Luckily for us, lines of many of the elements are not visible at classification dispersion, and indeed don't play a major role in the determination of the general properties of the star. Also, as mentioned above in the discussion of Keenan's nomenclature for red giants, there are certain groups of elements, such as the iron group, whose abundances seem to be coupled. Thus, in practice, the number of dimensions is not as large as might be feared.

The setting up of parallel standard systems for weak-lined and strong-lined stars is a very delicate process and must be approached with extreme care. Unfortunately, not very many attempts to date have been successful. A good example of a careful piece of work is that of Richard Gray, who, as a result of his work with me and with Olsen in Denmark, has carefully set up a preliminary set of standards for the weak-lined, F-type stars (Gray 1989).

8. Conclusion

The conclusion is simple and can be summed up in a sentence. Yesterday, at a Mexican restaurant here in Tucson, we were given Chinese fortune cookies (an interesting example of multiculturalism!) and, believe it or not, mine said: "Success starts with the STANDARDS you set for yourself."

Table 1. MK Standard Stars: Anchor Points September 1993

HD	HR or other	Star Name	MKK43 Table (Atlas)	MK53 Table 1 (Michpub1951)	MK73 Table 1,2 (K76M78 Atlases)
47839	HR 2456	15 S Mon	O7	(O7)	O7 (V)
214680	HR 8622	10 Lac	O9 V	O9 V	O9 V
36512	HR 1855	upsilon Ori	B0 V	B0 V	B0 V
37128	HR 1903	epsilon Ori	B0 I	B0 Ia	B0 Ia (B0 Ia)
41117	HR 2135	chi-2 Ori	B2 I	B2 Ia	B2 Ia (B2 Ia)
206165	HR 8279	9 Cep	B2 I	B2 Ib	(B2 Ib)
120315	HR 5191	eta UMa	B3 V (n)	B3 V	B3 V
32630	HR 1641	eta Aur	B3 V	B3 V	B3 V
53138	HR 2653	omicron2 CMa	B3 I	B3 Ia	B3 Ia (B3 Iab)
58350	HR 2827	eta CMa	B5 I	B5 Ia	B5 Ia (B5 Ia)
34085	HR 1713	beta Ori	B8 Ia	B8 Ia	B8 Ia
103287	HR 4554	gamma UMa	A0 V	A0 V	A0 V
172167	HR 7001	alpha Lyr	A0 V	A0 V	A0 V (A0 Va)
87737	HR 3975	eta Leo	A0 Ib	A0 Ib	(A0 Ib)
21389	HR 1040	+58 607	A0 Ia	A0 Ia	(A0 Ia)
197345	HR 7924	alpha Cyg	A2 Ia	A2 Ia	A2 Ia (A2 Ia)
216956	HR 8728	alpha PsA	A3 V	A3 V	A3 V
89025	HR 4031	zeta Leo	F0 III	F0 III	F0 III (F0 III)
36673	HR 1865	alpha Lep	F0 Ib	F0 Ib	F0 Ib (F0 Ib)
113139	HR 4931	78 UMa	F2 V	F2 V	F2 V (F2 V)
20902	HR 1017	alpha Per	F5 Ib	F5 Ib	F5 Ib (F5 Ib)
30652	HR 1543	pi-3 Ori	F6 V	F6 V	F6 V
194093	HR 7796	gamma Cyg	F8 Ib	F8 Ib	(F8 Ib)(WWM)
54605	HR 2693	delta CMa	F8 Ia	F8 Ia	(F8 Ia)(WWM)
109358	HR 4785	beta CVn	G0 V	G0 V	G0 V (PCK)
121370	HR 5235	eta Boo	G0 IV	G0 IV	(G0 IV) PCK
204867	HR 8232	beta Aqr	G0 Ib	G0 Ib	G0Ib(PCK) (G0Ib)
Sun	Sun	ASTEROIDS		G2 V	G2 V
20630	HR 996	kappa Cet	G5 V	G5 V	(G5 V)
161797	HR 6623	mu Her	G5 IV	G5 IV	G5 IV(G5 IV)note
206859	HR 8313	9 Peg	G5 Ib	G5 Ib	G5 Ib
101501	HR 4496	61 UMa	G8 V	G8 V	(G8 V)
188512	HR 7602	beta Aql	G8 IV	G8 IV	G8 IV
62345	HR 2985	kappa Gem	G8 III	G8 III	G8 IIIa
113226	HR 4932	epsilon Vir	G8 III	(G8 III)	G8 IIIab (G8III)
48329	HR 2473	epsilon Gem	G8 Ib	G8 Ib	G8 Ib
185144	HR 7462	sigma Dra	K0 V	K0 V	K0 V
62509	HR 2990	beta Gem	K0 III	K0 III	K0 IIIb
197989	HR 7949	epsilon Cyg	K0 III	K0 III	K0- III
222404	HR 8974	gamma Cep	K1 IV	K1 IV	K1 IV see notes
22049	HR 1084	epsilon Eri	K2 V	K2 V	(K2 V)
12929	HR 617	alpha Ari	(K2 III)	K2 III	K2 IIIab
153210	HR 6299	kappa Oph	K2 III	K2 III	K2 III
127665	HR 5429	rho Boo	K3 III	K3 III	K3 III
31398	HR 1577	iota Aur	K3 II	K3 II	K3 II
201091	HR 8085	61 Cyg A	K5 V	K5 V	K5 V
164058	HR 6705	gamma Dra	K5 III	K5 III	K5 III
6860	HR 337	beta And	M0 III	M0 III	M0 IIIa
1013	HR 45	chi Peg	M2 III	M2 III	M2+ III(M2 III)
39801	HR 2061	alpha Ori	M2 Ib	M2 Iab	M1-M2 Ia-Ib
206936	HR 8316	mu Cep	M2 Ia	M2 Ia	M2 Ia

HD 161797: G5 IV in atlas illustration, but IV-V in booklet table.

HD 222404: K1 IV in atlas, but K1 IV CN1 in booklet table.

Table 1. MK Standard Stars: Anchor Points September 1993 (Continued)

HD	KY88 (KM89)	KY85 (KP80)	WWM GK STD 86 Walborn OB, GRAY BAF
47839			O7 V((f))
214680			O9 V
36512			B0 V
37128			B0 Ia
41117			B2 Ia
206165			B2 Ib
120315			B3 V
32630			B3 V
53138			B3 Ia
58350			B5 Ia
34085			B8 Ia GRAYSTD/Wb
103287			A0 Van GRAYSTD
172167			A0 Va GRAYSTD
87737			A0 Ib GRAYSTD
21389			A0 Ia
197345			A2 Ia
216956			A3 Va GRAYSTD
89025			F0 IIIa
36673			F0 Ib GRAYSTD
113139			F2 V
20902			
30652			
194093			
54605			
109358	G0 V	G0 V	G0 V
121370			G0 IV
204867	G0 Ib	G0 Ib	
	G2 V	G2 V	
20630	G5 V	G5 V	
161797	G5 IV	G5 IV	G5 IV
206859	G5 Ib	G5 Ib	
101501	G8 V	G8 V	G8 V
188512	G8 IV	G8 IV	G8 IV
62345	G8 III	G8 IIIa	G8 III
113226	G8 IIIab	G8 IIIab	
48329	G8 Ib	G8 Ib	
185144	K0 V	K0 V	K0 V
62509			K0 III
197989	K0 III	K0- III	K0 III
222404			
22049	K2 V	K2 V	
12929			
153210	K2 III	K2 III	
127665			K3 III
31398			
201091	K5 V	K5 V	K5 V
164058	K5 III	K5 III	K5 III
6860	M0+ IIIa	M0+ IIIa	
1013	M2+ III	M2+ III	
39801	M1-M2 Ia-Iab var	M1-M2 Ia-Iab	
206936	M2- Ia	M2- Ia	

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Discussion

Keenan: Why consider the best standards to be those which have not had their types changed? Actually just those stars for which the most improved spectra are available are those that have had their types changed. On the other hand, many of the stars with unchanged types have merely been kept the same because better spectra have not been obtained.

Garrison: Your point is well taken, and I worried about that problem. Therefore, I also required that the "Anchor Points" be stars which also have been carefully considered by Walborn, Gray or myself from modern spectra of the best quality, so I don't think any of the Anchor Points suffer from the lack of good data.

There are, of course, stars which don't have a history, but have been introduced recently and have been found to be exceptionally good standards. These are what I call primary standards. Primary standards include the Anchor Points as a subset.

Abt: The MK system applies primarily to population I stars. Morgan wanted to extend the system for intermediate (FG) stars to population II. Keenan has faced that partially for later types. Do you feel that some slightly metal-poor stars have crept into the standards?

Garrison: Obviously there is a continuum of spectral types between any two population types, so in some sense, at the highest resolution and with the best fine analyses, the stars will not all belong to particular populations. However, in my experience, it is possible to distinguish fairly small differences in the line strengths, yet I have not found any problem with assigning most of the bright stars to a single population. I doubt that this is much of a problem for the primary standards.

Abt: A related question is that if people wish to apply the MK system to 20th mag stars, perhaps by using automated spectral classification, they will encounter a much larger fraction of population II stars. Do you think that there are adequate standards for them?

Garrison: Certainly not yet! We have really only begun to set up the system for metal weak stars, but we have made a good start.

Olsen: In connection with your reply to Helmut Abt, I have a question. I have noted that Richard Gray has defined an *extension* to the MK system by setting up new, independent standards in the range F5-G5 V-III for metal weak stars. Does your reply to Abt mean that you don't approve of his approach?

Garrison: Not at all. Richard has made a very good attempt at a first step for that small range of types.

Crawford: Relative to the skeleton structure, you may not need them all. I remember very well many years ago, when a cataloger was criticising Morgan for not having standards for some spectral classes, Bill replied that if God made some more stars, he'd classify them. I think that if they are there, observers will find candidates, and then you can critique them.

Garrison: I've heard the same comment and it is inevitable that when new stars are classified from massive surveys, there are bound to be stars which fall between the cracks among the standards, yet are not extrapolations from the system, but are merely easy interpolations.

Osterbrock: In the beginning of your talk you emphasized correctly, that the MK system is *defined* by its standards. Yet at the end of your talk you spoke of setting up a network of faint secondary standards, and seemed to imply that not all types would be included, but only enough to interpolate between. This seems to me to be inconsistent with your earlier statement. No matter how you arrive at the approximate type by interpolation, in the end the acid test of the type must be that it matches the standard stars (perhaps secondary) of that type more closely than it matches any other type.

Garrison: What you say is correct as far as it goes. A star of a given type is, in principle, exactly like the standard at the resolution of the MK system. However, from a practical point of view, the secondary standards do not in themselves define the system. They are surrogates which approximate the system of primary standards and "Anchor Points".

In practice, it is necessary at times to use interpolation, perhaps because we don't happen to have been able to observe some particular standard. Also, sometimes it is possible to see a smaller difference in a smoothly varying feature than is given in the grid of standards. In principle, it may not be pure to interpolate, but in practice, we sometimes have to do so.

Roman: In answer to Don Osterbrock: if I understand him, he said that a GO V must match a GO V standard. This is impossible. No two stars look identical. The interpolation is necessary. The GO V must look *more* like a GO V standard than like any other type.

Has the line strength parameter method also been applied to the metallic line stars?

Garrison: No, the line strength parameter has not been applied to the Am stars yet, but I believe that some variation of it should be applied to them now that there are enough of them to treat as a significant sample set.

McCarthy: Regarding the use of the word "strong" speaking of stellar standards, it will be important to avoid misunderstanding "strong" to mean "prominent" or "principal" and "strong" to mean "intense" or "metal rich". This is a linguistic item, but deserves to be clearly distinguished.

Garrison: Your point is very well taken and it didn't occur to me that this would be a problem. The word "strong" in describing what Morgan meant as "really reliable" was a direct quote from the handwritten list of 1986 from Morgan. I will try to avoid that in my list of previous types. (Changed in the manuscript.)

Parthasarathy: It may be difficult to set up fainter (10-16 mag range) secondary MK standards for the complete MK types of stars. However, setting up fainter secondary MK standards for low luminosity stars, dwarf stars, carbon stars and metal rich stars is useful for galactic and extragalactic work.

For setting up of metal poor MK standard stars, the results of the analysis of high resolution spectra of large number of metal poor stars are now available covering the range in $T_{\rm eff}$, $\log g$, and [Fe/H].

Garrison: As I said, in setting up the faint secondary standards, we will accept suggested "candidates" from *any* technique, but we will then examine them critically using MK process techniques before calling them secondary standards.

For the faint secondary standards, we are having no problem setting up standards at faint magnitudes for cool main sequence stars. The problem is with the rare, luminous stars.

Weaver: Automatic classification techniques are starting to distinguish classifications in the sub-subclass region. Should the standards/Anchor Points be taken as defining a discrete bin or as an exact class, e.g., F2.0?

Garrison: The sub-subtypes, if they really can be distinguished, should be based on the Anchor Points as defining the exact zero point. For example, γ Dra is K5.000 III.

Gray: You have suggested diaphragming down a large telescope to build a library of bright standard stars. This would not necessarily be a good idea. As the incoming beam into the spectrograph would have a higher f/ratio, the collimator would be underfilled, and the resolution (as fewer lines on the grating would be illuminated) might suffer.