I. DEFINITIONS AND TERMINOLOGY

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THE USE OF TERMS AND DEFINITIONS IN THE STUDY OF Be STARS

(Review Paper)

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Abstract: *In this paper I shall examine the use and misuse of some astronomical terminology as it is commonly found in the literature. The incorrect usage of common terms, and sometimes the terms themselves, can lead to confusion by the reader and may well indicate misconceptions by the authors. A basic definition of the* Be *phenomena is suggested and other stellar characteristics whose interpretation may change when used for non-spherical stars, is discussed. Special attention is paid to a number of terms whose semantic nature is misleading when applied to the phenomena they are intended to represent. The use of model-dependent terms is discussed and some comments are offered which are intended to improve the clarity of communication within the subject.*

Introduction

At the 111th meeting of the AAS in 1961, D.Nelson Limber (1962) felt compelled, in the face of a generally perceived decline in astronomical interest in stellar astronomy, to declare to the audience his "passionate interest in rotating stars". It is an interest I am sure is still shared by those in attendance at this conference for only such a "passionate interest" will sustain your attention to such an apparently boring subject as the definition of terms. Yet is upon these definitions that all our understanding of stellar phenomena rests and every now and then it behooves us to examine them to see if they are still useful, or if they obscure rather than enlighten.

During our professional careers, all of us have encountered terms and phrases which have left us bewildered as to their meaning. In some instances, I suspect that the bewilderment extends to the author. Rarely do we phrase new thoughts and ideas in their clearest and most comprehensible form. Such is the nature of dealing with new concepts. However, we must make the effort to adjust to new notions, discard old concepts when they no longer apply to new phenomena, and sharpen the meaning of venerable terms to suit contemporary problems, if we are to advance our knowledge. It is unusual for a conference to concern itself with such mundane matters as the definition of terms, but my own reading of the literature would lead me to believe that many disciplines would profit from occasionally doing so. The organizers of the conference are to be congratulated for acknowledging such a need and I am grateful for the opportunity to discuss some of these problems.

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I make no claim that this discussion will involve all the terms which members of the community find offensive or confusing, I will rather concentrate on concepts with a few carefully selected examples in the hope that the logical extensions to additional areas will be obvious. Many will find examples of which they have been guilty; indeed that group includes the author, for 'to err is human', but to ignore errors once identified, is irresponsible. It is appropriate to begin any discussion of terms and definitions with some general comments on the nature of definitions.

The development of Logical Positivism in the first half of this century brought sharply into focus the necessity for the clear assignment of an unambiguous meaning to terms and concepts. Perhaps foremost among these concepts was the notion of an operational definition. Regardless of one's contemporary view of Logical Positivism, the functional utility of operational definitions cannot be challenged. Without them, communication in the physical sciences would be virtually impossible. They are so pervasive in our discipline, that we occasionally take them for granted and forget that the operationalism appropriate for some physical descriptions may not be capable of extension to general situations. We must always remember that an operational definition must, in principle, be able to be performed. Should this not be the case, the term has no meaning and any structure built upon it is fatally flawed. However, if the term is to be really useful an even tighter constraint on its definition exists. Should the term be intended to provide some link between theory and observation, its operational aspect must be performable in practice as well as in principle. For example, in order for the total energy output of a star to be a useful concept, we must be assured that some method of actually obtaining an accurate sample of that energy output exists and can be carried out by the observer. While this may be possible for spherically symmetric stars, it is not in general true for distorted stars. This includes the tidally distorted stars of close binaries as well as those distorted by rotation.

This example points out one of the primary sources of difficulty for the definition of terms for use in the study of stellar rotation. The evolution of stellar astrophysics beyond the comfortable simplicity of spherical stars has outrun many of the definitions which are only appropriate for spherical stars. This same evolution has often led us to expect more of the early definitions, which were frequently based on the spherical morphology attributed to stars, often subjective in nature, and so convenient when the subject was new, than these definitions could ever deliver. These expectations have led different investigators to assign different meanings to the same term. In the theory of stellar atmospheres, a prime example of this is the term "LTE". For our purpose, the term "Be Star" will suffice.

It would be sad should this conference adjourn without the participants having a clear understanding of the defining properties of a Be star. While the original definition may not be deemed by all to be the "best", it is certainly the one upon which most of the literature rests and for that reason alone, it is worthy of consideration as the operational definition appropriate for Be stars. In 1922, Fowler (1922) put before the First General Assembly of the International Astronomical Union the following suggestion regarding the use of "e" to denote emission lines in the spectra of stars:

> *"It is suggested that spectra showing bright lines be denoted by the letter "e" (emission), except in classes where bright lines are normally present (as in O,P,and Q)."*

Fowler (1922) continues to specifically discuss the A and B stars, pointing out that often the emission is confined to $H\alpha$. In the intervening half century since it was presented, this general definition has survived largely unchanged in the greater part of the literature with the exception that supergiants have been specifically excluded as candidates for the Be star designation. With this in mind, I suggest that we follow Jaschek et al (1981) and paraphrase their contemporary operational definition for Be stars:

> *"A non-supergiant B-type star whose spectrum has, or had at some time, one or more Balmer lines in emission."*

Some may object that this definition is too broad to be useful, while others will correctly observe that the definition may be time dependent for some stars as well as possibly equipment dependent. Such objections apply to virtually all terms in astronomy if one allows sufficient time and a sufficient variety of equipment. The definition is somewhat subjective as it depends on dispersion, contrast obtainable by the detector,and perhaps the observers ability to discern weak emission in the absorption core of a line. As a result, the definition will have its primary utility as a generic label for a large class of stars. It also corresponds closely to the present widest usage of the term. In addition to the definition for Be stars, Jaschek et al (1981), have also presented further useful definitions for B [e] Stars and B-type Shell Stars, in the tradition of spectral classification, which share the virtues and faults of the Be Star definition.

While this definition of a Be Star is deliberately broad and somewhat subjective, it is still useful in that it selects from an even wider population of stars, those of specific spectral type which have at sometime or other, shown emission lines in their spectra. That such a class is worthy of our study is demonstrated by this and similar conferences. Although it is a general function of science to look for common explanations for common characteristics, we should not be surprised if it is not always possible to find them as any single characteristic may embody a wide variety of physical phenomena. Thus we should not be surprised if there is no common cause for the emission lines in the spectra of some B type stars. Many known physical processes can result in the production of stellar emission lines and, while it is true that many of these stars appear to exhibit rapid rotation, it would be a mistake to assume that rapid rotation is a necessary and sufficient condition for the phenomena to occur.

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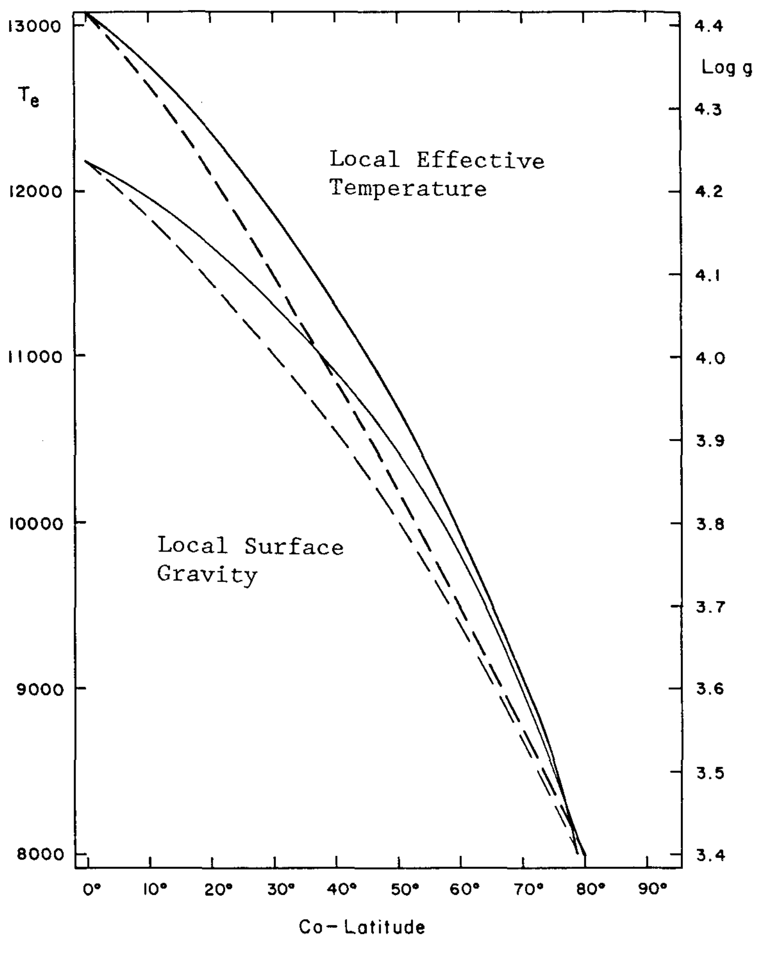
The Loss of Spherical Symmetry

I have indicated that the loss of spherical symmetry destroys the utility of some of our favorite descriptive terms for stars. Let us consider some of these and see what can be done to salvage the concepts by putting them on a rigorous foundation. For spherical stars, the integral, at any point on the surface of the star, of the Specific Intensity over all the emerging rays is equal to the integral of the Specific Intensity, directed toward the observer, and integrated over the entire visible surface of the star. This rather long winded phrase basically says 'what happens locally also happens globally for spherical stars'. Unfortunately this is not true for stars which are distorted by rotation or gravitational interactions. The flux of radiation emanating from the apparent stellar disk and seen by the observer will not, in general, be the same as the flux from any particular point on the surface. There will be no simple relationship between the global properties accessible to observation and the local values for those properties. While this is generally considered to be obvious for some parameters (ie. the surface gravity g), its acceptance for others such as the effective temperature, T_e, is less general. The concept of a global temperature for a distorted star is just as meaningless as the notion of a global surface gravity. Figure 1 gives some idea of the extent of the variation of these local parameters for a star rotating near its critical velocity. Curves have been included for both rigid rotation and modest differential rotation in which the angular velocity increases slowly by about 50% from the equator to the pole (see Collins and Smith 1985). The models have been contrived so that the polar values of the parameters are the same.

It is clear that the values depend on the extent of differential rotation as well as on the equatorial velocity. While the gravity ranges from the polar value typical of non-rotating stars of that mass to near zero at the equator, it is also clear that the local effective temperature exhibits a similar range regardless of what darkening law you believe. Some are content with observing that the cooler equatorial regions are also fainter and so don't matter that much, but in fairness, they must also concede that the area covered by the equatorial regions is also proportionally greater than the polar regions. Thus, we should not be surprised if the variation of physical parameters over the surface produce observable, and possibly difficult to interpret, effects. Our notion of the 'temperature' and 'gravity', as gleaned from observing the integrated light of the star, may have little to do with the conditions which prevail over the majority of the stellar surface.

What is to be done to salvage the notion of stellar temperature which is so deeply ingrained in the literature and our way of thinking? The search for a solution should begin with the operational definitions of observationally determined temperatures. The terms, Color Temperature, Ionization Temperature, Excitation Temperature, and Effective Temperature all contain an indication of how they are determined. However, only the Color Temperature has a simple enough operational definition to readily allow theory to provide a comparison with observation. Since all these temperatures are determined by radiation coming from various parts of the stellar disk, they at best represent some average temperature.

Figure 1. *The variation of the local effective temperature and surface gravity with co-latitude from pole to equator is shown for two stars differing only in the form of the rotation law. The two stars have a mass of* $3.5M_{\odot}$ *, a polar radius of* $2.4R_{\odot}$*, and a bolometric luminosity of* $104L_{\odot}$*. The fully self-consistent model is the dashed differential rotator wherein the angular velocity increases by 20% from the equator to the pole. The rigid rotator (solid lines) is based on a Roche potential with the polar values of radius and gravity forced to those of the differentially rotating model as well as the value for the bolometric luminosity. The generally cooler temperatures of the differential rotator result from the larger surface area produced by the differential rotation law.*



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Unfortunately the average is not operationally defined in any sensible manner. While the same is also true for the Color Temperature, since it only involves radiation from the continuum, it is at least possible to model this parameter without becoming involved in the difficulties associated with the variation of line strengths over the surface of the star. Useful as the notion of color temperature is, the fact that it varies with wavelength makes it unsuitable as a major defining characteristic of the star. A more functional alternative would be the *photometric temperature*. This is defined as *the effective temperature of a spherical star having the same photometric color as the star in question*. The term contains the root of its operational definition thereby avoiding the association with the total luminosity possessed by the term effective temperature. Yet this is an unambiguously defined global mean temperature which conveys some insight into the thermal processes that one should expect to find exhibited in the stellar spectrum.

We can approach the problems caused by a variable surface gravity in a like manner. It is a relatively common practice to estimate the gravity of a star by modeling the wings of the Balmer lines. For distorted stars this will produce some intensity weighted average value for the gravity. However, since various parts of the wings are effectively formed at different levels of the atmosphere, at varying temperatures, are smeared by rotational doppler broadening, and modifyed by aspect dependant limb-darkening, the average is not a simply defined quantity. The term *Spectroscopic Gravity* is sufficiently qualified to indicate its origin and could be operationally defined as *the gravity determined by matching some property of the spectrum of a non-rotating star of known gravity and having the same photometric temperature*.

A similar problem with operational definitions can be found by considering the effects of stellar distortion on the emergent radiation field. No longer will the observed flux, when corrected for distance and reddening, be an accurate measure of the total energy output of the star. The widely read literature does not even contain the proper language for this concept. However, some 15 years ago George Rybicki (1969) suggested the term Specific Luminosity to represent the observed energy output of a star as seen by an observer. This parameter would then depend on the relative orientation of the star as well as the intrinsic stellar energy generation processes. For rotating stars which exhibit axial symmetry, only the inclination of the spin axis to the line of sight is required to make this definition unique. Thus we can follow Kandel's (1973) definition of *Specific Luminosity*

$$\mathcal{L} \equiv 4\pi r^2 F(i), \qquad (1)$$

where F(i) is the observed flux at a distance r and is dependent on the inclination i. However, this definition is useful only at large distances from the star where the dilution factor is $\sim r^2$ and would therefore, be inappropriate in close binary systems. A more general, and perhaps more descriptive definition (Collins 1973) is

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$$\mathcal{L}(\omega,i) \equiv 4\pi\int_A I(\theta,\phi)\hat{\eta}(\theta,\phi)\cdot\hat{o}(\theta,\phi)dA(\theta,\phi), \tag{2}$$

where $\hat{\eta}(\theta,\phi)$ and $\hat{o}(\theta,\phi)$ are position-dependent unit vectors normal to the surface and directed toward the observer respectively. The area A over which the Specific Intensity $I(\theta,\phi)$ is to be integrated is the observable surface defined by the inclination i and the stellar shape. For rotating stars, this surface will also depend on the degree and type of rotation indicated by the angular velocity distribution ω. Thus the Specific Luminosity becomes a function, not only of the internal energy processes of the star, but also the shape and isophotal intensity distribution over the surface of the star. The relation between the Specific Luminosity and that standard of stellar interior studies, the total luminosity $\mathbf{L}$ is just

$$\bullet \quad \mathbf{L} \equiv \frac{1}{4\pi}\oint \mathcal{L}(\omega,i)\ d\Omega\ . \tag{3}$$

It seems logical to extend this definition to the magnitude scale by appending the adjective "Specific" to the magnitude in question. Thus the Apparent Visual Magnitude would become the Specific Apparent Visual Magnitude etc. However, in reality, all apparent magnitudes are Specific Apparent Magnitudes, so that a modification to the term would appear to be redundant. Modification to our conventional thinking is required. We must remember that, in addition to reddening and intrinsic luminosity, the aspect presented to the observer can affect the apparent brightness of a star. In the case of stellar absolute magnitude, some modification is required. Since the common use of the term Absolute Magnitude is intended to reflect something about the intrinsic energy output of the star, a change is required to denote that distance independent parameter which is derived from the apparent magnitude corrected for reddening. It would seem that the appropriate term would be *Specific Absolute Magnitude* by analogy with the Specific Luminosity.

While this addition of parameters such as the inclination and stellar shape, generates unfortunate complications in the interpretation of observed stellar luminosities, it has now become possible to model these effects so we must be prepared to do so. It is a fair question to inquire as to the extent that these effects can influence our interpretation of observations. The answer to this question is not simple as it involves at a very fundamental level, exactly how the comparison is to be made and the types of stars to be considered.

For purposes of demonstration let us consider a zero-age late type B star of 3.5 $M_\odot$, rotating near its critical velocity. Figure 2 shows the variation of the Specific Absolute Visual Magnitude M_V as well as the dependence of $(B-V)_0$ and the associated photometric temperature on the inclination for such a star. The temperature-color relationship is taken to be self consistent with the models by interpolating in the results of Collins and Smith (1985) and is similar to that of Novotny

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(1973) which tends to be about 1000K cooler than that of Harris (1963). Again curves are presented for both rigid and differential rotation. The forms of the curves are the same, indicating that stars viewed from increasing angles of inclination will seem progressively, apparently cooler and fainter than their non-rotating counterparts. The amount of the effect can be as large as several thousand degrees in the photometric temperature and nearly a magnitude in the specific absolute visual magnitude. As anyone knows who has heard the heated debates regarding temperature scales, these are not small effects and their existence must be respected.

Effects of rotation on the spectroscopic gravity are more difficult to estimate and will depend on the lines used for the determination. The commonly used Balmer lines provide an interesting set of rotational effects which differ with spectral type. For the B stars in general, we would expect a reduction in surface gravity to weaken the line by reducing the amount of pressure broadening. However, the reduction in the local effective temperature which accompanies the lower gravity of the equatorial regions will tend to produce stronger lines. In addition, the change in limb-darkening for the line caused by rotational distortion and the observed aspect of the star, complicate the resulting line strength. For late B stars of the type used above, the effects nearly cancel and the wings of the integrated line profiles for a rapidly rotating star displaying different angles of inclination, are remarkably constant and similar to those of a non-rotating star of the same mass and age. However, the variation of the photometric temperature of the stars with inclination would cause them to be compared with non-rotating models of a different mass making the interpretation of the spectroscopic gravity exceedingly difficult. Peters (1976) attempted to determine values for the surface gravity of Be stars by comparing their Balmer line profiles to non-rotating models of the same effective temperature. In general, she found that models of rather low gravity ($\log g \sim 3.5$) provided a reasonable fit to observations. Unfortunately, the definition of the effective temperature was sufficiently obscure for the program stars as to make comparison with rotating models impossible. However, the likelihood of such results is assured by Figure 2. That the variation of the spectroscopic gravity, determined from $H\beta$, should be as large as that displayed in Figure 2, is rather surprising. The range of the spectroscopic gravity with inclination rivals that of the local gravity with co-latitude. Thus, in addition to the notion of a single gravity for a rapidly rotating star being inappropriate, the spectroscopic gravity may differ from the polar value by up to a factor of ten should the star have a large value of the inclination.

<u>Figure 2.</u> *The variation of the observed color and the associated Photometric Temperature as well as the Specific Absolute Visual Magnitude with inclination,is shown for the same defining stellar parameters as those used for Figure 1. The appropriate values for a non-rotating star of the same mass are indicated by an arrow at the lower left of the figure. The spectral types associated with the photometric colors are also indicated. These must be considered only as*

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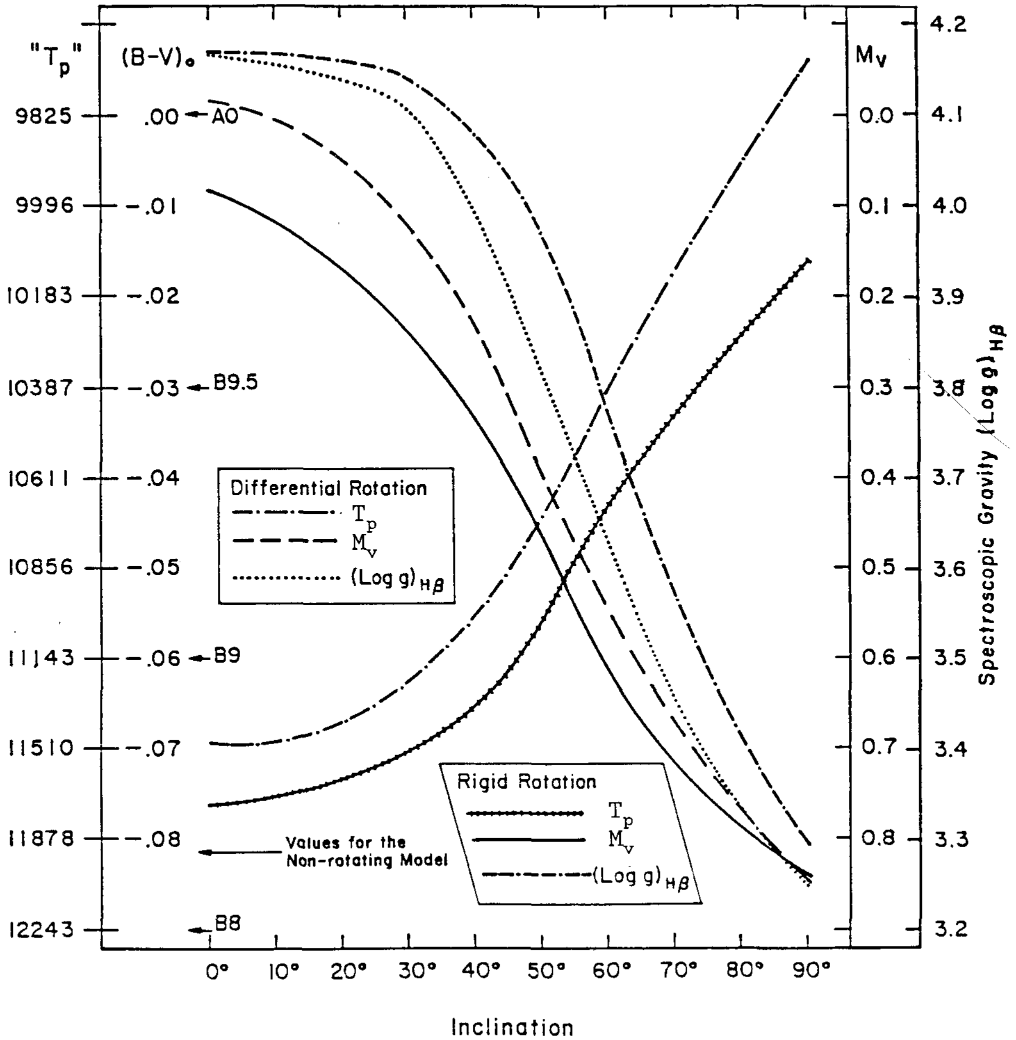
approximate, as the definition of the spectral type depends on spectral features, not the $(B-V)_0$ *colors. As one might expect, the effects are somewhat larger for the differentially rotating models as the differential rotation law produces a greater distortion of the stellar surface than does rigid rotation. The variation of the Spectroscpic Gravity as determined from* Hβ *is also displayed. The gravity is determined by matching the wings of the line of the rotating model, between* 6Å *and* 30Å *from the line center, with the wings of a non-rotating model having the same* $(B-V)_0$. *The continuum is assumed to be reached at* 50Å *from the line center. The dotted line shows the effect for differentially rotating models used in the earlier figures. Note the abrupt drop in the Spectroscopic Gravity for inclinations greater than about 30°. The range in this 'integrated' parameter is comparable to the variation of the local gravity with co-latitude (see figure 1).*



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While it is true that I have chosen an extreme example of rotational distortion in order to dramatize the extent of these effects, we (Collins and Smith 1985) have investigated the systematic effects that one could expect from an ensemble of stars with a random distribution of rotational axes and having a truncated gaussian distribution of rotational velocities, and found systematic shifts in the main sequence in excess of a tenth of a magnitude with a spread (variance) of more than a tenth of a magnitude. In addition, since we are dealing with a class of stars which exhibit rotational velocities systematically larger than ordinary stars of the same spectral type, we must be prepared to accept that the maximum effects may often be present. But to me the most important reason to adopt these terms, is the implied conceptual understanding that many stars are not spherical and we must be ever mindful of the complications their asphericity presents.

I would be remiss in proposing these definitions if I did not make some comments about what constitutes a 'non-rotating' star. If I am to be very precise, I will be unable to find any star which shows absolutely no rotation. Even allowing for perfect instruments and correct models, there always remains the possibility that my candidate could be rapidly rotating and have an inclination of zero. In any event, extremely stringent conditions on rotational velocity would yield too small a sample of stars to be operationally useful for comparison standards. I would claim that we can seek some relief from these problems by considering the known effects of rotation on stars. Virtually all studies over the last twenty years indicate that stars rotating at less than 50% of their critical velocity exhibit departures from sphericity of less than 5%. Under these conditions it is reasonable to assume that the observed mean properties represent the conditions that actually prevail on the surface of the star. While nothing can be done about the possibility of including stars of low inclination in the sample, we are at least statistically safe if we compare to a number of stars exhibiting <50 km/sec doppler broadening of their spectral lines (sharp line stars).

By using an absolute value such as 50 km/sec.in order to be explicit, I find it is necessary to issue a final caveat on the subject in order to be correct. A velocity of 50 km/sec. will represent a significant fraction of the critical velocity for supergiants and late-type giants and hence 'sharp line' as defined above would be useless as an indicator of rotational distortion. Hence the term should only be applied to giants, dwarfs, and subdwarfs, earlier than F5 in spectral type.

Further objection to these definitions might be made in that they are model dependent and therefore may prove to be unduly subject to change as models become more sophisticated and it is this aspect of terminology we shall discuss in the next section.

Models, Definitions and Terminology

It is the nature of astronomy that the objects with which we are concerned are basically inaccessible to direct experiment. Thus we construct 'pictures' of these objects based upon sound physical principles which we call models. It is then these models, that are subjected to the tests we call observation. To the extent that the models describe the observations we say that the astronomical objects themselves can be represented by the model. Since all we can do is model the astronomical universe, it makes perfectly good sense to use properties of those models as sources for the definitions of terms to be used in their description. However, realizing the ephemeral nature of models, we must be prepared to abandon or revise those definitions when the models are found to no longer describe the observations.

A classic example is that of the venerable Struve Model for rotating stars. Fifty years ago, it made perfectly good sense to describe stars as rigidly rotating, uniformly bright spheres. Astronomers at the time were perfectly aware that such a model was inconsistent with what was known about stars, but since neither the theory, the computing power, nor the observational sophistication existed to describe and test the extent of these inconsistencies, they were quite properly ignored. One of the beautiful properties of the Struve Model is that it has a unique and well defined rotational angular velocity which is constant and produces a doppler broadening of any 'sharp' line profile which can be characterized by a single number - $v_e \sin(i)$ where v_e is the rotational speed at the equator and i is the inclination of the spin axis to the line of sight. Within the context of this model, Shajn and Struve (1929) even provided a simple and elegant method for calculating the resulting line shape to be expected for sharp lines and a given value of $v_e \sin(i)$. The half-width (full width at half maximum) could be uniquely related to the value of $v_e \sin(i)$ and a physical interpretation attached to the result.

Even though we realize that no self-gravitating gas sphere which is rotating can remain spherical, the simplicity of the Struve Model and the associated definitions have made them hard to abandon. We still measure half-widths and express them as v sin(i) albeit the cautious have dropped the subscript 'e' in the realization that even if the value of the inclination were known, the value for v would\have little to do with the equatorial speed of the star. We know now, as I suspect Struve did then, that differential rotation, limb-darkening, gravity darkening, and the variation of the ionization - excitation equilibrium over the surface of a rotating star all contribute to defeat the simple relation given by the Struve Model between the equatorial speed, the inclination of the spin axis and the resulting line profile. The difference is that we are now in a position to model most of these effects remaining mindful that what is measured are line profiles and half-widths. However, the term v sin(i) is too pejorative to remain a valid term for the observations. *"Doppler half-width"* measured in km/sec. would imply much less and still describe what is measured. Only when a specific model which defines a unique equatorial speed,

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inclination and yields a line profile for comparison is used, are we entitled to use the term $v_e \sin(i)$.

There is one additional commonly used term which is so prejudicial in its form, that we should all make a conscious effort to eliminate it from our vocabulary. Twenty years ago I was quite properly chided by a well known theoretical astrophysicist when I referred to a star rotating at "break-up velocity". He pointed out the obvious; namely, that stars do not break up, they merely reach a speed at which the centripetal acceleration balances the gravitational forces at the equator. When this happens, the effective potential has been reduced by a factor of two. This critical velocity is still short of the escape velocity by a factor of $\sqrt{2}$. Any larger equatorial velocity would simply inject matter into Keplerian orbits which can hardly be considered a condition of 'break-up'. The picture of material pinwheeling away from a star rotating at 'break-up' velocity is so misleading as to markedly impair the way in which one envisions such stars. For example, it is this picture which leads many to believe that Be stars must be rotating at 'break-up' velocity in order for the material producing the emission lines to escape from the star. Since rotation can only directly provide half of the required energy, nothing could be further from the truth. A useful, and increasingly used, term which denotes the velocity at which the effective gravity at the equator goes to zero is the *'Critical Velocity'*. It is a non-prejudicial term which is applicable in a wide variety of circumstances.

Generic Comparatives

There are a number of terms which we use in a short hand fashion for purposes of comparison with which we should be more careful. The problem here generally arises from the assumption that it is perfectly clear to what the comparison is being made. Classic examples are "*pole-on*" *and* "*equator-on*". *To some, these terms mean* inclination 0° and 90° respectively. Such a meaning is too specific to have any utility as a comparative. A far more useful *definition would be "pole-on"* means $i<30°$ and "*equator-on*" for $i>60°$. It seems fairly clear from the literature that the initiators of these terms (Slettebak 1949) indeed, had this fairly loose meaning of the term in mind for the stars to which it was applied. This definition is also compatible with that of Jaschek et al (1981). Of course comparatives can always be used where the referent is explicitly stated such as "this star is more *pole-on* than that star".

The "pole-on" Be stars provide an interesting example of the problems that can be raised by the choice of comparison. W.W.Morgan (see Slettebak 1949) first noticed that the Balmer-line wings of these stars are unusually strong. Burbidge and Burdidge (1953) attempted to quantify this result by comparing a few "pole-on" stars and normal stars of the same luminosity class. They concluded that the wings of the Balmer lines were indeed stronger in the "pole-on" stars and that the effect must be due to broadening by electron scattering in circumstellar shell. However, more recent computations which allow for

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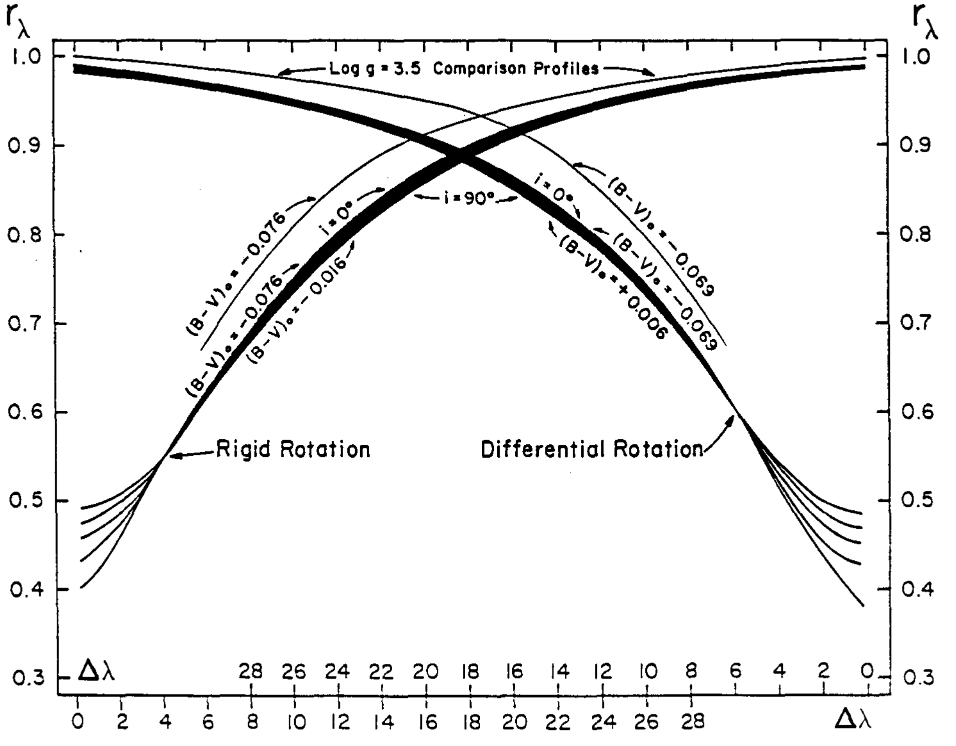
the inclusion of rotational distortion, limb and gravity darkening, and a more complete theory of Balmer line broadening indicate that it may well be possible to account for Balmer profiles of "pole-on" stars as orginating within the photosphere itself.

In any study of a comparative effect, the treatment of the comparison standards is as important as the analysis of the object itself. For the late B stars modeled in this paper, the Hβ line of the typical Be star (ie i~60°) will be very similar to the line profile of a non-rotating star of the same color, but much lower gravity. However, the line profile of a non-rotating star with the same low gravity, but the color of a "pole-on" rapid rotator will exhibit an Hβ line profile with much weaker wings (see figure 3). Thus, if the non-rotator is used as the standard, the line profile of the rotator will be said to be unusually strong. While figure 3 quantifies this only for the late Be stars, the processes of line formation are sufficiently similar for the B stars in general, that I would expect a qualitatively similar result throughout the entire spectral class.

Figure 3. *The Hβ line profiles for the rotating models are shown here with the rigid rotation models on the left and the differentially rotating models on the right. The solid line wings are the envelope of all profiles with inclinations between 0° and 90°. The line profile for a non-rotating star with the same color as a typical* Be *model (ie i~60°) and* log g = 3.5 *would also lie within the envelope. The thin solid line represent the profile for a model with the same* $(B-V)_0$ *as the rotating models with inclination* 0°.



The truly misleading comparatives are to be found among those whose referents are always implied and in some cases are non-existent. "Sharp-line" stars is an example of the former while a conspicuous example of the latter is the term "Extreme Be star". Rare indeed, is the author who will tell you what other star or stars and for what lines his "sharp-line" star is sharper than. Often this term is considered to be synonymous with "slowly rotating" which, although technically wrong, may be used, with care, to sample the slowly rotating stellar population among the early spectral types. In the absence of specific qualifications, I have suggested that the term *"Sharp Line" star* be reserved for stars exhibiting doppler widths less than about 50 km/sec. In regard to the term "Extreme Be star", I have never been clear as to whether the word "Extreme" is being used as a comparative or a labeling adjective for which there exists a unique definition. If it is the latter, then it is a poorly chosen label indeed, as the very word 'extreme' invites comparison. What physical property of the star or its spectrum is to be considered extreme and compared to what sample of stars? Since several venerable members of our profession have specifically asked me to consider this term, let us examine it in some detail.

It is my purpose here, only to investigate the functional utility of the concept. The original definition of the term (Schild, 1966) is based on the appearance of the spectra of seven stars in the cluster h & χ Persei, five of which have the same spectral type (B1.5 III) while the other two are within half a sub-type of the other five (B1 III, B2 III). Their distinguishing characteristic appears to be that they have unusually broad "underlying Balmer absorption" while "the lines of all elements other than hydrogen are suprisingly narrow", and "the He I lines are quite weak compared to those of ordinary Be stars of similar spectral type". Nothing in the comparison seems to justify the use of the term "Extreme". The published comparison sample consists of nine stars which range from B0.5 to B2 in spectral type, but span a luminosity range from V to Ia. Indeed, two of the comparison stars are supergiants. Even the notion of repeatability, so essential to any subjective definition, seems lacking as Slettebak (1968) has been unable to find the defining properties in the original sample.

Efforts (Schild 1973, Schild and Romanishin 1976) to clarify the criteria for "Extreme Be Star" status have again apparently failed to meet the requirement of repeatability (Slettebak 1985) which is essential to the viability of a definition. The term "Extreme Be Star" fails badly as a comparative, generic or otherwise. As a label to denote properties of the spectrum, it lacks repeatability, reliability and the statistical validity which must be established before the search for physical interpretation can be undertaken. I will not comment further on the validity of the formidable structure which has been raised on this definition except to observe that any edifice, regardless of its beauty or appeal, is no more secure than its foundation.

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When considering the definitions of terms which rely on the subjective interpretation of stellar spectra, it best to keep in mind that spectral classification itself is a subjective spectral evaluation system whose repeatability, reliability, and validity, rest on samples of tens of thousands of stars classified by hundreds of investigators. Indeed, it is not possible to demonstrate the internal reliability and validity of such a system unless a large sample of the subject and investigators are utilized. Even when this has been demonstrated, the physical interpretation of the resulting classification sequence is not guaranteed and in the best of cases is hampered by the lack of quantified information. For example, it is extremely difficult to translate what is meant by 'line strength' into a measured quantity such as equivalent width, half-width, or central depth. Difficulties such as this make the comparison with physical models, upon which our real understanding rest, qualitative at best. When the original definition is poorly posed, the task becomes impossible.

Conclusions

When we legitimately try to improve the description of the physical world, we are of necessity working on the ragged edge of understanding. All that keeps us from slipping over is the adherence to the basic concepts of physical science and a continuing insistence that we can unambiguously formulate our ideas so that they can be generally understood. At the foundations of any such formulation are the definitions of the terms that we use to describe phenomena. Precision in those definitions is essential if we are to make any progress in our task. As any science progresses, the rigor of the past may prove insufficient for the problems of the future. When this occurs, we must refine and reaffirm those definitions which are central to our understanding. I have attempted to demonstrate some instances wherein the comfortable terms appropriate for spherical stars are inappropriate for the distorted stars that today capture our interest.

The anisotropic nature of the radiation field of a distorted star eliminates from direct observational measurement, the notion of total energy output of the star. Local physical properties such as temperature, pressure and gravity are no longer general characteristics of the star, but may vary widely over the surface of the star. This greatly complicates the nature of the information which we receive at the earth as we can only observe the integrated radiation emanating in our direction from the visible surface.

While we have always relied on physical models of stars to test our ideas of the physical world against observation, the nature of those models must now become rather more sophisticated if that comparison is to meaningfully test our understanding of the phenomena we hope to describe. Fortunately rapid advances in computing power have made such models possible. However, model makers must be ever mindful of what can be observed, while the observers must become acquainted with the limitations of existing theory lest they draw more conclusions from their data than are warranted by the theory. Extreme care must be exercised in the application of terms, appropriate to the simple models of the past, to the complicated phenomena which we presently attempt to describe. Additional care must be employed when dealing with adjectives meant to describe an approximate condition lest they be interpreted as indicating a specific state. I have discussed a few, but certainly not all, of such terms. Those terms, which by their very nature are misleading, should be avoided at all costs as they will produce the opposite effect from that intended by their authors.

I have offered a few definitions which some have found useful in dealing with some of the problems posed by rotating stars and have suggested some terms which should quietly disappear from the literature. However, I have no illusions that these suggestions will be universally adopted. There are no formal penalties exacted from those who abuse the language and rigor of science except the eventual consignment to obscurity. Only the self-discipline of astronomers as authors and referees can eliminate the use of inappropriate terms. However, there are some distinct rewards, other than virtue, which attend those who exercise clarity of thought and unambiguously describe what they have done. They have the chance to advance the science in a manner comprehensible to others. This is not only our opportunity, it is our responsibility.

I would like to thank all of the numerous colleagues who offered their advice and suggestions regarding material for inclusion in this work. I apologize for being unable to include it all. Special thanks are due Arne Slettebak who, more than once, tempered my zeal with reason.

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IAU Colloquium 92

DISCUSSION FOLLOWING COLLINS

Abt:

I would like to suggest two modifications to your definition of Be stars. The first is to refer to "optical region" spectra because we do not know whether our separation between B and Be stars holds for Lyman and Paschen lines too.

Collins:

Although I suspect a case can be made for including all hydrogen emission in such a definition, as the term "Be star" is a generic label only, I would agree that since the MK type is based only on the optical, the "e" classification should be as well. So, in the interest of self-consistency, I will modify the definition for the written paper to read "Balmer-lines" instead of "hydrogen lines."

Abt:

Second, to separate "classical" Be stars from binaries showing emission at certain phases, I recommend saying that Be stars show hydrogen emission "continuously for long time intervals." Long means months or years.

Collins:

I have tried to emphasize the generic value of the term "Be star" as a broadly based label based on the appearance of the spectrum alone. I have no objection, indeed I can see a significant value in defining subcategories of Be stars. I would only ask that any such definition be clearly made.

Underhill:

A word which requires careful use is "envelope". Those who study the interior of stars use the word to refer to the part of the star between the energy-generating core and the photosphere. I suggest that it be used only for this part of the star. Observers should use another term to refer to the circumstellar plasma outside the photosphere which gives rise to emission lines and, sometimes, extra absorption lines.

Collins:

As I indicated in the talk, I could not discuss all terms that astronomers find confusing. However, while I admit the possibility of confusing the "envelope" of stellar interiors with the circumstellar envelope that will be discussed in this conference, I personally do not see much danger in confusing the two as long as the envelope surrounding the star is denoted by the term "circumstellar envelope".

Mendoza:

Your definition of Be star does not make a distinction between two groups of Be stars, namely, "classical Be", and Herbig's Be stars. These groups are different, as discussed in the paper I will present later in this conference.

Collins:

The definition of a Be star given here was not intended to distinguish between physically similar classes of stars, but only to serve as a broad label based on properties of the spectrum *alone*. I suspect that there are more than two subgroups of Be stars and would welcome their clear operational definition.

Buscombe:

In referring to "differential rotation", do you anticipate equatorial acceleration (the solar case) or the opposite, polar acceleration?

Collins:

The differentially rotating models shown here are based on an angular velocity field which increases toward the pole, as this type of velocity field will show the maximum distortion and thus provides the best chance for producing observable effects. I find the terms "equatorial" and "polar accelerations" particularly misleading to describe the spatial variation of the angular velocity field in a star. Acceleration refers to a time- rate of change of a velocity, not a change in space.