30. RADIAL VELOCITIES (VITESSES RADIALES)

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1. Introduction

The present report on the activities of IAU Commission 30, covering the triennium June 1, 1984 through June 1, 1987, will be somewhat different from its recent predecessors in both content and style. Over the preceding decade or so, the reports mainly emphasized the dramatic improvements in observing efficiency, achieved primarily through the general adoption of cross-correlation techniques, combined with modern detectors attached to either specialized spectrometers or to existing, more conventional instruments. A great surge of observational activity followed, directed towards a variety of astrophysical problems, some of which are of a more classical nature, but many of which are in entirely new classes of research. At the time of the previous reports, most of the major observational projects were still underway, even if some preliminary results were emerging. The proceedings of IAU Colloquium No. 88, *Stellar Radial Velocities* (L. Davis Press, 1985) contains a collection of papers on instrumentation and reduction techniques as well as on ongoing observing programs which remains a very useful source of references to this developmental phase as well as to the current state of the art.

In contrast, the past triennium has been a period rather of maturity and refinement on the technical side; no major new developments have been reported. The main contributors of accurate photoelectric cross-correlation determinations of radial velocities continue to be the instruments at the Center for Astrophysics (CfA), the Dominion Astrophysical Observatory (DAO), and the Franco-Swiss CORAVEL spectrometers operating at Observatoire de Haute-Provence, France, and at ESO in Chile; typically, the same instrument/detector/software systems are used to observe widely different types of object, both galactic and extragalactic.

With the instrumentation now working in a routine fashion, the astronomers have concentrated their attention on the astrophysical problems. As an appetizer for the more detailed account below, we shall mention just a few of the new, exciting scientific results which have been based on radial-velocity measurements: The recent revolution in our ideas concerning the large-scale structure of the Universe, with the unexpected distribution of the (luminous) matter in bubble-like structures surrounding huge voids, is due to the systematic and painstaking collection of accurate velocity (redshift) measurements for thousands of faint galaxies. The secular stability of dwarf spheroidal galaxies in the Local Group, and the possible presence of dark matter also in these old, distant systems, has been investigated by means of accurate radial-velocity data for individual, very faint ($V \approx 17$) member stars. Finally, the first accurate radial-velocity curves for extragalactic Cepheid variables (in the Magellanic Clouds) have been obtained.

Turning to objects in our own Galaxy, radial velocities for numerous faint, individual member stars in several globular clusters have contributed significantly to the new, much more profound understanding of the structure and dynamical evolution of these clusters. In open clusters, the central concentration of the spectroscopic binaries, along with the blue stragglers and other massive stellar constituents, has been demonstrated observationally. The dynamics of the Galaxy itself - both disk and halo components - is being studied from data sets which exceed earlier samples by orders of magnitude in precision and homogeneity as well as in num-

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ber. Similar improvements in the observational basis for Baade-Wesselink analyses of the radii, luminosities, and pulsation properties of RR Lyrae stars are providing independent, fundamental data for these important distance indicators and are being brought to bear on other types of pulsating variables; with high-precision techniques, pulsations with amplitudes of a few tens of m s^{-1} have been discovered in Arcturus and other bright stars. Long-accepted results on the frequency of (spectroscopic) binaries amongst various types of stars are being challenged as new observations become available and quality standards stricter. And, last but not least, ultra-precise radial-velocity measurements over nearly a decade have produced the first substantial (if not indisputable) evidence for the existence of planet-size companion(s) to at least one other solar-type star.

An exhaustive account of all published and ongoing research involving determination of (stellar or other) radial velocities during the past triennium, as has traditionally been the goal, would now far exceed the allotted space for this report and, moreover, presumably be of limited interest to the readership. It will not be attempted. Instead, the intention is to highlight, primarily for the benefit of readers from *outside* the Commission, what appears to be the more significant developments during this period in a number of selected subjects. References to some of the key papers are given, with no pretention of completeness, while the reader is referred to the appropriate sections of *Astron. Astrophys. Abstracts* for a more complete bibliography on subjects of her/his specific interest. The main weight of the report will be on programs in stellar astronomy, with a certain bias towards the contributions of those colleagues who supplied material in time for its inclusion.

This approach has some foundation in the composition of the Commission membership, currently at 64 after a 25% increase at the 1985 General Assembly. This is far fewer than the number of IAU members actively engaged in research based on radial-velocity data, especially in non-stellar fields. Hence, this report should be considered, in a sense, as the "tip of the iceberg"; many results have been included in the reports of other Commissions (*e.g.* 9, 26, 27, 28, 29, 33, 40, 42). Similarly, while IAU Colloquium No. 88, *Stellar Radial Velocities* (see above) was the only meeting during the triennium entirely devoted to the subject of radial velocities, Commission 30 co-sponsored several other meetings: IAU Symposium No. 132, *The Impact of High S/N Spectroscopy on Stellar Physics* (Meudon, June-July 1987), IAU Colloquium 95, *Second Conference on Faint Blue Stars* (Tucson, May-June 1987), and IAU Colloquium No. 97, *Wide Components in Double and Multiple Stars* (Brussels, June 1987), as well as the future IAU Colloquium No. 107, *Algols* (Victoria, August 1988) and the Joint Discussion on *Formation and Evolution of Stars in Binary Systems* at the upcoming IAU General Assembly. Radial velocity work featured prominently at many other meetings.

Commission 30 itself continues to fill an important role of coordination and standardization, as exemplified by the initiative to publish a Commission *Newsletter* (by Dr. A. Florsch, Observatoire de Strasbourg), and by the current effort to refurbish the IAU system of radial-velocity standard stars to meet present-day demands (see 8, below). In is also appropriate to record here the valuable contribution made by the publication of the *Bibliographic Catalogue of Stellar Radial Velocities*, by Barbier-Brossat and Petit (*Astron. Astrophys. Suppl.* 65, 59), and the imminent publication, by the same authors, of the corresponding *Catalogue of Mean Stellar Radial Velocities*.

2. Large-Scale Distribution of Matter in the Universe

As noted above, an extensive account of extragalactic radial-velocity work is outside the scope of this report. It is, however, appropriate to review the redshift survey projects which have recently made a major impact and received considerable public attention. The following section was kindly prepared by D.W. Latham:

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Mapping out the distribution of galaxies is a first step towards understanding the origin and evolution of large-scale structure in the universe. Over the past few years, surveys of the redshifts (radial velocities) of galaxies have uncovered unexpectedly large structures. The 21-cm survey by Giovanelli and Haynes (*Astron. J.* **90**, 2445) delineated the Perseus-Pisces chain. Optical redshift surveys were used to probe the enormous void in Boötes (Kirshner, Oemler, Shectman, and Schechter, *Astrophys. J. Lett.* **248**, L57) and the remarkably similar structure in the adjacent Corona Borealis region (Postman, Huchra, and Geller, *Astron. J.* **92**, 1238). The completion of the first slice of the extension to the CfA Redshift Survey (de Lapparent, Geller, and Huchra, *Astrophys. J. Lett.* **202**, L1) suggested that galaxies are distributed on thin sheets which surround or nearly surround vast regions nearly devoid of bright galaxies in a bubble-like structure. The completion of a second slice adjacent to the first (Geller, Huchra, and de Lapparent, *IAU Symp. 124*, p. 301) supports this picture. Further slices are now being observed at the CfA.

Surveys in the south reach less deep than those in the north, but a recently completed survey once again reveals enormous voids and sheet-like structures (da Costa, Pellegrini, Sargent, Tonry, Davis, Meiksin, and Latham, *Astrophys. J.* in press). Deeper surveys in the south are needed to help investigate whether a fair sampling of the universe has been achieved, to help determine the average properties of the large-scale structure, and to help analyze the large-scale flows.

3. Stars in Local Group Galaxies

Once the possibility of determining accurate radial velocities for very faint stars was established, the brightest giants in some of the nearby dwarf spheroidal galaxies became targets of high priority. Not only could accurate systemic velocities for these objects help to estimate the total mass of our own Galaxy, but their velocity dispersions would indicate whether they could be stable over the long periods indicated by their colour-magnitude diagrams, and could be used to estimate their total mass as well as the presence (and nature) of any dark matter within them. The pioneering attempt in Draco and Ursa Minor by Aaronson (*Astrophys. J.* **266**, L11) was followed up by work on the Carina, Fornax, and Sculptor systems by Seitzer and Frogel (*Astron. J.* **90**, 1796), Armandroff and da Costa (*Astron. J.* **92**, 777) and Aaronson and Olszewski (*Astron. J.* **92**, 580; **94**, 657). The latter authors conclude that conventional forms of dark matter (low-mass stars) are adequate to explain the observations.

In the nearest Local Group galaxies, the Magellanic Clouds, hundreds of individual stars are accessible to existing instruments. Adding to previously existing data of lower precision, mostly on earlier-type supergiants, catalogues of CORAVEL radial velocities have been published for some 400 late-type supergiants in the LMC (Prévot et al., *Astron. Astrophys. Suppl.* **62**, 37) and for about 230 such stars in the SMC (Maurice et al., *Astron. Astrophys. Suppl.* **67**, 423). The results are currently being studied for determination of the rotation parameters and mass of (especially) the LMC. A similar study has been carried out from accurate radial velocity measurements of planetary nebulae by Dopita and collaborators (*ESO Workshop on Galactic Halos*, Garching, April 1987). With the best current and future instruments, these observations can be extended to the fainter giant stars (young and old), and lead to a better understanding of the dynamical history of both field and cluster population in the MC.

Finally, accurate radial-velocity curves have been observed for several Cepheid variables in the LMC (Imbert et al., *Astron. Astrophys. Suppl.* **61**, 259) - the first such data for extragalactic Cepheids. These data have been used in a Baade-Wesselink analysis by Imbert (*Astron. Astrophys.* **175**, 30) to determine radii and luminosities for the variables, and hence a value for the LMC distance. No doubt, with more good radial velocity curves combined with photometry in suitable colours and better understanding of the pulsation phenomenon, this approach will supply important independent data on the distance to the Clouds and thereby on the extragalactic distance scale.

4. Structure and Dynamics of the Milky Way

The study of the structure and dynamics of our own Galaxy is another field which has received new vitality with the relatively easy access to obtaining accurate radial velocities for large numbers of faint stars. Here, however, typical observing programs comprise hundreds or thousands of stars, and the resulting radial velocities require supplementary, homogeneous photometric, spectroscopic, and astrometric data of matching quality for their interpretation in terms of the past evolution and present structure of the Galactic disk and halo. Hence, results are presently available mostly as progress reports, while full exploitation of the information inherent in the data will take considerable time. A few programs are designed to simply provide velocity data for a complete sample of stars for future analysis. Among these, we mention the large-scale Marseille-Haute-Provence objective-prism and spectrographic program to supply radial velocities for the HIPPARCOS stars, where some 17 000 spectra have already been measured to give radial velocities with a precision of about ±4 km s^{-1} for some 5000 stars (3-4 plates per star); the publication by Griffin (*MNRAS* **219**, 95) of velocities for more than 400 faint stars in the Clube selected areas; and the completion of radial velocity data for all stars in the *Bright Star Catalogue* by Nordström et al. (*Astron. Astrophys. Suppl*. **59**, 15; **61**, 53).

Several large-scale programs are designed to explore the information contained in the correlations between the kinematics, the metal abundances, and the ages of stars in the Galactic disk and halo. The criteria used to define the sample under study, and the various biases they introduce into the correlations to be examined, are then of crucial importance. Different approaches are being followed simultaneously, the main sample definition criteria being either proper motion, which introduces a kinematical selection but in principle no metallicity bias, or photometric or spectroscopic metallicity or age indices applied to a magnitude-limited parent sample, which in principle avoids both kinematic and chemical bias.

The two main projects of the first type are the surveys of proper-motion stars by Sandage and Fouts (*Astron. J.* **93**, 74) and by Carney and Latham (*Astron. J.* **93**, 116), both of which discuss radial velocities and *UBV* photometry for some 900 stars from the Lowell Proper Motion Survey, the overlap between the two programs being 30-40%. Sandage and Fouts conclude that their data support the classical Eggen, Lynden-Bell, and Sandage view that the galaxy collapsed from a spherical halo to a flat rotating disk in essentially a single free fall time of about 10^8 years, although with the addition of the Gilmore and Wyse (*Astron. J.* **90**, 2015) "thick disk". The Carney-Latham data seem to support the alternate view (Norris, *Astrophys. J. Suppl*. **61**, 667) that the collapse was more chaotic and lasted many free fall times. The Carney-Latham photometric metallicity indices are being supplemented by abundance measurements on the low-S/N spectra obtained for the radial-velocity determinations (Carney et al., *Astron. J.* **94**, 1066) as well as by photometry in other bands to improve the accuracy of their distance determinations. Both surveys give preliminary values for the Galactic escape velocity of 500-550 km s^{-1}.

Surveys based on essentially magnitude-limited samples defined by objective-prism and/or photometric data on spectral types, metal abundances, and ages are being carried out by several groups. Halo red giants were studied by Carney and Latham (*Astron. J.* **92**, 60). Ardeberg and Lindgren are carrying out a massive survey of *uvbyβ* photometry and radial-velocity determination for some 5000 metal-poor F, G, and K stars; a detailed description and progress report is given in *IAU Colloq. 88*, p. 151. Andersen, Mayor, Nordström, and Olsen have completed radial-velocity observations for some 5000 nearby F dwarfs in the whole sky, selected from the complete, magnitude-limited catalogue of homogeneous *uvbyβ* photometry by Olsen

(*Astron. Astrophys. Suppl.* **54**, 55); these include all stars with metal abundances less than about half of that of the Sun as well as all those for which individual photometric ***ages*** - the salient characteristic of this program - can be computed. Extension of the observations to some 1200 fainter F stars in the direction of the North Galactic Pole, and to an all-sky sample of about 2000 G dwarfs, is under way. An outline of the program is given in *IAU Colloq. 88*, p. 171, and a preliminary analysis in the (perhaps last) paper by B. Strömgren in *The Galaxy* (Ed. G.F. Gilmore and R.F. Carswell, in press). Finally, Sandage and Fouts (*Astron. J.* **93**, 592, 610) use radial velocities of magnitude-limited samples of stars in three directions to estimate that the "thick disk" contributes about 10%, and the halo 0.5%, of the stars near the Sun, much higher than earlier estimates.

The new possibilities for obtaining accurate radial velocities for very faint stars are being used to study the halo population *in situ*, rather than inferring its properties from data for samples near the Sun. Extensive programs are being conducted by G. Gilmore and others; Ratnatunga and Freeman (*Astrophys. J.* **291**, 260) found an unexpectedly low velocity dispersion for a sample of metal-poor giants toward the South Galactic Pole.

5. Star Clusters

The pioneering work by Gunn and Griffin in 1979 (*Astron. J.* **84**, 752) of obtaining and analyzing radial velocities for a large number of individual stars in the globular cluster M3 with measuring errors much smaller than the expected internal velocity dispersion of the cluster produced a breakthrough in the theoretical modelling of globular cluster dynamics. The additional constraints on the models posed by the detailed knowledge of the velocity dispersion in the centre of the cluster as well as its radial variation showed the inadequacy of simple one-component models, and multi-mass King models with anisotropic velocity dispersions in the outer parts of the cluster were introduced.

During the past three years, this observational material has been greatly extended and refined, and similar data and analyses are now available for five additional clusters: M2 (Pryor et al., *Astron. J.* **91**, 546), M13 (Lupton et al., *Astron. J.* **93**, 1114), M92 (Lupton et al., *IAU Symp. 113*, p. 19), ω Cen (Meylan, *Astron. Astrophys.* **184**, 144), and 47 Tuc (Meylan and Mayor, *Astron. Astrophys.* **166**, 122). In all except M2, velocity anisotropy was found to be important, strongest in ω Cen. Significant rotation has been found in three clusters (M13, 47 Tuc, and ω Cen), with a maximum of 6-8 km s^{-1} at a distance of a few core radii from the centre. Masses derived for the clusters are in the range 0.4-0.9 10^6 $M_\odot$, with the exception of the unique giant cluster ω Cen (~4 10^6 $M_\odot$). The mass fraction locked up in unobserved heavy remnants (presumed to be white dwarfs) seems to vary from some 2% (M3) through ~10% (M2) and ~30% (ω Cen, 47 Tuc) to perhaps 50% (M13); the origin of these is not yet fully understood. Extensive radial velocity data are becoming available for many further clusters, from observations by both Griffin et al. (Palomar), Mayor et al. (ESO), and Pryor et al. (DAO).

Galactic *open clusters* are, in fact, even more challenging from an observational standpoint than globular clusters, due to their far smaller internal velocity dispersions of typically 1 km s^{-1} or even less. Several current instruments can achieve a precision substantially better than this figure. However, any binary systems present in the clusters with periods of decades, or even centuries, can have velocities - even when observed with infinite precision - which differ from the γ-velocity of the system by amounts similar to the velocity dispersion of the cluster. For the derivation of the true velocity dispersion of the cluster, orbital motion in binaries is a major factor and must be considered carefully - yet another example of a field where observational uncertainty has ceased to be the main limitation.

Precise radial velocity data are, first, an effective means of identifying member and non-member stars in the cluster field - especially important if the field contains a single star of singular interest, e.g. a Cepheid (Mermilliod et al., *Astron. Astrophys. Suppl.* **70**, 389). Moreover, identification not only of cluster members, but also of cluster binaries, is crucial for a correct interpretation of the details of a cluster colour-magnitude diagram, as shown beautifully by Nissen et al. (*Astron. J.* **93**, 634), who used the accurate radial velocity data for M67 (and M11) by Mathieu et al. (*Astron. J.* **92**, 1100). The same data enabled Mathieu and Latham (*Astron. J.* **92**, 1364) to conclude that the spectroscopic binaries and blue stragglers in M67 were (equally) concentrated toward the cluster centre relative to the single stars, an effect readily explained as the result of dynamical relaxation (reviewed by Mathieu, *IAU Symp. 113*, p. 427); the same result was found for NGC 188 by Harris and McClure (*IAU Colloq. 88*, p. 257). Finally, we mention the alternative method for age determination of open clusters from the cutoff period for tidal circularization of cluster spectroscopic binary orbits proposed by Mathieu and Mazeh (*Astrophys. J.*, in press), a further development of the observation by Mayor and Mermilliod (*IAU Symp. 105*, p. 411).

6. Spectroscopic Binaries

While detection and orbit determination of spectroscopic binaries are within the domain of Commission 30, progress in the study of binary frequencies in various stellar types and determination of masses and other physical properties from observations of binaries are thoroughly reviewed in the reports of Commissions 42 (close binaries) and 26 (visual binaries) elsewhere in this volume. Hence, the present report will be limited to a few highlights:

Much progress has been made on the detection and frequency determination of spectroscopic binaries in various types of stars during the triennium under review. The earlier belief that spectroscopic binaries are rare or absent in Population II has been proved wrong by Stryker et al., (*PASP* **97**, 247), Carney and Latham (*Astron. J.* **93**, 116), and Ardeberg and Lindgren (*IAU Colloq. 88*, p. 371); one example is the spectroscopic orbit for the extremely metal-deficient star BD+13°3683 ([Fe/H]≈-2.3) published by Jasniewicz and Mayor (*Astron. Astrophys.* **170**, 55). Progress in identifying and measuring orbits for the spectroscopic binaries in the Hyades has been made by Griffin et al. (*Astron. J.* **90**, 609). Griffin is also making steady progress in defining the long-period part of the spectroscopic binary population in his long series of papers in *Observatory* and elsewhere, which includes the first binary with $K < 1$ km s^{-1} (McClure et al., *PASP* **97**, 740) and the first S-type binary (*Obs.* **104**, 224). Similar systematic work, on a smaller scale, is done by the Toulouse group, who have also published their 14th *Catalogue Complémentaire* (Pédoussaut et al., *Astron. Astrophys. Suppl.* **58**, 601). From some eight years of data on Ba II, CH, and R-type carbon stars, McClure has determined complete or partial orbits for 17 out of 20 Ba II stars; both the Ba II and the CH stars appear to have significantly lower orbital eccentricities than normal red giants.

The binary Cepheid DL Cas was studied by Harris et al. (*Astron. J.* **94**, 403) and Mermilliod et al., (*Astron. Astrophys. Suppl.* **70**, 389); both groups are continuing work on binary Cepheids. Also the frequency and properties of triple and multiple systems are being studied in greater detail than before, e.g. by Mayor and Mazeh (*Astron. Astrophys.* **171**, 151) and Duquennoy (*Astron. Astrophys.* **178**, 114); see also the report of Commission 26. At the limit of very large separations, Mazeh and Latham (*IAU Colloq. 97*, in press) find a real cutoff in the number of physical pairs at separations greater than about 0.1 pc. Finally, on this subject, the reality of some published orbits has been called into doubt by Morbey and Griffin (*Astrophys. J.* **317**, 343); while it is not clear that future, more definitive results on binary frequencies will differ substantially from earlier estimates, the uncertainties are clearly larger than previously believed, and standards for accepting orbital solutions will be stricter in the future than before.

A special case of a spectroscopic binary survey is that by Campbell and Walker (*IAU Symp. 132*, in press), who from six years of data with a precision of about ± 15 m s^{-1} find a few stars to exhibit velocity variations which are plausibly (but not unequivocally) explained as due to companions of a few Jupiter masses. Companions of masses corresponding to those expected for brown dwarfs were not detected, which suggests that brown dwarfs - should they exist at all - are generally not found as companions to solar-type stars.

Finally, a few examples to illustrate how application of the modern techniques allows new types of results on some individual binary systems: High-resolution, high S/N observations in the far red allowed Tomkin and Popper (*Astron. J.* **91**, 1428) to measure the orbit of the very faint secondary of α CrB; such systems are especially informative in comparisons with stellar evolution models. The ability of the cross-correlation method to "see" only the late-type system in a composite spectrum has been utilized by, e.g. Knee et al. (*Astron. Astrophys.* **168**, 72) and Griffin and Griffin (*J. Astrophys. Astron.* **7**, 195). Finally, the mere improvement in precision possible with the new instruments has been used by Andersen et al. (*Astron. Astrophys.*, in press) in the hitherto most successful comparison of stellar evolution models with observations of a star (AI Phe) other than the Sun.

7. Pulsating stars

Measurement and analysis of precise radial-velocity curves of pulsating variables is another field which has seen enormous progress in the period covered by this report. Not only can observations be obtained of fainter and more distant stars than before - even of stars in the Magellanic Clouds (Imbert et al., *Astron. Astrophys. Suppl.* **61**, 261) - but the new level of observational accuracy has stimulated the theoretical work on their interpretation. This is especially true as regards the application of the Baade-Wesselink method to the determination of radii, luminosities, and distances to such stars as RR Lyrae and Cepheid variables. These stars are of prime importance as extragalactic (and Galactic) distance indicators, but their absolute-magnitude calibrations are still affected by considerable uncertainties.

Jones et al. (*Astrophys. J.* **312**, 254, and further papers in press) have shown that self-consistent radius variations (from photometry and spectroscopy) for RR Lyrae variables can be obtained *if* light curves in the *K* band are used and the *V-K* colour index is used to infer the temperature variations over the cycle; a systematic program is under way for field and globular cluster variables which should place our knowledge of the absolute magnitudes of RR Lyrae stars, and their dependence or otherwise on metallicity, on a new observational basis. Similar work, utilizing photometry in the Geneva system, is carried out by Burki et al. (*Astron. Astrophys.* **156**, 139; **159**, 255, 261; **181**, 34) on RR Lyrae, δ Scuti, and other types of variables. At the CfA, observations are under way under the coordination of J.P. Huchra to obtain radial-velocity curves for all the calibrating Cepheids in Galactic clusters, as part of one of the Key Programs for the Hubble Space Telescope. Similar programs are also under way by the CORAVEL group and elsewhere. Work is also in progress to examine to what extent the methods developed for Baade-Wesselink analysis of RR Lyrae stars can be applied to the Cepheids, which have much more extended atmospheres; in the Cepheids, the cross-correlation profiles show a decidedly non-static behavior of the photosphere during the expansion phase.

Finally, the techniques developed for ultra-precise radial-velocity measurements have also been applied to the detection and measurement of pulsating stars. The Arizona group has recently discovered that Arcturus is a pulsating star with a peak-to-peak range of 160 m s^{-1} and a period near 2 days, while Pollux, and perhaps Aldebaran, pulsate with much smaller velocity ranges (~10 m s^{-1}) and periods near 3 hours (Smith et al., *Astrophys. J.* **317**, L79 and *IAU Symp. 132*).

8. The IAU System of Standard Stars

At its 1985 meeting in New Delhi, Commission 30 decided to appoint a Working Group, consisting of J. Andersen (chairman), W.I. Beavers, B.Campbell, D.W. Latham, M. Mayor, and R.D. McClure, with the task of proposing a new system of radial-velocity standard stars, the existing (1955) system having been rendered hopelessly inadequate by the recent great improvements in observational accuracy (see, e.g. Batten, *IAU Colloq. 88*, p. 325). The Working Group was to report to the Commission at its meeting in Baltimore in 1988; meanwhile, intensive observation was recommended of those of the former standard stars with $|\delta|<20°$ which had proved to be most stable (Mayor and Maurice, *IAU Colloq. 88*, p. 308), as well as of minor planets for the purpose of establishing the velocity zero-point. The radial velocities of these minor planets can be calculated from their known orbital elements to a precision better than 10 m s^{-1}.

These observations have been pursued during the period of this report, the main weight of the data originating again from the three photoelectric instruments at the CfA, the DAO, and the southern CORAVEL in Chile. At the time of writing, about 250 minor planet observations have already been collected (nearly 200 from the CfA alone, primarily through the efforts of R.P. Stefanik), and typically 100-200 observations over a 7-10 year baseline are available for each of the stars under consideration as future primary standards. These observations are currently being collected for analysis by the Working group.

Preliminarily, the minor planet observations by each group appear to confirm the validity of their individual zero-points to about ±100 m s^{-1}. It remains to be seen whether their observations of the standard star candidates can be reconciled after being adjusted to a common zero-point. However, our original goal of proposing, in 1988, a revised set of about 20 bright, late-type, primary standard stars for which the individual velocities and the common zero-point are known to about ±100 m s^{-1}, still appears to be within reach. Moreover, results from the Canadian programme of high-precision radial velocity observations by the HF absorption-cell technique indicate that a half-dozen or so of these stars may have velocities which are constant to about ±10 m s^{-1} over almost a decade; after independent verification, these stars would be candidates for later adoption as "standards of relative radial velocity". Note that, due to uncertainties in the effects of gravitational redshifts and convective blueshifts in stars other than the Sun, the actual *center-of-mass* velocities of these stars will not be known to similarly high accuracy; however, for most or all known applications, this limitation should be of no practical consequence.

The Working Group is also considering the situation as regards secondary and early-type standards. Velocity standards for use with large telescopes and modern detectors may have to be as faint as V=13-15 in order to be easily observable. Such stars can be readily measured relative to the primary standards with existing instruments; stars in open clusters whose velocities agree with the cluster mean appear to offer the best prospects for selecting long-term constant-velocity stars from a relatively short series of observations. For the early-type stars, cross-correlation techniques are also being developed to greatly increase the observational accuracy. However, the difficulties of having to deal with spectra suffering from appreciable rotational broadening, and of establishing the long-term stability of prospective standards to the new, higher level of accuracy remain; with luck, the Commission may perhaps be able to celebrate the start of the next millennium by adopting a set of radial-velocity standards covering all major spectral types.

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