COMMISSION 30. RADIAL VELOCITIES (VITESSES RADIALES)

PRESIDENT: C.D. Scarfe
VICE-PRESIDENT: J.B. Hearnshaw
ORGANIZING COMMITTEE: W.D. Cochran, L.N. da Costa, A.P.Fairall, F.C. Fekel, K.C. Freeman, M. Mayor, B. Nordström, R.P. Stefanik, A. Tokovinin

1. RADIAL VELOCITIES OF GALAXIES, by A.P. Fairall in consultation with J. Huchra

A new generation of major redshift surveys, with numbers of redshifts that far surpass those of earlier investigations, is getting under way. These surveys make use of fibre optics, but differ from earlier systems in that often hundreds - not just tens - of galaxies can be observed simultaneously, by means of improved fibre management techniques. One of the most prominent is the Sloan Digital Survey (63.013.080) which aims to provide photometry and redshifts for a million galaxies, using a dedicated 2.5 m telescope that is soon to commence operations. The Two-degree Field instrument on the 3.9 m Anglo-Australian Telescope (63.031.120) will have up to 400 fibres per field - while one field is being exposed, a robot will work on positioning a further 400 fibres, ready for the next exposure. Similarly the DENIS (63.036.281) and 2MASS surveys, mapping in the near-infrared, will require very large numbers of follow-up redshifts. Also, in terms of new technology, the 8.5 m Hobby-Eberly Telescope, a dedicated spectroscopic telescope, is soon to see first light; its low-resolution spectrograph should be able to service galaxies down to $V = 23.5$.

In the meantime, an "intermediate" generation of surveys has produced impressive results. The Las Campanas Fibre-Optic Survey (63.161.239 & 254) has now measured some 26000 redshifts in six strips, each 1.5 by 80 degrees; its plots, to a depth of 50000 km s^{-1}, suggest a repetition of structures on scales of 10000 km s^{-1}. The ESO Slice Project (63.161.207) has obtained approximately 5000 redshifts so far in a parallel strip; its plots confirm the extension of some of the Las Campanas structures. The Century Survey and a new survey of galaxies selected from the digitised Palomar Sky Survey (both Harvard-Smithsonian) confirm an effective upper limit of void sizes of 5000 km s^{-1}. The QDOT group are gathering redshifts for all IRAS galaxies with $f_{60} > 0.6Jy$ - some 15000 galaxies. The FLAIR system (63.034.023) on the Anglo-Australian Schmidt Telescope has also produced thousands of redshifts over wide-field surveys. Similarly efforts to map structures partially hidden behind the Milky Way have produced thousands of new redshifts.The CFRS survey is probing faint galaxies to deep redshifts to examine evolutionary effects. The CNOC survey is looking at clusters.

However, with more than a hundred papers, concerning radial velocity measurements of galaxies, appearing each year, it is quite impossible to give representative coverage in this brief report, or even to make mention of numerous major investigations. The total number of measurements to date must now be far in excess of 100000. Sadly, fewer than half of these are published, or otherwise made public - a situation that has already existed for many years, and which could be exacerbated in the future. The eventual worth of the measurements depends upon their being accumulated in major databases. NED (Nasa Extragalactic Database) at Caltech, the Strasbourg Data Centre and LEDA (Lyon) are acting as such repositories, while the long running ZCAT (Huchra) and SRC (Southern redshifts - Fairall) continue.

2. THE MILKY WAY, by B.W. Carney

Radial velocities of CO-bearing and He I-emitting stars near Sgr A* by Krabbe et al. (1995, ApJ 447, L95) and Haller et al. (1996, ApJ 456, 194) confirm many previous determinations of the mass near the Galactic center, $\approx 2 - 3 \times 10^6\ M_\odot$. The complex motions in Sgr A West and

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 521–526.

their possible relations to Sgr A* have been studied by Yusef-Zadeh et al. (63.155.148), Liszt & Burton (63.155.093), and Roberts et al. (1996, ApJ 459, 627).

The kinematic signature of a central bar was studied by Weinberg (61.155.007), who noted that both the current structure and the history are being probed. The HI rotation curve in the bulge was analyzed by Burton & Liszt (58.155.005). The rotation and velocity dispersion obtained from stars within the bulge have been studied by many groups. Izumiura et al. (63.155.081) have obtained velocities for SiO masers associated with IRAS sources. Minniti's Ph.D. thesis (62.155.032) showed the metal-poor giants and clusters in the bulge to have nearly constant low net rotation and high velocity dispersion. Blum et al. (1995, ApJ 449, 623) studied kinematics of M giants with $R_{GC} < 300$ pc, and Blum (63.155.136) derived a mass estimate for the bulge of 2 x 10^{10} $M_{\odot}$. Ibata & Gilmore (1995, MNRAS 275, 605) studied over 1500 K and M giants in the bulge, noting that the angular momentum distributions of the bulge and halo are similar, and different from the disk populations.

At the other extreme of the Galaxy, the velocity field of the outer Galaxy was studied by Brand & Blitz (58.155.008) using velocities and distances to H II regions.

Radial velocities have been crucial to the study of stellar populations. Perhaps most dramatic was the discovery of the Sagittarius dwarf (Ibata et al. 62.157.123, 1995, MNRAS 277, 781), a galaxy apparently in a fatal embrace with the Galaxy. Evidence for a prior accretion of a Carina-like galaxy was presented by Preston et al. (62.155.005), based on blue, presumably young, metal-poor stars with kinematics intermediate between the halo and the disk.

Space motions of a larger sample of disk F dwarfs were studied by Marsakov & Shevelev (61.155.080, 63.155.195), and detailed chemical compositions were compared to ages and space motions by Edvardsson et al. (58.155.010). An old metal-rich population of M giants was studied kinematically by Sharples et al. (63.155.120), who found the stars belonged to mixed thin and thick disk populations. The lower metallicities of the disk population were probed by Rodgers & Roberts (58.155.111, 58.155.153), who found evidence for [Fe/H] values as low as -1.5 for stars with disk-like kinematics.

Layden's work on RR Lyraes (1995, AJ 110, 2288) revealed a sudden kinematic transition at [Fe/H] $\approx$ -1, separating the thick disk and halo populations.

Evidence that the metal-poor halo populations may actually include two distinct histories, including stars and clusters associated with the formation of the Galaxy as well as accreted later, has been presented by several groups. Da Costa & Armandroff (63.154.078) studied the kinematics of globular clusters (noting that 4 belong to the Sagittarius dwarf). Norris (62.155.061) modelled the space motions and velocity dispersions of stars selected from proper motion catalogs, while Kinman et al. (62.155.017) and Beers & Sommer-Larsen (63.155.050) used kinematically unbiased samples of blue horizontal branch stars and spectroscopically-selected metal-poor stars, respectively. Evidence for possible "streams" associated with particular merger events was presented by Kinman et al. (1996, AJ 111, 1164).

3. STAR CLUSTERS, by J.-C. Mermilliod

3.1. Open clusters. Numerous radial-velocity observations of red giants in intermediate-age and old open clusters were obtained (1) to study the kinematics of the system of old clusters by Friel and coworkers (59.153.041; 1995, AJ 109, 1706), (2) to determine cluster membership and detect spectroscopic binaries in several clusters, by Minniti (1995, A&AS 113, 299), Glushkova et al. (58.153.056), Milone (62.153.020) and Mermilliod et al. (62.153.018; 1995, A&A 299, 53; 1996, A&A 307, 80).

Radial velocities of dwarf stars were obtained to determine the membership of faint main sequence stars by Prosser & Giampapa (62.153.008) and Daniel et al. (61.153.028), of candidate brown dwarfs in Hyades and Pleiades by Stauffer et al. (62.153.003; 63.153.031) and of pre-main sequence stars in the Lupus and Chamaeleon regions (Dubath et al. 1996, A&A 308, 107).

Several papers reported also radial-velocity observations of cepheids in the field and open clusters. Additional bibliographic references can be obtained from the database for stars in open clusters (BDA) on the World Wide Web at http://obswww.unige.ch/bda/, with a keyword like "radial_velocity". Published radial velocities are stored in BDA and can be obtained from Jean-Claude.Mermilliod@obs.unige.ch.

3.2. Globular clusters. The largest effort has been made by Côté et al. (61.154.010) who got 1859 radial velocities for 1316 stars in NGC 3201. The mean cluster RV is 494.2 km s^{-1}. The incidence of binaries seems consistent with their frequency among field stars of periods in the range $0.1 < P < 5 - 10$ yr. Another systematic study of this triennium has been published by Peterson et al. (63.154.045). They studied nearly 200 stars in the globular cluster M4 and determined a mean velocity of 70.9 $\pm$ 0.6 km s^{-1}, with a velocity dispersion at the core of 3.5 $\pm$ 0.3 km s^{-1}.

Minniti (1995, A&AS 113, 299) obtained radial velocity for about 340 red giants in 25 globular clusters, a part of a larger spectroscopic study. Shetrone (61.154.036) studied 23 giants in M13 and found an increasing number of stars presenting radial-velocity variations among those approaching the red giant tip, which is attributed to the effect of increasing mass outflow.

4. INTRINSIC VARIABLE STARS, by N.N. Samus in collaboration with A. Rastorgouev

Most work on radial velocities of intrinsic variables was devoted to Cepheids. Two large lists of new Cepheid velocities were published (Bersier et al. 62.122.095: 1203 observations of 40 Cepheids; Gorynya et al. 1996, Ast. Lett. 22, 175: 2140 observations of 86 Cepheids). Pont et al. (61.111.101) presented from 4 to 7 observations for each of 96 faint Cepheids. A number of papers deal with spectroscopic binarity of Cepheids derived from new radial velocities. Thus, Gorynya et al. (1996, Ast. Lett. 22, 33) present mean velocities for 68 stars and orbital elements (in some cases, incomplete) for 19 stars; they estimate the lower limit on the incidence of spectroscopic binaries among Cepheids to be 22%. Imbert (1996, A&AS 116, 497) determined orbits for 4 binary Cepheids.

Butler (58.122.131) analysed for 4 Cepheids, in detail, differences of velocity curves from lines of different excitation and ionization. Sabbey et al. (63.122.101) studied the effect of line asymmetry on Cepheid radial velocity. They found the p-factor to vary with phase; the system velocity may be offset by 1 km s^{-1}. This introduces bias into distance determination. Among Baade - Wesselink studies for Cepheids, the paper by Laney & Stobie (63.122.074) deserves being mentioned; it contains results for 49 stars.

Radial velocity studies of pulsating variables belonging to other types were not numerous, but rather important. Skillen et al. (58.122.119) applied the Baade - Wesselink technique to their IR photometry and radial velocities for 4 RR Lyraes and derived a relation between the absolute magnitude and the abundance of iron. Layden (62.122.009) used radial velocities of 303 RR Lyrae stars for a study of kinematics. Fernley (61.122.059) argued that the zero point from the recent Baade - Wesselink analyses of RR Lyrae stars is 0.07 mags too faint due to an inappropriate value of the p-factor having been used. Radial velocity data were used to derive physical parameters for δ Scuti and SX Phoenicis stars (Wilson et al., 58.122.029; Kim et al., 58.122.071; Milone et al., 62.122.032; Udovichenko, 61.122.071). Aerts et al. (61.122.051) and Mathias et al. (62.122.038) carried out frequency analyses of their photometric and radial velocity measurements of β Cep itself and of the β Cephei star 12 Lac. The Van Hoof effect was studied for β Cephei stars by Mathias & Gillet (58.122.041), and for RR Lyr, by Mathias et al. (63.122.098). Fernie & Lawson (58.122.141) analyzed photometry and radial velocities of R CrB and found evidence for the 43-day periodicity only for some years. Periodicities in the radial velocities of the R CrB variable RY Sgr were studied by Clayton et al. (62.122.059). Lobel et al. (62.122.058), from Baade-Wesselink analysis, concluded that the hypergiant ρ Cas was pulsating nonradially. An extremely accurate search for velocity variations in the rapidly oscillating Ap star α Cir (Hatzes & Kuerster 61.122.067) gave negative results.

Lawson et al. (58.122.120) revealed variations of radial velocities for 5 extreme helium stars. Rzaev (61.112.071), from his analysis of radial velocity changes observed for the early-type supergiant HD 21291 in 1976 - 1988, concluded that the star showed complex pulsations.

Evidence for low-amplitude short-period pulsations was found in the radial velocities of several late-type giants, some of which are in the lists of velocity standards (Hatzes & Cochran 58.116.058, 61.116.025, 62.116.035, Horner 1996, ApJ 460, 449). Lehmann et al. (1995, A&A 300, 783) searched for velocity variations, attributable to pulsations, for a number of suspected Maia variables, but with success only in two cases (γ UMi and γ CrB).

5. SPECTROSCOPIC BINARIES, by S. Udry and M. Mayor

The period covered by this report will remain a very special one in the domain of the search for very low amplitude SB's, with an extraordinary explosion of interest after the discovery of the first extrasolar gaseous giant planet around the solar type star 51 Peg by Mayor & Queloz (1995, Nature 378, 355). This discovery acted as a tremendous stimulant and in the following months several planetary companions with masses lower than 10 Jupiter masses were detected by radial velocity techniques: 70 Vir (Marcy & Butler, 1996, ApJ 464, L147), 47 UMa (Butler & Marcy, 1996, ApJ 464, L153), plus additional ones unpublished at the end of the period covered by this report. These new perspectives have been made possible by the always continuing improvements in the techniques for the measurement of high-precision velocities (section 6 below). Reaching a long-term precision better than 20 m s^{-1} is now a common performance and researchers are looking toward the 1 m s^{-1} limit. The unexpected orbital elements of most of these Jovian planets, especially the small separation between the planets and the main stars, questioned our "simplistic" views on planet formation and boosted new research in domains largely extending beyond the SB area.

In the somewhat larger mass domain of the brown dwarfs, a few new candidates with $M_2 \sin i$ between 10 and 40 M_J have also been announced: HD 140913 (Stefanik et al., 61.118.035), HD 29587 (Mazeh et al. 1996, ApJ 466, 415) and additional objects unpublished at the end of the period of this report. The growing set of brown dwarf candidates removes in a statistical way the mass indeterminacy coming from the inclination of the orbital planes, probing the existence of brown dwarfs, and allows a first glance at the low mass distribution function (Marcy & Butler, 63.012.089, 63.115.025).

Combination of spectroscopic and astrometric data provides unambiguous star masses. Illustrative results are given by speckle interferometric techniques (Scarfe et al. 61.118.007, Tokovinin, 61.118.022, 61.118.023). The long-base interferometry program Mark III at Mt. Wilson has also produced valuable results (58.120.017, 61.012.001, 61.120.010, 62.120.029).

New hierarchical multiple systems are regularly observed, e.g. Fekel et al. (62.120.002), Smekhov (61.118.024) and Tokovinin (62.118.002; 1995, Ast. Lett. 21, 250). A Multiple Star Catalog is in preparation by Tokovinin.

Systematic surveys for duplicity in different populations and environments remain fundamental in order to obtain unbiased distributions of orbital elements, tracers of the binary star formation and also providing constraints on star evolution theories. Waiting for the interpretation of still ongoing large surveys, SBs continue to be accumulated among various stellar populations: pre-main sequence stars (a complete review is given by Mathieu, 62.121.108), Herbig stars (Corporon et al., 61.120.006), upper main sequence stars (Stickland et al., 58.120.001, 58.120.004, 61.120.013, 61.120.020, 62.120.004; Gies et al., 61.120.012), white dwarfs (Jomaron et al., 58.120.012), post-AGB stars (van Winkel et al., 63.120.005), Cepheids (Szabados, 61.122.181; Gorynya et al., 63.120.003) and K-dwarfs (Tokovinin et al., 61.120.008).

Some samples already allow interpretational works as for example: a statistical reinvestigation of binaries among chemically peculiar stars (Seggewiss, 62.120.016), the determination of the mass ratio distribution for cepheid stars (Evans, 63.120.017) or the study of tidal circularization in binaries containing giant stars (Verbunt & Phinney, 63.117.199). In order to take advantage of the growing available information, new numerical investigational methods have been developed such as TODCOR, a two-dimensional correlation algorithm for SB2s (Mazeh et al., 58.036.373, 61.120.007) or the non-parametric statistical model for the inversion of the observed SB1 mass function distribution (Heacox, 63.120.023).

In cluster environments, the acknowledged influence of binaries is documented in the Calgary SPCS meeting on *the origins, evolution and destinies of binary stars in clusters.* Binary frequencies in particular open (Latham et al., Mermilliod) and globular clusters (Barden et al., Mayor et al.) are presented. In this context, we can also mention the search for binaries in the NGC 3201 globular cluster (Côté et al., 61.154.010) and the mass ratio study in the Pleiades (Goldberg & Mazeh, 61.153.010).

Finally, we would emphasize the ongoing effort of R.F. Griffin in his production of binary orbits (almost every issue of The Observatory) for all kind of stars (composite spectra, eclipsing binaries, long P, etc.).

6. PRECISE STELLAR RADIAL VELOCITIES, by J.B. Hearnshaw

Interest in the precise determination of stellar radial velocities (taken here to signify those with random errors of less than 100 m s^{-1}) has increased rapidly in the last few years. Several groups have demonstrated a capability of measuring differential velocities (i.e. with an arbitrary zero-point) at the level of about ten to a few tens of m s^{-1} (Cochran & Hatzes 61.111.008; Horner & Brown 58.036.356; Marcy & Butler 63.115.025; Mayor & Queloz 1995, la Lettre de l'OHP 14, 1; McMillan et al. 61.111.008; Murdoch & Hearnshaw 58.118.025; Walker et al. 1995, Icarus 116, 359) or even better (e.g. Butler et al. 1996 PASP 108, 500).

The primary goal of these groups has been the detection of substellar mass companions (brown dwarfs or planets) in orbit around solar-type stars. The recent successes (section 5) have justified the effort and interest in the precise velocity technique. In the case of 51 Peg, the challenge is now to explain the formation of a half-Jupiter-mass planet in a 4.2-d orbit only 0.05 AU from a solar-type dwarf star, even though Boss (1995, Science 267, 360) had (prophetically!) predicted shortly beforehand that the first extrasolar planet to be discovered would probably be of about a Jovian mass but in an orbit of less than 1 AU. The other two well-established planets around solar-type stars have orbits of 0.43 AU (70 Vir) and 2.1 AU (47 UMa), which are less dissimilar to typical solar system values. Other possible planets have been reported, including one by Noyes et al. (1996, IAUC 6316) for HR 152. In spite of these successes in planetary detection, the message from the results of all of these surveys is that both lower mass brown dwarfs and Jovian-mass planets are relatively rare in orbit around solar-type stars (Marcy & Butler 63.115.025); at most only a few per cent of solar-type stars have such companions within 5 AU.

The other major application of precise radial velocities has been the study of low-amplitude velocity variations in various F to M stars (mainly giants or supergiants) due to pulsation or to rotational modulation from a spotted surface. Hatzes & Cochran have studied long-period variations in three K giants (58.116.058) and short-period pulsations in Arcturus (61.116.025), Butler has investigated differential effects with excitation and ionization in Cepheids (58.122.131), Larson et al. have studied the long-period variation in Pollux (58.116.021), Bedford et al. have searched for acoustic p-mode non-radial oscillations in Procyon (58.118.027) and Cummings et al. have studied velocity variations in L2 Puppis and other K and M giants (1995, S. Stars 36, 201). A wide variety of time-scales is found for different stars, and the discussion has centred mainly on whether the variability can be explained by radial pulsations, non-radial pulsations, rotational modulation or an unseen orbiting companion.

The techniques employed to obtain differential precise velocities have been refined considerably. Three groups are using iodine cells to provide a stable velocity reference, one is using a hydrogen fluoride cell, two are cross-correlating fibre-fed echelle spectra, one is using a Fabry-Perot interferometer with order separation from an echelle spectrometer, while one is using a double magneto-optical filter to measure the shoulders of the 7699 Å potassium line. In addition Connes (61.036.272) has proposed using a tunable laser to calibrate a Fabry-Perot etalon in a technique described as absolute astronomical accelerometry. The precision corresponding to the photon-noise limit (which is about 1.2 m s^{-1} for a S/N ratio of 200 for a late-type star at resolving power 60000) can now be approached within a factor of two or three, as shown by

Butler et al. (1996, PASP 108, 500). Such high precisions may allow lower mass planetary companions to be detected in the future.

7. IAU STANDARD STARS, by R.P. Stefanik

For many years several observatories have been monitoring the radial velocity of a large number of stars in order to establish a list of standard radial velocity stars which do not vary more than 100 m s^{-1}. These stars include the original IAU standard radial velocity stars as well as additional early and late type candidates. Lists of these candidate stars are given in the 1991 Commission 30 Report (Trans. IAU XXIB, 269). Stars whose velocities were known to vary by more than 1.0 km s^{-1} at that time were removed from these lists. Additional comments about the candidates can be found in the 1994 Commission 30 Report. Below is an update on the status of the candidates.

Early spectral-type stars: Fekel continues to monitor the velocities of the candidates for early type standards at KPNO. He reports that the following stars are variable or probably variable and should be removed from the candidate list: HD 145570, HD 147394, HD 179761 and HD 196426. He also recommends that HD 48843 and HD 184171 be added to the list.

Late spectral-type stars: The velocities of the late spectral type stars continue to be monitored at a number of observatories. The following stars should now be removed as constant velocity stars: HD 29587, HD 42397, HD 140913 and HD 171232. HD 29587 and HD 140913 have orbital solutions with semiamplitudes of $K = 1.02$ and 1.93 km s^{-1}, respectively (Mazeh et al., 1996, ApJ 466, 415). HD 42397, discovered to be a double-line spectroscopic binary by Scarfe in the last triennium, has continued to vary slowly, according to CfA observations. The combined CfA and DAO observations of HD 171232 show a 4 km s^{-1} velocity decrease during the past 14 years.

A number of the candidate stars are suspected to be very low-amplitude variables, and two stars now have orbital solutions indicating low mass companions: HD 114762 ($K = 0.59$ km s^{-1}) (Mazeh et al., 1996, ApJ 466, 415, Hale 63.117.227) and HD 217014 (51 Peg - see section 5).

The color-dependence in the comparison of velocities from several observatories continues to be an unresolved problem. The combined mean data from CfA and DAO do not show any color dependence or a difference in zero-point between the bright and faint groups of standards. However, the differences between CfA+DAO and the mean velocities from CORAVEL are correlated with the color indices of the stars, becoming increasingly negative for redder stars. Toward resolving this problem the standard stars are being reobserved by the Geneva team using ELODIE for comparison with the CORAVEL results.

An up-to-date list of the candidate constant velocity stars with the combined CfA and DAO results can be obtained by e-mail from stefanik@cfa.harvard.edu.

As is apparent, each section of this report has been prepared by one or two members of the commission who are active in the areas discussed. The material has been edited, to minimize overlap and to conform to the IAU's guidelines, by the president, who wishes to express his gratitude to all the contributors.