**Clyde W. Tombaugh Observatory**
**University of Kansas**
*Lawrence, Kansas 66045-2151*

## I. PERSONNEL

This report covers the period from August 1986 to August 1987. Within the Department of Physics and Astronomy, those currently involved in astronomical research are Dr. J.P. Davidson (IUE Data Analysis), Dr. Adrian Melott (Cosmology and Theoretical Astrophysics), Drs. David Beard and Thomas P. Armstrong (Solar System Studies), Drs. Barbara J. Anthony-Twarog, Stephen J. Shawl, Bruce A. Twarog and adjunct colleague Dr. Scott Baird of Benedictine College (Stellar and Galactic Studies). Dr. David Beard retired from the University of Kansas in May of 1987.

## II. INSTRUMENTATION AND DATA ANALYSIS

Installation of the Mid-American Astronomical Image Processing Laboratory (MAIPL) is complete, with hardware consisting of an International Imaging Systems Model 75 image processor display with three independent picture memory channels. Programs to reduce two-dimensional photometric data and one-dimensional spectra are available for general use and include DAOPHOT for stellar CCD photometry, R2D2 for image operations, and RETICENT for spectrum analysis. Programs to extract spectra from two-dimensional arrays are being installed. In addition, the plotting package MONGO is now available on the Department of Physics and Astronomy VAX 11/750 with laser graphics output. Interested users are urged to inquire. A Microvax II (KUSMOS) has been purchased and is dedicated to numerical cosmology. With a 17 Megabyte memory, it will be a powerful new tool for large-scale computing.

## III. RESEARCH

*a. Stellar and Galactic Studies*

Supernova 1987a provided a unique opportunity for astronomy, astrophysics and particle physics. At the University of Kansas, Melott, Munczek, and Ralston considered whether the recorded neutrino events at the IMB and Kamiokande detectors could be used to constrain the mass of the electron neutrino, using the dispersion in arrival times of the neutrinos. The most important neutrinos were six events arriving within two seconds, with a typical energy of 7 MeV. The two-second spread in arrival time, after about 150,000 years of flight from the supernova, led to an upper limit on the neutrino mass $m_\nu \lesssim 9.5$eV. A paper presenting the detailed arguments and the limit was submitted to Physical Review D. Ralston presented a talk on this work at the Mid-America Regional Astrophysics Conference held in Kansas City in April.

Shawl, and Don Bord (University of Michigan at Dearborn), as a part of their search for companions to long period variables, have continued obtaining current-epoch periods and times of maximum (minimum) through additional analysis of plate material from the Harvard Damon Southern Survey. At the time of this writing, no new results are available. This work has received partial support from the University of Kansas General Research Fund.

Shawl and Jim Hesser (DAO), having completed and published all necessary work preliminary to the full analysis of their extensive Fabry-Perot spectra of the integrated light from the galactic globular clusters, are currently engaged in those reductions.

Work by Davidson using the VIRIS-VAX IUE data analysis system with the adapted programs for Wavelength Coincidence Statistics (WCS) method of ion identification has investigated the IUE long wavelength image (1900 Å– 3200 Å) of the magnetic star HD 215441. Results have been compared with the work of Adelman. An analysis based on the known magnetic null lines in this wavelength range for this star is currently in progress.

Melott has proposed that the large observed flux of $H_\alpha$ from HI clouds in and near our Galaxy is due to decay of massive neutrinos (perhaps tau neutrinos) which produce photons $\lambda < 912$ Å which would not be directly observable on Earth. Ralston, McKay, and Melott have proposed a model which provides this decay and also explains the deficit of neutrinos from the sun by interaction with magnetic fields.

Baird, with Horace Smith (Michigan State University), is carrying out a study of the stellar population in the Small Magellanic Cloud in the region of transition from the inner halo to the northeast arm. The short-period variables in this region of the SMC are receiving particular attention. Baird has obtained CCD frames across this region at Cerro Tololo and is processing them at the Univ. of Kansas MAIPL facility. Preliminary results presented at the June AAS/CAS meeting (with Smith and J. A. Graham) indicated a younger population in the northeast arm.

Baird has continued work on RV Tauri variable stars. *UBVRI* light curves of 40 southern RV Tauri stars, obtained with Dennis Dawson (Central Michigan University) are nearing completion, and work on model atmospheres has begun. With Phillip Flower (Clemson University), Baird has identified a number of superluminous giants in the LMC cluster NGC 1866; these results have now been published.

The program of photographic photometry in open clusters involving Twarog, Anthony-Twarog and Caldwell (Whipple Observatory) is continuing. Results of studies in the cluster IC 4651 indicate an age of $\sim 2.4 \times 10^9$ years for this metal-rich cluster, and a very sparsely populated lower main sequence; these results, which include some CCD *BV* photometry as well, are in press. Studies in NGC 6259, NGC 2354 and NGC 3680 are essentially complete, and are in preparation for publication. NGC 3680 has proved to be particularly interesting since the presence of a bifurcated upper main suggested in the *uvby* study of Nissen (1987) has been confirmed in our high precision photographic photometry, completed with the collaboration of undergraduate student Erich A. Heim. Measurements in the open cluster NGC 2360 are in progress, with much of the work being completed by undergraduate Ray Murray.

As a candidate for her masters degree in Computational Astronomy under direction of Anthony-Twarog and Twarog, Tamara Whitacre has begun observations and analysis of photometry in the field of NGC 3293, with 6 nights on the CTIO 0.9m CCD camera in March 1987. This young cluster, associated with the Carina nebula complex, is intriguing for the large spread in age between the nuclear age attributed to the main sequence turnoff, $\sim 6 \times 10^6$ years, and the apparent age implied by the lower main sequence turn-on sequence of contracting stars, at least $25 \times 10^6$ years. Whitacre has obtained *UBVRI* frames to a depth approximately that of the lower main sequence turn-on point in eight fields within 10′ of the cluster center. The cluster has large and patchy reddening; comparison of *UBV* and $R-I$ color indices will assist in sorting out the effects of reddening and cluster membership.

Results of a main sequence *uvby* photometric study by Anthony-Twarog in the globular cluster NGC 6397 indicated the possible presence of a small sample of main sequence binaries, thanks to a main sequence color-magnitude diagram considerably cleaned of non-members by the additional information provided by $m_1$ indices. Anthony-Twarog and Suntzeff (C.T.I.O.) have proposed to directly test the binary nature of the candidate stars with radial velocity measurements at

CTIO in 1988, while Anthony-Twarog and Twarog will seek more photometric candidates through additional *vby* photometry in selected fields in the cluster.

Based on the initial sucesses of applications of CCD's as detectors to the *uvby* photometric system, Anthony-Twarog has proposed to remedy the lack of faint standards by beginning work to set up and calibrate fields for use as CCD standards. Observations have begun at Cerro Tololo using the 0.9m CFCCD camera with TI chip, using the equatorial standards of Olsen (1983) as principal standards for a number of candidate fields within 20 degrees of the celestial equator. Candidate fields have been sought with uncrowded stars between $V = 8$ and 14, with a sizeable range in $b - y$ color and/or luminosity or metallicity indices. Field suggestions are always welcome!

Masters candidate Krishna Mukherjee is studying the main sequence morphology of $\omega$ Centauri for her thesis research under Anthony-Twarog. They are analyzing deep *uvby* CCD frames, about 8 in each color, obtained with the Cerro Tololo 4m PFCCD in 1986 and 1987. The goal is to constrain the primordial spread in the main sequence metal abundance by examination of the dispersion in $m_1$ and $b - y$ among stars near the turnoff. Preliminary results show a dispersion in $m_1$ consistent with the $\Delta b - y$ width of 0.08, which can be attributed to a spread of about 1 dex in [Fe/H]; preliminary examination of the distance-independent H-R diagram, the $c_1, b - y$ diagram, suggests that a spread in age is not a major factor in the cm diagram morphology. Continued analysis will focus on improving the mean errors of the photometric indices resulting from combination of a large number of frames. The CCD *uvby* and *BV* photographic studies have been completed with the support of the National Science Foundation through grant AST 8420209, and this support is gratefully acknowledged.

One logical extension of the seccessful application of CCD's as detectors for *uvby* photometry is to attempt the same extension of the H$\beta$ system. Observations at Cerro Tololo with the 4m PFCCD camera and with the University of Nebraska Behlen Observatory's 0.75m CCD camera system have been analyzed by Anthony-Twarog, Twarog and Undergraduate Research Awardee Michael Luhman. Although slight offsets between successive frames persist, the most encouraging results are from the Nebraska observations in July 1987, particularly in a field of M25 where $\beta$ indices with internal precisions of $\sim 0.017$ were obtained from 3 frames in each filter. The transformation equation appears to have a unit slope. We plan to continue further observations, with the collaboration of E. G. Schmidt (Univ. Nebraska), and express our gratitude for telescope time and assistance.

Twarog and Anthony-Twarog are continuing their collaboration with John Laird (Bowling Green State University) to develop and calibrate a new metallicity index for the Strömgren photometric system using a 90 Å filter centered on the Calcium II H and K lines, intended particularly for cooler and metal–poor stars. The initial phase of observing southern G and K dwarfs brighter than $V = 6.5$ is expected to require an additional year of observations at Cerro Tololo, while observations of a wider range of metallicity objects have also begun. Preliminary results indicate that, as expected, the Ca index loses sensitivity with decreasing temperature for metal-rich stars, due to the saturation of the Calcium lines. We have found the luminosity dependence of the index to be minimal except for supergiant classes. Most significantly, the new index retains its metallicity sensitivity, numerically about twice that of the $m_1$ index, to values of [Fe/H] as low as $-4.5$, based on recent observations.

Twarog and undergraduate Joe Shields (currently at Univ. California–Berkeley) completed their theoretical modelling of the A star distribution away from the Galactic plane. A quantitative estimate of the contribution of blue stragglers was made, with particular attention to the spatial distribution of early-type stragglers at large distance from the Galactic plane. Blue stragglers were assumed to be created in the disk at a rate consistent with the empirical data from open clusters while nine plausible combinations of star formation and scale height histories were modelled. It was concluded that normal evolution without the inclusion of blue stragglers was incapable of producing early-type stars at large distances from the plane, while the addition of blue stragglers adequately fills the rather weak observational constraints. In addition, it is shown that if blue stragglers are produced at a rate implied by the models, roughly 30% of the A stars in the solar neighborhood could be blue stragglers. Differences in scale height and star formation histories among the models produce significant differences in the scale height as a function of temperature and the percentage of A stars at large distance from the plane at a level which is observationally detectable using currently available techniques. The results are in press in the Astrophysical Journal.

Twarog has completed a survey on the *uvby* system of over 300 A,F, and early G stars away from the Galactic plane in the direction of the South Galactic Pole in an effort to understand the halo-disk transition and the scale height history of the old disk. The metallicity distribution demonstrates that a significant population of stars is present within 1500 pc of the plane down to [Fe/H] = -1.2. Taking into account the uncertainty in the metallicity calibration and photometric scatter, our data indicates that the boundary between the halo and the disk lies at [Fe/H] $= -1.1 \pm 0.2$. It has been suggested on occasion that the boundary could lie as high as -0.6 because of the paucity of stars in the -1.0 to -0.6 range near the sun. However, our data show that while there is a dramatic decline in the number of metal-poor stars below -0.5, this population does exist, but is spread more uniformly away from the plane than the metal-rich stars, i.e., it appears to have a significantly higher scale height. Whether one calls this sample old disk, thick disk, or young halo seems irrelevant. The role of this transition population is consistent with the result that age estimates through comparisons with isochrones almost always produce ages of 14 $\times 10^9$ years or more for these stars. At the other end of the age scale, we conclude that the scale height of the young disk must be less than 150 pc for stars with ages less than 2.5 $\times 10^9$ years.

Twarog, undergraduate Scott Daniels, R. Mathieu (Univ. of Wisconsin), and D. Latham (CFA) are continuing their photometric and radial velocity survey of the old open cluster, NGC 752. The radial velocity data to date have identified a number of probable binaries and eliminated a few nonmembers from the proper motion survey of Cannon. This has led to a decreased scatter in the color-magnitude diagram of the lower main sequence, a scatter which should be reduced even more through the collection of CCD photometry planned for Fall 1987 at Behlen Observatory in Nebraska.

### *c. Cosmology and Theoretical Astrophysics*

Melott and graduate student Cohen are analyzing the new galaxy survey data of De Lapparent, Geller and Huchra (CFA) to see whether this "Slice of the Universe" supports the idea that voids are "bubbles" surrounded by shells of superclusters.

Melott and graduate student Jiang, in collaboration with P.J.E. Peebles (Princeton Univ.) are using the Microvax KUSMOS to test the idea that the Local Group of galaxies began as small "seed" masses, growing by accretion and falling toward each other.

Melott has studied numerical models to "estimate" their mass density (which is a known input parameter) in the same way observers have used the infall of our Local Group toward the Virgo cluster to estimate the mass density of the Universe. He found that methods in general use tend to systematically underestimate the mass density.

Melott, in collaboration with J. Einasto, M. Gramman, M. Einasto, E. Saar, and V. Saar, of Tartu Astrophysical Observatory, Estonia, USSR, has used percolation techniques to study the shapes of superclusters. They find that: *(1)* the

actual superclusters in the Universe occupy a small fraction of the volume, most of it being empty, and *(2)* this behavior is best duplicated in "biased" galaxy formation theories, in which galaxies only form at high peaks of mass density.

Melott has studied the size of voids and the large–scale velocity flows in a comparison between different theories. He has found that models characterized by hot dark matter (e.g. massive neutrinos) produce much larger voids and velocities than other theoretical models, but even these have difficulty in reproducing bulk flows recently observed. Melott, in collaboration with R. Matzner (University of Texas, Austin) has proposed that such apparent flows could be reproduced in a Universe in which there was an early velocity field, and that the microwave background rest frame is no longer the same as the matter rest frame.

Melott, in collaboration with D. Batuski (Space Telescope Science Institute) and J. O. Burns (Univ. of New Mexico) has been studying the autocorrelation of Abell clusters in comparison with that of clusters in simulations. They find no theoretical model that is successful in reproducing the statistics.

Melott, in collaboration with R. Scherrer (Harvard University) have been studying the formation of structure with cosmic strings. They find that previous estimates of autocorrelations based on rare large strings loops were not a true reflection of the behavior of total mass. This work is continuing, with a planned extension to include a Universe with cosmic strings and hot dark matter, a currently popular idea; the collaboration has added E. Bertschinger of M. I. T. and D. N. Schramm of the University of Chicago.

Melott, in collaboration with J. R. Gott and D. Weinberg (Princeton University) and S. Bhavsar (University of Kentucky) are engaged in a long–term project to study theory and data on the topology of the large–scale structure of the Universe. They have shown that models which begin with a Gaussian spectrum of fluctuations, as is expected from inflation, have a "spongelike" topology with interconnected superclusters and voids. They have developed statistical measures of topology which can be used to distinguish Gaussian fluctuations from other models such as cosmic explosions or strings. The changes in this topology with dynamical evolution were studied. For example, hot dark matter models evolve from a "spongelike" topology toward a "bubbly" one, which has isolated voids. The group is now concentrating on analysis of a number of magnitude–limited galaxy redshift surveys.

In collaboration with J. N. Fry (University of Florida), M. Haynes (Cornell Univ.), and R. Giovanelli (Arecibo Observatory), Melott has begun a study of hierarchial clustering theories and high–order correlations in large–scale structure. The results seem to indicate strong dynamical evolution in the real Universe, and good agreement with hierarchial clustering, not with "pancake" or "biasing" theories.

Melott has begun a project with J. P. Ostriker (Princeton Univ.) and Staszek Bajtlik (Warsaw Univ., Poland) to study the interaction of multiple explosions. A major goal here is to calculate the scattering of microwave background photons off hot gas, to find out what level of fluctuations would be expected.

Melott with D. G. York (Univ. Chicago) and A. P. S. Crotts (McDonald Observatory) are examining the clustering of absorbers in QSO spectra. By examining the clustering of these objects, they hope to learn about the formation of structure and have an indirect test of the mass density of the Universe.

## IV. TEACHING AND PUBLIC SERVICE

Melott acted as a consultant to Adler Planetarium for the design of a mural on the large–scale structure of the Universe, and gave a talk at its unveiling in Chicago. He has also acted as a consultant to Australian television and West German public radio on stories concerning the spongelike structure of the Universe, and as a consultant to the magazine *The World and I* for an article on large–scale structure.

Melott has given talks to gifted junior–high students from Lawrence about careers in physics and astronomy and about current research in cosmology, and to the Johnson County Unitarian Fellowship. Articles on the topology research have appeared in a number of publications, including the November 9, 1986 issue of the *New York Times*, *Sky and Telescope*, December 1986, and *Chronicles of Higher Education*, January 14, 1987.

The Midwest Astronomy Camp was held at the University of Kansas for the eleventh year, drawing 19 students from Kansas and nine other states to study astronomy and observe at the Clyde W. Tombaugh Observatory. The program was administered under the direction of Davidson, with the assistance of graduate students Whitacre and Mukherjee.

## V. MISCELLANEOUS

Bachelor of Science degrees in Astronomy were granted to Scott Randle, Roger Herndon, and to Erich Heim who also received the N. Wyman Storer award for service to the Astronomy Program at the University of Kansas. A Master of Science in Computational Physics and Astronomy degree was awarded to Jerry Manweiler, who has accepted employment at Boeing Aircraft Corporation.

Undergraduate Michael Luhman received an Undergraduate Research Award to pursue analysis of H$\beta$–CCD photometry in the summer of 1987. As a major in physics and astronomy, Luhman is also the 1987 Stranathan scholar.

Shawl was appointed a member of the AAS Education Advisory Committee, and has continued as a Shapley lecturer having visited DePauw University in Greencastle, Indiana.

The University of Kansas and several other universities in our region are preparing to host the 1988 summer meeting of the American Astronomical Society in Kansas City, to be held at the Hyatt Regency Crown Center Hotel, June 5–9, 1988.

University of Kansas astronomers and physicists Ralston, Melott, Baird, Twarog, Shawl and Anthony-Twarog attended the 17th meeting of the Mid-America Regional Astrophysics Conference in Kansas City, Missouri accompanied by students Heim, Mukherjee, Shodhan, Whitacre and Payne. Melott was the invited speaker, discussing "Topology of the Large Scale Structure of the Universe."

Davidson attended the annual meeting of the Kansas Academy of Sciences at Wichita State University and presented a paper with R. Desko (now of Digital Equipment Corportation) entitled "The Ultraviolet Spectrum of the $A_{pm}$ Star HD 215541."

Melott presented colloquia at Harvard University and the Universities of New Mexico and Florida. He gave a talk at the *XIIIth* Annual Texas Symposium on Relativistic Astrophysics Conference (Chicago) and the Spring meeting of the American Physical Society (Washington, D. C. ). He will present lectures on the subject of dark matter at the 2nd Erice School in May 1988. Melott has received a Dudley Observatory Award, of $8,000 for "Topology of the Universe" (August 1987).

Richard N. Boyd (Ohio State University) visited the University of Kansas for an extended stay in October of 1987. He is an experimentalist interested in the astrophysics of dark matter as well as the effect of the presence of quark nuclei on stellar evolution. His visit was funded by a University of Kansas Short-Term Visiting Professor grant, to Anthony-Twarog, Melott and Ralston of the Department of Physics and Astronomy.

S. F. Shandarin of the Institute of Physical Problems (Moscow) will visit during the spring of 1988. He is an expert on cosmology, especially large–scale structure. He will be the Guest of Honor at a Workshop on the Topology of the Large-Scale Structure of the Universe, to be held at K.U. April 27-29, 1988.

## VI. PUBLICATIONS

Anthony-Twarog, B. J. 1987, "CCD *uvby* Photometry in M67", *A. J.*, **93**, 647.

Anthony-Twarog, B. J. 1987, "An Application of CCD *uvby* Photometry to the Globular Cluster NGC 6397", *A. J.*, **93**, 1454.

Anthony-Twarog, B. J. and Twarog, B. A. 1987, "*uvby*H$\beta$ Photoelectric and CCD Photometry of IC 4651", *A. J.*, in press for November 1987.

Anthony-Twarog, B. J., Mukherjee, K., Caldwell, C. N., and Twarog, B. A. 1987, "*BV* Photographic and CCD Photometry of IC 4651", submitted to *A. J.*.

Baird, Scott R. and Flower, Phillip J. 1987, "Superluminous Giant Candidates in NGC 1866", *A. J.*, **93**, 851.

Batuski, D., Melott, A. L. and Burns, J. 1987, "Comparisons of Large-Scale Structure Models with Gaussian Initial Conditions Against the Distribution of Abell Clusters", *Ap. J.*, in press.

Batuski, D., Melott, A. L., and Burns, J. 1987, "Simulations of Large-Scale Structure Compared to Abell Cluster Distribution", in *Observational Cosmology*, proceedings of IAU Symposium 124, A. Hewitt, G. Burbidge, and L.Z. Fang, eds. (Dordrecht:Reidel).

Bord, D. and Shawl, S. J. 1987 "Current Epochs for Faint Southern Long–Period Variable Stars" *Astron. J.*, **93**, 898.

Bord, D. and Shawl, S. J. 1987, "Period Determinations for Southern Hemisphere Red Variables", *A. J.*, **93**, 898.

Centrella, J. and Melott, A. L. 1986, "Three-Dimensional Simulation of Large Scale Structure in the Universe", in *Inflationary Cosmology* , a collection edited by L.F. Abbott and S.Y. Pi (World Scientific: Singapore).

Desko, R. D., Bord, D. J., and Davidson, J. P. 1986, "VIRIS – VAX Interactive Reduction of *IUE* Spectra", *Pub. A. S. P.*, **98**, 948.

Einasto, J., Gramann, M., Einasto, M., Melott, A. L., Saar, E., and Saar, V. 1987, "Structure of Superclusters and Supercluster Formation VII: Supercluster-Void Topology and Structure" *M.N.R.A.S.*, in press.

Gott, J. R., Weinberg, D., Melott, A. L. 1987, "A Quantitative Approach to the Topology of Large Scale Structure", *Ap. J.*, **319**, 1.

Melott, A. L. 1986, "Comment on "Nonlinear Gravitational Clustering in Cosmology", *Phys. Rev. Let.*,**56**, 1992.

Melott, A. L. 1986, "Deviation from Hubble Flow, Biased Galaxy Formation, and the Mass Density of the Universe", *Phys. Rev. Let.*, **57**, 257.

Melott, A. L. 1986, "Virgo Infall and the Mass Density of the Universe", in *Galaxy Distances and Deviations from Universal Expansion*, B.F. Madore and R.B. Tully, eds. (Dordrecht:Reidel).

Melott, A. L. 1987, "Topology of the Universe: Motivation for the Study of Large-Scale Structure, in *Proceedings of the XIIIth Texas Symposium on Relativistic Astrophysics* (M. Ulmer, ed.).

Melott, A. L. 1987, "Topology of the Universe", *Bulletin of the American Physical Society*, **32**, 1012.

Melott, A. L. 1987, "Voids and Velocities in Initially Gaussian Models for Large Scale Structures", *M.N.R.A.S.*, in press.

Melott, A. L., and Scherrer, R. J. 1987, "The Formation of Large-Scale Structure from Cosmic String Loops and Cold Dark Matter", *Nature*, **328**, 691.

Melott, A. L., Weinberg, D. H., and Gott, J. R. 1987, "The Topology of Large Scale Structure II: Nonlinear Evolution of Gaussian Models", *Ap. J.*, in press.

Melott, A. L., McKay, D. W., and Ralston, J. P. 1987, "Has Dark Matter Decay Been Detected?", *Ap. J. Lett.*, submitted.

Nissen, P., Twarog, B. A., and Crawford, D. L. 1987, "*uvby*H$\beta$ Photometry of Main Sequence Stars in M67", *A. J.*, **93**, 634.

Ralston, J. P., McKay, D. W., and Melott, A. L. 1987, "One Model for Magnetic Solar Neutrino Interactions, Cosmological Neutrino Decays, and New Particle Resonant Production by Neutrino Interactions from Cygnus X-3", *Phys. Let. B*, submitted.

Reed, B. C., Hesser, J. E., and Shawl, S. J. 1987 "Intrinsic Colors of Galactic Globular Clusters in the UBVRI System", *Pub. A. S. P*, in press.

Shawl, S. J. 1987, "An Attempt to Satisfy all the Students Most of the Time in Introductory Astronomy", *Jour. College Sci. Teaching*, **16**, 447.

Shawl, S. J. 1987, *Instructor's Manual to Accompany "The Essentials of the Dynamic Universe, 2nd Edition"* (West: St. Paul ).

Twarog, B. A. 1986, "Stellar Photometry with Small Telescopes" in IAU Symp. No. 118, *Instrumentation and Research Programs for Small Telescopes*, ed. by J.B. Hearnshaw and P.L. Cottrell, (Dordrecht:Reidel), p. 135.

Twarog, B. A., and Shields, J. C. 1987, "The Role of Blue Stragglers in the Solar Neighborhood", *B. A. A. S.*, **19**, 145.

Twarog, B. A., and Wheeler, J. C. 1987, "A Reanalysis of Galactic Primary Nucleosynthesis", *Ap. J.*, **316**, 153.

Weinberg, D., Gott, J. R., and Melott, A. L. 1987, "The Topology of Large Scale Structure I: Topology and the Random Phase Hypothesis", *Ap. J.*, **321**, 2.

White, R. E. and Shawl, S. J. 1987, "Axial Ratios and Orientations for 100 Galactic Globular Clusters", *Ap. J.*, **317**, 246.