Final Technical Report for NASA Grant NAGW-2945

Statistical Analysis of Trigonometric Parallaxes

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The present project was initiated with two specific medium-term goals: first, to develop a novel approach, based on global modelling and maximum likelihood, to the study of databases of stellar data, with specific attention to the results to be obtained by the Hipparcos mission; and second, to apply and test the methodology developed to existing ground-based data. The long-term goal was of course to integrate the methodology and the ground-based data into a global study of the results of the Hipparcos mission, which were expected to be made available in 1995 or 1996.

The closing of the project is due to the recent change of home institution of the PI, who has moved from the University of Illinois to Johns Hopkins University. As a consequence of this move, the three scientists involved in this project will be in close proximity, thereby hopefully improving their ability to collaborate and increasing the productivity of the project. Continued funding for the project has been requested from Johns Hopkins University.

This report describes briefly the results obtained so far both on the technical aspect of software development and on the scientific side of applications to existing ground-based data. Significant progress has been made on both counts, with several papers published in (or submitted to) refereed journals and in conference proceedings. Because it is hoped that the project can be successfully continued with NASA support, the report of the progress in each area includes also an assessment of how the current results fit in the expected continuation of the project.

Our results to date include: code development (essentially completed); a detailed study of the kinematics and dynamics of stars escaping from the Hyades cluster, relevant to the question of membership in the Hyades; a study of the kinematics and luminosity calibration of nearby dwarfs; an assessment of the quality of the photometry included in the Hipparcos Input Catalog; and two studies of properties of nearby clusters, including a moving-cluster determination of the distance to Praesepe. The bibliography includes three papers submitted to refereed journals, two of which have already been published, and four contributions to conference proceedings.

Finally, the work so far has also provided a very good introduction to stellar dynamics and astrometry for an undergraduate student, with educational benefits that had not been foreseen in the original proposal.

Methodology and software development

From the point of view of method development, the computer code that embodies the application of our method to both true and simulated data has been rewritten and ported from the original environment (VAX/VMS) to the Sun/Unix environment that was required for compatibility, availability of computing power, and flexibility. The large number of special-purpose routines we had developed during several years have been rewritten and adapted to a common architecture, in which a master program acts as a driver and as a user interface allowing data input, choice of options and optimization. Among the latest additions, already extensively used, are the ability to model open clusters and to use data from different sources, allowing for catalog-dependent zero points in any of the observables studied.

The software development has been made possible by two SPARC workstations which have been purchased with grant funds and are being used primarily for this research effort. Although most of the programming work has been done by each of us separately, two visits at our respective institutions, also financed from this grant, have been necessary to coordinate our work towards a unified code.

Scientific results

Dynamics of the Hyades

Membership determination is often a vexing task in the study of the properties of open clusters. This is especially if the cluster for very nearby clusters, such as the Hyades, which occupy a relatively large area in the sky. Space velocity (proper motion and radial velocity) is often used as an important criterion in establishing membership. However, an important question arises for stars that are at more than a few parsecs from the center of the cluster. Examples are the stars in the so-called Hyades 'Supercluster' and the 'halo' stars found at several degrees from the centers of other clusters, such as Praesepe. For distant clusters, these stars, because of their larger distance from the cenetr, offer improved leverage for the use of the 'moving cluster' method and will permit a more accurate distance determination.

A study of the dynamical evolution of these stars, specifically aimed at the Hyades Supercluster, has been carried out in the form of a summer project by Aaron Shiels, an undergraduate student at the University of Illinois, under the supervision of SC. We show that stars originally related to the Hyades will still be in their vicinity only if a mass enhancement of order of $10^6\,M_\odot$ exists within about 100 pc of the Sun. Observational limits on the distribution of nearby stars indicate that this mass enhancement is likely to be mostly in the form of dark matter. A paper describing this work has appeared in the Astrophysical Journal (Casertano, Iben and Shiels, 1993). The undergraduate student has been supported with funds from the current grant.

Luminosity and kinematics of nearby dwarfs

In a previous paper, we had studied the luminosity calibration of nearby dwarfs on the basis of available trigonometric parallaxes. One of us (KUR) has used the method we have developed, in collaboration with A. R. Upgren, to study the kinematics of the same sample. They have determined that the population of nearby dwarfs is clearly divided into two groups, the old and the young disk, with different kinematics and luminosity calibration. The kinematic parameters of the two groups can be found with an accuracy of about $1\,km\,s^{-1}$ for the young disk and of $3\,km\,s^{-1}$ for the old disk. Each luminosity calibration has a mean error of about 0.1 mag. These results could not have been acheived with conventional methods, and are based on a relatively small sample of about 800 stars. They are described in Ratnatunga and Upgren (1993).

Data collection; the Hipparcos Input Catalog

A large part of our efforts must be devoted to obtaining and scrutinizing stellar data in the form and quality needed for our method to work. A major compilation that have become available recently is the Hipparcos Input Catalog. In order to assess the accuracy of catalog data, we have compared the magnitudes and colors given in the Input Catalog with independent, unpublished photoelectric measurements for about 1000 stars. The Input Catalog magnitudes are generally reliable, within the error stated in the catalog. Colors fall into two categories: for about 30% of the stars, they are derived from photoelectric measurements, and they are generally reliable, with realistic stated errors of 0.03 mag or less. For the remaining 70%, colors have been estimated from spectral classifications; such colors have been found to be in error by as much as 0.8 mag, and are in general quite unreliable, probably because of errors in the spectral classification itself. However, we find (from Monte Carlo

simulations) that even with only the stars with good photometry, we can derive a mean luminosity calibration for intrinsically bright stars (early-type dwarfs and K giants) with an accuracy of about 0.02 mag.

Properties of nearby open clusters

The maximum likelihood description has also been used to determine the kinematics and distance of nearby open clusters. The method can in principle be used to obtain pure moving-cluster distance estimates for systems up to 200–300 pc away from us, much further than currently possible (the practical limit is about 100 pc with conventional methods). The first application has been for the Praesepe cluster, which we place at a distance of 140 ± 10 pc on the basis of a limited data set (Casertano, Lattanzi and Ratnatunga 1993). Preliminary calculations for Stock 2 indicate that this cluster is beyond our range for distance estimates, but an accurate determination of its internal kinematics is within reach (results presented at the Cambridge meeting). We are presently establishing a database of proper motion information on several open clusters in our distance range, including Hyades, Pleiades, and Perseus, in order to apply our method systematically to these objects. We have also applied for early release of the relevant Hipparcos results.

A special (sub)program for preliminary Hipparcos data

An opportunity has been recently, and somewhat unexpectedly, offered by the Hipparcos Science Team to apply for the release of preliminary (18 month) Hipparcos data before the end of the year. In order to take advantage of this opportunity, we have developed and submitted for their consideration a smaller research program, covering only a limited spectral range (O through B2). Even with the preliminary Hipparcos parallaxes, we should be able to obtain a purely trigonometric luminosity calibration for the main sequence stars in this range, with an expected error of order of 0.1–0.2 mag.

Papers completed with grant support

Papers in refereed journals

S. Casertano, D. J. Bell, K. U. Ratnatunga, & K. M. Yoss, 1993, "The quality of photometric information in the Hipparcos Input Catalog", AJ 105, 2344–2352.

S. Casertano, I. Iben, Jr, & A. Shiels, 1993, "The Hyades Cluster-Supercluster Connection—Evidence for a Local Concentration of Dark Matter", ApJ 410, 90–98.

K. U. Ratnatunga & A. R. Upgren, 1993, "Kinematics of Common Dwarf Stars: A Maximum Likelihood Analysis", Ap.J., submitted.

Conference proceedings

S. Casertano & K. U. Ratnatunga, 1992, "Maximum Likelihood Analysis of Star Catalogs", in *Astronomy from Large Databases, II*, editors A. Heck and F. Murtagh (ESO Publications, Garching), pp. 219–223.

K. U. Ratnatunga & S. Casertano, 1992, "Galaxy Model Parameters using Numerical Maximum Likelihood Estimation", in *Back to the Galaxy*, editors S. S. Holt and F. Verter (American Institute of Physics, New York), pp. 369–372.

S. Casertano & K. U. Ratnatunga, "Applications of Maximum Likelihood to the Analysis of Large Stellar Catalogs", in *Databases for Galactic Structure*, editor A. G. D. Phillips, in press.

S. Casertano, M. G. Lattanzi, & K. U. Ratnatunga, "Maximum Likelihood and the properties of Open Clusters", in *Databases for Galactic Structure*, editor A. G. D. Phillips, in press.

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Grant-supported activities

Funds from NASA grant NAGW-2945 have been used to support salary for the PI and an undergraduate assistant, the purchase of computing equipment, and domestic and foreign travel.

Salary support

During the term of the grant, the PI was Visiting Assistant Professor at the University of Illinois on a nine-month appointment. Grant funds have been used for two months' summer salary each year. In addition, an undergraduate assistant, Aaron Shiels, has been supported in the summer of 1992 for about 20 hours per week; his work has resulted in one publication.

Equipment support

Desktop workstations have been purchased for both the PI and one Co-I (KUR). Both workstations have been used principally in the research described above, with special emphasis on developing and running the maximum-likelihood software.

A portable computer (Intel-based notebook) has been purchased in support of the PI's extended trip to Europe, where he has collaborated with astronomers at Torino and Firenze in support of the project's objectives. This notebook has proven comparable in power to the desktop workstations; the calculation of the distance and structure parameters of two nearby open clusters has been carried out almost exclusively on it.

Finally, we have purchased a number of smaller items of moderate cost, namely a power backup unit, two surge protectors, two modems for communications, two transceivers to plug into the local ethernet network, and a portable printer.

Travel support

We have presented our method and results in four meetings: "Astronomy from Large DataBases II", held near Strasbourg, France; "Back to the Galaxy", in College Park, Maryland; "Databases for Galactic Structure", held in Swarthmore, PA; and "Galactic and Solar System Optical Astrometry: Observation and Application", in Cambridge, UK. The two European meetings have been especially important in fostering communication and collaboration with the Hipparcos community, mainly centered in Europe. Travel to these meetings has been funded partly from the grant.