Stellar Motion Survey by Automation

Abstract. *The proper motion survey on plates taken with the 48-inch Schmidt telescope at Mount Palomar Observatory has now progressed to the point where some 250,000 new motions for faint stars have been measured, and 5,000 new white dwarfs and degenerate stars and 3,000 stars of low luminosity have been added.*

The automated-computerized plate scanner and measuring machine funded by the National Aeronautics and Space Administration and built by Control Data Corporation has now been fully operative for more than 2 years. A detailed description of the design, construction, and operational possibilities of this machine has been given in the *Proceedings of the First Conference on Proper Motions* held in Minneapolis in April 1970 under the auspices of the International Astronomical Union. Now, for the first time we can talk about results achieved.

A proper motion survey is conducted on pairs of plates taken with the same telescope, of the same part of the sky, but some years apart, and the purpose is to find those stars which have moved, especially those which have moved a great deal. Stellar motion simply is the best statistical indication we have of distance, and hence of intrinsic luminosity. The ideal material consists of the National Geographic–Palomar survey made between 1949 and 1958, which in 936 pairs of blue and red plates covers the sky north of declination $-33°$ (1875), or 77 percent of the entire sky.

Between 1962 and 1971 the Hale Observatories awarded me numerous guest-investigatorships and altogether some 150 nights with the 48-inch Palomar Schmidt telescope. Since this instrument can be used only during the dark of the moon, 150 nights are the equivalent of 10 months full use of this marvelous telescope. Surely, in the records of any institution's generosity to outsiders this must stand as a landmark! It enabled me to repeat virtually all the red plates—the few remaining ones were taken for me by observatory staff members.

Before our present machine was completed a proper motion survey had to be done with an instrument called the blink-microscope, and had to be done with the human eye and the human hand. An average pair of Palomar plates, with some 100,000 star images on each, would take me from 30 to 40 hours to "blink" and I would find an average of 400 moving objects. It would then take student assistants a good 200 hours to measure the motions of the objects found, and some further 50 to 100 hours of paper work before the final results became available.

The same pair of plates is now scanned by our machine in about 2½ hours, and the data obtained are recorded on magnetic tape. This is then processed on a CDC 6600 computer in about 45 minutes central processor time. A second and sometimes even a third processing is then done—but this takes only a few minutes. We finally obtain a printout giving rectangular coordinates and image diameters to 0.1 micron, celestial coordinates to 0.1 second in right ascension and 1 arc second in declination, red magnitudes (deduced from the diameters), annual total motion to 0.001 arc second, and directions in degrees. In addition we have a set of quality indexes from which the reliability of the motion can be judged. The average such printout contains mainly two lists, one with usually 50 to 80 stars having motions larger than 0.18 arc second annually—these are individually important and I determine photographic magnitudes and colors for them from the blue plates—and a second with 400 to 600 stars with motions between 0.09 and 0.18 arc second—these are only of statistical interest.

As an incidental piece of information the computer also lists the total number of star images recorded, between given limits of image diameter, and thus provides a complete star count. Since we have now processed close to 600 pairs of plates we are well past the 120,000,000 mark in number of star images recorded, with coordinates and diameters expressed to 0.1 micron.

While the machine was primarily designed to detect and measure displacements—that is, stellar motions—we have also used it to measure stellar brightness and color by scanning blue and red plates against each other, and with trifling changes in the software it could be used for a multiplicity of other purposes: it is extremely versatile.

Since I had very little to do with either the design or the construction of the machine I can properly say that I believe that, with the exception of the large optical telescopes and radio dishes, this machine represents the most important addition to our astronomical instrumentarium in the past 25 years.

Several years ago a somewhat similar machine was built in Britain—the GALAXY—and a few words may be said about the relative performances. According to the makers of GALAXY this machine, when in the measuring mode, will measure 900 stars per hour, to 0.1 micron. However, I understand that, because of possible systematic errors, each plate has to be measured again in the reversed position, hence the real speed is 450 stars per hour. Since our machine does 100,000 stars on each of two plates in about 2½ hours, it measures 80,000 stars per hour and thus is 180 times faster. While both machines record positions to 0.1 micron this is only an illusory accuracy. The repeatability error for both machines (that is, the difference in remeasuring the same plate) is about 1 micron, but even this is hardly significant. The real and major error in measuring star positions lies in the plate error; this generally amounts to 2.5 microns and often is more. Hence all one can ask of a measuring machine is that its added repeatability error should not materially increase this. Even if these repeatability errors range from 0.7 to 1.5 microns, the increase in overall error is only from 2.6 to 2.9 microns—hardly a significant difference.

Some astronomical results may be mentioned. Altogether we have now published, or have in press, data for 26,000 stars, mainly with motions larger than 0.18 arc second annually, but also including some double stars and white dwarfs with smaller motions, and all of these data are new. This number is about three times larger than the total number of such motions published by all others in the field (with the exception of my own survey made with the Bruce telescope at Harvard Observatory and the Palomar hand-blinked plates) since 1910, when the method using the blink microscope first came into use. In addition we have data on printouts and magnetic tape for another 250,000 stars with motions between 0.18 and 0.09 arc second; these will be made available through the NASA Data Center at Greenbelt, Maryland.

In the matter of very large motions the Bruce and Palomar surveys together have now produced between 1900 and 2000 new motions larger than 0.5 arc second annually, while from all other sources some 1400 have become known. Including the data obtained from the hand-blinked plates, we have now published data on some 5000 new white dwarfs and degenerate stars, or more than 90 percent of those known. Similarly, we have found and published data on some 3000 stars of low luminosity—those which are indicated, statistically, to be of less than one-thousandth of the sun's luminosity. In this matter the plates of the Palomar 48-inch Schmidt telescope are unique, for from all other sources barely 30 such stars have been announced.

Although a very large part of the operational expense of our machine lies in the computer costs, still the overall costs in terms of results achieved are remarkably low. This is very important these days when, because of dwindling federal support for science, we are all of us becoming cost conscious. When I did the Bruce survey on Harvard plates it produced some 80,000 new motions at a total cost of \$180,000, or \$2.25 per new motion (in 1930–1950 dollars). From the hand-blinked Palomar plates I published some 65,000 new motions against a total cost of \$275,000 in National Science Foundation grants, or \$4.25 per new motion (1962–1972 dollars). The total operational cost of our machine has been \$280,000 to date (NASA and NSF); hence the 26,000 new large motions published have cost a little under \$11 apiece (1972–1974 dollars), while if we add in the 250,000 smaller motions the average cost comes down to just about \$1 (1972–1974 dollars). The only remotely comparable stellar motion survey which has now been in operation for about 18 years has produced fewer than 6000 new motions for a total cost of over \$300,000, or well over \$50 per new motion (1956–1974 dollars).

Even if we amortized the entire cost of constructing our machine, \$787,000, in our present operations—that is, if we retired our machine tomorrow and put it in storage—we would still have produced 26,000 new large motions at a cost of \$1,067,000, or \$41 per new motion (even this is much better than our only competitor), and counting the 250,000 smaller motions (all of them new) the cost would be less than \$4 per new motion.

We are now approaching the end of our operations on the Palomar survey plates, and we can justifiably claim that the machine has proved to be fantastically and superlatively successful.

Personally I would consider it a great pity if the machine were now retired—"pickled," and put in storage. A machine as versatile as this could be quite easily adapted to a host of other programs, and I for one would welcome any and all applications for such use from other scientists.

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Cyclization of the Phosphate Side Chain of Adenosine Triphosphate: Formation of Monoadenosine 5′-Trimetaphosphate

Abstract. *Monoadenosine 5′-trimetaphosphate has been prepared from adenosine 5′-triphosphate by a carbodiimide-mediated condensation. The molecule was characterized by ^{31}P nuclear magnetic resonance, and its ^{31}P spectrum was simulated through the assumption of a three-phosphorus spin system. The molecule is highly reactive and is rapidly converted to adenosine triphosphate upon contact with water.*

The adenosine 5′-monoester of trimetaphosphate (**1**), a molecule which can be pictured as arising from adenosine triphosphate (ATP, **2**) by an intramolecular condensation between the α and γ groups of the tripolyphosphate side chain, has been considered as a possible intermediate in reactions involving ATP.

In 1949 Michelson and Todd (*1*) obtained ATP by reacting dibenzyl phosphochloridate with the disilver salt of adenosine 5′-monophosphate and then removing the benzyl groups by hydrogenation. They concluded that a reaction which produced **1** as an intermediate occurred at some stage, probably during the debenzylation, and that hydrolysis of **1** at the esterified phosphate position then took place to produce the linear triphosphate derivative, ATP.

Smith and Khorana (*2*), in studies on the chemical synthesis of nucleoside 5′-diphosphates and 5′-triphosphates, found that the triphosphates were formed as the major products when nucleoside 5′-monophosphates were condensed with excess orthophosphoric acid in anhydrous pyridine with use of excess amounts of dicyclohexylcarbodiimide. This was interpreted as taking place through the formation of the trimetaphosphate esters (**1**, in the case of adenosine) which were hydrolyzed to the corresponding linear tripolyphos-