THE DETERMINATION OF THE PROPER MOTIONS OF X-RAY SOURCES

Heinrich Eichhorn, George D. Gatewood and Sabatino Sofia
University of South Florida

I. INTRODUCTION

At the University of South Florida Observatory, a program is under way to determine the proper motions of the star-like objects which are possibly or probably associated with X-Ray sources. The objects under study are Sco X-1, and objects believed to be identical with Cen X-2, Cyg X-2, and Co D -32° 1057. Since it has been speculated that these might be neutron stars, an effort was made to study not only their proper motions but also those of other stars in the neighborhood to ascertain membership of any moving cluster with known age and distance, whereby their own ages and distances might become known. These efforts were successful so far in the case of Sco X-1 (Sofia, Eichhorn and Gatewood, 1969), whose proper motion is virtually identical to that which a member of the Scorpio-Centaurus Association would have at this position, so that the membership of Sco X-1 in this association becomes highly probable. On the basis of this and other information, Gatewood and Sofia (1969) conclude that Sco X-1 is quite likely a neutron star. The reduction was described in detail by Gatewood (1968). No definitive results are available yet for the other three objects.

II. THE MATERIAL

The stars under consideration believed to be X-Ray sources are too faint to have their early epoch positions recorded in the zones of the Astrographic Catalogue. Sources of early epoch positions had, therefore, to be found elsewhere. The material used for Sco X-1 was described in the above mentioned paper (Sofia et al, 1969).

In the region of Cen X-2 (WXCen), six Bruce plates were made available by the Harvard Observatory, and one plate taken at the Normal Astrograph of Sydney Observatory was put at our disposal through the courtesy of Mr. Harley Wood. The sixteen new epoch plates for this object were lent to us by the Cape Observatory, the Sydney Observatory and the Yale Columbia Southern Station, the latter thanks to Dr. Adriaan Wesselink.

The positions of stars in the Smithsonian Astrophysical Observatory Star Catalogue served as the reference material. No overlap solutions have yet been performed on the material for this object for reasons to be discussed below. A preliminary position, and preliminary proper motion components only are available for this object; they are (on the system of the FK4)

α	μ_α	δ	μ_δ
$13^h09^m38.^s096$	$-0.^s00177$/yr	-63° 07' 51."21	-0."0078
r.m.s. errors: .012	.00060	.07	0051

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The star supposedly and hopefully associated with Cyg X-2 has been identified on three early epoch Bruce plates, and new photographs, made on the Lick Carnegie astrograph, have been put at our disposal. The measurement of these plates has begun. Three early epoch plates of another object hopefully identified as X-Ray source, CoD -32° 1057 have been borrowed from the Harvard collection of Bruce plates, and the preparations for finding the proper motion of this star have begun.

III. THE REDUCTION TECHNIQUE

Since the proper motions of these objects, whose accuracy is essentially limited by the accuracy of the early epoch positions, are not very large, we decided to derive, not only proper motions but also to give carefully reduced positions, together with the positions of a number of other stars in the field, in order to provide investigators in the future with better early epoch material than was available to us. The positions of the other stars in the field are intended to serve a dual purpose.

First, they are provided in order better to define the system on which the object's position is given, so that its statistical parallax may be determined, and to provide material for the eventual determination of the object's motion relative to its neighboring stars, and second, to help to find any other objects that have the same proper motion at the X-Ray source. Also, if the identification of the object is wrong, the real X-Ray source may be one of the other objects whose proper motion and position were measured.

Since the systematic accuracy of positions increases with the number of available reference positions, all available reference stars were employed. This was done also with the intention of studying certain aspects of the reducing technique, in particular the choice of the model for the connection between measured coordinates and standard coordinates. These studies were performed on the new epoch plates of Cen X-2.

Inadequate reduction models are a very dangerous source for systematic errors in the derived positions. A too simple reduction model may fail to properly account for the geometry of the projection and leave systematic residuals, while too flexible a reduction model may result in a large plate constant variance and thereby introduce systematic errors into the positions finally derived.

IV. THE CHOICE OF THE REDUCTION MODEL

So far, the authors know of no method that would allow one to select the reduction model which is the optimum one. Eichhorn and Williams (1963) have, however, derived a criterion that allows one to decide which of two different reduction models will likely result in positions with the smaller (overall) systematic errors. Using this criterion, one may thus gradually go from simple to more complicated models and stop making the model

more flexible when the criterion indicates that the addition of new terms would increase the chance for higher systematic errors.

This method was applied to the sixteen recent epoch plates of Cen X-2 in an effort to get an idea of the optimum reduction model for each telescope. New terms involving, besides the measured coordinates of the images also their diameters and colors, were introduced in a certain sequence.

The surprising result concerned chiefly the y-coordinate. Invariably, the criterion indicated that general third order terms in the measured coordinates, and a linear color equation were necessary to minimize the expected systematic error in the results. Except for two plates taken with the Cape Astrograph, the cubic terms come out very similar for the Bruce telescope and the Carnegie Astrograph, and it is apparent that even the Cape instrument gives rise to cubic terms which are generated from the others by adding terms for radial cubic disortion. Even more remarkable is the fact that the color equation is identical for all plates within the mean error of the individual determinations. This is very unlikely due to differential atmospheric dispersion since the three observatories at which the plates were obtained are all at similar latitudes.

The only conclusion is that the cubic terms as well as the color equation terms represent peculiarities of the reference stars rather than of the plates, and should thus better be left off the reduction model. One would, under these circumstances, wonder whether a very conservative approach to the choice of the reduction model is not perhaps the best, unless there is good evidence to the contrary. Thus, a camera would be assumed to have the projection properties of a pinhole camera until the contrary is established, say, by investigating different regions of the sky with this camera, and getting essentially identical non-gnomonic terms from different reference stars.

Nevertheless, the problem of finding an optimum reduction model in each case is still an open one.

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