Determining the Astrometric Error in CSC2 Source Positions

Arnold Rots, SAO

Introduction

The source positions in the Chandra Source Catalog version 2 (CSC2) are characterized by error ellipses (circles for Version 1 of the CSC) which are based on the spatial distribution of the photons for an individual source detection. In the case of multiple detections of the same source the error ellipse is derived from the error ellipses associated with the individual detections. These error ellipses provide a good measure of the statistical uncertainty of the location of the source in the frame of the observation, but leave out a series of potential sources of error that are external to the observation:

- The error in the mean aspect solution for the observation; clearly, the effect of this error will be diminished when multiple detections of the same source are combined.
- The calibration of the geometry of the spacecraft, in particular the optical axes of the aspect camera and the HRMA.
- The astrometric errors in the Guide Star Catalog; this should be very small.
- The calibration of the geometry of the focal plane, its projection on the detectors, and the distortions therein.

For all practical purposes, we shall combine these errors and call it an astrometric systematic error, even though not all of its components are truly systematic. The intent of this study is to derive the value of this compound quantity in order to add it to the CSC statistical position error to obtain a reliable absolute error for each of the CSC sources.

Procedure

The CSC2-SDSS cross-match catalog contains 17703 objects that are classified as stars in the SDSS DR13 catalog. Since these sources are, by their nature, point-like we assume their optical and X-ray positions to be well-determined and coincident. We have further narrowed the sample down by requiring the match probability to be greater than 90%. By using the combined spatial error estimate of each object pair as independent variable and analyzing the statistical distribution of the measured separations, it is possible to derive the value of the missing astrometric error in the CSC2. The assumption here is that the astrometric error is relatively small compared to the CSC2 uncertainties, especially off-axis, and will therefore mainly affect the pairs with small combined errors.

The separation is a single-axis radial measure and, in order to perform the analysis correctly, the positional uncertainties also need to be converted to a single-axis radial quantity. CSC2 provides the major and minor axes of an error ellipse, while the SDSS gives independent errors in RA and Dec, which are also assumed to represent an error ellipse. The combined error is then derived by

adding the geometric means of the major and minor axes for CSC2 and SDSS in quadrature; in other words: the square root of the sum (CSC2 plus SDSS) of the products of major and minor axis. We want to be dealing with 1-σ values and since the CSC2 error ellipses refer to a 95% confidence level, the CSC2 values are to be multiplied by 0.408539.
To put all this in mathematical expressions:

- ε_0 : semi-major axis of CSC2 95% confidence ellipse
- ε_1 : semi-minor axis of CSC2 95% confidence ellipse
- σ_{RA} : 1-σ error in RA for SDSS positions
- σ_{Dec} : 1-σ error in Dec for SDSS positions
- σ_c : 1-σ combined statistical radial position error for CSC2-SDSS cross-matches
- σ_a : 1-σ astrometric error
- σ_c' : 1-σ combined corrected statistical radial position, including astrometric error
- ρ : (radial) separation of CSC and SDSS positions for a cross-match pair: measured

error

- $\rho_N(\sigma)$: normalized sample error
- $\tilde{\chi}^2$: reduced χ^2

$$\sigma_c = \sqrt{0.1669041 \,.\, \varepsilon_0 \,.\, \varepsilon_1 + \sigma_{RA} \,.\, \sigma_{Dec}}$$

$$\sigma_c' = \sqrt{0.1669041 \,.\, \varepsilon_0 \,.\, \varepsilon_1 + \sigma_{RA} \,.\, \sigma_{Dec} + \sigma_a^2}$$

$$\rho_N\,(\sigma) = \frac{\rho}{\sigma}$$

$$\tilde{\chi}^2 = \frac{\sum_1^n {\rho_N}^2}{n-1}$$

In the following, σ_c (or σ_c') is the independent variable, ρ or ρ_N the dependent variable. All values are in units of arcsecond.

Analysis

The results discussed here have been obtained by following the procedure described in Rots, A.H. & Budava'ri, T. 2011, ApJS 192, 8. An estimated astrometric error was added to the values of sigmas σ_c (σ_c' in what follows). Two histograms were produced:

- Reduced Chi-sq $\tilde{\chi}^2$as a function of σ_c' (Fig. 1A).

This should be a flat distribution.

- Distribution of ρ for ranges of σ_c' (Fig. 1B).

This distribution should be a Rayleigh distributions

It turned out that the 2CXO errors needed to be scaled by a factor 0.9. These sigmas were derived from 95% confidence ellipses, assuming Gaussian behavior. Since the errors are more sharply peaked than a Gaussian distribution, true sigmas are narrower than one would expect for a pure Gaussian.

The astrometric error is varied and its most likely value determined by inspecting the histogram shapes and comparing these with the expected behavior. The result is a best value of 0.29". This is significantly larger than what was found for CSC1. We recognize that the pointing of the spacecraft has drifted slightly over the mission, while the absolute error also varies with off-axis angle. The remedy would be to slice up the data in time and off-axis angle. However, as this is not practical for CSC2, we had to accept the larger value for the absolute astrometric error.

Conclusion

Our conclusion is that the astrometric error in CSC2 positions, resulting from the four components listed in the Introduction, is 0.29" ±0.01". Adding this value in quadrature to the current error will result in a reliable value for the absolute position errors in the CSC2.

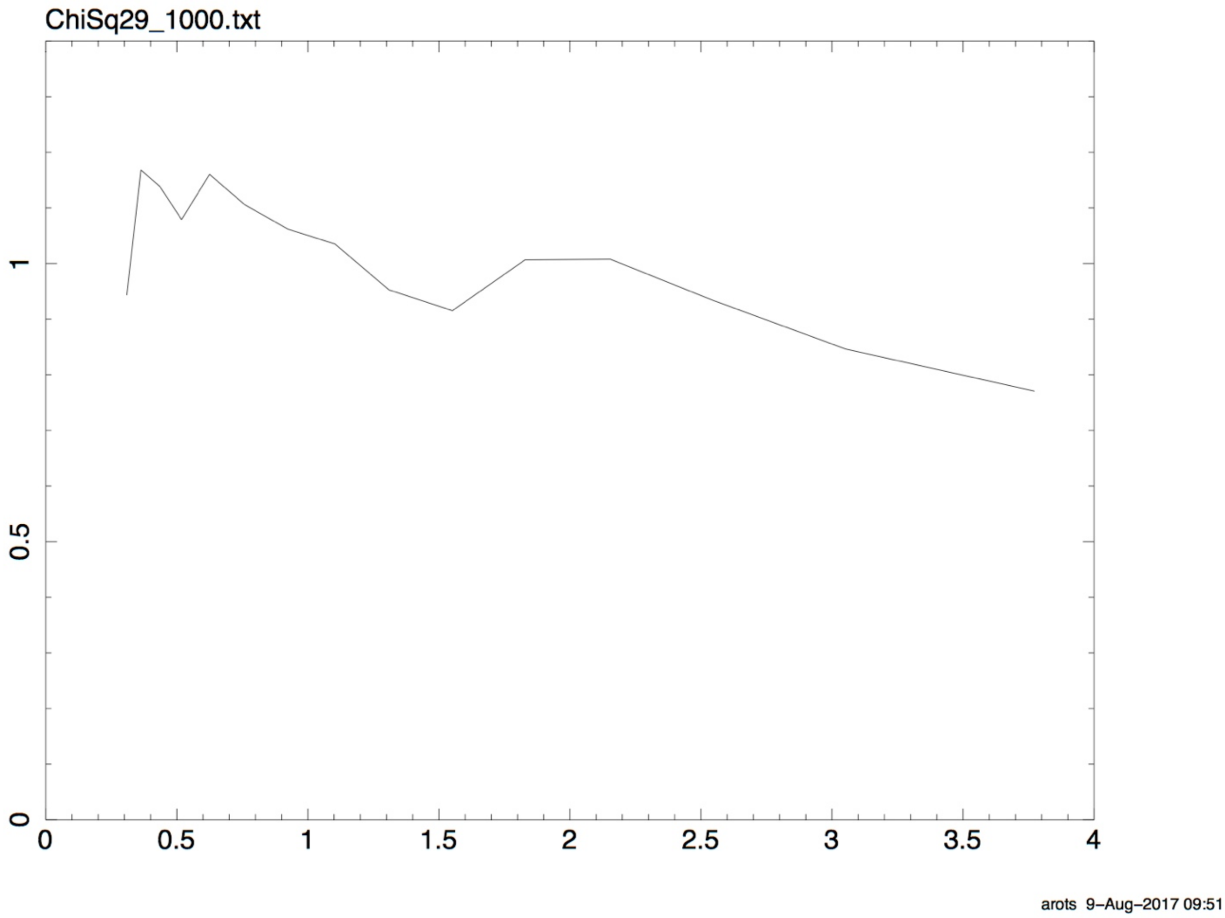

Fig. 1A $\tilde{\chi}^2$ (ρ_N (σ_c) as a function of σ_c' for bins of 100, 200, 300, 400, 500, 500,… sources.

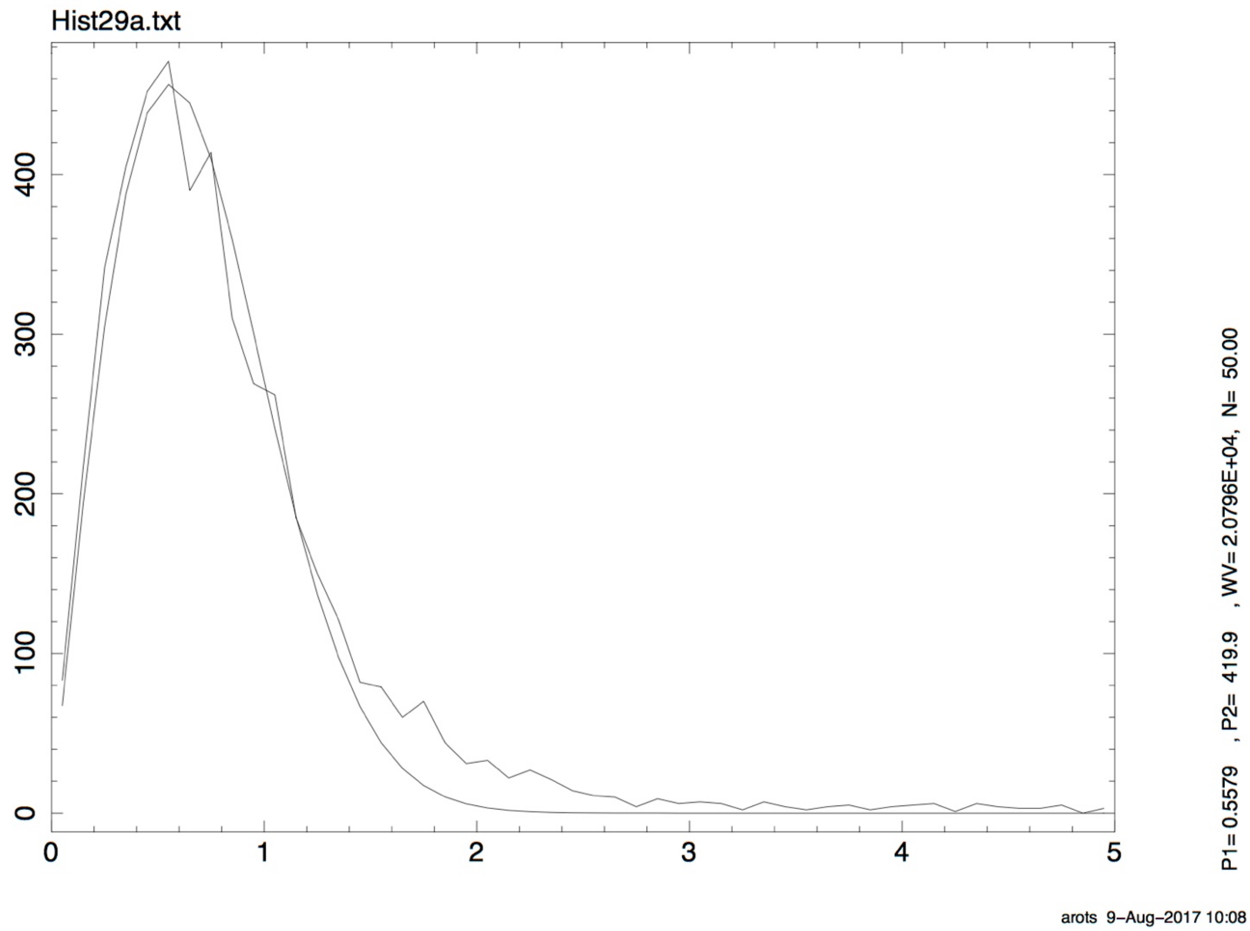

Fig. 1B ρ as a function of σ_c' for bins of 100, 200, 300, 400, 500, 500, … sources.