ASTROMETRIC DETECTION OF FAINT COMPANIONS

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ABSTRACT. The resolution of pairs of objects closer then the scale of seeing, and of difference of magnitude larger then ten percent is unreliable by direct imaging. The resulting image FWHM differs from a true PSF by no more then four percent. Yet, the peak of the associated Gaussian is shifted to a larger proportion. Here we present the description of the FWHM and peak location shifts as function of the seeing scale, the centers separation, and of the magnitudes difference. The shifts are hence compared to the astrometric precision nowadays derived from ground observations and reference catalogues. As case study, observations of the Pluto-Charon system are analyzed. A 0.6m telescope was used, under seeing conditions around 1.5 arcseconds, and the UCAC2 catalogue furnished the reference frame. The maximum separation of the system is 1 arcsecond and the magnitudes difference is about 2. The orbit of Charon was reconstructed from an uneven sample of 493 observations, distributed along four years.

1. THEORETICAL APPROACH

The observed flux distribution from a pointlike source can be associated to a normal distribution. Although it is not the only one possible, the Gaussian representation is of competitive efficiency, possessing the advantage of easy analytical handling. It will be used here throughout to discuss the composite image of two close sources merged by the seeing. As case test, the Pluto-Charon system is used. This was motivated by the recent campaign on the occasion of the UCAC2 2625 7135 star occultation (Sicardy et al., 2005).

Treating the Gaussian representation, without loss of generality, in one dimension, the Pluto and Charon composite flux $\mathbf{f_{P+C}(x)}$ is given by

$$f_{P+C}(x) = A_P\ exp(-x^2/(2\sigma^2))[1 + k\ exp(-d_{PC}{}^2/(2\sigma^2))\ exp((xd_{PC})/\sigma^2)] \tag{1}$$

Where indexes **P** and **C** refer to Pluto and Charon respectively; **d** is their mutual distance; σ is the standard deviation, assumed common for the two intervening pointilike sources, as given by the seeing (here the FWHM equal to 2.35σ); **A** is the amplitude and **k** is the Charon to Pluto amplitude ratio.

Now deriving on **x** to obtain the maximum amplitude, say, at $\mathbf{x_M}$, it is obtained

$$k(x_M - d_{PC})\ exp(d_{PC}(2x_M - d_{PC})/(2\sigma^2) + x_M = 0 \tag{2}$$

Figure 1 depicts the different Gaussians that describe the image of the Pluto-Charon pair for the condition of $\mathbf{x_M}$, and their differences. There, the data for a separation $\mathbf{d_{PC}}$=1.092 is adopted. Henceforth, $\mathbf{x_M}$=0.098; σ=1.079; and the intensity at maximum $\mathbf{I_M}$=1.093.

$$I = 1.093\ exp(-(x - 0.098)^2/(2{\times}1.079^2)) \tag{3}$$

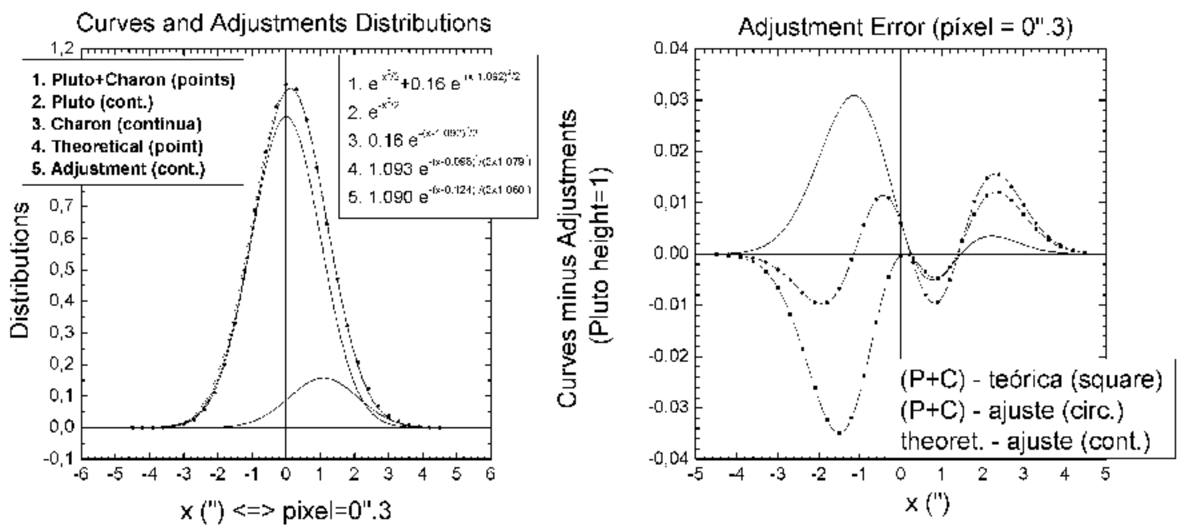

Figure 1: On the left, the intensity map (on **x**) of the combined Pluto-Charon pair, plus the Gaussian curves for the Charon image, for the Pluto image, for the theoretical combination of the images, and the one adjusted to the combined images. On the right the differences between the intensity map and Gaussians relative to the combined images.

2. OBSERVATIONAL DATA

The observational data comprises 493 observations made at the LNA (Laboratório Nacional de Astrofísica/MCT, ϕ= -22° 32' 04", λ= +45° 34' 57", and h=1864m). The telescope is a 0.6m Boller & Chivens cassegrain, the pixel scale is 0".61, and the equivalent field is 10'.44 across. The typical seeing was 1".5. The data was gathered in 6 missions from 2003 to 2005. The astrometrical precision was at 45mas ($\mathbf{\Delta}\alpha\mathbf{cos}\delta$) and 44mas ($\mathbf{\Delta}\delta$).

For each observation the O-E (observed minus ephemeris) right ascension and declination residuals relatively to Pluto were calculated. The residuals distribution clearly trace the Charon orbit, as shown in the next figure.

The expressions (1) to (3) then enable to obtain the correction to go from the observed photocenter to Pluto's photocenter. Applying the photocenter correction the residuals dispersion drops from 82mas to 52mas in right ascension and from 117mas to 31mas in declination, after removing 14 observations above the 2.5σ threshold. These values are well within the astrometric

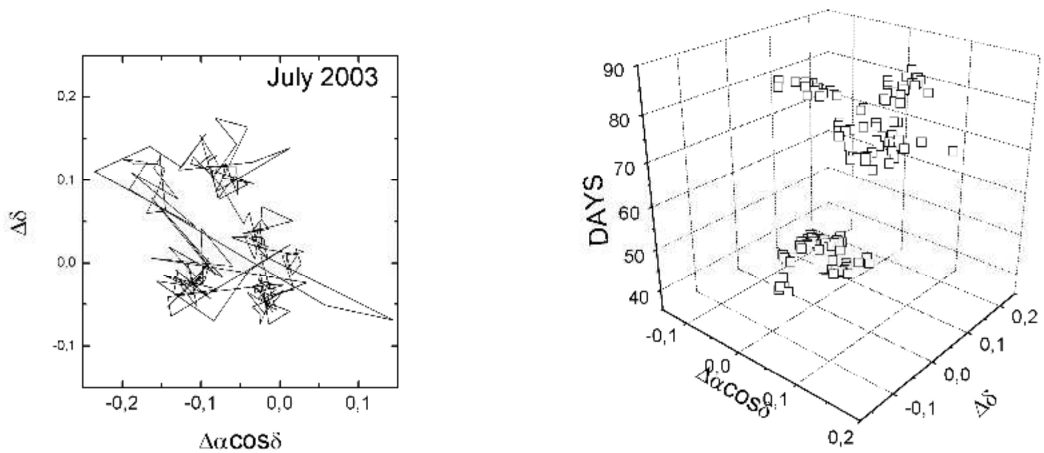

Figure 2: On the left, O-E residuals distribution for a mission covering the complete Charon orbit. On the right, time evolution of the O-E residuals along the observations.

limit stated above, indicating that the model is correct within the validity of the Pluto-Charon system data precision, that is 20mas (DE405, Standish 2005).

3. RESULTS AND CONCLUSIONS

The modern techniques of image analysis combined with the present accuracy level of the astrometric methods and reference frames open new possibilities to derive relative positions of close, dynamically tied bodies. The image analysis can reveal the small periodic variations on the amplitude, on the width, and on the location of the center from an intensity distribution seemingly created by a pointlike source.

In the present paper we discuss the simplest case where the intensity distribution is adjusted to a Gaussian distribution, and the twist of the center of the distribution is analyzed. As case study the Pluto-Charon system is examined. This was motivated by the campaign regarding the occultation of a bright, astrometrically and photometrically stable star. 493 observations, from 2003 to 2005, encompassing six missions where the period of Charon orbit was covered were either reviewed or reduced. The results show that the application of the photocenter correction effectively reduces the observed minus ephemeris residuals. The improvement is from 82mas to 52mas on right ascension and from 117mas to 31mas on declination. Charon orbit is clearly seen on the obtained plots.

Further studies are on course to establish the limits of the method, to develop analytical tools using other model distributions, and to tackle the variation on the standard deviation in two orthogonal directions. This effect drops rapidly for separations smaller than the seeing measure, but is nearly insensitive to motions of the system baricenter. Also the very Pluto-Charon case is going to be further studied by recovering and re-analyzing former observations.

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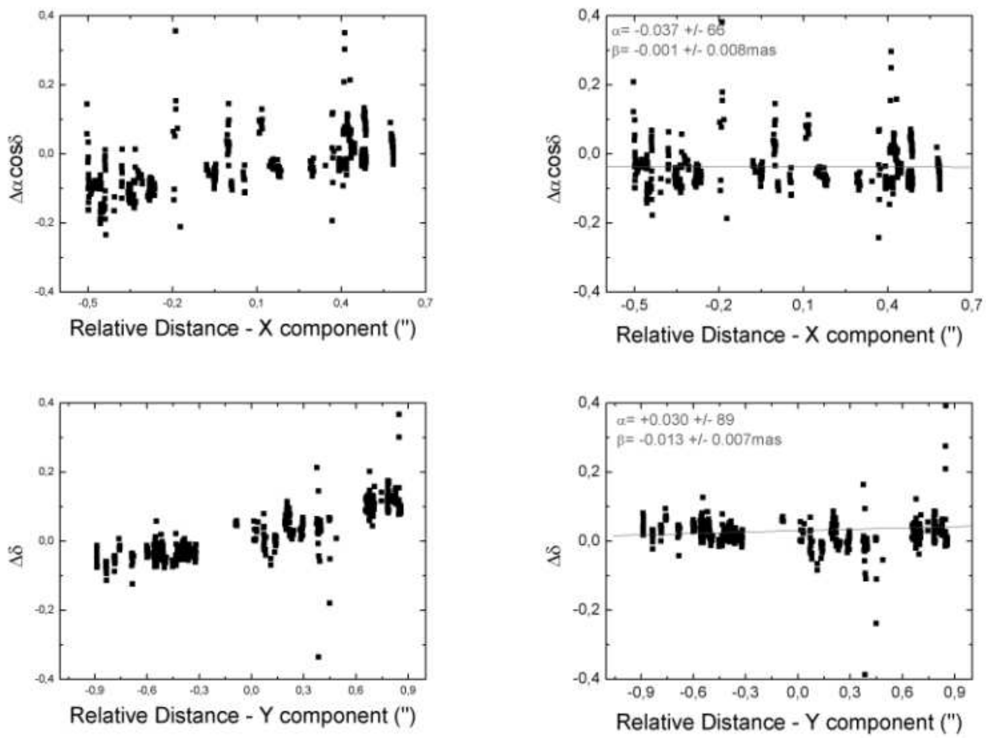

Figure 3: Plots of the O-E residuals against the relative distance Pluto-Charon, either on right ascension (X on top) or declination (Y on bottom). On the left the raw residuals are shown. On the right, the residuals after the photocenter correction; the linear (α) and angular (β) coefficients of a line fit are shown to be close to the zero level horizontal.