Astrometric bias caused by inhomogeneous background

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Overview

Introduction

Basic problems in measurements:

- All kinds of measurements are taken against some background.
- We use SNR to quantify how “far” our measurements are with respect to the background.
- What is boundary SNR value for accepting or/and rejecting measurements?

Under some assumptions, we will show that it is possible to quantify an error related.

Hypotheses

Assume distribution of light for a stellar-like point in the focal plane to be

$$i\left(\vec{r}\right) = \frac{I_0}{2\pi\sigma^2} e^{-\frac{\left(\vec{r}-\vec{r}_0\right)^2}{2\sigma^2}} + B\left(\vec{r}\right)$$

where

$$B\left(\vec{r}\right) = \pm k \left|\vec{r} - \vec{r}_1\right| + c$$

describes the light background, and $k > 0$, $c > 0$, $I_0 > 0$, $\sigma > 0$.
The chosen background $B\left(\vec{r}\right)$ satisfies

$$\left|\vec{\nabla} B\right| = k.$$

Gaussian image and background

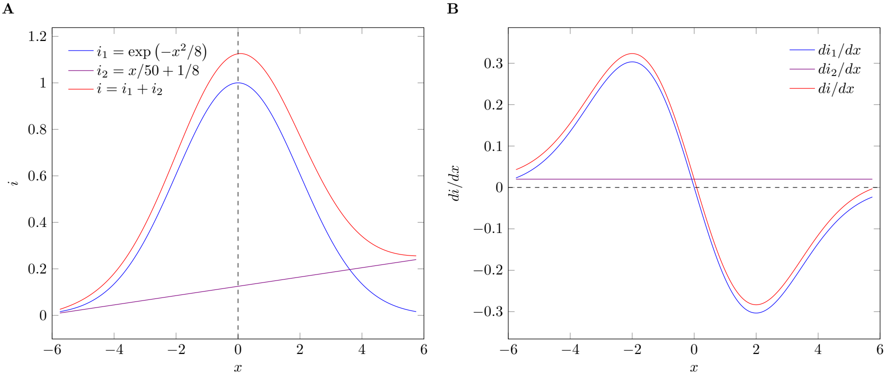

Figure: Light distribution in the focal plane along the local background gradient.

Analytic solution

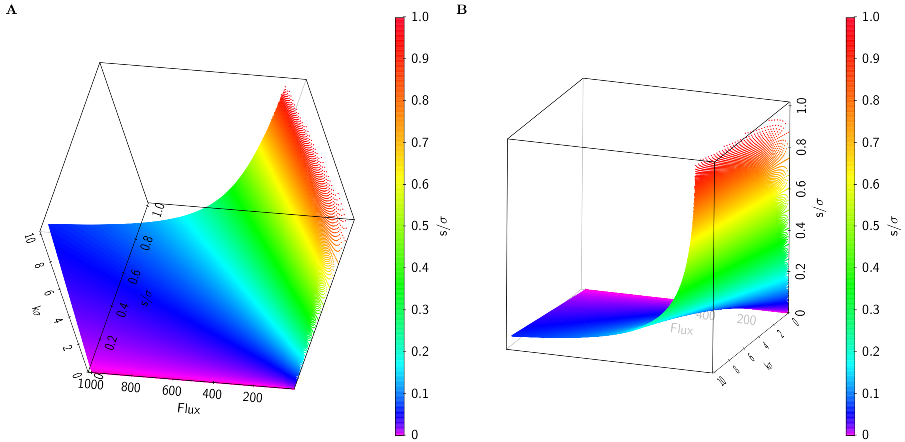

Figure: Photocenter bias ratio s/σ as the function of the flux I_0 and the background growth per image size $k\sigma$ seen from different aspects.

Analytic solution

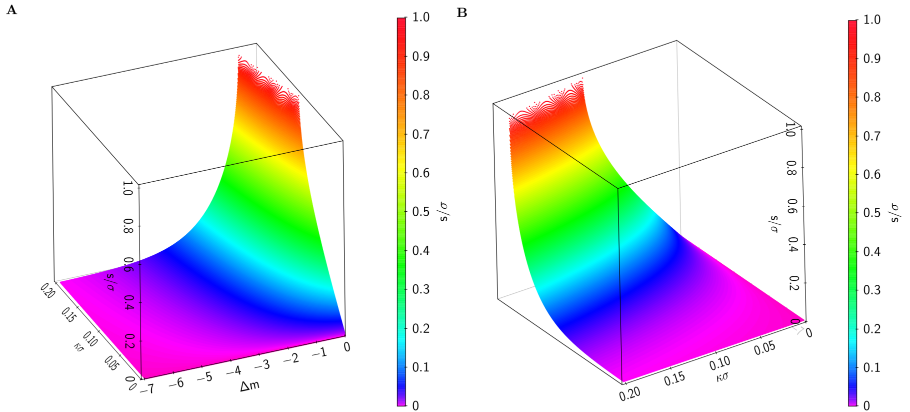

Figure: The same photocenter bias ratio s/σ while the flux difference Δm wrt the background and its grows per image size $\kappa\sigma$ are given in magnitudes.

Topographic map of the solution

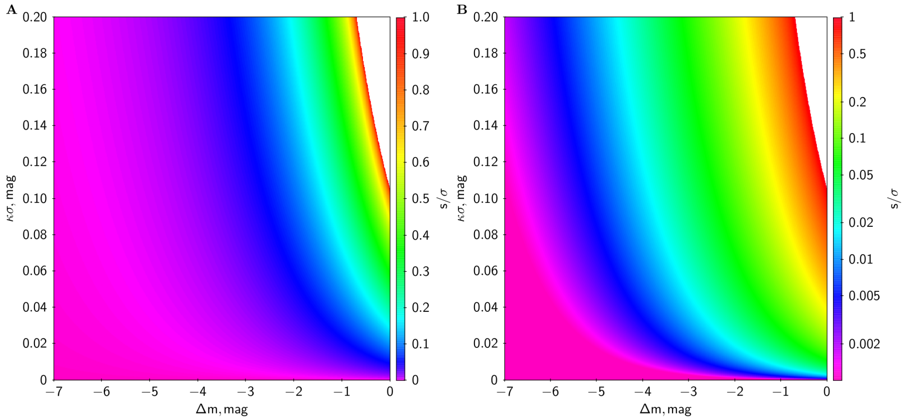

Figure: Photocenter bias ratio s/σ as a function of the flux difference Δm wrt the background and its growth per image size $\kappa\sigma$ in mag. The left subfigure is shown in the *linear* scale, while the right in the *logarithmic*.

Conclusions I

- The light background is present in each image and its inhomogeneity can be taken into account. The found solution can be applied to both spectra and stellar images. The photocenter bias can be considered as an *instrumental* error as it depends on both $FWHM$ and $k\sigma$ values.
- The inhomogeneous background mostly affects the positions of faint sources with fluxes close to the background flux. It has an upper bound $\sigma = FWHM/2\sqrt{2\ln 2}$ for the Gaussian-like image.
- *Recommendation:* do not rely on the positions of objects with small SNR. They *always deteriorate* the reductions or calibrations. The weighted approach is necessary.

Conclusions II

- The proposed linear model can be used in most cases *while the change of the light background gradient within the image size can be neglected*. Usually, the stellar images are small to the background variations ($k\sigma$), so we can apply the *instantaneous* (local) value of the background gradient at the place where the object is located.
- We explain the “exponential” looking degradation of the measurement errors with the magnitude due to the discussed effect.