Centroiding experiment for determining the positions of stars with high precision

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Introduction

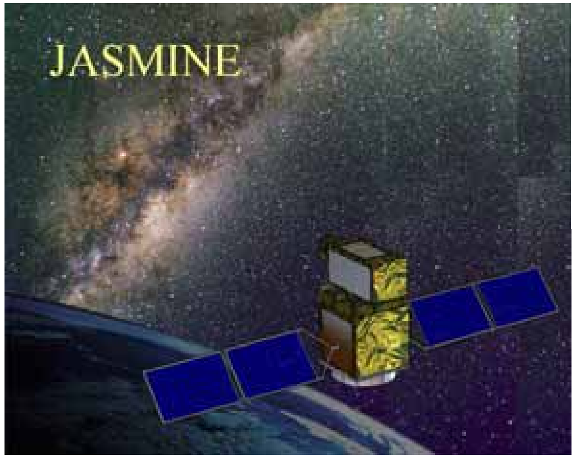
- JASMINE project

- Japan Astrometry Satellite Mission for INfrared Exploration-

- Infrared Astrometry Satellite
- Mainly in progress at the National Astronomical Observatory of Japan

The objective

investigate the bulge components of the Milky Way galaxy

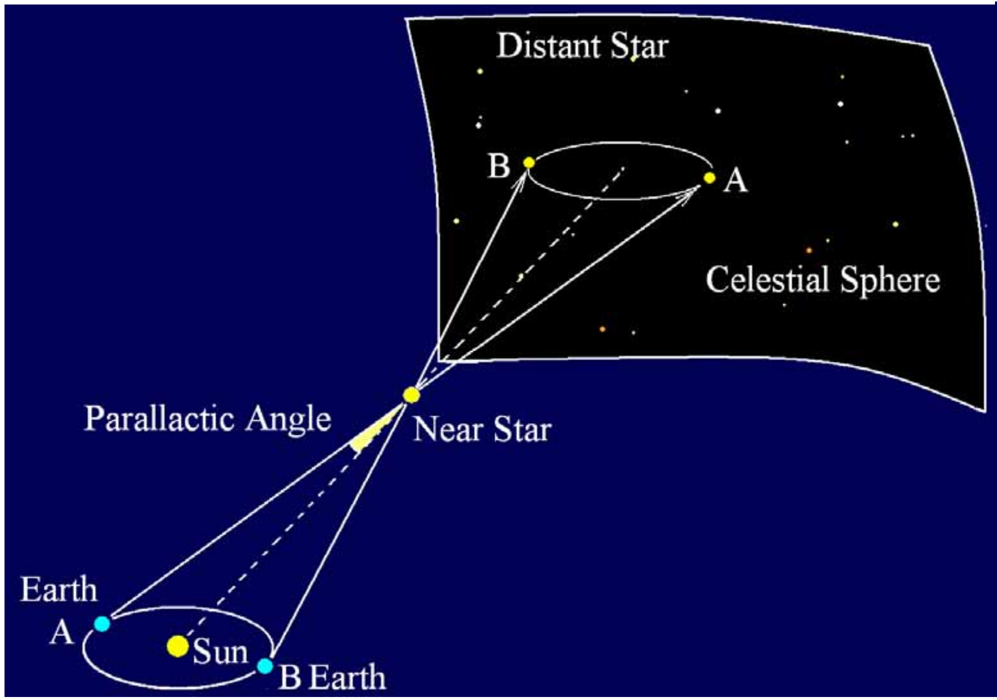


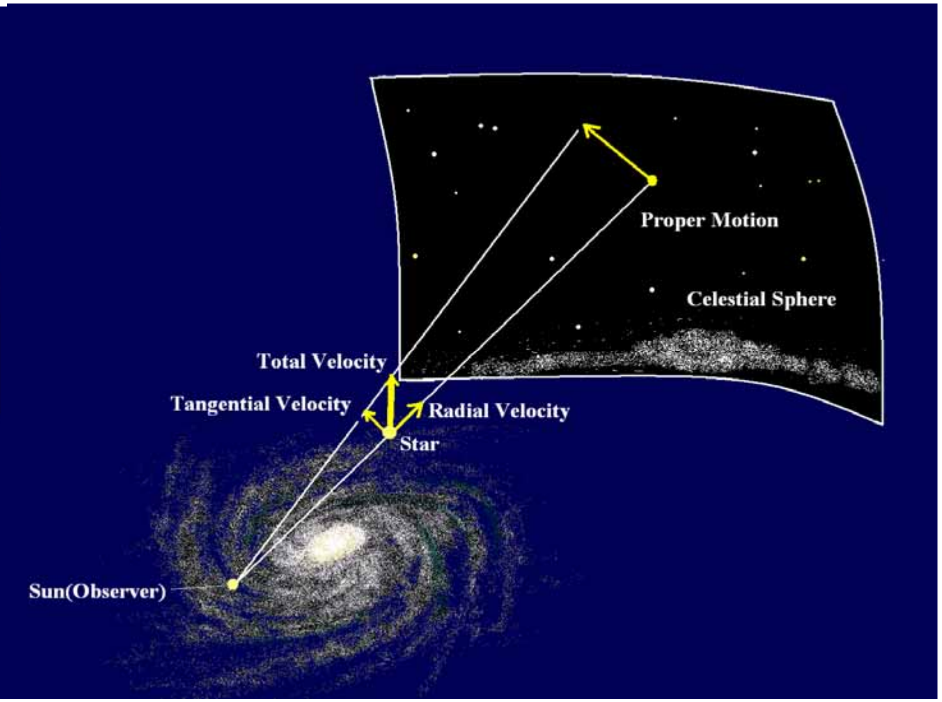
Introduction

In order to accomplish these objectives,

- JASMINE will measure positions, proper motions, and the annual parallaxes of bulge stars with the precision of 10μas.

(10μas is needed for determining the distance of bulge stars.)

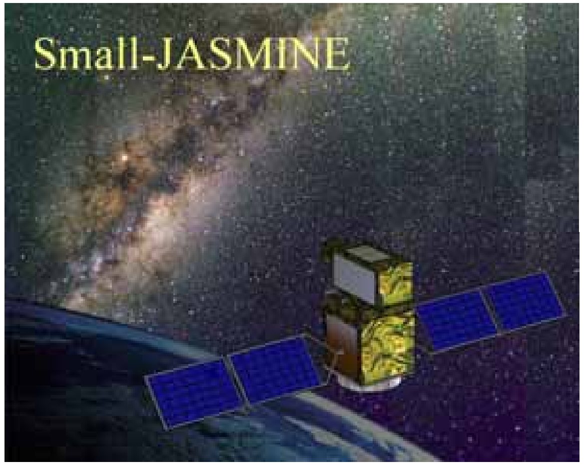


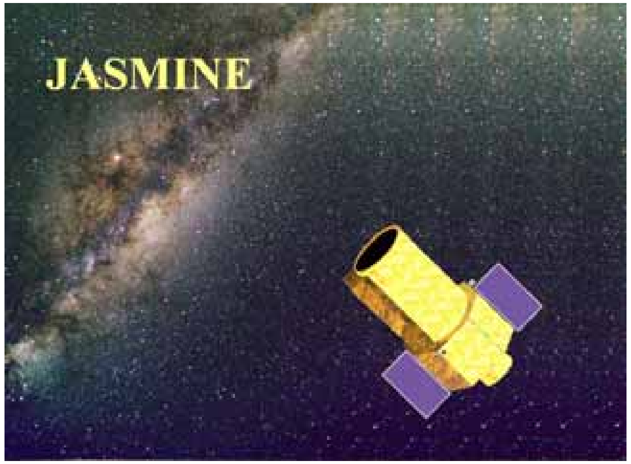


Introduction

Specifications

	Small-JASMINE	JASMINE
Aperture	30cm	80cm
Wavelength	2micron	2micron
Planned Launch date	〜2015	2020s

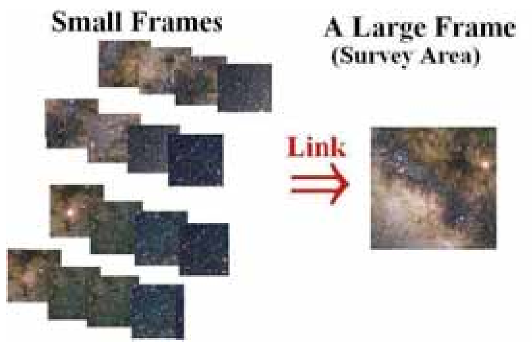




Observational Method

JASMINE will observe the bulge stars in the following procedure.

- **We take star image and measure the positions of stars with the precision of about 10^{-2} pixel for one exposure.**



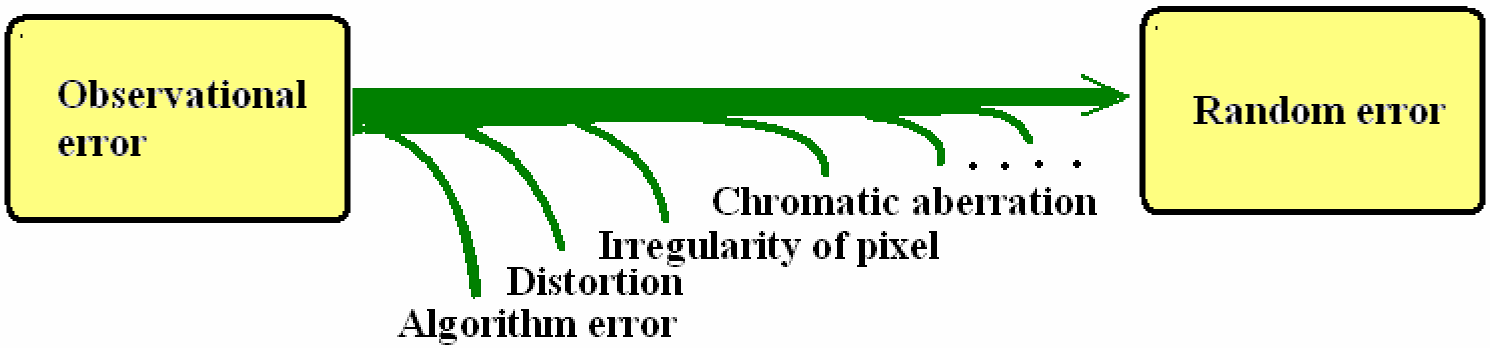
- **We continue to take many images during the mission time and estimate the positions of stars with the precision of about 10 microarcsec, that is, of about 10^{-4} pixel for all the observations.**

To the 10 microarcsec in the experiment

In the experiment we must show the following two points.

- **the positional error is about 10^{-2} pixel for one exposure.**
- **the position of a star is estimated with a precision of about 10^{-4} pixel for all the observations.**

If we can remove or estimate the systematic error adequately, the error of the position decreases as the random error.



Experiment 1

1. Determination of the position with a precision of about 10^{-2} pixel for one exposure

2. Determination of the position with a precision of about 10^{-4} pixel using about 10^{4} images

Determination of the position

It is difficult to determine the position of stars with high accuracy.

- **If we substitute photon-weighted mean for the position of a star, we obtain the position with a precision of a few tenth of pixels.**

- **However it is difficult to estimate the position with a precision of about 10^{-2} pixel level.**

So we need some idea to estimate the accurate position.

photon-weighted mean : positional mean using the number of photons

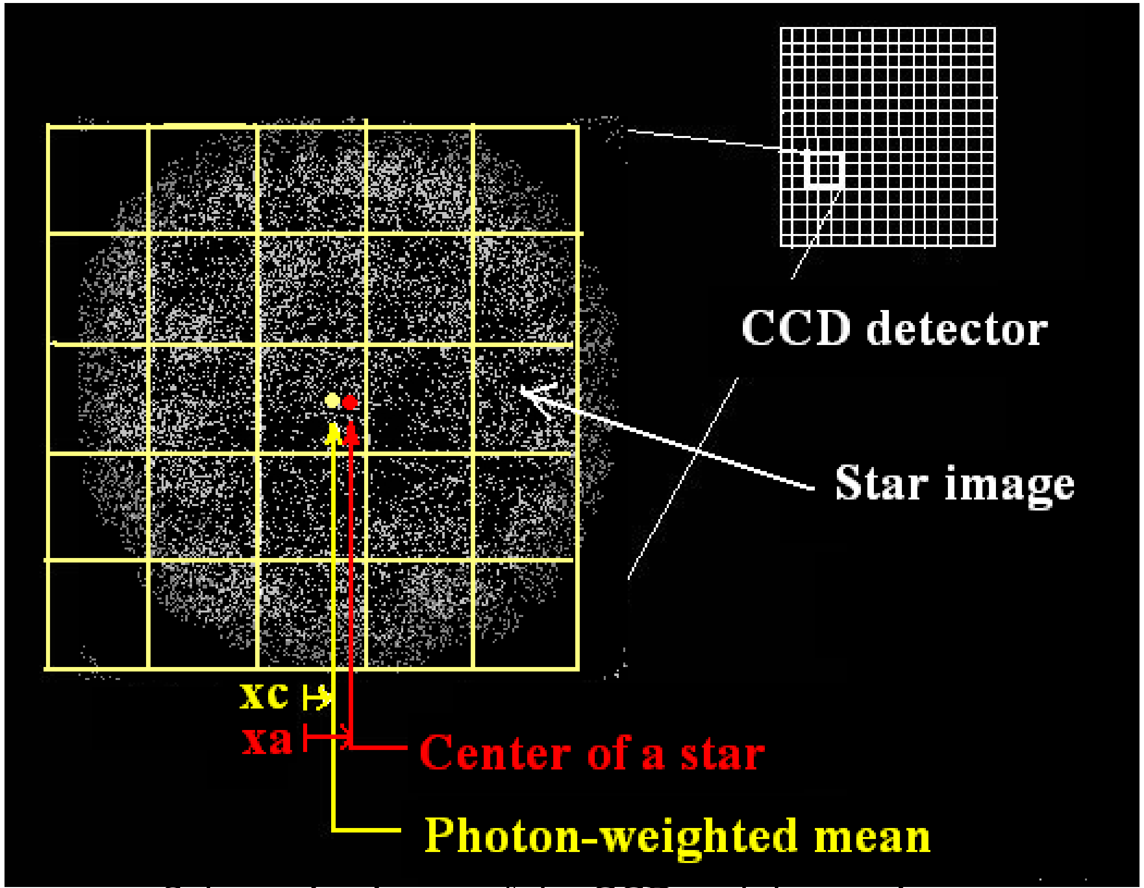
Algorithm

We need to estimate a center of a star image

On the other hand, it is easy to calculate photon-weighted mean.

So, we estimate a center of star from the photon-weighted mean

Note) Photon weighted mean of a star is different from the center of the star.



Schematic picture of the CCD and the star image

Algorithm

Procedure

1. Select two stars to measure the distance

2. Pick up a square subset of 5x5 pixels around the peak pixel of each star image

peak pixel : the pixel in which the number of photons is maximum

3. Calculate the photon-weighted mean of each star (xc, yc)

4. Assume that the difference between the photon-weighted mean and the real position is proportional to the deviation of the photon-weighted mean from the center of the pixel

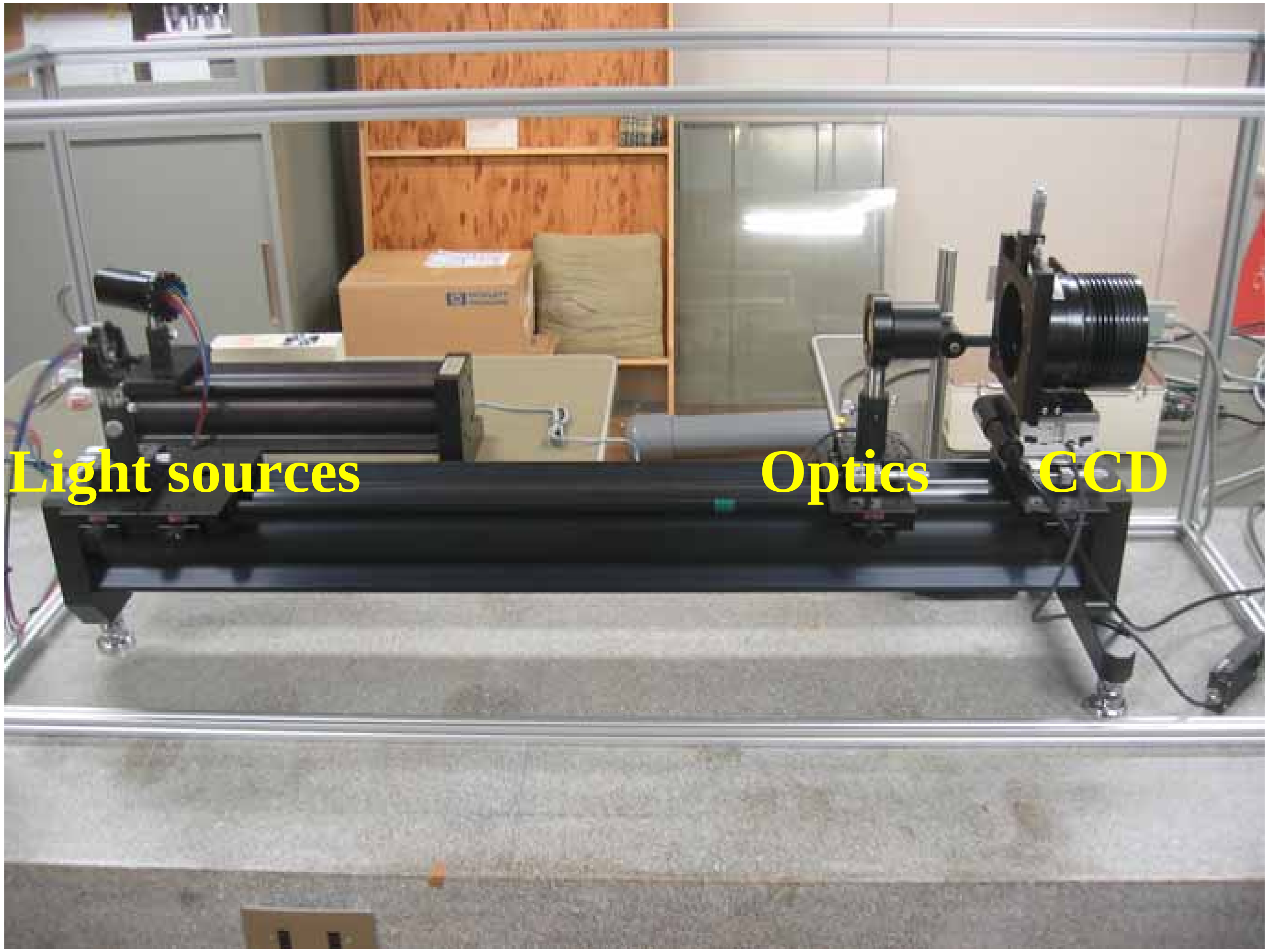
$$xa - xc = k\, xc \quad \text{(Linear correction)}$$

xc: photon weighted mean

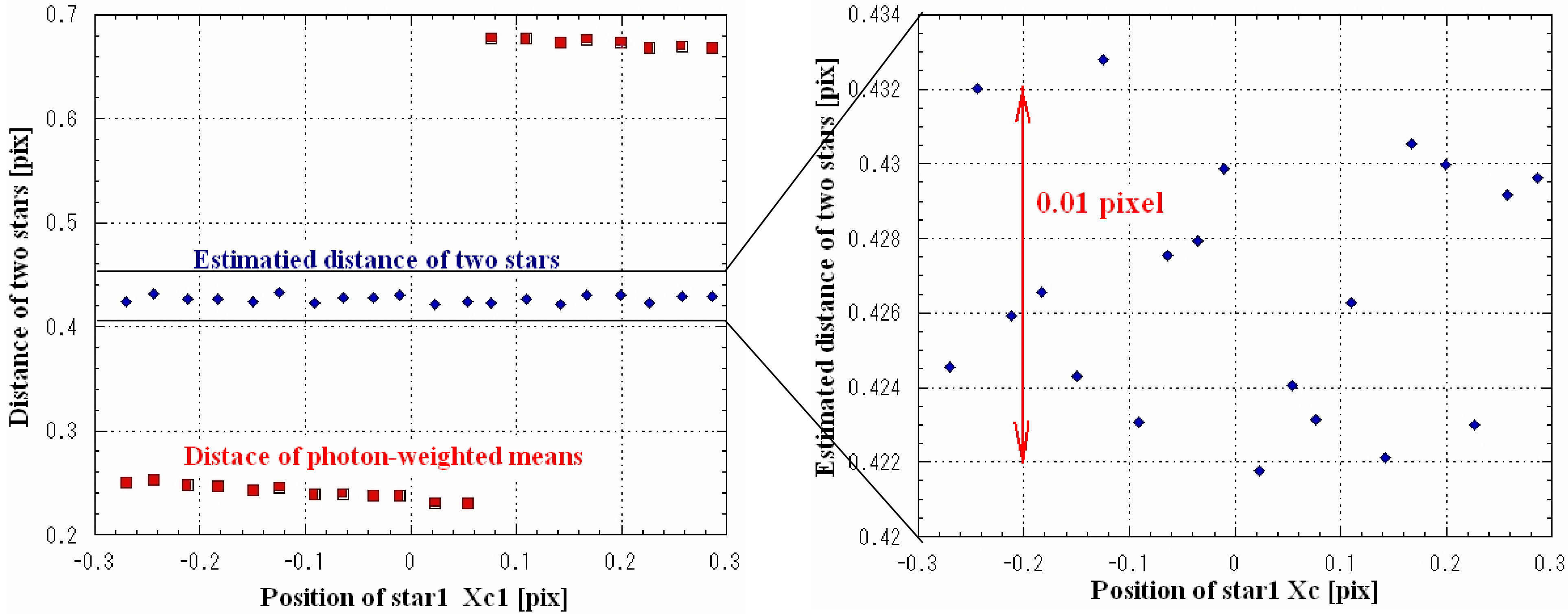
xa: real position of a star

5. Estimate the parameter k from the several images using the least square method

Experimental Equipment



Result 1



■Distance between the photon-weighted mean of two stars

◆Estimated distance between two stars (linear Correction)

We obtained the variance of less than 10^{-2}pixel for one exposure.

Experiment 2

1. Determination of the position with a precision of about 10^{-2} pixel for one exposure

2. Determination of the position with a precision of about 10^{-4} pixel using about 10^4 images

To the 10 microarcsec

We would like to determine a position of a star with a precision of about 10^{-4} pixel using about 10^4 images.

However if there exist systematic error which we do not realize, variance does not decrease according to $1/\sqrt{N}$.

We must remove the systematic errors using a model or control them so that we can neglect them.

In our experiment, we control the systematic errors.

control: ex. chromaticity effect ⇒we use same colors for all stars

Method

- Obtain many images (In this case, 8000 images)
- Calculate the mean distance and variance from one set of 10 images.
- Calculate the mean distance and variance from one set of the above 10 values

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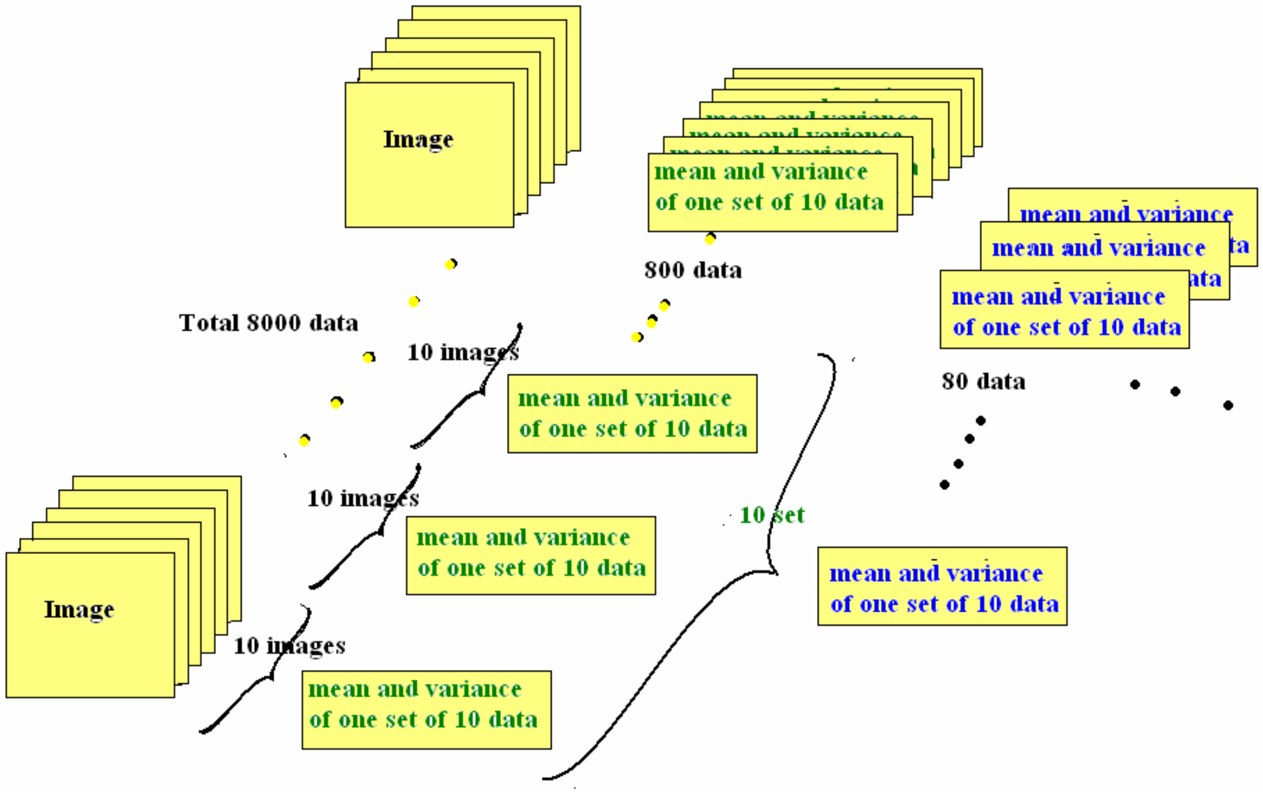
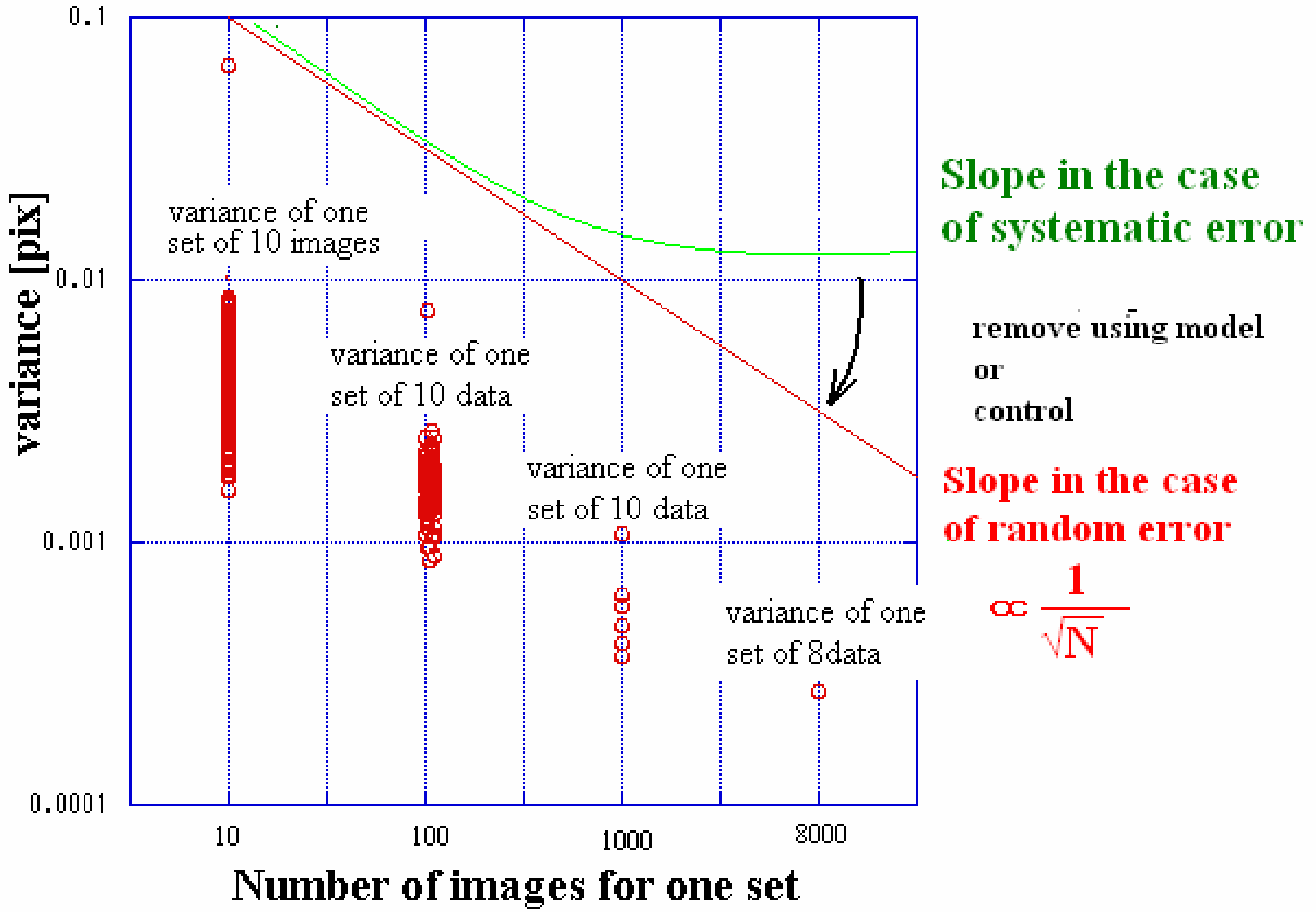


Result 2 (Variance vs. Number of images)



- variances decrease according to the slope in the case of random error.
- We do not find a systematic error which we do not realize.

Summary and the Future plan

Summary

- We obtained the precision of less than 10^{-2}pixel for one measurement.
- positional error decrease according to the slope in the case of random error ($1/\sqrt{N}$).

Future plan

- We will obtain much more data to improve the statistical errors.
- We will remove the systematic errors, such as the distortion of the image, chromaticity effect, irregularity of pixels using a model.
- We will experiment using a different algorithm, such as PSF fitting method.