*Formation and Evolution of Galaxy Bulges*
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# JASMINE: constructor of the dynamical structure of the Galactic bulge

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**Abstract.** We introduce a Japanese space astrometry project which is called JASMINE. JASMINE (Japan Astrometry Satellite Mission for INfrared Exploration) will measure distances and tangential motions of stars in the Galactic bulge with yet unprecedented precision. JASMINE will operate in z-band whose central wavelength is 0.9 micron. It will measure parallaxes, positions with accuracy of about 10 micro-arcsec and proper motions with accuracy of about 10 micro- arcsec/year for the stars brighter than z=14 mag. The number of stars observed by JASMINE with high accuracy of parallaxes in the Galactic bulge is much larger than that observed in other space astrometry projects operating in optical bands. With the completely new "map of the Galactic bulge" including motions of bulge stars, we expect that many new exciting scientific results will be obtained in studies of the Galactic bulge. One of them is the construction of the dynamical structure of the Galactic bulge. Kinematics and distance data given by JASMINE are the closest approach to a view of the exact dynamical structure of the Galactic bulge.

Presently, JASMINE is in a development phase, with a target launch date around 2016. We comment on the outline of JASMINE mission, scientific targets and a preliminary design of JASMINE in this paper.

**Keywords.** infrared: general — astrometry — Galaxy: bulge

## 1. Introduction

### 1.1. *JASMINE project*

Understanding the Galaxy in which we live is needed to clarify the formation history of galaxies, stars and human beings. For a quantitative analysis of the Milky Way properties, distances and two-dimensional (better three-dimensional) motions of stars are needed. Most of the stars, and a lot of interesting dynamics, are found at low Galactic latitudes, in crowded fields such as the Galactic bulge: measuring their astrometric parameters accurately is of prime importance. JASMINE is a satellite mission to provide distances and transverse motions of stars in the Galactic bulge (Gouda *et al.* 2007).

Bulges in spiral galaxies are the key to study galaxy formation and the evolution of galaxy types. However, the size, shape and kinematical properties of even the bulge in our Galaxy are pending problems. If we understand the fundamental information on the dynamical structure such as the gravitational potential and phase space distribution function of all matter in the Galactic bulge, we can get the correct shape and size of the bulge, density distribution of all matter, mean streaming, velocity dispersions and so on. To know this fundamental information requires access to all matter which we cannot observe directly by electromagnetic waves. This is provided by gravity because all matter, by definition, has mass which generates the gravitational potential. The gravitational potential determines the characters of stellar orbits. Hence we can estimate the gravitational potential and the phase space distribution function using the characters of observed stellar orbits. Hence to know many stellar orbits in the bulge is very important for the construction of the dynamical structure of the bulge. Information on stellar orbits can be provided by astrometric measurements. So we would like to emphasize that "astrometric eye" is very important to construct the dynamical structure.

### 1.2. *Space astrometry projects*

Astrometric measurements provide fundamental parameters of stars such as absolute trigonometric parallaxes, positions on the celestial sphere and annual proper motions. These parameters allow to derive distances and space motions of stars. This information is fundamental for many branches of astronomy and astrophysics. Improvement of astrometric measurements enables advances across numerous branches of astronomy and astrophysics.

The Hipparcos satellite was launched to measure astrometric parameters without being limited by atmospheric turbulence, refraction, etc., that affect ground-based measurements. Hipparcos provided remarkably interesting results in many fields of astronomy (Kovalevsky 1998). However, the accuracy of the astrometric parameters obtained by Hipparcos is not good enough to study the dynamics and kinematics in the Galaxy as a whole. As observed values are affected by random errors and selection effects, distance estimates can be biased. The "bias" means that the true distance will differ from the distance derived using an observed parallax with associated random errors. Various kinds of bias exist, such as Lutz-Kelker bias (Arenou & Luri 1999). Such bias effects are negligible when the parallax uncertainty, $\sigma/\pi$, is smaller than 0.1 (10% error). Here $\pi$ is a trigonometric parallax of a target star and $\sigma$ is its observational error. When observational errors are larger than about 10%, bias effects are important and a statistical treatment should be used to correct for bias effects. However, it is difficult to find "correct" statistical treatments. Thus, observational errors smaller than 10% are desirable to obtain reliable distances from observed parallaxes. The accuracy of Hipparcos' parallaxes is about 1 mas. This implies that reliable distances can be obtained only for stars closer than about 100 pc. Accurate distances to stars 10 kpc away (annual parallax is 100 $\mu$as) are required to investigate the bulge, halo and inner disk structures of the Galaxy. Hence, a level of 10 $\mu$-as accuracy is necessary. Several plans for astrometric missions able to achieve this level of the accuracy are presently proposed.

Proposed space projects employing optical astrometry are GAIA, SIM, and OBSS (refer to URL of each mission in the reference list). GAIA is a survey-type astrometric mission proposed by ESA. GAIA intends to measure positions and parallaxes accurate to 7 $\mu$as at V= 10 mag and 10 $\sim$ 25$\mu$as at 15 mag. OBSS is a survey-type mission proposed by USNO. OBSS will measure parallaxes accurate to 10 $\mu$as at V= 14 mag; its limiting magnitude is V= 23 mag for the bulge region. Also a pathfinder project to achieve an accuracy of mas, using a micro-satellite (MAPS), is proposed by USNO . SIM is a mission of NASA, using an optical interferometer with a 9 m baseline. SIM will be a pointing instrument that will observe selected targets of about $10^4$ stars brighter than V = 20 mag. SIM can measure absolute parallaxes accurate to 4 $\mu$as.

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In Japan, JASMINE will measure astrometric parameters in an infrared band. That is advantageous to observe stars in the Galactic plane, hidden by interstellar dust at optical wavelengths.

## 2. JASMINE mision

### 2.1. *Outline of JASMINE*

JASMINE is an astrometric mission that observes in the infrared (z-band: central wavelength is 0.9 $\mu$m, bandwidth is 0.2 $\mu$m). It is designed to perform a survey towards the Galactic bulge (20°(along the galactic longitude) × 10°(along the galactic latitude)), determining positions and parallaxes accurate to ∼10 $\mu$as for stars brighter than z = 14 mag, and proper motion errors of ∼ 10$\mu$as/yr. JASMINE can detect about one million bulge stars with $\sigma/\pi \leqslant 0.1$, about 1000 times more than the number of stars measured by GAIA (about 400 stars) in the survey area of JASMINE. This was derived using the modified Galactic model whose original one was made by Cohen and his co-workers (Cohen 1994; Cohen 1995; Cohen, Sasseen & Bowyer 1994; Wainscoat *et al.* 1992).

The Hipparcos and GAIA missions perform an all-sky survey. These satellites, while rotating, observe simultaneously two fields of view, separated by a large angle, the "basic" angle. Tracing great circles allows to achieve their intended resolution: fields of view can be linked based on this basic angle. JASMINE will not observe two fields of view simultaneously, but will observe only one field of view ("small-field"). Here, a whole survey region is composed by linking stars in an overlap region between two consecutively observed small-fields. This is called the "frames-link" method (Gouda *et al.* 2007). This method can be used when the number of stars in each small-field is so large that a large-frame of the whole survey region can be made with the required accuracy. The star density in the Galactic bulge is sufficient to apply this method.

### 2.2. *Scientifc targets*

The main scientific target of JASMINE is, as described before, to clarify the structure, dynamics and kinematics of the Galactic bulge. We believe that problems on the bulge growth, which is related to the Hubble type, and the activity of the Galactic center can be addressed, using the dynamical and kinematical structures obtained by JASMINE. We are now investigating a construction method of the dynamics, in which the gravitational potential and phase space distribution function can be estimated by using the information on many stellar orbits (refer to the paper by Yano in this proceedings).

Furthermore the astrometric parameters of the many stars in the bulge, obtained by JASMINE, will have a large impact on star formation knowledge. For example, JASMINE will provide such distances and absolute luminosities of stars in the bulge to estimate the initial mass function of the stars. Moreover, the fraction of lensing events is about $10^{-3}$ and so about $10^4$ lensing events are expected.

### 2.3. *Preliminary instrument design*

A candidate for the optics of the JASMINE telescope is a modified Korsch system (Korsch 1977) with three mirrors and four folding flats to fit the focal length into the available volume . The telescope has a circular primary mirror with ∼ 75 cm diameter and 22.5 m focal length.

The telescope provides a flat image plane that contains an array of large format CCDs with a field of view of 0.7° × 0.7°. A total of 81 2k×2k CCDs with 15 $\mu$m square pixels are read out. JASMINE will observe in the infrared z-band and thus CCDs with a very high z-band sensitivity are necessary. A new, suitable, CCD type has been developed in collaboration with a Japanese company. This will be a set of back-illuminated, fully-depleted CCD's, with a quantum efficiency of about 90%.

## 3. Nano-JASMINE project

A nano-JASMINE project is planned to demonstrate space astrometry in Japan and to examine some technical issues for JASMINE (Kobayashi *et al.* 2006; Suganuma *et al.* 2006). Nano-JASMINE uses a nano-satellite whose size and weight are about 40 $cm^3$ and 14 kg, respectively. The size of the telescope is reduced to 5cm diameter with a focal length of about 1.7m. One CCD with 1k $\times$ 1k pixels will be put in the focal plane. A candidate orbit for Nano-JASMINE is a sun-synchronous orbit. We will examine damage due to radiation on the CCD, on-board processing, thermal variations of the optical system and so on. The cost of Nano-JASMINE is low and it will be launched around 2009. The development of the spacecraft is ongoing, in collaboration with Prof. Nakasuka and his group at the University of Tokyo.

## 4. Management and schedule

The establishment of a JASMINE working group at JAXA was approved in 2003 by a science committee of ISAS (Institute of Space and Astronautical Science) of JAXA. The working group includes about 80 scientists and engineers. JASMINE project office has been established at NAOJ(National Astronomical Observatory of Japan) since 2004. The basic design of JASMINE and technical problems have been investigated in collaboration with JAXA and some universities in Japan. We aim at a proposal for the JASMINE mission to JAXA, to get launch approval and the required budget from the Japanese government around 4 years later. We hope that JASMINE will be launched in around 2016. It takes a long time to get the accurate astrometric parameters in the Galactic bulge. We would like to ask you for your continuous encouragement and cooperation.

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GAIA:http://www.rssd.esa.int/index.php?project=GAIA

SIM:http://planetquest.jpl.nasa.gov/SIM/

OBSS:http://ad.usno.navy.mil/OBSS/

JASMINE:http://www.jasmine-galaxy.org/index.html