JAPAN ASTROMETRY SATELLITE MISSION FOR INFRARED EXPLORATION (JASMINE)

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ABSTRACT

We introduce a Japanese plan for infrared (z-band: 0.9μm) space astrometry (the JASMINE project). It will measure parallaxes, positions with the accuracy of 10 μas and proper motions with the accuracy of 10 μas/year for stars brighter than z $\sim$ 14 mag. JASMINE can observe about one hundred million stars belonging to the disc and bulge components of our Galaxy, which are hidden by the interstellar dust extinction in optical bands. The number of stars with $\sigma_\pi/\pi < 0.1$ in the direction of the Galactic central bulge is about 10^3 times larger than those observed in optical bands.

The main objective of JASMINE is to provide very useful and important astrometric parameters for studying fundamental structures and evolutions of the disc and bulge components of the Milky Way Galaxy. Furthermore the astrometric parameters given by JASMINE will give us exact absolute luminosities and motions of many stars in the bulge and the disc far away from us and so it will promote the study of stellar physics. The information from infrared astrometry that JASMINE will provide is very useful also for investigating stars in star formation regions, gravitational lens effects due to disc stars, extra-solar planets, etc. We hope that JASMINE, which is due to be launched in around 2014, can be complementary to Gaia for surveying the bulge and the disc far away from us.

Furthermore, we introduce a Nano-JASMINE project which uses a nano-satellite whose size is about 30 cm^3 and whose weight is a few kilograms. The objective of Nano-JASMINE is verification of the observing strategy adopted in JASMINE and examination of some important technical issues for the JASMINE project. It will be launched around 2006.

Key words: JASMINE; Infrared space astrometry; Galaxy: bulge.

1. INTRODUCTION

The success of Hipparcos has triggered several proposals for astrometric satellites that would observe more stars with better accuracies than those of Hipparcos. We need better astrometry because a significant increase in the accuracy and the number of parallaxes and proper motions would yield remarkable advances in understanding the kinematics and dynamics of the Galaxy and furthermore in the fields of stellar evolution, extra-solar planets and the extragalactic distance scale.

If we have parallaxes with errors larger than about 10%, we would have some biases in deriving distances from the parallaxes and so we could not determine the distances with sufficient accuracy. The accuracy of the parallaxes in Hipparcos is about 1 mas, and then we cannot accurately evaluate the distances of the stars which are about 100 pc or more distant from us using the parallaxes given by Hipparcos. Accurate distances of stars which are at least around 10 kpc distance from us are required in order to investigate the bulge component and the inner disc structure of the Galaxy. Hence we need a level of 10 μas accuracy of the parallax. Proposed astrometric satellites perform astrometric measurements with this level of accuracy.

The proposed space projects of optical astrometry are Gaia and SIM. It should be noted that both Gaia and SIM observe stars in optical bands. In Japan, we have an infrared space astrometry project which is called JASMINE. It will measure astrometric parameters in the infrared band (z-band: 0.9μm) . JASMINE has the advantage of observing stars on the Galactic plane which are hidden by the interstellar dust in optical bands. JASMINE will perform an astrometric survey of the Galactic plane, determining positions and parallaxes accurate to 10μas for stars brighter than z = 14 mag, with proper motion errors of $\sim$ 10μas/year. JASMINE will observe about 100 million stars around the bulge and disc of the Galaxy.

In this paper, we introduce the outline of the JASMINE project. In Section 2, we describe the scientific objectives of JASMINE and the advantage of infrared space astrometry. We briefly review a mission design, an instrument design and a spacecraft system in Sections 3, 4 and 5, respectively. In Section 6 a management plan of JASMINE is briefly mentioned. Finally, Section 7 describes a summary.

2. SCIENTIFIC OBJECTIVES & ADVANTAGE OF INFRARED ASTROMETRY

JASMINE will provide the astrometric parameters to promote studies in many branches of astronomy and astrophysics. One of the most important scientific objectives among them is the formation, evolution and structure of the Milky Way Galaxy. The quantitative analysis of the Galaxy needs distances, 2-dimensional (better 3-dimensional) motions of stars in the Galaxy. Especially, most of the stars, and almost all of the interesting dynamics, are found at low Galactic latitudes, in crowded fields. So there is a great requirement to measure accurate astrometric parameters of stars in the fields at low Galactic latitudes. On the other hand, the light in optical bands from the stars at low Galactic latitudes is effectively absorbed by the interstellar dust. This extinction effect decreases both the number of observable stars and the accuracy of the astrometric parameters. So we need to measure the astrometric parameters in near-infrared bands which penetrate the obscuring dust. Here we will explain the necessity of infrared astrometry based on the quantitative analysis using a Galaxy model.

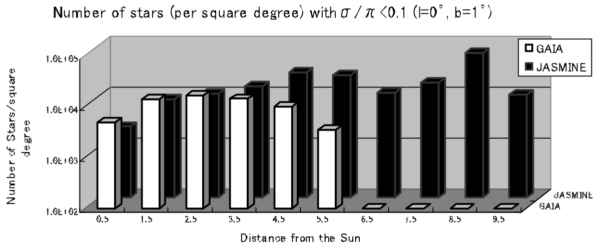

Figure 1. Number of stars (per square degree) measured with $\sigma_\pi/\pi \leq 0.1$ toward the direction of $\ell = 0°$ and $b = 1°$

JASMINE performs the unique astrometric measurements in the infrared band (z-band: 0.9μm) in order to get the accurate astrometric parameters of many stars on the Galactic plane. For example, Figure 1 shows the expected numbers of stars per square degree to be observed with $\sigma_\pi/\pi \leq 0.1$, estimated using our Galaxy model. Here π is the parallax and σ_π is an error of the parallax. This model is based on the "sky" model developed by Cohen and his collaborators (Wainscoat et al. 1992; Cohen 1994; Cohen et al. 1994; Cohen 1995). The center of the field of view is pointed toward Galactic longitude $\ell = 0°$ and Galactic latitude $b = 1°$. The horizontal line represents the distance from us. The Galactic centre is assumed to be at 8.5 kpc. The black histogram shows the number of the stars evaluated for JASMINE's z-band observations while the white histogram shows those for V-band observations with the parallax accuracies of 10 μas accuracy at V = 15 mag. We can see from Figure 1 that the number of stars observed in the z-band is much larger than that observed in the V-band at distances of more than a few kpc away from the Sun on the Galactic plane. JASMINE can detect about 7.3 × 10^5 stars of the bulge within the survey area of JASMINE ($|b| \leq 4.0°, \ell = 0° \sim 360°$) with $\sigma_\pi/\pi < 0.1$.

The confusion limit could be a problem. That is, it may not be possible to accurately determine the position of the stars fainter than the confusion limiting magnitude due to the contamination in crowded regions. We estimated the confusion limit magnitude in the survey area of JASMINE using our Galaxy model. We found that the minimum magnitude of the confusion limit, which is achieved around the center of the Galaxy, is z = 18 mag. This value is above the limiting magnitude of JASMINE ($\sim$ 17 mag) and then we need not worry about the confusion limit for JASMINE.

3. MISSION DESIGN

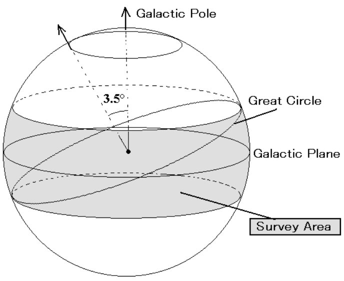

Figure 2. The JASMINE spacecraft precesses around the Galactic pole in about 37 days and the sky area around the Galactic plane is scanned during this precession.

A possible candidate orbit for JASMINE is a Lissajous orbit around the Sun-Earth Lagrange point L2 because the region provides a very stable thermal environment, minimization of eclipses, and so on. The launch strategy is based on a dual launch with a H-IIA rocket of JAXA or a GX-rocket in Japan. The mission lifetime will be 5 years.

The JASMINE spacecraft rotates slowly with a period of about 5 hours with a rotation axis perpendicular to the viewing directions of two fields of view. JASMINE observes two fields of view separated by a basic angle of 99.5° simultaneously.

The rotation axis of the JASMINE spacecraft will be aligned 3.5° from the spacecraft-Galactic pole line as shown in Figure 2. The precession of the JASMINE spacecraft will be forced and JASMINE can survey the Galactic plane with a region of 360° (along the Galactic longitude) × 8° (along the Galactic latitude: 3.5°×2+1°(F.O.V)) with a precession period of about 37 days as shown in Figure 2.

The direction toward the Sun from the spacecraft overlaps with that of the Milky Way in two quarters of a year (summer and winter seasons). In these seasons, the spin axis of the JASMINE spacecraft is changed to be almost perpendicular to the Galactic pole-spacecraft line and then JASMINE observes toward the halo regions instead of the Milky Way. The observing mode for the Milky Way is then restricted to one half of the total mission life.

4. INSTRUMENT DESIGN

The JASMINE instrument uses a beam combiner to observe two fields of view simultaneously. The effective field of view is 0.23 square degrees. The beam combiner consists of two flats that feed a common telescope with fields of view separated by the basic angle of 99.5°. The value of the basic angle should be such as to avoid unwanted correlations of measurements on successive scans and so its value should not be an integer divisor of 360°. These values are ideally determined by limits of certain Fibonacci series. The basic angle of about 99.5° is near the limit of a Fibonacci series in which the first and the second term are $2\pi/3$ and $2\pi/4$, respectively.

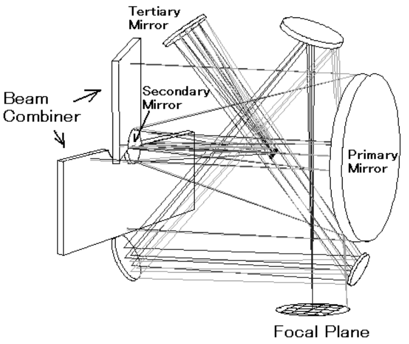

Figure 3. Optics of the JASMINE telescope.

The two fields of view are fed into a common telescope with 50 m focal length and a circular primary mirror with 1.5 m diameter. The JASMINE telescope has three mirrors (modified Korsch system) with 4 folding flats to fit the back focal length into the available volume (Figure 3; see also Yano et al. (2005)). A candidate material for the telescope is a new, high-strength, reaction-sintered silicon carbide (RS-SiC) which is now being developed at a Japanese company.

The telescope provides a flat image plane consisting of an array of large format CCDs. A total of 98 4k×2k CCDs with 15 μm square pixels are read out in TDI mode to transfer the charge across the devices at the same rate that the images are moving due to the spacecraft rotation. TDI mode makes it possible to decrease the effect of readout noise on the signal of star images. JASMINE observes in the z-band and so we need CCDs whose sensitivity is very high in the z-band. We are developing a new type of CCD in collaboration with a Japanese company. This is a back-illuminated, fully-depleted CCD image sensor. The quantum efficiency of the CCD will be about 90% in the z-band.

5. SPACECRAFT SYSTEM

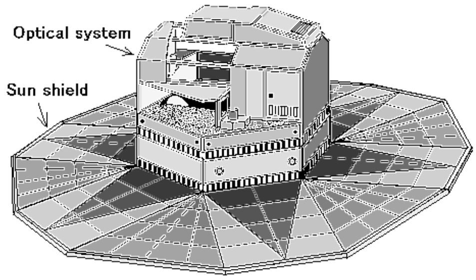

Figure 4. Schematic figure of the JASMINE spacecraft.

The JASMINE spacecraft system has been investigated in collaboration with the Japan Aerospace Exploration Agency (JAXA).

The spacecraft rotates slowly and precesses as described in Section 3. A 3-axis stabilization will be carried out during the observation phase. The attitude control system must meet stringent requirements on the instrument line-of-sight stability, as well as on the spin-axis pointing and rate measurements during the operation mode. The relative pointing error of 60 mas is required during 3.5 s in order to avoid blurring during each sub-field of view integration time period of 3.5 s. Absolute pointing error is about 3 arcmin in order that a coming spiral band after one revolution can overlap along the cross-scan direction at least a 1/8 region of the spiral band observed just before.

High stability in the opto-mechanical aspects of the payload is required in the JASMINE spacecraft. In particular, high stability of the basic angle of the beam combiner is required over the satellite revolution period (5 hours). The short-term basic angle stability over 5 hours is the only critical parameter so far identified which cannot be properly calibrated by on-ground data processing. A basic angle stability of 10 μas rms should be attainable. A basic angle variation of 10 μas rms corresponds to the thermal gradient variation of $\sim$ 1 mK at the beam combiner. We are examining methods of thermal control in the JASMINE spacecraft. If such a stability cannot be attained, we should measure the variation of the basic angle with an accuracy of 10 μas. We are investigating measurement devices such as a wave-front sensor.

We have other technical problems beside those described above. The investigations are going on in collaboration with JAXA. Furthermore, we plan a Nano-JASMINE project whose objective is the verification of the observing strategy and the examination of some technical issues in JASMINE. Nano-JASMINE uses a nano-satellite whose size and weight are about 30 cm^3 and a few kg, respectively. The definition of a “nano-satellite” is that the range of its weight is between 1 kg and 10 kg. The size of the telescope is reduced to 5 cm diameter of a primary mirror with a focal length of about 1.7 m. We put one CCD with 1k × 1k pixel on the focal plane. The candidate orbit is a Sun-synchronous orbit. The primary objective of Nano-JASMINE is the verification of the observing strategy adopted in JASMINE such as a great circle reduction. Furthermore, we will examine the operation of the TDI mode on the new type of CCD, damage due to radiation on the CCD, on-board processing, thermal variation of the basic angle and so on. The cost of Nano-JASMINE is low and it will be launched in 2 or 3 years. The development of the spacecraft is going on in collaboration with Professor Nakasuka and his group at the University of Tokyo. His group successfully launched a nano-satellite, Cube-Sat(XI-IV), in June 2003.

6. MANAGEMENT OF JASMINE

The establishment of the JASMINE working group at JAXA was approved last year by a science committee of ISAS (Institute of Space and Astronautical Science) of JAXA. The working group includes many scientists and engineers, and they are investigating the basic design of JASMINE and technical problems. The working group aims at a proposal of the JASMINE mission to JAXA to get an approvement of launch in 4 or 5 years.

7. SUMMARY

JASMINE will measure parallaxes, proper motions and positions of about one hundred million stars mainly within the central bulge and disc components of the Galaxy. JASMINE aims at the high precision astrometry of 10 μas for stars brighter than z $=$ 14 magnitude in z-band. The primary scientific goals of JASMINE are to clarify the structure and evolution of the bulge and the disc. The instrument parameters and scanning law of JASMINE are summarized in Tables 1 and 2, respectively.

Jasmine is the name of a flower and means elegance. We greatly hope that JASMINE will be *elegantly* successful in future. For further details please refer also to the JASMINE web page: http://www.jasmine-galaxy.org/index.html.

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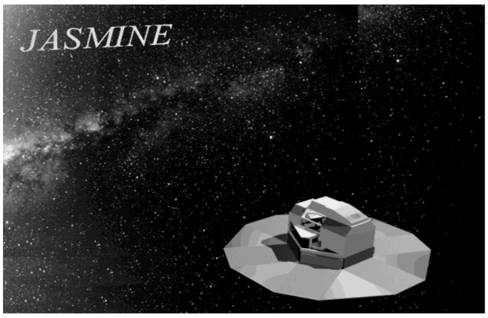

Figure 5. An artist's impression of the JASMINE spacecraft.

Table 1. Summary of the instrument parameters.

Optics design	Korsch System (3 mirrors)
Aperture size	1.5 m
Focal length	50.0 m
pixel size	15 μm
pixel on sky	61.9 mas
Array size	6cm$\times$3 cm
Pixels per detector	4096 $\times$ 2048
Number of detectors	98 (7 $\times$ 14)
Basic Angle	99.5°

Table 2. Summary of the scanning law.

Mission Time	5 years
Rotation Period	5.0 hours
Precession Period	36.9 days
Rotation Axis	around the Galactic Pole
Launcher	H-II A or GX
Orbit	Lissajous orbit around the Sun-Earth L2 point

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