# Introduction of Japanese astrometry satellite mission for infrared exploration(JASMINE)

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## ABSTRACT

We introduce a Japanese future plan of the IR space astrometry(JASMINE-project). JASMINE is an infrared(K-band) scanning astrometric satellite. JASMINE(I and/or II-project) is planned to be launched between 2013 and 2015 and will measure parallaxes, positions and proper motions with the precision of 10 microarcsec at K=12∼14mag. JASMINE can observe about a few hundred million stars belonging to the disk and the bulge components of our Galaxy, which are hidden by the interstellar dust extinction in optical bands. Furthermore JASMINE will also measure the photometries of stars in K, J and H-bands. The main objective of JASMINE is to study the fundamental structure and evolution of the disk and the bulge components of the Milky Way Galaxy. Furthermore its important objective is to investigate stellar physics.

**Keywords:** astrometry, infrared, the Galaxy, stellar physics

## 1. INTRODUCTION

Astrometry is the part of astronomy which provides positions, trigonometric parallaxes(distances) and proper motions of objects on the celestial sphere. If we have furthermore information on radial velocities of the objects, we can see the 6-dimensional phase space densities of the objects. Needless to say, this information is most fundamental in many fields of astronomy and astrophysics. For example, the 6-dimensional phase space densities of stars in our Galaxy will give us dynamical structures of star clusters and the Milky Way. Moreover an accurate distance of a star brings us the accurate luminosity of the star. The information of the accurate luminosity is useful for distance indicators and necessary for analyzing stellar physics. Furthermore motions of each star will bring us information on physical characters of binary systems and the information of the motions is also useful to detect planetary systems outside the solar system.

Hipparcos satellite has offered more accurate information on the astorometric parameters rather than that measured on the ground. The parallax accuracy is about 1 milli-arcsecond(mas). This accuracy corresponds to 10% distance error at 100pc. The proper motion accuracy of 1 mas/year given by Hipparcos corresponds to the velocity error of $\sim 5$ km/s at 1kpc. The astrometric measurement by Hipparcos has certainly brought us a revolution in astronomy and astrophysics. But it is still a small revolution. We need a parallax accuracy of less than $\sim 10\%$ error because errors larger than $\sim 10\%$ cause bias effects when we convert the parallax to the distance. Then in Hipparcos we can measure distances of stars accurately only within 100pc. In this case, we have only a few interesting stellar objects in this area. Figure 1 shows "the Milly Way". The small circle(radius of 100pc) around the Sun is the horizon for distances accurate to 10% by Hipparcos.

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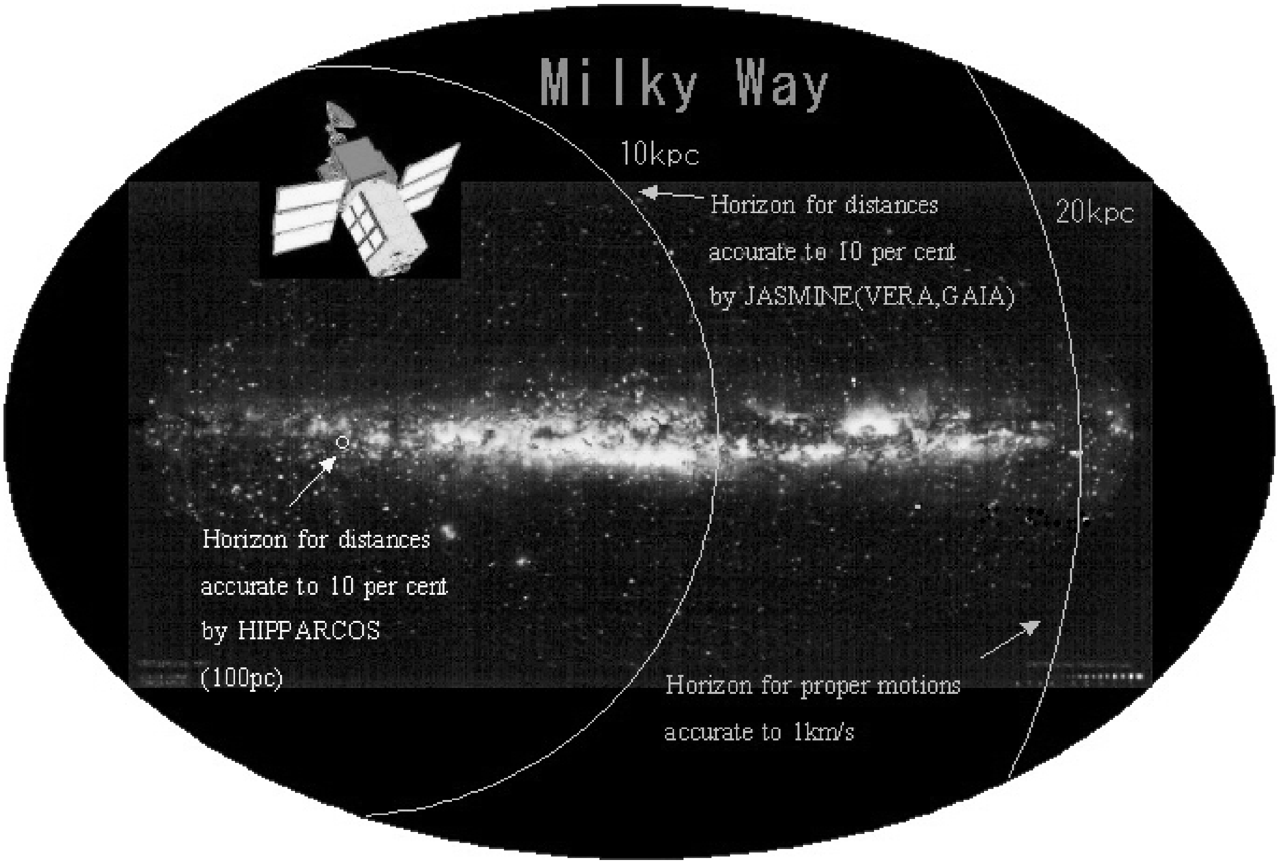


**Figure 1.** The horizons for distances accurate to 10% by Hipparcos(100pc) and JASMINE(VERA, GAIA)(10kpc) in the Milky Way. The horizon of proper motions accurate to 1km/s in JASMINE(VERA,GAIA)(20kpc) is also shown.

**Table 1.** Summary of Space Astrometory Projects

| Mission | Agency | Launch | # of stars | Mag.limit | Accuracy |
|---|---|---|---|---|---|
| Hipparcos | ESA | 1989 | 120000 | 12 | 1mas@V=10 |
| DIVA | Germany | $\sim$ 2006 | 35 million | 15 | 190$\mu$mas@V=10 |
| FAME | USNO(U.S.A) | ??? | 40 million | 15 | 50$\mu$mas@V=9 |
| SIM | NASA | $\sim$2009 | 10000 | 20 | 4$\mu$mas@V=20 |
| GAIA | ESA | $\sim$ 2012 | 1 billion | 20 | 10$\mu$mas@V=15 |

In future, we need big revolutions by high accurate astrometric measurements. We require a parallax accuracy of $\sim 10\mu$as. This accuracy corresponds to 10% distance error at 10kpc(see figure 1). The tangential velocity error is 1km/s at 20Kpc(see figure 1). These astrometric measurements will certainly cause breakthrough in many fields of astronomy and astrophysics.

## 2. FUTURE SPACE ASTROMERY PROJECTS

Table1 summarizes the future space astrometry projects in the western countries. DIVA, FAME and GAIA are telescope-types and SIM is an interferometer-type. It should be noted that all space projects described here will observe in optical bands. On the other hand, in our JASMINE-project, we will operate the near infrared (K-band;2.2$\mu$m) because the near infrared measurement has some advantages which will be described in §3. Please refer to each web-page for detailed explanations of the other space astrometry projects (DIVA:http://www.ari.uni-heidelberg.de/diva/, FAME:http://www.usno.navy.mil/FAME/, SIM:http://sim.jpl.nasa.gov/index.html, GAIA:http://astro.estec.esa.nl /SA-general/Projects/GAIA/).

Furthermore, VERA-project is the revolutionary important project of radio interferometer on the ground to measure the astrometric parameters with the accuracy of 10$\mu$as(http://veraserver.mtk.nao.ac.jp/index.html). It will start operating in 2003 or 2004.

## 3. JASMINE-PROJECT

JASMINE(Japanese Astrometry Satellite Mission for INfrared Exploration) is a scanning satellite for infrared exploration[1]. JASMINE is planned to measure parallaxes, positions and proper motions of stellar objects in K-band with the precision of 10$\mu$as at $K = 12 \sim 14$mag. We can measure a few hundred million stars around the bulge and the disk of our Galaxy. Furthermore we will measure photometries in J, H and K-band. Infrared astrometry is important for the investigations of obscured objects when studying the bulge, the galactic plane and star formation regions: Interstellar dust hides the visible light of stellar objects located at low galactic latitudes. The inteterstellar extinction depends on the wavenumber and it is much smaller in K-band than that in optical bands. Then we can see more stars in K-band rather than those in optical bands.

We calculated the expected number of stars to be observed by JASMINE using our Galaxy model. This model is based on the "sky" model developed by Cohen and his collaborators[2~5]. We also took into account the dust map observed by DIRBE when we consider the dust extinction. Each panel of figure 2 shows the expected number of stars for $V \leq 15$, $K \leq 12$ and $K \leq 14$ at a distance $r$ from the sun. Parallaxes of better than 10$\mu$as accuracy will be provided for brighter stars than $V = 15$ , $K = 12$ and $K = 14$ for GAIA, JASMINE-I and JASMINE-II projects(see §4.1 and §4.2), respectively. We can see from figure 2 that the number of stars observed in K-band is much larger than that observed in V-band at the distance of more than a few kpc away from the sun on the galactic plane. Therefore we must operate in near infrared bands such as K-band if we would like to measure many objects in the galactic plane at a distance of more than a few kpc. This is one of the advantages for operating in K-band. Furthermore stars such as K-giants and M-giants which are considered to kinematically trace the galactic gravitational potential are bright in K-band. This is also an advantage for operating in K-band.

As for the scientific targets of JASMINE, we focus on the structure of the bulge at first. The morphology and kinematics of the bulge is very important information for solving the formation history of the bulge and our Galaxy itself. Furthermore it is very interesting to investigate the dynamical structure of the bulge from the point of view in physics(relaxation process, quasi-equilibrium structure *etc.*) of collisionless self-gravitating systems.

Second, the analysis of the stellar orbits on the disk plane is a big target. This analysis will clarify the origin of the spiral arms pattern and the nature of the stellar warp.

Third, JASMINE can pierce star formation regions where the visible light of stellar objects is buried by interstellar dusts.

The main objective of JASMINE is to study the fundamental structure and evolution of the disk and the bulge components of the Milky Way Galaxy. Furthermore its important objective is to investigate stellar physics. Observations of extra-galaxies near our Galaxy are also interesting targets of our JASMINE project.

## 4. PRELIMINARY DESIGN OF JASMINE

The accuracy of the astrometric parameters(position, parallax, proper motion per year) is roughly estimated as $\sigma \sim \lambda/D\sqrt{N}$. Here $\sigma$ is an error dispersion. $\lambda$ and $D$ are wavelength of photons and a diameter of mirror, respectively. $N$ is the number of detected photons of a target star during the observation period. Since observed number of photons obeys the Poisson distribution, the accuracy is proportional to $N^{-1/2}$. Then large $N$ is required in order to get high accuracy. So we need a large mirror and furthermore many good detectors for achievement of large F.O.V.(field of view) on focal planes. In the optical bands, we can use CCD detectors in which TDI(time delayed integration)mode, that is, drift scan mode, can be operated. In TDI mode, the rate

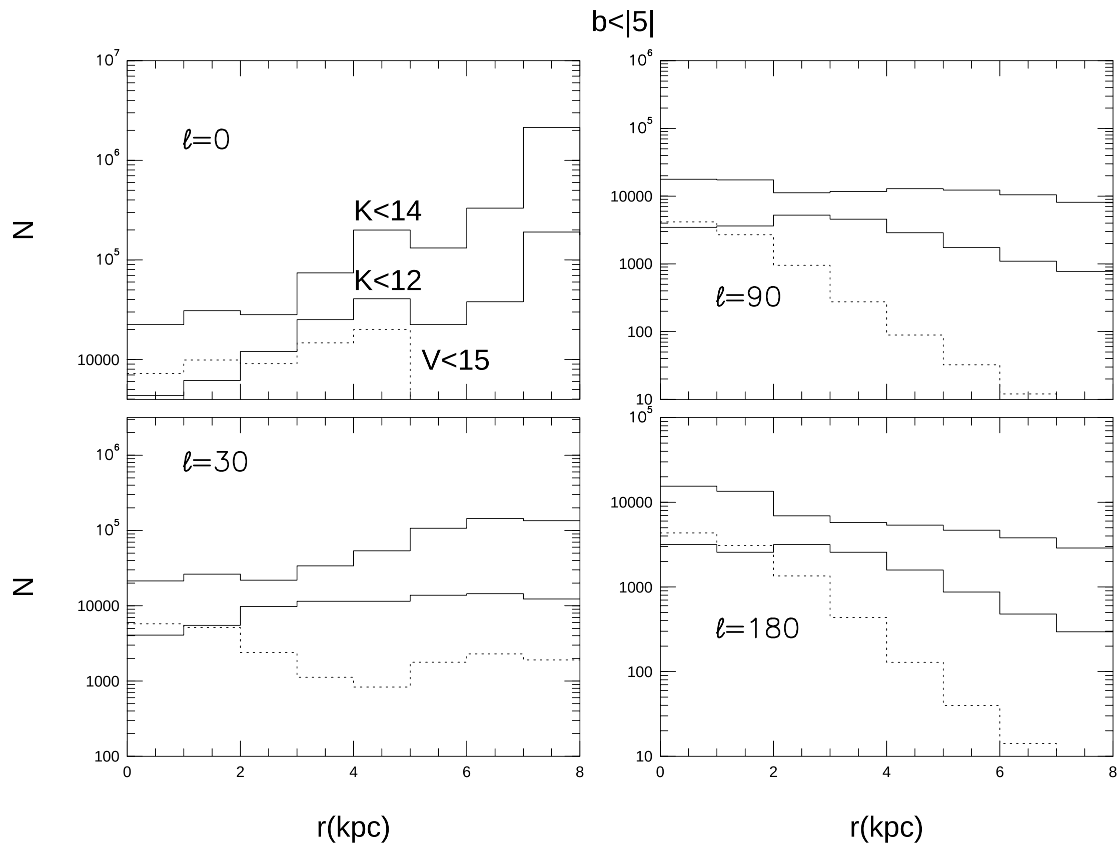


**Figure 2.** The expected number of stellar objects in the direction of the galactic longitude $\ell$ shown in each figure. The absolute value of the galactic latitude, $b$, of the field of view is restricted within $5^\circ$. The angular scale of the field of view along the galactic longitude is $1^\circ$. $N$ is the expected number of stars for V $\leq$ 15, K $\leq$ 12 and K $\leq$ 14, and $r$ is the distance from the sun.

of charge transfer rate is synchronized with the scan velocity of the spinning satellite. By using TDI mode, we can gather large number of photons without distortion of stellar images. However we do not have a good IR detector in which TDI mode can be used. This is one of the technical challenges in our project(see §5.2).

We plan the following two options in our project, JASMINE-I and JASMINE-II. The size of the instruments is smaller in JASMINE-I than in JASMINE-II and then the cost is less expensive. So JASMINE-I has high possibility for its early realization although the K-band magnitude at which 10$\mu$as accuracy can be achieved is reduced and the survey area is narrower than in JASMINE-II.

### 4.1. JASMINE-I project

JASMINE-I is planed to be launched in around 2013 by a rocket like M-V rockets of ISAS(Institute of Space and Astronautical Science) in Japan. JASMINE will be designed for operation in Sun-Earth L2 point.

As for the payload, the diameter of the primary mirror for the astrometric filed is 1.8m. The diameter of the F.O.V. is $0.4^\circ$. The focal length, $f$, is 66.6m. An example of optical configuration for the astrometric field is shown in Figure 3. The optical system is optimized for the astrometric measurement in K-band. So

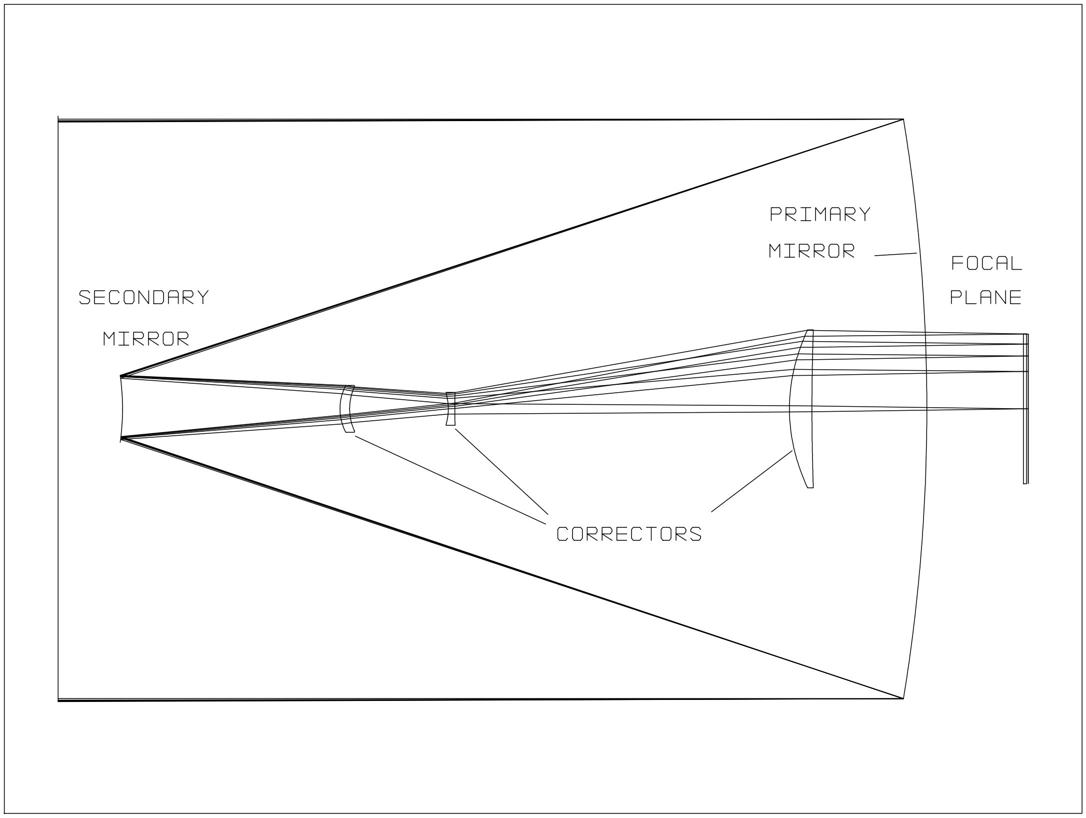


**Figure 3.** Optical configuration of the astrometric instrument for JASMINE-I. The optical system is optimized for the astrometric measurement in K-band.

the dispersion of the centric points of stellar images is very small and symmetric on the whole focal plane in K-band(see Figure 4).

On the astro-focal plane, we put about 80 detectors, such as HgCdTe for the astrometric field. The detector has 2048 × 2048 pixels of size 18.5 $\mu$m. On the focal plane, $\lambda f/Dw$ is equal to 4 pixels, where $w$ is the pixel size (18.5 $\mu$m). The effective filed of view for the astrometric filed is $0.25° \times 0.28°$.

JASMINE has other one or two small mirrors (the diameter is about 0.5m)beside the main mirror for the scientific targets. The extra mirror has the field of view separated by a large basic angle from the field of view of the main mirror. The objective of this extra small mirror is to measure the positions of bright stars in V-band (V≤10mag) as "guide" stars in order to obtain absolute parallaxes by directly comparing very different parallax factors and improve the rigid system of the star positions and proper motions by linking widely separated regions of the sky.

The accuracy of parallaxes and proper motions is about 10$\mu$as at K=12mag: Many stellar objects can be observed in K-band toward the direction of the galactic plane. We found from our calculations based on our Galaxy model that the contamination of background faint stars makes it impossible to achieve the accuracy of 10$\mu$as around the bulge for the fainter stars above 13 or 14 mag. So we take 12 mag as the largest magnitude for obtaining the astrometric parameters with such high accuracy of 10$\mu$as. In this case, the accuracy is about $\sim 4.0\mu$as on 10mag stars and $\sim 16\mu$as on 13mag stars. Furthermore, JASMINE will measure the photometries of stars in K, J and H-bands.

In this project, the primary objective is a survey of stellar objects only around the galactic plane and the bulge.

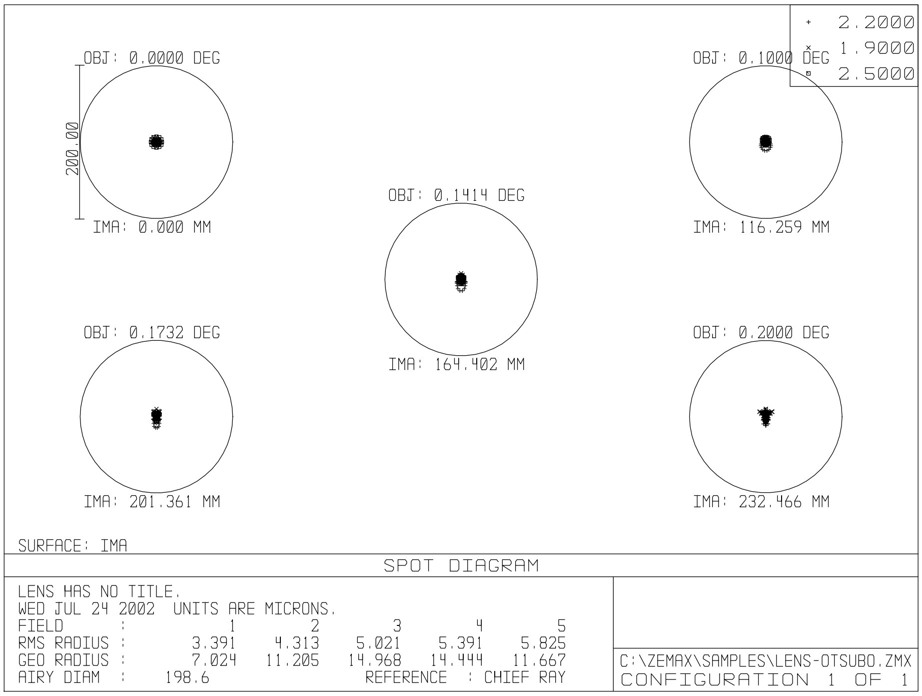


**Figure 4.** Spot Diagram in the optical configuration for JASMINE-I.

### 4.2. JASMINE-II project

Second one of our project is JASMINE-II project. JASMINE-II is planed to be launched around in 2015 by a H-IIA rocket which is larger than a M-V rocket. H-IIA rockets have been developed by NASDA(NAtional Space Development Agency of Japan). The first experimental launch of the H-IIA rocket succeeded on the 29th of August in 2001.

The main target in this project is the survey toward the whole galactic plane including the bulge. The accuracy of parallaxes and proper motions is about 10$\mu$as at K=14mag in the survey regions beside the galactic center region. The survey area is $360^\circ \times 10^\circ$. As for the payload, we will use a large primary mirror whose aperture is 3.6m$\times$1.8m for scientific targets. JASMINE has other small mirrors for measuring the positions of bright "guide" stars in V-band. On the astro-focal plane, we put about 130 detectors for the astrometric field.

## 5. TECHNICAL CHALLENGES OF JASMINE

We have many technical issues which have to be solved in order to realize our mission. The main issues are as follows.

### 5.1. Ultralight mirror

We need a large mirror to get many photons for achievement of high accurate astrometry. Furthermore the mirror is expected to be very light for a launch. Then we have to develop ultra lightweight mirrors suitable for M-V and H-IIA rockets. The development of ultra light mirrors is now eagerly challenged as a common issue in many space missions. Furthermore, in JASMINE project, the mechanical and thermal stability of the ultra light mirror is demanded in order to achieve the high accuracy for the measurements of stellar positions.

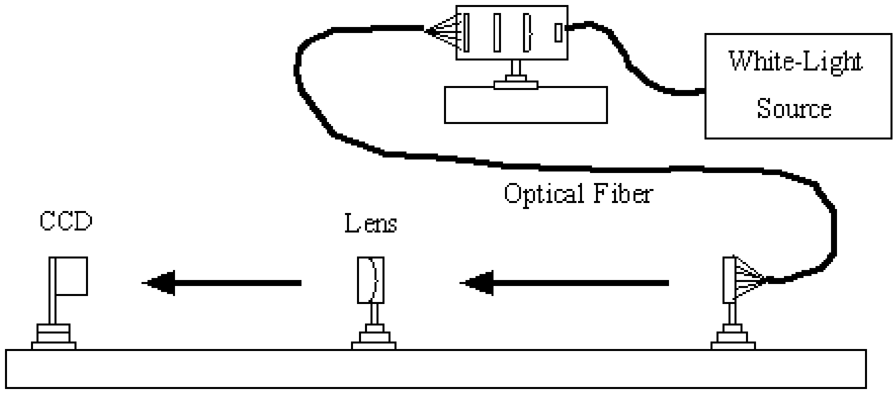


**Figure 5.** Centroiding Experiment Layout

### 5.2. Development of detectors

As mentioned above, TDI mode is very powerful for obtaining the high accuracy in measuring the centroids of stellar images. However, we do not have any infrared detectors with good quantum efficiency of detection in which TDI mode can be operated. We need develop good infrared detectors in which TDI can be operated. We have an idea for making the detectors: An IR detector with TDI mode could be realized by bonding a thinned back-illuminated CCD with a HgCdTe censor by using indium bumps. Since this is a very important issue for realization of JASMINE, we will do our best to develop such detectors from now on. If we will get such good infrared detectors in future, the detectors can be used for other survey projects in infrared astronomy and they must contribute to the enormous improvement in the fields of infrared astronomy.

### 5.3. CCD centroiding experiment

To achieve the requirements of the astrometric accuracy, the instrument of JASMINE must achieve a single look centroiding accuracy with $\sim 1/400$ pixels while operating the focal plane in TDI mode. We need demonstrate that the required single look centroiding precision could be achieved in a simulated operating environment using a traceable CCD detector array. As mentioned before, we do not have any good detectors for K-band in which TDI mode can be operated. But as a first step, we will demonstrate that the required accuracy could be achieved in experiments using CCDs. We are starting the experiment with the collaboration of ILOM(In-situ Lunar Orientation Measurement)-project team at National Astronomical Observatory of Japan. Our experiment is similar to the experiment designed for FAME[6)]. The schematic design of our centroiding experiment is shown in Figure 5. It consists of a starfiled projector which produces scaled multi-spectral point spread functions and a CCD focal plane mounted on a precision linear stage to simulate the linear sweep of the starfiled across the CCD array. Star images are produced with an array of 25 optical fibers. The fibers are illuminated with a white light source. We have already made the centroiding algorithm which is a modified one of the algorithm for the FAME centroiding experiment[6)]. We are now waiting for the experimental data.

### 5.4. Scanning law

DIVA, FAME and GAIA satellites will scan the whole sky in the way similar to Hipparcos. On the other hand, JASMINE will scan the restricted regions around the galactic center and the galactic disk plane. In this case, the way how to obtain the accurate parallaxes, positions and proper motions is a big problem which has never been considered. We are now studying a design of instruments with small mirrors beside the main mirror and we are investigating how to scan the survey area in order to effectively get both the scientific objectives and the accurate absolute parallaxes. Furthermore, we are studying another design in which JASMINE has two same big mirrors for the astrometric measurements of scientific targets in K-band and another small mirror for the measurements of guide stars in V-band.

## 6. SUMMARY

JASMINE is expected to measure parallaxes, proper motions and near-infrared photometries of about a few hundred million stars mainly within the bulge and disk components of our Galaxy. JASMINE aims at the high precision astrometry of 10$\mu$as level in K-band. The primary scientific targets of JASMINE are to clarify the structure and evolution of the bulge and the disk components of the Galaxy. Jasmine is a name of plants. The flower language of jasmine is elegance. Then we greatly hope that JASMINE will be *elegantly* successful in future.

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