TWO ASTROMETRIC PROJECTS: LIGHT (LIGHT INTERFEROMETER SATELLITE FOR THE STUDIES OF GALACTIC HALO TRACERS) AND MIRA (MITAKA/MAUNA KEA/MAUI OPTICAL AND INFRA-RED INTERFEROMETER ARRAY)

M. YOSHIZAWA, K. SATO, J. NISHIKAWA, T. FUKUSHIMA

AND

M. MIYAMOTO
National Astronomical Observatory
Mitaka, Tokyo, Japan

1. Introduction

The projects LIGHT and MIRA are the space-borne and ground-based optical/Infrared-interferometer projects of the National Astronomical Observatory of Japan. The contents of each project are gradually developing, and the descriptions given below are the preliminary ones studied at the present time.

2. An Astrometric Satellite with Fizeau-type Optical/IR Interferometer

2.1. LIGHT

LIGHT (Light Interferometer satellite for the studies of Galactic Halo Tracers) is a scanning astrometric satellite for stellar and galactic astronomy planned to be launched between 2007 and 2010 by a M-V launcher of ISAS, Japan. Two sets of Fizeau-type 40cm-pupil interferometers with 1 m baseline are the basic structure of the satellite optics. The multi-color (U, B, V, R, I, and K) CCD arrays are planned to be used in the focal plane

I. M. Wytrzyszczak, J. H. Lieske and R. A. Feldman (eds.),
Dynamics and Astrometry of Natural and Artificial Celestial Bodies, 561, 1997.

of the interferometer, optimized for detecting the precise locations of fringe patterns. LIGHT is expected to observe the parallaxes and proper motions of nearly a hundred million stars up to 18^{th} visual (15^{th} K-band) magnitude with the precision better than 0.1 milli-arcsecond (about 50 micro-arcsecond in V-band and 90 micro-arcsecond in K-band) in parallaxes and better than 0.1 milli-arcsecond per year in proper motions, as well as the precise photometric characteristics of the observed stars. Almost all of the giant and supergiant stars belonging to the disk and halo components of our Galaxy within 10 to 15 kpc from the sun will be observed by LIGHT to study the most fundamental structure and evolution of the Galaxy. LIGHT will become a precursor of a more sophisticated future astrometric interferometer satellite like GAIA (Lindegren and Perryman, 1996).

2.2. OPTICAL SYSTEM OF LIGHT

The main optical feature of LIGHT is a Fizeau-type interferometer with the baseline $B = 1\,\mathrm{m}$ and pupil diameter $D = 40\,\mathrm{cm}\times 2$ of off-axis Ritchey-Chretien type. Two sets of the beam combiners with semi-circular aperture combine the light rays from two different directions of about 114 degrees apart on the celestial sphere within a plane perpendicular to the Z (spin) axis. The satellite scans the whole sky by precessing the spin axis, rotating with a rate of about 10 revolutions a day.

The Astrometric Field occupies the central part of the focal plane. A total of nine chips of CCDs and K-band detectors are arranged in the Astrometric Field which has a field of view of about $0.^{\circ}3 \times 0.^{\circ}3$. Multi-color Photometry Regions surround the Astrometric Field.

Observation with V-band

fringe width: $\lambda/B = 0.''11$ ($\lambda = 550\,\mathrm{nm}$, $B = 1\,\mathrm{m}$)
  $\rightarrow 0.''03$/pixel and 4 pixels/fringe (scanning direction)
 Airy disk $= 1.22\lambda/(D/2) = 0.''69$
  $\rightarrow 1.''5$/pixel (Z-axis direction)
focal length: the condition of $3\,\mu$m/pixel requires $f = 20.6\,\mathrm{m}$
 CCD: $0.^{\circ}1 \times 0.^{\circ}1$/chip
  total number of pixels/chip$= 12\,000 \times 240 = 2.88 \times 10^6$
  1 chip $= 36\,\mathrm{mm} \times 36\,\mathrm{mm}$

Observation with K-band

fringe width: $\lambda/B = 0.''44$ ($\lambda = 2.2\,\mu\mathrm{m}$, $B = 1\,\mathrm{m}$)
  $\rightarrow 0.''12$/pixel and 4 pixels/fringe (scanning direction)
 Airy disk $= 1.22\lambda/(D/2) = 2.''8$
  $\rightarrow 5.''5$/pixel (Z-axis direction)
detector: $0.^{\circ}1 \times 0.^{\circ}1$/chip (NICMOS ?)

Total number of pixels/chip = $3000 \times 60 = 1.8 \times 10^5$
1 pixel = $0\farcs12 \times 6'' = 12\,\mu\mathrm{m} \times 600\,\mu\mathrm{m}$
$\rightarrow$ 1 chip = $36\,\mathrm{mm} \times 36\,\mathrm{mm}$
required sensitivity: 4μJy/frame(2.4 s) (1σ)
$K = 12$ mag $\rightarrow$ $S/N = 4000$ (2.4 s) or σ_{frame} $(K = 12) = 3.5$ mas
$K = 15$ mag $\rightarrow$ $S/N = 250$ (2.4 s) or σ_{frame} $(K = 15) = 14$ mas
cooling: telescope (mirrors, etc.) $\rightarrow$ passive cooling
detectors $\rightarrow$ passive/liquid He/cryostat

2.3. SCIENTIFIC TARGETS OF LIGHT

The basic branches of galactic astronomy which can be studied by the LIGHT satellite are:

A) Non-rotating celestial coordinate system (reference frame) fixed to QSOs
A unified frame of optical and radio (VLBI) systems

B) Trigonometric parallaxes of stars within a volume of 3–5 kpc cube ($\pi = 0.1$ mas $\rightarrow$ 10 kpc)
Cosmic distance scale
Fine structure of the C-M diagram
$\rightarrow$ post-main-sequence evolution
absolute luminosity
stellar mass and radius

C) Stellar luminosity, temperature, metallicity, and extinction
$\rightarrow$ photometric distance estimate
stellar evolution (together with B)
glactic chemical evolution

D) Absolute proper motion of stars precise to < 0.1 mas/yr (0.5 km/s/kpc)
Spatial variation of stellar velocity dispersions
Correlations between chemical abundance and kinematics of stars
Dark halo structures (galactic rotation curve)
Deviations from axisymmetric feature (warp, barred structure)
Spatial motion of the magellanic system

E) Relative separations and monthly proper motions of special objects precise to < 0.1 mas
MACHO mass, distance, and trajectory
$\rightarrow$ IMF for stellar masses $< 1 M_{\odot}$
dark halo structures
Multiple stellar system (mass, formation process)

3. MIRA-II and MIRA-III: Mitaka/Mauna Kea optical and InfraRed Array

3.1. MIRA SERIES

MIRA is a series of ground based optical/infrared interferometer arrays for astrometry and astrophysics in the first decade of the next century, promoted by GOJIRA group (Group Of Japanese optical and Infra-Red interferometer Astronomy). At present we are operating at Mitaka campus of NAOJ an experimental two-element interferometer MIRA-I. MIRA-I has 4-m North-South baseline and pupil diameter of 25 cm. The MIRA-I will be upgraded to a multi-element MIRA-II within a few years with which we will try actual astrometric observations with the accuracy better than 10 mas, together with some mapping observations. Our final goal is MIRA-III, which should be constructed at one of the world's best sites for astronomical observations, like Mauna Kea, Hawaii, hopefully in 2002 to 2005. Under the present design the main structure of MIRA-III is a thirteen-element (seven fixed plus six movable) Y-shaped optical/infrared (up to K-band) interferometer with the maximum baseline length close to 1.4 km. The size of the mirror of individual siderostat is planned to be 1.5 m in diameter.

3.2. OBJECTIVES AND TECHNICAL CHALLENGES OF THE SERIES

The scientific objectives and main technical targets of each interferometer of the MIRA series are summarized as follows:

- MIRA-I.x: two-element experiment series; baseline length 4 m; operated at Mitaka campus of NAOJ.
- MIRA-II: multi-element interferometer; maximum baseline length 128 m; to be constructed at Mitaka campus.
- MIRA-III: long baseline interferometer; to be constructed at one of the best sites in the world.

3.3. OPTICAL LAYOUT OF MIRA-II

The layout of the stations of fixed and movable elements (siderostats) is shown in Figure 1, together with the beam paths leading to the fine and coarse delays from each position of the siderostat. The central four fixed stations will be used for astrometric observations with the help of laser metrology to monitor the movement of the stations.

The star light reflected by a siderostat is compressed to a 6 cm beam by a Cassegrain telescope ($\phi = 20$ cm) of each beam line, and led to a delayline building through the vacuum pipes. The fine delaylines have a

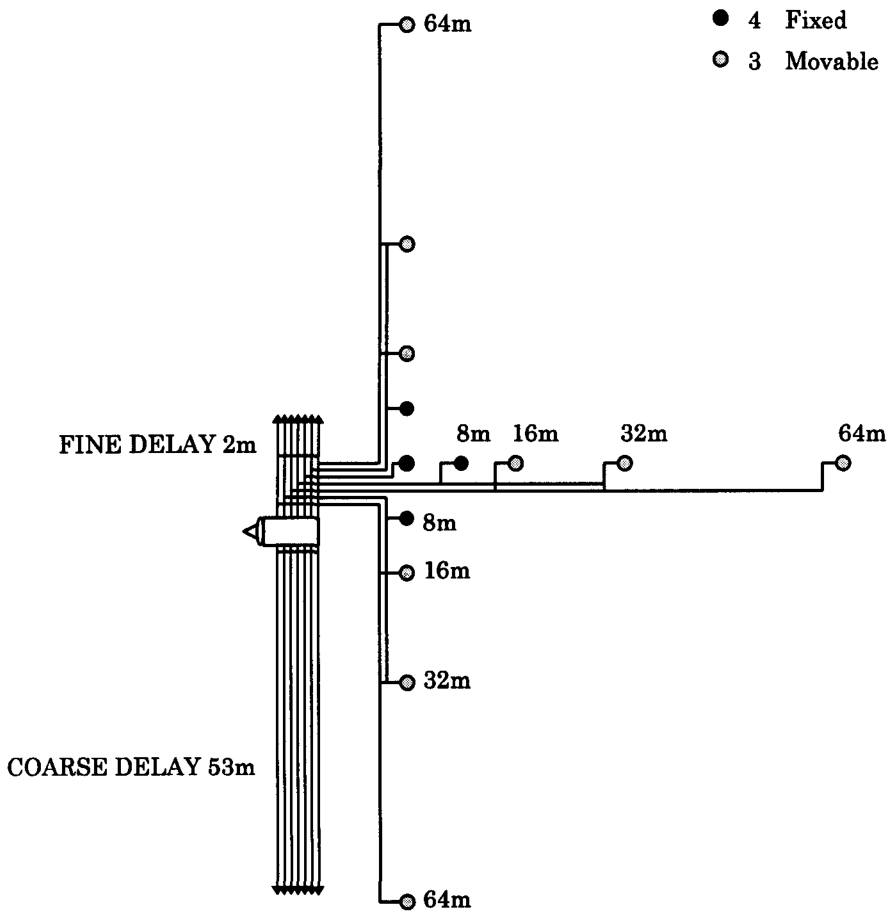

Figure 1. The MIRA-II layout of the fixed and movable stations of siderostat pupils (30 cm in diameter) aligned in the north-south-east directions, together with the beam paths (feed path diameter 60 mm) leading to the two delay lines.

moving range of 2 m to cover 10-minutes continuous observations, whereas the long delaylines of 53 m which is long enough even for the experiments of some polar stars.

Each of the fine delaylines consists of a cable-dragger cart, a motor cart, and an optics cart carrying a retro-reflector. The retro-reflector is a Cassegrain telescope with a piezo-actuating flat mirror on its Cassegrain focus. The stroke of the piezo-electric actuator is 90 μm, which is enough for fast-delay compensation to absorb the effect of the atmospheric turbulence. The main body of the retro-reflector should be attached to the cart with the help of a damper in order to keep accelerated movements as weak as possible. The coarse (long) delaylines are changed by controlling the timing belts. The

https://doi.org/10.1017/S0252921100047126 Published online by Cambridge University Press

TABLE 1. Characteristics of MIRA series

Series No.	Objective	Technical Items	Astrometry Accuracy	Resolution @V-band	Resolution @K-band
MIRA-I.2	Astrometry	Vacuum Pipe	(10 mas)	28 mas	——
MIRA-I.3	Astrometry	Baseline stabilization, K-band	10 mas	28 mas	113 mas
MIRA-II	Astrometry, Mapping	Multi-elements	(1 mas)	0.89 mas	3.5 mas
MIRA-III	Astrometry, Mapping	Long Baseline	(1 mas)	0.08 mas	0.3 mas

retro-reflector of the coarse delaylines has a parabolic primary mirror and a fixed flat secondary. The diameter of the primary mirrors of the retro-reflectors of both fine and coarse delaylines is 20 cm.

After passing the two delaylines the optical beams are compressed again from 6 cm to 1 cm in diameter, and fed into an interference section where a set of array detectors measure the positions of the interference fringes between two beams combined in a non-redundant manner. Optical and infrared (up to K-band) fringe detectors are planned to be installed, as well as spectrograph.

References

Lindegren, L. and Perryman, M.A.C.: 1996, *Astron. Astrophys., Suppl. Ser.* **116**, 579–595.

https://doi.org/10.1017/S0252921100047126 Published online by Cambridge University Press