A FIZEAU OPTICAL INTERFEROMETER ASTROMETRIC SATELLITE

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ABSTRACT

Consistent with the philosophy of small, fast, and cheap, it is proposed to design, build and launch in 2000 a small astrometric instrument on an artificial satellite. The instrument and spacecraft are being designed to fly a slowly-spinning satellite that will repeatedly scan great circles on the sky and precess such that, over a period of time, it will cover the complete sky and repeat in a manner somewhat similar to the Hipparcos mission. The instrument will use the two fixed dilute aperture telescopes to measure a fixed angle between stars, and detect the positions, magnitude, and color of all the stars coming through the field of view to a visual magnitude of approximately 15 mag.

The primary purpose of the instrument is to obtain a catalog of positions, proper motions and parallaxes of all stars down to about 15 mag, with a magnitude-dependent accuracy of positions of 20–800 microarcsec, proper motions of 20–800 microarcsec per year, and parallaxes of 20–800 microarcsec. Measurements will be made in five different wavelength bands, providing comprehensive information for positions and characteristics for about 10 million stars brighter than 15 mag. This scientific goal in itself would be, in our opinion, an outstanding result. However, many other areas of astrophysics will be impacted by these measurements.

Determination of stellar luminosities, masses, and radii; investigation of stellar evolution; refinement of the cosmic distance scale; searches for binaries, brown dwarfs, and planetary companions; and studies of stellar kinematics, chemical abundances, the solar system, and general relativity effects are only some of the disciplines affected.

Key words: space astrometry, FAME, GAIA, interferometry

1. MISSION PROFILE

The Fizeau Astrometric Mapping Explorer (FAME) is designed to be an astrometric survey mission flying in orbit similar to that of Hipparcos. It would be the first space optical interferometer flown to observe a large number of stars. It would be a follow-on to Hipparcos, and possibly a precursor to GAIA, AIM, OSI, POINTS, or TOPS. It would fly a 2.5-year mission, with the possibility of an extension beyond that. The astrometric accuracy expected is 50 microarcsec at 9 mag, and it would provide complete coverage down to 14 mag which would be over 10 million stars. This is as a MIDEX proposal, which has a $70 million cap covering costs through launch plus 30 days, excluding the launch vehicle and mission operations.

The accuracy of FAME is indicated in the distance magnitudes phase space diagram (Fig. 1) comparing FAME to the FK5 and Hipparcos.

2. SCIENCE SUMMARY

FAME will provide astrometric positions at magnitude-dependent accuracies ranging from 20 microarcsec for stars brighter than 8 mag to 800 microarcsec at 15 mag, and corresponding accuracies for proper motions and parallaxes. Those data provide the capability to do a large range of exciting science, in addition to the basic value of the data themselves. This science includes providing astrometric calibrations for essentially all standard candles and, therefore, will complement the NASA Great Observatories that can get relative distances (Fig. 2).

The primary science is to provide a homogeneous and complementary distance indicator to make improvements in cosmology and physics of distant objects. Thus, significant improvement can be achieved for the distances to the Cepheid variables, RR Lyrae variables, Hyades, Pleiades, and luminous blue and red stars. The mission will provide comprehensive information concerning stars, positions, proper motions, and parallaxes, along with selected spectral band photometry. It will be developed for approximately 10 million stars down to 15 mag. Thus, parallaxes out to 500 parsecs will be at the 1 per cent accuracy level and 2 per cent accuracy level to one kiloparsec. With these parallax accuracies, luminosities, masses, and radii will be available for modelling stars.

The dynamics of the Galaxy can be investigated, such as questions like the Oort Problem or the vertical mass distribution of the Galactic disk, the spiral arm structure, the shape of dark matter halo, the disk halo, the warp and deviations, axisymmetry, galaxies formed from cold, dark matter lumps, dark matter in galactic disks, and the rotation curve of the Galaxy. With proper motions accurate to the 0.1 milliarcsec per year and smaller, the kinematics of some of the nearby open clusters and OB associations can be studied.

Figure 1. The accuracy of FAME indicated in the distance magnitudes phase space diagram comparing FAME to the FK5 and Hipparcos.

Figure 2. Distance calibration targetted by FAME

In addition to the astrometric star catalog that will result, the optical reference frame will be at least as accurate as the radio reference frame, so that the frames will be tied together and associations between radio and optical sources will be possible with improved accuracy. In addition, the tenth of a milliarcsec per year proper motion accuracy required by Gravity Probe B will be achievable.

In general relativity, the light bending at the Jovian limb is predicted to amount to 17 milliarcsec and light bending at the limb of the Earth is at the 40 micoarcsec level, so measurements of light bending will be possible based on these planets and Saturn. The detection of the planetary systems and brown dwarfs, based on the data for a 2.5-year mission, is questionable. However, combining the data of Hipparcos and FAME should provide indications of inconsistencies in proper motions which could be due to double stars or smaller planetary and brown dwarf companions. From the two data sets, candidate stars for planetary systems and brown dwarfs would certainly be identified.

Whenever new observing capabilities, and new accuracy levels are achieved, and large quantities of systematic new accurate data are collected, the possibility exists that the most exciting discoveries may be serendipitous.

3. THE FAME INSTRUMENT DESCRIPTION

The FAME instrument is two dilute aperture telescopes operating in 'Fizeau' mode viewing two fields separated by approximately 80°. The interferometer would have a 50 cm baseline and approximately 10×20 cm collecting apertures. The detections would be done at wavelengths between 0.5 and 0.9 microns. The satellite would be spinning at approximately one rotation per 2.5 hours, with six spin-axis revolutions per year. The detectors would be an array of eight 4×1 K large format CCD detectors with 15×30 micron pixels. Detection would be done in a single array, with the readout synchronize d to the spin rate. A nominal 2.5-year lifetime is planned.

The photon-limited astrometric performance is expected to be 20 microarcsec at the 5 mag, 43 microarcsec at 9 mag, 101 microarcsec at 11 mag, and 800 microarcsec at 15 mag. The systematic error is expected to be less than 16 microarcsec. These optics result in a field of view which is $0.059 \times 0.47^\circ$ with four pixels per image. The distortion of the optics is less than 4 microns across the field, and detection would be done by a low-resolution 8-channel spectrometer.

Narrow-band detection gives high range visibility while wide-band collects more photons. Thus, the approach taken is an eight spectral band spectrometer with a glass wedge placed at the entrance pupils, which disperses the starlight orthogonal to the spin direction. This should provide high visibility across the entire band and a minimal chance of confusion. There is some penalty to this approach.

The detector camera optics are eight $4K \times 1K$ detectors arranged in a 1×8 line, with the length of the line being perpendicular to the spin direction. The detectors are back-side illuminated, and passively cooled to -60°C. The readout would be synchronized to the spin rate, giving a 1.5 sec integration time. On-chip binning would be done at a 4:1 ratio, and five electron readout noise is anticipated. Sixty-four readout channels, eight per detector, would be used. All the readout registers are located on one side of the detector. The readout electronics would be comprised of 64 readout signal chains, containing one microprocessor for every four signal chains.

The spacecraft is shown in the rocket nose in Fig. 3. The spacecraft requirements are such that the launch vehicle would be a Delta-Lite Launch vehicle lifting approximately 400 kg. The orbit would be a high, large eccentricity, 30 000 km by 200 000 km orbit to minimize perturbations on the spacecraft and maximize communications capability. The payload would be approximately 150 kg with a cylindrical shape of approximately 2 m in diameter, 0.7 m high, plus the electronics.

The spacecraft would have a spin axis of 45° with respect to the Sun, a spin period of 2.5 hours, and a precession period of 6.3°/day. Spin stability is to be one part in 10 000 in the spin direction over 10 min, which comes out to 144 arcsec/sec$\pm$14.4 mas/sec. The stability orthogonal to the spin direction would be one part in 200 over 10 min. The satellite would use passive stability and a 0.5° spin axis stability over 2.5 hours.

Figure 3. The FAME spacecraft shown in the rocket nose.

4. SUMMARY

Consistent with the philosophy of 'small, fast, and cheap', it is proposed to design, build, and launch, in the year 2000, FAME, a small Fizeau optical interferometer on an artificial satellite. The satellite should provide, at an approximately 50 microarcsec accuracy level, positions, proper motions, and parallaxes for stars to 9 mag. These data provide an exciting range of scientific information, probably the most important of which is an astrometric calibration of the cosmic distance scale.