Structure Analysis for Astrometry of Compact Extragalactic Sources for a FAME/ICRF Tie

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Scientific category: AGN/QUASARS
Scientific keywords: ASTROMETRY, SURVEY, RADIO-LOUD QUASARS, BL LAC OBJECTS AND BLAZARS, HOST GALAXIES
Instruments: WFPC2 Proprietary period: 0
Number of targets: 32

Abstract

The Full-sky Astrometric Mapping Explorer (FAME) is an astrometric satellite designed to determine with unprecedented accuracy the positions, distances, and motions of 40 million stars within our galactic neighborhood. FAME will allow a more accurate connection between the stellar and extragalactic reference frames than was achievable with *Hipparcos*. The FAME mission will be capable of observing compact objects brighter than about $V = 16^m$. The link of the FAME reference frame to the International Celestial Reference Frame (ICRF) will be accomplished through observations of radio stars and extragalactic objects in a weighted solution. HST observations proposed here are required to survey the best extragalactic radio sources for optical structure on a resolution level similar to FAME ($0\overset{''}{.}2$, FWHM of FAME point spread function) in order to select the most suitable candidates for the FAME/ICRF frame tie. This can only be provided by HST. An accurate alignment between the radio and optical frames will allow astrophysical interpretations of high–resolution multi–wavelength imaging observations and will be required to tie the internal FAME reference frame to an inertial frame, thus removing the bias in FAME proper motions of all galactic sources.

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Observing Summary:

Target	RA	DEC	V	Configuration,mode,aperture spectral elements	Total orbits	Flags
0109+224	01 12.1	22 44	15.7	WFPC2 IMAGE B,V,R,I	0	
0118−272	01 20.5	−27 01	15.6	WFPC2 IMAGE B,V,R,I	0	DUP
0153+744	01 57.6	74 42	16.0	WFPC2 IMAGE B,V,R,I	0	
0219+428	02 22.7	43 02	15.2	WFPC2 IMAGE B,V,R,I	0	
0241+622	02 45.0	62 28	12.2	WFPC2 IMAGE B,V,R,I	0	
0405−123	04 07.8	−12 11	14.9	WFPC2 IMAGE B,V,R,I	0	
0521−365	05 23.0	−36 27	14.6	WFPC2 IMAGE B,V,R,I	0	DUP
0637−752	06 35.8	−75 16	15.8	WFPC2 IMAGE B,V,R,I	0	
0716+714	07 21.9	71 20	15.5	WFPC2 IMAGE B,V,R,I	0	DUP
0754+100	07 57.1	09 56	15.0	WFPC2 IMAGE B,V,R,I	0	DUP
0818−128	08 21.0	−12 58	15.0	WFPC2 IMAGE B,V,R,I	0	
0851+202	08 54.8	20 06	15.4	WFPC2 IMAGE B,V,R,I	0	DUP
0955+326	09 58.3	32 24	15.8	WFPC2 IMAGE B,V,R,I	0	
1101+384	11 04.5	38 12	12.9	WFPC2 IMAGE B,V,R,I	0	DUP
1128+385	11 30.9	38 15	16.0	WFPC2 IMAGE B,V,R,I	0	
1133+704	11 36.4	70 09	14.5	WFPC2 IMAGE B,V,R,I	0	DUP
1147+245	11 50.3	24 17	15.7	WFPC2 IMAGE B,V,R,I	0	DUP
1156+295	11 59.5	29 14	14.4	WFPC2 IMAGE B,V,R,I	0	
1215+303	12 17.9	30 07	15.6	WFPC2 IMAGE B,V,R,I	0	DUP
1302−102	13 05.5	−10 33	15.2	WFPC2 IMAGE B,V,R,I	0	
1308+326	13 10.5	32 20	15.2	WFPC2 IMAGE B,V,R,I	0	
1322−427	13 25.5	−43 01	12.8	WFPC2 IMAGE B,V,R,I	0	
1355−416	13 59.0	−41 52	15.9	WFPC2 IMAGE B,V,R,I	0	
1418+546	14 19.8	54 23	15.7	WFPC2 IMAGE B,V,R,I	0	DUP
1424+240	14 27.0	23 48	15.0	WFPC2 IMAGE B,V,R,I	0	DUP
1514−241	15 17.7	−24 22	14.8	WFPC2 IMAGE B,V,R,I	0	DUP
1652+398	16 53.9	39 45	13.8	WFPC2 IMAGE B,V,R,I	0	DUP
1727+502	17 28.3	50 13	16.0	WFPC2 IMAGE B,V,R,I	0	DUP
1807+698	18 06.8	69 49	14.2	WFPC2 IMAGE B,V,R,I	0	DUP
2005−489	20 09.4	−48 49	13.4	WFPC2 IMAGE B,V,R,I	0	DUP

Observing Summary:

Target	RA	DEC	V	Configuration,mode,aperture spectral elements	Total orbits	Flags
2155−304	21 58.9	−30 13	13.1	WFPC2 IMAGE B,V,R,I	0	
2344+092	23 46.6	09 30	16.0	WFPC2 IMAGE B,V,R,I	0	
				Grand total orbit request	0	

■ Scientific Justification

1 Introduction

The Full–sky Astrometric Mapping Explorer (FAME) is an astrometric satellite designed to determine with unprecedented accuracy the positions, distances, and motions of 40 million stars within our galactic neighborhood. It is a collaborative effort between the U.S. Naval Observatory (USNO) and several other institutions and will launch in 2004 as a NASA MIDEX mission. FAME is a survey mission and will make astrometric position measurements with a precision of 50 μas for objects $V \leq 9^m$ and 500 μas for objects at $V \approx 15^m$.

FAME will accurately measure, to 10% error or better, the absolute trigonometric parallaxes (*i.e.* the distances), positions, and proper motions, as well as the apparent magnitudes, of stars with $V \leq 9^m$ that lie within 2.5 kpc of the Sun. Results of this survey will definitively address five key scientific objectives having far–reaching astrophysical and cosmological significance: 1) Definitive calibration of the absolute luminosities of the standard candles (the galactic Cepheid variables and the RR Lyrae stars) that are fundamental in defining the distance scale to nearby galaxies and clusters of galaxies; 2) Calibration of the absolute luminosities of solar–neighborhood stars, including Population I and II stars, thus enabling diverse studies of stellar evolution and other interesting science; 3) Definitive determination of the frequency of solar–type stars orbited by brown dwarf companions in the mass range 10 to 80 $M_{\rm Jupiter}$ and with orbital periods as long as about twice the duration of the mission; 4) Proper motions and distances for individual stars in star forming regions for determinations of ages and kinematics; 5) A study of the kinematic properties of the survey of 4×10^7 stars within 2.5 kpc of the Sun, and in particular, assess the abundance and distribution of dark matter in the galactic disk with much greater sensitivity and completeness than previously possible.

However, positions and motions will initially be on a FAME internal reference frame, subject to an arbitrary position and rotation (proper motion) zero–point. To make the FAME reference frame inertial (similar to *Hipparcos*), a link to an extragalactic, non–rotating frame like the ICRF is required. The high astrometric accuracy of FAME will allow a more accurate connection between the stellar and extragalactic frames than was achievable with *Hipparcos*. The Hipparcos Catalogue was linked to a quasi–inertial celestial frame by observations of radio stars whose positions were determined in the frame of the International Celestial Reference Frame (ICRF). The ICRF is defined by the VLBI derived radio positions of 212 extragalactic objects and is the IAU endorsed fundamental astronomical reference frame (Ma et al. 1998, AJ, 116, 516). At optical wavelengths, the Hipparcos Catalogue now serves as the primary realization of the extragalactic reference system. The standard errors in the alignment of the coordinate axis of the ICRF and *Hipparcos* frames, at epoch 1991.25, are believed to be ±0.6 mas, with a possible rotation between the frames of about ±0.25 mas yr^{-1} (Kovalevsky et al. 1997, A&A, 323, 620). The errors associated with this link are too large to enable milliarcsecond level astrometry between radio and optical images, and notably, the link is actually degrading with time. The current (epoch 2000) error in the alignment of the ICRF/Hipparcos link exceeds 2 mas. In addition to the uncertainties in the frame tie, there are also errors associated with the measured positions, proper motions, and parallaxes of individual sources, *eg.* for Algol these are respectively, 0.61 mas, 0.18 mas yr^{-1}, and 0.59 mas (Kovalevsky et al. 1997). All of these errors combine to seriously limit the ability to align radio and optical images of particular sources. Frame rotation and proper motion errors are particularly insidious, as their effect is cumulative over time.

Although the present day fundamental celestial reference frame (the ICRF) is based on the VLBI determined radio positions of extragalactic sources, the internal precision of the FAME reference frame will surpass the accuracy of the ICRF by an order of magnitude or more and may quite possibly define the next generation ICRF. However, an accurate link between the ICRF and FAME frames is still needed as it will allow astrophysical interpretations of high–resolution multi–wavelength imaging observations, including future HST observations.

The radio emission from extragalactic objects is known to be extended on spatial scales larger than the precision of their radio astrometric positions. High resolution structure analysis at optical wavelengths is required to select the most suitable candidates and to estimate how the FAME mission will see these sources.

2 Need for HST

The main reason for using HST is the high resolution imaging capability, currently not available with any other instrument. This snapshot proposal is a first step to survey all compact, extragalactic ICRF sources accessible to FAME, in preparation for more detailed astrometric observations (ground–based and HST) to follow over the next few years.

Radio images of about 400 ICRF sources show structure for most of them on the several mas level. HST observations are required to detect any optical structures at the 50 to 1000 mas level. We also expect some objects to be resolved (wider than stellar image profile, host galaxy) because of indications from previous observations. The assumption that the centers of radio and optical emissions of these sources coincide has already be verified on the 30 to 50 mas level (e.g. Zacharias et al. 1999, AJ, 118, 2511) and new ground–based CCD observations indicate the same on the 10 to 20 mas level (http://ad.usno.navy.mil/ucac). Even with some image structure, high precision astrometry can be expected as long as the core of the objects image profile is symmetric. A high resolution screening of unsaturated images, to be obtained with HST, is required. The proposed HST imaging will push the limit in optical resolution by a factor of at least 4 over previous observations, slightly exceeding the resolution of FAME.

Observations with several medium to wide band filters are desirable in order to cover the bandpass range from 400 to 900 nm of the FAME mission. Changes in possible source structure and position as a function of wavelength need to be investigated.

Objects identified as most suitable for the FAME/ICRF link based on optical structure analysis will be given higher priority for future VLBI observations in order to improve the radio positions.

3 Scientific Goals of the Proposed Observations

The questions we hope to answer through the proposed observations are as follows:

- Are there any optical structures at the 50 to 1000 mas level in these objects?
- Are the image profiles circularly symmetric?
- What is the variability of any optical structures in these objects?
- How do the possible optical structures correlate with the radio structures?
- How much do the optical centers shift as a function of the bandpass (400 nm to 900 nm is the FAME bandpass)
- Which are the sources most suitable for the FAME/ICRF link?

In addition, the proposed short exposure with unsaturated images of the cores of the ICRF sources will be of general interest for a better understanding of the astrophysics of these compact, extragalactic, radio–loud sources.

4 Glossary of Acronyms

FAME Full–sky Astrometric Mapping Explorer (approved NASA space mission)

FWHM full width at half maximum

Hipparcos European Space Agency astrometric mission

IAU International Astronomical Union

ICRF International Celestial Reference Frame

mas milli arcsecond (= 10^{-3} arcsecond)

μ**as** micro arcsecond (= 10^{-6} arcsecond)

PC Planetary Camera of the WFPC2 (high resolution CCD)

USNO United States Naval Observatory

VLBI Very Long Baseline Interferometer (at radio wavelengths)

■ Description of the Observations

All targets proposed here are ICRF sources with optical counterparts that have been detected optically with ground–based telescopes, so there are no empty fields. All targets should be close to the center of the PC (highest angular resolution). The roll angle of HST can be arbitrary.

Any medium to wide bandpass filter in the range of 400 to 900 nm is acceptable, like B,V,R,I or the Stromgren filter set. Observations should take no more than ≈ 4 min per object per filter for these $12-16$ magnitude objects, with integration times on the order of 3 to 30 seconds for individual frames and overhead of about 2 min per object. Thus, one object could be observed with one filter in about 6 min, two filters in about 10 min, three filters in about 14 min, and four filters in about 18 min. Observations do not need to be complete for all colors.

Exposure times need to be short in order to prevent target saturation. Several dithered frames taken on a given target are beneficial, but not mandatory for this first look.

The gain setting should be selected to cover a large dynamic range, including counts up to the saturation level.

Special Requirements

None.

Coordinated Observations

Ground–based astrometric observations at CTIO and KPNO telescopes as well as with the USNO CCD astrograph and other instruments have been made over the last few years. These programs continue and additional ground–based observations taken close to the epoch of the HST observations are expected. VLBI astrometric and imaging observations for improvements to the ICRF will continue as well.

All these observations are independent and need not be coordinated with the structure analysis survey observations proposed here.

Justify Duplications

About half of the proposed targets have been observed previously with the WFPC2 of HST. However most of these observations are long exposures, showing a saturated target, which is not acceptable for our proposed observations. In addition, the short integration observations on the sources marked as DUP in the observing summary were observed almost exclusively with the F702W filter. Thus most of the archive data could only be used to complement the investigation proposed here. In some cases our observations will allow a check for time variable structure in combination with archive data. Radio observations indicate variability on the scale of months.

Previous HST Programs

There are no previous HST programs.