NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: September 29, 2000 **Category:** EGAL - Other

Structure analysis and astrometry of extragalactic sources for a FAME/ICRF link

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
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.

We propose WIYN observations of ≈ 100 candidate extragalactic link sources with V$\leq 16^m$. The proposed observations have 2 goals: 1) survey non–ICRF extragalactic sources with confirmed radio flux for optical structure, and 2) pilot investigation aimed at highest astrometric accuracy for a sub–set of the link sources. Only a small fraction ($\approx 1/8$) of these optically bright sources are ICRF sources (radio bright). The positions of many of the remaining sources could be determined in the system of the ICRF with the expensive phase referencing technique, however the most suitable candidates need to be selected first.

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.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	WIYN	MIMO	2	grey	Feb - Jul	Feb - Jul
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

The period from about April 1 to May 15 can not be used because of the scheduled re–location of the USNO CCD astrograph.

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

The Full–sky Astrometric Mapping Explorer (FAME, Johnston et al.1999) 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 $V \approx 15^m$. Results of this survey will have a profound impact in areas like the calibration of the absolute luminosities of RR Lyrae, Cepheid and solar–neighborhood stars out to 2.5 kpc, determination of the frequency of solar–type stars orbited by brown dwarf companions in the mass range 10 to 80 $M_{\rm Jupiter}$ and galactic kinematics studies in general.

However, positions and motions will initially be on a FAME internal reference frame, subject to an arbitrary orientation and rotation zero–point. To make the FAME reference frame inertial (similar to *Hipparcos*), a link to an extragalactic, non–rotating frame like the ICRF (Ma et al. 1998) is required. The alignment of the coordinate axes of the ICRF and the *Hipparcos* frames also degrade with time, by 0.25 mas per year since 1991 (Kovalevsky et al. 1997). 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 needed as it will allow astrophysical interpretations of high–resolution multi–wavelength imaging observations.

The radio emission from extragalactic objects is known to be extended on spatial scales larger than the precision of their radio astrometric positions ($\approx$ 0.25 mas). Radio images of about 400 ICRF sources show structure for most of them on the several mas level. High resolution (sub–arcsec) structure analysis at optical wavelengths is required to select the most suitable candidates. We expect some objects to be resolved (wider than stellar image profile, host galaxy). Even with some image structure, high precision astrometry can be expected as long as the core of the objects image profile is symmetric. 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).

In addition a sub–set of all sources best suited for the FAME/ICRF link will be observed with the WIYN telescope utilizing its large field of view in connection with data to be taken at the US Naval Observatory CCD astrograph (http://ad.usno.navy.mil/ucac/) for a tie to the *Hipparcos* system. This will be a pilot investigation to explore the limits of this technique and to estimate the final reference frame tie accuracy and the amount of effort required for future proposals.

This proposal is part of a larger investigation, which includes proposed HST observations to image the ICRF sources at FAME resolution. The next best link objects are non–ICRF, optically bright QSO and BL–Lac sources with radio emission high enough for phase referencing in the radio. Optical structure analysis of these candidates is proposed here as a first step, utilizing the high resolution of the WIYN telescope. Objects identified as most suitable for the FAME/ICRF link based on optical structure analysis will be given high priority for future radio reference frame observations. As a result, the currently small number of extragalactic sources which could be used for the FAME/ICRF link will be enlarged, strengthening the link significantly.

References

Johnston et al. 1999, FAME Concept Study Report, US Naval Observatory, Washington DC

Kovalevsky et al. 1997 A&A, 323, 620.

Ma et al. 1998 AJ, 116, 516.

Zacharias et al. 1999 AJ, 118, 2511.

Zacharias et al. 2000 AJ, 120, 1148.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. List all telescopes on which you have applied for or been granted time for observations related to this project. For each, indicate the nature of the observations, and describe the importance of the observations proposed here in the context of the entire program. (limit text to one page)*

The structure analysis will be performed using standard filters (e.g. Gunn b,g,r). Short exposures ($\approx$ 30 to 100 sec) will be sufficient to bring the 15 to 16 mag sources close to saturation. This will allow a high–dynamic range analysis of possible optical structure.

The astrometric pilot investigation will use a customized filter (579–642 nm) matching the bandpass of the astrograph, thus minimizing differential refraction effects. Within about a week the same fields will be observed at the USNO CCD astrograph, providing reference stars to R=16 with 20 mas accuracy on the Hipparcos system. Thus, problems with unknown proper motions and parallaxes of the link stars will be avoided. The astrograph data will also be used to map the WIYN telescope field distortions, together with overlapping frames taken at the WIYN in selected, dense calibration fields. Multiple short exposures are required to average out atmospheric turbulence effects on the astrometry.

Our HST and this WIYN proposal belong to the same large investigation. However, they are independent of each other, dealing with a different sub–set of sources.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the Principal Investigator during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal.*

The following observing runs have been granted over the past 2 years at NOAO facilities, sorted backwards:

telescope	date	project
CTIO 0.9 m	Jan 2001	UCAC link
CTIO 0.9 m	Oct 2000	UCAC link
CTIO 0.9 m	Jul 2000	UCAC link
CTIO 0.9 m	Mar 2000	UCAC link
CTIO 0.9 m	Dec 1999	UCAC link
CTIO 0.9 m	Oct 1999	UCAC link
CTIO 0.9 m	Jun 1999	UCAC link
CTIO 0.9 m	Mar 1999	UCAC link

Reduction procedures and results from CTIO and KPNO observations of extragalactic reference frame link sources have recently been published (Zacharias et al. 1999). Optical images of about 600 ICRF sources, exclusively obtained from CTIO and KPNO observations, are provided on the Web at ftp://rorf.usno.navy.mil/OID/oid.html.

The USNO CCD astrograph is currently stationed at CTIO, for latest results see (Zacharias et al. 2000).

Why CTIO? *(For CTIO proposals only.) Explain why access to the southern hemisphere is needed to achieve your scientific goals.*

Observing Run Details for Run 1: WIYN/MIMO

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

The structure analysis requires the highest angular resolution possible from the ground, thus the WIYN telescope must be used, in good seeing ($\approx$ 0.7 arcsec).

An estimated 0.5 hours is required for each source. This includes about 10 exposures of 1 minute duration plus readout times and guide star acquisition. There are $\approx$ 100 sources globally on the list for structure analysis, of which about 1/4 will be accessible at any given observing run. The astrometric pilot investigation will take about 5 hours in medium to good seeing ($\approx$ 1.5 to 0.8 arcsec). Thus a total of 2 nights are required.

The sources are bright and the exposure times are short, so a quarter moon phase is acceptable.

Targets will be selected based on the date of the observing run and the position of the moon at that time.

Instrument Configuration

Filters: Gunn b,g,r and custom	Slit:	Fiber cable:
Grating/grism: none	Multislit:	Corrector:
Order:	$\lambda_{\rm start}$:	Collimator:
Cross disperser:	$\lambda_{\rm end}$:	Atmos. disp. corr.:

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

In case observing time at the WIYN is granted, we will need to order a customized 4 inch interference filter prior to the observing run and would need a slot for it in the WIYN filter wheel.