PROSPECTS FOR FUTURE ASTROMETRIC MISSIONS

P.K. SEIDELMANN
U.S. Naval Observatory

Abstract. Hipparcos and the Hubble Space Telescope have demonstrated the astrometric capabilities in space. SIM and GAIA are being studied for future missions. There have been many proposals for new astrometry missions from many different countries, but most of them have not been funded.

The best possibility for a mission within the next five years would be through a collaborative effort for a small, fast, cheap spacecraft which could be a precursor for future, larger, more accurate missions, which are under study.

1. Introduction

In 1997 there will be available the Hipparcos Astrometric Satellite star catalog of 120,000 stars with accuracies of 1 milliarcsecond (mas) and proper motions of 1.1 mas year^{-1} for stars brighter than 9th magnitude. In addition, the Tycho Catalog will include one million stars with accuracies of 30 mas. The Hubble Space Telescope can do only a limited amount of astrometry due to the competition for observing time.

Ground-based astrometric, optical observations over wide angles will be made at mas accuracies with optical interferometers, such as the Navy Prototype Optical Interferometer, for several thousand stars. CCD observations of small fields can be made with 30–50 mas relative accuracies.

There are many proposals for future astrometric missions. They can be divided into scanning and pointed missions. The scanning missions, like Hipparcos, can observe many stars repeatedly and achieve good accuracy. The pointed missions measure relative positions more accurately, but cannot make as many observations and cannot observe as many stars. The technological improvements are based on the use of CCD detectors, optical

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interferometers, metrology systems, and increased data rates. The Space Interferometry Mission (SIM) in the U.S. and the Global Astrometric Interferometer for Astrophysics (GAIA) in Europe have some financial support for studies.

2. Why Future Astrometric Space Missions?

The real prospects for future astrometric missions must be tied to the reasons for such missions. The observables are positions, proper motions, parallaxes, photometry and images. New missions can achieve more accuracy and more stars. There are the traditional astrometric applications of navigation, guidance, and reference frames. In addition, space activities have added space surveillance and autonomous space navigation as applications for accurate astrometric data. However, this probably will not justify a future astrometric mission. So consider the purpose in terms of NASA's four themes, where astrometry has a fundamental scientific role:

2.1. STRUCTURE AND EVOLUTION OF THE UNIVERSE

- Calibrate the cosmological distance scale by measuring absolute parallaxes of Cepheids and RR Lyrae.
- Detemine positions, proper motions, and absolute parallaxes to 10% accuracy or better (as well as apparent magnitudes and spectral energy distributions) of a complete sample of stars brighter than 14th magnitude within 2.5 kiloparsecs of the Sun.
- Calibrate the absolute luminosities of solar neighborhood stars, including population I and II stars, enabling studies of stellar evolution.
- Determine transverse velocities of a complete sample of stars within 2 kpc of the Sun to 14th magnitude. From this, the mass distribution and gravitational surface mass density in the disk near the Sun can be determined. This relates directly to the dark matter implied by dynamical studies of globular clusters and rotation of galaxies (the "Oort problem").
- Detect astrometric perturbations of lensed sources during a microlensing event, and directly image a MACHO object shortly after a lensing event.
- Determine parallaxes and relative positions of binaries to determine masses, including unusual systems such as those containing white dwarfs and black holes, by analysis of positions of photocenter emission and use of multiple colors.
- Calibrate the distances to open star clusters and determine the absolute color magnitude diagrams of newly formed star clusters.

- Determine accurate reference frames which will ensure identification of sources in radio, optical, infrared and X-ray wavelengths.

2.2. SEARCH FOR ORIGINS AND PLANETARY SYSTEMS.

- Identify candidate stars for brown dwarfs and planets from inconsistent proper motion values.
- Detect astrometrically planets and brown dwarfs from non-linear proper motions.
- Image brown dwarfs and planets directly using interferometric nulling.
- Image the scattered light from the disks and exo-zodiacal dust surrounding young stars and main sequence stars like Beta Pictoris using interferometric nulling.
- Calibrate the cosmological distance scale which is critical to the origins of the universe question.

2.3. SOLAR SYSTEM EXPLORATION.

- Determine the accurate relationships between the radio, optical and dynamical reference frames which are necessary for solar system exploration.
- Make accurate positional observations of asteroids which will contribute to determination of asteroid masses.
- Make accurate observations of small bodies to improve the ephemerides for mission objectives.
- Make accurate observations of positions of near Earth objects which will improve knowledge of the motions of these objects.

2.4. SUN EARTH CONNECTION.

- Image other Suns and determine their radius, mass, luminosity and distance.

3. Possible Future Astrometric Missions

At this time two missions seem to be the most likely for future launch and are being actively studied. The Space Interferometer Mission (SIM) (OSI 1996) is a U.S. spacecraft with pointed Michelson interferometers of variable baselines and a nulling interferometer backend. It can observe about 5000 stars down to 20th magnitude to an accuracy of 0.004 mas. Plans are to launch SIM by 2005. It is a precursor for the ExNPS mission and will test technology for that future mission.

The Global Astrometric Interferometry for Astrophysics (GAIA) (Lindegren and Perryman 1995) is a European Space Agency study for a stack of three scanning Fizeau interferometers. It can observe 50,000,000 stars at an accuracy of 0.010 mas brighter than 15th magnitude. It is currently competing for a cornerstone mission with a possible launch date of 2015.

TABLE 1. Small scanning astrometric missions.

	FAME	LIGHT	DIVA
Purpose	Astrometry Photometry	Galactic Halo Tracer	Astrometry Photometry
Technique	Fixed Angle Scanning	Scanning Fizeau Interferometer	1/10 size Gaia
Num. of Stars	10,000,000	10,000,000	100,000
Accuracy	0.05 mas	0.1 mas	0.8 mas
Mag. Limit	15	15	10.5
Launch Date	2001	2007	2005
Status	Proposal	Proposal	Proposal

There are currently three proposals (Table 1) for a scanning instrument similar to Hipparcos, but using CCD detectors and higher data rates, so that more stars and accuracy can be achieved: FAME from USA (Seidelmann *et al.* 1995), LIGHT from Japan (Yoshizawa *et al.* 1997), and DIVA from Germany (Bastian *et al.* 1997). One such mission would fill the needs for a large all sky, very accurate star catalog down to about 15th magnitude. In addition to excellent science, such as calibrating the distance scale, this project would provide both a second epoch for Hipparcos and an independent set of short-time-period proper motions. The comparison between the sets of short-period proper motions and long-period proper motions should identify discrepancies and thus most likely candidates for planetary systems and brown dwarfs. This type of project is currently the most needed, unfunded astrometric spacecraft.

Two pointed spacecraft have been proposed (Table 2), POINTS (Chandler and Reasenberg 1990) and a scaled down POINTS called Newcomb (Johnston *et al.* 1995). These have been supplemented by the SIM project. A number of Russian spacecraft have been proposed in the last decade. The three most actively being discussed at the present time are AIST or Struve (Yershov *et al.* 1995; Chubey *et al.* 1995; Kopylov *et al.* 1995), Lomonosov (Nesterov *et al.* 1990) and Zenith (Table 3).

TABLE 2. Pointed astrometric missions.

	NEWCOMB	POINTS
Purpose	Astrometry	Astrometry
Technique	Stacked, small Michelson Interferometer	Rigid Michelson Interferometer
Num. of Stars	3,000	5,000
Accuracy	0.1 mas	0.001 mas
Mag. Limit	15	12
Launch Date	?	?
Status	Unfunded	Unfunded

TABLE 3. Russian astrometric missions.

	AIST/STRUVE	LOMONOSOV	ZENITH
Purpose	Astrometry Photometry	Astrmetry Photometry	Astrometry
Technique	2 Schmidt telescopes, Fixed angle scanning	1 m Mirror 90° separation, rotating	Michelson Interferometer, pointing
Num. of Stars	500,000	400,000	3,000
Accuracy	0.3 mas	2–10 mas	0.1 mas
Mag. Limit	18	10	12
Launch Date	2001	2003	?
Status	Study	Study	?

There are also discussions about observations from the Moon (Mission ι the Moon 1992). These proposals try to take advantage of the large ırface, absence of interference, distance to Earth, or lunar characteristics ʼable 4). All of these ideas appear to be far in the future.

Conclusion

he Hipparcos satellite has proven to be a great success and demonstrated ıe capability to do astrometry in space. Since its design, there have been ʒnificant technical developments that make it possible to build a satel-

TABLE 4. Proposed lunar based observations.

TECHNIQUE	PURPOSE
VLF Array of antennas	Extragalactic
Optical Interferometer	Small angel astrometry
Earth-Moon VLBI	Astrometry
Complex Optical Interferometer	Imaging
1 M Transit Telescope with CCDs	Macho detection

lite which can observe many more stars much more accurately. There is excellent scientific justification for future astrometric satellites.

As a result many satellites have been proposed for astrometric, photometric and imaging purposes. At this time the SIM and GAIA proposals appear to be the most likely to be launched. These two satellites complement each other in their capabilities and the differences in their launch dates. There appears to be good scientific justification for a scanning satellite with 50 microarcseconds accuracies for stars brighter than 9 magnitude launched in the first years of the twenty first century.

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