THE USE OF SPACE TELESCOPE TO TIE THE HIPPARCOS REFERENCE FRAME TO AN EXTRAGALACTIC REFERENCE FRAME

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Because of the nature of observations with the HIPPARCOS, the observations will be reduced to a set of positions, motions, and parallaxes with respect to a rigid reference frame (HIPPARCOS Instrumental System). This reference frame will have an unknown a priori rotation with respect to both an inertial reference frame and an extragalactic reference frame.

414 stars, mostly in the magnitude range 9-11, in the vicinity of 175 radio sources (mainly QSOs and BL Lac objects) have been submitted to the HIPPARCOS Project. A subset of these objects will be observed with the NASA/ESA Space Telescope's Fine Guidance Sensors to determine the positions and motions of the Extragalactic objects in the HIPPARCOS Instrumental System, and thence to derive the overall rotation of the HIPPARCOS Instrumental System with respect to the Extragalactic system. These observations will allow a direct comparison between the HIPPARCOS Instrumental System and any radio interferometric coordinate system which contains a set of the extragalactic objects observed. Relative changes of the radio and optical centroids at the level of a few milliarcseconds/year should also be readily apparent. Observations of these changes are of great astrophysical interest.

H. K. Eichhorn and R. J. Leacock (eds.), Astrometric Techniques, 613–624.

1 Introduction.

The HIPPARCOS Satellite will produce a set of stellar positions, proper motions, and parallaxes by effectively observing chords on the celestial sphere. The basic reference system for these data will be the HIPPARCOS Instrumental System (HIS). The HIS will have an unknown overall "solid-body" rotation with respect to a non-rotating reference frame, whether it is an inertial frame or an extragalactic frame. This rotation must be evaluated and removed in order for motions measured by HIPPARCOS, or motions referred to the HIPPARCOS coordinate system, to be dynamically meaningful. (See the Phase A Study of HIPPARCOS (ESA 1979), the International Colloquium on the Scientific Aspects of the HIPPARCOS space astrometry mission (Perryman and Guyenne 1982), and references therein for more details.)

We are undertaking a project to use the Fine Guidance Sensors (FGS) of the Space Telescope (ST) to determine the rotation of the HIS with respect to an extragalactic frame. (C.f. Hemenway, et. al. 1982) for a preliminary description of this project.) The extragalactic objects are assumed to be so distant that any cosmic transverse angular motion will be so small as to be undetectable, and that any apparent motions due to physical changes in the objects will be random among the objects. The plan is to make observations of the positions and apparent motions of extragalactic objects with respect to the HIS. Then, by assuming that the observed "motions" are entirely due to a residual rotation of HIS, the rotation of HIS with respect to the extragalactic sources may be determined. The relation between the extragalactic frame and one defined by the laws of physics as observed locally is not considered here (Schwarzschild 1967).

Should a sufficient number of extragalactic objects be common to this program and to the various radio astrometric programs, then an actual transfer of the coordinate system from a radio interferometric system to the HIS might be attempted. Other objects, such as radio stars, might serve in this capacity as well.

2 The Role of Space Telescope.

The FGSs are expected to be capable of relative position measurements of $\pm 0\farcs002$ rms within a pickle shaped field of view (Jefferys 1980). Each of the three guiding systems views a field which is part of the main focal plane of ST. These fields subtend 90° arcs around an annulus of inner radius 10' and outer radius of 14' in the focal plane. The nominal operating range will be 9^{th} to 17^{th} magnitude in the orange, with the capability of observing as bright as 4th magnitude with a neutral density filter in a collimated portion of the beam. The maximum extent of a pickle is about $18\farcm7$.

https://doi.org/10.1017/S0074180900077111 Published online by Cambridge University Press

The basic observational data from the FGSs are encoder readings of individual star positions, similar to metric readings from a measuring engine. Thus, in "relative astrometry mode", the FGS produces readings on one object, moves from that object to another, and provides readings on the second object. This procedure continues through the objects to be observed in the field. The basic observation type for tying the HIPPARCOS frame to the extragalactic frame will be relative positions of the extragalactic objects with respect to a HIPPARCOS star or stars within one pickle. The proper motions will be derived from observations spaced over several years.

This scenario will work for HIPPARCS program stars between magnitudes 4^{th} and 11^{th} and extragalactic objects between magnitudes 9^{th} and 17^{th}. Because the FGSs are interferometers, the stars must be essentially unresolved by ST. Thus, stars should not be double at the 0".04 level or larger, or the guiding system will have difficulty "locking onto" the stars. In order to reach brighter magnitudes, the neutral density filters already mentioned may be used. Ways of calibrating the positional effects of changing filters are being investigated.

In order to reach much fainter extragalactic objects, a method is proposed here which uses either the Wide Field/Planetary Camera (WF/PC) or the Faint Object Camera (FOC) in conjunction with the FGSs. In this case, the camera is used as a detector of the two objects whose positions are to be measured, but one at a time. The Space Telescope is aligned so that two guide stars are positioned in the FGSs to be used for guiding on both objects. The camera is pointed at one object (say the HIPPARCOS star) and its position is measured with respect to the camera itself. The ST is then offset so that the camera is pointing to the other object (say a QSO, now at 20^{th} or 21^{st} magnitude), and the position of the object is also measured with respect to the camera. The difference in position is simply the difference between the centroided image centers in the camera frame, plus the difference between the FGS pointings to the same guide stars. Thus we would use ST in a "transit circle" mode to determine relative settings to a projected accuracy only slightly worse (by a factor of two at most) than a direct measurement with the FGS itself, but on objects much fainter than the FGS can operate on directly. Should the HIPPARCOS star be too bright for the camera, we could measure the relative positon of the HIPPARCOS star with respect to background stars using the FGS directly, and then measure the QSO with respect to the background stars using the "transit circle" technique.

Single separations and rates provide sufficient data to derive the rotation of the HIS with respect to extragalactic objects. However, by using <u>two</u> HIPPARCOS stars near one extragalactic object, two components of the motion are available, strengthening the solution, providing orientation information, and giving a <u>local</u> check on the "apparent" motion of the extragalactic object. Therefore, we

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will concentrate on fields with more than one unresolved HIPPARCOS star near the extragalactic object.

3 The Extragalactic Objects.

We have selected extragalactic objects against which to measure the HIPPARCOS rotation.

In 1978, Commission 24 of the International Astronomical Union set up a working group on Optical/Radio Sources for the Establishment of an Inertial Reference Frame. (An overview and history of the Working Group was given by Argue, (Argue 1982).) The work of this group has been reported several places (c.f. (Argue and deVegt 1982), and references therein). The main result has been a list of radio sources, common to VLA and VLBI programs, with components brighter than 1 Jy at 5 GHz, mostly with known optical counterparts. The list has been recommended by IAU Commission 24 as the standard from which sources should be chosen for the comparison of radio and optical position systems. The list will be referred to as IAU82.

(Hewitt and Burbidge 1980) have prepared a catalogue of QSOs which provides information on a large number of optical objects distributed over the sky. (Argue and Baxter 1982) have searched for some stars near southern QSOs.

We searched the SAO catalogue for stars within 20' of the positions in the IAU82 list. Because only a small number of stars were found near bright objects in the list, we searched all objects brighter than 17.0 magnitude in Hewitt and Burbidge (1980). Finally, we included some southern sources of Argue and Baxter (1982).

The result is a list of 414 SAO stars near 172 extragalactic objects and/or radio sources. Table 1 gives a list of these "fiducial" objects and the radio and optical characteristics which bore on the selection.

Table 1:
Column 1 The radio source name.
Column 2 IAU82?
Column 3 Optical Type.
Column 4 Optical Magnitude.
Column 5 Reference: I=IAU82
A=Argue and Baxter
HB=Hewitt and Burbidge
Column 6 VLA quality 1=≤3% resolution to 30 km.
2=3%<resolution<20% to 30 km.
3=20%<resolution to 30 km.

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4=completely resolved/complex.
?=insufficient data or conflicting data.
ND=No data.
(from the VLA calibrator Manual, Perley, private communication.)

Column 7 VLBI quality:1=fringe visibility≥0.8.
2=0.8>visibility>0.1.
3=0.1>visibility>sigma(visibility).
4=resolved.
5=conflicting data.
ND=No data.
(from JPL VLBI visibilities, Preston, private communication.)

EF refers to a known empty field, and
ID? refers to a questionable identification.

These are the objects next to which we have found SAO stars. These stars have been submitted to the HIPPARCOS Project for observ3tion by both HIPPARCOS and Space Telescope.

4 The Stars.

We have found 414 SAO stars near the extragalactic objects listed in Table 1. These stars have been submitted to the HIPPARCOS Project. They are listed in Table 2.

Space Telescope observing time will be a premium commodity. Therefore, only a relatively small number of objects will be able to be observed for this project. We expect between 50 and 75 extragalacitc fields will be all that we will be able to obtain time for. Further, we will observe the SAO stars and optical objects in each field several times during the lifetime of ST, to determine the "proper motions" in the HIS. Speckle interferometric observations are being made to select star-QSO pairs which will give optimum observability with ST.

The speckle observations, to filter out stars unsuitable for the interferometric FGSs because of duplicity, are proceeding. In the southern hemisphere, Noel Argue and Brian Morgan's group at the Imperial College, London have analyzed data taken with the Anglo-Australian Telescope on 37 stars, of which 1/4 show clear duplicity. Similar statistics appear in preliminary results from Otto Franz at the Lowell Observatory and Harold McAlister at the George State University, using the Georgia State Speckle Camera on the Perkins 1.8 meter telescope. Because the atmospheric disturbances limit the resolution to about 0".08, and ST will have a resolving power of about 0".04, we have requested funds from NASA to continue the speckle observations at the 4-meter Mayall Telescope at Kitt Peak. McAlister and Franz would include those stars, found to be "single" at the 0\".08 level, in their ongoing double star program at KPNO. Thus, only stars observed to be single would be selected for ST observations, saving ST from observing stars on which the FGS could not lock, due to duplicity. This program will provide some very interesting statistics on the rate of duplicity, at the hundredth of an arcsecond level, of stars randomly selected around the sky.

5 Conclusion.

We plan to use ST observations to tie the HIPPARCOS Instrumental System to extragalactic objects, thereby producing a HIPPARCOS Extragalactic Reference System (HERS). The goals will be:

1. To determine the overall rotation of the HIPPARCOS Instrumental System with respect to a set of extragalactic objects,

2. To allow the transfer of an accurate radio reference frame to the HIS, and,

3. To look for motions in the optical centroids of compact extragalactic objects at the level of 0\".001/year.

To this end we have selected 172 radio sources and extragalactic objects, and have found 414 SAO stars near the extragalactic objects, for inclusion in the HIPPARCOS Project. These stars are undergoing screening by speckle interferometry, to select a final set of about 50 extragalactic objects with one or more stars close enough to observe with FGS astrometry of Space Telescope. Stars and extragalactic objects in the resulting set will be observed over the lifetime of ST to derive the "motions" of the extragalactic objects with respect to the HIS. The assumption will then be made that these observed motions are due entirely to a solid-body rotation of the HIS with respect to the extragalactic frame embodied by the objects observed. The components of the rotation vector will be determined, and the rotation removed from the HIS. Finally, any significant residual motions observed in the individual objects will be attributed to internal motions--an observation of great astrophysical interest.

6 Acknowledgements.

We wish to thank our colleagues of the IAU Commission 24 for advice and cooperation in this effort. We also thank William Jefferys and Peter Shelus for ideas and support, and we thank the people who are obtaining the speckle observations: Noel Argue, Otto Franz,

TABLE I

RADIO SOURCE	IAU 82	TYPE	MAGNITUDE	REFERENCE	VLA QUALITY	JPL VLBI QUALITY
0109+224					1/2	ND
0111+021	x	G	16.3	I	2	ND
0113-118	x	Q	18.5	I	2	2
0119+041	x	Q	19.5	I	1	1
0122+003					1/2	3
0134+329			16.2	HB	4?	3
0133+476	x	L	18.0	I	1	2
0135-247	x	Q	16.9	I	1/2	2
0138-097	x	L	17.5	I	2	2
0153+744	x	Q	16.0	I	1	ND
0150-334			16.5	A	1	1
0202+149	x	Q	22.0	I	2/3	2
0212+735	x	L	19.0	I	1	ND
0224+671	x	?	20.0	I	1	4
0234+285	x	Q	18.5	I	2	1
0237-233	x	Q	16.6	I	1	2
0241+622			16.4	HB	ND	ND
0256+075	x	Q	18.0	I	ND	2
0316+413	x	G	15.1	I	1	3
0402-362	x	Q	16.0	I	1?	2
0405-123			14.8	HB	NB	2
0422+004					ND?	2
0422-380			16.5	A	1	ND
0430+052		G	14.8	A	2/3	2
0454+844	x	L	16.5	I	1	ND
0528-250	x	Q	17.0	I	1	2
0529+075	x	Q	19.0	I	2	4
0537-441	x	Q	16.0	I	1/2	ND
0539-057					2	4
0552+398	x	Q	18.0	I	1	1
0605-085					1?	2
0607-157	x	Q	18.5	I	1	2
0615+820	x	Q	17.5	I	2	ND
0711+356	x	Q	19.0	I	1	1
0716+714	x	L	13.0	I	1?	ND
0723-008			18.0	A	2	2
0735+178	x	L	16.0	I	1	2
0736+017	x	Q	18.0	I	1/2	2
0742+103	x	EF	EF	I	1	2
0743-006	x		17.7	A,I	ID?	2
0804+499	x	Q	17.5	I	1	ND
0818-128			16.0	HB	ND	2
0826-373	x	Q	16.0	I	1	3
0828+493	x	Q	18.5	I	1	1
0827+243	x	Q	17.5	I	1?	1
0833+585	x	Q	18.0	I	2	ND

https://doi.org/10.1017/S0074180900077111 Published online by Cambridge University Press

TABLE I (CONT.)

RADIO SOURCE	IAU 82	TYPE	MAGNITUDE	REFERENCE	VLA QUALITY	JPL VLBI QUALITY
0836+710	x	Q	16.5	I	2	2
0851+202	x	L	14.5	I	1	1/2
0859-140	x	Q	19.0	I	1?	2
0912+297			16.3	HB	ND	2
0919-260	x	Q	19.0	I	1	3
0923+392	x	Q	17.8	I	4	2
0954+658	x	Q	18.0	I	1/2	ND
0955+326			15.78	B	2/3	2
1004+140	x	Q	18.0	I	ND	2
1019+309			17.0	HB	ND	2
1020-103			16.5	HB	1	ND
1031+567	x	G	19.5	I	1/2?	2
1032-199	x	Q	19.0	I	2	?
1034-293	x	Q	18	I	2	1/2
1038+064	x		16.6	A,I	ND	2
1055+018	x	Q	18.0	I	2/3	2
1123+264	x	Q	18.5	I	1	1
1127-145	x	Q	16.9	I	1	2
1130+009	x	Q	19.0	I	ND	1
1144-379	x	?	17.6	I	2	2
1143-245	x	Q	18.5	I	2	1/2
1150+497			16.1	HB	4	2/3
1150+812	x	L	18.6	I	1	ND
1155+251	x	G	17.5	I	1?	3
1211+334			17.0	HB	ND	2
1215+303			15.25	HB	ND	2
1219+285	x	L	15.0	I	1?	2
1226+023	x	Q	12.86	I	2	3
1244-255	x	Q	17.0	I	ND	2
1245-197	x	EF	EF	I	4	ND
1252+119			16.6	HB	1/2?	2
1253-055	x	Q	17.0	I	2	2
1255-316	x	Q	18.5	I	1	2/3
1302-102	x	Q	15.2	I	2	2
1308+326	x	Q	19.0	I	ND	?
1311+678	x	EF	EF	I	2?	4?
1313-333			18.5	A	2	2
1323+321	x	G	19.0	I	1	4
1328+307	x	Q	18.0	I	4	3
1331+170			16.0	HB	ND	2
1345+125	x	G	17.0	I	1/2	3
1349-439	x	?	21.0	I	ND	2
1354-152	x	Q	18.5	I	1?	2
1404+286	x	G	14.0	I	1	2
1416+067			16.79	HB	ND	3
1418+546	x	Q	14.5	I	1?	ND

TABLE I (CONT.)

RADIO SOURCE	IAU 82	TYPE	MAGNITUDE	REFERENCE	VLA QUALITY	JPL VLBI QUALITY
1430-178	x	Q	19.0	I	1?	2
1435+638	x	Q	15.0	I	2	ND
1442+101	x	Q	18.5	I	1?	2/3
1451-375			17.0	A	1	2
1458+718			16.78	HB	1?	3
1508-055			17.0	HB	4?	2/3
1510-089	x	Q	17.8	I	ND?	2
1514-241			13.8	A	4	2
1519-273	x	Q	18.5	I	1	1/2
1546+027	x	Q	18.0	I	1	2
1555+001	x	Q	19.0	I	1	1
1600+335						2
1607+268	x	EF	EF	I	1?	2/3
1633+382	x	Q	18.0	I	ND?	2
1637+574	x	Q	17.0	I	1/2	ND
1638+398	x	L	18.5	I	1	2
1641+399	x	Q	16.3	I	2	2
1656+053	x	Q	17.5	I	2	2
1717+178	x	Q	18.5	I	1	1
1721+343			16.4	HB	ND	2/3
1725+044			18.8	A	1?	2
1727+502			16.0	HB	ND	3
1732+389	x	G	19.5	I	1?	ND
1741-038	x	Q	18.5	I	1	2
1749+701	x	L	16.5	I	2/3	1
1749+096	x	Q	16.5	I	2	2
1748-253			18.24	A	1?	ND
1751+441					2	ND
1803+784	x	L	16.6	I	1	ND
1821+107	x	L	16.0	I	2	?
1828+487			16.81	HB	ND	3
1830+285			17.0	HB	1?	?
1908-202	x	?	22.0	I	1	2
1921-293	x	Q	17.0	I	ND?	2/3
1928+738	x	Q	15.5	I	1	ND
1933-400	x	Q	19.0	I	1?	2
1936-155	x	?	19.0	I	1?	2
1947+079	x	Q	20.0	I	1	2/3
1958-179	x	Q	18.5	I	2	1/2
2007+776	x	L	16.5	I	1	ND
2008-068	x	EF	EF	I	1?	2
2008-159			18.0	A	2	1
2021+614	x	Q	19.0	I	1	2/3
2030+547	x	?	18.7	I	ND	1/2?
2037+511	x	?	21.0	I	4?	2/3
2044-168			16.9	HB	2	2

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TABLE I (CONT.)

RADIO SOURCE	IAU 82	TYPE	MAGNITUDE	REFERENCE	VLA QUALITY	JPL VLBI QUALITY
2106-413	x	Q	18.4	I	1	2
2113+293	x	Q	19.5	I	1?	2
2128-123	x	Q	16.0	I	1	2
2128+048	x	EF?	16.24	HB, I	1	ND
2131-021	x	Q	19.0	I	1/2?	ND
2134+004	x	Q	18.0	I	1	2/3
2136+141	x	Q	18.5	I	1	2/3
2144+092	x	Q	18.6	I	4	2
2145+067	x	Q	17.0	I	1?	2
2155-152	x	Q	18.0	I	2	2
2200+420	x	L	14.0	I	1	1/2?
2201+315	x	Q	14.5	I	1?	2/3
2203-188	x	Q	19.5	I	4	3
2216-038	x	Q	17.2	I	2	2
2223-052			18.4	A	ND?	2/3
2227-088	x	Q	18.0	I	1	2
2234+282	x	Q	19.0	I	1	2
2243-123	x	Q	17.0	I	1	2
2245-328	x	Q	16.5	I	1	1/2
2247+140			17.0	HB	4	4
2251+158	x	L	16.1	I	2	2
2253+417	x	Q	18.8	I	ND	ND
2254+074	x	Q	16.0	I	1?	2
2255-282	x	Q	16.3	I	2	?
2318+049	x	Q	19.0	I	1?	?
2319+272	x	?	20.0	I	1?	2
2320-035	x	Q	17.8	I	ND	ND
2329-162	x	Q	20.0	I	2?	2/3
2328+107	x	Q	18.1	I	1	2
2331-240	x	G	16.5	I	1	1
2337+264	x	Q	20.0	I	1	2
2344+092	x	Q	17.5	I	2	2/3
2345-167	x	Q	18.5	I	1?	2
2352+495	x	G	19.0	I	1	2

https://doi.org/10.1017/S0074180900077111 Published online by Cambridge University Press

Harold McAlister, and Brian Morgan and his group. We appreciate the extensive radio data supplied prior to publication by Richard Perley of the VLA and Robert Preston of JPL. Finally, we thank the NASA for continued support under Grant NAGW-233.

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Discussion:

MURRAY: What accuracy do you expect?

HEMENWAY: Assuming the 0".002 rms accuracy will be achieved, the standard errors will be approximately 0".002/Δ t (seconds per year) where Δ t is the time interval in years. We expect to observe these objects throughout the lifetime of the space telescope, say 20 years. Each object should thus have an "apparent" motion known to a few times 0".0001. The system solution will be limited by systematic effects.