VLBI MEASUREMENTS OF RADIO SOURCE POSITIONS AT THE JET PROPULSION LABORATORY

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ABSTRACT

We present the results of approximately 1300 observations of 67 radio sources. Most of our measurements were made at the stations of the Deep Space Network in California, Spain, and Australia, at wavelengths of 13.1 and 3.6 cm, between 1971 and 1978. The formal errors in the derived source positions are generally in the neighborhood of 0.01 seconds of arc, and the positions agree fairly well with those published by other groups.

INTRODUCTION

The observational material I am going to discuss this afternoon is identical with what Brooks Thomas discussed this morning in connection with the geophysical parameters – namely baselines, UT1, and polar motion. However, I am going to consider it now from the standpoint of the source positions.

Historically, JPL has been interested in radio source positions as an adjunct to its VLBI measurements of parameters required for spacecraft navigation, in particular, UT1, polar motion, and station locations. When our system becomes fully operational, we expect to make measurements of station locations and polar motion accurate to 30 cm or better, and UT1 at a comparable level. In order to achieve this goal, we require a source catalog with positions accurate to something like $0\rlap{.}''01$. Furthermore, we expect to observe at arbitrarily assigned times, with only about 2 hours of data per week on each baseline. Our catalog therefore needs to be fairly large, say a hundred sources; and we want the objects well distributed over the accessible sky.

JPL is also interested in using extragalactic sources more directly for spacecraft navigation by making differential measurements between spacecraft and nearby natural sources. For that reason, we have a special interest in sources near the ecliptic – particularly those parts of the ecliptic where spacecraft are likely to turn up.

Finally, we have recently started a project to test the stability of the celestial reference frame by measuring differential proper motion in a few close pairs of sources.

EQUIPMENT, OBSERVATIONS, AND REDUCTION PROCEDURES

I am not going to dwell on our equipment and reduction procedures, because Brooks has already discussed those in some detail, and they have been described elsewhere (Purcell et al., 1978); but I would like to remind you of some of the salient points. Our data consist of about 1300 observations of 67 sources made in the course of 30 observing sessions between 1971 and 1974 and in 1977 and 1978. Most of these sessions involve the baselines between the Deep Space Network stations in California and Spain, and California and Australia; but there is also one session between Haystack and Owens Valley. During the earlier years, we observed only at a wavelength of 13.1 cm, and we measured only fringe rates; more recently, we have been using bandwidth synthesis methods to measure delays as well as rates; now, we generally observe simultaneously at 13.1 and 3.6 cm. In several of these sessions, we have combined data at the two frequencies to reduce the corrupting influence of the ionosphere on the observations.

In the final step of the reduction procedure, we fitted all the data simultaneously with an analytic model containing 384 adjustable parameters. Of these parameters, 133 describe the source positions, the others are divided among the clock model (129), the troposphere model (64), UT1 and polar motion (43), and station locations (14).

RESULTS

Figure 1 shows the distribution on the sky of our 67 sources, and, on a different scale, the formal errors on the estimated right ascensions and declinations. Very large errors, those greater than 0.″03, have not been plotted. In addition, one source, NRAO 140, was used as the reference point for right ascension and therefore has no horizontal error bar. The figure shows that the sources are, in fact, fairly well distributed over the visible sky, and that the errors in the positions are mostly in the neighborhood of 0.″01. You can see that the positions of southern sources – ones that we can observe only on the California-to-Australia baseline – are generally less well determined than those of the northern sources. I attribute this result largely to the fact that these southern sources are visible for only about 4 hours. This circumstance leads to correlations among the errors in some of the parameters, and thus to a general weakening of that part of the solution. Until recently, there were very large errors in the declinations of some sources near the equator that had been observed only on the California-to-Spain baseline, which has a small polar projection. However, we have relieved much of that problem now by adding some observations of these sources on the other baseline.

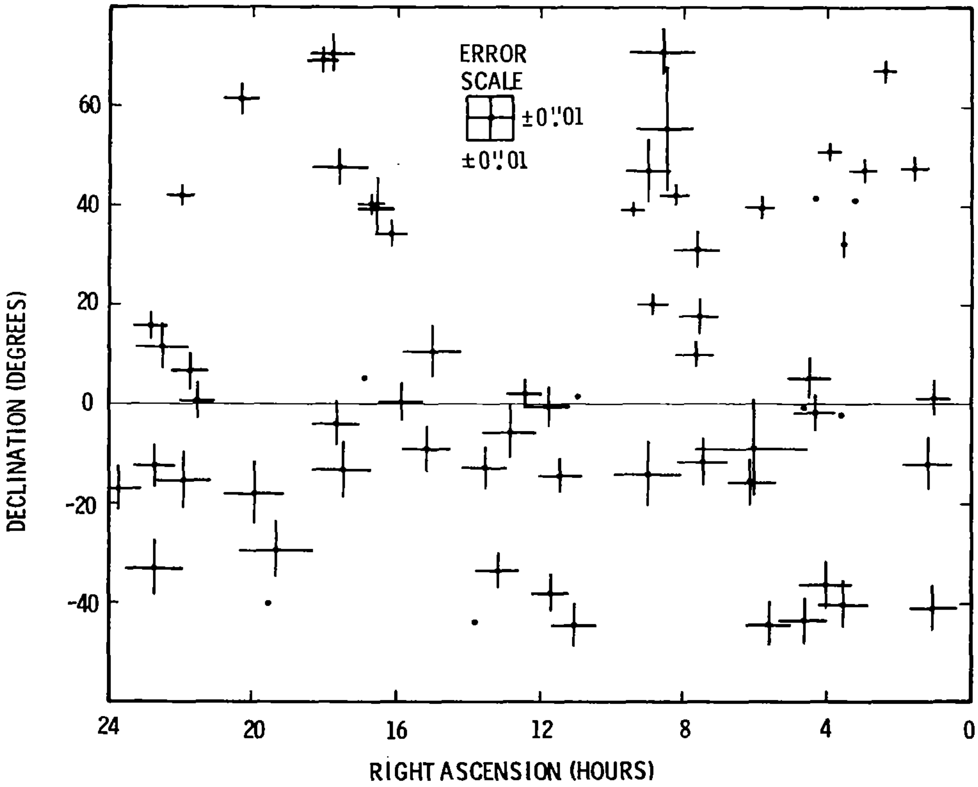

Figure 1. Distribution of sources.

I would like to emphasize today the progress our group has made in the last year or so. Figures 2 and 3 are histograms that show the distributions of the formal errors in our source positions as they were 9 months ago (the white blocks) and as they are now (the black blocks). Notice that each error bin contains a white column and a black column, with the shorter column always placed in front so that both can be seen. Figure 2 shows that the mean formal error in right ascension has decreased from about 0.″032 (for 52 sources) in September of last year to 0.″014 (for 63 sources) now - an improvement of better than a factor of two. The improvement in the declinations is even more dramatic (figure 3), from 0.″030 (for 45 sources) to 0.″011 (for 63 sources).

We are, of course, continuing to compare our results with those of other groups. To this end, we have constructed a composite reference catalog from the lists of Clark et al. (1976), Elsmore and Ryle (1976), and Wade and Johnston (1977). This catalog is a weighted average of the three lists, with slight adjustments in the origin of right ascension of two of them, to produce the best overall agreement. In a few cases of serious discrepancy, we deleted individual values from the average. Finally, we readjusted the origin of right ascension of the composite list to produce the best overall agreement with our own list, and computed the residual differences between the two.

Figure 4 shows the differences between the right ascensions in the reference catalog and those in our list, for 28 sources. I think you can see that the scatter in the points is entirely consistent with the error bars; in fact, chi-square per degree of freedom is 0.99. However, the agreement in the declinations, shown in figure 5, is quite poor, owing mainly to a mean difference between the reference list and the JPL list of about -0.″02. We have as yet no satisfactory explanation for this difference.

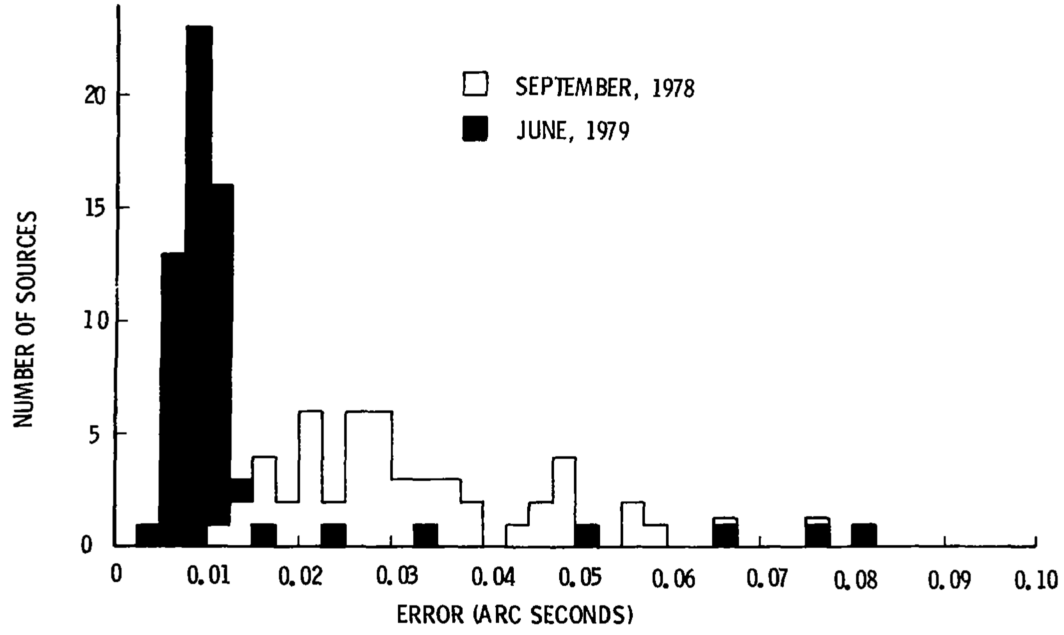

Figure 2. Distribution of errors in right ascension.

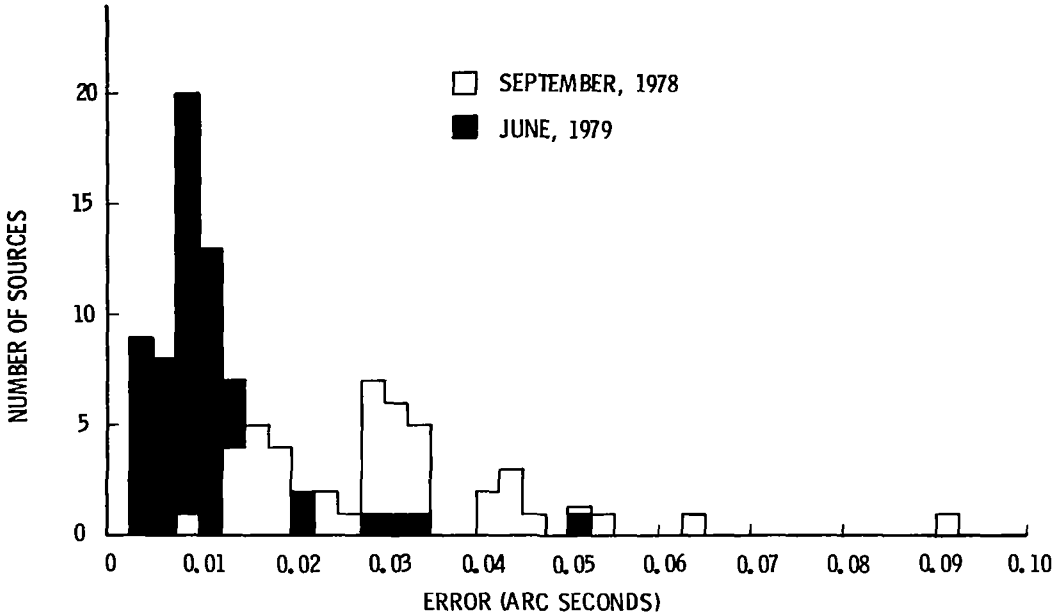

Figure 3. Distribution of errors in declination.

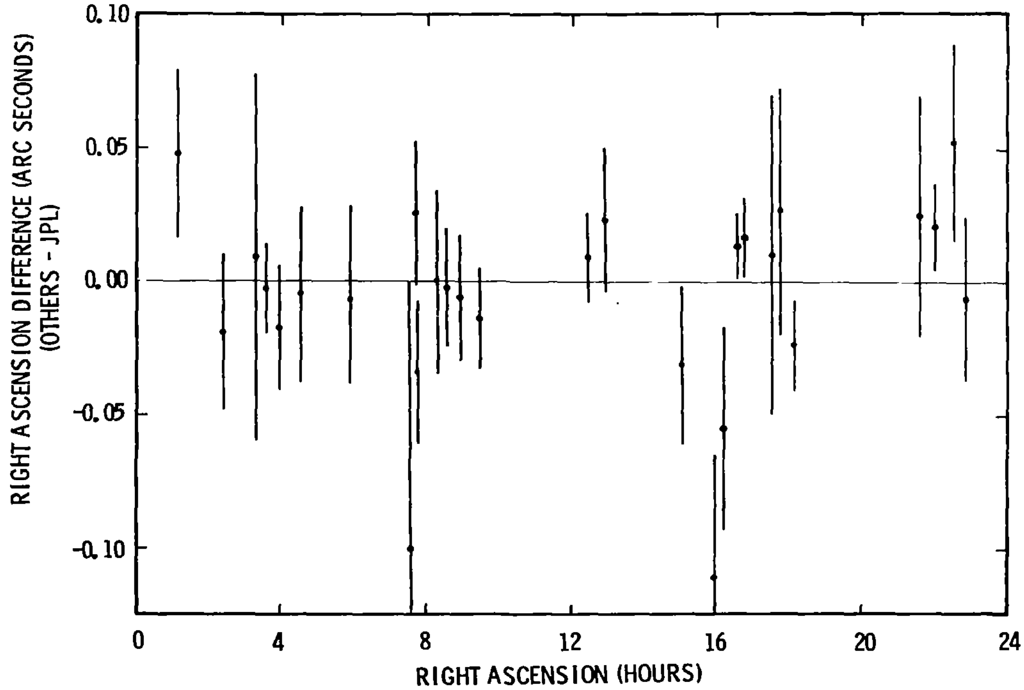

Figure 4. Comparison of right ascensions.

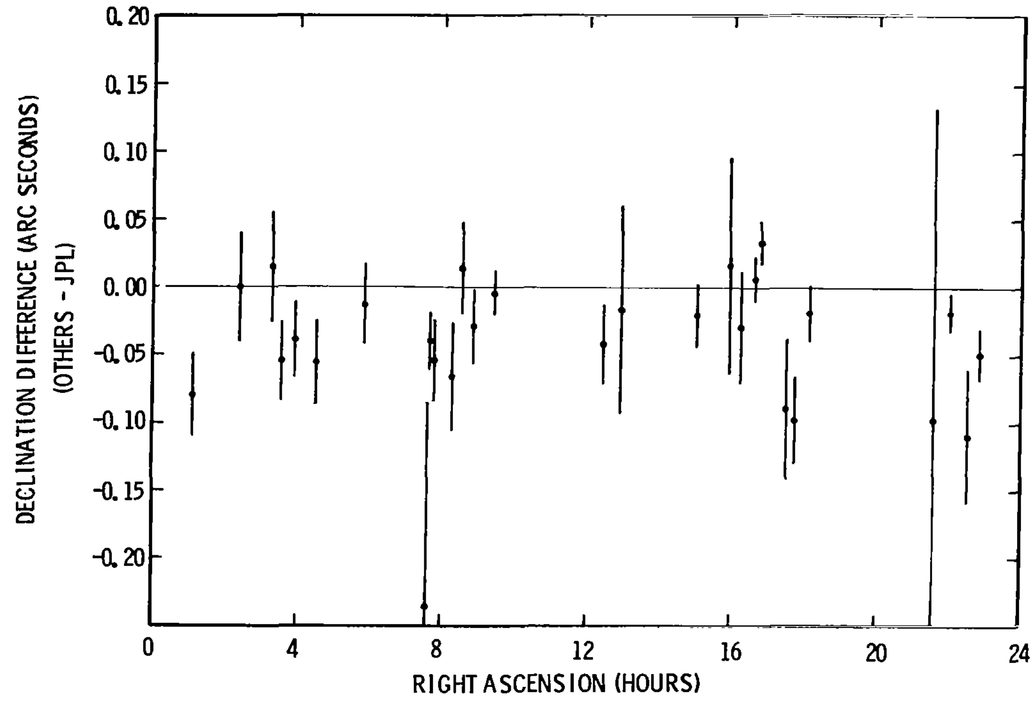

Figure 5. Comparison of declinations.

The general problem of comparing two sets of source positions is an awkward one just now. The fact that different groups are reducing their data using different nutation series and different rates of precession is certain to lead to systematic differences in results at a level of 0.″01, especially when the epochs of the observations differ. Fortunately, it seems likely that we can resolve these differences in the near future.

Table 1 presents the source positions themselves. Note that these positions are barycentric. To obtain positions consistent with normal practice in optical catalogs, you must add the elliptic aberration terms that are provided. Keep in mind also that we reduced the positions to 1950.0 coordinates using the conventional (Woolard) nutation series and Newcomb's value of the precession constant.

FUTURE PLANS

We have made substantial progress in the past year, and we expect this progress to continue in the near future. Even at our present level of sensitivity, we can easily reach 50 or 60 more sources. We are improving our calibration techniques to account better for fluctuations in instrumental and propagation delays. We are also continuing to improve our delay model in anticipation of accuracies substantially better than 0.″01.

Table 1
Radio Source Positions

SOURCE NAME	SOURCE POSITION (SOLAR SYSTEM BARYCENTER, 1950.0)				ELL. ABERRATION	
	RIGHT ASCENSION	ERROR	DECLINATION	ERROR	R.A.	DEC.
P 0104-408	$01^{h}04^{m}27^{s}.57081$	$0^{s}.00092$	$-40°50'21''.3385$	$0''.0106$	$0^{s}.00263$	$-0''.2442$
P 0106+01	01 06 04.51419	0.00054	+01 19 01.1607	0.0080	0.00215	-0.0207
P 0113-118	01 13 43.21450	0.00074	-11 52 04.4395	0.0118	0.00297	-0.0977
DA 55	01 33 55.09459	0.00066	+47 36 12.6398	0.0053	0.00724	0.2273
DW 0224+67	02 24 41.14105	0.00083	+67 07 39.4256	0.0049	0.02483	0.2741
OE 400	03 00 10.09103	0.00060	+47 04 33.5013	0.0055	0.01868	0.1882
3C 84	03 16 29.54517	0.00593	+41 19 51.7340	0.0310	0.01869	0.1564
P 0332-403	03 32 25.20880	0.00091	-40 18 23.8807	0.0099	0.01999	-0.1861
NRAO 140	03 33 22.38543	*	+32 08 36.5561	0.0058	0.01809	0.1104
CTA 26	03 36 58.91001	0.01674	-01 56 16.8612	1.1855	0.01559	-0.0370
NRAO 150	03 55 45.23306	0.00058	+50 49 20.1587	0.0038	0.02673	0.1598
P 0402-362	*04 02 02.56611*	*0.00094*	*-36 13 11.7154*	*0.0107*	*0.02144*	*-0.1545*
VRO 41.04.01	04 20 27.96800	0.04666	+41 43 06.7997	0.6590	0.02470	0.1123
P 0420-01	04 20 43.51973	0.00059	-01 27 28.6683	0.0085	0.01846	-0.0337
3C 120	04 30 31.58204	0.00064	+05 14 59.6152	0.0091	0.01908	-0.0112
P 0438-43	04 38 43.14982	0.00092	-43 38 53.4225	0.0098	0.02687	-0.1437
NRAO 190	04 40 05.27072	0.00218	-00 23 20.5738	0.0327	0.01951	-0.0298
P 0537-441	05 37 21.03832	0.00088	-44 06 44.6030	0.0097	0.03038	-0.0891
DA 193	05 52 01.37726	0.00058	+39 48 21.9245	0.0048	0.02889	0.0277
P 0605-08	06 05 36.00444	0.00164	-08 34 20.2899	0.0216	0.02271	-0.0368
P 0607-15	06 07 25.95624	0.00074	-15 42 03.2823	0.0103	0.02336	-0.0424
P 0727-11	07 27 58.07365	0.00074	-11 34 52.5831	0.0106	0.02284	-0.0150
P 0735+17	07 35 14.10211	0.00061	+17 49 09.3064	0.0082	0.02335	-0.0502
OI 363	07 38 00.15161	0.00077	+31 19 02.1255	0.0087	0.02594	-0.0655
DW 0742+10	07 42 48.44097	0.00056	+10 18 32.6957	0.0062	0.02241	-0.0435
OJ 425	08 14 51.64006	0.00057	+42 32 07.8557	0.0043	0.02854	-0.1099
4C 55.16	08 31 04.34169	0.00147	+55 44 41.4885	0.0287	0.03617	-0.1428
4C 71.07	08 36 21.49599	0.00291	+71 04 22.6217	0.0107	0.06203	-0.1609
OJ 287	08 51 57.22910	0.00048	+20 17 58.5040	0.0046	0.02063	-0.0894
OJ 499	08 59 39.95510	0.00093	+47 02 56.9833	0.0139	0.02778	-0.1586
P 0859-14	08 59 54.92583	0.00100	-14 03 38.8984	0.0143	0.01950	0.0186

*NRAO 140 right ascension reference

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract NAS7-100.

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Table 1 (continued)

SOURCE NAME	SOURCE POSITION (SOLAR SYSTEM BARYCENTER, 1950.0)				ELL. ABERRATION	
	RIGHT ASCENSION	ERROR	DECLINATION	ERROR	R.A.	DEC.
4C 39.25	$09^h23^m55^s.29607$	$0^s.00048$	$+39°15'23''.7306$	$0''.0037$	$0^s.02258$	$-0''.1607$
P 1055+01	10 55 55.29831	0.01438	+01 50 04.5763	1.4224	0.01039	-0.0383
P 1104-445	11 04 50.35273	0.00091	-44 32 53.1988	0.0093	0.01346	0.1971
P 1127-14	11 27 35.65773	0.00061	-14 32 54.5078	0.0082	0.00775	0.0534
P 1144-379	11 44 30.84975	0.00073	-37 55 30.8424	0.0083	0.00747	0.1804
P 1148-00	11 48 10.11818	0.00065	-00 07 13.1473	0.0089	0.00554	-0.0279
3C 273	12 26 33.24224	0.00052	+02 19 43.3448	0.0065	0.00178	-0.0424
3C 279	12 53 35.83076	0.00080	-05 31 08.0123	0.0119	-0.00091	0.0044
OP-322	13 13 20.04317	0.00076	-33 23 09.8640	0.0087	-0.00343	0.1627
DW 1335-12	13 34 59.80762	0.00065	-12 42 09.8032	0.0091	-0.00511	0.0455
P 1349-439	13 49 50.30438	0.00484	-43 57 48.3349	0.0224	-0.00891	0.2071
OR 103	15 02 00.17015	0.00085	+10 41 17.8086	0.0117	-0.01310	-0.0804
P 1510-08	15 10 08.91346	0.00072	-08 54 47.6550	0.0103	-0.01369	0.0144
DW 1555+00	15 55 17.70879	0.00061	+00 06 43.5522	0.0087	-0.01686	-0.0290
DA 406	16 11 47.93564	0.00057	+34 20 19.9820	0.0060	-0.02170	-0.1427
NRAO 512	16 38 48.19450	0.00070	+39 52 30.2209	0.0137	-0.02534	-0.1361
3C 345	16 41 17.62954	0.00054	+39 54 10.9214	0.0046	-0.02551	-0.1341
DW 1656+05	16 56 05.63938	0.00513	+05 19 46.8476	0.2463	-0.02037	-0.0429
NRAO 530	17 30 13.55606	0.00085	-13 02 45.8376	0.0123	-0.02217	-0.0033
OT 465	17 38 36.34191	0.00118	+47 39 28.8555	0.0083	-0.03244	-0.0908
P 1741-038	17 41 20.63771	0.00067	-03 48 48.8899	0.0100	-0.02197	-0.0223
1749+701	17 49 03.45582	0.00189	+70 06 39.7017	0.0087	-0.06503	-0.0866
3C 371	18 07 18.61013	0.00128	+69 48 57.1599	0.0050	-0.06517	-0.0616
OV-236	19 21 42.25904	0.00121	-29 20 26.3129	0.0132	-0.02579	-0.0520
P 1933-400	19 33 51.15233	0.00709	-40 04 47.4184	0.0518	-0.02909	-0.0689
OV-198	19 58 04.62966	0.00092	-17 57 16.9055	0.0142	-0.02272	-0.0604
OW 637	20 21 13.34445	0.00104	+61 27 18.0444	0.0071	-0.04349	0.1094
P 2134+004	21 34 05.22134	0.00052	+00 28 25.1264	0.0084	-0.01682	-0.0267
P 2145+06	21 45 36.09253	0.00058	+06 43 40.9133	0.0085	-0.01614	0.0001
OX-192	21 55 23.25580	0.00081	-15 15 30.0017	0.0130	-0.01588	-0.0941
VRO 42.22.01	22 00 39.37976	0.00052	+42 02 08.4480	0.0046	-0.02010	0.1516
CTA 102	$22^h30^m07^s.81548$	$0^s.00079$	$+11°28'22''.7831$	$0''.0102$	$-0^s.01286$	$0''.0286$
OY-172.6	22 43 39.80282	0.00063	-12 22 40.2035	0.0097	-0.01173	-0.0912
P 2245-328	22 45 51.51756	0.00099	-32 51 44.2844	0.0127	-0.01342	-0.1852
3C 454.3	22 51 29.52926	0.00047	+15 52 54.2989	0.0061	-0.01121	0.0549
P 2345-16	23 45 27.68691	0.00068	-16 47 52.4898	0.0102	-0.00606	-0.1229

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