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Time stability of the ICRF2 axes⋆ (Research Note)

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ABSTRACT

Aims. I assess the astrometric stability of the 295 defining sources of the current best realization of the International Celestial Reference System (ICRS): the second realization of the International Celestial Reference Frame (ICRF2), constructed and published in 2009 after the analysis of millions of VLBI observations at 2 and 8 GHz between 1979.6 and 2009.2. I also assess the time evolution of the ICRF2 axis stability.

Methods. I derived coordinate time series of hundreds of quasars monitored by the regular geodetic VLBI program of the International VLBI Service for Geodesy and Astrometry (IVS). The axis stability was studied by constructing annual reference frames based on the ICRF2 defining sources. The time variable frame stability was obtained by computing the deformation parameters that lead from one frame to the next.

Results. I show that, although the astrometric stability of some of the ICRF2 defining sources has slightly degraded since 2009.2, the ensemble still constitutes a very stable reference frame. The current estimation of the axis stability over 1979.6–2013.1 remains at the same level as the one estimated over 1979.6–2009.2, i.e., on the order of 20 μas for each axis.

Key words. astrometry – reference systems – techniques: interferometric

1. Introduction

In 2009, the International Astronomical Union (IAU) adopted the second realization of the International Celestial Reference Frame (ICRF2), made up of precise coordinates of 3414 extragalactic radio sources observed with very long baseline radio interferometry (VLBI) at 2 and 8 GHz (Fey et al. 2010). This new fundamental catalog took advantage of recent improvements in the VLBI technique, both at the observational level (new antennas, better data acquisition systems) and at the analysis level (improved analysis methods). The noise floor of the ICRF2 was evaluated at the level of 40 μas. The frame axes are defined by the coordinates of 295 so-called defining sources and are stable at the level of 10 μas over the period running from 1979.6 to 2009.2.

The celestial reference frame plays an important role in geodetic VLBI analysis, especially for precise estimates of the Earth's orientation with respect to a space-fixed reference frame: if not taken into account, any deformation of the ICRF axes could arise in either the nutation or the Earth rotation angles (IERS 1996, II–17). This is particularly critical since several studies have used VLBI nutation series to infer interesting physical parameters relevant to the Earth's core and inner core (Mathews et al. 2002; Koot et al. 2008, 2010; Koot & Dumberry 2011).

Geodetic VLBI observations and analyses are mainly managed within the International VLBI Service for Geodesy and Astrometry (IVS, see Schuh & Behrend 2012), an international collaboration of laboratories and agencies for development, operation, and support of VLBI. Some IVS analysis centers have processed the geodetic VLBI observational database to obtain radio source coordinate time series. These time series represent the motion of the centroid of the radio source as seen by the network, and were intensively used in the past to build up a more stable reference frame (see, e.g., Feissel-Vernier 2003; Feissel-Vernier et al. 2005, 2006; Lambert & Gontier 2009). The selection of the ICRF2 defining sources was partly based on these series (Fey et al. 2010): the authors defined a stability criterion and ranked the sources from the most to the less stable. Then, they used the most recent computations of structure indices (e.g., Charlot 1990; Fey & Charlot 1997) in order to eliminate sources with significant structures. Finally, they loosened the selection threshold for lower declinations to allow sources in the southern hemisphere to be selected and to improve the homogeneity of the defining source distribution over the celestial sphere.

Can the ICRF2 defining sources still be considered as defining in the light of post-ICRF2 observations? Are the ICRF2 axes still undeformed? In this paper, I analyzed recent coordinate time series of the 295 ICRF2 defining sources, for which new observations have been accumulated since 2009.2. I investigated whether they can still be considered as stable in the astrometric sense, hence be conserved in the ICRF2 defining set. Section 2 explains how the coordinate time series are generated. In Sect. 3, I investigate the astrometric stability of the defining sources and the time stability of the ICRF2 axes. Section 4 presents some conclusions.

2. Generation of the coordinate time series

The Paris Observatory IVS analysis center (Lambert & Barache 2012) provided a set of coordinate time series for

⋆ Table 1 is available in electronic form at http://www.aanda.org

3791 sources[1]. They were obtained by analyzing of 5441 diurnal sessions using single- and multi-baseline networks between August 1979 and January 2013. The full set of time series was obtained after four solutions. In each solution, one fourth of the sources' coordinates were estimated as session parameters. Others were estimated as global parameters, including three fourths of the 295 ICRF2 defining sources that are constrained by a no-net rotation (NNR) condition with a priori coordinates taken in the ICRF2 catalog. In all solutions, the elevation cut-off was set to 5°. Station coordinates were estimated as global parameters with no-net rotation and no-net translation constraints with respect to the VTRF 2008A (Böckmann et al. 2010) on the coordinates and velocities of 24 stations. Nonlinear motions of antennas at Fort Davis (Texas), Pie Town (New Mexico), Fairbanks (Alaska), TIGO at Concepción (Chile), and Tsukuba (Japan) were modeled by splines. A priori zenith delays were determined from local pressure values (Saastamoinen 1972), which were then mapped to the elevation of the observation using the Vienna mapping functions (Böhm et al. 2006). Zenith wet delays were estimated as a continuous piecewise linear function at 20-min intervals. Troposphere gradients were estimated as 6-hr east and north piecewise functions at all stations. Station heights were corrected for atmospheric pressure and oceanic tidal loading. The relevant loading quantities were deduced from surface pressure grids from the NCEP/NCAR reanalysis project atmospheric, global circulation model (Kalnay et al. 1996; Petrov & Boy 2004) and from the FES 2004 ocean-tide model (Lyard et al. 2004). A priori precession and nutation comply with the IAU 2000/2006 resolutions, which include the nutation model of Mathews et al. (2002), the improved precession model of Capitaine et al. (2003b), and the nonrotating origin-based coordinate transformation between terrestrial and celestial coordinate systems (Capitaine et al. 2003a). The calculations used the Calc 10.0/Solve 2010.05.21 geodetic VLBI analysis software package, which was developed and is maintained at NASA Goddard Space Flight Center. To suppress large outliers in the time series, I removed points that are away from the mean by more than ten times their formal error. This rejection scheme was iterated a few times.

3. Analysis and results

3.1. Astrometric stability of the defining sources

Figure 1 displays the observational history of the ICRF2 defining sources. As mentioned in Fey et al. (2010), the southern hemisphere suffers from a lack of observations. The discrepancy between north and south still shows up over 2009.2–2013.1, particularly for declinations lower than 50°S. The overall stability of a time series, as defined by Eq. (8) of Fey et al. (2010), is

$$s = \sqrt{\mathrm{rms}^2_{\alpha\cos\delta}\chi^2_\alpha + \mathrm{rms}^2_\delta\chi^2_\delta}. \quad (1)$$

Comparing this quantity computed over the ICRF2 time span (1979.6–2009.2) and over the full time span (1979.6–2013.1) tells which sources underwent significant changes in their stability due to post-ICRF2 observations (Table 1). Results are displayed in Fig. 2, where one can see that the changes in the stability brought by the post-ICRF2 observations are never greater than 0.8 mas in absolute value, and become smaller when the number of post-ICRF2 observations increases. The averaged stability change is 0.007 mas. It is slightly larger for southern sources.

[1] http://ivsopar.obspm.fr/radiosources

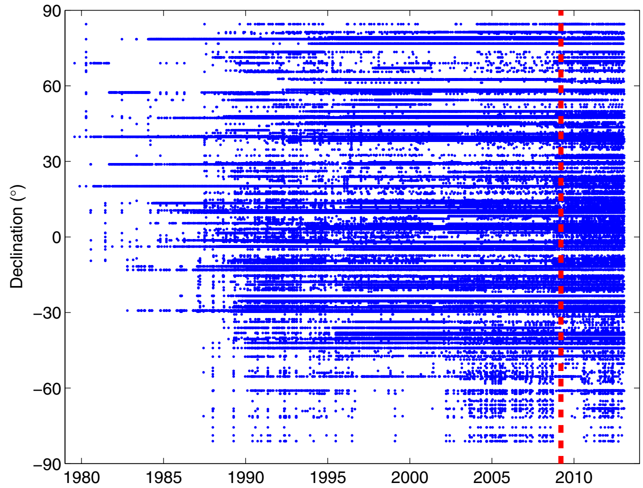

Fig. 1. Observational history of the 295 ICRF2 defining sources. The red vertical line indicates the end date of the ICRF2 data span.

These changes in the stability can occur when the structure of the source changes with time, but also when a source that is poorly observed at the ICRF2 time is observed again. In the latter case, the accumulation of new observations allows more accurate conclusions about the astrometric suitability of the source. Indeed, if the number of sessions is small, the statistical quantities used during the selection process are less reliable than for well-observed sources. It basically tells us that the election of the source as defining could have been premature. This is especially true for the southern sources that were chosen, for some of them, not for reasons of stability but to balance out the source distribution between the two hemispheres.

3.2. Axis stability

From session coordinate time series, I computed annual points by applying a weighted moving average. (The averaging window is one year long and is displaced by steps of one year, so that there is no overlapping of data.) Doing so, I assumed that a year is representative of the time scale on which a significant radio center displacement can occur. Each annual point was affected by an uncertainty made up of the weighted standard deviation of the data within the averaging window.

I could therefore construct annual representations of the ICRF2 by taking the annual coordinates of the ICRF2 defining sources to check whether these annual frames deform from one year to the next. The radio source coordinate difference between two catalogs can be modeled by a coordinate transformation that takes the global rotation between the two catalogs into account, as well as the deformations. The coordinate transformation recommended by the IERS and in use at the ICRS-PC reads (IERS 1996, II–32) as

$$\Delta\alpha = R_1\cos\alpha\tan\delta + R_2\sin\alpha\tan\delta - R_3 + D_\alpha(\delta-\delta_0), \quad (2)$$
$$\Delta\delta = -R_1\sin\alpha + A_2\cos\alpha + D_\delta(\delta-\delta_0) + B_\delta. \quad (3)$$

wherein R_1, R_2, and R_3 are rotation angles around the X, Y, and Z axes, respectively; D_α and D_δ are slopes in right ascension and declination as a function of the declination; and B_δ is a bias in declination. This transformation will be referred to as T_1 in the following.

A simplified version of this transformation was used in several studies (e.g., Feissel-Vernier et al. 2006; Lambert & Gontier 2009; Fey et al. 2010). It neglects the slope parameters D_α

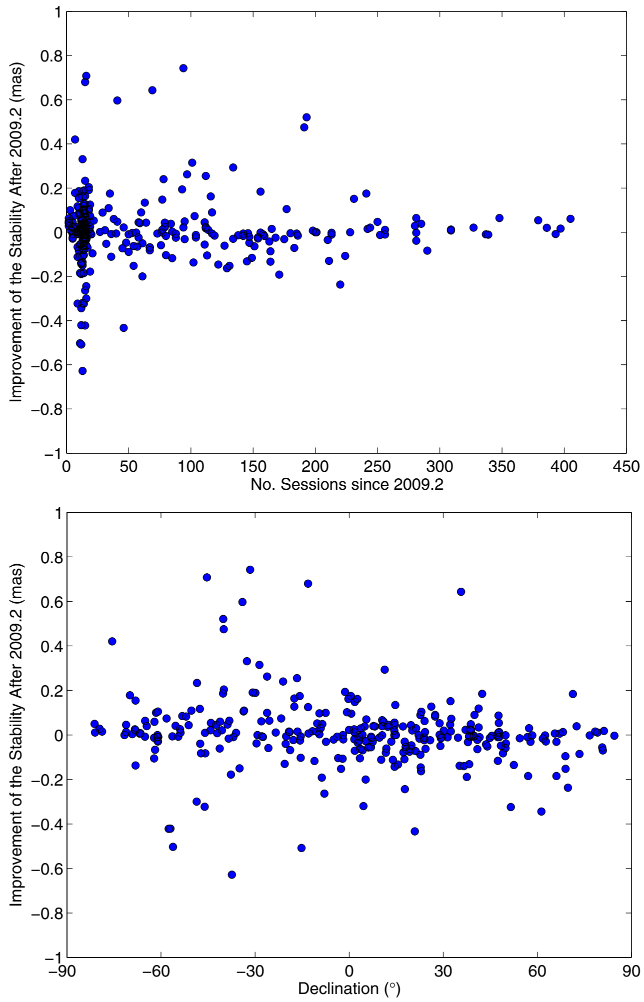

Fig. 2. Improvement in the stability brought by the observations after 2009.2 as a function of (*top*) the number of sessions and (*bottom*) the declination: a negative value means that the source becomes less stable.

and D_δ and keeps the bias B_δ (also known as equatorial tilt and designed by dz):

$$\Delta\alpha = R_1 \cos\alpha \tan\delta + R_2 \sin\alpha \tan\delta - R_3, \quad (4)$$

$$\Delta\delta = -R_1 \sin\alpha + R_2 \cos\alpha + \mathrm{d}z. \quad (5)$$

This transformation will be referred to as T_2.

Both transformations T_1 and T_2 imply, however, that a privileged direction exists, that is the Z-axis. A more general coordinate transformation is made up of three rotations, of angles noted R_i, plus another three parameters D_i expressing a dipolar deformation of the coordinate field. It corresponds to the first-degree magnetic (toroidal) and electric (spheroidal) harmonics of the vector spherical harmonics development of a vector field (see, e.g., Mignard & Morando 1990; Oviedo 1996; Mignard & Klioner 2012):

$$\begin{aligned}\Delta\alpha &= R_1 \cos\alpha \tan\delta + R_2 \sin\alpha \tan\delta - R_3 \\ &\quad - (D_1 \sin\alpha - D_2 \cos\alpha)/\cos\delta, \quad (6)\\ \Delta\delta &= -R_1 \sin\alpha + R_2 \cos\alpha \\ &\quad - D_1 \cos\alpha \sin\delta - D_2 \sin\alpha \sin\delta + D_3 \cos\delta. \quad (7)\end{aligned}$$

In each of these equations, the first line corresponds to the rotation, and the second line expresses the dipolar deformation.

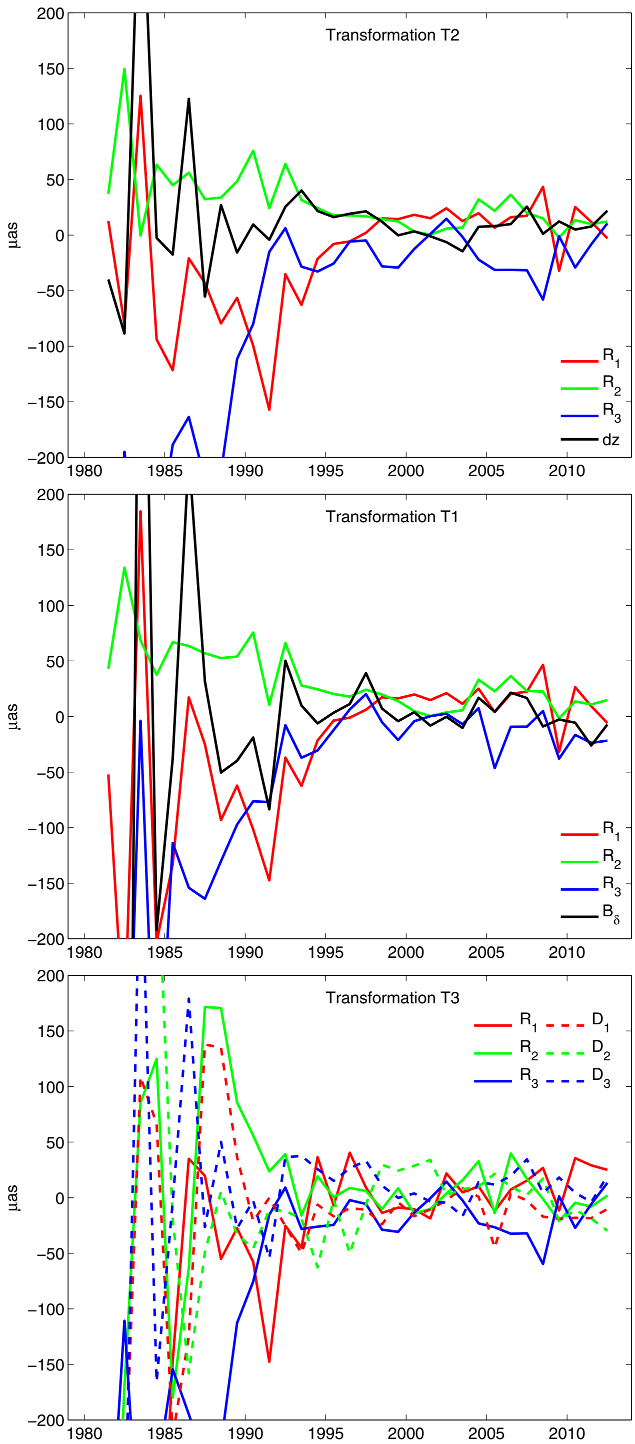

Fig. 3. Annual parameters obtained by fit to the annual frames using the three transformations.

This last transformation is referred to as T_3. In both transformations T_1 and T_3, relatively high correlations arise between D_δ and B_δ (∼0.5) for the former and between R_1 and D_2 or R_2 and D_1 (∼0.4) for the latter.

For annual frames made up of more than four sources observed in more than ten sessions, parameters of the three transformations above were fitted to the annual coordinate differences of the defining sources by weighted least squares and reported in Fig. 3. The three transformations give consistent results. One can see that the axis stability does not change drastically

Table 2. The rms of the annual transformation parameters for two time periods.

Transformation T_1	R_1	R_2	R_3	D_α	D_δ	B_δ
1979.6–2009.2	27	17	26	1	0	23
1979.6–2013.1	26	15	22	1	1	21
Transformation T_2	R_1	R_2	R_3	–	–	dz
1979.6–2009.2	26	16	30	–	–	14
1979.6–2013.1	25	15	26	–	–	12
Transformation T_3	R_1	R_2	R_3	D_1	D_2	D_3
1979.6–2009.2	26	23	29	22	26	21
1979.6–2013.1	25	20	26	18	24	18

Notes. Units are μas, except for D_α and D_δ, which are in μas/degree.

after 2009.2. It remains around 20 μas for each axis. (In the ICRF2 work, the authors mention a stability of 10 μas, which does not contradict with this study, since they uses a different method to derive the axis stability: they compare the relative orientation of various subsets of sources.) Table 2 displays the rms of the annual transformation parameters for 1979.6–2009.2 and 1979.6–2013.1. It appears that there is no drastic degradation after 2009.2.

4. Concluding remarks

Using coordinate time series of the ICRF2 defining sources, I assessed the ICRF2 defining sources and axis stability. I showed that there is no noticeable deformation of the celestial reference frame axes after 2009.2, the date of the ICRF2 release. There is therefore no need to amend the definition of the frame axes by the list of 295 so-called defining sources.

In the future, such a study should be undertaken regularly and source coordinate time series updated (e.g., on a yearly basis) so that the geodetic VLBI community can be informed of any problem due to the centroid displacement of some sources, and take it into account in the operational analysis by, e.g., removing the problematic sources from the constraint. This process of validating the ICRF2 axes is part of the tasks of the International Celestial Reference System Product Center (ICRS-PC) of the International Earth Rotation and Reference Systems Service (IERS). The monitoring of the sources through coordinate time series complements the regular VLBI imaging undertaken by the IVS in the RDV sessions. These observations permit the computation of the source structure index, the other fundamental criterion used in the selection of the ICRF2 defining sources.

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Table 1. Variation in the stability due to post-ICRF2 observations.

	1979.6–2009.2		1979.6–2013.1	
	No. Sessions	Stability (mas)	No. Sessions	Stability (mas)
0002 − 478	30	1.224	39	1.107
0007 + 106	30	0.389	68	0.329
0008 − 264	45	0.797	59	0.698
0010 + 405	23	0.334	38	0.356
0013 − 005	66	0.599	79	0.437
0016 + 731	463	0.377	627	0.463
0019 + 058	42	0.556	153	0.612
0035 + 413	18	0.280	32	0.290
0048 − 097	1826	0.446	1911	0.443
0048 − 427	30	0.942	88	0.897
0059 + 581	1991	0.285	2272	0.287
0104 − 408	1213	0.892	1540	0.871
0107 − 610	26	0.723	36	0.732
0109 + 224	38	0.271	88	0.360
0110 + 495	20	0.194	36	0.253
0116 − 219	19	0.678	38	0.604
0119 + 115	1197	0.475	1324	0.536
0131 − 522	31	1.036	42	0.953
0133 + 476	1378	0.240	1715	0.249
0134 + 311	17	0.358	230	0.369
0138 − 097	34	0.665	47	0.568
0151 + 474	21	0.321	34	0.267
0159 + 723	34	0.243	48	0.204
0202 + 319	63	0.357	82	0.310
0215 + 015	39	0.281	153	0.270
0221 + 067	69	0.368	83	0.376
0230 − 790	54	0.632	65	0.617
0229 + 131	2626	0.482	2760	0.512
0234 − 301	16	1.153	30	0.964
0235 − 618	19	0.958	22	0.858
0234 + 285	1285	0.429	1300	0.428
0237 − 027	37	0.351	168	0.503
0300 + 470	774	0.480	793	0.479
0302 − 623	44	0.808	60	0.821
0302 + 625	39	0.270	53	0.299
0306 + 102	75	0.401	90	0.361
0308 − 611	125	0.689	302	0.584
0307 + 380	12	0.223	157	0.355
0309 + 411	46	0.693	60	0.574
0322 + 222	30	0.315	189	0.332
0332 − 403	25	1.085	218	0.564
0334 − 546	33	0.677	38	0.685
0342 + 147	46	0.457	61	0.457
0346 − 279	12	0.481	100	0.488
0358 + 210	16	0.276	61	0.348
0402 − 362	862	1.008	893	0.999
0403 − 132	20	1.522	35	0.842
0405 − 385	299	1.187	379	1.204
0414 − 189	40	0.345	107	0.413
0420 − 014	1366	0.837	1459	0.643
0422 + 004	33	0.718	68	0.543
0426 + 273	35	0.502	50	0.419
0430 + 289	53	0.193	114	0.243
0437 − 454	35	2.161	51	1.453
0440 + 345	37	0.284	54	0.296
0446 + 112	44	0.572	178	0.279
0454 − 810	54	0.584	65	0.573
0454 − 234	2644	0.555	2900	0.544
0458 − 020	2216	0.423	2416	0.423
0458 + 138	27	0.311	36	0.423
0506 − 612	47	0.552	97	0.561
0454 + 844	166	0.397	312	0.401
0506 + 101	42	0.350	78	0.461
0507 + 179	62	0.331	74	0.385

Table 1. continued.

	1979.6–2009.2		1979.6–2013.1	
	No. Sessions	Stability (mas)	No. Sessions	Stability (mas)
0516 − 621	37	0.620	50	0.561
0515 + 208	11	0.216	57	0.649
0522 − 611	22	0.674	27	0.699
0524 − 460	28	0.692	32	0.683
0524 − 485	11	1.470	26	1.237
0524 + 034	13	0.345	67	0.407
0529 + 483	16	0.261	163	0.309
0534 − 611	20	0.531	28	0.531
0534 − 340	33	1.499	74	0.902
0537 − 441	1194	0.701	1573	0.647
0536 + 145	73	0.488	152	0.444
0537 − 286	59	1.052	160	0.737
0544 + 273	67	0.502	127	0.412
0549 − 575	10	0.427	25	0.849
0552 + 398	4348	0.269	4528	0.273
0556 + 238	611	0.425	715	0.437
0600 + 177	44	0.351	59	0.381
0642 + 449	1267	0.226	1405	0.240
0646 − 306	42	1.340	60	1.149
0648 − 165	59	0.688	171	0.433
0656 + 082	409	0.763	694	0.725
0657 + 172	184	0.408	268	0.370
0707 + 476	26	0.364	39	0.355
0716 + 714	171	0.383	327	0.199
0722 + 145	43	0.396	59	0.341
0718 + 792	1290	0.298	1367	0.287
0727 − 115	3441	0.423	3838	0.406
0736 + 017	63	0.275	77	0.294
0738 + 491	20	0.272	87	0.354
0743 − 006	33	0.630	47	0.528
0743 + 259	697	0.280	801	0.304
0745 + 241	165	0.465	177	0.403
0748 + 126	150	0.297	261	0.252
0759 + 183	12	0.294	69	0.359
0800 + 618	10	0.391	152	0.408
0805 + 046	14	0.351	27	0.671
0804 + 499	1438	0.231	1494	0.232
0805 + 410	589	0.218	740	0.282
0808 + 019	231	0.258	414	0.329
0812 + 367	23	0.411	35	0.551
0814 + 425	163	0.693	176	0.508
0823 + 033	1421	0.471	1589	0.496
0827 + 243	83	0.376	101	0.363
0834 − 201	33	0.590	48	0.630
0851 + 202	3620	0.405	4006	0.385
0854 − 108	16	0.342	101	0.459
0912 + 029	32	0.640	242	0.675
0920 − 397	241	2.331	432	1.856
0920 + 390	65	0.281	159	0.259
0925 − 203	70	0.459	281	0.589
0949 + 354	16	0.416	28	0.555
0955 + 476	2072	0.266	2328	0.276
0955 + 326	31	0.405	45	0.389
0954 + 658	285	0.412	300	0.405
1004 − 500	24	1.065	58	0.956
1012 + 232	35	0.799	49	0.695
1013 + 054	14	0.142	75	0.342
1014 + 615	22	0.229	34	0.573
1015 + 359	11	1.207	80	0.564
1022 − 665	28	0.772	32	0.766
1022 + 194	42	0.283	55	0.358
1030 + 415	29	0.300	41	0.266
1030 + 074	154	0.590	169	0.603
1034 − 374	13	0.658	32	0.836

Table 1. continued.

	1979.6–2009.2		1979.6–2013.1	
	No. Sessions	Stability (mas)	No. Sessions	Stability (mas)
1034 − 293	1949	0.892	2230	0.930
1038 + 528	198	0.422	211	0.557
1039 + 811	54	0.244	71	0.314
1042 + 071	13	0.176	24	0.231
1045 − 188	33	0.465	49	0.450
1049 + 215	29	0.708	41	0.678
1053 + 815	701	0.275	813	0.257
1055 + 018	331	0.634	350	0.609
1101 − 536	57	0.890	62	0.864
1101 + 384	527	0.283	567	0.289
1111 + 149	42	0.576	105	0.442
1123 + 264	167	0.573	181	0.446
1124 − 186	1161	0.448	1470	0.436
1128 + 385	1275	0.224	1460	0.230
1130 + 009	49	0.520	63	0.424
1133 − 032	12	0.162	92	0.266
1143 − 696	14	0.880	21	0.702
1144 + 402	203	0.386	320	0.296
1144 − 379	969	0.842	1317	0.778
1145 − 071	164	0.581	179	0.612
1147 + 245	20	0.243	33	0.305
1149 − 084	15	0.289	186	0.481
1156 − 663	14	0.516	25	0.508
1156 + 295	1336	0.341	1455	0.356
1213 − 172	53	0.750	68	0.623
1215 + 303	20	0.303	33	0.284
1219 + 044	1270	0.491	1297	0.490
1221 + 809	36	0.203	50	0.259
1226 + 373	32	0.431	111	0.408
1236 + 077	31	0.289	47	0.320
1240 + 381	18	0.396	34	0.428
1243 − 072	69	0.568	87	0.469
1244 − 255	133	0.629	209	0.688
1252 + 119	54	0.566	68	0.646
1251 − 713	43	0.701	53	0.701
1300 + 580	974	0.165	1149	0.196
1308 + 328	55	0.267	158	0.194
1313 − 333	336	1.235	354	1.129
1324 + 224	76	0.333	277	0.333
1325 − 558	27	0.778	38	1.281
1334 − 127	2829	0.552	3027	0.545
1342 + 662	32	0.206	127	0.237
1342 + 663	56	0.537	70	0.722
1349 − 439	45	1.177	57	1.156
1351 − 018	900	0.645	1124	0.752
1354 − 152	137	0.507	210	0.513
1357 + 769	1840	0.155	2053	0.157
1406 − 076	59	0.280	74	0.544
1418 + 546	739	0.219	925	0.234
1417 + 385	280	0.273	392	0.249
1420 − 679	15	0.683	20	0.662
1423 + 146	14	0.570	29	0.551
1424 − 418	946	0.901	1255	0.893
1432 + 200	30	0.271	78	0.318
1443 − 162	35	0.582	51	0.567
1448 − 648	13	0.582	15	0.519
1451 − 400	54	1.935	64	1.749
1456 + 044	15	0.398	82	0.467
1459 + 480	25	0.285	37	0.272
1502 + 106	625	0.708	640	0.642
1502 + 036	29	0.351	142	0.456
1504 + 377	32	0.372	44	0.561
1508 + 572	55	0.378	66	0.563
1510 − 089	353	0.808	367	0.778

Table 1. continued.

	1979.6–2009.2		1979.6–2013.1	
	No. Sessions	Stability (mas)	No. Sessions	Stability (mas)
1511 − 100	34	0.519	46	0.467
1514 + 197	33	0.297	47	0.359
1520 + 437	11	0.292	174	0.334
1519 − 273	686	0.439	844	0.448
1546 + 027	64	0.552	180	0.390
1548 + 056	280	0.872	295	0.802
1555 + 001	237	0.473	283	0.451
1554 − 643	15	0.755	17	0.715
1557 + 032	43	0.397	55	0.406
1604 − 333	49	1.415	59	1.306
1606 + 106	2348	0.281	2504	0.282
1611 − 710	13	0.404	18	0.359
1614 + 051	157	0.458	172	0.420
1617 + 229	12	0.307	134	0.453
1619 − 680	32	1.056	42	0.901
1622 − 253	2240	0.680	2521	0.616
1624 − 617	17	0.552	26	0.619
1637 + 574	332	0.465	348	0.435
1638 + 398	1233	0.248	1350	0.254
1639 + 230	32	0.206	161	0.369
1642 + 690	200	0.243	221	0.339
1633 − 810	18	0.765	20	0.715
1657 − 261	101	1.172	198	0.910
1657 − 562	31	0.991	40	0.998
1659 − 621	23	0.590	34	0.696
1705 + 018	66	0.547	143	0.399
1706 − 174	139	0.800	154	0.636
1717 + 178	29	0.421	45	0.665
1726 + 455	1373	0.272	1426	0.275
1730 − 130	686	1.374	705	1.249
1725 − 795	14	0.491	16	0.463
1732 + 389	62	0.313	98	0.321
1738 + 499	18	0.298	32	0.336
1738 + 476	28	0.459	43	0.372
1741 − 038	3497	0.397	3890	0.405
1743 + 173	53	0.371	67	0.449
1745 + 624	928	0.299	940	0.301
1749 + 096	2779	0.277	3031	0.289
1751 + 288	44	0.449	66	0.396
1754 + 155	12	0.442	176	0.575
1758 + 388	41	0.314	82	0.266
1803 + 784	2439	0.223	2681	0.208
1800 + 440	39	0.318	71	0.370
1758 − 651	32	0.482	41	0.490
1806 − 458	37	1.054	47	1.137
1815 − 553	344	1.629	403	1.588
1823 + 689	10	0.171	64	0.323
1823 + 568	214	0.310	234	0.319
1824 − 582	10	0.798	16	0.724
1831 − 711	25	0.598	37	0.585
1842 + 681	26	0.314	39	0.301
1846 + 322	11	0.489	242	0.338
1849 + 670	149	0.232	165	0.226
1908 − 201	914	0.949	1056	0.955
1920 − 211	114	0.779	192	0.539
1921 − 293	1900	1.213	2128	1.213
1925 − 610	28	0.836	33	0.865
1929 + 226	35	0.535	64	0.446
1933 − 400	55	1.032	73	0.828
1936 − 155	85	0.547	99	0.650
1935 − 692	33	1.085	43	1.081
1954 + 513	58	0.581	72	0.905
1954 − 388	915	0.864	1165	0.817
1958 − 179	1398	0.414	1552	0.437

Table 1. continued.

	1979.6–2009.2		1979.6–2013.1	
	No. Sessions	Stability (mas)	No. Sessions	Stability (mas)
2000 + 472	17	0.155	166	0.271
2002 − 375	14	0.939	27	1.567
2008 − 159	116	0.700	357	0.525
2029 + 121	46	0.443	58	0.407
2052 − 474	307	1.101	597	1.184
2059 + 034	60	0.457	340	0.428
2106 + 143	12	0.374	24	0.517
2106 − 413	56	1.206	68	1.146
2113 + 293	535	0.335	874	0.346
2123 − 463	13	0.657	22	0.980
2126 − 158	714	0.911	802	0.936
2131 − 021	90	0.568	104	0.588
2136 + 141	1026	0.344	1103	0.345
2142 − 758	22	1.781	29	1.361
2150 + 173	46	0.257	59	0.366
2204 − 540	46	0.835	60	0.825
2209 + 236	233	0.203	291	0.227
2220 − 351	20	1.080	33	1.230
2223 − 052	1015	0.340	1162	0.361
2227 − 088	85	0.281	180	0.232
2229 + 695	47	0.220	267	0.457
2232 − 488	51	0.847	67	1.147
2236 − 572	10	0.246	22	0.667
2244 − 372	24	0.624	43	0.634
2245 − 328	36	1.373	49	1.042
2250 + 190	42	0.433	106	0.389
2254 + 074	52	0.398	66	0.358
2255 − 282	1623	1.187	2028	1.126
2300 − 683	20	0.590	122	0.727
2318 + 049	811	0.363	965	0.391
2326 − 477	69	1.004	82	1.043
2333 − 415	15	0.930	31	0.991
2344 − 514	14	0.862	16	0.818
2351 − 154	39	0.605	51	1.113
2353 − 686	37	0.438	44	0.413
2355 − 534	42	1.057	52	0.972
2355 − 106	200	0.496	365	0.481
2356 + 385	808	0.372	1052	0.351
2357 − 318	9	1.452	103	0.709