5 Characterization of Source Structure (PC, AC, ALF, RO, DAB)

As noted above, there is now a large amount of imaging data which can be used to both filter out the most extended sources and identify the most compact sources for defining the ICRF2 frame. In order to assess the astrometric quality of the sources, we used the so-called "structure index" (SI) defined by Fey & Charlot [1997], modified as to obtain a continuous structure index scale as described below. The structure index indicates the expected magnitude of the effects of intrinsic source structure on VLBI delay observations according to the median value of the structure delay corrections, $\tau_{\rm median}$, calculated for all projected VLBI baselines that could be observed with Earth–bound VLBI, using the algorithm devised by Charlot [1990]. While Fey & Charlot [1997] separated the sources into four categories, with values of the structure index ranging from 1 to 4, we adopted a continuous scale for the present work and defined the structure index SI as follows:

$$\mathrm{SI} = 1 + 2\log\left(\tau_{\rm median}\right) \tag{1}$$

where $\tau_{\rm median}$ is expressed in picoseconds (ps). Additionally, we constrained SI values to remain always positive by setting SI = 0 when $\log\left(\tau_{\rm median}\right) < -0.5$ (i.e., $\tau_{\rm median} <\sim 0.3$ ps). As shown in Figure 11, there is close correspondence at the (discrete) SI boundaries between the continuous SI values defined here and the values defined in Fey & Charlot [1997] (SI = 1.95 vs 2 for $\tau_{\rm median}$ = 3 ps, SI = 3.00 vs 3 for $\tau_{\rm median}$ = 10 ps, SI = 3.95 vs 4 for $\tau_{\rm median}$ = 30 ps). Therefore, the recommendation of Fey & Charlot [1997] that sources with SI values of 3 or 4 should preferably not be used for high-precision VLBI astrometry remains largely valid with this new definition of the structure index.

Based on the above definition, structure indices were derived for 701 different sources by using a total of 3046 X-band VLBI images from the USNO Radio Reference Frame Image Database and the Bordeaux VLBI Image Database for epochs between 1994 and 2008. The vast majority of the images for the sources north of about −40° declination were obtained from RDV sessions or from earlier VLBA sessions [Fey et al., 1996; Fey & Charlot, 1997, 2000]. For the sources in the far south, the images are from dedicated southern-hemisphere VLBI sessions [Ojha et al., 2004, 2005]. Nearly half of the sources (331 sources) have been imaged at only a single epoch whereas the most-intensively observed source (0727−115) has 32 images available. For the sources imaged at more than one epoch, an additional step was taken and the mean SI over all epochs was calculated. The time series of structure indices were also scrutinized to check for outliers, possibly caused by images with low dynamic range or poor resolution, which may affect the mean SI values, and for SI variability over time, which is indicative of astrophysical instabilities.

All source structure indices derived in this way, including the number of images on which the mean SI values are based, are reported in Table 1. Sources with good structure index (SI < 3.0) but which show significant SI variations over time or have bad structure at S band are also marked in the table. The distribution of the mean SI values is plotted in Figure 12. These values peak at about 2.75, corresponding to a value of 7.5 ps for the delay structure correction. Also marked in Figure 12, are the special handling sources discussed in the previous section, all of which except 0438−436 have a structure index available. Based on our calculation, it is found that 26 sources of these have a SI value larger than 3.0, which is an indication of extended emission. In addition, 6 of the remaining 12 sources that have a mean SI smaller than 3.0 (0528+134, 0919−260, 0923+392, 1044+719, 2145+067, 2234+282) are marked as variable in Table 1, which indicates that they are likely to show positional

instabilities. Overall, more than 80% of the special handling sources are thus found to be unsuitable for the highest astrometric accuracy when considering solely their structure, in agreement with the findings in the previous section.

Finally, it is to be noted that the structure index values listed in Table 1 represent a snapshot of the imaging data available at the time this work was carried out and that these values may evolve with time. While sources with already many images are likely to show only small variations of structure index in the future, those with only a single image may in some cases show larger variations due to temporal changes in their structure.

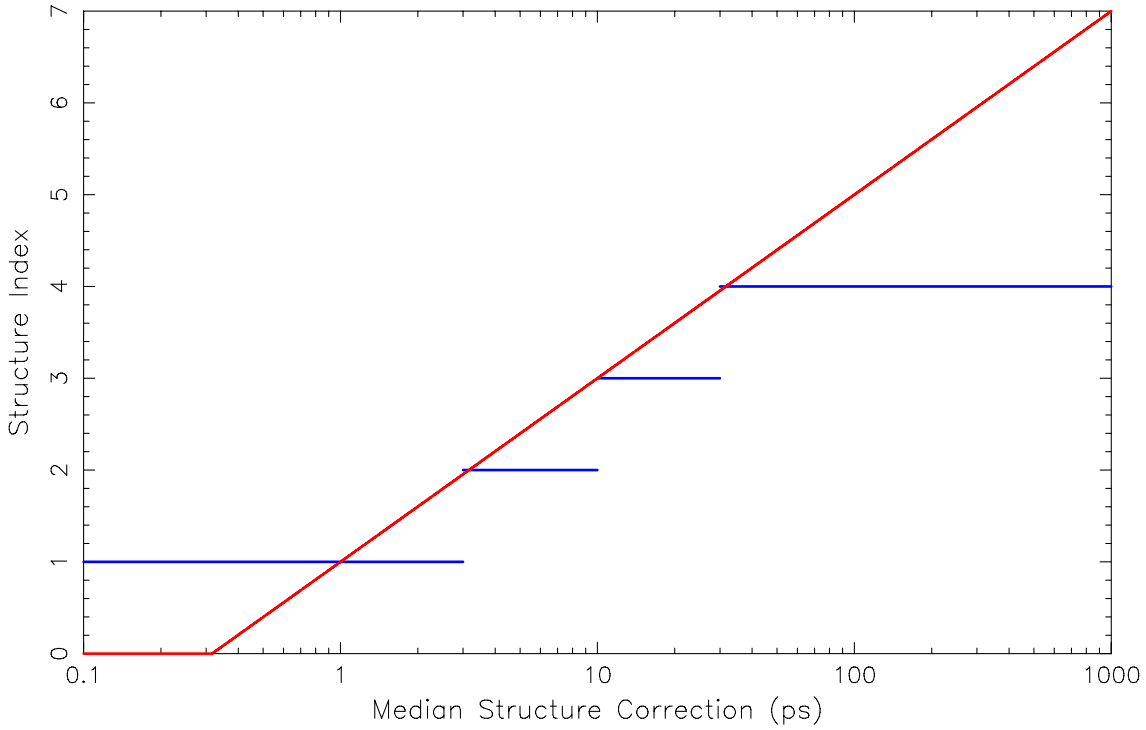

Figure 11: Correspondence between the discrete structure index defined by Fey & Charlot [1997], plotted in blue, and the continuous structure index from Equation 1, plotted in red.

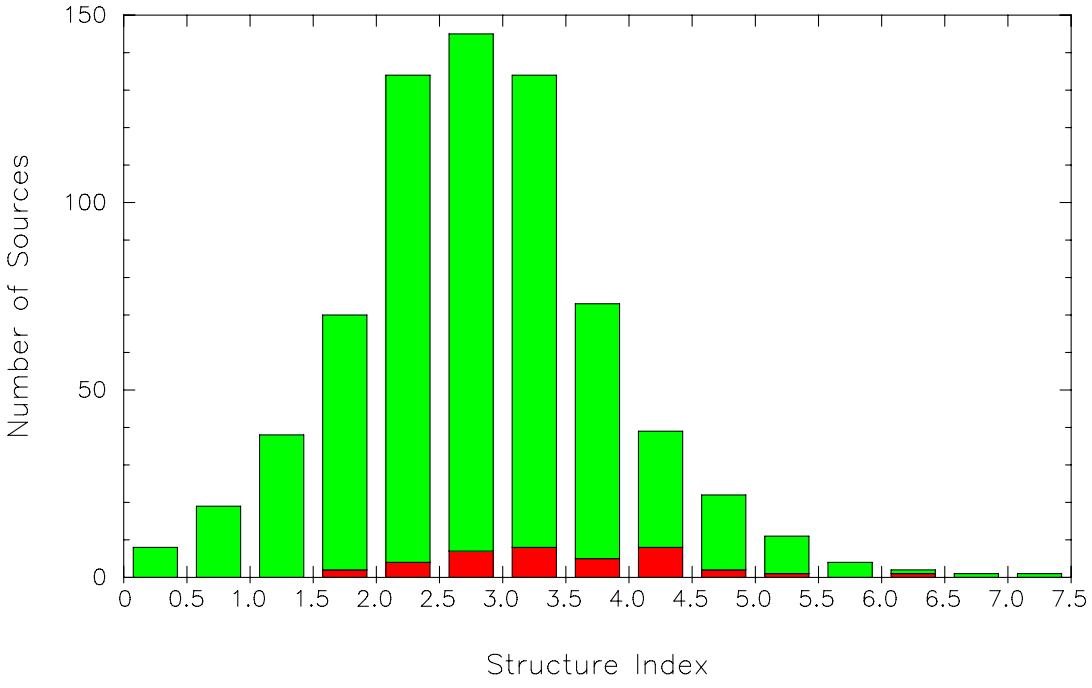

Figure 12: Distribution of the mean structure index for 701 sources with VLBI images available from the USNO Radio Reference Frame Image Database or the Bordeaux VLBI Image Database. The special handling sources discussed in §4 are color-coded in red.

Table 1: Mean source structure index values at X-band (8.4 GHz) for 701 sources with VLBI images available from the USNO Radio Reference Frame Image Database (RRFID) or the Bordeaux VLBI Image Database (BVID).

Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index
0003−066	25	3.1	0138−097	5	2.6	0312+100	1	2.5
0003+380	3	3.4	0144+209	1	4.6	0316+413	1	4.4
0007+106	3	0.9	0146+056	4	3.3	0316−444	1	2.5
0007+171	3	3.7	0148+274	1	3.8	0317+188	2	3.0
0008−264	1	1.6	0149+218	5	2.9‡	0319+121	2	4.0
0009+081	1	0.6	0150−334	1	4.5	0322+222	1	1.8
0010+405	2	2.6	0151+474	2	2.2	0325+395	1	0.9
0013−005	2	2.2	0153+744	2	5.0	0326+277	1	4.3
0014+813	22	2.5	0159−117	1	3.4	0332−403	1	2.3
0016+731	2	2.1†	0159+723	3	1.9	0333+321	2	3.7
0017+200	1	2.2	0201+113	21	3.1	0335−364	1	3.6
0019+058	3	1.4	0202+149	21	3.1	0336−019	28	3.0†
0025+197	1	1.6	0202−172	1	3.2	0338−214	1	3.4
0026+346	1	5.0	0202+319	4	1.8	0340+362	1	2.5
0035−252	1	1.8	0202−765	1	3.4	0341+158	1	2.5
0035+413	1	2.8	0208−512	1	2.3	0342+147	2	2.9
0039+230	3	4.2	0209+168	1	3.2	0345+460	1	3.1
0046+316	5	3.1	0211+171	1	0.8	0346−279	1	2.3
0047−579	1	3.8	0212+735	6	3.1	0347−211	1	2.4
0048−097	28	1.1	0215+015	1	1.4	0350+465	1	2.4
0048−427	1	1.8	0219+428	4	3.1	0355+508	2	2.0
0054+161	1	1.2	0220−349	2	3.2	0358+040	1	1.4
0055+300	1	3.6	0221+067	4	2.4	0358+210	1	0.8
0056−001	1	4.3	0224+671	4	3.3	0400+258	4	3.0
0056−572	1	5.0	0229+131	20	2.4	0400−319	1	3.0
0059+581	29	1.6	0234+285	18	2.6	0402−362	19	2.4
0103+127	1	3.6	0235+164	13	1.8	0403−132	1	0.6
0104−408	25	1.3	0237−027	2	2.0	0405−123	4	3.1
0106+013	6	3.2	0237+040	1	2.4	0405+304	1	1.8
0108+388	1	5.1	0237−233	2	5.6	0405−385	9	2.3
0109+224	2	2.0	0238−084	16	4.4	0406+121	3	2.9
0111+021	11	3.4	0239+108	3	3.0	0406−127	2	3.1
0111+131	1	2.4	0239+175	1	3.0	0409+229	2	3.4
0112−017	1	4.2	0241+622	2	2.9†	0410+110	1	2.5
0113−118	2	3.4	0244−452	1	3.6	0414−189	3	1.8
0115−214	1	2.5	0248+430	4	4.3	0415+398	1	1.6
0118−272	1	5.0	0252−712	1	6.6	0420−014	3	2.5†
0119+041	20	2.9†	0256−005	1	2.5	0420+417	4	3.3
0119+115	25	2.3	0256+075	2	3.1	0422+004	4	2.0
0123+257	4	3.0	0259+121	2	3.9	0422−380	1	4.1
0130−171	1	4.0	0300+470	5	2.5	0423+051	1	3.4
0131−522	1	2.4	0302+625	2	2.7	0423+237	1	2.7
0133+476	26	2.0	0305+039	2	3.1	0425+048	1	3.2
0134+311	1	2.7	0306+102	2	2.8	0426+273	4	2.6
0135−247	2	3.2	0307+380	1	0.0	0426−380	1	4.1
0137+012	1	1.5	0308−611	1	1.4	0430+052	16	4.3
0137+467	1	1.2	0309+411	2	2.1	0434−188	5	3.3

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(Table 1: continued)

Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index
0437−454	2	2.2	0609+607	3	3.3	0747+185	1	0.7
0440−003	2	2.9	0611+131	2	2.2	0748+126	6	2.1
0440+345	1	2.8	0615+820	2	3.5	0749+540	9	2.7†
0442+389	1	2.4	0620+389	1	2.5	0754+100	4	3.1
0444+634	1	2.0	0625−354	1	3.1	0759+183	1	2.4
0446+112	4	2.4	0627−199	1	2.5	0804+499	20	1.8
0451−282	1	3.3	0629+160	1	4.6	0805−077	2	3.3
0454−234	27	1.9	0632−183	1	1.3	0805+410	11	2.1
0454−463	1	1.2	0636+680	1	1.7	0808+019	4	1.6
0454−810	1	2.5	0637−337	1	2.8	0809−493	1	3.9
0454+844	11	2.9	0637−752	1	4.3	0812+020	1	1.9
0457+024	2	4.2	0639−032	1	2.7	0812+367	1	2.8
0458−020	30	2.6	0641+392	1	2.6	0814+425	2	2.3
0458+138	2	2.9	0642+214	1	3.8	0818−128	1	3.5
0459+060	1	3.5	0642+449	24	1.5	0820+560	3	3.2
0459+252	1	3.0	0645+209	1	3.1	0821+248	1	1.7
0500+019	1	4.3	0646−306	3	2.7	0821+394	4	2.4‡
0502+049	1	3.4	0648−165	5	1.8	0823+033	27	2.7
0506+056	1	2.3	0648−287	1	0.8	0823−223	1	1.8
0506+101	2	1.3	0650+371	1	3.2	0823−500	1	6.0
0506−612	1	2.7	0654+244	1	3.5	0826−373	1	4.2
0507+179	3	2.9	0656+082	9	2.9	0827+243	3	2.4
0511−220	1	2.8	0657+172	4	2.2	0828−222	1	2.1
0518+165	1	4.1	0707+476	2	2.5	0828+493	1	2.3
0519+142	1	3.3	0710+439	4	5.7	0829+046	3	3.0
0521−365	1	3.6	0711+356	2	4.6	0831+557	3	5.1
0522−611	2	2.8	0716+714	2	1.9	0833+585	2	3.3
0524+034	1	1.1	0718+793	8	2.5	0834−201	2	2.3
0528+134	29	2.6†	0721−071	1	2.4	0834+250	1	2.8
0528−250	1	2.9	0722+145	2	2.7	0836+710	3	3.6
0529+075	1	4.0	0723−008	1	3.3	0838+133	1	3.2
0530−727	1	3.9	0723+219	1	0.6	0839+187	3	4.3
0536+145	3	1.4	0725+219	1	2.1	0850+581	3	3.2
0537−158	1	3.4	0727−115	32	2.0	0851+202	32	2.6†
0537−286	1	0.8	0727−365	1	3.7	0859−140	3	3.8
0537−441	22	2.7	0728+249	1	2.3	0859+470	2	3.1
0538+498	5	4.4	0729+259	1	3.4	0906+015	1	3.1
0539−057	2	2.8	0733−174	2	4.9	0906−048	1	2.2‡
0544+273	5	2.1	0735+178	2	3.4	0912+029	2	2.3
0547+234	1	2.0	0736+017	3	2.3	0912+297	3	2.5
0548+378	1	1.8	0736−332	1	4.3	0917+449	3	3.1
0552+398	31	2.5	0738+313	2	4.1	0917+624	3	3.1
0554+242	2	2.9†	0738+491	5	1.4	0918−297	1	3.6
0556+238	14	1.3	0738−674	2	3.1	0919−260	18	2.7†
0558−396	1	2.3	0742+103	10	3.9	0920+390	1	1.1
0600+177	2	2.8	0743−006	2	1.9	0920−397	16	2.5
0601+245	1	3.1	0743+259	9	2.1	0923+392	23	2.8†
0602+673	10	3.5	0743+277	1	1.5	0925−203	2	2.2
0605−085	3	3.4	0743−673	1	4.2	0927+469	1	3.4
0606−223	1	2.9	0745+241	3	2.5	0942+358	1	3.3
0607−157	15	2.2	0746+483	1	2.7	0945+408	3	3.6

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(Table 1: continued)

Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index
0949+354	2	2.6	1124−186	27	1.5	1257+145	1	2.1
0951+268	1	1.8	1125+366	1	1.0	1300+580	17	1.3
0951+693	3	2.7	1127−145	2	4.3	1302−102	2	3.3
0952+179	3	3.0	1128−047	1	3.3	1306+360	1	1.6
0953+254	16	3.2	1128+385	22	2.0	1307+121	1	3.6
0954+658	4	2.6	1130+009	1	2.4	1308+326	23	3.3
0955+326	4	2.8	1142+052	1	3.0	1308+328	3	2.7
0955+476	24	1.2	1143−245	3	3.5	1308+554	1	2.1
0958+346	1	2.1	1143−332	1	2.8	1313−333	18	2.7
1003+351	1	3.4	1144−379	26	2.2	1315+346	3	3.5
1004+141	10	3.5	1144+402	3	1.5	1323+321	1	4.6
1004−500	1	2.6	1145−071	17	2.8	1324+224	2	0.3
1011+250	2	3.2	1145+268	1	3.3	1328+307	1	5.7
1012+232	4	2.8	1146+596	1	4.1	1330+022	1	2.9
1013+127	1	1.1	1147−192	1	3.0	1330+476	1	0.8
1013+208	1	3.7	1147+245	2	2.6	1333−152	2	2.3
1020+400	1	3.1	1148−001	1	4.6	1333−337	1	2.5
1021−006	2	4.6	1150+497	2	3.2	1334−127	27	2.3
1022+194	5	2.6	1150+812	3	3.2	1338+381	3	3.8
1030+415	1	0.6	1155+251	3	4.7	1342+662	2	1.9
1032−199	2	3.2	1156−094	1	3.6	1342+663	3	2.8
1034−293	31	2.4	1156+295	26	2.5†	1345+125	1	5.4
1038+064	4	3.5	1212+171	1	2.2	1347+539	4	3.0‡
1038+528	1	2.8	1213−172	2	2.2	1348+308	1	2.1
1039+811	1	2.3	1213+350	2	3.3	1349−439	1	2.2
1040+123	1	3.9	1215+303	2	2.5	1351−018	17	2.3
1040+244	1	1.6	1216+487	3	3.1	1352−104	2	2.6†
1042+071	1	2.5	1218+339	1	2.0	1354−152	3	1.7
1044+719	23	2.2†	1219+044	15	1.9	1354+195	1	3.7
1045−188	4	3.0	1219+285	1	3.8	1357+769	22	0.7
1046−409	1	1.6	1221+809	3	2.6	1402+044	2	3.0
1047+147	1	2.4	1221−829	1	2.7	1404+286	24	3.6
1048−313	1	4.3	1222+037	1	4.5	1406−076	3	2.3
1049+215	2	3.0	1222+131	1	2.2	1409+218	2	2.5
1053+704	3	1.8	1223−188	2	2.6	1412+461	1	3.3
1053+815	13	2.3†	1226+023	1	5.5	1413+135	3	1.9‡
1054+004	1	2.9	1226+373	2	1.5	1416+067	3	3.1
1055+018	5	2.8	1228+126	21	3.6	1417+273	4	2.6
1056+212	1	1.9	1236+077	3	2.8	1417+385	10	1.9
1057−797	2	3.4	1237−101	1	4.3	1418−192	1	0.8
1059+282	1	1.4	1240+381	3	2.8	1418+546	20	3.0
1100+122	1	2.1	1241+166	1	2.0	1420+326	1	1.0
1101−325	1	3.0	1243−072	1	2.1	1424+240	1	2.1
1101+384	22	2.3	1244−255	1	0.2	1424+366	1	2.6
1104+728	1	2.1	1246+489	1	2.3	1424−418	18	2.5
1105−680	1	4.9	1251−197	1	2.5	1428+422	1	1.6
1107+485	1	1.5‡	1251−713	1	2.8	1430−178	1	3.9
1111+149	3	2.5	1252+119	3	2.9	1432+200	3	2.3
1116+128	3	3.3	1253−055	3	4.1	1433+304	1	2.4
1119+183	1	3.8	1255−316	15	3.2	1435−218	1	4.5
1123+264	2	2.4	1256−220	1	1.9	1435+638	1	4.2

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(Table 1: continued)

Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index
1441+252	1	1.6	1637+826	7	3.7	1758−651	1	1.7
1442+101	2	3.6	1638+398	22	1.6	1759−396	1	2.4
1443−162	1	2.8	1639−062	1	2.3	1800+440	4	2.2
1445−161	2	3.5	1639−200	1	1.8	1803+784	22	2.5†
1448+762	6	2.7	1639+230	2	1.3	1806+456	1	0.0
1451−375	16	3.0	1640−231	1	3.7	1807+698	4	3.2
1458+718	3	4.0	1641+399	2	4.1	1814−637	1	5.5
1459+480	3	2.6	1642+690	5	3.0	1817−254	1	3.5
1502+036	3	1.7	1645+271	1	2.9	1821+107	3	3.2
1502+106	4	2.9	1645−329	1	3.7	1822+033	1	2.1‡
1504−166	3	3.5	1647−296	1	2.3	1823+568	3	2.5†
1504+377	1	2.0	1648+084	1	0.0	1826+796	1	4.4
1505+428	1	3.4	1651+391	1	1.0	1829−207	1	4.8
1508−055	1	3.0‡	1652+398	4	3.4	1830+285	2	3.6
1510−089	3	2.9	1655+077	3	3.2	1842+681	3	1.9
1511−100	2	2.6	1656+053	2	3.2	1845−273	1	0.0
1514+004	1	3.1	1656+348	3	3.1	1845+797	2	3.9
1514+197	2	2.0	1656+477	1	4.0	1846+322	1	1.0
1514−241	16	3.5	1657−261	6	2.1	1849+670	3	1.5
1519−273	12	1.8	1705+018	2	2.6	1856+736	2	3.6
1520+319	1	1.8	1705+456	3	3.3	1901+319	2	3.9
1531−352	1	1.2	1706−174	4	2.4	1903−802	1	4.6
1532+016	2	4.1	1710−323	1	3.7	1908−201	25	2.5
1538+149	2	2.4	1717+178	3	2.8	1908+484	1	0.7
1540−828	1	7.2	1718−259	1	2.2	1909+161	1	2.7
1541+050	1	3.4	1718−649	1	5.4	1910+052	1	2.6
1546+027	4	2.7	1722+330	1	2.0	1920−211	2	2.5
1547+507	3	3.3	1725+044	3	3.2	1921−293	24	2.8
1548+056	2	2.9	1725+123	1	2.5	1922+155	1	2.3
1549−790	1	4.8	1726+455	15	2.2	1923+210	11	3.3
1555+001	2	1.8	1729−373	1	5.2	1925−206	2	2.1
1555−140	1	4.0	1730−130	3	2.5	1926+087	1	3.2
1557+032	1	2.1	1732+389	3	1.7	1928+738	4	3.9
1600−294	2	2.8	1736+324	1	1.5	1929+226	2	2.5
1600+335	2	4.0	1738+476	2	2.7	1932+204	3	2.1
1604−333	1	2.8	1738+499	3	2.3	1934−638	2	6.4
1606+106	30	2.5	1739+522	21	1.5	1936−155	4	2.1
1607+268	1	4.4	1741−038	28	1.9	1937−101	2	3.6
1608+243	1	1.5	1742−078	1	3.3	1943+228	1	1.3
1610−771	1	6.4	1743+173	1	2.6	1947+079	1	5.1
1611+343	24	3.2	1744+557	1	3.5	1951+355	1	2.7
1614+051	1	3.0	1745+624	22	1.7	1954−388	22	2.6
1616+063	2	2.8	1745+670	1	3.5	1954+513	2	2.6
1617+229	1	2.2	1746+470	4	1.1	1955+335	1	1.4
1622−253	25	2.0	1748−253	1	3.9	1958−179	10	1.5
1622−297	2	3.8	1749+096	31	1.3	2000+148	1	0.7
1624+416	1	3.7	1749+701	2	3.0	2000−330	2	4.1
1627+476	1	2.0	1751+288	2	2.3	2000+472	1	2.1
1633+382	1	3.4	1751+441	2	3.2	2005+403	1	3.6
1636+473	1	2.5	1754+155	1	2.1	2005−489	1	4.1
1637+574	3	2.5	1758+388	2	2.2	2007+777	2	3.4

(continued on next page)

(Table 1: continued)

Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index	Source name	Number of maps	Structure Index
2008−068	3	4.1	2145+067	26	2.8†	2252−089	3	3.3
2008−159	4	1.6	2145+082	1	2.8	2253+417	2	3.6
2013+163	1	1.4	2147+077	1	4.9	2254+024	3	1.0
2017+743	4	2.2	2149+056	3	2.6	2254+074	2	2.2
2018+282	1	0.0	2149−306	2	3.6	2255−282	22	1.9
2021+317	4	3.3	2150+173	3	2.8	2259−375	1	4.9
2021+614	1	4.8	2152−699	1	4.5	2300−307	1	3.8
2023+336	2	3.4	2155−152	2	3.7	2300−683	1	2.1
2029+024	1	0.4	2155−304	1	2.1	2309+454	1	2.8
2029+121	2	2.7	2155+312	1	1.3	2312−319	1	3.1
2030+547	1	4.1	2200+420	18	3.5	2314−409	1	2.8
2037−253	1	3.3	2201+315	5	3.2	2318+049	12	2.6
2037+511	14	3.3	2205+166	1	2.5	2319+272	4	3.1
2048+312	4	3.0	2205+743	1	3.1	2319+317	1	1.7
2052−474	12	2.4	2209+236	9	1.9	2320−035	2	3.2
2054−377	1	3.1	2210−257	1	3.1	2320+506	3	3.6
2056−369	1	3.1	2211−388	1	4.5	2325+093	1	1.9
2059+034	1	2.1	2214+350	1	1.9	2325−150	1	2.5
2059−786	1	4.1	2216−038	2	3.3	2328+107	1	3.9
2106+143	1	2.6	2216+178	1	0.9	2329−162	3	3.7
2109−811	1	3.6	2223−052	13	2.3	2329−415	1	2.7
2113+293	11	2.8	2227−088	2	1.6	2331−240	1	3.5
2120+099	1	4.7	2227−399	1	3.8	2335−027	2	3.0
2121+053	4	3.0	2229−172	1	3.4	2337+264	2	4.8
2126−158	10	2.4	2229+695	1	2.6	2344+092	2	3.4
2127−096	1	2.9	2230+114	6	4.2	2345−167	1	3.8
2128−123	6	4.2	2233−148	2	3.3	2351−154	2	2.5
2131−021	2	2.8	2234+282	20	2.4†	2351+456	3	3.4
2134+004	6	3.5	2235+731	2	3.2	2353−686	1	2.9
2135−184	1	2.0	2239+096	1	2.9	2353+816	1	2.7
2136+141	19	2.8	2243−123	24	3.8	2355−106	1	0.7
2142+110	2	2.7	2245−328	1	2.8	2356+385	11	1.9
2143−156	3	3.1	2250+194	5	2.3	2358+189	1	1.9
2144+092	2	3.4	2251+158	4	3.7			

‡ Source has very extended S band structure
(information provided only for sources with SI $\leq$ 3.0).
† Time series of structure indices or maps indicate variability
(information provided only for sources with SI $\leq$ 3.0).