VVV Survey - ESO Phase 3
VVV Infrared Astrometric Catalogue (VIRAC) v1 release

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Data Collection	VVV
Release Number	4.1
Data Provider	Leigh Smith, Philip Lucas et al.
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Abstract

We describe the VIRAC proper motion catalogue (Smith et al.2018) based on the VVV survey data, in the form that is provided in the ESO archive. The VVV survey (ESO programme 179.B-2002) spanned a 5 year period (2010-2015) observing a 560 deg^2 area of the Galactic bulge and the adjacent southern mid-plane. There were tyically ~80 epochs of observation in Ks in the bulge fields and ~55 epochs in the Galactic disc fields. There were also observations in the ZYJH passbands: the VIRAC product provides ZYJHKs bandmerged magnitudes for each star, wherein the Ks magnitude is a mean value. Although VVV was designed as a variable star survey rather than an astrometric survey, these data enabled relative proper motion measurements with typical precision of 0.67 mas/yr for bright stars (11<Ks<14). These data complement the Gaia satellite by providing kinematic information in optically obscured parts of the Galactic plane. The precision is sufficient to study the kinematics of stellar population studies across the Milky Way. Full details of the VIRAC calculation methods for proper motions and parallaxes are described in Smith et al. (2018). This release description describes the details of the proper motion product for 312 million stars. The VIRAC parallax catalogue is not included since that much smaller product was included in the journal paper.

Overview of Observations

The VISTA Variables in the Via Lactea Survey (VVV, Minniti et al.2010) was conducted with the 4m VISTA telescope at Carro Paranal using the VIRCAM infrared camera (Sutherland et al.2015). VIRAC version 1 was constructed from all VVV Ks data that were judged to be of sufficient quality to be used in the astrometric calculations. These data taken between January 2010 and October 2015. A single epoch of Z, Y, J and H data is also included in this release: these data were from multi-colour ZY or JHKs OBs that were typically observed in the 2010-2011. A 2nd epoch of multi-colour OBs taken in 2015 was used to fill in some gaps caused by poor data. All the approved VVV data were processed by v1.3 of the CASU pipeline.

VIRCAM has 16 HgCdTe infrared array detectors that are spatially separated from each other. VVV observations used the usual VIRCAM tiling pattern, in which 6 telescope pointings, which we call “pawprints”, are used to cover a tile with an area of 1.4x1.1 degrees. Every part of the tile area is covered by at least 2 pawprints, except for the edges.

VIRAC proper motion solutions are initially calculated using the multi-epoch pawprint catalogues produced by the v1.3 CASU pipeline, rather than the tiles, because the pawprints can be better calibrated for precise astrometry. However, these pawprint-based astrometric products were then combined with overlapping pawprints, using inverse variance weighting, to produce a more precise proper catalogue for each VVV tile. This averaging is also done across tile boundaries, so all parts of the survey footprint except the outer border benefit from averaging across pawprints.

This Phase 3 release of the proper motion data has 348 tile catalogues and a metadata file listing the 348 file names. The total volume is 59 GB. In addition the release includes the 156206 pawprint images from which the CASU catalogues were produced.

The VVV dataset is divided into different Galactic disc and bulge tiles. The tile nomenclature goes from d001 to d152 in the disc, and from b201 to b396 in the bulge. The coordinates of the tile centers are listed in Tables 1 and 2 below, for the bulge and disc, respectively. These Tables contain the tile ID and equatorial coordinates RA and DEC (J2000) in degrees. The map with the field IDs is shown in Figure 1, overlapped on the extinction map from Schlegel et al.(1997).

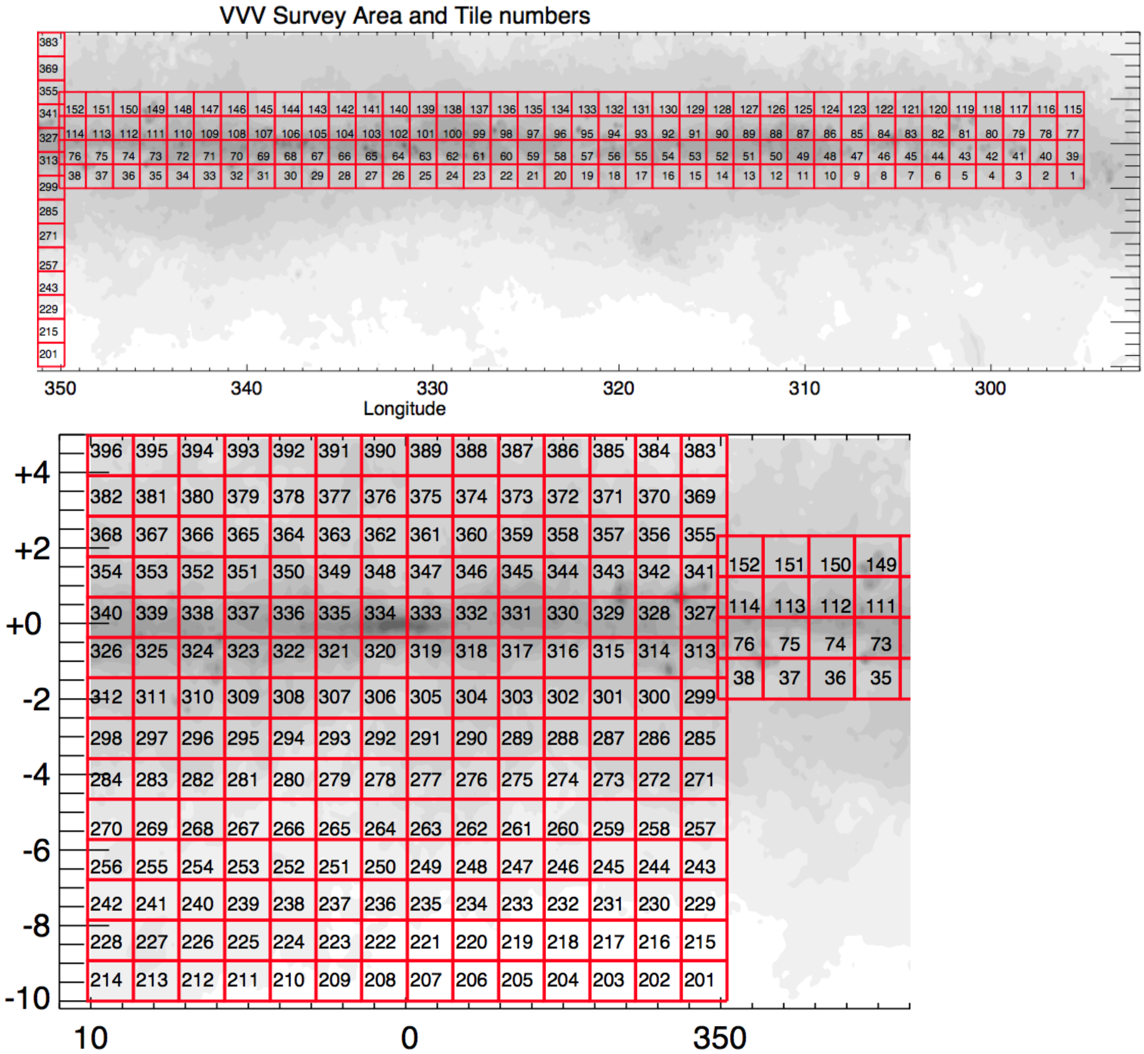

Figure 1. Maps showing the VVV tile numbers and Galactic coordinates for the bulge and the disc. The disc fields cover the approximate latitude range -2<b<2°.

Release Content

TABLE 1: Tile coordinates and number of epochs at end of survey

ID	RA	Dec	Longitude	Latitude
b201	18:04:24.77	-41:44:35.9	350.753	-9.689
b202	18:08:00.58	-40:27:11.5	352.231	-9.689
b203	18:11:29.83	-39:09:34.6	353.709	-9.688
b204	18:14:53.35	-37:51:45.4	355.187	-9.689
b205	18:18:11.50	-36:33:44.3	356.665	-9.689
b206	18:21:25.06	-35:15:56.9	358.138	-9.692
b207	18:24:33.43	-33:57:14.0	359.622	-9.688
b208	18:27:38.04	-32:38:48.1	1.099	-9.688
b209	18:30:39.00	-31:20:15.4	2.577	-9.689
b210	18:33:36.43	-30:01:37.2	4.055	-9.688
b211	18:36:30.94	-28:42:54.0	5.533	-9.689
b212	18:39:22.54	-27:24:06.1	7.011	-9.688
b213	18:42:11.74	-26:05:16.4	8.489	-9.689
b214	18:44:58.75	-24:46:40.1	9.963	-9.691
b215	17:59:16.27	-41:13:36.8	350.751	-8.596
b216	18:02:56.38	-39:56:49.9	352.225	-8.596
b217	18:06:29.88	-38:39:45.7	353.698	-8.596
b218	18:09:57.17	-37:22:27.8	355.172	-8.596
b219	18:13:19.09	-36:04:57.9	356.646	-8.596
b220	18:16:36.24	-34:47:28.3	358.117	-8.599
b221	18:19:48.00	-33:29:24.0	359.593	-8.596
b222	18:22:56.21	-32:11:46.0	1.061	-8.600
b223	18:25:59.90	-30:53:13.9	2.540	-8.596
b224	18:29:00.24	-29:34:58.8	4.014	-8.596
b225	18:31:57.79	-28:16:49.4	5.485	-8.599
b226	18:34:51.98	-26:58:32.5	6.956	-8.600
b227	18:37:43.22	-25:39:38.9	8.435	-8.596
b228	18:40:32.38	-24:21:03.2	9.909	-8.596
b229	17:54:12.86	-40:41:49.2	350.749	-7.504
b230	17:57:57.26	-39:25:49.8	352.216	-7.507
b231	18:01:34.46	-38:09:29.5	353.683	-7.508
b232	18:05:05.30	-36:52:20.3	355.159	-7.504
b233	18:08:30.67	-35:35:19.7	356.629	-7.504
b234	18:11:50.81	-34:18:06.5	358.098	-7.504
b235	18:15:06.17	-33:00:40.7	359.569	-7.504
b236	18:18:17.11	-31:43:05.5	1.038	-7.504
b237	18:21:24.00	-30:25:21.4	2.508	-7.504
b238	18:24:27.02	-29:07:27.5	3.978	-7.504
b239	18:27:26.86	-27:49:27.1	5.448	-7.504
b240	18:30:23.83	-26:31:33.6	6.915	-7.507
b241	18:33:17.42	-25:13:08.8	8.388	-7.504
b242	18:36:08.74	-23:54:51.5	9.858	-7.504
b243	17:49:14.33	-40:09:10.1	350.747	-6.412
b244	17:53:02.06	-38:53:33.7	352.214	-6.412
b245	17:56:42.70	-37:37:34.3	353.681	-6.411
b246	18:00:17.47	-36:21:21.6	355.147	-6.412
b247	18:03:46.15	-35:04:51.0	356.614	-6.412
b248	18:07:09.48	-33:48:06.8	358.081	-6.412
b249	18:10:28.22	-32:31:22.4	359.545	-6.415
b250	18:13:41.62	-31:13:58.4	1.014	-6.412

b251	18:16:51.58	-29:56:51.4	2.478	-6.415
b252	18:19:56.33	-28:37:50.2	3.965	-6.400
b253	18:22:59.30	-27:21:28.4	5.414	-6.412
b254	18:25:58.34	-26:03:42.1	6.881	-6.412
b255	18:28:54.34	-24:45:49.0	8.347	-6.412
b256	18:31:47.81	-23:27:48.6	9.814	-6.412
b257	17:44:20.50	-39:35:44.2	350.746	-5.320
b258	17:48:11.76	-38:20:41.6	352.21	-5.320
b259	17:51:55.97	-37:05:17.2	353.674	-5.320
b260	17:55:34.03	-35:49:48.4	355.135	-5.322
b261	17:59:05.57	-34:33:34.6	356.602	-5.320
b262	18:02:31.90	-33:17:17.2	358.066	-5.320
b263	18:05:53.09	-32:00:46.4	359.53	-5.320
b264	18:09:09.96	-30:44:13.6	0.992	-5.322
b265	18:12:22.20	-29:27:18.7	2.455	-5.323
b266	18:15:30.07	-28:09:57.2	3.922	-5.320
b267	18:18:34.68	-26:52:38.6	5.386	-5.320
b268	18:21:35.88	-25:35:11.8	6.85	-5.319
b269	18:24:34.08	-24:17:37.0	8.314	-5.320
b270	18:27:29.54	-22:59:55.7	9.778	-5.320
b271	17:39:31.66	-39:01:31.1	350.745	-4.228
b272	17:43:25.99	-37:47:04.2	352.206	-4.228
b273	17:47:13.73	-36:32:26.9	353.666	-4.231
b274	17:50:54.10	-35:17:02.4	355.13	- 4.228
b275	17:54:28.85	-34:01:31.1	356.592	-4.228
b276	17:57:57.94	-32:45:42.8	358.054	-4.228
b277	18:01:21.89	-31:29:38.8	359.516	-4.228
b278	18:04:40.94	-30:13:18.5	0.978	-4.227
b279	18:07:55.66	-28:56:44.9	2.440	-4.228
b280	18:11:06.19	-27:39:59.0	3.902	-4.227
b281	18:14:13.06	-26:23:02.4	5.364	-4.228
b282	18:17:16.37	-25:05:55.0	6.826	-4.227
b283	18:20:16.56	-23:48:39.2	8.287	-4.228
b284	18:23:13.80	-22:31:13.8	9.749	-4.227
b285	17:34:47.71	-38:26:47.0	350.741	-3.138
b286	17:38:44.71	-37:12:41.4	352.204	-3.135
b287	17:42:34.97	-35:58:24.6	353.664	-3.136
b288	17:46:18.55	-34:43:43.7	355.125	-3.135
b289	17:49:55.99	-33:28:41.9	356.585	-3.135
b290	17:53:27.67	-32:13:22.4	358.045	-3.135
b291	17:56:54.07	-30:57:43.2	359.505	-3.135
b292	18:00:15.70	-29:41:49.2	0.966	-3.136
b293	18:03:32.93	-28:25:51.2	2.424	-3.138
b294	18:06:45.43	-27:09:14.8	3.886	-3.135
b295	18:09:54.41	-25:52:38.3	5.347	-3.136
b296	18:12:59.69	-24:35:50.6	6.807	-3.135
b297	18:16:01.78	-23:18:52.6	8.268	-3.135
b298	18:19:00.72	-22:01:45.5	9.728	-3.135
b299	17:30:08.04	-37:51:07.2	350.74	-2.046
b300	17:34:07.87	-36:37:36.5	352.202	-2.043
b301	17:38:00.94	-35:24:04.3	353.659	-2.046
b302	17:41:46.90	-34:09:41.4	355.121	-2.043
b303	17:45:26.88	-32:55:09.8	356.58	-2.043
b304	17:49:01.30	-31:40:29.6	358.037	-2.046
b305	17:52:29.86	-30:25:03.4	359.499	-2.043
b306	17:55:53.66	-29:09:32.8	0.958	-2.043
b307	17:59:12.86	-27:53:46.7	2.417	-2.043
b308	18:02:27.65	-26:37:45.1	3.876	-2.043
b309	18:05:38.57	-25:21:28.8	5.336	-2.043

b310	18:08:45.82	-24:05:00.6	6.795	-2.043
b311	18:11:49.68	-22:48:19.8	8.254	-2.043
b312	18:14:50.18	-21:31:34.0	9.712	-2.043
b313	17:25:32.76	-37:14:32.6	350.743	-0.951
b314	17:29:35.30	-36:01:46.6	352.202	-0.951
b315	17:33:30.62	-34:48:34.6	353.66	-0.951
b316	17:37:19.27	-33:34:56.6	355.119	-0.951
b317	17:41:01.49	-32:20:52.4	356.578	-0.951
b318	17:44:38.18	-31:06:50.8	358.031	-0.955
b319	17:48:09.05	-29:51:40.3	359.495	-0.951
b320	17:51:34.97	-28:36:34.6	0.954	-0.951
b321	17:54:56.16	-27:21:10.4	2.412	-0.951
b322	17:58:13.01	-26:05:30.1	3.871	-0.951
b323	18:01:25.82	-24:49:35.0	5.33	-0.951
b324	18:04:34.78	-23:33:24.5	6.789	-0.951
b325	18:07:40.30	-22:17:01.3	8.247	-0.951
b326	18:10:42.89	-21:00:51.1	9.701	-0.955
b327	17:21:02.45	-36:37:42.6	350.74	0.139
b328	17:25:07.06	-35:25:19.6	352.201	0.141
b329	17:29:04.68	-34:12:39.2	353.66	0.141
b330	17:32:55.51	-32:59:30.1	355.119	0.141
b331	17:36:39.58	-31:46:10.6	356.573	0.140
b332	17:40:18.53	-30:31:55.9	358.036	0.141
b333	17:43:51.58	-29:17:34.4	359.495	0.141
b334	17:47:19.25	-28:03:06.8	0.950	0.140
b335	17:50:42.70	-26:47:51.4	2.412	0.141
b336	17:54:01.39	-25:32:31.6	3.871	0.141
b337	17:57:15.93	-24:16:56.2	5.33	0.141
b338	18:00:26.54	-23:01:04.4	6.789	0.141
b339	18:03:33.72	-21:44:59.6	8.247	0.141
b340	18:06:37.80	-20:28:54.5	9.703	0.138
b341	17:16:36.05	-35:59:49.6	350.743	1.233
b342	17:20:43.01	-34:48:12.6	352.202	1.233
b343	17:24:42.67	-33:36:03.2	353.661	1.233
b344	17:28:35.52	-32:23:24.0	355.12	1.233
b345	17:32:22.06	-31:10:16.3	356.58	1.233
b346	17:36:02.66	-29:56:44.5	358.039	1.233
b347	17:39:37.82	-28:43:00.5	359.496	1.231
b348	17:43:07.42	-27:28:28.6	0.958	1.233
b349	17:46:32.38	-26:13:50.5	2.417	1.233
b350	17:49:52.70	-24:58:52.0	3.876	1.233
b351	17:53:09.14	-23:43:49.1	5.333	1.231
b352	17:56:21.43	-22:28:16.7	6.792	1.230
b353	17:59:29.74	-21:12:13.7	8.254	1.233
b354	18:02:34.99	-19:56:09.6	9.714	1.233
b355	17:12:14.18	-35:21:31.3	350.744	2.326
b356	17:16:23.06	-34:10:28.2	352.204	2.325
b357	17:20:24.62	-32:58:48.7	353.664	2.326
b358	17:24:19.42	-31:46:38.6	355.124	2.325
b359	17:28:07.75	-30:33:59.4	356.585	2.326
b360	17:31:50.21	-29:20:53.5	358.045	2.325
b361	17:35:26.93	-28:07:21.7	359.505	2.325
b362	17:38:58.51	-26:53:25.1	0.966	2.325
b363	17:42:25.06	-25:39:06.5	2.426	2.326
b364	17:45:47.14	-24:24:29.5	3.887	2.325
b365	17:49:04.75	-23:09:32.4	5.347	2.325
b366	17:52:18.50	-21:54:17.3	6.807	2.325
b367	17:55:28.46	-20:38:44.9	8.267	2.325
b368	17:58:35.09	-19:22:55.9	9.728	2.325

b369	17:07:56.47	-34:42:39.6	350.744	3.418
b370	17:12:07.25	-33:32:07.1	352.206	3.417
b371	17:16:10.39	-32:20:58.6	353.668	3.418
b372	17:20:06.86	-31:09:18.4	355.129	3.418
b373	17:23:57.19	-29:57:20.5	356.589	3.415
b374	17:27:41.02	-28:44:24.0	358.054	3.418
b375	17:31:19.56	-27:31:17.8	359.515	3.417
b376	17:34:52.54	-26:17:43.4	0.977	3.418
b377	17:38:20.59	-25:03:49.7	2.439	3.418
b378	17:41:44.26	-23:49:28.2	3.901	3.418
b379	17:45:03.46	-22:34:49.4	5.363	3.418
b380	17:48:18.48	-21:19:51.6	6.825	3.418
b381	17:51:29.81	-20:04:35.0	8.287	3.418
b382	17:54:37.66	-18:49:01.6	9.749	3.418
b383	17:03:42.94	-34:03:25.2	350.743	4.507
b384	17:07:55.03	-32:53:12.5	352.209	4.510
b385	17:11:59.88	-31:42:33.1	353.673	4.510
b386	17:15:57.96	-30:31:19.9	355.137	4.510
b387	17:19:49.25	-29:19:48.0	356.597	4.509
b388	17:23:35.30	-28:07:18.8	358.065	4.510
b389	17:27:15.26	-26:54:33.5	359.530	4.510
b390	17:30:45.46	-25:43:04.8	0.961	4.508
b391	17:34:15.58	-24:29:12.8	2.430	4.510
b392	17:37:40.80	-23:15:26.6	3.891	4.507
b393	17:41:01.09	-22:00:52.5	5.358	4.510
b394	17:44:17.50	-20:46:11.3	6.822	4.510
b395	17:47:30.12	-19:31:10.9	8.286	4.510
b396	17:50:39.17	-18:15:53.3	9.750	4.510
d001	11:43:27.74	-63:31:38.3	295.443	-1.648
d002	11:56:15.41	-63:52:19.9	296.902	-1.648
d003	12:09:20.18	-64:08:44.5	298.361	-1.648
d004	12:22:38.06	-64:20:44.2	299.820	-1.648
d005	12:36:05.54	-64:28:13.4	301.279	-1.648
d006	12:49:38.06	-64:31:10.2	302.738	-1.648
d007	13:03:11.21	-64:29:27.6	304.197	-1.648
d008	13:16:40.42	-64:23:10.7	305.656	-1.648
d009	13:30:01.27	-64:12:21.6	307.115	-1.648
d010	13:43:07.58	-63:57:24.8	308.569	-1.652
d011	13:56:02.26	-63:37:32.7	310.033	-1.648
d012	14:08:35.52	-63:13:49.8	311.492	-1.648
d013	14:20:47.04	-62:46:08.5	312.951	-1.648
d014	14:32:34.58	-62:14:40.9	314.410	-1.648
d015	14:43:42.53	-61:40:42.2	315.836	-1.652
d016	14:54:39.50	-61:02:24.0	317.295	-1.652
d017	15:05:10.61	-60:20:37.0	318.759	-1.648
d018	15:15:13.66	-59:36:15.5	320.218	-1.648
d019	15:24:50.21	-58:49:11.6	321.677	-1.648
d020	15:34:00.86	-57:59:37.7	323.136	-1.648
d021	15:42:46.42	-57:07:46.9	324.595	-1.648
d022	15:51:07.87	-56:13:46.2	326.054	-1.648
d023	15:59:06.12	-55:17:47.8	327.513	-1.648
d024	16:06:42.36	-54:20:02.0	328.972	-1.648
d025	16:13:57.77	-53:20:48.1	330.429	-1.651
d026	16:20:53.06	-52:19:59.5	331.885	-1.652
d027	16:27:30.36	-51:17:13.9	333.349	-1.648
d028	16:33:50.04	-50:13:47.6	334.805	-1.651
d029	16:39:53.11	-49:08:42.0	336.267	-1.648
d030	16:45:40.30	-48:02:59.6	337.722	-1.650
d031	16:51:14.42	-46:55:46.9	339.185	-1.648

d032	16:56:33.77	-45:48:07.9	340.64	-1.649
d033	17:01:41.93	-44:39:08.6	342.103	-1.648
d034	17:06:37.75	-43:29:37.0	343.562	-1.648
d035	17:11:22.70	-42:19:22.8	345.021	-1.649
d036	17:15:57.60	-41:08:39.1	346.478	-1.651
d037	17:20:22.10	-39:57:08.3	347.935	-1.650
d038	17:24:38.88	-38:44:46.3	349.398	-1.648
d039	11:45:55.20	-62:28:16.3	295.442	-0.556
d040	11:58:16.78	-62:48:13.0	296.901	-0.556
d041	12:10:50.64	-63:04:13.4	298.355	-0.560
d042	12:23:39.43	-63:15:48.6	299.813	-0.560
d043	12:36:36.00	-63:23:01.7	301.271	-0.560
d044	12:49:41.07	-63:25:37.0	302.736	-0.556
d045	13:02:43.30	-63:23:59.6	304.195	-0.556
d046	13:15:41.95	-63:17:57.8	305.653	-0.556
d047	13:28:33.10	-63:07:34.3	307.112	-0.556
d048	13:41:13.61	-62:52:53.0	308.571	-0.556
d049	13:53:39.77	-62:34:01.2	310.030	-0.556
d050	14:05:48.53	-62:11:10.0	311.488	-0.556
d051	14:17:37.68	-61:44:25.4	312.947	-0.556
d052	14:29:05.40	-61:14:00.2	314.405	-0.556
d053	14:40:10.13	-60:40:06.2	315.864	-0.556
d054	14:50:49.58	-60:03:15.5	317.318	-0.56
d055	15:01:07.25	-59:22:36.8	318.781	-0.556
d056	15:10:58.73	-58:39:26.6	320.240	-0.556
d057	15:20:25.78	-57:53:35.2	321.699	-0.556
d058	15:29:28.82	-57:05:14.3	323.157	-0.556
d059	15:38:08.11	-56:14:31.9	324.616	-0.556
d060	15:46:24.77	-55:21:42.1	326.075	-0.556
d061	15:54:19.25	-54:26:52.1	327.533	-0.556
d062	16:01:52.94	-53:30:13.0	328.992	-0.556
d063	16:09:06.70	-52:31:50.9	330.451	-0.556
d064	16:16:01.46	-51:31:56.3	331.909	-0.556
d065	16:22:38.40	-50:30:35.6	333.368	-0.556
d066	16:28:58.06	-49:28:17.4	334.821	-0.56
d067	16:35:02.30	-48:24:11.9	336.283	-0.559
d068	16:40:51.17	-47:19:19.2	337.739	-0.56
d069	16:46:26.50	-46:13:04.8	339.200	-0.559
d070	16:51:48.14	-45:05:46.0	340.661	-0.556
d071	16:56:57.60	-43:58:13.1	342.115	-0.56
d072	17:01:55.61	-42:49:02.6	343.579	-0.556
d073	17:06:42.65	-41:39:30.6	345.037	-0.556
d074	17:11:19.82	-40:29:29.8	346.493	-0.559
d075	17:15:47.26	-39:18:45.0	347.950	-0.56
d076	17:20:06.07	-38:07:05.5	349.411	-0.559
d077	11:48:12.67	-61:24:46.4	295.442	0.536
d078	12:00:07.22	-61:44:12.5	296.896	0.532
d079	12:12:21.34	-61:59:17.2	298.360	0.536
d080	12:24:43.03	-62:10:26.4	299.819	0.536
d081	12:37:12.10	-62:17:23.3	301.278	0.536
d082	12:49:45.38	-62:20:06.0	302.737	0.536
d083	13:02:16.94	-62:18:36.0	304.191	0.535
d084	13:14:47.59	-62:12:47.9	305.650	0.535
d085	13:27:11.52	-62:02:46.3	307.109	0.535
d086	13:39:26.02	-61:48:36.7	308.568	0.535
d087	13:51:29.40	-61:30:19.1	310.031	0.536
d088	14:03:15.41	-61:08:11.4	311.490	0.536
d089	14:14:43.73	-60:42:19.1	312.949	0.536
d090	14:25:52.27	-60:12:52.4	314.407	0.536

d091	14:36:40.32	-59:39:59.8	315.867	0.536
d092	14:47:04.90	-59:04:13.8	317.320	0.532
d093	14:57:09.62	-58:24:42.5	318.784	0.536
d094	15:06:50.26	-57:42:41.4	320.243	0.536
d095	15:16:06.77	-56:58:09.8	321.698	0.535
d096	15:25:02.11	-56:10:59.2	323.157	0.535
d097	15:33:35.40	-55:21:27.7	324.616	0.535
d098	15:41:48.34	-54:29:34.1	326.079	0.536
d099	15:49:39.29	-53:35:52.4	327.538	0.536
d100	15:57:10.15	-52:40:18.1	328.996	0.536
d101	16:04:22.06	-51:43:01.6	330.455	0.536
d102	16:11:15.77	-50:44:08.2	331.914	0.536
d103	16:17:52.18	-49:43:47.3	333.373	0.536
d104	16:24:11.50	-48:42:18.0	334.828	0.535
d105	16:30:16.87	-47:39:04.3	336.291	0.536
d106	16:36:06.91	-46:34:55.6	337.750	0.536
d107	16:41:43.13	-45:29:39.8	339.209	0.536
d108	16:47:06.43	-44:23:26.9	340.667	0.536
d109	16:52:17.66	-43:16:15.6	342.126	0.536
d110	16:57:17.59	-42:08:13.2	343.586	0.536
d111	17:02:06.58	-40:59:24.7	345.044	0.536
d112	17:06:45.65	-39:49:50.2	346.503	0.536
d113	17:11:15.31	-38:39:35.6	347.962	0.536
d114	17:15:36.19	-37:28:41.9	349.421	0.536
d115	11:50:21.26	-60:21:07.9	295.443	1.628
d116	12:01:56.33	-60:39:45.4	296.902	1.628
d117	12:13:43.66	-60:54:30.2	298.362	1.628
d118	12:25:40.25	-61:05:15.7	299.821	1.628
d119	12:37:43.90	-61:11:58.2	301.281	1.628
d120	12:49:51.02	-61:14:34.4	302.741	1.628
d120	12:49:51.02	-61:14:34.4	302.741	1.628
d121	13:01:58.46	-61:13:03.0	304.200	1.628
d122	13:14:00.77	-61:07:41.2	305.655	1.624
d123	13:26:01.94	-60:57:42.5	307.119	1.628
d124	13:37:51.91	-60:43:59.9	308.579	1.628
d125	13:49:30.50	-60:26:23.3	310.039	1.628
d126	14:00:53.14	-60:05:06.7	311.494	1.627
d127	14:12:03.53	-59:39:54.4	312.958	1.628
d128	14:22:54.29	-59:11:18.2	314.418	1.628
d129	14:33:25.94	-58:39:22.7	315.877	1.628
d130	14:43:35.86	-58:04:27.1	317.332	1.627
d131	14:53:28.37	-57:26:08.9	318.796	1.628
d132	15:02:58.06	-56:45:11.2	320.256	1.628
d133	15:12:06.53	-56:01:33.6	321.715	1.628
d134	15:20:54.07	-55:15:27.7	323.175	1.628
d135	15:29:20.69	-54:27:00.4	324.635	1.628
d136	15:37:27.18	-53:36:23.8	326.094	1.628
d137	15:45:14.06	-52:43:46.6	327.554	1.628
d138	15:52:41.81	-51:49:14.2	329.014	1.628
d139	15:59:51.34	-50:52:59.2	330.473	1.628
d140	16:06:43.42	-49:55:05.2	331.933	1.628
d141	16:13:18.96	-48:55:40.4	333.393	1.628
d142	16:19:38.50	-47:54:53.6	334.852	1.628
d143	16:25:43.22	-46:52:47.6	336.311	1.628
d144	16:31:33.74	-45:49:29.6	337.771	1.628
d145	16:37:10.78	-44:45:18.0	339.228	1.626
d146	16:42:35.28	-43:39:52.2	340.688	1.625
d147	16:47:47.69	-42:33:13.3	342.150	1.628
d148	16:52:49.08	-41:26:08.9	343.607	1.625

d149	16:57:39.62	-40:17:47.4	345.069	1.628
d150	17:02:20.45	-39:08:52.1	346.529	1.628
d151	17:06:51.91	-37:59:15.0	347.988	1.628
d152	17:11:14.57	-36:48:57.2	349.448	1.628

Release Notes

Data Reduction and Calibration

The photometric and astrometric calibrations of the VVV/VIRAC v1 product are both derived from the 2MASS Point Source Catalogue. (This will be superseded in version 2, where the Gaia DR2 absolute reference frame will be used.) Users should be aware that VIRAC v1 relative proper motions typically differ from absolute proper motions by up to 6 mas/yr, depending on Galactic coordinates. If absolute motions are required, users can perform a simple approximate correction by matching to Gaia DR2 for the field in question.

The data reduction and calibration procedures for individual epochs are as described in the VVV DR4 release. Since this is an advanced product, the details are not repeated here. All of the VIRAC v1 photometry is aperture photometry with an aperture diameter of $\sqrt{2}$ arcsec. The CASU aperture photometry attempts to deblend the fluxes of adjacent sources with overlapping apertures but the results are not as good as profile fitting photometry (which is much more computationally intensive). VIRAC version 2 will employ profile fitting photometry.

The VVV saturation limit is near Ks=11 mag, with some variation depending on observing conditions and variation between the 16 VIRCAM detectors. However, the centroiding of the CASU v1.3 pipeline remains good for sources as bright as Ks=10 mag. Moreover, a saturation correction was done for bright stars using an aperture corresponding to an annulus with inner diameter of 2 arcsec and outer diameter of 4 arcsec.

Data Quality

The Quality Control for the Phase 3 data from v1.3 was performed with involvement of ESO and of many scientists from the VVV Survey Science Team. Algorithmic quality control cuts to identify tile images with low zero points (after correcting for the seasonal trend), seeing that was significantly outside specification, or high average ellipticity were applied and the component pawprints were not used in VIRAC. Additional procedures identified a small number of tiles or pawprints where telescope guiding had been lost and fields with blurred or distorted image profiles. In addition we also identified some bad tiles where there was a large variation in the seeing or in the zero points between the 6 constituent pawprints, even though the values for the tile had passed the quality threshold.

For VIRAC v1, additional cuts were made to reject the following:

(i) pawprint catalogues with seeing > 1.2 arcsec in Ks;

(ii) pawprint catalogues in which one or more of the 16 arrays contained fewer than 25% of the median source counts for the pawprint set. (A pawprint set is defined in VIRAC as a sequence of spatially coincident VVV pawprints, with a tolerance of 30 arcsec);

(iii) pawprint catalogues for which the median astrometric residual to the CASU v1.3 pipeline astrometric solution across all 16 arrays is > 0.2 arcsec.

Following Gaia DR2, comparisons of Gaia absolute proper motions and VIRAC relative proper motions were made for all fields. Gradients in the VIRAC reference frame exist on small scales but these are generally at a level slightly below the measurement uncertainty for individual stars.

Proper motion quality flags

A "*reliable*" flag is included as a column in all VIRAC tables. Data with *reliable* = 1 correspond to more reliable proper motion solutions based on at least 2 pawprint sets.

High proper motion stars are included in VIRAC, with sensitivity to motions in excess of 10 arcsec per year. All 432 sources with *reliable* = 1 and proper motion, μ >200 mas/yr were visually inspected and found to be bona fide high proper motion stars, with one slightly ambiguous exception caused by blending. However, a number of false-positive high proper motion stars with μ <200 mas/yr were independently shown to be present in the very crowded Galactic centre region, caused by blending-related issues (Fernandes et al., 2018AAS...23123715G). Such false-positives typically, but not always, have unusually high values of "*ell*", the mean Ks ellipticity parameter. Bona fide high proper motion sources can have *reliable* = 0, so the *reliable* flag should be used as a simple way of selecting a less complete but more reliable subsets of measurements from a field. Reliability can be further improved by selecting stars with *ell* < 0.3.

For each star, an error flag value, *epm flag,* was computed for every proper motion solution that contributes to the final average. (Separate solutions were calculated for each pawprint set before averaging.) *epm flag* = 0 indicates no issues with the solution; *epm flag* = 1 indicates either a saturated star or a faint star near the detection threshold, such that the median proper motion uncertainty for the pawprint set is over 5 mas/yr for stars at the given Ks magnitude. *epm flag* = 2 indicates an unusually high proper motion uncertainty for the given Ks magnitude, above a threshold defined as median uncertainty plus 3 times the spread (where the spread is defined as max(0.3 mas/yr, median absolute deviation)). *epm flag* is additive, so it has a range from 0 to 3 for each proper motion solution.

The present VIRAC product provides proper motions only after averaging across all the solutions for a star (using inverse variance weighting). Therefore we provide information on the *epm flag* values through the parameters *n_epmf_0, n_epmf_1, n_epmf_2* and *n_epmf_3,* which represent the number of proper motion solutions with each of the *epm flag* values. The number of proper motion solutions for a star is given by the *dets* parameter. Good (averaged) solutions therefore typically have *n_epmf_0 = dets.*

To be flagged as 'reliable' a source must have a minimum of two proper motion solutions, all solutions must be from different pawprint sets, and *epm flag* = 0 for all solutions. This corresponds to *dets* ≥ 2, *dets* = *pawprintdets*, and *n_epmf_0* = *dets*. Here *pawprintdets* is the number of pawprint sets (typically 1 to 6) that contribute to the proper motion average. Typically, *dets* = *pawprintdets* but a pawprint set may occasionally have more than one proper motion solution for a star, corresponding to different parts of the time series. E.g. in the case of a faint star near the detection threshold or a high proper motion star, this occurs if successful cross-matching across multiple observing seasons occurred at a late stage in the calculation.

Known Issues

The CASU v1.3 pipeline has some imperfections with regard to photometric calibration. The Z and Y calibration is fairly good for fields located >2° off the Galactic equator but at present it remains unreliable for fields at latitudes |b|<2°. This issue is somewhat improved in the new v1.5 pipeline but this new pipeline has not yet been run on the VVV data. Calibration of all filters in very crowded fields in the inner bulge remains a work in progress.

Data Format

File Types

There is one type of catalogue file, in FITS format. E.g. "virac_v1_d001.fits" contains proper motion data for VVV tile d001. Each of the 348 catalogue files contains the provenance data for the corresponding VVV tile, i.e. the list of pawprint images that made up each of the 6 pawprint sets in the tile. Each file has 45 columns. This is slightly more than the 41 columns described in the original VIRAC release available at vvv.herts.ac.uk: 4 columns were added, corresponding to detection flags for the Z, Y, J and H passbands for each stars.

The 156206 pawprint image files from which the proper motion catalogue files were ultimately constructed are provided in compressed FITS format. Each files is nameed by observing date and file number on the night in question. E.g. "v20130325_00036_st.fits.fz". Here the "st" suffix indicates that the pawprint image is a stack of 2 images at 2 positions a few arcsec apart.

Catalogue Columns

1	sourceid	unique source identifier
2	ra	RA from astrometric fit at epoch 2012.0
3	de	Dec from astrometric fit at epoch 2012.0
4	mag	Ks band magnitude (Vega system). mag and emag are inverse variance weighted averages across overlapping pawprint sets. A magnitude and uncertainty from each pawprint set are the median and median absolute deviation of Ks measurements from all epochs in the pawprint set.
5	emag	Error on Ks band magnitude. See "mag" description above.
6	ell	Mean Ks band ellipticity
7	pm	Total proper motion (mas/yr). The proper motion measurements and their errors are inverse variance weighted averages across their measured values from all pawprint sets.
8	epm	Error on total proper motion

9	rapm	Proper motion in RAcosDec
10	erapm	Error on proper motion in RAcosDec
11	depm	Proper motion in Dec
12	edepm	Error on proper motion in Dec
13	epochs	Total number of epochs across all pawprint sets contributing to the measurement.
14	dets	The number of separate pawprint sets/epoch groups (see pawprintdets) in which the source was detected. For sources detected in only 1 tile, there may be up to 6 pawprint sets (more typically 2). Faint sources or high proper motion sources can occasionally have more than 1 det (i.e. multiple epoch groups) within a pawprint set if they are not matched between consecutive observing seasons until a late stage of the calculation.
15	stellardets	The number of pawprint sets in which the modal morphological classification of the source was stellar.
16	pawprintdets	the number of separate pawprint sets in which a source was detected. Technically 'dets' can be greater than this value where e.g. a high proper motion or faint source was not matched between consecutive observing seasons until a late stage of the calculation.
17	n_epmf_0	Number of pawprint sets with proper motion error flag ‘0’
18	n_epmf_1	Number of pawprint sets with proper motion error flag ‘1’
29	n_epmf_2	Number of pawprint sets with proper motion error flag ‘2’
20	n_epmf_3	Number of pawprint sets with proper motion error flag ‘3’
21	reliable	Reliability flag for proper motion: '1' is more reliable, ‘0’ is less reliable. This is a combination of dets >=2, dets=pawprintdets, and no proper motion error flags in any pawprint sets (n_epmf_0=dets)
22	Zmag	VVV DR4 Z band magnitude
23	eZmag	Error on VVV DR4 Z band magnitude
24	Zell	Ellipticity of Z band detection
25	Zclass	Z band morphological classification. 1 = resolved (e.g. blended stars or a galaxy); 0 = noise; -1 = stellar -2 = probably stellar -3 = probable galaxy -7 = bad pixel within 2" aperture -9 = saturated (saturation correction attempted)
26	Zsep	Distance to Z band detection (arcsec)
27	Ymag	VVV DR4 Y band magnitude
28	eYmag	Error on VVV DR4 Y band magnitude
29	Yell	Ellipticity of Y band detection
30	Yclass	Y band morphological classification, see column 25.
31	Ysep	Distance to Z band detection (arcsec)
32	Jmag	VVV DR4 J band magnitude
33	eJmag	Error on VVV DR4 J band magnitude

34	Jell	Ellipticity of J band detection
35	Jclass	J band morphological classification, see column 25.
36	Jsep	Distance to Z band detection (arcsec)
37	Hmag	VVV DR4 H band magnitude
38	eHmag	Error on VVV DR4 H band magnitude
39	Hell	Ellipticity of H band detection
40	Hclass	H band morphological classification, see column 25.
41	Hsep	Distance to H band detection (arcsec)
42	Zdetflag	Z detection flag, 1=not detected, 2=not observed
43	Ydetflag	Y detection flag, 1=not detected, 2=not observed
44	Jdetflag	J detection flag, 1=not detected, 2=not observed
45	Hdetflag	H detection flag, 1=not detected, 2=not observed

Acknowledgments

Please cite the VIRAC paper (Smith et al.2018, MNRAS 474, 1826) when using data from this release. Please also use the following statement in your articles: based on data products from VVV Survey observations made with the VISTA telescope at the ESO Paranal Observatory under programme ID 179.B-2002.

Further Details

More detailed information can be found in the peer-reviewed journal paper:

L. C. Smith, P. W. Lucas, R. Kurtev, R. Smart, D. Minniti, J. Borissova, H.R.A Jones, Z.H. Zhang, F. Marocco, C. Contreras Peña, M. Gromadzki, M.A. Kuhn, J.E. Drew, D.J. Pinfield, L.R. Bedin, 2018, MNRAS, 474, 1826

- the VIRAC web page (https://vvv.herts.ac.uk)
- the CASU webpages http://casu.ast.cam.ac.uk/surveys-projects/vista/

- by contacting Leigh Smith (lsmith [at] ast.cam.ac.uk) or Philip Lucas (p.w.lucas [at] herts.ac.uk)

- the VVV Science Team papers:

D. Minniti, P. W. Lucas, J. P. Emerson, R. K. Saito, M. Hempel, P. Pietrukowicz, A. V. Ahumada, M. V. Alonso, J. Alonso-García, J. I. Arias, R. M. Bandyopadhyay, R. H. Barbá, L. R. Bedin, E. Bica, J. Borissova, L. Bronfman, M. Catelan, J. J. Clariá, N. Cross, R. de Grijs, I. Dékány, J. E. Drew, C. Fariña, C. Feinstein, E. Fernández Lajús, R. C. Gamen, D. Geisler, W. Gieren, B. Goldman, O. González, G. Gunthardt, S. Gurovich, N. C. Hambly, M. J. Irwin, V. D. Ivanov, A. Jordán, E. Kerins, K. Kinemuchi, R. Kurtev, M. López-Corredoira, T. Maccarone, N. Masetti, D. Merlo, M. Messineo, I. F. Mirabel, L. Monaco, L. Morelli, N. Padilla, M. C. Parisi, G. Pignata, M. Rejkuba, A. Roman-Lopes, S. E. Sale, M. R. Schreiber, A. C. Schröder, M. Smith, L. Sodré Jr., M. Soto, M. Tamura, C. Tappert, M. A. Thompson, I. Toledo, M. Zoccali, “VISTA Variables in the Via Lactea (VVV): The public ESO near-IR variability survey of the Milky Way”, 2010, New Astronomy, 15, 433 (arXiv:0912.1056)

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