**Appendix 1. Arm tracer coordinates and distances**

*12CO coordinates*

|  |  |  |  |
| --- | --- | --- | --- |
| arm | tangent galactic longitude (degrees) | distance from Sun/Earth (kpc) | comment |
| Carina | 282.5 | 5 | 282 and 283 since year 2000 |
| Crux-Centaurus | 310 | 6 | midpoint since year 2010 |
| Norma | 328.4 | 7 | \*Average as presented in Vallée 2016 |
| Sagittarius | 49.4 | 4 | 2015 value |
| Sagittarius start | 344 | 7.5 | 1987 value, no others given and not used in fitting |
| Scutum | 30.5 | 5 | 2015 value, indistinguishable from 2011 (31o) |
| start Perseus | 336.8 | 8 | \*Average as presented in Vallée 2016 |

\*Average as presented in Vallée 2016 where error less than 1o

*Other arm tracer coordinates (omits pre-2000 values)*

|  |  |  |  |
| --- | --- | --- | --- |
| arm | tangent galactic longitude (degrees) | distance | tracer |
| Carina | 284.2 | 5 | dust 870 |
| Crux-Centaurus | 311 | 6 | dust 870 |
| Crux-Centaurus | 311.7 | 6 | dust 870 |
| Norma | 327.2 | 7 | dust 870 |
| Norma | 332 | 7 | dust 870 |
| Perseus | 337.5 | 8 | dust 870 |
| Perseus | 338 | 8 | dust 870 |
| Sagittarius | 49.2 | 4 | dust 870 |
| Sagittarius | 49 | 4 | dust 870 |
| Scutum | 31 | 5 | dust 870 |
| Scutum | 30.7 | 5 | dust 870 |
| Carina | 281.2 | 5 | HI |
| Carina | 283 | 5 | HI |
| Crux-Centaurus | 309.3 | 6 | HI |
| Crux-Centaurus | 310.4 | 6 | HI |
| Norma | 328 | 7 | HI |
| Norma | 328.4 | 7 | HI |
| Perseus | 336.8 | 8 | HI |
| Perseus | 336.9 | 8 | HI |
| Sagittarius | 50.8 | 4 | HI |
| Sagittarius | 51 | 4 | HI |
| Scutum | 30.8 | 5 | HI |
| Scutum | 33.2 | 5 | HI |
| Carina | 283.3 | 5 | HII |
| Carina | 284 | 5 | HII |
| Crux-Centaurus | 309 | 6 | HII |
| Crux-Centaurus | 311.7 | 6 | HII |
| Norma | 323 | 7 | HII |
| Norma | 328.1 | 7 | HII |
| Perseus | 337.2 | 8 | HII |
| Sagittarius | 49.4 | 4 | HII |
| Sagittarius | 51 | 4 | HII |
| Sagittarius | 56 | 4 | HII |
| Scutum | 30.6 | 5 | HII |
| Scutum | 32 | 5 | HII |
| Carina | 284.5 | 5 | methanol maser |
| Crux-Centaurus | 312.2 | 6 | methanol maser |
| Norma | 329.3 | 7 | methanol maser |
| Norma | 331.5 | 7 | methanol maser |
| Perseus | 337 | 8 | methanol maser |
| Perseus | 338 | 8 | methanol maser |
| Sagittarius | 49.3 | 4 | methanol maser |
| Sagittarius | 49.6 | 4 | methanol maser |
| Scutum | 26 | 5 | methanol maser |
| Scutum | 28 | 5 | methanol maser |
| Scutum | 30.8 | 5 | methanol maser |
| Crux-Centaurus | 307.5 | 6 | old stars |
| Crux-Centaurus | 307 | 6 | old stars |
| Perseus | 338.3 | 8 | old stars |
| Sagittarius | 55 | 4 | old stars |
| Scutum | 30 | 5 | old stars |
| Scutum | 32.6 | 5 | old stars |

*Arm tracer distances from 12CO locations (pc), mean and SEs (multiple values within the same arm are averaged first)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | methanol maser | dust 870 m | HII | HI | old stars |
| Carina | 174.5 | 148.3 | 100.4 | -34.9 |  |
| Sagittarius | -3.5 | 20.9 | -190.7 | -104.7 | -390.8 |
| Crux-Centaurus | 230.4 | 141.4 | 36.6 | -15.7 | -288.0 |
| Scutum | 194.9 | -30.5 | 479.8 | -130.9 | -69.8 |
| Norma | 244.3 | 146.6 | -348.1 | -24.4 |  |
| Perseus | 97.7 | 132.6 | 55.9 | 7.0 | 209.4 |
|  |  |  |  |  |  |
| mean | 156.4 | 93.2 | 22.3 | -50.6 | -134.8 |
| SE | 38.3 | 31.8 | 115.4 | 22.2 | 132.8 |

**Appendix 2. Earth and Solar System event ages and sources**

Age and references for impacts greater than 20 km diameter with error ≤ 4 Myr, the top three most ecologically and/or taxonomically severe (McGhee et al. 2013) and the origin of the Solar System. Events listed in order of age. Earth Impact Database (2017) used for impact crater diameters. Three pairs of impacts > 20 km are included with overlapping errors. These pairs are counted as single events in the statistical analyses, and are identified in Figure 2 using ages with lowest errors (best supported in the literature, bold). Other studies have identified temporal clusters of impacts across a range of crater diameters (e.g. Clube & Napier 1984, Napier 2015).

|  |  |  |  |
| --- | --- | --- | --- |
| Event (impact crater diameter, km) | Age (Ma) | error (Myr) | Reference |
| Ries (24) | 14.808 | 0.021 | Schmieder et al 2018 |
| **Chesapeake Bay** (40) | 35.67 | 0.28 | Jourdan 2012 |
| Popigai (90) | 36.4 | 0.81 | Jourdan *et al.* 2009 |
| **Kamensk** (25) | 50.37 | 0.4 | Jourdan 2012 |
| Montagnais(45) | 51 | <1? | Jourdan *et al.* 2009 |
| Boltysh(24) | 65.82 | 0.74 | Jourdan 2012 |
| **Chicxulub** (150) and end-Cretaceous extinction | 66.04 | 0.05 | Renne et al. 2013;  66.021, Clyde *et al.* 2016 |
| Kara (65) | 70.3 | 2.2 | Trieloff *et al.* 1998 |
| Lappajärvi (23) | 76.2 | 0.29 | Schmieder & Jourdan 2013 |
| Morokweng (70) | 145.2 | 0.8 | Jourdan 2012 |
| Puchezh-Katunki (40) | 193.8 | 1.1 | Meier & Holm-Alwmark 2017 |
| end-Triassic extinction | 201.564 | 0.22 | Blackburn *et al.* 2013 |
| Rochechouart (23) | 206.92 | 0.32 | Cohen *et al.* 2017 |
| Manicouagan (85) | 214.56 | 0.05 | Jourdan 2012 |
| Lake Saint Martin (40) | 227.8 | 1.1 | Schmieder *et al.* 2014 |
| end-Permian extinction | 251.959 | 0.018 | Baresel *et al.* 2017 |
| Araguainha (40) | 254.7 | 2.5 | Tohver *et al.* 2012 |
| West Clearwater (36) | 286.2 | 2.6 | Schmieder *et al.* 2015 |
| end-Ordovician extinction (Hirnantian) | 445.2 and ~ 444 | 1.4 (445.2) | Melchin *et al.* 2013;  Jones *et al.* 2017 |
| Carswell (39) | 485.5 | 1.5 | Meier & Holm-Alwmark 2017 |
| Sudbury (130) | 1849.3 | 0.3 | Jourdan 2012 |
| Vredefort | 2023 | 4 | Jourdan 2012 |
| Earth-Moon system | 4426-4417 |  | Connelly & Bizzarro 2016 |
| earliest Solar System (CAI) | 4567.3 | 0.16 | Connelly *et al.* 2012 |

**Appendix 3. Superchron data**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| superchron end age (Ma) | superchron start (Ma) | duration | midpoint | superchrons with midpoints less than average duration | midpoint summary with averaged values |
| 83.07 | 113.3 | 30.23 | 98.185 |  | 98.185 |
| 265 | 316.8 | 51.8 | 290.9 |  | 290.9 |
| 488.7 | 528 | 39.3 | 508.35 |  | 508.35 |
| 1055 | 1093 | 38 | 1074 |  | 1074 |
| 1151 | 1259 | 108 | 1205 | 1 | 1216.5 |
| 1170 | 1286 | 116 | 1228 | 1 |  |
| 1420 | 1439 | 19 | 1429.5 | 2 | 1448.25 |
| 1458 | 1476 | 18 | 1467 | 2 |  |
| 1589 | 1613 | 24 | 1601 | 3 | 1621.75 |
| 1633 | 1652 | 19 | 1642.5 | 3 |  |
| 1769 | 1785 | 16 | 1777 |  | 1777 |
| 1838 | 1863 | 25 | 1850.5 |  | 1850.5 |
| 2051 | 2098 | 47 | 2074.5 |  | 2074.5 |
| 2125 | 2170 | 45 | 2147.5 |  | 2147.5 |

All data from Driscoll and Evans (2016) except the two most recent end-points (references in main text). The eleven ages in the final column are used in the statistical analysis.

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