|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Date | Asteroid | V Mag | Int Time (s) | | Phase Angle | |  |
| 13-Sep-07 | | 13 Egeria | 10.86 | 1080 | 13.2 | | 0.8 | | |
| 21-Feb-07 | | 19 Fortuna | 11.39 | 1000 | 11.4 | | 1.05 | | |
| 8-Jan-13 | | 34 Circe | 11.96 | 720 | 9.2 | | 0.9 | | |
| 11-Jun-07 | | 38 Leda | 12.65 | 720 | 2.6 | | 0.9 | | |
| 21-Jun-08 | | 38 Leda | 13.67 | 960 | 17.6 | | 0.83 | | |
| 29-Aug-04 | | 41 Daphne | 11.08 | 1200 | 10.4 | | 0.85 | | |
| 15 May 2008\*\* | | 41 Daphne | 10 | 1440 | 19.5 | | 0.75 | | |
| 2-Mar-03 | | 48 Doris | 11.56 | 720 | 6 | | 0.95 | | |
| 22-Feb-07 | | 51 Nemausa | 10.14 | 800 | 6.5 | | 0.95 | | |
| 28-Feb-03 | | 66 Maja | 13.69 | 1600 | 8.9 | | 0.9 | | |
| 30-Oct-10 | | 70 Panopaea | 11.38 | 1680 | 3.3 | | 0.85 | | |
| 30-Apr-07 | | 78 Diana | 12.47 | 1440 | 28.1 | | 0.85 | | |
| 15-May-06 | | 105 Artemis | 11.77 | 1440 | 23.9 | | 0.88 | | |
| 30-Jan-12 | | 109 Felicitas | 11.88 | 1440 | 20 | | 0.85 | | |
| 23 Jul 2013\*\* | | 127 Johanna | 12.7 | 1260 | 8.2 | | 0.95 | | |
| 14-May-06 | | 130 Elektra | 13.12 | 2160 | 11.5 | | 0.76 | | |
| 12-Jun-07 | | 130 Elektra | 12.38 | 1200 | 8.8 | | 0.95 | | |
| 25-Aug-13 | | 130 Elektra | 12.01 | 1740 | 15.5 | | 0.93 | | |
| 30-Oct-10 | | 144 Vibilia | 10.38 | 1440 | 9 | | 0.85 | | |
| 21-Jun-04 | | 156 Xanthippe | 11.81 | 720 | 17.8 | | 0.9 | | |
| 21-Jun-04 | | 159 Aemilia | 13.22 | 1200 | 7.8 | | 1.4 | | |
| 27-Feb-03 | | 163 Erigone | 11.98 | 1040 | 10.2 | | 1 | | |
| 27-Jun-12 | | 168 Sibylla | 13.22 | 1620 | 12.5 | | 0.87 | | |
| 22-Nov-07 | | 176 Iduna | 13.03 | 2400 | 21.2 | | 0.95 | | |
| 17-Sep-06 | | 200 Dynamene | 11.88 | 1200 | 7.9 | | 0.87 | | |
| 20-Mar-02 | | 207 Hedda | 13.02 | 1560 | 13.8 | | 0.88 | | |
| 2-Mar-03 | | 211 Isolda | 12.01 | 720 | 2.5 | | 0.8 | | |
| 22-Sep-05 | | 345 Tercidina | 12.11 | 1920 | 12.5 | | 0.88 | | |
| 28-Feb-03 | | 404 Arsinoe | 11.94 | 1520 | 10.3 | | 0.88 | | |
| 12 Jun 2007\*\* | | 405 Thia | 12.12 | 300 | 17.6 | | 0.9 | | |
| 30-Oct-10 | | 407 Arachne | 12.38 | 1440 | 9.9 | | 0.85 | | |
| 7-Sep-06 | | 554 Peraga | 12.21 | 1080 | 21.1 | | 0.88 | | |
| 17-Sep-06 | | 554 Peraga | 11.94 | 1200 | 17.7 | | 0.9 | | |
| 22-Jul-09 | | 554 Peraga | 12.37 | 2400 | 4.1 | | 0.93 | | |
| 23 Jul 2013\*\* | | 576 Emanuela | 12.63 | 1440 | 5.3 | | 0.95 | | |
| 12-Sep-07 | | 602 Marianna | 12.43 | 1320 | 22.7 | | 0.85 | | |
| 20-Mar-02 | | 654 Zelinda | 11.52 | 1160 | 32.4 | | 0.85 | | |
| 7 Sep 2009\*\* | | 694 Ekard | 11.59 | 1080 | 24.5 | | 0.93 | | |
| 30-Aug-04 | | 754 Malabar | 13.69 | 1200 | 4.8 | | 0.85 | | |
| 16-May-06 | | 776 Berbericia | 12.36 | 1440 | 3.6 | | 1.05 | | |
| 21-Jun-08 | | 791 Ani | 13.25 | 1200 | 13.1 | | 0.93 | | |
| 26-Jun-13 | | 1467 Mashona | 13.93 | 720 | 19.7 | | 1 | | |
|  | |  |  |  |  | |  | | |

Table 1: Observing circumstances for targets. Integration time is calculated from the number of frames, co-adds per frame, and exposure time per co-add. V magnitude and phase angle were provided by the JPL Horizons ephemeris service. The beaming parameter () is the best-fit value as described in the Observations section. \*\*Night had precipitable water values > 6 mm.

|  |  |  |
| --- | --- | --- |
| Date | Standard Stars | PW Range (mm) |
| 20 March 2002 | SAO 138636, SAO 183975, SAO 161514, SAO 158315, SAO 117108 | 0.9-1.2 |
| 27 February 2003 | HD 119550, SAO 119691, L102-1081 | 1.6-2.0 |
| 28 February 2003 | L102-1081, HD 98562, HD 131715 | 0.8-1.6 |
| 2 March 2003 | SAO 65083, L102-1081 | 0.6-0.9 |
| 21 June 2004 | 16 Cyg B, HD 137781, HD 184700 | 2.6-6\* (6.7) |
| 29 August 2004 | HD 184700, HD 174466, HD 156802, HD 213199 | 1.4-1.6 |
| 30 August 2004 | 16 Cyg B, HD 184700, HD 170717, HD 151450 | 1.0-1.7 |
| 22 September 2005 | 16 Cyg B, HD 211476 | 3.1-3.9 |
| 14 May 2006 | HD 128596, HD 602981, HD115762 | 1.4-1.8 |
| 15 May 2006 | HD 107146, HD 119638, HD 60298 | 0.8-1.3 |
| 16 May 2006 | HD 115642, HD 144821, HD 107146 | 0.8-1.1 |
| 7 September 2006 | HD 12846 | 1.4-1.5 |
| 17 September 2006 | HD 12846, HD 177082, HD 193193, HD 211476, HD 224383 | 3.1-3.9 |
| 21 February 2007 | HD 107146, HD 110747 | 2.9-3.0 |
| 22 February 2007 | HD 107146, HD 128596, HD 60298, HD 77730, HD 88371 | 2.2-2.9 |
| 30 April 2007 | HD 102196, HD 119638, HD 77730 | 0.9-1.1 |
| 11 June 2007 | HD 151928, HD 184700, HD 189499, HD 205027 | 0.5-1.4 |
| 12 June 2007 | HD 140990, HD 198273 | 4.1-6\* |
| 12 September 2007 | HD 211476, HD 23169, HD 31867, HD 377 | 2.2-3.3 |
| 13 September 2007 | HD 13043, HD 211476, HD 26749, HD 377 | 1.9-2.4 |
| 22 November 2007 | HD 205027, HD 377 | 3.5-4.5 |
| 15 May 2008 | HD 110747, HD 114821, HD 153631, HD 88371, | 4.3-6\* (6.0) |
| 21 June 2008 | HD 153631, HD 198273 | 1.9-2.8 |
| 22 July 2009 | HD 126868, HR 6697, HR 206827, HD 1835 | 3.5-4.9 |
| 7 September 2009 | HD 205027 | 5.0-5.9 |
| 30 October 2010 | HD 23169, HD 60298, HR 1024, HR 9107 | 1.1-1.2 |
| 30 January 2012 | HD 12846, HD 60298 | 1.1-1.4 |
| 27 June 2012 | 16 Cyg B, HD 128596, HD 203311 | 0.7-0.8 |
| 8 January 2013 | HD 42160, HD 77730, Hya 64 | 1.0-1.8 |
| 26 June 2013 | HD 184700, HD 223238 | 1.0-2.3 |
| 23 July 2013 | HD 177911, HD 193193, HD 223238 | 6\* (8.2) |
| 25 August 2013 | SA155-271, SAO 142780, SAO 161608 | 0.6-1.0 |

Table 2: Observing nights. Precipitable water is range calculated for all objects during the night. Entries with 6\* indicate precipitable water amount went higher than 6 mm during night. Numbers in parentheses indicate highest precipitable water on those nights as calculated using CSO 225 GHz measurements (see footnote 1 for reference).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Asteroid | | Class | Diameter (km) | | Albedo | Semi-major axis (AU) |
| 13 Egeria | Ch | | | 227 | 0.069 | 2.57 |
| 19 Fortuna | Ch | | | 223 | 0.050 | 2.44 |
| 34 Circe | Ch | | | 113.2 | 0.054 | 2.69 |
| 38 Leda | Cgh | | | 116 | 0.062 | 2.74 |
| 41 Daphne | Ch | | | *179.6* | *0.078* | 2.76 |
| 48 Doris | Ch | | | 223.4 | 0.062 | 3.11 |
| 51 Nemausa | Ch | | | 142.6 | 0.10 | 2.37 |
| 66 Maja | Ch | | | *71.8* | *0.062* | 2.65 |
| 70 Panopaea | Ch | | | 139 | 0.040 | 2.61 |
| 78 Diana | Ch | | | *126.5* | *0.064* | 2.62 |
| 105 Artemis | Ch | | | 119 | 0.047 | 2.37 |
| 109 Felicitas | Ch | | | 89 | 0.071 | 2.70 |
| 127 Johanna | Ch | | | *114.2* | *0.065* | 2.76 |
| 130 Elektra | Ch | | | 198.9 | 0.071 | 3.12 |
| 144 Vibilia | Ch | | | 142.2 | 0.06 | 2.65 |
| 156 Xanthippe | Ch | | | 110.7 | 0.050 | 2.73 |
| 159 Aemilia | Ch | | | 127.4 | 0.061 | 3.10 |
| 163 Erigone | Ch | | | 81.6 | 0.033 | 2.37 |
| 168 Sibylla | Ch | | | 144 | 0.057 | 3.38 |
| 176 Iduna | Ch | | | 122.1 | 0.082 | 3.19 |
| 200 Dynamene | Ch | | | 122.1 | 0.082 | 2.74 |
| 207 Hedda | Ch | | | 130.5 | 0.052 | 2.28 |
| 211 Isolda | Ch | | | 143 | 0.060 | 3.04 |
| 345 Tercidina | Ch | | | 99 | 0.059 | 2.33 |
| 404 Arsinoe | Ch | | | 98.7 | 0.045 | 2.59 |
| 405 Thia | Ch | | | 125 | 0.047 | 2.58 |
| 407 Arachne | Ch\* | | | *97.54* | *0.052* | 2.62 |
| 554 Peraga | Ch | | | *96.98* | *0.049* | 2.37 |
| 576 Emanuela | Cgh\* | | | 77.2 | 0.052 | 2.99 |
| 602 Marianna | Ch\* | | | 126.8 | 0.052 | 3.09 |
| 654 Zelinda | Ch | | | 127 | 0.043 | 2.30 |
| 694 Ekard | Ch\* | | | *92.11* | *0.045* | 2.67 |
| 754 Malabar | Ch | | | *102.8* | *0.043* | 2.99 |
| 776 Berbericia | Cgh | | | 151.1 | 0.066 | 2.93 |
| 791 Ani | Ch\* | | | 82.5 | 0.052 | 3.12 |
| 1467 Mashona | Ch\* | | | 104.1 | 0.061 | 3.38 |

Table 3: Physical properties of target asteroids. *Italicized* values are taken from AKARI survey (Usui et al. 2011), others from WISE survey (Masiero et al. 2011). Asteroid classes are taken from SMASS survey (Bus and Binzel 2002b), save those with \*, which are taken from the S3OS2 survey (Lazzaro et al. 2004).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Meteorite** | **Source** | **Wavelengths** | **File** | **Reference** |  |
| ALH84033,21 | RELAB | 0.3-25 µm | ncmp14 | Hiroi et al. (1996b) |  |
| Y74642 | RELAB | 0.3-25 µm | ncmb75 | Hiroi et al. (1996a) |  |
| Bells | RELAB | 0.3-25 µm | ncmb53 | Hiroi et al. (1996a) |  |
| Y-82098 | RELAB | 0.3-25 µm | ncmp08 | Hiroi et al. (1997) |  |
| EET87522,29 | RELAB | 0.3-25 µm | ncmp21 | Hiroi et al. (1997) |  |
| Y-793321 | RELAB | 0.3-25 µm | ncmp13 | Hiroi et al. (1997) |  |
| MAC88100,30 | RELAB | 0.3-25 µm | ncmp22 | Hiroi et al. (1997) |  |
| Y-791198 | RELAB | 0.3-25 µm | ncmp12 | Hiroi et al. (1996b) |  |
| Y-86789 | RELAB | 0.3-25 µm | ncmp10 | Hiroi et al. (1996b) |  |
| Y74662 | RELAB | 0.3-25 µm | ncmb76 | Hiroi et al. (1996a) |  |
| Y-74662,101 | RELAB | 0.3-25 µm | ncmp11 | Hiroi et al. (1996a) |  |
| Murray | RELAB | 0.3-25 µm | ncmb56 | Hiroi et al. (1996a) |  |
| ALHA81002 | RELAB | 0.3-25 µm | ncmb50 | Hiroi et al. (1996a) |  |
| Mighei | RELAB | 0.3-25 µm | ncmb55 ,bkr1ma62, bkr1ma63 | Hiroi et al. (1996a) |  |
| ALHA77306,45 | RELAB | 0.3-25 µm | ncmp19 | Hiroi et al. (1996b) |  |
| Nogoya | RELAB | 0.3-25 µm | ncmb62 | Hiroi et al. (1996a) |  |
| ALH85013,32 | RELAB | 0.3-25 µm | ncmp23 | Hiroi et al. (1997) |  |
| Murchison | RELAB | 0.3-25 µm | ncmb64 | Hiroi et al. (1996a) |  |
| LEW87022,26 | RELAB | 0.3-25 µm | ncmp20 | Hiroi et al. (1996b) |  |
| LEW90500 | RELAB | 0.3-25 µm | ncmb54 | Hiroi et al. (1996a) |  |
| GRO85202,16 | RELAB | 0.3-25 µm | ncmp17 | Hiroi et al. (1996b) |  |
| LEW87148,15 | RELAB | 0.3-25 µm | ncmp16 | Hiroi et al. (1996b) |  |
| ALH84029 | RELAB | 0.3-25 µm | ncmb52 | Hiroi et al. (1996a) |  |
| LEW85311,36 | RELAB | 0.3-25 µm | ncmp24 | Hiroi et al. (1997) |  |
| ALH83100 | RELAB | 0.3-25 µm | ncmb51 | Hiroi et al. (1996a) |  |
| ALH84044,16 | RELAB | 0.3-25 µm | ncmp15 | Hiroi et al. (1996b) |  |
| Bells | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| Ivuna | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| LAP 022777 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| MET 00639400 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| MAC 02606 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| MIL 077000 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| QUE 97990 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| QUE 99038 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| Cold Bokkeveld | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| LAP 03786 | Takir | 0.4-4 µm |  | Takir et al. (2013) |  |
| Dhofar 225 | RELAB | 0.3-25 µm | bkr1ma78 | Hiroi, PI |  |
| MET 00639 | RELAB | 0.3-25 µm | bkr1ph032 | Hiroi, PI |  |
| WIS 91600 | RELAB | 0.3-25 µm | bkr1ph033 | Hiroi et al. (2005) |  |
| QUE97077 | RELAB | 0.3-50 µm | bkr1ph052 | Hiroi, PI |  |
|  |  |  |  |  |  |

Table 4: Meteorites with spectra used in this study. “Hiroi, PI” means that these were present in the RELAB public database and were obtained by Takahiro Hiroi but have not been featured in a publication.