Radar Characterization of NEAs: Moderate Resolution Imaging, Astrometry, and a Systematic Survey

Anne K. Virkki (Arecibo Observatory, UCF), Patrick A. Taylor (LPI, USRA), Flaviane C.F. Venditti, Sean E. Marshall, Dylan C. Hickson, Luisa F. Zambrano-Marin (Arecibo Observatory, UCF), Edgard G. Rivera-Valentín, Sriram S. Bhiravarasu, Betzaida Aponte-Hernandez (LPI, USRA), Michael C. Nolan, Ellen S. Howell (U. Arizona), Tracy M. Becker (SwRI), Jon D. Giorgini, Lance A. M. Benner, Marina Brozovic, Shantanu P. Naidu (JPL), Michael W. Busch (SETI), Jean-Luc Margot, Sanjana Prabhu Desai (UCLA), Agata Rożek (U. Kent), Mary L. Hinkle (UCF), Michael K. Shepard (Bloomsburg U.), and Christopher Magri (U. Maine)

Summary

We propose the continuation of the long-running project R3035 to physically and dynamically characterize the population of near-Earth asteroids with the Arecibo S-band (2380 MHz; 12.6 cm) planetary radar system. The objectives of project R3035 are to: (1) provide basic characterizations (size, shape, and radar scattering properties) of dozens of objects, (2) report ultra-precise radar astrometry for all detections, and (3) conduct a monthly survey of newly discovered objects around new moon. These observations will be carried out as part of the NASA-funded Arecibo planetary radar program, Grant No. 80NSSC19K0523, to PI Anne Virkki (Arecibo Observatory, University of Central Florida) with Patrick Taylor as Institutional PI at the Lunar and Planetary Institute (Universities Space Research Association).

Background

Radar is arguably the most powerful Earth-based technique for post-discovery physical and dynamical characterization of near-Earth asteroids (NEAs) and plays a crucial role in the nation's planetary defense initiatives led through the NASA Planetary Defense Coordination Office. Recent efforts of ground- (and space-) based observations are driven by the *George E. Brown, Jr. Near-Earth Object Survey Act*, which tasked NASA to detect, track, and characterize 90% of all NEAs larger than 140 meters. The *National Near-Earth Object Preparedness Strategy and Action Plan*, a report by the National Science & Technology Council, and *Finding Hazardous Asteroids Using Infrared and Optical Wavelength Telescopes*, a report by the National Academies of Sciences, Engineering, and Medicine, emphasize radar's unique role in tracking and characterization as critical to fulfilling the goals of the George E. Brown Act and for attaining full understanding of the Earth impact hazard including preparation for impact mitigation, if necessary.

Ultra-precise radar measurements with fractional precision of one part in ten million provide astrometry in terms of the line-of-sight velocity down to millimeters per second and the line-of-sight distance to less than one kilometer for objects millions of kilometers away. Radar astrometry, which is orthogonal to optical plane-of-sky astrometry, substantially improves our knowledge of asteroid trajectories (Ostro & Giorgini, 2004) by reducing uncertainties in orbital elements by orders of magnitude and increasing the range of Earth-encounter predictability by decades, if not centuries. This is especially important for preventing newly discovered NEAs from being lost and requiring re-discovery in the future. With increasing signal strength, radar is uniquely capable of measuring the sizes of NEAs directly and can provide basic shape descriptions for a number of the objects targeted by this proposed work.

Observing Program Status

We requested 284 hours of telescope time for R3035 for the 2019 calendar year. Through 8 months, 192.5 hours of the request were possible and 145.75 hours (76%) have been scheduled. This discrepancy is due in part to competition for telescope time around new moon with atmospheric campaigns, the lack of viable targets throughout survey nights, and opportunities to combine observing tracks with our companion project R3037. Six (of 8) survey nights around new moon were scheduled, though one was lost due to equipment failure, resulting in 16 detections of newly discovered objects, which is consistent with our historical average of $\sim$3 per night. Through August, we have detected all 11 possible moderate-imaging targets and 10 of 13 astrometry targets. So far this calendar year, the Arecibo planetary radar program has detected 74 asteroids and 93 in the past 12 months, all while working with a single klystron rather than the optimal two.

NASA's Solar System Observations program supports the Arecibo planetary radar program to observe NEAs for at least 600 hours per year. We propose to continue our survey-oriented approach using 294.50 hours of telescope time to collect precise astrometry and basic characterizations: circular polarization ratios and radar cross sections, plus size, shape, and spin-state constraints as signal strength allows, on several dozen NEAs with a relatively short amount of telescope time, *i.e.*, one to three tracks, per target. A companion proposal (Taylor et al.) concentrates on those 14 objects with the highest expected signal strengths, which will provide more detailed physical characterizations using significantly more telescope time per object and totaling 297.75 hours. Combining the target lists of our companion proposals totals more than 40 likely detections of previously known NEAs. Newly discovered asteroids observed during survey nights and as targets of opportunity during other scheduled tracks, i.e., no additional telescope time, historically nearly double the number of detections per year, up to $\sim$80 in this case, using our proposed 592.25 hours of telescope time. Proposals to observe NEAs not included in this or the companion proposal, newly discovered or recovered objects whose detectability could not be predicted in advance, historically account for 15% of time requests such that we expect to surpass 600 hours requested in 2020. Recent pressworthy objects in this vein include equal-mass binary asteroid 2017 YE5[1] and 2019 OK[2], which came within one-fifth of the distance to the Moon in late July.

Proposed Observing Program

This observing proposal consists of three parts: moderate-resolution imaging, where we request up to three tracks per target to determine its basic shape (15 NEAs, 32 tracks, 114.5 hours; see Table 1), astrometry, where we request one or two tracks per target to obtain the precise line-of-sight velocity of and distance to the target (24 tracks, 84 hours; see Table 2), and a monthly "survey night" scheduled within $\pm$3 days of new moon (12 tracks, 96 hours). Survey nights do not have a predetermined target list and concentrate on objects discovered just days before by optical survey programs as the moon wanes. In all, we request 294.50 hours of telescope time (including transmitter warm up) in this survey-oriented proposal.

In general, very little is known in advance about the proposed targets other than their absolute magnitudes. This lack of prior information is precisely why radar is important; radar efficiently provides physical characterization for objects where knowledge is otherwise lacking. Radar

[1] https://www.nasa.gov/feature/jpl/observatories-team-up-to-reveal-rare-double-asteroid/

[2] http://www.naic.edu/~pradar/press/2019OK.php

showed that 363599 (2004 FG11) is a binary, Asclepius *might* be a binary, and (85989) 1999 JD6 is a contact binary; further observations of these and others may refine knowledge of their physical properties. Three previously observed targets of particular dynamical interest are 137924 (2000 BD19), 66391 (1999 KW4), and 35107 (1991 VH). 2000 BD19 and 1999 KW4 are part of a long-term astrometric monitoring campaign led by team member Jean-Luc Margot to use ultra-precise radar astrometry to separate the orbital perturbations of Yarkovsky orbital drift, solar oblateness, and General Relativity on objects with low perihelia (Margot and Giorgini, 2010). For 2000 BD19, the 2020 apparition is the best yet to physically characterize this object and will extend the astrometric arc from radar to 14 years; for 1999 KW4, the prototypical binary NEA, the 2020 apparition will be the sixth opportunity for radar astrometry over a 20-year span. Detection of the Yarkovsky effect on 1999 KW4 or known binary 1991 VH will allow for an independent mass estimate for comparison to that of the motion of the satellite in its mutual orbit.

We note that the signal-to-noise ratios (SNRs) presented here are often lower bounds due to conservative assumptions about the size, rotation period, and viewing geometry of many of the targets, which means some could be an order of magnitude brighter than predicted. Attempting observations of objects predicted to have low SNRs can only increase the scientific return of the program. Past astrometry tracks resulted in the discovery of binary asteroid (163693) Atira (Rivera-Valentín et al., 2017) and rare equal-mass binary 1994 CJ1 (Taylor et al., 2014), possibly the smallest binary known. The binary nature of each would not have been determined without this program pushing to observe more asteroids with lower predicted SNRs.

Some potential targets require optical astrometry to reduce the plane-of-sky pointing uncertainties sufficiently for observation with the arcminute-scale Arecibo radar beam. These targets typically attain visual magnitudes less than 21 at solar elongations of around 90 degrees or more prior to the expected flybys of Earth such that optical astrometry is likely to materialize from the extensive community of professional and amateur astronomers who prioritize recovery of possible radar targets. Only the cases where the current uncertainties are several degrees may affect the timing (for scheduling) and distance (for signal strength) significantly and will be monitored in case their tracks must be shifted or cancelled.

Student Participation

Graduate student Luisa Zambrano-Marin (U. Granada), member of the local Arecibo team, is using radar scattering models to constrain the surface properties of asteroids and comets. Graduate student Sanjana Prebhu Desai (UCLA) has conducted observations under this program and leads observations of 441987 (2010 NY65) under project R3037. Graduate student Mary Hinkle (UCF) is combining infrared observations of 433 Eros with radar observations obtained with R3037. Research Experience for Undergraduates (REU) student Daniel Repp (Western Washington University) participated in observations and data analysis under projects R3035 and R3037 during 2019 and is working on a three-dimensional shape model of asteroid 2015 DP155. Former REU student Riley McGlasson (Macalester College) is working on a shape model of 1981 Midas using radar data collected under R3037. Team members Anne Virkki, Patrick Taylor, Flaviane Venditti, Sean Marshall, Tracy Becker, Shantanu Naidu, and Agata Rożek all used radar data or radar-data products from Arecibo collected under R3035 and R3037 or their predecessors as part of their graduate studies. Other (under)graduate students not specifically named among the proposing team are welcome to gain observing and research experience through this proposed work.

References

Chesley, S.R., et al. Direct detections of the Yarkovsky effect: Status and outlook, Proc. IAU 318, 2016.

Greenberg, A.H., et al., Yarkovsky drift detections for 159 near-Earth asteroids, 2017, submitted.

Mainzer, A.K., et al., NEOWISE Diameters and Albedos V2.0., urn:nasa:pds:neowise_diameters_albedos::2.0. NASA Planetary Data System, 2019.

Margot, J.L., and J.D. Giorgini. Probing general relativity with radar astrometry. IAU 261, 183-188, 2010.

Ostro, S.J., and J.D. Giorgini, The role of radar in predicting and preventing asteroid and comet collisions with Earth. Mitigation of Hazardous Comets and Asteroids. Cambridge University Press, 38-65, 2004.

Rivera-Valentín, E.G., et al., (163693) Atira, Central Bureau for Astronomical Telegrams, CBET 4347, 2017.

Taylor, P.A., et al., The smallest binary asteroid? The discovery of equal-mass binary 1994 CJ1, DPS #46, 409.03, 2014.

Warner, B.D., A.W. Harris, and P. Pravec, The asteroid lightcurve database, Icarus 202, 134-146, 2009. Updated January 2019. https://www.MinorPlanet.info/lightcurvedatabase.html

Object	H mag	Diam [km]	P_{spin} [h]	Prev Obs?	Start-End Dates	RTT [s]	SNR /day	Notes
137924 (2000 BD19)	17.2	0.97	10.6	Y	Feb 05-Feb 13	114	80	G W J Y
2017 BM123	23.7	*0.05*	2.1	Y	Feb 21-Feb 26	34	120	N G A
4581 Asclepius (1989 FC)	20.7	*0.22*	4.4	Y	Mar 18-Mar 31	71	72	B? P N
363599 (2004 FG11)	21.0	0.15	4.0	Y	Apr 07-Apr 09	60	20	B P G W Y
2016 HP6	25.3	*0.03*	*0.25*		May 03-May 07	11	230	N G
2013 XA22	22.8	*0.08*	*0.25*		Jun 04-Jun 14	27	83	N G A
2006 NL	20.0	*0.30*	*2.1*		Jul 10-Jul 13	57	80	G
85989 (1999 JD6)	17.1	1.45	7.7	Y	Jul 18-Jul 26	131	43	P G W
2002 BF25	22.2	0.15	*0.25*	Y	Jul 26-Jul 30	30	77	N G W
85275 (1994 LY)	16.1	2.51	2.7		Aug 03-Aug 09	151	32	I W
5645 (1990 SP)	17.1	1.67	30.4		Oct 20-Oct 31	144	72	G W
2017 WJ16	24.3	*0.04*	*0.25*		Nov 18-Nov 22	13	310	N G A
501647 (2014 SD224)	22.3	*0.10*	*0.25*		Dec 26-Dec 29	21	220	N G
2003 AF23	20.9	*0.20*	*2.1*		*Jan 01-Jan 08	47	100	P G
2016 CO247	20.5	*0.24*	*2.1*		*Jan 03-Jan 10	50	100	P G A

Table 1: We request two or three tracks for each of 15 objects totaling 32 tracks and 114.5 hours of telescope time (including transmitter warm up time; see Table 3 for detailed time requests). "Start-End" dates bracket the acceptable dates for observations. Absolute magnitudes H are taken from the JPL Small-Body Database. Diameters are taken from previous radar observations or infrared observations by NEOWISE (Mainzer et al., 2019) when available; otherwise, italicized diameters are estimates based on H assuming a brighter-than-average optical albedo of 0.2. Rotation periods P_{spin} are taken from the asteroid Lightcurve Database (Warner et al., 2009) when available. Previously observed objects ("Prev Obs?" column) have radar-estimated spin periods consistent with P_{spin}. Italicized periods are assumed very rapid at 2.1 h for $H < 22$, which gives a more conservative signal-to-noise ratio (SNR), and 0.25 h for $H > 22$. The closest approach is given by the round-trip time, RTT, for light to reach the target and return. Notes include known binary asteroids (B), potentially hazardous asteroids (P), NHATS-compliant objects (N), Goldstone radar targets (G), planned IRTF near- and thermal-infrared targets (I), objects previously observed by the NEOWISE spacecraft (W), objects with low perihelia usable for constraints on solar oblateness and General Relativity (J; Margot and Giorgini, 2010), and Yarkovsky-drift detections or candidates (Y) from Chesley et al. (2016; updated on NeoDys) and Greenberg et al. (2017), and objects that require optical astrometry prior to radar observations (A). SNR estimates assume single-klystron mode at 350 kW and will effectively double if a second klystron returns to operation. * indicates dates are in early January 2021.

Object	H mag	Diam [km]	P_{spin} [h]	Prev Obs	Start-End Dates	Preferred Date	RTT [s]	SNR /day	Notes
418849 (2008 WM64)	20.6	0.24	2.4	Y	2019 Dec 26-Dec 28	Dec 27	82	15	P
2019 AE3	27.2	*0.01*	*0.25*		Jan 03	Jan 03	13	57	N A
438661 (2008 EP6)	19.4	*0.39*	5.4	Y	Jan 07-Jan 12	Jan 09	106	13	P
2011 CT4	20.8	*0.21*	*2.1*		Jan 16-Jan 17	Jan 16	73	12	P A
2009 BH2	22.4	*0.10*	*0.25*		Jan 19-Jan 20	Jan 20	40	18	A
437316 (2013 OS3)	18.4	*0.62*	*2.1*		Jan 20-Jan 24	Jan 23	97	34	
250577 (2005 AC)	18.2	*0.68*	*2.1*		Feb 05-Feb 07	Feb 05	89	53	
35107 (1991 VH)	16.7	1.30	2.6	Y	Feb 05-Feb 23	Feb 11, 12	304	3	B P N Y
2015 BK509	22.4	*0.10*	*0.25*		Feb 27-Feb 29	Feb 28	47	13	A
65690 (1991 DG)	19.0	*0.47*	*2.1*		Mar 25-Mar 29	Mar 28	88	27	P Y
2015 FC35	21.9	*0.12*	*2.1*		Mar 28-Mar 29	Mar 29	56	16	P G A
2019 HM	25.8	*0.02*	*0.25*		Apr 15-Apr 18	Apr 16	20	23	N
66391 (1999 KW4)	16.5	1.32	2.8	Y	Jun 02-Jun 07	Jun 03, 04	188	5	P J Y
242450 (2004 QY2)	14.7	2.54	*2.1*		Jul 06-Jul 11	Jul 08	163	37	P W
2016 YO3	20.1	*0.28*	*2.1*		Jul 08-Jul 10	Jul 09	82	19	A
480936 (2003 QH5)	20.1	0.54	*2.1*		Jul 15-Jul 21	Jul 17	87	39	P W
2015 FP332	17.3	*1.03*	*2.1*		Jul 24-Jul 26	Jul 24	130	23	
2019 AN5	21.2	*0.17*	*2.1*		Aug 13-Aug 16	Aug 15	59	28	P
411165 (2010 DF1)	21.8	0.16	*2.1*		Aug 22-Aug 24	Aug 23	55	39	P W
465824 (2010 FR)	21.7	*0.14*	*2.1*		Sep 04-Sep 10	Sep 07	50	49	P G
2017 SL16	25.8	*0.02*	*0.25*		Sep 22-Sep 23	Sep 22	23	16	N
2000 TU28	20.8	*0.21*	*2.1*		Oct 16-Oct 18	Oct 17	70	16	P

Table 2: Assuming each track is 3.5 h (including transmitter warm up), we request 24 tracks and 84 hours of telescope time to observe the 22 objects listed above. ”Start-End” dates bracket the acceptable dates for observations, while ”Preferred” is the desired track. Priority, if necessary, should be given to known binary asteroids (B), potentially hazardous asteroids (P), NHATS-compliant objects (N), objects previously observed by the NEOWISE spacecraft (W), objects with low perihelia usable for constraints on solar oblateness and General Relativity (J; Margot and Giorgini, 2010), and Yarkovsky-drift detections or candidates (Y) from Chesley et al. (2016; updated on NeoDys) and Greenberg et al. (2017). Some objects require optical astrometry prior to radar observations (A). Column descriptions are otherwise the same as in Table 1. SNR estimates assume single-klystron mode at 350 kW and will effectively double if a second klystron returns to operation.

Observing Requests

Table 3. We request 32 tracks and 114.5 hours to observe the 15 moderate-imaging targets in Table 1. Requested tracks are marked with a +; unmarked tracks are acceptable alternatives. The rise/set times do NOT include one hour of transmitter warm-up time prior to the source rising. Calculations assume the physical parameters from Table 1 and a radar albedo of 0.1 unless estimated from previous radar observations. When unknown, the sizes and spin rates used tend to give conservative estimates of the SNR. Nominal system parameters are assumed: transmitter power = 350 kW (single-klystron mode), sensitivity $\sim$7 K/Jy (post-Maria, also a function of declination), and system temperature = 24 K. SNRs will effectively double if a second klystron returns to operation.

Request: 3 tracks, 11.25 hours

UT Date **137924 (2000 BD19)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Feb-05	145	15.7	+22	34	5	31	09:49-12:35
2020-Feb-06	133	16.2	+22	38	7	43	10:14-13:01
2020-Feb-07	124	16.8	+22	41	9	57	10:44-13:33
+2020-Feb-08	118	17.4	+21	44	11	72	11:18-14:09
+2020-Feb-09	114	18.1	+19	45	12	80	11:56-14:46
+2020-Feb-10	115	18.8	+16	44	12	79	12:34-15:23
2020-Feb-11	119	19.5	+13	41	11	67	13:12-15:55
2020-Feb-12	126	20.1	+10	36	8	52	13:48-16:20
2020-Feb-13	136	20.6	+07	31	6	36	14:20-16:39

Request: 2 tracks, 7.25 hours

Note: Requires optical astrometry prior to radar observations (7 arcmin)

UT Date **(2017 BM123)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Feb-21	52	9.8	+12	90	3	31	02:59-05:35
2020-Feb-22	48	9.9	+15	102	4	43	02:56-05:39
2020-Feb-23	44	10.0	+18	113	5	62	02:56-05:42
+2020-Feb-24	40	10.1	+22	123	8	86	02:59-05:44
+2020-Feb-25	37	10.2	+27	126	10	120	03:09-05:43
2020-Feb-26	34	10.4	+32	109	9	94	03:31-05:34

Request: 2 tracks, 7.50 hours

UT Date **4581 Asclepius (1989 FC)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Mar-18	86	3.2	+12	55	4	32	18:36-21:13
2020-Mar-19	82	3.5	+13	59	5	39	18:46-21:28
2020-Mar-20	79	3.8	+15	63	6	48	18:58-21:43
2020-Mar-21	76	4.1	+17	66	7	56	19:13-22:00
2020-Mar-22	73	4.5	+19	69	7	63	19:30-22:18
+2020-Mar-23	72	4.9	+21	70	8	69	19:50-22:38
+2020-Mar-24	71	5.3	+23	70	8	72	20:12-22:57
2020-Mar-25	71	5.7	+24	69	9	72	20:35-23:18
2020-Mar-26	71	6.2	+25	67	8	69	20:59-23:38
2020-Mar-27	72	6.6	+26	65	8	64	21:22-23:59
2020-Mar-28	75	7.0	+27	62	7	56	21:44-00:19
2020-Mar-29	77	7.4	+27	59	6	48	22:05-00:38
2020-Mar-30	81	7.8	+27	57	5	41	22:23-00:56
2020-Mar-31	84	8.1	+27	54	4	34	22:39-01:12

Request: 2 tracks, 7.25 hours

UT Date **363599 (2004 FG11)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
+2020-Apr-07	80	15.5	+23	62	1	12	05:32-08:17
+2020-Apr-08	69	15.8	+29	64	2	20	05:56-08:23
2020-Apr-09	60	16.4	+36	36	2	16	06:59-08:11

Request: 2 tracks, 7.25 hours

UT Date **(2016 HP6)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-May-03	19	14.0	+21	263	3	54	02:21-05:09
2020-May-04	17	14.5	+18	304	5	91	02:43-05:31
+2020-May-05	14	15.0	+14	349	8	160	03:15-06:00
+2020-May-06	12	15.8	+09	353	12	230	04:04-06:30
2020-May-07	11	16.7	+01	218	13	190	05:26-06:48

Request: 2 tracks, 7.25 hours

Note: Requires optical astrometry prior to radar observations (10 degrees!)

UT Date **(2013 XA22)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Jun-04	32	12.9	+05	114	3	35	23:30-01:30
2020-Jun-05	30	12.6	+07	132	4	53	22:57-01:08
2020-Jun-06	29	12.1	+09	149	5	65	22:22-00:44
2020-Jun-07	28	11.7	+11	162	6	76	21:46-00:15
+2020-Jun-08	27	11.2	+13	170	6	83	21:10-23:44
+2020-Jun-09	27	10.6	+15	174	6	82	20:33-23:11
2020-Jun-10	28	10.1	+16	174	5	77	19:57-22:38
2020-Jun-11	29	9.6	+17	169	5	67	19:23-22:05
2020-Jun-12	30	9.2	+18	163	4	57	18:51-21:34
2020-Jun-13	32	8.7	+18	154	3	45	18:22-21:05
2020-Jun-14	34	8.4	+19	144	3	36	17:55-20:38

Request: 2 tracks, 7.50 hours

UT Date **(2006 NL)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Jul-10	57	18.6	+34	52	6	47	03:05-04:44
+2020-Jul-11	59	18.4	+25	80	9	80	02:15-04:53
+2020-Jul-12	63	18.2	+16	78	7	64	01:56-04:39
2020-Jul-13	68	18.0	+09	62	5	43	01:52-04:14

Request: 2 tracks, 7.25 hours

UT Date **85989 (1999 JD6)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Jul-18	134	2.5	+31	29	5	29	10:10-12:18
2020-Jul-19	132	3.0	+32	29	5	30	10:35-12:41
2020-Jul-20	131	3.5	+31	29	6	32	10:59-13:07
2020-Jul-21	131	4.0	+31	30	5	31	11:21-13:34
2020-Jul-22	134	4.4	+30	31	5	30	11:42-14:00
+2020-Jul-23	137	4.8	+29	32	8	43	12:00-14:26
+2020-Jul-24	142	5.2	+27	32	7	39	12:17-14:49
2020-Jul-25	148	5.6	+26	32	6	33	12:32-15:09
2020-Jul-26	155	5.9	+24	31	5	28	12:45-15:27

Request: 2 tracks, 6.75 hours

UT Date **(2002 BF25)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Jul-25	30	9.6	+00	67	9	74	17:17-18:24
+2020-Jul-26	33	9.5	+05	113	7	77	16:38-18:41
+2020-Jul-27	36	9.4	+10	124	6	72	16:16-18:43
2020-Jul-28	39	9.3	+14	124	4	54	16:01-18:40
2020-Jul-29	42	9.2	+17	118	3	40	15:50-18:34
2020-Jul-30	45	9.2	+20	110	2	30	15:41-18:26

Request: 2 tracks, 6.50 hours

UT Date **85275 (1994 LY)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Aug-03	178	17.9	+09	24	5	27	00:19-02:43
2020-Aug-04	173	17.9	+08	24	6	29	00:18-02:36
+2020-Aug-05	169	17.8	+06	23	6	32	00:18-02:28
+2020-Aug-06	164	17.8	+05	22	6	30	00:18-02:19
2020-Aug-07	160	17.8	+03	20	7	30	00:21-02:08
2020-Aug-08	155	17.8	+02	18	7	32	00:25-01:56
2020-Aug-09	151	17.8	+00	13	8	28	00:33-01:40

Request: 2 tracks, 5.75 hours

UT Date **5645 (1990 SP)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Oct-20	144	8.9	-00	9	18	65	11:03-11:47
2020-Oct-21	146	9.1	+00	14	18	60	10:59-12:09
2020-Oct-22	148	9.3	+01	18	17	66	10:58-12:27
+2020-Oct-23	150	9.5	+03	20	16	72	11:00-12:41
+2020-Oct-24	153	9.7	+04	22	15	69	11:02-12:54
2020-Oct-25	157	9.9	+05	23	14	66	11:06-13:06
2020-Oct-26	160	10.1	+06	24	14	71	11:09-13:16
2020-Oct-27	165	10.2	+07	24	13	65	11:13-13:26
2020-Oct-28	169	10.4	+07	24	12	59	11:17-13:34
2020-Oct-29	174	10.6	+08	24	11	53	11:20-13:42
2020-Oct-30	179	10.8	+09	24	10	48	11:24-13:49
2020-Oct-31	184	10.9	+10	24	9	43	11:28-13:55

Request: 3 tracks, 11.00 hours
Note: Requires optical astrometry prior to radar observations (10 degrees!)

UT Date **(2017 WJ16)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Nov-18	19	8.3	+09	224	7	110	07:43-10:05
+2020-Nov-19	17	8.0	+14	277	9	160	07:17-09:55
+2020-Nov-20	15	7.7	+20	318	13	240	06:51-09:34
+2020-Nov-21	14	7.3	+27	319	17	310	06:29-08:58
2020-Nov-22	13	6.8	+34	211	13	200	06:19-07:51

Request: 2 tracks, 7.50 hours

UT Date **501647 (2014 SD224)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Dec-26	21	20.9	+35	126	13	150	18:18-19:46
+2020-Dec-27	23	20.5	+22	211	15	220	17:14-19:56
+2020-Dec-28	26	20.3	+11	174	10	130	17:00-19:32
2020-Dec-29	30	20.1	+03	105	5	54	17:09-18:55

Request: 2 tracks, 7.25 hours

UT Date **(2003 AF23)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2021-Jan-01	51	12.1	+33	62	5	40	08:57-10:43
2021-Jan-02	48	11.3	+32	71	6	52	08:04-09:59
2021-Jan-03	47	10.6	+30	84	6	63	07:05-09:16
+2021-Jan-04	47	9.8	+27	94	10	100	06:06-08:33
+2021-Jan-05	49	9.1	+23	97	9	93	05:14-07:52
2021-Jan-06	52	8.5	+19	94	7	74	04:32-07:14
2021-Jan-07	57	8.0	+14	84	5	52	04:00-06:38

Request: 2 tracks, 7.25 hours
Note: Requires optical astrometry prior to radar observations (10 arcmin)

UT Date **(2016 CO247)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2021-Jan-03	56	14.4	+32	62	5	40	11:03-12:59
2021-Jan-04	52	13.7	+33	64	6	50	10:18-12:10
2021-Jan-05	50	12.9	+32	71	7	61	09:23-11:21
2021-Jan-06	50	12.1	+30	80	7	67	08:23-10:35
+2021-Jan-07	51	11.3	+27	87	11	100	07:25-09:52
+2021-Jan-08	54	10.6	+24	88	9	84	06:35-09:13
2021-Jan-09	58	10.1	+20	84	6	63	05:55-08:37
2021-Jan-10	64	9.6	+17	76	5	44	05:24-08:05