Arecibo Radar Observations of 14 High-Priority Near-Earth Asteroids in CY2020 and January 2021

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Summary

We propose the continuation of the long-running project R3037 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 R3037 are to: (1) collect high-resolution radar images of and (2) report ultra-precise radar astrometry for the strongest predicted radar targets for the 2020 calendar year plus early January 2021. Such images will be used for three-dimensional shape modeling as the data sets allow. 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.

Radar is uniquely capable of measuring the sizes of NEAs directly as dedicated spacecraft are costly and the use of stellar occultations is in its infancy due to the small sizes of NEAs. With its unmatched sensitivity and resolution from the ground, radar has discovered more than 70% of the known NEA binary systems, which make up $\sim$15% of the population larger than 200 m, and identified that contact binaries, two similar-size bodies resting against one another, make up a similar fraction of the NEA population. Arecibo radar observations routinely provide astrometry with fractional precision of one part in ten million as well as images with resolution as fine as 7.5 m revealing surface features, such as boulders, concavities, and ridges. Our SHAPE software (Hudson, 1994; Magri et al., 2007) inverts these radar images to obtain spin-state estimates and three-dimensional shape models limited only by echo strength and orientational coverage.

Observing Program Status

Proposals for project R3037 have requested 287 hours of telescope time since September 2018. Of these, 227.75 hours (79%) have been scheduled. The discrepancy is almost solely due to the klystron failure in October 2018 and the time required to commission a new klystron by mid-December. Overall, the Arecibo planetary radar program has detected 93 asteroids in the past 12 months while working with a single klystron rather than the optimal two. Pressworthy results since last September include observations of extremely elongated (and extremely slowly rotating, ∼285 hours) asteroid 163899 (2003 SD220) (Rivera-Valentín et al., 2019) and comet 46P/Wirtanen as well as participation in the International Asteroid Warning Network observing campaign of binary asteroid 66391 (1999 KW4). The remaining four months of the calendar year include six high-priority targets and 70.5 hours of telescope time requested.

NASA's Solar System Observations program supports the Arecibo planetary radar program to observe NEAs for at least 600 hours per year. We propose radar imaging, detailed physical characterization, and orbit refinement of our 14 highest-priority NEAs during 2020 and early January 2021 using 297.75 hours of telescope time. A companion proposal (Virkki et al.) with a more survey-oriented approach requests 294.50 hours and concentrates on basic characterization and precise astrometry for dozens more objects bringing the total proposed time request to 592.25 hours. 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.

Proposed Observing Program

Time requests for each target in 2020 and early January 2021 are dictated by the science goals and the estimated signal-to-noise ratio (SNR). For all targets we will measure the circular polarization ratio and radar cross section, which are gauges of near-surface roughness and near-surface density and can correlate with composition (Benner et al., 2008) and metallicity (Shepard et al., 2015), provide precise astrometry, determine binarity, and constrain the size, shape, and spin state, which when combined with photometric and/or spectroscopic measurements constrain the optical albedo and composition. Past experience demonstrates the key factor in our ability to secure shapes and spin-state estimates is good sky and rotational coverage over several days of observations, especially when we lack prior knowledge about the target. If it is found that the complete request is not necessary, due to weaker signal than expected or completion of science goals with fewer dates, the remaining time requests can be used for targets of opportunity available at the same times or relinquished for use by other projects or maintenance.

Table 1 describes our targets and lists synergistic observations, including 12 potentially hazardous asteroids (PHAs). Since PHAs are by definition large bodies that come close to Earth, barring other information, they tend to populate the list of highest-predicted-signal targets. The objects requested at the Goldstone radar (more maneuverable, but less sensitive than Arecibo) will have greater coverage from longer daily tracks and observations outside the Arecibo declination window, which may lead to tighter constraints on physical parameters. Overlapping tracks with Goldstone may allow for bistatic X- or C-band experiments with resolutions of 3.75 or 1.875 m, which are otherwise unachievable from the ground. A subset of radar targets will be observed through a coordinated program with the NASA InfraRed Telescope Facility (IRTF) for spectral characterization and application of radar-derived shape information to thermophysical modeling (e.g., Howell et al., 2018). Speckle tracking (Busch et al., 2010) with the Very Long Baseline Array (VLBA) can be used to resolve the prograde/retrograde-rotation ambiguity of radar, but will require full power (dual-klystron mode) for even the best speckle target, 438908 (2009 XO), in Table 1. Table 2 lists specific track requests for each target.

About half of the high-priority targets listed in Table 1 have been observed before with radar attaining various degrees of characterization completeness. 441987 (2010 NY65) has made close approaches to Earth for the last several years, which will allow for shape modeling and strong constraints on the Yarkovsky orbital drift of its semimajor axis, which also yields a mass estimate given knowledge of the target's thermal properties. Previous imaging of candidate contact binary 144411 (2004 EW9), spheroidal 159402 (1999 AP10), and elongated 7753 (1988 XB) combined with this apparition will allow for shape reconstruction and stronger constraints on their spin states and scattering properties. Asteroids 388945 (2008 TZ3) and 8014 (1990 MF) have very limited prior datasets, mainly radar astrometry; observations this year will drastically improve the physical characterizations of these objects. Some targets have no previous knowledge other than their absolute magnitude, while some have only a measurement of their rotation period from optical lightcurves or an inferred diameter from the NEOWISE infrared spacecraft. This lack of prior information is precisely why radar is important; radar efficiently provides physical characterization for objects where knowledge is otherwise lacking. In the case of NEOWISE targets, radar provides direct size and shape estimates for comparison to the inferred sizes from thermophysical modeling. Ryugu presents a unique case as it is the first NEA visited by a spacecraft *prior* to radar observations. Ryugu will provide an important calibration test of radar versus ground-truth from spacecraft and test biases in our shape modeling algorithms much in the way that Bennu has. We request time for Ryugu here essentially as a placeholder. A separate proposal will likely be submitted at the next proposal deadline with further details and justification.

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, including leading observations of 441987 (2010 NY65), as well as under companion project R3035. 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 during 2019 and is working on a three-dimensional shape model of asteroid 2015 DP155 using radar images obtained under this project. Undergraduate intern at LPI, Emily Whittaker (U. Maryland), used data collected under project R3037 to test methods for determining the diameters of radar-observed asteroids with confidence. Former REU student Riley McGlasson (Macalester College) is working on a shape model of 1981 Midas using radar data collected under this project. Team members Patrick Taylor, Anne Virkki, Flaviane Venditti, Sean Marshall, Tracy Becker, Shantanu Naidu, and Agata Rożek all used radar data or radar-data products from Arecibo collected under R3037 or its 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.

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Object	H mag	Diam [km]	P_{spin} [h]	Prev Obs?	Next App	Start-End Dates	RTT [s]	SNR /day	Notes
163373 (2002 PZ39)	18.9	*0.49*	*2.1*		2091	Feb 09-Feb 19	39	920	P G I
52768 (1998 OR2)	15.8	*2.06*	4.1		2079	Apr 08-Apr 24	48	3030	P G I
388945 (2008 TZ3)	20.4	*0.25*	44.2	Y	2022	Apr 24-May 04	38	870	P G I
438908 (2009 XO)	20.5	*0.24*	*2.1*		2086	Apr 29-May 07	23	2050	P G S
136795 (1997 BQ)	18.1	*0.71*	*2.1*		2244	May 11-May 17	50	420	P G
2000 KA	21.7	*0.14*	*2.1*		2056	May 14-May 17	26	560	P G
441987 (2010 NY65)	21.5	0.18	5.5	Y	2181	Jun 16-Jul 02	27	540	P G W Y
144411 (2004 EW9)	16.6	1.70	49.9	Y	2081	Jun 20-Jul 06	117	650	G
8014 (1990 MF)	18.7	*0.54*	*2.1*	Y	2050	Jul 09-Jul 20	56	170	P G
159402 (1999 AP10)	16.1	1.80	7.9	Y	2189	Oct 02-Oct 15	82	490	G I
162173 Ryugu	19.3	0.87	7.6		2033	Nov 01-Dec 02	80	140	P N G Y
7753 (1988 XB)	18.6	1.80	$\sim$30	Y	2061	Nov 23-Dec 12	66	2030	P G Y
153201 (2000 WO107)	19.3	0.51	*2.1*		2040	Nov 28-Dec 04	29	3020	P G I W Y
332446 (2008 AF4)	19.7	*0.34*	*2.1*		2183	2021 Jan 09-Jan 14	29	1440	P G I

Table 1: We propose to observe our 14 highest-priority NEAs in a combined 297.75 hours (including transmitter warm-up time; see Table 2 for detailed time requests). 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 and from the Hayabusa2 spacecraft in the case of Ryugu; 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 $H < 22$. Assumptions of more rapid spins and brighter albedos (smaller sizes) lead to more conservative estimates for the signal-to-noise ratio (SNR). SNR estimates assume single-klystron mode at 350 kW and will effectively double if a second klystron returns to operation. "Start-End" dates bracket the acceptable tracks. The closest approach is given by the minimum round-trip time, RTT, for light to reach the target and return. Notes include potentially hazardous asteroids (P), NHATS-compliant objects (N), Goldstone radar targets (G), VLBA speckle-tracking targets (S), planned IRTF near- and thermal-infrared targets (I), objects previously observed by the NEOWISE spacecraft (W), and Yarkovsky-drift detections or candidates (Y) from Chesley et al. (2016; updated on NeoDys) and Greenberg et al. (2017). "Next App" indicates the next comparable close approach to Earth of less than 1.2 times the RTT (within a factor of 2 in SNR) of the upcoming apparition. Almost all are not re-observable at the same proximity to Earth for several decades meaning this is our best chance to characterize them with radar.

Observing Requests

Table 2. We request 85 tracks and 297.75 hours to observe 14 asteroids. 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. Several days of observations spread over the observing window allow for complete rotational coverage (assuming typical rotation periods) and better constraints on the spin state. 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 ~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: 7 tracks, 25.00 hours

UT Date	RTT	RA	Dec	Runs	SNR	SNR	UT rise-set
163373 (2002 PZ39)	[s]	[h]	[deg]		/run	/day	
2020-Feb-09	68	7.3	+27	66	12	97	01:17-03:47
2020-Feb-10	61	6.9	+28	72	17	150	00:53-03:20
2020-Feb-11	55	6.5	+28	79	26	230	00:25-02:49
+2020-Feb-11	49	6.0	+28	88	38	350	23:49-02:12
+2020-Feb-12	44	5.3	+28	98	53	520	23:05-01:29
+2020-Feb-13	41	4.5	+26	109	70	730	22:12-00:40
+2020-Feb-14	39	3.6	+23	121	82	900	21:13-23:49
+2020-Feb-15	39	2.8	+19	124	82	920	20:16-22:56
+2020-Feb-16	41	2.0	+15	116	71	770	19:27-22:04
+2020-Feb-17	44	1.4	+10	100	54	550	18:49-21:15
2020-Feb-18	49	0.8	+06	78	38	340	18:23-20:29
2020-Feb-19	54	0.4	+03	55	23	170	18:06-19:46

Request: 9 tracks, 31.50 hours
Note: 8 consecutive tracks sample complete rotation multiple times

UT Date **52768 (1998 OR2)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Apr-08	108	8.2	+33	31	19	100	22:32-00:23
2020-Apr-09	104	8.2	+32	34	21	130	22:27-00:26
+2020-Apr-10	99	8.2	+31	38	25	150	22:22-00:29
2020-Apr-11	95	8.3	+30	42	29	190	22:18-00:32
2020-Apr-12	91	8.4	+29	47	53	360	22:14-00:35
2020-Apr-13	87	8.4	+28	51	63	440	22:11-00:38
2020-Apr-14	83	8.5	+27	56	74	540	22:08-00:41
2020-Apr-15	78	8.6	+25	60	89	670	22:07-00:44
+2020-Apr-16	74	8.7	+24	65	110	830	22:05-00:47
+2020-Apr-17	70	8.8	+22	70	130	1050	22:05-00:50
+2020-Apr-18	67	8.8	+20	75	160	1320	22:07-00:53
+2020-Apr-19	63	8.9	+17	79	190	1660	22:09-00:55
+2020-Apr-20	59	9.1	+15	82	230	2070	22:14-00:57
+2020-Apr-21	56	9.2	+12	84	280	2560	22:21-00:57
+2020-Apr-22	53	9.3	+08	81	350	3030	22:33-00:55
+2020-Apr-23	50	9.5	+04	71	360	2920	22:50-00:48
2020-Apr-24	48	9.7	+00	44	430	2590	23:21-00:30

Request: 6 tracks, 20.00 hours

UT Date **388945 (2008 TZ3)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Apr-24	87	13.4	+15	56	8	63	02:25-05:06
2020-Apr-25	81	13.4	+14	59	10	80	02:20-05:00
2020-Apr-26	76	13.4	+13	63	13	100	02:14-04:53
2020-Apr-27	71	13.3	+12	66	16	130	02:09-04:46
+2020-Apr-28	66	13.3	+12	70	21	180	02:04-04:38
+2020-Apr-29	61	13.2	+10	73	28	240	01:59-04:29
+2020-Apr-30	57	13.2	+09	77	37	320	01:54-04:19
+2020-May-01	52	13.1	+08	79	50	450	01:50-04:07
+2020-May-02	47	13.1	+06	80	70	620	01:47-03:53
+2020-May-03	42	13.0	+03	76	87	740	01:47-03:34
2020-May-04	38	12.8	+00	57	130	870	01:54-03:06

Request: 6 tracks, 21.00 hours

UT Date **438908 (2009 XO)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Apr-29	61	5.7	+22	82	5	51	18:15-21:01
2020-Apr-30	54	5.9	+22	92	8	82	18:24-21:10
2020-May-01	48	6.2	+21	105	13	140	18:36-21:23
+2020-May-02	41	6.5	+21	122	22	240	18:53-21:41
+2020-May-03	35	7.0	+20	144	38	450	19:17-22:06
+2020-May-04	30	7.7	+18	172	66	840	19:51-22:42
+2020-May-05	26	8.6	+14	196	110	1490	20:41-23:28
+2020-May-06	23	9.7	+08	194	150	2050	21:52-00:21
+2020-May-07	23	10.8	+01	115	140	1360	23:30-00:58

Request: 4 tracks, 14.75 hours

UT Date **136795 (1997 BQ)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-May-11	80	6.3	+28	56	12	87	18:13-20:41
2020-May-12	74	6.3	+25	64	15	120	18:06-20:44
+2020-May-13	69	6.4	+22	72	20	170	18:01-20:45
+2020-May-14	63	6.4	+18	79	27	240	17:58-20:44
+2020-May-15	58	6.4	+14	83	36	320	17:58-20:39
+2020-May-16	54	6.5	+09	81	47	420	18:04-20:29
2020-May-17	50	6.5	+03	64	54	420	18:22-20:07

Request: 3 tracks, 10.50 hours

UT Date **(2000 KA)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
+2020-May-14	26	16.0	+26	176	43	560	03:44-06:19
+2020-May-15	31	15.8	+14	152	25	310	03:25-06:03
+2020-May-16	37	15.7	+05	98	12	120	03:32-05:32

Request: 6 tracks, 21.00 hours

UT Date	RTT	RA	Dec	Runs	SNR	SNR	UT rise-set
441987 (2010 NY65)	[s]	[h]	[deg]		/run	/day	
2020-Jun-16	62	6.6	+13	77	6	51	16:04-18:43
2020-Jun-17	55	6.8	+15	89	9	83	16:08-18:51
2020-Jun-18	48	7.0	+17	104	14	140	16:15-19:02
+2020-Jun-19	42	7.3	+21	120	22	240	16:28-19:16
+2020-Jun-20	36	7.7	+25	134	37	410	16:52-19:34
+2020-Jun-21	31	8.3	+30	133	39	440	17:36-19:54
2020-Jun-22	27	9.2	+36	70	61	540	19:05-20:09
...	Target is north of the Arecibo declination window						
+2020-Jun-26	32	14.5	+33	104	35	350	23:43-01:35
+2020-Jun-27	38	15.1	+29	116	32	340	23:58-02:24
+2020-Jun-29	43	15.6	+25	111	20	210	00:12-02:52
2020-Jun-30	50	15.8	+22	100	12	120	00:22-03:08
2020-Jul-01	56	16.1	+20	89	8	76	00:31-03:18
2020-Jul-02	63	16.2	+18	79	5	49	00:37-03:24

Request: 8 tracks, 27.50 hours

Note: Spacing required to sample full rotation

UT Date	RTT	RA	Dec	Runs	SNR	SNR	UT rise-set
144411 (2004 EW9)	[s]	[h]	[deg]		/run	/day	
2020-Jun-20	117	4.1	+00	19	150	570	14:01-15:17
+2020-Jun-21	122	4.0	+03	25	130	650	13:39-15:21
+2020-Jun-22	127	4.0	+05	28	120	600	13:21-15:21
+2020-Jun-23	132	3.9	+07	30	120	620	13:07-15:20
+2020-Jun-24	138	3.8	+08	31	100	540	12:55-15:17
2020-Jun-25	143	3.8	+10	31	87	480	12:44-15:13
2020-Jun-26	149	3.7	+12	31	76	420	12:34-15:09
+2020-Jun-27	155	3.7	+13	31	66	360	12:25-15:04
+2020-Jun-28	161	3.6	+14	30	58	310	12:17-14:59
2020-Jun-29	167	3.6	+16	29	51	270	12:10-14:54
2020-Jun-30	173	3.5	+17	28	45	230	12:04-14:48
2020-Jul-01	180	3.5	+18	28	39	200	11:58-14:43
2020-Jul-02	186	3.5	+19	27	35	180	11:52-14:38
+2020-Jul-03	193	3.5	+20	26	31	150	11:47-14:32
+2020-Jul-04	199	3.5	+21	25	27	130	11:42-14:27
2020-Jul-05	206	3.4	+22	24	24	120	11:37-14:22
2020-Jul-06	213	3.4	+22	23	22	100	11:33-14:17

Request: 5 tracks, 18.25 hours

UT Date **8014 (1990 MF)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Jul-09	81	14.1	+12	57	7	57	22:03-00:37
2020-Jul-10	78	14.0	+13	61	8	66	21:52-00:30
2020-Jul-11	75	13.9	+15	65	9	78	21:40-00:22
2020-Jul-12	72	13.8	+17	68	11	91	21:28-00:12
+2020-Jul-13	70	13.7	+19	71	12	110	21:16-00:01
+2020-Jul-14	67	13.5	+21	73	14	120	21:05-23:49
+2020-Jul-15	65	13.4	+23	74	16	140	20:53-23:34
+2020-Jul-16	63	13.2	+26	74	18	160	20:42-23:17
+2020-Jul-17	61	13.0	+28	73	20	170	20:31-22:58
2020-Jul-18	59	12.8	+31	67	14	120	20:22-22:34
2020-Jul-19	58	12.6	+33	58	15	120	20:14-22:05
2020-Jul-20	56	12.3	+36	40	17	100	20:12-21:28

Request: 7 tracks, 24.75 hours

Note: Spacing due to ∼8-h rotation period

UT Date **159402 (1999 AP10)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Oct-02	118	22.6	+04	28	21	110	01:25-03:16
+2020-Oct-03	114	22.6	+05	33	23	130	01:13-03:17
2020-Oct-04	111	22.6	+07	37	30	180	01:03-03:18
+2020-Oct-05	107	22.5	+09	40	33	210	00:53-03:17
2020-Oct-06	104	22.5	+11	44	37	250	00:44-03:16
+2020-Oct-07	101	22.5	+13	47	41	280	00:35-03:13
2020-Oct-08	98	22.5	+15	50	46	320	00:28-03:10
+2020-Oct-09	95	22.4	+17	52	51	360	00:21-03:06
2020-Oct-10	93	22.4	+20	54	56	400	00:15-03:01
+2020-Oct-11	91	22.4	+23	54	61	440	00:11-02:54
2020-Oct-12	88	22.4	+25	53	66	470	00:09-02:45
+2020-Oct-13	87	22.4	+28	50	71	490	00:09-02:34
+2020-Oct-14	85	22.3	+31	45	48	320	00:12-02:20
2020-Oct-15	84	22.3	+34	34	51	300	00:22-01:58

Request: 8 tracks, 27.50 hours
Note: 7 consecutive tracks sample complete rotation

UT Date **162173 Ryugu (1999 JU3)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Nov-01	124	22.6	+25	38	6	41	23:03-01:40
2020-Nov-02	123	22.6	+25	39	7	43	22:57-01:36
2020-Nov-03	121	22.6	+24	40	7	45	22:52-01:32
2020-Nov-04	120	22.6	+23	40	7	48	22:47-01:28
2020-Nov-05	118	22.6	+23	41	8	51	22:42-01:24
2020-Nov-06	117	22.6	+22	42	8	54	22:37-01:20
2020-Nov-07	115	22.6	+21	43	8	57	22:32-01:17
+2020-Nov-08	114	22.6	+21	43	9	59	22:28-01:13
2020-Nov-09	113	22.6	+20	44	9	63	22:23-01:09
2020-Nov-10	111	22.6	+19	45	10	67	22:19-01:05
2020-Nov-11	110	22.6	+19	45	10	70	22:15-01:01
2020-Nov-12	108	22.6	+18	46	11	74	22:11-00:57
2020-Nov-13	107	22.6	+17	46	11	77	22:08-00:53
2020-Nov-14	106	22.6	+17	47	12	81	22:04-00:49
2020-Nov-15	104	22.6	+16	47	12	85	22:01-00:45
2020-Nov-16	103	22.6	+15	48	13	90	21:58-00:41
2020-Nov-17	101	22.6	+14	48	14	95	21:56-00:37
2020-Nov-18	100	22.6	+13	48	14	99	21:53-00:33
2020-Nov-19	99	22.6	+13	48	15	100	21:51-00:29
2020-Nov-20	97	22.6	+12	48	16	110	21:49-00:24
+2020-Nov-21	96	22.7	+11	48	16	120	21:47-00:20
+2020-Nov-22	95	22.7	+10	47	17	120	21:46-00:15
+2020-Nov-23	93	22.7	+09	47	18	130	21:45-00:10
+2020-Nov-24	92	22.7	+08	46	19	130	21:44-00:05
+2020-Nov-25	91	22.7	+07	45	20	140	21:43-00:00
+2020-Nov-26	89	22.8	+06	44	21	140	21:44-23:54
+2020-Nov-27	88	22.8	+05	43	20	130	21:44-23:49
2020-Nov-28	87	22.8	+04	41	21	130	21:45-23:42
2020-Nov-29	85	22.8	+03	38	22	130	21:47-23:35
2020-Nov-30	84	22.9	+02	35	23	130	21:50-23:27
2020-Dec-01	83	22.9	+01	30	24	130	21:55-23:18
2020-Dec-02	81	22.9	+00	24	26	120	22:01-23:07

Request: 6 tracks, 20.50 hours

Note: 6 consecutive tracks sample complete rotation

UT Date **7753 (1988 XB)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
2020-Nov-23	66	10.6	+01	36	270	1570	10:17-11:36
+2020-Nov-24	67	10.3	+04	49	260	1810	09:39-11:28
+2020-Nov-25	69	10.0	+06	57	280	2030	09:06-11:16
+2020-Nov-26	70	9.7	+09	61	250	1950	08:37-11:00
+2020-Nov-27	73	9.4	+11	63	220	1740	08:12-10:44
+2020-Nov-28	76	9.2	+14	62	190	1520	07:49-10:26
+2020-Nov-29	79	8.9	+15	61	170	1290	07:27-10:09
2020-Nov-30	83	8.7	+17	59	140	1080	07:08-09:52
2020-Dec-01	87	8.4	+19	57	120	900	06:50-09:35
2020-Dec-02	91	8.2	+20	54	100	740	06:34-09:18
2020-Dec-03	96	8.0	+21	51	86	600	06:19-09:03
2020-Dec-04	101	7.8	+22	48	72	490	06:05-08:48
2020-Dec-05	106	7.7	+23	46	61	400	05:51-08:33
2020-Dec-06	112	7.5	+24	43	51	330	05:39-08:19
2020-Dec-07	117	7.4	+24	41	43	270	05:27-08:06
2020-Dec-08	123	7.3	+25	39	37	220	05:16-07:54
2020-Dec-09	129	7.1	+25	37	31	190	05:05-07:42
2020-Dec-10	135	7.0	+26	35	26	150	04:55-07:30
2020-Dec-11	141	6.9	+26	33	23	130	04:46-07:20
2020-Dec-12	147	6.8	+26	31	19	110	04:36-07:09

Request: 5 tracks, 18.00 hours

UT Date **153201 (2000 WO107)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
+2020-Nov-28	31	10.0	+06	119	190	2050	08:58-11:01
+2020-Nov-29	29	8.4	+16	158	240	3020	07:02-09:34
+2020-Nov-30	33	6.7	+22	142	160	1870	05:17-07:51
+2020-Dec-01	41	5.5	+24	112	72	770	03:59-06:32
+2020-Dec-02	52	4.7	+25	90	32	310	03:06-05:41
2020-Dec-03	64	4.2	+24	74	15	130	02:30-05:07
2020-Dec-04	77	3.8	+23	62	8	64	02:04-04:44

Request: 5 tracks, 17.50 hours

UT Date **332446 (2008 AF4)**	RTT [s]	RA [h]	Dec [deg]	Runs	SNR /run	SNR /day	UT rise-set
+2021-Jan-09	29	11.9	+07	137	120	1440	08:02-10:15
+2021-Jan-10	33	11.5	+14	145	83	990	07:21-10:00
+2021-Jan-11	37	11.2	+20	131	54	610	06:55-09:38
+2021-Jan-12	42	10.9	+24	112	35	370	06:37-09:15
+2021-Jan-13	47	10.7	+27	94	24	230	06:24-08:53
2021-Jan-14	53	10.5	+30	78	10	90	06:14-08:31