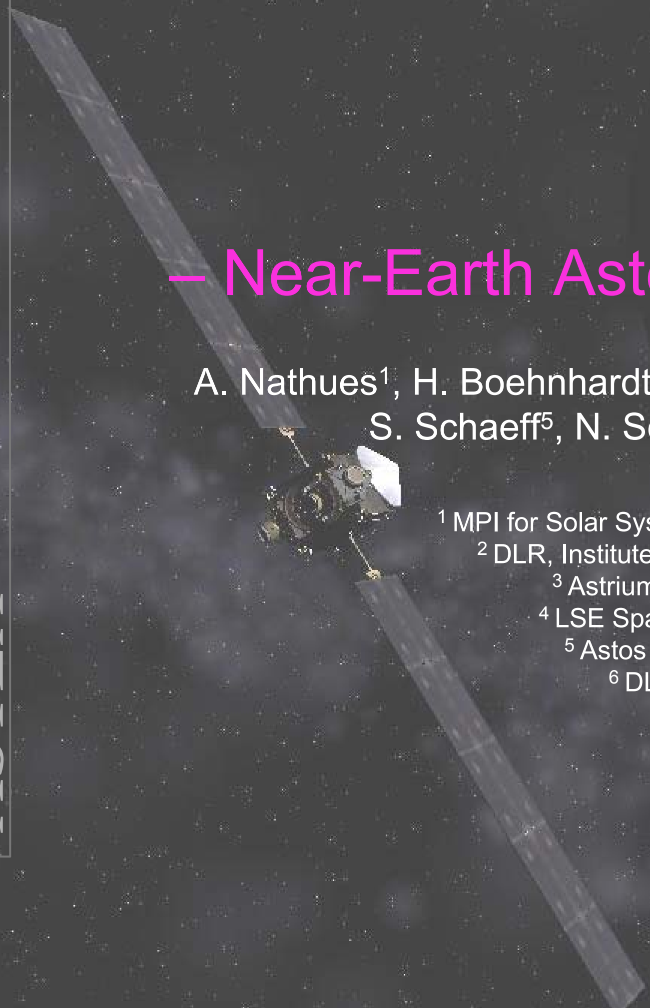

ASTEX

– Near-Earth Asteroid Mission Concept Study –

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Primary Objectives of the ASTEX Study

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Identification of the required technologies for an in-situ mission to two near-Earth asteroids.

- **Selection of realistic mission scenarios**
- **Definition of the strawman payload**
- **Analysis of the requirements and options for the spacecraft bus, the propulsion system, the lander system, and the launcher**
- **Definition of the requirements for the mission’s operational ground segment**

ASTEX Primary Mission Goals

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- The mission scenario foresees to visit two NEAs which have different mineralogical compositions: one “primitive‘‘ object and one fragment of a differentiated asteroid.

- The higher level goal is the provision of information and constraints on the formation and evolution history of our planetary system.

- The immediate mission goals are the determination of:

  – Inner structure of the targets
  – Physical parameters (size, shape, mass, density, rotation period and spin vector orientation)
  – Geology, mineralogy, and chemistry
  – Physical surface properties (thermal conductivity, roughness, strength)
  – Origin and collisional history of asteroids
  – Link between NEAs and meteorites

Target Selection (I)

Updating the NASA Database	
• Go to: http://neo.jpl.nasa.gov/cgi-bin/neo_elem	
• Select from the pull-down menu: "unlimited rows per page"; activate the "show full table" flag; "Display table" BUTTON	Asteroids 5000
• Select all NEA rows (no header row) from "433 Eros" to the end	
• Copy (CTRL+C; takes approx. 30 seconds)	
• **IMPORTANT NOTE: The Firefox macro does not work with Excel 2000!**	
• Launch Macro "Update_NASA" or press the button to the right (takes approx. 25 seconds)	Check OK
• Control in sheet "Merged NEA Data" that cell "K1" and "D2" contain the same number of asteroids:	

Updating the EARN Database	
• Go to: http://earn.dlr.de/nea/	
• Select "Table on Physical Properties of NEOs"	Asteroids 689
• Select all NEA rows (no header row) from "433 Eros" to the end and copy (CTRL+C)	
• Launch Macro "Update_EARN" or press the button to the right (takes approx. 15 seconds)	
• Click on "OK" when requested to overwrite the data	Check OK
• Control in sheet "E.A.R.N." that all the names are similar to NASA database (column S and T6:W15):	

Updating the User Database	
• Go to "User Database" sheet	
• Insert the data according to the existing scheme	Entries 134
• Launch Macro "Update_User" or press the button to the right (takes approx. 1 minutes)	
• Control in sheet "User Database" that all the names are similar to NASA database (column H)	
• In case of failures (name not found) insert manually the correct names	Check OK
• Re-launch macro "Update_User" or press the button to the right (takes approx. 1 minutes)	

Merged Database

• All three databases "NASA", "EARN" and "User" are merged in sheet "Merged NEA Data"

Number of Asteroids with Known Taxonomy

NASA 0 + EARN 386 + User 134 ⇒ Merged 431

ASTEX NEO pre-selection tool

(contains information from NEO NASA, EARN DLR, and a user database)

- Computation of mission minimum Δv requirement
- Computation of minimum mission fuel consumption
- Computtation of minimum mission duration
- etc.

Merged list of asteroids => 5000 asteroids

NASA — 5000 Asteroids, *Updated on 01.12.2007*

Object Name & Number	Epoch (TDB)	a (AU)	e	i (deg)	w (deg)	Node (deg)	M (deg)	q (AU)	Q (AU)	P (yr)	H (mag)	MOID (AU)	ref	class
433 Eros	54200	1.458	0.2	10.83	179	304	104	1.1334	1.78	1.76	11.2	0.15	235	AMO
719 Albert	54200	2.629	0.6	11.55	156	184	113	1.1777	4.08	4.26	15.8	0.19	27	AMO
887 Alinda	54200	2.484	0.6	9.333	350	111	162	1.0815	3.89	3.92	13.8	0.1	60	AMO
1036 Ganymed	54200	2.665	0.5	26.67	132	216	356	1.2429	4.09	4.35	9.45	0.34	180	AMO
1221 Amor	54200	1.92	0.4	11.88	26.5	171	59.8	1.0855	2.75	2.66	17.7	0.11	27	AMO
1566 Icarus	54200	1.078	0.8	22.85	31.3	88.1	285	0.1866	1.97	1.12	16.9	0.03	55	APO*
1580 Betulia	54200	2.197	0.5	52.1	160	62.3	182	1.1253	3.27	3.26	14.5	0.13	78	AMO
1620 Geographos	54200	1.245	0.3	13.34	277	337	71.5	0.8276	1.66	1.39	15.6	0.03	143	APO*
1627 Ivar	54200	1.863	0.4	8.448	168	133	196	1.1237	2.6	2.54	13.2	0.11	237	AMO
1685 Toro	54200	1.367	0.4	9.381	127	274	211	0.7712	1.96	1.6	14.2	0.05	122	APO
1862 Apollo	54200	1.471	0.6	6.355	286	35.8	315	0.6473	2.29	1.78	16.3	0.03	139	APO*
1863 Antinous	54200	2.26	0.6	18.4	268	347	116	0.8885	3.63	3.4	15.5	0.18	29	APO
1864 Daedalus	54200	1.461	0.6	22.19	326	6.71	62	0.5633	2.36	1.77	14.9	0.27	120	APO
1865 Cerberus	54200	1.08	0.5	16.09	325	213	108	0.5757	1.58	1.12	16.8	0.16	41	APO
1866 Sisyphus	54200	1.894	0.5	41.19	293	63.6	88.6	0.8739	2.91	2.61	13	0.1	167	APO
1915 Quetzalcoatl	54200	2.541	0.6	20.42	348	163	169	1.0881	3.99	4.05	19	0.1	5	AMO
1916 Boreas	54200	2.273	0.4	12.88	336	341	239	1.252	3.29	3.43	14.9	0.25	46	AMO
1917 Cuyo	54200	2.15	0.5	23.95	194	188	194	1.0653	3.23	3.15	13.9	0.07	67	AMO
1943 Anteros	54200	1.43	0.3	8.705	338	246	303	1.0642	1.8	1.71	15.8	0.06	114	AMO
1980 Tezcatlipoca	54200	1.71	0.4	26.86	115	247	93.1	1.0858	2.33	2.24	13.9	0.25	101	AMO
1981 Midas	54200	1.776	0.7	39.84	268	357	114	0.6214	2.93	2.37	15.5	0	62	APO*
2059 Baboquivari	54200	2.646	0.5	11.03	191	201	27.3	1.2455	4.05	4.3	15.8	0.25	47	AMO
2061 Anza	54200	2.264	0.5	3.773	156	208	233	1.0472	3.48	3.41	16.6	0.05	12	AMO
2062 Aten	54200	0.967	0.2	18.93	148	109	182	0.7901	1.14	0.95	16.8	0.11	9	ATE
2063 Bacchus	54200	1.078	0.3	9.434	55.2	33.2	7.26	0.7013	1.45	1.12	17.1	0.07	48	APO
2100 Ra-Shalom	54200	0.832	0.4	15.76	356	171	58.5	0.4689	1.2	0.76	16.1	0.15	109	ATE
2101 Adonis	54200	1.875	0.8	1.334	43.1	350	293	0.443	3.31	2.57	18.7	0.01	17	APO*
2102 Tantalus	54200	1.29	0.3	64.01	61.6	94.4	93.1	0.9045	1.68	1.47	16.2	0.04	25	APO*
2135 Aristaeus	54200	1.6	0.5	23.05	291	191	325	0.795	2.4	2.02	17.9	0.01	7	APO*
2201 Oljato	54200	2.172	0.7	2.517	96.3	76.6	168	0.6232	3.72	3.2	15.3	0	32	APO*
2202 Pele	54200	2.291	0.5	8.738	218	170	336	1.1196	3.46	3.47	17.6	0.15	7	AMO
2212 Hephaistos	54200	2.166	0.8	11.75	209	28.3	1.8	0.3591	3.97	3.19	13.9	0.12	175	APO
2329 Orthos	54200	2.405	0.7	24.41	146	169	77.3	0.8242	3.99	3.73	14.9	0.1	60	APO
2340 Hathor	54200	0.844	0.4	5.854	39.9	212	198	0.4642	1.22	0.78	19.2	0.01	36	ATE*
2368 Beltrovata	54200	2.104	0.4	5.237	42.6	288	254	1.2333	2.98	3.05	15.2	0.23	67	AMO
2608 Seneca	54200	2.503	0.6	15	35.6	168	134	1.0594	3.95	3.96	17.5	0.11	7	AMO
3102 Krok	54200	2.152	0.4	8.416	154	172	43	1.1878	3.12	3.16	15.6	0.19	67	AMO
3103 Eger	54200	1.405	0.4	20.93	254	130	114	0.9069	1.9	1.66	15.4	0.08	160	APO
3122 Florence	54200	1.768	0.4	22.16	27.7	336	199	1.0207	2.52	2.35	14.2	0.04	147	AMO*
3199 Nefertiti	54200	1.574	0.3	32.97	53.4	340	126	1.1273	2.02	1.98	14.8	0.22	132	AMO
3200 Phaethon	54200	1.271	0.9	22.18	322	265	168	0.1398	2.4	1.43	14.5	0.02	187	APO*
3271 Ul	54200	2.102	0.4	25.03	159	159	34.5	1.2708	2.93	3.05	16.7	0.28	12	AMO
3288 Seleucus	54200	2.033	0.5	5.932	349	219	225	1.1037	2.96	2.9	15.3	0.1	71	AMO
3352 McAuliffe	54200	1.879	0.4	4.772	15.8	107	59	1.1863	2.57	2.58	15.8	0.2	72	AMO
3360 Syrinx	54200	2.467	0.7	21.42	62	244	222	0.6324	4.3	3.88	16.3	0.11	10	APO
3361 Orpheus	54200	1.21	0.3	2.685	302	190	325	0.8191	1.6	1.33	19	0.01	30	APO*
3362 Khufu	54200	0.989	0.5	9.919	55	153	71.3	0.5258	1.45	0.98	18.3	0.01	16	ATE*
3551 Verenia	54200	2.094	0.5	9.503	193	174	280	1.0746	3.11	3.03	16.8	0.08	20	AMO

Asteroids with Known Taxonomy => 431

E.A.R.N. — 689 Asteroids, *Updated on 06.12.2007* | Calculation at Aphelion

Object Name & Number	H (mag)	Albedo	Diameter (km)	Taxonomy	Period (hrs)	Amplitude (mag)	Binary	ΔV_1 (km/s)	$V_{s/c}$ (km/s)	V_{aphel} (km/s)	ΔV_2 (km/s)	ΔV_{HT} (km/s)	ΔV_{incl} (km/s)	$\Delta V_{total,1}$ (km/s)	$m_{fuel,ch}$ (%)	$m_{fuel,el}$ (%)
	6	*7*	*8*	*9*	*10*	*11*	*2*									
433 Eros	10.31	0.21	23.6	S	5.27	0.04-1.4		3.92	18.94	19.71	0.77	4.69	3.57	7.58	84.96	37.73
719 Albert	15.80M	m	2.4	S	5.801	0.74-0.9		7.97	9.25	9.87	0.62	8.58	1.86	9.93	91.64	46.23
887 Alinda	13.83	0.23	4.2	S	73.97	0.35		7.79	9.66	9.95	0.29	8.08	1.57	9.38	90.43	44.37
1036 Ganymed	9.5	0.17	38.5	S	10.31	0.12-0.4		7.97	9.23	10.05	0.81	8.79	4.26	12.31	95.39	53.67
1221 Amor								6.29	13.12	13.53	0.41	6.70	2.71	9.03	89.55	43.14
1566 Icarus	15.95	0.33	1.3	SU;Q	2.273	0.05-0.2		4.52	17.42	8.81	-8.61	13.13	3.49	13.81	96.83	57.81
1580 Betulia	14.53	0.077	4.57	C	6.1324	0.21-0.6		7.08	11.27	11.78	0.51	7.59	9.90	16.99	98.57	65.43
1620 Geographos	16.5	0.19	5x2x1.5	S	5.2233	1.10-2.0		3.49	20.05	18.88	-1.16	4.66	4.39	8.03	86.57	39.46
1627 Ivar	13.24	0.15	9.12	S	4.795	0.25-1.1		6.01	13.77	14.37	0.59	6.61	2.03	8.13	86.89	39.83
1685 Toro	13.96	0.31	3	S	10.196	0.60-1.4		4.49	17.49	16.01	-1.48	5.97	2.62	7.50	84.66	37.42
1862 Apollo	16.23	0.26	1.4	Q	3.065	0.15-0.6	B	5.36	15.35	13.10	-2.25	7.61	1.45	8.03	86.58	39.47
1863 Antinous	15.81	0.18	1.8	S,Sq	7.4568	0.14-0.2		7.51	10.28	9.81	-0.47	7.98	3.14	10.68	93.08	48.71
1864 Daedalus	15.02	mh	3.1	SQ;Sr	8.572	0.88-1.0		5.52	14.96	12.03	-2.93	8.45	4.63	11.00	93.61	49.71
1865 Cerberus	16.97	0.26	1	S	6.81	1.48-2.1		3.18	20.87	17.37	-3.50	6.68	4.86	9.17	89.90	43.62
1866 Sisyphus	11.7 R	0.15	8.48	S	2.4	0.11		6.55	12.49	11.89	-0.60	7.16	8.36	14.94	97.61	60.69
1915 Quetzalcoatl	18.97	0.31	0.4	SMU	4.9	0.26		7.88	9.44	9.78	0.33	8.22	3.35	11.25	93.99	50.48
1916 Boreas	15.03	mh	3.1	S	3.4746	0.35		7.10	11.21	12.21	0.99	8.10	2.51	9.81	91.39	45.83
1917 Cuyo	14.7	mh	5.2	Sl	2.69	0.11-0.4		7.02	11.40	11.69	0.30	7.32	4.73	11.76	94.72	52.06
1943 Anteros	16.01	0.18	1.8	L	2.8695	0.05-0.1		3.99	18.77	19.12	0.35	4.34	2.85	6.86	82.00	34.86
1980 Tezcatlipoca	13.96	0.14	6.7	SU;Sl	7.2523	0.47-0.9		5.45	15.12	15.58	0.45	5.90	7.03	12.49	95.60	54.19
1981 Midas	15.18	h	2.2	S;V	5.22	0.65-0.8		6.59	12.42	10.30	-2.11	8.70	7.02	13.92	96.92	58.10
2059 Baboquivari								7.94	9.32	10.14	0.83	8.77	1.79	9.91	91.61	46.17
2061 Anza	16.60M	m	1.7	TCG*	5.75,11.50	0.08-0.2		7.34	10.67	10.87	0.20	7.54	0.70	8.07	86.70	39.61
2062 Aten	17.12	0.2	0.9	S,Sr	40.77	0.26		0.96	26.97	25.28	-1.70	2.66	8.31	9.44	90.57	44.58
2063 Bacchus	16.83R	mh	1.2	Q;Sq	14.904	0.22-0.4		2.62	22.35	20.02	-2.33	4.95	3.29	6.65	81.05	34.03
2100 Ra-Shalom	16.12	0.082	2.78	S,Sr;C	19.7998	0.35-0.4		1.32	25.93	20.31	-5.62	6.94	5.57	9.23	90.06	43.85
2101 Adonis	18.70M							7.13	11.15	7.93	-3.22	10.35	0.18	10.36	92.49	47.65
2102 Tantalus	16.20M	m	3.3	Q	2.391	0.08		3.57	19.85	19.20	-0.66	4.22	20.35	23.93	99.75	77.58
2135 Aristaeus								5.61	14.75	13.59	-1.16	6.76	5.43	11.16	93.86	50.21
2201 Oljato	16.86	0.24	2.1	E;Sq	26	0.1		7.61	10.05	8.27	-1.78	9.39	0.36	9.43	90.53	44.53
2202 Pele								7.32	10.72	11.21	0.48	7.80	1.63	9.02	89.52	43.10
2212 Hephaistos	13.5	mh	3.3	SG;C	>20.	0.08-0.1		7.86	9.48	6.12	-3.37	11.23	1.25	11.46	94.30	51.13
2329 Orthos								7.88	9.44	8.71	-0.73	8.62	3.68	11.64	94.55	51.68
2340 Hathor	20.2	mh	0.3	CSU;Sq				1.44	25.60	20.08	-5.52	6.96	2.05	7.33	83.99	36.75
2368 Beltrovata	15.20M	0.13	2.3		5.9	0.84		6.66	12.23	13.19	0.95	7.62	1.12	8.13	86.91	39.85
2608 Seneca	17.50M	0.16	0.9	S	8	0.5		7.84	9.53	9.73	0.21	8.05	2.49	10.34	92.46	47.60
3102 Krok	16.2 R	m	1.6	QRS,S	151.8	1.3-1.6		6.87	11.75	12.51	0.76	7.63	1.72	8.76	88.80	42.14
3103 Eger	15.38	0.53	2.5	E;Xe	5.7059	0.72-0.9		4.31	17.95	17.39	-0.56	4.87	6.32	10.65	93.03	48.61
3122 Florence	14.2	0.2	2.5	E;S	2.3581	0.18		5.86	14.15	14.23	0.09	5.94	5.44	11.29	94.06	50.63
3199 Nefertiti	15.1	0.41	1.8	S;Sq	3.0202	0.11-0.3		4.67	17.06	17.75	0.69	5.36	9.68	14.37	97.25	59.27
3200 Phaethon	14.51	0.11	5.1	F,B	3.604	0.11-0.3		5.61	14.75	6.44	-8.31	13.91	2.48	14.27	97.18	59.02
3271 Ul								6.59	12.42	13.55	1.13	7.72	5.38	12.09	95.13	53.02
3288 Seleucus	15.34	0.27	3.4x1.4x1.4	K	75	1		6.63	12.31	12.77	0.46	7.10	1.27	7.99	86.43	39.31
3352 McAuliffe	15.54R	0.18	2.4	A	6	0.2		5.96	13.91	14.78	0.87	6.82	1.16	7.40	84.29	37.04
3360 Syrinx	16.30M	0.07	1.8					8.16	8.82	7.29	-1.54	9.70	2.71	11.27	94.03	50.57
3361 Orpheus	19.03	m	0.5	S ; V	3.58	0.32		3.26	20.66	19.38	-1.28	4.53	0.91	4.82	70.07	26.03
3362 Khufu								2.62	22.35	18.09	-4.27	6.89	3.13	7.91	86.16	39.00
3551 Verenia	16.80M	0.53	0.87	V*	4.93	0.11-0.1		6.86	11.78	12.12	0.33	7.19	1.95	8.84	89.02	42.44

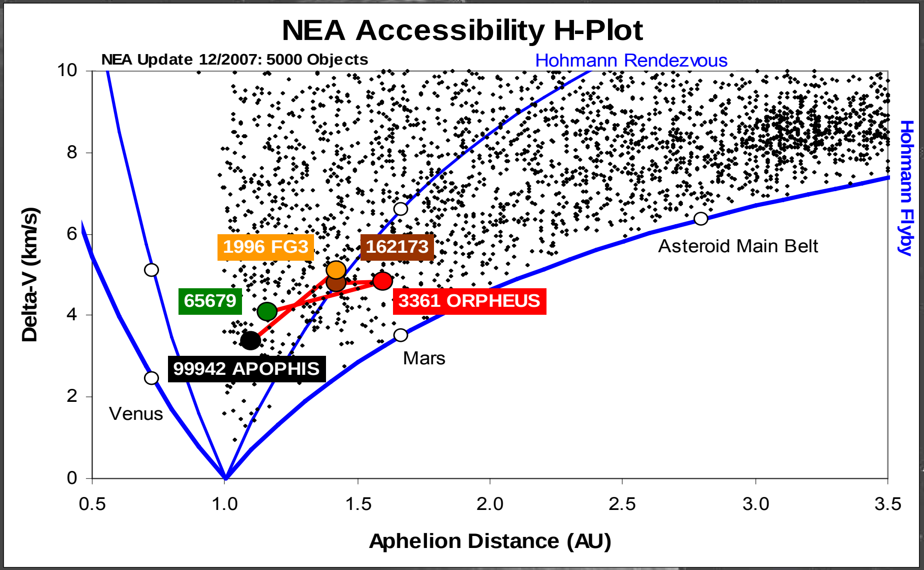
ASTEX

Target Selection (II)

1. Pre-selection
   - H < 22.5 *mag*
   - Δv < 7 km/s for 1st target
2. Hohmann transfer computations
   - Combinations with Δv > 11km/s rejected
3. Patched conics computations
   - Time interval of missions: 2015 to 2040
   - Max. mission duration: 15 years
4. Identification of interesting NEA pairs
   - Primitive asteroid of type: C, D, P, B, F
   - Evolved fragment of type: E, V, M, S, A, Q, R
5. Prioritizing
   - V and E types favored
   - Rotation period between 2h and 80h
   - Min. time of stay around NEA: 6 months
   - Max. total mission duration < 10 years
6. Low-thrust computations of complete transfers for 29 missions scenarios and selection.

➢ Output: 3 primary missions

ASTEX



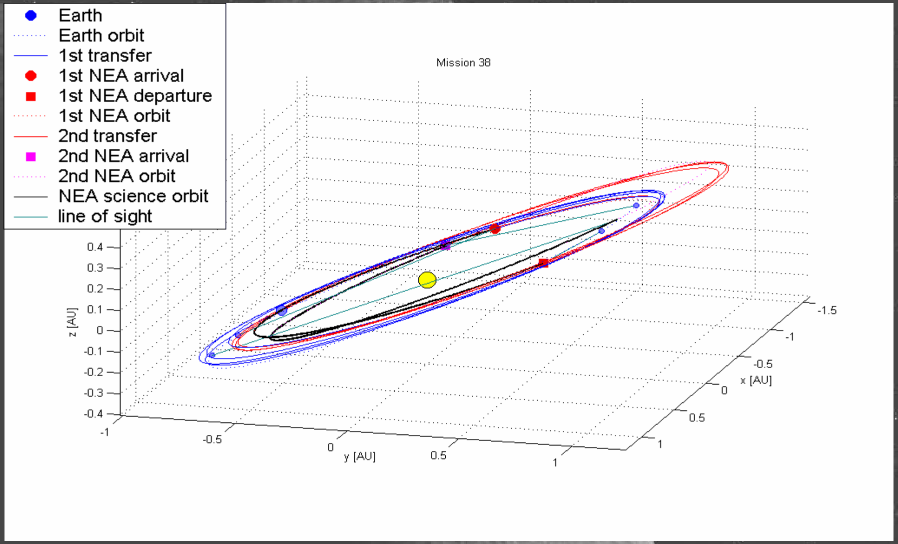
Mission Index	1st Target	Taxonomy of 1st	2nd Target	Taxonomy of 2nd
38	99942 Apophis	Sq	1996 FG3	C
150	162173 1999 JU3	Cg	3361 Orpheus	S, V
152	65679 1989 UQ	B	3361 Orpheus	S, V

Mission Analysis -Transfer-

- Propulsion system
  - Δv requirement of up to 11 km/s
  - Chemical propulsion system is insufficient
  - High Isp for low fuel consumption
  - → Ion engines required

Index	38
1st Target	99942 Apophis
2nd Target	1996 FG3
Taxonomy 1st	Sq
Taxonomy 2nd	C
Start Mission	20 May 2023
Arrival 1st	08 Jun 2027
Departure 1st	05 Dec 2027
Arrival 2nd	30 Dec 2031
End Mission	27 Jun 2032
1st Transfer Time	1480 d
Stay Time 1st	180 d
2nd Transfer Time	1486 d
Stay Time 2nd	180 d
Mission Duration	9.11 years
Delta-V to 1st	3.838 km/s
Delta-V to 2nd	5.276 km/s
Delta-V Mission	9.114 km/s
Fuel Mass	287.3 kg

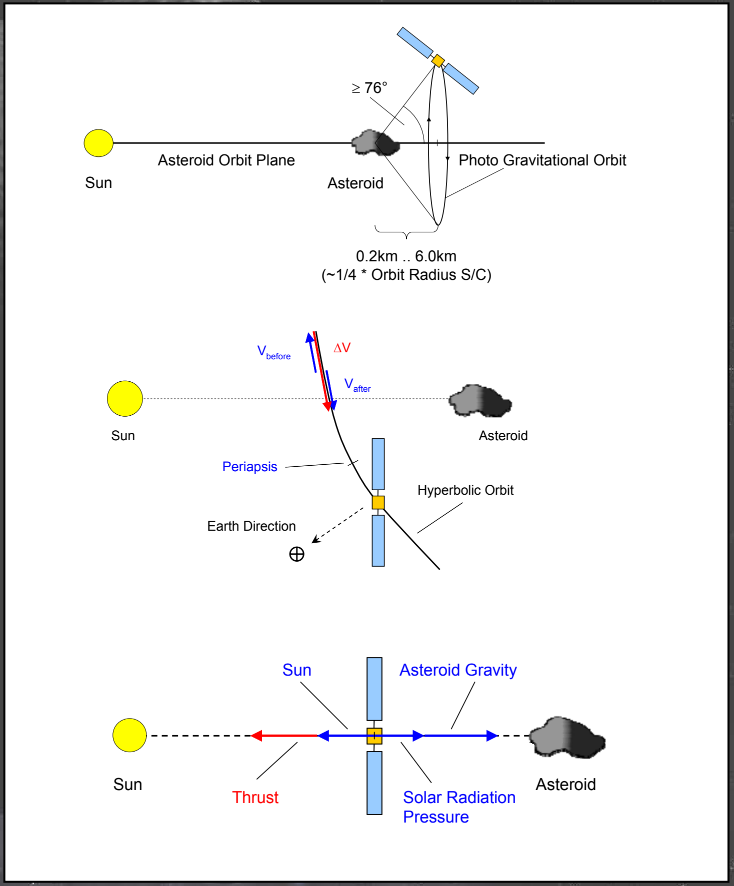
ASTEX baseline mission



ASTEX

Proximity Operations

- Orbiting
  - Uncontrolled stable orbiting (thrust free)
  - Controlled orbiting (periodic correction maneuvers required)
- Flyovers
  - High-altitude flyovers
  - Low-altitude flyovers
- Hovering
  - Inertial hovering
  - Body-fixed hovering
- Landing



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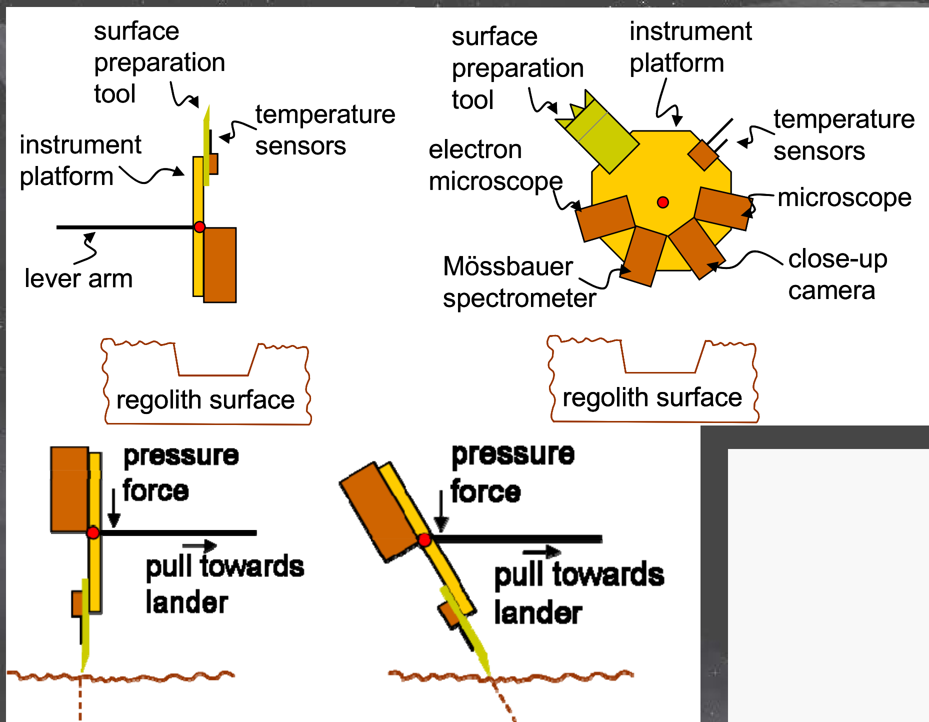
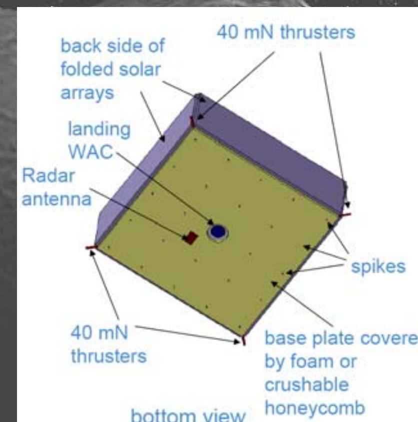
Conclusions:

- Hovering [imaging phase] and (stable) terminator orbit [radar phase]
- Autonomous active lander descent with visual navigation on sunlit asteroid side
- Further investigations especially for binary systems needed

ASTEX Lander



Payload platform with surface preparation tool



Lander rear side

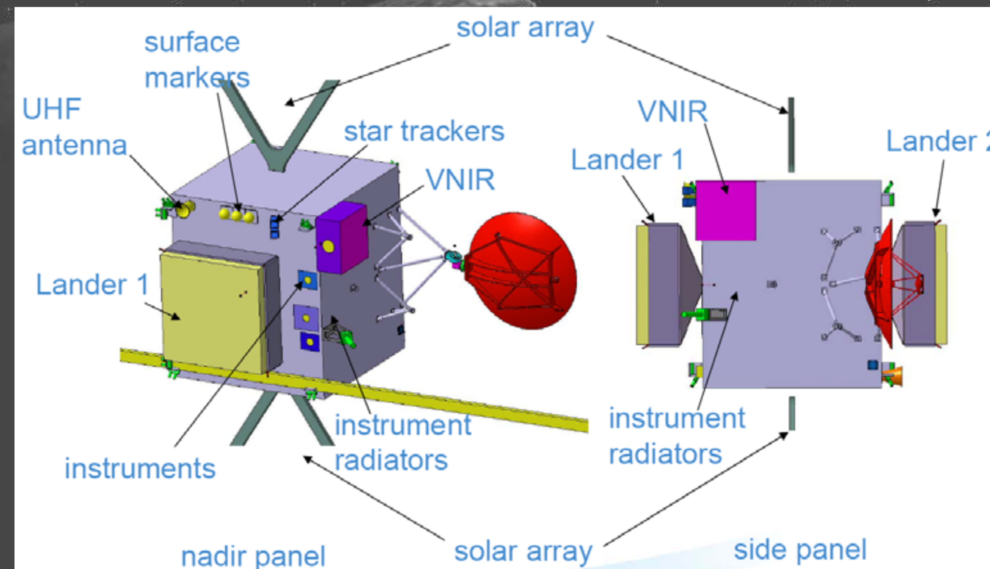
Surface analysis

ASTEX

ASTEX Spacecraft

ASTEX

- Carries two landers and the remote sensing payload
- SEP
- Power generation by 40 m² solar arrays
- Visual navigation during target approach
- Autonomous collision avoidance
- Mono-prop system for proximity operations
- Extended tracking mode at second target possible



Low cost launcher: Soyuz-Fregat ST offers sufficient performance for direct Earth escape of the ASTEX S/C (mass 1598 kg, incl. 20% margin).

ASTEX Strawman Payload

ASTEX

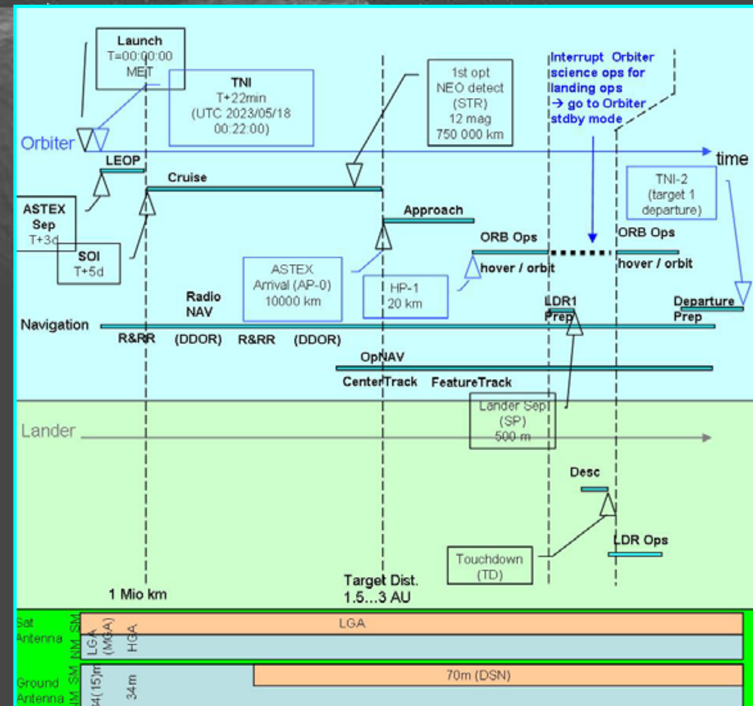
Orbiter Instruments	Mass [kg]	Size [mm³]	Power Consumption [W]
Radar Reflection Tomographer	12	Antennas: 15 m length each Electronics: 160 x 250 x 110	100 (peak)
Cameras	2 * 5.5	160 x 190 x 380	18 (average)
VNIR Spectrometer	15	500 x 500 x [illegible]	20 (average)
Laser Ranger	5	140 x 120 x 120	9 (peak)

Lander Instruments	Mass [kg]	Size [mm³]	Power Consumption [W]	Comment
Panoramic Camera (two camera heads)	2 x 0.5	2 x (90x60x80)	2 x 2.5 (peak)	On robotic arm or elevated rotatable platform
Microscope	0.3	125x60x50	5 (peak)	On robotic arm
Close-Up Camera	0.5	90x60x80	6 (peak)	On robotic arm
Electron Microscope	0.5	50x50x80	3 (peak)	On robotic arm
Temperature Sensor (16 sensors)	16 x 0.02	10x10x3	16 x 0.01	On robotic arm and distributed over lander on representative positions
Mössbauer-Spectrometer	0.8	90x50x40	5 (peak)	On robotic arm
Common DPU/ PSU	4.0	120x120x60	12	On lander base

Mission Flight Phases

ASTEX

ORBITER	Phase	Description	Distance from Target [km]	LANDER	Phase	Description
Launch and Cruise	LEOP					
	Commissioning					
	IC	nterplanetary cruise starts at SOI distance				
Approach	AP-0	initial approach point	10000			
	AP-1	approach step 1	2000			
	AP-2	approach step 2	100			
	AP-3	approach step 3	50			
Hovering and / or Orbiting	HP-1	hover position 1	20			
	HP-2	hover position 2	10			
	HP-3	hover position 3	1.5			
	OP-1	orbit insertion 1 (optional)	1			
	OP-2	orbit insertion 2 (optional)	0.5			
Lander Separation	SP	Lander separation betw. HP-2 and OP-2 (interrupt Orbiter Ops)	0.5 .. 10	Lander Ops	SP	Lander separation position
Target Science Ops	HP-X	...further hover positions			LP	Touchdown at landing point
	OP-X	...further orbit phases			LO-1	Start lander ops 1
	FO-X	...further fly-overs			LO-2	Start lander ops 2



ASTEX timeline for the baseline mission in graphical form

Conclusions

ASTEX

- The ASTEX mission to two NEAs of different composition would represent a giant step forward in the exploration of the Solar System.
- The ASTEX study demonstrates the overall technical feasibility of the mission and highlights some technological challenges that require further study and development.
- The favoured system concept being one orbiter to perform the remote-sensing campaigns and carry two identical lander units.