National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Maneuver Analysis and Targeting Strategy for the Stardust Re-Entry Capsule

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LOCKHEED MARTIN

Agenda

- Mission Overview
- Spacecraft Overview
- Maneuver Strategy
- Approach Events
- Conclusion

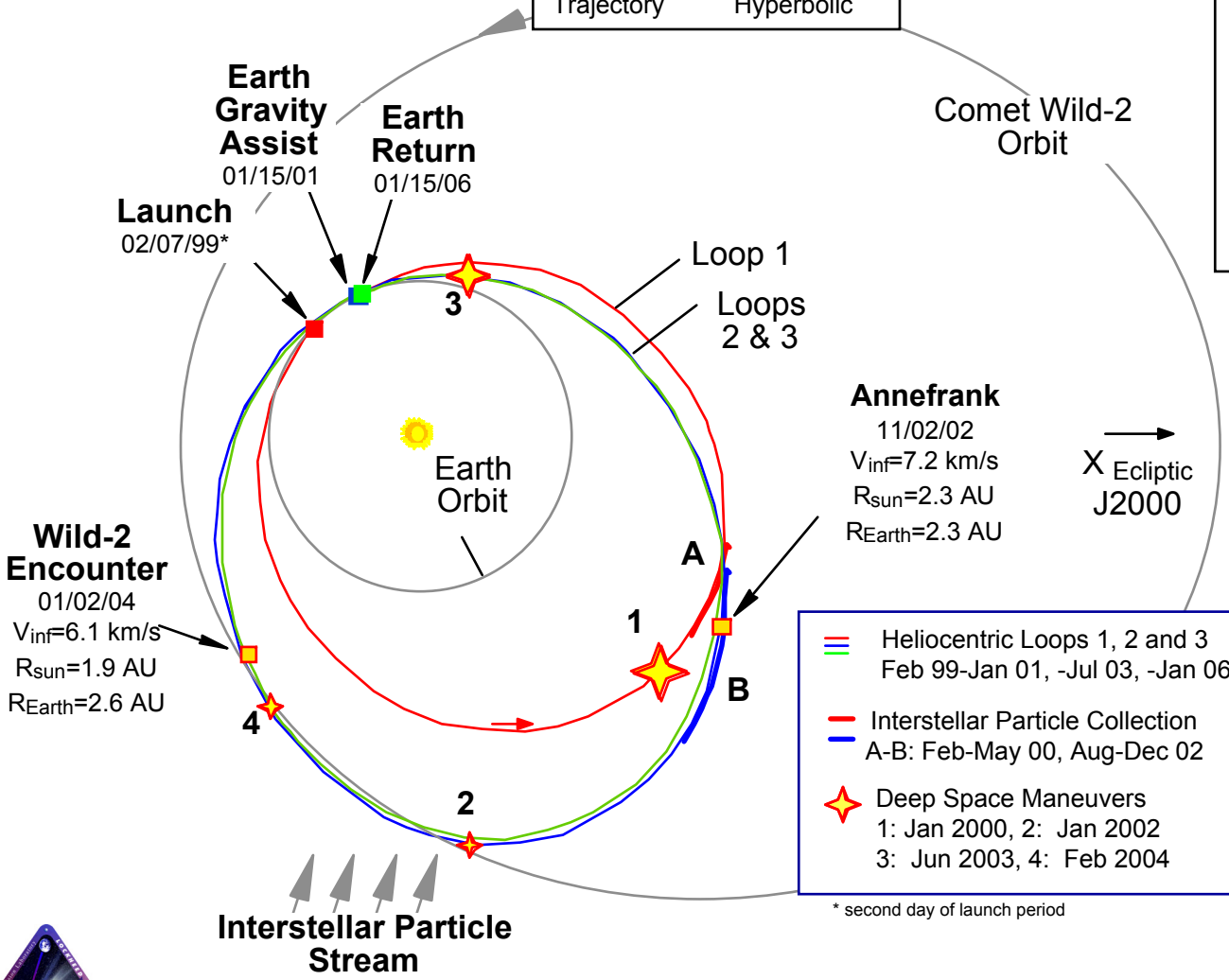
Mission Overview

Mission Detail

Samples	Comet, IDP
Solar Range	1.0 - 2.7 AU
Trajectory	Hyperbolic

Safe Mode Entry Summary

Date	Cause	Fix
Mar '99	All Stellar FSW	Patch
Mar '99	FSW Priority	Patch
Jul '99	PACI Reset	Patch
Jul '99	PACI Reset	Patch
Oct '00	Star Camera	I/O Patch
Nov '00	Solar Flare	Monitoring
Mar '01	FP inaccuracy	Flight Rule
Aug '01	Star Camera	I/O Patch
Oct '03	Solar Flare	Monitoring
Jul '05	Bit Errors/Flare	Monitoring



Heliocentric Loops 1, 2 and 3
Feb 99-Jan 01, -Jul 03, -Jan 06

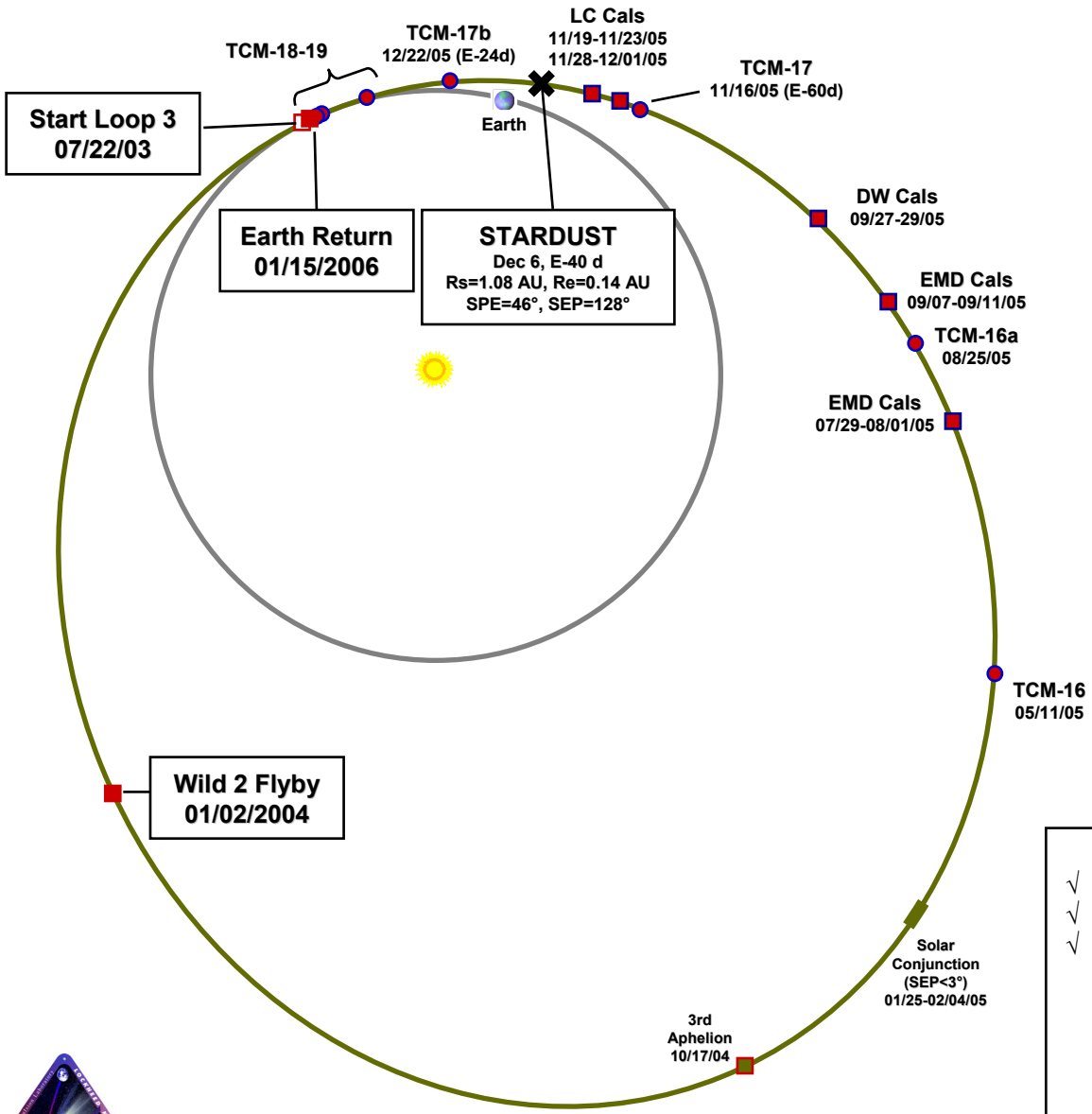
Interstellar Particle Collection
A-B: Feb-May 00, Aug-Dec 02

Deep Space Maneuvers
1: Jan 2000, 2: Jan 2002
3: Jun 2003, 4: Feb 2004

* second day of launch period

STARDUST

Loop 3 Plan



Event	Date	to Earth
√ TCM-16	05/11/05	-249 d
√ EMD Cals	07/29/05	-170 d
√ TCM-16a	08/25/05	-143 d
√ EMD Cals	09/07/05	-130 d
√ DW Cals	09/27/05	-110 d
√ TCM-17	11/16/05	-060 d
√ LC Cals	11/19/05	-057 d
√ LC Cals	11/28/05	-048 d
TCM-17b	12/22/05	-024 d
TCM-18	01/05/06	-010 d
TCM-18a	01/09/06	-006 d
TCM-19	01/14/06	-029 h
TCM-19a/b	01/14/06	-012 h
SRC Release	01/15/06	-004 hrs
Entry	01/15/06	--

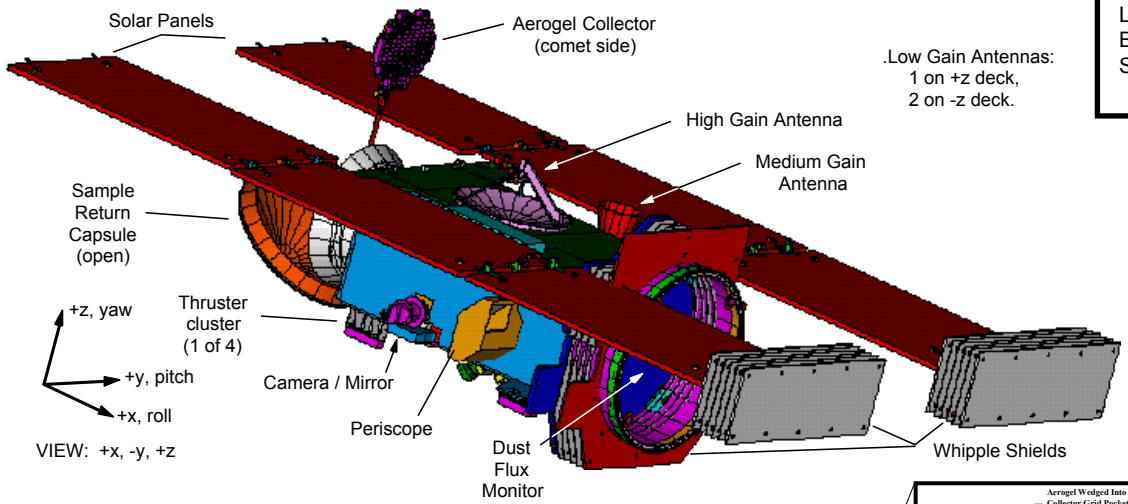
Return Detail	
Return C3	41.2 km^2/s^2
Return Target	UTTR
Approach SPE	90°
Entry Velocity (inertial)	12.8 km/s
Entry Flight Path Angle	-8.2°
Entry Inclination	41 deg
Entry Time (local)	2.57 am
Return Season	Winter

	Attitude	Dband/Antenna	Date	to Earth
√	Sun point	2-2-10°/HGA	--	--
√	HGA to E	2-2-10°/HGA	07/11/05	-188 d
√	MGA to E	2-2-10°/MGA	11/22/05	-054 d
	57° Off-S	2-2-10°/LGA	12/22/05	-024 d
	29° Off-S*	0.25°/LGA	12/27/05	-019 d
	29° Rolled*	0.25°/LGA	01/05/06	-010 d
	Release	0.25°/LGA	01/14/06	-029 h

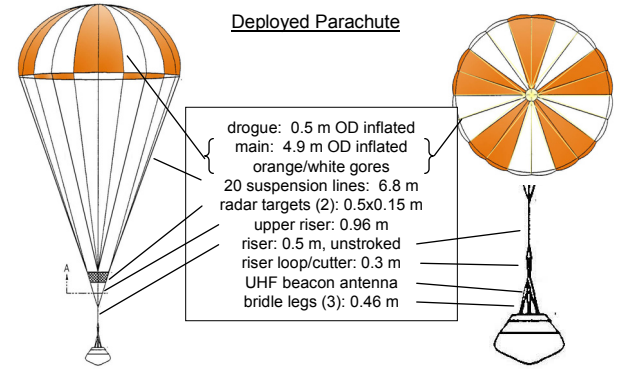
* Same off-sun angle as SRC Release @ E-29h

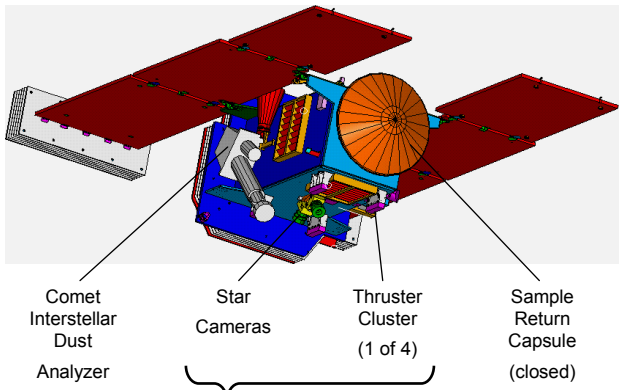
STARDUST

Spacecraft Overview

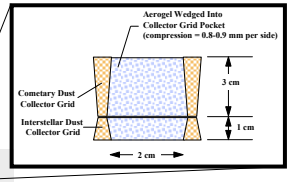


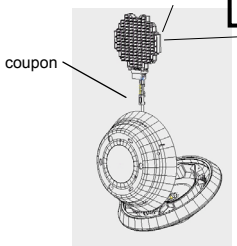
Launch Mass: 385 kg (848 lb), Fuel at launch: 85 kg (187 lb)
Bus: 254 kg (560 lb), 4.9 m long, 3.0 m wide (tip-to-tip solar arrays)
SRC: 46 kg (101 lb), 0.81 m max dia, 0.50 m top dia, 0.50 m tall
119° blunt nose, 60° b/shell, 0.28 m nose to seal

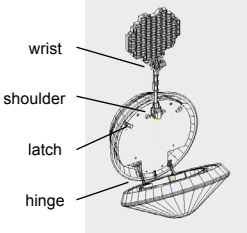


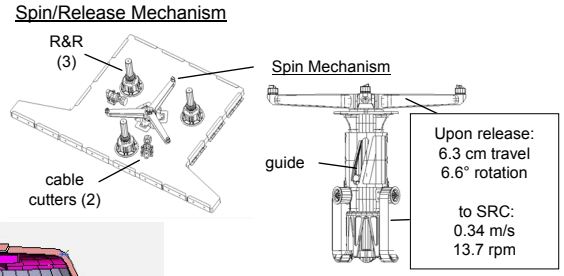


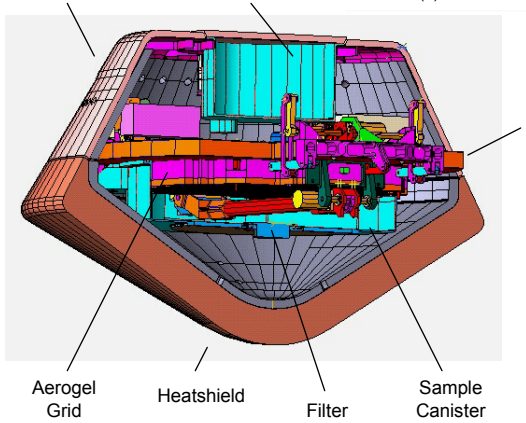
ACS/PROP package:
Blowdown Hydrazine, Titanium Tank
Three-axis stabilized, deadband control
IMU (accelerometer, gyro), Star Cameras, Sun Sensors

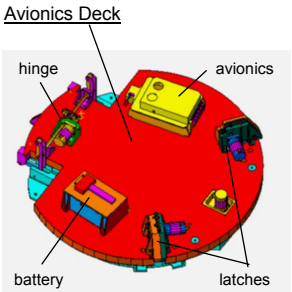












Spacecraft Detail

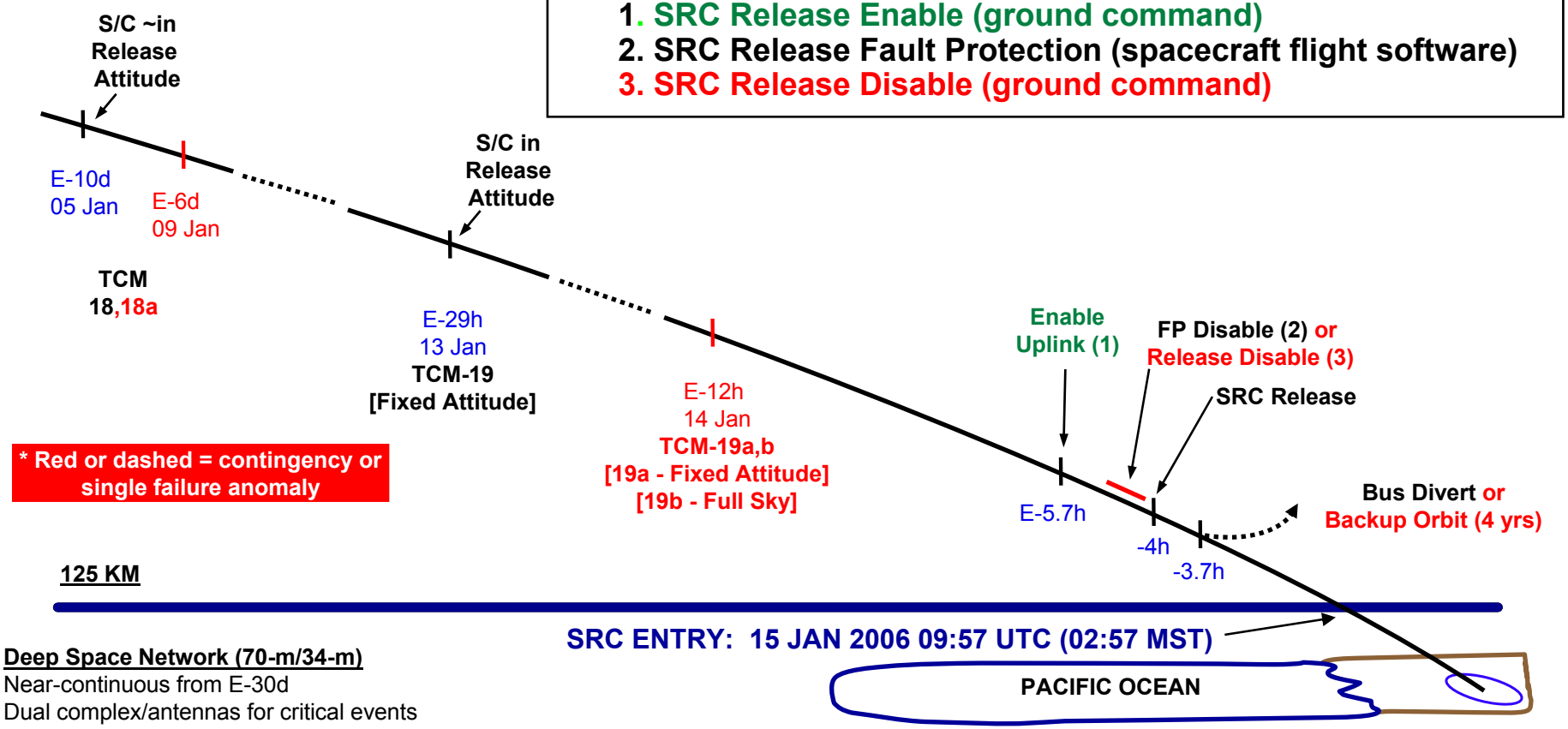
Subsystem	Detail
Attitude Control	3-axis, deadband, IMU, Sensors
Propulsion	Unbalanced, blowdown
Telecom	X-band HGA, MGA, LGA, max 33k bps
EPS	Solar + one battery
C&DH	20 MHz RAD 6000, EEPROM, CMIC, DRAM
Thermal	Heaters, Passive, Louvers
SRC to S/C Bus	46 kg : 339 kg
SRC Size	0.8m OD, 0.5m tall
Connection/Cabling	Bolts/Internal
Release	Spin Table/Springs
SRC Entry	Ballistic, Fixed EDL circuitry
Parachute Deploy	G-trigger, Mortar, Drogue, Round chute, Cutter

Highlights of Maneuver Strategy

- Stardust employed biased maneuvers to limit turns and minimize execution errors
- Biased maneuvers also addressed planetary protection and safety issues
- Stardust utilized a fixed-direction burn for the final maneuver to match the prevailing attitude so no turns were needed
- Performance of the final burn was calibrated in flight

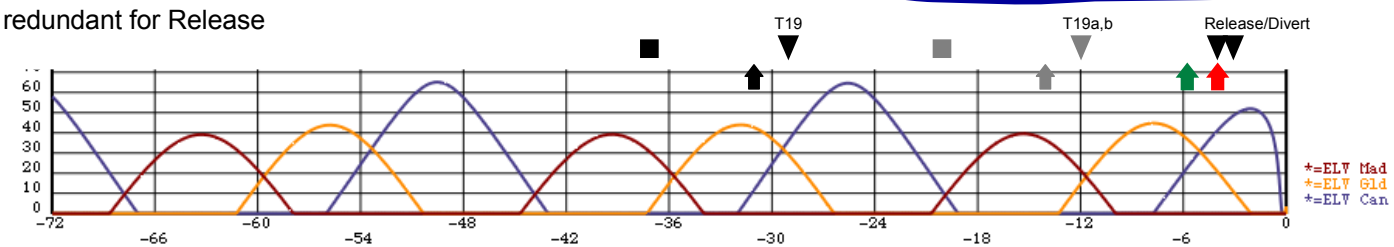
Terminal Approach Events

Earth Entry Decision Mechanisms:
1. SRC Release Enable (ground command)
2. SRC Release Fault Protection (spacecraft flight software)
3. SRC Release Disable (ground command)



*** Red or dashed = contingency or single failure anomaly**

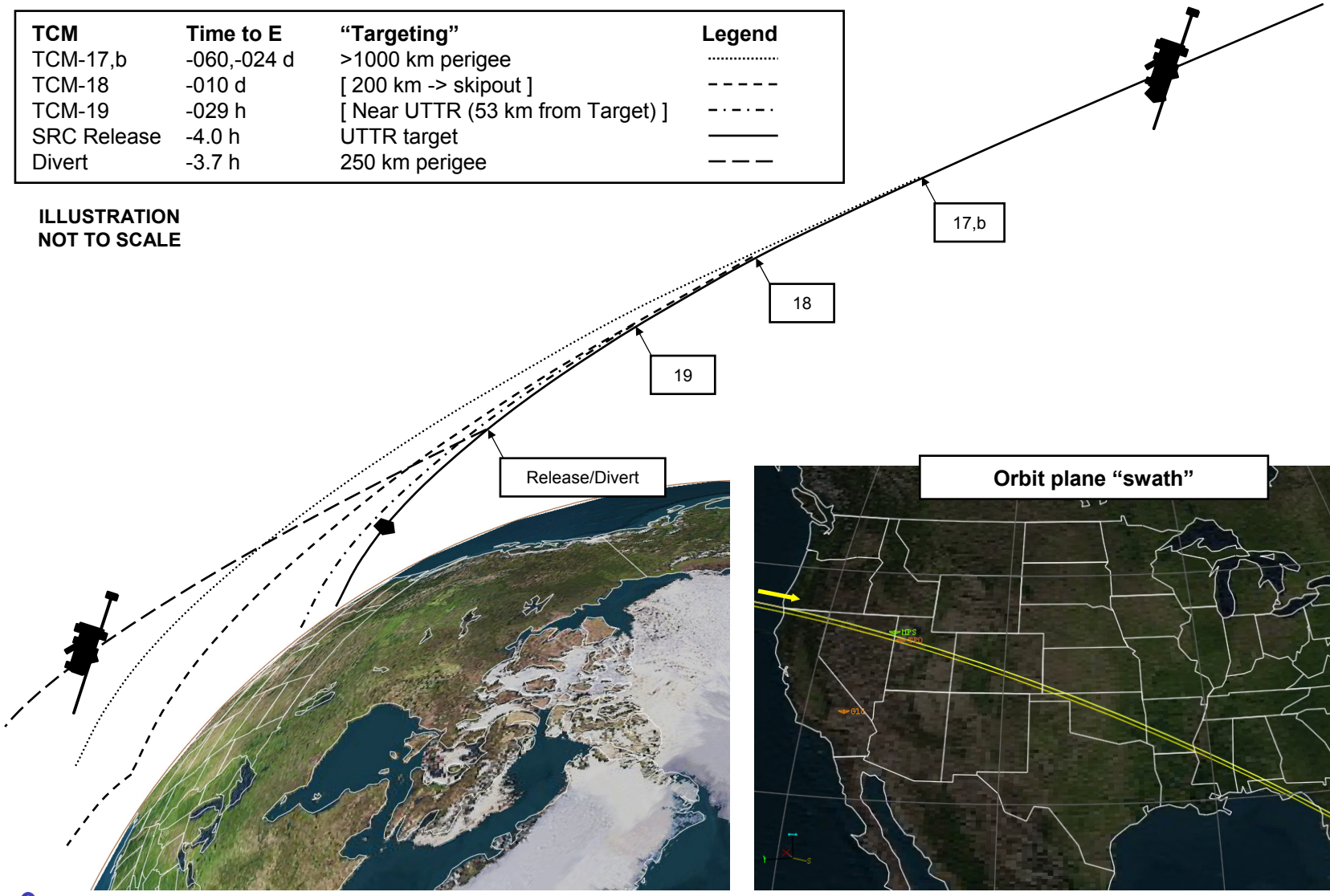
Deep Space Network (70-m/34-m)
Near-continuous from E-30d
Dual complex/antennas for critical events
Six antenna redundant for Release



Approach Navigation

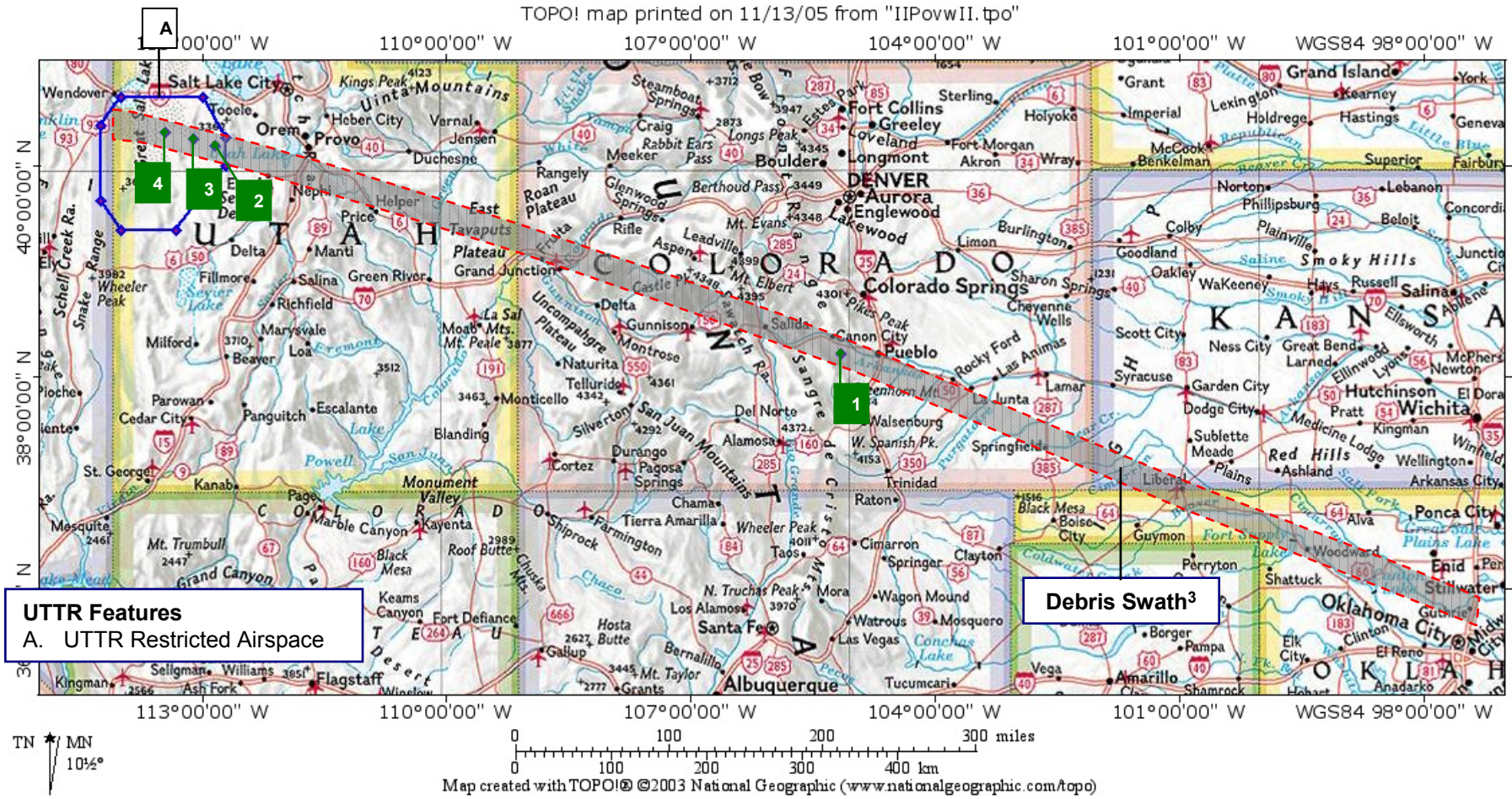
TCM	Time to E	"Targeting"	Legend
TCM-17,b	-060,-024 d	>1000 km perigee	.....
TCM-18	-010 d	[200 km -> skipout]	- - - - -
TCM-19	-029 h	[Near UTTR (53 km from Target)]	- · - · - ·
SRC Release	-4.0 h	UTTR target	———
Divert	-3.7 h	250 km perigee	— — —

ILLUSTRATION NOT TO SCALE



Orbit plane "swath"

Instantaneous Impact Track



Point	Time	Body[1]	Event Description[2]	to Target
1	E-29h	Debris	47% TCM-19	753 km
2	E-29h	SRC	100% TCM-19	53 km
3	E-4h	SRC	0% SRC Release	30 km
4	E-4h	SRC	100% SRC Release	0 km

Notes:
1. Points assume SRC "magically" separates and enters atmosphere nominally.
2. Last event before S/C suffers complete failure, i.e. ballistic propagation to entry.
3. East of Point 1, nominal SRC would skip out, but debris elements enter.
4. Divert results in similar debris swath during execution; 13% achieves skip-out condition, 45% (at nominal execution time) achieves 125 km altitude.

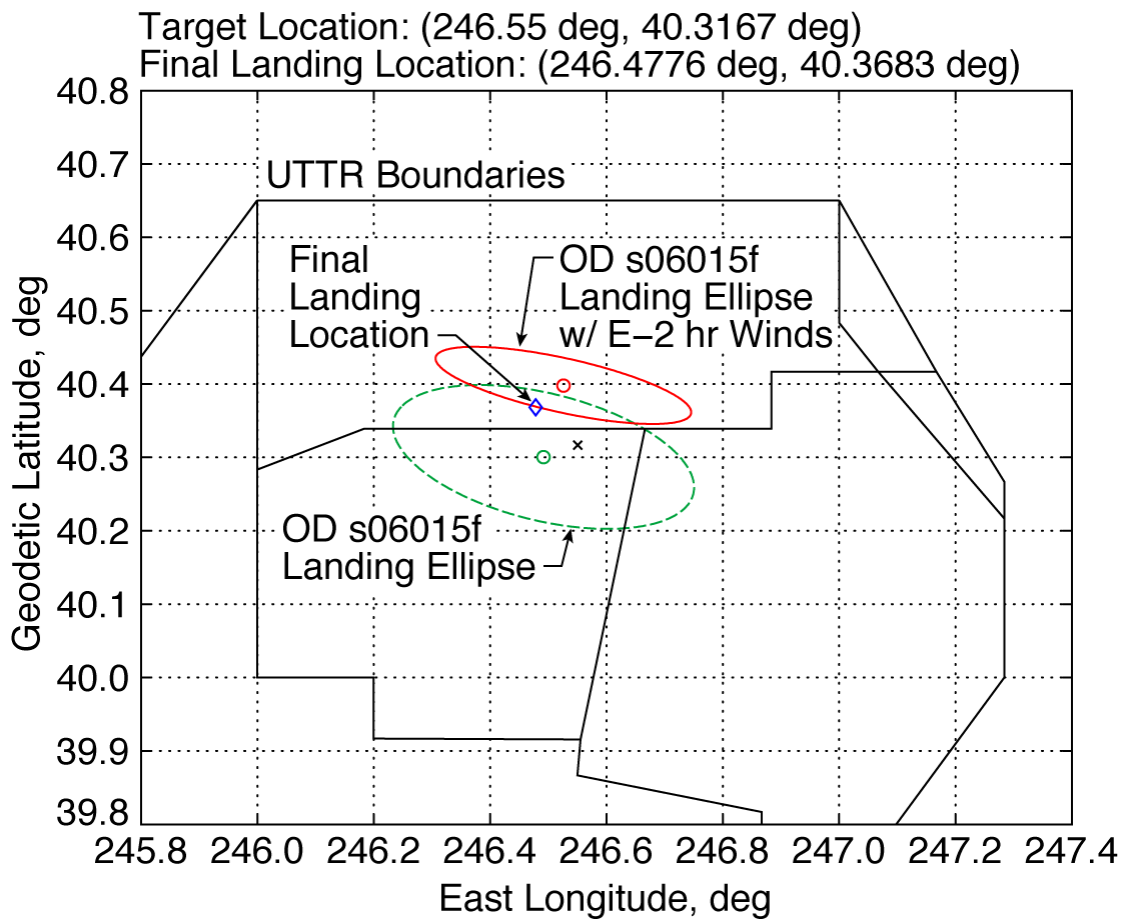
Conclusion

- Maneuvers executed as planned:

Event	Epoch (UTC)	Final Design ²v (m/s)
TCM-17	16-Nov-2005 21:00	4.17
TCM-18	05-Jan-2006 18:00	2.39
TCM-19	14-Jan-2006 04:54	1.30
Entry	15-Jan-2006 09:57	---

- Stardust SRC landed 8.1 km from target
- Stardust experience underscores the importance of balanced thrusters on sample return missions

Final Landing Location



Picture courtesy of P. Desai