Mars Sample Return Navigation: Rendezvous in Mars Orbit

by

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ABSTRACT

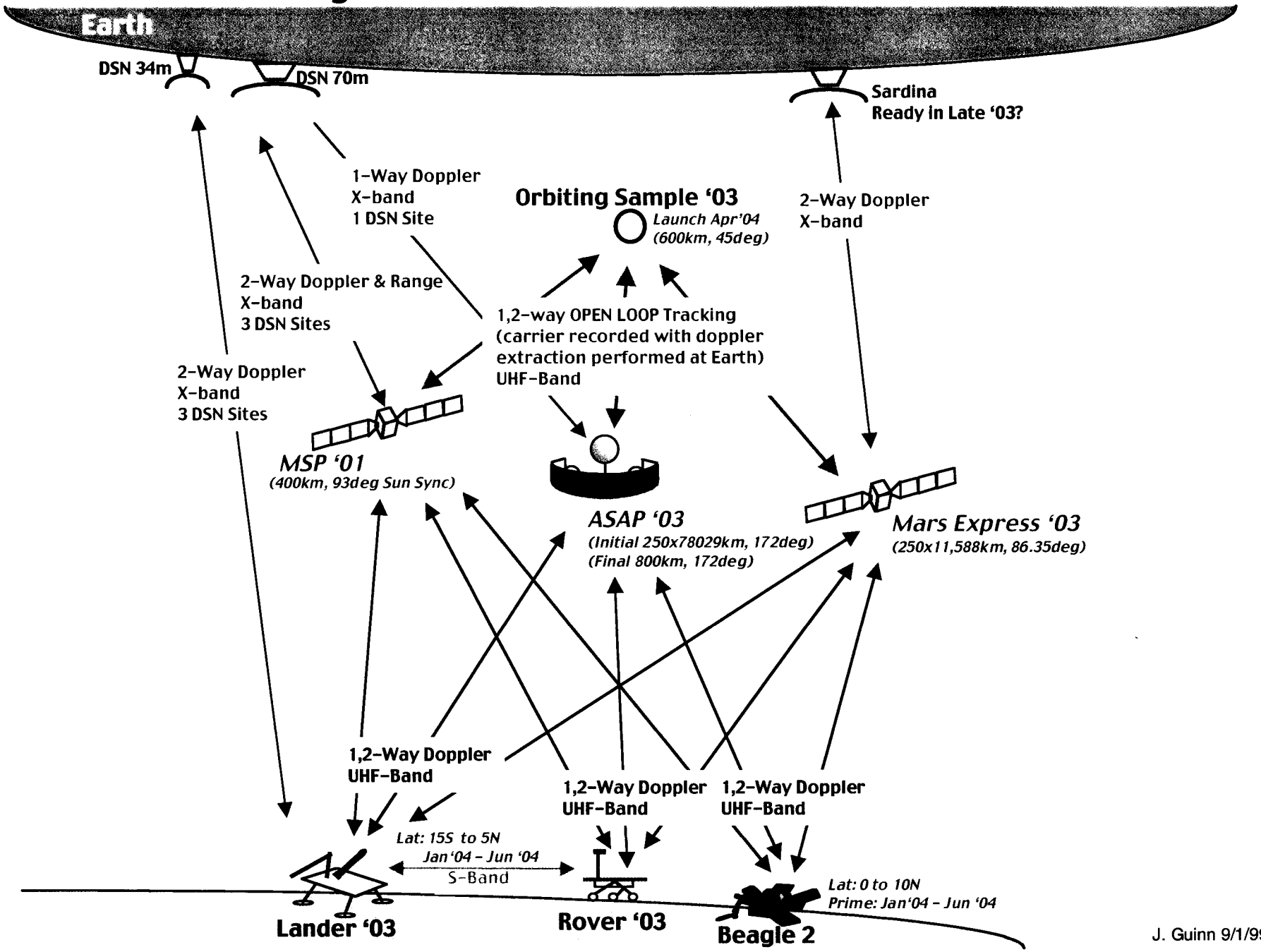
Mars Sample Return Navigation: Rendezvous in Mars Orbit

A mission to retrieve Martian rock and soil samples is under development by an international Mars Sample Return (MSR) design team managed by JPL. The first Martian samples are collected and launched into low Mars orbit in 2004. In 2007 another set of samples is placed in orbit near the first, followed by a rendezvous orbiter capture of each and subsequent Earth return in 2008. Rendezvous of both samples is accomplished using a combination of Radio Direction Finding (RDF) and laser radar sensors. Just after Mars orbit insertion in 2007, the first rendezvous begins with an orbit matching phase referred to as the intermediate rendezvous. A final terminal phase begins once the rendezvous orbiter and orbiting sample are within a range of five kilometers (currently the maximum operational range of the laser radar). A similar procedure is repeated to capture the second sample. Deep Space Network (DSN) doppler tracking of the rendezvous orbiter is combined with the *insitu* RDF observations of the samples to provide orbit determination solutions that support intermediate phase maneuver design. Terminal rendezvous is performed autonomously using both RDF and laser radar observations. Orbit determination performance during the intermediate rendezvous phase is analyzed accounting for:

1) observation collection strategies (DSN and sensor visibilities)
2) observation errors (RDF angle measurement accuracy verses range)
3) dynamic model errors (Mars gravity field and solar pressure)
4) maneuver execution errors
5) use of additional tracking assets (Mars '01, Mars Express, Mars Network Orbiter)

For MSR mission design, orbit error estimates are computed using the LEXUS consider/covariance analysis tool capable of non-optimal filter solutions mapped throughout the intermediate rendezvous to the beginning of the terminal phase. These estimates support refinement of trajectory and maneuver designs as well as development of preliminary operations concepts.

Mars Navigation Architecture (December 2003 – March 2006)



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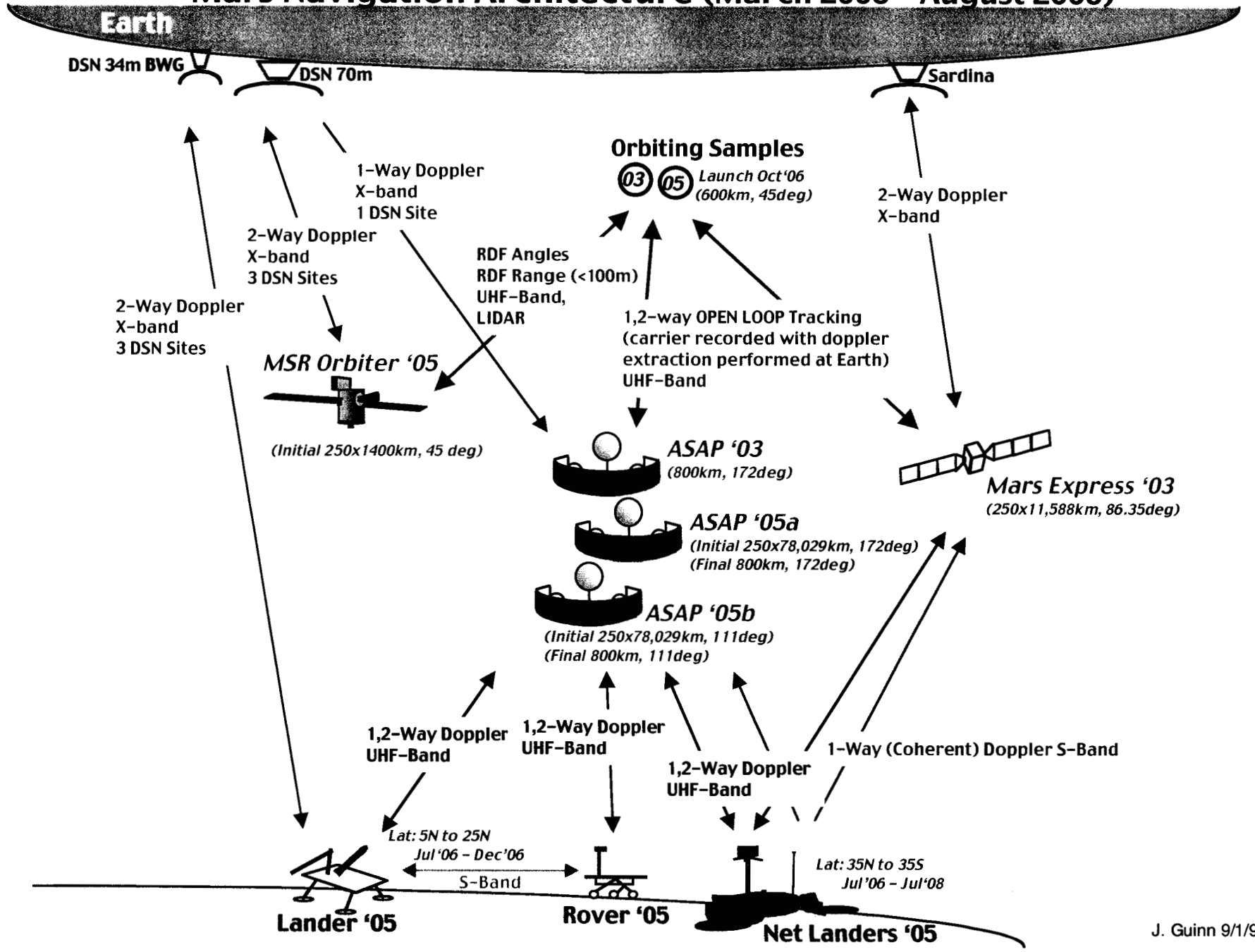
Mars Navigation Architecture (March 2006 – August 2008)



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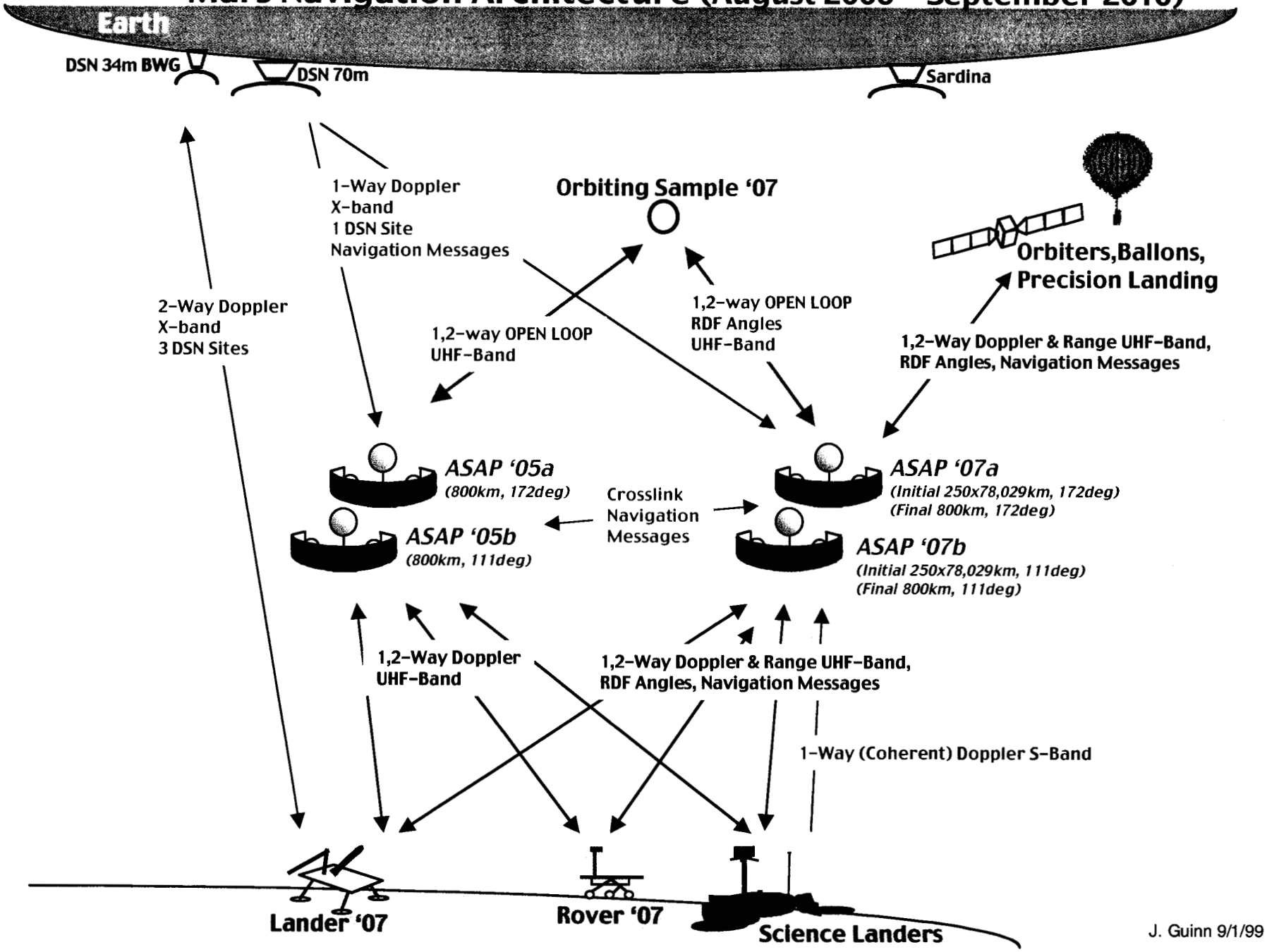
Mars Navigation Architecture (August 2008 – September 2010)



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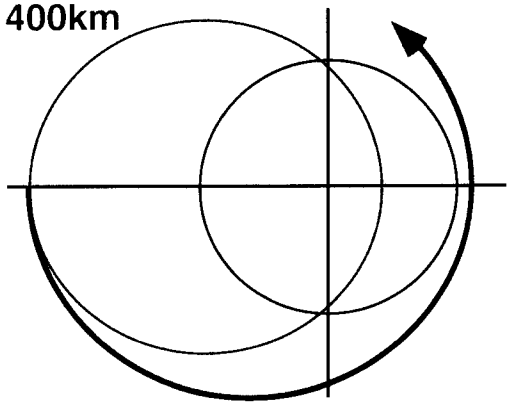
Mars Sample Return Intermediate Rendezvous

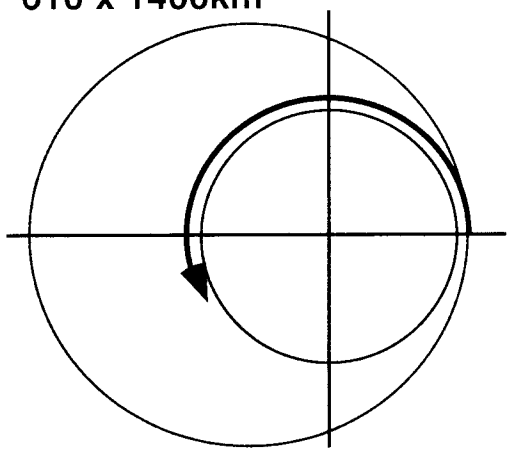
Rendezvous Orbiter
250 x 1400km

Orbiting Sample
600 x 600km



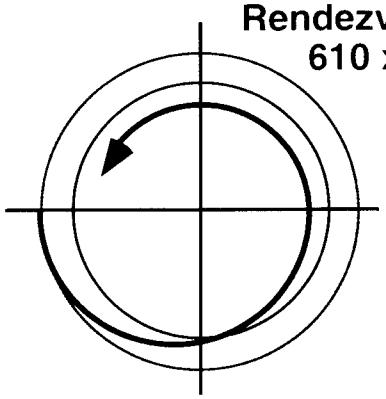
❶ Raise Periapsis

Rendezvous Orbiter
610 x 1400km



② Lower Apoapsis

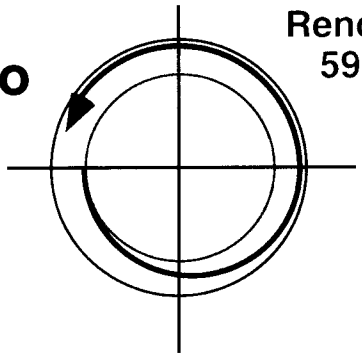
Rendezvous Orbiter
610 x 610km



③ & ④
Hohmann Transfer to 200m Below Sample

❺ & ⑥
Hohmann Transfer to 20m Below Sample

Rendezvous Orbiter
599.8 x 599.8km



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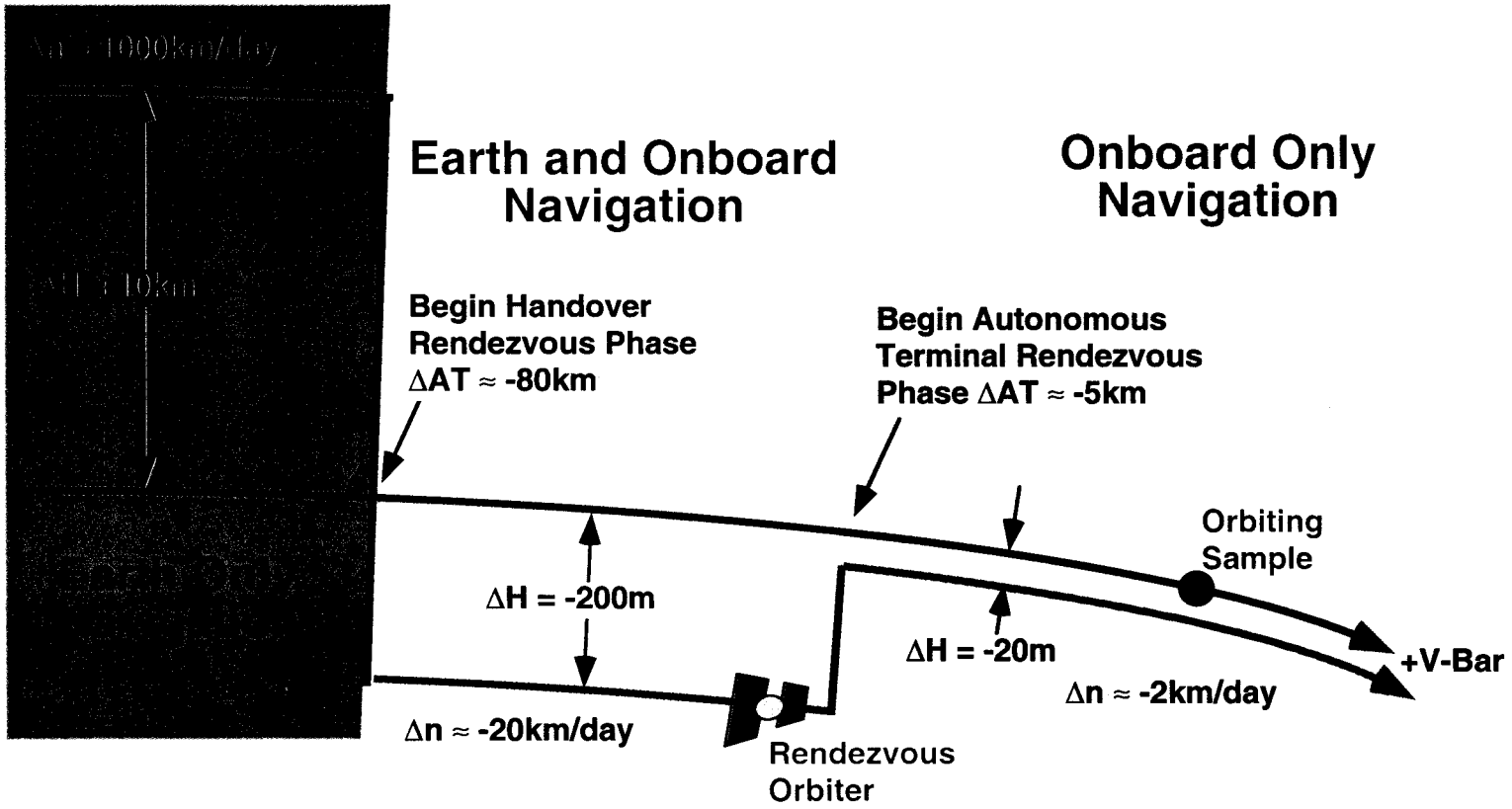
MSR Intermediate to Terminal Rendezvous Handover Strategy



NOTES:
During Handover Rendezvous, Orbit Determination is performed using RDF Angle Observations Only

During Autonomous Terminal Rendezvous, Orbit Determination is performed using RDF Angles and LIDAR Range Observations (may also get RDF Range Observations at less 100m)

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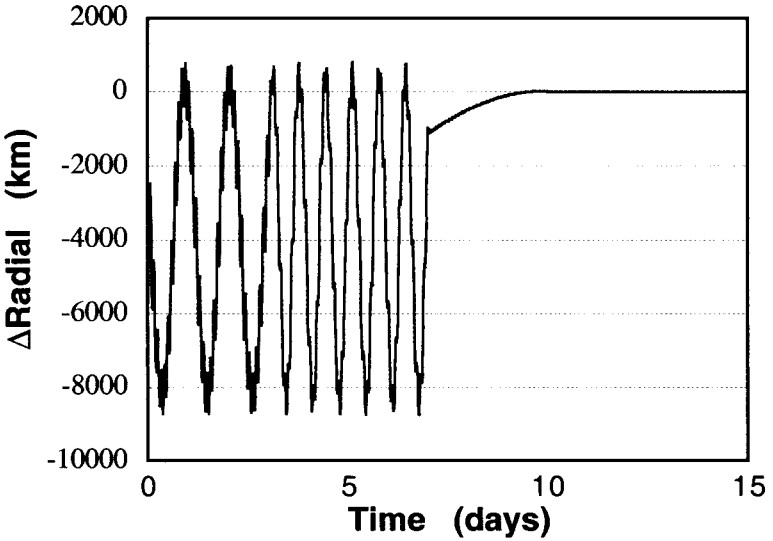
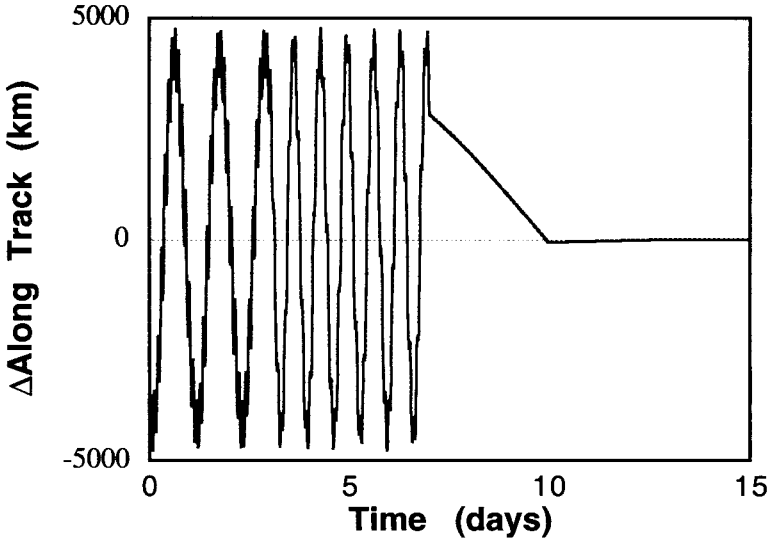
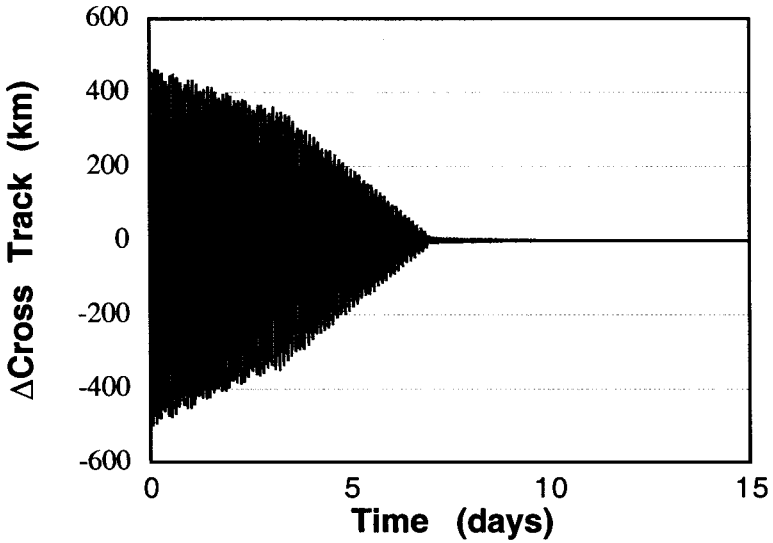
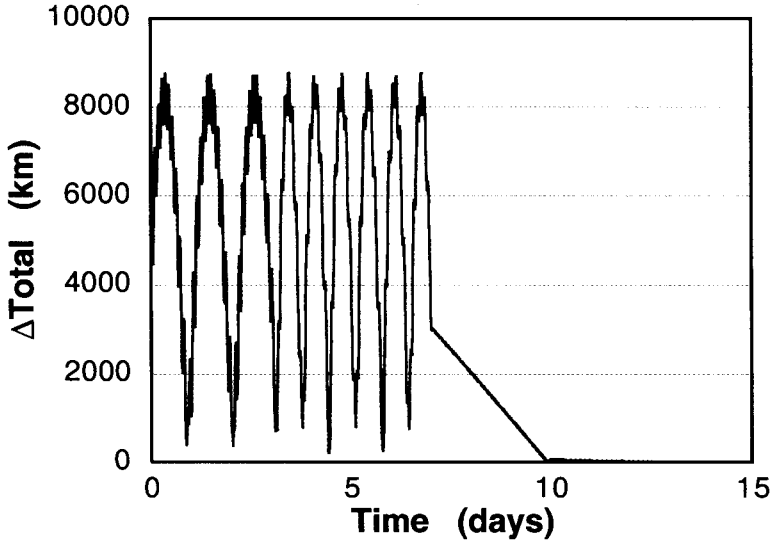
MSR Intermediate Rendezvous - RTN Differences









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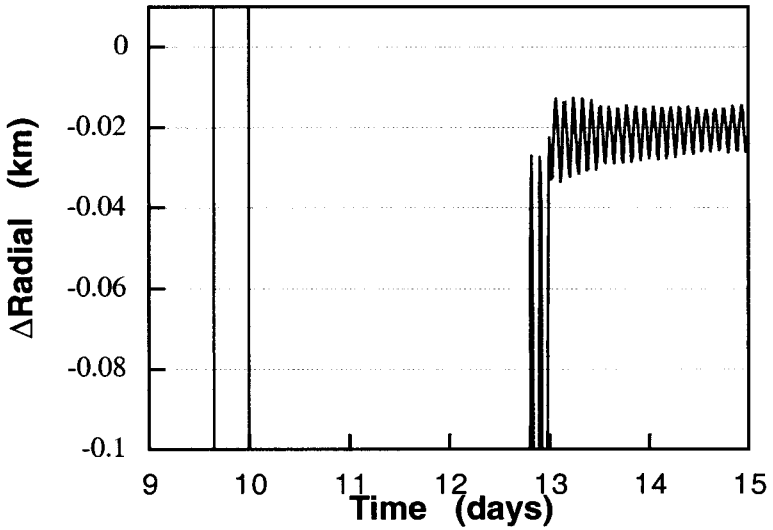
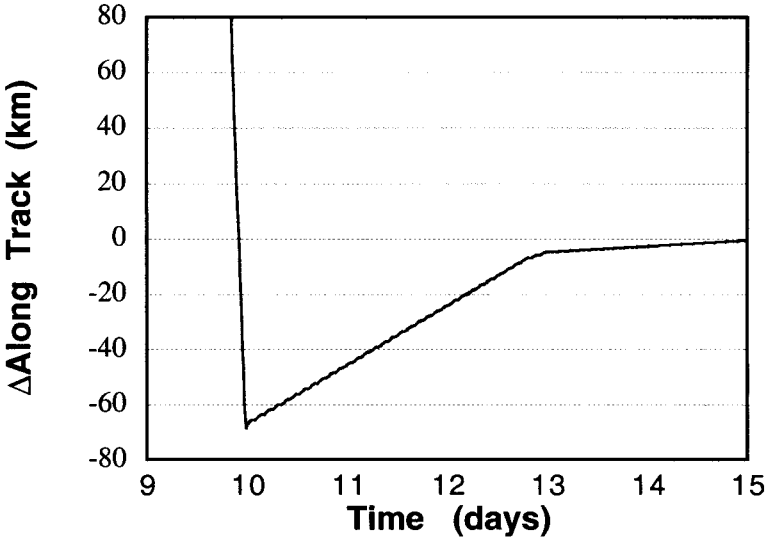
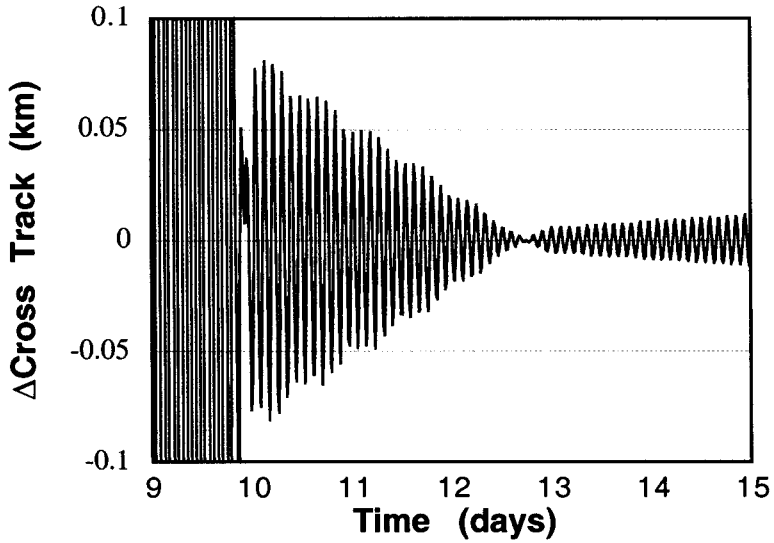
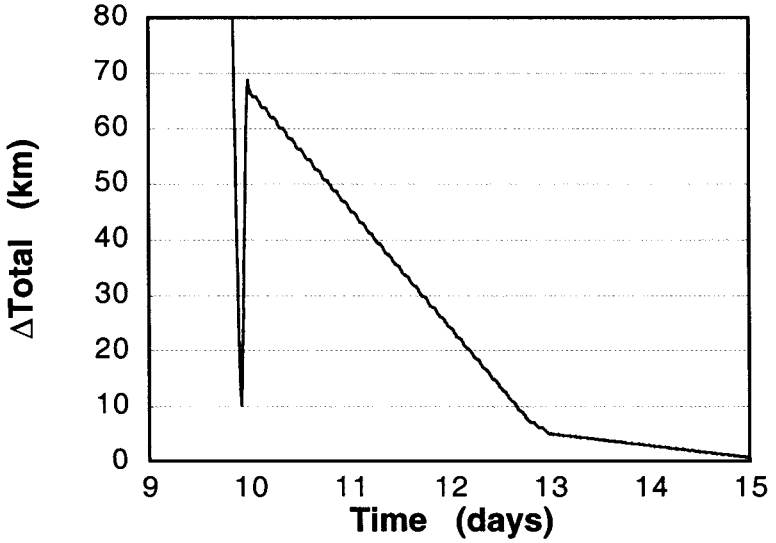
MSR Intermediate Rendezvous - RTN Differences (Detail)









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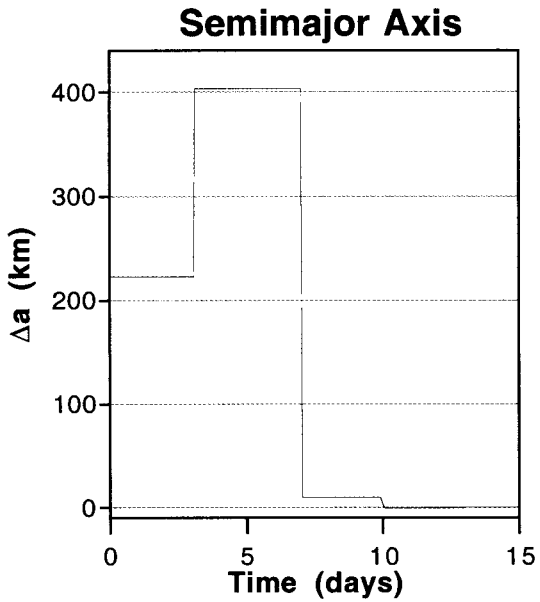
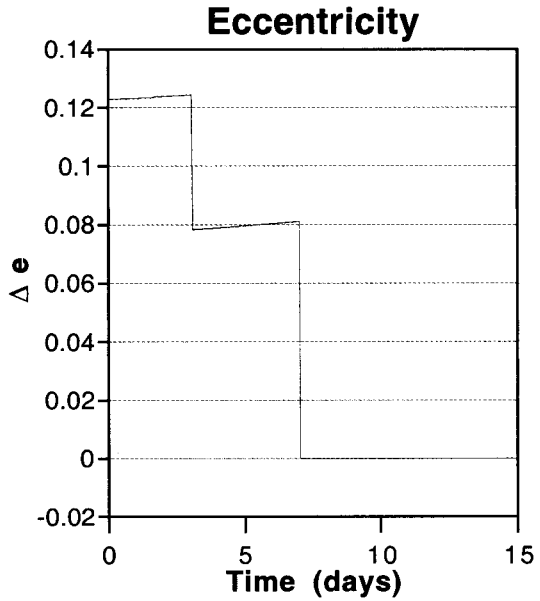
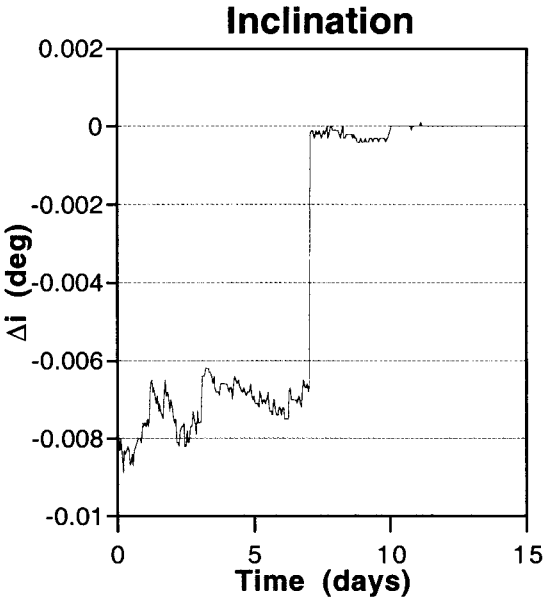
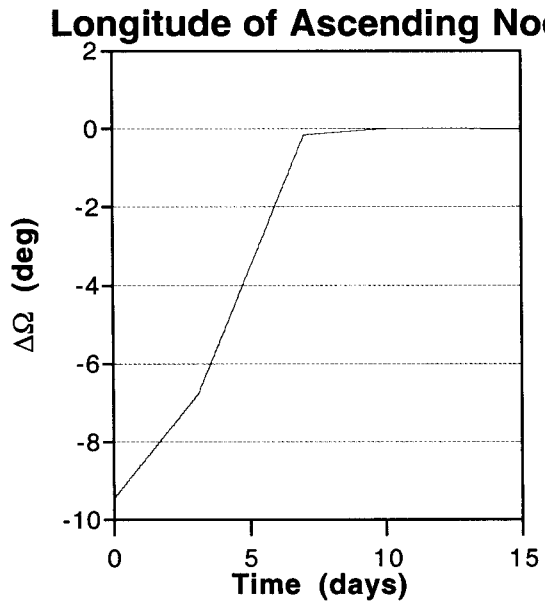
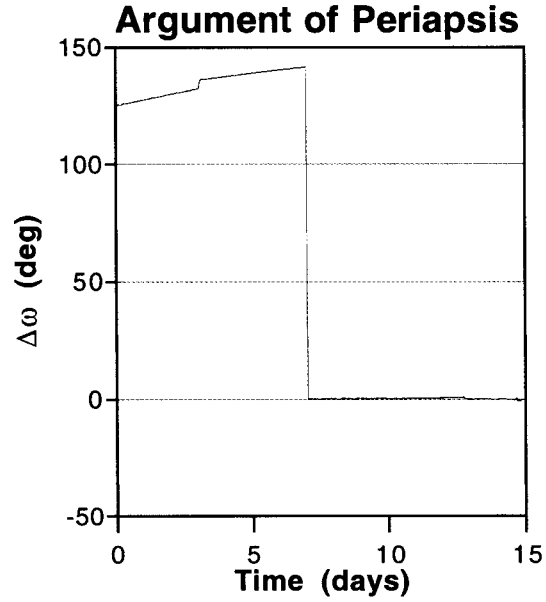
MSR Intermediate Rendezvous - Mean Orbit Element Differences

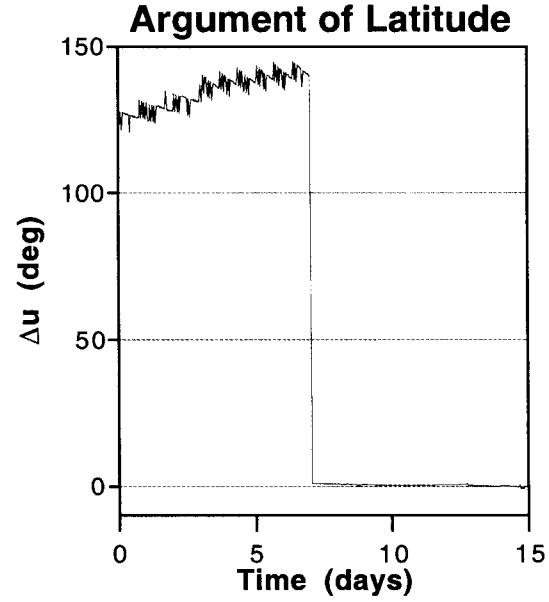












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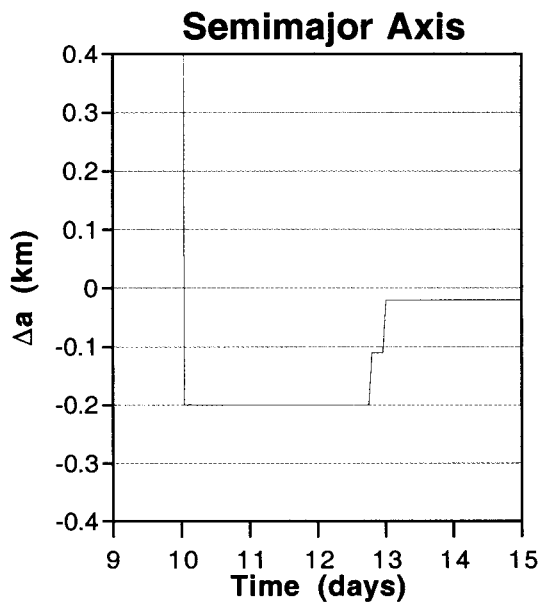
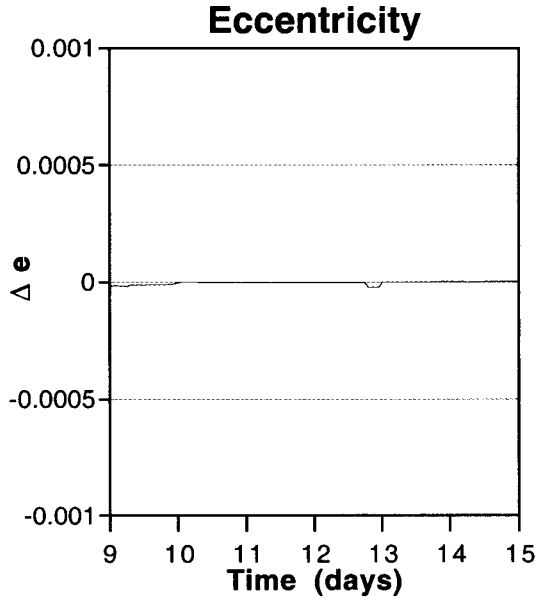
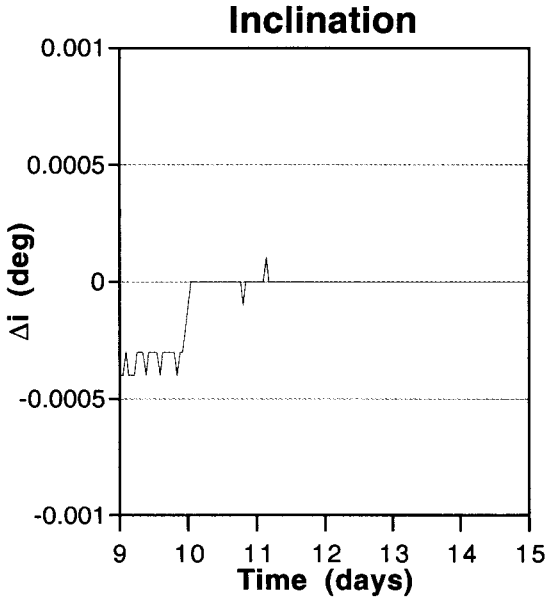
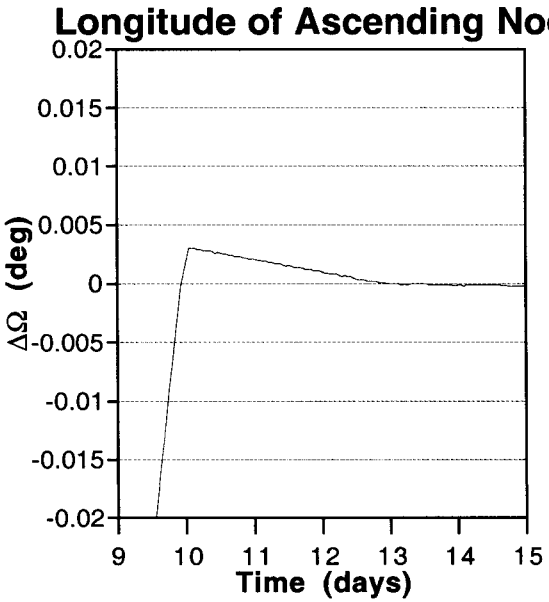
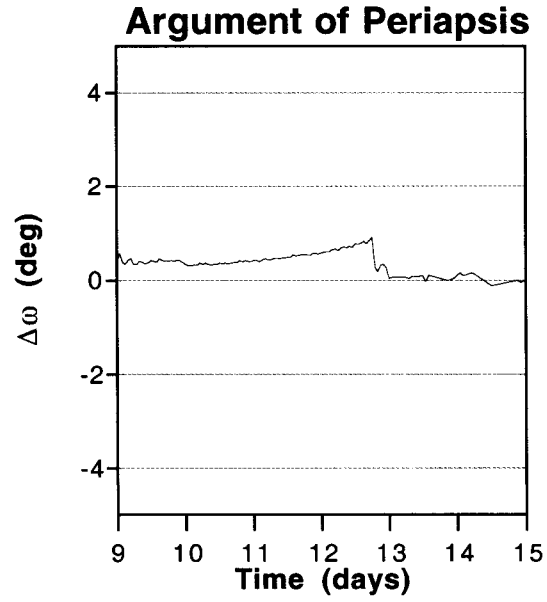
MSR Intermediate Rendezvous - Mean Orbit Element Differences (Detail)

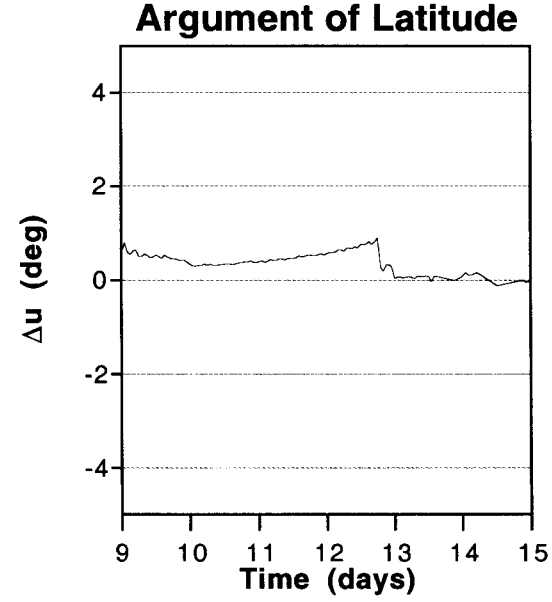












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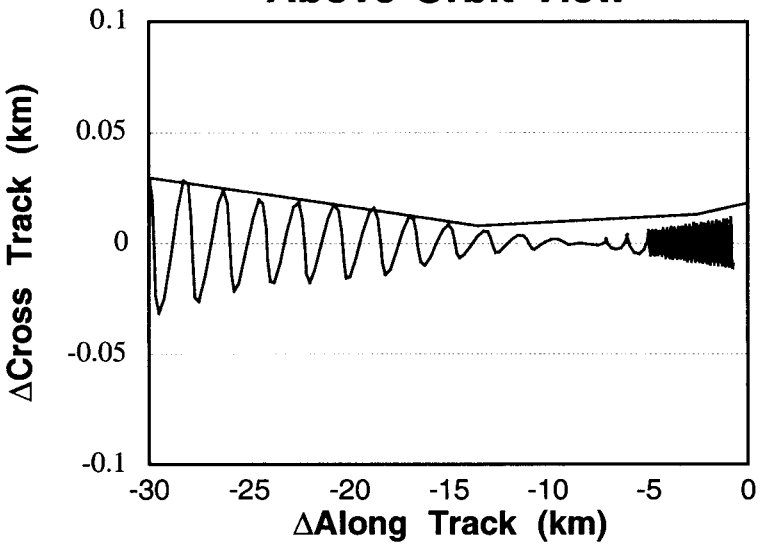
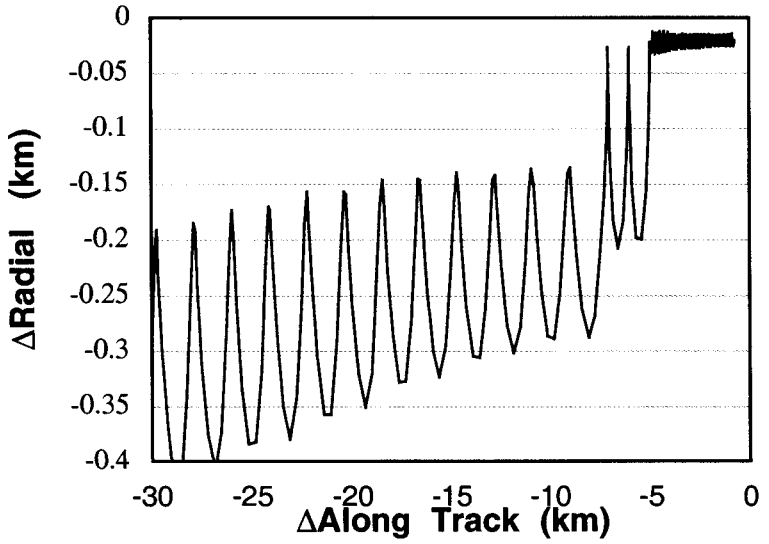
MSR Intermediate Rendezvous - Orthographic Orbit Projections

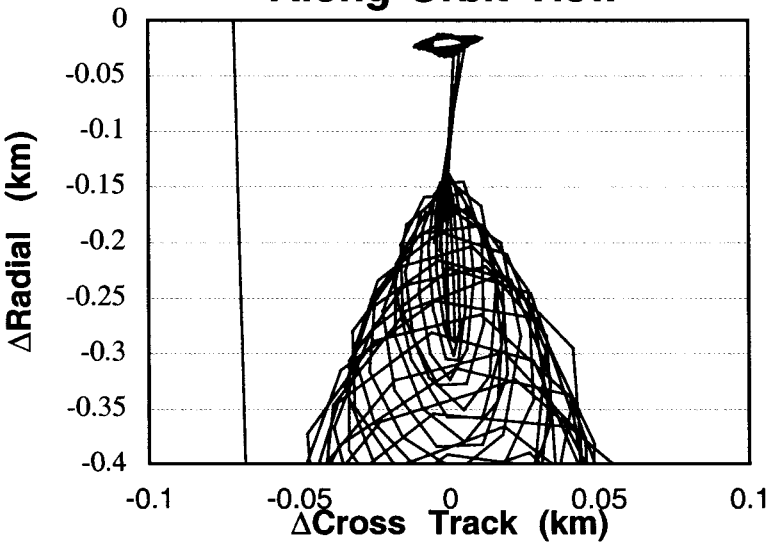
Above Orbit View



Orbit Normal View



Along Orbit View



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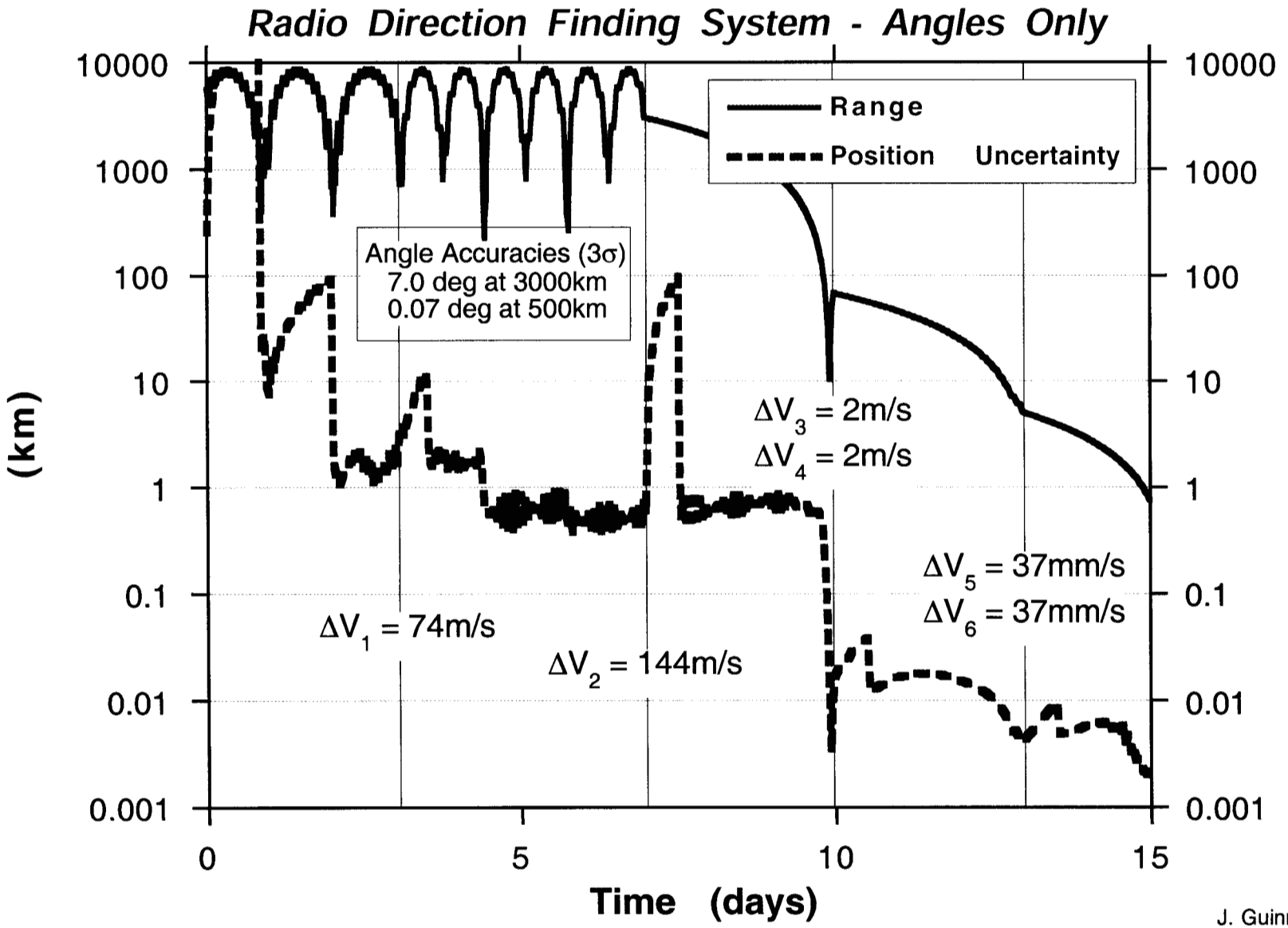
MSR Intermediate Rendezvous Orbit Determination Analysis



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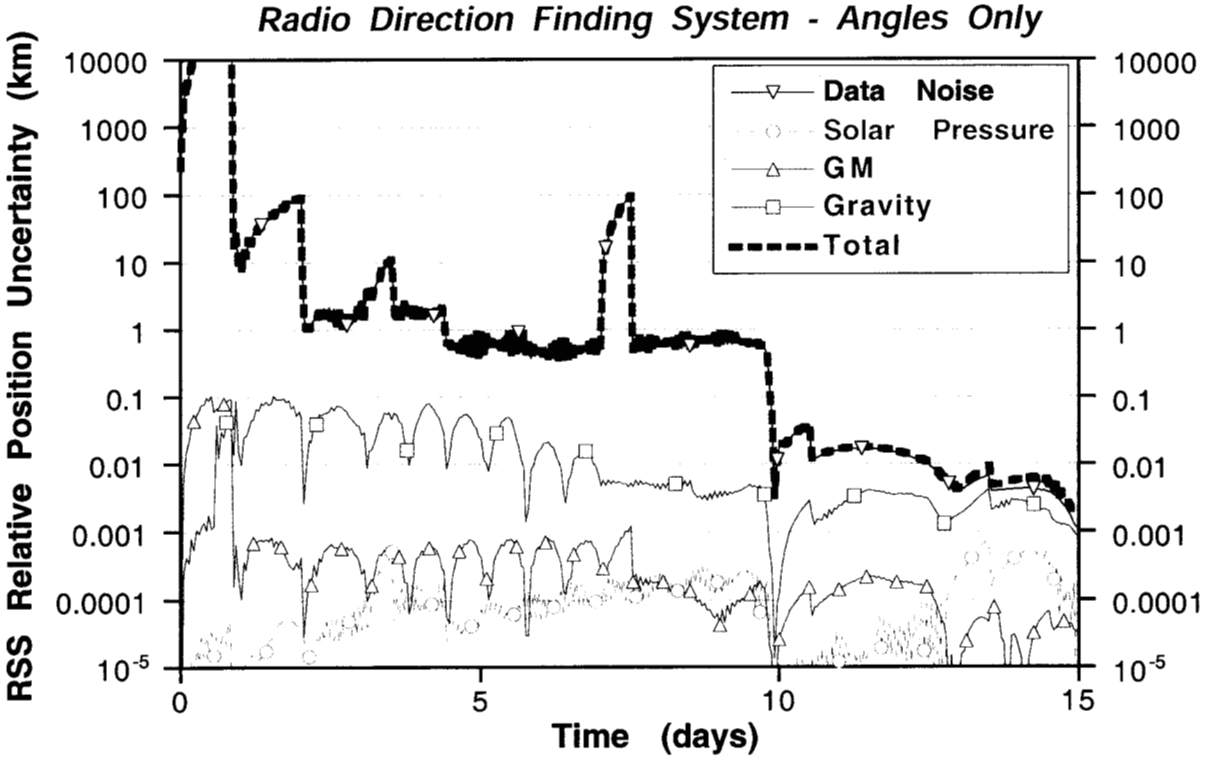
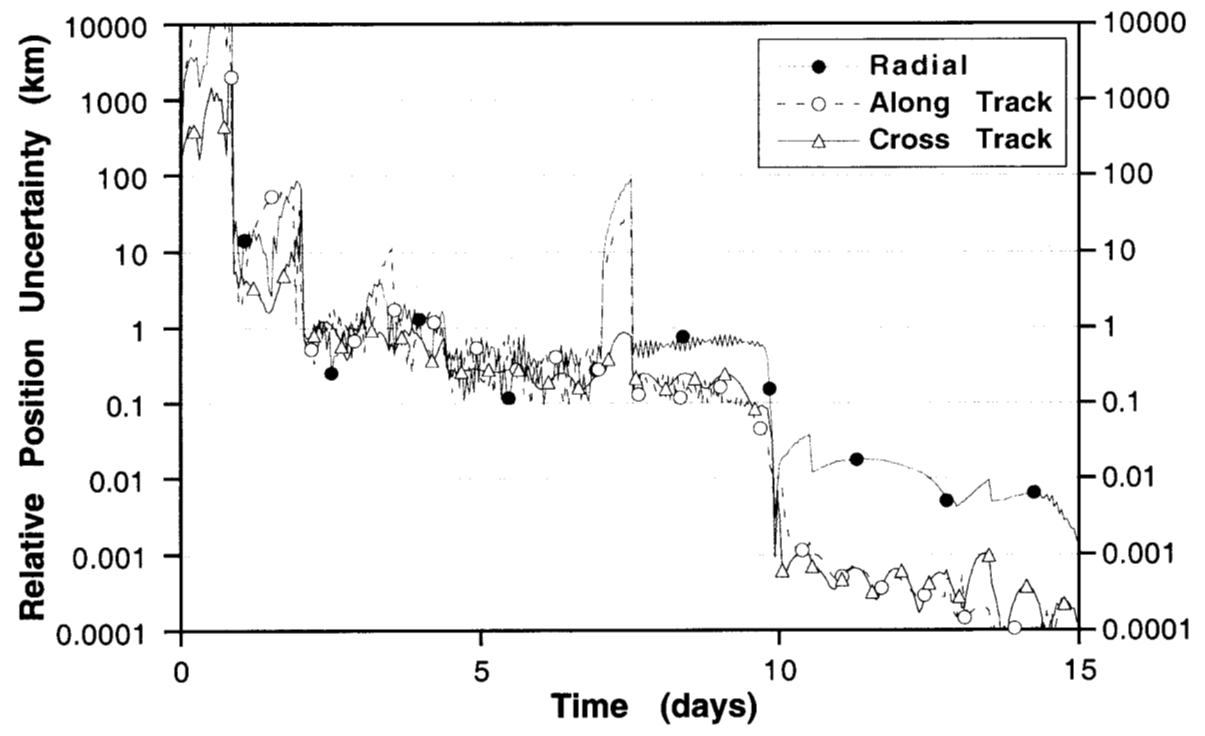
MSR Intermediate Rendezvous Covariance Analysis

Orbiting Sample Relative to Rendezvous Orbiter

Radio Direction Finding System - Angles Only



Components of Orbit Determination Uncertainties



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ASSUMPTIONS:
Mars Sample Return Orbit Determination Consider/Covariance Analysis

Mean Orbit Elements at Epoch 7-APR-2007 00:00:00 UTC

05-Orbiter	03-Sample
h = 250x1400 km	h = 600x600 km
e = 0.136	e = 0.001
i = 45.0 deg	i = 45.0 deg
Ω = 70.1 deg	Ω = 79.5 deg
ω = 79.8 deg	ω = 314.8 deg
M = 266.1 deg	M= 94.0 deg

Apriori State Uncertainties (1σ):
Positions: 10000km, Velocities: 100m/s

Dynamics:
Gravity: Mars, Sun, 75x75 (MGS75B model), Error Covariance Considered
Solar Radiation Pressure (Conical Shadow Model) 10% Errors Considered

05-Orbiter/DSN Doppler Measurements:
2-way X-band doppler: continuous, 600sec intervals, 0.05mm/s (1σ) data noise
Minimum elevation (DSN to Orbiter): +10 deg
Mars occultation data deleted

05-Orbiter/Sample Angle Measurements:
RA & DEC angles: continuous, 60sec intervals
Apriori random data noise (3σ): 7.0deg at ranges > 3000km, 0.07deg at ranges < 500km
Hourly angle bias updates modeled as white noise with σ = 1deg
Minimum elevation (Orbiter to Sample): -90 deg
Maximum range (Orbiter to Sample): 1000km
No measurements during Mars occultations
No measurements when Orbiter or Sample are in Mars shadow

05-Orbiter/Sample Doppler Measurements:
2-way UHF-band doppler: continuous, 60sec intervals, 0.5mm/s (1σ) apriori data noise
1-way UHF-band doppler: continuous, 60sec intervals, 0.5mm/s (1σ) apriori data noise
Short term frequency stability (60sec) modeled as Random Walk with σ = 0.3PPM
Hourly frequency bias updates modeled as white noise with σ = 0.3PPM
Minimum elevation (Orbiter to Sample): -90 deg
Maximum range (Orbiter to Sample): 1000km
No measurements during Mars occultations
No measurements when Orbiter or Sample are in Mars shadow

05-Orbiter Maneuver Execution Errors (3σ):
Magnitude: 0.5% for maneuvers > 1m/s, 2% for maneuvers $\leq$ 1m/s
Direction: 7mrad for maneuvers > 1m/s, 20mrad for maneuvers $\leq$ 1m/s

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