International Planetary Probe Workshop

MarsNEXT Multiple Lander Targeting and Navigation

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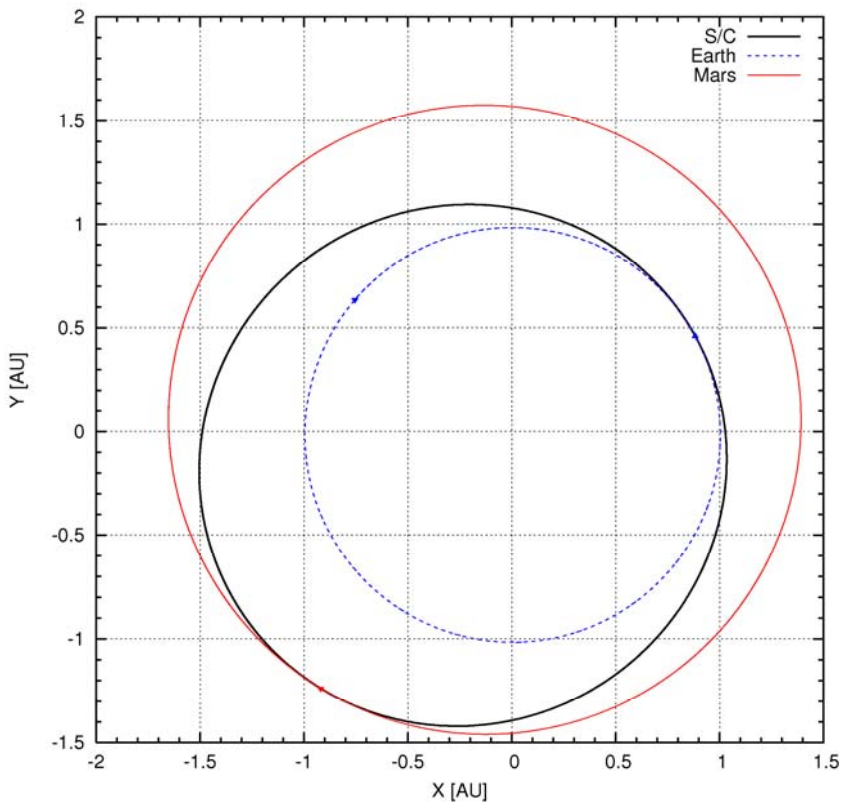
INNOVATING SOLUTIONS

Overview

- Approach trajectory Analysis
  - Assumptions
  - Lander Targeting Problem
  - Single Lander Entry Errors
  - Lander Retargeting Costs
  - Lander Deployment Sequence Design
- Navigation Analysis
  - Assumptions
  - Navigation Analysis Results
- Conclusions

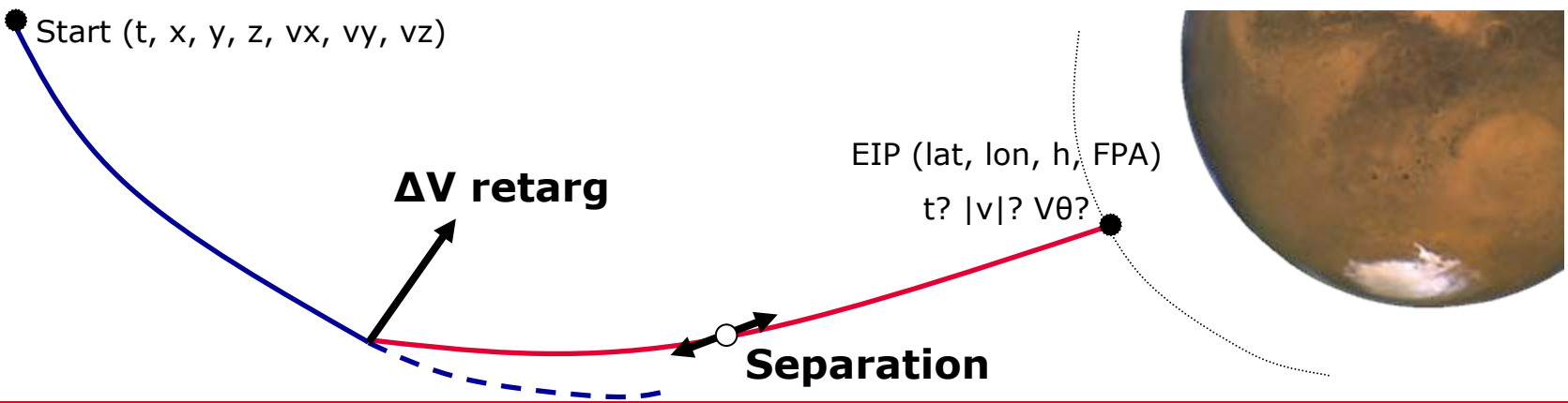
Approach Trajectory: Assumptions

- Case 2014T4 Transfer Selected
  - Arrival at MJD 7345 (2020/2/10) with v_∞ = 2.53 km/s
- Initial mass: 1500 kg
- 3 landers:
  - 125 kg each
  - Separation ΔV: 0.5 m/s
  - EIP at 120 km (spherical)
  - FPA -14° (rotating frame)
- Carrier S/C orbit:
  - 45° incl., 500 km h_p
- Perturbations:
  - 3rd body Sun



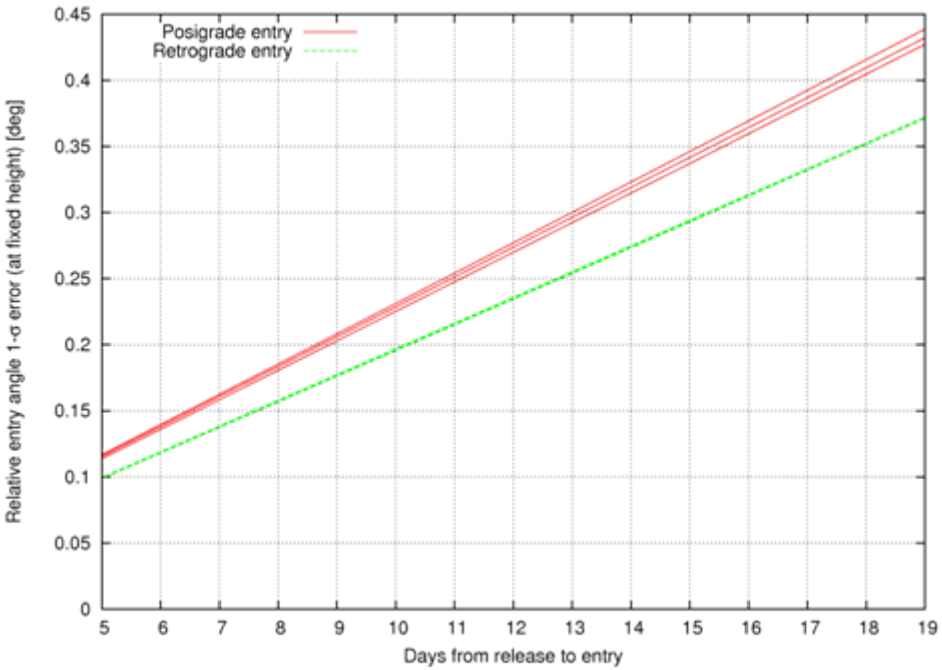
Lander Targeting Problem

- Two-point boundary value problem with free final time
  - Starting point in the incoming hyperbola
  - End point fixed to the planet equatorial rotating frame → EIP (lat, lon, height)
  - Entry angle (FPA) fixed
  - Retargeting manoeuvre at a fixed time after starting point
- Constrained optimisation problem:
  - 3 optimisation variables: entry time, velocity modulus, azimuth of velocity vector
  - 3 constraints: difference in position vector at retargeting
- Output: ΔV at retargeting
- Possibility to include separation ΔV: parallel to V at EIP



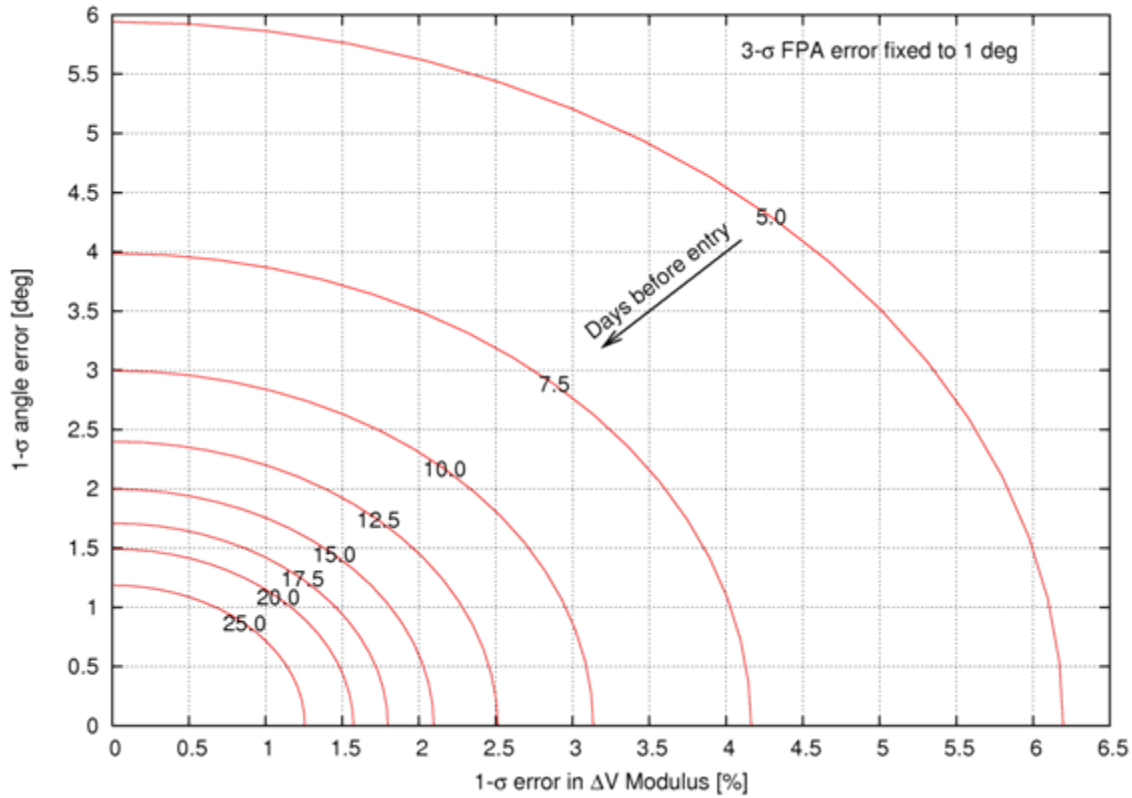
Single Lander Entry Errors

- ONLY errors in separation ΔV (0.5 m/s) considered. Hypothesis:
  - Direction aligned to entry relative velocity
  - 5% 3-σ error in modulus
  - 4 deg 3-σ error in direction
- Generic target longitude, 3 different target latitudes, fixed altitude
- No corrections after separation
- Error in FPA at EIP at fixed altitude is linear with release time
- Differences prograde-retrograde approach, 15 days before:
  - P: 0.35° 1-σ error in FPA
  - R: 0.29° 1-σ error in FPA
- **Sets a limit for the earliest release time of first lander**



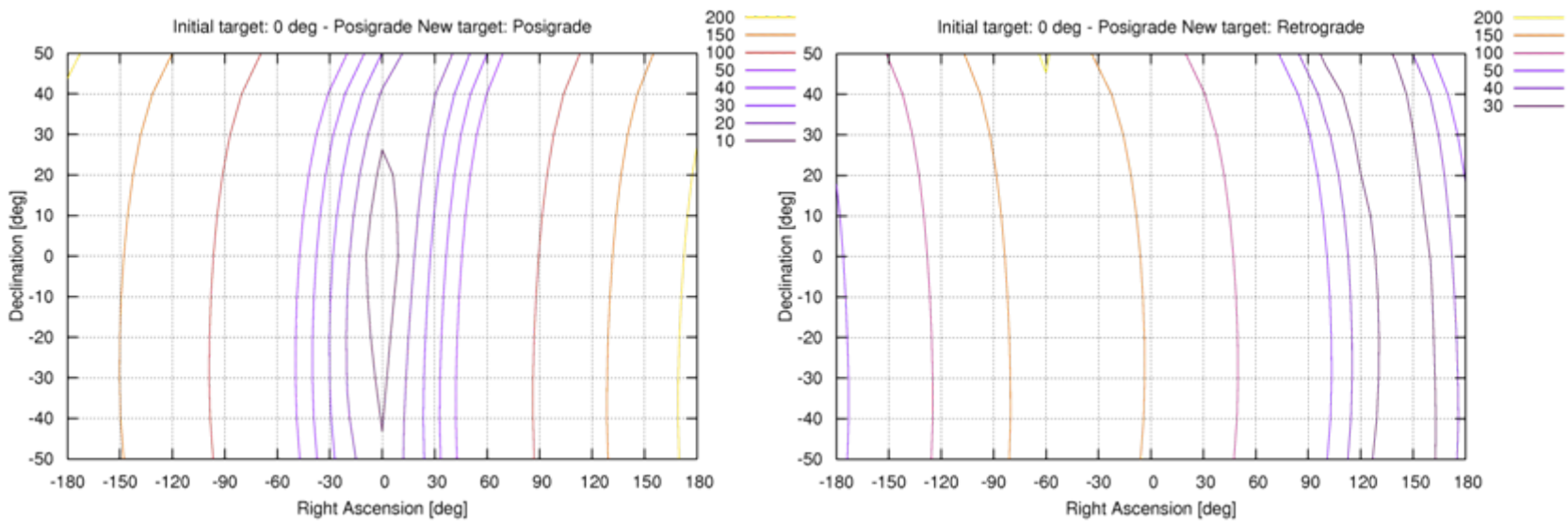
Single Lander Entry Errors (II)

- Separation: 0.5m/s
- FPA error fixed (0.333 deg 1-σ)
- Effect of the errors in modulus and direction on the allowable release date:
  - Separation 20 days before → ~1% mod. and ~1 deg direction (1-σ) requirement on release mechanism



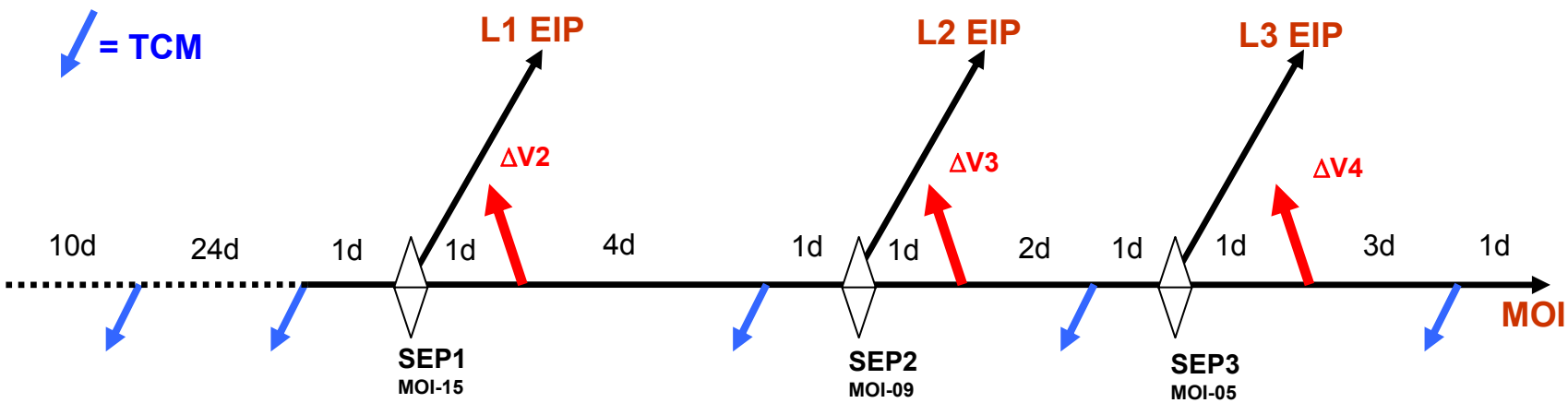
Lander Retargeting Cost

- Calculate costs to retarget to a different target latitude and shift the target longitude of the EIP
- Changes in target latitude are cheap in terms of ΔV
- Optimum changes in target longitude:
  - Pro to Pro or Retro to Retro: longitude shift of zero degrees
  - Pro to Retro or Retro to Pro: longitude shift of 150° east / west
- Size of retargeting ΔV inversely proportional to release time. ΔVs introduce errors → earlier release desirable to reduce size



Lander Deployment Sequence Design

- Two sequences designed: retro-pro-prograde & prograde x 3
- Iterative process with navigation analysis to define optimum timing.
- Final sequence selected:
  - Separations at MOI-15 (L1), MOI-09 (L2) and MOI-5 (L3)
  - Retargeting ΔV one day after separation (incl. last ΔV for carrier)
  - TCM slots one day before separations or MOI (for navigation)



Sequence 1: Retro-Pro-Prograde

- Low retargeting ΔV: 28 m/s in total
- Lower FPA errors expected

Date [MJD200]	Day	Event				
7324.33	-20	Start	$V_{inf}r$	[km/s]	2.530	
7329.33	-15	Release L1 (SEP1)	ΔV L1 | Carrier	[m/s]	0.458	0.042
7330.33	-14	Retargeting 2 L2 (ΔV2)	ΔV	[m/s]	**11.861**	
7335.33	-9	Release L2 (SEP2)	ΔV L2 | Carrier	[m/s]	0.455	0.045
7336.33	-8	Retargeting 2 L3 (ΔV3)	ΔV	[m/s]	**11.914**	
7339.33	-5	Release L3 (SEP3)	ΔV L3 | Carrier	[m/s]	0.450	0.050
7340.33	-4	Retargeting 2 MOI (ΔV4)	ΔV	[m/s]	**3.628**	
7344.33	0	EIP L1	Velocity Inertial | Relative	[km/s]	5.546	5.784
			Longitude | Latitude	[deg]	-8.00	-2.00
			FPA Inertial | Relative	[deg]	-14.62	-14.00
			Solar Hour	[h]	23.13	
7344.35	0.02	EIP L2	Velocity Inertial | Relative	[km/s]	5.544	5.334
			Longitude | Latitude	[deg]	-160.00	-30.00
			FPA Inertial | Relative	[deg]	-13.46	-14.00
			Solar Hour	[h]	13.41	
7344.36	0.03	EIP L3	Velocity Inertial | Relative	[km/s]	5.543	5.351
			Longitude | Latitude	[deg]	-150.00	30.00
			FPA Inertial | Relative	[deg]	-13.51	-14.00
			Solar Hour	[h]	14.20	
7344.36	0.03	Pericentre/MOI	Pericentre height	[km]	500.0	
			Inclination	[deg]	45.0	

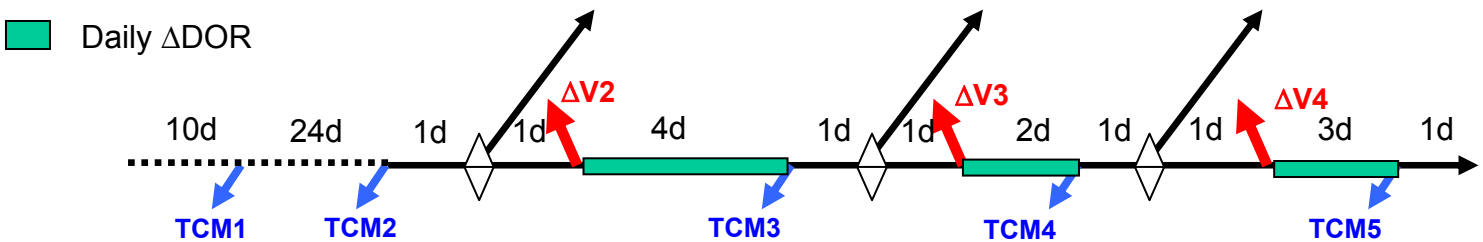
Sequence 2: Prograde x 3

- High retargeting ΔV: 78 m/s in total (main contributor ΔV2)
- All landings in daylight

Date [MJD200]	Day	Event				
7324.95	-20	Start	$V_{inf}r$	[km/s]	2.530	
7329.95	-15	Release L1 (SEP1)	ΔV L1 | Carrier	[m/s]	0.458	0.042
7330.95	-14	Retargeting 2 L2 (ΔV2)	ΔV	[m/s]	**59.013**	
7335.95	-9	Release L2 (SEP2)	ΔV L2 | Carrier	[m/s]	0.455	0.045
7336.95	-8	Retargeting 2 L3 (ΔV3)	ΔV	[m/s]	**12.107**	
7339.95	-5	Release L3 (SEP3)	ΔV L3 | Carrier	[m/s]	0.450	0.050
7340.95	-4	Retargeting 2 MOI (ΔV4)	ΔV	[m/s]	**6.886**	
7344.63	-0.32	EIP L3	Velocity Inertial | Relative	[km/s]	5.546	5.307
			Longitude | Latitude	[deg]	100.00	-30.00
			FPA Inertial | Relative	[deg]	-13.46	-14.00
			Solar Hour	[h]	13.36	
7344.64	-0.31	Pericentre/MOI	Pericentre height	[km]	500.0	
			Inclination	[deg]	45.0	
7344.64	-0.31	EIP L2	Velocity Inertial | Relative	[km/s]	5.573	5.380
			Longitude | Latitude	[deg]	110.00	30.00
			FPA Inertial | Relative	[deg]	-13.51	-14.00
			Solar Hour	[h]	14.16	
7344.95	0	EIP L1	Velocity Inertial | Relative	[km/s]	5.573	5.364
			Longitude | Latitude	[deg]	-8.00	-2.00
			FPA Inertial | Relative	[deg]	-13.39	-14.00
			Solar Hour	[h]	13.57	

Navigation Assumptions

- Measurements:
  - Range (every 60 min) & Doppler (every 10 min), Ceb. & New Norc.
  - ΔDOR (every 4 days, daily if critical): Ceb.-New Norc. & Ceb.-Santiago
- All errors (1σ) are conservative:
  - Initial position & velocity dispersion: 100 km and 1 m/s in x, y, z
  - Range noise and bias: 20 m and 2 m
  - Doppler noise: 0.3 mm/s
  - ΔDOR noise: 6 cm
  - Ground station location bias: 0.14 m in x, y and z
  - Non-gravitational acceleration ECRV (1 day): $6 \cdot 10^{-12}$ km/s^2
  - Separation ΔV errors: 1.667% in modulus, 1.333° in angle
  - Retargeting ΔV and TCM errors : 0.6% in modulus, 0.5° in angle



Navigation Analysis Results

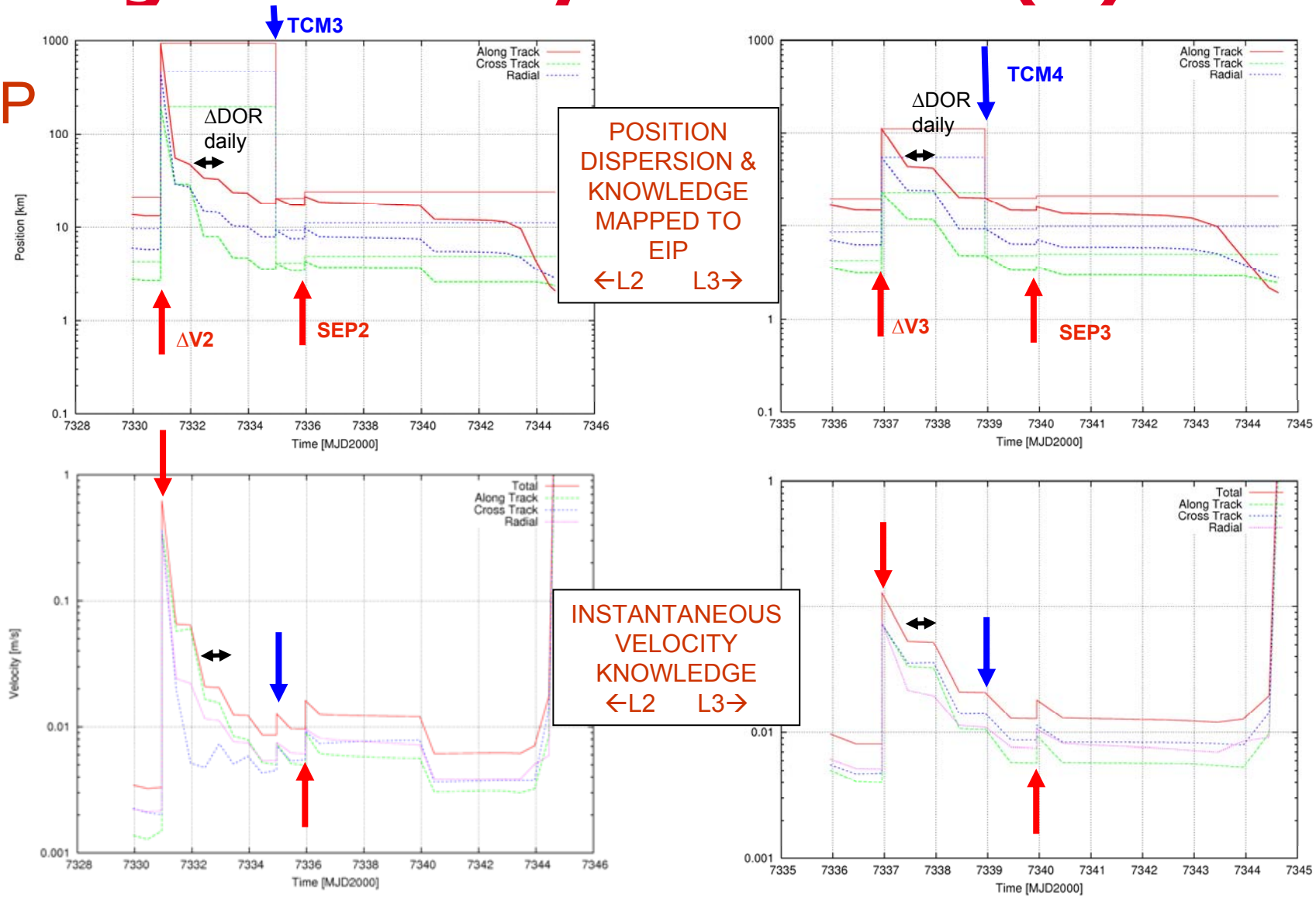
	Measurements Strategy	FPA 1σ errors [deg]		
		L1	L2	L3
RPP	Range & Doppler	0.4832	1.8100	1.1325
	ΔDOR CEB-NNO	0.3008	1.6176	0.7554
	ΔDOR SGO-CEB	0.3424	1.7173	0.7787
	ΔDOR CEB-NNO daily	0.3008	0.5483	0.5544
	ΔDOR SGO-CEB daily	0.3424	0.3701	0.2714
	ΔDOR 2 baselines	0.3000	1.5908	0.7208
	ΔDOR 2 basel. daily	**0.3000**	**0.2837**	**0.2561**
PPP	Range & Doppler	0.5258	3.5648	2.2850
	ΔDOR CEB-NNO	0.3569	3.3147	1.0904
	ΔDOR SGO-CEB	0.4042	3.0307	1.0214
	ΔDOR CEB-NNO daily	0.3569	0.6933	0.5615
	ΔDOR SGO-CEB daily	0.4042	0.3639	0.4688
	ΔDOR 2 baselines	0.3550	3.0153	1.0070
	ΔDOR 2 basel. daily	**0.3550**	**0.3568**	**0.3587**

FPA errors at fixed altitude

- Most relevant source of error: retargeting ΔVs
- Daily ΔDOR after ΔVs from two baselines necessary
- RPP sequence gives lower entry FPA errors (as expected)
- Entry FPA errors can be reduced to less than 0.36 1σ for all 3 landers
- Error ellipse at MOI pericentre for carrier:
  - 7x1 km for RPP
  - 10x1 km for PPP

Navigation Analysis Results (2)

PPP



Conclusions and Future Work

- **Generic multiple lander deployment trajectories designed and analyzed:**
  - Separation ΔV error ⇨ minimum possible error in FPA for a given separation time from arrival ⇨ Limit on earliest release date.
  - Retrograde trajectories have smaller errors in FPA than prograde ones.
  - Execution errors of the retargeting manoeuvres are largest contributors of errors in FPA at EIP ⇨ A TCM after each retargeting manoeuvre and before next lander separation is required to reduce FPA errors.
  - Sequences with small deterministic retargeting manoeuvres can be found depending on relative location of landing sites.
  - Effective measure to mitigate the effect of these errors and increase the accuracy of the TCMs are daily ΔDOR measurements after retargeting manoeuvres ⇨ Shall be requirement on Operations

Thank you !!!!

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INNOVATING SOLUTIONS

Backup slides

MarsGen – Netlander Scenario (6 landers)

- ⇨ 50 kg lander (130 kg EDLS)
- ⇨ goal: Geophysics and Meteorology

MarsRex – Rover (50 kg class)

- ⇨ ~70 kg (7 kg P/L)
- ⇨ goal: either Science instruments or sampling

MarsLev – Surface Station

- ⇨ ~ 50 kg surface station, landed by NASA
- ⇨ goal: stationary instruments from ExoMars