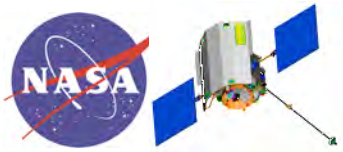

MESSENGER Navigation for Mercury 2 Flyby

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Navigation Team Chief

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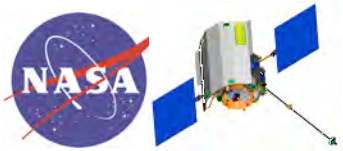
805-791-8094



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Topics

- Heliocentric Trajectory
- Encounter Geometry
- Delivery Errors and Costs
- Navigation Considerations
- Delta-DOR Timeline
- Doppler/Ranging Timeline
- Summary

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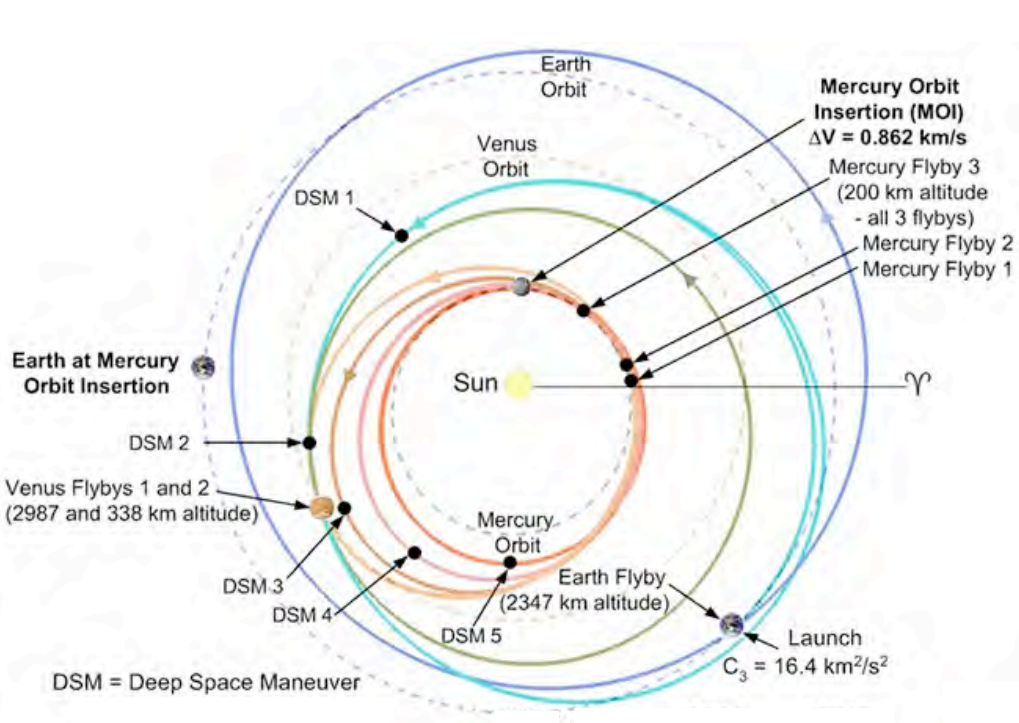
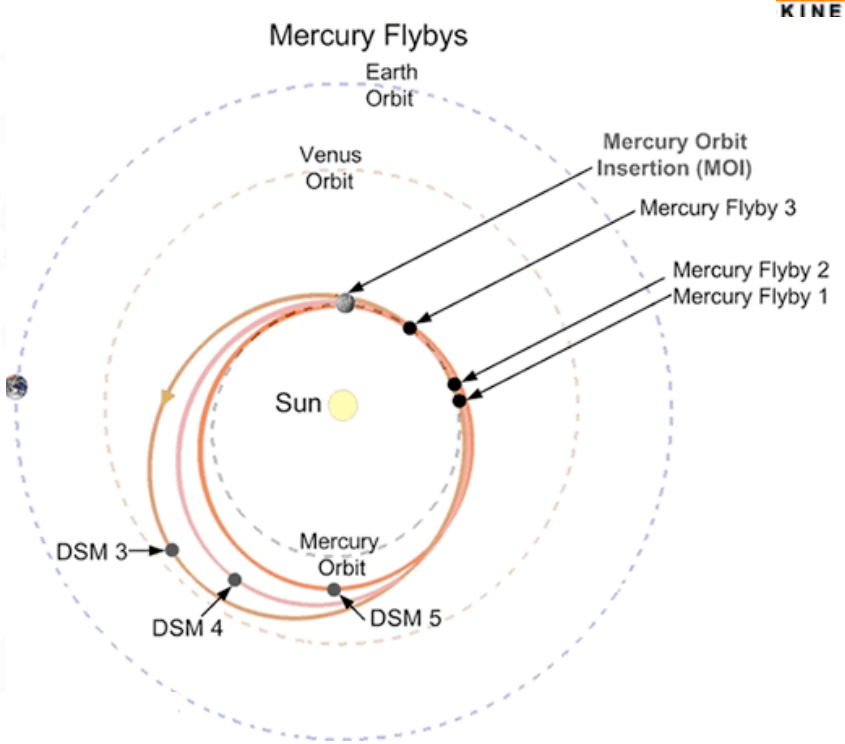
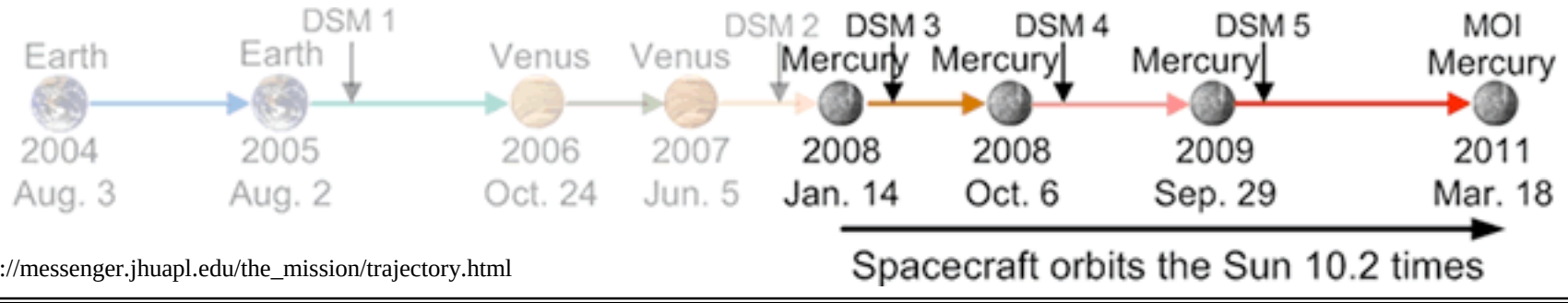
Heliocentric Trajectory







Source: http://messenger.jhuapl.edu/the_mission/trajectory.html

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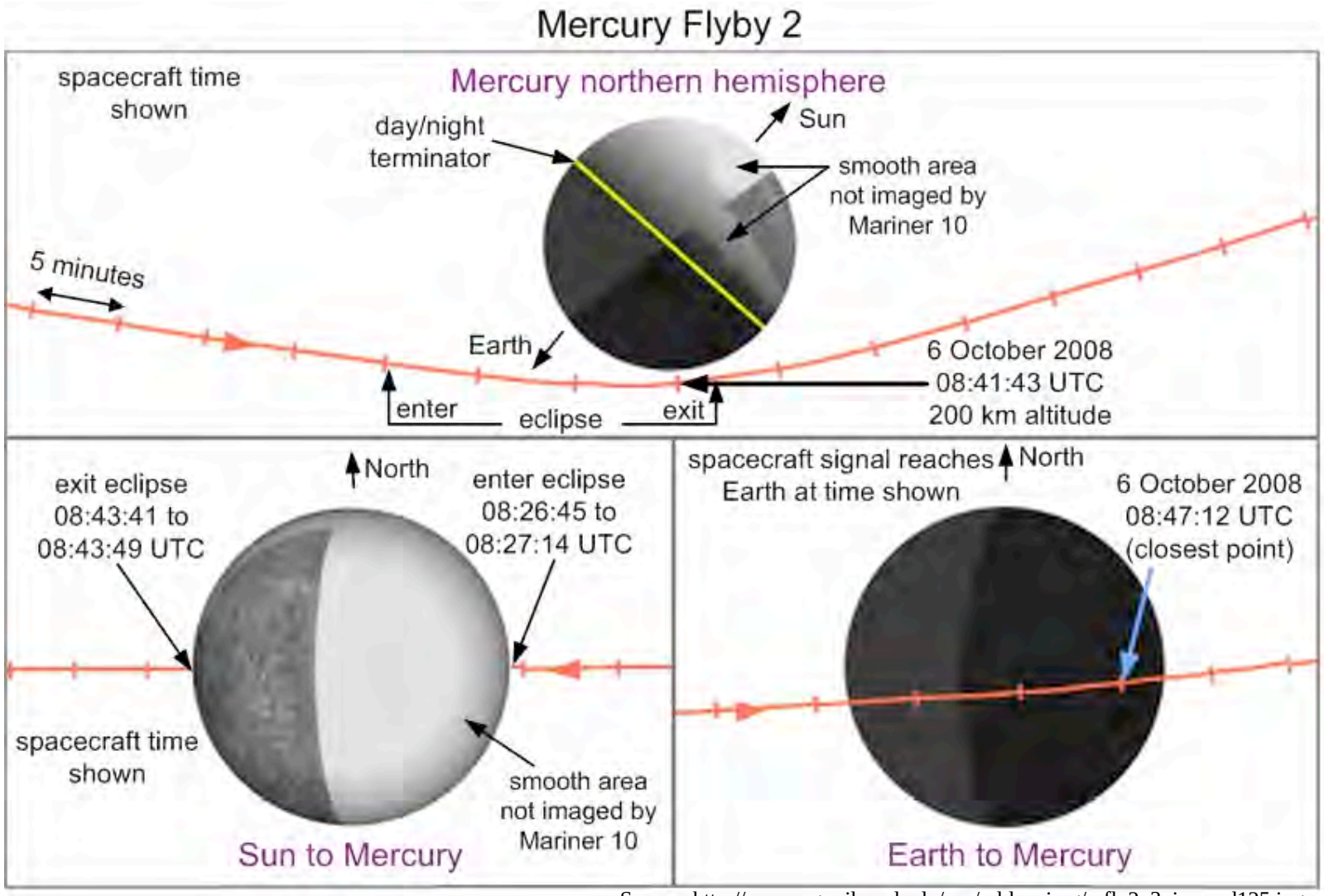
Encounter Geometry



Source: http://messenger.jhuapl.edu/soc/reldoc_img/mfly2_3view_od125.jpg

NOTE: Actual times may vary - Dependent on OD changes, spacecraft attitude and TCMs

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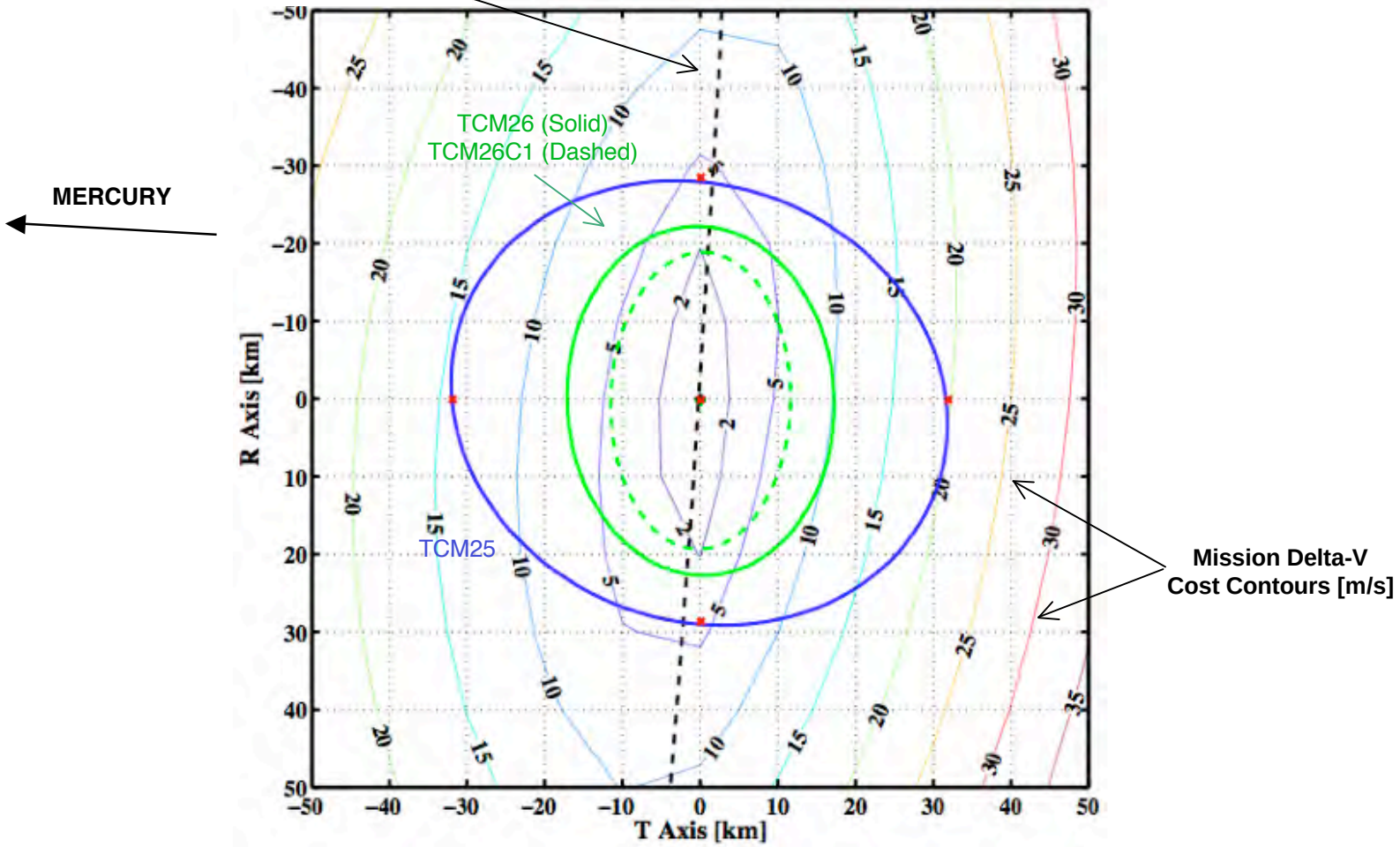
Delivery Errors and Costs

Mercury 2 Baseline



Delivery Error (3-Sig)	a [km]	b [km]	Orient [deg]	LFT [sec]
TCM25	32.5	28.1	20	27.5 (948)
TCM26	22.5	17.2	87.5	10.5 (948)
TCM26C1	19.1	11.5	-89	9.33 (948)

Navigation Considerations

What's Different about Mercury 2 Versus Mercury 1?

- DSM for M1-M2 Leg Already Completed with Excellent Outcome
  - ~10 cm/sec at TCM-25 (Aug 28 or M2 - 39d) to achieve M2 targeted aimpoint
  - TCM-25 or subsequent TCM- 26 might be reduced or eliminated altogether by "solar sailing" sufficiently close to aimpoint
- DE405 Mercury Ephemeris Verified
  - Difference of only ~2 km established after M1 Reconstruction
  - OpNavs demoted from critical operations to tests until Mercury orbit in 2011
  - Need for close-in TCM-27 eliminated
- No Long Solar Conjunctions
  - Superior Conjunction (SEP < 3 deg) 4-8 June (non-critical period)
  - Inferior Conjunction (SEP 2-3 deg) 6-7 October (around encounter, but little or no degradation in tracking data)
- No Earth Occultation
  - Had been out of contact about 48 min for Mercury 1
- Closest Heliocentric Range Yet
  - Down to ~0.3 AU after flyby

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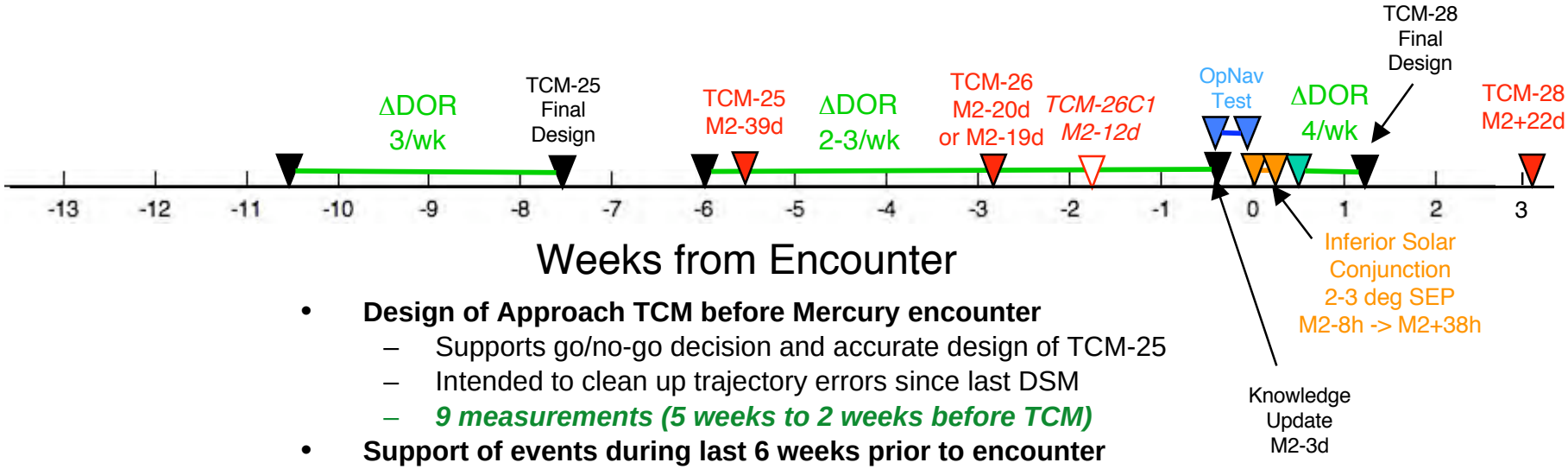
Delta-DOR Requirements

Proposed Delta-DOR Schedule for Mercury 2 Approach



- **Design of Approach TCM before Mercury encounter**
  - Supports go/no-go decision and accurate design of TCM-25
  - Intended to clean up trajectory errors since last DSM
  - ***9 measurements (5 weeks to 2 weeks before TCM)***
- **Support of events during last 6 weeks prior to encounter**
  - Reconstruction of TCM, go/no-go decision, design and reconstruction of any maneuvers remaining before M2
  - ***18 measurements (M2 – 6 weeks to M2 – 3.25 days; reducible if TCM cancelled)***
- **Encounter reconstruction and support of post-encounter cleanup maneuver**
  - Determines outbound trajectory and cleanup of encounter errors at TCM-28
  - ***4 measurements (M2 + 3 days to M2 + 9 days)***
- **Delta-DORs should be balanced between each DSN baseline and not bunched up**
  - ***As shown with 50% Goldstone-Madrid and 50% Goldstone-Canberra***

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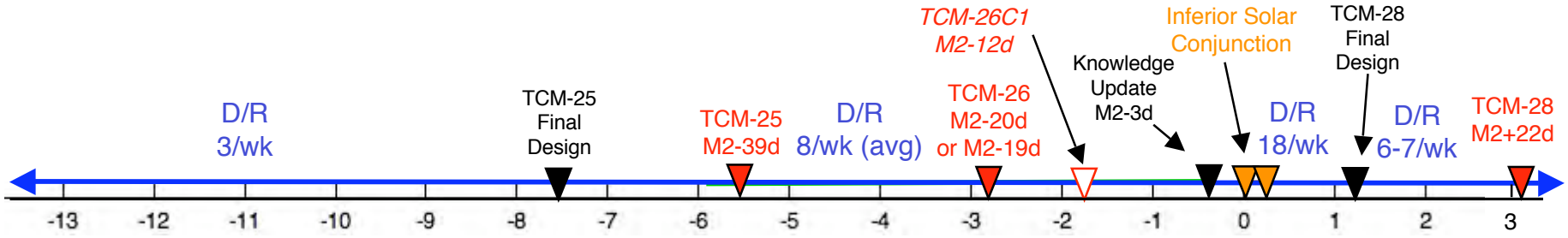
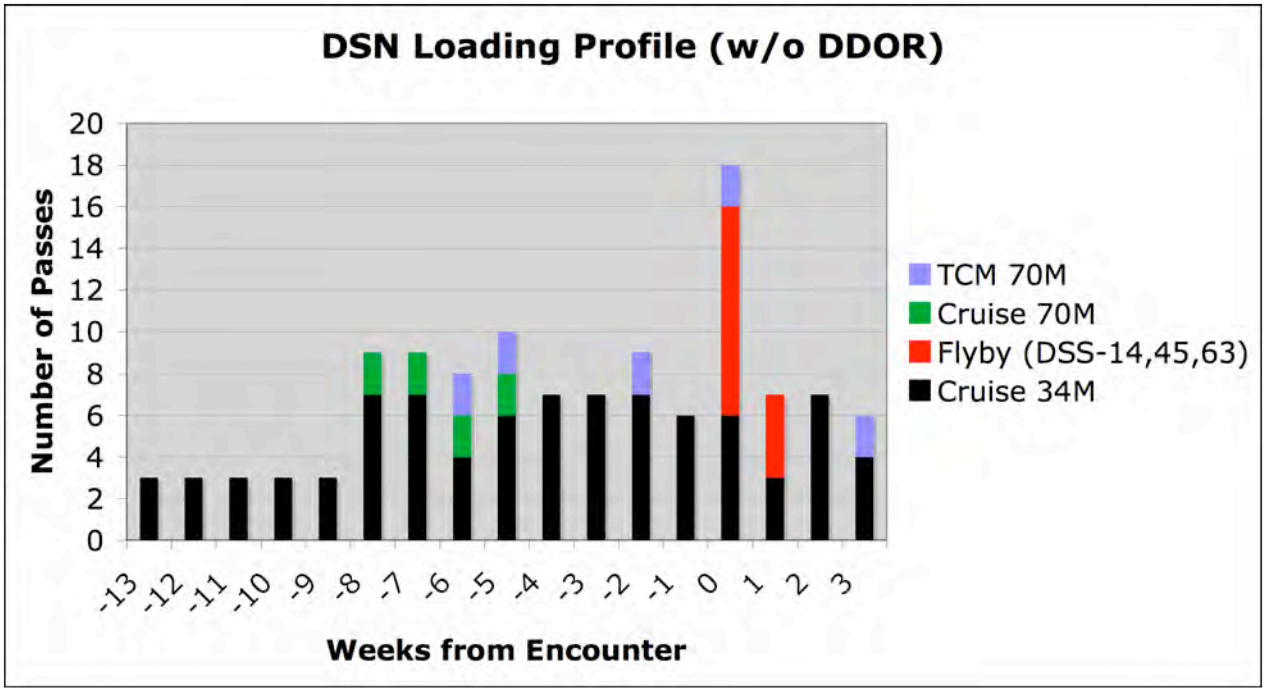
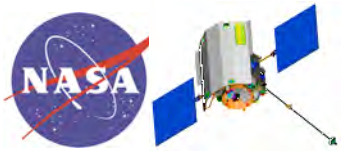
Doppler-Ranging Requirements

Proposed Doppler/Ranging Schedule for Mercury 2 Approach



Weeks from Encounter





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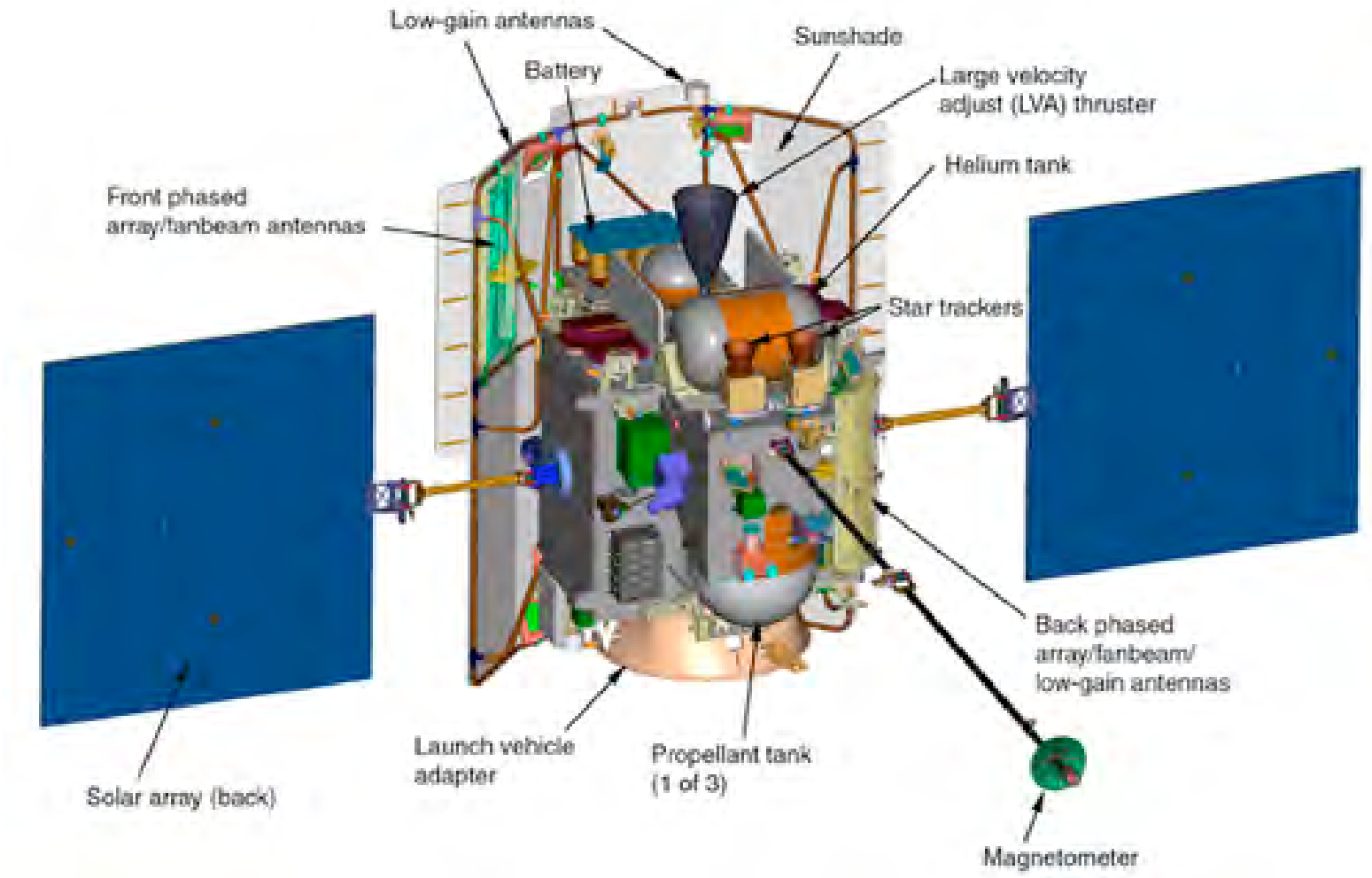
Summary

- Adequate Delta-DOR and Doppler/ranging tracks to support accurate flyby trajectory reconstruction
- Projected delivery errors and costs relatively benign
- Specific Navigation recommendations:
  - Do not change planet ephemeris (stay with DE405 for operations prior to Mercury orbit in 2011)
  - Perform OpNavs as tests to further develop and refine capabilities leading eventually to landmark tracking in Mercury orbit in 2011
  - Attempt attitude adjustments to “sail” sufficiently close to the target, but leave approach maneuver opportunities in place for now
    - Delete TCM-27 (no late update)
    - Move TCM26 farther out and add TCM26C1 (contingency)
    - If approach maneuver required, keep option open to adjust Mercury TCA to allow completely lateral (or radial) implementation
- See http://messenger.jhuapl.edu for more information

Backup Slides

MESSENGER

Spacecraft Overview



Source: http://messenger.jhuapl.edu/spacecraft/index.html

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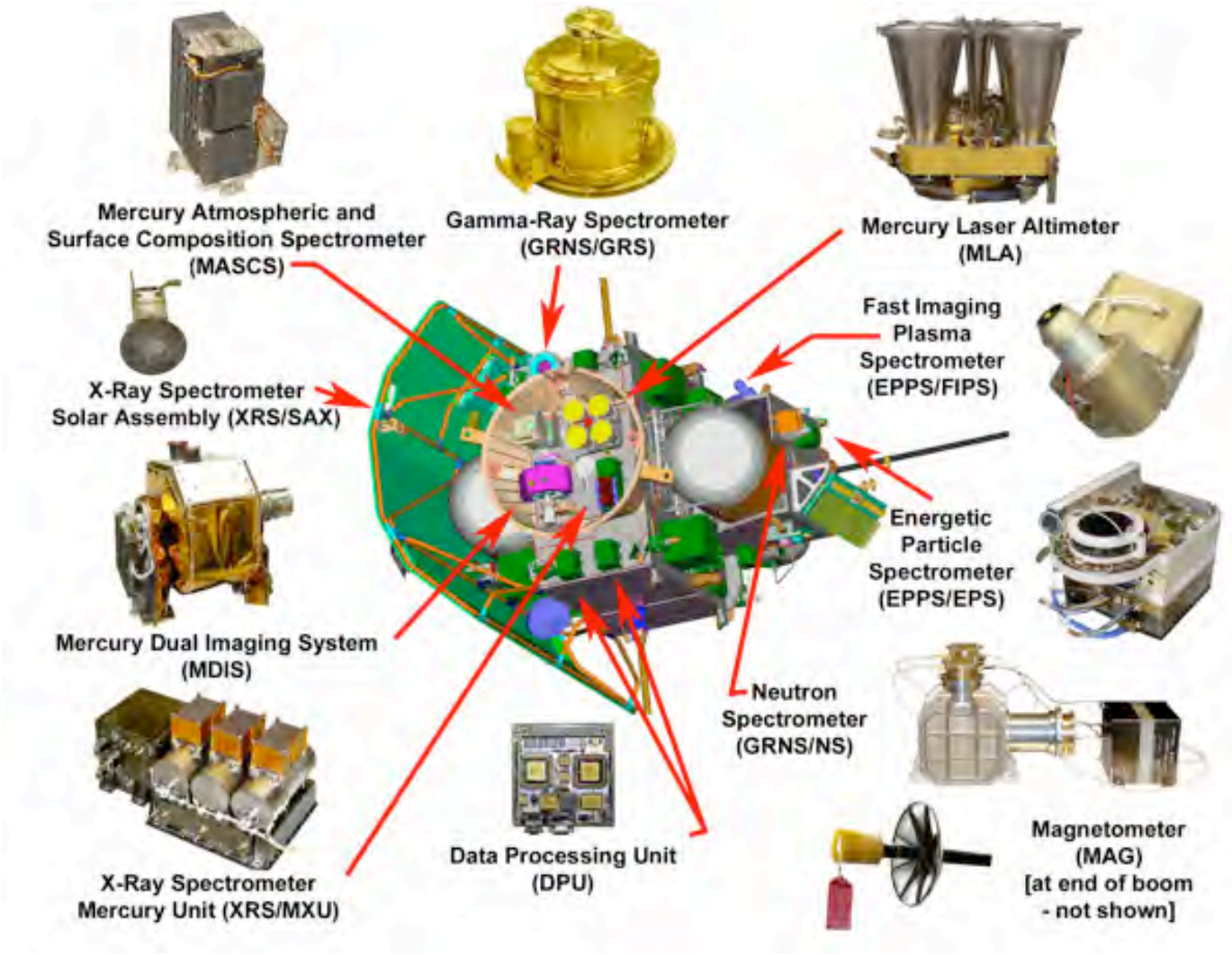
Instrument Overview



Source: http://messenger.jhuapl.edu/instruments/index.html

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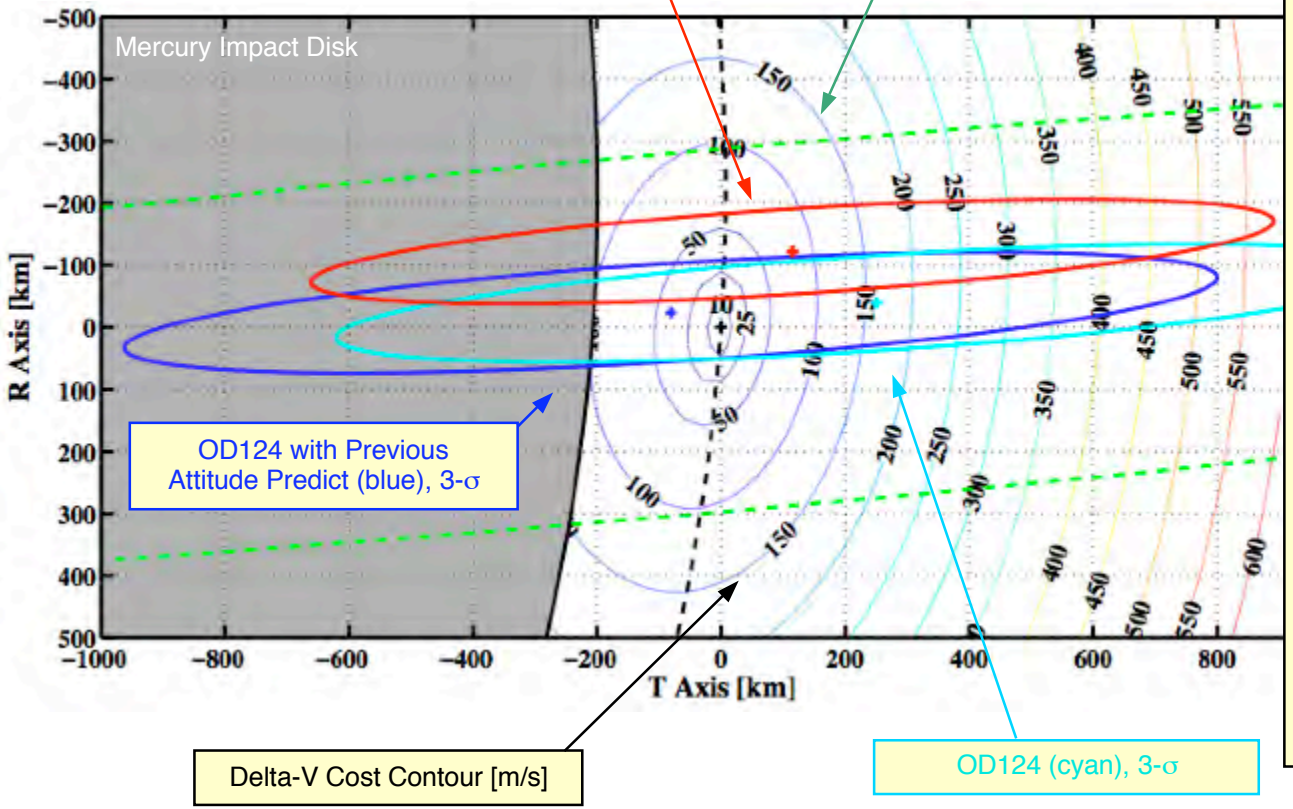
Mercury B-plane as of 10 April 2008

Mercury B-plane (06-Oct-2008, EMO2000)



Positions, Times, 3-σ Errors

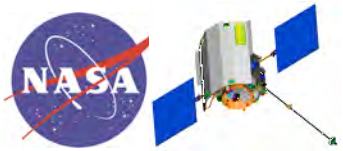
- **Pre-DSM-3 Nominal Delivery Prediction:**
  - B•T, B•R = 3349, 220 km
  - Ellipse: 4050 x 291 km, -5 deg
  - TCA: 08:40:00.7 ET ± 48 min
- **Nav OD124 (02 Apr 2008):**
  - B•T, B•R = 3600, 181 km
  - Ellipse: 873 x 77 km, -4 deg
  - TCA: 08:38:03.7 ET ± 466s
- **Nav OD124 with Previous Attitude Predict:**
  - B•T, B•R = 3268, 196 km
  - Ellipse: 883 x 79 km, -4 deg
  - TCA: 08:40:58.5 ET ± 471s
- **Nav OD125 (10 Apr 2008):**
  - B•T, B•R = 3464, 98 km
  - Ellipse: 778 x 68 km, -4 deg
  - TCA: 08:39:15.7 ET ± 414s
- **reop021a Target ([0,0] on Plot):**
  - B•T, B•R = 3349, 220 km (Aimpoint)
  - TCA: 08:42:48.1 ET

Proposed Mercury 2 OpNav Test

- **General Characteristics**
  - Slightly Reduced Number of OpNav Images
    - 8 OpNav events vs. 9 for M1
    - Still 8 images per event
  - Relatively More Compressed Observation Schedule
    - First image after M2-3.3d (> 40 deg off Sun)
    - Last image much closer to Encounter than M1 (~M2-15h)
    - After last pre-encounter Delta-DOR
  - Relatively More Relaxed Processing Schedule
    - OpNav activity now passive (testing) rather than active (part of critical operations)
    - Therefore, no specific turn-around requirement
    - Playback of images according to priorities established by Science

- **Schedule**

OpNav #	DOY	Date (UTC)	Start Time (UTC)	Start Relative to Encounter (hrs)
1	277	3-Oct-2008	3:30	-77
2	277	3-Oct-2008	16:00	-65
3	278	4-Oct-2008	4:00	-53
4	278	4-Oct-2008	12:00	-45
5	278	4-Oct-2008	20:00	-37
6	279	5-Oct-2008	4:00	-29
7	279	5-Oct-2008	12:00	-21
8	279	5-Oct-2008	18:00	-15



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Mercury 2 OpNav Test Sequence

- **General Characteristics**
  - 8 Images taken in as rapid succession as possible
  - Spacecraft attitude settled and recorded as quaternion at time image shuttered
  - Pivot angle fixed for entire sequence
  - Auto-exposure parameters based on DN levels instead of exposure times per recommendation of MDIS Team
- **Specific Requirements**

Image #	Include Star*	Include Mercury	Camera	Exposure	DPU Binning	Filter	Note
1	Yes	No	NAC	10 sec	1x1	Clear	Star within 5-10 deg of planet and 20 pixels of boresight
2	Yes	No	NAC	10 sec	2x2	Clear	
3	Yes	No	NAC	10 sec	2x2	Clear	Offset 10 pixels to observe star relative to camera noise
4	No	Yes	NAC	≤2400 DN (auto)	1x1	Clear	Planet within 20 pixels of boresight
5	No	Yes	NAC	≤1400 DN (auto)	1x1	Clear	
6	Yes	Yes	WAC	10 sec	1x1	Clear	Same attitude and pivot angle; minimize time between WAC images
7	Yes	Yes	WAC	≤2400 DN (auto)	1x1	Clear	
8	Yes	Yes	WAC	≤1400 DN (auto)	1x1	Clear	

*Star to Target:

OpNav #	Star ID (Tycho Catalog)	Visual Magnitude
1	1396-02758-1	3.9
2	1396-02758-1	3.9
3	1396-02758-1	3.9
4	1960-01550-1	3.0
5	1960-01550-1	3.0
6	1396-02758-1	3.9
7	1960-01550-1	3.0
8	1960-01550-1	3.0

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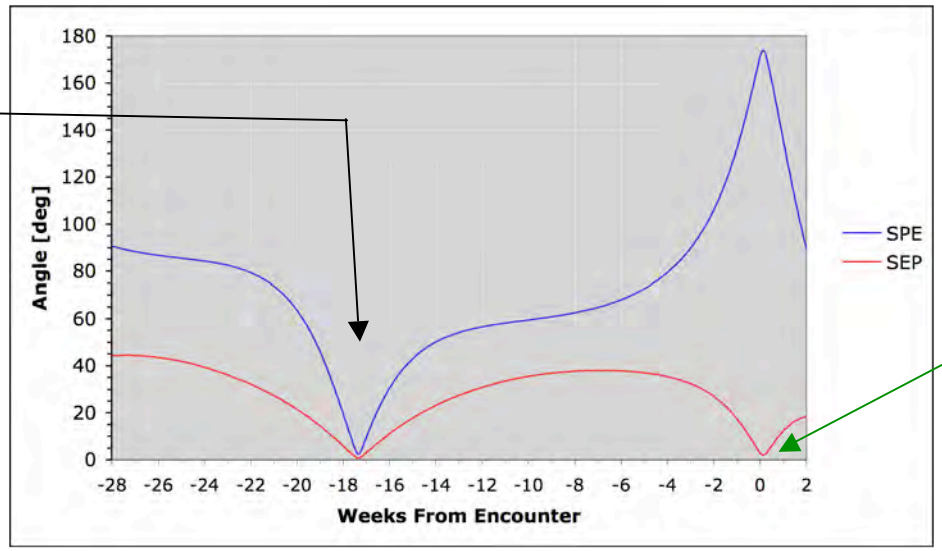
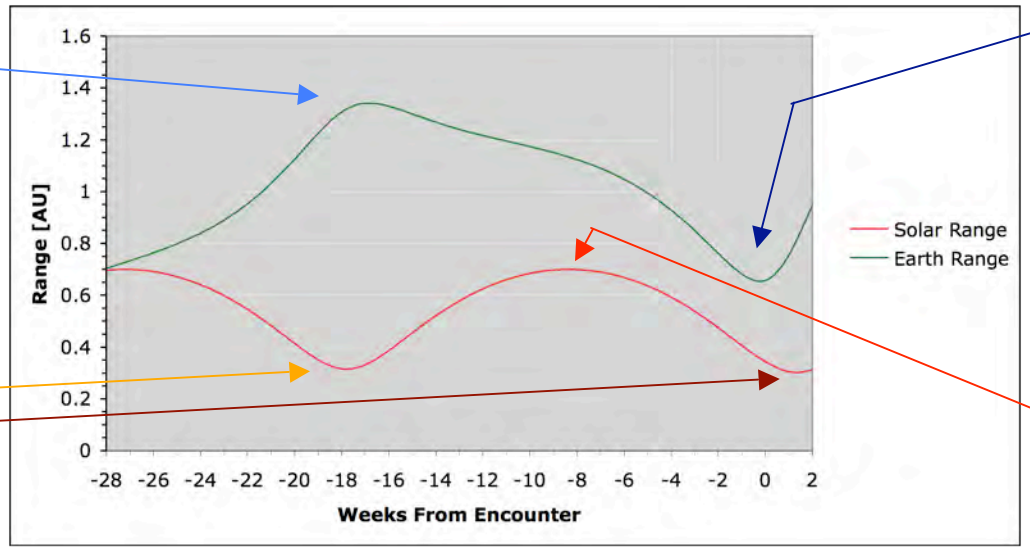
Sun-Earth Geometry Over Remainder of M1-M2 Leg

Superior Solar Conjunction
4-8 June 2008
(SEP ≤ 3 deg)



Inferior Solar Conjunction
6-7 Oct 2008
M2-8h -> M2+38h
(2-3 deg SEP)

Maximum Earth Range
9 June 2008
(1.341 AU)



Minimum Earth Range
4 Oct 2008
(0.654 AU)

Perihelia:
- 3 June 2008 (0.316 AU)
- 15 Oct 2008 (0.302 AU)

Aphelion
8 Aug 2008
(0.700 AU)