Conjunction Assessment Plans for the Juno Earth Flyby

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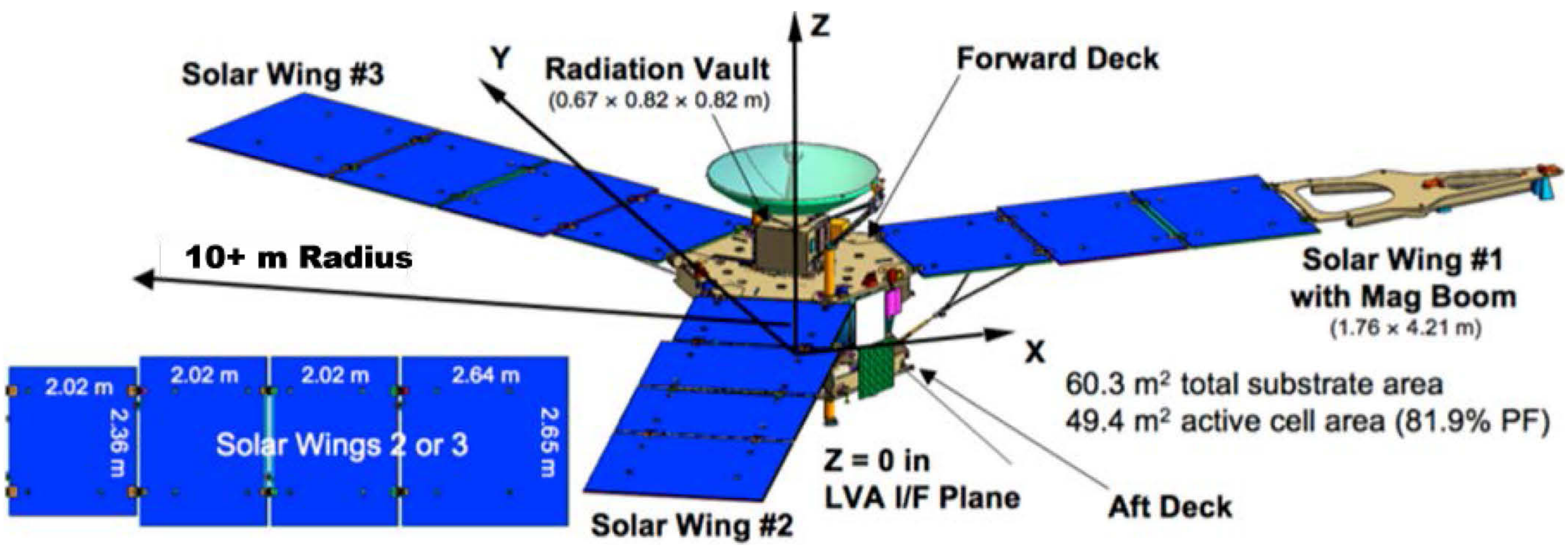
Juno Mission Overview

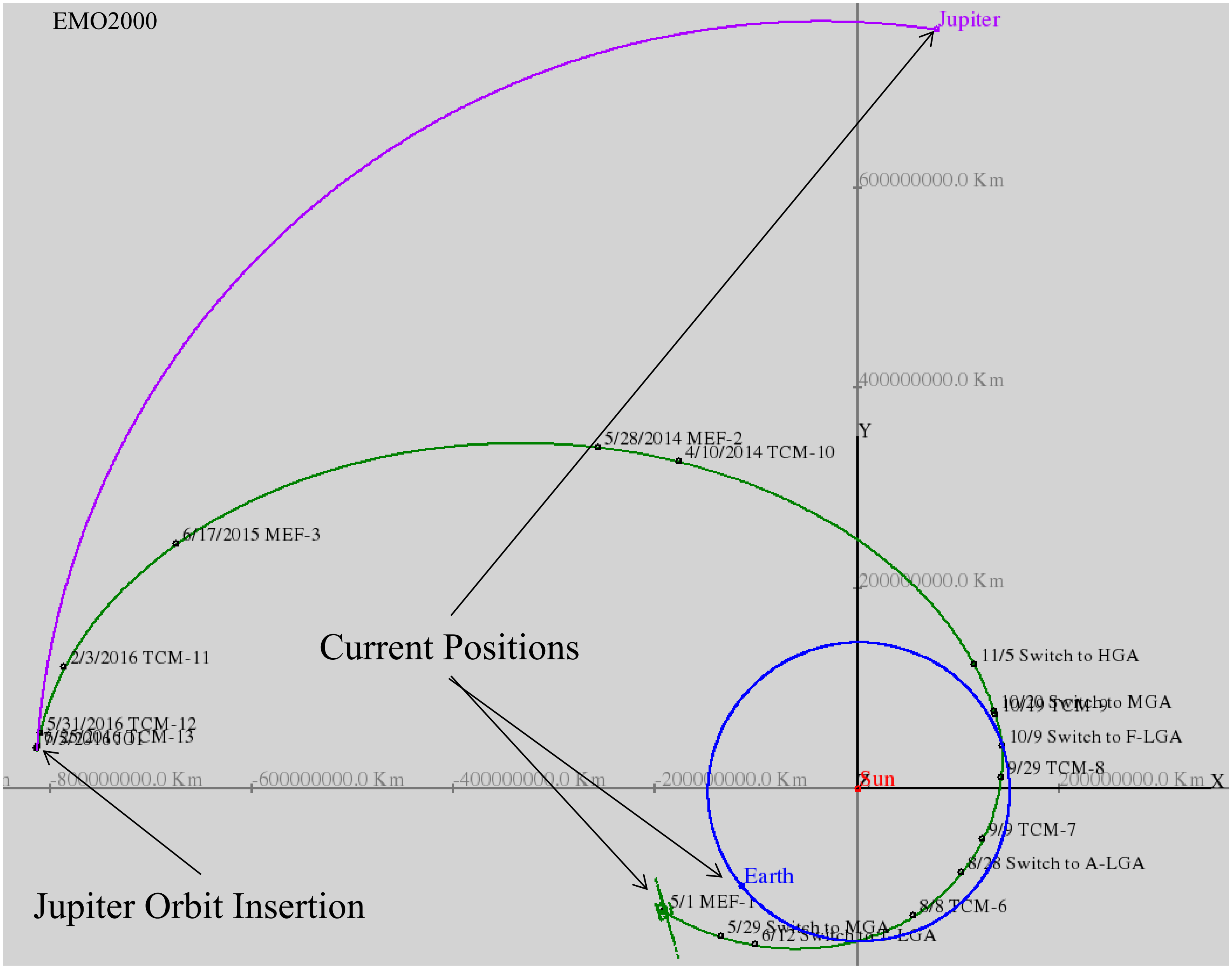
- Juno is a New Frontiers mission that launched on August 5th, 2011 and is scheduled to arrive at Jupiter in July of 2016
- Juno will be placed in a polar orbit around Jupiter for approximately one year, after which the spacecraft will be disposed of by impacting Jupiter
  - Primary Goal of the mission is to improve our understanding of the solar system by understanding the origin and evolution of Jupiter
- Juno is using a delta-velocity Earth gravity assist (ΔV-EGA) trajectory to reach Jupiter
  - The Deep Space Maneuvers, successfully performed earlier this year, targeted the Earth Flyby for October 9, 2013
  - The Earth Flyby (EFB) provides 7.3 km/s Gravity Assist
- Prior to the EFB, there are three Trajectory Correction Maneuvers planned at EFB – 60 days, EFB – 30 days & EFB – 10 days, with a contingency opportunity also planned for EFB – 5 days
  - Each of these maneuvers will be designed to target the spacecraft back to the reference trajectory

Juno Spacecraft

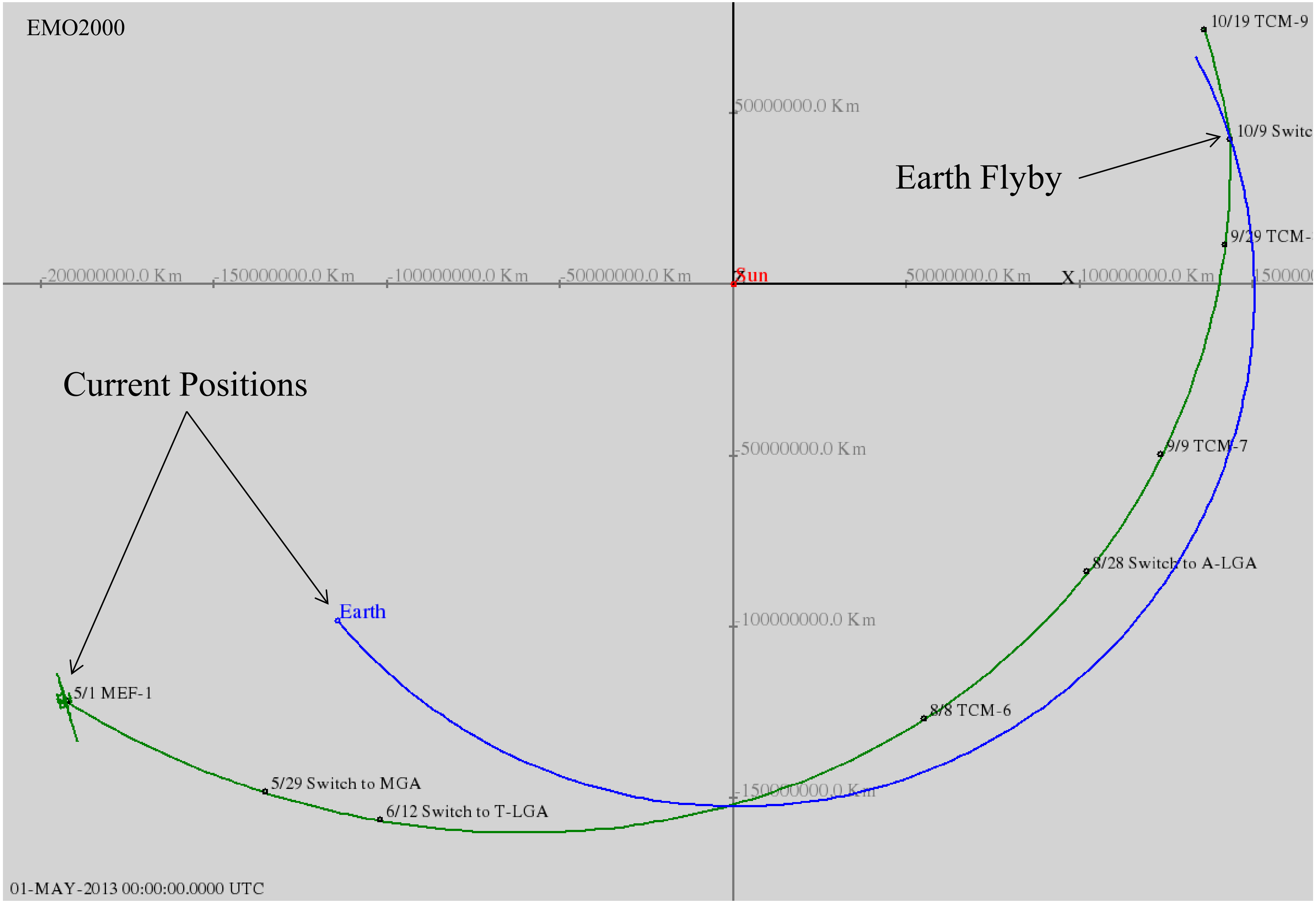
- As a solar powered mission to the outer solar system, the solar arrays are large, giving Juno more than a 20 m diameter (total Z-direction cross-area is about 72 m^2)
- Juno is spin-stabilized, with spin direction being coincident with the positive Z-axis
- The main engine is mounted on the aft deck and is fixed in the negative Z-direction
  - Next primary usage is for the Jupiter Orbit Insertion maneuver
- The balanced RCS thrusters are used for all the future interplanetary maneuvers
  - Three mounted on each of the four thruster towers (2 on the forward deck and 2 on the rear deck)
- RCS maneuvers are performed in vector mode (an axial component followed by a lateral component)



Juno Trajectory (5/1/2013 to Jupiter Arrival)



Juno Trajectory (5/1/2013 to EFB + 10 days)



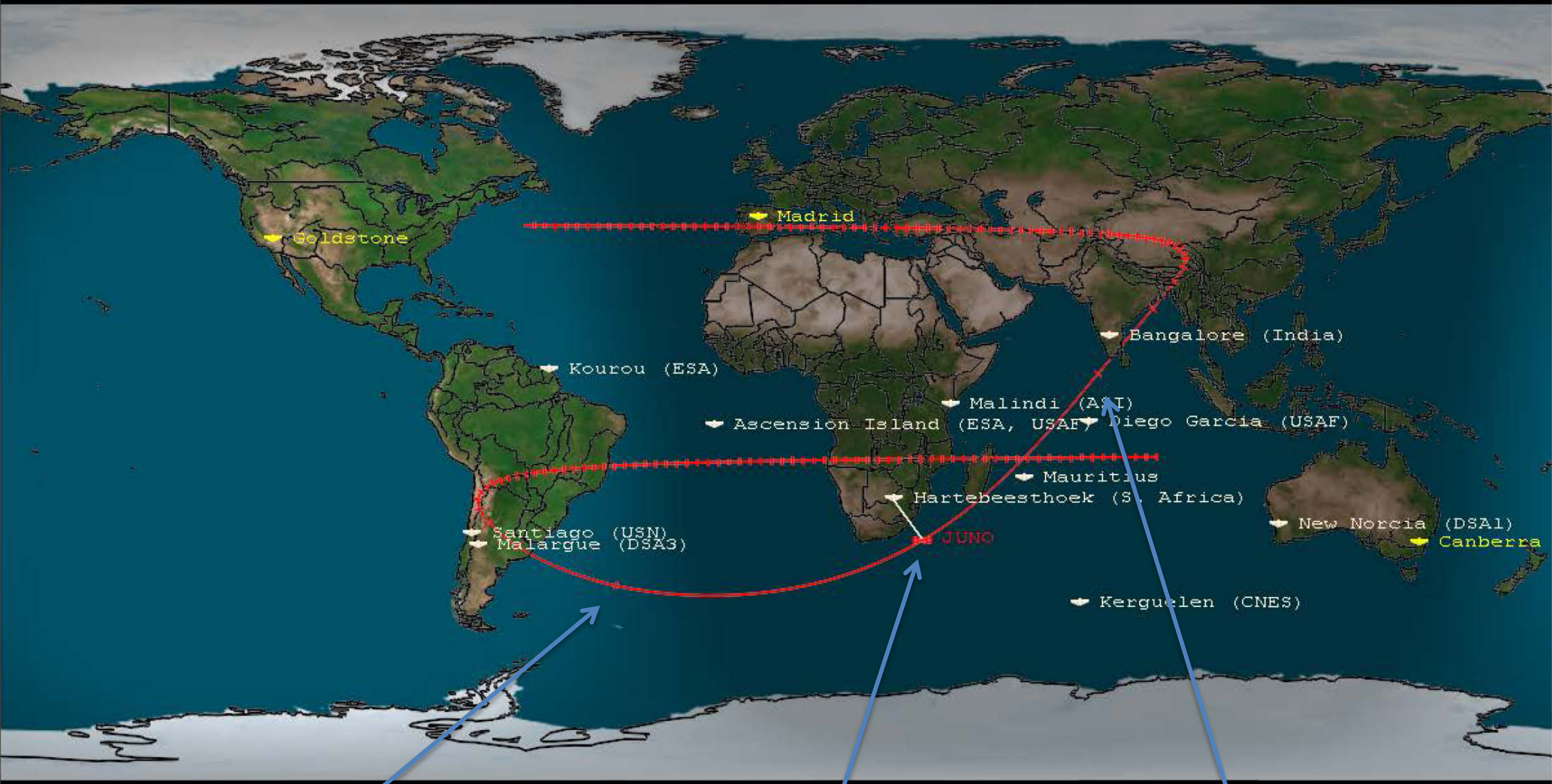
Earth Flyby Characteristics

- Closest Approach (from current reference trajectory):
  - Date/Time = 9-Oct-2013 19:21:48 UTC
  - Altitude = 559 km (Roughly the same altitude as Hubble)
  - Inclination = 47.14 degrees (relative to Earth mean equator)

- The last planned targeting maneuver, at EFB – 10 days, has the following delivery statistics (1-sigma):
  - B-Plane semi-major axis uncertainty = 14.9 km
  - B-Plane semi-minor axis uncertainty = 12.0 km
  - Linear Time-of-Flight uncertainty = 1.7 seconds

- Prediction uncertainty drops significantly as we collect post-TCM tracking and get closer to EFB

Earth Flyby Groundtrack
C/A time: 2013/10/09 19:21:48 UTC (OD052)

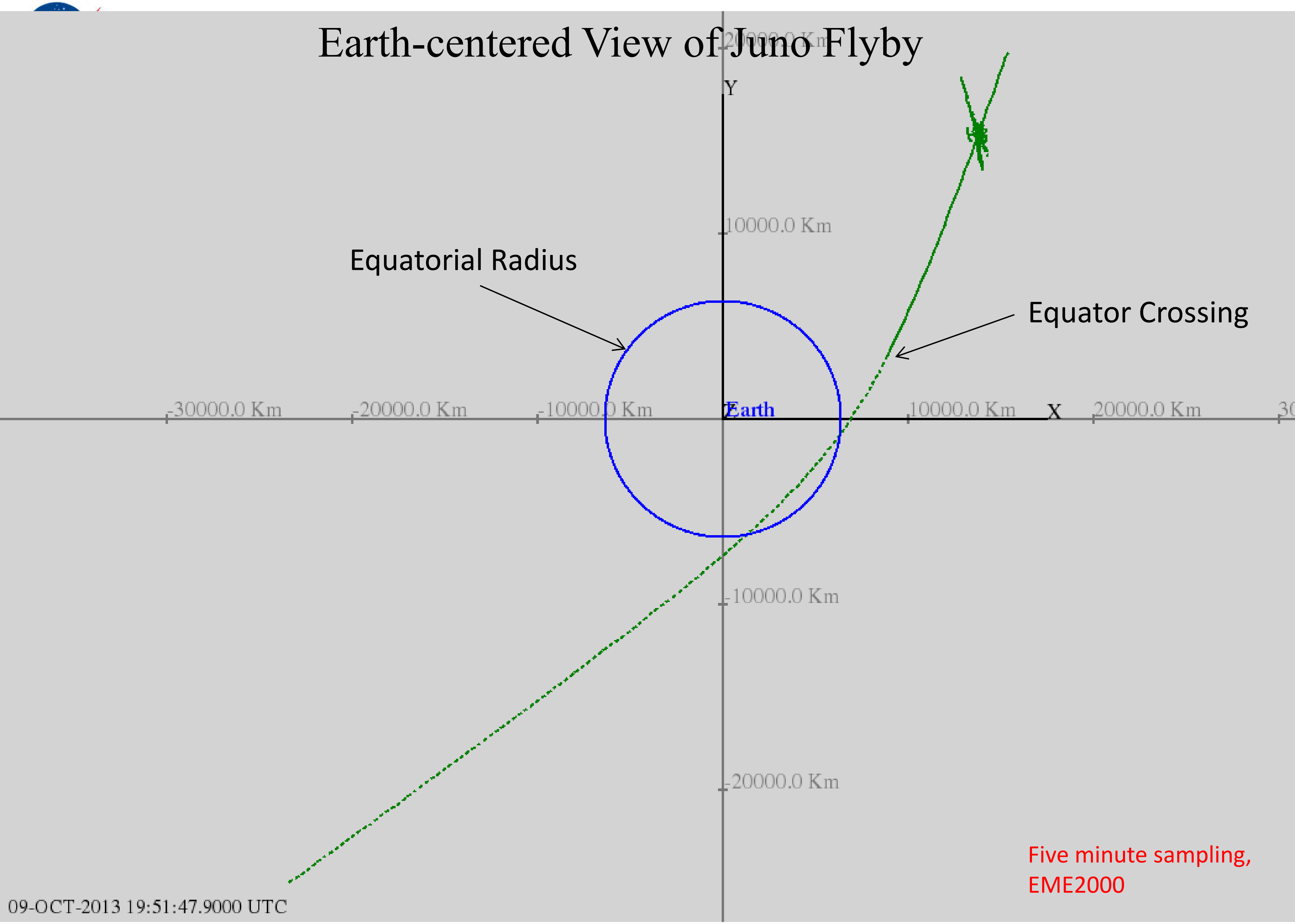


Closest Approach – 10 minutes:
Altitude = ~3930 km

Closest Approach:
Altitude = ~559 km

Closest Approach + 10 minutes:
Altitude = ~3920 km

Earth-centered View of Juno Flyby

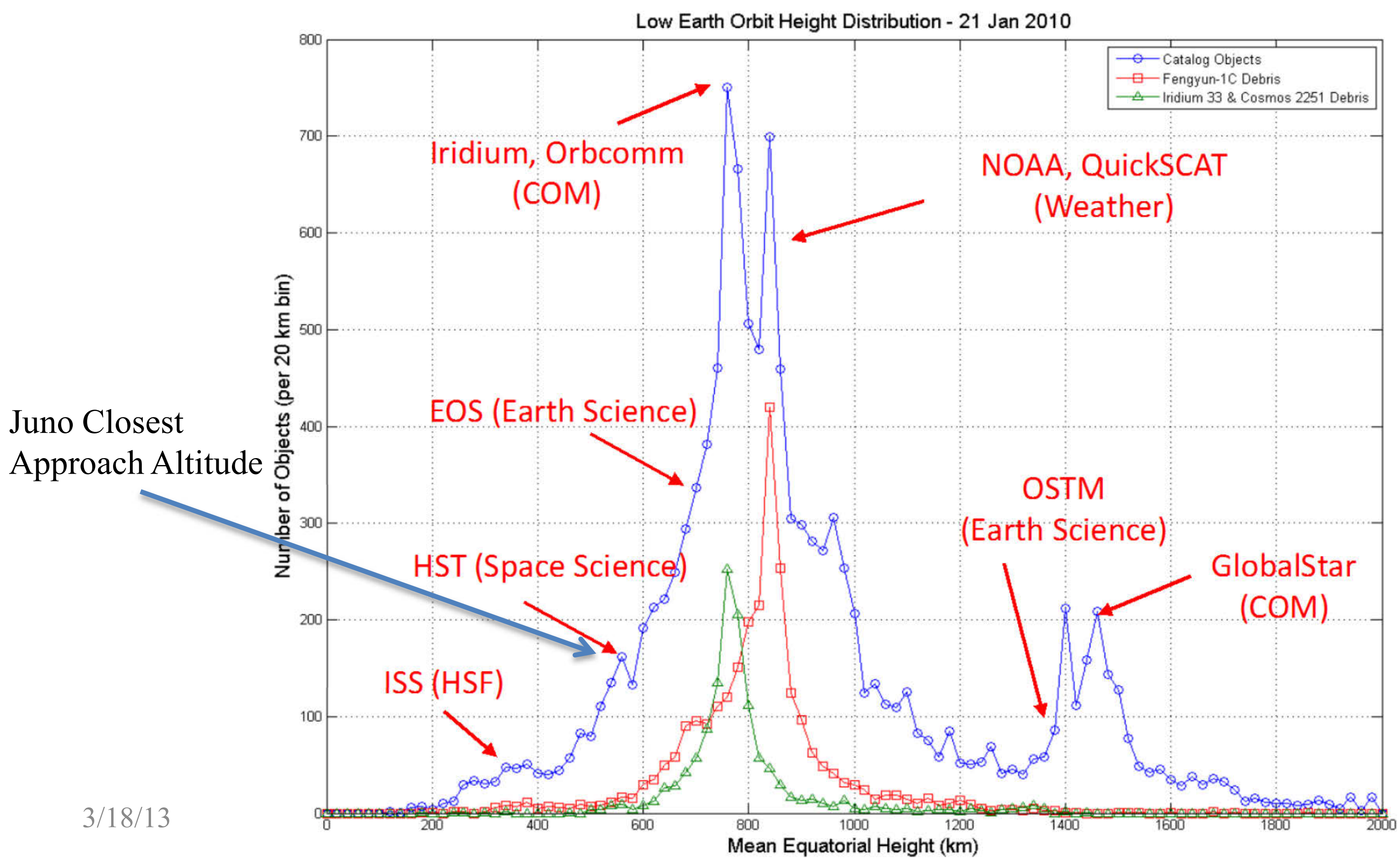


Sun-centered View of Juno Flyby

Looking down on Ecliptic plane,
5 minute sampling

09-OCT-2013 19:51:47.9000 UTC

Current LEO Debris Altitude Distribution



Collision Avoidance Maneuver (CAM) Design

- The CAMs will be designed & ready for execution well in advance of the EFB, with design scheduled to begin in May of 2013
- The two maneuvers will be designed to execute at EFB – ~12 hours (Oct 9, 2013 07:30 UTC) and change the closest approach time by +/- 1 second. The following are approximate values:

Collision Avoidance Maneuver	Magnitude	Axial Component	Lateral Component
+1 second	0.26 m/s	-0.24 m/s	0.09 m/s
-1 second	0.26 m/s	0.24 m/s	0.09 m/s

- Since the majority of the DV for these +/- 1 sec maneuvers is in the s/c Z-direction, the implementation will only include the axial portion of the maneuvers
  - This simplifies the spacecraft activity & also significantly reduces the execution errors
  - It's recognized that performing only the axial portion of the maneuver results in a B-plane shift
  - Additionally, by skipping the lateral portion of the CAM, the change in closest approach time is smaller than the designed +/-1 second
  - The following three slides give more details on the effects of performing an axial-only CAM

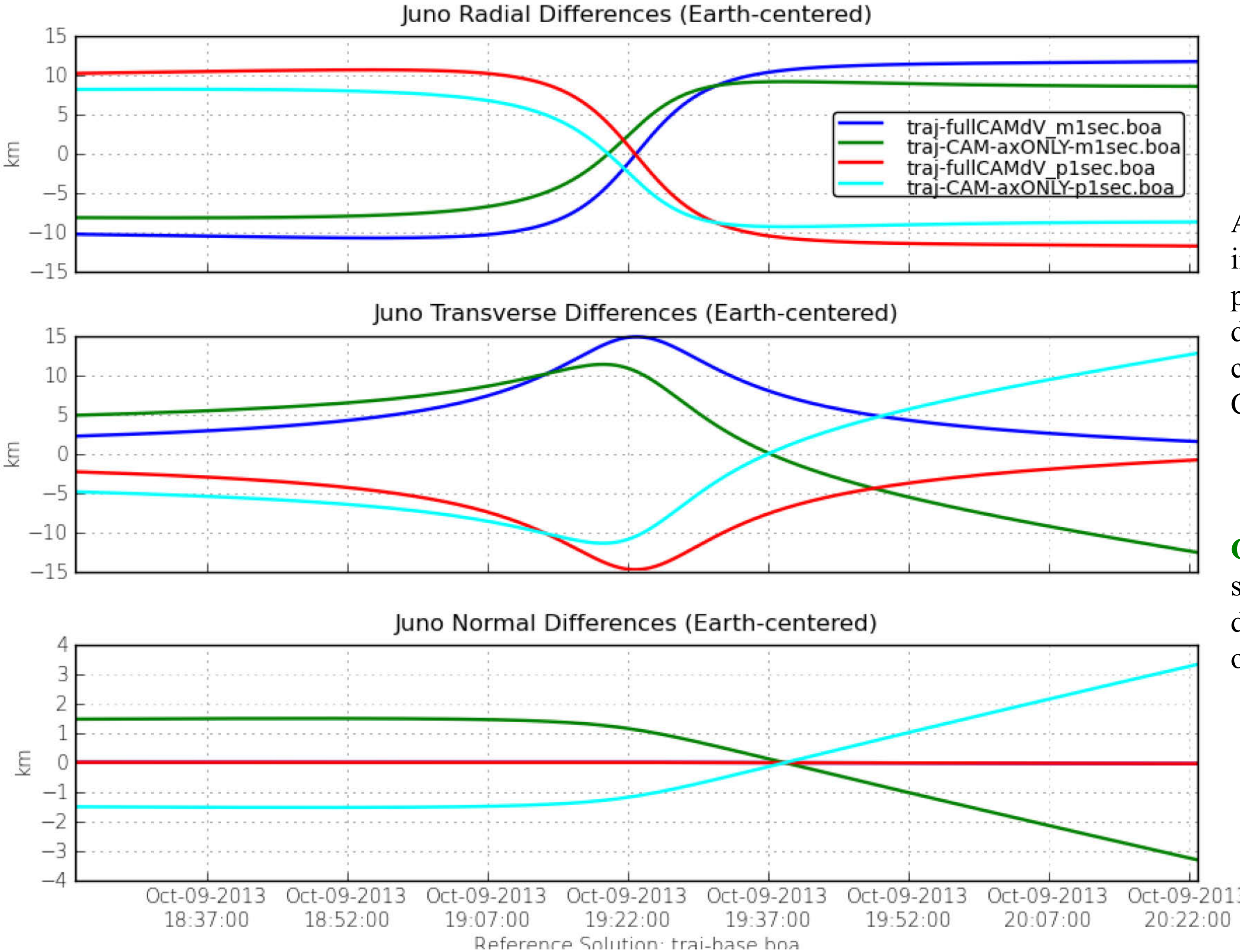
Collision Avoidance Maneuver Design

- When the maneuver is designed to change the time of closest approach by +/- 1 second, there is no B-Plane change caused by performing the CAM
  - This results in very little downstream Delta-V cost
- Performing the axial portion of the CAM & skipping the lateral portion results in a change to both time of closest approach and the B-Plane, these changes are summarized below:

Collision Avoidance Maneuver	Closest Approach Shift	B•R Shift	B•T Shift
+1 second, Axial-only	+0.76 sec	-1.3 km	-3.7 km
-1 second, Axial-only	-0.76 sec	+1.3 km	+3.7 km

- Depending on the final approach maneuver delivery, the Delta-V penalty for this amount of B-plane shift could be ~2.5 m/s
- For reference, the TCM-8 B-Plane 1-sigma delivery statistics are as follows:
  - B-Plane semi-major axis uncertainty = 14.9 km
  - B-Plane semi-minor axis uncertainty = 12.0 km
  - Linear Time-of-Flight uncertainty = 1.6 seconds

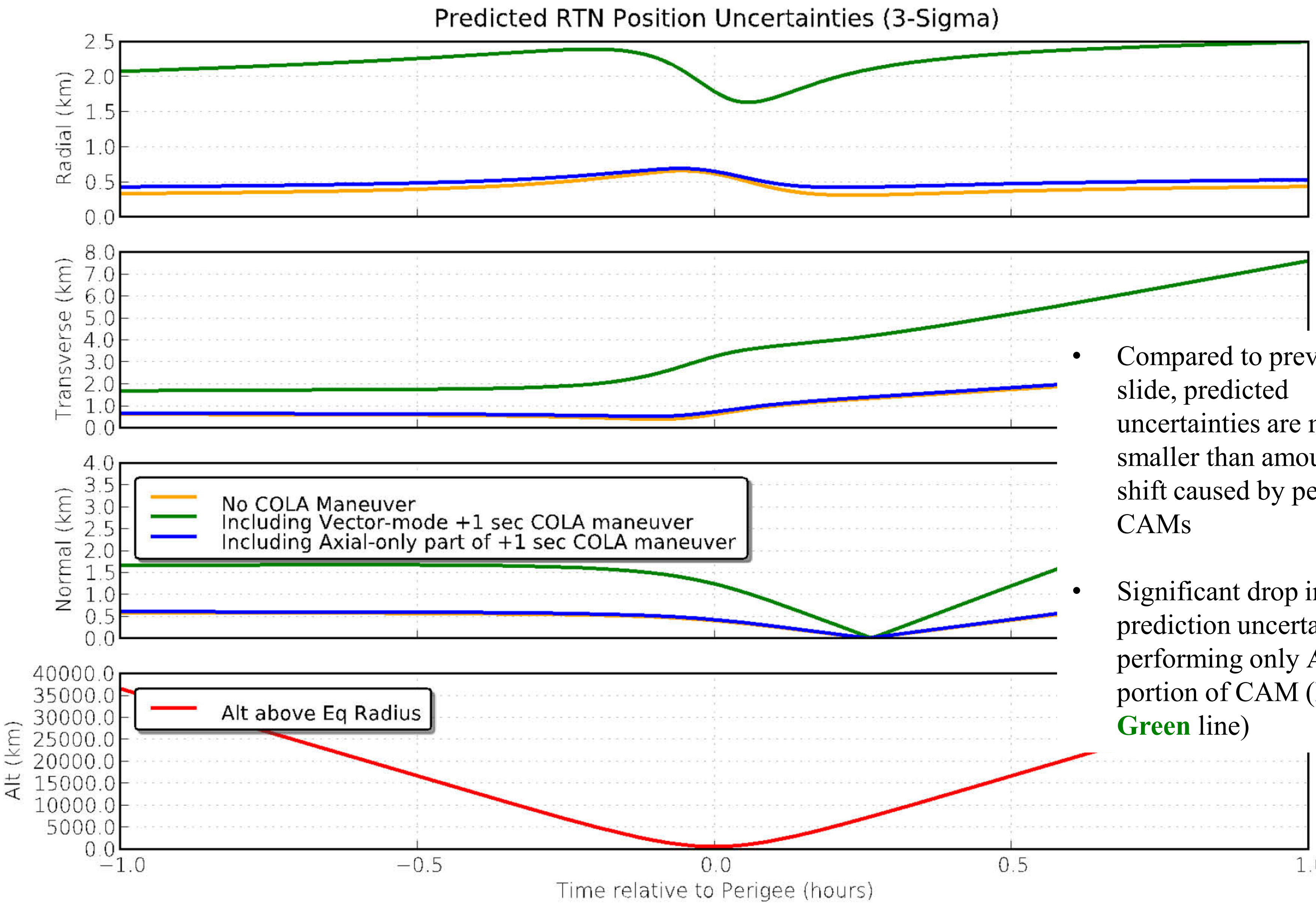
Trajectory Differences Caused by CAMs



At least 10 km shift in trajectory by performing CAMs during 2 hours centered at Earth Closest Approach

Green & **Cyan** lines show trajectory differences for **Axial-**only maneuvers

Predicted Position Uncertainties During EFB, Data Cutoff at EFB – 36 Hours (Final Go/No-Go DCO)



- Compared to previous slide, predicted uncertainties are much smaller than amount of shift caused by performing CAMs
- Significant drop in prediction uncertainty by performing only **Axial** portion of CAM (**Blue** vs **Green** line)

Time inside Geosynchronous Orbit Radius ≈ EFB - 1 hour to EFB + 1 hour

CAM Go/No-Go Strategy

- The CARA (Conjunction Assessment and Risk Analysis) group at Goddard will be our interface with JSpOC for performing the conjunction assessments and providing the information used to determine the need to perform a collision avoidance maneuver
- The first conjunction assessment will be performed at EFB – 90 days
  - This is too far in advance to learn anything about the risk associated with the actual flyby conditions, but will make sure that there are no problems in any part of the process
- Starting at EFB – 10 days, Juno Navigation will deliver the predicted ephemeris and associated covariance files to CARA on a daily basis
  - Each day, there will be three different cases delivered:
    1. Nominal predicted trajectory/covariance
    2. Predicted trajectory/covariance including the axial-only +1 second collision avoidance maneuver
    3. Predicted trajectory/covariance including the axial-only -1 second collision avoidance maneuver
- CARA works with JSpOC to determine risk of impact with Earth-orbiting objects for each delivery
- At EFB – 1 day the final Go/No-Go decision will be made on whether to perform one of the Collision Avoidance maneuvers
  - In the days leading up to the EFB, we expect to be able to see the trend of how things look, so we shouldn't be surprised on the last day about the need to perform one of the collision avoidance maneuvers
  - The current criteria for choosing to perform one of the collision avoidance maneuvers is given on the following page

CAM Criteria

- A collision avoidance maneuver will be performed if both of the following conditions apply:
  - The Probability of Impact with any object using the predicted nominal (no-burn) trajectory is greater than 0.01%
  - Either of the +/- 1 second collision avoidance maneuver trajectories reduces the probability of impact by more than a factor of 100

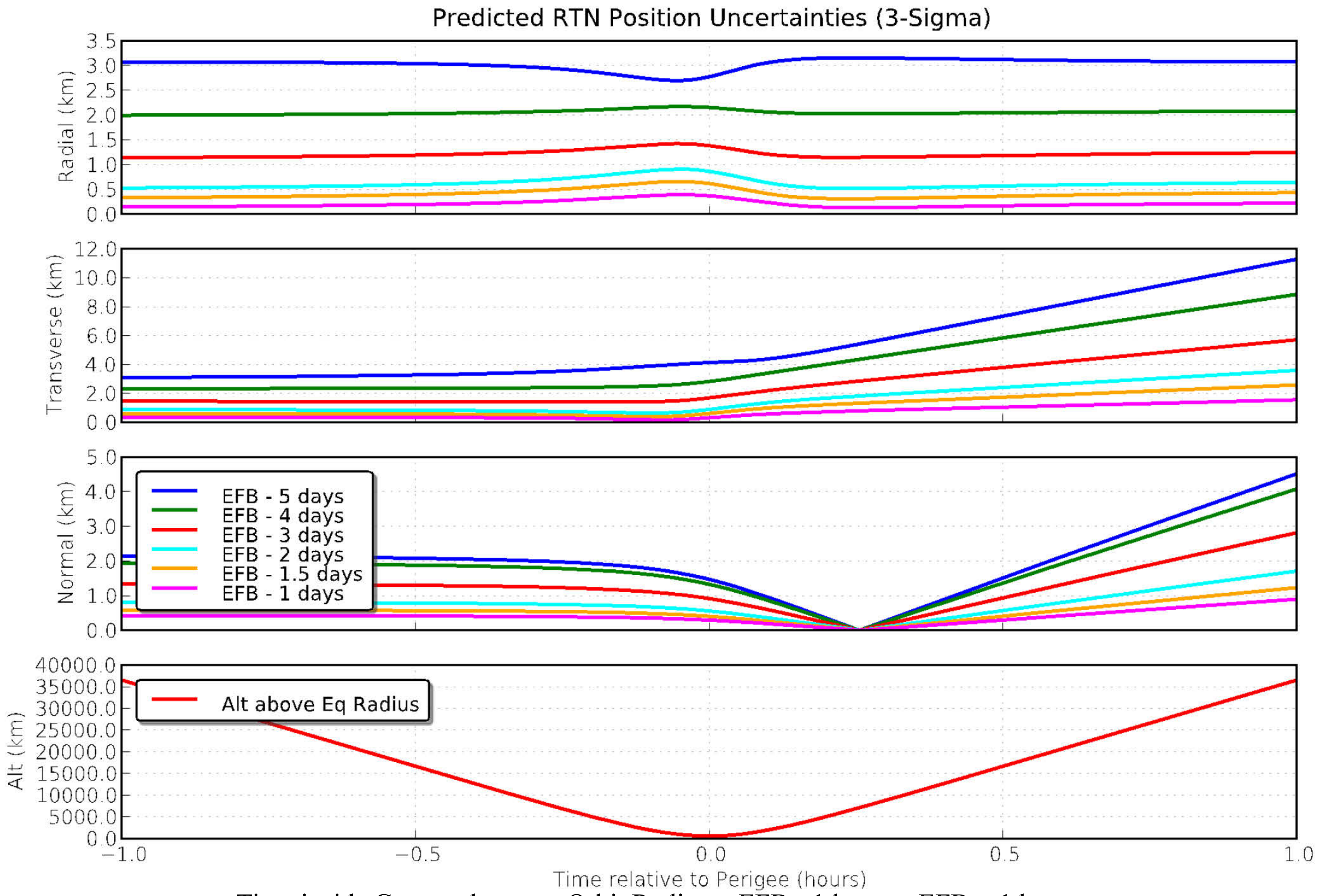
- If the above indicates that a CAM is needed, the decision between the two maneuvers (+/- 1 second) will be made according to the following:
  - If only one of the collision avoidance maneuvers reduce the probability of impact by more than a factor of 100, then the CAM that reduces the probability of impact the most is chosen
  - If both of the collision avoidance maneuvers reduce the probability of impact by more than a factor of 100, then the CAM that moves the spacecraft closer to the B-Plane target will be chosen (to save propellant)

Final CAM Go/No-Go Decision Timeline

Date/Time (UTC)	Event Description
10/08, 08:00	EFB – 35.5 hrs: Data Cutoff (Canberra Pass)
10/08, 12:00	EFB – 31.5 hrs: Deliver all three cases to CARA team (no-burn & 2 COLA maneuver cases)
10/08, 18:00	EFB – 25.5 hrs: CARA analysis delivered to Juno Nav Team
	~12 hours covers margin and time to decide if anything needs to be done and upload appropriate maneuver, if needed
10/09, 07:30	EFB – 12 hrs: Execute collision avoidance maneuver, if needed

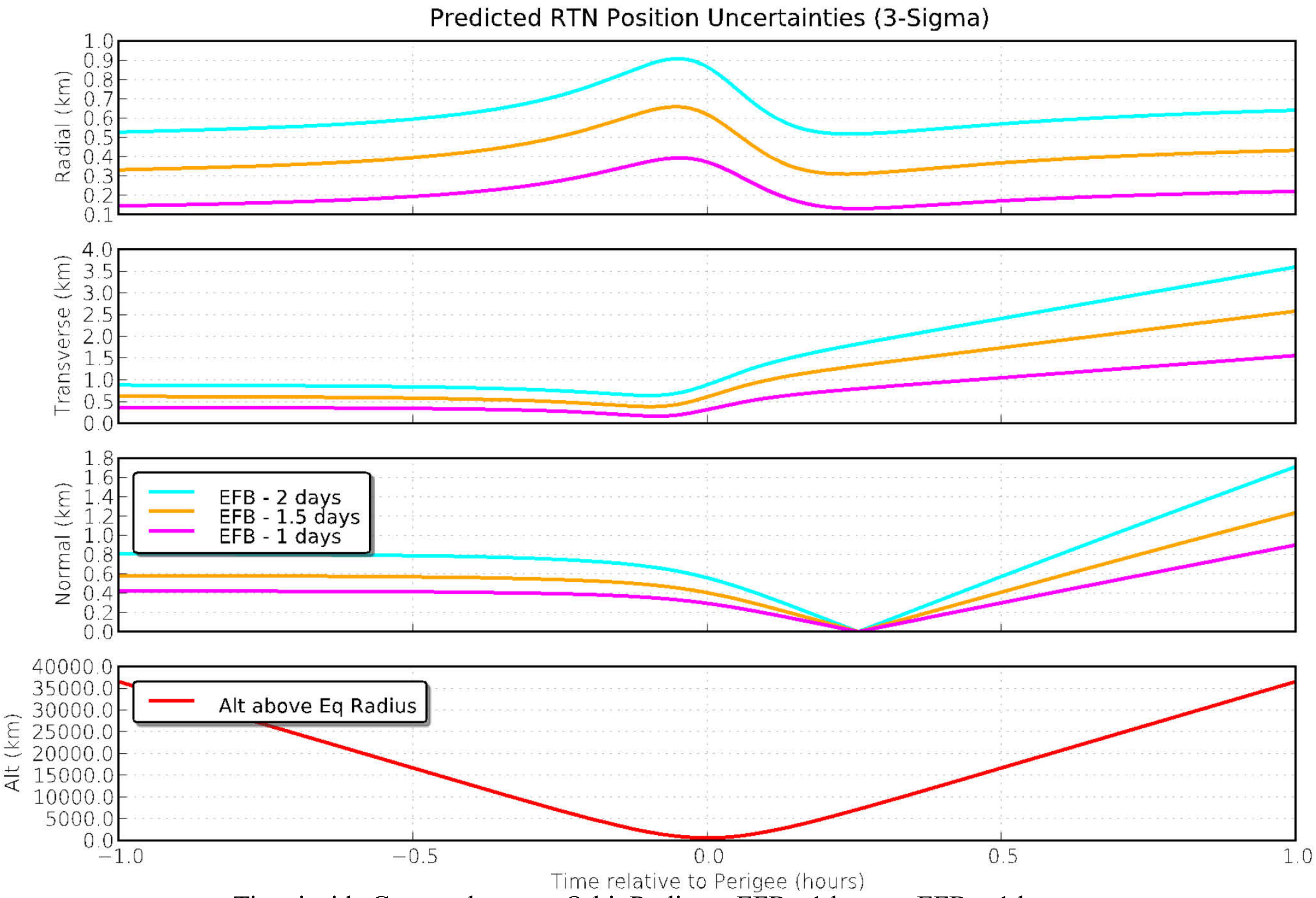
BACK-UP MATERIAL

Predicted Juno Position Uncertainties during EFB



Time inside Geosynchronous Orbit Radius = EFB - 1 hour to EFB + 1 hour

Predicted Juno Position Uncertainties during EFB
(last couple days)



Time inside Geosynchronous Orbit Radius = EFB - 1 hour to EFB + 1 hour

Predicted EFB Velocity Uncertainties