



**Jet Propulsion Laboratory**  
California Institute of Technology

# Maneuver Operations During Juno's Approach, Orbit Insertion, and Early Orbit Phase

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# Summary

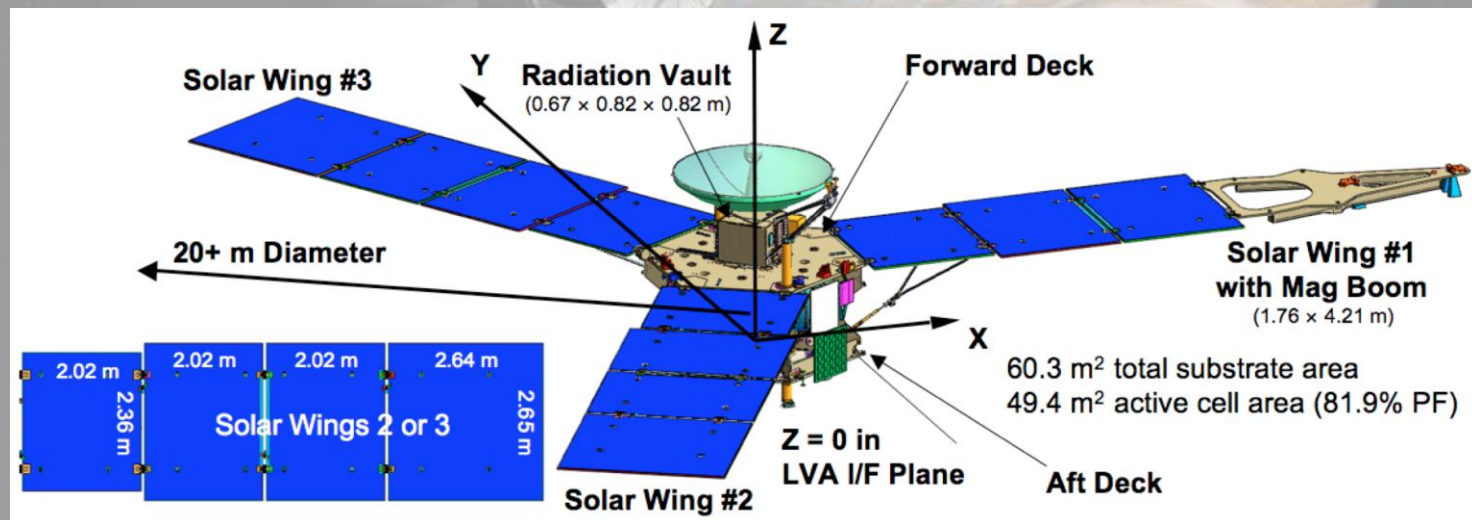
- Juno is currently in orbit at Jupiter after successful Jupiter Orbit Insertion
- Target requirements have been achieved in all equator crossings
- There were many changes to the mission that effected the maneuver team
  - Maneuver cancellations
  - Added maneuvers
  - Maneuver locations and purposes

# Agenda

- Propulsion system overview
- Maneuver modes overview
- Approach Phase
- Jupiter Orbit Insertion Maneuver
- Capture Orbit Phase
- Period Reduction Maneuver
- Science Orbit Phase
- Questions

# Propulsion System

- Main-engine (ME)
  - 662 Newton
  - Pointed along spin axis
  - Used for large DV maneuvers
- Reaction Control System (RCS)
  - 4.5 Newton
  - Balanced
  - Axial thrusters
    - Cant  $10^\circ$  away spin axis
  - Lateral Thrusters
    - Cant  $12.5^\circ$  toward spin axis and 5 away from solar panel wing with magnetometer

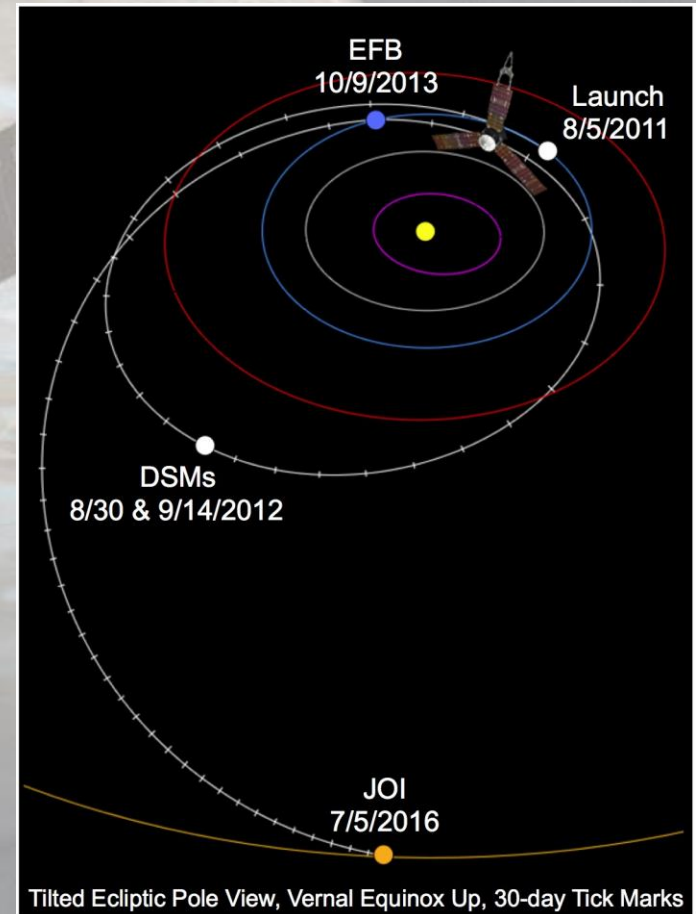


# Maneuver Modes

- Turn-Burn-Turn
  - Turn to burn attitude
  - Burn
  - Turn back to previous Earth point attitude
- Vector-Mode
  - Remain in Earth point attitude
  - Decompose the maneuver vector
    - Axial component
      - Continuous pulsing
      - Point parallel to spin axis
    - Lateral component
      - Pulse width of  $\pm 30^\circ$  due to spacecraft spin
      - Point radially outward from spin axis

# Approach Phase

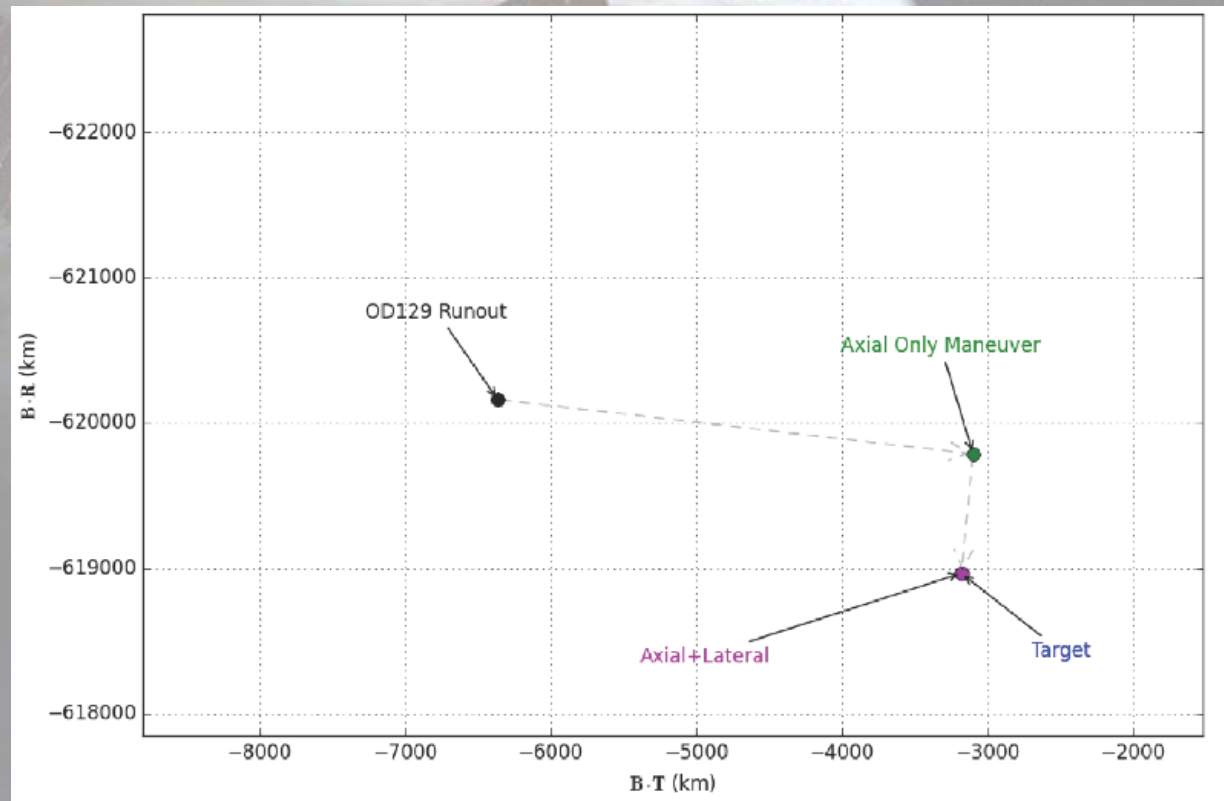
- B-plane targets to set up Jupiter Orbit Insertion conditions
- Maneuvers during approach
  - TCM11 (JOI-5 months)– deterministic
  - TCM12 (JOI-34 days) – statistical, canceled
  - TCM12a (JOI-19 days) – statistical, canceled
  - TCM13 (JOI-9 days) – statistical, canceled



# Trajectory Correction Maneuver (TCM) 11

Feb 3, 2016 18:00:00 ET (JOI-5 months)

- Targets: Jupiter Orbit Insertion B-plane parameters
- Mode: Vector
- $\Delta V$  Total: 0.307 m/s
  - Axial 0.279 m/s
  - Lateral 0.139 m/s
- Thruster: RCS



# Jupiter Orbit Insertion (JOI)

July 5, 2016 2:30:00 UTC

- Inertially-fixed
- Centered around perijove (PJ)
- Mode: Turn-burn-turn
- $\Delta V$ : 541.65 m/s
- Thruster: Main-engine
- Duration: 2097.0 seconds
- Resulting Orbit: 53.5 days





# Capture Orbit Operations

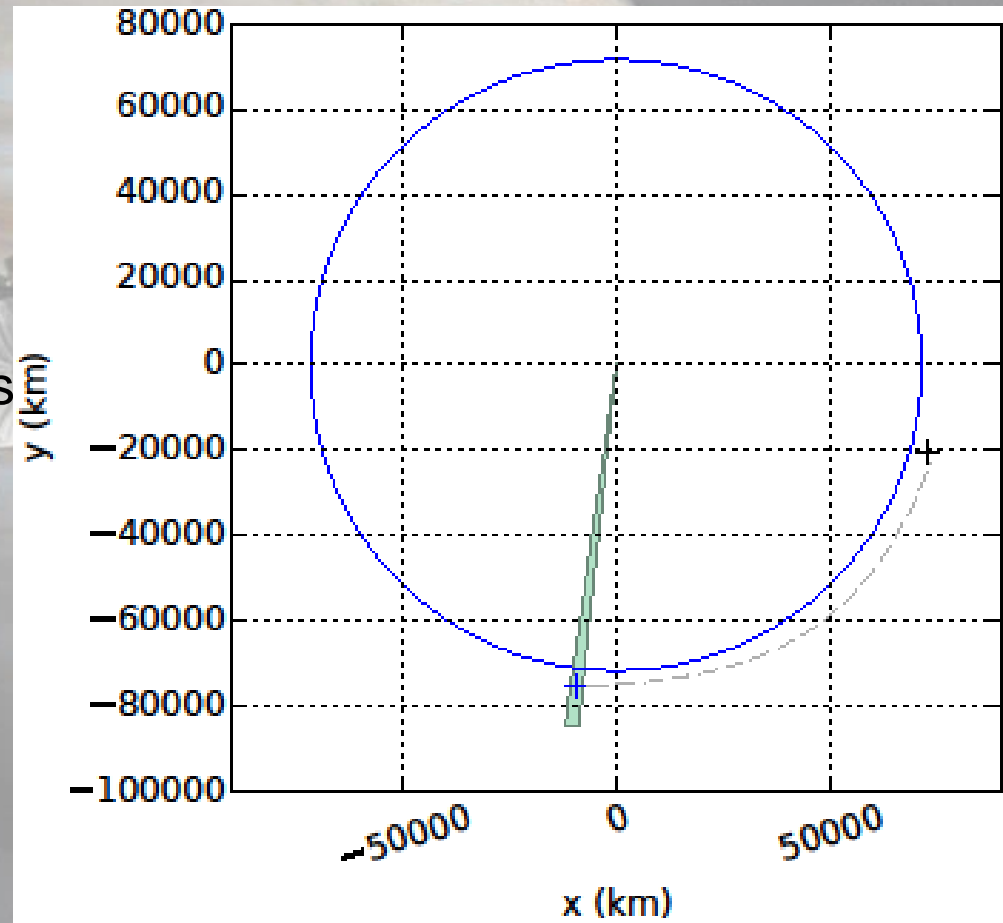
A large, semi-transparent image of the Juno spacecraft is overlaid on the slide. The spacecraft is shown from a perspective that suggests it is approaching the planet Jupiter, which is visible in the background as a large, orange and white striped sphere. The spacecraft's main body, solar panels, and antenna are clearly visible.

- Capture orbits were the first two orbits of Jupiter
- Analyze/reconstruct JOI
- Gather science data from one perijove pass
- Perform capture orbit maneuvers
  - JOI Clean-Up – deterministic
  - **Orbit Trim Maneuver (OTM) 00 – statistical, canceled**
  - OTM01 – deterministic
- Final design of Period Reduction Maneuver

# JOI Clean-Up (JOI-CLN)

July 13, 2016 18:00:00 ET (PJ0+8.6 days)

- Targets: PJ01 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 4.918 m/s
  - Axial 1.155 m/s
  - Lateral 4.831 m/s
- Thruster: RCS
- Corrects JOI execution errors
- Green longitude wedge  $\pm 1^\circ$  from desired target



# OTM00

July 27, 2016 18:00:00 ET (PJ0+22.6 days)

- Targets: PJ01 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 0.062 m/s
  - Axial 0.040 m/s
  - Lateral 0.049 m/s
- Thruster: RCS
- Statistical maneuver
- Maneuver was not needed therefore canceled

# OTM01

Sep 14, 2016 18:00:00 UTC (PJ01+18.2 days)

- Targets: PJ02 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 0.604 m/s
  - Axial -0.051 m/s (negative number indicates burn direction)
  - Lateral 0.600 m/s
- Thruster: RCS
- After first science pass
- Target Period Reduction Maneuver initial conditions

# Period Reduction Maneuver (PRM)

Oct 19, 2016 18:00:00 UTC (PJ02)

- Inertially-fixed
- Centered around perijove (PJ02)
- Target: Orbit Period of 14 days
- Mode: Turn-burn-turn
- $\Delta V$  Total: 395.17 m/s
- Thruster: Main-Engine
- Duration: 1305.4 seconds
- Canceled due to valve anomaly at checkout

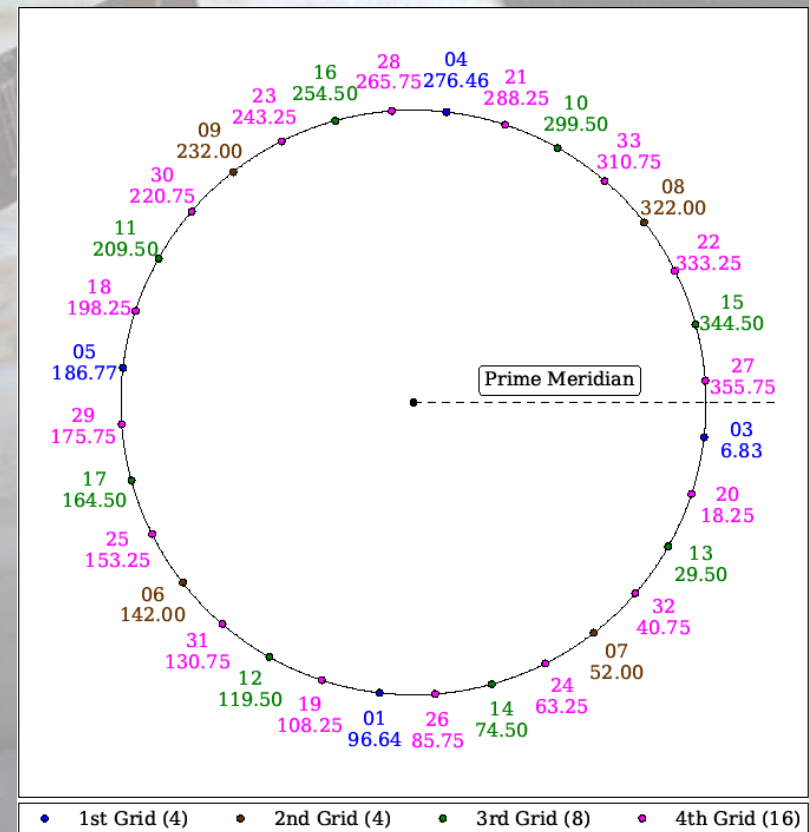
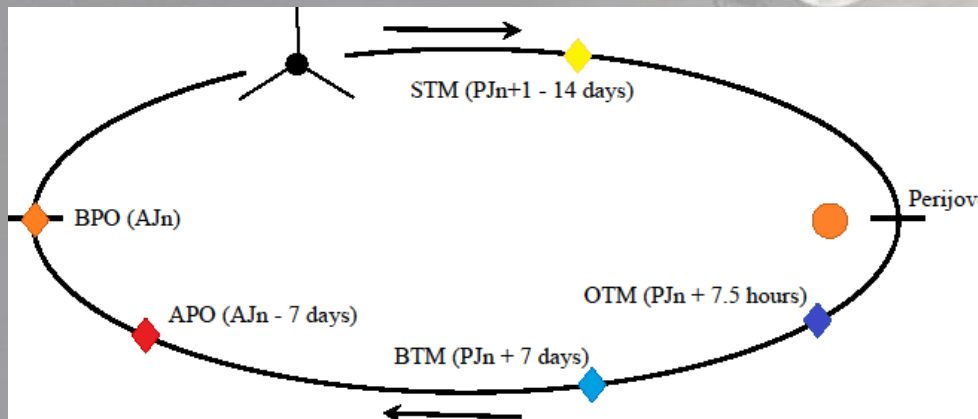
# OTM02

Oct 25, 2016 18:00:00 ET (PJ02+6 days)

- Targets: PJ03 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 2.618 m/s
  - Axial 0.585 m/s
  - Lateral 2.580 m/s
- Thruster: RCS
- Added due to PRM cancellation
- Due to safing event at PJ02, OTM02 changed targets midway through the design process

# Science Orbit Phase

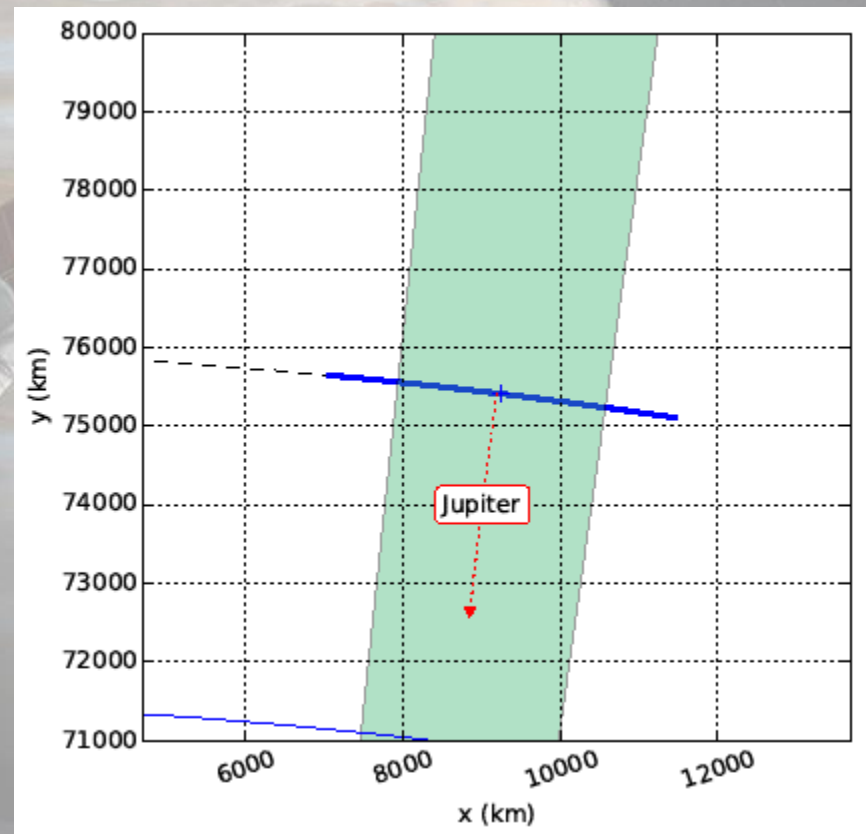
- Complete 32 orbits with evenly spaced equator crossing longitudes
- Maneuver opportunities increased from two to five (Note: Not every orbit needs nor utilizes all of these maneuvers)
  - OTM (PJ+7.5 hours)
  - BTM (PJ+7 days)
  - APO (AJ-7 days)
  - BPO (AJ)
  - STM (PJn+1 -14 days)



# OTM03

Dec 12, 2016 00:34:00 UTC (PJ03+7.5 hours)

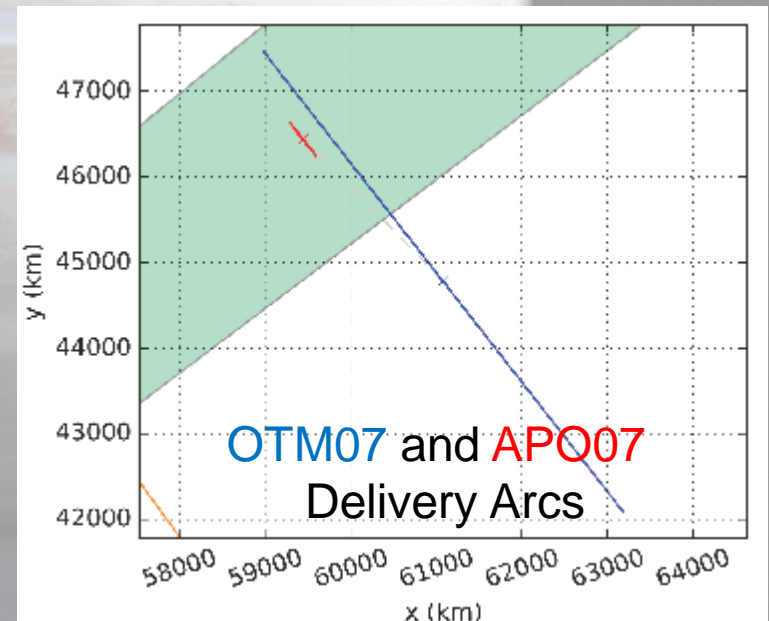
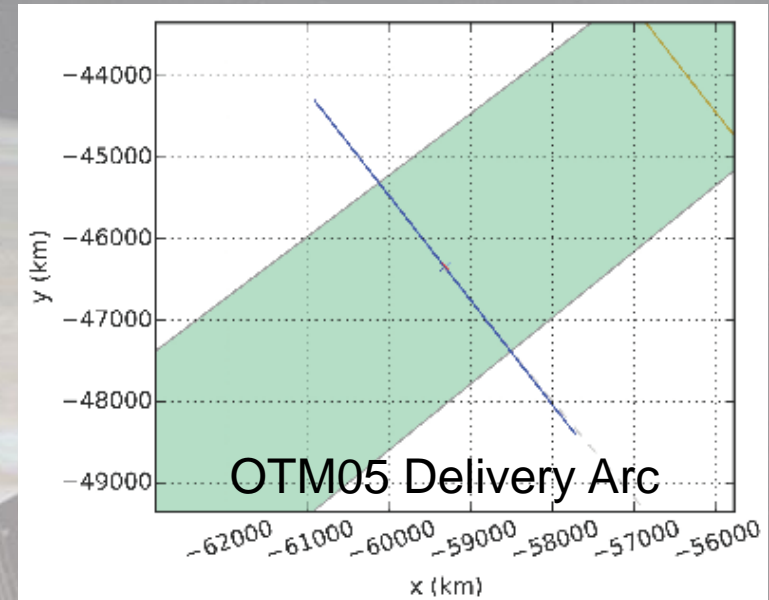
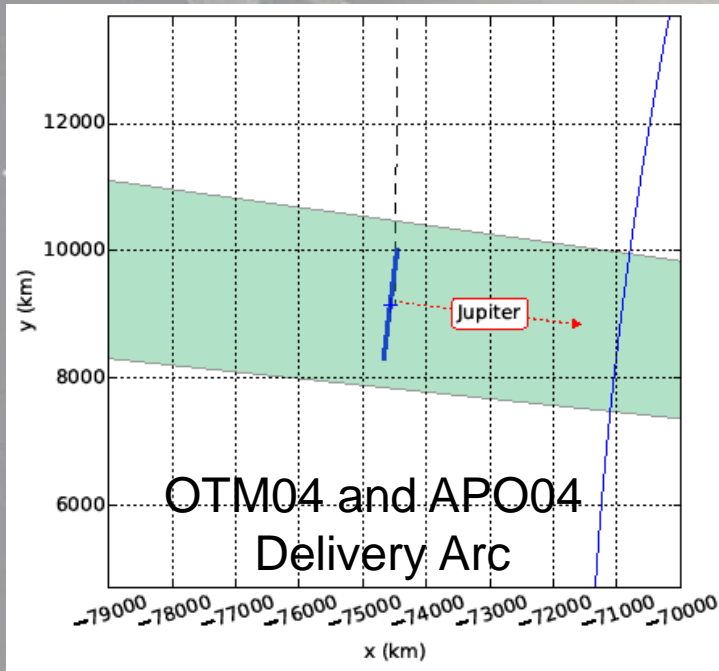
- Targets: PJ04 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 1.201 m/s
  - Axial -0.264 m/s
  - Lateral 1.159 m/s
- Thruster: RCS
- Only maneuver needed to target PJ04
- Blue arc is  $1\sigma$  delivery arc





# Other Maneuver Deliveries

Material found in paper

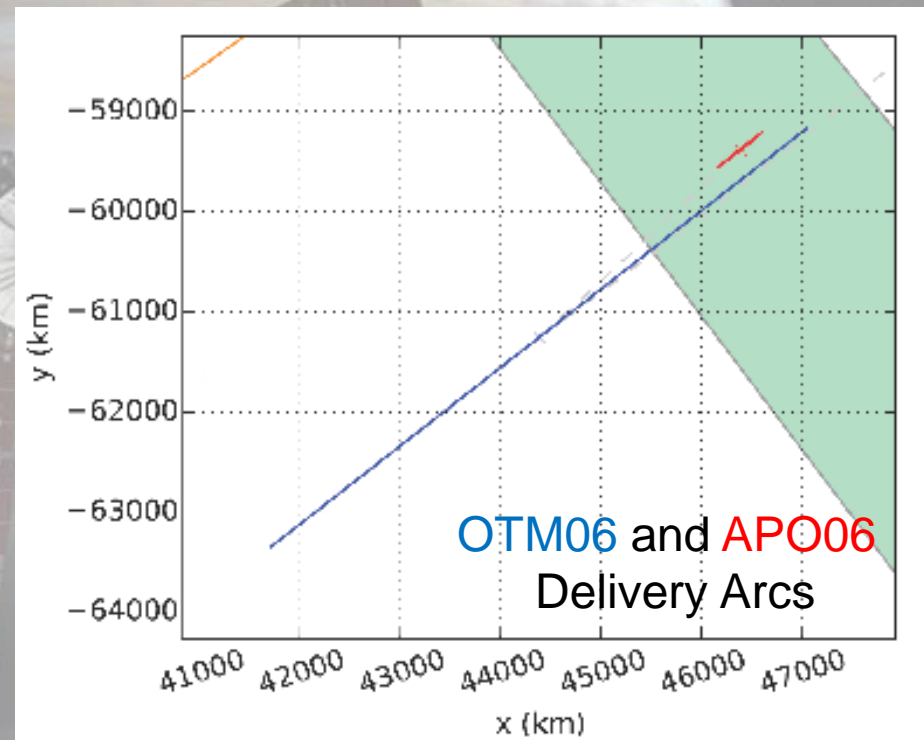


Note: Delivery Arcs are  $1\sigma$

# APO06

June 8, 2017 18:00:00 UTC (PJ06+20.5 days)

- Targets: PJ07 Radius and West Longitude
- Mode: Vector
- $\Delta V$  Total: 1.095 m/s
  - Axial 0.008 m/s
  - Lateral 1.095 m/s
- Thruster: RCS
- Axial minimum  $\Delta V$  12 mm/s
- Axial portion canceled
- Removal of axial effects
  - Radius: 0.262 km
  - Longitude: 0.015 degrees



# Summary

- Juno is currently in orbit at Jupiter after successful Jupiter Orbit Insertion
- Target requirements have been achieved in all equator crossings
- There were many changes to the mission that effected the maneuver team
  - Maneuver cancellations
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Questions?

A composite image featuring the planet Jupiter in the background, showing its characteristic orange and white horizontal bands. In the foreground, the Juno spacecraft is visible, with its three large, reddish-brown solar panels extended. The spacecraft is positioned as if orbiting the planet. The text "Backup Slides" is overlaid in the center of the image.

**Backup Slides**

# Maneuver Performance Table

Table 2. Estimated Maneuver Performance vs. Design

Maneuver	$\Delta V$ Magnitude (m/s)			Right Ascension (deg)			Declination (deg)		
	Est.	Design	$AP \sigma$	Est.	Design	$AP \sigma$	Est.	Design	$AP \sigma$
TCM11 Axial	0.282	0.279	0.002	359.659	359.660	0.239	-2.582	-2.547	0.239
TCM11 Lateral	0.139	0.139	0.015	265.424	265.677	2.3	-31.058	-29.840	2.0
JOI	542.107	541.655	0.451	268.481	268.446	0.494	62.408	62.376	0.229
JOI-CU Axial	1.160	1.155	0.003	350.349	350.381	0.180	-5.340	-5.327	0.179
JOI-CU Lateral	4.838	4.831	0.016	249.583	250.185	1.949	-50.115	-49.682	1.261
OTM01 Axial	0.054	0.051	0.003	181.752	181.652	0.811	0.408	0.397	0.811
OTM01 Lateral	0.605	0.600	0.015	267.601	267.694	1.671	-38.821	-38.465	1.308
OTM02 Axial	0.590	0.585	0.003	9.536	9.546	0.245	2.948	2.988	0.245
OTM02 Lateral	2.586	2.580	0.018	104.396	104.444	1.553	29.753	30.226	1.342
OTM03 Axial	0.266	0.264	0.003	197.340	197.412	0.331	-6.091	-6.113	0.329
OTM03 Lateral	1.152	1.159	0.016	291.082	291.087	2.418	-53.854	-53.402	1.442
OTM04 Axial	0.081	0.080	0.003	201.648	201.780	0.685	-7.671	-7.634	0.679
OTM04 Lateral	0.282	0.282	0.015	297.950	297.933	3.506	-55.660	-55.091	2.006
APO04 Axial	0.624	0.616	0.003	21.878	21.827	0.244	7.709	7.69	0.241
APO04 Lateral	3.753	3.744	0.019	103.439	103.184	2.787	-61.408	-61.815	1.316
OTM05 Axial	0.384	0.382	0.003	198.520	198.553	0.283	-6.151	-6.198	0.282
OTM05 Lateral	1.773	1.769	0.019	292.441	292.402	2.332	-54.193	-53.755	1.379
OTM06 Axial	0.744	0.733	0.003	13.140	13.144	0.231	4.025	4.061	0.231
OTM06 Lateral	2.781	2.773	0.018	112.370	112.222	2.067	50.075	49.741	1.336
APO06 Axial	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
APO06 Lateral	1.099	1.095	0.016	101.931	102.488	2.511	-54.220	-54.683	1.452
OTM07 Axial	0.750	0.741	0.003	13.795	13.798	0.231	4.574	4.574	0.230
OTM07 Lateral	2.774	2.773	0.018	113.837	113.664	2.092	50.695	50.298	1.336

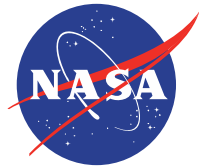
# Maneuver And Delivery Tables

**Table 4. Maneuver Design Summary**

Maneuver	Epoch (UTC)	Relative Timing		Type	$\Delta V$ (m/s)		
		Event	$\Delta$ Time		Ideal	Axial	Lateral
TCM11	3-Feb-16 17:58:51	PJ0	-152 days	RCS	0.307	0.279	0.139
JOI	5-Jul-16 02:30:00	PJ0	Centered	ME	541.65	541.65	-
JOI-CLN	13-Jul-16 17:58:51	PJ0	+8 days	RCS	4.918	1.155	4.831
OTM00	27-Jul-16 17:58:51	PJ0	+22 days	RCS	0.062	0.04	0.049
OTM01	14-Sep-16 17:58:51	PJ01	+18 days	RCS	0.604	-0.051	0.6
PRM	19-Oct-16 18:00:00	PJ02	Centered	ME	395.17	395.17	-
OTM02	25-Oct-16 17:58:52	PJ02	+6 days	RCS	2.618	0.585	2.58
OTM03	12-Dec-16 00:34:00	PJ03	+7.5 hours	RCS	1.201	-0.264	1.159
OTM04	2-Feb-17 20:28:03	PJ04	+7.5 hours	RCS	0.297	-0.08	0.282
APO04	22-Feb-17 17:00:00	PJ04	+20 days	RCS	3.766	0.616	3.744
OTM05	27-Mar-17 16:22:14	PJ05	+7.5 hours	RCS	1.828	-0.382	1.769
OTM06	19-May-17 13:30:43	PJ06	+7.5 hours	RCS	2.835	0.733	2.773
APO06	8-Jun-17 18:00:00	PJ06	+20 days	RCS	1.095	0.008	1.095
OTM07	11-Jul-17 09:24:51	PJ07	+7.5 hours	RCS	2.835	0.738	2.772

**Table 3. Equator Crossing Delivery Comparison**

Equator Crossing	Epoch (ET)		West Longitude (deg)	
	Target	Achieved	Target	Achieved
PJ01	27-Aug-16 12:53:54.3	27-Aug-16 12:53:18.6	97.00	96.64
PJ02	19-Oct-16 18:13:52.0	19-Oct-16 18:13:49.4	348.85	348.82
PJ03	11-Dec-16 17:07:14.6	11-Dec-16 17:06:58.0	7.00	6.83
PJ04	02-Feb-17 13:01:43.3	02-Feb-17 13:00:49.1	277.00	276.45
PJ05	27-Mar-17 08:56:13.4	27-Mar-17 08:55:50.8	187.00	186.77
PJ06	19-May-17 06:05:06.3	19-May-17 06:05:07.9	142.00	142.02



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