Juno at Jupiter:

The Mission and Its Path to Unveiling Secrets of the History of the Solar System

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Focus of paper

Introduction: Background and Science Objectives [1/2]

- Second New Frontiers mission, selected in 2005, launched in 2011

Science objectives:

Origin – Constrain the abundance of water and place an upper limit on the mass of Jupiter's dense core to distinguish among theories of the planet's origin

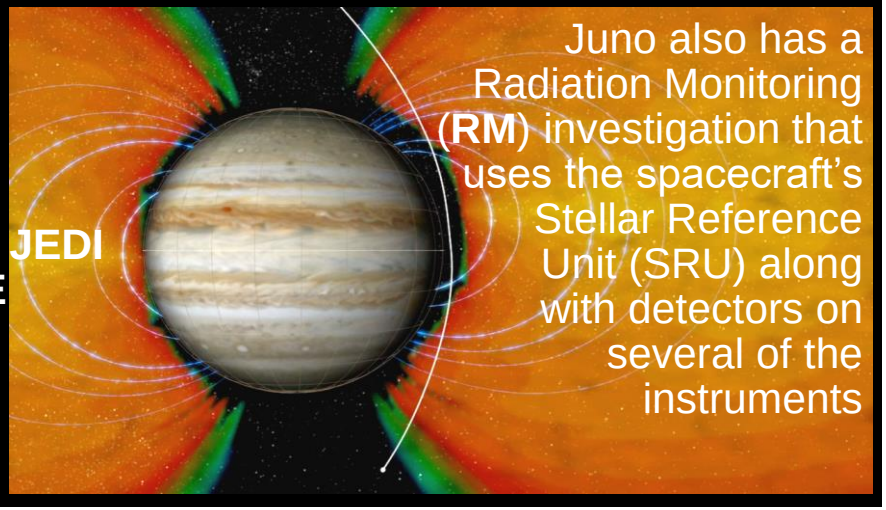
Interior – Investigate Jupiter's interior structure and how material moves deep within the planet by mapping its gravitational and magnetic fields

Atmosphere – Map variations in atmospheric composition, temperature, cloud opacity, and dynamics to depths greater than 100 bars at all latitudes

Magnetosphere – Characterize and explore the three-dimensional structure of Jupiter's polar magnetosphere and auroras

Instruments:

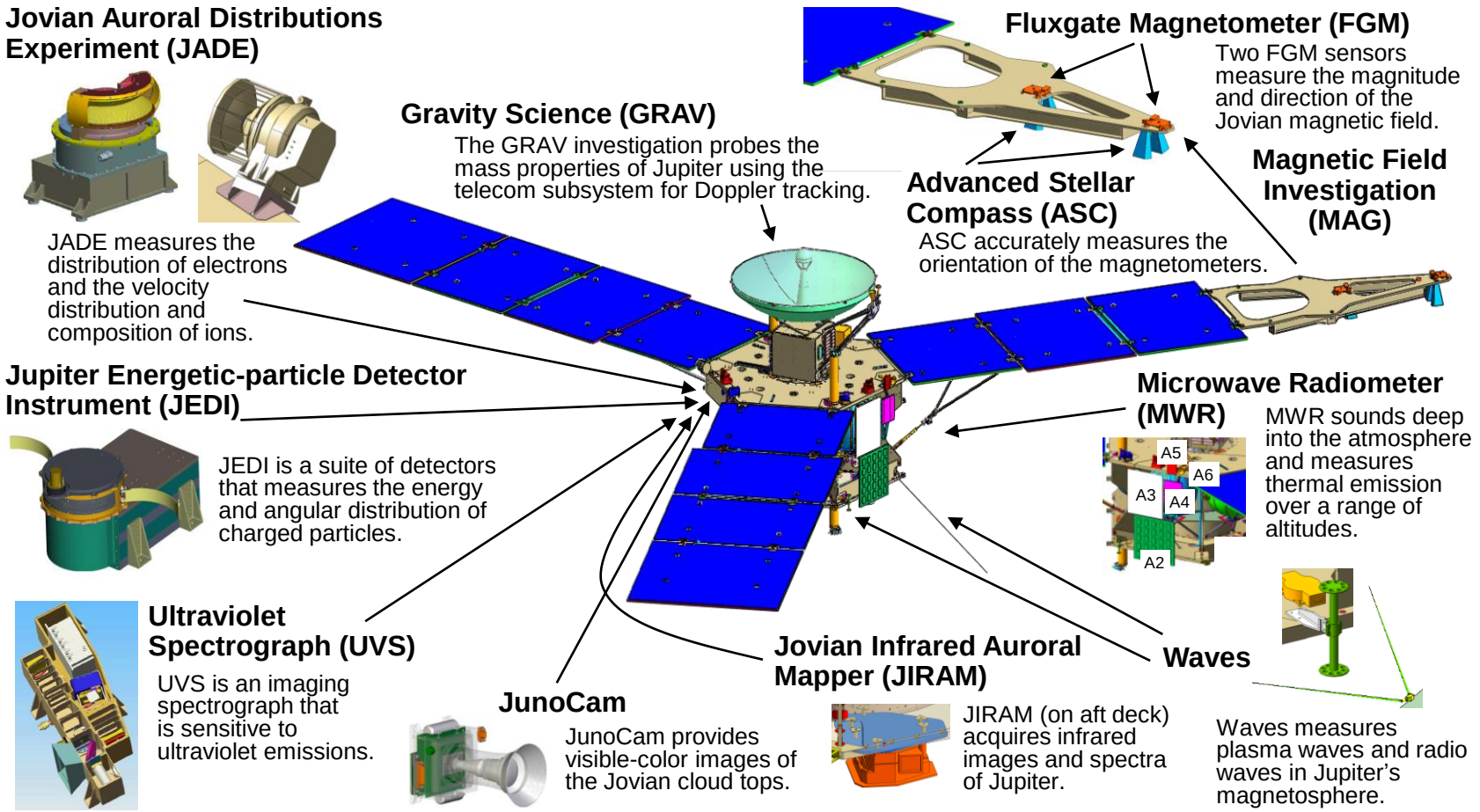
*** Gravity Science – **GRAV**
** * Magnetometer – **MAG**
**** Microwave Radiometer – **MWR**
* Jupiter Energetic-particle Detector Instrument – **JEDI**
* Jovian Auroral Distributions Experiment – **JADE**
* Radio and Plasma Waves Instrument – **Waves**
* Ultraviolet Spectrograph – **UVS**
** Jovian Infrared Auroral Mapper – **JIRAM**
* Visible Camera – **JunoCam**



Juno also has a Radiation Monitoring (**RM**) investigation that uses the spacecraft's Stellar Reference Unit (SRU) along with detectors on several of the instruments

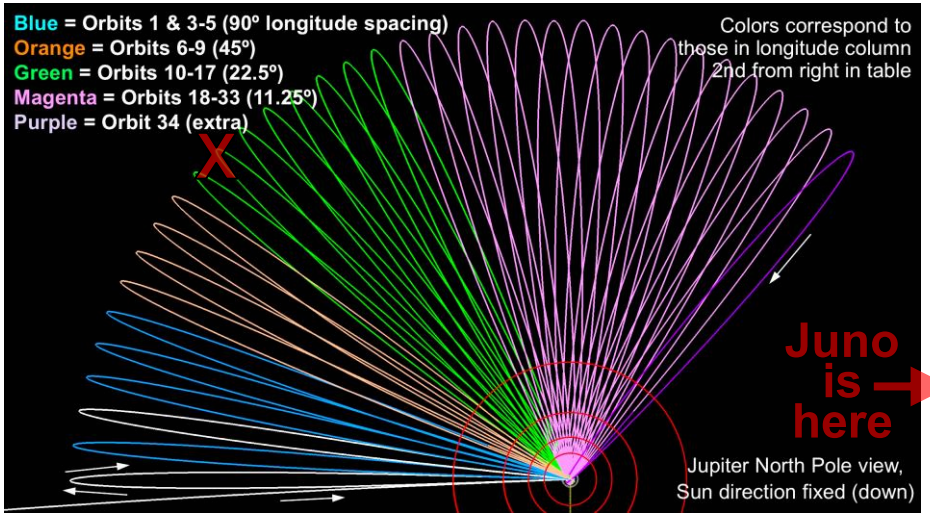
Introduction: Background and Science Objectives [2/2]

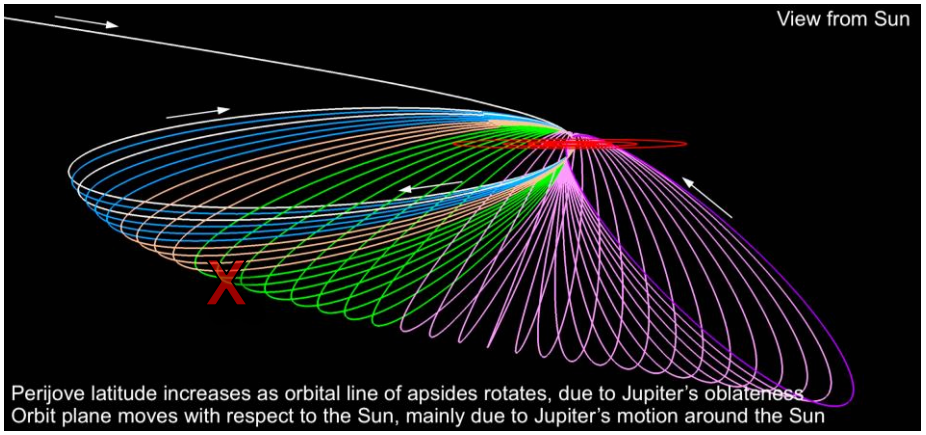
- Instruments (RM uses the SRU, plus JIRAM, ASC, and UVS):



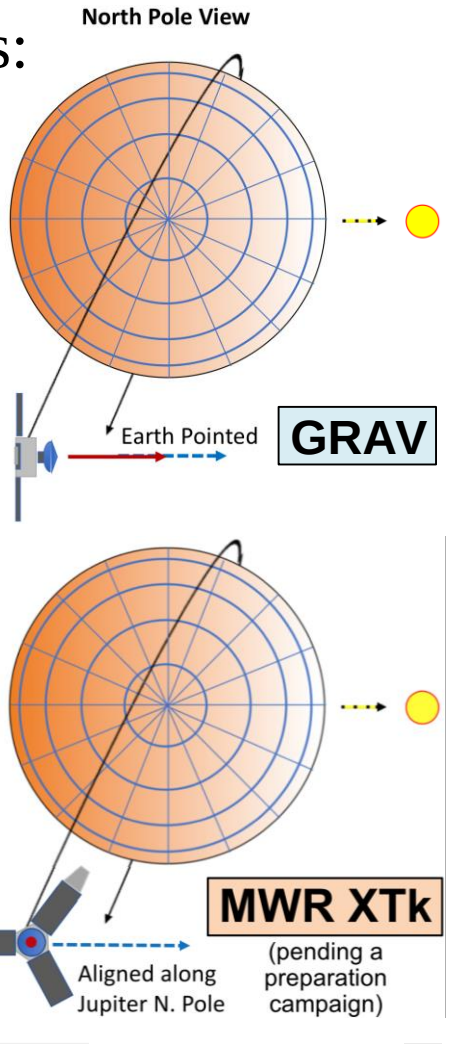
Juno Mission Plan [1/5]

- Juno orbital trajectory ... and perijove attitudes:



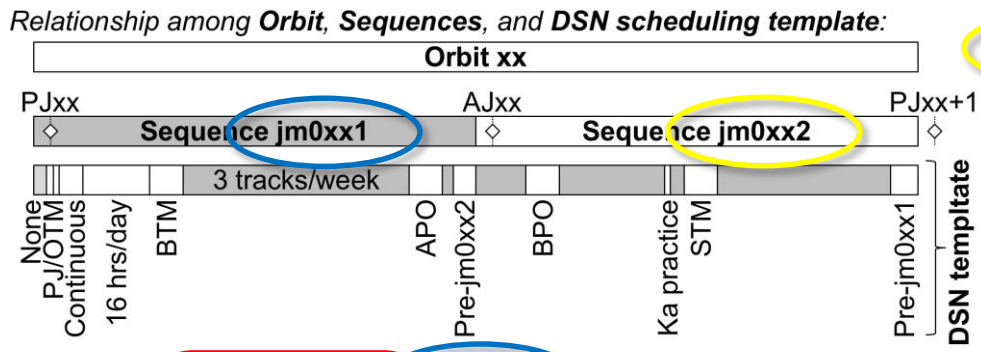


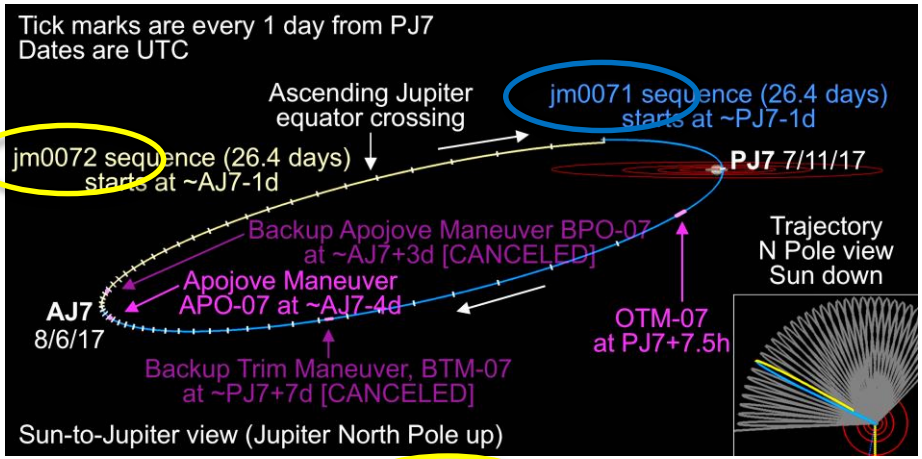
Perijove (PJ)			Lat at PJ (°)	Sys III W Long at EqX (°)	Local Time at AJ (hrs)
#	Type	Date (UTC)			
0	JOI	Jul 5, 2016	2.7	33.3	6.0
1	GRAV	Aug 27, 2016	3.8	96.6	5.7
2	Post-SM	Oct 19, 2016	4.7	348.8	5.5
3	GRAV	Dec 11, 2016	5.6	6.8	5.2
4	MWR	Feb 2, 2017	6.6	276.5	4.9
5	MWR Tilt	Mar 27, 2017	7.6	186.8	4.7
6	GRAV	May 19, 2017	8.5	142.0	4.4
7	MWR	Jul 11, 2017	9.5	51.9	4.2
8	GRAV	Sep 1, 2017	10.4	321.9	3.9
9	MWR Tilt	Oct 24, 2017	11.3	232.0	3.6
10	GRAV	Dec 16, 2017	12.2	299.5	3.4
11	GRAV	Feb 7, 2018	13.1	209.5	3.1
12	GRAV	Apr 1, 2018	14.0	119.5	2.9
13	GRAV	May 24, 2018	14.9	29.5	2.6
14	GRAV	Jul 16, 2018	15.7	74.5	2.4
15	GRAV	Sep 7, 2018	16.6	344.5	2.1
16	GRAV	Oct 29, 2018	17.4	254.5	1.9
17	GRAV	Dec 21, 2018	18.1	164.5	1.7
18	MWR XTk	Feb 12, 2019	18.9	198.2	1.4
19	GRAV	Apr 6, 2019	19.6	108.3	1.2
20	GRAV	May 29, 2019	20.3	18.2	0.9
21	GRAV	Jul 21, 2019	21.0	288.2	0.7
22	GRAV	Sep 12, 2019	21.6	333.2	0.4
23	GRAV	Nov 3, 2019	22.4	243.3	0.2
24	GRAV	Dec 26, 2019	22.9	63.3	23.9
25	GRAV	Feb 17, 2020	23.4	153.2	23.7
26	GRAV	Apr 10, 2020	24.0	85.8	23.4
27	GRAV	Jun 2, 2020	24.6	355.8	23.2
28	GRAV	Jul 25, 2020	25.3	265.7	22.9
29	GRAV	Sep 16, 2020	25.9	175.7	22.6
30	GRAV	Nov 8, 2020	26.6	220.8	22.4
31	GRAV	Dec 30, 2020	27.3	130.7	22.1
32	GRAV	Feb 21, 2021	28.0	40.7	21.8
33	GRAV	Apr 15, 2021	28.8	310.8	21.6
34	Extra	Jun 7, 2021	29.6	220.7	21.3
35	Deorbit	Jul 30, 2021	30.5		

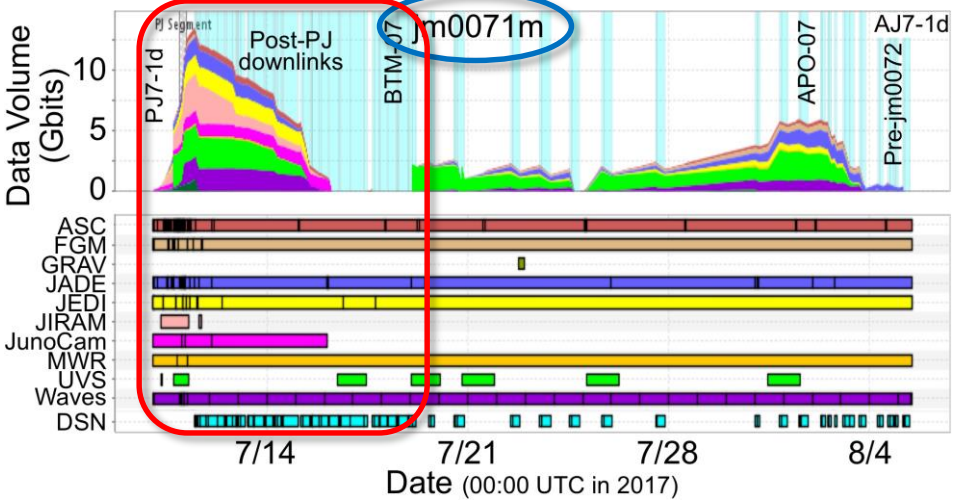


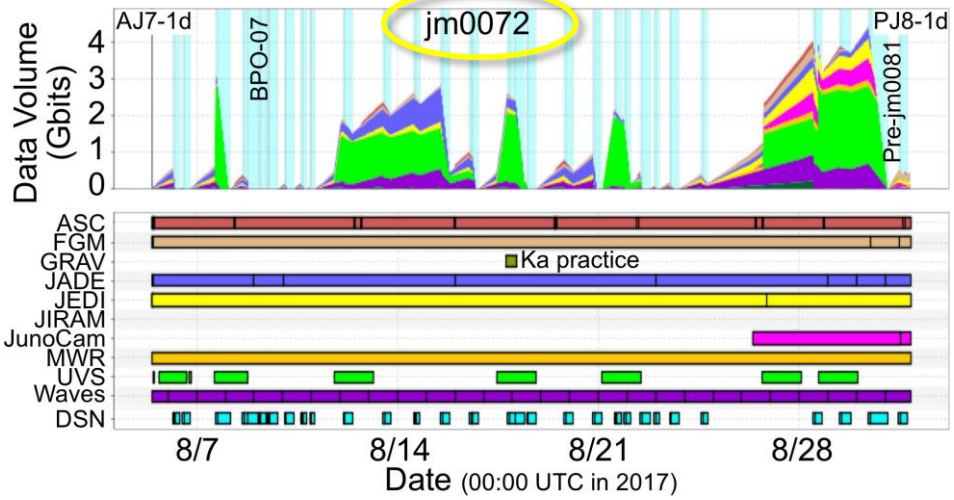
Juno Mission Plan [2/5]

- 2 background sequences per orbit (S/C & instrument commands & DSN passes) + maneuvers:



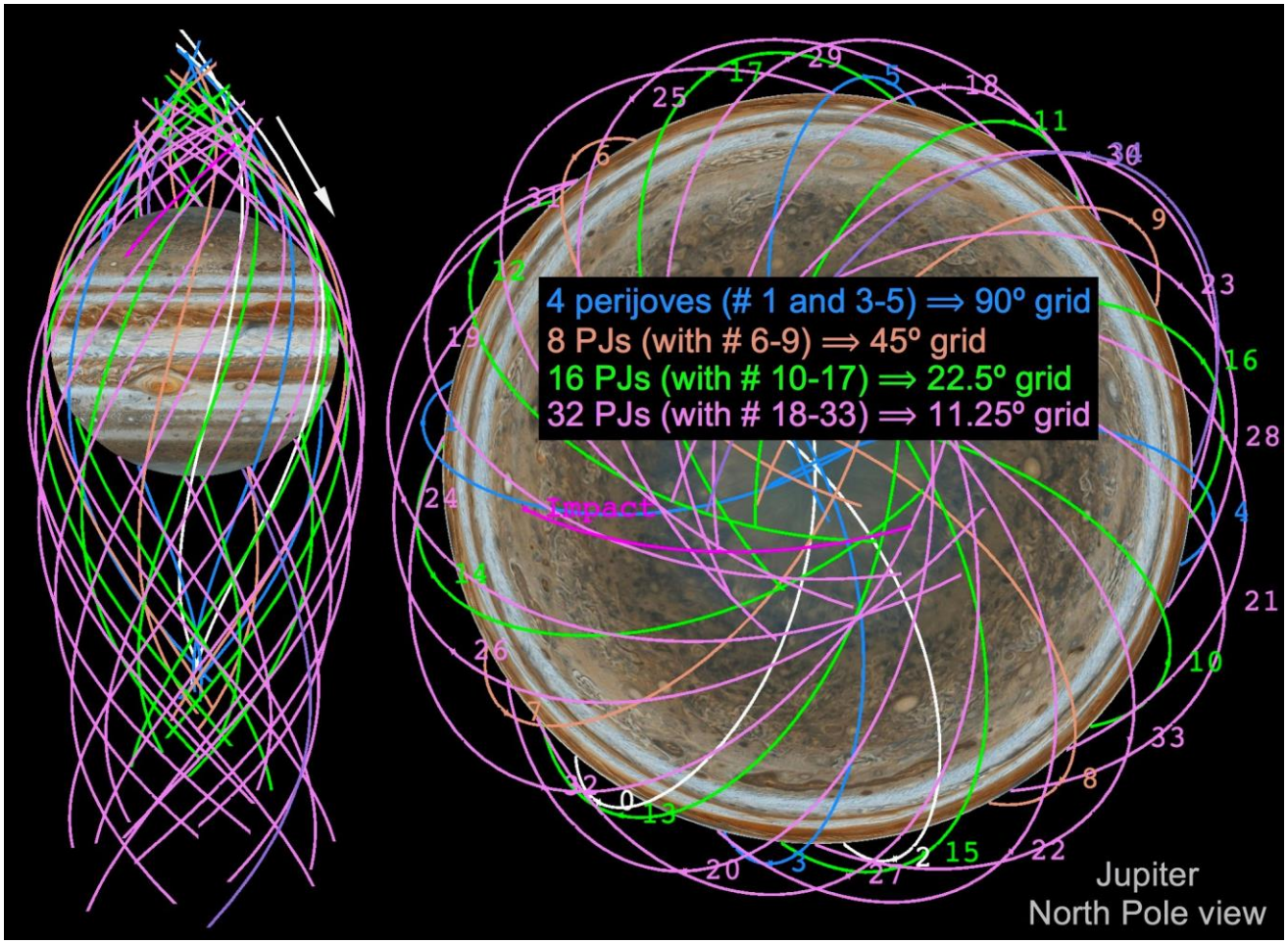






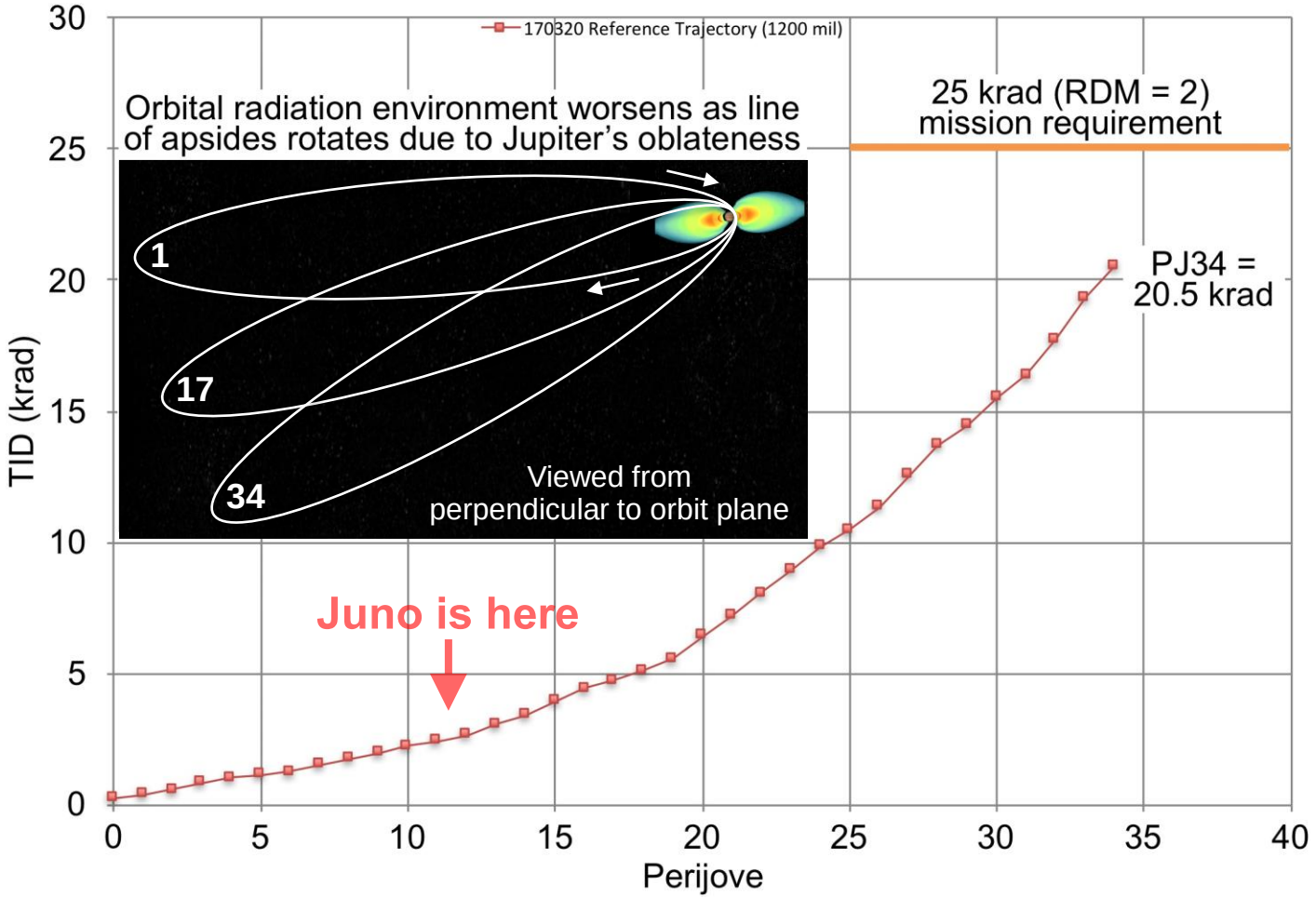
Juno Mission Plan [3/5]

- Global magnetic field map – planning 32 evenly spaced longitudes:



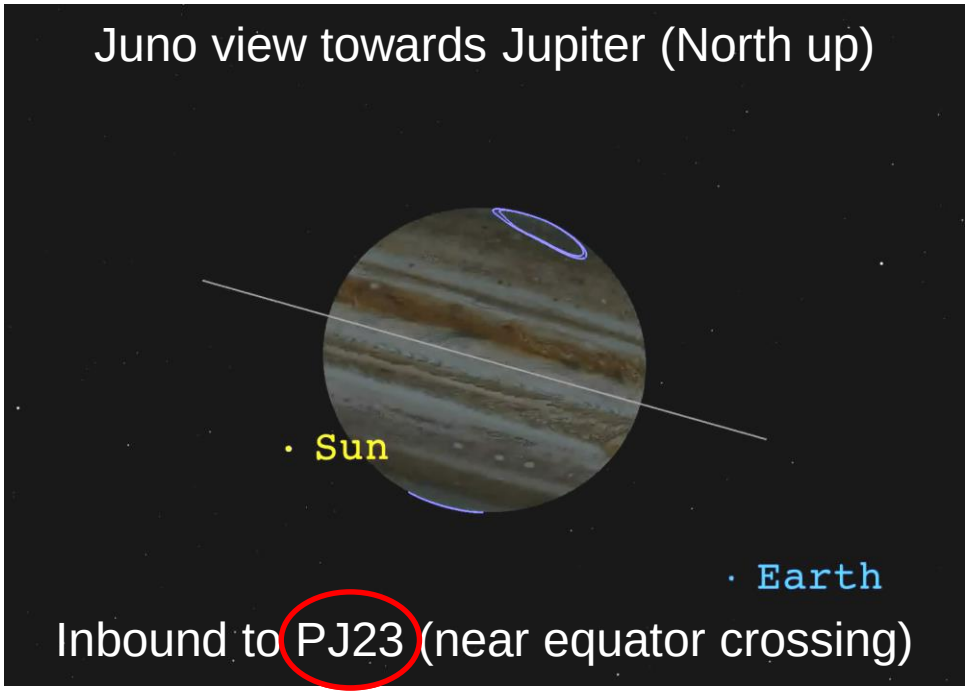
Juno Mission Plan [4/5]

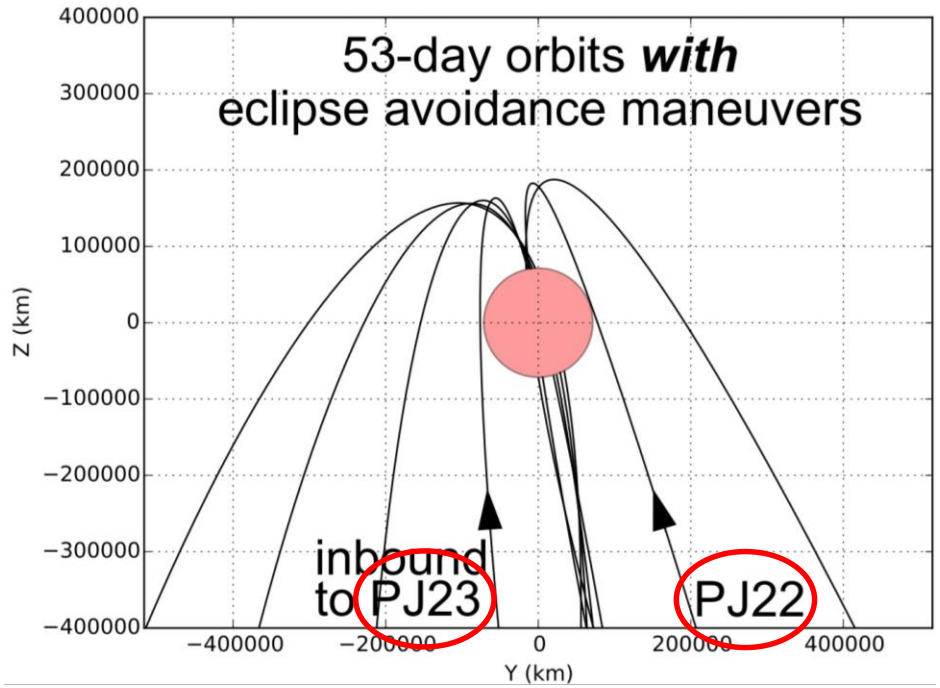
- Predicted radiation accumulation (TID = total ionizing dose):



Juno Mission Plan [5/5]

- Eclipse avoidance:



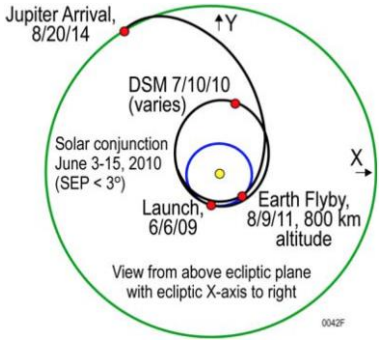


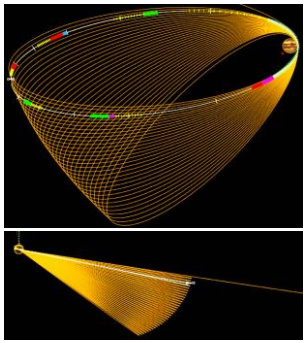
Evolution of Mission Plan: Choices and Lessons [1/5]

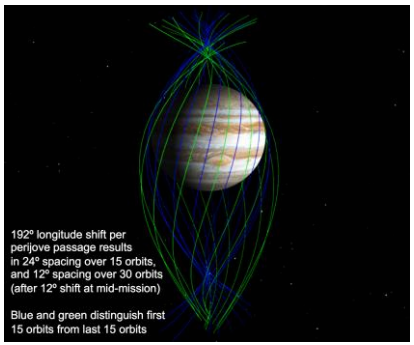
- The Mission Plan began with the **2005 NF Concept Study Report**:

		2005 New Frontiers CSR
Major updates		Initial concept study report (proposal)
MP changes	**Cruise and early orbital trajectory**	Jun 2009 launch
		1 DSM *
		JOI directly to 11d orbits *
	Science orbit period	11 days
		15-15 longitude grid *
		34 PJs (JOI, cleanup, 30 science, spare, impact)
		Aug 2015 EOM
	PJ attitudes	5 MWR + all the rest GRAV
		GRAV off in MWR orbits, & MWR/JunoCam off in GRAV orbits
	DSN	~4.5 x 8h tracks/week
		All 34-m

JOI directly to 11d orbits (DSM)







Evolution of Mission Plan: Choices and Lessons [2/5]

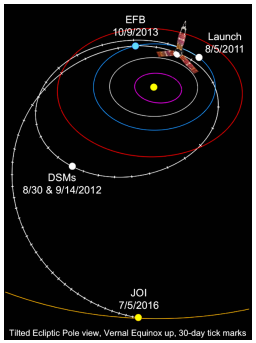
- Significant **2011 Pre-Launch** changes are highlighted in red:

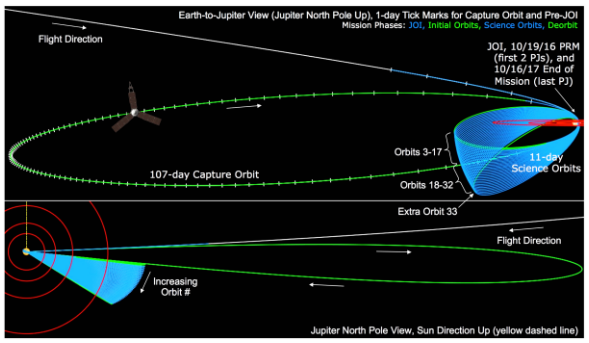
		2005 New Frontiers CSR	2011 Pre-Launch MP
Major updates		Initial concept study report (proposal)	NF selection, Phases B-E, trade studies
MP changes	**Cruise and early orbital trajectory**	Jun 2009 launch	Aug 2011 launch
		1 DSM	2 DSMs *
		JOI directly to 11d orbits	JOI to 107d capture orbit * + PRM
	Science orbit period	11 days	
		15-15 longitude grid *	
		34 PJs (JOI, cleanup, 30 science, spare, impact)	35 PJs (previous + PRM)
		Aug 2015 EOM	Oct 2017 EOM
	PJ attitudes	5 MWR + all the rest GRAV	
		GRAV off in MWR orbits, & MWR/JunoCam off in GRAV orbits	
	DSN	~4.5 x 8h tracks/week	
		All 34-m	All 34-m + 1 x 70-m/orbit (early & late orbits only)

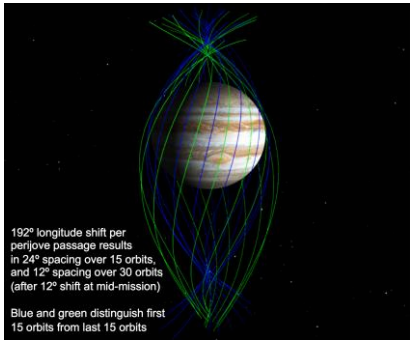
2 Deep Space Maneuvers (DSMs)

JOI to 107-day capture orbit + PRM to 11-day orbits

15-15 longitude grid



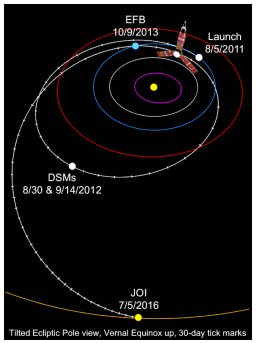


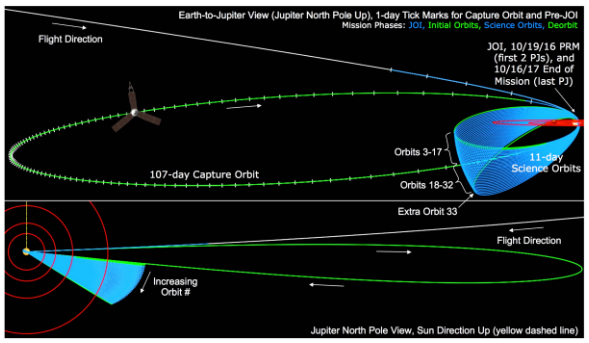


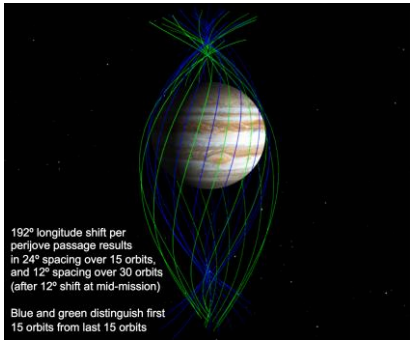
Evolution of Mission Plan: Choices and Lessons [3/5]

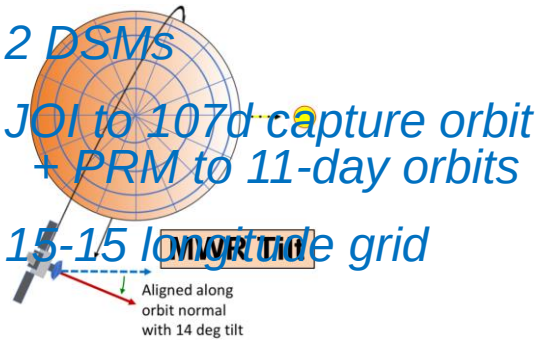
- Significant **2014 Post-Earth Flyby** changes are highlighted in red:

		2005 New Frontiers CSR	2011 Pre-Launch MP	2014 Post-Earth Flyby MP
Major updates		Initial concept study report (proposal)	NF selection, Phases B-E, trade studies	Post-EFB safe modes, side swap
MP changes	**Cruise and early orbital trajectory**	Jun 2009 launch	Aug 2011 launch	
		1 DSM	2 DSMs *	
		JOI directly to 11d orbits	JOI to 107d capture orbit * + PRM	
	Science orbit period	11 days		
		15-15 longitude grid *		
		34 PJs (JOI, cleanup, 30 science, spare, impact)	35 PJs (previous + PRM)	
		Aug 2015 EOM	Oct 2017 EOM	
	PJ attitudes	5 MWR + all the rest GRAV		4 MWR + 1 MWR tilt *
		GRAV off in MWR orbits, & MWR/JunoCam off in GRAV orbits		GRAV on in MWR orbits, & MWR/JIRAM/JunoCam on in GRAV orbits
	DSN	~4.5 x 8h tracks/week		
		All 34-m	All 34-m + 1 x 70-m/orbit (early & late orbits only)	All 70-m, except DSS-25 for PJ





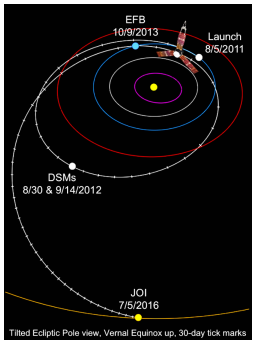


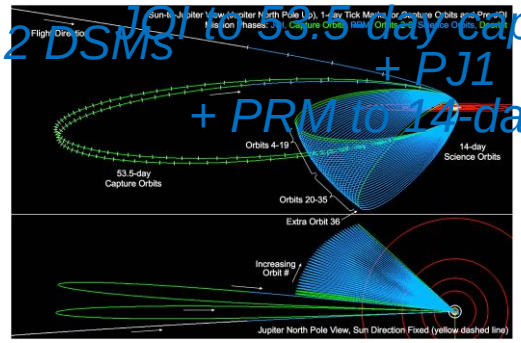


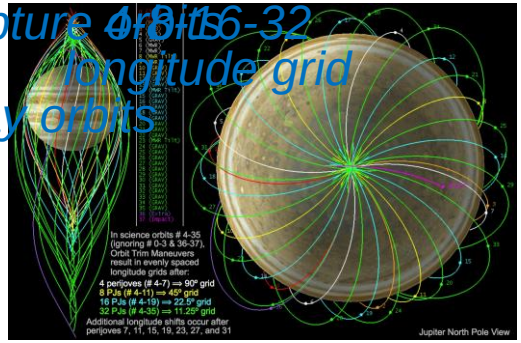
Evolution of Mission Plan: Choices and Lessons [4/5]

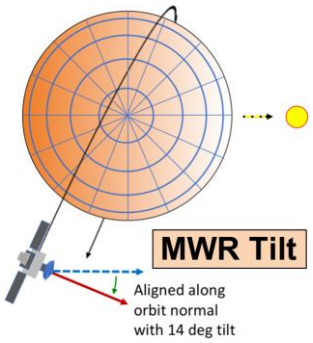
- Significant **2016 Pre-JOI** changes are highlighted in red:

		2005 New Frontiers CSR	2011 Pre-Launch MP	2014 Post-Earth Flyby MP	2016 Pre-JOI MP
Major updates		Initial concept study report (proposal)	NF selection, Phases B-E, trade studies	Post-EFB safe modes, side swap	Decided on 14d orbits, replanned
MP changes	**Cruise and early orbital trajectory**	Jun 2009 launch	Aug 2011 launch		
		1 DSM	2 DSMs *		
		JOI directly to 11d orbits	JOI to 107d capture orbit + PRM		JOI to 53.5d capture orbits + PJ1 + PRM *
	Science orbit period	11 days			14 days *
		15-15 longitude grid			4-8-16-32 longitude grid *
		34 PJs (JOI, cleanup, 30 science, spare, impact)	35 PJs (previous + PRM)		38 PJs (previous + PJ1 + 32 science vs. 30) *
		Aug 2015 EOM	Oct 2017 EOM		Feb 2018 EOM
	PJ attitudes	5 MWR + all the rest GRAV		4 MWR + 1 MWR tilt	4 MWR + 3 MWR tilt *
		GRAV off in MWR orbits, & MWR/JunoCam off in GRAV orbits		GRAV on in MWR orbits, & MWR/JIRAM/JunoCam on in GRAV orbits	
	DSN	~4.5 x 8h tracks/week			~11 x 8h tracks/week (with 4d post-PJ continuous)
		All 34-m	All 34-m + 1 x 70-m/orbit (early & late orbits only)	All 70-m, except DSS-25 for PJ	





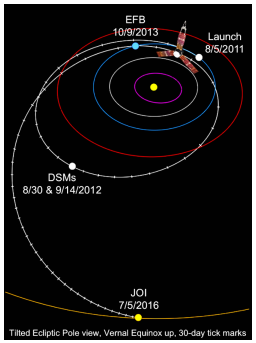


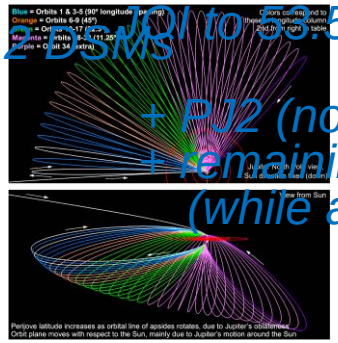


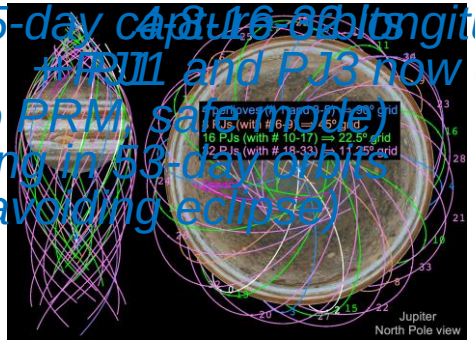
Evolution of Mission Plan: Choices and Lessons [5/5]

- Significant **Current (Late-2017)** changes are highlighted in red:

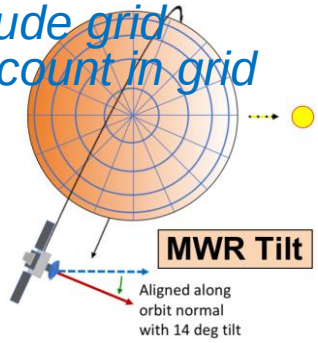
		2005 New Frontiers CSR	2011 Pre-Launch MP	2014 Post-Earth Flyby MP	2016 Pre-JOI MP	Current (Late 2017) MP
Major updates		Initial concept study report (proposal)	NF selection, Phases B-E, trade studies	Post-EFB safe modes, side swap	Decided on 14d orbits, replanned	No PRM, pre-PJ2 safe mode, replanned again
MP changes	**Cruise and early orbital trajectory**	Jun 2009 launch	Aug 2011 launch			
		1 DSM	2 DSMs *			
		JOI directly to 11d orbits	JOI to 107d capture orbit + PRM		JOI to 53.5d capture orbits + PJ1 + PRM	JOI to 53.5d capture orbits * + PJ1 + PJ2
	Science orbit period	11 days			14 days	53 days, & avoiding eclipse *
		15-15 longitude grid			4-8-16-32 longitude grid	*
		34 PJs (JOI, cleanup, 30 science, spare, impact)	35 PJs (previous + PRM)		38 PJs (previous + PJ1 + 32 science vs. 30)	36 PJs (previous - no cleanup - PJ1 now counts in grid) *
		Aug 2015 EOM	Oct 2017 EOM		Feb 2018 EOM	Jul 2021 EOM
	PJ attitudes	5 MWR + all the rest GRAV		4 MWR + 1 MWR tilt	4 MWR + 3 MWR tilt	2 MWR + 2 MWR tilt * + 1 MWR cross-track + TBD
		GRAV off in MWR orbits, & MWR/JunoCam off in GRAV orbits		GRAV on in MWR orbits, & MWR/JIRAM/JunoCam on in GRAV orbits		
	DSN	~4.5 x 8h tracks/week			~11 x 8h tracks/week (with 4d post-PJ continuous)	~7 x 8h tracks/week (with 2d post-PJ continuous + 5d of 16h/day until BTM)
		All 34-m	All 34-m + 1 x 70-m/orbit (early & late orbits only)	All 70-m, except DSS-25 for PJ		Mix of 70-m & 34-m, with ~3 x 70-m/week

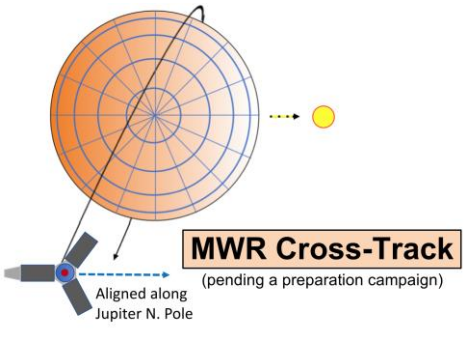






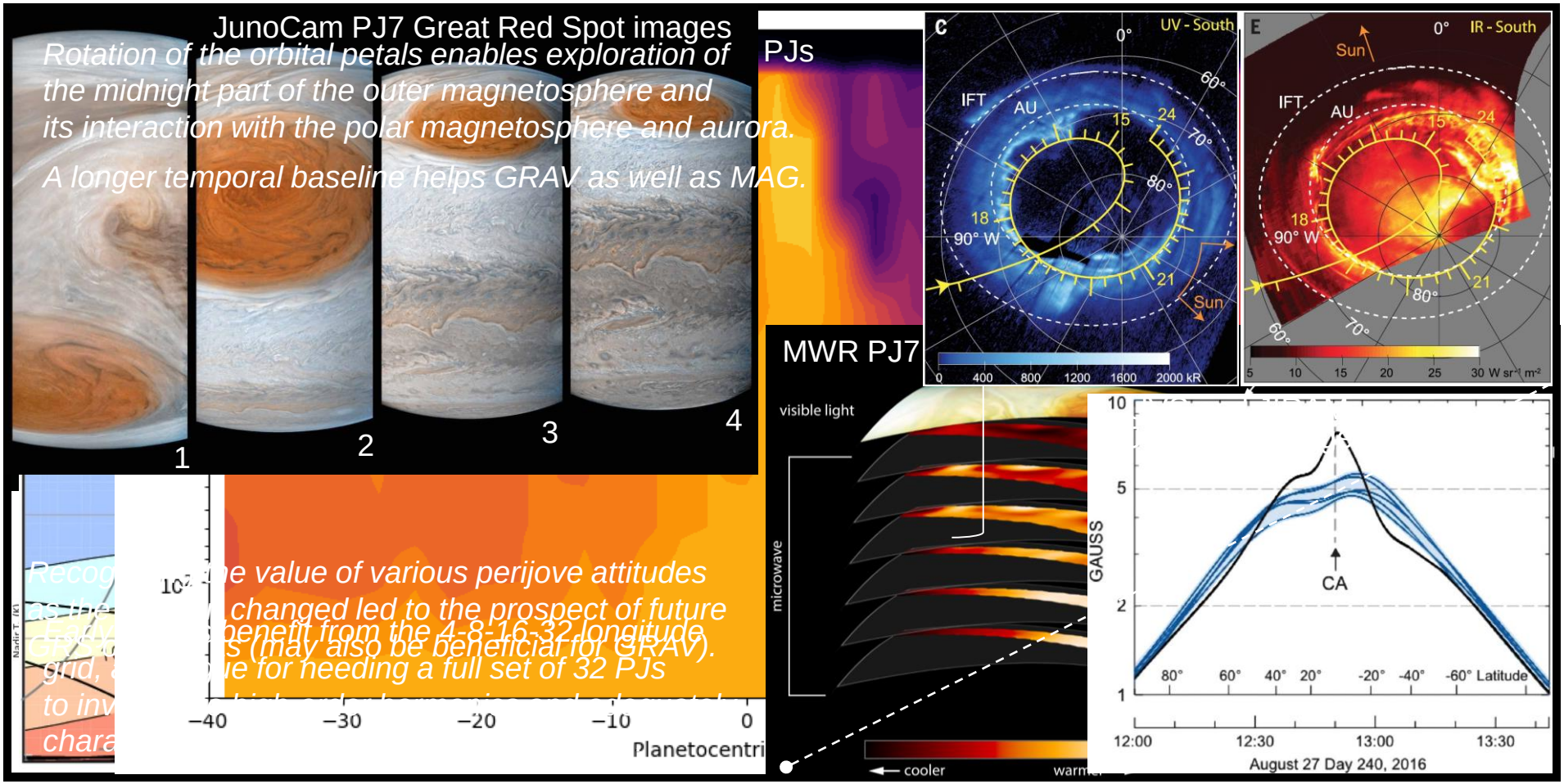
JOI to 53.5-day capture orbit
2 DSMs
+ PJ2 (no PRM, safe mode)
+ remaining in 53-day orbits (while avoiding eclipse)
4-8-16-32 longitude grid
+ PJ1 and PJ3 now count in grid





Preliminary Science Results

- Mission Plan changes positively affected science return:



Summary – Brief Conclusions and Mission Planning Lessons

- Two capture orbits led to valuable early PJ1 science, including an early up-close look into the Jupiter environment.
- Long 53-day orbits reduced ops risk, and improved science return – e.g., with midnight orbits and longer temporal baselines.
- A 4-8-16-32 longitude grid is more robust for MAG.
- Adopting new PJ attitudes in later orbits may lead to more Great Red Spot overflights or other science improvements.
- A mix of DSN antennas, 70-m and 34-m, protected valuable PJ science data as well as the spacecraft (enabling faster anomaly characterization and recovery), and enabled more science return.
- And a general lesson ... Add risk mitigation and flexibility for the highest-priority science in the orbit – at perijove in Juno's case.