IAC-05-A3.2.A.04

THE JUNO NEW FRONTIERS MISSION

Steve Matousek
Jet Propulsion Laboratory, California Institute of Technology,* United States
Steven.E.Matousek@jpl.nasa.gov

ABSTRACT

Peering down through the clouds and deep into Jupiter's atmosphere, Juno reveals fundamental processes of the formation and early evolution of our solar system. Using a simple, solar powered, spinning spacecraft in an innovative, highly elliptical polar orbit, Juno avoids Jupiter's highest radiation regions. The mission combines high heritage instruments and spacecraft with an experienced science and engineering team. The designs of the individual instruments are straightforward and have excellent heritage from previous space missions. Juno's scientific payload includes a dual frequency gravity/radio science system, a six wavelength microwave radiometer for atmospheric sounding and composition, a dual-technique magnetometer, plasma detectors, energetic particle detectors, a radio/plasma wave experiment, and an ultraviolet imager/spectrometer. Juno's payload also includes a color camera to provide the public with their first glimpse of Jupiter's poles. Juno will launch in July, 2010 or August, 2011 and arrive at Jupiter 5.2 years later. The nominal mission ends one year after Jupiter arrival with a deorbit into Jupiter's atmosphere.

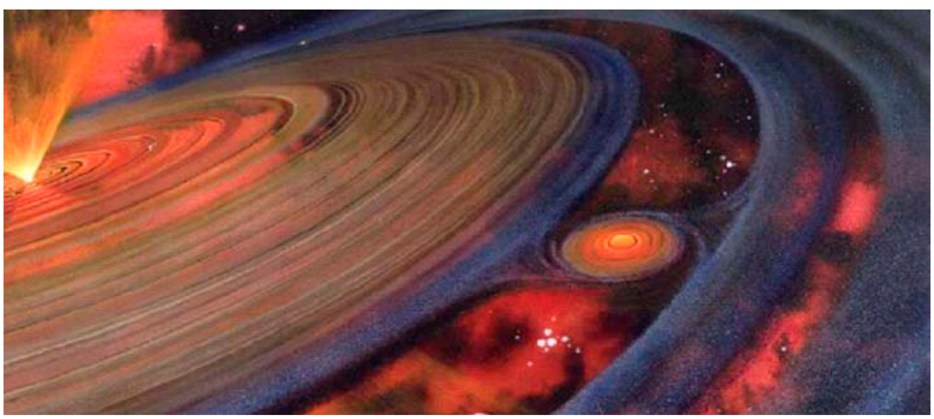


Fig. 1: Juno looks deep inside Jupiter to unlock the secrets of solar system formation.

OVERVIEW

Juno's goal is to understand the origin and evolution of Jupiter. Juno's science focuses on the Origin, Interior, Atmosphere and Magnetosphere of Jupiter. The mission addresses: Origin by examining the mass of the solid core and the abundance of heavy elements in the atmosphere to discriminate among models for giant planet formation; Interior by mapping the gravitational and magnetic fields to determine Jupiter's structure; Atmosphere by sounding to pressures > 100 bars using microwave frequencies to produce a 3-dimensional map of

*The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

the water and ammonia abundances; and Magnetosphere by exploring the polar regions of the Jovian magnetosphere and its coupling to the atmosphere. Juno will achieve the mission science goal by sending a spinning, solar-powered spacecraft (S/C) into a unique Jupiter polar orbit with close perijove.

SCIENCE

Understanding the formation, evolution and structure of Jupiter is the primary science goal of Juno. The mission will answer critical science questions and addresses objectives central to all three NASA Science Themes: Earth-Sun System, Solar System, and Universe. Juno builds upon previous Jupiter missions by determining the higher harmonics of the planet's gravity and magnetic fields, investigating the convection that drives the general circulation, determining the global oxygen abundance and local meteorology-driven variations in water and ammonia. Additionally, Juno is able to explore the auroral zones and their magnetic coupling to the Jovian nebula and satellites from its unique polar orbit.

Juno's science focuses on:

Origin

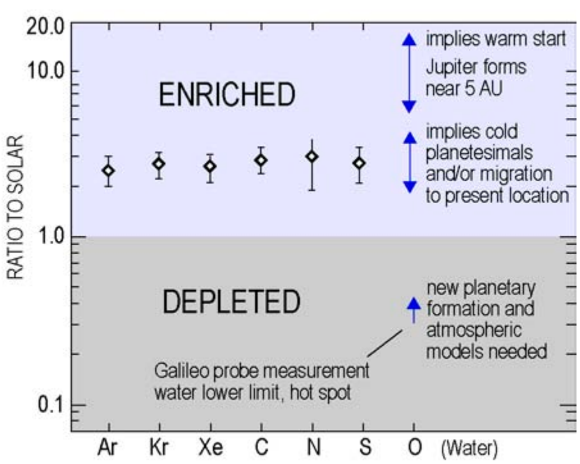


Fig. 2: Juno's measurement of O discriminates among Jupiter's formation scenarios as shown in this figure. Abundances of Ar, Kr, Xe, C, and S are well determined on Jupiter at 3× Solar. O is not yet determined. Juno determines both the N and O abundances.

Interior

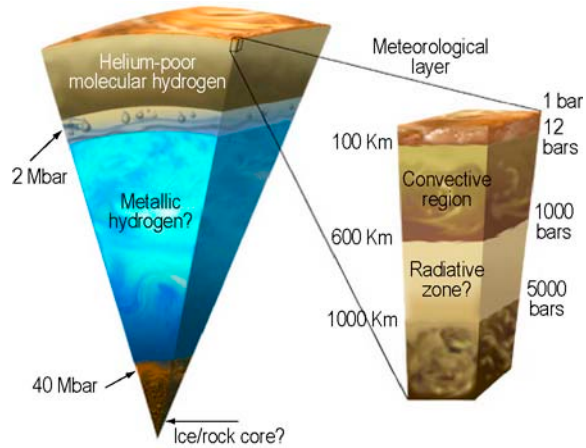


Fig. 3: Juno investigates the structure and convection of Jupiter's interior by reaching through the meteorological layer. A possible inner "rock" core is shown, surrounded by a "blue" metallic hydrogen envelope and "yellow" outer envelope of molecular hydrogen, all hidden beneath the visible cloud deck.

Gravity sounding explores the distribution of mass inside the planet. The lowest even zonal harmonics of the gravity field J_2, J_4, and J_6 give constraints on the mass of the core. They show the non-linear centrifugal response of the planet to its own rotation, whose effect on these harmonics depends on the extent to which the planet's mass is concentrated toward the center.

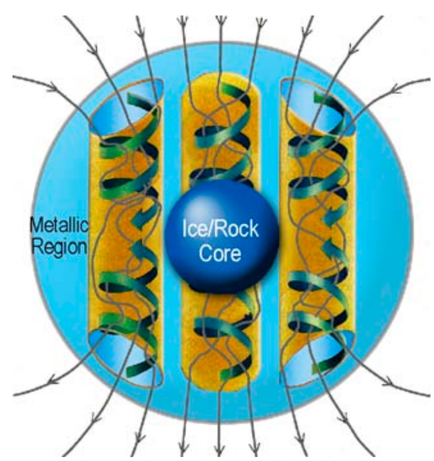


Fig. 4: Juno uses secular variations of the magnetic field to measure flow patterns on the core surface. This figure shows a plausible Jovian dynamo with columnar structures in the flow organized about a putative core.

Atmosphere

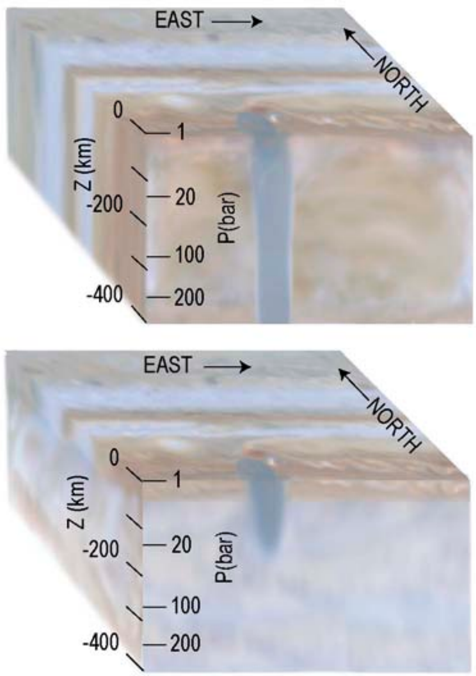


Fig. 5: Juno provides three-dimensional views of the atmosphere to depths greater than 100 bars resolving basic questions about the depth of the circulation. The figure illustrates two possible scenarios for Jupiter's deep atmosphere. Top panel: large-scale flow dominates and the belt-zone structure penetrates to depths > 200 bars. Bottom panel: small-scale convection dominates and the belt zone structure disappears below the water cloud base at 6 bars. Vertical exaggeration is ~50.

Magnetosphere

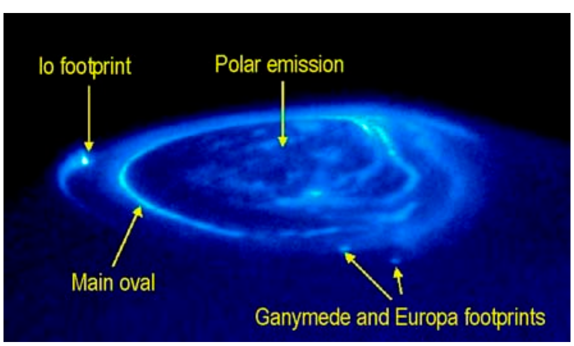


Fig. 6: Three types of auroras are revealed in this HST image of Jupiter's UV aurora. Each are signatures of momentum transfer processes.

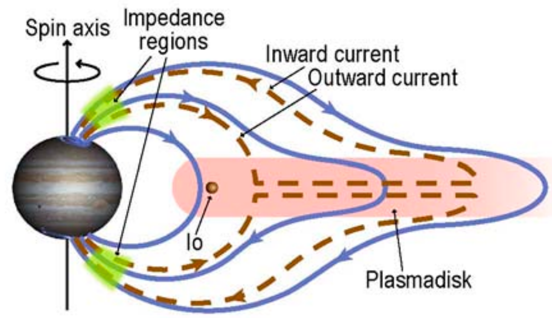


Fig. 7: Juno measurements target each critical path in this closed circuit that transfers angular momentum from Jupiter to its nebula.

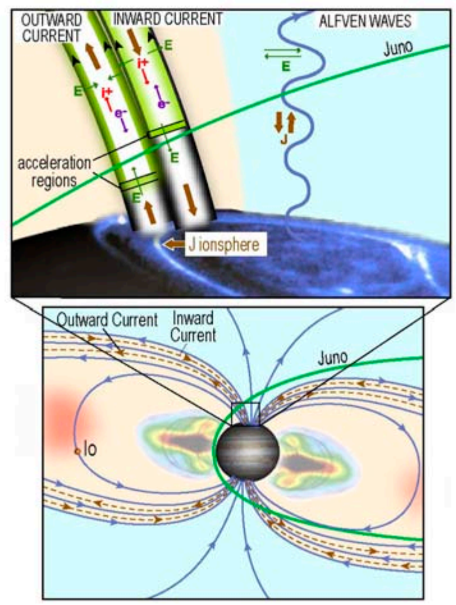


Fig. 8: Juno measures signatures of different auroral processes as it traverses the poles.

MISSION

Juno places a spinning, solar powered spacecraft into an elliptical polar orbit about Jupiter for a period of ~1 year. To reach Jupiter requires a ΔV-EGA (Delta-Velocity Earth Gravity Assist) with a 2010 or 2011 launch on an Atlas 551 from Cape Canaveral Air Force Station. A deep space maneuver one year after launch adjusts the trajectory so that an Earth flyby about 2 years after launch gives the Juno spacecraft additional energy to reach Jupiter (see Figure 9). 5.2 years after launch the spacecraft arrives at Jupiter. A Jupiter Orbit Insertion (JOI) and JOI clean up

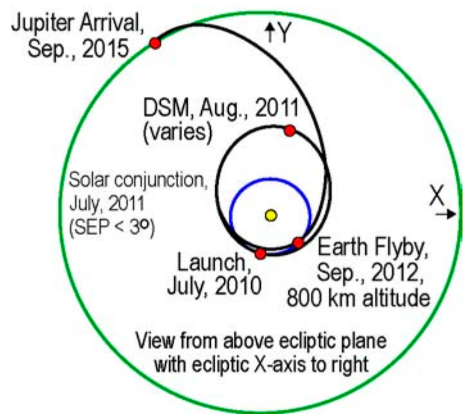


Fig. 9: The ΔV-EGA trajectory reduces the launch energy. Launch may also occur in 2011. If so, add 13 months to all dates.

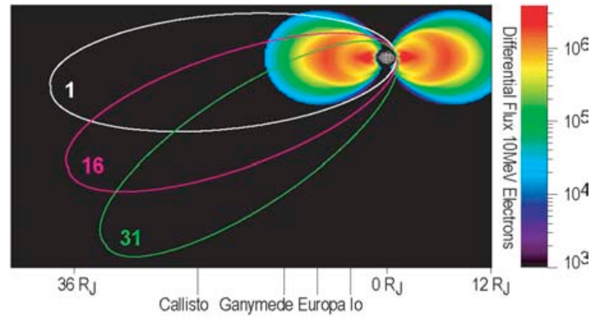


Fig. 10: Juno spends most of the mission away from Jupiter's high radiation environment. The line of apsides moves southward over the mission lifetime.

over the next two perijoves (closest point to Jupiter) ensures an ~11-day orbit. Perijove at 1.06 R_J and apojove at ~39 R_J, combined with the90° polar orbit, provides the resolution and global viewing geometry required for science. The polar orbit with close perijove also allows the spacecraft to avoid the bulk of the Jovian radiation field. During the one year, 32 orbit nominal mission, the line of apsides of the orbit precesses due to Jupiter's oblateness (see Figure 10). The 32 orbit one year mission at Jupiter fits nicely between solar conjunctions, further simplifying operations.

The Juno mission design provides maximum delivered payload to Jupiter and a unique polar orbit which satisfies the science measurement requirements while minimizing the radiation exposure.

PAYLOAD

There are five main elements in the science instrument suite: 1) Microwave Radiometer (MWR), 2) Magnetometer (MAG), 3) Gravity Science (GS), 4) Fields and Particles, and 5) JunoCam. Each instrument is fully accommodated with system-level approaches to key spacecraft challenges such as radiation shielding, mass, power, alignments, and electromagnetic cleanliness. For example, the instrument electronics is clustered where possible in a vault that simultaneously maximizes radiation shielding effectiveness, reduces total mass, and maximizes hardware heritage (see Figures 11–13).

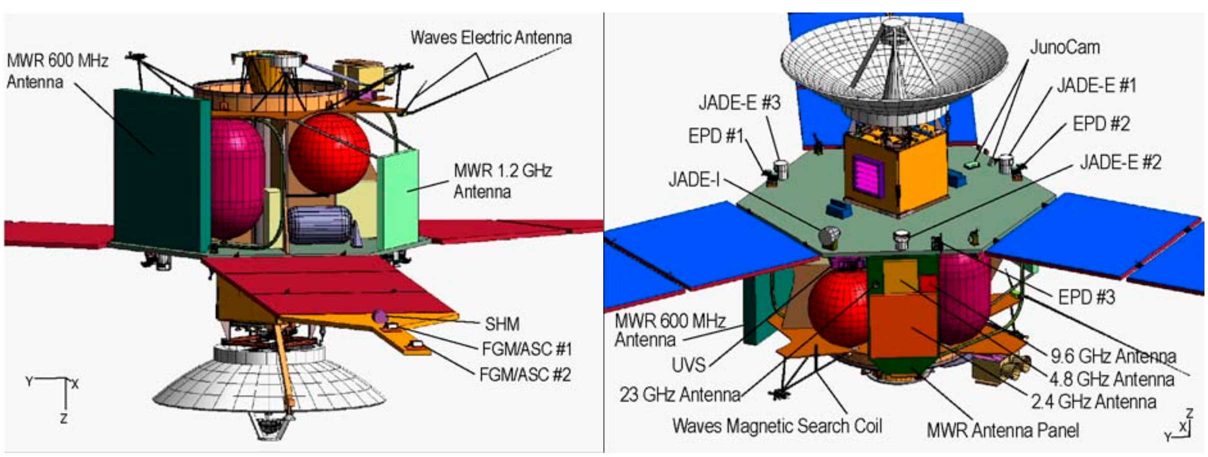
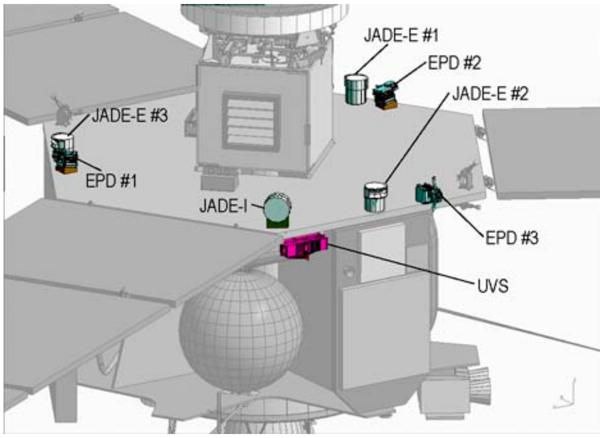


Fig. 11: Spacecraft design fully accommodates all science instrument requirements.



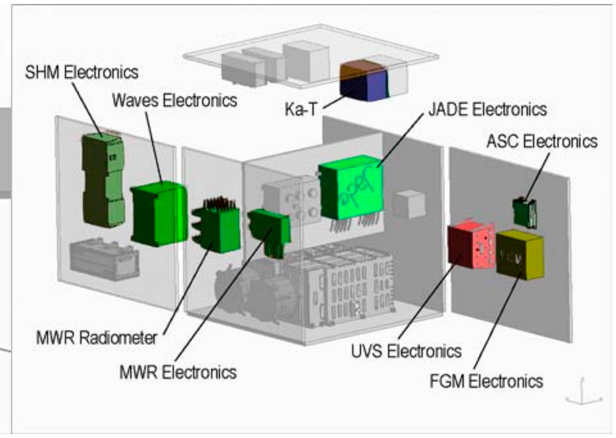


Fig. 12: Deck-mounted instruments simplify integration and test.

Fig. 13: Vault protects instruments from radiation.

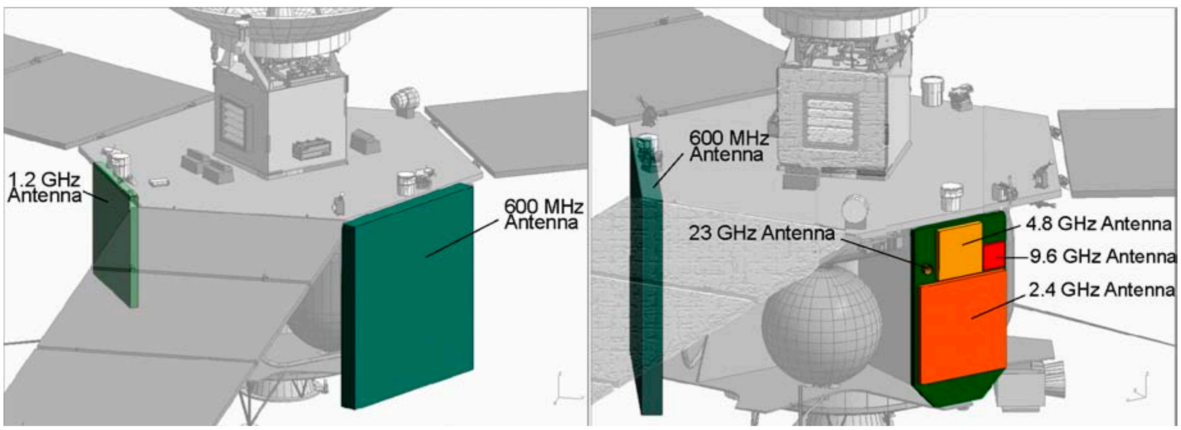


Fig. 14: MWR antennas are mounted to maximize FOV.

MWR

JPL will build the MWR. It consists of six peripherally mounted antennas, radiometers, and control/calibration electronics for six frequencies from 600 MHz to 23 GHz (see Figure 14). Space Systems/LORAL builds the MWR antennas to take advantage of their communications satellite experience.

MAG

The MAG investigation utilizes dual fluxgate magnetometers (FGM) sensors from Goddard Spaceflight Center for measurement of the vector field and a 3-cell scalar helium magnetometer (SHM) sensor from JPL for measurement of field magnitude. Fully redundant, co-located star cameras from Danish Technical University supply precise attitude reference for each FGM sensor on the MAG boom (see Figure 15).

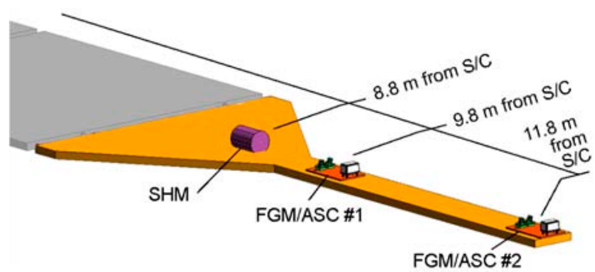


Fig. 15: Radial separation of FGM sensors on MAG Boom improves measurement of S/C magnetic fields. S/C fields are greatly reduced by >8.8m distance.

Gravity Science

JPL will build the Ka-band telemetry system. This investigation processes Ka-band telemetry on the ground via the telecom subsystem, augmented with a Ka-band translator and downconverter, enabling a 2-way Ka radio science link with the Deep Space Network (DSN). X band is also utilized with this investigation to yield X up/down and Ka up/down simultaneously (see Figure 16).

Fields and Particles Instruments

The Jovian Auroral Distributions Experiment (JADE) instrument provided by SwRI measures ions and electrons. Four instrument deck mounted sensors (3 electron analyzers and 1 ion mass spectrometer) provide a $360° \times 90°$ field of view (FOV) for electrons and $270° \times 90°$ for ions. The Energetic Particle Detector (EPD) from Johns Hopkins University Applied Physics Laboratory (JHU/APL) utilizes three sensors to detect electrons and ions and sort particle species by energy. Located on the instrument deck, they provide a $360° \times 12°$ FOV in the spin plane and $180° \times 12°$ along the spin axis. The Waves experiment from the University of Iowa is an electric dipole antenna mounted aft on the spacecraft, perpendicular to the spin axis, and a magnetic search coil mounted parallel to the spin axis. Receivers are mounted in the electronics vault. The Ultraviolet Spectrometer (UVS) from SwRI is a telescope/spectrometer mounted below the instrument deck. Its $6° \times 0.05°$ FOV is perpendicular to the spin axis.

JunoCam

JunoCam is the E/PO camera. It is not a science instrument, and has no science requirements. JunoCam will not be permitted to impact S/C or science requirements. JunoCam captures 3-color images of Jupiter with spatial resolution to approximately 15 km/pixel for public engagement and E/PO. It is mounted on the instrument deck with an unobstructed $18° \times 3.4°$ FOV in the spin plane.

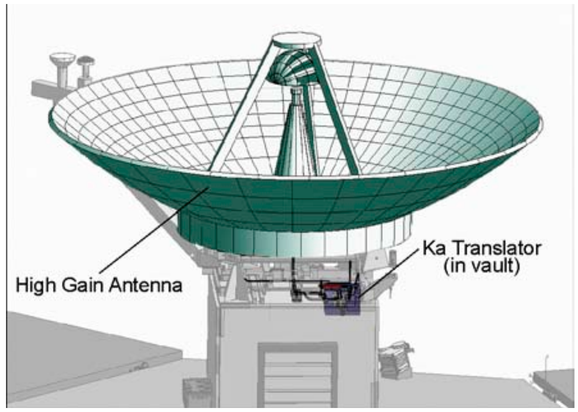


Fig. 16: Gravity components are mounted inside vault.

SPACECRAFT

Juno's science objectives require a spinning spacecraft (see Figure 17). The Jupiter polar orbit avoids the bulk of the radiation and enables solar power to be utilized. The Lockheed-Martin built and integrated spacecraft remains continuously in sunlight from launch through end of mission except for a short 10-minute period during the earth flyby. This results in benign and stable thermal conditions and maximum solar array power production. Spacecraft spin stability eliminates complex, power-hungry attitude control components such as reaction wheels. The electronics vault protects the heritage spacecraft and instrument electronics from the Jovian radiation environment. The instruments are accommodated by careful placement on the upper deck, solar array booms, and the lower deck (see Figures 18 and 19).

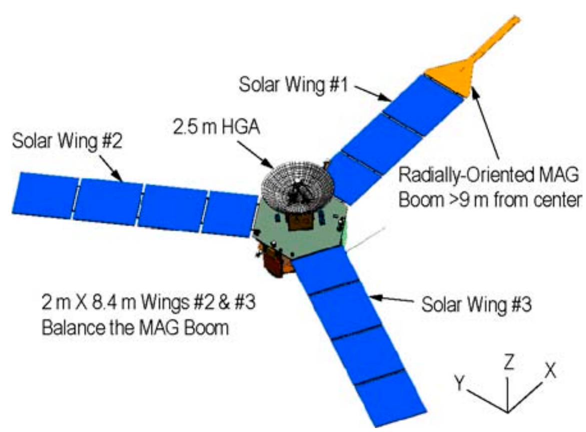


Fig. 17: Spinning S/C provides stability, accurate pointing, and simple operations.

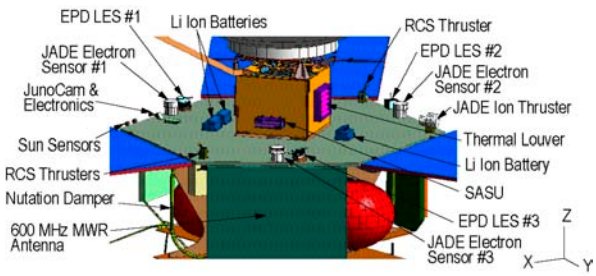


Fig. 18: Roomy upper deck easily accommodates instruments.

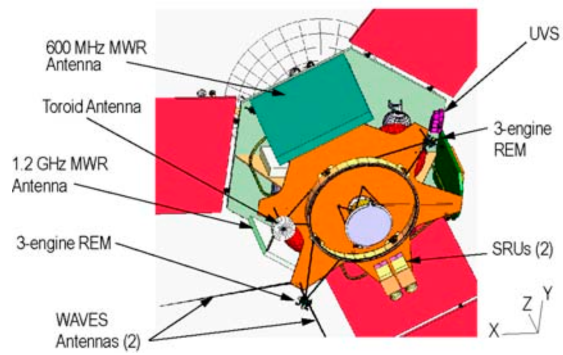


Fig. 19: All components are balanced.

OPERATIONS

During the long cruise to Jupiter, the mission events provide training opportunities. For example, the deep-space maneuver (DSM) is a chance to rehearse JOI. And the Earth Flyby (EFB) is a chance to rehearse the perijove passage of a science orbit at Jupiter. Every 12–18 months during the cruise to Jupiter instrument calibrations are taken. At about 6 months before JOI, the flight team is fully staffed and test and training commences for JOI and the subsequent science orbit phases. Simplified science operations takes advantage of repeatable sequence blocks to reduce flight team work load and complexity.

The Juno spacecraft provides large margins for science data storage. Each science orbit requires only 6 DSN passes (see Figure 20). The DSN passes are spaced in time and between the 3 DSN complexes to satisfy science, spacecraft engineering, and navigation data requirements.

Primary science measurements are taken only at ± 3 hours from perijove for all science orbits. Outside of this perijove time, the payload takes lower data rate measurements. Throughout the one year Jupiter orbital mission, only two spacecraft science modes are required (see Figure 21). The MWR orbits have the MWR instrument on, along with the other payload elements except for the gravity science payload elements. The MWR measurements are taken with the solar array plane of the spinning spacecraft passing through the center of Jupiter on orbits 2, and 4–7. The GS orbits leave all other instruments in the same mode as MWR orbits, except the MWR instrument is powered down to standby mode before orbit 8, and after orbit 8, turned off. In GS mode, the High Gain Antenna (HGA) points to the earth throughout the entire perijove science passage. As in MWR perijove passages, the GS mode has primary science taken during the period ± 3 hours around perijove.

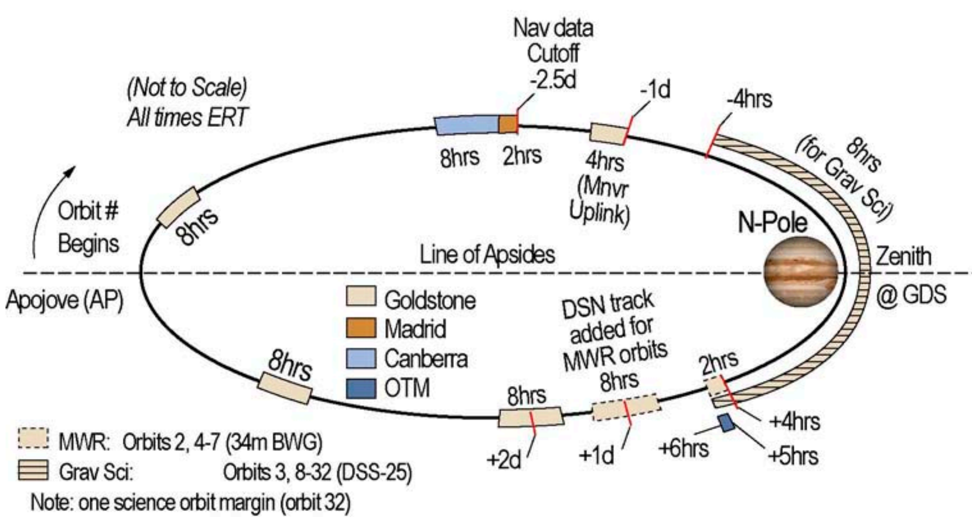


Fig. 20: Repetitive orbit geometry enables a simple DSN strategy.

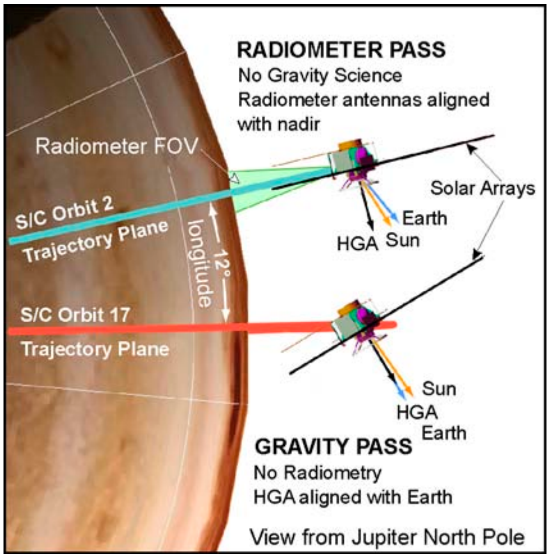


Fig. 21: The mission requires only two S/C attitudes during science perijove passages, thereby simplifying operations.

Another feature of the science orbit is that the equatorial crossings all occur at equal longitude spacing. The magnetic field investigation requires that the longitude be controlled. Consequently, the longitude spacing for orbits 2–16 is 24°. And, a maneuver just after perijove of orbit 16 adjusts the longitude crossing by 12°. This provides an ultimate equatorial longitude spacing during the nominal one year mission of 12° (see Figure 22).

For the GS measurements, Ka-up and downlink is only available from the DSN station Deep Space Station (DSS)-25 at Goldstone, California. So, the perijove passages of the GS orbits need to occur over DSS-25 at maximum elevation (when viewed from the DSS-25 ground station on earth). This constraint, combined with the science requirement for the 12° spacing, yields an orbit of 10.9725 days (measured from perijove to perijove).

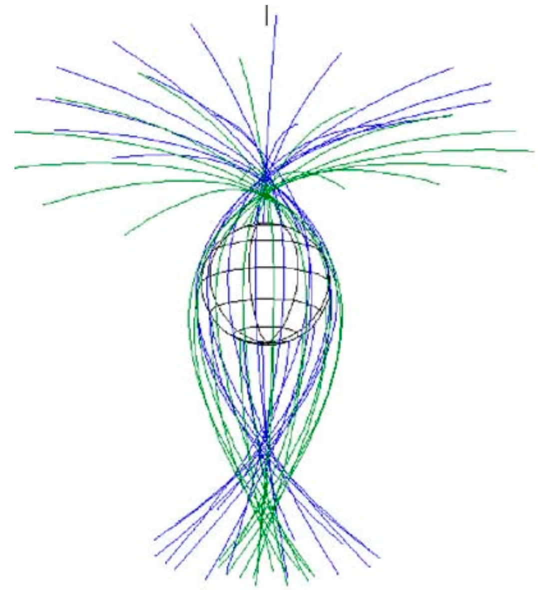


Fig. 22: Juno wraps Jupiter in a uniform net enabling observations that constrain Jupiter's core and characterize its dynamo. The primary science is performed within six hours of perijove. The first six months are shown in blue (orbits: 2–16) and second six months shown in green orbits: (17–31).

CONCLUSION

Juno is a unique match between the science goals and the mission. The polar orbit with close perijove provides optimum science measurement opportunity while avoiding the bulk of the Jovian radiation. The spinning, solar-powered spacecraft provides the right platform for the science instruments. This next mission to Jupiter should provide many discoveries that will help unlock the mysteries of the largest planet in our solar system.

ACKNOWLEDGMENTS

I would like to thank the entire talented and hardworking team involved in the Juno Concept Study. This paper distills the Concept Study to a manageable size for a conference.