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AN OVERVIEW OF THE JUNO MISSION TO JUPITER

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Abstract

Arriving in orbit around the planet Jupiter in 2016 after a five-year journey, the Juno spacecraft will begin a one-year investigation of the gas giant in order to understand its origin and evolution by determining its water abundance and constraining its core mass (Figure 1). In addition, Juno will map the planet's magnetic and gravitational fields, map its atmosphere, and explore the three-dimensional structure of Jupiter's polar magnetosphere and auroras.

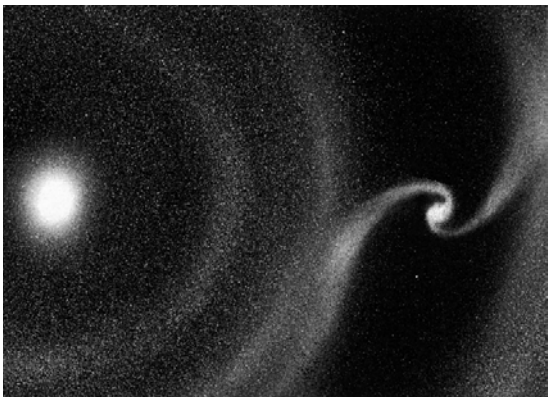

Figure 1: Juno will discriminate among different models for giant planet formation.

These investigations will be conducted over the course of thirty-two 11-day elliptical polar orbits of the planet. The orbits are designed to avoid Jupiter's highest radiation regions.

The spacecraft is a spinning, solar-powered system carrying a complement of eight science instruments for conducting the investigations. The spacecraft systems and instruments take advantage of significant design and operational heritage from previous space missions.

Juno's scientific payload consists of a dual-technique magnetometer, a microwave radiometer for mapping atmospheric composition and dynamics, a dual-frequency radio-gravity science system, plasma detectors, energetic particle detectors, an ultraviolet imager/spectrometer, a plasma wave experiment, and a visible camera for imaging Jupiter's poles for the first time.

Operations at Jupiter are simple and repetitive. When the investigation is complete, the spacecraft will de-orbit into the planet itself.

Contents

1 Overview

Juno's goal is to understand the origin and evolution of Jupiter. As a gas giant, Jupiter can provide a wealth of knowledge that can help us understand the origin of our own solar system as well understand other planetary systems being discovered around other stars.

Using a spinning, solar powered spacecraft, Juno will produce global maps of the gravity, magnetic fields, and atmospheric composition from a unique polar orbit with a close perijove (closest point to Jupiter) (Figure 2). The nominal 32-orbit mission will produce an extensive sample of Jupiter's full range of latitudes and longitudes. Juno will accomplish its mission through a combination of in situ and remote observations.

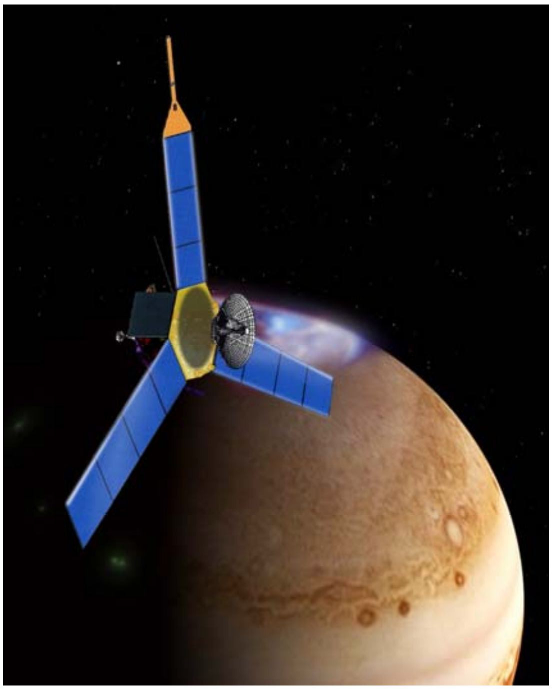

Figure 2: Using a spinning, solar powered spacecraft, Juno will produce global maps of the gravity, magnetic fields, and atmospheric composition from a unique polar orbit with a close perijove.

Juno's investigations divide into four major themes: Origin, Interior Structure, Atmospheric Composition and Dynamics, and the Polar Magnetosphere. Origin discriminates among different models for giant planet formation, constraining the mass of the solid core by measuring the gravitational field and determining the abundance of certain heavy elements (oxygen and nitrogen) in Jupiter's atmosphere via microwave observations of water and ammonia.

Interior Structure maps the gravitational and magnetic fields with sufficient resolution to determine the origin of the magnetic field, the core mass and the nature of deep convection.

Atmospheric Composition and Dynamics is measured by atmospheric sounding to pressures greater than 100 bars, producing a three-dimensional map of the water and ammonia abundances; and determining how deep the belts, zones, and other features penetrate.

The largest structure in the solar system, Jupiter's polar magnetosphere and its coupling to the atmosphere are explored by measuring auroral emissions, plasmas, fields, waves and radio emissions.

2 Project Implementation

The Juno project is implemented as part of NASA's New Frontier Program, under the leadership of Dr. Scott Bolton, the Principle Investigator (PI) from Southwest Research Institute (SwRI). The day-to-day project management and implementation is delegated to the Jet Propulsion Laboratory (JPL), under the leadership of Rick Grammier, the Project Manager (PM).

SwRI and JPL teamed with several companies, universities and other NASA centers to provide the scientific instruments and spacecraft systems. JPL is providing the overall management, project engineering, mission design and navigation, mission operations, payload management, telecommunications/gravity science system, microwave radiometer (MWR) experiment, and part of the dual-technique magnetometer.

Lockheed Martin (LM) is the primary spacecraft contractor and is responsible for the design, build, and test of the spacecraft as well, as the integration of the payload instruments. LM also performs mission operations with JPL.

The home institution of the PI, SwRI provides two of the instruments for the polar magnetosphere investigation—Ultraviolet Spectrometer (UVIS) and Jovian Auroral Distributions Experiment (JADE)—and manages the science team and the education and public outreach program.

Goddard Space Flight Center (GSFC) is providing the combined magnetometer experiment. Applied Physics Lab (APL) is providing the Energetic Particle Detector (EPD). The University of Iowa is providing the Waves experiment. The visible camera provider has not yet been selected. (The visible camera is not a science instrument and has no scientific requirements associated with it.)

2.1 Science Investigations

2.1.1 Origin

The primary science goal of understanding planetary formation and evolution is directly related to the study of Jupiter's interior and atmosphere. The mass of Jupiter's core helps distinguish among competing scenarios regarding the planet's formation. Jupiter's water abundance is key in understanding giant planet formation and the delivery of volatiles throughout the solar system (Figure 3).

The microwave radiometer (MWR) instrument determines the water abundance in Jupiter. It maps the water over all latitudes, thus eliminating sampling bias inherent in limited probe measurements.

The instrument consists of six different antennas, radiometers, and control/calibration electronics. The MWR uses six frequencies for atmospheric sounding, from 0.6 GHz to 23 GHz (Figure 4). The wavelengths are chosen to sound atmospheric ammonia and water from below the ammonia cloud tops to as deep as practical.

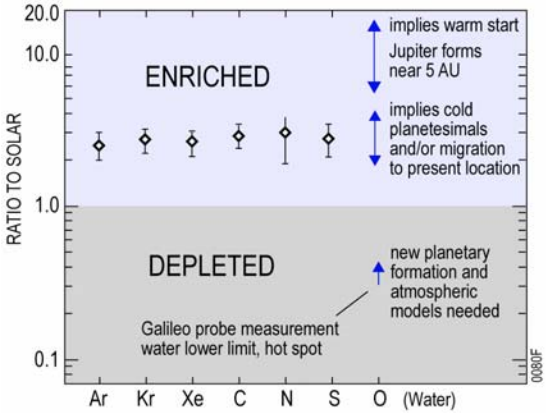

Figure 3: Juno's measurement of O discriminates among Jupiter's formation scenarios. Abundances of Ar, Kr, Se, C, and S are well determined on Jupiter at 3x Solar. O is not yet determined. Juno determines both the N and O abundances.

The number of channels is sufficient to fully sample the desired pressure range and reach below 100 bars.

The instrument is based upon a number of previous, Earth-orbiting experiments, with the most recent heritage to the Advanced Microwave Radiometer (AMR) for the Ocean Surface Topography Mission (OSTM).

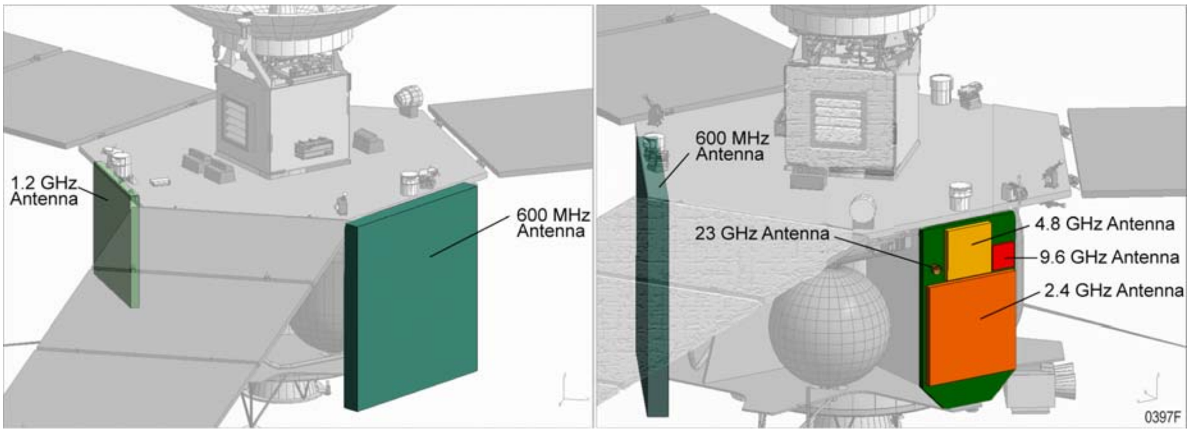

Figure 4: Each of the six MWR antennas uses a different frequency from a range chosen to sound atmospheric ammonia and water from below the ammonia cloud tops to as deep as practical.

2.1.2 Interior

Juno measures the gravity field, magnetic field, and water abundance, to determine the structure of the planet, the nature of deep convection, and the process of magnetic field generation. Juno's low perijove allows the measurement of the gravity field to a high harmonic degree and unprecedented accuracy. The Juno measurement of the low-order gravitational harmonics, together with microwave data on envelope composition, provide key constraints on planetary structure and the mass of Jupiter's core (Figure 5).

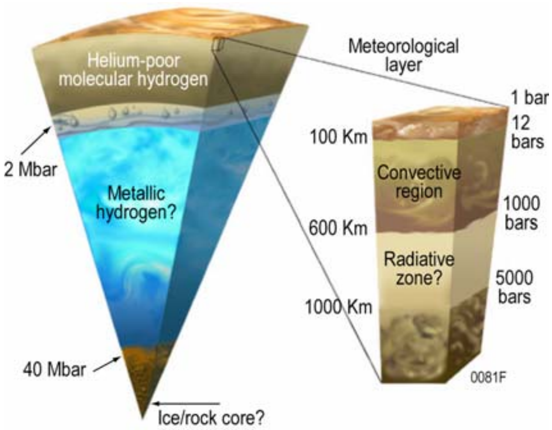

Figure 5: Juno investigates the structure and convection of Jupiter's interior by reaching through the meteorological layer. A possible inner "rock" core is shown, surrounded by a "blue" metallic hydrogen envelope and a "yellow" outer envelope of molecular hydrogen, all hidden beneath the visible cloud deck.

Juno's gravity-science experiment provides data on Jupiter's internal convection and deep winds (Figure 6). This experiment is capable of both X- and Ka-band uplink and downlink. During the mission, the X-band portion is the primary communications uplink/downlink for engineering and science data. It is based upon the Small Deep Space Transponder (SDST), flown on several previous JPL missions. The X-band system is augmented with an external Ka-band translator with a 3.5-watt solid-state power amplifier (SSPA). The gravity science experiment can thus employ a combination of X band with Ka-band downlink and X- and Ka-band uplink/downlink.

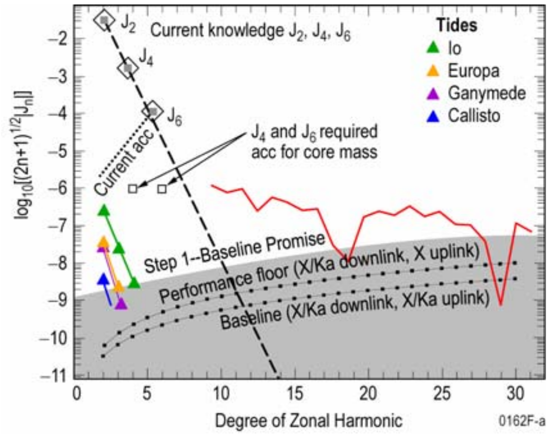

Figure 6: Juno's precise gravity measurements provide new constraints on Jupiter's core mass and internal convection. Diamonds represent current knowledge. Triangles show expected tidal responses. The lines show signatures of solid-body (dashed lines) and differential (red line) rotation.

By mapping Jupiter's magnetic field with a resolution exceeding that available for any other planet, including Earth, Juno seeks to understand the origin of planetary magnetic fields. Juno also seeks to detect magnetic-field secular variation in order to image fluid motions at the surface of the dynamo-generating region. The experiment measures the high harmonics of the magnetic field at small distance, which is crucial to understanding the dynamo mechanism (Figure 7).

The Magnetometer experiment consists of a pair of fluxgate sensors (FGM) that measure the three components of the vector magnetic field, and an orthogonal array of scalar helium magnetometer (SHM) cells that measure the magnitude of the field. Both the FGM and SHM are flight proven designs with substantial inheritance. To obtain the precise measurements desired and minimize the effects of spacecraft-generated magnetic fields, Juno placed a boom at the end of one of its solar array panels to host the magnetometers (Figure 8).

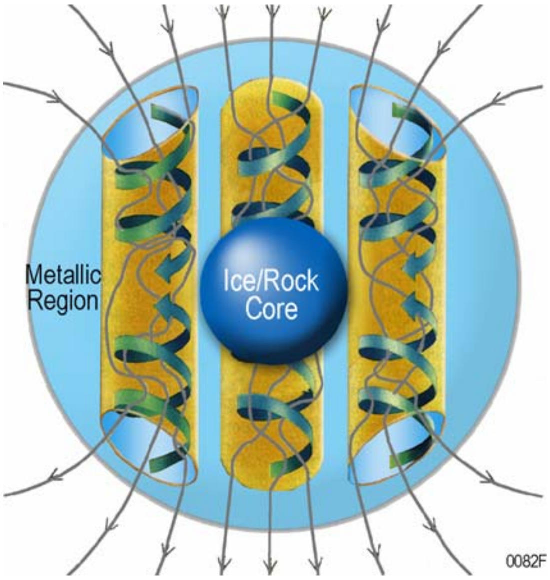

Figure 7: Juno uses secular variations of the magnetic field to measure flow patterns on the core surface. Shown here is a plausible Jovian dynamo with columnar structures in the flow organized about a putative core.

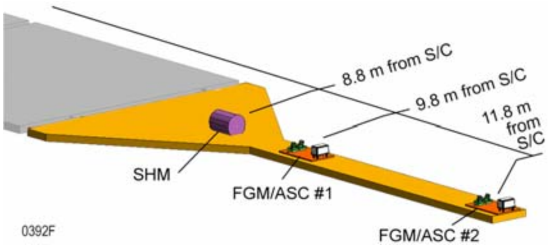

Figure 8: Radial separation of FGM sensors on the MAG boom improves measurement of magnetic fields. Spacecraft magnetic fields are greatly reduced by the greater-than 8.8-m distance

2.1.3 Atmosphere

Juno produces five pole-to-pole latitudinal maps of microwave opacity as a function of altitude. Latitudinal mapping of water and ammonia to depths greater than 100 bars indicates whether large-scale circulation is deep or shallow. Jupiter has no solid or liquid surface, so the dynamical structures could extend to 100 bars or deeper (Figure 9). Juno reveals the root of the belts, zones, and other cloud features by measuring variations in the ammonia and water abundance. The MWR instrument described in Section 2.1.1 provides the data for this scientific theme.

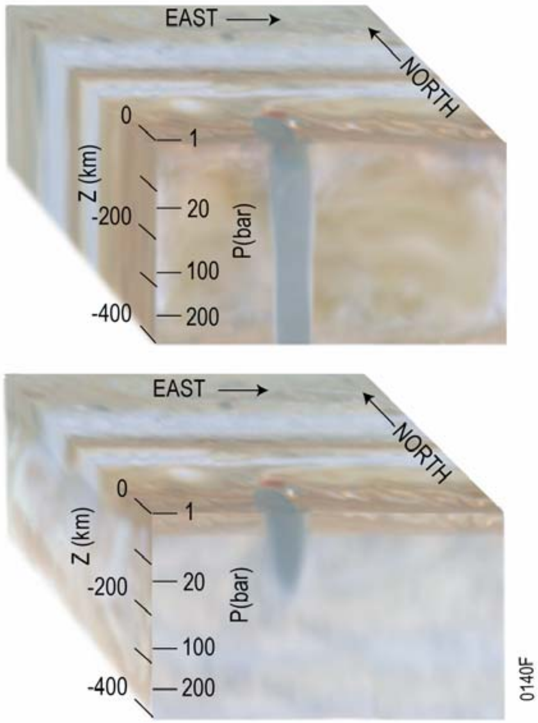

Figure 9: Juno provides three-dimensional views of the atmosphere to depths greater than 100 bars, resolving basic questions about the depth of the circulation. The figure illustrates two possible scenarios for Jupiter's deep atmosphere. Top panel: large-scale flow dominates and the belt-zone structure 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.

2.1.4 Magnetosphere

Exploration of the polar magnetosphere gives access to understanding the universality of the aurora beyond the diversity of its sources. Juno's unique polar orbit is critical to understanding how auroras are generated. Juno determines the physical processes occurring in the high latitude magnetosphere, which can be related to the understanding of the equatorial magnetosphere.

Jupiter's auroras are driven by the rotation of the planet (primary energy source), motion of its satellites across the rotating Jovian magnetic field lines, and the solar wind. These three sources are reflected in the three types of auroras observed (Figure 10).

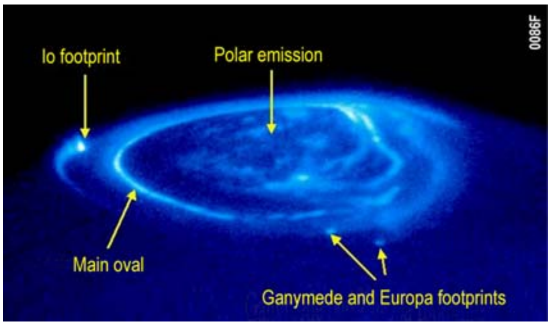

Figure 10: Each of the three types of auroras revealed in this Hubble Space Telescope image of Jupiter's UV aurora are signatures of momentum transfer processes.

To study Jupiter's magnetosphere, Juno carries a suite of fields and particles instruments (Figure 11):

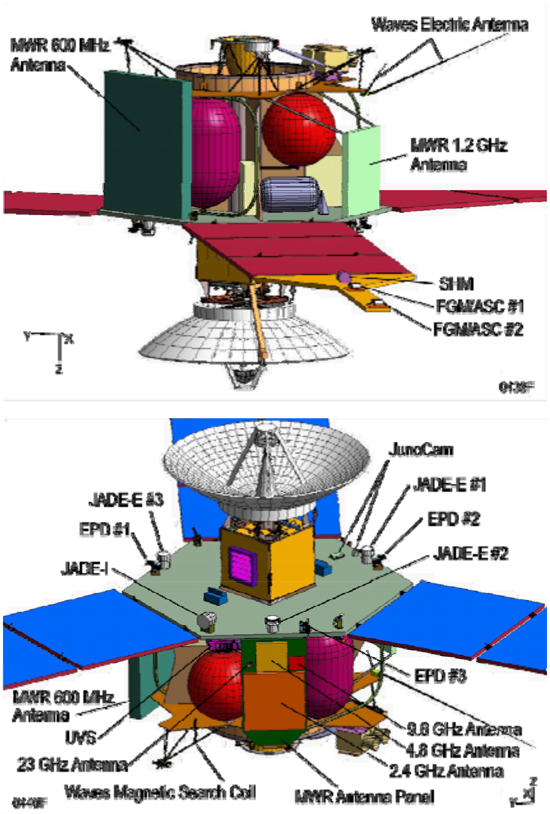

Figure 11: Juno's Instrument Suite.

The JADE instrument is designed to study the plasma field and consists of a single ion mass spectrometer with a 270° x 90° field of view, and three identical electron energy per charge analyzers with contiguous 120° x 90° fields of view (for a total of 360° x 90°) to measure the full auroral electron and ion particle distributions.

The EPD instrument, designed to detect the energetic particles consists of three separate sensing heads. Each head has a field of view of 180° x 12°, and each 180° field of view is segmented into six ion and six electron views. It sorts incoming ions into mass species and energy and discriminates electrons from ions.

The Waves instrument utilizes an electric dipole antenna and a magnetic search coil. The V-shaped antenna has a tip-to-tip length of about 4 meters and is oriented such that the sensitive axis is perpendicular to the spacecraft spin axis. The magnetic search coil is oriented such that the sensitive axis is parallel to the spacecraft spin axis. It is used to analyze plasma waves in the frequency range of 50 Hz to 100 kHz.

The UVS instrument provides spectral imaging of Jupiter's UV auroral emissions; its measurements are used to determine global auroral precipitation characteristics, providing context for in situ data and for locating key magnetospheric source regions.

3 Mission Design

Juno launches in August 2011 on an Atlas V 551 launch vehicle. The nominal cruise time to Jupiter is approximately 5.2 years. The trajectory requires a large deep-space maneuver about one year after launch and an Earth flyby about 26 months after launch, to acquire the additional energy to reach Jupiter.

Upon reaching Jupiter, the spacecraft executes a very long burn of its main engine for Jupiter Orbit Insertion (JOI) and a smaller JOI clean-up burn to achieve the 11-day polar orbit desired for the nominal science mission at Jupiter.

The 11-day orbit is characterized by a perijove of 1.06 RJ and an apojove (furthest point from Jupiter) of about 39 RJ. This orbit optimizes the viewing geometry for the science mission while avoiding the bulk of the Jovian radiation field. The altitude at perijove ranges between 4200 km and 5200 km.

The nominal mission is scheduled for thirty-two 11-day orbits or for about one Earth year. The first two orbits are used for JOI and clean up, and the last 30 orbits are used for science acquisition. Upon completion of the last science orbit, Juno will deorbit and enter Jupiter for disposal.

The primary acquisition of science data occurs at ± 3 hours around perijove. Outside of this window, operations are mainly focused upon navigation and maneuvers to adjust the orbit, and upon transmission of engineering telemetry and science data from the just-completed perijove science.

There are two basic science modes for the science orbits: radiometer passes and gravity-science passes (Figure 12). During radiometer sciences passes, the MWR instrument is on, the gravity science payload elements are off, and the rest of the payload elements are on.

The MWR measurements are taken with the solar array plane of the spinning spacecraft passing through the center of Jupiter and the radiometer antennas aligned with nadir. During gravity science passes, the MWR is powered down, the gravity-science payload instruments and the remaining payload elements are powered on, and the high-gain antenna is pointed toward the earth.

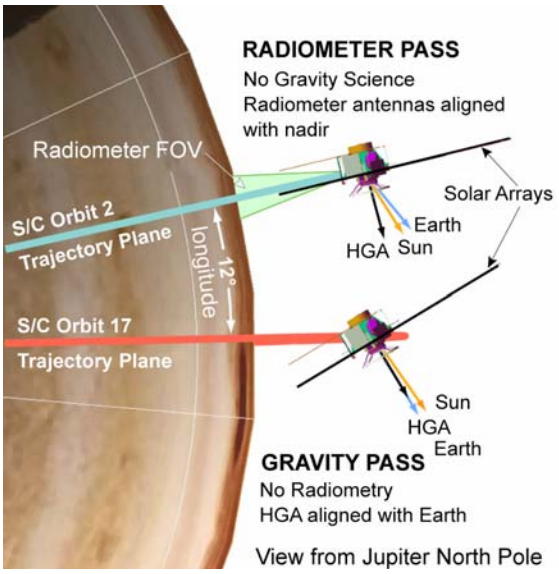

Figure 12: The mission requires only two spacecraft attitudes during science perijove passages, thereby simplifying operations.

The science orbits are required to have equatorial crossings at equal longitudinal spacing, and the magnetic-field investigation requires that the longitude be controlled. Thus, the science orbits have a longitudinal spacing of 24° for orbits 2 through 16; the orbit is then adjusted by 12°, resulting in an overall equatorial longitude spacing of 12° during the nominal science mission (Figure 13)

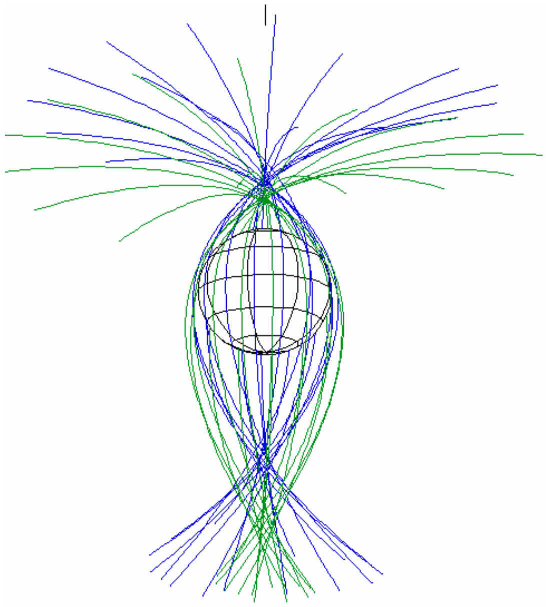

Figure 13: Juno wraps Jupiter in a uniform net, enabling observations that constrain Jupiter's core and characterize its dynamo. The primary science is performed within six hours of perijove. The first six months are shown in blue (orbits 2–16) and second six months shown in green (orbits 17–31).

4 The Spacecraft

The Juno spacecraft is designed to spin, simplifying science operations once it is in orbit about Jupiter. Lockheed Martin Corporation is responsible for the design and build of the spacecraft, as well as for the integration of the payload elements. The polar-orbit design allows the spacecraft to be illuminated by the sun for virtually the entire mission, thereby enabling a solar-powered spacecraft.

Most of the spacecraft subsystems contain a high degree of inheritance from previous robotic spacecraft missions, and the overall spacecraft design and implementation takes maximum advantage of this inheritance.

As shown in Figure 14, the spacecraft has three large solar arrays, which provide about 40 m^2 of solar-cell area. One of the arrays is modified to hold a boom for the magnetometer experiment but sized such that the spacecraft stability is not compromised.

A 2.5-m high-gain antenna provides X- and Ka-band communications and gravity science; it is gimbaled to provide the accurate pointing required during gravity science passes at Jupiter.

The spacecraft is primarily designed and built around the electronics radiation vault, which protects the heritage spacecraft and instrument electronics. The spacecraft uses a monopropulsion system and a bipropulsion system for attitude control maneuvers and larger deep-space and JOI maneuvers respectively. The instruments are placed on the upper deck, lower deck and solar-array booms (see Figure 15).

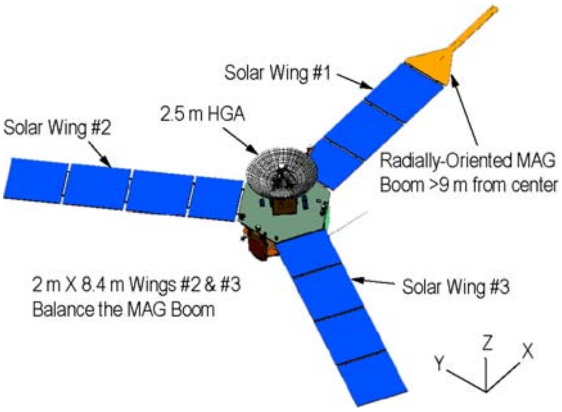

Figure 14: The spacecraft's three solar arrays provide 40 m^2 of solar-cell area, with one of the arrays modified to function as a boom for the magnetometer experiment.

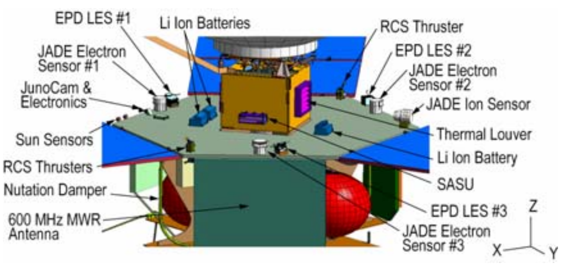

Figure 15: Instruments are placed on the upper deck, lower deck, and solar-array booms.

5 Conclusion

The Juno mission is designed to answer fundamental questions about the formation of Jupiter and our solar system, as well as the formation of gas giants and how that might apply to planetary systems outside our solar system.

To make this mission a reality, NASA turned to two experienced institutions (Southwest Research Institute and JPL) to provide scientific, planning, and managerial leadership. In turn, this leadership selected experienced scientific teams to supply and operate the science payload and an experienced industry partner (Lockheed Martin) to design and build the spacecraft.

This Juno team designed a simplified mission approach that maximizes science return, minimizes operational complexity, and avoids a significant amount of the harsh Jupiter radiation environment. The payload is selected to acquire the primary science and operate in a complementary manner.

Finally, both the spacecraft and payload have significant heritage from other deep-space and Earth-orbiting missions, which reduces development risk and helps ensure that the project meets its cost and schedule commitments.

Juno's mission to Jupiter will provide many new discoveries about the solar system's largest planet and lead to a better understanding of our solar system's formation and history.

6 Acknowledgements

This paper attempts to summarize the several hundred pages of the Concept Study Report (CSR) into a few pages that provide the essence of the Juno mission. This paper would not have been possible without the tremendous efforts of the entire Juno Concept Study Team, comprising members from all of the participating organizations. Most of the information presented here was developed by this team and documented in the Juno CSR.

Acknowledgements

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