Contents

Homework 1

Notation

ABC	explanation 1
DEF	explanation 2

1.1 Introduction

1.2 High level goals

Juno is a NASA spacecraft orbiting Jupiter. Built by Lockheed Martin and operated by NASA, it was launched by Atlas V551 on 5^{th} August 2011. After 5 years, during which many manoeuvres occurred, including an Earth flyby, Juno entered a polar orbit around Jupiter and started its observation, which lasts to this day. Its aim is to study the planet to understand its composition and evolution, analyzing its gravitational and magnetic fields and its atmosphere dynamics. The mission should have ended in 2017, but is still ongoing and it will end in a de-orbit destroying the spacecraft into the planet's atmosphere to avoid contaminating the environment.
Through an analysis of the mission and payload, the main goals of the mission can be highlighted.
LA TABELLA CON I GOALS O I SCIENTIFIC OBJECTIVES? CHE PERO SONO PRATICAMENTE UGUALI PER TUTTO

1. How did Jupiter form and influence the solar system?
   Since Jupiter is the biggest planet of the solar system, it has influenced the formation of all other planets. Its composition has remained unchanged ever since, making it like a time capsule: understanding how and where it has formed can give knowledge on Earth and the whole solar system's origin, evolution and characteristics.
2. What's Jupiter's deep structure?
   One important aspect of the mission is the analysis of Jupiter's deep structure through the measurement of radiations, magnetic and gravitational fields. This allows to comprehend wether or not the planet has a solid nucleus, if so how large it is, and to analyze the supposed layer of metallic hydrogen, compressed so much that it loses its electrons creating a conducting layer. Moreover, Juno will possibly reveal if Jupiter is rotating as a solid body or if the rotating interior is made up of concentric cylinders.
3. What's the structure of Jupiter's atmosphere?
   One of Juno's goals is to study the composition and dynamics of Jupiter's atmosphere, composed by stripes and dots made of different gasses and vapors, including water, whose percentage has to be defined. A significant aspect of the analysis is the great red spot, a swirling mass of gas bigger than Earth, which resembles a hurricane but is very different in the way it works. The movement of stripes and dots is dictated by the weather, characterized by lighting an thunderstorms, which are observed by Juno.
4. What do the poles look like and what are the physical processes generating auroras?
   The observation of Jupiter's poles had never been possible before because of the absence of a polar orbiting spacecraft. Thanks to Juno we have been able to study Jupiter's auroras, representative of the interaction between charged particles and the atmosphere. This can allow a better understanding of the atmospheric composition and the magnetic field's structure and extension.

Guiding questions	**Science objectives**
How did Jupiter form and influence the solar system?	Map Jupiter's composition and image the whole planet
What's Jupiter's deep structure?	Analyze gravitational field, magnetic field and radiations
What's the structure of Jupiter's atmosphere?	Screen the planet, analyze atmospheric processes and emissions
What do the poles look like and what are the physical processes generating auroras?	Image Jupiter, study interactions between atmosphere and magnetic field

Table 1.1: Guiding questions for high level goals

1.3 Mission drivers

Being Juno an interplanetary mission starting from a distance of around 1 AU, with a final nominal distance from the Sun of 5.2 AU, and operating in an highly radiation intense environment, the following drivers have been identified:

1. **Using proven technologies** THE Juno Mission
   The total program is financed with 1.1 Billion $ for 74 months from the launch date and includes development of the S/C, science instruments, launch services, mission operations, science processing and relay support. The simplicity and the need of proven technologies was thus fundamental. The S/C is mainly maintained stable during the manuevers thanks to its spin, raised to 5 RPM from 2, nominal condition during science operations, reducing the need of active stabilization methods.
2. **Providing enough electricity during the duration of the mission**

The journey of Juno is long and passes through different regions of the solar system. Solar panels were chosen to provide electric energy across the mission over a nuclear source, since it has been decided that it was better to advance technology of solar cells rather than developing a new reactor. It is the first S/C to operate with solar panels at such distance from the Sun. The system needed is thus oversized at 1 AU: the solar radiation on Jupiter is in fact up to 96% lower than on Earth. Furthermore the operations are scheduled to begin around 5 years into the mission, so degradation of the solar cells must be taken into account. The final design consists in 3 solar arrays, 2 are 9 by 2.65 m each, meanwhile the third one is shorter at about and only 2 m wide, resulting in about 60 m^2 and granting a maximum power of 14 KW around Earth and up to 500 W around Jupiter. This configurations is needed to mount the MAG faraway from the electronics and store everything correctly inside the fairing. Its solar panels are mounted on the side of hexagonal body of the S/C at 120° one by the other and are deployed after second stage separation. The spacecraft is spinning at around 1.4 RPM during this phase and the deployment of the solar arrays slows it down. A crucial element must be considered during the cruise phases: nominally the high gain antenna, that is mounted with the same positive direction of the solar arrays, is doing Earth pointing to communicate data but, at some point during the cruise phase, due to the proximity of the Sun, thermal requirements dictate a change in attitude and thus the spacecraft won't be pointing directly the Sun. Moreover, since the fly-by around Earth is done to gain ΔV, the S/C will be in an eclipse for around 10 minutes: attention must be paid in battery sizing. Two lithium-ions battery of 55 Ah each are present to make sure power is always provided. The nominal polar orbit around Jupiter allows Sun pointing during the majority of nominal Science Operation phase. INSERIRE RIFERIMENTI: VIDEO, SLIDES LAVAGNA, JUNO Mission, batteries

3. **Shielding the instruments from the harsh environment of Jupiter**
   To accomplish its goals, Juno will need to cross the Jupiter radiation belts: a heavy shielding structure is needed. The magnetosphere represents a great challenge for Juno: the value of the magnetic field measured at its perigee is 776 μT, 50 % higher than expected. The main issue with Juno orbit is represented by the ionizing particles present in the belt around Jupiter: with measured value up to of tens and hundreds of MeV ions located between 2 and 4 R_J, order of GeV were expected under 2 R_J, where Juno should pass through to reach a lower altitude, thanks to its highly elliptical orbit, where radiations are lower, to perform science. The vault in which all the electronics is preserved is cubed shaped and it is made of 1 cm thick titanium alloy, 144 Kg in total. The top deck of Juno is planned to receive a radiation dose of 22 $Mrad$. Moreover, star trackers are also heavily shielded.

4. **Maintaining communication during the journey and the science operations**
   The attitude of the S/C is defined in a way to point Earth during most of the cruise and science operations. This configurations, given the distance from the Sun and the Earth, grants also a sufficient inclinations of the solar panels with respect to the Sun to provide enough electric power. The ground equipment used by Juno is NASA's DSN.

1.4 Functional analysis

Functional analysis is performed in order to identify the functionalities that the spacecraft must perform during the mission. The identified functionalities are schematized in Figure 1.1. [1]

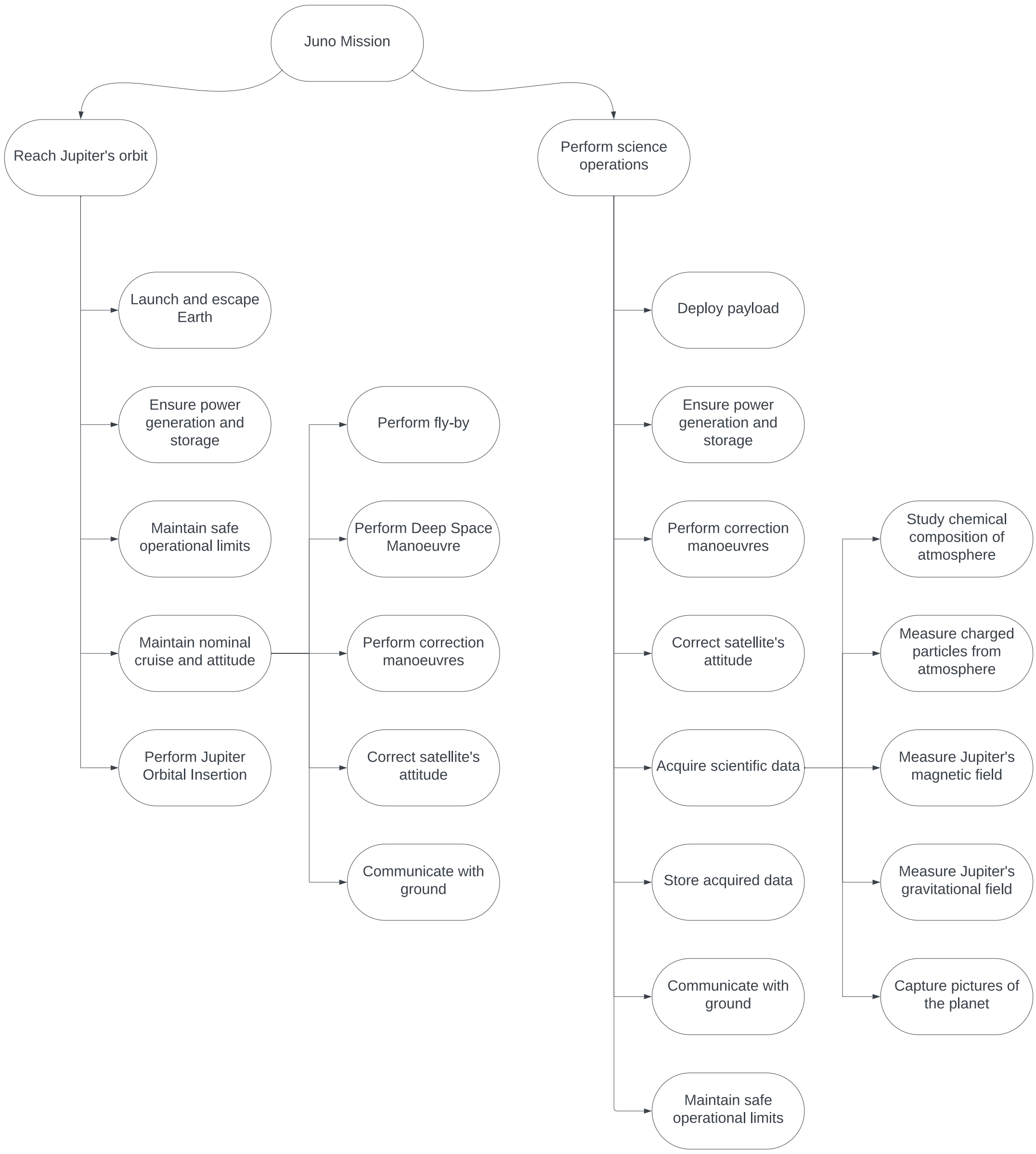

Figure 1.1: Functional analysis for Juno mission

1.5 Main mission phases

The JUNO mission was divided into five phases: Launch, Cruise, Insertion, Science Operations and De-orbit.

1. **Launch**
   The launch took place on August 5 2011, 16:25 UTC from Cape Carnival, in Florida. The selected launcher was Atlas V551, which injected the spacecraft in the desired trajectory. This phase began with the ignition of the booster engine system, and ended with spacecraft separation from the upper stage, about 54 minutes after. The solar panels deployment was performed about five minutes after the spacecraft separation, and it took approximately five minutes.
2. **Cruise**
   At the beginning of this phase, the spacecraft was injected in an interplanetary trajectory with the aim of reaching Jupiter. The cruise had a duration of about five years, during which two deep space manoeuvres and an Earth fly-by were performed. All manoeuvres will be better described in section 1.8. This phase also included instruments testing and verification, to ensure they were functioning properly and ready for the usage during the mission. This phase was also characterized by initial science observations of Jupiter.
3. **Insertion**
   This phase began four days before the start of orbit insertion manoeuvre and ended one hour after the start of the orbit insertion manoeuvre. The latter occurred at closest approach to Jupiter and slowed the spacecraft enough to let it be captured by Jupiter in a 53 days period orbit. The Jupiter orbit insertion burn was performed by the

main engine, and it lasted 30 minutes. After the burn, the spacecraft was in a polar orbit around Jupiter. The 53-days orbit provided substantial propellant savings with respect to the direct insertion in the operational orbit.

4. **Insertion**
   Before starting with the science operations, it was planned to reduce the period of the orbit from 53 to 14 days. However, due to problems with helium valves in the propulsion system, it was decided to remain in the 53-day orbit. The Juno polar, highly eccentric orbit, was designed to facilitate the close-in measurements and to minimize the time spent in the Jupiter radiation belts.

5. **De-orbit**
   The de-orbit phase occurs during the final orbit of the mission. The latter was designed to satisfy NASA's planetary protection requirements and ensure that JUNO doesn't impact any of Jupiter's moons. A de-orbit burn will be performed, placing the spacecraft on a trajectory towards Jupiter surface. JUNO was not designed to operate in the atmosphere and will burn up.

1.6 ConOps

The mission Conceptual Operations are summarized in Figure 1.2.

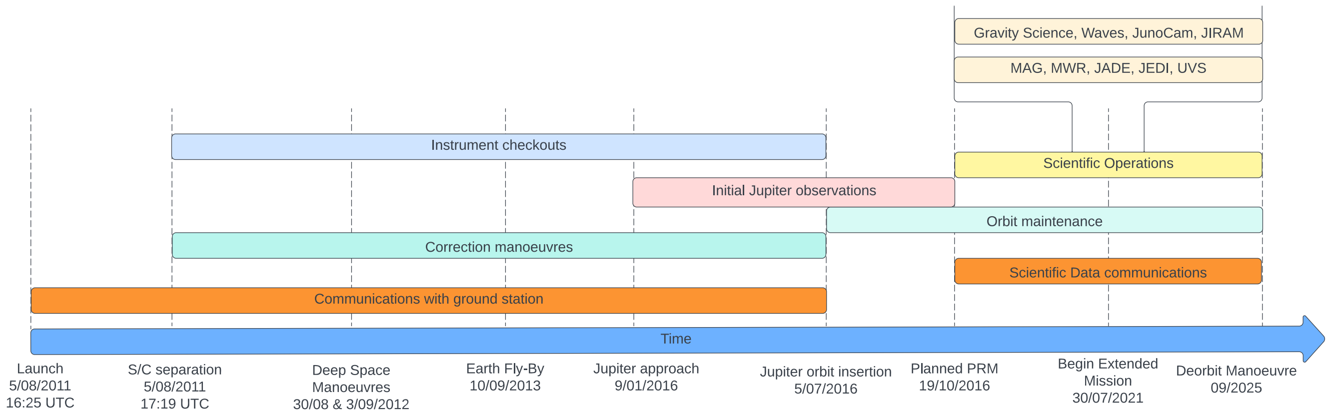

Figure 1.2: Conceptual Operations, time not in scale

1.7 Payload analysis

1.7.1 Instruments overview

As previously described in section 1.2 the mission scientific goals are quite numerous and diverse. Thus, to achieve all of them the payload consists of several instruments, nine to be precise, covering a wide spectrum of experimentation. In its entirety the payload has a mass of around 174 kg and consumes approximately 125 W of power excluding the Gravity science experiment. Here we have a brief overview of all the singular instruments where, unless otherwise specified, only the sensors are mounted on the exterior of the spacecraft while all the relevant electronics are located inside the radiation vault.

- **Magnetometer (MAG):** As the name implies its objective is to accurately measure Jupiter's magnetic field, achieved by employing two flux-gate magnetometers, a scalar helium magnetometer and two star cameras. All the sensors are mounted on the magnetometer boom located at the end of one of the solar array wings to reduce the interference from the spacecraft itself. Even then the presence of two magnetometers allows to subtract this contribution from the measurement.
- **Microwave Radiometer (MWR):** It consists of six antennas which measure six different frequencies (600 MHz, 1.2 GHz, 2.4 GHz, 4.8 GHz, 9.6 GHz and 22 GHz) in order to investigate the Jovian atmosphere below the visible external layer. A key objective of this analysis is also the determination of the abundance of water inside the planet. The antennas are mounted on two sides of the hexagonal prism that constitutes the main body of the spacecraft relying on its spin to survey Jupiter.
- **Gravity science:** It's quite a unique instrument as it's composed both by a space and a ground elements, which mainly consists with the telecommunication systems of both the spacecraft and ground stations. This is because this experiment is based on measuring the doppler shift in the returning signal from Juno which allows to characterize Jupiter's gravitational field. Thus the instrument can't really be separated from the telecommunication hardware which is the reason its weight and power requirement were omitted in the previously shown totals.

- **Jupiter Energetic-particle Detector Instrument (JEDI):** It detects high energy electrons and ions present in the Jovian magnetosphere which are discriminated by composition. Each sensor is characterized by six electron and six ion viewing directions that together cover a $160° \times 12°$ field of view. In total three sensors are present on Juno, two arranged to obtain an almost compete 360° view perpendicular to the spacecraft spin axis while the third one is instead aligned with it to achieve a full scan of the sky over one spin period. As the JEDI sensors are self-contained units no electronic hardware is present within the radiation vault.
- **Jovian Auroral Distribution Experiment (JADE):** It detects low energy electrons and ions with the same goal of characterizing the magnetosphere as JEDI. The instrument comprises of three identical electron energy per charge analyzers (JADE-E) and a single ion mass spectrometer (JADE-I). The electron sensors are located on the three sides of the spacecraft that do not house the solar arrays pointing outwards, to again obtain a complete view normal to the spin axis. The spectrometer field of view, instead, contains the spin axis and like the third JEDI sensor it scans all the sky over a full rotation.
- **Ultraviolet Spectrograph (UVS):** This instrument images and measures the spectrum of the Jovian aurora in order to understand its morphology and source. The chosen ultraviolet range of $68 \div 210\ nm$ covers all of the most important UV emissions form the aurora, mainly the H Lyman series and longer wavelengths from hydrocarbons. The sensor is mounted on the side of Juno, relying once more on the spinning of the spacecraft to achieve a full sweep of the planet.
- **Radio and Plasma Waves (Waves):** Its objective is to study both components of the electromagnetic field generated by plasma and radio waves inside the polar regions of Jupiter's magnetosphere to understand its interaction with the atmosphere and magnetic field. To detect the electric component a V-shaped dipole antenna is used, while for the magnetic component a much smaller magnetic search coil is employed. Both sensors cover a vast range of frequencies, namely from 50 Hz up to 40 MHz.
- **Visible-spectrum Camera (JunoCam):** It's designed to provide highly detailed color images of Jupiter to help and support public engagement of the mission without any real scientific purpose .The instrument is thus only comprised of the camera itself, mounted on the side of the spacecraft, and all the necessary electronics which, given the less critical objective and relaxed radiation tolerance requirements, aren't housed in the radiation vault.
- **Juno Infra-Red Auroral Mapper (JIRAM):** It's an infra-red imager and spectrometer that studies the Jovian atmosphere in the $2 \div 5\ \mu m$ range complementing both the atmospheric and magnetospheric experiments. This instrument is also completely housed outside of the radiation vault since it is a late addition after mission selection, reason for both the relaxed radiation requirements and less than ideal positioning of the sensor on the aft deck of the spacecraft.

All the instruments positions can be seen in the following image

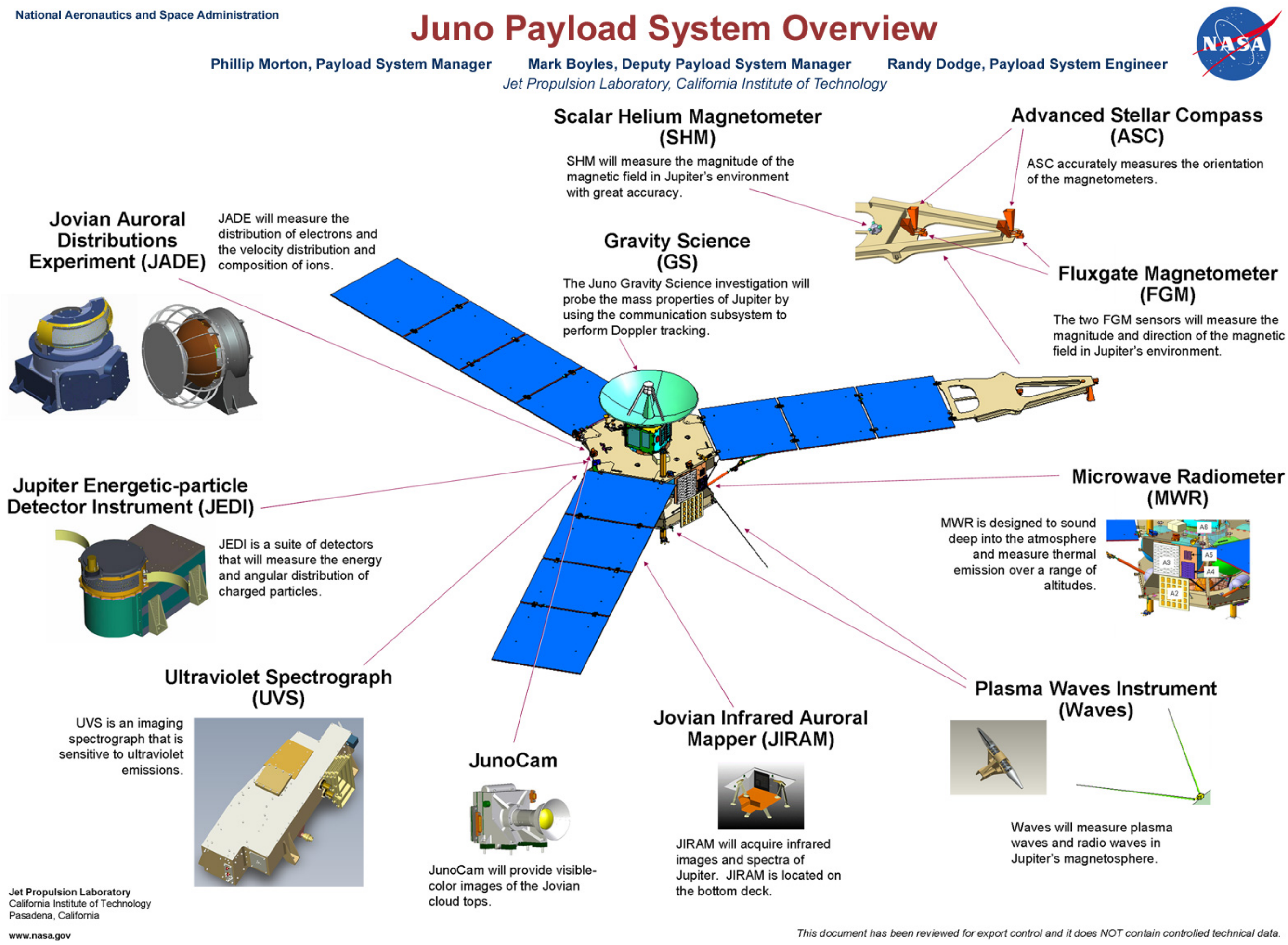

Figure 1.3: Positioning of the instruments on the spacecraft

1.7.2 Payload and Goals correlation

There is a notable overlap in the main objectives of the payload instruments, both in the sense that multiple ones collaborate towards a single scientific goal, but also in the sense that a single instrument can address multiple goals. All of these relations are exemplified in the following table.

Guiding questions	**Science objectives**	**Measurements objectives**
How did Jupiter form and influence the solar system?	Determine Jupiter's inner composition	Composition analysis: MWR
What's Jupiter's deep structure?	Analyze gravitational and magnetic field, measure water abundance in the planet	Gravitational field analysis: Gravity science Magnetic field analysis: MAG Water abundance measurements: MWR
What's the structure of Jupiter's atmosphere?	Analyze atmospheric composition and dynamics	Atmospheric composition determination: MWR Atmospheric dynamics study: JIRAM
What do the poles look like and what are the physical processes generating auroras?	Image auroras, study interactions between atmosphere and magnetic field, characterize the magnetosphere in the polar regions	Imaging auroras: UVS, JIRAM Atmosphere-magnetic field interaction: JIRAM Characterize the magnetosphere: Waves, JADE, JEDI

Table 1.2: Mission goals and instrument objectives correlation

It can be noted that the JunoCam instrument doesn't appear in the table since it's not part of the scientific goals of the mission, as previously mentioned in its description.

1.7.3 Payload and Phases/ConOps correlation

Another high-level correlation can be highlighted between the mission phases/ConOps and the activities of the payload as shown below.

Mission phases	**Payload activities**
LEOP	Mag boom is deployed together with solar arrays
Cruise	Instruments checks are performed regularly and the high gain antenna (used for Gravity science) is calibrated and aligned
Jupiter approach	Final instruments checks are carried out together with some initial scientific observations of Jupiter
Science orbits	Complete nominal operation of the payload with observations divided between Gravity science passes (Earth pointing) and MWR passes (Nadir pointing)
De-orbit	No planned payload operations

Table 1.3: Mission phases/ConOps and Payload activities correlation

1.8 Mission analysis

1.8.1 Launch and cruise

The spacecraft was launched into orbit with an Atlas V 551 Rocket from Cape Canaveral. The actual launch date belonged to a 21-day time window limited by a number of events and their timings such as the Deep Space Maneuvers, the Earth Flyby, the Jupiter Insertion and the science orbits.
Following the launch, after booster separation, Juno was put in a parking orbit around Earth thanks to a first burn of the Centaur upper stage. Afterwards, at time L+645 s, via a second burn given by the same stage, Juno entered an heliocentric trajectory. Solar arrays were deployed and initial checks on the instruments were performed at this time. The specific trajectory followed by Juno is called "2+ dV-EGA", which means that the spacecraft will perform an Earth gravity assist at around two years after launch. During the initial cruise various correction maneuvers were performed: the main ones being the two DSMs needed to place Juno on the correct path to achieve the planned fly-by. DSMs were performed near the apocentre, located farther away from the Sun than Mars' orbit, causing the spacecraft to pass as close al 0.88 AU before approaching Earth. The fly-by around Earth occurs on the 10^{th} of September 2013 and puts the spacecraft on its final trajectory to Jupiter. Particularly, the fly-by gave the spacecraft 7.3 km/s, avoiding a fire-up of the Leros 1b main engine of Juno.

1.8.2 Jupiter insertion

1.8.3 Science operations

1.8.4 Extended mission

1.8.5 Mission disposal

Bibliography

[1] Howard D. Curtis. *Orbital Mechanics for Engineering Students*. Elsevier, 2014.