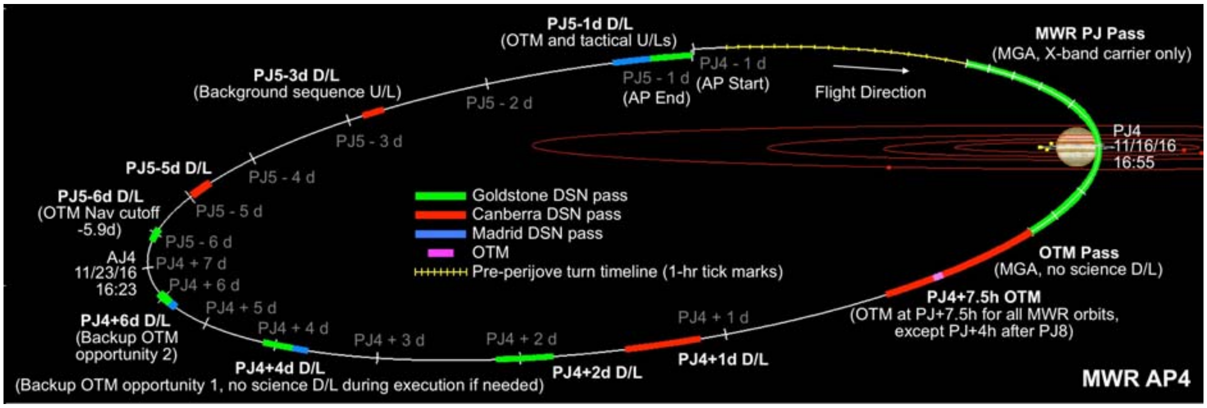
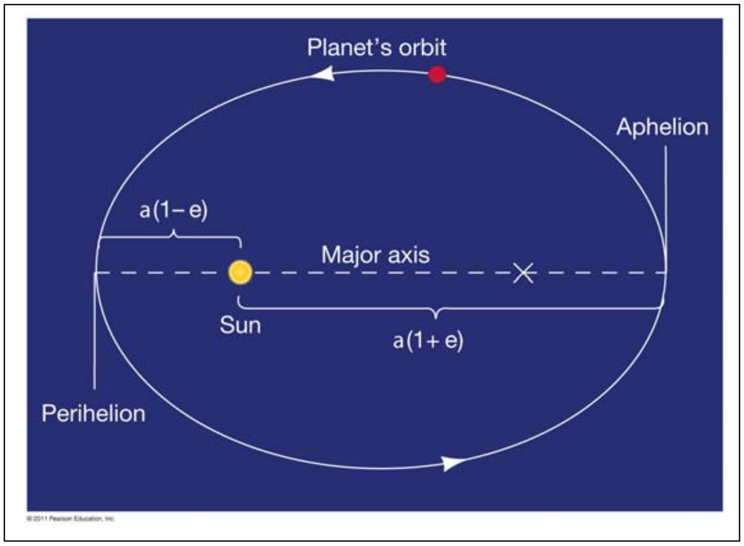
Exploring the Orbit of Juno



The Juno spacecraft arrived at Jupiter on July 5, 2016 and following a brief burn of its rocket engines, settled into an orbit around Jupiter. This initial orbit was much different than the carefully planned science orbits to follow, and which are shown in the above figure. The initial orbit has a period of 53 days, and after the completion of two of these insertion orbits, it will fire its rockets one last time on October 19, 2016 to settle into the optimum polar orbit with a period of 14 days. Jupiter's gravity accelerated the approaching spacecraft to ca. 266,000 km/h (74 km/s). On July 5, 2016, between 03:18 and 03:53 UTC Earth-received time, an insertion burn lasting 2,102 seconds decelerated Juno by 542 m/s and changed its trajectory from a hyperbolic (fly-by) orbit to an elliptical, polar Jovian orbit with a period of about 53.5 days. This will be followed by a series of Period Reduction Maneuvers leading to insertion into the final 14-day Science Phase Orbit.

There will be 36 Science-Phase orbits with periods of 13 days and 23.3 hours. The first clean science orbit (Number 4) will start on November 16, 2016 and the last on February 6, 2018 (#36, Extra Orbit). The above figure shows the detailed scheduling events for Science Orbit Number 4. The science orbits have been planned so that each time a pass over the north pole of Jupiter is completed, the plane of the next orbit gradually shifts by about 1 degree so that different parts of the Jovian radiation environment can be measured. This shift also improves models of the gravitational field of Jupiter, which will let scientists model the interior of the planet in great detail.

The orbits have been designed so that Juno spends as little time as possible in the most intense parts of the radiation environment. To make sure the instruments survive the 10 hours they will be exposed, the spacecraft is equipped with a “Radiation Vault", with 1-centimeter-thick titanium walls, which aid in protecting and shielding Juno's electronics. Despite the intense radiation, *JunoCam* and the *Jovian Infrared Auroral Mapper* (JIRAM) are expected to endure at least eight orbits, while the microwave radiometer instrument should endure at least eleven orbits.

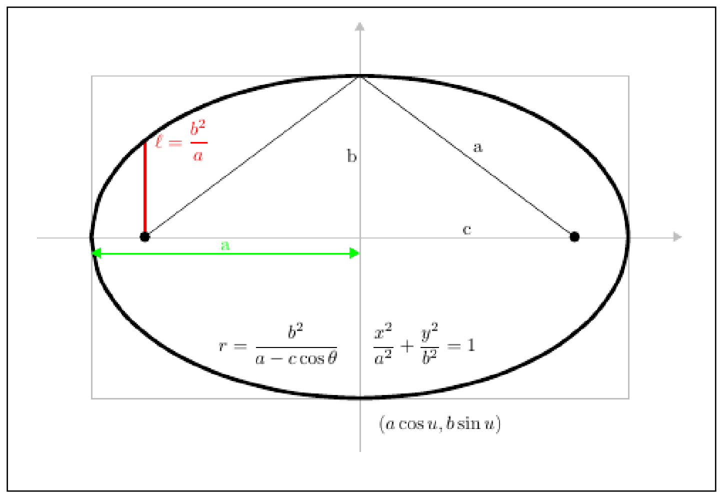


Planets and satellites orbit more massive bodies along paths that are elliptical in shape. We often refer to two specific points on these orbits by the prefix 'ap' and 'peri' where *aphelion* means the farthest point on the orbit from the sun and *perihelion* is the closest point to the sun. Similarly, we use *perigee* and *apogee* for corresponding points on orbits near Earth, and *apojove* and *perijove* for orbits near Jupiter. These important points can be mathematically defined as well.

Mathematically, we can define the equation of an ellipse centered on the point (h, k) in 'Standard Form' as

$$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$$

where **a** is the semi-major axis length and **b** is the semi-minor axis length. The eccentricity of an ellipse defined as $\mathbf{e^2 = (a^2 - b^2)/ a^2}$ and is the distance from the center of the ellipse to one of its foci. Apojove is then defined as R_A = a(1+e) and perijove as R_P = a(1-e).



Problem 1 – The planet Jupiter is located at one focus of an ellipse and the *Juno* spacecraft travels on an elliptical path. From the information provided, if the apojove distance of *Juno* is 39.0 and the perijove distance is 1.0, what are the eccentricity, semi-major axis and semi-minor axis values? (Note: the units for the distances are in multiples of the radius of Jupiter of Rj = 69,900 km)

Problem 2 – Write the equation for the orbit of *Juno* in Standard Form where h=k=0.

Problem 3 – What will be the distance of *Juno* from Jupiter when x = 3.0 Rj? Give your answer in units of Rj and in kilometers, rounded to two significant figures.

Problem 1 – The planet Jupiter is located at one focus of an ellipse and the *Juno* spacecraft travels on an elliptical path. From the information provided, if the apojove distance of *Juno* is 39.0 and the perijove distance is 1.0, what are the eccentricity, semi-major axis and semi-minor axis values? (Note: the units for the distances are in multiples of the radius of Jupiter of Rj = 69,900 km)

Answer: *Apojove is defined as* $R_A = a(1+e)$ *and periJove is* $R_P = a(1-e)$*, so adding* R_P+R_A *you get*

$R_P+R_A = 2a$*, and so* $a = (1.0 + 39.0)/2 = 20.0$. $\mathbf{a = 20}$

But $R_P = a(1-e)$ *then* $e = 1 - R_P/a$ *and so*

$e = (1 - 1.0/20) = 0.95$. $\mathbf{e = 0.95}$

Then from $e^2 = (a^2 - b^2)/a^2$ *we also get*

$b^2 = a^2 (1-e^2)$ so $b = 20.0\ (0.30) = 6$. $\mathbf{b=6}$

Problem 2 – Write the equation for the orbit of *Juno* in Standard Form where h=k=0.

$$\mathbf{x^2/400 + y^2/36 = 1}$$

Problem 3 –If Jupiter is located at the focus on the positive x-axis, what will be the distance of *Juno* from Jupiter when x = 3.0 Rj? Give your answer in units of Rj and in kilometers, rounded to two significant figures.

Answer: The point on the ellipse for x=3.0 is found from the equation of the ellipse in Standard Form as:

$9/400 + y^2/36 = 1$ which can be solved for y to get two points.

$Y^2 = 36 - 36*9/400$ so $y^2 = 35.2$ and so y = +/- 5.9 so the points are (3.0, +5.9) and (3.0, -5.9).

Jupiter is located at the positive-x focus located at the point (+ea,0), which is the point (+19, 0).

From the Pythagorean distance formula $d^2 = (x2-x1)^2 + (y2-y1)^2$, we get

$D^2 = (19-3)^2 + (0-5.9)^2$, so $d^2 = 290$,

and so the distance of Juno from Jupiter at this point is just **17Rj**, which in kilometers is 17 x 69,900 km = **1.2 million kilometers.**