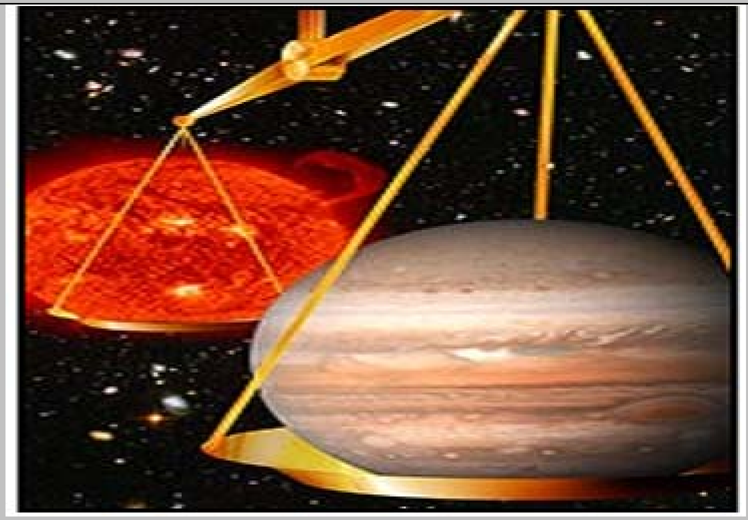
Watch your weight in the cosmos

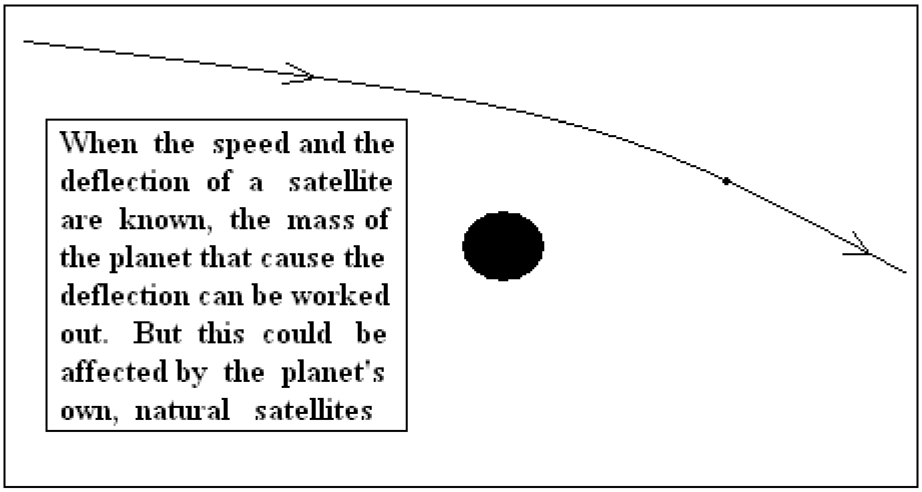


Different kinds of weighing scales can be used in estimating the mass of the heavenly bodies, says S.Ananthanarayanan.

The time tested method is from the days or months a satellite takes to orbit the cosmic object. As the speed of orbit depends on gravitational attraction, this speed indicates the mass of the centre of attraction. An international team working at the ***Commonwealth Scientific and Research Organisation*** (CSIRO), Sydney, Australia, has reported a new way, using radio signals from pulsars!

Time tested way

The orbit of a satellite is a balance of the tendency of the satellite to fly straight past the attracting object, and the force of attraction that bends the path. As the satellite comes nearer the centre, the force of attraction increases, but so does the speed of the satellite. But if the satellite moves away, it uses up its movement energy and slows down. The result is that the approaching motion and the moving away keep compensating and the satellite moves in an ellipse (oval shape). And in the case of satellites of the solar system, the ellipses are almost circles.



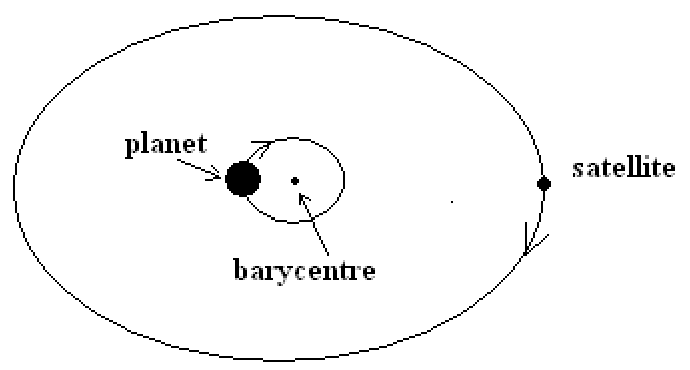
The force of attraction depends on 3 factors – the mass of the central object, the mass of the satellite and the distance and the force reduces with the square of the distance. This force is balanced, in the case of an orbit, by the 'centre fleeing' force due to the motion. This force depends only upon the mass of the satellite, its speed and the size of the orbit. As the two forces are equal, the mass of the satellite cancels out, being common, and only the mass of the centre, the speed and the distance remain. If we know the distance, and the time it takes to orbit, we can work out the mass of the centre.

This is the way we have worked out the mass of the sun and in the case of the planets, we know their mass with the help of their own satellites. In the case of a planet without a satellite that is easy to observe, we can send out a space ship which flies past the planet and the deflection in the path gives away the mass of the planet.

The new method

The time tested way depends on some factors that can have errors in measurement, for example the distance of the satellite from the centre. Or, in some cases, it is not practical to send out a spacecraft to fly pas the planet. In future space missions, knowing the mass of heavenly bodies very accurately may be of great importance.

The new method uses the slight movement, or 'wobble', that the movement of each planet causes in the position of the sun and all other planets. We are familiar with this idea from a method that is used to detect the planets of distant stars. In these cases, the glare of the parent star makes it impossible to spot the dim, reflected light from the comparatively smaller star, at least from a great distance, down here on earth. But even then, the motion of the planet causes the star also to move, just a little. Although we say the planet is in orbit around the star, in fact, the star is also in orbit, the real motion is that both the objects move in circles around the centre of gravity of the two objects taken together. The motion of star then causes shifts in the frequency of light, which is detected, to work out the dimensions of the satellite.

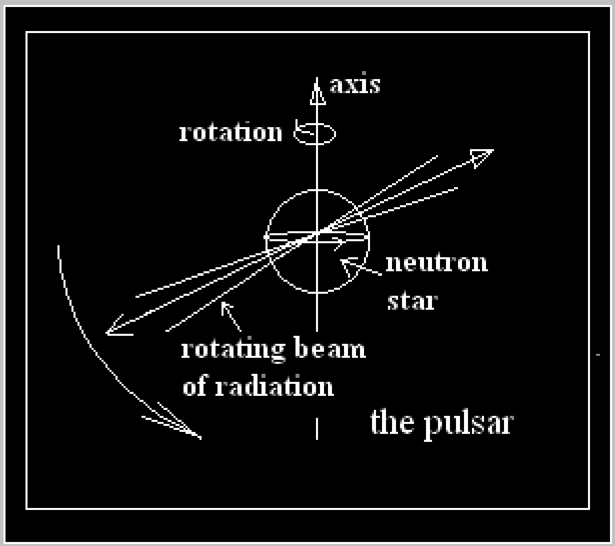


Wobble of the central planet with one satellite

In the same way, the sun and all the planets have a common centre of gravity. As the planets are in motion according to their own speeds and patterns, this common centre of gravity, although stable in space, is not fixed with respect to any of them, as they move from one side to another, relative to the sun and relative to each other. The Australian group has made use of an effect of this changing separation of the common centre of mass, relative to the planets, to gauge the individual masses themselves.

Pulsars

Pulsars are rapidly spinning cores of collapsed stars. When stars run out of the nuclear fuel that keeps them burning, they cease their cycle of collapse and expansion and go into continuous collapse. The atomic nuclei constituting the core get stripped of charges and they no longer mutually repel, but get pressed together, to create the densest form of matter – a ***neutron star***.



In the course of collapse to this fractional size, any orbital motion gets magnified and the star is in a rapid, but steady spin. As everything has some internal charge distribution, this spin creates intense magnetic fields and high energy radiation, which flashes as the object spins, like a cosmic lighthouse.

The pulsar is thus a source of ***rock steady periodic signals*** and any variation in their rhythm would be an accurate measure of the movement of the place where the signals are detected

Pulsars and planets

In the case of pulsars and the solar system, any steady state or systematic drift is with respect to the pulsar and the centre of mass of the solar system, also called its ***barycentre***. While the signals from pulsars would be strictly steady at the barycentre, this is not true at individual planets, like the earth. The measurement of the ***Time of Arrival*** of the signals at the earth then needs to be corrected to correspond to the actual period of the pulsar. The changes are because of the orbital motion of the earth, the drift of the pulsar, interstellar disturbances and relativistic effects, but the main variable effect is because of the movement of the earth with respect to the solar system barycentre.

This distance variation is as high as 300 million km and the delays can be of the order of 500 seconds. The pulsar timing can be measured correct to microseconds. The timing method thus provides a sensitive measure of exact drift from the barycentre.

The worked out barycentre drift is with the help of the ***ephemeris***, which is a tabulation of the present and future position of the planets. The ephemeris is created out of available data of the movement of the planets and their mutual interaction and has limitations of accuracy. As it is possible to make timing measurements with a large number of pulsars, and over long periods of time, this method provides scientists with reliable means to verify many of the parameters that go into preparation of the ephemeris. Typically, this includes masses of planets, and not just planets but the whole planet system, that is, the planet along with its satellites.

The CSIRO researchers made use of the extensive data that has been collected for detecting gravity waves. Gravity waves are minute variations in space itself, which could be propagated by pairs of pulsars and could be detected by changes in separation of distant points which detect the same pulsar flash. The CSIRO team analysed pulsar data collected in these experiments and has deduced masses of the planets that are in close agreement with the existing data, based on satellite fly-past, for most planets. In many cases it is clearly a more accurate measurement and as this method provides the mass of the whole planet system, it is preferable for many purposes

The paper detailing the work has been accepted for publication by the Astrophysical Journal and has been circulated by the American Astronomical Society.