Orbital dance around Saturn

Well, we all know that Saturn is surrounded by many rings and moons. Two of those moons **Janus** and **Epimetheus** orbit Saturn so close together that it seems as though their different orbital speeds should make them crash into each other. However, due to their mutual gravitational attraction and their very slightly different distances from Saturn, instead of colliding, they exchange orbital positions.

The satellites do their swap once every 4 years. Their mutual dance was observed by the Cassini-Huygens space probe on 21st January 2006. During the swap, Janus moved from the outside to the inside while Epimetheus moved from the inside to the outside. The swap itself took about 100 days.

Here is how the dance works. Janus and Epimetheus are small, irregularly-shaped moons with diameters of about 120 and 180 kilometres. The orbital radii of the moons are strangely separated by less than the radii of the moons themselves. Their orbits around Saturn differ by only 50 kilometres, while the sum of their radii is 150 km!

Since Cassini arrived at Saturn, Epimetheus has been the inner of the two satellites. Because Epimetheus was closer to Saturn, it traveled at a faster angular rate than Janus. Hence, Epimetheus was slowly catching up the outer Janus. As they approached each other, Epimetheus exerted a gravitational attraction force on Janus, while Janus excerted an equal and opposite force on Epimetheus.

This mutual attraction caused them to exchange angular momentum. Epimetheus gained momentum, was accelerated and raised in orbit as Janus lost an equivalent amount of momentum,was deccelerated and fell in orbit. Because Janus is four times more massive than Epimetheus, it fell four times less than Epimetheus raised. They then began moving away from each other with Janus now in the lower orbit and Epimetheus in the higher orbit. Their roles have simply switched. The switch of orbital altitudes made Janus the faster of the two. As a result, Janus moved slowly ahead. It continued to move slowly ahead of Epimetheus until it cought up from behind 4 years later, in January 2010 when the reverse swap took place.

By knowing the masses of the moons and the semi-major axes of their orbits, using simple classical mechanics I estimated the distance of their closest approach at about 6,000 kilometres. However, the problem is a little more complicated than that. In reality, the satellites always experience each other's gravitational effect. In addition, Janus and Epimetheus aren't only tugging on each other. They also tug on the particles in Saturn's rings. It was observed that ring particles at the outer edge of the A ring of Saturn orbit Saturn seven times for each orbit of Janus and Epimetheus. Through this resonance, they help contain Saturn's main rings. However, it would be very interesting to see what happens to the particles in the ring when the moons change their places.

But how may such a system form? One hypothesis is that the bodies originally formed at essentially the same radius, in the L4, L5 configuration (such as the Trojan moons). Once formed, they suffered various random perturbations. A small change in one moon's velocity put the coorbiting moons at slightly different radii and this might cause their strange orbital dance.

Finally, I can say that as far as it is currently known this arrangement is unique in the solar system. The orbital relationship between Janus and Epimetheus can be understood only in terms of the circular restricted three-body problem, as a case in which the two moons, the third body being Saturn are similar in size to each other.