Only about 90 years ago we, as humans, thought that the Milky Way, the galaxy we live in, was the entire Universe. Other nearby galaxies, like the Andromeda galaxy, were thought to be clouds of gas within the Milky Way. That all changed with Edwin Hubble who, in 1922-23, discovered that these "clouds" were actually much too far away to be part of the Milky Way and were actually entire galaxies outside our own.

Since then these “island universes”, as they were known, have been discovered in vast numbers, spread throughout the Universe. Originally the Universe was thought to be unchanging, but now we know the Universe is expanding and that galaxies interact with each other – sometimes with devastating consequences.

Collisional Ring Galaxies (CRGs) are one of the rarest types of galaxies. They are so rare that out of the millions, if not billions, of known galaxies, only about 130 CRGs have ever been found. Two types of galaxies are usually involved in the formation of a CRG, namely an elliptical and a spiral. An elliptical galaxy is basically an enormous, nearly spherical ball of stars, often much larger than the Milky Way. Spiral galaxies are those like the Milky Way, flat discs of stars and gas shaped a bit like a fried egg. What makes CRGs so rare, and also gives them their name, is the unusual way they form. A nearly perfect chance alignment between two galaxies is required**.** Then, if the elliptical galaxy collides head on with the spiral, it causes an explosion outwards from the spiral's centre in the form of an expanding ring of gas and stars. What results is one of the most beautiful sights in astronomy. A CRG.

Recently, astronomers from the University of Concepcion, in collaboration with others in Santiago, Germany and Australia, made an amazing discovery. Using the Subaru telescope in Hawaii for a recent survey of the outer parts of our own Milky Way galaxy they noticed a very distant galaxy in the background. Not only that, it looked like it might be a previously undiscovered CRG.

The team, which includes astronomers Dr Richard Lane and Dr Rory Smith from UdeC, looked at the CRG with the Gemini North telescope (LINK TO GEMINI WEBPAGE HERE??) in Hawaii attempting to prove what they suspected. Using a technique known as spectroscopy, where the light from a distant object is collected with a telescope and then split into different wavelengths, the motions of the different parts of the CRG can be seen, and its distance can be calculated. Using the spectroscopy technique they found that it is about 1.5 billion light years away (about 15 thousand billion billion kilometers). Because of the time taken for the light emitted from it to travel to us, life on Earth only consisted of simple single celled organisms when the light we are seeing left the CRG. At this distance, Auriga's Wheel is the most distant well studied CRG in the Universe. Figure 1 shows a colour image of the galaxy and a cartoon showing the different parts. What they discovered was that the two galaxies are definitely forming a new CRG. It has become known as "Auriga's Wheel" because it is in the constellation of Auriga, the chariot.

"Ring galaxies are formed when a 'bullet' galaxy ploughs through the centre of

a spiral galaxy", explains Dr Smith. "The unsuspecting spiral galaxy reacts to the gravitational pull of the intruder by generating the ring-like structure that is so strikingly reminiscent of ring galaxies. In many of these objects there is often some uncertainty as to which galaxy was the guilty intruder...but this isn't the case with Auriga's Wheel. The presence of a faint bridge of stars linking the ring to a closely neighbouring elliptical galaxy leaves us with little doubt as to which galaxies were involved."

Dr Lane and Dr Smith go on to explain that "The presence of the bridge of stars is important because it has rarely been seen before. It means we are catching the elliptical galaxy in the action of transforming a spiral galaxy into a ring galaxy. The gravitational forces during the interaction of the two galaxies are quite extreme...they have torn out a stream of stars from one of the galaxies."

This bridge is what prompted the researchers to look at the interaction with computer models. "We wanted to know what will happen to these galaxies in the future," they explain. "Will these two galaxies separate and go on their merry way never to meet again? Or will they eventually combine to form a larger, single, object? From the image alone, it is difficult to know what going on. Are the stars being stripped out of the elliptical galaxy and flowing on to the ring galaxy, or vice versa? Our computer model was also designed to try to understand how such a bridge of stars could have formed, and perhaps explain why they are so rarely seen."

"We ran computer simulations to try to reproduce the appearance of the ring galaxy. A really good model would also match the dynamics of the ring galaxy. This would allow us to study how the two galaxies must have looked before
they interacted, and also how they ended up looking as they do today. The computer simulations are a little like playing a computer game," Dr Smith says, "I would fire one galaxy at another, each time varying the properties of the individual galaxies involved, and how they interacted. Many of the final results looked nothing like Auriga's Wheel...the gravitational forces between the galaxies made a complete mess of both galaxies!"

"Eventually we found what we were looking for: the right combination of a spiral galaxy and elliptical galaxy that matched the properties of Auriga's Wheel very well following their encounter with each other. There were several important ingredients. The galaxies involved were not unusual in anyway. However the first key ingredient was that they had to collide in an almost perfectly head-on collision. This is important for generating a ring that is close to circular and is not broken."

"The second ingredient was the velocity of the encounter. The galaxies initially fall towards each other at 150 km/s. This may sound incredibly fast, but in galaxy terms we would call this a 'low velocity encounter'. For example, some other ring galaxies are believed to have formed in collisions as fast as 1000 km/s! The low velocity of the encounter is very important as it allows the stellar bridge to form."

"We find that the stellar bridge is dragged out of the spiral galaxy, and flow towards the elliptical. At higher velocities, the galaxies move past each too fast for the stars in the spiral galaxy to respond, and the bridge does not form. So the galaxy encounter has to be quite slow, in order to produce the observed stellar bridge. The low velocity between the two galaxies is actually important for the future evolution of the galaxies."

"Normally astronomers are content to understand the processes that led to the formation of the galaxy we are observing. However, we wanted to know what the future had in store for Auriga's Wheel. So we decided to continue our computer simulations so as to model the future evolution of the two galaxies."

"What we discovered was really cool - we found that the two galaxies will become one! The low velocity of the encounter means that the elliptical galaxy does not have enough speed to continue after forming the ring galaxy. The elliptical actually loses a huge amount of speed in the collision. This dooms it to eventually combine with the ring galaxy to form a single galaxy - something we call a 'galaxy merger'. This helps us explain why the stellar bridge is so rare. They can only exist when a CRG is formed in a low speed collision, and when that happens, the two colliding galaxies tend to merge together to form a single galaxy. This means the bridge is only visible for a short period of time before it is absorbed."

"Another interesting thing is that the ring galaxy actually merges with the elliptical galaxy piece-by-piece. First the nucleus of the ring galaxy falls into the elliptical along the path of the stellar bridge. It is some time later before the expanding ring ceases to expand, and falls back inwards, finally also merging with the elliptical galaxy. The final result is a much larger elliptical. Many people believe that galaxy merging is the way all galaxies grow." Figure 2 shows snapshots from the computer model of the encounter.

So, it appears that the mysteries of Auriga's Wheel have been solved. Its properties are well produced by a near head-on collision between a spiral galaxy and an elliptical galaxy.
"We are lucky to be able to witness this sight...such a direct hit between two galaxies is not a common occurrence. We are even luckier to glimpse the two galaxies while they are still linked by a rare and short-lived bridge of stars! A spectacular find and impressive stuff. "

FIGURE 1 CAPTION:

Left panel: The colour image of the CRG from the original Subaru survey. Right panel: A cartoon showing the different parts of the object. Shown are the ring of star forming gas -- gas which has been compressed into forming new stars because of the interaction -- the nucleus -- a dense knot of stars in the centre of the ring caused by the gravitational attraction of the elliptical as it passed through the disc of the spiral galaxy -- the stellar/gas bridge -- a structure linking the nucleus/ring with the elliptical which formed as stars were dragged out of the disc galaxy by the elliptical -- and the elliptical itself. The ring is expanding and rotating as shown by the arrows. The

expansion is due to the collision, but the rotation is due to the initial rotation of the spiral galaxy.

FIGURE 2 CAPTION:

Snapshots from the simulations of Auriga's Wheel.

In each panel the time is shown in millions of years. The upper panels are in the past and lower panels are the future evolution. The elliptical can be seen approaching the spiral until they collide. After the collision the ring forms and expands. Eventually the two galaxies merge to become a single object. Notice that the panel representing the current view (labelled “NOW”) shows all the features highlighted in Figure 1.