

Astronomers have known for a long time that stars can collide and merge into a new star. Among objects that undergo such cosmic collisions are normal stars similar to the Sun and more evolved red giants and white dwarfs. The reasons why these stars merge are very poorly known but most likely they are very different than those leading to collisions between two massive black holes that recently were observed through gravitational waves. In the case of the black holes, it is the emission of the gravitational waves itself that is the direct cause of the merger, whereas the mechanisms leading to the collisions between the less exotic and less massive stars are more complex. Numerical simulations of such stellar systems exist but they inevitably are somewhat incomplete and often lead to contradictory results. In the project proposed here, we would like to understand what are the causes and results of stellar collisions by performing detailed and novel observations of stellar mergers, instead of relying on the simulations.

It is suspected that many well-known and exotic types of stars were created in a stellar merger. Among these objects are blue stragglers, carbon stars of types R and R Coronae Borealis, rapidly rotating FK Com stars, young and massive stars including the famous  $\eta$  Car system, and many others. In case of these objects, the collision must have taken place very long time ago. It would be very hard to identify any direct signatures of that event and convincingly (empirically) show that such merger indeed took place. Since very recently, however, we know a group of objects, known as *red novae*, which undergo collisions before our eyes, that is we observe them during the merger event and, in rare cases, even just before the catastrophic stellar collision. Because the remnants of red novae contain information about the physical processes that caused the collision, they are the main targets of the observations we are proposing here. We know of five Galactic red novae and expect to observe a few additional ones in the coming years.

Just after the collision, all red novae become very cool and in their surroundings are rich in dust and cool molecular gas. From preliminary observations, it appears that the structure of this cool environment is very complex and often composes of disks, jets, outflows, and dusty tori. In properties of these structures is written the history of the past stellar collision. Through observations of red novae, we will be able to say, for instance, how much angular momenta is deposited in these structures and in the star, and then compare these values to the angular momentum of the system prior to the collision. The simulations mentioned above are not able to reliably predict how the angular momentum is redistributed in the merger remnant. The aim of the project is to fully characterize the red-nova remnants and to use that information to decode the processes responsible for the stellar collisions. This will also allow to make better numerical models.

Because most of the material surrounding red novae is cool and the gas has a molecular form, our research will be conducted mainly in the infrared and microwave ranges. These ranges contain signatures of many relevant molecules from which it is straightforward to determine the motions of material surrounding the star. In the investigations, we plan to apply a brand new approach to the observations of red novae and use interferometric techniques to obtain detailed maps of the regions where the stars collided. We are going to use the ALMA interferometer which by combining 43 radio antennas will allow us to obtain maps at a level of detail comparable to that requiring a single telescope of a diameter of 15 km! In the infrared, we are going to use two interferometers, *Gravity* and *Matisse*, very recently installed on the biggest optical telescope on Earth, VLTI. They will deliver fine observations of the newly formed stars and their immediate surroundings, allowing us to solve the mysteries on how stars collide.