DJORGOVSKI: Let's now move on to slightly different subject, which is star clusters. And they have numerous uses, but they're actually where the first-- and still are main probe of stellar evolution. This is a picture of a freshly minted young cluster in Magellanic clouds. And you can still see there is nebula with the leftover protostellar material that's been now ionized by these young stars.

Roughly speaking, star clusters come in two varieties-- the so-called open clusters, and globular clusters. And open clusters are always found in the galactic disc. And they have relatively small numbers of stars. This turns out to be an artifact, because there are many more small ones that are made than there are really massive ones. And there ages range from some millions of years to a billion years at most. Billion year ones are really rare. Typical ages of open clusters are maybe some tens of millions of years.

Globular clusters, on the other hand-- the name kinda implies their shape-- contain many, many more stars. Tens of thousands of millions. And they're old. They're also found in different places. They're floating in the halo of the Milky Way. They are older stars. Less chemically evolved. And they're the surviving part of the much larger population that was there. In the beginning, the small ones tend to be evaporated, and I'll now explain how.

So we can use clusters to probe two different things. One is stellar evolution theories, and the other one is dynamics of stellar systems. Considering clusters as a ball of gas, where stars are like molecules.

Here's a typical open cluster, M25. A lot of bright, blue stars. Those are the ones that are easily seen, because they're the most luminous ones. There are many, many more dimmer ones that are a little cooler and less luminous. And they tend to be regular, inheriting the geometry of the protostellar cloud from which it had formed.

Globular clusters, on the other hand, tend to look well relaxed. Denser in the middle, for dynamical reasons. Stars are moving along in random orbits. And there are about 150 of these now left in the Milky Way. Andromeda has more like 500. But a big elliptical galaxy like M87 in Virgo, has something like 10,000.

So how do we test stellar evolution? The problem here is that this is a physical process that happens in time scales that are much, much bigger than the age of humans, or duration of graduate student PhD thesis, or human civilization. Billions of years. So the only thing you can hope to do is get a whole bunch of snapshots of stars at different ages. And star clusters come very handy, because we believe that by and large-- and again, star clusters, most of them kind of form more or less at the same time, within a million years or thereabouts. And therefore, you have a whole set of stars of different mass. If you find clusters of different ages, that could map the whole thing nicely.

Now, the second thing is that they're all same distance, essentially. The spatial extent of clusters may be parsecs, at most. Whereas they're kiloparsecs away. So for all practical purposes, all stars are the same distance. Therefore, if you measure, somehow, distance to the cluster, you know them all. You don't even have to do that, if you can measure relative velocities.

So by large, they also form-- they have the same composition because they form from the same protostellar cloud. And therefore they provide a really good set of samples to test our models. So when this was done first, with open clusters, the disc clusters, it was discovered that they have a range of different HR Diagrams. They all shared common main sequence, but different clusters had different lengths of the main sequence extending to higher luminosities and higher temperatures. And then they all kind of bend over, and then there'll be this red giant branch off to the side.

So now this is understood, why this happens as a consequence of stellar evolution. And in fact, this was some of the key observations that led us into understanding of how stellar evolution works.

So here are the HR Diagrams of globular clusters. They look very different. Actually, all kind of look the same. They do have a little bit of main sequence, very low luminosity stars. They show this turn off, and then well developed red giant branch. And they have this horizontal branch, occasionally have another giant branch, called asymptotic giant branch.

This is actual measurements. And those dots that do not belong to the sequence are just random foreground stars that happened to be in the field of view. But if you isolate cluster stars alone, they're very clean, one dimensional sequences.

Because now we believe that this turn off of the main sequence corresponds to the age, as massive stars evolve away and go through the red giant branch. If we can measure where this turn off occurs, and compare that to theoretical models, we can age date clusters. And that, in fact, has been done, in great and gory detail.

And what you usually get are comparison plots like these, lines called isochrones, which are not evolutionary tracks of stars, but of the entire cluster. Where these sequences will be is a function of time, and their fine structure like composition, and what have you.

And it turns out that the average age of the Milky Way globular clusters is a little over 12 billion years. That fits nicely with our present understanding that the universe is about 13.8 billion years old. Take some time to make the galaxy. And globular clusters are the oldest parts of our galaxy. They're survivors from the time our galaxy was formed, which makes them extra-more interesting. They also provide an interesting cosmological constraint, how old is the universe.