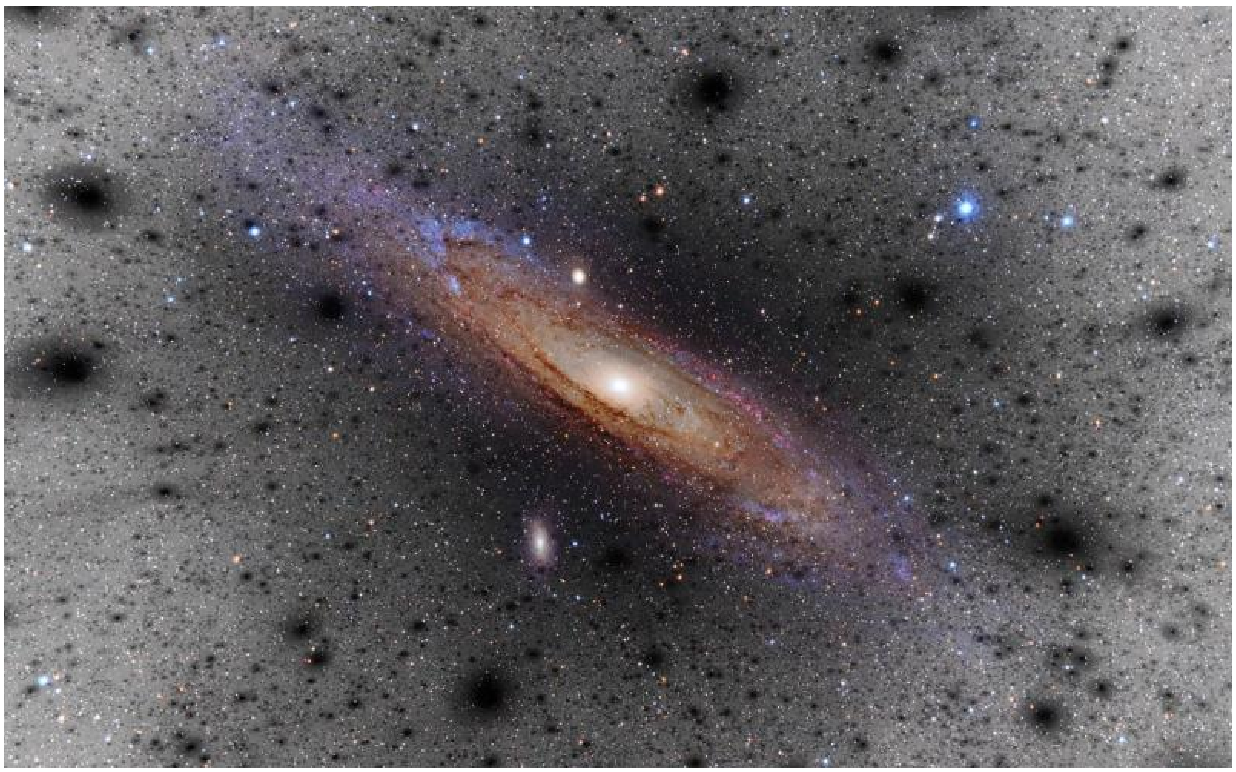
Massive holes 'punched' through a trail of stars likely caused by dark matter

September 7 2016, by Sarah Collins



Artist's impression of dark matter clumps around a Milky Way-like galaxy. These clumps are invisible and can only be detected through their gravitational effect on visible matter. The clumps, also known as subhaloes, come in a range of sizes with the smallest one set by the mass of the yet to be discovered dark matter particle. The more massive the dark matter particle, the slower the dark matter moves, and the easier it is for regions in the early universe to collapse and form small subhaloes. In this work, a tidal stream from a disrupting globular cluster is used to probe their presence. Credit: V. Belokurov, D. Erkal, S.E. Koposov (IoA, Cambridge). Photo: Color image of M31 from Adam Evans.

Dark matter clumps from Aquarius, Volker Springel (HITS)

The discovery of two massive holes punched through a stream of stars could help answer questions about the nature of dark matter, the mysterious substance holding galaxies together.

Researchers have detected two massive holes which have been 'punched' through a stream of stars just outside the Milky Way, and found that they were likely caused by clumps of dark matter, the invisible substance which holds galaxies together and makes up a quarter of all matter and energy in the universe.

The scientists, from the University of Cambridge, found the holes by studying the distribution of stars in the Milky Way. While the clumps of dark matter that likely made the holes are gigantic in comparison to our Solar System – with a mass between one million and 100 million times that of the Sun – they are actually the tiniest clumps of dark matter detected to date.

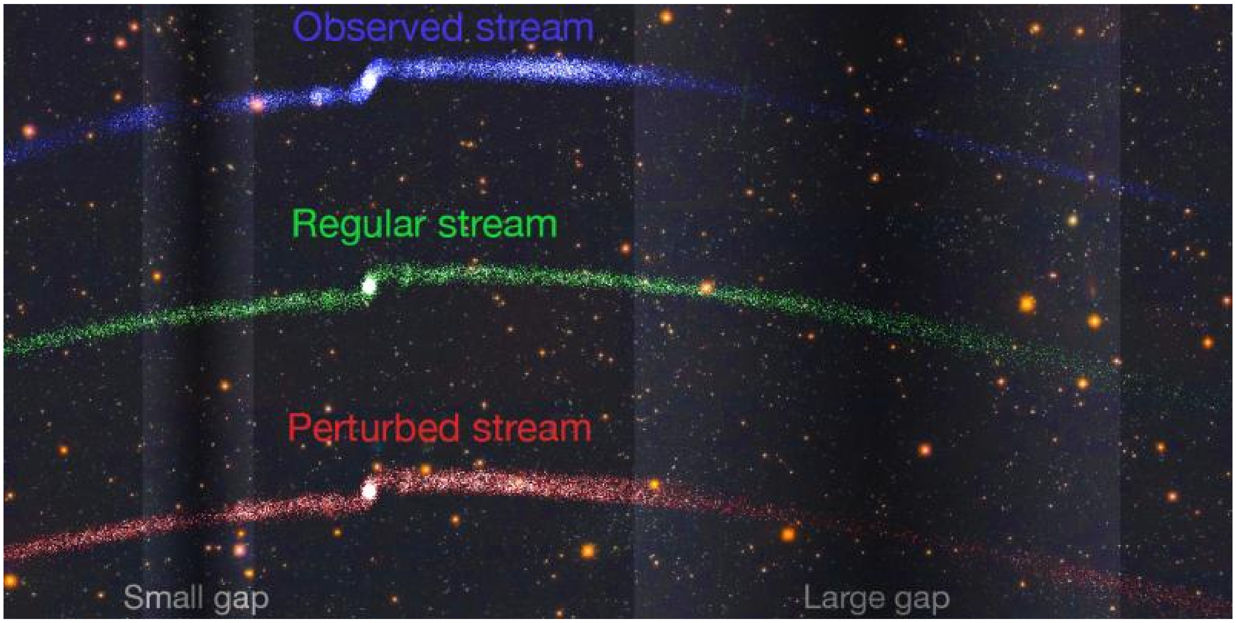
The results, which have been submitted to the Monthly Notices of the Royal Astronomical Society, could help researchers understand the properties of dark matter, by inferring what type of particle this mysterious substance could be made of. According to their calculations and simulations, dark matter is likely made up of particles more massive and more sluggish than previously thought, although such a particle has yet to be discovered.

"While we do not yet understand what dark matter is formed of, we know that it is everywhere," said Dr Denis Erkal from Cambridge's Institute of Astronomy, the paper's lead author. "It permeates the universe and acts as scaffolding around which astrophysical objects made of ordinary matter – such as galaxies – are assembled."

Current theory on how the universe was formed predicts that many of these dark matter building blocks have been left unused, and there are possibly tens of thousands of small clumps of dark matter swarming in and around the Milky Way. These small clumps, known as dark matter sub-haloes, are completely dark, and don't contain any stars, gas or dust.

Dark matter cannot be directly measured, and so its existence is usually inferred by the gravitational pull it exerts on other objects, such as by observing the movement of stars in a galaxy. But since sub-haloes don't contain any ordinary matter, researchers need to develop alternative techniques in order to observe them.

The technique the Cambridge researchers developed was to essentially look for giant holes punched through a stream of stars. These streams are the remnants of small satellites, either dwarf galaxies or globular clusters, which were once in orbit around our own galaxy, but the strong tidal forces of the Milky Way have torn them apart. The remnants of these former satellites are often stretched out into long and narrow tails of stars, known as stellar streams.



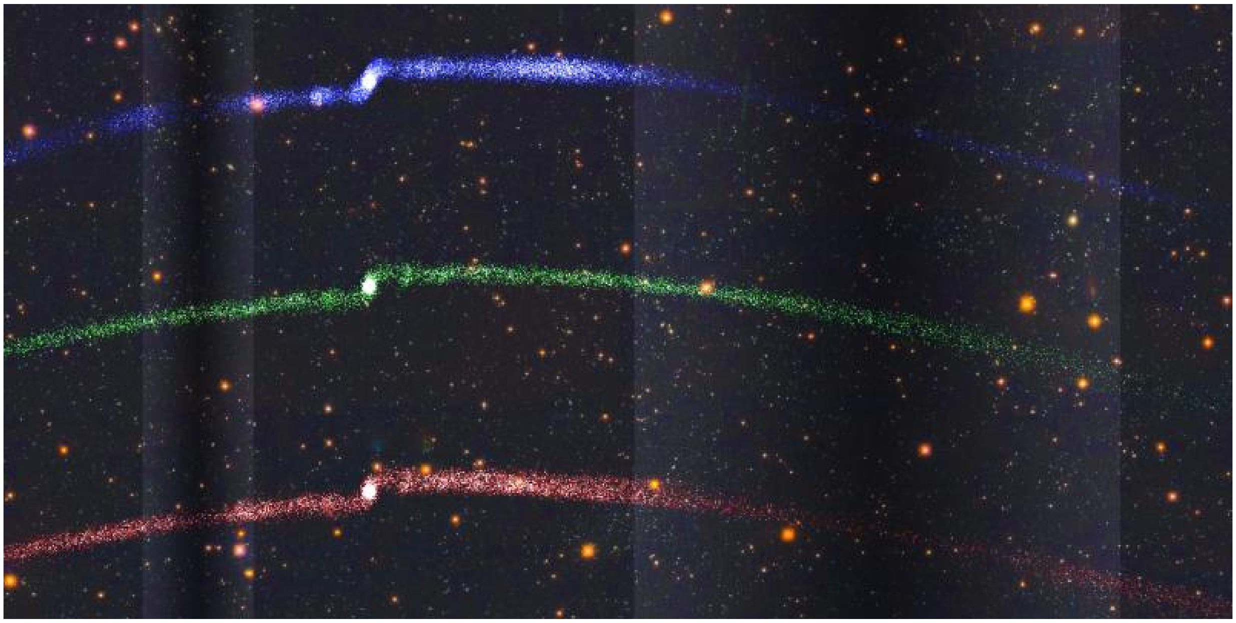
Comparison between the observed stream and two simulated streams. The blue points show the observed stream which has been colored blue to distinguish it from the other streams. In reality, the color of its stars look more like the previous figure. Note the underdense regions on the left and right. The green points show a simulated stream evolved in a smooth potential without dark matter clumps. In contrast to the observed stream, this stream appears smooth and does not have any gaps. The red points show a simulated stream which has been struck by two clumps of dark matter with masses of one million Suns (left) and fifty million Suns (right). These perturbations produce the same gaps as what is seen in the data. Although the dark matter clumps themsevlves are invisible, they create gaps in the stream which can be detected. If confirmed, these two dark subhaloes would represent the lowest mass clumps detected to date. Credit: V. Belokurov, D. Erkal, S.E. Koposov (IoA, Cambridge)

"Stellar streams are actually simple and fragile structures," said co-author Dr Sergey Koposov. "The stars in a stellar stream closely follow one another since their orbits all started from the same place. But they don't actually feel each other's presence, and so the apparent coherence of the stream can be fractured if a massive body passes nearby. If a dark matter sub-halo passes through a stellar stream, the result will be a gap in the stream which is proportional to the mass of the body that created it."

The researchers used data from the stellar streams in the Palomar 5 globular cluster to look for evidence of a sub-halo fly-by. Using a new modelling technique, they were able to observe the stream with greater precision than ever before. What they found was a pair of wrinkled tidal tails, with two gaps of different widths.

By running thousands of computer simulations, the researchers determined that the gaps were consistent with a fly-by of a dark matter sub-halo. If confirmed, these would be the smallest dark matter clumps detected to date.

"If dark matter can exist in clumps smaller than the smallest dwarf galaxy, then it also tells us something about the nature of the particles which dark matter is made of – namely that it must be made of very massive particles," said co-author Dr Vasily Belokurov. "This would be a breakthrough in our understanding of dark matter."



Comparison between the observed stream and two simulated streams. This is the same as the previous figure but with no labels. Credit: V. Belokurov, D. Erkal, S.E. Koposov (IoA, Cambridge)

The reason that researchers can make this connection is that the mass of the smallest clump of dark matter is closely linked to the mass of the yet unknown particle that dark matter is composed of. More precisely, the smaller the clumps of dark matter, the higher the mass of the particle.

Since we do not yet know what dark matter is made of, the simplest way to characterise the particles is to assign them a particular energy or mass. If the particles are very light, then they can move and disperse into very large clumps. But if the particles are very massive, then they can't move very fast, causing them to condense – in the first instance – into very small clumps.

"Mass is related to how fast these particles can move, and how fast they can move tells you about their size," said Belokurov. "So that's why it's so interesting to detect very small clumps of dark matter, because it tells you that the dark matter particle itself must be very massive."

"If our technique works as predicted, in the near future we will be able to use it to discover even smaller clumps of dark matter," said Erkal. "It's like putting dark matter goggles on and seeing thousands of dark clumps each more massive than a million suns whizzing around."

More information: Denis Erkal et al. 'A sharper view of Pal 5's tails: Discovery of stream perturbations with a novel non-parametric technique.' arXiv:1609.01282 , arxiv.org/abs/1609.01282

Provided by University of Cambridge

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