How Slippery Is Dark Matter?

By: **Monica Young** | March 30, 2015

Dozens of galaxy cluster collisions confirm that dark matter particles probably slip right past each other within messy cluster mergers.

The existence of dark matter would solve many problems in our universe: it enables spiral galaxies to rotate quickly at their outer edges, keeps galaxy clusters from flying apart, and forms the universe's cosmic web structure.

But dark matter, or at least our understanding of it, creates its own set of problems. Simulations show that dark matter pools in gravitational wells, creating galaxies and clusters of galaxies with far denser cores than observed. That pooling happens when dark matter particles are slippery. Weakly interacting massive particles (WIMPs), physicists' most popular dark particle, are downright antisocial — they glide right past one another rather than interacting.

One way to overcome the pooling problem is to make dark matter less

This collage shows six of the 30 galaxy cluster collisions studied by Harvey and colleagues. They found that dark matter (blue), mapped by gravitational lensing, and galaxies alike slip right past one another. The tenuous X-ray-emitting gas (pink) collides, offsetting it from the dark matter and galaxies.
NASA / ESA / STScI / CXC

slippery. In alternative models, so-called "hidden-sector" dark matter particles make contact, says Jonathan Feng (University of California, Irvine). Just like people at a party, he explains, particles that constantly bump into each other tend to spread out, rather than all congregating in the kitchen. Many of these models have the added benefit of explaining a mysterious X-ray spectral line seen in some galaxies and galaxy clusters.

Perfectly slippery dark matter particles should have a *self-interaction cross section* (a measure of how strongly they interact, measured in square centimeters per gram) of 0. Hidden-sector models propose cross-sections that range between 0.1 and 10.

But now these sticky dark matter models face a challenge. David Harvey (Observatoire de Sauverny, Switzerland, and University of Edingburgh, UK) and colleagues studied 30 galaxy clusters and found that dark matter particles appear to be quite slippery, with a cross section no higher than 0.47 cm^2/g.

When Clusters Collide

Astronomers can indirectly measure the stickiness of dark matter by looking at galaxy cluster collisions. When clusters collide, most galaxies sweep right past one another — space is after all very, very empty. But the tenuous

The Bullet Cluster is the textbook example of merging galaxy clusters. Hot gas (*pink*) sloshes around the gas halos surrounding the galaxies crash into each other and produce beautiful and complex X-ray emission.

galaxies (*red, green, blue*) that are anchored in dark matter (*blue*).
X-ray: NASA / CXC / CfA / M.Markevitch et al.; Lensing Map: NASA / STScI / ESO WFI / Magellan / U.Arizona / D.Clowe et al.; Optical: NASA / STScI / Magellan / U.Arizona / D.Clowe et al.

If it's slippery, dark matter will stay closely aligned with the galaxies. (The dark matter isn't seen directly, but by its gravitational distortion of background light.) But if dark matter particles interact with one another, they'll do one of two things: the dark mass will slow down, lagging behind the galaxies' motion, or the dark particles will scatter, displacing the dark mass from the galaxies.

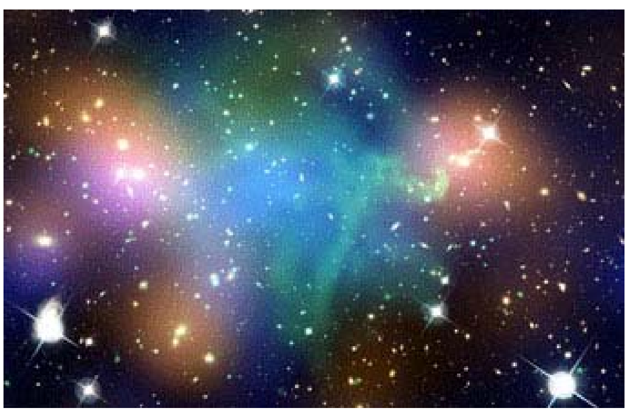
By far the best-studied cluster collision, the Bullet Cluster has already provided one estimate on dark matter slipperiness — observations limit the cross section to less than 1.25 cm^2/g, which still leaves plenty of wiggle room for hidden-sector theories. Observations of other clusters haven't narrowed the possibilities, mostly because the 3D geometry of the systems is difficult to understand.

So Harvey's team set out to take a statistical approach instead, averaging out the measurements of lots of galaxy clusters to do away with any 3D uncertainty. Drawing from the archives of the Hubble Space Telescope and Chandra X-ray Observatory, Harvey and his colleagues looked at 30 nearby galaxy clusters. In each cluster, the team measured the offset between the hot gas (observed in X-rays) and the galaxies (seen in the visible-light images), which gives the direction of the collision.

Then the team measured the offset between the galaxies and the dark mass, which they pinpointed thanks to its gravitational lensing effect on background light. The astronomers found that across 30 clusters, the offset was essentially zero. Dark matter must be slippery indeed, with a cross section less than 0.47.

The Fine Print

There are limitations to this approach, says Douglas Clowe (Ohio University). For one, it's all archival data, collected for disparate science goals. So Hubble imaged some clusters through multiple filters and some through only a single filter. To



Abell 520, the Train Wreck cluster, at one point appeared to show hints of "sticky" dark matter. Starlight (orange) has been smoothed to show the location of most galaxies. Dark matter (blue) was mapped by weak gravitational lensing.

level the playing field, the team *NASA / ESA / CFHT / CXO / M.J. Jee / A. Mahdavi* opted to limit their analysis to a single filter for all the clusters. But that makes it difficult to separate cluster galaxies from foreground and background galaxies. While necessary, the decision added uncertainty to their measurements.

Nevertheless, Clowe adds, "Within the limitations of their data, they have produced an excellent analysis." In addition to improving on the Bullet Cluster measurements, he says, these types of statistical studies, which pull in huge amounts of information on dozens of galaxy clusters, show what we can look forward to in five to ten years, when next-gen telescopes such as WFIRST, LSST, and Euclid come online.

But don't count out hidden-sector models just yet, says Feng. Even with the tighter limit from Harvey's study, these models have enough wiggle room to remain viable. "The really interesting message here," Feng adds, "is that these observations are getting tighter and tighter in a very interesting region of parameter space." In the near future, studies like this one might rule out self-interacting dark matter . . . or better yet, find evidence for its existence.

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