# Dark matter 'proof' called into doubt

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WHEN Douglas Clowe of the University of Arizona in Tucson announced on 21 August that his team had "direct proof of dark matter's existence", it seemed the issue had been settled. Now proponents of the so-called modified theories of gravity, who explain the motion of stars and galaxies without resorting to dark matter, have hit back and are suggesting that Clowe's team has jumped the gun.



"One should not draw premature conclusions about the existence of dark matter without a careful analysis of alternative gravity theories," writes John Moffat, of the University of Waterloo in Ontario, Canada, who pioneered an alternative theory of gravity known as MOG (www.arxiv.org/astro-ph/0608675).

The controversy centres on the pattern of gravitational lensing, or the bending of light, around the Bullet cluster of galaxies, which formed from the collision of two clusters. While most of the Bullet cluster's visible mass lies in a pool of hot gas near the centre, galaxies can also be seen on either side. Clowe's study of lensing indicates that most of the mass is contained in the two lobes, rather than in the pool of gas. The team says this is evidence of dark matter surrounding the galaxies.

Moffat claims that his MOG theory can explain the Bullet cluster without an ounce of dark matter. In MOG, gravity acts as predicted by Newton's inverse square law up to a certain distance from the gravitating mass, after which it gets a little stronger. In the Bullet cluster, the complex arrangement of galaxies and hot gas combines to make gravity strongest in the lobes, so that is where the lensing would be most apparent. Moffat has worked this out for the Bullet cluster using a one-dimensional model, and is now trying to extend this to two dimensions. If he succeeds, it will contradict Clowe's claims that the cluster's lensing can be cited as direct evidence of dark matter.

Moffat is not the only researcher claiming that a modified gravity theory does away with the need for dark matter. Two months before Clowe made his claim, HongSheng Zhao of the University of St Andrews in the UK and his collaborators applied a theory of modified gravity called TeVeS to the Bullet cluster. In TeVeS, an extra field kicks in when the gravitational field falls below a threshold strength, which is equivalent to the gravity of a sheet of paper. TeVeS boosts gravity in places such as the outskirts of galaxies and has an effect on lensing. "We noticed that even where there is no matter there is [bending] of light," Zhao says (www.arxiv.org/astro-ph/0606216).

Unlike MOG, TeVeS requires the presence of heavy neutrinos to explain lensing, though Zhao does not see this as a problem. "We know neutrinos exist and we know they have mass," he says. Measurements of the neutrino's mass put it at between 0.02 and 2.2 electronvolts; Zhao assumes it to be 2 electronvolts.

So are fast-moving "hot" neutrinos a good substitute for the dark matter that Clowe's team claims to have found? "I'm guessing that when they really look at it, they will need much more dark matter," Clowe says.

Zhao says that his team is about to publish fuller details of their explanation of the Bullet cluster, which will show no dark matter is needed. "This bullet did not hurt TeVeS that much," he says. "It placed no additional constraints on modified gravity theories because it didn't add anything we didn't already know."

**Still in the dark**

The Bullet cluster is not the only place where modified gravity is jousting with cold dark matter. Large-scale structures in the universe are fair game, too.

Explaining the rapid evolution of galaxies has always been a problem for cosmologists, who have to include dark matter in their models to account for it. Scott Dodelson of the University of Chicago and Michele Liguori of the University of Padua, Italy, have found that an unexpected feature of TeVeS, a modified gravity theory, could provide the extra gravity needed.

The new feature is called a vector field and was added by Jacob Bekenstein of the Hebrew University in Jerusalem, Israel, to explain gravitational lensing. Dodelson has found that instabilities in this field could provide the extra gravity needed to form galaxies. "Sometimes theories are smarter than their authors," a surprised Bekenstein told Dodelson on learning of the result.

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