

Mapping the mass of a galaxy cluster

When light from far-off galaxies passes near a massive object on its way toward us, the warped spacetime in the area bends the light's path. That effect, known as gravitational lensing, produces distorted, magnified, and sometimes multiple images of the distant galaxies and is a powerful tool for studying cosmic expansion and the structure of the universe (see the article by Leon Koopmans and Roger Blandford, *PHYSICS TODAY*, June 2004, page 45). The *Hubble Space Telescope* Frontier Fields program, begun last fall, is exploiting the gravitational lensing by six galaxy clusters to probe the very distant, ancient universe.

This *Hubble* image shows one of the clusters, MCS J0416.1–2403, some 5.5 billion light-years away. During 80 orbits earlier this year, the telescope trained its Advanced Camera for Surveys on the cluster. An international team of astronomers has now used the collected data to map the cluster's mass with unprecedented precision; the map is superposed here in blue, with the more intensely colored regions having higher density.

To create the map, the astronomers scrutinized the *Hubble* data for galaxies that, thanks to gravitational lensing, appeared in multiple places in the images. They identified 68 galaxies, quadruple the number from previous surveys. The researchers then calculated the distribution of visible and dark matter that would account for those observations. The result, which projects a mass of 160 trillion Suns in an area 650 000 light-years across, is the first cluster map to reach 1% precision. In addition to calibrating the lensing produced by the cluster, the map gives astronomers new insights into the cluster itself. (M. Jauzac et al., *Mon. Not. R. Astron. Soc.* **443**, 1549, 2014; image by ESA/Hubble, NASA, HST Frontier Fields, courtesy of Mathilde Jauzac and Jean-Paul Kneib.)

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