A Direct Empirical Proof of the Existence of Dark Matter

Clowe et al 2006, ApJL 658:L109-L113

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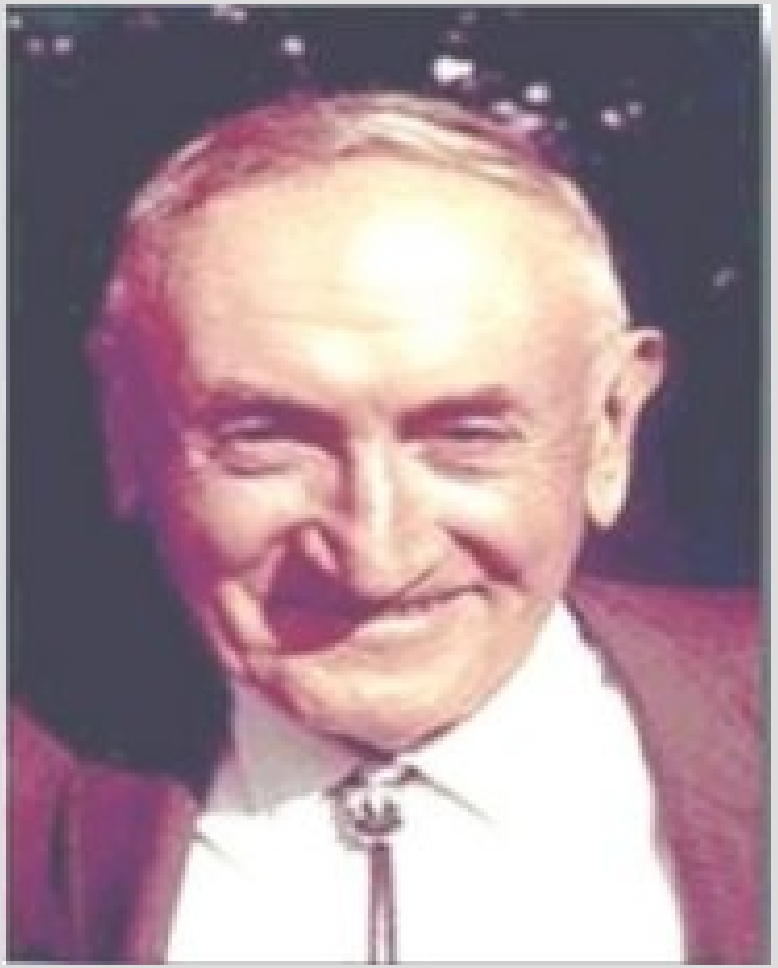
Outline

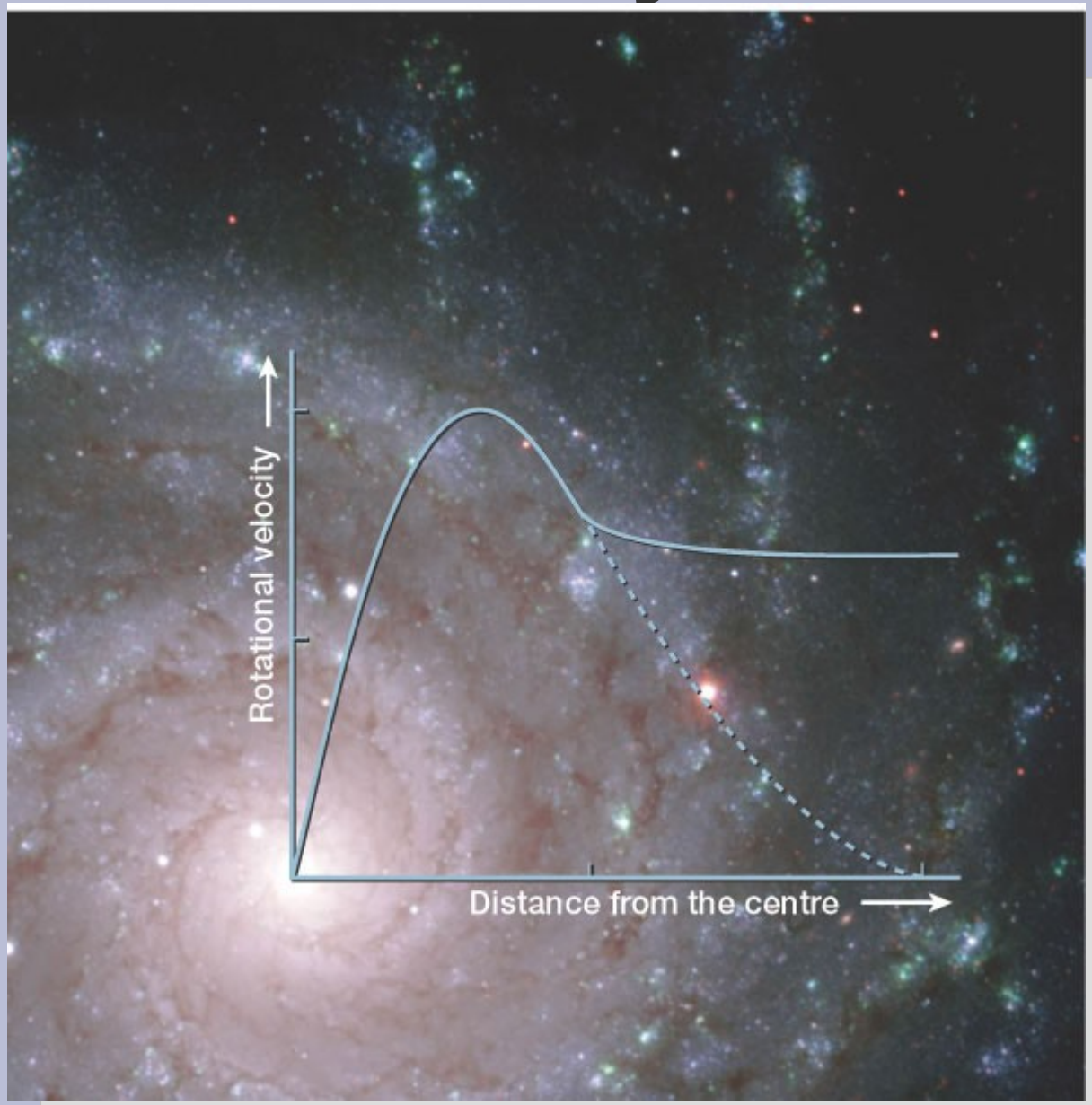
- Why Dark Matter?
- How is a Cluster Merger Useful?
- Procedure
- Results
- Arguments against Dark Matter

Why Dark Matter?

- Fritz Zwicky used the virial theorem to show not all mass is accounted for by luminosity



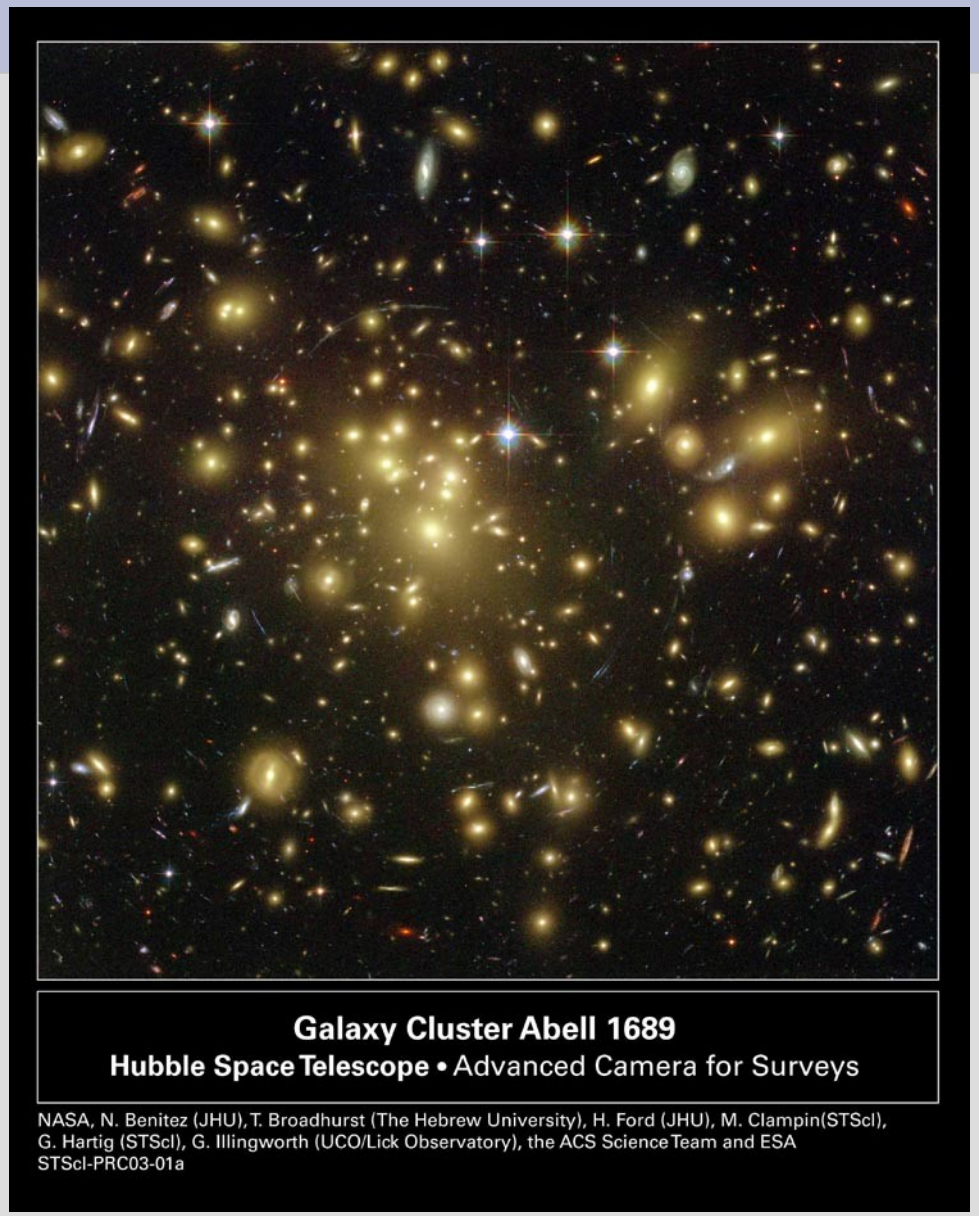
Why Dark Matter?



- Rotation Curves too “flat” for mass within galaxy
  - Unseen Matter
  - New Gravitational Force Law

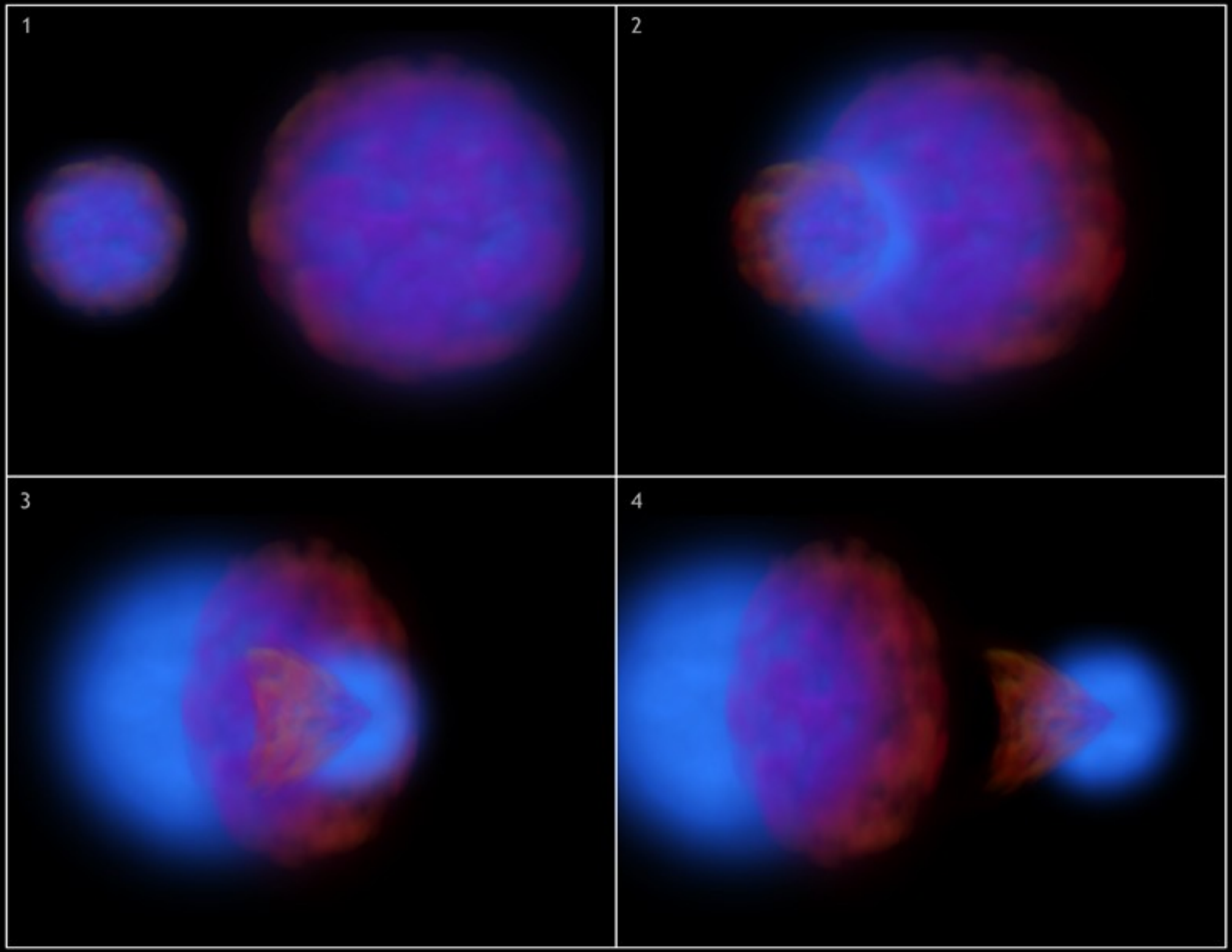
Fukugita, M., Nature 422, 489-491

Why Dark Matter?



Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a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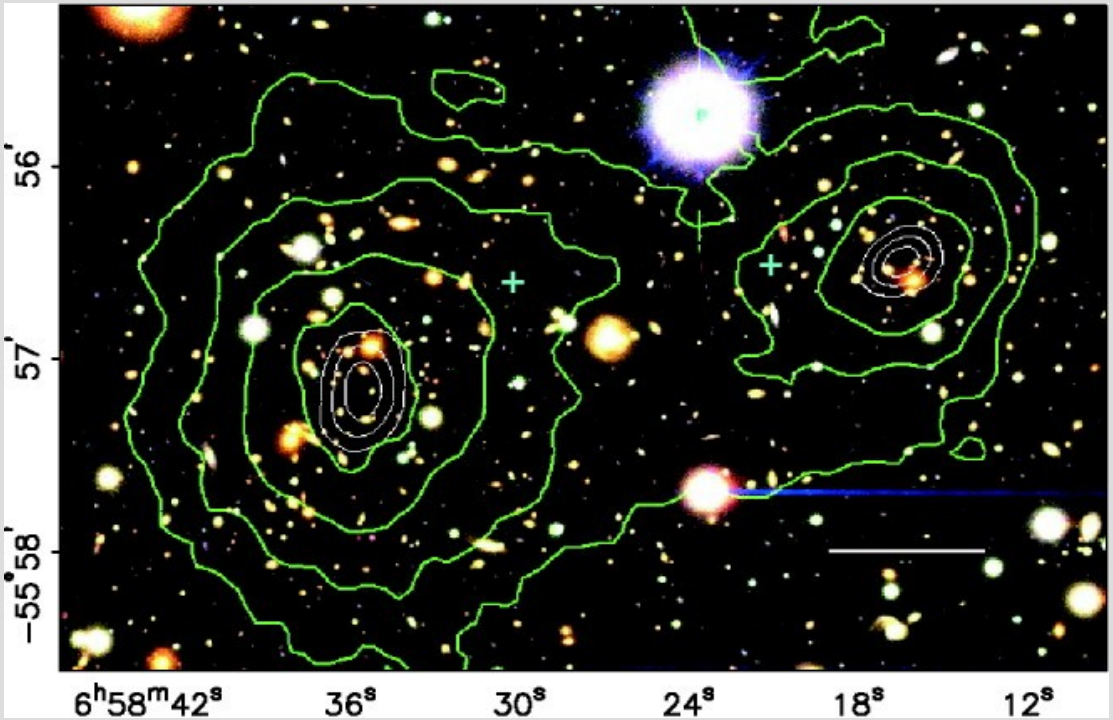
Procedure

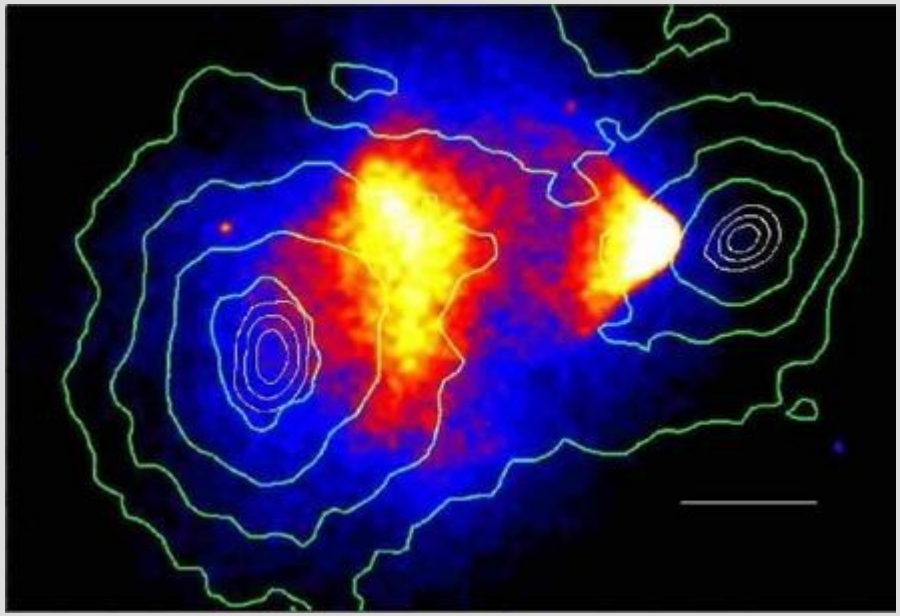
- Shear (reduced) can be related to mass by a combination of derivatives



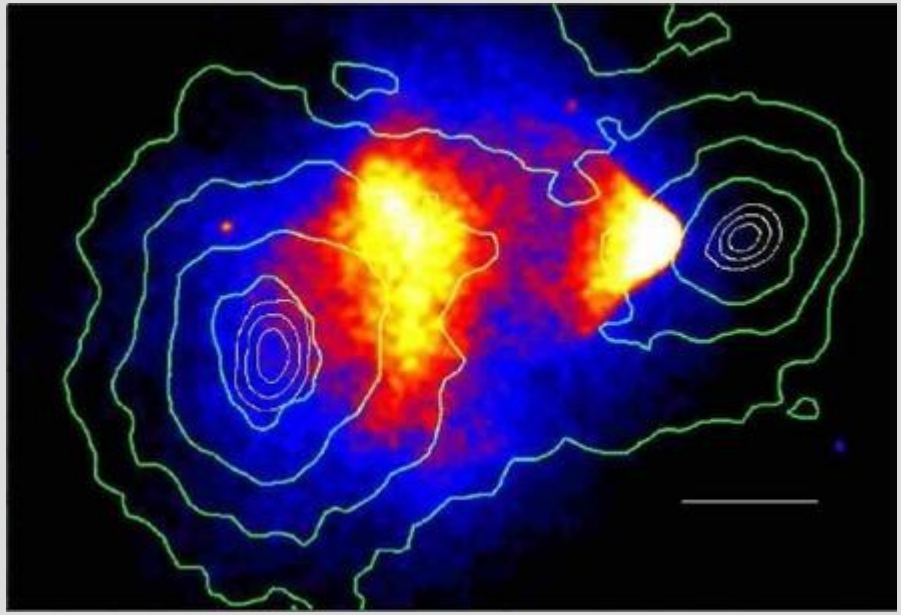
$$\nabla ln(1-\kappa) = \frac{1}{1-g_1^2-g_2^2} \begin{pmatrix} 1+g_1 & g_2 \\ g_2 & 1-g_1 \end{pmatrix} \begin{pmatrix} g_{1,1}+g_{2,2} \\ g_{2,1}-g_{1,2} \end{pmatrix}$$

Procedure

- *Chandra* X-Ray Data relate X-Ray energy to plasma mass



Results



Arguments against Dark Matter

- Lensing only produces a 2-dimensional mass model
  - Background galaxies are around $z \sim 1$ and lens is $0.18 < z < 0.39$
  - The number density with these lensing strengths ~0.001 per arcmin
  - Probability of having two structures within a square arcminute of the observed cluster cores: $\sim 10^{-7}$

Arguments against Dark Matter

- Intersections of Matter Filaments?
  - For these mass densities, filaments would have to be several Mpc long and exactly along the line of sight. Probability: ~10^{-6}
  - Relative velocity of 4700 km/s provides an additional probability reduction of ~10^{-5}

Argument against Dark Matter

- Alternate Theory of Gravity
  - No evidence of Mass Concentrations between two peaks
  - Convergence to light ratios, X-ray temperatures and velocity dispersions correspond well to other observed clusters, just separated in this case
  - X-ray mass does not match lensing mass reconstruction, a problem which is exaggerated in non-traditional gravitational theories.

See Also

- Clowe, D., Bradac, M., Gonzalez, A., Markevitch, M., Randall, S., Jones, C., Zaritsky, D., 2006, ApJ, 648, L109-L113
- Fukugita, M., Nature 422, 489-491.
- Zwicky, F., ApJ 86, 217-246.