Multi-Wavelength Simulation of the Bullet Cluster

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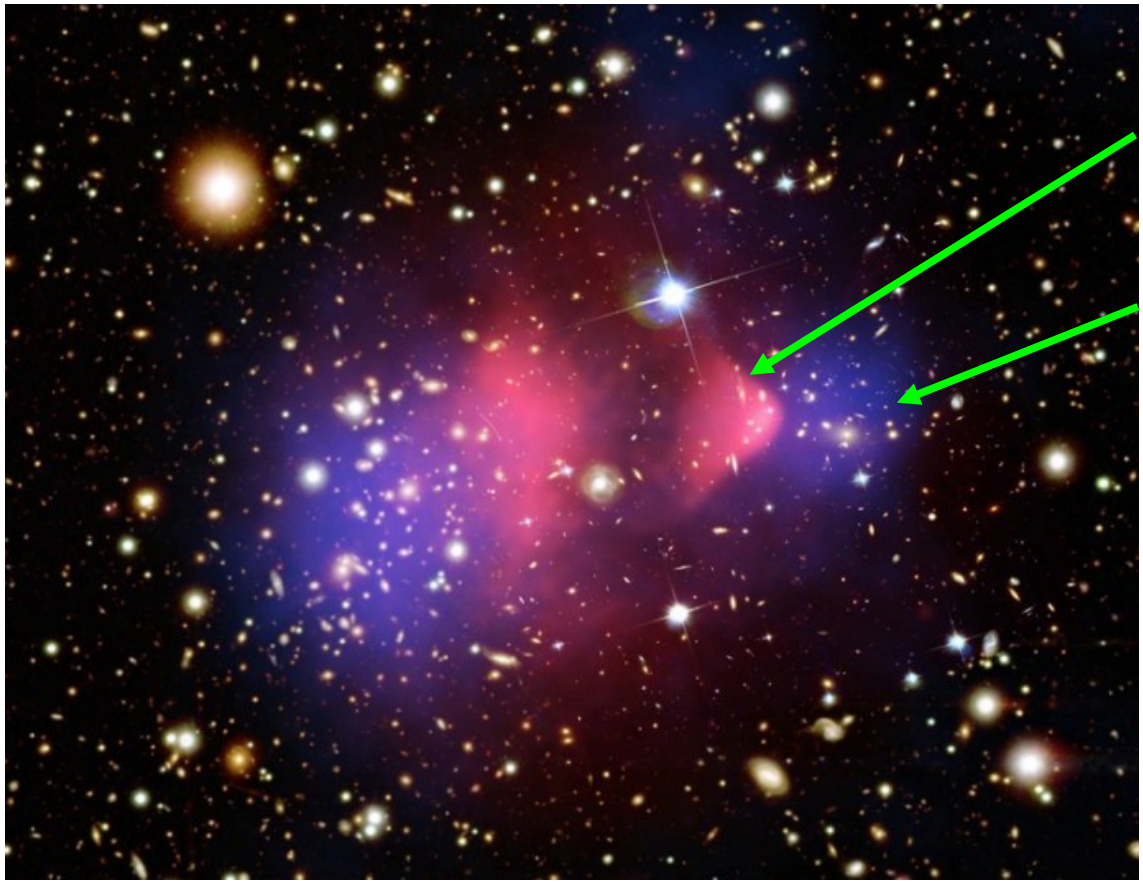
Bullet Cluster Summary



X-Ray Intensity(pink)

Lensing Mass Density(Blue)

Photo from Clowe et.al.

- **Ongoing collision of two massive galaxy clusters**
- **In constellation Carina – southern hemisphere**
- **Distance ~1.2Gpc (z = 0.296)**
- **Combined cluster mass ~ 10^{15} M_{sun}**
- **Considered the best “proof” of the existence of dark matter.**

Introduction

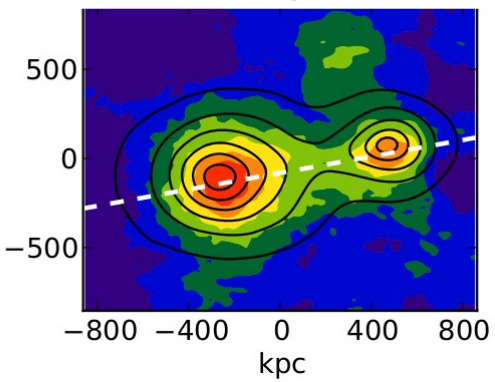
- **Simulation tool – Enzo w/MHD**
  - **~2.5E6 grid cells w/AMR**
  - **~5E6 DM particles.**

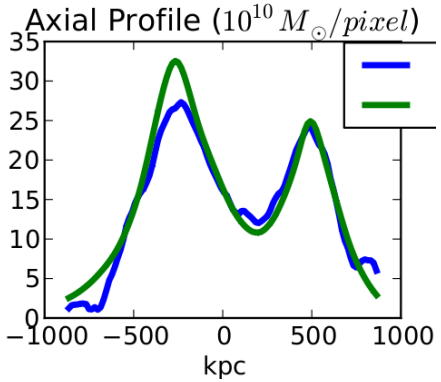
- **Pixel-by-pixel fit to multiple data sets:**
  - **Mass Lensing data (Bradac, et.al.)**
  - **X-ray flux (Chandra)**
  - **Plasma Temperature (Markevitch)**
  - **S-Z Effect Δ T (Halverson, et.al.)**
  - **Radio Flux (Liang, et.al.)**

- **Simple Initial Conditions:**
  - **Two spherically symmetric clusters.**
  - **NFW DM profiles.**
  - **Isothermal-β plasma profiles.**
  - **Random initial B-field with Kolmogorov spectrum.**

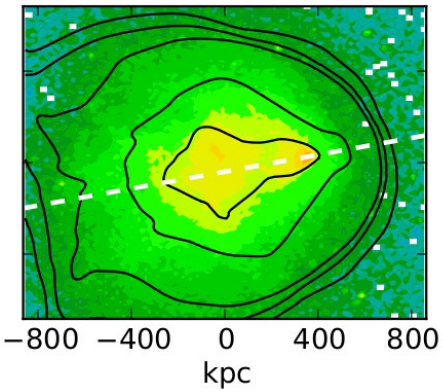
Best Fit Simulation – Reduced $\chi^2 = 1.56$

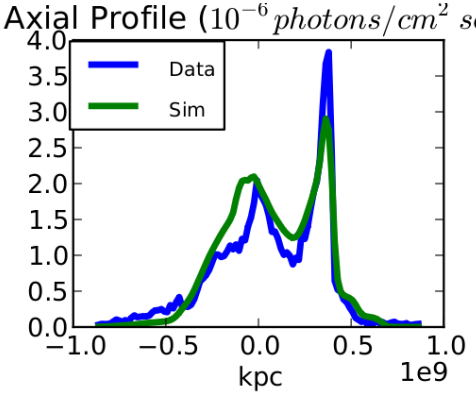
Lensing Mass



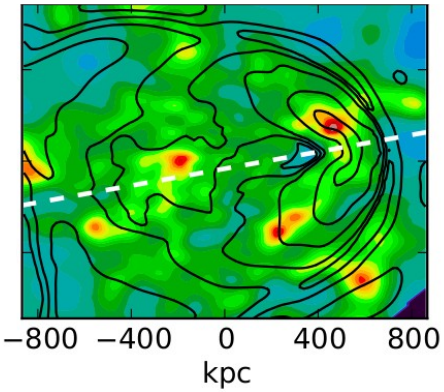


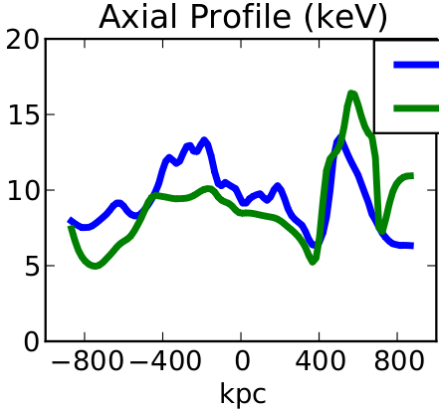
Xray Flux



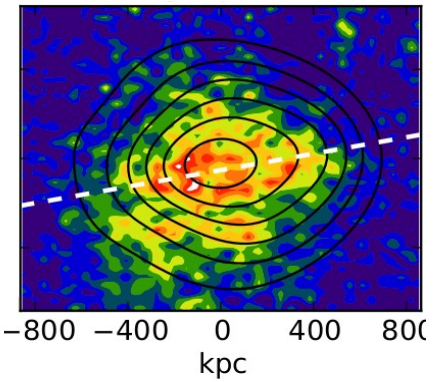


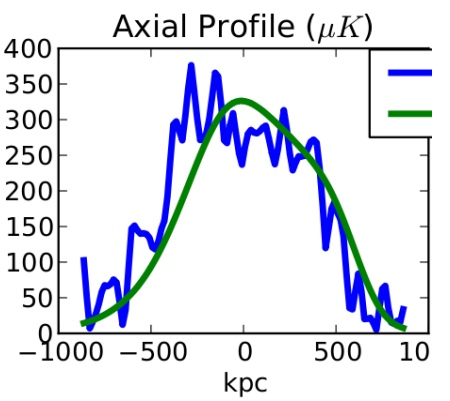
Plasma Temp





SZE Δ T



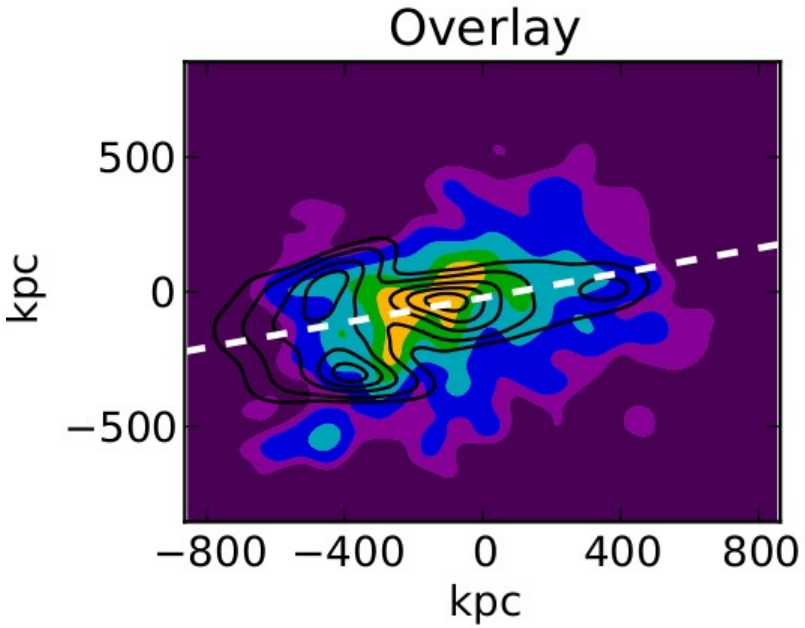


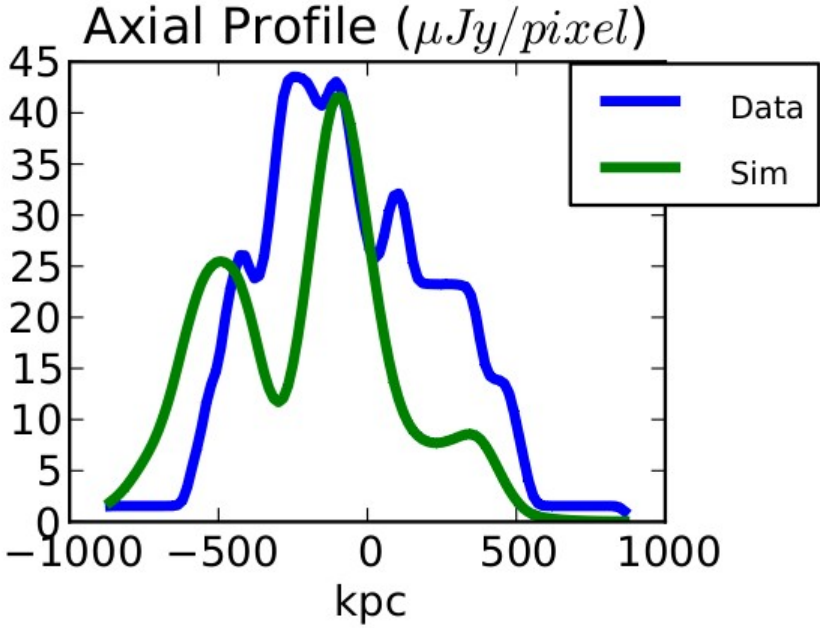
Cluster	Main	Bullet
Mass	5.5 +/- 1.4 E14 Msun	1.7 +/- 0.4 E14 Msun
Concentration	1.65 +/- 0.53	3.28 +/- 0.89
Gas Fraction	17 +/- 4 %	14+/- 4.0 %

Total of 15 free parameters

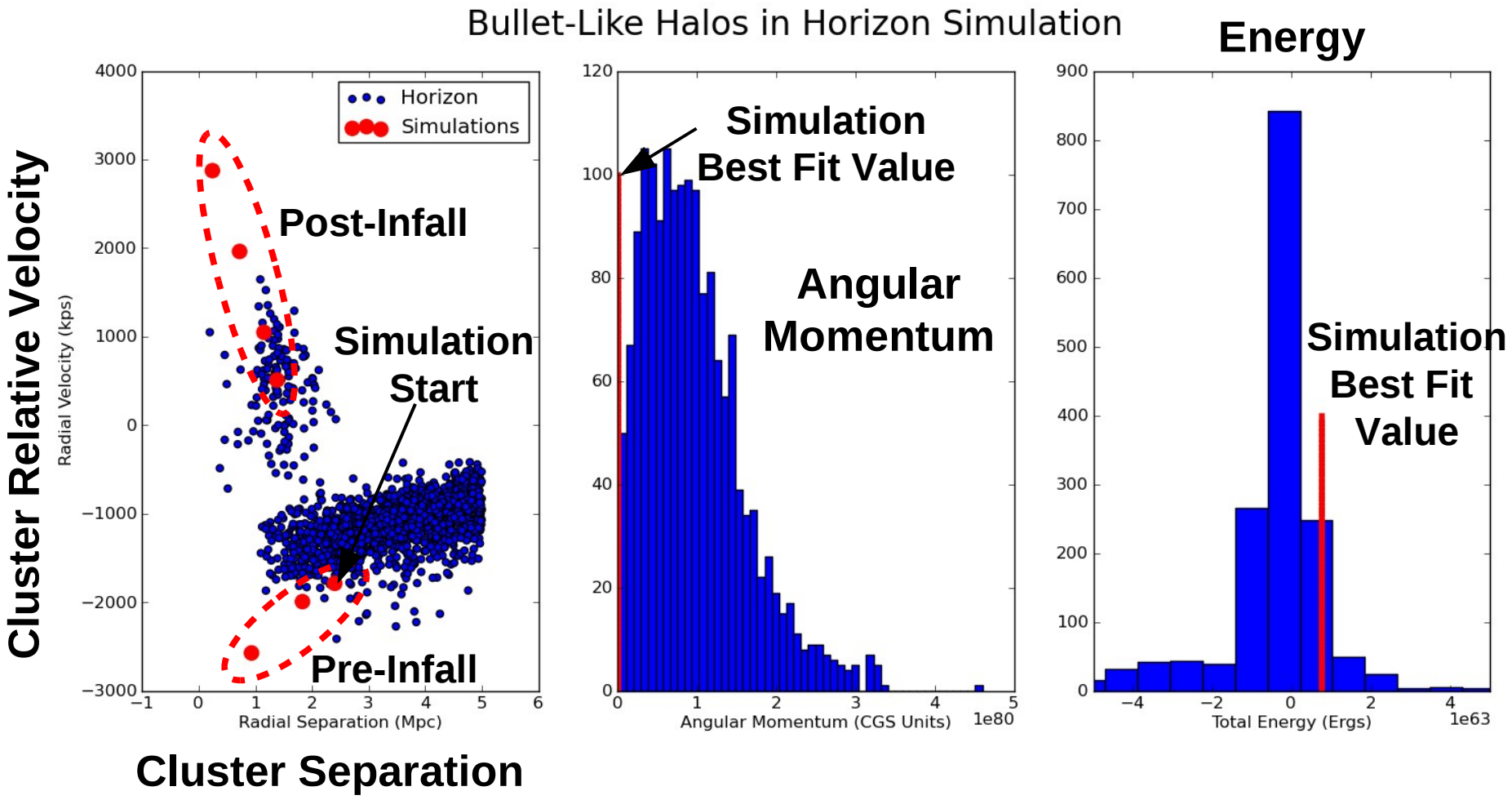
Radio Emission - 1.3GHz - Liang, et.al.

- **Given B-field what is Radio flux prediction?**
- **Assume e^- power law tail in equipartition with magnetic energy.**
- **Gives good agreement on magnitude, location, and spectral index with observations.**





Comparison to Horizon Simulations



Bullet parameters fall within the range of galaxy cluster pairs from the Horizon simulation.

Conclusions

- **Simple Initial Conditions give good fit.**
- **'Exceptional' infall velocities not required.**
- **Baryon fractions close to Λ -CDM value of 16%.**
- **Biggest errors in temperature fit:**
  - **Improved modeling of plasma energy balance planned.**

Movie of Simulation