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Do Electrons Ghost Ions After a Merger?: A NuSTAR Investigation of Intracluster Plasma in Abell 2146

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Galaxy clusters are the most massive gravitationally bound objects in the universe. Cluster mergers convert

upwards of 10^{65} ergs of gravitational potential energy into the kinetic energy of the intracluster medium (ICM), the hot ionized plasma between galaxies in a cluster (Zuhone & Su, 2022). Merger features in the ICM help constrain plasma physics parameters such as electron-ion thermal equilibration timescales (eiTETs) across shock fronts between equilibration in a matter of seconds (instant model) and equilibration over tens of millions of years (collisional model). This summary shares results of processing a ~260 kilo-second NuSTAR observation of the galaxy cluster merger Abell 2146 and reports best fits of the post-shock temperatures and the eiTETs in the two ~10 keV shock fronts the cluster possesses.

So far, constraints on eiTETs in cluster mergers have shown a mixed bag of results, potentially due to Chandra X-ray telescope's over-estimation of temperatures beyond its upper limit of 10 keV (Wallbank, 2022). This makes using NuSTAR's hard X-ray imaging capabilities on the Chandra – studied Abell 2146 an important calibration experiment.

While NuSTAR's sensitivity at higher energies (>10 keV) is superior to Chandra's, allowing more accurate temperature measurements, the former's point spread function (PSF) is about 36 times worse than Chandra's.

Thus, nearby regions with different temperatures can cross-contaminate each other due to NuSTAR's blurrier vision which can consequently distort the true temperatures of the shock regions. However, we can model this cross-contamination of light, with the NuCrossARF software package ("nucrossarf", 2020), and obtain better temperature estimates in all regions, including the shock regions. NuSTAR spectra are extracted from 15 regions (12 – diffuse ICM regions; 3 – point sources) while emission from 12 diffuse and 4 point sources are modeled by thermal and power law models respectively. The choice of these regions is motivated by a preliminary NuSTAR temperature map and the detailed study of Abell 2146 through the eyes of Chandra published by Russell et al. in 2022.

Source model parameters are simultaneously constrained and scaled according to region-region scattering ratios determined by NuCrossARF, resulting in significantly improved temperature estimates compared to the preliminary NuSTAR temperature map. We measure a NuSTAR bow shock temperature of 10.6 keV compared to Chandra's 9 keV, slightly favoring the collisional equilibration model but record a significantly lower temperature of 7.3 keV for the upstream shock compared to Chandra's11.5 keV. The upstream shock

estimates for NuSTAR agree with a secondary drop in temperature observed by Chandra and could shed some light on additional shock structures observed in hydrodynamical simulations in Chadayammuri et al. (2022). Ultimately, more work is needed to effectively constrain eiTET timescales, especially in the upstream shock.

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