NASA/CR-97- 205848

Final Technical Report

NASA *Ginga* Visiting Investigator Program

Grant Title "Cooling Flow Spectra in *Ginga* Galaxy Clusters"

Principal Investigator Raymond E. White III
Department of Physics & Astronomy
Box 870324
University of Alabama
Tuscaloosa, AL 35487-0324

Grant Number NAG 8-228

Period of Performance 15 March 1992 - 14 March 1997

The primary focus of this research project, entitled "Cooling Flow Spectra in *Ginga* Galaxy Clusters," has been a joint analysis of *Ginga* LAC and *Einstein* SSS X-ray spectra of the hot gas in galaxy clusters with cooling flows. This work was in collaboration with Charles Day (*NASA/GSFC*), Isamu Hatsukade (Miyazaki Univ.) and Jack Hughes (CfA). These two non-imaging spectral instruments had very different fields of view ($1^\circ \times 2^\circ$ FWHM for the LAC and a $6'$ circular diameter for the SSS), which allowed spatially-resolved information to be extracted from their joint analysis, despite the inherent lack of spatial resolution in the individual detectors.

We studied four clusters (A496, A1795, A2142 & A2199) and found their central temperatures to be cooler than in the exterior, which is expected from their having cooling flows. More interestingly, we found central metal abundance enhancements in two of the clusters, A496 and A2142 (see White et al. 1994). In the pre-*ASCA* era, abundance gradients were not well-established in any cluster other than Virgo. Now, of course, *ASCA* observations are providing other examples of clusters with abundance gradients. In more recent work with my graduate student Renato Dupke, we have used spatially resolved *ASCA* spectral data to confirm the existence of the central abundance enhancement in A496 (Dupke & White 1997). Furthermore, the element ratios of the central enhancement are characteristic of Type I supernovae ejecta, while the rest of the cluster has an abundance mix which is characteristic of Type II ejecta.

The *Ginga* research described above led to a broader investigation of abundance gradients in clusters. Dupke and I have been assessing whether the abundance gradients (or lack thereof) in intracluster gas is correlated with galaxy morphological gradients in the host clusters (Dupke & White 1998). In rich, dense galaxy clusters, elliptical and S0 galaxies are generally found in the cluster cores, while spiral galaxies are found in the outskirts. If the metals observed in clusters came from proto-ellipticals and proto-S0s blowing winds, then the metal distribution in intracluster gas may still reflect the distribution of their former host galaxies. However, Dupke and I find that in general there is not a detailed correlation between abundance gradients in intracluster gas and galaxy morphological gradients. Some clusters show a reasonably close correspondence of abundances with morphological gradients, but others have abundance gradients on spatial scales much too small ($\sim$ 100 kpc) to be attributable to any trend in the galaxy morphologies. Central abundance enhancements on such small spatial scales points instead to either a local accumulation of stellar mass loss by the central dominant galaxy or to centrally concentrated ram-pressure stripping of gas from other galaxies. Either of these processes may be consistent with the SN I element ratios observed in the central regions (Dupke & White 1997) of A496.

Still other clusters have morphological gradients which are not reflected in their apparently flat distributions of metals. This erratic incidence of abundance gradient suggests that more than one of the following processes is involved: metallicity gradients can be created by ram-pressure stripping of gas from galaxies, by morphology gradients in wind-blowing proto-galaxies, and by stellar mass loss in central dominant galaxies. Abundance gradients may be subsequently destroyed when clusters merge.

In a research project which was inspired by the success of the *Ginga* LAC/*Einstein* SSS work, Mark Henriksen (Univ. of North Dakota) and I jointly analyzed X-ray spectra from the *HEAO-A2* MED and the *Einstein* SSS to look for temperature gradients in cluster gas. The *HEAO-A2* MED was also a non-imaging detector with a large field of view compared to the SSS, so we used the differing fields of view of the two instruments to extract spatial information. We found some evidence of cool gas in the outskirts of clusters, which may indicate that the nominally isothermal mass density distributions in these clusters are steepening in the outer parts of these clusters (Henriksen & White 1996).

Publications

- *Abundance Gradients in Cooling Flow Clusters: Ginga LAC & Einstein SSS Spectra of A496, A1795, A2142 & A2199*
  R.E. White III, C.S.R. Day, I. Hatsukade, & J.P. Hughes 1994, *Astrophys.J.*, **433**, 583-601.
- *Are Gradients in Intracluster Metals and Galaxy Morphology Related?*
  R. Dupke & R.E. White III 1994, *Bull.Amer.Astron.Soc.*, **26**, 1499
- *Ginga LAC and Einstein SSS X-ray Spectral Evidence of Abundance Gradients in Galaxy Clusters*
  R.E. White III, C.S.R. Day, I. Hatsukade, & J.P. Hughes 1994, *Bull.Amer.Astron.Soc.*, **25**, 1374.
- *Non-isothermal X-ray Emitting Gas in Clusters of Galaxies*
  M.J. Henriksen & R.E. White III 1996, *Astrophys.J.*, **465**, 515-522.
- *Evidence for Central Abundance Enhancements in A496*
  R. Dupke & R.E. White III 1996, *Bull.Amer.Astron.Soc.*, **189**, 37.01.
- *Evidence for a Central Abundance Enhancement in A496*
  R. Dupke & R.E. White III 1997, to be submitted to the *Astrophys.J.*.
- *On the Relation Between Abundance Gradients and Galaxy Morphology Gradients in Galaxy Clusters*
  R. Dupke & R.E. White III 1998, in preparation.

Invited Talk

- *Abundance Gradients in Intracluster Gas*
  Aspen Center for Physics workshop on Clusters of Galaxies, Aspen, Colorado (June 1994)