# Final Technical Report

NASA (*ROSAT*) Grant: NAG 5-1779
Title: Complex QSO Absorbers: High-Redshift Clusters of Galaxies?
PI: Prof. David M. Meyer (Northwestern University)

Using the PSPC instrument on the *ROSAT* satellite, we have obtained deep exposures of the fields centered on the QSOs 1556+335, 1037-271, and 0854+191 in an effort to search for extended X-ray emission corresponding to complex QSO absorption-line systems (QALSs) that could be indicative of clusters of galaxies at high redshift. The QSO 1556+335 is known to have a pair of complicated C IV absorption systems at $z$=1.610 ($\Delta v$=988 km s$^{-1}$) and $z$=1.650 ($\Delta v$=1677 km s$^{-1}$) near the $z$=1.641 QSO redshift (Morris et al. 1986, ApJ, 310, 40). Morris et al. have suggested that the absorption may be due to two rich clusters, one containing the QSO itself. The QSO 0854+191 ($z_{em}$=1.89) has 6 strong C IV absorption systems in 2 close groups at $z$=1.2954, 1.2973, 1.3019 and $z$=1.3522, 1.3543, 1.3558 (Sargent et al. 1988, ApJS, 68, 539). Assuming $q_o$=0.5 and $H_o$=50 km s$^{-1}$ Mpc$^{-1}$, the redshift range of this absorption-line cluster corresponds to a radial distance of 44 Mpc. Interestingly, there is a nearby (≈30') QSO (0856+189) with a projected separation of 16 Mpc whose redshift ($z$=1.29) is similar to that of the absorbing material toward 0854+191 (Romani et al. 1991, PASP, 102, 431). In the case of 1037-271 ($z_{em}$=2.18), common QALSs have been observed at $z$=1.90, 1.96, 2.02, 2.08, and 2.14 (a radial range of 66 Mpc) in its spectrum and that of its neighbor Tol 1038-272 ($z_{em}$=2.32) whose 18' separation corresponds to a linear distance of 9 Mpc at $z$≈2 (Jakobsen et al. 1988, ApJ, 326, 710). The length scales implied by the absorbers toward 0854+191 and 1037-271 are interesting in that they suggest structures more akin to superclusters than clusters.

Among our *ROSAT* observations, the 1556+335 image represents our deepest exposure with a net integration time of 28.5 ksec obtained in July 1991. The 1037-271 and 0854+191 images were acquired in June and May of 1992 with respective exposure times of 20.1 and 5.2 ksec. Although we detect X-ray emission at the expected position of the QSO in the 1556+335 and 0854+191 fields, in both cases it is most likely due to the QSO rather than some foreground cluster since the emission is unresolved. Indeed, we find no convincing evidence of any extended X-ray emission in the central portions of any of the fields we observed.

The significance of the lack of extended X-ray emission in our QSO fields is most easily expressed in terms of a comparison with that expected from Perseus-like clusters at the redshifts of the QALSs toward these QSOs. In this comparison, we will assume that $q_o$=0.5, $H_o$=50 km s$^{-1}$ Mpc$^{-1}$, and

that the intracluster gas is hot enough to produce a relatively flat (index=0) spectrum. With a redshift of 0.0182 (Chincarini & Rood 1971, ApJ, 168, 321), the Perseus cluster's 10' core radius corresponds to 0.3 Mpc. Applying the cosmological relations of luminosity-distance and angular diameter with redshift, this radius would correspond to angular diameters ranging from 70" at $z \approx 1.3$ toward 0854+191 to 74" at $z \approx 2$ toward 1037-271. Based on the Perseus 0.5-3.0 keV core luminosity of $4 \times 10^{44}$ ergs $s^{-1}$ (Branduardi-Raymont et al. 1981, ApJ, 248, 55), the appropriate "K" corrections, and Galactic H I column densities of $3.2 \times 10^{20}$, $2.3 \times 10^{20}$, and $5.0 \times 10^{20}$ $cm^{-2}$, one would expect to detect 0.5-2.4 kev fluxes of $6.2 \times 10^{-14}$, $4.3 \times 10^{-14}$, and $3.0 \times 10^{-14}$ ergs $cm^{-2}$ $s^{-1}$ from potential clusters at $z \approx 1.3$, 1.6, and 2.0 toward the QSOs 0854+191, 1556+335, and 1037-271 respectively. In comparison, we can place corresponding $2\sigma$ upper limits of $5.0 \times 10^{-14}$, $2.5 \times 10^{-14}$, and $3.0 \times 10^{-14}$ ergs $cm^{-2}$ $s^{-1}$ on the 0.5-2.4 keV fluxes of 70" diam. regions near the QSO positions in our *ROSAT* images. This limit is easiest to evaluate for the 1037-271 field since there is no X-ray emission at the QSO position. In the case of the 1556+335 field, the $1.7 \times 10^{-13}$ ergs $cm^{-2}$ $s^{-1}$ flux of the unresolved (FWHM=25") source at the QSO position could mask a cluster but only if it was directly intervening and its core radius was appreciably smaller than Perseus. The 0854+191 field is interesting in that there is an unresolved source only 1.4' to the southeast of the QSO. With a $1.0 \times 10^{-13}$ ergs $cm^{-2}$ $s^{-1}$ flux, this source is nearly twice as X-ray bright as a Perseus-like cluster at $z \approx 1.3$ but also would require a much smaller core radius to be consistent with a cluster interpretation.

Although these observations do not rule out the possibility that clusters of galaxies are responsible for the QALSs toward 0854+191, 1556+335, and 1037-271, they do place some limits on the cluster hypothesis. In particular, it appears that any such clusters would have to be either gas-poor or cooler than Perseus. If subsequent deep optical images of these fields do indeed reveal the presence of high-redshift clusters, our X-ray results would have important evolutionary implications in understanding the nature of intracluster gas. On the other hand, our results can be seen as fortifying the argument that clusters of galaxies are typically not responsible for complex QALSs. Further studies of the unresolved X-ray sources in the interesting 0854+191 region may provide more clues as to the nature of these absorbers. Indeed, we have recently obtained deep optical images of the 0854+191 field, found the optical counterpart of the X-ray source near 0854+191, and acquired a spectrum of it. All of these X-ray and optical results are being compiled into a paper which will be submitted to the Astrophysical Journal. Our initial findings were presented at the AAS meeting in Berkeley, CA in June 1993 (Meyer, Ulmer, and Nichol 1993, BAAS, 25, 838).