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FINAL REPORT

PROJECT TITLE: X-ray Emission from the Edge-on Spiral Galaxy NGC 4631

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This grant supported research of the X-ray emission from the disk and halo of the edge-on spiral galaxy NGC 4631, using data from the ROSAT satellite. The data were obtained on the basis of a proposal submitted by the PI, which was highly ranked in the peer review. It is a pleasure to say that the goals of the project, imaging and spectroscopy of hot gas in the disk and halo of a vigorously star forming galaxy, have been achieved. The results of the project have been submitted for publication, and are in press.

The energy input from supernova explosions and stellar winds is expected to lead to the presence of a hot phase of the interstellar medium in the disks of spiral galaxies. The hot gas, which is characterized by temperatures in the range 10^5 to 10^7 K will not be confined to the disk but is expected to flow out of the disk into the halo. In one model, this outflow takes place as a galactic fountain, while another model predicts that the gas flows through galactic chimneys, whose walls are formed by the cooler interstellar medium that is being pushed aside by the hot gas. As a result, hot gaseous halos are expected to be present around spiral galaxies. The existence of hot halos had also been predicted on the basis of the presence of cool gas clouds at high latitude in our Galaxy. These need to be confined somehow to stay intact; a surrounding hot, low-density medium could play this role. Little observational evidence, however, existed, for either widely distribution hot gas in the disk or halos of normal spiral galaxies. We therefore proposed a detailed study with ROSAT of a suitable galaxy to look for the putative hot medium.

The galaxy NGC 4631 was chosen for this study, since it represented such a unique target. It is nearby, almost perfectly edge-on, a necessary requirement to be able to detect *halo* gas, it is at high Galactic latitude, which implies that the absorption of soft X-ray photons by the Galactic interstellar medium will be minimal, and it is characterized by vigorous star formation over its entire disk, particularly over the inner 4 kpc. The activity is most likely triggered by the gravitational interaction with several neighboring galaxies. If ROSAT would not be able to detect a hot halo in NGC 4631, there would be little hope to find

it in other spirals. We had deep optical images available in continuum light and several emission lines. The latter are sensitive to the warm, roughly 10^4 K ionized gas distribution, enabling a comparison between the two ionized gas distributions. In addition, we had access to a recent image of the neutral atomic hydrogen distribution.

Our experiment was quite successful, in that we detected both the hot gas in the disk and in the halo of NGC 4631. The 23,000 second ROSAT observation allowed us to not only image the hot gas, but also study its spectral characteristics, thereby constraining the possible temperature range of the gas. Comparison with the optical images showed a likely association of the hot gas with what appear to be structures that look like the predicted chimneys. These show up in the distribution of the warm ionized gas, as long filaments perpendicular to the disk of NGC 4631. A particularly interesting result is that most of the hot gas in the halo is possibly at a lower temperature than originally predicted. This could have important consequences for our understanding of gaseous halos and the energy balance in galaxies. Interestingly, the relatively low temperature of the gas implies that it is in fact a large energy sink, because the cooling time for gas at sub-million degree temperatures is much shorter than for gas at higher temperatures. In any case, the results confirm the basic idea that spiral galaxies have hot gaseous halos. Unfortunately, because so few targets will turn out to be feasible even for study with ROSAT, it is not yet clear from our project if *all* galaxies will have such halos. Nevertheless, the ROSAT results present a first unique view of this phase of the interstellar medium in a spiral galaxy. We are currently studying the hot interstellar medium in more spirals, using data from the ROSAT archives.

PUBLICATIONS

The results of our project have been described in three papers. Copies of the first two, which appeared in conference proceedings, have been sent with earlier reports. The third paper will appear soon in the Astrophysical Journal. Originally we had planned on submitting two papers, however, we decided that it would be better to present all results in one large paper. I include copies of the latter with this report. References are given below.

1. Walterbos, R.A.M., Braun, R., Norman, C.A., 1992, "The Disk-Halo Interface in Edge-on Galaxies", in The Evolution of Galaxies and their Environments, eds. D. Hollenbach, H. Thronson, & M. Shull, NASA Conference Publ. 3190, p326

2. Walterbos, R.A.M., Steakley, M.F., Wang, Q.D., Norman, C.A., Braun, R., 1994, "The Soft X-ray Halo of the Spiral Galaxy NGC 4631". in The First ROSAT Science Symposium, eds. E. Schlegel & R. Petre, AIP, p173

3. Wang, Q.D., Walterbos, R.A.M., Steakley, M.F., Norman, C.A., Braun, R., 1995, "ROSAT Detection of Diffuse Hot Gas in the Edge-on Galaxy NGC 4631", ApJ, in press (January 95 issue).