## Motivation

X-ray astronomy is currently one of the most active and evolving fields of research. With the two major working space observatories *Chandra* and *XMM Newton* in orbit, and *Astro-E2* being launched later this year, the prospects for continuing discoveries in this field are very promising. My main research interest is the hot interstellar gas in elliptical galaxies, which is heated to temperatures of $\sim 10^6 - 10^7$K. *Chandra* has revolutionized our understanding of early-type galaxies since its start of operations in 1999. Due to its unprecedented spatial resolution, it was possible for the first time to resolve a large part of the extended X-ray emission of elliptical galaxies into discrete point sources and to disentangle their contribution from the diffuse emission of the hot gas in these systems. These point sources are now believed to consist mainly of low-mass X-ray binaries (LMXB), characterized by their hard power-law spectrum.

*Chandra*'s extraordinary spatial resolution is complemented by *XMM Newton*'s higher sensitivity and better spectral resolution. These two major tools of X-ray astronomy allow detailed studies of individual early-type galaxies, which have shattered our classic view of elliptical galaxies being simple, rather round, hydrostatic objects. New data reveal dramatic features such as large-scale shocks (NGC 4636, Jones et. al, 2002), interactions with radio sources (M84, Finoguenov & Jones, 2001), cavities (NGC 4472, Biller et. al, 2004), ram-pressure stripping (NGC1404, Machacek et. al, 2005), and a rotationally supported cooling disk (NGC1700, Statler & McNamara, 2002). Thus, the long-standing debate about the dynamic state of the hot gas is being reinvigorated. Traditional questions about the role of AGN feedback, outflows, winds, cooling inflows, rotational support, environmental effects, or mergers still largely remain to be answered. With the wealth of data residing in public data archives of *ROSAT*, *XMM Newton* and particularly *Chandra*, we now have the chance to successfully address these important problems.

## Current Work

Motivated by this goal, I am conducting a complete *Chandra* archival survey of 70 early-type galaxies under the supervision of my advisor Tom Statler. Our intention is to understand the morphological and spectral properties of the hot gas. To be properly comparable, all observations have been homogeneously re-reduced with the same calibration files.

Despite the major improvements in spatial resolution, there is still a significant fraction of point sources below *Chandra*'s detection limit due to their low individual luminosities. Thus, to understand the gas, one must first understand the properties of the numerous point sources (between 20 and 200 resolved per observation), in order to accurately remove their remaining contribution to the diffuse emission. An analysis of the point source luminosity function (LF) of our sample of galaxies reinforces the result by Kim & Fabbiano (2004), that the previously reported "knee" in the LF (Sarazin, 2001), marking the transition from neutron star to black hole binaries, is not present. A simultaneous spectral analysis of our catalogue of over 4000 individual point sources shows that they all share similar spectral properties which are luminosity independent.

We exploit this universal character of point sources to remove the unresolved point source contribution to the diffuse emission (Diehl & Statler, 2005). This allows us for the first time to reveal the uncontaminated, true X-ray gas morphology. In order to properly interpret these new gas maps, it is essential to bin the very sparse X-ray data. Due to the lack of existing suitable algorithms, we have developed a new adaptive binning technique that makes use of centroidal weighted Voronoi tesselations (Diehl & Statler, 2005). This new algorithm can be used to create intensity and hardness maps, and can be easily extended to derive temperature and absorption distributions. While retaining a minimum signal-to-noise per bin at the same time, this new binning scheme does not produce spurious features or spread flux around in the image, in contrast to existing programs like the adaptive smoothing technique *asmooth* (Ebeling, White & Rangarajan, 2005).

We have also carried out a full spatial and spectral analysis of all galaxies in our sample. Fitting the radial surface brightness profiles with various models allows us to characterize each galaxy with an X-ray half-light radius, $R_X$, and the corresponding average surface brightness, $I_X$, within that radius. Together with the fitted temperature, $T_X$, we discovered that these three properties form a narrow plane in the $R_X$-$I_X$-$T_X$ parameter space. We have named this relation the “X-ray gas fundamental plane” (XGFP) of normal elliptical galaxies (Diehl & Statler, 2005). Because the origin of this relationship is still elusive, we are continuing to compare various theoretical model predictions against this observational result. We are also extending our parameter space to include morphological properties such as ellipticity or disturbedness, as well as environmental influence, including AGN activity or group interactions. Additional correlations between these fundamental characteristics are expected.

This new ensemble of X-ray relations has the potential to put observational constraints on theoretical models. This could be the first step to shed light on the origin of the hot gas in elliptical galaxies, which is still a matter of debate. Competing models suggest that the gas either comes from internal stellar mass loss or from accretion of external gas through infall or mergers. The second part of my doctoral dissertation is aimed at addressing the latter idea, specifically investigating early type galaxy mergers (E-E). A recent analysis of the merger history of early-type galaxies (Khochfar & Burkert, 2003) showed that more than half of all present-day elliptical galaxies brighter than $M_B = -21$ should be remnants of an E-E merging event. However, no detailed hydrodynamic simulations have been conducted and simulations of cosmological structure formation lack the resolution to address the question what effect such mergers would have on the interstellar medium of individual objects. For this reason, I am currently carrying out combined N-body and Smooth Particle Hydrodynamics (SPH) simulations under the additional supervision of Chris Fryer at Los Alamos National Laboratories (LANL). The goal is to create self-consistent models that reproduce the observational properties found in our galaxy survey and to find out how E-E mergers modify these characteristics.

## Research Interests and Future Work

At the observational frontier of extragalactic X-ray astronomy, new discoveries will be made through the compilation of large samples of galaxies and very deep observations of individual objects. Deep X-ray observations of early-type galaxies are necessary to probe the low-luminosity end of the point source luminosity function. The information gained on the spectral properties of these sources will either justify our assumptions about the similar nature of the faint sources, or provide us with a spectral template to use in the future. I am currently actively involved in a very large Cycle 7 *Chandra* proposal, to observe the nearby elliptical galaxy NGC 3379 for 1Msec. If approved, this observation will lead to the first detailed analysis of the hot gas in an X-ray faint elliptical galaxy, with the possibility to either constrain wind model parameters or reveal the presence, or absence, of a dark matter halo surrounding this object.

While my *Chandra* archival survey has been successful in determining global and morphological X-ray parameters, a detailed investigation of temperature or abundance gradients has been restricted to very X-ray bright galaxies. Thus, a similar archival analysis of *XMM* data, targeted at these specific goals, would be complementary and provide further insight into the state of the gas. Assuming a common structure for very faint galaxies, a statistical analysis might be able to uncover general trends in temperature and abundance profiles even for X-ray faint elliptical galaxies.

One of the main foci in theoretical X-ray astronomy is currently the role of AGN feedback onto the hot gas. Merger simulations provide the ideal tool to address the effects of minor or major merging events onto fueling and activating the central AGN. In general, two results from merging scenarios are possible. In the first potential outcome, the merger remnant is not able to hold onto its shock-heated gas and the gas is expelled in a galactic wind, creating a halo of cool gas around the galaxy. The alternative is that cooling close to the galaxy center will be efficient enough for the gas to drop out of the X-ray phase. The developing cooling inflow will eventually start fueling the central AGN. Hybrid scenarios also lie within the realms of possibility, where the gas is first expelled in a wind, creating a reservoir for a later fallback on a larger time scale. I intend to thoroughly examine the progenitors' parameter space to reveal how sensitive the outcome is to general properties such as gas contents, galaxy sizes or merger mass ratios. Including an additional external pressure from a surrounding intracluster medium could uncover important differences between galaxy evolution in clusters and the field.

In conclusion, there is currently a gap in linking theoretical galaxy models to observations. The quality and quantity of modern X-ray observations is good enough, in principle, to constrain model parameters, yet there is an evident lack of definite predictions in the literature. My aim is to fill this gap and to provide new insights into the nature and origin of the hot gas in elliptical galaxies.

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