Mass, Enrichment, and Entropy in a Typical Isolated Elliptical Galaxy

1. Abstract

We propose a 100 ksec XMM observation of the isolated elliptical galaxy NGC2325, a fairly typical galaxy in terms of its X-ray and optical luminosity. Studies of isolated galaxies allow us to investigate the intrinsic properties of the hot gas halos in early-type galaxies without the complicating effects of a cluster or group environment, and we will study in detail the metallicity, entropy, and temperature profiles in this galaxy as indications of the effectiveness of enrichment and feedback processes. In addition, we will shed light on the debate over the dark matter density profiles of ellipticals by uniquely determining the mass profile of the same isolated galaxy using both deep X-ray and optical dynamical measurements.

2. Description of the proposed program

A) Scientific Rationale:

Since early studies with Einstein, it has been known that many early-type galaxies host hot gas halos with X-ray luminosities that correlate with stellar luminosity (e.g. Forman et al. 1985), albeit with large scatter which may relate to galaxy environment, age, or mass. Current X-ray observatories offer a new window on our understanding of the hot gas halos of galaxies allowing us to detect thermal emission from a large number of early-type galaxies. Spectral decomposition with the sensitivity and bandpass of XMM and Chandra allow one to distinguish galactic thermal emission from unresolved X-ray binaries or AGN, and for reasonably nearby galaxies, the spatial resolution of both instruments can cleanly separate extended halo emission from a central, bright AGN or surrounding ICM gas. For example, studies of early-type, satellite galaxies in groups and clusters have revealed that the majority of bright galaxies retain hot gas halos even in dense environments where mechanisms like ram-pressure stripping can act to remove the gas (Jeltema et al. 2008; Sun et al. 2007). Active stripping is, however, observed for a small fraction of group/cluster galaxies in the form of X-ray tails. Our recent study of field early-type galaxies suggest a complex interplay between the ICM and the hot gas halos of galaxies. Specifically, we find a steeper relationship between X-ray luminosity and K-band luminosity for field galaxies compared to those in denser environments (Fig. 1, Mulchaey & Jeltema 2010) partly due to a population of low luminosity early-type galaxies ($L_{\rm K} <\sim L_\star$) in groups and clusters which host significant hot gas halos while their counterparts in the field appear to be largely devoid of gas. Therefore, while some galaxies in dense environments show evidence of gas stripping, in lower luminosity galaxies winds and AGN feedback may act to drive gas out of more isolated galaxies where in dense environments the ICM may act to help confine gas.

Observations of isolated ellipticals allow us to study the intrinsic properties of galactic hot gas and dark matter halos independent of the complicating effects of the cluster or group environment. The dark matter content and mass distribution of elliptical galaxies is still an open question. Traditional optical mass estimates from stellar kinematics are limited to small radii where the dark matter contribution is minimal, but can be extended using the dynamics of planetary nebulae (PN) or globular clusters (GC). In X-rays, galaxy mass may be estimated by assuming that the hot gas is in hydrostatic equilibrium within the galaxy potential well. On the high mass end X-ray studies of luminous early-type galaxies (typically group and cluster galaxies) find dense dark matter halos (Humphrey et al. 2006; Fukazawa et al. 2006; Das et al. 2010), although some galaxies appear to have much lower mass to light ratios than others (O'Sullivan et al. 2007), and comparison to stellar dynamics in central galaxy regions may indicate non-thermal pressure support in the gas (e.g. Das et al. 2010). In more normal $L_\star$ galaxies, the few extended optical measurements using PN, however, suggest low-concentration dark matter halos, perhaps reflecting the lower-density environments of these galaxies or else a mass-dependent interplay between baryons and dark matter (e.g., Romanowsky et al. 2003; Napolitano et al. 2009). Complicating the studies of elliptical masses is the fact that most of the early-type galaxies studied thus far lie in the dense environments of clusters or groups where the galactic dark matter and gas can be reduced through tidal and ram-pressure stripping (in the case of satellite galaxies) or be enhanced through the inflow of gas (in the case of central galaxies).

To date, only a handful of the brightest isolated early-type galaxies have X-ray mass determinations (O'Sullivan et al. 2007, 2004; Memola et al. 2009) and only a few nearby, very X-ray faint isolated ellipticals have PN or GC dynamical measurements. A comparison of independent mass estimates for normal field ellipticals are sorely needed, but are currently lacking. The identification and dedicated follow-up of an isolated $L_\star$ elliptical with both a sufficient amount of hot gas for X-ray study and near enough for in depth optical study would be invaluable for helping to resolve the open questions about galactic dark matter profiles, given in particular the discrepancies found in studies of the brighter group and cluster galaxies like NGC 1407, NGC4649, and M87 (Romanowsky et al. 2009; Gebhardt & Thomas 2009; Shen & Gebhardt 2010; Das et al. 2010). This is one of the key components of our proposed program.

In addition, we will study the properties of the hot gas in a typical galaxy unaffected by a surrounding ICM. The hot gas in elliptical galaxies is thought to originate from stellar mass lost from evolved stars (e.g. Mathews 1990; Bregman & Parriot 2009). In galaxies, SN feedback can heat and remove gas by driving galactic winds with an effectiveness that will depend on galaxy mass and SN rate (e.g. Pellegrini & Ciotti 1998; David et al. 2006). Similar to groups and clusters, AGN feedback may also play a role in the properties of galactic hot halos. Measurements of metallicity, entropy, and cooling in isolated ellipticals can help shed light on the effectiveness of these enrichment and feedback processes, but are currently available only for a few of the brightest isolated ellipticals and only with a few spectral bins (O'Sullivan et al. 2007, 2004). Here we propose a deep XMM observation of an $L_\star$, isolated elliptical galaxy to examine in detail the properties of its hot halo. We will derive more accurate and detailed measurements of the hot gas properties than possible with previous observations of isolated ellipticals, and this study will extend to lower masses and more typical X-ray and optical luminosities investigations of enrichment and feedback in ellipticals.

B) Immediate Objective:

We propose a deep, 100 ksec observation of the isolated, $L_\star$ elliptical galaxy NGC2325. We choose an isolated galaxy to allow us to cleanly study the intrinsic properties of an early-type galaxy without the complicating effects of a surrounding dense environment and a nearby $L_\star$ galaxy as an example of a fairly typical galaxy. With this observation we will:

• Trace in detail the density and temperature profiles of the hot gas halo and determine the total mass profile under the assumption of hydrostatic equilibrium. This will allow us to determine the dark matter profile and mass to light ratio of a typical elliptical galaxy and to extend the observed mass-concentration relation to lower masses (Buote et al. 2007).

• Obtain stellar and PN dynamics (possibly also GCs) using IMACS or LDSS3 on the Magellan Telescopes (Carnegie Observatories time through Co-I Mulchaey) to compare the X-ray and optical dynamical determinations of galaxy mass. No other isolated elliptical has both extended optical and X-ray mass measurements for the same galaxy.

• Determine the metallicity, entropy profile, and cooling time as indications of the effects of feedback and enrichment in this galaxy.

The proposed observation will lead to the detailed X-ray study of a typical isolated elliptical galaxy, extending to lower mass X-ray studies of mass, entropy, and metallicity in ellipticals, and it will uniquely allow the comparison of X-ray and dynamical measures of the mass profile in the same isolated galaxy.

Target Selection:

NGC2325 is an ideal target for this study. It was selected as isolated in the study of Ellis & O'Sullivan (2006), and we have confirmed using NED that it has no near neighbors. NGC2325 has a K-band luminosity close to $L_\star$ ($L_K = 10^{11.18} L_\odot$ and $L_{K\star} = 10^{11.08} L_\odot$) and its X-ray emission places it very close to the $L_X - L_K$ relation for field galaxies (Fig. 1, Mulchaey & Jeltema 2010), making it a typical galaxy in terms of both its optical and X-ray luminosity. In addition, it is one of only a couple of isolated elliptical galaxies that are both near enough (z=0.007) that we can obtain spectra for PN and GCs as optical, dynamical estimates of the galaxy mass while also having detected thermal X-ray emission bright enough to allow us to trace the mass profile (as well as temperature, metallicity, and entropy profiles). A couple of fainter isolated ellipticals

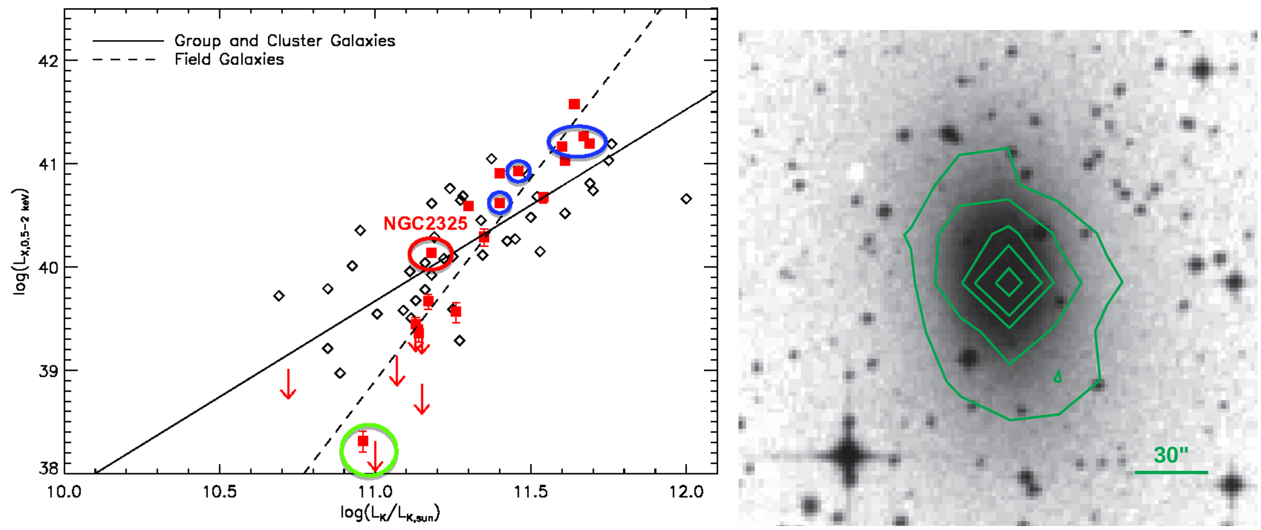

Figure 1: *Left:* Comparison of the $L_X - L_K$ relation for field early-type galaxies (red squares, dashed line) to the relation for satellite early-types in groups and clusters (open diamonds, solid line) for galaxies observed with Chandra or XMM (Mulchaey & Jeltema 2010; Jeltema et al. 2008; Sun et al. 2007). L_X reflects the thermal component of the luminosity only. Upper limits are plotted for a few $L_{K\star}$ or fainter field galaxies which are detected but have spectra consistent with having no thermal component. NGC2325 is circled in red. Isolated early-type galaxies with previous X-ray mass measurements are marked in blue, while galaxies with extended optical mass measurements (PN or GC) are marked in green (Romanowsky et al. 2003; Arnold, Romanowsky et al. in prep.). *Right:* XMM PN+MOS contours (0.5-2 keV, log spaced) overlaid on the DSS image of NGC2325.

with well studied optical dynamics have been targeted by Chandra, but have little or no thermal X-ray emission, NGC3115 ($L_K = 10^{10.96} L_\odot$, $L_X = 10^{38.32}$ ergs/s) and NGC821 ($L_K = 10^{11.00} L_\odot$, $L_X < 10^{38.31}$). These galaxies will, however, allow some comparison to X-ray faint and perhaps lower mass systems. A few brighter isolated ellipticals have X-ray estimates of their masses ($L_X > 4 \times 10^{40}$; O'Sullivan et al. 2007, 2004; Memola et al. 2009), but are too distant to trace the galaxy dynamics at reasonably large radii. The X-ray data for these galaxies are a bit shallower than proposed here, not allowing for detailed temperature, mass, and entropy profiles, but will nevertheless allow us a comparison to higher mass galaxies.

NGC2325 has been previously observed with XMM for 14.4 ksecs (usable flare-free exposure time of 11 ksec for the PN and 14 ksec for the MOS detectors) and was analyzed as part of our study of the average properties of early-type field galaxies (Mulchaey & Jeltema 2010). XMM detects extended emission from this galaxy (Fig. 1), and the X-ray spectrum reveals a thermal component with an average temperature of 0.61 keV and a luminosity (thermal only) of $L_{X,0.5-2keV} = 1.38 \times 10^{40}$ ergs/s. The gas metallicity is not well constrained in the current observation.

3. Justification of requested observing time, feasibility and visibility

We propose a 100 ksec XMM observation of NGC2325 to allow an in depth study of its hot gas halo as well as an accurate determination of its mass profile. Based on the XMM determined flux of the hot halo in this galaxy of F_X (0.5-2 keV)$= 1.24 \times 10^{-13}$ ergs cm^{-2} s^{-1} (thermal component only after accounting for a possible power law LMXB/AGN component), we find a PIMMS predicted count rate of 0.106 counts/s for the PN and of 0.052 counts/s for MOS1+MOS2 in the 0.3-7 keV band for a total of 15,800 source counts in the proposed observation. (We will consider a broad band to better separate thermal emission from any LMXB/AGN contribution as discussed below, but we also expect more than 15,000 counts in the 0.5-2 keV band where the thermal emission is most prominent.) This observation will provide comparable depth for an $L_\star$ elliptical to current X-ray observations of much brighter group and cluster ellipticals (i.e. those galaxies which have been studied in detail thus far) (e.g. Humphrey et al. 2006; Das et al. 2010).

Determination of spectral properties and profiles: Based on the observed XMM surface brightness profile and the background in the current observation, we find that with the proposed observation we will be able to detect X-ray emission from NGC2325 with a signal-to-noise of three or more out to a radius of approximately 150" or 21.5 kpc ($\sim 3.5R_e$ and beyond the optical diameter $D_{25} = 29$ kpc). This radial coverage will allow us to trace the mass profile to radii where dark matter dominates the mass. Using WebSpec, we estimate that we will be able to determine the gas temperature to better than 10% accuracy with 500 or more counts, meaning that we will be able to construct a well-sampled temperature profile. This will in turn allow us to accurately determine the mass and entropy profiles of NGC2325 and to look for cooling in the galaxy center. Finally, we will be able to determine the average galaxy metallicity to ∼10% accuracy.

Separation of the thermal emission: NGC2325 is very extended compared to the XMM PSF, and we will be able to trace the shape and extent of the X-ray emission and separate the extended emission from the galaxy from any central AGN (none obvious in the current XMM image). Using the X-ray spectrum, we can separate out the contribution of the thermal gas from the harder spectrum of low mass X-ray binaries (LMXBs). As was done in previous studies, we will model the spectrum as a combination of a thermal component plus a power law to account for the LMXB/AGN contribution. In addition, we may individually detect and remove the brighter X-ray binaries in the galaxy.

NGC2325 is visible for long periods during AO10 (mid-Sept. to mid-Nov. and mid-March to mid-May).

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4. Report on the last use of XMM-Newton data

(suppressed)

5. Most relevant applicant's publications

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