Session 1: Plasma and Fresh Nucleosynthesis Phenomena

1-3. Galaxies and Their Clusters

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METAL ABUNDANCES IN THE HOT ISM OF ELLIPTICAL GALAXIES

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1. Introduction

In elliptical galaxies, where most of the stars were formed at an early epoch, the total mass, spatial distribution, and relative abundances of metals are intimately connected to the galaxy formation process. Determinations of the hot interstellar medium metallicity from X-ray spectral analysis are more direct, less model-dependent, and more radially extensive than optical estimates based on broad-band colors or line indices, and provide a view into the nucleosynthetic histories of elliptical galaxies.

2. Abundances in Gas-Rich Ellipticals

ASCA spectra can generally be decomposed into soft and hard components (Matsumoto *et al.* 1997). The soft component consists of emission from hot interstellar gas originally ejected from evolved stars, and shows a wide range of X-ray-to-optical flux ratios. The hard component generally scales linearly with optical luminosity, with a relative normalization and spectrum consistent with measurements of the integrated emission from X-ray binaries in spiral galaxy bulges. In this brief review, we focus on the 18 gas-rich ellipticals that have the most reliable abundance estimates, drawing upon the results presented in K. Matsushita's thesis, as well as on our own analysis.

The metallicities derived from fitting thermal plasma models are driven primarily by the Fe abundance, and range from 0.1 to 0.7 solar. Since it has generally been assumed that abundances of the mass-losing stars are supersolar, and since Type Ia SN are expected to further enrich the hot gas to Fe abundances of at least three times solar, X-ray abundances of elliptical galaxies are 3-30 times lower than what might naively be expected.

K. Koyama et al. (eds.), The Hot Universe, 53-56.

3. Reconciling Optical and X-ray Abundances

Clearly, either the SNIa rate is much lower than estimated, and/or SNIa ejecta is not efficiently mixed into the hot ISM. Can optical and X-ray abundances be reconciled, even if SNIa enrichment is neglected?

Hot gas abundances can be diluted by accretion of primordial or intergalactic material (Brighenti & Mathews 1997); however, since metallicities are not lower in more gas-rich systems this cannot be a dominant effect.

Plasma code inadequacies are an extra source of uncertainty for X-ray abundances; however, excluding the questionable Fe L region in spectral fits does not systematically raise the metallicity (Buote & Fabian 1997). Higher abundances can also be accommodated in more complex spectral models. Buote and Fabian have recently found that the best fit to *ASCA* data often consists of a two-temperature plasma, with $kT \sim 1.5$ keV in the secondary component, and that the abundances in such fits are systematically higher by about a factor of 2 compared to models with a single gas phase plus X-ray binaries. However, we have found that the temperature obtained from the He-like to H-like Si line ratios is in excellent agreement with the single-phase model, and is not consistent with the presence of hotter gas in the amounts suggested by Buote and Fabian.

The conventional wisdom that elliptical galaxies have supersolar abundances is based on measurements of the nuclear Mg2 index. However, when one accounts for the Mg overabundance with respect to Fe and aperture effects, it becomes clear that the global Fe abundances of the stars and hot gas are not grossly discordant. We have compared recent estimates of the global Fe abundance using optical data (Trager 1997) with the X-ray measurements. Comparing the 8 galaxies present in both samples reveals generally minor discrepancies, although a few galaxies still have unaccountably low X-ray abundances (Figure 1). The average optical Fe abundances are about 0.45 solar compared to 0.3 solar for the hot gas.

4. Silicon-to-Iron Ratios

Elemental abundance ratios provide constraints on the primordial IMF and relative numbers of Type Ia and Type II supernovae. In variable abundance fits for 7 ellipticals, we find Si-to-Fe ratios consistent with, or somewhat less than, the solar value (Figure 2). This is lower than the Mg-to-Fe ratio derived from nuclear optical spectra, and is more in line with what has been measured in intergroup media. The Si abundance provides an independent and iobust (to plasma code uncertainties) strong upper limit on the effective SNIa rate that is consistent with what is derived using Fe – about 0.03 SNU.

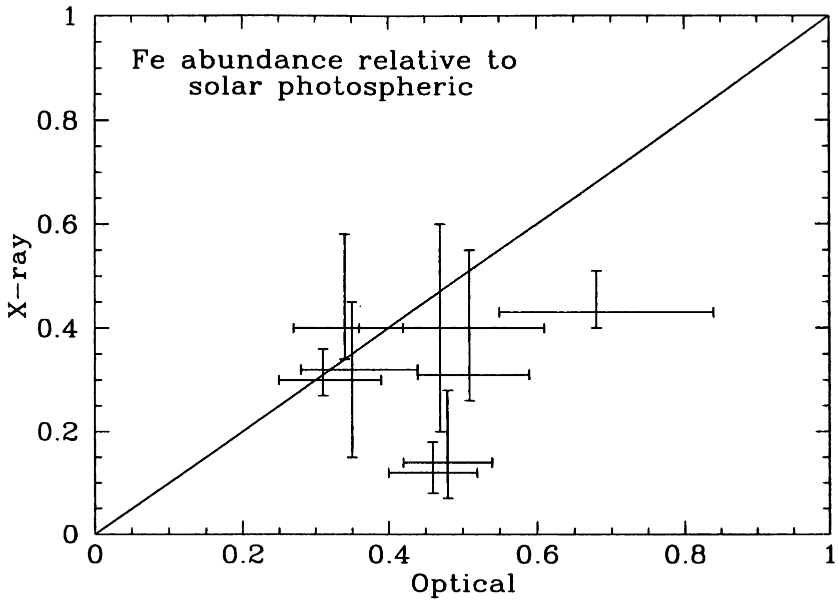

Figure 1. X-ray versus optical global iron abundance.

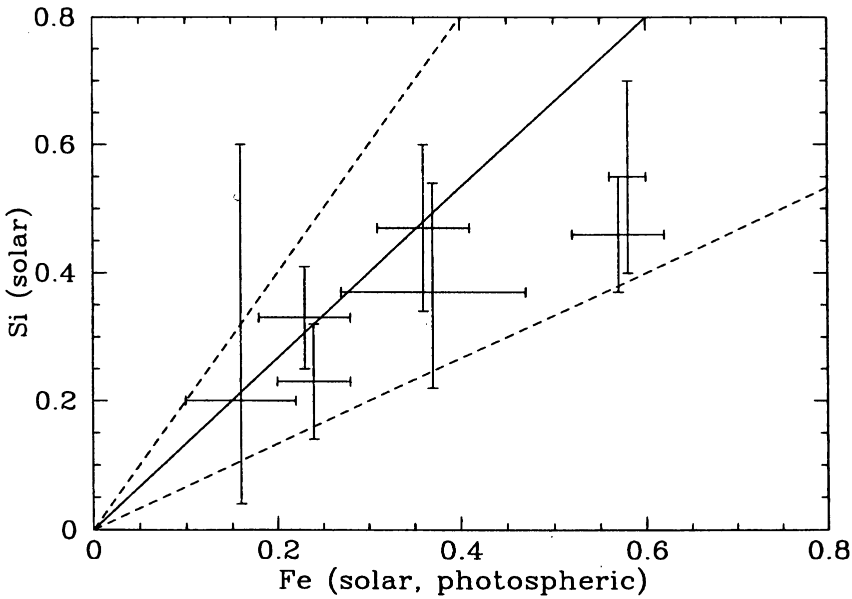

Figure 2. Si versus Fe abundance in the hot X-ray emitting gas. The solid line denotes Si:Fe in the ratio 1:1, while the broken lines denote the ratios 3:2 and 1:2 with respect to the (meteoritic) solar ratio.

5. Implications of Low Abundances for ICM Enrichment

The mass-averaged Fe abundance in an elliptical galaxy, based on X-ray and optical data, is about one-half solar – only slightly higher than what is measured in the intracluster medium. Since the gas-to-galaxies mass ratio is 2-10, there is several times more Fe in the ICM than is locked up in stars. If all cluster metals come from the same SNII-enriched proto-elliptical galaxy gas, then 50-90% of the original galaxy mass has been lost. However, the actual amount of material directly associated with the SNII ejecta is roughly an order of magnitude less: if there is selective mass-loss of nearly pure SNII ejecta, it is possible to lose most of the metals without losing most of the mass. It is also possible that there is another significant source of ICM enrichment, although this fails to explain why the ICM Fe mass correlates so well with total elliptical galaxy luminosity (Arnaud *et al.* 1992).

6. Concluding Remarks

X-ray spectra of elliptical galaxies are adequately fit by models consisting of gas with subsolar Fe abundance and roughly solar Si-to-Fe ratio, plus a hard X-ray binary component. The consistency of the strength and spectrum of the hard component with that expected from X-ray binaries, along with its more compact spatial distribution supports this model over ones where the hard component is primarily due to a hotter gas phase. Complications in the form of an extra soft continuum or multiple phases can be considered, but the consistency of Si line diagnostic and continuum temperatures demonstrates that the data – at the present level of sensitivity and spectral resolution – do not require these. Optical and X-ray Fe abundance estimates are converging, although there are some cases with anomalously low X-ray values. Problems in the Fe L spectral region remain; however, the main effect of improvements in atomic parameters is likely to be improved spectral fits rather than a radical upward revision in abundances.

Occam's razor would seem to demand that we provisionally accept the reality of low abundances in elliptical galaxies. As a result, we need to seriously reevaluate our notions of elliptical galaxy chemical evolution, intracluster enrichment, and Type Ia supernova rates.

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