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NEEDS AND REQUIREMENTS FOR FUTURE X-RAY OBSERVATIONS OF HOT GALACTIC HALOS

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RESUMEN

Las galaxias son objetos clave para estudiar la cosmología, los ciclos de la materia y la evolución estelar. Las observaciones de rayos-X nos ofrecen una ventana importante a estos componentes del Universo y nos permiten investigar su gas caliente. El estudio de este plasma caliente tiene relevancia cosmológica y aunque se esperan avances significativos con *Chandra* y *XMM*, existen problemas fundamentales que requerirán de una nueva generación de telescopios de rayos-X. Estos deberán tener áreas colectoras de 10 a 30 metros cuadrados, con resoluciones similares a las de *Chandra* e instrumentos que permitan hacer imágenes espectroscópicas de moderada y alta resolución.

ABSTRACT

Galaxies are key objects for the study of cosmology, the life cycle of matter, and stellar evolution. X-ray observations have given us a new key window into these building blocks of the Universe, that allows us to investigate their hot gaseous component. While the study of these hot plasmas has important astrophysical and cosmological relevance, and significant advances in our knowledge are expected from *Chandra* and *XMM*, there are a number of fundamental questions that require a next generation of X-ray telescopes. These telescopes need to be 10–30 square-meter class telescopes, with *Chandra*-like resolution, and with a suite of instruments allowing spectral imaging at moderate to high resolution.

Key Words: **GALAXIES: HALOS — ISM: JETS AND OUTFLOWS — X-RAYS: GALAXIES**

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1. WHY GALAXIES IN X-RAYS?

- Galaxies are key objects for the study of cosmology, the life cycle of matter, and stellar evolution. Insights into the nature and evolution of the Universe have been gained by using galaxies to trace the distribution of matter in large scale structures; mass measurements, whenever feasible, have revealed the presence of Dark Matter; galaxies' evolution and intercourse with their environment are responsible for the chemistry of the Universe and ultimately for life (Fig. 1). X-ray observations have given us a new key band for understanding these building blocks of the Universe, with implications ranging from the the study of extreme physical situations, such as can be found in the proximity of Black Holes, or near the surface of neutron stars; to the interaction of galaxies and their environment; to the measure of parameters of fundamental cosmological importance.

- Hot gaseous halos are uniquely visible in X-rays. Their discovery in E and S0 galaxies has given us a new, potentially very powerful, tool for the measurement of Dark Matter in galaxies, as well as for local estimates of Ω (Fig. 2).

- Galaxy ecology—the study of the cycling of enriched materials from galaxies into their environment—is *inherently* an X-ray subject. Escape velocities from galaxies, when thermalized, are kilovolt X-ray temperatures. The X-ray band is where we can directly witness this phenomenon (e.g., in M82; NGC 253; see Fabbiano 1989; Fabbiano 1996; and references therein).

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- The study of hot halos and outflows in the local universe allows us to establish the astrophysics of these phenomena. This knowledge can then be used to understand the properties of galaxies at the epoch of formation and their subsequent evolution, both in the field and in clusters (Fig. 3).

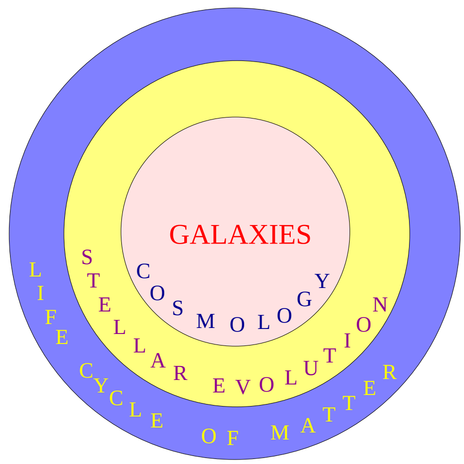

Fig. 1. Galaxies and our understanding of the Universe.

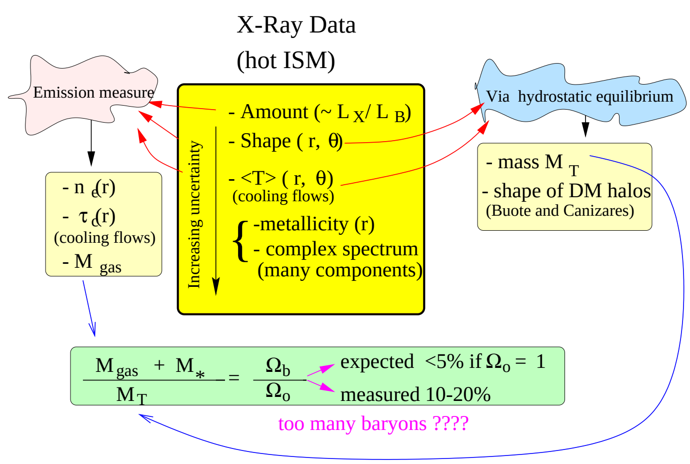

Fig. 2. From X-ray data to cosmological constants.

2. HOT HALOS

Although the existence of hot halos has been established, there are some basic questions that need to be explored further before we understand their evolution and physical state.

- There is a whole range of X-ray emitting halos in E and S0 galaxies (see e.g., Fabbiano 1989; Fabbiano 1996), from halos dominating the X-ray luminosity of the galaxy, to galaxies where, with the present data, no halo emission can be unequivocably discriminated from the integrated emission of X-ray binaries.

  Chandra subarcsec imaging is needed to clearly map and separate point source and diffuse emission components at distances out to Virgo. The *Chandra* image of NGC 5128 (Cen A) clearly reveals a population of ~ 60 point-like sources, as well as complex extended emission, some of which at least may be of thermal gaseous origin (Kraft et al. 2000). Although not connected with the study of hot halos,

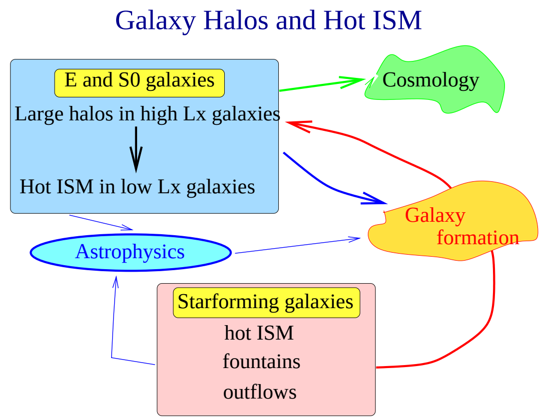

Fig. 3. Implications of galaxy halos and hot ISM.

the study of the properties of the X-ray source populations in different galaxies is a very important topic, offering us a very exciting hunting ground for intermediate size black holes and a tool for the direct study of the more massive portion of the stellar population.

- Why is there this range of halo properties? Correlating X-ray properties with other galaxian properties suggests that large hot halos may be related to both the characteristics of the gravitational potential and to the galaxy environment or recent evolution (e.g., Eskridge, Fabbiano, & Kim 1995a, 1995b; Pellegrini 1999; Fig. 4). While the characteristics of the potential, and therefore original formation mechanisms are key for the retention of large halos (see box in Fig. 4), environmental effect may have favorable or contrary influence (e.g., in the case of recent merging and star formation, which may be related to the blowing off of hot ISM; Fabbiano, Schweizer, & Mackie 1997; Mackie & Fabbiano 1997).

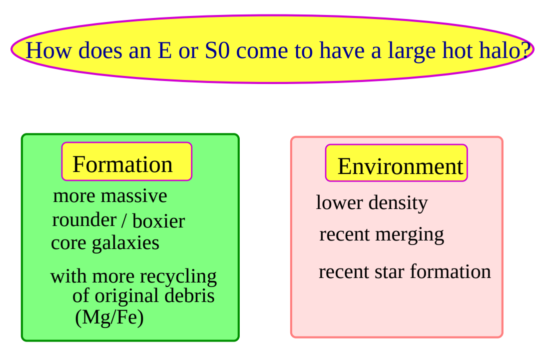

Fig. 4. Factors aiding or impeding the formation of large hot halos.

- What is the metal abundance of the halos? This is a fundamental question because its answer can provide strong constraints to our understanding of the enrichment history and therefore, the stellar evolution history of the parent galaxy. However, present answers are controversial, because of the relatively poor resolution of the available spectra (e.g., *ASCA* CCD spectra or, worse, proportional counter spectra), combined with non-unique model fitting (e.g., Fabbiano 1995; Fabbiano 1996; see Fig. 5), that can only be solved with high quality, high resolution ($\lambda/\Delta\lambda \sim 1000$) spatially resolved spectra.

- What is the physical state of a given halo (e.g., is the hot gas infalling, outflowing, stationary, does it have localized cooling, etc.), and can we discriminate (by using spatially and spectrally resolved data) among models of halo evolution?

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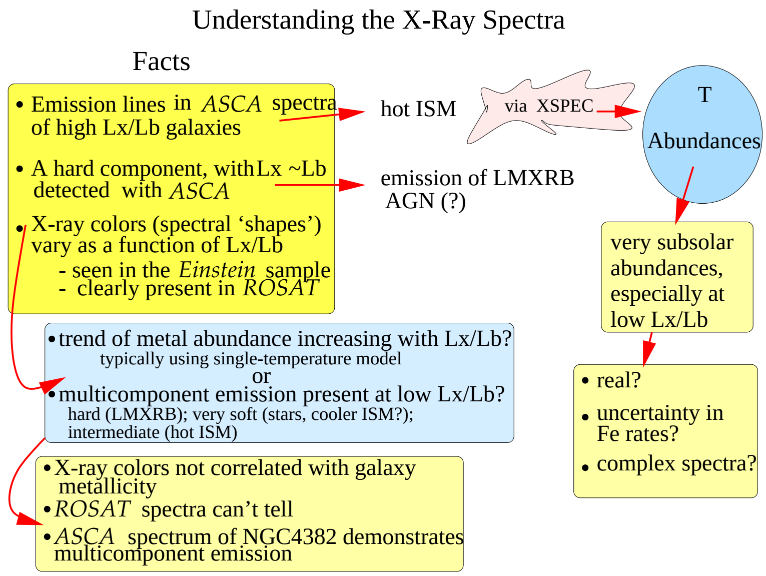

Fig. 5. X-ray spectra interpretation issues.

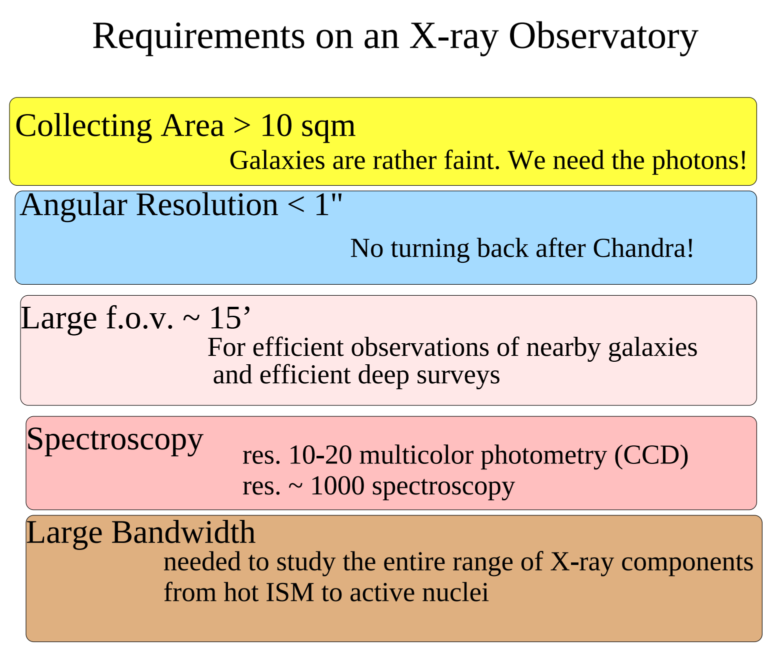

Fig. 6. Science-driven requirements for a future X-ray telescope.

3. REQUIREMENTS FOR AN X-RAY TELESCOPE

Figure 6 summarizes the requirements for an X-ray telescope that will significantly advance our knowledge of galaxies. The purpose of this telescope is two-fold:

- To allow very detailed studies of the X-ray components of nearby galaxies and their properties, to gain the needed deeper astrophysical understanding.

- To allow the study of deep X-ray fields, where galaxies are likely to be a very large component of the source population. Looking back in time, and comparing these results with the detailed knowledge of the X-ray properties of more nearby objects, we will be able to study galaxy evolution in the X-ray band. We will be able to look at galaxies when substantial outflows were likely to occur and therefore witness the chemical enrichment of the Universe at its most critical time.

Three key elements are: collecting area, angular resolution, and spectral capabilities.

- A collecting area in the 10–30 square meters range is needed for both in-depth studies of individual galaxies in the nearby Universe (Fig. 7), and for looking back in time (Fig. 8).

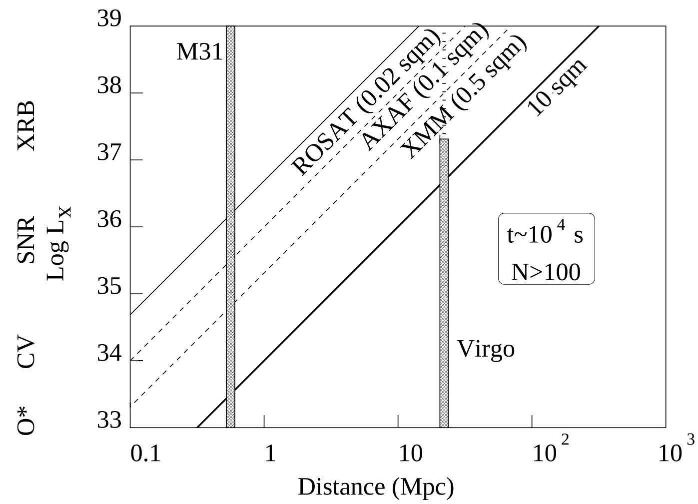

Fig. 7. Detection limits of sources in galaxies.

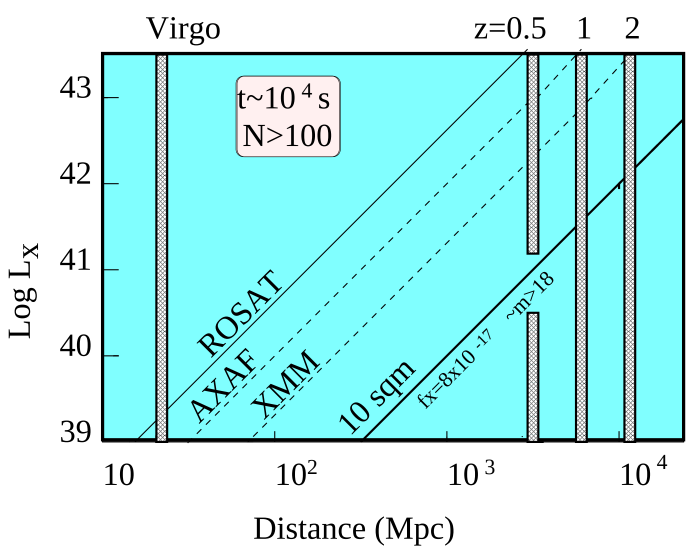

Fig. 8. Detection limits of galaxies as a function of distance.

- Arcsecond or better angular resolution is a must, to avoid confusion in both the study of nearby galaxies, and in the study of deep fields. *Chandra* images demonstrate the richness of detail one obtains with subarcsec resolution. With *Chandra*-like angular resolution galaxies can be picked out easily from unresolved stellar-like objects in deep exposures. Such deep exposures (Fig. 9) would allow the study of the

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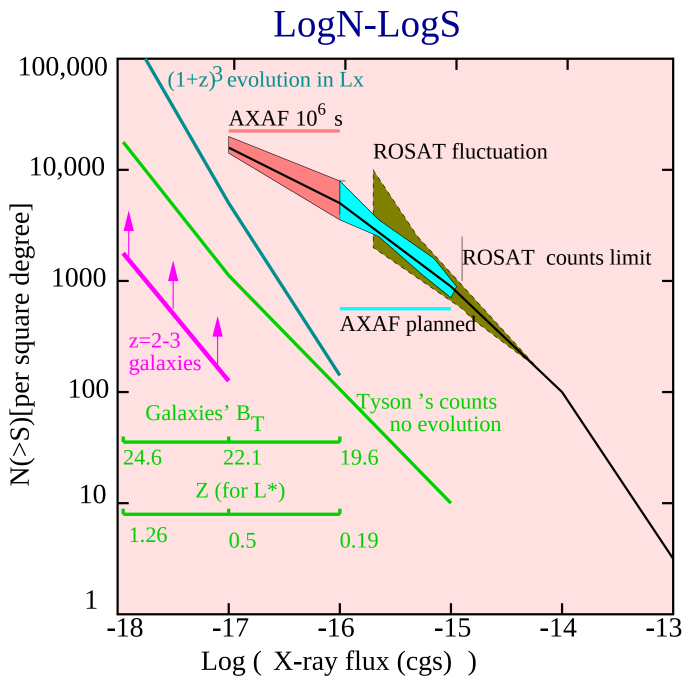

Fig. 9. Deep X-ray count that can be reached with a 25 square meter telescope in 100ks. In the deepest decade galaxies may dominate the counts. Based on the HDF results (Gwyn & Hartwick 1996) high z galaxies may be visible.

evolution of galaxies in X-rays, and of the evolution of their stellar binary population as well as of their hot gaseous component. If hot outflows are prominent at early epochs we will have a first hand account of the metal enrichment of the Universe.

- Figure 10 illustrates the scope of spectral work one would like to perform. With X-ray spectroscopy we can both determine the physical status of hot plasmas as well as their chemical composition. We can also measure cooler ISM by studying the absorption spectra of background quasars.

How these requirements compare to the characteristics of planned future X-ray observatories (*Constellation X* under study by the NASA community, and *XEUS* under study in Europe) is shown in Figures 11 and 12. While spectra and bandwidth characteristics of these missions under study accomplish our goals in both cases, the other requirements fall below those we need. *XEUS* has the required large collecting area, while *Con-X* area is significantly smaller. In both cases angular resolution is significantly sub-*Chandra*. Based on what *Chandra* has shown and on the characteristics of the objects we want to study—galaxies are complex objects—a *Chandra*-like resolution is a must. The field of view is also small in both cases, especially in the case of *Con-X*.

As we have done in the past (Elvis & Fabbiano 1996) we advocate that NASA consider a large area, *Chandra*-like resolution mission to push X-ray astronomy from an exploratory discipline to a discipline at a par with the other wavelength astronomies. Both the scientific potential of the studies that can be performed with such a telescope, and more directly the exciting discoveries resulting from *Chandra*'s high resolution images, support this project.

I acknowledge partial travel support from the *Chandra* Science Center NAS8-39073. This talk was also given at the Cosmic Genesis Workshop held at Sonoma State University, Oct 27-30, 1999, and will be included in the proceedings of that meeting, which are going to be posted on the Web. Part of the material presented here has also been presented elsewhere (e.g., at the *XEUS* Symposium 1999 and the Santorini Conference 1999).

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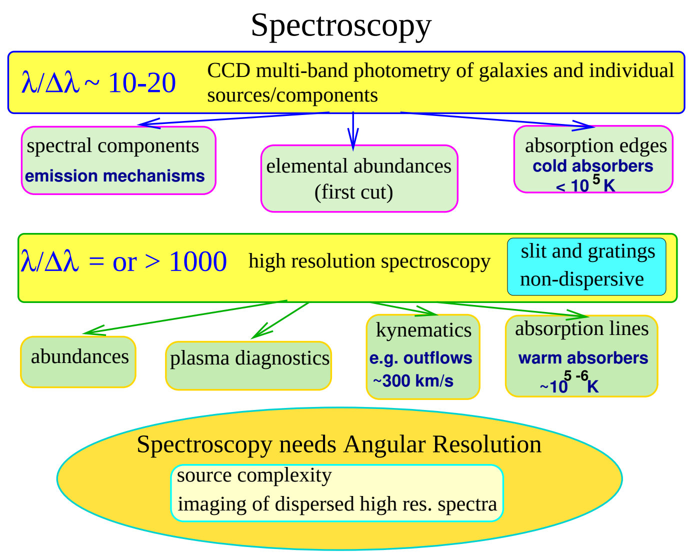

Fig. 10. Spectroscopy goals.

Future Prospects: Constellation X (NASA)

	Coll. Area	Ang.Res.	F.o.V.	Spectra	Bandwidth
We need	>10 sqm	Chandra <1"	~15'	res. 12-20 ~1000	0.1 - 10 keV
Con. X	1.5 sqm	15"-5"	~2'	OK	OK

The Con X team has achieved 15" res. and is now moving towards 5"
Can better resolutions be achieved?

Recent developments of large f.o.v. multi-pixel calorimeters very exciting for the study of extended complex objects (Blas Cabrera's group at Stanford).

Can the collecting area be increased by adding more spacecraft?

Fig. 11. Comparison of our goals with the *Constellation X* plans.

Future Prospects: XEUS (ESA)

	Coll. Area	Ang.Res.	F.o.V.	Spectra	Bandwidth
We need	>10 sqm	Chandra <1"	~15'	res. 12-20 ~1000	0.1 - 10 keV
XEUS	25 sqm	5"-2"	~5'	OK	OK

Optics based on XMM model. Team confident about 5", 2" goal.
Can better resolutions be achieved?

Can the F.o.V be larger?

Fig. 12. Comparison of our goals with the *XEUS* plans.

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