INTERSTELLAR, INTRACLUSTER AND SUPERCLUSTER GAS

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I. INTRODUCTION

The topics which this talk has to cover range in size from about 100 Pc to 100 MegaPc but in many respects are remarkably similar. In all cases we are considering hot tenuous plasmas with temperatures in the range $10^6 \rightarrow 3.10^8$ °K and densities of $10^{-6} \rightarrow 10^{-3}$ cm^{-3}. The dominant radiation processes are thermal bremstrahlung and collisional line excitation and all except the very hottest objects will have observable X-ray emission lines. However the most important unifying point is the angular scales involved. For the interstellar gas one may expect structure ranging in size from about 10' (shadowing by IS clouds; Fried *et al.* 1980) to tens of degrees (nearby evolved supernova remnants (Nousek *et al.* 1981). Nearby (distance ~20 M Pc) irregular clusters will have structure on galaxy scalelengths of a few minutes, which is similar to the core sizes of distant more regular clusters (e.g. Forman and Jones 1982). The cores of very distant clusters at z=1 will be resolvable at 30'' → 1' [e.g. Henry *et al.* 1979]. Superclusters will have sizes of degrees [e.g. Murray *et al.* 1978].

Thus there are an enormously wide range of problems which an instrument with a spatial resolution of ½' → 1' and a field of view of degrees could tackle. Though there are problems in these areas which such an instrument could not cover,* I think it is fairly clear that what we need most is an instrument of this general type.

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*Examples are the spatial mapping of cooling flows in clusters (Fabian *et al.* 1981) or the mapping of gas around galaxies in distant irregular clusters.

Of the three classes of problems listed in the title the only one on which we have really excellent X-ray data is the clusters [e.g. Forman and Jones 1982]. We have a good deal of information on X-ray emission from the interstellar gas both from rocket flights and the HEAO 1 and SAS C experiments [e.g. Fried *et al.* 1980]. Finally we have very little solid information of any sort on the superclusters. Despite this diversity in existing understanding, the way to the future in all three areas must be through larger collecting areas.* In the rest of the talk it will be seen that there are many problems where a highly *spectral* resolution [R $\sim$ 100-1000] would be useful or even essential. However, we could make a great deal of progress with an instrument of moderate resolution (R $\sim$ 10) provided we could obtain the necessary increase in sensitivity.

A rather incomplete list of important problems in these fields is as follows:

<u>Interstellar Gas</u>:

Mapping at moderate (1') spatial resolution:	Morphology of individual structures in the IS gas
	Separation of stellar and gaseous contributions to the soft X-ray background
	Interstellar cloud shadowing Structure of the galactic halo
(High Spectral Resolution Studies:)	Chemical composition of the galactic halo
	X-ray absorption line studies of the disk and halo
	Spectroscopy of individual structures

*The necessity for large area applies irrespective of the spectral resolution.

Clusters:

Mapping at 1' resolution:	Samples of distant clusters/cluster evolution
	Outer halos of rich homogeneous clusters
	Interaction of galaxies and cluster gas in irregular clusters
	Morphology of gas in clusters
(High spectral resolution studies:)	Spectroscopy of the centers of radiatively cooling clusters
	Abundance gradients
	Primordial material in irregular clusters
Superclusters:	Detection and mapping of hot gas
	Interaction between clusters and superclusters
(High spectral resolution studies:)	Chemical enrichment in intercluster gas

I've split the list into experiments which could be performed without high spectral resolution and those in which it is essential. I think it's worth noting that roughly 50% of the experiments require high spectral resolution as well as the imaging capability. Clearly if both sensitivity and high spectral resolution could be obtained this would be ideal.

I now want to consider a few of these topics in more detail. The choice is somewhat arbitrary and I have avoided topics which are touched on elsewhere (in particular in the talks of Fabian and of Shull).

II. SUPERCLUSTER GAS

It seems increasingly probable that the general intergalactic gas lies at temperatures less than 10^6 °K and probably cannot be detected by its X-ray emission (e.g. Sargent *et al.* 1979). As yet the arguments and observations of this point are in no way compelling but it seems worthwhile to focus our attempts to detect the IGM in the X-rays on those regions where the heat input is most likely to be concentrated.

The best location for this is probably in the intercluster regions of the superclusters. Bookbinder *et al.* (1980) have argued that galaxies of present visual luminosity $L_* = 10^{10.5}\ L_\odot$ release about $10^{61.7}$ ergs into the intergalactic gas at temperatures around $10^{9.0}$ K in their early stages of evolution. Such material will not be bound to any cluster of which the galaxy is a member. At this stage the cluster would then possess a hot outflowing wind.*

Assuming that the net visual luminosity of a typical supercluster is around $10^{14}\ L_\odot$, the total energy release would amount to about 2×10^{65} ergs. If this occurred at z=5, allowing for adiabatic expansion losses, it would heat a gas of density $n_e = 9.6\times10^{-6}\Omega h^2\ \mathrm{cm}^{-3}$, ($h = H_o/100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$), filling a radius of 20 Mpc to a temperature of $\sim2\times10^6\Omega^{-1}h^{-2}$ °K.** The total mass of gas in the supercluster is $10^{16}\Omega h^2\ M_\odot$ while the galaxies will have released about $5\times10^{14}\ M_\odot$ of processed gas or about 10^{14}

*As was first pointed out by Ostriker (1979), this has two very attractive features. Firstly it drives out any primordial gas which would like to fall into the cluster. Secondly, by removing very metal enriched gas from the cluster it can solve various abundance problems of the type discussed by deYoung (1978).

**A complete self consistent calculation would follow the evolution of the blast wave generated by the overlapping cluster winds and calculate the temperature from this (Ostriker and Cowie 1981). The result is very close to the quick estimate given above and the present radius of the blast wave is around 20 Mpc for Ω=1.

$M_\odot$ of metals (Bookbinder *et al.* 1980). The metallicity may therefore be a substantial fraction of cosmic particularly if Ω is less than 1.

Assuming that the emissivity is around 10^{-23} n_e^2 ergs cm^3 s^{-1}, a temperature of about 200 ev-1 Kev, as is suggested by the above calculation, the total luminosity of the supercluster would be around 10^{45} $\Omega^2 h^4$ ergs s^{-1} and its surface brightness about 5×10^{-9} $\Omega^2 h^4$ ergs/cm^{-2} s^{-1} ster^{-1} or a fraction of the diffuse X-ray background at these energies.

In general terms and independent of this specific model it is clear that the most important requirement for a supercluster search is the ability to exclude member clusters and other X-ray objects from the field and to consider only the intercluster component. This requires an angular resolution of at least a fraction of a degree. The experiment must also be capable of imaging the whole supercluster which would generally mean a FOV of several degrees for relatively nearby superclusters.

For a supercluster of radius 3° at a distance of 500 Mpc we can estimate that a 3σ detection above fluctuations in the background would crudely require a source with 10% of the diffuse X-ray flux in the same region (Levine *et al.* 1977, Schwarz 1980). This would imply that a sensitive experiment could reach surface brightness limits of about 2×10^{-9} ergs cm^{-2} sec^{-1} ster^{-1} (Fried *et al.* 1980) and constrain $\Omega < 1$ or so for an individual supercluster. Clearly a survey of a large number of superclusters could provide very interesting constraints on the IGM density.

A spectroscopic instrument, measuring the relative line strengths, could also constrain the metallicities of the gas. This could be of crucial importance, if and when the superclusters were detected, in distinguishing between cluster heating of the intracluster gas as discussed above and alternative heating mechanisms such as gravitational in-fall. The history of cluster X-ray emission studies should remind us how important such information can be.

III. CLUSTER X-RAY SOURCES

I want to say relatively little about this topic, since the problems are so well known to everyone. Discussion can be found in the reviews of Cowie (1981) and Forman and Jones (1982). Briefly, a large area imaging instrument is needed to study distant clusters and to extend the Einstein results of Henry and coworkers (e.g. Henry *et al.* 1979). Realistically there is little hope of obtaining cosmological information from this type of measurement but a very large sample of distant clusters may allow us to obtain the evolution of the average X-ray luminosity and gas core radius for individual classes of cluster. Hopefully we may at least determine if there has been any evolution of the potential of the cluster over recent ($z \lesssim 1$) times. However, one should contrast the results of Cowie and Perrenod (1979) with those of Perrenod (1977) to see how small the expected differences are.

A second direct application of a large area imaging detector would be the study of gas lossage by galaxies in irregular clusters (e.g. Fabian *et al.* 1980). Pushing existing results farther back in z would probably help us understand the nature of galaxy stripping in clusters, gas evolution in galaxies and cluster galaxy evolutionary effects such as the color changes described by Butcher and Oemler (1978). Models for the formation of cluster atmospheres such as those by Norman and Silk (1979) or Sarazin (1979) make detailed and testable predictions of the evolution of the gas distribution in clusters which could be checked.

There are a number of additional problems which a spectroscopic instrument could tackle. Perhaps the most interesting would be an extension of the fascinating Einstein SSS and FPCS results (e.g. Canizares *et al.* 1980, Mushotzky *et al.* 1981) on the cooling central cores of clusters out to more distant clusters. Refinement of the cluster metallicities which can be obtained in this way could be of primary importance in understanding galaxy evolution within the clusters and cluster gas evolution.

IV. INTERSTELLAR GAS

In this section I want to consider two very specific experiments, one of which illustrates what could be done with a large area imaging detector and one of which would additionally require high resolving power.

a. Cloud Shadowing of the Soft X-Ray Background

The great majority of the soft X-ray background appears to be truly diffuse, arising primarily from a local hot spot in the galactic disk and from a hot gaseous galactic halo (Marshall and Clark 1981). About 20-30% at 1 Kev and substantially less at 200 eV arises from dM stars (Rossner *et al.* 1981) with about 10 stars in each square degree contributing most of the flux. The fractional contributions from Pop II stars to the halo emission may still constitute a problem. However if the soft X-ray background could be imaged on a scale of minutes, fluctuation analyses of the type given by Levine *et al.* (1977) at larger scales should allow us to obtain a stringent limit to the stellar contribution. Imaging of the X-ray background at such scales is a demanding problem however, since the high galactic latitude photon arrival rate in the 200 eV-1 Kev range is only around 5×10^{-6} ph cm^{-2} sec^{-1} $(\square')^{-1}$. Therefore both a large area detector with long exposure and a low background are necessary.

As Fried *et al.* (1980) have recently pointed out, typical diffuse interstellar clouds with column densities of 3×10^{20} cm^{-2} or more are opaque to radiation in the 200 eV energy range. The local hot gas behind such regions and, more importantly, the hot halo gas or halo star contribution will be substantially shielded by such regions. A typical line of sight at high latitudes is most likely to pass through exactly one cloud but has a finite possibility of passing through none or more than one (e.g. Spitzer 1977). Since the cloud sizes are large compared to arcmins (at 100 pc a 1 pc radius cloud has an angular radius of 30'), individual clouds will appear as large shadowed regions on the diffuse X-ray background at low energy. Since we may also estimate the distance from the amount of missing soft X-rays this type of measurement could determine the size spectrum of interstellar clouds a quantity of crucial importance to theories of the ISM (McKee and Ostriker 1977). It is worth commenting that this quantity is remarkably difficult to determine by other methods.

b. X-Ray Absorption Lines from the Hot ISM

The possibility of making X-ray absorption line studies, analogous to the optical and UV absorption line studies which have been so important in studying the interstellar medium, has only recently begun to be considered. The reasons for this are clear – the instrument requirements are quite severe both as regards effective area and spectral resolution – but the potential for studying the intergalactic medium (Shapiro and Bahcall 1980) and the hot interstellar medium and the galactic halo (York and Cowie 1981) are enormous. The reason for this is that the absorption lines directly measure column densities of a given ionization stage and remain sensitive to low density gas in contrast to the emission lines.

In Table I, I have summarized from York and Cowie the strongest available lines together with the expected equivalent widths for a $10^{18.5}$ cm^{-2} column density of hot gas at the optimal temperature. This value is representative of the hot ISM (e.g. McKee and Ostriker 1977).

It can be seen from Table I that a resolution of at least $R \approx 100$ is required to discriminate neighboring strong lines. In addition, one may simply estimate on the basis of photon statistics the required instrument parameters. The necessary effective area

Table 1 (adapted from York and Cowie 1981).

Species	Line Wavelength (Å)	Logarithmic Temp. at Which Species is Dominant Ionization Stage	f (Oscillator Strength)	W_E/E ($N=10^{18.5}$)
C V	40.27,40.73,41.47	5.7	0.65	3×10^{-4}
C VI	33.70	6.0	0.42	1.6×10^{-4}
O IV	22.86	5.4	0.45	1.6×10^{-4}
O V	22.52	5.4	0.62	3×10^{-4}
O VII	21.8,21.6	6.0	0.69	3×10^{-4}
O VIII	19.0	6.3	0.42	1.6×10^{-4}
Si VIII	61.0	6.0	1.2	10^{-}

A is given in terms of the source intensity I by

$$A(\mathrm{cm}^2)Rt(\mathrm{hrs}) = 3\times10^4\ n^2\Big/\left[\left\{\frac{(W_E/E)}{10^{-4}}\right\}^2 I(\mathrm{kev}/(\mathrm{cm}^2\ \mathrm{s\ kev}))\right].$$

For a source with $I = 5$ kev cm^{-2} s^{-1} kev^{-1} at 500 eV, such as the Crab (Charles *et al.* 1979), a 3σ detection of a line with $W_E/E = 3\times10^{-4}$ in an hour's exposure would require $A(\mathrm{cm}^2)R = 6000$. In rough terms this is a factor of 30 or so over the FPCS detectors aboard Einstein (Giacconi *et al.* 1979).

There are a number of problems with this technique, of course, not least that of finding sufficiently strong background sources with well defined continua in the neighborhood of the absorption lines. In some cases (e.g. ScoX1) there may be relatively narrow emission lines which will confuse the absorption line studies. Synchrotron sources such as the Crab are ideal, of course.

V. SUMMARY

Clearly this has been an idiosyncratic and personal view of a complex range of topics, but I think two points are very clear. Firstly, a large area imaging instrument could cover a great deal of ground with or without a spectroscopic capability. However, high resolution spectral capability is highly desirable and would greatly enhance the power of such an instrument. Either class of instrument would be highly flexible, capable of dealing with a wide range of problems and of great general utility.

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