The transmission grating spectrometers on AXAF have sufficient sensitivity and energy resolution to detect resonance X-ray absorption lines in the spectra of distant quasars. Such lines would be produced in an ionized, and somewhat chemically enriched component of the inter-galactic medium. The bulk of the baryonic content of the universe at redshifts \( \leq 2 - 3 \) could be in this form and would thus be revealed by AXAF.

The Advanced X-ray Astrophysics Facility (AXAF)\(^a\), now scheduled for launch in late 1998, will carry two transmission grating spectrometers that give unprecedented energy resolution and good sensitivity over 0.07-8 keV. These are the Low Energy\(^b\) and High Energy Transmission Gratings\(^b\) (LETG and HETG), each of which is optimized for a portion of the energy band, and each of which can achieve resolving powers of up to \( E/\Delta E \approx 1000 \).

We plan to use AXAF’s spectroscopic capability to probe the hot component of the inter-galactic medium (IGM). This is an analog of the well established studies of cooler IGM material through UV and optical spectroscopy, which have revealed the Lyman \( \alpha \) forest, damped Ly \( \alpha \) clouds, metal line systems, etc. As in those studies, we will be looking for spectral features imposed by the intervening material on the X-ray continuum of distant quasars.

In the X-ray band, the features of interest are resonance lines from highly ionized heavy elements, some of which are listed in Table 1. Several of these (marked with an asterix) are the Ly \( \alpha \) lines of hydrogenic species, whose energy is 13.6 \( Z^2 \) eV (where \( Z \) is the atomic number). Some other K lines of He-like alpha elements and L lines of Ne-like to H-like Fe may also be of interest. In principle, absorption edges from bound-free transitions of heavy elements in any

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\(^a\) [http://asc.harvard.edu](http://asc.harvard.edu)

\(^b\) for HETG see [http://space.mit.edu/HETG](http://space.mit.edu/HETG), for LETG see [http://www.rosat.mpe-garching.mpg.de/axaf](http://www.rosat.mpe-garching.mpg.de/axaf)
Table 1: Resonant X-ray Absorption Lines (* denotes Ly α lines of hydrogenic ions)

| Ion   | E (keV) | Ion  | E (keV) |
|-------|---------|------|---------|
| OVII  | 0.57    | MgXII* | 1.47    |
| OVIII* | 0.65    | SiXIII | 1.87    |
| FeXVII | 0.83    | SiXIV* | 2.01    |
| NeIX  | 0.92    | FeXXV  | 6.70    |
| NeX*  | 1.02    | FeXXVI* | 6.97    |
| MgXI  | 1.35    |       |         |

ionization stage should also be present, but in practice the optical depths for edges are likely to be too small.

The sensitivity of the AXAF spectrometers is such that we will readily detect absorption lines with equivalent widths comparable to our spectral resolution element of ≈ 1 eV (or 10⁻² A) at 1 keV. One might push as much as an order of magnitude lower in selected observations. To produce such a feature requires a column density of the appropriate ion of ≈ 10¹⁶ cm⁻² which in turn implies hydrogen column densities of ≈ 2 × 10²⁰ f⁻¹ [A/A(Fe)⊙]⁻¹, where f is the ionization fraction and A/A(Fe)⊙ is the element abundance relative to the solar value for Fe.

To put this in an astrophysical context, it would suffice to have 3 × 10¹² M⊙ spread over a sphere of radius 0.5 Mpc if it had 0.3 solar abundance; this would correspond to a density 2.5 × 10⁻⁴, or an overdensity of 50 times critical at the present epoch.

Thus AXAF spectrometers will probe any moderately dense regions along the line of sight containing material that is both ionized and somewhat enriched with heavy elements. Ionization could be either collisional or radiative, corresponding to thermal plasma with temperatures above ≈ 3 × 10⁶ K or ionization parameters ξ ≥ 0.1, respectively.

There is good reason to believe that ionized, chemically enriched regions not only exist, but may well represent most of the baryonic content of the universe at redshifts less than 2-3. Standard big bang nucleosynthesis predicts baryon densities of Ω_B ≈ 0.1 – 0.3, and recent estimates of the number and density of Ly α clouds at high redshift are consistent with this value. But Ω_B in stars or cool clouds at lower redshift is less than 0.004 (values quoted are for H₀ = 70 km s⁻¹ Mpc⁻¹). Scaling from groups and clusters of galaxies supports the hypothesis that, at lower redshift, most of the baryons are in the form of hot plasma. It is also plausible that this plasma is at least moderately enriched with heavy elements. Even at high z, the Ly α clouds appear to have metallicities as high as ≈ 0.1 solar.

It is instructive to consider the densest clouds seen in the optical/UV, namely damped Ly α systems (DLA). These have hydrogen column densities approaching 10²¹ cm⁻² s⁻¹ and metallicities 10% of solar. We estimate that the X-ray background, though highly uncertain, is ten times too weak to photoionize a typical DLA sufficiently to give detectable X-ray lines. On the other hand, it may well be that the clouds are also ionized by shocks and/or by a local source of photoionizing radiation, as suggested by the detection of OVI lines. In that case the DLA could be seen in X-rays as well.

Observationally, rather than focus on the few DLA quasars already detected in X-rays, we have chosen to take an approach that simply maximizes the sensitivity to randomly distributed X-ray absorbers. During the first several months of the AXAF mission, we will observe the brightest X-ray quasars with z ≥ 2, 0836+7104 and 2149-304. Lower redshift absorbers will be probed by several observations of more local quasars and BL Lac objects.

Although our program is something of a fishing expedition, it has the considerable potential
of providing an entirely new probe of the IGM and of revealing the bulk of the baryons in the universe.

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