The Cosmic X-ray Background

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1. INTRODUCTION

Every electromagnetic waveband from radio to gamma rays has an associated cosmic background, and X-rays are no exception. The Cosmic X-ray Background (CXB) was first observed in the 60s as diffuse emission detected via a rocket mission intended to study reflected X-rays from the Moon. Instead of detecting the Moon, they instead discovered examples of the two dominant components of X-ray emission in the sky: a bright compact source (the neutron star X-ray binary Scorpius X-1), and a bright nearly isotropic background (the CXB) (Giacconi et al. 1962). With each major X-ray all-sky mission launched, we have learned successively more about this CXB. This paper provides a brief review of its origins and discusses the observed spectrum.

2. ORIGINS

Since discovery, we have learned that observed X-ray background is due to a soft galactic component that is truly diffuse, and a harder extragalactic component that is resolvable into discrete sources by modern high resolution X-ray telescopes.

2.1. *The softest X-rays are dominated by hot local Galactic gas*

At soft energies ($\lesssim$0.25 keV), the background emission is anisotropic, unlike the emission at harder energies. It is thought that the observed X-ray background at this energy is dominated by thermal emission from hot ($\sim 10^6$ K) gas. This gas is thought to originate from within a few hundred parsecs of the Sun. As reviewed in McCammon & Sanders (1990), this explanation is the result of a process of elimination of other known X-ray emission mechanisms. First, to rule out the sum of discrete sources, the low level of intensity fluctuations imply that the sources of the emission must have a spatial density of $>$0.2 sources pc^{-3}, greater than the density of all Milky Way stars. If this emission were due to bremsstrahlung or Inverse Compton (IC) scattering of starlight, the associated high energy electrons would ionize more of the surrounding ISM than is observed. If instead the emission were due to IC scattering of CMB photons, the even more relativistic electrons would produce a large flux of $\sim$100 MeV gamma rays that is not observed. Finally, if the emission were due to synchrotron processes within the weak $\sim \mu$G galactic magnetic fields, these ultra-relativistic electrons would cool within $\sim$5000 years. The engine(s) (e.g. very frequent Galactic supernovae or substantial AGN activity from the Galactic Center) required to accelerate these electrons have not been observed.

2.2. *Harder X-rays are largely due to the sum of emission from AGN*

The background at $\sim$2 keV and above is largely isotropic on scales $>>$0.01 deg (Moretti et al. 2003). Similar to the soft background, various X-ray observatories have attempted to identify the origin of this emission by first looking to see if it's the sum of discrete sources. Between 2-10 keV, these efforts have been largely successful. Deep extragalactic fields with ROSAT at 1 keV have associated $\sim$80% of the total observed flux with individual sources. With its improved spatial resolution of 0.5", Chandra improved this

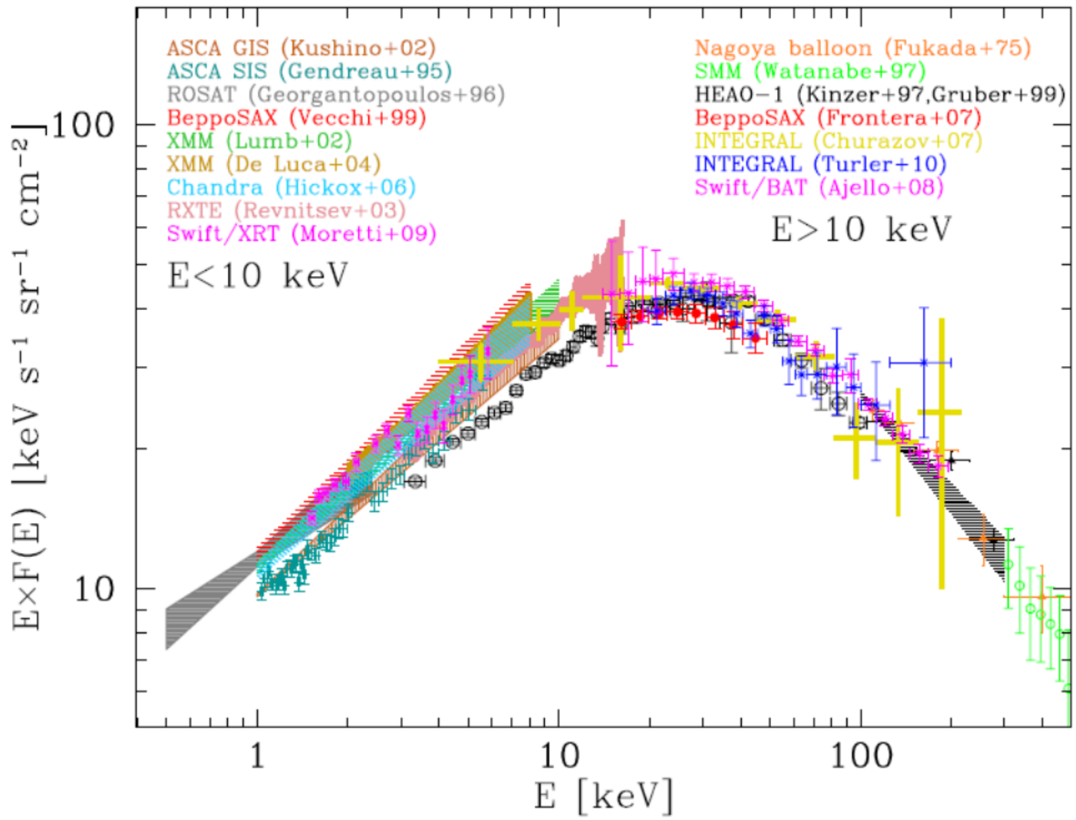

Figure 1. The energy spectrum of the cosmic X-ray background from ∼1 - 500 keV as compiled from a number of space based X-ray observatories. Figure from Revnivtsev (2014).

result to >90% between 0.5-2 keV (Brandt & Hasinger 2005). XMM-Newton extended this result to 2-9 keV, resolving ∼80% of the CXB (Gilli et al. 2007). The majority of these discrete sources have been identified with bright AGN (Setti & Woltjer 1989), while a small component comes from galaxy clusters (Wu & Xue 2001) and starbursting galaxies (Persic & Rephaeli 2003).

Similar studies at harder X-rays have been more challenging. The INTEGRAL and Swift/BAT instruments have resolved only ∼1% of sources at 20-30 keV (Krivonos et al. 2007; Ajello et al. 2012; Vasudevan et al. 2013). The strongest result at hard X-ray wavelengths has come from NuSTAR, which has resolved ∼33-39% of the X-ray background in the 8-24 keV band (Harrison et al. 2016). The population resolved by NuSTAR is consistent with estimates from extrapolating the AGN X-ray luminosity function, suggesting that AGN remain the dominant population up to 24 keV. It's thought that AGN of various populations can explain the X-ray background at higher energies still (e.g. Ueda et al. 2014), but direct observational confirmation awaits the launch of a next generation hard X-ray instrument.

3. THE ENERGY SPECTRUM OF THE CXB

The unresolved CXB spectrum takes the shape of peak at ∼30 keV, with a power law rise and fall on either side. Adopting the traditional X-ray spectrum parameterization of $dN/dE \propto E^{-\Gamma}$, the rise can be approximated with Γ = 1.4 (from 1-10 keV) and the fall can be approximated with $\Gamma = 2.5$ (at energies above 50 keV) (Revnivtsev 2014). This spectrum is illustrated in Figure 1.

Back of the envelope background estimation: Note that $\Gamma < 2$ corresponds to a rise in E $\times$ F(E), because you get one factor of E from multiplying and another from integrating. Likewise, $\Gamma > 2$ corresponds to a drop in E $\times$ F(E). The peak value is E $\times$ F(E) $\approx$ 40 keV s^{-1} sr^{-1} cm^{-2}. Thus, a good rule of thumb is that at the 30 keV peak, you would expect a photon flux of order 1 photon per second per steradian per cm^2. At 1 keV, this rises to $\sim$10 photons s^{-1} sr^{-1} cm^{-2}, and at 100 keV, this falls to $\sim$1/4 photons s^{-1} sr^{-1} cm^{-2}.

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