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DISCOVERY OF EXTREME-ULTRAVIOLET RADIATION FROM THE SEYFERT GALAXY TON S180 (=EUVE J0057−223)[1]

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ABSTRACT

We report the detection of intense EUV radiation from the Seyfert 1 galaxy Ton S180. The source EUVE J0057−223, discovered in the *Extreme-Ultraviolet Explorer* all-sky survey, is only 25″ away from its optical counterpart, well within the position error circle. We present a complete broadband energy distribution of Ton S180 using infrared (*IRAS*), optical, ultraviolet (*IUE*) and X-ray (*ROSAT*) flux measurements, and we find that the measured EUV flux, corrected for neutral hydrogen and helium absorption in the Galaxy, suggests the presence of a strong EUV to soft X-ray flux excess. We briefly discuss the implications for models of active galaxies.

Subject headings: galaxies: individual (Ton S180) — galaxies: nuclei — galaxies: Seyfert — ultraviolet: galaxies — X-rays: galaxies

1. INTRODUCTION

The UV-excess object KUV 00549−2239, from the Second Kiso Catalog of stellar-like sources (Kondo, Noguchi, & Maehara 1984), has been identified as a candidate counterpart to the bright EUV source EUVE J0057−223 (Bowyer et al. 1994). KUV 00549−2239 has not been classified; with its dual membership in the Kiso and *Extreme-Ultraviolet Explorer* (*EUVE*) catalogs, it could belong to any class of hot, EUV, or X-ray emitting objects. However, a close examination of Hamuy & Maza's (1989) and Bowen et al.'s (1994) charts of this field prove that KUV 00549−2239 is identified with Ton S180 (Chavira 1958), a well-studied Seyfert 1 galaxy (Véron-Cetty 1984) at a redshift of $z = 0.0613$ (Véron-Cetty & Véron 1986) or 0.0607 (Winkler 1992).

Adopting the accurate ($\pm 0\farcs5$) Kiso coordinates ($\alpha_{2000} = 0^h57^m19\fs9$, $\delta_{2000} = -22°22'59\farcs2$) we determine that the Seyfert galaxy Ton S180 is only 25″ from the *EUVE* source ($\alpha_{2000} = 0^h57^m20^s$, $\delta_{2000} = -22°22'36''$), well within the *EUVE* position error circle, and is a likely optical counterpart to the *EUVE* source. The field surrounding this object is relatively empty, the source being near the south Galactic pole ($l = 138.9$, $b = -85.07$). Hamuy & Maza (1989) have obtained *UBVRI* photometry of the brightest objects in a $28' \times 28'$ field surrounding Ton S180. Their measurements show no other blue objects near the EUV source; the only other nearby object is quite faint ($V = 15.29$) and according to color indices is probably a K5 star. We conclude that the Seyfert 1 galaxy Ton S180 is the source of EUV radiation detected during the *EUVE* all-sky survey, a conclusion supported by the low interstellar medium (ISM) column density reported toward the south Galactic pole in the Bell Laboratories H I Survey ($n_{\rm H}^{\rm ISM} = 1.3$–$1.8 \times 10^{20}$ cm^{-2}; Stark et al. 1992). Other Seyfert galaxies detected in the *EUVE* and *ROSAT* Wide-Field Camera (WFC) surveys include 1H 0419−577, NGC 4051, Mrk 279, NGC 7213 (Bowyer et al. 1994), and Mrk 478 (Pounds et al. 1993). Marshall, Fruscione, & Carone (1995) conclude that the relatively large number of Seyfert galaxies detected in EUV surveys is in itself a strong indication for intrinsic EUV/soft X-ray excesses in these objects. Elvis et al. (1994) summarize the spectral properties of active galactic nuclei (see also Wilkes & Elvis 1987).

A search in the NED database[5] shows Ton S180 as an *Infrared Astronomical Satellite* (*IRAS*) source with detection at 12, 25, and 60 μm (see also Kirhakos & Steiner 1990). The *ROSAT* source RX J0057.3−2222 is also associated with Ton S180 (from the HEASARC database). We present in § 2 the circumstances of the *EUVE* detection as well as blue spectroscopy of KUV 00549−2239 (=Ton S180) obtained at Michigan-Dartmouth-MIT Observatory (MDM). We also present additional archival data in the X-ray, UV, and infrared, and the corresponding flux measurements. Although these measurements are not necessarily simultaneous or even contemporaneous, we discuss in § 3 broadband spectral properties of Ton S180 and the implications for an EUV/soft X-ray excess in Seyfert galaxies. We summarize our results in § 4.

2. OBSERVATIONS

2.1. *Extreme Ultraviolet Photometry*

The source EUVE J0057−223 was detected as part of the *EUVE* all-sky survey; the region was scanned from 1992 December 22–28 (Table 1). Bowyer et al. (1994) estimated a count rate in the Lexan band (58–174 Å with peak sensitivity at 89 Å) of $C_{100\,\text{Å}} = 0.053 \pm 0.008$ counts s^{-1}. Marshall et al. (1995) report extreme variability (up to a factor of 10) in *EUVE* broadband flux measurements of the Seyfert galaxy Mrk 478 over a short timescale (≤1 day); the *EUVE* survey data of Seyfert galaxies therefore constitute a sampling that may or may not be representative of the average state of activity.

[1] Based in part on observations obtained at the Michigan-Dartmouth-MIT Observatory.

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[5] The NASA/IPAC Extragalactic Database (NED) is operated by JPL, Caltech, under contract with NASA.

TABLE 1

SUMMARY OF *ROSAT*, *EUVE* SURVEY, AND *IUE* OBSERVATIONS

Instruments	Dates	Measurements	Units	t_{exp} (s)
ROSAT PSPC ROR:				
701141	1992 Jun 18	1.85 ± 0.03	counts s^{-1}	2963
701142	1992 Jun 19	3.57 ± 0.04	counts s^{-1}	3109
701139	1992 Jun 28	2.76 ± 0.05	counts s^{-1}	1464
701140	1992 Jun 28	3.24 ± 0.05	counts s^{-1}	1524
701139	1992 Dec 18	1.92 ± 0.03	counts s^{-1}	2854
701140	1993 Jan 10	2.27 ± 0.04	counts s^{-1}	1762
EUVE	1992 Dec 22–28	0.053 ± 0.08	counts s^{-1}	918
IUE:				
lwp23323	1992 Jun 19	...	...	1800
swp44957	1992 Jun 19	5.2×10^{-14} [a]	ergs cm^{-2} s^{-1} Å^{-1}	6600
swp45039	1992 Jun 30	4.8×10^{-14}	ergs cm^{-2} s^{-1} Å^{-1}	6600
swp45040	1992 Jun 30	4.0×10^{-14}	ergs cm^{-2} s^{-1} Å^{-1}	2700
swp46527	1992 Dec 18	4.6×10^{-14}	ergs cm^{-2} s^{-1} Å^{-1}	4800
swp46698	1993 Jan 10	4.5×10^{-14}	ergs cm^{-2} s^{-1} Å^{-1}	9240
swp47952	1993 Jun 25	4.5×10^{-14}	ergs cm^{-2} s^{-1} Å^{-1}	8100

[a] Ultraviolet flux at 1510 Å.

2.2. *Blue Spectroscopy*

We observed KUV 00549−2239 (=Ton S180) at the McGraw-Hill 1.3 m telescope of MDM observatory on 1994 October 21 (UT) as part of our program of identification of EUV sources detected during the *EUVE* survey. We used the Mark III spectrograph and a thinned Tektronix 1024 × 1024 CCD chip; our spectra covered 3650−6030 Å with 4.5 Å resolution. We flux- and wavelength-calibrated the spectra using standard IRAF procedures. Because we have adopted a narrow slit aperture (1."5) some light was lost, and we did not attempt to determine an absolute flux scale; we therefore renormalized our spectrum (Fig. 1) to $m_V = 14.4$ (Hamuy & Maza 1987). We completed the optical data set using an average of Hamuy & Maza's *UBVRI* photometric measurements circa 1985–1986. Note that photometric variability studies of Ton S180 (Hamuy & Maza 1987; Winkler et al. 1992) show an approximately 10% variation over a timescale of a few months.

2.3. *ROSAT PSPC Flux Measurements*

White, Giommi, & Angelini (1995) report a series of *ROSAT* pointing observations (Table 1) of the Seyfert galaxy Ton S180 (identified as RX J0057.3−2222 or WGA J0057−2222). We used their count rate measurements and noted that they indicate ±30% flux variations over a short timescale (<1 day). Because the *EUVE* survey observations were carried out over several days and occurred between two separate *ROSAT* observations, we adopt an average of *ROSAT* count rates (2.6 ± 0.7 counts s^{-1}) for comparison with the *EUVE* flux measurements.

2.4. *Ultraviolet and Infrared Measurements*

We obtained and reduced a series of *International Ultraviolet Explorer* (*IUE*) spectra (Table 1) of Ton S180 (identified as RX J0057.3−2222) from the archive at the Regional Data Analysis Facility (RDAF) at GSFC. The spectra exhibit strong emission in Lyα, N V λ1240, C IV λ1550, Mg II λ2800, and a number of weaker lines (Fig. 1). We note the presence of a narrow absorption trough near 2200 Å; it seems unlikely that this feature can be attributed to the broad depression associated with grain absorption in the Galaxy. Indeed, the low column density reported in this line of sight (Stark et al. 1992) converts to a reddening index of $E_{B-V} = 0.022$–0.033 following a well-established relationship. A reasonable estimate of the uncertainty in this relation allows a reddening index as large as $E_{B-V} = 0.1$, still too small to be directly detected. Therefore, we adopted $E_{B-V} = 0.03$ and dereddened both UV spectrophotometry and *UBVRI* flux measurements using the Seaton (1979) extinction law.

Ton S180 was also observed with *IRAS*; the NED reports flux measurements at 12 μm (0.12 ± 0.03 Jy), 25 μm (0.26 ± 0.06 Jy), and 60 μm (0.28 ± 0.04 Jy). An upper limit at

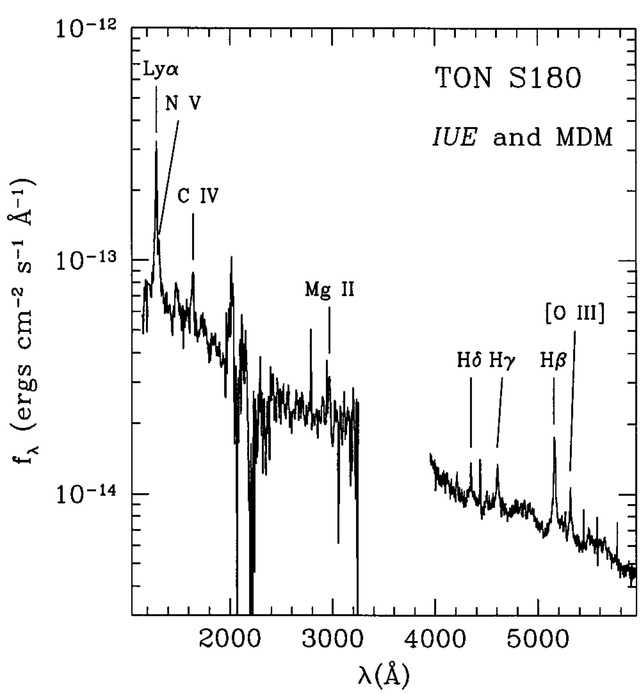

FIG. 1.—MDM optical spectroscopy of Ton S180 showing Hβ, Hγ, Hδ, and [O III] λ5007 in emission and *IUE* ultraviolet spectrophotometry showing strong Lyα and C IV λ1550 emission. The wavelength scale is in the observer frame.

TABLE 2

BROADBAND FLUX MEASUREMENTS

Instruments	Measurements	Units	ν^a (Hz)	$\nu f_\nu{}^b$ (ergs cm^{-2} s^{-1})
IRAS 100 μm	<0.43	Jy	3.0×10^{12}	$<1.3\times10^{-11}$
IRAS 60 μm	0.28 ± 0.04	Jy	5.0×10^{12}	1.4×10^{-11}
IRAS 25 μm	0.26 ± 0.06	Jy	1.2×10^{13}	3.3×10^{-11}
IRAS 12 μm	0.12 ± 0.03	Jy	2.5×10^{13}	3.2×10^{-11}
I	13.92	mag	3.3×10^{14}	2.1×10^{-11}
R	14.16	mag	4.3×10^{14}	2.8×10^{-11}
V	14.39	mag	5.5×10^{14}	3.8×10^{-11}
B	14.58	mag	6.8×10^{14}	4.8×10^{-11}
U	13.62	mag	8.2×10^{14}	6.4×10^{-11}
IUE SWP	$(4.6\pm0.4)\times10^{-14}$	ergs cm^{-2} s^{-1} Å^{-1}	2.0×10^{15}	1.0×10^{-10}
EUVE Lexan	0.053 ± 0.008	counts s^{-1}	3.4×10^{16}	3.9×10^{-11}
ROSAT PSPC	2.6 ± 0.7	counts s^{-1}	2.4×10^{17}	8.0×10^{-12}

[a] Adopted representative frequencies.

[b] Dereddened flux ($E_{B-V} = 0.03$) and EUV/X-ray fluxes corrected for interstellar hydrogen and helium attenuation (assuming $\alpha = 1.4$ and $n_{\rm H} = 1.6\times10^{20}$ cm^{-2}).

100 μm was also obtained (<0.43 Jy). We summarize the dereddened infrared, optical, and UV flux measurements in Table 2. The ultraviolet spectral range is represented with the dereddened flux at $\lambda = 1510$ Å.

3. EXTREME-ULTRAVIOLET EXCESS IN SEYFERT GALAXIES?

3.1. *Extreme-Ultraviolet and X-Ray Flux Measurements in the Seyfert 1 Ton S180*

Two complementary measurements cover a range of energy from 0.1 to 2.5 keV; both measurements are dependent upon the intrinsic spectral shape of the source as well as the intervening Galactic absorption. The *EUVE* flux is severely attenuated by Galactic material. Using Stark et al.'s (1992) column measurements of 1.3–1.8 × 10^{20} in the vicinity of Ton S180, the helium ionization fractions from Vennes et al. (1993; He I/H I = 0.07 and He II/H I = 0.03), and Rumph, Bowyer, & Vennes's (1994) photoionization cross sections, we find τ (89 Å) = 3.1–4.3. Uncertainties in the column measurements dominate the error analysis. At higher energy, the *ROSAT* data, with an optical depth of only τ (10 Å) = 0.017–0.024 (using Morrison & McCammon's 1983 cross sections), are less sensitive to Galactic attenuation and are mostly a function of the spectral index.

Early analyses of X-ray observations of Seyfert 1 galaxies did not always distinguish between hard (2–10 keV) and soft X-ray (0.2–2 keV) energy distributions. *EXOSAT* low-energy (LE) and medium-energy (ME) observations of Seyfert 1 galaxies indicate that the X-ray spectral index (in a relation of the form $f_\nu \propto \nu^{-\alpha}$) is close to $\alpha = 0.5$–0.9. For example, Singh, Rao, & Vahia (1991) obtain an index of ≈0.6–0.9 for IC 4329A and find no evidence for a LE excess; Piro et al. (1991) obtain an index of ≈0.55–0.85 in the range 0.05–10 keV for Mrk 464. However, Turner & Pounds (1988) have established the existence of a two-component X-ray spectrum in Mkn 335 with a strong soft X-ray excess (in the LE band) above an extension of the hard X-ray power law (in the ME band) typical of Seyfert 1 galaxies. Analysis of *ROSAT* PSPC spectral distribution of a sample of Seyfert 1 galaxies also reveals a large soft X-ray (0.1–1.0 keV) excess with a spectral index $\alpha \approx 1.4$ (Turner, George, & Mushotzky 1994; Walter & Fink 1993). Following Turner et al. (1994), we adopt a probable range of 1.1–2.1 for the intrinsic EUV to X-ray spectral index of Ton S180. We use representative wavelengths, $\lambda_0(E_0)$, of 89 Å (0.14 keV) and 12 Å (1 keV) for *EUVE* and *ROSAT*, respectively. The corresponding flux measurements, f_0, can therefore be extracted from equation (1),

$$C = \frac{f_0 \nu_0^\alpha}{h} \int \nu^{-(\alpha-1)} A_\nu e^{-\tau\nu}\, d\nu, \qquad (1)$$

in which h is Planck's constant, α the spectral index, C the measured count rate, A_ν the instrument effective area as a function of frequency, and τ_ν the optical depth in the ISM. We report the corresponding flux measurements in Table 2 for a representative index.

3.2. *From the Infrared to the Soft X-Ray*

We present in Figure 2 the complete energy distribution of the Seyfert galaxy Ton S180. The most prominent feature is a UV bump that becomes apparent shortward of 1 μm. A UV bump is often mentioned as a spectral signature of an accretion disk. The *ROSAT* data are represented with a characteristic bow-tie diagram assuming a range of power-law indices from 1.1 to 2.1 (*solid line*); the extent of the measured variability is shown with downward- and upward-shifted bow-tie diagrams (*dotted lines*). The error bars on the EUV data reflect current uncertainties on neutral hydrogen column density in the line of sight. We show that the X-ray and EUV data are joined with a power-law index of $\alpha \approx 2.1$, which largely exceeds the hard X-ray slope observed in Seyfert 1 galaxies and extends toward lower energy the *ROSAT* spectral distributions of Seyfert 1 galaxies with large *soft* X-ray (0.1–1.0 keV) excesses. An extension of the soft X-ray excess to the EUV range has important implications for internal absorption (see Fiore et al. 1994), and our *EUVE* observation of Ton S180 may set an upper limit to an intrinsic absorption column comparable or inferior to the foreground Galactic column (i.e., $\leq 10^{20}$ cm^{-2}). From Figure 2 we measure a ratio $\nu F_{1374\,Å}/\nu F_{2\,\rm keV} \approx 100$ which, in combination with an X-ray energy index of ≈2.1, indicates that Ton S180 is an average Seyfert galaxy according to Walter & Fink's (1993) correlation between the UV bump strength and the X-ray spectral slope. Because of the large amplitude of the EUV variability, it is tempting to speculate that the *EUVE* survey data were sampled during a particularly high state of activity, translating into a large EUV flux excess.

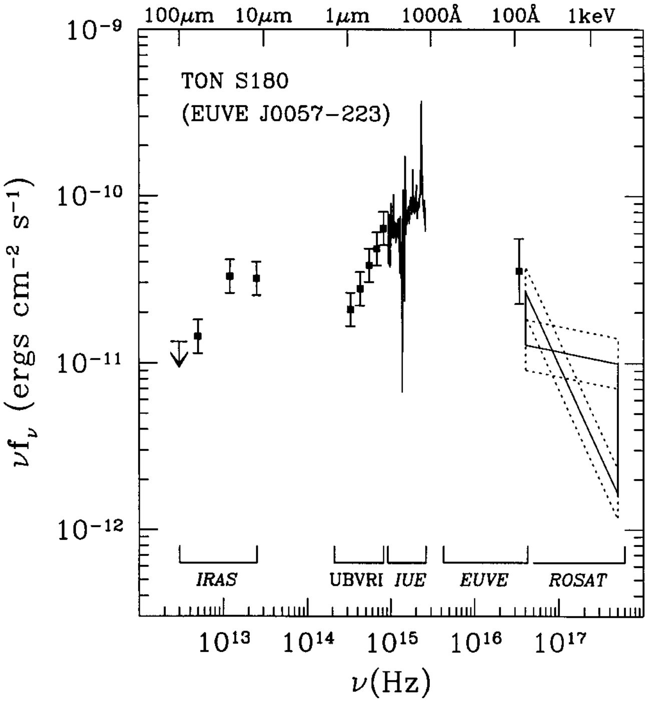

FIG. 2.—Energy distribution of Ton S180 from the infrared to the X-ray in units of νf_ν (ergs cm^{-2} s^{-1}) vs. ν (Hz) in the observer frame. Translate the abscissa by −0.0256 to transform into the rest frame. See Table 2 and § 3.2.

4. SUMMARY

We report the identification of the *EUVE* source EUVE J0057−223 with the Seyfert galaxy Ton S180. We demonstrate a likely EUV excess in this Seyfert galaxy. Simultaneous X-ray, UV, EUV, and infrared observations will be necessary to confirm this excess. A time-dependent study of broadband flux measurements may permit the establishment of a physical link between the EUV excess found in this Seyfert galaxy and other spectral properties such as the UV bump. *EUVE* spectroscopy of the Seyfert 1 galaxy NGC 5548 shows the possible presence of a weak line emission (Kaastra et al. 1994) that may offer important clues to the nature of the EUV excess and its variability; EUV spectroscopic observations of Ton S180 may reveal similar properties. An accurate H I column density measurement in the line of sight of Ton S180 will be required to improve the EUV flux measurement.

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