First Results from the MUSCLES Treasury Survey of UV and X-ray Emission from K and M Host Stars

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Abstract

We present complete spectral energy distributions (SEDs) for 11 exoplanet hosting stars (4 K and 7 M dwarfs). The SEDs consist of contemporaneous X-ray observations by Chandra and XMM-Newton, UV spectra with the COS and STIS instruments on HST, and optical spectra. We reconstruct the Lyman-α fluxes (important for photochemistry of exoplanet atmospheres) and infer 100-912 Å EUV fluxes (important for computing planetary mass-loss rates). These high-resolution 5 Å-5.5μm spectra, which are available on the STScI MAST website, are critical for assessing atmospheric chemistry and habitibility.

1 Motivation and Observing Program

Although host star radiation is essential for understanding the chemical composition and evolution of exoplanet atmospheres and thus habitability, there are few available ultraviolet spectra of the most common host stars, M dwarfs, and no complete spectral energy distributions (SEDs) obtained at the same time for these variable stars. To satisfy the need for the shapes and absolute fluxes at all wavelengths, we have obtained contemporaneous X-ray, UV and optical data for 11 nearby host stars with the MUSCLES (*Measurements of the UV Spectral Characteristics of Low-mass Exoplanetary Systems*) Treasury Survey. Table 1 lists the properties of the target stars and their exoplanets. The UV and blue spectral coverage of the medium- and low-resolution COS and STIS grating observations during 125 orbits of HST time are listed in Table 2.

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Table 1: MUSCLES Treasury Survey – Target List

Star	Distance (pc)	Type	T_{eff} (K)	P_{rot} (days)	$\langle r_{HZ} \rangle^a$ (AU)	Exoplanet Mass $M \sin i$ ($M_\oplus$)	Semi-major Axis (AU)	Ref.
GJ 1214	14.6	M4.5	2935	53	0.096	**6.4**	0.0143	1,2,3
GJ 876	4.7	M5	3062	96.7	0.178	615, 194, **5.7**, 12.4	0.208, 0.130, 0.021, 0.334	3,4,5
GJ 581	6.3	M5	3295	94.2	0.146	15.9, **5.4**, **6.0**, **1.9**	0.041, 0.073, **0.218**, 0.029	3,4,6
GJ 436	10.3	M3.5	3281	48	0.211	23	0.0287	3,4,7
GJ 176	9.4	M2.5	3416	38.9	0.262	**8.3**	0.066	3,4,8
GJ 667C	6.9	M1.5	3327	105	0.172	**5.7**, **4.4**	0.049,**0.123**	3,1,9
GJ 832	4.9	M1.5	3816	40^c	0.235	203, **5.4**	3.6, **0.16**	3,4
HD 85512	11.2	K6	4305	47.1	0.524	**3.5**	0.26	3,10,11
HD 40307	12.9	K2.5	4783	48	0.674	**4.1**, **6.7**, 9.5, **3.5**, **5.1**, **7.0**	0.047, 0.080, 0.132, 0.189, 0.247, 0.600	3,10,12
ϵ Eri	3.2	K2	5162	11.7	0.726	~400	3.4	3,10,13
HD 97658	21.1	K1	5156	38.5	0.703	**6.4**	0.080	3,14,15

^{a}The habitable zone distance is defined as the average of the "runaway greenhouse" and "maximum greenhouse" limits (Kopparapu et al. 2014).

References: 1. Neves et al. (2014), 2. Berta et al. (2011), 3. Simbad parallax distance, 4. Gaidos et al. (2014), 5. Rivera et al. (2010), 6. Robertson et al. (2014), 7. Demory et al. (2007), 8. Kiraga & Stepien (2007),9. Anglada-Escudé et al. (2013),10. Tsantaki et al. (2013),11. Pepe et al. (2011),12. Mayor et al. (2009), 13. Donahue et al. (1996),14. Valenti & Fischer (2005),15. Henry et al. (2011)

^{c}GJ 832 has no published rotation period, we assume a relatively short period due to the persistence of UV flare activity in this star.

FIGURE 1:

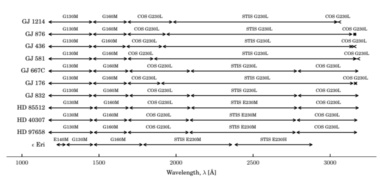

FIGURE 2:

2 Spectral Energy Distributions (SEDs)

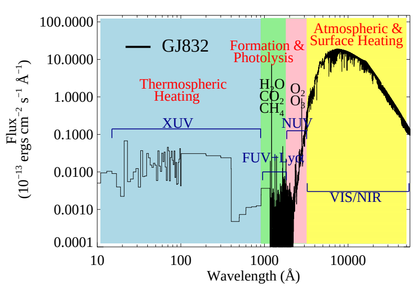

FIGURE 3: The SED of GJ832 (M1.5 V) showing the stitching together of the different data sets and the effect of each spectral region on the atmosphere of an Earth-like planet. The flux in the 100–912 Å region is inferred from the reconstructed Lyman-α flux.

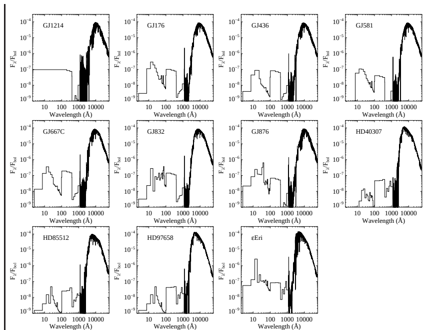

FIGURE 4: The SEDs of the 11 target stars. All of the target stars and likely most or all M dwarf host stars emit X-ray and UV radiation. The most active stars show X-ray and EUV fluxes per Å that are approximently 10^{-7} of the bolometric flux.

3 Data Products and First Results

All of the primary and ancillary data products are available at https://archive/stsci/edu/prepds/muscles/. The first 3 publications are now submitted to ApJ.: (1) France et al. "The MUSCLES Treasury Survey I: Motivation and Overview", (2) Youngblood et al. "The MUSCLES Treasury Survey II: Intrinsic Lyman Alpha and Extreme Ultraviolet Spectra of K and M Dwarfs with Exoplanets", and (3) Loyd et al. "The MUSCLES Treasury Survey III: X-ray to infrared spectra of 11 M and K stars hosting planets".

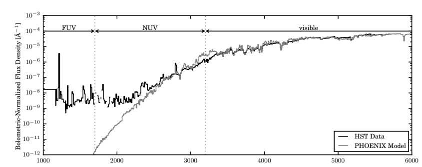

FIGURE 5: The observed spectrum of GJ832 is orders of magnitude brighter than PHOENIX photospheric model in the NUV where abiotic photolysis of O_2 and O_3 is important and in the FUV where the creation of oxygen from the photolysis of H_2O, CH_4, and CO_2 are important.

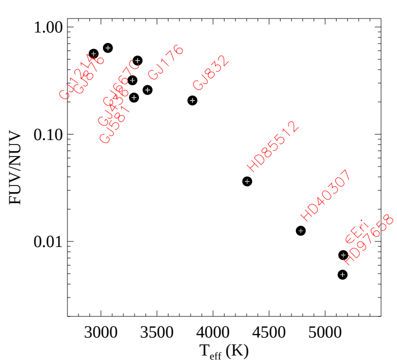

FIGURE 6: Ratios of the FUV (912–1700 Å) to NUV (1700–3000 Å) flux for M dwarfs (upper left) and K dwarfs (lower right) that control the abiotic oxygen budget in the upper atmospheres of exoplanets. The solar FUV/NUV ratio is 0.0004.

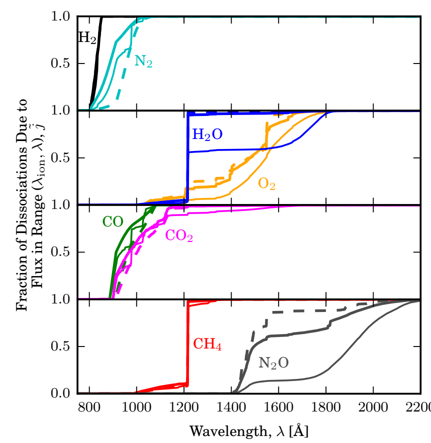

FIGURE 7: Cumulative photodissociation spectra of different molecules for 3 stars: GJ 581, the M star with the lowest FUV flux (dashed lines), ϵ Eri, the K star with the highest FUV flux (solid grey lines), and the Sun (solid black lines). The curves show the increasing fraction of photodissociation with increasing wavelength assuming no attenuation of the stellar flux. Note the importance of Lyman-α for the dissociation of H_2O and CH_4.

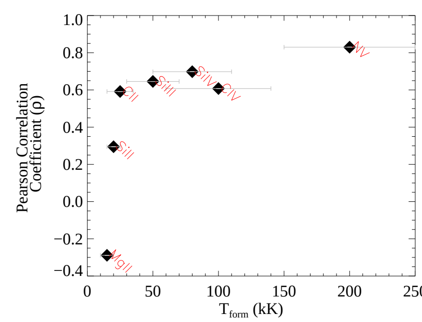

FIGURE 8: Tentative evidence that star-planet interaction (SPI) deposits energy into the transition regions of K and M host stars. The figure shows the correlation coefficients for L(emission line)/L(bol) vs the ratio of planetary mass to semi-major axis for emission lines formed at different temperatures from the chromosphere (MgII) to the transition region (SiIV, CIV, and NV).

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