Quantifying the relation between UV and X-ray flux in nearby dM stars

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Context

M dwarf (dM) stars are the most numerous (70% - 90%) in the Galaxy. They are cooler (2000<Teff<4000 K) and less massive than the Sun (0.1 - 0.3 $M_\odot$). Their ultraviolet (UV) emission is almost entirely due to magnetic activity in the chromosphere and transition region, while X-ray emission probes activity in the corona. Because of their low bolometric luminosities (~0.02% - 6% $L_\odot$), the habitable zones of dM stars are located within ~0.05 - 0.4 AU of the host star. Both types of radiation are crucial for the evolution of the atmospheres of the planets but the UV properties of late-type stars and their relative importance is poorly known.

Sample and data

We extracted all dM stars within 7 pc from the Sun, listed in the Nearby X-ray and XUV-emitting Stars database (*NEXXUS*, *Schmitt & Liefke, 2004, A&A, 417, 651*) . *NEXXUS* provides a compilation of X-ray luminosities from various satellites (ROSAT, Einstein, XMM-Newton). Cross-matching the 82 dM stars in this sample with the *GALEX* GR6 data release, available at MAST (http://galex.stsci.edu/casjobs, Morrissey et al., 2007, ApJ, 173, S682), we detected all but one dM stars covered by the GALEX survey. Among this 39 dM stars, after removing 2 stars (one with off-axis > 0.50° and the other one with ghosts), our sample contains 30 dM stars, 7 being unresolved binaries. Six of these, were detected only in NUV. The mean exposure time is 800/900s in FUV/NUV respectively, ranging from ~100s to ~15 ks.
The subsample of stars detected in FUV and NUV can be considered representative of the total sample of dM stars having X-ray emission, as shown in Fig. 1.

The Galaxy Evolution Explorer (GALEX)

The first comprehensive map of the sky in the UV from GALEX makes possible to measure fluxes of many late-type stars. It performs a wide-field (1.2° diameter) imaging in two ultraviolet bands, FUV (λ_{eff}=1539 Å, $\Delta\lambda$= 1344 - 1786 Å) and NUV (λ_{eff}=2316 Å, $\Delta\lambda$= 1771 - 2831 Å), with a spatial resolution of 4.2/5.3" (Martin et al. 2005, ApJ, 619, L1, Morrissey et al. 2007, ApJS, 173, 682). Imaging surveys are carried out with different depth and coverage (e.g. Bianchi, 2009, ApSS, 320, 11). Typical exposure times and limiting fluxes are summarized in the following table:

Survey	Typical exp. Time [s]	Limiting flux FUV/NUV [erg/s/cm²/Å]
All Sky Survey	100	5.2/1.1 x 10^{-16}
Medium Imaging Survey	1500	4.3/1.8 x 10^{-17}
Deep Imaging Survey	30000	5.7/3.8 X 10^{-18}

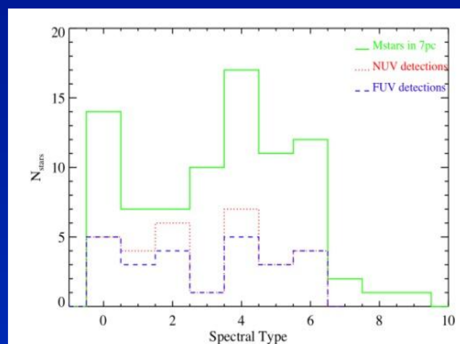

Fig. 1 Spectral type distribution of the *NEXXUS* dM star sample within 7 pc and the subsample of dM stars detected with GALEX in FUV and NUV bands.

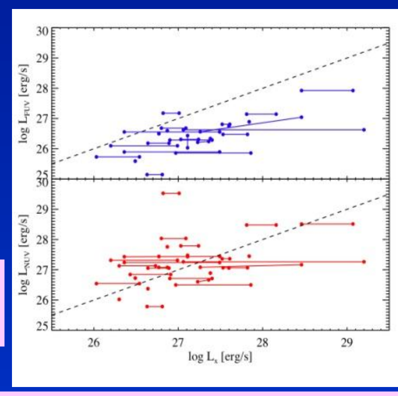

Fig. 2 NUV and X-ray luminosities approximately span the same range of luminosity while FUV luminosities are lower. Points connected by line refer to the same star having two measures of luminosity.

Comparison of the observed SEDs with atmosphere models

In order to estimate the UV excess, if any, we compared the Spectral Energy Distribution (SED) with NEXTGEN (Hauschildt et al., 1999, ApJ, 512, 377) stellar atmosphere grid models. We used aperture photometry provided by GALEX GR6 source catalog using 12.8" radius. In addition, where available, U, B, V, R, I, Sloan Digital Sky Survey (SDSS)-u, -g, -r, -i, -z, J, H, Ks magnitudes were also used (see Fig. 3). The best-fit model, obtained by χ^2 fitting all available bands but GALEX with grid models, allows us to derive the stellar parameters (effective temperature, gravity). This task was performed using the VOSA tool (Virtual Observatory SED Analyzer, http://laeff.inta.es/svo/theory/vosa, Bayo et al. 2008, A&A, 492, 277).

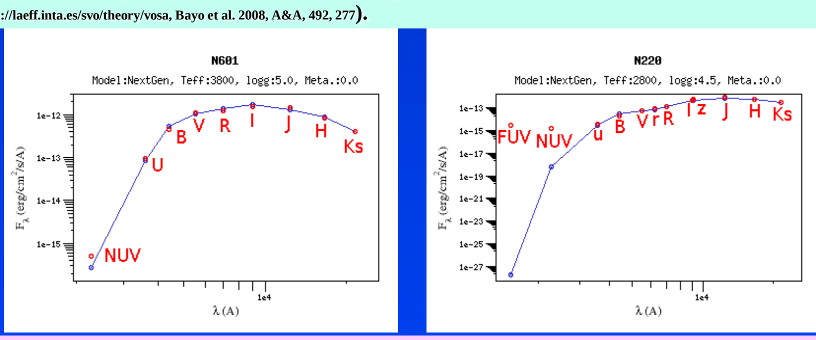

Fig. 3 FUV to near -infrared SEDs from GALEX, SDSS, U, B, V, R, I, 2MASS (red dots) with the best-fit models (blue lines) obtained excluding GALEX bands for the dM1, GJ 191 (N601) and dM6, UV Ceti (N220). Most of the dM stars in our sample show a very pronounced FUV and NUV excess such as UV Ceti while GJ 191 has a NUV emission roughly consistent with the photospheric one and it is undetected in FUV.

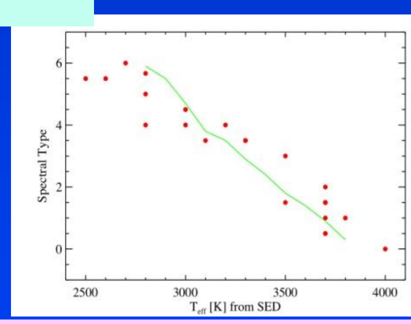

Fig. 4 Spectral type from the literature versus effective temperature (red points), as obtained from best-fit SED models . Our points are consistent with the relation (green line) derived from the comparison of dM0 to dM9 low-resolution spectra with PHOENIX stellar atmosphere models as found by Reylé et al. 2011, (arXiv:1102.1263).

Activity indices

Similarly to the widely used definition of R_{HK} we computed the R_{UV} activity index as:

$$R_{UV} = (UVflux^{Obs} - UVflux^{mod})/flux^{bol}$$

where $UVflux^{Obs}$ is the observed FUV or NUV flux, $UVflux^{mod}$ is the photospheric flux inferred from the best-fit SED models integrated with the bandwidth, and $flux^{bol}$ is the bolometric flux obtained from SED fits;

the X-ray activity index as:

$$R_X = \text{X-ray flux}/flux^{bol}$$

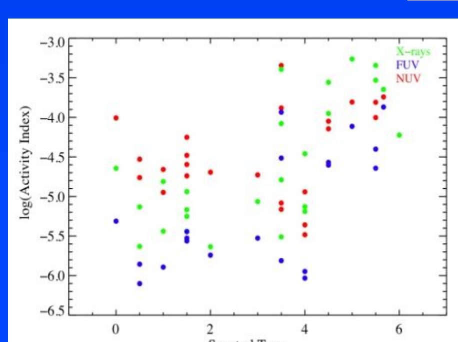

Fig. 5 UV and X-ray activity indices vs. spectral type. FUV, NUV and X-ray indices show a very similar trend. The bimodality between M0…M3 and M4…M6 could be due to later dM stars being saturated.

Preliminary results

With the aim of investigating the relation between X-ray and UV emission, we have analyzed a volume-limited sample of dM stars in the solar neighborhood.

• UV luminosities and R_{UV} activity indices appear related to X-ray luminosity and R_X respectively, indicating a common magnetic origin.

• The trend of the UV and X-ray activity indices as a function of the spectral type is very similar and shows a bimodality between early- and mid-M spectral types, possibly because activity is saturated for spectral type M4 and later.

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