The ultraviolet extinction properties of the Tarantula Nebula

Guido De Marchi (ESTEC), Nino Panagia (STScI)

Recently, we investigated the extinction law in the massive star-forming Tarantula Nebula (30 Dor), located in the nearest galaxy to us, the Large Magellanic Cloud (LMC). The Tarantula Nebula is the nearest extragalactic starburst region and its low metal content makes it an ideal laboratory to investigate how stars formed in the early Universe. In our study at optical and near infrared wavelengths, with the Hubble Space Telescope, we used the ubiquitous bright Red Clump (RC) giants as standard candles and were able to derive a solid, reliable, and fully empirical extinction law based on thousands of stars in the field (see **Figure 1**). We discovered a ratio of total to selective extinction $R_V=A_V/E(B-V)$ of about 4.5 (see **Figure 2**), which indicates that in the Tarantula Nebula there is a larger proportion of large grains than in the diffuse interstellar medium of our own Milky Way. The question is where are these extra large grains coming from…

Possible origins include coalescence of small grains, grain growth, or selective destruction of small grains. Alternatively, there could be fresh injection of large grains, e.g. by supernova explosions, as recently revealed by Herschel and Alma observations. The first three mechanisms would severely deplete the fraction of small grains, but the fourth would leave the amount of small grains unchanged. The presence or absence of small grains is imprinted in the shape of the extinction law in the ultraviolet. From a study of the properties of three Wolf-Rayet stars in 30 Dor (R139, R 140, R145), observed 40 years ago with the International Ultraviolet Explorer (see **Figure 3**), we show that the small grains are still there (see **Figure 4**). Thus, the excess of large grains in the Tarantula Nebula does not come at the expense of small grains, which are still present. We can safely conclude that fresh injection of large grains by supernova explosions is the dominant mechanism.

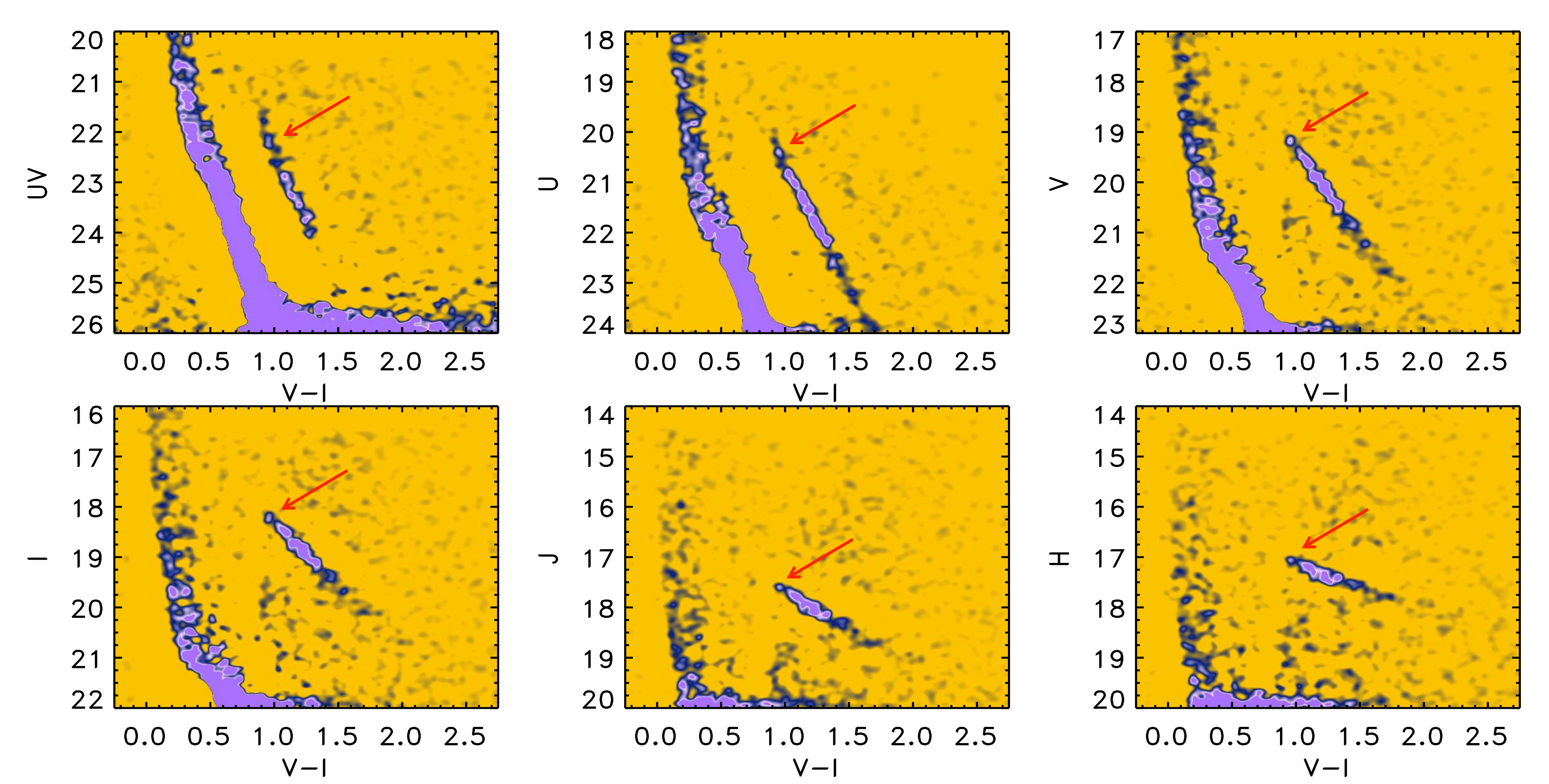

Figure 1 – The colour–magnitude diagrams (CMD) allow us to derive the absolute extinction in all bands towards thousands of red giants that belong to the RC. The arrows indicate the position of the un-reddened RC. Due to the high and variable levels of extinction, RC stars are spread across the CMD defining tight strips. **The slope of such strips in all bands provide a direct measure of the extinction law**. Application of the unsharp-masking kernel to the CMDs reduces the contrast of the low-frequency component, resulting in a vastly improved definition of the sharp, elongated RC.

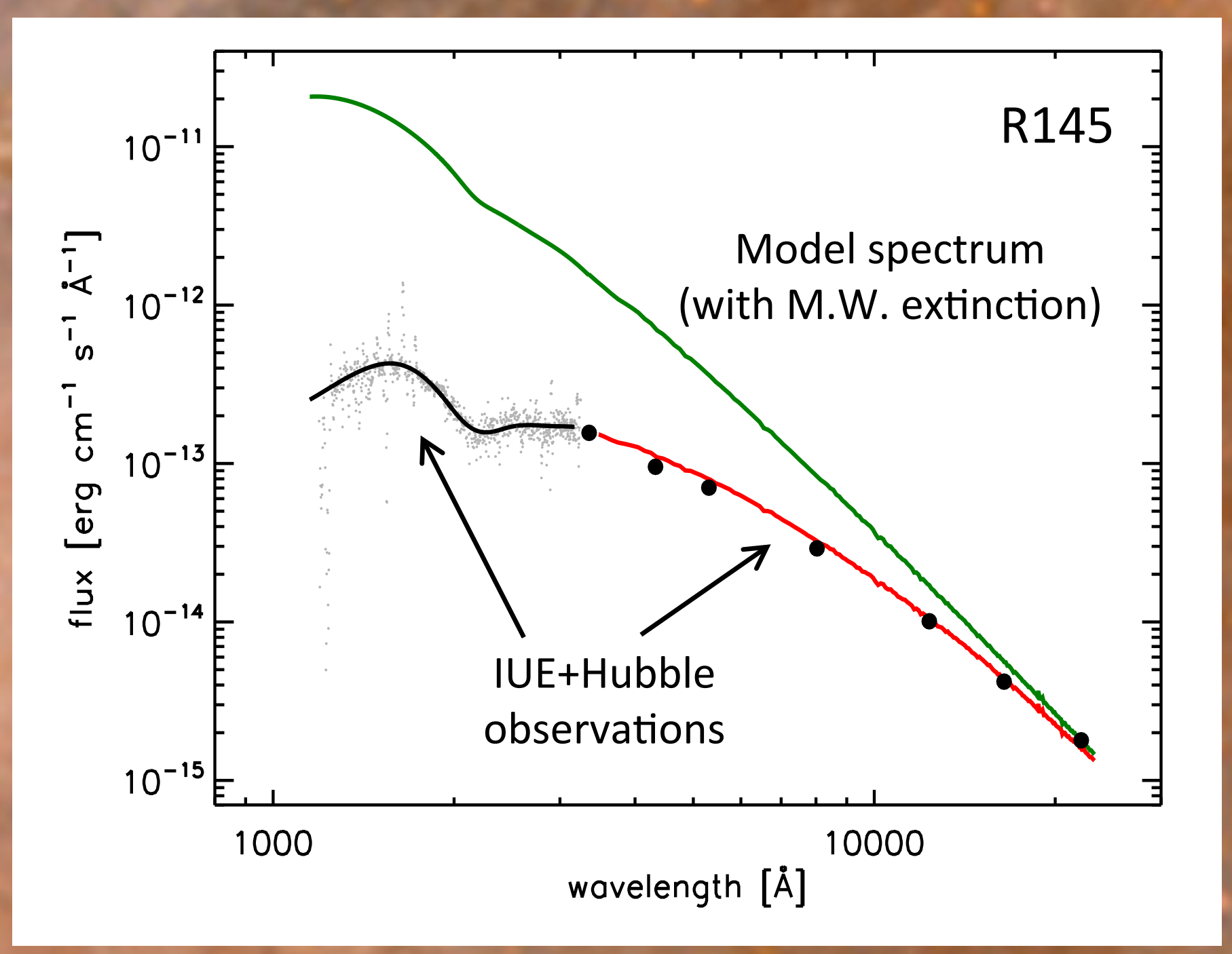

Figure 3 – Following the method presented by Fitzpatrick & Massa (2005), we compared the observed spectra of three young massive Wolf-Rayet stars located in the core of the Tarantula nebula (R139, R140, R145) with theoretical models for the specific physical parameters of these stars, including metallicity. In this figure R145 is shown. The theoretical model (green curve) is already reddened for the Milky Way extinction along the line of sight. At optical and infrared wavelengths we already know the Tarantula extinction law and the absolute extinction, i.e. E(B-V), so we obtain an excellent fit to the optical and infrared observations (dots and red curve). This gives us a solid reference to anchor the ultraviolet spectra (grey dots). The ratio of the observed IUE continuum (black curve) and the model (green curve) gives us the ultraviolet extinction law intrinsic to the Tarantula Nebula. For comparison, we have applied the same method also to two Wolf-Rayet stars located outside the Tarantula nebula, R53 and R129, observed with the IUE in the same way.

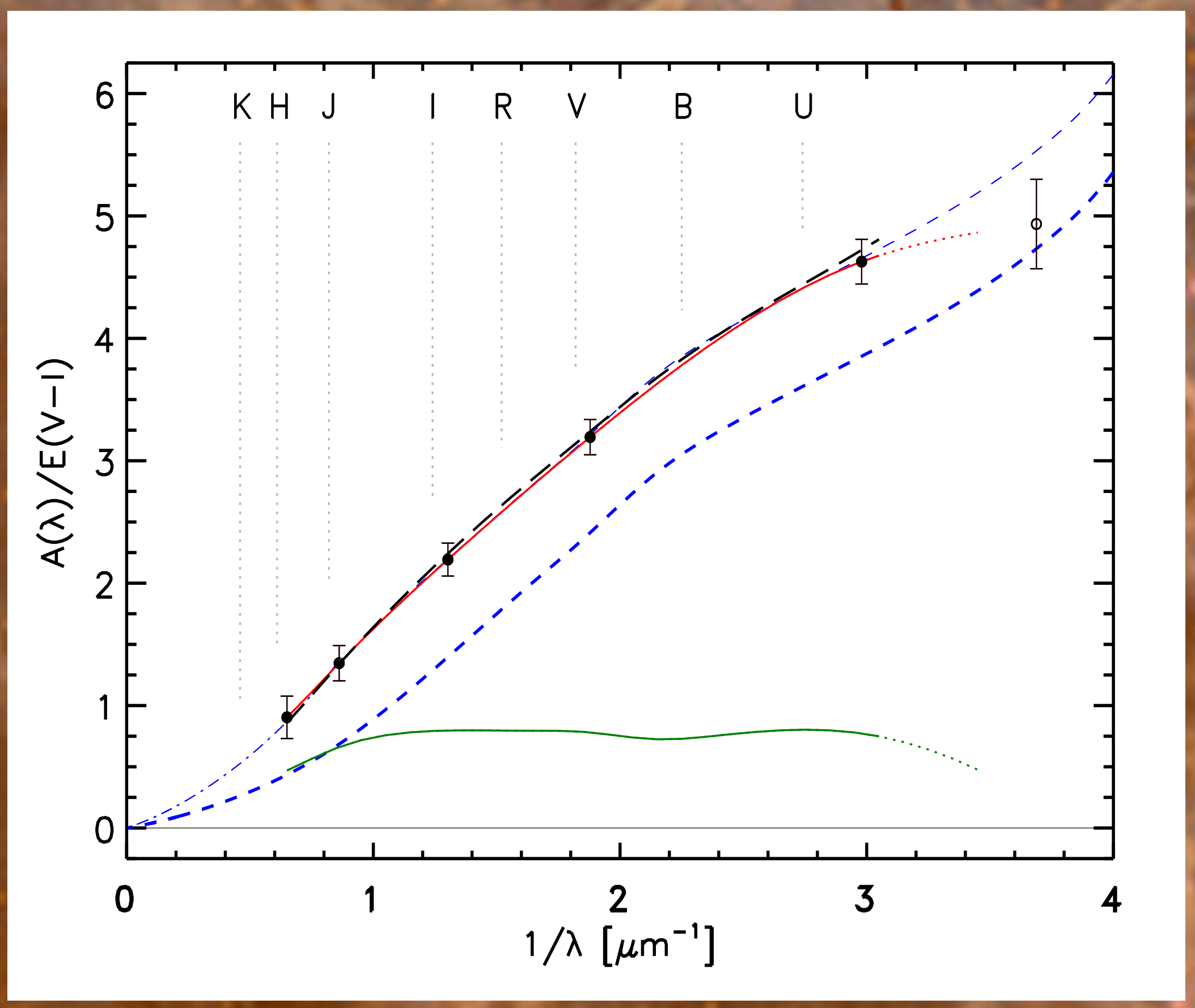

Figure 2 – The extinction law that we measure in the Tarantula (dots and red line; De Marchi et al. 2016) is very different from that of the diffuse Galactic ISM, where R_V=3.1 (thick blue dashed line). In the Tarantula we find R_V=4.5 ± 0.2, in excellent agreement with the measurements inside R136 at its centre (R_V=4.4 ± 0.4, black line; De Marchi & Panagia 2014) and in a field 6ʹ west of it (R_V=5.4 ± 0.3, not shown; De Marchi, Panagia & Girardi 2014).

At optical wavelengths the extinction law is practically parallel to the Galactic law, being shifted to higher values of R by an amount of 0.8 (thin blue dashed line). The difference between the extinction law in the Tarantula and in the Galaxy (green line) is remarkably flat in the optical. This indicates that **the extinction curve in the Tarantula is due to dust of the same type as in the Galaxy, but with an extra "grey" component**, i.e. one that does not depend on wavelength. At wavelengths longer than of ~1 μm the contribution of this grey component tapers off as $\lambda^{-1.5}$, like in the Milky Way (dot-dashed line), further suggesting that the nature of the grains is otherwise similar to those in our Galaxy, **but with a ~2 times higher fraction of large grains.**

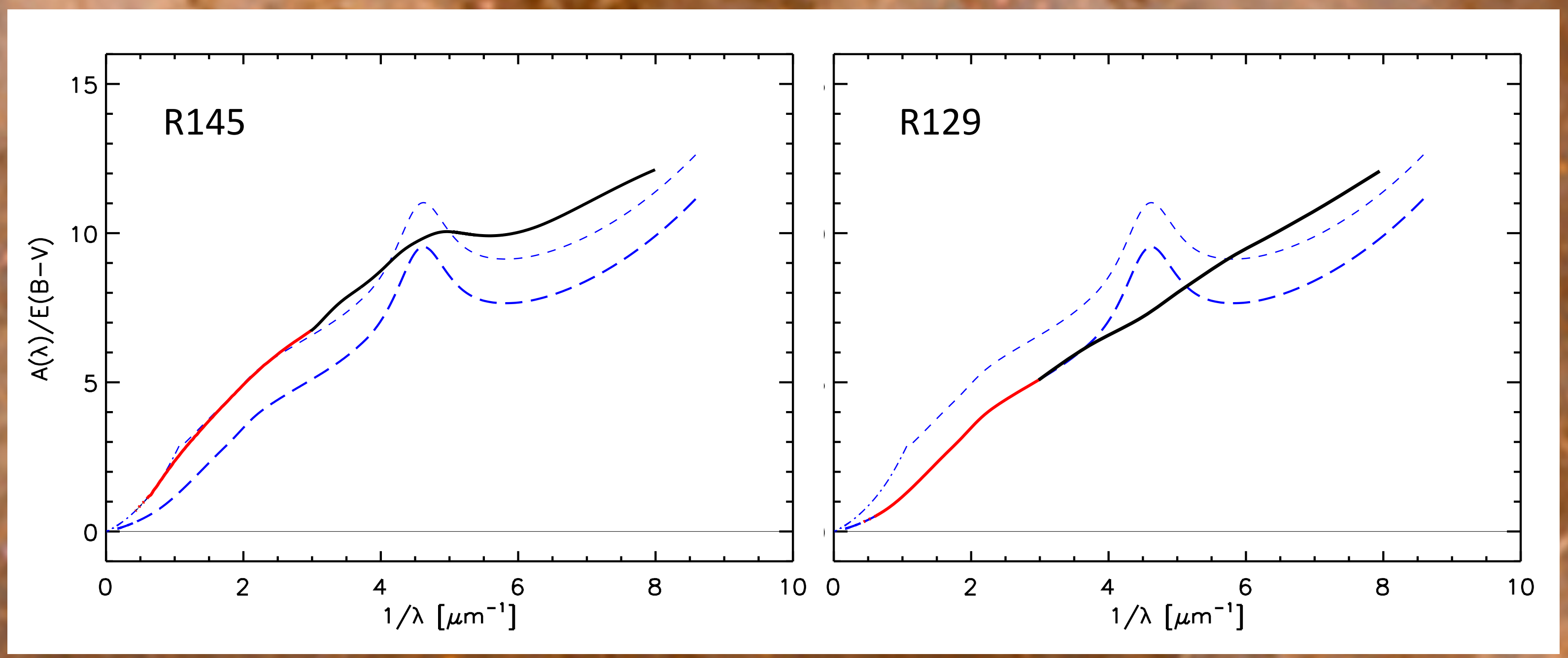

Figure 4 – The extinction curves measured for the WR stars inside and outside the Tarantula rise steeply in the ultraviolet, and this is a clear sign that small grains are present in large amounts. As an example, we compare the extinction curve for R145, inside the Tarantula, with that for R129, located in a more diffuse region of the LMC. Both rise steeply in the ultraviolet, but at optical wavelengths R129 does not reveal any excess of large grains and its extinction curve is consistent with that measured in the diffuse ISM of the Milky Way (thick blue dashed line). So **the excess of large grains is only seen in regions of recent/ongoing star formation, like the Tarantula Nebula, and does not come at the expense of small grains**, which are still present. These results are consistent with the addition of "fresh" large grains by type II supernova explosions, as recently revealed by the Herschel and ALMA observations of SN 1987A and imply that **the ISM is dynamically altered as large fresh grains are produced and later destroyed**.

References – De Marchi, G., et al. 2016, MNRAS, 455, 4373 • De Marchi, G., Panagia, N. 2014, MNRAS, 445, 93 • De Marchi, G. Panagia, N., Girardi, L. 2014, MNRAS, 438, 513 • Fitzpatrick, E., Massa, D. 2005, AJ, 130, 1127