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Research Note

Observational constraints on the ERE interpretation*

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Abstract. Empirical relationships on the properties of the Extended Red Emission (ERE) are presented. They are based on published observational data and on new results obtained on reflection nebulae illuminated by cold stars. The plot of the width versus the central wavelength of the ERE band is in agreement with laboratory properties of the materials commonly proposed as the ERE carriers. But this is not the case for the plot of the ERE band width versus the effective temperature of the nebula illuminating star.

Key words: ISM: general – ISM: reflection nebulae – ISM: dust, extinction – ISM: H II regions – ISM: planetary nebulae: general – galaxies: individual: M 82

The Extended Red Emission (ERE) is a continuous emission band observed in the red part (6000–8000 Å) of the spectrum of various astrophysical objects: reflection nebulae (Schmidt et al. 1980; Witt & Boroson 1990), planetary nebulae (Furton & Witt 1992), galactic and extragalactic H II regions (Perrin & Sivan 1992; Sivan & Perrin 1993; Darbon et al. 1998), high-latitude galactic cirrus clouds (Szomoru & Guhathakurta 1998), the halo of the galaxy M82 (Perrin et al. 1995) and the diffuse galactic medium (Gordon et al. 1998). The ERE band is found to vary significantly both in position and width from one object to an other. The diversity of objects where the ERE is detected and the diversity of the observed band characteristics lead us to search for empirical relationships that should help identification of the ERE carriers.

For all the available observations, we have plotted in Fig. 1 the width as a function of the central wavelength of the ERE bands. For reflection nebulae, we have used the values of Witt & Boroson (1990). For all the other objects, we have made measurements according to the same definitions as Witt & Boroson: the central wavelength splits the band luminosity into two equal parts and the width is measured as the difference between the wavelengths of the first and third quartiles. Note that for planetary nebulae the values derived from the published spectra of Furton & Witt (1992) are underestimated.

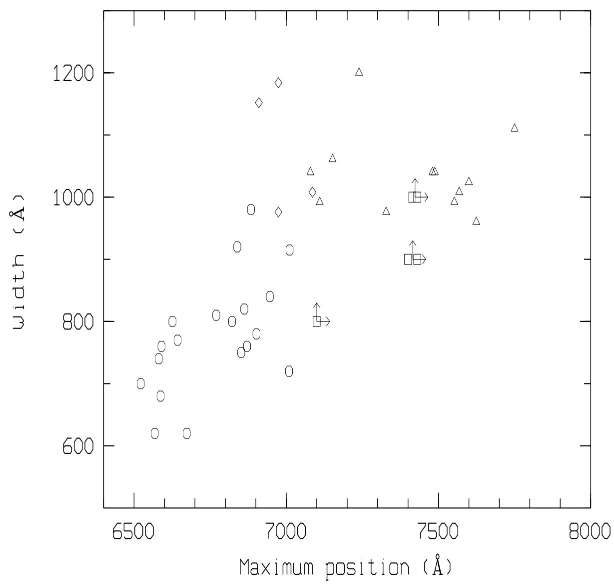

Fig. 1. This diagram plots the position of the maximum (Å) versus the width (Å) of the ERE band for a number of objects of various types: H II regions (△) (Perrin & Sivan 1992; Sivan & Perrin 1993; Darbon et al. 1998, Darbon et al., 1999), planetary nebulae (□) (Furton & Witt 1992), reflection nebulae (○) (Witt & Boroson 1990) and the halo of M82 (◇) (Perrin et al. 1995).

The diagram in Fig. 1 reveals a clear correlation between the position of the maximum and the width of the band. We derived a correlation coefficient $r = 0.68$. This result confirms and reinforces the tendency previously noted by Witt & Boroson (1990) from reflection nebulae only: the correlation coefficient was $r = 0.52$. The same effect is observed in laboratory experiments: Hydrogenated Amorphous Carbon (HAC) grains (Furton & Witt 1993) and nanocrystals of silicon (Witt et al. 1998; Ledoux et al. 1998) exhibit luminescence bands whose width increases with the maximum wavelength.

Also, it is found that the plotted values in Fig. 1 are split into two groups: reflection nebulae with smaller widths and bluer peaks and H II regions and planetary nebulae with larger widths and redder peaks (the halo of M82 lies at the border of these

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* Partly based on observations made at Observatoire de Haute Provence du CNRS and at European Southern Observatory (ESO), La Silla (Chile)

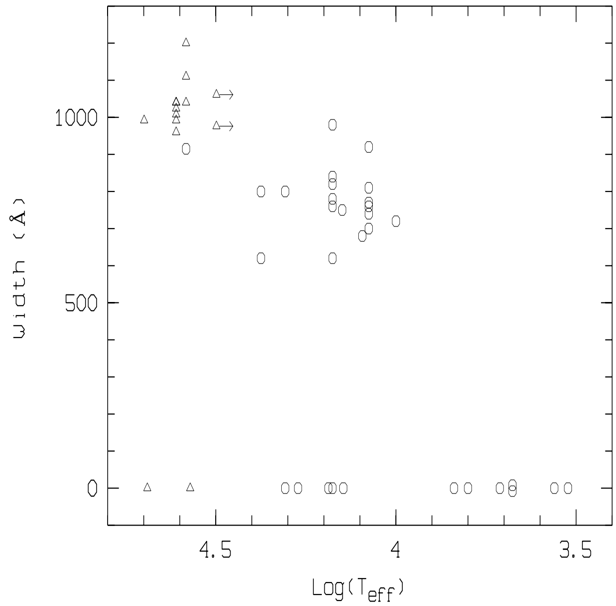

Fig. 2. Width of the ERE band as a function of the logarithm of the effective temperature of the exciting and/or illuminating star as measured on H II regions (△) and reflection nebulae (○). The exciting star of Sh 152 is embedded in a dusty cocoon so that the effective temperature of the spectral energy distribution that actually illuminates the regions observed by Darbon et al. (1999) is over-estimated.

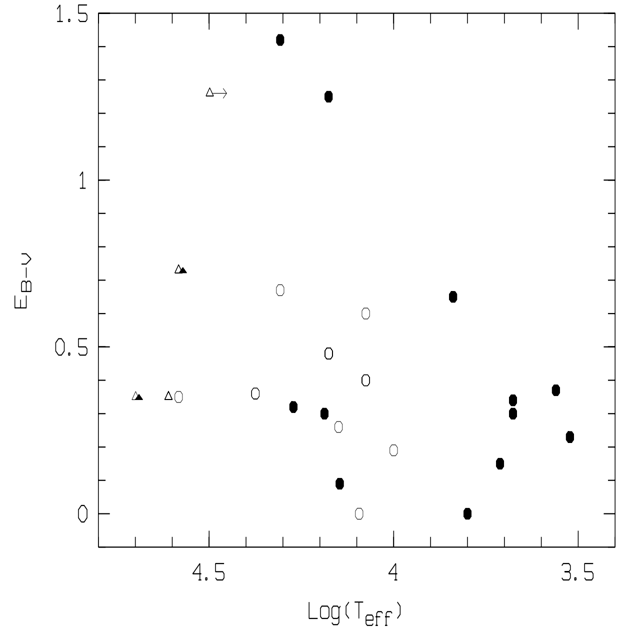

Fig. 3. Color excess as a function of the logarithm of the effective temperature of the illuminating star for: H II regions with ERE (△), reflection nebulae with ERE (○), H II regions without ERE (▲) and reflection nebulae without ERE (●).

two groups). This repartition might be related to the presence or absence of plasma within the nebula, in agreement with laboratory results (Wagner & Lautenschlager 1986; Robertson & O'Reilly 1987)

As a mean, in Fig. 1, the reflection nebulae are illuminated by stars less energetic than the other nebulae. This repartition suggests that the characteristics of the ERE might depend on the spectral distribution of the exciting flux. This has lead us to study the variation of the ERE band width as a function of the effective temperature of the exciting stars. BVI photometric and spectrophotometric observations, conducted respectively by Witt & Schild (1985) and Witt & Boroson (1990), deal with reflection nebulae illuminated by stars with a spectral type earlier than A0 (i.e. $T_{eff} \gtrsim 10000$ K): most of these nebulae exhibit ERE. But laboratory results show that the ERE can be excited by low energy visible radiation. So, the observation of reflection nebulae illuminated by stars colder than A0 (i.e. with a spectral energy distribution peaking in the visible) should be useful in order to detect the presence or the absence of the ERE in their spectra. One such nebula, illuminated by an M giant star, has been observed by Witt & Rogers (1991). We have observed six additional nebulae illuminated by cold stars. They are listed in Table 1, together with spectral type and the effective temperature of the illuminating stars. We obtained low resolution spectra for these objects. Data reduction were conducted as previously described in Perrin et al. (1995). None of these nebulae exhibits ERE in its spectrum.

Table 1. Reflection nebulae illuminated by cold stars

Nebula	Spectral Type (MK)	T_{eff} (K)	Observation site
VDB003	K0III	4750	OHP (a)
VDB035	G8III	4900	OHP (a)
VDB037	(g)M5III	3330	OHP (a)
VDB120	F7II	6310	OHP (a)
VDB133†	F5Iab	6900	OHP (a)
VHE14B	K0III	4750	ESO (b)
IC2220	(g)M1II	3635	UTSO (c)

(a) observed at the Cassegrain focus of the 193 cm telescope of the Observatoire de Haute Provence du CNRS using the Carelec spectrograph equipped with a 512×512 thinned back-illuminated Tektronic CCD

(b) observed at the Cassegrain focus of the 152 cm telescope of the European Southern Observatory at La Silla using the Boller & Chivens spectrograph equipped with a 2048×1024 thinned back-illuminated CCD

(c) observed by Witt & Rogers (1991) with the University of Toronto Southern Observatory (UTSO) 61-cm telescope equipped with a CCD camera and B, V, R, I filters.

† the main illuminating star HD195593A has a hotter companion HD195593B (spectral type B6-B8) (Uchida et al. 1998).

In Fig. 2, we have plotted the ERE band width as a function of the effective temperature of the exciting star for the reflection nebulae and H II regions of Fig. 1 and for the nebulae of Table 1. For the nebulae without ERE, the width value is set to zero. Clearly, no ERE appears for $T_{eff} \lesssim 7000$ K. On the contrary, for $T_{eff} \gtrsim 10000$ K, most of the plotted objects exhibit the ERE albeit few of them do not. This suggests a cut-off in effective temperature might exist between 7000 and 10000 K (unfortunately no observation is available for this range). This cut-off cannot be accounted for by extinction effects as demonstrated by Fig. 3: the presence or the absence of the ERE in a nebula does not appear to be correlated to the color excess of its illuminating star.

The fact that no ERE is present for stars whose effective temperature is smaller than 7000 K does not agree with current laboratory data on various materials such as HACs and silicon nanocrystals. These materials exhibit red luminescence features when they are irradiated by photons of low energy, namely of energy smaller than 3 eV (see e.g. Sussmann & Ogden 1980, Lin & Feldman 1981, Fang et al. 1988, Wilson et al. 1993).

Further observations of reflection nebulae illuminated by cold stars would be useful to confirm our finding. We cannot completely rule out that the absence of ERE in these nebulae could be simply due to the absence of any luminescent material.

This is probably the case for the nebulae without ERE belonging to the left-hand part of the diagram in Fig. 2 ($T_{eff} \gtrsim 10000$ K). This suggests that the ERE carriers would not be present everywhere in the interstellar medium.

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