BASIC PARAMETERS AND PROPERTIES OF WOLF-RAYET STARS

KAREL A. VAN DER HUCHT
Space Research Organization Netherlands, Utrecht, The Netherlands

Abstract. The numbers, space distribution and energy distributions of Wolf-Rayet stars are reviewed. The numbers of known WR stars in the Galaxy, the LMC and the SMC are 189, 114, and 10, respectively. Distances and galactic distributions determined by various authors are compared and consequences for with evolutionary studies are discussed. Finally energy distributions from the optical to the radio regime are reviewed.

Key words: stars: Wolf-Rayet – intrinsic parameters – energy distributions – galactic distribution

1. Introduction

It are their hot dense stellar winds with velocities in the range $v_\infty = 1000$–$2500\ \mathrm{km\,s^{-1}}$ and mass loss rates of $\dot{M} = [2\text{–}10] \times 10^{-5}\ \mathrm{M_\odot\,yr^{-1}}$ (Willis 1991) which characterize the Population I Wolf-Rayet (WR) stars (see, *e.g.*, van der Hucht 1992). It is in the dense WR stellar winds where the strong broad emission lines originate which define the WR phenomenon, and where the free-free μm to cm radiation originates.

In the past 1.5 decade its has been widely accepted that that WR stars are evolved hot massive stars, close to the end of their nuclear burning phase. Evidence for this has come from atmospheric studies, evolutionary studies and studies of their ambient circumstellar *c.q.* interstellar environment. Massive stars are responsible for the nucleosynthesis of the majority of the heavy elements, and through their large mass loss rates they dominate the chemical enrichment in at least the early phases of galactic evolution (Abbott 1982; van der Hucht *et al.* 1986; Leitherer *et al.* 1992).

WR stars are highly luminous, which make them tracers of massive star populations. Because of their concentration to the galactic plane, many WR stars suffer significant extinction, sometimes exacerbated by additional local extinction either by material left over from their parent cloud or circumstellar dust produced by themselves. Knowledge of their distances and luminosities is required for many purposes, *e.g.*, location in the HR diagram for comparison with stellar models, and location in the Milky Way to study the striking dependence of WR subtype with galactocentric distance (van der Hucht *et al.* 1988).

2. Inventory

The galactic WR census of van der Hucht *et al.* (1981, 1988) has been complemented by the discovery of 32 new WR stars: Acker & Stenholm (1990)

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 7–14.

reclassified the alleged planetary nebula Th3-28 (Thé 1964) as a new WN2.5-3 star (WR93a); Panov & Seggewiss (1990) found that the quadruple system WR153 (GP Cep) harbours two WN+O systems; Cohen *et al.* (1991) classified IRAS 17380-3031 as a new WC8-9 star (WR98a); Shara *et al.* (1991) discovered in a dedicated survey 13 new WR stars (11 WN and 2 WC); Crawford & Barlow (1991) classified the emission line star We21 (Weaver 1974) as a new WN8 star (WR47a); van Kerkwijk *et al.* (1992) discovered that Cygnus X-3 has in the IR a variable WN4-7 spectrum (WR145a); Mereghetti *et al.* (1994) identified the X-ray source 1E 1024.0-5732 with the emission line star Th35-42 (Thé 1966) and classified it as WN6 (WR20c); Shara *et al.* (Brussels 1993 colloquium poster, not published) continued their dedicated optical survey to discover 10 new WR stars (7 WN and 3 WC); and Hoffman, Weigelt & Seggewiss (these proceedings) resolved four individual WN stars in WR43, the central object of cluster and H II region NGC 3603. This brings the number of known galactic WR stars up to 189, of which 105 are WN types, 7 are WN/WC types (Conti & Massey 1989, Conti *et al.* 1990), 75 are WC types and 2 are WO types (Barlow & Hummer 1982). The optical search for new WR stars down to $v \approx 17$ mag by Shara *et al.* is continuing, as well as searches at IR (Cohen, these proceedings) and X-ray wavelengths (Mereghetti *et al.* , these proceedings). On the basis of the cumulative distribution of absorption A_v values for WR stars determined by Conti & Vacca (1990), van den Bergh (1992) argues that $\sim$ 40% of the WR stars within 2 kpc from the Sun still remain to be discovered.

For the LMC, Lortet (1991) refers to 27 new WR stars discovered since the census by Breysacher (1981). Excluding the 12 Of/WN stars among them, this brings the number of LMC WR stars up to 114. This number can readily increase, since high spatial-resolution imaging has shown some LMC and SMC WR stars to be actually double or multiple (*e.g.,* Heydari-Malayeri 1991; Schild & Testor 1992). A possible new LMC WC9-type (Heydari-Malayeri *et al.* 1990), a subtype otherwise unknown in the LMC, appeared to be a rather unique Of?p-like object (Moffat 1991; Heydari-Malayeri & Melnick 1992).

Since the WR census in the SMC by Azzopardi & Breysacher (1979), one new WN+O system has been discovered by Morgan *et al.* (1991). The SMC WR object HD 5980 has been classified as a WN+WN binary (Barba & Niemela, these proceedings). This brings the total number to 10 WR stars, among which 9 WN types and 1 WO type.

3. Basic parameters

Intrinsic parameters of Wolf-Rayet stars, like intrinsic colours, colour excesses and absolute visual magnitudes, have been derived and discussed by, *e.g.,* Lundström & Stenholm (1984), Massey (1984), van der Hucht *et al.*

(1988), Torres-Dodgen & Massey (1988) and Vacca & Torres-Dodgen (1990). New empirical methods, based on observed emission line strengths and ratios, have been developed by Conti & Massey (1989), Conti & Morris (1990) and Smith *et al.* (1990) to determine absolute visual magnitudes of WN stars, interstellar reddening of WN stars and distances of WC stars, respectively. Schmutz & Vacca (1991) developed a model dependent method to determine the interstellar reddening from *ubv* photometry. Van der Hucht *et al.* (1988) used available narrow-band filter photometry in the system of Smith (1968a,b) and Lundström & Stenholm (1979, 1984) to derive colour excesses, intrinsic colours and absolute visual magnitudes for galactic WR stars only, adopting distances and colour excesses found in studies of WR stars in galactic open clusters and associations by Lundström & Stenholm (1984) as the basis of their calibration.

Massey (1984) and Torres-Dodgen & Massey (1988) derived synthetic line-free photometry from spectrophotometry of WR stars. In addition, Vacca & Torres-Dodgen (1990) derived colour excesses from the strength of the 2200Å absorption feature in low resolution *IUE* spectra of galactic and LMC WR stars.

In spite of the limited number of WR stars in galactic clusters and associations (42 stars, distributed over 18 WR subtypes), van der Hucht *et al.* (1988) warn against averaging of galactic and LMC basic parameters. Their concern is shared by Hamann (1991) and Koesterke *et al.* (1991), who found from quantitative spectroscopy that LMC WN stars have on the average lower luminosities than their galactic counterparts. In the meantime, verification of galactic cluster and association membership of OB and WR stars is receiving attention (*e.g.*, Garmany & Stencel 1992; Garmany 1994).

A new approach to reddening and distance determinations is offered by the infrared wavelength region, which is less affected by extinction than the optical wavelength region. IR photometry of WR stellar winds can be used to deriving photometric distances by determining IR absolute luminosities from observations of WR stars whose distances are known independently from their membership in stellar clusters and associations. The IR flux from WR stars not having thermal emission by heated circumstellar dust is a combination of photospheric and stellar wind free-free emission, with the latter dominating at longer wavelength. Because the classification of WR stars is based on emission lines formed in strong stellar winds, the stellar wind continua may be better correlated with spectral subtype than the photospheric continua. Also, because the stellar wind has a flatter spectrum ($\propto \nu^{0.8}$) than the photosphere ($\propto \nu^2$), it will come do dominate the continuum at some wavelength in the IR. Finally, the IR is much less susceptible to reddening than the optical. The $v-$IR photometric distance determination method was applied to WR147 (AS 431, WN8) by Churchwell *et al.* (1992) and to WR125 (IC14-36, WC7+O9) by Williams *et al.* (1992), demonstrating the impor-

https://doi.org/10.1017/S0074180900201502 Published online by Cambridge University Press

TABLE I

Average absolute visual magnitudes of galactic WR stars in open clusters and associations (van der Hucht, Williams & Setia Gunawan (HWS) in preparation)

spectral type	M_v	s.d.	ns	nb	ΔM_v	spectral type	M_v	s.d.	ns	nb	ΔM_v
WN2	−2.4		1		1.4	WC4					
WN3	−2.2		1		1.6	WC5	−3.6	.2	2		0.2
WN4	−3.3	.3	1	1	0.5	WC6	−3.7	.4	2	1	0.1
WN4.5	−4.1	.7		3	−0.3	WC7	−4.1	.4	2	3	−0.3
WN5	−3.7	.4	1	1	0.1	WC8	−4.4	.3	1	2	0.4
WN6	−4.8	.4	3	3	−1.0	WC9	−4.6	.3	2		0.2
WN7	−6.5	.6	5	3	−1.0						
WN8	−6.7		1		−1.2	WO2	−2.7		1		
WN9											

Notes: ns: number of single WR stars; nb: number of WR components in binaries; Averages weighted: single stars have double weight. ΔM_v = M_v(HWS) − M_v(Conti & Vacca 1990).

tance of improved distances determinations for the assessment of X-ray and radio luminosities and mass loss rates. This method is being explored further by van der Hucht, Williams & Setia Gunawan (in preparation), using a set of IR photometry for 112 galactic WR stars.

Since the calibration of galactic WR absolute magnitudes is based on distances of open clusters and associations, any new cluster or association study can be relevant. Since 1988 new distances have been published for seven open clusters and seven OB associations containing WR stars. This leads to a revised M_v *vs.* sub-type calibration, presented in Table I (van der Hucht *et al.* in preparation). The dispersion in M_v(WR) found is not larger than that for O-type stars (Garmany 1988, Table 3-1).

4. Continuum energy distributions

Study of the continuum energy distribution of WR stars over large wavelength regions, especially in the free-free emission range (μm–cm) is instructive for aspects of mass loss rates, recombination and possible non-thermal emission.

By combining and power-law fitting *IUE* and optical spectrophotometry of 69 galactic, 55 LMC and 5 SMC WR stars, Morris *et al.* 1993 (see also Morris, these proceedings) show that for each WR star a single spectral index $\alpha_{0.15-1.0\mu m}$ (with $S_\nu \propto \nu^\alpha$) can be determined. For the complete sample they find $\alpha_{0.15-1.0\mu m} = 0.85 \pm 0.40$ with no differences between the WN and WC sequences or the Galaxy and the LMC. They conclude that $\alpha_{0.15-1.0\mu m}$ is at least not sensitive to differences in atmospheric chemical composition.

Williams *et al.* (1990) observed γ Velorum (WC8+O9I) at *UKIRT* and *JCMT* from 1.25 to 1100 μm and found $\alpha_{1.25\mu m-1.1mm} = 0.69 \pm 0.02$. A homogeneous, isothermal, spherically expanding wind with $\rho(r) \propto r^{-2}$ should display $\alpha = 0.60$ (Wright & Barlow 1975). A larger spectral index could imply a variation of $T(r)$ and/or recombination at larger distances.

Apparently deviations from $\alpha = 0.60$ are quite normal for WR stars. Altenhoff *et al.* (1994) observed 11 WR stars at *IRAM* at 1.2 mm and found an average $\alpha_{1.2mm-6cm} = 0.82 \pm 0.09$. For a subset of WN stars, they find a weak correlation of α with $T_{\rm eff}$.

5. Galactic distribution

Studies of the galactic distribution of WR stars as a diagnostic for the determination of their initial masses and (sub-type) evolution since Maeder *et al.* (1980), have been attempted by van der Hucht *et al.* (1988), using galactic data only, and by Conti & Vacca (1990), mixing galactic and LMC data. Maeder & Meynet (1994) compared their evolutionary model predictions with the results of both van der Hucht *et al.* (1988) and Conti & Vacca (1990), each showing good agreement in subtype ratios *vs.* galactocentric distance with evolutionary calculations. Comparison of the two observational studies also indicates that photometric distances of WR *field* stars have an accuracy of $\sim$ 50%. Observational studies of the overall galactic WR distributions agree surprisingly well with each other, in spite of the different data sets and methods used. Notably the concentration of WR stars in galactic spiral arms, their absence toward the galactic anti-center (Orion spur) (Roberts 1962), and the concentration of late-WC stars toward the galactic center (Smith 1968c), are confirmed by the two studies. For the sample of known WR stars with $d < 2.5$ kpc van der Hucht *et al.* (1988) find a galactocentric distribution with $N_{WN}/N_{WC} \approx 1$ for $R > 7.5$ kpc and $N_{WN}/N_{WC} \approx 0.4$ for $R < 7.5$ kpc. For the same sample they find that perpendicular to the galactic plane $|z| = 46$ pc, in good correspondence with the $|\ z\ |$-distribution of O-type stars (Garmany *et al.* 1982).

The distribution of WR stars in the LMC and the SMC is given by Garmany (1984).

As early as 1980, Maeder *et al.* proposed an explanation of the observed frequency of WR stars as a function of galactocentric distance, by a relation between the local metallicity Z and single WR mass loss rates. At large Z (*e.g.,* inner galactic regions) the gas opacities are larger and consequently more momentum is transferred to the stellar wind by radiation pressure. Therefore in large Z environments mass loss by stellar winds in massive O-type stars is larger and thus more WR stars are formed. To quantify this, the Geneva group (Maeder & Meynet 1994) calculated grids of evolutionary models for various values of the metallicity Z ($Z = 0.001$-0.040), and adopted $\dot{M} \propto Z^{0.5}$, as indicated by stellar wind models of Kudritzki *et al.* (1987) and confirmed by Leitherer and Langer (1991).

Adopting 'standard' pre-WR mass loss rates (de Jager *et al.* 1988), $\dot{M} = 4 \times 10^{-5}$ $M_\odot\,yr^{-1}$ during the WNL phase and $\dot{M} \sim M^{2.5}$ during the WNE and WC phase (Langer 1989), Maeder & Meynet found WR lifetimes as a function of Z of the order of 5×10^5 yr and initial masses M_i as low as 25 $M_\odot$, which compares well with the observed minimum value of 25 $M_\odot$ found by van der Hucht *et al.* (1988), and the minimum value of 23 $M_\odot$ found by Vanbeveren (1991) in comparing binary observations and binary evolution models. For $Z \geq 0.02$ all stars with $M_i \geq 25$ $M_\odot$ finish their evolution with masses in the range 5-10 $M_\odot$ (Maeder 1991a), while the duration of the WR phase increases strongly with increasing metallicity and mass loss rate. To explain the WR/O, WC/WR and WC/WN number ratios as observed in the Milky Way (Conti & Vacca 1990), in the LMC (Azzopardi & Breysacher 1985), and in M31 and M33 (Armandroff & Massey 1991), the 'standard' pre-WR mass loss rates in the evolutionary models, however, have to be doubled.

Maeder & Meynet (1994) also indicate that, in cases where many WR stars are observed in regions with low Z, at least a fraction of those WR stars have to originate through alternative 'channels' of WR formation, *e.g.*, from massive binary evolution with mass transfer, an important topic of this symposium (reviews by Langer, de Greve and Maeder, these proceedings). However, Maeder & Meynet find that this fraction is quite small, $\sim$ 5%, much smaller than the 20–40 % found in binary evolution studies of, *e.g.*, Vanbeveren & de Loore (1993) and Podsiadlowski *et al.* (1992).

The Geneva model calculations confirm an overall general evolutionary sequence WNL → WNE → WCL → WCE → WO. For binaries, observational studies by Moffat (these proceedings and references therein) also point toward a continuous WCL → WCE/WO subtype evolution. Of the allowed subtype evolution paths, based on the observed WR galactic distribution (van der Hucht *et al.* 1988), *i.e.*,

- at galactocentric radius $R < 8.5$ *kpc*: WNL → WCL
- at $R > 6.5$ *kpc*: WNL → WCE → WO
- and in general: WNE → no WC stars,

the first two paths agree well with models with high M_i and low Z values, respectively. The third path corresponds only to lower M_i at low Z, but may be somewhat relaxed since WNE stars and WCE stars have some overlap in galactocentric distances. The galactic distribution of the WC subtypes as determined by van der Hucht *et al.* (1988) has been explained quantitatively in terms of the galactic metallicity gradient by Smith & Hummer (1988) and Smith & Maeder (1991): high Z_i and M_i lead to WCL subtypes, while low

Z_i and M_i lead to WCE subtypes.

Acknowledgements

A travel grant from the Koninklijke Nederlandse Akademie van Wetenschappen is gratefully acknowledged.

References

Abbott, D.C. 1982, *ApJ* **259**, 282
Acker, A., Stenholm B. 1990, *A&A Suppl.* **86**, 219
Altenhoff, W.J., Thum, C., Wendker, H.J. 1994, *A&A* **281**, 161
Armandroff, T.E., Massey, P. 1982, *AJ* **102**, 927
Azzopardi, M., Breysacher, J. 1979, *A&A* **75**, 120
Azzopardi, M., Breysacher, J. 1985, *A&A* **149**, 213
Barlow, M.J., Hummer, D.G. 1982, in: C. de Loore & A.J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, *Proc. IAU Symp. No. 99* (Dordrecht: Reidel), p. 387
van den Bergh, S. 1992, *ApJ* **390**, 133
Breysacher, J. 1981, *A&A Suppl.* **43**, 209
Churchwell, E., Bieging, J.H., van der Hucht, K.A., Williams, P.M., Spoelstra, T.A.Th., Abbott, D.C. 1992, *ApJ* **393**, 329
Cohen, M., van der Hucht, K.A., Williams, P.M., Thé, P.S. 1991, *ApJ* **378**, 302
Conti, P.S., Massey, P. 1989, *ApJ* **337**, 251
Conti, P.S., Morris, P.W. 1990, *AJ* **99**, 898
Conti, P.S., Vacca, W.D. 1990, *AJ* **100**, 431
Conti, P.S., Massey, P., Vreux, J.-M. 1990, *ApJ* **354**, 359
Crawford, I.A., Barlow, M.J. 1991, *A&A (Letters)* **252**, L39
Garmany, C.D., Conti, P.S., Chiosi, C. 1982, *ApJ* **263**, 777
Garmany, C.D. 1984 *PASP* **96**, 779
Garmany, C.D. 1988, in: P.S. Conti & A.B. Underhill (eds.) 1988, O Stars and Wolf-Rayet Stars, *NASA SP-497*, p. 157
Garmany, C.D., Stencel, R.E. 1992, *A&A Suppl.* **94**, 211
Garmany, C.D. 1994 *PASP* **106**, 25
Hamann, W.-R. 1991, in: K.A. van der Hucht & B. Hidayat (eds.), Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies, *Proc. IAU Symp. No. 143* (Dordrecht: Kluwer), p. 81
Heydari-Malayeri, M, Melnick, J., Van Drom, E. 1990, *A&A (Letters)* **236**, L21
Heydari-Malayeri, M. 1991, in: K.A. van der Hucht & B. Hidayat (eds.), Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies, *Proc. IAU Symp. No. 143* (Dordrecht: Kluwer), p. 647
Heydari-Malayeri, M., Melnick, J. 1992, *A&A (Letters)* **258**, L13
van der Hucht, K.A., Conti, P.S., Lunström, I., Stenholm, B. 1981, *Sp. Sci. Rev.* **28**, 227
van der Hucht, K.A., Cassinelli, J.P., Williams, P.M. 1986, *A&A* **168**, 111
van der Hucht, K.A., Hidayat, B., Admiranto, A.G., Supelli, K.R., Doom, C. 1988, *A&A* **199**, 217
van der Hucht, K.A. 1992, *The A&A Rev.* **4**, 123
van der Hucht, K.A., Williams, P.M., Spoelstra, T.A.Th., de Bruyn, A.G. 1992, in: L. Drissen, C. Leitherer, A. Nota (eds.), Non-isotropic and Variable Outflows from Stars, *ASP Conf. Series* **22**, p. 253
de Jager, C., Nieuwenhuijzen, H. van der Hucht, K.A. 1988, *A&A Suppl.* **72**, 259
van Kerkwijk, M.H., Charles, P.A., Geballe, T.R., King, D.L., Miley, G.K., Molnar, L.A., van den Heuvel, E.P.J., van der Klis, M., van Paradijs, J. 1992, *Nature* **355**, 703
Koesterke, L., Hamann, W.-R., Schmutz, W., Wessolowski, U. 1991, *A&A* **248**, 166
Kudritzki, R.P., Pauldrach, A., Puls, J. 1987, *A&A* **173**, 293

Langer, N. 1989, *A&A* **220**, 135
Leitherer, C., Langer, N. 1991, in: R.F. Haynes & D.K. Milne (eds.), The Magellanic Clouds, *Proc. IAU Symp. No. 148* (Dordrecht: Kluwer), p. 480
Leitherer, C., Robert, C., Drissen, L. 1992, *ApJ* **401**, 596
Lortet, M.-C. 1991, in: K.A. van der Hucht & B. Hidayat (eds.), Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies, *Proc. IAU Symp. No. 143* (Dordrecht: Kluwer), p. 513
Lundström, I., Stenholm, B. 1979, *A&A Suppl.* **35**, 303
Lundström, I., Stenholm, B. 1984, *A&A Suppl.* **58**, 163
Maeder, A., Lequeux, J., Azzopardi, M. 1980, *A&A (Letters)* **90**, L17
Maeder, A. 1991a, *QJRAS* **32**, 217
Maeder, A. 1991b *A&A* **247**, 93
Maeder, A., Meynet, G. 1994, *A&A* **287**, 803
Massey, P. 1984, *ApJ* **281**, 789
Mereghetti, S., Belloni, T., Shara, M., Drissen, L. 1994, *ApJ* **424**, 943
Moffat, A.F.J. 1991, *A&A (Letters)* **244**, L9
Morgan, D.H., Vassiliadis, E., Dopita, M.A. 1991, *MNRAS* **251**, 51P
Morris, Brownsberger, K.R., Conti, P.S., Massey, P., Vacca, W.D. 1993, *ApJ* **412**, 324
Panov, K.P., Seggewiss, W. 1990, *A&A* **222**, 117
Podsiadlowski, Ph., Joss, P.C., Hsu, J.J.L. 1992, *ApJ* **391**, 246
Roberts, M.S. 1962, *AJ* **67**, 79
Schild, H., Testor, G. 1992, *A&A Suppl.* **92**, 729
Schmutz, W., Vacca, W.D. 1991, *A&A Suppl.* **89**, 259
Shara, M.M., Moffat, A.F.J., Smith, L.F., Potter, M. 1991, *AJ* **102**, 716
Smith, L.F. 1968a, *MNRAS* **138**, 109
Smith, L.F. 1968b, *MNRAS* **140**, 409
Smith, L.F. 1968c, *MNRAS* **141**, 317
Smith, L.F., Hummer, D.G. 1988, *MNRAS* **230**, 511
Smith, L.F., Shara, M.M., Moffat, A.F.J. 1990, *ApJ* **358**, 229
Smith, L.F., Maeder, A. 1991, *A&A* **241**, 77
Thé, P.S. 1964, *Contr. Bosscha Obs.* No. 26
Thé, P.S. 1966, *Contr. Bosscha Obs.* No. 35
Torres-Dodgen, A.V., Massey, P. 1988, *AJ* **96**, 1076
Vacca, W.D., Torres-Dodgen, A.V. 1990, *ApJ Suppl.* **73**, 685
Vanbeveren, D. 1991 *A&A* **252**, 159
Vanbeveren, D., de Loore, C.W.H. 1993, in: J.P. Cassinelli *et al.* (eds), *ASP Conf. Series* **35**, 257
Weaver, W.B. 1974, *ApJ* **189**, 263
Williams P.M., van der Hucht, K.A., Sandell, G., Thé, P.S. 1990, *MNRAS* **244**, 101
Williams, P.M., van der Hucht, K.A., Bouchet, P., Spoelstra, T.A.Th., Eenens, P.R.J., Geballe, T., Kidger, M.R., Churchwell, E.B. 1992, *MNRAS* **258**, 461
Willis, A.J. 1991, in: K.A. van der Hucht & B. Hidayat (eds.), Wolf-Rayet Stars and Interrelations with Other Massive Stars in Galaxies, *Proc. IAU Symp. No. 143* (Dordrecht: Kluwer), p. 265
Wright, A.E., Barlow, M.J. 1975, *MNRAS* **170**, 41

DISCUSSION:

Conti: This seems a better way to go for extinction. (1) Did you correct for emission lines in the IR bands? (2) Any idea why in some cases previous optical studies have had such apparently anomalous extinctions?

van der Hucht: (1) We did use H and L, which have less emission-line contamination than J and K. The errors (one way) in H and L are of the order of 0.03–0.15 mag and 0.06–0.18 mag, respectively, depending on sub-type. (2) Not yet studied in detail. Will do.

https://doi.org/10.1017/S0074180900201502 Published online by Cambridge University Press