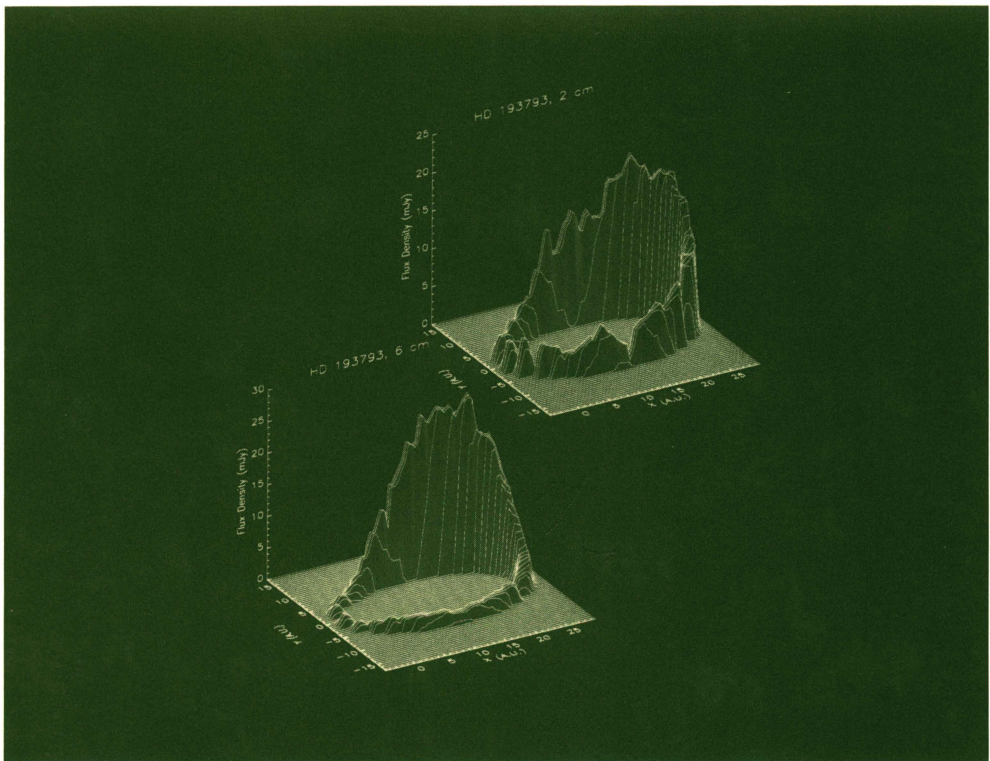


INTERNATIONAL ASTRONOMICAL UNION

SYMPOSIUM No. 163

WOLF-RAYET STARS: BINARIES, COLLIDING WINDS, EVOLUTION

Edited by KAREL A. VAN DER HUCHT and PEREDUR M. WILLIAMS



INTERNATIONAL ASTRONOMICAL UNION

KLUWER ACADEMIC PUBLISHERS

WOLF-RAYET STARS: BINARIES, COLLIDING WINDS, EVOLUTION

INTERNATIONAL ASTRONOMICAL UNION
UNION ASTRONOMIQUE INTERNATIONALE

WOLF-RAYET STARS: BINARIES, COLLIDING WINDS, EVOLUTION

PROCEEDINGS OF THE 163RD SYMPOSIUM OF THE
INTERNATIONAL ASTRONOMICAL UNION,
HELD IN LA BIODOLA, ELBA, ITALIA,
MAY 2–6, 1994

EDITED BY

KAREL A. VAN DER HUCHT

*Space Research Organization Netherlands,
Utrecht, The Netherlands*

and

PEREDUR M. WILLIAMS

*Royal Observatories,
Edinburgh, Scotland, United Kingdom*



KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON



A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 0-7923-3183-4 (HB)

*Published on behalf of
the International Astronomical Union
by
Kluwer Academic Publishers, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.*

*Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.*

*Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.*

*In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.*

Printed on acid-free paper

*All Rights Reserved
© 1995 International Astronomical Union*

*No part of the material protected by this copyright notice may be reproduced or utilized
in any form or by any means, electronic or mechanical including photocopying,
recording or by any information storage and retrieval system, without written permission
from the publisher.*

Printed in the Netherlands

TABLE OF CONTENTS

Preface	xiii
The Organizing Committee	xv
Conference photograph	xvi
List of participants	xix
WELCOMING ADDRESSES	
Chairman Local Organizing Committee, <i>Federico Ferrini</i>	1
Chairman Scientific Organizing Committee, <i>Karel A. van der Hucht</i>	2
AN HISTORICAL INTRODUCTION, <i>Lindsey F. Smith</i>	3
1971 revisited; fossils alive and dead	
SESSION I. – Chair: <i>Lindsey F. Smith</i>	
Basic parameters, properties of single Wolf-Rayet stars	
<i>K.A. van der Hucht</i>	
Basic parameters and general properties of Wolf-Rayet stars (<i>Invited</i>)	7
<i>N. Langer</i>	
Structure and evolution of massive single stars and their relevance for close binary systems (<i>Invited</i>)	15
<i>L.J. Smith</i>	
Properties of hot massive stars from studies of their ring nebulae (<i>Invited</i>)	24
<i>J.S. Nichols</i>	
The interstellar medium around Wolf-Rayet stars: clues to evolution (<i>Invited</i>)	34
<i>K.-H. Hofmann, G. Weigelt, W. Seggewiss</i>	
Resolution and evolution of the core of the giant HII region NGC 3603	43
Session I poster summaries	
<i>L.F. Smith, M.M. Shara, A.F.J. Moffat</i>	
Philosophy of classification for WN stars	48
<i>K. Rochowicz</i>	
Ultraviolet classification of Wolf-Rayet stars	50
<i>A. Niedzielski</i>	
A search for spectral variability in WR1	52
<i>L. Georgiev, M.M. Ivanov</i>	
Line profile variability of EZ CMa	54
<i>I.I. Antokhin, J.-F. Bertrand, R. Lamontagne, A.F.J. Moffat</i>	
The absence of a short period in the WN5 star EZ Canis Majoris	56
<i>C. Lloyd, D.J. Stickland</i>	
Periodic variations in the IUE data of HD 50896	58
<i>S. Lépine</i>	
Wavelet analysis of variable Wolf-Rayet emission lines	60
<i>I.I. Antokhin, J.-F. Bertrand, R. Lamontagne, A.F.J. Moffat</i>	
3.5 hour periodic variability of WR66 (HD 134877, WN8): the first example of non-radial pulsations among Wolf-Rayet stars?	62

<i>P. Bratschi</i> Pulsations of Wolf-Rayet stars: observational results for five Wolf-Rayet stars	64
<i>L. Norci, V.F. Polcaro, C. Rossi, R. Viotti</i> Multiwavelength study of the WO star Sand 2	66
<i>V.F. Polcaro, R. Viotti, C. Rossi, L. Norci</i> The WO stars and their environment	68
<i>F. Brighenti, A. D'Ercole</i> Ring nebulae around moving Wolf-Rayet stars	70
<i>G. García-Segura, M.-M. Mac Low, N. Langer</i> The imprint of massive stellar evolution on circumstellar gas	72
<i>A. Manchado, G. García-Segura, Y.-H. Chu</i> High resolution IRAS images of large shells around Wolf-Rayet stars	74
<i>S. Mereghetti, T. Belloni</i> ROSAT observations of the HII region RCW49	76
<i>A. Nota, M. Clampin, M. Sirianni, P. Greenfield, D.A. Golimowski</i> The inner M1-67 nebula: coronagraphic imaging and echelle observations	78
<i>G. Testor</i> Wolf-Rayet and OF stars in the OB associations LH101 and LH104 in the LMC	81
<i>M. Azzopardi, G. Muratorio, J. Breysacher, G. Testor</i> A search for Wolf-Rayet stars in NGC 300	83
<i>S.K. Górný, A. Acker, G. Stasińska, B. Stenholm, R. Tylenda</i> [Wolf-Rayet]-type central stars of planetary nebulae	85
 SESSION II – Chair: Sir Robert Wilson	
Model atmospheres for single Wolf-Rayet stars	
<i>I.I. Antokhin</i> Observational aspects of Wolf-Rayet atmospheres (<i>Invited</i>)	87
<i>P.W. Morris</i> Continuum and emission line observations of Wolf-Rayet stars: single and “WR+abs” objects (<i>Invited</i>)	96
<i>W.-R. Hamann</i> Model atmospheres and spectral analyses of Wolf-Rayet stars (<i>Invited</i>)	105
<i>D.J. Hillier</i> Status of Wolf-Rayet models (<i>Invited</i>)	116
<i>W. Schmutz</i> Hydrodynamic line-blanketed atmospheres of Wolf-Rayet stars (<i>Invited</i>)	127
<i>S.P. Owocki, K.G. Gayley</i> The dynamics of Wolf-Rayet winds (<i>Invited</i>)	138
<i>P.A. Crowther, L.J. Smith, D.J. Hillier</i> The evolutionary status of WNL stars	147
 Session II poster summaries	
<i>P.A. Crowther, L.J. Smith, A.J. Willis</i> The physical nature of WR8 (WN6/WC4)	152

<i>M.J. Dalton, P.A. Crowther, A.J. Willis</i>	154
An empirical study of Wolf-Rayet stellar wind ionization stratification	
<i>P.R.J. Eenens, P.M. Williams</i>	156
New analysis of Wolf-Rayet infrared lines	
<i>K.G. Gayley, S.P. Owocki</i>	158
The non-isotropic diffusion approximation in Wolf-Rayet winds	
<i>A.F. Kholtygin</i>	160
A clump model for Wolf-Rayet star atmospheres	
<i>T. Nugis</i>	162
New determinations of the chemical composition of Wolf-Rayet stars	
<i>E. Santolaya Rey, A. Herrero, J. Puls</i>	164
Synthetic line profiles from unified model atmospheres	
<i>L.C. dos Santos, V. Jatenco-Pereira, R. Opher</i>	166
Alfvén waves and radiation pressure in the winds of Wolf-Rayet stars	
<i>D. Schaerer</i>	168
Multi-line transfer and line-blanketing in a clumpy Wolf-Rayet wind	
<i>U. Springmann, J. Puls</i>	170
The ‘momentum problem’ of Wolf-Rayet stars: can it be explained by the multiple scattering mechanism?	
<i>D. Eichler, A. Bar Shalom, Y. Oreg</i>	172
Thick winds from Wolf-Rayet stars	
<i>U. Wessolowski, W.-R. Hamann, L. Koesterke, D.J. Hillier, J. Puls</i>	174
X-ray emission from Wolf-Rayet stars	
SESSION III – Chair: Gloria Koenigsberger	
Anisotropic mass loss, disk formation	
<i>R.E. Schulte-Ladbeck</i>	176
Spectropolarimetry and wind asymmetries of Wolf-Rayet stars (Invited)	
<i>J.C. Brown, L.L. Richardson</i>	186
Wolf-Rayet star variability and wind inhomogeneities	
<i>J.P. Cassinelli, R. Ignace, J.E. Bjorkman</i>	191
Winds from rotating Wolf-Rayet stars: the wind-compressed zone model (Invited)	
<i>G. Shaviv</i>	203
Optically thick winds in novae (Invited)	
SESSION IV – Chair: Allan J. Willis	
Properties of Wolf-Rayet binaries	
<i>A.F.J. Moffat</i>	213
Properties of Wolf-Rayet binaries: the key to understanding Wolf-Rayet stars (Invited)	
<i>V.S. Niemela</i>	223
Revised Wolf-Rayet binary orbits and new binaries (Invited)	
<i>K. Annuk</i>	231
Spectroscopic observations of the long-period Wolf-Rayet binaries HD 193793 and HD 192641	
<i>G.M. Hill, A.B. Underhill</i>	235
WR+O binaries observed from the DAO	

Session IV poster summaries*C. Lloyd, D.J. Stickland*

Wind absorption effects in the NIV 1718Å line in the WN4+O5 binary HD 9061

G. Rauw, J.-M. Vreuz, E. Gosset, D. Hutsemekers, P. Magain, J. Manfroid, M. K. Rochowicz

A seven year campaign on WR 22

P.M. Veen, A.M. van Genderen, M.A.W. Verheijen, K.A. van der Hucht

A radial-velocity curve for WR46 (WN3p)

V.S. Niemela, R.H. Barbá, M.M. Shara

The radial velocity variations of WR46 (WN3p)

J.-F. Bertrand

Evidence for shocking behaviour in WR133 (HD 190918, WN4.5+O9.5I)

M.F. Corcoran, I.R. Stevens, A.M.T. Pollock, J.H. Swank, S.N. Shore, G.L. Ra
X-ray variability in V444 Cygni: evidence for colliding winds*V.S. Niemela, W. Seggewiss, A.F.J. Moffat*

The multiple system Sk-67°18 in the LMC

R.H. Barbá, V.S. Niemela

The changing spectrum and orbital motion of the SMC Wolf-Rayet binary HD 5

L. Georgiev, N. Kaltcheva

UBVRI polarimetry of Wolf-Rayet stars

*L.L. Richardson, J.C. Brown*Polarimetric *versus* photometric variability of Wolf-Rayet star winds*C.V. Rodrigues, A.M. Magalhães*

Polarization in Wolf-Rayet binaries: Monte Carlo simulations

SESSION V – Chair: Anthony F.J. Moffat**Stellar winds and massive binary evolution***A.M. Cherepashchuk*Optical and X-ray observations of stellar winds in Wolf-Rayet binaries (*Invited*)*L. Kaper*Stellar winds in high-mass X-ray binaries (*Invited*)*A. Maeder*Wolf-Rayet stars in galaxies and the role of binaries and hydrodynamics (*Invited*)*J.P. De Greve*The evolution of close binary stars: conditions in the winds (*Invited*)*D. Schaerer, A. de Koter, W. Schmutz*

Complete stellar models for massive stars

*H. Braun, N. Langer*New massive close binary models and the ²⁶Al yield of the WR component of γ *H. Nussbaumer*Similarities and differences between Wolf-Rayet winds and symbiotic novae (*Invited*)**Session V poster summaries***G. Meynet*

Wolf-Rayet stars in starbursts

<i>L. Deng, A. Bressan, C. Chiosi</i>	320
New models for Wolf-Rayet stars: global diffusion	
<i>K.J.R. Ødegaard</i>	322
Chemical evolution and mixing processes in massive stars	
<i>E.I. Staritsin</i>	324
Semi-convection mixing and its influence on case B mass-exchange in massive binaries	
<i>J. Fliegner, N. Langer</i>	326
Models of rotating Wolf-Rayet stars	
<i>E.J.A. Meurs, E.P.J. van den Heuvel</i>	329
The galactic number of Wolf-Rayet stars produced via close binary evolution	
<i>P.A. Crowther, L.J. Smith, A.J. Willis</i>	331
MCA1B - A dormant LBV in M33?	
<i>G.L. Israelian, A.G. Nikoghossian, L.V. Tamboutseva</i>	333
Dynamics of the wind of LBV stars	
SESSION VI – Chair: André Maeder	
Dust formation near Wolf-Rayet stars and other circumstellar phenomena	
<i>P.M. Williams</i>	335
Dust formation around WC stars (<i>Invited</i>)	
<i>I. Cherchneff, A.G.G.M. Tielens</i>	346
Dust formation in hot stellar winds (<i>Invited</i>)	
<i>V.G. Zubko</i>	355
The physics of carbon dust around WC stars	
<i>M. Cohen</i>	359
An IRAS-based search for new dusty WCL Wolf-Rayet stars	
<i>M.F. Bode</i>	363
Episodic dust formation in astrophysical sources (<i>Invited</i>)	
Session VI poster summaries	
<i>T. Nugis</i>	371
IR excesses of late-type WC stars: no dust needed in most cases	
SESSION VII – Chair: Peredur M. Williams	
Hydrodynamics and high-energy physics of colliding winds	
<i>D.R. Gies</i>	373
Colliding winds in O-type binaries (<i>Invited</i>)	
<i>T.W. Berghöfer, J.H.M.M. Schmitt</i>	382
The ROSAT view of the massive eclipsing O-type binary system 29 UW Canis Majoris	
<i>N. St-Louis</i>	388
UV and optical spectroscopic observations of colliding winds in WR+O binaries (<i>Invited</i>)	
<i>S.V. Marchenko</i>	397
Wind-wind collision effects in close massive WR+O binaries (<i>Invited</i>)	
<i>P. Bartzakos, A.F.J. Moffat</i>	406
A spectroscopic search for colliding winds in a complete sample of WC/WO stars in the Magellanic Clouds	

S. Lépine	411
Effects of wind clumping on colliding winds	
S. Lührs	416
A colliding wind model for WR79	
R. Walder	420
Simulations of colliding winds in 3 dimensions	
<i>O.A. Tsiopa</i>	425
The colliding wind-formed structures of supernova precursors	
A.M.T. Pollock	429
The X-ray view of the Wolf-Rayet stars (<i>Invited</i>)	
R.L. White, W. Chen	438
Theory and observations of non-thermal phenomena in hot massive binaries (<i>Invited</i>)	
R.H. Becker, R.L. White	450
An eight year study of the radio emission from the Wolf-Rayet binary HD 193793 (<i>Invited</i>)	
Y. Hervieux	460
A CCD spectroscopic orbit and line-variability near periastron for HD 193793	
K.P. Panov, J. Stegert, W. Seggewiss	464
UBV photometry of the Wolf-Rayet stars WR137 and WR140	
D.Y.A. Setia Gunawan, K.A. van der Hucht, P.M. Williams, L. Kaper, H. Henrichs, W.M. Wamsteker	466
IUE monitoring of WR140 (WC7+O4-5)	
S.L. Skinner, F. Nagase, K. Koyama, Y. Maeda, Y. Tsuboi	471
ASCA X-ray observations of the Wolf-Rayet stars HD 193793 and HD 93162	
A.J. Willis, H. Schild, I.R. Stevens	476
Colliding-wind X-rays in γ Velorum (WC8+O9I)	
S. Mereghetti, T. Belloni, F. Haberl, W. Voges	481
X-ray selected Wolf-Rayet stars	
I.R. Stevens	486
Colliding stellar winds: X-ray emission and instabilities (<i>Invited</i>)	
V.V. Usov	495
Hydrodynamics and high-energy physics of Wolf-Rayet colliding winds (<i>Invited</i>)	
Session VII poster summaries	
P.M. Williams, K.A. van der Hucht, T.A.Th. Spoelstra, J.P. Swaanenvelt	504
Radio light-curves and circumstellar mapping of the colliding wind binary WR140	
R.E. Schulte-Ladbeck, K.H. Nordsieck, K.S. Bjorkman, M.R. Meade, B.L. Babler	506
Spectropolarimetric monitoring of WR140	
D.Y.A. Setia Gunawan, K.A. van der Hucht, D.J. Stickland, C. Lloyd, P.M. Williams, W. Wamsteker	508
An ultraviolet radial velocity orbit for WR140 (WC7+O4-5)	
A.M.T. Pollock, M.F. Corcoran, I.R. Stevens, P.M. Williams, K.A. van der Hucht	510
ASCA X-ray spectroscopy of WR140 near periastron	
A.M.T. Pollock, F. Haberl, M.F. Corcoran	512
The ROSAT PSPC survey of the Wolf-Rayet stars	

A.C. Rovero	518
Search for TeV γ -rays from Wolf-Rayet stars	
I.I. Antokhin, S.V. Marchenko, A.F.J. Moffat	520
Intensive narrow-band continuum photometric monitoring of the WN5+O6 binary V444 Cygni: evidence for wind collision?	
I.R. Stevens, A.M.T. Pollock	522
Stagnation-point flow in colliding-wind binary systems	
M. Jardine, H.R. Allen, A.M.T. Pollock	523
Magnetic annihilation in colliding-wind binary systems	
R. Walder, D. Folini	525
Instabilities in colliding winds	
SESSION VIII – Chair: Regina E. Schulte-Ladbeck	
Hydrodynamics and high-energy physics of winds accreting on neutrons stars and black holes	
M.H. van Kerkwijk	527
Cygnus X-3 an evolutionary missing link found? (<i>Invited</i>)	
G. Koenigsberger	538
Line profile variations in WR + collapsed companion systems (<i>Invited</i>)	
R.J. Davis, M.F. Bode, K.A. van der Hucht, P.M. Williams	547
Radio images of Wolf-Rayet 147	
B.E. Zhilyaev, V.R. Khalack, I.A. Verlyuk	550
Some results of high-speed two-channel photometry of Wolf-Rayet stars with suspected compact companions	
E.J.A. Meurs, A.J.M. Pijpers	554
OeBe stars with possible compact companions observed at X-rays	
Session VIII poster summaries	
K.A. van der Hucht, P.M. Williams, T.A.Th. Spoelstra, J.P. Swaanenveld	559
Radio monitoring of the non-thermal Wolf-Rayet objects WR125, WR146 and WR147	
S.V. Marchenko, I.I. Antokhin, J.-F. Bertrand, R. Lamontagne, A.F.J. Moffat, A. Piceno, J.M. Matthews	562
Search for short-time periodic variations among WR+c binaries	
SESSION IX – SUMMARY	
P.S. Conti	565
Summary talk (<i>Invited</i>)	
AUTHOR INDEX	573
OBJECT INDEX	575