

IAU Symposium

361

8–13 May 2022

Ballyconnell, Republic of Ireland

Proceedings of the International Astronomical Union

Massive Stars Near and Far

Edited by

Jonathan Mackey

Jorick S. Vink

Nicole St-Louis

ISSN 1743-9213

International Astronomical Union



CAMBRIDGE
UNIVERSITY PRESS



MASSIVE STARS NEAR AND FAR
IAU SYMPOSIUM 361

COVER ILLUSTRATION:

Hubble Space Telescope image of the cluster of massive stars, Pismis 24, and part of the emission nebula NGC 6357 (Credit:NASA/ESA/Hubble and Jesús Maíz Apellániz) overlaid on an image of the Poul nabrone Dolmen in the West of Ireland

Credit: Steve Ford Elliott. Poster credit: Morgan Fraser, Sophie Murray.

IAU SYMPOSIUM PROCEEDINGS SERIES

Chief Editor

JOSÉ MIGUEL RODRIGUEZ ESPINOSA, General Secretariat

Instituto de Astrofísica de Andalucía

Glorieta de la Astronomía s/n

18008 Granada

Spain

IAU-general.secretary@iap.fr

Editor

DIANA WORRALL, Assistant General Secretary

HH Wills Physics Laboratory

University of Bristol

Tyndall Avenue

Bristol

BS8 1TL

UK

IAU-assistant.general.secretary@iap.fr

INTERNATIONAL ASTRONOMICAL UNION
UNION ASTRONOMIQUE INTERNATIONALE

International Astronomical Union



MASSIVE STARS NEAR AND FAR

PROCEEDINGS OF THE 361st SYMPOSIUM OF
THE INTERNATIONAL ASTRONOMICAL UNION
BALLYCONNELL, REPUBLIC OF IRELAND
8–13 MAY 2022

Edited by

JONATHAN MACKEY

Dublin Institute for Advanced Studies, Ireland

JORICK S. VINK

Armagh Observatory and Planetarium, Northern Ireland

and

NICOLE ST-LOUIS

Université de Montréal, Canada



CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
1 Liberty Plaza, Floor 20, New York, NY 10006, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

© International Astronomical Union 2024

This book is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of the International Astronomical Union.

First published 2024

Printed in Great Britain by Henry Ling Limited, The Dorset Press, Dorchester, DT1 1HD

Typeset in System L^AT_EX 2 ϵ

*A catalogue record for this book is available from the British Library of Congress
Cataloguing in Publication data*

This journal issue has been printed on FSCTM-certified paper and cover board. FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests. Please see www.fsc.org for information.

ISBN 9781108490658 hardback
ISSN 1743-9213

Table of Contents

Preface to the Proceedings	xvi
Editors of the Proceedings	xx
List of Participants	xxi
Open questions in massive star research	1
<i>N. Langer</i>	
Chapter I: Observations of massive stars near and far	
ULLYSES and Complementary Surveys of Massive Stars in the Magellanic Clouds	15
<i>Paul A. Crowther</i>	
Massive Stars in Low-metallicity Galaxies in the CLASSY Survey	26
<i>Danielle A. Berg, Beth L. James, Teagan King, Meaghan McDonald, Zuyi Chen, John Chisholm, Timothy Heckman, Crystal L. Martin, Dan P. Stark and The CLASSY Team</i>	
Observations of Very Low-Metallicity Massive Stars	36
<i>Miriam Garcia</i>	
Global Properties of Star-Forming Galaxies from Ultraviolet Spectroscopy	46
<i>Claus Leitherer, Ilyse Clark, Karla Arellano-Córdova and Danielle A. Berg</i>	
One step closer to the First Stars: +150 OB stars in the metal-poor galaxy Sextans A	52
<i>Marta Lorenzo, Miriam Garcia and Francisco Najarro</i>	
NGC 3125-A1 revisited at higher spectral resolution with COS G160M	58
<i>A. Wofford, A. Sixtos, L. Smith, S. Charlot and G. Bruzual</i>	
Massive stars in metal-poor dwarf galaxies are often extreme rotators	63
<i>Abel Schootemeijer, Danny J. Lennon, Miriam Garcia, Norbert Langer, Ben Hastings and Christoph Schürmann</i>	
Constraining the behaviour of the young massive stars through interferometry	70
<i>Emma Bordier, Abigail J. Frost, Hugues Sana and Antoine Mérand</i>	
The Gaia view on massive stars: EDR3 and what to expect from DR3	76
<i>Jesús Maíz Apellániz, Rodolfo H. Barbá, Michelangelo Pantaleoni González, Michael Weiler, B. Cameron Reed, Román Fernández Aranda, Pablo Crespo Bellido, Alfredo Sota, Emilio J. Alfaro and J. Alejo Molina Lera</i>	
Dynamical vs Supernova Acceleration of OB Stars in the Small Magellanic Cloud	82
<i>M. S. Oey, J. Dorigo Jones, G. D. Phillips, N. Castro, M. M. Dallas and M. Moe</i>	

Dissecting the very metal-poor galaxy SBS0335-052E with MUSE: massive stars vs. nebular HeII emission	88
<i>C. Kehrig, J. M. Vílchez, M. A. Guerrero, J. Iglesias-Páramo, L. K. Hunt, S. Duarte Puertas and G. Ramos-Larios</i>	
Hot stars in the Gaia-ESO Survey	95
<i>R. Blomme, S. Daflon, M. Gebran, A. Herrero, A. Lobel, L. Mahy, F. Martins, T. Morel, S. R. Berlanas, E. Gosset, J. Maíz Apellániz and GES Working Group 13</i>	
An infrared view of NGC3603	97
<i>Raúl Castellanos, Francisco Najarro, Miriam García, Lee R. Patrick, Christopher J. Evans, Elizabeth S. Bartlett and J. S. Clark</i>	
The largest and most ambitious quantitative spectroscopic analysis of B-type supergiants in the Milky Way	100
<i>Abel de Burgos, Sergio Simon-Díaz and Miguel A. Urbaneja</i>	
Apparently isolated massive stars within Galactic HII regions	103
<i>Diego de la Fuente, Amparo Marco, Ignacio Negueruela, Lee R. Patrick, Artemio Herrero and Stephen S. Eikenberry</i>	
MAGIC Intensity Interferometer as a powerful tool to understand massive stars	105
<i>Irene Jiménez Martínez, V. A. Acciari, E. Colombo, J. Cortina, C. Delgado, C. Díaz, D. Fink, M. Fiori, D. Guberman, T. Hassan, E. Lyard, S. Mangano, M. Mariotti, G. Martínez, R. Mirzoyan, G. Naletto, T. Njoh Ekoume, N. Produit, M. Polo, J. J. Rodríguez, T. Schweizer, R. Walter, C. Wunderlich and L. Zampieri for the MAGIC collaboration</i>	
Fundamental parameters for 222 B-type stars for the X-shooter Spectral Library	108
<i>C. J. K. Larkin, Kristiina Verro, Anaïs Gonneau and S. C. Trager</i>	
Alicante Survey of Massive Stars in H II regions (A-SMASHER)	111
<i>A. Marco, I. Negueruela, D. de la Fuente, L. R. Patrick, A. Herrero and S. S. Eikenberry</i>	
Infrared studies of the massive stellar population at the Galactic Center and the inner disk	114
<i>Francisco Najarro, J. S. Clark, Marcus Lohr, Lee R. Patrick, Miriam García, Raúl Castellanos, Gonzalo Muñoz-Sánchez and Diego de la Fuente</i>	
Unraveling massive star and binary physics in the nearby low-Z galaxy SMC as a proxy for high-redshift galaxies	116
<i>Daniel Pauli</i>	
Revisiting the Cygnus OB associations	119
<i>Alexis L. Quintana and Nicholas J. Wright</i>	
An exploration of Cygnus OB2 and perspectives for the upcoming WEAVE High-Resolution Cygnus Survey	122
<i>Sara R. Berlanas and Artemio Herrero</i>	

Chapter II: Stellar atmospheres and winds

Stellar Atmospheres and Supernovae: Systematic Errors	127
<i>D. John Hillier</i>	
Spectroscopic analyses of massive stars at different metallicities	139
<i>Wolf-Rainer Hamann</i>	
Next generation spectroscopic analysis for large samples of massive stars	145
<i>Joachim M. Bestenlehner</i>	
MUSE 3D spectroscopy of BA-type supergiants in NGC 300	151
<i>Gemma González-Torà, Miguel A. Urbaneja, Norbert Przybilla, Stefan Dreizler, Martin M. Roth, Sebastian Kamann and Norberto Castro</i>	
SPAMMS: applications and use cases for the 3D spectroscopic analysis technique to study deformed massive stars	157
<i>Michael Abdul-Masih</i>	
Mass loss and the Eddington parameter	163
<i>Joachim M. Bestenlehner</i>	
New empirical mass-loss rates and clumping properties of massive stars	168
<i>Calum Hawcroft, Hugues Sana, Laurent Mahy, J. O. Sundqvist, M. Abdul-Masih, J. C. Bouret, S. A. Brands, A. de Koter, F. A. Driessen and J. Puls</i>	
ISOSCELES: Grid of stellar atmosphere and hydrodynamic models of massive stars	174
<i>Ignacio Araya, Natalia Machuca, Michel Curé and Catalina Arcos</i>	
Access platform to our database of CMFGEN spectra for atmospheric studies of massive stars	177
<i>A. Payen-Sandoval, L. Arias, J. Zargó, A. Arrieta, C. R. Fierro-Santillán and J. Klapp</i>	
CMD for atmospheres of massive stars created by using CMFGEN synthetic spectra	179
<i>Anabel Arrieta, Agustín Payen-Sandoval, Lorena Arias, Janos Zsargo, Celia Fierro-Santillán and Jaime Klapp</i>	
Clumping and X-rays in cool B-Supergiants	182
<i>Matheus Bernini-Peron, W. L. F. Marcolino and A. A. C. Sander</i>	
The clumped winds of the most massive stars	184
<i>Sarah A. Brands, Alex de Koter, Joachim M. Bestenlehner, Paul A. Crowther, Jon O. Sundqvist, Joachim Puls, Saida M. Caballero-Nieves, Michael Abdul-Masih, Florian A. Driessen, Miriam García, Sam Geen, Götz Gräfenor, Calum Hawcroft, Lex Kaper, Zsolt Keszthelyi, Norbert Langer, Hugues Sana, Fabian R. N. Schneider, Tomer Shenar and Jorick S. Vink</i>	
New self-consistent wind parameters to fit optical spectra of O-type stars	190
<i>Alex Camilo Gormaz-Matamala</i>	

Structure in stellar winds of early B type supergiants	192
<i>Timothy N. Parsons, Raman K. Prinja, Lidia M. Oskinova and Derck L. Massa</i>	
Upper Mass-Loss Limits and Clumping in the Intermediate and Outer Wind Regions of OB stars	194
<i>M. M. Rubio-Díez, J. O. Sundqvist, F. Najarro, A. Traficante, J. Puls, L. Calzoletti and D. Figer</i>	
Astro+: Design, construction, and scientific exploitation of a large-scale massive star spectroscopic database	197
<i>Klaus Rübke, Amparo Marco, Ignacio Negueruela, Artemio Herrero, Sergio Simon-Diaz, Hugo Tabernero and Lee Patrick</i>	
Quantitative spectroscopy of mid B-type supergiants	200
<i>David Weßmayer, Norbert Przybilla and Keith Butler</i>	
Chapter III: Physical processes in massive stars	
Wind line variability and intrinsic errors in observational mass loss rates	205
<i>Derck Massa and Raman Prinja</i>	
Magnetic massive stars from stellar mergers	212
<i>Fabian R. N. Schneider, Sebastian T. Ohlmann, Philipp Podsiadlowski, Friedrich K. Röpke, Steven A. Balbus, Rüdiger Pakmor and Volker Springel</i>	
Asteroseismology reveals the near-core magnetic field strength in the early-B star HD 43317	218
<i>D. M. Bowman, D. Lecoanet and T. Van Reeth</i>	
Constraining physical processes in pre-supernovae massive star evolution	224
<i>Erin R. Higgins, Jorick S. Vink, Andreas Sander and Raphael Hirschi</i>	
3D effects of rotation on spectroscopic observables	230
<i>Michael Abdul-Masih</i>	
First results of a magnetic survey of classical Cepheids	233
<i>James A. Barron, Gregg A. Wade, Colin P. Folsom and Oleg Kochukhov</i>	
A comprehensive empirical investigation of Galactic fast-rotating O-type stars	236
<i>N. Britavskiy, G. Holgado, S. Simón-Díaz, J. Maíz Apellániz, M. Pantaleoni González, Y. Nazé, S. Burssens and J. J. Eldridge</i>	
Can we detect deep axisymmetric toroidal magnetic fields in stars?	238
<i>Hachem Dhouib, Stéphane Mathis, Lisa Bugnet, Timothy Van Reeth and Conny Aerts</i>	
Apsidal motion in NGC 6231: Sounding the internal structure of massive stars	241
<i>S. Rosu, G. Rauw, M.-A. Dupret, A. Noels and M. Farnir</i>	
Apsidal Motion in Massive Binaries: CPD-41° 7742, an Extreme Case?	248
<i>S. Rosu, G. Rauw, Y. Nazé, E. Gosset and C. Sterken</i>	
Stability analysis of radial oscillation modes in massive stars	251
<i>J. P. Sánchez Arias, S. Guha and M. Kraus</i>	

Spins of stripped B stars support magnetic internal angular momentum transport 253
Christoph Schürmann, Norbert Langer, Xiao-Tian Xu and Chen Wang

Slowly-rotating nitrogen-rich O stars in 30 Doradus 256
F. Tramper

Nitrogen production in population III stars 259
S. Tsiatsiou, C. Georgy, S. Ekström and G. Meynet

Obliquely Rotating Massive Star Magnetospheres 261
Asif ud-Doula and Stanley P. Owocki

Chapter IV: Stellar multiplicity

The Nature of Unseen Companions in Massive Single-Line Spectroscopic Binaries 267
Hugues Sana, Michael Abdul-Masih, Gareth Banyard, Julia Bodensteiner, Dominic M. Bowman, Karan Dsilva, C. Eldridge, Matthias Fabry, Abigail J. Frost, Calum Hawcroft, Soetkin Janssens, Laurent Mahy, Pablo Marchant, Norbert Langer, Timothy Van Reeth, Koushik Sen and Tomer Shenar

Multiplicity of Galactic Luminous Blue Variable stars 273
Laurent Mahy, Cyprien Lanthermann, Eric Gosset, Damien Hutsemékers, Jacques Kluska, Alex Lobel, Maddalena Reggiani and Hugues Sana

Hunting for red supergiant binaries: UVIT photometry of the SMC 279
Lee R. Patrick, David Thilker, Danny Lennon, Luciana Bianchi, Abel Schootemeijer, Ricardo Dorda, Norbert Langer and Ignacio Negueruela

The impact of binary interaction on the main-sequence morphology of young star clusters 286
Chen Wang, Norbert Langer, Abel Schootemeijer, Antonino Milone, Ben Hastings, Xiao-Tian Xu, Julia Bodensteiner, Hugues Sana, Norberto Castro, D. J. Lennon, Pablo Marchant, A. de Koter and Selma E. de Mink

The spin rate properties of Galactic massive O-type stars 292
G. Holgado, S. Simón-Díaz, A. Herrero and R. H. Barbá

Near and far: a hunt for binary-interaction products 299
J. Bodensteiner, H. Sana, L. Mahy, T. Shenar, G. Banyard and C. Wang

Formation of black holes in the pair-instability mass gap: Hydrodynamical simulation of a massive star collision & evolution of a post-collision star 302
Guglielmo Costa, Alessandro Ballone, Michela Mapelli, Alessandro Bressan and Morgan MacLeod

Constraining the dynamical mass of the massive binary 9 Sagittarii 305
Matthias Fabry, Calum Hawcroft, Abigail J. Frost, Laurent Mahy, Pablo Marchant, Jean-Baptiste Le Bouquin and Hugues Sana

HR 6819 – a post-interaction binary system originally thought to be a triple system containing a black hole	307
<i>Abigail J. Frost, Julia Bodensteiner, Thomas Rivinius, Dietrich Baade, Antoine Merand, Fernando Selman, Michael Abdul-Masih, Gareth Banyard, Emma Bordier, Karan Dsilva, Calum Hawcroft, Laurent Mahy, Maddalena Reggiani, Tomer Shenar, Mauricio Cabezas, Petr Hadrava, Marianne Heida, Robert Klement and Hugues Sana</i>	
Contact Tracing of Massive Binary Stars	311
<i>Jan Henneco, Fabian R. N. Schneider, Saskia Hekker and Eva Laplace</i>	
Hunting for massive binaries with a black-hole component using Gaia data	313
<i>Soetkin Janssens, T. Shenar, H. Sana, S. Faigler, N. Langer, P. Marchant, T. Mazeh, C. Schürmann and S. Shahaf</i>	
Multiplicity of Northern bright O-type stars with optical long baseline interferometry. Results of the pilot survey	316
<i>Cyprien Lanthermann</i>	
Deciphering hard disks	319
<i>Yaël Nazé, Gregor Rauw, Myron A. Smith and Christian Motch</i>	
Study of the Be/X-ray binary IGR J21343+4738 physical parameters based on the 15-years monitoring	321
<i>Evgeniia Nikolaeva and Ilfan Bikmaev</i>	
X-ray emission characteristics of an O+O binary HD 93205	323
<i>Bharti Arora and Jeewan C. Pandey</i>	
Massive stars and their large-separation low-mass companions in Sco OB1	326
<i>T. Pauwels, M. Reggiani, A. Rainot and H. Sana</i>	
Phase-resolved spectroscopic analysis of the eclipsing black hole X-ray binary M33 X-7	329
<i>Varsha Ramachandran</i>	
MWC 656: A Be+BH or a Be+sdO?	332
<i>Th. Rivinius, R. Klement, S. D. Chojnowski, D. Baade, K. Shepard and P. Hadrava</i>	
Observations south of HD 5980	334
<i>Andrés Sixtos, Aida Wofford and Antonio Peimbert</i>	
Plaskett's Star: a fundamental revision of the architecture of the system	336
<i>E. Stacey, G. A. Wade, J. H. Grunhut, C. P. Folsom and O. Kochukhov</i>	
Evolution and final fate of massive post-common-envelope binaries	339
<i>Dandan Wei, Fabian R. N. Schneider, Philipp Podsiadlowski, Eva Laplace, Jan Henneco, Friedrich K. Röpke and Marco Vetter</i>	

Chapter V: Stellar structure and evolution of single stars

Stellar Structure and Evolution of Massive Rotating Single Stars	343
<i>R. Hirschi, E. Kaiser, P. Eggenberger, S. Ekström, C. Georgy, A. Maeder and G. Meynet</i>	
Entrainment in 3D hydrodynamics simulations of neon burning	353
<i>F. Rizzuti, R. Hirschi, C. Georgy, W. D. Arnett, C. Meakin and A. StJ. Murphy</i>	
Two-dimensional models of fast rotating stars and mixing processes	359
<i>Michel Rieutord and Damien Gagnier</i>	
Very Massive Stars: Near and Far	369
<i>Sébastien Martinet, Georges Meynet, Sylvia Ekström, Cyril Georgy, Lionel Haemmerlé, Devesh Nandal and Raphael Hirschi</i>	
Massive star interiors revealed by gravity wave asteroseismology and high-resolution spectroscopy	376
<i>Dominic M. Bowman</i>	
Fundamental Properties of O and B Stars with Optical Interferometry	382
<i>Kathryn D. Gordon, Douglas R. Gies and Gail H. Schaefer</i>	
On the elusive detection of O-type stars close to the ZAMS: the empirical birthline of massive stars	388
<i>G. Holgado, S. Simón-Díaz and L. Haemmerlé</i>	
How to make an 85 Solar Mass Black Hole	391
<i>Ethan Winch, Jorick S. Vink, Erin Higgins and Gautham Sabhahit</i>	

Chapter VI: Cool supergiants

Variable mass loss on 100 yr timescales from massive yellow hypergiants	397
<i>René D. Oudmaijer and Evgenia Koumpia</i>	
Analytic, Turbulent Pressure Driven Mass Loss from Red Supergiants	404
<i>N. Dylan Kee and the MAESTRO Project</i>	
Strong lithium lines in red supergiants at different metallicities	410
<i>Ignacio Nequeruela, Javier Alonso-Santiago, Ricardo Dorda and Lee R. Patrick</i>	
On the Z-(in)dependence of the Humphreys-Davidson Limit	416
<i>Gautham N. Sabhahit, Jorick S. Vink, Erin R. Higgins and Andreas A. C. Sander</i>	
Red Supergiants in M31: The Humphreys-Davidson limit at high metallicity	422
<i>Sarah L. E. McDonald, Ben Davies and Emma R. Beasor</i>	
Luminous red supergiants in the Magellanic Clouds	429
<i>S. De Wit, A. Z. Bonanos, F. Tramper, M. Yang, G. Maravelias, K. Boutsia, N. Britavskiy and M. Zapartas</i>	

ASSESSing evolved massive stars in NGC 6822 and IC 10	432
<i>G. Munoz-Sanchez, G. Maravelias, A. Z. Bonanos, F. Tramper, S. de Wit and M. Yang</i>	

Chapter VII: Unsteady mass loss

Luminous blue variables and B[e] supergiants	437
<i>Andrea Mehner</i>	
Introducing the ASSESS project: Episodic Mass Loss in Evolved Massive Stars - Key to Understanding the Explosive Early Universe	447
<i>A. Z. Bonanos, G. Maravelias, M. Yang, F. Tramper, S. de Wit, M. Zapartas, K. Antoniadis, E. Christodoulou and G. Munoz-Sanchez</i>	
Using machine learning to investigate the populations of dusty evolved stars in various metallicities	454
<i>Grigoris Maravelias, Alceste Z. Bonanos, Frank Tramper, Stephan de Wit, Ming Yang, Paolo Bonfini, Emmanuel Zapartas, Konstantinos Antoniadis, Evangelia Christodoulou and Gonzalo Munoz-Sanchez</i>	
Wray 15-906 low mass Luminous Blue Variable in a pre-supernova stage	460
<i>O. Maryeva, V. Gvaramadze, A. Kniazev and L. Berdnikov</i>	

Chapter VIII: WR stars and Stellar Feedback

Wolf-Rayet stars: recent advances and persisting problems	465
<i>Tomer Shenar</i>	
The enigmatic winds of Wolf-Rayet stars: Results from dynamically consistent atmosphere modelling	473
<i>Andreas A. C. Sander</i>	
X-raying massive stars and their feedback near and far	479
<i>Lidia Oskinova</i>	
Properties of Primitive Galaxies	485
<i>Sara R. Heap, I. Hubeny, J.-C. Bouret, T. Lanz and J. Brinchmann</i>	
Intrinsic polarization of Wolf-Rayet stars due to the rotational modulation of the stellar wind	490
<i>Slah Abdellaoui, Jiří Krtička and Petr Kurfürst</i>	
Dependence of Wolf-Rayet wind clumping on the surface temperature	493
<i>André-Nicolas Chené, Nicole St-Louis, Guillaume Lenoir-Craig, Anthony F. J. Moffat and Kenneth Gayley</i>	
The multiplicity of Galactic Wolf-Rayet stars	496
<i>Karan Dsilva, Tomer Shenar, Hugues Sana and Pablo Marchant</i>	
M1-67 and RCW 58: nebulae around WN8h stars formed through CE evolution	499
<i>P. Jiménez-Hernández, S. J. Arthur, J. A. Toalá and A. P. Marston</i>	

Double Vision: Combining X-ray and Spectropolarimetric Observations of WR Binaries	502
<i>R. A. Johnson, Y. Nazé, T. Panzera, A. G. Fullard, J. R. Lomax, J. L. Hoffman and K. H. Nordsieck</i>	
Investigating the impact of different velocity fields on the spectral appearance of Wolf-Rayet stars	505
<i>R. R. Lefever, T. Shenar, A. A. C. Sander, L. Poniatowski, K. Dsilva and H. Todt</i>	
A search for correlations between Wolf-Rayet stochastic wind variability and stellar parameters	507
<i>Guillaume Lenoir-Craig, Nicole St-Louis, Anthony F. J. Moffat and Herbert Pablo</i>	
PION: Simulating bow shocks and circumstellar nebulae around massive stars	510
<i>Jonathan Mackey, Samuel Green, Maria Moutzouri, Thomas J. Haworth, Robert D. Kavanagh, Maggie Celeste, Robert Brose and Davit Zargaryan</i>	
Metal-poor Wolf-Rayet star enriching the ISM by nitrogen in the galaxy NGC 4068	513
<i>Anastasiya Yarovova, Oleg Egorov, Alexei Moiseev and Olga Maryeva</i>	
A SITELLE view of the Galactic Wolf-Rayet Nebulae NGC6888 and NGC2359	515
<i>N. St-Louis, C. Dumontier, M. Ruest and L. Drissen</i>	
 Chapter IX: Massive star formation near and far	
Formation of Very Low-metallicity Stars	521
<i>Kazuyuki Omukai</i>	
The origin of massive stellar systems via disk fragmentation	528
<i>G. André Oliva and Rolf Kuiper</i>	
Metallicity Dependences of Massive Star Formation from Theoretical and Observational Perspectives	534
<i>K. E. I. Tanaka, Y. Zhang, T. Shimonishi and R. Matsukoba</i>	
Formation of Supermassive Stars and the Direct Collapse to Black Holes	539
<i>John A. Regan</i>	
Constraints on the stellar upper mass limit from simulations of UV disk ablation	550
<i>N. Dylan Kee and Rolf Kuiper</i>	
Binarity in Massive Young Stellar Objects	556
<i>Robert G. Shenton, René D. Oudmaijer and Stuart L. Lumsden</i>	
In-Situ Field Massive Star Formation in the Small Magellanic Cloud	559
<i>I. Vargas-Salazar, M. S. Oey, J. R. Barnes, X. Chen, N. Castro, K. M. Kratter and T. A. Faerber</i>	

Chapter X: Stellar endpoints and gravitational waves

The Diversity of Massive Stellar Transients Found in Sky-surveys	565
<i>Joe Lyman</i>	
Weak Mass Loss from the Red Supergiant Progenitor of SN 2021yja	575
<i>Griffin Hosseinzadeh</i>	
Constraining massive star mass loss through supernova radio properties	580
<i>Takashi Moriya</i>	
Exploring a direct observational method to measure high-redshift cloud collapse timescales and GRB progenitor lifetimes	584
<i>Jeff Cooke, Nandita Khetan, Sandra Savaglio, Jielai Zhang and Mark Suhr</i>	
Metallicity distributions of core-collapse supernovae within 30Mpc: Evidence for a lack of single massive Ib progenitors at low metallicities	590
<i>Joanne L. Pledger, Rudi Ganss, Anne E. Sansom, Philip A. James, Joachim Puls and Stacey M. Habergham-Mawson</i>	
The evolution of binary-stripped stars: consequences for supernovae and black hole formation	596
<i>Eva Laplace, Fabian Schneider, Philipp Podsiadlowski, Selma de Mink, Stephen Justham, Mathieu Renzo, Ylva Göteborg, Rob Farmer and David Vartanyan</i>	
Low-frequency radio view of a fast-blue optical transient - AT 2018cow	602
<i>A. J. Nayana and Poonam Chandra</i>	
How Much Hydrogen is in Type Ib and IIb SN Progenitors?	605
<i>Avishai Gilkis and Iair Arcavi</i>	
Supplying angular momentum to the jittering jets explosion mechanism using convection in inner star layers	607
<i>Dmitry Shishkin</i>	
Observations and modeling of two Type IIP supernovae in M61: similar yet so different	610
<i>Rishabh Singh Teja, G. C. Anupama and D. K. Sahu</i>	
Progenitors and companions of stripped-envelope supernovae	612
<i>E. Zapartas, O. Fox, T. Fragos, M. Renzo, J. Andrews, S. S. Bavera, A. Dotter, M. Drout, S. van Dyk, D. Milisavljevic, K. Koulakas, D. Misra, K. Rocha, N. Smith, B. Williams and Z. Xing</i>	
Numerical modeling of IR SEDs of dusty CCSN within a Bayesian framework	615
<i>Szanna Zsíros, Ilse De Looze and Tamás Szalai</i>	

Chapter XI: Future instrumentation and facilities

Ultraviolet observations of massive stars and the instrumentation to come	621
<i>Ana I. Gómez de Castro</i>	

The CubeSpec space mission: Asteroseismology of massive stars from time-series optical spectroscopy	630
<i>D. M. Bowman, B. Vandebussche, H. Sana, A. Tkachenko, G. Raskin, T. Delabie, B. Vandoren, P. Royer, S. Garcia, T. Van Reeth and the CubeSpec Collaboration</i>	
Polstar : a FUV Spectropolarimetry Mission	633
<i>Nicole St-Louis and the Polstar consortium</i>	
Author Index	637

Preface to the Proceedings

The organisers of IAU Symposium 361, “Massive Stars Near and Far”, were delighted to finally welcome participants to Ireland from 8-13th May 2022. This was the first IAU Symposium hosted in Ireland since IAUS 230: “Populations of High-Energy Sources in Galaxies” in 2005, and followed a milestone event for the development of Astronomy research in Ireland: the accession of Ireland to the European Southern Observatory (ESO) in 2018. The conference was originally scheduled for May 2020 but was among the first wave of meetings that had to be postponed indefinitely following the outbreak and global spread of the COVID-19 pandemic in February and March 2020. At the time we couldn’t imagine that all of our lives would be so fundamentally changed in the intervening period, or that it would take so long just to reschedule an international conference! During this time the LOC had two PhD graduations, one retirement, babies born and many career paths changed.

The Symposium was the latest in the long-standing series of Massive Star conferences, taking place roughly every four years since the first one in 1971 in Buenos Aires, Argentina (IAU Symposium 49: “Wolf-Rayet and High-Temperature Stars”). The last meeting in this series was the very successful IAU Symposium 329 in Auckland, NZ in 2016, “The lives and death-throes of massive stars”. The Ireland meeting was originally to take place in Puerto Rico but, following the devastating hurricane that hit the island, the organisers realised it would be impossible to host the conference, and so a call went out in January 2018 from IAU Commission G2 for expressions of interest proposing a new venue. Once Ireland was selected as the host, we set up an all-island LOC including researchers from the Republic and Northern Ireland, and chose the Slieve Russell Hotel and Country Club, near the border in Ballyconnell, Co. Cavan, as the meeting hotel. The SOC was drawn from a diverse group of researchers from all over the world. Little did the LOC and SOC members expect that they would be serving for 4 years, through planning for two in-person meetings (the first one postponed) and one virtual preview meeting, including 3 calls for abstracts that had to be reviewed by the SOC. We are very grateful to the enthusiastic and committed members of the LOC and SOC, who remained engaged and contributed hugely to making the meetings a success.

The short-notice postponement of the conference in May 2020 was difficult for both organisers and participants as many costs had already been paid for or committed. We are grateful to the vast majority of participants for their support and patience as we refunded registration fees. As it became clear that the pandemic would continue for some time, we decided to host a Virtual Preview Meeting in the week of 3-7 May 2021, so that the early career researchers with invited and contributed talks could finally present their research to the community. This virtual meeting was a great success, regularly having 180-200 participants logged-on for the talks, with an archive of talks on a private youtube channel for those in timezones that prevented live participation. A standout memory is Dylan Kee giving his talk live from Hawaii in the small hours of the morning, and still being awake enough to ask questions to the other speakers in the session.

The organisers are grateful to the IAU for allowing us to schedule the in-person meeting for 8-13 May 2022 and renewing the travel grant offers, enabling 35 researchers from 19 countries to come to the meeting in-person who otherwise would not have had the resources to participate. In total we had 211 participants from 32 countries representing all continents except Antarctica. The meeting venue, the Slieve Russell Hotel in Ballyconnell, Co. Cavan, Ireland, is located in a rural setting with almost all participants staying at the meeting hotel, ensuring plenty of informal interaction during the week over meals and walking on the extensive grounds. The excellent conference facilities

helped with social distancing and ventilation - high ceilings and a room that holds over 500 allowed us to seat everyone classroom style with generous spacing between tables, and with a large space for posters at the back of the hall.

The Symposium brought together observational and theoretical astrophysicists to discuss all aspects of massive stars: their formation, evolution, demise as supernovae and GRBs, and (for the first time in this series of Massive Stars Symposia!) gravitational waves from mergers of stellar-remnant neutron stars and black holes. The special focus for this meeting was on massive stars in the Early Universe, how they were born, lived and died, how they compare with massive stars in our Galaxy, how we can observe them and their imprint on the cosmos, and what we can learn from very low-metallicity galaxies in the local Universe. The scientific sessions were:

- | | |
|--|---------------------------|
| 1. Observations of massive stars near and far | (Chair: Jorick Vink) |
| 2. Stellar Atmospheres and Winds | (Chair: Nicole St Louis) |
| 3. Physical Processes in Massive Stars | (Chair: Dany Vanbeveren) |
| 4. Stellar Multiplicity | (Chair: Alceste Bonanos) |
| 5. Stellar Structure and Evolution of Single Stars | (Chair: Paco Najarro) |
| 6. Cool Supergiants | (Chair: Lidia Oskinova) |
| 7. Unsteady Mass Loss | (Chair: Morgan Fraser) |
| 8. Wolf-Rayet Stars and Stellar Feedback | (Chair: Raman Prinja) |
| 9. Massive Star Formation Near and Far | (Chair: Asif Ud-Doula) |
| 10. Stellar End-Points and Gravitational Waves | (Chair: Heloise Stevance) |
| 11. Future Instrumentation and Facilities | (Chair: Jonathan Mackey) |

“Massive stars: Near & Far” offered the opportunity for researchers working on massive stars in the Local Universe to interact with those working on massive stars at cosmological distances. After an opening by Prof Langer on the key outstanding questions from the birth to death of massive stars, Paul Crowther discussed the HST UV Legacy Project ULLYSES that targets local massive stars in nearby low metallicity galaxies, such as the LMC and the SMC.

After this introduction to massive stars in the local Universe (“Near”), we moved up in redshift, where the rest-frame UV is shifted towards higher wavelengths. Allison Strom started her talk explaining the relevance of “Cosmic Noon” where star formation in the Universe peaked, and massive stars look very different from those nearby. The speakers on the remainder of the first day intermittently discussed observations Near & Far. The final discussion was very lively, as it became clear that the combination of projects such as ULLYSES and CLASSY will be critical for understanding the data from the first generations of massive stars with JWST (first results had not yet come out at the time of the meeting, although there was great excitement and anticipation among the community).

The second & third day focused on the physics and evolution of single & binary massive stars nearby. One highlight was the discovery of a huge Mega-Gauss interior magnetic field at the core-envelope boundary from asteroseismology, by Dominic Bowman and collaborators. It is clear that multi-dimensional simulations are helping to progress our understanding of stellar interiors and surface layers, and promise significant advances in this decade. For studying populations of massive stars and identifying unusual objects, new surveys producing huge quantities of data, together with machine learning and other analysis tools, are rapidly expanding our knowledge of stellar diversity.

On Thursday the focus shifted to the formation of massive stars, both locally and in the early Universe, including a very informative overview talk by Ralf Klessen on “The First Stars”. As if massive stars and very massive stars (VMS), with masses over 100 solar masses, are not sufficiently spectacular, the discussion moved on to the formation

and existence of supermassive stars of order 100,000 Solar masses, which seem to be required to explain the formation of supermassive black holes already at very early times in the Universe.

It is an exciting time for transient science, with new discoveries from ongoing surveys and new facilities coming online in the next few years. Strategies for dealing with the deluge of data so that they can be dealt with by humans was a recurring theme of the session on stellar end-points and gravitational waves on Thursday. On Friday morning Ana Gomez de Castro told us about the planned future UV observatories, a key waveband for observations of massive stars and currently covered only by HST.

The week ended, like the life of a massive star, but this time not as a supernova or direct collapse to a Black Hole but with a golf analogy by Alex de Koter. The Summary was both informative and entertaining and participants departed in good spirits with huge amounts of energy and new ideas, after talking to old and new colleagues and friends after a 2 year delay.

Despite the limitations imposed on us by COVID-19, we still were able to run some of our planned public engagement and education activities related to massive stars. Deirdre Kelleghan (artist, amateur astronomer and educator) visited 4 primary schools in the Cavan area on the 9th and 10th of May, talked to them about astronomy, stars, telescopes including JWST, and the beauty of our Universe through painting and drawings. The Armagh Observatory and Planetarium generously donated their mobile planetarium and staff time for school visits on the 11th of May, a fabulous experience for the students.

There were two conference excursions, one to the Marble Arch Caves and the Cuilcagh Lakelands UNESCO Global Geopark, and the other to the seaside surfing town of Bundoran on the Wild Atlantic Way. The organisers got great feedback on both tours. The weather had not been great for the first two days, and so everyone appreciated a fresh and windy outdoor afternoon with a good walk in the hills or along the coastal cliffs, and even (for the brave few) sea swimming and surfing lessons.

During and after the meeting we received a lot of mostly positive feedback, mainly about how great it was for people to finally meet up again in-person with colleagues and friends from around the world. The conference facilities of the Slieve Russell Hotel were excellent and many people expressed surprise and delight that the B&B room rates were so reasonable for such facilities. Despite the Covid-precautions we took, we could not escape it completely with so many participants from many different countries at different stages of the pandemic. Quite a few of the participants reported to have tested positive for COVID after the end of the conference; thankfully most people had mild symptoms and as far as we know all made a complete recovery. There is no doubt that the meeting benefited from the feel-good factor of people being at a face-to-face meeting for the first time in more than 2 years, and this was reflected in the overwhelmingly positive spirit pervading the discussions, questions and answers, and social interaction throughout the week. The secluded location with a large residential conference hotel also contributed to this.

It bears repeating that we are especially grateful to the long-serving SOC and LOC who in the end planned two in-person meetings and one virtual meeting, and to the Organising Committee of Commission G2 and divisions G, B and C who supported us. The SOC went through nearly 500 abstracts over the 3 years of their service for the original meeting, the virtual preview, and the rescheduled meeting. Significant in-kind support for administration and finances from the Dublin Institute for Advanced Studies (DIAS) is also greatly appreciated. Local organisation was a marathon team effort from researchers and students at DIAS, Armagh Observatory and Planetarium, University College Dublin, Maynooth University and Trinity College Dublin.

In the months since the meeting took place we have seen the first spectacular results from JWST, fully justifying the investment of time and resources that this observatory required, and surpassing the hopes and expectations of the community with new discoveries about massive stars in our Galaxy and at the highest redshifts. Similarly, the first results from ULLYSES and related surveys are out and are enabling new discoveries about the low-metallicity population of massive stars in the local Universe. With the new Gravitational Wave observing runs starting in mid-2023, it is an exciting time to be working in our field. We look forward with great anticipation to the next Massive Stars Symposium in a few years time, and wish the organisers a successful meeting.

The Editors: Jonathan Mackey, Jorick S. Vink, Nicole St-Louis

Editors of the Proceedings

- Jonathan Mackey (Dublin Institute for Advanced Studies, Ireland)
- Jorick S. Vink (Armagh Observatory and Planetarium, Northern Ireland)
- Nicole St-Louis (Université de Montréal, Canada)

Scientific Organising Committee

- Paula Benaglia Instituto Argentino de Radioastronomía, Argentina
- Alceste Bonanos National Observatory of Athens, Greece
- Alex Carciofi Universidade de São Paulo, Brazil
- Sylvia Ekström University of Geneva, Switzerland
- Ana Gómez de Castro Universidad Complutense de Madrid, Spain
- Jose Groh Trinity College Dublin, Ireland
- Claus Leitherer Space Telescope Science Institute, USA
- Emily Levesque University of Washington, USA
- Jonathan Mackey (co-chair) Dublin Institute for Advanced Studies, Ireland
- Fabrice Martins CNRS, France
- Elena Rossi University of Leiden, Netherlands
- Nicole St-Louis Université de Montréal, Canada
- Jorick S. Vink (co-chair) Armagh Observatory and Planetarium, Northern Ireland
- Daniel Whalen University of Portsmouth, UK
- Naoki Yoshida University of Tokyo, Japan

Local Organising Committee

- Ioana Boian Trinity College Dublin, Ireland
- Seán Brennan University College Dublin, Ireland
- Morgan Fraser University College Dublin, Ireland
- Anne Grace Dublin Institute for Advanced Studies, Ireland
- Samuel Green Dublin Institute for Advanced Studies, Ireland
- Erin Higgins Armagh Observatory and Planetarium, Northern Ireland
- Jonathan Mackey Dublin Institute for Advanced Studies, Ireland
- Kate Maguire Trinity College Dublin, Ireland
- Maria Moutzouri Dublin Institute for Advanced Studies, Ireland
- Sophie Murray Dublin Institute for Advanced Studies, Ireland
- John Regan Maynooth University, Ireland
- Gautham Sabhahit Armagh Observatory and Planetarium, Northern Ireland
- Jorick S. Vink Armagh Observatory and Planetarium, Northern Ireland

List of Participants

Abdellaoui, Slah
Abdul-Masih, Michael
Aghakhanloo, Mojgan
Agliozzo, Claudia
Aguilera-Dena, David R.
Allan, Andrew
Andrassy, Robert
Antoniadis, Konstantinos
Araya, Ignacio
Arias, Lorena
Arora, Bharti
Arrieta, Anabel
Backs, Frank
Banyard, Gareth
Barron, James
Beasor, Emma
Berg, Danielle
Bernini Peron, Matheus
Bestenlehner, Joachim
Björklund, Robin
Blanchard, Peter
Blomme, Ronny
Bodensteiner, Julia
Bonanos, Alceste
Bordier, Emma
Bostroem, Azalee
Bowman, Dominic
Brands, Sarah
Brennan, Sean
Britavskiy, Nikolay
Broekgaarden, Floor
Brose, Robert
Bursens, Siemen
Burton, Michael
Byrne, Robert
Cannon, Emily
Castellanos Sánchez, Raúl
Chene, Andre-Nicolas
Christodoulou, Evangelia
Cooke, Jeff
Costa, Guglielmo
Crowther, Paul
Davies, Ben
de Burgos Sierra, Abel
de Koter, Alex
de la Fuente Guillen, Diego
de Mink, Selma
de Wit, Stephan
de Wit, Willem-Jan
Derkink, Annelotte
Dhouib, Hachem
Dorda, Ricardo
Drout, Maria
Dsilva, Karan
Ekström, Sylvia
Fabry, Matthias
Farrell, Eoin
Fitzpatrick, Beth
Fraser, Morgan
Frost, Abigail
Gagnier, Damien
Garcia, Miriam
Gilkis, Avishai
Goetberg, Ylva
Goldberg, Jared
Gomez de Castro, Ana
González-Torà, Gemma
Gordon, Kathryn
Gormaz Matamala, Alex
Graefener, Goetz
Grasha, Kathryn
Grassitelli, Luca
Green, Samuel
Gull, Maude
Haemmerle, Lionel
Hamann, Wolf-Rainer
Hawcroft, Calum
Heap, Sara
Henneco, Jan
Herrington, Nicholas
Higgins, Erin
Hillier, John
Hirschi, Raphael
Ho, Anna
Holgado, Gonzalo
Hosseinzadeh, Griffin
Hussaini, Maryam
J. Santos, Wilton
Jacobson-Galan, Wynn
Janssens, Soetkin
Jiménez Martínez, Irene
Jiménez-Hernández, Palmira
Johnson, Rachel
Johnston, Cole

Jung, Moo-Keon	O'Brennan, Hannah
Kamp, Keefe	O'Grady, Anna
Karamehmetoglu, Emir	O'Neill, David
Kee, N. Dylan	Oey, Sally
Kehrig, Carolina	Oliva, G. Andre
Keszthelyi, Zsolt	Olivier, Grace
Klement, Robert	Omand, Conor
Klencki, Jakub	Omukai, Kazuyuki
Klessen, Ralf	Oskinova, Lidia
Kolaczek-Szymanski, Piotr	Oudmaijer, Rene
Kotysz, Krzysztof	Owocki, Stanley
Kravtsov, Ihor	Pantaleoni, Michelangelo
Kremer, Kyle	Parsons, Timothy
Kummer, Floris	Patrick, Lee
Labadie-Bartz, Jonathan	Pauli, Daniel
Langer, Norbert	Pauwels, Tinne
Lanthermann, Cyprien	Penny, Laura
Laplace, Eva	Pistinner, Shlomi
Larkin, Cormac	Pledger, Joanne
Lazzarini, Margaret	Poniatowski, Luka
Lefever, Roel	Prentice, Simon
Leitherer, Claus	Prinja, Raman
Lenoir-Craig, Guillaume	Quintana Isasi, Alexis
Lorenzo, Marta	R. Aguilera-Dena, David
Lyman, Joe	Ramachandran, Varsha
Mackey, Jonathan	Regan, John
Madura, Thomas	Ren, Yi
Mahy, Laurent	Renzo, Mathieu
Maíz Apellániz, Jesús	Reyero Serantes, Sabela
Maravelias, Grigoris	Rickard, Matthew
Marchant, Pablo	Ricker, Paul
Marco, Amparo	Rieutord, Michel
Martinet, Sébastien	Rivinius, Thomas
Maryeva, Olga	Rizzuti, Federico
Massa, Derck	Roberti, Lorenzo
McDonald, Sarah	Rodriguez Berlanas, Sara
McQuinn, Kristen	Røed Ødegaard, Knut Jørgen
Mehner, Andrea	Rosen, Anna
Moens, Nicolas	Rosu, Sophie
Moriya, Takashi	Rubio Díez, Maria del Mar
Morris, Patrick	Rübke, Klaus
Moutzouri, Maria	Sabhahit, Gautham
Munoz Sanchez, Gonzalo	Sanchez, Julieta
Murphy, Laura	Sander, Andreas
Murray, Sophie	Schneider, Fabian
Najarro, Francisco	Schootemeijer, Abel
Nandal, Devesh	Schultz, William
Nazarenar Rodriguez, Cinthya	Schürmann, Christoph
Naze, Yael	Sen, Koushik
Negueruela, Ignacio	Senchyna, Peter
Nikolaeva, Evgeniia	Shenar, Tomer

Shenton, Robert	Vargas-Salazar, Irene
Shishkin, Dmitry	Villasenor, Jaime
Simón-Díaz, Sergio	Vink, Jorick S.
Sixtos, Andres	Wade, Gregg
Smartt, Stephen	Wang, Chen
Smith, Keith	Weßmayer, David
Smith, Nathan	Williamson, Marc
St-Louis, Nicole	Winch, Ethan
Stacey, Erik	Wofford, Aida
Stanway, Elizabeth	Woods, Paul
Stevance, Heloise	Woods, Tyrone
Stoop, Mitchel	Yarovova, Anastasiya
Strom, Allison	Yoon, Sung-Chul
Sushch, Iurii	Zapartas, Manos
Tanaka, Kei	Zsíros, Szanna
Teja, Rishabh Singh	Sana, Hugues
Telford, Grace	Humphreys, Roberta
Tinyanont, Samaporn	A.J., Nayana
Toonen, Silvia	Dorn-Wallenstein, Trevor
Tramper, Frank	Wei, Dandan
Tsiatsiou, Sophie	Massey, Philip
Tuquet, Selin	Neugent, Kathryn
ud-Doula, Asif	Cantiello, Matteo
van Son, Lieke	
Vanbeveren, Dany	

