



Universiteit
Leiden
The Netherlands

Orion's Dragon and other stories: Feedback by massive stars

Pabst, C.H.M.

Citation

Pabst, C. H. M. (2021, March 18). *Orion's Dragon and other stories: Feedback by massive stars*. Retrieved from <https://hdl.handle.net/1887/3147353>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3147353>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/3147353> holds various files of this Leiden University dissertation.

Author: Pabst, C.H.M.

Title: Orion's Dragon and other stories: Feedback by massive stars

Issue date: 2021-03-18

Orion's Dragon and Other Stories

Feedback by massive stars

ISBN: 978-94-6419-144-8

An electronic copy of this thesis can be found at <https://openaccess.leidenuniv.nl>

Cover design: As Orion, the Greek mythological hunter, was passing by the star-forming region of the nebula named in his honor, he beheld, by virtue of his infrared glasses, the funny creature that lived in its midst. The rotated and cropped data cube of the carbon far-infrared emission line came to be called Orion's Dragon. Front cover background image credit: Uwe Kindziorra; dragon drawing credit: Janneke de Jonge. Back cover: [C II] emission in three velocity channels (blue: 4-5 km s⁻¹, green: 8-9 km s⁻¹, red: 12-13 km s⁻¹).

Orion's Dragon and Other Stories

Feedback by massive stars

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof. dr. ir. H. Bijl,
volgens besluit van het College voor Promoties
te verdedigen op donderdag 18 maart 2021
klokke 16.15 uur

door

Cornelia Hilke Manuela Pabst

geboren op 18 september 1989
te Marburg, Duitsland

Promotores: Prof. dr. A. G. G. M. Tielens (Universiteit Leiden)
Dr. J. R. Goicoechea (Consejo Superior de Investigaciones Científicas)

Promotiecommissie

Voorzitter: Prof. dr. H. J. A. Röttgering (Universiteit Leiden)
Secretaris: Prof. dr. P. P. van der Werf (Universiteit Leiden)
Overige leden: Dr. L. D. Anderson (West Virginia University)
Dr. M. Gerin (École Normale Supérieure)
Prof. dr. C. R. O'Dell (Vanderbilt University)

Voor iedereen

„Zwei Dinge erfüllen das Gemüt mit immer neuer und zunehmender Bewunderung und Ehrfurcht, je öfter und anhaltender sich das Nachdenken damit beschäftigt: der bestirnte Himmel über mir und das moralische Gesetz in mir. Beide darf ich nicht als in Dunkelheiten verhüllt oder im Überschwenglichen, außer meinem Gesichtskreise suchen und bloß vermuten; ich sehe sie vor mir und verknüpfe sie unmittelbar mit dem Bewusstsein meiner Existenz.“

– Immanuel Kant („Kritik der praktischen Vernunft“, 1788)

Contents

1	Introduction	1
1.1	Feedback and the evolution of galaxies	1
1.2	Ionized gas, PDR structures, and forbidden lines	1
1.3	The Orion molecular cloud	4
1.4	SOFIA/upGREAT	5
1.5	Thesis outline	8
1.6	Outlook	9
1.7	Epilogue	11
2	[C II] emission from L1630 in the Orion B molecular cloud	13
2.1	Introduction	14
2.2	Observations	16
2.2.1	[C II] Observations	16
2.2.2	Dust SED Analysis	17
2.2.3	CO(1-0) Observations	18
2.2.4	H α Observations	19
2.3	Analysis	19
2.3.1	Kinematics: velocity channel maps	19
2.3.2	Global morphology	19
2.3.3	Kinematics: velocity-resolved line spectra	22
2.3.4	Edge-on PDR models	24
2.3.5	Correlation diagrams	26
2.4	Discussion	29
2.4.1	[C II] Emission from the PDR	29
2.4.2	[C II] Emission from the H II region	30
2.4.3	FIR emission and beam-dilution effects	31
2.4.4	Column densities, gas temperature, and mass	32
2.4.5	Excitation properties from [^{13}CII]	35
2.4.6	Photoelectric heating and energy balance	36
2.4.7	Line cuts	38
2.4.8	Geometry of the L1630 molecular cloud	40
2.4.9	Comparison with models	41
2.4.10	Comparison with OMC1 in the Orion A molecular cloud	43
2.5	Conclusion	44
2.A	Calculating [C II] optical depth and excitation temperature	47
2.B	Face-on calculation	47
3	Disruption of the Orion molecular core 1 by wind from the massive star θ^1 Orionis C	49
3.A	Methods	56
3.A.1	SOFIA observations	56
3.A.2	Orion	61
3.A.3	Kinematics of the gas	61
3.A.4	Mass estimates of the Veil	64

4 Expanding bubbles in Orion A: [C II] observations of M42, M43, and NGC 1977	69
4.1 Introduction	70
4.2 Observations	73
4.2.1 [C II] observations	73
4.2.2 CO observations	73
4.2.3 Dust maps	73
4.2.4 H α observations	75
4.3 Analysis	75
4.3.1 Global morphology	75
4.3.2 The expanding Veil shell – M42	76
4.3.3 M43	83
4.3.4 NGC 1977	86
4.4 Discussion	89
4.4.1 The pressure balance	92
4.4.2 Rayleigh-Taylor instability of the Veil shell	95
4.4.3 The structure of M43	97
4.4.4 The Veil stellar-wind bubble	98
4.4.5 The expanding bubble of θ^2 Ori A	101
4.4.6 The thermal bubbles of M43 and NGC 1977	102
4.4.7 Stellar wind versus thermal expansion of bubbles	103
4.5 Conclusion	106
4.A SED results	108
4.B The expanding Rim	108
4.C PV diagrams	111
5 [C II] 158 μm line emission from Orion A. I. A template for extra-galactic studies?	115
5.1 Introduction	116
5.2 Observations	118
5.2.1 [C II] observations	118
5.2.2 CO(2-1) observations	118
5.2.3 Dust SEDs	118
5.2.4 Ancillary photometric data	119
5.3 Analysis	120
5.3.1 Global morphology of the emission	120
5.3.2 Correlation plots of gas and dust tracers	121
5.4 Discussion	124
5.4.1 Comparison with Orion B	125
5.4.2 The [C II] deficit	126
5.4.3 The photoelectric heating efficiency	131
5.4.4 The origin of [C II] emission	132
5.4.5 Tracers of the star-formation rate	132
5.5 Conclusion	138
5.A Calculation of the ionization parameter γ	140

6 [C II] 158 μm line emission from Orion A. II. PDR physics	141
6.1 Introduction	142
6.2 Observations	144
6.3 Analysis	145
6.3.1 Global morphology and channel maps	145
6.3.2 Definition of regions	148
6.3.3 Edge-on PDR models	149
6.3.4 FIR versus distance	150
6.3.5 [C II] versus 70 μ m	152
6.3.6 [C II] versus FIR	154
6.3.7 [C II] versus 8 μ m	156
6.3.8 FIR versus 8 μ m	158
6.3.9 [C II] versus CO(2-1)	160
6.3.10 Summary of the correlation studies	161
6.4 Discussion	162
6.4.1 Comparison of PDR models with observations	162
6.4.2 The G_0 - p_{th} relationship	167
6.4.3 The origin of [C II] emission and CO-dark gas	169
6.4.4 Photoelectric heating efficiency	172
6.5 Conclusion	178
6.A Comparison with Lombardi SED fits	179
6.B Correlation plots from free- β SED fit	181
6.C SED fits to single points	183
6.D Spectral line fits	183
6.D.1 M42	183
6.D.2 M43	186
6.D.3 NGC 1977	186
6.D.4 Spectra behind the Bar	189
Samenvatting	203
Zusammenfassung	213
Publications	223
Curriculum Vitae	225
Acknowledgements	227

