

If you thought that science was certain -
well, that is just an error on your part.

Richard P. Feynman

NATURE AND NURTURE IN GALAXY FORMATION SIMULATIONS

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van de Rector Magnificus prof.mr. P.F. van der Heijden,
volgens besluit van het College voor Promoties
te verdedigen op dinsdag 7 december 2010
klokke 11.15 uur

door

Marcel Richard Haas

geboren te Oosterhout in 1983

Promotiecommissie

Promotor: Prof. dr. Marijn Franx

Co-promotor: Dr. Joop Schaye

Overige leden: Dr. Jarle Brinchmann
Prof. Dr. Koenraad Kuijken
Prof. Dr. Simon Portegies Zwart
Prof. Dr. Huub Röttgering
Prof. Dr. Scott Trager (Rijksuniversiteit Groningen)
Prof. Dr. Frank van den Bosch (Yale University)

Contents

| | | |
|----------|---|------------|
| 1 | Introduction | 1 |
| 1.1 | Galaxy formation | 2 |
| 1.2 | Numerical simulations | 7 |
| 1.3 | The Overwhelmingly Large Simulations | 10 |
| 1.4 | Thesis summary | 10 |
| 1.5 | The (near) future | 12 |
| 2 | Physical properties of simulated galaxies from varying input physics | 13 |
| 2.1 | Introduction | 14 |
| 2.2 | Numerical techniques | 16 |
| 2.3 | Cosmology | 28 |
| 2.4 | Metal-line cooling | 30 |
| 2.5 | Reionization variations | 33 |
| 2.6 | The polytropic equation of state for high density gas | 35 |
| 2.7 | The star formation law | 35 |
| 2.8 | The stellar initial mass function | 38 |
| 2.9 | Supernova feedback | 43 |
| 2.10 | AGN feedback | 55 |
| 2.11 | Conclusions | 58 |
| 2.A | Numerical convergence tests | 62 |
| 2.B | The energy and momentum in momentum driven wind models | 66 |
| 3 | Disentangling galaxy environment and host halo mass | 69 |
| 3.1 | Introduction | 70 |
| 3.2 | Popular environmental parameters | 72 |
| 3.3 | Environmental parameters and their relation to halo mass | 75 |
| 3.4 | Environment as a measure of halo mass | 84 |
| 3.5 | Environment independent of halo mass | 87 |
| 3.6 | Conclusions | 96 |
| 3.A | Obtaining the halo mass from environmental parameters | 98 |
| 4 | The simulated galaxy luminosity function: input physics, dust attenuation and galaxy selection | 105 |
| 4.1 | Introduction | 106 |
| 4.2 | Simulations | 108 |
| 4.3 | Population synthesis | 111 |
| 4.4 | Dust attenuation | 116 |
| 4.5 | Mock images and galaxy selection | 120 |

CONTENTS

| | | |
|----------|--|------------|
| 4.6 | Conclusions | 127 |
| 4.A | Column densities in SPH simulations | 129 |
| 5 | Variations in Integrated Galactic Initial Mass Functions due to Sampling Method and Cluster Mass Function | 141 |
| 5.1 | Introduction | 142 |
| 5.2 | The underlying mass functions | 144 |
| 5.3 | Sampling techniques | 146 |
| 5.4 | Integrated galactic initial mass functions | 150 |
| 5.5 | The number of O-stars in the Milky Way | 158 |
| 5.6 | Galaxy evolution models | 162 |
| 5.7 | Conclusions | 167 |
| 6 | Nederlandstalige samenvatting | 171 |
| | Bibliography | 182 |
| | Publications | 193 |
| | Curriculum vitae | 194 |
| | Nawoord | 195 |