



Universiteit  
Leiden

The Netherlands

## **Elementary: the chemical fingerprints of massive galaxy formation over cosmic time**

Cheng, C.M.T.

### **Citation**

Cheng, C. M. T. (2026, June 25). *Elementary: the chemical fingerprints of massive galaxy formation over cosmic time*. Retrieved from <https://hdl.handle.net/1887/4307012>

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/1887/4307012>

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

# Elementary

The chemical fingerprints of massive galaxy formation  
over cosmic time

## Proefschrift

ter verkrijging van  
de graad van doctor aan de Universiteit Leiden,  
op gezag van rector magnificus prof.dr. S. de Rijcke,  
volgens besluit van het college voor promoties  
te verdedigen op donderdag 25 juni 2026  
klokke 13:00 uur

door

Chloe Mai Tam Cheng

geboren te Toronto, Canada  
in 1998

**Promotores:** Prof.dr. M. Kriek  
Prof.dr. P. G. van Dokkum (Yale University)

**Promotiecommissie:** Prof.dr. H. Hoekstra  
Prof.dr. I. A. G. Snellen  
Dr. J. A. Hodge  
Prof.dr. A. van der Wel (Universiteit Gent)  
Dr. R. Bezanson (University of Pittsburgh)

ISBN: 978-94-6534-444-7

Cover:  
*Design and layout by Jessica Lin*

*The price of success is steep and I've never been able to distinguish it from the feeling of sacrifice. If I could hold success in my hand, it would be a beating heart.*  
– Weike Wang, *Joan is Okay* (2022)

*There is no problem in science that can be solved by a man that cannot be solved  
by a woman.*  
– Vera C. Rubin, *Bright Galaxies, Dark Matter* (1996)



# CONTENTS

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Our working picture of massive galaxy formation . . . . .	1
1.2	Stellar populations: tracers of galaxy formation . . . . .	4
1.2.1	A stellar population cookbook . . . . .	4
1.2.2	Using stellar populations to investigate chemical enrichment . . . . .	7
1.2.3	Deducing stellar population properties with photometry . . . . .	10
1.2.4	Stronger inferences with spectroscopy . . . . .	12
1.3	Observational evidence for galaxy formation . . . . .	13
1.3.1	Clues from the low-redshift Universe . . . . .	15
1.3.2	Closing in on galaxy formation at higher redshifts . . . . .	17
1.4	This thesis . . . . .	20
1.5	Conclusions and outlook . . . . .	21
<b>2</b>	<b>Age and metal gradients in massive quiescent galaxies at <math>0.6 &lt; z &lt; 1.0</math>: implications for quenching and assembly histories</b>	<b>23</b>
2.1	Introduction . . . . .	24
2.2	Data and sample . . . . .	26
2.2.1	LEGA-C spectra . . . . .	26
2.2.2	Sample selection . . . . .	27
2.3	Methods . . . . .	29
2.3.1	Optimal extraction . . . . .	29
2.3.2	Convolved $R_e$ . . . . .	31
2.3.3	Full spectrum fitting . . . . .	33
2.4	Results . . . . .	34
2.4.1	Observed gradients . . . . .	34
2.4.2	Intrinsic metallicity gradients . . . . .	39
2.5	Discussion . . . . .	42
2.5.1	Colour gradients . . . . .	42
2.5.2	Implications for galaxy evolution . . . . .	45
2.5.2.1	Young quiescent galaxies . . . . .	45
2.5.2.2	Growth of the quiescent galaxy population . . . . .	46
2.5.2.3	Future work . . . . .	47
2.5.3	Caveats . . . . .	48
2.6	Summary and conclusion . . . . .	50
	Appendices . . . . .	53
2.A	Mock spectra tests . . . . .	53

2.B Duplicate objects . . . . .	56
<b>3 Ages and metallicities of quiescent galaxies: confronting broad-band (<math>UVJ</math>) colours with stellar absorption lines</b>	<b>59</b>
3.1 Introduction . . . . .	60
3.2 Data and methods . . . . .	62
3.2.1 LEGA-C . . . . .	62
3.2.2 Spectral extraction and full-spectrum modelling . . . . .	64
3.3 Results . . . . .	65
3.3.1 Trends with age and metallicity . . . . .	66
3.3.2 Comparison to stellar population models . . . . .	67
3.4 Discussion . . . . .	74
3.4.1 Comparison to previous work . . . . .	74
3.4.2 Implications for galaxy evolution studies . . . . .	75
3.4.3 Implications for SPS models . . . . .	79
3.4.4 Caveats . . . . .	81
3.5 Summary and conclusions . . . . .	83
<b>4 Clues to inside-out quenching in quiescent galaxies at <math>1.2 \lesssim z \lesssim 2.2</math>: Age, Fe-, and Mg-abundance gradients from <math>JWST</math>-SUSPENSE</b>	<b>87</b>
4.1 Introduction . . . . .	88
4.2 Data and sample . . . . .	90
4.3 Methods . . . . .	93
4.3.1 Correction of resampling noise . . . . .	93
4.3.2 Spectral extraction . . . . .	94
4.3.3 Determining distances and radii . . . . .	95
4.3.4 Full spectrum fitting . . . . .	97
4.4 Results . . . . .	100
4.4.1 Spatially resolved ages and elemental abundances . . . . .	100
4.4.2 Trends between gradients and galaxy parameters . . . . .	104
4.5 Discussion . . . . .	105
4.5.1 Implications for galaxy evolution . . . . .	105
4.5.1.1 Quenching at $z \sim 2$ . . . . .	106
4.5.1.2 Galaxy evolution towards $z \lesssim 1$ . . . . .	107
4.5.2 Caveats . . . . .	108
4.6 Summary and conclusions . . . . .	110
Appendices . . . . .	112
4.A Mock observations . . . . .	112
4.B Wiggle correction algorithm . . . . .	112
<b>5 Hidden mass in early galaxies revealed by bottom-heavy initial mass functions</b>	<b>117</b>
5.1 Article . . . . .	118
5.2 Methods . . . . .	127
5.2.1 Observing Strategy and Data Reduction . . . . .	127
5.2.2 Full-spectrum fitting . . . . .	128

---

5.2.3	Stellar velocity dispersions and virial masses . . . . .	132
5.3	Extended Data . . . . .	133
5.4	Supplementary Information . . . . .	140
<b>Bibliography</b>		<b>140</b>
<b>English Summary</b>		<b>163</b>
<b>Nederlandse samenvatting</b>		<b>171</b>
<b>Publications</b>		<b>179</b>
<b>Curriculum Vitae</b>		<b>183</b>
<b>Acknowledgments</b>		<b>187</b>