



Universiteit
Leiden
The Netherlands

Measuring gold molecular gas across cosmic time

Frias Castillo, M.

Citation

Frias Castillo, M. (2024, June 20). *Measuring gold molecular gas across cosmic time*. Retrieved from <https://hdl.handle.net/1887/3764659>

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/1887/3764659>

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

Measuring Cold Molecular Gas Across Cosmic Time

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 20 juni 2024
klokke 12.30 uur

door

Marta Frías Castillo

geboren te Granada, Spanje
in 1997

CONTENTS

1. Introduction	1
1.1. The Interstellar Medium	1
1.1.1. Star Formation	2
1.2. Cold Molecular Gas	4
1.2.1. Tracers of cold molecular gas	4
1.2.1.1. Carbon Monoxide	4
1.2.1.2. Atomic Carbon	5
1.2.1.3. Dust	6
1.2.2. Current results	7
1.3. Submillimeter Galaxies	8
1.3.1. Molecular Gas in SMGs	9
1.3.2. Towards large spectroscopically-confirmed SMG samples . .	12
1.4. Instruments	13
1.4.1. Karl G. Jansky Very Large Array (JVLA)	14
1.4.2. NORthern Extended Millimeter Array (NOEMA)	14
1.4.3. Atacama Large sub-Millimeter Array (ALMA)	14
1.5. This Thesis	16
1.6. Future Work	17
2. Kiloparsec-scale imaging of the CO(1-0)-traced cold molecular gas reservoir in a $z\sim 3.4$ submillimeter galaxy	19
2.1. Introduction	20
2.2. Observations and data reduction	22
2.2.1. JVLA K-Band	22
2.2.2. Plateau de Bure Interferometer	22
2.3. Results	23
2.3.1. CO(1-0) Line Detection	23
2.3.2. Moment Maps	27
2.3.3. Source Size Estimation	27
2.3.4. SED Fitting	27
2.4. Analysis	31
2.4.1. Molecular Gas Mass, Gas Fraction and Depletion Time . .	31
2.4.2. Dynamical Modeling and CO-H ₂ Conversion Factor	32
2.4.3. Gas Excitation	34
2.5. Discussion	36
2.5.1. Comparison with the literature	36

2.5.2. The fate of SMM J13120	37
2.6. Conclusion	39
2.7. Acknowledgements	40
Appendices	40
2.A. Appendix	40
3. At the end of cosmic noon: Short gas depletion times in unobscured quasars at $z \sim 1$	45
3.1. Introduction	46
3.2. Observations and data reduction	49
3.2.1. Target sample	49
3.2.2. NOEMA observations and data reduction	50
3.3. Results	51
3.3.1. CO(2–1) line	51
3.3.2. Rest-frame 1.3-mm continuum	51
3.3.3. Upper limits on outflow flux	57
3.3.4. Spectral energy distribution decomposition	57
3.3.5. Spectral stacking - Upper limits on dense-gas tracers	59
3.4. Analysis	59
3.4.1. Unobscured QSOs on the SFR– M_* plane	61
3.4.2. L'_{CO} versus L_{IR}	61
3.4.3. L'_{CO} and gas masses	64
3.4.4. Gas fractions and depletion times	67
3.4.5. Comparison with simulations	70
3.5. Discussion	72
3.6. Conclusions	74
3.7. Acknowledgements	75
Appendices	76
3.A. Observations summary	76
3.B. SED fits	76
4. VLA Legacy Survey of Molecular Gas in Massive Star-forming Galaxies at High Redshift	81
4.1. Introduction	82
4.2. Observations and data reduction	83
4.2.1. Sample	83
4.2.2. Observations	86
4.3. Results	86
4.3.1. Line Detections	86
4.3.2. SED Fitting	89
4.4. Analysis	91
4.4.1. CO Line Luminosities	91
4.4.2. Gas masses, gas fractions and depletion times	93
4.4.3. Comparison with Dust-based Gas Mass Estimates	96
4.4.4. CO Spectral Line Energy Distributions and Line Ratios	98
4.4.5. Comparison With Semi-analytic Models	103

4.5. Conclusions	105
4.6. Acknowledgements	106
Appendices	108
4.A. Curve of Growth	108
4.B. Non Detections	108
5. A Comparative Study of the Ground State Transitions of CO and [C I] as Molecular Gas Tracers at High-Redshift	111
5.1. Introduction	112
5.2. Data Reduction and Results	115
5.2.1. Sample	115
5.2.2. JVLA CO(1-0) Data	116
5.2.3. ALMA Data and Reduction	116
5.2.4. [C I] Line and Continuum Detections	119
5.3. Analysis	119
5.3.1. [C I] Line Luminosities	119
5.3.2. PDR Modelling	121
5.3.3. Comparison Between Molecular Gas Tracers	122
5.3.3.1. [C I](1-0) Line Emission as a Gas Mass Tracer	123
5.3.3.2. Dust Continuum Emission as a Gas Mass Tracer	124
5.3.4. CMB Effect on CO and [C I] Emission at High Redshift	125
5.4. Discussion	128
5.5. Conclusions	131
5.6. Acknowledgments	131
Appendices	132
5.A. CMB Effect on Dust Emission	132
Bibliography	132
English Summary	149
Nederlandse samenvatting	153
Resumen	157
Publications	161
Curriculum Vitae	163
Acknowledgements	165

