

# Table of contents

1	Introduction	9
1.1	Star formation process	9
1.1.1	The challenge of high-mass star formation	10
1.2	The importance of high-mass star-forming regions for the Solar system formation	16
1.3	Astrochemical processes in the interstellar medium	18
1.3.1	Gas-phase chemistry	20
1.3.2	Type of reactions	21
1.4	Isotopic fractionation in the context of star formation	24
1.4.1	The evolution of chemical complexity during star formation	24
1.4.2	The heritage of the Solar system	26
1.4.3	Deuterium enrichment during star formation	29
1.4.4	Nitrogen fractionation in the ISM	35
1.5	Thesis project	57
2	Nitrogen and hydrogen fractionation in high-mass star-forming regions	59
2.1	Introduction	60
2.2	Observations and data reduction	61
2.3	Results: column densities and isotopic ratios	62
2.3.1	$\text{H}^{15}\text{NC}$ , $\text{HN}^{13}\text{C}$ , $\text{HC}^{15}\text{N}$ , and $\text{H}^{13}\text{CN}$	62
2.3.2	DNC	75
2.4	Isotopic fractionation	78
2.4.1	$^{15}\text{N}$ -fractionation as a function of evolutionary stages	78
2.4.2	D-fractionation	83
2.4.3	Comparison between D/H and $^{14}\text{N}/^{15}\text{N}$	83
2.5	The HCN/HNC ratio	84
2.6	Conclusions	86

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup\_best\_practice)

Laura Colzi, *Isotopic fractionation study towards massive star-forming regions across the Galaxy*, © 2021 Author(s), content CC BY 4.0 International, metadata CC0 1.0 Universal, published by Firenze University Press (www.fupress.com), ISSN 2612-8020 (online), ISBN 978-88-5518-380-2 (PDF), DOI 10.36253/978-88-5518-380-2

3	Nitrogen fractionation across the Galaxy	89
3.1	Introduction	90
3.2	Sample and observations	91
3.2.1	Description of the sample	91
3.2.2	Observations	94
3.3	Results	95
3.3.1	Line detection	95
3.3.2	Fitting procedure and column density calculation	100
3.3.3	$^{14}\text{N}/^{15}\text{N}$ ratios	115
3.4	The Galactocentric behaviour	117
3.4.1	Linear analysis	117
3.4.2	Parabolic analysis	119
3.5	Discussion and Conclusions	122
4	Enhanced nitrogen fractionation at core scales	129
4.1	Introduction	130
4.2	Source and observations	131
4.3	Results	135
4.3.1	Continuum map	135
4.3.2	Morphology of $\text{N}_2\text{H}^+$ and $^{15}\text{N}$ -isotopologues emission	135
4.3.3	Fitting procedure and column density calculation	138
4.3.4	$^{14}\text{N}/^{15}\text{N}$ ratios	147
4.4	Discussion of the results	148
4.4.1	Comparison between line and continuum emission maps	148
4.4.2	Is N-fractionation a core-scale effect?	150
4.4.3	$^{15}\text{NNH}^+$ vs $\text{N}^{15}\text{NH}^+$	152
4.4.4	$^{14}\text{N}/^{15}\text{N}$ ratios in diffuse regions	153
4.5	Conclusions	154
5	Carbon isotopic fractionation: a new detailed chemical study	157
5.1	Introduction	158
5.2	Model	162
5.2.1	Chemical model	162
5.2.2	Introduction of $^{13}\text{C}$ -fractionation in the chemical model	165
5.2.3	Isotopic exchange reactions	166
5.3	Results and Discussion	168
5.3.1	The fiducial model	169
5.3.2	The importance of $\text{C}_3$ isotopic-exchange reaction	174
5.3.3	Parameter space exploration	178
5.4	Conclusions	182
6	Summary and Main Conclusions	185
A	Appendix: Spectra simulation tests	191
A.1	$^{15}\text{N}$ -isotopologues at lower spectral resolution	191
A.2	$\text{N}_2\text{H}^+$ at higher spectral resolution	192

A.3 The effect of a possible $\text{N}_2\text{H}^+$ line saturation	193
Bibliography	197
Ringraziamenti	223
Acknowledgments	225