UNIVERSITY of CALIFORNIA
SANTA CRUZ

THE LOW IONIZATION GASEOUS CONTENT IN INTERMEDIATE REDSHIFT GALAXIES

A dissertation submitted in partial satisfaction of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ASTRONOMY AND ASTROPHYSICS

by

Christopher W. Churchill

March 1997

The dissertation of Christopher W. Churchill is approved:

Steven S. Vogt, Chair

Frank D. Drake

Kenneth M. Lanzetta

Charles C. Steidel

Dennis Zaritsky

Dean of Graduate Studies

The Low Ionization Gaseous Content
in Intermediate Redshift Galaxies

Copyright © by
Christopher W. Churchill
1997

Abstract

The Low Ionization Gaseous Content
in Intermediate Redshift Galaxies

by

Christopher W. Churchill

The kinematic, chemical, and ionization conditions and spatial distributions of low ionization gas associated with early epoch galaxies have been studied using high resolution (6.6 km s^{-1}) absorption line spectra.

The absorption profiles for a total of 48 Mg II selected systems were obtained from 25 quasar (QSO) spectra observed with the HIRES spectrograph on the Keck I telescope. In addition to the Mg II $\lambda\lambda 2976, 2803$ doublet, also observed were the Mg I $\lambda 2853$ transition and multiple transitions of Fe II. In some cases, Mn II and Ca II were detected. The absorption profiles were objectively searched for weak absorbing subsystems. For each overall system, and for each of their multiple subsystems, absorption properties were measured directly from the flux values in the spectra. Additionally, the systems were fitted by Voigt Profile (VP) decomposition using an algorithm written for this work. Extensive simulations of the VP decomposition were performed in order to establish confidence levels on inferences based upon VP profile fits.

Main results include: (1) "High velocity" subsystems exhibit rest–frame equivalent widths less than 0.1 Å and velocity widths less than 10 km s^{-1}. There is no evidence of a turnover in the equivalent widths of these subsystems down to 0.005 Å. Thus, no lower limit on the size and column density of the clouds has been found to this limit. (2) The individual cloud temperatures are $\sim 30,000$ K and they are relatively quiescent in that they are consistent with having a zero non–thermal broadening component. (3) The power–law slope of the column density distributions for Mg II, Fe II, and Mg I were measured to be -1.58, -1.65, and -2.22. Within uncertainties, the Fe II slope is consistent with that of Mg II. (4) For a subsample of 15 systems, the number of absorbing clouds does not follow any trend with projected galactocentric distance, suggesting that the gas clouds are *not* distributed isothermally within galactic halos, for example. (5) The spatial/kinematic model that is most consistent with the data is that in which the absorbing clouds are in an extended rotating disk with a surrounding diffuse infalling halo. The halo clouds are optically thin in H I and the dispersion in the disk is ~ 15 km s^{-1}.

Contents

List of Figures xiii

List of Tables xvii

Dedication xxi

Acknowledgements xxiii

1 Introduction **1**
- 1.1 Background . . . 1
- 1.2 Motivations . . . 2
- 1.3 The Data . . . 3
  - 1.3.1 The HIRES Spectra . . . 3
  - 1.3.2 SDP Galaxies . . . 3
- 1.4 HIRES/Keck Observations . . . 4

2 Data Reduction and Analysis **7**
- 2.1 Data Reduction . . . 7
  - 2.1.1 Instrumental Calibration . . . 7
  - 2.1.2 Cosmic Ray Removal and Calibration Uncertainties . . . 8
  - 2.1.3 Optimized Extraction of the Spectra . . . 9
  - 2.1.4 Wavelength Calibration . . . 10
  - 2.1.5 Heliocentric Correction . . . 10
- 2.2 Analysis of the Spectra . . . 10
  - 2.2.1 Continuum Normalization . . . 11
  - 2.2.2 Feature Identifications . . . 12
  - 2.2.3 The Absorber Redshifts . . . 13
  - 2.2.4 Limiting Rest Frame Equivalent Widths . . . 14
- 2.3 Equivalent Widths . . . 15
  - 2.3.1 Errors in the Equivalent Widths . . . 16
  - 2.3.2 Doublet Ratios and Their Errors . . . 17
- 2.4 Mean Velocities, Widths, and Asymmetries . . . 18
  - 2.4.1 AOD Mean Velocities . . . 18
  - 2.4.2 AOD Widths . . . 18
  - 2.4.3 AOD Asymmetries . . . 19

2.4.4 Errors in the AOD Mean Velocity, Width, and Asymmetries 19
2.5 Apparent Column Densities 21
2.5.1 Errors in the Apparent Column Densities 22
2.5.2 Adopted Apparent Column Densities 23
2.6 Voigt Profile Decomposition 24
2.6.1 Profile Fitting Philosophy 26
2.6.2 Profile Fitting: AUTOFIT and PROFIT 26
2.6.3 χ^2 Minimization: MINFIT 27

3 The Absorbing Systems 41
3.1 Absorption Properties of the Observed Systems 41
3.2 Redshift Distribution and Detection Sensitivity 42
3.3 Discussion of Individual Systems 44
3.3.1 Q0002 + 051 44
3.3.2 Q0058 + 019 44
3.3.3 Q0117 + 212 45
3.3.4 Q0420 − 014 46
3.3.5 Q0450 − 132 46
3.3.6 Q0454 + 039 47
3.3.7 Q0454 − 220 48
3.3.8 Q0823 − 223 48
3.3.9 Q1101 − 264 49
3.3.10 Q1148 + 384 50
3.3.11 Q1206 + 459 50
3.3.12 Q1213 − 003 51
3.3.13 Q1222 + 228 52
3.3.14 Q1225 + 317 53
3.3.15 Q1241 + 174 54
3.3.16 Q1248 + 401 54
3.3.17 Q1254 + 044 55
3.3.18 Q1317 + 274 55
3.3.19 Q1329 + 412 56
3.3.20 Q1354 + 193 57
3.3.21 Q1421 + 331 57
3.3.22 Q1548 + 093 59
3.3.23 Q1622 + 235 59
3.3.24 Q1634 + 706 60
3.3.25 Q2128 − 123 61
3.3.26 Q2145 + 064 61
3.4 Exploring the Absorption Properties 62
3.4.1 Spearman and Kendall Non–Parametric Tests 62
3.4.2 Overall Absorption Properties 63
3.4.3 Subfeature Absorption Properties 65
3.5 Comparing Integrated AOD and VP Column Densities 67

4 Assessing VP Decomposition of HIRES Spectra 217
4.1 Generation of the Simulated Spectra 218
4.1.1 VP Component Selection Criteria for Analysis 219
4.2 Simulation 1A: Column Density Completeness 220
4.2.1 The Lower–Limit Detectable Column Densities 220
4.2.2 Recovering Input Mg II Column Densities 221
4.3 Simulations 1B and 1C: Modeling Sensitivity 221
4.3.1 Effects of Input Model 222
4.4 Simulation 2: N and b Distributions 223
4.4.1 Recovering Input VP Parameters 223
4.4.2 Recovering Fe II to Mg II Input Relations 225
4.4.3 Inferred Turbulence in Thermal Clouds 226
4.5 Simulation 3: Effects From Blending 227
4.5.1 Effects on the Number of Components per System 229
4.5.2 Effects on the Inferred Distribution of Column Densities 229
4.5.3 Recovering the Fe II to Mg II Input Relations 230
4.5.4 Inferred Cloud Thermal/Non–Thermal Properties 231
4.5.5 Effects on the Doppler b and Velocity Distributions 231

5 Column Densities, Line Broadening, and Kinematics of Mg II Clouds 257
5.1 The Mg II, Fe II, and Mg I Column Densities 258
5.1.1 Distribution of VP Component Column Densities 261
5.2 Doppler Parameters 265
5.2.1 Distribution of Doppler Parameters 265
5.2.2 Inferring the Cloud Temperatures 266
5.2.3 Are Mg II Clouds Quiescent? 267
5.3 The Kinematics of Mg II Absorbing Gas 269
5.3.1 The Observed TPCF 269
5.3.2 Modeling the Cloud Kinematics 270

6 Exploring the Galaxy–Absorption Connection 299
6.1 Executive Summary 300
6.2 Introduction 300
6.3 Observations 301
6.4 Analysis 302
6.5 Testing For Correlations 303
6.6 A Second Look at the Galaxy/Halo Model 304
6.7 Discussion 306
6.8 Conclusions 308

7 Summary 319
7.1 Overview of Study 319
7.2 Main Results 321
7.3 Concluding Remarks 325

Bibliography **329**

List of Figures

2.1 Q0002 + 052: Feature and Equivalent Width Limit 33
2.2 Q0058 + 019: Feature and Equivalent Width Limit 33
2.3 Q0117 + 212: Feature and Equivalent Width Limit 33
2.4 Q0117 + 212: Feature and Equivalent Width Limit 34
2.5 Q0117 + 212 and Q0420 − 014: Feature and Equivalent Width Limit 34
2.6 Q0450 − 132: Feature and Equivalent Width Limit 34
2.7 Q0454 + 036: Feature and Equivalent Width Limit 35
2.8 Q0454 − 220: Feature and Equivalent Width Limit 35
2.9 Q0823 − 223: Feature and Equivalent Width Limit 35
2.10 Q1101 − 264: Feature and Equivalent Width Limit 36
2.11 Q1148 + 384 and Q1206 + 456: Feature and Equivalent Width Limit 36
2.12 Q1206 + 456 and Q1213 − 003: Feature and Equivalent Width Limit 36
2.13 Q1213 − 003 and Q1222 + 228: Feature and Equivalent Width Limit 37
2.14 Q1225 + 317 and Q1241 + 174: Feature and Equivalent Width Limit 37
2.15 Q1248 + 401: Feature and Equivalent Width Limit 37
2.16 Q1254 + 044: Feature and Equivalent Width Limit 38
2.17 Q1317 + 274 and Q1329 + 412: Feature and Equivalent Width Limit 38
2.18 Q1329 + 412: Feature and Equivalent Width Limit 38
2.19 Q1354 + 193 and Q1421 + 331: Feature and Equivalent Width Limit 39
2.20 Q1421 + 331: Feature and Equivalent Width Limit 39
2.21 Q1548 + 093 and Q1622 + 235: Feature and Equivalent Width Limit 39
2.22 Q1622 + 235: Feature and Equivalent Width Limit 40
2.23 Q1634 + 706: Feature and Equivalent Width Limit 40
2.24 Q2128 − 123 and Q2145 + 046: Feature and Equivalent Width Limit 40

3.1 Redshift Distribution of Systems 154
3.2 Distribution of Equivalent Width Detection Thresholds 155
3.3 Redshift Distribution of Equivalent Width Detection Thresholds 156
3.4 Redshift Distribution of Selected Overall Absorption Properties 157
3.5 Comparison of Selected Overall Absorption Properties 158
3.6 Equivalent Width Proportionality to Number of Clouds 159
3.7 Distribution of Selected Overall Absorption Properties 160
3.8 Velocity Distribution of Selected Subfeature Absorption Properties 161
3.9 Distribution of Selected Subfeature Absorption Properties 162

3.10 The Velocity Distribution of Absorption Subfeatures 163
3.11 Distributions of High Velocity Subfeature Absorption Properties 164
3.12 Distributions of Subfeature Equivalent Widths Below 0.3 Å 165
3.13 Apparent Column Densities of Selected Systems 166
3.14 Apparent Column Densities verses VP Column Densities 167
3.15 $Q0002+051$ at $z = 0.5915$: Transitions and VP Fits 168
3.16 $Q0002+051$ at $z = 0.8514$: Transitions and VP Fits 169
3.17 $Q0058+019$ at $z = 0.6127$: Transitions and VP Fits 170
3.18 $Q0058+019$ at $z = 0.7252$: Transitions and VP Fits 171
3.19 $Q0117+212$ at $z = 0.5764$: Transitions and VP Fits 172
3.20 $Q0117+212$ at $z = 0.7291$: Transitions and VP Fits 173
3.21 $Q0117+212$ at $z = 1.0480$: Transitions and VP Fits 174
3.22 $Q0117+212$ at $z = 1.3250$: Transitions and VP Fits 175
3.23 $Q0117+212$ at $z = 1.3430$: Transitions and VP Fits 176
3.24 $Q0420-014$ at $z = 0.6330$: Transitions and VP Fits 177
3.25 $Q0450-132$ at $z = 0.4939$: Transitions and VP Fits 178
3.26 $Q0450-132$ at $z = 1.1746$: Transitions and VP Fits 179
3.27 $Q0454+036$ at $z = 0.8596$: Transitions and VP Fits 180
3.28 $Q0454+036$ at $z = 1.1533$: Transitions and VP Fits 181
3.29 $Q0454-220$ at $z = 0.4744$: Transitions and VP Fits 182
3.30 $Q0454-220$ at $z = 0.4833$: Transitions and VP Fits 183
3.31 $Q0823-223$ at $z = 0.7055$: Transitions and VP Fits 184
3.32 $Q0823-223$ at $z = 0.9110$: Transitions and VP Fits 185
3.33 $Q1101-264$ at $z = 0.3563$: Transitions and VP Fits 186
3.34 $Q1101-264$ at $z = 0.3590$: Transitions and VP Fits 187
3.35 $Q1148+384$ at $z = 0.5534$: Transitions and VP Fits 188
3.36 $Q1206+456$ at $z = 0.9276$: Transitions and VP Fits 189
3.37 $Q1206+456$ at $z = 0.9343$: Transitions and VP Fits 190
3.38 $Q1213-003$ at $z = 1.3200$: Transitions and VP Fits 191
3.39 $Q1213-003$ at $z = 1.5541$: Transitions and VP Fits 192
3.40 $Q1222+228$ at $z = 0.6681$: Transitions and VP Fits 193
3.41 $Q1225+317$ at $z = 1.7948$: Transitions and VP Fits 194
3.42 $Q1241+174$ at $z = 0.5505$: Transitions and VP Fits 195
3.43 $Q1248+401$ at $z = 0.7730$: Transitions and VP Fits 196
3.44 $Q1248+401$ at $z = 0.8546$: Transitions and VP Fits 197
3.45 $Q1254+044$ at $z = 0.5194$: Transitions and VP Fits 198
3.46 $Q1254+044$ at $z = 0.9342$: Transitions and VP Fits 199
3.47 $Q1317+274$ at $z = 0.6600$: Transitions and VP Fits 200
3.48 $Q1329+412$ at $z = 0.5008$: Transitions and VP Fits 201
3.49 $Q1329+412$ at $z = 0.8934$: Transitions and VP Fits 202
3.50 $Q1329+412$ at $z = 0.9984$: Transitions and VP Fits 203
3.51 $Q1354+193$ at $z = 0.4566$: Transitions and VP Fits 204
3.52 $Q1421+331$ at $z = 0.8432$: Transitions and VP Fits 205
3.53 $Q1421+331$ at $z = 0.9029$: Transitions and VP Fits 206

3.54 Q1421 + 331 at $z = 1.1726$: Transitions and VP Fits 207
3.55 Q1548 + 093 at $z = 0.7706$: Transitions and VP Fits 208
3.56 Q1622 + 235 at $z = 0.6561$: Transitions and VP Fits 209
3.57 Q1622 + 235 at $z = 0.7971$: Transitions and VP Fits 210
3.58 Q1622 + 235 at $z = 0.8913$: Transitions and VP Fits 211
3.59 Q1634 + 706 at $z = 0.9056$: Transitions and VP Fits 212
3.60 Q1634 + 706 at $z = 0.9902$: Transitions and VP Fits 213
3.61 Q2128 − 123 at $z = 0.4297$: Transitions and VP Fits 214
3.62 Q2145 + 064 at $z = 0.7908$: Transitions and VP Fits 215

4.1 Grid of Single VP Component Mg II λ2796 Simulated Profiles 238
4.2 Mg II Doublet Column Density Detection Fractions 239
4.3 Normalized Probability Distribution verses Column Density 240
4.4 Normalized Probability Distribution verses Column Density 241
4.5 Output verses Input: Column Densities and b Parameters 242
4.6 Column Density Distribution of Single VP Component Simulations 243
4.7 Doppler b Distributions from Single VP Component Simulations 244
4.8 The $\log N(\text{Fe II}) - \log N(\text{Mg II})$ and $b(\text{Fe II}) - b(\text{Mg II})$ planes 245
4.9 Inferred Non–Thermal Line Broadening 246
4.10 Mosaic of Simulated Blended Mg II Profiles: (0.008 Å) 247
4.11 Mosaic of Simulated Blended Mg II Profiles: (0.020 Å) 248
4.12 Full Set of Ion/Transitions: Detail of Blending Simulation #71 249
4.13 Number of Components and Column Density Distribution 250
4.14 The $\log N(\text{Fe II}) - \log N(\text{Mg II})$ and $b(\text{Fe II}) - b(\text{Mg II})$ planes 251
4.15 Inferred Non–Thermal Line Broadening 252
4.16 Distribution of b Parameters and Velocities 253
4.17 The $\log N - b$ Plane from Blending Simulations 254
4.18 The $v - \log N$ Plane from Blending Simulations 255

5.1 Fe II and Mg I verses Mg II VP Column Densities 278
5.2 Fe II/Mg II and Mg I/Mg II verses Mg II VP Column Densities 279
5.3 Fe II/Mg II and Mg I/Mg II verses Mg II VP Column Densities 280
5.4 Fe II/Mg II verses Mg I/Mg II VP Column Densities 281
5.5 Distribution of Mg II, Fe II, and Mg I VP Column Densities 282
5.6 Mg I Apparent Column Density verses Mg II Doublet Ratio 283
5.7 Distribution of Doppler b Parameters for Mg II and Fe II 284
5.8 The Doppler b Parameters of Fe II and Mg I verses Mg II 285
5.9 Ratios of Fe II/Mg II and Mg I/Mg II Doppler b Parameters 286
5.10 The Thermal Doppler b of Selected VP Components 287
5.11 Doppler b verses VP Column Densities 288
5.12 The VP Column Densities and Doppler Parameters verses Velocity 289
5.13 The Observed Two–Point Clustering Function (TPCF) of Mg II Clouds . . . 290
5.14 The Mg II Absorption Lines For an Infall Halo Model 291
5.15 The Mg II Absorption Lines For a Disk Plus Infall Halo Model 292
5.16 Two–Point Clustering Functions for Kinematic Models 293

5.17 Subfeature Properties verses Velocity for Models D+IH 1 & 2 294
5.18 High Velocity Subfeature Absorption Properties for Model D+IH 2 295
5.19 High Velocity Subfeature Absorption Properties for Model D+IH 1 296
5.20 Input verses MINFIT for D+IH Models 1 & 2 297

6.1 The Q0002 + 051 $z = 0.8519$ Absorbing System 314
6.2 Mg II λ2796 Profiles verses Galaxy Impact Parameter 315
6.3 Mg II λ2796 Equivalent Width versus the Number of Clouds 316
6.4 Mg II λ2796 Equivalent Width versus QSO–Galaxy Impact Parameter . . . 317
6.5 $A(\Delta v)$ versus QSO–Galaxy Impact Parameter 318

List of Tables

1.1 Journal of HIRES/Keck Observations 5

2.1 Metal Line Transitions 32

3.1 Mg II Absorbing Systems: Profile Properties 68
3.1 Mg II Absorbing Systems: Profile Properties 69
3.2 Mg II Absorbing Systems: Absorption Properties 70
3.2 Mg II Absorbing Systems: Absorption Properties 71
3.3 Mg II Absorbing Kinematic Subsystems 72
3.3 Mg II Absorbing Kinematic Subsystems 73
3.3 Mg II Absorbing Kinematic Subsystems 74
3.3 Mg II Absorbing Kinematic Subsystems 75
3.3 Mg II Absorbing Kinematic Subsystems 76
3.4 Spearman–Kendall Tests of Overall Profile Properties 77
3.5 Spearman–Kendall Tests of Profile Subfeature Properties 78
3.6 $Q0002+051$ $z_{\rm abs} = 0.591485$ 79
3.7 $Q0002+051$ $z_{\rm abs} = 0.851394$ 80
3.8 $Q0058+019$ $z_{\rm abs} = 0.612672$ 81
3.9 $Q0058+019$ $z_{\rm abs} = 0.725173$ 82
3.10 $Q0117+212$ $z_{\rm abs} = 0.576398$ 83
3.11 $Q0117+212$ $z_{\rm abs} = 0.729055$ 84
3.12 $Q0117+212$ $z_{\rm abs} = 1.047971$ 85
3.13 $Q0117+212$ $z_{\rm abs} = 1.325003$ 86
3.14 $Q0117+212$ $z_{\rm abs} = 1.342969$ 87
3.15 $Q0420-014$ $z_{\rm abs} = 0.633004$ 88
3.16 $Q0450-132$ $z_{\rm abs} = 0.493937$ 89
3.17 $Q0450-132$ $z_{\rm abs} = 1.174615$ 90
3.18 $Q0454+039$ $z_{\rm abs} = 0.859565$ 91
3.19 $Q0454+039$ $z_{\rm abs} = 1.153254$ 92
3.20 $Q0454-220$ $z_{\rm abs} = 0.474410$ 93
3.21 $Q0454-220$ $z_{\rm abs} = 0.483340$ 94
3.22 $Q0823-223$ $z_{\rm abs} = 0.705472$ 95
3.23 $Q0823-223$ $z_{\rm abs} = 0.911017$ 96
3.24 $Q1101-264$ $z_{\rm abs} = 0.356286$ 97

3.25 $Q1101-264$ $z_{\rm abs}=0.359002$ 97
3.26 $Q1148+384$ $z_{\rm abs}=0.553362$ 98
3.27 $Q1206+459$ $z_{\rm abs}=0.927602$ A 99
3.28 $Q1206+459$ $z_{\rm abs}=0.927602$ B 100
3.29 $Q1206+459$ $z_{\rm abs}=0.934283$ 101
3.30 $Q1213-003$ $z_{\rm abs}=1.320059$ 102
3.31 $Q1213-003$ $z_{\rm abs}=1.554148$ 103
3.32 $Q1222+228$ $z_{\rm abs}=0.668052$ 104
3.33 $Q1225+317$ $z_{\rm abs}=1.794833$ 105
3.34 $Q1241+174$ $z_{\rm abs}=0.550482$ 106
3.35 $Q1248+401$ $z_{\rm abs}=0.772957$ 107
3.36 $Q1248+401$ $z_{\rm abs}=0.854558$ 108
3.37 $Q1254+044$ $z_{\rm abs}=0.519389$ 109
3.38 $Q1254+044$ $z_{\rm abs}=0.934232$ 110
3.39 $Q1317+274$ $z_{\rm abs}=0.660051$ 111
3.40 $Q1329+412$ $z_{\rm abs}=0.500785$ 112
3.41 $Q1329+412$ $z_{\rm abs}=0.893337$ 113
3.42 $Q1329+412$ $z_{\rm abs}=0.998358$ 114
3.43 $Q1354+193$ $z_{\rm abs}=0.456588$ 115
3.44 $Q1421+331$ $z_{\rm abs}=0.843247$ 116
3.45 $Q1421+331$ $z_{\rm abs}=0.902871$ 117
3.46 $Q1421+331$ $z_{\rm abs}=1.172609$ 118
3.47 $Q1548+092$ $z_{\rm abs}=0.770646$ 119
3.48 $Q1622+235$ $z_{\rm abs}=0.656114$ 120
3.49 $Q1622+235$ $z_{\rm abs}=0.797107$ 121
3.50 $Q1622+235$ $z_{\rm abs}=0.891253$ 122
3.51 $Q1634+704$ $z_{\rm abs}=0.905554$ 123
3.52 $Q1634+704$ $z_{\rm abs}=0.990240$ 124
3.53 $Q2128-123$ $z_{\rm abs}=0.429735$ 125
3.54 $Q2145+064$ $z_{\rm abs}=0.790777$ 126
3.55 $Q0002+051$: VP Decomposition 127
3.56 $Q0058+019$: VP Decomposition 128
3.57 $Q0117+212$: VP Decomposition 129
3.58 $Q0420-014$: VP Decomposition 130
3.59 $Q0450-132$: VP Decomposition 131
3.60 $Q0454+039$: VP Decomposition 132
3.61 $Q0454-220$: VP Decomposition 133
3.62 $Q0823-223$: VP Decomposition 134
3.63 $Q1101-264$: VP Decomposition 135
3.64 $Q1148+384$: VP Decomposition 136
3.65 $Q1206+456$: VP Decomposition 137
3.66 $Q1213-003$: VP Decomposition 138
3.67 $Q1213-003$: VP Decomposition 139
3.68 $Q1222+228$: VP Decomposition 140

3.69 $Q1225+317$: VP Decomposition 141
3.70 $Q1241+174$: VP Decomposition 142
3.71 $Q1248+401$: VP Decomposition 143
3.72 $Q1254+044$: VP Decomposition 144
3.73 $Q1317+274$: VP Decomposition 145
3.74 $Q1329+412$: VP Decomposition 146
3.75 $Q1354+193$: VP Decomposition 147
3.76 $Q1421+331$: VP Decomposition 148
3.77 $Q1548+093$: VP Decomposition 149
3.78 $Q1622+235$: VP Decomposition 150
3.79 $Q1634+706$: VP Decomposition 151
3.80 $Q2128-123$: VP Decomposition 152
3.81 $Q2145+064$: VP Decomposition 153

4.1 Blending Sim, $f(N)$ Maximum Likelihood Slope 236
4.2 Spearman–Kendall Tests: Blending Sim, 0.008 Å 236
4.3 Spearman–Kendall Tests: Blending Sim, 0.02 Å 237

5.1 Spearman–Kendall Tests of VP Component Parameters 276
5.1 Spearman–Kendall Tests of VP Component Parameters 277

6.1 The SDP QSOs 311
6.2 Absorbing Galaxy Properties 312
6.3 Spearman and Kendall Rank Correlation Tests 313

With all my love to

my happy, shining, creative daughter, Tanya

my energetic, bright, boundless son, Ben

and

my dedicated, loving wife, Deneyse.

Acknowledgements

"Houston. It's been a long way, but we're here". Those are the words of Alan B. Shepard, America's first astronaut in space, as he firmly planted his first footprint into the Moon's surface. They are seemingly unpoetic words from a man experiencing no less than walking on another world and seeing his insignificant home planet floating in black nothingness through the tears in his eyes. But, for him, and for the few that knew him, the words are deep in meaning. Following his first and only spaceflight, Shepard had been grounded for 10 years with the incurable Ménière's syndrome and was told he would never fly in space again. He never gave up his dream, subjected himself to a risky inner ear operation, and promptly got himself *command* of an Apollo mission. And that was only the first hurdle.

While in translunar flight, the Lunar Module (LEM) docking latch would not capture with that of the Command Module. No capture, no Moon walk. Shepard suggested a dicey space walk in which he would manually pull the two craft together– anything to complete his Mission, to walk on the Moon. The space walk was overruled by Houston, but– after several agonizing hours of repeated docking attempts– the latch finally captured. Fate, luck, or raw persistence, whatever one wants to call it, had played a hand and his Mission was "GO".

Days later, Shepard and Mitchell were descending to the surface of the Moon in the LEM, when another show stopper hit. The landing radar was locked on infinity (nobody knew it at the time) and there was no local data on the LEM's position and velocity. Mission rules mandated an abort at 13,000 feet if the radar was still malfunctioning. With something less than a 1000 feet before the required abort, a young engineer monitoring a console in Houston "worked the problem". The radar breaker was recycled and a lock on the lunar surface was obtained. Shepard was "GO" for powered descent.

Finally, after 10 years and two near aborts, Al Shepard was standing on the edge of forever and must have experienced that surreal sensation as one realizes a hard won dream is happening– *this is reality*. Indeed, the Moon is a long way, but that had little to do with what Al Shepard said to those in Houston who had witnessed his Journey.

I think there are a few analogies to Shepard's story (which is the romantic stuff of history) and the making of my Ph.D. (which will go down quietly and anonymously).

The first is that, one Shepard's Mission was started, it could not be completed alone. In fact, it would have completely failed several times over without a capable and dedicated support network. So it is true for this work. Many times during the stresses of graduate student life, such as no health insurance for dependents, low income in the face if unforeseen disasters, my support network was there for me.

It begins with my parent's, William and Carol Churchill, who would never allow me to fail simply because events had forced the issue to quit and get a decent paying job without finishing my dissertation. Behind almost every success story there is the most important institution ever devised by humans– the family. Thanks to them, I never had to abort *my* mission. This work would not have been completed without their decades of loving care, financial support, and deep belief in their only son.

A key member of the support network is Dr. Jane Charlton (Penn State), whom I met at an ESO meeting in November 1994, just before that glorious January Keck run. As funds dried up to carry on QSO research at Lick Observatory, she hired me long distance and supported my research. She has also served as a uniquely inspiring collaborator who has played a central role in my "coming of age" as a scientist. In the spirit of a young NASA engineer, she "worked the problem" (many times over) with a do–or–die zeal and never accepted even the possibility of a "mission abort". The words "eternally grateful" apply.

Another key member of my support network is my advisor, Dr. Steven Vogt. Without Steve, the mission could not even be dreamed. He built the HIRES spectrograph, and then placed his faith in me and donated his entire Keck allotment for 1995, and part for 1996, to my dissertation. He even sent me to Keck alone, while he observed remotely from Santa Cruz. I hope he can say with no reservation, that his faith was not misplaced. Because of the blessings of three long wintery clear skies, we obtained the data necessary to really go after the nature of these Mg II absorbers. With data in hand, he continued to place his faith in me to pull out the information hiding in every pixel. He took a healthy "hands–off attitude", wisely counseled me, and nurtured me through this research with the clear goal of allowing me to become an autonomous research scientist. I would like to think he has succeeded. However, through all of it, I must say that a most enjoyable time for me was when Steve and I went to Keck and observed together. In the three years that I had worked for/with Steve, that was the only time we observed together. Thanks for the support and guidance, Steve. I hope you find many planets with Marcy and Butler!

And finally, I owe it all to my wife, Deneyse. She gave herself to this effort even more than I. For five years she has almost single handedly nurtured our children into healthy, happy, and loving young people and has managed our household on nothing more than a financial shoestring. In a sense, her job has been far more important and challenging than mine and she has been even more successful (to see that all you need to do is meet our children!). Without her devoted self sacrifice for them and for me, this work would likely have never been completed.

To these people, I too can say, "It's been a long way, but we're here", and they all know exactly what that means.

I would also like to acknowledge several of my fellow graduate students for their support and friendship over the years at Santa Cruz. Natalie Stout and here family have been wonderful companions and friends. I wish them well in their life in Brazil. It was always enjoyable to chat with Matthew Shetrone about the nitty–gritty details of echelle data reduction. I owe a great deal to Steve Allen, who had a *correct* answer for every computer related question I ever threw at him. I also enjoyed knowing Debra Fisher, Ian Walker, Kathrine Wu, Romeel Davé, Scott Trager, Dan Kelson, Jennifer Johnson, and Jarita Holbrook. I wish them all well in their careers. That I was not a big participant in the "extra curricular" activities of the graduate students was only because of my duties as a family man.

I also mention Tony Misch, who taught me the ABC's of observing at Lick Observatory. Those were fun and exciting days for me and I thoroughly enjoyed his companionship at the telescope and his wonderful family. There will always be a special place in my heart for Dr. Graeme Smith and for Dr. Frank Drake. I have immensely enjoyed knowing them and working with them. They each have served as personal counselor and a

source of inspiration, both in their upstanding characters and their professional abilities.

To Joe, Chris, and James, I say thanks for the sharing in the making of some mighty fine music. Playing drums for Mojave Green was one of my favorite "other life" experiences– particularly the late night San Francisco club scenes!

I cannot conclude without mentioning Frank Timmes and Melinda Weil– I will never forget, but do forgive, what they tried, and failed, to do. How does the old saying go? – "to err is human..." For Dr. Stan Woosley, I have the deepest admiration and gratitude for his wisdom and humanity.

And finally, special thanks to Dr. Chuck Steidel and Dr. Ken Lanzetta. It all started when I read their 1992 PASP articles on QSO metal–line absorption systems (once Mike Keane turned me on to the "Mg II problem"– thanks Mike!). I sent each of them email to make contact with the leaders in the field. Both of them were very friendly and forthcoming. Their responses made all the difference in the world to a young unknown graduate student in search of a beginning. I thank them both for their continued support of my young career.