

Contents

1	Introduction	1
1.1	Supernova explosions	1
1.2	Supernovae classification	1
1.3	General properties of type II supernovae	4
1.4	Goals of this dissertation	5
2	H_{α} Spectral diversity of type II supernovae	6
2.1	Abstract	6
2.2	Introduction	7
2.3	SN II data and measurements	8
2.4	Results	11
2.5	Discussion	12
2.6	Conclusions	14
3	Sample characterization	17
3.1	Abstract	17
3.2	Introduction	18
3.3	Data sample	20
3.3.1	The Cerro Tololo Supernova Survey	24
3.3.2	The Calán/Tololo survey (CT)	25
3.3.3	The Tololo Supernova program, SOIRS	25
3.3.4	The Carnegie Type II Supernova Survey (CATS)	25
3.3.5	The Carnegie Supernova Project (CSP)	25
3.4	Observations and data reduction	25
3.4.1	Observations	26
3.4.2	Data reduction	41
3.5	Explosion epoch estimations	42
3.5.1	SNID implementation	42
3.5.2	New SNID templates	43

3.6	Sample properties	57
3.7	Spectral line identification	59
3.7.1	The H _{α} P-Cygni profile	62
3.7.2	H _{β} , H _{γ} and H _{δ} absorption features	65
3.7.3	He I λ 5876 and Na ID λ 5893	66
3.7.4	Fe-group lines	66
3.7.5	The Ca II IR triplet	66
3.7.6	O I lines	67
3.7.7	Cachito: Hydrogen High Velocity Features or the Si II λ 6355 line? .	67
3.7.8	Nebular Features	67
3.8	Spectral measurements	69
3.8.1	Expansion velocities	69
3.8.2	Velocity decline rate	71
3.8.3	Pseudo-equivalent widths	71
3.9	Line Evolution analysis	71
3.9.1	Expansion velocity evolution	76
3.9.2	Velocity decline rate of H _{β} analysis	77
3.9.3	pEWs evolution	77
3.9.4	Cachito: Hydrogen HV features or the Si II λ 6355 line?	79
3.9.5	O I λ 7774	84
3.10	Conclusions	86
4	Spectroscopic and photometric correlations	89
4.1	Abstract	89
4.2	Introduction	89
4.3	Data	92
4.4	Measurements	93
4.4.1	Spectral measurements	93
4.4.2	Photometric measurements	94
4.5	Physical implications	95
4.6	Results	97
4.6.1	Spectral correlations in the photospheric phase	98
4.6.2	Spectroscopic and photometric properties	101
4.7	Discussion	106
4.7.1	H _{α} P-Cygni diversity	106
4.7.2	The Si II λ 6355 line	108
4.7.3	Other comparisons	108

4.8 Conclusions	109
5 Summary	121
Bibliography	123
A SNe II spectral series	136
B SNe II spectral matching technique	158

List of Figures

1.1	Spectra of SNe	3
1.2	Classification scheme	4
2.1	SN II H _α P-Cygni profiles	10
2.2	Light curve and spectral measurements	11
2.3	Correlations between H _α and photometric parameters	13
3.1	Redshift distribution	24
3.2	Number of spectra distribution	41
3.3	Spectral matching example	56
3.4	Spectral matching and non-detection methods comparison	57
3.5	Distribution of the number of spectra as a function of epoch	58
3.6	Distribution of the first and last spectrum	59
3.7	s ₂ distribution	60
3.8	Line identification in the early spectra	61
3.9	Line identification at 31 days	62
3.10	Line identification at ~ 70 days	63
3.11	Line identification in the nebular phase	64
3.12	H _α P-Cygni profile evolution in SN 1992ba	65
3.13	Complicated H _α P-Cygni profile of SN 2007X	68
3.14	Nebular spectral of seven different SNe of our sample.	69
3.15	Examples of pEWs measured	72
3.16	Appearance of lines in SNe II	73
3.17	Expansion velocity evolution at 50 days	77
3.18	Distribution of the H _α velocity at 50 days	78
3.19	Distribution of the expansion ejecta velocities at 50 days	79
3.20	pEWs evolution at 50 days	80
3.21	H _α P-Cygni profile of low and intermediate velocity SNe II	81
3.22	Evolution of <i>a/e</i> between explosion and 120 days	82

3.23 Velocity evolution of Cachito: Si II λ 6355	83
3.24 Velocity evolution of Cachito: High velocity features	84
3.25 Spectral evolution of the H $_{\alpha}$ and H $_{\beta}$ lines of SN 2004fc.	85
3.26 Correlation between pEW(O I)/pEW(H $_{\alpha}$ abs) and s ₂	86
4.1 Correlation matrix of the individual velocity measurements at 50 days	98
4.2 Correlation matrix of the individual pEW measurements at 50 days.	99
4.3 Relations between H $_{\alpha}$ velocities and the pEWs	100
4.4 Relations between Fe II λ 5169 velocities and the pEWs	101
4.5 Relations between Na I D velocities and the pEWs	102
4.6 Correlation matrix of spectral and photometric parameters	103
4.7 Correlations between Pd and s ₃	104
4.8 Correlations between Pd and six different parameters.	105
4.9 Correlations between s ₃ and five different parameters.	105
4.10 Correlations between ^{56}Ni and the expansion velocities	106
4.11 Correlations: M _{max} vs. velocities; M _{max} vs. pEWs	107
4.12 Correlations between pEW(Fe II λ 5018) and Pd	110
A.1 SN II spectral series	137
A.2 SN II spectral series	138
A.3 SN II spectral series	139
A.4 SN II spectral series	140
A.5 SN II spectral series	141
A.6 SN II spectral series	142
A.7 SN II spectral series	143
A.8 SN II spectral series	144
A.9 SN II spectral series	145
A.10 SN II spectral series	146
A.11 SN II spectral series	147
A.12 SN II spectral series	148
A.13 SN II spectral series	149
A.14 SN II spectral series	150
A.15 SN II spectral series	151
A.16 SN II spectral series	152
A.17 SN II spectral series	153
A.18 SN II spectral series	154
A.19 SN II spectral series	155

A.20 SN II spectral series	156
A.21 SN II spectral series	157
B.1 Best spectral matching of SN 1986L	158
B.2 Best spectral matching of SN 1988A	159
B.3 Best spectral matching of SN 1990E	159
B.4 Best spectral matching of SN 1990K	160
B.5 Best spectral matching of SN 1991al	160
B.6 Best spectral matching of SN 1992af	161
B.7 Best spectral matching of SN 1992am	161
B.8 Best spectral matching of SN 1992ba	161
B.9 Best spectral matching of SN 1993A	162
B.10 Best spectral matching of SN 1993K	162
B.11 Best spectral matching of SN 1993S	162
B.12 Best spectral matching of SN 1999br	163
B.13 Best spectral matching of SN 1999ca	163
B.14 Best spectral matching of SN 1999cr	163
B.15 Best spectral matching of SN 1999eg	164
B.16 Best spectral matching of SN 1999em	164
B.17 Best spectral matching of SN 2002fa	165
B.18 Best spectral matching of SN 2002gd	166
B.19 Best spectral matching of SN 2002gw	166
B.20 Best spectral matching of SN 2002hj	167
B.21 Best spectral matching of SN 2002hx	168
B.22 Best spectral matching of SN 2002ig	169
B.23 Best spectral matching of SN 210	170
B.24 Best spectral matching of SN 2003B	170
B.25 Best spectral matching of SN 2003E	171
B.26 Best spectral matching of SN 2003T	171
B.27 Best spectral matching of SN 2003bl	172
B.28 Best spectral matching of SN 2003bn	173
B.29 Best spectral matching of SN 2003ci	173
B.30 Best spectral matching of SN 2003cn	173
B.31 Best spectral matching of SN 2003cx	174
B.32 Best spectral matching of SN 2003dq	174
B.33 Best spectral matching of SN 2003ef	175
B.34 Best spectral matching of SN 2003eg	175

B.35 Best spectral matching of SN 2003ej	176
B.36 Best spectral matching of SN 2003fb	176
B.37 Best spectral matching of SN 2003gd	177
B.38 Best spectral matching of SN 2003hd	177
B.39 Best spectral matching of SN 2003hg	178
B.40 Best spectral matching of SN 2003hk	179
B.41 Best spectral matching of SN 2003hl	179
B.42 Best spectral matching of SN 2003hn	180
B.43 Best spectral matching of SN 2003ho	180
B.44 Best spectral matching of SN 2003ib	181
B.45 Best spectral matching of SN 2003ip	182
B.46 Best spectral matching of SN 2003iq	182
B.47 Best spectral matching of SN 2004ej	182
B.48 Best spectral matching of SN 2004er	183
B.49 Best spectral matching of SN 2004fb	183
B.50 Best spectral matching of SN 2004fc	184
B.51 Best spectral matching of SN 2004fx	184
B.52 Best spectral matching of SN 2005J	185
B.53 Best spectral matching of SN 2005K	185
B.54 Best spectral matching of SN 2005Z	186
B.55 Best spectral matching of SN 2005af	186
B.56 Best spectral matching of SN 2005an	187
B.57 Best spectral matching of SN 2005dk	187
B.58 Best spectral matching of SN 2005dn	188
B.59 Best spectral matching of SN 2005dt	188
B.60 Best spectral matching of SN 2005dw	189
B.61 Best spectral matching of SN 2005dx	190
B.62 Best spectral matching of SN 2005dz	191
B.63 Best spectral matching of SN 2005es	191
B.64 Best spectral matching of SN 2005me	192
B.65 Best spectral matching of SN 2006ai	193
B.66 Best spectral matching of SN 2006bc	193
B.67 Best spectral matching of SN 2006be	194
B.68 Best spectral matching of SN 2006bl	195
B.69 Best spectral matching of SN 2006ee	196
B.70 Best spectral matching of SN 2006it	197
B.71 Best spectral matching of SN 2006iw	197

B.72 Best spectral matching of SN 2006ms	198
B.73 Best spectral matching of SN 2006qr	198
B.74 Best spectral matching of SN 2007P	199
B.75 Best spectral matching of SN 2007U	200
B.76 Best spectral matching of SN 2007W	200
B.77 Best spectral matching of SN 2007X	201
B.78 Best spectral matching of SN 2007Z	202
B.79 Best spectral matching of SN 2007aa	202
B.80 Best spectral matching of SN 2007ab	203
B.81 Best spectral matching of SN 2007av	203
B.82 Best spectral matching of SN 2007bf	204
B.83 Best spectral matching of SN 2007hm	204
B.84 Best spectral matching of SN 2007il	205
B.85 Best spectral matching of SN 2007it	206
B.86 Best spectral matching of SN 2007ld	206
B.87 Best spectral matching of SN 2007oc	207
B.88 Best spectral matching of SN 2007od	207
B.89 Best spectral matching of SN 2007sq	208
B.90 Best spectral matching of SN 2008F	208
B.91 Best spectral matching of SN 2008H	209
B.92 Best spectral matching of SN 2008K	209
B.93 Best spectral matching of SN 2008M	210
B.94 Best spectral matching of SN 2008W	210
B.95 Best spectral matching of SN 2008ag	211
B.96 Best spectral matching of SN 2008aw	211
B.97 Best spectral matching of SN 2008bh	211
B.98 Best spectral matching of SN 2008bk	212
B.99 Best spectral matching of SN 2008bm	212
B.100 Best spectral matching of SN 2008bp	213
B.101 Best spectral matching of SN 2008br	214
B.102 Best spectral matching of SN 2008bu	214
B.103 Best spectral matching of SN 2008ga	215
B.104 Best spectral matching of SN 2008gi	216
B.105 Best spectral matching of SN 2008gr	216
B.106 Best spectral matching of SN 2008hg	217
B.107 Best spectral matching of SN 2008ho	217
B.108 Best spectral matching of SN 2008if	218

B.109	Best spectral matching of SN 2008il	218
B.110	Best spectral matching of SN 2008in	219
B.111	Best spectral matching of SN 2009N	219
B.112	Best spectral matching of SN 2009W	220
B.113	Best spectral matching of SN 2009ao	221
B.114	Best spectral matching of SN 2009au	221
B.115	Best spectral matching of SN 2009bu	222
B.116	Best spectral matching of SN 2009bz	222

List of Tables

2.1	SNe II spectral and photometric parameters at t_{tran}	15
2.2	Pearson's values between all the parameters at t_{tran}	16
3.1	SNe II sample	21
3.2	Spectroscopic observations information	27
3.3	Reference SNe II	43
3.4	Explosion epoch estimations	44
3.5	Spectral features used in the statistical analysis	70
3.6	KS-Test values	74
3.7	Model properties	75
4.1	Average of correlations	97
4.2	Photometric parameters	112
4.3	Velocity values at 50 days	115
4.4	pEW values at 50 days	118