Contents

Foreword v

List of Figures vii

List of Tables xi

List of Examples xiii

Glossary xvii

Introduction xxiii

1. Samples and Selection Effects 1

1.1 Introduction: which sample for which science goal? . 1

1.1.1 General rules to optimize the scientific returns from a survey of distant galaxies . . 1

1.2 General rules for estimating magnitudes 5

1.2.1 Monochromatic and integrated magnitudes . 5

1.2.2 Photometric systems 6

1.2.3 Total magnitudes and proxies 7

1.2.4 Absolute magnitudes 8

1.3 Pre-selection of a sample prior to redshift measurement 9
1.3.1 Photometric catalogs 9
1.3.2 Statistics: which size for a redshift survey? . 9
1.3.3 Cosmological variance 11
1.3.4 Depth of the photometry and selection effects related to surface-brightness 11
1.3.5 Other selection effects: Malmquist bias, Eddington bias, and lensing effects 13
1.3.6 K-correction and choice of the selecting magnitude 17
1.4 Redshift surveys 21
1.4.1 Redshift measurements and spectroscopic selection effects 21
1.4.2 Determination of the LF, uncertainties and completeness tests 24
1.4.3 Examples of surveys (CFRS, DEEP2, VVDS, zCOSMOS, and WIGGLEZ) 30
1.5 Photometric redshifts 34
1.6 Selection of very distant galaxies at $z \gg 1$ 37
1.6.1 Lyman break galaxies (LBGs) 37
1.6.2 Balmer and 400nm break drop-out galaxies . 40
1.6.3 Lyα emitters (LAEs) 41
1.6.4 Indirect probes: damped Lyα systems (DLAs) and gamma ray burst hosts 41
1.6.5 Dust-enshrouded galaxies 42
1.6.6 Towards an overview of the high-z galaxy population and a fair determination of the LFs 42
1.7 Relating distant and nearby galaxies 44
Bibliography 48

2. Imaging and Photometry 55
2.1 Introduction 55

2.2 Basic Elements of imaging and image analysis 57
2.2.1 Spatial resolution 57
2.2.2 Depth 62
2.2.3 Spectral Bandwidth 68
2.2.4 Observing with imagers 73
2.3 Data Reduction 75
2.3.1 Basic principles 75
2.3.2 Description of basic calibration frames 77
2.3.3 Reducing and calibrating images 78
2.3.4 S/N ratio 82
2.4 Galaxy Morphology 86
2.4.1 Morphological classifications 87
2.4.2 Characterizing morphology at high redshifts 89
2.4.3 Empirical methods — Eyeball classifications 92
2.4.4 Light decomposition using software 92
2.4.5 Automatic methods with two or more parameters 96
2.4.6 A pragmatic and conservative approach to classify distant galaxies 101
2.5 Multi-wavelength photometry 107
2.5.1 Cross-correlating images at different wavelengths 108
2.5.2 Aperture photometry 110
2.6 Spectral energy distributions (SEDs) 119
2.6.1 Impact of the stellar populations: which wavelength tells you what? 119
2.6.2 Impact of dust and gas 121
2.6.3 Estimating galaxy properties from an SED . 126
2.6.4 Estimating stellar mass 130
2.6.5 Estimating galaxy SFRs 136
Bibliography 141

3. Integrated Spectroscopy 155
3.1 Introduction . . . 155
3.1.1 Desiccating a galaxy spectrum . . . 157
3.1.2 Integrated spectroscopy of distant targets . . 161
3.2 Basics of spectroscopy . . . 162
3.2.1 Multi-object spectrographs . . . 164
3.2.2 Slit-less grism spectrographs . . . 165
3.2.3 NIR spectrographs . . . 166
3.3 Preparing observations . . . 166
3.3.1 The choice of spectral resolution . . . 167
3.3.2 Optimization of the S/N ratio . . . 168
3.3.3 Minimizing the impact of the sky background . . . 172
3.4 Data reduction . . . 178
3.4.1 Main steps . . . 178
3.4.2 Characterize the quality of the data reduction . . . 183
3.5 Emission lines . . . 186
3.5.1 Emission line properties . . . 186
3.5.2 Proper methods for measuring emission lines . . . 188
3.5.3 Low S/N regime: measurement bias . . . 193
3.6 Emission diagnostics of the ionized ISM . . . 194
3.6.1 Dust extinction . . . 195
3.6.2 Active galactic nuclei . . . 203
3.6.3 Star formation rate (SFRs) . . . 207
3.6.4 Direct measurement of the gas metallicity (T_e method) . . . 210
3.6.5 Indirect metallicity estimates from strong line ratios . . . 215
3.7 Absorption line diagnostics of ISM & IGM . . . 219
3.7.1 Measuring absorption lines . . . 220
3.7.2 Back-illuminated neutral Hydrogen gas . . 224
3.7.3 Absorption lines from the ISM of distant starbursts . . . 233

3.8 Properties of stellar populations 239
3.8.1 Spectral Evolution of SSPs 241
3.8.2 Lick indices 245
3.8.3 Full spectra fitting 248
3.8.4 Velocity dispersion 253
3.9 Conclusion 253
Bibliography 255

4. Integral Field Spectroscopy 267

4.1 Introduction 267
4.2 Basics of IFU instruments 271
4.2.1 Fiber instruments 272
4.2.2 Image slicer instruments 273
4.2.3 Compromise between resolutions and S/N . . 274
4.2.4 Spatial resolution 275
4.2.5 Spectral resolution and crosstalk 277
4.2.6 Observing with IFU instruments 280
4.3 Data reduction of IFU observations 281
4.3.1 Reduction of fiber data 282
4.3.2 Reduction of image slicer data 284
4.3.3 Correcting for atmospheric dispersion 285
4.3.4 Spatial, spectral smoothing, and binning . . 286
4.3.5 Optimizing sky subtraction with NIR IFUs 288
4.4 Mapping galaxy properties from a data cube 290
4.4.1 Measuring emission lines: methods and error budget 291
4.4.2 Mapping physical properties 294
4.4.3 Mapping the kinematics 295
4.5 Kinematics of distant galaxies 297
4.5.1 A fundamental reference: kinematics of nearby galaxies 297
4.5.2 Kinematics of distant galaxies and beam smearing 302
4.5.3 Classifications based on pure kinematics . . . 308
4.5.4 The kinematic classification 313

4.5.5 The morpho-kinematic classification 317
4.6 Conclusion 318
Bibliography 318

5. Applications and Scaling Relations 323
5.1 Applications to different distant galaxy studies . . . 323
5.2 Dissecting the properties of distant galaxies 324
5.2.1 An example of a multi-instrument and multi-wavelength survey 324
5.2.2 Description of a few individual distant galaxies 325
5.2.3 Spiral disk building and merger rate 330
5.3 Evolution of scaling relations 331
5.3.1 Tully–Fisher Relation 331
5.3.2 The evolution of the M–Z relation 337
5.3.3 SFR-$M_{\rm stellar}$ diagram 342
5.4 An important challenge: baryonic mass estimate . . . 345
5.4.1 Stellar mass estimates 345
5.4.2 Gas mass estimates 347
Bibliography 349

Appendix A Most intense emission and absorption lines 355

Index 359