

Contents

	Preface	page xix
Part I	DSLRs for Astrophotography	1
1	Welcome to DSLR Astrophotography	3
1.1	What is a DSLR?	4
1.1.1	Digital Single-Lens Reflex Cameras	4
1.1.2	DSLRs without Mirrors: MILCs	5
1.2	DSLRs versus Other Cameras	7
1.2.1	Dedicated Astrocameras	7
1.2.2	Fixed-Lens Digital Cameras?	8
1.2.3	What about Film?	9
1.3	Choosing a DSLR	10
1.3.1	Canon vs. Nikon vs. Others	10
1.3.2	Camera Features	11
1.3.3	Shopping Strategy	13
1.4	Choosing Software	14
1.5	Choosing the Computer	15
1.6	Choosing the Telescope or Lens	16
1.6.1	The Aperture Counterrevolution	16
1.6.2	The 500-mm Optimum	16
1.6.3	Ease of Use	17
1.7	Choosing the Mount	17
1.8	The Craft of Astrophotography	18
1.8.1	Building your Skill and Judging your Achievements	18
1.8.2	Pushing Limits or Staying within Them	18
1.8.3	Testing as a Means or an End	18
1.8.4	Philosophical and Ethical Issues	19
1.8.5	Amateur or Professional?	19

Contents

2	Digital Image Technology	21
2.1	What is a Digital Image?	21
2.1.1	Bit Depth	21
2.1.2	Linear or Gamma-corrected?	22
2.1.3	Color Encoding	23
2.1.4	The Alpha Channel	23
2.1.5	Frames	23
2.2	File Formats	24
2.2.1	File Size	24
2.2.2	Compression	24
2.2.3	Raw Files	24
2.2.4	<i>dcraw</i> and Adobe DNG	25
2.2.5	JPEG	25
2.2.6	TIFF	26
2.2.7	PNG	26
2.2.8	FITS	26
2.2.9	XISF	27
2.3	Color Imaging in Detail	27
2.3.1	The Bayer Matrix (CFA)	27
2.3.2	Low-pass Filtering	28
2.3.3	Nebulae are Blue or Pink, not Red	28
2.3.4	Color Balance (White Balance)	30
2.3.5	Gamut	30
2.4	Image Size and Resizing	31
2.4.1	Dots per Inch	31
2.4.2	Resampling	31
2.4.3	Binning	32
2.4.4	The Drizzle Algorithm	32
2.5	Histograms, Brightness, and Contrast	32
2.5.1	Histograms	32
2.5.2	Histogram Equalization	33
2.5.3	Curve Shape	33
2.5.4	Gamma Correction in Detail	34
2.6	Sharpening	35
2.6.1	Edge Enhancement	35
2.6.2	Unsharp Masking	35
2.6.3	Spatial Frequency and Wavelet Transforms	37
2.6.4	Multiscale Processing	37
2.6.5	Deconvolution	40
3	DSLR Operation	43
3.1	Taking a Picture Manually	43
3.1.1	Shutter Speed and Aperture	43
3.1.2	Manual Focusing	44

Contents

3.1.3	ISO Speed	45
3.1.4	Do You Want an Automatic Dark Frame?	46
3.2	Menu Settings	47
3.2.1	Things to Set Once and Leave Alone	47
3.2.2	Settings for an Astrophotography Session	48
3.3	How to See that Tiny Screen	49
3.4	More Features of the Camera Body	50
3.4.1	The Eyepiece Diopter	50
3.4.2	The Strap and Eyepiece Cover	51
3.4.3	Limiting Light Emission from the Camera	51
3.5	Tripping the Shutter without Shaking the Telescope	52
3.5.1	Self-timers and Remote Controls	52
3.5.2	Mirror Lock and Prefire	55
3.5.3	Electronic First-curtain Shutter (EFCS)	55
3.5.4	Other Tricks	56
3.5.5	Vibration-reducing Lenses	57
3.6	Focusing	57
3.6.1	Magnified Preview on the Screen	57
3.6.2	Stars and Spikes	57
3.6.3	Computer Focusing	58
3.6.4	Focusing Telescopes with Moving Mirrors	59
3.7	Other Image Quality Issues	59
3.7.1	Grain	59
3.7.2	Star Eaters	60
3.7.3	Dust on the Sensor	60
3.8	The Camera as Your Logbook	62
4	Five Simple Projects	63
4.1	Telephoto Moon	63
4.2	Afocal Moon	65
4.3	Stretching – The Processing Technique to Learn Now	66
4.4	Stars from a Fixed Tripod	69
4.5	Nightscapes	71
4.6	Piggybacking	71
4.7	Going Further	74
Part II Equipment and Techniques		77
5	Deep-sky Image Acquisition	79
5.1	How to Avoid Most of This Work	79
5.2	How Long to Expose	80
5.3	Dithering	82
5.4	Taking Calibration Frames	82
5.4.1	Dark Frames	82

Contents

5.4.2	Flats	83
5.4.3	Flat Darks	86
5.4.4	Bias Frames	86
6	Coupling Cameras to Telescopes	88
6.1	Optical Configurations	88
6.1.1	Types of Telescopes	88
6.1.2	Newer Telescopes	90
6.1.3	Types of Coupling	94
6.2	Fitting it All Together	97
6.2.1	Types of Adapters	97
6.2.2	Sensor Position Matters	100
6.3	Optical Parameters	100
6.3.1	Focal Length	100
6.3.2	Aperture	101
6.3.3	f -Ratio and Image Brightness	101
6.3.4	Field of View	103
6.3.5	Sensor Size	104
6.3.6	Arc-seconds per Pixel	105
6.3.7	“What is the Magnification of This Picture?”	106
6.4	Vignetting and Edge-of-field Quality	107
7	Camera Lenses	108
7.1	Why You Need Another Lens	108
7.1.1	Big Lens or Small Telescope?	110
7.1.2	Field of View	110
7.1.3	f -Ratio	112
7.1.4	Zoom or Non-zoom?	112
7.2	Lens Quality	113
7.2.1	Sharpness, Vignetting, Distortion, and <i>Bokeh</i>	113
7.2.2	Reading MTF Curves	114
7.2.3	Telecentricity	116
7.2.4	Construction Quality	116
7.3	Which Lenses Fit Which Cameras?	117
7.3.1	Canon	117
7.3.2	Nikon	117
7.3.3	Lens Mount Adapters	119
7.3.4	What if there’s no Aperture Ring?	120
7.3.5	Adapter Quality	120
7.3.6	The Classic M42 Lens Mount	121
7.4	Supporting and Mounting a Lens	122
7.5	Testing a Lens	124
7.5.1	How to Test	124
7.5.2	Limitations of the Lens Design	124

Contents

7.5.3	Defects of a Particular Lens	126
7.6	Diffraction Spikes around the Stars	127
7.7	Understanding Lens Design	129
7.7.1	How Lens Designs Evolve	129
7.7.2	The Triplet and its Descendants	132
7.7.3	The Double Gauss	133
7.7.4	Telephoto and Retrofocus Lenses	134
7.8	Special Lenses	134
7.8.1	Macro Lenses	134
7.8.2	Mirror Lenses	134
7.8.3	Image Stabilization (Vibration Reduction)	135
7.8.4	Diffraction Optics	135
8	Tracking the Stars	138
8.1	Two Ways to Track the Stars	138
8.2	The Rules Have Changed	141
8.3	Types of Equatorial Mounts	141
8.3.1	Fork Mounts on Wedges	141
8.3.2	Sky Trackers	142
8.3.3	German Equatorial Mounts (GEMs)	143
8.4	Hardware	146
8.4.1	Dovetails	146
8.4.2	Counterweights	148
8.5	Setting up a Computerized Equatorial Mount	148
8.5.1	The Difference Between Polar and Go-to Alignment	149
8.5.2	Don't Judge it by the First Star	149
8.5.3	Must You Level the Tripod?	150
8.5.4	Hints for Go-to Alignment	150
8.5.5	Go-to Alignment with just a Telephoto Lens	151
8.5.6	Using Go-to Alignment to Refine Polar Alignment	151
8.6	Classic Methods	152
8.6.1	Finding the Pole in the Sky	152
8.6.2	More about Polar Scopes	152
8.6.3	The Drift Method	154
8.6.4	Automated Drift Method	155
8.6.5	Why the Drift Method is Best	155
8.7	How Accurately Must We Polar-align?	155
9	Precision Tracking and Guiding	157
9.1	Why Telescopes Do not Track Perfectly	157
9.2	Must We Make Guiding Corrections?	158
9.2.1	Sometimes, no	158
9.2.2	A Futile Quest	158
9.3	Mount Performance	158

Contents

9.3.1	How Tracking Error is Measured	158
9.3.2	Periodic Gear Error	160
9.3.3	Backlash	161
9.3.4	Flexure	162
9.4	Periodic-error Correction (PEC)	162
9.5	Autoguiding	164
9.5.1	The Concept	164
9.5.2	Subpixel Accuracy	164
9.5.3	Communication with the Mount	165
9.5.4	Autoguiding Software	165
9.6	Cameras, Guidesopes, and Off-axis Guiders	166
9.6.1	The Guide Camera	166
9.6.2	Guidesopes	166
9.6.3	Off-axis Guiders	167
9.6.4	On-axis Guiding	168
9.7	Using an Autoguider	169
9.7.1	Choosing a Guide Star	169
9.7.2	Hot Pixels and Dark Frames	169
9.7.3	Calibration	170
9.7.4	Autoguider Settings	170
9.7.5	Algorithms	171
9.7.6	Quality of Guiding	171
9.7.7	Interpreting Guiding Graphs	172
9.7.8	Right Ascension and Declination are Different	174
9.7.9	PEC while Autoguiding?	174
9.7.10	Good Autoguiding, Bad Pictures	175
9.8	The Challenge of Round Star Images	175
9.8.1	What Should a Star Image Look Like?	175
9.8.2	How Roundness is Measured	176
9.8.3	Some Practical Tips	176
9.8.4	Downsampling	178
9.8.5	Deconvolution	179
10	Power and Camera Control in the Field	182
10.1	Portable Electric Power	182
10.1.1	Power for the Telescope	182
10.1.2	DC Power Connectors	184
10.1.3	Voltage	185
10.1.4	Powering the Computer and Camera	186
10.1.5	Care of Li-ion Batteries	187
10.1.6	Ground Loop Problems	187
10.1.7	Safety	188
10.2	Camera Control	188
10.2.1	How Camera Control is Done	188

Contents

10.2.2	Choosing a Laptop	189
10.2.3	Cables	189
10.2.4	Camera Control Software	190
10.3	Networking Everything Together	191
10.4	Operating at Very Low Temperatures	191

Part III Image Processing **193**

11	Deep-sky Image Processing	195
11.1	Processing Workflow	195
11.2	Calibration	195
11.2.1	Image Arithmetic	195
11.2.2	Components of a Raw Image	197
11.2.3	Master Darks, Flats, Flat Darks, and Bias Frames	198
11.2.4	Should Flats Be Binned or Smoothed?	198
11.2.5	Method 0: Just Lights and Darks	199
11.2.6	Method 1: Lights, Darks, Flats, and Flat Darks	199
11.2.7	Method 2: Lights, Darks, Flats, and Bias	200
11.2.8	Method 3: Lights, Darks, Flats, Flat Darks, and Bias	200
11.2.9	Scaling the Dark Frames	201
11.3	Cosmetic Correction	202
11.4	DeBayerization	202
11.5	Stacking	203
11.5.1	The Concept	203
11.5.2	Confusing Term: <i>Integration</i>	203
11.5.3	How Images Are Combined	204
11.6	Before We Stack, We Align	206
11.7	Nonlinear Stretching (Gamma Correction)	206
11.7.1	The Concept	206
11.7.2	Digital Development Processing (DDP)	207
11.8	Postprocessing	208
12	Workflow with Specific Software	209
12.1	Before We Start	209
12.1.1	Screen Stretch	209
12.1.2	Methods and ISO Settings	209
12.2	<i>DeepSkyStacker</i>	210
12.2.1	User Interface	211
12.2.2	Setting up	211
12.2.3	Calibrating and Stacking Images	211
12.2.4	Viewing and Selecting Images to Stack	212
12.2.5	Stretching	213
12.3	<i>Nebulosity</i>	214
12.3.1	User Interface	215

Contents

12.3.2	Basic File Editing	216
12.3.3	Calibration	216
12.3.4	DeBayering	216
12.3.5	Choosing Images to Stack	217
12.3.6	Aligning and Stacking Images	218
12.3.7	Stretching	220
12.4	<i>MaxIm DL</i>	220
12.4.1	User Interface	221
12.4.2	Basic File Editing	222
12.4.3	Choosing Images to Stack	222
12.4.4	Calibration and Stacking	222
12.4.5	Stretching	225
12.5	<i>PixInsight</i>	226
12.5.1	User Interface	226
12.5.2	Basic File Editing	228
12.5.3	Choosing Images to Stack	229
12.5.4	Raw or FITS?	229
12.5.5	Calibration and Stacking	229
12.5.6	Stacking (Integration) as a Separate Step	234
12.5.7	Stretching	234
12.5.8	<i>PixInsight</i> Workflow Summary	236
13	More Image Processing Techniques	239
13.1	Flattening the Background	239
13.1.1	The Concept	239
13.1.2	Subtract or Divide?	241
13.1.3	Linear or Gamma-corrected?	241
13.1.4	<i>Nebulosity</i>	241
13.1.5	<i>MaxIm DL</i>	241
13.1.6	<i>PixInsight</i>	242
13.2	Removing Noise	242
13.2.1	The Concept	242
13.2.2	Luminance vs. Chrominance	242
13.2.3	Linear or Gamma-corrected?	243
13.2.4	<i>Nebulosity</i>	244
13.2.5	<i>MaxIm DL</i>	245
13.2.6	<i>PixInsight</i>	245
13.3	Color Saturation	246
13.3.1	The Concept	246
13.3.2	Linear or Gamma-corrected?	246
13.3.3	<i>Nebulosity</i>	246
13.3.4	<i>MaxIm DL</i>	246
13.3.5	<i>PixInsight</i>	246
13.4	Masks	247

Contents

13.5	Who Moved? The Difference between Two Pictures	248
13.5.1	The Concept	248
13.5.2	Preparing the Images	248
13.5.3	<i>PixInsight</i>	250
13.5.4	<i>MaxIm DL</i>	252
13.5.5	<i>Nebulosity</i>	252
13.5.6	<i>Photoshop</i>	254
13.6	High Dynamic Range (HDR)	254
14	Sun, Moon, Eclipses, and Planets	255
14.1	Full-face Lunar and Solar Images	255
14.1.1	Optics and Field of View	255
14.1.2	Exposure	256
14.1.3	Tracking	256
14.1.4	Stacking	258
14.1.5	The Moon	258
14.1.6	The Sun	259
14.1.7	Eclipses, Solar and Lunar	259
14.2	High-resolution Video: How it's Done	263
14.2.1	Overview of the Process	263
14.2.2	Acquiring the Images	264
14.2.3	How Long to Expose	265
14.2.4	Preparation and Stacking	268
14.2.5	Multiscale Sharpening	268
14.2.6	RGB Alignment	270
14.3	High-resolution Video: Technical Matters	271
14.3.1	Matching Focal Length to Pixel Size	271
14.3.2	Why High-resolution Video Works	271
Part IV	Advanced Topics	275
15	Sensor Performance	277
15.1	Generations of DSLRs	277
15.2	How Sensors Work	278
15.2.1	Photoelectrons	278
15.2.2	CCD and CMOS Sensors	279
15.2.3	What We Don't Know	279
15.3	Sensor Performance Basics	281
15.3.1	Pixel Size	281
15.3.2	Quantization and DN _s (ADUs)	281
15.3.3	Bias (Offset), Dark Clipping, and Compression	282
15.3.4	Linearity	282
15.3.5	ISO Speed Adjustment	283
15.3.6	Gain	283

Contents

15.3.7	Color Balance (White Balance)	284
15.3.8	The Anti-aliasing Filter	284
15.4	Image Flaws	285
15.4.1	Bad Pixels	285
15.4.2	Pixel Inequality	285
15.4.3	Blooming	286
15.4.4	Amplifier Glow (Electroluminescence)	287
15.4.5	Cosmic Rays	287
15.4.6	Degradation with Age	289
15.5	Noise, in Detail	289
15.5.1	What Noise Is	289
15.5.2	Signal-to-noise Ratio (SNR)	289
15.5.3	Shot Noise	290
15.5.4	Read Noise	291
15.5.5	Dark Current (Thermal Noise)	292
15.5.6	Chrominance Noise	292
15.5.7	Effect of Stacking, Binning, and Downsampling	292
16	Testing Sensors	294
16.1	ISO Invariance	294
16.2	True ISO Speed	295
16.3	Dynamic Range	295
16.4	Noise Analysis	297
16.5	Quantum Efficiency and Other Parameters	298
16.6	Obtaining Data from Your Own Sensor	299
16.6.1	Overview	299
16.6.2	<i>PixInsight</i>	300
16.6.3	<i>MaxIm DL</i>	301
16.7	Specific Tests	301
16.7.1	Dynamic Range from One Light Frame and One Flat Dark	301
16.7.2	Read Noise in DN from Two Flat Darks or Bias Frames	302
16.7.3	Gain in DN/e ⁻ from a Pair of Generously Exposed Flats	303
16.7.4	Read Noise Measured in Electrons	304
16.8	Going Further	304
17	Spectral Response and Filter Modification	306
17.1	DSLR Spectral Response	306
17.2	Filter Modification	307
17.2.1	What Filter Modification Achieves	307
17.2.2	Is Filter Modification Necessary?	308
17.3	Filters to Cut Light Pollution	310
17.3.1	How Light Pollution can be Removed	310
17.3.2	Filters to Favor Nebulae	313
17.3.3	The Middle Ground	314

Contents

17.4	How Filters Are Made	315
17.4.1	Dye Filters	315
17.4.2	Interference Filters	316
17.4.3	Didymium Glass	316
17.4.4	Precautions	317
18	Tools for Astronomical Research	318
18.1	Star Maps	318
18.2	<i>Simbad</i> , <i>Aladin</i> , and <i>VizieR</i>	320
18.3	Case Study: An Unnamed Nebula in Monoceros	320
18.4	Plate Solving for Identification and Position	323
18.5	Case Study: Have I Discovered a Star Cluster?	324
18.6	Variable-star Photometry	325
18.6.1	Acquiring Images	326
18.6.2	Aperture Photometry	326
18.6.3	Photometry Software	327
18.6.4	Example: Light Curve of EH Librae	328
18.7	Asteroid or Nova?	329
18.8	Research Literature On Line	330
	Part V Appendices	331
A	Digital Processing of Film Images	333
B	Exposure Tables	336
B.1	Sun	336
B.2	Moon	336
B.3	Planets	337
B.4	Deep-sky Objects	337
B.5	How Exposures are Calculated	338
	Index	339