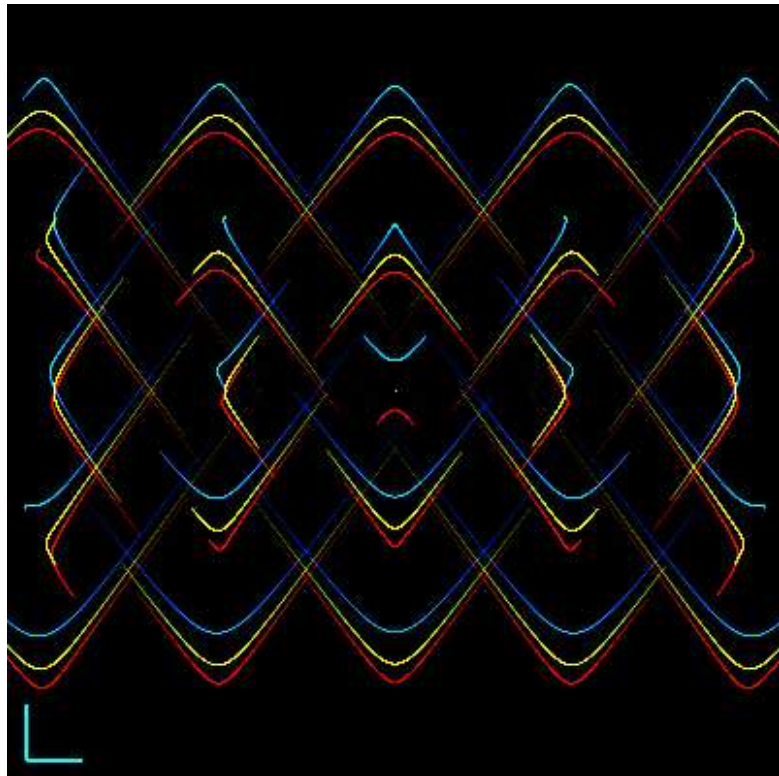


Proposal for a book to be published by

in the category
CCDs & Astrophotography



**Forms of images in stellar photography,
the companion**
Prime focus astrophotography at the lower limit

Markus Wildi, Arthur von Känel

Figure on the front page

Simulation of a $1^\circ \times 1^\circ$ field with 25 stars on a regular grid. Each triple (red, yellow, blue equal to $\lambda = 650, 550, 450$ nm) represents a resultant star trail in the focal plane. The star trails are magnified by a factor of 120 in order to make them visible. The corresponding scale bar on the lower left is $2.5''$ long. The brightness of the star trail is the indicator of the velocity relative to the center. These kind of plots can be compared with those first published in [22] and later in [3].

Field center $\delta = -20^\circ$

Local hour angle at the beginning $\tau = 3^h$

Local hour angle at the end $\tau = +3^h$

Exposure time $t = 21600$ s

Height above sea level $H = 550$ m, latitude $\phi = 47.5^\circ$

Meteorological data $T = 273.15$ K, relative humidity $r = 0.5$

Aperture diameter $D = 200$ mm, focal length $f = 1260$ mm

Hour axis distance from the celestial pole $\lambda = 0''$, its hour angle $h = 0^h$

Guiding on the center at the wavelength 550 nm (yellow pixel in the center)

The detector has a uniform spectral response and its efficiency equals 1.

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1 The authors

Markus Wildi: Born April, 29th 1958 in Basel.

Studies in Physics, Mathematics and Astronomy from 1979 to 1986. 1992 PhD in experimental physics at the University of Basel in the field of strong interaction, LADS experiment at the Paul Scherrer Institute (Villigen) measuring in flight π^+ absorption on ^3He .

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“There is nothing more practical than a good theory”.

Published together with Diana Fahrner the complete oeuvre of the painter Kurt Fahrner in 1998: Kurt Fahrner, das gesamte Werk, F. Reinhardt Verlag, Basel, 1998 (<http://www.kurt-fahrner.ch>).

Arthur von Känel: Born February, 7th 1961 in Grosshöchstetten, Berne.

Active in the field of amateur astronomy since 1977. Built a permanent observatory in Vermes equipped with an Astrophysics refractor AP Starfire 180 F/7 mounted on AP 1200 GTO with the guiding system SBIG STV. Mainly interested in deep sky photography with conventional film material with 35 mm or middle format cameras.

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“Finally we’d like to provide a practical guide for a precise polar alignment, which is profoundly explained to all interested astrophotographers.”

The preparation of this manuscript and the necessary programming started in August 2001 and the raw version was completed in August 2003. This manuscript is not the result of a leisure time activity. During the summer of 2001 Markus Wildi took a sabbatical and spent most of the time working on this project. There are no external funds used so far.

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2 Our proposal

For further questions concerning the contents of the proposed book, please refer to the draft, which is included in a separate document. Please note, that the figures in this document have to be magnified in case of reading them on screen, for sometimes certain features are about just one pixel wide. Not all figures are present in the book and where they are missing the term “Bild” appears instead. In order to make the book a little bit more appealing, we would like to put a photograph similar to figs. 3 and 4 on the left side of each beginning of a chapter.

The presented proposal and manuscript, although prepared thoroughly, is meant to be a matter of discussion and is by no means fixed.

In case where these two PDF files are not displayed correctly use Acrobat reader version 5 or higher.

Title: *Forms of images in stellar photography, the companion.*

The title of the work at issue is derived from E.S. King’s article [8], written to provide detailed instructions for the installation and operation of an equatorially mounted telescope for photographic purposes.

Subtitle: *Prime focus astrophotography at the lower limit.*

The subtitle places the emphasis on the fruits of all the work ahead.

Category: CCD’s & Astrophotography or Math & Celestial Mechanics

Involved persons: Dr. Markus Wildi (author), Arthur von Känel (co-author), Dr. Martin Federspiel (internal scientific reader and corrector).

Completion date: Manuscript August 2003

Current status of the text: The manuscript is completed. It’s now in the correction phase, scientifically and language.

Main conclusions: The precise alignment ($0 \dots \approx \pm 80''$, depending on the observed declination $\delta = 90 \dots 0^\circ$, the latitude ϕ and the field diameter) of the hour axis is a key requirement for the astrophotography even for real short exposure times not only in the region of the celestial pole.

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The only possibility to compensate the field rotation due to refraction is to position the hour axis according to [22]. If this is not the case only small fields in the vicinity of the guiding star and/or short integration times are possible. We showed in our manuscript that exposure times between two and four hour in the range of $0 < \delta \leq 90^\circ$ are feasible (format $1^\circ \times 1^\circ$) with a fixed setting of the hour axis.

From the astrophotographer's point of view the alignment is an equal important factor like the quality of the mounting and the optics.

The precise polar alignment does not depend on expensive new equipment. In the basic variant the measurement can be carried out with a stopwatch, a calibrated eyepiece with reticle, a pencil and paper.

So it is open to all who spend the time reading this book.

Reasons for writing: The newly set up refractor of A. von Känel failed to produce "pinpoint" like stars images. Instead we observed significant star trails (fig. 1) whose changing directions over the photograph were neither compatible with a rotation of the field nor with well known geometrical aberrations. The edges of the individual star images were partly yellow- and bluish even though the triplet lens is color corrected to a higher extent. This was a cold shower to deal with.

Our research, based on amateur astronomy literature and on the web hardly provided "ready to use instructions" to get our problem solved, nor useful approaches how to treat the topic and eventually to calculate the effects in question. In addition, the archived discussion on the astrophotography mailing list (APML) over the past seven years showed, that the knowledge about refraction and dispersion and their effects in the focal plane during an exposure can at best be described as nebulous. Which means that we were in good company.

A non representative investigation of deep sky photographs published in the column "gallery" in Sky&Telescope revealed, that the average exposure time is well below one hour and the average aperture is larger than 30 cm at F/6 - not the typical equipment of an

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amateur astronomer - beside a few remarkable exceptions. Hence we found the clear evidence, that this problem is not a matter of the used equipment, but due to our lack of knowledge, how to install and operate a telescope properly.

Finally the introduction of the article [6] in the year 1982 by A.V. Filippenko: "The purpose of this paper is to remind spectroscopists of the large effects of atmospheric dispersion (...) as a function of the object position in the sky" motivated us to dig deeper into the topic and produce a "finite set of executable instructions" suitable for anybody who is used to the well known but time consuming and often inaccurate drift alignment method. The systematic errors produced by the incorrect movement of the glass fibers in the focal plane of an multi object spectrograph have of course the identical source as the star trails in an ordinary photograph.

Reasons for publishing: The effects of refraction and dispersion are by no means "differential" (infinitesimal) as the often used expression differential refraction implies. These difference effects must be understood or at least known in order to obtain satisfying photographs on a routinely basis.

The widely used drift alignment method is not suitable for a precise polar alignment as A.A. Rambaut pointed out [12]. There are two reasons. The first reason is, that the effects of refraction have to be taken into account. The second one is, despite the description of the drift alignment method pretends that there is a "finite set of executable instructions" no star will stay on the cross hair of the eyepiece for more than a very short period of time. This fact was concisely proved by E.S. King in [8] more than hundred years ago.

Every astrophotographer who intends to use a telescope with focal length longer than ~ 80 cm and exposure times longer than ~ 20 minutes needs to align the hour axis properly.

Interestingly our proposal coincides with an article in Sky & Telescope August 2003 p. 124, Coping with Atmospheric Dispersion. We fully share the conclusion of Thomas A. Dobbins: "(...) Today's marketplace features a vast array of specialized telescopic accessories, (...). It is really quite surprising that some enterprising manufacturer has yet to introduce an atmospheric-dispersion corrector to

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cure a problem that affects telescopes of every optical configuration – reflector, refractor, and catadioptric – and visual observers, photographers and CCD imagers alike. (...)”. The proposed book shows in detail the advantages of these atmospheric dispersion correctors. In our example it is a Risley prism.

Following the given instructions an aperture of about 150 millimeter is sufficient under real sky conditions to deliver photographs which compare to an aperture of approximately 300 ... 400 millimeter if observing time is not a key issue. The smaller aperture can be easily compensated by exposure time assuming an instrument with the same focal ratio and given the above mentioned average exposure time. We like to encourage people getting started with astrophotography who have a limited budget. The money need not to go into a huge “photon dump”. We think that in the majority of the cases a well balanced system – telescope, mounting and detector together with good observing skills – is more satisfactory at the long run.

It is our considered opinion that this book should be accessible to a wide readership and therefore we decided to get it published in English.

Reasons for NOT publishing: We discussed the topic of the proposed book with our colleagues and the two most often mentioned reasons were:

This precision is often not required A little bit more relaxed accuracy in setting up the hour axis allows certainly an hour long exposure time farther away from the pole.

With the feasible exposure time of up to four hours it is possible to make e.g. a LRGB composite image within one night, without a loss of resolution. This longer integration time opens new fields e.g. RGOB narrow band images as explained on p. 128 in *Sky & Telescope* July 2003 or even spectroscopy.

Usage of CCD cameras Today the CCD cameras are widely used which allow short integration times due to the higher quantum efficiency. The integration time of a filtered LRGB image is typically two hours and thus is comparable to the conventional color film material. As the chip size will grow (e.g. Kodak’s KAF 22000 with 4080 times 5440 pixels) all the problems of the

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conventional photography will be back. It has to be stressed, that the movement of the stars relative to the field center (guided telescope) is not a simple function of time and therefore that movement can be quite large in parts of the imaged field if the hour axis is not set adequately.

The currently affordable chips with their small linear dimensions need a precise pointing, in order to reduce the time to search for an given object. Precise pointing is a natural by product of the correct alignment of the hour axis.

Readership: Amateur astronomer interested in

1. photography (CCD and conventional)
2. setting up the hour axis with precision
3. understanding the underlying physics and geometry
4. building new equipment

Astronomy teachers on various levels

Students in the field of astronomy

Manufacturers of

1. equatorial and azimuthal mounts
2. guiding systems
3. telescopes designed for photography and auxiliary optical systems

Concerning the last group we closely followed the impressive improvement of the quality and the wide range of functions amateur telescopes were equipped with during the former 30 years. Not all functions are equally important for taking photographs. There are several proposals found in the scientific literature for auxiliary optical systems (e.g. DIMM [14] and Risley-prism [24], see article Coping with Atmospheric Dispersion, Sky & Telescope, August 2003 p.124 - 127), enhancements to the steering software and the motion (not to be mixed up with the sidereal rotation) of the hour axis during exposure. The usefulness is demonstrated thanks to our simulation.

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Having this motorized positioning system of the hour axis, the remaining difference to an automatic precision polar alignment system is small. The task, which has to be carried out, is to write an additional piece of software based on A.A. Rambaut's method and to integrate it into an already existing guiding system.

Concept: The basic idea is to constitute a link between the sophisticated scientific articles and the knowledge of an average amateur astronomer. This is managed on three levels characterized as follows:

1. *Astrophotographer*, wanting to apply the rules (chapters 4, 5 and 6).
2. *Amateur astronomer*, wanting to calculate the relevant quantities and diagrams for the current observing site (chapters 2 through 6) and follow the instructions in detail.
3. *Advanced amateur astronomer*, wanting to additionally build the proposed equipment (chapters 1 through 6 and supplementary the cited literature) and/or simulate the underlying physics and geometry.

In the proposed book all readers who can be assigned to one of these categories will find a wide range of information in order to carry out their own ideas.

The present text is mainly based on [2], [16], [12], [20], [7], [8], [22] and [3]. The results of dealing with these different sources are compiled into one chapter and thoroughly explained (chapter 3). For these texts are hardly readable for the average amateur astronomer extensive comments and figures representing the effects in the focal plane are provided. These figures are obtained by a simulation, which basically follows the idea in [22]. The work, which has to be carried out, is described in a step by step manner suitable to anybody being capable to make a good use of the drift alignment method. The book is divided into three parts described below:

1. Introduction of the topic, methods and the necessary mathematics and principles of the measurements (chapters 1 - 3).
2. Description of the effects in the focal plane and how to counteract (chapter 4).

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3. Practical part, with detailed instructions how to install a telescope and the necessary measurements (chapter 5) and a consideration about the dimensions (aperture D , focal length f) of a telescope designed for photographic purposes in combination with the detector's resolution under real sky conditions (chapter 6). The book is completed by our wish list based on our work.

The vast majority of our statements is represented either by a graph or a simulated or real photograph in order to ensure a simple plausibility.

After studying the proposed book a reader should have a fairly good imagination of how accurate a certain measurement has to be carried out.

The proposed book is not supposed to be a complete guide to astrophotography.

Used methods and tools: Calculations and the simulation are based on the literature cited above. In addition, we used the library SLALIB [21] to program the simulation and the CERN data analysis package root [1] to generate the distributions of the virtual photons (black body radiation), of the Fraunhofer diffraction and the virtual detector was built around the histogramming functions. All figures have been prepared with The Gimp [9]. The program, which combines all items has been written with the GNU C compiler which runs on a GNU/Linux operating system. The whole conglomerate of soft- and hardware compares approximately to a star of 10^m shining on an aperture of 200 mm.

Reason for the simulation: The figures can be produced in a completely controlled manner lacking any disturbing effects of the optics and the mounting, like any kind of aberrations, flexure of the tube among many others. In addition, the refraction and dispersion can be shown separately from the effects of the alignment.

Besides all the total amount of pure observing time needed for the figures presented exceeds 1000 hours. This time is reduced to about twenty hours plain computing time.

Content of the book: The chapter titles are

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Foreword

How to read this book

1. Introduction
2. The atmosphere as a prism
 - 2.1 Refraction
 - 2.2 Dispersion
 - 2.3 Magnitudes of the effects and tolerances
3. The Equatorial
 - 3.1 The bearing of the mounting and the optical axis
 - 3.2 The field center
 - 3.1.1 Minimization in the δ -direction
 - 3.1.2 Minimization of the field rotation
 - 3.3 Position measurement of the hour axis
 - 3.3.1 Method of J. Scheiner and A.A. Rambaut
 - 3.3.2 Method of E.S. King
 - 3.3.3 Automatic procedure
4. Difference effects
 - 4.1 Compensation by simple means
 - 4.2 Compensation of the dispersion
 - 4.3 Compensation of the refraction
 - 4.3.1 The field center
 - 4.3.2 The drive rate and the polar distance
 - 4.3.3 The field
 - 4.4 Tolerance of the positioning
 - 4.5 Telescope steering and guiding system
 - 4.6 Conclusions and recommendations
5. Alignment of the hour axis
 - 5.1 Drift alignment method
 - 5.2 Some prerequisites
 - 5.2.1 Leveling of the tripod
 - 5.2.2 Vernier

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- 5.2.3 Zero position of the setting circles
 - 5.2.4 Electronic setting circles
 - 5.2.5 Periodic error and rate of the telescope
 - 5.2.6 Conversion of the common units
 - 5.2.7 Local hour angle τ
 - 5.2.8 Orientation in the equatorial system
 - 5.2.9 Calibration and orientation of the eyepiece
 - 5.2.10 Measurement of the star trail at the eyepiece
 - 5.2.11 Calibration and orientation of the camera
 - 5.2.12 Measurement of the star trail on the photograph
 - 5.2.13 Corrections k, A after A.A. Rambaut
 - 5.2.14 Corrections k, A after E.S. King
 - 5.2.15 Adjustment of the hour axis
 - 5.3 Rough alignment
 - 5.4 Precise alignment
 - 5.5 Method of A.A. Rambaut
 - 5.5.1 Visual variant
 - 5.5.2 Photographic variant
 - 5.6 Method of E.S. King
 - 5.6.1 Photographic variant - graphical data reduction
 - 5.6.2 Visual variant
 - 5.6.3 Photographic variant
 - 6. Telescope and Detector
 - 6.1 Seeing
 - 6.2 Diameter versus dispersion
 - 6.3 Diameter versus exposure time
 - 6.4 The new amateur telescope
 - A. List of symbols
 - B. Index
 - C. Bibliography

Preparation of the manuscript: The format is a \LaTeX -file (obviously like Star Testing Telescopes [18]) and the document class is `book.cls`

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and the bibtex style is `plain`. All figures and photographs will be included as EPS-files.

Comparison with competing books: The main topic of the book is how to obtain routinely photographs where the star trails are cut down to a level on which they are even during a four hour exposure almost invisible (format $1^\circ \times 1^\circ$, focal length 2 meters). In accordance to this this book is complementary to the existing amateur astronomy literature, which has been published roughly over the past 25 years. The content is – apart from a few items – not fundamentally new, but to our knowledge, the material presented here, has never been published in other volumes beside the original scientific articles and some aspects on contemporary web sites, e.g. www.eso.org.

The current amateur astronomy literature only provides only a few hints of why and how to align the hour axis precisely. Besides [15] quite a few authors mention E.S. King’s method (e.g. [23]) without a sufficient explanation. The generalized method of A.A. Rambaut is almost completely ignored despite the fact, that an equatorial mounting can be set up in roughly one hour with a precision of $\pm 30''$, even without having access to the region close to the celestial pole. Only in [13] (p. 239) are improved instructions of the drift alignment method presented based on an analysis of T. Krajci. He introduced the “46-to-1” rule which is in fact a rediscovery of J. Scheiner’s work published in [16] which is the basis of the well known the drift alignment method.

Comparison with complementary books: Star Testing Telescopes [18] explains in depth what can be expected from a real telescope under an ideal sky. We do the opposite, we explain what can be expected from an ideal telescope under a real sky including the effects introduced by the setting of the hour axis. Together with the two mentioned books a reader gets a rather complete picture of the focal plane.

3 Outline of the chapters

We hope, that the following outline of the chapters of the proposed book, along with the manuscript will provide a sufficient amount of information to ensure an

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easy decision making. In order to ensure an easier readability, we included the native references of the original text in this summary. We used the abbreviations *fig.* for references to section **A** in this proposal and *Kap.*, *Abb.*, *Tab.*, *Gl.* and *Seite* for chapter, figure, table, equation and page references in and concerning our original text.

Foreword

The foreword is initiated with two personal paragraphs why we came to think about refraction and dispersion (fig. **1**). The results of two informal investigations are presented: the first in the archives of the APML (mailing list) and the other in the magazine *Sky&Telescope*. Next, the aim is presented and the main conclusion of the text ahead. A statement concerning J. Scheiner's method (drift alignment method): This method does not lead to satisfactory results but can only be achieved with A.A. Rambaut's method. At the end our thanks goes to the contributors and we show what we achieved in fig. **2**.

How to read this book

The contents of the chapters are summarized and a guideline how to read them is provided.

1. Introduction

The explanation of the topic dealt with in this book, is followed by a brief retrospective of the beginnings of the astrophotography starting with the works of the different astronomers already mentioned. A quotation of E.S. King shows (Seite **1**, in English), that the problem is by no means new and another quotation of A.V. Filippenko (Seite **2**, in English) reminding his colleagues, to take care of the effects of the refraction and dispersion at least in spectroscopy.

An overview (Seite **2**) of the simulation is presented, it is a three step process:

- 1 the generation of the black body radiation and the Fraunhofer diffraction distributions.
- 2 the transformation to the azimuth coordinate system, adding the wavelength λ dependant refraction R , which leads to the dispersion, transformation back to the equatorial system of the telescope. The position of the telescope defines the center of the projection into tangent plane.

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- 3 The coordinates (ξ, η) and the wavelength λ are then passed to the data analysis program, where the conversion to RGB values occurs and the spatial information is stored in three two dimensional histograms representing the detector. These histograms are then normalized and the output file is written in a format ready to be displayed.

Abb. 1.1 through 1.10, 1.13 and 1.14 with the exception of Abb. 1.4 show what can be expected from the simulation.

There are basically two different ways how to present the simulated photographs. To wit the direct mode (Abb. 1.11) and the difference mode (Abb. 1.12). The direct mode equals a CCD camera attached to the telescope. The dimensions of the detector can for sure vary as long as the amount of pixels fits into the memory of the used computer.

The difference mode is nothing else than an ordinary telescope equipped with a perfect guiding system including the possibility to enlarge the star trails.

These two modes can basically be seen as the representation of Gl. 3.24, 3.25 with or without the movement of the center ($\xi = 0, \eta = 0$) subtracted.

Beside the diffraction images of a star (Abb. 1.9, 1.10) a three color representation shows the star trails at different discrete wavelengths (e.g. Abb. 1.12 and the figure on the front page).

The seeing is programmed simply as a Gaussian smear and therefore the result is compared against the description in [4] (Abb. 1.3, Tab. 1.1). The result is in good agreement.

There could be an additional element in the virtual optical path: the Risley prism. They correct the dispersion of the atmosphere as a function of the local hour angle and the declination. They are programmed according to [5] and realized as an objective prism since we don't have to pay for the glass and don't care about tube flexure. But by the way, it is made of Schott F4 and SK10 [11].

2. *The atmosphere as a prism*

The refraction and dispersion (Gl. 2.1, 2.3) are explained and the plots show the dependency of the field compression as a function of the zenith distance ζ along the great circle bearing the zenith Z (Abb. 2.2) for a field of 1° length and as a function of the declination δ and the local hour angle τ (Abb.

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2.3). After these plots it is evident that the atmosphere can not be neglected. The resolution even of a small telescope is better than the variation of the field compression.

In addition the dependency of the dispersion ΔR on the wavelength λ , zenith distance ζ (Abb. 2.6), temperature T (Abb. 2.9), air pressure p (Abb. 2.8), chemical composition r (Abb. 2.7) is shown. It is necessary that the reader gets a fairly good idea about the quantitative aspects and Abb. 2.10 shows the increasing length of the spectrum caused by the dispersion (see Tab. 2.1 - 2.3). The effects on a short 1 second exposure of our standard “open cluster”, stars of spectral types O - N on a regular grid, are plotted in Abb. 2.11 and with the seeing added in Abb. 2.12.

3. *The Equatorial*

This chapter is the central part of the whole manuscript and we first point out why all these derivations are necessary. A source of motivation is Abb. 3.1 where E.S. King established a first lower limit of what can be achieved.

The reason, why this manuscript is to our opinion complementary to the existing (amateur) literature, is based on this chapter.

3.1 *The bearing of the mounting and the optical axis*

The discussions on APML and with our colleagues revealed, that the knowledge about the influences of the two main errors, the non orthogonality of the hour and the declination axis and the collimation error (this is not the alignment of the optical elements), is almost lacking.

We follow the derivation given by F. Brünnow [2], since the full derivation produces a jungle of equations without additional content. The simple form stresses the geometrical aspects. The equations are presented by means of intermediate steps, in order to ensure that a reader, being familiar with mathematics, is capable to calculate the final result without simplifications.

We initially present the transformation between the telescope coordinate system and the true equatorial system (starting on Seite 20 Gl. 3.1 - 3.8). Furthermore we continue with the transformation between the telescope system affected by the two errors (Seite 22, Gl. 3.10 - 3.11) and the idealized telescope frame mentioned before.

This leads to the conclusion, that these errors have no effects on the tracking of a field.

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The first result is needed in section 3.2 on Seite 25 and the second in section 3.3 starting on Seite 40.

3.2 *The field center*

In this section we calculate the effect of the refraction and the position of the hour axis on the field center and plot the angle velocity as a function of the hour angle τ in the δ - and τ -directions (among other figures, refraction: 3.9, 3.8 and position 3.12, 3.11).

The main conclusion is that there exists no fixed setting of the hour axis which allows an observer to take photographs from any part of the sky with equal quality. This means that the polar distance λ of the hour axis must be set according to the observed declination.

It has to be stressed, that there are two sources of field rotation: the first is due to refraction and the second due to the position of the hour axis relative to the true celestial pole. The topic of the following two sections is the method of E.S. King (minimization of the movement of the center relative to the true coordinates) and that of A.S. Hinks / P.T. Wallace & K.P. Tritton (minimization of the rotation of the instrumental relative to the true north direction).

3.1.1 *Minimization in the δ -direction*

The movement of the center is calculated by means of Gl. 3.20, 3.19 and the result is Gl. 3.21 on Seite 27.

Having settled the polar distance λ the drive rate can be calculated (programmed) with Gl. 3.19. These rates are plotted (Abb. 3.14 - 3.21) for various latitudes ϕ and can be compared with the so called King's rate and a typical setting, which can be achieved by using the drift alignment method. We further explain, why the drift alignment method often fails regardless the kind of performance.

Despite the fact, that this equation 3.21 is meant to be used off the meridian, it provides an acceptable correction of the movement and to a lesser extent a correction of the rotation when $\tau = 0^h$ and λ is constant during the exposure.

3.1.2 *Minimization of the field rotation*

The result Gl. 3.31 on Seite 36 is generated the same way as the equations in Kap. 3.1.

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The results are presented graphically starting with the rotation of the field due to refraction (Abb. 3.26), after the compensation (Abb. 3.28: Gl.3.31, 3.29: Gl. 3.21), a comparison with Gl. 3.21 and 3.31 (Abb. 3.27), the movement in the δ -direction (Abb. 3.31) and the drive rate (Abb. 3.30).

The quintessence of this paragraph is the fact, that the field rotation due to the refraction can be compensated to a large extent by setting the hour axis according to Gl. 3.31.

3.3 Position measurement of the hour axis

Since the hour axis has to be set with sufficient precision a measurement has to be carried out. This in general is carried out according to the method of J. Scheiner (drift alignment method) in conclusion not knowing where the axis points to. This is not only a big disadvantage but simply not useful if the requirements mentioned above should be met.

3.3.1 Method of J. Scheiner and A.A Rambaut

J. Scheiner was well aware of the disadvantages of his method and mentioned them in his original article [16] but was nonetheless convinced that the measurement accuracy should be sufficient.

A.A. Rambaut generalized the thoughts of J. Scheiner. We derive the expressions for the correction in elevation k and azimuth A_z (Gl. 3.50, 3.49, Seite 45) of the hour axis and present an estimation of the error of these final quantities and two plots (Abb. 3.36, 3.35, Seite 46). This estimation provides an unequivocal instruction where to measure. A simplification of the measurement, especially suitable for setting up a non permanent telescope, proposed by M. Schürer in [17] (Seite 45) is included. It is the nothing else than the “46-to-1” rule which appeared [13].

3.3.2 Method of E.S. King

Despite the fact, that A.A. Rambaut’s method is applicable almost everywhere in the sky, there is nonetheless good reason to carry it out close to the celestial pole P . The variation of the refraction over the local hour angle τ is that subordinate, that it can be neglected. The measurement and the calculation can be carried out as though the atmosphere is non existent. Taking a photograph of the polar region

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provoques the derivation of a method in the tangent plane at the position of the apparent pole P_r . This method is presented along with an estimation of the relative error (Seite 50) and the simplification proposed by H.H. Schaefer in [15] are included on Seite 51 (Gl. 3.60, 3.61). The final projection of the correction into the azimuthal coordinate system completes the calculation.

The fact, that all star trails depicted on a photograph are identical, is explained with by means of several simulated photographs (Abb. 3.38, 3.39 and 3.40). The effects, given the drive rate is not sidereal are presented in Abb. 3.41 and 3.42.

Beside the calculation a more graphically oriented method is presented (Seite 53).

We point out, that all the methods can be applied either for the data reduction of a photograph or a visual measurement at the telescope. Therefore, a matching practical method for any circumstances (permanent or temporary observatory) can be derived.

3.3.3 Automatic procedure

Every step manageable by hand, can be carried out supported by hard- and software. A concept to perform a precision polar alignment automatically with existing components (with the exception of the azimuth and elevation motors to move the hour axis) is written down below.

4. Difference effects

The entire chapter is qualified to make the obtained results visible.

4.1 Compensation by simple means

Abb. 4.1, our standard “open cluster” on a $1^\circ \times 1^\circ$ grid in the difference mode with diffraction, shows that a photograph has to be taken in symmetry to the meridian.

Abb. 4.2 shows the effect of the relative position of the guiding star and its effect on the star trails in case of not being situated in the center.

Abb. 4.3 shows the effect of the mean guiding wavelength $\lambda = 360 \text{ nm}$ (blue, left) and $\lambda = 780 \text{ nm}$ (red, right).

Abb. 4.4 shows what can be achieved with an existing color film or RGB-CCD camera. By scanning and decomposing an image into the RGB channels, the relative position of the three frames are given by

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the dispersion (Gl. 2.1) and the parallactic angle q for the mean wavelengths of the RGB filters (see Tab. 4.2). Alternatively a star with an appropriate spectral type can be used.

This type of image processing is illustrated in Abb. 4.5 and is better visible in 4.6 and 4.7 all three taken a zenith distance $\zeta > 40^\circ$. In this real photographs, the colored edges almost vanish completely.

Abb. 4.8 shows the result of a modified RGB composite image. The guiding system and the detector were simultaneously equipped with the same filter type. This is a conclusion of the paragraph on Seite 57. The star trails are substantially reduced and their forms are almost symmetric to the center, which means that each star has only a small tail at the edges. As already pointed out, this is a four hours lasting exposure at the declination $\delta = 0^\circ$, $\phi = 47.5^\circ$. Given the filter for the guiding system is not properly in place the trails reappear as shown in Abb. 4.9.

4.2 *Compensation of the dispersion*

Abb. 2.10 (right side), 4.10, 4.11 and 4.12 show the correction introduced by the Risley prism. The result is convincing and an four hours lasting exposure with a color film is feasible again, for the star trails almost disappeared.

4.3 *Compensation of the refraction*

As already mentioned above, the refraction can only be compensated by the correct setting of the hour axis. The derived equations in chapters 3.2.1 and 3.2.2 are by no means intuitive and the result of the correction on a star field (off center) is still unclear at this point in the text.

We demonstrate the outcomes basically with two different approaches: First we discuss, what can be detected in the focal plane given a telescope is strictly driven at sidereal rate and at constant declination. Which means, in other words, there is no intervention during exposure. Second, the normal case, where the telescope is guided.

Both approaches show different facts. The first one shows the effect on the center and the second one on the whole field. For the explanation of the entire effect both approaches are necessary.

4.3.1 *The field center*

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Each Abb. 4.13 - 4.17, 4.21 and 4.22 is a composite of seven simulations and, for the sake of comparison are condensed into one figure. The lowest trail represents the declination $\delta = -20^\circ$ progressing with $\delta = 0, 20, 40, 60, 80$ and 90° . The last trail is in most cases a single dot. The orientation is always north up east to the left even in cases where the declination exceeds that of the the zenith.

For non circumpolar declinations the trails start when the star is situated about 20° above horizon. In order to generate an idea on the hour angle dependency, each star trail is bearing red marks, representing the point $\tau \bmod 15^\circ = 0$. The length of the red part indicates a twenty minute interval, then it turns white again. We like to stress, that these figures are the result of the simulation and not just a simple plot of the functions derived more recently.

We consider the following cases:

Hinks: Polar distance λ of the hour axis set according to Gl. 3.31, minimization of the field rotation.

King: Polar distance λ of the hour axis set according to Gl. 3.21, minimization of the field rotation.

Fest I: Polar distance constant (fixed) at $\lambda = (P_r - P)/2$ in the direction of the zenith, this is approximately the E.S. King's recommendation in [8], page 177.

Fest II: Polar distance constant (fixed) at $\lambda = (P_r - P)$, being the position of the apparent pol P_r , E.S. King's recommendation in [8], page 158.

The last two cases are considered, for the hour axis of the existing mountings do not provide a possibility for a rapid change of its position with the required precision. These settings have to be considered as a compromise. All four cases are reconsidered in Chapter 4.3.3.

Abb. 4.13 is the most simple case. A telescope on earth without an atmosphere and the hour axis lies on the meridian at a polar distance $\lambda = 0.0015^\circ$. The result matches the predicted behavior.

Abb. 4.14 shows the situation where the hour axis points on the celestial pole P with atmosphere. This figure shows purely

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the effects of the refraction in the frame of the true equatorial system. Since $\lambda = 0$ the second expressions in Gl. 4.3. 4.2 do not contribute. A closer inspection shows, that the forms of the simulated star trails match E.S. King's prediction:

$$\delta = \frac{\pi}{2} \quad \text{circle}$$

$$\delta > \frac{\pi}{2} - \phi \quad \text{ellipse}$$

$$\delta = \frac{\pi}{2} - \phi \quad \text{parabola (not present)}$$

$$\delta < \frac{\pi}{2} - \phi \quad \text{hyperbola}$$

The cases **Fest I** and **Fest II** are presented in Abb. 4.15 and 4.16. The effect of the different polar distance λ can easily and best be seen at the declination $\delta = 90^\circ$. The circle is reduced by a factor of 2 in the first and to a radius equals 0 in the second case. The star trails are squeezed in the δ -direction in Abb. 4.16 as it was intended. The interesting part of this figure are the centers of the trails having a declination $\delta = 40, 60$ and 80° . These tiny structures are enlarged in Abb. 4.17. Despite the fact, that there is no reason to mistrust these loops, we try to put it on a more concrete basis. Nonetheless these loops only occur when the polar distance of the hour axis lies between $\lambda = 47 \dots 63''$ ($\phi = 47.5^\circ$). In Abb. 4.21 and 4.22 we show the movement of the center for the cases **Hinks** and **King**. There in all cases the loops are absent again. The two Abb 4.19 and 4.20 demonstrate the field distortion.

4.3.2 *The rate and the polar distance*

In this section we thoroughly research the drive rate and point out the possibilities offered by Gl. 3.19. The realization of E.S. King's idea mentioned in the footnote on Seite 70 is only a question of programming it into an existing electronic device and the precise polar alignment. But E.S. King presented his results (Abb. 3.1) hundred years ago and there was neither a mechanical nor a electronic device, to fulfill his requirements.

The analysis in this chapter of E.S. King's plate traces his thoughts and it is our convinced opinion, that his settings were special. But we consider this photograph as a big success and as well a confirmation of the idea, that a mounting can principally be used without any guiding system (fading out for the moment all those hassles to deal with concerning a real telescope and

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mounting). The simulation shows, that the length of the trails, given by E.S. King, are absolutely realistic.

Abb. 4.23 left: the polar axis points on the celestial pole P and the drive rate was sidereal.

Abb. 4.23 right: the polar axis points on the apparent pole, the drive rate being the same as above. The trails are confined in declination and they are shorter.

Abb. 4.24 left: the polar axis points on the apparent pole, the drive rate is equal to the so called King's rate. The trails are definitely shorter in the τ -direction. This plot shows, that the King's rate does provide almost no improvements for a long time exposure.

Abb. 4.24 right: the polar axis points on the apparent pole, the drive rate is set according to Gl. 3.19, that means, depending on τ . The result is striking, since there is no movement in the τ direction anymore.

Abb. 4.25 shows what can be achieved by taking E.S. King method serious. The drive rate is τ dependant as well as the polar distance λ (Gl. 3.19 and 3.21). In order to make this result visible the form of presentation had to be switched including the diffraction distribution. On the right side is the same figure but smeared with a Gaussian seeing $\sigma = 1.5''$. This figure is presented to get a better idea, how E.S. King derived the length of the star trails.

4.3.3 *The field*

In this section we compare the already mentioned settings of the hour axis in the way a photograph is in general obtained. The telescope is guided and the figures show our standard "open cluster".

In order to obtain a better idea the results are presented by means of the difference mode (guided) along with a three color representation of the star trails. Compared to the trails produced by the diffraction images (Abb. 4.27), this representation has the advantage that a "moderate" worst case is detected (wavelengths $\lambda = 450, 550$ and 650 nm instead of $\lambda = 380, 780 \text{ nm}$ at the limits of the interval). The trails produced by diffraction images

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cover up the way how they came into existence.

The easiest way to generate a concrete idea of what can be achieved is the comparison between Abb. 4.28 and 4.34. The first figure shows the results obtained if the drift alignment method is applied. The star remained 30 minutes on the cross hair of our real telescope and the final setting of the hour axis was $\lambda = 236''$ and $h = 18^{\text{h}}30^{\text{m}}$ (measured afterwards with E.S. King's method), pretty far off. On the left side is a one hour and on the right the standard four hours exposure. The trails are quite long, being the best case possible ($\delta = 40^\circ, \phi = 47.5^\circ$). Abb. 4.29 - 4.40 are then compared one by one and discussed.

4.4 *Tolerance of the positioning*

As already mentioned, the procedures, how to align the hour axis precisely is hardly described in the recent (amateur) literature. Since a meaningful physical measurement always bears an error bar, we try to define these limits depending on the observed declination. An analytical expression can only be provided in the vicinity of the celestial pole. Bearing in mind the trails presented in the last section, an integration of the bow element (Bogenelement normally labeled as ds) as a function of the hour angle τ , can not generate reliable results, since the trails are frequently severely bent and the radius being small. Our method to define those limits is the simulation and we point out, that a star trail is significantly different from the one at the minimum, given its area is larger by 10% (Abb. 4.41 and 4.42). Examples of the area in question can be found on the right side in blue, with the background being red. The results are compiled into Tab. 4.3 along with the position according to Gl. 3.31. At the celestial pole there is surely no error bar :-)) but the limits at $\delta = 0^\circ$ give an idea, why amateur astronomers are capable to take photographs at all. Please, consider the last sentence as a joke.

4.5 *Telescope steering and guiding system*

Approximately hundred years ago E.S. King had clearly demonstrated, that the apparent motion of a star (field) can be traced by a telescope without intervention. A.S. Hinks and P.T. Wallace & K.P. Tritton demonstrated by means of the same manner, that the field rotation can be effectively compensated. A.A. Rambaut pointed out, that there is a generalized (automatic) procedure to align the hour axis with

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the required precision. M. Sarazin showed in [14] that the seeing can be measured and that this measurement is independent from a possible tracking error. Rephrasing the last statement: the seeing and the tracking errors can be measured simultaneously.

We came to the conclusion that it is high time to take the logical step and enhance the steering software and the capabilities of the equatorial mounting.

The systematic part of the telescope movement is already thoroughly analyzed and can be programmed into a micro controller, including the dirty effects like e.g the periodic error of the worm gear and the tube flexure etc. The remaining errors have to become corrected as rapid and often as possible. The heavy burden can for sure be unloaded from the current guiding correction systems, for these systems don't have to make a decision, whether to correct or not to correct a given deviation, they simply have to.

4.6 *Conclusions and recommendations*

The main conclusion is to set the hour axis according to Gl. 3.31, in cases lacking this possibility it has to be set on the apparent pole P_r , as pointed out by E.S. King, and given the vicinity of the pole can be excluded use $\lambda = (P_r - P)/2$.

5 *Alignment of the hour axis*

The description is written in a “cook book manner”, for it comes along as a step by step guide based on one concrete example referred to throughout the chapter. Since most observatories are run temporarily we start on the “green meadow” explaining all auxiliary (calibration) measurements including the rough set up of the hour axis based on landmarks

The precise alignment can be carried out using an eyepiece optionally with an grid like reticle, conventional camera, CCD camera or a Webcam. The latter can be used as replacement of the eye.

5.1 *Drift alignment method*

For the drift alignment method is widely applied and considered to be adequate, we show why this method is not convenient for our purposes. At first following the instructions given by The Astronomical League [19] (cited in English) the simulation is carried out.

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In Abb. 5.1 and 5.2 the drift alignment method is presented without atmosphere and it is shown, that under these circumstances the method provides correct results for all declinations. The instrumental pole is at the position $h = 18^{\text{h}}30^{\text{m}}$ and the polar distance $\lambda = 236''$. With atmosphere (Abb. 5.3, 5.4) the results are still more or less in agreement close to the meridian, but for the local hour angle $\tau = -6^{\text{h}}$ it seems to fail (the trails point into the opposite direction, applying the same color coding as on page 22 of this proposal). This comes from the fact that the apparent pole lies $51.8''$ above the true pole in this example. The above mentioned coordinates of the instrumental pole indicate, that it is now below the apparent pole. It is then explained that the effects of refraction are small but can not be neglected. That it is mandatory to correct the measured star trails (or the observed movement in the eyepiece) for the effects of the refraction is then further explained with Abb. 5.5 and 5.6 where the instrumental pole coincide with the apparent pole. Again in the meridian the results are fine, but at $\tau = -6^{\text{h}}$ the movement in declination is not zero, only for $\delta = 80^\circ$ it is small. This is not surprising, because in Gl. 3.21 E.S. King predicted, that for each pair (τ, δ) there exists exact one setting of the hour axis at the polar distance λ so that the movement in the δ -direction is fully compensated. That is the reason, why the drift alignment method must be reconsidered and the additional rules are given on Seite 98. The same equation says, that each star will stay on the cross hair only for an infinitesimal amount of time. Of course under real observing conditions with an accuracy of let's say $\pm 5''$ this period is more or less long and the amount of time until a movement is seen is a rough measure of the position of the hour axis. The two Abb. 5.8 and 5.9 show this movement as a function of the local hour angle τ and for various declination δ and for two settings of the polar distance $\lambda = 0''$ (left) and λ set according to Gl. 3.21 (right). In the latter case, there is a horizontal tangent at the beginning for all declinations, which indicates the correct setting of the hour axis. From the presented practical difficulties of the "simple" drift alignment method we conclude, that the generalized methods of A.A. Rambaut or E.S. Kings should be applied. Both of them overcome all the drawbacks completely.

5.2 *Some prerequisites* In this section all the necessary things are ex-

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plained in great detail and always with the same example.

Usually the leveling of the tripod is considered as unnecessary. This is indeed true in the case where the drift alignment method is used. The corrections obtained from A.A. Rambaut's and E.S. King's method are provided in the alt azimuth frame. So the leveling is necessary to reach the pole.

In order to make the setting circles more usable the construction of a vernier is described.

How to define the zero point of the setting circles is described with remark about precision of the electronic setting circles.

Because both methods rely heavily on the exact sidereal rate of the drive, the issues of the periodic error is discussed and a method is presented how to measure and how to circumvent it (Abb. 5.14, 5.15).

There are several units used to measure angles. The conversion between the different used units is explained. All the calculations are based on decimal degrees and arcseconds with the exception of the angle $\Delta\tau$, which represents the movement of the telescope during a measurement.

In every calculation the local hour angle τ must be known. The determination of τ is presented in a graphical way, one based on the planetarium programs and one based entirely on a computation following [10].

It is utmost important that the τ - and δ -directions are known under any circumstances. The same thing holds true for the directions in the alt-azimuth frame. It is explained how these directions can be determined experimentally for the different telescope types including the two possibilities of Newtonian.

In all variants the detector, e.g. the eyepiece or the camera, must be calibrated. In case of the visual variants there are three possibilities depending on the orientation of the reticle (Abb. 5.22 - 5.24). For any type of camera the orientation is always along the τ - and δ -directions.

The measurement of the star trail in the eyepiece or on the photograph is shown and in the latter case a description of the useful star trails is given (Abb. 5.28). After that, the raw measurement of the star trails into arcseconds is performed.

After the determination of the components of the movement of the star

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one can derive the corrections in azimuth and elevation of the hour axis. This is done for both methods.

Having done this it is time to move the hour axis. A method which delivers precise results is listed together with a faster but less precise variant (Abb. 5.31).

5.3 *Rough alignment*

There are various methods to set up the hour axis roughly. Our method is based on at least three landmarks, spirit level, the telescope itself and a map of the location and can be carried out at day time. The aim is a precision of about $0.1 \dots 0.2^\circ$ depending on scales of the setting circles.

If someone often returns to a observing place the rough alignment needs special attention. After the precise alignment was established the rough alignment can always be done with the precision of the setting circles and three previously measured landmarks. Electronic setting circles with their higher accuracy will cut the time for the precise adjustment considerably.

5.4 *Precise alignment*

This is a introduction to the alignment process and a list of criterions is presented with a short explanation how a given method should be chosen. The idea is, that an amateur with almost no auxiliary equipment and a temporary set up can align the hour axis as well as an owner of stationary observatory equipped with a computer.

At the beginning it might be difficult to follow all the points presented in the section 5.2 in detail. Therefore a stripped down version based on the method of E.S. King is explained with the aim to emphasis the main points and not the precise alignment. This method needs only a calibrated eyepiece with reticle, paper and pencil.

5.5 *Method of A.A. Rambaut*

The method is presented in two variants. A visual and a photographic method.

5.6 *Method of E.S. King*

The basic variants are the same but in addition we describe an almost graphical data reduction based on a conventional photograph of the polar region including the refracted pole (Abb. 5.33 - 5.36). The data

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reduction describes the method in an intuitive way, because the main parts of it can be done with a pair of compasses, ruler and pencil.

6 *Telescope and detector*

Even if every step has been thoroughly followed a deep sky photograph, of e.g. a nebula with a detailed structure, can be a disappointing result, for the accumulated photons per unit area might in certain regions be below threshold. The simple solution to the problem is evidently to extend the exposure time or to increase the diameter which is not the correct answer to the initial problem. At this point it seems as though the requirements for a scientific and an appealing amateur photograph start to differ. And quite frequent the question emerged: “Why are my stars shaped like squares” in cases a CCD camera was used. And the frequent reply: “Accommodate the focal length of your telescope in order to sample a star by approximately six to ten pixels”. The reply should include the hint, that the exposure time t has to be increased by a factor $(f_{new}/f_{old})^2$ under ideal circumstances.

Following the Nyquist criterion there are two pixels needed to resolve one point. We demonstrate, that the parameters focal length f , diameter D and the linear resolution of a detector (conventional film material or a CCD detector) have to match Gl. 6.3 (Seite 151) in order to obtain the maximum information with the shortest possible exposure time. The stars again are shaped like squares and if an esthetically satisfying photograph is desired the pixels have to be rebined by means of a decent image processing software offline. This step is justified for we left the concrete ground of scientific work.

Under the real sky the resolution of the aperture is not the limiting factor anymore. The described star trails and the seeing are the relevant quantities. E.g., if the seeing limits the resolution the conclusion is going to be quite obvious. The reduction of the focal length reduces the exposure time significantly without any loss (Abb 6.1, 6.2, Tab. 6.2).

Assuming real sky conditions we figure out the minimum size of an aperture. There is surely the tradeoff between diameter and exposure time and given the time is not the key issue the lower limit is about 150 millimeter. Often the requirements of a typical amateur are not based on what the sky provides and for being a hobby only the best is good enough. For those with a limited budget or being interested in a well balanced system of mounting, telescope and detector the considerations presented are essential. Instead of buying a

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huge aperture the money can be spent on a better mounting, a larger CCD camera or a pair of Risley prism lacking any real drawback. To give the upper statements a proper foundation we present star images as a function of different observing parameters. All these figures are normalized the same way and having the same scale so that a direct comparison of the area of the star trails and the magnitude/pixel can be drawn. We consider 4 diameters: 100, 152, 200 and 400 millimeter.

Abb. 6.3 provides information concerning the size of the dispersed diffraction image of a star (spectral type G) as a function of the zenith distance ζ as seen through an aperture of 200 mm. Each horizontal bar represents a cut through the diffraction image along the great circle bearing the zenith Z . In the upper left corner the diffraction image is shown, on the lower left the image is smeared by a Gaussian seeing of $\sigma = 2.5''$, on the upper right side the correction introduced by the Risley prism for the diffraction image and finally the same for the smeared image.

Abb. 6.4 shows the same for a star of spectral type O. Abb. 6.5 and 6.6 shows the same for a aperture of 100 mm.

A comparison of the diffraction images for the mentioned diameters is presented in Abb. 6.7 ($\zeta = 47.5^\circ$) and Abb. 6.8 ($\zeta = 67.5^\circ$) without and with a seeing $\sigma = 2.5''$ Abb. 6.9, Abb. 6.10 with Risley prism correction at $\zeta = 47.5^\circ$ and the same for $\zeta = 67.5^\circ$ (Abb. 6.11 and 6.12).

The main conclusions are that the lower limit of the aperture should be 152 mm although taking photographs with an aperture of 100 mm is still feasible. In order that a small telescope can produce meaningful results compared to the big apertures it is necessary to make real long exposure photographs. A prerequisite is the presented precise alignment of the hour axis, which is of course not limited to the small telescopes. Before one thinks about adaptive optics one should take care of the dispersion.

A *List of symbols*

A complete list of the symbols employed is provided. We tried to keep the symbols consistent with the original articles, but this wasn't possible in all cases.

We failed in providing a unique meaning only in case of a few symbols, e.g. λ is simultaneously with the wavelength and the polar distance of the hour axis. But in these cases the context provides the necessary information.

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B *Index*

We will build a sensible index.

Bibliography

All the cited literature is placed here.

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A Figures

All photographs in this section were taken in the prime focus with a refractor (aperture diameter 180 mm, $f = 1260$ mm) built by Astrophysics. The film format was 24 mm \times 36 mm. The observatory is located at the latitude $\phi = 47.1^\circ$, altitude 550 meters. With the exception of fig. 1, the position of the hour axis was ($\lambda = (P_r - P)/2$, $h = 0^h$) with the precision of $\pm 10''$. The image processing was limited to the adjustment the darkest and brightest point.

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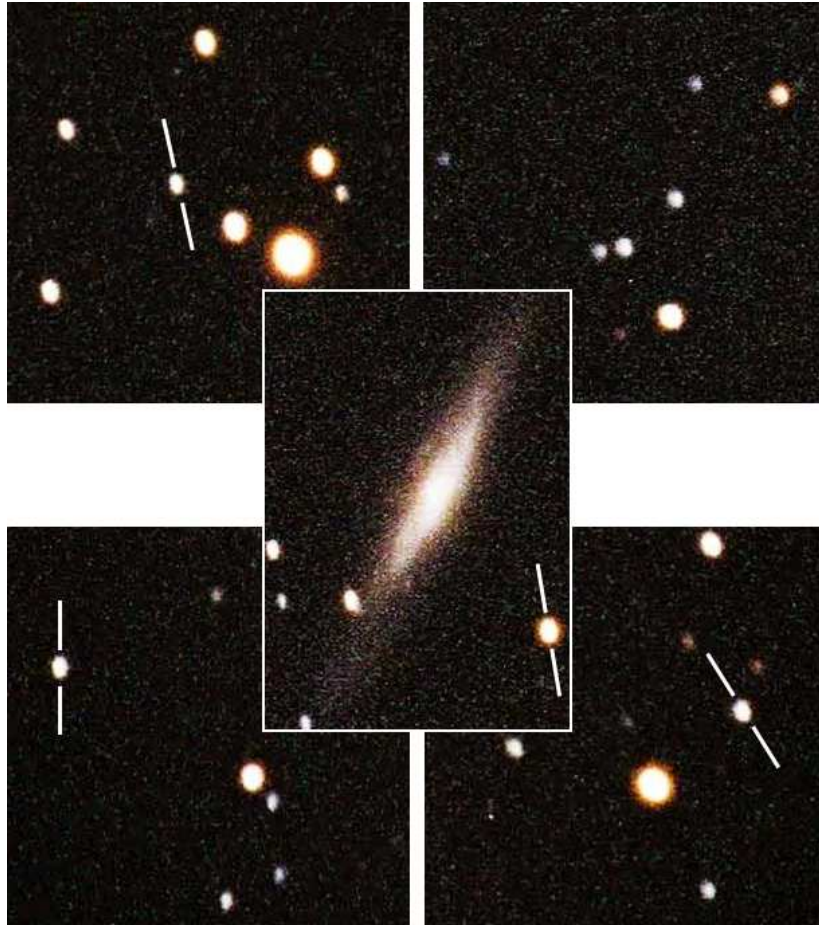


Figure 1: The galaxy NGC 2683, the star trails have different lengths and directions depending on the coordinates in the field. Only the star images in the upper right corner are acceptable. In the center the movement of the plate, which compares with the bright nucleus, is the limit of the resolution and not the seeing. The different colors at the edges of the individual star images due to the dispersion are clearly visible at lower right. The individual parts are taken from the corresponding corner and center of the photograph and enlarged.

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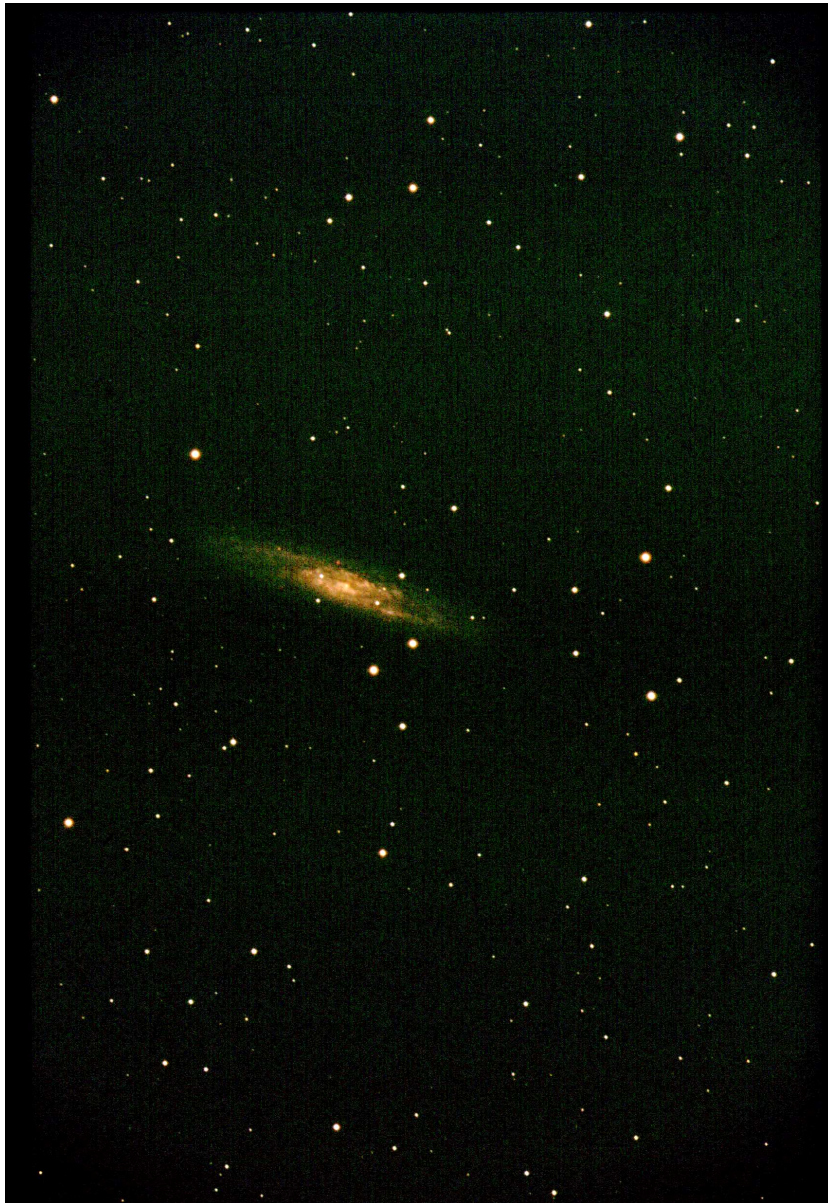


Figure 2: An object being better be photographed in the south: NGC 253, $\delta = -25.28^\circ$, elevation = 17° . Taken on September, 13th 2002, 3 o'clock am, exposure time 40 minutes on Kodak Ektachrome Elite 200. Compare equipment, exposure time, format and star images on this photograph with plate 9 after page 142 in [23].

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Figure 3: Omega nebula (M 17), 35 minutes on Kodak Elite 200, April 16th, 2002, 03:30 local time.

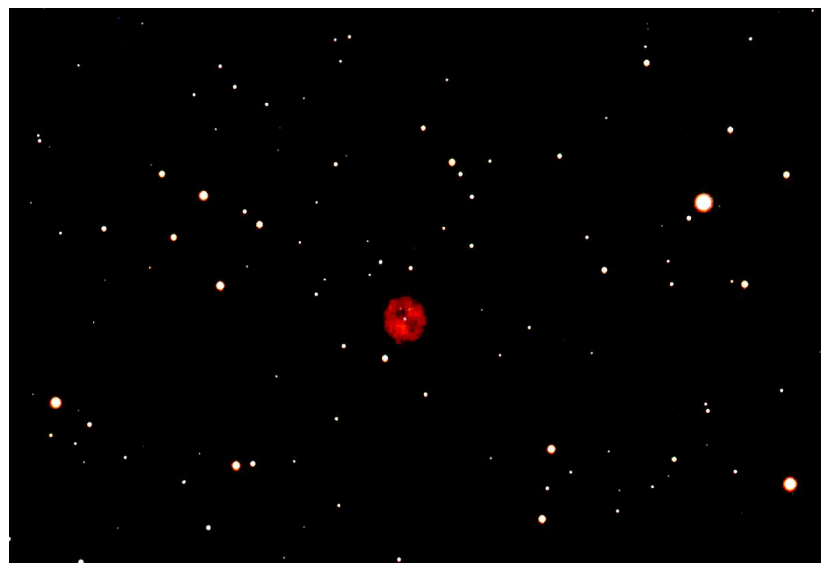


Figure 4: M 97, 50 minutes on Kodak Elite 200, February 23rd, 2003, 23:45 local time.

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