

Chapter 2

The “Perfect AIS”

2.1 In a Perfect World...

It would be wonderful if you, as an amateur astronomer, had access to equipment that performed flawlessly, was capable of multiple types of data acquisition, was available at the flip of a switch, and not only allowed you to enjoy working directly with your equipment, but also to acquire your data without being out in the inclement weather. It would also not be too much to ask if you could acquire this equipment at a very low cost, within the next 2 days, and have it up and running tonight. Unfortunately, this last sentence describes what many of us, as beginners, expect when acquiring our telescope, cameras, and accessories. In a perfect world, this would be the expectation; however, while the amateur scientific pursuit of astronomical knowledge is neither quick nor easy, it is very doable by almost anyone who is willing to learn the appropriate skills and obtain the necessary knowledge (Fig. 2.1).

Three fundamental factors must balance each other in astronomical pursuits—Equipment Cost, Available Time, and Skills/Knowledge. As a beginner, you may have some knowledge of the night sky from high school or college classes, and you may have had a small refractor as a child or young adult. Now that you have access to some disposable income, you want to invest in a nice telescope and are *very* interested in these modern charge-coupled device (CCD) cameras people are using today, so you purchase one of those too. Of course, you want to invest in the best equipment you can afford, and you figure that even though you have no experience with the latest equipment, if you buy the “good stuff,” it should be able to do things for you that you may or may not be aware of and/or want to do for yourself. You are also very interested in getting into imaging and tracking comets or minor planets. The reader can see where this might lead....



Fig. 2.1 An image of the lunar surface taken by amateur astronomer David Abbou using a Celestron Neximage webcam-based CCD camera on December 31, 2011 (Courtesy of David Abbou)

So, here you are with your big 10-in. Schmidt-Cassegrain telescope on your nice fork mount with your fancy go-to system so you can just point and click to slew to your asteroids. You also bought one of those nice “astrocams” that everyone on the web forum said was the best one to get to image minor planets. You ordered your equipment from one of those nice astronomical equipment web stores online and got your order in less than a week! Yippee! Of course, you received your equipment in the middle of a work week, but that’s not going to stop you from getting out this evening. You set up your equipment indoors to see how it all works and want to go out tonight to see if you can find an asteroid. However, you realize you don’t know where to look. Uh-oh... Well, no big deal, you can point your telescope and CCD camera somewhere near the ecliptic and maybe catch one of those asteroids in the act.

Of course, as an intrepid amateur, you have a good time messing with your equipment, setting it up, and probably spending half the evening trying to get a good polar alignment because that is what the people on the forum said was important to be able to use that fancy go-to system. So time flies by, and before you have been able to image anything, it’s late and you have to go to work in the morning!

Over the next few days and weeks, it dawns on you that you should probably back up and reevaluate what you need to do to get that astrophoto of that asteroid. You probably spend a few sessions getting your equipment to work as it says it should in the manual and learning how to use that software to process the initial images you have acquired. You have a tough time just figuring out where the telescope is pointing because your images do not correspond to the fields where the mount is pointing. You also have problems with focusing on the stars, and the field

of view (FOV) is not as big as you expected. As a result, you have a very difficult time getting those wily asteroids in your pictures at all. You start asking pointed questions on the forums specific to your equipment and techniques; everyone agrees: Yep! You are doing the right thing as you describe it. The results just aren't there. So you continue with several observing sessions over the next few weeks, but still with not much progress.

You get better at setting up your equipment faster so you do not waste as much time, but the results are not any better. There is something missing. You start to wonder if your equipment is bad, or something else. You start to doubt yourself, but you are doing everything the equipment manual says. What is wrong?

This is the point where frustration takes over, and you do one of two things: you sell the equipment at a loss and buy a simple refractor just to enjoy the night sky (if you are up to it), or you sell the equipment and *invest twice as much as before* on new equipment that will “probably” solve all your problems. Of course neither is the correct course because the equipment is not the problem. It is, of course, *you*. You lack the knowledge and skills in the use of the equipment to attain your goal. It is very important to recognize that you absolutely must balance your skills and knowledge with the needs of the equipment you want to use. Once you have attained a certain level of skill and knowledge, it will drive you to operate your equipment proficiently and also allow you to determine the correct equipment for your observing program. This in turn will dictate the budget necessary to run your observing program.

You must also be prepared to invest the necessary time in the endeavor to realize the results you want to see. Do not overlook the importance of dedicating the proper time to obtaining the skills and knowledge to run an effective observing program. Be prepared to spend the better part of 1–2 years (30–40 observing sessions) in learning the basics before you can start being productive in your observing program. This includes investing in the appropriate level of equipment to serve as a learning Astronomical Imaging System (AIS). This book is designed to help you maximize your learning during each observing session.

The goal is to set you on the correct path to avoid the frustrating and expensive lesson described above. There is a lot to learn, but think of it as an investment in yourself—the more you know the more money you can save. There is also another interesting dynamic; when you obtain the proper skills and knowledge, and as your skills/knowledge increase, your *need* for more or better equipment *legitimately* increases. You use your level of skills and knowledge to drive your equipment-buying decisions and therefore make maximum use of your investment...in yourself. This is a much better way to approach your goals in scientific astrophotography.

2.2 The AIS Design Basis

In the nuclear power industry and nuclear plants, all of the reactor's systems have a design basis. The definition of a design basis in a nuclear plant is the totality of the design requirements, goals, expected performance, testing requirements, and

limiting conditions for operation of the structures, systems, and components (SSC) in the plant to provide the maximum margin of safety while obtaining the desired output (results). In the case of the nuclear plant, the results expected are safe, reliable, conservative operations, a high capacity factor, and the desired/expected megawatt output. In the same way, you need to initially examine and jot down the goals for your *Observing Program*. This drives the design basis of your AIS. An Observing Program could have many different goals, but let’s focus on the frustrated user from before.

You do not have to be too rigorous or specific at this point; you just want to outline some basic parameters of your program. Some features are common to all observing programs; other features are very specific to an individual program. The following is an example of a minor planet *Observing Program Design Basis (OPDB)*:

Observing Program Name

Minor Planet Observations

Object Characteristics

Solar System Moving Object (predominantly located near the Ecliptic)
Brightness Range of 10th–18th Magnitude

Program Goals

- Measure Minor Planet Brightness (Differential Photometry)
- Measure Minor Planet Position (Astrometry)
- Take Measurements Over Time to Gain Knowledge of:
 - Rotation Rate
 - Orbital Parameters

Measurement Performance

| | |
|-------------------------|------------------------|
| Differential photometry | ±0.1 magnitude |
| Astrometry residual | ±0.2 arcseconds |
| Absolute time reference | ±0.1 s |
| Rotation rate | ±1 min |
| Orbital parameters | ±1% of accepted values |

Program Databases

| | |
|------------------------------|---------------------------|
| Minor planet center database | Real-time object position |
| USNO UCAC 3 stellar database | Astrometry/photometry |

Program Focus

- Near-Earth Objects
- Trojan Asteroids
- Main Belt Asteroids

Program Implementation

| | |
|---------------------------------|------------------------------|
| Expected observation production | 10 reduced observations/week |
| Expected opportunities/week | 2 sessions @ 5 h each |
| Total number of images | 100 per session |
| Observation throughput | 50% |
| Weather limits—temperature | 20°F–90°F |
| Wind | < 10 knots |

This is enough to start to define the equipment needs of the system once you have learned what is required to take these measurements. This book gets you up to speed on all that is necessary to make intelligent decisions on the specific equipment, procedures, and support data needed to successfully create an Observing Program.

2.3 Balancing Expected Results with Budgetary Constraints

The quality of the results you obtain in your observing program is a combination of the level of performance of your equipment and the skills and knowledge you bring to the table operating that equipment. You should be prepared to understand and set your expectations at a realistic level while you are learning how to take astrophotographs in support of your scientific observing program. The requirements for scientific astrophotography are different than for “pretty picture” astrophotography. In some cases, the needed skills and equipment are not as rigorous for scientific astrophotography. In most cases though, discipline is required to keep track of equipment settings and techniques used. In all cases, there is an absolute need for attention to detail and for understanding the underlying principles that lead to the results observed. This cannot be emphasized enough.

As mentioned previously, once you have acquired a high level of knowledge and skills, you will be better qualified to evaluate any piece of equipment that you need for your observing program. You will be able to judge for yourself whether it is worth the money for the performance expected from the equipment and whether it will add value to your observing program. The goal is to get the best value in performance, regardless of how much or how little you want to spend. The bottom line is that based on your budgeted amount, you should expect a known level of performance whether it is excellent or just fair.

A common question posed on the Internet astronomy forums is how much should I spend on my telescope mount, telescope, or camera, for effective imaging. You should look at it as a total budget evaluation—invest a particular percentage of your budget for each major subsystem of your AIS. It is important to consider that if you have a low initial budget of about \$2,500, then you will have a difficult time imaging effectively without going through some growing pains, and frustration. This book is designed to minimize that frustration.

The biggest assumption here is that you already have a computer system capable of running the software, and it has the appropriate interfaces for your hardware. The minimum cost AIS is really only a training system, and its performance is limited in providing quality scientific data. The minimum requirement for an effective scientific imaging system that minimizes the frustration that you will experience is described below as the Midrange AIS. That is not to say that acquiring scientifically valid data is not possible with the lower-cost systems. It just takes a very dedicated amateur who has honed his/her skills and knowledge to a fine edge. The skills and knowledge presented in this book go a long way toward helping you make effective use of these lower end systems.

There are also “experts” out there who say that if you want to get into astrophotography at the midrange level, then you should invest in a high-end mount at the start. Although this makes some sense because you would be purchasing for the long term, it represents false economy on several levels. The main reason is that, as a novice, you need access to all the different basic pieces of equipment to learn how to perform effectively. If you put all your funds into a mount—let’s say about 60–70% of a \$5,000 budget—then you would have only about \$1,500 for the rest of your equipment. Shortchanging yourself at this level means that although your mount is very capable and can handle just about any scientific imaging you would want to do, your astrograph and camera are not up to the task. This is guaranteed to frustrate you.

It is strongly suggested that you approach the task of building your AIS with a balanced view, using your design basis to guide you. For beginners, create your design basis with the goal of learning the *how and why* of performing scientific astrophotography. Once you are done “training,” then you can improve the quality of your data by investing in the higher end equipment necessary. You must first gain the necessary experience in using the tools of the trade before expecting to make many scientifically useful observations, although there are amateurs out there who are doing cutting-edge work with lower-end equipment. One good way to minimize your equipment budget is to focus on a very specific object type in your observing program. You can design your AIS specifically for this program and save some hard-earned cash.

In the following cost breakdown tables, each cost area consists of several items, which, when combined, make up the AIS. Listed here are the suggested components for each cost area. It is important to keep in mind that the lower cost systems will not have the full range of components that would be purchased for the mid-range AIS and above.

Telescope Mount—a go-to capable mount and tripod system (as a minimum) with a hand controller and computer interface/driver. Software for the mount is either freely available and/or comes with the mount from the manufacturer. The mount also accommodates a standard telescope mounting plate of either a Vixen style or Losmandy style, which is standard for low-cost to mid-range telescopes. Higher end mounts accommodate custom style plates necessary for mounting the heavier, high-end astrographs.

Telescope/Astrograph—the main *optical tube assembly (OTA)* and its mounting rings and/or plate. This element of the system also includes a focuser (2-in. or larger) that is manual in lower end astrographs and may or may not be motorized in higher end astrographs. Other parts may come with your OTA, such as a finder scope, dew heaters, and/or extra eyepieces. These may or may not be useful to you. Several manufacturers of replacement focusers can provide a motorized focuser if that is one of your requirements. Several manufacturers also can provide correcting optical elements for your astrograph to reduce the focal length, flatten the field, etc. These elements are usually considered part of the camera system if not fully integrated into the OTA.

Camera System—the main imaging camera plus any other optical elements meant to help your AIS perform as an effective astrograph. This system also includes those elements necessary to adapt your camera to the focuser and provide the proper spacing of the camera in the imaging train. Filter wheel systems may also be included in the camera system for added capability.

Support System—any external systems that interface to the mount/telescope/camera. These may include a laptop or net book computer system with appropriate hard drive systems, and software used to control the mount/telescope/camera systems. It may also include an auto-guiding system or drive corrector that provides external support to the mount. In addition, the support system may include any data analysis software used to process and analyze your images. Software used to access databases of star, asteroid, planetary, or other type of celestial objects may be included. It is important to recognize that Internet connectivity is an important feature in amateur astronomy today and gives you free access to most if not all the software applications and data that you may need in day-to-day operations of your AIS. The Internet is also an important source of information on the operation and maintenance of your AIS. Here are some suggested budgets and percentages for you to consider (all costs are in 2012 US dollars):

Minimum Cost AIS: Total Budget \$2,500

| | | |
|----------------------|-----|------------------|
| Telescope mount | 40% | \$1,000 |
| Telescope/astrograph | 25% | \$625 |
| Camera systems | 30% | \$750 |
| Support systems | 0% | Freely available |

Low-Cost AIS: Total Budget <\$5,000

| | | |
|----------------------|-----|----------|
| Telescope mount | 40% | <\$2,000 |
| Telescope/astrograph | 30% | <\$1,500 |
| Camera systems | 20% | <\$1,000 |
| Support systems | 10% | <\$500 |

Midrange AIS: Total Budget \$5,000–\$15,000

| | | |
|----------------------|-----|-----------------|
| Telescope mount | 35% | \$2,000–\$5,000 |
| Telescope/astrograph | 30% | \$1,500–\$4,500 |
| Camera systems | 30% | \$1,500–\$4,500 |
| Support systems | 5% | \$500–\$750 |

High-End AIS: Total Budget >\$20,000

| | | |
|----------------------|-----|----------|
| Telescope mount | 40% | >\$8,000 |
| Telescope/astrograph | 30% | >\$6,000 |
| Camera systems | 25% | >\$5,000 |
| Support systems | 5% | >\$1,000 |

Very High-End AIS: Total Budget >\$50,000

| | | |
|----------------------|-----|-----------|
| Telescope mount | 30% | >\$15,000 |
| Telescope/astrograph | 45% | >\$22,500 |
| Camera systems | 20% | >\$10,000 |
| Support systems | 5% | >\$2,500 |

The basis for this structure is balancing the need for effective, quality imaging with the minimum needed to get useful results. Throwing money at the issue only gets you, at the most, halfway toward the high-quality, near-perfect images you desire. Skills and knowledge get you most of the way there, especially when investing in the low-cost AIS. As you can see, in most cases, the highest percentage of your budget should be invested in the telescope mount. This is explained in detail in Chap. 7, but it should be obvious that the telescope mount is the foundation for excellent, high-quality, astrophotographs.

For the low-cost and high-end AIS system costs, the percentage of the total budget specified for the mount is higher than for the midrange AIS. For the low-cost AIS, this is because the total budget is low, and you must make a minimum level of investment in your telescope mount to obtain the quality astrophotographs necessary for scientific investigation. Also, to overcome a guaranteed level of frustration, it helps to spend a little more cash. No matter the patience, skills, and knowledge you may possess, under-spending on your telescope mount will result in images that will not achieve the necessary level of quality. In the case of the high-end AIS, because a wealth of funds is available, it makes sense to invest for the long term by purchasing a very nice mount. The expectation is that this mount will probably last the rest of your life, giving you trouble-free, excellent service.

Telescopes and astrographs are available at a wide range of prices—Chap. 3 discusses what makes a good imaging telescope. However, most amateurs use telescopes with an objective diameter from 5–10 in. The planetary imagers use

astrographs greater than 10 in. in diameter to obtain the *image scale*, or magnification necessary to perform the super high-resolution imaging desired. There are certainly some tradeoffs you can make in the percentage of your budget devoted to various pieces of equipment, depending on the specific goals of your imaging program. This is no truer than when considering the amount to spend on the telescope or astrograph. The size and focal length of the astrograph is driven by whether you want to do stellar imaging or planetary imaging. Astrophotographers who focus on stellar imaging opt for the wider field, shorter focal length imaging systems, whereas those who do lunar or planetary imaging tend to use the longer focal length AIS. However, there are always exceptions. Some diehard amateurs image the faintest, smallest objects they can find. This is an especially challenging program to pursue.

The choice of camera systems available to the amateur astronomer is vast. We are very lucky to live in an age with so many good choices. Of course, as with most items you choose to buy, you get what you pay for. There are features in camera systems that you may consider a necessity, and others that are nice to have and contribute to comfort in using these cameras. Again, you can spend as little or as much as you choose on a camera system, but you must be prepared to apply your skills and knowledge when using these systems. Future chapters provide plentiful information for making an informed choice.

The small amount budgeted for support systems goes toward the computer systems and software necessary to acquire raw data and process it into a useful form. This amount seems small because there is a wealth of free software available on the Internet that covers most of the processing that you are likely to do in your work. We are very lucky that in the amateur astronomy community, we have people who love to provide the tools and techniques necessary and choose to share them with anyone who wants to learn. The support system also includes any external correction systems you may add to your mount, such as auto-guiding or drive corrector systems. In addition, other professional-level tools that you may want to invest in to add to your support tools will provide an elevated level of quality and certainty in analyzing of your data. Investment in these tools may also give you options that you might not have otherwise. Future chapters cover these tools and discuss why one would consider investing in them.

2.4 AIS Operations and Maintenance

As an observatory director (that sounds impressive, doesn't it), you are responsible for the *operations and maintenance (O&M)* of your observatory. This means learning all there is to know about your equipment and maintenance. You need to be aware of the environmental requirements for storage and operation if it is a portable observatory, or what shelter you need if it is a permanent observatory. To maintain the expected performance of your telescope, mount, CCD camera, and other accessories, you must be able to detect any problems that may arise and keep up with any problems that others have identified, known as operational experience (OE) in the nuclear industry.

The equipment you invest in will provide you with years of service when maintained appropriately and will not become a hindrance to you in reaching your goal of acquiring excellent scientific imaging data. It is important to understand the proper operation of your equipment based on the vendor instructions and on the design of the equipment. There are times when you may be tempted to operate your equipment outside the specified operating range (that can be useful at times), but it is important to understand the limits of your equipment and the impact that operating beyond those limits will have on your data. You may be able to operate certain pieces of equipment outside their limits by compensating in the way you operate other parts of your system. These limits are usually specified in the operating manual that comes with your equipment.

For example, suppose you have invested in a telescope mount that has a load capacity of 40 pounds (lbs) (18 kilograms (kg)). The following chapters recommend that to get the best imaging data, you normally do not want to push the limits of the load capacity of your mount. However, although you do not have the budget to upgrade your mount’s capacity, you want to acquire data using your larger 10-in. reflector and your biggest CCD camera (with accompanying accessories). This equipment weighs in at 38 lbs (17 kg) and is at the nominal limit for your mount’s capacity. In this case, you must use your judgment and fully understand the impact that pushing the capacity of your mount will have on being able to obtain the data you need. You may be limited in the total exposure time you can expect while maintaining a defined quality of image. You may need to be extra sensitive to any movements around the mount when you are taking images. You may need to take extra care that no cables are loose and present a snagging hazard. You get the idea.

As another example, suppose you want to take the most precise and accurate measurements of the position of a minor planet, but are limited in the resolution. First, you need to balance your FOV to the image scale of your system to ensure you can not only measure the position accurately, but also place the object in your FOV at all. Your goal is to be able to set up quickly and start your imaging, so you do not spend much time getting a “perfect” polar alignment on your mount. In addition, because you want to get the most precise and accurate measurement, you will initially push your equipment’s performance by setting the pixel scale to less than 1 arcsecond/pixel. This, in turn, narrows the FOV significantly. The narrow FOV, coupled with the imprecise mount alignment, causes you to spend extra time on every object ensuring that it is placed within the FOV. If, on the other hand, you had spent some time evaluating the situation, you might have opted for spending the extra 15 min ensuring your polar alignment and pointing accuracy were better. There is nothing more frustrating than learning that you have not placed your target in the FOV after spending valuable time imaging that portion of the sky.

You can see that it is important to understand the capabilities and limits of your equipment when setting your goals and operating your AIS. It is also important to balance the capabilities of all the pieces of equipment involved with taking the data of interest. By balancing the various options and performance issues, you obtain that “perfect AIS.”

The following chapters discuss in detail the steps to prepare and make your observations—doing it right the first time and every time with your “perfect AIS.”

2.5 Are You Up to the Task?

Based on the previous discussion, you may find the whole process of choosing a system somewhat overwhelming...and it is a lot to learn and understand. However just like any other technical subject, if you break down the material into specific topics, and continually review how the individual items relate to your end goals, then it is not as difficult as it may seem. This book leads you down a well-worn path, giving you numerous examples and specific exercises to help you build not only your skills and knowledge, but also your discipline and your sense of excellence, all of which will serve you well into the future.

Remember, frustration is borne of lack of knowledge about cause and effect. All of us have problems that arise during every imaging session. The important point is that you are equipped to identify and understand the symptoms, and are able to identify the root cause of the problem. Sometimes it is necessary to put a work-around or quick fix in place to finish the session, but it is also necessary to evaluate the issue after the session to get to the root cause and permanently remedy it.

If you are up to the task, you will value the skills and knowledge you gain through your diligent work using the disciplined approach outlined within the following chapters. This is an investment in your time that is valuable, so make the most of it!

Further Reading

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