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Making Your Own Astronomical Camera

by Susan Kern and Don McCarthy

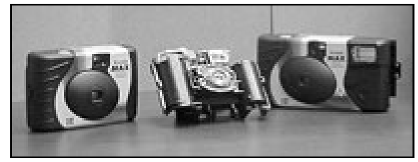
People are fascinated by the night sky. By patiently watching, one can observe many astronomical and atmospheric phenomena, yet the permanent recording of such phenomena usually belongs to serious amateur astronomers using moderately expensive, 35-mm cameras and to scientists using modern telescopic equipment. At the University of Arizona's Astronomy Camps, we dissect, modify, and reload disposed "One-Time Use" cameras to allow students to study engineering principles and to photograph the night sky.

Elementary school students from Silverwood School in Washington state work with their modified One-Time Use cameras during Astronomy Camp. Photo courtesy of the authors.

Today's disposable cameras are a marvel of technology, wonderfully suited to a variety of educational activities. Discarded plastic cameras are free from camera stores. Students from junior high through graduate school can benefit from analyzing the cameras' optics, mechanisms, electronics, light sources, manufacturing techniques, and economics. Some of these educational features were recently described by Gene Byrd and Mark Graham in their article in the *Physics Teacher*, "Camera and Telescope Free-for-All!" (1999, vol. 37, p. 547). Here we elaborate on the cameras' optical properties and show how to modify and reload one for astrophotography.

An Education in Optics

The "One-Time Use" cameras contain at least six interesting optical components. Three of these items are found on a single piece of molded plastic, which is associated with the viewfinder and can be removed as a single unit for further study and experimentation. This "viewfinder assembly" is a Galilean optical system using two lenses. As pointed out by Byrd and Graham, you can use it in reverse to act as a simple telescope. Other components include a simple magnifier for the exposure counter, a "light pipe" with a diffusing surface for the flash indicator, a parabolic reflector for the flash tube, and a cylindrical lens over the flash unit.



The KODAK One-Time Use cameras with (right) and without (left) the flash unit. The assembly at center is a non-flash unit with its front and back covers removed. Photo courtesy of the authors.

The camera's main aperture follows the design of a "front landscape" lens. It features a steeply curved, aspheric meniscus lens followed by a physical aperture "stop" to limit blurring by spherical aberration. Figure 1 shows a ray-trace of the approximate system, revealing its simplicity, wide field-of-view (~ 60 degrees), moderate distortion (~ 5 percent), curved focal plane (~ f/10), and a spot-size consistent with the resolution of the human eye (< 1 arcminute). The main lens has a focal length of about 26 mm. The underlying stop limits its collecting diameter to 2.5 mm, roughly similar to the pupil of the human eye in daylight but smaller than the eye's approximately 8-mm opening at night. Although far from perfect in its optical performance, this simple lens yields images consistent with viewing by the human eye. The design principles of the viewfinder and main aperture are provided in R. Kingslake's classic optics text, *Lens Design Fundamentals* (Academic Press: San Diego).

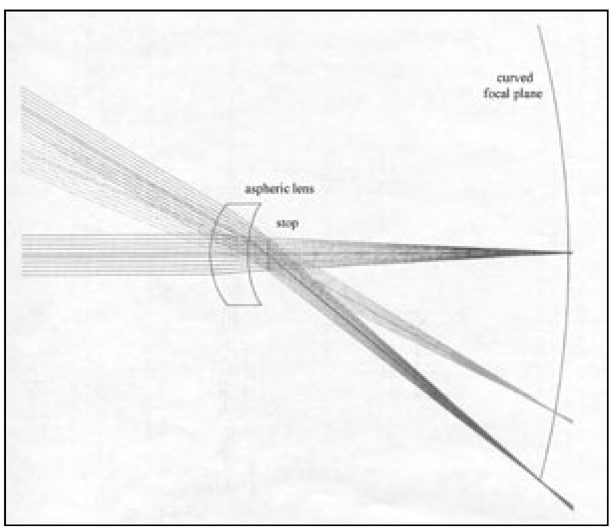


Figure 1. Computer ray trace of the simulated optics in a One-Time Use camera. This diagram shows the main aspheric lens followed by a "stop" which reduces the effects of spherical aberration in the final image. The side field-of-view and curved focal plane are also apparent. Drawing courtesy of Roland Sarlot, Steward Observatory.

Making Your Own Astronomical Camera

Dissect & Modify the Camera

The first step is to open and inspect the camera body. If your camera has a flash unit, you must open the covers very cautiously to avoid electrical shock. As described by Byrd and Graham, the flash unit contains a large capacitor (120-160 micro-farads rated for 330 volts), which can retain its electrical charge long after the battery has been removed and can be quite dangerous if not discharged thoroughly. Do not use the flash units for this activity unless you can be sure the students will avoid touching the internal circuit board. Once the camera is opened, you can "short" the cylindrical capacitor using an insulated piece of metal to connect both leads to each other. It is important to short the capacitor several times and to be sure the battery has been removed from the side compartment.

Notice that there are snap locks on both sides of the camera body, one of which should already be open since it contained the film removed by the developer. To open the camera body, peel back some of the yellow sticker identifying the camera as KODAK on the top and bottom of the camera and unsnap the plastic pieces. The top and bottom should separate without much force. You should now have four pieces: the front cover, back cover, middle (main camera with lens), and a cylindrical spool.

The shutter mechanism must be removed for long-exposure photography. You need to remove the lens assembly temporarily. The lens is mounted in a black plastic housing which can be pulled off from one corner once you have removed a "C-shaped" metallic band. The latter may not be present in all cameras and can be discarded once removed. Avoid touching the lens; your fingerprints could deposit an oily film or scratch the lens surface and ruin its focusing ability. Dust on the lens can be removed by blowing air sideways across the lens. Once the lens assembly has been removed, you should see the shutter mechanism: a dark gray metallic piece hinged to a small plastic post and also connected to a spring. Remove the spring and the gray piece. Replace the lens assembly by locating it back on its plastic locating posts and snapping it back into place. Replace the front cover of the camera.

If you plan to do this activity with a large class, go to a photo-finishing store and ask to collect their disposable camera bodies. For loading new film, as described below, you should also acquire the used film canisters with the toothed spindle. WalMart has been very generous to us -- they will let you sort through their recycling bags for the specific items you need.

Loading the Film

Since the disposable cameras do not have a rewind mechanism, they operate backwards from an ordinary 35-mm camera. You will put the film in the camera so that, as you take pictures, the film is rolled into its canister which can later be removed for processing. From a camera store you can buy a roll of film and re-rollable film canisters (30-60 cents each) with screw-tops. You don't need a full roll of film for each camera. We generally figure three to four cameras per roll of film (36 exposures), putting six pictures on each camera with an extra one to two frames needed to attach the film with lag and lead.

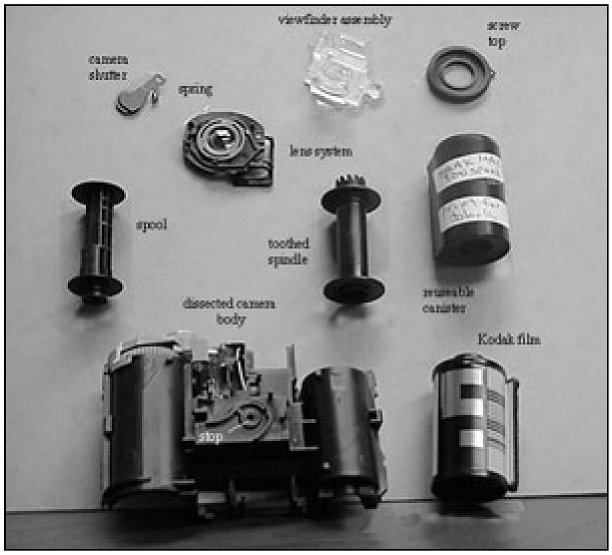


Figure 2. A disassembled One-Time Use camera with its internal components shown to the sides. Also shown are the items necessary for reloading these cameras with film. Photo courtesy of the authors.

The following procedure should be done in total darkness. You can practice in the light with previously exposed film, making careful mental notes and paying close attention to the feel of the following steps. Figure 2 illustrates the components discussed below.

1. Remove the toothed spindle located in the center of the film canister you procured from the developer. You can pry the canister open with a fork. Be careful not to cut yourself on the sharp edges.

2. Open the re-rollable film canister and replace the center spool with the special spindle from step #1. Attach the end of the film to this spindle with a small piece of masking tape and roll the film onto it. Put it into the re-rollable film canister with a little "leader" sticking out. Secure the screw-top to make it light-tight. With another small piece of tape, fasten the leader to the cylindrical spool that was originally in the camera.

3. Wind the film onto the cylindrical spool and place both the spool and canister in the proper compartments inside the camera. Then replace the back of the camera, snapping it into place on all four sides. To close the side doors fully, you must press the doors inward as you snap them in place.

4. Once the camera is assembled, cover all the seams with electrical tape to prevent light-leaks. Also, place some electrical tape over the lens on the outside cover to function as your new shutter. Be careful not to tape the lens itself.

Occasionally, the side doors (for film and battery) detach from the camera body due to fatigue in the plastic upon repeated bending. We have found that these doors can still snap back in place and that they can be sealed against light-leaks by using electrical tape to fasten them to the camera body.

Making Your Own Astronomical Camera

Turning the Camera Skyward

A reconfigured camera can take wide-field exposures of astronomical objects (constellations, the Milky Way, zodiacal light, moving artificial satellites, meteor showers, variable stars, etc.) to reveal much fainter objects and structures than seen by naked eye. Such pictures can be "still" frames to record, for example, the circular motions of stars due to the Earth's rotation, or "tracked" frames in which the camera is mounted in a simple tracking device which follows the moving stars to keep objects in focus.

One type of tracking device is called a "barndoor tracker." It is conceptually simple and very rewarding to build. In the process, students will apply the concepts of celestial north and sidereal motions, utilize simple geometry or trigonometry, and learn about elementary woodworking. Many undergraduate students in McCarthy's college astronomy class have chosen to build barndoor trackers for astrophotography projects with their "One-Time Use" cameras; similar projects are certainly open to high-school students, as well.

Figure 3. The constellation Orion setting in the western sky north of Tucson, Arizona. KODAK 800 speed IMAX film was used for this 25-minute, untracked exposure. The colors of the stars are clearly revealed in the photo, yet not in this black & white image, indicating their relative temperatures. The streaking is caused by the Earth's rotation during the exposure and can be used to show that all celestial objects appear to move around the celestial poles during a 24-hour period. Students can frame their photographs to include

both celestial and local objects in a creative combination.
Photo courtesy of the authors.

Figure 3 shows a still frame of the constellation Orion setting in the western sky. This image was obtained in a 25-minute exposure. In Figure 4, Orion was tracked in a 15-minute exposure. This picture reveals objects more than 2.5 times fainter than can be seen by the naked eye, including not only stars but also the Orion nebula (M42), where new stars are being born. Figure 5 shows the "flash" of reflected sunlight from an orbiting Iridium communications satellite. All these pictures used KODAK 800 Max color film. We have also succeeded with KODAK 400 NC color portrait film which can be purchased more economically in a bulk roll (100 feet).

Figure 4. The constellation Orion imaged with a disposable camera mounted on a barndoor tracker. This 15-minute exposure from Steward Observatory on Kitt Peak, southwest of Tucson, Arizona, reveals stars as faint as 7th magnitude, about 2.5 times fainter than the human eye can see. The Orion nebula, M42, is apparent in the "sword" of Orion and is a location where new hot stars are being born. Photo courtesy of the authors.

To obtain your own night-time pictures, begin by finding the darkest possible site away from neighborhood or city lights. Position the camera away from any wind on a stable platform to avoid vibration. Before you begin, the film must be initialized: advance the film by pushing the shutter button, and rotate the advance wheel until you can see or feel the button depress and pop back. Then advance the wheel a little more until it resists further motion. Turning the wheel may require more force than a normal camera, so be prepared to use a small coin or screwdriver for assistance. The counter mechanism no longer operates so you must keep a record of your pictures and the number of remaining exposures. After your last picture, the advance wheel will become very difficult to turn because you will be pulling directly against the tape used to fasten the film to the spool.

Your pictures can be developed at quality photo-finishing stores. We recommend removing the film canister and taking it directly to the store. Instruct the developers to "print for black" or "print for stars" so they know the pictures will contain a black background with small faint points of light (i.e., the stars). Otherwise, they may not see any recognizable objects and elect not to print any of your pictures. Also, ask them "not to cut the negatives" so they won't cut your picture in half by mistake. Be sure to inspect the negatives yourself using a small magnifier. You may find pictures the developer should have printed. Ask for the canister to be returned with your pictures.

Figure 5. The "flash" of an Iridium satellite as it reflects sunlight towards Tucson while moving rapidly around Earth. This untracked picture is a 7-minute exposure taken in evening twilight. The visual magnitude of the satellite was -7. If you know your latitude and longitude, you can use the following website to predict the times, locations, and brightnesses of the Iridium satellites: www.heavens-above.com. Photo courtesy of the authors.

You can be very creative with your astronomical camera. In addition to taking pretty pictures of celestial and local objects, you can search for trails from moving objects (meteors, satellites, airplanes), and look for variable stars, such as the eclipsing binary Algol in Perseus. You can even use your camera to measure the effects of light pollution around your neighborhood by determining the magnitudes of the faintest stars in exposures of the same length. For more information about light pollution, see the website of the International Dark-Sky Association.

SUSAN KERN and **DON MCCARTHY** have been doing research and educational activities together for several years at The University of Arizona in Tucson. Susan receives her undergraduate degree in astronomy, physics, and religious studies this year and promptly heads to MIT where she is enrolled in the graduate program in Planetary Sciences. Don is an infrared astronomer specializing in instruments and techniques which remove the effects of atmospheric blurring. Using the Hubble Space Telescope at infrared wavelengths, Susan and Don have recently discovered an apparent impact feature on the icy surface of one of the Solar System's most distant objects, 1995 GO. Susan and Don can be reached via email at susank@as.arizona.edu and dmccarthy@as.arizona.edu, respectively.

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Tracking the Sky

In its simplest form, a barndoor tracker consists of two pieces of wood which are hinged together. A camera mounted on the upper piece and the hinge connecting the two pieces is directed toward the star Polaris, at the celestial north pole. A simple screw is turned continuously by hand to push the two pieces of wood apart to compensate precisely for Earth’s rotation. In essence, you have an equatorial telescope mount for your camera to track the stars anywhere in the sky. The tracked star images will be crisp pinpoints and you will get the full benefit of the light-collecting power of your camera. The trick is to locate the screw at a particular distance from the hinge so you can turn it once per minute and achieve precise tracking.

Two barndoor trackers with disposable cameras mounted on top. The tracker to the lower left is the simple type used by McCarthy in his classrooms. The camera itself can easily be mounted on an adjustable post to point anywhere in the sky. Students turn the lever one turn per minute to track at the sidereal rate. The tracker at the upper right belongs to John Waack of the Steward Observatory staff. It shows more customization and woodworking skill but still operates on the same principle. Photo courtesy of the authors.

Astronomy Camp for All Ages

From the dark-sky environment at the Catalina Observatories atop scenic Mt. Lemmon near Tucson, Arizona, campers of all ages explore the heavens with large telescopes and experience the joys of scientific inquiry. Astronomy Camp, sponsored by the University of Arizona’s Alumni Association, offers all "Campers" an opportunity to experience the Universe in a new and exciting way. Teenage students gain a cosmic perspective of Earth and themselves, examine career alternatives, and reinforce school lessons through real scientific and engineering applications. Adults get away from normal routines and pose questions of a lifetime.

At night, Campers observe celestial objects under a dark sky using the 40-inch and 60-inch telescopes on Mt. Lemmon and the 16-inch Schmidt and 61-inch telescopes on nearby Mt. Bigelow. Campers become astronomers, operating research telescopes, keeping nighttime hours, interacting with leading scientists, and interpreting their own observations. Astronomy is about exploration, and Astronomy Camp fosters that philosophy.

Astronomy Campers use the research telescopes and equipment at the mountain-top observatories on Mt. Lemmon north of Tucson, Arizona. Shown here are the 1.54 meter Kuiper telescope (left) and the 0.4 meter Schmidt telescope. This picture shows the trails of stars seen in a time exposure looking toward the north celestial pole. Photo courtesy of Jeff Regester.

Campers have an amazing array of unique tools to help them explore their universe. All telescopes can be equipped with a selection of instruments, including 35mm cameras, a photometer, CCD imagers, and a CCD spectrometer. The Advanced Camps feature access to professional instruments for imaging at visual and infrared wavelengths with large format CCD and NICMOS electronic cameras, respectively. A complement of computers allows Campers to analyze data using professional languages and to simulate astronomical phenomena.

During the daytime, internationally known scientists speak on current scientific topics, including the latest NASA space missions. Students also explore the diverse geology and ecology of Mt. Lemmon though hiking and outdoor demonstrations. Space artists illustrate how science becomes art. All Camps include an in-depth tour of the University of Arizona’s Mirror Laboratory, now producing the world’s largest telescope mirrors.

For more information on Astronomy Camp, visit the Camp’s internet headquarters at ethel.as.arizona.edu/astrocamp/ or contact the authors via email.

For More Information

• To learn more about "one-time use" cameras, visit Kodak’s website at www.kodak.com or Fujifilm’s at www.fujifilm.com

• For instructions on building a camera mount for your astrocamera, the following are good sources:

Dennis di Cicco, "A Simple Camera Mounting for Astrophotography," *Sky & Telescope*, October 1985, p. 391.

G. Haig, "A Simple Camera Mounting for Short Exposures," *Sky & Telescope*, April 1975, p. 263.

John Iovine, "Build an Astrophoto Platform," *Astronomy*, November 1992, p. 60.

• To determine the times and brightnesses of "Iridium flashes" and those of other artificial satellites, simply go to this fascinating website: www.heavens-above.com