USING AN INEXPENSIVE DIGITAL CAMERA TO TAKE MARS-ANALOG PHOTOGRAPHS AT NEAR-INFRARED WAVELENGTHS. D. M. Burt[1] [1]Dept. of Geological Sciences, Arizona State Univ., Box 871404, Tempe, AZ 85287-1404 (dmburt@asu.edu).

Introduction: The twin Panoramic Cameras (PanCams) on the Mars Exploration Rovers Spirit and Opportunity [1,2] have taken tens of thousands of multispectral photos of Mars rock and soil outcrops as 1024 pixel-square images (i.e., 1 megapixel), and have imaged features as small as 1 mm. In that they accomplish this by placing various filters (in an 8-position filter wheel) in front of the main lens, rather than in front of each sensing element on the charge-coupled device (CCD) sensor, they differ from typical consumer-level digital cameras (digicams). CCD's on *both* consumer digicams and the Mars pancams are light-sensitive from the long-wave ultraviolet, UV into the near infrared, IR (wavelengths from about 350 to 1100 nanometers, nm), whereas our eyes can perceive colors only over the visible light range, from about 400 to 700 nm (blue-violet to red). The glass lenses on a consumer digicam block most UV, and a special IR-blocking filter inside the digicam blocks most near-IR, so that the colors that the digicam CCD sensor records correspond to what our eyes see. The multispectral Mars PanCams have no IR-blocking filters, and thus can see into the near-IR. In fact, a large proportion of the grayscale images on the Rover web pages were taken with Filter #2, at about 750 nm, well into the near-IR range, and synthesized "approximate true color" renderings are generally taken using this IR filter, rather than a visible red filter. The other near-IR filters (at 803, 864, 903, 934, and 1009 nm) have been less commonly used, perhaps because CCDs are less light sensitive towards the upper range of near-IR wavelengths (cf. Fig. 1).

Methods: For imaging Mars analog materials in the near-IR using consumer-level digicams, two solutions are available. The first and most obvious is to remove the IR-blocking filter from the light path. Some higher-end Sony digicams (e.g., the older Sony DSC-F707 and F717) do this automatically in "night mode" (the blocking filter swings out), but all of these digicams, as of this writing, are crippled by limiting exposure times to 1/60th or 1/30th of a second or longer. This "feature" limits the camera to night use only, unless thick neutral density (ND) camera filters are affixed to the front of the camera for daytime use. Removal of the IR blocking filter on some digicams can also be done permanently, if the IR-blocking filter is replaced by clear glass (so as not to alter focussing requirements). However, this alteration requires delicate internal surgery on the camera, voids its warranty, and renders the camera useless for normal visible light photography. For popular camera models (especially, digital single lens reflex, or DSLR) several web merchants will do this surgery for you, at a cost of many hundreds of dollars and up, depending on the camera. You then have a near-IR-only digicam.

The second solution is much cheaper, more practical, and less permanent. That solution is to spend about $35 for a special filter (IR filter) that blocks all *visible* light from the digicam's CCD, allowing only the near-IR wavelengths to get through. Such a filter is also required for digicams from which the IR-blocking filter has been removed (first solution above). The second solution depends on the fact that the IR blocking filters on most digicams are not 100% efficient, so that enough near-IR light can get through to allow autofocussing and taking an exposure, if all visible wavelengths are blocked. The camera's electronic viewfinder (EVF) and/or LCD monitor then shows the appearance of the subject in the near-IR. An added advantage is that near-IR and visible-light photos of the same subject can be be taken in sequence simply by adding and removing the IR filter from the front of the camera (e.g., Fig. 1). Note: the wide-open aperture required may decrease the depth of field of the near-IR photo.

Camera Requirements: Many consumer level digicams can be used for near-IR photography, some much more conveniently than others. As it happens, by far the the best digicams are now-obsolete 2 megapixel models sold about 5-6 years ago. Apparently, most of these share the same CCD chip set and relatively inefficient IR-blocking filter. These camera models included (among others) the Nikon Coolpix 950, Canon S10, Olympus C-2000 and C-2020, and especially, the Olympus C-2100UZ. (The Olympus E-100RS, a 1.4 megapixel model, can also be used, albeit somewhat less conveniently.) A newer 2 megapixel model suitable for near-IR work is the Panasonic Lumix FZ1, with its EVF, 12X zoom lens with IS, and manual white balance. With these cameras, enough IR light gets through the blocking filter to allow daytime exposures in the range 1/10 to 1/100 of a second (depending on sunlight intensity, the subject, and the camera), and thus handheld use (especially if the camera also offers IS). Almost all other, newer digicams, with CCD sensors of 3 megapixel resolution and above, require use of a tripod, because daylight exposures may range from 1/10 of a second to several seconds (i.e., their IR-blocking filters are *too* efficient). My favorite camera for near-IR work is the Olympus C-2100UZ, because, in addition to extraordinary IR sensitivity and a 10X zoom lens with IS, it offers a big, bright EVF (but no manual white balance). Near-IR photos out of a passenger jet window are quite practical with this camera.

Lens adaptor. An important requirement for near-IR usability is that the digicam be capable of accepting screw-in IR filters via a permanent threaded mount (as on the Olympus C-2100UZ) or via the far more common optional lens adaptor that screws into the camera around the extending zoom lens. If this capability is lacking (as for the Canon S10), third-party lens adaptors may screw into the tripod mount on the bottom of the camera. Step-up rings are needed to match larger IR filter sizes to a smaller camera or lens adaptor. Of course, teleconverter or wide-angle or close-up lenses [3] can be used in addition to the IR filter.

Light sources. Sunlight is by far the best light source for near-IR work, as on Mars. For indoor work, incandescent lights provide abundant near-IR illumination, whereas fluorescent or LED lights provide none. IR-only light sources (e.g., the beam from your TV remote) are also sold, mainly for surveillance purposes.

Auto vs. manual white balance. By far the most inexpensive and commonly used IR filter, the Hoya R72 (about $35) has its 50% cut-off at 720 nm, meaning that a small amount of visible red gets though, in addition to all near-IR wavelengths. This light can yield bright red images (akin to the red tint in some bad Mars science fiction films). The auto white balance on some digicams largely compensates, rendering a pale red photo, appropriate for Mars analog use (cf. Fig. 1). If the camera offers manual white balance, pointing the camera at something "white" (including green grass or leaves), can yield an IR image close to the usual gray scale. Saturation reduction during post-processing can also eliminate undesirable colors. For artistic purposes, many IR photos posted on the web have had false colors added (usually pale pastels). An active community of near-IR photographers has created many useful and informative websites (too many to cite here).

Results: Normal terrestrial subjects appear rather "otherworldly" in near-IR. Contrast is greatly enhanced. Blue sky becomes black, because it does not scatter light at near-IR wavelengths, whereas even thin clouds become white. Blue water (if it is more than about half a meter deep) likewise becomes black, because water preferentially absorbs red and near-IR light (why underwater scenes appear blue-green, whatever their "normal" color). Sunglasses or tinted car windows can appear transparent. Dark green grass, leaves, flowers, and stems become snow-white, because vegetation is almost perfectly reflective in the near-IR (as are red paint and red hematite). Unlike green leaves, green painted objects (also, blue-green copper minerals) are dark in the near-IR; this feature has long been used by the military to detect camouflage. Another militarily useful feature of near-IR is that it cuts almost magically through dust and haze, as in reconnaissance photos taken from high-flying airplanes.

Cutting through dust and haze probably motivates the use of near-IR wavelengths on Mars. The distinctive black appearance of standing water and the distinctive white appearance of vegetation may provide a further motivation. An unfortunate by-product is high contrast. Lower contrast is attained by using the blue or green visible light filters on the PanCams.

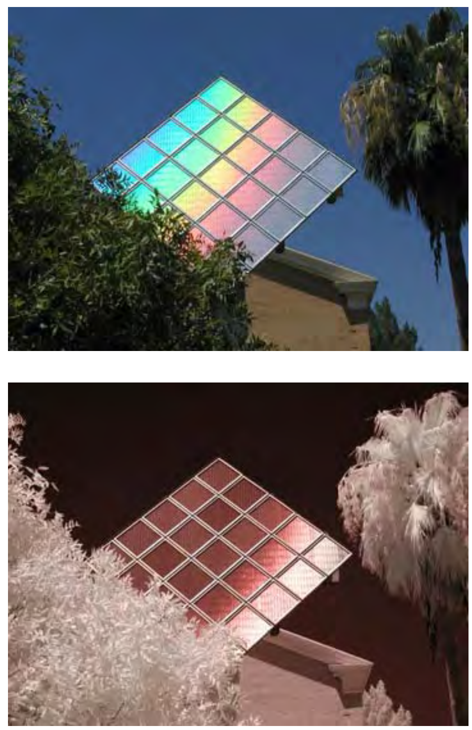

Fig. 1. Visible vs. near-IR photo of decorative diffraction grating, ASU Main, Tempe, AZ, taken by placing Hoya R72 IR filter on Olympus C-2100UZ digicam. Hand-held, auto white balance, no post-processing. Note Mars-like reddish tint, black sky, and white vegetation in near-IR photo; also, that main IR sensitivity of camera CCD is just outside visible range (akin to using 750 nm filter on MER PanCam).

References: [1] Bell, J. F. III et al. (2004) *Science, 305,* 800-806. [2] Bell, J. F. III et al. (2004) *Science, 306,* 1703-1709. [3] Burt, D.M. (2005), *LPS XXXVI*, Abstract #1705.