FILTERS FOR ASTRONOMY & AEROSPACE

OMEGA® OPTICAL

Bringing Information to Light

Filters for Astronomy and Aerospace

Glowing in the constellation Aquila like a giant eye, the planetary nebula NGC 6751 is a cloud of gas ejected several thousand years ago from the hot star visible in its center. Images are taken through different filters, including Omega filter F555W, in order to isolate nebular gases of different temperatures. The images are then digitally combined and pseudo-colored. Image courtesy of NASA's Jet Propulsion Laboratory.

Introduction

OMEGA OPTICAL designs and manufactures custom filters and standard prescription filters to the highest imaging quality standards for astronomers, atmospheric scientists, and aerospace instrumentation companies worldwide. Applications include both terrestrial and space-based observational instruments. We have supplied projects and programs for a wide variety of prestigious universities, observatories, government agencies, and international consortia. As instrument technologies and applications evolve, we work collaboratively with customers to develop solutions for the spectral, optical, and environmental demands that will define observational astronomy and aerospace applications in the future.

Large Format Filters

As observational instruments and detectors increase in sensitivity and size, we continue to support the needs of the astronomy community through development of capabilities to produce filters with apertures as large as 210mm. These filters are well matched for manufacture using Omega's proprietary ALPHA™ Technology, producing a wide variety of bandwidths with highly controlled cut-on and cut-off edge slope. Available scientific glasses can be combined to match existing requirements or to define novel filters. We continue to offer the highest finesse Fabry-Perot interference filters using both metal and dielectric reflectors.

Custom Filters

Many astronomy imaging applications require the custom design and manufacture of filters and filter sets. With more than twenty vacuum deposition systems—including IAD, electron beam, plasma enhanced, and multi-planet coating technologies—we are able to produce filters of extreme uniformity and precision in quantities of one to one thousand according to the following general specifications:

- Wavelength Range: UV to mid IR
- Bandwidths: 0.15nm to several hundred nm
- Tolerances: Critical throughput, bandshape and bandwidth requirements
- Sets: Matching physical and optical performance attributes
- Materials: Space-flight compatible

Capabilities and Features

High Spectral Performance

We provide interference passband filters with peak wavelengths located from the UV to the mid-IR and with bandwidths ranging from 0.15nm to several hundred nanometers wide. Our filters meet demanding throughput and bandshape requirements while adhering to very close tolerances on bandwidth and peak transmission wavelength. Many of our filters are designed for high attenuation of adjacent emission lines. Our coating processes assure uniformity of spectral performance over the physical area of large filters.

High Optical Performance

Our filters are made to rigorous imaging requirements. We start by polishing optical glasses to requisite flatness and wedge values prior to coating and assembly. By designing each coating for the longest free spectral range, we minimize the number of laminations that cause internal reflection and fringe patterns. After assembly, our filters are polished to achieve minimum wavefront distortion. Our Broadband Achromatic Twyman-Green interferometer enables us to evaluate transmitted wavefront at the filter's principal wavelength. Durable anti-reflective coatings are deposited on outer surfaces to increase transmission and reduce ghosting.

Physical Attributes

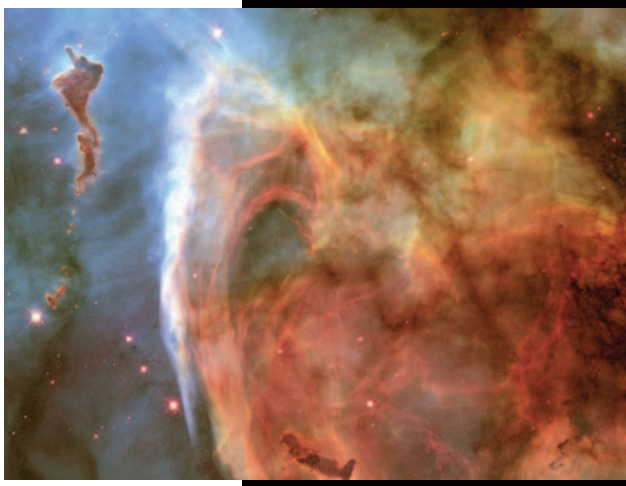
Many of our astronomy filters are made in sets or as supplements to existing sets. Each filter is designed to match the others in attributes such as optical thickness, bandshape, throughput, attenuation, sensitivity to system focal ratio, sensitivity to temperature, and imaging quality. Continuum filter sets are made with precise matching of the cut-on and cut-off wavelengths of spectrally adjacent filters. Space-based application filters are manufactured using "space-flight compatible" materials.

Photometric Filter Sets

We produce a variety of photometric filter sets (often called "UBVRI") that isolate broad areas of the spectrum. These filters are made by combining a number of filter glasses and/or dielectric spectral control films. They are useful for both color imaging and photometric classification. We produce many sets with modified designs to achieve required performance, such as accommodating the spectral response of detectors or maximizing peak energy.

Narrow-Band Filters

Our narrow-band filters are highly effective at isolating monochromatic emission and absorption lines, featuring high throughput, deep out-of-band attenuation, and close control of spectral location. The performance of narrow-band filters is critically dependent upon system speed and operating temperature. Much care and attention is given to the design, manufacture, and measurement of these filters to assure that peak performance is reached at the designated system and operating environment.



Previously unseen details of a mysterious, complex structure within the Carina Nebula, one of the outstanding features of the Southern-Hemisphere portion of the Milky Way, as revealed by NASA's Hubble Space Telescope image of the "Keyhole Nebula." The picture is a montage assembled from four telescope pointings with Hubble's Wide Field Planetary Camera 2, using six color filters, including Omega Optical's F439W, F555W, and F814W. Image courtesy of NASA's Jet Propulsion Laboratory.

Bessell Sets

OUR STOCK Bessell Photometric Sets, manufactured to the definition put forth by M. Bessell, offer high optical quality suitable for demanding imaging requirements. Filters are polished to stringent transmitted wavefront, wedge, and flatness specifications and are then anti-reflective coated. Each filter's spectral response is determined by the combined responses of Schott filter glasses polished to prescription thicknesses. The individual glasses are then laminated into a single-piece optical assembly. The result is a set of precision filters at an economical price.

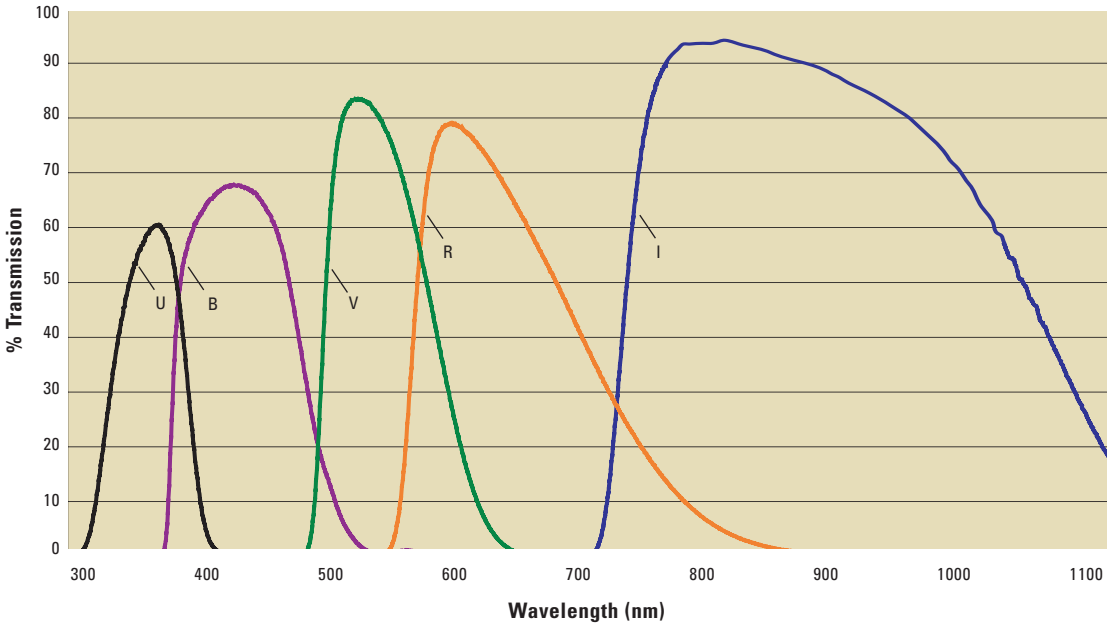


Figure 1: Bessell Photometric Set
Spectral curves of Bessel U, B, V, R, I filters.

N 49 is a supernova remnant within the Large Magellanic Cloud, a nearby, small companion galaxy to the Milky Way, visible from the Southern Hemisphere. The Hubble Heritage image of N 49 is a color representation of data taken with Hubble's Wide Field Planetary Camera 2. Omega filters F814W (I) and F547M were used to sample light emitted by sulfur ([S II]), oxygen ([O III]), and hydrogen (H-alpha). Image courtesy of NASA's Jet Propulsion Laboratory.

Imaging Enhancement Attributes

- Transmitted Wavefront Distortion: λ/4 (or better) per inch.
- Wedge: Less than 30 arc seconds.
- Flatness: λ/4 (or better) per inch.
- Surface Quality: E/E as defined by Mil-C-48497A.
- Anti-Reflective Coating: multi-layer dielectric AR coating on both surfaces. R typically <0.5% to increase transmission and reduce ghosting.
- Anti-Reflective Coating Durability: to moderate abrasion as defined by Mil-C-48497A.

	Filter U 1.0 mm of UG 1 1.0 mm of S-8612 3.0 mm of WG 305	Filter B 2.0 mm of GG 385 2.0 mm of S-8612 1.0 mm of BG 12	Filter V 2.0 mm of GG 495 3.0 mm of S-8612	Filter R 2.0 mm of OG 570 3.0 mm of KG 3	Filter I 2.0 mm of WG 305 3.0 mm of RG 9	Complete Set (Filters U–I)
Formats	**Part #: XBSSL/U**	**Part #: XBSSL/B**	**Part #: XBSSL/V**	**Part #: XBSSL/R**	**Part #: XBSSL/I**	**Part #: XBSSL**
25mm Round	$100	$100	$100	$100	$100	$400
25mm Square	$100	$100	$100	$100	$100	$400
28mm Round	$125	$125	$125	$125	$125	$500
32mm Round	$125	$125	$125	$125	$125	$500
38mm Round	$150	$150	$150	$150	$150	$600
50mm Round	$250	$250	$250	$250	$250	$900
50mm Square	$250	$250	$250	$250	$250	$900
SBIG†	$175	$175	$175	$175	$175	$600

Note: Spectrophotometric curve(s) are provided for each filter or set. Instructions for handling and cleaning surface-coated optics are provided for each filter or set.

† Mounted in 1 1/8 in. eyepiece, compatible with SBIG filter wheel.

Prices listed are U.S. domestic prices. Duties, fees, and taxes required for international sales are additional.

Hubble Space Telescope

OMEGA OPTICAL has supplied filters for the Hubble Space Telescope's Wide Field and Planetary Cameras WFPC2 and WFPC3, which have been in service since 1993. These filters were designed to meet the stringent optical and environmental specifications of the mission, and have been used to produce countless images of galaxies, nebula, and other astronomical features. Omega provided five Broad Band and six Medium Band filters for the WFPC2.

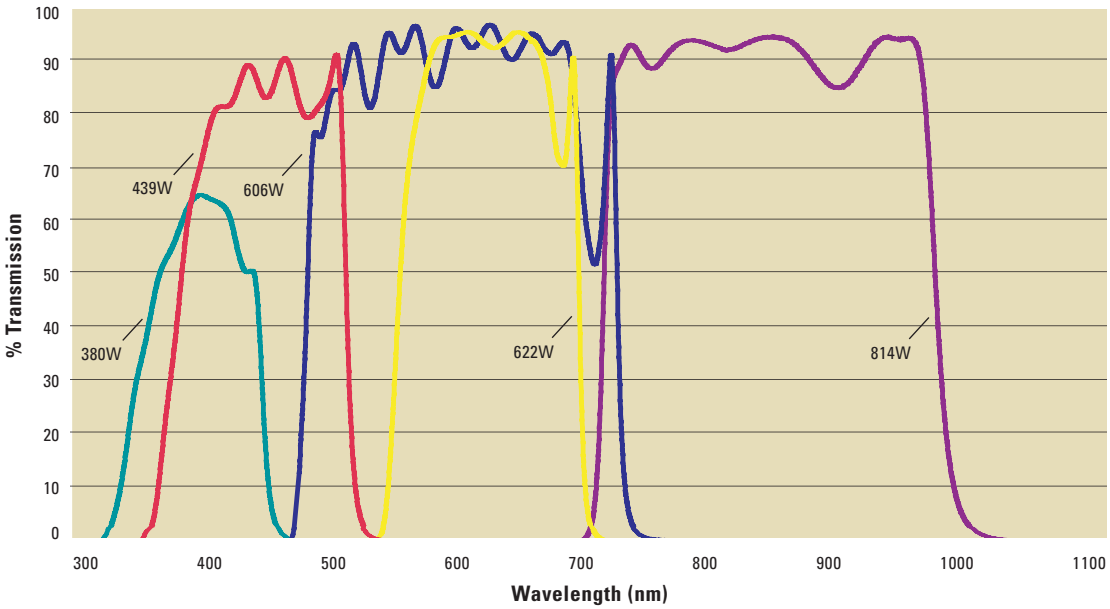


Figure 2: Wide Field and Planetary Camera (WFPC2) Broad Band Filters
Spectral profiles in Figure 2 are actual measured curves of filters installed and operational on WFPC2 since 1993.

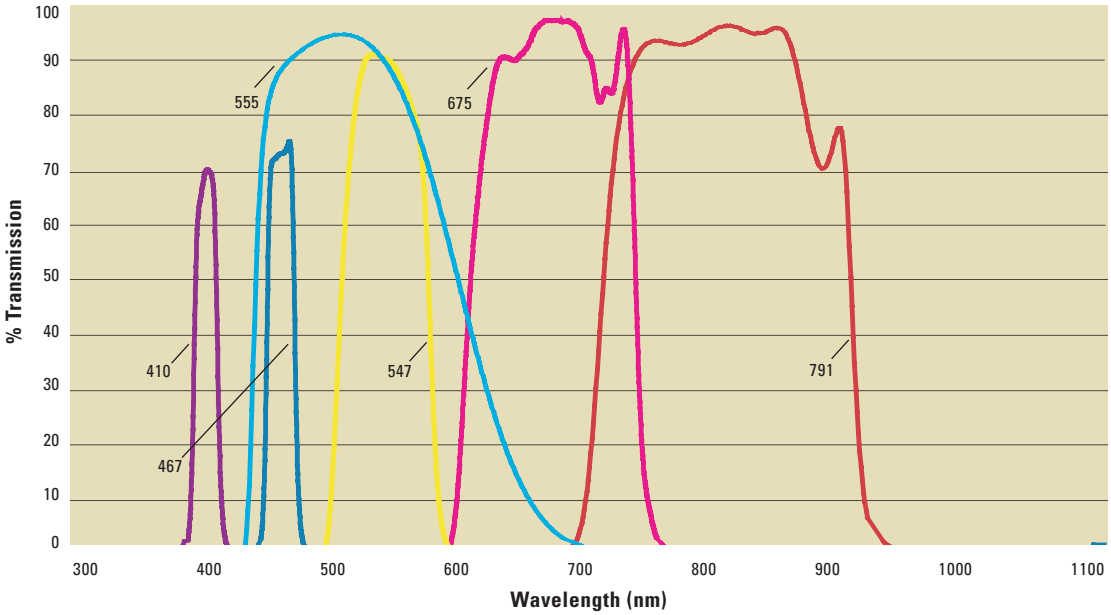
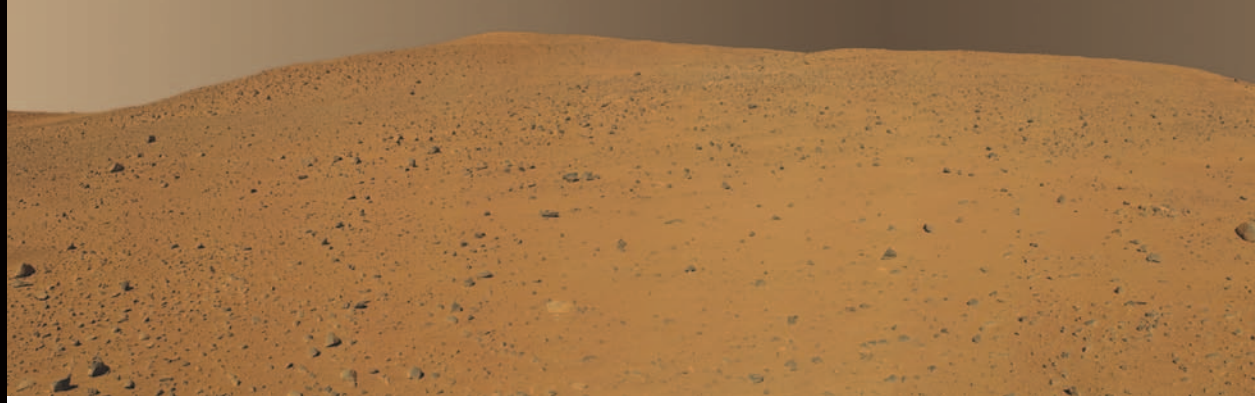
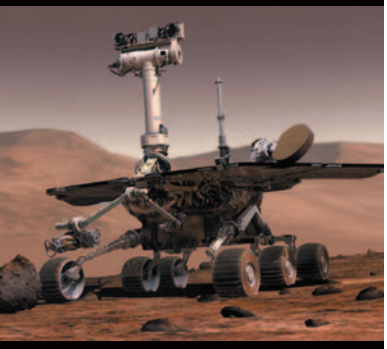


Figure 3: Wide Field and Planetary Camera (WFPC2) Medium Band Filters
Spectral profiles in Figure 3 are actual measured curves of filters installed and operational on WFPC2 since 1993.

Hubble image of a giant star-forming region in the southern sky known as the Carina Nebula (NGC 3372), combining the light from three different filters tracing emission from oxygen (blue), hydrogen (green), and sulfur (red). The color is also representative of the temperature in the ionized gas: blue is relatively hot and red is cooler. Omega Optical filters F439W, F555W, and F814W were used to make this image. Image courtesy of NASA's Jet Propulsion Laboratory.



The panoramic picture at right is part of a 360° view comprised of 243 images taken by *Spirit's* panoramic camera over several Martian days (sols) during the Thanksgiving holiday, 2004 near Husband Hill. It is an approximate true-color rendering generated from images taken through Omega Optical's 750, 530, and 480nm filters. Photo courtesy of NASA/JPL/Cornell.



Mars Exploration Rovers

OMEGA OPTICAL provided all filters for the two Mars Exploration Rovers (MER), *Spirit* and *Opportunity*, launched in 2003. Working with NASA Jet Propulsion Lab and Cornell University, Omega manufactured filters which serve as integral components of each MER's three camera systems, utilized for scientific imaging and navigation. The Panoramic Camera (Pancam) is a stereo camera equipped with eight filters per detector which provides high-resolution, multispectral panoramic images of the Martian landscape. The filters include those for geological investigation as well as solar imaging. The Rover is also equipped with two Navigation Cameras (Navcams) and four Hazard Avoidance Cameras (Hazcams), all of which use Omega filters.

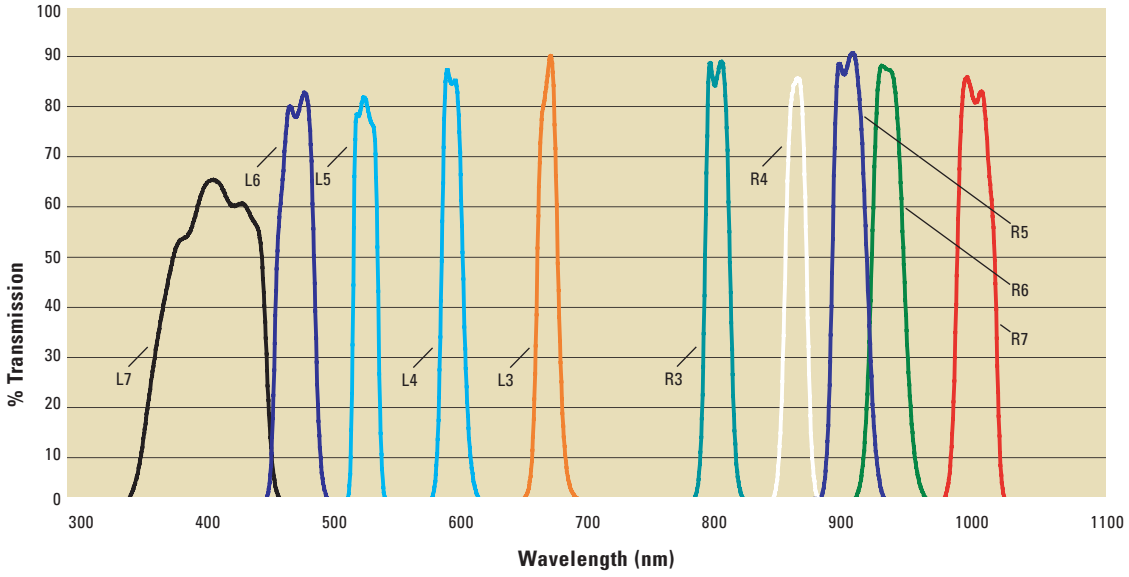
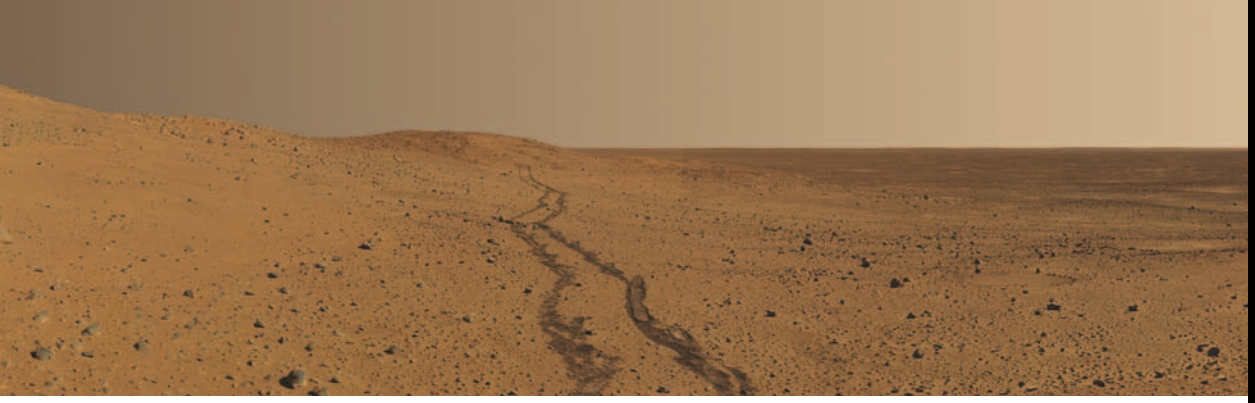


Figure 4: Mars Exploration Rover Panoramic Camera Filters
Spectral profiles are actual measured filters from Rovers Spirit *and* Opportunity, *which have been imaging the Martian surface since 2004.*

	Name	λeff (nm)	Bandpass (nm)	Comment		Name	λeff (nm)	Bandpass (nm)	Comment
Left Filter Wheel	L1	719	179	EMPTY	Right Filter Wheel	R1	440	25	Blue Stereo R
	L2	753	20	Red Stereo L		R2	754	19	Red Stereo R
	L3	673	16	Geology		R3	803	20	Geology
	L4	602	17	Geology		R4	864	17	Geology
	L5	535	19	Geology		R5	903	25	Geology
	L6	483	27	Geology		R6	933	24	Geology
	L7	440	25	Blue Stereo L		R7	1001	28	Geology
	L8	440	20	Solar ND5		R8	880	20	Solar ND5

Table 1: Pancam Filter Characteristics



Optical Filter Capabilities

Omega has extremely broad capabilities servicing the professional astronomy market. Following is a partial list of filters supplied to researchers, university programs, and government agencies.

Solar Observation

- H-Alpha
- H-Beta

Nebula and Cometary Studies

- OII
- OIII
- SII
- C^{III}
- C^{II}
- Narrow bandpass

IR Astronomy

- J,H,K bands

Photometric Sets

- Bessell (U,B,V,R,I)
- Johnson/Cousins (U,B,V,R,I)
- Stromgren (U,B,V,Y) Beta wide and narrow
- SDSS (u', g', r', I', z')
- Thuan-Gunn

Other

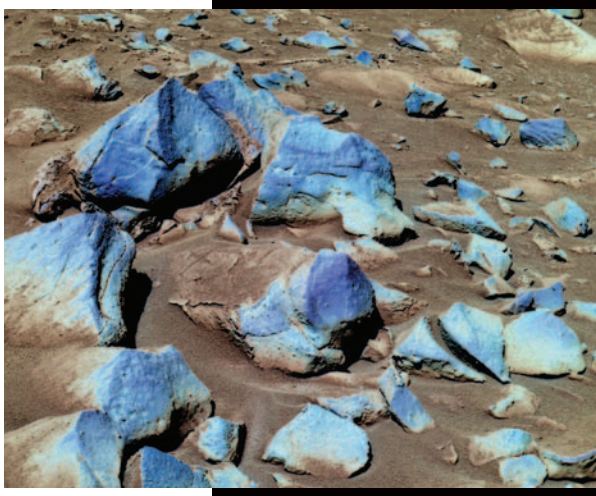
- Detector Compensation
- Harris R
- Mould R-I

Projects

Omega Optical has years of experience designing and manufacturing imaging system filters critical to astronomical and aerospace projects and programs including:

- AURA
- Canadian-France-Hawaii Telescope Company
- CONICA
- ESA Giotto Mission
- European Southern Observatory Very Large Telescope
- GRANTECAN
- NASA JPL Star Dust Project
- NASA JPL Hubble Space Telescope: WFPC2 and WFPC3
- NASA JPL Martian Rovers 2003–2004: *Opportunity* and *Spirit*
- Observatories of the Carnegie Institute of Washington

Obtained using 13-filter, 11-color multispectral composites of selected soil, outcrop, and loose rock targets, such as those in the picture below, the visible to near-IR images reveal mineralogical detail through characteristic reflectance signatures. Images were obtained by *Spirit* at the Gusev Crater and *Opportunity* at the Meridiani Planum. Photo courtesy of NASA/JPL/Cornell.



Cover image courtesy of NASA JPL Hubble Space Telescope
WFPC2 Planetary Nebula NGC 6369 The Little Ghost