Electromagnetic Surveillance

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Ultraviolet

1. Introduction

Ultraviolet radiation is invisible to humans, extending just beyond the part of the visible spectrum that we perceive as the color violet. Ultraviolet, infrared, and visible radiation together comprise the range of frequencies we call the *light spectrum*. Most people are familiar with 'black lights' which cause some colors to emanate an eerie blue-white glow. This glow is an example of ultraviolet *fluorescence* in which the ultraviolet radiation excites chemical substances to emit light that we can see in the visible spectrum.

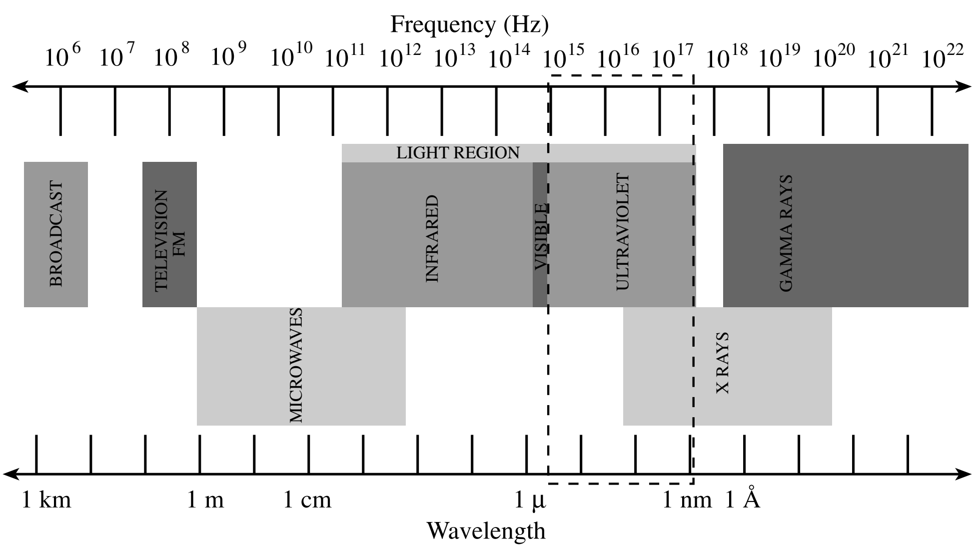
The wavelengths associated with ultraviolet radiation are shorter than visible light which, in turn, are shorter than infrared. Sensing devices that operate in the optical frequencies are called *photodetectors* and some broadband devices that detect radiation in the visible spectrum also detect infrared and ultraviolet frequencies. Advanced multispectral imaging systems often sense a wide portion of the optical spectrum, thus including UV frequencies.

Because humans can't see ultraviolet light, it is difficult to gauge our exposure to Ultraviolet-B. UV-B can have adverse effects on the human body, the most obvious of which is sunburn. Not all damage from ultraviolet can be readily seen. Purdue researcher Richard Grant and Forest Service worker Gordon Heisler explain that UV-B doesn't shine as directly as visible light, but rather bounces around in the atmosphere. They took fish-eye photos like the one above to get a complete picture of the sky and how much was actually obstructed, employing a novel strategy for assessing UV-B exposure. [Purdue 1997 news photo, released.]

While the ultraviolet spectrum consists of wavelengths that are invisible to human eyes, other creatures may perceive all or some of this ultraviolet spectrum. Birds are known to respond to ultraviolet reflected from specialized feathers (e.g., on their crests) and some insects appear to locate food sources through ultraviolet colors on flowers that make the pollen or nectar areas stand out.

Unlike the visible spectrum, which is not generally harmful to humans, or the infrared spectrum, which can sometimes be perceived as heat and avoided, the ultraviolet spectrum may be difficult to detect and can cause harm if contact with it is too strong or prolonged. Ultraviolet rays contribute to skin damage before the person is aware that it has happened. The Sun, tanning lamps, and UV lights emit ultraviolet light. Fortunately, the Earth's atmosphere filters out some of these harmful rays from the Sun, making the planet safer and more habitable. Ozone contributes substantially to the filtering of ultraviolet. Frequent or prolonged exposure to ultraviolet radiation may predispose a person to skin cancer and health care professionals warn people to wear hats, glasses, and sunscreen when they are exposed to ultraviolet from natural or synthetic sources.

Ultraviolet illuminators are used for inspecting artworks, documents, entry access stamps on skin, and ancient murals and paintings on the walls of archaeological finds. Astronomers use it to glean more information about the cosmos and it is incorporated into space-based spectral imaging systems. Due to the health hazards associated with ultraviolet exposure, it tends to be used for surveillance in situations where protective goggles can be worn or where it is not being shone directly at people, especially in their eyes.



The ultraviolet spectrum is a band of short-wavelength radiation beyond the visible spectrum, ranging approximately from 190 to 400 nanometers. As the scale across the bottom of the chart shows, this can also be expressed as 1900 to 4000 ångströms or 0.19 to 0.40 microns. [Classic Concepts ©2000, used with permission.]

Ultraviolet is interesting and useful. Some substances may react to ultraviolet radiation by re-emitting longer wavelengths that can be seen by the unaided eye. This process is known as *fluorescence*. By using substances and chemical treatments that are known to fluoresce, it is possible to discretely 'mark' items for tracking or identification.

This chapter describes a variety of ultraviolet technologies that are used in surveillance, particularly for entrance control, security, identification, aerial imaging, forensics, astronomy, and archaeological site investigations.

2. Types and Variations

As part of the optical spectrum, much of the terminology associated with ultraviolet is the same as that associated with infrared and visual spectra. An individual unit or 'packet' of ultraviolet radiation is called a *photon*.

Units

Ultraviolet wavelengths are very small, so they are typically expressed in *nanometers* or *ångströms* (Å). A nanometer is one billionth of a meter. An ångström is even smaller, one ten-billionth of a meter. One nanometer = 10 ångströms, thus, 320 nm = 3200 Å. The ångström (often written *angstrom* in English) is named after Swedish physicist Anders J. Ångström.

Categories

Ultraviolet is produced naturally by the Sun and other 'hot' celestial bodies and can be generated synthetically by heating substances to high temperatures.

Ultraviolet radiation has been generally grouped into three categories, based on wavelength. There is no actual dividing line between the categories, but rather a gradual transition of effects from one to the next. Nevertheless, these categories are useful for making generalizations about ultraviolet characteristics and effects:

UV-A - between about 320 and 400 nm. This is the lowest energy (longest wavelength) form of ultraviolet radiation that is emitted by our Sun. Most of the Sun's UV-A radiation reaches the Earth, as it is only partially absorbed by the ozone layer. This is the region emitted by the lights in tanning beds. Over time, UV-A can break down collagen and elastin tissues in biological organisms.

UV-B - between about 290 and 320 nm. In the mid-range, at slightly higher energy levels, some of the ultraviolet rays are absorbed by the ozone layer, but some also reach the Earth's surface. Ultraviolet can influence a wide variety of biological processes on Earth and causes sunburn. Variations in ultraviolet radiation which are, in part, influenced by the amount of ozone in the atmosphere, can cause changes in the Earth's environmental balance that may significantly affect our lives over time. Smog may be more prevalent in ozone-depleted regions.

UV-C - between about 190 and 290 nm. In the higher-energy-level ranges, near the region called X-rays, ultraviolet light can have significant harmful effects. We are protected from these effects by the Earth's atmosphere, which filters out UV-C before it reaches the Earth's surface.

For astronomical research, extreme-ultraviolet radiation (EUV) has been defined as wavelengths between about 100 Å and 1,000 Å (10 nm to 100 nm).

Chemical Interactions

Ultraviolet is useful for surveillance because of the way it affects various substances. Some substances fluoresce naturally when exposed to ultraviolet illumination and others will fluoresce if chemically treated. Knowledge of various substances and their reaction to ultraviolet light has helped inventors create technologies that exploit these properties and has helped practitioners use them for identification purposes.

Sunscreens are products developed to shield the body from the harmful effects of ultraviolet radiation on the skin. They range from products that absorb ultraviolet to those that absorb and reflect. Titanium dioxide and zinc oxide are two substances that are used to block out ultraviolet. Sunscreens and sunblocks are used by sunbathers and those who frequently work outdoors, as well as those exposed to ultraviolet radiation in a laboratory setting. An ultraviolet-radiation numerical index scale has been developed to provide information on the danger of skin damage. Sunblocks can be useful for field or laboratory experiments in which selective blocking of ultraviolet radiation or reflection is desired by applying them to surfaces.

3. Context

Ultraviolet radiation is naturally occurring, so it helps to understand the sources of ultraviolet in order to use it to best advantage. Synthetic ultraviolet surveillance devices need to be used in ways that minimize interference from natural sources. Natural ultraviolet devices need to be used in ways that best exploit their properties.

Like infrared and visible radiation, ultraviolet is used in many surveillance technologies, particularly for imaging or detecting marks that are normally invisible to the unaided eye. It's very convenient to be able to mark something so that the mark is invisible, but can be revealed at will.

Sources and Intensity of Ultraviolet Radiation

Most of the ultraviolet radiation in our environment comes from the Sun. The amount of ultraviolet radiation reaching the surface of the Earth depends upon many factors, including how much is emitted by the Sun, its frequency, how much is scattered or absorbed by the Earth's atmosphere, and its angle of travel in relation to the Earth.

The Sun's rays hit the Earth at different angles at different times of the day and year. Ultraviolet reaches the Earth at a more direct angle over the equator and during the summer. When the rays travel a shorter distance, they encounter fewer obstacles and are subject to less attenuation. In other words, the UV radiation hitting the equator (and other latitudes during the summer months) is more intense than at the poles. Around noon, when the Sun is at its 'highest' (most direct) angle in relation to the Earth, the ultraviolet rays are more intense as well. (This is why medical practitioners advise bathers to limit their exposure to the Sun during the noon hours when they are more vulnerable to burning.)

Similarly, ultraviolet radiation travels a shorter distance when it encounters mountain tops than when it reaches sea level. Not only is the atmosphere thinner at higher elevations, thus absorbing less of the radiation, but it is also a 'nearer' destination, resulting in slightly less attenuation than if the rays had to travel farther through the more numerous particles and gases associated with the atmosphere at sea level. In general, ultraviolet radiation is greater on Earth's mountain tops than it is at sea level. There is generally greater exposure to ultraviolet in snow-covered areas, due to the UV rays being reflected off the snow and hitting objects from all angles.

The Earth's *ionosphere* is a region of free electrically charged particles extending from approximately 50 to 500 kilometers above the Earth's surface. There are subregions within the ionosphere that have varying properties depending on the Sun's activities (e.g., Sun spots) and the time of day. Ion sources include the solar winds as well as gases that have been ionized by the ultraviolet radiation from the Sun. Thus, ionization from ultraviolet radiation makes an important contribution to surveillance technologies by allowing us to bounce radio waves off the ionosphere to achieve greater distances.

Ozone is a gas formed through a photochemical reaction when oxygen is ionized (e.g., by ultraviolet radiation). Ozone is a pungent, irritating gas that is harmful to humans, but extremely beneficial up in the stratosphere around the Earth where it blocks ultraviolet rays, especially UV-C, thus protecting us from the most dangerous ultraviolet frequencies.

Absorption, Reflection, and Scattering

When the atmosphere is 'thicker,' in other words, when it is cloudy from increased water vapor in the air, ultraviolet radiation is absorbed further and less of it reaches the Earth. Thick clouds will tend to absorb more ultraviolet than thin clouds, as will precipitation which both absorbs and scatters the radiation. Particulate matter such as dust from storms or pollution will also tend to cut down on the amount of UV radiation that reaches the surface of the Earth.

Ultraviolet radiation doesn't just stop moving when it reaches the Earth or the objects on its surface. Some of the radiation is reflected back from surfaces in varying quantities. Water tends to absorb most ultraviolet radiation, reflecting back only about 5%, whereas lightly colored, smooth, reflective surfaces like some buildings, parabolic antennas, light-colored automobiles, and snow, may reflect up to 85% of the radiation, bouncing it around to other reflective and nonreflective surfaces until it eventually dissipates or is absorbed.

Because ultraviolet is emitted by the Sun, there can be interference from sunlight when using ultraviolet for detection purposes. Unlike infrared, however, ultraviolet is quite easy to screen out. A dark room, dark box, or even a hand casting a shadow will often sufficiently screen out the Sun's ultraviolet so that a synthetic source can be used to examine objects with ultraviolet signatures or imprints. This is one of the characteristics that makes UV useful for surveillance tasks.

Some surveillance systems need to be protected from the Sun's ultraviolet radiation. Satellites, high-flying aircraft, and space probes all may be exposed to significant ultraviolet doses that can break down paints, plastics, and delicate structures. Vehicles, boxes, and compartments for storing or deploying sensitive electronic equipment may also be coated to resist damage from ultraviolet. There are a wide variety of commercial products designed to reduce or block ultraviolet radiation, including gel coatings and specialized paints.

Some substances will absorb ultraviolet radiation and re-emit the energy at another wavelength. Substances that *fluoresce* are absorbing radiation and re-emitting it in the visible spectrum. Out in space, regions of cosmic dust have been found to absorb ultraviolet radiation and re-emit it as mid- and far-infrared, allowing us to detect starlight with infrared telescopes and probes.

Astronomers are interested in all the different types of radiation emanating from bodies in and beyond our solar system. Since 'hot' bodies typically emit ultraviolet, there is a lot to be learned by developing detection systems and telescopes that can image ultraviolet. However, hydrogen and helium are gases that are abundant in the universe and they absorb extreme ultraviolet, making it a technical challenge to observe ultraviolet radiation emanating from celestial bodies. Conventional telescopes are not well-suited to ultraviolet observation, as the radiation is influenced by conventional coated surfaces (e.g., mirrors). Adjustments in mirror angles and surfaces are necessary in order to reduce scattering and absorption.

Chemical Marking and Illumination

Ultraviolet-reflecting chemicals are very handy for marking papers, cartons, clothing, currency, valuables, and skin. They are also used as markers or 'tags' for microscopic examinations and for marking birds for experimental observation or conservation. Ultraviolet chemical stamps are frequently used as entrance monitors at public events.

In surveillance devices, ultraviolet is typically used in conjunction with ultraviolet illuminators and ultraviolet-reflecting chemicals. As an example, an object or person's hand can be 'stamped' with an ultraviolet-sensitive chemical which may itself be either visible or invisible. When an ultraviolet-emitting light source is shone on the mark, it will 'glow' faintly (fluoresce) to indicate its presence. Ultraviolet-detection and analysis technologies are also used in astronomical research, many satellites are equipped with ultraviolet sensors.

Some substances fluoresce naturally when exposed to ultraviolet light. Others fluoresce if they have been chemically treated. In some instances, a simple handheld UV illuminator is used, in others, the UV light is carefully processed through a filter to isolate the desired wavelengths. Consumer devices tend to work with simple commercial illuminators, while scientific devices may require precise filtering or staining to achieve the desired result. In fact, the science is now sufficiently advanced that it is possible to detect as few as 50 fluorescing molecules per cubic micron through a microscope.

4. Origins and Evolution

When we represent infrared and ultraviolet symbolically, they are shown as regions on either side of the visible spectrum, with infrared at the longer wavelength (red) and ultraviolet at the shorter wavelength (violet). Infrared and ultraviolet share characteristics with the visible spectrum which led to their discovery at about the same as time color was being more closedly studied. The nature of light itself was of great interest, starting around the 17th century, and theories and experiments to discover the wave/particle aspects of light provided an important basis for understanding ultraviolet radiation once it was known to exist. It is recommended that you cross-reference the histories of Visual Surveillance and Infrared Surveillance to get an overall understanding of the development of light technologies.

Early Observations

The most important early contributions to the discovery and development of ultraviolet technologies involve the understanding of light and basic observations on ultraviolet radiation and its place within the optical spectrum.

During the 1600s, scientists generally considered light to be a wave phenomenon. By the 1700s there was important speculation and experimentation by Isaac Newton (1642-1727) leading to the theory that light might, in fact, be a particle phenomenon. He described his 'corpuscular' theories of light in "Opticks" in 1704. This was almost a century before the discovery of invisible radiation within the optical spectrum, so Newton didn't live to see that wave and particle theories of light would eventually be applied to wavelengths that are invisible as well as those that are visible.

Many great discoveries in science are based on simple observations and subsequent theories to confirm and predict simple effects. Karl Wilhelm Scheele (1742-1786) was aware, in 1777, that silver chloride darkened when exposed to sunlight, but he made a further important observation that it darkened most rapidly at the violet region of the visible spectrum. This observation of different effects in different parts of the spectrum became very important to the eventual discovery of ultraviolet and other forms of radiation.

In 1792, Thomas Wedgwood was working with bodies heated to high temperatures in kilns and noted that all objects turned certain colors at certain temperatures, regardless of their composition. Thus, metal or clay heated to several hundred or thousand degrees, would glow with the same colors, in spite of the fact that they had markedly different compositions. Gustav Robert Kirchhoff (1824-1887) further refined Wedgwood's observations and proposed a mathematical relationship between the emitted and absorbed power of a surface in thermal equilibrium.

In 1800, Thomas Young (1773-1829) challenged Newton's theory of light 'corpuscles,' or particles, and proposed a wave model based on longitudinal waves. Meanwhile, F. Wilhelm (William) Herschel (1738-1822) was studying the colors of light through a prism with a thermometer. He noticed that changes in temperature that were apparent in the different colors of the spectrum continued beyond the red region even though he couldn't see any more colors in that region. From this he correctly concluded that there were wavelengths beyond the color red that were invisible, but of a similar character to visible light. Thus, Herschel had discovered *infrared*.

Prism experiments with light were important at this time, but in 1801, Johann Wilhelm Ritter (1776-1810) used chemicals to further investigate the effects of individual colors. Just as Herschel had inferred the presence of wavelengths beyond the visible spectrum from the change in temperature that occurred in the infrared region, Ritter inferred the presence of ultraviolet by the interaction of each portion of the spectrum with chloride. In the visible violet region, the light darkened the chloride; in the invisible ultraviolet region, it darkened it even more. Ritter had taken Scheele's observation and Herschel's experiment one step further and discovered *ultraviolet*.

In 1842, Edmond Becquerel (1820-1891) photographed the solar spectrum and, since the film was sensitive to ultraviolet, his photographs included wavelengths extending into the ultraviolet.

Theoretical/Mathematical Frameworks

In the 1850s, James Clerk-Maxwell (1831-1879) made important observations and developed theories related to electricity and magnetism. He developed the framework within which we now understand that ultraviolet is a type of *electromagnetic* energy along with radio waves, infrared, visible light, X-rays, and gamma rays. Clerk-Maxwell's predictions and calculations, known as *Maxwell's equations*, were remarkable considering that most of these forms of electromagnetic energy would not be discovered for another four decades.

Fluorescence has been observed for thousands of years, as it occurs naturally, but the phenomenon of fluorescence was not really understood scientifically until about the middle of the 1800s. George Stokes (1819-1903) observed that fluorspar would 'glow' when it was illuminated with ultraviolet light and coined the term *fluorescence*. He further observed that the fluorescent light had longer wavelengths than the light causing the excitation. Since that time, we have learned more about materials which will fluoresce in their natural form or when chemically treated, knowledge that we now use in commercial applications.

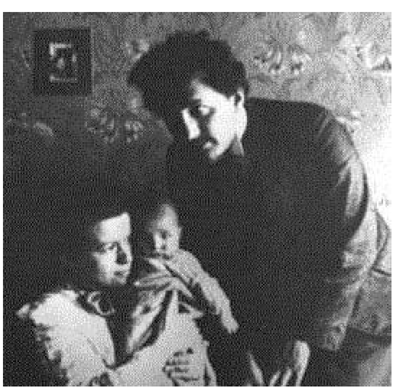
In the 1870s, scientists studied the influence of ultraviolet on biological organisms. They observed that bacteria and certain pathogens are influenced by specific wavelength regions of sunlight and that UV-C could slow or stop their growth. This observation would eventually lead to new methods of environmental control of bacteria, molds, and other organisms. The discovery would also lead to practical applications a century later in chemical surveillance, 'clean' rooms, hospitals, and waste-destruction facilities.

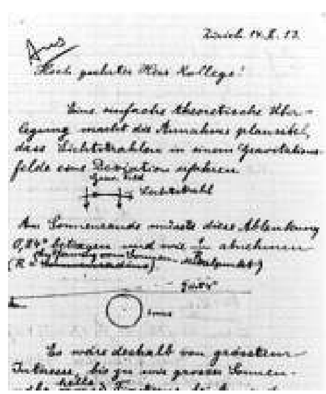
In 1886 and 1887, Heinrich (Rudolf) Hertz (1857-1894) performed some important experiments that helped to confirm Clerk-Maxwell's theories about electromagnetic energy by applying voltages to metal spheres with a narrow gap between. He further discovered that ultraviolet light can influence a metallic surface to emit electrons. His work led to the understanding that it was the *frequency* of the light that was important to this effect and that the light's intensity (which we perceive as brightness) influenced the number of electrons ejected, but did not influence their kinetic energies. (Einstein later studied this *photoelectric* effect in more detail.) As a picture of the electromagnetic spectrum and its characteristics emerged, visible light, which is so significant to humans, was found to be only a tiny portion of the electromagnetic spectrum.

In the early years of the 20th century, researchers looked beyond the Earth to the primary source of our electromagnetic energy, the Sun. They studied sunspots and speculated as to their character. By study and experimentation over a period of about 30 years, they found an electrified region of the Earth's atmosphere which was reflective and decided that most of the ionization in the atmosphere was a result of ultraviolet radiation from the Sun. They further realized that long-distance radio communications were intrinsically linked with this ionization process.

The Emergence of Quantum Physics

A revolution in physics was occurring in the early 1900s. Physicist Max Planck (1858-1947) was endeavoring to explain *blackbody* radiation (a black body is an idealized model of an object which is defined as absorbing and radiating all frequencies). Until this time, our understanding of thermodynamics and electromagnetism was not complete enough to explain a few important concepts. For example, scientists mathematically modeling the optical spectrum predicted that the intensity of the radiation would continue to increase indefinitely, from infrared to ultraviolet, implying that any body would emit an infinite amount of energy. Practical models didn't seem to support this theoretical prediction and the discrepancy was termed the *ultraviolet catastrophe*. Planck pointed out that a particle explanation, rather than a wave explanation, could resolve the theoretical and experimental discrepancy.





Left: Albert Einstein with his wife and son around the time he was formulating his Special Theory of Relativity, approximately 1904. Right: A portion of a letter written to G. E. Hale by Einstein in 1913, with an illustration of how gravity should affect light passing near the Sun, causing deviations in the visually recorded position of stars, depending on the position of the Sun, implying the warping of space. [Detail: The Albert Einstein Archives, The Jewish National & University Library, The Hebrew University of Jerusalem, Israel, ca. 1904. The Observatories of the Carnegie Institution of Washington, 1913, copyrights expired by date.]

At this time, Albert Einstein (1879-1955) was developing his Special and General Theories of Relativity and was probing another problematic area of physics called the *photoelectric effect*, discovered two decades earlier by Hertz. Einstein improved our understanding of the nature of light by explaining the photoelectric effect in terms of particles or *photons*, thus resolving some of the inconsistencies encountered by previous scientists.

Other important scientists were providing significant insights to our understanding of the universe. *Quantum physics,* which challenged all previous ideas about physics at the atomic level, was emerging. As a result, our notions of optical radiation as being either waves or particles were challenged with the bold assertion that it depended on how you looked at it; under some circumstances, light appeared to behave as particles, under others, it appeared to behave as waves. The more precisely you tried to design your experiments, the more elusive the answer became. Yet, over the next several decades, the field of quantum physics gained an uneasy credibility along with classical Newtonian physics. It is now one of the most important and exciting areas of research within physics and is better understood from the perspective of probabilities than of the hard and fast rules of classical models.

Experimental and Practical Applications

In spite of the economic difficulties, a great deal of scientific discovery occurred during the depression years in both America and Europe that related directly to surveillance technologies. Radio ranging technologies for navigation, cathode-ray tubes, radio communications, and ultraviolet technologies all developed in important ways in the early and mid-1930s. The World War II years, in which research funding was made available for defense and warfare technologies, were also significant for practical applications of ultraviolet, as were postwar commercial developments.

Karl Von Frisch (1886-1982), a Viennese zoologist, studied communication in animals and insects. He is best remembered for his work with bees. In the course of his research, he paired colored cards with bowls of sugar water and discovered that the bees were attracted to the bowls on the basis of the color on the cards. He noted that they could see particularly well at the violet and ultraviolet end of the spectrum, beyond what humans are able to see. This contradicted earlier assertions that bees were color blind and sparked interest in ultraviolet vision systems.

Astronomers had known for decades that the planet Venus was shrouded with a mysterious white cloud, but they could only speculate as to what it might be and what it might hide. Frank E. Ross (1874-1966), an American astronomer, made some of the first ultraviolet photographs and some of the pioneering planetary photographs, as well. Using plates and ultraviolet-sensitive film, he photographed the cloud formations around Venus in 1928, providing new insight into the composition of the particles that cloak her surface.

In the 1930s, Haitinger and others developed secondary fluorescence which allowed chemical treatments to ‘stain’ various materials. This has been useful in creating ultraviolet ‘markers’ and in staining substances for examination with specialized microscopes. It has gradually come to be an important tool of forensic chemistry.

In the 1950s, Coons and Kaplan demonstrated important biological localization techniques using tissues stained with fluorescien-tagged antibodies. This was an important contribution to microscopy.

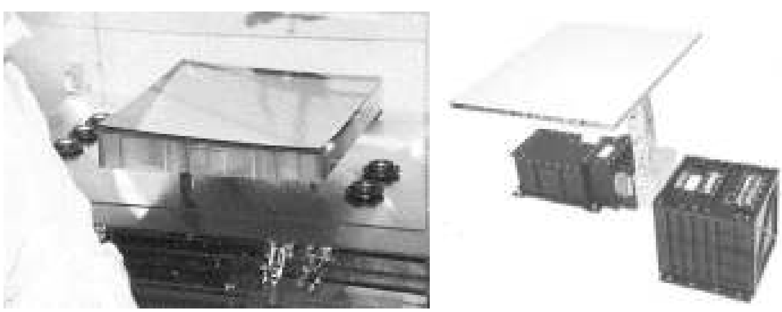
With new technologies, the interest in studying our solar system and the rest of the galaxy increased. Scientists began to be able to detect extreme-ultraviolet by the late 1950s, when they found shorter wavelengths emanated from the Sun. Because the extreme-UV is easily absorbed or scattered, it is difficult to detect from conventional ground-based telescopes.

The 1970s was a time when ultraviolet began to be used in a wide variety of applications, including astronomical observation, birding, and lasing.

Until the late 1950s and 1960s, astronomers considered it extremely difficult to observe radiation in the extreme ultraviolet, yet there was potentially a great deal of information about the universe that could be gained by finding solutions. Experimental ultraviolet astronomical photography began to show results by about the mid-1960s.

Left: The S-13 experimental Ultraviolet Astronomical Camera tested on the Gemini II space flight in 1966. The purpose of the experiment was to image the ultraviolet radiation from hot stars and to develop new ultraviolet photography techniques and devices. Middle and Right: Two frames of film from one of the early ultraviolet-sensing photography experiments that were carried out on the Gemini flight in August 1966. Black and white 70 mm film was used. [NASA/JSC news photo, released.]

Research into space flight, telescope modifications, and mirror optics in the mid-1970s began to make it possible to develop extreme-ultraviolet (EUV) sensing systems and, eventually, EUV telescopes and space missions.



Left: Ultraviolet instruments require special attention to fabricating the smoothness, coatings, and angle of installation of the mirrors, as ultraviolet is easily scattered or absorbed. This image shows a prototype mirror for the Far-Ultraviolet Sensing Explorer (FUSE) satellite about to be coated with a UV-reflective material. Two of the FUSE mirrors were coated with lithium fluoride (LiF) and two with silicon carbide (SiC). The coating is carried out in a 'clean room' in a vacuum tank, shown here at the NASA Goddard Space Flight Center. Right: Each of the LiF mirrors in the FUSE satellite is equipped with a Fine Error Sensor built by Com Deve Ltd. of Cambridge, Ontario, supplied to the FUSE project by the Canadian Space Agency. Shown here is a full-scale model with the CCD camera, radiator, and controller box. [NASA 1997 news photos, released.]

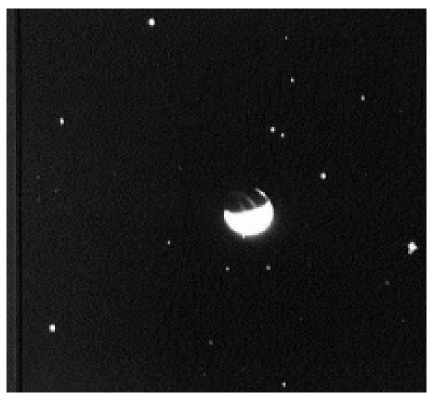
UV Photos from Space

Taking UV photographs from a spaceship is both a challenge and an opportunity. The spacecraft has to be oriented so the desired photos are possible and care has to be taken to protect the crew from ultraviolet exposure, but the amount of ultraviolet radiation in space is considerable and can yield information that can't be obtained from within the protection of Earth's ozone layer.

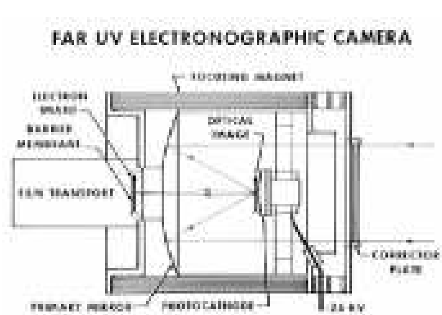
In July 1971, Apollo 15 was launched into space on what was considered primarily a science mission, which was to include ultraviolet photography. Because ultraviolet passes more readily through quartz than through glass, Window 5 in the Command Module had been specially fitted with quartz window panes. The high quality Hasselblad cameras that were carried along on the mission could then also be used to take ultraviolet-sensitive photos of the Earth and the Moon. When used for UV photos, a Hasselblad was fitted with a 105 mm UV-transmitting lens and four exchangeable filters. Since there was no ozone layer to protect the astronauts from dangerous UV radiation coming through the window, a special transparent polycarbonate shade was designed to cover the window between photographic sessions.

In order to shoot UV photos from space, the Apollo spacecraft had to be oriented so that Window 5 was facing toward the Earth or the Moon. While in position, about eight images could be taken, with two images for each of the four different filters.

The use of ultraviolet photography was continued in 1972 on the Apollo 16 mission with a specialized far-ultraviolet camera.



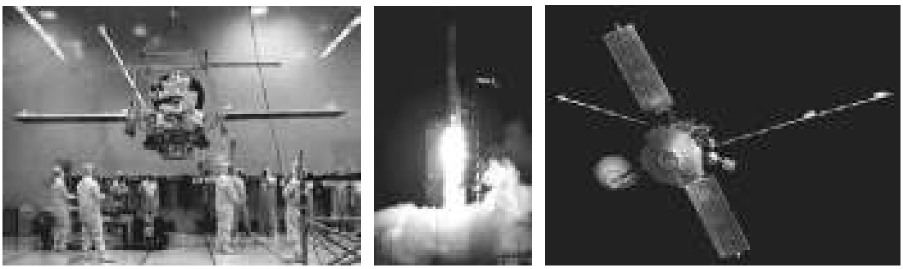
Left: After the success of UV photography from Apollo 15, a far-ultraviolet camera was readied for use on the subsequent Apollo 16 mission, in 1972. Here it is being examined by astronauts Charles Duke, Jr. and John Young. Right: This far-ultraviolet (1304 Å) image of the earth was taken from space by John Young, commander of the Apollo 16 mission, on 21 April 1972. [NASA/JSC news photo, NASA/Kennedy Space Center photo, released.]



Left: In the foreground, in front of Astronaut John Young, is an ultraviolet camera with a protective coating of gold to help maintain a safe operating temperature. The camera is aimed to record the large Magellanic Cloud from this position on the surface of the Moon, on 22 April 1972. Right: A November 1973 engineering drawing for the design of a far-ultraviolet electronographic camera to be used on Skylab 4 to photograph aspects of the comet which can't be seen from the surface of the Earth. [NASA/JSC news photos, released.]

Photos during Interplanetary Fly-bys

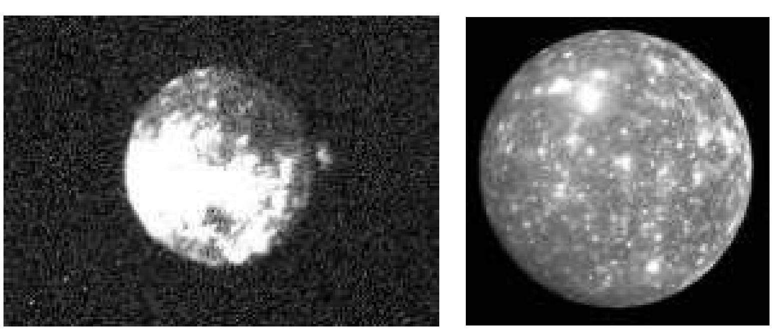
In November 1973, the Mariner 10 space probe used Venus' gravity to help it reach Mercury in 1974. It provided the first close-up ultraviolet images of Venus' atmosphere and the scope and behavior of its cloud cover. The craft was able to accomplish three fly-bys of Mercury before it ran out of the gas used to control its attitude, whereupon it moved into a solar orbit. In all, it was able to transmit more than 12,000 images of Venus and Mercury.



Left: Assembly of the Mariner 10 space probe. Middle: The launch in November 1973 on the Atlas Centaur launch rocket. Right: Artist's rendering of the Mariner 10 as it would have appeared during flight. The craft gathered data that indicated a thin atmosphere and magnetic field associated with the planet Mercury and earlier provided ultraviolet images of the Venutian atmosphere. [NASA 1973 news photos, released.]

In 1975, the Apollo-Soyuz Test Project, a joint project of American astronauts and Soviet cosmonauts, provided some exciting new information when NASA crew members used a command and service module to aim an extreme-ultraviolet telescope at a number of preselected targets. The successful detection of several of these targets established the feasibility of EUV surveillance of space.

In January 1978, the International Ultraviolet Explorer (IUE) satellite was launched as a cooperative effort among three agencies, the Smithsonian Environmental Research Center (SERC), The European Space Agency (ESA), and the National Aeronautics and Space Administration (NASA). It was placed in a 24-hour elliptical orbit around the Earth to communicate with the Goddard Space Flight Center and the Vilspa ground-station near Madrid, Spain. The IUE showed a hot gaseous region around the Milky Way galaxy among other discoveries.



Left: An ultraviolet photo of Io, one of the moons of the planet Jupiter, taken on a Voyager 2 spacecraft mission, the evening of 4 July 1979. The dramatic bright blotch on the right is the plume of a volcanic eruption, more than 200 kilometers high. Right: Callisto, a moon of the planet Jupiter, taken on 8 July 1979. This is a composite false color image, with ultraviolet light used to add the pseudo-blue component. Ultraviolet helps to provide contrast to the surface regions to make the image easier to interpret. [NASA news photos, released.]

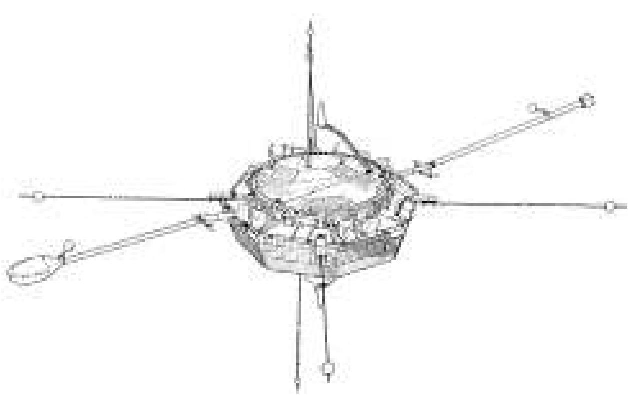
In the early 1970s, scientists began to study ultraviolet-sensing capabilities in birds, and by 1978, it was known that pigeons could sense ultraviolet light. There is speculation that this not only helps them find ripe foods, but that it might aid navigation. Since then, it has been discovered that many migratory birds are sensitive to ultraviolet (and possibly also infrared). This means that leg bands or dyes for bird surveillance should be carefully chosen so they don't interfere with the birds' mating or foraging behaviors when they are being studied or marked. Fluorescent and UV markers or aerosols have traditionally been used for bird research and may be suitable in some circumstances but not others.

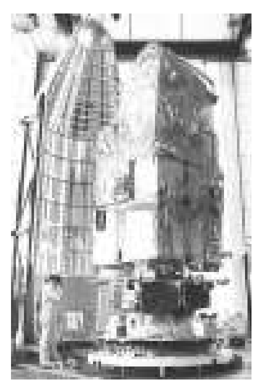
Scientists at the IBM Research Center noticed that ultraviolet pulsed lasers interacted with organic matter in unique ways; they would decompose in a particular way with as little as one laser pulse. This knowledge could be used to design advanced laser 'etching' tools.

Ultraviolet Effects

We began using ultraviolet in commercial applications about a decade before we really understood its influence on our ecosystem. The 1980s was a time when scientists more carefully studied extraterrestrial sources and uses of UV radiation and further refined the technologies within a broader framework of understanding. Scientists began putting ultraviolet sensors into space on board satellites even though, at this time, they were still a fairly new technology.

The Viking satellite, Sweden's first satellite, was launched in 1986 with a variety of sensing instrument payloads, including an ultraviolet imaging experiment. The University of Calgary in Canada supplied two ultraviolet cameras that captured auroral images to give a new view and set of data of the northern lights. The UV imaging experiment also provided data that could be used in conjunction with or compared to data from the other sensors (magnetometer, electric field sensors, and others).





The Viking satellite, after some delays, was launched from Korou on the Ariane 1 rocket in February 1986. It was initially placed in an 822 km circular orbit, which was subsequently raised to 13,530 km. It was controlled from a ground-station at Esrange until a short-circuit in a power modulator on the satellite caused communications contact to be lost about a year later. [Swedish Space Corporation 1986 news photos, released.]

In the 1980s, we began to understand the deleterious effects of pollution on the ozone layer and to notice the thinning of this layer. Ozone was found to be essential to our survival in many ways, as it screened out deadly solar UV rays.

Research and Applications

In the 1980s and 1990s, there was commercialization and further investigation into synthetic and natural ultraviolet sensors. Fish and birds were studied for their ultraviolet-sensing abilities. It was also a time when satellites began to explore the extreme-ultraviolet regions, and forensic scientists were using ultraviolet for investigations and weathering tests.

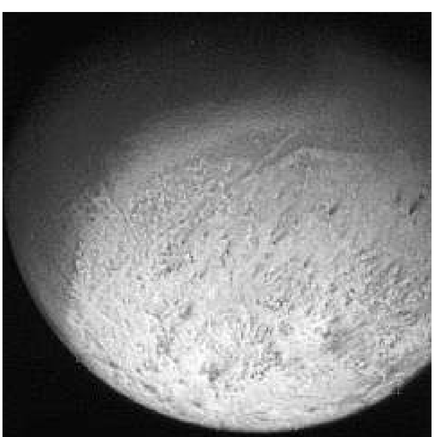
Science usually has to prove itself fairly definitively before it is allowed into the courtroom. Fingerprint technology has been gradually accepted as a routine identification technique, but other aspects of applied science, including lie detector tests and DNA profiles have been slow to gain acceptance and are still not admissable in court in some areas. However, the application of science to investigations and courtroom proceedings is gradually being accepted as these sciences become more precise and able to identify violent criminals who might otherwise continue to endanger other people.

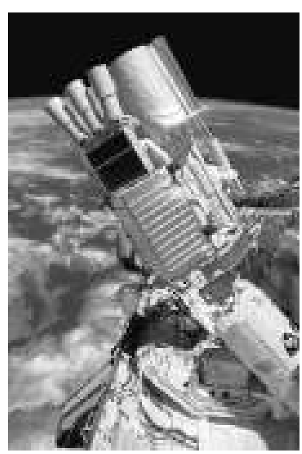
Since the 1970s, researchers have increasingly demonstrated the application of ultraviolet research to various branches of forensics. It was found that ultraviolet weathering could help determine the age of materials, that ultraviolet lights could help reveal stains and marks that would otherwise go unnoticed, and that ultraviolet markings could be used to track materials that might have been disturbed or stolen.

Astronomical Research Using Ultraviolet

Ultraviolet sensing began to really evolve in the later 1980s and 1990s. Space Shuttle missions, space probes, aerial UV-sensing aircraft, and many other ultraviolet technologies were being developed and tested at this time.

Once the basic logistics of taking pictures with special lenses, filters, cameras, and ultraviolet-sensitive film had been worked out, scientists began combining images taken with different filters and creating *pseudocolor* or *false color* images that were easier to interpret and more enjoyable to view.





Left: An image of Triton, the planet Neptune's largest moon, taken on the Voyager II space mission in August 1989. Pictures were taken through green, violet, and ultraviolet filters and combined to create this image. Right: This is the Astro-1 on the Space Shuttle Columbia mission in December 1990. In the foreground are a variety of X-ray and ultraviolet sensors, including the Hopkins Ultraviolet Telescope (HUT), the Ultraviolet Imaging Telescope (UIT), and the Wisconsin Ultraviolet Photopolarimetry Experiment (WUPPE). [NASA/Marshall news photos, released.]

The Extreme Ultraviolet Explorer (EUVE) was launched from a Delta II rocket on June 1992 to engage in all-sky (50 to 740 Å) and deep ecliptic (65 to 360 Å) studies. This was a milestone in space surveillance, as these bands had not been explored to any great extent up to this time. The EUVE included three grazing-incidence scanning telescopes and an extreme ultraviolet (EUV) spectrometer/deep survey instrument. The first portion of the satellite mission was to survey and map the EUV sky with the scanning telescopes, the second portion to act as a space observer.

In April 1993, the ALEXIS (Array of Low-Energy X-Ray Imaging Sensors) satellite, funded by the U.S. Department of Energy, was launched into Earth orbit. ALEXIS was equipped to make celestial observations in the extreme-ultraviolet with six remarkably compact telescopes. The satellite also carried scientific payloads that sensed other types of electromagnetic radiation, including the Blackbeard radio experiment and the ALEXIS telescopes.

Other Branches of Science

In the biological sciences, particular types of fish were found to possess photoreceptors sensitive to ultraviolet and salmon and rainbow trout became the subjects of numerous studies. It was discovered that ultraviolet-detecting structures in the retinas of young salmon gradually disappear until they are essentially gone from the main retina at about seven months of age [Kunz et al., 1995]. Trout have a similar pattern, although the mechanism can be influenced by the experimental introduction of hormones [Browman and Hawryshyn, 1994].

Lasers have been an important aspect of many technologies including printers, measuring instruments, cutting tools, sighting mechanisms, and much more. Different types of lasers and different potential applications continued to be developed through the 1990s. Until the early 1980s, lasers almost exclusively used visible or infrared light. By the mid-1990s, however, scientists had developed practical ultraviolet lasers which could precisely etch biological and synthetic materials without further chemical processing.

Airborne Ultraviolet Sensing

Aerial sensing in all regions of the electromagnetic spectrum were becoming important in the mid-1990s. Infrared, visual, and ultraviolet detectors and imaging technologies were being fitted into a wide variety of scientific, military, and commercial aircraft.

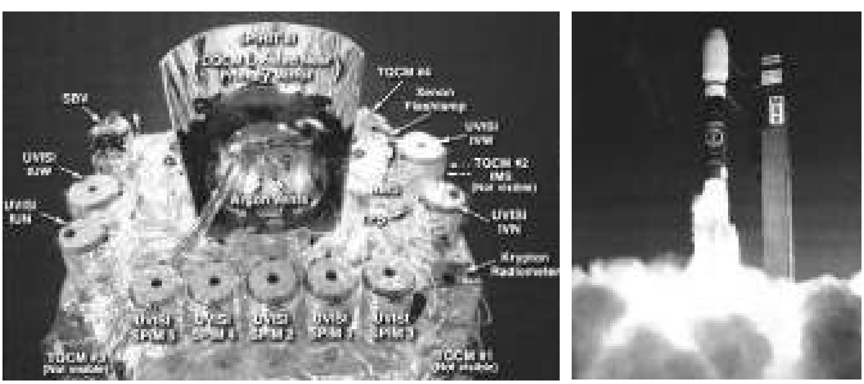
Left: An experimental SR-71 Blackbird was equipped with a UV video camera in the nose in March 1993 to test the feasibility of the equipment and the effects of turbulence. Here a Blackbird is shown over the mountains, in December 1994. The Blackbird is capable of speeds of over 2000 mph (Mach 3+). Right: A variety of experimental aircraft. The eerie Blackbird stealth plane, shown here in 1997, would disappear if it were photographed against a dark background. It was designed three decades earlier as a reconnaissance plane for the U.S. Air Force. [NASA/Dryden Flight Research Center news photo, released.]

In March 1993, NASA sent an experimental SR-71 Blackbird aircraft into the descending night from the Dryden Flight Research Center. The SR-71 was equipped with an ultraviolet video camera mounted on the nose so that it was aimed at the sky. It was intended to capture UV images of stars, comets, and asteroids. Part of the reason for the flight was to test the camera's reaction and performance in turbulent conditions at high speeds. Another reason for equipping the Blackbird with UV-sensing was its high-altitude capacity. The aircraft could fly to over 85,000 feet, a photographic vantage point that could not be attained by the telescopes at the Earth's surface.

The Continued Evolution of Space Science

In the mid-1990s, research into the astronomical use of ultraviolet sensing became more sophisticated and was now a regular part of space science missions.

In April 1996, the Midcourse Space Experiment (MSX) was launched into a circular orbit around Earth at an altitude of about 900 kilometers. It is used by the U.S. Ballistic Missile Defense Organization for the purpose of characterizing ballistic missile signatures during midcourse flight, that is, the period between booster burnout and re-entry. In the past, detection and targeting of incoming ballistic missiles were difficult technical challenges. The MSX was designed to observe a wide spectrum of wavelengths, including the far ultraviolet. It included five primary instruments with eleven optical sensors aligned for simultaneous observations to more precisely track moving targets. The system had other sensing applications, including the capability to monitor global environmental changes, especially ozone and carbon dioxide, and the ability to surveil terrestrial and celestial targets. The estimated mission life at the time of launch was about four years.

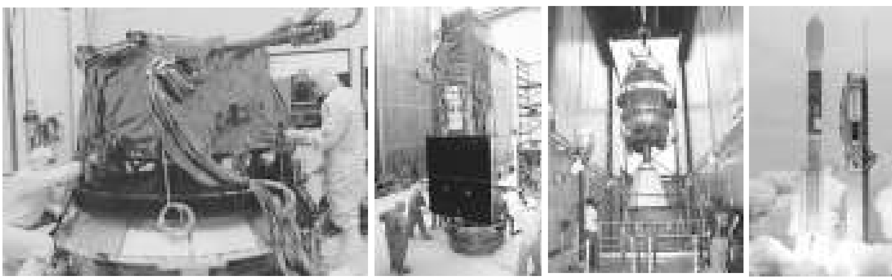


Left: The numerous sensors incorporated into the instrument section of the MSX are shown here. Note the UVISI sensors across the bottom. The MSX also includes an infrared telescope. Right: The MSX, with far-ultraviolet sensing, is launched by a Delta rocket from the Vandenburg Air Force Base in April 1996. [U.S. DoD BMDO 1996 news photos, released.]

In September 1996, after 18 years of successful service, the International Ultraviolet Explorer (IUE) satellite was turned off. It was the main ultraviolet-sensing instrument for the international astronomical community during its years of operation.

In February 1997, the Space Shuttle Discovery made a rendezvous with the orbiting Hubble Space Telescope (HST). On this mission, among other changes, the Faint Object Spectrograph (FOS) was removed and replaced by the NICMOS infrared camera/spectrograph. The FOS, which was installed in Hubble's axial bay, generated data in the ultraviolet spectrum.

In June 1999, NASA launched the Far-Ultraviolet Spectroscopic Explorer (FUSE) satellite. Orbiting at 768 km, it has provided new ways to surveil the composition and origins of the universe and preliminary results have been promising. FUSE is equipped with four telescopes which collect UV light and channel it to a high-tech instrument which breaks down the UV into component wavelength regions spectrographically. The far ultraviolet portion of the light spectrum sensed by FUSE is not visible to many of the other space-based sensing platforms, including the Hubble Space Telescope. The FUSE spectrograph is serving as a model for updating older systems and led to the Cosmic Origins Spectrograph, an instrument intended installation into the Hubble Space Telescope platform in 2003.



Left: The FUSE satellite during final tests in the 'clean room' at the Orbital Sciences Corporation. The telescopic instruments are attached to the top of the structure. Middle Left: The FUSE ready to go with solar panels attached prior to transport to the launch pad. Middle Right and Right: The Delta II rocket second-stage assembly being hoisted into position on the launch pad in preparation for the launch of the FUSE satellite and the launch on 24 June 1999. [NASA 1999 news photo by NASA; 1998 news photo by Orbital Sciences Corp.; 1999 news photo by NASA; 1999 news photo by NASA/KSC, released.]

The Increasing Importance of UV Sensing in Space

The payload of the 1998 Space Shuttle STS-95 mission was significant for at least two reasons. Not only were many of the payload instruments designed for ultraviolet sensing, but the Payload Specialist was the famed astronaut John Glenn, then in his 70s, taking a return flight almost 37 years after becoming the first American astronaut to orbit the Earth.

One of the things that space exploration has taught is us that the world above and beyond our planet is rich in variety and phenomena we haven't even begun to map or understand. Ultraviolet emissions form an important part of this diverse environment. The STS-95 Shuttle Mission was primarily a scientific mission.* Other highlights related to astronomical surveillance focused heavily on ultraviolet studies and included

UVSTAR - an extreme-ultraviolet spectrographic telescope that can sense and resolve images of sources of plasma in space, including the plasma from hot stars and Io, one of Jupiter's moons. It can be used to study Earth's ultraviolet emissions.

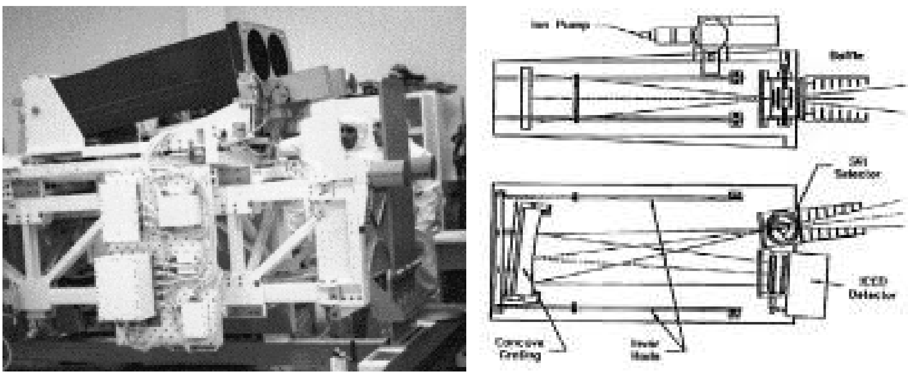
EUVI - an extreme-ultraviolet imaging system aboard the UVSTAR for taking extreme-UV measurements of Earth's atmosphere. Two imagers are used to scan the Earth's 'shadow line,' to map the intensity of helium and oxygen ions in the atmosphere. It permits precise measurements of the Earth's plasmosphere and ionosphere.

STARLITE - a telescope and imaging spectrograph for studying astronomical targets identified as ultraviolet targets, thus making it possible to gather data on sky background emissions, supernova remnants, nebulae, star-forming regions and volcanic emissions from the moon Io.

*One of the studies included checking on the health, progress, and physiological changes in John Glenn, the oldest astronaut ever to go into space.

SEH - instruments designed to gather data on absolute extreme-ultraviolet/far-ultraviolet fluxes (energy outputs). SEH interprets EUV/FUV emissions from objects in the solar system, plasmosphere, and magnetosphere, as well as solar system objects. Changes in the Earth's atmosphere resulting from solar extremes during the daytime can also be assessed.

Some of the UV instruments described here have been improved and updated since the STS-94 flight as research in UV sensing continues to result in better sensing technologies.



Left: The UVSTAR spectrographic telescope shown here operates in the 500 to 1250 Å waveband. Right: The UVSTAR consists of a pair of telescopes and concave-grating spectrographs to cover overlapping spectral ranges. The first telescope operates in the far-ultraviolet range, the second telescope operates in the extreme-ultraviolet spectral range. [NASA and Italian Space Agency news photos, released.]

XUV Research

While many of the most exciting applications of ultraviolet surveillance in the late 1990s occurred in astronomy, there were also breakthroughs in the use of ultraviolet in optical physics and microelectronics at this time. Ultraviolet is at the high-energy end of the light spectrum bordering with X-rays and, thus, extreme-ultraviolet (XUV) shares some common properties with X-ray technologies that allow some of the research on X-rays to be applied to ultraviolet. In microelectronics, ultraviolet has been studied for its potential to be used for lithography for the production of integrated circuits (ICs) and for the fabrication of high-precision mirrors. Thus, ultraviolet may eventually evolve into an important industrial tool for the production of optical and microelectronic surveillance devices.

Forensic Sciences

In the 1990s, the use of ultraviolet in forensics increased with the availability of fluorescing fingerprint powders, ultraviolet illuminators, specialized UV cameras, and microscopes that could be used to minutely analyze fibers or documents in visible and ultraviolet spectra.

Ultraviolet experiments in astronomy and other sciences, and the practical application of ultraviolet sensing to forensics and archaeology, continue to this day.

5. Description

Photographs are an essential aid to scientific, historic, and forensic documentation. Sometimes, ultraviolet light is used to illuminate old paintings, frescoes, cave drawings, crime scene stains, and historic documents. This means of viewing them is invaluable, but is even better if the discoveries can also be photographically documented.

One of the most valuable aspects of ultraviolet in surveillance is the fact that it can be used to view and record many types of faint or nonvisible phenomena. Thus, one of the areas that is of interest to surveillance professionals is the photographic recording of ultraviolet light. Here are some introductory guidelines for basic ultraviolet photography.

Film and Lenses

Black and white film is the most suitable for most medium-ultraviolet documentary applications as ultraviolet is not perceived by us as color, and most color films have a layer that blocks UV light. Many people also have inexpensive UV-blocking filters to slightly reduce haze in their pictures and to protect their expensive camera lenses. Remember to remove UV filters when taking pictures intended to emphasize ultraviolet. The lens and associated filters must let ultraviolet light pass through to the film. Unfortunately, with some coated lenses, the coating itself in part screens out UV (to reduce 'haze'), which interferes with UV photography. Using older uncoated lenses can sometimes reduce the possibility of this happening.

Quartz lenses allow ultraviolet light to readily pass, but may be out of the user's price range. If a spectrophotometer is available, it can be used to check if the desired glass lens allows UV light to pass through.

UV photography generally uses the longer UV frequency ranges from about 300 to 400 nanometers. Some filters allow both visible and ultraviolet light to pass through the lens and others screen out the visible light and allow only the ultraviolet. Which type is best depends on the application. For most forensics work, it is helpful to have the visible information as a guideline (e.g., detecting a forged signature over another that has been erased on a bank check), but even here there are exceptions.

TMAX film with 400 or 3200 ASA is suitable for UV photography. For professional quantities of films that are sensitive to ultraviolet, one option is the Fine Grain Positive Release bulk roll film (#5302) available from Kodak.

Filters

An *exciter filter* can be used to allow only wavelengths which cause fluorescence to pass. The most commonly used filter for this purpose is the Wratten 18A. Like ultraviolet, infrared rays focus just slightly farther from the lens than visible light rays due to refractive differences, and adjustments need to be made. Many lenses have a little red tick mark next to a yellow tick mark that indicates the amount of adjustment that may be necessary. If a fluorescing screen is used, the sharpness of the screen image will indicate if the scene is properly focused.

While black and white films are preferred for many UV applications, color negative and slide film can also be used with an exciter filter. A *barrier filter* that allows only the fluorescence to pass through the lens is pale yellow, such as the Wratten 2A, 2B, or 2E. With yellow filters used to record fluorescence, focusing is done in the normal way and most current meters are sensitive enough to automatically calculate the exposure.

Some photographic filters will screen out most visible light (around 400 to 750 nanometers), while permitting light energy toward the infrared and ultraviolet regions to be transmitted to the film. Since infrared and ultraviolet have different focal points, either one or the other will be in focus, but not both. The Schott UG1 filters out visible light and allows ultraviolet radiation from about 280 to 420 nanometers to be admitted, peaking at about 360 nanometers, and infrared radiation from about 690 to 1100+ nanometers to transmit, peaking at the transition to near-infrared, which is about 750 nanometers.

Hoya has a series of specialized filters for ultraviolet photography:

ultraviolet and visible filters - These filters include the UV-22 which has a fairly broad range of transmission and UV-28, UV-30, UV-32, UV-36, and UV-38 which absorb the shorter wavelengths and transmit visible light. The numbers correspond roughly to the lower end of the range of wavelengths that can pass through the filter. For example, UV-28 transmits UV at about 280 nanometers and above and UV-32 transmits light at about 320 nanometers and above. These frequencies correspond approximately to the line spectra of mercury lamps. The filters themselves appear almost black.

ultraviolet filters - There is a series of Hoya filters for transmitting ultraviolet and screening out (absorbing) visible light (they also allow a bit of infrared to be admitted). These include the U-330, U-340, U-350, and U-360. As the numbers go higher the breadth of the spectral admission tends to decrease. For example, U-330 allows wavelengths from about 200 to about 450 nanometers to be transmitted through the lens, a range of about 250 nanometers, peaking at about 330 nanometers. The U-350 transmits from about 300 to about 480, with a range of about 180 nanometers, peaking at about 350 nanometers.

Flash and Illumination

When ultraviolet is being photographed, it uses either *reflected ultraviolet* from a secondary source of illumination or the *radiated illumination* from a substance which fluoresces when stimulated. Reflected ultraviolet is mainly used in forensic and medical photography. Fluorescence is used in biochemical sciences, archival applications, archaeology, and sometimes in forensic and medical applications.

If extra illumination is needed, it is best to use a professional mercury arc lamp with certified eye protection, but in some instances a commercial "black light" or flash that does not have a coating to absorb ultraviolet light can be used. A black light is a mercury-vapor tube coated with phosphors on the inside (somewhat like the inside surface of a computer monitor screen). When stimulated by the mercury vapors inside the tube, the phosphors emit longer-wave UV near the violet portion of the visible spectrum. Since certain UV can kill bacteria, the technology is used in medical sterilization procedures and there are medical lamps that emit shorter-length UV rays, but be sure to exercise caution and use protection. As lamps emit shorter UV waves, the price generally increases because quartz has to be used rather than glass, which hinders short-UV.

If artificial UV illumination is being used, depending on the filter, it may be necessary to block the windows, turn off the room lights, and use a high-ASA (fast) film and long exposure times. Take several pictures at different aperture settings (this is called *bracketing* the exposures). Photographic and scientific suppliers can aid in selecting UV illuminators and protective eyewear.

When photographing short-wave ultraviolet, the photography can be done in the dark without the filter, but special lenses are usually necessary, as regular optical glass tends to absorb the desired wavelengths. Pinhole cameras, quartz lenses, and special plastic lenses may be used. Substances that fluoresce will be recorded as a combination of the reflected ultraviolet and some of the visible light that is emitted in the fluorescing process. For very-shortwave ultraviolet, normal film emulsions may absorb the radiation and special emulsions such as those coated with silver halides must be used.

Digital Processing

With digital processing software, even more possibilities are open for ultraviolet image analysis. By shooting images with and without different UV filters, scanning the results at high resolution, and superimposing the images, it becomes possible to reveal and study features from new perspectives.

6. Applications

Ultraviolet-reflecting substances are useful for many types of marking and identification, including crowd control, valuables marking, fingerprint detection, mineral identification, and stamp and currency security encoding. Ultraviolet itself is useful for forensic weathering tests and astronomical research.

6.a. Archival Investigations and Preservation

When ultraviolet light is shone on paper, ink, or paint, a surprising new world sometimes opens up, where details that couldn't previously be seen can be studied or read. This makes it a valuable surveillance tool for historians studying old documents, archivists developing preservation techniques, or investigators trying to locate subtle clues or to determine if something is a forgery.

Ultraviolet has aided archivists in examining, studying, and preserving historical documents. Ultraviolet has even made it possible, in some instances, to detect hidden writing or older writing (or painting) under the current surface layer. It can help reveal details of the ink and paper and changes in the materials over time, which provides valuable information for the development of preservation techniques. It can help reveal possible forgeries or aid in determining the age of a specimen.

Ultraviolet fluorescence and ultraviolet reflectance are used in assessing works of art, in combination with infrared and laser-illumination technologies.

6.b. Scientific Investigations

Archaeology and Anthropology

Just as ultraviolet can be used to examine documents and paintings, it can also be used to light up cave paintings and marks on old pottery, papyrus, and walls. In catacombs in the Mediterranean region, ultraviolet was found to reveal intricate, ancient embellishments that had never been noticed before in previous investigations with candles and flashlights. This provides a new glimpse into history and adds to our understanding of ancient cultures.

Ultraviolet can also reveal clues as to age, cracks, moisture content, and other important data that help determine the condition and history of historical artifacts.

Because of the importance of recording archaeological discoveries and the process of recovery and restoration, long-wave ultraviolet, which is the easiest to record photographically, is generally used for documentation in this field. Shortwave ultraviolet does not pass through glass, which is why most cameras are not suitable for shortwave UV photography.

Remains Identification

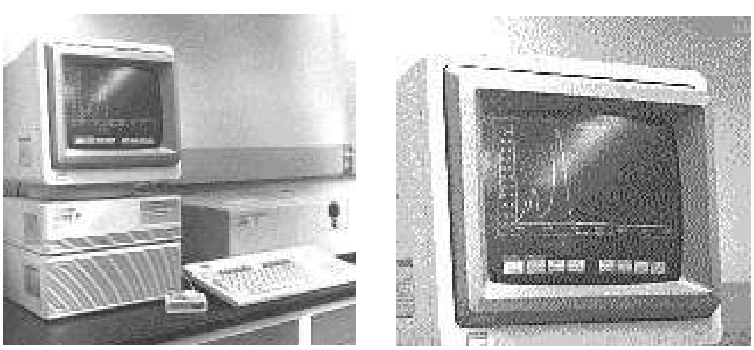
Sometimes tools common to archaeological research are used in forensics to identify the bodies of victims of wars or accidents that are many years old. In one interesting case, the U.S. Army Central Identification Laboratory (CIL) aided in identifying the crew members of a C-87 cargo plane that crashed in the Himalayas in 1944.

The wreckage of the plane was discovered in 1993 on a glacial slope. The remains of three of the bodies were recovered and returned to the U.S. DNA identification was still a young science at the time and sometimes other means of identification are used in conjunction with DNA technology, as in this case. CIL members hiked to the wreckage and noted the serial number of the plane. Meal chits were discovered that held the signatures of the crew members. Using ultraviolet and infrared illumination, the CIL staff brought out the information on the faded cards, revealing three out of five names. This allowed the relatives to bury their loved ones and receive closure after half a century of waiting and wondering what had happened to their family members [Rodricks, 1997].

In another, more celebrated case, ultraviolet photography has been used to try to help confirm or deny the authenticity of the Shroud of Turin, a shroud in which Jesus was said to have been buried. This and various other blood and chemical evidence shows, however, that the shroud probably originated at about the same time that it first came to public attention, in the early part of the Italian Renaissance. One of the most interesting observations scientists have made about the shroud is that the shape of the face doesn't match the fat, stretched-out shape that always occurs when a shroud is wrapped around a rounded object, like a head (you can try this for yourself). The natural proportions of the face on the shroud would likely only arise if it had been somehow painted on the fabric or impressed on the fabric from a shallow bas-relief (which were common adornments on buildings at that point in history).

Industrial and Resource Sciences

In industrial research, the chemical and geological sciences are often combined to assess natural resources and carry out gas and mineral exploration. Spectrometers and chromatographs (discussed further in Chemical Surveillance) are used in this research, including ultraviolet-visible spectrophotometers. Spectrophotometers are used in planetary sciences, fiber forensics, and for identifying narcotics and various other chemical samples.



A single-beam, microprocessor-controlled, ultraviolet-visible spectrophotometer with a diode array detector can aid in determining the transmission and absorbing properties of materials in the frequency ranges from about 200 to 800 nanometers. Different substances transmit and absorb in different patterns and proportions, yielding profiles that can aid in identifying a substance. This allows a spectrophotometer to be used for cataloging and comparing fibers and various other materials. [NASA/GSC news photo, released.]

Ultraviolet-visible spectrophotometers are used in the Johnson Space Center (JSC) Environmental Health Laboratory along with other instrumentation to monitor work environments on Earth and in space, including the assessment of air, water, and hazardous waste materials.

Sometimes it is important to detect certain gases in the air, e.g., the presence of hydrocarbon vapors. Ultraviolet and infrared illuminators can be used to radiate the area and, when intercepted by a receiver and compared against reference values, indicate the presence of certain gases [Dankner et al., 1995].

6.c. Crime Scene and Accident Investigations

Ultraviolet is used in a number of ways to gather evidence of a crime. When a victim of homicide is discovered at a crime scene, for example, the body is sometimes days, weeks, or even months old. To help establish the time of the crime, the evidence is examined for insects, decay, weathering, and other clues. Sometimes, however, it's not a murder case that is under investigation. Crimes of vandalism, theft, kidnap, or rape require other types of clues to reveal details about the events and when they took place.

Accelerated Weathering

Sometimes when a crime scene is very old, it becomes difficult to reconstruct the date that it occurred. However, there may be objects at the scene that have been subjected to sun exposure and weathering, such as photos, books, a baseball mitt, watch, or purse. Sometimes it may be possible to find similar materials and subject them to artificial weathering to gain the same effect and then compare the weathered materials to the materials found at the crime. This, in turn, can sometimes provide clues as to the length of time that has passed since the objects were first placed at the scene.

Accelerated weathering is a way of exposing a substance to ultraviolet and/or chemicals that have been predetermined to simulate the weathering effects of sunlight, condensation and the level of precipitation that might be common to the area. Both UV-A and UV-B lamps may be used in this process, along with moisture to simulate the condensation and rain.

Stain Detection

Stains on clothing, sheets, mattresses, walls, documents, phones, weapons, and vehicles can all provide clues at a crime or accident scene. Mercury-xenon lamps are sometimes modified with filters to provide an ultraviolet illumination source. Using protective goggles, an investigator can shine the light on various areas suspected of having stains and locate them more readily. Bodily fluids tend to fluoresce at a UV level of about 440 nanometers. The frequency can be controlled to some extent with different filters, which usually range around 420 ± 30 nanometers. Once a stain is located, it can be sampled and studied further in a lab, which will probably include microscopic examination in visible and ultraviolet frequencies and may also include ultraviolet-visible spectrophotometry.

Note that if stains, prints, and other clues are being photographed with ultraviolet light as part of an investigation, it is important to take the photos before covering the evidence with protective plastics, tapes, or varnishes. Part of the way in which these materials preserve the evidence is by screening out ultraviolet radiation, in which case they would also prevent the ultraviolet rays from exposing the photographic film.

Fiber and Natural Substance Detection

A number of types of microscopes are used in forensics to evaluate hair, fibers, and other substances that might be found on a victim's body or in the suspect's clothing, shoes, house, or vehicle. Cat hairs, tobacco leaves, and car mat fibers are all examples of materials that have helped investigators link a suspect to the scene of a crime. Ultraviolet-visible spectrophotometers may be used in this type of investigation.

Fraud Detection

Heat-sensitive recording materials, such as thermal papers, can be impregnated with chemicals that respond to ultraviolet or infrared stimulation. This permits the fabrication of *security papers* and *security inks*, materials that can be used for certificates, bank notes, and other negotiable instruments or confidential documents and *security fabrics* that can be used for special purposes. Ultraviolet-sensitive powders can be used to coat materials to detect tampering or theft.

Fluorescing inks can be made with chemicals such as fluorescein and certain dyes. Since inks can be impregnated with ultraviolet-sensitive chemicals, it follows that typewriter and computer printer ribbons could also be designed this way, to add an extra measure of protection to documents that are not mass-produced.

Ultraviolet products are commonly used for monitoring entrances and exits at music, religious, political, and sports events. These applications are likely to continue as they are inexpensive and relatively easy to use.

Narcotics Detection

Stain detection and narcotics detection use some of the same laboratory tools and techniques. For example, ultraviolet-visible spectrophotometry can be used to investigate a chemical solution with ultraviolet and visible light ranging between approximately 300 and 800 nanometers. Depending upon its composition, the substance will absorb some of the light, causing the energy level of the light to be shifted. The detector then assesses the amount of light that transmits through the substance. By calculating the relationship of the absorbed light to the transmitted light a chemical 'signature' can be generated that aids in identification. Each substance has its own signature, which includes peak absorption levels at certain wavelengths. When these patterns are plotted on a graph, a 'picture' of the chemical can be created that can be compared to reference chemicals to attempt to find a match.

Injury Detection and Assessment

When examining a body for forensic purposes, it is important to document any injuries that may be present. These may not be easy to see with the unaided eye. Ultraviolet light can be used to make surface bruises, bite marks, scars, cuts, and scratches more visible and ultraviolet photography can aid in documenting these marks.

6.d. Scientific Research

Fluorescent Microscopy

The level of light that reaches the eye when ultraviolet is used to fluoresce an autofluorescing or chemically treated substance is very small. Most of the photons are absorbed, rather than reflected back to the eye. For this reason, powerful illuminators, usually arc lamps, are used with fluorescent microscopes to increase the level of excitation. Xenon and mercury-burner lamps are commonly used.

Astronomy and Cosmology - Ultraviolet-Sensing Satellites

As described in the historical introduction in Section 4, ultraviolet sensing has fairly recently become an essential aspect of astronomical research. Ultraviolet-sensing satellites are designed to allow us to surveil Earth's envelope and characteristics of other bodies in the universe. 'Hot' celestial bodies emit ultraviolet, giving us a means to detect and map their characteristics and positions. White dwarfs and binary stars are just two types of celestial bodies that emit ultraviolet radiation in sufficient quantities to allow us to detect them from greater distances than is possible with visible light sensors.

Ultraviolet telescopes are designed to overcome some of the UV-scattering characteristics of conventional telescopes, with special adjustments and ultra-smooth mirrors. UV-detectors often need to be highly selective when they are operating in Earth-orbits where there is interference from the Sun's UV radiation.

Earlier missions that sensed ultraviolet radiation include the Astronomy Netherlands Satellite and NASA's Orbiting Astronomical Observatories. Examples of more specialized UV-sensing astronomical missions include

The International Ultraviolet Explorer - launched in January 1978, the IUE was designed to sense ultraviolet radiation in the following wavelengths:

- 115 to 200 nanometers with a short-wavelength Prime camera (SWP)
- 190 to 320 nanometers with long-wavelength Prime (LWP) and Redundant (LWR) cameras

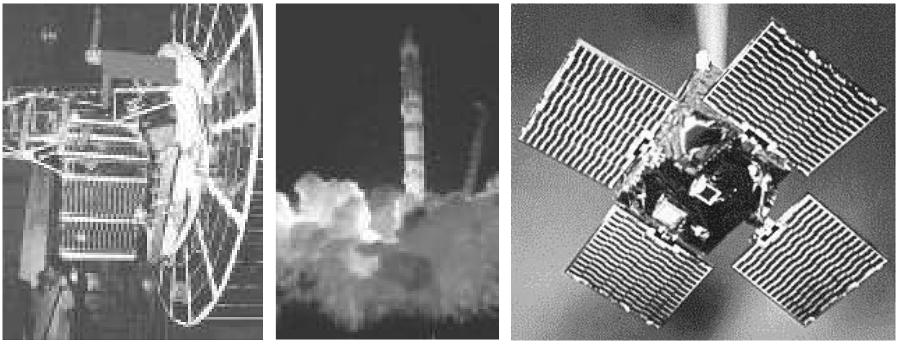
During observations, the spectrum is displayed as an image through a television camera with an optimum signal-to-noise ratio of about 20:1. Since camera and film technologies vary in sensitivity in different wavelengths, the calibration and design of these instruments can be quite challenging.

The Extreme-Ultraviolet Explorer - the EUVE satellite, launched in June 1992 is designed to sense extreme-ultraviolet radiation. It was placed into low-Earth orbit (LEO) below the Earth's geocorona, so that it could be serviced by space shuttle missions. (Space shuttle astronauts have carried out a number of repairs and adjustments to various orbiting platforms, including the Hubble Space Telescope and the MIR space station.) EUVE sensing ranges include

- all-sky (approx. 50 to 740 Å)
- deep ecliptic (approx. 65 to 360 Å)

Other space agencies have been contributing to the knowledge base that makes space exploration possible. ASTRID is a small, spin-stabilized, scientific satellite launched by the Swedish Space Agency in January 1995. ASTRID carries a number of imaging sensors, including an *energetic neutral atom analyzer*, an *electron spectrometer* and two *ultraviolet imagers* for imaging the aurora. The platform was designed and developed by the Swedish Space Corporation's Science Systems Division in Solna, Sweden, while the payload was developed by the Swedish Institute of Space Physics in Kiruna. The control and command station is in Kiruna, a town in northern Sweden where a large parabolic antenna complex has been established.

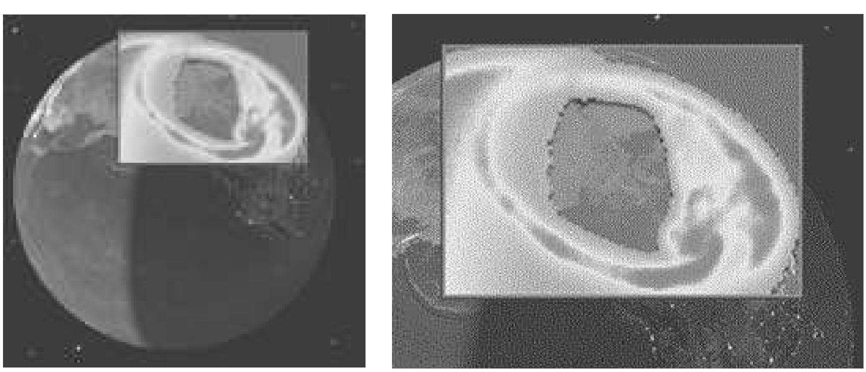
ASTRID-2 is the successor to the Swedish ASTRID satellite. This spin-stabilized, scientific satellite was launched from Plesetsk in December 1998 aboard a Kosmos 3M rocket. Contact was lost in July 1999, but a large amount of data was secured during the satellite's operation. One of the missions of the satellite was to collect ultraviolet auroral images and atmospheric UV-absorption measurements.



The ASTRID, a small, scientific satellite, is equipped with ultraviolet Miniature Imaging Optics (MIO) - stainless-steel-mounted photometers installed in the satellite spin plane. One sensor observes the Lyman alpha emission from the Earth's geocorona, while the other observes auroral emissions. The satellite was launched along with the Russian navigation satellite Tsikada on a Kosmos-3M rocket supplied by the Design Bureau Polyot, Omsk. [Swedish Space Agency 1995 news photos, released.]

Left: Tests at Plesetsk necessitate the disassembly of the main avionics unit to fix a problem on the main processor board. Middle: The Astrid-2 Kosmos 3M rocket ready to launch in Plesetsk. Right: The Astrid-2 control center at the Swedish Space Agency headquarters at Solna, Sweden. [Swedish Space Agency 1998 and 1999 news photos, released.]

The Ultra-Violet Auroral Imager



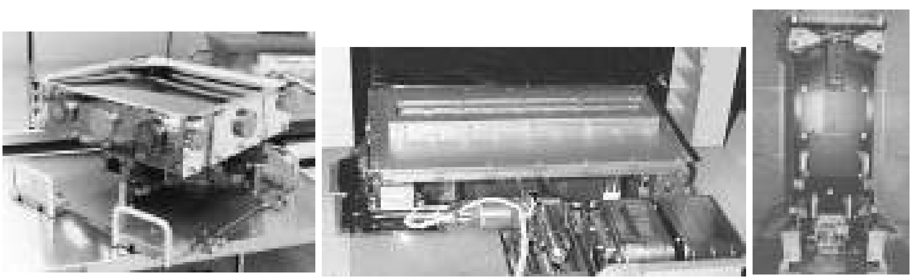
This composite image shows the position of the Earth from space, featuring a 'swirl' over northern Canada from a UV Auroral Imager (UVAI) image of a magnetic space storm that was superimposed over the image of the Earth for reference. The UVAI image was taken 1 March 1997 and has been color-coded to symbolically represent the intensity of the aurora. [Canadian Space Agency 1997 news photo, released.]

The Canadian Space Agency's Ultra-Violet Auroral Imager (UVAI) was launched onboard Russia's Interball-2 satellite. Images from sensing systems like these are sometimes hard to interpret by themselves, but they can be combined with photographs and computer-generated pictures to provide reference points and a view of the relationship of the recorded phenomena to the Earth.

The Far-Ultraviolet Spectroscopic Explorer

The Far Ultraviolet Spectroscopic Explorer (FUSE), launched June 1999, provides several telescopes equipped to image radiation from distant galaxies, providing information on the character and origin of the universe.

The design, development, and launch of the FUSE satellite have involved the collaborative efforts of many corporations and educational institutions. The illustrations below show three instrumentation components that make up part of the 'payload' of the FUSE system, each assembled at a different location.



Left: One of four telescope mirror assemblies, assembled and tested in the 'clean room' at the Johns Hopkins University Homewood Campus. The light from the four mirrors is aligned and channeled into the spectrograph. Middle: One of the two detector assemblies, both of which serve as electronic 'retinas' to sense ultraviolet light and convert the energy into electrical signals that form the digital data that are communicated back to the Earth-based station. The sensors were constructed and tested at the University of California, Berkeley. Right: The FUSE spectrograph which contains the gratings (top) and detectors (bottom center) used to detect and analyze ultraviolet light. The spectrographic analyzer was assembled at the University of Colorado. [NASA 1998 news photos by Johns Hopkins University/APL; UC Berkeley; and University of Colorado, released.]

Left: A view down through one of the four telescopes in the FUSE satellite, called Lithium Fluoride #1. Right: The FUSE Satellite Control Center at Johns Hopkins University Homewood Campus. Satellite communications and data are sent and received at this center. [NASA 1999 news photo by the CCAS Mechanical Team; 1998 news photo by Johns Hopkins University, released.]


The FUSE ground station antenna at the University of Puerto Rico, Mayaguez, during installation in 1998 and from another angle, after subsequent installation of a protective radome. [NASA 1998 and 1999 news photos by UPRM, released.]

Ultraviolet-sensing satellites often have other types of sensors in additional to UV sensors. X-ray sensing is an important aspect of astronomical research that often goes hand-in-hand with UV sensing.

6.e. Spill Detection

Ultraviolet remote-sensing techniques are used in conjunction with other detection and imaging technologies for various environmental studies, including coastal monitoring, the detection of spills, and the determination of spill thickness, spread, and scope. Ultraviolet is also useful for measuring the effectiveness of various dispersants. Many oil-spill aerial-detection systems combine one or more visual imaging systems in combination with an ultraviolet camera and an infrared camera.

6.f. Commercial Products

Detection Substances

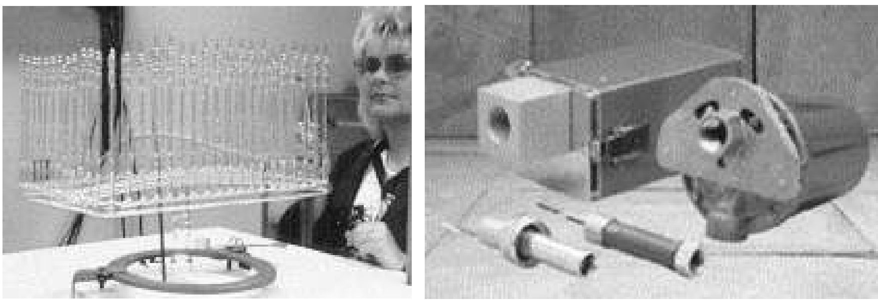
Ultraviolet detection products (known as 'spy dust') are commonly available for monitoring theft and tampering and to provide positive identification. They are used for marking currency, valuables, doorknobs, safes, and items that need to be identified at some later date or at a different location. The powder, gel, or UV 'ink' is usually dispensed from a small vat, tube, or marking pen and when applied, cannot be seen with the unaided eye. Then, if there is tampering or theft, the area or the recovered object can be studied by exposing it to appropriate frequencies of ultraviolet light. It can be noted whether they have been touched or transferred to other objects or someone's hands or clothing and sometimes even fingerprints can be detected.

UV detection powders typically sell for about $15 per ounce, with lower prices for bulk purchases. An ultraviolet illuminator is also required to stimulate the particles to fluoresce so they can be seen if they are later inspected.

Flame Detectors

Ultraviolet flame detectors can sense the UV radiation from hydrocarbon flames and indicate *flame* or *no flame* conditions for fire surveillance. They are used in a variety of industrial settings where generators or burners might be at risk of combustion.

Honeywell products include a gallium nitride solid-state sensor and two types of Geiger Mueller detectors that are sensitive to ultraviolet at 1800 to 2600 Å. At this spectral-response level, the detector does not respond to ground-level solar radiations nor blackbody emissions up to 2600°F.

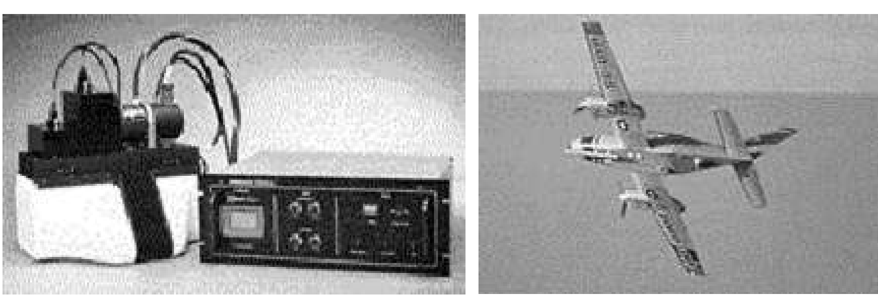


Ultraviolet flame detectors from Honeywell include tube (minitube and power tube) and solid-state varieties. Left: Minitube technology is more robust for environments with heat and vibration. Right: Power tube technology has the same sensitivity but is more suitable for lower heat/vibration space- and aircraft applications. [Honeywell 1999 news/product photos, released.]

The Honeywell flame-monitor system has been utilized in fire surveillance applications on the NASA Skylab.

Maritime Surveillance Products

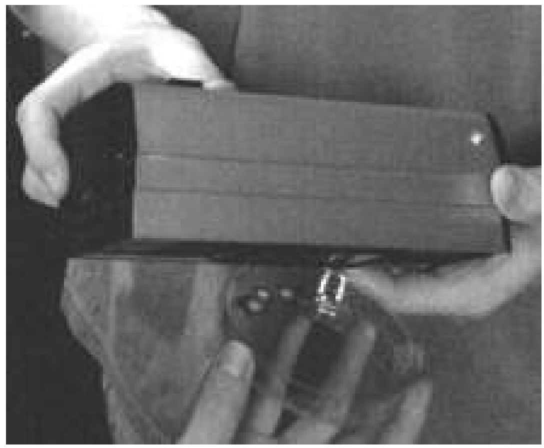
Ultraviolet sensing devices are often used in conjunction with visible and infrared sources for many types of aerial surveillance activities, such as aerial surveillance of marine craft and surface and underwater marine environments.



Left: The Daedalus AAD1221 Maritime Surveillance Infrared/Ultraviolet (IR/UV) Scanner operates in the 8.5 to 12.5 µm region and in the 0.32 to 0.38 µm region (ultraviolet) as part of the Maritime Surveillance System supplied by the Swedish Space Corporation. The Swedish Coast Guard has been using this system on Cessna 402C airplanes. [Swedish Space Corporation news/product photos, released.]

The Swedish Space Corporation (SSC) offers an infrared/ultraviolet scanner, the Daedalus AAD1221 Maritime Surveillance Scanner. This is a subsystem of the Maritime Surveillance System (MSS) originally developed for the Swedish Coast Guard, in operation for over 15 years. This equipment is suitable for use at low altitudes for imaging oil spills, for example. The system obtains ultraviolet data during the day and maps the extent of a slick, irrespective of thickness. False-color images are displayed in realtime. Other components of the MSS include side-looking airborne radar, a microwave radiometer, and handheld cameras.

Experimental Sensors

Purdue chemistry student Matthew Allen shines ultraviolet light on a dish of porous silicon held by chemist Jillian Buriak. Buriak has found a way to stabilize the surface of porous silicon so its light-emitting properties can be used to develop new types of sensors and opti-electronic devices. The silicon in the dish responds to the UV stimulation by emitting a bright orange light. Buriak has succeeded in overcoming some of the conditions that limit the photoluminescent properties of porous silicon, and it may someday be practical for developing fine-tuned sensors to perform realtime measurements or new flat-screen computer displays. [Purdue 1998 news photo, released.]

Ultraviolet Light Meters

Light meters that respond to ultraviolet light are used in a number of chromatography, sterilization, and forensic investigation tasks. They are also known as radiometers. UV light meters use photoelectric cell sensors and filters to meter only the UV light. For professional purposes, they are priced around $1,000 and it is best to get meters that have been certified (e.g., U.S. NIST).

7. Problems and Limitations

Because of their potential for damage to humans, ultraviolet-generating products should be handled with caution. Those which sense ultraviolet without creating it are usually not harmful in themselves, but the rays influencing them may be.

Visibility

One of the limitations of working with ultraviolet-sensing technologies is that ultraviolet cannot be seen by humans. For this reason, we must rely on data- or light-conversion techniques to detect or image ultraviolet sources. Making substances fluoresce is one way of taking advantage of their chemical properties to reveal the presence of UV in the visible spectrum. Using ultraviolet-sensitive film and photographic techniques is another way to make ultraviolet emissions visible.

Hazards

Ultraviolet devices must be used with a reasonable amount of care. Remember that the far-ultraviolet spectrum is adjacent to X-rays which can inflict significant harm on humans and other living things.

Many ultraviolet products are not shone directly at humans or, if they are, only for a short time. Some ultraviolet products illuminate in the portion of the ultraviolet spectrum that is close to the visible spectrum (violet) which is less dangerous to humans. Nevertheless, it is prudent to remember that ultraviolet exposure can permanently damage skin and eye tissues and that people taking antibiotics, tranquilizers, or birth control pills may be especially sensitive to their effects. Sunblock products (SPF 30+), intended to protect humans from sunburn, can also be used to protect hands or other body parts that may be exposed to ultraviolet illuminators in labs or other environments.

The *UV Index* is a scale from zero to 10 that is used by the Environmental Protection Agency and the National Weather Service to report on the amount of UV radiation reaching an area. Levels of five or above are considered hazardous and protection should be worn.

Surveillance devices that emit UV radiation should not be left on for extended periods of time and should not be shone directly at people's eyes. UV-blocking goggles should be worn, especially if the ultraviolet is in the higher frequency ranges. For basic goggles to protect from the blue 'haze' that emanates from UV wavelengths, ANSI 287.1-1989 and OSHA 1910.133 goggles can be worn. Goggles can also help increase contrast when viewing UV-illuminated evidence or documents.

Fortunately, most small commercial UV illuminators are designed to work in wavelengths that are close to the violet region of the visible spectrum, which are less harmful, but it's still wise to be careful. Used with common sense, UV surveillance tools are especially useful for crowd control at large events, for detecting tampering or theft, and for studying archaeological finds.

8. Restrictions and Regulations

With the exception of industrial standards for UV-sterilization products, safety gear, UV-resistent paints and gels, and ultraviolet lights (such as tanning lights and UV illuminators), there are not a lot of restrictions to using ultraviolet-sensing technologies in a variety of commercial, scientific, educational, and personal applications. Thus, ultraviolet has become a valuable aspect of surveillance, particularly in archaeology, space science, geology, biochemistry, and forensics.

9. Implications

Many of our discoveries about ultraviolet are new. Ultraviolet-sensing studies in astronomy and wildlife biology are very recent, barely three decades in many cases, and less than eight years in some. Ultraviolet lasers are also recent inventions. The author feels certain there is much more that we have to learn about the biological processes associated with ultraviolet and that there are probably many practical applications for UV-sensing that will be developed in the future.

The study of ultraviolet-sensing in birds and other creatures is not just important for our scientific understanding and the possible medical benefits available through technology; it is also important because advancements in biology and chemistry allow us to genetically engineer cells to contain characteristics not spontaneously found in nature. This opens up a

Pandora's Box of possibilities.

Many species of birds have better vision than humans. In fact, as a group, birds tend to have better vision than mammals. Many mammals have poor visual acuity and poor color-sensing abilities. Even the octopus, a cephalopod mollusk, has better vision than most mammals. Humans are unusual in their ability to see well and to see colors. Dogs and cats (with the exception of Siamese cats) apparently see the world in monochrome. In contrast, many birds, especially birds of prey, have remarkable acuity and color vision. Some of them can see five to 10 times better than humans and they apparently see not just the colors humans see, but can sense into the ultraviolet and infrared spectra, as well. Bird plumage probably appears more 'colorful' to birds than it appears to us, with ultraviolet variations that add to each bird's individuality.

Just as dolphin research has helped us to understand and design sonar devices, bird research has taught us new things about ultraviolet. This knowledge may lead to new types of chemical sensors or even to birds trained to seek out ultraviolet and sound a signal. We have also learned that the extra ultraviolet-sensing abilities of birds are at least partly chemical and there is undoubtedly some hormonal and perceptual processing that works in conjunction with the chemical structures in the eye itself. Despite the difficulties inherent in genetic procedures, scientists and philosophers have already proposed genetically inserting ultraviolet-sensing genes into humans in the embryonic stage in order to see if the human visual range can be extended into the ultraviolet [Sandberg et al., 1997]. A decade from now the idea may not be farfetched.

Sunblock products bring up another issue related to ultraviolet. Since they block ultraviolet light, they can be used in scientific studies of birds and other animals to note behavioral changes related to reduction in ultraviolet 'colors.' But in terms of surveillance, they could also theoretically be used by someone wanting to hide ultraviolet markings, perhaps for clandestine or illegal purposes.

10. Resources

Inclusion of the following companies does not constitute nor imply an endorsement of their products and services and, conversely, does not imply their endorsement of the contents of this text.

10.a. Organizations

American Astronomical Society (AAS) - A Washington, D.C.-based professional society for astronomers providing support, publications, grants, and educational programs. http://www.aas.org/

Astro Space Center (ASC) - A branch of the Lebedev Institute of Astrophysics in Moscow, Russia. The ASC engages in upper atmospheric, solar, and astronomical research. Research includes spectrographic studies and astronomics ranging from ultraviolet to cosmic rays. The facility is equipped to design, construct, and calibrate space experiments. http://www.asc.rssi.ru/

Canadian Space Agency (CSA) - A Canadian Agency, founded in 1989 from scientific developments dating back to the 1800s, that is involved in atmospheric sciences, space exploration, and space astronomy. CSA plans and implements Canada's Space Science Program. CSA also supplies scientific instruments to a variety of NASA projects including the FUSE satellite.
http://www.science.sp-agency.ca/

Center for EUV Astrophysics (CEA) - CEA was opened in September 1990 to support research into extreme-ultraviolet astronomical sensing. In 1997 CEA assumed command and control operations for the EUVE satellite system. CEA publishes an EUVE Observation Log, image and information archives, and supports a Guest Observer (GO) program online. It is located at the University of California, Berkeley. http://www.cea.berkeley.edu/

Center for Science Education - U.C. Berkeley Space Sciences Laboratory educational site which includes resources for educators and scientists, including lesson plans, study units, and information about educational programs. The Solar Max 2000 section includes information on space flight and solar cycles and the Center for Science Education has a Light Tour guide to the optical spectrum which allows the user to input wavelengths of interest. http://cse.ssl.berkeley.edu/

Fluorescent Mineral Society (FMS) - This is an international nonprofit society of professional and amateur mineralogists and gemologists founded in 1971. The organization shares knowledge and examples of luminescent minerals and organizes seminars and research projects.
http://www.uvminerals.org/

Forensic Consulting Associates along with **New England Forensics** - Provides seminars on specific aspects of forensic investigations, including specialized and advanced photography courses, some of which utilize ultraviolet photography. http://www.forensicconsulting.com/

Forensic Document Services (FDS) - This Australian firm, with branches worldwide, provides scientific examination services to government and commercial firms for investigating handwriting and documents. Technologies include spectral comparison, microscopy, and ultraviolet and infrared imaging. The company also provides courses and seminars. http://www.asqde.org/fds/

International Association of Financial Crimes Investigators (IAFCI) - A nonprofit, international organization of law enforcement officers and special agents founded in 1968 to provide professional fraud prevention consulting and fraud investigation services. http://www.iafci.org/

International Astronomical Union (IAU) - A professional (Ph.D. and beyond) organization founded in 1919 to promote the science of astronomy through international cooperation. http://www.iau.org/

International Ultraviolet Association (IUVA) - A professional association interested in the development and research of ultraviolet sciences. Its members are involved in general and specialized areas of UV research, including sterilization, water purification, etc.

National Aeronautics and Space Administration (NASA) - NASA handles a vast research, development, and applications structure devoted to space science and related spinoff technologies. NASA cooperates with many agencies and contractors and disseminates a great quantity of news and educational information related to its work. Of interest to ultraviolet sensing are the many UV telescopes, photographic systems, and aerial sensing systems that have been used and are continually being developed. http://www.nasa.gov/

10.b. Print Resources

Green, A. E. S., Editor, "The Middle Ultraviolet: Its Science and Technology," New York: Wiley, 1966, 390 pages.

McEvoy, R. T., "Reflective UV Photography," IX Log 911, Rochester, New York: Eastman Kodak, 1987.

Rabalais, J. Wayne, "Principles of Ultraviolet Photoelectron Spectroscopy," New York: Wiley, 1977, 454 pages.

Radley, J. A.; Grant, Julius, "Fluorescence Analysis in Ultra-Violet Light," New York: Van Nostrand, 1954

Redsicker, David R., "The Practical Methodology of Forensic Photography," New York: New York, 1991.

Articles

Barsley, Robert E.; West, Michael H.; Fair, John A., "Forensic Photography - Ultraviolet Imaging of Wounds on Skin," *American Journal of Forensic Medicine and Pathology*, 1990, V.11(4), pp. 300-308.

Bennett, A.; Cuthill, I, “Ultraviolet Vision in Birds: What is its Function?” *Vision Research*, 1994, V.34, pages 1471-1478. Reviews evidence for UV vision in birds, discusses the properties of UV light, and discusses the functions of UV vision in birds.

Bennett; Cuthill; Partridge; Maier, “Ultraviolet vision and mate choice in zebra finches,” *Nature*, 1996, V.380 pages 433-435.

Dankner, Yair; Jacobson, E.; Goldenberg, E.; Pashin, Sergey, “Optical-Based UV-IR Gas Detector for Environmental Monitoring of Flammable Hydrocarbons and Toxic Gases,” *SPIE Proceedings,* V. 2504, 1995, pp. 35-38.

Elias, Eliadis, “UV Photography,” available on the Web. The author has experience on archaeological photography. The author describes color film and slide photography, UV light sources and many practical tips for getting the best UV mineral pictures. A very worthwhile, illustrated article that can be read on the Fluorescent Mineral Society Web site.

Emmermann, Axel, “Photographing Fluorescent Minerals,” Antwerp Mineral Club, Belgium.

Holberg, J. B.; Ali, B.; Carone, T. E.; Polidan, R. S. "Absolute Far-Ultraviolet Spectrophotometry of Hot Subluminous Stars from Voyager," *Astrophysics Journal*, V.375, pp. 716, 1991.

Holberg, J. B. "EUV Results from Voyager," *Extreme Ultraviolet Astronomy*, R.F. Malina and S. Bowyer, Editors, Pergamon Press, 1989.

Krauss, T. C., “Forensic Evidence Documentation Using Reflective Ultraviolet Photography,” *Photo Electronic Imaging*, February 1993, pp. 18-23.

Krishnankutty, Subash; Yang, W.D.; Nohava, T.E., “UV Detectors at Honeywell,” *Compound Semiconductor Magazine*, 1998, Summer, pp. 4-5.

Kunz, Y. W.; Wildenburg, G.; Goodrich, L.; Callaghan, E., “The Fate of Ultraviolet Receptors in the Retina of the Atlantic Salmon,” *Opthalmic Literature,* 1995, V.48(2), p.116.

Linick, S.; Holberg, J. B., "The Voyager Ultraviolet Spectrometers - Astrophysical Observations from the Outer Solar System," 1991, *J.B.I.S.*, V.44, p. 513.

Marshall, Justin; Oberwinkler, Johannes, “Ultraviolet vision: The colourful world of the mantis shrimp,” *Nature*, 1999, V.401(6756), pp. 873-874. Describes four types of UV photoreceptors found in the shrimp.

Pex, James O., “Domestic Violence Photography,” Oregon State Police, Coos Bay Forensic Laboratory. This describes the basics of photography and provides some practical tips on infrared and ultraviolet photography.

Rodricks, Dan, “After Nearly 54 Years, Pilot Comes Home,” *SunSpot,* 26 Dec. 1997.

Sandberg, B.; Tuominen, H.; Nilsson, O.; Moritz, T.; Little, C. H. A.; Sandberg, G.; Olsson, O., “Growth and Development Alteration in Transgenic Populus,” Fort Collins, Co.: U.S. Forest Service, Rocky Mountain Research Station, 1997, pp. 74-83.

Schneider, Russell E.; Cimrmancic, Mary Ann; West, Michael H.; Barsley, Robert E.; Hayne, Steve, “Narrow Band Imaging and fluorescence and its role in wound pattern documentation,” *Journal of Biological Photography*, 1996, V.64 (3), pp. 67-75.

Starrs, James E., “New techniques: Ultra-violet imaging - Don't go west, young man, Mississippi Court says; The "West Phenomenon" seen as less blue light than blue smoke and mirrors,” *Scientific Sleuthing Review*, 1993, V.17(1), pp. 13-14.

West, M. H.; Barsley, R. E.; Hall, J. E.; Hayne, S.; Cimrmancic, M., “The Detection and Documentation of Trace Wound Patterns by the Use of an Alternative Light Source,” *Journal of Forensic Sciences*, November 1992, V.37(6), pp. 1480-1488.

West, Michael H.; Billings, Jeffrey D.; Frair, John, “Ultraviolet Photography:Bite Marks on Human Skin and Suggested Technique for the Exposure and Development of Reflective Ultraviolet Photography,” Sept. 1987, *Journal of Forensic Sciences*, V.32(5), pp. 1204-1213.

West, Michael H.; Frair, John A.; Seal, Michael D., "Ultraviolet Photography of Wounds on Human Skin," *Journal of Forensic Identification*, 1989, V.39(2), pp. 87-96.

Journals

"Astronomical Journal," American Astronomical Society professional journal in publication for over 150 years, published monthly.

"Astronomy and Astrophysics: A European Journal," professional journal published on behalf of the Board of Directors of the European Southern Observatory (ESO).

"The Astrophysical Journal," published by the University of Chicago Press for the American Astronomical Society, three times monthly, in publication since 1895.

"Journal of Forensic Identification," a scientific publication of the International Association for Identification. http://www.theiai.org/publicationjfi.htm

"Journal of Forensic Sciences," a publication of the American Academy of Forensic Sciences. http://www.aafs.org/Journal.htm

"Journal of Optics A: Pure and Applied Optics," formerly Journal of Optics, it has been split into two publications. This journal of the European Optical Society covers modern and classical optics.

"Physics in Medicine and Biology," applications of theoretical and practical physics in medicine, physiology, and biology.

"Security Journal," international journal with contributions from many scientific disciplines related to protecting assets from loss, published in association with the American Society for Industrial Security Foundation.

10.c. Conferences and Workshops

Many of these conferences are annual events that are held at approximately the same time each year, so even if the conference listings are outdated, they can still help you determine the frequency and sometimes the time of year of upcoming events. It is very common for international conferences to be held in a different city each year, so contact the organizers for current locations.

Many of these organizations describe the upcoming conferences on the Web and may also archive conference proceedings for purchase or free download.

The following conferences are organized according to the calendar month in which they are usually held.

"Meeting of the American Astronomical Society," 196th assembly, Rochester, New York, 4-8 June 2000.

"From X-rays to X-band: Space Astrophysics Detectors and Detector Technologies," Baltimore, Maryland, 26-30 June 2000.

"The United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE)," UNISPACE was held in October 1998 and in July 1999.

"International Symposium: Adaptive Optics: From Telescopes to the Human Eye," Murcia, Spain, 13-14 November 2000.

"International Conference on Space Optics-ICSO 2000," Toulouse Labege, France, 5-7 December 2000.

10.d. Online Sites

The following are interesting Web sites relevant to this chapter. The author has tried to limit the listings to links that are stable and likely to remain so for a while. However, since Web sites sometimes change, keywords in the descriptions below can help you relocate them with a search engine. Sites are moved more often than deleted.

Another suggestion, if the site has disappeared, is to go to the upper level of the domain name. Sometimes the site manager has changed the name of the file of interest. For example, if you cannot locate http://www.goodsite.com/science/uv.html *try going to* http://www.goodsite.com/science/ *or* http://www.goodsite.com/ *to see if there is a new link to the page. It could be that the filename* uv.html *was changed to* ultraviolet.html, *for example.*

Center for Science Education - U.C. Berkeley Space Sciences Laboratory eduational site which includes resources for educators and scientists, including lesson plans, study units, and information about educational programs. The Solar Max 2000 section includes information on space flight and solar cycles and the Center for Science Education has a Light Tour guide to the optical spectrum which allows the user to input wavelengths of interest. http://cse.ssl.berkeley.edu/

Electronic Newsletter of the EUVE Observatory - A quarterly publication of the EUVE Science Archive group issued by the Center for Extreme Ultraviolet Astrophysics at Berkeley, which describes the Extreme Ultra-Violet Explorer program and scientific discoveries made since the launch of the EUVE in 1992. Issues dating back to 1991 are available in text form, current issues by email subscription request. The site also includes some prelaunch information from a NASA brochure which explains the unexplored ultraviolet radiation surveillance windows and their potential for scientific discovery. http://www.cea.berkeley.edu/~science/html/Resources_pubs_newsletter.html

Far-Ultraviolet Spectroscopic Explorer (FUSE) - This site provides background information, mission status, technical details, news, and FAQs related to the NASA-supported astronomical explorer launch in June 1999. http://fuse.pha.jhu.edu/

IUE Analysis - A Tutorial. This is a step-by-step multipage technical site providing information on the *International Ultraviolet Explorer Satellite*. It explains how to extract data from an IUE tape and conduct a simple data analysis. It was created by R.W. Tweedy and Martin Clayton in 1996 in association with CCLRC/Rutherford Appleton Laboratory, Particle Physics & Astronomy Research Council. A hard copy is also available for download.
http://www-star.st-and.ac.uk/starlink/stardocs/sg7.htx/sg7.html

Microscopy Primer - Fluorescence Microscopy. This extensive scientific site provides an introductory history and explanation of ultraviolet as it relates to fluorescence and microscopic research. It includes fundamentals, light sources, transmitted and reflected light, optimization and fluorochrome data tables. It is well-organized and -illustrated and includes Java demos. The site is managed by M. W. Davidson, M. Abramowitz, through Olympus America Inc., and the Florida State University, in collaboration with the National High Magnetic Field Laboratory.
http://micro.magnet.fsu.edu/primer/techniques/fluorescence/fluorhome.html

School of Photographic Arts and Sciences at RIT. This excellent site recounts several dozen examples of experiments with infrared, ultraviolet, and conventional photography. Professor Andrew Davidhazy has compiled these works which include suggestions for exposures, films, filters, and lenses. The author even describes how to shoot high speed images of moving bullets with an Agfa 1280 digital camera and demonstrates how ultraviolet and infrared films can be used to reveal 'hidden' writing and art forgeries or altered works. http://www.rit.edu/~andpph/articles.html

Note: If you don't enjoy typing in long Web addresses (URLs), you can access the links on the support site set up by the author for your convenience. http://www.abiogenesis.com/surveil

11. Glossary

Titles, product names, organizations, and specific military designations are capitalized; common generic and colloquial terms and phrases are not.

black light	colloquial term for a relatively inexpensive phosphor-coated mercury-tube lamp which emits light in the near-ultraviolet and causes certain things (especially whites) to appear to humans to glow
diffraction grating	a device designed to spread light into its component wavelengths, often with many finely etched parallel (or nearly parallel) lines or grooves. Diffraction gratings are used in precision instruments like spectrographs.
FARUV	far ultraviolet
FES	fine-error sensors. Instruments used in conjunction with precision instruments to aid in such tasks as navigation and aiming (as in a telescope).
fluoresce	to react to stimulation by re-emitting wavelengths that are ‘shifted’ in frequency such as ultraviolet energy being absorbed and then re-emitted in the visual spectrum
FUSE	Far Ultraviolet Spectroscopic Explorer
geocorona	a huge region of gases encircling the Earth that becomes thinner at the outer boundaries as it transitions into space. Ionization occurs in this region and the ion particles are held by the Earth’s gravity. The geocorona causes scattering of extreme ultraviolet radiation, a phenomenon that is less pronounced at night.
stains - fluorochrome	secondary fluorescence stains that are used in microscopy to ‘tag’ specific objects or substances so that they will react to ultraviolet light if they do not automatically fluoresce.
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor. One of the instruments used upon the UARS system.
UARS	Upper Atmosphere Research Satellite. An environmental satellite launched in September 1991. One of its many tasks is to provide data on the ozone layer which shields us from ultraviolet radiation.
UV	ultraviolet
UVAI	Ultra-Violet Auroral Imager. A Canadian Space Agency imager on the Russian Interball-2 satellite.
UVIR	ultraviolet infrared
UVPI	ultraviolet plume imager/instrument
UVSP	Ultra-Violet Surveillance Program
VLIM	very local stellar medium. A natural space phenomenon consisting of atoms of interstellar gas that move through the solar system as we move through our galaxy. These electrically neutral interstellar ‘winds’ scatter extreme ultraviolet radiation, creating an apparently unavoidable interference or ‘noise’ to UV detectors and telescopes.
WUPPE	Wisconsin Ultraviolet Photo-Polarimetric Experiment. A pioneer space-based polarization and photometry experiment in the UV spectrum jointly carried out with NASA.