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THE COMET COMETH

SOON after March '73 when Lubos Kohoutek, a Czech astronomer working in Hamburg, discovered his namesake-to-be, the comet Kohoutek was predicted to burst into a gleaming spectacle. Already glowing at a magnitude of +16 while still half-a-billion km from Earth, it was expected to beam bright as Venus by the time it yo-yoed past the Sun in late December.

By sheer coincidence, in November a new crew was scheduled to be lofted aboard the orbiting laboratory, Skylab. Here then arose a serendipitous opportunity to study a comet from well above the ultraviolet curtain and image-smearing shimmer of our atmosphere. This article will stress the all-out effort made by NASA to study Kohoutek from the vantage point of a stationary, manned space laboratory.

Further study of comets is surely needed. Despite the fact that several are sighted each year, our knowledge concerning them remains fragmentary. What does a comet consist of? What is its temperature? Where does it originate? What is its age? How big and massive are they? How can a canny comet like Kohoutek taunt observers into announcing that it will soon shine spectacularly then whimsically dim its light? These and other questions have baffled astronomers for generations; here was the chance to seek some conclusive answers.

Whipple's (1949) "icy conglomerate" or, less formally, "dirty snowball" model of a comet prevails but with some recent modifications. Ranging up to 200 km diameter, its nucleus is thought to consist mostly of cold, solid hydrates and free radicals of the lighter elements (hydrogen, carbon, nitrogen, oxygen) while lesser quantities of heavier elements dot the background.

A cloud of gas surrounds the nucleus. Called the coma, it consists of more volatile material sublimed from the nucleus. The tail of a comet is also composed of these volatile materials, sublimed by infrared radiation from the Sun and pumped to ionization by radiation from shorter solar wavelengths. Until 1969, those three components — nucleus, coma, tail — would have fully characterized a comet. In that year, however, instruments on the Orbiting Astronomical Observatory, 0A0-2, detected another component, a hydrogen cloud surrounding the comae on both comets visible at the time.

Careful observation of the tails of comets reveals that they are split in two. One tail consists of dust, smoothly and gently curving away from the Sun; it results from solar radiation. The plasma tail is straight. It has been explained as resulting from solar wind; atomic particles flying off the Sun sweep the ionized fragments of the tail into a turbulent swirl of filaments. Color photos of the tails of the comet Bennett show the dust tail to be yellowish, the color of small particles reflected in sunlight. Its gas tail is blue caused by emissions of the ionized molecules present.

Thus far only molecular fragments — daughters — have been discovered spectroscopically on comets. Such fragments as C_2, C_3, and CH have been identified in the nucleus. Spectra of the coma reveals neutral as well as ionized molecular fragments: H, OH, O, CN, C_2, C_3, CO^+, NH, NH_2, CH, and N_2^+. Only ionized fragments have been found in the tail: CO^+, CO_2^+ and N_2^+. As the comet approaches the Sun, atomic spectra of heavier elements such as sodium, iron, oxygen and nickel are emitted.

Parents of these fragments may well hold the key to the origin of comets. Although never identified spectroscopically, parent molecules are thought to include water, ammonia, methane as well as molecular nitrogen, carbon and carbon dioxide. Whipple has theorized that comets originate at the outer edges of the solar system. If so, their composition should be similar to that of the outer planets. If, on the other hand, comets originate outside of the solar system, their composition would resemble that of interstellar dust. In such circumstances, more complex molecules would be expected, according to theories of A.G.W. Cameron of Harvard.

Altogether, three theories have been proposed for the origin of comets. The earliest, in disfavor today, is that they are composed of effluents from volcanoes that have erupted on the planets or their satellites. Dating back to the beginning of the 19th century, this theory was postulated when it was noted that the orbits of many comets passed close to that of Jupiter. For a volcano to erupt so violently that it could eject material at escape velocity does, however, seem implausible to modern astronomers.

Whether Whipple's (solar system origin) or Cameron's (outside of the solar system) theory is correct may come from spectroscopic evidence brought back from Skylab. In addition to seeking bands of parent molecules, astronomers will be looking for atomic lines. Analysis of moon rock has helped prove that the Moon did not spin off from the molten Earth: the abundance ratio of elements on both bodies is significantly different. (Radioactive dating of rocks from the Moon also showed it to be much older than the Earth but, obviously, it is not possible to date Kohoutek remotely.)

Why are comets luminous? What is the mechanism whereby dust and gases near absolute zero in temperature are stimulated to glow? One clue to the luminosity of comets is the observation that the intensity of all comets steadily increases as they approach th Sun. It appears to be the sole source of light emission from comets. Under conditions that would result in absorption on Earth, emission occurs in the rarefied atmosphere of a comet. But the actual mechanism has not been duplicated on Earth and so can only be surmised. Is it one of resonance, the wavelength of emission being identical to the wavelength of excitation from the Sun? Or is it fluorescence in which the wavelength of emission is longer than the wavelength of excitation from the Sun?

Conclusive proof of either has yet to be demonstrated. A means for finding the answer has, however, been proposed and many measurements have been taken over the years. The method is to compare intensities of lines within well known molecular bands produced in a comet with the same lines produced in the laboratory. In 1941, Swings made such measurements and found that the intensity distribution was markedly different. He attributed these differences to the "holes" in the black-body excitation from the Sun due to Fraunhofer absorption. His calculations supported the resonance hypothesis.

Accurate measurement of intensities of lines comprising a molecular band requires a large high-dispersion spectrometer. In 1957, Greenstein pointed the 200-inch Palomar telescope at the comet Mrkos and attained excellent spectra with the spectrograph at its coude focus. Dispersion of his instrument was around 20 A/mm, about four times as good as prism spectrographs previously used.

If comets condensed from the solar nebula in the region where Jupiter formed, as many astronomers believe, then the parent molecules would be expected to include water, methane and ammonia. On the other hand, if the cometary ices represent aggregated interstellar material, then many more complex substances, including formaldehyde and the other organic molecules that radio astronomers have found in galactic clouds and regions of presumed star formation, should be present. As already mentioned, hydrogen was first detected in comets a few years ago. Lyman-alpha (1216A) photos showed that the hydrogen atoms occupied an enormous cloud, typically larger than the Sun, surrounding the visible coma.

Comets are occasionally perturbed into the inner solar system where we see them briefly as the long-period comets. Others have been captured in small orbits. These short-period comets include the famous Halley, due to return in 1986, and last seen in 1910. Kohoutek is at least, a long-period comet (10,000 to 80,000 years perhaps) and recent trajectory information raises the possibility that this is the first time that this comet has ever approached the Sun. Because Kohoutek may be in a relatively undisturbed state, the possibility of obtaining especially valuable information seems clear. The goal set for Operation Kohoutek Manager Stephen P. Maran and Science Pilot Edward G. Gibson is a comprehensive investigation of the nature and evolution of the coma and tails as the comet approaches, passes and recedes from the Sun:

1. To identify the parent molecules of the gases ("daughter products") observed in comets;
2. To determine the processes that break down the parent molecules and that form the daughter products and excite their radiation spectra;
3. To determine the physical nature and causes of transient events in the comet and their relation to solar activity and phenomena of the interplanetary plasma;
4. To measure the solar wind velocity in the inner solar system;
5. To search for helium, deuterium, molecular hydrogen and other substances that have not yet been found in comets.

Why all the fuss about Kohoutek? From early observations and calculations it appeared that Kohoutek is larger than average and would become extremely bright. This would facilitate measurements at very high spectral, spatial and time resolutions, providing maximum scientific data return. Thanks to Kohoutek's quite small perihelion distance from the Sun, observations of its interactions with the solar wind should reveal new facts about the charged particle environment well within the orbit of Mercury.

As a new or long-period comet in a highly eccentric orbit, Kohoutek may differ substantially from comets such as Encke and Halley that remain within the planetary system, bounded by the orbits of the outer planets. The short-period comets spend a greater fraction of their lives under the influence of solar particles and radiation, and are subject to planetary perturbations. On the other hand, Kohoutek in its present tour of near-solar space should develop a great coma and tails, thanks to the large amount of matter that will be liberated from the frozen nucleus.

Often, the discovery of a major comet comes only a few months before it reaches perihelion, (the closest approach to the Sun) but Kohoutek was found almost 10 months in advance. This early warning allowed systematic planning and adequate preparation for a wide variety of coordinated experiments. On the other hand, the time involved was far too short to permit development of new spacecraft. Thus the response to the challenge of Kohoutek must make use of existing systems, or ones already well on the way to completion when Kohoutek was found.

Skylab offers a unique opportunity to observe Kohoutek, thanks to its capabilities for

- long-term viewing
- near-perihelion viewing
- astronaut response
- payload optimization (Fig. 1).

The array of astronomical and solar experiments on Skylab permits the flight crew to monitor Kohoutek in the UV and visible light ranges regardless of its angular separation from the Sun. This is a critical consideration, because Kohoutek's Sun angle will not exceed 45° until January 18th. By contrast unmanned spacecraft are generally constrained to observing at either very large or very small sun angles. They can observe Kohoutek at perihelion when the comet is brightest and receives the most solar energy. At that time, ground-based observations are of very limited scope, due to scattered sunlight in the atmosphere.

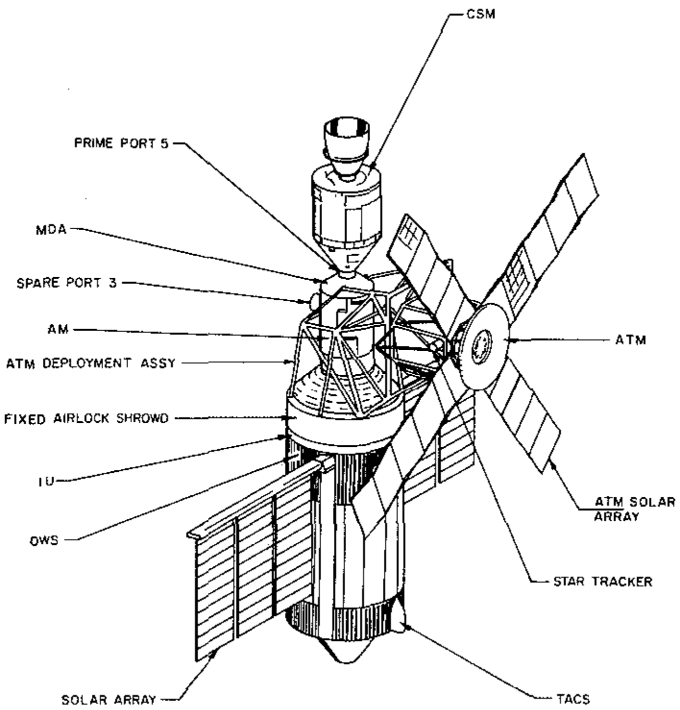


Fig.1 Skylab orbital configuration. Most of the astronomical instruments are attached to the Apollo Telescope Mount (ATM), a cylinder about 11 feet in diameter. Other abbreviations are: CSM, Crew Space Module; MDA, Multiple Docking Adapter: OWS, Orbiting Workshop; TACS, Thruster Attitude Control System.

Only on Skylab, among existing spacecraft, can mission planners change experiments or modify instruments to take advantage of an unexpected phenomenon such as the appearance of Kohoutek. One new instrument is the S201B far ultraviolet camera of T.L. Page and G. Carruthers (Naval Research Laboratory), which is needed to photograph the hydrogen cloud that will surround the head of the comet. Filters to isolate cometary emissions, a UV-transmitting lens, and extra film to support the desired high frame rates near perihelion are among the other new items sent up with Skylab.

For Skylab to achieve the greatest versatility, stability, and simultaneous pointing of many instruments, the Apollo Telescope Mount was designed. ATM can be aimed by astronauts on Skylab or from the ground, stepping motors assuring pointing accuracy of better than 2 arc-seconds. Provided originally for recording stellar and solar features, the following ATM-mounted instruments when turned on Kohoutek will be of particular importance:

White light Coronograph S052
Extreme Ultraviolet (EUV) Spectroheliometer S055A
Extreme Ultraviolet Coronal Spectroheliograph S082A
Extreme Ultraviolet Chromospheric Spectrograph S082B

White light imagery (S052 experiment) will be performed on ATM at frame rates up to four per minute, much faster than possible with OSO-7, and with higher spatial resolution. Simultaneous mapping of the coma in four UV wavelengths can be accomplished (S055), and high dispersion spectroscopy (S082) may detect the existence of helium and deuterium for the first time in a comet.

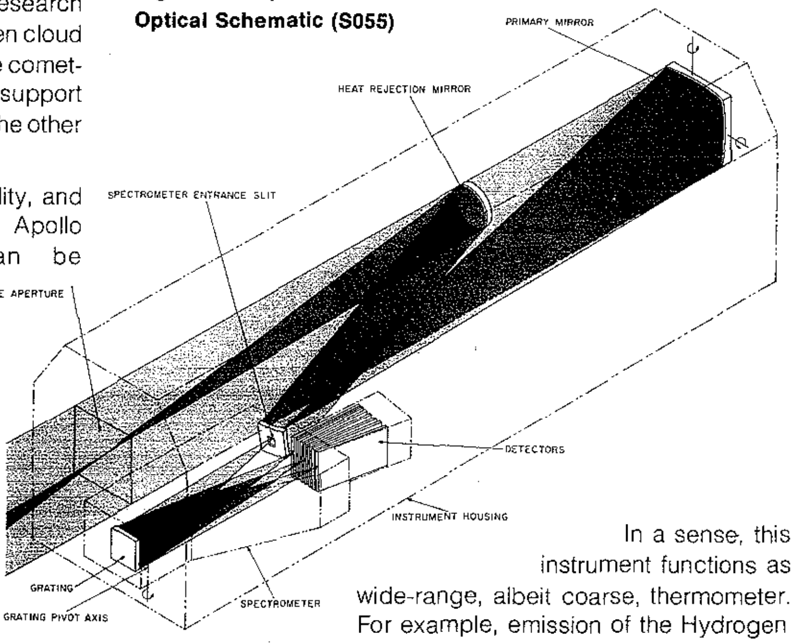
White Light Coronograph S052

Over the range 3500-7000A, this instrument is designed to photographically monitor the coronal brightness and polarization as well as study the coma of the comet. An external occulter blanks out the central portion of an object to reduce the instrumentally scattered light by about 10^{10}. The occulter includes a stepped wedge for calibrating each exposure. The experiments are being supervised by R.M. MacQueen at the High Altitude Observatory in Boulder, Col.

Extreme Ultraviolet (EUV) Spectroheliograph S055

To help us through the maze of jargon, NASA spectroscopists split the vacuum ultraviolet (VUV) into three. The EUV is the region from about 280-1350A. This instrument, designed by a Harvard College Observatory group under E.M. Reeves, is shown schematically in Fig. 2. After being reflected by a mirror which absorbs the infrared, the incoming light is reflected by a mirror at the slit to fold the light path to the primary mirror, an off-axis parabola. From here the light passes through the entrance slit to a concave grating and then to a stack of seven windowless Channeltron detectors which slice up the radiation. The concave grating may be turned on its axis a few degrees without upsetting the focus unduly, irradiating the seven detectors with different wavelengths of choice.

Fig. 2 EUV Spectroheliometer Optical Schematic (S055)



In a sense, this instrument functions as wide-range, albeit coarse, thermometer. For example, emission of the Hydrogen Lyman-alpha line at 1216A is indicative of a plasma at about 10,000K while emission of the Iron XVI resonance line at 355A requires a temperature of 3,000,000K. By judicious placement of each of the seven detectors and raster scanning of the instrument across the Sun, data is generated which is characteristic of temperatures ranging from 10,000K to 1,500,000K.

XUV Spectroheliograph S082A

Designed under the direction of R. Tousey, this Naval Research Laboratory instrument is a slitless objective grating spectrograph operating over the range adjacent to the x-ray region, 150-630A. A single concave grating with 3600 grooves/mm is rotated between two positions to select either the range 150-335A or 321-630A. In front of the film, a 0.1-micron thick aluminum filter excludes any stray radiation above 835A. Because the instrument is slitless, resultant spectra appear as a series of superimposed monochromatic images of the Sun, one for each emission line in the wavelength range chosen. This instrument is particularly well suited for the study of small intense features such as flares on the Sun. These appear well separated in hundreds of emission lines.

Ultraviolet Spectrograph S082B

Truly high-resolution spectra will be taken from atop Kitt Peak with the 300-foot long McMath solar telescope. Fitted with a huge (35 x 45 cm) replica grating, its accessory spectrograph is capable of resolving lines 0.003A apart. Such resolution is needed to examine rotational lines of elements like oxygen for temperature measurements.

Somewhat more modest in size but much more sophisticated is NRL's ultraviolet spectrograph mounted on the ATM. Though hardly a match for the resolution of the McMath instrument, its resolution is still an imposing 0.04A. Two novel pre-dispersing gratings, ruled in 10 strips of differing dispersion approximating a continuous change, serve to reduce astigmatism and so increase effective speed. Instead of light being wasted in long tails characteristic of so many ultraviolet spectrographs, this light is directed toward the center of each line, reinforcing it.

The main concave grating on this spectrograph has a focal length of 100 cm and is ruled at 600 grooves/mm. In addition to photographic readout, an image dissector helps the astronauts aim the spectrograph at a particular feature. The resulting video display serves two other purposes: Several instruments are hooked to the display to permit them to be aimed at the same point Thus, it is possible to obtain simultaneous information at the hydrogen-alpha line, the normal UV, the EUV and the XUV. Its third purpose is to operate a servo system which controls the primary mirror of the spectrograph so that spectra, say, across the limb of the Sun can be taken automatically.

The ATM X-ray experiments are not listed since the prospects for detectable cometary radiation in this wavelength range seem poor. However, a major solar flare could induce fluorescence in Kohoutek, leading to a positive result with the S054 x-ray spectrographic telescope.

For a few days just before and just after perihelion, the ATM capabilities will be somewhat reduced due to the larger Sun angles of the comet. During these intervals, however, Kohoutek is too close to the Sun to be observed through the workshop's anti-solar airlock. These are the times for the astronauts to conduct EVA operations. The instruments operated during space walks would be the T025 coronagraph and the new S201B far ultraviolet camera. The T025 observation requires pointing the instrument fairly accurately toward the Sun. For the S201B photography, the Skylab must be maneuvered so that the camera is shadowed by the ATM solar array.

At the airlock, the instruments, including S201B, will operate well before and well afer perihelion. An articulating mirror system will be mounted on the airlock and a roll of the spacecraft of up to 90° will be made. Implementation of about 24 of these rather major Skylab maneuvers during the mission are being considered. Ordinarily, no more than one would be performed per day.

Comets are known for their unpredictability — for sudden flarings and shape changes. Such transient events are expected to occur in Kohoutek during the Skylab 4 mission and the astronaut crew will react by bringing appropriate instruments into play and increasing the camera frame rates for brief intervals, or taking other special measures.

All of the ATM instruments are operated remotely by the astronauts from the console in their Orbital Workshop (OWS), comfortably warmed and thoughtfully provided with a breathable atmosphere. But the ATM has its limitations. To be pointed anywhere requires the entire space vehicle to be turned. To point one instrument separately from the others requires an extension mirror poking outside of the port, a mirror which, though articulated axially and laterally, limits the field of view.

For these reasons several instruments have been designed for the astronauts to operate "outdoors," in a near-vacuum at temperatures approaching absolute zero: S019, Ultraviolet Stellar Spectrograph; S063, Ultraviolet Air-glow Camera; S183, Ultraviolet Panorama Camera; and T025, Multi-filter Coronagraph. The S019 instrument will obtain ultraviolet spectra that will be studied to determine the composition of the comet nucleus and the effects of the solar wind. The S063 camera will obtain ultraviolet and visible color photographs which can help determine the distribution of selected constituents in the coma and tail. The S183 photometric data will help determine the distribution, lifetime and the effect of hydroxyl in the coma. The T025 coronagraph's ultraviolet and visible light photographs should yield information on the particulate production and distribution in the coma and tail. Two of these have been singled out as particularly powerful and impressively designed.

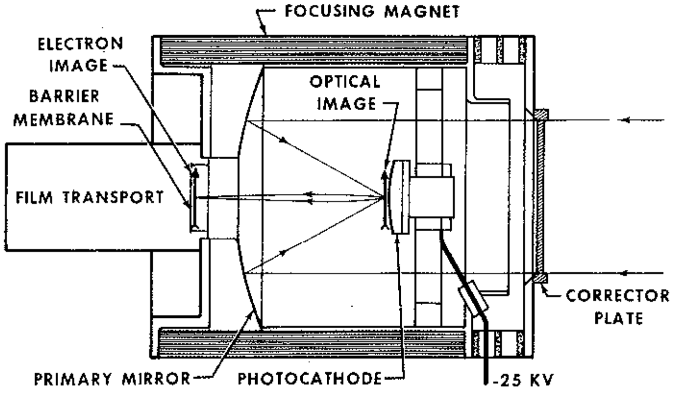


Fig. 3 Far Ultraviolet Electronographic Camera (S201B)

Far UV Electronographic Camera S201B

One of the most intricate instruments aboard Skylab is simply a camera incorporating a couple of interchangeable filters. But to record the extreme ultraviolet while operating in outer space, the camera becomes exceedingly complex.

As shown in Fig. 3, the camera is a marriage of optical and electronic imaging techniques. Incoming light first passes through a corrector plate which also seals the vacuum inside of the camera. Next the light passes through one of two filters. Consisting of deposited layers of metals, these filters isolate, respectively, the 1216A line for admitting hydrogen emissions or the region 1304-1356A for admitting and photographic molecular oxygen bands. An automatic mechanism inserts first one and then the second filter and produces a series of four graded exposures from 1 to 15 seconds in hydrogen light followed by four graded exposures from 3 to 107 seconds in oxygen light.

Between the filters and the film is an ingenious electro-optical system. A 5-inch diameter mirror concentrates the filtered light on a photocathode. This, in turn, generates electrons, accelerating them toward the photographic film and in so doing intensifying the image many-fold. A membrane composed of an evaporated layer of aluminum on Mylar separates the film from the main body of the camera.

The camera may be operated either inside an airlock aboard the Skylab or, outdoors, mounted on the ATM truss. Inside, its field of view is restricted to 7° and pointing direction limited by an articulated mirror system. Outside on a special mount, the view is expanded to 20°. From here the astronauts can point the camera in any direction except toward the Sun which would immediately burn a hole in the photocathode. Two film packs (350 frames) have been reserved for photographing Kohoutek while a third pack will photograph the Earth's atmosphere, including tropical airglow oxygen bands, polar aurorae, and the very thin hydrogen atmosphere some experimenters believe exists on the Moon.

Earthbound scientists will envy the evacuation technique for the camera. Its canister is simply vented for 30 minutes. This is done to prevent internal electrical arcs from fogging the film. Since moisture degrades the photocathode, the camera must be kept under nitrogen when not evacuated.

The strong magnet for focusing the electronic image presents another problem. Should a steel tool or other magnetic object come within 10 feet of the instrument while it is operating the object could distort the magnetic field and degrade the focus. The focusing field is, in fact, so strong that it can easily pull free-floating magnetic objects from up to 10 feet away, causing them to crash into the sealed container. The astronauts' watches have been found to speed up when brought closer than 3 feet to the canister. Luckily, when removed they return to normal.

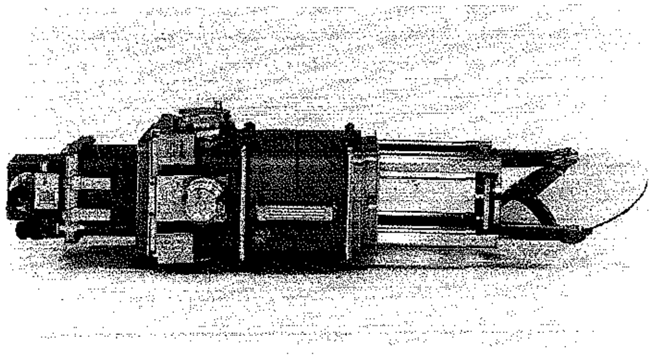


Fig. 4 View of Articulated Mirror System with the S019 Ultraviolet Spectrograph attached.

Ultraviolet Stellar Spectrograph S019

Fig. 4 is a photograph of the objective prism spectrograph terminating in its articulated mirror which, extended through a port in Skylab's airlock, permits examination of a 30° band in the sky. Before Kohoutek, the primary objective of this spectrograph was to study the 1300-3000A region of stars, its resolution of 2A at 1500A being 5 times better than that in the first Orbiting Astronomical Observatory. Early type stars which exhibit strong emission and absorption band in this region are of particular concern. The AOA studies showed anamolous intensities in these stars. The S019 instrument is capable of making exact intensity and intensity ratio measurements which data can then be compared with theory. Small differences between predictions and observations will be used to correct and improve our knowledge of the temperature, ages, compositions, and atmospheric structures of these stars; large differences may indicate completely unexpected physical phenomena of special astrophysical interest. Pointed at Kohoutek, the spectrograph should be able to yield similar information on the comet.

Skylab is equipped with several more specialized cameras and spectrographs which, though originally intended for other observations, will be trained on Kohoutek, too. There are two Hydrogen-alpha (6563A) telescopes. One is ancillary to the UV Spectrometer-spectroheliometer and will provide simultaneous photographs in red light for comparison purposes. The second Hydorgen-alpha telescope is a 6.5" diameter, f/30 Cassegrain instrument that will feed its information to a Vidicon camera. Instead of a normal interference filter, the half-width bandpass of which would be comparatively poor, the key element in this telescope is a Fabry-Perot Etalon with a half-width of 0.7A.

Then there are two specialized UV cameras. One is designed for the study of airglow. Installed at the anti-solar position in the airlock of Skylab, the instrument will produce UV and visible color photographs for determining the distribution of select constituents in the coma and tail of the comet. It is essentially a 35-mm camera with ultraviolet-transmitting optics. Interference filters are available for isolating specific spectral regions such as around 2500A for oxygen bands, 3914A for ionized nitrogen, 5577A and 6300A for atomic oxygen.

The second is a UV Panorama Camera. This will obtain photometric data for studying the distribution, lifetime and the effects of the hydroxyl radical in the comet. It is essentially a double camera, providing two simultaneous images at different spectral bands. These may be selected since the dispersion element is a diffraction grating.

But even more important than the highly sophisticated state-of-the-art devices are the trained men aboard Skylab. They provide that one ingredient essential to all successful experiments: human judgment, or in NASA jargon, "astronaut response capability." A few months from now, Stephen P. Maran, Goddard Space Flight Center, Beltsville, Md. should be able to reveal extensive information about this comet. As manager of Operation Kohoutek, he will coordinate the mass of data to be accumulated not only from Skylab but from sounding rockets and high-flying jets, and from dozens of observatories spotted throughout the world.

Leo Esaki Shares Nobel Prize in Physics

Leo Esaki, now an IBM Fellow at its Thomas J. Watson Research Center in Yorktown Heights, is one of the winners of the Nobel Physics Prize for his work in tunneling. This research was done in the '50s while he was employed by the Sony Corporation and as part of his thesis at the University of Tokyo. By preparing exceedingly narrow p-n junctions with heavily-doped semiconductors, he was able to provide a clear demonstration of Zener tunneling in the backward direction. Reducing the junction width even further to less than 150A he was able to demonstrate forward tunneling. Putting the theoretical and practical ends together, he went on by correctly interpreting the phonomenon which gives rise to the familiar negative resistance curve of the tunnel diode.

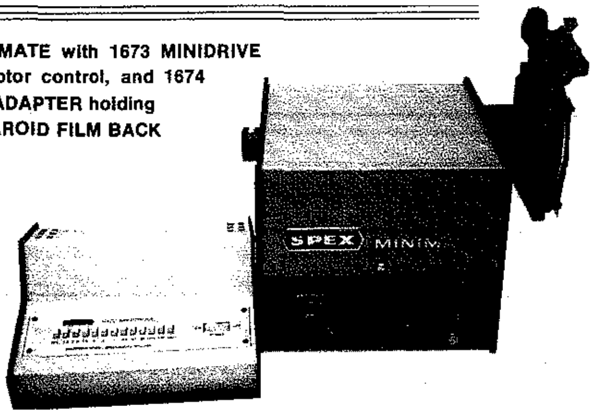
One of Dr. Esaki's present projects is in Raman investigations of pseudo-binary alloys which have already shown great potential as semiconductors. Room-temperature injection lasers of these alloys may turn out to be the long-awaited means for transmitting messages through fiber optics bundles instead of wires.

The composition of one class of such alloys is $Ga_{1-x}Al_xAs$. Depending on the initial blend of GaAs and AlAs, the concentration of x can be made to vary considerably in the final mixed crystal with attendant wide differences in properties. The concentration can readily be determined by Raman spectroscopy. The position of one of the Raman focal modes at around delta-292 cm^{-1} shifts downward by about 7 cm^{-1} for an x value of 0.2 (20% aluminum). Quantification by conventional chemical analytical techniques is quite difficult.

Esaki's main interest is the preparation and study of semiconductors consisting of alternate layers of very thin Ga As and $Ga_{1-x}Al_xAs$ alloys. If the period of alternation of these thin films is less than the electron mean free path, the material will have what is called an "electonic superlattice." The interaction of electron waves with the superlattice potential should make possible a class of high-speed electronic devices, such as microwave oscillators, with essentially no upper frequency limits.

Esaki points out that laser-Raman spectroscopy is an ideal tool for the study of such ultrathin epitaxial layers. Most other analytical tools penetrate substances under analysis to a distance of at least 1 micron. By contrast, penetration of a laser beam can be as short as 500A, 1/20 of that distance.

1670 MINIMATE with 1673 MINIDRIVE stepper-motor control, and 1674 CAMERA ADAPTER holding 1628 POLAROID FILM BACK



HARD-TO-RESIST GIMMICKS

MICROMATE ORDER-SORTA: a glass filter that flips into position at 400 nm and stays put to the top of the wavelength scale at 800 nm, blocking second and third orders, so that all emerging light is as read.

But if you cringe at such flippancy, or your application does not require a filter, read on. We have not defaced the simplicity of our MICROMATE Spectrometer. The ORDER-SORTA is a take-it-or-leave-it accessory. The 100-mm MICROMATE, in its rugged cast aluminum housing, will continue to combine these hard-to-beat features:

Hard-to-increase optical throughput, f/2.5
Hard-to-improve resolution, 2 nm
Hard-to-find astigmatism, coma and scattered light
Forbidden-to-duplicate optical layout (patented)
Easy-to-read 3-digit nm counter
Easy-to-use, slits-adjust reads in nm bandpass

Down-to-earth price, $630 (plus $75 for the #1696 Order-Sorta). We can hardly wait for you to ask about the novel combination of entrance and exit slit in a straight-through path. Just drop a hint and we'll send the literature flying.

or **Would you rather take a picture with our MINIMATE?**

A CAMERA ADAPTER can change places with the exit slit of this 220-mm spectrometer and accommodate either Polaroid or standard 4" x 5" film or plates.

GC/OE

Introduction

Mention GC/IR and GC/MS to any analytical chemist and you elicit warm praise for the powerful combinations of these three basic techniques. Do the same for GC/OE (Gas Chromatography/Optical Emission) and you are likely to get a blank look in return. Yet the GC/OE method of analysis has at least the same potential as the other techniques mentioned. A Spex instrument under development takes full advantage of the possibilities.

GC/OE is the combination of gas chromatography with Optical Emission Spectroscopy that easily detects all of the non-metallic elements normally found in organic compounds (and many of the metallic ones as well) unambiguously and quantitatively. It can be utilized to detect elemental ratios and thus elucidate empirical formulae.

Operation

The sample, eluting from the GC column is split so that one portion is directed, as usual, to a TC or FID in the chromatograph; the other portion flows through a capillary tube which contains a microwave-sustained helium plasma (and a small flow of scavenger gas to prevent buildup of deposits on the wall of the capillary). Atomic emission spectra of each element in the effluent are then recorded by passing the radiation through a diffraction grating spectrometer and detecting with a PM tube and associated electronics. At the present time the system is set up as a tunable single element determinator; however, it is being expanded to detect more than one element simultaneously.

Range & Detection Limits

The dynamic range of the system is approximately four decades with detection limits for some typical elements as follows:

C - 0.8 ng
H - 0.3 ng
F - 0.6 ng
Cl - 0.6 ng
Br - 1.2 ng
I - 0.5 ng
S - 0.9 ng
P - 0.9 ng

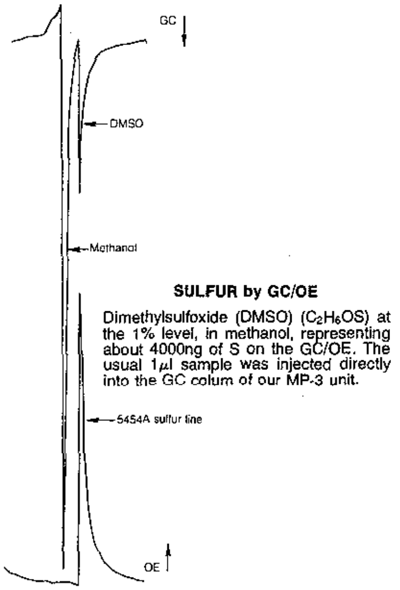
Experimental Results

Below are a number of traces obtained on the Spex prototype instrument which illustrate the selectivity and sensitivity of the system.

The instrument can be interfaced to other gas chromatographs although in the case of the prototype it is interfaced to our MP-3-Multipurpose Thermal Analyzer-Gas Chromatograph to provide the greatest versatility. Thus, solid samples can be analyzed directly without resorting to solution techniques, extractions, etc.

Applications

When it was first invented, the laser was described as a solution awaiting problems. This is not quite so with GC/OE; already, a number of important applications have developed.

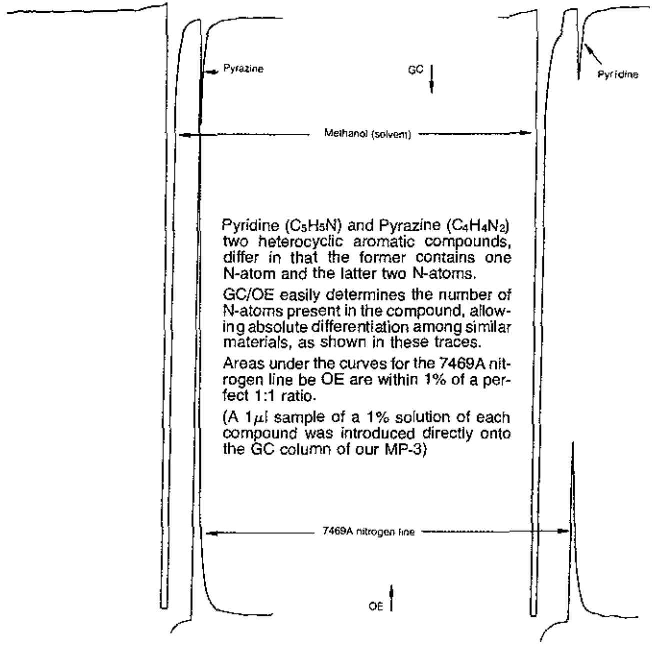


SULFUR by GC/OE

Dimethylsulfoxide (DMSO) (C_2H_6OS) at the 1% level, in methanol, representing about 4000ng of S on the GC/OE. The usual $1\mu l$ sample was injected directly into the GC colum of our MP-3 unit.

SEE
GC/OE at
Booth 616
Cleveland
Mar 4-8

NITROGEN as a major constituent by GC/OE



Pyridine (C_5H_5N) and Pyrazine ($C_4H_4N_2$) two heterocyclic aromatic compounds, differ in that the former contains one N-atom and the latter two N-atoms.

GC/OE easily determines the number of N-atoms present in the compound, allowing absolute differentiation among similar materials, as shown in these traces.

Areas under the curves for the 7469A nitrogen line be OE are within 1% of a perfect 1:1 ratio.

(A $1\mu l$ sample of a 1% solution of each compound was introduced directly onto the GC column of our MP-3)

Some of these are:

1. Pesticide residue analysis — Phosphorus is determined from vegetable surfaces at levels of 0.5 ppb. H.A. Moye, Anal. Chem., 1441, 1967.
2. Differentiating substances with almost identical GC retention times. Pyrazine can be distinguished from Pyridine through the intensity of nitrogen emission.
3. Determination of halogen-containing impurities in solvents. One example is methylene dichloride in solvents.
4. Determination of dissolved oxygen in hydrocarbons.
5. Determination of metal chelates such as Al, Be, Cr.

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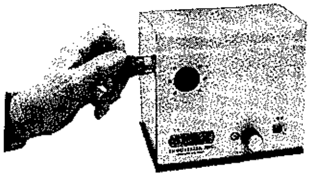

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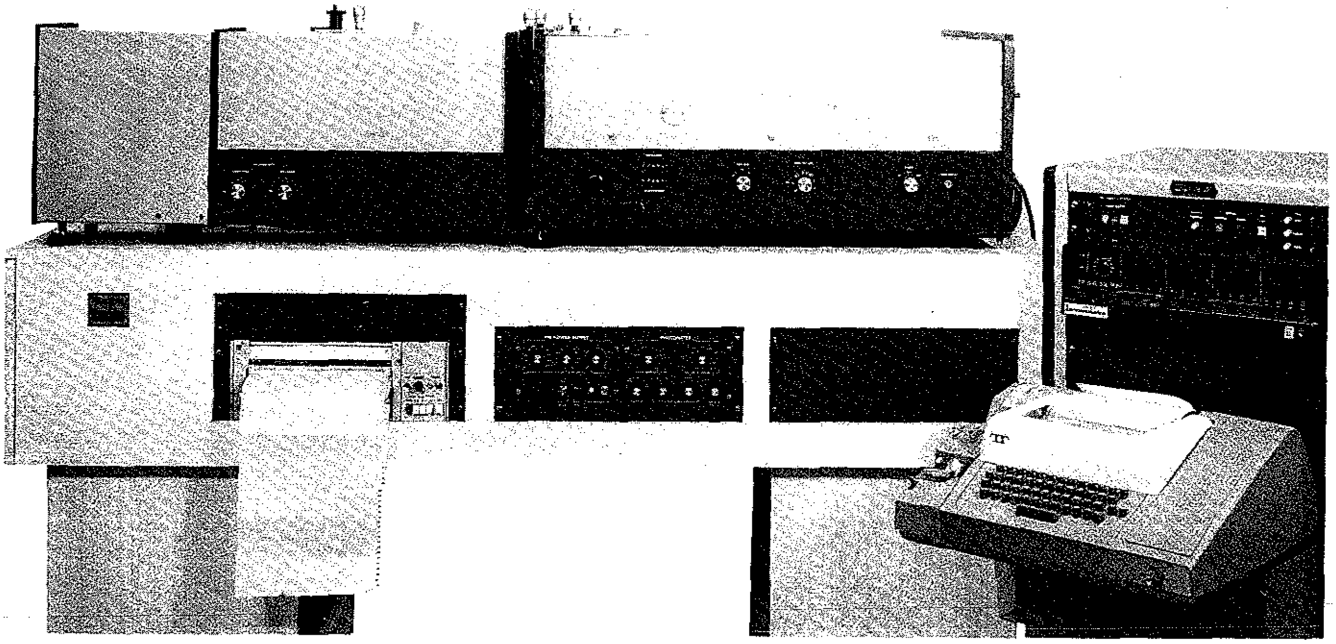

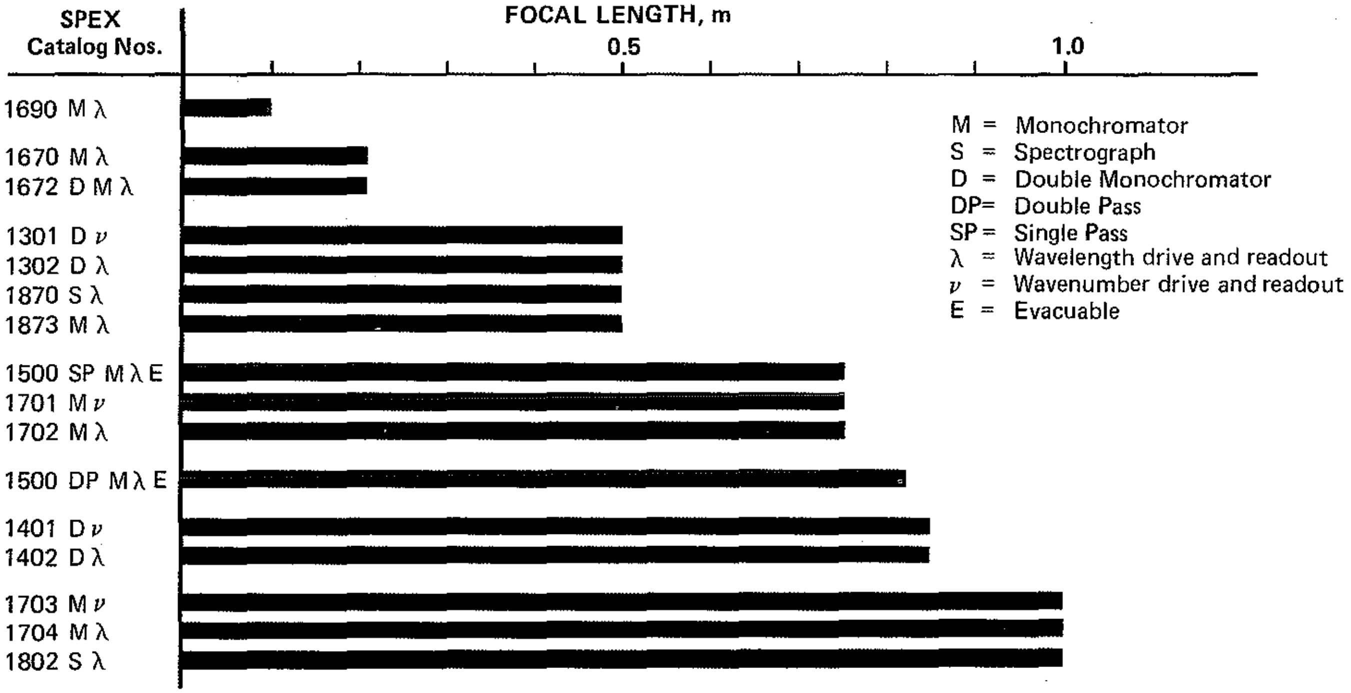

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