Astrophysics Branch Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

T. Greene, Chief SSA

Ices in Kuiper Disk Objects

Dale P. Cruikshank, Yvonne J. Pendleton, Robert H. Brown and Glenn J. Veeder

Beyond the planet Neptune lies a disk-shaped distribution of small, primitive bodies called the Kuiper Disk. This region is named after the prominent astronomer, Gerard P. Kuiper, who predicted its existence in 1951. Kuiper speculated that such a population of objects must exist in order to explain the orbital characteristics of the short-period comets (periods less than 200 years) that currently come to the inner part of the Solar System at the rate of about 10-20 per year. The first of these 'trans-Neptunian' objects was found in 1992, and about 80 of them have been detected as of January 1999. Their dimensions are approximately 50 to 500 kilometers; much smaller ones surely exist but are too faint to be found with telescopes presently available. Because these bodies are implicated in the transport of volatiles and complex organic materials to the pre-biotic Earth and other terrestrial planets, Ames scientists have conducted astronomical observations to establish their compositions.

The trans-Neptunian objects are expected to be composed of the same materials that make up the short-period comets, which are typically one-third ices of frozen water, carbon dioxide, carbon monoxide, and others, one-third silicate dust, and one-third complex organic solid material. Remote sensing measurements of these bodies to establish their compositions and to search for variations among them are a challenge for presently available astronomical techniques; only the largest 15-20 bodies can be observed with infrared spectrometers on the world's largest telescopes.

A new Ames spectroscopic study with the Keck 10-meter telescope on Mauna Kea, Hawaii, is showing that the trans-Neptunian objects are diverse in their surface compositions. At least one (designated 1993 SC) shows evidence for hydrocarbon ices (possibly methane), while others show the spectroscopic signature of frozen water. In addition, the strong red color of the surfaces of several of these bodies is evidence for the presence of organic solid material that has been produced in interstellar space and further processed since incorporation into the Solar System. The color and spectral properties of the red trans-Neptunian objects are closely matched by "tholins," which are complex organic materials synthesized in the laboratory by the irradiation of simple gases and ices with ultraviolet light and charged particles.

The results of the spectroscopy of ten trans-Neptunian objects, their 'cousins' the Centaurs (bodies in temporary orbits that cross the paths of the major planets), and the irregular outer satellites of the major planets shows that they are compositionally diverse. The planet Pluto and Neptune's satellite Triton probably represent two of the largest bodies in the Kuiper disk population, and each of these two bodies has a complex icy surface and a tenuous atmosphere. The Ames study includes remote sensing observations of all these objects, in search for unifying threads of evidence that may link their compositions with the comets and other bodies that have impacted Earth and the other planets, bringing volatile and organic matter from the most distant reaches of the Solar System. ❏

Point of contact: Dale P. Cruikshank
(650) 604-4244
cruikshank@ssa1.arc.nasa.gov

AIRES - A Facility Spectrometer for SOFIA

Edwin Erickson, Michael Haas, and Sean Colgan

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is an airborne telescope facility currently under development and construction. A Boeing 747 will be equipped to carry a 2.7-meter telescope to be operated altitudes up to 45,000 feet. Thus, SOFIA will enable astronomical observations with unprecedented angular resolution at infrared wavelengths that are obscured from the ground. It is being developed jointly by NASA and DLR, the German Aerospace Center. It will be based at Ames Research Center and will begin operations in 2002.

An Ames team led by Ed Erickson, Mike Haas, and Sean Colgan were one of six American groups selected by peer review to build a focal plane instrument for early observations with SOFIA. The Ames instrument, AIRES, the Airborne Infrared Echelle Spectrometer, will be a general-purpose facility instrument. After development by the Ames team, it will be operated for the science community by the Universities' Space Research Association (USRA), NASA's prime contractor for SOFIA.

AIRES will operate at far infrared wavelengths, roughly 30 to 400 times the wavelengths of visible light. This means it will be ideal for spectral imaging of gas-phase phenomena in the interstellar medium (ISM), the vast and varied volume of space between the stars. Measurements of far infrared spectral lines with AIRES will probe the pressure, density, luminosity, excitation, mass distribution, chemical composition, heating and cooling rates, and kinematics in the various gaseous components of the ISM. These lines offer invaluable and often unique diagnostics of conditions in such diverse places as star forming regions, circumstellar shells, the Galactic Center, starbursts in galaxies, and the nuclei of active galaxies energized by accretion of material on massive black holes. AIRES will provide astronomers with new insights into these and other environments in the ISM. It will also be useful for studies of solar system phenomena such as planetary atmospheres and comets, and a variety of other astronomical problems.

The AIRES design incorporates what will be the world's largest monolithic (echelle) grating (see Figure 2), and four different types of infrared array detectors operating at temperatures between 2 and 8 degrees Kelvin. In the past year the team has demonstrated that this cryogenic optical system can be designed to achieve the theoretically limited performance required by AIRES. Development of a comprehensive data system and associated software system, which will permit effective utilization of AIRES, is well underway. ❑

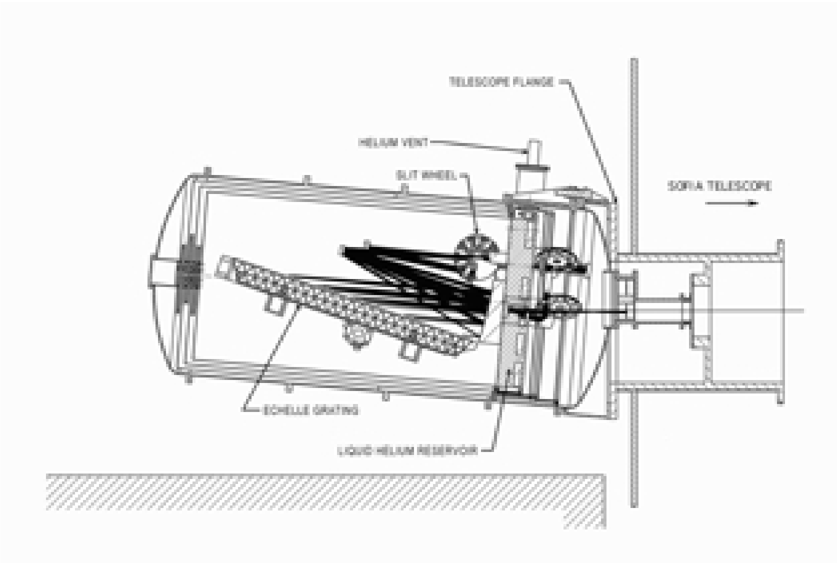

Figure 2. The AIRES design concept is shown; the echelle grating is roughly 42 inches long.

Point of contact: Edwin Erickson
(650) 604-5508
erickson@cygnus.arc.nasa.gov

Calculation of Instrument Functions

David Goorvitch

Point of contact: David Goorvitch (650) 604-5502
dgoorvitch@mail.arc.nasa.gov

In many situations, analysis of a spectrum is contingent on knowing the response of the measuring instrument. One popular analytical method is to obtain these instrumental parameters by iteratively fitting a theoretical spectrum to the observed spectrum until they match. This method involves convolving the theoretical spectrum with the response function of the measuring instrument. The iteration process is usually a nonlinear process and is repeated many times to reach convergence of the theoretical and observed spectra. Since the instrument response function is convolved with the theoretical spectrum in each measurement, accurately knowing the response function can eliminate potential errors in the derived spectroscopic information. A new Ames study has shown how instrument response functions can be calculated more rapidly and accurately.

The calculation of a response function, more commonly called the instrument function, is complicated even in a simple case. The complication arises when the instrument function is made up of several effects. For example, the mathematical instrument function for the Fourier transform spectrometer, even for the unapodized case, is composed of a rectangle representing the physical travel of the instrument and a 'sinc' function (equal to the sin function divided by its argument) representing the collimation of the beam. Each of these functions is also well described in the frequency realm of the measured spectra. However, the composite mathematical instrument function results in an integral of a sinc function between finite limits. This integral can not be represented as a simple analytical function, so it must be approximated.

A new Ames research effort has attacked this problem by transforming it into the orthogonal physical space where its equations can be solved analytically or by a simpler approximation. Transformation to an orthogonal space is facilitated by the convolution theorem, which states that the convolution of two functions can be obtained by multiplying their transforms and then back transforming to the original space. In addition, the convolution theorem has the added advantage that calculating the Fourier transform and inverse Fourier transform is faster than computing the direct calculation of the convolution. The computing time it takes to perform a transformation using the fast Fourier transform is proportional to $N \log_2 N$, while the direct convolution time is proportional to N_2. Thus this new technique has a potential savings in computational time of which is proportional to $N/\log_2(N)$ for N measurements in each spectrum.

This study has shown the power of using the convolution theorem in calculating instrument functions in several examples including an apodized Fourier transform spectrometer which is illuminated with uncollimated radiation and whose mirrors are misaligned. The instrument functions in these cases are far from ideal, but the new technique was successful in calculating them quickly and accurately. ❑

Organic Molecules in Comets

B.N. Khare, S.J. Clemett, R.N. Zare, and D.P. Cruikshank

Point of contact: Bishun Khare
(650) 604-2465

Comets are the oldest, most primitive organic-rich bodies in the Solar System, and they have preserved in them the earliest record of material from the nebula in which the Sun and the planets formed.

Simulations of the organic molecules in comets are undertaken in the Cosmochemistry Laboratory at Ames. Mixtures of ices comprised of various combinations of simple molecules are irradiated with sources of energy such as ultraviolet light and charged particles. This results in the formation of colored solids of low volatility which, when analyzed reveal a complex array of polymers, C_1 through C_5 hydrocarbons, nitriles, alkanes, alkenes, and nitrogen heterocyclic compounds. This colored solid material is collectively termed 'tholin.' The complex optical indices of this solid material are determined over a wide range of wavelengths, so that those indices can be used in mathematical models of the spectra of comets, planetary satellites, and other bodies of the Solar System. Tholins formed by irradiating various initial combinations of ices (and gases) appear to be uniquely capable of providing the coloration and spectral properties observed telescopically in many Solar System bodies.

In a particular experiment designed to simulate the solid organic material in comets, Ice Tholin I was produced by the irradiation of a mixture of H_2O (water) and C_2H_6 (ethane) ices present in a 6:1 ratio. Analysis of the solid residue produced by the irradiation was accomplished with the newly developed technique of microprobe two-step laser mass spectrometry (L^2MS) in the laboratory of R. Zare (Stanford University). The analysis revealed for the first time the presence of polycyclic aromatic hydrocarbons (PAHs) in tholins. A PAH-containing Ice Tholin II (see figure 3) was produced from a more complex mixture of ices made of H_2O, CH_3OH (methanol), CO_2 (carbon dioxide), and C_2H_6 (ethane) in the ratio 100:20:4:1. This mixture of four ices closely simulates the composition of comets.

In Ice Tholin I the PAHs are not distributed uniformly, but are found in microscopic concentrated regions where the concentration is greater than 300,000 parts per million. The PAH distribution in Ice Tholin I is characterized by simple 1-, 2-, and 3-ring PAH species with extensive side-chain alkylation (replacement of -H with $-(CH_2)_nH$). In Ice Tholin II, the PAHs are distributed more uniformly; naphthalene and its n=1 and n=2 alkylated homologues dominate.

The detection of PAHs in laboratory simulations of comets opens the pathway to the interpretation of PAHs found in the comet particles that are collected in the Earth's high stratosphere (interplanetary dust particles), and those collected at Comet P/Wild 2 and returned to Earth by the Stardust mission early in the next Century. ❑

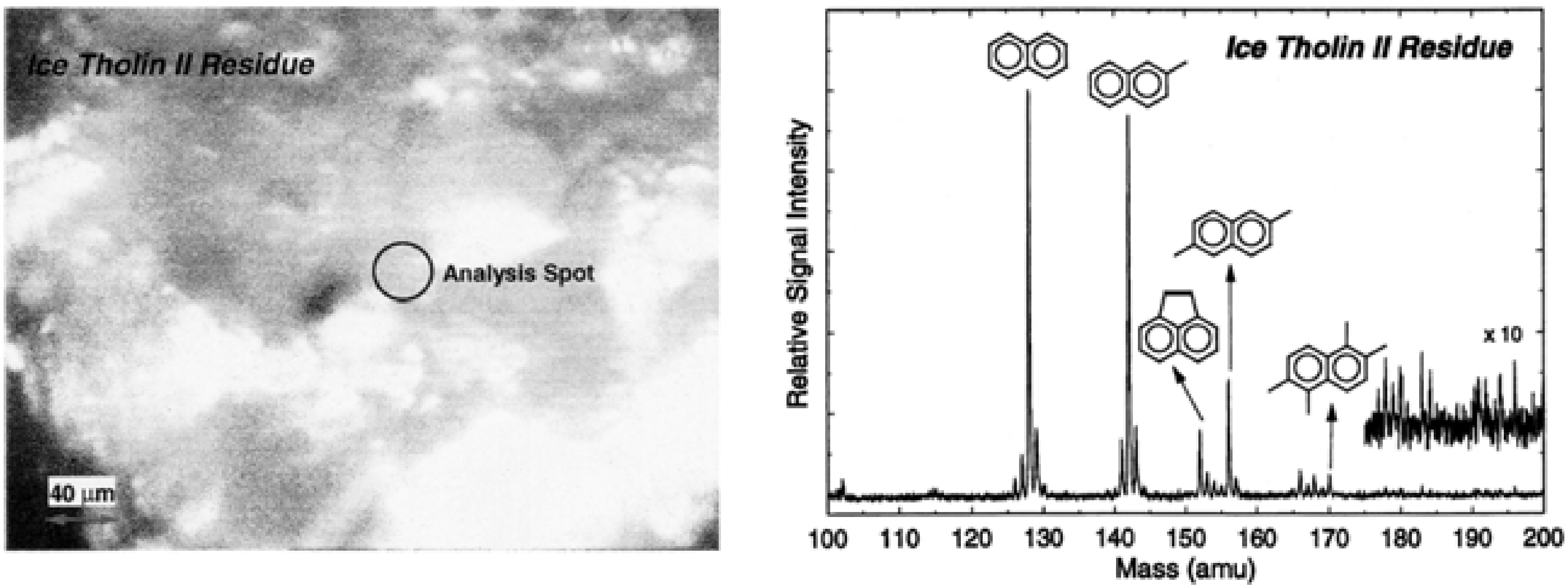

Figure 3. Photomicrograph of a film of Ice Tholin II, showing the area in which the two-step laser technique detected polycyclic aromatic hydrocarbons.

A Testbed for Detection of Earth-Sized Planets

David Koch, William Borucki, and Larry Webster

Detection of Earth-size planets beyond our solar system is one of the fundamental goals identified in NASA's Strategic Plan. Only in recent years have planets of any size been detected beyond our solar system. Those found to date are all on the order of the mass of Jupiter or larger. The challenge is to find planets which are 30-600 times less massive than Jupiter, i.e., one-half to ten times the mass of the Earth. The concept for a space-based instrument to accomplish this goal has been developed and named the *Kepler Mission*.

If most stars like the Sun have planetary systems similar to our own, it is estimated that this mission would discover on the order of 500 habitable planets. The capabilities have been set high, so that if no such planets are detected this 'null result' would have a profound impact on our understanding of planet formation. The mission concept is to continuously and simultaneously monitor the brightness of 100,000 solar-like stars. The 'light-curves' for each star are analyzed for fluctuations due to transits of Earth-size planets. Light-curves measured during three transits across a star, all with consistent period, brightness change, and duration, will provide a rigorous method of detection and confirmation. The size of a planet can be calculated from the relative brightness change that occurs during transit, and the orbital size can be calculated and the planet's temperature estimated from the period.

At the heart of the proposed Kepler Mission is an instrument containing an array of charged-coupled-device (CCD) detectors for measuring stellar brightness. These devices are similar in principle to those used in video cameras but are much larger in size and more sensitive. The critical property of the CCDs is their relative photometric precision, that is, how well they can measure the brightness of a given star relative the average brightness of the many thousands of stars nearby.

To demonstrate this, a testbed is being constructed which will utilize a CCD similar to that being proposed for the space-based mission, however, the test will view a star field with a ground-based instrument. The objective of the current testbed project is to demonstrate the technological readiness of the mission. Unfortunately, distortions caused by the atmosphere prevent measuring to the relative precision required which is 1 part in 100,000; the best photometric precision that has been achieved from the ground is only somewhat better than 1 part in 1,000. This is why the planet-detection goal cannot be achieved with a ground-based instrument looking through the atmosphere. To overcome this problem in the test and demonstrate that the CCDs do have the inherent relative precision required, an instrument is being constructed in which a calcite beam splitter is placed in front of the CCD. This produces a pair of identical images on the CCD. The photometric capability of the CCDs will be demonstrated by comparing the ratios of the brightness for each star pair. The instrument for performing these measurements is currently being constructed. Successful completion of the test should demonstrate the technology readiness for a space mission.

For further information on the proposed *Kepler Mission*, see the world wide web at: http://www.kepler.arc.nasa.gov ❑

Point of contact: David Koch
(650) 604-6548
dkoch@mail.arc.nasa.gov

The SOFIA Water Vapor Monitor

Thomas L. Roellig, Robert Cooper, Anna Glukhaya, and Michael Rennick

As part of the development of the Stratospheric Observatory for Infrared Astronomy (SOFIA), scientists at Ames Research Center have developed an instrument that will measure the amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor is critical for proper calibration of the observed emission. The design of such a water vapor monitor is now complete.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line of sight at a 40° elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. A picture of this water vapor line as it would appear from SOFIA, together with the measurement bands of the SOFIA water vapor monitor, is shown in Figure 4.

The SOFIA water vapor monitor must provide knowledge of the amount of precipitable water vapor to 2 microns or better, 3-sigma, measured at least once a minute, along the telescope line-of-sight. In addition, knowledge of the water vapor to the zenith is needed to equivalent accuracy. Water vapor levels along other telescope lines-of-sight or to the zenith will then be determined by calculation from the 40° measurements. This imposes more restrictive accuracy requirements on the water vapor monitor sensitivity, namely 1.33 microns precipitable, 3-sigma, measured at least once a minute. The monitor hardware consists of three physically distinct sub-systems:

1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window.

2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A/D converters, and a RS-422 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and the water vapor monitor computer.

3) A host computer that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA mission and communications control system. These electronics are located in a rack elsewhere in the aircraft and are connected to the drive electronics through a RS-422 serial line. ❑

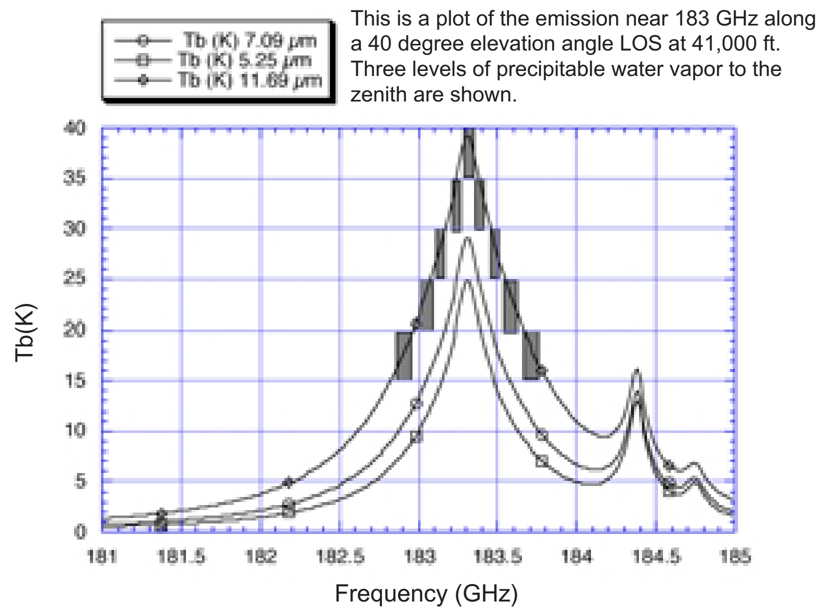

Figure 4. The 183.2 GHz water line at 41,000 ft. with three levels of water vapor. The 184.4 GHz line of ozone can also be seen. The shaded areas delineate the frequency coverage of the five double side-band water vapor monitor intermediate frequency bands.

Point of contact: Thomas Roellig
(650) 604-6426
troellig@mail.arc.nasa.gov

Spectroscopic Detection of Interstellar Organic Materials

Farid Salama, Thomas Halasinski, Bin Chen, Lou Allamandola, and Robert Walker

Understanding the origin, properties, and distribution of the biogenic elements in the universe is central to Astrobiology. The Ames Astrochemistry Laboratory has studied the ultraviolet irradiation of the molecular building blocks of interstellar and planetary organic materials. The aim of this research is to provide quantitative information to analyze astronomical spectra.

Our laboratory work has shown that polycyclic aromatic hydrocarbons (PAHs) play an important role in the interstellar medium. PAHs are complex organic molecules with the structure shown in Figure 5. Their signature is present in the ultraviolet and visible spectrum of starlight. PAHs, present as neutral, and positively negatively charged species, contain a substantial fraction (20-40%) of the organic carbon in space.

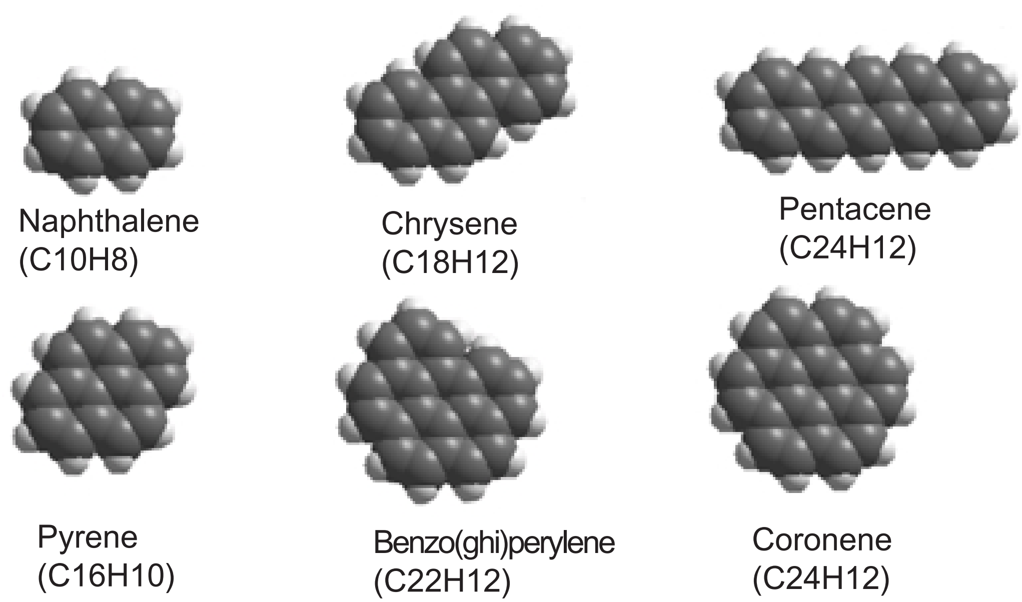

Figure 5. The three-dimensional structures of several common polycyclic aromatic hydrocarbon molecules.

Up to now, cosmic material analogs were produced in the laboratory under conditions close to, but not exactly reproducing, those expected in the interstellar medium (using cryogenic temperatures and high vacuum). The absorption and emission properties of these materials (neutral molecules and charged ions) are probed using the techniques of low temperature molecular spectroscopy. Laboratory measurements of PAHs isolated in the condensed phase (a technique called Matrix Isolation Spectroscopy) show that neutral PAHs absorb strongly in the UV. When ionized, PAHs also absorb in the visible, remarkably close to the positions of known Diffuse Interstellar Bands. Identifying the specific molecular carriers responsible for these yet unidentified bands is crucial to understand the complex organic chemistry that takes place throughout the galaxy.

There has been a great experimental challenge to measure the spectra of PAH ions in the gas phase under conditions which mimic exactly those in the interstellar medium. Within the past year, the absorption spectra of PAH cations have been measured for the first time in the gas phase using the combined techniques of Supersonic Free-Jet Expansion Spectroscopy (JES) and Cavity Ring Down Absorption Spectroscopy (CRDAS). This approach, achieved in collaboration with several research groups, allowed the first direct comparison between laboratory and astronomical data. Based on the initial laboratory results it has been concluded that a distribution of neutral and ionized PAHs represents a promising class of candidates to account for the Diffuse Interstellar Bands seen in both absorption and in emission. The results obtained so far represent a real breakthrough in astrophysics and astrochemistry as well as in molecular spectroscopy. For the first time, the absorption spectrum of a PAH cation has been measured under conditions which entirely mimic the cold and isolated molecular ions found in the interstellar environment. ❑

Point of contact: Farid Salama
(650) 604-3384
fsalama@mail.arc.nasa.gov