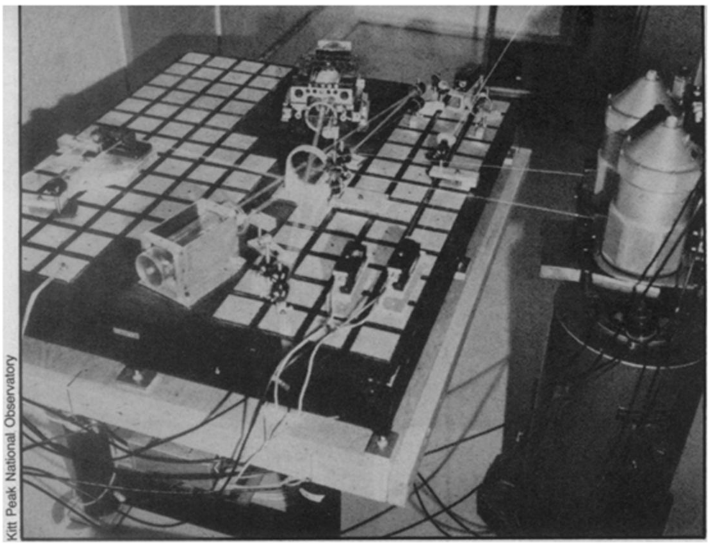


Kitt Peak's Fourier transform spectrometer: For quicker, better resolved spectra of stars.

Spectroscopy by Interferometer

Fourier transform spectroscopy delivers quick, high-resolution spectra in visible and infrared

BY DIETRICK E. THOMSEN

Spectroscopy is astronomy's most fundamental interpretive tool. Indeed the ability to break down the light from a celestial object into its constituent colors and to read and interpret the resulting spectrum changed astronomy from a positional and kinematic science into a physical and chemical one. Nearly everything we know about the external universe is derived from spectroscopic observation: chemical compositions, energy states, velocities in the line of sight, distance estimates, temperatures, magnetic fields.

Spectroscopy has an old history as scientific disciplines go. Isaac Newton did it with a prism. In recent generations spectroscopy has also been done with diffraction gratings. The advent of photography made possible the recording of spectrograms on plates and film for preservation and more leisurely study.

So it is not often that a radically new technique for spectroscopy comes into use. In the hundred years or so since photography began, things have been done more or less the same way. (Films and cameras have improved, of course.) Now there is a new spectroscopic technique being applied. It is called Fourier transform spectroscopy, and it depends not on the bending of light rays as do prisms and gratings, but on the comparison of rays that have traveled over slightly different paths.

Fourier transform spectroscopy is based not on refraction like a prism or diffraction like a grating, but on interferometry. It promises to provide spectral data more quickly, more precisely and from fainter sources than the older methods. Astronomers who are using the recently installed Fourier transform spectrometer (FTS) at Kitt Peak National Observatory in southern Arizona are enthusiastic about it.

The basic idea of this kind of spectroscopy is not extremely new. (In fact the instrument around which it is built, the Michelson interferometer, goes back to the late 19th century.) George A. Vanasse of the Air Force Geophysics Laboratory in Bedford, Mass., mentions in a talk he gave at the recent meeting of the Optical Society of America in Tucson, Ariz., that in the 1950s scientists began to realize the possible advantages of using a Michelson interferometer for spectroscopy. Early work began at Johns Hopkins University under the direction of John Strong. Through the '60s the work was continued at the Air Force Cambridge Research Laboratories (then the name of the Air Force Geophysics Laboratory.)

A Michelson interferometer is a device that uses half-silvered and fully silvered mirrors to split a beam of light in two, send the two parts over different paths and recombine them to see how they interfere. If both paths contain an integral number of wavelengths (assuming the light is monochromatic) the interference will be constructive when the split beam is reunited, and one will see a bright image at the point of reunion. If one of the paths is not an integral number of wavelengths, there will be destructive interference, and any amount of shading down to utter darkness will appear depending on how far out of phase the two paths are. If the incoming light is polychromatic, the degree of interference will vary according to the wavelength for any single setting of the interferometer, because the phase relation will be different for each wavelength. This is the key to making a spectrometer out of an interferometer.

The most important advantages of such an arrangement can be summed up in two words. Donald N. B. Hall of Kitt Peak, who has been using the FTS to observe some of the youngest objects in the galaxy, emphasizes "throughput." To this Vanasse adds "multiplexing." The significance of the words can be pointed up by going back to prism and grating spectroscopy for a moment. Both devices depend on their ability to bend different wavelengths to different angles from the entering ray. But to measure angles accurately one has to start with a narrow entering beam. So these instruments accept light through a narrow slit only, wasting most of what comes from the celestial object. The interferometer can take all the light it can get, and that is an important advantage for study of the many classes of faint objects that are particularly interesting nowadays.

Because prism and grating spectrometers bend each wavelength to a different angle, each color must be sought out and measured separately, whether this means actually swinging an eyepiece around half a circle or inspecting a photographic print. Multiplexing means that a single output from the FTS contains information about all wavelengths present in the incoming light. One sets the mirrors that establish the light paths a fixed distance apart (governed precisely by the known wavelength of a reference laser), and then each wavelength in the incoming light interferes by a different amount depending on the relation between its wavelength and the distance between the mirrors.

The single output must, of course, be analyzed to get data on the presence and strength of each of the various wavelengths. This is where Fourier comes in.

Baron Jean Baptiste Joseph Fourier (1768-1830) was a French mathematician, whose most famous work is in the theory of harmonic analysis: combining and separating waves of different shapes and lengths. By hand, Fourier analysis is extremely tedious, but it is the sort of thing that computers do well and happily. So here is another modern instance in which astronomical data pop out of the computer's maw instead of directly from the telescope's eyepiece.

We first heard of Kitt Peak's FTS in connection with infrared observation—indeed on the afternoon we actually saw the instrument it had just been trying to get an infrared spectrum of a particular star. Hall and his associates, Susan G. Kleinman and Doreen A. Weinberger of Massachusetts Institute of Technology, Stephen T. Ridgway and Robert S. Wojslaw of Kitt Peak, are engaged in a survey of infrared stars and their surroundings. It seems appropriate that this should be a major use of the new instrument because the older spectroscopic methods are not so good in the infrared. (Infrared is not visible; however, the portion of the infrared closest to the red does print on some kinds of photographic emulsions.)

An object examined early in their program is the bright source called IRC +10° 216. In the course of that examination they discovered a previously unknown organic molecule in the interstellar clouds, acetylene (SN: 9/4/76, p. 149). This opens not only a new chapter in the discovery of interstellar molecules (nearly all the previously known three dozen were found by radio spectroscopy), but also, Hall now thinks, a bonanza of organics. He and his collaborators have seen a strong spectral band around 3.1 microns wavelength that happens to represent the energy change involved in a fundamental stretch vibration of a chemical bond between carbon and hydrogen that occurs in many organic molecules. So there may be a whole series of molecules containing that band waiting to be discovered.

But finding new molecules is only one part of the survey, which aims to find out as much as it can about infrared-emitting objects. Hall says the central object in IRC +10° 216 is rendered completely invisible by the surrounding clouds. Outermost is a large cloud, detectable by radio, that is about 100 times the solar system's diameter. Inside are two small shells, one ten times the solar system, the other a few times the solar system in size. All these are expanding at about 10 kilometers per second.

It appears, Hall says, that these clouds are blown off in a single cataclysm. The central star blasts its entire surface layer. And these blasts have happened not very long ago, astronomically speaking. The radio cloud came off about 5,000 years ago, but the smaller ones are really young, 100 years for one and 20 years for the other. So this is a kind of astronomy in which changes can be watched over a relatively short number of years.

Of course this successive blasting off of the surface of the star can't go on forever. Still there are 80 to 100 known similar cases, and it may be that this is a stage that all massive stars go through. In IRC +10° 216 we may be watching a star forming a planetary nebula. That could have implications for our own history. It is from such a nebula that our planets are believed to have condensed, and the complicated organic chemistry that Hall and his co-workers are beginning to see may tell a story that could be similar to the history of the compounds in our own bodies.

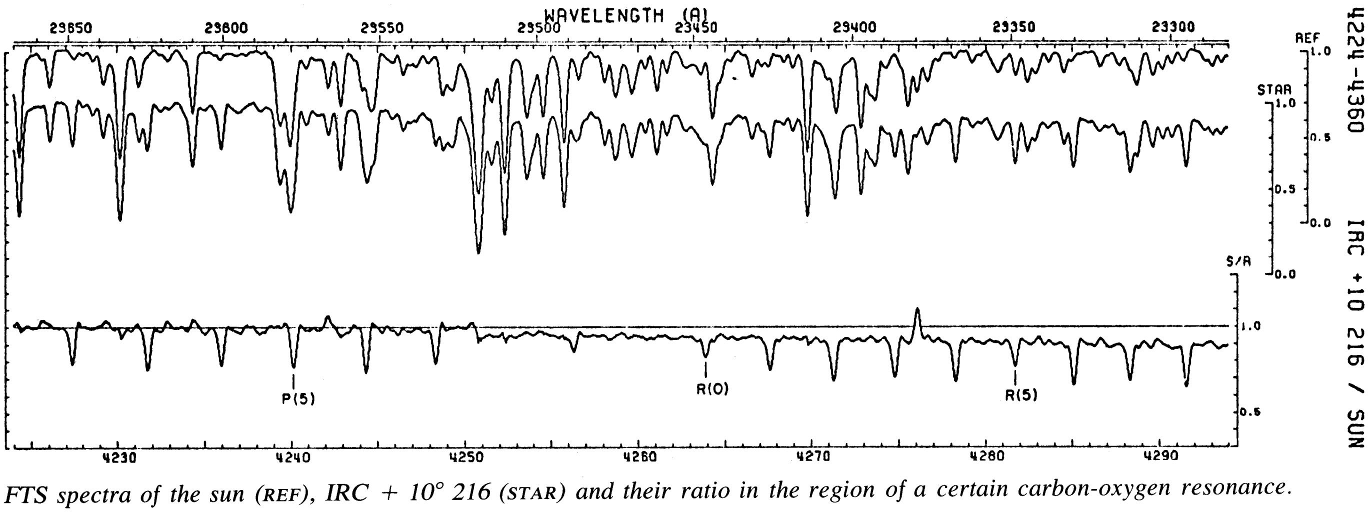
A great advantage of the infrared work is that it can be done in the daytime, and thus not conflict with the desires of visible-light observers who have to work at night. (Telescope time is extremely difficult to get. The demand far outruns the supply, and anything that increases the hours of a telescope's usefulness is welcome.) Hall says the sky is as black in infrared wavelengths in the daytime as it is at night for visible light. Of course the sun is there, and the sun is a strong infrared emitter. But you can still work, says Hall, if you stay at least 45° away from the sun. The objects of observation are invisible in any case so the telescope is pointed automatically. For the 4-meter telescope on Kitt Peak, to which the FTS is currently attached, the automatic pointing accuracy is within two seconds of arc, equivalent, Hall says, to pointing from Tucson at a given person in Los Angeles. This sort of accuracy combined with the extremely good spectral resolution of the FTS allows observations that are almost unbelievable by older standards: Motions can be discovered in the atmospheres of stars, different parts moving at different speeds. Also, Hall believes, the FTS should be able to pick up the Doppler shift in spectral wavelengths caused by the wobble of a star's motion due to the presence of a planet-sized companion.

The excellences of the FTS will bring it also into the domain of visible light, where the older methods have long held the field. Ironically, one of the early applications intended is to the sun, the brightest object in the sky. "We intend to do atlassy sorts of things, profiles of selected lines across the face of the sun," says James W. Brault. The observations would be done in the wavelength range 4,000 to 11,000 angstroms, or rather more than the eye can see. Here too the magic words throughput and multiplex come into play. Very accurate spectra of transient occurrences are possible. Take sunspots. The FTS can get a good spectrum of a sunspot in an hour, Brault says. Astronomers will be able to watch the spectrum of a spot as it goes across the sun. Similar studies of other solar transients, plages, faculae and prominences, are possible.

Conversely, one can look at integrated light from the whole visible disk of the sun (because the spectometer doesn't need a narrow entrance slit for the light), treating the sun as if it were any star. This is important because, as Brault puts it: "One of the big reasons for solar physics is to use the sun as a model for other stars," a standard reference, so to speak.

One interesting class of other stars is the so-called M stars. These are very peculiar chemically, containing "molecules we don't understand," Brault says. Such understanding could be helped by laboratory applications of the FTS. It could record spectra of substances of interest to stellar physics and do it possibly when they are in unusual energy states that last fleetingly in the laboratory but may be present in some of these poorly understood stars.

So there it is, a quick spectrometric method with very high resolution that is good from at least 4,000 angstroms (violet) to 250,000 angstroms (well into the infrared; visible red is about 7,000 angstroms). Its one drawback is that it is a large and delicate piece of hardware and not readily portable. That is not very serious in a place like Kitt Peak, which is equipped with all the latest in multipurpose telescopes, but a little bit of a rub comes out when Brault is asked whether he can observe the sun's corona during an eclipse. The FTS can't be taken to a remote site, in West Africa or Patagonia or central Siberia, say. Brault doesn't know when the next total eclipse is scheduled for the Kitt Peak area, but he doesn't propose to wait for it. □



FTS spectra of the sun (REF), IRC + 10° 216 (STAR) and their ratio in the region of a certain carbon-oxygen resonance.