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Infrared Spectroscopy of Multiple Star Systems

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ABSTRACT: Up to this time infrared spectroscopy has been only occasionally used in binary star research due to both the insensitivity of infrared spectrographs and the difficulty of getting observing time on a limited number of spectrographs. However, infrared spectroscopy has a number of interesting applications in binary star research. We present an example of an application to the long-period symbiotic system CH Cyg. Due to the recent development of infrared arrays, infrared spectroscopy (1) is becoming available at a much larger number of telescopes and (2) in the 1.0–2.5 μm region is capable of going to limiting magnitudes nearly as faint as those reached by CCD's.

1. INTRODUCTION

Infrared spectroscopy has a number of interesting advantages over visual spectroscopy in the detection and/or monitoring of certain types of multiple star systems. In systems containing a cool star, for example symbiotic binaries, the cool star is best observed in the infrared because the energy distribution peaks in the infrared and contamination of the spectrum from a hot companion is minimized in the infrared. The infrared, especially the 1.5–2.5 μm region, offers minimal reddening. This is essential for highly obscured pre-main sequence systems or stars in regions such as the galactic center. A number of interesting spectral diagnostics are found in the infrared, e.g., He I 10830, atomic hydrogen lines from series including Paschen, Brackett, and Pfund, and numerous molecular bands, especially from the ubiquitous and highly useful CO molecule. There are also some special applications of infrared spectra, which might be of interest to binary star work. Perhaps the most notable among these is the large increase of Zeeman splitting in the infrared. Also of interest is the potential for detecting temperature differences in stellar spots.

2. TECHNIQUES — FTS

Until recently infrared detectors were available only in single pixel format and were plagued with very high inherent noise levels. Recording narrow spectral elements of an astronomical source one by one with such a detector was virtually impossible. Fourier transform spectroscopy (FTS) features a natural multiplexing strategy which encodes many spectral elements on a single detector. As long

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as detector noise dominates, FTS offers a gain on order of the number of spectral resolution elements. More or less by chance, FTS also offers a number of wonderful instrumental features: no slit; continuously adjustable and unlimited spectral resolution; well understood instrumental line profile; very large spectral coverage; very high throughput; no scattered light; accurately known, internally calibrated frequency scale without a dispersion relation; noise dominated wavelength precision; inherently photometric spectra. Unfortunately, FTS has the severe limitation that it can not reach "faint" sources. FTS is also an exotic technology and has only been implemented for astronomy at the KPNO and CFHT 4-meter telescopes.

3. TECHNIQUES — INFRARED ARRAYS

Infrared arrays with dimension of 256×256 pixels are now widely available in a number of materials (InSb, HgCdTe, PtSi). While infinite increase in size is not possible, arrays a factor of 2 larger are likely. These arrays offer a large number of pixels with each pixel having very low noise. The array detectors are integrating detectors, rather than the continuous readout as were the single element detectors of the past. Assuming high quality devices of both types (NEP for the single element detector is 10^{-18} watt/sqrt(Hz) and the readout noise for the integrating detector is assumed to be 30 e^- with negligible dark current), then the signal to noise (S/N) and integration time in seconds (t) are related by:

$$\log_{10}(relative\ S/N\ [integrating/analog]) = 0.5 \log_{10}(t) + 0.5$$

(Ridgway & Hinkle 1992).

Comparing detectors, we conclude that a grating spectrometer with an infrared array will be on the order of 100× more sensitive than an FTS. Generally, a spectrograph that takes advantage of infrared arrays is cryogenic. Infrared arrays become background limited in warm spectrographs at wavelengths longer than about 1.8 μm. Several cryogenic spectrographs have now been built to use infrared arrays (CSHELL at IRTF and CGS4 at UKIRT). These spectrographs offer two pixel resolution of about 20000, with 40000 at the limiting end of their performance. At NOAO, we have been working on a resolution 70,000–100,000 spectrograph intended for use on the 2.1- and 4-meter telescopes.

4. AN EXAMPLE — CH CYG

An interesting example of an application of infrared spectroscopy to a binary system is CH Cyg. Since 1979 we have been observing the 1.6–2.5 μm infrared spectrum of CH Cygni at high resolution ($\lambda/\Delta\lambda$=70000) with the FTS at the KPNO 4-meter telescope. CH Cyg is the visually brightest symbiotic star. Our goal was to monitor the spectrum a few times each year to look for intrinsic variations in the M giant and to search for orbital motion. Infrared spectra offer two advantages over visual spectra for this project. First, in the infrared the M giant dominates the spectrum. The visual spectrum is heavily contaminated

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by line and continuum emission from the high excitation source. Second, spectra of bright infrared sources like CH Cygni may be observed during daytime making year–around monitoring possible. In fact, because of the high northern declination of CH Cyg, nearly all the observations were taken in daytime.

To date, a time series of 70 spectra have been observed. Typical resolution is $\sim$0.07 cm^{-1} ($\lambda/\Delta\lambda$ $\sim$70000) and S/N$\sim$70. Velocities have been derived from the CO Δv=2 and Δv=3 lines. Formal errors are $\sim$0.2 km s^{-1}. Note that the infrared velocities sample the motion of only the M6 III. The velocities show two periods, one of about 750 days and a second of about 15 years. The velocity changes do not appear to be the result of stellar pulsation. The velocities are well fit by orbital motion, assuming that the system is triple. Orbital parameters and more details are given in Hinkle *et al.* (1992)

The infrared results show that the CH Cyg system consists of three stars. We argue that the 750 day binary system is the interacting symbiotic system. This orbital period is similar to that of a number of other symbiotic binaries. The mass function for the 750 day orbit is $0.00147\mathcal{M}_\odot$ and for the 15 year orbit $0.0565\mathcal{M}_\odot$. Observations of the radio jet by Taylor *et al.* (1986) imply that the orbit is seen nearly edge on since both radio lobes are visible. However, the requirement that the M6 giant have a mass $< 2\mathcal{M}_\odot$ implies the inclination is $< 30°$ for a typical white dwarf mass of $\sim 0.5\mathcal{M}_\odot$ for the secondary. We conclude that the 750 day orbit is either seen nearly edge on, in which case the secondary mass is $\sim 0.2\mathcal{M}_\odot$ or the jet is not collimated by an accretion disk, in which case the inclination is smaller and the white dwarf mass can approach $0.5\mathcal{M}_\odot$. In either case, the unseen third star in the CH Cyg system is probably a G–K dwarf.

In 1979 Yamashita & Maehara (1979) produced an orbit for CH Cyg from visual spectra radial velocities. The period they derived was 5750 days (15.8 years) and corresponds to our long period orbit. However, this orbit is not that of the symbiotic pair. In the spirit of this meeting, a truly complementary approach would be to derive an orbit for the hot star from the visual/UV lines and for the cool star from the infrared lines. Unfortunately, the available visual/UV observations appear highly corrupted by activity occurring during the stellar outbursts.

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