Infrared 3-5 Micron Spectroscopy with NIRC2 and Keck II Adaptive Optics:
Feasibility Observations of HD141569 and NGC7027

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ABSTRACT

The near infrared wavelengths between 3 and 5 microns present a challenging regime for spectroscopy with NIRC2 and Adaptive Optics (AO). Thermal radiation from the atmosphere and telescope optics creates high level of background signal. This project was to research the calibration issues related to L and Ms band spectroscopy and to test its feasibility by observing HD141569 and NGC7027. HD141596 is a five million year old B 9.5 type star that has been observed to have a proto-planetary dust disk surrounding it. The disk is nearly 5" in size in the 3-5 micron region and presents a challenging target due to its small size and the brightness of the parent star. NGC7027 is a planetary nebula with a high state of excitation from molecular and atomic transitions. NGC7027 has been observed many times before as an object to test the capability of instruments. The dust disk of HD141569 was not well detected in our Ms band observations, it was seen only as a small excess of flux in the north-south direction. In NGC7027 polycyclic hydrocarbons were observed at 3.29, 3.31, and 3.33μm and the Hydrogen I Brα line at 4.052μm which confirmed our wavelength solution for NIRC2. Presented in this paper are discussion of data acquisition and reduction as it relates to L and M band spectroscopy with AO.

INTRODUCTION

The initial goal of this project was to observe a proto-planetary disk with the NIRC2 spectrometer, and measure the rotational velocity of the disk. To find targets I researched using NASA Astrophysics Data System (ADS) web site to find disks that have been observed to be edge-on. I started by listing about a dozen objects that were known to have edge on dust disks. Then I looked at whether these objects were visible this time of year from Mauna Kea. There was one object that was visible, though low in the sky. HR4796a is an A type star that is about eight million years old (Augereau 1999). It is at an intermediary stage of planet formation. Previous observations of HR4796a by Koerner et. al. (1998) have shown that the central region is cleared of large debris suggesting that large bodies have already formed there. The outer region is still thick dust made partly of water ice.

In order to make an observation of the disks rotational velocity a very precise measurement of wavelength is needed. We needed to determine the wavelength solution for NIRC2 in the 3-5 micron range in order to measure the small change in wavelength such a rotating disk would cause. I expect that under Keplarian motion the dust near the edge of the disk would show a 15 Angstrom shift in wavelength from one edge to the other edge. The shift that could be resolved is 300 Angstroms and thus this shift is not resolvable. Because few spectral observations have been made on NIRC2 in the 3-5 micron range we decided to go ahead and continue the calibration of the instrument and study the feasibility issues of spectroscopy in the infrared.

A face on proto-planetary disk HD141569 was chosen to be a test of resolving power in these bands. HD141569 is an A type star and is about five million years old. The disk is known to have CO emissions in the 4-5μm range (Brittain 2003). The disk is about five arcseconds in size in the near infrared (Boccaletti 2003) and we hope to image the CO emission from the disk. If the disk is spatially resolved we will take spectra of the disk in the 3-5 micron range as well.

We also chose to observe NGC7027 because it could be used as a test object of the instrument's capabilities. NGC7027 is a planetary nebula with a white dwarf at the center. The gaseous nebula is highly excited by the radiation form the hot central star. This excited gas re-emits at specific wavelengths that are well known atomic and molecular transitions.

OBSERVATION

Our observations of HD141569 and NCG7027 were done on 26 June 2004 UT at the W.M. Keck observatory atop Mauna Kea Hawaii. We used NIRC2 infrared imager and spectrograph which is mounted behind the Adaptive Optics (AO) bench on Keck II. For observation of HD141569 we used the narrow field camera which gives a plate scale of .009942 (+/- .0005) arcsec/pixel and a total field of view of 10x10 arcseconds. For the imaging data of HD141569, we used the Ms filter with band pass of 4.549-4.790 microns. The first series of images used only the central 512x512 pixel portion of the array and were dithered in a box pattern on the array by 1.0" into three of the four quadrants. A total of six images were taken with integration times of .05 seconds and 50 coadds. Two series with the full array were taken with .18 second integrations and 25 coadds. They were dithered by 2.5" in the same fashion as before. A total of 16 images were taken on the full array. Images of a point spread function, PSF star, HD161743 were taken in the same configuration as HD141569 with 25 coadds and .2 second integrations.

For the spectroscopic observation of NGC7027 we used the wide field camera which has a field of view of 40"x40" and a plate scale of .039686 (+/- .0005) arcsec/pixel. The observations were made with the 120 milliarsecond slit at a position of 12.5mm and the low resolution grism. We used the L filter with integration times of 120 seconds and two coadds. Sky spectra were also taken in this same configuration.

On 2 July 2004 UT observations of the spectroscopic flux of standard star HD181597 were made with NIRC2 in the L band. The low resolution grism was used with the 80 milliarsecond slit at a position of 12.5mm. The wide field camera was used with integration times of 2.0 seconds and 10 coadds.

DATA REDUCTION

All the data reduction was conducted with IDL for UNIX. We wrote a routine that undithered, removed bad pixels, sky subtracted and flat fielded a series of images of HD141569. These individual images were then shifted and added together based on the measured centroid of the bright star. Combining the data enhanced the signal to noise ratio of the observation. We used other IDL routines to calculate the bad pixels that were removed and to make the flat fields used to calibrate the images. This process was done for all thirty six images of HD141569.

The spectroscopic data reduction began by removing the bad pixels and flat fielding the images. The atmosphere and telescope radiation was removed from the observed spectrum by taking the difference of two spectra images. With these corrected images we then used an IDL routine to extract a narrow region of pixels that contained the spectral features. These rows were then averaged and plotted. In order to determine the wavelengths of observed features we used the product of a model of the atmospheric transmission by Tokunaga and a spectral irradiance model (Cohen et. al.) of our standard star HD181597. A plot of the model spectrum is compared to the observed spectrum in

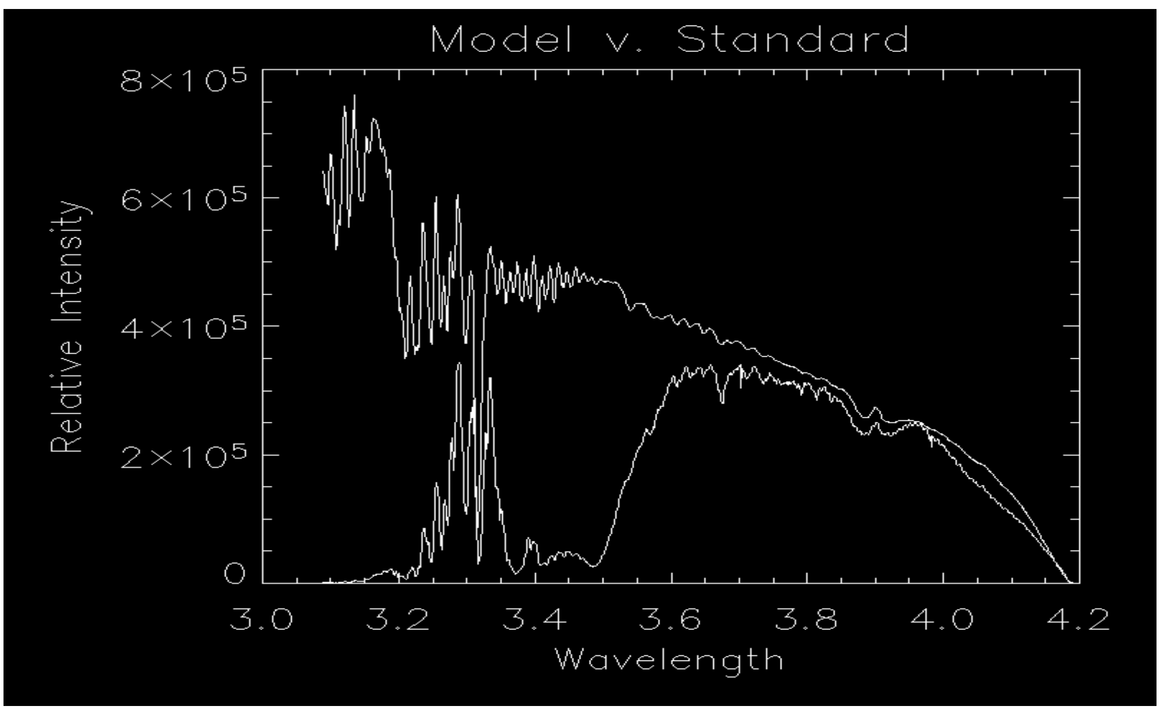

figure one.

Figure one: A comparison of the model spectrum for standard star HD181597 and the observed spectrum of HD181597. The line on top is the model which is modulated only by the atmosphere. The line on the bottom is the observed spectrum and it is cut off by the filter at shorter wavelengths. The close alignment of the features shows the goodness of the fit between the model and observed spectrum.

The model spectrum was created by multiplying the atmospheric transmission and standard star irradiance together. The model represents a spectrum that has the same features as our observed spectrum. By overlaying the spectrum of our standard star and that of the model spectrum we could see the features that lined up. The line on top is the model spectrum modulated only by the atmosphere. The line on the bottom is the observed spectrum and it is modulated by the atmosphere and the telescope optics and filter. The modulation of the filter can be seen as a loss of signal near 3.2 microns and absorption from 3.35 to 3.55 microns. We were then able to determine the wavelength solution of the observed spectrum by fitting the model to it. This is the first wavelength solution obtained for NIRC2 in the 3-5 micron range. The fit is good as the two lines distinct features lay on top of each other. This wavelength solution provides a wavelength calibration within +/- .05µm.

The primary difference between the model spectrum and the actual spectrum is that the actual spectrum is also modulated by the filter's band pass and optics. There is also a large absorption feature on the standard star's spectrum between 3.25 and 3.55 microns that is likely caused by the glue on the grism.

RESULTS

HD141569: The disk was not visible in any of the single images because the disk is very faint compared to the sky signal. When all thirty six images of the disk were added together with a total integration time of 132 seconds, the disk became just barley visible as shown in figure two. The scale is 5.09 x 5.09" and north is upwards for both figures two and three. Comparing figure two with the point spread function star HD 161743 in figure three it is visible that the features seen in figure two are not just diffraction spikes from the secondary support struts.

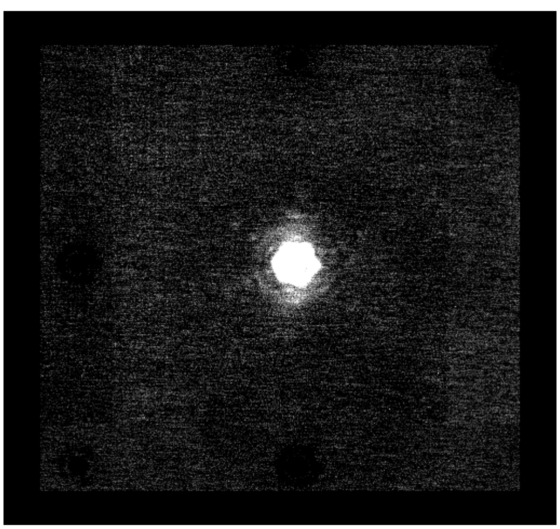

Figure two: The sum of all 36 individual images of HD141569. A disk is possibly visible as an excess of north-south flux. North is oriented upwards and the image is 5.09" on each side.

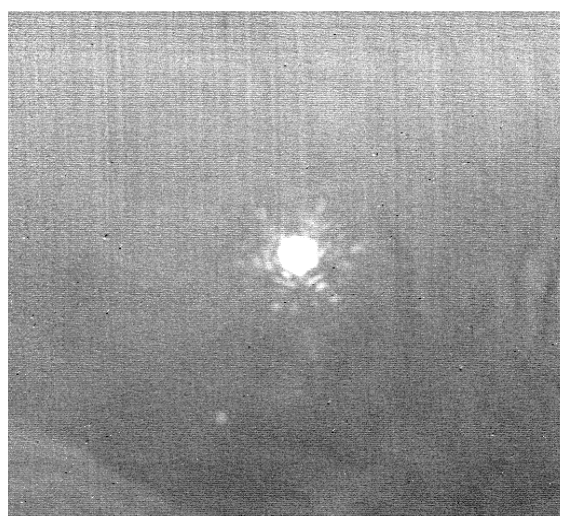

Figure three: This is the point spread function star HD161743. The diffraction spikes are clearly visible in a hexagon pattern. North is oriented upwards and the image is 5.09" x 5.09".

Looking closely at figure two, one can see that there is an excess of flux in the north-south direction. The excess agrees north-south emission agrees with prior observations by K.A. Marsh (2002) that show an excess of emission in the north-south direction at 12.5μm. Because of the low signal to noise ratio of our observation we can not be certain that the features are the disk but it is very probable.

NGC7027: Figure four shows the plot of NGC7027's emission lines. There are two main features visible at 3.29μm and 4.052μm. The first feature is polycyclic hydrocarbons (PAH) with peaks at 3.29, 3.31, and 3.33 μm. The second feature is the Brα Hydrogen I line (Allen's Astrophysical Quantities 2000). This result partially agrees with observations by S. Sandford (1991) which showed PAH features at 3.29 and 3.4μm and the Pfund-γ Hydrogen I line at 3.74μm.

There are a few reasons why we do not show the same features as Sandford. Sandford's observation had a much better signal to noise ratio that us and they resolved much finer features. NGC7027 is an extended object about 12" in size (Jurgenson 2003) and Sandford observed the entire nebula while we observed only a small sliver. This could account for why we did not observe the same features. Also, the wavelength range that Sandford observed in ended at 3.8μm and thus they would not have seen the Brα line at 4.052μm.

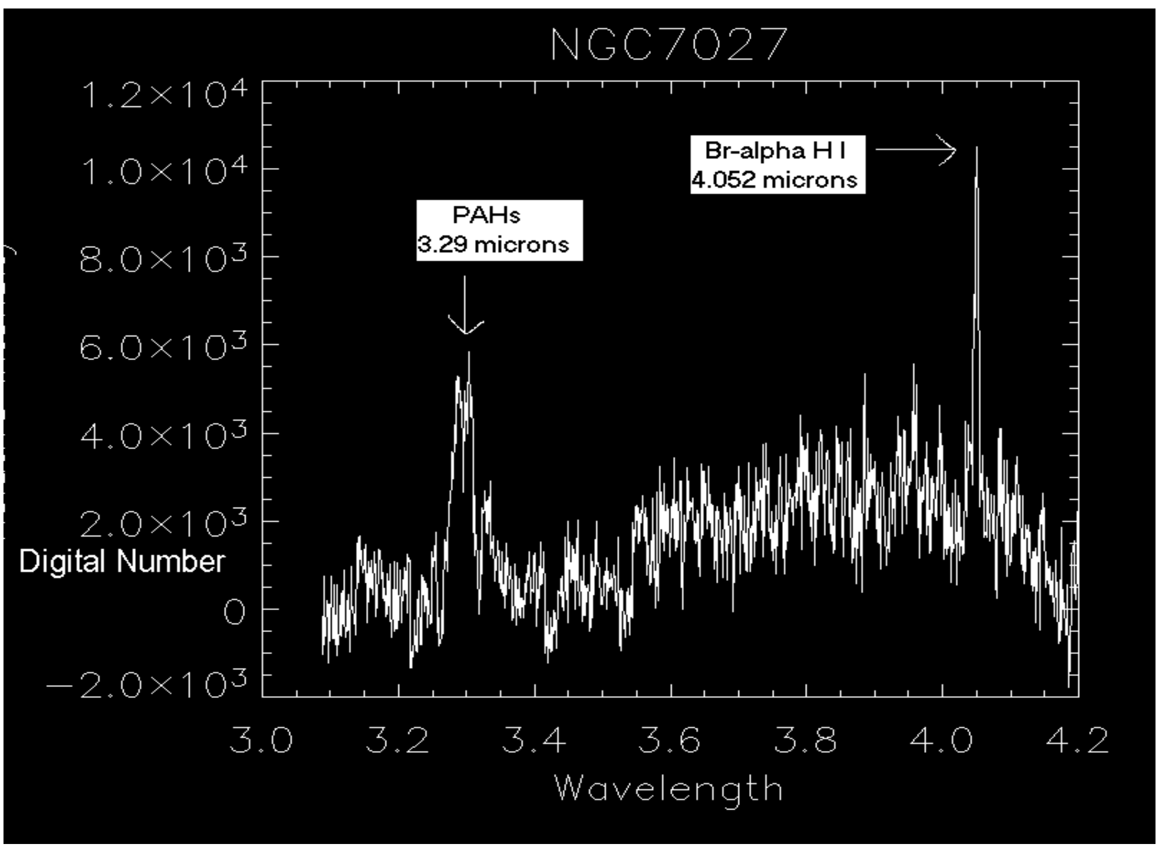

Figure four: The spectrum of NGC7027 between 3.1 and 4.2 microns. PAH features are visible at 3.29, 3.31, and 3.33 microns and the Hydrogen I Brα line is visible at 4.052μm.

CONCLUSION

Our observation of HD141569 possibly shows some disk features, although these features are not well detected. This observation demonstrates the difficulty of imaging dust disk sources. It did show however, that longer integration times may improve the signal to noise ratio enough to resolve dust disks with NIRC2 in the 3-4 micron range.

NGC7027 was shown to have PAH features at 3.29, 3.31, and 3.33 microns. We were also able to observe the Brα Hydrogen I line at 4.052μm. We were able to successfully calibrate the NIRC2 in 3-5 microns and find the wavelength solution. It has also been shown that 3-5 micron spectroscopy is feasible with NIRC2.

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