INSTRUMENT TRADE STUDY AND DESIGN FOR MID TO FAR-IR ATMOSPHERIC REMOTE SENSING OF AN OUTER SOLAR SYSTEM PLANET BASED ON HIGH TEMPERATURE BOLOMETERS. E. C. Brageot[1], M. A. Lindeman[1] and G. Orton[1]. [1]NASA-Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak grove Drive, Pasadena CA 91109, Emily.C.Brageot@jpl.nasa.gov, Mark.A.Lindeman@jpl.nasa.gov.

1. Introduction: The study of the atmospheres of giant planets their satellites such as Saturn, Titan, Uranus or Neptune requires a wide range of wavelengths to probe different depths into the atmosphere, with longer wavelengths generally able to peer to greatest depths. The atmospheres of these bodies are opaque at shorter wavelengths due to the broad pressure-broadened absorption of H_2 and He and, in some cases (e.g. Neptune and Titan), CH_4 and N_2. For this reason, the composition of the atmosphere of the gas and ice giants and their satellites has been studied by remote sensing using far-IR thermal radiance spectroscopy. In addition, new science would be unlocked by imaging fast dynamic processes, such as moving clouds or storms, while resolving narrow and weak spectral features to detect their composition as they are moving in the atmosphere.

Performing these studies requires a high sensitivity, high-spectral and -spatial resolution instrument capable of acquiring spectra in a short time window. Such an instrument would be ideally installed on-board an orbiting or fly-by spacecraft in the outer solar system and provide the next generation of Cassini CIRS-like measurements.

Recent advances in the yttrium barium copper oxide (YBCO) high temperature superconducting kinetic inductance bolometers (KIBs) and their development into pixel arrays have enabled the design study of such an instrument. These detectors have multiple advantages for the considered science applications including a high sensitivity over a wavelength range potentially spanning from the visible to the far Infra-Red (500microns) and a fairly high operation temperature of 50K which opens up the possibility of a passively cooled instrument considering its use in the outer solar system. Furthermore, these capabilities would allow us to merge the three separate channels of the CIRS instrument to obtain a smaller instrument with a 2-dimension array of pixels instead of line arrays, and with a two orders of magnitude higher predicted sensitivity.

In this paper, I will first present the design trade study based on both science goals and the projected performance of the YBCO KIBs array through radiometric modelling and how that led us to the concept of an on-orbit or fly-by mid- to far-Infra-Red Fourier Transform Imaging spectrometer design for outer planets of the Solar System. I will then present its current optical design and main instrument parameters as well as the remaining challenges of its design.

2. Science goals and trade-off study: The ideal instrument we are envisioning would be able to characterize the methane cycle, D/H and He/H_2 ratios and atmospheric dynamics of these outer solar system bodies. The equivalent black-body temperatures of these planets range between 50 and 100K, which corresponds to peak wavelengths between 30 and 60µm. The He/H_2 ratio measurement corresponds to tracking the shape of a spectral continuum and therefore does not require high spectral resolution [1]. On the other hand, trace constituents such as CH_4, NH_3 and PH_3 display sharp spectral features that require a spectral resolution of at least $0.5cm^{-1}$ to resolve different emission bands and retrieve mixing ratios accurately [2]. A higher spectral resolution of $0.1cm^{-1}$ adds further insight to the H/D ratio measurements in methane by singling out isolated lines of CH_3D and CH_4 whose ratio can be used to eliminate uncertainty on the abundance of CH_4 [3,4].

An on-orbit instrument wavelength range of 20 to 100µm (100 to $500cm^{-1}$) with a spectral resolution better than $0.1cm^{-1}$ would therefore enable these measurement with a high spatial resolution. A radiometric model of the Signal-to-Noise Ratio (SNR) in the case of Titan showed this design is possible with an all reflective Fourier Transform Imaging Spectrometer using YBCO KIBs arrays, and would yield a predicted spectra SNR value of 2960 for an equivalent scene black body temperature of 90K while keeping the instrument volume as small as possible.

3. Current instrument parameters and optical design: The instrument parameters were set by both the detector performance, the desired IFOV and spectral resolution, and the need for a compact design. All of these were input and balanced out using the afore mentioned radiometric model and yielded the results listed in table 1.

Instrument parameter	*Value*
IFOV	1 mrad
FOV	2.86x2.29 deg

F-number	11.2
Focal length	1000 mm
Spectral resolution	0.1 cm^{-1}
Complete spectra acquisition time	200s
Modelled Spectra SNR for 90K scene	2960

Tab 1- Main instrument parameters.

Due to the large wavelength range to cover, the optical design is all-reflective and therefore both achromatic and isothermal save for the synthetic diamond beam splitter [5]. Both the telescope design and the focusing optics are off-axis to avoid having a central obscuration that would lower the SNR of the instrument.

The optical design illustrated in Figure 1 is kept as compact as possible by using a corner cube mirror as the moving mirror. This effectively shortens the needed travel of the mirro by a factor 2.

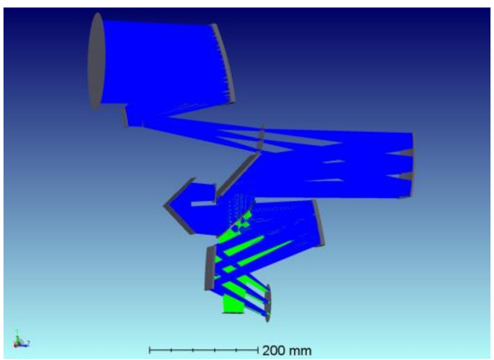

Fig 1- 3D rendering of the interferometer optical design. The 2-mirror telescope can be seen on top the image while the detector is at the bottom right. The corner cube moving mirror can be seen in the middle left of the image. The two paths of the light in the interferometer part of the instrument are represented in blue and green.

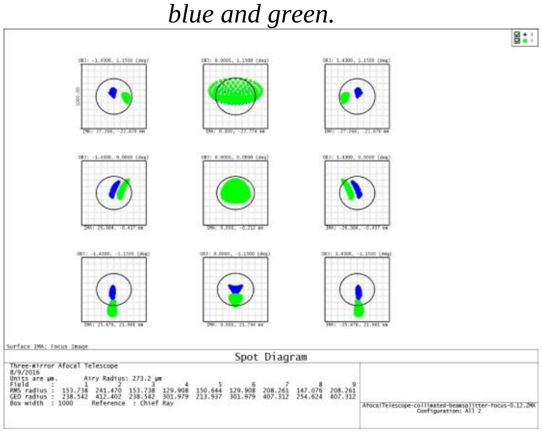

Fig 2- Spot diagram of the interferometer optical design. The blue and green color correspond to the image spots at extreme positions of the moving mirror while the box size corresponds to the pixel size.

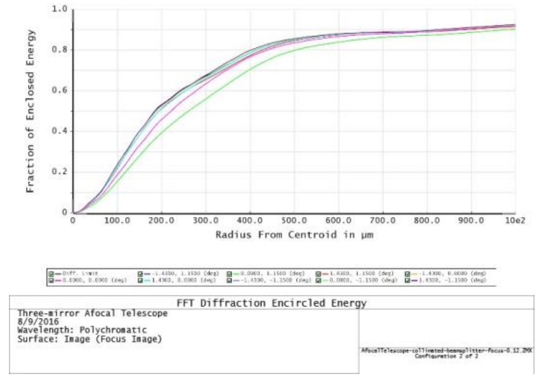

Fig 3- Diffraction encircled energy of the interferometer optical design across the Field Of View.

3. Remaining challenges: Several challenges remain for the complete design of this instrument concept. Firstly, the optical aberrations over the FOV vary a lot due to the off-axis design, a study of the variation of the spectral resolution across the FOV will be done to quantify them and attempt to calibrate them out. Second, the large FOV will make the baffling design a challenge even though the telescope image plane is accessible for a stop to be installed. Thirdly, the YBCO KIBs currently have a fill ratio of 50%. We are thus pursuing options to focus the light with an addtionnal array on top of the detector plane to be able to use all the incoming light beam. Finally, we are investigating the passive thermal designs available to this instrument.

References:

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