THERMAL INFRARED IMAGING INTERFEROMETER PERFORMANCE FOR PLANETARY APPLICATIONS. P. G. Lucey[1*] and S. T. Crites[1], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 1680 East West Road, Honolulu, HI 96822, *lucey@higp.hawaii.edu

Introduction: Interferometer spectrometers feature signal to noise characteristics that differ substantially from dispersive or filter based spectrometers [1]. Among the most important from a sensitivity performance standpoint are the multiplex, or Fellgett, advantage and the throughput, or Jacquinot advantage [1]. The Fellgett advantage arises from the simultaneous measurement of all spectral bands (today shared by array dispersive spectrometers), while the Jacquinot advantage arises from the fact that a Fourier Transform Spectrometer (FTS) does not require a slit for its measurement, and so admits substantially more light into the system. "Advantage" in these cases is something of a misnomer, and only applies to systems are dominated by read noise, that is, photon noise is negligible as will be discussed further below. However, in the read-noise dominated case the advantage can be substantial.

In this abstract we present a model that reproduces the performance of interferometer spectrometers to about 15% across all wavelengths. We also present preliminary results a cooled detector array, a Sofradir 530L mercury cadmium telluride device.

Model For Uncooled Detectors: The signal to noise ratio for imaging interferemeters using uncooled arrays is:

$$SNR_\sigma = \frac{\sqrt{N}P_\sigma}{NEP_\sigma}$$

Where N is the number of samples that ultimately go into the construction of the interferogram. (This number includes any spatial or temporal coadding, as well as the conventional multiplex value of the number of samples in the interferogram). P_σ is the wavelength dependent signal power, and NEP_σ is the wavelength dependent noise equivalent power.

P_σ is given by:

$$P_\sigma = M_\sigma L_\sigma \tau_i \Delta\sigma A_d \Omega_c$$

and NEP_σ is given by:

$$NEP_\sigma = NE\Delta T \frac{\tau_o A_D \Omega_c \int_\sigma r_\sigma \frac{\Delta L}{\Delta T} d\sigma}{r_\sigma}$$

where the listed quantities are given in Table 1.

Table 1. Quantities required for SNR calculation

Camera	F-number	Ω	steradians
	Pixel area	A_D	m^2
	Spectral transmission	τ_σ	unitless
	Noise equivalent delta temperature	$NE\Delta T$	kelvins
	Normalized responsivity	r_σ	unitless
Interferometer	Spectral transmission	τ_σ	unitless
	Spectral modulation	M_σ	unitless
	Samples composing interferogram and other coadding	N	unitless

Applying this model to data collected with a Sagnac interferometer spectrometer equipped with a BAE SCC 500 640x488 microbolometer camera core with 30 micron pixels, we find that the model slightly

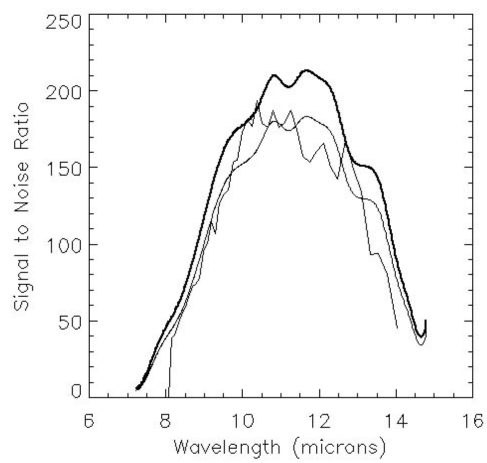

Fig. 1. Measured signal to noise ratio (jagged line) of the Sagnac interferometer using the BAE camera compared to the raw model result (bold line) and scaled by 0.85 (fine line). The model reproduces the shape of the response curve well; the overestimate of SNR by the raw model result we attribute to the lack of spatial nonuniformity in the model.

over estimated the instrument performance which is consistent with the fact that the model does not include noise due to residual nonuniformity that plagues all hyperspectral sensors. The shape of the curve closely mimics the measurement suggesting the basic approach is sound.

Model For Cooled Detectors: Because the cooled detector is a photon-detecting device, where noise is sensitive to signal, the SNR relationships are quite different. The signal detected by the interferometer is:

$$q_\sigma = L_\sigma A\Omega t\Delta\sigma\tau m_\sigma QE_\sigma$$

where

q_s is the detected photoelectrons
L_s is target photon spectral radiance (photons/wavenumber-steradian-sec-m2)
W is the system solid acceptance angle (assumed governed by the camera cold stop)
A_d is the pixel area
$\Delta\sigma$ is the spectral resolution
m_s is the modulation efficiency
QE_s is the spectral quantum efficiency
τ is the transmission of the optical system
t is the integration time

The camera will also detect the emitted radiance from the optics, which are very low in the case of the interferometer that that has no slit jaws viewed by the detector. This equation neglects the camera emission reflected by the interferometer because the detector and cold stop are very cold and should impose negligible radiance.

$$q_T = \varepsilon\Omega At\int_\sigma B(T_L)QE_\sigma$$

where

ε is the emissivity of the optical system
B is the Planck function
T_L is the optics temperature

In an interferometer, each pixel in the detector array sees signal from all the bands from the target transmitted to the detector, so this is a key noise component in this photon-noise dominated case.

$$q = \int_\sigma q_\sigma$$

The noise variance is then

$$V_n = q + q_T + I_e + R^2$$

where q is the detected signal integrated over all wavelengths, q_T is the thermal emission from the optics, I_e is the dark current in units of electrons/pixel and R is the read noise.

$$SNR_\sigma = \frac{q_\sigma\sqrt{N}}{\sqrt{V_n}}$$

Using the same methodology as above, we measured the SNR of an interferometer equipped with a HgCdTe cooled detector from Sofradir.

Table 2. Parameters used in cooled detector performance model

System solid acceptance angle (assumed governed by the camera cold stop)	W	0.2 sr
Pixel area	A_d	$(30\ \mu m)^2$
Spectral resolution	$\Delta\sigma$	10 wavenumbers
Modulation efficiency	m_s	Measurement
Spectral quantum efficiency	QE_s	Measurement
Integration time	t	150 ms
Transmission of the optical system	τ	0.9
Emissivity of the optical system	e	0.1
Optics temperature	T_L	300K
Dark current in units of electrons/pixel and	I_e	$2x10^{11}$ electrons/pixel-second
Read noise	R	700 electrons

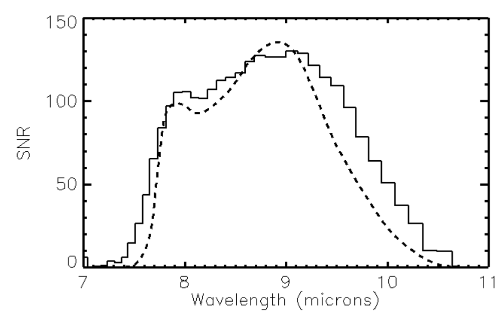

Figure 2. Measured SNR performance of the Sagnac interferometer with the cooled detector array (solid, histogram style line) and model performance using the equations above and the parameters in Table 2.

Conclusions: The two models reproduce the measured performance of real instruments within a few percent. Using these models we can extrapolate the use of these spectrometers with state of the art arrays to planetary applications.

References: [1] P. R. Griffiths, and J. A. de Haseth, *Fourier Transform Infrared Spectroscopy*, Chemical Analysis, vol. 83, Wiley, NY (1986).