Heterodyne Spectrometer Instrument (HSI) for Far-IR Spectroscopy Space Telescope (FIRSST)

Martina C. Wiedner[1*], Andrey Baryshev[2], Paul Grimes[3], Vicotor Belitsky[4], Vincent Desmaris[4], Yan Delorme[1], Juan-Daniel Gallego[5], Cristina García Miró[5], Paul Hartogh[6], Netty Honingh[7], Bernd Klein[8], Jean-Michel Krieg[1], Gary Melnick[3], Sebastiano Ligori[9], Boon-Kok Tan[10], Bertrand Thomas[11], Volker Tolls[9], Jeanne Treuttel[l], Jérôme Valentin[1]; David Clements[12], Ray Blundell[3], Asantha Cooray[13], Meredith McGregor[14]

***Abstract*—The Heterdyne Spectrometer Instrument (HSI) is one of two instruments on the Far-IR Spectroscopy Space Telescope (FIRSST) proposal to NASA. It would be the first heterodyne array receiver in space and has 3 frequency bands, each containing two 5-pixel arrays, one per polarizations. HSI uses high TRL (>6) components and is an innovative, but low-risk instrument.**

***Keywords*—THz, heterodyne array.**

I. INTRODUCTION

The Far-IR Spectroscopy Space Telescope (FIRSST) is proposal submitted to the NASA Astrophysics Probe Explorer call in Nov 2023. FIRSST will determine how planets form in disks, will explain how water arrives on planets, and how galaxy grow. FIRSST has a 1.8m cryogenically cooled mirror and carries two instruments: the Direct Detection Spectrometer Instrument (DDSI) employing MKIDs behind a grating or a VIPA, as well as the Heterodyne Spectrometer Instrument (HSI) described here.

II. THE HETERODYNE SPECTROMETER INSTRUMENT

The Heterodyne Spectrometer Instrument (HSI) is designed around the trail of water science case, which requires wide RF bandwidth to tune to many water lines, but only moderate IF bandwidth (4GHz) at high spectral resolution (up to 10^7), as well as some mapping capacity. With an international team from 6 European countries and the US we designed the HSI to have 3 frequency bands covering 500 to 790 GHz, 882 to 1250 GHz and 1500 to 2000 GHz. Each band has two 5-pixel arrays, one for each linear polarization. The optics directs the astronomical signal to all of the arrays simultaneously using dichroic filters and grids. HSI uses double sideband state-of-the-art superconducting mixers, SIS mixers for band 1, HEB for band 3; for band 2 currently both options SIS and HEB are pursued.

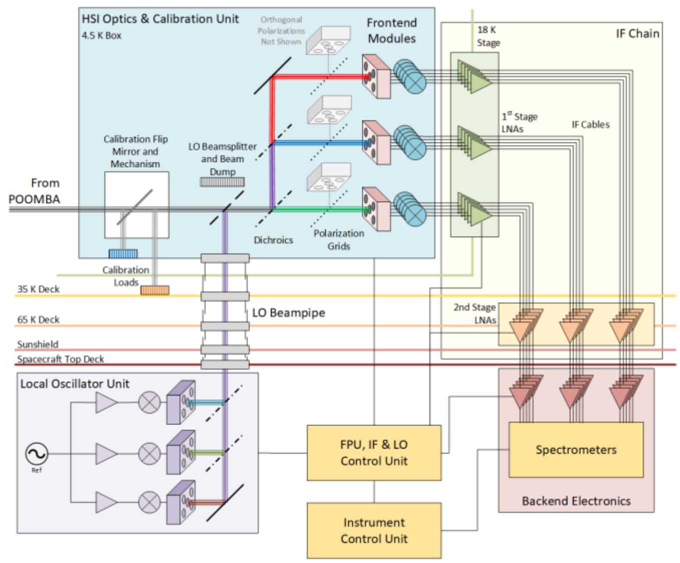

Fig. 1. Schematics of the Heterodyne Spectroscopy Instrument (HIS) on the Far-IR Spectroscopy Space Telescope (FIRSST) proposal. The light from the astronomical object enters the instrument on the left and is then superimposed with the artificial monochromatic signals from the three Local Oscillators. The Local Oscillator Unit is located in the warm space bus and consist of amplifier multiplier chains. Dichroics split the light into the three different bands. (Grids split the signal further into the two linear polarizations, so that 3 bands in 2 polarizations can be observed simultaneously (the components for the other polarization is not drawn, but there is a hint in light grey). In each band the signals (sky and local oscillator) are mixed and the beat signal is further amplified and then detected with spectrometers. The Instrument Control Unit steers the receiver and transmits the data to the central computer of the satellite.

[11]Observatoire de Paris, Paris, 75014, France, [2]Kapteyn Astronomical Institute University of Groningen, Groningen, Netherlands; [3]Center for Astrophysics Harvard & Smithsonian, Cambridge, *MA 02138*, USA; [4]Group for Advanced Receiver Development (GARD), *41296, Gothenburg, Sweden*; 5 Yebes Observatory, 19141 Yebes, Guadalajara, Spain; 6Max Planck Insitut for Solar System Research, Goettingen, Germany; 7Universitaet zu Koeln Cologne, Germany; 8Max Planck Institut fuer Radioastronomie, Bonn, Germany; 9NAF-OA Torino, Italy; 10Oxford University, Oxford, UK; 11 RPG, Meckenheim, Germany; 12Imperial College, London, UK; 13University of California, Irvine, CA 92697, USA; 14Johns Hopkins University, Baltimore, Maryland 21218, USA [*]Corresponding author (email: martina.wiedner@obspm.fr).

NOTES:

The biggest challenges for the design of heterodyne arrays in space are the limited availability of cryogenic cooling and electrical power. The cryogenic heat load is largely determined by the first amplifiers. For HSI we intend to use < 2mW InP amplifiers that will be heat sunk to the 18K stage, but are physically close to the 4.5K mixers. The subsequent IF will have further amplification around 70K and 300K. The electrical power consumption is mostly due to the spectrometer backends and the local oscillators. We selected Chirp transform spectrometers and autocorrelation spectrometers (ACS), very similar to those of SWI/JUICE, as backends, each requiring below 10W. HSI has amplifier-multiplier Local Oscillators, also building on the SWI/JUICE heritage. We attempt to limit the power consumption to below 2W per pixel. The Local

Oscillators is located in the space bus at ambient temperature and their signal is directed to the cold optics assembly via several baffles and filters in order to limit thermal radiation and stray light to the neighboring instrument. HSI is managed by an ICU, that controls the cold optics, mixers, LO, IF, and spectrometer subsystems. It also processes and transfers data and controls the calibration sequence. As the mission is very quick with a launch in 2032, HSI needs components with TRL > 6.

HSI has at least two observing modes: one mapping mode, where 10 pixels of one band will be observing simultaneously and scanned across the sky, and a multifrequency pointed observing mode, where all three bands will observe in both polarizations simultaneously, but only with 2 pixels (i.e. 3 x 2 x 2 pixels in total). During the pointed observations HSI will carry out a double pixel switch, so that one pixel is always on the astronomical object while the other is off-source.

In conclusion, it is now possible to design small heterodyne array receivers with high TRL components for future space missions.

HSI PARAMETERS				
PARAMETER		BAND		
		BAND 1	BAND 2	BAND 3
Wavelength (μm)		380 - 600	240 - 340	150 - 200
Frequency (GHz)		790 - 500	1250 - 882	2000 - 1500
Resolving power (λ/Δλ)*		10^6 to 10^7		
Beam size		52″ - 83″	33″ - 47″	21″ - 28″
Instantaneous FoV		300″×200″	150″×100″	150″×100″
Spectral channels*		1024 or 10,000		
Array size		5 pixels × 2 polarizations		
Aperture efficiency		80%		
Mixer Type		SIS	HEB	HEB
Receiver noise temperature (DSB)	CBE MEV Sci. Reqt.	60K 72K 80K	300K 400K 430K	400K 500K 525K
IF bandwidth		4GHz		
Optical bench temperature		4.7K with ±0.1K stability (not critical)		
LNA temperature (1^{st} stage)		18K with ±0.1K stability during Allan time		
Mixer temperature		4.7K with ±10mK stability during Allan time		
RMS WFE budget (nm)	Requirement Allocated Margin	<7500 3000 250%		

Fig. 2. Parameters of the Heterodyne Spectroscopy Instrument.

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