National Aeronautics and Space Administration

A 6U Monolithic Millimeter-wave Integrated Circuit (MMIC) Low Noise Spectrometer for Carbon Monoxide All-Sky Survey with a CubeSat

Principal Investigator: Lorene Samoska (386), P. Goldsmith (326), A. Tang (386), S. Padmanabhan (386), P. Kangaslahti (386), M. Alonso (386), Joshua Gundersen (U. Miami) Program: Topical

Project Objective:

In this work, we have designed a high-resolution millimeter-wave spectrometer into a package suitable for a CubeSat, for an all-sky survey instrument to study CO in our galaxy, called the CO Surveyor using MMICs (COSMMIC). The goal was an end-to-end millimeter-wave pixel, which could be proposed on a CubeSat. We have designed the instrument to be centered on the CO 2-1 transition at 230 GHz, using state of the art MMIC LNA technology (designed at JPL and fabricated at NGC) paired with a breakthrough CMOS miniature spectrometer. The MMIC LNAs with integrated spectrometer, along with the COSMMIC mission concept, will enable new science observations utilizing small satellites.

FY19 Results: We have designed an 18 cm on-axis Cassegrain system with a secondary reflector, 45 degree flat mirror, and calibration system, to have the instrument fit within the volume of a 6U CubeSat. The design of the instrument is shown in Fig. 1. The fixturing and alignment of the secondary reflector is critical to the optical performance, and so we have devised a scheme to fixture the secondary in place with three narrow metal struts, constructed inside a ring which mounts into a 30 cm x 20 cm frame, as shown in Fig. 2. The on-axis Cassegrain primary and secondary reflector system were simulated and found to have a beam efficiency of ~70%, with the beam pattern shown in Fig. 3. A prototype primary reflector (shown in Fig 2) was machined, and a feed was designed and has been tested. In addition, while we have LNA chips in-hand (the same LNAs that we designed for the TEMPEST-D CubeSat), we had an opportunity to design some new LNAs and mixer chips in NGC's 35 nm InP HEMT MMIC process. The new LNAs have been wafer probed and found to have more than 17 dB gain at 230 GHz. The opportunity to get new chips fabricated was important in order to try to design a subharmonic IQ mixer for 230 GHz, as this part is not available commercially. The mixer was also fabricated, and a mixer housing design has been completed. Chip photos are shown in Fig. 4. A Table of the instrument mass and power budget is shown below, dissipating < 10 Watts and under 3 kg.

Benefits to NASA and JPL (or significance of results):

The development of a compact, integrated high resolution spectrometer, centered at 230 GHz for the CO 2-1 transition will be a major breakthrough towards future instrument concepts for spectroscopy in astrophysics, enable new science observations, and provide a path toward future low cost science instruments and missions. No existing missions or ground-based telescopes can offer the nearly all-sky coverage essential for the science that would be enabled by this technology development. It is also the first demonstration of a millimeter-wavelength MMIC-based spectroscopic system that could fit in a CubeSat volume, and since only the front-end components of the systems would differ, is a precursor to other science missions at shorter wavelengths where the Earth's atmosphere is totally opaque.

Carbon Monoxide Surveyor using MMICs (COSMMIC)

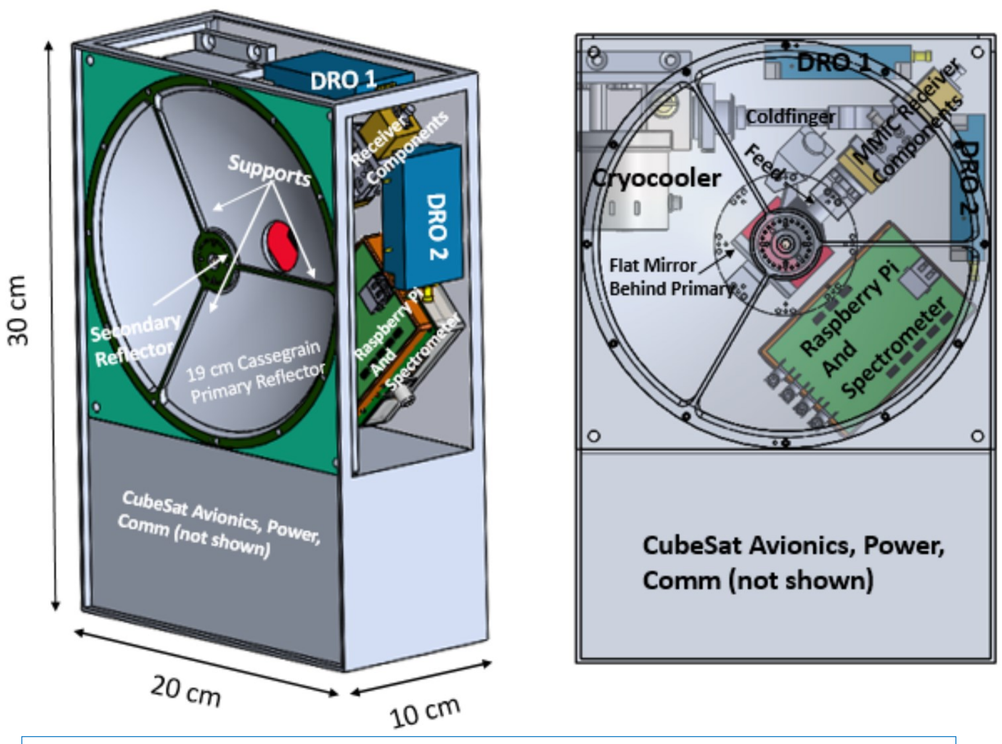


Figure 1. New design of COSMMIC instrument to fit into a 6U CubeSat using an 18 cm on-axis Cassegrain reflector.

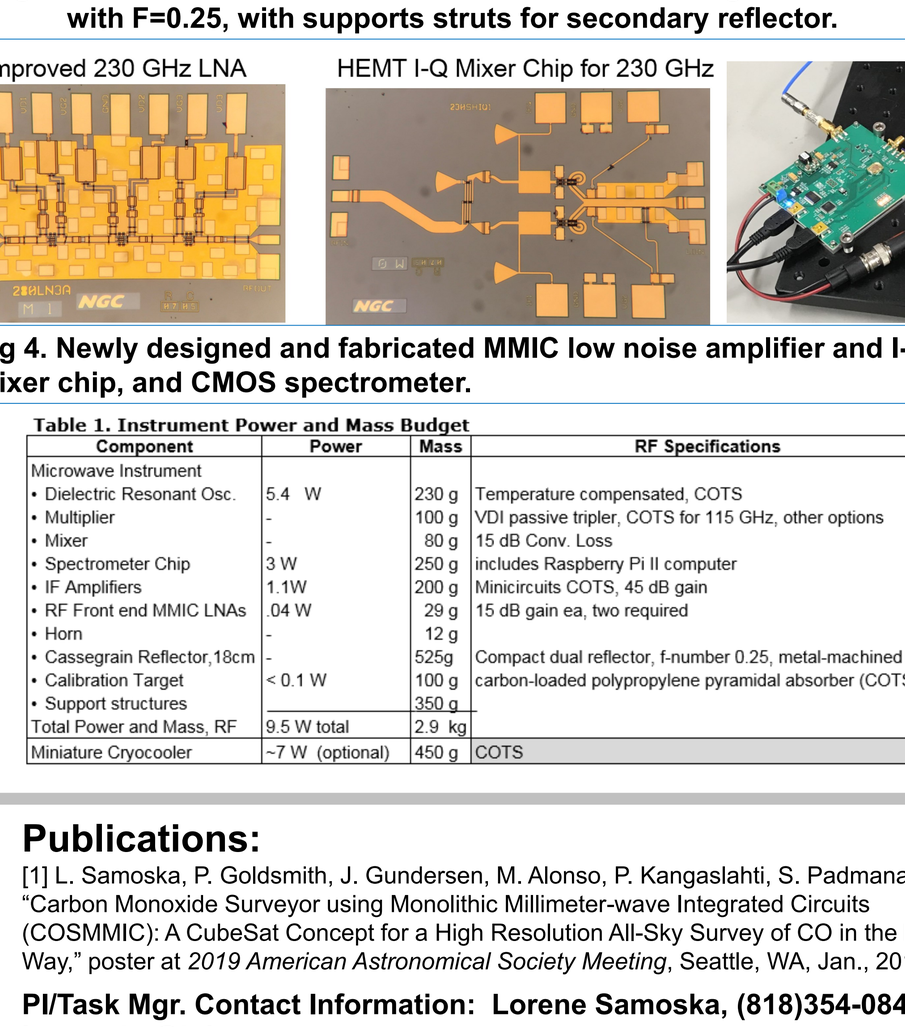
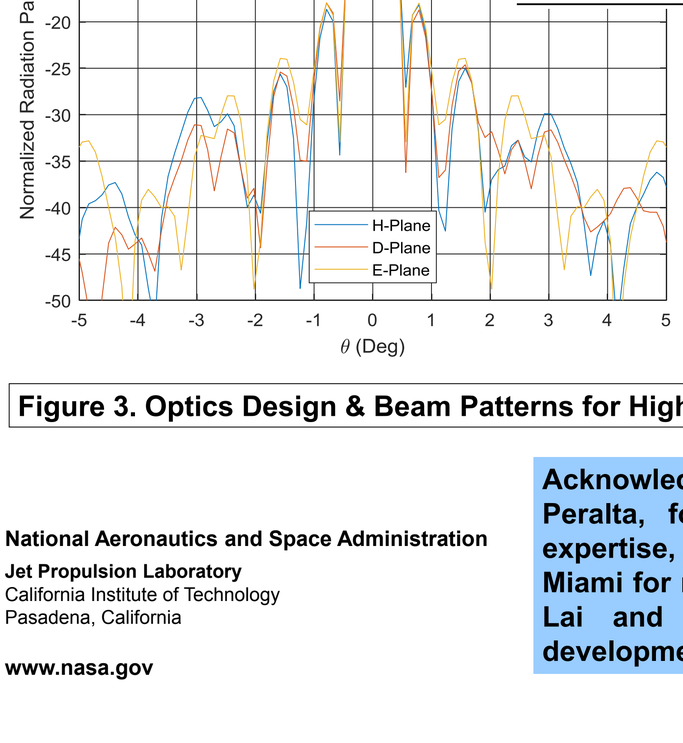


Figure 2. 6U CubeSat Frame with 18 cm on-axis Cassegrain reflector with F=0.25, with supports struts for secondary reflector.



Antenna Performance without Struts		With Struts
Directivity Main Beam	52.74 dB	52.73 dB
Efficiency Main Beam	77.55%	73.47 %
Total Directivity	51.63 dB	51.39 dB
Taper Efficiency	77.45%	73.31%
Gain	51.16 dB	50.89 dB
Aperture Efficiency	69.56%	65.33%

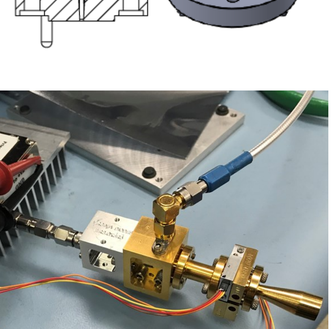


Figure 3. Optics Design & Beam Patterns for High Resolution Spectroscopy at 230 GHz

Improved 230 GHz LNA

HEMT I-Q Mixer Chip for 230 GHz

Fig 4. Newly designed and fabricated MMIC low noise amplifier and I-Q mixer chip, and CMOS spectrometer.

Table 1. Instrument Power and Mass Budget

Component	Power	Mass	RF Specifications
Microwave Instrument			
• Dielectric Resonant Osc.	5.4 W	230 g	Temperature compensated, COTS
• Multiplier	-	100 g	VDI passive tripler, COTS for 115 GHz, other options
• Mixer	-	80 g	15 dB Conv. Loss
• Spectrometer Chip	3 W	250 g	includes Raspberry Pi II computer
• IF Amplifiers	1.1W	200 g	Minicircuits COTS, 45 dB gain
• RF Front end MMIC LNAs	.04 W	29 g	15 dB gain ea, two required
• Horn	-	12 g	
• Cassegrain Reflector,18cm	-	525g	Compact dual reflector, f-number 0.25, metal-machined
• Calibration Target	< 0.1 W	100 g	carbon-loaded polypropylene pyramidal absorber (COTS)
• Support structures		350 g	
Total Power and Mass, RF	9.5 W total	2.9 kg	
Miniature Cryocooler	~7 W (optional)	450 g	COTS

Publications:

[1] L. Samoska, P. Goldsmith, J. Gundersen, M. Alonso, P. Kangaslahti, S. Padmanabhan, "Carbon Monoxide Surveyor using Monolithic Millimeter-wave Integrated Circuits (COSMMIC): A CubeSat Concept for a High Resolution All-Sky Survey of CO in the Milky Way," poster at *2019 American Astronomical Society Meeting*, Seattle, WA, Jan., 2019.

PI/Task Mgr. Contact Information: Lorene Samoska, (818)354-0849, lsamoska@jpl.nasa.gov

Acknowledgments: Mr. Robert Lin, Mr. Alejandro Peralta, for mechanical drawing and assembly expertise, Mr. Mohammad Najjar of the Univ. of Miami for mechanical drawing, & also Drs. Richard Lai and M. Barsky of NGC for InP MMIC development and fabrication.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Poster No. RPC-049