COSMMIC - Carbon Monoxide Surveyor using Monolithic Millimeter-wave Integrated Circuits on a CubeSat

Joshua Gundersen[1], Lorene Samoska[2], Paul Goldsmith[2], Adrian Tang[2], Maria Alonso[2], Pekka Kangaslahti[2], Joelle Cooperrider[2], Hans Kristian Eriksen[3], and Ingunn Wehus[3]

[1]University of Miami, [2]Jet Propulsion Laboratory California Institute of Technology, [3]University of Oslo

Abstract

We describe a mission concept of a CubeSat that will conduct an all-sky survey of Galactic carbon monoxide (CO). The scientific objectives of the proposed mission address two of NASA Astrophysics broad scientific questions; How did we get here? and How does the universe work? The Planck satellite showed for the first time the locations of the CO in our galaxy (Figure 1), including significant out-of-plane molecular gas, but it lacked the velocity information to quantify the CO kinematics since the spectral lines were completely unresolved. A modest aperture, high spectral resolution mission is required to determine the location and kinematics of the out-of-plane CO emission. Measuring the velocity of out-of-plane clouds will enable understanding of the role of the galactic halo in the ecosystem of the galaxy, and its contribution to star formation in the disk of the Milky Way. Star formation in the disk of our galaxy is directly linked to 'how we got here'. In addition, the resulting full-sky CO map will provide a unique template enabling separation of CO emission from polarized dust emission in ongoing and future cosmic microwave background (CMB) B-mode polarization experiments. A whole host of recent and ongoing CMB B-mode experiments (such as CLASS, Simons Array and BICEP Array) and future large scale efforts (such as CMB-S4 and LiteBird) will be susceptible to the same CO emission that generated spurious signals in the Planck maps and complicated Planck's ability to separate CMB, CO and galactic dust (Figure 4). If any of these experiments detect evidence of CMB B-polarization due to primordial gravitational waves, this will advance our understanding of 'how the universe works'. Prior knowledge of Galactic CO emission will significantly aid in these efforts.

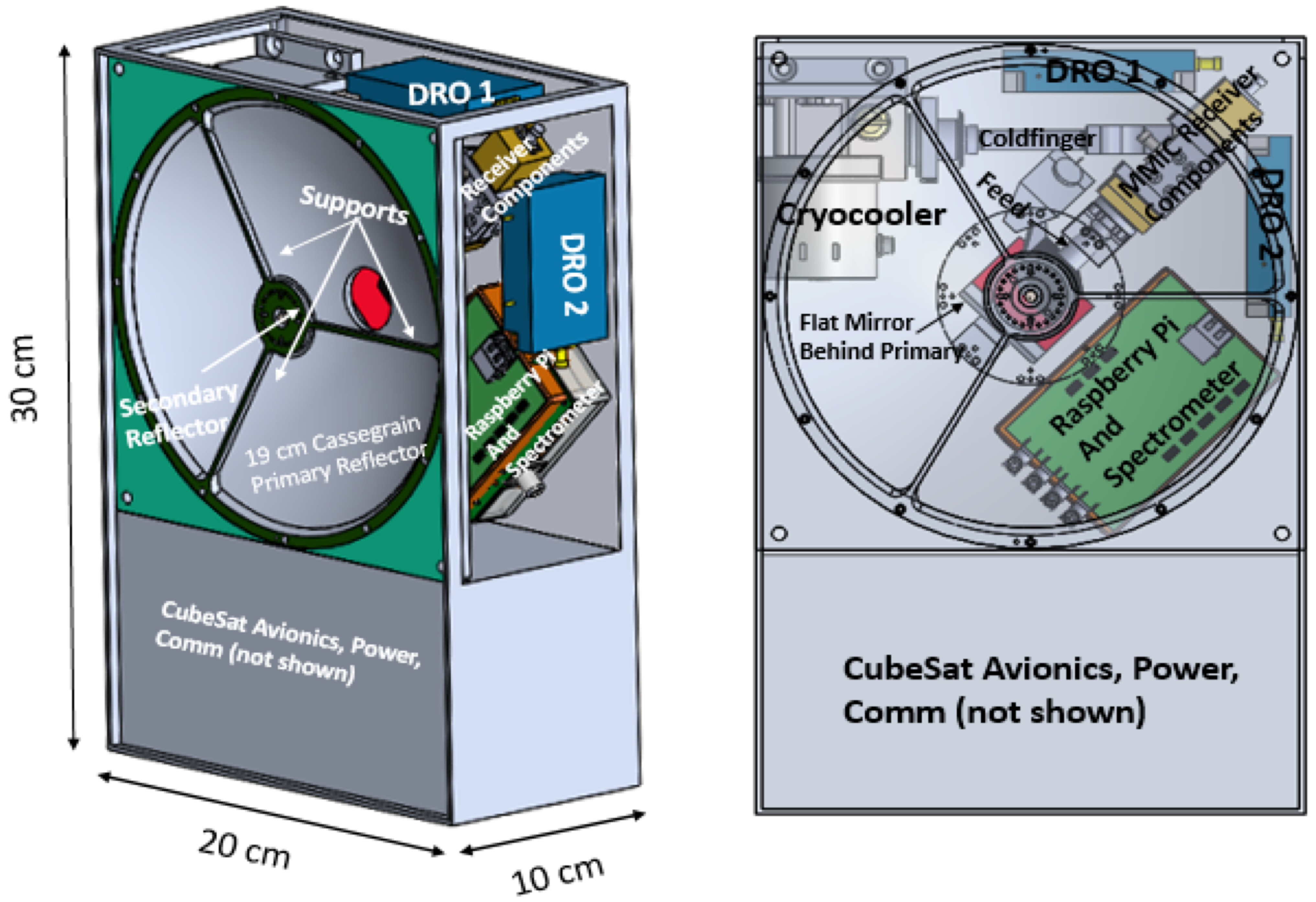

Figure 2. Preliminary design of the COSMMIC instrument designed to fit in a 6U CubeSat. A 19 cm diameter Cassegrain telescope couples incident radiation to the MMIC receiver components. These amplify and mix the signal down to a frequency suitable for the CMOS spectrometer. CubeSat avionics, power, solar panels, communications system not shown. Optional cryocooler shown for scale.

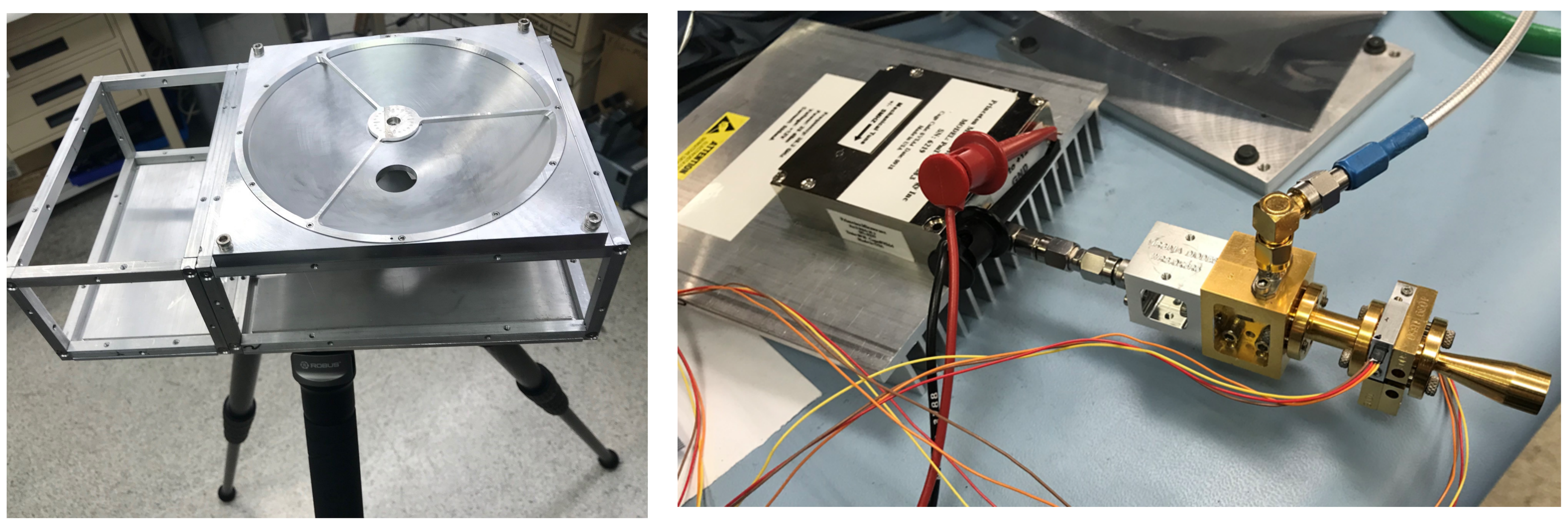

Figure 3. left: *COSMMIC's prototype Cassegrain telescope and 6 U enclosure shown on left, and* **right:** *COSMMIC's breadboard receiver and spectrometer being tested at JPL.*

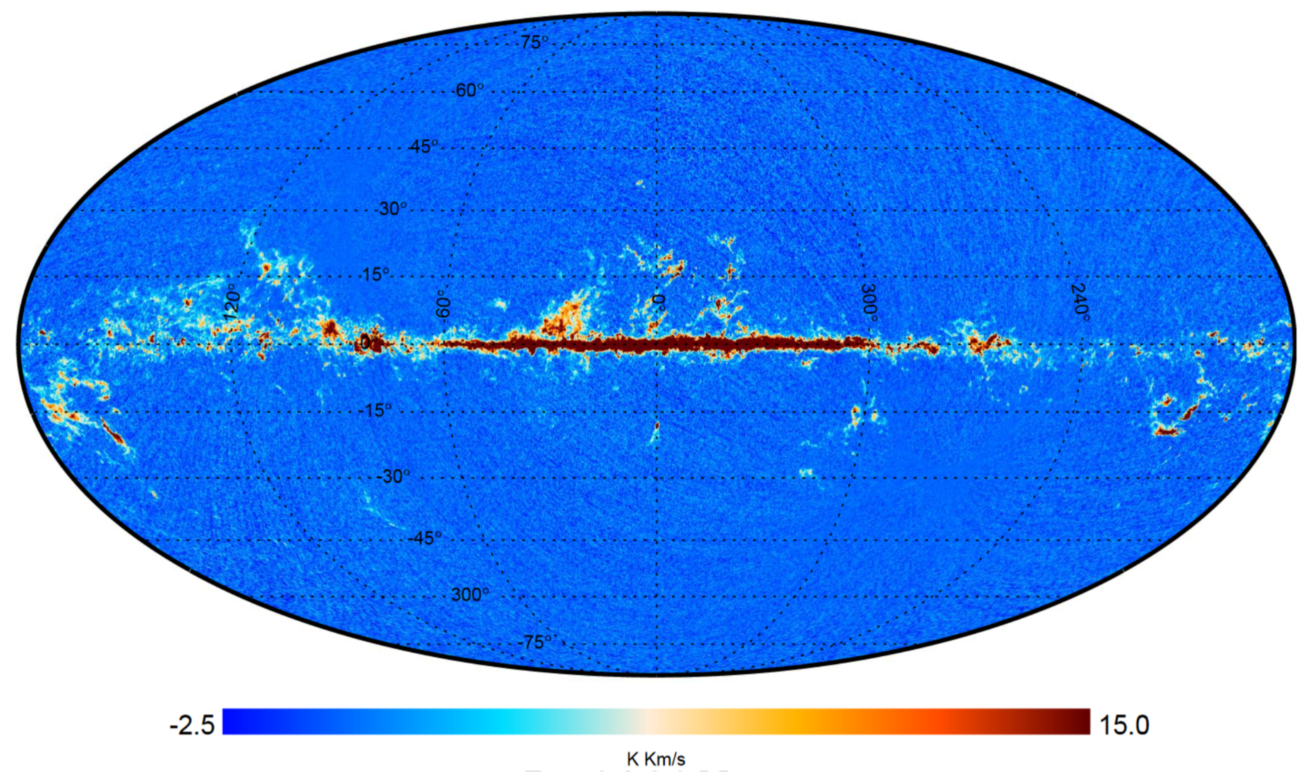

Figure 1*. Planck survey of CO in the Milky Way Galaxy (2013) Planck Collaboration[1].*

Mission Concept

Recent developments in small satellites enable low cost missions for carrying out surveys of individual molecular lines such as CO. JPL has played the leading role in developing the instrumentation we plan to use, including the monolithic millimeter-wave integrated circuit low noise amplifiers (MMIC LNAs) and mixers as well as the low-power spectroscopic analysis system. We have leveraged this in-house know-how to develop an instrument for a mission capable of achieving the science objectives in the abstract. This instrument is named CO Surveyor using a MMIC low noise receiver (or COSMMIC), and it uses a MMIC LNA receiver and low cost spectrometers coupled to a 19 cm diameter Cassegrain telescope shown in Figures 2 and 3. The receiver is sensitive to both the ^{12}CO line at 230 GHz and its isotopologue, ^{13}CO at 220 GHz. Both molecules were observed by Planck at high galactic latitudes and both contributed spurious signals to the analysis of the Planck CMB data as shown in the top of Figure 4.

The COSMMIC telescope provides a resolution of 30′ that is suitable to study the effects of CO on CMB B-mode measurements as shown in Figure 5. For Galactic science, this resolution enables the determination of the flux of mass onto and away from the galaxy as well as the measurement of column densities, kinematics, and cloud masses throughout the galactic plane. The unique features of the proposed CO surveys is that they will be all sky, will make use of a uniform, high precision calibration, and will be sensitive to two CO lines simultaneously, with the ^{13}CO survey of the Galactic Plane being the first of its kind. No existing missions or ground-based telescopes can offer the all-sky coverage with uniform calibration that is essential for the science goals. This will be the first astrophysics-focused, mm-wavelength spectroscopic system that can fit in a CubeSat. Since only the front-end components of the systems would differ, it is a precursor to other science missions at shorter wavelengths where the Earth's atmosphere is totally opaque.

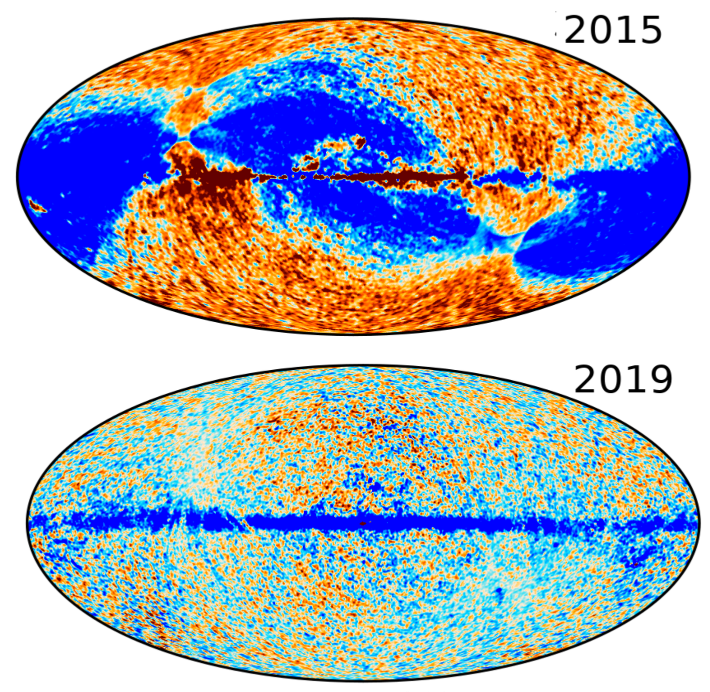

Figure 4*. Comparison of (data-minus-model) residual maps for one Planck 353 GHz channel before (top; Planck Collaboration XII 2015 [2]) and after (bottom; Planck Collaboration 2019, in preparation) modelling foreground-induced bandpass mismatch during mapmaking. The color range is ±10 μK for both maps.*

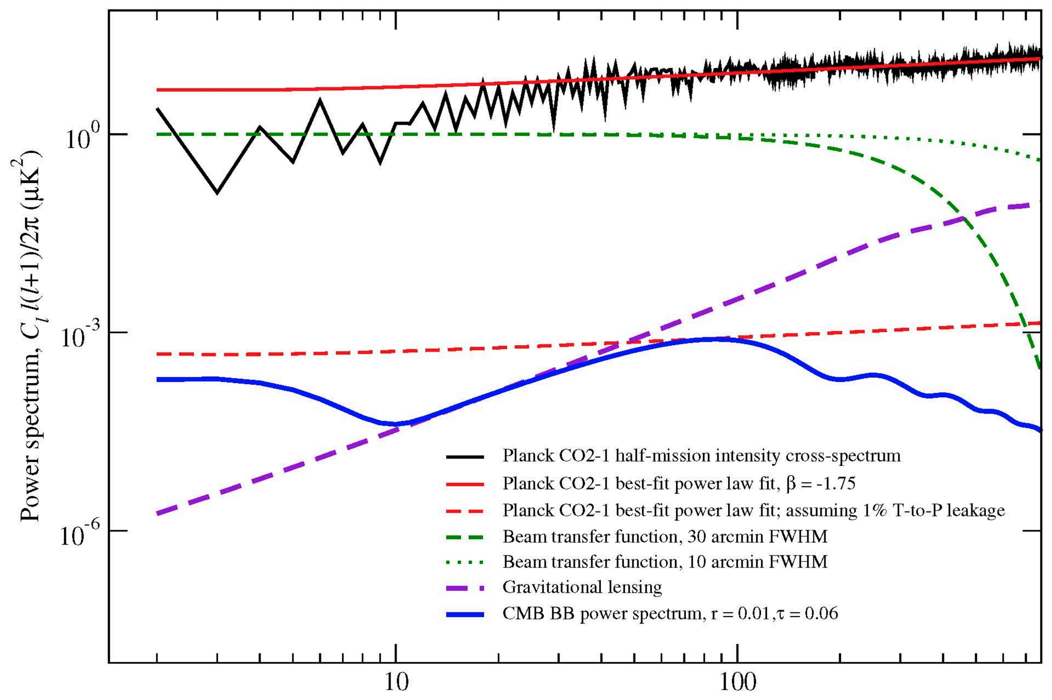

Figure 5*. Angular power spectra of the Planck CO2-1 emission (black) with a best fit power law spectrum (red) compared to the CMB BB power spectrum (blue). If an instrument has a temperature-to-polarization leakage of 1%, the resulting spurious `polarized' CO spectrum (dashed red) is larger than the CMB BB power spectrum at all angular scales. The baseline full-width half-maximum (FWHM) beam size of 30′ (dashed green) will measure CO structure out to multipoles of 200. This is adequate to remove CO emission at angular scales where the CMB BB spectra is expected to be largest.*

Bibliography:

[1] Planck Collaboration, Planck 2013 results. XIII. Galactic CO emission, *Astronomy & Astrophysics*, Vol. 571, 2014, A13.
[2] Planck Collaboration, "Planck 2015 results. XII. Full Focal Plane Simulations," *Astronomy & Astrophysics*, Vol. 594, 2016, A12.

Acknowledgments:

Mr. Robert Lin, Mr. Alejandro Peralta, for mechanical drawing and assembly expertise, and Mr. Mohammad Najjar of the Univ. of Miami for mechanical drawing. Dr. Richard Lai of NGC for MMIC fabrication

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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