X-Spec: A Multi-Object, Trans-Millimeter-Wave Spectrometer for CCAT

Scott C. Chapman[1], Charles M. Bradford[2], Eric Shirokoff[2], Steve Hailey-Dunsheath[2], XSPEC team

[1]Dalhousie University, Halifax, NS, B3H1R4 Canada

[2]California Institute of Technology, Pasadena, CA, 91125 USA 10pt

Abstract—X-Spec is a multi-beam, R=400-700 survey spectrometer covering 190-520 GHz under development for CCAT. It measure the bright atomic fine-structure and molecular rotational transitions that cool galaxies' interstellar gas, in particular, the 158 μm rest-frame [CII] transition which is accessible from z=9.5 to z=3.5, With the wide bandwidth and multi-object capability, X-Spec / CCAT will be more powerful than ALMA for redshift-blind galaxy surveys and tomographic intensity mapping. X-Spec uses SuperSpec filterbank spectrometer technology with TiN KIDs. Because the density of sources is small, galaxy follow-up will be most efficient with a front-end steering unit which we have prototyped. Our baseline instrument concept has 84 steered beams arrayed over the 1 degree CCAT field, each beam couples to 4 chips (2 bands x 2 polarizations) each chip with ~500 detectors, making a total of ~170,000 KIDs in the full instrument.

INTRODUCTION

The X-Spec instrument is a moderate-resolution (R=400–700), multi-beam survey spectrometer covering the 190-520 GHz band under development for the Cerro-Chajnantor Atacama Telescope (CCAT). It designed to probe galaxy growth and evolution throughout cosmic time, from the epoch of reionization, the era near the formation of the first galaxies in the Universe, to the present day. X-Spec will measure the bright atomic fine-structure and molecular rotational transitions that cool galaxies' interstellar gas. In particular, the 158 μm rest-frame ionized carbon ([CII]) fine-structure transition will be the primary tool for studying the early Universe with CCAT/X-Spec; it is accessible from z=9.5 to z=3.5, spanning the end of reionization and the early rise of star formation in the Universe.

I SCIENTIFIC METHODOLOGY

While the new millimeter interferometer, the Atacama Large Millimeter Array (ALMA), is more sensitive than CCAT X-Spec for a single object in a single line with the known redshift, CCAT/X-Spec will be more powerful for blind surveys of large numbers of galaxies. Targeting sub-samples of galaxies such as those which seem to be at the largest distantances, or highest redshifts based on submillimeter colors, X- Spec will survey tens of thousands of galaxies over its lifetime. Bright sources will have individual [CII] detections, immediately providing redshifts. With redshifts in hand (via X-Spec or other means), spectral stacks in sub-samples can reveal the other fine-structure lines which reveal the conditions in the ionized gas around the newly forming stars and black holes. X-Spec on CCAT will also undertake blind spatial-spectral [CII] surveys to reveal the 3-D large-scale structure as a function of cosmic time.

II INSTRUMENT TECHNOLOGY

X-Spec will employ the superconducting lithographically-patterned on-chip spectrometer we call SuperSpec. SuperSpec is a novel, ultra-compact spectrometer-on-a-chip for millimeter and submillimeter wavelength astronomy, consisting of a filter bank made from planar, lithographed superconducting transmission line resonators. Each mm-wave resonator is weakly coupled to both the feedline and to the inductive portion of a lumped element Kinetic Inductance Detector (KID). We will discuss several related laboratory tests of prototype SuperSpec devices, including the ongoing optical characterization of small filter banks and tests of several new device designs featuring twin-slot antennas with silicon lenses and modified mm-wave architecture. Each X-Spec chip spectrometer will be a silicon die on order 10 square cm in size, it will couple the submm-wave radiation from a single CCAT beam (in a single polarization) to ~500 channels covering a ~1:1.65 bandwidth. Detectors are titanium-nitride (TiN) lumped-element kinetic inductance detectors (KIDs) as for the CCAT cameras, but with smaller-volume inductors and lower-Tc TiN to provide the required low noise-equivalent power (NEP) of 3e-18 W/sqrt(Hz).

For following up individual galaxies, the density on the sky is 0.001 to 0.1 per CCAT beam. Thus at present, X-Spec is best implemented as a steered multi-object spectrometer (MOS). We have designed and prototyped a positioner system to couple a single beam to an arbitrary position on the sky within a few-arminute 'patrol region.' In the currently-envisioned implementation, 84 of these positioners will be mounted to the front of the cryostat, each coupled to a 2000-detector module. We describe the opto-mechanical subsystems and optics of this positioner system, and tests of it's functionality and precision.

REFERENCES

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