Snowmass2021 - Letter of Interest

On-chip spectrometers for long walvength photon detection

Thematic Areas:

■ (IF2) Photon detectors (primary)
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
■ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before

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Abstract:

Recent advances in both detector design and low-loss lithographic transmission lines make possible a new class of ultra-compact spectrographs-on-a-chip for millimeter and submillimeter wavelength astronomy. Their very small size, wide spectral bandwidth, and highly multiplexed detector readout will enable construction of powerful integral field unit spectrometers capable of mapping the spectral lines from high-redshift galaxies and providing a wealth of information regarding the early Universe.

Introduction

As discussed in other LOIs, there is a wealth of information regarding the early Universe which can only be observed using spectroscopic instruments operating at millimeter and submm wavelenth.[1–3]. Line intensity mapping (LIM), in which atomic and molecular spectral lines from early galaxies are mapped in both space and redshift has the potential to measure large-scale structure well beyond the reach of optical galaxy surveys, improving cosmological constraints from large-scale structure (LSS) measurements. Mm-wave LIM builds on the successful heritage of cosmic microwave background (CMB) experiments, which over the last 30 years have demonstrated precise, background-limited measurements of faint, diffuse structure over large sky areas with low systematics.

Currently deployed technology - grating spectrometers and Fourier spectrometers - provide a wealth of astronomical information about individual objects and will soon make the first intensity mapping detections at mm-wavelength[4,5]. However, in order to reach the depth of observations required for precision cosmological science, hundreds to thousands of pixels, each containing hundreds of spectral channels are necessary. Such instruments will require extremely dense focal planes containing many hundreds of thousands of detectors. The most promising technology to achieve this is the use of an array of on-chip spectrometer.

Technology and state of the art

Several approaches to on-chip spectroscopy exist at a range of technological readiness. Two examples, the recently deployed DESHIMA and soon to be deployed SuperSpec instruments employ a filter bank consisting of planar, lithographed superconducting transmission line resonators. Each mm-wave resonator is weakly coupled to both the feedline and to the inductive portion of a Kinetic Inductance Detector (KID). Incoming mm-wave radiation breaks Cooper pairs in the KID, modifying its kinetic inductance and resonant frequency, allowing for frequency-multiplexed readout. The designs are realized using thin film lithographic structures on a silicon wafer, with either aluminum or titanium KID resonators. Laboratory demonstrations of a similar design constructed using transition edge sensors (TESes) have been carried out as part of the TIME instrument[6–8].

There are three alternative techniques currently in development. The first uses multi-path interference within waveguide to effectively create a virtual grating, as demonstrated by the microSpec project. The second is the design of an on-chip Fourier transform device using microstrip whose wave-speed can be adjusted using an external bias[9]. The third is the design of a filter bank spectrometer using free-space transmission elements, either machined in metal blocks as in W-SPEC or fabricated from micromachined silicon structures[10].

Opportunities

While there are several laboratory demonstrations and near-term or recently deployed instruments which employ this technology to make pointed observations with a small number of pixels, cosmological results will require scaling this technology to include hundreds to thousands of pixels, as well as additional development of microwave readout technology to accommodate these arrays. A number of proposed projects which will allow for intensity mapping are currently in development, including near-term instruments for the South Pole Telescope and the Large Millimeter Telescope, as well as collaborations working to design deploy much larger future instruments.

References

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