WSPEC: A waveguide focal plane array spectrometer for millimeter wave astronomy and cosmology

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James Aguirre at UPenn
George Che, Philip Mauskopf, Christopher Groppi at ASU
Simon Doyle at Cardiff
Daniel Flanigan, Bradley Johnson, Glenn Jones at Columbia
Alessandro Monfardini at Institut NÉEL
Tony Mroczkowski at NRL
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Heather McCarrick’s talk

Daniel Flanigan’s Poster
CII/CO and SZ Science in mm-waves

CII is 0.1-1% of FIR Light from Galaxies

CII and CO lines in High-z Galaxies
(Carilli and Walter
Rev. AA 51:105-161 2013)

Peculiar Velocity of Galaxy Clusters with kSZ
(Mauskopf et al.

Cross-correlation among instrument frequencies for CO intensity mapping

Figure 1. The individual contributions to the interstellar cooling \(n(X)/n(H)\cdot L(X)/\tau\) by electron impact excitations.
Enabling Technology

- Spectroscopy
  - \( R \sim 200 \) for intensity mapping
  - \( R \sim 600-1000 \) or higher for individual objects

- Imaging
  - Wide field surveys for objects and intensity mapping
  - **Focal plane arrays** for higher mapping speed

- On-chip grating: MicroSpec
- Waveguide grating: Z-Spec
- On-chip filter banks: SuperSpec, DESHIMA, CAMELS
- Waveguide filter bank: **WSPEC**
- Imaging FTS is also possible
Prototype Device

Input from Feed Horn

Narrow Coupling Section

Resonant Section

Narrow Section

Output to Thru Detector

Rounded Corners from Machining

(0.015” for WR10)

(0.005” for full instrument)
Fabrication

• The LEKIDs are a single aluminum layer and a ground plane
  • University Cleanroom
  • Foundry Service like Star Cryo

• Feed horns, backshorts, and spectrometer are precision CNC milled. Split-block.
  • ASU Group
  • Precision Machine Shops
Measurement Setup

- Filters
- Main Waveguide
- Programmable Multimeters
- WR-10 VNA Extender
- Pyramidal Horns
- Test Pixel
- Diode Detectors
- Signal Generator
Prototype Device

- High Efficiency
  - Ideal ~ 50%
- Center Frequencies agree within 0.5%
- R is within 20%
- Out of band is about -25 dB

Measurements and Model in Bryan et al. IEEE Trans. THz DOI:10.1109/TTHZ.2015.2433919
Detector Model

- Aluminum LEKID detectors
- Simulated optical efficiency and reflection is good
- Include non-ideal termination effects in full spectrometer model
Cascade Channels

- 54 channels fill the single-moded passband at R=200
- Interpolate between hand-tuned designs to get dimensions for each channel
- Cascade individual channels together
  - Terminate with physical simulated detectors to get full model
  - Includes simulated optical efficiency of the detectors
**Full Device Model**

- Good optical efficiency
- Out-of-band at -25 dB
- Center Frequencies and profiles look good
Science Array

• WR4 and WR6 would enable CO/SZ science
  • Avoid atmospheric lines
  • Use a few channels as atmosphere monitors

• Diplexer for two bands under one horn
  -or-

• Dichroic (pictured)

• Would have 1,350 LEKID detectors
Beyond 50%...

- Nominally, all filterbanks are limited to ~50% optical efficiency per channel
- Each channel could have its own narrow band backshort, enabling in principle 100% optical efficiency
- Concept should work for any filterbank (e.g. SuperSpec, DESHIMA, WSPEC)
- Great for sparse filterbanks
- Design optimization for fully sampled filterbank underway
Conclusions

• Millimeter and sub-mm spectroscopy is a window on galaxies, reionization, and structure formation
• WSPEC is a compact focal plane architecture with proven technology that enables high mapping speed for spectroscopic surveys
• The WR10 prototype performs well, and we have a design and physical model for a science array
• Next steps:
  • WR5 prototype to verify higher frequency performance
  • Continuing aluminum LEKID testing and development
  • Build a LEKID-based device soon
  • Per-channel backshorts to increase optical efficiency
Scaling to Higher Frequencies

- Conductor loss limits the maximum quality factor (i.e. resolution) of the waveguide cavity

\[ \frac{1}{R_{tot}} = \frac{1}{R} + \frac{1}{Q_{loss}} \]

- ASU precision machine shop can achieve 1 micron tolerance

- \( R = 200 \) achievable below \( \sim 700 \text{ GHz} \)