Studying the influence of magnetic fields in star formation with submillimeter polarimetry

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Abstract
Submillimeter polarimetry provides an effective means of studying the role of magnetic fields in the earliest, highly obscured stages of star formation, via the polarized emission from aligned elongated dust grains. The Cardiff Astronomy Instrumentation Group has pioneered the development of submillimeter and millimeter-wave polarimeters by designing, manufacturing, and testing crystal and metal-mesh achromatic half-wave plates (HWPs), as well as their dielectric and meta-material anti-reflection coatings. These cutting-edge technologies have been successfully implemented in several ongoing experiments (e.g., BLAST-Pol, SCUBA-2, PILOT). Here we review the BLAST-Pol polarimeter and its ability to recover Stokes Q (or U) from a single scan, while different HWPs positions allow measurement of the other one through polarization rotation. We also present a new method to account for the HWP non-idealities in the map-making algorithm, which we have implemented to obtain polarization measurements of unprecedented accuracy at 250, 350, and 500 μm.

Submillimeter polarimetry
• measure direction and strength of the plane-of-the-sky component of the magnetic field by tracing the linearly polarized thermal emission from aligned dust grains
• probe the role of magnetic fields in dust-enshrouded star-forming molecular clouds in our Galaxy
• the combination of maps obtained with experiments such as BLAST-Pol and SCUBA-2 will trace magnetic structures in the cold ISM from scales of 0.01 pc out to 5 pc, and help discriminate between models of star formation driven by magnetic fields or turbulent gas flows

Optimal polarization recovery strategy
• differences of adjacent detectors give Q, but require accurate knowledge of their optical efficiencies /and suffer from 1/f noise
• the presence of a HWP compensates for the above effects, and provides polarization modulation to recover U without grids at 45/135º
• take differences of adjacent detectors, at two HWPs positions that are 45º apart:

\[
\text{HWP angle } \left[0, \frac{\pi}{2}\right] \\
\text{HWP zero angle } \left[0, \frac{\pi}{2}\right]
\]

the photometric equation for a real HWP

\[
d_\text{HWP} = \sum_i \left[ d_i \left( \theta = 0 \right) - d_i \left( \theta = 45\degree \right) \right] + d_i \left( \theta = 0 \right)
\]

HWP Mueller matrix vs frequency @ 4K

Dichroic filters

BDAs

Lyt-stop

HWP rotator with baffle

data cube (spectra/rotation) – HWP @ 120K

Conclusions
We have presented the polarization modulation scheme that has been successfully retrofitted on BLAST-Pol. We have performed a full spectral characterization at cryogenic temperatures, of the five-plate sapphire BLAST-Pol HWP, which is, to our knowledge, the most achromatic ever built at mm and submm wavelengths. We have found that most of the non-idealities of the HWP assembly can be accounted for by quantifying one frequency-dependent parameter, the position of the equivalent axes of the HWP, as a function of the spectral signature of a given astronomical source. We have subsequently included this parameter in the BLAST-Pol map-maker. BLAST-Pol has completed in January 201 its first successful 9.5-day flight over Antarctica, mapping ten star-forming regions with unprecedented combined mapping speed, sensitivity and resolution. These maps comprise an exciting dataset for studying the role played by magnetic fields in star formation. The polarization maps are currently being finalized, stay tuned at http://blastexperiment.info/