Development of data analysis method and image synthesis pipeline for 100GHz band Nobeyama 45m MKID Camera
（野辺山 45m 鏡 100GHzMKID カメラのデータ解析法と画像合成パイプラインの開発）

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Summary

In this thesis, we present a raw data handling and image synthesis pipeline for the 100GHz-band Microwave Kinetic Inductance Detector (MKID) camera designed for Nobeyama 45m telescope. The camera is being developed for distant galaxy survey and survey of the massive star-forming regions in the Galactic plane at 3mm wavelength. This wavelength has some advantages for observing high redshift distant galaxies and a good tracer for star-forming regions in the local galactic plane.

The MKID camera records observed intensity in terms of the shift of the resonance frequency, unlike conventional radio telescope receivers. The frequency-shift needs to be converted to proper units for astronomical measurements, with a method unique to MKID devices. Since the MKID camera is a multi-array detector with a large field-of-view, all pixels in the detector observes the sky simultaneously at different locations. Due to such distinctive features, more control is required over the data analysis as well as image synthesis methods.

In order to satisfy these requirements, we propose a dedicated data analysis and image synthesis pipeline designed specifically for the MKID camera. The pipeline consists of several new methods and algorithms that have been created from scratch and bundled into a software package written in Python along with some adaptation and implementation of previously existing methods. These tools provide the user with a wide range of necessary functions required for data reduction, noise removal, and image synthesis from the raw data acquired during an observation.

The data acquired by the MKID Data Acquisition System (DAQ) contains contamination from sky fluctuations and electronic variations during the readout, and requires the removal of such signatures. Since in the case of the MKID camera, all individual pixel's frequency-shift value experiences similarly related effects from sky fluctuations, electronic readout voltage changes, etc., the readout data from each pixel are correlated. Decorrelation methods such as Principal Component Analysis (PCA) has been in use for decorrelation in data science and statistical analysis to reduce the dimensionality of the data. However, it is not ideal for direct implementation on the data. This thesis proposes a new decorrelation algorithm based on PCA method called ChunkPCA. We discuss the effects of ChunkPCA on improving signal strength loss and removing artifacts.

To calibrate the frequency-shift raw data from the MKID camera into antenna temperature, T_a*, is also a major requirement. We propose a calibration method and verify that the calibration is correct by deriving the Main Beam efficiency, η_{mb}. It is cross-checked with the values of previously published results. The pipeline workflow is designed to store the cleaned and calibrated data in a file for later use, as it can be used for beam measurements and image synthesis.

The other requirement for image synthesis is the antenna pointing coordinates. The recorded values from the telescope collimators and controllers are compiled into a single file. The pipeline workflow integrates the calculations for the conversion of the antenna pointing coordinates to rectify the pointing offset using different columns of the antenna log and give the proper pointing coordinates.

We confirm that the previously obtained intensity values and the pointing coordinates can be used for image synthesis. For this purpose, the thesis uses a recently developed versatile convolution-based gridding tool called Cygrid. This has an added benefit to the project since it supports Hierarchical Equal Area isoLatitude Pixelation of a sphere (HEALPix) and World Coordinate system (WCS), which will be useful to compile survey data. We also demonstrate and compare the effects of different gridding parameters.

To verify the functionality of the gridding system, we use data from a Mars observation from the 2nd commissioning of the camera from June, 2018. The gridding algorithm is implemented to produce Single-pixel Beam-maps, and Combined Beam-maps. We analyse the Beam-shape, Beam-size, and Beam-position for individual pixels, and verify it with the simulated results. Utilizing the above Beam characteristics and the WCS support of the gridding algorithm, a Sky-map with celestial projection in the RA-Dec coordinate is also generated.

Finally, we discuss the synthesized images and use them to perform a quantitative analysis of the MKID camera by checking the Beam characteristics. We also check for the improvements caused by the new ChunkPCA method for a quantitative analysis of decorrelation using the images obtained. The cleaned data are compared side by side to demonstrate the artifacts removed in the time-series data, as well as the synthesized images. We verify the reduction in the RMS of the Combined maps as more maps are combined together. Additionally, other tools incorporated into the pipeline specifically designed to use the MKID detector frequency-shift values are discussed. It can be used to obtain other important quantities such as atmospheric opacity constant τ.