Temperature map of the galactic plane based on infrared wavelength intensity across 5 bands

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**ABSTRACT**

When studying deep sky objects such as H II regions (regions of ionized hydrogen), molecular clouds, or stellar nurseries, it is very useful to know general temperatures for the region being studied. The Hi-GAL dataset can be used to generate such temperature data. The Hi-GAL dataset includes data for 5 different infrared wavelengths (70, 160, 250, 350, and 500 micron). Using a subset of this dataset, we analyzed the differences in intensity in these wavelengths, and then used these differences to create a temperature map of that subsection of the galactic plane.

**CCS Concepts**

• **Applied computing → Physical sciences and engineering → Astronomy**

**Keywords**

Galactic plane temperature; Hi-GAL; Herschel; galactic temperature map

# INTRODUCTION

Blackbody radiation, such as that from interstellar dust clouds, can be used to determine an approximate temperature of the emitting body using Wien’s Law (Fritzsche, 2016). This radiation is emitted at varying wavelengths, with the peak wavelength being the wavelength at which the most light is emitted. It is this peak wavelength that can be converted to an approximate temperature using Wien’s Law. For each data point, we attempted to match the intensities of each of the 5 different wavelengths to a normal blackbody radiation curve to determine the peak wavelength (and its corresponding temperature) for that data point. We would then have been able to generate an accurate temperature map based on the calculated temperature for each data point. However, we had to use a backup method to analyze the data giving us less accurate, but still valuable results.

There have been several studies that used these infrared wavelengths to look at and generate temperature maps for a portion of the galactic plane, but not at this resolution or for this much of the galactic plane. Although we did not generate results for the entire Hi-GAL dataset, we did succeed in generating results for one quarter of the dataset.

# MOTIVATION

The Hi-GAL dataset is relatively new and holds a great deal of promise in areas of research including star formation and molecular dust cloud structure. A temperature map of the galactic plane would provide a basis to perform deeper analysis and be very useful in identifying areas of further research.

# RELATED WORK

There have been numerous analyses involving the Hi-GAL dataset, but relatively fewer dealing with creating a temperature map of the galactic plane. Here are a few of the most pertinent:

## Dust temperature maps of the Galactic plane by Zhu J. and Huang M.

This study used both the radiative transfer code, Cloudy, and the DustEM dust model, to analyze the dust continuum emission in two Hi-GAL science-demonstration phase (SDP) fields to explore the effect of radiative transfer on dust temperature. The authors were able to derive dust temperature maps of the two SDP fields by comparing the observation with the Cloudy and DustEM model predictions. They concluded that the FIR SED of the SDP fields is affected by the radiative transfer, resulting in a higher temperature distribution than the dust-only fit. They also confirmed that the star formation field has a higher temperature than the non-star formation field. (Zhu, 2014).

This study is similar to what we have done here in that they performed some temperature mapping, but different because they were specifically looking at the effect of radiative transfer on dust temperature. Our work focused on the map making itself, and covered a larger area than this study.

## Mapping the column density and dust temperature structure of IRDCs with Herschel by Peretto N., Fuller G. A., Plume R., et al.

This study uses the first Herschel data from the Hi-GAL galactic plane survey to map dust temperature and column density of Infrared Dark Clouds (IRDCs). The authors used a gray-body function to analyze a sample of 22 IRDCs and found that dust temperatures decrease significantly within those IRDCs, and that those decreased temperatures corresponded with areas of dense stellar dust, indicating possible massive prestellar core candidates.

This study is also similar to what we have done here in that they performed some temperature mapping. This study is different in that they also looked at dust could density and possible prestellar core candiate areas. Our work focused on making the temperature maps, and covered a larger area than this study. (Peretto, 2010).

## Temperature as a third dimension in column-density mapping of dusty astrophysical structures associated with star formation by Marsh K. A., Whitworth A. P., and Lomax O.

This study produced resolution-enhanced image cubes of differential column density as a function of dust temperature and position using images of dust continuum emission at multiple wavelengths. (Marsh, 2015).

Again, this is similar to what we have done in that they performed some temperature mapping, but different that they also looked at dust could density. Our work is focused on the map making itself, and covered a larger area than this study.

# DESIGN AND IMPLEMENTATION

## Data and Data Management

The Hi-GAL dataset is in the FITS (Flexible Image Transport System) file format, and is approximately 13 GB of data, with roughly one billion data points. The relevant attributes of the data are galactic latitude, galactic longitude, intensity, wavelength, and angular size, all of which are numeric and discrete data types. Three different instruments aboard Herschel collected the data, each generating different resolutions. This caused there to be missing data for some wavelengths in certain areas, and Galactic latitude and longitudes did not line up perfectly across the different wavelengths. It should be noted that this is a private dataset. Thanks to Professor John Bally (Department of Astrophysical and Planetary Sciences, CU Boulder) for giving us access to the data, and permission to use the data in our report.

To manage and work with the data, we used Montage: a tool kit developed at IPAC (Infrared Processing and Analysis Center, at Caltech) and used for preprocessing and producing images from FITS files. We also used AstroPy, which contains a library for working with FITS headers and FITS data arrays within Python. The Python library SciPy contains the curve\_fit function, which we intended to use to match our data points to a corresponding temperature.

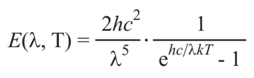
## Preprocessing

Using Montage, we processed the data to align each wavelength’s dataset with the galactic coordinate system. This preprocessing consisted of taking our raw data as input and exporting new FITS files that were of the same angular size for each data point which addressed our resolution problem. The preprocessing also realigned the data so that each image was aligned to the same exact galactic coordinates. This was necessary in order to compare the different wavelengths during the data analysis step later on.

One small subsection of the data turned out to be anomalous to the extent that it was unusable, so it was necessary to use backup data that we also had in our possession. However, the backup data had a problem of its own: it contained zero values where the other files would have had NaNs (Not-a-Numbers). This caused issues during reprojection, so it became necessary to do some preprocessing to transform the zeros to NaNs. The Montage package includes a module that should have been able to help us with this transformation, however at the time of discovery the module was not working properly. We contacted Montage’s senior software engineer who then made changes to the module, and we were then able to reproject the data using the backup data.

## Analysis Techniques

We originally wanted to use SciPy’s curve\_fit function to match our data points to the blackbody radiation cure defined by the equation:



where h is Planck’s constant, c is the speed of light in a vacuum, λ is the wavelength in meters, k is Boltzmann’s constant, and T is temperature in Kelvin.

Unfortunately, we were unable to generate usable data with the curve\_fit function. We have identified a possible reason for this. The blackbody radiation curve is fairly flat in the temperature and wavelength ranges we are dealing with, making it difficult for the curve\_fit function to return valid data. Fortunately, we had a backup plan in place. Instead of using the curve\_fit function, we simply mined the data for the max intensity wavelength for each data point and generated new FITS files for each wavelength. The new files contained data for only those galactic coordinates that corresponded to max intensity values. We then correlated the max intensity values to their corresponding temperature values. While this backup method did allow us to generate results, we realize that this method is considerably less accurate than matching data to an actual curve generated by the blackbody radiation equation. Specifically, we were only able to find local maximums across our wavelength ranges and we then used that as our peak wavelength value. There certainly could have been global maximum wavelength values that fell outside of our wavelength range, meaning our local maximum wavelength values were not the true peak wavelength values.

# EVALUATION

## What we learned

# PROJECT CHECKPOINT

## Review of proposed work

We plan on extracting data from the Herschel Hi-GAL dataset in order to make a temperature map of the galactic plane. We want to match each data point to a corresponding black body radiation curve. The black body radiation curve will give us a peak wavelength, which can then be converted to a temperature value to be used for map generation. Our subtasks are to: mosaic the existing data, determine our method of pattern matching, and develop code to convert the data into their corresponding temperature values. Our final task will be to use the temperature values to create the temperature map.

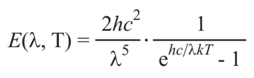
## Accomplishments so far

### Mosaicked existing data

We have mosaicked the data using Caltech’s Montage software for all 5 wavelengths.

### Determined method of pattern matching

We are going to use SciPy’s curve\_fit function to match the data points (wavelengths and intensities) to a blackbody radiation curve. The curve\_fit function will output a corresponding temperature value based on the data. The black body radiation function we will be using is:



Where h is Planck’s constant, c is the speed of light, k is Boltzmann’s constant, E(λ, T) is the intensity as a function of wavelength λ and temperature T. The intensity and wavelength values will be obtained from the data set and fed into the curve\_fit function to generate a corresponding temperature.

### Started writing code for the pattern matching

We have started writing the code for pattern matching using the curve\_fit function as described above.

## Key results, lessons, any changes

One result of mosaicking the data is that we found the 160 band contains one flawed image. The Montage package includes a module that we should be able to use to fix the data, however at the time of discovery the module was not working properly. We’ve been in touch with Montage’s senior software engineer and he has made changes to the module and believes it to be working properly now.

We’ve also become aware of a potential hurdle in working with our data. The data has different resolutions for each the different wavelengths, making it more difficult to make sure we are comparing the same galactic coordinates across the dataset. We have come up with a few methods of dealing with this issue, and we are currently deciding which will be the best to use in our situation.

Another lesson learned is that we might not be able to use data points that don’t contain a peak wavelength inside of our wavelength range. We are still working on this issue, and may be able to still fit the data using the SciPy curve\_fit function, but it will come down to how accurate the results are. If needed, we may need to throw away data points that don’t contain a peak wavelength.

## Remaining tasks

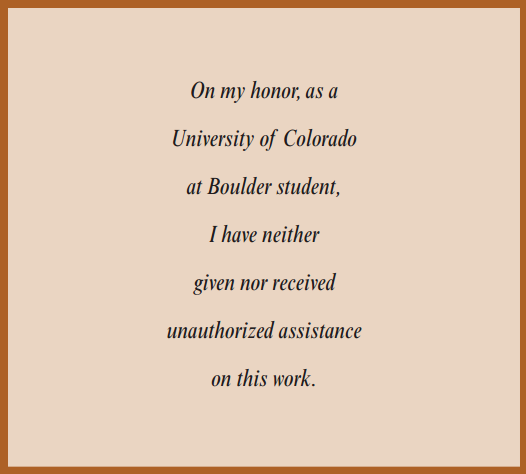
* Fix the 160 micron mosaic
* Choose and implement method for dealing with the different resolutions to achieve galactic coordinate consistency across the dataset
* Finish the code for the pattern matching
* Test our method with small medium dataset first
* Generate the temperature map based on the temperature values obtained

# REFERENCES

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Appendix

Honor code pledge:



Work done by individual group members:

* Jon Allured:
  + Researched Hi-GAL dataset
  + Did the data preprocessing including all reprojections, mosaics, and data cleaning
* Jacob C. Levine
  + Researched curve-fitting methods
  + Wrote the Python code for data analysis including trying to get the curve\_fit function to work and implementing code for the backup plan after determining the curve\_fit was not working