Design Reference Mission Case Study
Stratospheric Observatory for Infrared Astronomy Science Steering Committee

The Physics of Infrared Cirrus

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Scientific category: INTERSTELLAR MEDIUM
Instruments: SUPERHAWC CAMERA/POLARIMETER
Hours of observation: 66

Abstract

Infrared cirrus is an important contributor to the integrated emission from many galaxies including our own, but it is poorly understood. Although the extent of cirrus emission is best surveyed from space, an imaging far-IR polarimeter on SOFIA can give unique information regarding specific regions: 1) the density structure on scales down to 0.01 pc, 2) the magnetic field structure as inferred from the position angles of far-infrared continuum polarization, and, 3) the composition of cirrus dust, as inferred from the wavelength dependence of the flux density and degree of polarization. We will identify a sample of cirrus patches classified by large-scale appearance in IRAS maps, map their structure using SuperHAWC with 15 times better angular resolution than IRAS, and simltaneously measure their polarization characteristics. We will investigate whether cirrus filaments are shaped by magnetic effects or other processes. The marriage of large, low-noise detector arrays with SOFIA and the introduction of multi-wavelength polarization sensitivity are key to this project.

Observing Summary:

Target	RA	Dec	F_{Jy}	Configuration/mode	Hours
CIRRUS FILAMENT			~ 0.4 per $20''$ pixel	100 μm MOSAIC	12
			~ 0.3 per $20''$ pixel	200 μm SNAPSHOT	4
ROUNDED CIRRUS			~ 0.4 per $20''$ pixel	100 μm MOSAIC	12
			~ 0.3 per $20''$ pixel	200 μm SNAPSHOT	4
LOW-LAT. CIRRUS			~ 2.0 per $20''$ pixel	100 μm MOSAIC	1
			~ 1.5 per $20''$ pixel	200 μm SNAPSHOT	1
CLUMPY CIRRUS			~ 0.4 per $20''$ pixel	100 μm MOSAIC	12
			~ 0.3 per $20''$ pixel	200 μm SNAPSHOT	4
SMOOTH CIRRUS			~ 0.4 per $20''$ pixel	100 μm MOSAIC	12
			~ 0.3 per $20''$ pixel	200 μm SNAPSHOT	4
				Grand total hours	66

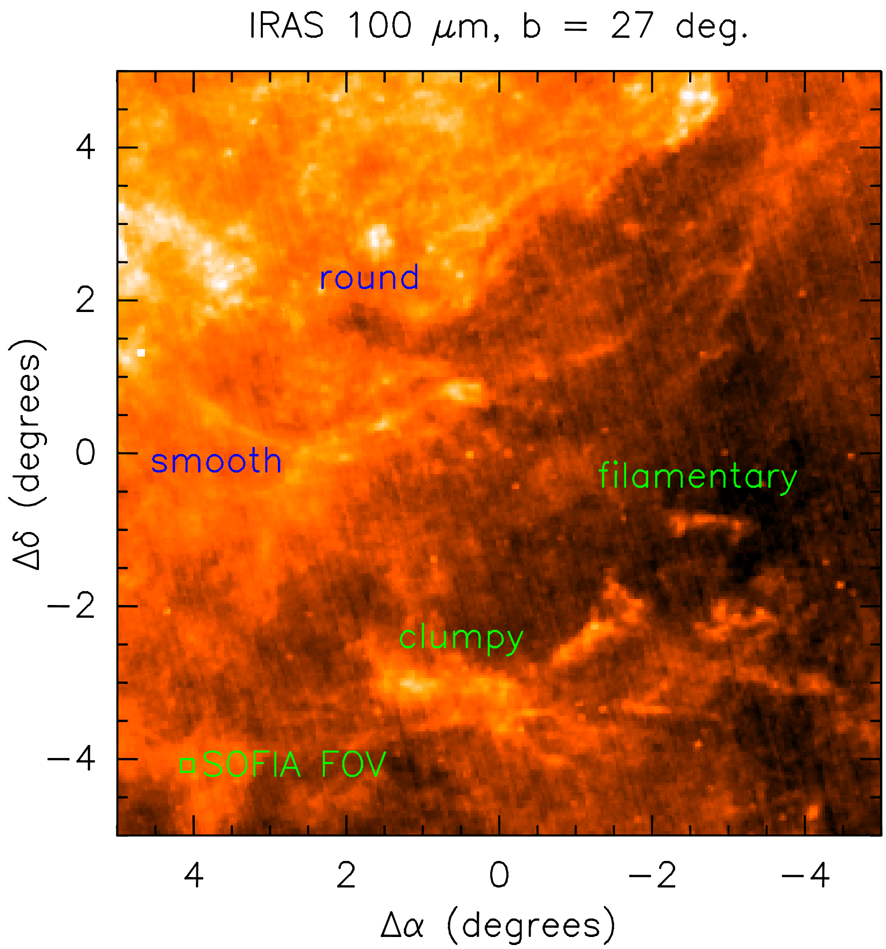

Figure 1: IRAS 100 μm image of a typical intermediate-latitude region of the Galaxy showing widespread cirrus. Representative shapes for a SOFIA survey are indicated. The most common shape of cirrus is filamentary, which can be smooth or clumpy at IRAS resolution. In certain regions, the cirrus takes a more rounded form. We indicate at lower left the 10$'$ SuperHAWC field of view, encompassing ~10 IRAS resolution elements and ~1000 SOFIA resolution elements.

Scientific Objectives

The infrared cirrus consists of moderately far-IR bright (10-100 MJy/steradian), widely extended, predominantly filamentary Galactic dust emission visible over most of the sky. With a mean temperature of 25 K (Low et al. 1984), it is best studied at $\lambda = 100 - 200$ μm, although it partially correlates with 21 cm neutral hydrogen emission and tracers of molecular hydrogen (Deul & Burton 1990; Weiland et al. 1986). The origin of the cirrus is not yet known, but in its present state it is perhaps a relatively simple laboratory for studying the interaction of dust, gas, magnetic fields, and interstellar radiation due to the low optical depth, distance from stellar formation and evolution processes, and infrequency of shock signatures (Low et al. 1984; Hearty et al. 1999; Turner 1995).

We propose to study infrared cirrus with the SuperHAWC camera/polarimeter aboard SOFIA, addressing the following topics:

substructure – Maps of dust emission are excellent tracers of mass; therefore the SuperHAWC maps will give insight into evolutionary timescales for cirrus when combined with velocity maps from atomic hydrogen emission or tracers of molecular hydrogen. In particular, we can search for clumps of gas on scales down to 0.01 pc and determine if they are gravitationally bound, as found for one bright cirrus core (Heithausen, Bertoldi, & Bensch 2002).

magnetic field structure – The detection of polarization will address the origin of cirrus. A basic question is whether the mean magnetic field is parallel to cirrus filaments, suggesting formation by compression, or perpendicular, suggesting formation by gravitational contraction guided by field lines. Probing further, the dispersion of the polarization constrains the strength of the magnetic field. Comparison of SuperHAWC polarization and density maps with theoretical models of the ISM (e.g., Heitsch, Zweibel, et al. 2001) will result in quantitative measures of the components of energy density of cirrus clouds. Although infrared cirrus has low surface brightness, and the emission is only partially polarized, we predict that the favorable grain alignment conditions and likely ordered magnetic fields in cirrus will lead to degrees of polarization in excess of 10% which are readily detectable with Super-HAWC.

polarization spectrum – The multi-wavelength detection of polarization constrains the composition of cirrus dust beyond what can be learned from the spectral energy distribution alone. Observations of cirrus will test the hypothesis that the constituent grains are composed of indepedent unpolarized, warmer graphite grains and polarized, cooler silicate grains. A far-infrared polarization spectrum which rises with increasing wavelength is a signature of this scenario. An attempt to detect this signature in the envelopes of high-mass star forming clouds has been defeated by the complex temperature structure of such clouds (Hildebrand et al. 1999).

We expect some variation in cirrus properties from cloud to cloud, and the pilot survey of various cirrus forms is designed to capture that. Perhaps we should expect the largest degrees of magnetic field order and polarization in the smooth, filamentary cirrus, and gravitational or turbulent disturbance of the field in the clumpy or rounded cirrus.

SOFIA Uniqueness/Relationship to Other Facilities

Only SOFIA could have the ability to measure the far-infrared polarization of cirrus. Spitzer and Herschel do not measure polarization. Ground-based access to $\lambda = 100 - 200$ μm is extremely limited by atmospheric transmission and noise. Balloon-based experiments are unlikely to match the angular resolution of SOFIA, and wide field balloon surveys are unlikely to have sensitivity to detect polarization from a particular cirrus cloud.

Observing Strategy

Our basic observing strategy will be chopping and nodding. The chopper amplitude will be the maximum possible ($\sim$10′), and the orientation will be chosen to minimize reference beam emission, based on IRAS maps.

Our goal will be to make 10′ by 10′ maps for each cirrus target, and we will assume a field of view of this size for SuperHAWC at 200 μm. We will strive to detect at 15σ the emission in 20″ beams (rebinned at 100 μm) receiving the average amount of flux tabulated in the Observing Summary. In computing the integration times, we assume a sensitivity of 1

Jy/beam rms in 1 second at each wavelength and an observing efficiency of 50%. To match spatial coverage of the 100 μm and 200 μm maps, it may be necessary to mosaic up to 4 images at 100 μm, and we have included that factor in the integration time estimate.

SuperHAWC will be designed to measure polarization simultaneously with measuring total emission. In each $20''$ beam with average flux detected at 15σ, we will achieve polarization uncertainty of 10% – perhaps insufficient to detect polarized dust emission. We will therefore re-bin the data to $1'$ resolution, resulting in a polarization uncertainty of 3%. Given that the 100 μm polarization from complex molecular cloud envelopes can rise to near 10% at their edges (Hildebrand et al. 1999), we predict that detection of polarization at $1'$ resolution in isolated cirrus is likely. This resolution is sufficient to establish the relation of the magnetic field direction to the structure of cirrus on arcminute to degree scales as well as to measure the polarization spectrum.

Special Requirements

This proposal involves the detection of emission and polarization from widely extended regions with low surface brightness. Polarization sensitivity and large detector arrays with high quantum efficiency such as in SuperHAWC are required. In particular, we need instantaneous coverage of at least 25 arcmin^2 as well as a method of modulating the polarization. The 100 and 200 μm bands of SuperHAWC are the most valuable for this project.
Minimum FOV: 25 arcmin^2 at 100 μm

Precursor/Supporting Observations

The IRAS survey remains the best source for selecting cirrus, despite also being the experiment which discovered it over two decades ago (Low et al. 1984). For now, we will use the catalog of Jackson, Werner, & Gautier (2003) to identify suitable candidates for observation with SOFIA. As Herschel mapping of cirrus with an order of magnitude better resolution than IRAS becomes available, we will have efficient means for selecting regions to study with SOFIA polarimetry.