Direct Estimates of Cirrus Noise in Herschel Hi-GAL Images

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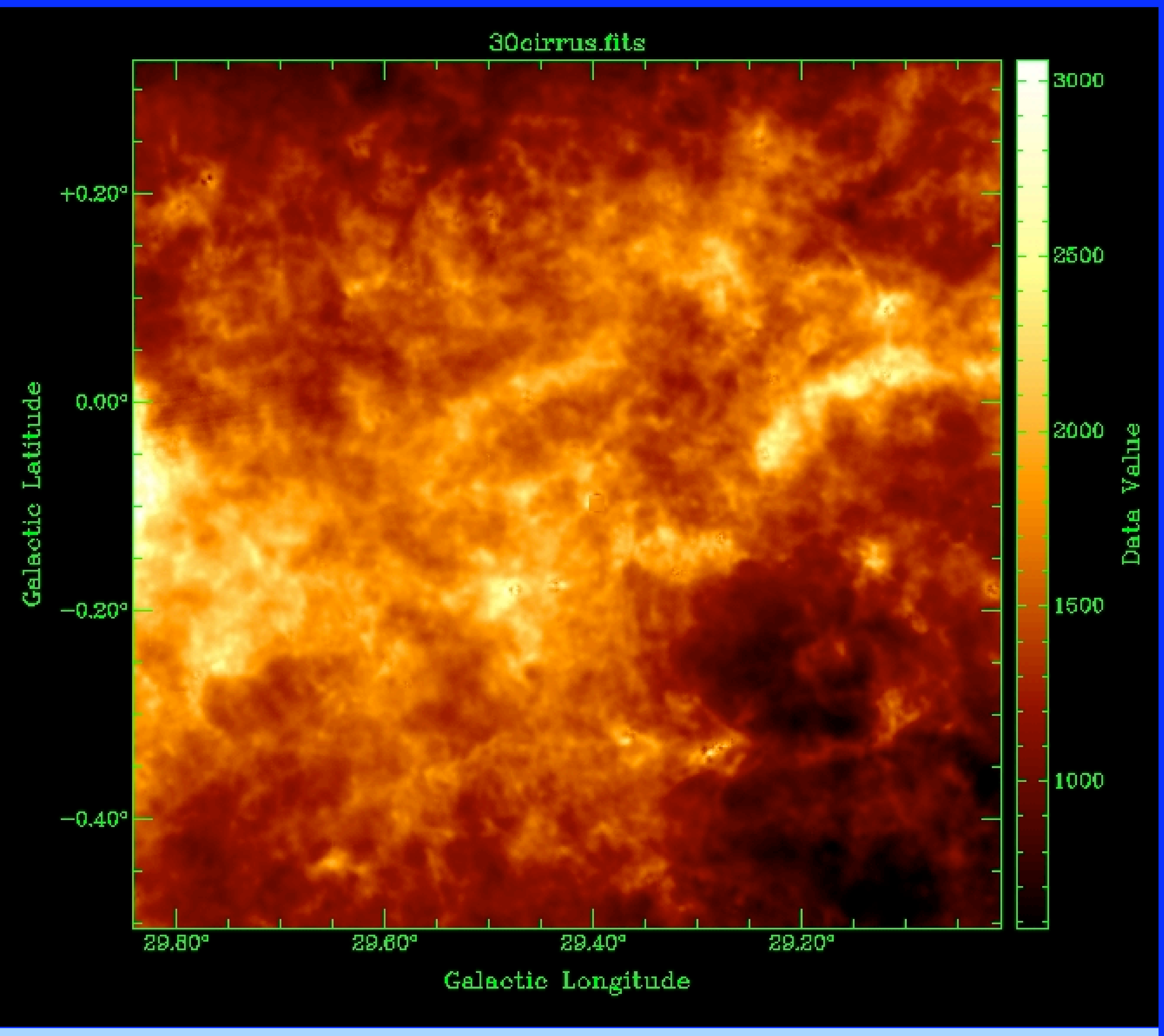
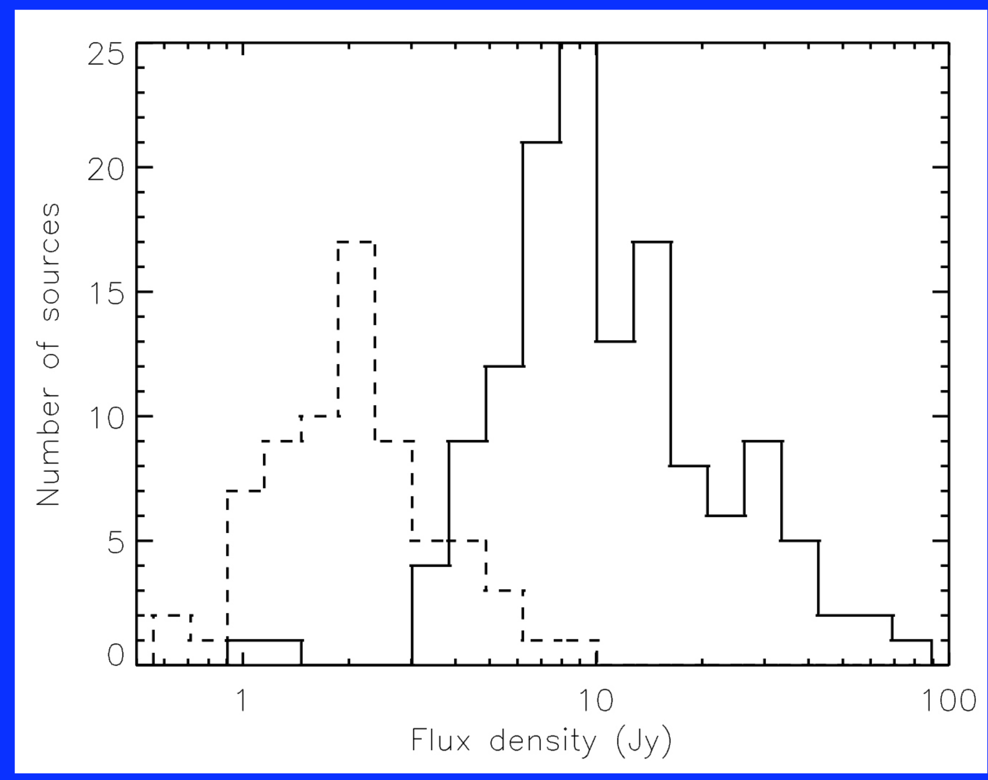


The cirrus in this field at l=29 is so bright that it is difficult to see sources fainter than 10 Jy. Try!

Cirrus noise is operationally defined as the `statistical error to be expected in photometric measurements due to confusion in a background of fluctuating surface brightness.' The fluctuating background can be very bright in star-forming regions and in the Galactic plane (left: Hi-GAL image with bright sources removed). Examination of a wide range of mass of the stellar precursors, requires measurement of sources with a wide range of luminosity, or at each wavelength, flux density. *Herschel* catalogs of compact sources are cut off at the faint end because of cirrus confusion noise (right: histograms).

Cirrus noise can be estimated directly. Just decide on how one does photometry (e.g., by an aperture plus annulus, or by fitting a Gaussian plus background) and do this again and again at random places in the image. Calculate the rms `source' flux density measured. That is by definition the cirrus noise. For example, if we use a 25″ Gaussian (about the size of typical sources in the 250 um image), the cirrus noise is 1.7 Jy.

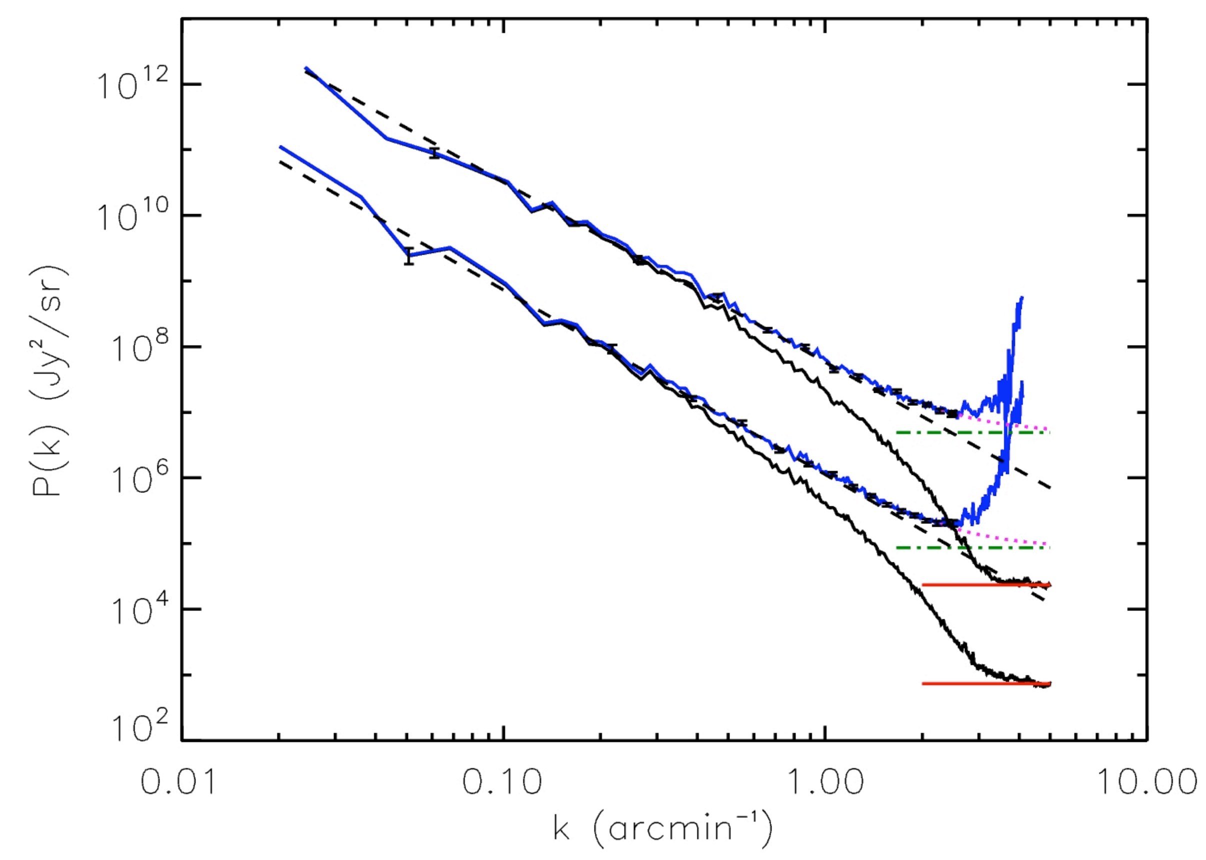


Solid histogram: sources cataloged at 250 um in a representative large degree-sized sub-region of Hi-GAL l=30 field (f30). Dashed histogram: sources cataloged in a sub-region of l=59 field (f59) that has a factor 5.8 lower median brightness. The faint-end cutoffs are not intrinsic to the underlying source population. They are caused by cirrus noise, which varies with field brightness. This effect of cirrus noise should be sobering, if not alarming!

There is a rich literature on cirrus noise (beginning with Gautier et al. 1992), based on the power spectrum of the image and using the fact that the cirrus fluctuations are well described by a power law.

$$P(k) = \Gamma(k)\,[P_{\rm cirrus}(k) + P_{\rm source}(k) + P_{\rm CIB}(k)] + N(k).$$

The power spectrum has many contributions, from the cirrus, residual compact sources, the cosmic infrared background, all rolled over because of the PSF at large spatial frequencies k (small angular scales), plus noise. See the analysis in the Figure below.



Top curves: power spectrum at 250 um for the f30 field. Decay at large k in lower of the two curves, P(k), is due to Γ(k) from the PSF. Plateau at high k is from residual ``noise" N in the map. At very small scales, where the astronomical signals become correlated within the beam, P meets N. Upper curve is P_cirrus (k) +P_source, after subtracting the noise and dividing by Γ(k) to remove the effect of the beam. Upper curve has been fit over the range 0.06 < k < 2.5 by a simple model (dotted curve) consisting of a power law (dashed line) with P_0 (at k = 1) = (58 +/- 1) 10^6 Jy^2/sr plus a constant P_source = (4.9 +/- 0.3) Jy^2/sr (dash dot line). The power-law exponent is -2.74 +/- 0.03.
Bottom curves: power spectrum for the fainter f59 field. The `noise' level, P_0, and P_source have all decreased, roughly as the square of the median brightness. The power-law exponent -2.81 +/- 0.03 is not significantly different.

Table 1. Parameters[a] for SPIRE $\Gamma(k)$ at 250, 350, 500 μm

a_0	a_1	a_2	a_3	a_4
0.789137	−0.466966	-0.070793	0.349304	−0.068133
0.671082	−0.807737	0.294573	0.250785	−0.125454
0.402564	−0.897627	0.095114	1.785801	−0.720592

[a] $\Gamma(k) = [1 + \sum_{i=1,4} a_i k^i] \times \exp[-k^2/(2a_0^2)]$

The SPIRE PSF is not a simple Gaussian and so care must be taken to calculate Γ from the empirical PSF based on scans of Neptune, using the method of Roy et al. 2010.

Cirrus noise has been calculated analytically for various photometric templates (Gautier et al.). This provides insight into how cirrus noise changes with the statistical properties of the fluctuations and with the operational parameters of the photometry. See the summary equation. Using direct measurement of cirrus noise on simulated cirrus maps, we have calculated the appropriate amplitude A_t for the Gaussian measurement strategy (one that remains useful in crowded regions). A_t = 0.054. R_t is the scaled FWHM. Using this formula and the power spectrum (see figure), we recover the same cirrus noise as measured directly on the actual images.

$$\sigma_{\rm cirrus} = A_t\, R_t^{2.5} \left(\frac{\lambda/250\ \mu{\rm m}}{D/3.5\ {\rm m}}\right)^{2.5} \left(\frac{P_0}{10^6\ {\rm Jy}^2\ {\rm sr}^{-1}}\right)^{0.5}\ {\rm Jy}.$$

Formula summarizing how the cirrus noise depends on various parameters of the cirrus fluctuations and of the photometric measurement strategy. R_t is a scale factor for the measurement template in units of λ/D.

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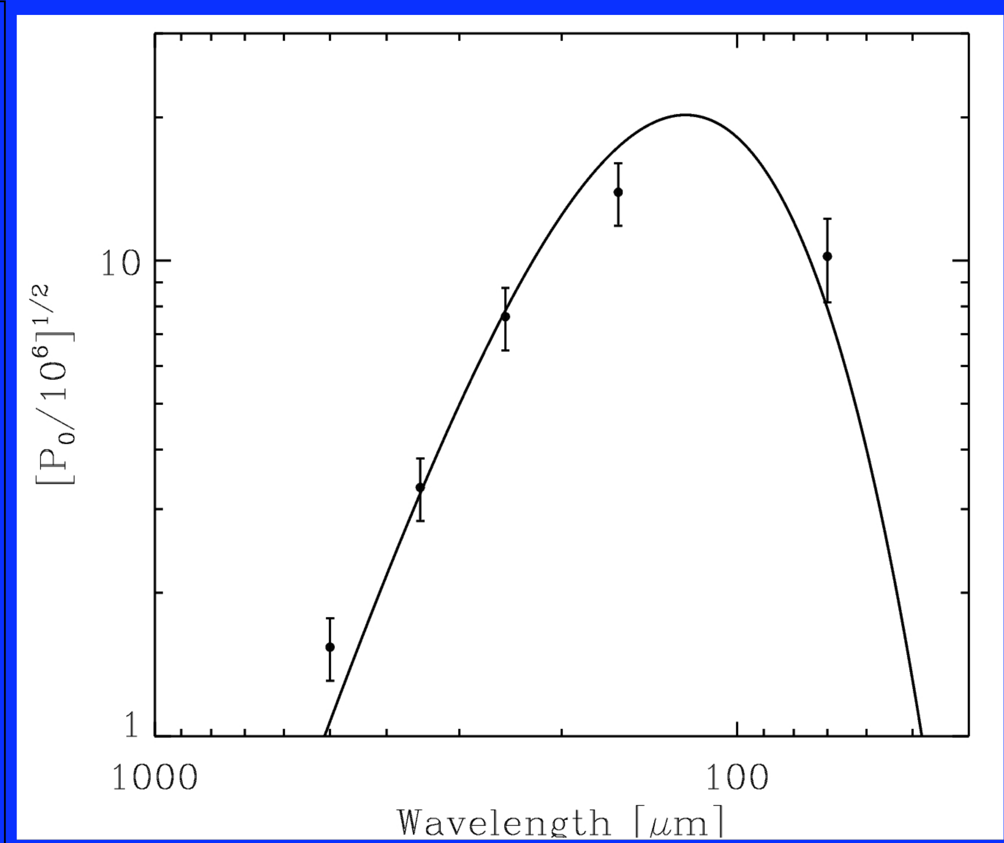
Wondering how the cirrus noise varies with wavelength? Look at the equation and then this figure. SED obtained from the square root of the amplitudes P_0 obtained from fits to power spectra in the f30 field. Solid curve is from the fit of a β = 2 modified blackbody, with temperature 23.6 K. This shows that the SED of the cirrus noise is much like the SED of the cirrus brightness. It can be warmer or cooler than the SED of the compact sources, affecting the S/N of the extracted flux density.



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