Herschel Space Observatory Calibration Workshop,
Dec 1-3, 2004, Leiden

The impact of (cirrus) confusion noise on Herschel/[PACS/SPIRE]

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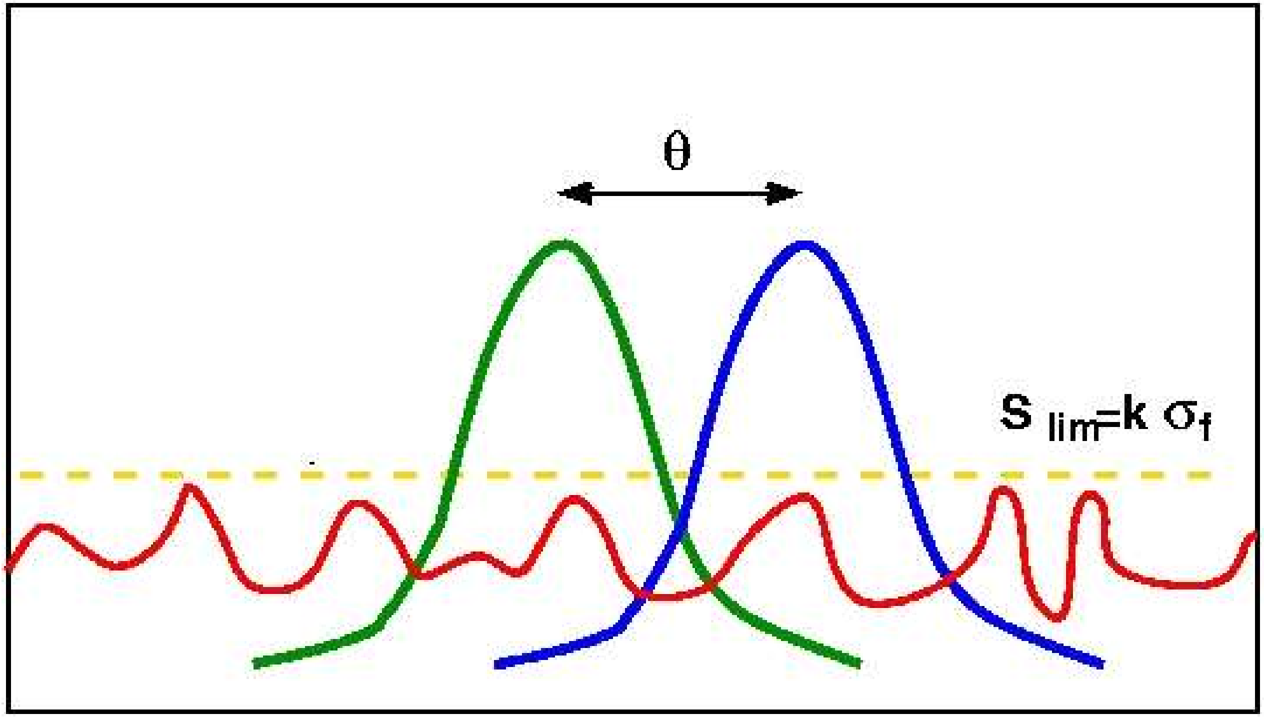
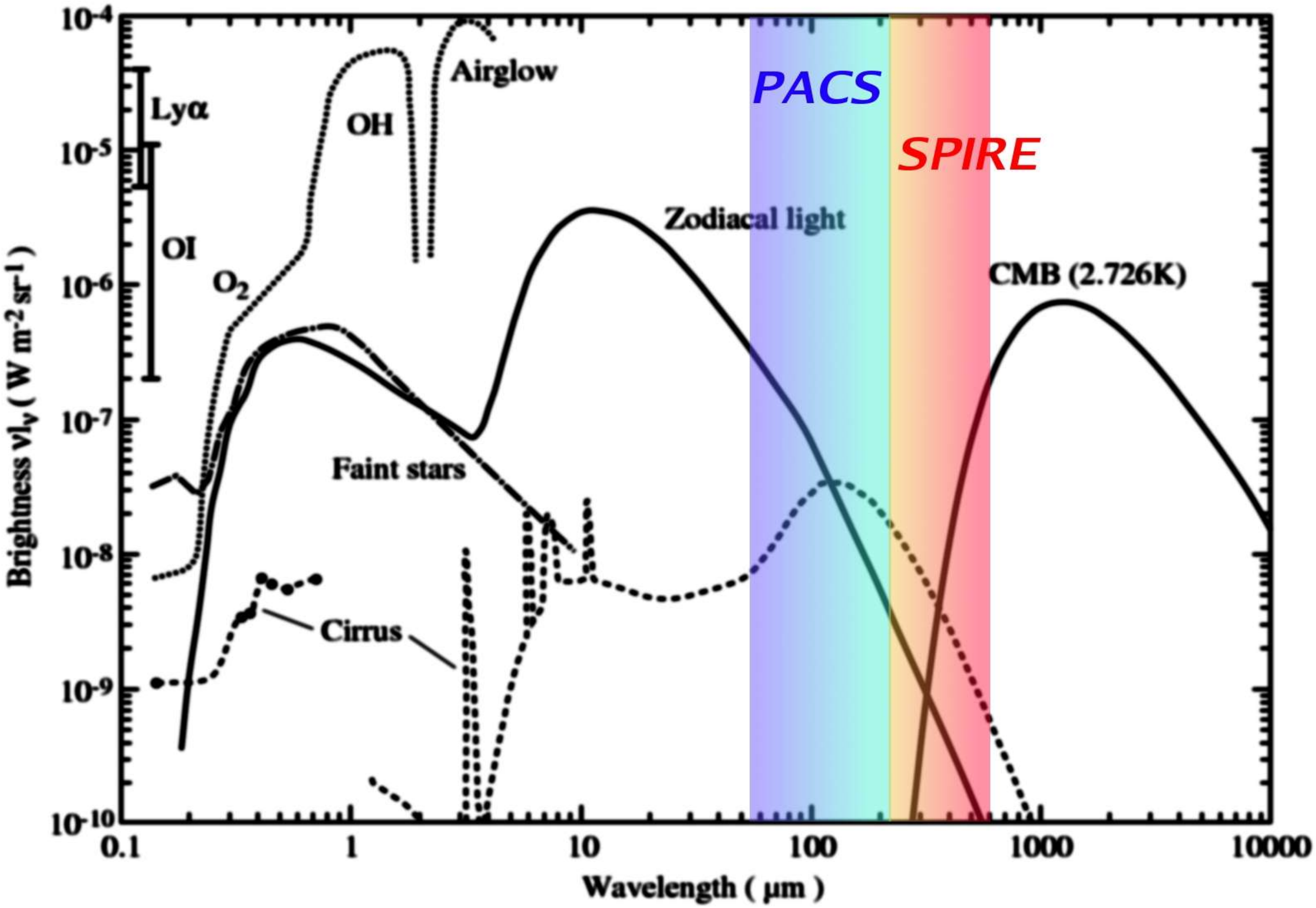
- The far-infrared sky background
- Sky structure and confusion noise
- How to estimate cirrus confusion noise (for Herschel)
- The Herschel Confusion Noise Model

Confusion noise

- Confusion noise: uncertainty in point source flux determination due to sky background fluctuations
- Two main criteria of detectability: source density (accumulated) and photometry (both accumulated and diffuse)
- Final confusion noise value depends on the spatial structure of the background components



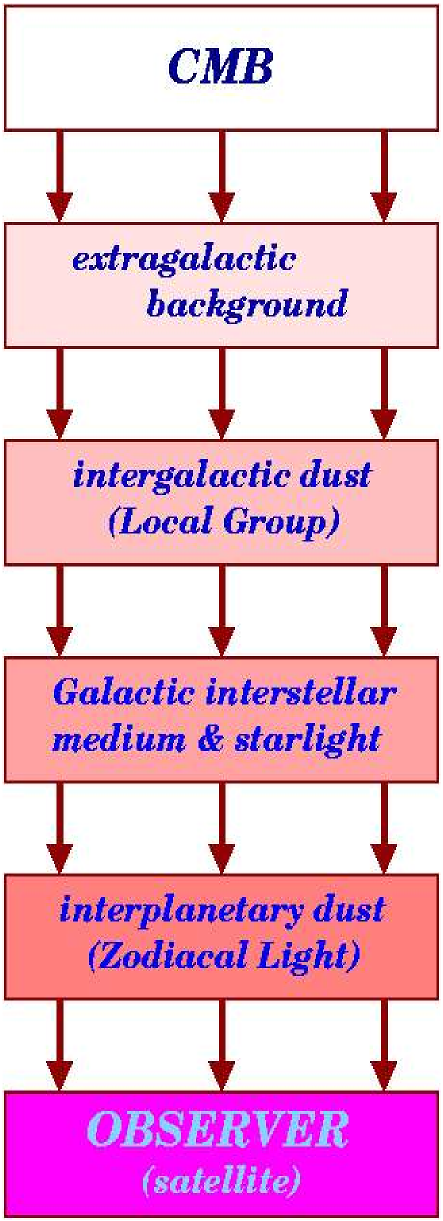
The far-infrared sky background



(Leinert et al., 1998)

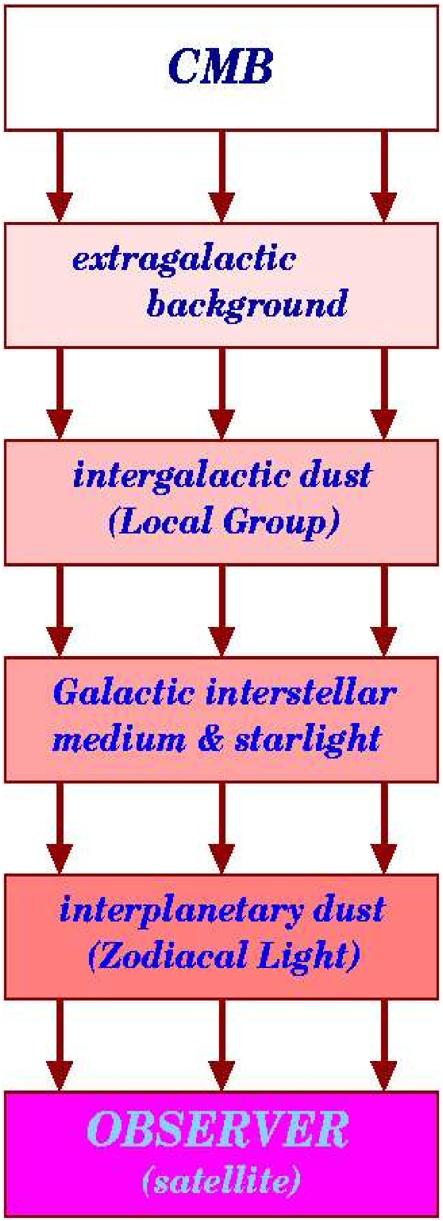
The far-infrared sky background

- Galactic cirrus emission (diffuse Galactic light):
  - thermal emission of dust in HI clouds in the Galaxy
  - dominates the sky brightness at $\lambda \gtrsim 60\mu$m
  - power-law power spectrum (indicates scale-invariant, fractal structures); fluctuation power is decreasing fast with the resolving power
  - fluctuation power is correlated with the average surface brightness of the fields
- Cosmic far-infrared background:
  - accumulated light of unresolved (redshifted) galaxies in the line of sight; “starlight” absorbed by dust and re-emitted in the infrared; most significant contribution from sources with $1 \leq z \leq 2$
  - flat power spectrum at low spatial frequencies (Poissonian distribution), steeper at high spatial frequencies due to clustering
  - extended modeling by several groups



The far-infrared sky background

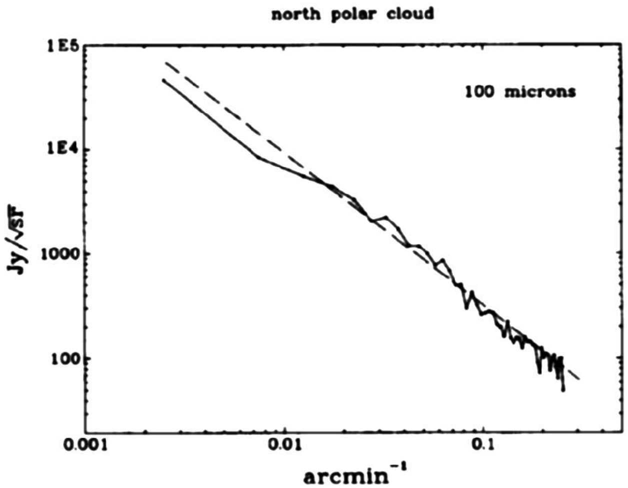
- Cosmic microwave background:
  - Wien part of the CMB contributes to the FIR sky background
  - superior to cirrus at $\lambda \geqslant 400\mu m$ (SPIRE)
  - inhomogenities are below the Herschel sensitivity level ($\delta F/F \approx 10^{-5}$)
- Zodiacal light:
  - thermal dust emission of interplanetary dust
  - concentrated on the ecliptic plane
  - lacks small-scale structures (up to the ISOPHOT resolution; Ábrahám et al., 1997)

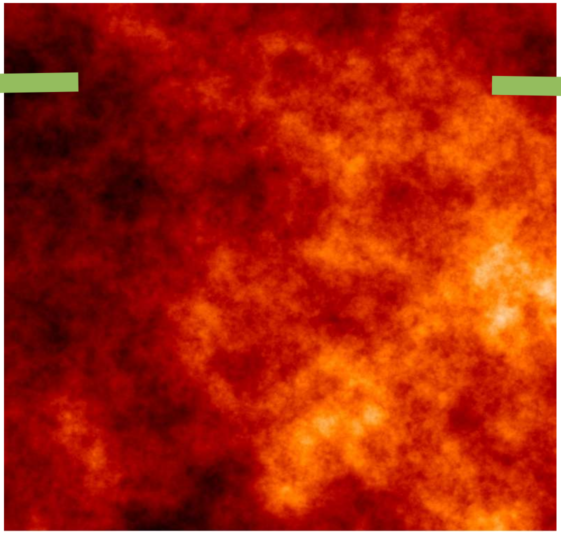


IS IT IMPORTANT FOR HERSCHEL ?

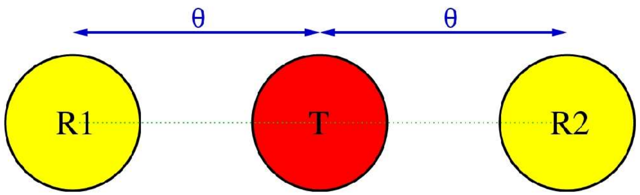
Sky structure and confusion noise

Fourier power spectrum





pixel-to-pixel correlation



Correlation function:

$$C(\theta) = \langle \delta F(x) \cdot \delta F(x+\theta) \rangle$$

Structure function:

$$S(\underline{\theta}, k) = \left\langle \left| B(\underline{x}) - \frac{1}{k} \cdot \sum_{k} B(\underline{x} + \underline{\theta}_k) \right|^2 \right\rangle_{\underline{x}}$$

$S(\theta)$ can be express as a linear combination of $C(\theta_i)$-s

Structure noise:

$$N_{str}(\theta, k) = \sqrt{S(\theta, k)} \times \Omega$$

Confusion noise:

$$N_{str}^2 = N^2 + q \cdot N_{inst}^2$$

Typical parametrization of the spectrum (definition of the spectral index α):

$$P(f) = P_0 (f / f_0)^{\alpha}$$

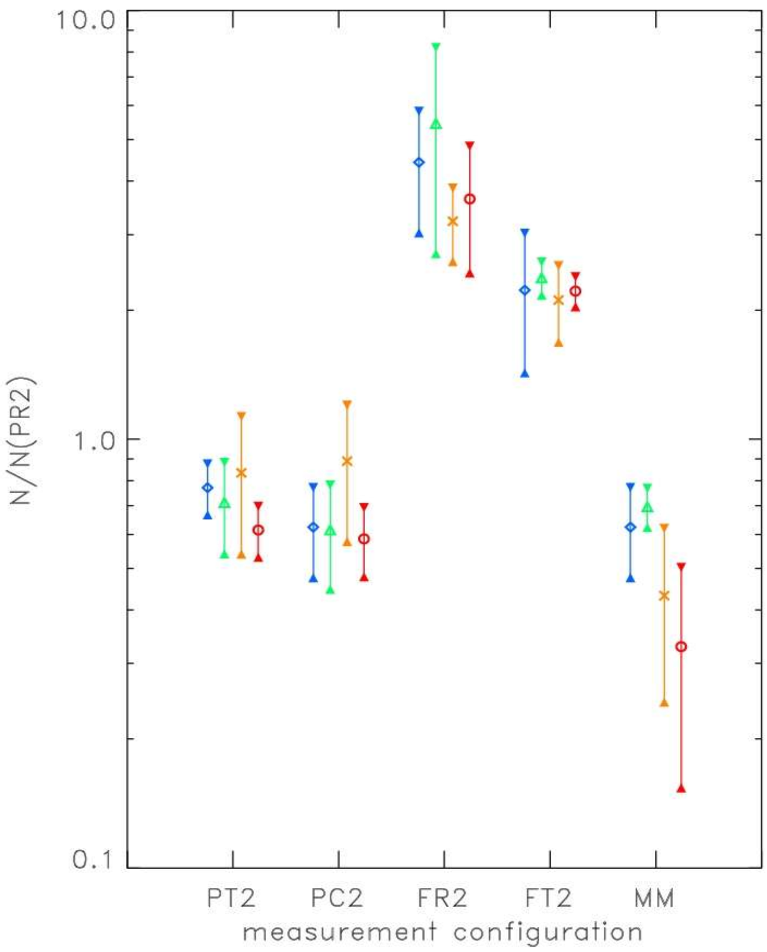
Connection between the two representations:

$$C(\theta) = \frac{1}{2\pi} \int_0^{\infty} P(f') \, J_0(f'\theta) \, f' \, df'$$

Sky structure and confusion noise

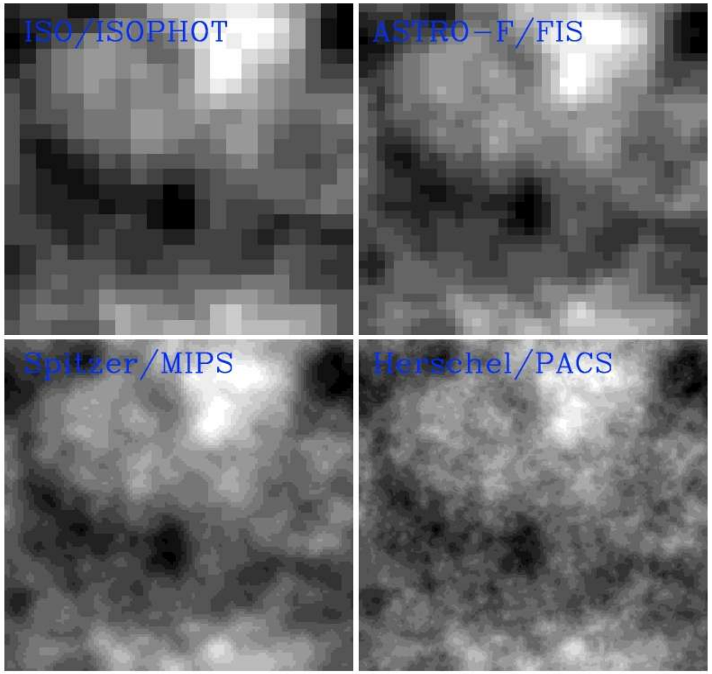
Cirrus confusion noise estimates for other telescopes/instruments based on ISO/ISOPHOT results

- Detailed confusion noise analysis of ISOPHOT measurements; dependence on
  - surface brightness
  - wavelength
  - measurement configuration (number of reference apertures, geometry, etc.)
- Provides:
  - scaling laws (surface brightness, wavelength)
  - less/more optimal measurement configurations concerning confusion noise



Sky structure and confusion noise

Cirrus confusion noise estimates for other telescopes/instruments based on ISO/ISOPHOT results

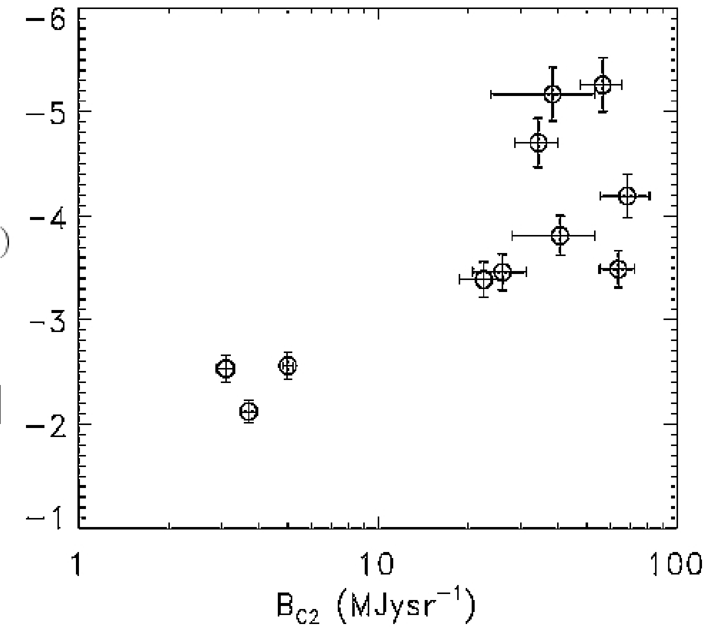


- Simple way: scaling down the fluctuation power in spatial frequencies by extending the power spectrum (e.g. $\alpha = -3$)
- Complications:
  - the spectral index is not constant (depends on surface brightness)
  - the resolving power is messed by pixel effects
  - final confusion noise values strongly depend on the measurement configuration
- Solution: comparison of confusion noise values measured on simulated fractal maps (with prescribed α) as seen by different instruments (the measurement configuration is fixed) ✚ Scaling of confusion noise with *surface brightness* based on ISOPHOT 90, 100, 170 and 200μm data.

Sky structure and confusion noise

Cirrus confusion noise estimates for other telescopes/instruments based on ISO/ISOPHOT results

- Solution for the variable α : based on Kiss et al. (2003), $\alpha = A_1 \cdot \log_{10} \langle B - B_{CFIRB} \rangle + A_0$, with $A_0 = -1.67 \pm 0.47$ and $A_1 = -1.57 \pm 0.38$.
- Scaling for non-investigated wavelengths (Gautier et al., 1992):
  - $$\frac{N(\underline{\theta}, k, \lambda)}{1\,\mathrm{mJy}} = C_0(\underline{\theta}, k, \lambda) + C_1(\underline{\theta}, k, \lambda) \cdot \left\langle \frac{B}{1\,\mathrm{MJy\,sr^{-1}}} \right\rangle^{\eta(\underline{\theta}, k, \lambda)}$$
  - $C_0(\lambda_0,\theta,k)^{1-\beta/2} = C_0(\lambda_1,\theta,k)^{1-\beta/2}$, where β is the spectral index of the CFIRB
  - $C_1(\lambda_0,\theta,k)^{1-\alpha/2} = C_1(\lambda_1,\theta,k)^{1-\alpha/2}$, where α is the spectral index of the cirrus emission
  - According to Kiss et al. (2004), does η not change much with wavelength, i.e. $\eta(\lambda_0,\theta,k) = \eta(\lambda_1,\theta,k)$



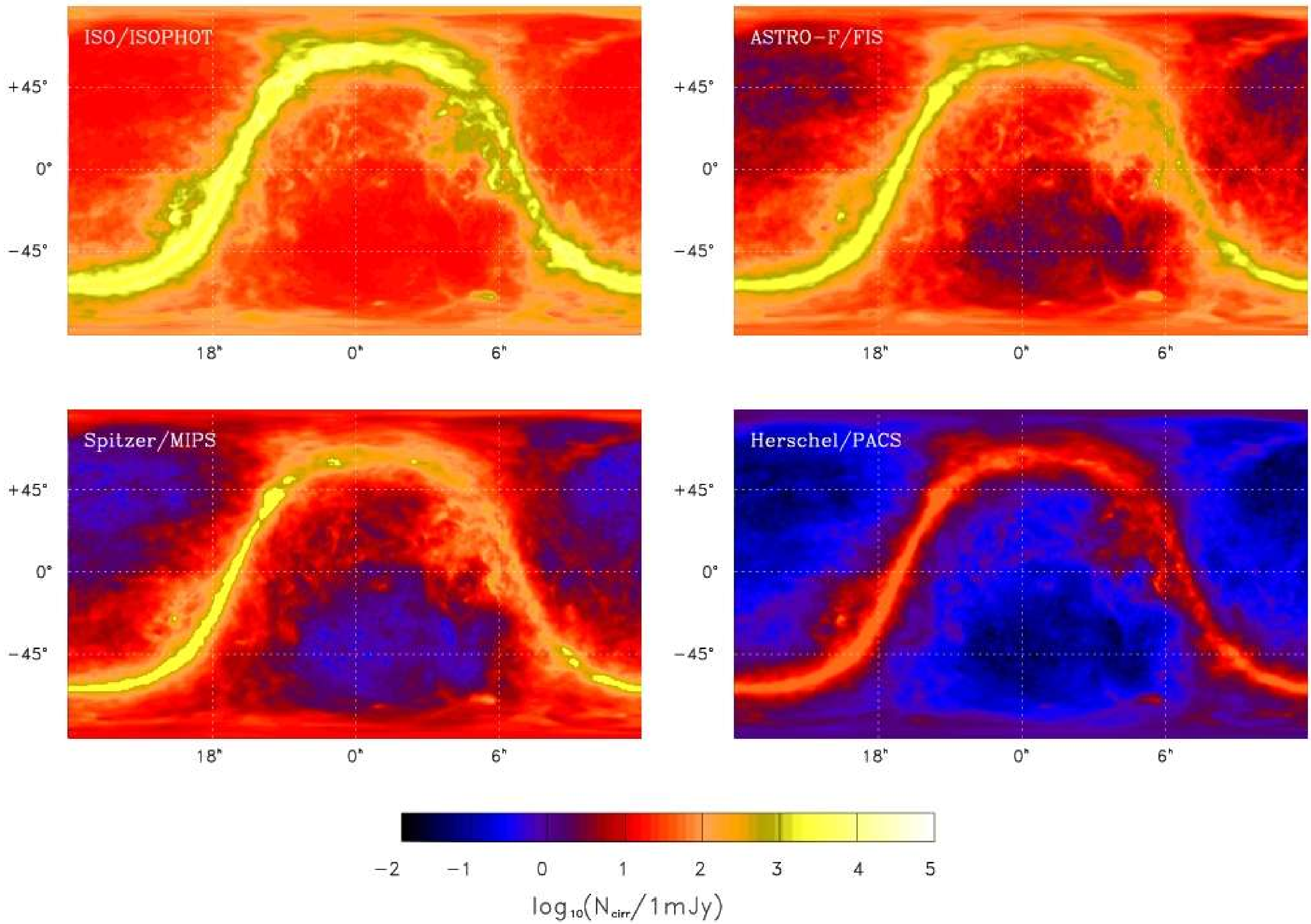
Sky structure and confusion noise

Estimates for other telescopes/instruments based on ISO/ISOPHOT results

- Example of calculated 1 cirrus confusion noise values and 5 sensitivity limits for Herschel/PACS 110 and 175m (including CFIRB fluctuations and noise due to the warm telescope mirror):

Name	N(110) (mJy)	S(110) (mJy)	N(175) (mJy)	S(175) (mJy)
G159.1-20.7	1.12	6.74	9.27	48.34
G169.8-16.1	0.48	4.45	4.3	25.49
G180.0-03.4	0.85	5.68	6.42	34.9
G053.0+03.1	2.08	11.06	16.92	85.71
G179.6-23.5	0.66	5.01	4.48	26.23
G337.1-04.9	2.05	10.92	10.1	52.33
G356.5-04.5	2.73	14.14	14.95	76.01
G057.1+04.4	1.4	7.93	10.25	53.04
G178.0-09.7	0.63	4.9	4.65	26.97
G172.1-15.2	0.57	4.71	4.95	28.3
G171.5-14.9	0.71	5.16	6.11	33.48
G171.9-05.2	0.72	5.2	5.15	29.17
G093.9+07.6	1.19	7.05	8.31	43.72
G115.4-03.7	1.22	7.16	8.03	42.43
G175.3-16.7	0.66	4.98	5.02	28.58

Sky structure and confusion noise



Sky structure and confusion noise

An alternative solution: Jeong et al. (2004) [astro-ph/0411431]

- Method:
  - 100μm Schelgel et al. (1998) maps, with high spatial frequency noise added
  - high frequency power spectrum follows that of the low frequency range
  - SED for longer wavelengths is extrapolated using temperature maps constructed of COBE/DIRBE data and one/two component dust models
- (Dis)Advantages:
  - local (more local than COBE/DIRBE maps) ✚
  - does not depend directly on surface brightness (there is not need for a fluctuation power – surface brightness relation) ✚
  - does not take into account pixel and configuration effects ✘
  - assumes a uniform power law for any wavelength ✘
  - features related to structures of cold dust (T<15K) are missing (does not appear at $\lambda \leq 100\mu$m) ✘

The Herschel Confusion Noise Model

- **Fundamental requirements; the HCNM should provide:**
  - cirrus spatial scaling model down to 1″ spatial resolution
  - point source confusion noise (mJy) and background surface brightness fluctuation ($MJysr^{-1}$) estimates per for PACS/SPIRE photometric bands, for a specific background surface brightness or sky coordinate (in the latter case using large scale data: COBE/DIRBE, IRAS, ISO, etc.)
  - relative abundance of false sources due to cirrus
  - optimized AOTs selected for:
    - performing (cirrus) confusion noise tests
    - maximal photometric sensitivity (confusion noise contribution is the minimal in this configuration)

The Herschel Confusion Noise Model

- **Preparatory observations:**
  - spatial structure on optical/NIR IR extinction maps
  - spatial structure on optical/NIR IR reflected light maps
  - spatial structure of high resolution HI and/or CO maps
- **HCNM user interface:**
  - HCNM user interface integrated into HSPOT/PHS, with all the fundamental requirements as outputs
  - ability to import user selected images (local determination of confusion noise)

The Herschel Confusion Noise Model

PV PHASE AND EARLY MISSION ACTIVITIES / GOALS OF A DEDICATED "CONFUSION SURVEY"

- mapping of low surface brightness (high Galactic latitude) "cosmic windows" for the characterization of CFIRB fluctuations
- determination of the surface brightness turn-over point of the CFIRB domain
- completeness limit, surface density and photometric accuracy on low surface brightness fields via source counts
- measurements of high surface brightness cirrus and molecular material at medium and low Galactic latitudes

The Herschel Confusion Noise Model

PV PHASE AND EARLY MISSION ACTIVITIES / GOALS OF A DEDICATED "CONFUSION SURVEY"

- determination of confusion noise scaling laws (as a function of surface brightness and/or Galactic latitude)
- checking the detectability of point sources on various surface brightness values
- comparison to preceding surveys (ISO, IRAS, DIRBE)
- checking of rotation and scale invariance
- feedback to the HCNM, update of the user interface

The Herschel Confusion Noise Model

TIMELINE

- End 2004: detailed work plan and feasibility study
- Early 2005: preliminary scaling functions at PACS/SPIRE resolutions, proposals for preparatory observations
- Mid 2005: preliminary look-up tables, opening the HCNM web page, searchable tables using a web tool
- Late 2005: IA toolbox first release; search tool integration into PHS, noise estimator in CUS; draft documentation
- Mid 2006: alternative models, consolidated documentation
- Mid 2007: preparation of AORs for dedicated survey fields
- Late 2007: implementation of measured constrains into HCNM