Drift subtraction for scanning bolometer arrays making use of the redundancy

Hélène Roussel (IAP)

application to Herschel photometers: *Scanamorphos* software

input: flux-calibrated brightness time series, with attached sky coordinates

output: signal, error, weight and drift maps

main functionalities:

- subtraction of **instrumental brightness drifts** (additive)
- calibration of relative gains (for space instruments)
- second-level deglitching and masking of instabilities
- projection onto a map

basic principles

Scanamorphos does not rely on any noise model nor filtering: it **exploits the redundancy** to derive the drifts from the data (each spot visited by several bolometers at multiple times).

main sources of noise in Herschel scan data:

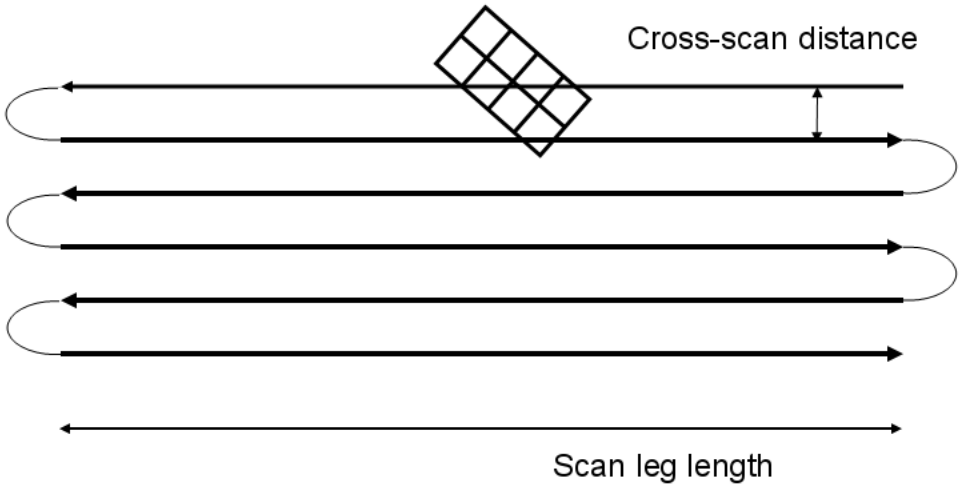
- high-frequency noise:
  white noise, quantization noise, glitches
- instrumental drifts, i.e. low-frequency noise:
  * thermal drift (strongly correlated among bolometers)
  * flicker noise (uncorrelated)

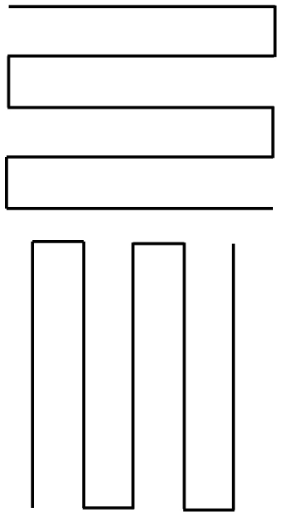
different decomposition of the drifts for *Scanamorphos*:

* average drift (the same time series for all bolometers)
* individual drifts (uncorrelated)

important observation characteristics

– scan pattern allowing to separate drifts from signal:





scan "a"

scan "b"

at least 2 scans with position angles separated by > 20°
(Waskett et al. 2007)

– scan speed and sampling rate: affecting the available redundancy

main steps

1− computation of space and time grids adapted to the problem

(*) 2− computation of high-frequency noise levels
(to serve as noise normalization + thresholds)

(#) 3− subtraction of long-timescale drifts

(*) 4− subtraction of short-timescale drifts (t_c < scan leg duration)

5− projection of signal, error, drift and weight maps
on user-specified grid

(*) deglitching done within several modules
(#) optionally with masking of instabilities (brightness jumps)

main steps

1− computation of space and time grids adapted to the problem

(*) 2− computation of high-frequency noise levels
(to serve as noise normalization + thresholds)

(#) 3− subtraction of **long-timescale drifts**

(*) 4− subtraction of short-timescale drifts (t_c < scan leg duration)

5− projection of signal, error, drift and weight maps
on user-specified grid

(*) deglitching done within several modules
(#) optionally with masking of instabilities (brightness jumps)

long-timescale drifts

in the form of linear baselines, covering:
- flux-calibration offsets
- major part of average drift
- small part of individual drifts

subtracted in two steps, each with several iterations:

- preliminary simple fits (not physical): `signal = f(t)`
  average signal on whole scans, then single bolometers on scan legs

- corrections using the redundancy, by a destriping module:
  reference map built from all scans, or scans "a", or scans "b"
  `(recorded signal - signal simulated from ref. map) = f(t)`
  -> requiring the signal from all bolometers and all scan legs
  to be consistent, to first order

long-timescale drifts (continued)

The strategy is not the same for all types of fields:
the aim is **to preserve real brightness gradients**.

a) fields with a flat background:
one free fit per scan leg for each bolometer

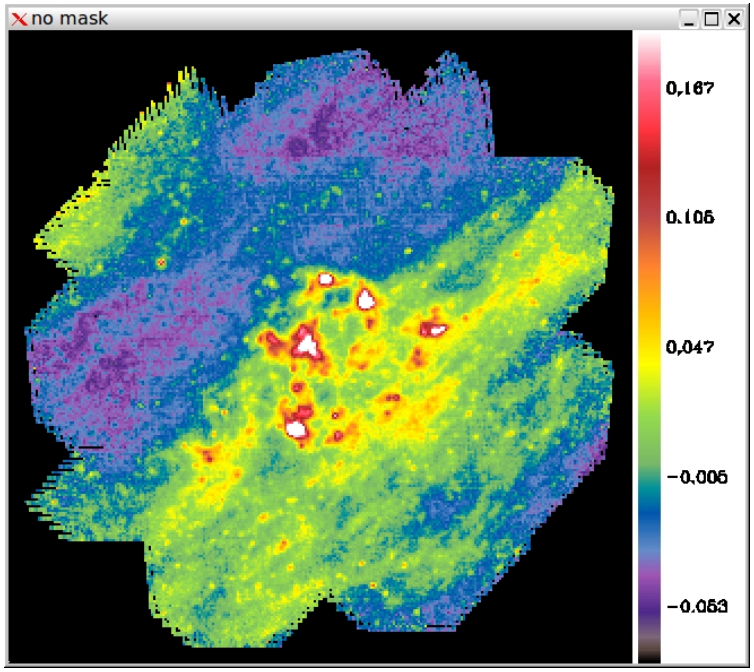
b) fields with extended emission throughout the map:
fits on scan legs constrained: bolometer-average slope = 0

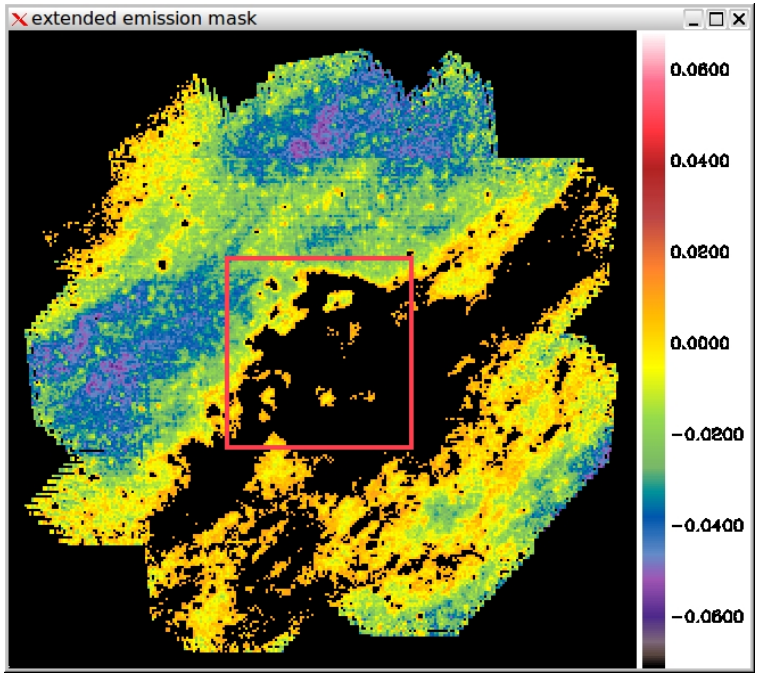
c) very bright and complex fields (dedicated */galactic* option):
- simple fits: flux calibration offsets only
- destriping: additional steps wrt general case:
first on scans, then blocks of 4 scan legs, then each scan leg

long-timescale drifts (technicalities)

The linear fits are robust least absolute-deviation fits:
- iteratively excluding deviant samples
- using a source mask (transferred to the time domain)

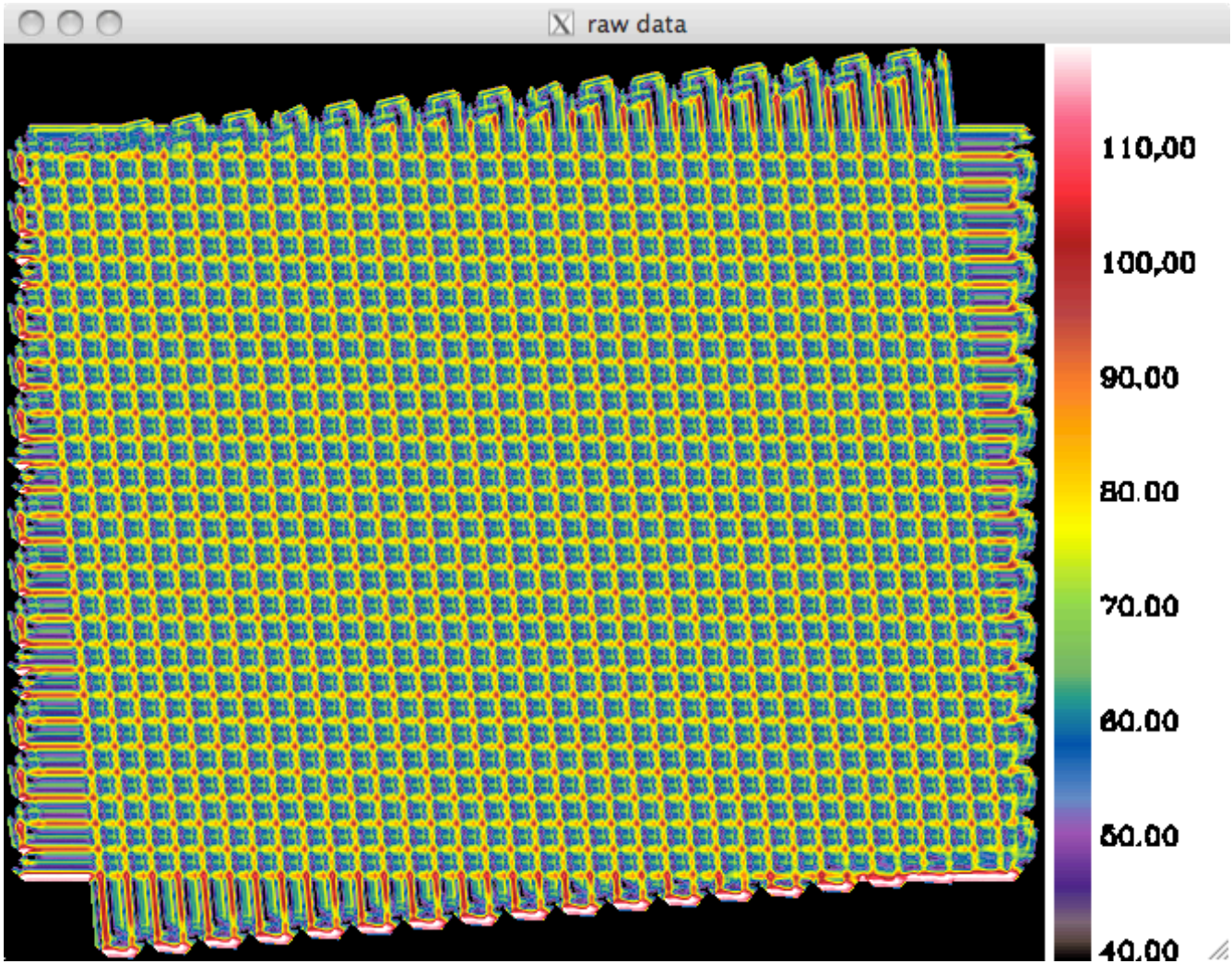
distinction between cases a) and b) made automatically:
based on fraction of pixels above a given threshold located within the central part of the map





long-timescale drifts (continued)

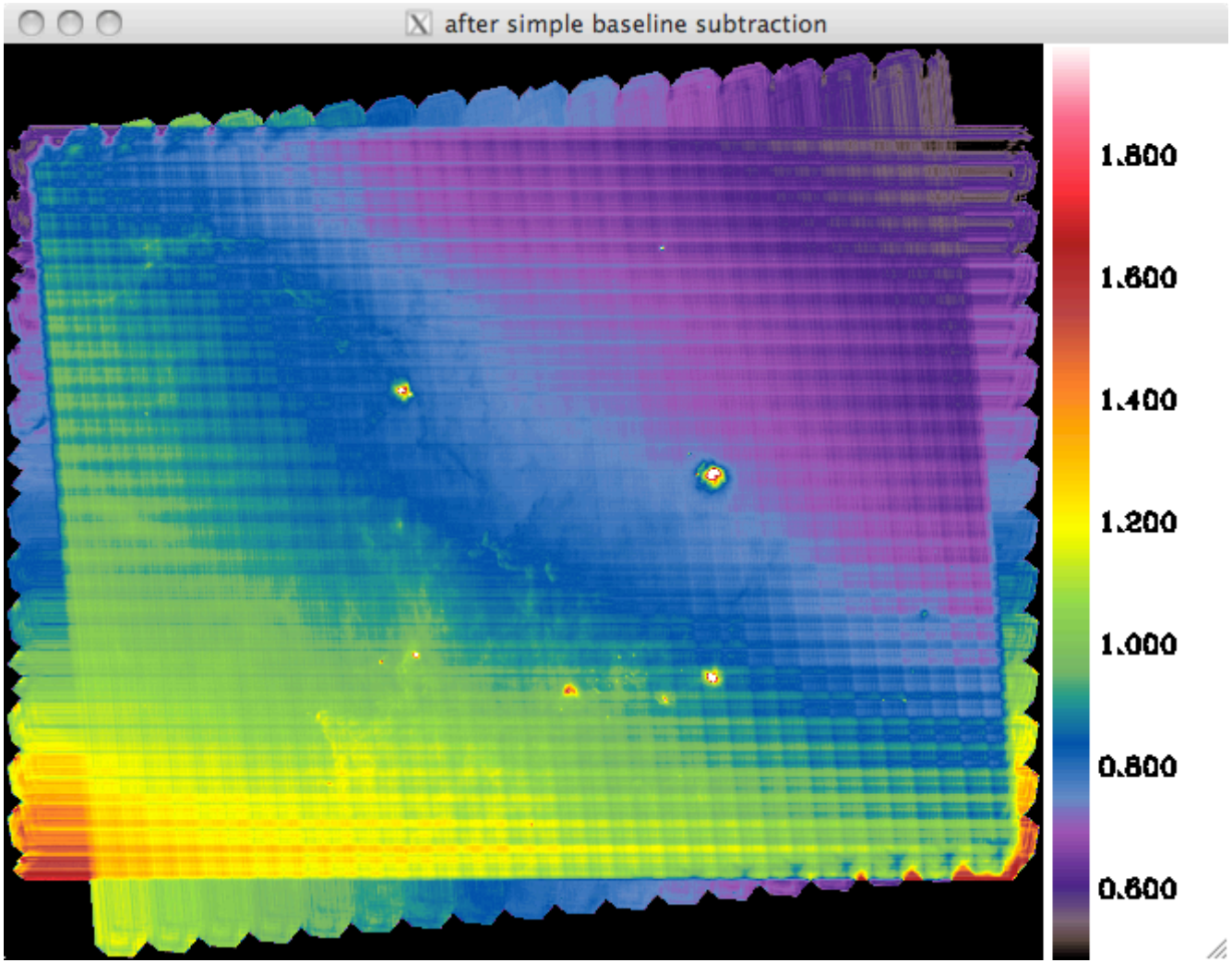
effect on complex fields (with */galactic* option):



raw data

long-timescale drifts (continued)

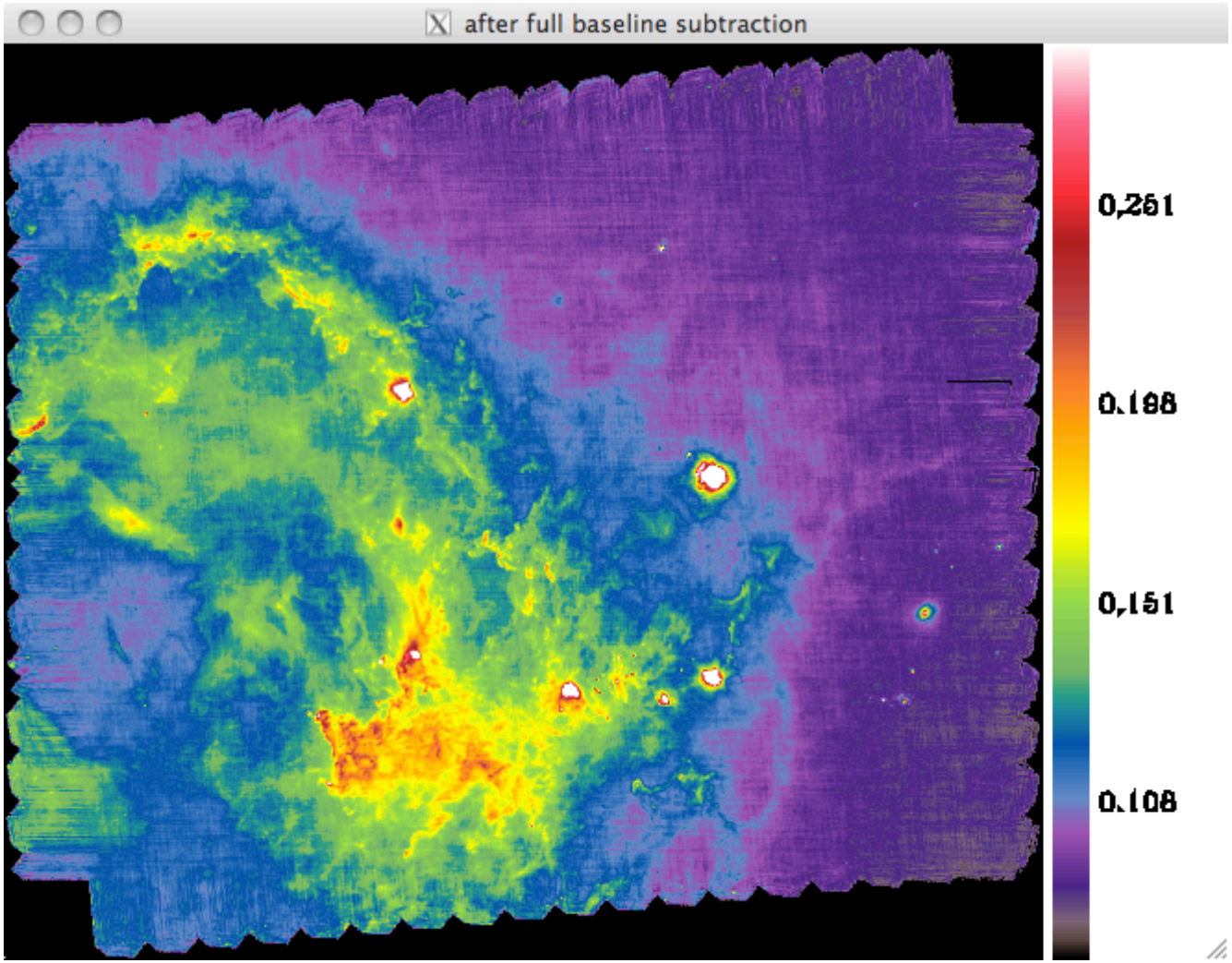
effect on complex fields (with */galactic* option):



after subtraction of preliminary simple fits (offsets)

long-timescale drifts (continued)

effect on complex fields (with */galactic* option):



after destriping (constrained linear baselines)

residual noise: short-timescale drifts (next steps)

main steps

1− computation of space and time grids adapted to the problem

(*) 2− computation of high-frequency noise levels
(to serve as noise normalization + thresholds)

(#) 3− subtraction of long-timescale drifts

(*) 4− subtraction of short-timescale drifts (t_c < scan leg duration)

5− projection of signal, error, drift and weight maps
on user-specified grid

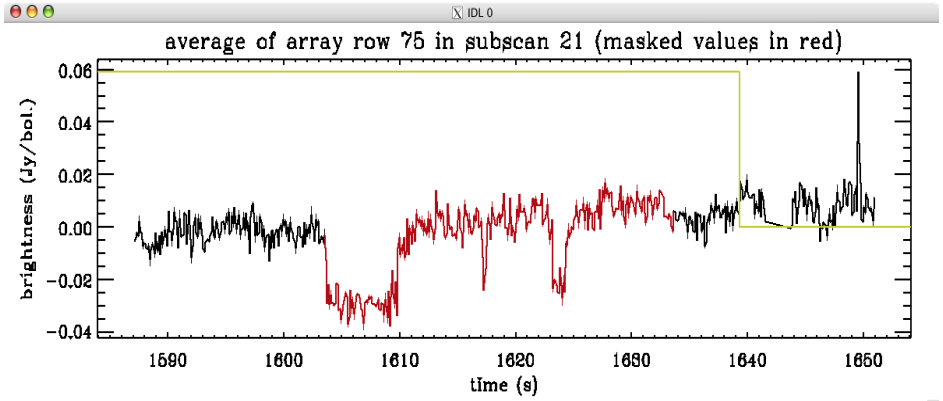
(*) deglitching done within several modules
(#) optionally with masking of **instabilities (brightness jumps)**

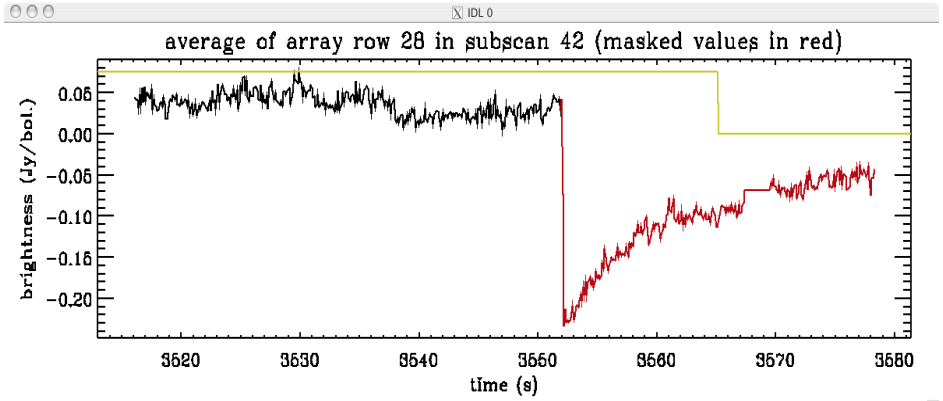
detection and masking of jumps

/jumps_pacs option (not usable jointly with */galactic*)

two jump types:
- electronic instabilities
  (most unstable bolometers systematically masked,
  but random bolometers can also go unstable for a time)
- discontinuities caused by glitches

neither pure high-f (glitches) nor pure low-f (drifts) artefacts
-> specific module to detect and mask them





main steps

1− computation of space and time grids adapted to the problem

(*) 2− computation of high-frequency noise levels
(to serve as noise normalization + thresholds)

(#) 3− subtraction of long-timescale drifts

(*) 4− subtraction of **short-timescale drifts (t_c < scan leg duration)**

5− projection of signal, error, drift and weight maps
on user-specified grid

(*) deglitching done within several modules
(#) optionally with masking of instabilities (brightness jumps)

short-timescale drifts: underlying assumptions

recorded signal R = time-invariant sky emission S
+ additive drifts D (low-f noise)
+ white noise + glitches (high-f noise)

$R(t, b_i) = S(p) + D_{aver}(t) + D_{indiv}(t, b_i) + HF(t, b_i)$

variables: time t , bolometers b_i , pixels p

assumption about the drifts: minimum timescale t_c
–> definition of a **stability length** $l_s \leq t_c \times v_{scan}$

requirement: enough statistics within l_s to compute drifts
$N_{samples}\ (l_s) = l_s / v_{scan} \times f_{sampling} \geq 6$

$l_s = k \times FWHM$ (PACS nominal: k = 2.5, 2.0, 1.5 at 70, 100, 160 μm)
(corresponding timescales: t_c = 0.7 s, 0.7 s, 0.9 s)

computation grids

1) coarse spatial grid for the drifts: pixels of size l_s
drifts and sky both assumed stable within l_s
−> sources protected by explicit exclusion mechanism
(dispersions compared with high-f noise thresholds)
to better sample the drifts: two grids offset by $l_s/2$ in each direction

2) finer spatial grid for intermediate maps: pixels of size FWHM/2

3) coarse time grid for the drifts: time step $\geq t_c$

4) brightness normalization: white noise amplitude W
convergence criterion: drifts amplitude < W

note: blue array in parallel mode −> $f_{sampling}$ = 5 Hz instead of 10 Hz
−> l_s doubled

protection of sources

decision tree for each coarse pixel **p**:

- samples corrected for pointing differences within **p**
  using the current map (if variations not dominated by noise)
- samples arranged in distinct bolometer crossings
- mean and dispersion computed for each crossing

case 1: < 70 to 80% of crossings have a dispersion
smaller than high-f noise threshold
−> **p** contains sources or steep gradients
−> data not used for drifts computation

case 2: **p** contains uniform emission
data suitable for drifts computation
−> only crossings with high dispersion (glitches) discarded

short-timescale drifts: workings

average drift: differences between pairs of bolometer crossings

$$\Delta(t_1, t_2) = R(t_1, b_i) - R(t_2, b_j)$$
$$= \cancel{S(p) - S(p)} + D_{aver}(t_1) - D_{aver}(t_2) + D_{indiv}(t_1, b_i) - D_{indiv}(t_2, b_j)$$

$\Delta(t_1, t_2)$ terms coadded for all pairs (b_i, b_j) and all pixels p
−> coadded terms reduce to $D_{aver}(t_1) - D_{aver}(t_2)$
if enough redundancy (D_{indiv} terms uncorrelated)

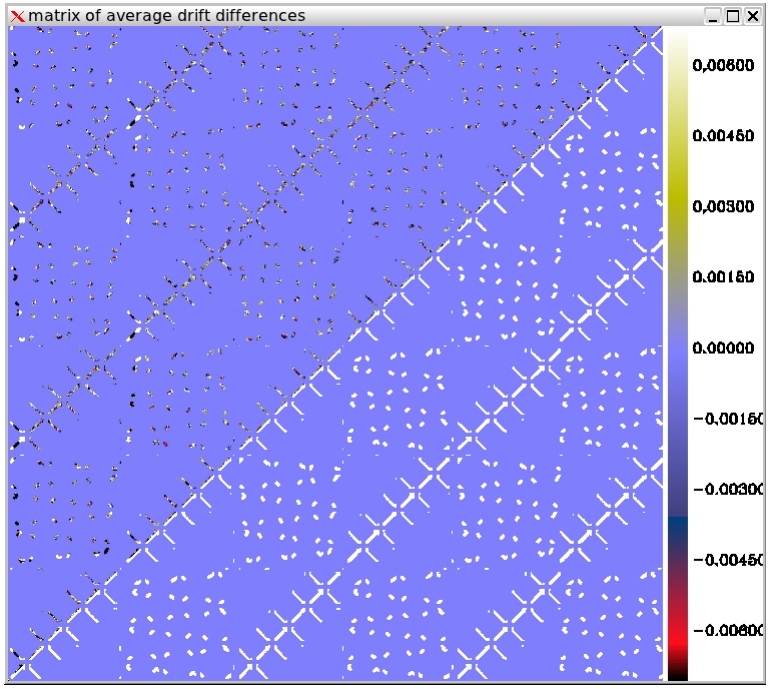
individual drifts: differences between each bolometer crossing and average of all crossings

$$\delta(t, b_i) = R(t, b_i) - 1/N \Sigma_{k=1,...N} R(t_k, b_k)$$
$$= \cancel{S(p) - S(p)} + \cancel{D_{aver}(t)} + D_{indiv}(t, b_i) - 1/N \Sigma (\cancel{D_{aver}(t_k)} + D_{indiv}(t_k, b_k))$$

$\delta(t, b_i)$ reduces to $D_{indiv}(t, b_i)$ by same token as above

short-timescale average drift: corrections

matrix of coadded $\Delta(t_1, t_2)$ terms:

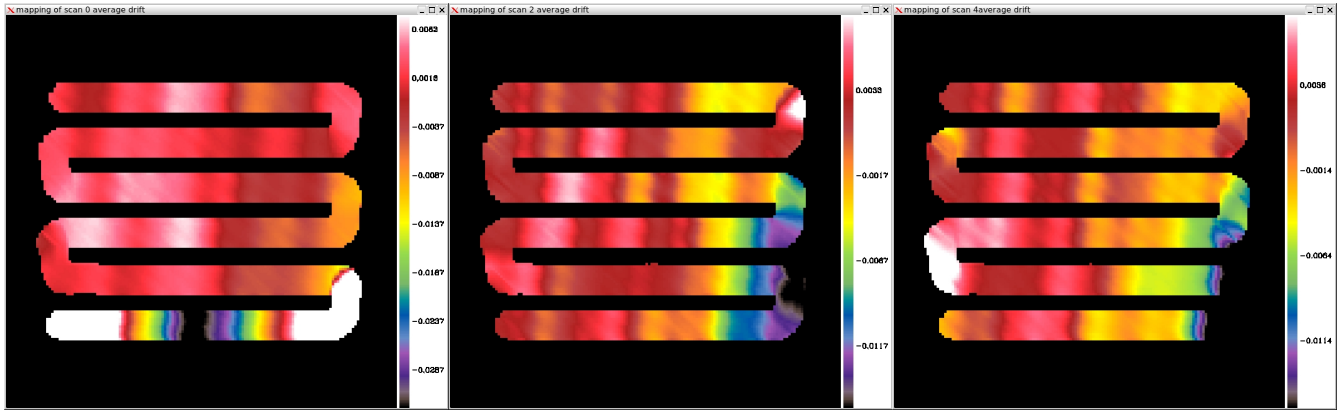


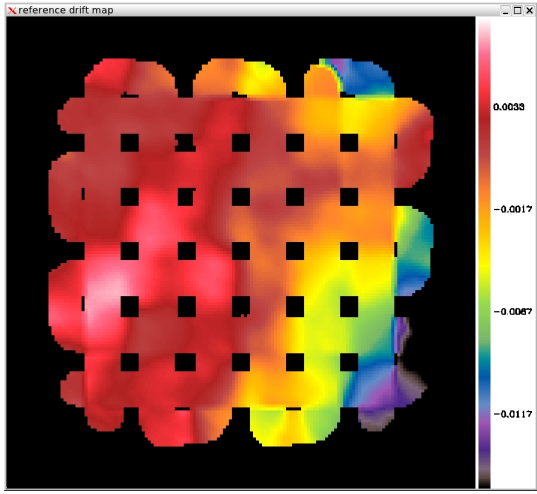
$t_2 > t_1$: $D_{aver}(t_1) - D_{aver}(t_2)$
mirror term below diagnonal: associated weights

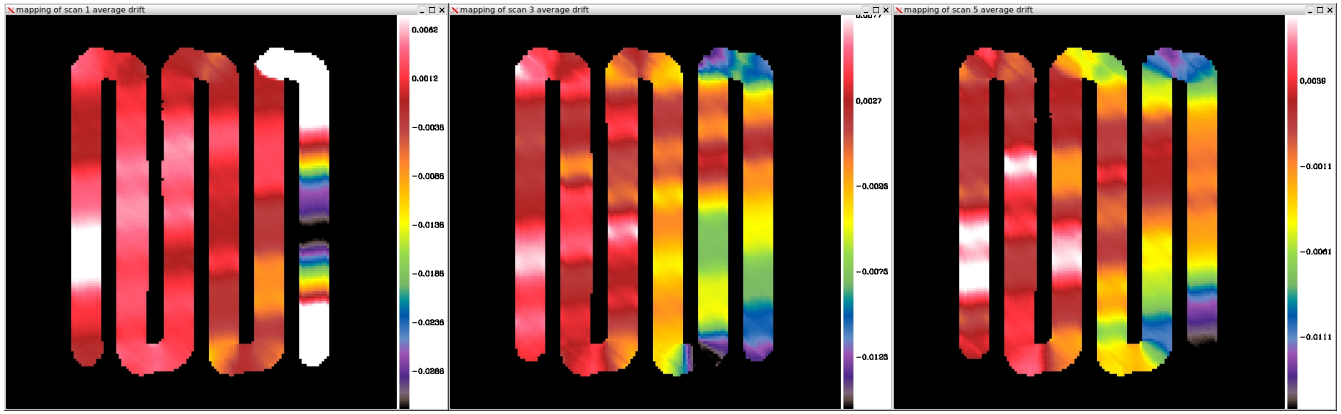
matrix scanned until convergence
−> $D_{aver}(t)$ + spurious periodic component
(period of spatial coordinates)

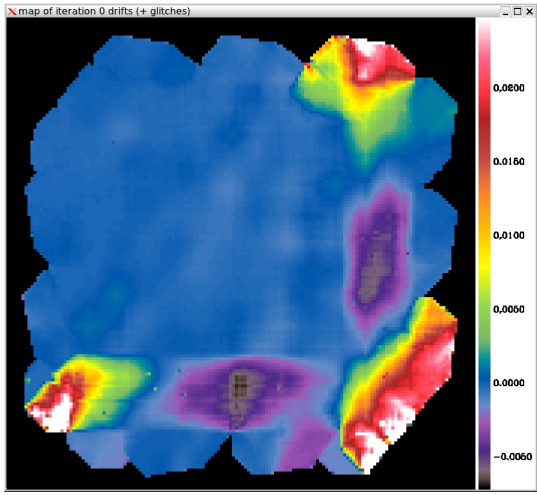
excess drift removed by mapping the drift scan by scan and extracting the common (smoothly varying) part

excess drift removed by mapping the drift scan by scan and extracting the common (smoothly varying) part:









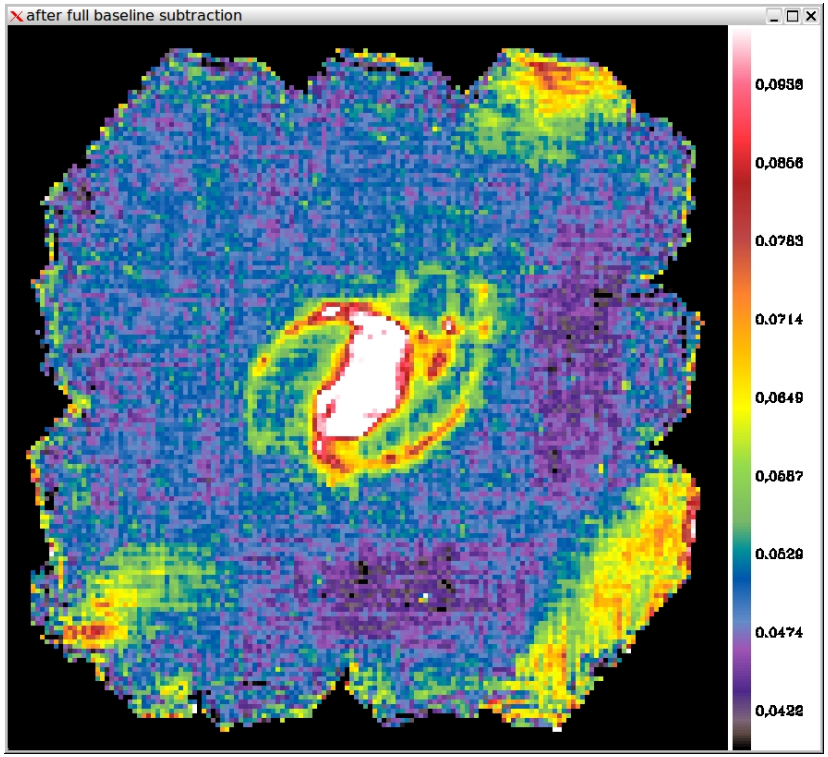
$D_{aver}(t) = D(t)$ extracted from matrix – excess drift

short-timescale average drift: illustration

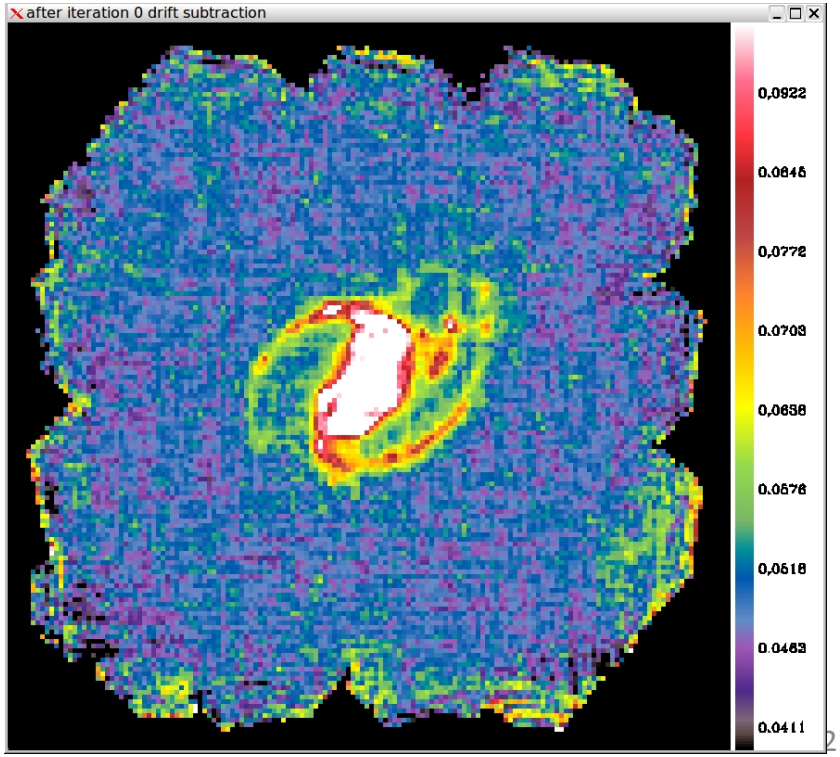
obvious source of non-linear drifts:
transients following calibration blocks

average drift subtraction can mitigate them:

after destriping:

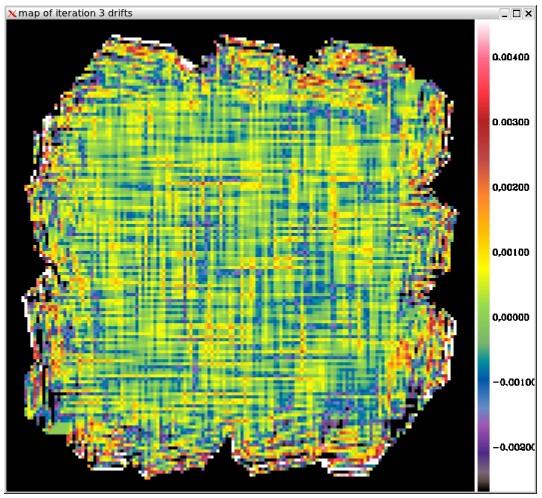


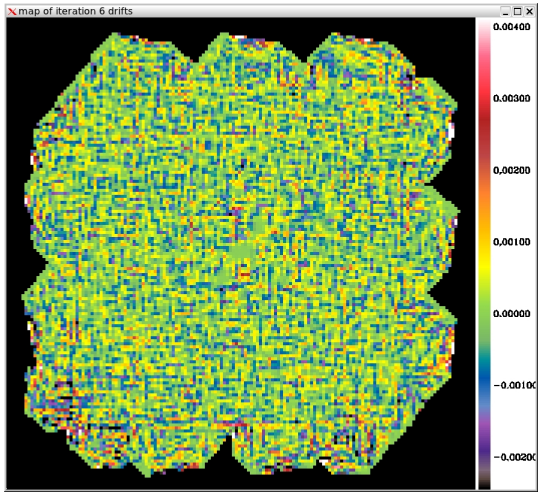
after average drift subtraction:



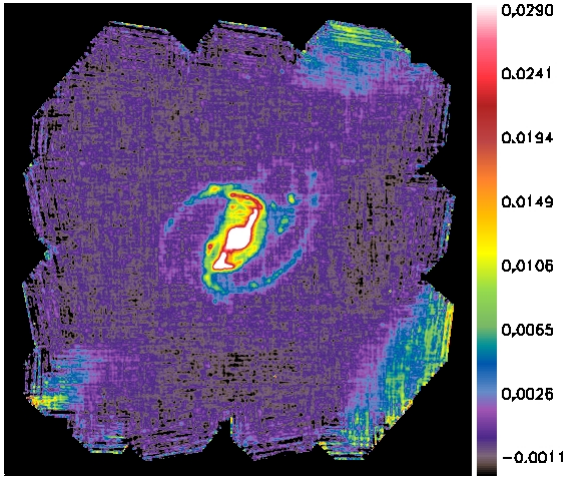
individual drifts: illustration

typical maps of removed indiv. drifts:

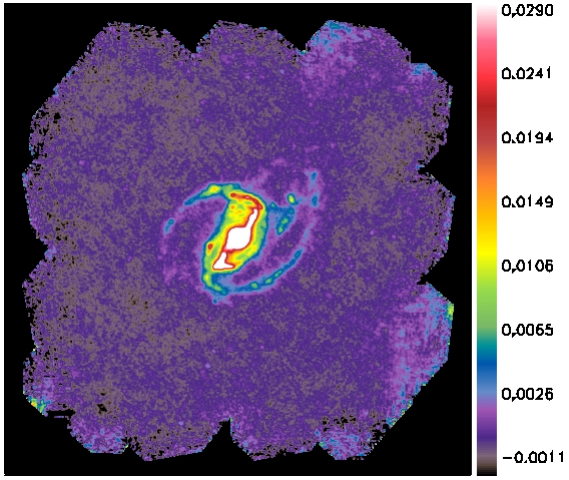




without short-timescale drift subtraction:



with full drift subtraction:



individual drifts: sliding timescale

better noise subtraction if the individual drifts
are first averaged into large time bins

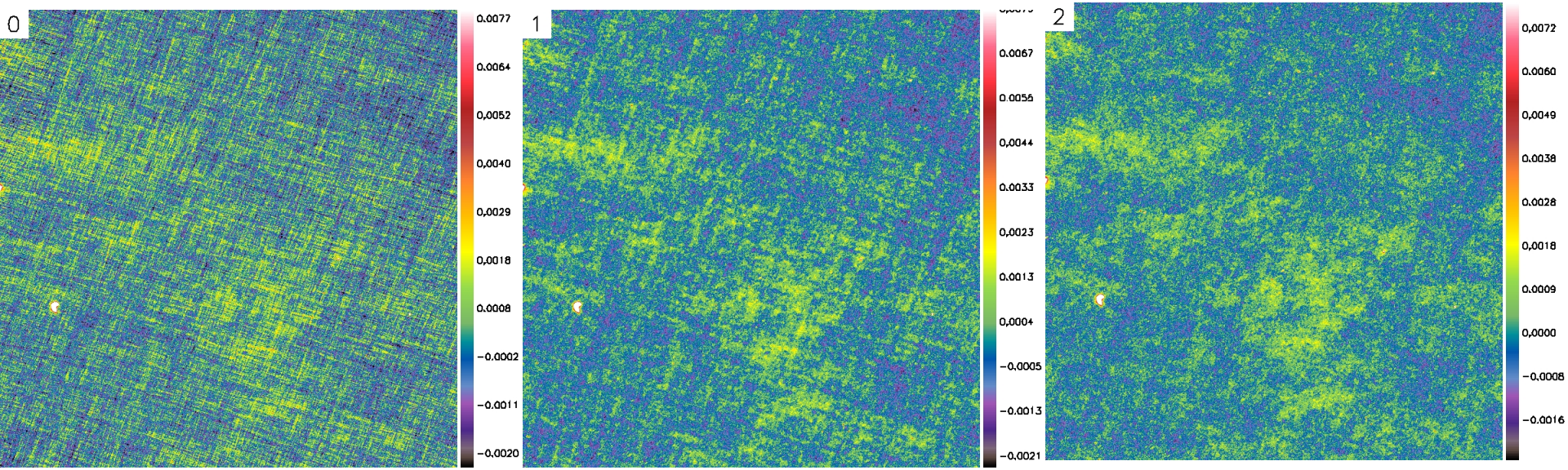
$\delta(t, b_i) = D_{indiv}(t, b_i) - 1/N \, \Sigma \, D_{indiv}(t_k, b_k)$

right-hand term comes closer to 0 (averaged on many more samples)

no short-timescale drift correction:

timescale t_c on all iterations:

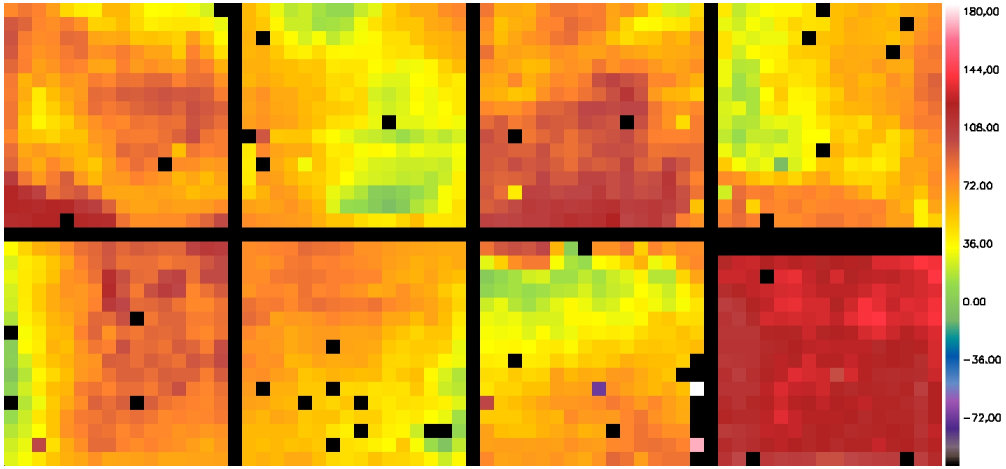
successive timescales $9\ t_c$, $3\ t_c$, t_c :



(~ 2.2 degrees on a side)

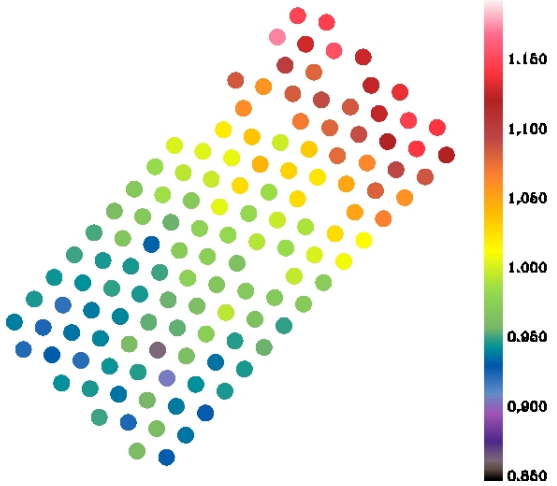
data volume and redundancy

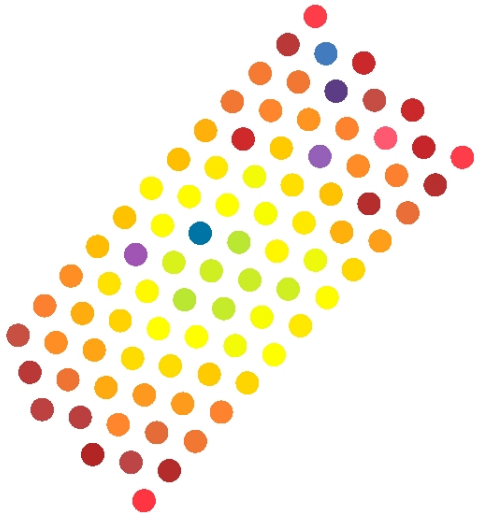
array structure:



PACS: 512 (red array) and 2048 (blue array) bolometers

SPIRE: 43, 88 and 139 bolometer with feedhorns





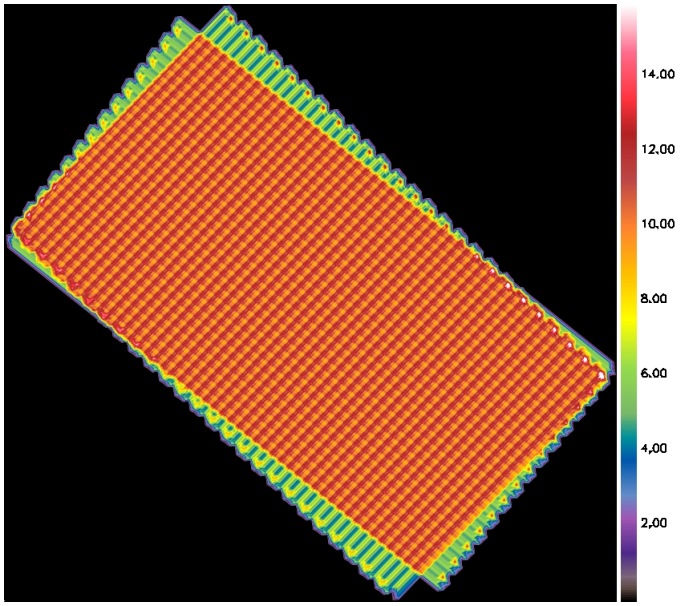


data volume and redundancy

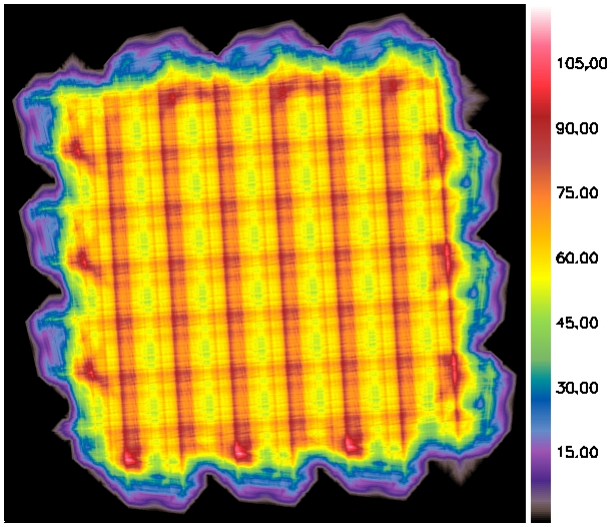
typical redundancy in PACS data:
~ 10 samples per FWHM/4 pixel
at the minimum sampling rate of 5 Hz (2 scans)
coverage can be rather inhomogeneous

processing time < observation time in all cases

2 scans, parallel mode, blue array



6 scans, nominal mode, blue array

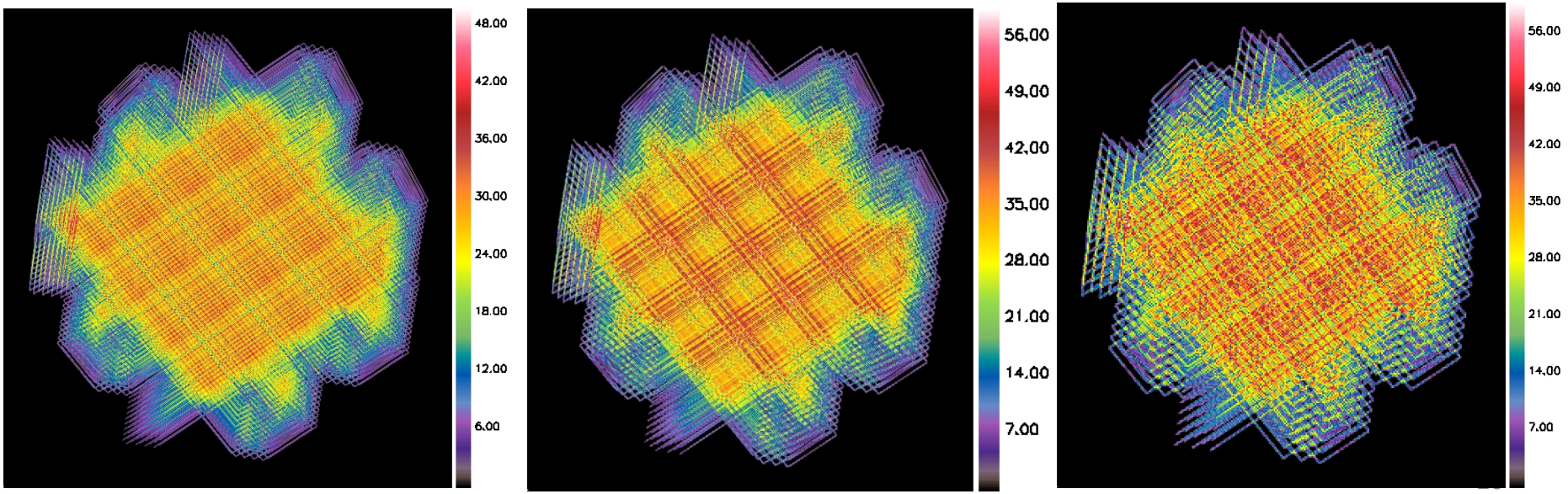


data volume and redundancy

typical redundancy in SPIRE data:
~ 10 samples per FWHM/4 pixel
coverage can be rather inhomogeneous

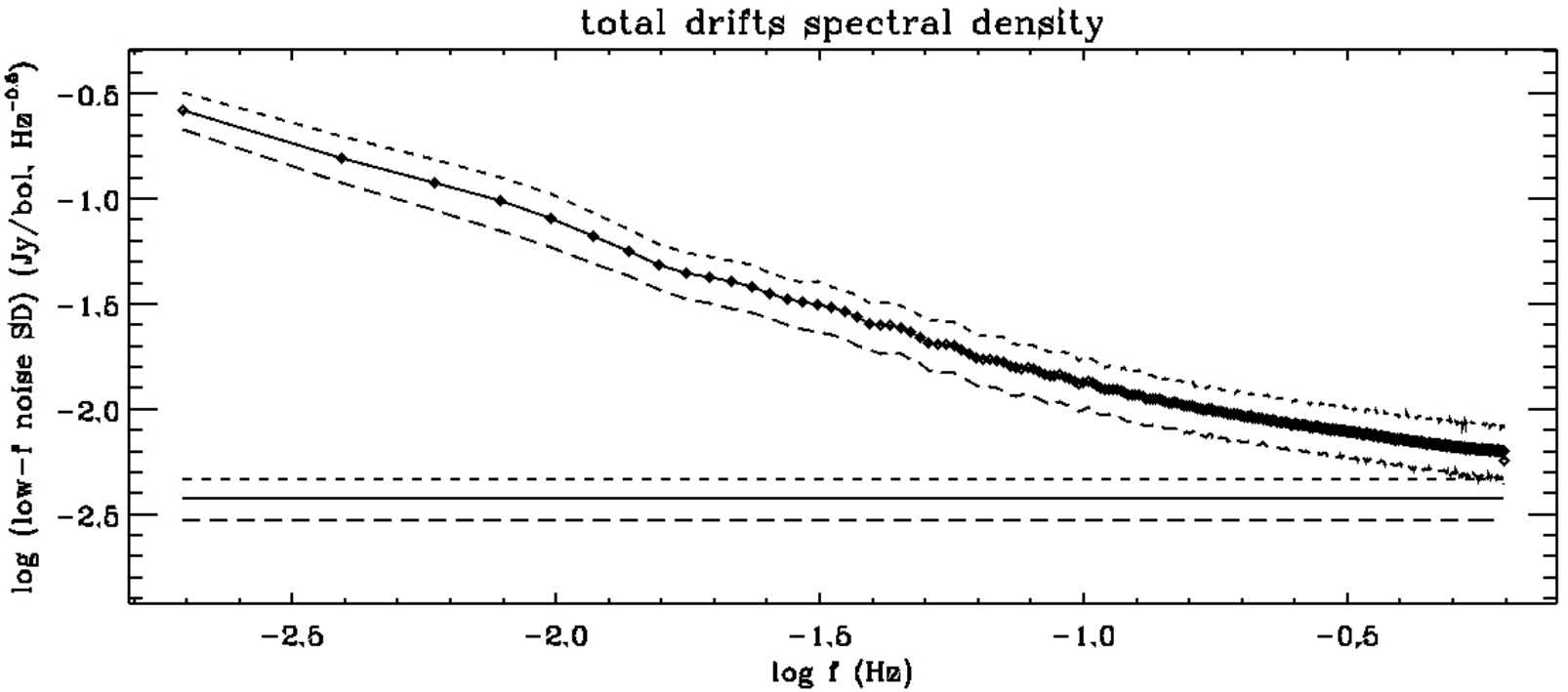
processing time << observation time

6 scans, nominal mode



low-f noise characteristics in PACS

knee frequency above 1 Hz
maximum freq. for drift subtraction: 1.4 and 1.1 Hz
(smaller at lower sampling rate and higher scan speed)



thermal drifts from the atmosphere

possible to subtract them with this method
only if the sampling rate is high enough:

- fundamental assumption that drifts are stable within l_s
- at least 6 samples per l_s to compute simple statistics

$\rightarrow f_{sampling} > 6\ f_c$

typical strategy for observations with low $f_{sampling}$:
assume source size < array size
and subtract the array median
(can be iterated after masking the brightest sources)
but more effective to exploit the redundancy

code and documentation:

http://www2.iap.fr/users/roussel/herschel/

arXiv 1205.2576:

- detailed description of the algorithm
- illustrations of the processing steps
- PACS simulations for a star formation region and a nearby galaxy