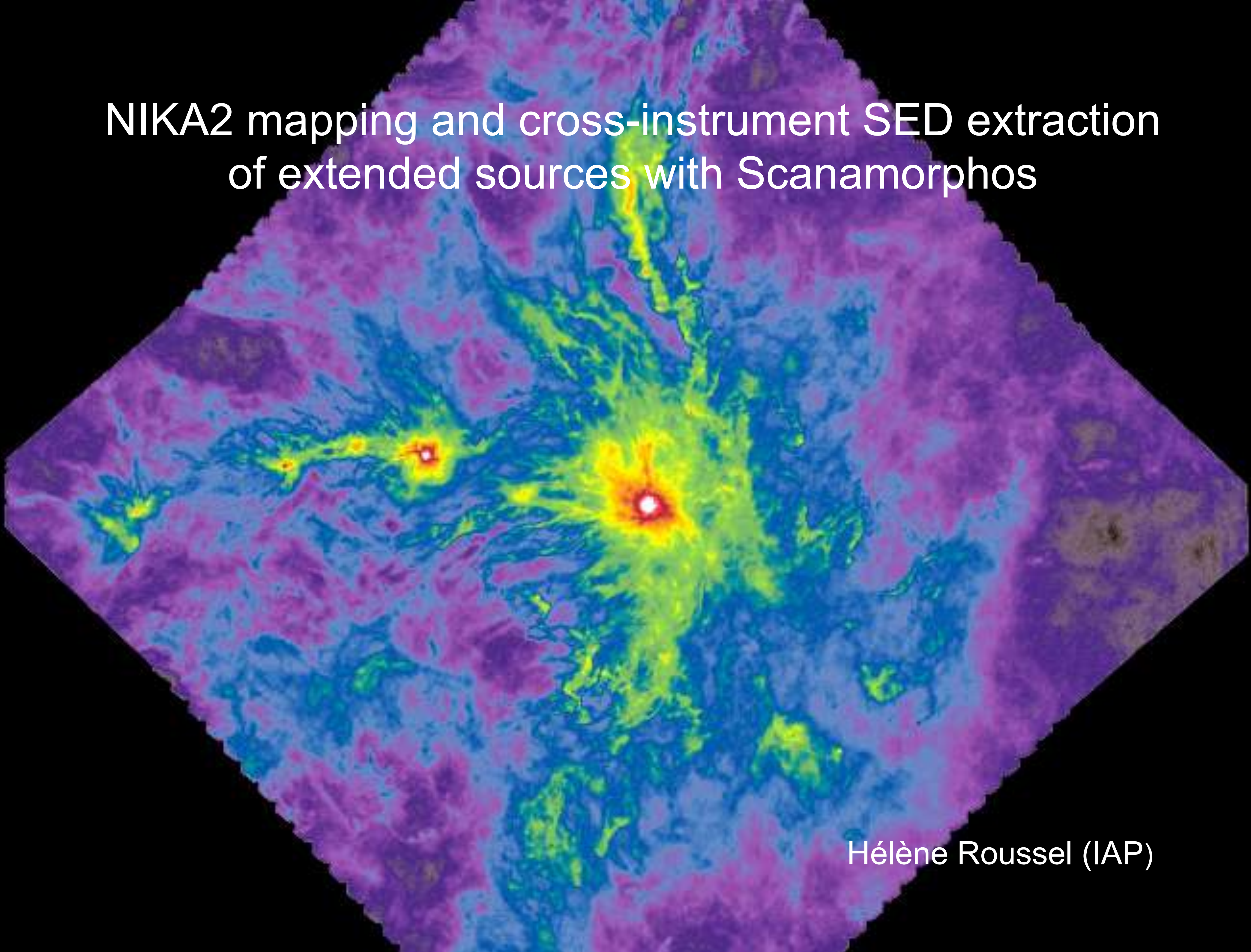


NIKA2 mapping and cross-instrument SED extraction of extended sources with Scanamorphos

Hélène Roussel (IAP)

infrared-mm continuum mapping of wide fields (Galactic clouds, nearby galaxies, etc)
very efficient with OTF observations
many NIKA2 programs targetting sources with a large range of spatial scales

but drifts and time-variable foregrounds calling for special processing methods
can dominate the astrophysical signal by several orders of magnitude

need for a method removing the low-frequency (LF) noise
while preserving emission on all scales < map size

- NIKA2 team pipeline unbeatable for point / compact sources
- need for alternative tools to compare results on extended sources

scanam_nika is such a tool, already adapted and tested on NIKA1 and NIKA2 data

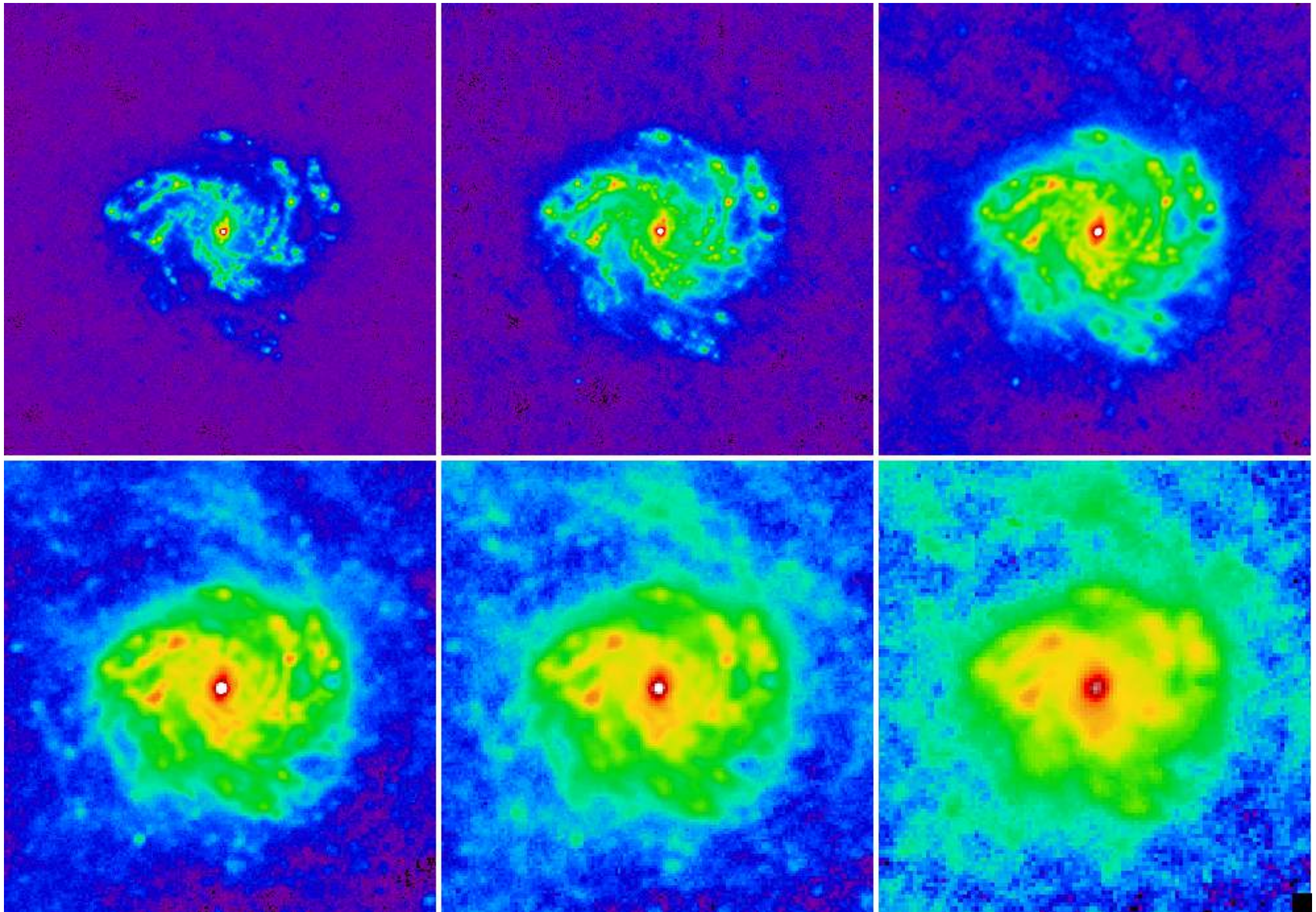
one of the incarnations of the Scanamorphos algorithm (Roussel, H. 2013, PASP 125, 1126)
`http://www2.iap.fr/users/roussel/herschel`

designed to subtract the LF noise by completely exploiting the redundancy
(each position on the sky sampled by multiple detectors at multiple times)
no work in Fourier space, no explicit filtering

a brief history of the Scanamorphos algorithm:

- initiated on SPIRE simulations and P-ArTéMiS data before Herschel launch
  (only uncorrelated noise)

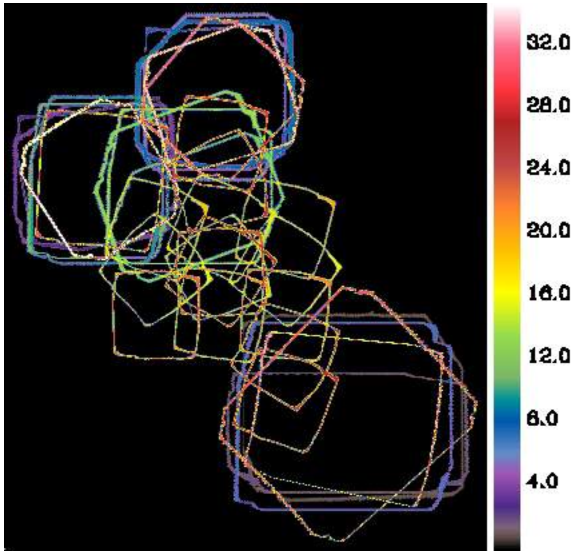
- full algorithm developed for PACS and SPIRE observations
  → proof of concept, 25 versions released in total
  code public and maintained throughout Herschel lifetime, used by many teams
  calibration of relative gains from obs. of bright molecular clouds
  + fancy options such as detection of transient sources



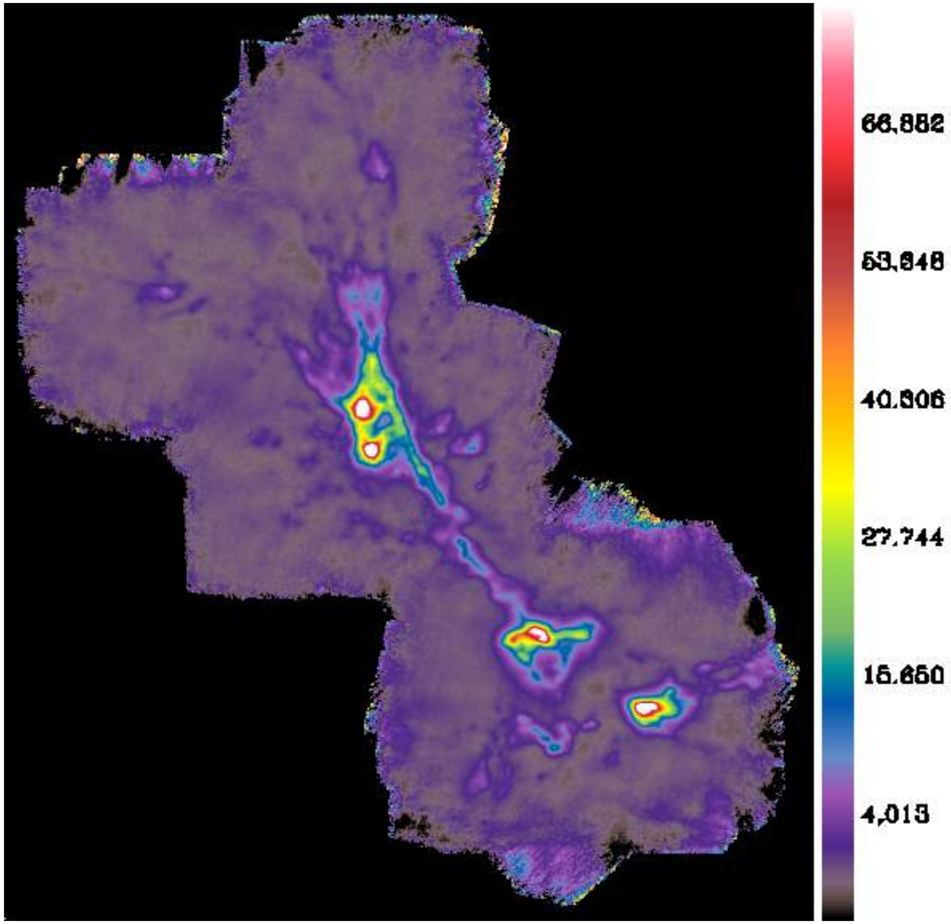
a brief history of the Scanamorphos algorithm:

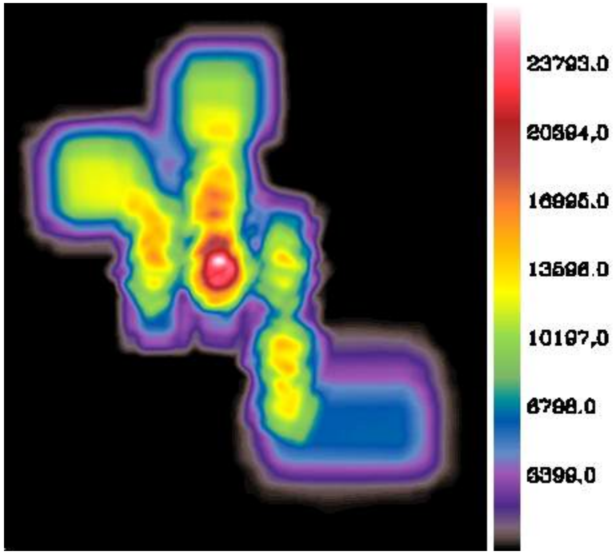
- initiated on SPIRE simulations and P-ArTéMiS data before Herschel launch (only uncorrelated noise)
- full algorithm developed for PACS and SPIRE observations
  → proof of concept

- algorithm adapted to ArTéMiS (350-450 μm camera on APEX)
  → proof that it works for ground-based instruments
  code public since march 2018



challenging observing strategy !!!

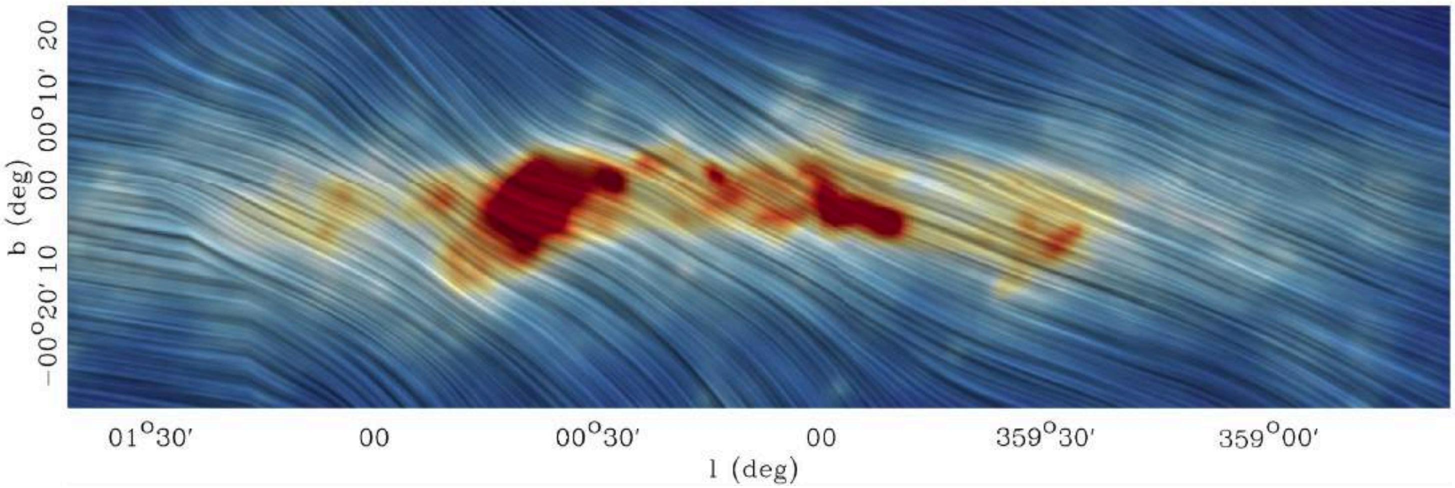




a brief history of the Scanamorphos algorithm:

- initiated on SPIRE simulations and P-ArTéMiS data before Herschel launch
  (only uncorrelated noise)
- full algorithm developed for PACS and SPIRE observations
  → proof of concept
- algorithm adapted to ArTéMiS (350-450 μm camera installed on APEX)
  → proof that it works for ground-based instruments

- algorithm adapted to work in polarization (still work in progress)
  on PILOT data (balloon experiment at 240 μm, already 2 flights)
  polarization obs. with discrete HWP positions
  cf Mangilli et al. 2019, submitted to A&A



- algorithm adapted to NIKA1 and then NIKA2 (still work in progress)

NIKA2 mapping and cross-instrument SED extraction of extended sources with Scanamorphos

- historical notes and broad principles

- calibration of gains for extended emission using the atmosphere

- step by step example of a reduction

- results on various sources

- applying the NIKA2 obs. + processing transfer function to Herschel data

- plans for release

broad principles:

− high inter-detector redundancy, but usually poor single-detector redundancy/coverage
+ dominant highly correlated noise
→ corrections for different detectors cannot be independently derived

− sources can extend over the whole map
→ decorrelation with iterative source mask will not always be enough
exploiting the redundancy holds the promise of recovering more extended emission

low-frequency (LF) noise and parasitic signal (atmosphere)
usually decomposed according to their physical origin:

- correlated component from the atmosphere / small T fluctuations / block electronics
- uncorrelated component from flicker noise / individual detector instabilities

here: decomposed into:
- average drift (whole array / whole electronic blocks)
- individual drifts (the complement)

basic assumptions:

- sky signal invariant in time
- probability distribution of individual drifts symmetric about zero
  (but no specific model assumed, i.e. not necessarily Gaussian)

All multiplicative effects must have been corrected beforehand.

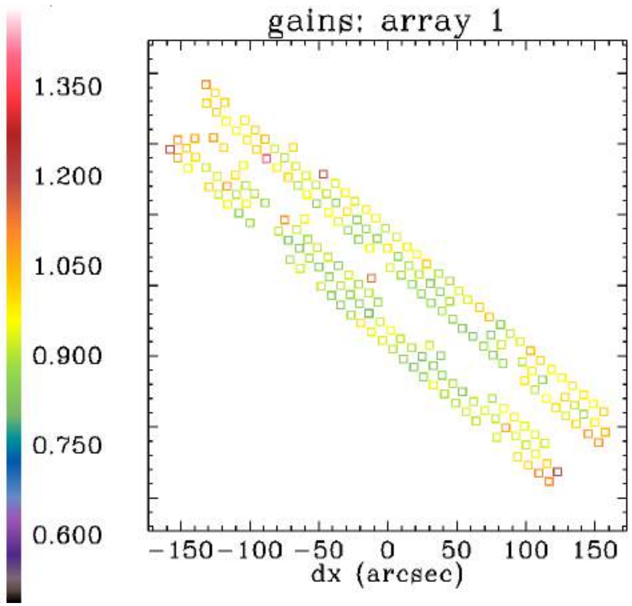
calibration of gains for extended emission using the atmosphere

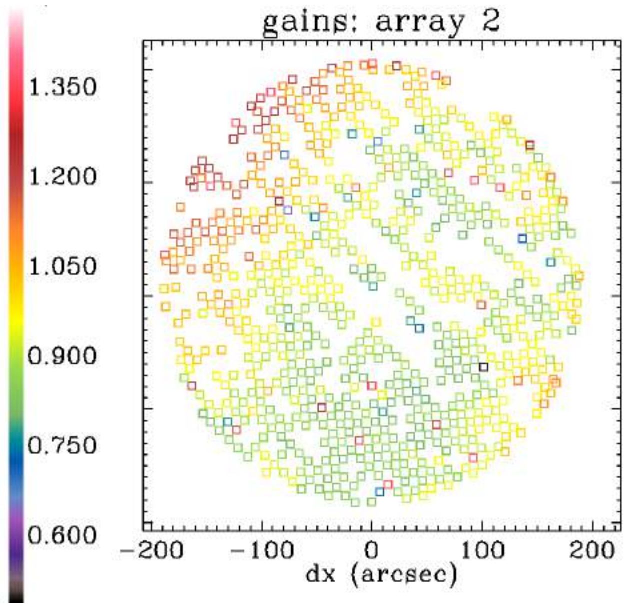
Detectors have different responses to the atmosphere (i.e. infinitely-extended emission). It is possible to recalibrate them using all the available observations in a given configuration, and check their stability.
should be done for each campaign, using all scans longer than ~ 5 min

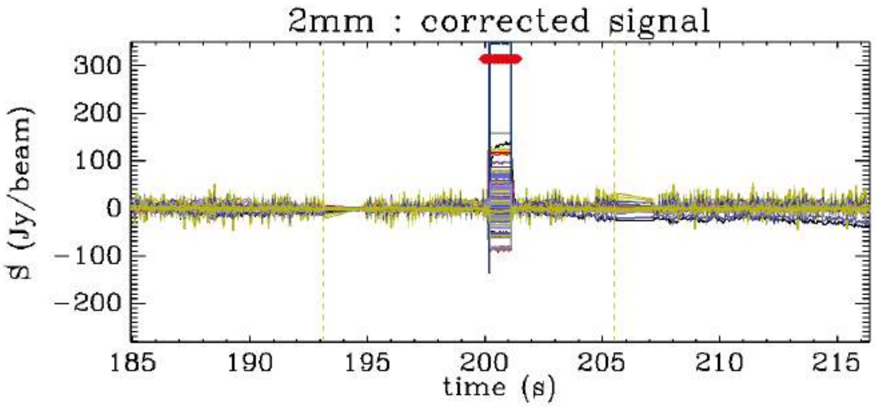
It all started in run 14:

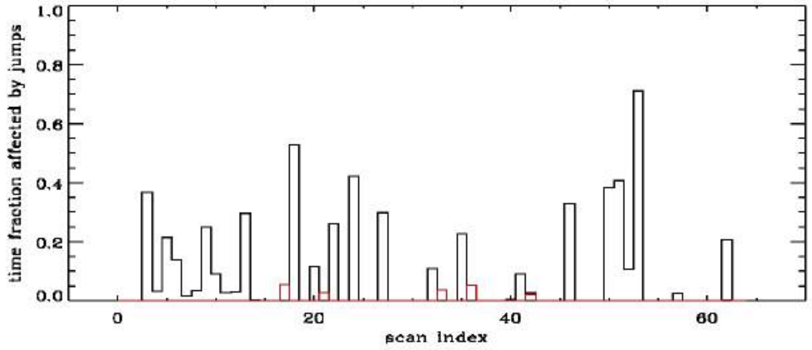
1mm array made of only two elec. boxes

2mm array affected by very frequent jumps









computation of responses to the atmosphere:

- assuming that all detectors see the same atmosphere at any given time (effect of changing the “reference” detectors tested)
- considering only scans > 5 min to be as immune as possible to short-term signal variations (induced by scanning bright sources or by atmospheric gradients)

iterative method for each scan (gains g_i initialized to 1 and offsets a_i initialized to 0):

1 - atmosphere signal estimated as the median signal of all valid detectors:

$$S_m = \text{median}((S_i - a_i) / g_i)$$

2 - fit of the signal of each detector as an affine function of the atmosphere:

$$S_{i\ \text{fit}} = a_i + g_i S_m$$

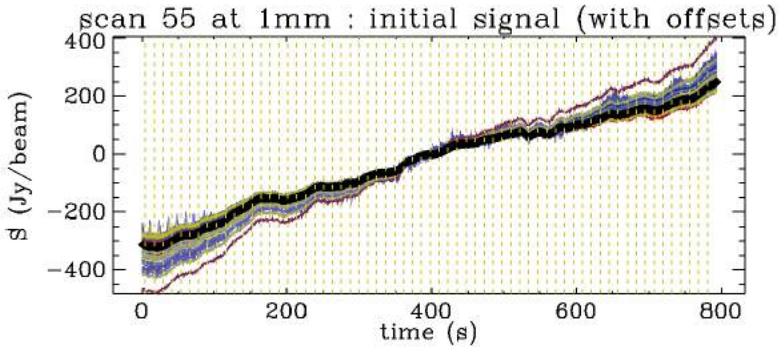
(using robust least absolute deviation fits, insensitive to short-term variations)

3 - jumps and rogue detectors identified and corrected/masked

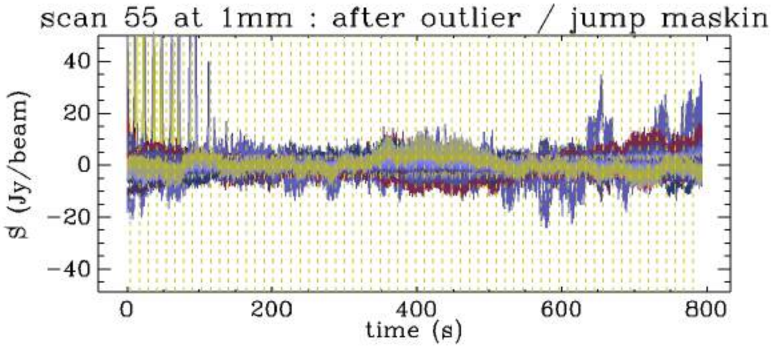
gains g_i well constrained provided S_m has high dynamic range

→ weighting of gains from each scan by dynamic range of atmosphere brightness

$S_i - a_i$

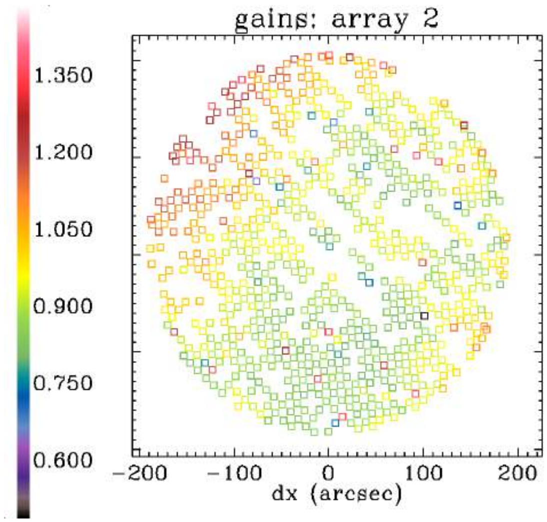


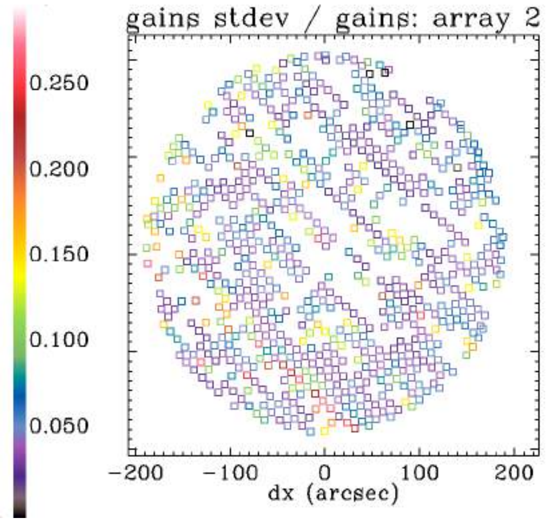
$S_i - (a_i + g_i S_m)$

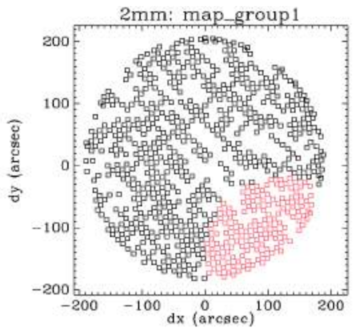


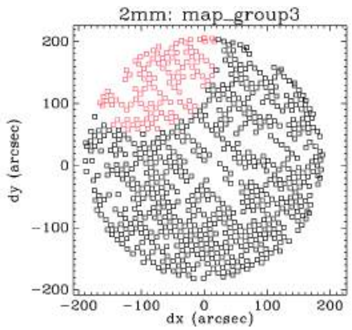
atmosphere gradients across the array are not a concern
(using the many long scans available within a run):

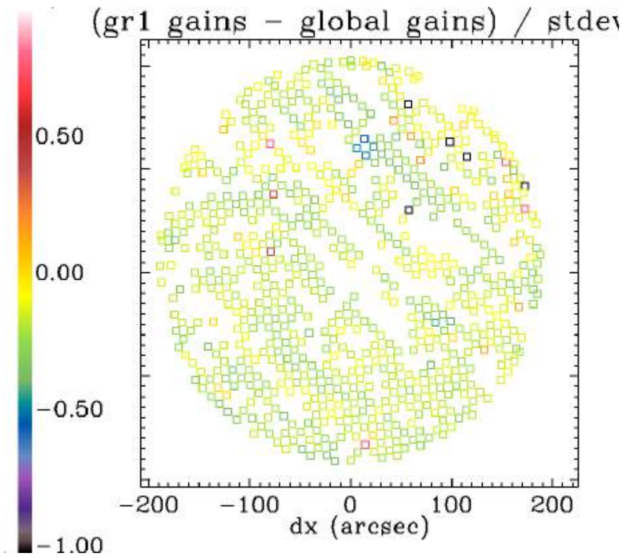
illustration for run 14

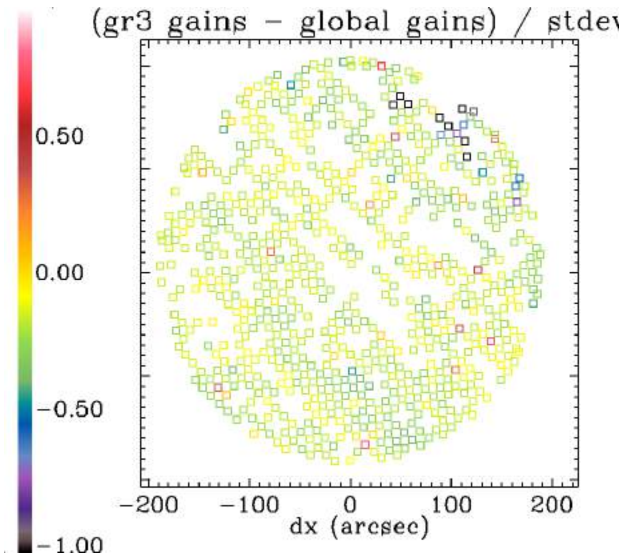






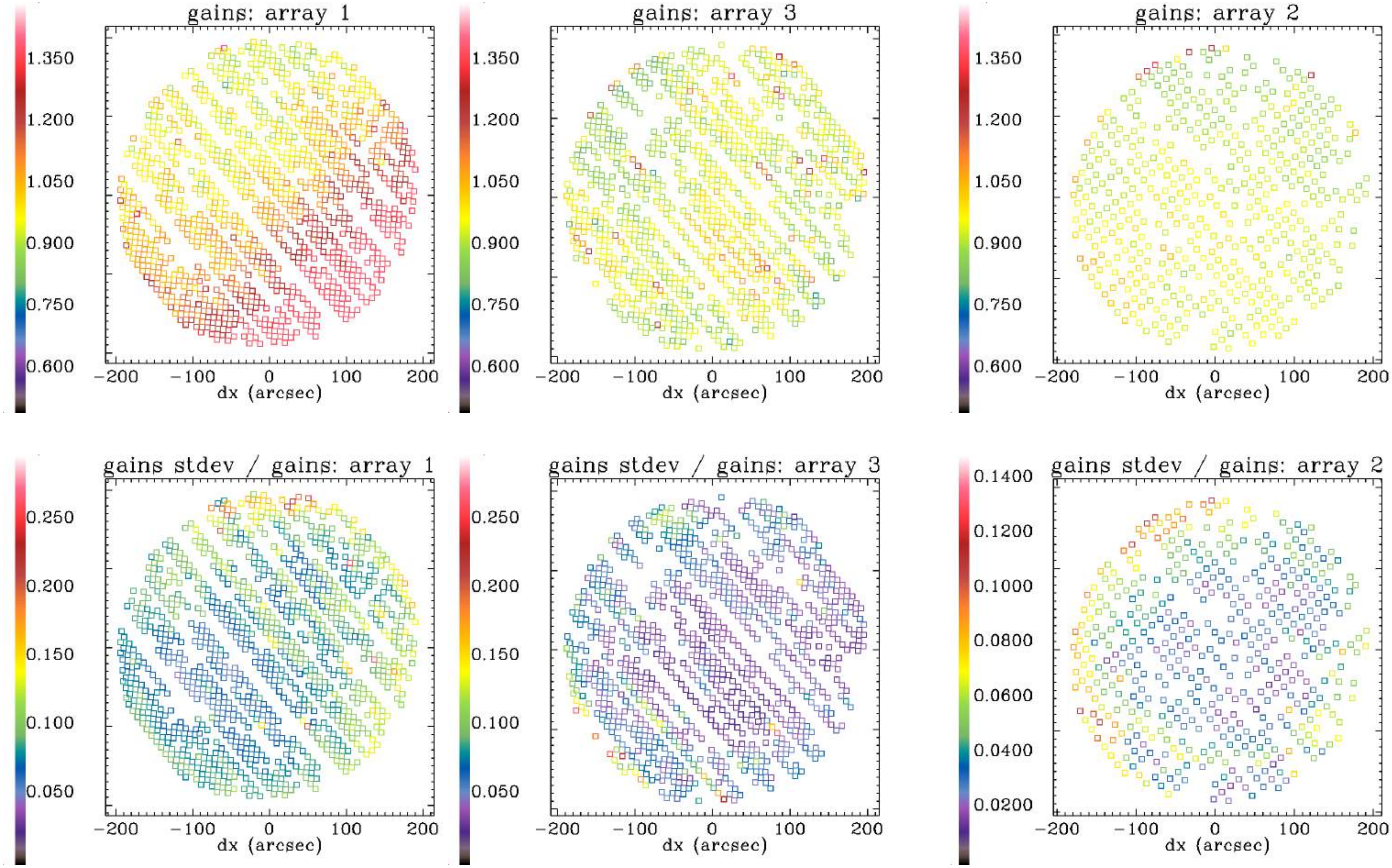




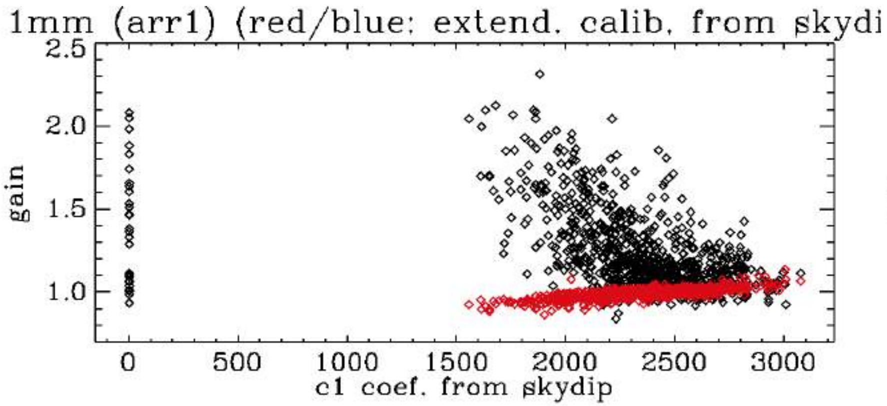


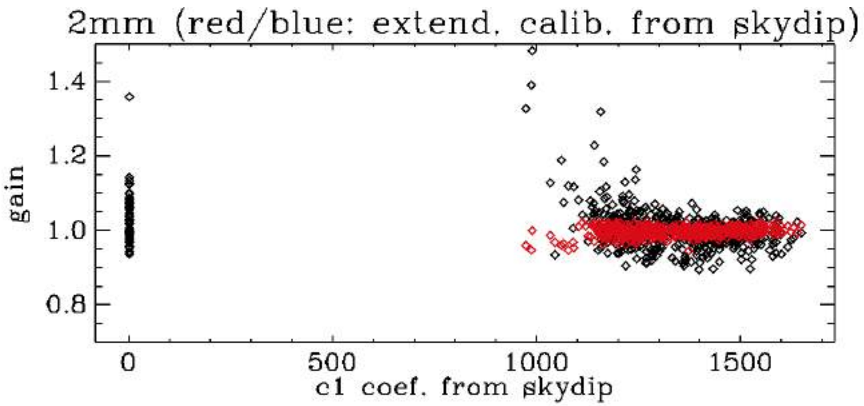
resulting errors: difference with respect to gains computed in the normal way, divided by their standard deviation results for run 19:

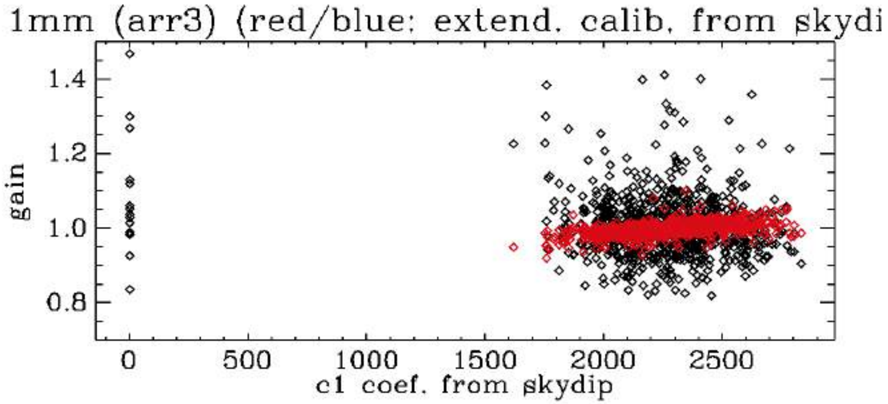
N.B. atmospheric signal at 1mm from array 3 only
median gain of (array 1) = 1.16
by construction, for other arrays: median gain = 1.

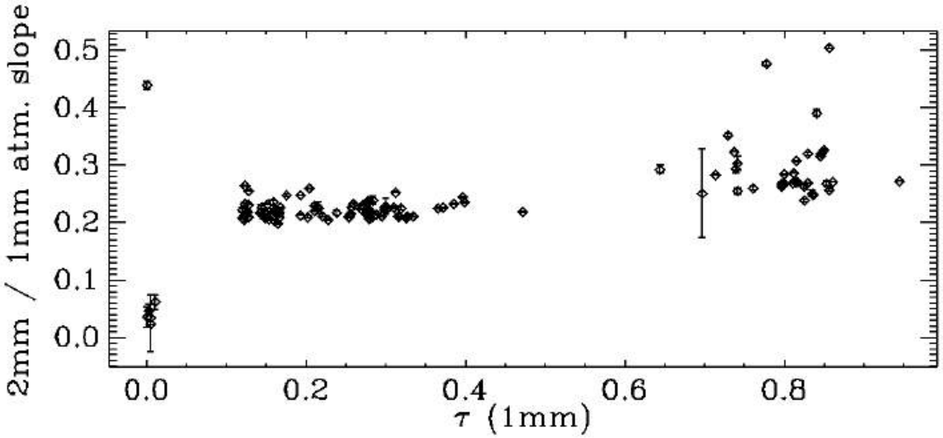


gains calibrated in this way not completely equivalent to those obtained from the analysis of skydips









black: responses to the atmosphere with point source calib.
(analysis on all the long scans of the run allows to retrieve more detectors)

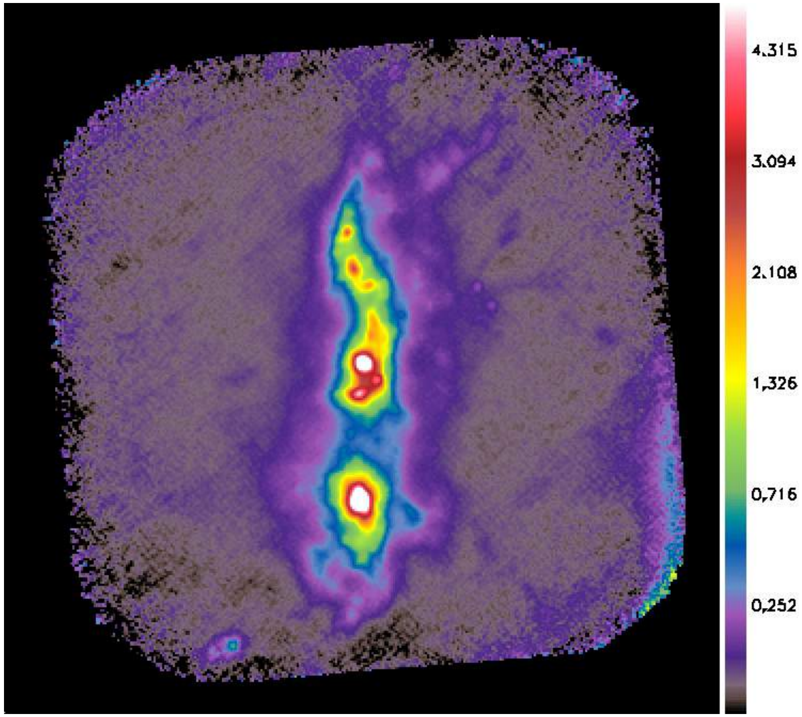
red: responses normalized by kidpar coefficients for extended source calib.

linear correlation of the residual gains with the c1 coefficient except at 2mm

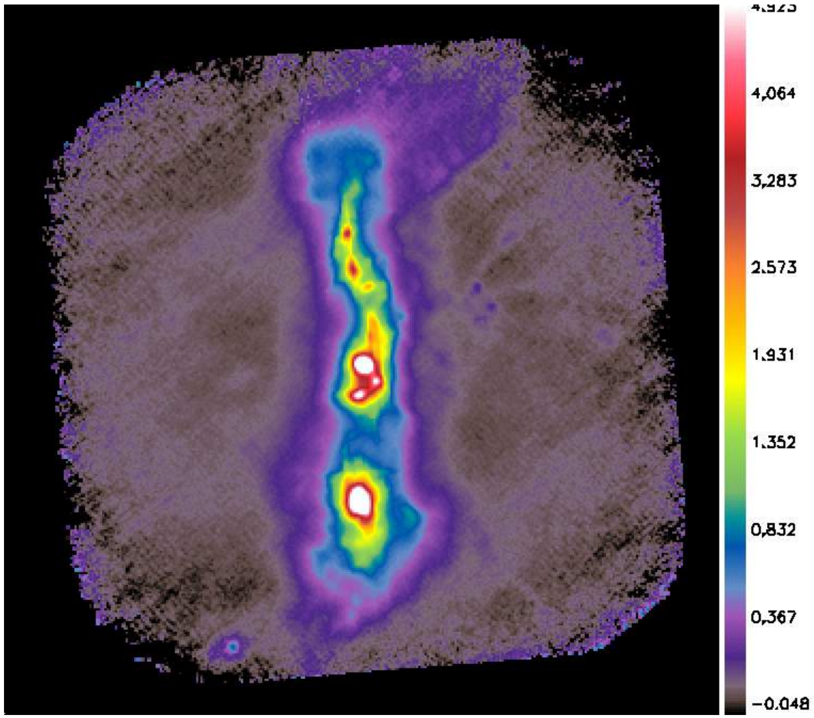
S_m (2mm) ~ (0.2 - 0.35) S_m (1mm, array 3) application of the gains can have non-negligible effects

ex.: DR21 OH (1mm, run 19)

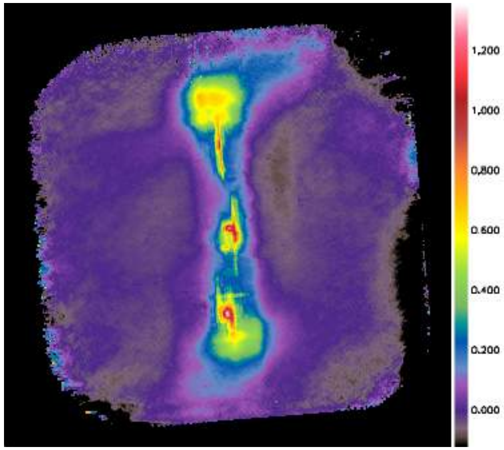
with gains



without gains



difference map:



usage of the NIKA2 team pipeline: for opacity correction and calibration

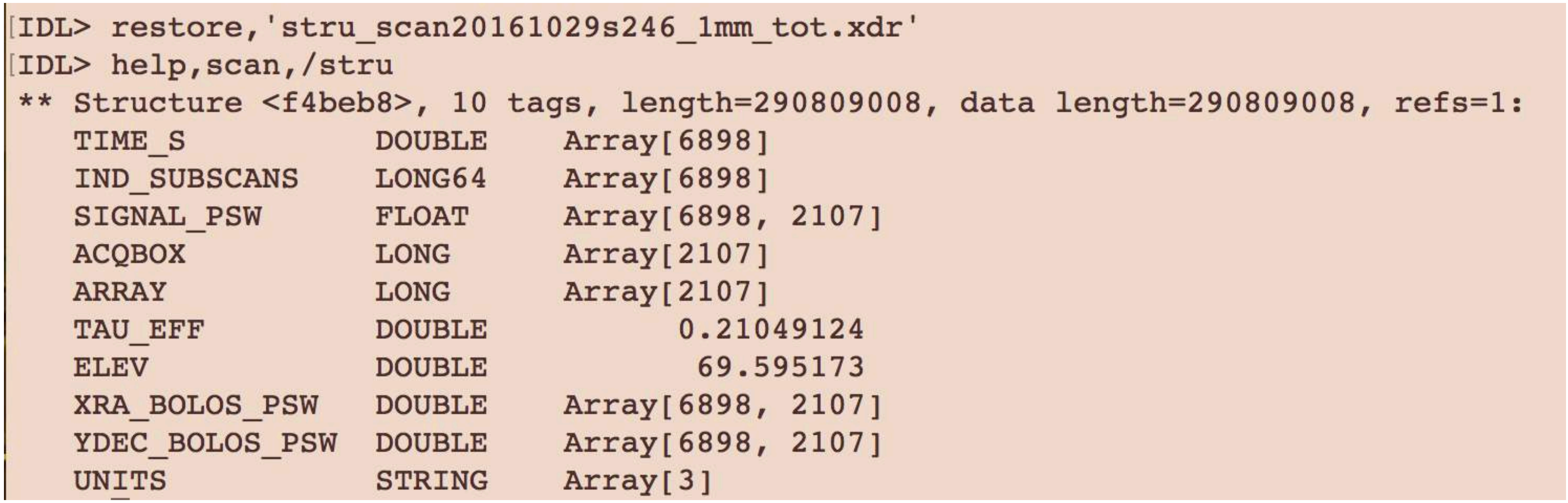
+ rejection of detectors with cross-talk

branching out before starting the processing

saving of time series of brightness and coordinates

- time vector
- array parameters (array number, acquisition box number)
- obs. parameters (opacity, elevation, scan leg number)

→ two IDL structures per scan (1mm and 2mm)



```
[IDL> restore,'stru_scan20161029s246_1mm_tot.xdr'
[IDL> help,scan,/stru
** Structure <f4beb8>, 10 tags, length=290809008, data length=290809008, refs=1:
   TIME_S          DOUBLE    Array[6898]
   IND_SUBSCANS    LONG64    Array[6898]
   SIGNAL_PSW      FLOAT     Array[6898, 2107]
   ACQBOX          LONG      Array[2107]
   ARRAY           LONG      Array[2107]
   TAU_EFF         DOUBLE          0.21049124
   ELEV            DOUBLE           69.595173
   XRA_BOLOS_PSW   DOUBLE    Array[6898, 2107]
   YDEC_BOLOS_PSW  DOUBLE    Array[6898, 2107]
   UNITS           STRING    Array[3]
```

step by step example of a reduction: DR21OH (run 19)

1) long-timescale drifts

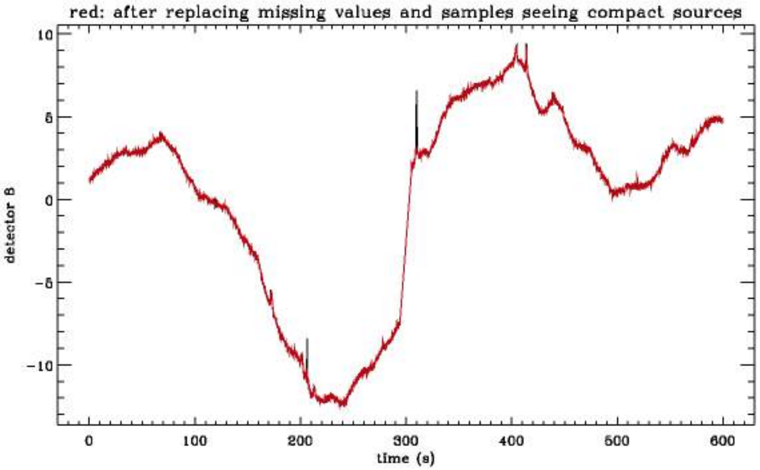
in the form of linear baselines, covering:
- flux-calibration offsets
- major part of average drift, dominated by the atmosphere
- small part of individual drifts

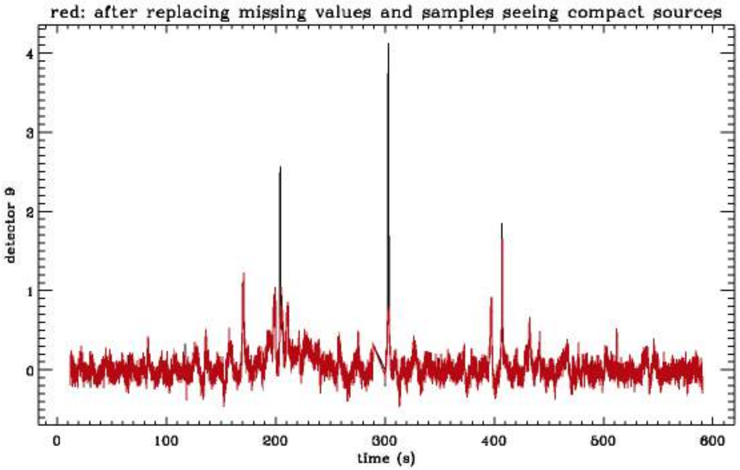
subtracted at several points in the processing, each with several iterations:

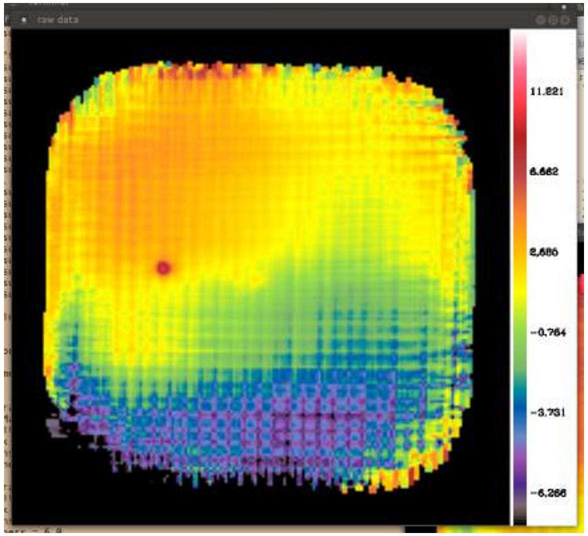
simple linear fits signal = f(t) rejecting samples belonging to source mask
- on whole scans: offsets for each detector
  fit of average signal (averaged over all detectors)
- on segments of 4 scan legs: fit of average signal
- on individual scan legs: offsets for whole array or each electronic box
  fit of average signal
  fit of each electronic box if possible

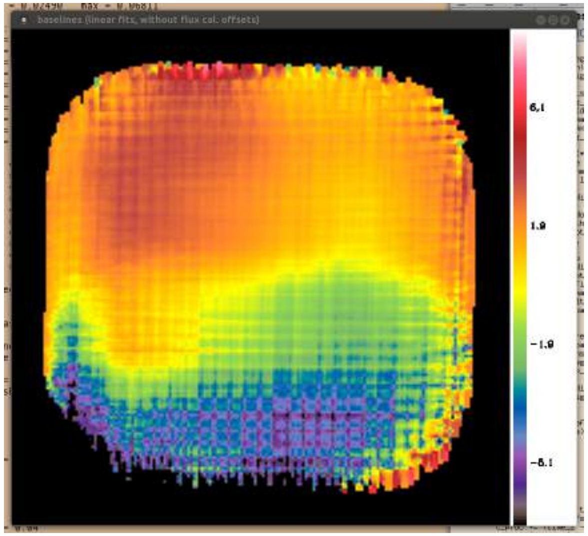
step by step example of a reduction: DR21OH (run 19)

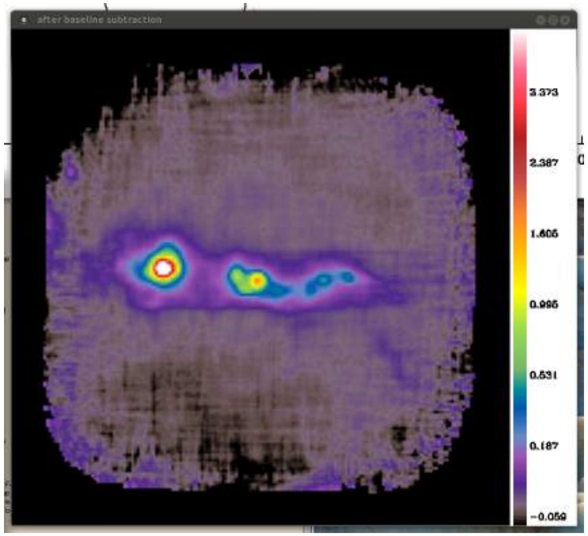
1) long-timescale drifts



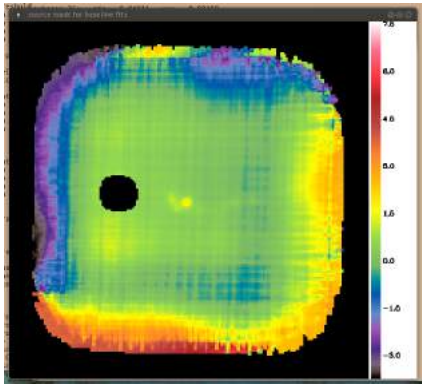
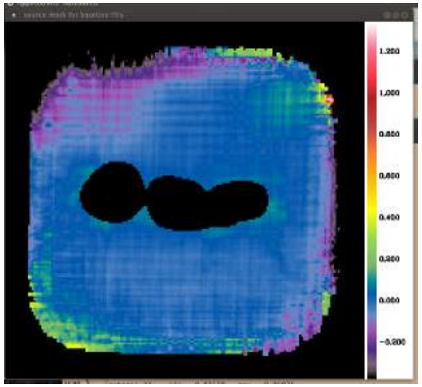
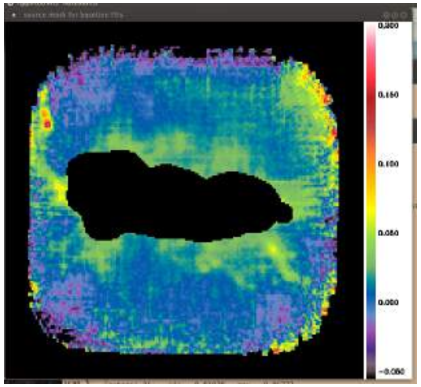
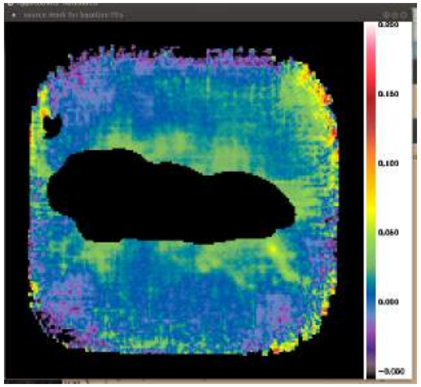
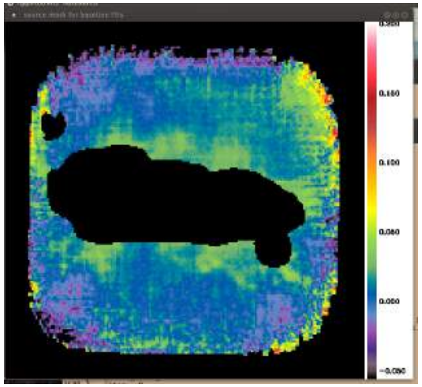
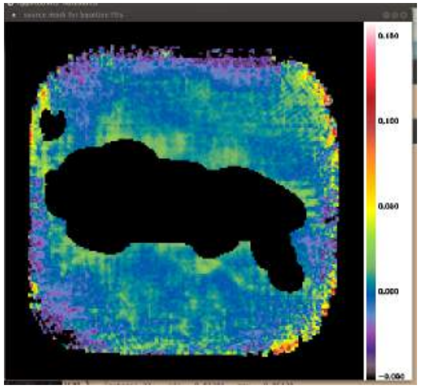
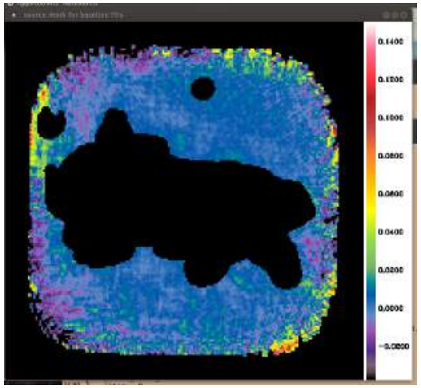
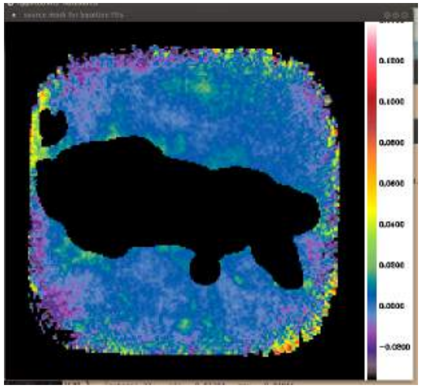
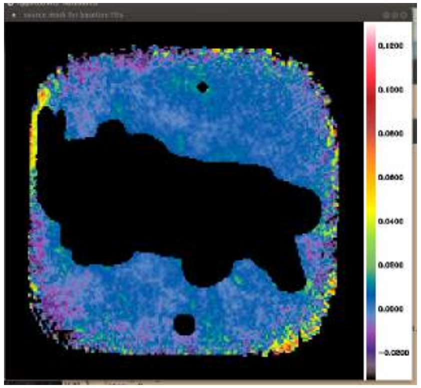








The linear fits are robust least absolute-deviation fits:
- iteratively excluding deviant samples
- using a source mask (transferred to the time domain), automatically built

step by step example of a reduction: DR21OH (run 19)

2) short-timescale drifts

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 , detectors 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

$N_{samples}(l_s) = l_s / v_{scan} \times f_{sampling} \geq 7$

$l_s = k \times FWHM$ (typically $k < 1$ and timescale $t_c \sim 0.4$ s)

step by step example of a reduction: DR21OH (run 19)

2) short-timescale drifts

computations done within each coarse pixel p of size l_s

average drift: differences between pairs of detector 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 detector crossing and weighted average of all crossings

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

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

step by step example of a reduction: DR21OH (run 19)

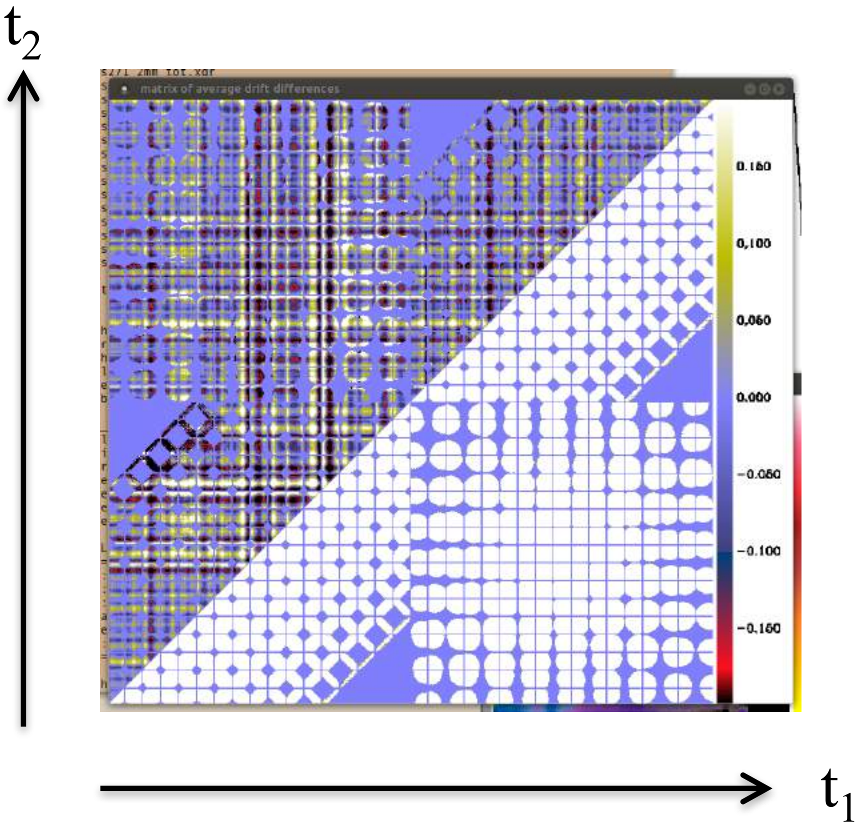
2) short-timescale drifts: average drift

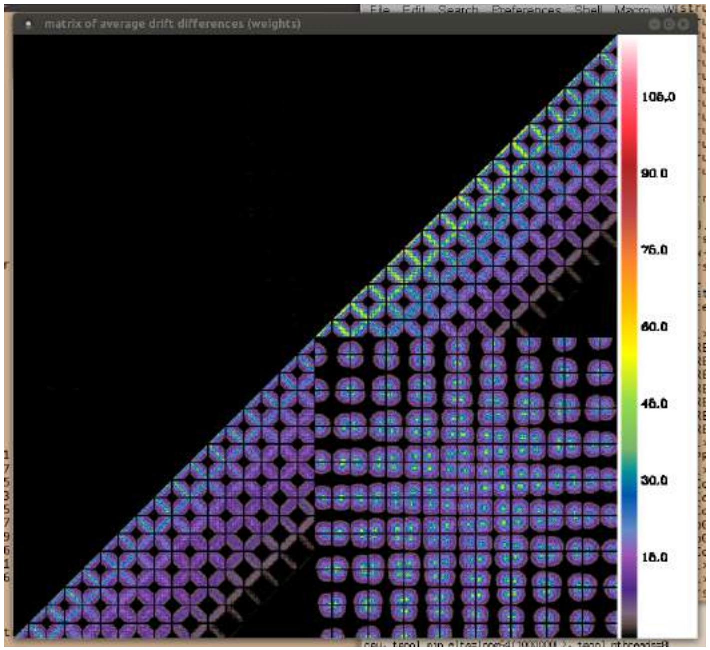
matrix of coadded $\Delta(t_1, t_2)$ terms:

$t_2 > t_1$: $D_{aver}(t_1) - D_{aver}(t_2)$

mirror term below diagnonal:

associated weights



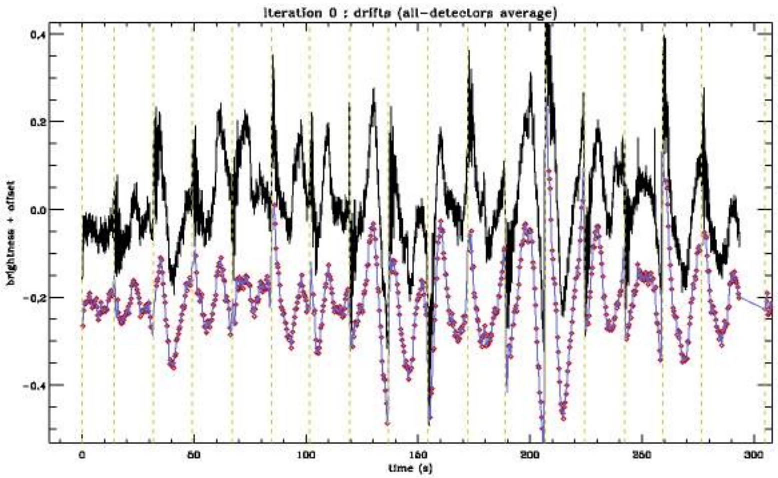


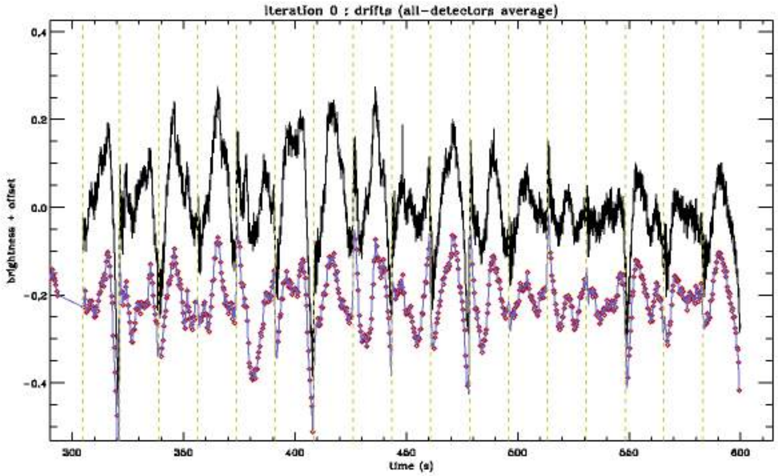
matrix scanned until convergence

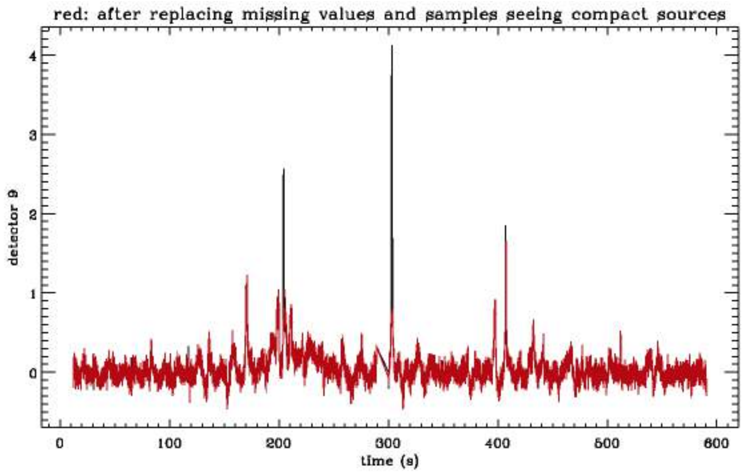
–> $D_{aver}(t)$ + spurious periodic component (period of spatial coordinates)

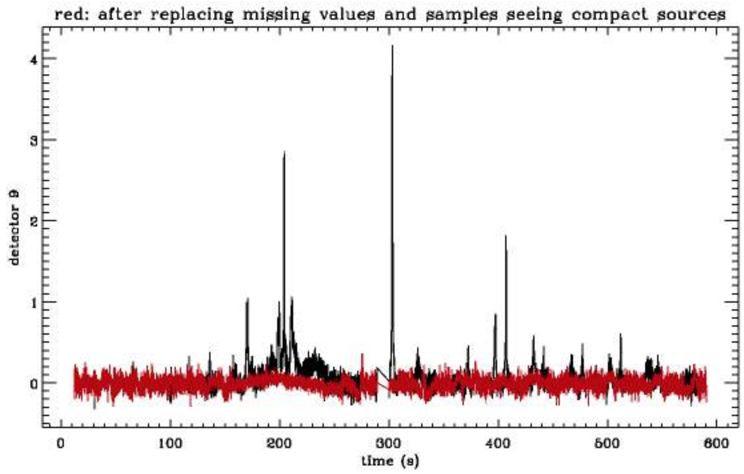
step by step example of a reduction: DR21OH (run 19)

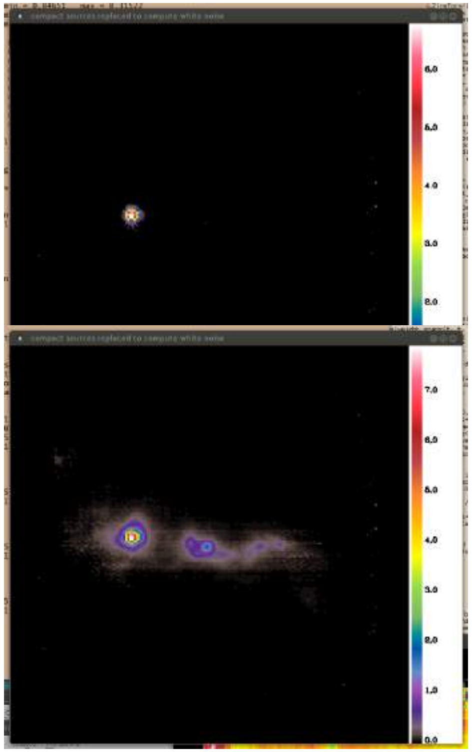
2) short-timescale drifts: average drift





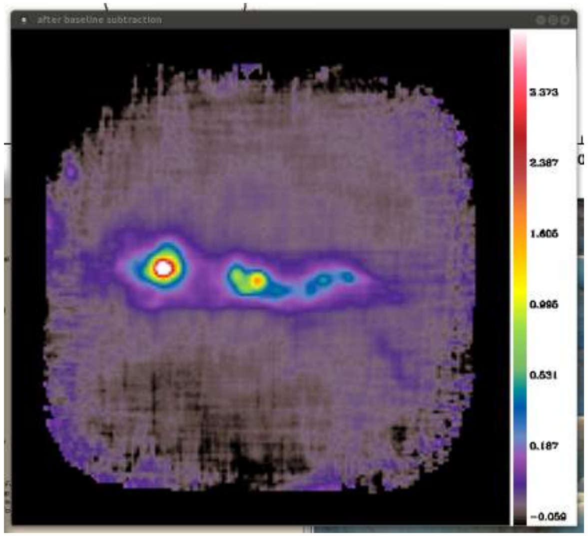


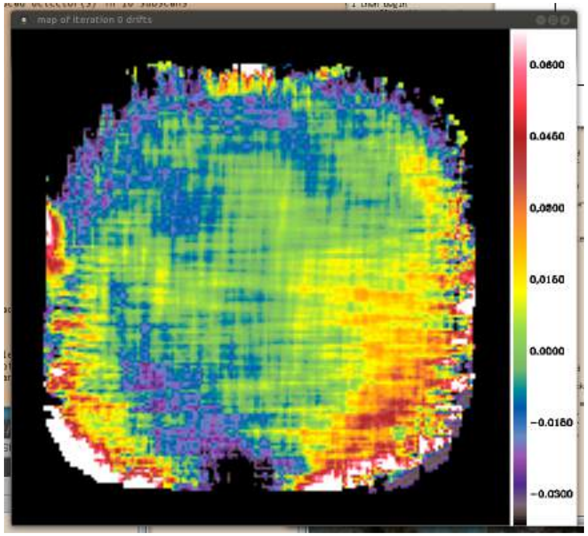


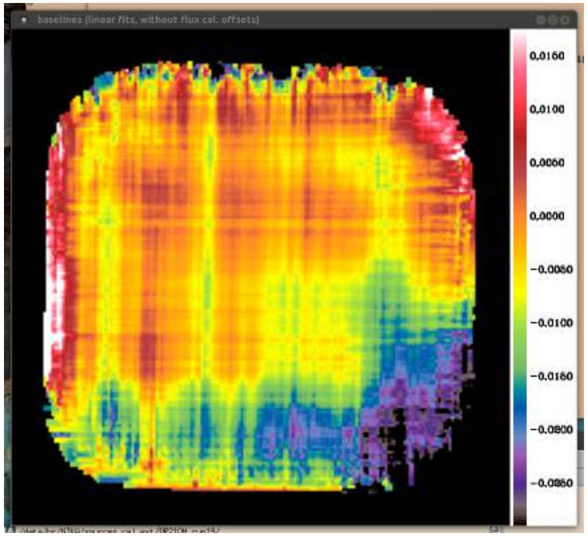


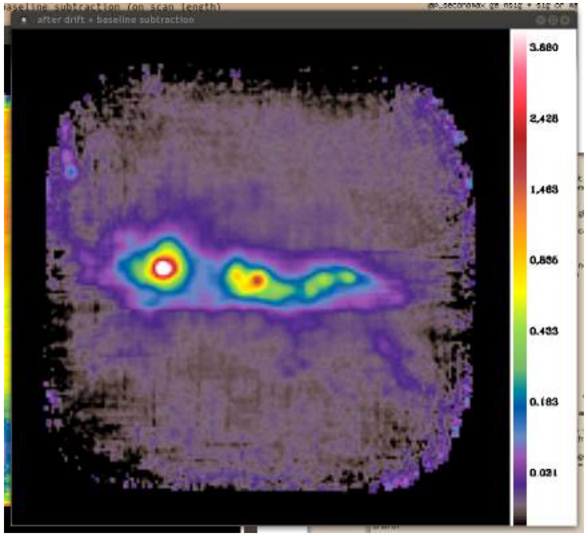
step by step example of a reduction: DR21OH (run 19)

2) short-timescale drifts: average drift









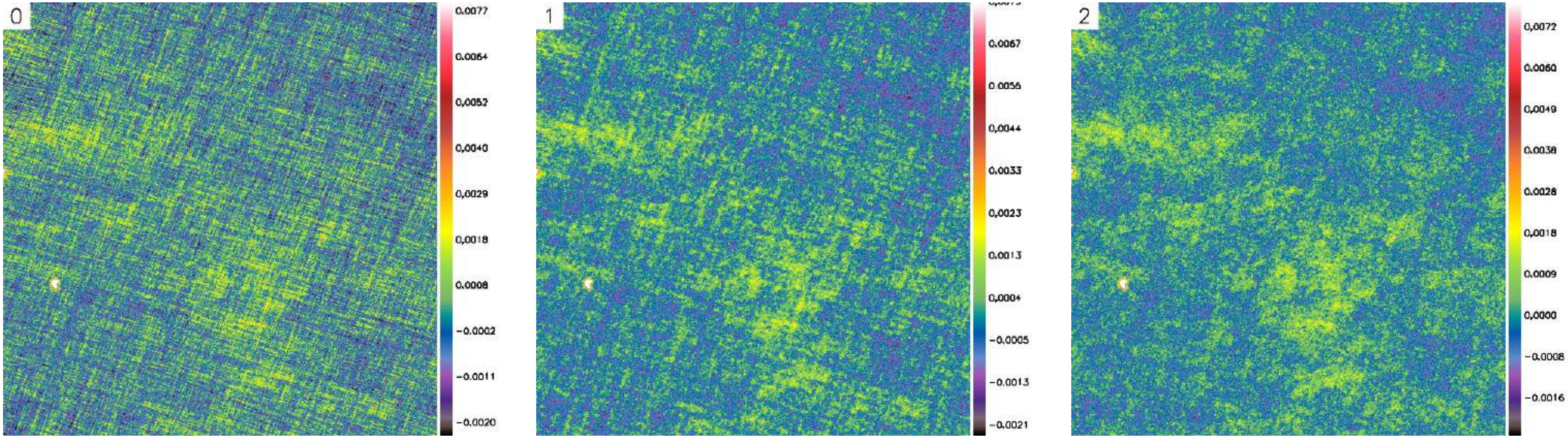
new instance of baseline subtraction necessary to remove the spurious periodic component

2) short-timescale drifts: average per electronic box,
followed by baselines and individual drifts

why it is necessary to do it on successively smaller timescales
(starting with ~ scan leg duration / 2):

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

right-hand term comes closer to 0 in large time bins (averaged on many more samples)



no short-timescale drift correction:

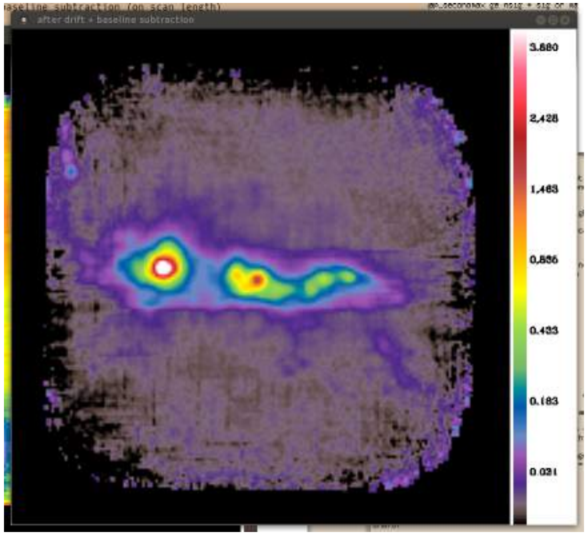
timescale t_c on all iterations:

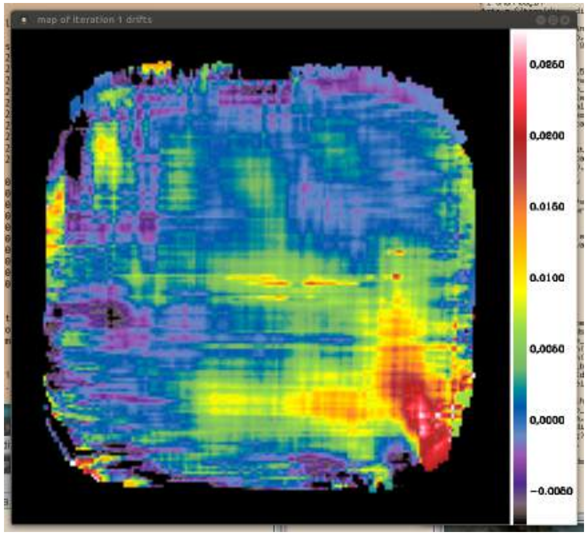
successive timescales $9\ t_c$, $3\ t_c$, t_c :

(Herschel-PACS data on a diffuse field, ~ 2.2 degrees on a side)

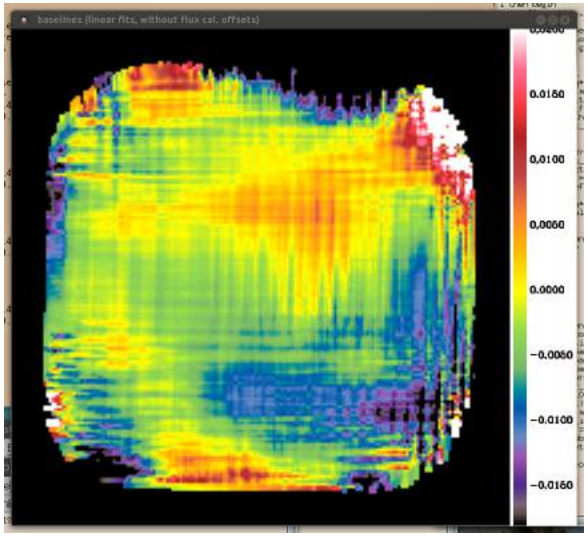
step by step example of a reduction: DR21OH (run 19)

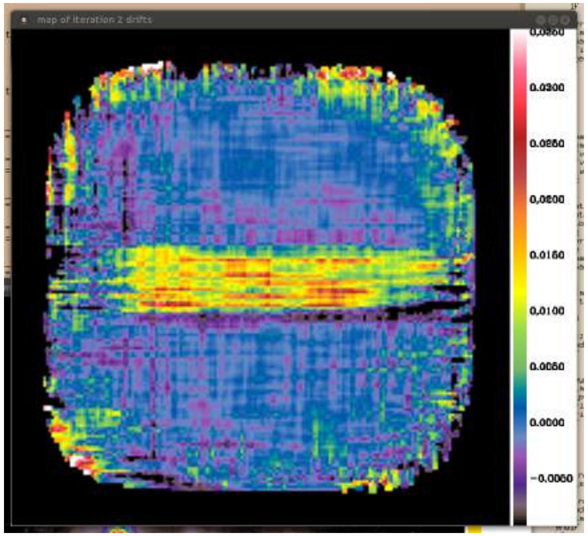
2) short-timescale drifts: average per electronic box (no average per subband yet), followed by baselines and individual drifts

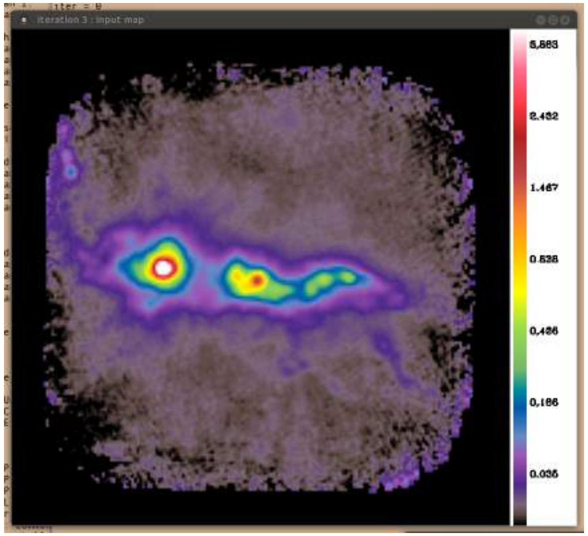




timescale: 9 x t_s

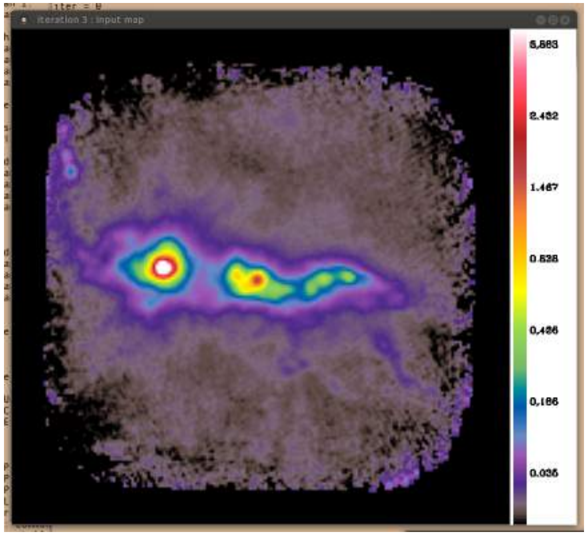


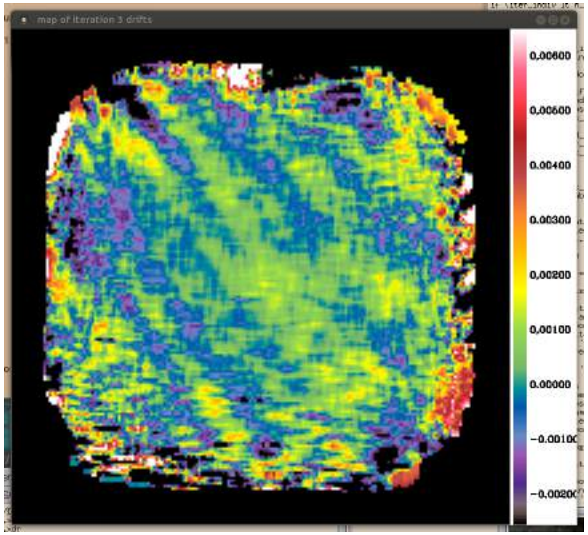




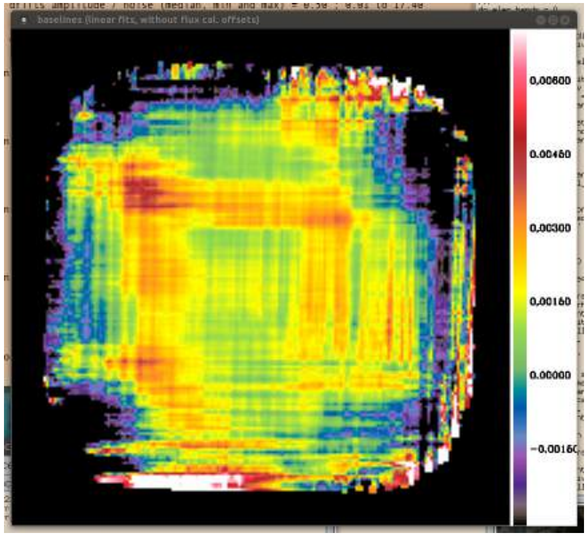
step by step example of a reduction: DR21OH (run 19)

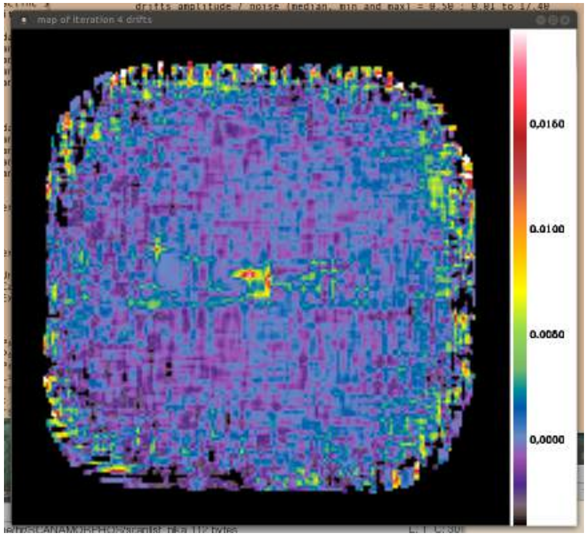
2) short-timescale drifts: average per electronic box,
followed by baselines and individual drifts

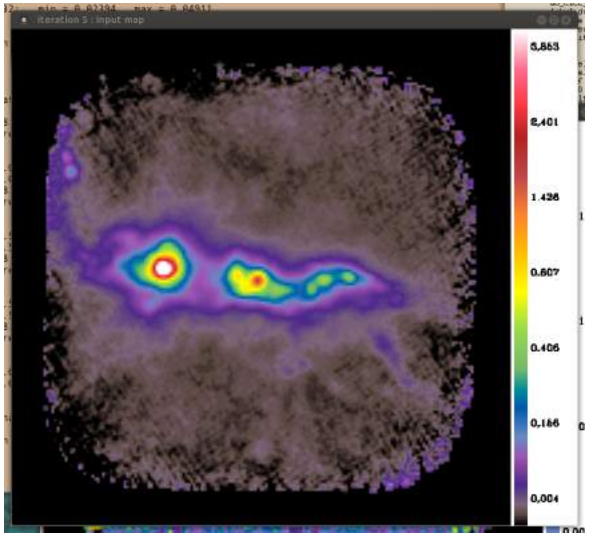




timescale: 3 x t_s

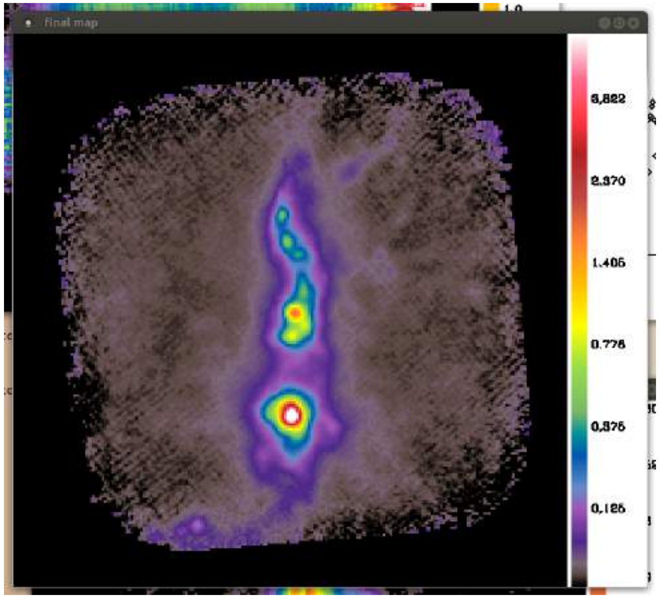


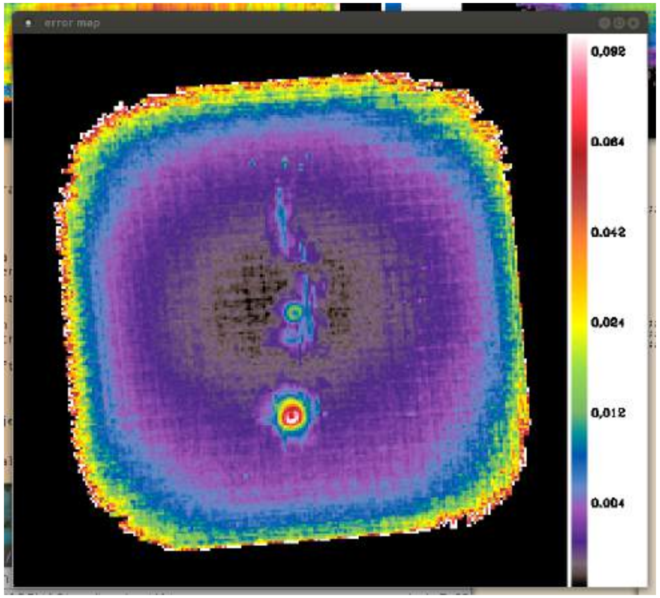


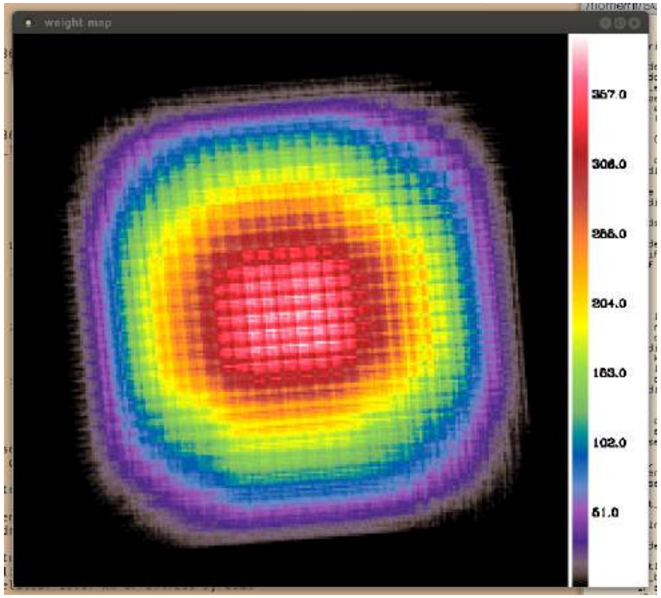


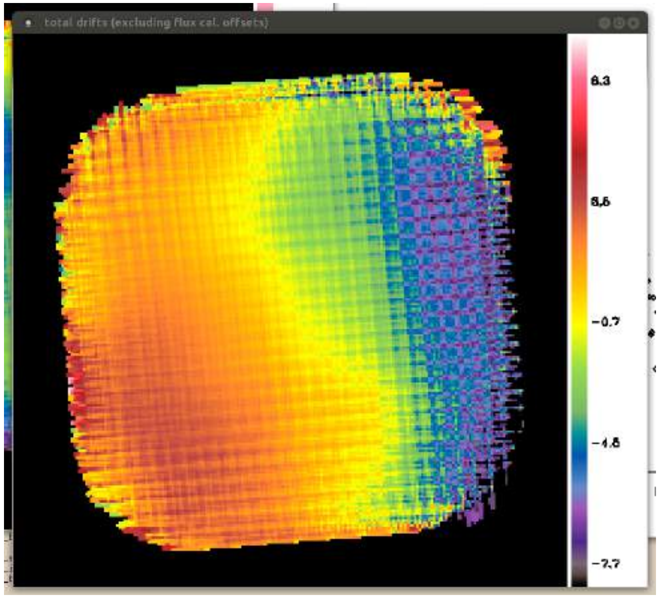
final results for DR21OH (run 19)

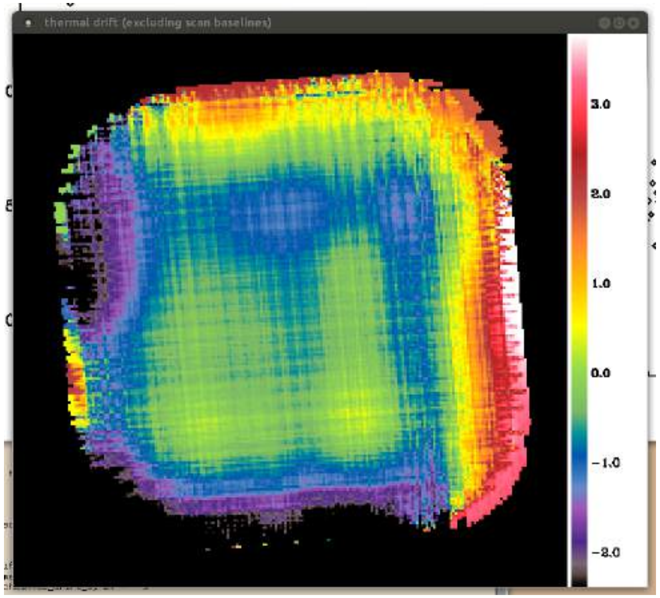
t_proc / t_obs = 0.55 at 2mm, 2.1 at 1mm (obs. duration 10 min)

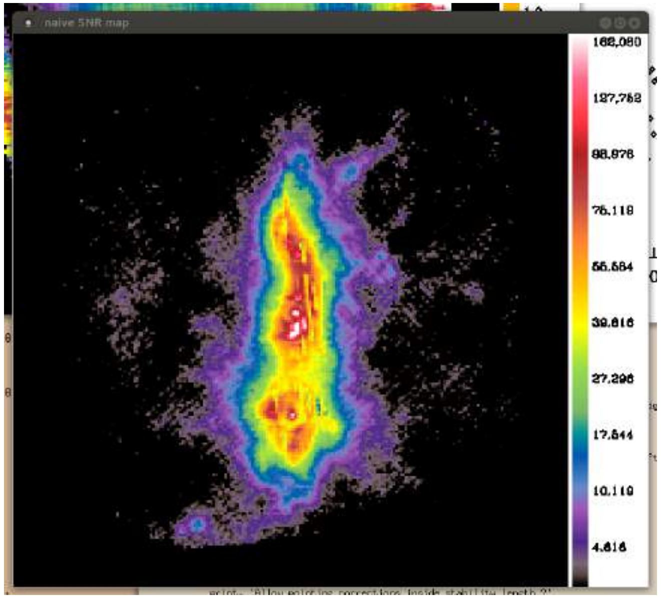






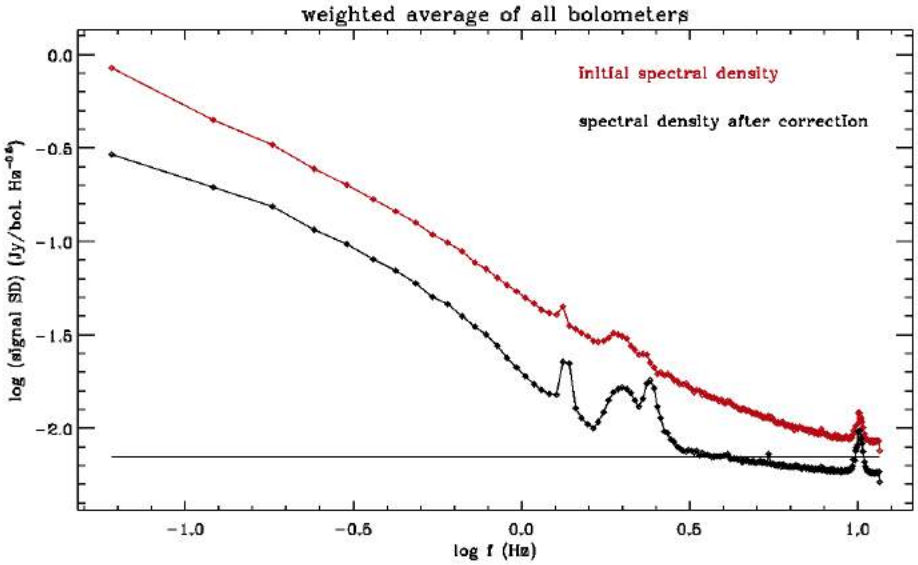




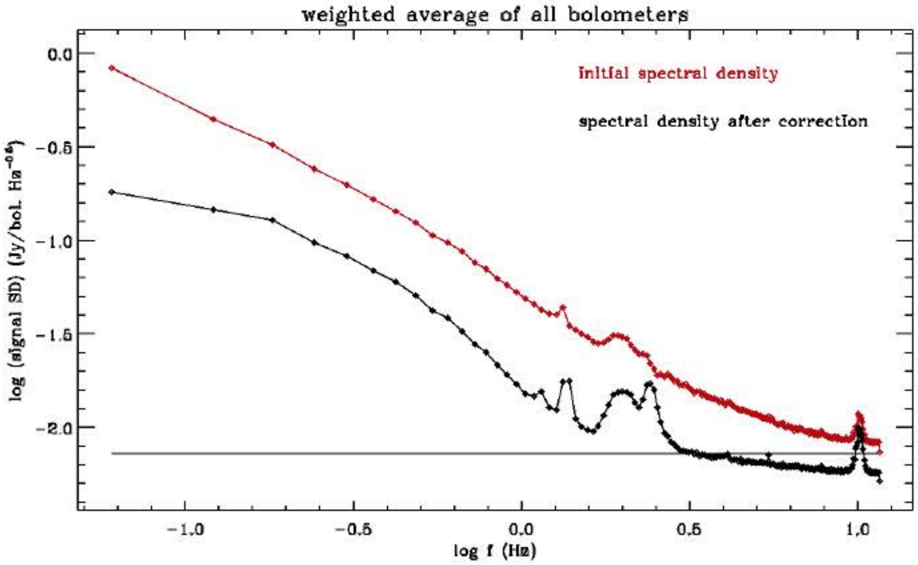


final results for DR21OH (run 19)

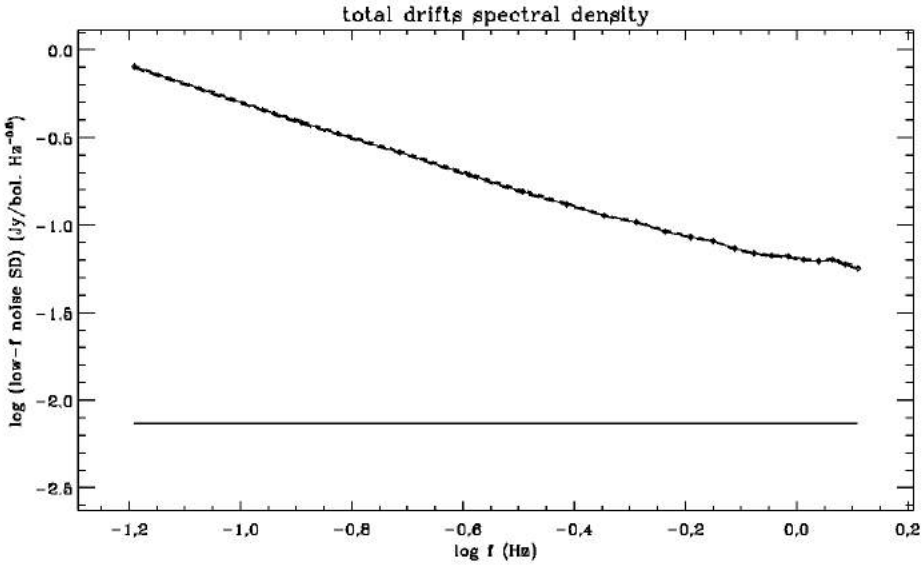
t_{proc} / t_{obs} = 0.55 at 2mm, 2.1 at 1mm (obs. duration 10 min)



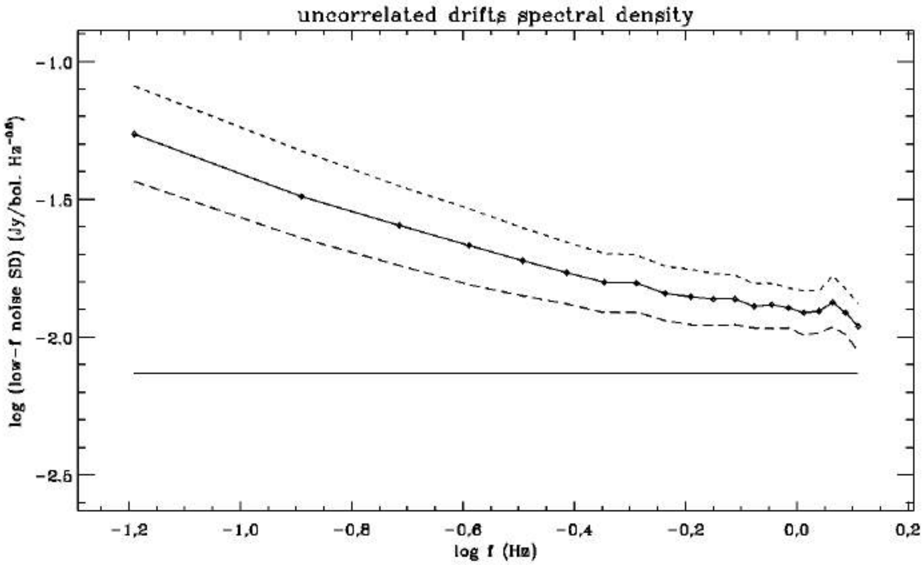
weighted average of all bolometers



weighted average of all bolometers



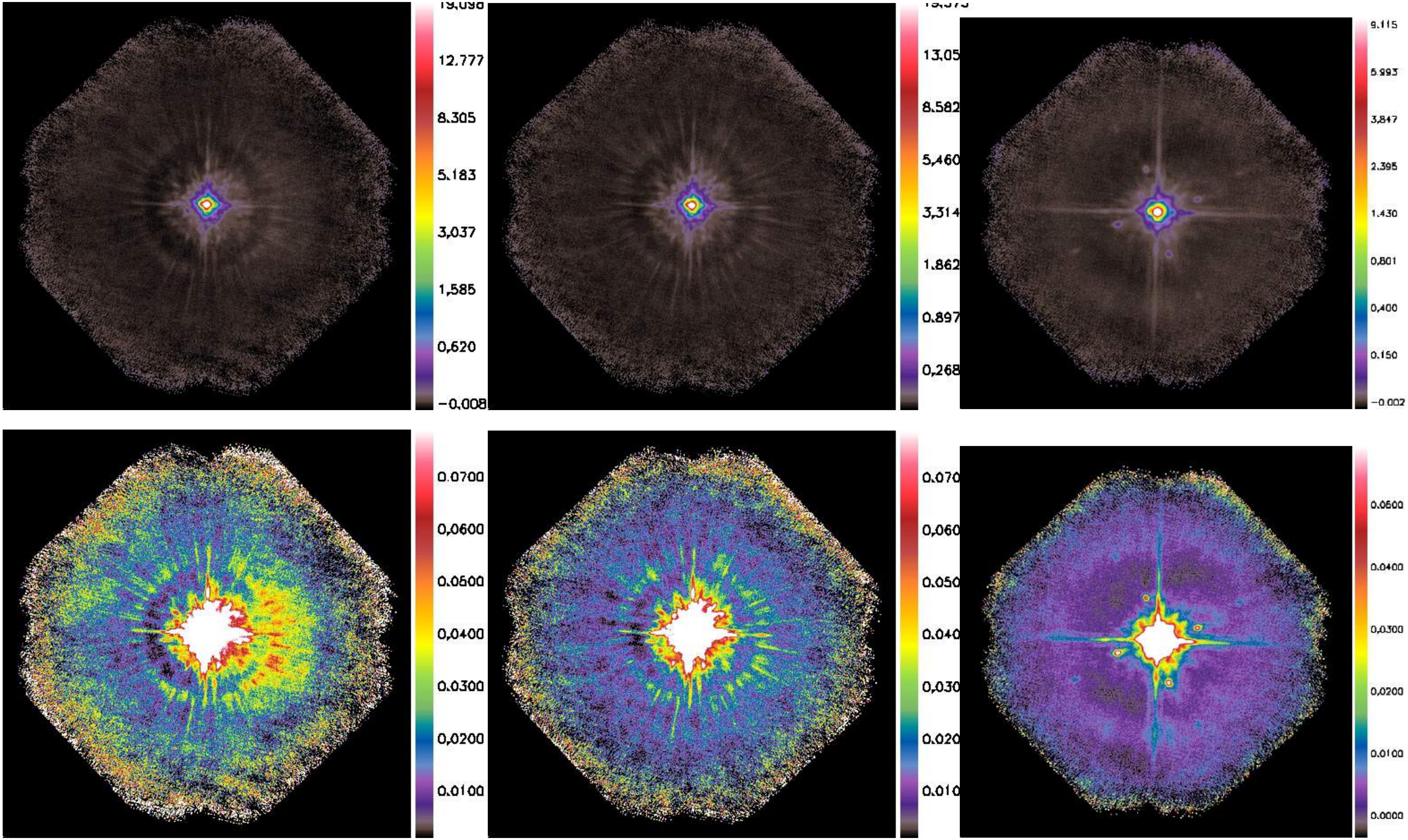
total drifts spectral density



uncorrelated drifts spectral density

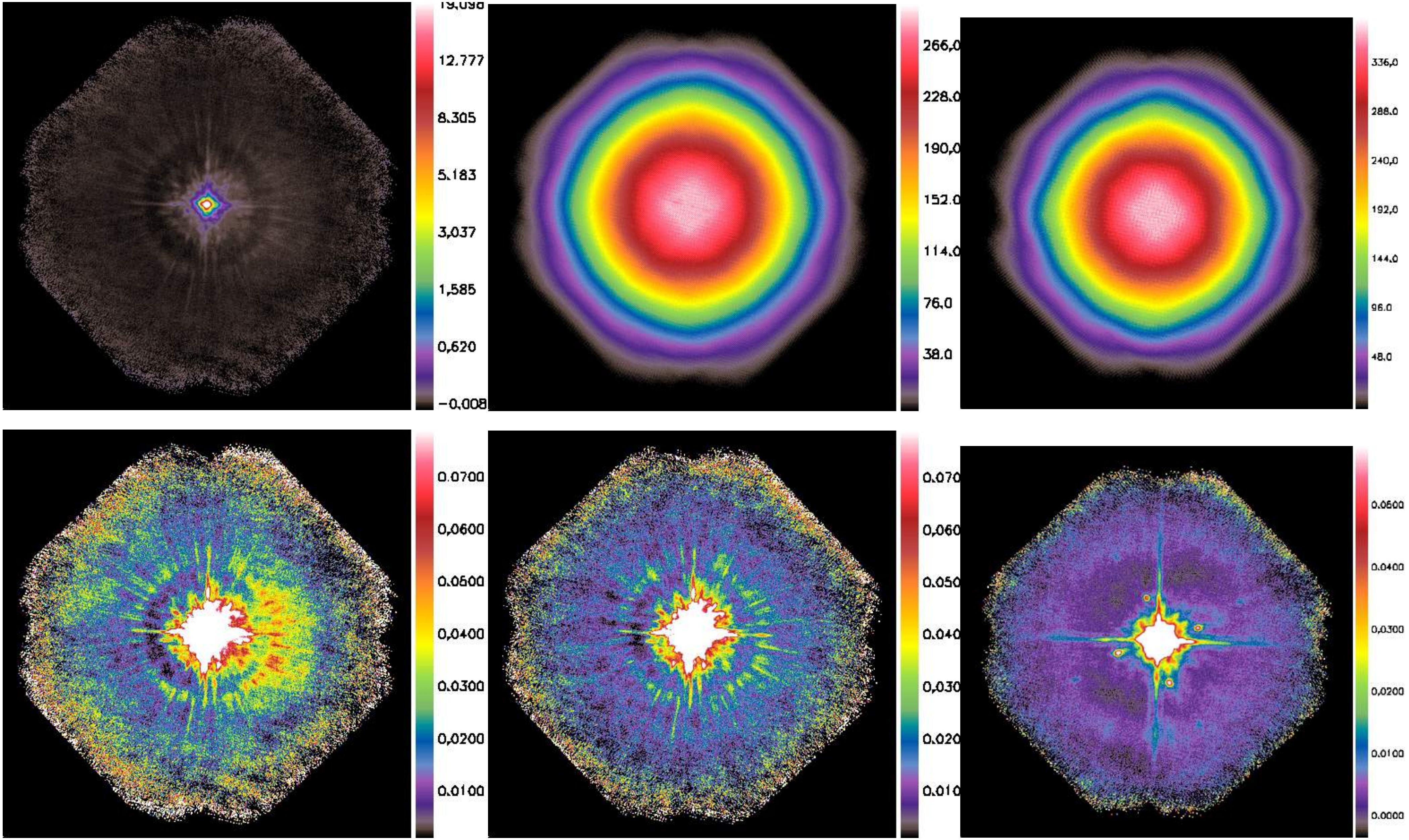
results on some sources:

Mars beammap in run 26 (with non-optimal gains derived from the obs. itself)
Nasmyth coordinates, map size ~ 20 arcmin



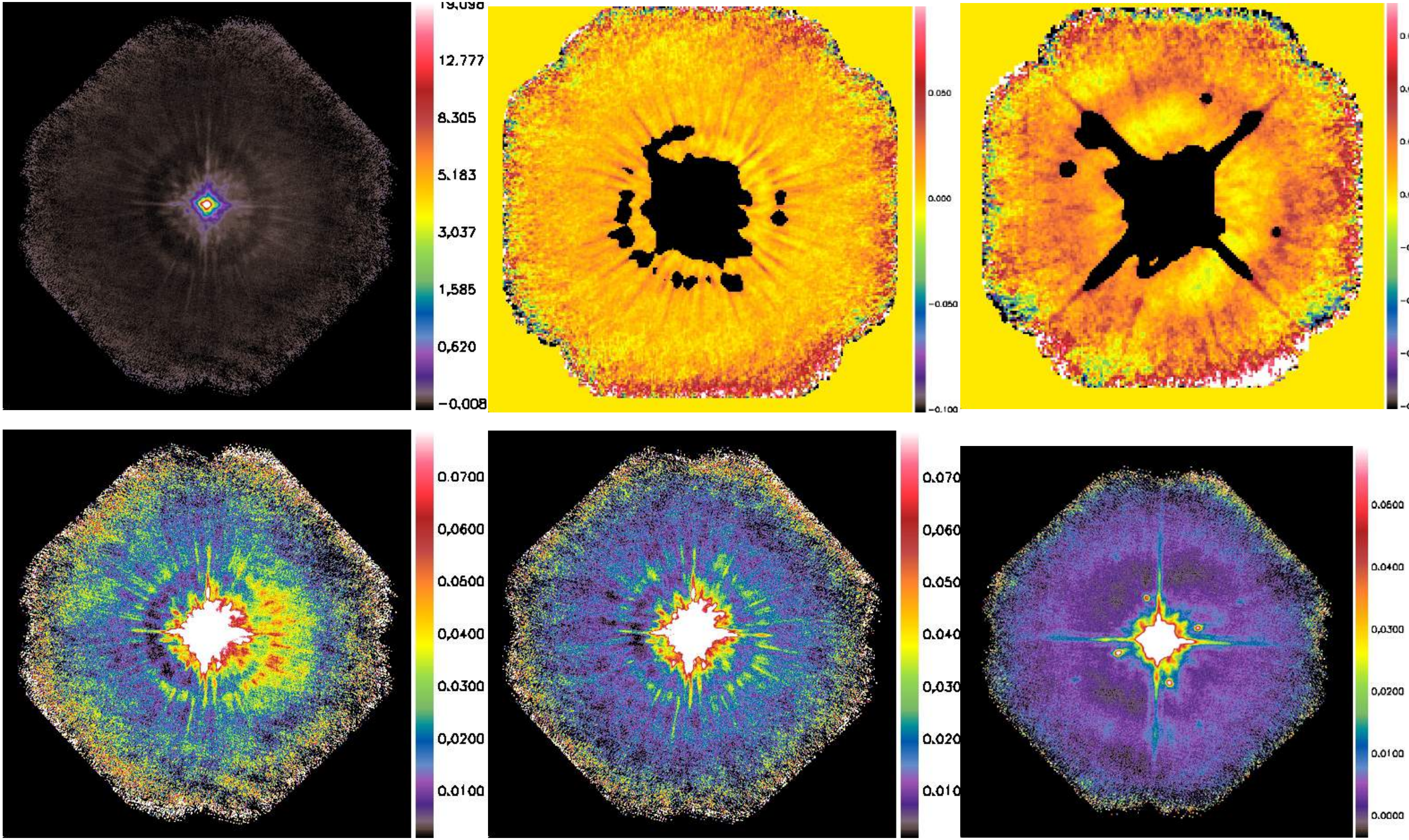
results on some sources:

Mars beammap in run 26 (with non-optimal gains derived from the obs. itself)
Nasmyth coordinates, map size ~ 20 arcmin



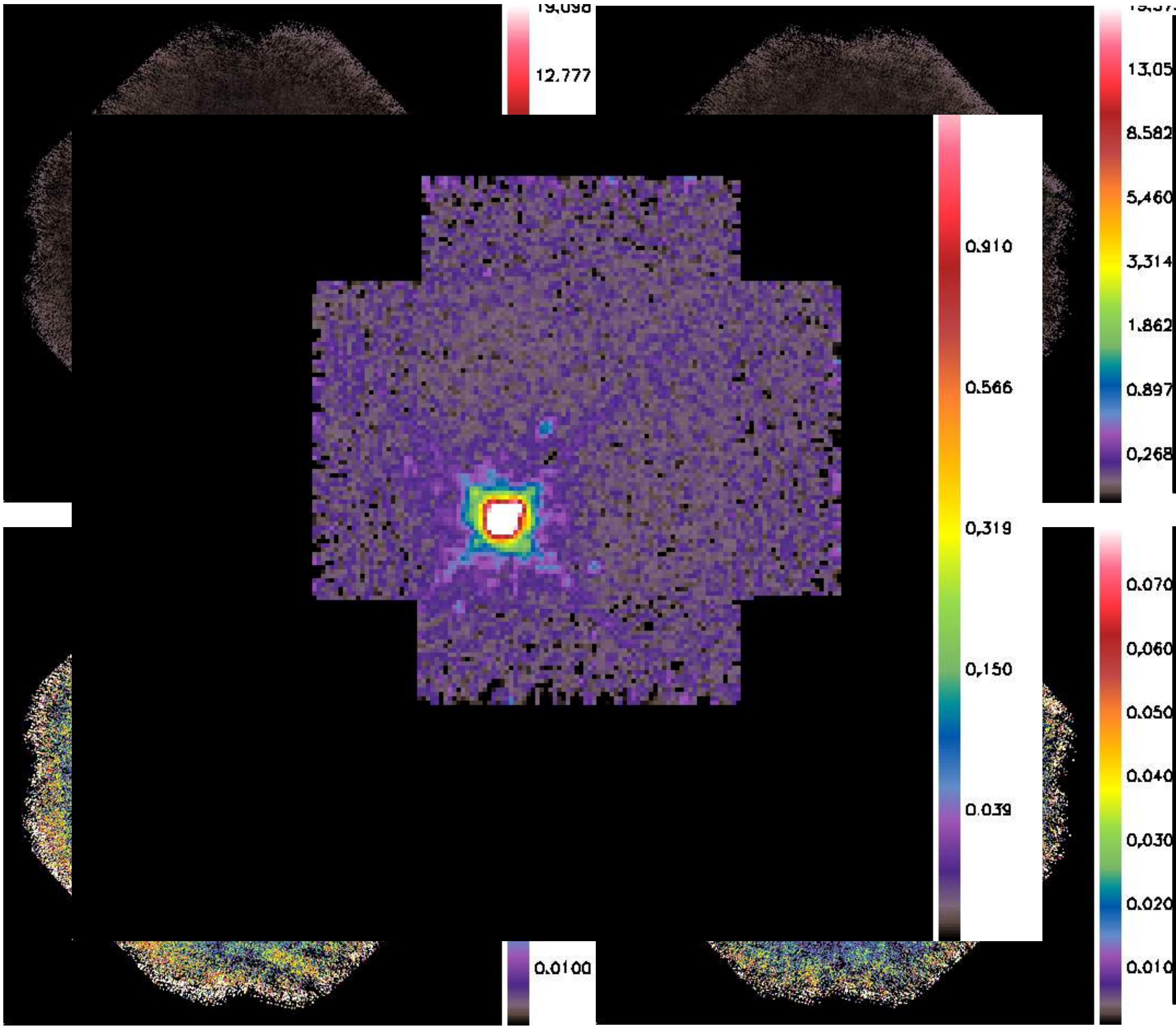
results on some sources:

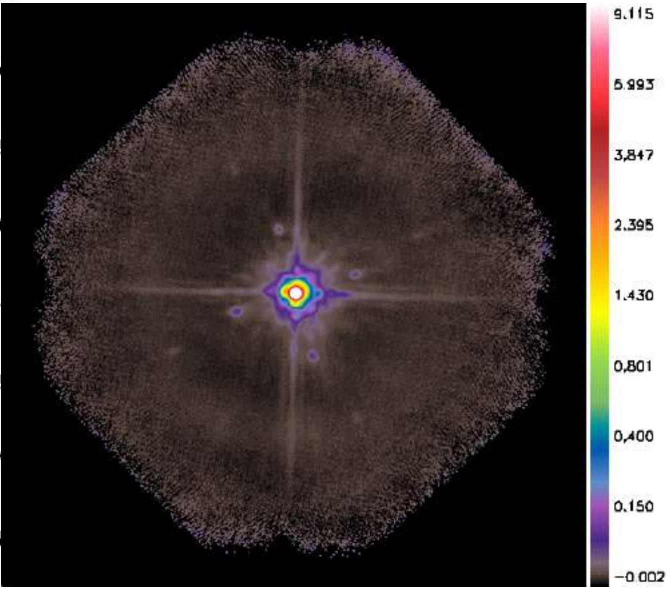
Mars beammap in run 26 (with non-optimal gains derived from the obs. itself)
Nasmyth coordinates, map size ~ 20 arcmin

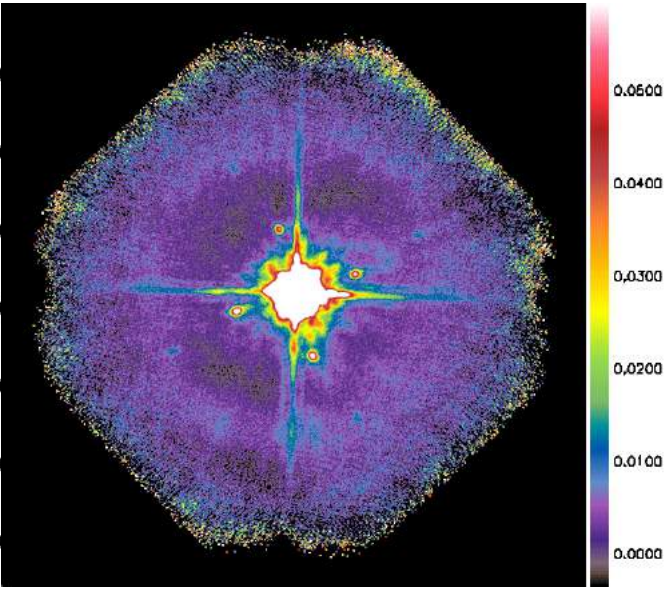


results on some sources:

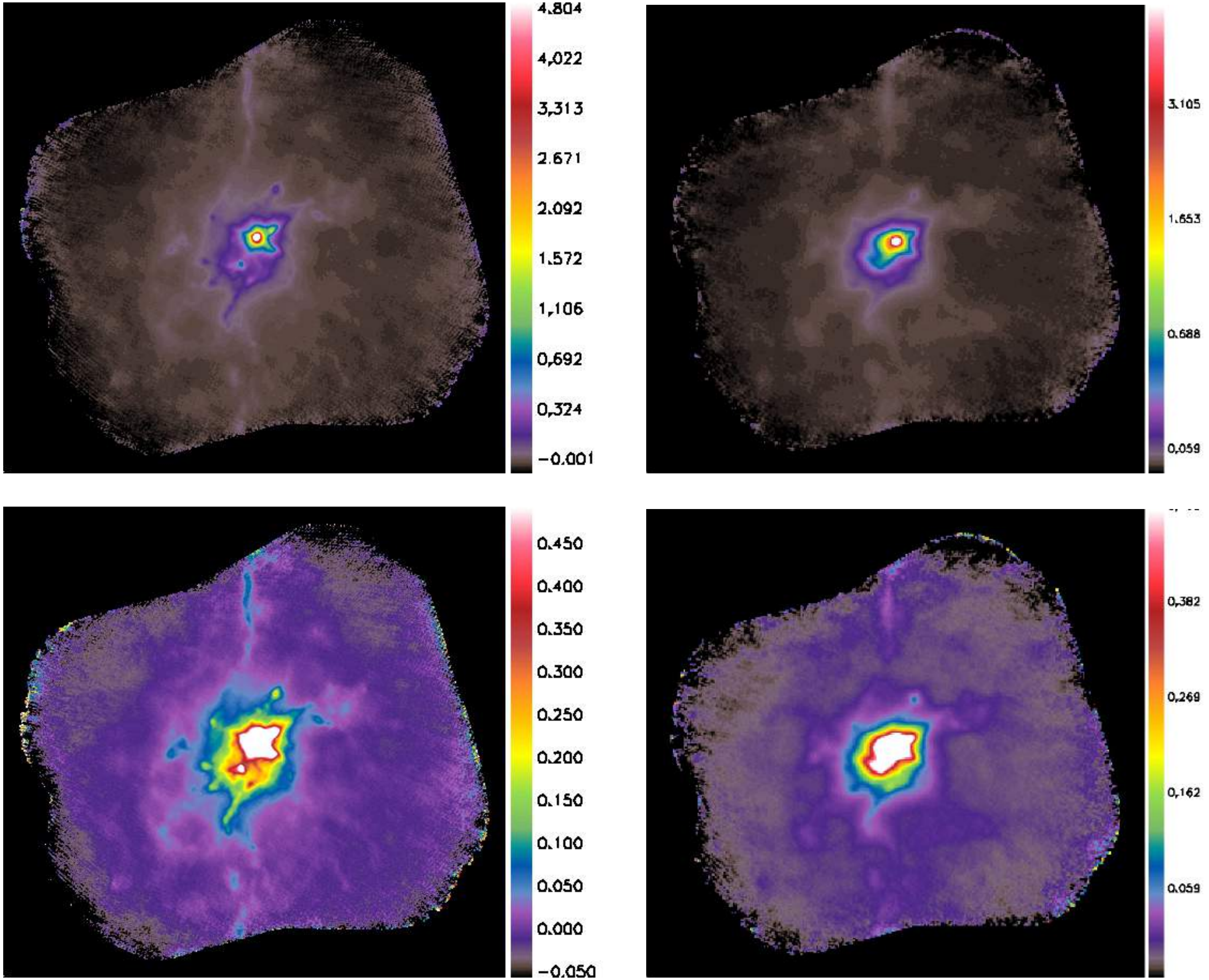
Mars beammap in run 26 (with non-optimal gains derived from the obs. itself)



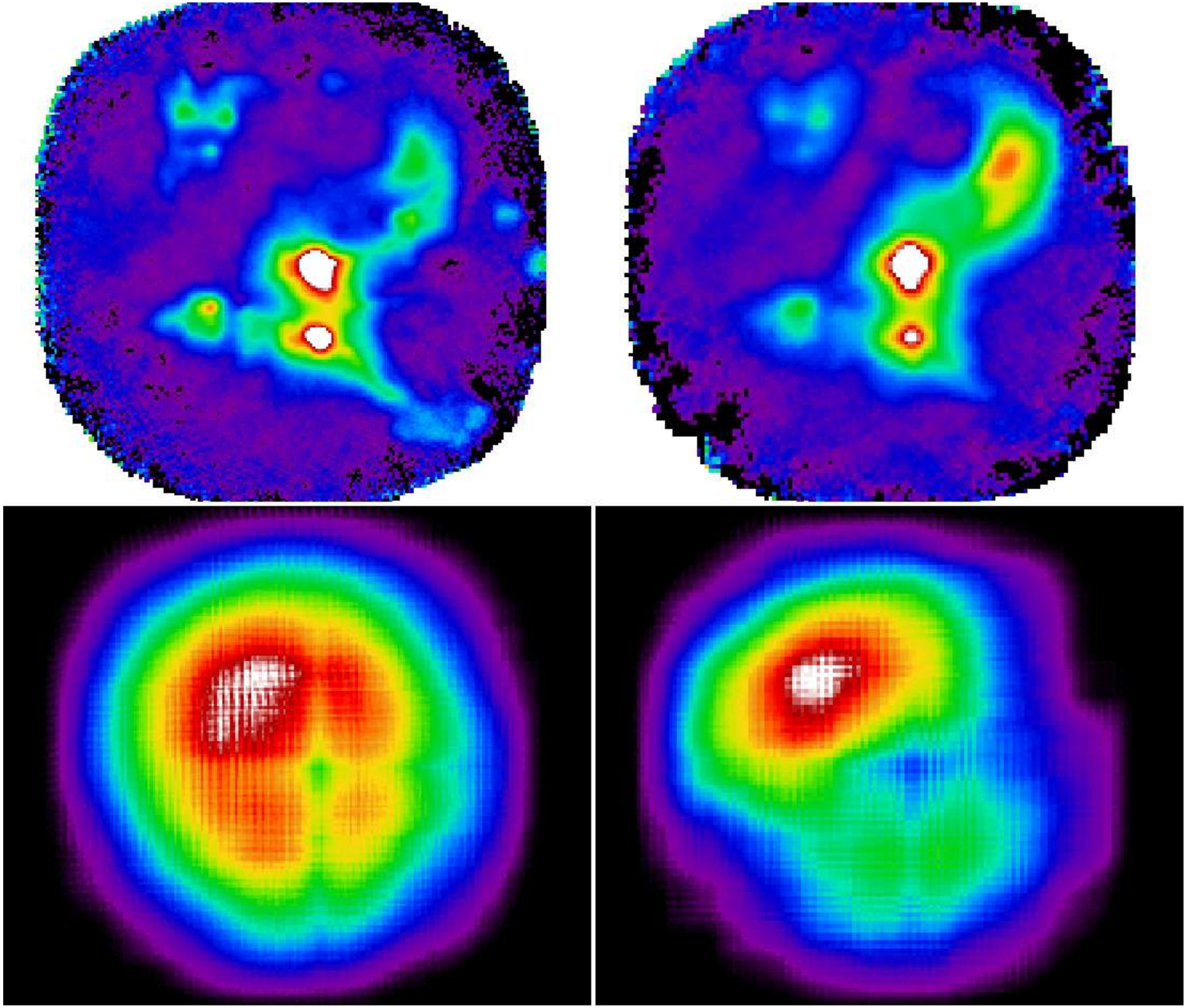




results on some sources:
most spectacular of secondary calibrators: G34.3

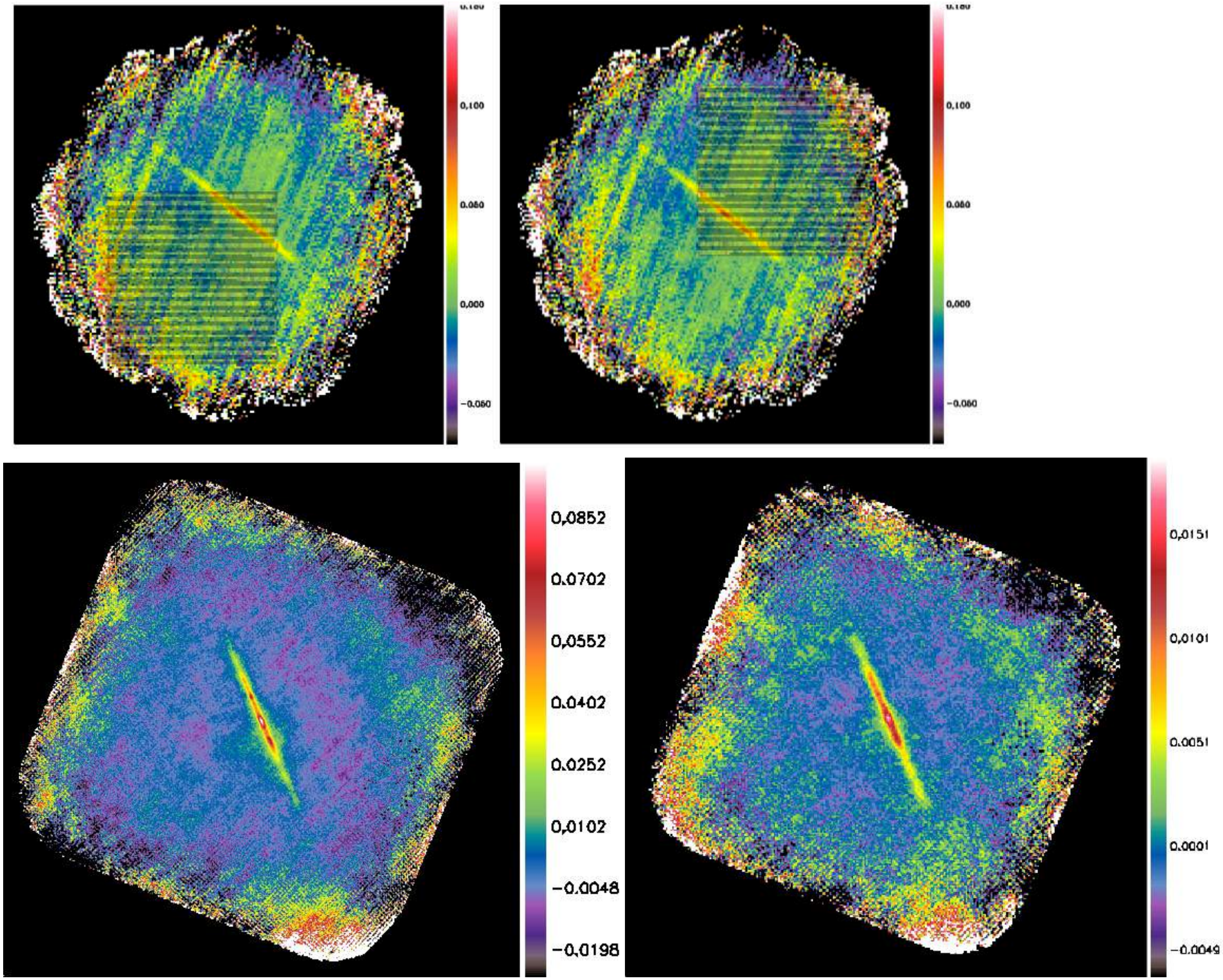


another secondary calibrator:
N7538 (4 scans in March 2016, run 16)



importance of devising wisely the obs. geometry (scan size + orientation):

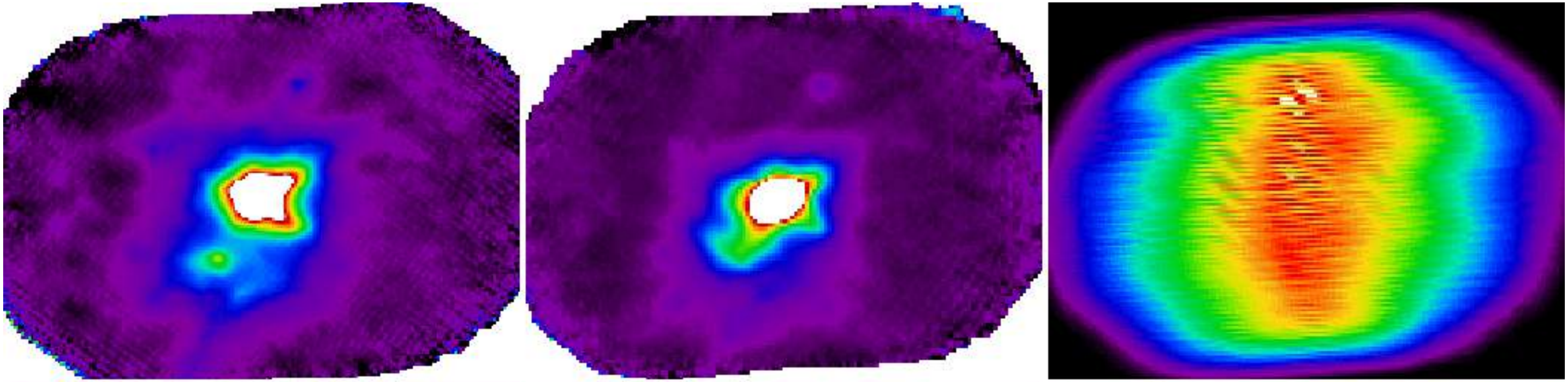
− preferable to have sufficient margins around sources of interest
  covered by a significant fraction of the detectors

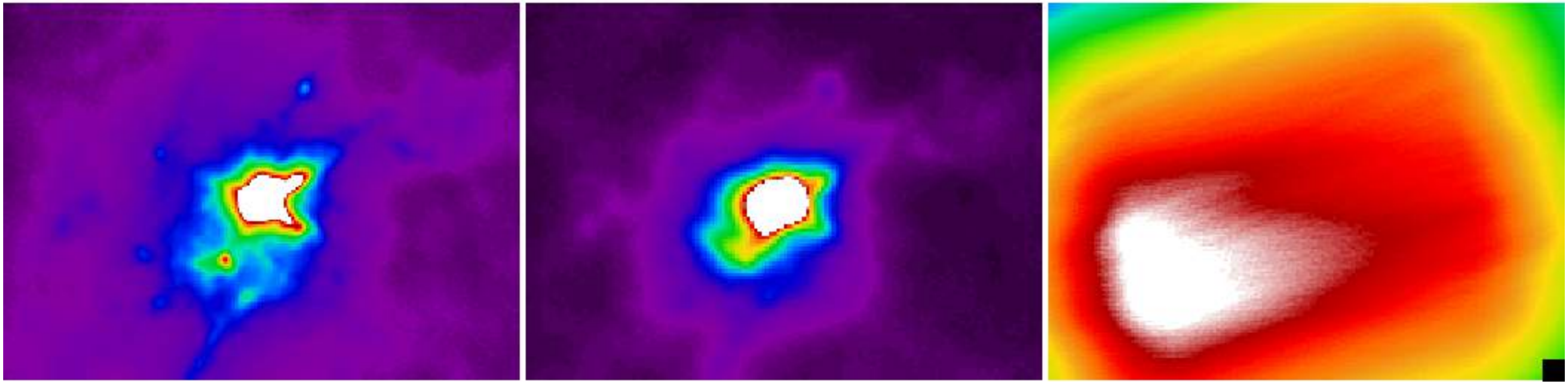


importance of devising wisely the obs. geometry (scan size + orientation):

- preferable to have sufficient margins around sources of interest covered by a significant fraction of the detectors
- also need for weights as homogeneous as possible (best: 2 orthogonal scan directions)

small map of G34.3 in run 19



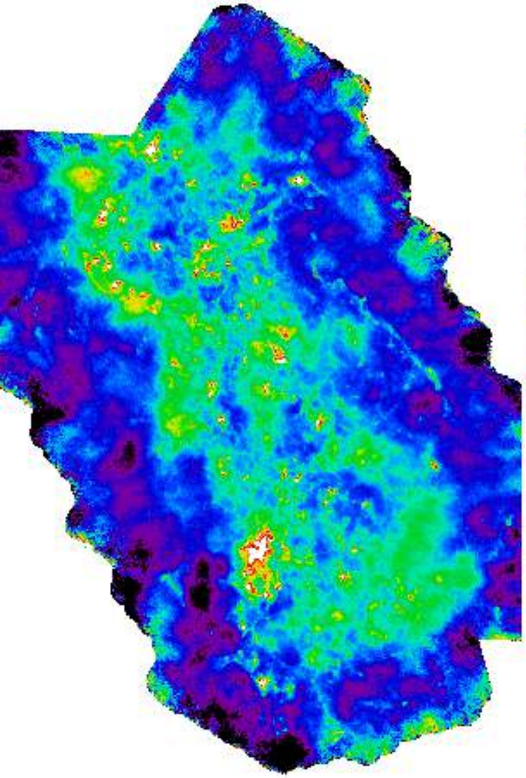


larger map in run 16 (with slightly larger opacity)

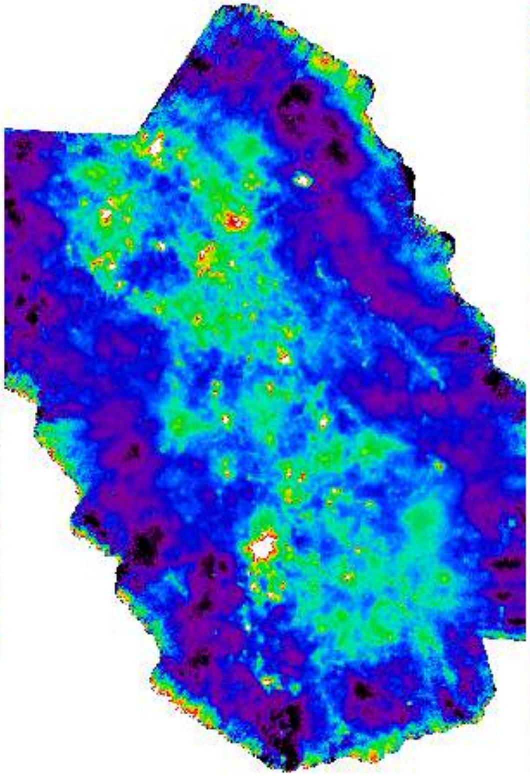
GASTON LP (71 scans in runs 25, 27 and 28)

total vertical extent ~ 2.5 degree

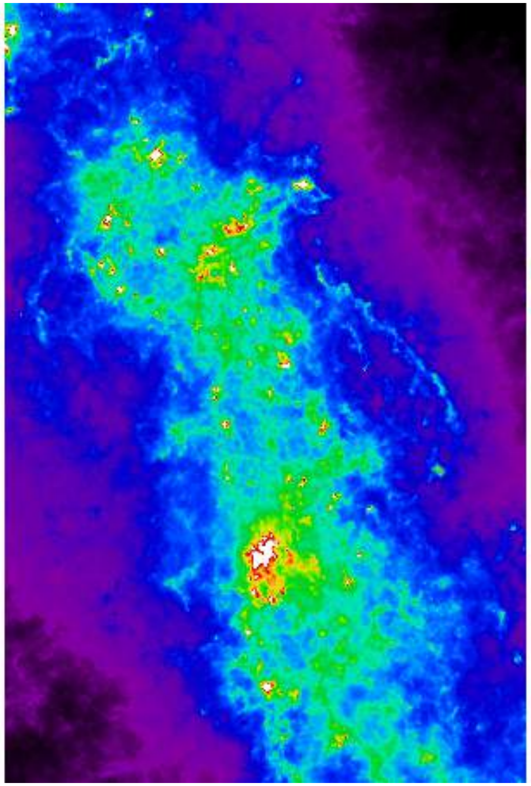
1mm



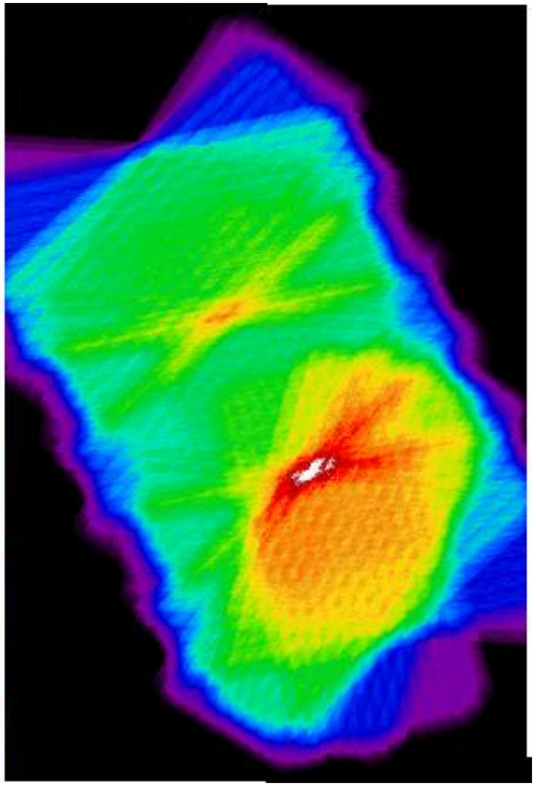
2mm



Herschel 350 μm

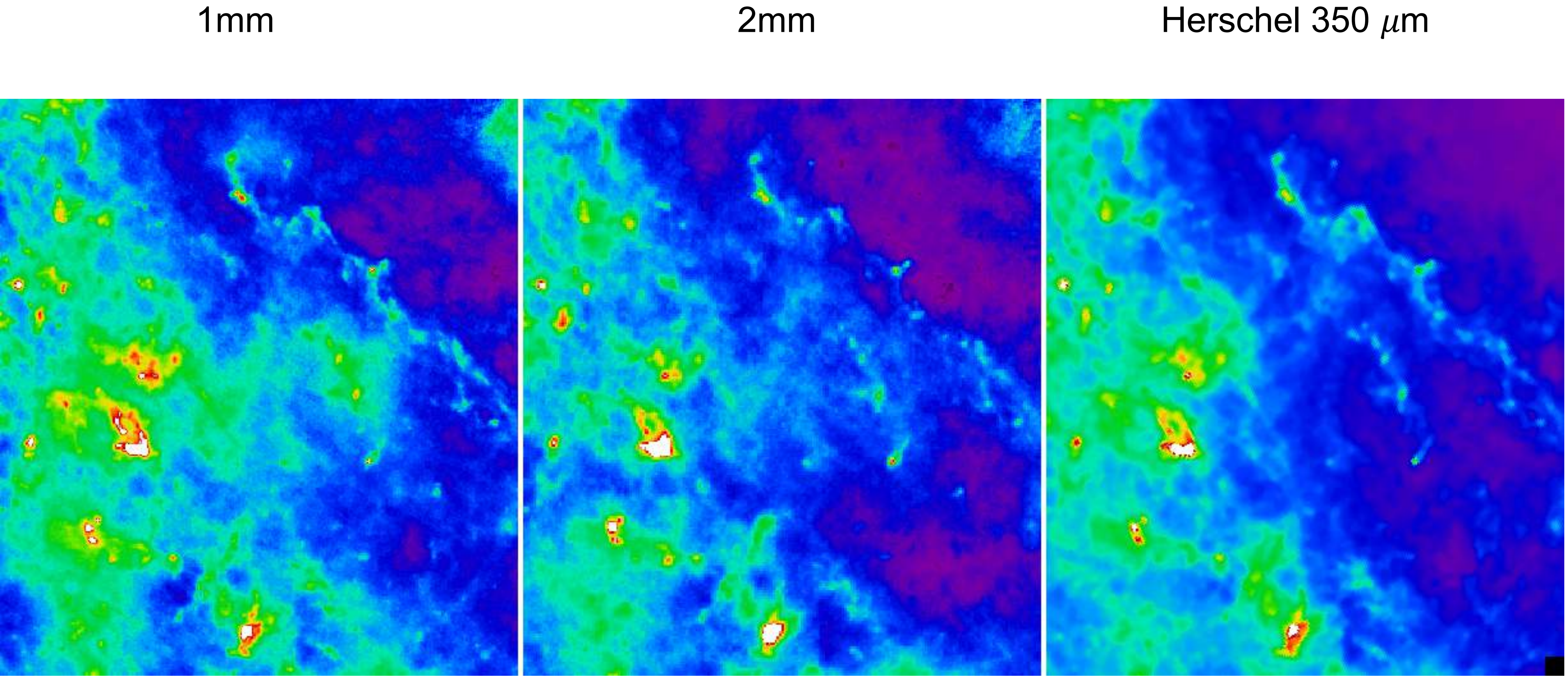


1mm weights



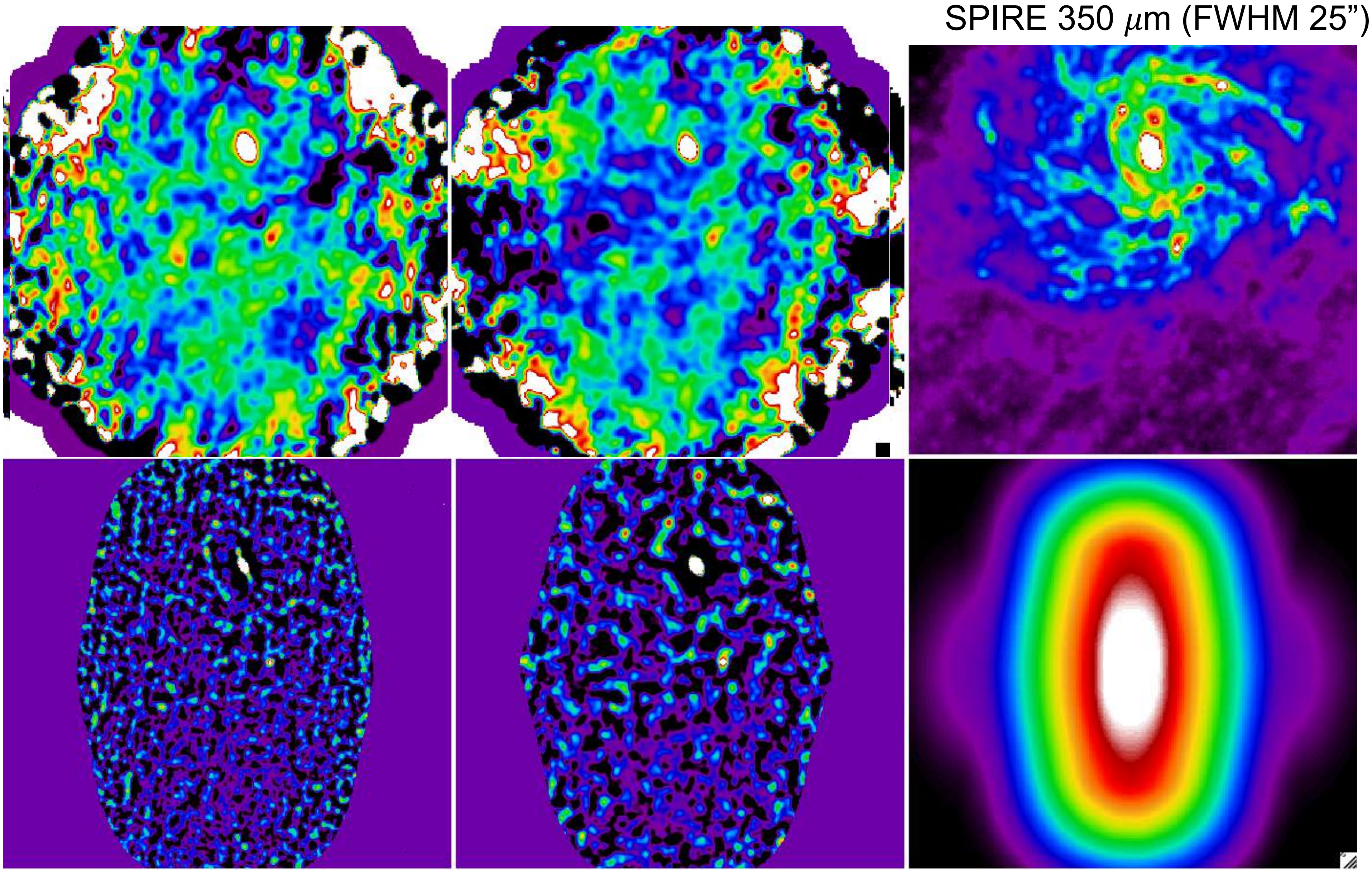
with sliding baselines instead of a unique baseline per scan leg

GASTON LP (71 scans in runs 25, 27 and 28)



results on some sources: IC342 (P.I. Chris Clark)

30 scans in run 25 (oct. 2017) + 14 scans in run 27 (jan. 2018)
t_{proc} / t_{obs} = 2.8 at 2mm (total obs. duration 9 hours / 24 requested)
full extent ~ 26 arcmin

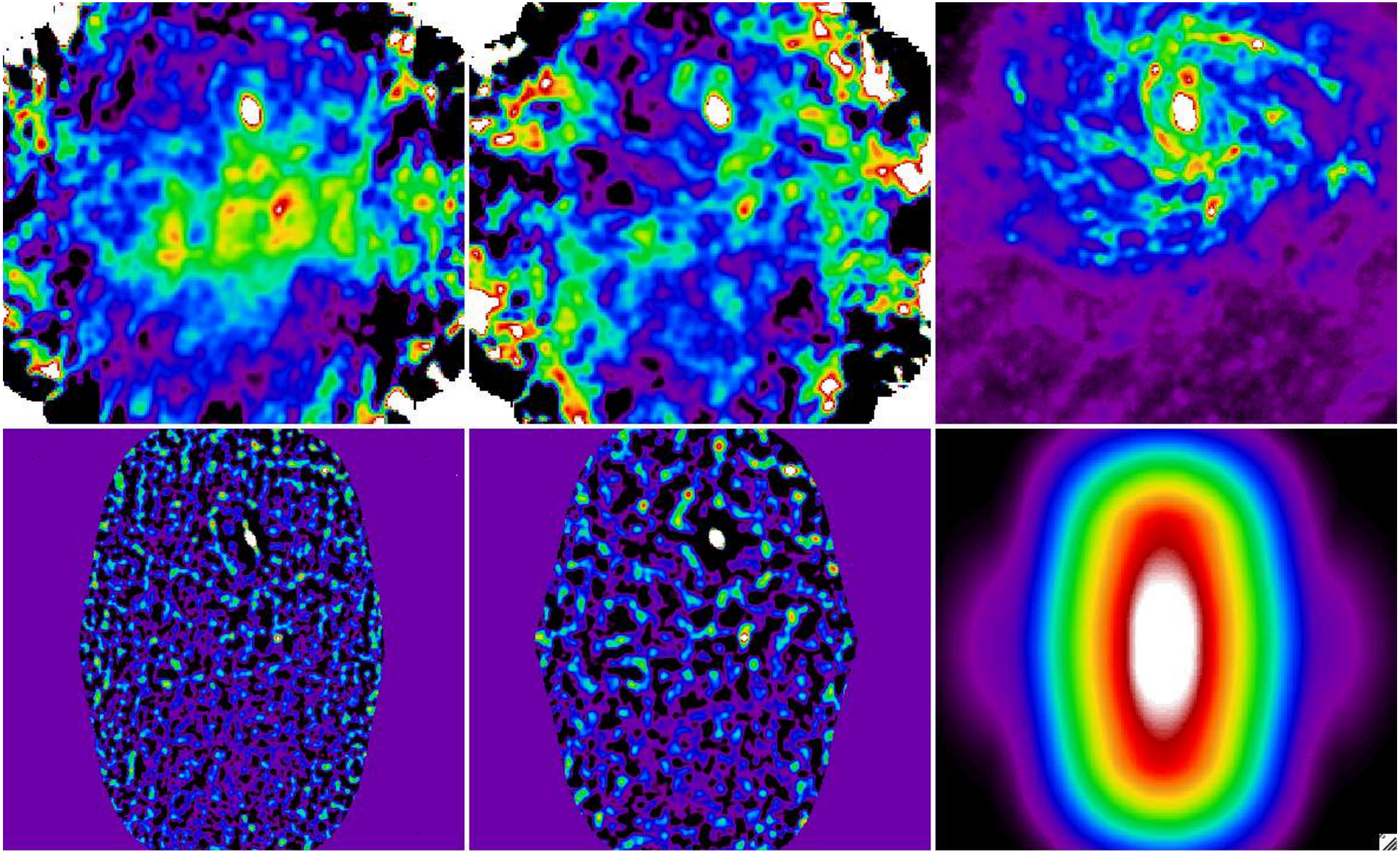


SPIRE 350 μm (FWHM 25”)

results on some sources: IC342 (P.I. Chris Clark)

30 scans in run 25 (oct. 2017) + 14 scans in run 27 (jan. 2018)

Not all tested ideas prove to be good...


SPIRE 350 μm (FWHM 25")

Construction of coherent spatially-resolved SEDs over the IR-mm range

combining maps from Spitzer, Herschel and NIKA2
→ SEDs of individual regions within extended objects (galaxies, clouds or clumps)

need for same angular resolution, but not enough:
mm observations are the limiting factor because of atmosphere and scan pattern
(small maps with very inhomogeneous weights and noise)
→ unavoidable filtering of large spatial scales and diffuse emission
noise increase + large bias (signal systematically decreased)

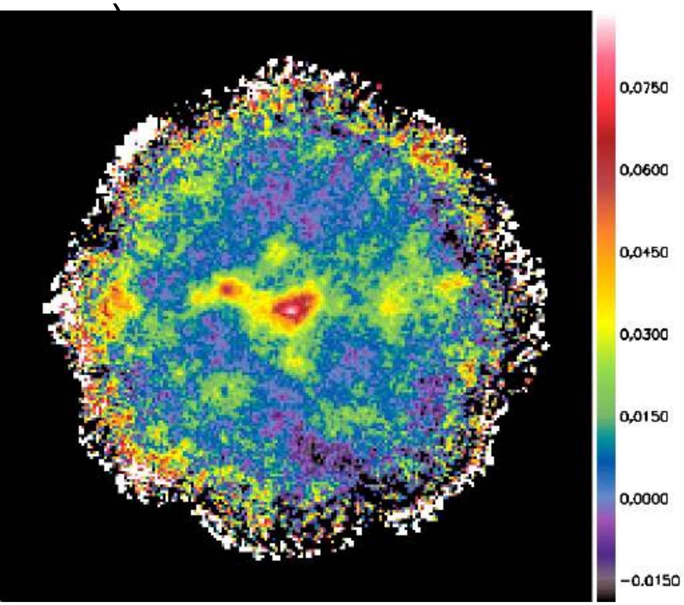
one possible solution: apply the same transfer function
(noise + scan pattern + processing) to all the data

1) processing of NIKA2 data → save time series of subtracted LF noise
+ measurements of HF noise
2) take Herschel maps convolved to NIKA2 beam and renormalize them
3) extract simulated noise-free time series with the NIKA2 obs. geometry
4) add to them the LF + HF NIKA2 obs. noise
5) process them in the same way as NIKA2 data
6) back-renormalization

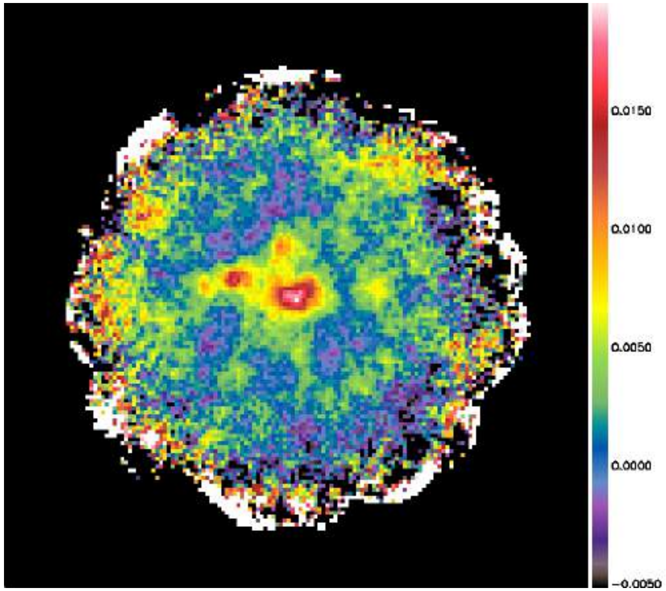
preliminary test of the method to construct combined SEDs

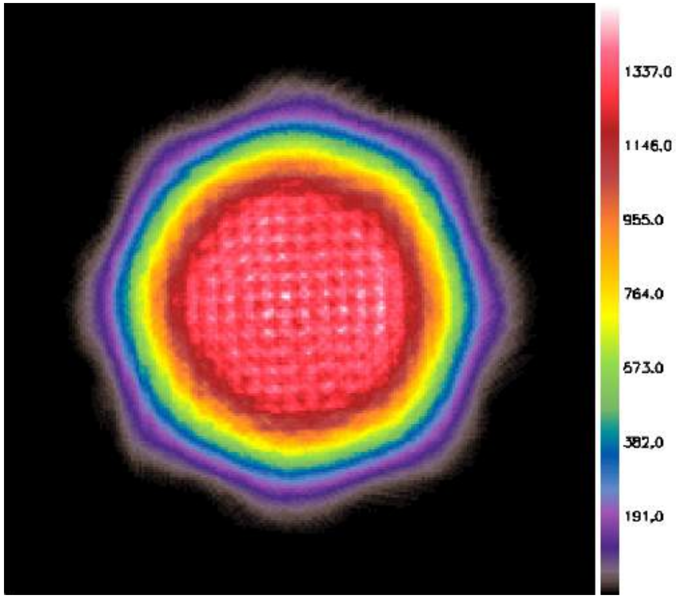
example of cold core G82 (run 10, P.I. Isabelle Ristorcelli)

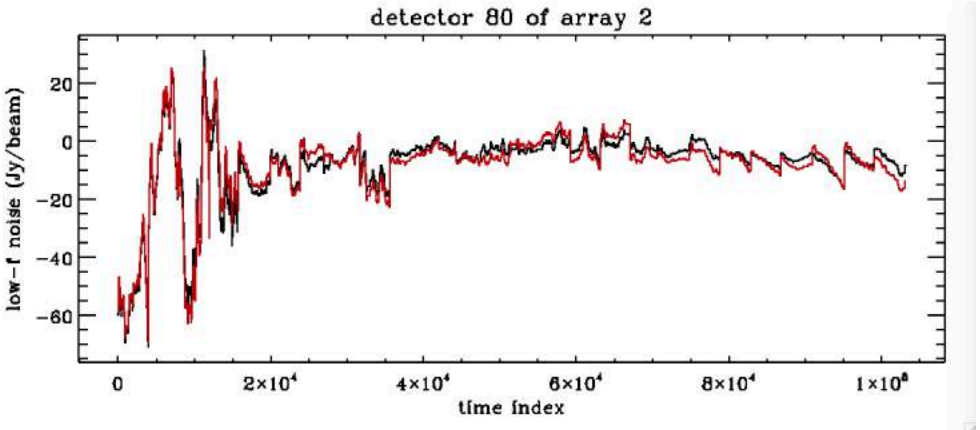
1mm (FWHM ~ 12”)

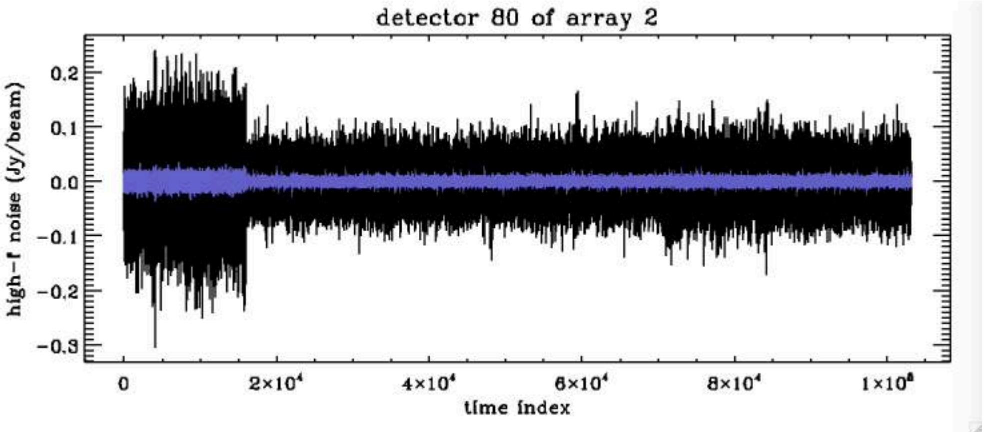


2mm (FWHM ~ 18”, same as SPIRE 250 μm



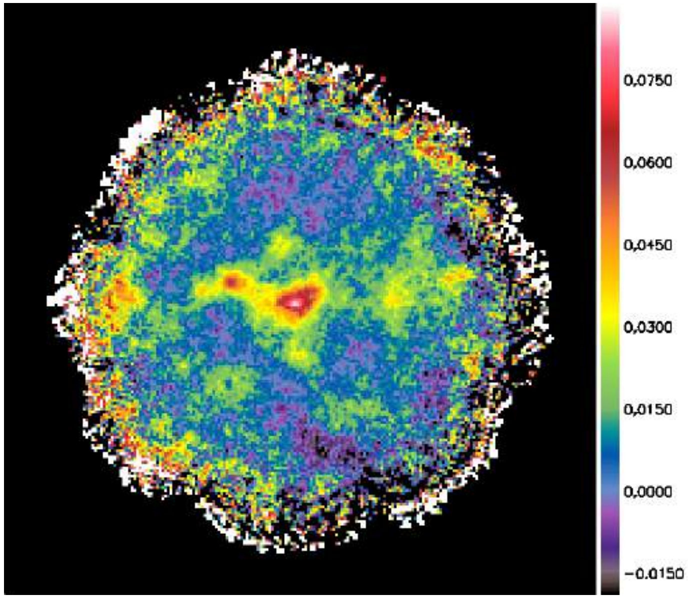


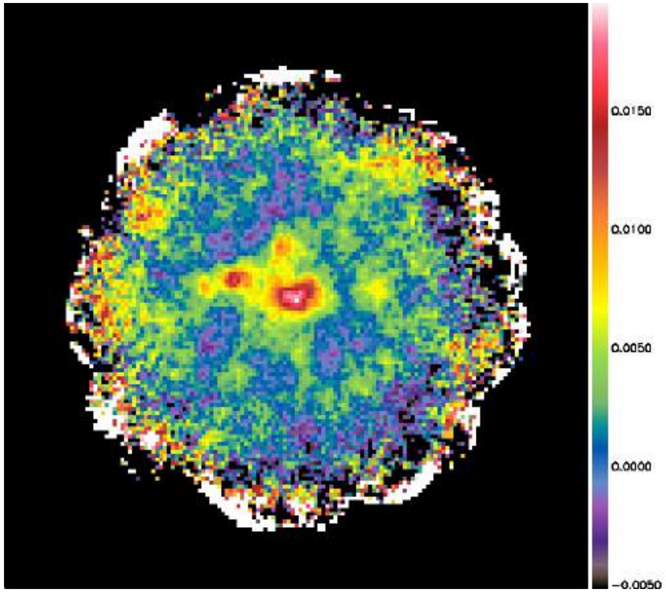




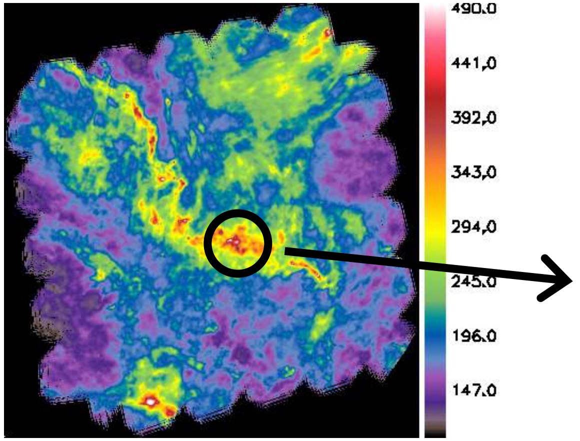
preliminary test of the method to construct combined SEDs

example of cold core G82 (run 10, P.I. Isabelle Ristorcelli)



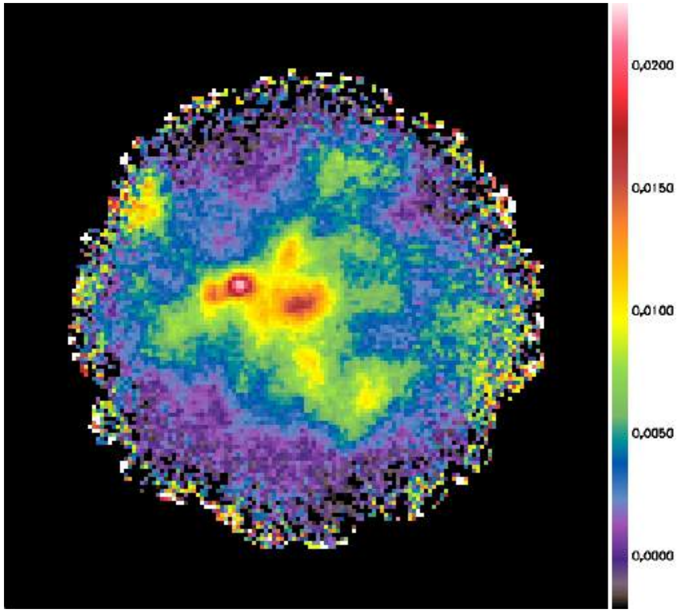


~ 9 arcmin

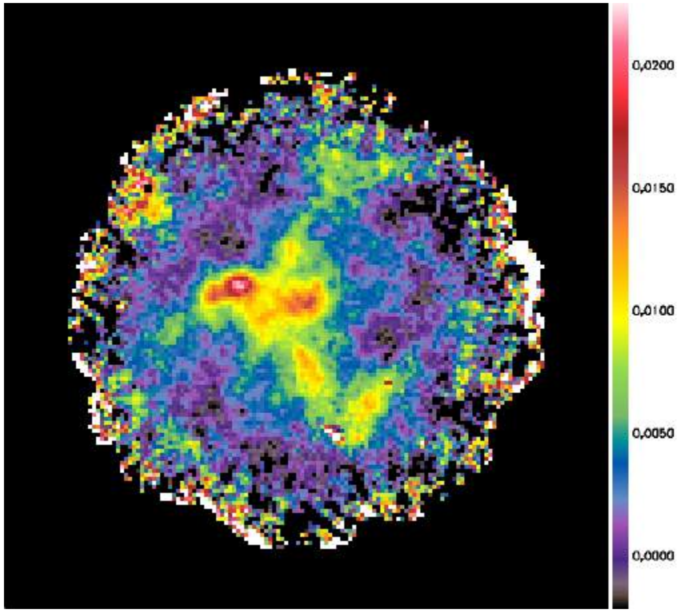


Herschel 250 μm

with NIKA2 high-f noise, no proc.



with NIKA2 total noise



By way of conclusion

code will be shared with NIKA2 team during summer
to undergo further testing
documentation still to be written

then publicly released and useable by everybody

will continue to be improved and maintained throughout NIKA2 life
forever a work in progress !

to be used optimally:

- requires the extended-source gains to be derived for the run(s) of the obs.
  (contact me if I have not derived them yet)

- A map of a bright calibrator (Uranus) observed during the same run
  should be processed in the same way → absolute flux calibration

Warm thanks to the whole NIKA2 team !