Herschel PACS Data Reduction

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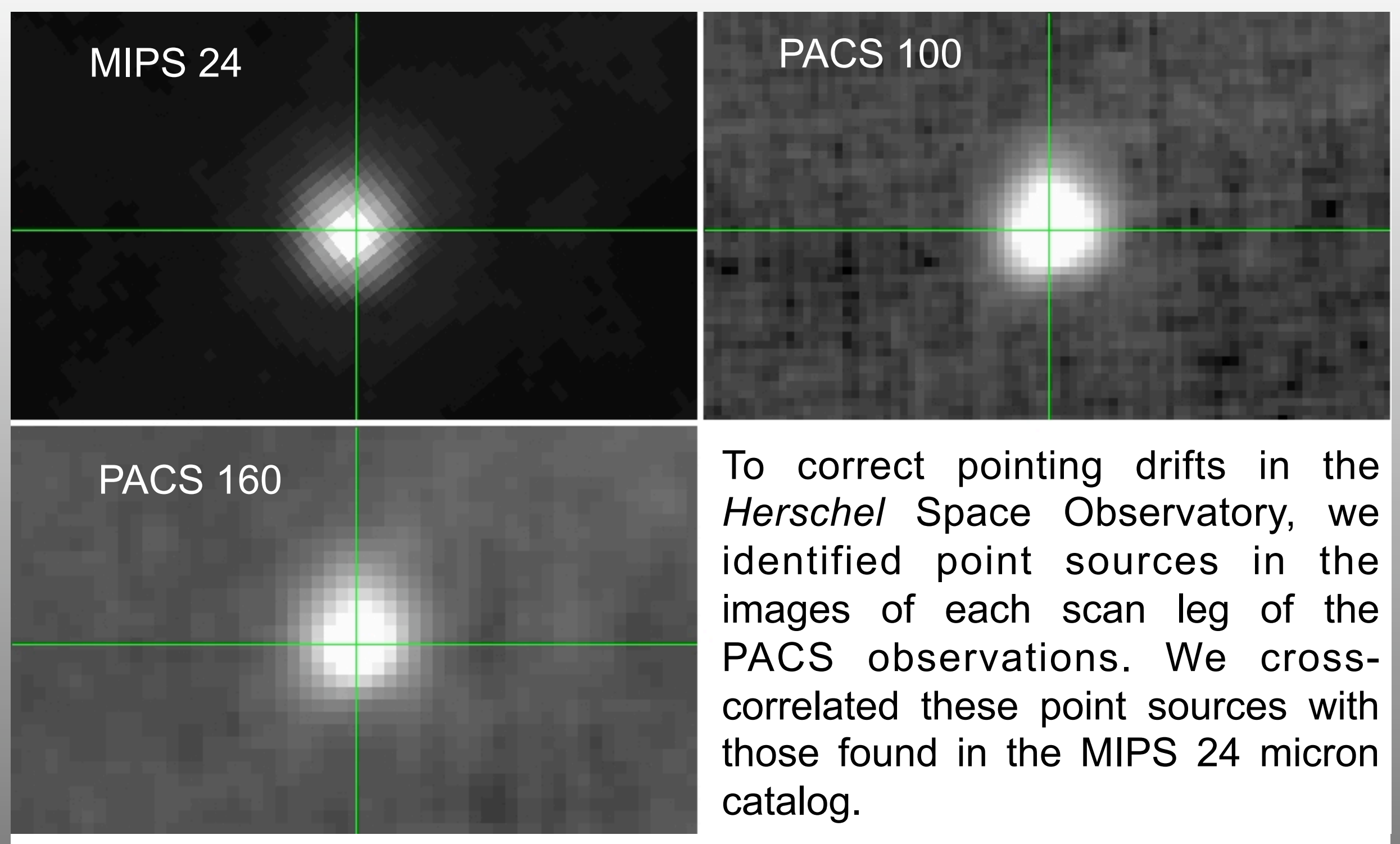
Summary

The basic PACS data reduction was performed starting from the level 0 product to the level 1 product using the standard pipeline in the HIPE version 4.2.0 data reduction software (Ott 2010). In particular, bad and saturated pixels were masked, a flat field correction and the photometric calibration were applied. The baseline drift of each bolometer due to 1/sqrt(f) noise was first corrected by subtracting a linear fit to the end points of each scan legs (Fig. 1a, b). This 0th order baseline subtraction allowed us to successfully apply the multi-resolution median transforms (MMT) deglitching algorithm to correct sudden jumps in the timeline, or glitches, due to cosmic ray hits on the detector. The baseline drift was then more thoroughly estimated and removed using a custom IDL algorithm based on previous IRAS 100 micron and MIPS 160 micron data (Meixner et al. 2006) for the PACS 100 micron and PACS 160 micron bands respectively (Fig. 1c-1f, Fig. 2, 3, 4). For the blue band, the MMT deglitching algorithm was applied with less stringent parameters than for the red band to avoid removing the core of the PSF of point sources. As a result, a second deglitching step, called "second level deglitching", had to be applied to the blue band after baseline subtraction. In addition, we found the presence of long glitches appearing as severe jumps in the signal and affecting an entire array in the PACS 100 band (Figs. 6,7). We developed a custom algorithm to remove those artifacts by subtracting a polynomial fit of order 2 to each side of the jumps (Fig. 6). The baseline corrected PACS timelines were projected on two-dimensional maps using the standard PhotProject software in HIPE. Following the mapping step, we corrected the astrometry of each scan leg by cross-correlating point sources identified in the PACS and MIPS 24 micron images, and subtracting the median value of the offset between the common point sources to the RA/DEC of each scan leg, before remapping the astrometrically corrected timelines (Fig. 8). We investigated the correlation between PACS160 and MIPS160, and PACS 100 and IRAS 100 to establish the accuracy of the point source and extended source calibrations. We found that the PACS160/MIPS160 ratio, taking into account the latest PACS responsivity based on the extended PSF and relevant color corrections, is consistent with the quoted absolute calibration error (10%). For the PACS100 band, the PACS100/IRAS100 ratio is 1.3, significantly above the quoted error (Fig.).

Astrometry

Fig. 8



To correct pointing drifts in the *Herschel* Space Observatory, we identified point sources in the images of each scan leg of the PACS observations. We cross-correlated these point sources with those found in the MIPS 24 micron catalog.

Finally, we subtracted from the RA/DEC of each scan leg the median offset between the matched source coordinates in the MIPS 24 and PACS point source catalogs. This procedure not only provided an astrometry accuracy < 1" between MIPS and PACS, but also was able to correct large astrometric offsets due to speed jumps in select HERITAGE AORS.

Baseline Subtraction

Fig. 1 describes the steps taken in the baseline reduction.

1. A linear fit to the end points of each scan leg, located outside the galaxy, is removed from the timeline of each bolometer (Fig 1a, b)

2. The PACS timelines are smoothed approximately to MIPS 160 (resp. IRAS00) resolution by using a 1D slice through the 2D convolution kernel to go from PACS160->MIPS160 resolution (resp. PACS100->IRAS100), see Fig. 1c. The shape of MIPS point sources or bright extended sources with small scale variations is not reproduced by smoothing the PACS timelines in 1D (Fig. 2, only the convolution of the image with the 2D kernel would reproduce comparable shapes). Since we estimate the baseline as the difference between the smoothed PACS timelines and the MIPS timelines, removing such an estimate of the baseline would produce over-subtraction around point sources or bright extended sources with small scale variations (Fig. 3).

4. Bright regions and point sources are therefore masked (Fig. 4), and the smoothed PACS timelines and MIPS timelines are interpolated between the closest points outside the region (Fig. 1d).

5. The baseline is estimated as the difference between the smoothed, interpolated PACS timelines and the MIPS/IRAS timelines (Fig. 1e), and removed (Fig. 1f).

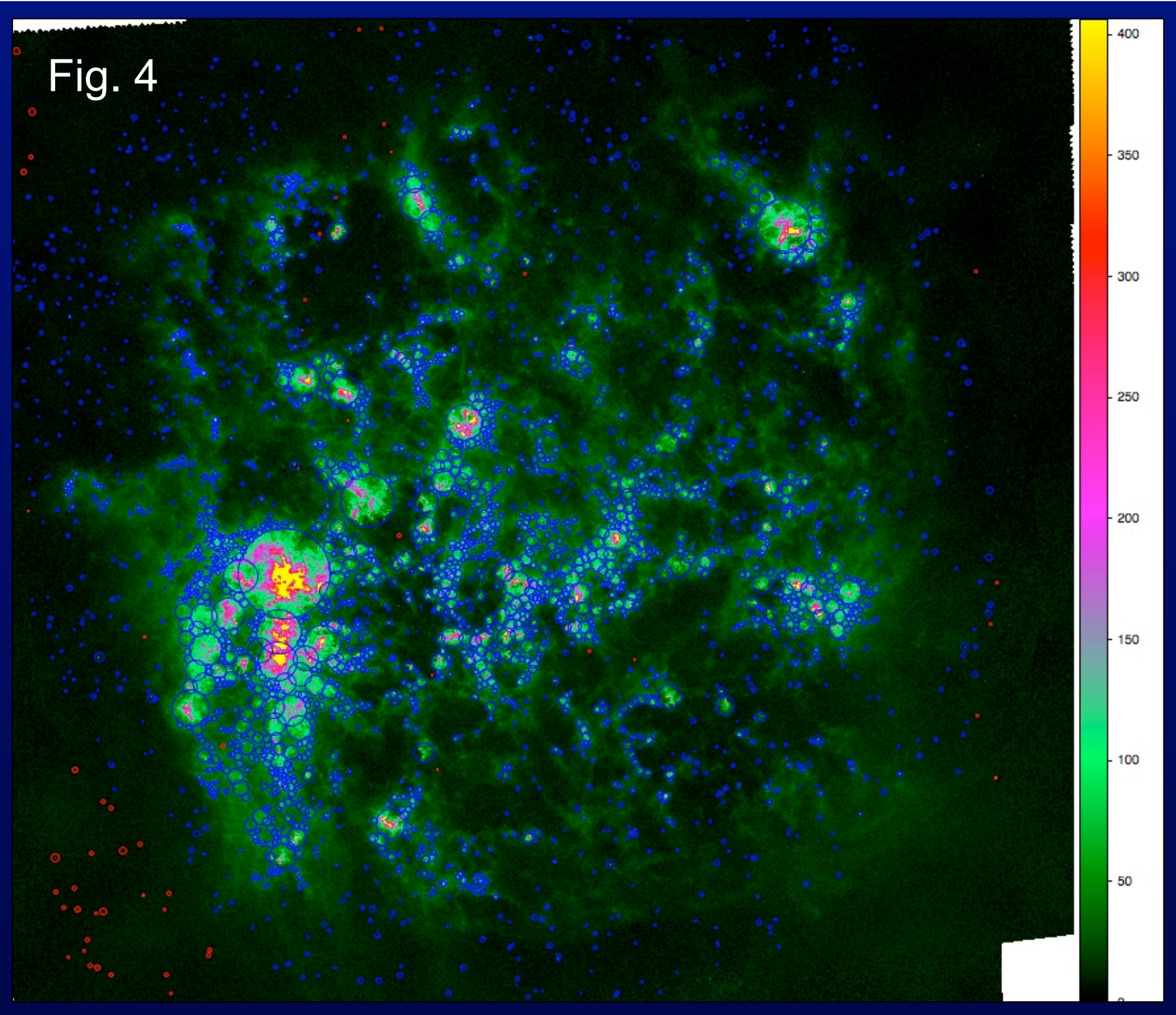
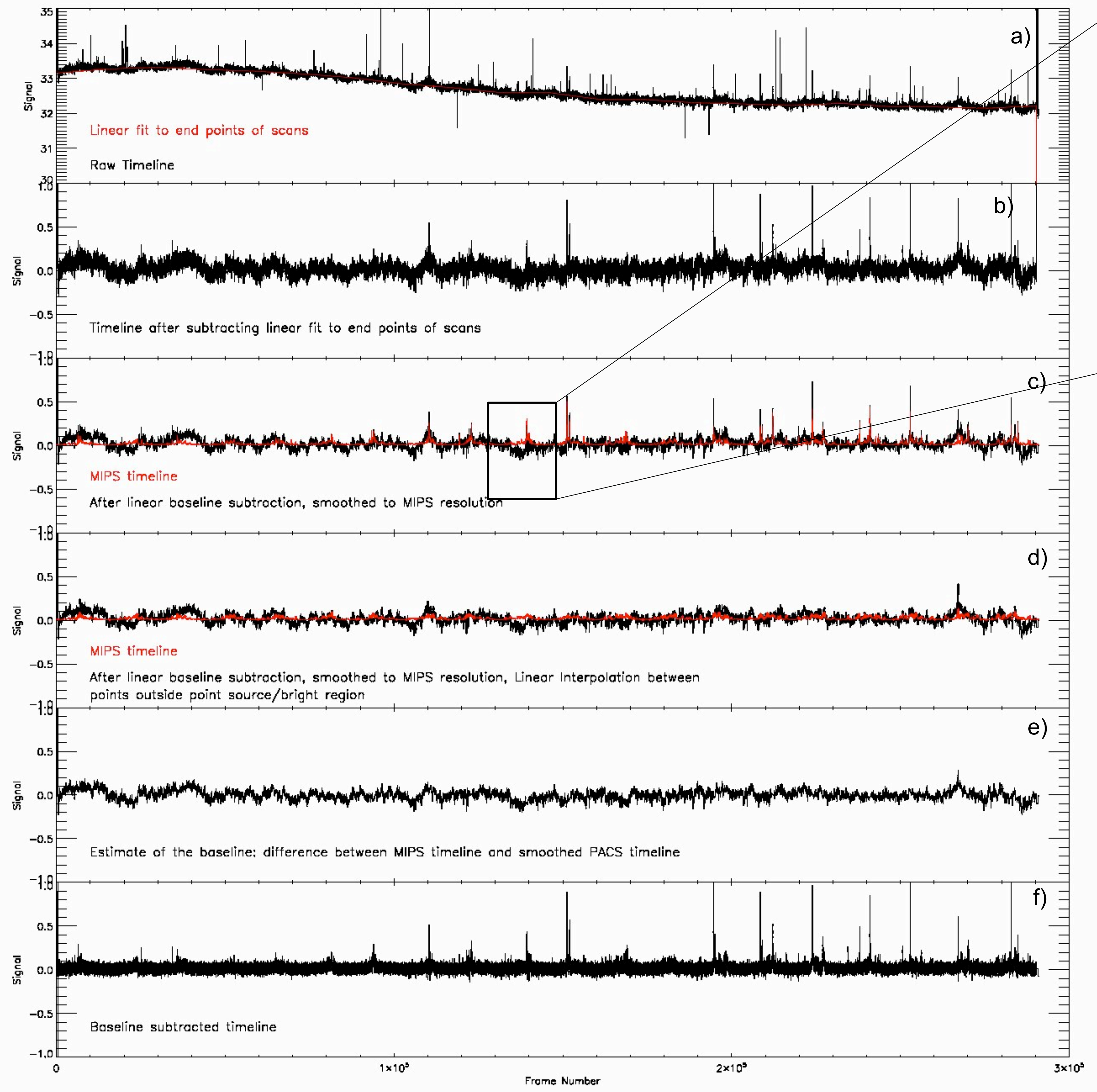


Fig. 4: Masks over bright regions (example of the LMC) used to prevent over-subtraction during the baseline subtraction process

Fig. 1: Baseline subtraction steps



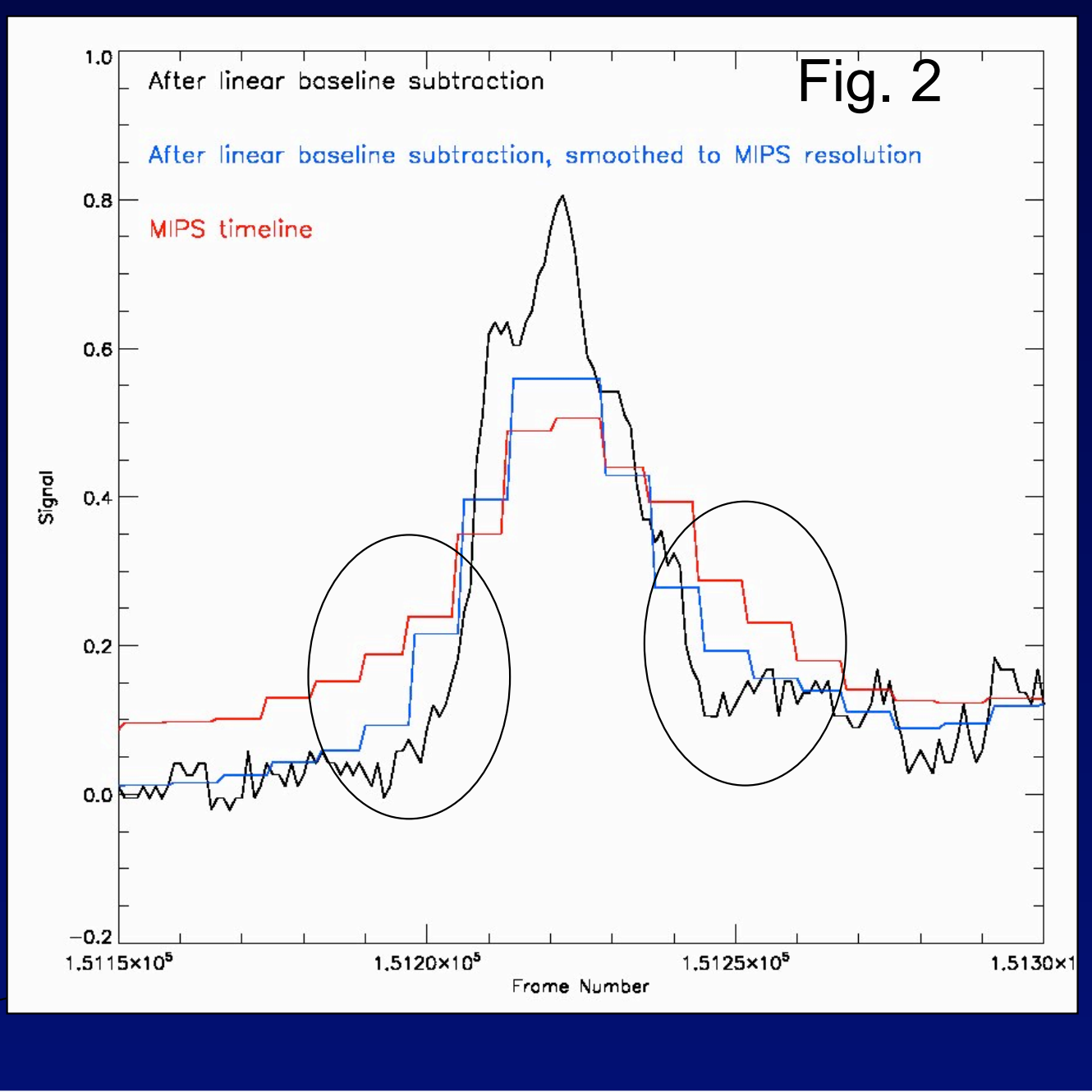


Fig. 2: Mismatch between shapes of point sources, extended sources with small scale variations between MIPS (resp. IRAS) timelines and PACS smoothed timelines

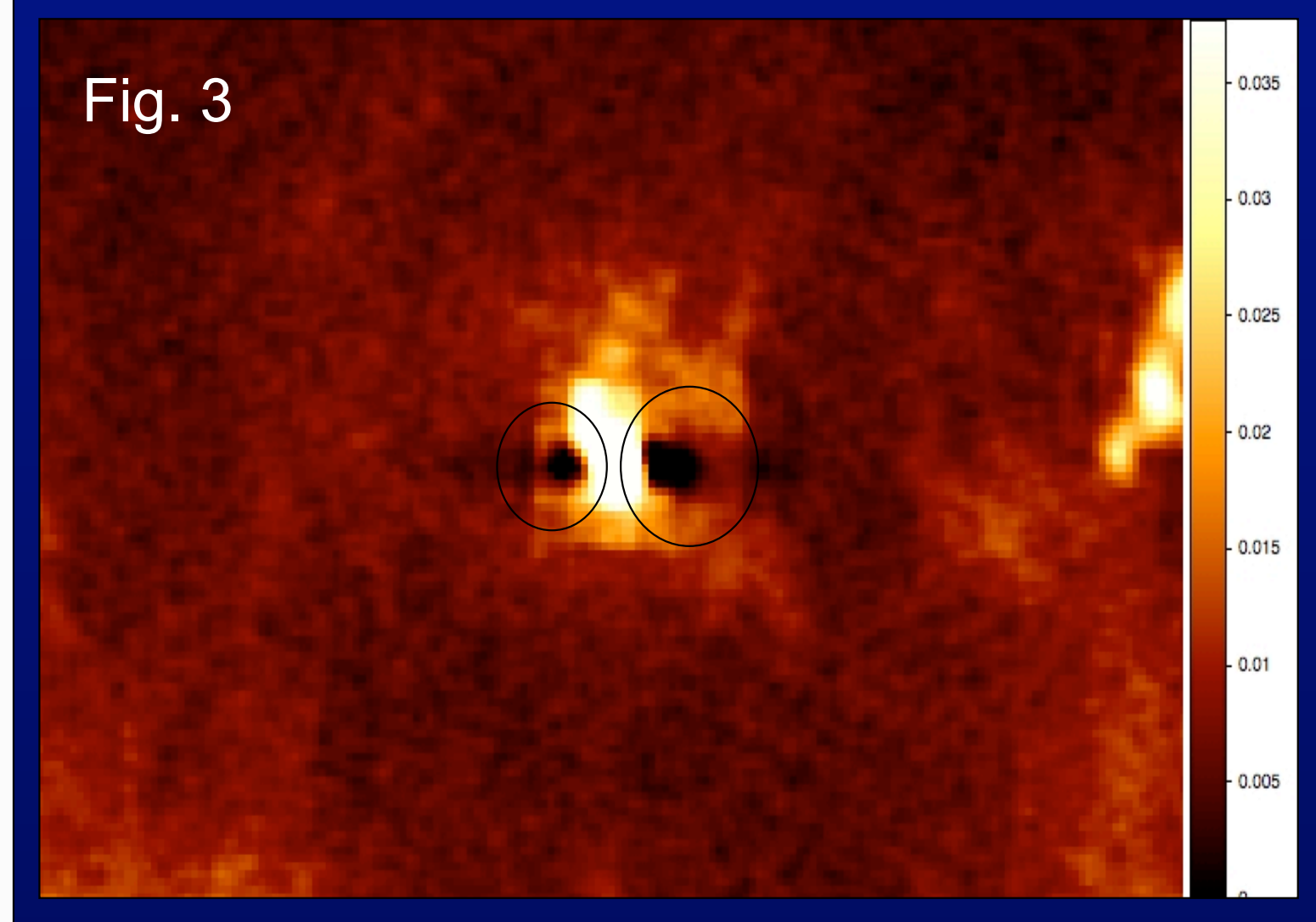
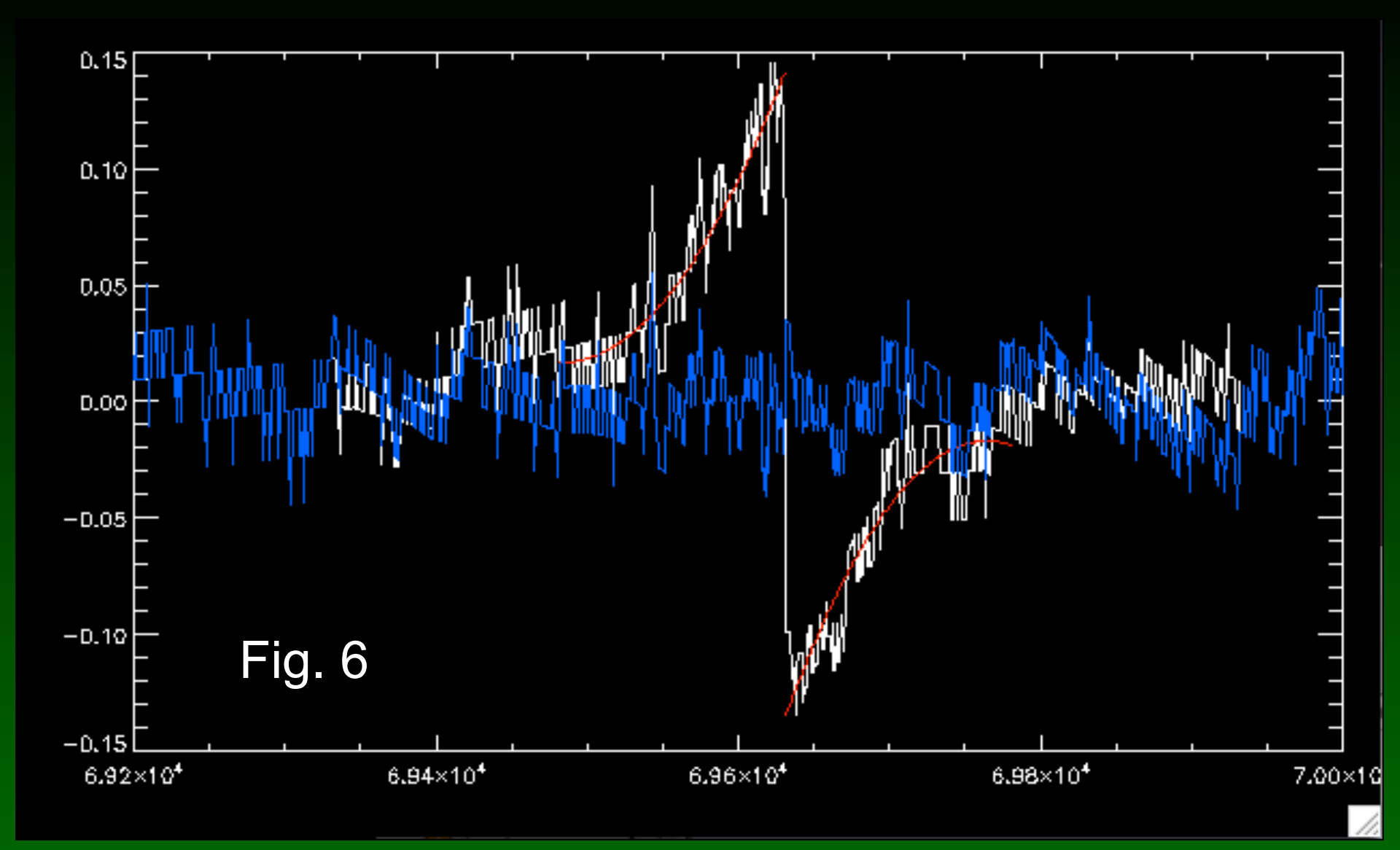
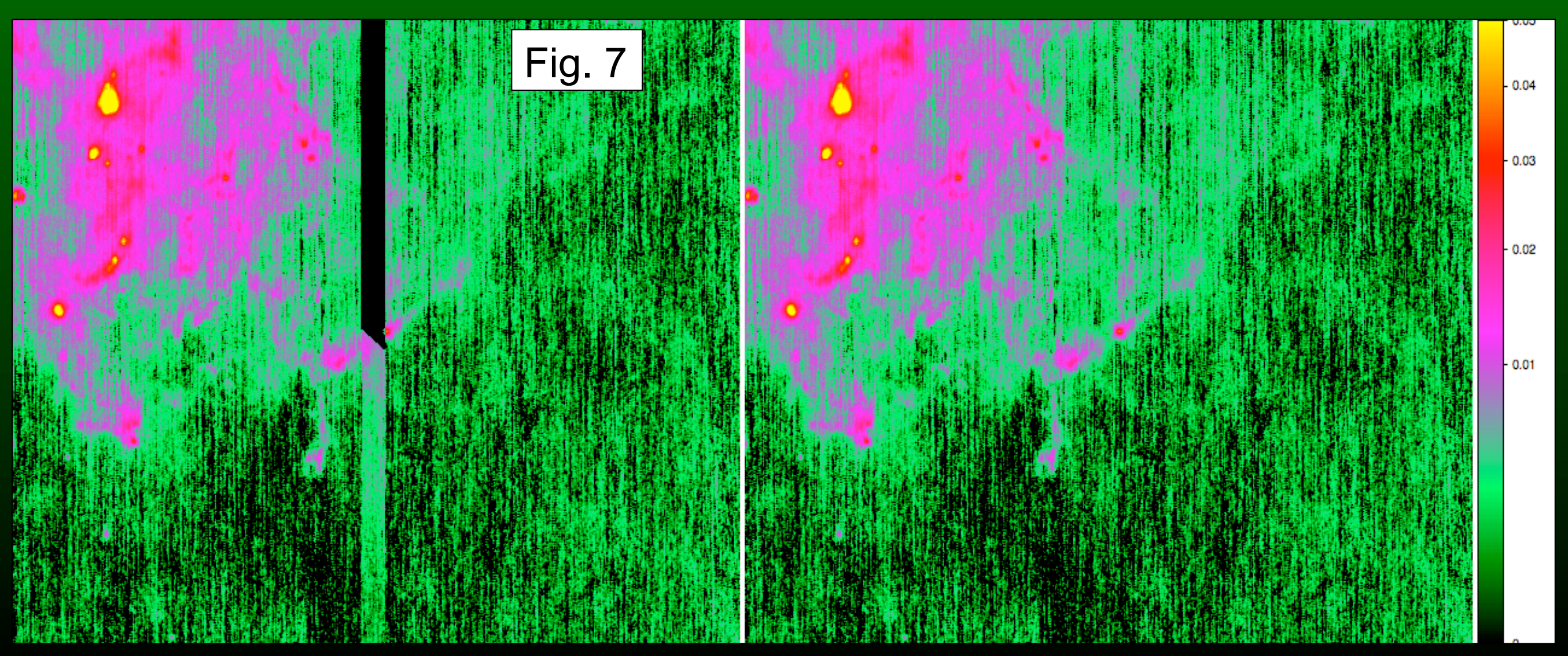


Fig. 3: Removing the baseline estimated as the difference between PACS smoothed timelines and MIPS 160 (resp. IRAS100) timelines causes over-subtraction on the sides of point sources or extended sources with small scale variations.

Removal of Long Glitches



The PACS 100 band is affected by long glitches, which affect an entire line of the detector array and produce a severe jump in the signal. These long glitches are not removed by the standard MMT and second-level deglitching algorithms available in HIPE. We have developed a custom, interactive IDL algorithm to correct these artifacts. First, candidate glitches are identified by selecting frames over which the total signal in a detector line jumps above a given threshold from one frame to another. All the candidates are examined by eye until the long glitch is identified. A polynomial fit of order 2 is then fit to each side of the jump, over a number of frames defined by the user for each glitch. As last, the fit is subtracted from the timeline to correct the signal. Fig. 7 shows an image of a region affected by a long glitch before (left) and after (right) correction.



PACS Calibration

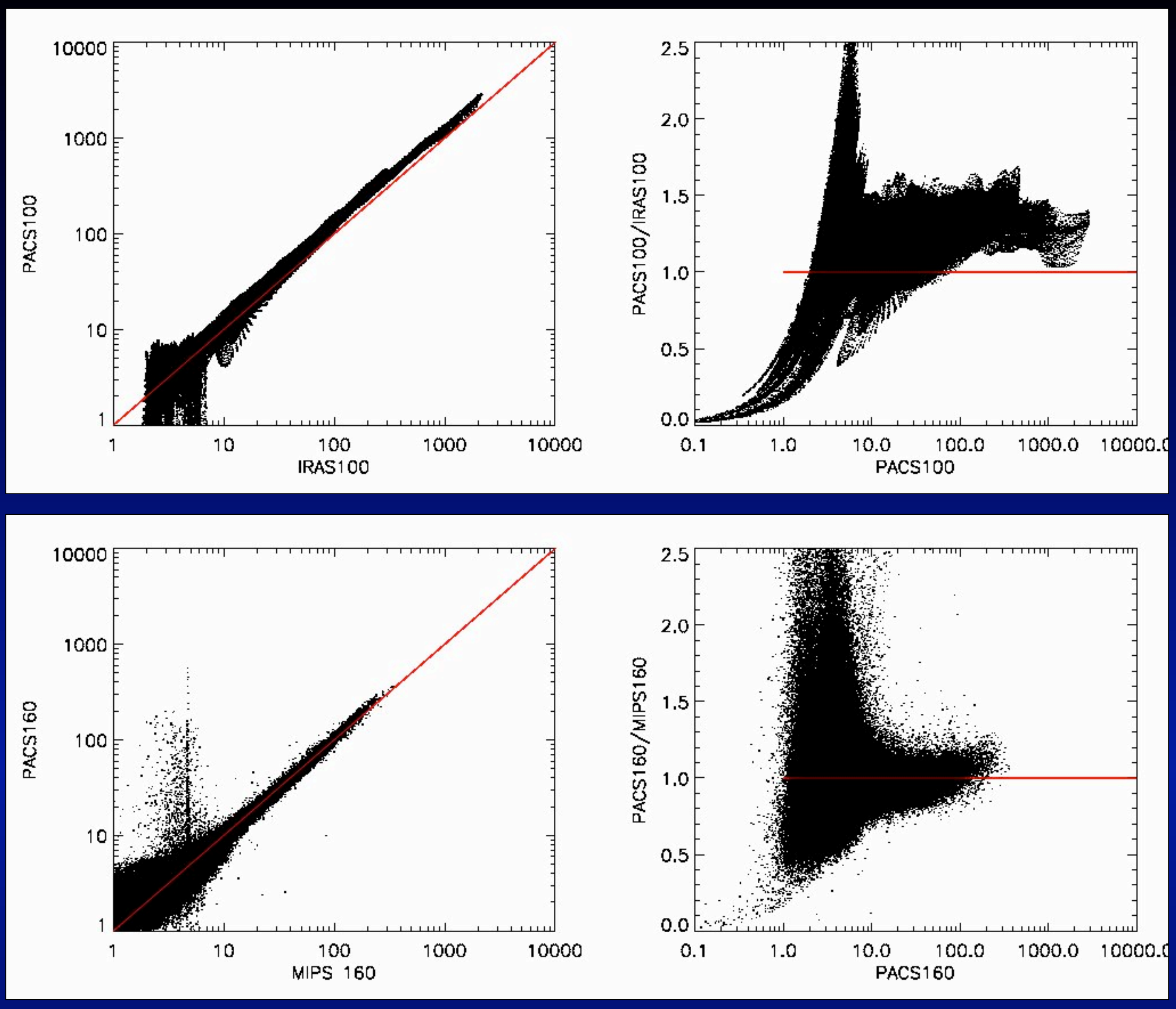
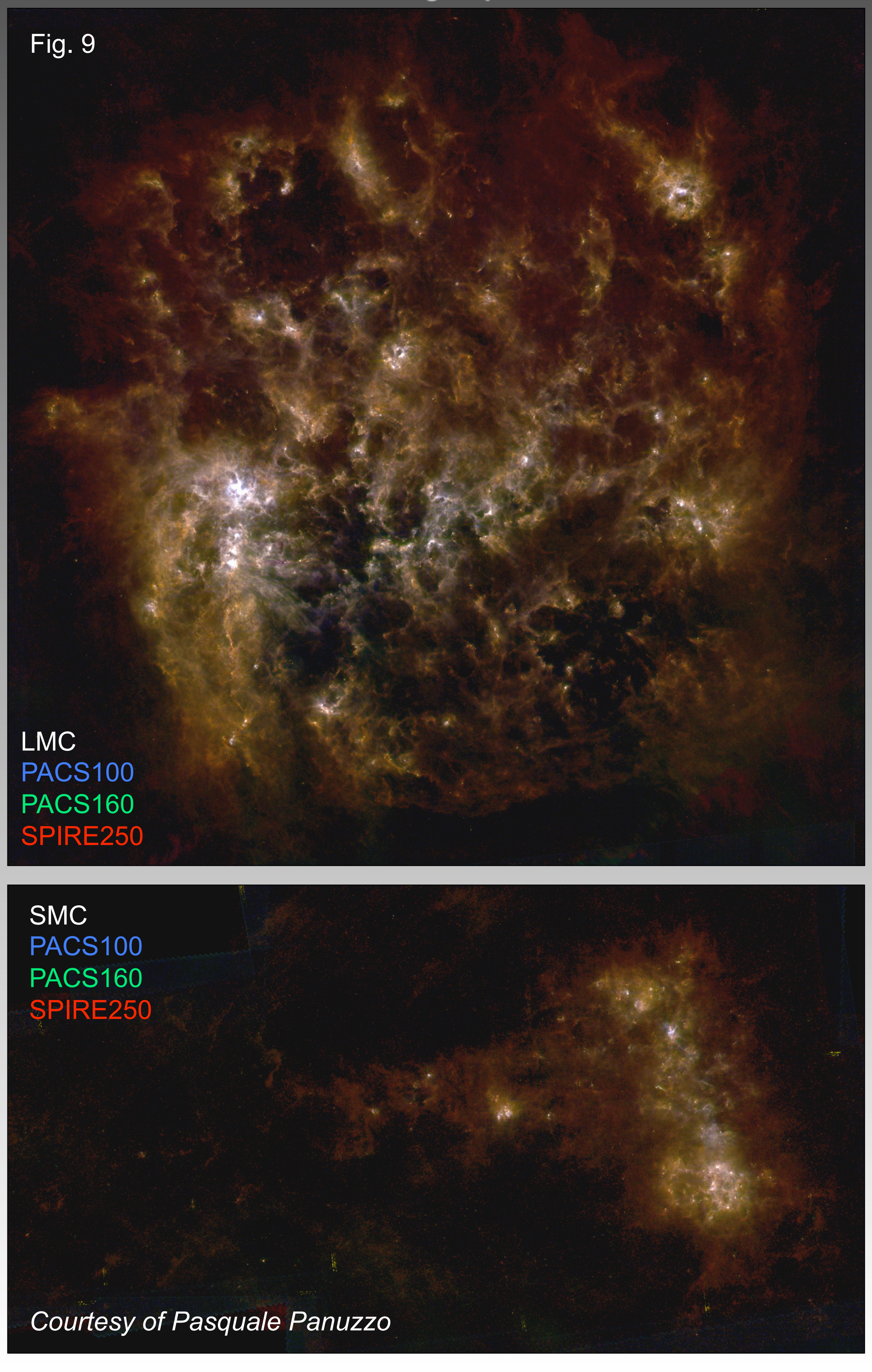


Fig 8. shows the pixel-to-pixel correlation between PACS100 and IRAS 100 (top, for the LMC) and between PACS160 and MIPS160 (bottom, for the SMC). A color correction was applied to all data, assuming a black body of temperature 20K and emissivity index β = 1.5. For the 100 micron band, the PACS map was convolved to the IRIS100 resolution (4.3') using a gaussian kernel of width 4.29' (√4.3'²-8"²) and resampled on the same grid. For the 160 micron band, the PACS map was convolved to MIPS160 resolution using a kernel by Gonzalo Aniano (KINGFISH team) before being resampled. The average ratio of PACS100/IRIS100 is 1.3, while the ratio of PACS160/MIPS160 is 0.95. The latter is consistent with the quoted error on the absolute calibration, while the former is not.

Resulting Maps



Courtesy of Pasquale Panuzzo