PACS scan map simulations

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General context for a timeline simulator

$$f_{i,t} = [A_i]_{t,p} s_p + n_{i,t} + d_{i,t}$$

Flux of pixel *i* in the TOD

Pointing matrix for detector pixel *i*

Signal at pixel *p*

1/*f* noise

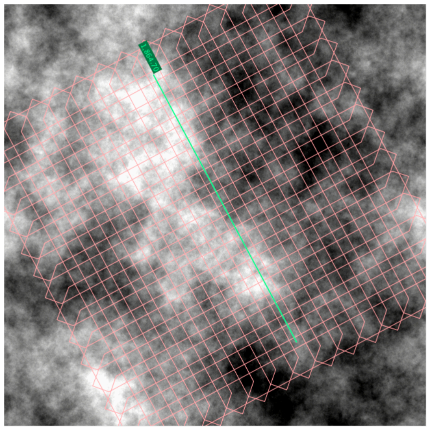
quantization noise

The inverse solution $I_p = P(f_{i,t}) + C$ can be tested against s_p,

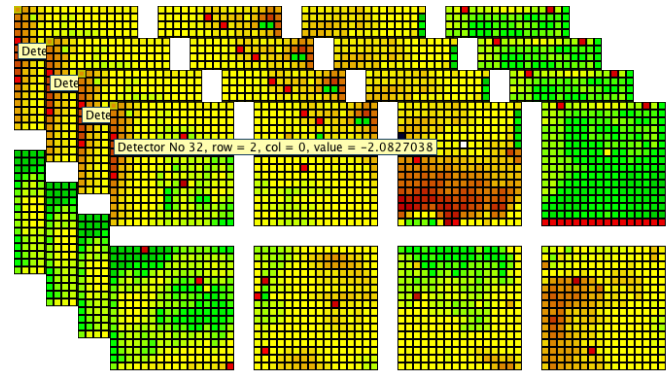
In the simulation all components of the equation are provided, the output is $f_{i,t}$ in the form of a TOD cube (PACS Level 1 frames)

Hybrid simulation concept

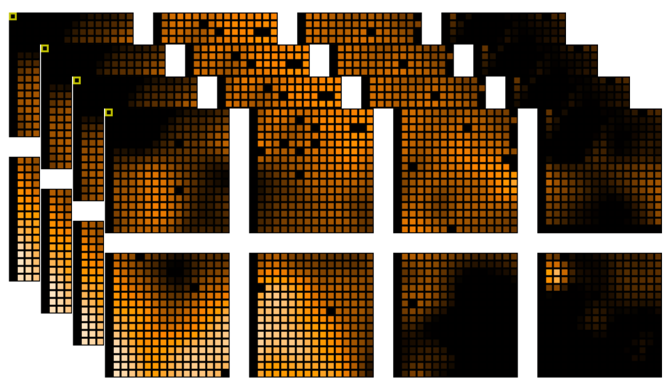
Sky donor image



Noise donor cube
(Staring calibration observation)



Receptor cube
(Scan observation subject to simulate)



Simulation components

- Noise donor calibration observation: Simulating non-stationary features (discontinuities, glitches, transients…) and real detector behaviour would be difficult. A long staring observation at a low FIR-background position of the sky is more suitable. This dataset consist pure instrument noise and telescope background measured at nominal detector setup (detector bias and readout mode). A section of this noise sample is copied into the flux cube of the receptor science observation.

- Receptor science observation: Placeholder of the simulated dataset. Its flux cube is replaced by the noise donor Level 0 timeline. When reaching processing Level 1 the back-projected sky model is superimposed over the timeline. The AOT setup is typical for a PACS scan-map observation in terms of scan-speed, redundancy (map repetitions) and observing strategy (multiple coverages at orthogonal scan angles).

- Sky model donor image: A realistic sky model image either a superior quality high S/N measured dataset or a simulated image. The pixel size of the input sky map (model sky granularity) is in practice limited by available memory.

Simulation components

Receptor cube								
Id	OBSID	Band	Orientation	Size	Repetitions	Scan speed	Start time	PA
R#1	1342216420	blue2 (green)	45	35x35	1	20	3/20/11	~250.5
R#2	1342216421	blue2 (green)	135	35x35	1	20	3/20/11	~250.5

Sky donor image				Noise donor cube			Projections	
Id	File in Dropbox	Pixel size	Scaling factors on normalized image	Id	OBSID	Band	Pixel size blue	Pixel size red
S#1	Pink noise simulation	1"	bright: 1/30	N#1	1342182424	blue+red	2"	3"
	simDonor_sky_cirrus.fits		faint: 1/90	N#2	1342182427	green+red		

- Sky donor: pink-noise image (P. Chanial)
  - Advantage of instrument noise-free image
  - Pink noise is well representing a star-formation field diffuse background

- Noise donor: low-frequency noise characteristaion
  - ~3.2 hrs staring observation on ISOPHOT Dark Field
  - From early in the mission: OD 97
  - Nominal bias and detector readout mode

- Receptor cubes: NGC 6946 (nearby galaxy), typical setup for medium-size survey fields
  - ~1.02 hrs total on OD 675
  - Medium scan speed (20"/sec)
  - Homogeneous coverage
  - Square map
  - Orthogonal coverages

Simulation process

1. Take Level-0 data of a real PACS observation of a dark field (i.e. the noise donor) and copy into the Level 0 flux cube of the receptor observation;
2. Add improved pointing product to receptor observation;
3. Run pipeline (HIPE v11.876) on receptor cube up to Level 1 frames generation. This will produce flux-calibrated 1/f noise timeline;
4. Create WCS for input sky model, as well as standard WCS for projections (based on the receptor cube footprint);
5. Calculate map-index á la photProject (task by M. Wetzstein): obtain the RA and DEC for every sampling point in the Level-1 timelines of the receptor cube, then assign pixels from the sky-model map at the RA and Dec of a given sampling point in the receptor timeline. Map-indexing takes into account the fractional overlap of detector pixels and sky model pixels. Map-indexing from L2 sky model to L1 receptor cube has been done with pixfrac=1.0;
6. Apply broad-width HPF on the receptor cube with pure instrument noise. Using photProject and standard WCS project this cube noise with pixfrac=0.1;
7. From the above created noise-map determine suitable scaling factors required for bright- and faint simulation cases;
8. Create point-source catalogue of uniformly distributed fluxes in the [10.0 - 500.0] mJy range and produce source images, convolve the sky model as well as the point-source images with Gaussian PSFs and create composite images used for timeline projection;
9. Using the map-index product, project the sky simulation composite images onto the L1 flux cubes;
10. Correct for digitization effect to simulate proper quantization noise;
11. Using the standard projection WCS, project with photProject the L1 pure sky simulation flux cube with pixfrac=0.1. This will serve as the reference map containing the pure geometrical footprint of the naive projection mechanism.
12. Co-add noise- and projected sky model flux cubes and copy back to Level 1 simulated cubes;
13. Create Observation Context with simulated Level 1 cubes

Bright/faint cases

- bright = faint x 3
- Median flux per pixel:
  - ~0.3 Jy/pix red bright, ~0.1 Jy/pix red faint
  - ~0.075 Jy/pix blue bright, ~0.025 Jy/pix blue faint
- Only the background scales, the PSC fluxes are kept constant (e.g. higher PSC contrast in the faint case)
- Flat SED (same flux in the green and red bands)

Simulation products

$$f_{i,t} = [A_i]_{t,p} s_p + n_{i,t} + d_{i,t}$$

Flux of pixel *i* in the TOD

Pointing matrix for detector pixel *i*

Signal at pixel *p*

1/*f* noise

quantization noise

Regridded truth map

$$T_p \cong s_p$$

Regridded input image to the standard WCS

Reprojected truth map

$$T_p = P([A_i]_{t,p} s_p + d_{i,t})$$

Reprojected sky signal to the standard WCS

Naïve projection with pixfrac=0.1

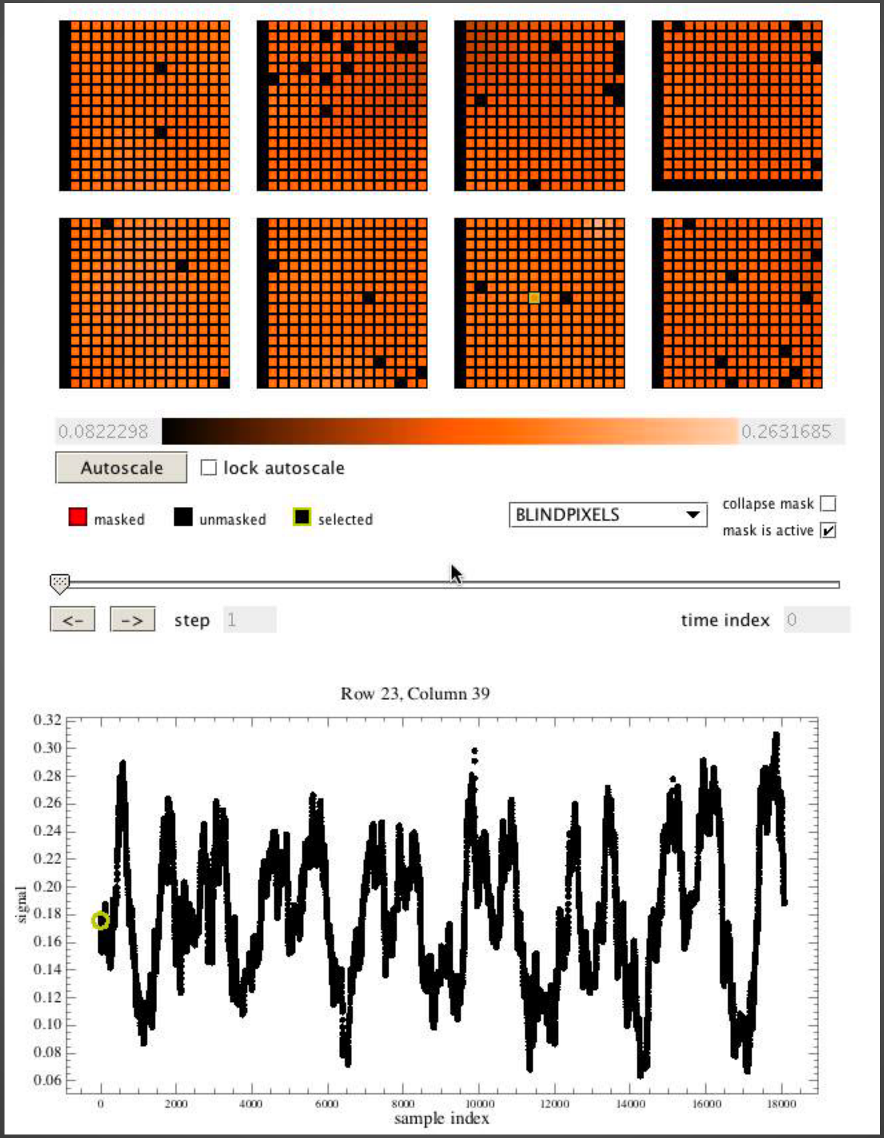
No-noise digitized timeline back-projected with pixfrac=1.0

Reprojected truth map

- A reference affected by the geometrical footprint of the simulation process and timeline digitization
- Considered being a suitable reference map to investigate the spectral response of the map-maker

Scanning through the simulated sky

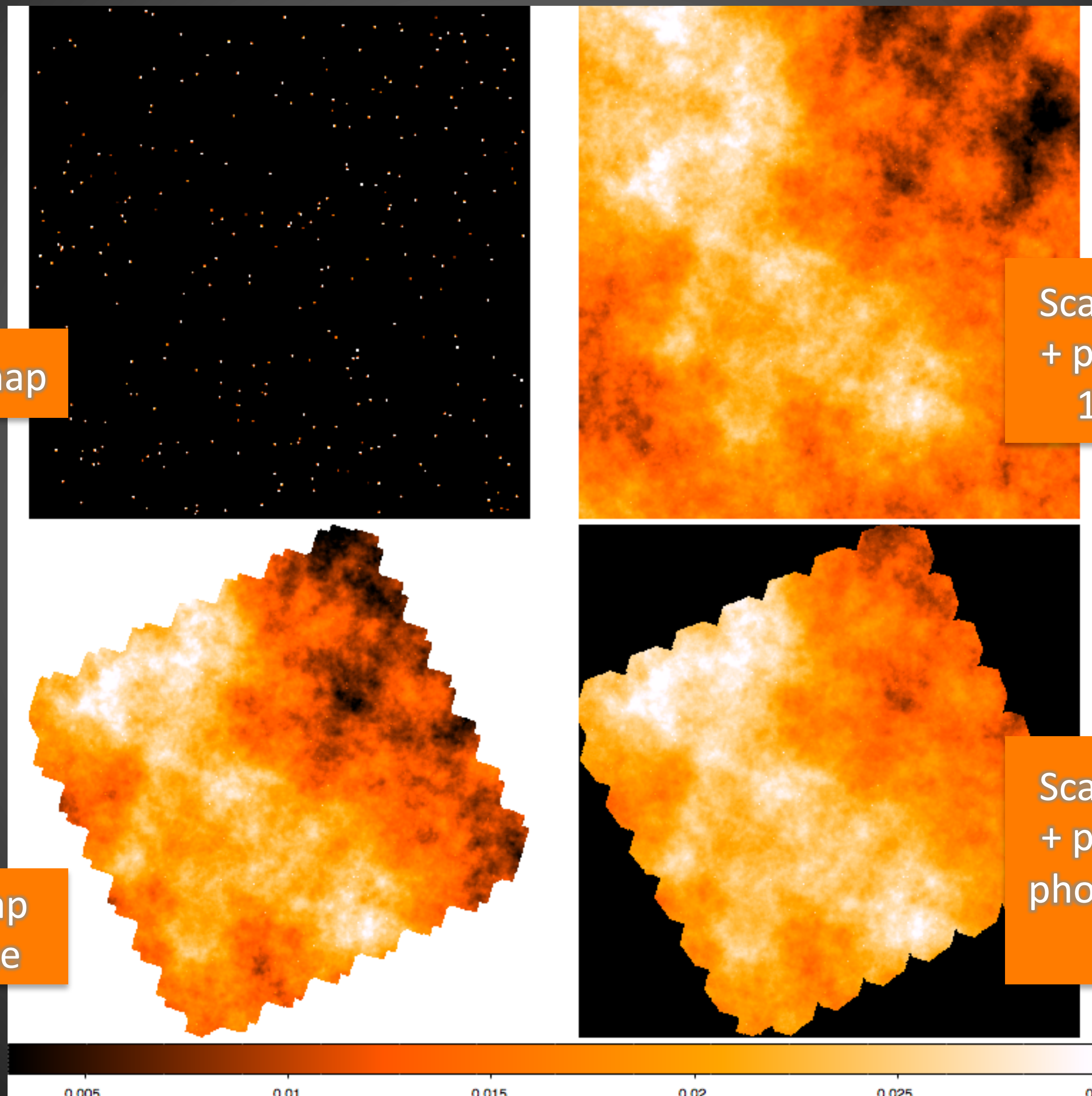
The movie shows the PACS blue bolometer footprint scanning through the simulated sky (no noise in this case)



Blue bright case, sky only, no digitization

Truth maps

(blue/bright case)



Point source map

Scaled input sky + point sources, 1” pixel size

Regridded map to 2” pixel size

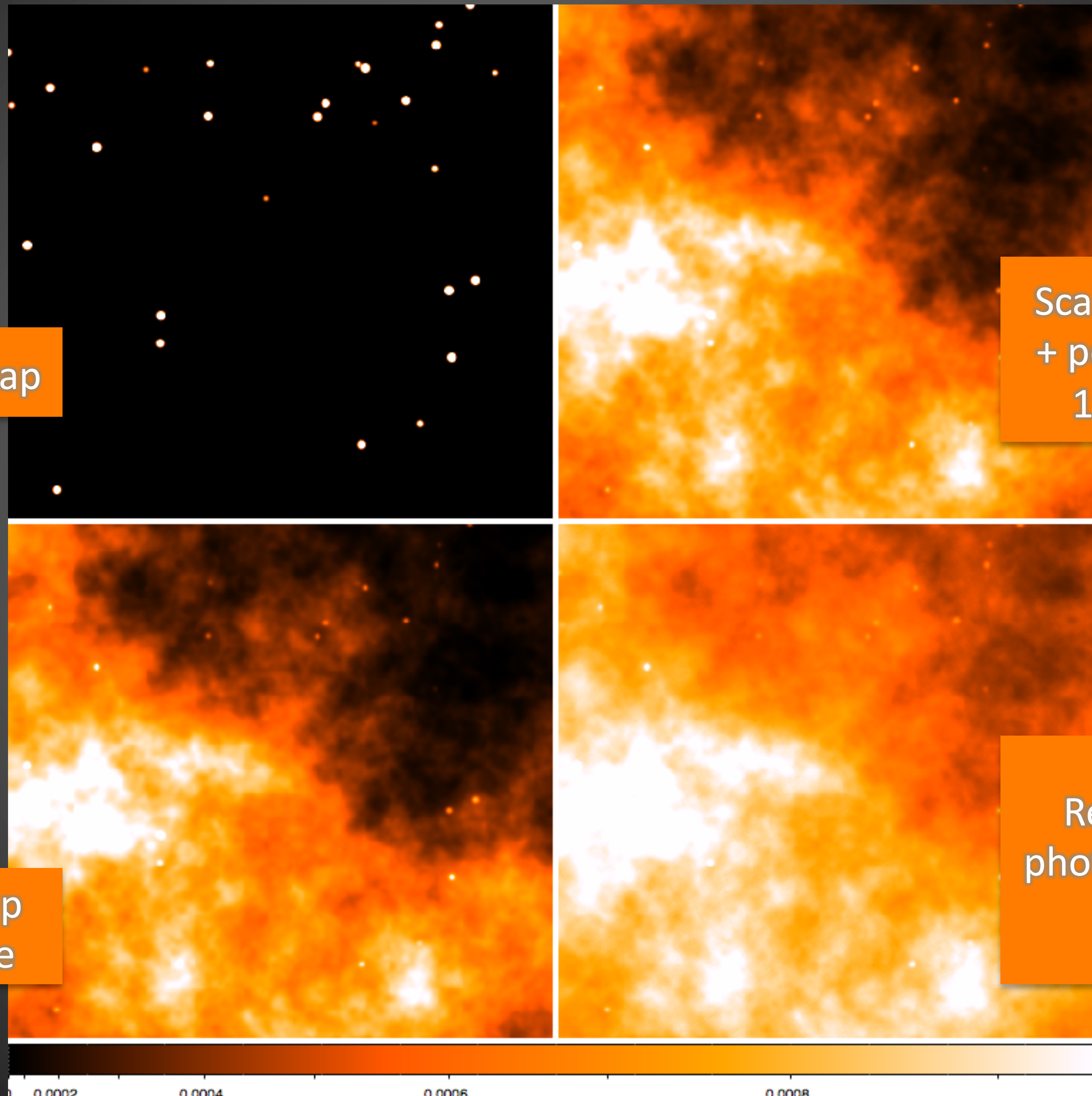
Scaled input sky + point sources, photProject to 2” pixel size

Truth maps

(blue/bright case)

Point source map

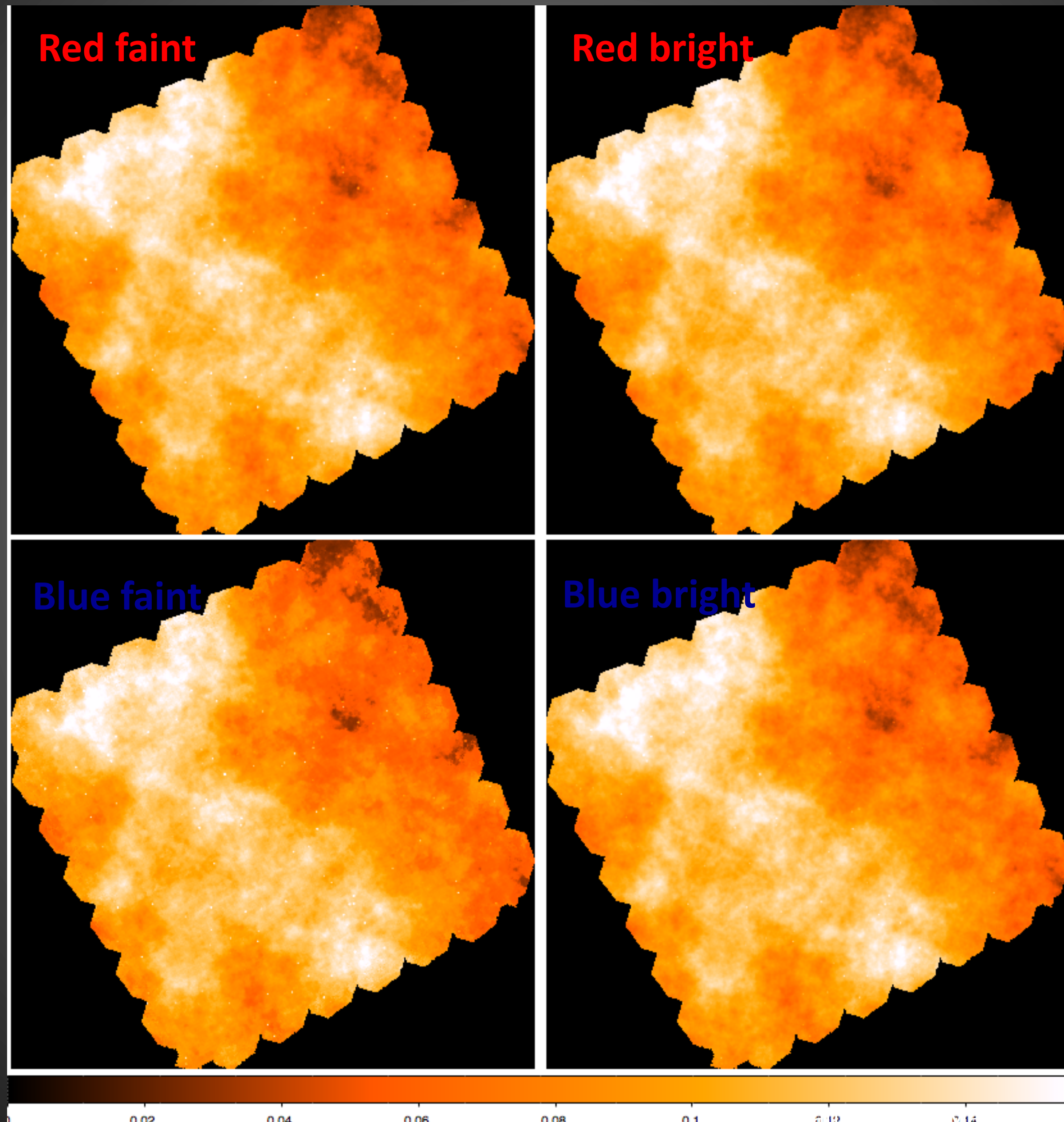
Scaled input sky + point sources, 1” pixel size



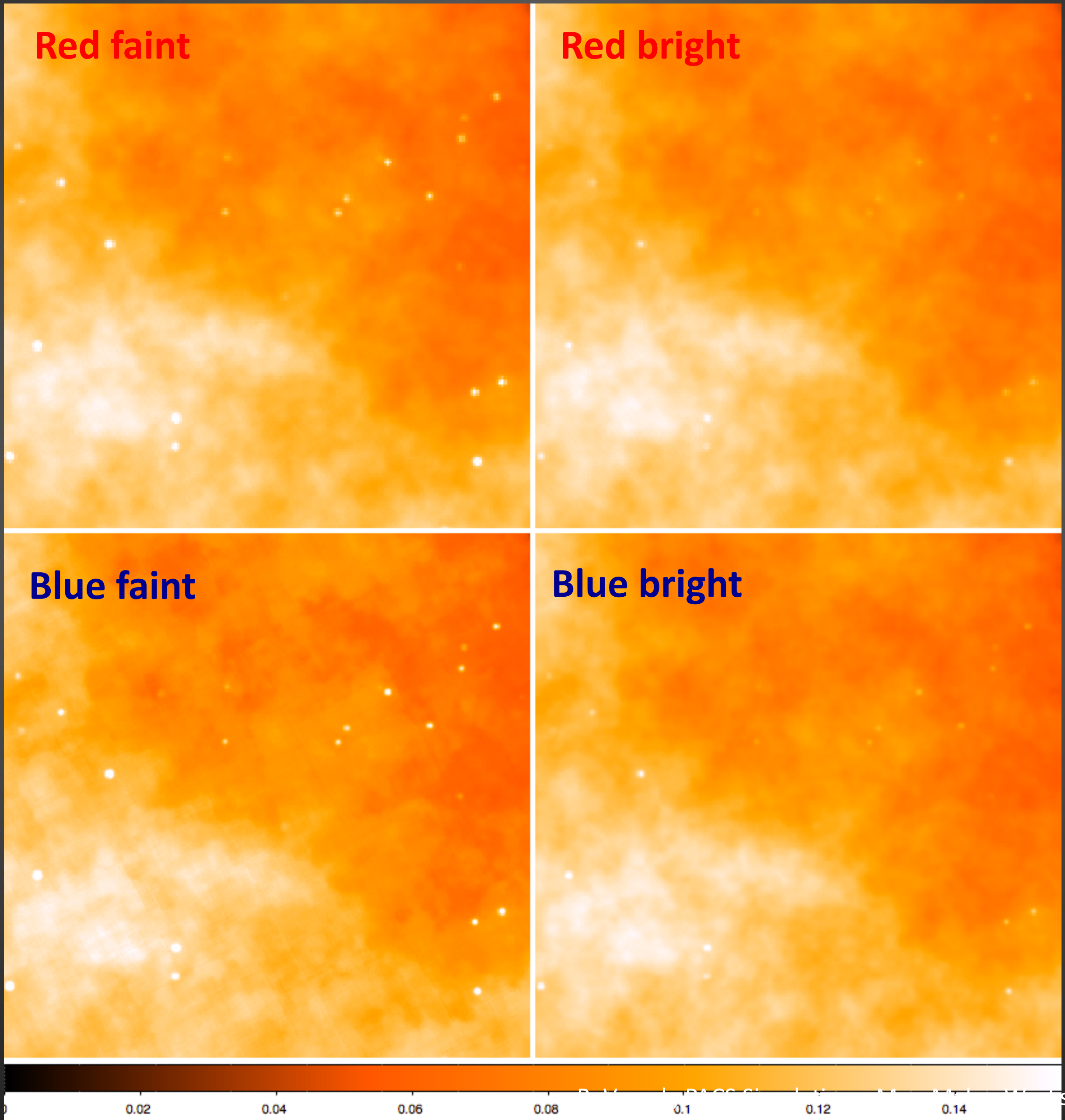
Regridded map to 2” pixel size

Reprojected, photProject to 2” pixel size

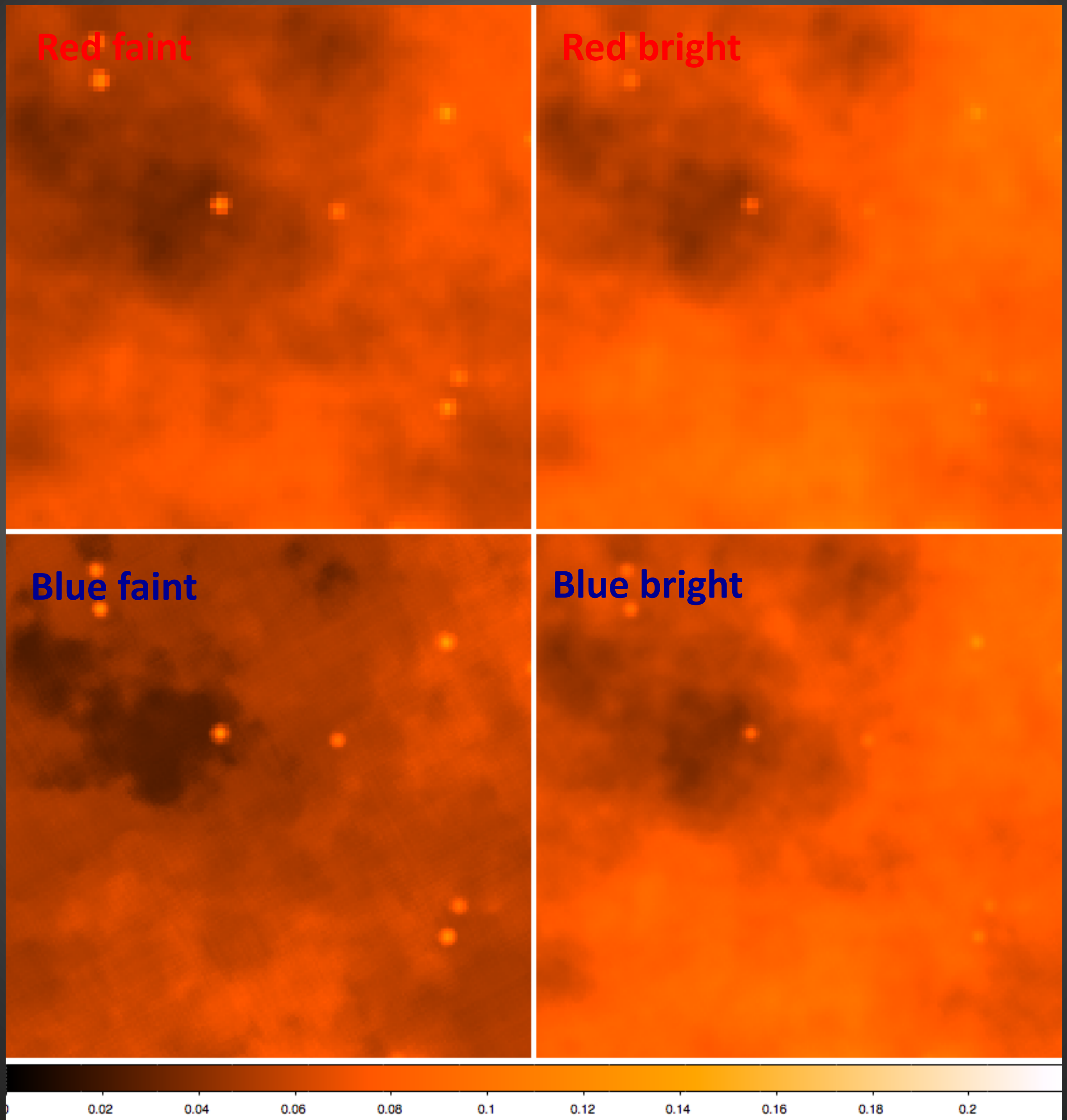
Reprojected truth maps



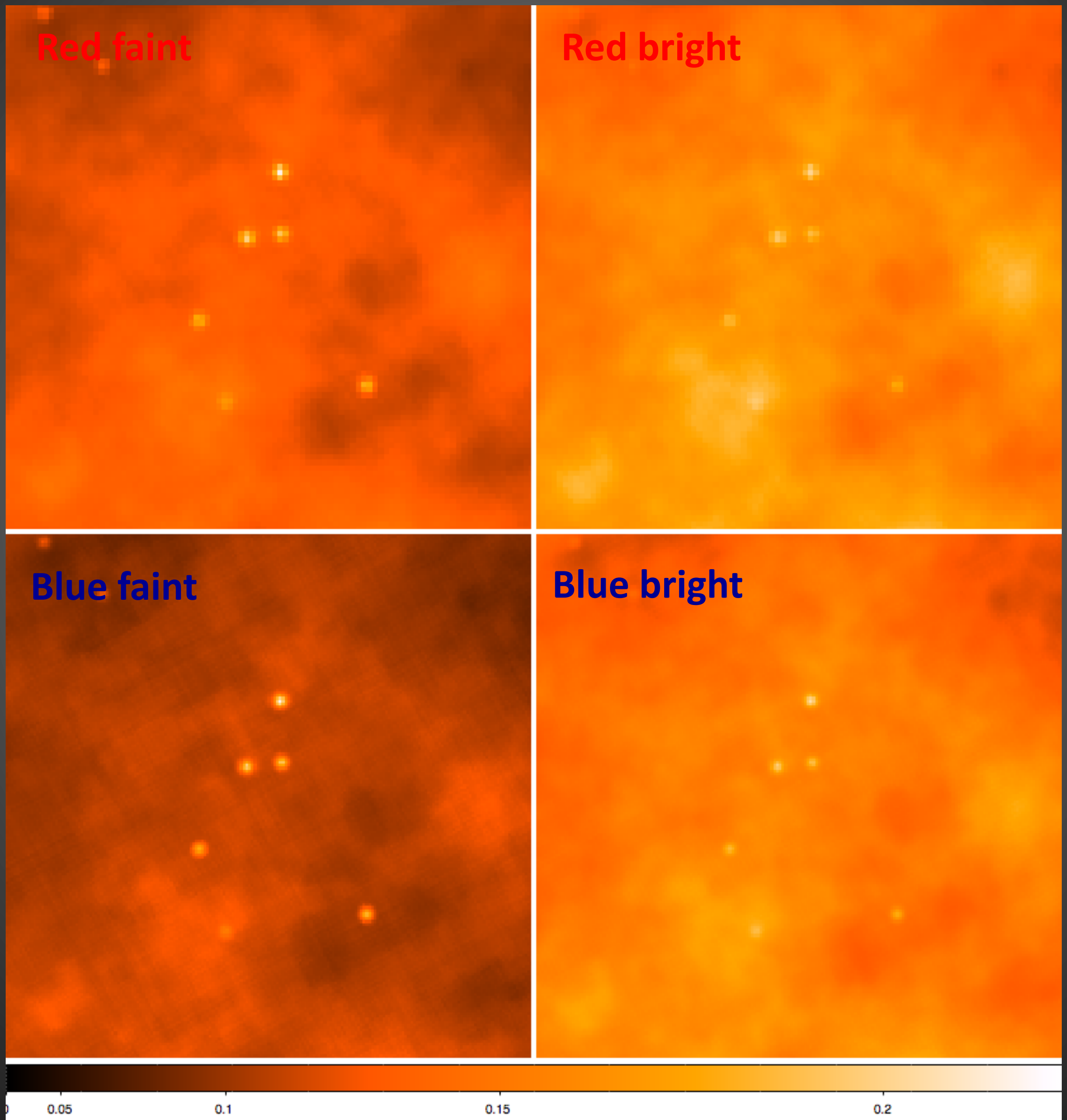
Reprojected truth maps



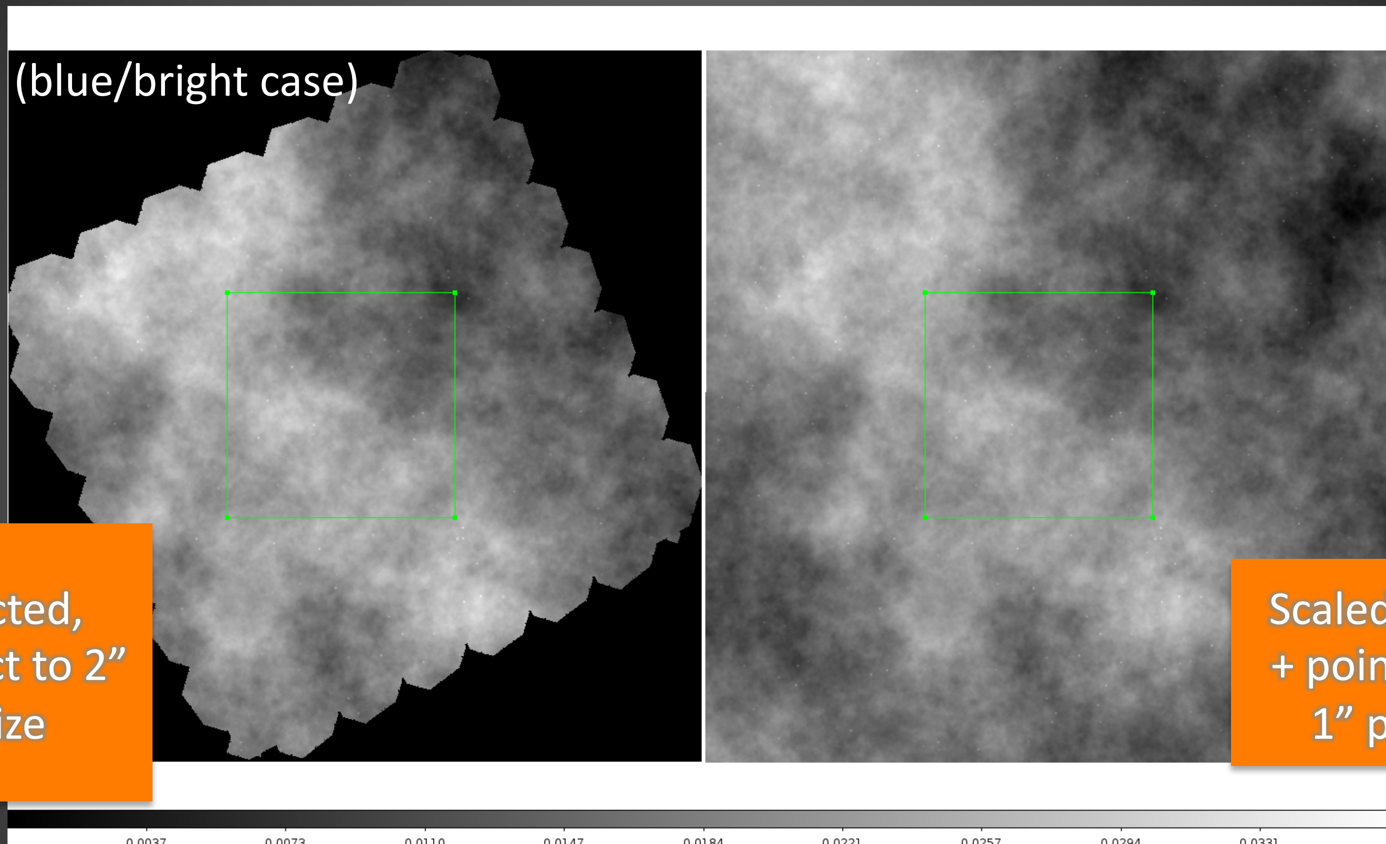
Reprojected truth maps



Reprojected truth maps



Flux conservation – extended emission



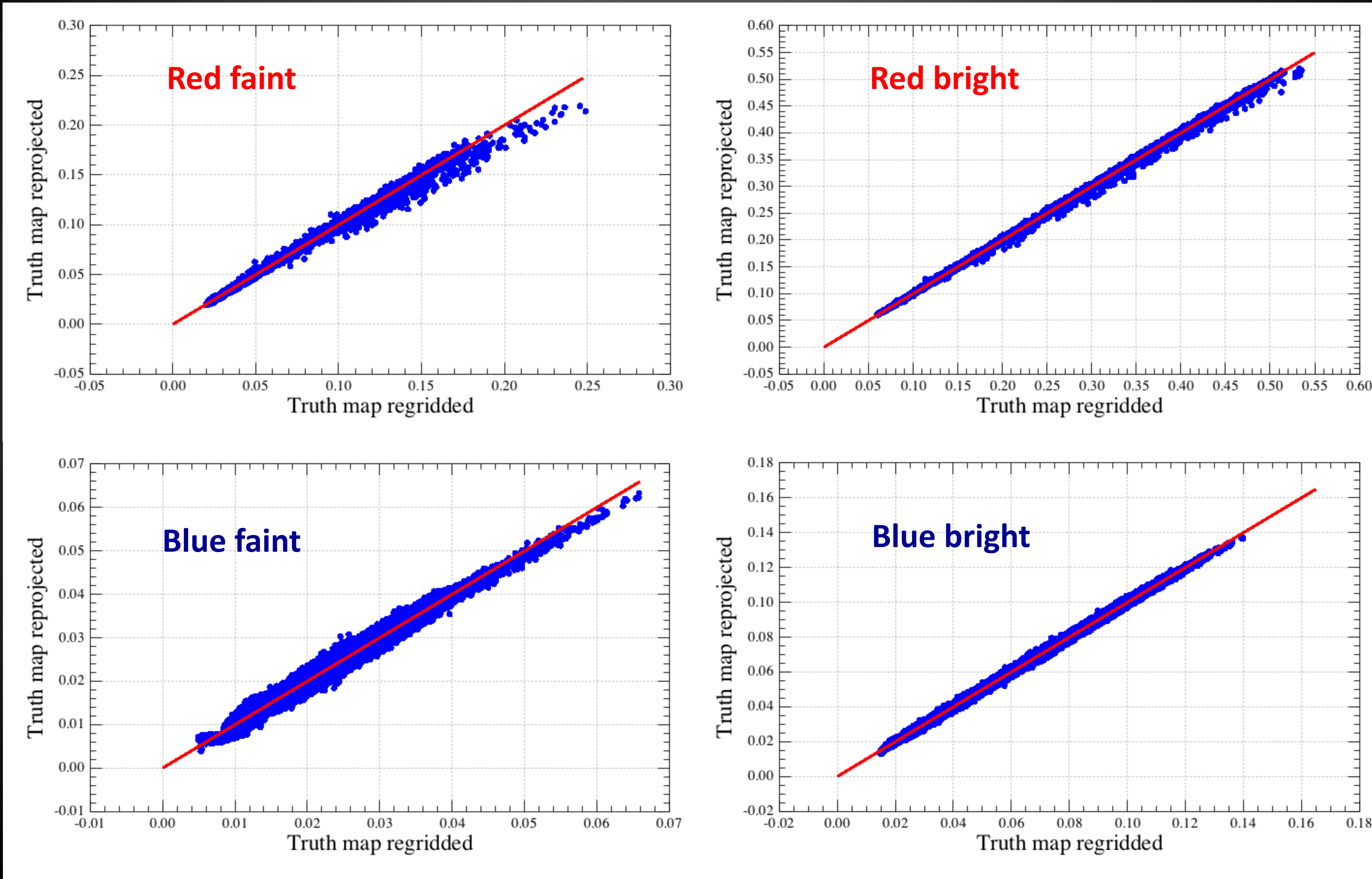
Reprojected, photProject to 2" pixel size

Scaled input sky + point sources, 1" pixel size

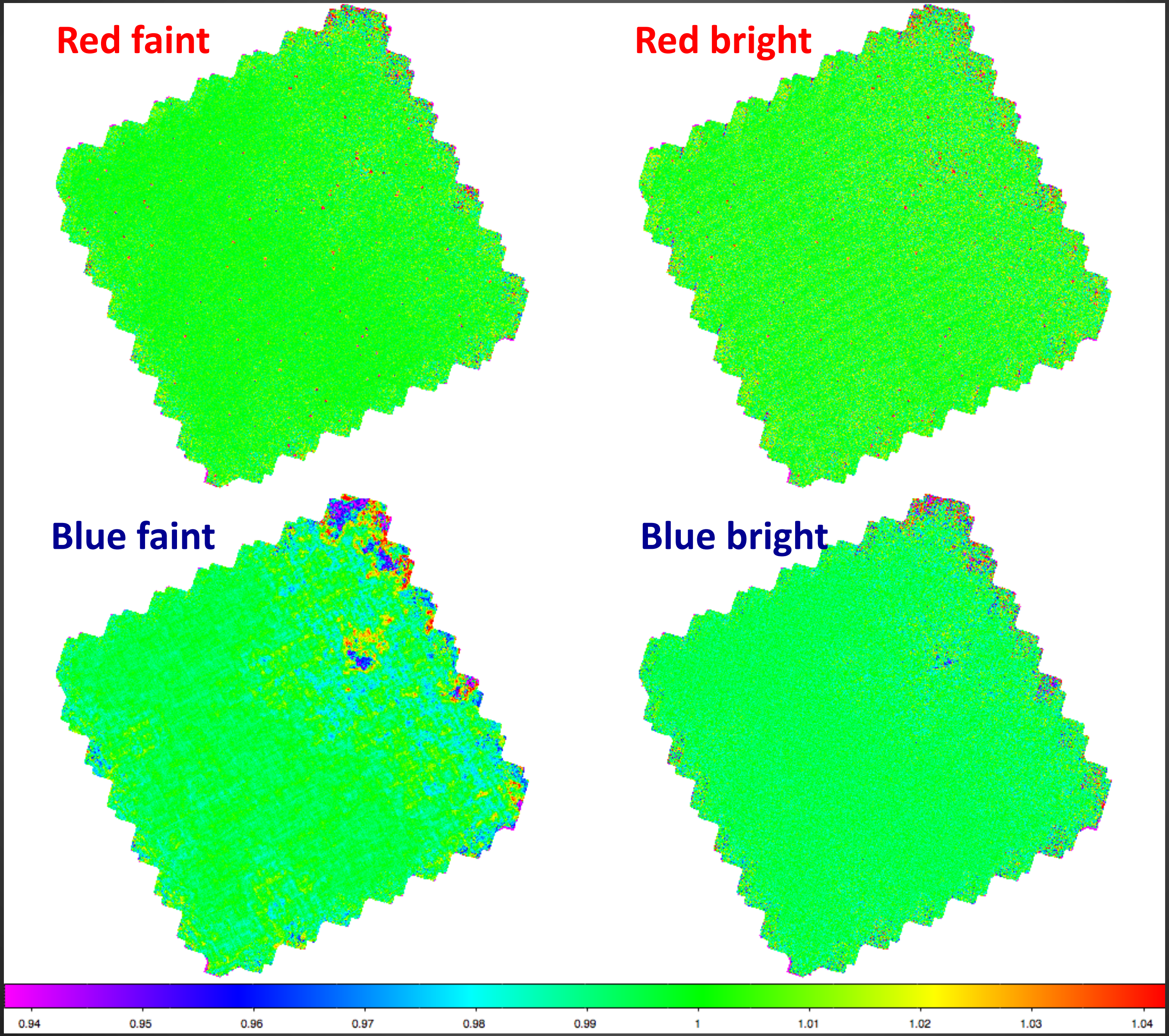
Reprojected truth map / input sky map

Blue faint	Blue bright	Red faint	Red bright
0.9911	0.9923	0.9932	0.9954

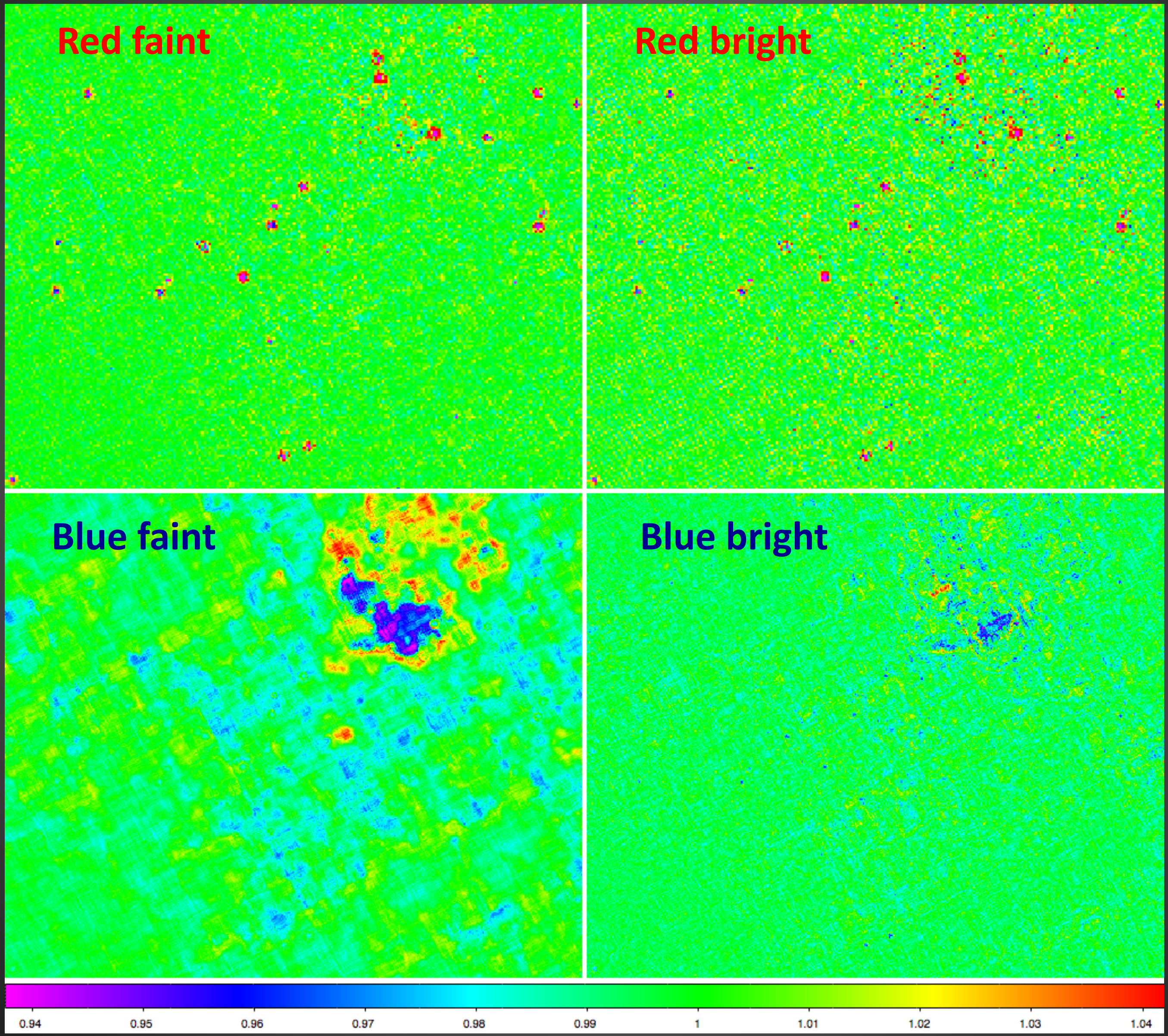
Flux conservation: reprojected vs. regridded



Flux conservation: reprojected/regridded

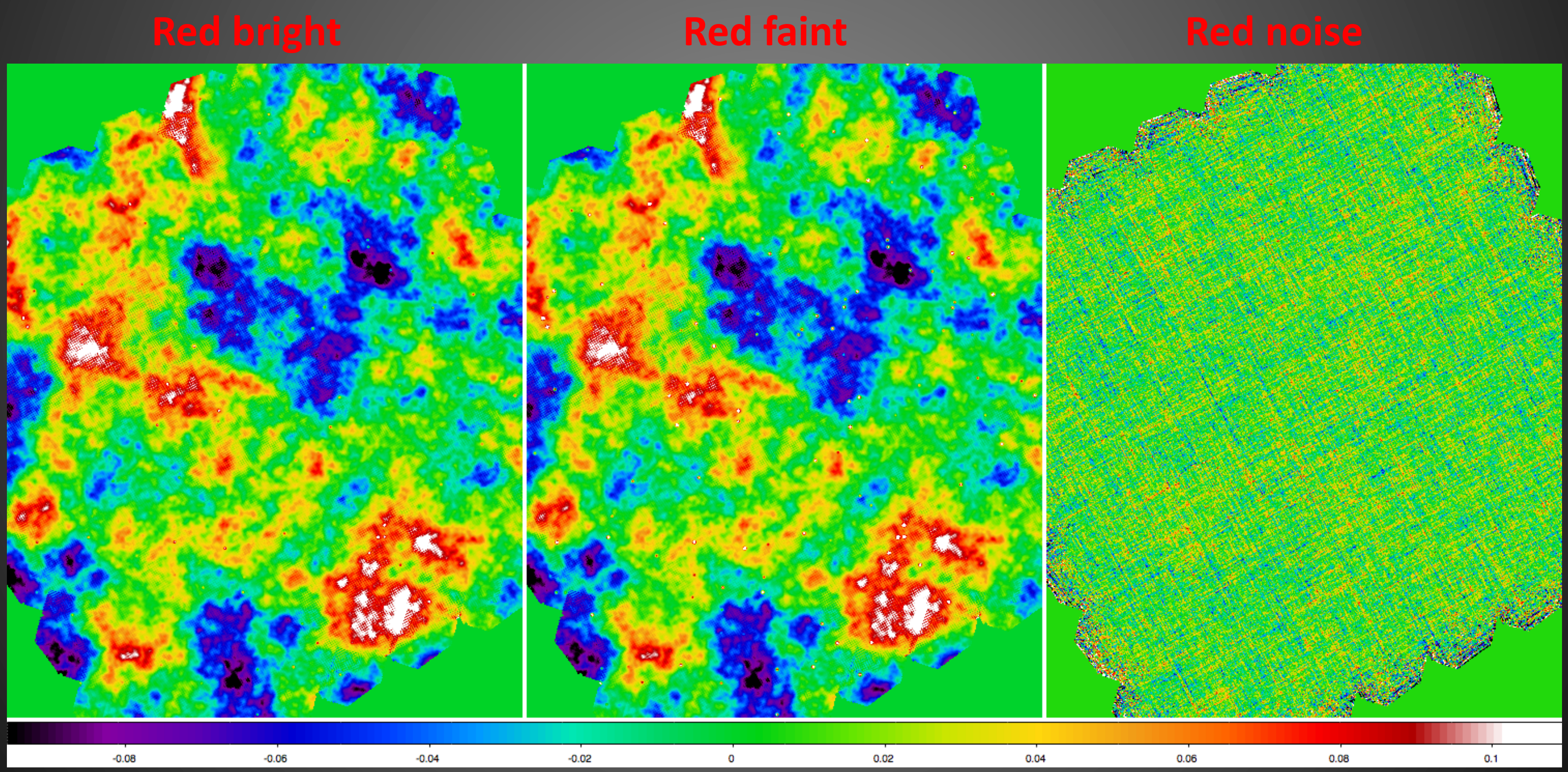


Flux conservation: reprojected/regridded



Signal-to-noise on the reprojected maps

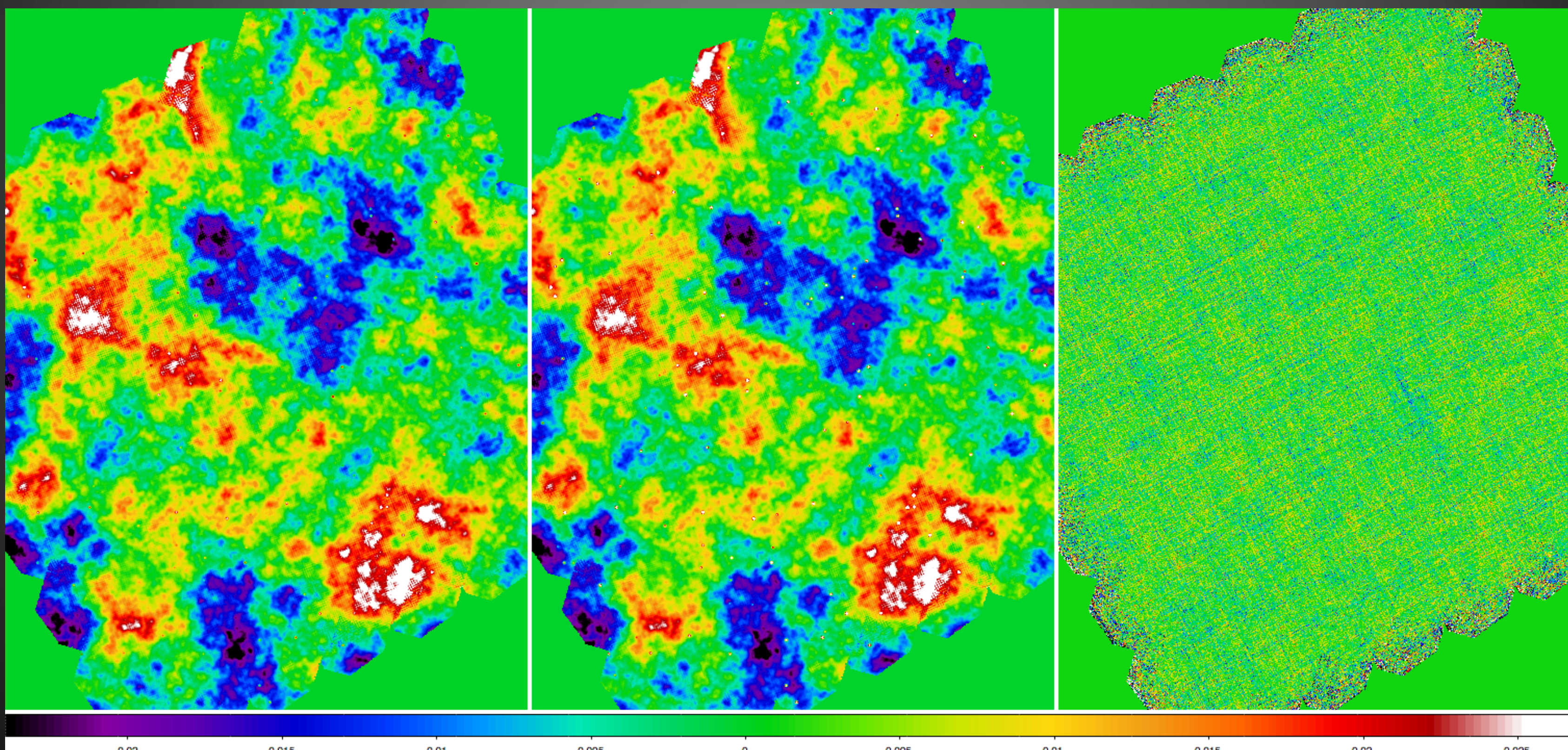
Broad HPF filter applied and naïve re-projected



Signal-to-noise on the reprojected maps

Broad HPF filter applied and naïve re-projected

Blue bright **Blue faint** **Blue noise**



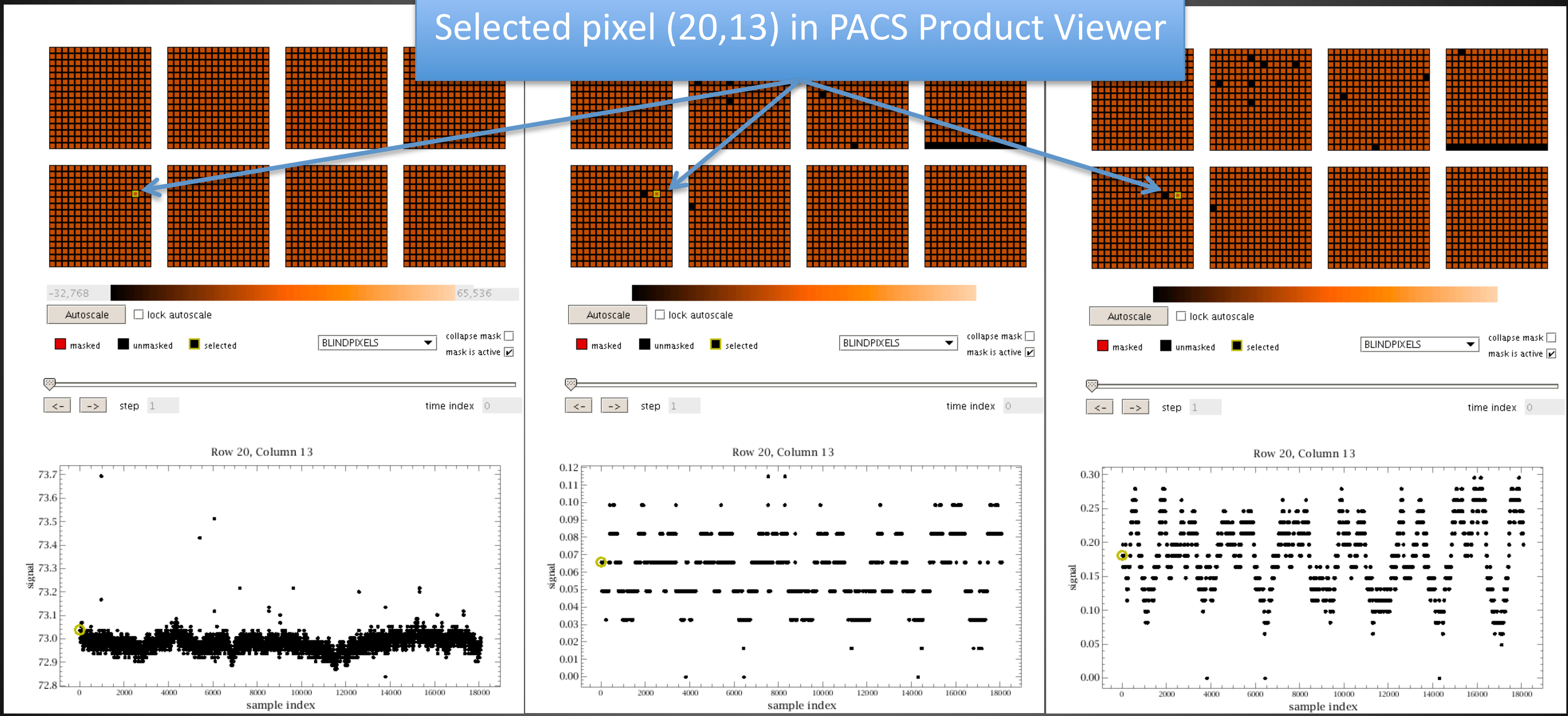
Limitations of v3.0

- Pointing effects are not simulated (i.e. infinite accuracy attitude is being considered)
- No detector effects (finite time constant, transients)
- No lossy compression (on-board frame averaging)
- No real beam profile (the standard aperture correction factor does not apply and point-source response is slightly affected)
- Simple approach to digitization

Blue channel (green filter) noise-free naïve projection: the digitization effect (faint case)

Blue channel (green filter) timeline comparison

Selected pixel (20,13) in PACS Product Viewer



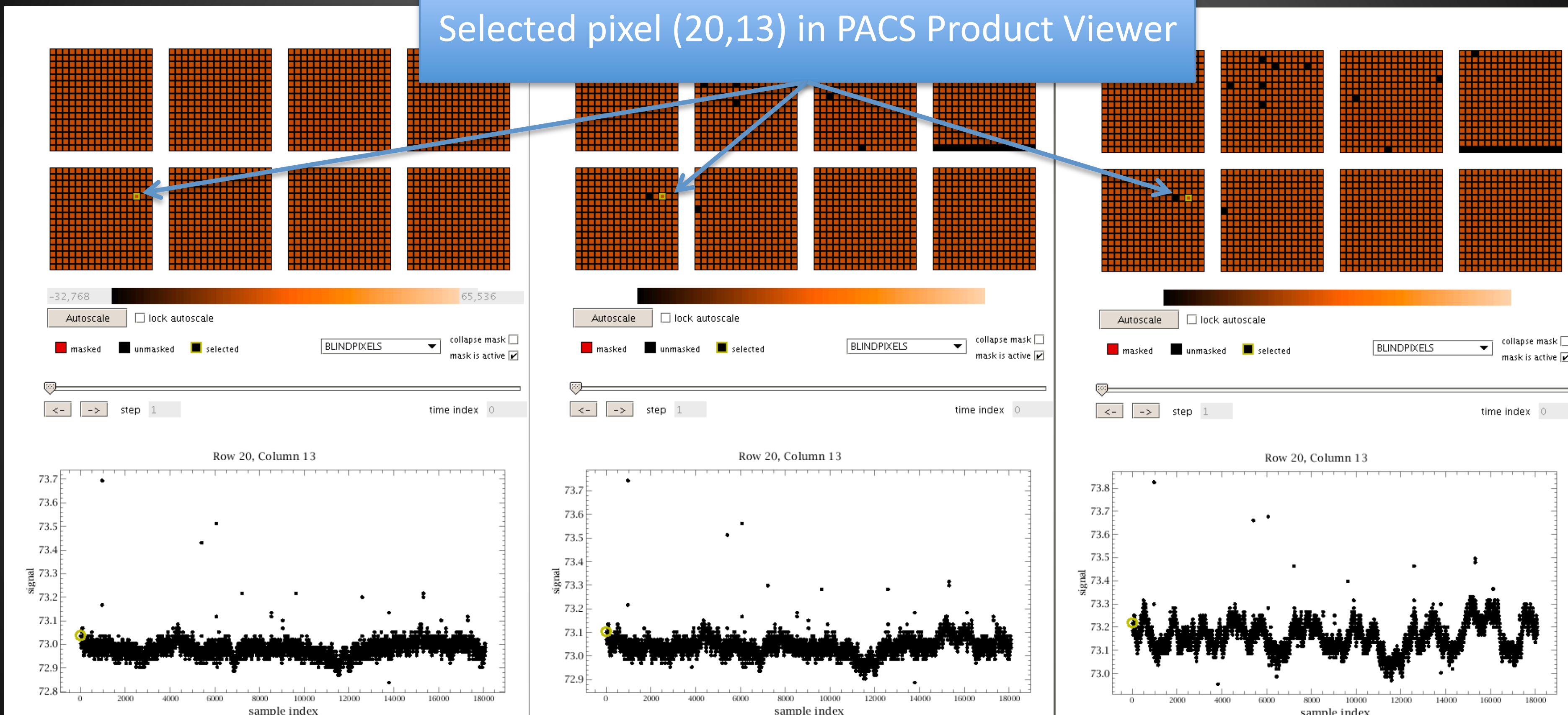
Instrument noise only

faint sky

bright sky

Blue channel (green filter) timeline comparison

Selected pixel (20,13) in PACS Product Viewer



Instrument noise only

Instrument noise + faint sky

Instrument noise + bright sky

Quantization noise in the simulations

- Only a small portion of the PACS dynamic range is used by the sky signal
- The low-frequency drift has to be accommodated in the dynamic range even if the observation samples only the higher-frequency domain (i.e. short observation). The drift appears as a flat-field variation in this case.
- The digitization step on the flux calibrated timeline is ~18 mJy (blue). Is this compliant with the nominal SPU bit rounding?
- Faint sources are strongly affected by digitization noise, the point-source response is a complex term affected by source flux, the beam profile, redundancy… to be investigated

Digitization in the code:

- D(F1) = D(noise) + D(sky) — This is the current solution
- D(F2) = D(D(noise) + R[-q/2;+q/2] + sky) — To be implemented (suggested by R. Ottensamer)
- $\sigma(F1) \approx> \sigma(F2)$

Conclusions and perspectives

- A PACS scan-observation hybrid timeline simulator is available in Jython
- To be implemented in HIPE as a plug-in
- Map-makers can deal with its output L1 frames product
- MMT and 2nd order glitch masks are provided (no false positives!)
- Further iterations are needed, especially on the digitization part and adding the measured beam profiles
- Besides the map-making benchmarking it can be used for extended-emission analysis studies (i.e. instrumental and map-maker footprint on spatial power spectrum)