Imaging the spatial, spectral, and temporal sky via information field theory

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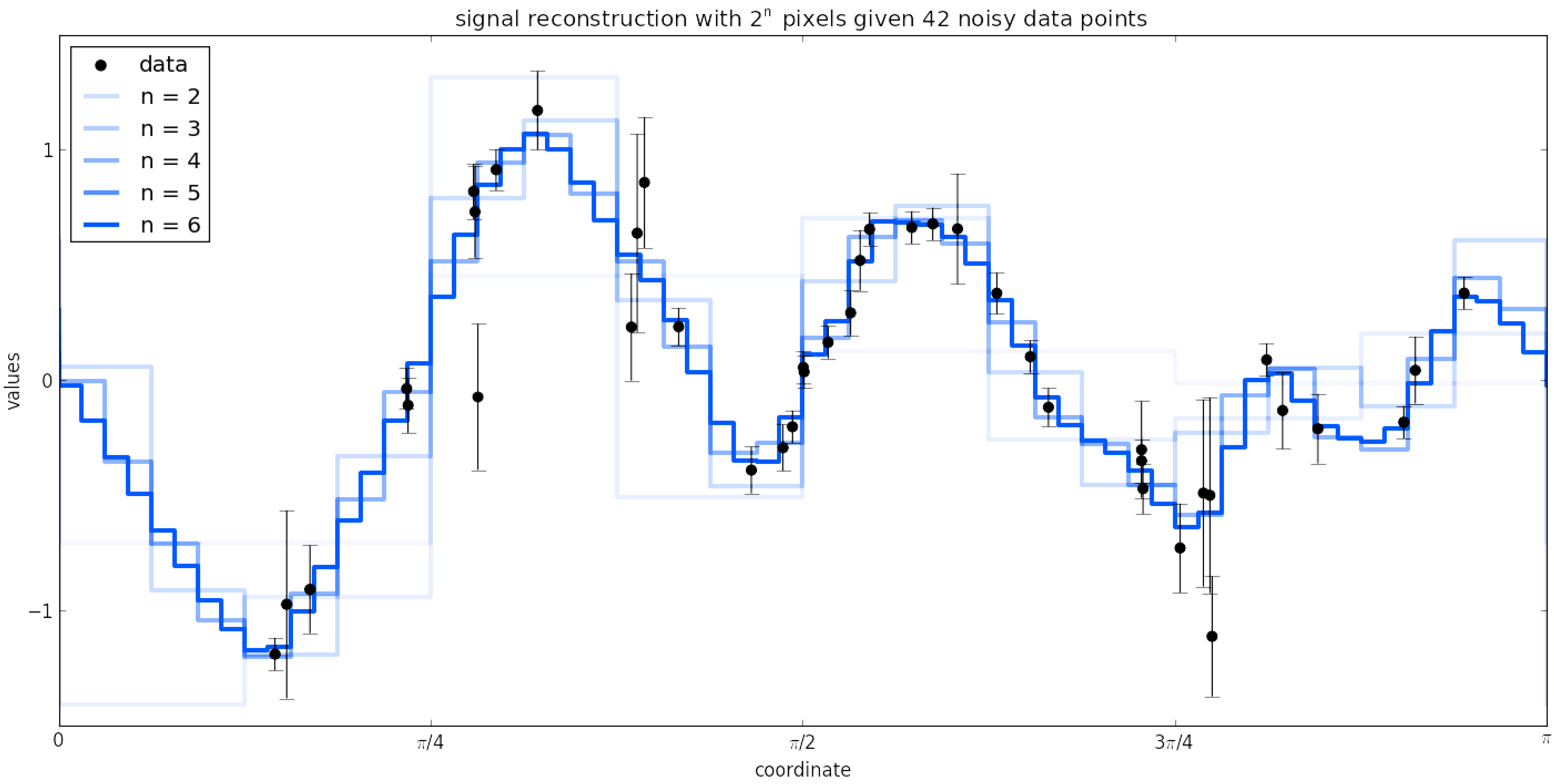
Information Field Theory

$s =$ signal

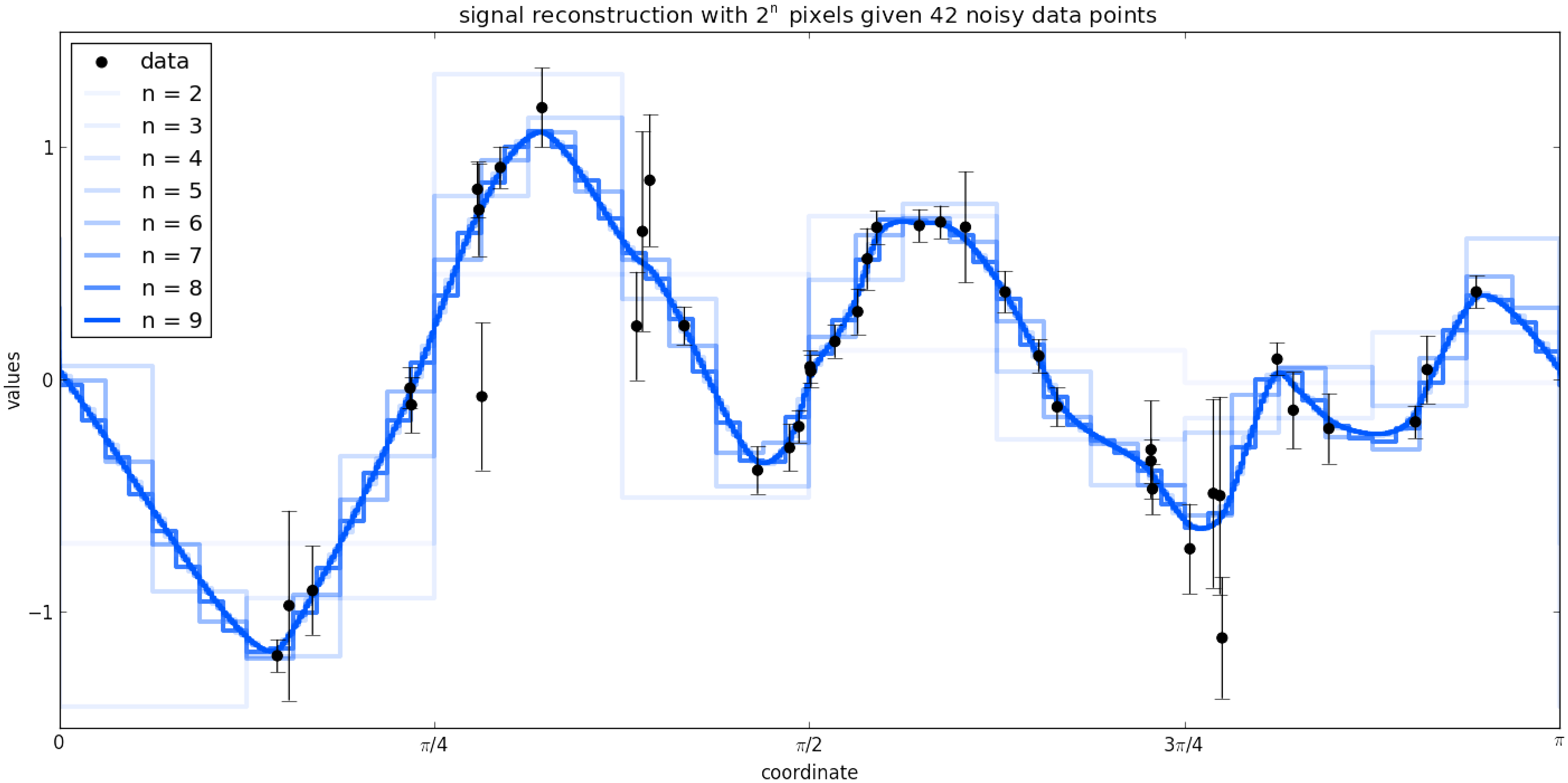
$d =$ data

$$\mathcal{P}(s|d) = \frac{\mathcal{P}(d|s)\,\mathcal{P}(s)}{\mathcal{P}(d)} = \frac{1}{Z(d)}\,e^{-H(d,s)}$$

$$\begin{aligned} H(d,s) &= -\log \mathcal{P}(d,s) \\ Z(d) &= \int \mathcal{D}s\,\mathcal{P}(d,s) \end{aligned}$$



signal reconstruction with 2^n pixels given 42 noisy data points
data
n = 2
n = 3
n = 4
n = 5
n = 6
1
0
−1
values
0
π/4
π/2
3π/4
π
coordinate

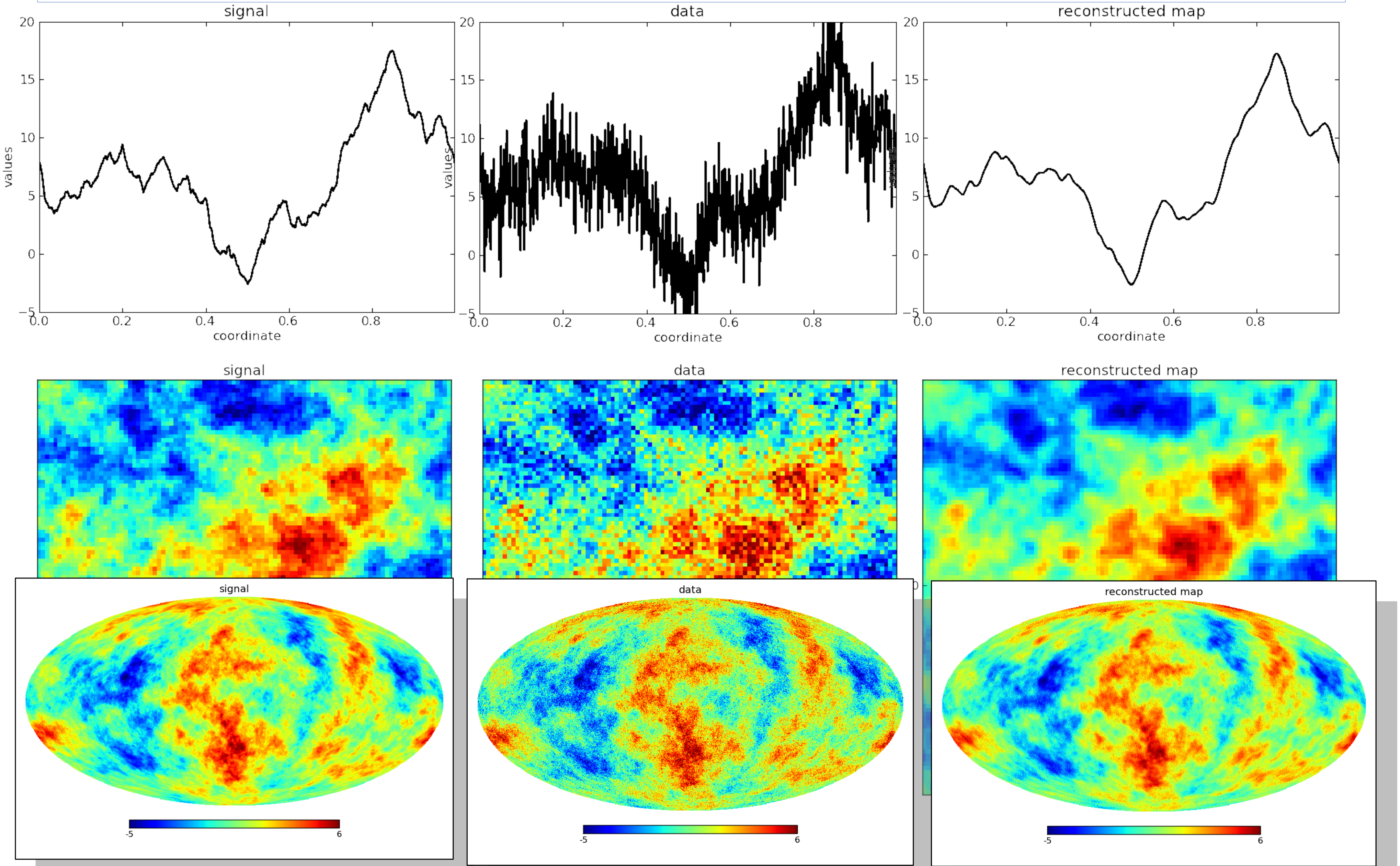


signal reconstruction with 2^n pixels given 42 noisy data points
data
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7
n = 8
n = 9
values
1
0
−1
0
π/4
π/2
3π/4
π
coordinate

NIFTY - Numerical Information Field Theory

Selig et al. (2013), Steininger et al. (sub.)

Code @ https://gitlab.mpcdf.mpg.de/ift/NIFTy



Denoising, Deconvolving, and Decomposing Photon Observations

Selig et al. (2014)
www.mpa-garching.mpg.de/ift/d3po

D^3PO

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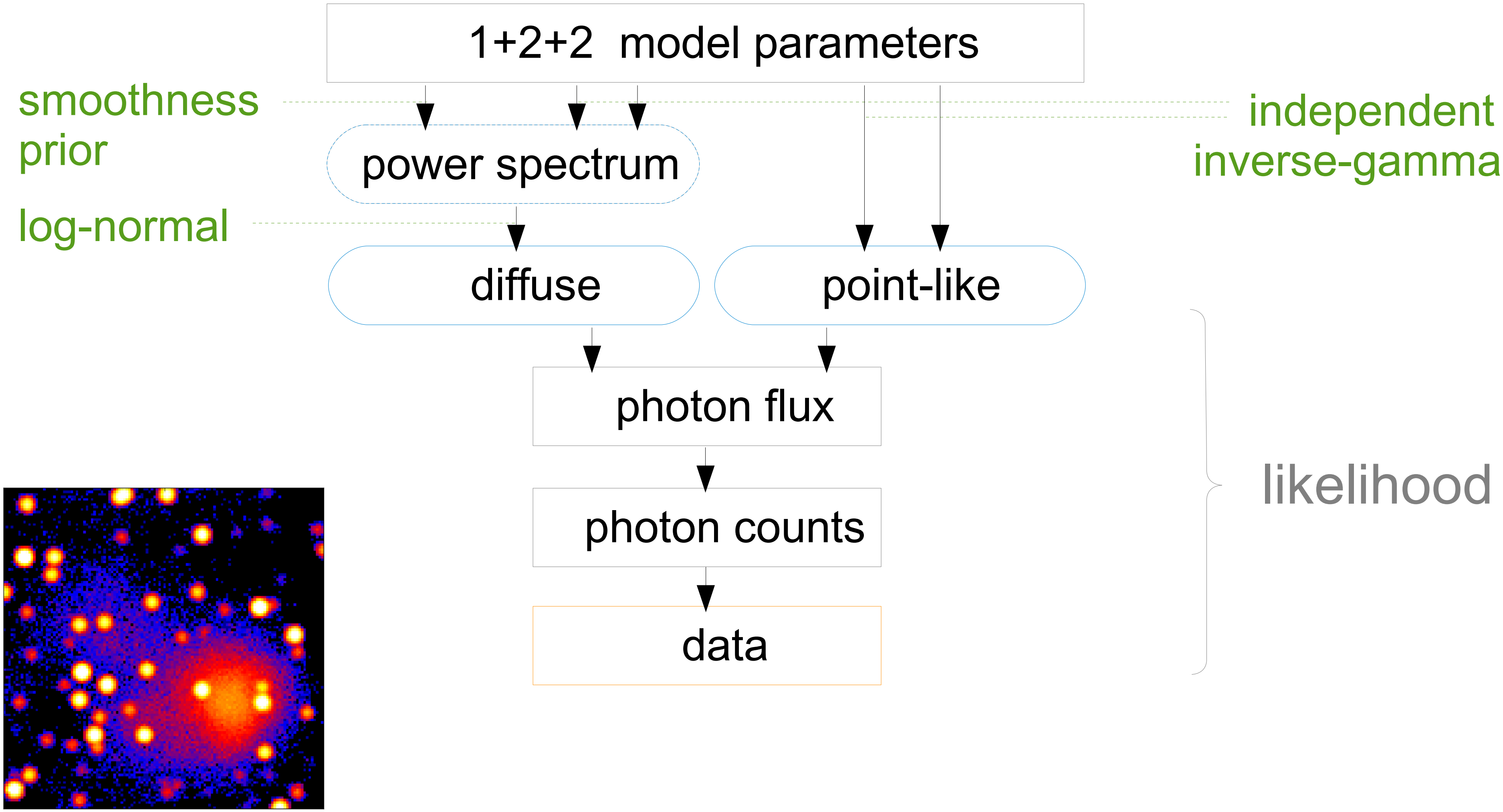
D³PO – challenges & assumptions

Selig & Enßlin (2014)
arXiv: 1311.1888



D³PO – challenges & assumptions

Selig & Enßlin
(2014)
arXiv: 1311.1888

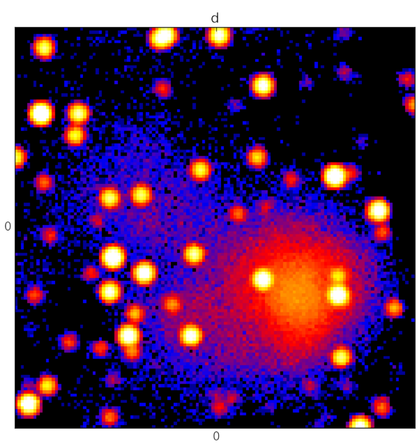
$$\mathcal{H}(\boldsymbol{s}, \boldsymbol{\tau}, \boldsymbol{u}|\boldsymbol{d}) = -\log \mathcal{P}(\boldsymbol{s}, \boldsymbol{\tau}, \boldsymbol{u}|\boldsymbol{d})$$

$$= H_0 + \mathbf{1}^\dagger \boldsymbol{R}\left(\mathrm{e}^{\boldsymbol{s}} + \mathrm{e}^{\boldsymbol{u}}\right) - \boldsymbol{d}^\dagger \log\left(\boldsymbol{R}\left(\mathrm{e}^{\boldsymbol{s}} + \mathrm{e}^{\boldsymbol{u}}\right)\right)$$

$$+ \frac{1}{2}\log\left(\det\left[\boldsymbol{S}\right]\right) + \frac{1}{2}\boldsymbol{s}^\dagger \boldsymbol{S}^{-1}\boldsymbol{s}$$

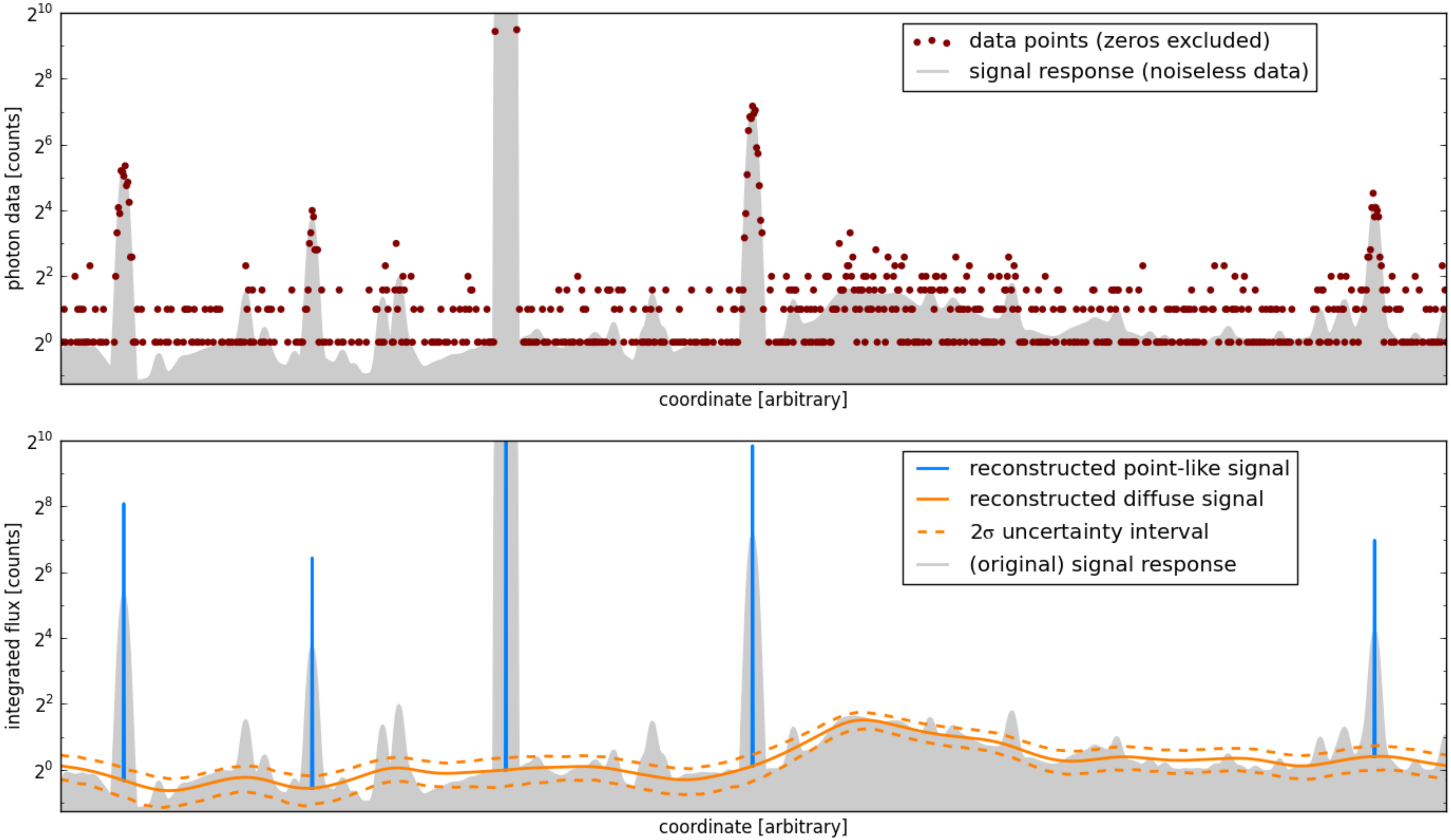
$$+ (\boldsymbol{\alpha} - \mathbf{1})^\dagger \boldsymbol{\tau} + \boldsymbol{q}^\dagger \mathrm{e}^{-\boldsymbol{\tau}} + \frac{1}{2}\boldsymbol{\tau}^\dagger \boldsymbol{T}\boldsymbol{\tau}$$

$$+ (\boldsymbol{\beta} - \mathbf{1})^\dagger \boldsymbol{u} + \boldsymbol{\eta}^\dagger \mathrm{e}^{-\boldsymbol{u}}$$



$$\boldsymbol{S} = \sum_k \mathrm{e}^{\tau_k} \boldsymbol{S}_k$$

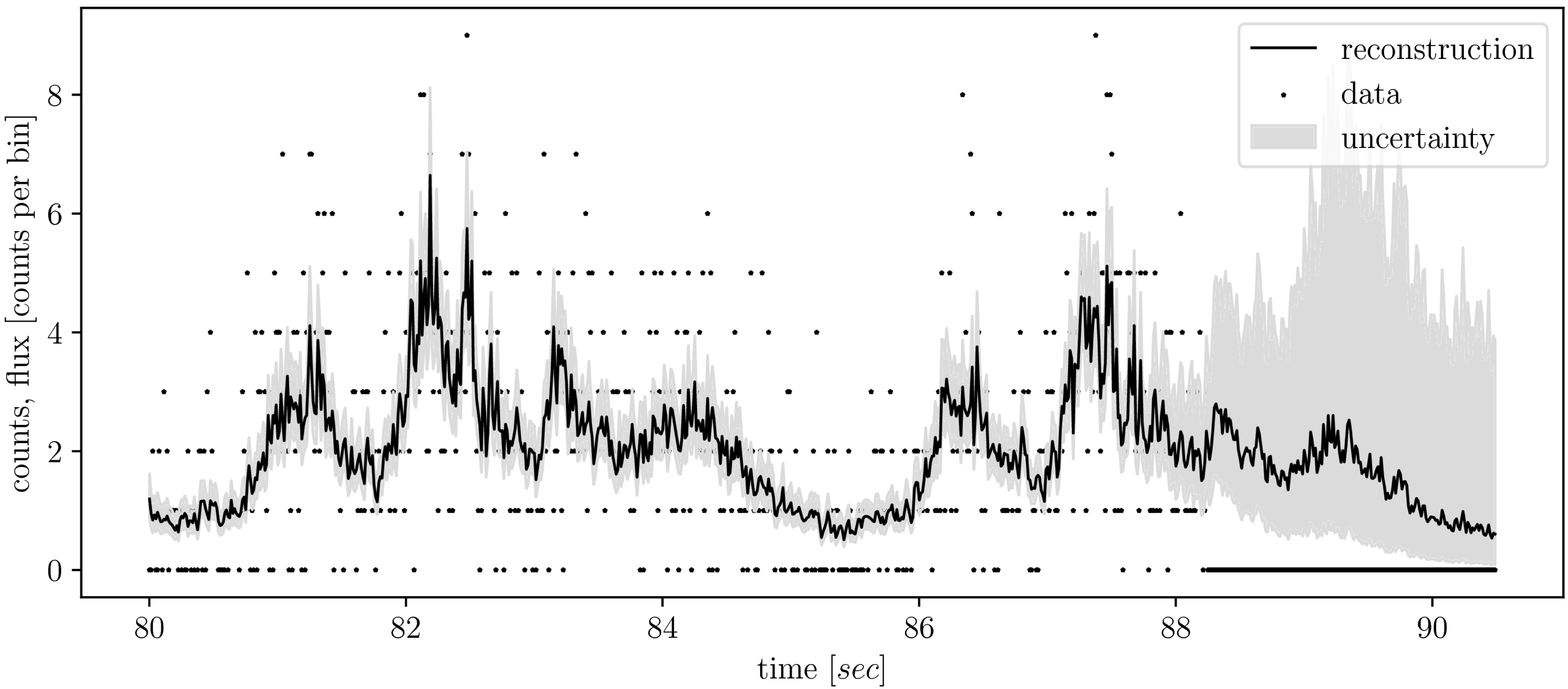
D³PO – 1D scenario



D³PO in 1D & QPOs

Magnetar flare SGR 1900+14

Pumpe et al. arXiv:1708.05702



D³PO in 1D & QPOs

Magnetar flare SGR 1900+14

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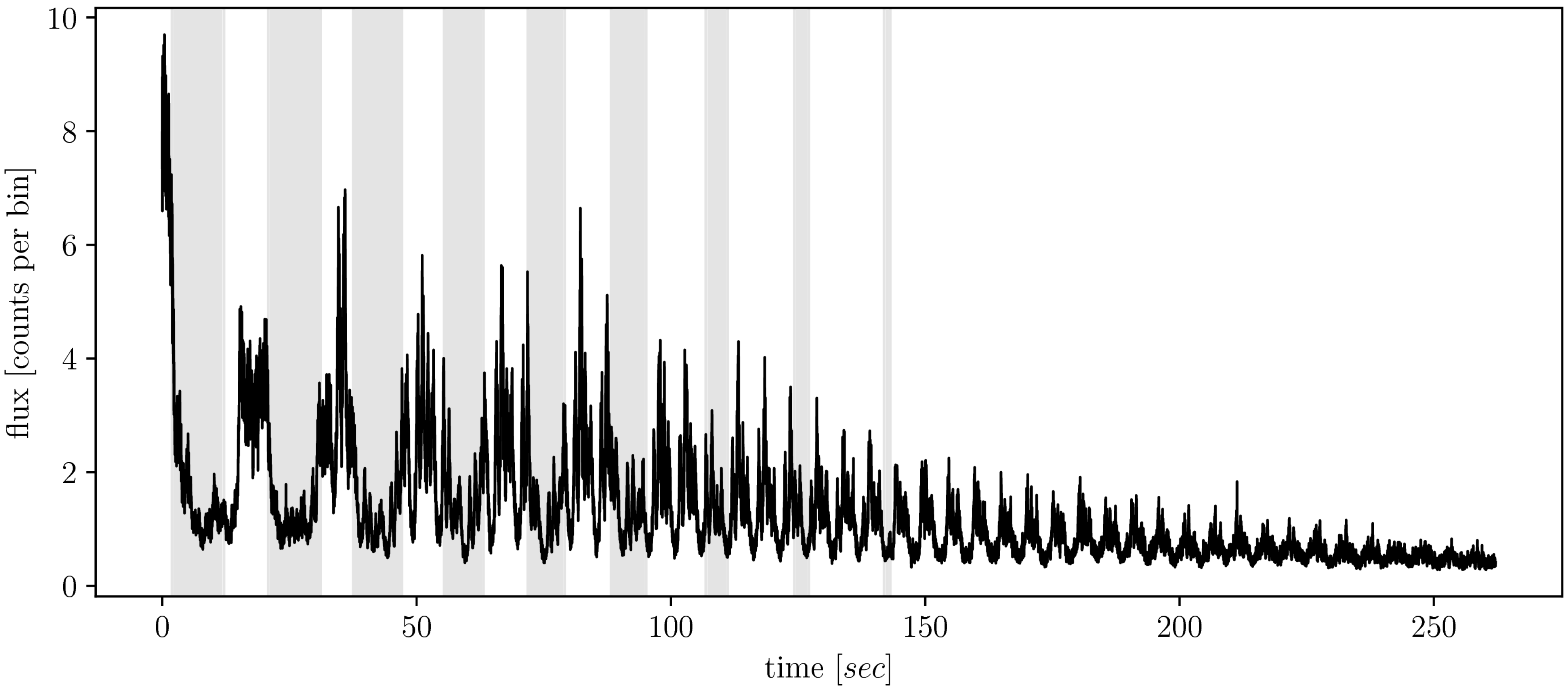
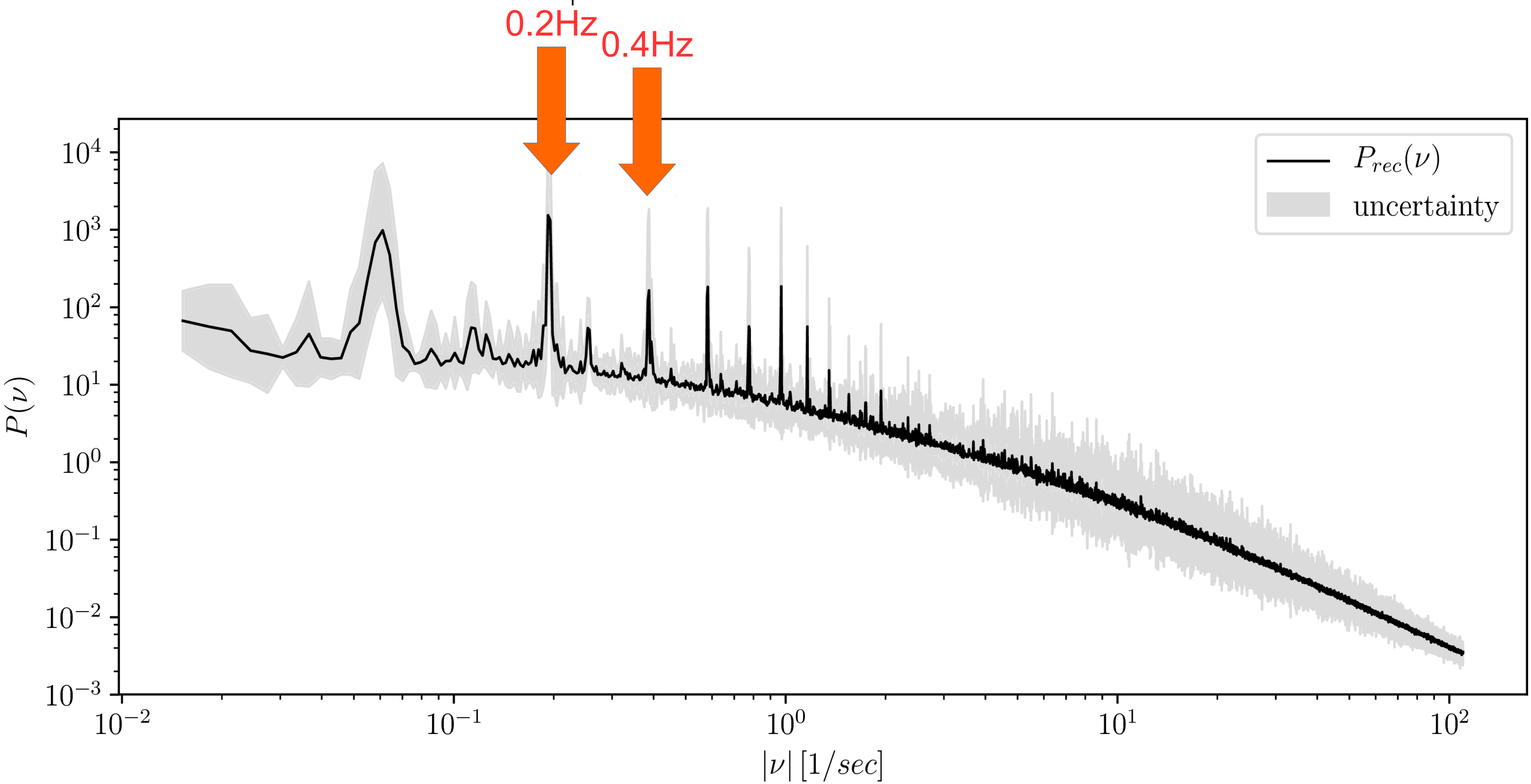


D³PO in 1D & QPOs

Magnetar flare SGR 1900+14

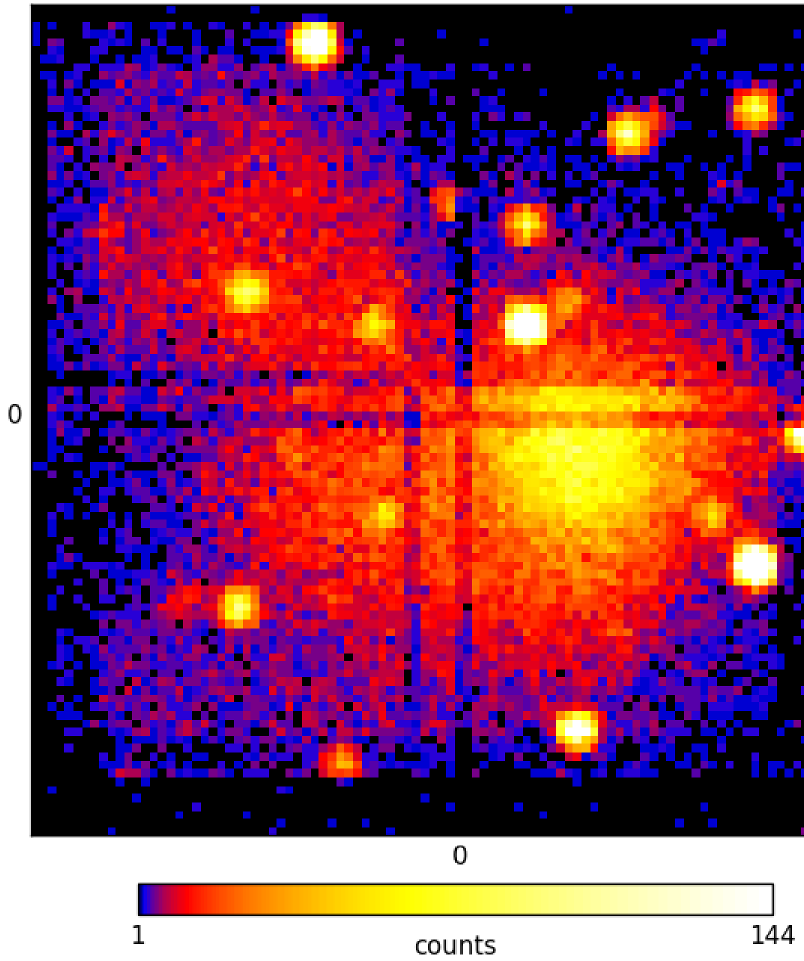
Pumpe et al. arXiv:1708.05702



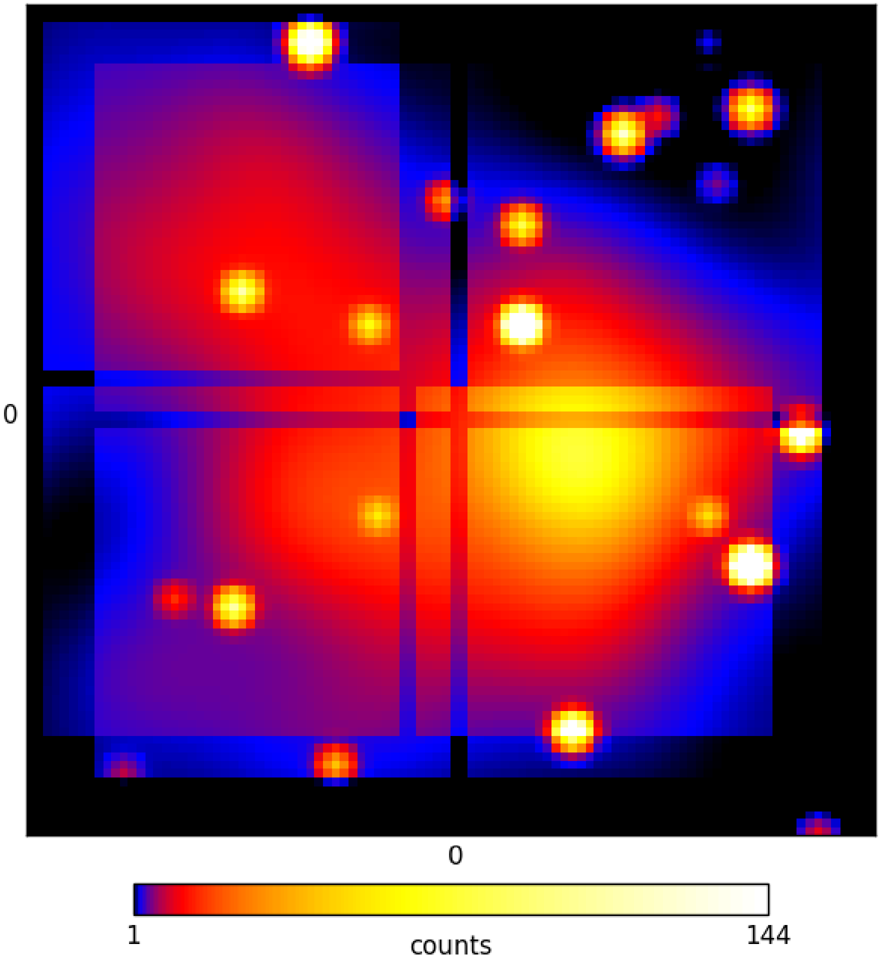
D3PO a guided demo

D1PO

raw input data

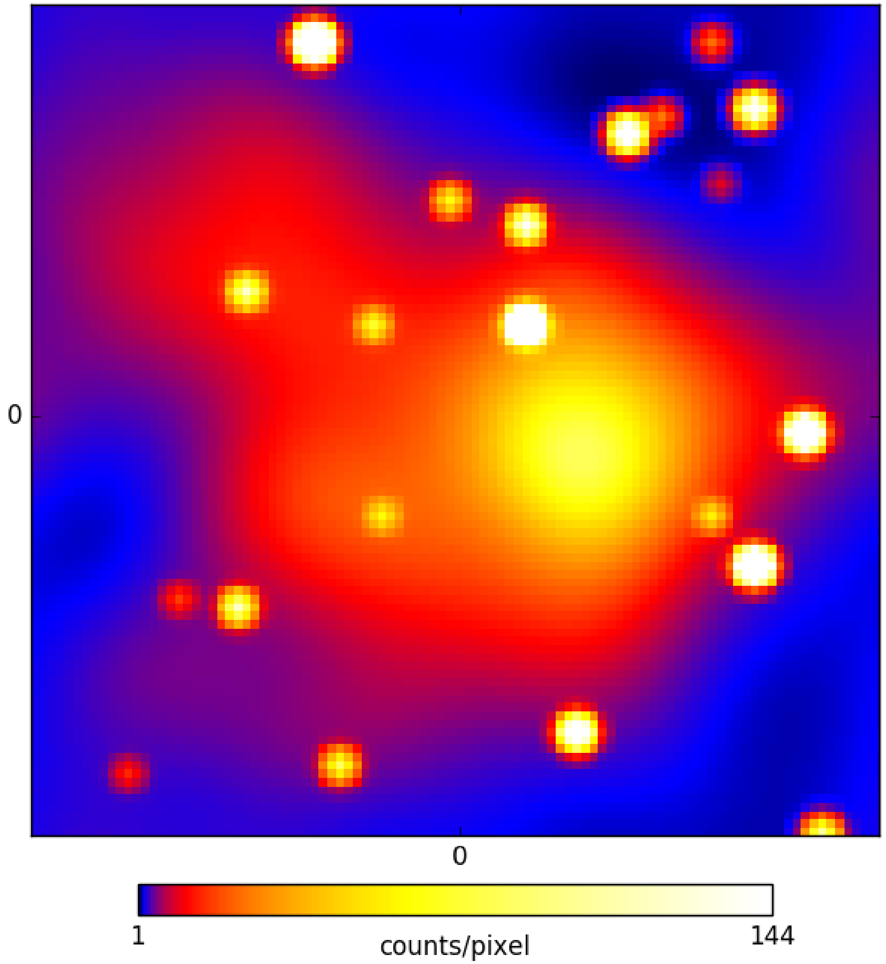


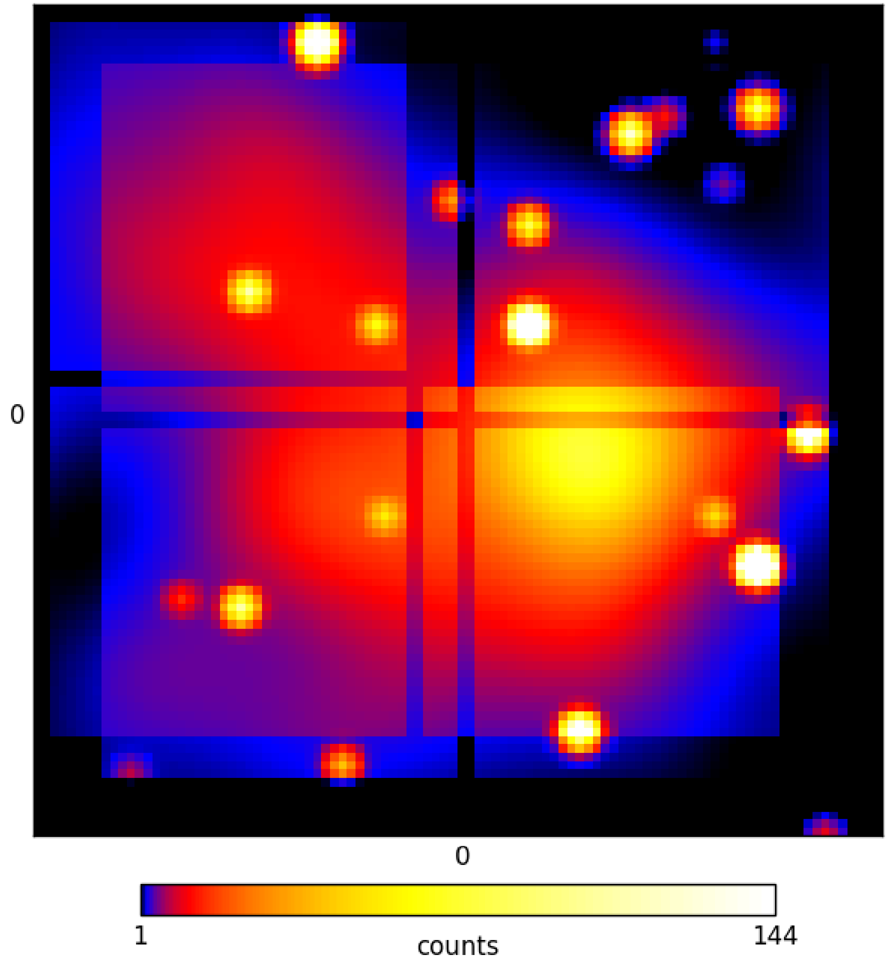
denoised observations



D3PO a guided demo

D2PO

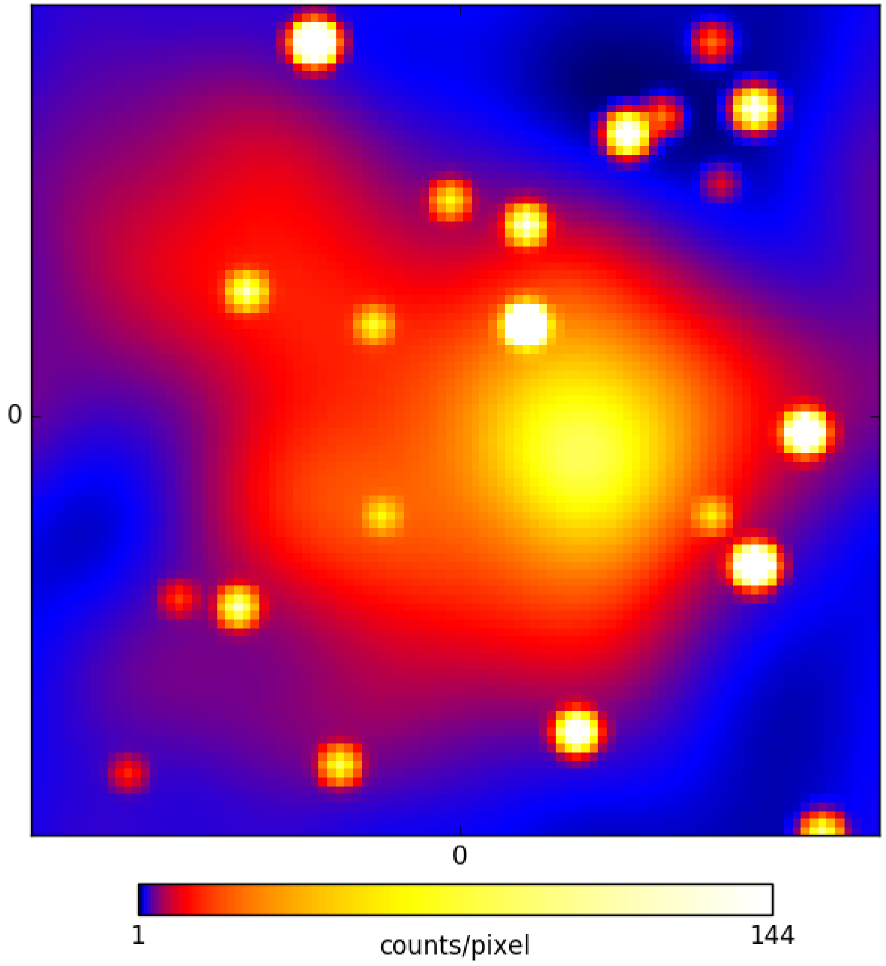




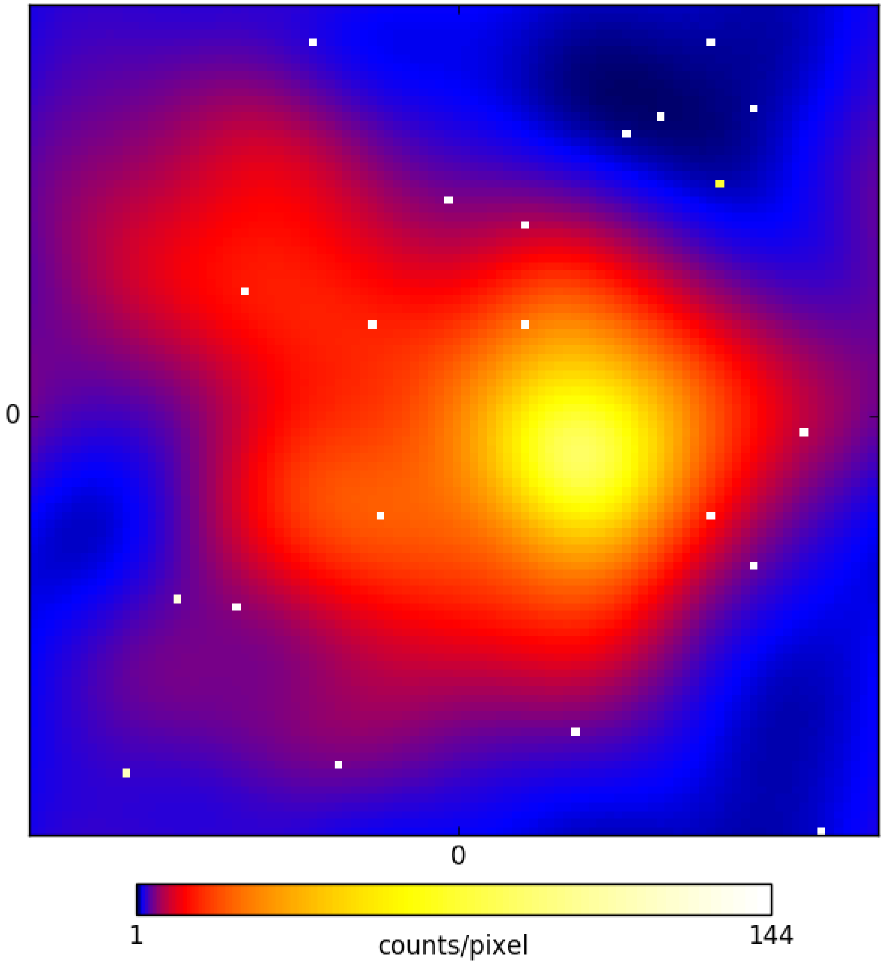
D3PO a guided demo

D2PO

demasked flux



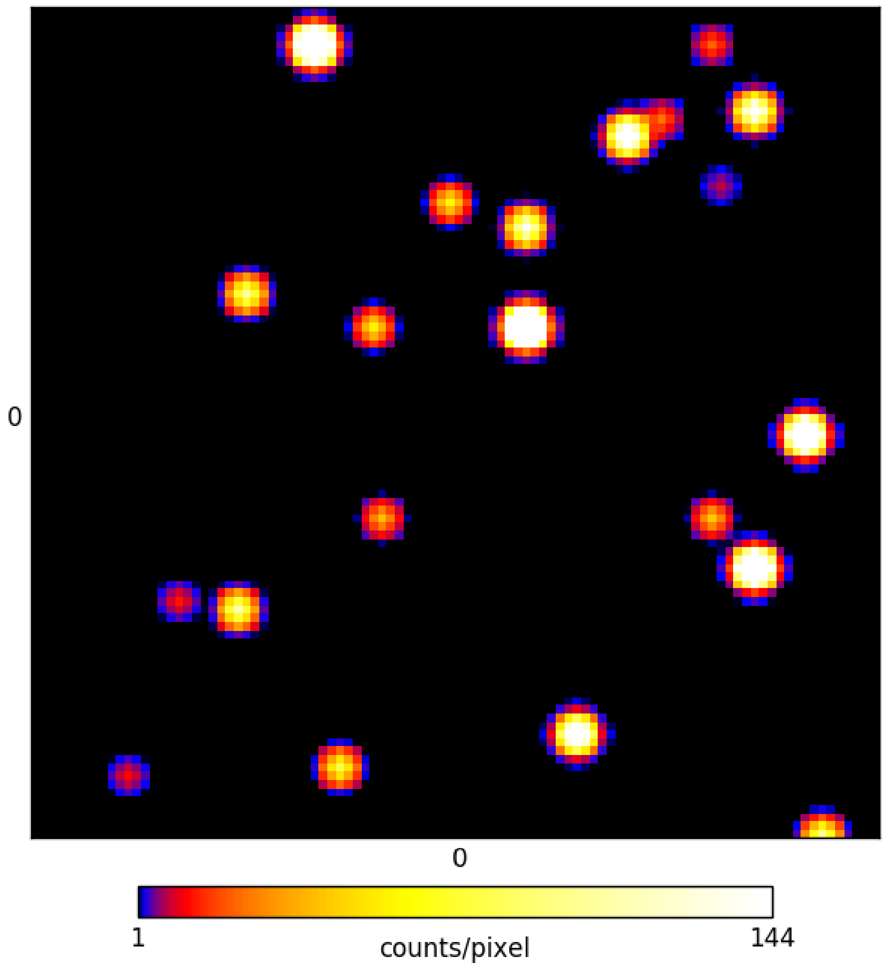
deconvolved flux



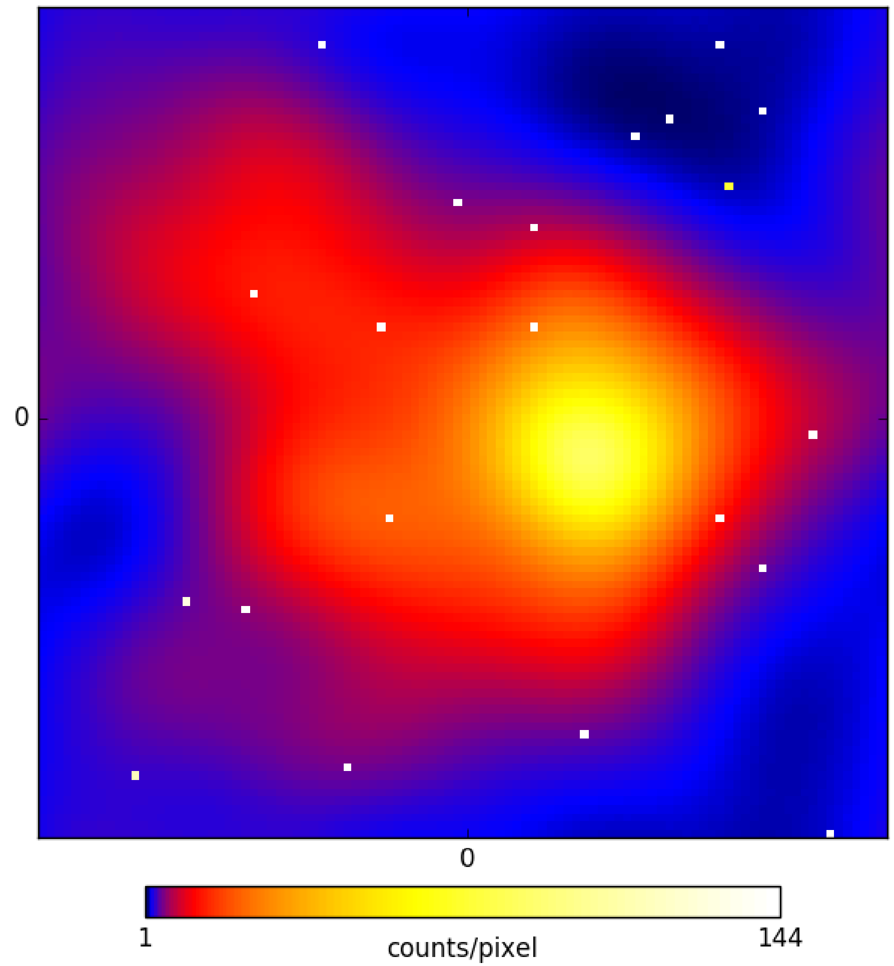
D3PO a guided demo

D2PO

reconvolved point sources

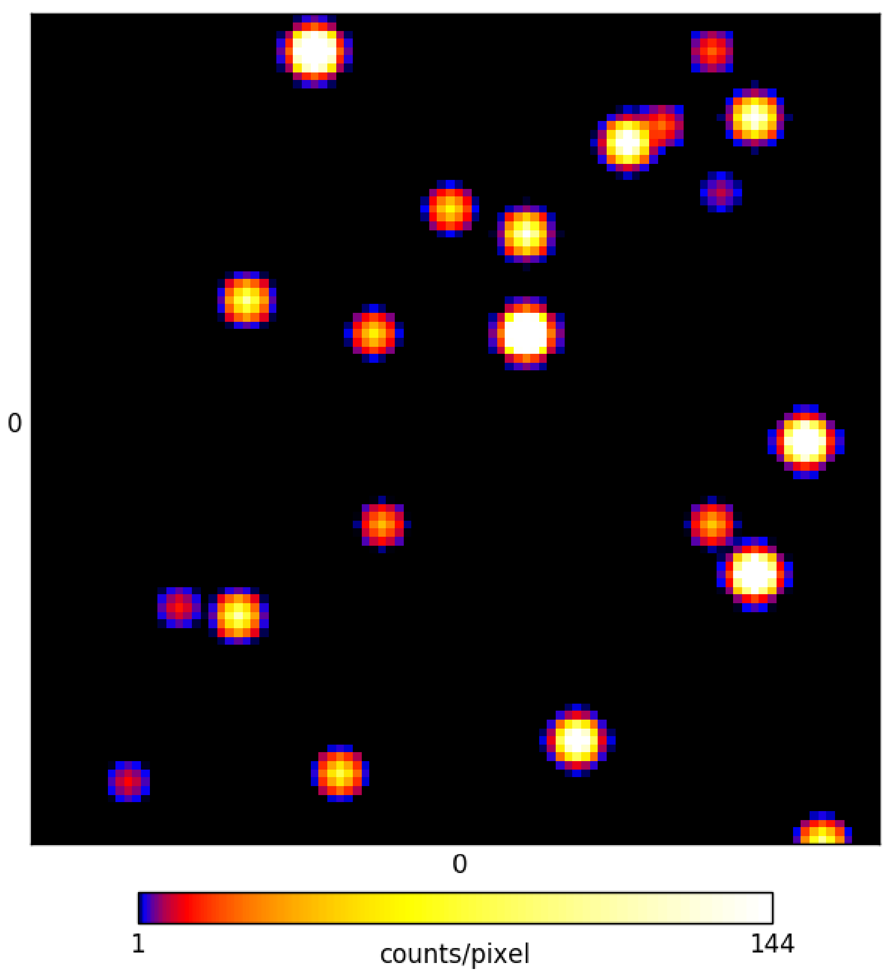


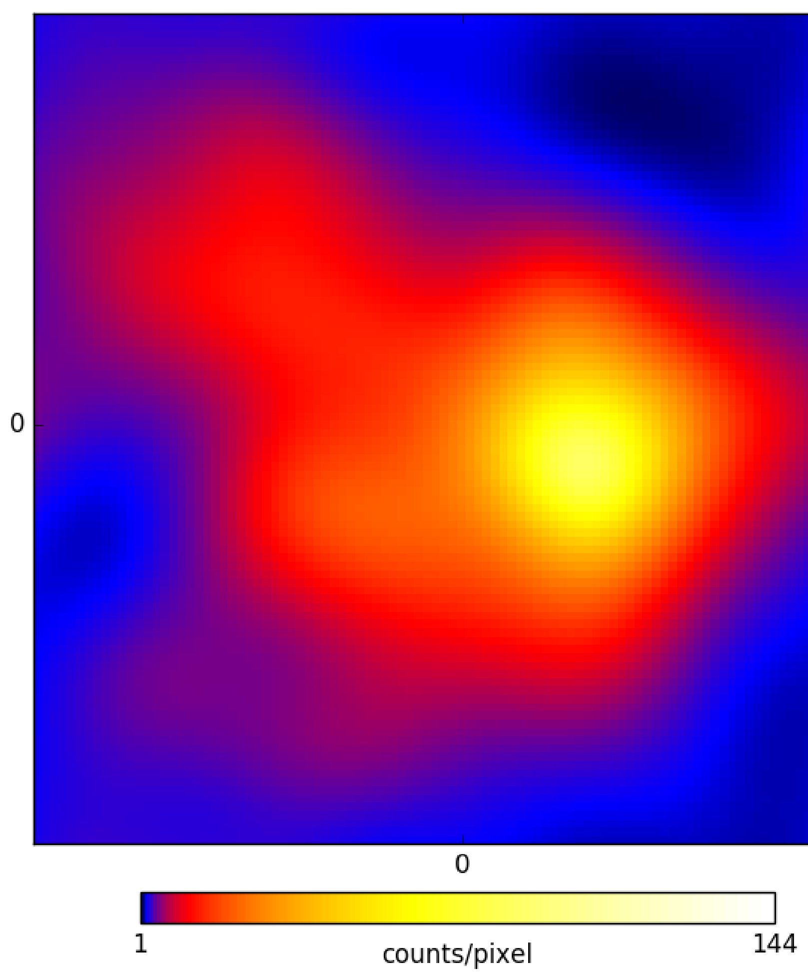
deconvolved flux

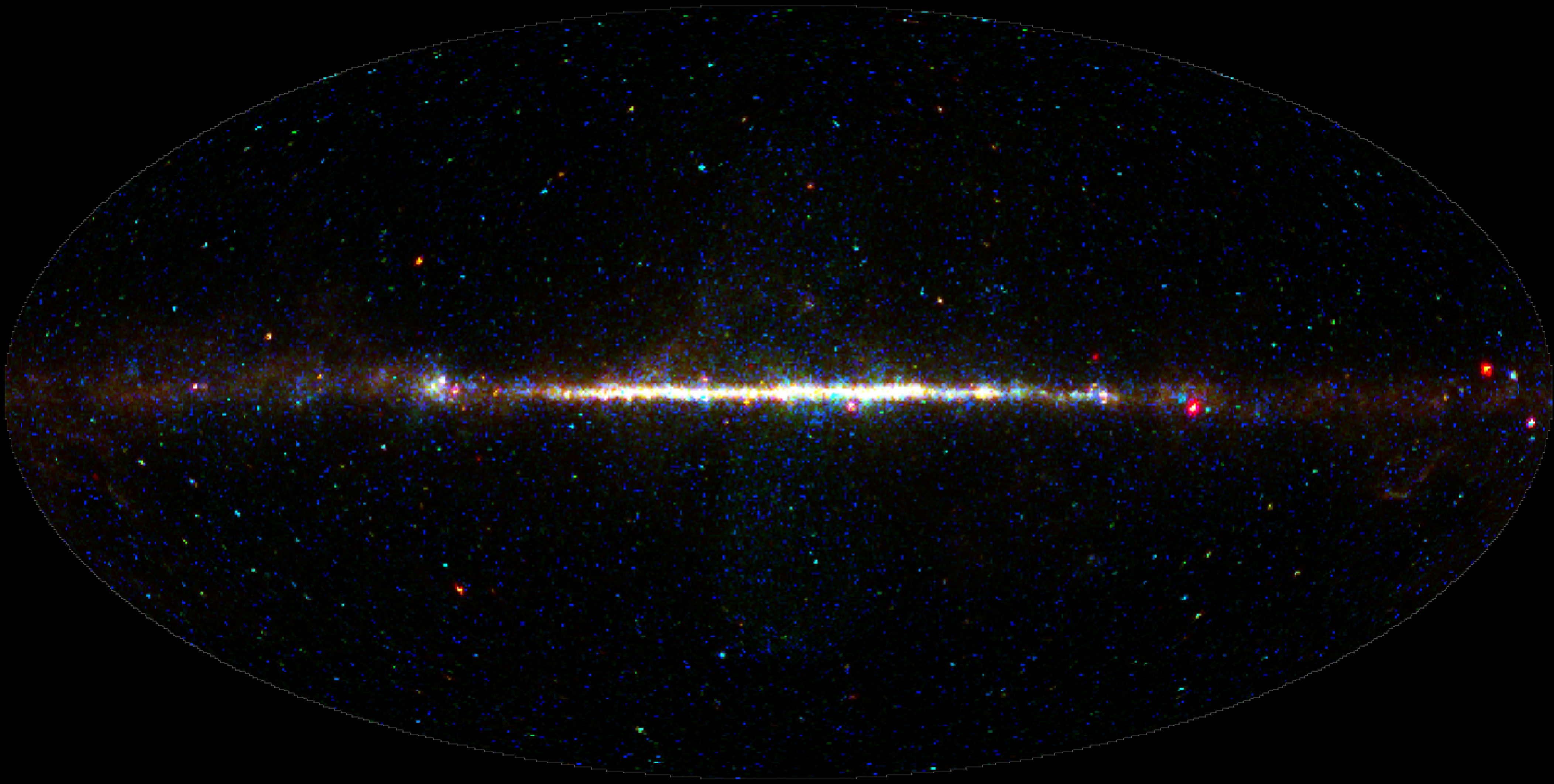


D3PO a guided demo

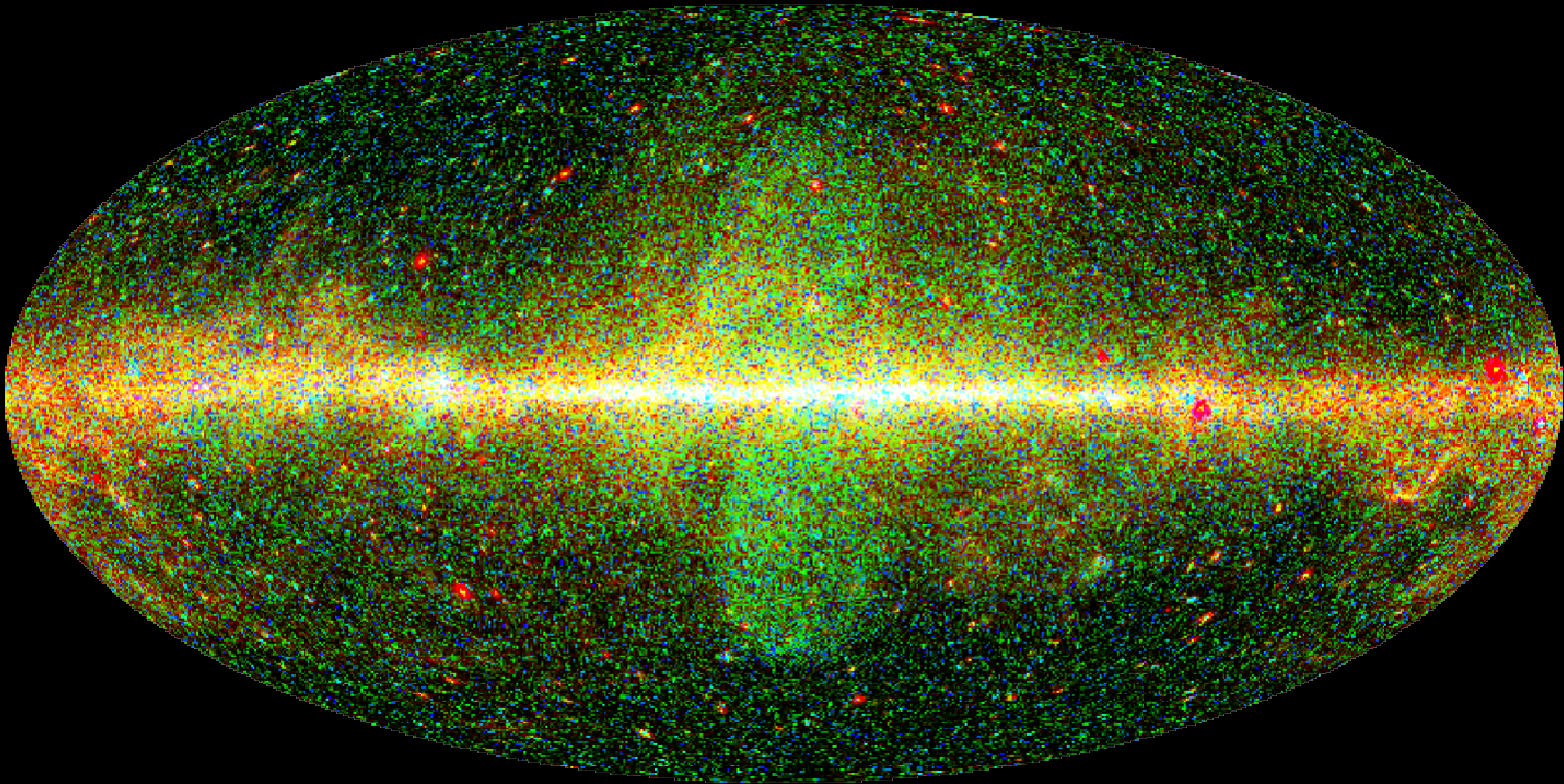
D3PO



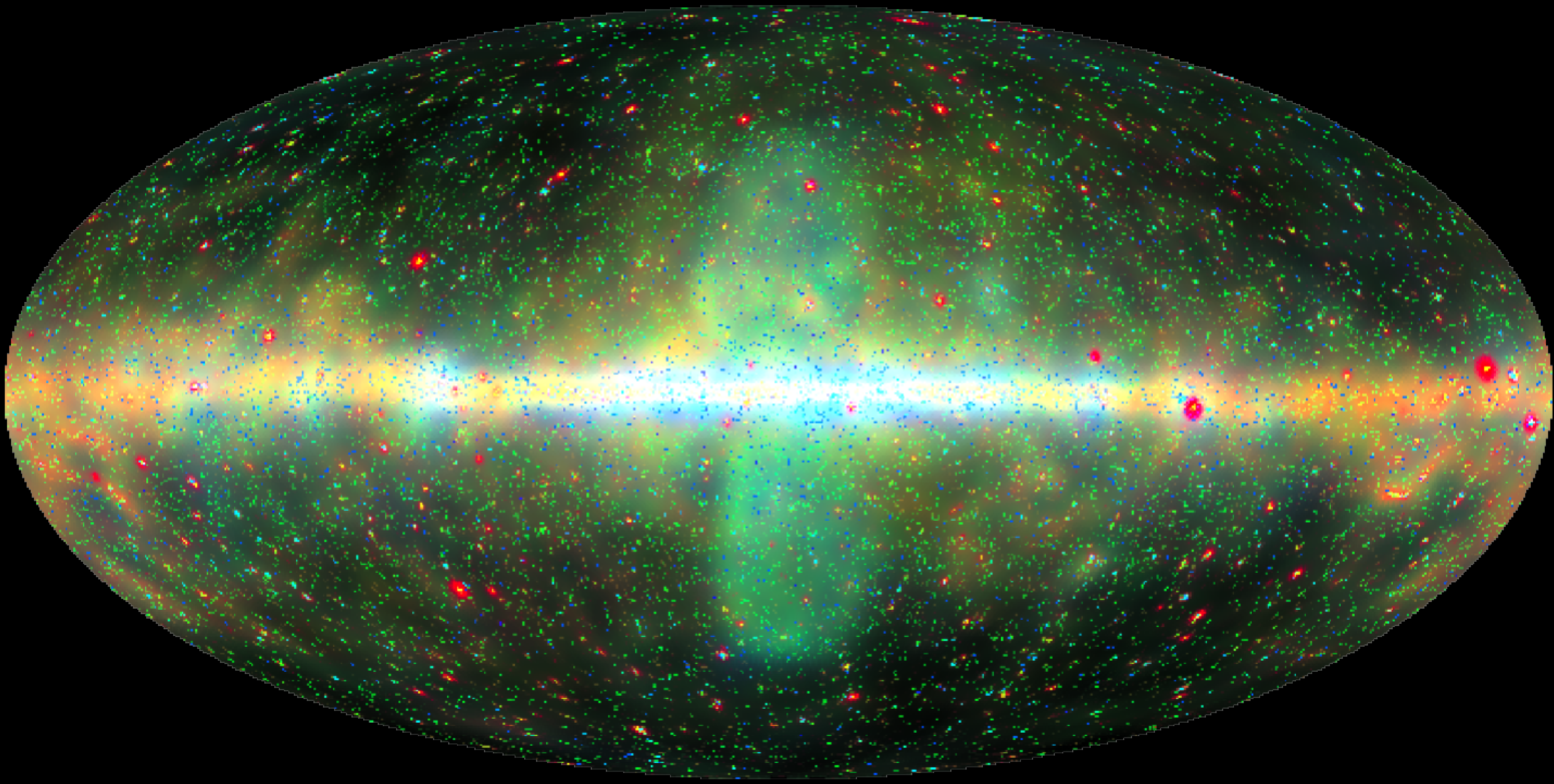




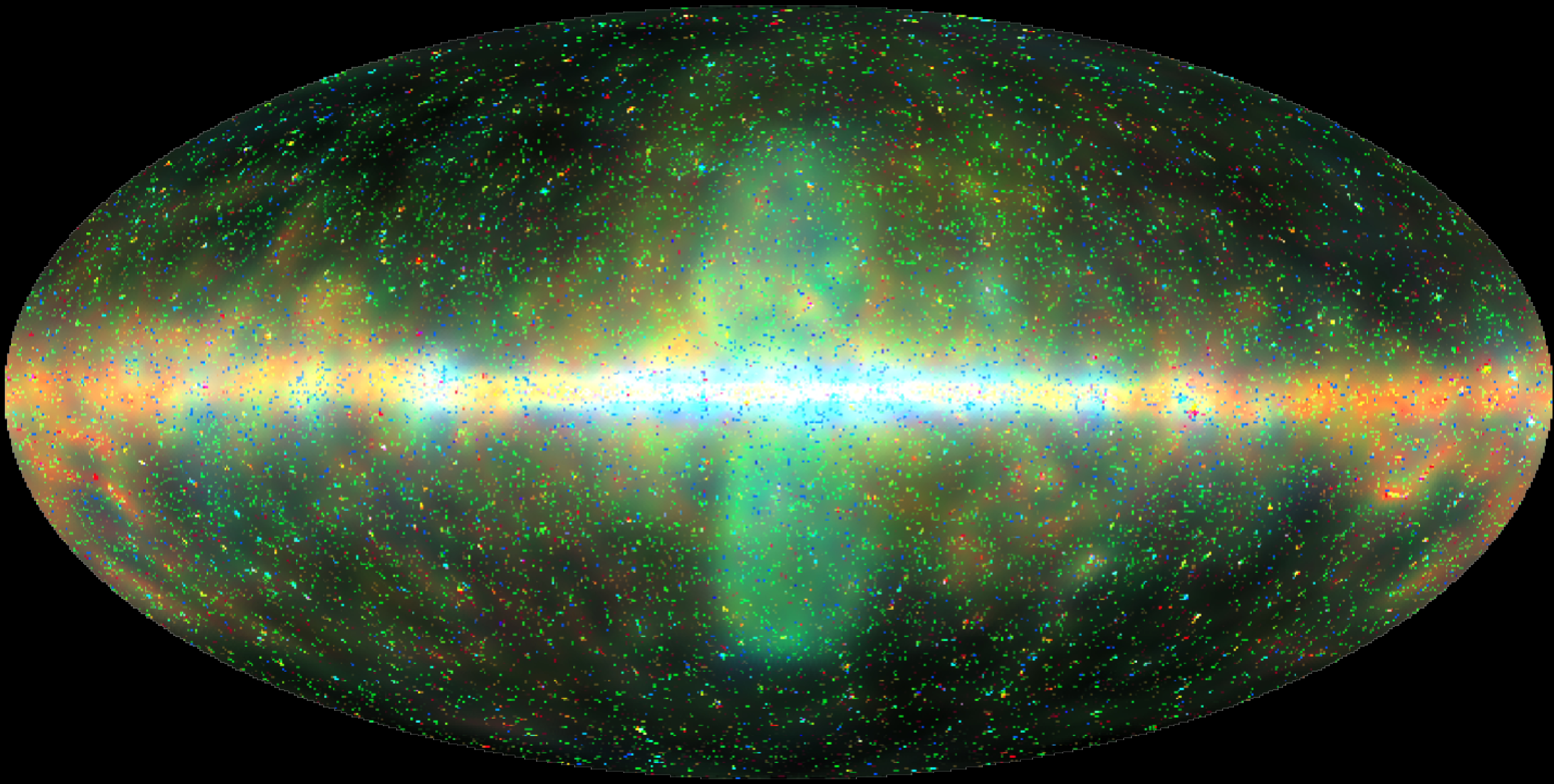
data



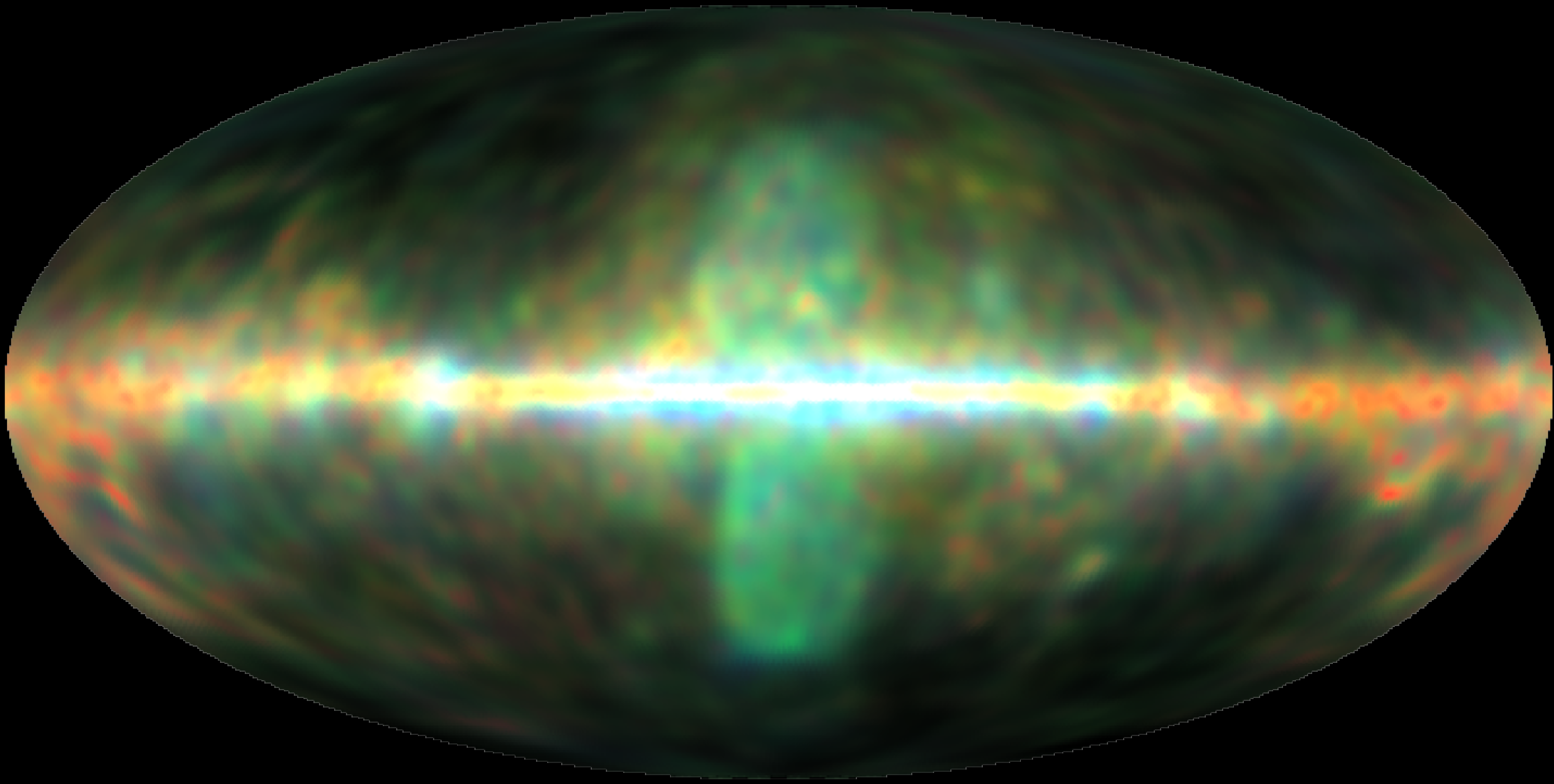
log-data



log-data … denoised

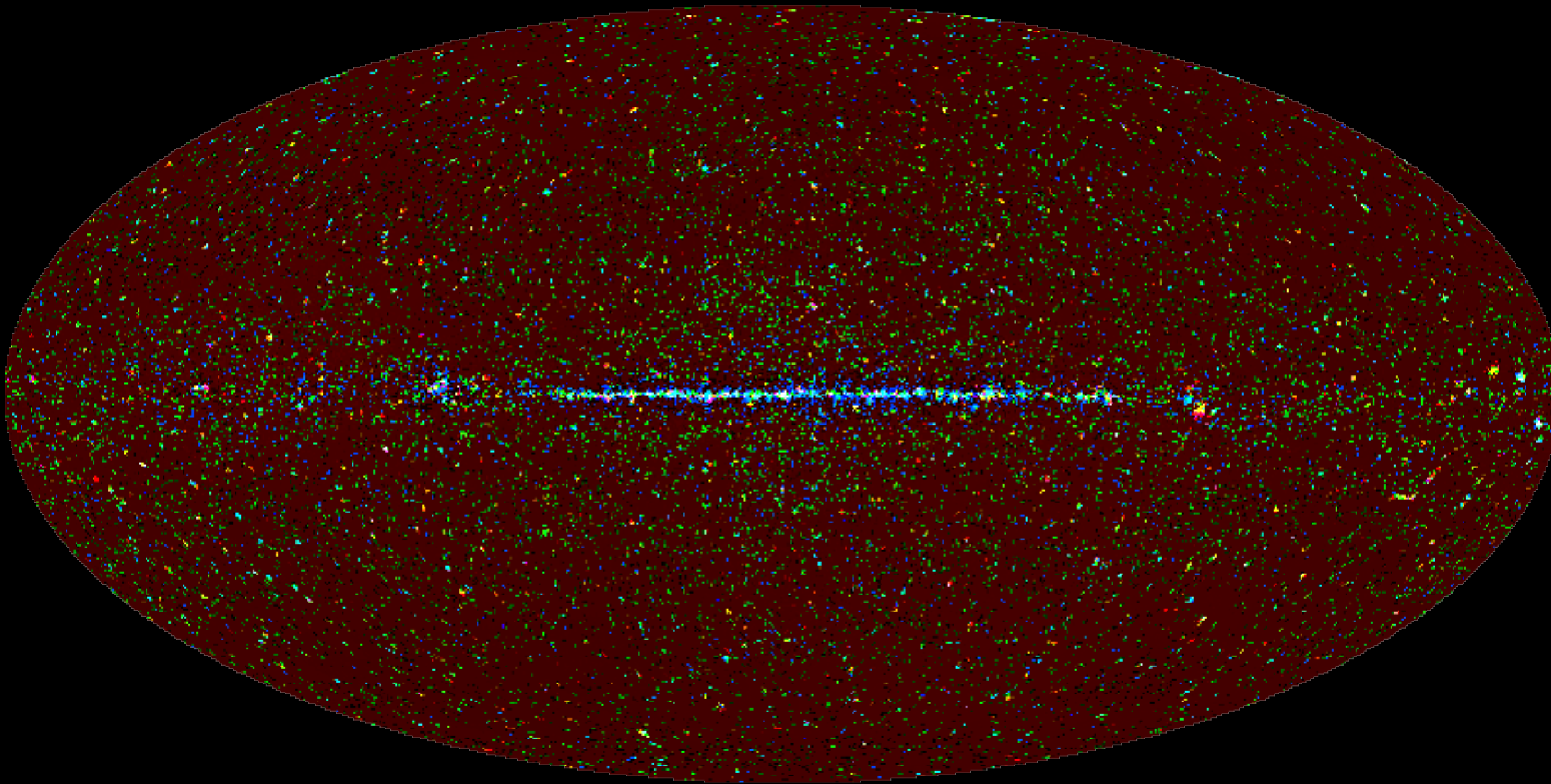


log-data … denoised … deconvolved



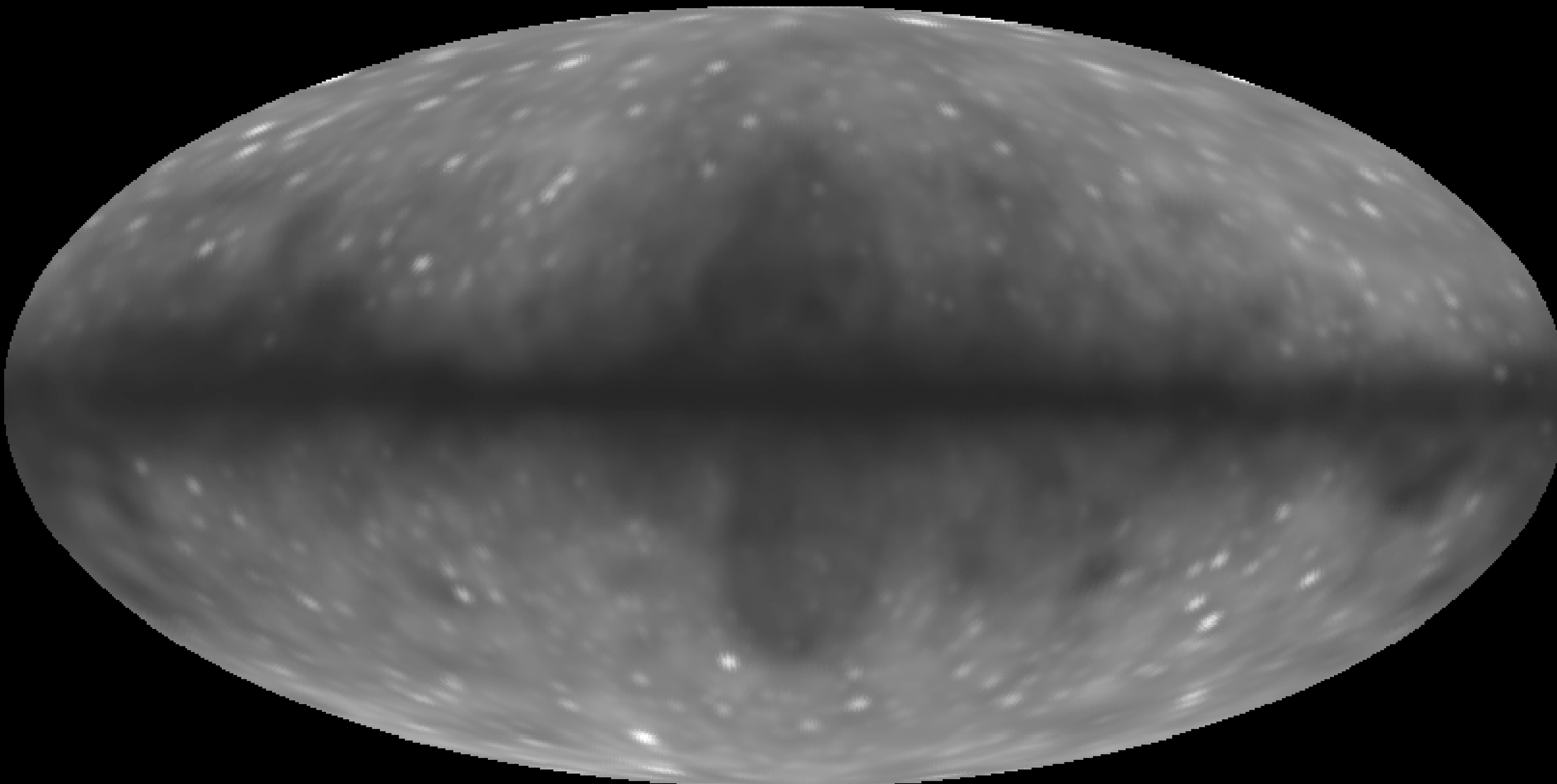
log-data … denoised … deconvolved … decomposed

Selig, Vacca, Oppermann, Enßlin (2015)

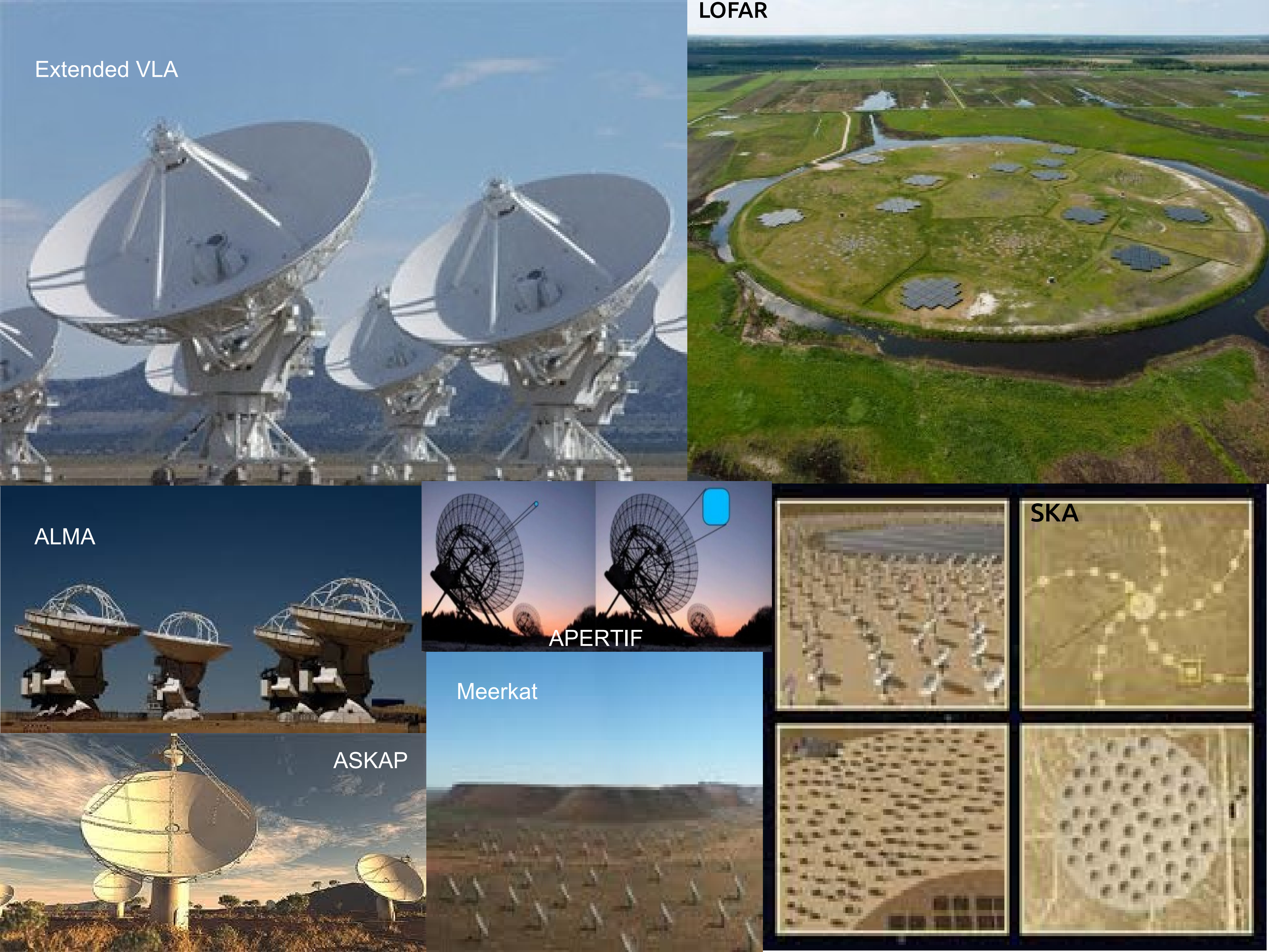


log-data … denoised … deconvolved … decomposed

Selig, Vacca, Oppermann, Enßlin (2015)

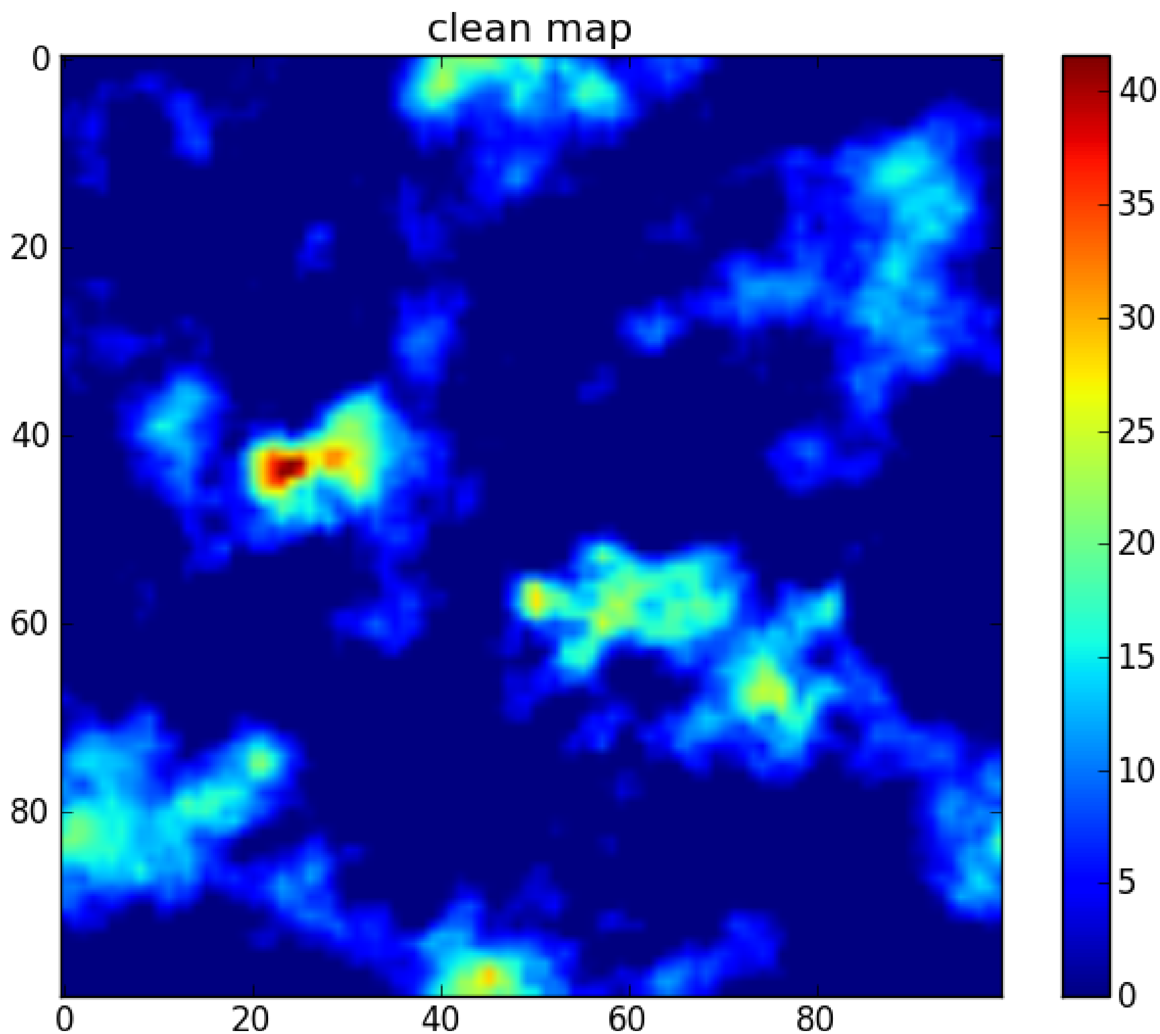


relative uncertainty of diffuse emission


Extended VLA
LOFAR
ALMA
APERTIF
SKA
Meerkat
ASKAP

Radio Interferometry

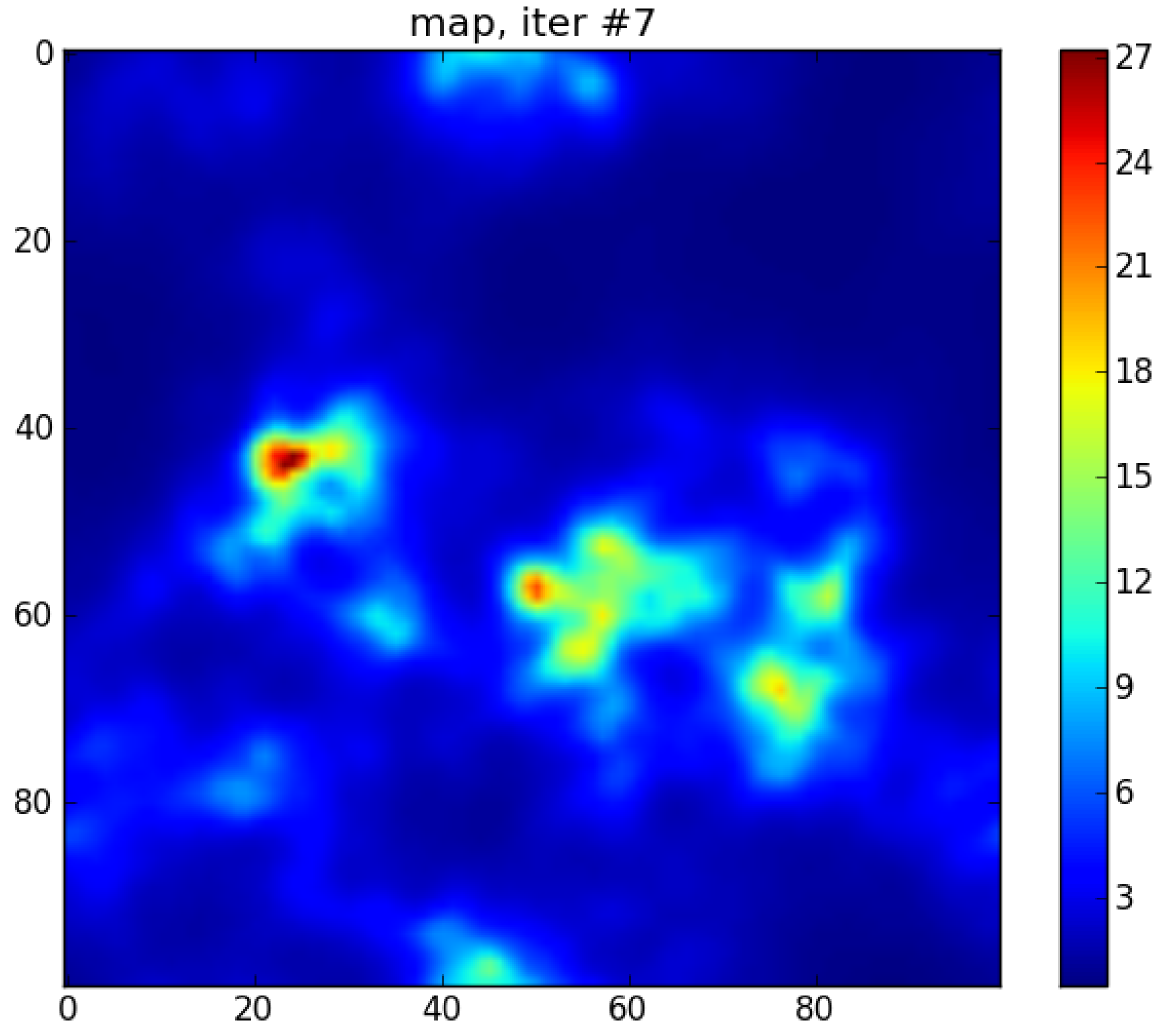
Junklewitz et al. (arXiv:1311.5282)



low noise, 40% uv-coverage

Radio Interferometry

Junklewitz et al. (arXiv:1311.5282)



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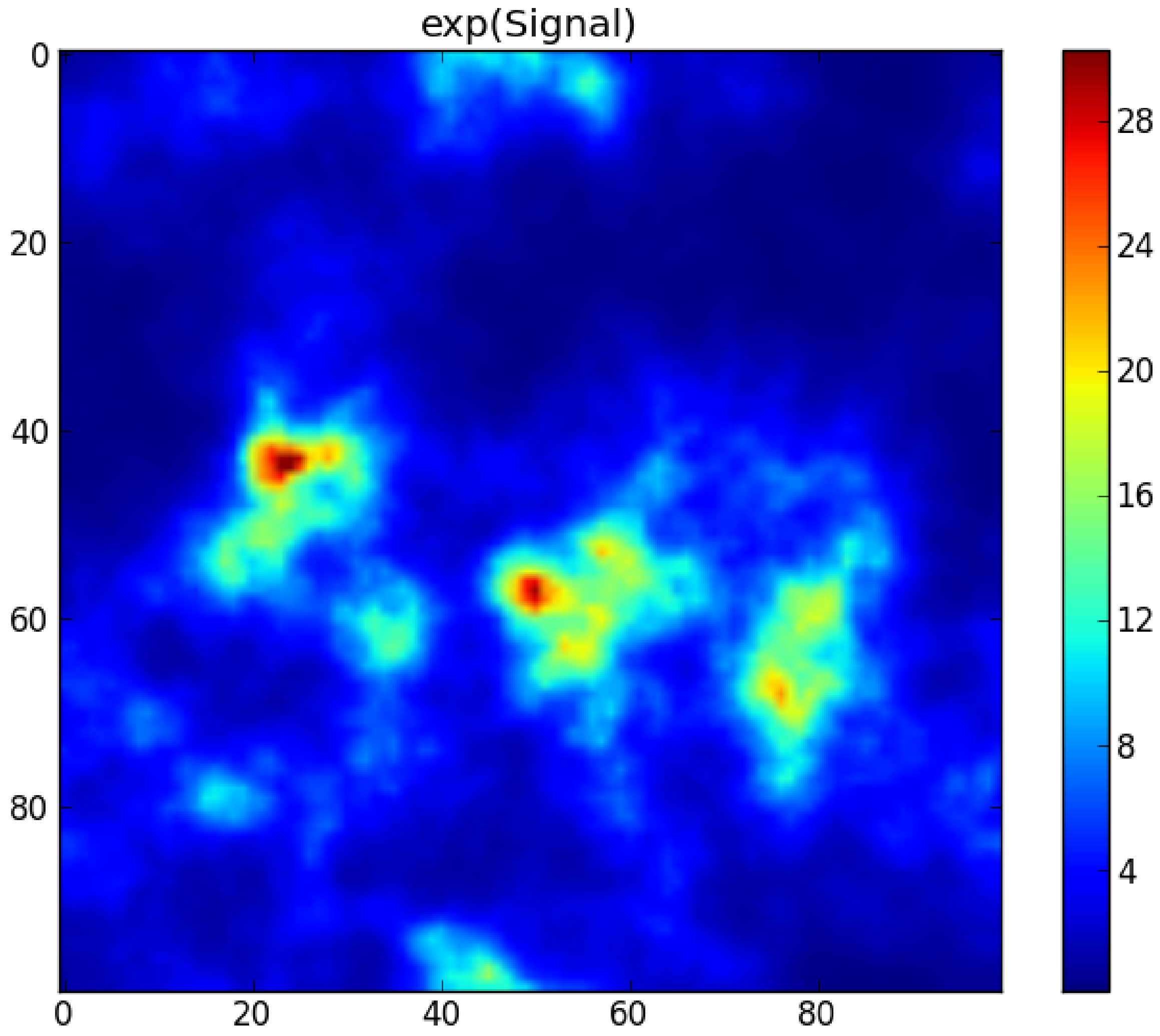
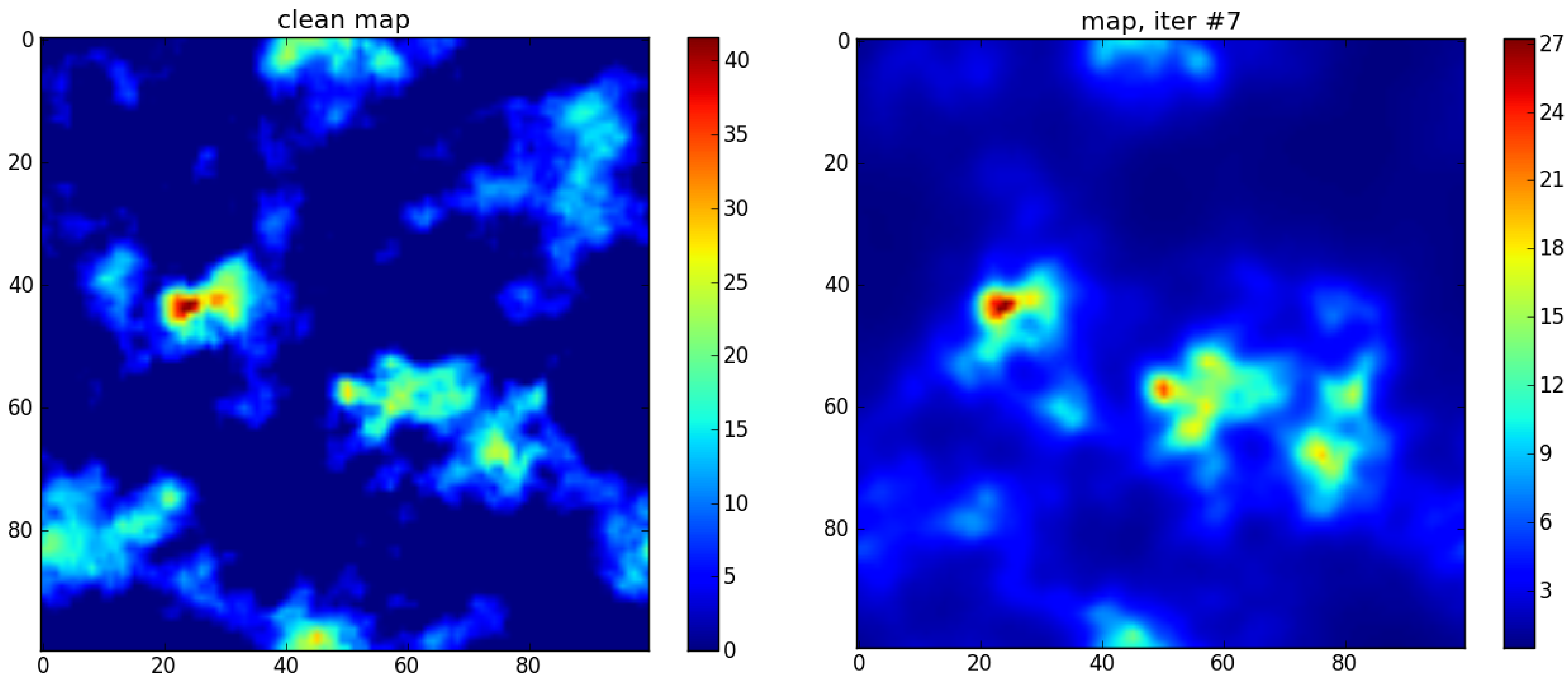


simulated signal

Radio Interferometry

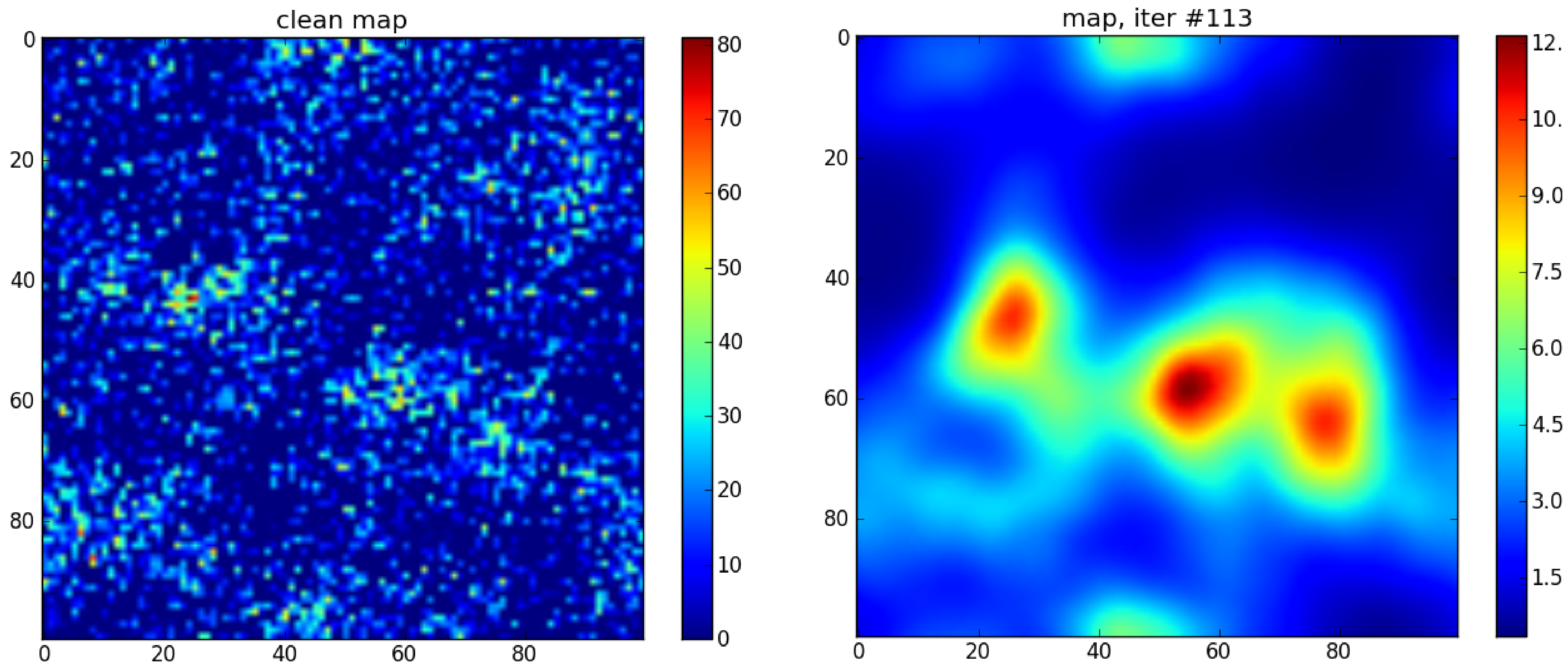
Junklewitz et al. (arXiv:1311.5282)



low noise, 40% uv-coverage

Radio Interferometry

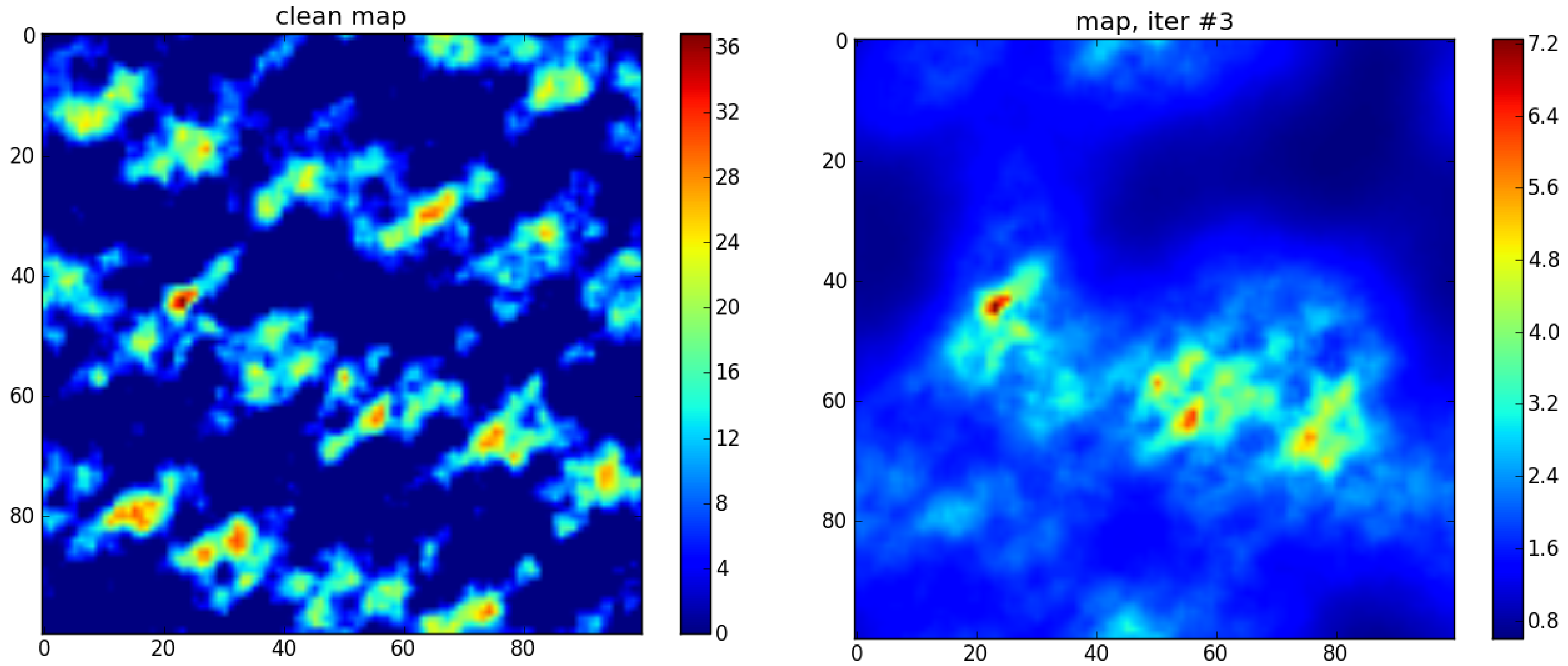
Junklewitz et al. (arXiv:1311.5282)



high noise, 40% uv-coverage

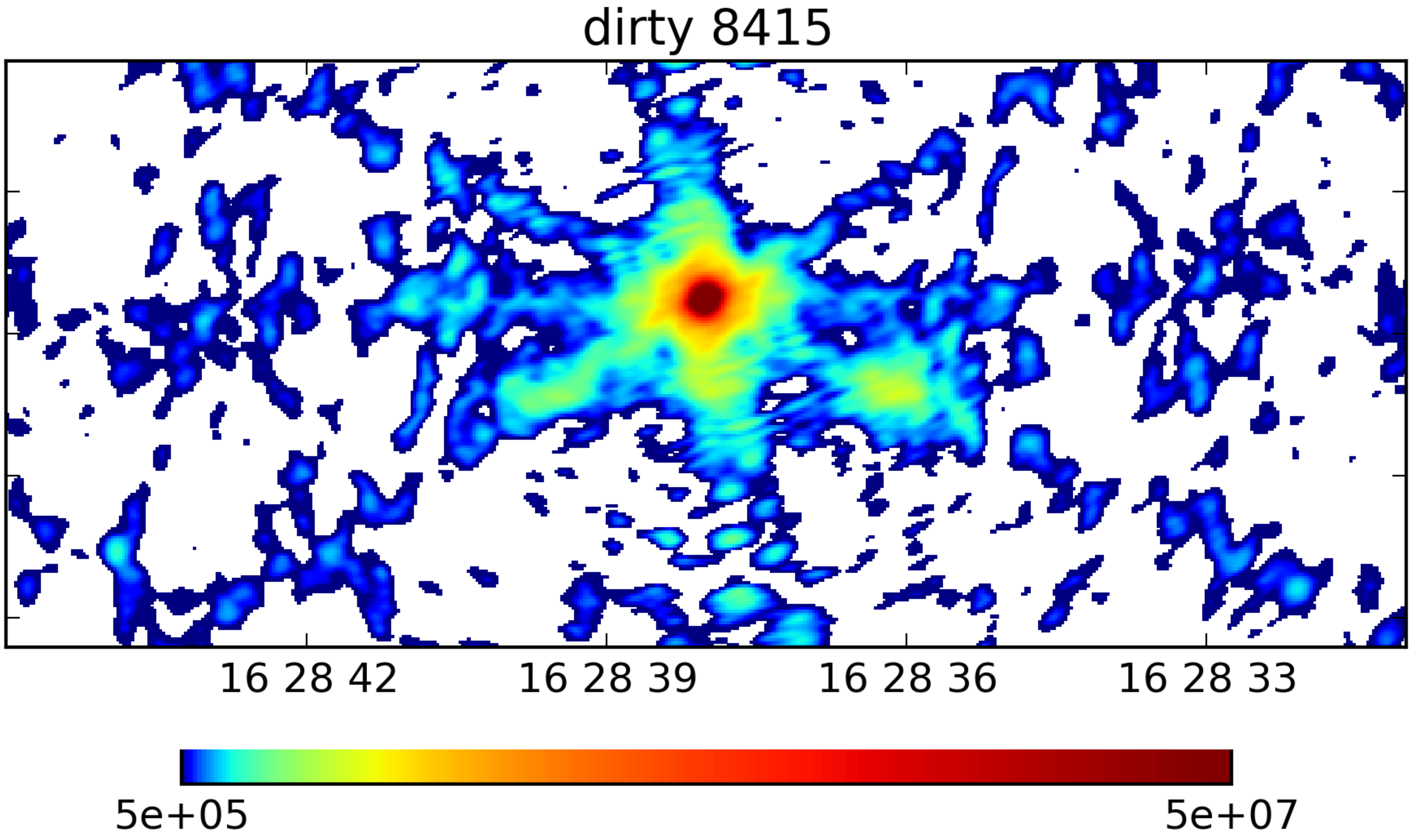
Radio Interferometry

Junklewitz et al. (in prep.)

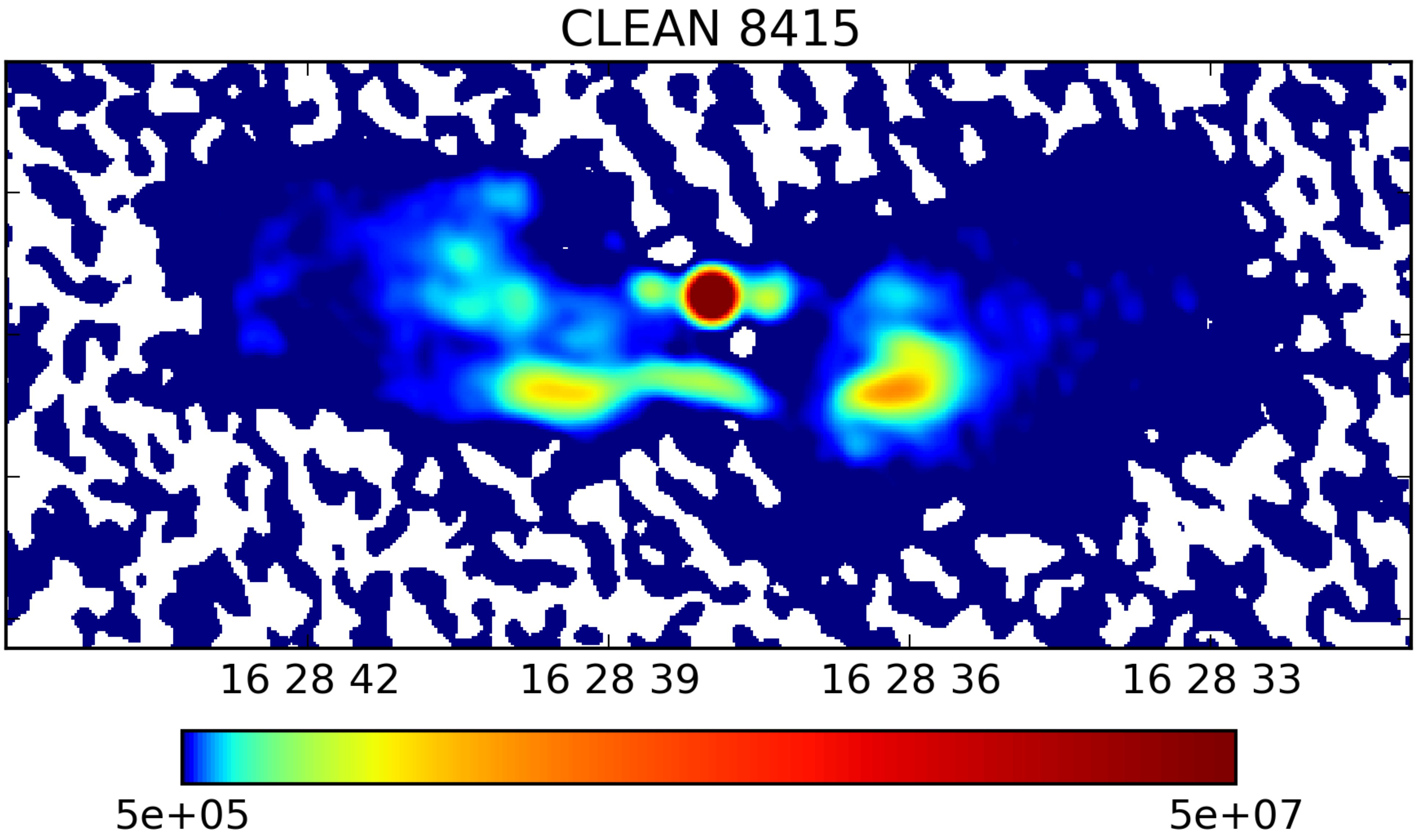


low noise, 10% uv-coverage

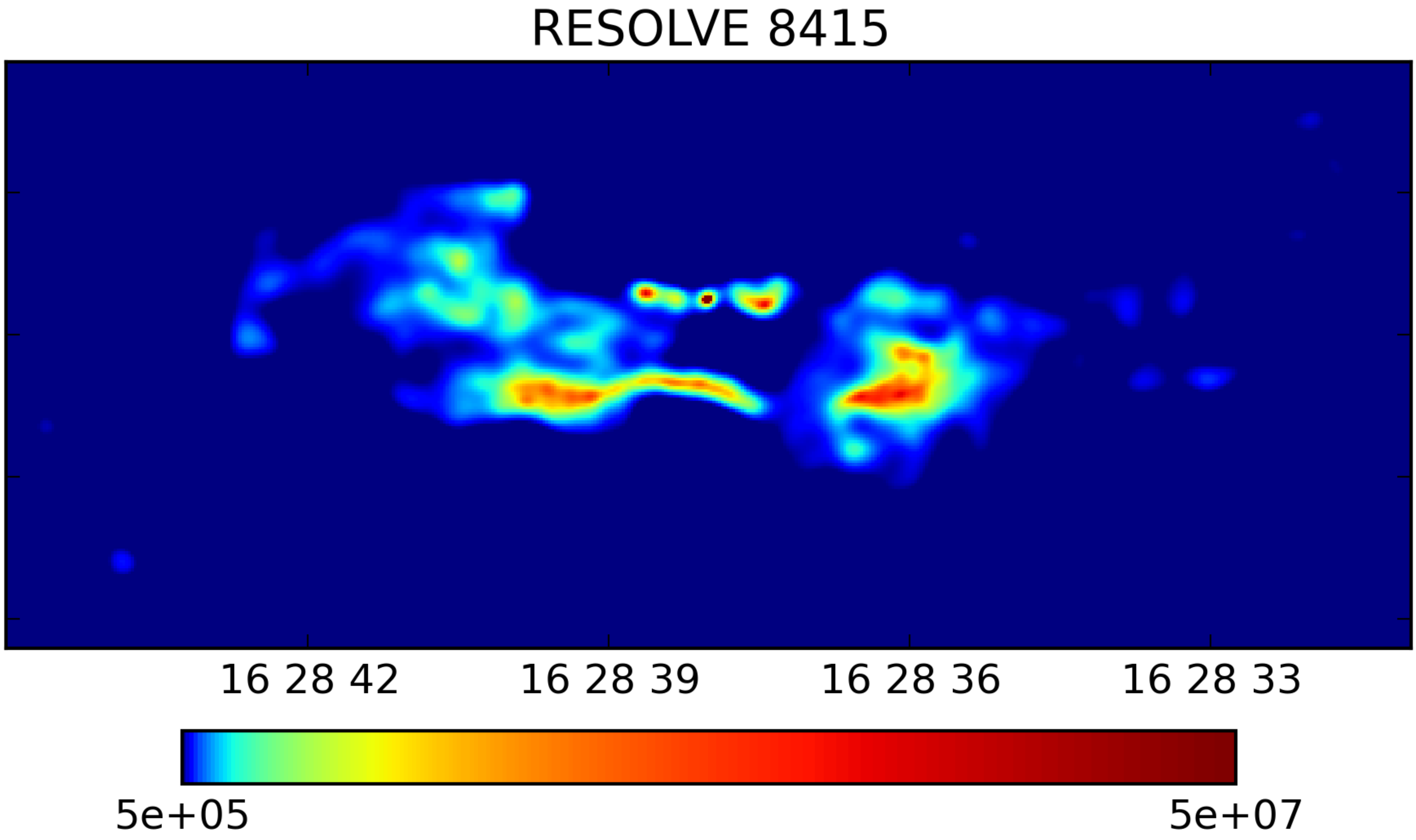
Abell 2219 @ 8415 MHz - data by Valentina Vacca



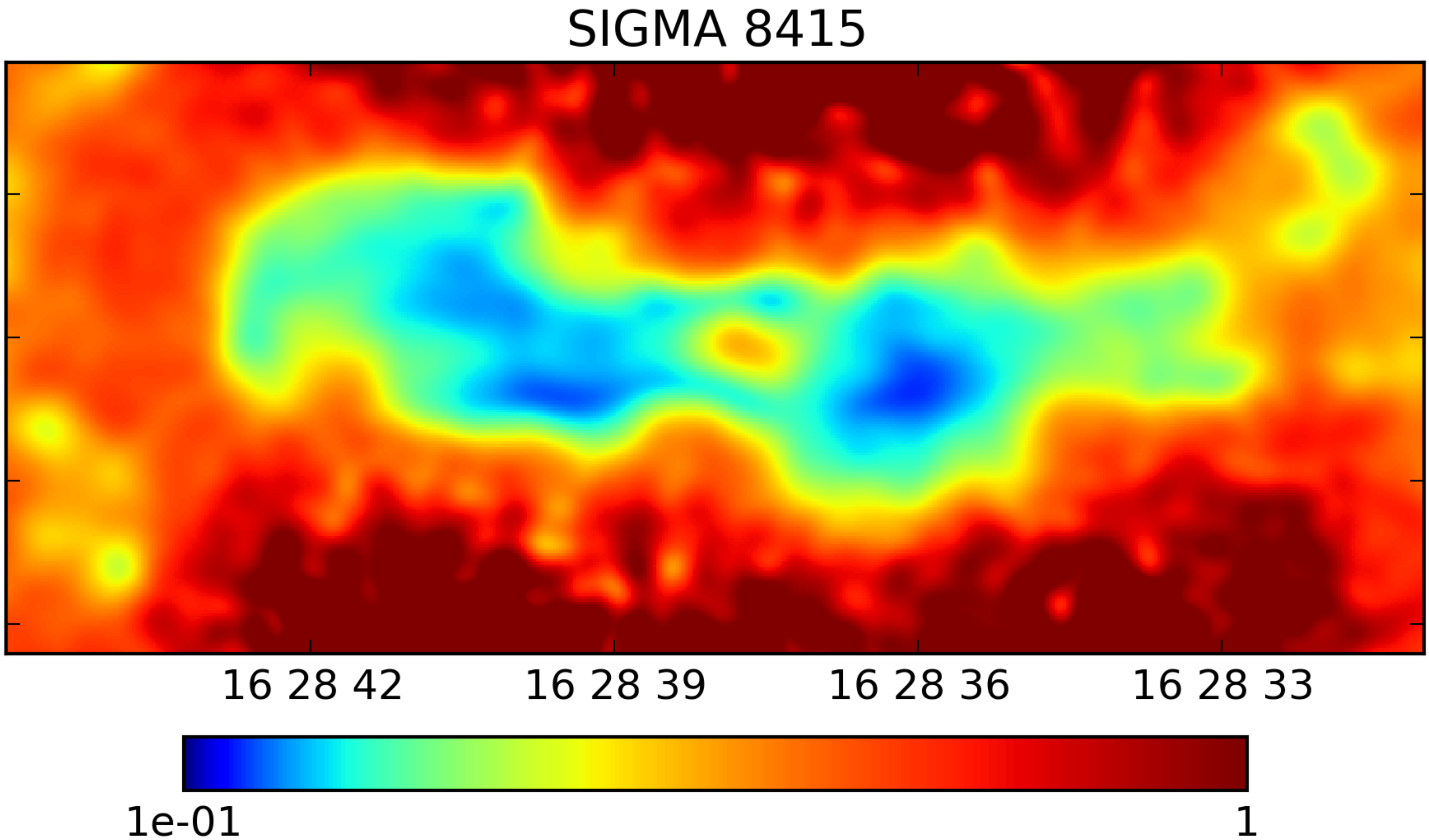
Abell 2219 @ 8415 MHz – CLEAN map by Valentina Vacca



Abell 2219 @ 8415 MHz – **fast-RESOLVE** map by Maksim Greiner



Abell 2219 @ 8415 MHz – **fast-RESOLVE** uncertainty map by Maksim Greiner



3D RESOLVE

multifrequency imaging
Faraday synthesis
component separation

Jakob Knollmüller
Component separation
MPA

Daniel Pumpe
Sectral-Spatial Imaging
MPA

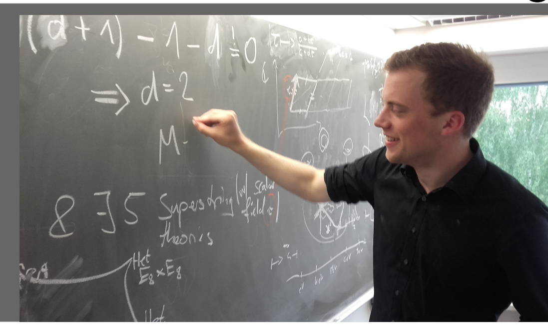
Maksim Greiner
fastRESOLVE
ML
MPA→Insight Perspective Technologies

Crew:

Henrik Junklewitz
MR. RESOLVE
now in data science

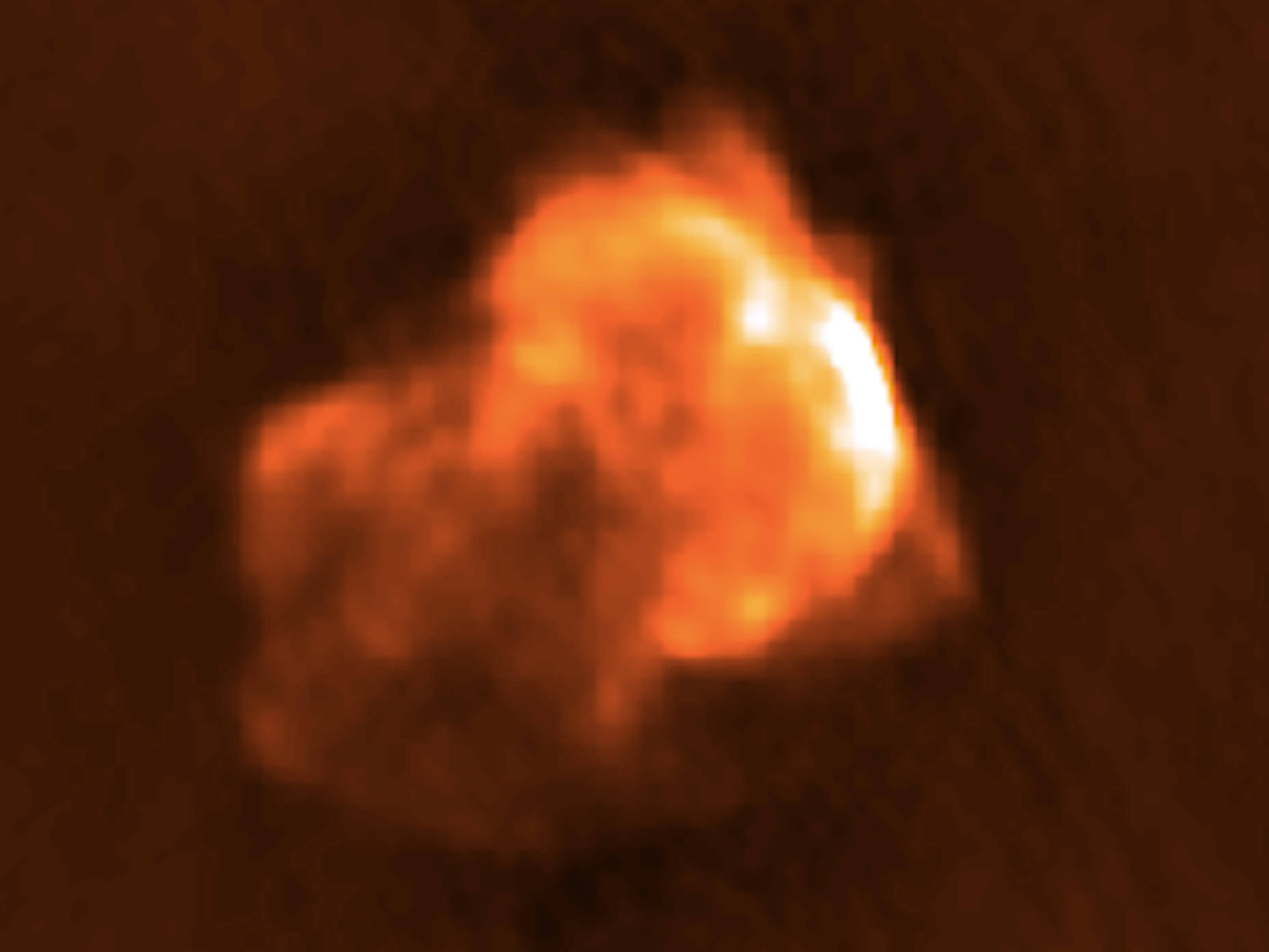
Rüdiger Westermann
Computer Graphics
& Visualization
TUM

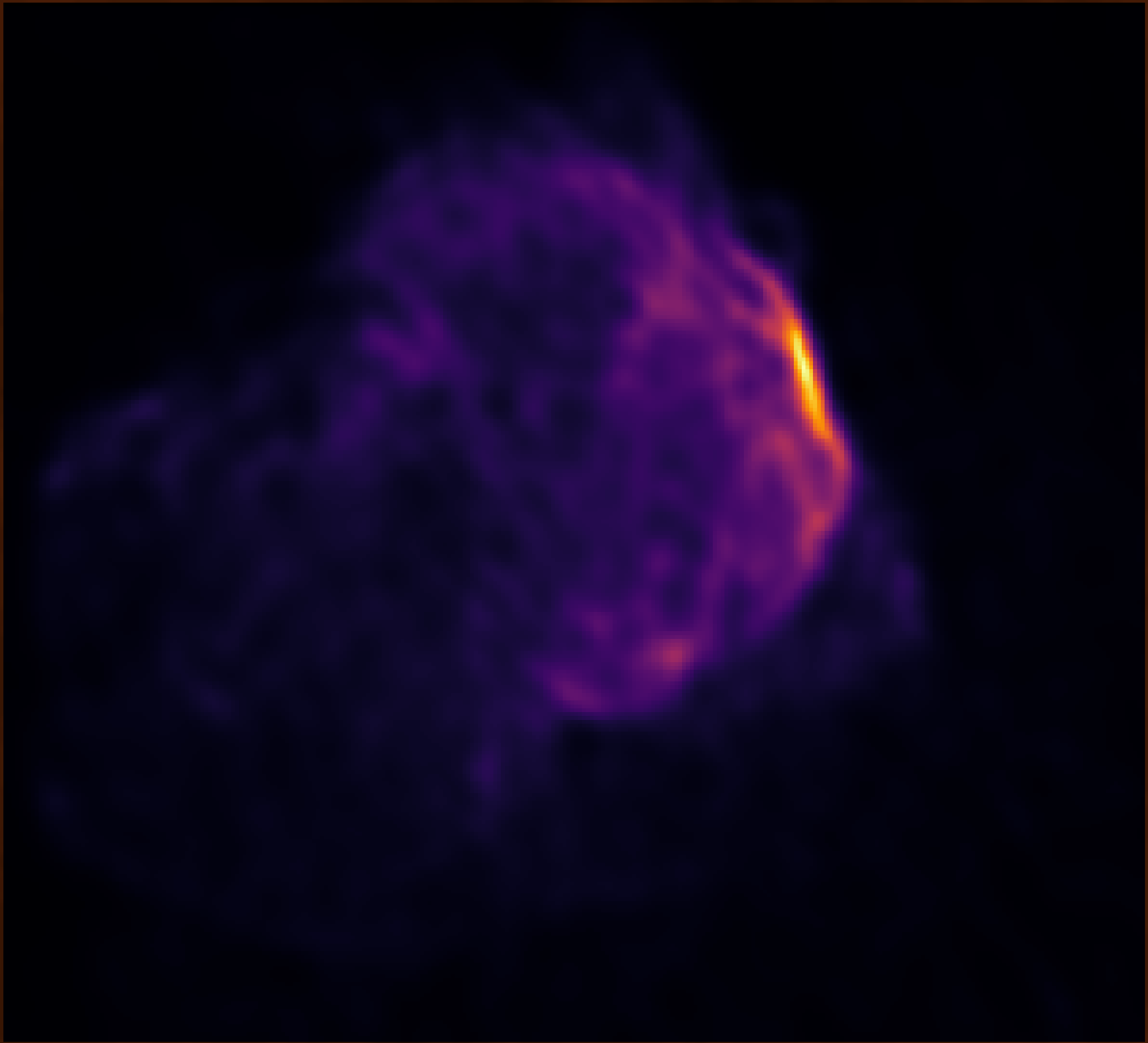
Philipp Arras
String Theory & soon
IFT + Radio Astronomy
TUM – MPA – LMU

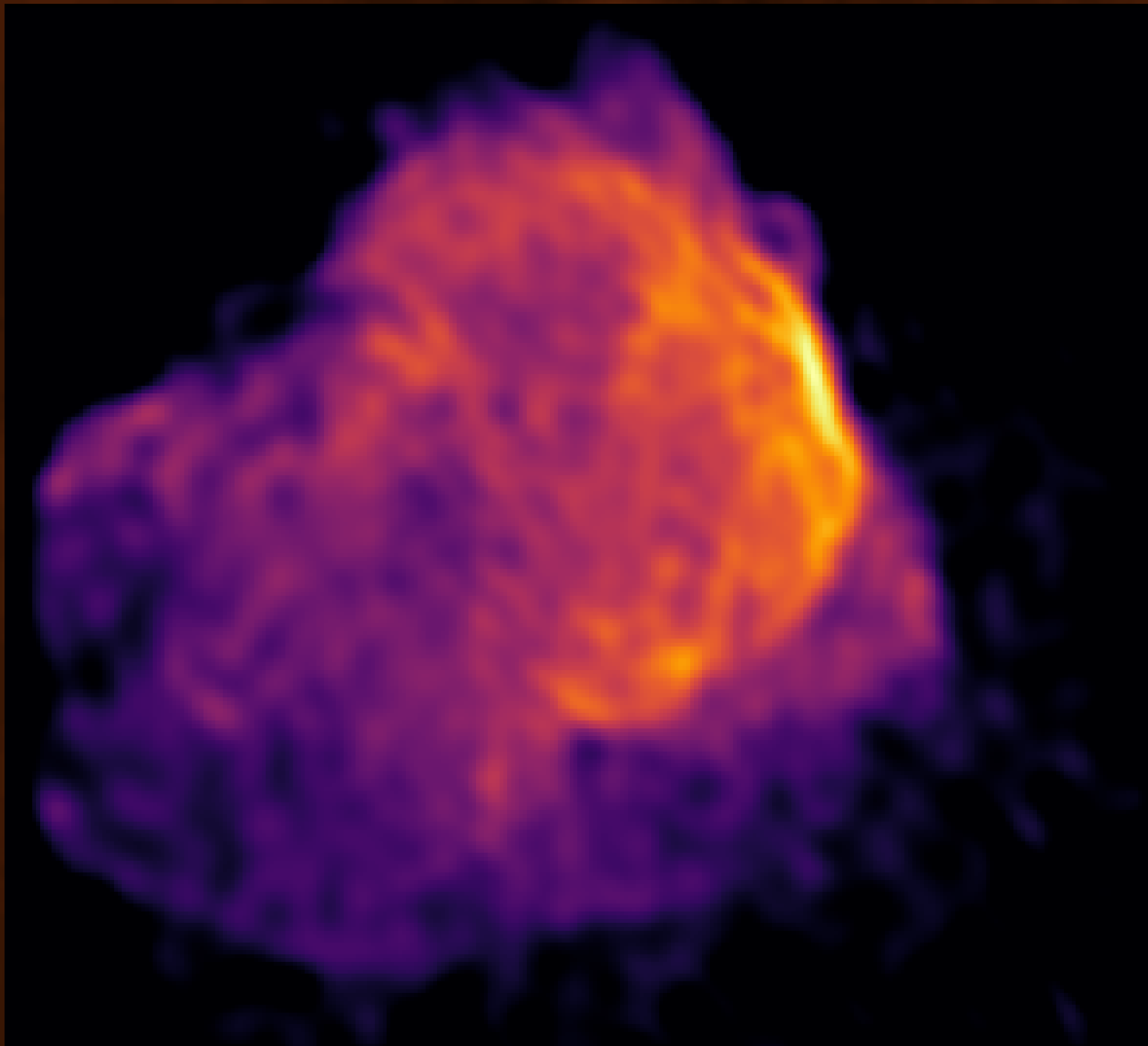


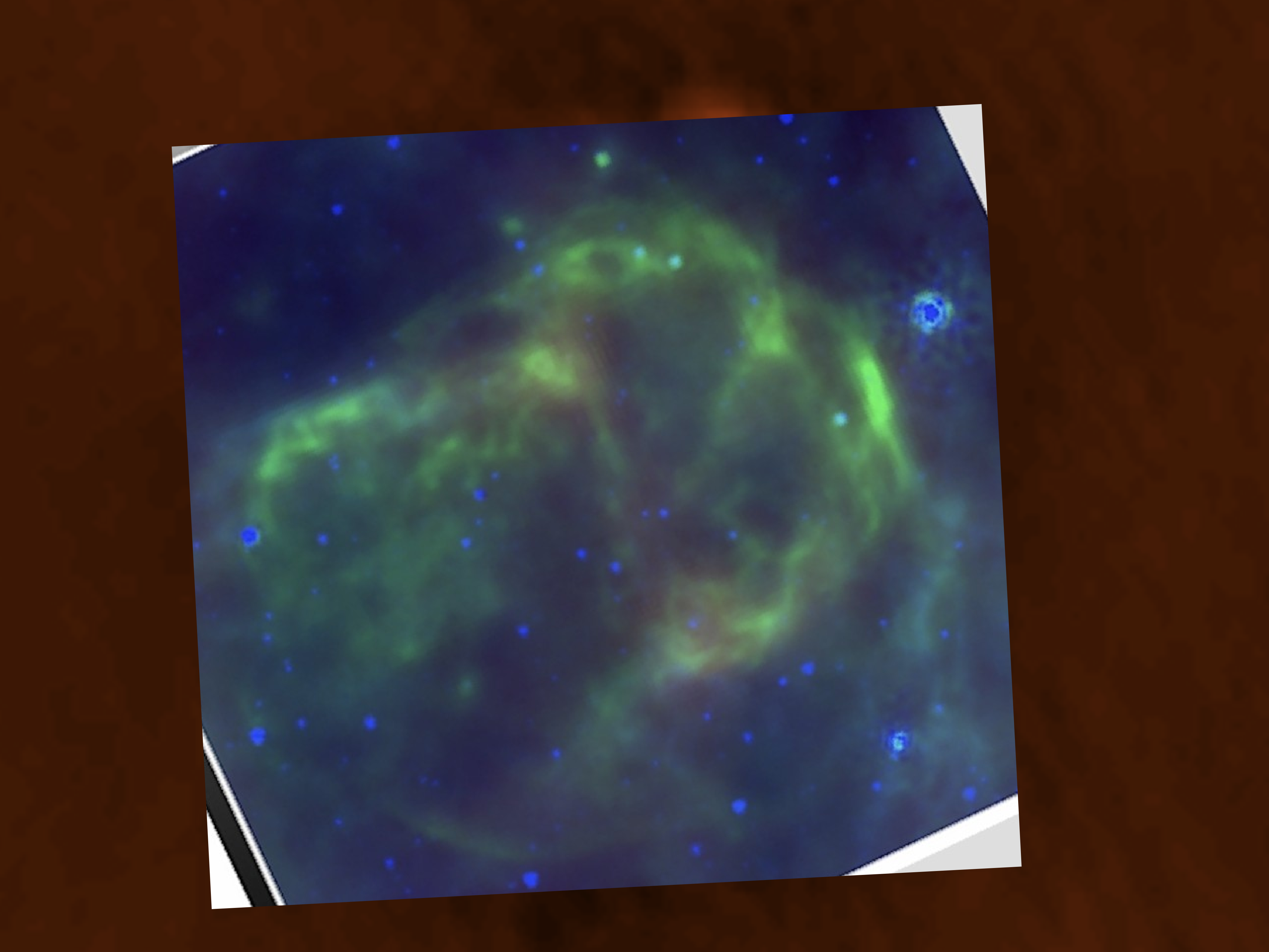
Torsten Enßlin
Information Field Theory
& Radio Astronomy
MPA

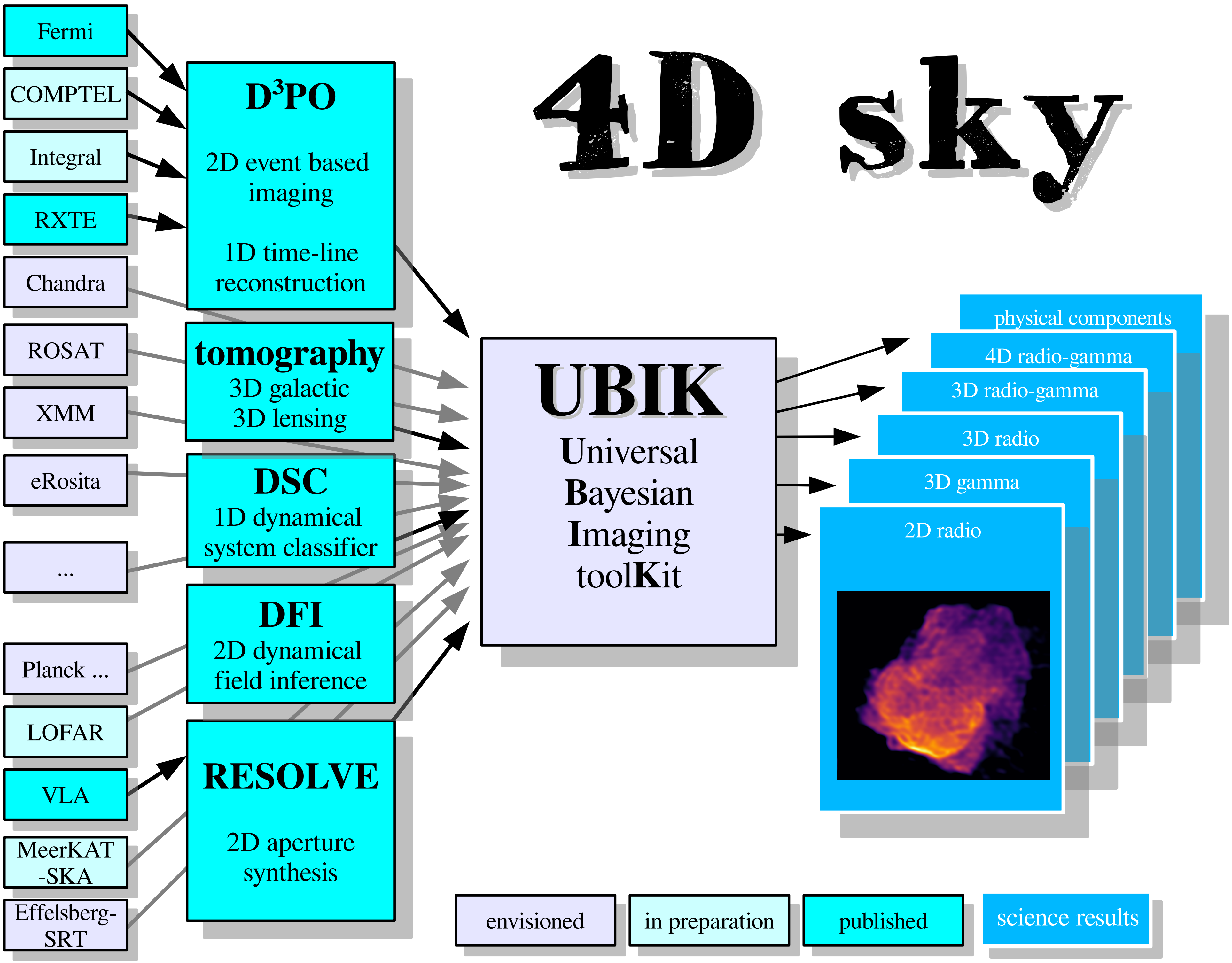
Jochen Weller
Cosmology
LMU











4D sky
Fermi
COMPTEL
Integral
RXTE
Chandra
ROSAT
XMM
eRosita
...
Planck ...
LOFAR
VLA
MeerKAT
-SKA
Effelsberg-
SRT
D³PO
2D event based
imaging
1D time-line
reconstruction
tomography
3D galactic
3D lensing
DSC
1D dynamical
system classifier
DFI
2D dynamical
field inference
RESOLVE
2D aperture
synthesis
UBIK
Universal
Bayesian
Imaging
toolKit
physical components
4D radio-gamma
3D radio-gamma
3D radio
3D gamma
2D radio
envisioned
in preparation
published
science results

UBIK: reality support

Source: https://martinacecilia.deviantart.com/art/Try-Ubik-New-and-powerful-204640851

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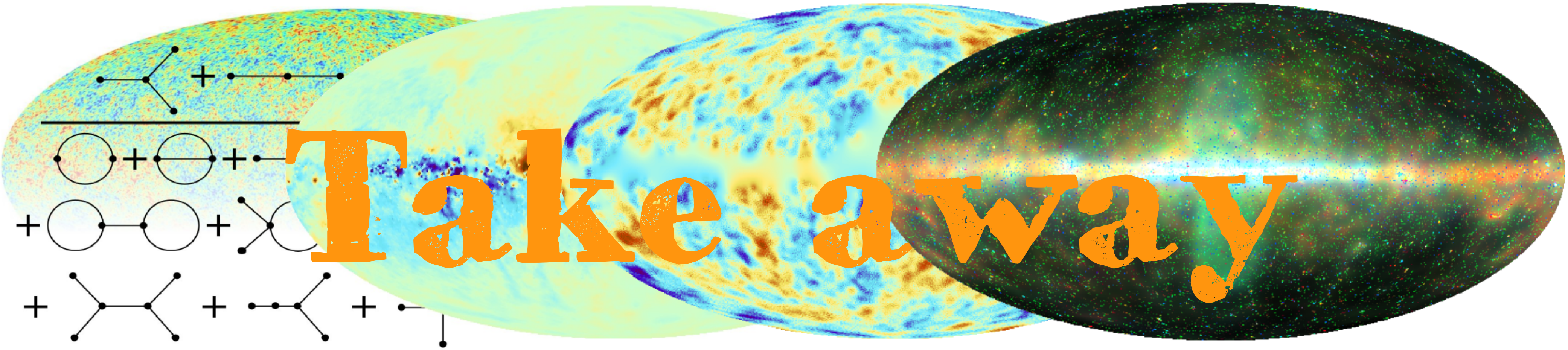
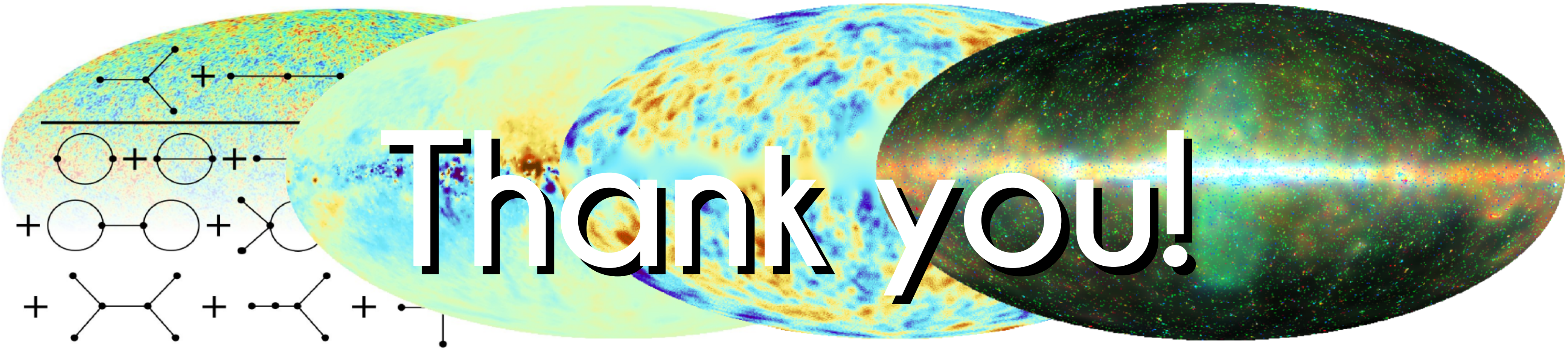


Take away

IFT	information field theory
NIFTy	nummerical IFT
D³PO	photon/event imaging
RESOLVE	interferometric imaging
UBIK	universal imaging
4D sky	multi-instrument & -dimension spatio-spectral-temporal imaging



Thank you!

Online material (info/codes/docu/data/maps):

IFT: www.mpa-garching.mpg.de/ift

lecture: wwwmpa.mpa-garching.mpg.de/~ensslin/lectures