BSS and deep learning

Victor Bonjean

Joint ARGOS-TITAN-TOSCA workshop - 6th/7th June 2024

TITAN ARTIFICIAL INTELLIGENCE IN ASTROPHYSICS
FORTH INSTITUTE OF COMPUTER SCIENCE
Signal Processing Laboratory
CosmoStat
cea
Funded by the European Union

What is component separation?

What is component separation?

$$X = S_0 + S_1 + S_2$$

What is component separation?

Observation

$$X = S_0 + S_1 + S_2$$

What is component separation?

Observation

$$X = S_0 + S_1 + S_2$$

3 components

What is component separation?

Multiple frequencies

Observation

$$X_i = a_i.S_0 + b_i.S_1 + c_i.S_2$$

3 components

What is component separation?

$$\begin{Bmatrix} X_0 \\ X_1 \\ \dots \\ X_n \end{Bmatrix} = \begin{Bmatrix} a_0 & b_0 & c_0 \\ a_1 & b_1 & c_1 \\ \dots & \dots & \dots \\ a_n & b_n & c_n \end{Bmatrix} \cdot \quad S_0 \, S_1 \, S_2$$

n frequencies

What is component separation?

nx3 « mixing matrix »

$$\begin{Bmatrix} X_0 \\ X_1 \\ \dots \\ X_n \end{Bmatrix} = \begin{Bmatrix} a_0 & b_0 & c_0 \\ a_1 & b_1 & c_1 \\ \dots & \dots & \dots \\ a_n & b_n & c_n \end{Bmatrix} \cdot \; S_0 \, S_1 \, S_2$$

n frequencies

What is component separation?

$$X = A.S$$

What is component separation?

$$X = \boxed{A}.S$$

1. We know **A**

« No problem »

$$S = A^{-1}.X$$

- Never the case

What is component separation?

$$\mathbf{X} = \mathbf{A}.\mathbf{S} + \mathbf{N}$$

Blind Source Separation (BSS)

1. We know **A**

« No problem »

$\mathbf{S} = \mathbf{A}^{-1}.\mathbf{X}$

- Never the case

2. We don't know **A**

Problem

- FastICA
- GMCA
- Unsupervised Learning

→ Prior on S

What is component separation?

$$\mathbf{X} = \boxed{\mathbf{A}}.\mathbf{S} + \mathbf{N}$$

Blind Source Separation (BSS)

1. We know A

« No problem »

$$\mathbf{S} = \mathbf{A}^{-1}.\mathbf{X}$$

- Never the case

1.5. We know a bit of A

Problem

- ILC
- GMCA
- Self-supervised Learning
- Template based fitting

→ Prior on A

2. We don't know A

Problem

- FastICA
- GMCA
- Unsupervised Learning

→ Prior on S

What is component separation?

$$\mathbf{X} = \boxed{\mathbf{A}} . \mathbf{S} + \mathbf{N}$$

Blind Source Separation (BSS)

1. We know A

« No problem »

$$\mathbf{S} = \mathbf{A}^{-1} . \mathbf{X}$$

- Never the case

1.5. We know a bit of A

Problem

- ILC
- GMCA
- **Self-supervised Learning** ✓
- Template based fitting

→ Prior on A

2. We don't know A

Problem

- FastICA
- GMCA

→ Prior on S

- **Unsupervised Learning** ✓

What is component separation?

$$\mathbf{X} = \boxed{\mathbf{A}} . \mathbf{S} + \mathbf{N}$$

Blind Source Separation (BSS)

1. We know A

« No problem »

$\mathbf{S} = \mathbf{A}^{-1} . \mathbf{X}$

- Never the case

1.5. We know a bit of A

Problem

- ILC
- GMCA
- **Self-supervised Learning**
- Template based fitting

→ Prior on A

1.75 My work

2. We don't know A

Problem

- FastICA
- GMCA
- **Unsupervised Learning**

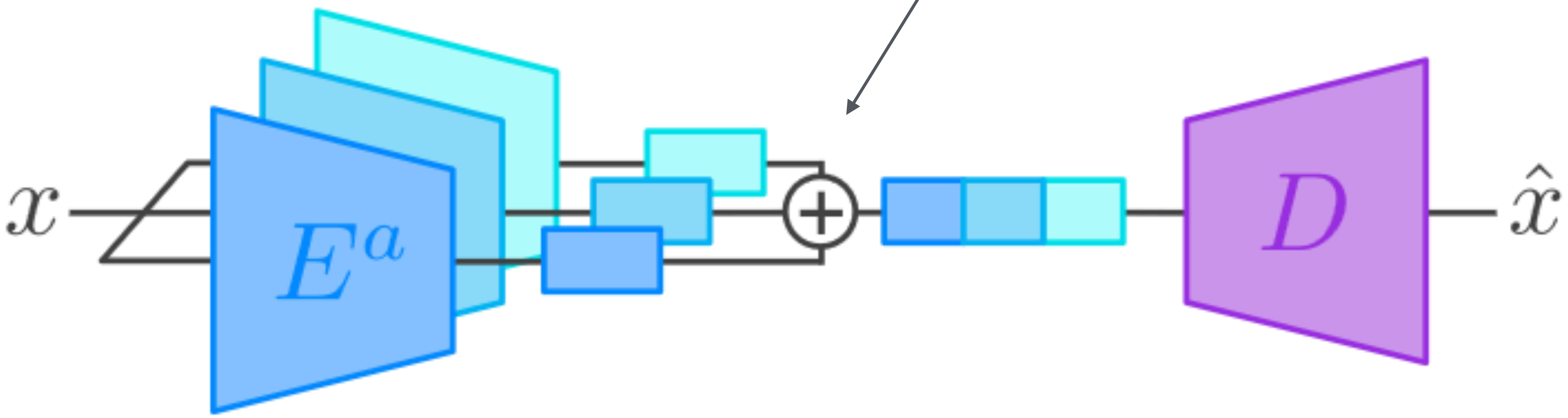
→ Prior on S

Component separation with deep learning

Anything you want (fitted mixing matrix, **non linear model**...)

Encoder

Decoder



Any loss you want

(a) Blind source separation training procedure.

Webster et al, 2023

Component separation with deep learning

Single channel mixture:

Webster et al, 2023

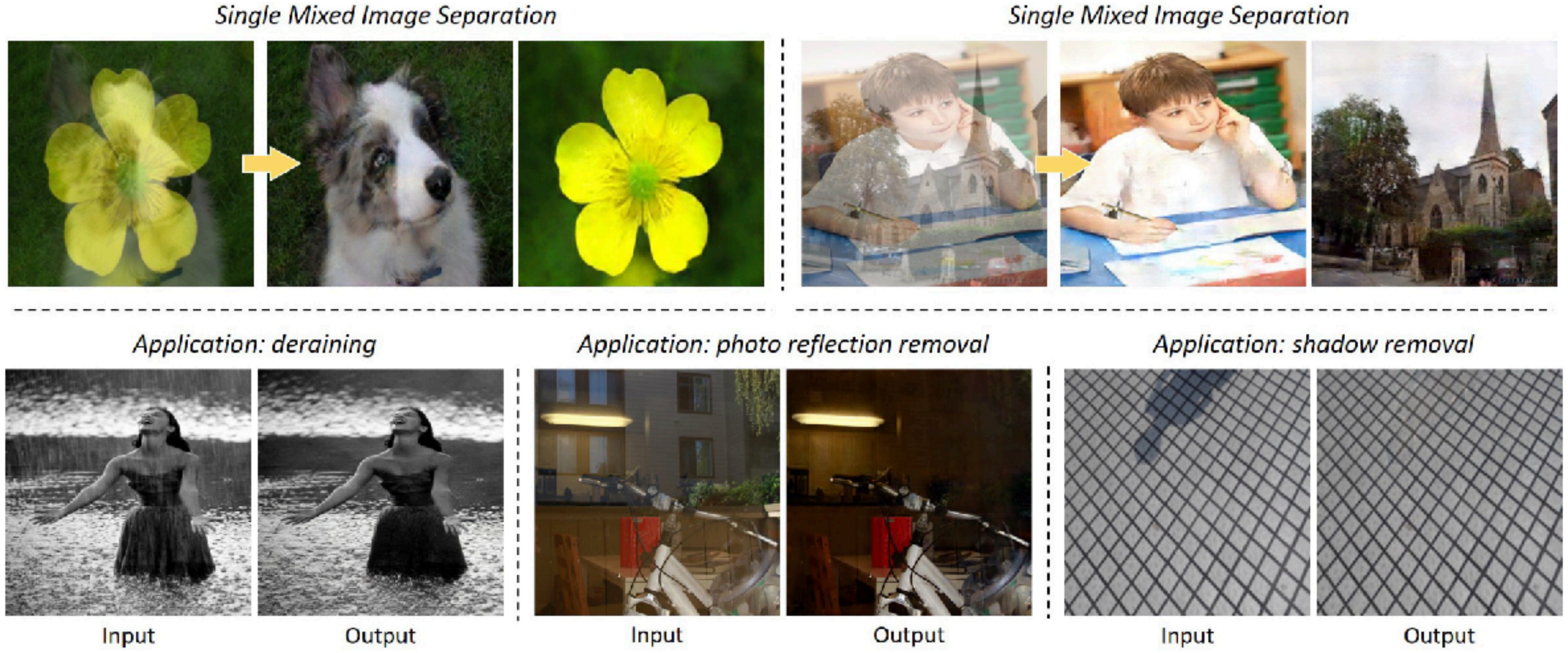


Figure 1: We propose a unified framework for single mixed image separation under an adversarial training paradigm. Our method can be applied to a variety of real-world tasks, including image deraining, photo reflection removal, image shadow removal, etc.

(+ regularization term on (non) correlation)

Component separation with deep learning

« Double-DIP »

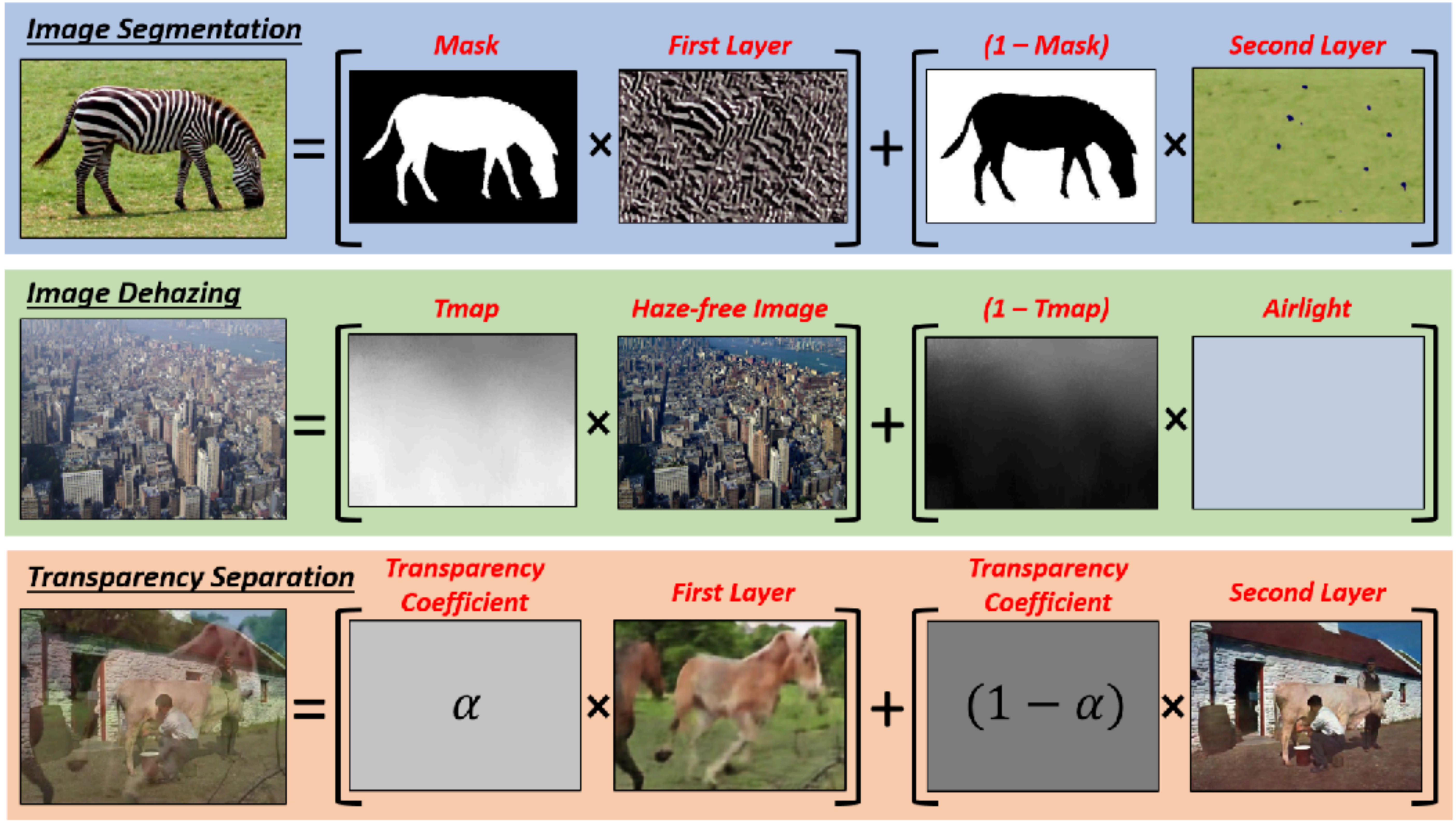


Figure 1: **A unified framework for image decomposition.** An image can be viewed as a mixture of "simpler" layers. Decomposing an image into such layers provides a unified framework for many seemingly unrelated vision tasks (e.g., segmentation, dehazing, transparency separation). Such a decomposition can be achieved using "Double-DIP".

Gandelsman et al, 2018

Component separation with deep learning

« Double-DIP »

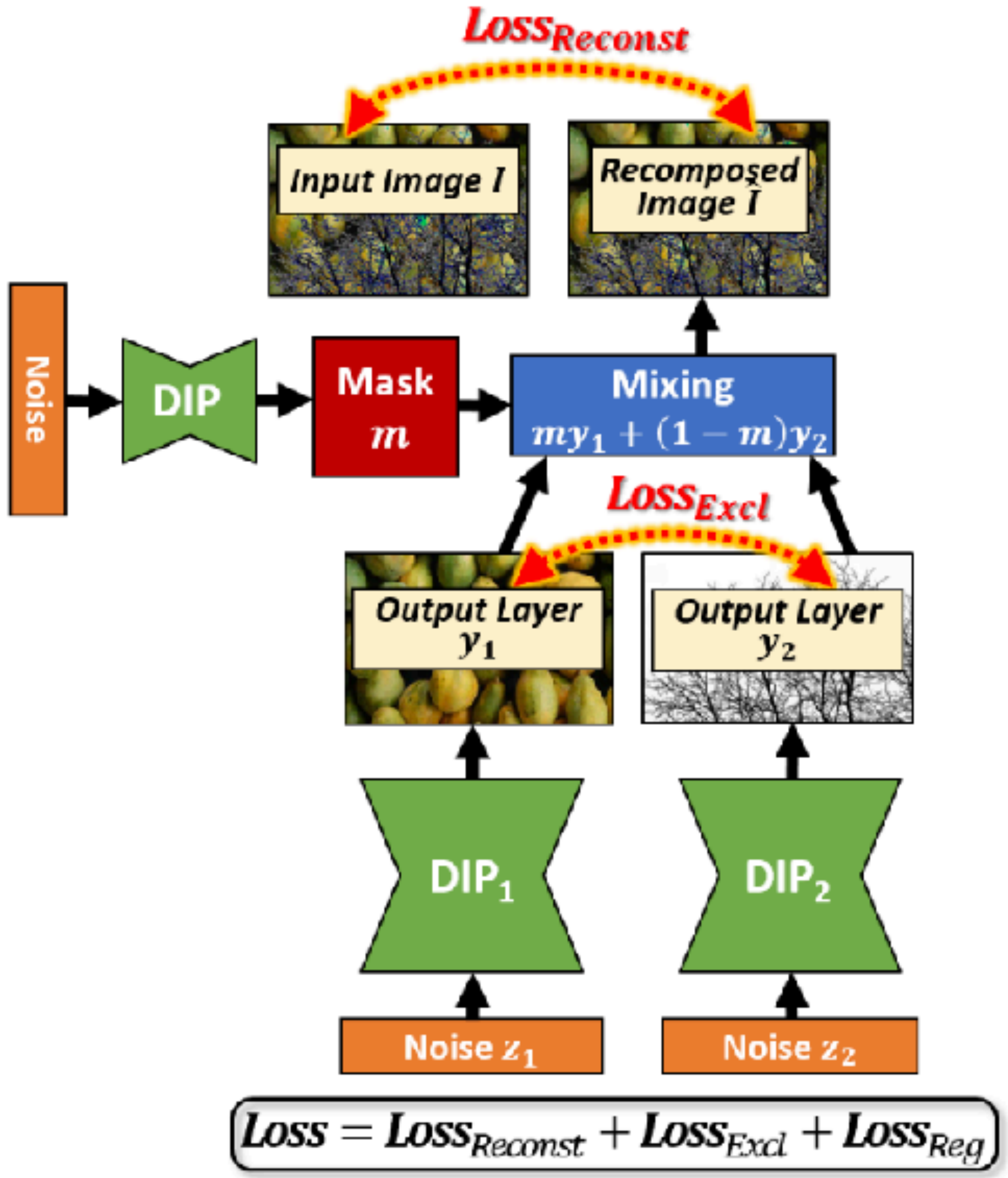
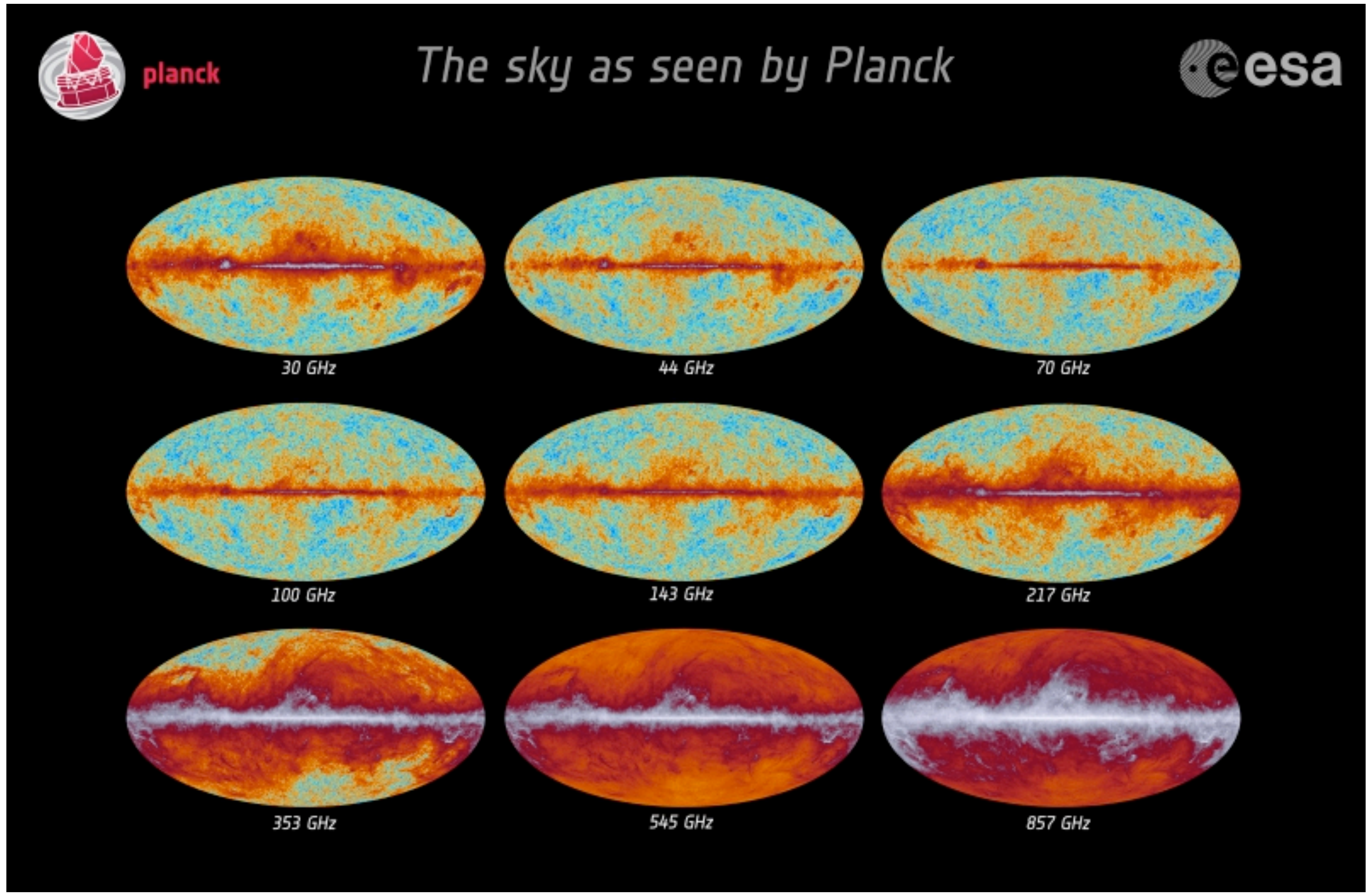


Figure 2: **Double-DIP Framework.** *Two Deep-Image-Prior networks (DIP_1 & DIP_2) jointly decompose an input image I into its layers (y_1 & y_2). Mixing those layers back according to a learned mask m, reconstructs an image $\hat{I} \approx I$.*

Gandelsman et al, 2018

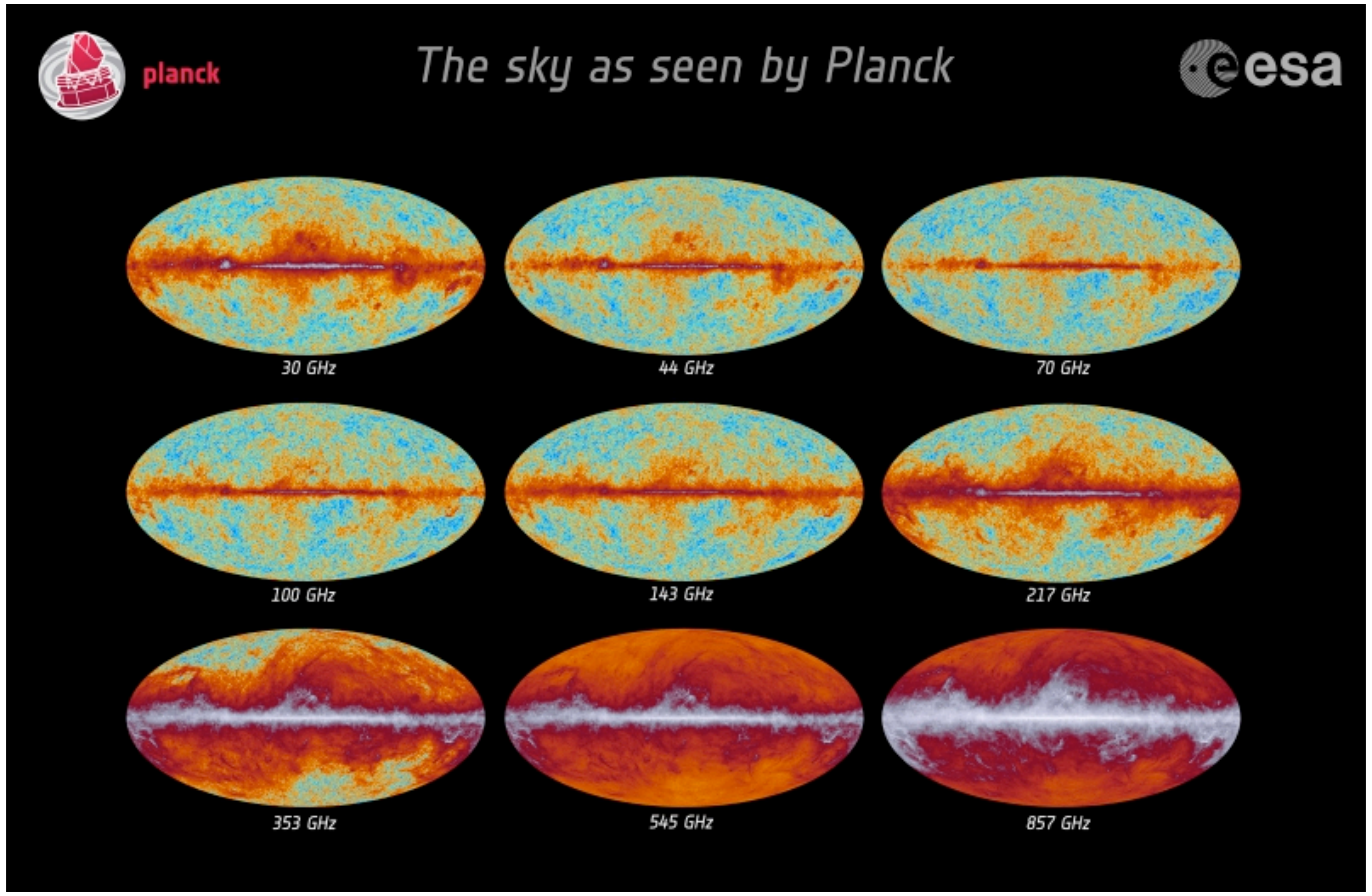
An application to CMB data - CIB removal - SZ extraction



• CMB	constant weights
• CIB	approximated weights
• tSZ	known weights
• Noise	known
• Beam	known
• kSZ	constant weights
• Radio	freq. > 90GHz
• Foregrounds (CO + dust + radio)	

Major issue

An application to CMB data - CIB removal - SZ extraction



- CMB — constant weights
- CIB — approximated weights
- tSZ — known weights
- Noise — known
- Beam — known
- kSZ — constant weights
- Radio — freq. > 90GHz
- Foregrounds (CO + dust + radio)

Major issue

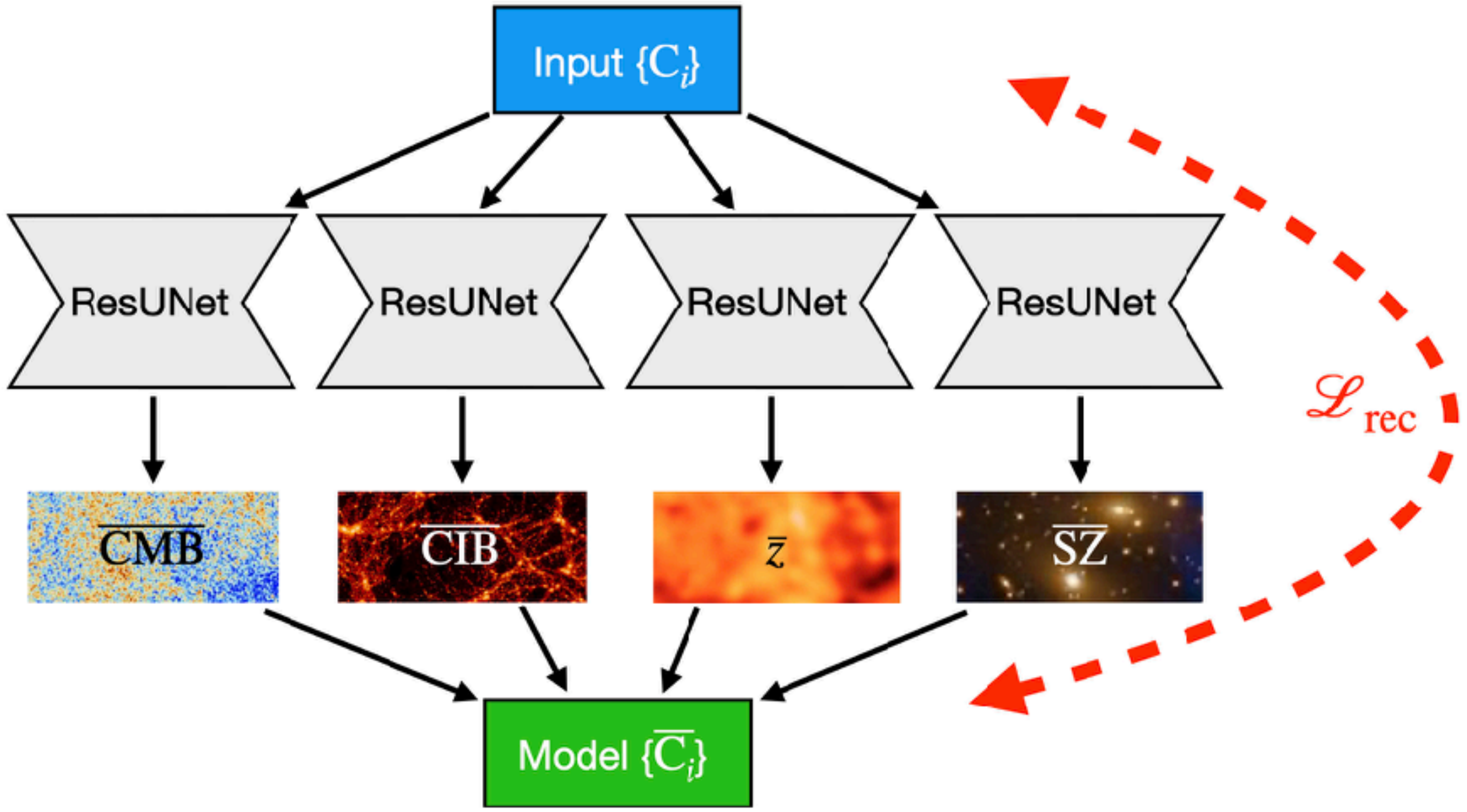
Not statistically independent

$\longrightarrow$ $\{C_i\}$ = Bi o (1*(CMB+kSZ) + fi*SZ + CIBi) + Ni

Non linear

An application to CMB data - CIB removal - SZ extraction

$\longrightarrow \quad \{C_i\} = \mathrm{Bi} \circ (1 * \mathrm{CMB} + \mathrm{fi} * \mathrm{SZ} + \mathrm{CIBi}) + \mathrm{Ni}$



$$\mathcal{L}_{\mathrm{rec}} = \sum_i \frac{\mathrm{MSE}(C_i, \bar{C}_i)}{\sigma(C_i)}$$

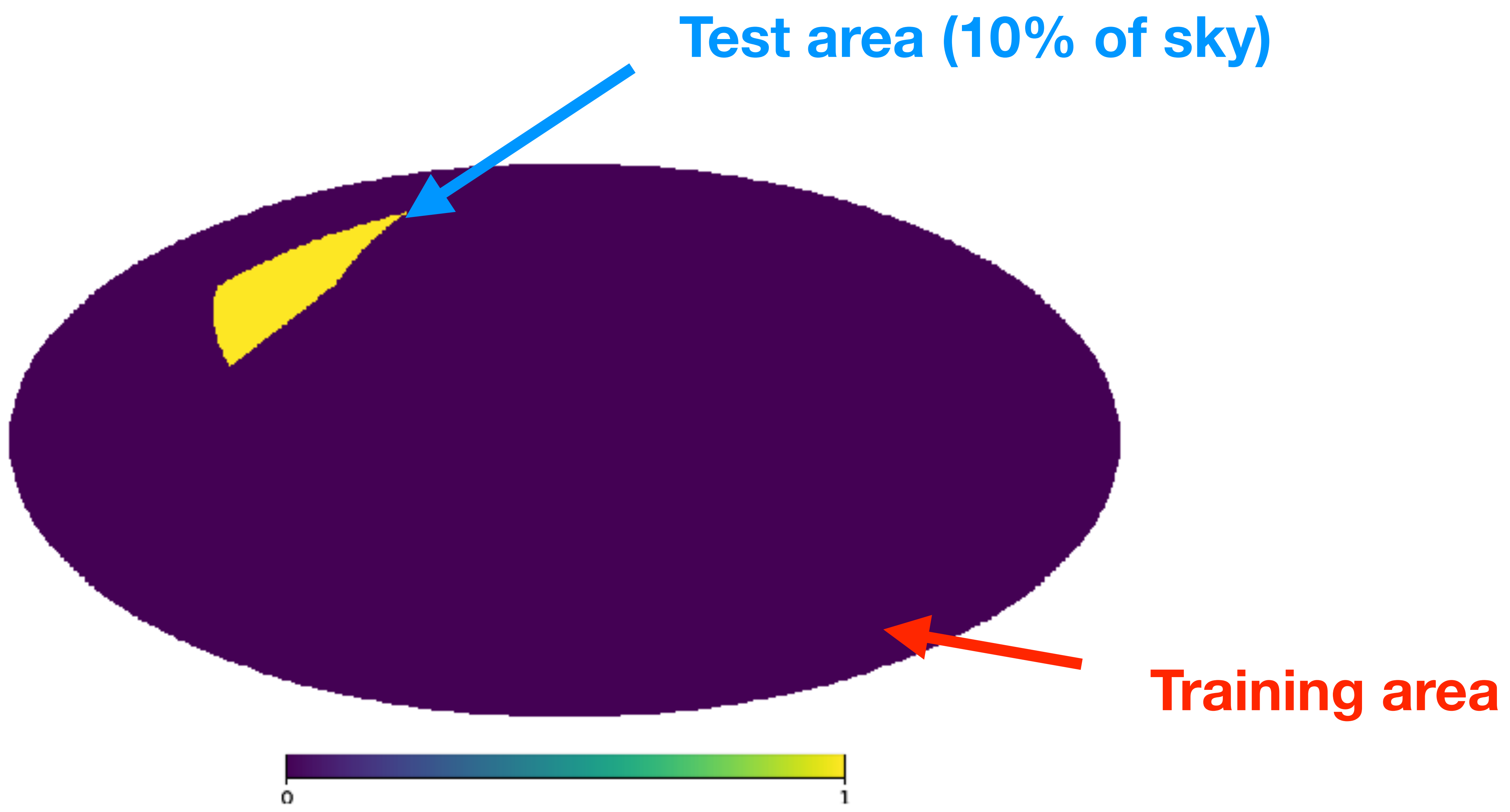
$\longrightarrow \quad \{\bar{C}_i\} = \mathrm{Bi} \circ (1 * \overline{\mathrm{CMB}} + \mathrm{fi} * \overline{\mathrm{SZ}} + \mathrm{gi}(\bar{z}) * \overline{\mathrm{CIB}})$

(gi -> Greybody)

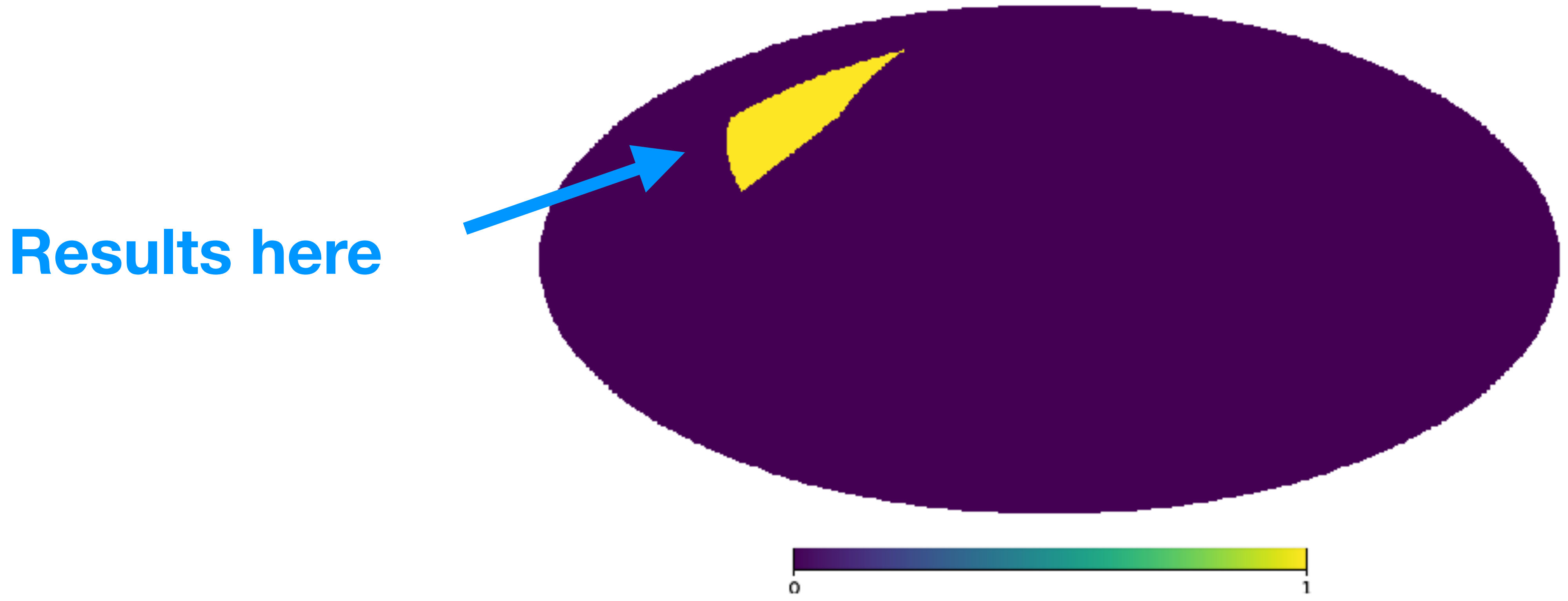
An application to CMB data - CIB removal - SZ extraction

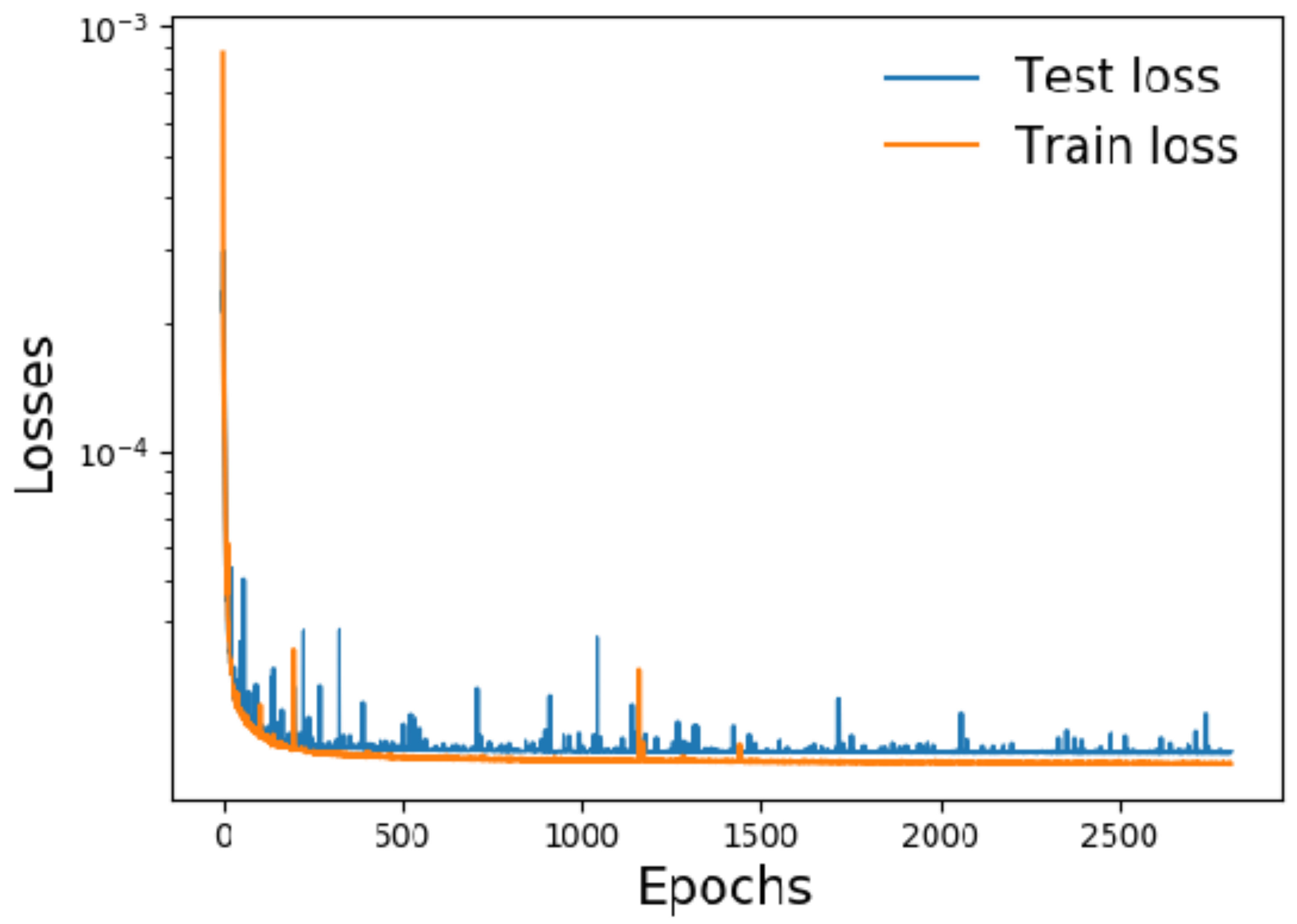
Healpix maps from WebSky numerical simulations (Stein et al., 2020):

- 90, 100, 143, 145, 217, 225, 280, 353, 545 GHz (Planck and SO)
- Healpix nside=4096
- CMB, CIB (all dust IR emission including point sources), SZ
- No noise, no beams
- 100,000 patches of 64x64 pixels (0.8°x0.8°)

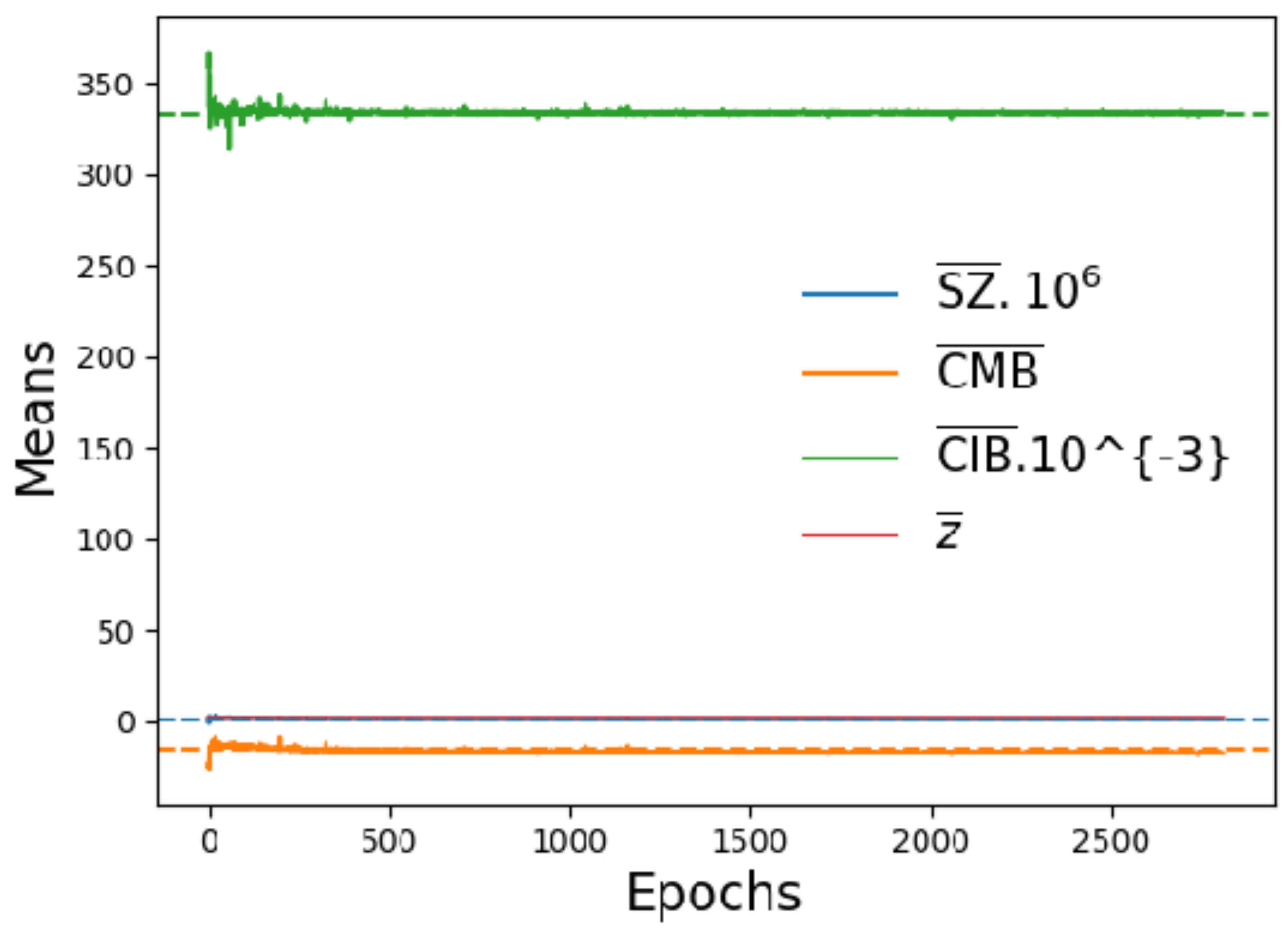


An application to CMB data - CIB removal - SZ extraction

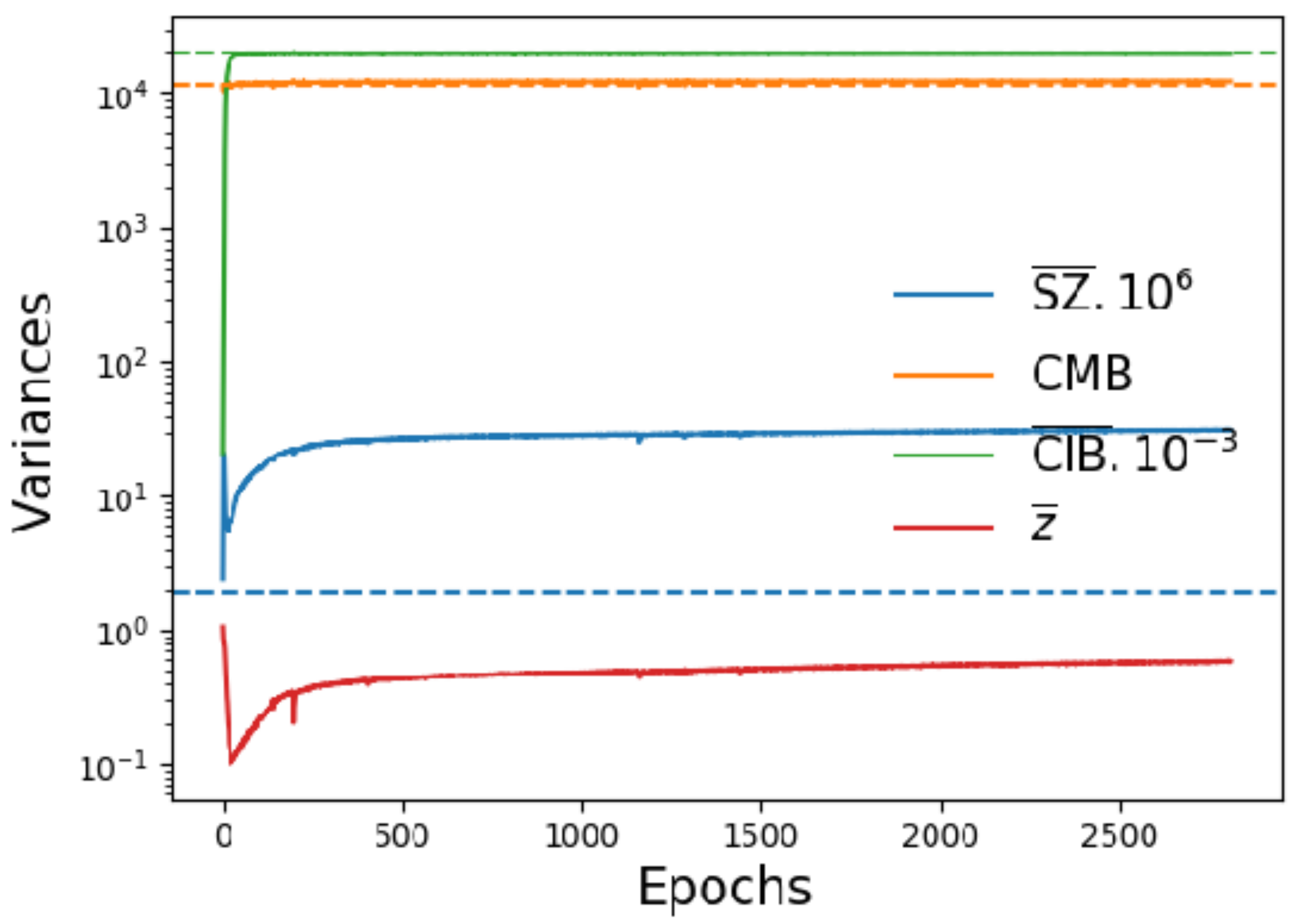




Means:



Variances:

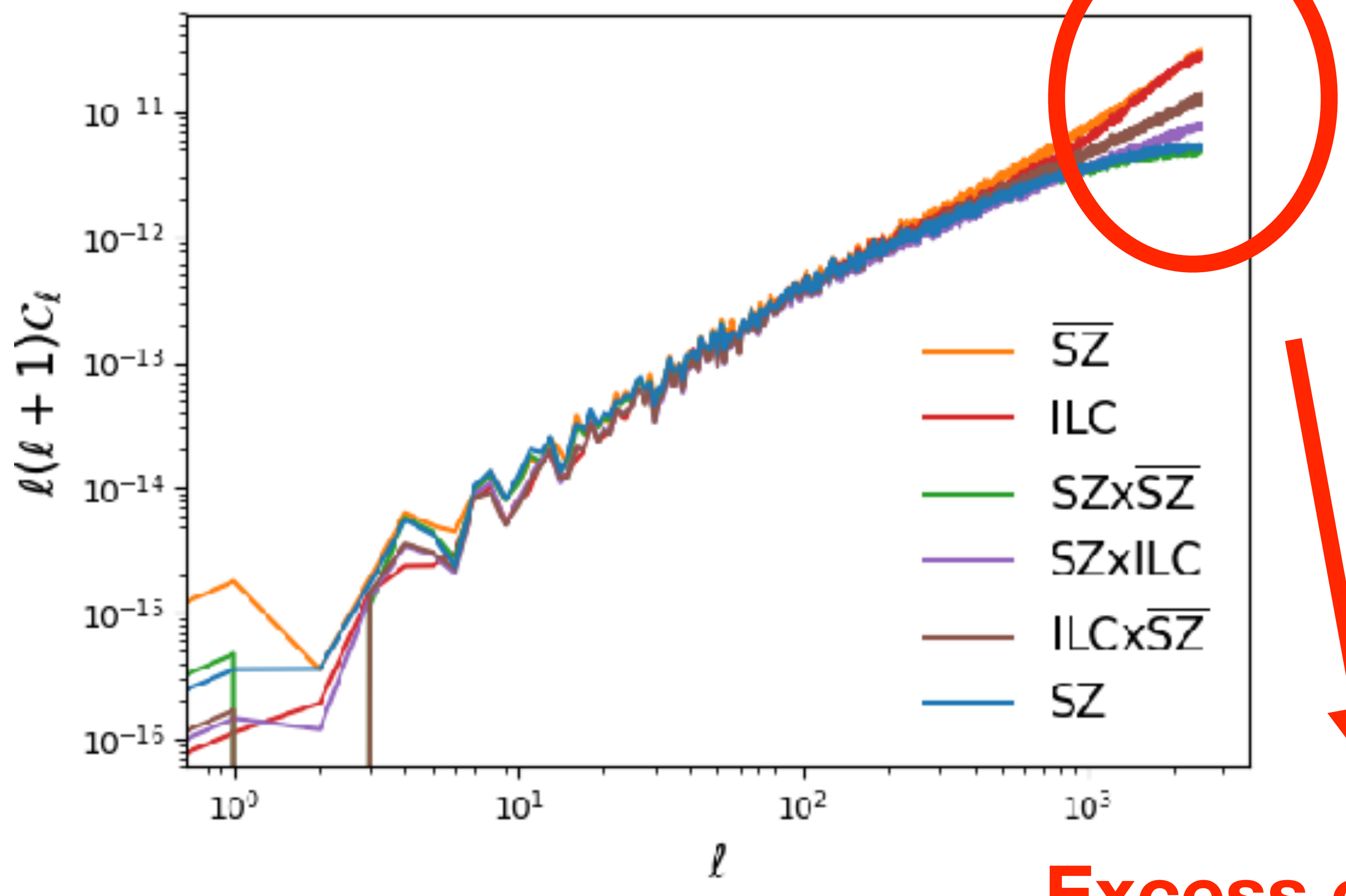


An application to CMB data - CIB removal - SZ extraction

Power-spectra:

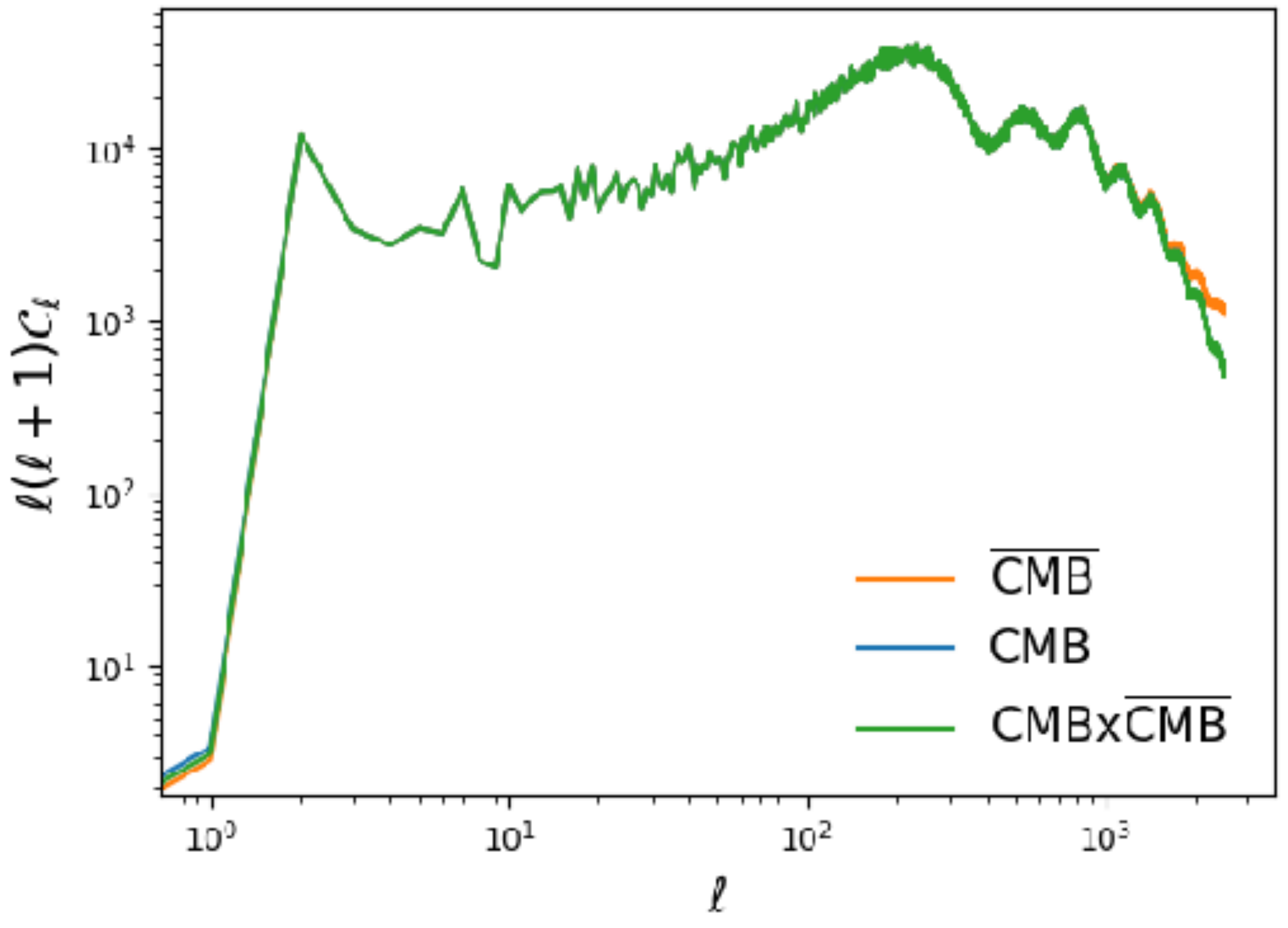
Comparison with MILCA applied on very same maps

SZ:

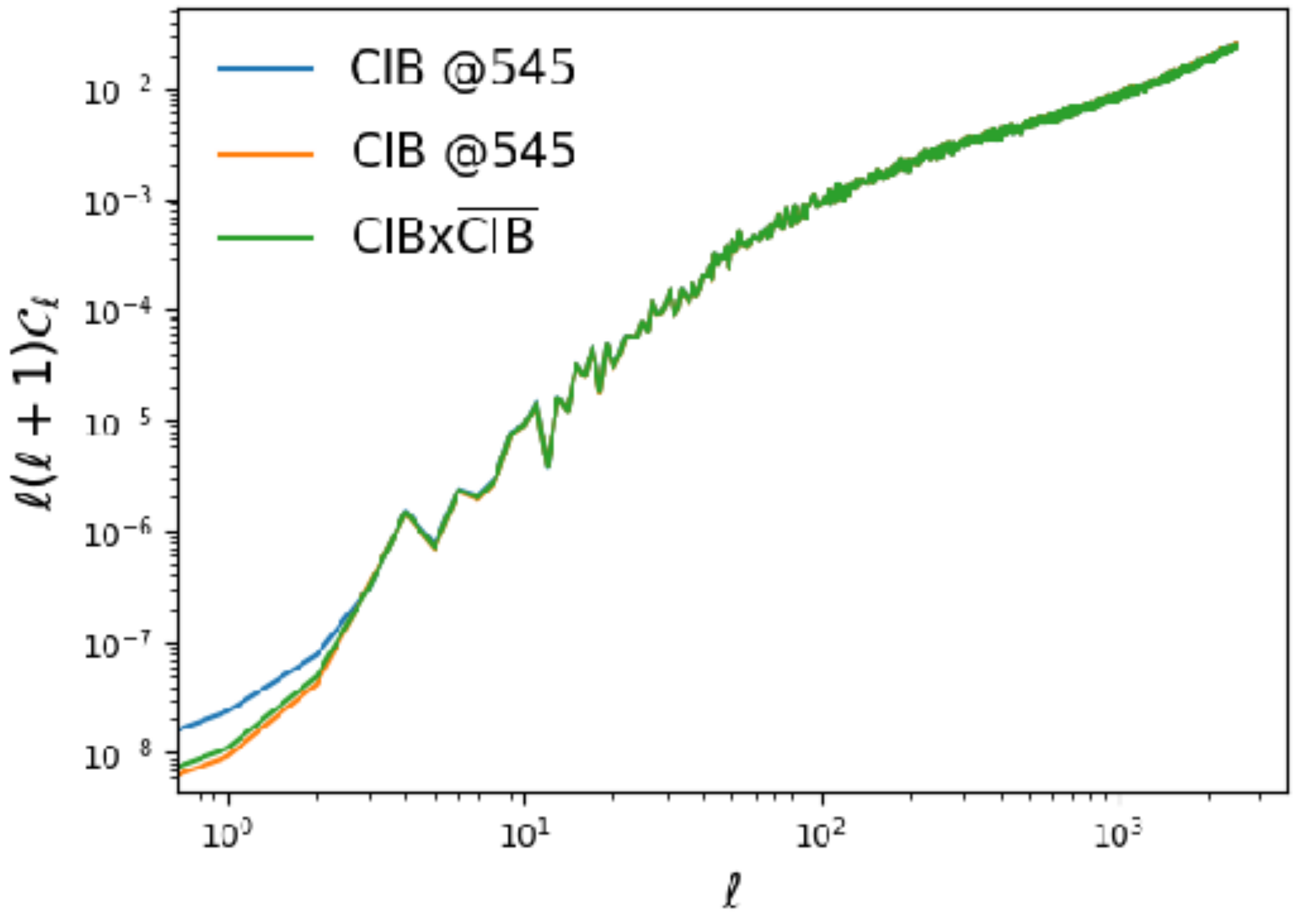


Excess of signal in SZxMILCA

CMB:



CIB:

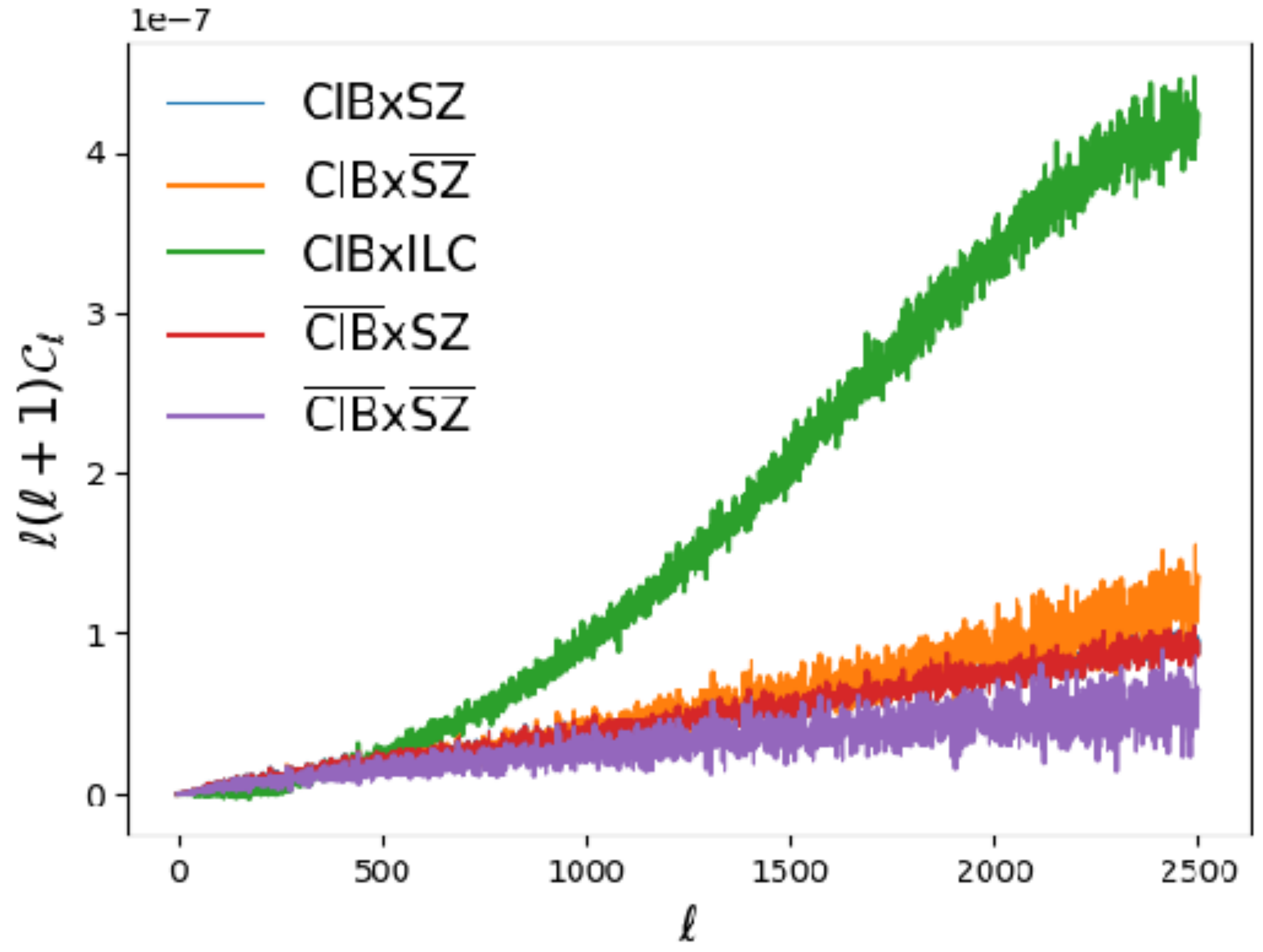


An application to CMB data - CIB removal - SZ extraction

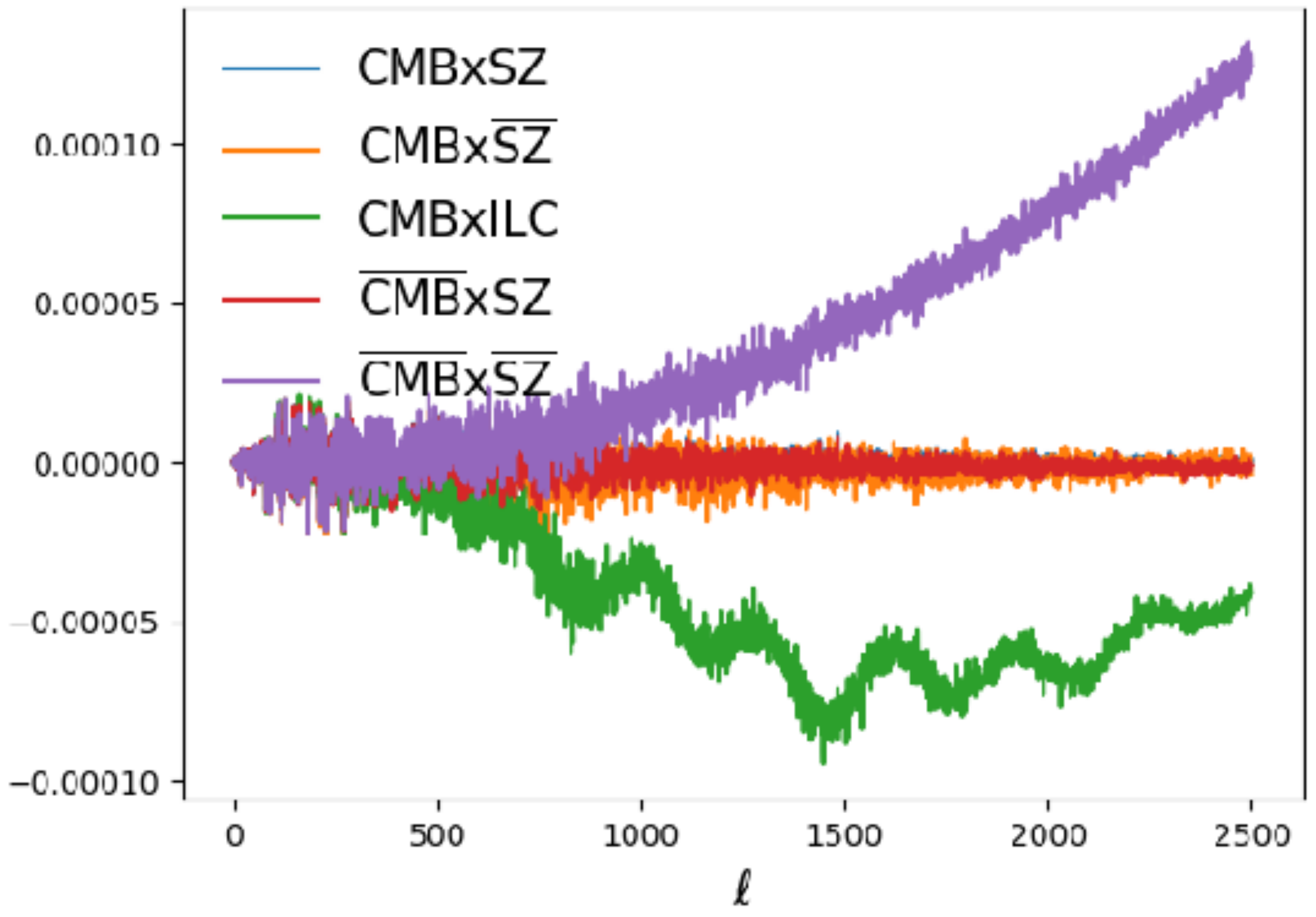
Cross-spectra:

SZ map less contaminated by other components

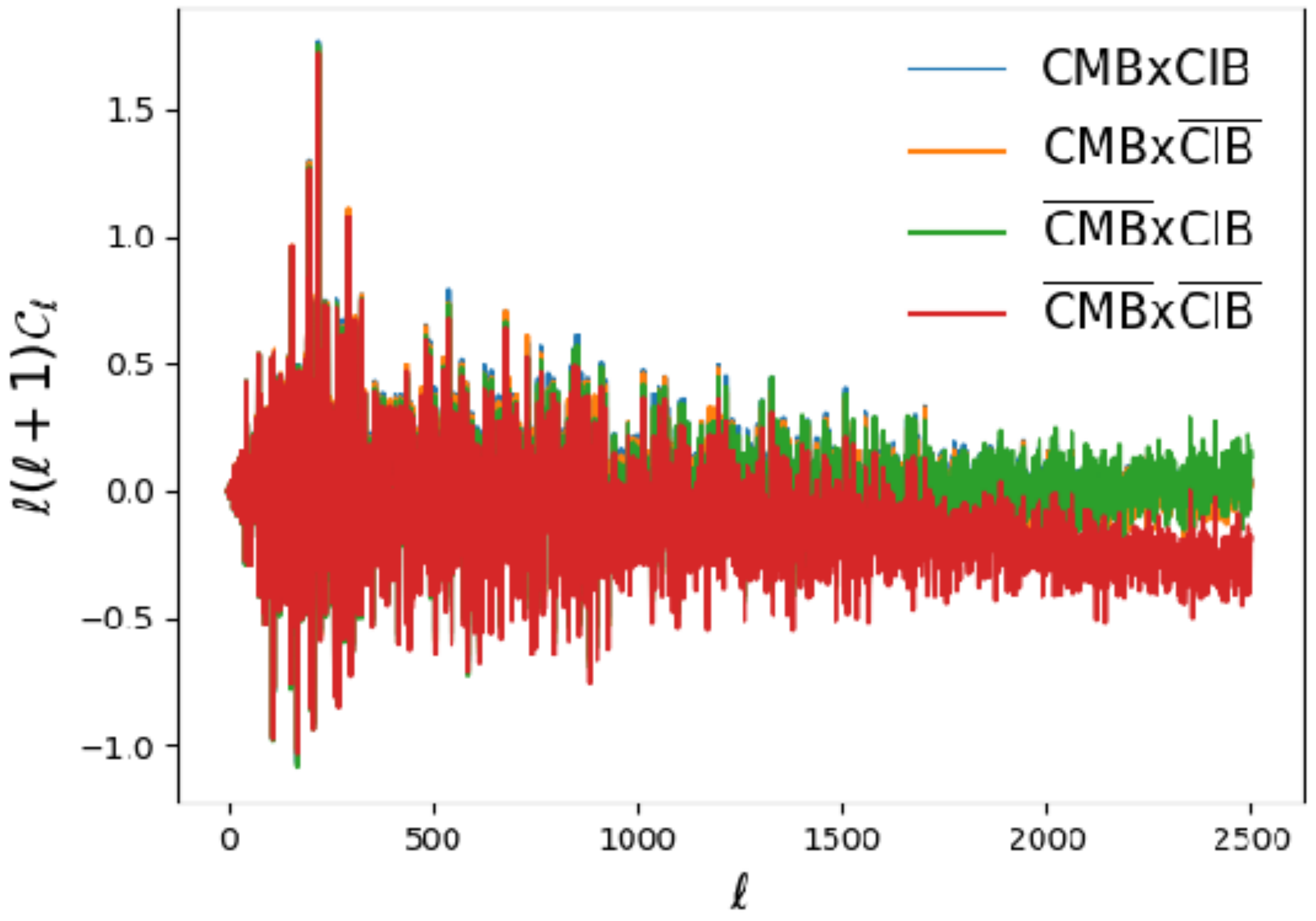
CIBxSZ:



CMBxSZ:

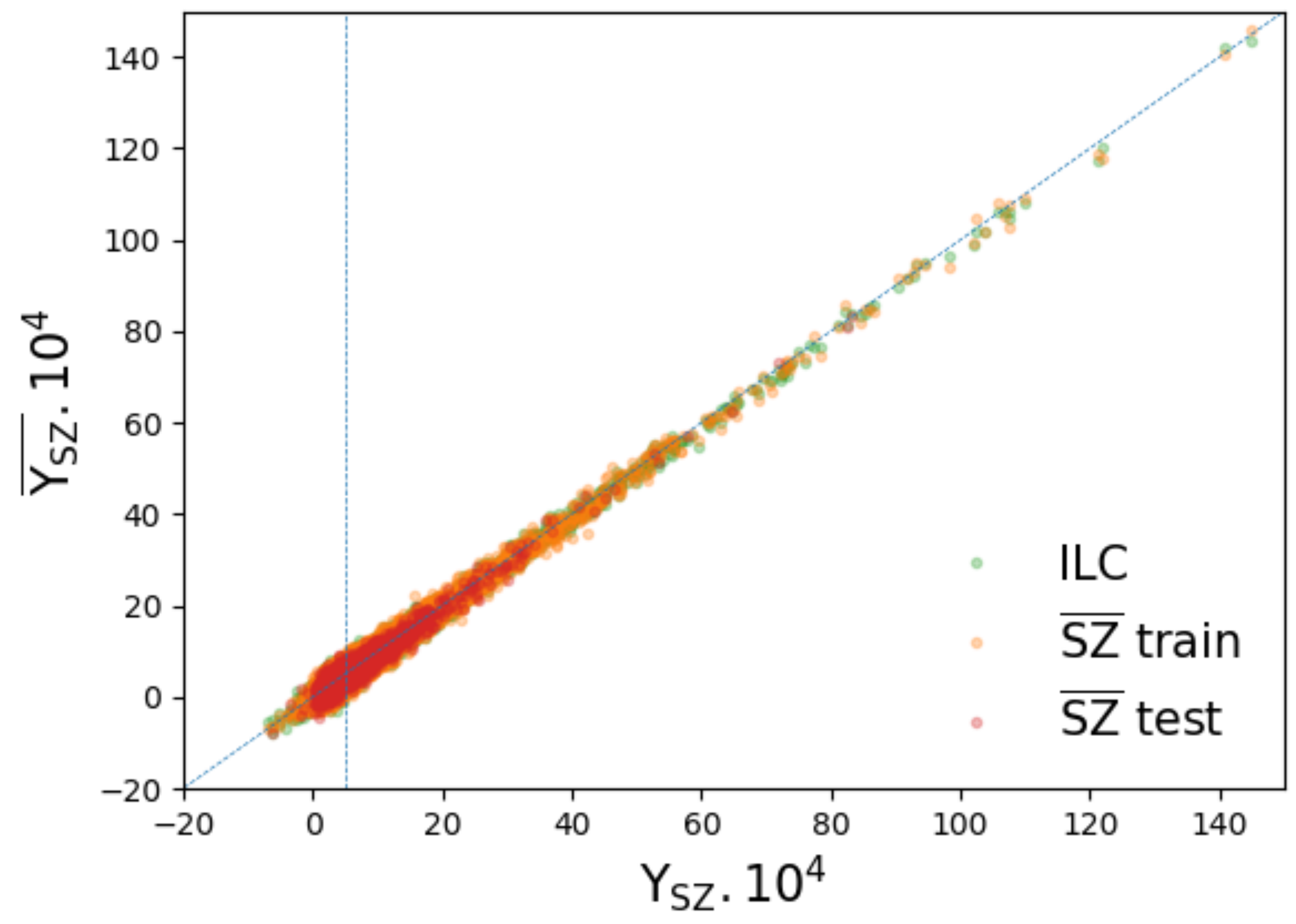


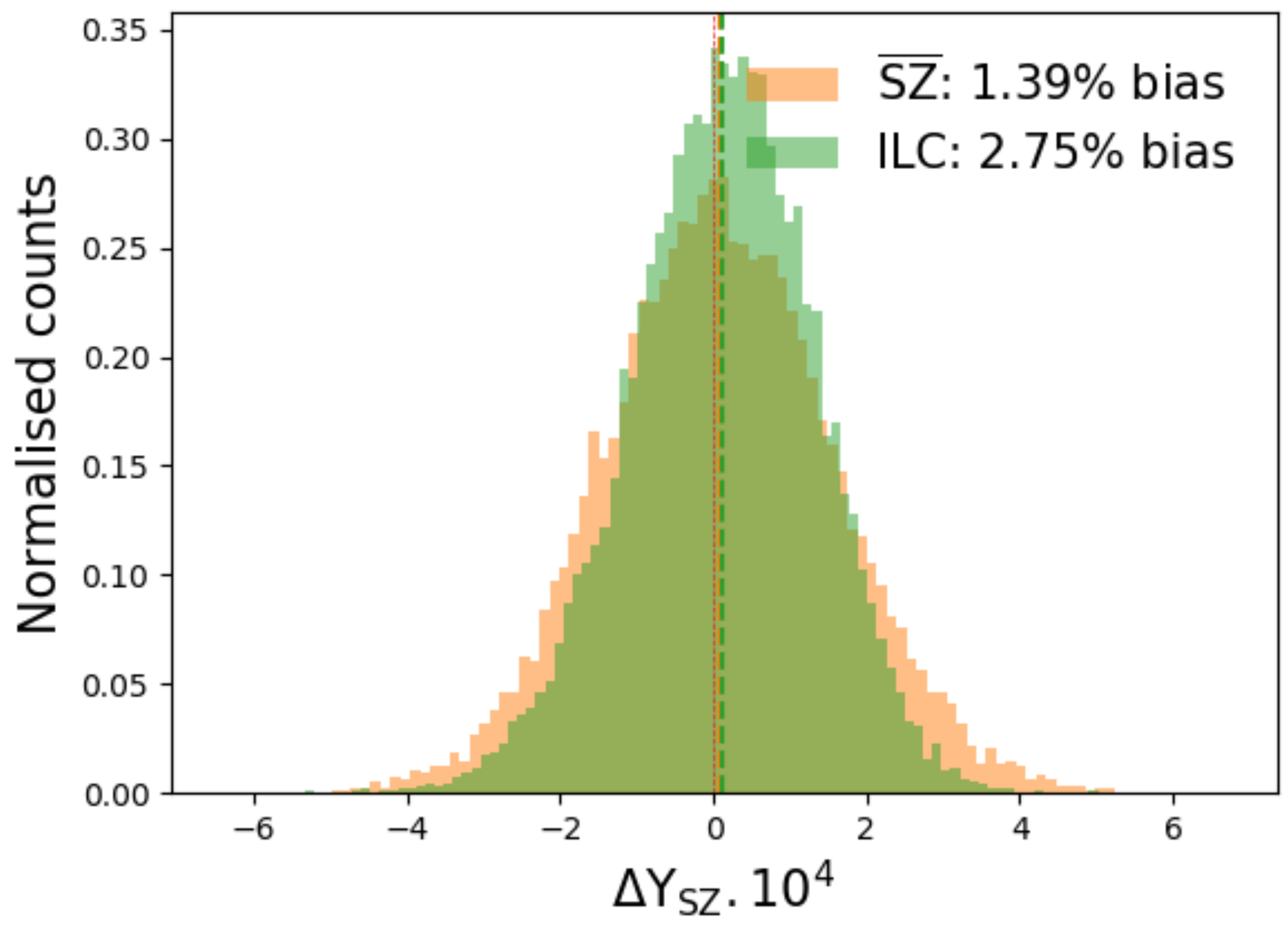
CMBxCIB:



An application to CMB data - CIB removal - SZ extraction

Focus on SZ fluxes around clusters:





Future applications

- CIB removal for CO/CII studies (Sia's talk)
- Single Channel Mixture for CO/CII separation?
- Foreground removal in radio (SKA) for HI and/or EoR?