A Sphere Packing Approach to Design Multiplexed Multispectral Filter Arrays

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PONTIFICIA UNIVERSIDAD CATÓLICA DE VALPARAÍSO

OPTOLAB

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Motivation

Agriculture

- Smart Farming
- Weed Control
- Disease Detection

Medical Imaging

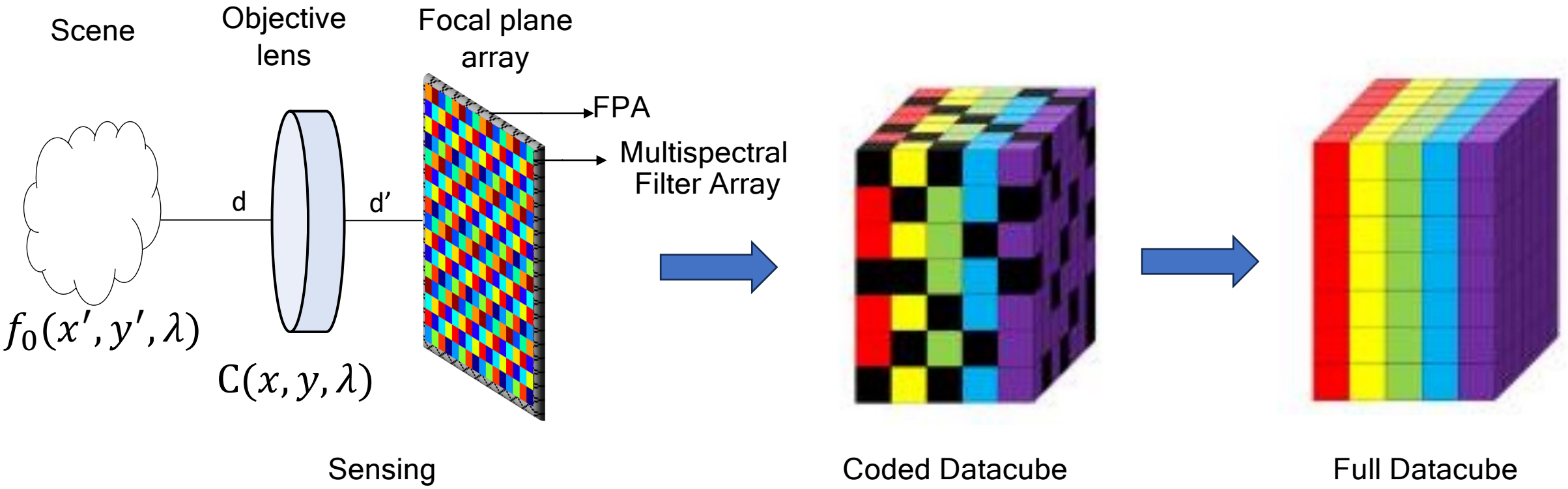
- Surgery
- Endoscopy
- Laparoscopy
- Smart Pills
- Tissue regeneration monitoring

Remote Sensing

- Global scale image analysis
- Environmental recovery
- Emission monitoring
- Event detection and disaster management

Source: IMEC

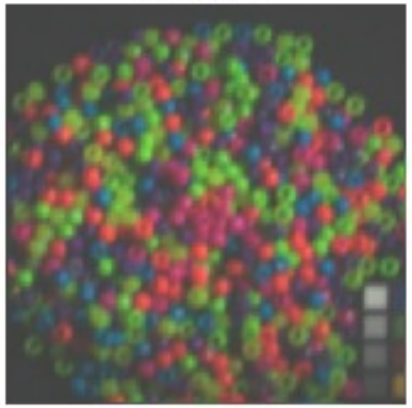
Acquisition Model



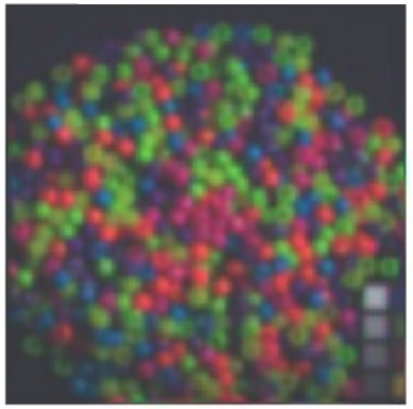
Motivation: Subsampling Problems in Higher Bands

Ground Truth

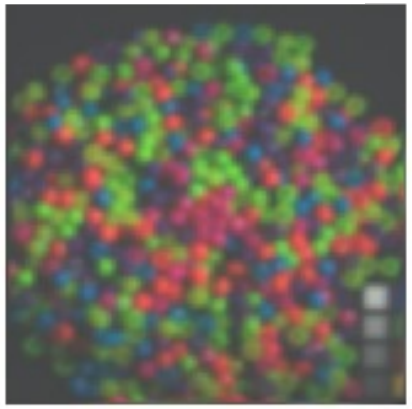
16 Bands

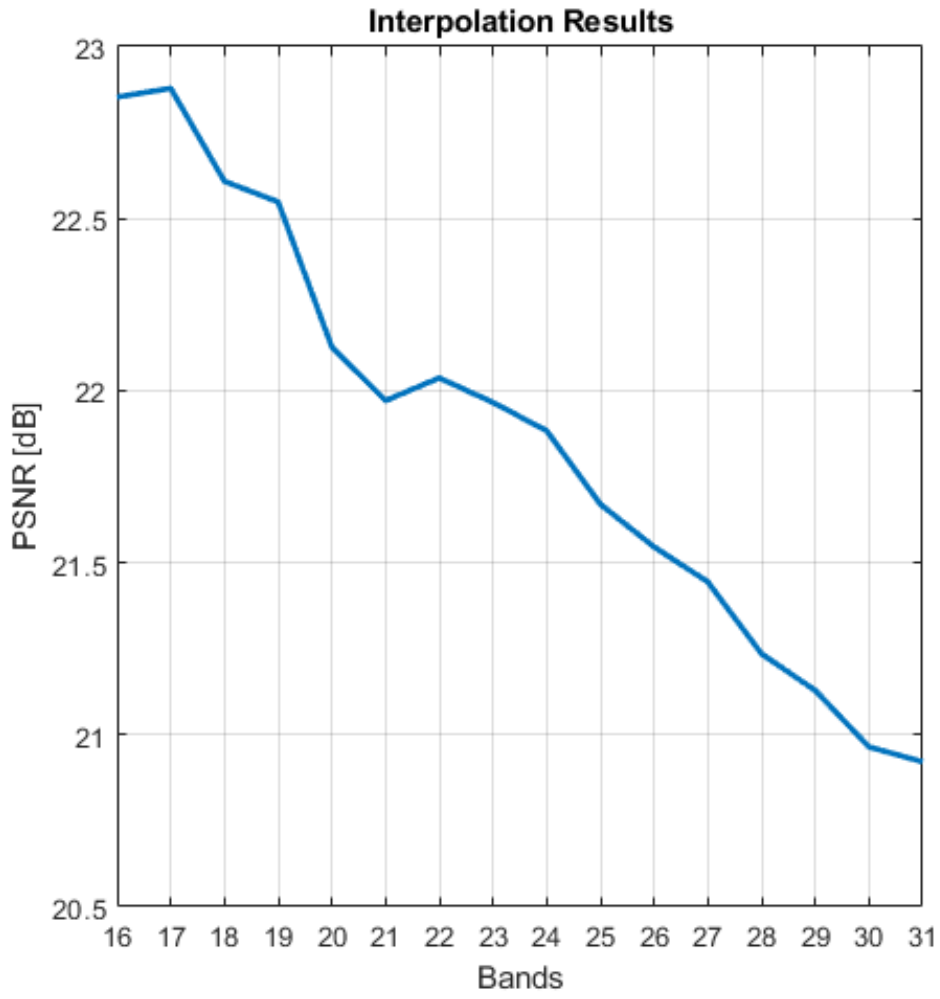


25 Bands



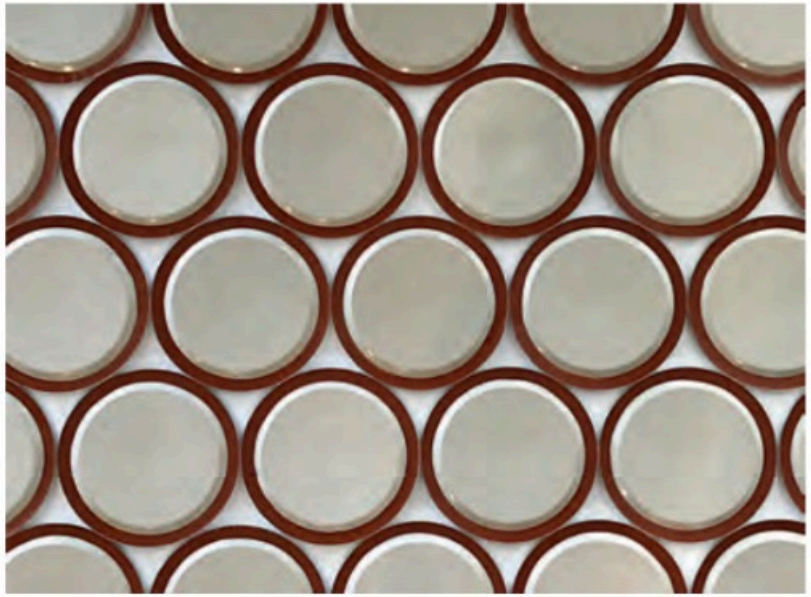
31 Bands





What is Sphere Packing?

2D

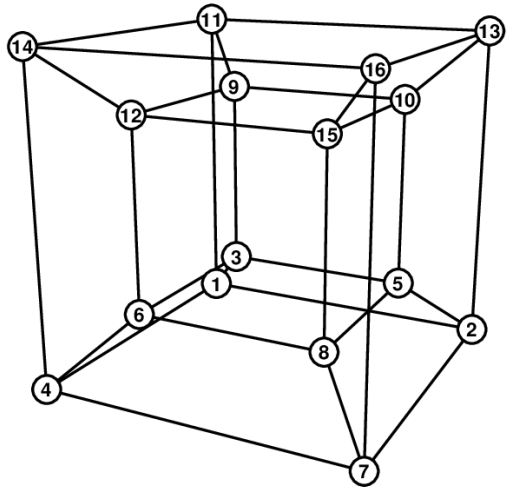


2D Density = 0.9061

3D

3D Density = 0.7404

4D



4D Density = 0.6169

Sphere Packing Density in Higher Dimensions

The distance function of L spheres is

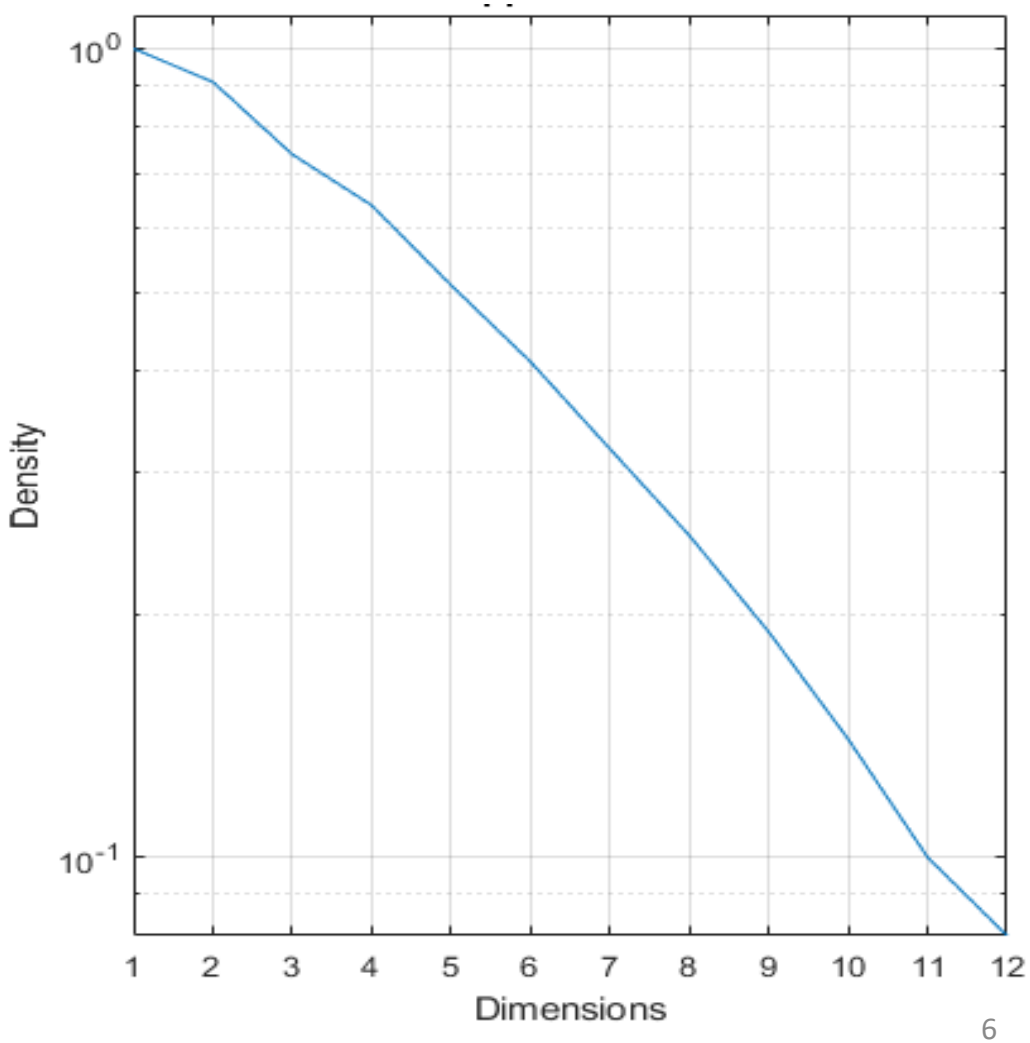
$$d^*(L) = \max(\min_{1 \le l_1 < l_2 \le L}, D_{l_1,l_2}),$$

where $D_{l_1,l_2} = \|\mathbf{p}_{l_1} - \mathbf{p}_{l_2}\|_2^2$ is the all pairwise distance matrix, $l_1, l_2 \in \{0, \ldots, L-1\}$, $\mathbf{p}$ are the centers of the spheres and index the l_1^{th}, and l_2^{th} spheres.

The density of a lattice is given by

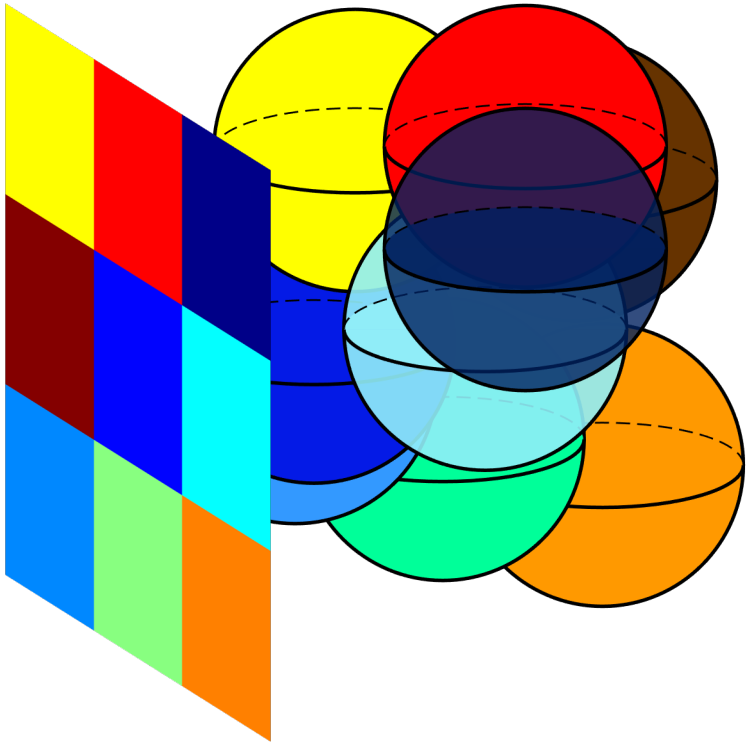
$$\frac{\text{Vol}(B_r^n)}{\text{Vol}(\mathbb{R}^n/\Lambda)}$$

where $\text{Vol}(B_r^n) = \frac{\pi^{n/2}}{(n/2)!} r^n$ is the volume of the n dimensional ball, $\text{Vol}(\mathbb{R}^n/\Lambda) = \sqrt{\det(\Lambda)}$ is the volume of the lattice.

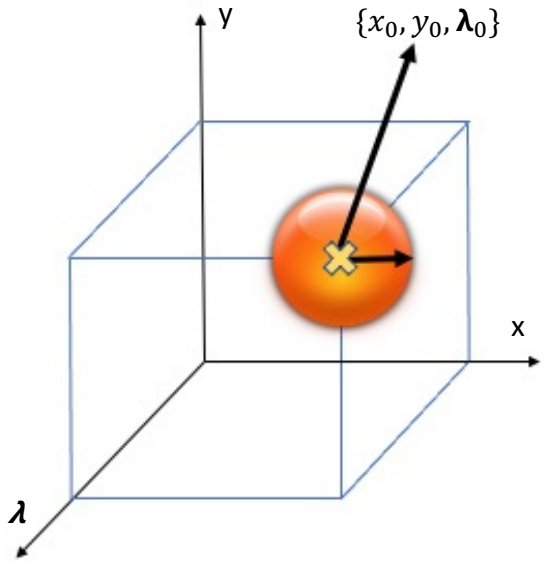


Multiplexed Multispectral Sphere Packing Design

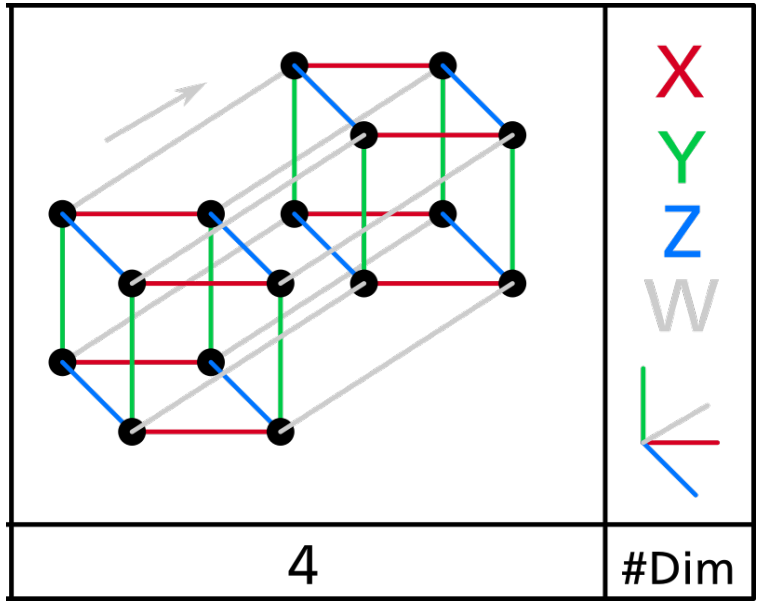
3D Sphere Packing
Single Filter MSFA (1)



Single Sphere

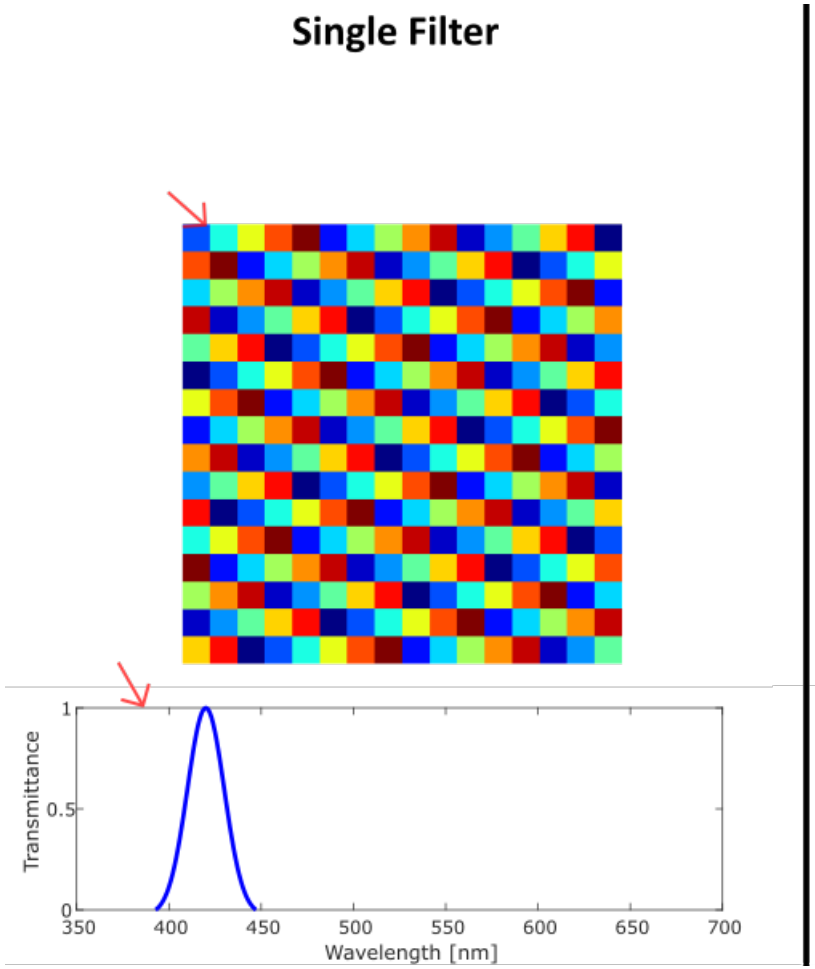


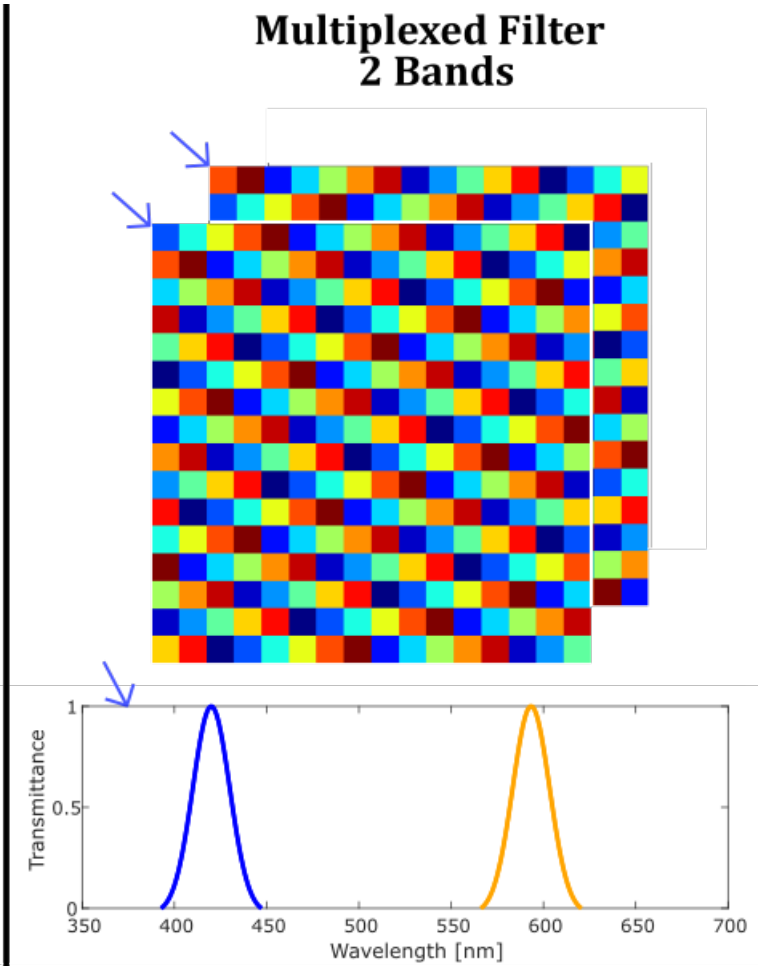
4D Structure

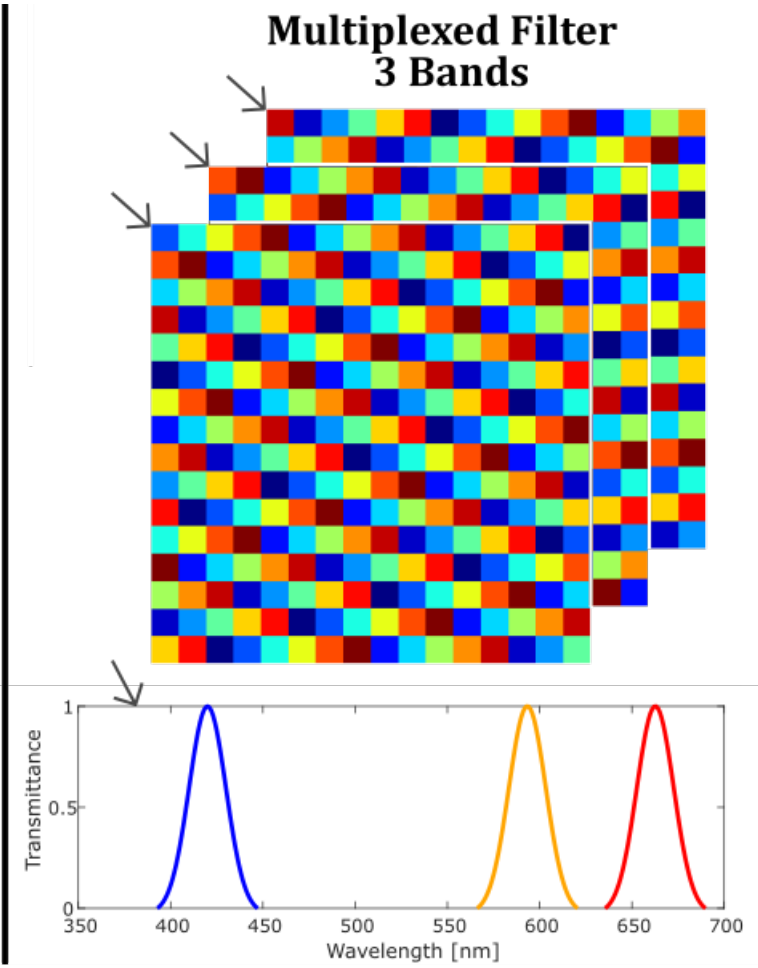


(1) N. Diaz, A. Alvarado, P. Meza, F. Guzmán and E. Vera, "Multispectral Filter Array Design by Optimal Sphere Packing," in IEEE Transactions on Image Processing

Single Filter vs Multiplexed Filter

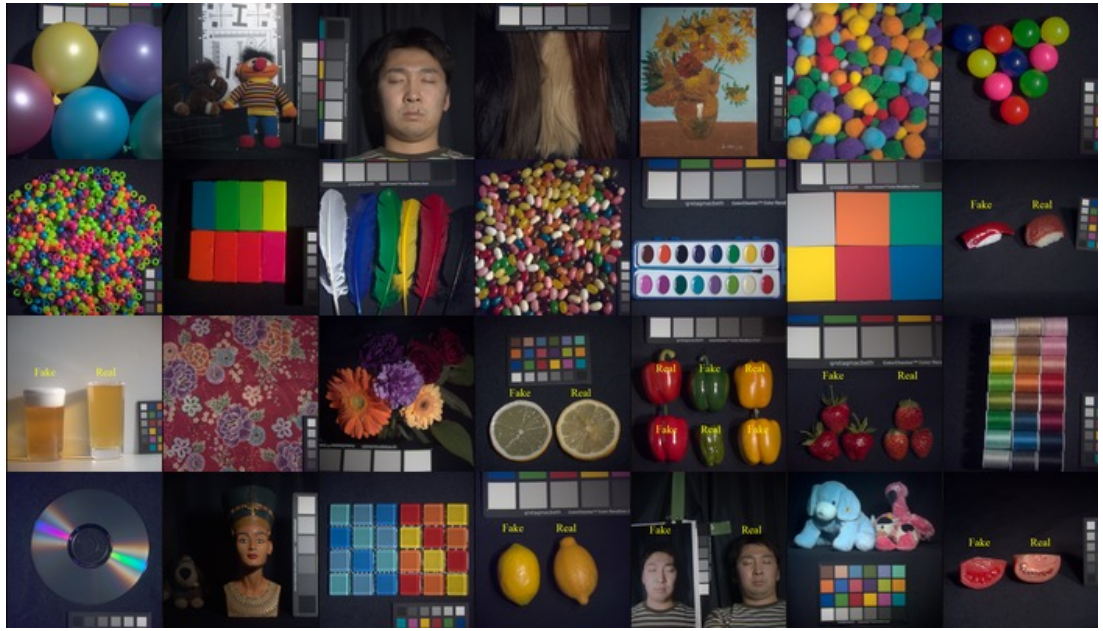






Experiment

- Cave Dataset(2) with resolution 256x256
- 16 Spectral bands
- Algorithms:
  - GAP-TV (3)
  - TRev-SCI (4)
- Masks:
  - Random
  - Sphere Packing



(2) F. Yasuma, T. Mitsunaga, D. Iso and S. K. Nayar, "Generalized Assorted Pixel Camera: Postcapture Control of Resolution, Dynamic Range, and Spectrum," in IEEE Transactions on Image Processing
(3) Liu, X. Yuan, J. Suo, D. J. Brady and Q. Dai, "Rank Minimization for Snapshot Compressive Imaging," in IEEE Transactions on Pattern Analysis and Machine Intelligence
(4) Z. Cheng et al., "Memory-Efficient Network for Large-scale Video Compressive Sensing," 2021 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)

Results with TRev-SCI

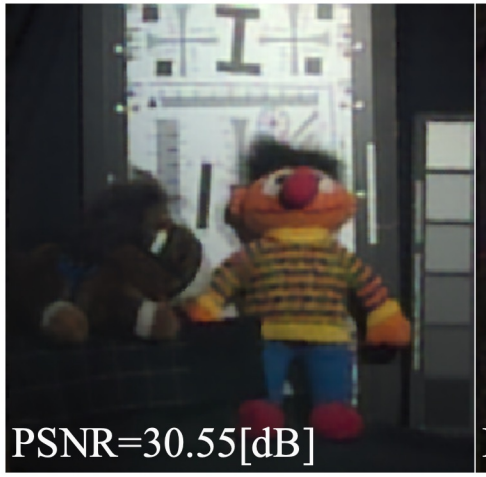
Ground Truth

OSP 1 Filter

OSP 2 Filters

OSP 3 Filters

RND 1 Filter



RND 2 Filters

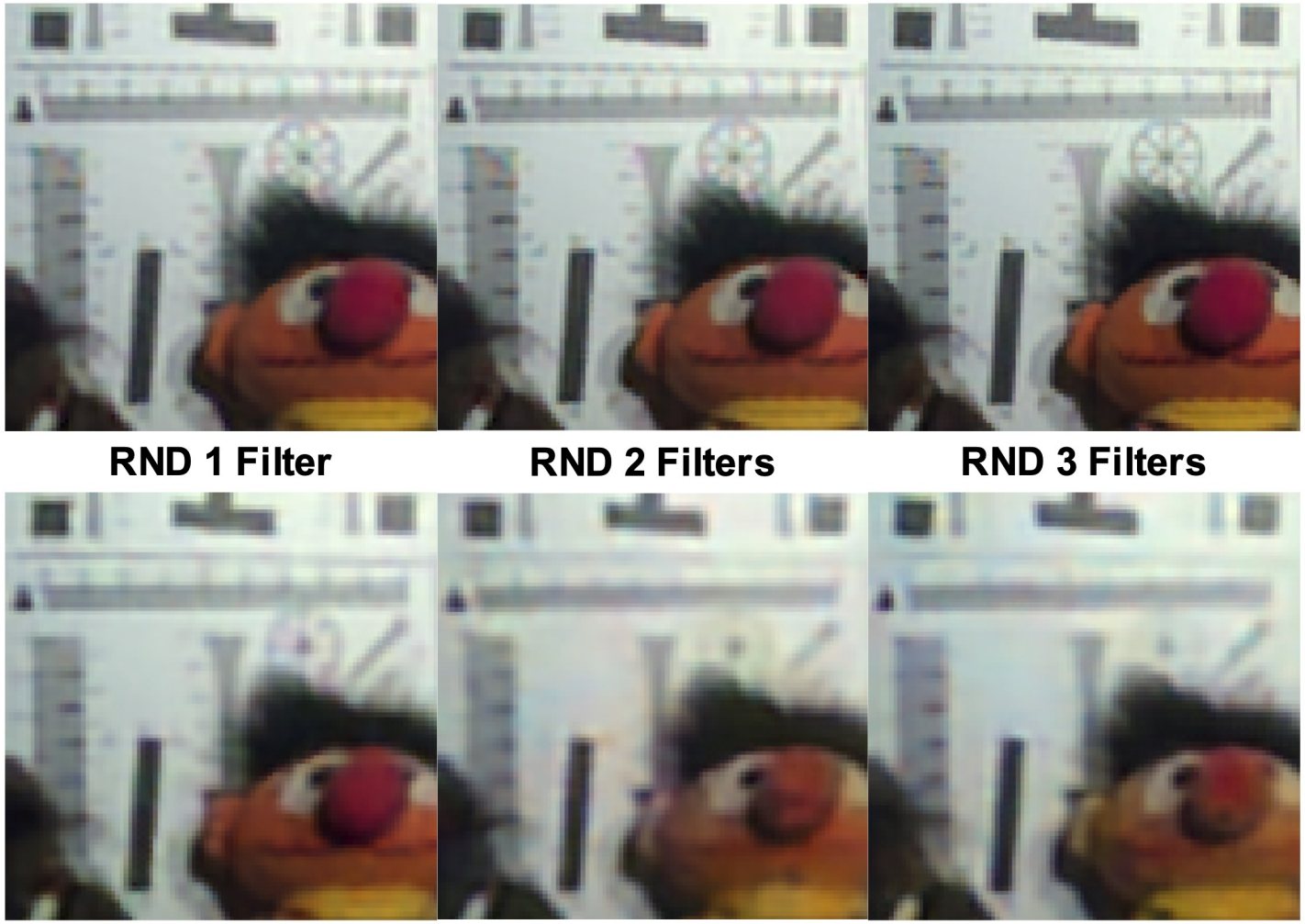
RND 3 Filters

Results with TRev-SCI

Ground Truth

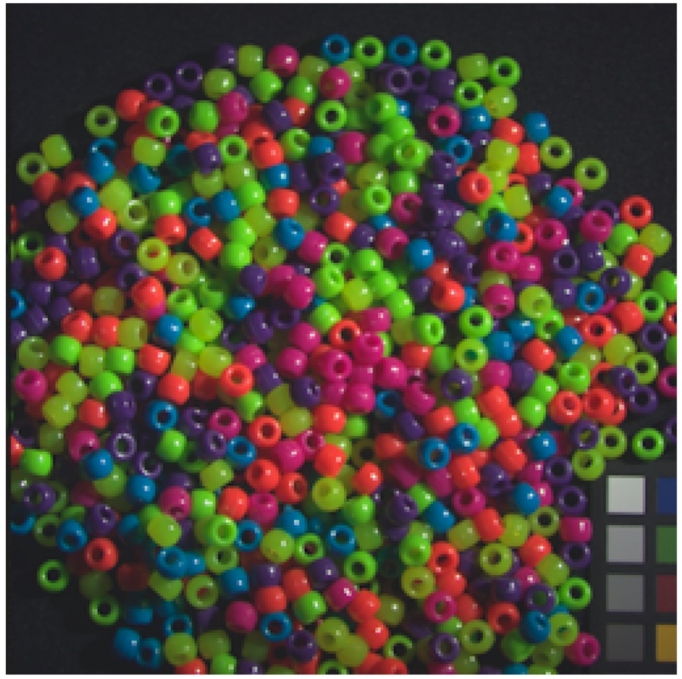
OSP 1 Filter | OSP 2 Filters | OSP 3 Filters

RND 1 Filter | RND 2 Filters | RND 3 Filters



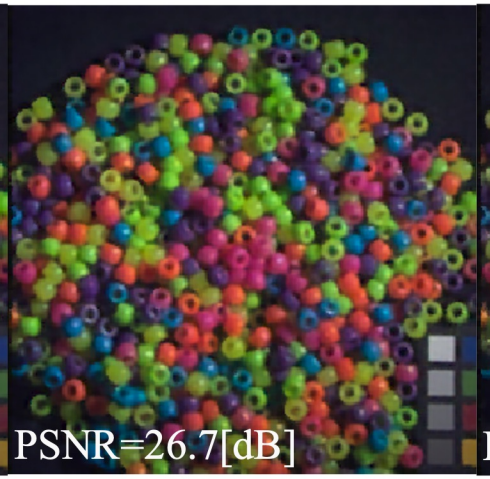
Results with TRev-SCI

Ground Truth

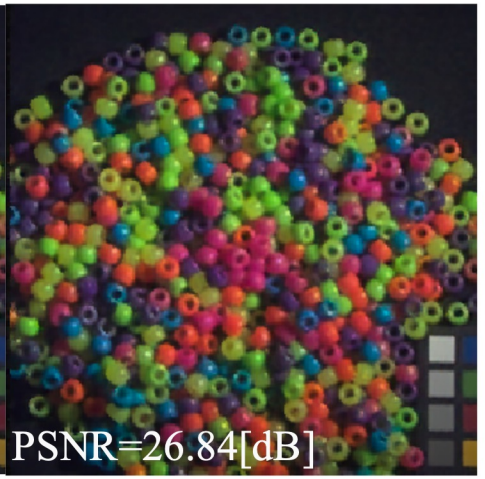


OSP 1 Filter

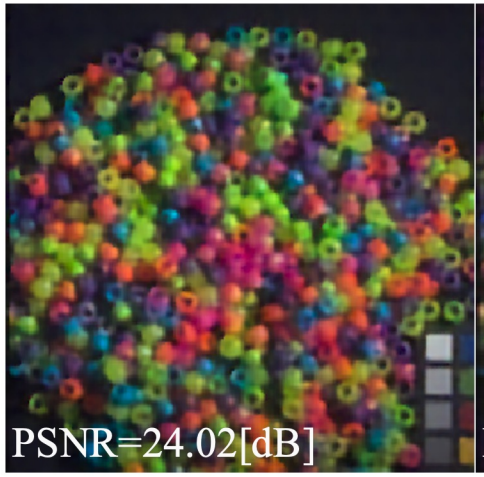
OSP 2 Filters



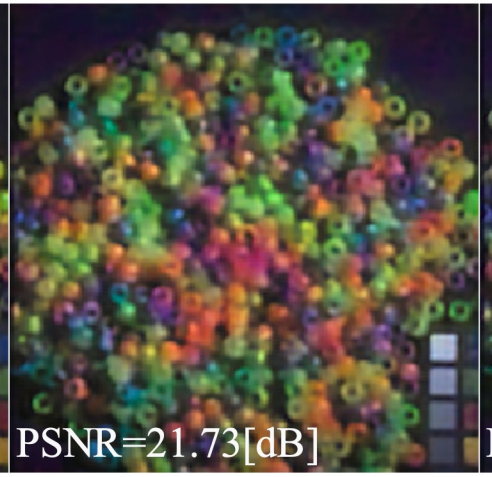
OSP 3 Filters



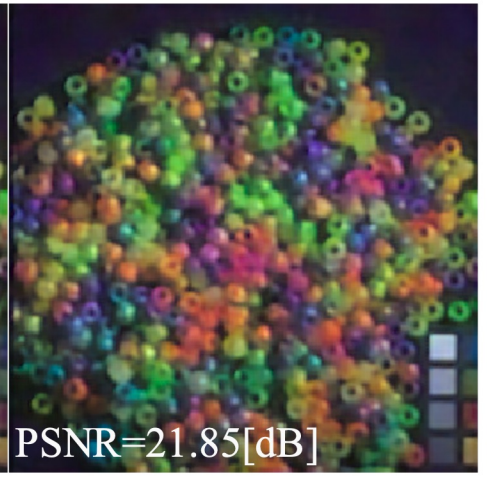
RND 1 Filter



RND 2 Filters

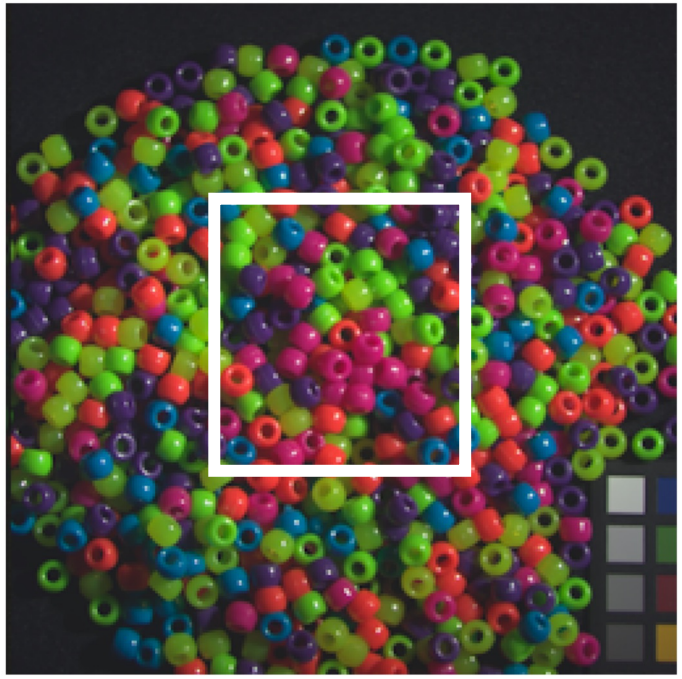


RND 3 Filters

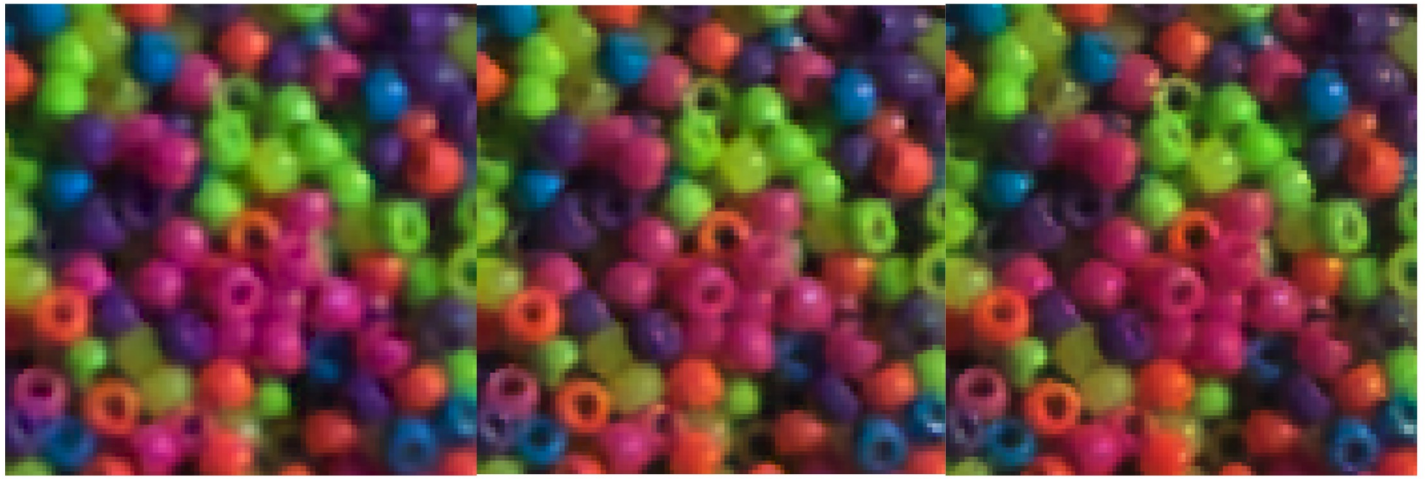


Results with TRev-SCI

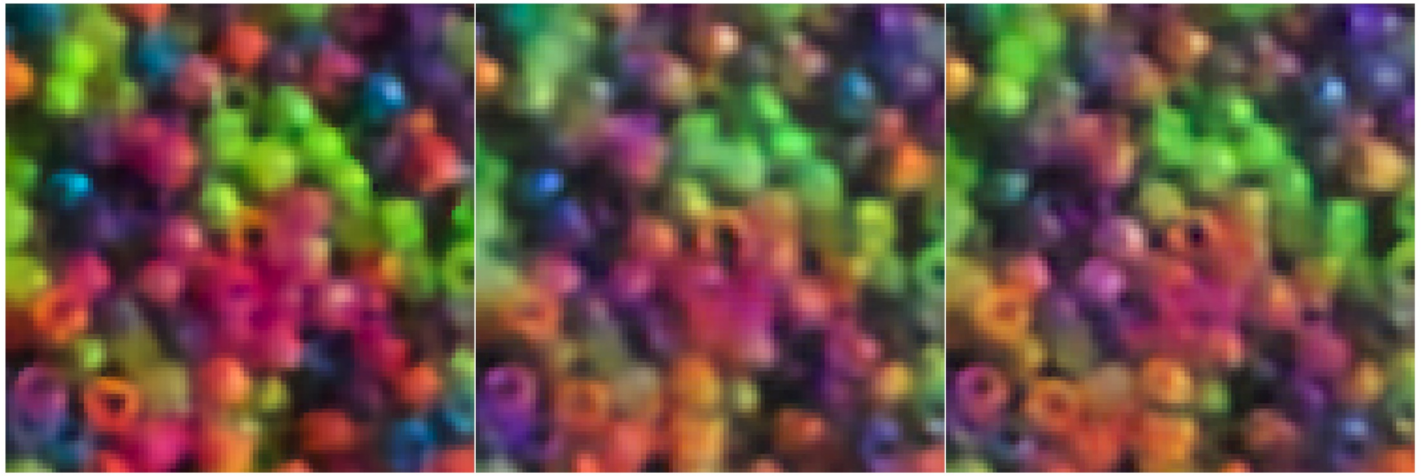
Ground Truth



OSP 1 Filter | OSP 2 Filters | OSP 3 Filters



RND 1 Filter | RND 2 Filters | RND 3 Filters

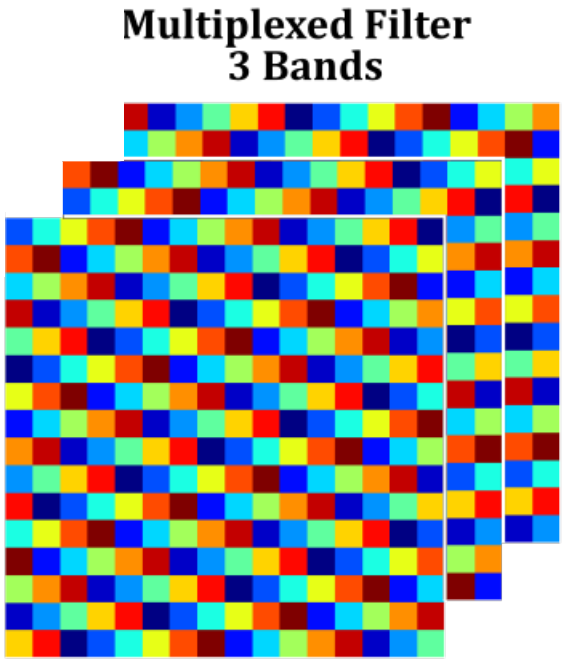


Results


PSNR
[dB]
37
35
33
31
29
27
25
RND1
OSP1
RND2
OSP2
RND3
OSP3
GAP-TV
Trev-SCI
SSIM
1
0,95
0,9
0,85
0,8
0,75
RND1
OSP1
RND2
OSP2
RND3
OSP3
GAP-TV
Trev-SCI
SAM
0,3
0,25
0,2
0,15
0,1
0,05
0
RND1
OSP1
RND2
OSP2
RND3
OSP3
GAP-TV
Trev-SCI

Conclusions

- We designed a novel method to design multiplexed MSFAs by using an optimal sphere packing approach, improving the spatio-spectral sampling and the signal-to-noise ratio of the measured multiplexed datacube.
- Reconstructions show promising results either using traditional reconstruction methods such as GAP-TV or novel deep neural networks.
- The results show that an OSP approach with 3 multiplexing is the optimum for multiplexing filters.
- We are working on the experimental demonstration of our new multiplexed MSFAs.



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Gobierno de Chile

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Thanks for your attention

Questions?

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