



# IEEE RESEARCH AND APPLICATIONS OF PHOTONICS IN DEFENSE

11-13 September 2023 • Miramar Beach, FL, USA

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## Compressive Spectral-Video by Optimal 3D/4D-Sphere Packing

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*Chile*



PONTIFICIA UNIVERSIDAD  
**CATOLICA**  
DE VALPARAISO



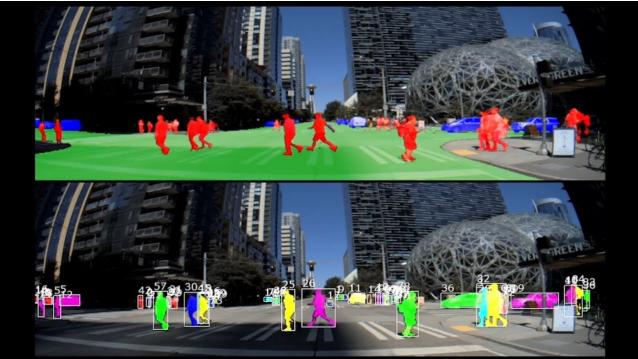
12 September 2023

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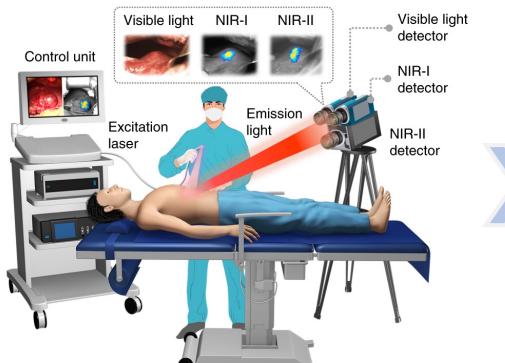
IEEE  
Photonics  
Society

IEEE

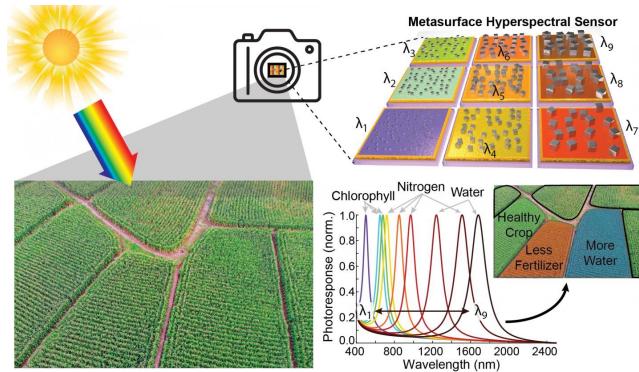
# Applications of Spectral-Video



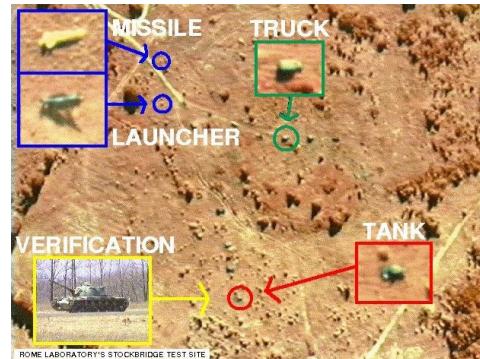
Self-driving car



Guided surgery

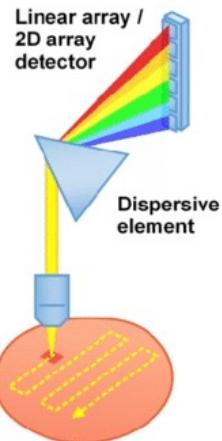
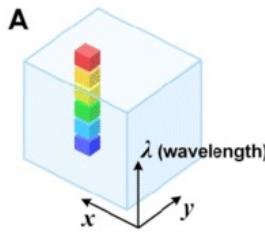


Smart farming

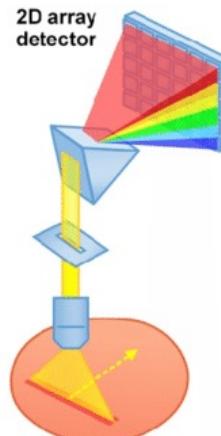
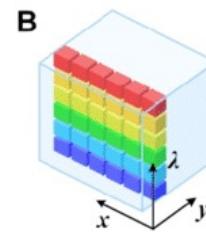


Camouflage detection

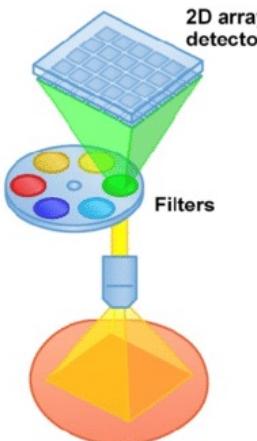
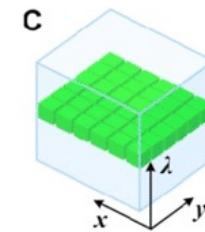
# Traditional Approaches to Capture Spectral Images



Spectral res: high  
Speed: low



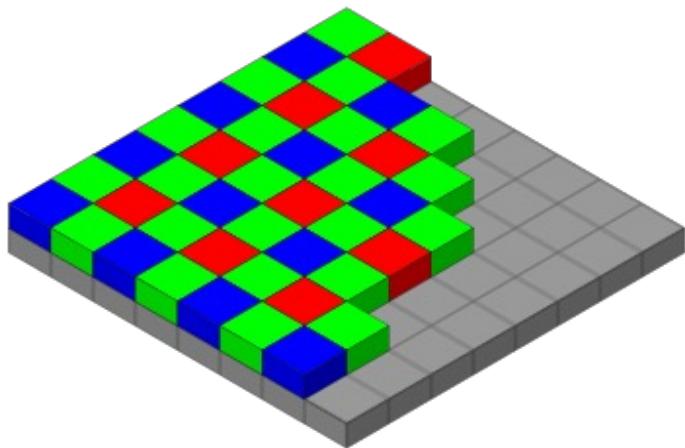
Spectral res: high  
Speed: medium



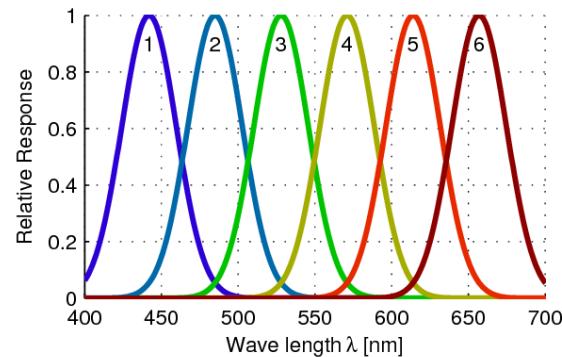
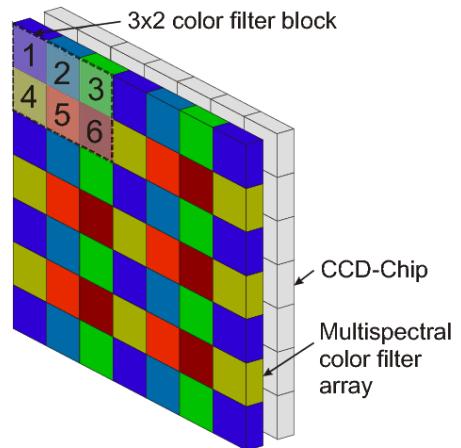
Spectral res: low – high  
Speed: medium / high

# Multispectral Filter Arrays (MSFA)

Bayer Filter



Multispectral Filter



# MSFA Design using Sphere Packing

Random

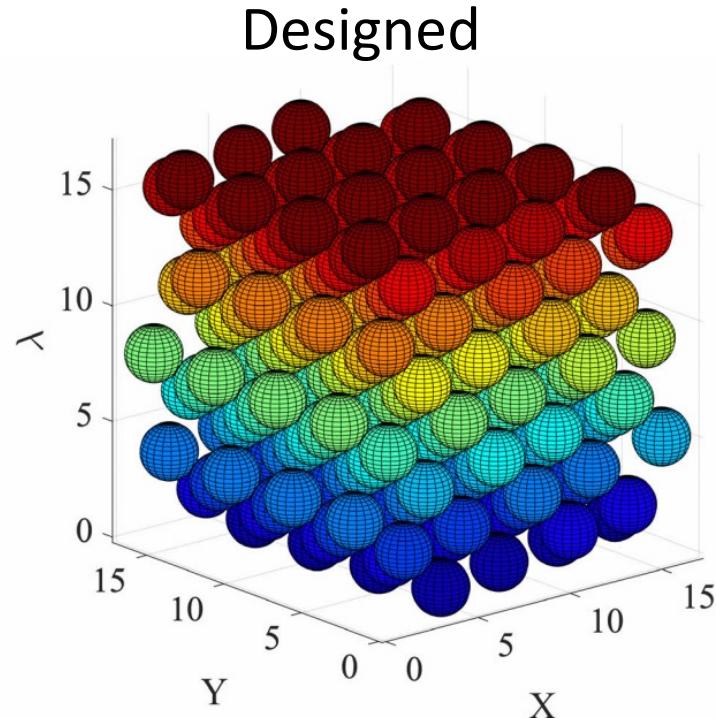
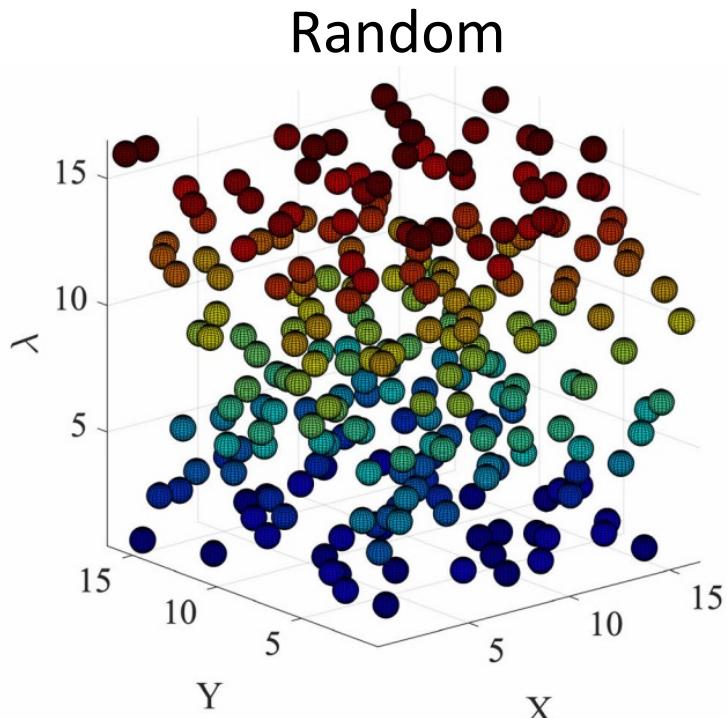
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16	7	1	6	14	8	11	13	3	2	15	4	10	9	5	12
16	9	5	4	10	7	1	6	12	8	3	2	15	11	13	14
9	7	13	15	10	3	12	2	1	16	14	6	8	4	5	11
15	2	4	11	13	1	16	6	14	5	10	9	7	12	8	3
14	7	11	9	6	4	3	2	15	8	13	16	10	12	5	1
7	15	5	11	10	14	13	4	8	9	12	16	3	2	6	1
2	6	1	5	9	11	3	4	16	8	13	10	14	7	12	15
7	15	10	12	1	9	16	11	3	8	6	13	14	5	2	4
6	12	2	14	7	4	1	15	11	5	16	10	13	8	3	9
11	8	12	14	15	7	1	10	13	4	3	9	16	2	5	6
5	2	13	3	15	1	9	6	7	12	8	14	10	11	16	4
6	9	2	15	7	13	16	12	10	4	1	8	11	14	3	5
7	1	12	13	16	3	2	8	14	11	6	15	5	9	4	10
10	11	6	12	13	14	2	9	1	15	4	16	3	7	5	8

Designed

9	12	15	2	5	8	11	14	1	4	7	10	13	16	3	6
14	1	4	7	10	13	16	3	6	9	12	15	2	5	8	11
3	6	9	12	15	2	5	8	11	14	1	4	7	10	13	16
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2	5	8	11	14	1	4	7	10	13	16	3	6	9	12	15
7	10	13	16	3	6	9	12	15	2	5	8	11	14	1	4
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1	4	7	10	13	16	3	6	9	12	15	2	5	8	11	14
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11	14	1	4	7	10	13	16	3	6	9	12	15	2	5	8
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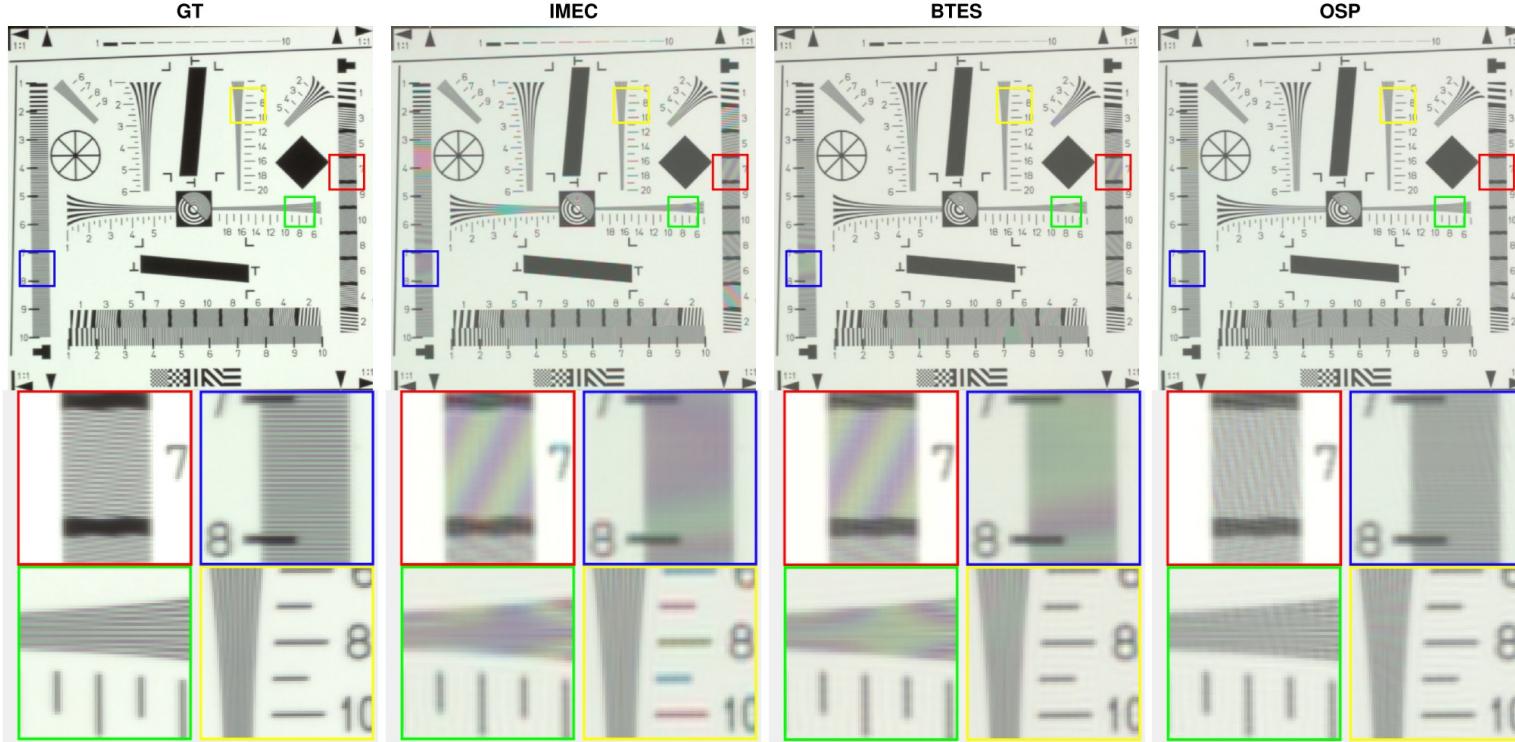
N. Diaz, A. Alvarado, P. Meza, F. Guzmán and E. Vera, "Multispectral Filter Array Design by Optimal Sphere Packing," in IEEE Transactions on Image Processing, vol. 32, 2023.

# MSFA Design using Sphere Packing



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, vol. 32, 2023.

# Reconstruction Results using MSFA



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, vol. 32, 2023.

# What is Sphere Packing?

The sphere packing problem asks for the densest packing of  $R^n$  with congruent balls.  
Equivalent to answer the question:

What is the largest fraction of  $R^n$  that can be covered by congruent balls with disjoint interiors?



# Optimal Sphere Packing Density

0	1	2	3	4	#Dim	
density	1	$\frac{\pi}{\sqrt{12}} \approx 0.9068$	$\frac{\pi}{\sqrt{18}} \approx 0.7404$	$\frac{\pi^2}{16} \approx 0.6168$		

The diagram illustrates the progression of sphere packing from 0 to 4 dimensions. It shows:

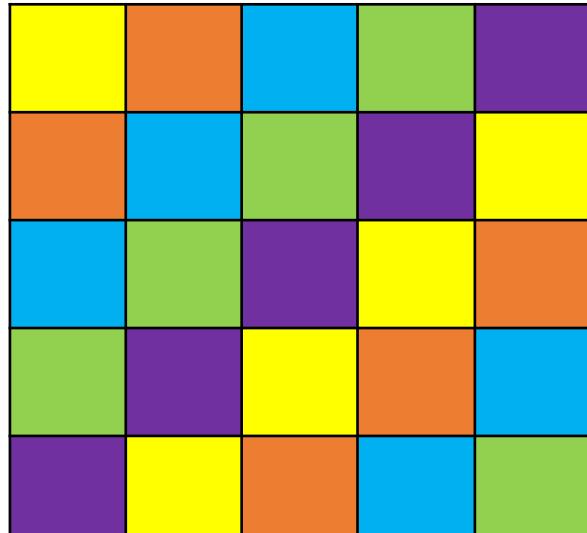
- 0 Dimension:** A single point.
- 1 Dimension:** Two points connected by a horizontal red line.
- 2 Dimensions:** Four points forming a square, with red edges connecting them and green arrows indicating the axes.
- 3 Dimensions:** Eight points forming a cube, with red edges connecting vertices and blue arrows indicating the axes.
- 4 Dimensions:** Sixteen points forming a tesseract, with red edges connecting vertices and blue and green arrows indicating the axes.

A legend on the right identifies the axes:

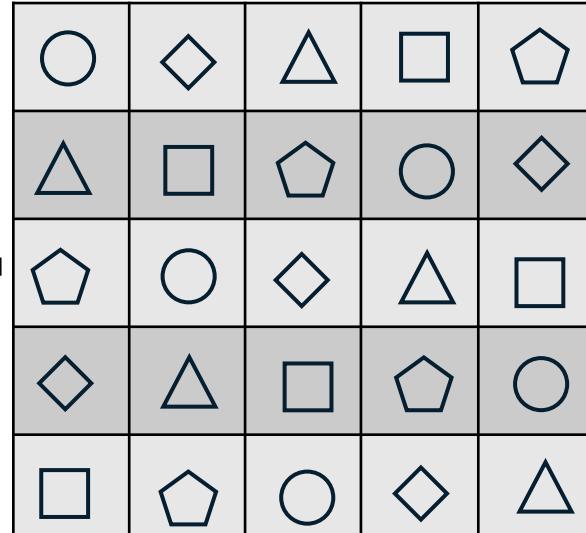
- X: Red arrow pointing right
- Y: Green arrow pointing up
- Z: Blue arrow pointing diagonally up-right
- W: Grey arrow pointing diagonally up-left

# Coded Aperture Design Strategy

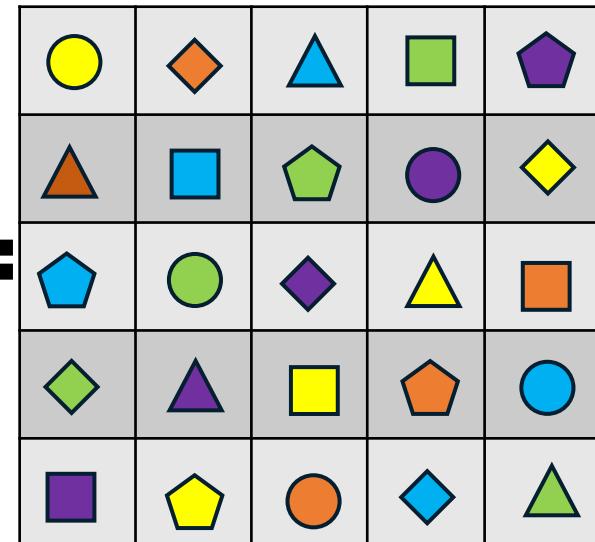
Temporal sampling



Spectral sampling



Spectral-video sampling



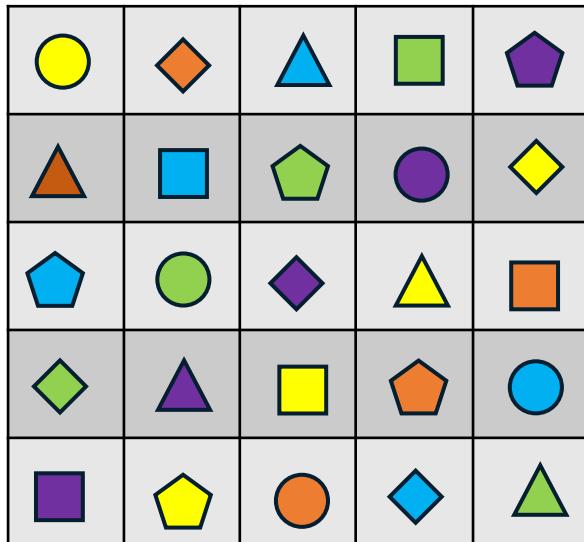
Army regiments

Army ranks

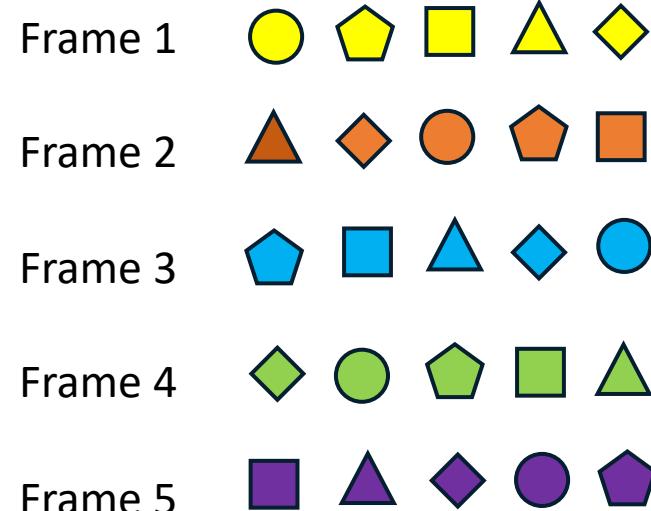
Leonhard Euler puzzle

# Coded Aperture Design Strategy

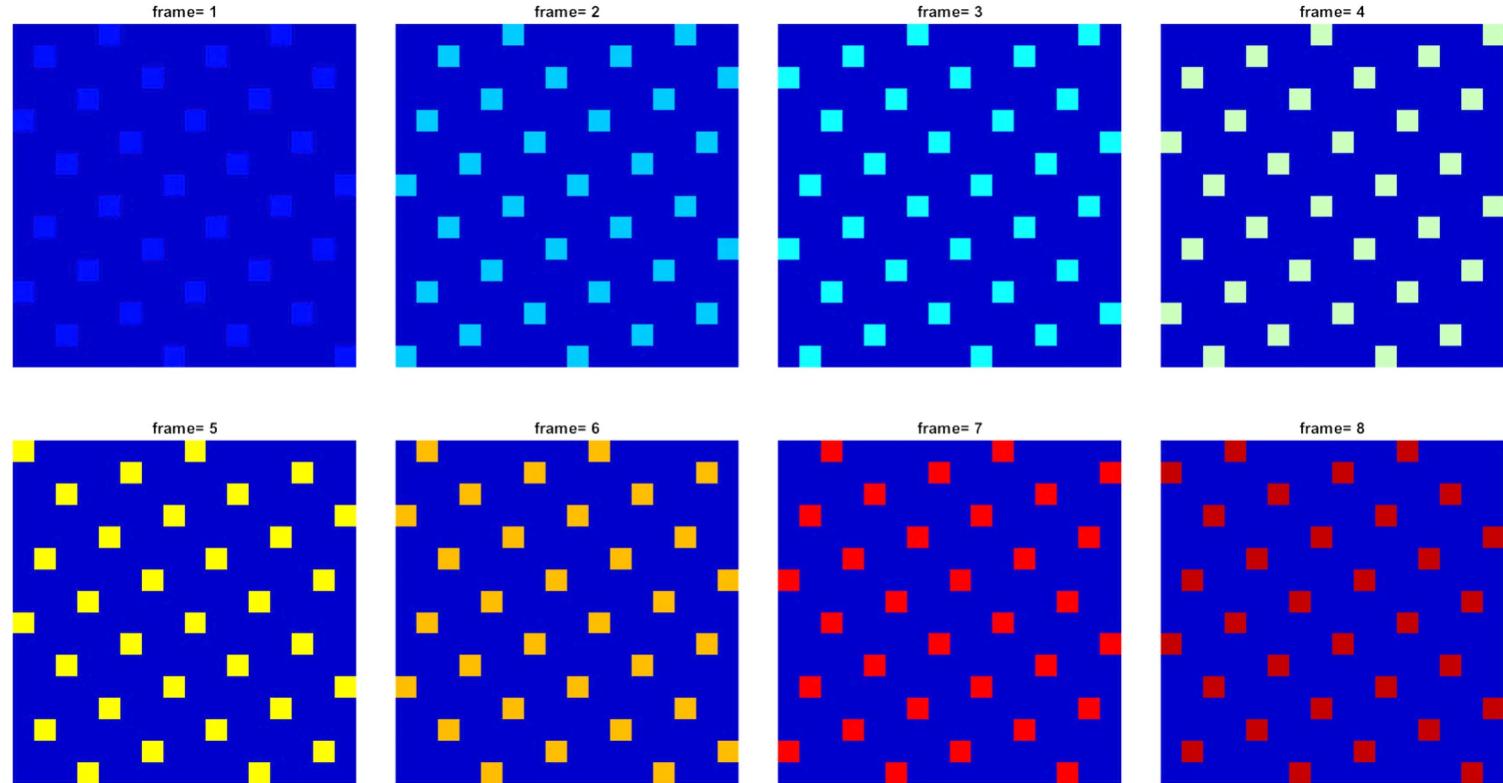
Spectral-video sampling



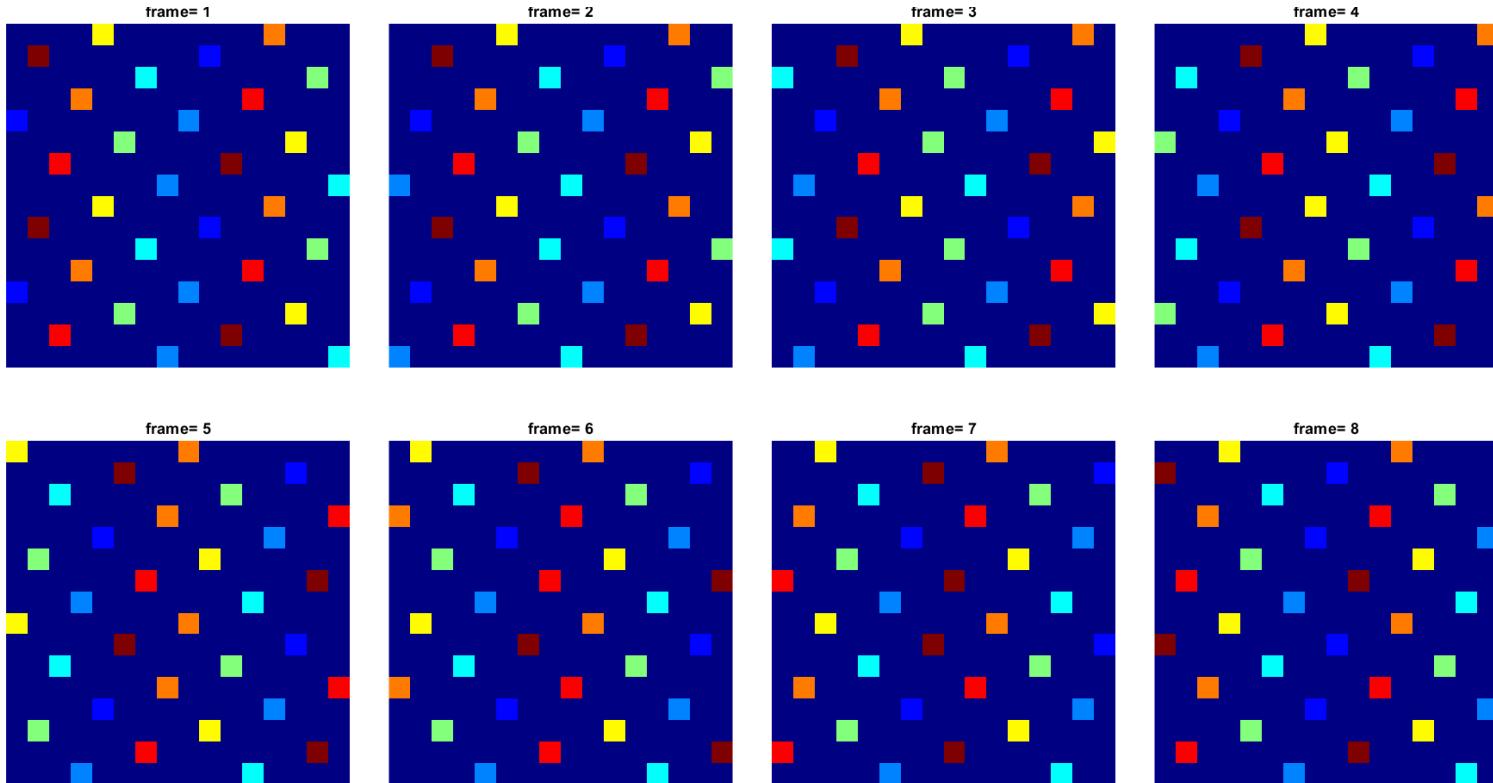
Leonhard Euler puzzle



# Temporal sampling

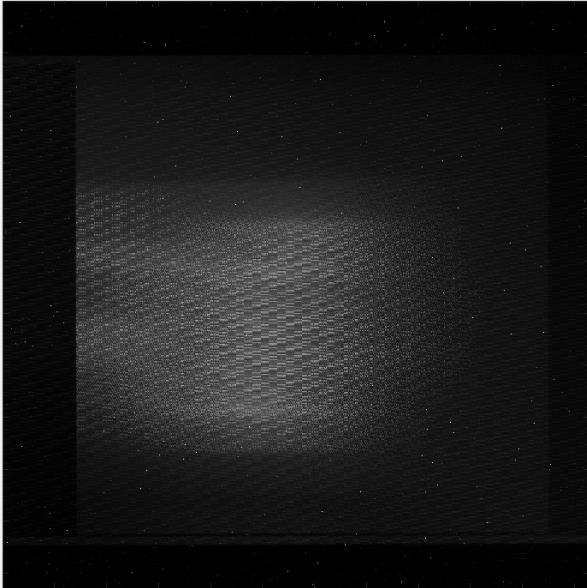


# Spectral-video sampling



# Spectral-Video Measurement

Snapshot measurement



1128 x 1128

# Reconstruction Results

Spectral-video Groundtruth



1128 x 1128 x 16 x 16

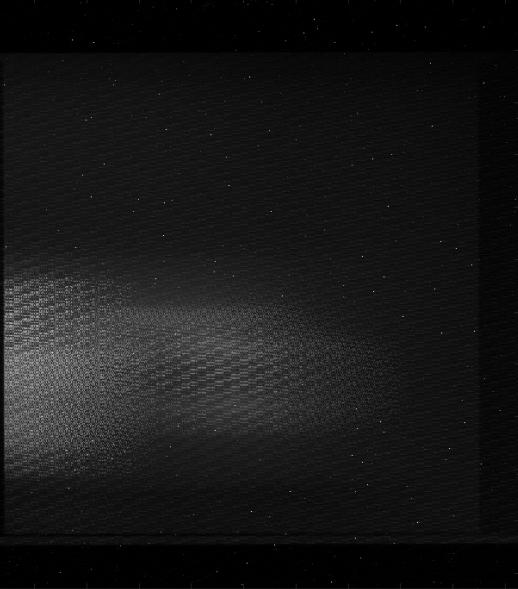
Spectral-video reconstruction



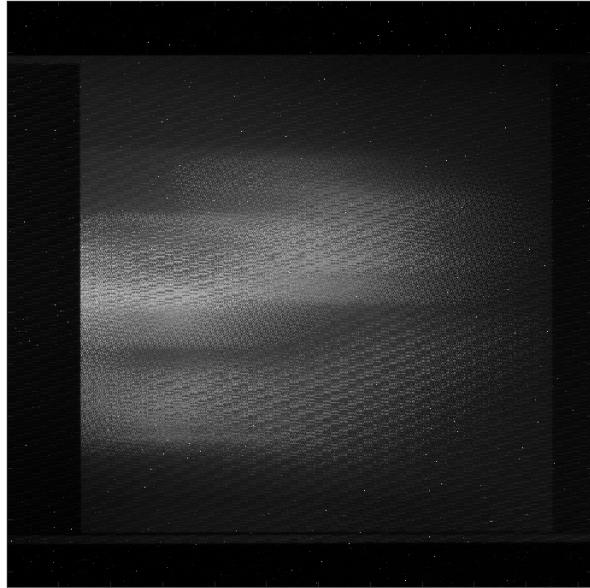
PSNR 26.96 dB, SSIM 0.79, SAM 0.24

# Spectral-Video Measurement of 3 different Scenes

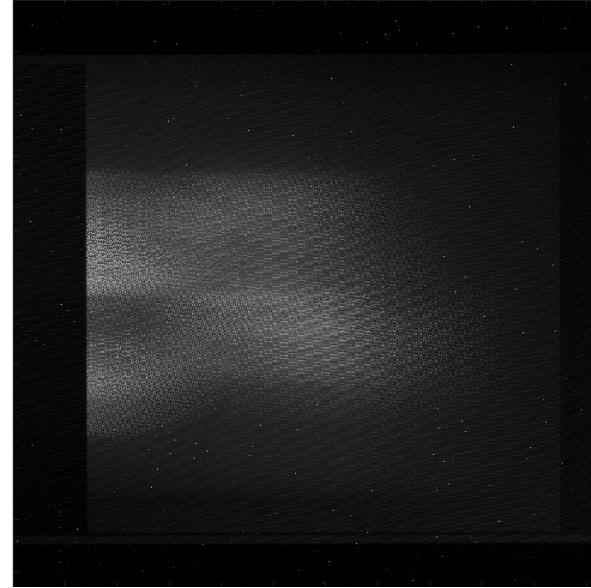
Scene 1



Scene 2



Scene 3



# Reconstruction Results

Reconstruction Scene 1



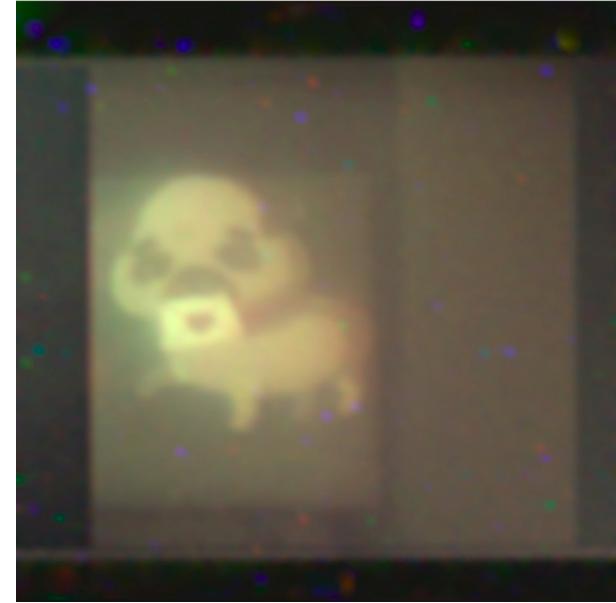
PSNR 28.02 dB, SAM 0.25

Reconstruction Scene 2



PSNR 28.02 dB, SAM 0.22

Reconstruction Scene3

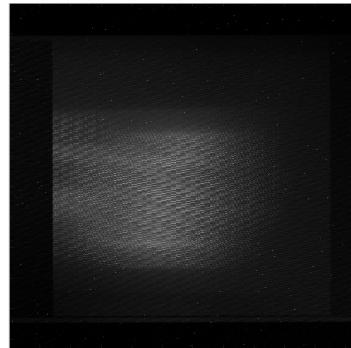


PSNR 27.07 dB, SAM 0.23

# Conclusions

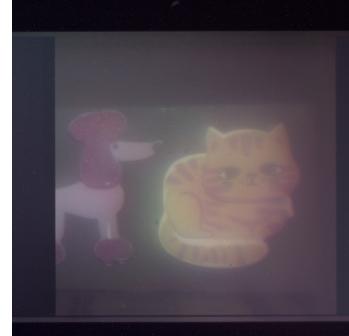
- We introduced a novel **compressive spectral-video sensing** approach that exploits optimal sphere packing.
- Our approach is able to accurately recover a spectral video from a **single snapshot**.
- The proposed approach obtains image reconstruction quality up to 26.96 [dB] of PSNR and 0.24 of SAM.

Compressive measurement



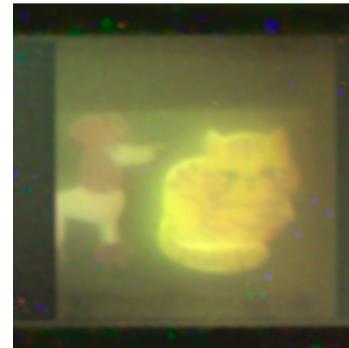
1128 x 1128

Groundtruth



1128 x 1128 x 16 x 16

Reconstruction



PSNR 26.96 dB, SAM 0.24

# Thank you!

<https://nelson-diaz.com/>



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