



# IEEE RESEARCH AND APPLICATIONS OF PHOTONICS IN DEFENSE

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

[www.ieee-rapid.org](http://www.ieee-rapid.org)

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

*Nelson Diaz and Esteban Vera*

*Pontifícia Universidad Católica de Valparaíso*

*Chile*



PONTIFICIA UNIVERSIDAD  
**CATOLICA**  
DE VALPARAISO



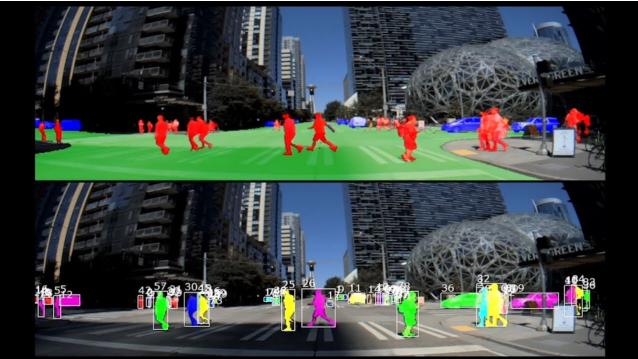
12 September 2023

**RAPID**  
Research and Applications of Photonics in Defense

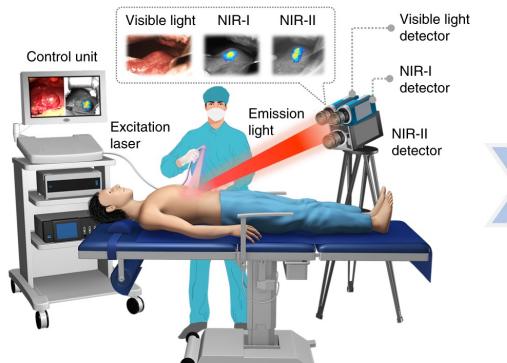
IEEE  
Photonics  
Society

IEEE

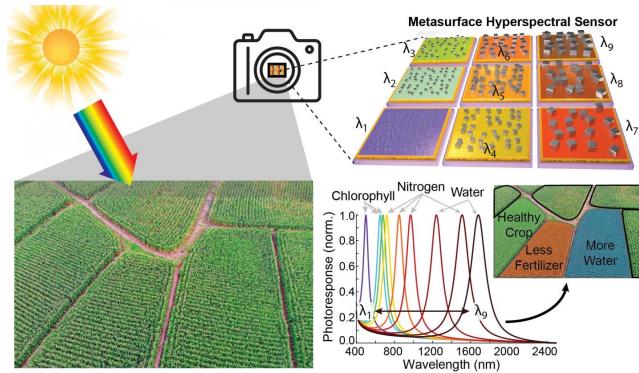
# Applications of Spectral-Video



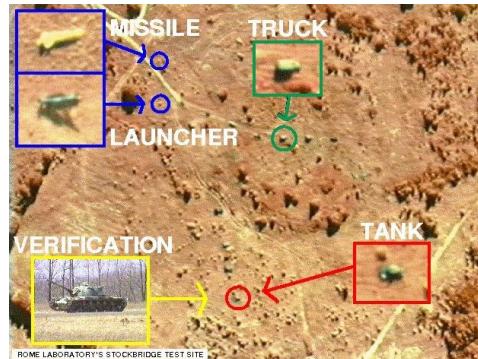
Self-driving car



Guided surgery

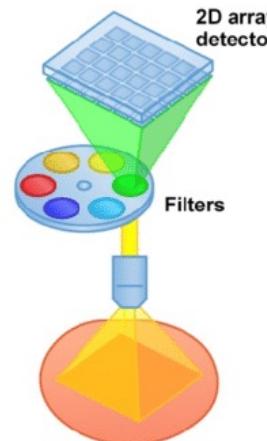
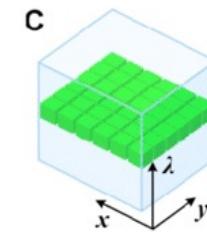
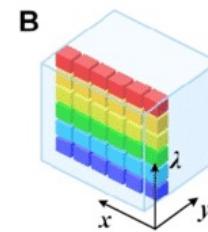
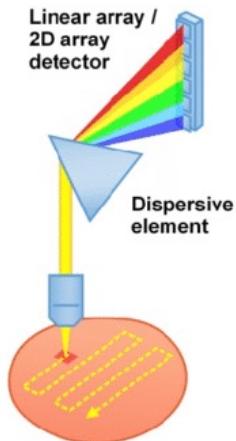
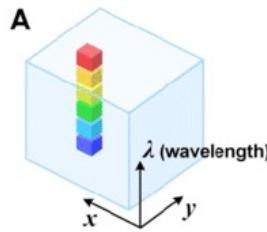


Smart farming



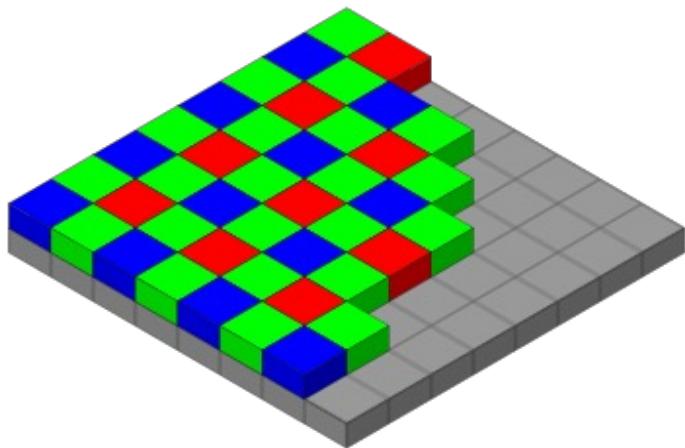
Camouflage detection

# Traditional Approaches to Capture Spectral Images

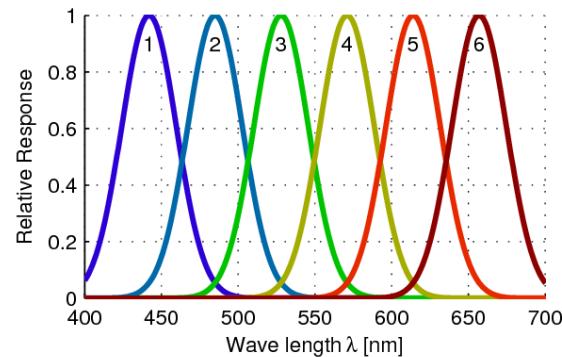
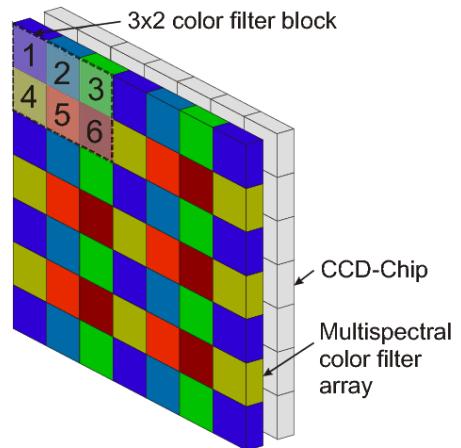


# Multispectral Filter Arrays (MSFA)

Bayer Filter



Multispectral Filter



# MSFA Design using Sphere Packing

Random

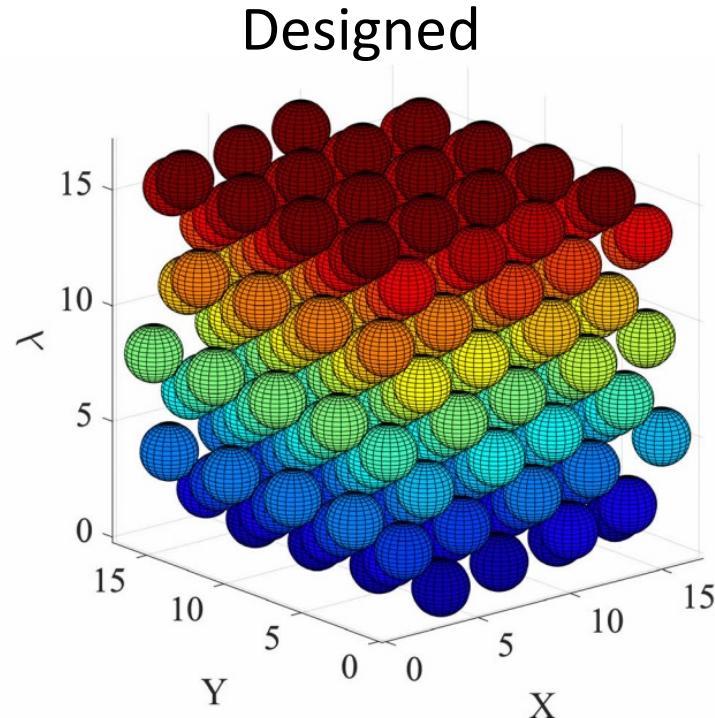
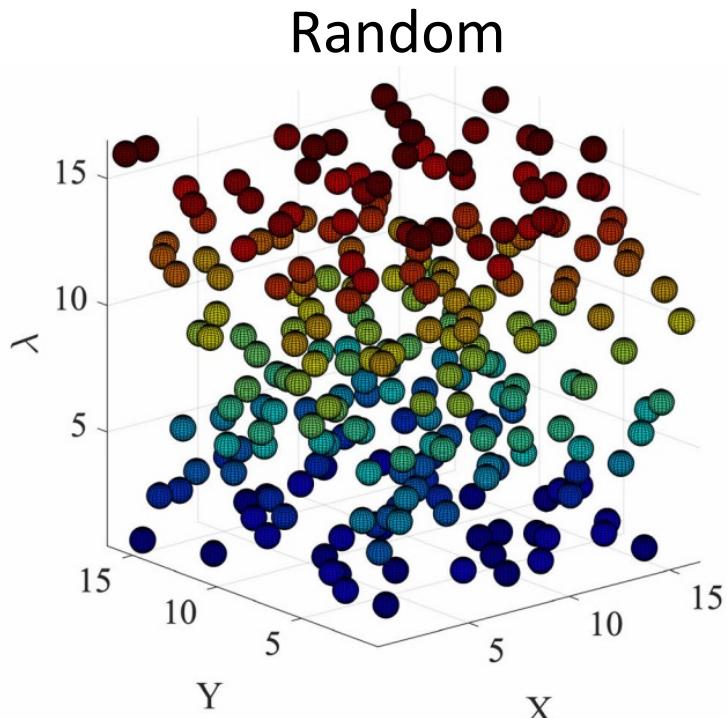
4	5	2	9	8	11	13	7	14	6	10	15	12	3	1	16
5	11	14	13	2	10	9	15	6	8	7	1	4	3	12	16
16	7	1	6	14	8	11	13	3	2	15	4	10	9	5	12
16	9	5	4	10	7	1	6	12	8	3	2	15	11	13	14
9	7	13	15	10	3	12	2	1	16	14	6	8	4	5	11
15	2	4	11	13	1	16	6	14	5	10	9	7	12	8	3
14	7	11	9	6	4	3	2	15	8	13	16	10	12	5	1
7	15	5	11	10	14	13	4	8	9	12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

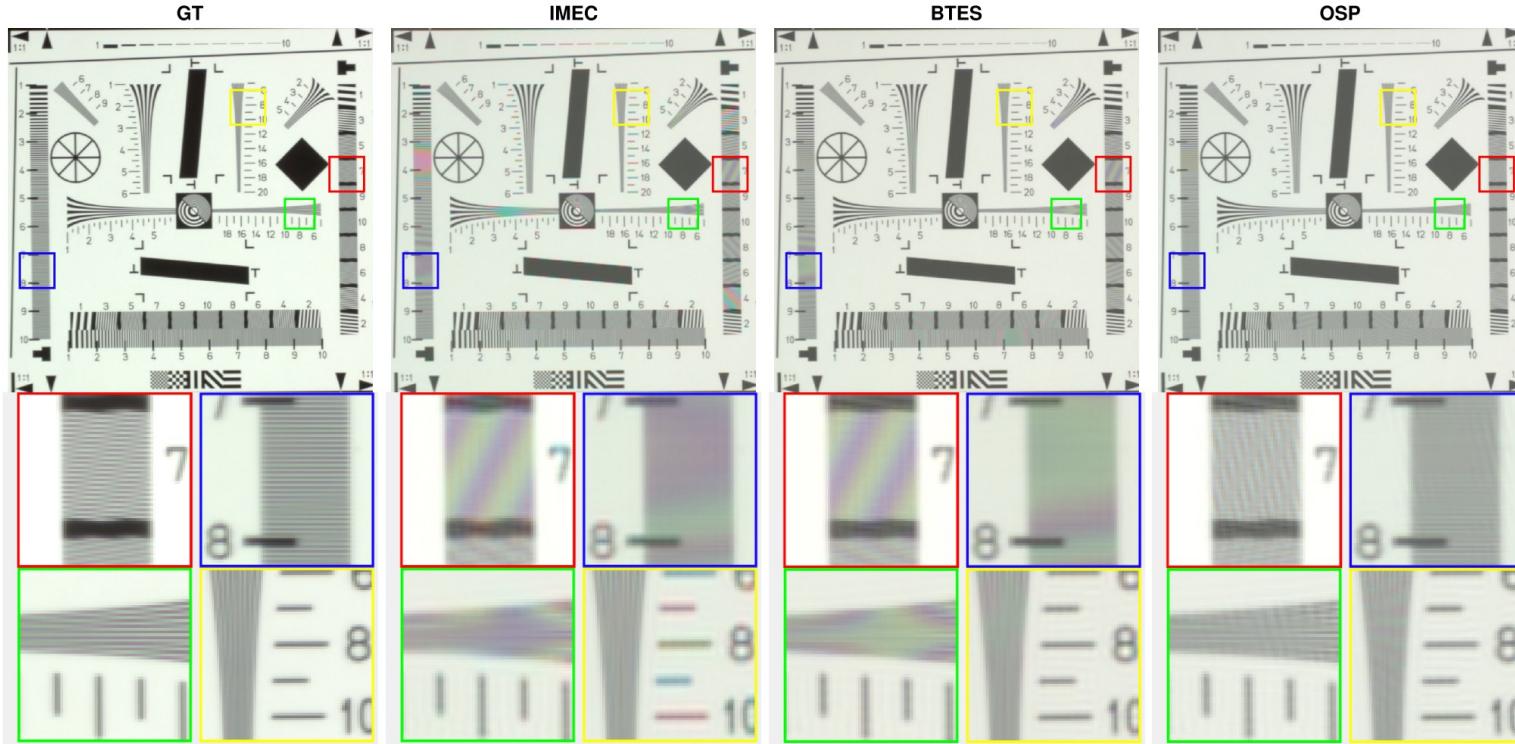
N. Diaz, A. Alvarado, P. Meza, F. Guzmán and E. Vera, "Multispectral Filter Array Design by Optimal Sphere Packing," in IEEE Transactions on Image Processing, vol. 32, 2023.

# 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?



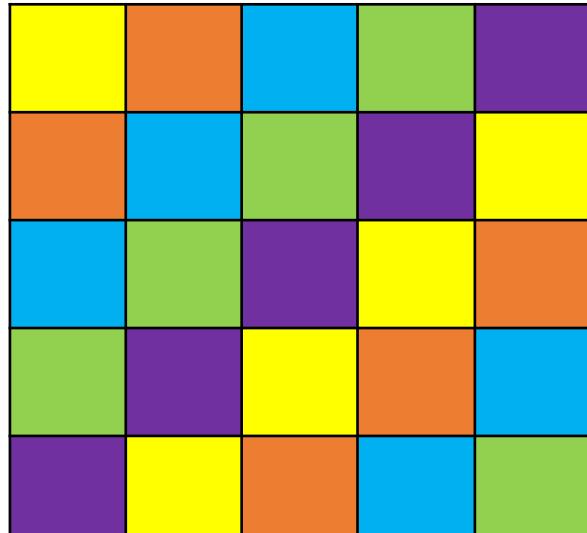
# Optimal Sphere Packing Density

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

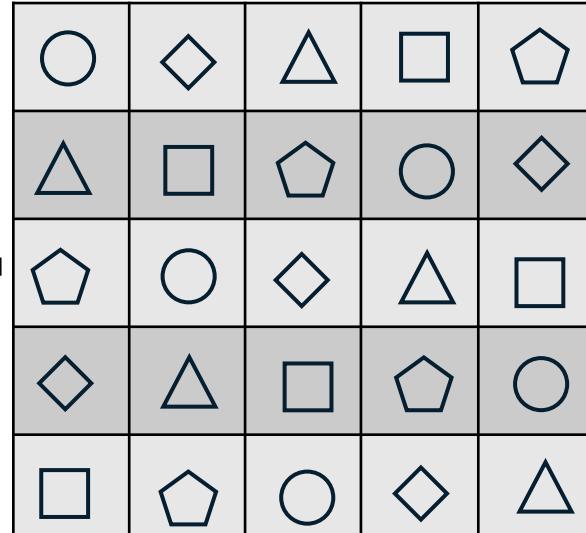
The diagram illustrates the progression of sphere packing from 0 to 4 dimensions. In dimension 0, a single sphere is shown. In dimension 1, two spheres are packed along a horizontal axis. In dimension 2, four spheres are packed in a square arrangement. In dimension 3, eight spheres are packed in a cube arrangement. In dimension 4, sixteen spheres are packed in a tesseract arrangement. A legend on the right shows coordinate axes: X (red), Y (green), Z (blue), and W (grey).

# Coded Aperture Design Strategy

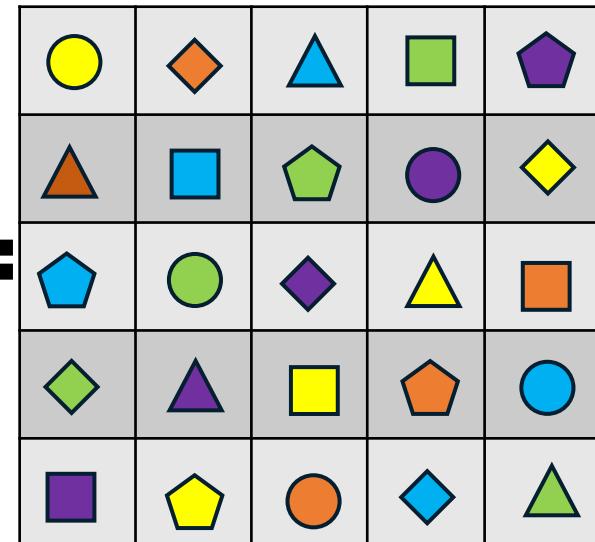
Temporal sampling



Spectral sampling



Spectral-video sampling



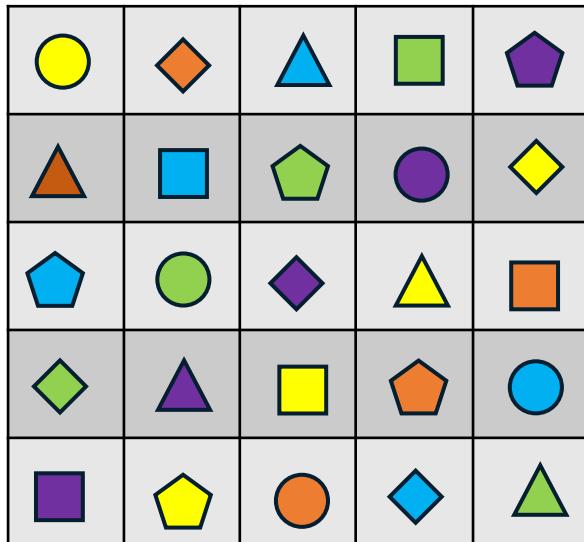
Army regiments

Army ranks

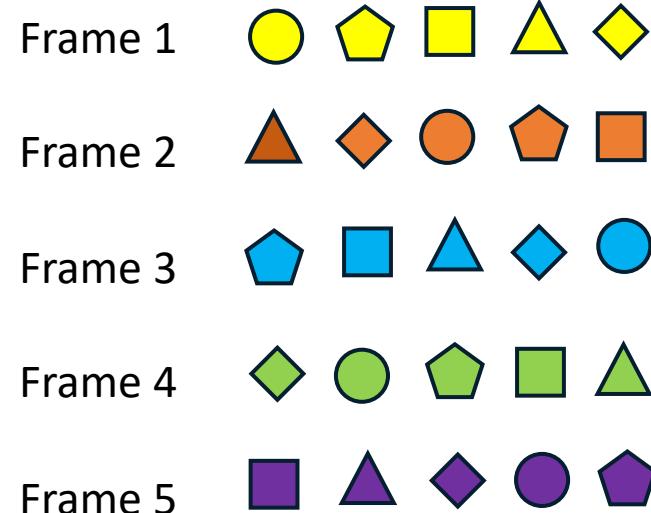
Leonhard Euler puzzle

# Coded Aperture Design Strategy

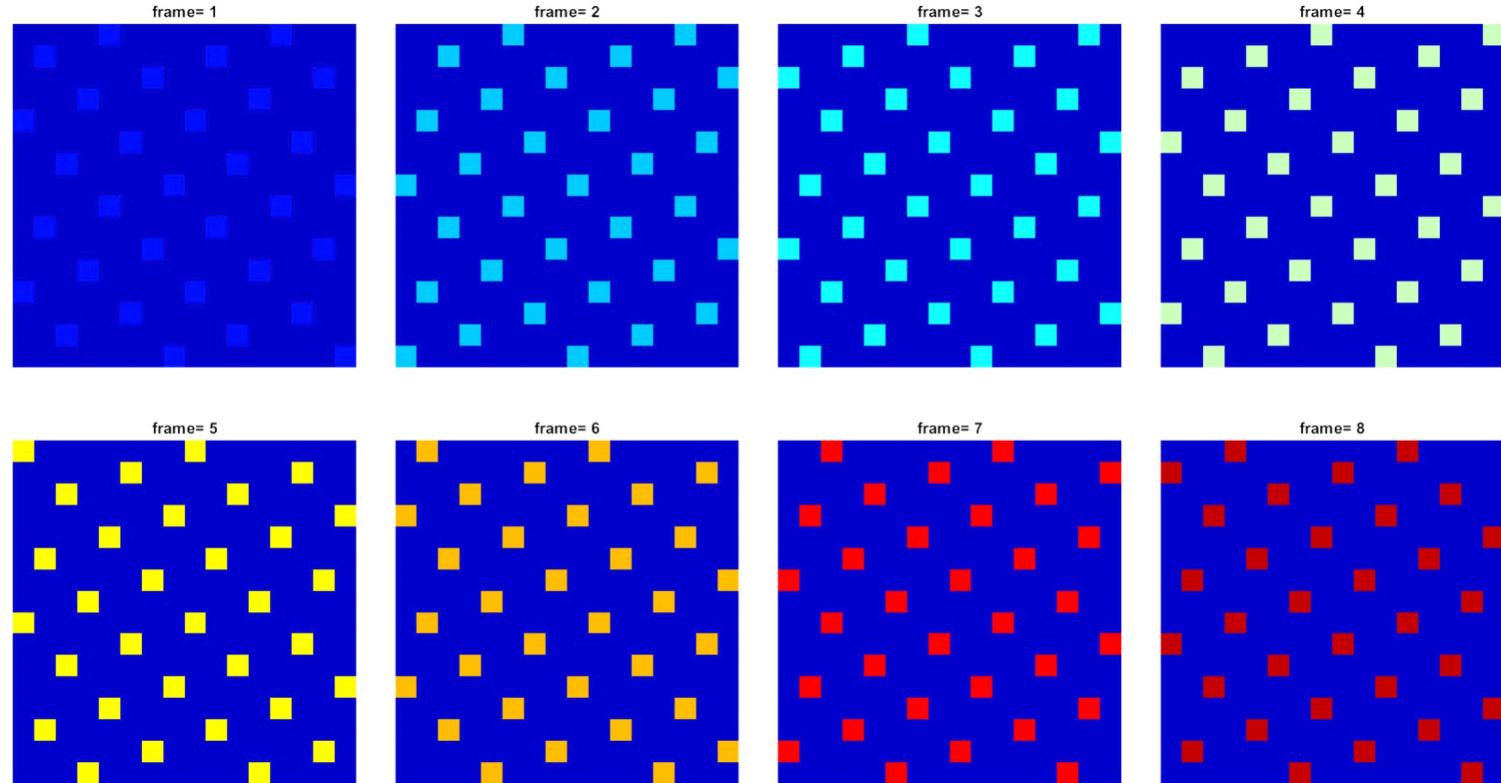
Spectral-video sampling



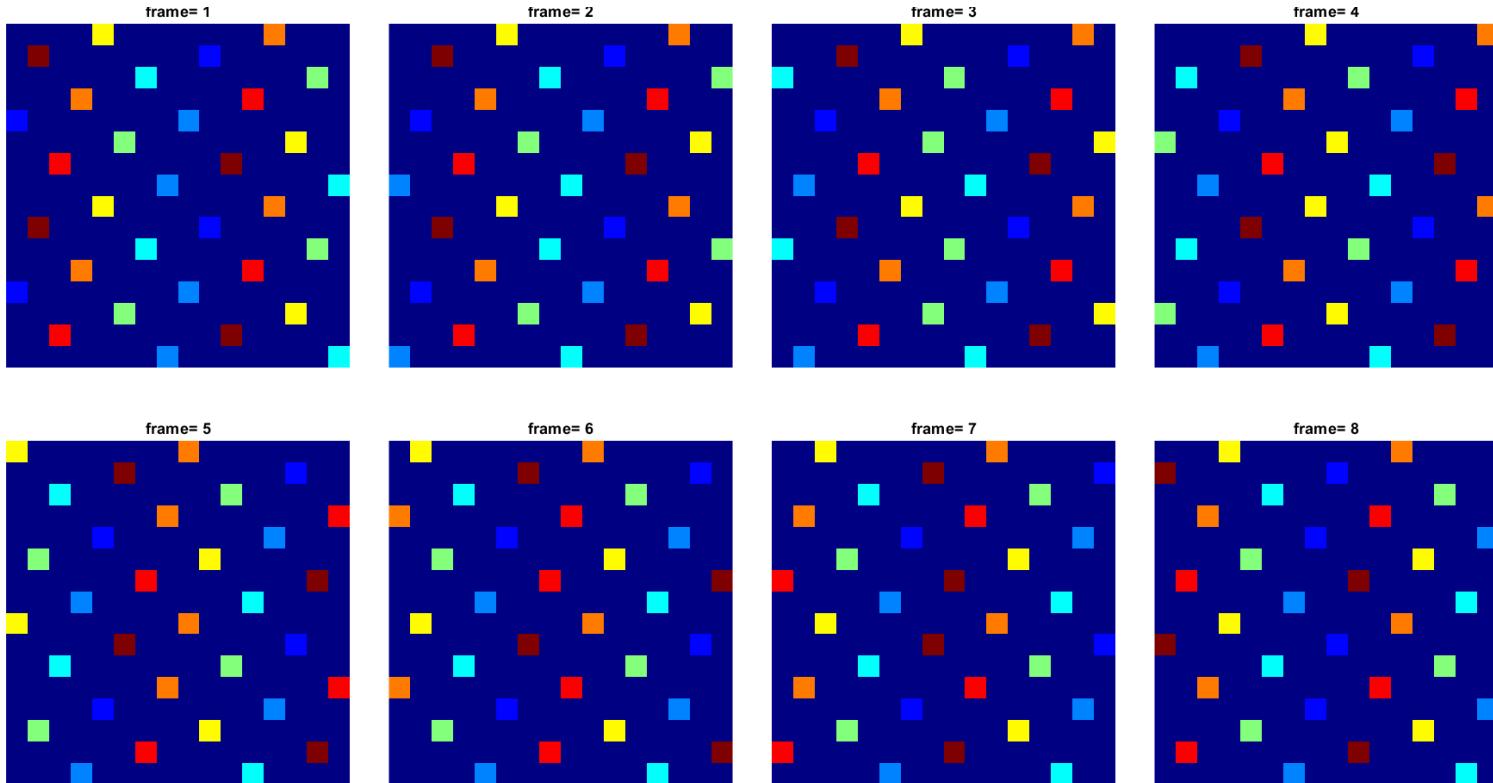
Leonhard Euler puzzle



# Temporal sampling

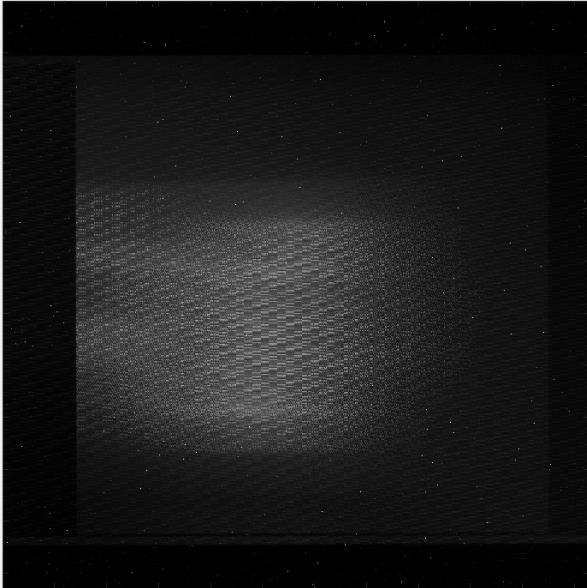


# Spectral-video sampling



# Spectral-Video Measurement

Snapshot measurement



1128 x 1128

# Reconstruction Results

Spectral-video Groundtruth



1128 x 1128 x 16 x 16

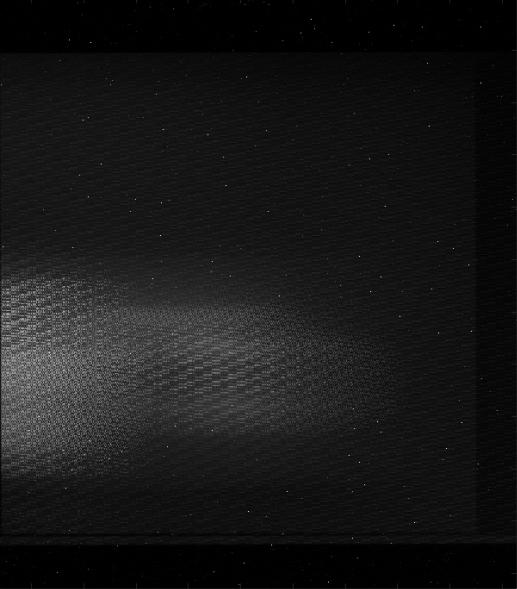
Spectral-video reconstruction



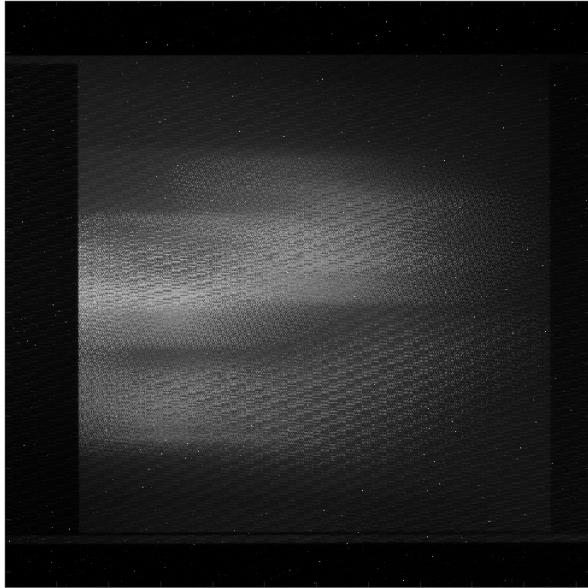
PSNR 26.96 dB, SSIM 0.79, SAM 0.24

# Spectral-Video Measurement of 3 different Scenes

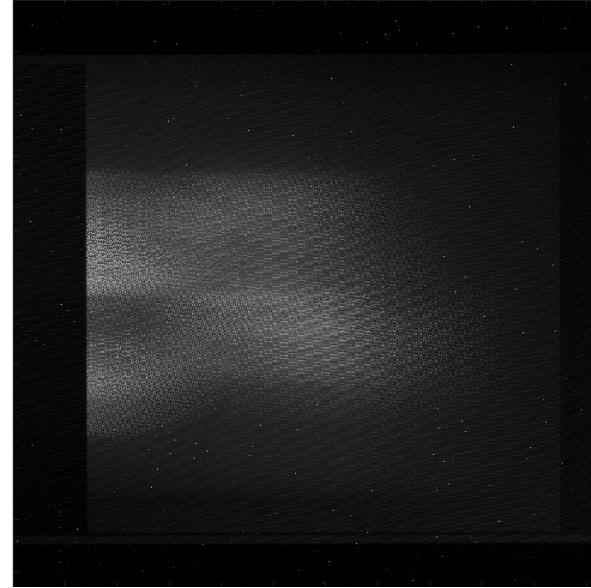
Scene 1



Scene 2



Scene 3



# Reconstruction Results

Reconstruction Scene 1



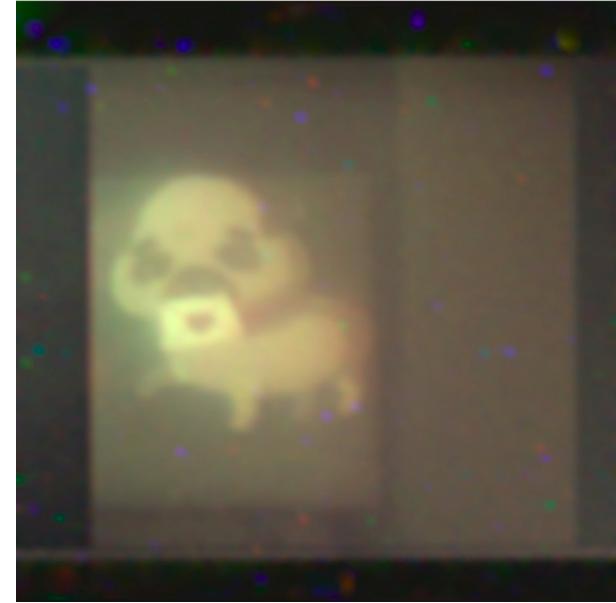
PSNR 28.02 dB, SAM 0.25

Reconstruction Scene 2



PSNR 28.02 dB, SAM 0.22

Reconstruction Scene3

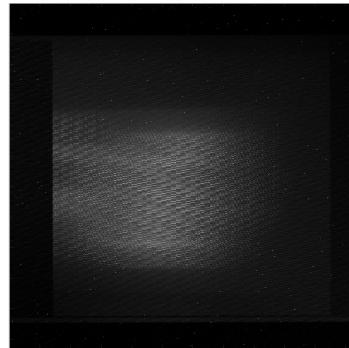


PSNR 27.07 dB, SAM 0.23

# Conclusions

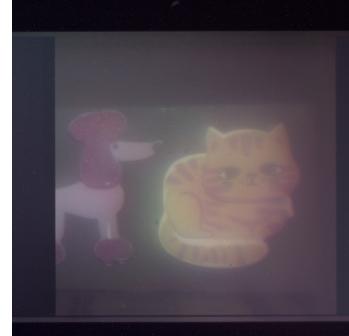
- We introduced a novel **compressive spectral-video sensing** approach that exploits optimal sphere packing.
- Our approach is able to accurately recover a spectral video from a **single snapshot**.
- The proposed approach obtains image reconstruction quality up to 26.96 [dB] of PSNR and 0.24 of SAM.

Compressive measurement



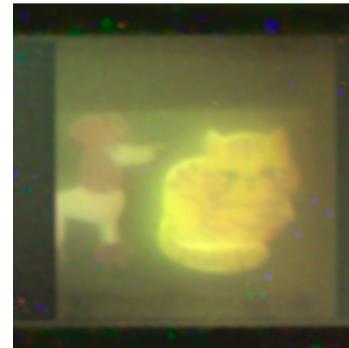
1128 x 1128

Groundtruth



1128 x 1128 x 16 x 16

Reconstruction



PSNR 26.96 dB, SAM 0.24

# Thank you!

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

nelson-diaz.com

Nelson Díaz

Publications

Conferences

Teaching

Code

News

CV



Dr. Nelson Díaz

Nelson Díaz, contact information: nelson [dot] diaz [at] pucv [dot] cl

## Dr. Nelson Díaz

I got my B.Sc. (Eng.), M.Sc. degree in Computer Science, and with an emphasis in Electronics from the Universidad Bucaramanga, Colombia, in 2012, 2015, and 2020, respectively. (2016-2019), I designed, simulated, and implemented adaptive spectral imaging for different tasks. Between those tasks are image classification, image reconstruction, and video sensing. Dr. [Henry Arguello](#). My research topics are compressive sensing and video sensing. In autumn-winter 2018-2019, I did an internship for Space and Aeronautics Laboratory [TéSA](#), Toulouse, France. During my internship, I developed a new algorithm for cardiac motion under the mentoring of Dr. [Jean-Yves Tourneret](#), and Dr. [Adrien Chabot](#). I obtained a postdoctoral position at the Pontificia Universidad Católica de Chile.

ANID ANILLOS ATE220022

ANID FONDECYT 1221883

ANID FONDECYT Postdoctorado 3230489.

