Optimization of an Active Spherical Coded Mask Gamma-ray Imager

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IEEE NSS/MIC
Strasbourg, France
29 October – 5 November 2016

Outline

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- Planar configuration
  - The High Efficiency Multi-modal Imager (HEMI)
- Spherical configuration
  - Portable Radiation Imaging Spectroscopy and Mapping (PRISM)
- Mask optimization
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- Conclusions

Gamma-ray Imaging

Motivation

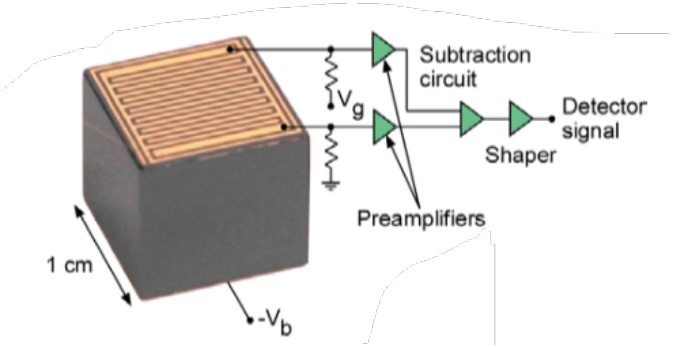
Detect, locate, identify, and characterize radioactive sources in the field. Ability to search for weak sources in complex environments and efficiently map radiation fields.

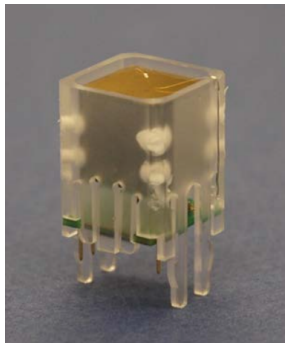
Need

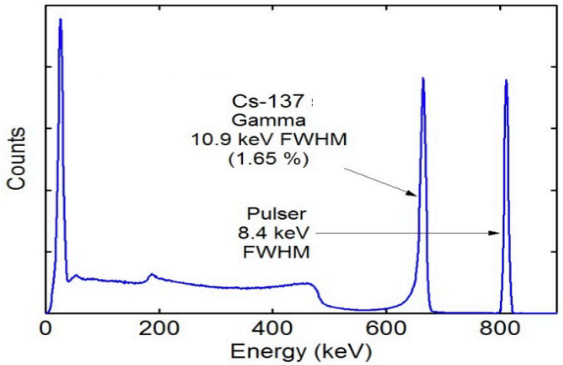
Hand-held, portable 3D imaging system with high efficiency, wide field-of-view, broad energy sensitivity, and high energy resolution.

Approach

Multiple room-temperature operated cm^3 CdZnTe (CZT) coplanar gird (CPG) detectors arranged to facilitate coded aperture and Compton imaging modalities.



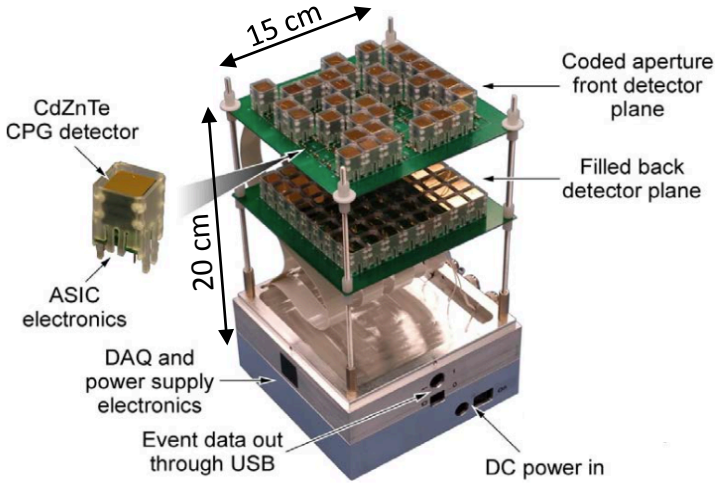


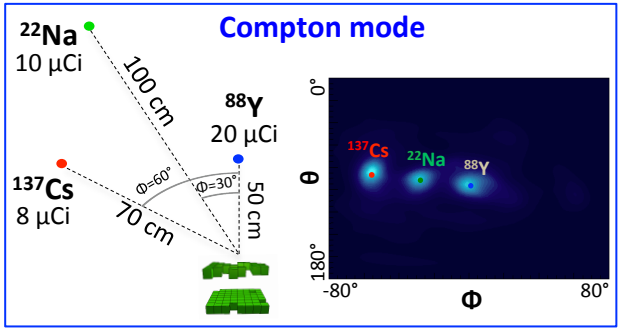


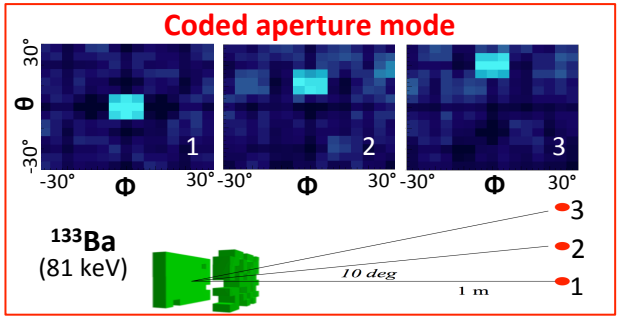
Planar Arrangement

High Efficiency Multi-modal Imager (HEMI)†

- 96 CZT CPG detectors (1 cm^3, ~2% FWHM at 662 keV).
- 32 in **active coded** front plane, 64 in fully populated back plane).
- Coded aperture (30 keV to 400 keV) and Compton imaging (300 keV to 3 MeV).
- ~10° resolution at 662 keV (Compton) and 186 keV (CA).
- < 10 lbs → Hand-portable. Also placed on UAVs.







→ **Limited field-of-view in both modalities, especially coded aperture.**

→ **GOAL: Redesign for a 4π FOV with coded aperture.**

† M. Galloway, *Characterization and Applications of a CdZnTe-Based Gamma-Ray Imager*, Ph.D. Thesis, 2014.

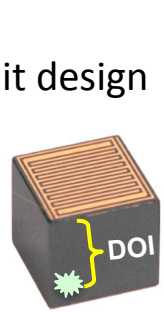
Spherical Arrangement

Rearrange the detectors into an **active spherical coded configuration** to enable **omnidirectional 4π coded aperture imaging.**

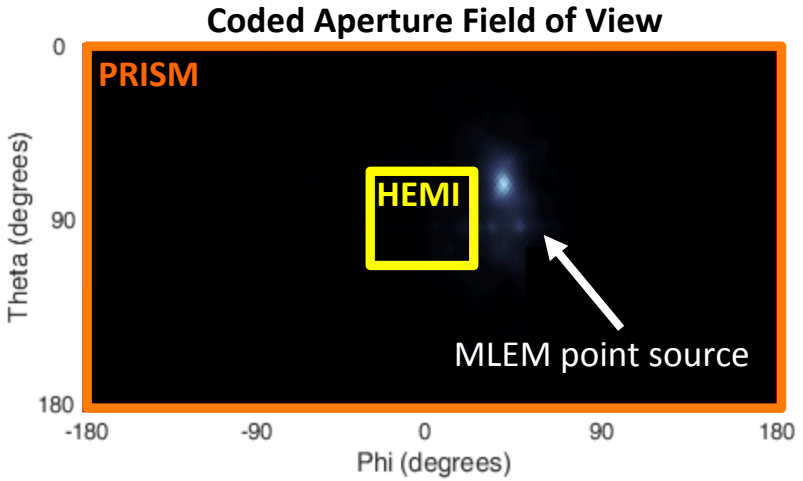
Feasibility study conducted for a spherical housing with **192** available detector locations.

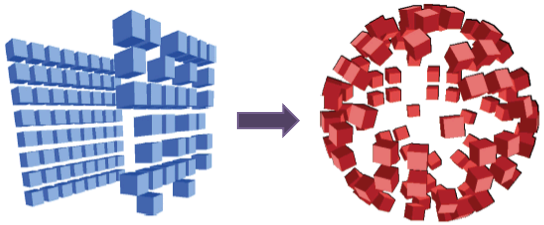
→ **P**ortable **R**adiation **I**maging **S**pectroscopy and **M**apping (PRISM)

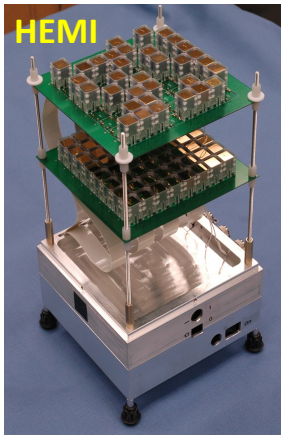
- 6 modular (identical) faces, flexible circuit design
- ≤ 2% FWHM at 662 keV
- < 10° resolution at 186 and 662 keV
- Depth-of-interaction (DOI) readout

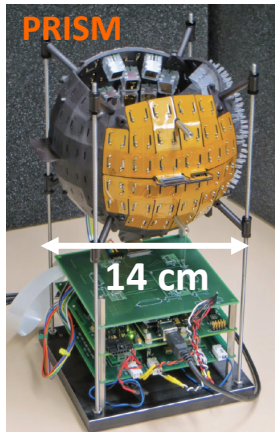


What is the optimal number and configuration of the detectors on the sphere?



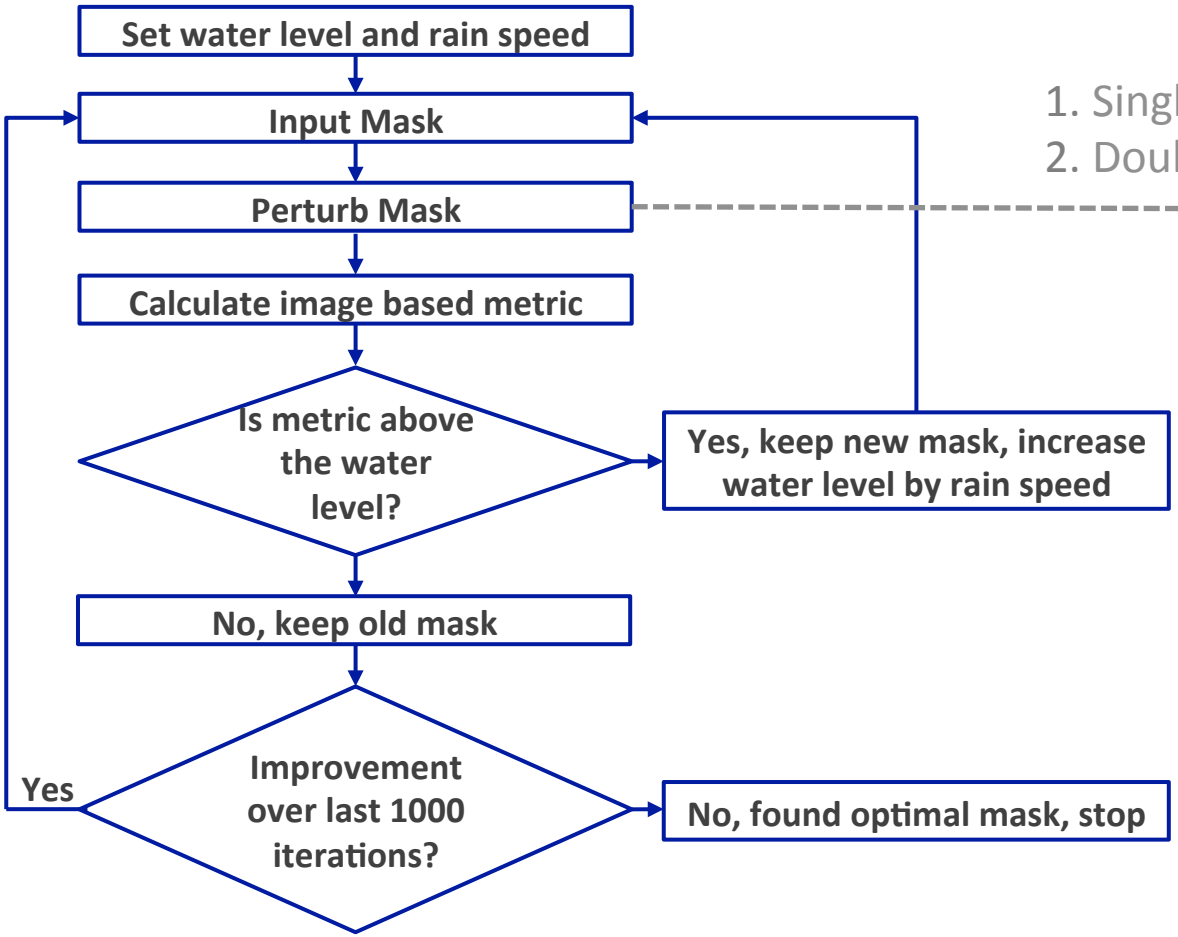




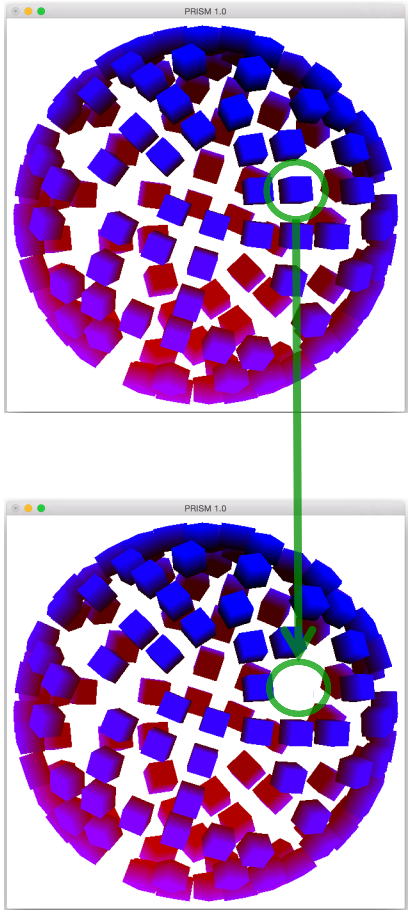


Optimization Procedure

→ The Great Deluge algorithm[†]:



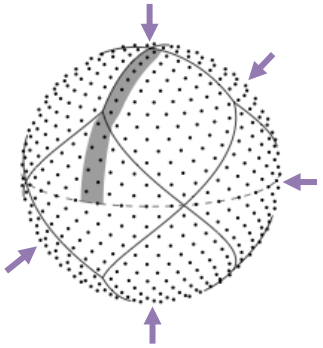
1. Single toggle
2. Double toggle



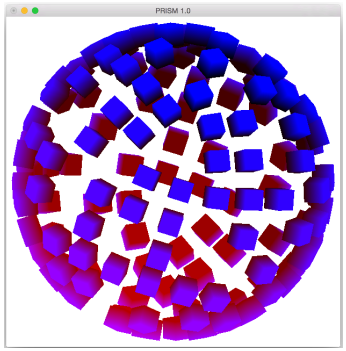
[†] G. Dueck, *Journal of Computational Physics*, vol. 104, pp. 86–92, 1993.

System Response Generation

- Image space pixelized into 3072 far-field equal area pixels with *HEALPix*[†].
- Geant4 simulation of point sources at all source angles → **O(min)**
- Graphics-based program in OpenGL to perform mask projection (no scattering, zero-energy) → **< 1.5 s**



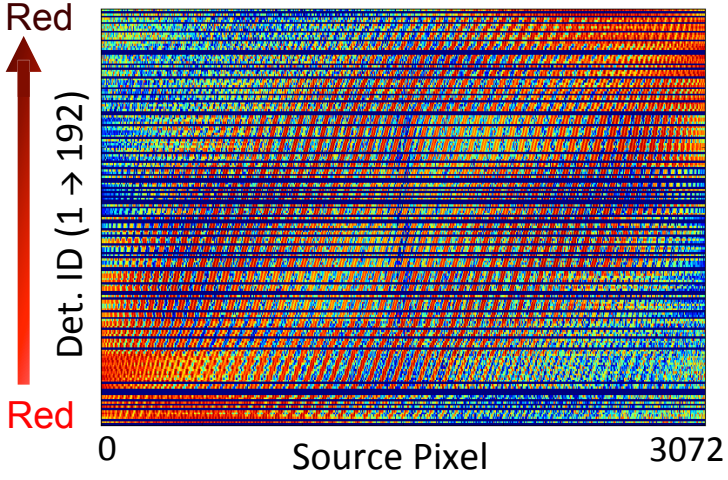
OpenGL Display



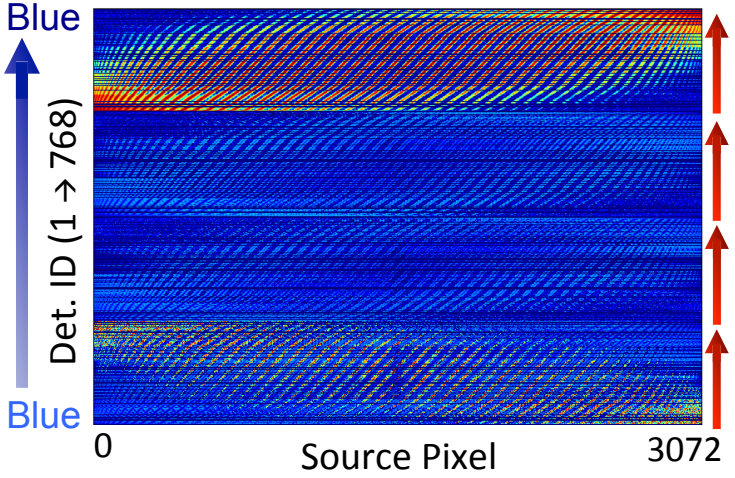
Red = Det. ID
Blue = Depth

Histogram pixels at each camera angle

*System Response, **No DOI***



*System Response, **4 DOI bins***



[†] ***H**ierarchical **E**qual **A**rea iso**L**atitude **Pix**elization of a sphere*: K. Górski *et al.*, *The Astrophysical Journal*, vol. 662, no. 2, pp. 759–771, 2005.

Optimization Results

- PRISM is reconfigurable → can optimize to variety of different scenarios, each using different metrics.
- To develop the framework, we optimize imaging accuracy and uniform sensitivity.

$$\sigma^2\left(\sum_{i=1}^{192} Y_{i,k}\right) + \sum_{k} B(\mu_k, k)$$

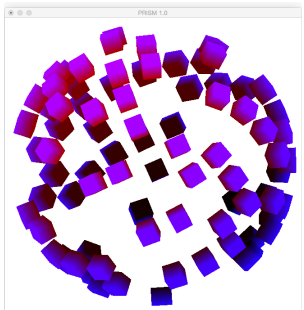
k = 3072 source angles

$Y_{i,k}$ = counts in detector i from source angle k

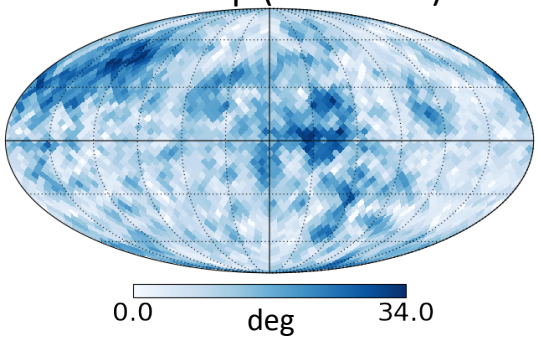
$\sigma^2()$ = variance

$B(\mu_k, k)$ = angle between mean pixel and true pixel

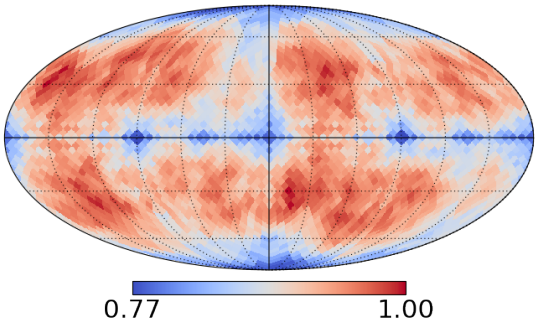
Starting
(Random)
82 detectors
43% populated



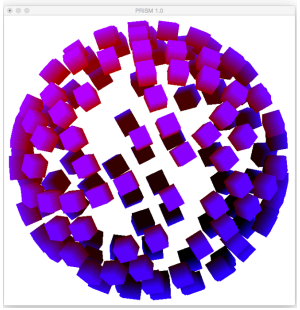
Bias Map (Σ = **34993**)



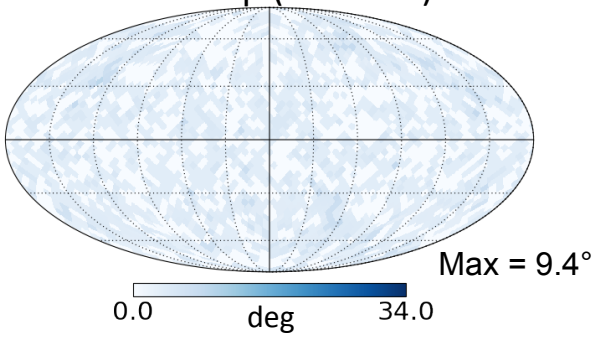
Sensitivity Map (σ^2 = **1.8 x 10^{-3}**)



Optimized
135 detectors
70% populated



Bias Map (Σ = **7757**)



Sensitivity Map (σ^2 = **6.8 x 10^{-4}**)

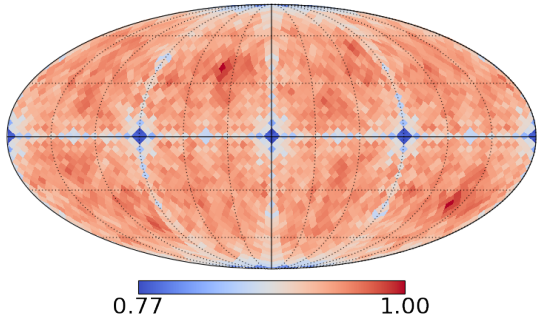
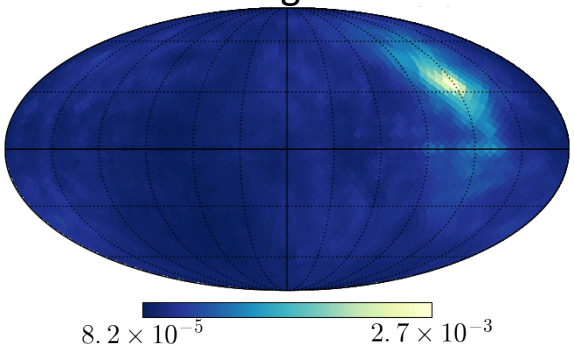


Image Reconstruction and DOI

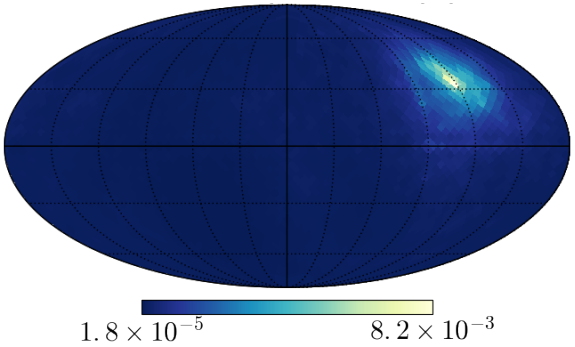
MLEM reconstruction (20 iterations) of far-field, zero-energy, point source in 4π.

Single source:

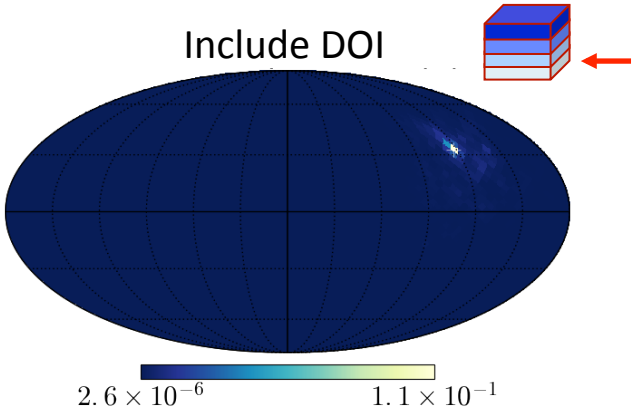
Starting Mask



Optimized Mask

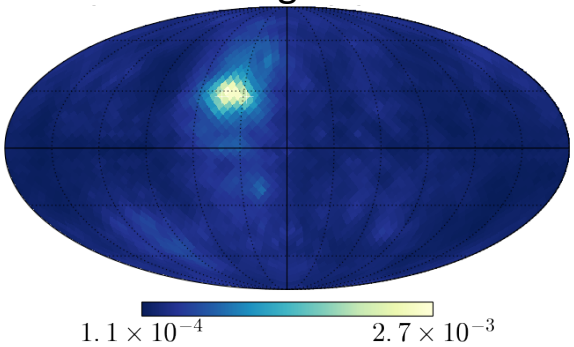


Include DOI

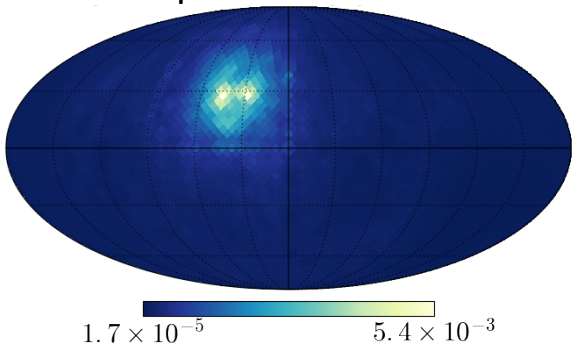


Two sources (15° separation):

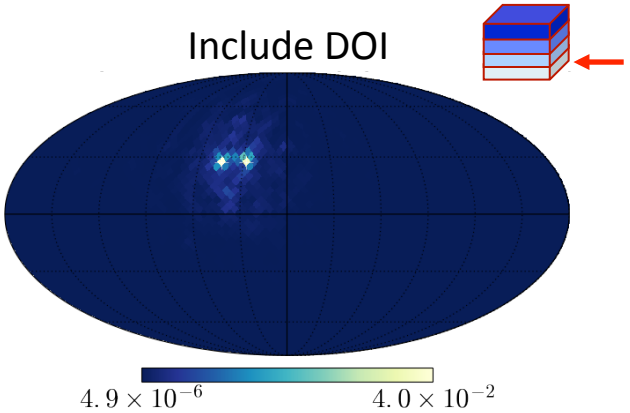
Starting Mask



Optimized Mask



Include DOI

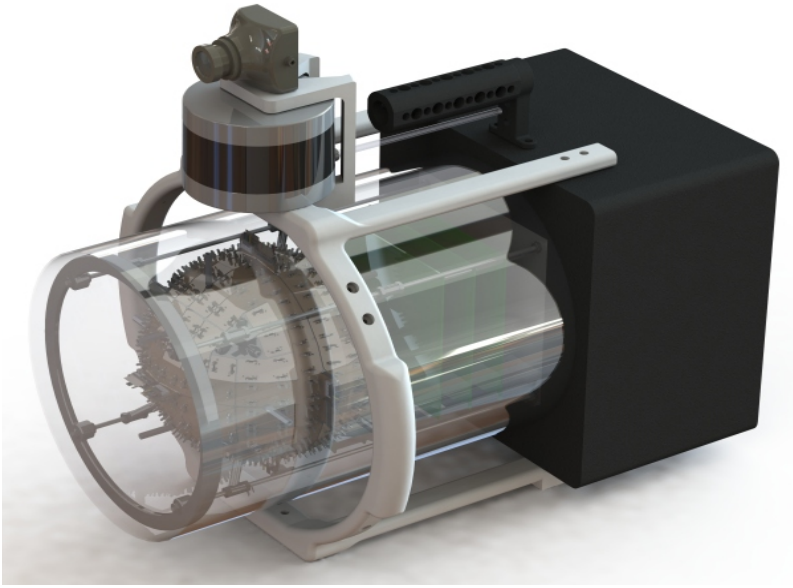


Conclusions

- **Successful demonstration of 4π active spherical coded aperture imaging.**
- A simulation and optimization framework has been developed to optimize the number and configuration of detectors on the sphere.
- Depth-of-interaction significantly improves coded aperture imaging (and should improve Compton imaging as well).

→ Many more metrics exist and are being explored.

→ DOI and energy being integrated into the optimization to observe effects on the optimal mask pattern.



Acknowledgements

Applied Nuclear Physics, Nuclear Science Division, LBNL
Andy Haefner, Marcos Turqueti, Ross Barnowski

Engineering Division, LBNL
Paul Luke, Mark Amman, Julie Lee

Defense Threat Reduction Agency, DOD
Hank Zhu, Marc Black

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This material is based on work supported in part by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number DE-NA-0003180 and the Defense Threat Reduction Agency under Contract Number DTRA10027-19346.

Thank you for your attention.

Questions?