Computational Multi-spectral Imaging

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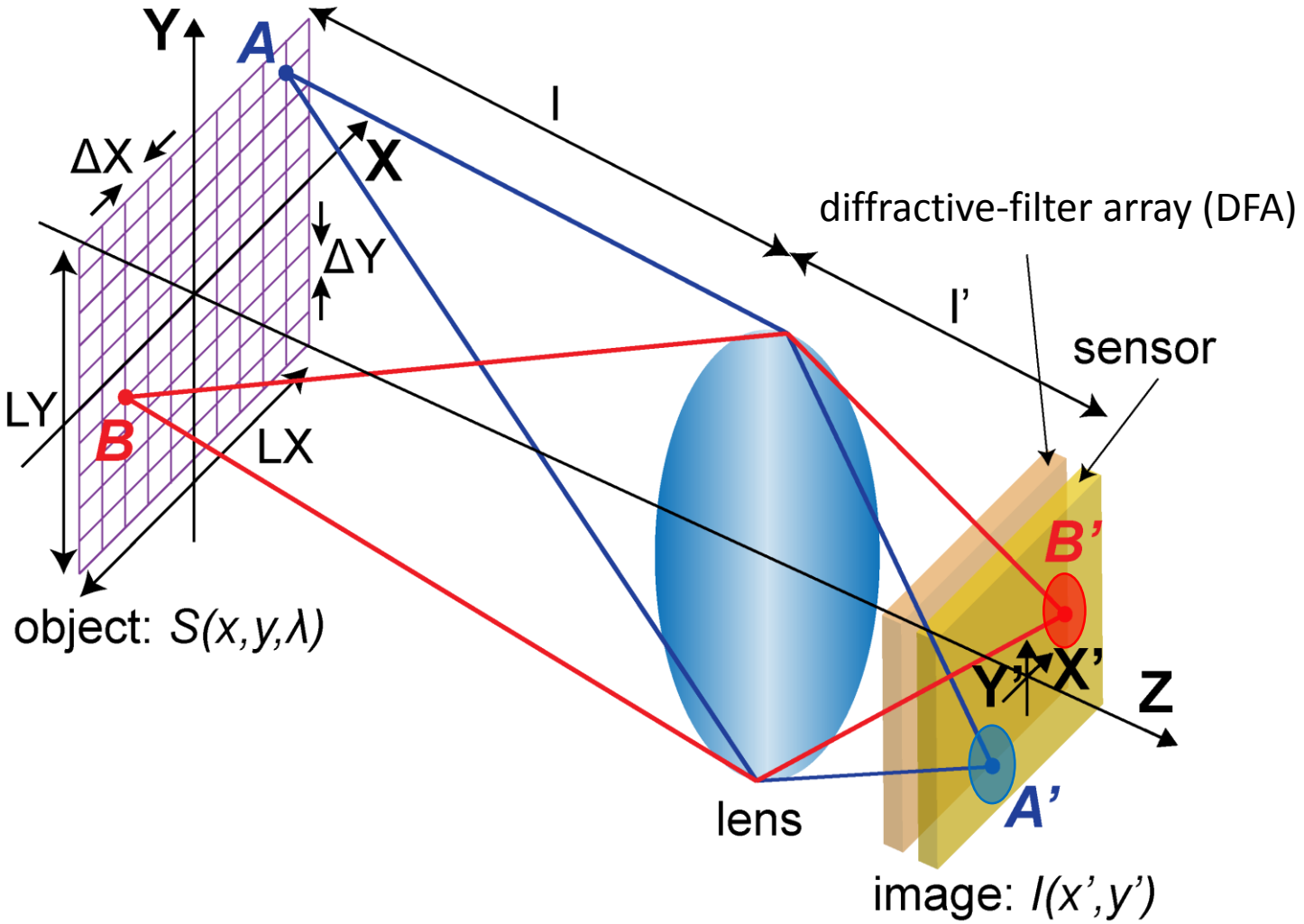
NASA MirrorTech 2017

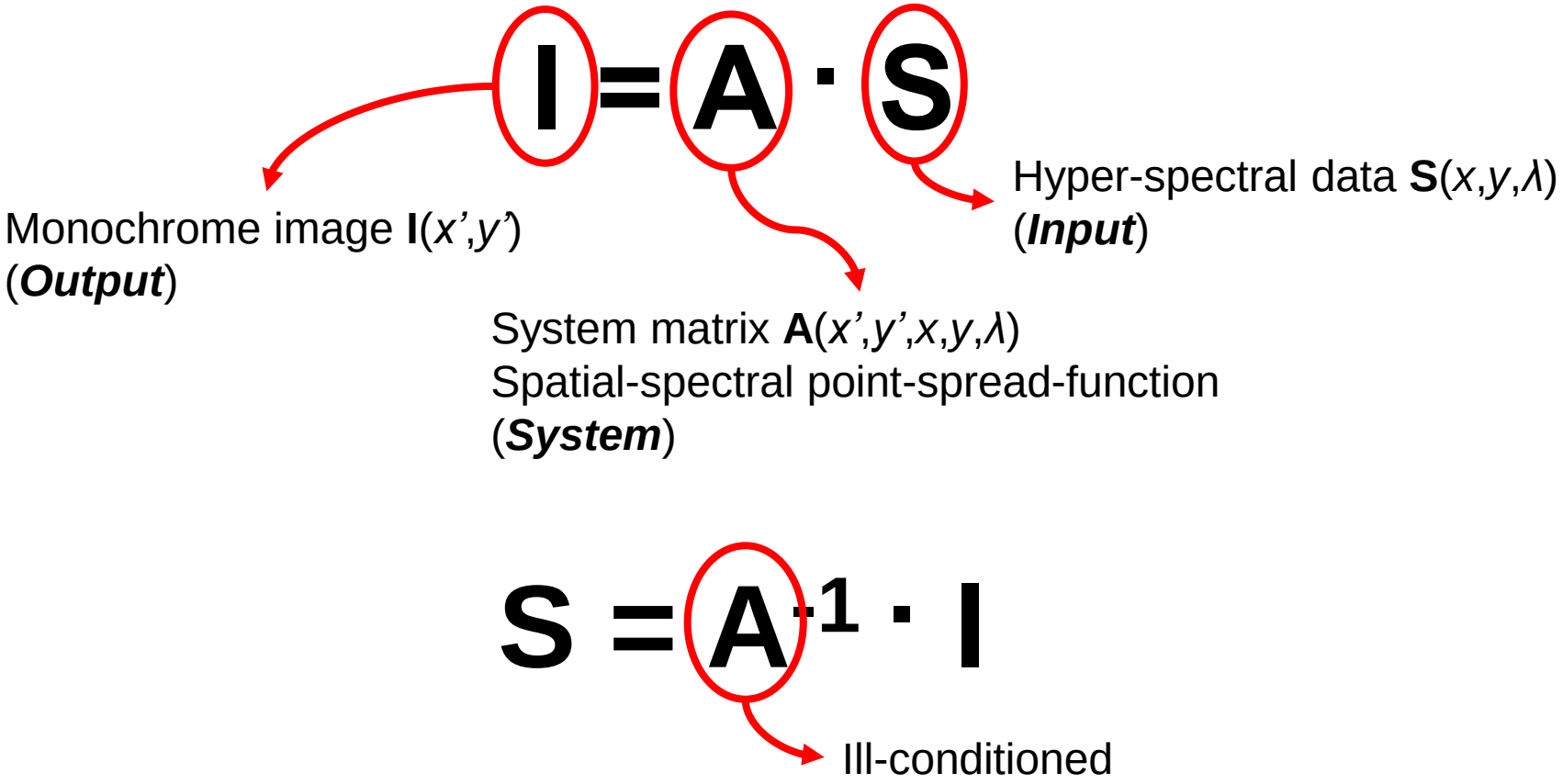
THE UNIVERSITY OF UTAH

Our Goal: Compact snapshot hyper- (or multi-) spectral camera



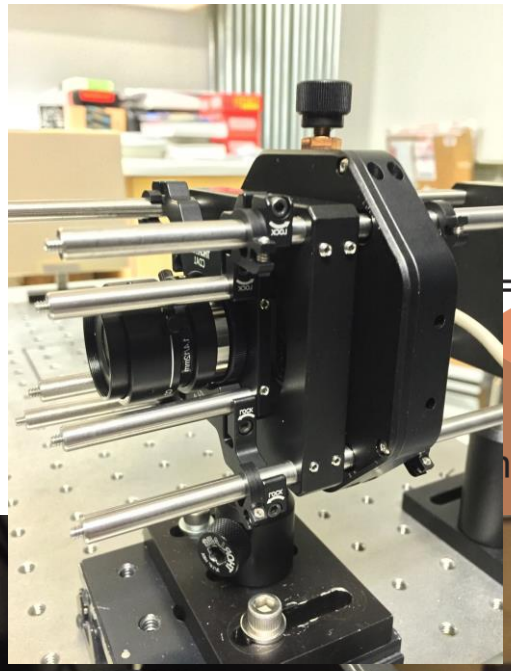
Spatially-variant & spectrally-variant PSFs

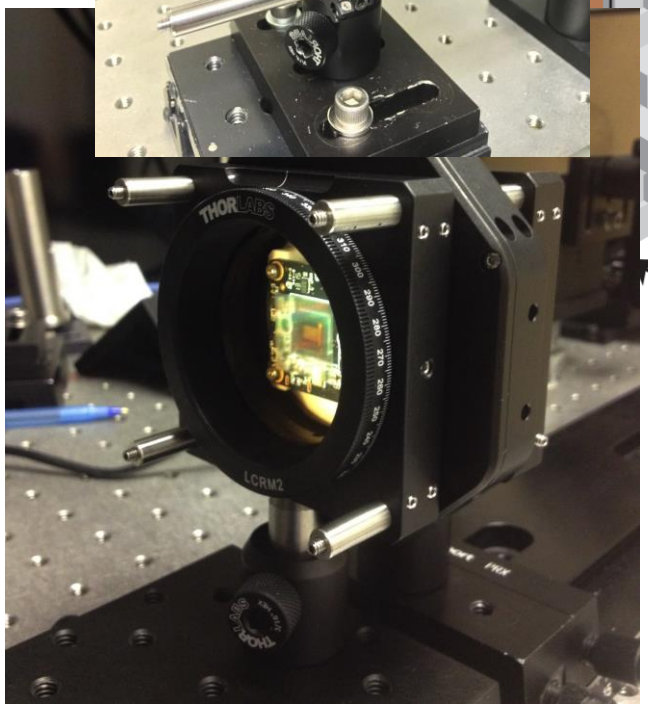
Step 2 – Mathematical description



Regularization: (1) Fast algorithm (~1s or <<1s)
(2) Noise reduction

The architecture of our multi-spectral imager





substrate

=18μm

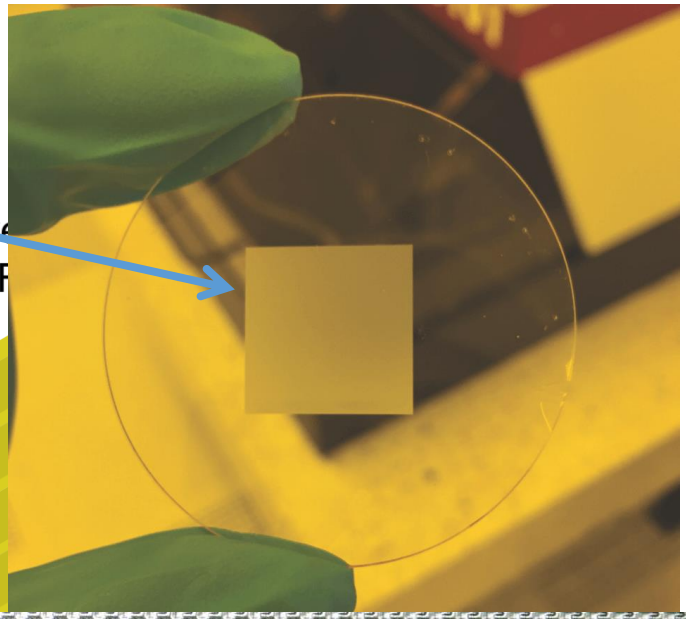
Δ=3μm

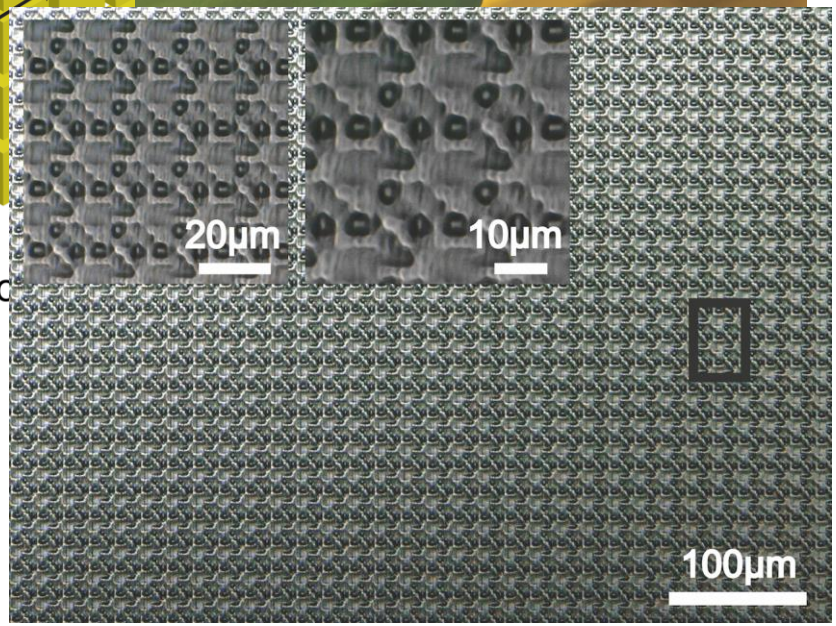
d

diffractive
array (DR

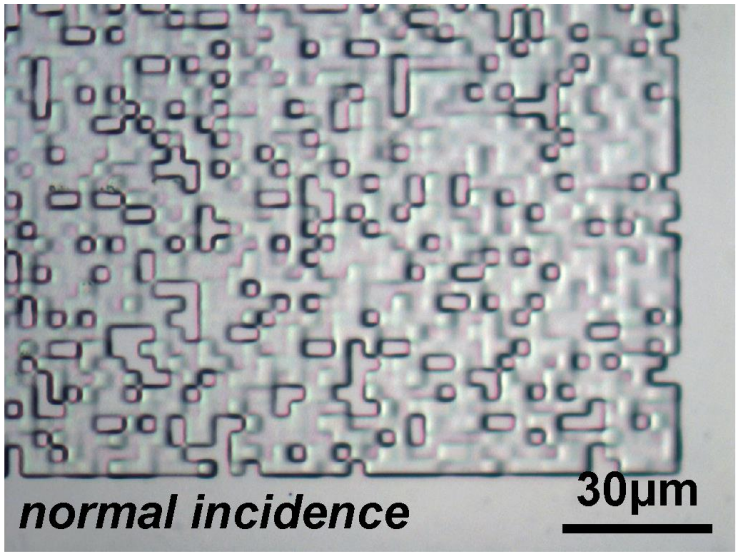
Y'
X'

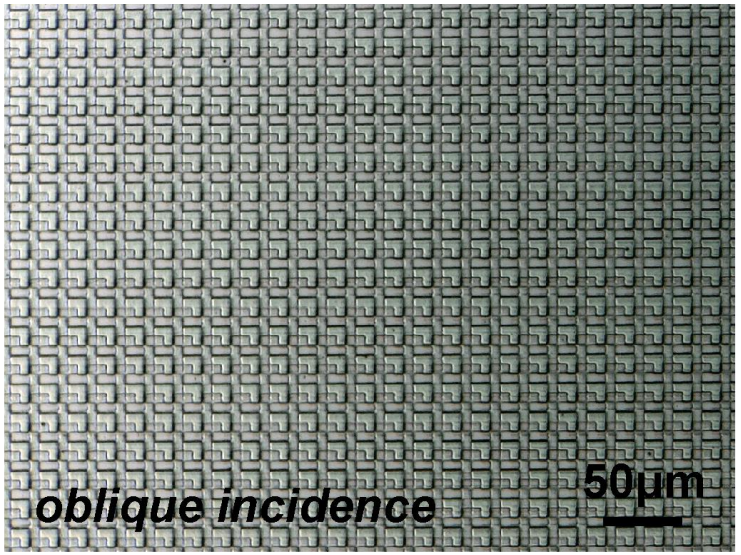
sensc

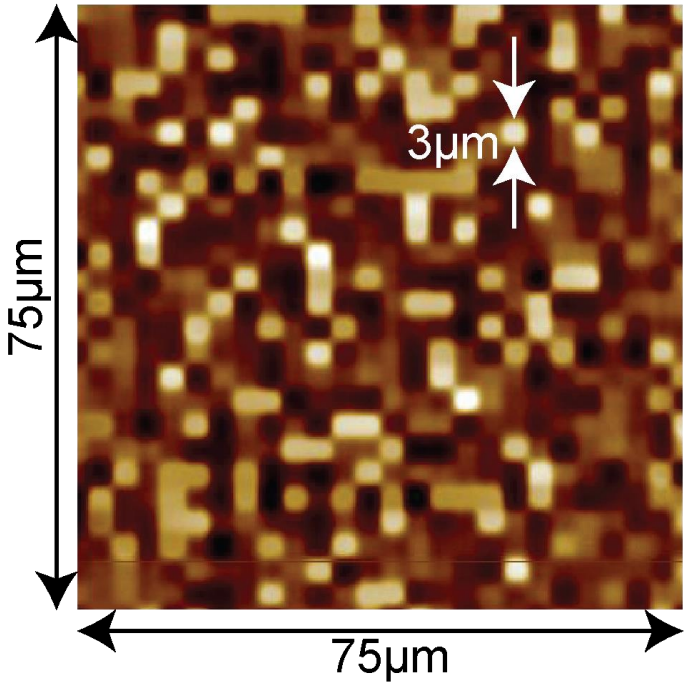


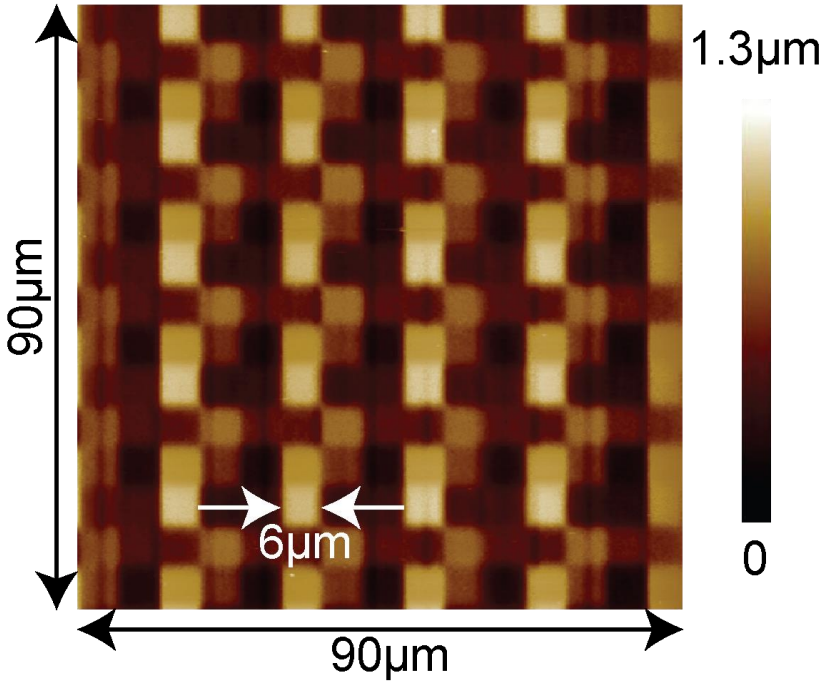


Diffractive-Filter Array (DFA)

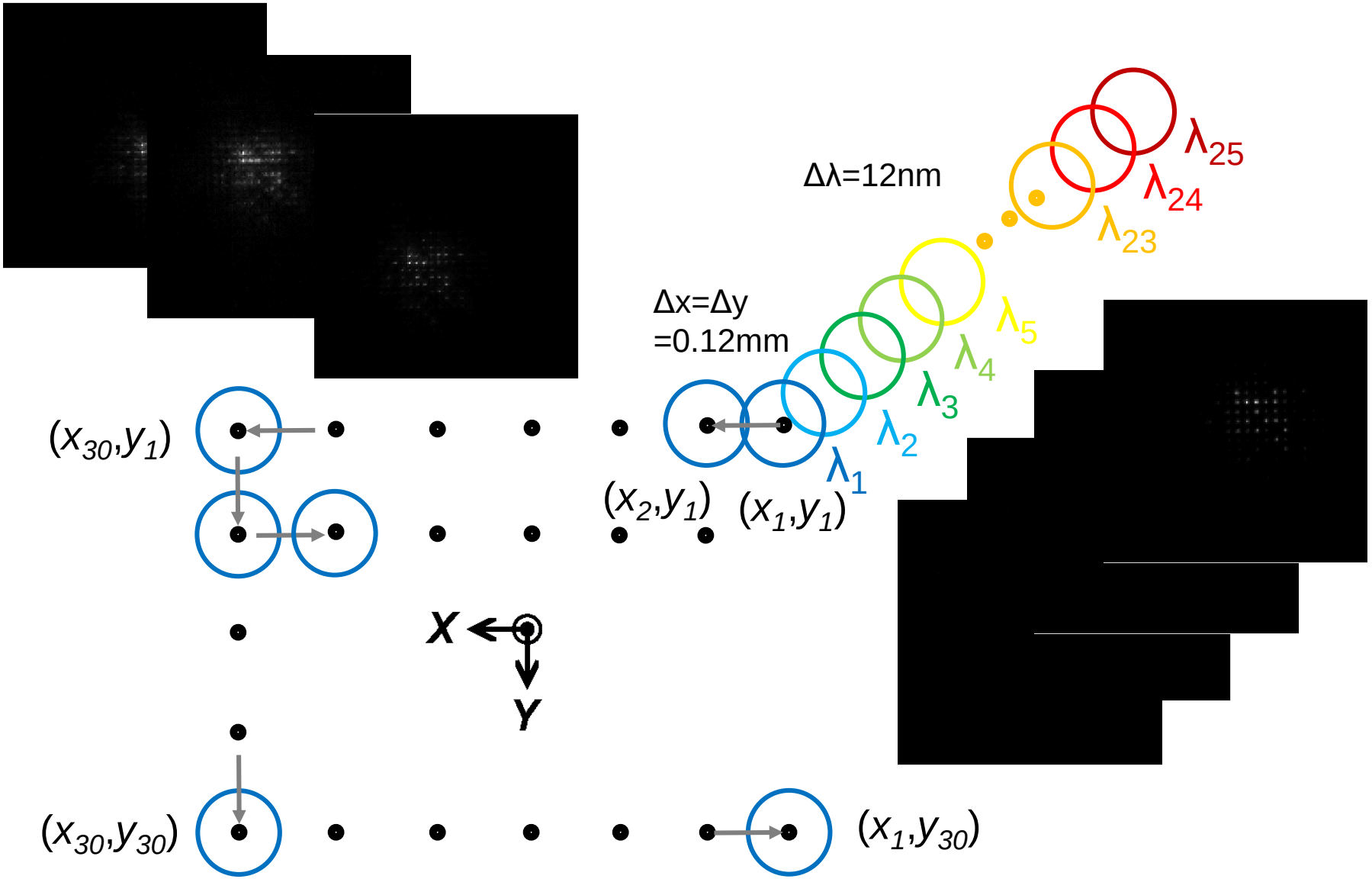




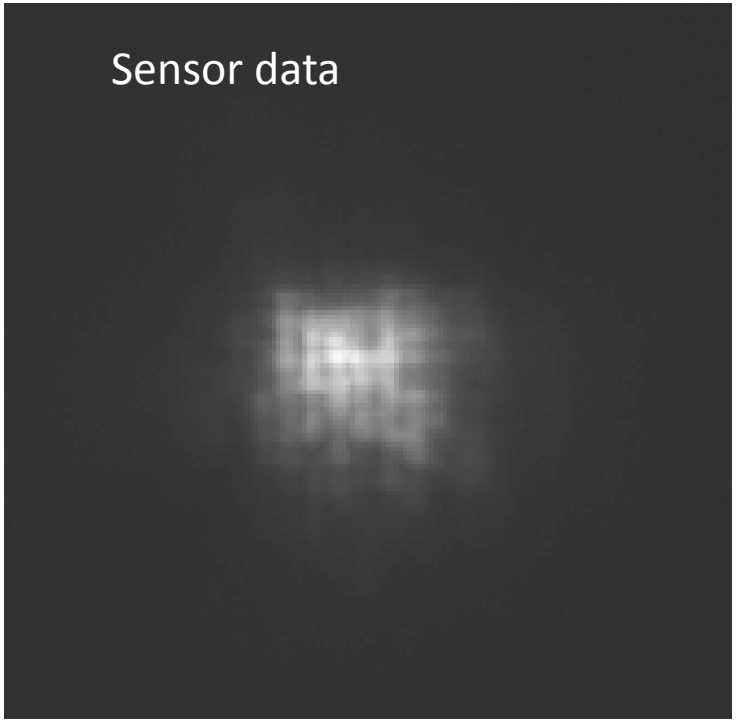




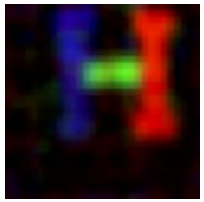
Spatial-Spectral Response Calibration

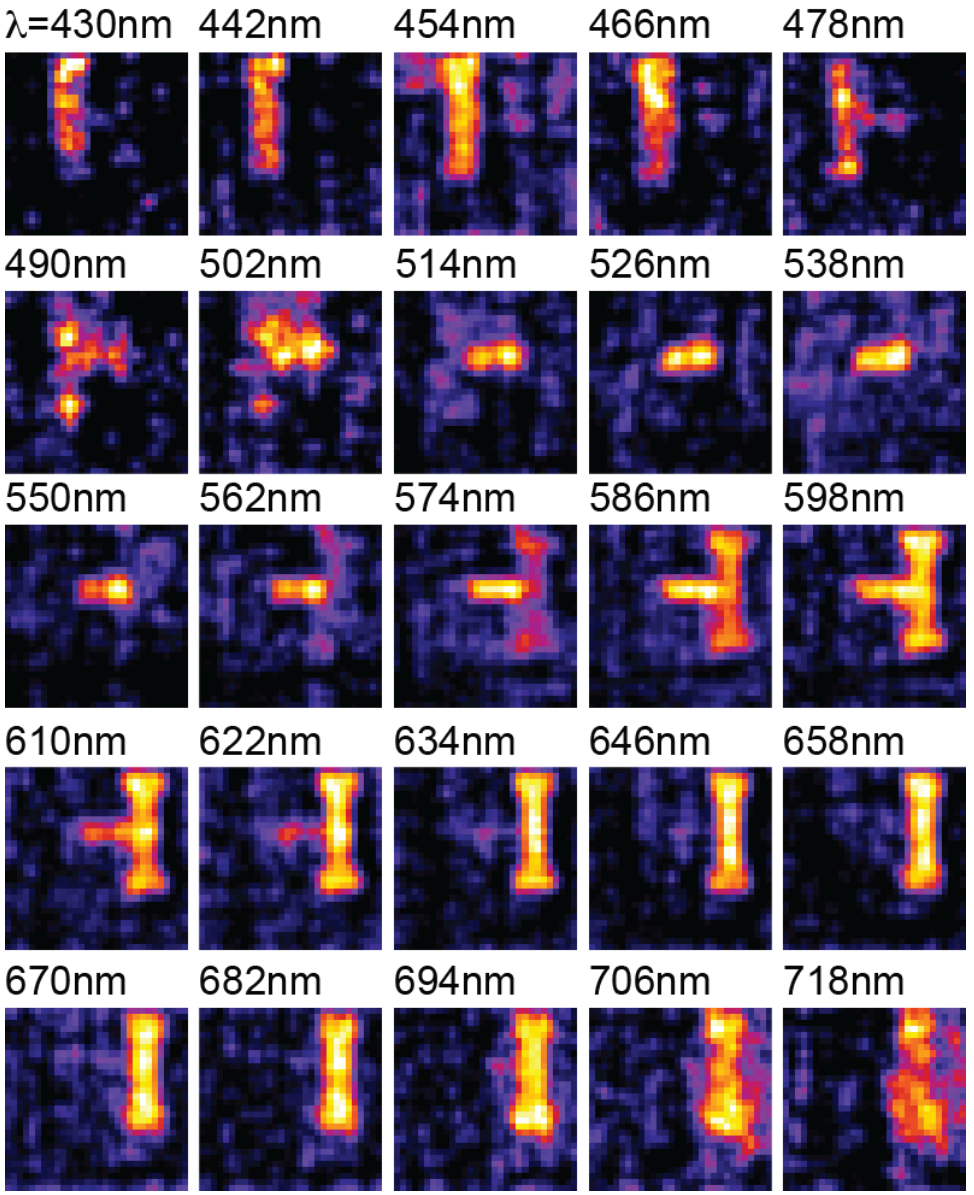


Results

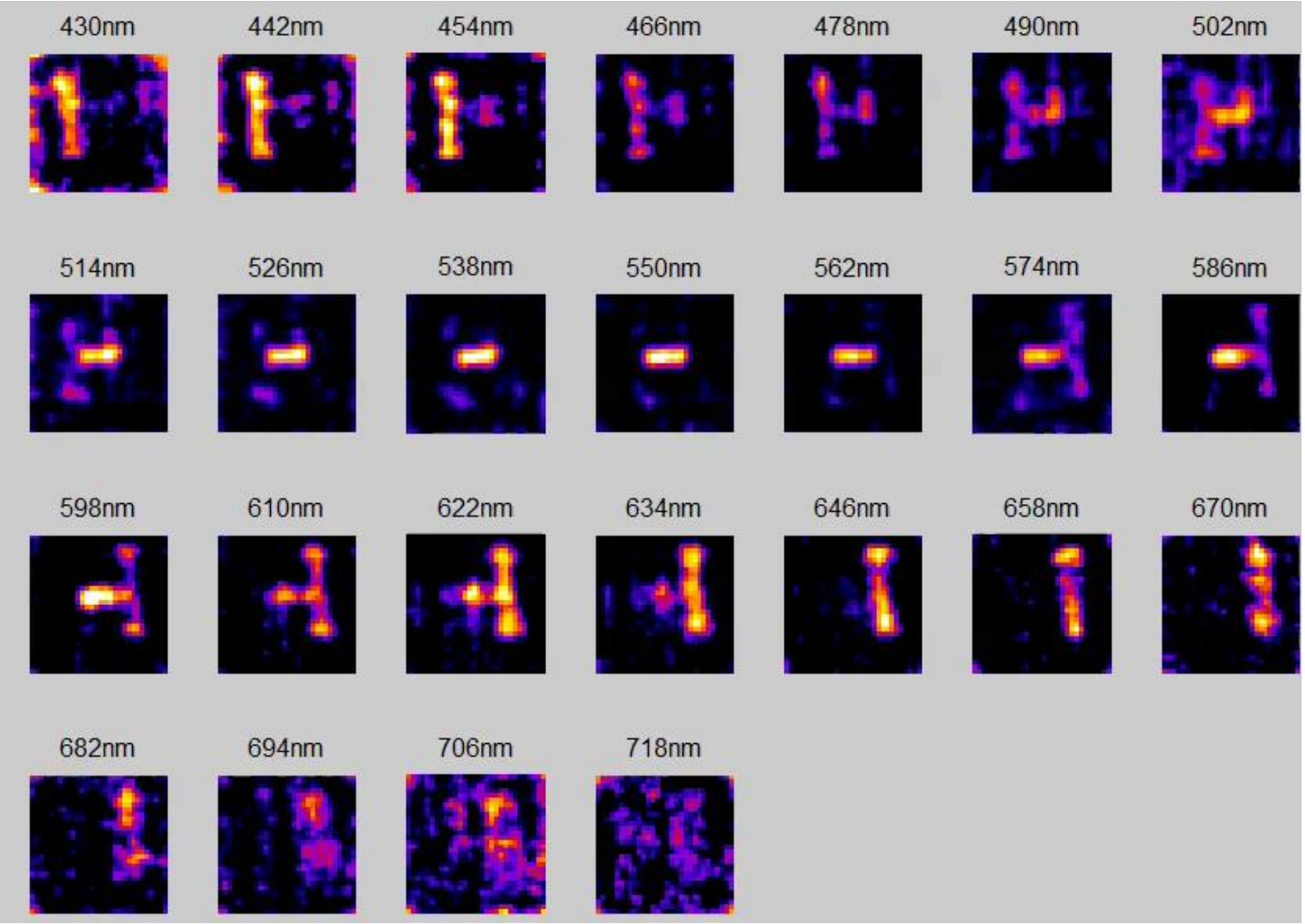


Reconstructed RGB image

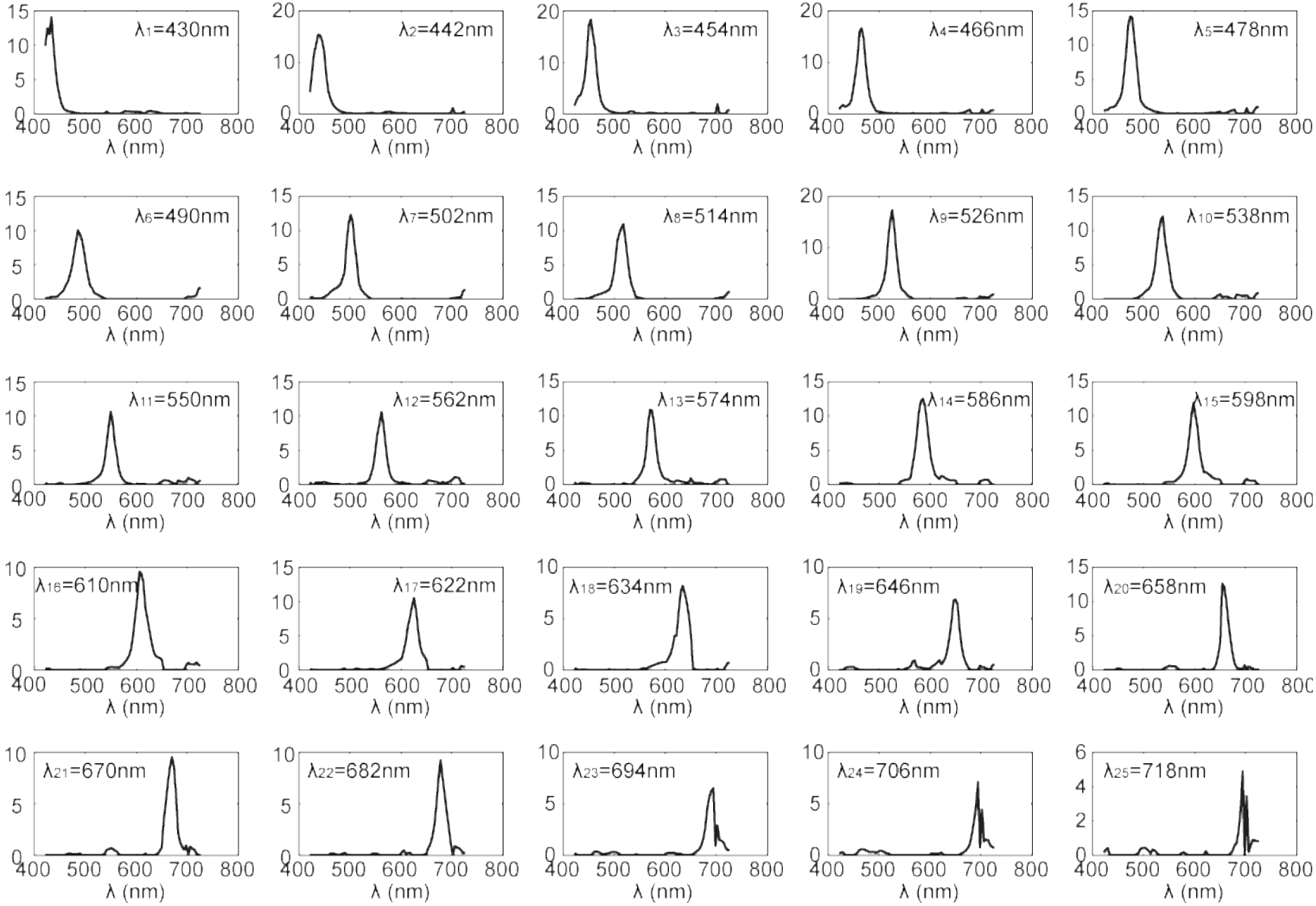




Multi-spectral video is possible

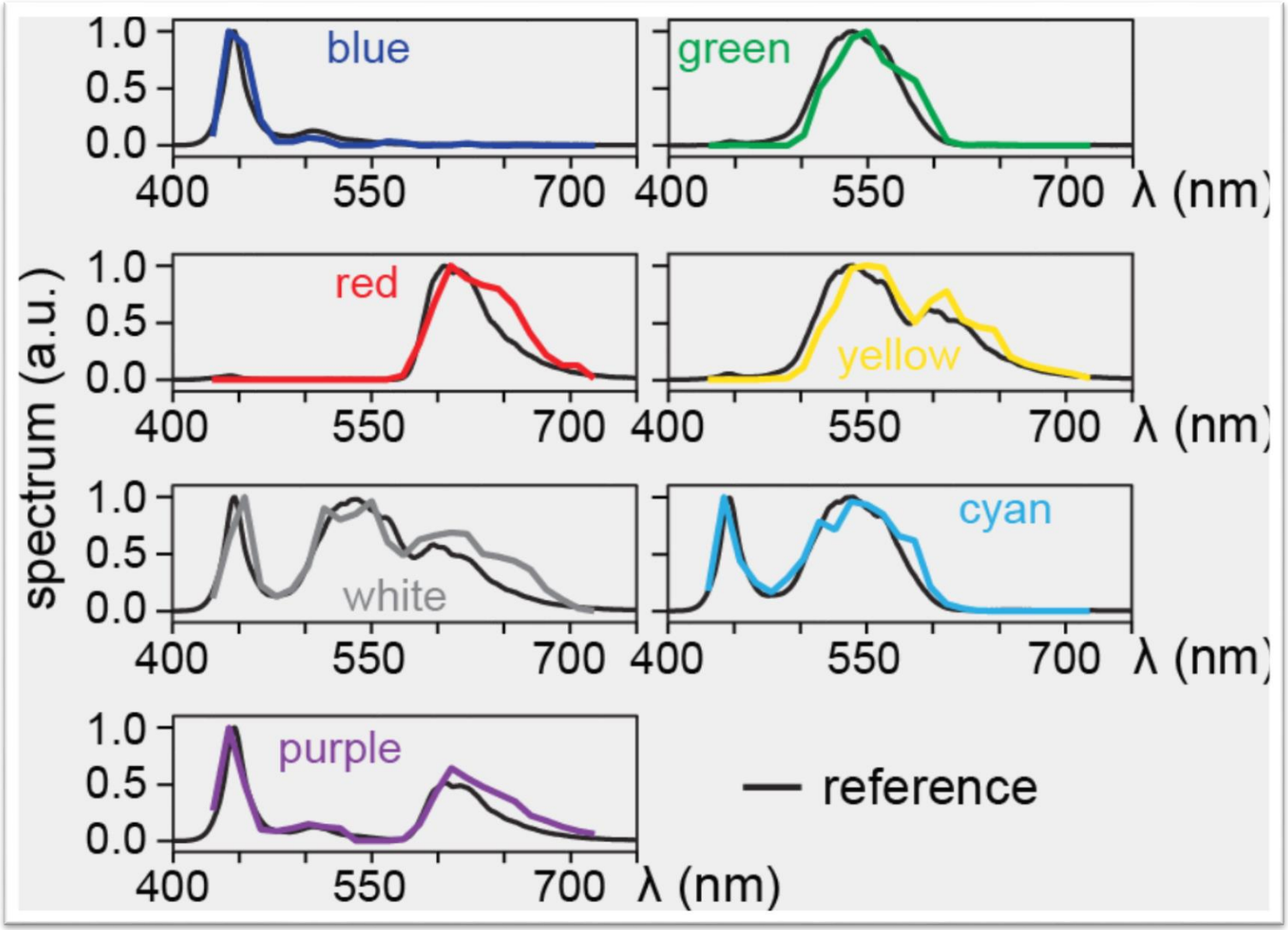


Spectral Response: 25 bands, FWHM ~ 12nm

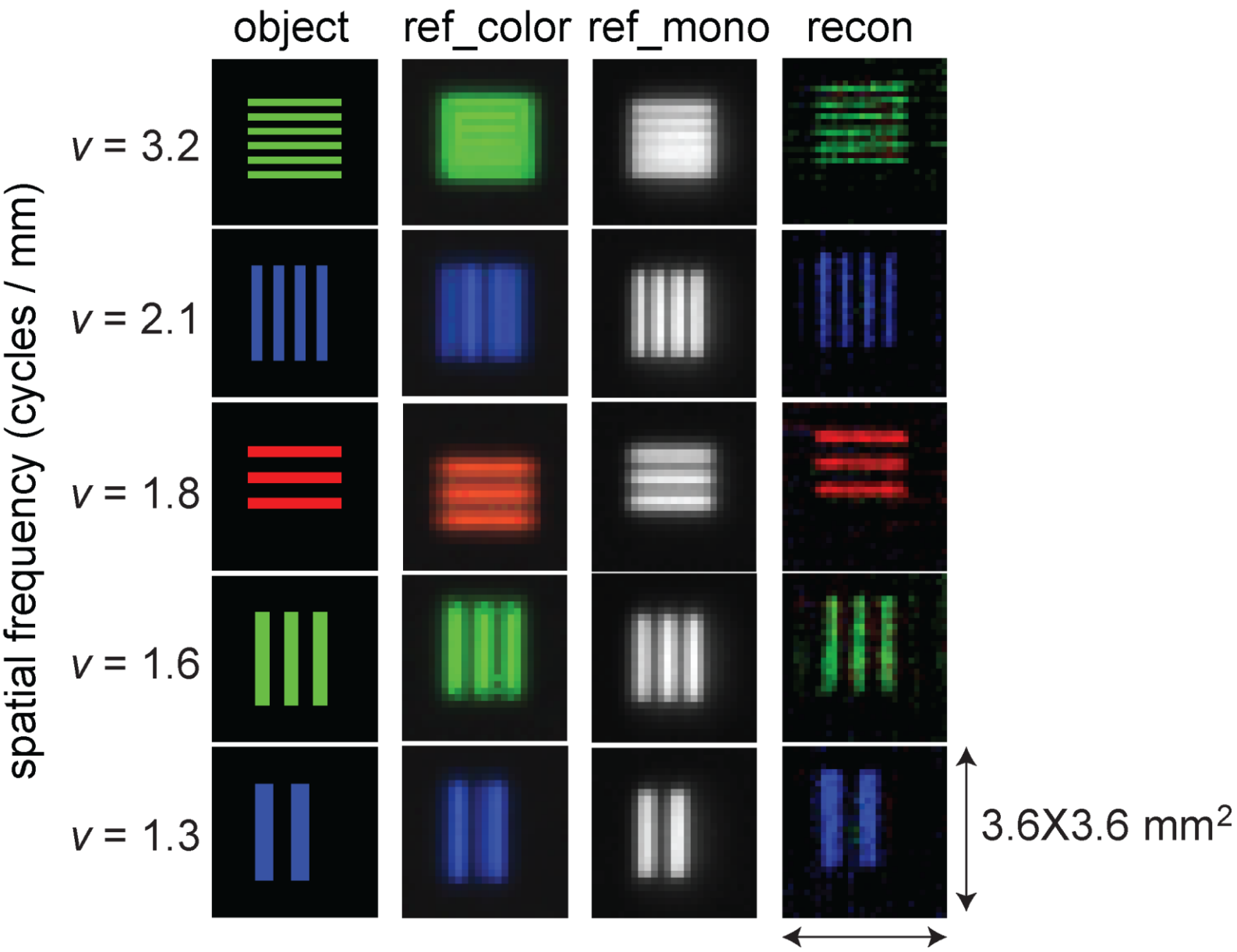


Note low sensor QE limits SNR for λ>~700nm.

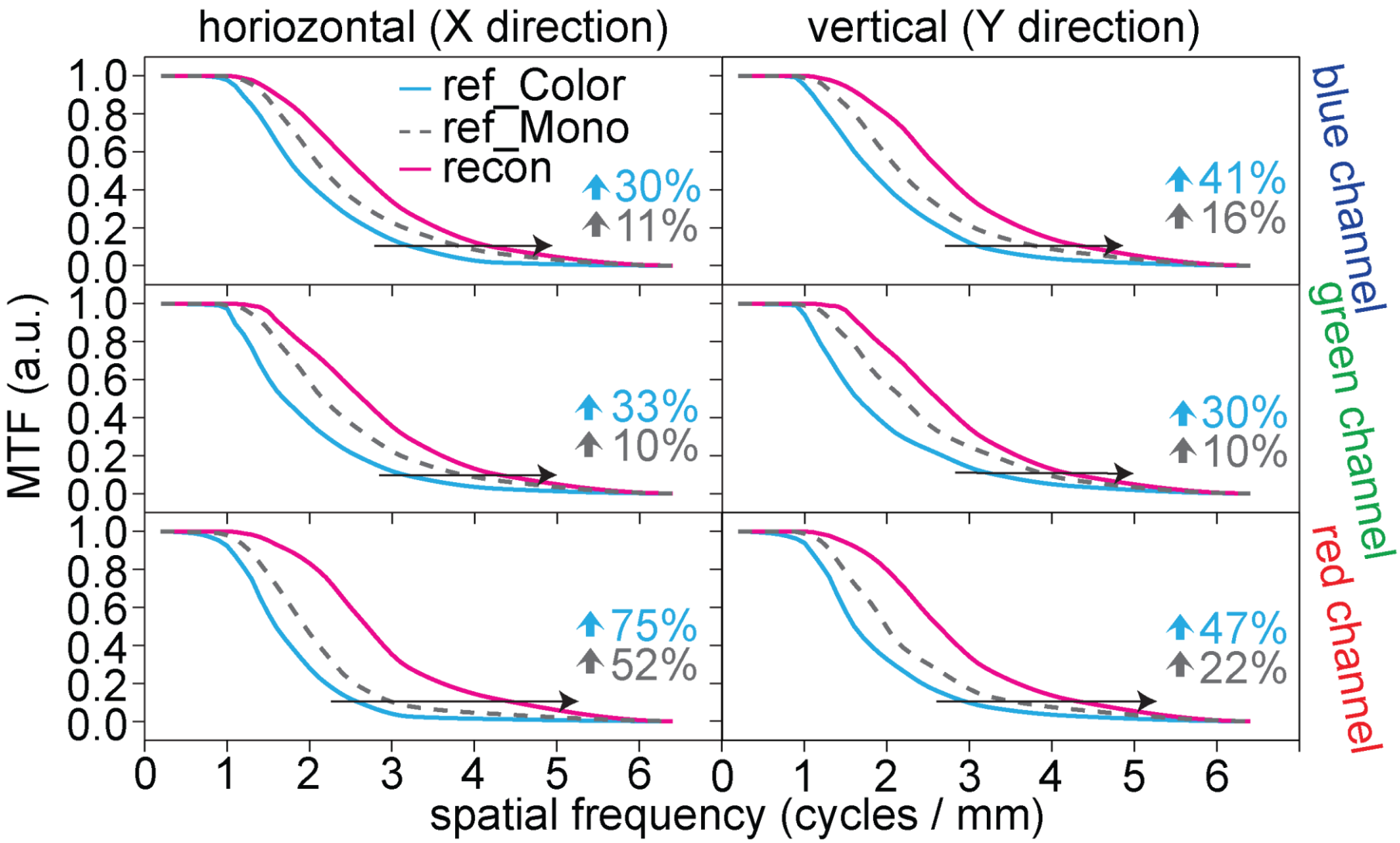
Spectral Reproduction Error < 8%



Spatial Resolution



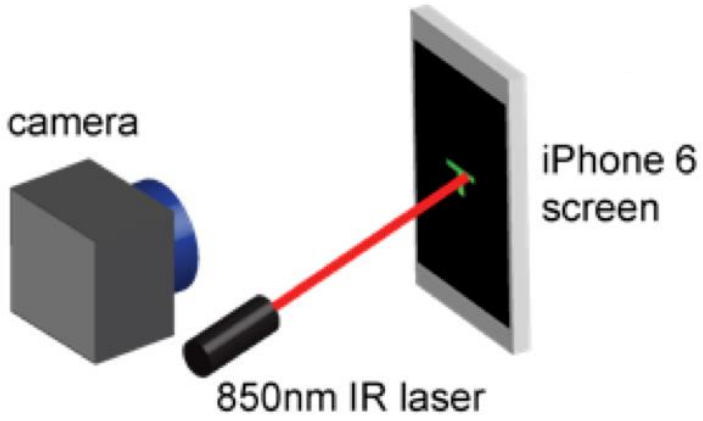
Modulation Transfer Functions



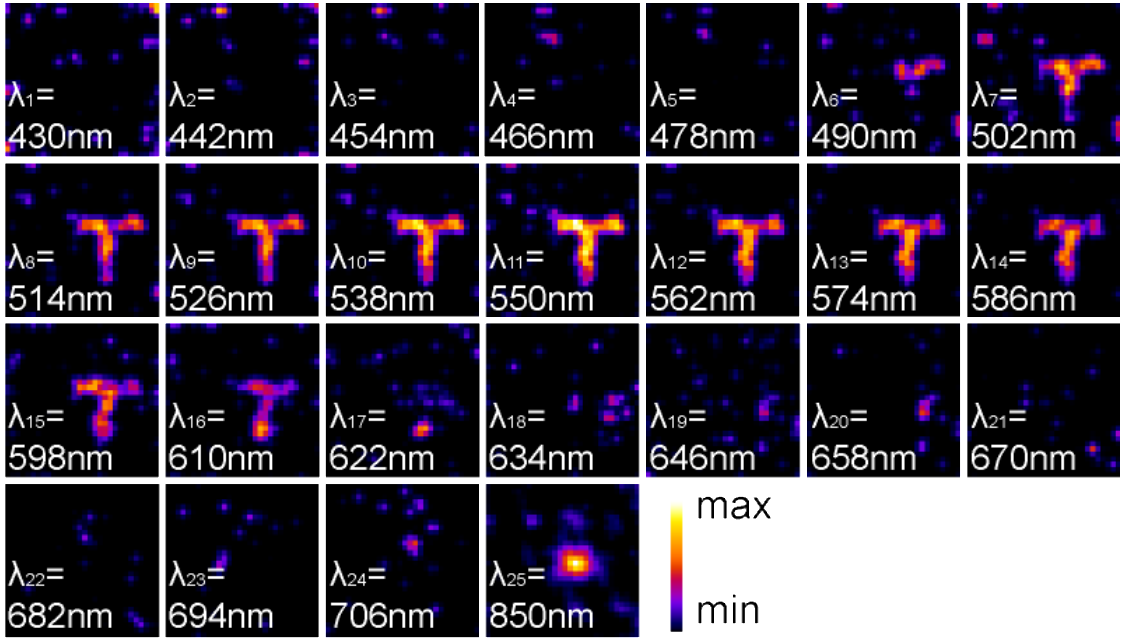
C. G. Ebeling, A. Meiri, J. Martineau, Z. Zalevsky, J. M. Gerton and R. Menon, “Increased localization precision by interference fringe analysis,” *Nanoscale*, 7, 10430-10437 (2015)

Imaging NIR & Vis bands with single sensor

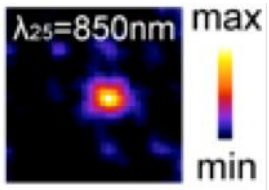
Experimental setup



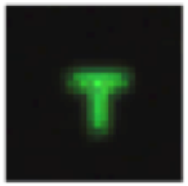
Multi-spectral image



NIR image



Reconstructed RGB

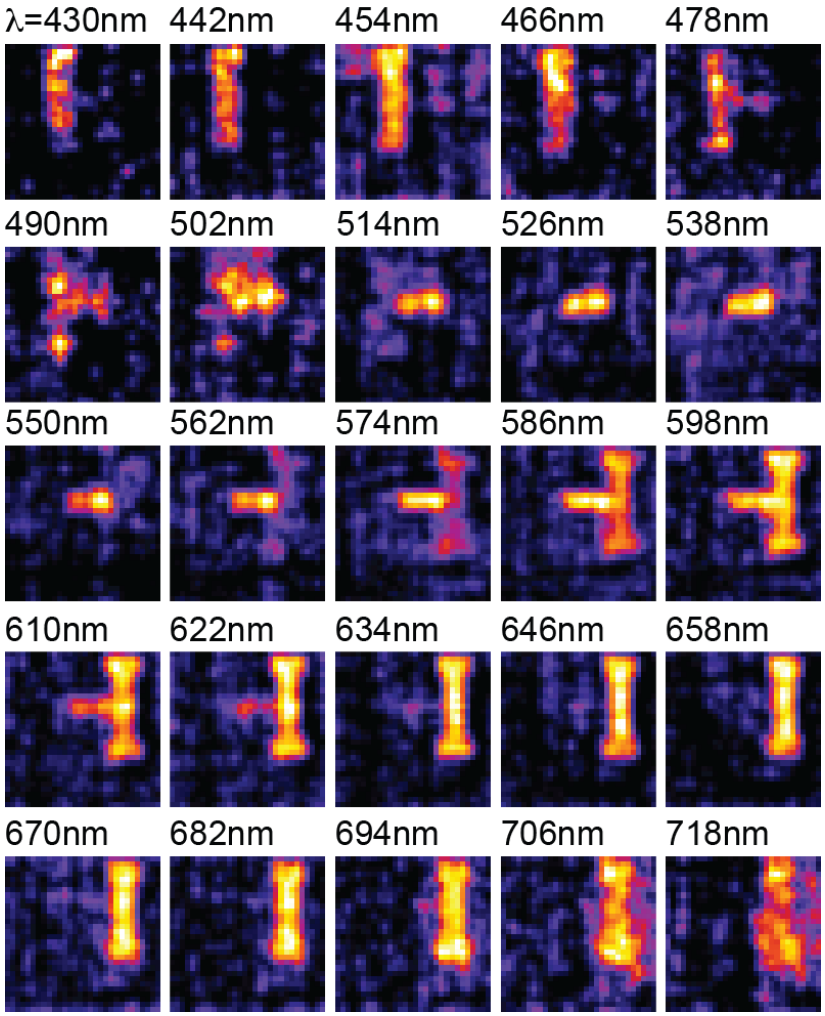


No discernible crosstalk

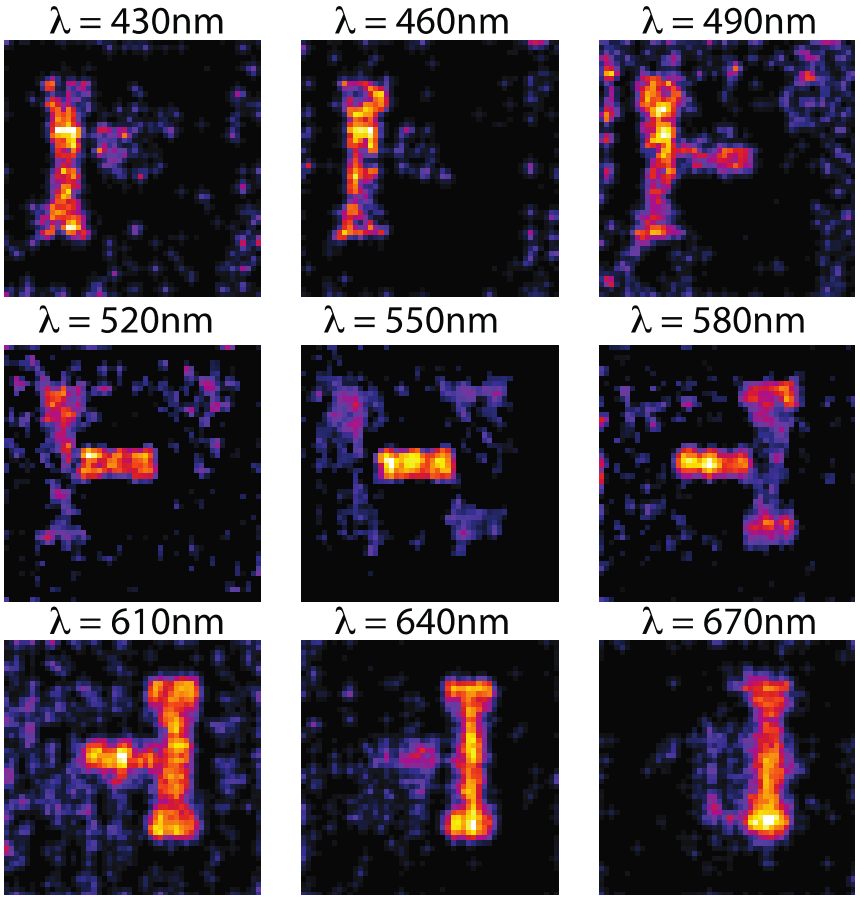
Computationally trade-off spatial & spectral resolutions

Same hardware

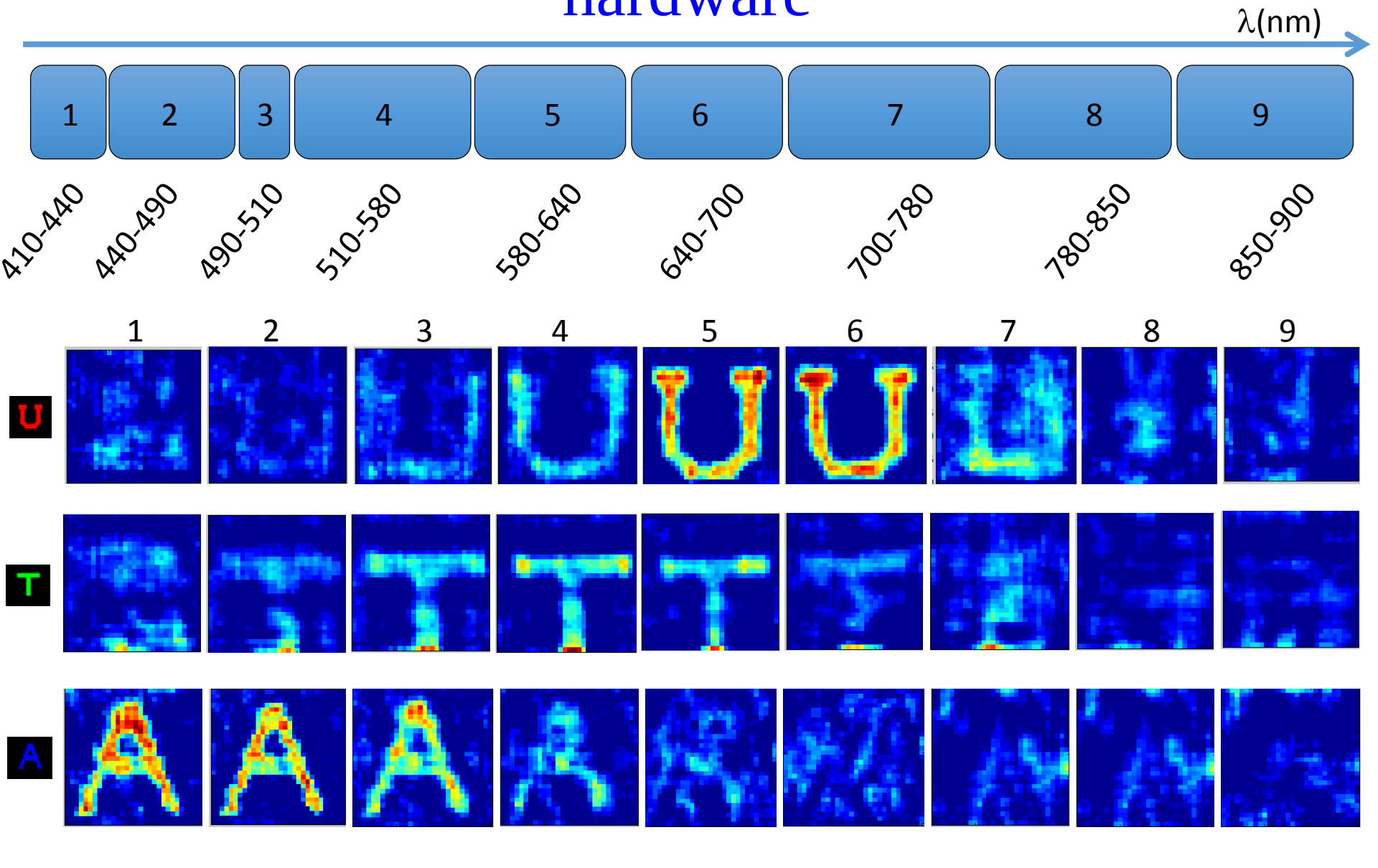
30 X 30 pixels X 25 bands



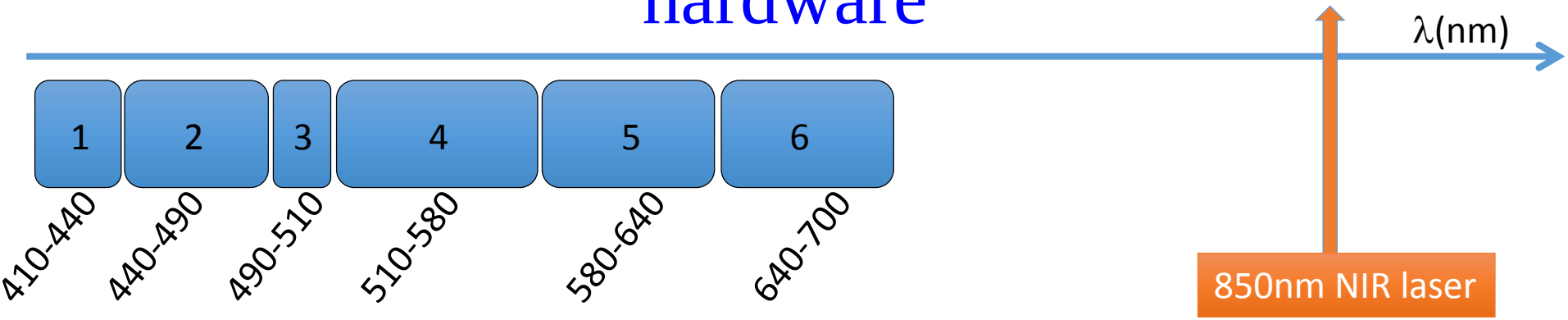
50 X 50 pixels X 9 bands

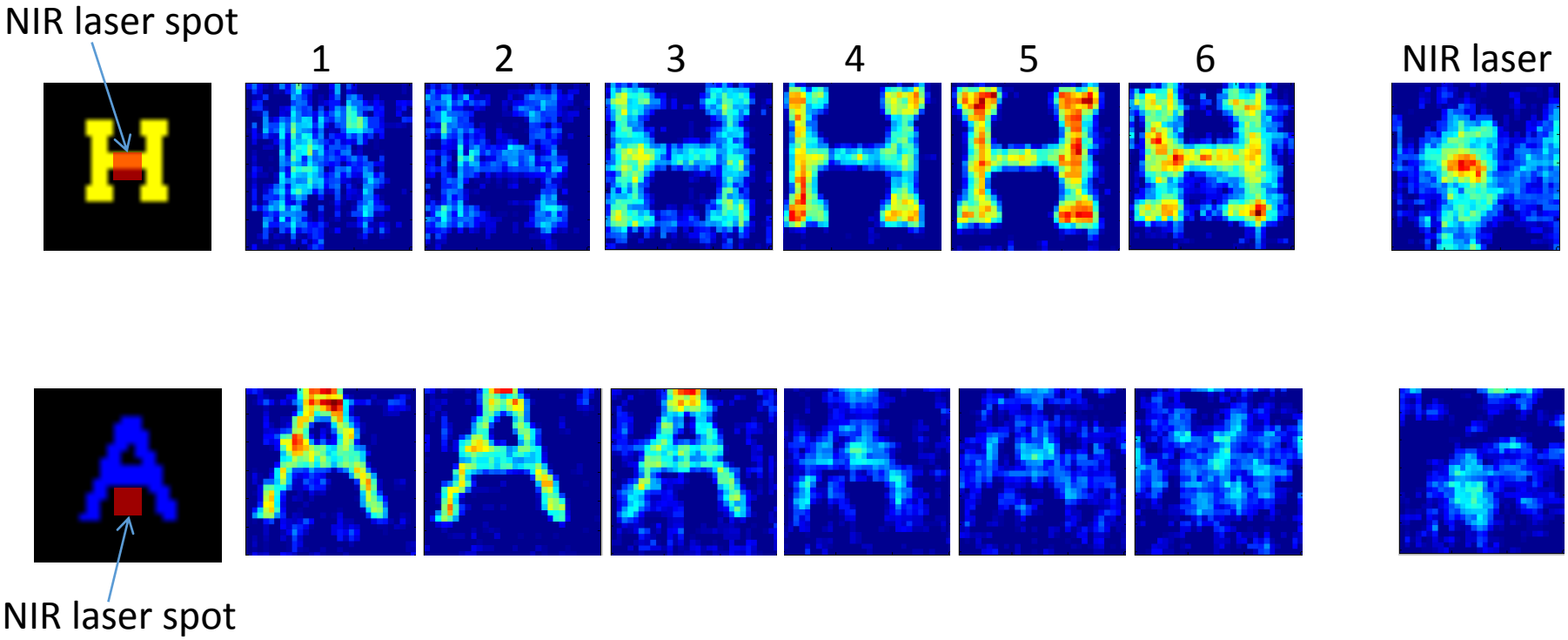


Imaging with non-equal bands: same hardware

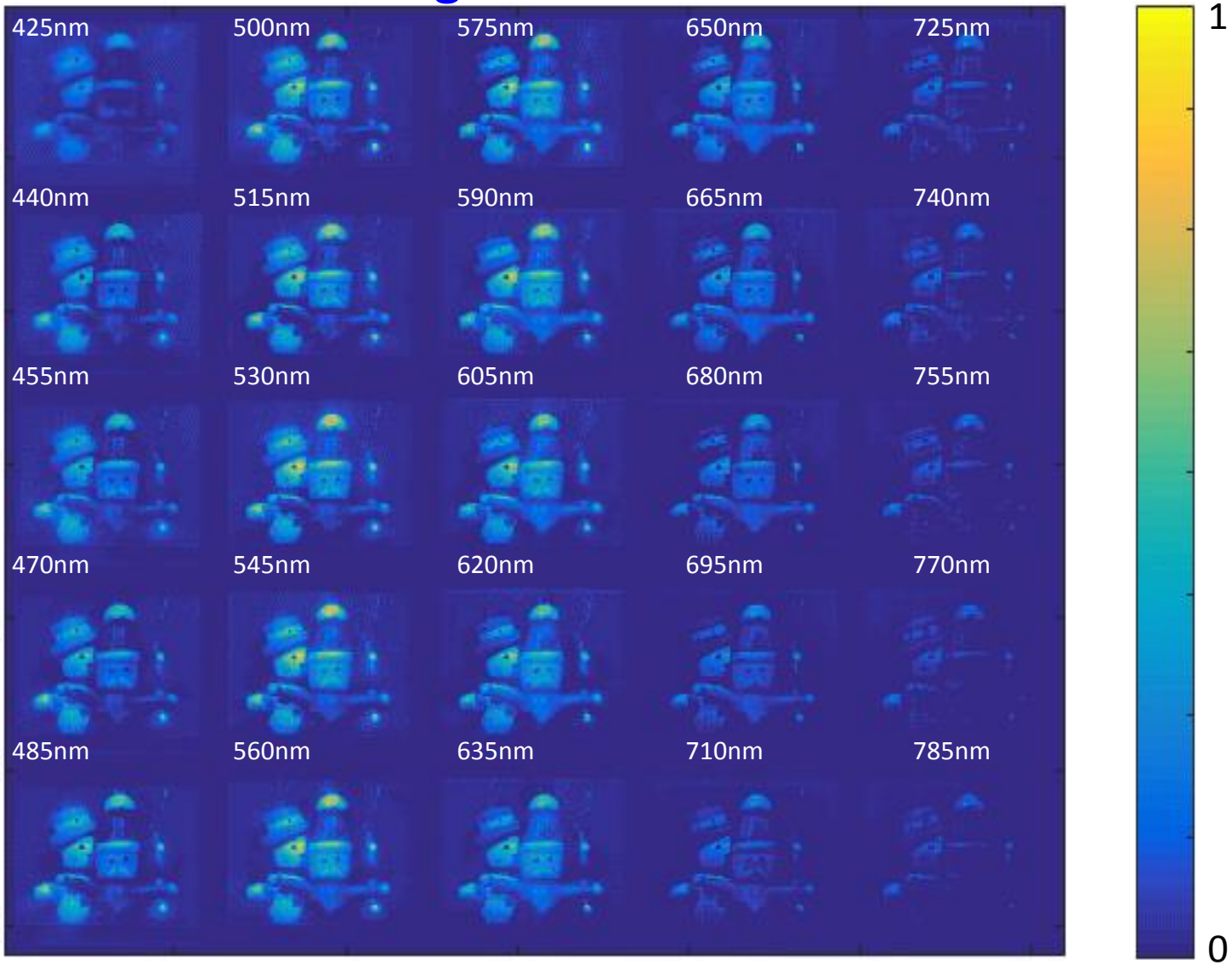


Computational spectral filtering: same hardware



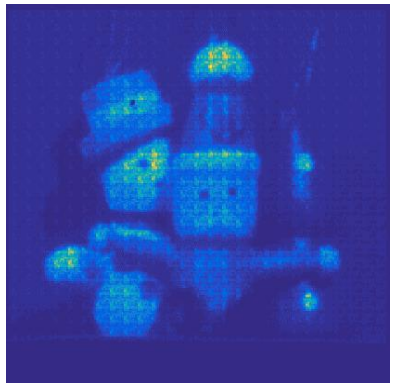


Multi-spectral image: 288X288 pixels X 25 bands
Higher NA lens



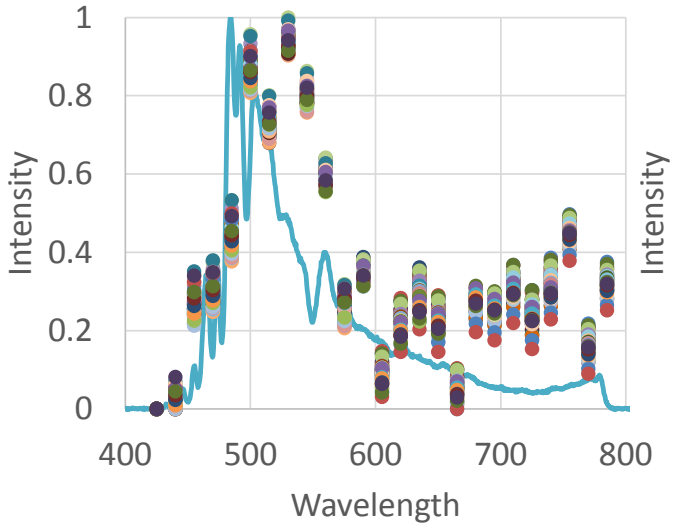
Rendered RGB Image (288 X 288 pixels)

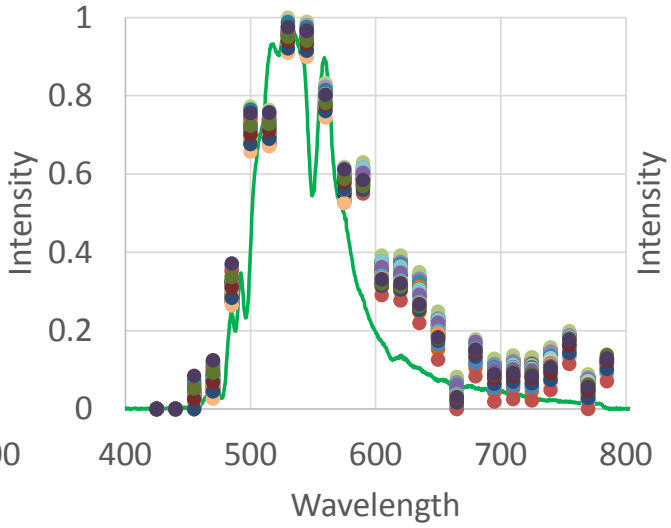
Raw sensor Image

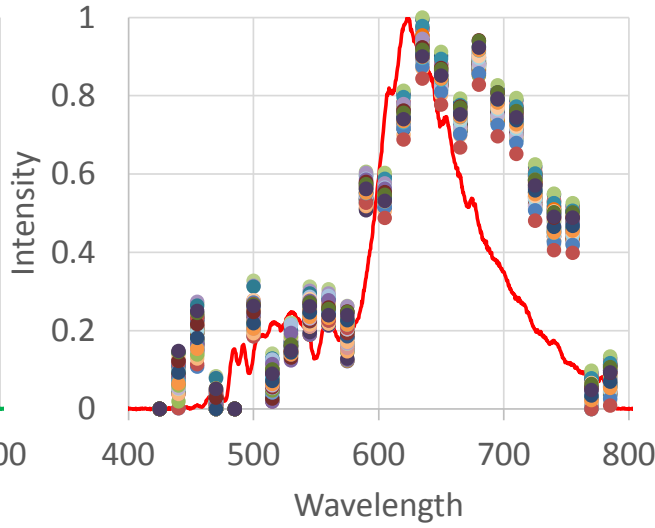


solid lines = reconstructed

each circle represents value in 16 X 16 pixel patch





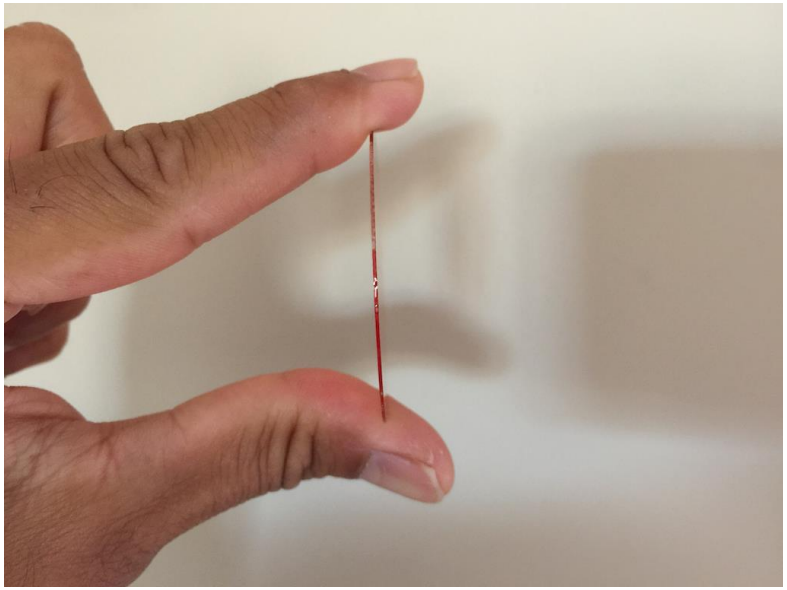


We demonstrated:

- compact
- lightweight
- multi- or hyper-spectral
- programmable spectral bands (no change in hardware)
- low-cost

Commercializing a system like this with > 8 spectral bands
Lumos Imaging

Flat Lightweight Optics



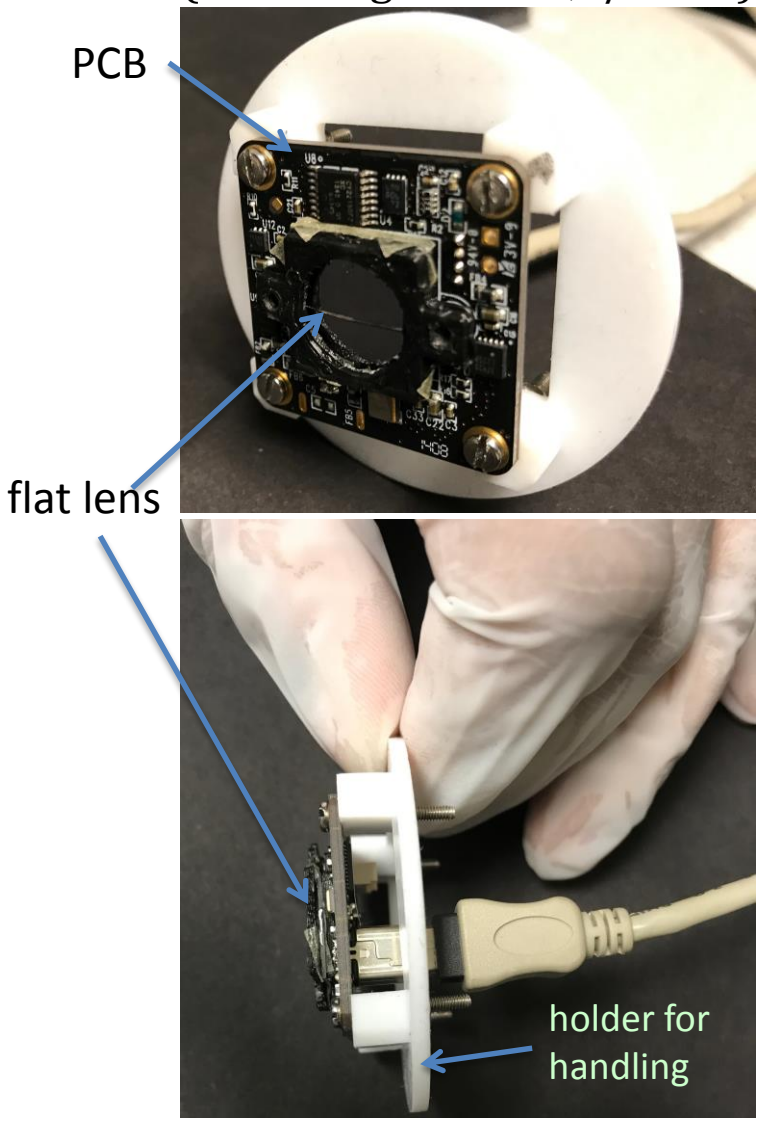
- **Thin, lightweight**
- **Broadband (UV, Vis, IR)**
- High NA possible
- Full wavefront control
- High efficiency
- Transmissive or Reflective
- Inexpensive to mass manufacture

Applications:

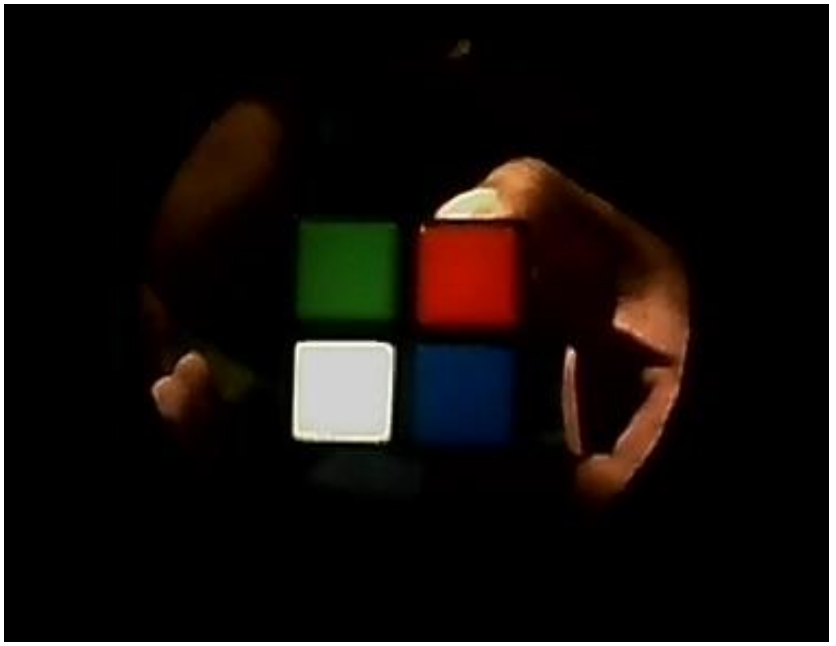
- Flat lens imaging
- IR projectors
- Holograms
- Security devices

Flat-lens camera

Demo camera with single flat lens
(focal length=1mm, f/#=10)



Video under sunlight

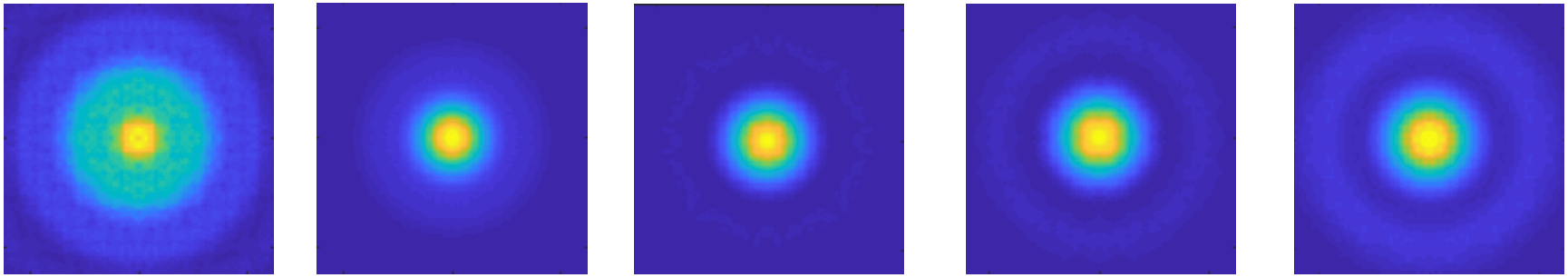


- Reduced thickness
- Fewer lens elements → less expensive assembly
- High NA → thinner HMDs
- Novel form factors

Flat broadband MWIR lenses possible
λ=8μm to 12μm

Example PSFs at NA = 0.05. Material used is polymer.

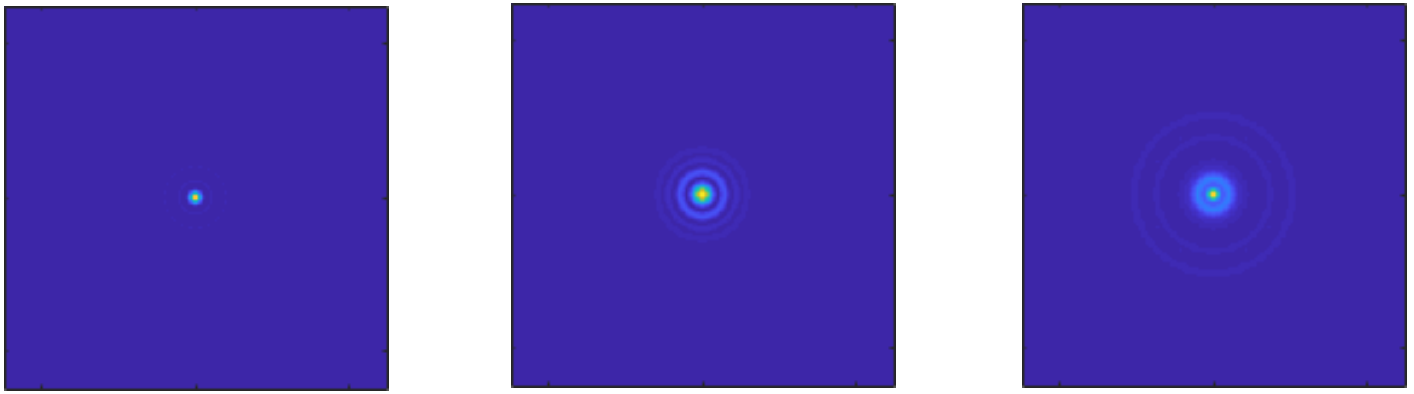
λ=8μm λ=9μm λ=10μm λ=11μm λ=12μm



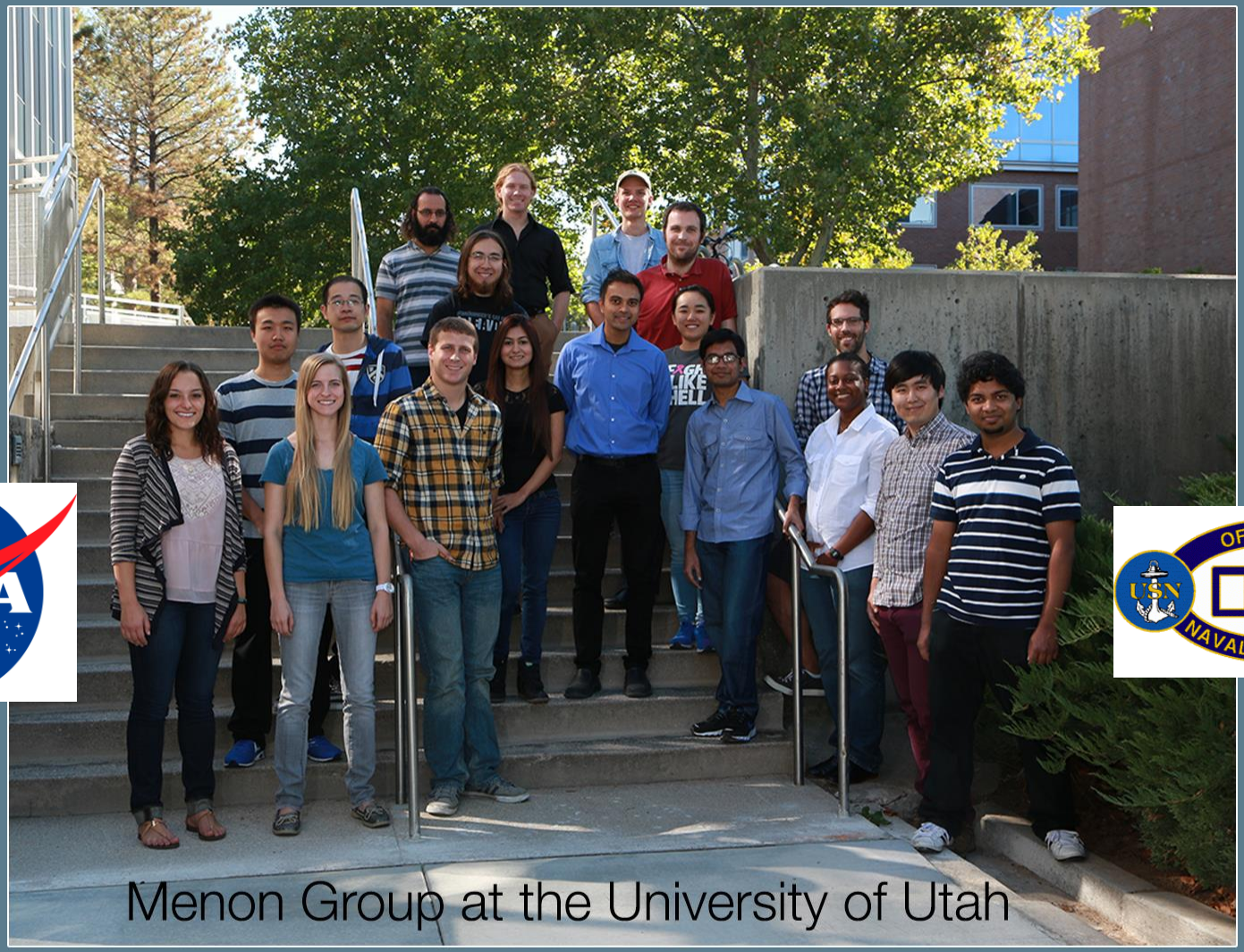
400μm

Example PSFs at NA = 0.44 (f#=1).

λ=10μm λ=11μm λ=12μm



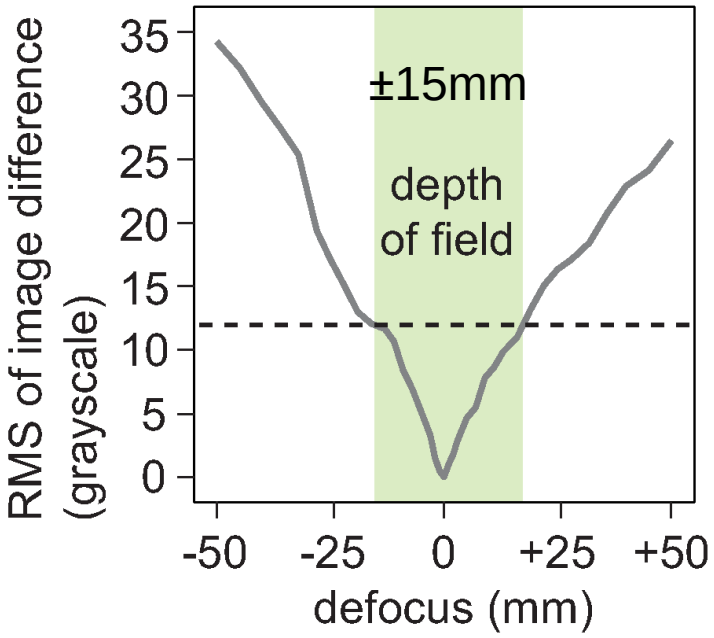
400μm

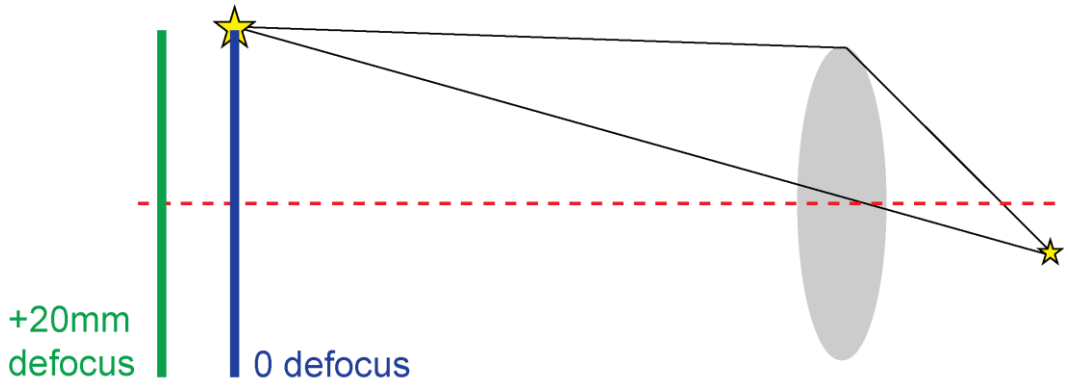


Menon Group at the University of Utah

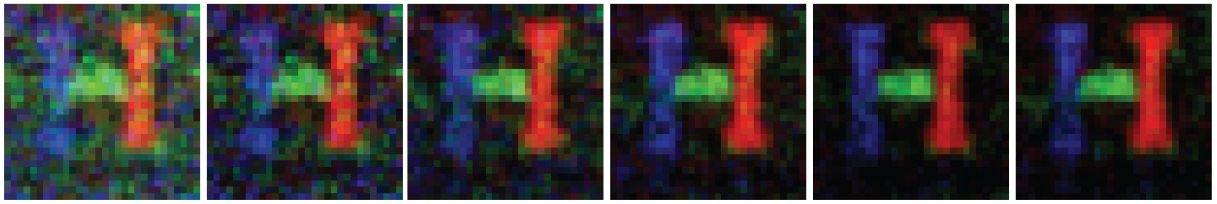
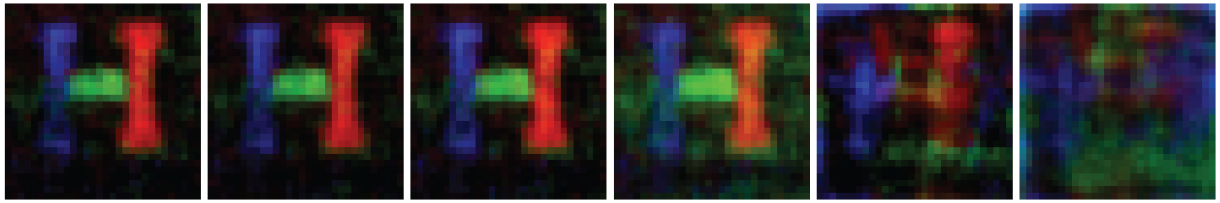
webpage: http://lons.utah.edu/

Depth-of-field





Dynamic range

exposure time	1.25ms	2.00ms	3.30ms	5.00ms	6.71ms	10.00ms
max pixel value in raw image	25	36	54	77	101	145
recon						
exposure time	12.50ms	17.86ms	20.00ms	25.00ms	33.33ms	50.00ms
max pixel value in raw image	179	254	255	255	255	255
recon						

Spectral response for NIR-VIS imaging