



# Image Processing & Deconvolution for Adaptive Optics

CfAO Spring Retreat - 2003



# Center Activities

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- **Cross Theme discipline**

- Necessary for vision science and for astronomical applications

- **Speakers**

- Deconvolution:

*Julian Christou – Deconvolution for astronomical and vision science applications.*

*Franck Marchis – Image Processing and Deconvolution*

- Object Modeling:

*James Larkin – Galaxy modeling with measured PSFs*

- Enhanced Resolution:

*Sina Farsia – Multi-frame Resolution Enhancement*

- Wavefront Sensing:

*James Fienup – Phase Retrieval and Wavefront Sensing*

- Discussion:



# Multi-frame Blind Deconvolution

## Incoherent Image Formation

$$g_i(r) = f(r) * h_i(r)$$

measurement

target

convolution operator  
(superposition integral)

point spread function  
(blur)

**Deconvolution** – given  $g(r)$  and  $h(r)$ , solve for  $f(r)$

**Blind Deconvolution** – given  $g(r)$ , solve for  $h(r)$  and  $f(r)$



# Application of MFBD

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- **Astronomy**
  - Extended source - Solar Imaging
  - Crowded field – Galactic Center
- **Vision Science**
  - Simulated retinal image
  - Macaque Retinal
  - Human Retina

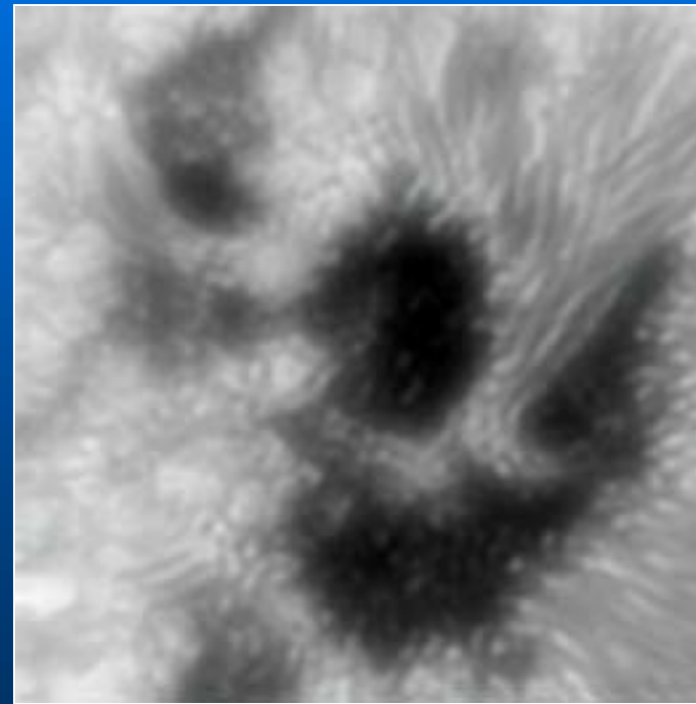
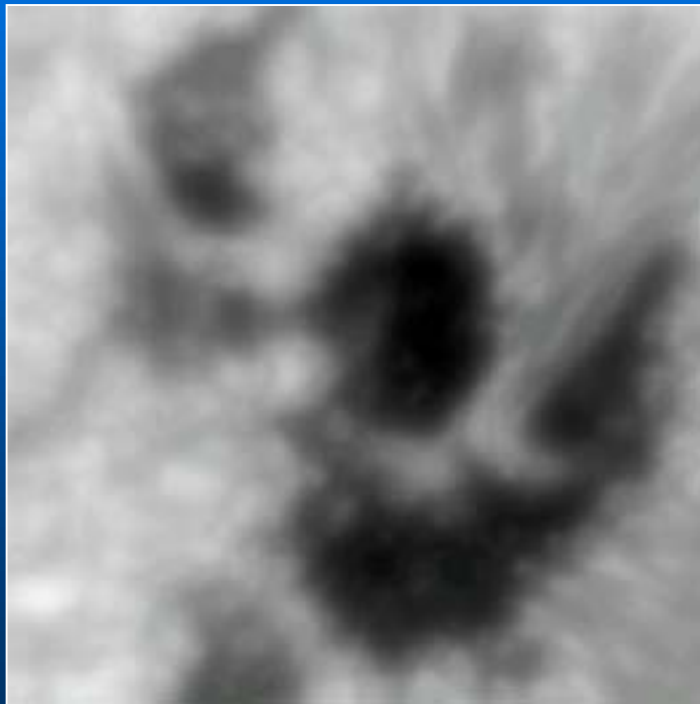


# Solar Imaging

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- **Rimmele, Marino & Christou**

- AO Solar Images from initial NSO low-order system.
- Blind deconvolution

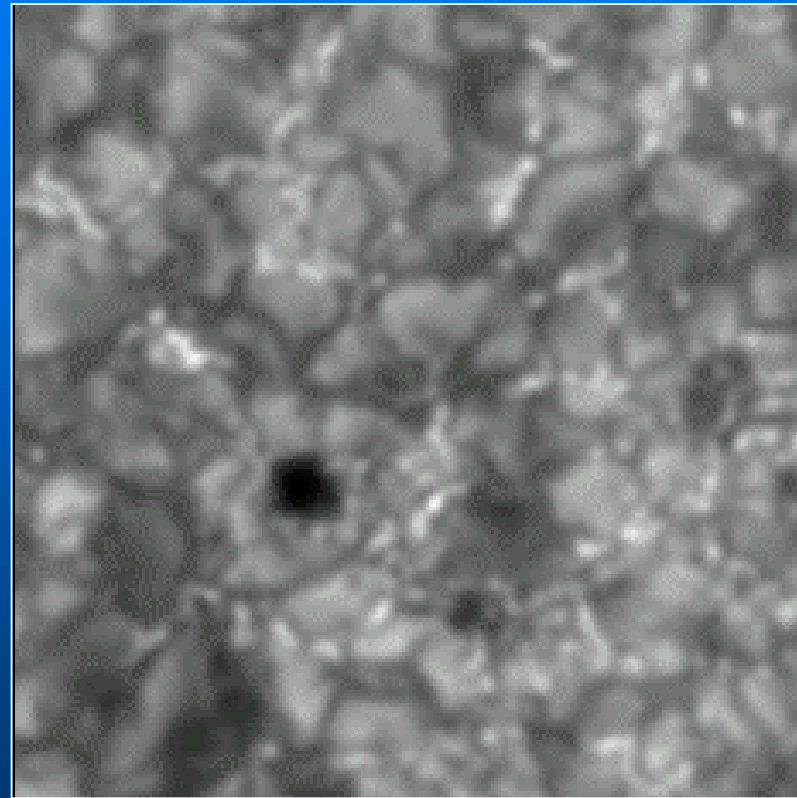
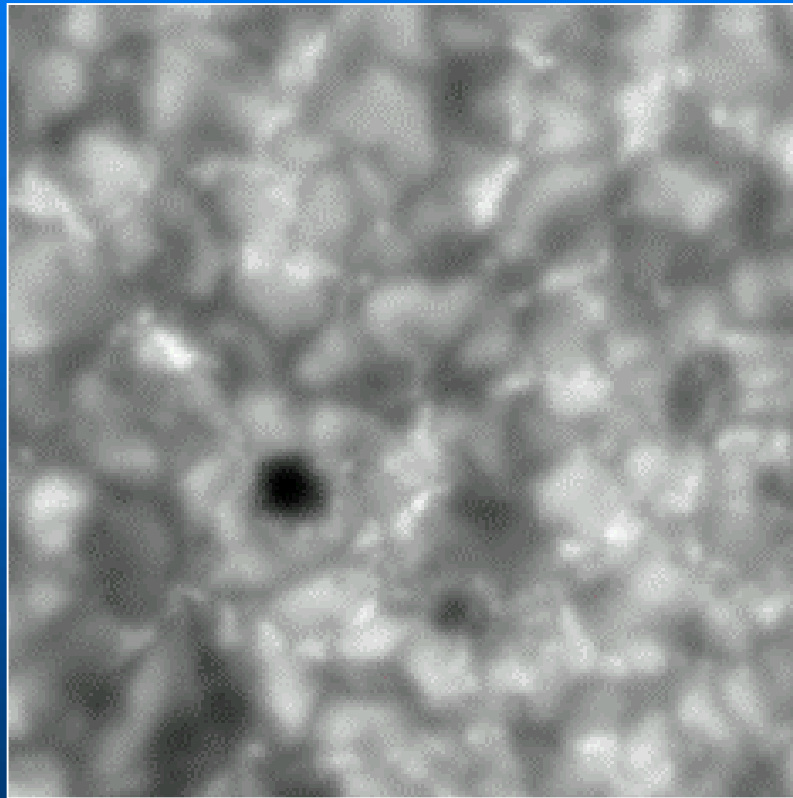


Sunspot Feature



# Solar Imaging

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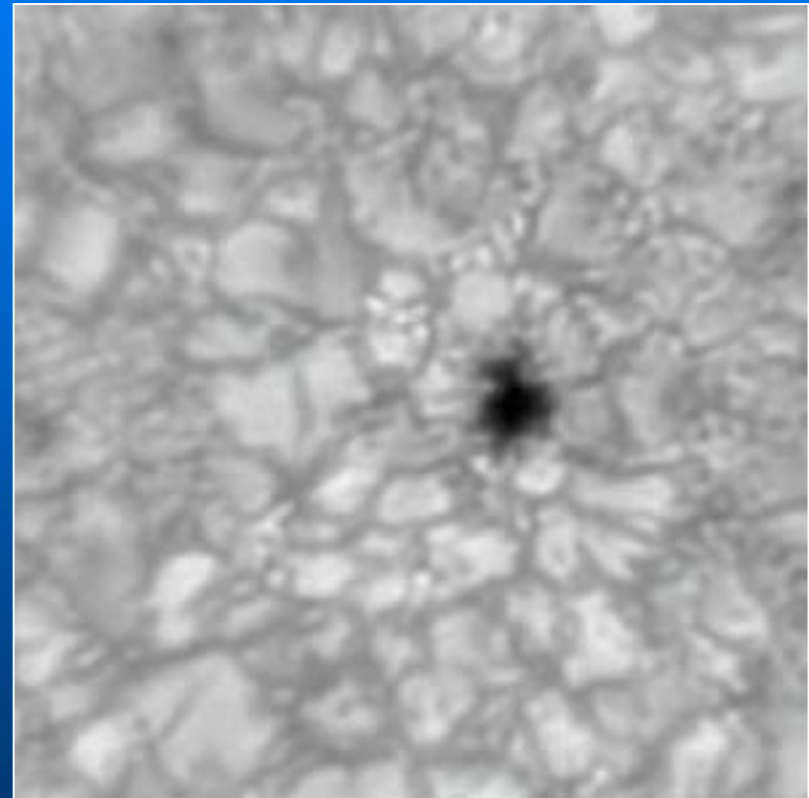
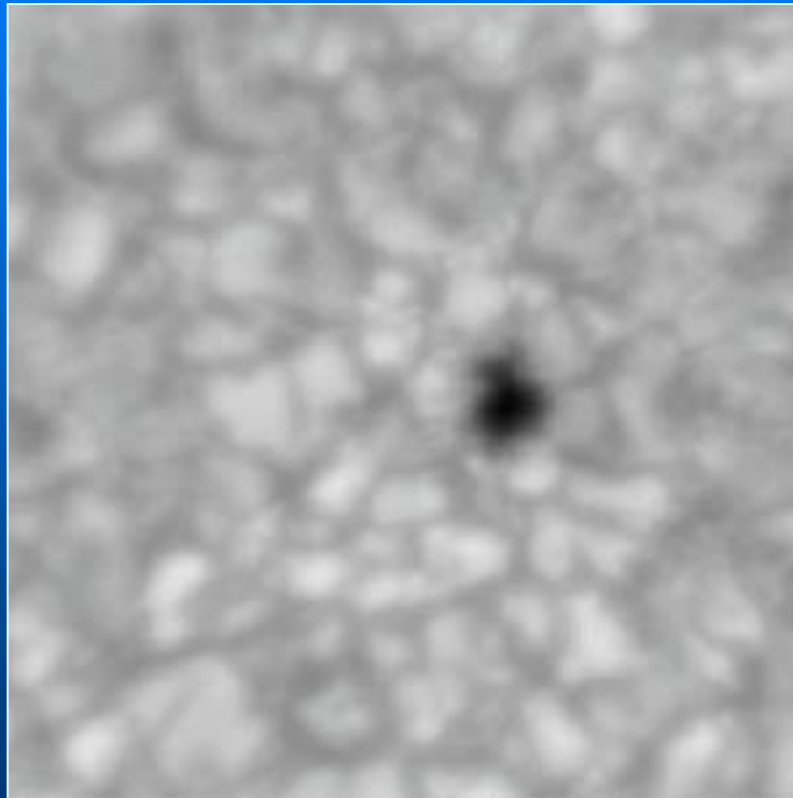


Sunspot & Granulation



# Solar Imaging

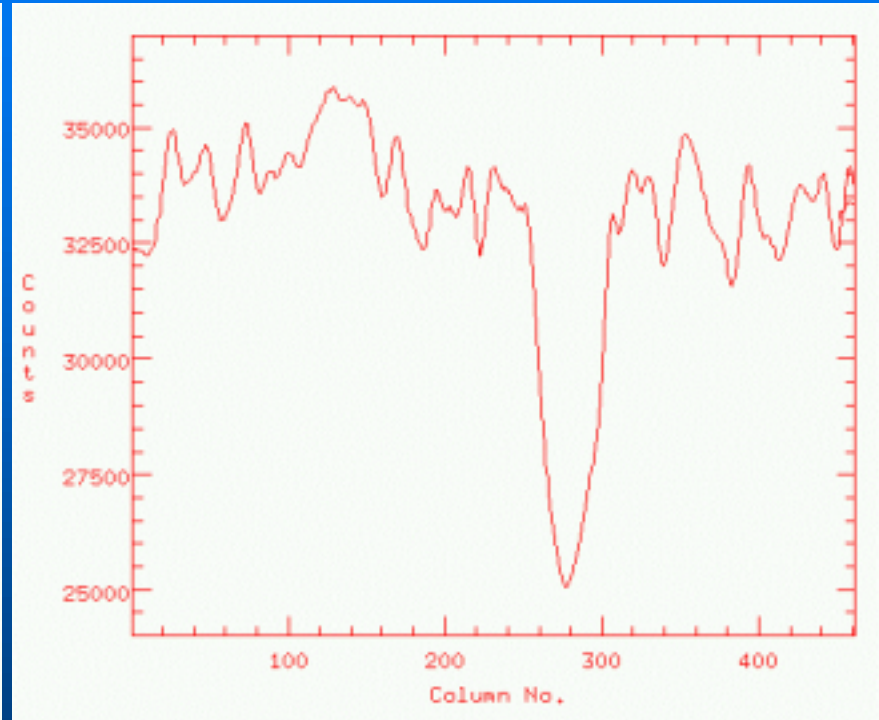
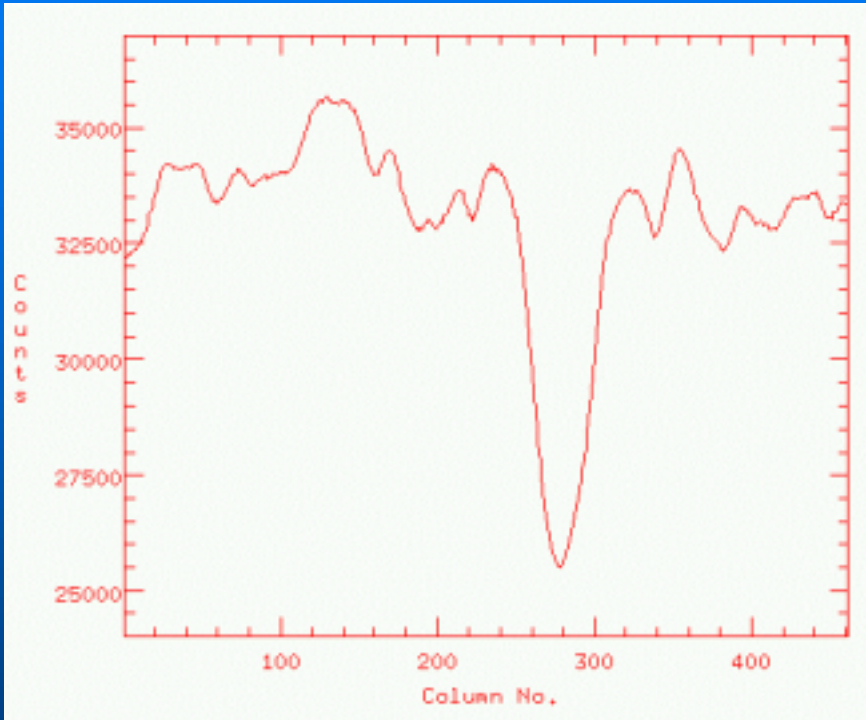
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Sunspot & Granulation



# Solar Imaging



Contrast Enhancement

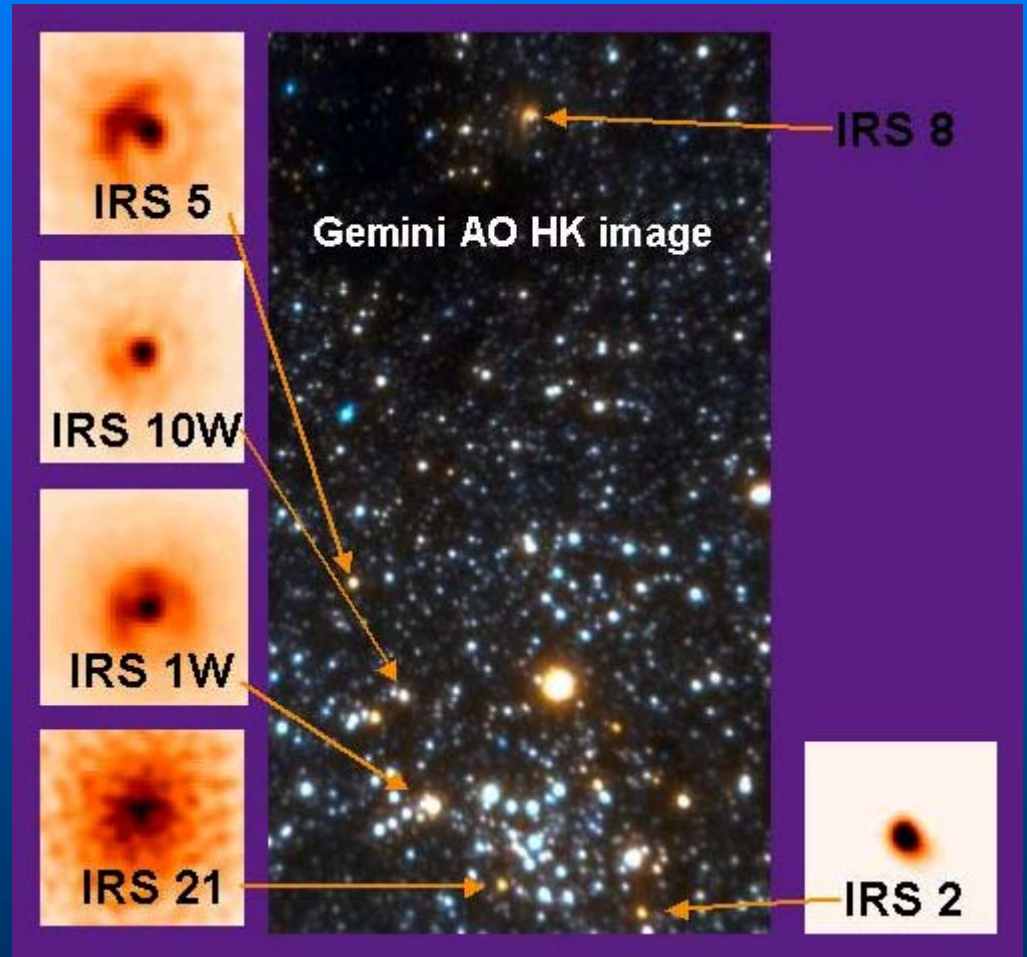


# Galactic Center – Northern Arm

- **Tanner, Ghez & Christou**
  - Keck Speckle Imaging.
  - Multi-frame Blind deconvolution

## Procedure

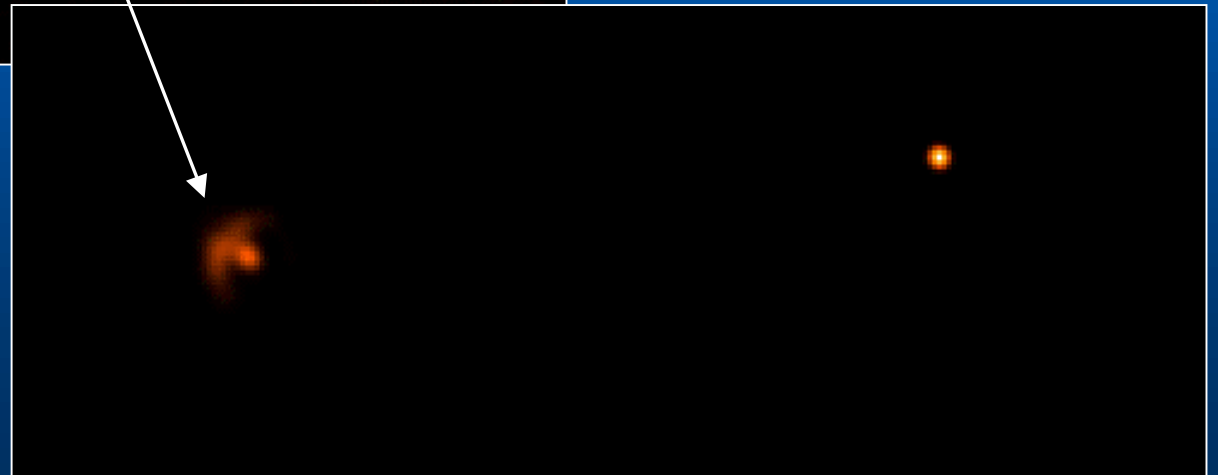
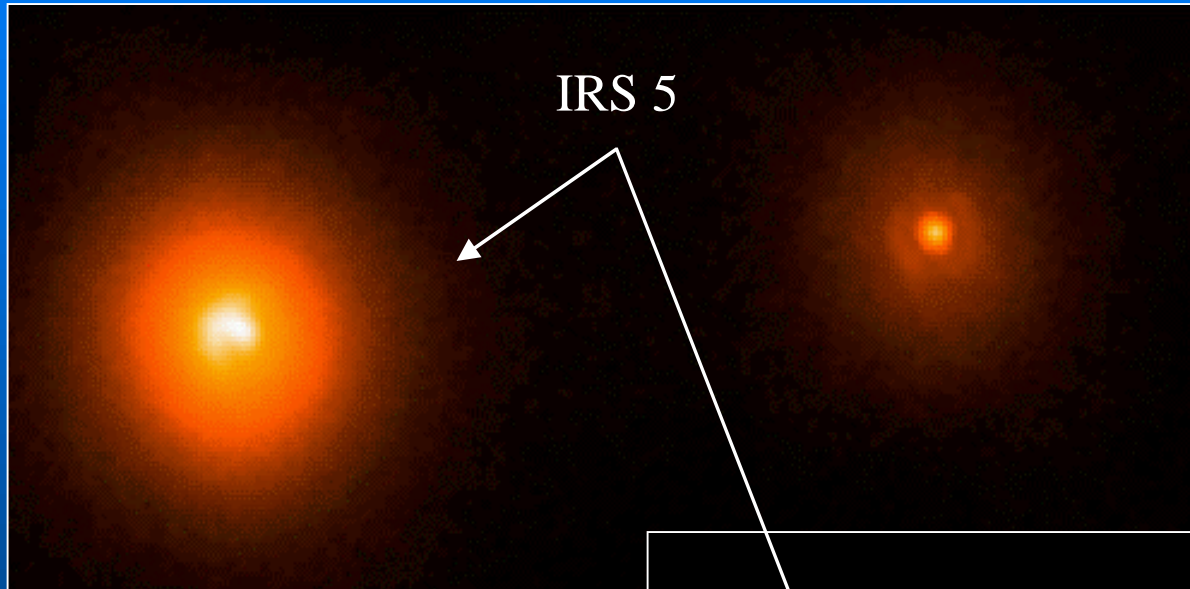
- Estimate a PSF from the field by fitting a double Gaussian to a point source (core & halo).
- Apply IBD algorithm.
- Use reconstructed PSFs and isolated point source to generate modified PSF.
- Deconvolve using “fixed” PSF
- Relax PSF with “blind” fit.





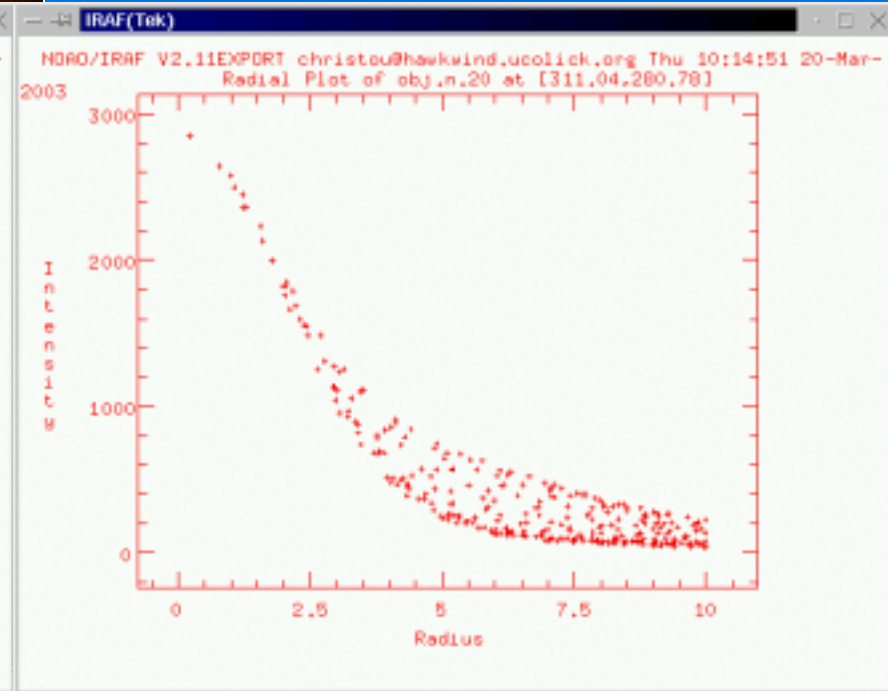
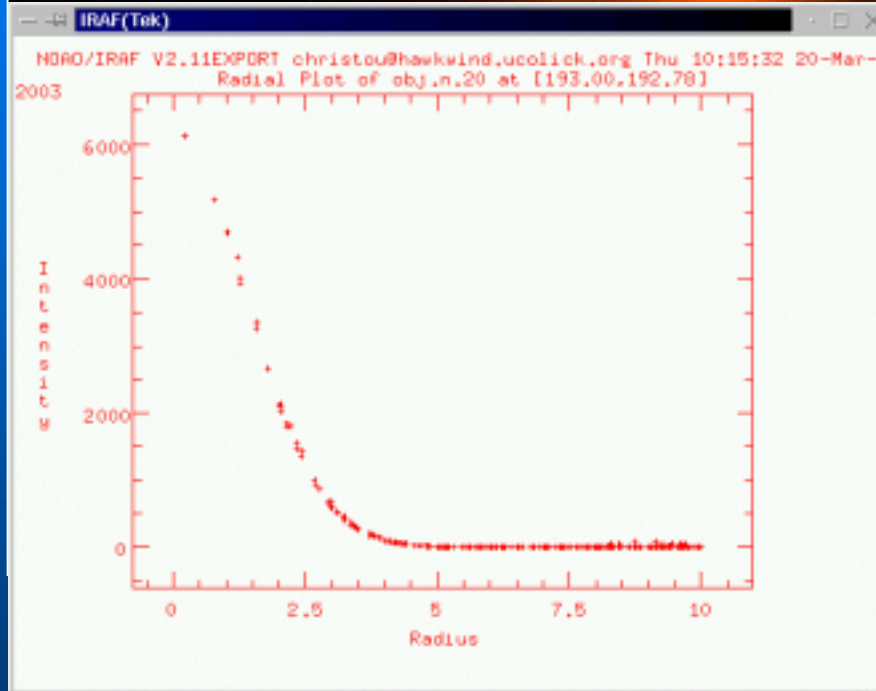
# Galactic Center – Northern Arm

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# Galactic Center – Northern Arm



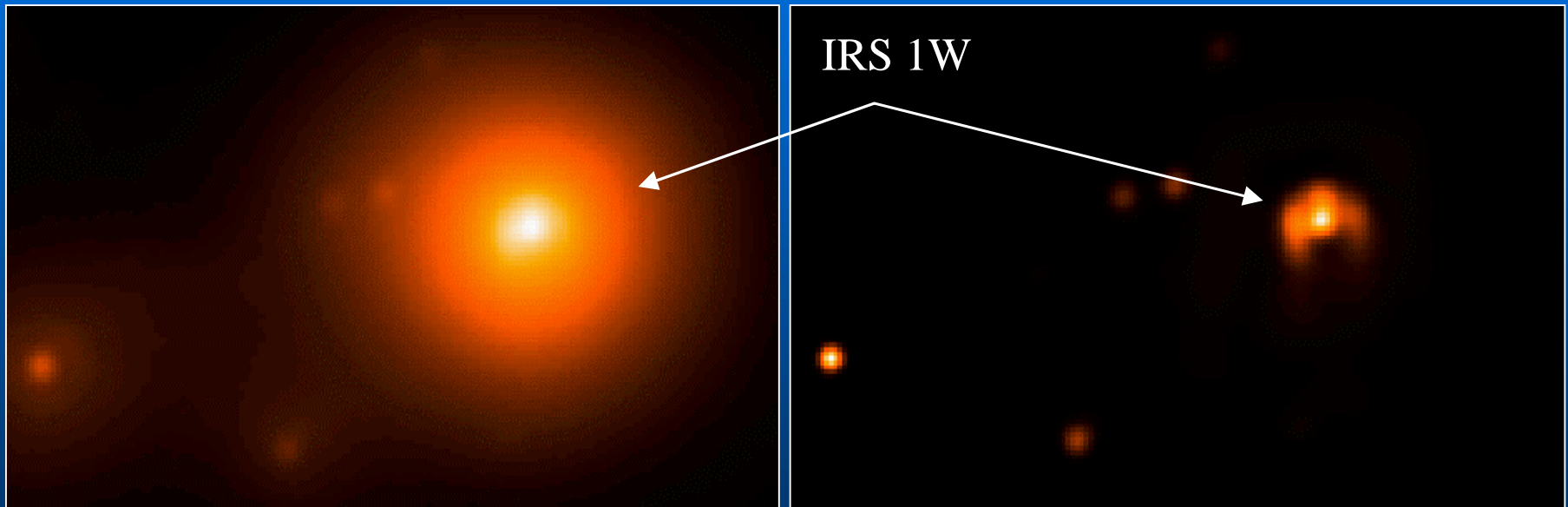
IRS 10EE  
(supergiant)





# Galactic Center – Northern Arm

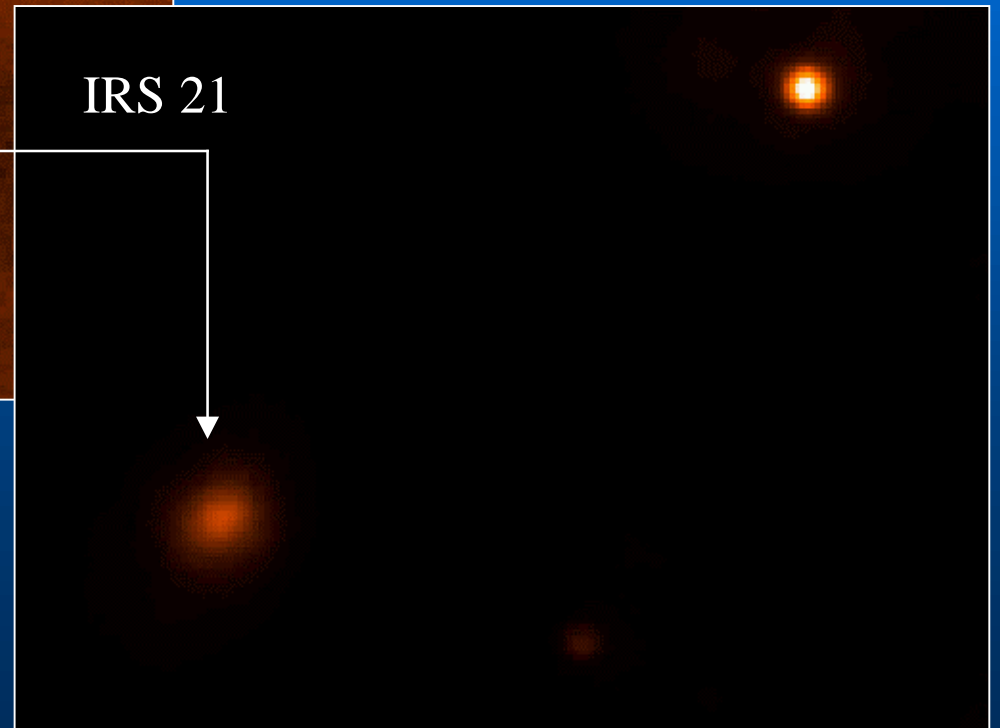
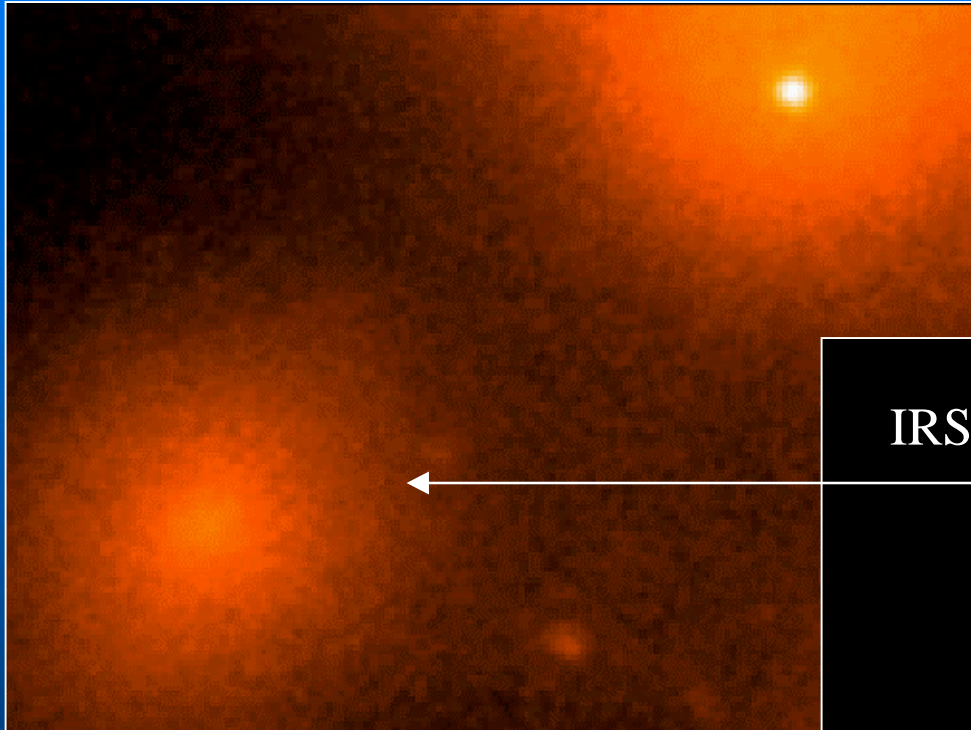
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# Galactic Center – Northern Arm

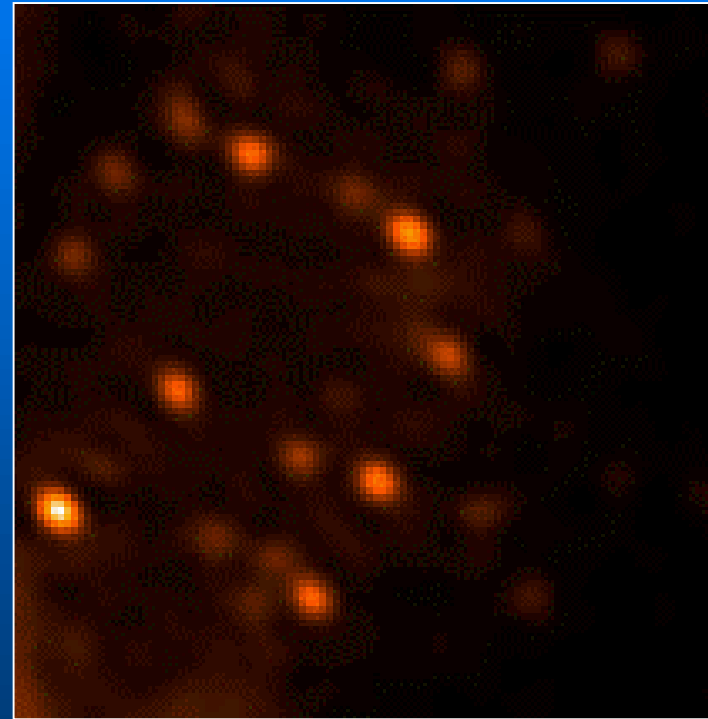
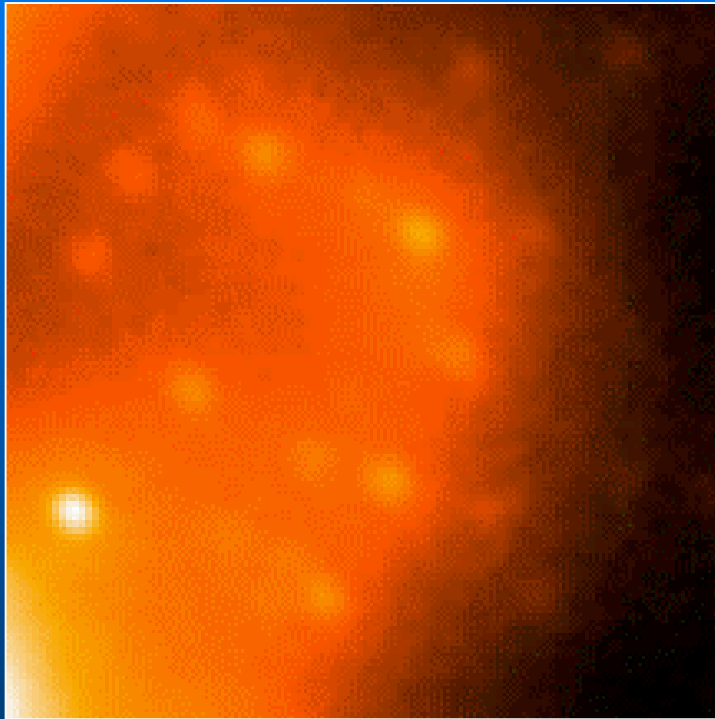
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# Galactic Center – Sgr A\*

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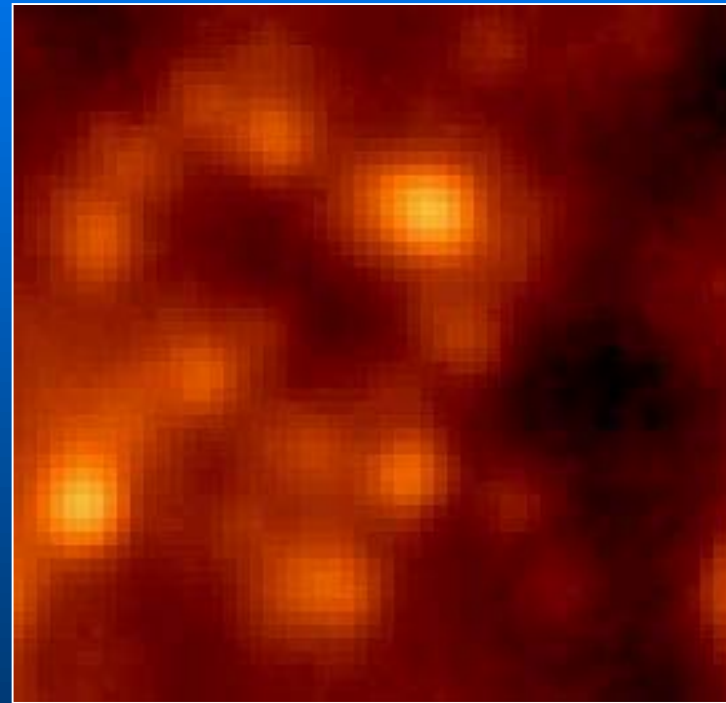
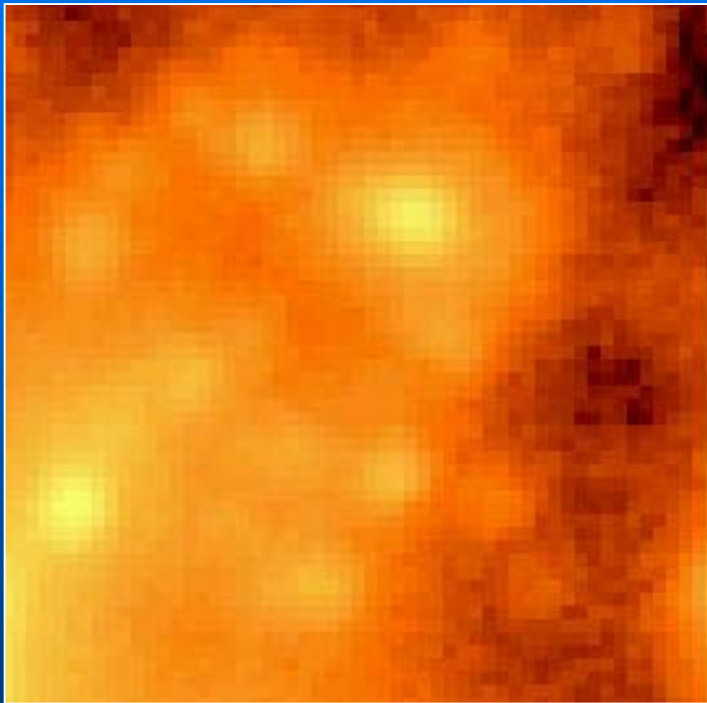


Keck K Speckle



# Galactic Center – Sgr A\*

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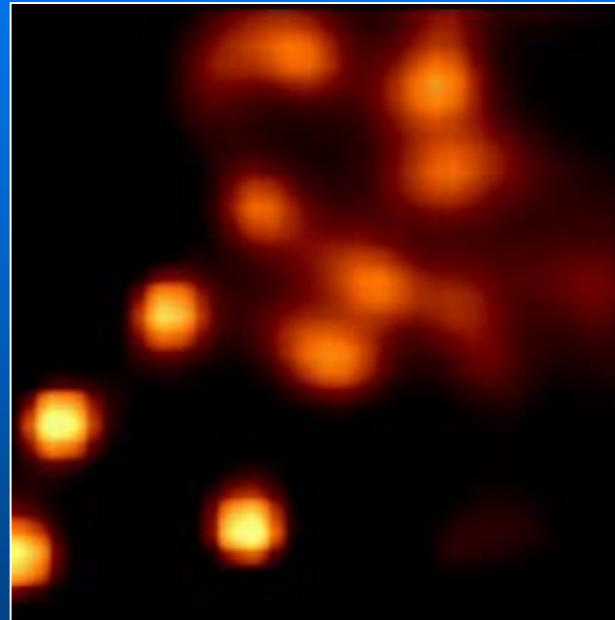
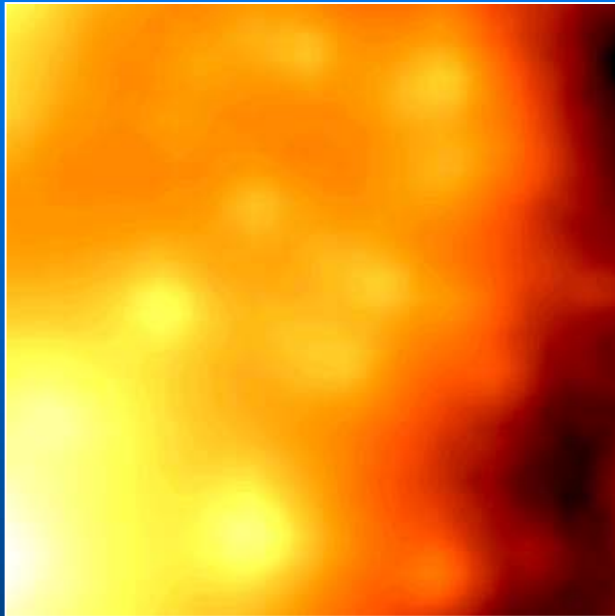


Keck L AO



# Galactic Center – Sgr A\*

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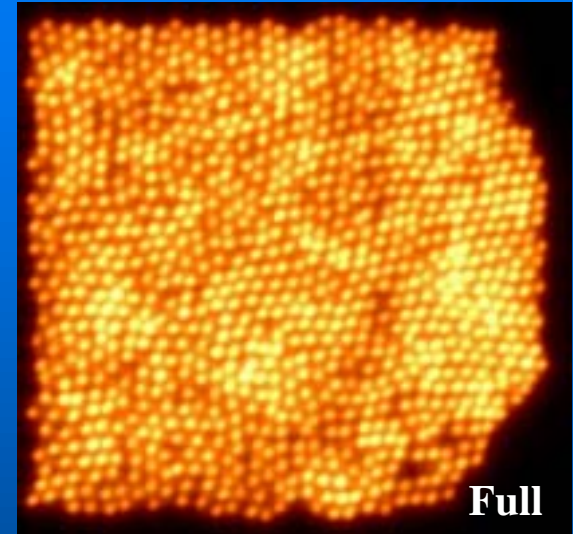
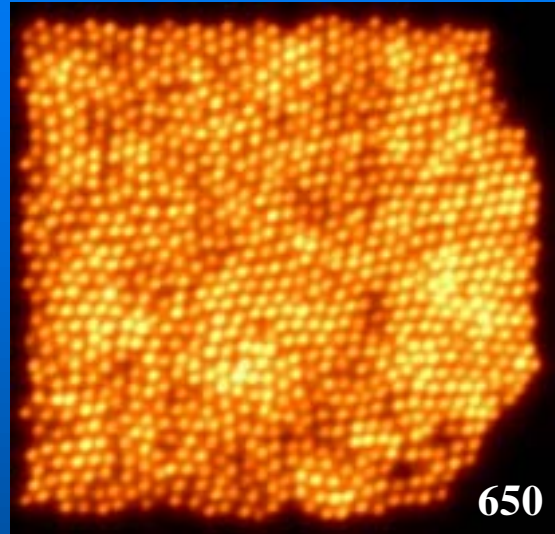
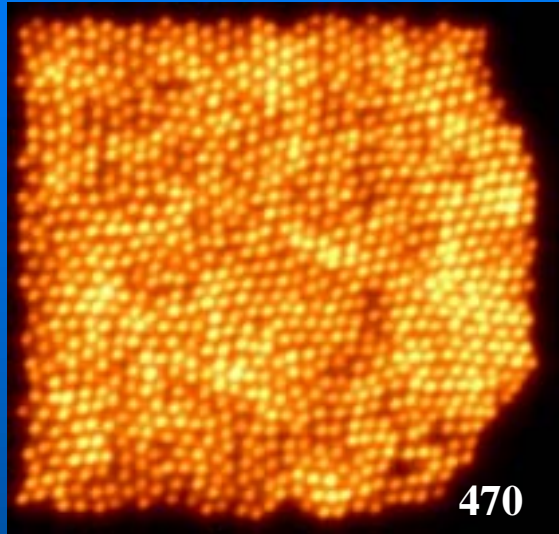


Gemini/Hokupa'a K AO



# Simulated AO Retinal Imaging

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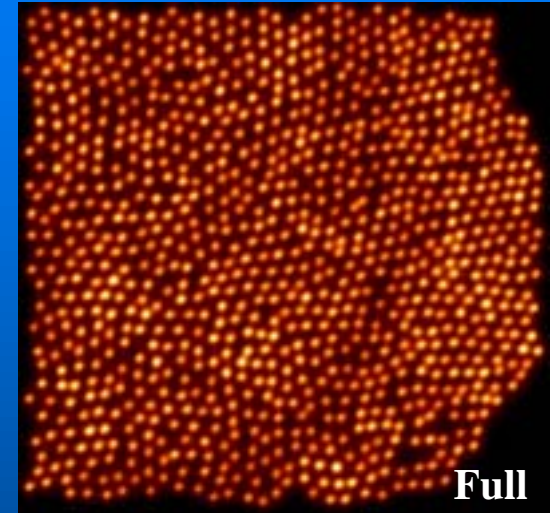
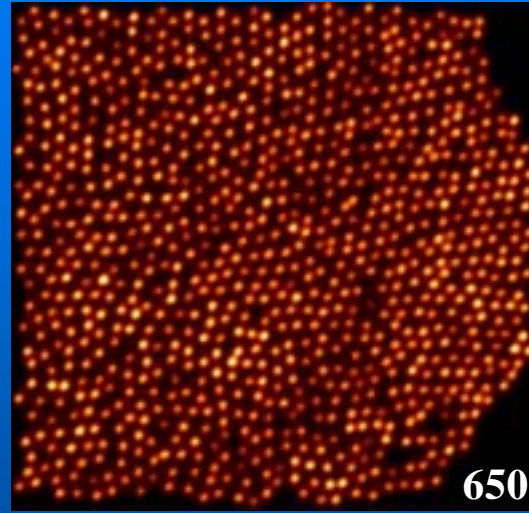
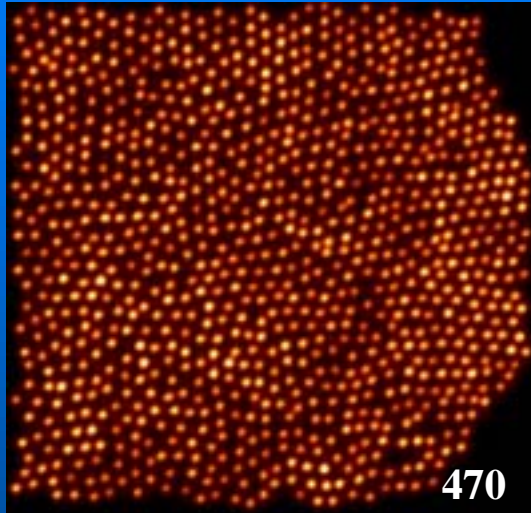


Simulated retinal images generated by Austin Roorda. They represent the Reflectance at the three different bleach levels.



## Simulated AO Retinal Imaging (MFBD)

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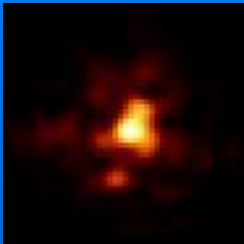


Multiframe blind deconvolution applied to the the 10 frame data sets for the three different bleach levels. Note the reduction in overlap between the cone reflectances which will make it easier to determine the cone classification. The measurements are currently in progress.

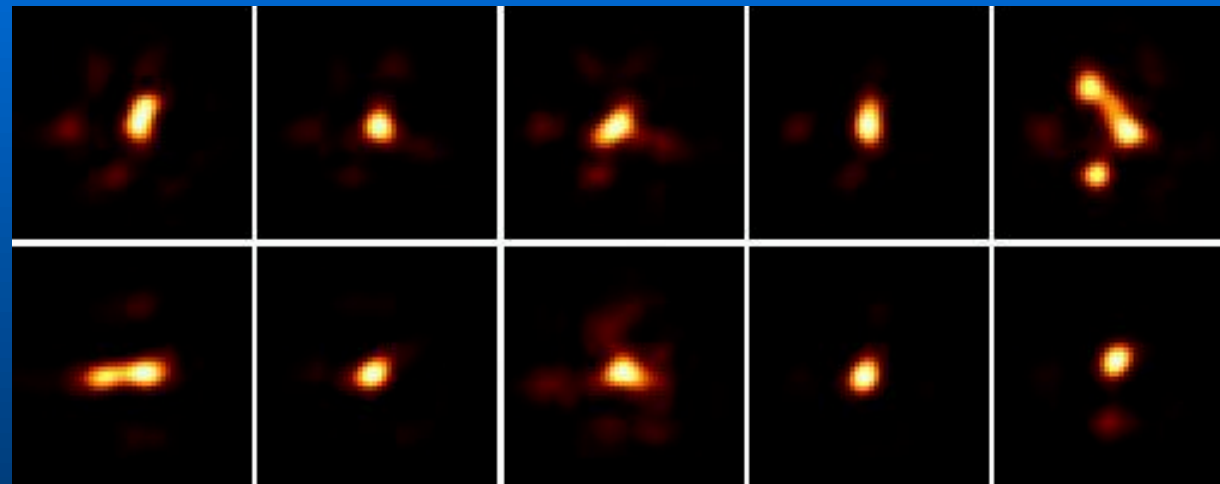


# Reconstructed PSFs

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Initial PSF Estimate – an average of a number of PSFs

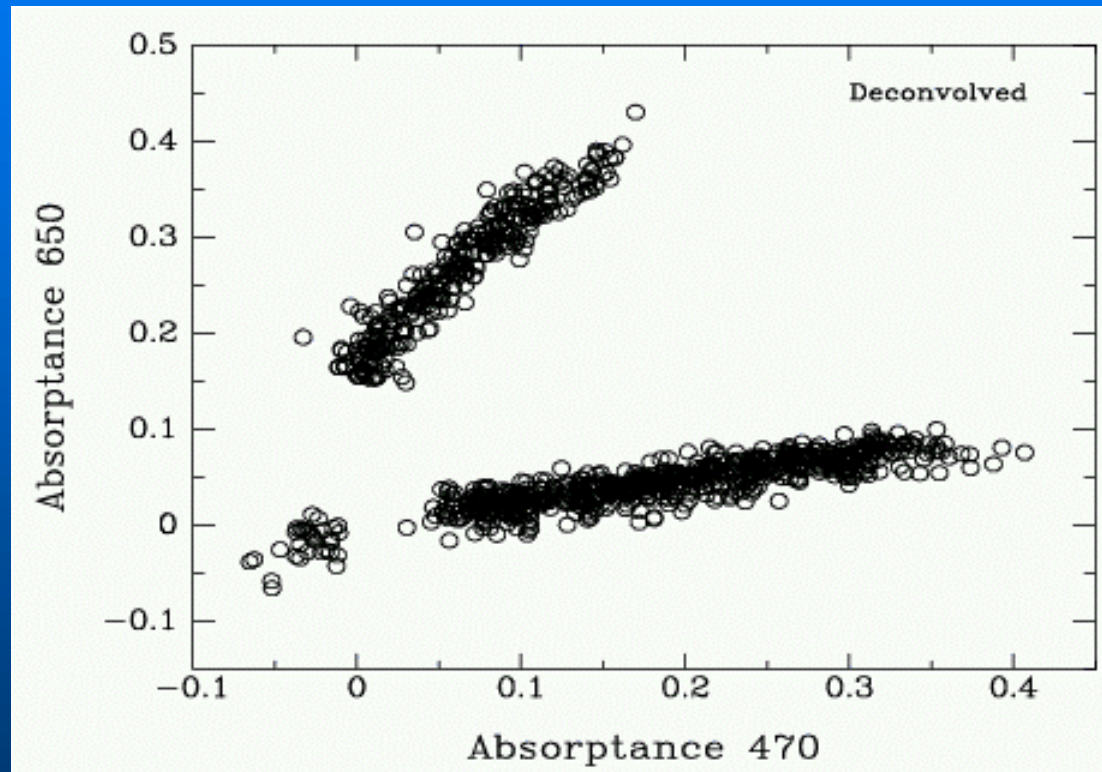


470 Bleach – reconstructed PSFs for 10 frame case.

A very good match to the provided PSFs



# Cone Classification - Simulation

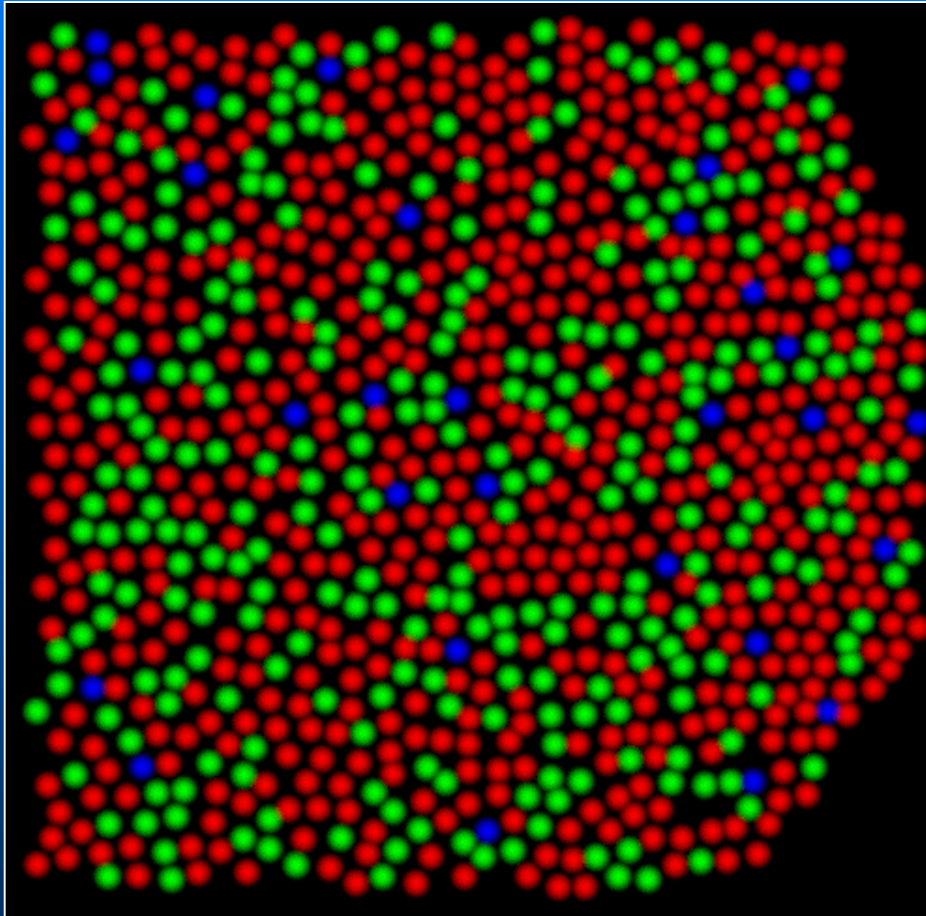


Two bleach absorbance plot for the deconvolved simulated data. The two distributions are clearly visible. The negative offset is due to different deconvolved resolutions when using a fixed size aperture for measuring reflectance from each cone.



# Cone Classification - Simulation

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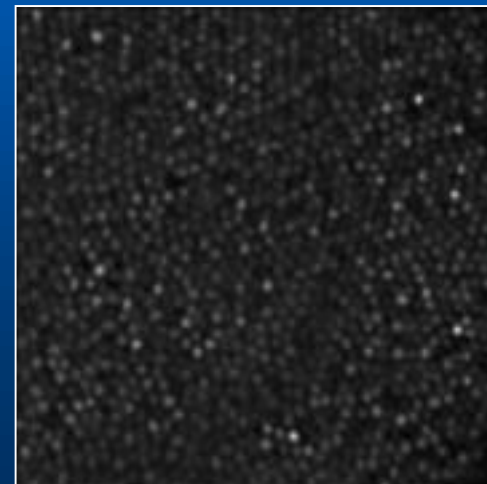
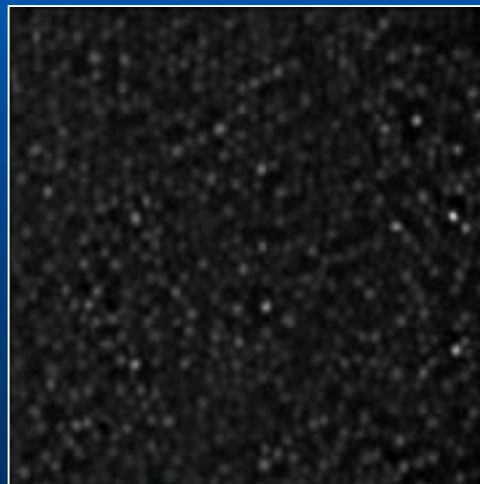
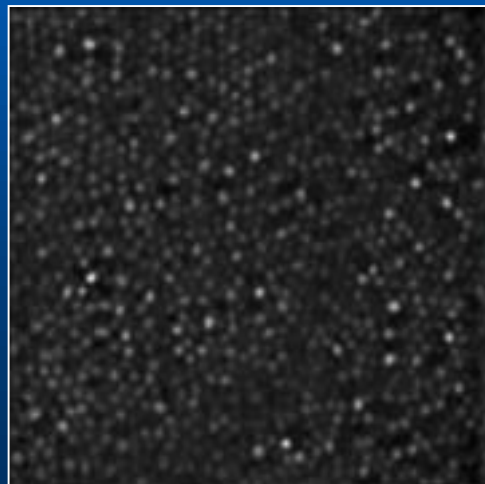
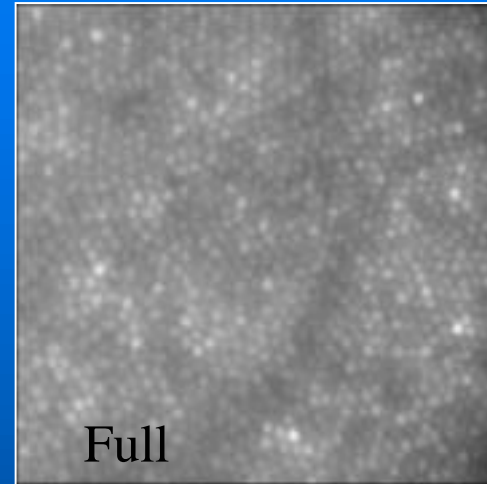
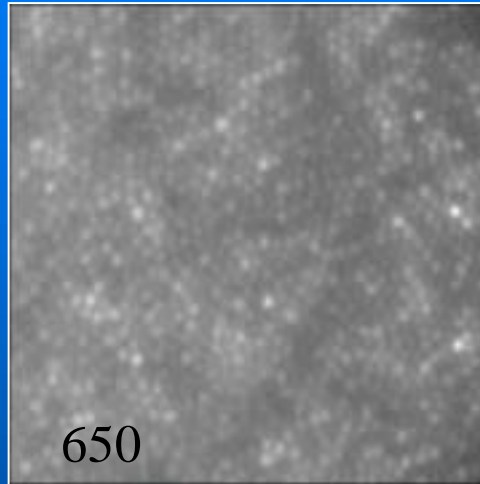
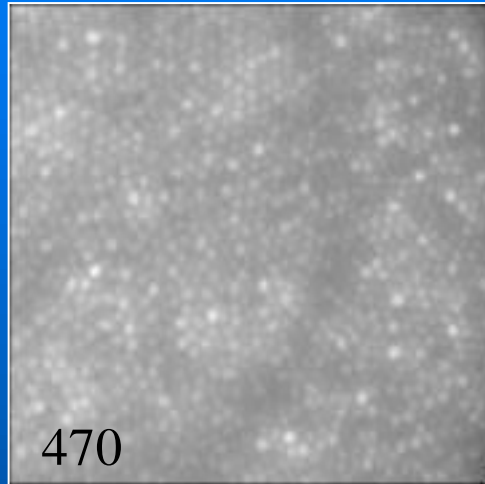


Cones identified from the absorptance plot. There is a one-to-one correspondence with the original synthetic data.



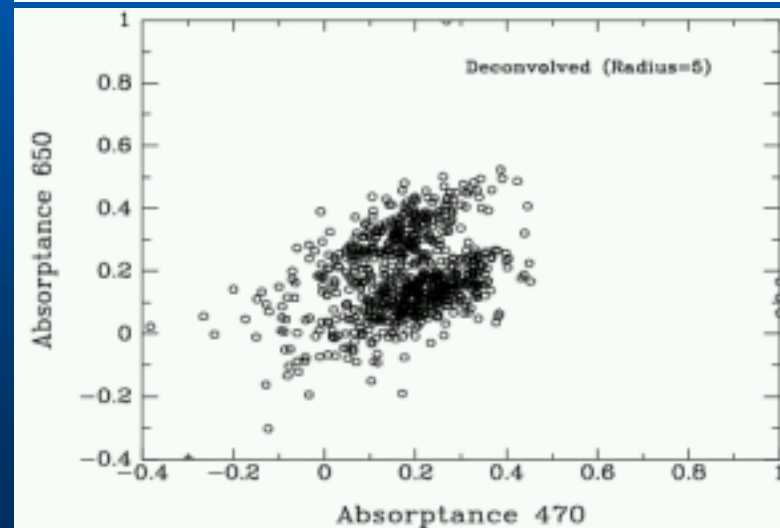
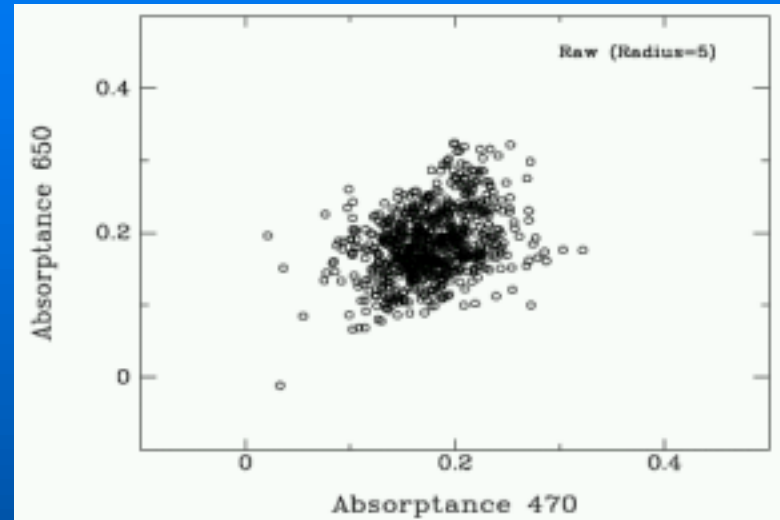
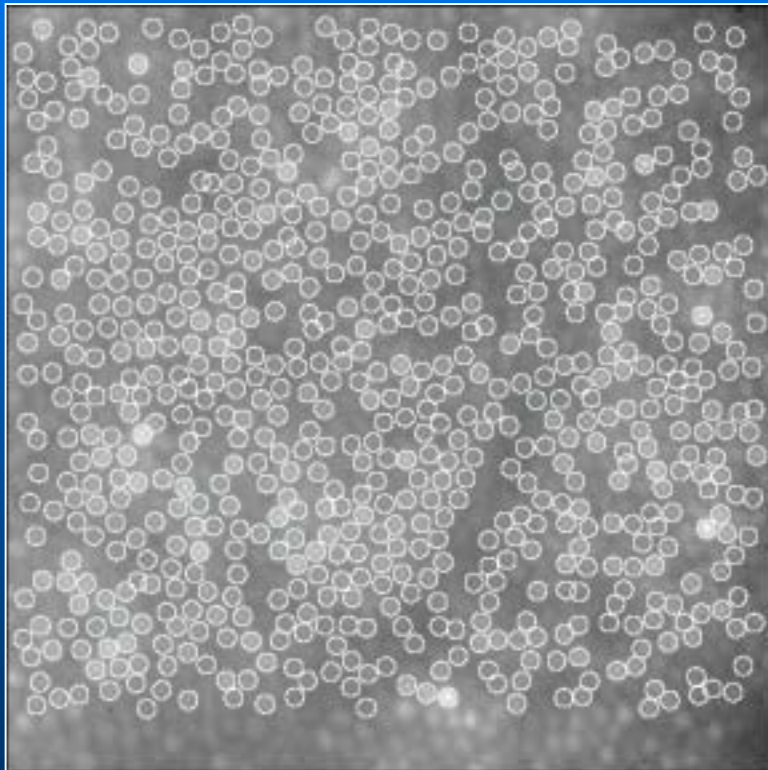
# Cone Classification – Macaque Data

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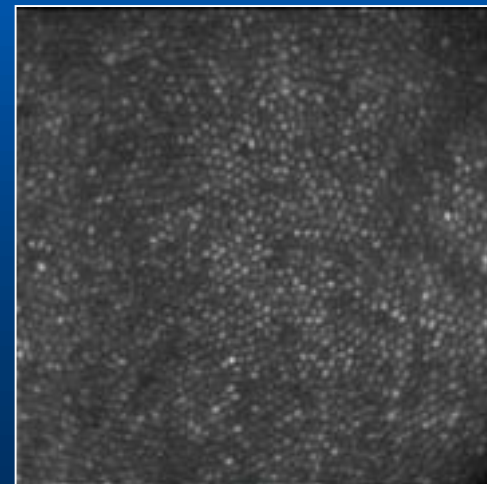
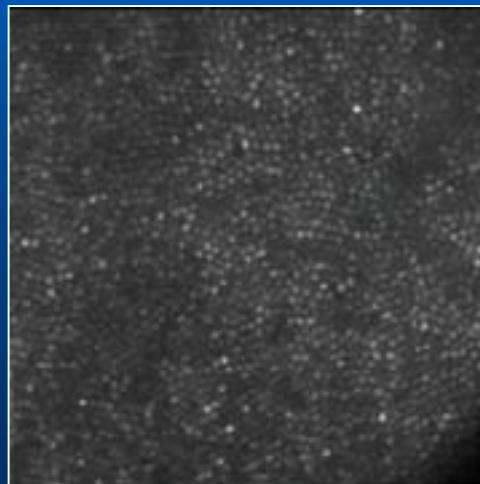
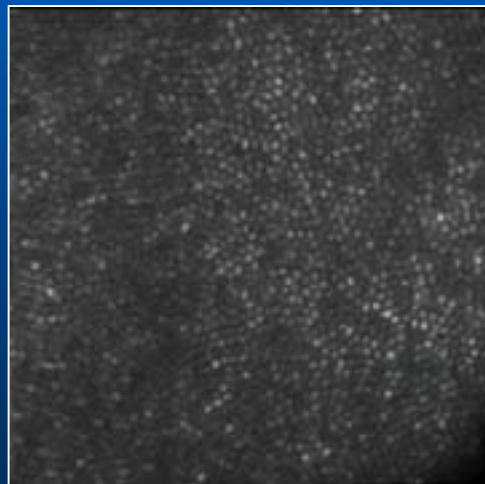
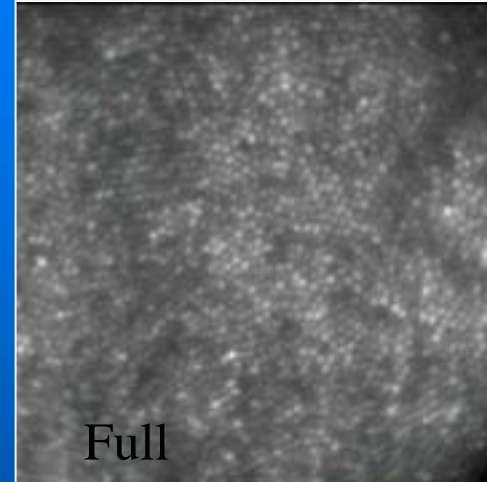
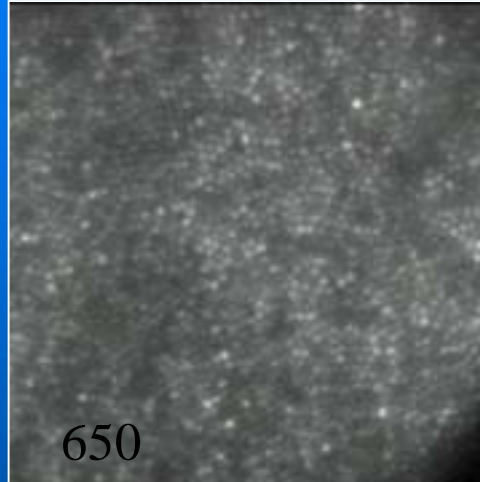
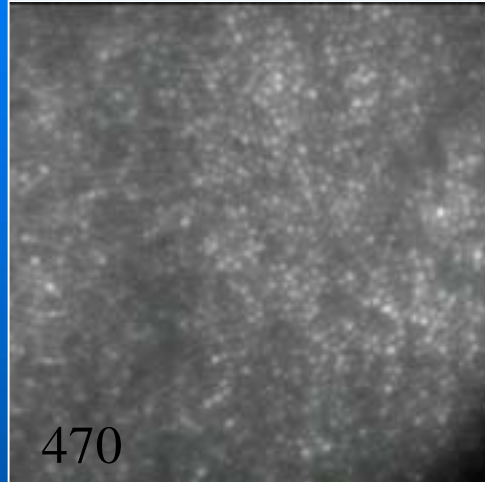
# Cone Classification – Macaque Data





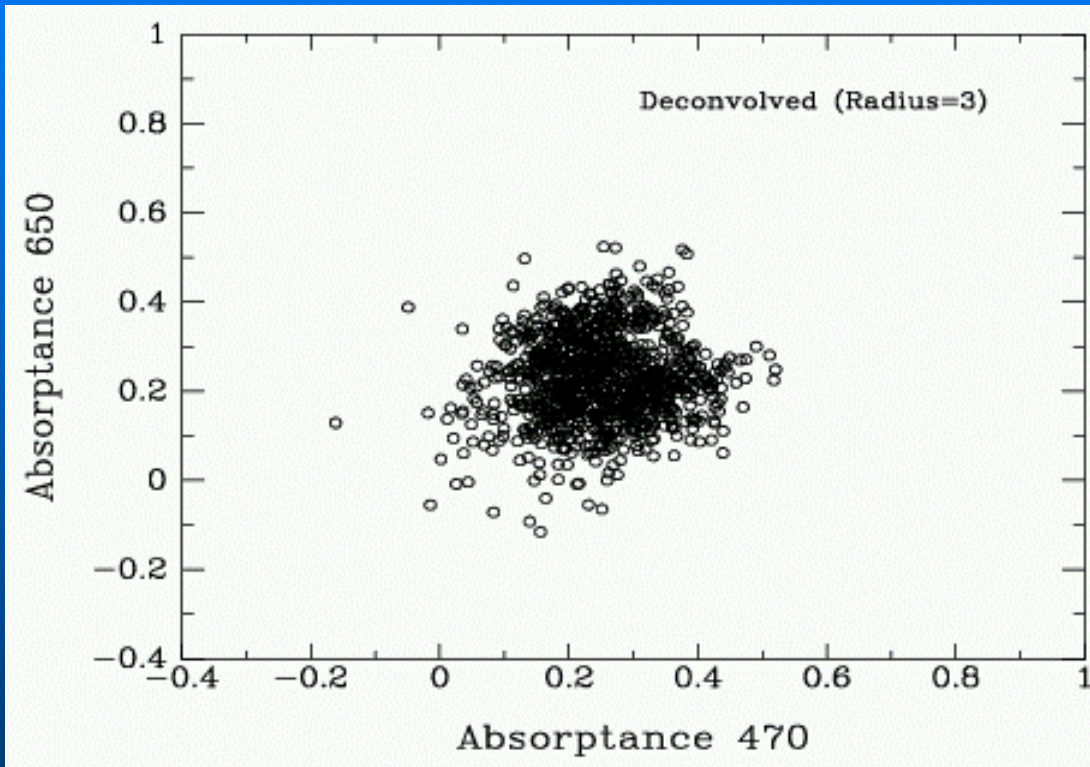
# Cone Classification – Human Data

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## Cone Classification – Human Data



Note that there is no significant distinction between the cone absorptances. No better than the raw data.

Why is this?

Two bleach absorbance plot for the deconvolved simulated data. The two distributions are clearly visible. The negative offset is due to different deconvolved resolutions when using a fixed size aperture for measuring reflectance from each cone.

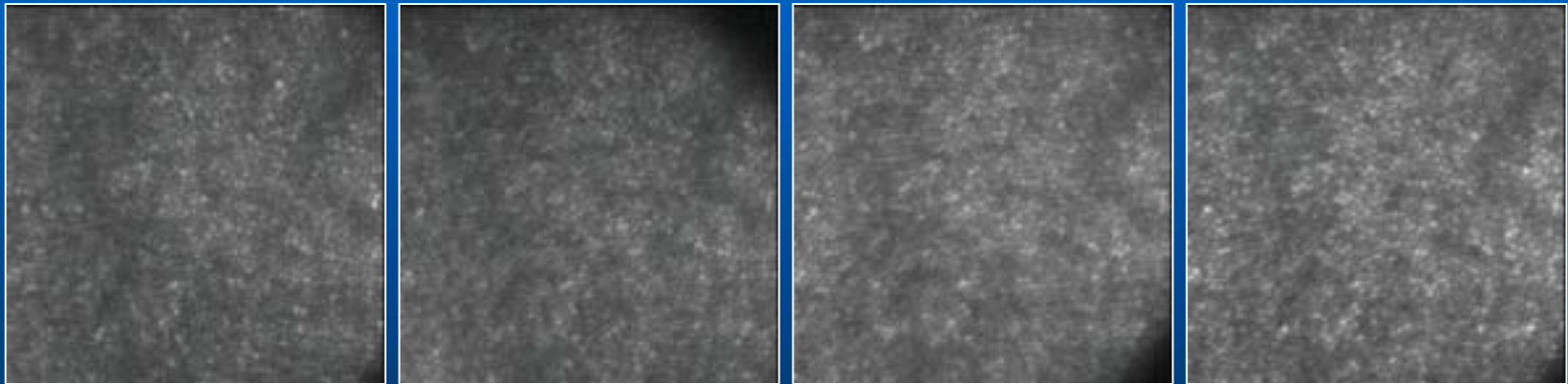


# Absorptance Measurements?

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**Deconvolution better isolates the individual cones for reflectance measurements reducing contamination from adjacent cones.**

**However, cone reflectance is highly variable**



Four full bleach frames show individual cone reflectance variability

**Algorithm, calibration or physiology?**



# Summary

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- **MFBD successfully applied to astronomical data.**

Significant improvement in the contrast of solar granulation features – factor of four.

Simulations (not shown) demonstrate good photometric fidelity.

Galactic Center shows improved source identification, source structure necessary for science (discussed in science section – Ghez).

- **MFBD successfully applied to Vision Science data.**

Simulations demonstrate that PSF calibration shows significantly improved cone identification as does the Macaque data.

On data set does not show improvement. Need to understand why this is so.