

# Restoration of seeing-degraded solar images

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# The Swedish 1-m Solar Telescope – SST



## Getting $\sim 0''.1$ resolution

- Great site: La Palma
- 97 cm aperture
- Good, simple optics
- Vacuum tube
- Adaptive optics
- Short exposures
- Post processing

# The Swedish 1-m Solar Telescope – SST

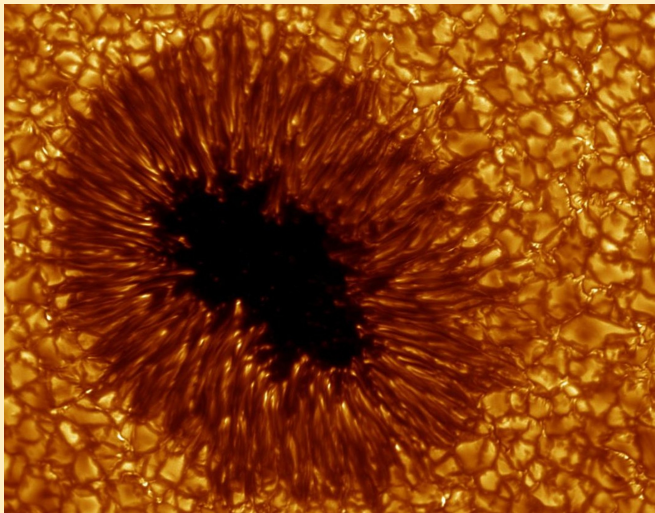


## Getting $\sim 0''.1$ resolution

- Great site: La Palma
- 97 cm aperture
- Good, simple optics
- Vacuum tube
- Adaptive optics
- Short exposures
- **Post processing**

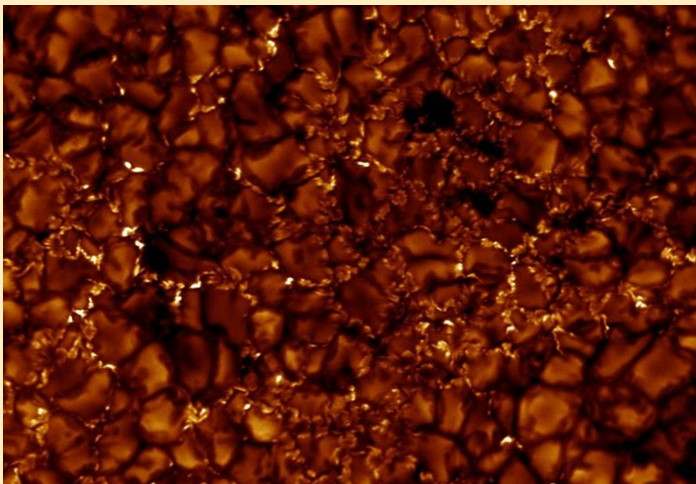
## Sunspot

(See poster by Langhans et al.)



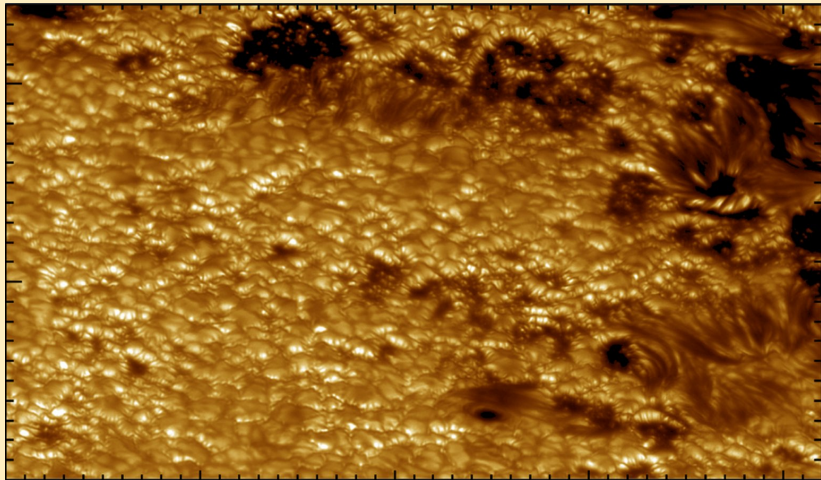
## Granulation and filigree

(G-band 430.5 nm)



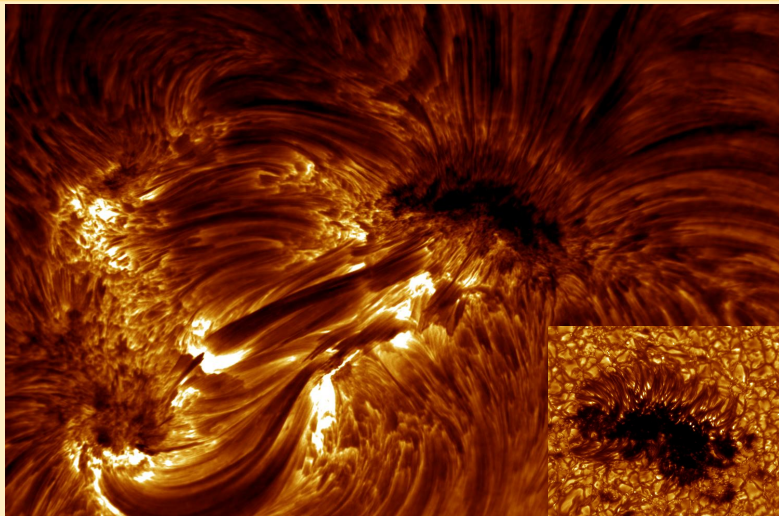
# Faculae

(1000 km tick marks)



## Small sunspot in the chromosphere

(H $\alpha$  656 nm)



## What's the problem with seeing?

It changes the PSF on a time scale of  $\sim 10$  ms.

## What is it?

Variable phase aberrations from turbulence in the atmosphere.

## What to do about it?

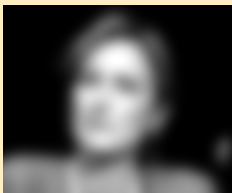
Space telescopes: Very expensive, particularly for large telescopes.

Adaptive Optics: Tricky but now possible. Partial correction of wavefront phase.

Post processing: Can make a more complete correction.  
Cannot recreate information lost in noise.

## Blind deconvolution: Joint estimation of object and aberrations

Image:

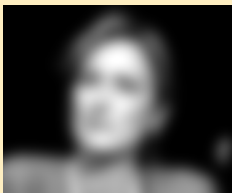


Deconvolution is easy if you know the PSF!

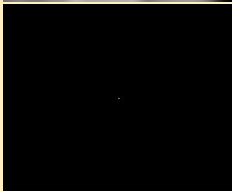
However...

## Blind deconvolution: Joint estimation of object and aberrations

Object:



PSF:

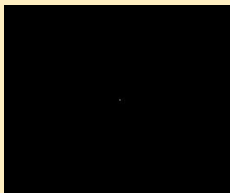


Perfect optics and fuzzy object?

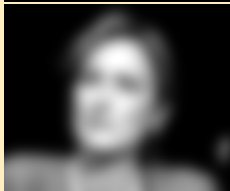
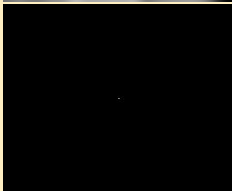
Or...

## Blind deconvolution: Joint estimation of object and aberrations

Object:



PSF:

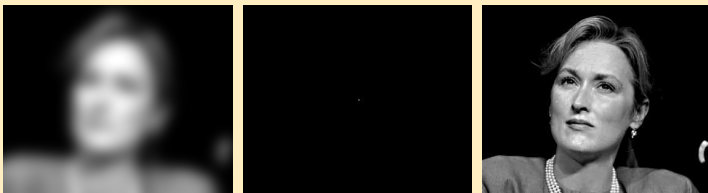


Stellar object and weird PSF?

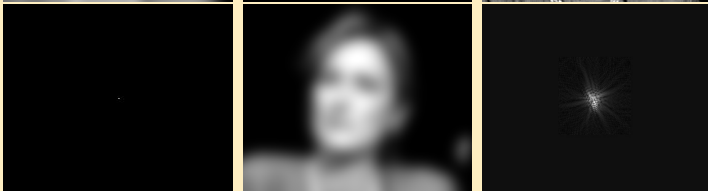
Or...

## Blind deconvolution: Joint estimation of object and aberrations

Object:

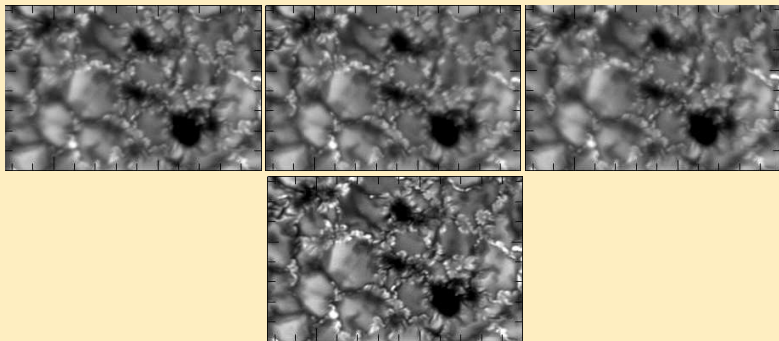


PSF:



Constraints: Optics, statistics, diversity, multiple objects...

## Multi-frame blind deconvolution (MFBD)

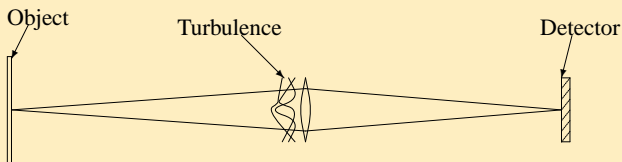


● Top: raw images

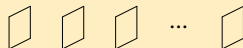
● Bottom: MFBD restored image

Estimate object and phase (PSF) = minimize difference  
between estimated quantities and observed data.

## Data collection model: MFBFD

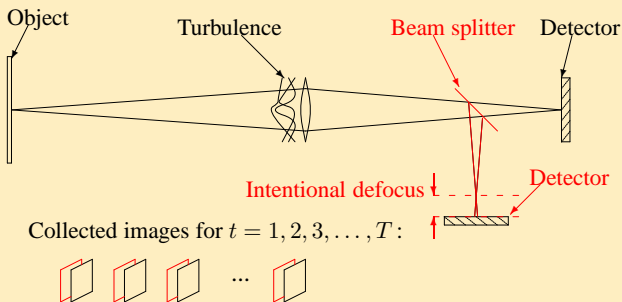


Collected images for  $t = 1, 2, 3, \dots, T$ :

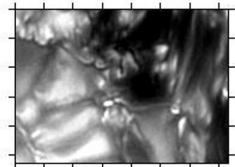
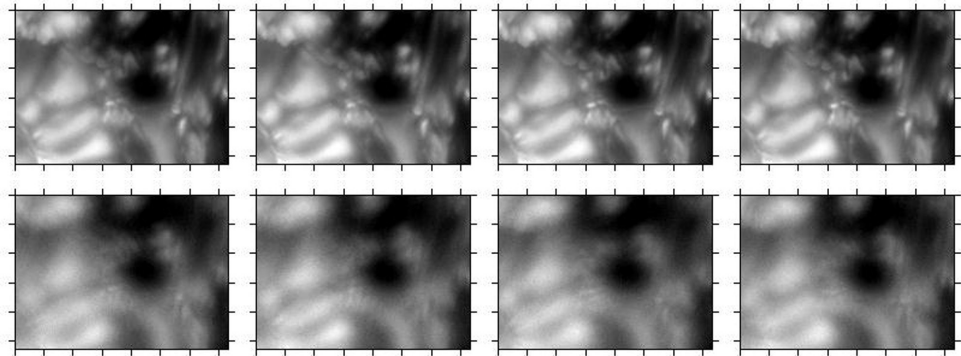


- Multiple samples (diversity) of random turbulence constrain the separation of object and PSF.
- Additional, known phase diversity from out-of-focus frames constrains even further.

## Data collection model: MFBD with phase diversity

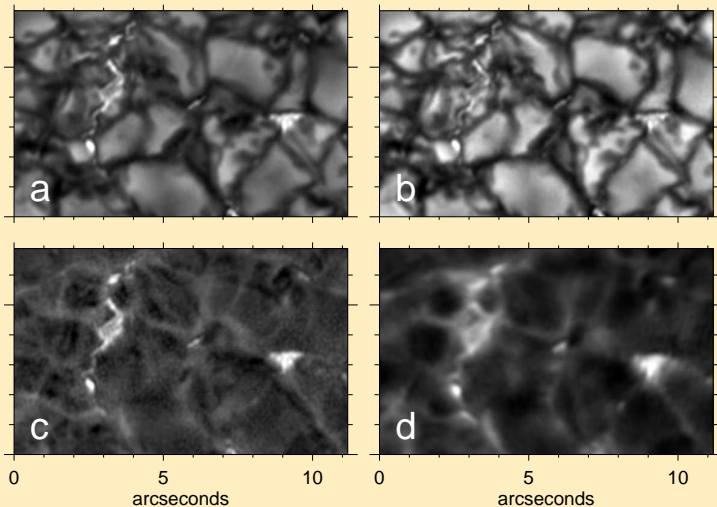


- Multiple samples (diversity) of random turbulence constrain the separation of object and PSF.
- Additional, known phase diversity from out-of-focus frames constrains even further.



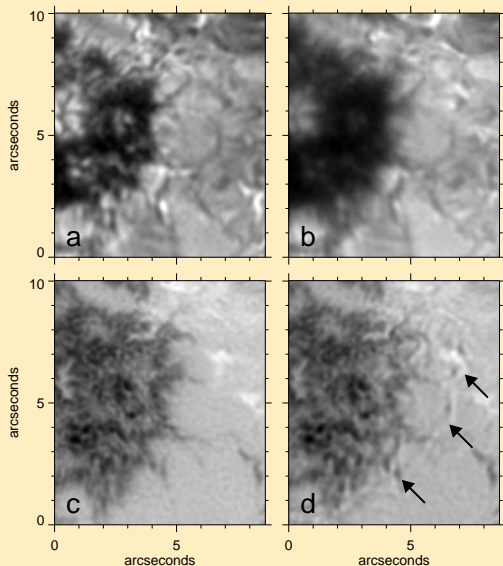
## Phase Diversity

- Top: conventional in-focus images
- Center: out-of-focus images
- Bottom: restored object



## Multi-Object MFBD

Calibrated  
alignment:  
a. G-band  
b. G-cont  
c. Diff  
d. Ca II H



### Artifacts avoided

- a. LCP
- b. RCP
- c. MOMFBD magnetogram
- d. Traditional magnetogram; note artifacts

# Conclusion

## For short-exposure observing:

- Post processing methods needed for full resolution and for increasing the useful observing time.
- Simple MFBD works for very good data.
- Additional, known phase diversity helps in worse seeing.
- Multiple objects can be co-processed.
- MOMFBD + calibration  $\implies$  registration w/o cross-correlation.