



Compressive Sensing Based Data Acquisition Architecture for Transient Stellar Events in Crowded Star Fields

Asmita Korde-Patel^{1,2}, Richard K. Barry¹, and Tinoosh Mohsenin²

¹NASA Goddard Space Flight Center, Greenbelt, MD, USA

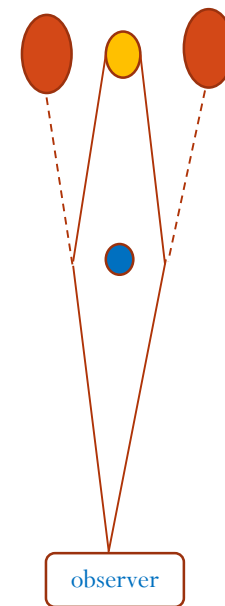
²University of Maryland, Baltimore County, Baltimore, MD, USA

Outline

- Transient stellar events- Gravitational Microlensing application
- Difference Imaging
- Compressive Sensing (CS) Motivation
- Compressive Sensing (CS) Theory and Architecture
- Simulation Setup
- Simulation Results
- Conclusion and Future work

Gravitational Microlensing

- Technique to detect exoplanets and other astrophysical entities
- Gravitational microlensing occurs when light travelling from a source star bends due to a lensing system and portrays a distorted set of the source star images
- The separation of the two images is so close that an observer only sees a change in magnification
- This variation in the magnification of the star is seen over time as the source star moves in relative motion of the lensing star

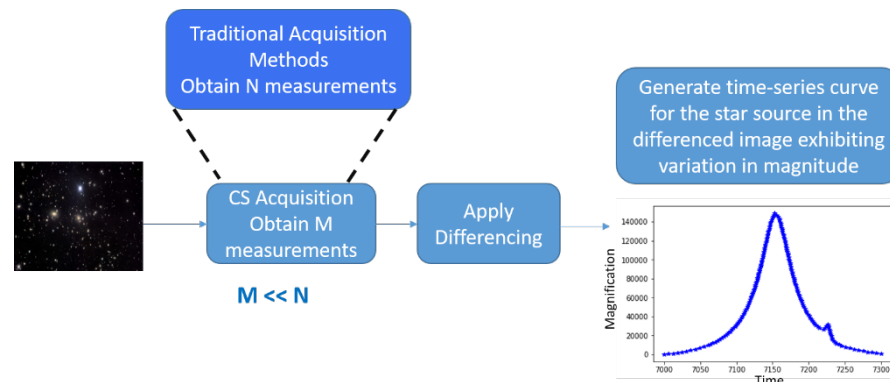


Difference Imaging

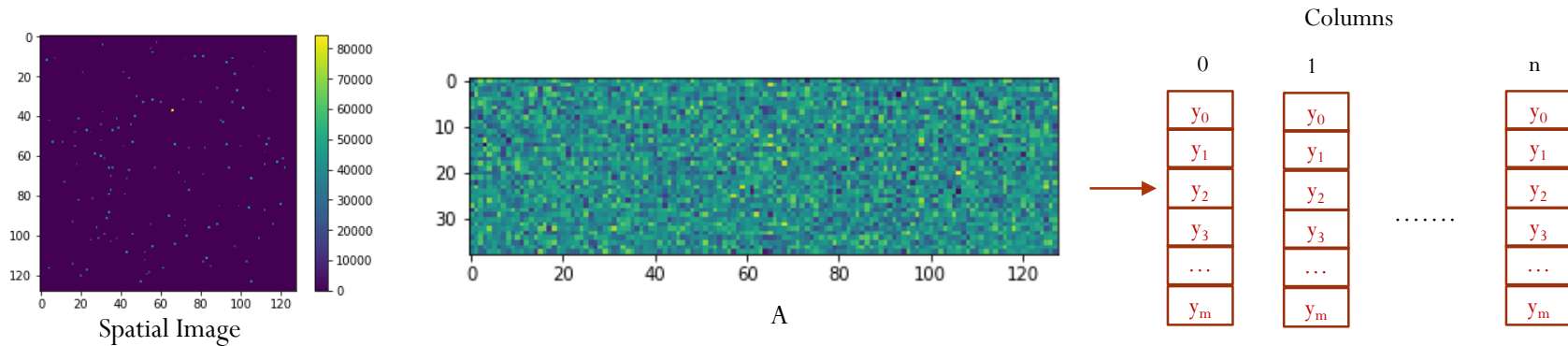
- Identify transient events in stellar fields
- Difference Imaging method:
 - Given a reference image with clean seeing –
 - Obtain a convolution kernel to match the seeing of the reference image with an observed image, which has wider point spread function output, causing a blurrier image
 - Subtract the convolved matched image and the observed image to obtain a difference image
 - $x_{diff} = x_{obs} - (x_{ref} * K)$
 - $x_{obs} = x_s * P_O$
 - $x_{ref} = x_s * P_R$
 - Where x_s is the spatial region of interest, P_O and P_R are the point spread functions of the observed and reference images, respectively

Compressive Sensing (CS) Motivation

- Acquiring each image pixel individually (sampling at the Nyquist rate) is wasteful when the information can be encoded in only a select few samples due to its sparse nature
- Exploit sparsity in images
- Microlensing Events are sparse in spatial domain when differenced
 - That is, at any given time only the stars exhibiting a microlensing event vary in flux
 - Only those stars are evident when differenced with a reference image



CS Theory



1) Obtain CS based measurements, y_o for a spatial image.

CS can be applied by projecting a matrix, A , onto the region of interest, x_o . This can be done on a column-by-column

basis for a $n \times n$ spatial region, x_o . Thus, for 2D images, y_o and A are of size $m \times n$, where $m \ll n$.

2) Given A and a clean reference image, x_r , construct measurements matrix y_r , where $y_r = Ax_r$

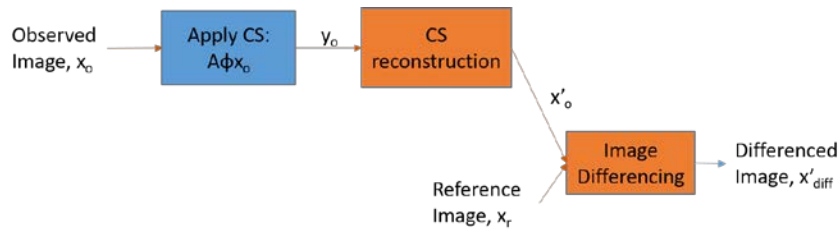
3) Apply a 2D differencing algorithm on y_o and y_r to

obtain a differenced image, y_{diff} , and the corresponding convolution kernel, M , which is used to match the observed and reference CS measurement vectors, y_o and y_r .

4) Reconstruct the differenced image, x'_{diff} using CS algorithms, given A and y_{diff} .

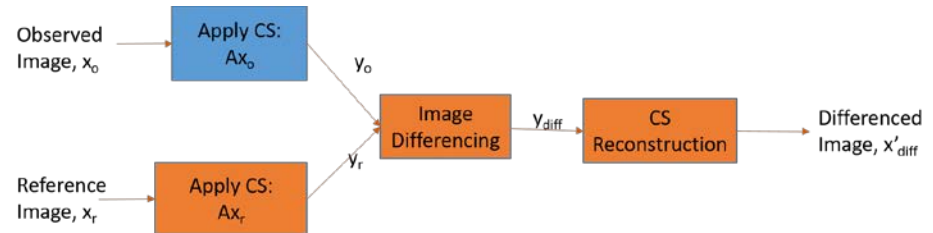
CS Architecture

Traditional Architecture



Differencing is applied on the CS reconstructed image

Novel Architecture

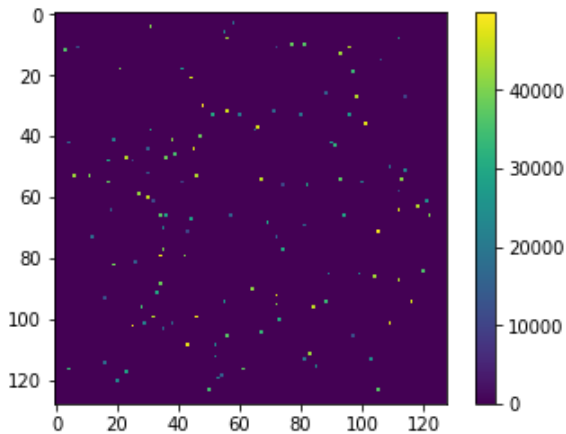


Differencing is applied on the CS measurements, resulting in only reconstructing the differenced image

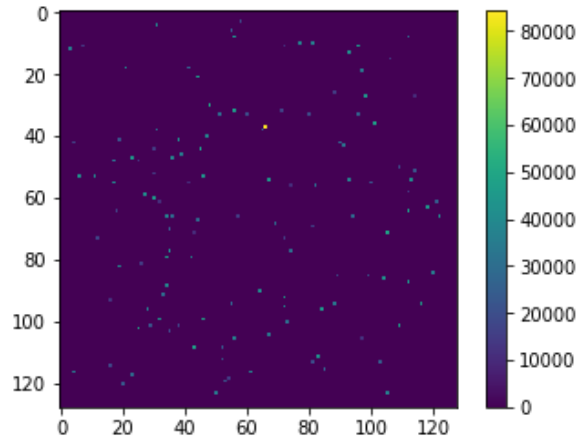
Simulation Setup

1. Generate star sources with uniform randomly spread pixel positions (x_1, x_2) and pixel magnitudes, ranging from 10000:50000 with Gaussian spread point spread functions (PSF)
2. Vary the magnitude of a selected star source to depict a binary lensed microlensing event over t time samples
 - Magnitude is derived from binary lens microlensing equations
3. Apply CS using the architecture proposed
4. Determine % error of the center pixel of the microlensing source star in the reconstructed image as compared to the center pixel of source star in the differenced image
 - Average error is calculated over 100 Monte Carlo simulation, where the CS projection matrix is varied each time
5. Repeat Step 1. for reference image with a narrower Gaussian spread PSF.

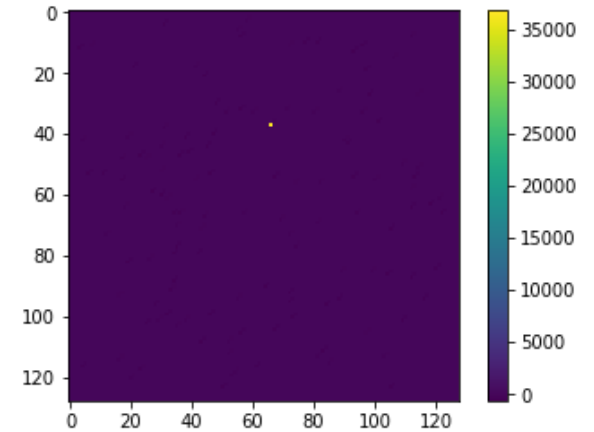
Simulation Setup Example



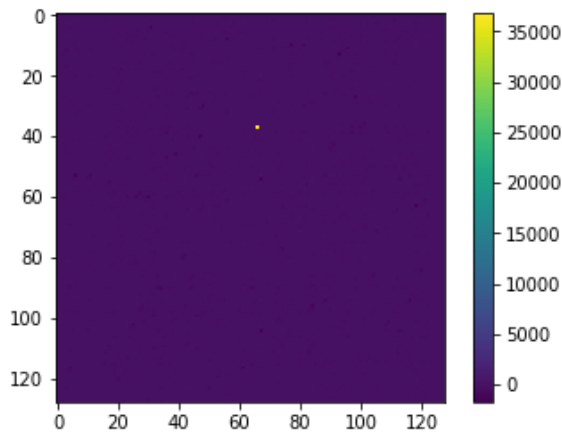
Reference image



Observed image with a star experiencing microlensing



Differenced Image



CS Reconstructed differenced image
using 10% of the Nyquist rate
measurements

Simulation Results

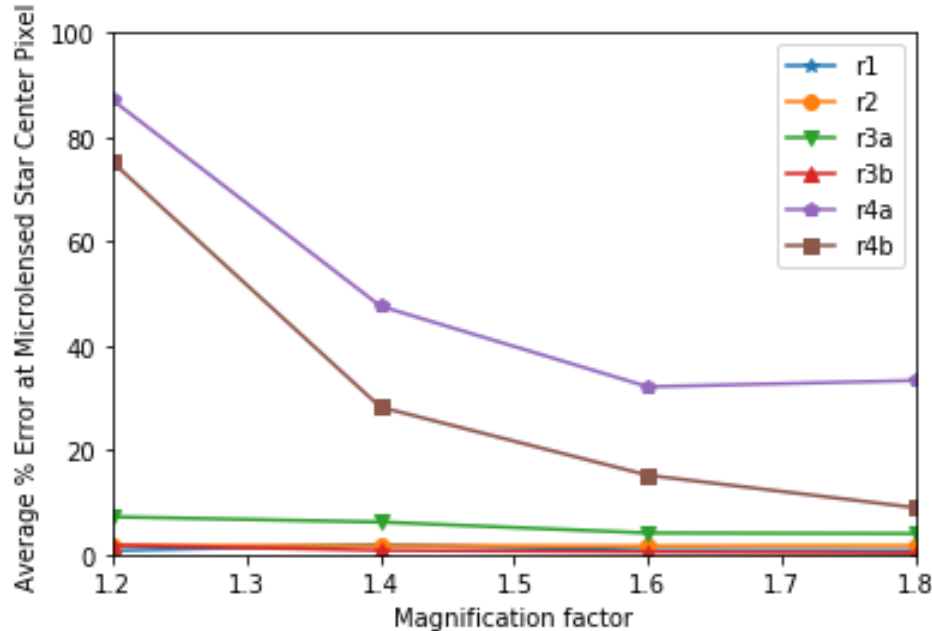


TABLE V
LEGEND DESCRIPTIONS FOR PLOTS IN FIGURE 8

Marker Name	Table Reference	Description
r1	Table I	Convolution Kernel is known 10% of Nyquist rate measurements used Observed image PSF = 0.3 Reference image PSF = 0.1
r2	Table II	Convolution Kernel is unknown 10% of Nyquist rate measurements used Observed image PSF = 0.1 Reference image PSF = 0.1
r3a	Table III	Convolution Kernel is unknown 10% of Nyquist rate measurements used Observed image PSF = 0.3 Reference image PSF = 0.1
r3b	Table III	Convolution Kernel is unknown 30% of Nyquist rate measurements used Observed image PSF = 0.3 Reference image PSF = 0.1
r4a	Table IV	Convolution Kernel is unknown 10% of Nyquist rate measurements used Observed image PSF = 0.5 Reference image PSF = 0.1
r4b	Table IV	Convolution Kernel is unknown 50% of Nyquist rate measurements used Observed image PSF = 0.5 Reference image PSF = 0.1

Conclusions and Future work

- CS is able to reconstruct images with fairly narrow PSFs, and which contain star sources experiencing magnification in their flux, using only *10% of traditional Nyquist rate measurements* with *less than 2% error*.
- This demonstrates that CS can be a potential game-changing data acquisition technology for transient photometry in crowded stellar fields
- Further work is required to reduce error for observed images with wider PSFs as compared to a reference image PSF

References

- [1] Seager, Sara. “Exoplanets.” Exoplanets (2010).
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