Characterization of image difference for transient detection

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  - Results
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- Conclusions
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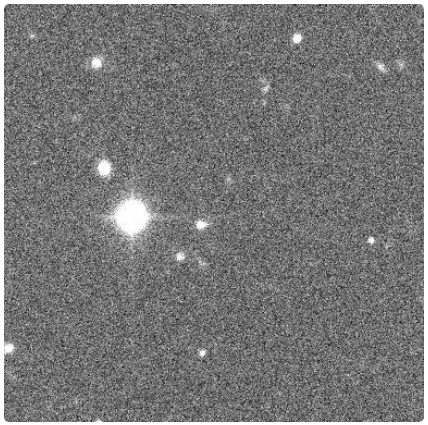
Introduction

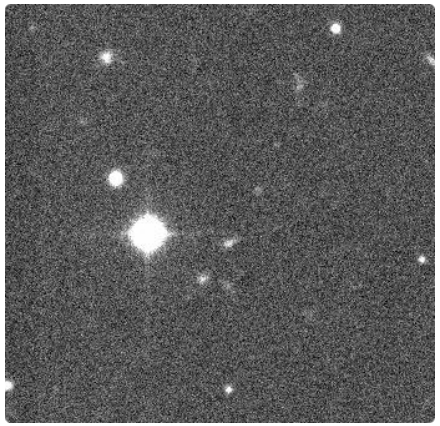
- **Transients:**
  - Flux varying objects or moving objects
  - Found by comparing flux intensities among several images
- **Flux variations**:
  - Cosmic rays
  - Plane misalignment
  - Moving stars
  - Instrumental defects
  - Astrometric distortion

Alard-Lupton[1] PSF-Matching subtraction: Basics

- Two input images:
  - $T(x,y)$: Template image, with the best PSF.
  - $S(x,y)$: Science image. It usually has the variation of interest.
- Variable PSF is calculated on each image using a grid approximation.



$S(x,y)$



$T(x,y)$

[1] Alard, C. and Lupton, R. (1998). *A Method for Optimal Image Subtraction*. *ApJ*, 503(1), pp.325-331.

Alard-Lupton PSF-Matching subtraction: Basics

- A Kernel convolution *K*(*x,y;u,v*) is calculated from the PSF of *S*(*x,y*) and *T*(*x,y*).
- The index *i* runs over all permutations of *n*, *p* and *q*. σ_n is the width of the n component of the Gaussian and p and q are the degrees of the polynomial used to represent *K*.

$$K(u,v;x,y) = \sum_i a_i K_i(u,v)$$

$$K_i(u,v) = e^{-\frac{u^2+v^2}{2{\sigma_n}^2}} u^p v^q$$

Alard-Lupton PSF-Matching subtraction: Basics

- $T(x,y)$ is convolved with $K(x,y,u,v)$ to PSF-match it to $S(x,y)$.
- The PSF-matched $T(x,y)$ is finally subtracted to $S(x,y)$ pixel to pixel.

$$S(x,y) - T(x,y) \otimes K(x,y,u,v) = D(x,y)$$

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- $D(x,y)$ is the Difference Image. Transients and variable objects are detected here.

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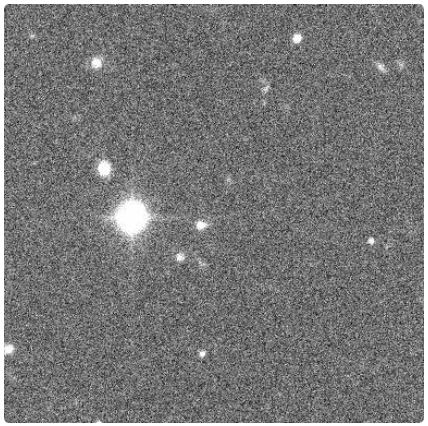
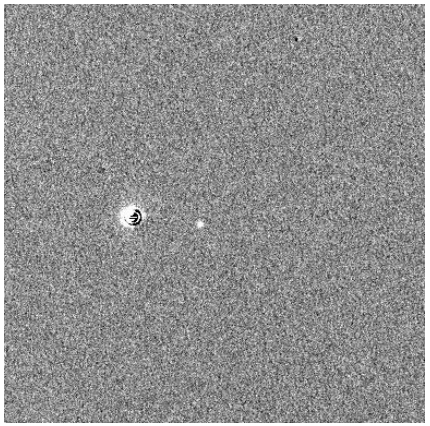


$S(x,y)$

$T(x,y)$



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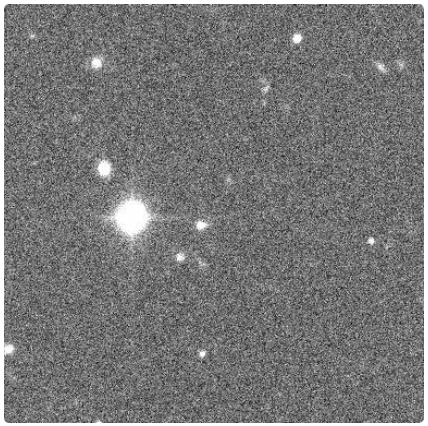

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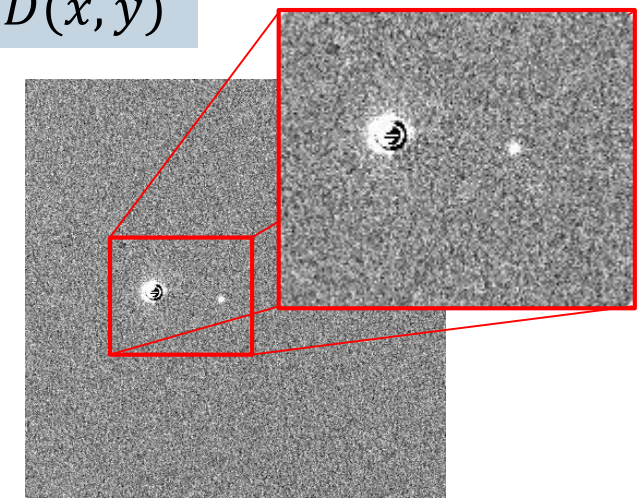

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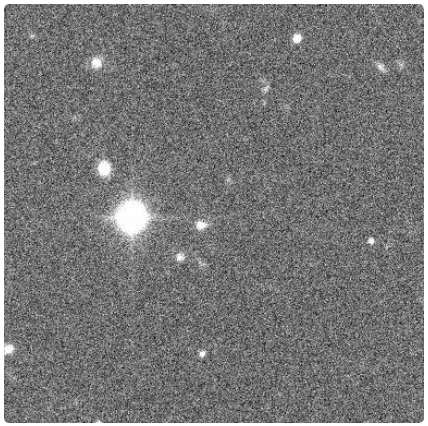

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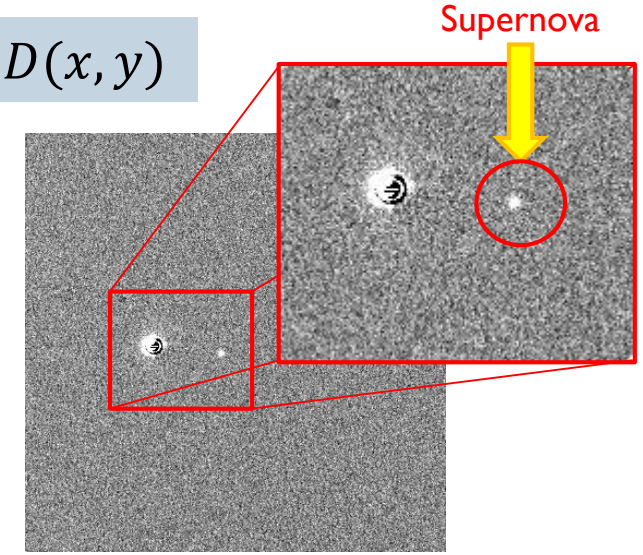
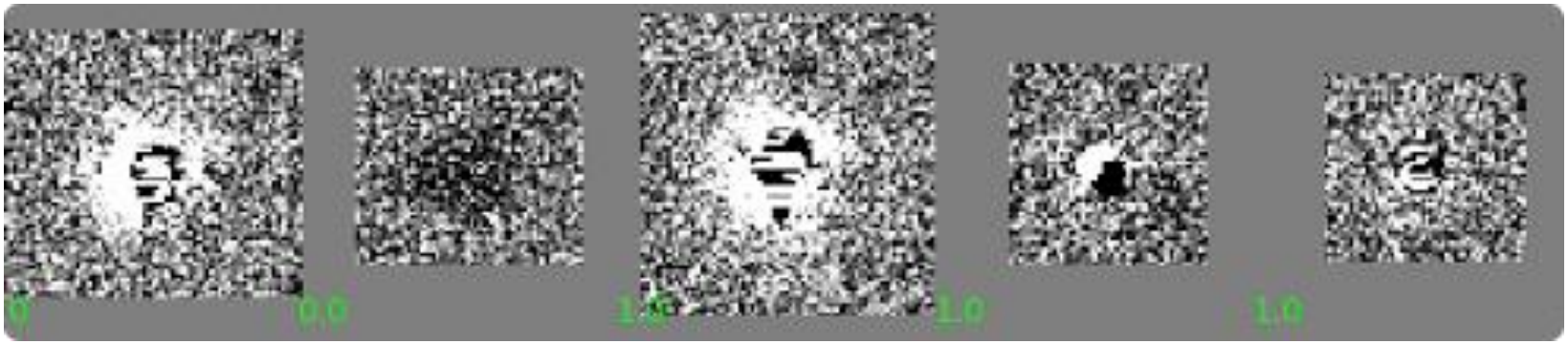


$D(x,y)$

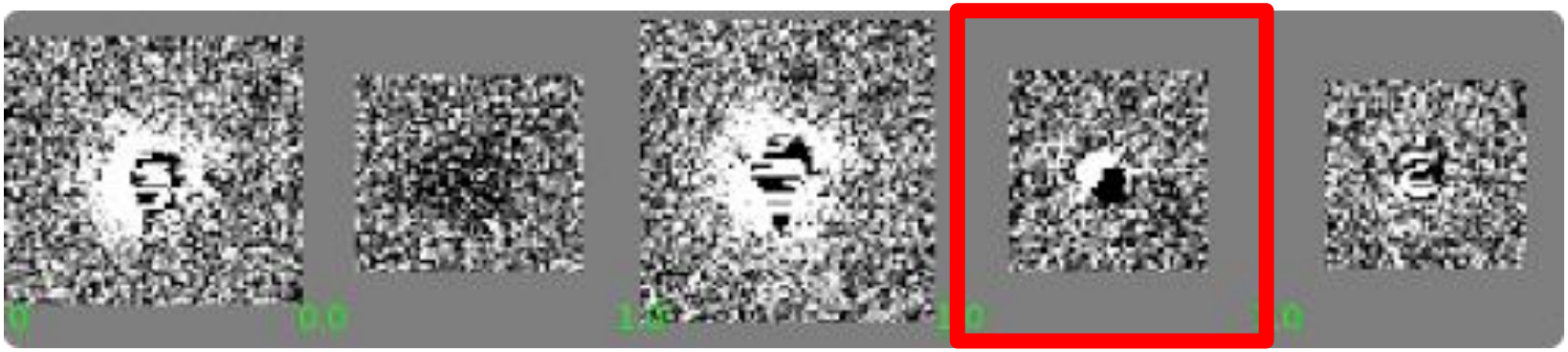
Alard-Lupton PSF-Matching subtraction: Artifacts

- Artifacts from Alard-Lupton method include:



Alard-Lupton PSF-Matching subtraction: Artifacts

- Artifacts from Alard-Lupton method include:
  - Dipoles (negative and positive regions more or less balanced).



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  - Fringes (kernel mismatch residuals).

Alard-Lupton PSF-Matching subtraction: Artifacts

- Artifacts from Alard-Lupton method include:
  - Dipoles (negative and positive regions more or less balanced).
  - Fringes (kernel mismatch residuals).
  - Noise.

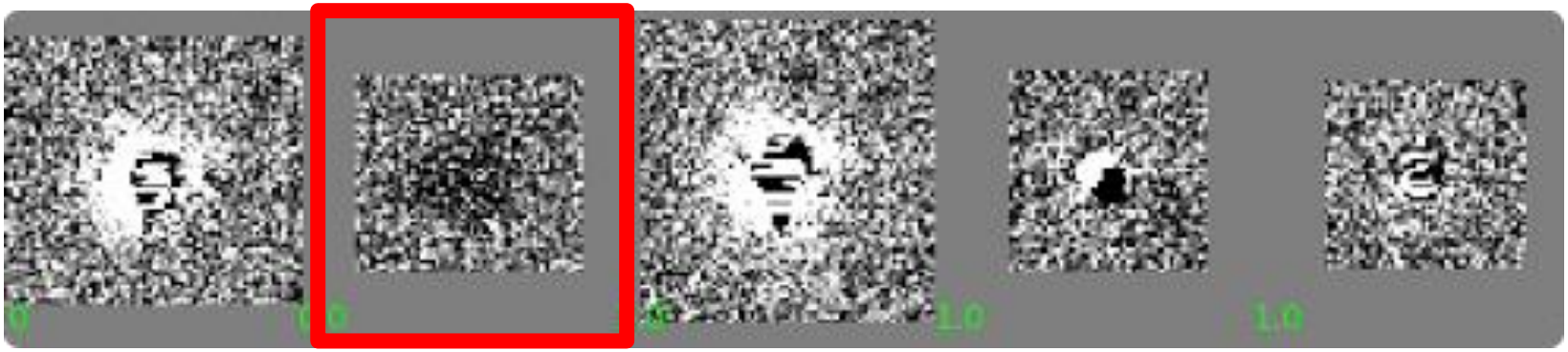


Image Difference on Stack: Qualitative Results

- Image Difference used on CFHT images.
- Sources on Difference Images (DIASources) are detected and measured.
- Significative DIASources are selected as those with flux over 5σ.

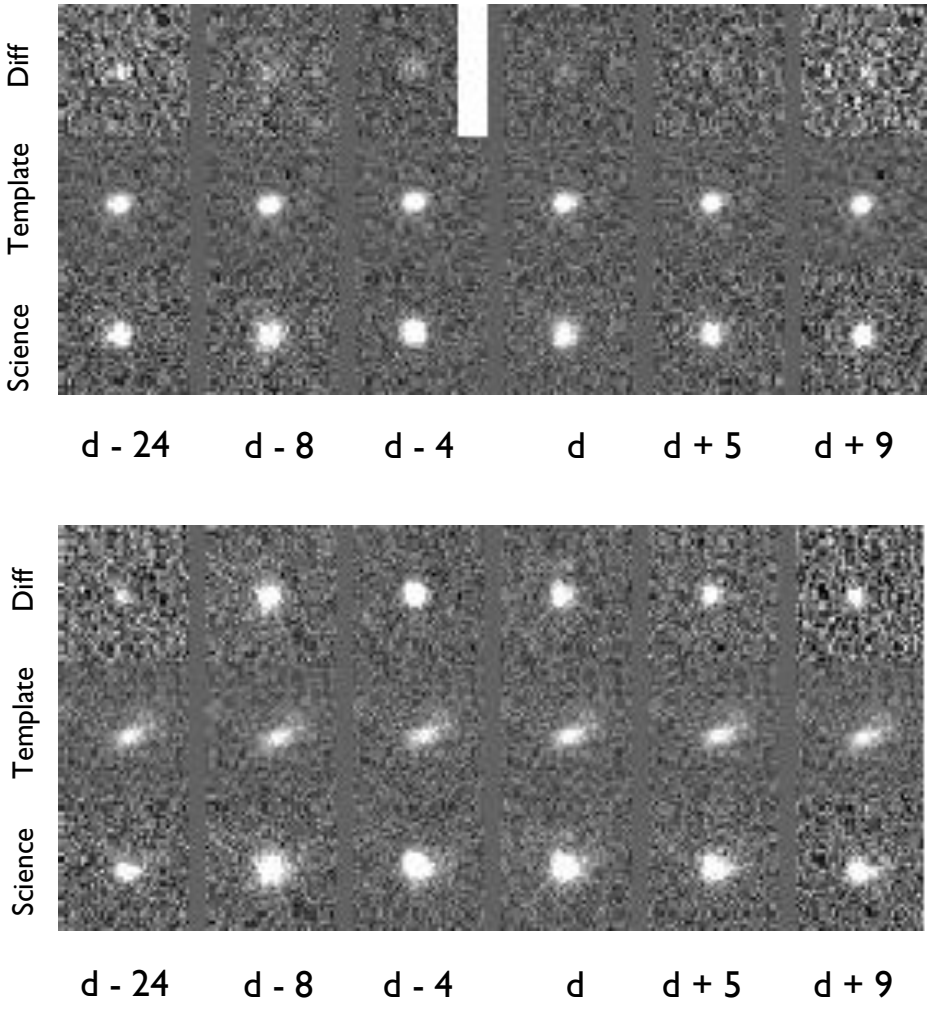
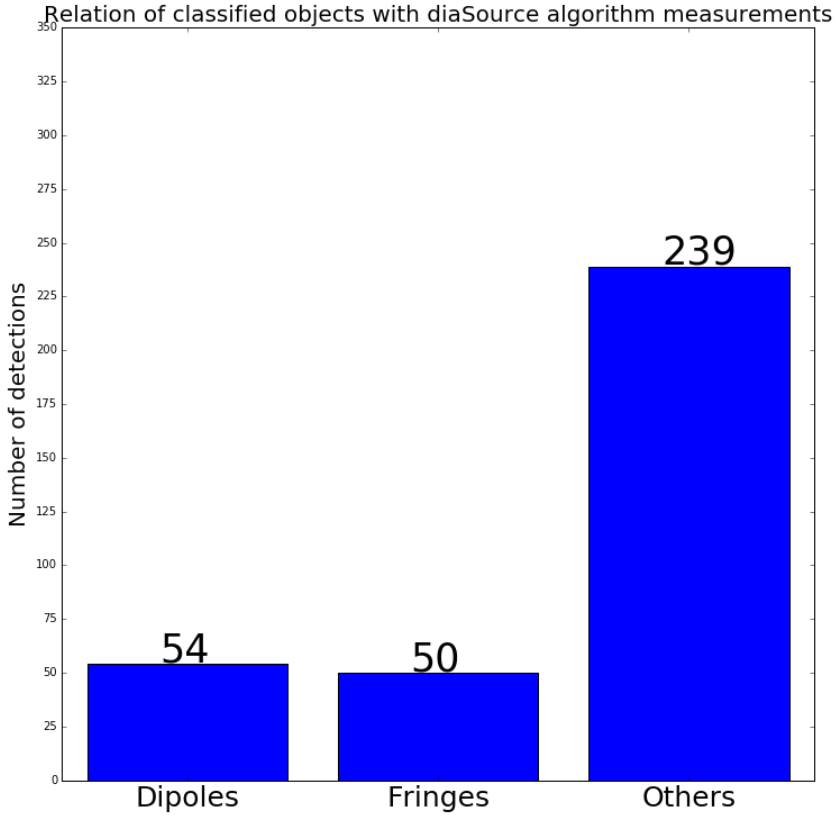


Image Difference on Stack: Classification of detections

- In our first test set, we used 6 images on field D3 from the CCD 14. We had previously identified a known supernova present on all these images. There were around 2500 significative DIASources detected per square degree.



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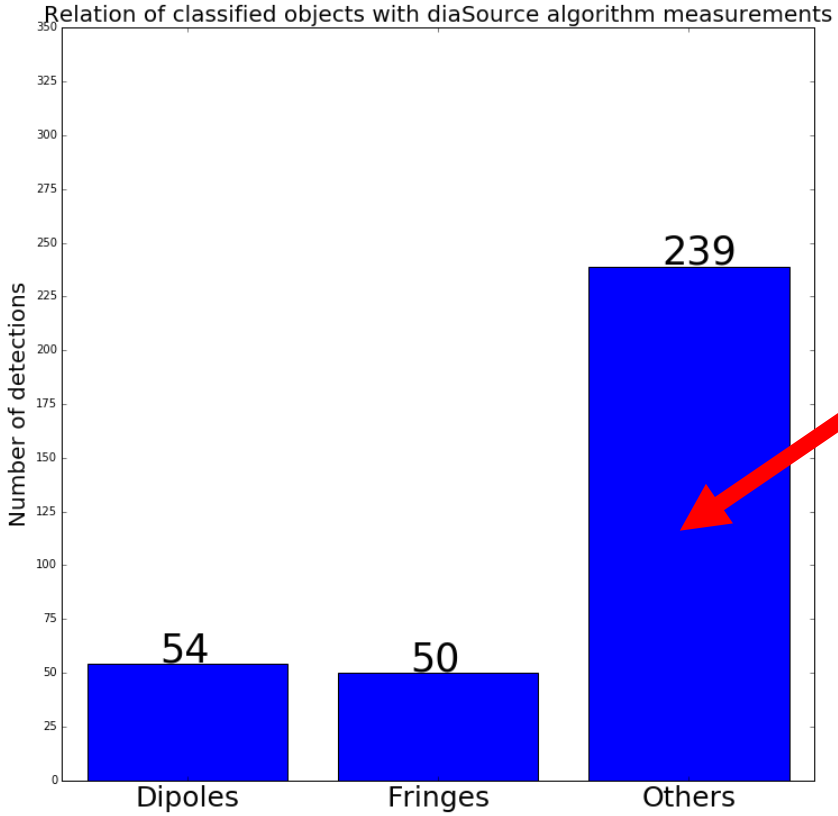
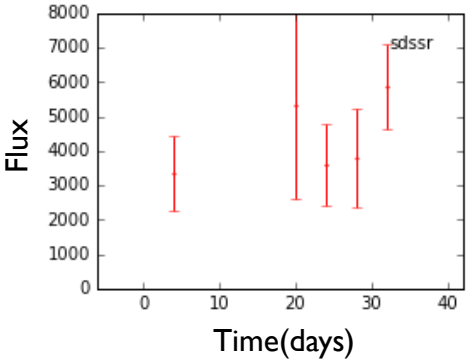
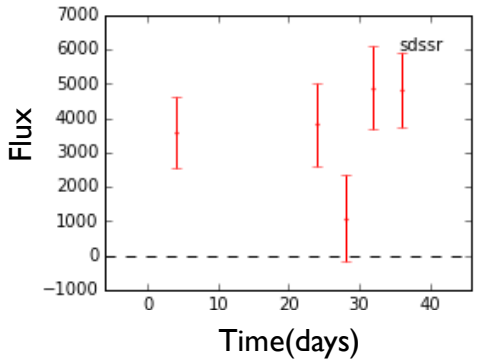


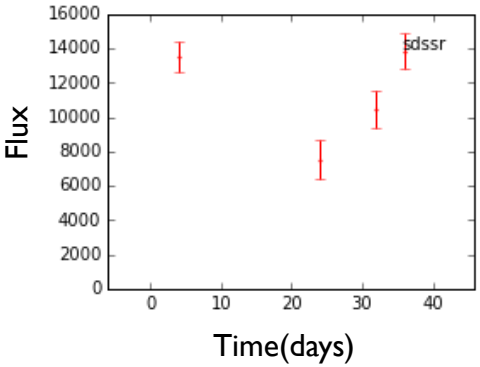
Includes 6 detections for the SN!

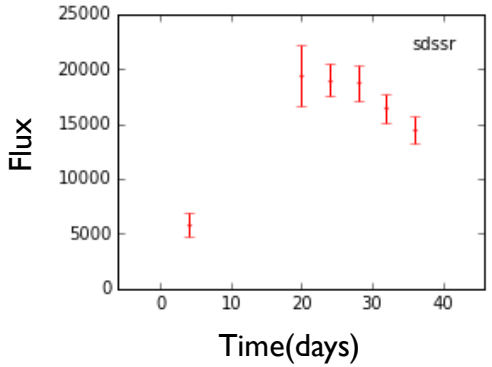
Image Difference on Stack: Light curves

- Using Sncosmo library. We traced the light curves for all the detections.
- Light curves with less than 3 points were rejected.
- DIASources tagged as dipoles were dismissed.
- Candidates went from 343 to 8 (on the 6 images).The supernova is among these sources.









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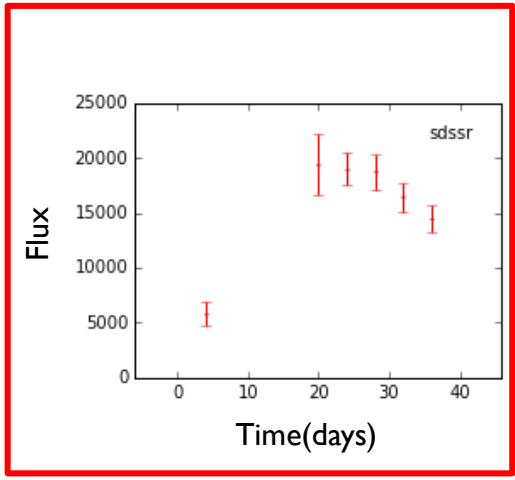

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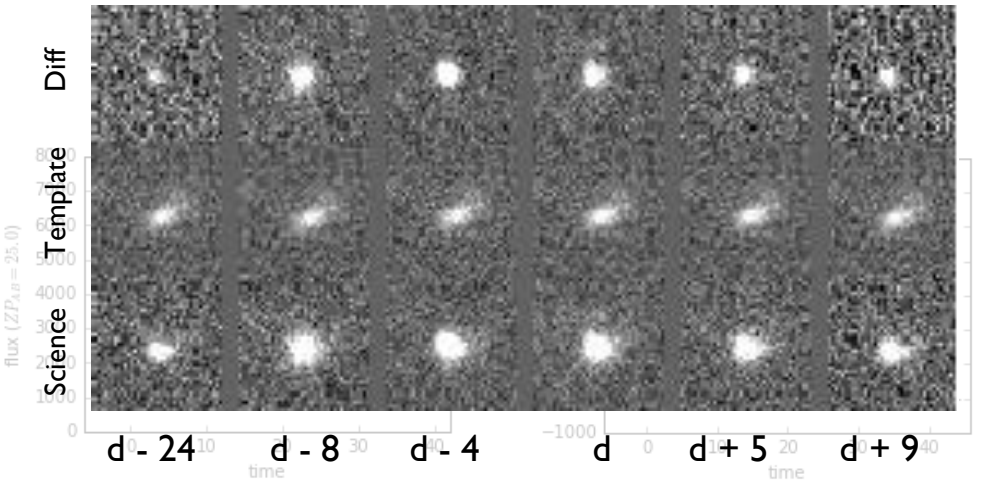
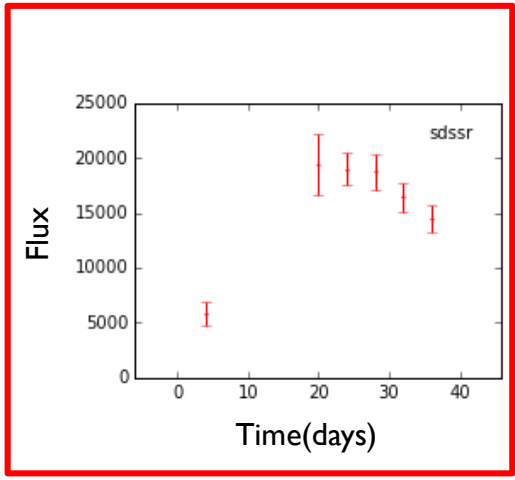
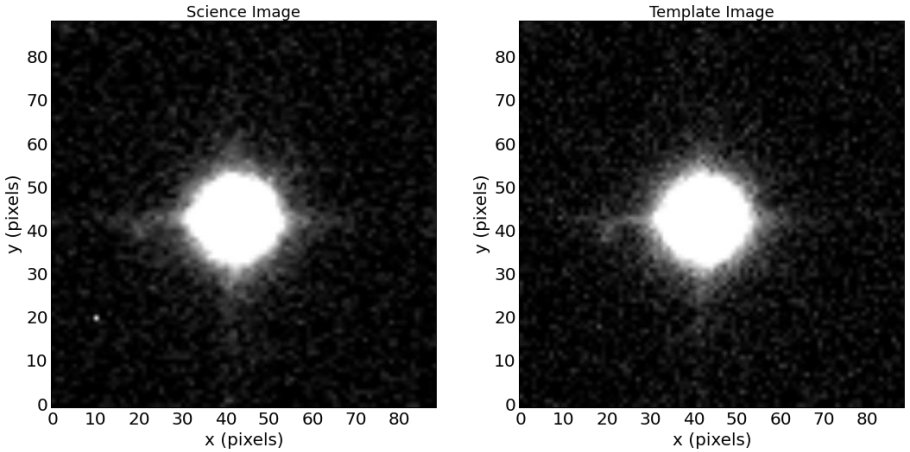


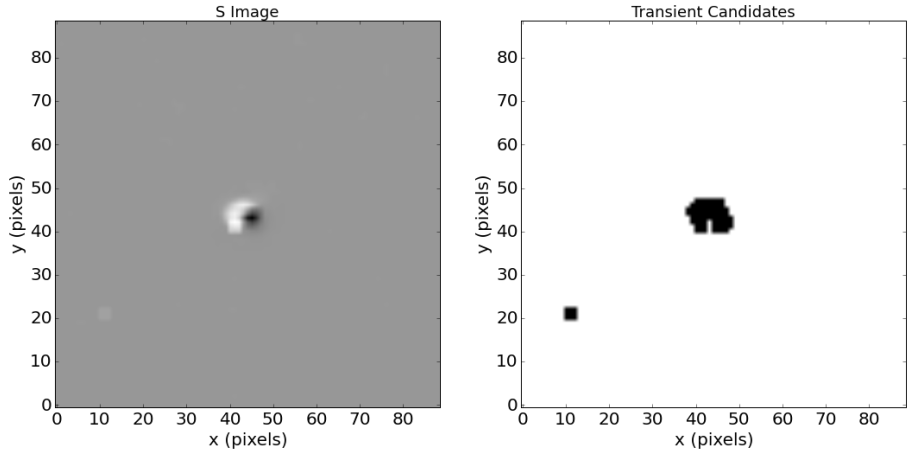


Other transient detection methods: Zackay-Ofek optimal transient detection[2]

- First implementation outside stack, using exclusively Python libraries.
- Zackay-Ofek method uses an optimal statistic approach for source detection (likelihood ratio test hypothesis: no source vs new source).



INPUTS



OUTPUTS

[2] Zackay, B., Ofek, E. and Gal-Yam, A. (2016). *Proper image subtraction - optimal transient detection, photometry and hypothesis testing*

Conclusions

- On Alard-Lupton Image Subtraction method:
  - Several transient objects were detected on the first test set and the Supernova was among them.
  - Characterization of sources detected on the difference image allows the creation of categories for further study.
  - It requires several tweaks to improve current results (including flexible testing).
- On Zackay-Ofek method (viability and efficiency) are currently a focus of research.
  - Benchmarking and comparison with Alard-Lupton algorithm are currently under investigation.

Perspectives

- On Alard-Lupton Image Subtraction method:
  - Improve selection criteria by using flux characteristics.
  - Implementation of automatic classification.
  - Study with more a priori transients.
- On Zackay-Ofek method:
  - Implementation on Stack.