Image difference

Transient search

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2. Image Difference
   - Introduction
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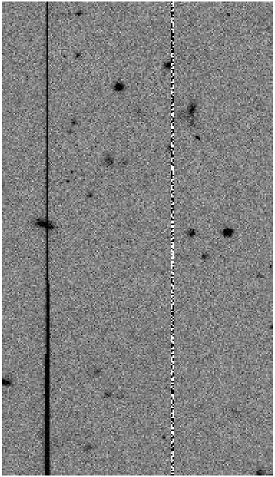
Transients

Introduction

Transients are of interest for various science topics : Variable stars ,quasars, microlensing, cosmology with supernovae, moving objects ...

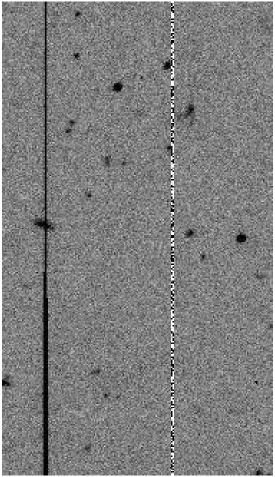
Moving Object

Example of a moving object (Dwarf Planet Beyond Neptune)



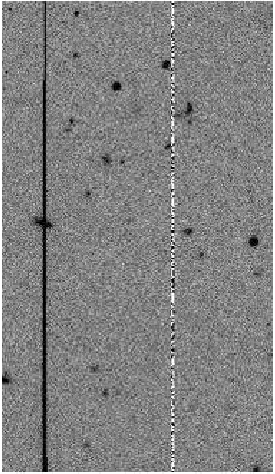
Moving Object

Example of a moving object (Dwarf Planet Beyond Neptune)
Capture on three visits



Moving Object

Example of a moving object (Dwarf Planet Beyond Neptune)
Capture on three visits
... over three hours



Microlensing

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Exercice !
Other extension and methods

Result targeting a crowded fields, with a massive star MOA-2016-BLG-227

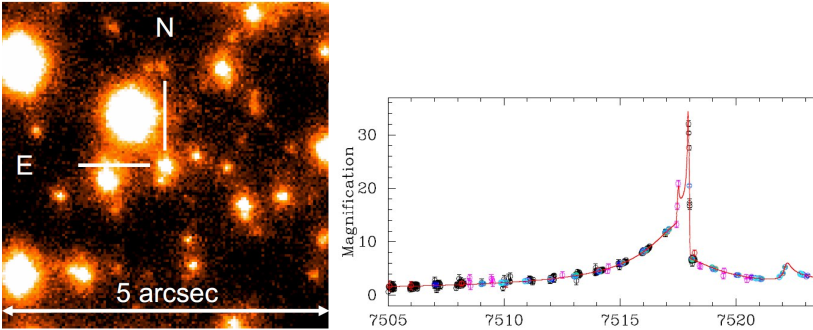
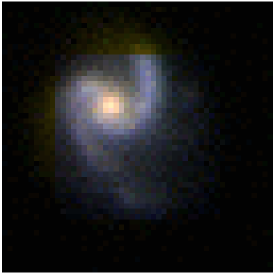


Figure : left: The star field ; right: The microlensing light curve

Supernova (sn2003ha)

superluminous Type Ia supernova : evolution of the explosion over 20 days

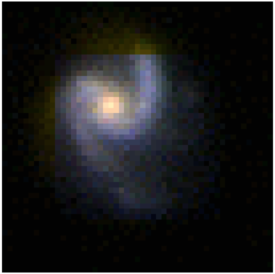
Host galaxy



Supernova (sn2003ha)

superluminous Type Ia supernova : evolution of the explosion over 20 days

Explosion observed before maximum luminosity



Supernova (sn2003ha)

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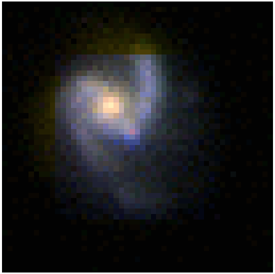
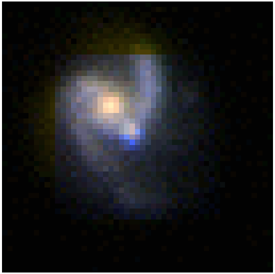


Supernova (sn2003ha)

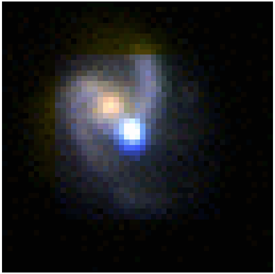
superluminous Type Ia supernova : evolution of the explosion over 20 days



Supernova (sn2003ha)

superluminous Type Ia supernova : evolution of the explosion over 20 days

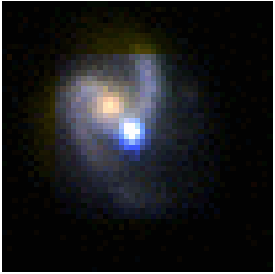
At maximum luminosity



Supernova (sn2003ha)

superluminous Type Ia supernova : evolution of the explosion over 20 days

Watch the PSF variation!



Supernova (sn2003ha)

superluminous Type Ia supernova : evolution of the explosion over 20 days

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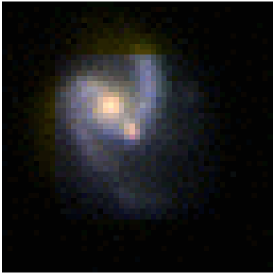

Observation

Observation

Two steps are mandatory : discovery and follow up. A follow up strategy is possible, either with dedicated intrument, pointing to the transient, or with a large field of view instrument with a rolling cadence strategy

Transient Discovery

Two epochs comparison

The flux of the same sky part is compare , either using a catalog of sources difference or an image difference

Multi epochs comparison

This is an extension a N times the two epoch comparison with the obtention of a time serie for transient candidate : eg the lightcurve

Two epochs comparison

Alignment

Geometric and photometric alignment is a necessary step to compare two visits

Catalog comparison

The flux of a catalog of sources from the same part of the sky is computed and after an astronomical match, their difference can be computed. The main problem comes from blended sources Ex: supernova on top of galaxy

Image difference

The flux of two images is subtracted at the pixel level. Prior to a pixel to pixel subtraction, the two images have to be aligned (WCS transformation) and the PSF on both images has to be equalized

Exercice !

Simulate a transient

Make a template image and new image(s) with transient(s)
Add basic seeing and noise

Image difference

Registration

A common sky coordinate has to be found between the two images

PSF matching

An optimal subtraction requires a processing to remove their PSF differences. This is known as PSF-matching the images.

Optimal Image Subtraction (aka Alard-Lupton)

OIS

This proposal was presented in [AL98] and later improved in [Ala00]. The OIS is based on approxi- mating the PSF of both images as a linear combination of gaussian functions multiplied by high degree polynomials. Such approximation is built from all the sources present in the image (and not only a subset) trying to create the best possible approximation. Then, the given equation is solved using least squares.

Alard-Lupton image difference algorithm

Method

The principle of the method is to find a convolution kernel (Kernel), that will transform a reference image (Ref) to fit a given image (I).

$$[Ref \otimes Kernel](x,y) = I(x,y)$$

Minimization

The kernel is found by minimizing :

$$\sum([Ref \otimes Kernel](x_i,y_i) - I(x_i,y_i))^2$$

Alard-Lupton image difference algorithm

Kernel linearisation

$$Kernel(u, v) = \sum_i a_i K_i(u, v)$$

The Kernel is linearised on a basis of functions.

Kernel gaussian approximation

$$K(u, v) = \sum_n e^{(u^2+v^2)/2\sigma_k^2} u_i v_j$$

Sum of gaussian multiply by polynomial (one can use Chebishev)

Alard-Lupton image difference algorithm

Solving the linear system

We have to solve

$$I = Ca$$

with

$$C_i = [Ref \otimes K_i]$$

Solving normal equation

$$I = Ca$$

$$C^T I = C^T Ca$$

of the form $\mathrm{b} = \mathrm{Ma}$

Alard-Lupton image difference algorithm

System to solve

We have to solve b = Ma, where :

$$M_{ij} = \int [R \otimes K_i](x, y) \frac{[R \otimes K_j](x, y)}{\sigma(x, y)^2} dxdy$$

and

$$B_i = \int I(x, y) \frac{[R \otimes K_i](x, y)}{\sigma(x, y)^2} dxdy$$

(Those equation do take into account the pixel variance σ, demonstration can been found in Becker 2012 arXiv:1202.2902)

Alard-Lupton image difference algorithm

Result on crowded field , using space varying kernel (simulation)

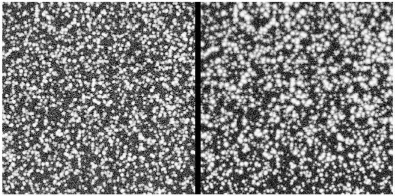

Fig. 1. Simulated of crowded field images. On the left is the image with constant PSF, and on the right is the image with PSF variations along the Y axis. Note the large amplitude of the PSF variations. A total of 2500 stars has been included in this simulation

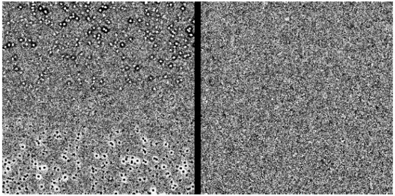

Fig. 2. On the left is the subtracted image obtained with constant kernel solution. Note the systematic pattern along the Y

Other extensions and methods

Other extensions and methods

Differents extension of Alard-Lupton by changing the kernel basis or psf determination.
(Zackay et al 2016) method to decorrelated the image obtained afetr kernek convolution

Exercice !

Subtract your simulated images

Make a simplified kernel base
Compute the b and M terms
subtract and find your transient