

# Detection of supernovae in J-VAR

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**Abstract.** Optical transient events are of great astronomical relevance, especially supernovae, which can provide us with information on distances in the Universe, chemical evolution, among others. The J-VAR survey is a J-PLUS ancillary project, dedicated to observing variable and transient objects. We describe the image subtraction technique used to identify transients, in particular supernovae, within the J-VAR survey. The J-VAR data is co-added and aligned using the softwares Swarp and WCSremap, respectively. The image subtraction is done by Hotpants and the supernova candidates are extracted from the subtracted image using the software Source-Extractor. As a result, 68 fields were analyzed and 16 supernovae were detected. There are 2 confirmed supernova, 4 candidates and 10 supernovae already identified by other surveys. Our pipeline is also very effective at the detection of variable stars, binary systems and AGNs. We aim to implement this pipeline in the analysis of J-VAR images as they are acquired, which will allow us to detect supernovae in real time.

**Resumo.** Os eventos transientes ópticos são de grande relevância astronômica, em especial, as supernovas, que podem nos fornecer informações de distâncias no Universo, de evolução química, entre outros. O levantamento J-VAR é um projeto auxiliar do J-PLUS, dedicado à observação de objetos variáveis e transientes. Com o auxílio de técnicas de subtração de imagens, é possível identificar transientes, particularmente supernovas, nos dados J-VAR analisando as imagens subtraídas. As imagens do J-VAR são somadas e alinhadas usando os softwares Swarp e WCSremap, respectivamente. A subtração da é feita pelo Hotpants e os candidatos a supernova são extraídos da imagem subtraída usando o software Source-Extractor. Como resultado, 68 campos foram analisados e 16 supernovas foram detectadas. Destas, 2 supernovas confirmadas, 4 candidatas e 10 supernovas já identificadas por outros levantamentos. Nosso pipeline também é muito eficaz na detecção de estrelas variáveis, sistemas binários e AGNs. Pretendemos implementar esse pipeline na análise de imagens J-VAR à medida que são adquiridas, o que nos permitirá detectar supernovas em tempo real.

**Keywords.** Supernovae: general – Methods: observational – Surveys

## 1. Introduction

Optical transients, such as supernovae, eclipses, and comets, fall within the time-domain branch of astronomy, and require our best abilities to detect them and understand their nature. These days, several wide field surveys are being carried out, and they are ideally suited to repeatedly observe the sky and discover new objects. When designing a survey, one needs to reach a compromise between the amount of sky that can be patrolled in a given night, the depth of the observations and the number of filters. In general, time-domain surveys opt for a large sky area in one filter at relatively shallow depths.

The Observatorio Astrofísico de Javalambre is an observatory dedicated to wide field surveys located in mainland Spain. It was initially conceived to carry out the Javalambre Photometry of the accelerating universe Astrophysical Survey (J-PAS, Benitez et al. 2014) and its calibration survey, the Javalambre Photometric Local Universe Survey (J-PLUS, Cenarro et al. 2019). It was soon realised that J-PLUS had the character of a scientific survey by itself and J-VAR is one of its ancillary projects, dedicated to observing variable and transient objects.

With the aid of image subtraction techniques, it is possible to identify transients, particularly supernovae. In addition to identifying the supernova, we can provide a preliminary classification using J-VAR's seven filters set. Our ultimate goal is to produce a semi-automatic pipeline, which selects the most promising candidates for spectroscopic follow up and rejects false detections.

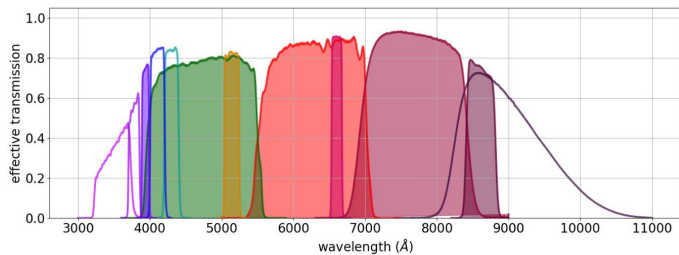
## 2. J-VAR Survey

J-VAR is a variability program carried out at the Observatorio Astrofísico de Javalambre. It is a project originally designed to be a filler in order to maximise the efficiency of the observatory and the scientific output of the J-PLUS survey. The J-VAR survey is carried out with four narrow band filters and three broad band filters (gSDSS, rSDSS, iSDSS). The filter set (see Fig. 1) has been chosen to maximise the throughput of the optical system. Based on simulations of the light curves of pulsating stars, it was estimated that 11 visits of a field would be enough to determine a pulsation period. Given the filler nature of the program, the fields are observed whenever J-PLUS cannot be observed. This means that the time difference between two consecutive observations is not fixed and time scales in a vast range from 15 minutes to months can be explored. Moreover, J-VAR also benefits from the well-calibrated photometry implemented in J-PLUS Data Release 3 by restricting observation points to those already published by J-PLUS.

There is already in place a working pipeline that analyses the images taken during one night, detects moving objects, extracts instrumental magnitudes and flags possible unknown objects. In this context, J-VAR works as a stand-alone survey.

## 3. Detection

The detection of an optical transient is, in principle, a trivial task. By definition, one is looking for an object which is detected on a given night but not on another night. This task is made more difficult in the case of supernovae because, in general, these



**FIGURE 1.** The J-VAR filter set (shown as filled curves) is a subset of the J-PLUS photometric system (empty and filled curves).

happen in galaxies, which appear as extended objects in typical astronomical images. In many cases, a supernova cannot be separated from the photometry of its host galaxy and the difference in image quality between images taken in different nights makes this effort almost impossible if based on photometry alone. In order to circumvent this problem, one can resort to differential imaging. In short, images from two different nights are aligned, convoluted so that they have the same image quality and then subtracted. The subtracted image is then used to detect variable objects.

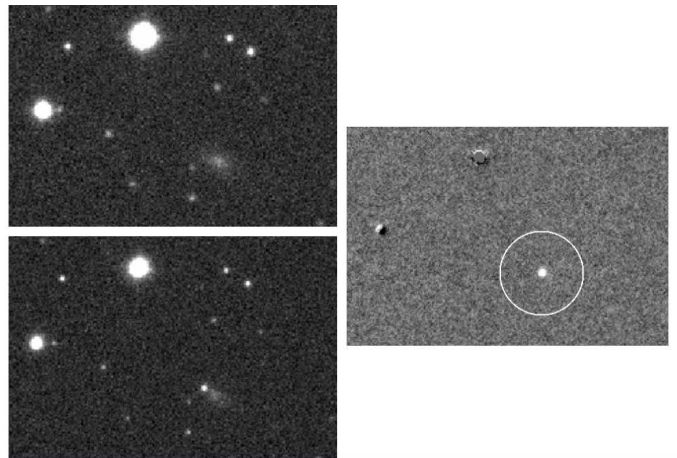
In order to select supernovae candidates from the J-VAR data, a Python pipeline was developed, in which a determined field is analyzed, by epoch and filter. In short, for a given field, the images from the same epoch and filter are co-added and aligned using the softwares Swarp (Bertin et al. 2002) and WCSremap, respectively. The image subtraction is done by Hotpants (Becker 2015) and the supernova candidates are extracted from the subtracted image using the software Source-Extractor (Bertin & Arnouts 1996).

To detect the supernova candidates only gSDSS and rSDSS filters are used. There are several observation dates for each analyzed field and, in each of them, at least three individual images are available in each filter. Two criteria were imposed to select the epochs for analysis: the interval between consecutive epochs must be greater than 15 days and the epoch with the smallest mean PSF is chosen if there are two or more epochs close to each other in time.

As mentioned, the first step in the detection of candidates in a J-VAR field, is to co-add images from the same epoch and filter. As a result, each epoch has one final image in the gSDSS and rSDSS filters. One epoch is always selected as the reference point, or template as we call it, to which all others can be compared. Thus, in order to subtract the images correctly from one another, we must align the images from each epoch with the template so that they can be subtracted properly. The next step is the subtraction of epochs in relation to the template and the inversion of that same subtraction (see Fig. 2). We then analyse the subtracted images in search for sources that changed between the epoch of the template and another epoch. We have to examine both the subtracted image and its inverted version, because the subtraction order matters. For example, if we have a supernova in the template it will be detected in the inverted subtraction.

The final step in the process is the extraction of candidates using Source-Extractor from both subtracted and inverted images. An ellipticity criteria ( $\epsilon \leq 2$ ) is imposed in order to select only round or roundish objects from the Source-Extractor candidates list. Finally, the lists of candidates from a given epoch in gSDSS and rSDSS are compared and the candidates that appear in only one filter are eliminated. There is also a final phase of automatic elimination. In this phase, candidates that appear in more than one epoch are eliminated if the interval between them is longer than 3 months.

For the analysis of the results, the candidates that are residues of the subtraction are manually eliminated and the final candidates are cross-matched with the SIMBAD (Wenger et al. 2000) and NED (Helou et al. 1991) databases as well as the Transient Name Server (TNS).



**FIGURE 2.** Detection of SN 2018fdz by our pipeline in 2021 (already reported by the Zwicky Transient Facility - ZTF - team). On the left we show the template (upper panel) and the detection epoch (lower panel). On the right is shown the subtracted image, where the supernova is highlighted.

#### 4. Results

In total, 68 fields were analyzed and 16 supernovae and candidates were detected. Ten of these objects had already been identified by other surveys: SN 2020amv, AT 2017eke, AT 2017dzn, AT 2019roh, AT 2019ioo, AT 2018fds, SN 2020cvy, SN 2017icq, SN 2019obw, AT 2020abzu. Thus, their detection by our pipeline were only a confirmation of its capabilities. We have discovered 1 confirmed supernovae and other 5 candidates are currently under analysis.

The first confirmed supernova discovered by JVAR is SN 2020admb, internally called SN JVAR20a. It was first spotted on December 20<sup>th</sup>, 2020 and after that it was observed in 17 epochs, until April 17<sup>th</sup>, 2021. Fig. 3 shows three light curves for this supernova, for the gSDSS, rSDSS and J0660 filters. Now classified as a Type Ia supernova at redshift 0.04, its maximum brightness was seen around January 11<sup>th</sup>.

One of the supernova candidates is AT 2021aggv, internally called SN JVAR21a, detected at redshift 0.043. One of the other candidates currently under analysis was detected at redshift 0.2. Due to the fact that it has not been observed by J-VAR in many epochs after detection, its light curve is not as complete as Fig. 3.

It is noteworthy that our pipeline is also very effective at the detection of variable stars, binary systems and AGNs. A total of approximately 300 of these objects were identified during the analysis of all 68 fields. Additionally, there are around 220 objects that do not match the characteristics of transients and may thus be unknown variable stars.

#### 5. Conclusion

As expected, it was possible to detect supernovae in J-VAR with image subtraction techniques. This project is still ongoing, as

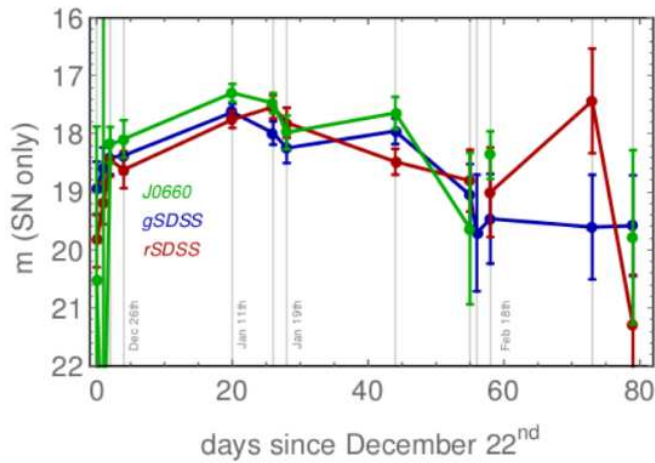


FIGURE 3. SN 2020admb 80 days light curves for the J0660, gSDSS and rSDSS filters, in green, blue and red, respectively.

completed J-VAR fields are continuously being analyzed. It has already been possible to detect unknown supernovae. We have candidates to be studied, and we have also detected variable stars, binary systems and AGNs. We have also identified more than 200 variable star candidates. Due to the development of this pipeline, the detection of candidates, either supernovae or variable stars, can be done in a completely automatic way, so that only the final analysis remains semi-automatic.

All the analysis described here was performed using completed J-VAR fields with images from different years, making the detection of unknown supernovae somewhat atypical. For example, sometimes we detect a SN but it is in a field from 2018, which means it was probably already detected by other surveys. As part of the J-VAR Legacy project we aim to implement this pipeline in the analysis of J-VAR images as they are acquired, which will allow us to detect supernovae in real time.

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