1) General information

Offer to which this application is related: 2019B (LP)

Title: J-VAR: the Variable Sky of J-PLUS

Field of the study: Stellar physics

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Abstract:

Large field of view telescopes are giving a great contribution to time-domain astrophysics. As a good example, one of the main projects of the next decade is the Large Synoptic Survey Telescope (LSST), whose main science case is the study of the variable sky.

J-VAR is a project intended to revive the time-domain science which can be done with JAST, without reducing the efficiency of J-PLUS. The main science projects are solar system objects, supernovae and variable stars (pulsating, active and binary stars). As an important by-product for J-PLUS, J-VAR will identify variable sources for which SED fitting (which is largely used for photometric redshift determination) may provide unreliable results.

Given its nature, J-VAR is a clear candidate to be a filler program and it has been designed to benefit the efficiency of the observatory.

Does this proposal belong to a research project?: No

Are the results of the observations to be used in a Phd?: No

Is this application the follow-up of a programme which has previously been awarded time to the team?: Yes

Previous programme(s) to which this application is related: 1800151 / J-VAR: the

Variable Sky of J-PLUS

Will you need observing time at OAJ in following semesters to complete this programme?: No

Number of semesters required: 4

2) Observations

Desired type of night: It does not matter

Desired worst acceptable seeing interval: > 1.5"

Desired worst acceptable airmass: It does not matter

Desired type of transparency: It does not matter

TOTAL TIME OF THE PROPOSAL (including overheads): **73.45 hours**

Observation 1

Telescope/camera: JAST/T80 - T80Cam

Observation mode: Queue

Pointing

Name: dummy01

RA (Right Ascension) - J2000.0: 00:00:0.000

DEC (Declination) - J2000.0: 00:00:0.000

Number of repetitions: 110

Filter/s (calculated times include rough estimations of the overheads):

1.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	J0395	**87**	**3**	**5.35**

Comment 1:

2.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	gSDSS	**33**	**3**	**2.65**

Comment 2:

3.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	J0515	**40**	**3**	**3**

Comment 3:

4.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	rSDSS	**40**	**3**	**3**

Comment 4:

5.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	J0660	**135**	**3**	**7.75**

Comment 5:

6.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	iSDSS	**34**	**3**	**2.7**

Comment 6:

7.	Filter	Time per exposure (s)	Number exposure	Total time (min)
	J0861	**160**	**3**	**9**

Comment 7:

Total time of the observation (including overheads): **3899.5 min**

3) Description of the application

Scientific rationale:

* Minor Bodies

There are almost 10^6 known minor bodies in the Solar System, ranging from Near Earth populations up to trans-Neptunian bodies and comets. Among them just a little fraction has actually decent-quality data, especially due to lack of devoted surveys (with a few exceptions). In particular, reflectivity properties remain largely unexplored. The sizes of minor bodies range from a few meters to up to a couple thousands kilometres with surface compositions showing from rocky material (silicates) to extremely volatile ices (nitrogen or carbon monoxide, for instance). Imposing constrains on the actual distribution of properties is crucial to understand the population of minor bodies as a whole in the context of the evolution of the Solar System.

Spectrophotometry in 7 filters will be extremely useful to study surface properties of minor bodies, as well as to estimate absolute magnitudes (H) which is related to sizes and could be used as its proxy.

We separate our science case in three topics:
(i) The absolute magnitude, (H) of a minor body is defined as its apparent magnitude if it were observed at 1 AU from the Sun. In practice, H is measured constructing phase curves which show the change in apparent magnitude (normalised to unit distance from the Earth and the Sun) with phase angle (the angular distance between the Earth and the Sun as seen from the object). H is related to size, reflecting area, and albedo, how the surface reflects the light. Measuring the magnitudes at different phase angles (at least in the g-filter) we will create phase curves and obtain H. These can be used to complement other surveys (including J-PLUS and J-PAS) and create the cumulative size distribution of the different subpopulations, helping to understand their collisional evolution.
(ii) The taxonomic distribution is very helpful to gain insight of how different surface properties are distributed in the Solar System. This distribution is the result of the dynamical evolution that re-shuffled the bodies and the chemical evolution that altered the pristine chemical composition. The filter set selected for this project is especially well suited for taxonomical characterisation, as it allows the identification of the absorption feature of silicates at 900 nm, the absorption due to aqueous altered material at 700 nm, and the decrease in reflectance below 450 nm due to phyllosilicates.
(iii) The recurrence of visits will be useful to re-observe objects that could still be in the field and compare if the surface reflectivity has changed. The change could be due to several reasons: patches of different reflectivity on the surface, cometary-like activity, or collisions. These data can also be confronted with serendipitous observations of the same targets by the J-* surveys.

Considering the limiting magnitude of J-VAR, closeness to the ecliptic is necessary to accomplish this project. Only the third science case mentioned above benefits directly form recurrence. Certainly, re-visits close in time would permit to re-observe fast moving objects (Near Earth Asteroids), while re-visits up to 10 days after the visit will permit to recover jovian trojans (the slowest moving objects reachable within J-VAR).

* Supernovae

Although type Ia supernovae (SNe) have been extensively used in cosmology as standard candles, the progenitors and the very nature of these explosions are still open questions. The possibility of evolution, for example, may put in risk current cosmological analysis using type Ia SNe.

In order to detect such transient phenomena, the technique of image subtraction is used, in which one compares images of (roughly) the same field in different nights, in the search for changes in luminosity that might be caused by SNe. Therefore, at least two images of a given field are needed.

So far, the largest amount of information on type Ia SNe comes from the SDSS Supernova Survey (M. Sako et. al., arXiv:1401.3317) and the Supernova Legacy Survey (A. Conley et. al., arXiv:1104.1443), whose combined results are compiled in M. Betoule et. al., arXiv:14014064. These surveys are based in broad band photometry (the usual SDSS ugriz system).

The J-VAR survey is expected to observe the chosen fields in 11 different epochs, in 7 different filters, which will result 7 light curves, with 11 points each (see "Technical Description" for details). With these observations we will be able to photometrically identify the type of the supernovae.

The main benefit of using narrow and intermediate band filters is the fact that we can obtain low resolution spectral information of every observed object, without taking a proper spectrum (Xavier et al., MNRAS 444, 2313, 2014). These would provide us with very consistent data, in the sense that all events will be observed by the same instrument, and will have similar information (filters and cadence). Such large consistent set of data could allow us to study correlations between host galaxy properties and supernovae light curves, rates of different types of SNe and, possibilly, improve light curve fitting for cosmology.

We would like to keep track of a SN light curve for about two months, since its explosion. For typical type Ia SNe, a cadence between 2-3 days would be the ideal, but cadences of up to 1 week are still acceptable. With each field being observed 11 times, the J-VAR cadence should be around 5-6 days, with fluctuations due to weather conditions.

* Variable Stars

** Pulsating Stars

Pulsating stars like the RR Lyraes and Cepheids are intrinsically relatively bright so they can be observed at very large distances. Their brightness amplitudes are also large enough to be detected with ease; the lowest amplitude for RR Lyrae stars is around 0.2 magnitudes being typically 0.5mag.

As it is already well known, these two types of objects are considered stellar candles that can be used as distance indicators. RR Lyrae stars are very convenient for surveying the Galaxy and their nearest members of the Local Group, while Cepheids are perfectly suited for the Local Group and even beyond. Concerning RR Lyrae stars, they are excellent tracers of the structure of the Milky Way. Given they are older than 10Gyrs, they behave as old population tracers too. Moreover they can be used as metallicity indicators.

With J-PLUS data it is expected to have a very complete and pure sample of RR Lyraes candidates from photometry alone. In that regard, J-VAR will be crucial for confirming those candidates as well as to get an estimation of the pulsation periods that are not going to be feasible with J-PLUS alone. Another important point is that an initial quantification of their metallicity is going to be addressed with J-PLUS. Adding J-VAR, those measurements are going to be contrasted with the ones coming from the use of the periods and the empirical laws that link period, metallicity and brightness.

Observations in the broad-band filters to maximize the throughput of the system, and so the distance range. The critical issue here is the number of epochs; the degree of success on estimating the periods relies very much on that. Some simulations have been done yielding an acceptable degree of successful period retrieval with a minimum of eleven epochs.

** Active Stars

A variety of stars presents chromospheric emission at different stages of their lives: young stars, solar-type dwarf stars with magnetic activity, non solar-type active stars, stars showing flares, etc. What all these stars have in common is that their activity can be measured through the flux in the Ca II H and K lines. In this regard, T80 has the ability to trace that emission using its unique set of filters. More particularly, the J0395 band is very convenient for that. The measurement of the flux may have its limitations, but the detection of variability in that band is expected to be feasible in the more energetic events with J-VAR. The use of J0395 band in conjunction with gSDSS broad-band (J0395-gSDSS) will be used for that purpose.

J-VAR is going to be unique due to the amount of area that can be surveyed with the large FoV of T80 and the advantage of having that J0395 band. Studies on the chromospheric emission and/or variability as a function of the stellar type or stellar parameters (borrowed e.g. from J-PLUS results) can be conducted with a very competitive (or even, unprecedented) statistical significance.

Observations in J0395 and gSDSS (close in time) during as many epochs as possible in order to detect any emission event (e.g. flares) or variability (e.g. caused by magnetic activity and stellar rotation).

** Binary Stars

Binary stars are key ingredients to the evolution of galaxies. For example, it is likely that the vast majority of massive stars are formed in multiple systems. Moreover, binary stars are expected to be progenitors of type Ia supernovae
(thermonuclear supernovae). In a more general perspective, eclipsing binaries are the best opportunity to derive complete physical properties of stars like radii and masses.

While most variability projects (e.g. CRTS, Kepler) only observe in one broad-band filter, the use of broad and narrow-band filters in J-VAR will allow not only the detection of the binarity of the object but also the nature of the two stellar components thus reducing the need of spectroscopic follow-up and leading to an increase in the understanding of these objects.

The vast majority of eclipsing binaries has periods of less than 10\,days. This can be easily detected with time series spaced by a few days. Even if the observation in one filter only would be enough to detect the binarity, the use of multi-filter would help to give a first classification of the components of the binary. It is also good that these stars are dsitributed all over the sky, thus not imposing critical restrictions to our pointing strategy.

Technical description:

* Filters
Filters have been chosen to be the most efficient (gSDSS, J0515, rSDSS, J0660, iSDSS, J0861) among the ones that are available on T80Cam. Moreover, the J0395 has been added to identify active stars.

* Exposure times
J-VAR is a project designed to be a filler, hence efficiency is key to this project. The filter set has been chosen to maximise the throughput of the system.

One observing block of J-VAR is a repetition (three times, with dithering) of the filters mentioned in the previous section. Although, the change of filter is less efficient than the movement of the telescope, this increases the time difference between two consecutive exposures in the same filter, hence allowing us to study variability on time-scales of about 10-15 minutes, which would be otherwise impossible.

The exposure times are chosen so that three combined images, taken in a bright night, with 1.2arcsec seeing at airmass 1.4, reach signal-to-noise 3 in an aperture which is twice the seeing at the magnitudes reported in the following "table":

J0395 20.5
gSDSS 21.5
J0515 20.5
rSDSS 21.5
J0660 21.0
iSDSS 21.5
J0861 21.0

Bright time has been chosen to mimic the loss in depth due to cloud cover.

* Pointings

The footprint to be observed is related to the one covered by J-PLUS for calibration purposes.

In order to maximise the probability to observe asteroids, one wants to observe at low Ecliptic latitudes. Similarly, the search for supernovae takes advantage of observing at high Galactic latitudes. The combination of these two requirements is taken into account at the time of selecting a pointing to be observed.

We already have developed a tool to identify ideal pointings. For simplicity, we are only assuming 11 repetitions of 10 dummy fields in this proposal. The final coordinates will be provided to the observatory in phase 2, following the development of J-PLUS.

* Cadence

Cadence is the fundamental ingredient of a time-domain study. In the case of J-VAR, the cadence is the result of two aspects: the weather (the program is a filler and, therefore, can be observed whenever J-PLUS is not carried out) and the science cases.

As observed in above, most science cases require observations spaced by a few days (ideally, not more than a week).

* Light curve extraction

Light curves will be obtained via differential photometry. The comparison star will be an "artificial star" made of stars which are nearby (less than 30") and match the brightness and g-r colour of the science object.
J-PLUS will be used to offset the light curves to a reference magnitude.
Our system is mostly in place and preliminary results can be seen in Fig.1 and 2. The former shows the light curve of an RR Lyrae folded on its (previously known) period. The latter shows a non-variable star whose light curve is folded over the same period. It is worth noting that, despite the observations are carried out in non photometric conditions, one can reach an accuracy of a few hundredths of a magnitude. These data are from the ongoing programme 1800151.

Previous use of OAJ facilities:

1600073 - "Recovery of Old Novae"; 60% of program carried out. A first analysis showed that the old novae could not recovered. Likely too faint.
1600091 - "Pilot study to find Ca II Infrared triplet emitters using photometry alone". Program executed for 100%. Results are being discussed among the collaborators.
1600092 - "The evolution of nova shells"; 60% of program carried out. No shell has been detected. Likely too faint.
1700111,1700132 - "SED characterisation of Gaia transients"; this ToO campaign turned out to be unsuccessful because targets would cluster either at the beginning or end of the night, thus missing the goal of a filler for bad weather at OAJ.
1600098 - "Testing our understanding of compact binary evolution: the quest for the elusive period bouncers"
1700118 - "Testing the theory of binary evolution"
These two (LP) proposals have been executed for about 50%. The data are being analyzed. Preliminary results have been showed in international conferences and spectroscopic follow-up of interesting targets in ongoing. The paper presenting the project is being written.
1800151 - "J-VAR: the Variable Sky of J-PLUS"; currently ongoing. A first set of data has been distributed to the science team two weeks ago. Preliminary results are shown in the figures attached to this proposal.

Minimum amount of data that could lead to partial scientific results:

Even one full pointing (i.e. one pointing observed 11 times) would likely lead to, at least, a publication.

Bibliography:

Large Program (LP) justification:

Time domain programs are peculiar in the sense that their duration, cadence and exposure times are mainly dictated by the physics that the observation is probing.

J-VAR is intended to complement the information that can be obtained from J-PLUS by providing variability information, trying to span variability times which are as diverse as a few minutes as well as a few days. This requirement drives the choice of observing one field 11 times (each epoch lasting about half an hour).

In fact, J-VAR and J-PLUS nicely complement each other. On one hand, one can use J-VAR to study the variability properties (if any) of objects selected with the SED of J-PLUS and, vice versa, one can use J-PLUS to study the spectropohotometric properties of objects which are found to be variable. Moreover, as commented above, fitting a template of a non-variable source to a variable one can lead, in the best case, to a mis-classification of a source. J-VAR is able to flag variable sources for J-PLUS, increasing the quality of the classification of this survey.

In principle, one would want to observe the whole J-PLUS footprint but this would be beyond the possibility of a LP, hence here we focus on 10 pointings.

Does the programme require special calibrations?: No

Will you need additional data with other facilities to fulfill the scientific objetives of this proposal?: No

Figure 1

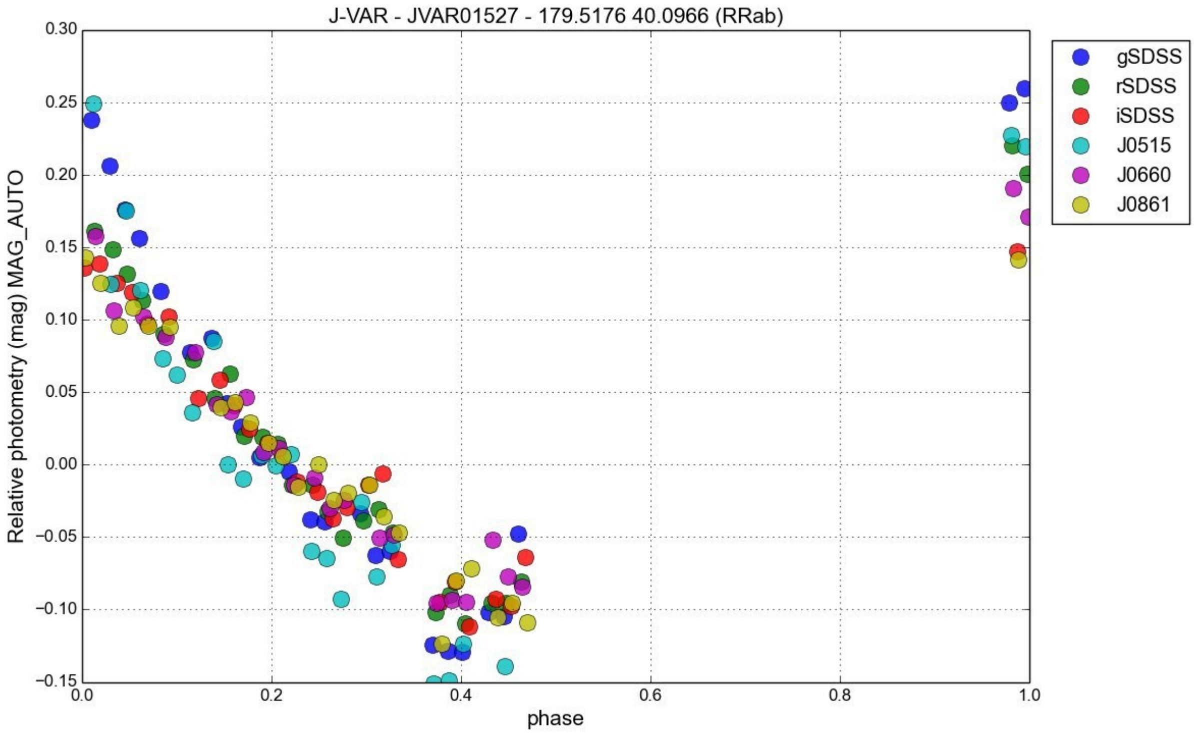

Figure 1. Phase folded light curve of an RR Lyrae observed during the 1800151 programme.

Figure 2

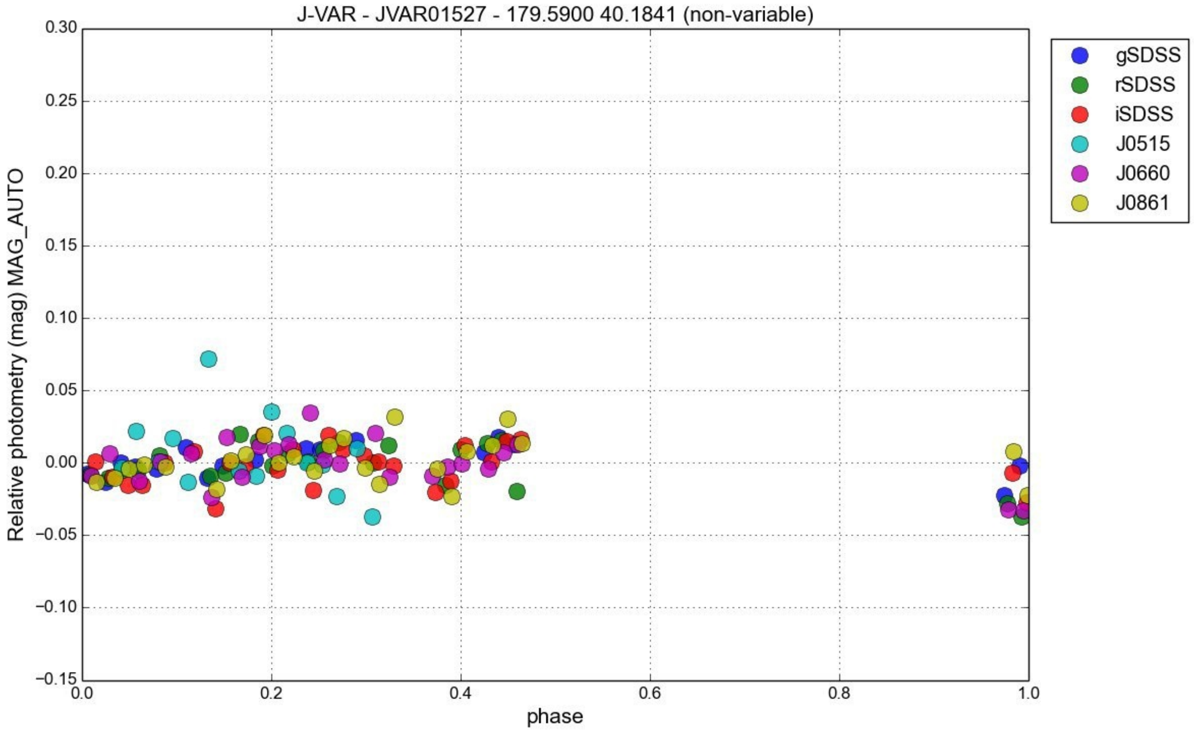

Figure 2. Non variable star observed in the same field as the previous variable star. The light curve is folded on the same period.