The JOLTEON Challenge: Phase 1 Data Release

The JOLTEON Team*: Erin Hayes[1], Dan Ryczanowski[2], Ana Sainz de Murieta[2], and Luke Weisenbach[2]

[1] *Institute of Astronomy and Kavli Institute for Cosmology, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*
[2] *Institute of Cosmology and Gravitation, University of Portsmouth, Burnaby Rd, Portsmouth PO1 3FX, UK*
*email: jolteon@googlegroups.com

March 13, 2025

1 Introduction

JOLTEON (JOint Lensed Transient Events Observation Network) is a community-driven challenge for testing discovery methods of strong gravitationally-lensed transients within the Vera C. Rubin Observatory's Legacy Survey of Space and Time (Rubin-LSST; Ivezić et al., 2019). The principal aim of the challenge is to provide a dataset that can test the efficiencies of different methods (and different implementations of these methods) to unearth the rare population of lensed transients from Rubin-LSST's unprecedented data volume. This document presents and outlines the data release for the first phase of the challenge, released March 2025.

2 Scientific Context

Transients such as supernovae affected by strong gravitational lensing are rare, but exciting probes of astrophysics and cosmology. The presence of a massive object such as a galaxy or cluster of galaxies along the line of sight of a background source acts as a lens to the source. This results in the appearance of multiple images of the background object which are often magnified relative to their non-lensed counterparts at the same redshift. These features enable a variety of novel studies, including enabling observations of the early-time light curve evolution of transients (e.g., Oguri, Suto, and Turner, 2003; Suwa, 2018), measurements of cosmological parameters (e.g., Arendse, Mörtsell, et al., 2025), and determining transient rates (e.g., Petrushevska et al., 2016) and progenitor properties (e.g., Dhawan et al., 2024) at high redshifts. For a general overview of lensed transients, see Oguri (2019).

Rubin-LSST is a large-scale photometric time-domain survey which will enable the discovery of orders of magnitude more lensed transients by regularly probing deeper and wider than any previous survey. Studies of rare classes of transients, including lensed transients, will particularly benefit from the large volume of transients expected to be discovered because of the unprecedented statistical samples of these objects that the survey will observe. For example, Rubin-LSST has been projected to discover up to ~ 40 gravitationally lensed type Ia supernovae (glSNe Ia) per year (Arendse, Dhawan, et al., 2024; Sainz de Murieta et al., 2024) – which would increase the sample of known glSNe by multiple orders of magnitude over the survey's lifetime. Rubin-LSST may also usher in the discovery of the first gravitationally lensed tidal disruption event (TDE; Mamuzic et al., 2025) or kilonova (KN; Smith et al., 2023), which have rates that are much lower but begin to become exciting over the full survey duration.

Due to the large scale of Rubin-LSST, the identification of lensed transients within the data stream arises as one of the biggest challenges to science with these objects. Because of the limited spectroscopic resources available for follow-up on so many transients, much identification must be done at the photometry or image level. Some methods for glSN discovery have been developed, for example within the Zwicky Transient Facility (ZTF; Bellm et al., 2018) data stream (Magee et al., 2023; Townsend et al., 2025). In addition, Arendse, Dhawan, et al. (2024) suggested methods for identifying glSNe Ia among samples of unlensed SNe Ia. However, there does not exist a data set to test in detail methods for discovering lensed transients among a diverse range of unlensed transients in data similar to what is expected from Rubin-LSST.

Therefore, we have developed the JOLTEON challenge to enable the preparation and testing of detection methods in advance of the survey commencing in late 2025. For Phase 1 of JOLTEON, we have produced a set of light curves from a diverse range of extragalactic transients and variable objects, including e.g., SNe, QSOs, TDEs, as well as glSNe and glKNe. The Phase 1 data release consists of a labelled subset of these light curves for the training and testing of detection methods. In §3, we describe the data set, including how to access the relevant files. In §4, we detail how teams can participate in the challenge and give a timeline for the challenge.

3 The Phase 1 Dataset

We are releasing datasets for the challenge in various phases in order to separate out analyses done on different kinds of data products. Phase 1 (this release) consists of full light curves of transient events, mimicking expectations of these events from LSST. In Phase 2, we plan to include image-level data products alongside photometry. There is scope for a 3rd phase, consisting of alert-level data products, depending on available resources and community interest.

3.1 Contents of the Phase 1 dataset

As will be the case in reality, the majority of transients within JOLTEON will not be lensed, only a small subset will. The light curves for the LSST-like non-lensed transients have been taken from the ELAsTiCC2[1] challenge previously run by the Rubin Dark Energy Science Collaboration (DESC). ELAsTiCC2 was a challenge run previously in 2022-2023 with the broad aim of testing infrastructure for time-domain science with LSST. As part of the ELAsTiCC2 release, light curves of many kinds of transients with a simulated LSST observing cadence were publicly released. Many of these, namely unlensed supernovae (SNe), active galactic nuclei (AGNs) and tidal disruption events (TDEs) are common false positives for lensed transient searches conducted to date. We use the truth tables to construct the base of the JOLTEON's Phase 1 dataset, sampling a fraction of the objects with a different photometric error model to match that of the lensed objects we include.

Since the ELAsTiCC data set does not include a large enough sample of lensed objects to allow for thorough training and testing of search methods[2], we include lensed transients from community-sourced models and sample at simulated LSST cadence using the OpSim v3.2 outputs. In Phase 1, we include lensed SN Ia, lensed core-collapse supernovae (including type II, type IIn, type Ib and type Ic) and lensed KNe. We include both resolved and unresolved lensed SNe in the dataset."Resolved", in this context means that each of the SN's multiple images is distinctly detected as a separate object, and therefore has its own unique light curve. Conversely, for unresolved lensed SNe, the fluxes of each image are combined into a single object, and hence into a single light curve. Unresolved SNe in the Phase 1 dataset satisfy the condition that the separation between the images θ, is $\theta < \frac{2}{3}$PSF, where PSF is the angular Full Width at Half Maximum (FWHM) of the point spread function of the (simulated) image. Our lensed SN light curves also include perturbations from microlensing simulated by a realistic caustic network. Details of the various components of the lensed SN modelling will be made public after the challenge is completed.

3.2 Dataset and challenge details

The JOLTEON dataset is constructed identically to the ELAsTiCC2 dataset, it consists of two separate files with different extensions: `.HEAD` and `.PHOT`. Very generally, the `.HEAD` file contains one row per object/light curve and contains relevant information such as its coordinates, redshift estimates (both photometric and spectroscopic) and pointers indicating which rows of the `.PHOT` file correspond to each object. The full dataset schema can be downloaded in .zip format by clicking here.

The dataset we publicly release is **not** the full data set we intend to use for the challenge, but rather a smaller "training set". The intention is for this to 1) train machine learning models and 2) test compatibility of methods with the challenge's file formats and data structure. Community members wanting to take part are then asked to send their search method as code (this can be raw files or compiled code) to the JOLTEON team who will then run this on the full data set. The purpose for this is twofold, firstly, having the analysis done by a single team avoids any ambiguity on how different groups may present results, and secondly allows the JOLTEON team to test methods on different instances of the dataset without requiring individual groups to complete multiple test runs. Examples of different instances of

[1] https://portal.nersc.gov/cfs/lsst/DESC_TD_PUBLIC/ELASTICC/

[2] ELAsTiCC did include a small subset of lensed supernovae, but these were not included in its training set. See https://portal.nersc.gov/cfs/lsst/DESC_TD_PUBLIC/ELASTICC/StrongLens_forELASTICC.pdf for more information.

the dataset may include ones with different redshift estimator models, error models, or survey cadences, but the underlying foundations (e.g. source types and the models used to generate them) will remain the same. If any of the above poses a problem for you but you still wish to take part in the challenge, please contact the JOLTEON team (see below) as we are happy to consider alternative arrangements if required.

3.3 Redshifts

Estimated redshifts are given for a subset of objects in the `.HEAD` file. If provided, these are redshifts for a simulated nearby galaxy for the transient, rather than explicitly for the transient itself. For most (unlensed) transients the nearby galaxy is a likely host, whereas for lensed transients this would correspond to the lens, rather than the background host galaxy. The spectroscopic redshifts of galaxies are drawn from the redshift values sampled in the original simulation, with an added variance of 0.0001. Photometric redshifts are assigned based on the observed distribution of photometric redshifts and their associated standard deviations, as measured from HSC galaxy data.

4 Participation in JOLTEON Phase 1

We welcome submissions from all members of the community, regardless of membership in LSST, as long as the method can be submitted in accordance with the below guidelines.

4.1 Submitting a search method for the challenge

If you would like to submit your code for the JOLTEON Phase 1 lensed transient challenge, or have any general questions, contact us either directly or within `#sl-transient-search-challenge` on the Discovery Alliance (previously LSSTC) Slack. You can also contact the team by email at `jolteon@googlegroups.com`. Submissions will ideally be as either raw or compiled code that has been tested on the training set provided. We recommend setting up a (possibly private) GitHub repository in order for the team to access your code.

4.2 Timeline

The phase 1 data release will be made available to the public on **13 Mar, 2025**. The challenge will end on **30 May, 2025** upon which date all search methods must be submitted. Updates regarding the release of phase 2 of the JOLTEON data set, which will include image-level data products, will be provided in the near future.

References

Arendse, N., S. Dhawan, et al. (July 2024). "Detecting strongly lensed type Ia supernovae with LSST". In: 531.3, pp. 3509–3523. DOI: 10.1093/mnras/stae1356. arXiv: 2312.04621 [astro-ph.CO].

Arendse, N., E. Mörtsell, et al. (Jan. 2025). "Microlensing of lensed supernovae Zwicky & iPTF16geu: constraints on the lens galaxy mass slope and dark compact object fraction". In: *arXiv e-prints*, arXiv:2501.01578, arXiv:2501.01578. arXiv: 2501.01578 [astro-ph.GA].

Bellm, E. C. et al. (Dec. 2018). "The Zwicky Transient Facility: System Overview, Performance, and First Results". In: *Publications of the Astronomical Society of the Pacific* 131.995, p. 018002. DOI: 10.1088/1538-3873/aaecbe. URL: https://dx.doi.org/10.1088/1538-3873/aaecbe.

Dhawan, S. et al. (July 2024). "Spectroscopic analysis of the strongly lensed SN: Constraints on cosmic evolution of Type Ia supernovae". In: *arXiv e-prints*, arXiv:2407.16492, arXiv:2407.16492. DOI: 10.48550/arXiv.2407.16492. arXiv: 2407.16492 [astro-ph.HE].

Ivezić, Ž. et al. (Mar. 2019). "LSST: From Science Drivers to Reference Design and Anticipated Data Products". In: 873.2, 111, p. 111. DOI: 10.3847/1538-4357/ab042c. arXiv: 0805.2366 [astro-ph].

Magee, M. R. et al. (Oct. 2023). "A search for gravitationally lensed supernovae within the Zwicky transient facility public survey". In: 525.1, pp. 542–560. DOI: 10.1093/mnras/stad2263. arXiv: 2303.15439 [astro-ph.HE].

Mamuzic, E. et al. (Feb. 2025). "Rates of Strongly Lensed Tidal Disruption Events". In: *arXiv e-prints*, arXiv:2502.19495, arXiv:2502.19495. DOI: 10.48550/arXiv.2502.19495. arXiv: 2502.19495 [astro-ph.HE].

Oguri, M. (Dec. 2019). "Strong gravitational lensing of explosive transients". In: *Reports on Progress in Physics* 82.12, 126901, p. 126901. DOI: 10.1088/1361-6633/ab4fc5. arXiv: 1907.06830 [astro-ph.CO].

Oguri, M., Y. Suto, and E. L. Turner (Feb. 2003). "Gravitational Lensing Magnification and Time Delay Statistics for Distant Supernovae". In: 583.2, pp. 584–593. DOI: 10.1086/345431. arXiv: astro-ph/0210107 [astro-ph].

Petrushevska, T. et al. (Oct. 2016). "High-redshift supernova rates measured with the gravitational telescope A 1689". In: 594, A54, A54. DOI: 10.1051/0004-6361/201628925. arXiv: 1607.01617 [astro-ph.GA].

Sainz de Murieta, A. et al. (Dec. 2024). "Find the haystacks, then look for needles: the rate of strongly lensed supernovae in galaxy-galaxy strong gravitational lenses". In: 535.3, pp. 2523–2537. DOI: 10.1093/mnras/stae2486. arXiv: 2407.04080 [astro-ph.CO].

Smith, G. P. et al. (Mar. 2023). "Discovering gravitationally lensed gravitational waves: predicted rates, candidate selection, and localization with the Vera Rubin Observatory". In: 520.1, pp. 702–721. DOI: 10.1093/mnras/stad140. arXiv: 2204.12977 [astro-ph.HE].

Suwa, Y. (Feb. 2018). "Supernova forecast with strong lensing". In: 474.2, pp. 2612–2616. DOI: 10.1093/mnras/stx2953. arXiv: 1711.00183 [astro-ph.HE].

Townsend, A. et al. (Feb. 2025). "Candidate strongly lensed type Ia supernovae in the Zwicky Transient Facility archive". In: 694, A146, A146. DOI: 10.1051/0004-6361/202451082. arXiv: 2405.18589 [astro-ph.HE].