Observing and understanding gravitationally lensed objects is a new and exciting field of study. The first examples of a strongly lensed supernova (SN) resolved into multiple images was SN "Refsdal" in 2014 (Figure 1; Kelly et al. (2015)). Subsequent work was done to classify Refsdal, as well as to measure time delays and magnification ratios (Kelly et al., 2016; Rodney et al., 2016). In addition, a lensed Type 1a SN was found by Goobar et al. (2016), and **the next decade is expected to yield observations of over 100 lensed SNe** that will require analysis (Oguri & Marshall (2010)). To date, **there is no public software package for analyzing multiply-imaged SNe.** The lack of a standard resource leaves researchers to write and implement their own ad hoc programs, which will become increasingly inefficient as the number of observed lensed SNe increases. An optimized software package with the ability to fully analyze a light curve would be extremely valuable to a wide range of research using current and next generation telescopes.

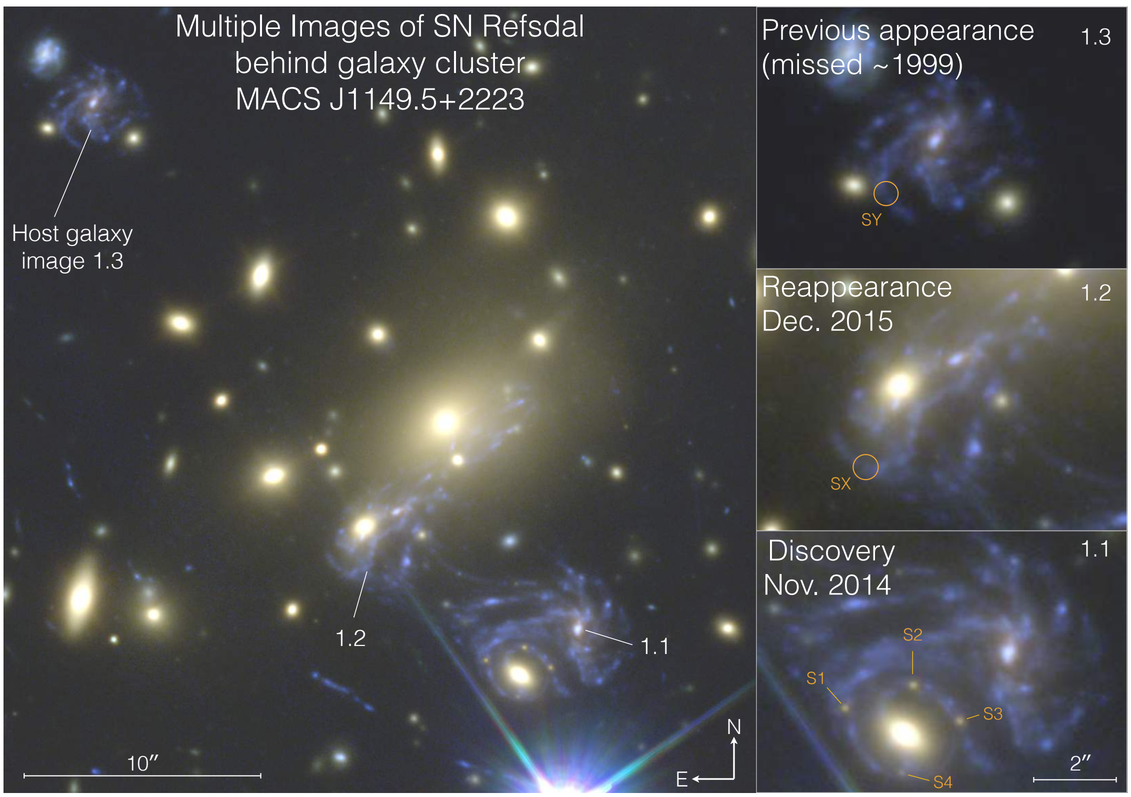

Figure 1: MACS J1149.6+2223 field, showing the positions of the three primary images of the SN Refsdal host galaxy (labeled 1.1, 1.2, and 1.3). SN Refsdal appears as four point sources in an Einstein Cross configuration in the southeast spiral arm of image 1.1 (Rodney et al. (2016))

The purpose of this work is to produce an open-source software package called Supernova Time Delays (*SNTD*). **This package will lead to an improved understanding of the complex effects acting on known and future multiply-imaged SNe.** There are currently two software packages that form the basis of this product: Python Curve Shifting (PyCS), and Supernova Cosmology (SNCosmo). There will be four components to this research: 1) Integrate SNCosmo and PyCS, giving researchers a tool that can model SN light curve data with the abilities present in either software package; 2) Extend and optimize the lensing and microlensing algorithm present in PyCS for SNe; 3) Simulate a large number of multiply-imaged SN light curves using SNCosmo and test the ability of *SNTD* to determine SN parameters; and 4) Explore the abilities of *SNTD* in analyzing POP III SNe using modeled light curves in anticipation of JWST and WFIRST observations.

While PyCS currently uses flexible functions to account for microlensing of quasars caused by transverse motion of stars in the lensing galaxy, there is a second form of microlensing unique to lensed SNe. The expanding photosphere of a SN interacts with an increasing volume of the caustic web, precipitating microlensing effects described by Dobler & Keeton (2006) that can exhibit magnitude fluctuations of $\sim$0.2 to $>$0.5 on timescales of weeks to months. This proposed work has already integrated the flexible function method (Figure 2), and will seek to include both types of microlensing effects to increase the precision and accuracy of time delay and magnification measurements. **No software package currently exists with this capability**, therefore the algorithm will be developed following the methodology of Dobler & Keeton (2006). In general, *SNTD* will be much more likely to correctly identify SN microlensing effects and produce simpler time delay measurements because, unlike for quasars, researchers already have a robust set of intrinsic light curve shapes to describe a range of different SN classes that will allow for physically motivated, less flexible models. By allowing certain constraints to float as free parameters, these models will also produce best-fit synthetic light curves from which time delay, magnifications, SN class, and redshift can be derived. By simulating large numbers of SNe with these synthetic light curves, we will be able to quantify the accuracy and efficiency of the software.

The era of JWST will make it possible for the first time to detect and study SNe at $\mathbf{z > 5}$ (Mesinger & Johnson (2006)), and WFIRST will add many more discoveries at lower redshift with a larger field of view in the mid-2020s. In addition, recent simulations of pair-instability (PI) SN light curves indicate that various solar mass PI and POP III Type IIn SNe will be visible to both JWST (z>30 and z$\sim$15 respectively) and WFIRST (z$\sim$20 and z$\sim$5 respectively) (Magg et al. (2016)). Whether it is a follow-up observation of a ground based detection, or a discovery made by one of these space telescopes, **having flexible software in place to analyze any SN light curve will be essential to SN cosmologists.** We expect this research to yield **multiple publications** about the methodology of the software itself and the simulation results for low and high redshift SNe, as well as advancements in our understanding of lensed SNe resulting from the use of *SNTD*. There are also plans to use this package for follow-up measurements of the two known multiply-imaged SN parameters, including the previously ignored microlensing effects. *SNTD* will be written in Python, a free and **open-source** programming language, and distributed to SN researchers with extensive documentation including descriptive tutorials. This combination will make *SNTD* a **free, widely accessible, and invaluable tool** in the SN research community.

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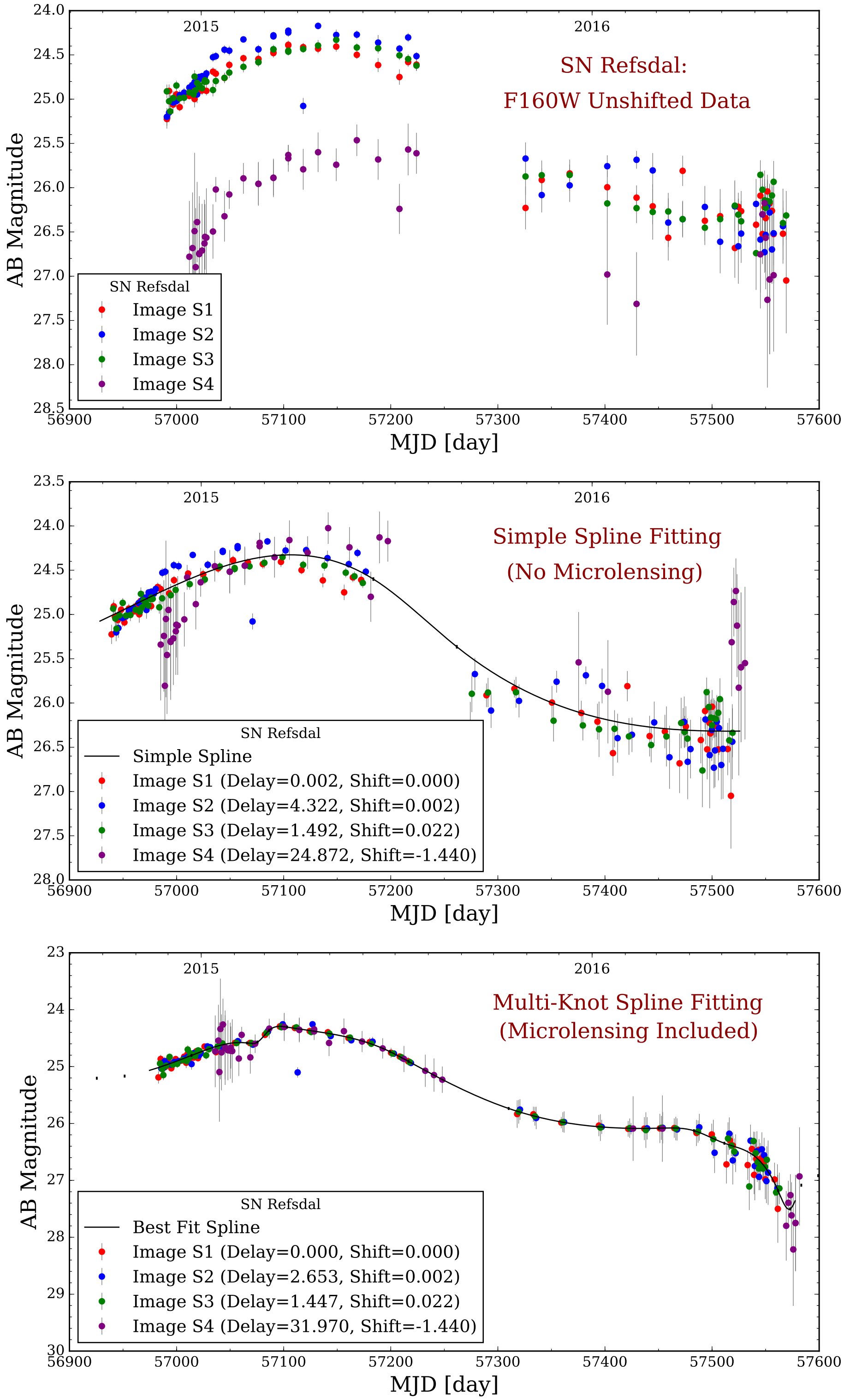

Figure 2: (Top) HST F160W data representing the four images of SN Refsdal (Figure 1), with no lensing or time shifts. (Middle) Method of fitting the SN Refsdal light curves from Rodney et al. 2016, which did not consider microlensing effects. (Bottom) Preliminary results from *SNTD* using a multi-knot spline to fit the data. This method includes microlensing effects, which leads to a slight adjustment in time delay measurements.