Characterizing Host Galaxies of Superluminous Supernovae

Alyson Tran[1], Allison Strom[2], Yijia Li[2]

[1] Department of Astronomy, The University of Texas at Austin, 2515 Speedway, Stop C1400, Austin, TX 78712, USA

[2] Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), Northwestern University, 633 Clark Street Evanston, Illinois, 60208, USA

Background

At the end of a massive star's life, it erupts in an extremely bright explosion called a *supernova*. Supernovae exist in a wide variety of classes and are believed to be caused by one of two physical mechanisms: core collapse and mass accretion. The most recently discovered class of SN, superluminous supernovae (SLSNe), are highly energetic events with peak luminosities ~10-100x brighter than typical CCSNe. Though the exact origin of these events are unknown, several theories for SLSN-1 progenitors have emerged.

Previous studies have utilized the calculated properties of the SLSN host galaxies to probe the conditions in which SLSNe occur, enabling constraint for theories of possible progenitors[1,2,3]. However, these studies have been inconsistent in selecting control samples and calculating metallicities.

Properties of Hosts Established by Previous Work:

- Low mass $(M_* < 10^{9.5} M_\odot)$
- Low metallicity $(12 + \log(O/H) \leq 8.4)$
- High specific star formation rates $(sSFR \sim 10^{-9} - 10^{-10} M_\odot yr^{-1})$

Objective of this study: Develop a consistent method of determining various properties of SLSN host galaxies and see if any new relations arise.

Sample Selection

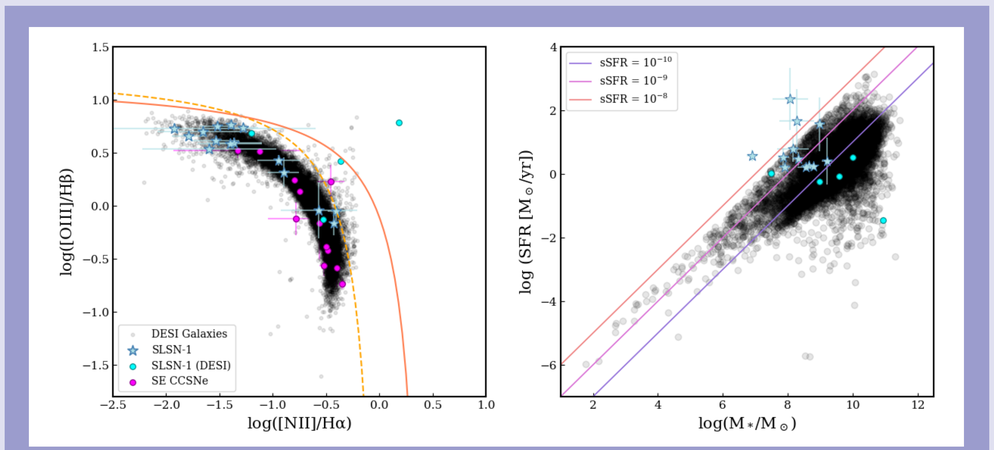

Figure 1. On the left, a BPT diagram comparing SLSN-1 and SN 1b/c hosts to the DESI DR 1 sample. On the right, a plot comparing SFR and mass with constant sSFR indicated by the legend. CCSN values are borrowed from Leloudas+ 2015.

Palomar Transient Factory:

Our sample includes 14 archival spectra of SLSN-1 hosts from the Palomar Transient Factory (PTF) which have previously calculated values we can compare to. Fig 1. shows a preliminary comparison using mass and SFR values from Perley+ 2016.

DESI Data Release 1:

Given the small sample of hosts, it is necessary to have a suitable control group. For this reason, we utilize DESI DR1. With a high signal cut off and the inclusion of only SFGs, the sample covers the full parameter space of SLSN hosts. We've also identified 5 additional SLSN-1 hosts within DESI using the RA and Dec of SLSN-1 detections from the Transient Name Server.

Methods

Emission Line Fitting

1. Baseline subtraction and redshift correction
2. Fitting Gaussians to expected emission lines and measuring fluxes
3. Account for dust extinction using CCM89 law[4]
4. Convert flux to luminosity using luminosity distance assuming Flat Λ CDM

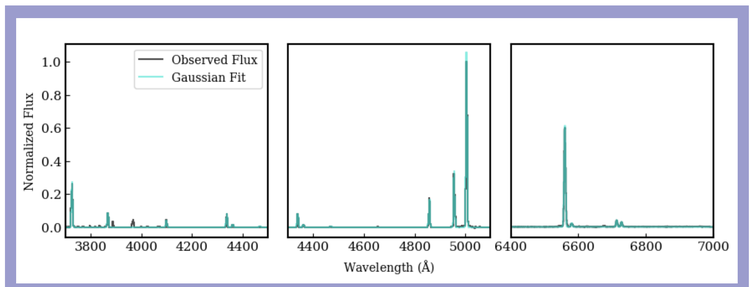

Figure 2. The spectrum of the host of PTF12dam. The observed flux is colored gray and fitted emission lines are highlighted in green.

Nebular Emission Modeling with Cue

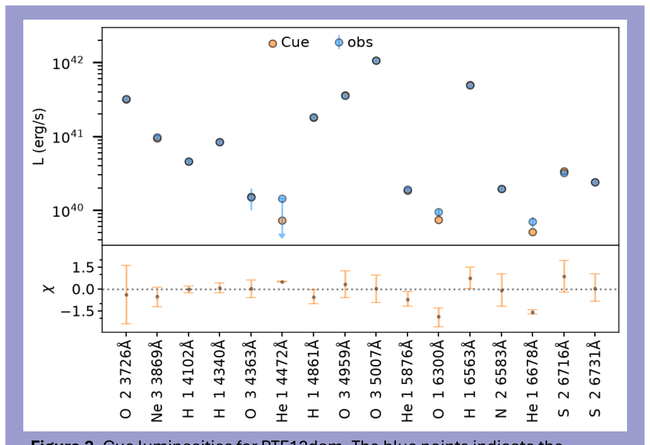

Figure 3. Cue luminosities for PTF12dam. The blue points indicate the observed luminosities while orange ones are estimated. Undetected lines are indicated by the arrows pointing downward. Chi values with lower and upper limits are in the lower plot.

Cue Framework

Cue[5] is a neural net emulator trained on CLOUDY, a photoionization code, that reconstructs the nebular emission and ionizing spectrum of a galaxy. Cue needs only the line luminosities, luminosity uncertainties, and upper limits of a spectrum to produce outputs. We run ~12000 predictions per galaxy or until results converge.

Outputs

- Shape of ionizing spectrum
- Ionization parameter
- Flexible [O/H], [N/O], [C/O] ratios
- Estimated line luminosities

Cue recovers values within 1-2σ of the posteriors

Results

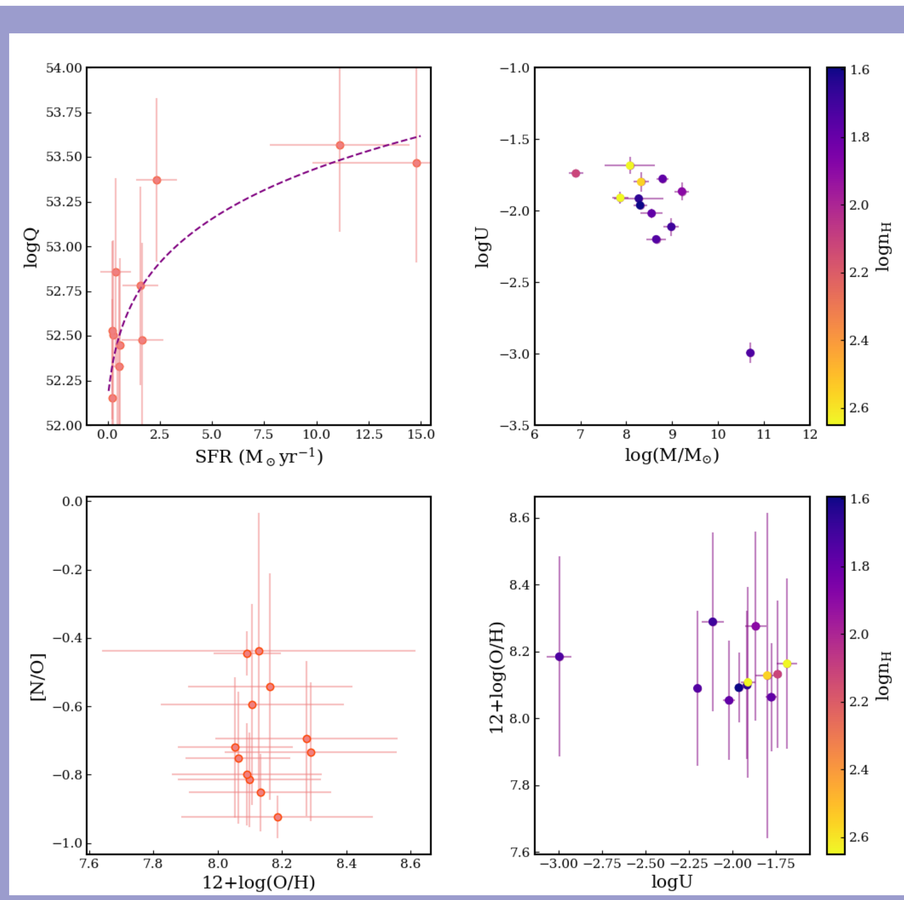

Figure 4. The top left figure displays the relationship between log Q, the ionizing photon rate, and Hα sSFR. The top right shows the relation between , mass, and log nH. The bottom left shows values of [O/H] vs [N/O]. Finally, the bottom left shows the gas-phase metallicity relative to and log nH. Masses and SFR are borrowed from Perley+ 2016.

Although the current sample is limited, we do observe potential trends:

- log Q, the ionizing photon rate, traces the Hα specific SFR, which indicates that Cue results maintain physical relations
- A relationship emerges between mass, gas density, and log U
- [N/O] appears to have relatively uniform values; resembles typical young SN hosts
- We currently observe no clear trend between metallicity and log U
  - For typical SFGs, we should expect an inverse correlation

Major advantage of Cue: Eliminates need for using different metallicity calibrations and allows for self-consistent inference of ionizing conditions

Key Takeaways

- DESI DR-1 is expansive, making an appropriate control sample
- Additional line measurements are needed to thoroughly understand the metallicity and ionizing conditions of hosts
- Cue provides a consistent method of calculating log U and [O/H] with relatively low uncertainties

Future Work:

The results of this study support the need for more consistent methods of characterizing host galaxies as well as the need for more host spectra, some of which may already exist in large surveys such as DESI or SDSS

References

1. Leloudas, G., Schulze, S., Kruhler, T., et al. 2015, MNRAS,449, 917, doi: 10.1093/mnras/stv320
2. Perley, D. A., Quimby, R. M., Yan, L., et al. 2016, ApJ,830, 13, doi: 10.3847/0004-637X/830/1/13
3. Schulze, S., Yaron, O., Sollerman, J., et al. 2021, ApJS,255, 29, doi: 10.3847/1538-4365/abff5e
4. Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ,345, 245, doi: 10.1086/167900
5. Leloudas, G., Gallazzi, A., Sollerman, J., et al. 2011, A&A,530, A95, doi: 10.1051/0004-6361/201116692
6. Li, Y., Leja, J., Johnson, B. D., et al. 2025, ApJ, 986, 9,doi: 10.3847/1538-4357/adcab4

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