Citation for published version:
Schady, P 2020, Studying the progenitors of long GRBs through their nearby environments. in *Yamada Conference LXXI: Gamma-ray Bursts in the Gravitational Wave Era 201.*

Publication date:
2020

Document Version
Early version, also known as pre-print

Studying the progenitors of long GRBs through their nearby environments

Patricia Schady,[1]

[1] Department of Physics, University of Bath, Claverton Down, Bath BA2 7AY, UK *E-mail: p.schady@bath.ac.uk*

Abstract

Spatially resolved spectroscopy of the environments of explosive transients carries detailed information on the physical properties of the natal stellar population, and thus the progenitor itself. We present MUSE integral field spectrograph observations of the host galaxies of the two closest long GRBs to date; the archetype of the GRB/supernova connection, GRB 980425/SN 1998bw, and the supernovaless GRB 111005A. Detailed emission-line maps from these observations yield physical parameters such as dust extinction, stellar age, and oxygen abundance on spatial scales of 160 pc and 270 pc respectively, providing insights on the properties of the progenitor star. The reliability of these results relies crucially on the fidelity with which our data trace the GRB local environment. We therefore also investigate the impact that spatial resolution and galaxy inclination has on our results, and discuss the limitations of using such techniques to study the progenitors of long GRBs. JWST will significantly extend the redshift out to which the local environments of GRBs can be studied. However, to optimise the scientific return, it will be essential to quantify the effect of spatial resolution when inferring the properties of the progenitors and environmental conditions that can host these spectacular stellar explosions.

Key words: GRB980425 — GRB111005A —- host galaxies — transients — spatial resolution

1. Introduction

The detailed analysis of the host galaxies and nearby environmental conditions of explosive transients has been widely and effectively used to investigate their progenitor systems. Emission line spectra carry detailed information on the chemical composition and star formation rates of the host environments, both of which are important properties in understanding the underlying stellar population and stellar evolution. Global or local imaging data of nearby supernova (SN) hosts and cosmological gamma-ray bursts (GRBs) or superluminous supernovae have likewise been used to compare progenitor models with the expected environments (Anderson et al. 2010; Leloudas et al. 2015; Perley et al. 2016).

A fundamental limitation of these studies is that the inferred physical properties may not be representative of the conditions in the vicinity of the progenitor. For example, steep metallicity gradients and inhomogeneities may result in galaxy-integrated metallicities that are notably different to the metallicity at the position of the transient. The properties of underlying stellar populations at the transient location will also be averaged out when based on poorly resolved observations.

Integral field spectroscopy (IFS) with high angular resolution is arguably the most comprehensive way of studying the environments of explosive transients. Over the past decade, the availability of new-generation integral field units (IFUs) such as ESO/MUSE, and large IFS surveys, such as CALIFA and SDSS/MaNGA, have greatly enhanced the opportunity to study the conditions of the stellar population and interstellar medium at the location of transients (Galbany et al. 2014; Galbany et al. 2016; Chen et al. 2017; Krühler et al. 2017; Tanga et al. 2018). However, even in the case where high spatial resolution observations are available, it is not clear what spatial resolution is required to truly trace the conditions of the progenitor star, and projection effects along the transient line of sight also increase the uncertainty.

Here we present high spatial resolution IFS observations taken with MUSE of the two closest, long GRBs to date, GRB 980425 and GRB 111005A, previously published in Krühler et al. (2017) and Tanga et al. (2018). However, to quantify how representative the reported physical properties are of the progenitor stars, here we investigate the effect that spatial resolution and inclination have on inferred physical properties. Specifically the Hα equivalent width (EW), which is a tracer of stellar age (Leloudas et al. 2011; Kuncarayakti et al. 2013; Schady et al. 2019), and dust reddening.

2. GRB host galaxy MUSE observations

2.1. The host galaxy of GRB 980425

The host galaxy of GRB 980425A, ESO 184-G82, is at $z = 0.0085$, and it is a barred spiral dwarf galaxy seen nearly face on. The MUSE observations covered the position of the GRB as well as a nearby Wolf-Rayet region with an effective spatial resolution of 160 pc. The Hα EW measured at the position of the GRB (and associated SN1998bw) indicate that the underlying stellar population is young, with an age in the range $5-8$ Myr, corresponding to lifetimes of stars with zero-age main sequence mass, $M_{\rm ZAMS}$, between approximately 25 $M_{\odot}$ and 40 $M_{\odot}$. The region in the vicinity of the GRB is dust-poor (E(B-V) $= 0.03^{+0.05}_{-0.03}$), and the measured metallicity is $12+\log({\rm O/H}) = 8.1-8.3$, depending on the metallicity diagnostic used, which corresponds to $0.3-0.4$ $Z_{\odot}$. These constraints on the progenitor initial mass and metallicity (assumed to be comparable to the local, gas-phase metallicity) are fully consistent with the expectations of the GRB collapsar model.

2.2. The host galaxy of GRB 111005A

The likely host galaxy of GRB 111005A, ESO 580-49, is at $z = 0.0133$ and it is a moderately star-forming, relatively metal-rich and dusty galaxy, atypical of GRB host galaxies (Michałowski et al. 2018; Tanga et al. 2018). The association between GRB 111005A and ESO 580-49 is based on chance super-position, as the optical afterglow was not detected due to the GRB lying too close to the Sun. This long GRB was highly unusual in that no accompanying SN was detected down to deep limits (~ 22 mag with *Spitzer*), despite extensive searches. The limits obtained constrain any associated SN to be at least 40 times fainter than SN1998bw, although the level of dust extinction along the GRB line of sight is uncertain.

The effective spatial resolution of the MUSE data was 270 pc, although the edge-on orientation of the galaxy greatly increases the uncertainty on any environmental properties inferred along the GRB line of sight. Assuming that no regions along the GRB line of sight are optically thick, the Hα EW measured at the GRB explosion site and within the closest (projected) HII region imply a progenitor age of $\gtrsim 10$ Myr, corresponding to a progenitor initial mass $M_{\rm ZAMS} < 15$ $M_{\odot}$. The metallicity at the GRB explosion site is about solar, and the visual dust-extinction based on the Balmer decrement is $A_V \sim 2$ mag, significantly smaller than the $A_V \sim 30$ mag that would be required to fully extinguish a SN1998bw-like event. In contrast to GRB 980425, the nearby environment of GRB 111005A is thus in apparent conflict with the expectations of the collapsar model.

3. Effect of data quality on measurements

Motivated by clear differences in the quality of the data for the host galaxy of GRB 980425 and GRB 111005A - namely a reduced spatial resolution and a larger galaxy inclination in the latter case - in this section we investigate how a loss of information effects some key physical galaxy properties. Specifically, in these proceedings we explore the effects of spatial resolution on the measured Hα EW, and how the inferred radial distribution of dust depends on the galaxy inclination.

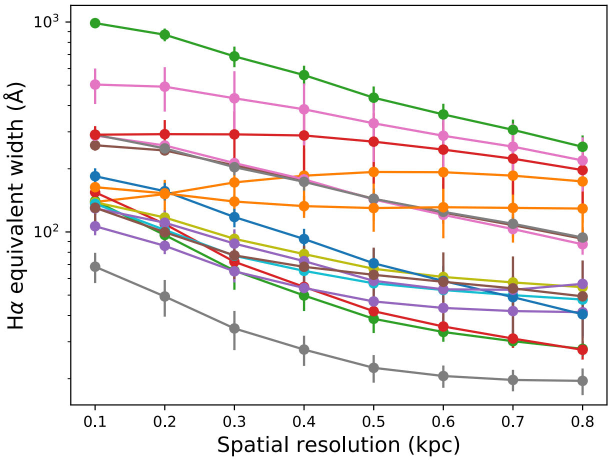

Fig. 1. Hα EW against image spatial resolution as measured at 17 star forming regions within the host galaxy of GRB980425/SN1998bw.

3.1. Effects of spatial resolution

To study the effects of spatial resolution on the measured Hα EW, we took the MUSE observations of the host galaxy of GRB 980425, which is nearly face on, and which had a physical spatial resolution of 160 pc. From these data we produced an Hα EW map and then artificially reduced the spatial resolution by convolving the map with a 2D Gaussian with a full width half-max (FWHM) between 200 pc and 1 kpc, increasing in steps of 100 pc. This gave us a total of ten Hα EW maps at decreasing spatial resolution. We then identified around 20 star forming regions from the unconvolved image, and then measured the Hα EW at these positions for each of our Hα EW maps within circular apertures with a diameter set to the FWHM of the corresponding image.

The results are summarised in Fig. 1, which show a rapid decrease in the Hα EW with deteriorating spatial resolution for all star forming regions considered, until a flattening occurs at ~ 600 pc, where presumably the average Hα EW of the galaxy is reached. There is also evidence for a steepening in the curves beyond ~ 200 pc, suggesting that at resolutions better than this, the Hα EW is representative of the true value of the corresponding star forming region.

A similar exercise was done for the host galaxy of SN2001fv, which is also near face on and has a spatial resolution of $\sim$ 110pc. The Hα EW measured in star forming regions of this galaxy similarly decayed with decreasing spatial resolution, and also showed a flattening

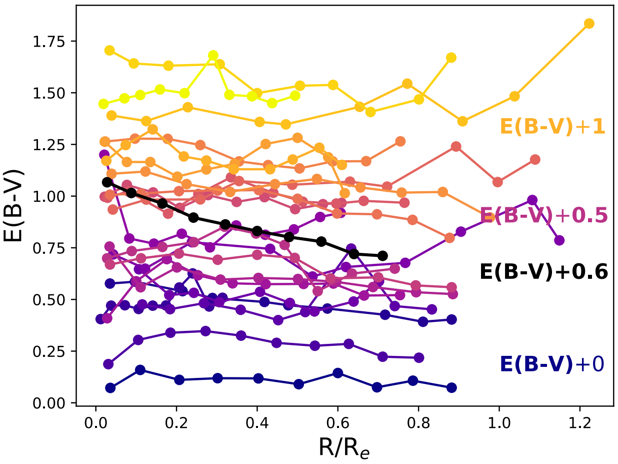

Fig. 2. Dust reddening as a function of radial distance from the galaxy centre for 24 galaxies with varying inclinations. Curves are colour coded and ordered by galaxy inclination, going from least inclined at the bottom (dark blue) to most inclined at the top (yellow). For clarify the curves are offset by the amount indicated on the right hand side. The black curve corresponds to the dust reddening radial profile of the host galaxy of GRB 111005A.

in the Hα EW value at spatial resolutions poorer than $\sim$ 600 pc. However, in this case there was no flattening at spatial resolutions $<$ 200 pc.

3.2. Effects of galaxy inclination

To investigate the dependence of the inferred dust distribution on galaxy inclination, we took a sample of star forming galaxies from the AMUSING survey (Galbany et al. 2016) and used the Balmer decrement to determine the average dust reddening, E(B-V), within annuli of increasing radii from the galaxy centre, after correcting for inclination. In Fig. 2 we show the results for a subsample of 24 galaxies with inclination in the range $i = 15 - 83$ deg. The curves are colour coded according to galaxy inclination, with least inclined shown in dark blue, and most inclined shown in yellow. The curves have been offset along the y-axis for clarity by the amount indicated along the right hand side of the figure. The black curve corresponds to the deprojected dust reddening radial profile of the host galaxy of GRB 111005A.

From this preliminary analysis, there is no indication that the dust reddening radial profiles become steeper for less inclined systems, or indeed that there is any notable dependence between the radial profile and galaxy inclination. This implies that the radial profiles inferred for inclined galaxies based on the Balmer decrement are generally not omitting large amounts of optically thick dust in the inner regions of the galaxy. This result is nevertheless based on a small sample of galaxies, and further analysis is planned on a larger sample of galaxies that can be separated by galaxy properties such as stellar mass and SFR.

4. Conclusions

We have carried out some preliminary analysis on the effect that spatial resolution and galaxy inclination has on the properties measured from IFU data on the nearby environments of explosive transients. We find that the Hα EW declines rapidly with decreasing spatial resolution, implying that at resolutions worse than $\sim$ 200 pc, Hα EW can only be used to place an upper limit on the ages of the underlying stellar population. Furthermore, from a small sample of 24 host galaxies of SNe of varying inclination ($i = 15 - 83$ deg), we find little trend between the derived (deprojected) dust reddening radial profile and galaxy inclination, suggesting that most ccSN host galaxies, even those that are very inclined, do not contain large amounts of dust in their centres that fully attenuate hydrogen emission from star forming regions.

IFU observations can provide a wealth of information on the properties of long GRB progenitors and other explosive transients. However, care is required to understand the limitations of the data, in particular in terms of spatial resolution. We plan to continue this work on much larger samples of star forming galaxies observed with MUSE, and to carry out a more complete analysis to quantify how a number of physical properties, such as stellar age, gas-phase metallicity, and dust reddening, vary as a function of spatial resolution.

References

Anderson, J. P., Covarrubias, R. A., James, P. A., et al. 2010, MNRAS, 407, 2660
Chen, T.-W., Schady, P., Xiao, L., et al. 2017, ApJL, 849, L4
Galbany, L., Stanishev, V., Mourão, A. M., et al. 2014, A&A, 572, A38
Galbany, L., Anderson, J. P., Rosales-Ortega, F. F., et al. 2016, MNRAS, 455, 4087
Krühler, T., Kuncarayakti, H., Schady, P., et al. 2017, A&A, 602, A85
Kuncarayakti, H., Doi, M., Aldering, G., et al. 2013, AJ, 146, 30
Leloudas, G., Gallazzi, A., Sollerman, J., et al. 2011, A&A, 530, A95
Leloudas, G., Schulze, S., Krühler, T., et al. 2015, MNRAS, 449, 917
MichałowskI, M. J., Xu, D., Stevens, J., et al. 2018, A&A, 616, A169
Perley, D. A., Tanvir, N. R., Hjorth, J., et al. 2016, ApJ, 817, 8
Schady, P., Eldridge, J. J., Anderson, J., et al. 2019, MNRAS, 490, 4515
Tanga, M., Krühler, T., Schady, P., et al. 2018, A&A, 615, A136