Constraining the Progenitor Properties of the Type Ib Core-Collapse Supernova iPTF13bvn through its Environment

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credit: **NASA**

Hubble Space Telescope (HST) with Wide Field Camera 3 (WFC3):

In this work we utilise HST's current WFC3 instrument in the UVIS (UV-Visible) channel, which offers a pixel scale of 0.04" and a 160"x160" field of view. Specifically, from MAST [1] we source 3 long-exposure (> 5000 seconds) images of iPTF13bvn's host galaxy (NGC 5806) in the F438W, F555W (Visible) and F225W (UV) filters. Stellar sources in all three images are PSF resolved using DOLPHOT, with magnitude detection limits being substituted for sources that are not uniformly resolved.

Very Large Telescope (VLT) with Multi Unit Spectroscopic Explore (MUSE):

This ground-based observatory - VLT - currently mounts the instrument MUSE, which provides Integral-Field Unit (IFU) spectroscopy. We source an IFU MUSE datacube of NGC 5806 from the ESO Archive Science Portal [2], with the wide-field mode providing 0.2" spatial sampling and a 1x1 $arcmin^2$ field of view. The low-resolution spectra cover a 4750-9350 Å wavelength range with 1.25 Å spectral sampling. In order to improve spectral signal-to-noise, 2x2 spaxels are rebinned into a single spaxel across the entire datacube.

credit: **ESO**

Environmental Analysis: Bayesian inference with WFC3

This work explores an alternative approach to constraining core-collapse supernovae progenitor properties by studying their environments - instead of relying on the community 'golden standard'. We aim to use a combination of stellar photometric analysis and stellar/gas/dust IFU spectroscopic analysis...

The stellar environment of iPTF13bvn is defined by a radius of 300 pc, as shown in the right panel of Figure 1. Within this environment there are 138 'good quality' objects with 3 apparent magnitudes - each acting as an independent probe in the Bayesian analysis. We use a **hierarchical Bayesian mixture model** [3, 4] to estimate **ages** and **extinctions** of stellar populations within the defined environment. The model is able to take the:

- Padova stellar isochrones [5] - fixed at solar metallicity.
- apparent magnitudes in 3 HST/WFC3 images.
- magnitude detection limit substitutions - found with artificial star testing.

and employ the **Nested Sampling algorithm** [6] to determine:

- the number of stellar populations within the environment - using the Bayesian evidence.
- independent age and extinction posterior probability distributions for each resolved stellar population.

This produced 2 stellar populations in the environment of iPTF13bvn, with the youngest population corresponding to:

$$log(age/years) = \tau = 6.59^{+0.04}_{-0.05}$$

$$extinction = A_V = 0.95^{+0.07}_{-0.06}\ mag$$

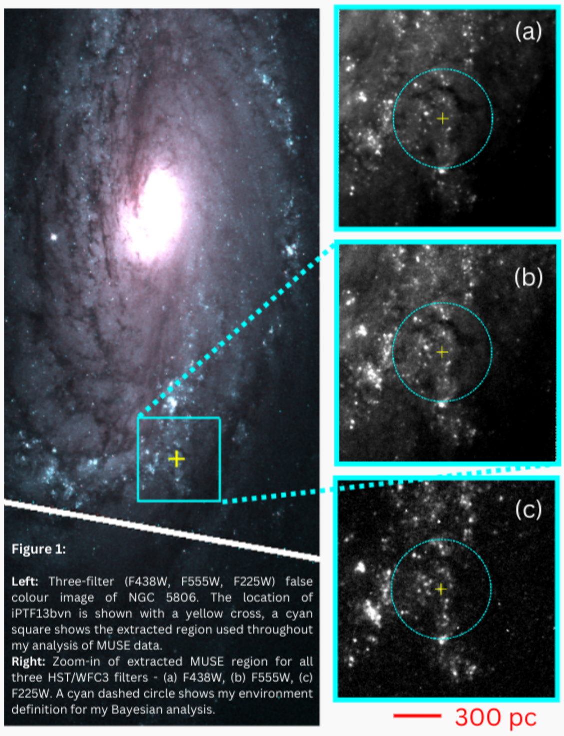

Figure 1:

Left: Three-filter (F438W, F555W, F225W) false colour image of NGC 5806. The location of iPTF13bvn is shown with a yellow cross, a cyan square shows the extracted region used throughout my analysis of MUSE data.
Right: Zoom-in of extracted MUSE region for all three HST/WFC3 filters - (a) F438W, (b) F555W, (c) F225W. A cyan dashed circle shows my environment definition for my Bayesian analysis.

Environmental Analysis: IFU Spectroscopy with MUSE

The gaseous environment of iPTF13bvn is defined by a square region with a width of ~1.2 kpc, represented by the cyan box in the left panel of Figure 1. Nebular emission lines in the spectra, namely the hydrogen Balmer series (Hα and Hβ), are fit by my own algorithm to diagnose the properties of the gas and dust. Some of these emission line properties are plotted as maps in Figure 2, allowing us to build a 3D picture of iPTF13bvn's environment. Multiple extinction values are reproduced using the Balmer decrement method, assuming T = 10,000 K:

'Bayesian' Summed Spectrum: $A_V = 1.738 \pm 0.052\ mag$

Weighted Mean: $A_V = 1.467\ mag$

'Single iPTF13bvn Spaxel: $A_V = 1.917 \pm 0.125\ mag$

These results raise multiple discussion points:

- poor assumptions when using population extinction values?
- increased 'small scale' extinction variability in iPTF13bvn's environment?
- limitations of Bayesian analysis only using stellar information?

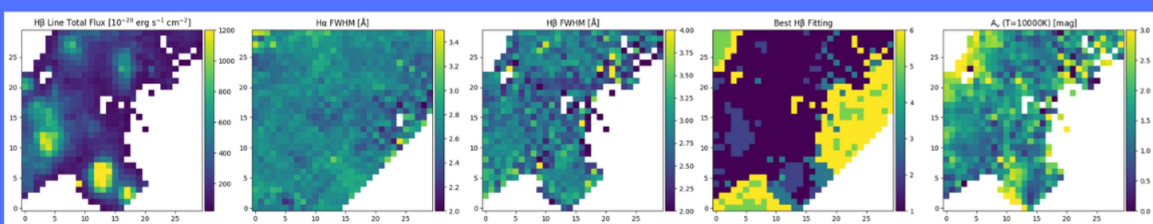

Figure 2: Multiple maps (30x30 spaxels) of MUSE environment region defined in Figure 1. Variables and their respective units are given in the title of each plot. The axis values correspond to spaxel coordinates, centred on iPTF13bvn's position - spaxel (14,14).

References:

[1] HST MAST. Available at: https://archive.stsci.edu/missions-and-data/hst (Accessed: 21 April 2024).

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[3] Jørgensen B. R., Lindegren L., 2005, A&A, 436, 127

[4] Maund J. R., Ramirez-Ruiz E., 2016, MNRAS, 456, 3175

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[6] Skilling J., 2004, in Fischer R., Preuss R., Toussaint U. V., eds, American Institute of Physics Conference Series Vol. 735, Bayesian Inference and Maximum Entropy Methods in Science and Engineering: 24th International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering. pp 395–405, doi:10.1063/1.1835238