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# HST STIS Observations of the Central Radio/X-Ray Source in the Compact Starburst Galaxy Henize 2-10

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**Abstract.** Based on radio and X-ray observations, it has been suggested that a black hole of mass $\sim 10^6$ $M_\odot$ resides in the dwarf starburst galaxy Henize 2-10. This unusual finding has important implications for the formation of massive black holes in the early universe since Henize 2-10 can be viewed as a low redshift analog to the first high-$z$ galaxies. We present long-slit *HST STIS* spectra that include the central radio/X-ray source. While recent *VLT-MUSE* spectroscopic observations with $0\farcs7$ seeing show no change in ionization near the central source, our higher spatial resolution *STIS* observations identify a distinct compact region at the location of the radio/X-ray source. Initial analysis reveals broader (FWHM $\sim 380\,\mathrm{km\,s^{-1}}$) blue-shifted lines of low ionization. Our analysis focuses on testing two scenarios: a LINER-like AGN and a young (few decades) SNR.

**Keywords.** galaxies: dwarf, galaxies: starburst, galaxies: individual (Henize 2-10)

## 1. Introduction

It is currently thought that in today's universe, all massive galaxies irrespective of Hubble type harbor massive black holes (MBHs) at their centers (see Kormendy & Ho 2013, for a recent review). Recently, MBHs have been identified in dwarf galaxies (e.g. Reines *et al.* 2013), but these hosts are not thought to resemble galaxies in the young universe, in which the first seed black holes likely formed. It was therefore of great interest when Reines *et al.* (2011) identified a candidate MBH in the blue compact dwarf galaxy Henize 2-10, and suggested the MBH causes the emission from both a non-thermal radio source (RS; identified by Johnson & Kobulnicky 2003) and coincident X-ray point source. Subsequent *VLBI* observations confirmed the RS to be non-thermal and compact, with size $\lesssim 3\,\mathrm{pc} \times 1\,\mathrm{pc}$, consistent with the base of a MBH-driven jet or young supernova remnant (SNR; Reines & Deller 2012). However, *VLBI HSA* observations by Ulvestad *et al.* (2007) detected no milliarcsecond sources in Henize 2-10, suggesting that the RS is larger than that scale and therefore not a supernova of age $\lesssim 10$ yr. Recent *VLT-MUSE* observations by Cresci *et al.* (2017) of Henize 2-10 with $0\farcs7$ seeing reveal no Seyfert-like high-ionization lines at the RS position, and they suggested that a young SNR better matched the radio observations and the more recent X-ray observations (Reines *et al.* 2016). Since the central region of Henize 2-10 is crowded and undergoing an intense starburst, higher spatial resolution spectroscopy is needed to reliably isolate the emission at the position of the RS. With its superior spatial resolution, *HST* provides an ideal opportunity to zero in on the emission from the central source, and help clarify its nature.

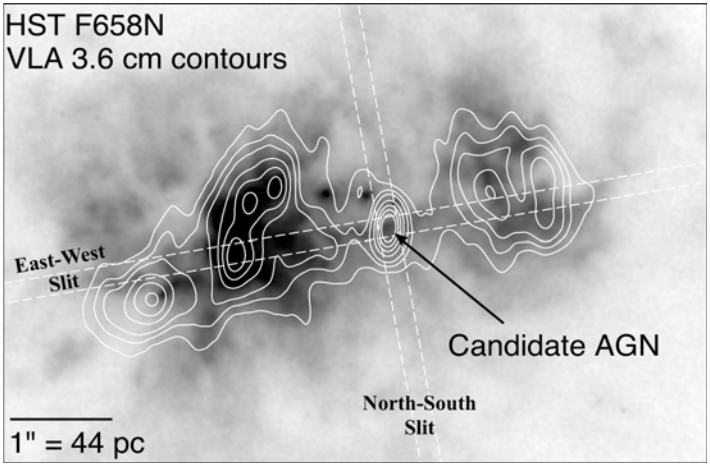


**Figure 1.** Gray: F658N filter H$\alpha$+continuum image from *WFPC2* on *HST*. White contours: *VLA* 3.6 cm radio (Reines *et al.* 2011). White dashed lines: two *STIS* slit locations.

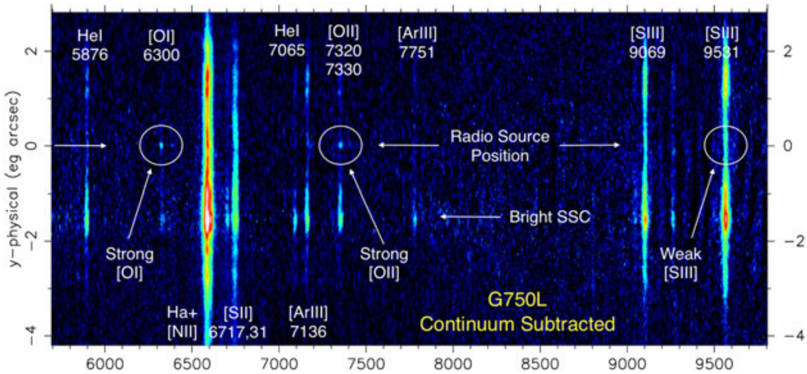


**Figure 2.** The continuum subtracted E-W G750L *STIS* spectral image. The [O I]$\lambda$6300 and [O II]$\lambda\lambda$7319, 30 lines are strong at the RS position. Conversely, the [S III]$\lambda\lambda$9069, 9531 lines are less enhanced. The slit also passes through a bright super-star cluster (SSC).

## 2. STIS Observations, Reduction & Measurements

We used the Space Telescope Imaging Spectrograph (*STIS*) to obtain spectral images along two orthogonal slits (see Figure 1) using four gratings: G430L, G430M, G750L, G750M. We used a half-integer dither to generate final spatial pixels of size $0\farcs025 \times 0\farcs2$, or $1\,\text{pc} \times 9\,\text{pc}$. We confirmed the two slit locations by cross-matching the H$\alpha$ emission in the spectral (*STIS*) and direct (*WFPC2*) images. Prior astrometry already tied the central RS to a weak H$\alpha$ knot, which we confirm falls within both slits.

Along the slit, we fit reddened Starburst99 (Leitherer *et al.* 1999) synthesis models to the continuum and Balmer emission lines, deriving ages of $\sim 3-8$ Myr and dust absorption $A_V \sim 1-1.5$ mag. We measured the line strengths from the RS component after using this continuum subtraction and correcting for ambient H II emission using the adjacent pixels.

Figure 2 shows the continuum subtracted G750L spectral image for the E-W slit. Although ambient H II emission from star formation is seen along the entire slit, *there is an additional component at the position of the RS*. This emission has significantly

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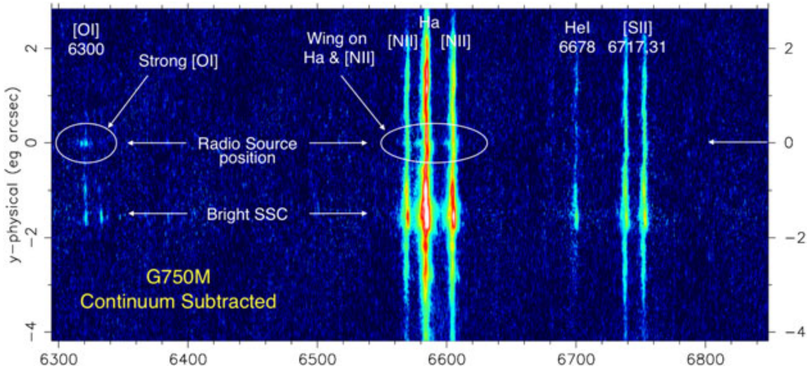


**Figure 3.** The continuum subtracted E-W G750M *STIS* image. At the RS position, blue wings are visible on the Hα and [N II]λ6584 lines, with profiles matching that of the strong [O I]λ6300 line.

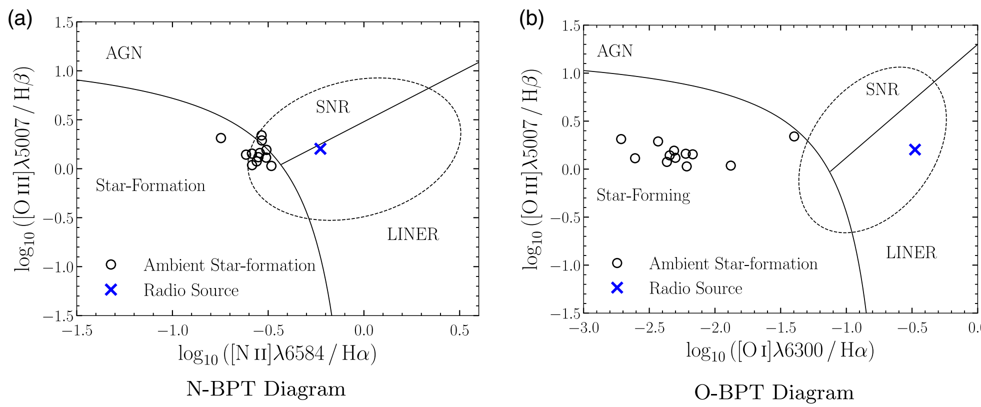


**Figure 4.** BPT diagrams for Henize 2-10. As expected, emission from most of the slit arises from star formation (open circles), while the RS (blue X) lies within the LINER (low powered AGN) and SNR regions. Kewley *et al.* (2006) created the dividing lines for the O-BPT diagram and the star-forming/non star-forming line, while Cid Fernandes *et al.* (2010) created the diving line between AGN and LINERs for the N-BPT diagram. We drew ellipse regions around known SNRs in M83 (Blair & Long 2004).

lower ionization, with very strong [O I]λ6300 and [O II]λλ7320, 30 lines. The G750M data (Figure 3) also reveals broad, $\sim 500\,\mathrm{km\,s^{-1}}$, blue wings at Hα, [N II]λ6548 and [O I]λ6300. As found by Cresci *et al.* (2017), neither the G430L (not shown) or G750L show any high-ionization lines, such as [Ne V]λ3426 or [Fe V]λ5721.

## 3. RS Ionization Mechanism and Velocity Field

Figure 4 shows two optical line ratio BPT diagrams (Baldwin *et al.* 1981). The RS emission lies well outside the Seyfert-like AGN region, as well as normal star formation. In these two BPT diagrams, the RS emission is equally consistent with LINER or SNR emission, though we note our SNR region is dominated by older SNR, while the radio and X-ray data are more consistent with a younger SNR, perhaps a few decades old. The line emission is marginally spatially resolved ($\sim 0\farcs1$) but with no measurable velocity gradient along the E-W or N-S slits ($< 50\,\mathrm{km\,s^{-1}}$ over $\pm 1$ pixel). For circular rotation about a compact object, this gives $M_{\rm BH} < 5 \times 10^5\,\mathrm{M_\odot}$. The line FWHM $\sim 380\,\mathrm{km\,s^{-1}}$ and blueshift is also consistent with a young SNR.

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## 4. Continuing Work

This project is in progress with a number of items still remaining to be explored:

• Compare the LINER and SNR possibilities more carefully. With the kinematic mass limit, what Eddington ratio would generate the low nebular radiation parameter? Are the emission line energetics and kinematics compatible with a Type II SNR, and if so, of what age? Do the radio and X-ray data better match an SNR or LINER/AGN?

• Make a more detailed comparison between young and old SNRs and the RS emission.

• Measure or place limits on any optical continuum emission from the RS. Does this help clarify the ionization mechanism?

• Can the extended emission and velocity field along the E-W slit be understood in terms of a bipolar outflow generated by an MBH?

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