Evidence Against a Redshift $z > 6$ for the Galaxy

**STIS 123627+621755**

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The identification of galaxies at extreme distances provides our most direct information on the earliest phases of galaxy formation. The distance implied by redshifts \( z > 5 \) makes this a challenging endeavor for even the most luminous sources; interpretation of low signal-to-noise ratio observations of faint galaxies is difficult and occasional misidentifications will occur. Here we report on STIS 123627+621755, a galaxy with a suggested spectroscopic redshift of \( z = 6.68 \) [1] and the most distant spectroscopically-identified object claimed. For the suggested redshift and reported spectral energy distribution, the galaxy should be essentially invisible at \( \lambda < 9300 \, \text{Å} \) because the intervening intergalactic medium absorbs essentially all light energetic enough to ionize neutral hydrogen (\( \lambda < (1 + z) \times 912 \, \text{Å}; \) the redshifted Lyman limit). The galaxy should be relatively bright in the near-infrared with \( f_\nu \approx 1 \mu\text{Jy} \). Here we report a detection of the galaxy at 6700 Å, below the Lyman limit for \( z = 6.68 \). We also report a non-detection at 1.2 \( \mu\text{m} \), implying the flux has dropped by a factor of three or more between rest 1216 Å and rest 1560 Å for \( z = 6.68 \). Our observations are inconsistent with the suggested extreme distance of STIS 123627+621755 and conservatively require \( z < 6 \).

During UT 1997 December 23-26, while the Wide Field Planetary Camera 2 obtained second epoch images of the Hubble Deep Field\(^2\) (HDF), the Space Telescope Imaging Spectrograph (STIS) obtained 4.5 hr of filterless imaging (\( \lambda_c = 5850 \, \text{Å}; \) FWHM = 4410 Å) and 13.5 hr of slitless spectroscopy of a 52″ × 52″ field 4.7 arcmin NNW of the HDF. The STIS field is sufficiently separated from the HDF that it lies outside the initial HDF flanking field imaging surveys; i.e., no supporting photometry is provided by the single orbit \( I_814 \) images of Williams et al.\(^2\), the deep Hawaii 2.2 m \( V, I, H + K \) images Barger et al.\(^3\), or the deep \( U, G, R \) images of Steidel et al.\(^4\). Chen et al.\(^1\) have analyzed the deep STIS data to identify distant protogalaxies and report that one faint source, STIS 123627+621755 (“galaxy A” in the discovery paper), has a \textit{probable} redshift of \( z = 6.68 \pm 0.005 \), which would make it the most distant object identified spectroscopically. The source is marginally resolved and has \( AB(\text{clear}) = 27.7 \pm 0.1 \). The redshift is based upon an emission line at 9337 ± 6 Å with a flux density of \( 2.6 \pm 0.5 \times 10^{-17} \text{ergs cm}^{-2} \text{s}^{-1} \), identified as Ly\( \alpha \), and an
extremely strong continuum break at \( \approx 9300 \, \text{Å} \), identified as absorption from the Ly\( \alpha \) forest.

For \( z = 6.68 \), the flux detected in the filterless image must derive almost exclusively from wavelengths longward of the Ly\( \alpha \) forest, implying STIS 123627+621755 has \( f_{\nu} \approx 1 \mu\text{Jy} \) (AB magnitude \( \approx 24 \)) longward of 9300 ˚A, and should be essentially undetectable at optical wavelengths shortward of 9300 ˚A. Assuming this source is a star-forming galaxy as suggested by Chen et al.\(^1\), the inferred 1700 ˚A absolute magnitude is \( M_{\text{AB}}(1700\text{Å}) - 5 \log h_{50} = -22.3 \) (assuming a flat spectrum source longward of Ly\( \alpha \), \( f_{\nu} \propto \nu^0 \), and \( H_0 = 50 \, h_{50} \, \text{km s}^{-1} \text{Mpc}^{-1} \), \( \Omega = 1, \Lambda = 0 \)). This is more luminous than all but a handful of the more than 700 galaxies at \( z > 2 \) identified by Steidel and collaborators\(^5\) over a field-of-view more than a 1000 times larger. If STIS 123627+621755 is a quasar at \( z = 6.68 \), the inferred blue luminosity is less atypical of the population with \( M_B \approx -22.9 \) (assuming a standard quasar optical spectral index of \( f_{\nu} \propto \nu^{-0.5} \)). However, the probability of identifying a faint (\( M_B \leq -22.5 \)) quasar at \( z \geq 6 \) in the STIS field-of-view is \( \approx 3 \times 10^{-4} \) (e.g., see Stern et al.\(^6\)).

These calculations show that STIS 123627+621755 is potentially a very unusual and interesting source, providing us with a uniquely luminous probe of the very early Universe. We therefore targeted it for deep studies with the Keck telescopes (Fig. 1). We do not detect STIS 123627+621755 in our \( J \)-band image, implying \( J_{\text{AB}} > 25.3 \) (3\( \sigma \) limit in a 2\( \prime \)0 diameter aperture). We report a 6\( \sigma \) detection of STIS 123627+621755 in our \( R \)-band image: \( R_{\text{AB}} = 26.8 \pm 0.1 \) measured in a 0\( \prime \)9 diameter aperture to avoid the neighboring galaxy to the east with aperture corrections applied assuming the source is unresolved. Between 1998 and 2000 we have also attempted slitmask spectroscopy of STIS 123627+621755 numerous times, never robustly detecting the source. As an example of one observation with good conditions and confident astrometry, on UT 2000 April 06 we observed STIS 123627+621755 for 2 hours with the Low Resolution Imaging Spectrometer\(^8\) and the 150 lines mm\(^{-1} \) grating. Our 3\( \sigma \) limit to spatially (1\( \prime \)0 FWHM) and spectrally (\( \sigma \approx 230 \text{km s}^{-1} \)) unresolved line emission at 9350 ˚A is \( \approx 2 \times 10^{-17} \text{ergs cm}^{-2} \text{s}^{-1} \), marginally at odds with the Chen et al.\(^1\) results. Note that the fringing and telluric OH emission which afflict ground-based CCD observations at long wavelength make this limit wavelength dependent.
Our results strongly imply STIS 123627+621755 cannot be at \( z > 6 \). In Fig. 2 we present the photometric and spectrophotometric data for STIS 123627+621755 overplotted with a model star-forming galaxy at \( z = 6.68 \). Our 1.2 \( \mu m \) non-detection is severely at odds with the spectral energy distribution reported by Chen et al.\(^1\), who predict a near-infrared magnitude approximately twice as bright. For the 9700 Å flux density reported from the slitless spectrum, our 1.2 \( \mu m \) non-detection implies an extremely blue continuum slope, \( \alpha_{\text{UV}} > 4.7 \) (95\% confidence limit) where \( f_\nu \propto \nu^{\alpha_{\text{UV}}} \). This is significantly steeper than the ultraviolet spectra of known star-forming galaxies\(^9\): longward of Ly\( \alpha \), the average spectral slope is \( \alpha_{\text{UV}} = -0.3 \) and few sources are bluer than \( \alpha_{\text{UV}} = 1.5 \). The slope implied by our observations is also bluer than the Rayleigh-Jeans tail of a black body spectrum (\( f_\nu \propto \nu^2 \)), requiring either photometric errors, variability, or a non-thermal origin to the flux.

Convolving the star-forming galaxy model (Fig. 2) with an \( R \)-band filter transmission and detector response, we predict that a \( z = 6.68 \) galaxy with \( f_\nu \approx 0.67 \mu \text{Jy} \) longward of Ly\( \alpha \) should have \( R_{\text{AB}} > 32 \). The \( R \)-band detection more than 100 times brighter than the prediction implies that STIS 123627+621755 cannot be at \( z = 6.68 \). Furthermore, much of the STIS filterless imaging flux must derive from wavelengths shortward of 9300 Å, implying that the spectrophotometric decrement at 9300 Å must be significantly less extreme than suggested. This is consistent with our 1.2\( \mu \text{m} \) non-detection and implies the 1\( \mu \text{m} \) spectral slope is not as extreme as discussed above.

What is the likely redshift for STIS 123627+621755? The marginally-resolved STIS morphology, reported emission line, red \( AB \) (clear) – R color, and blue ground-based color argue against a Galactic origin for the source. In particular, for \( R - J < 1.5 \), a stellar interpretation conservatively requires a classification earlier than K5 (e.g., Table 3.10 of Binney & Merrifield\(^{10}\)), implying a distance \( \gtrsim 100 \text{ kpc} \) for luminosity class V. A faint Galactic white dwarf identification is not ruled out by the ground-based color. If STIS 123627+621755 is comparable to the lowest luminosity white dwarf known\(^{11}\), ESO 439–26 with \( M_V \simeq 17.5 \), the implied distance is \( \approx 1 \text{ kpc} \). Most white dwarfs are 1.5–8 magnitudes more luminous\(^{12}\).

The imaging results are consistent with a flat spectrum source of \( \approx 27 \text{ magnitude} \). If we assume
the isolated emission line detected at 9337 Å is real, then [O II] $\lambda3727$ is the more likely identification and STIS 123627+621755 is similar in luminosity ($M_B \approx -17$) to the Small Magellanic Cloud at $z = 1.51$ (see Fig. 2). If so, the inferred restframe [O II] $\lambda3727$ equivalent width is $W_{[\text{O} \text{II}]} \approx 4$ Å, typical compared to local samples of star-forming galaxies\textsuperscript{15}. The flux decrement at 9300 Å is reproduced by this model, albeit at a less dramatic amplitude, and is associated with hydrogen Balmer absorption rather than hydrogen Lyman absorption. The blue $R - J$ color and failure of our extensive spectroscopy to detect any features both support this interpretation. However, the $AB(\text{clear}) - R$ color is $\approx 1$ magnitude too red and suggests either variability or a spectral break in the range $\lambda\lambda3000 - 6000$Å.

These results and other recent serendipitously-identified sources\textsuperscript{13,14} show that low luminosity, [O II]-emitting galaxies at $z \approx 1.5$ can be convincing doppelgängers of high-redshift galaxies. At $z \approx 3$ we know that the faint end of the galaxy luminosity function is steep\textsuperscript{5}. Low luminosity, [O II]-emitting galaxies are likely to be a significant contaminant to high-redshift Ly$\alpha$ searches, suggesting that such surveys should incorporate deep imaging bluewards of the emission line to distinguish the populations.

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Fig. 1.— Imaging of STIS 123627+621755 showing that the galaxy is detected at $R$, below the Lyman limit if $z = 6.68$. Fields are 20$''$0 on a side, with north at the top and east to the left. The 70 minute interference $R$-band ($\lambda_c = 6700 \, \text{Å}; \Delta \lambda = 1400 \, \text{Å}$) image was obtained on UT 2000 May 05 with the Echelle Spectrograph and Imager on the Keck II telescope in photometric conditions and 0$''$85 seeing. The image has been smoothed by a circular Gaussian of width 1 pixel (0$''$153). The 64 minute $J$-band ($\lambda_c = 1.25 \mu m; \Delta \lambda = 0.3 \mu m$) image was obtained on UT 2000 January 30 with the Near Infrared Camera on the Keck I telescope in photometric conditions and 0$''$9 seeing. A 3$''$0-long arrow indicates the location of STIS 123627+621755 ($\alpha_{2000}=12^h 36^m 27.38^s, \delta_{2000}=+62^\circ 17' 55.56''$); it is detected in the $R$-band and filterless (clear) STIS image, but is undetected in the $J$-band image. The bright galaxy NW of STIS 123627+621755 shows an emission line at 9660 Å, most likely identified with either [O II] $\lambda 3727$ at $z = 1.592$ or H\(\alpha\) at $z = 0.472$. 


Fig. 2.— The photometric detection of STIS 123627+621755 at 6700Å is not consistent with $z > 6$. Solid stars show our $R$- and $J$-band Keck photometry, where horizontal extent illustrates the width of the interference filters. Note that the $R$-band filter has a sharp red cutoff, unlike conventional $R$-band filters. Dotted circles are STIS imaging and spectrophotometric results from Chen et al.$^1$. Arrows are 3σ upper limits. The dotted and dot-dashed lines refer to 50 Myr old star-forming galaxy models at redshifts of $z = 6.68$ and $z = 1.51$, respectively. The model$^{16}$ is a 50 Myr old starburst ($Z = 0.020$, $\alpha_{\text{IMF}} = 2.35$, $M_{\text{low}} = 1M_\odot$, $M_{\text{up}} = 100M_\odot$, nebular lines included) with instantaneous star formation, attenuated by a model of the intervening intergalactic medium$^{17}$. Vertical lines indicate the strong edges due to the Ly$\alpha$ forest, the Ly$\beta$ forest, and the Lyman limit (rest-frame 912 Å) at $z = 6.68$. The Keck photometry does not support the suggested $z = 6.68$ redshift and spectral energy distribution. In particular, the detection at 6700 Å requires that STIS 123627+621755 is not at $z > 6$. The ground-based photometric data is more consistent with the emission line reported at 9337 Å being associated with [O II] $\lambda 3727$ from a star-forming galaxy at $z = 1.51$. In this case, the luminosity of STIS 123627+621755 is comparable to the Small Magellanic Cloud at a lookback time of $\approx 10$ Gyr.