The Astrophysical Journal, 432:L83–L86, 1994 September 10

HAWAII 167: A COMPACT ABSORPTION-LINE OBJECT AT $z = 2.35$

L. L. Cowie,[1] A. Songaila, E. M. Hu,[1] E. Egami,[2] J.-S. Huang, A. J. Pickles,
S. E. Ridgway, and R. J. Wainscoat
Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822

and

R. J. Weymann
Observatories of the Carnegie Institution of Washington, 813 Santa Barbara Street, Pasadena, CA 91101
Received 1994 February 25; accepted 1994 June 24

ABSTRACT

During the course of the Hawaii K-band (2.1 μm) survey (Songaila et al. 1994; Cowie et al. 1994) we have detected a compact object, Hawaii 167, lying at a redshift of 2.33, in which are seen both low- and high-ionization absorption lines. In the near-infrared we see broad Hα emission at a redshift of 2.35 but do not detect the other Balmer lines, [O II] λ3727, or [O III] λ5007. The absence of strong Mg II or C IV emission in the rest ultraviolet suggests that, at these wavelengths, we may be seeing a poststarburst galaxy rather than a quasar. Indeed, this class of object may be common enough to represent a major episode of galaxy formation, possibly the formation of the spheroids. However, Q0059−2735, the most extreme member of the class of Mg II absorbing broad absorption line quasars, is very similar to the present object, and there may be an evolutionary sequence or some other close connection between Hawaii 167 and the broad absorption line quasars.

Subject headings: cosmology: observations — galaxies: general — galaxies: individual (HAW 167) — galaxies: starburst — quasars: absorption lines

1. INTRODUCTION

In this *Letter* we report the discovery of a high-redshift object at $z = 2.33$ with a rest ultraviolet absorption-line spectrum. This object (Hawaii 167) was found in the complete identification of a $K = 18$ mag sample of galaxies and stars covering only 77 arcmin^2 of sky. The small area of the survey suggests that high-z absorbers could be quite common in faint near-infrared samples. As we shall discuss below, it is unclear whether Hawaii 167 is a starburst galaxy or a very exotic broad absorption line quasar (BALQSO); either interpretation has serious problems. It may indeed be that Hawaii 167 is a blend of quasar and starburst galaxy, and that its nearest low-z counterparts are IR-excess Seyfert galaxies and quasars like Mrk 231 and IRAS 13349+2438. Irrespective, if such objects are common, another class of high-z object is opened up for study, and we outline targeted search techniques to turn up further members.

2. DATA

Hawaii 167 was one of 64 galaxies, with $17 < K < 18$, spectroscopically observed in five fields covering 77 arcmin^2 during the Hawaii K-band survey (Songaila et al. 1994). The observed sample was chosen either on the basis of being spatially extended or of having $(B-I)$ and $(I-K)$ colors which differed from those expected for stars. All but two of these objects were identified as $z < 1$ galaxies or as stars; the other object is also likely to be a normal modest-redshift galaxy, but Hawaii 167 was found to be extremely anomalous. This $K = 17.2$ object, whose finding chart is given in Figure 1 (Plate L12), exhibits a complex absorption-line spectrum (Fig. 2) with an unambiguous redshift of $z = 2.33$. Hawaii 167 was the only compact object observed which was not a star, and its colors, which are summarized in Table 1, are quite unlike those of stars or quasars but fall within the range expected for a high-z star-forming galaxy (Cowie et al. 1994). Subsequent to its identification, IR spectra were obtained with the CGS4 spectrometer on UKIRT covering the J, H, and K bands. The only feature detected was a wide (5000 km s^{-1} FWHM) strong emission line at the position of redshifted Hα (Fig. 3). This Hα line is at a redshift of 2.357, placing it about 2600 km s^{-1} redward of the absorption lines. The Hα line is extremely strong, with a rest-frame equivalent width of 320 Å, whereas the Hα flux is more than 8 times that of Hβ (1 σ lower limit). The properties of the absorption and emission lines are summarized in Table 2.

3. DISCUSSION

Only one previously known object bears a close resemblance to Hawaii 167. This is the $z = 1.595$ object Q0059−2735 discovered by Hazard and collaborators during the course of their extensive quasar surveys (Hazard et al. 1987) which shows an absorption-line spectrum remarkably similar to that of Hawaii 167. Q0059−2735 is usually considered the most extreme member of the tiny class of Mg II absorbing BALQSOs (Weymann et al. 1991; Voit, Weymann, & Korista 1993), and the six or so members of this class may represent a sequence between BALQSOs and compact line absorbers (COLAs), such as Hawaii 167. However, Q0059−2735 does differ from Hawaii 167 both in having slightly stronger (though

[1] Visiting Astronomer, Canada-France-Hawaii Telescope (CFHT), which is operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

[2] Visiting Astronomer, United Kingdom Infrared Telescope (UKIRT), which is operated by the Royal Observatory Edinburgh for the UK Science and Engineering Research Council.

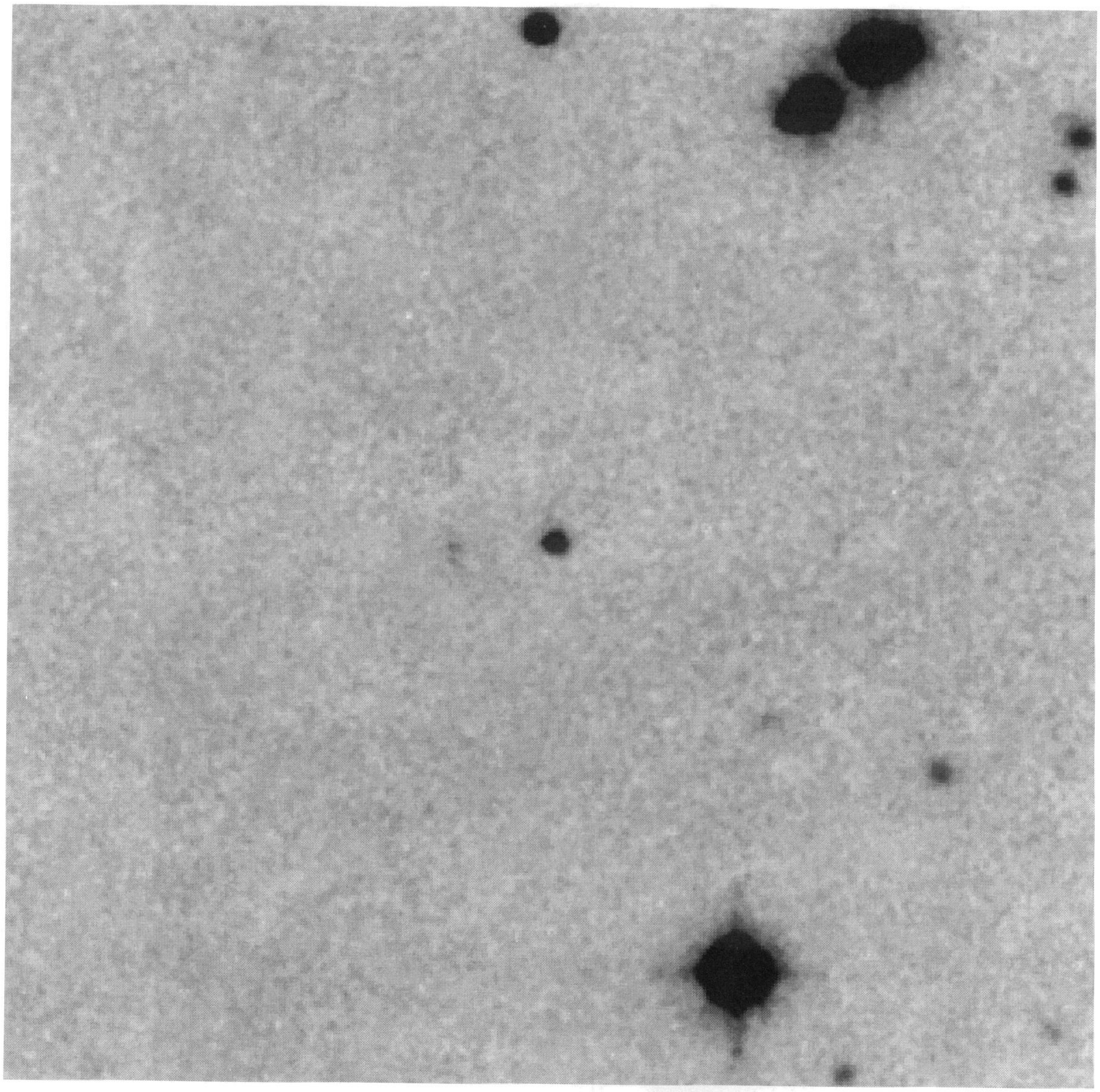

FIG. 1.—K' finding chart. Hawaii 167 is the bright centrally positioned object in this 1′ on a side field and lies at R.A.(1950) = $3^h54^m46^s.7$ and decl.(1950) = 1°02′21″. North is at the top, and east is to the left. The image is a 39 minute exposure taken with the NICMOS3 camera on the University of Hawaii 2.2 m telescope. The FWHM is just under 0″.9.

COWIE et al. (see 432, L83)

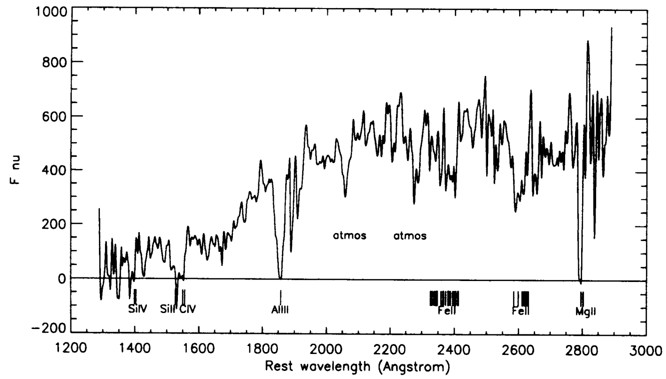

FIG. 2*a*

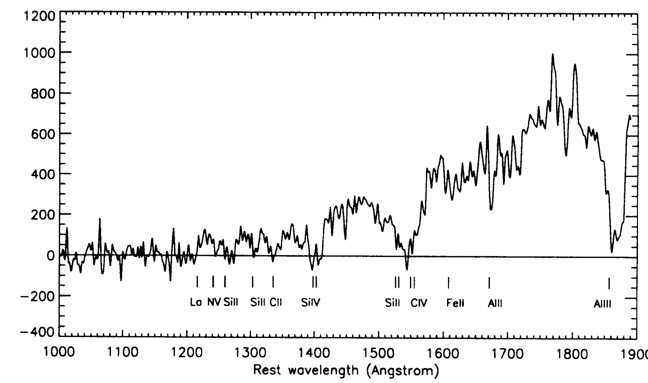

FIG. 2*b*

FIG. 2.—(*a*) Red and (*b*) blue spectra of Hawaii 167 obtained with the MOS-SIS spectrograph on CFHT. The red spectrum was obtained with the R300 grating, giving a resolution of 20 Å and a coverage from 4500 to 1000 Å. It is approximately calibrated to f_ν using observations of standard stars and is shown at a rest wavelength corresponding to $z = 2.33$. The positions of the stronger lines are marked. The blue spectrum, which is not flux-calibrated, was obtained with the B600 grating. This gives a resolution of 10 Å and a useful coverage from 3500 to 6300 Å. It, too, is shown in rest wavelength with the stronger lines marked.

still very weak) emission lines in the rest-frame ultraviolet and in having $(B-K')$ and $(H-K')$ colors which are bluer than those of Hawaii 167 (cf. Table 1). It is also considerably more luminous. Moreover, Hawaii 167 has somewhat narrower absorption lines. The FWHM of Mg II absorption is 1500 km s^{-1}, while that of the Al III doublet is 4000 km s^{-1}. Si IV has a FWHM of 4500 km s^{-1}, but here the component structure is clearly seen. The Mg II BALQSOs are themselves redder than normal BALQSOs (Weymann et al. 1991), which would be consistent with the idea that they form a sequence between the BALQSOs and much redder COLAs.

Initially, therefore, it would seem natural to identify Hawaii 167 as a very extreme BALQSO. The underlying continuum light source would then be the quasar, and the absorption troughs would arise in the dense outflow region surrounding the quasar (Weymann et al. 1991; Voit et al. 1993). The red color of the object could then be understood in terms of dust reddening of the underlying quasar (Sprayberry & Foltz 1992). The problem with applying this to Hawaii 167 is the absence of any significant Mg II emission in the red wing of the Mg II absorption. As is shown in Figure 2, the absorption does not extend redward enough to extinguish the red wing of an underlying broad quasar emission line, but despite this there is no significant emission at this position. We have measured a rest-frame half–equivalent width of Mg II of 2.9 Å in a 25 Å interval (2700 km s^{-1}) to redward of the zero-velocity position inferred from the Hα line. We have also estimated the equivalent noise level by measuring the equivalent width also in random 25 Å slices of the spectrum in the neighborhood of Mg II, and find a dispersion of 3.1 Å. (Since there is genuine structure in the spectrum, this number overestimates the true error.) We therefore adopt a 1 σ upper limit of 6 Å for the half–equivalent width of Mg II. This is about a factor of 2 less than is expected from the minimum Mg II equivalent width of ~20 Å seen in quasars (Steidel & Sargent 1991). There is no sign of redward emission in the rest-frame UV lines, but the complexity of the absorption spectrum makes it hard to quantify this. The weakness of the emission line suggests that the rest-frame ultraviolet of Hawaii 167 is not dominated by quasar light.

An alternative explanation is that we are seeing light from a starburst galaxy dominated by a population of super–metal-rich early B supergiants. Such an object can account for the broad blueshifted absorption-line troughs shown in Figure 2 without producing P Cygni profiles in the higher ions and can also produce the narrower lower velocity low ions (Kinney et al. 1993; Leitherer & Lamers 1991). The rest ultraviolet spectral energy distribution also matches that expected from such a population. The dominance of an early B supergiant population would imply that star formation occurred in a rapid single burst about 10 Myr prior to the observed time (Robert, Leitherer, & Heckman 1993). The main problem with this

TABLE 1

BROAD-BAND MAGNITUDES OF HAWAII 167 AND Q0059−2735

Band	Hawaii 167	Q0059−2735
K'	17.2 (19.2)	14.7 (16.7)
H	17.8 (19.3)	14.9 (16.4)
J	18.8 (19.8)	15.8 (16.8)
I	20.0 (20.5)	...
6475 ± 450 Å	(20.7)	...
V	...	17.6 (17.6)
B	23.0 (22.8)	18.2 (18.0)

NOTE.—Magnitudes are Wainscoat-Cowie *K'*; Johnson *J*, *H*, *V*, and *B*; and Kron-Cousins *I*. The quantities in parentheses are the corresponding *AB* magnitudes. All magnitudes were measured on the University of Hawaii 2.2 m telescope, except for the *B* and *V* magnitudes of Q0059−2735, which are taken from Warren et al. 1991.

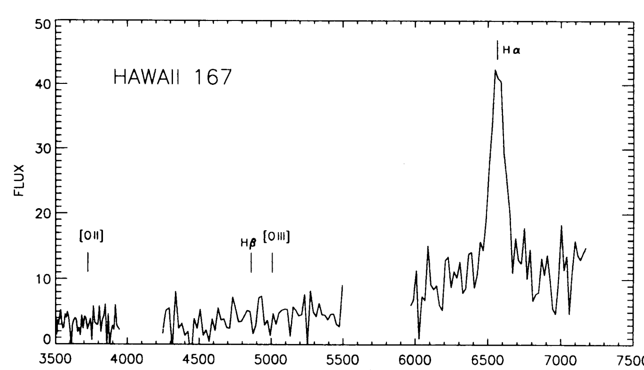

FIG. 3.—Near-IR spectrum of Hawaii 167 obtained using CGS4 on UKIRT. Spectral regions around [O II], Hβ and [O III], and Hα have been plotted as a composite spectrum, preserving the appropriate relative flux calibration. The positions of expected emission lines are shown for a redshift of 2.35.

TABLE 2

ABSORPTION AND EMISSION LINES

Wavelength (Å)	Identification	Redshift
Absorption Features		
9327	Mg II λλ2795.5, 2802.7	2.332
8633–8741	Fe II λλ2585–2631	...
7919–8026	Fe II λλ2327–2413	...
7613	*A* band (atm)	...
6872	*b* band (atm)	...
6376	Fe III λ1926.3	2.331
6304	Fe III λ1895.5	2.326
6192	Al III λλ1854.7, 1862.8	2.331
5548	Al II λ1670.8	2.321
5057–5171	C IV, Si II λλ1548.2, 1550.8; 1526.7, 1534.4	...
4643	Si IV λλ1393.8, 1402.8	2.320
4425	C II λ1334.5	2.316
4330	Si II λ1304.4	2.320
4202	Si II λ1260.4	2.334
4129	N V λλ1238.3, 1242.8	2.328
Mean	...	$\langle z \rangle_{abs} = 2.327$
Emission Features		
22010	Hα λ6562.8	2.354
5973	Fe II λ1786.4?	...
5861	?	...

interpretation lies with the rest-frame optical spectrum, where the broad Hα emission and the absence of [O II] and [O III] are much more suggestive of BALQSO behavior (Boroson & Meyers 1992). It may be possible to devise starburst models which would reproduce these features, but given this behavior and the presence of slightly more hermaphoroditic objects such as Q0059−2735, it seems more natural to assume that these objects exhibit a mixture of quasar and starburst characteristics in varying degrees as a function of wavelength.

In particular, it is tempting to extrapolate Sprayberry & Foltz's (1992) suggestion that the red color of the Mg II BALQSOs is caused by the dust shrouding of the quasar, and to assume that in objects such as Hawaii 167 the underlying quasar is completely extinguished in the rest-frame ultraviolet, leaving only the underlying starbursting galaxy at these wavelengths. While precise details would depend on the spectral shape of quasar and galaxy, and also on the characteristics of the dust, a reasonable approximation to the broad-band colors of Hawaii 167 can be obtained by reddening a flat-f_ν quasar with an AB magnitude of 16.7 with an extinction of $E(B-V) = 1$, and adding an unreddened flat-spectrum galaxy with an AB magnitude of about 20.5. Such a model predicts that about 75% of the light at Hα will arise in the quasar, but only about 10% will be quasar light at Mg II. A similar value of $E(B-V)$ is obtained from the Balmer decrement. In Q0059−2735, where the Mg II emission line has a rest equivalent width of about 7.7 Å (Hazard et al. 1987), the extinction would be smaller though still substantial. More quantitatively, if the intrinsic rest equivalent width of the quasar were around 50 Å, we would be seeing roughly 30% quasar light at Mg II in Q0059−2735.

A consistency check on this concept is the blackness of the Mg II absorption line. In Hawaii 167 Mg II is saturated (to the accuracy of a few percent to which we can measure). If we assume that the quasar has no Mg II absorption, then it can contribute at most a few percent of the light at this wavelength. In Q0059−2735 the optical depth in Mg II is around 90% percent, and the line is clearly not saturated (Hazard et al. 1987; Weymann et al. 1991), so around 10% of the light could be from the quasar. These estimates are slightly lower than those of the previous paragraph but are probably reasonable given that there may also be Mg II absorption from interstellar gas in the galaxy (York et al. 1990) and from broad absorption line troughs in the quasar.

The surface brightness profile of Hawaii 167 is indistinguishable from a nearby bright star in 0".9 FWHM seeing, implying that the deconvolved FWHM of Hawaii 167 is less than 0".5 and its size less than 4 kpc for $q_0 = 0.5$ and $H_0 = 50$ km s^{-1} Mpc^{-1}. This would be consistent with Hawaii 167's being a quasar, while if the observed optical light arises in a galaxy it must be quite compact—possibly suggestive of spheroid formation. Using the *I*-band magnitude together with a *K* correction appropriate for a flat-spectrum galaxy or quasar, we find an absolute magnitude $M_{AB} = -26.1$ for $q_0 = 0.5$ and $H_0 = 50$ km s^{-1} Mpc^{-1} in the 1500–3000 Å rest-frame wavelength range, or $f_\nu = 1.2 \times 10^{31}$ ergs cm^{-2} s^{-1} Hz^{-1}. If the light is from star formation, this would correspond to a mass of more than 10^9 $M_\odot$ in the dominant supergiant population, or about 10^{10} $M_\odot$ of total star formation, depending on the details of the initial mass function. While these numbers are very rough, Hawaii 167 would have to be a massive galaxy with a dust-reddened central quasar caught shortly after a very rapid single burst of star formation.

4. CONCLUSIONS

Clearly, additional members of this class of object must be detected to address the questions raised in § 3. Because Hawaii 167 was found in a small-area survey, it probably belongs to a class of objects fairly common in faint-infrared–selected samples. The 68% confidence range for the surface density should lie in the range 1 per 20 arcmin^2 to 1 per 420 arcmin^2 for $K < 18$ COLAs, making them at least as common as normal quasars of the same magnitude. For a density of 1 per 100 arcmin^2, the sky surface brightness of the class would be $S_\nu = 10^{-26}$ ergs cm^{-2} s^{-1} Hz^{-1} deg^{-2}, or about an order of magnitude smaller than the value expected from the dominant galaxy formation episode (Songaila, Cowie, & Lilly 1990). While objects of this type are hard to pick out in other ways from near-IR samples, Hawaii 167 is unique in its combination of compactness and color, and it is possible to imagine a targeted search which would use these characteristics to turn up additional members. In order to identify a substantial population, we would require a $K = 18$ survey covering about a square degree of sky. Such a survey should shortly be possible with the advent of 1024×1024 IR arrays.

This work was supported by the State of Hawaii and by NASA grant NAGW-959.

REFERENCES

Boroson, T. A., & Meyers, K. A. 1992, ApJ, 397, 442
Cowie, L. L., Gardner, J. P., Hu, E. M., Songaila, A., Hodapp, K.-W., & Wainscoat, R. J. 1994, ApJ, in press
Hazard, C., McMahon, R. G., Webb, J. K., & Morton, D. C. 1987, ApJ, 323, 263
Kinney, A. L., Bohlin, R. C., Calzetti, D., Panagia, N., & Wyse, R. F. G. 1993, ApJS, 86, 5
Leitherer, C., & Lamers, H. J. G. L. M. 1991, ApJ, 373, 89
Robert, C., Leitherer, C., & Heckman, T. M. 1993, ApJ, 418, 749
Songaila, A., Cowie, L. L., Hu, E. M., & Gardner, J. P. 1994, ApJS, in press
Songaila, A., Cowie, L. L., & Lilly, S. J. 1990, ApJ, 348, 371
Sprayberry, D., & Foltz, C. B. 1992, ApJ, 390, 39
Steidel, C. C., & Sargent, W. L. W. 1991, ApJ, 382, 433
Voit, G. M., Weymann, R. J., & Korista, K. T. 1993, ApJ, 413, 95
Warren, S. J., Hewett, P. C., Irwin, M. J., & Osmer, P. S. 1991, ApJS, 76, 1
Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23
York, D. G., Caulet, A., Rybski, P., Gallagher, J., Blades, J. C., Morton, D. C., & Wamsteker, W. 1990, ApJ, 351, 412