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# A Narrowband Imaging Search for [OIII] Emission from Galaxies at $z > 3$

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## ABSTRACT

We present the results of a narrow-band survey of QSO fields at redshifts that place the [OIII](5007Å) emission line in the  $\frac{\Delta\lambda}{\lambda} \sim 1\%$  2.16  $\mu\text{m}$  filter. We have observed 3 square arcminutes and detected one emission line candidate object in the field around PC 1109+4642. We discuss the possibilities that this object is a star-forming galaxy at the QSO redshift,  $z_{em} = 3.313$  or a Seyfert galaxy. In the former case, we infer a star formation rate of  $170M_{\odot}/\text{yr}$  for this  $K'=21.3$  object. The galaxy has a compact but resolved morphology, with a FWHM=0.6", or 4.2kpc at  $z=3.313$  ( $H_0 = 50 \text{ km s}^{-1}\text{Mpc}^{-1}$  and  $q_0 = 0.5$ ). The comoving density of such objects in QSO environments appears to be  $0.0033\text{Mpc}^{-3}$ , marginally lower ( $\leq 3\sigma$ ) than the density observed for  $H\alpha$ -emitters in absorption-line fields at  $z \sim 2.5$ , but similar to the density of Lyman Break Galaxies at  $z \sim 3$ . If on the other hand, most of the line emission is [OIII] from a Seyfert 2 nucleus at  $z=3.31$ , then the high inferred volume density could imply a large evolution in the Seyfert 2 luminosity function from the current epoch. We find the field containing the object to also contain many faint extended objects in the  $K'$  image, but little significant excess over the expected number-magnitude relation. We discuss the implication of the emission line being a longer wavelength line at a lower redshift.

*Subject headings:* cosmology : observation — galaxies : evolution — infrared : galaxies

## 1. Introduction

High redshift galaxy surveys were, once limited to detection of quasars and radio-loud AGN, have recently found a large population of normal galaxies at  $z > 2$ . Steidel *et al.* (1996, 1998) have found star-forming “Lyman break galaxies” (LBG) to be common at  $z > 3$ , greatly increasing the current understanding of the evolution of normal galaxies. In addition, deep narrow-band imaging has been used in several successful Ly $\alpha$  searches (Cowie *et al.* 1998, Hu & McMahon 1996, Francis *et al.* 1996). Though optical searches have the advantage of large area coverage, they are limited by the effects of dust reddening and a selection bias for the youngest (bluest) objects. The near-IR continuum, by contrast, samples the older stars, giving an independent view of the dominant stellar population and allowing direct comparison with similar observations at other epochs. At large redshifts, the strong emission lines associated with on-going star formation shift into the near infrared, allowing narrow-band imaging surveys to identify starforming galaxies.

Given that small amounts of dust reddening can completely extinguish Ly $\alpha$ -emission, H $\alpha$  is the strongest emission line in many starburst galaxies. To date there have been numerous successes in detecting emission line galaxies in the IR, targeted at H $\alpha$ . Given the relatively small area covered by the current generation of  $256 \times 256$  pixel IR arrays, IR searches have typically centered on known “signposts” such as quasars or absorbers where objects at the target redshift are already known. In Teplitz, Malkan & McLean (1998, hereafter TMM98), we detected 11 H $\alpha$ -emitters in 12 square arcminutes (down to a  $1\sigma$  limiting line flux of  $2 \times 10^{-17}$  ergs/cm<sup>2</sup>/s), in fields centered on metal absorption-line systems in quasar lines of sight. The comoving space density of these objects was found to be  $0.0135^{+0.0055}_{-0.0035}$  Mpc<sup>-3</sup>, Such a volume density is 3–5 times higher than the density of comparably luminous Lyman break galaxies (LBGs) at similar redshifts. The average inferred SFR for the galaxies is 50 M $_{\odot}$ /yr, consistent with other dereddened estimates for galaxies at  $z > 2$  (Dickinson, 1998). A similar search was conducted by Pahre & Djorgovski (1996) with the same instrument, though no detections were found in four fields, two of which were targeted on H $\alpha$ , one on [OIII] and one on [OII]. Thompson *et al.* (1996) covered  $\sim 300$  square arcminutes down to a survey depth of  $10^{-16}$  ergs/cm<sup>2</sup>/s. In this area they discovered a single strong line emitter, which they identify as a star forming galaxy at  $z = 2.43$ , with an inferred SFR  $\geq 240 M_{\odot}$ /year, assuming it is H $\alpha$  (Beckwith *et al.* 1998). In a companion survey targeted to Damped Ly $\alpha$  and metal absorption-line systems, the same group found 18 targets in 163  $\square'$ , at comparable depth (Mannucci *et al.* 1998, hereafter MTBW98).

The [OIII] doublet is, in many cases, the other strongest emission line. In fact, the [OIII]:H $\alpha$  ratio is about 0.6 in local star-forming galaxies (Thompson, Djorgovski, &

Beckwith 1994 and references therein). The relative strength of [OIII] is greater in more metal-poor gas, because the lower cooling efficiency results in a higher level of ionization. The primary complication of using [OIII] as a tracer of star-formation is the tendency of active galactic nuclei (AGN) also to produce strong [OIII] lines, powered by the hard non-stellar ionizing continuum in the nucleus. If a significant portion of the [OIII] flux comes from the Narrow Line Region (NLR) of an AGN, then this line would give an over-estimate of the star-formation rate (Kennicutt 1992). This risk is greatest for AGN with pure NLR spectra, *i.e.*, the Seyfert 2's, because their [OIII]/H $\alpha$  ratios are typically three times higher than in starburst galaxies. However, this sensitivity to narrow-line AGN is partially offset by the fact that they are rare. Optical searches (which observed the rest-frame UV emission lines) show the space density of AGN is considerably smaller than that of star-forming galaxies. For example, Lyman Break Galaxies (Steidel *et al.* 1996; hereafter LBG) are detected at ten times the rate of AGN using the Lyman dropout technique. TMM98 presented arguments that not all of the H $\alpha$  flux in their galaxies is the result of active nuclei, including the fact that their volume density would be too high. We will consider this issue further below when interpreting our observational results.

In this paper we present the results of a narrow-band search for [OIII] emission from galaxies at  $z > 3$  in quasar environments. By extending the search for emission lines in the infrared, we can answer two important questions. First, we evaluate the usefulness of [OIII] as a tracer of star formation at high redshift, and the prospects for using this line in a larger survey. An infrared search at  $z > 3$  will allow direct comparison of the near IR techniques with the Lyman break method, finally unifying the different approaches, and potentially applying each to the same field (for a Ly $\alpha$  counterpart see Cowie *et al.* 1998). Secondly, we can use observations pointed at signposts at  $z > 3$  to limit the *field* density of H $\alpha$ -emitting objects near lower redshift signposts. Previous targeted searches have called for more extensive control fields.

In section 2 we present a summary of the observations, data reduction and sensitivity limits. In section 3 we present the results of the narrow-band and continuum imaging. In section 4 we discuss the implications of the one survey candidate and the non-detections in other fields. Throughout the paper we assume  $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$  and  $q_0 = 0.5$ .

## 2. Observations

Using the NASA/IPAC Extragalactic Database (NED) we selected fields containing quasars at redshifts which would place redshifted [OIII] ( $\lambda_0 = 5007\text{\AA}$ ) in the Br $\gamma$ ( $2.16 \mu\text{m}$ ) filter (see TMM98 for a discussion of filter selection). We required the redshifts to fall

within  $3.299 < z < 3.329$ . All observations were taken with the Near IR Camera (NIRC) on the 10m Keck I telescope; the camera has a  $256 \times 256$  pixel InSb array, (Matthews *et al.*, 1994) and a field of view of  $38'' \times 38''$ ;  $0.15''/\text{pixel}$ . Table 1 lists the fields observed, integration times and limiting sensitivities. We also list the FWHM of the seeing disk for each field as measured from the quasar or other bright, unresolved objects in the field. For comparison, we include in Table 1 the field around QSO1159+123 surveyed by Pahre & Djorgovski (1996) with the same instrument (in a different filter).

Observations were taken and reduced with the same procedure described in TMM98, which will only be summarized here. We obtained images in a sequence of “dithered” exposures, offsetting the telescope between exposures in a  $3 \times 3$  grid spaced by  $3''$ . The data were reduced by dividing by a twilight flat and then subtracting a running median sky frame created from the nine exposures taken closest in time to each image. Objects were identified using the SExtractor (Bertin & Arnouts 1996) software. Photometry was performed using apertures of 2.5 times the seeing disk. The same aperture was applied to broad and narrow-band exposures. Photometric errors were estimated from aperture photometry performed on random positions in the frame. Errors in the narrow-minus-broad band color were estimated from Monte Carlo simulations. These simulations generated narrow and broad band magnitudes for line-free objects having the gaussian errors measured in the real data.

### 3. Results

Figure 1 shows the narrow-minus-broad band color-magnitude diagram for all the objects in the survey. One object in the PC1109+4642 field shows up as a clear candidate for excess flux in the narrow-band filter. The varying depths of the different fields makes the significance of this measurement somewhat difficult to distinguish from the combined figure, so we have not plotted the characteristic errors. Instead, we have re-plotted the objects in the 1109 field separately in Figure 2 along with the 99.5% confidence limits. The 1109 field was observed on a night of exceptionally good seeing, with a long integration time, and thus is more sensitive than most of the other fields (see Table 1). The emission-line object was observed again, on a separate night, to confirm the result and search adjacent sky area (though conditions were substantially worse on the second night). Good agreement was seen in the  $\text{Br}\gamma$  magnitudes across the nights. The broad-band magnitude was not checked as thoroughly (as the object fell in the low signal to noise ratio part of the dither pattern) and so there is a discrepancy in the photometry from the two nights. The range between them is plotted as the error bars in the figure. Figure 3 shows the 1109 field, together with

the broad- and narrow-band images of the candidate galaxy (hereafter 1109A).

We have also examined the continuum photometry for objects in each field. The 1109 field appears relatively crowded, but as already noted it is a deeper exposure. 81 galaxies were measured in  $K'$  in all the fields combined, of which 23 are in the 1109 field. To examine the significance of large number of galaxies, we have calculated the number-magnitude relation for that field and for the other five fields. Figure 4 shows the number counts, also compared with results from the literature. No attempt was made at star-galaxy separation for objects fainter than  $K'=20$ , but fortunately at this high galactic latitude, virtually all of these faint objects are galaxies. Completeness was estimated from recovery of mock objects in similar data. The number-magnitude relation for the other (four) comparably deep fields match the expectation from K-band surveys in the literature. The number of excess  $K' \geq 20$  galaxies in the 1109 field appears marginally significant (at the  $\sim 2\sigma$  level).

In the broad-band image, 1109A appears extended, though its faint magnitude makes its half-light radius hard to measure reliably (IRAF's IMEXAM task gives a FWHM=0.6"). In the  $Br\gamma$  image, the object has FWHM=0.55". The question arises whether the narrowband excess emission is likely to be from an active nucleus. This is possible, though there is some evidence to the contrary. The seeing disk is measured to be 0.45" from the (brighter) QSO. 1109A has a magnitude of  $K'=21.3$  and a broad-minus-narrow band color excess ( $\Delta m$ ) of 1.5 magnitudes, relative to featureless objects.

Object 1109A appears to be within 1.3" of another galaxy. However only 1109A is strongly detected in the narrowband. It is interesting to note that two other high-z emission line galaxies have been reported recently that also appear to be very close to another object. Francis *et al.*(1998) find that one of the AGN in the 2139-4344 cluster (see Francis *et al.* 1996, 1997) lies with 0.7" of another faint red galaxy in high-resolution NICMOS imaging. They suggest that the two galaxies are in the process of merging and that some of the extended  $Ly\alpha$  emission from which the object was initially identified results from star formation induced by the merger. Similarly, Beckwith *et al.* (1998) report that cK39 (an  $H\alpha$ -emitting galaxy at  $z=2.43$  from the Thompson *et al.* (1996) survey) lies within 1.3" of another red galaxy. They, too, interpret these as merging objects. We note that in the case of the cK39 there are arguments favoring an AGN source for the detected emission line.

#### 4. Interpretation

There are three possible explanations for the apparent excess flux in the  $Br\gamma$  filter. The object could be at the targeted redshift of the QSO. Secondly the emission line could

be  $H\alpha$ , the strongest optical emission line associated with ongoing star formation. Lastly, it could be a rest-frame near infrared line at a much lower redshift. The properties associated with the galaxy for each assumed emission line are given in Table 2.

#### 4.1. The [OIII] Emission Line at $z = 3.31$

The first, and we argue most likely explanation is that the flux is due to the [OIII]  $\lambda 5007$  emission line at the targeted redshift of 3.31. If that were the case, the  $K' \simeq 21.3$  apparent magnitude of the object ( $0.0025\mu\text{Jy}$ ) would correspond to an absolute magnitude of  $M_B \sim -24.1$ . Assuming a 1 Gyr burst of star formation at  $z > 5$ , we find that the passive evolution and K-correction from the GISSEL96 spectral synthesis models of Bruzual & Charlot (see Bruzual & Charlot 1993) predict this galaxy would be the precursor of a modern galaxy with  $0.5L_*$ . In that case the galaxy’s FWHM would correspond to 4.2kpc, in reasonable agreement with the expectation for a galaxy at this redshift (see for example Lowenthal *et al.* 1996). The projected separation of 1109A from the QSO at  $z_{em}=3.313$  would be 133kpc.

As discussed above, [OIII] is emitted both by starbursts as well as the NLR in an AGN. To distinguish unambiguously these two possibilities, it will be necessary to obtain a spectrum in either the optical or near-infrared. Such observations are planned with the LRIS (Oke *et al.* 1995) and NIRSPEC (McLean *et al.* 1998) instruments on the Keck II telescope, and will be presented in a future paper. Meanwhile, however, we consider the implications of each possibility.

From the  $\Delta m = 1.5$  of broad-minus-narrow-band color, we obtain  $EW=150\text{\AA}$  in the rest frame. Typical local spiral galaxies show a range in  $EW([\text{OIII}]) = 10 - 80$ , when it is detected at all (Kennicutt, 1992). On the other hand, local galaxies typically have SFRs a factor of 5–10 lower than that estimated for LBGs at  $z > 3$ , including extinction correction. If the line emission is dominated by current star formation, we can use Kennicutt’s (1983) relation to estimate the SFR based on [OIII] luminosity:

$$\text{SFR}(\text{total}) = \frac{L([\text{OIII}])}{6.7 \times 10^{40} \text{ergs s}^{-1}} \text{M}_{\odot} \text{yr}^{-1} \quad (1)$$

Under the assumption that the line is [OIII] from H II regions, its luminosity implies  $\text{SFR}=170\text{M}_{\odot}/\text{yr}$ .

We can also calculate the implied space density of emitters in QSO environments at that redshift. Given our rectangular search window, we survey  $0.47\text{Mpc}^3$  (physical

volume) per NIRC field, leading to a comoving number density of  $0.0033_{-0.0027}^{+0.008}$   $\text{Mpc}^{-3}$  (with a  $3\sigma$  upper limit on the density of  $0.026\text{Mpc}^{-3}$ , as estimated from Poisson statistics; see Gehrels 1986). This density can be compared to the  $0.0135\text{Mpc}^{-3}$  for  $\text{H}\alpha$ -emitters at redshifts of 2.3–2.5 from TMM98. We note that while the TMM98 search was targeted to both QSO environments and metal-absorption line system fields, most of the emitters detected were at absorber redshifts. A similar conclusion was reached in MTBW98 (with a density of  $9 \times 10^{-4}\text{Mpc}^{-3}$ , to shallower depth), so it is perhaps not surprising that the density of objects in QSO fields may be lower.

Another factor to consider is evolution in the density of objects with redshift. We can compare our inferred  $z=3.3$  density to the density of Lyman Break Galaxies at a similar redshift, which is  $0.004\text{Mpc}^{-3}$  at 2.75 (a redshift window of 2–3.5, see Madau *et al.* 1997). This comparable density argues in favor of object 1109A being part of the typical high- $z$  population of galaxies. Similarly, its SFR is not unusually high for an (extinction corrected) LBG (see Pettini *et al.* 1997). On the other hand, we must consider the second possible source of [OIII] emission: a Seyfert nucleus.

### Does the [OIII] Emission come from an AGN?

In TMM98 we argue that the space density of  $\text{H}\alpha$  emitters is inconsistent with the assumption that all the candidate objects are AGN. So we can ask: Is the space density of [OIII] emitters inferred from this one candidate also inconsistent with AGN? To answer that question, we must assume a luminosity function for Seyfert galaxies at  $z > 3$ . We will extrapolate the QSO luminosity function of Warren *et al.* (1994). That function was defined for the rest-frame continuum flux at  $1216\text{\AA}$ , under the  $\text{Ly}\alpha$  emission line. We, of course, do not have a measurement of the flux at that wavelength. Instead, we will make a rough estimate by assuming that the candidate object has the same observed frame  $V-K' \simeq 4.8$  color as the (also AGN-contaminated) MTM095355+545428, leading to a value of  $M_C = -21$  at  $z = 3.3$ . Using the evolving Schechter luminosity function suggested by Warren *et al.* leads to a comoving space density of such objects  $4 \times 10^{-4} \text{Mpc}^{-3}$ . This is almost an order of magnitude lower than the density inferred from our one candidate, but that is of course highly uncertain. Thus the density of AGN does not favor the interpretation of the possible [OIII] line having non-stellar (Seyfert 1) origin, but it doesn't absolutely preclude it either.

If 1109A has a Seyfert nucleus, it is more likely the object is a pure narrow-line AGN (a Seyfert 2) than a broad-line object because the former are relatively brighter by an order of magnitude in the  $5007\text{\AA}$  emission line. (We will ignore the small additional contribution



from 4959Å, especially because most of it would fall outside our narrow-band filter). Because the median equivalent width is about 20Å in low-luminosity quasars (Boroson & Green 1992) and about 200Å in Seyfert 2 galaxies (as measured from the spectrophotometry of De Bruyn and Sargent 1978), our search goes one order of magnitude deeper down the Seyfert 2 luminosity function than it does down the Seyfert 1/quasar luminosity function. The observed equivalent width would be extremely high for a quasar, but is within the range of values seen in Seyfert 2's. The Seyfert 2 hypothesis is also far more consistent with the fact that the galaxy is spatially *resolved*. (If a broad-line AGN actually were present, it would probably make 1109A very blue in the rest-frame UV. For a typical  $\alpha = -0.5$ , 1109A would have  $I \sim 23$  which could be easily checked with deep imaging. None has yet been published.)

Even with a large amount of luminosity evolution it is hard to reconcile the density of high-z line-emitting galaxies with the density of Seyfert 2's. We must realize, however, that the density of Seyfert 2's is not well known at high redshift. Complete samples of Seyfert 2's have been observed locally (Rush et al. 1993), and it is seen that Seyfert 1's and 2's above  $L_*$  have comparable densities. So, if Seyfert 2's do not evolve considerably more with redshift than Seyfert 1s, then the space density of high luminosity Seyfert 2's would fall short of the density observed in emission-line searches.

If 1109A is representative of such a numerous, strongly evolving population of Seyfert galaxies (of either type 1 or 2), it might have strong implications for their present-day descendants. By raising the volume density of AGN by an order-or-magnitude over what had been known from color-searches for quasars, this density could imply that a Seyfert phase was a common occurrence in the early evolution of most currently normal galaxies.

Spectroscopic evidence will of course be vital in settling the issue, but there are already some hints that this might be the case. A substantial proportion of the high-redshift galaxies discovered in emission-line searches do in fact show *mixtures* of starburst and Seyfert activity. For example, we discovered an emission line galaxy at  $z=2.495$  in the environment of the multiple C IV absorber in the line of sight of the quasar SBS0953+549 (Malkan, Teplitz & McLean 1995, 1996). Optical spectroscopy showed this galaxy to have young stellar absorption features as well as very strong Ly $\alpha$  emission, and weaker high-ionization emission lines which suggest an AGN contribution ( $\leq 30\%$ ) to the continuum flux. Ly $\alpha$  emission line searches have also found AGN as well as star-forming galaxies. Ly $\alpha$  has been seen as an indicator of both potentially high mass clusters (Francis *et al.* 1997,1998) and pre-merger proto-galactic clumps (Pascarella *et al.* 1997), even though both contain a large number of AGN. Thus whatever the source of excitation, since Ly $\alpha$  searches have found large clusters of objects at high-z, perhaps with a surprising proportion of active

nuclei, it is reasonable to suppose that the less extinguished [OIII] line may do the same.

Finally, we must consider the possibility that the emission-line is [OIII] but that the source of ionizing radiation is the nearby quasar, not intrinsic star formation or nuclear activity. At a minimum separation of 133kpc, 1109A only intercepts 0.1% of the emitting QSO radiation. It is unlikely that this fraction would be sufficient to produce the strong [OIII] emission line in 1109A. Assuming a typical rest-frame equivalent width for [OIII] to be  $\sim 80\text{\AA}$  in QSOs and the underlying QSO continuum to be  $1 \times 10^{-17}\text{ergs/cm}^2/\text{s}/\text{\AA}$ , gives an indication of the maximum possible energy that could be responsible for the candidate object’s emission line. This estimate agrees with the observed narrow-minus-broad band color of the QSO. The inferred energy, however, could only account for less than 1% of the observed line flux in 1109A.

#### 4.2. The H $\alpha$ Emission Line at $z = 2.3$

A second possible explanation for the excess narrow-band flux is that there is an H $\alpha$  emission line at  $z=2.3$ . This assumption would lead to an inferred luminosity  $L \sim 0.3L_*$  based on the model discussed above. The inferred star formation from an H $\alpha$  line would be  $\text{SFR}=45M_\odot/\text{yr}$ , which is close to the average found by TMM98, but lower than that in MTBW98 by a factor of 1.5. If the emission line is H $\alpha$  then we calculate a comoving space density of  $0.0055^{+0.009}_{-0.004} \text{Mpc}^{-3}$ , a factor of 2.5 less than the TMM98 survey. This again is a reasonable difference, given that at  $z=2.3$ , the current survey is *untargeted* and so would be probing the field galaxy population. Thus, if this object is at  $z=2.3$ , we take it to be a ( $< 3\sigma$ ) confirmation of the conclusions reached in TMM98 that metal absorber fields show a higher space density of star forming galaxies.

#### 4.3. A Low Redshift Near-IR Emission Line

The emission line could be something at a lower redshift, in the rest-frame near-infrared. The most likely transitions to consider are P $\alpha$ (1.875  $\mu\text{m}$ ), [FeII](1.64  $\mu\text{m}$ ), and [SIII](0.9532  $\mu\text{m}$ ). In each case, the galaxy would be considerably fainter, but would also have a reasonably smaller inferred SFR. To calculate the inferred SFR we apply a standard line ratio to H $\alpha$  for each IR emission line and then again refer to Kennicutt (1983). We take P $\alpha$ :H $\alpha$ = 0.1, which is the value for Case B recombination (see for example Hill *et al.* 1996 and the references therein). We assume [FeII]:H $\alpha$ = 0.034 (see Calzetti 1997). Finally, we use the ratio [SIII]:H $\alpha$ = 0.43, which is the unreddened ratio based on observations of Orion

often used as a diagnostic of extinction (see Waller *et al.* 1988 and references therein). While none of the inferred SFRs are surprisingly low for an assumed IR emission line (see Table 2), the inferred luminosities are, as they would require the object to be at most  $0.1L_*$ .

If the emission line is one of the near-IR lines longward of  $1\ \mu\text{m}$ , the implied densities of objects would be anomalously high for field galaxies (based, however on a small dataset). If we are seeing  $\text{P}\alpha$  at  $z=0.152$ , then we find a comoving density of  $\sim 0.8\text{Mpc}^{-3}$ . For comparison, the comoving density of objects brighter than  $0.001L_*$  at the current epoch is  $0.014\text{Mpc}^{-3}$  (Loveday *et al.* 1992). For  $[\text{FeII}]$  at  $z=0.317$  we find a density of  $0.12\text{Mpc}^{-3}$ .

For  $[\text{SIII}]$  at  $z=1.266$ , the implied density would be  $0.01\text{Mpc}^{-3}$ . We can compare this to the field density of objects at this redshift. We use the luminosity function at  $1 < z < 2$  measured by Sawicki *et al.* (1997), to calculate a comoving density of  $0.023\text{Mpc}^{-3}$  for galaxies brighter than  $0.1L_*$ . Thus on the basis of density alone we cannot rule out the interpretation of the emission line as  $[\text{SIII}]$ . To investigate further the implications of this interpretation, we can consider the dataset obtained in TMM98 as well as the current observations. In that survey, seven fields were observed with the same  $2.16\ \mu\text{m}$  filter, to similar depths. In that area, 5 line emitters were detected, one of which as been spectroscopically confirmed to be a Seyfert 1 at  $z=2.3$  and a second object which is anomalously bright and morphologically suggestive of a Seyfert. Considering the other three objects as a limiting case, we combine those data with the current survey and find an upper limit on the density of  $[\text{SIII}]$ -emitters at  $z=1.266$  of  $\sim 0.02\text{Mpc}^{-3}$ . Combining this with the inferred luminosity of  $0.1L_*$  makes  $[\text{SIII}]$  the most reasonable of the infrared emission line possibilities. Again, we do not consider this interpretation the most likely, however. We also could consider the lack of absorption systems in the QSO spectrum (Schneider *et al.* 1994) to be an argument against this galaxy being identified by the  $[\text{SIII}]$  emission line, but the projected distance is outside the radius expected for an absorber.

In summary, we have surveyed 3 square arcminutes down to a  $1\sigma$  limiting flux of  $3 \times 10^{-17}\text{ergs}/\text{cm}^2/\text{s}$ . In that area we find a single emission-line object in the field around PC1109+4642, with an emission-line flux of  $7 \times 10^{-17}\text{ergs}/\text{cm}^2/\text{s}$  and  $K'=21.3$ . If this object is a star-forming galaxy at the the QSO redshift, we calculate a comoving space density and inferred SFR consistent with other searches.

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Table 1. Targets

Field	$z$	date	$t_{K'}$ (s.)	$t_{n.b.}$ (s.)	$K'$ $5\sigma$	seeing (arcs.)	$1\sigma$ line flux (ergs cm <sup>-1</sup> s <sup>-1</sup> )
Q0234+013	3.30	01/14/98	540	3600	20.0	0.45	5.3e-17
PC1109+4642	3.313	03/17/98	2160	8640	21.1	0.45	2.3e-17
PC1109+4642 N <sup>1</sup>	3.13	03/18/98	2160	6480	21.0	0.6	2.6e-17
PC1153+4751	3.323	03/18/98	1620	6480	21.1	0.45	2.5e-17
Q1410+096	3.317	04/16/98	1620	4320	20.8	0.6	4.0e-17
PC1542+4744	3.312	06/27/96	1620	6480	21.2	0.6	2.1e-17
PC1542+4744 E <sup>1</sup>	3.312	03/18/98	1620	4320	21.2	0.6	4.2e-17
Q1159+123 <sup>2</sup>	3.502	04/05/94	...	...	...	0.75	3.15e-17

<sup>1</sup>The fields of PC1109 and PC1542 were reobserved, offset by 3/4 of the frame in order to examine an object of interest, so there is a 25% overlap between these double fields.

<sup>2</sup>Data on Q1159+123 taken from Pahre & Djorgovski 1995

Table 2. Properties of 1109A for various assumed line identifications

Line	$z$	$M_{AB}$	Lum. ( $L_*$ )	SFR $M_\odot/\text{yr}$	FWHM (kpc)	Dist. to QSO (kpc, projected)	density ( $\text{Mpc}^{-3}$ )
[OIII]	3.313	-24.3	>0.5	171	4.2	133	0.0033
H $\alpha$	2.30	-23.5	0.3	45	4.7	150	0.0055
[SiIII]	1.27	-22.0	0.1	28	4.7	163	0.010
[FeII]	0.32	-18.8	<0.01	18	2.4	108	0.12
P $\alpha$	0.15	-17.0	<0.001	12	1.9	64	0.80

Fig. 1.—  $(K' - 2.16 \mu\text{m})$  vs.  $K'$  for all the fields surveyed. The + symbols are for objects in the 1153 field; the \* for objects in the 1109North field. The diamonds for objects in the 1109 field; the triangles for objects in the 1542 field; the squares for objects in the 1542east field; and the x for objects in the 1410 field. The few objects that were observed twice between the 1109 and 1109N fields are plotted with the average value with error bars extended to the individual values. The large error bar is the result of the low signal to noise re-observation of the emission-line object 1109A

Fig. 2.—  $(K' - 2.16 \mu\text{m})$  vs.  $K'$  for the 1109+4642 field. Objects that were observed twice between 1109 and 1109N are plotted as the average with error bars extended to the individual values. The solid lines denote the three sigma errors for the 1109 field, not the 1109N field (which are larger). The \* indicate objects in the 1109 field and the + indicate objects in 1109N. 1109N was observed in poorer conditions, so the two + symbols outside the errors are not actually 3 sigma detections. The large error bar is the result of the low signal to noise re-observation of the emission-line object 1109A

Fig. 3.— The  $K'$  image of the 1109+4642 field. The small images at the bottom compare the broad-band (left) and narrow-band (right) observations of the line emitter. The region compared is indicated by the square in the larger picture.

Fig. 4.—  $K'$  number counts for objects in the 1109 field compared to objects in the other fields surveyed. The squares with error bars indicate the counts for all the other fields, while the asterisks with error bars indicate the counts in the 1109 field. Open symbols show the counts with no completeness correction. The crosses show the number counts from the literature (as compiled by Gardner 1998).









