1. INTRODUCTION

The availability (Abazajian et al. 2003) of a significant fraction of the spectra and images from the Sloan Digital Sky Survey (SDSS; York et al. 2000) provides us with a unique resource for the investigation of a wide variety of astrophysical phenomena. The quality and scale of the database are such that a number of serendipitous discoveries can be expected in the coming years. In this Letter we report the discovery, using SDSS spectra of unrelated objects, of the largest known planetary nebula (PN) on the sky.

2. DATA

In the course of a search for SDSS spectra that show the signature of two objects at different redshifts, the distinctive presence of the [O iii] \(\lambda\lambda4959, 5007\) doublet, at essentially rest-frame wavelength, in several adjacent spectra was noted. A more targeted search employed a simple 41 pixel (57 Å) median filter to generate a “continuum,” which was then subtracted from the original spectrum to produce a “difference” spectrum. Emission lines were identified in individual and composite difference spectra using standard matched filter techniques. The search revealed the presence of [O iii] \(\lambda\lambda4959, 5007\) in more than 100 spectra with the flux in the [O iii] \(\lambda5007\) line ranging from \(1.6 \times 10^{-15}\) down to the limit of detectability of \(8 \times 10^{-17}\) ergs s\(^{-1}\) cm\(^{-2}\). Surface brightnesses, per square arcsecond, can be obtained from the fluxes measured in the spectra by dividing by the fiber area (7.1 arcsec\(^2\)).

The detections were confined to objects in a region several degrees across centered at approximately \(\alpha = 10^h37^m, \delta = -00^\circ 18^\prime\) or \(159^\circ 3, -00^\circ 3\) (J2000.0). H\(\alpha\), H\(\beta\) [N ii] \(\lambda\lambda6548, 6583\), and [S ii] \(\lambda\lambda6718, 6732\) emission lines were also present in spectra of detectable [O iii] \(\lambda\lambda4959, 5007\) (filled circles), H\(\alpha\) (open circles), and [N ii] \(\lambda6583\) (crosses). The hatched area, extending to a radius of 1° from 10\(^h37\) and -00\(^\circ 18\), indicates a region where composite spectra, derived using groups of 25 spectra without individual [O iii] \(\lambda\lambda4959, 5007\) detections, show unambiguous evidence of [O iii] \(\lambda\lambda4959, 5007\) emission. Positions of objects with SDSS spectra for which no individual detections were obtained are also indicated (dots).

Figure 2 shows the wavelength regions containing [O iii] \(\lambda\lambda4959, 5007\) and H\(\alpha\), [N ii] \(\lambda\lambda6548, 6583\) plus [S ii] \(\lambda\lambda6718, 6732\) for a composite continuum-subtracted spectrum made using all the galaxy and quasar spectra within 0.5 of 10\(^h37\), -00\(^\circ 18\) (top panels). The measured emission-line fluxes for the composite spectrum are given in Table 1. Another composite, using objects from a more distant arc-shaped region to the southwest, is also shown (bottom panels). The arc-shaped region is defined by radial distance \(0^\circ 7-1^\circ 3\) from 10\(^h37\), -00\(^\circ 18\) and angular extent \(180^\circ \leq P.A. \leq 315^\circ\) relative to the same position. The composite from the central region displays very strong [O iii] \(\lambda\lambda4959, 5007\) and, while H\(\alpha\) and [N ii] \(\lambda\lambda6548, 6583\) are clearly visible, shows the relative weakness of the hydrogen lines. The composite spectrum from large radii to the southwest illustrates the falloff in the strength of the [O iii] \(\lambda\lambda4959, 5007\) emission with radius and the marked variation in the H\(\alpha/[N ii]\) \(\lambda\lambda6548, 6583\) ratio with position. The spectra of stars were not included in the generation of the composite spectra. To avoid contamination of the composite spectrum from unrelated emission and absorption features, wavelength regions associated with strong emission and absorption features in the rest frames of the galaxy and quasar spectra were excluded from the construction of the composite spectra.

Examination of the sky-subtracted sky spectra in SDSS
plates 273 and 274, which contain the region, shows no evidence for absorption at the location of any of the emission lines. The lack of absorption confirms that the emission-line fluxes associated with the \( \sim 2'' \) region, centered on \( 10^\circ 37', -00'18' \), are not affected significantly by more extended emission on scales of \( \sim 5'' \).

The resolution of the SDSS spectra (\( \approx 3.1 \) Å) precludes a reliable determination of the radial velocity. The centroids of the \([\text{O} \text{iii}] \) \( \lambda \lambda 4959, 5007 \), \([\text{H} \alpha] \), and \([\text{N} \text{ii}] \) \( \lambda \lambda 6583 \) emission lines in a composite of the 38 spectra showing the strongest \([\text{O} \text{iii}] \) \( \lambda \lambda 4959, 5007 \) emission give a heliocentric radial velocity of \( -5 \pm 5 \) km s\( ^{-1} \). However, the amplitude is comparable to the wavelength accuracy of the SDSS spectra, and variations of several tens of kilometers per second are evident from spectrum to spectrum. In summary, the heliocentric velocity of the gas is consistent with a value of \( 0 \pm 20 \) km s\( ^{-1} \).

The large angular extent and small radial velocity suggest a relatively local origin for the ionized gas. The Galactic coordinates, \( l = 248^\circ, b = +48^\circ \), further suggest that the gas is within a few hundred parsecs if the object lies within the Galactic disk. The weakness of the hydrogen lines and the lack of any bright early-type stars in the vicinity of the nebula rule out identification as an H\( \Pi \) region.

### 3. Further Investigations

Narrowband imaging of the \([\text{O} \text{iii}] \) \( \lambda \lambda 4959, 5007 \) lines \( (\lambda_c = 5008 \text{ Å}, \Delta \lambda = 100 \text{ Å}) \) and the \([\text{H} \alpha]+[\text{N} \text{ii}] \) \( \lambda \lambda 6548, 6583 \) lines \( (\lambda_c = 6568 \text{ Å}, \Delta \lambda = 95 \text{ Å}) \) was undertaken using the Wide-Field Camera (WFC) on the Isaac Newton Telescope (INT) on the nights of 2003 May 1 and 21–27. Exposure times of 900–1200 s (H\( \alpha \)) and 3 \( \times \) 900 s (\([\text{O} \text{iii}] \)) were used, with shorter exposures of 600 s for companion broadband images in \( g \) and \( r \) passbands. An area of roughly a square degree was imaged in both \([\text{O} \text{iii}] \) and H\( \alpha \). After processing through the INT WFC pipeline (Irwin & Lewis 2001) there was a clear detection of complex \([\text{O} \text{iii}] \) and H\( \alpha \) nebulosity extending over the whole region, confirming the reality of the spectroscopic detections. The resulting continuum-subtracted stacked \([\text{O} \text{iii}] \) and H\( \alpha \) images are shown in Figure 3. The central concentrated distribution of \([\text{O} \text{iii}] \) \( \lambda 4959, 5007 \) emission is particularly striking. A distinctive feature present in the \([\text{O} \text{iii}] \) image is the arc-like structure visible at center right.

In the less than 0\textquotesingle 5 composite (Figs. 2a and 2b) the \([\text{O} \text{iii}] \) \( \lambda 5007/\lambda 4959 \) ratio of 3.6 \( \pm \) 0.4 and the \([\text{N} \text{ii}] \) \( \lambda \lambda 6583/\lambda 6548 \) ratio of 2.8 \( \pm \) 0.3 are both consistent with their theoretical values, which depend only on atomic physics for the conditions pertaining in PNs, suggesting that the spectrum provides useful diagnostic information (although new spectra of the high surface brightness features are needed). H\( \beta \), which is clearly present in individual spectra with the strongest emission-line fluxes, is barely detectable in the less than 0\textquotesingle 5 composite spectrum. The H\( \alpha \)/H\( \beta \) ratio of 7.5 \( \pm \) 3.5 indicates some reddening (formally \( \Delta v \approx 0.9^{+0.3}_{-0.2} \)). Relatively weak underlying absorption in the Balmer lines would help explain the low H\( \beta \) flux while making little difference to the strength of H\( \alpha \). The nearly red-

### Table 1

| Species   | Wavelength (Å) | Flux \( (10^{-17} \text{ ergs s}^{-1} \text{ cm}^{-2}) \) |
|-----------|----------------|------------------------------------------------------|
| [Ne iii]  | 3870           | 6.5 \( \pm \) 1.0                                      |
| H\( \beta \) | 4861           | 1.0 \( \pm \) 0.8                                      |
| [O iii]   | 4959           | 10.6 \( \pm \) 1.5                                    |
|           | 5007           | 38.6 \( \pm \) 3.0                                    |
| [N ii]    | 6548           | 1.8 \( \pm \) 0.5                                    |
| H\( \alpha \) | 6563           | 7.7 \( \pm \) 1.2                                    |
| [S ii]    | 6717           | 1.7 \( \pm \) 0.7                                    |

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Emission-Line Fluxes in the Less than 0\textquotesingle 5 Composite Spectrum

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| [S ii]    | 6717           | 1.7 \( \pm \) 0.7                                    |


Figs. 3.—Left: Mosaic of 6 continuum-subtracted pointings in Hα+[N ii]; right: equivalent for [O iii]. The images are approximately 0′′8 on a side, with north to the top and east to the left. The position of the WD PG 1034+001 is indicated by a circle in the [O iii] image. Emission with complex structure is evident in the central regions of the images in both passbands. A well-defined arc, or boundary, is visible at center right in the [O iii] image.

Figs. 4.—Bj−R vs. R color-magnitude diagram for objects within 0′′75 of 10h37m, −00′18 using the APM sky catalog magnitudes of UKST Bj and R plates. All objects classified as stellar are plotted (dots) with the location of the WD PG 1034+001 highlighted (filled circle).

dening independent ratios of [N ii] λ6583/Hα = 0.8 ± 0.2 and [N ii] λ6583/[S ii] λ6716 = 2.9 ± 1 are both within the ranges observed in nitrogen-rich PNs. The [O iii] λ5007/Hβ ratio of 38 ± 10 is very high, although not unprecedented in PNs (and is biased high by the selection process). Further support for the classification as a PN comes from the detection of [Ne iii] λ3869. The absence of detectable emission from lines of He i and He ii is consistent with normal abundances and the signal-to-noise ratio of the composite spectrum. In summary, the emission-line properties of both composite and individual spectra are consistent with the properties of a PN with a relatively hot central star.

Indeed, the images in the atlas of ancient PNs (Tweedy & Kwitter 1996) contain some strikingly similar structures. The centrally concentrated morphology evident in the distribution of [O iii] λλ4959, 5007 emission is common, and large variations in emission-line ratio, including strong [N ii] and [S ii] toward the outer edges of old PNs due to interactions between the ejecta and the ambient interstellar medium, are often seen. The most unusual property of the structure reported here is the angular size, which at greater than 2′′ diameter exceeds that of Sh 2-216, also long considered the closest PN, with an angular size of 1′6 (Fesen, Blair, & Gull 1981; Tweedy & Napiwotzki 1992).

Since there was no plausible ionizing source in the SDSS photometric catalog, the Automatic Plate Measuring (APM) sky survey catalogs were used for further investigation of potential ionizing sources of radiation. In a 1′5 region centered on 10h37m, −00′20′′, one bright candidate ionizing source stood out at R.A. = 10h37m03′875, decl. = −00′08′19′59 (J2000.0; epoch 1982), with United Kingdom Schmidt Telescope (UKST) plate magnitudes and colors of R = 15.06 and Bj−R = −0.47 (see Fig. 4). Using the UKST plate as a reference frame, the refined APM POSS1 (epoch 1952) position of this source is R.A. = 10h37m04′047, decl. = −00′08′20′53 (J2000.0), giving a high proper motion of −86 ± 5, +31 ± 5 mas yr−1. The color, magnitude, and proper motion suggested that the object was probably a hot white dwarf (WD) at around 100 pc and a search, utilizing SIMBAD, reveals that the source is PG 1034+001, a bright, V = 13.23 (Landolt 1992), DO WD. A very crude kinematic age of ∼130,000 yr can be derived from the radius of the PN, ∼1″ at a distance of ∼150 pc, and a typical expansion velocity of PNs, ∼20 km s−1. The WD is currently close to the center of the region over which detectable emission is present in the SDSS spectra. The WD is also in
close proximity, ≈15′, to the region showing the strongest [O iii] λλ4959, 5007 emission; however, the proper-motion vector for the WD indicates a position for the WD to the east of the present location at the time the PN was formed. If the arclike feature visible in Figure 3 represents a shock or a boundary associated with material ejected at the time the PN was formed, then a lower limit to the kinematic age for the PN can be estimated by extrapolating the motion of the WD back to the origin of the radius of curvature of the arc. The resulting limit on the age, greater than 50,000 ± 10,000 yr, is plausible, but an understanding of the nature of the arclike feature is necessary to validate the argument. An age of ≈100,000 yr is consistent with all the evidence, but measurement of the expansion velocity and a more complete mapping of the morphology of the emission will provide a much improved estimate.

4. DISCUSSION

Given that all observations are consistent with a PN nature for the newly discovered nebulosity, we designate it Hewett 1. The proximity of the DO WD PG 1034+001 (Wesemael, Green, & Liebert 1985) makes it probable that PG 1034+001 is responsible for the ionizing radiation. The existence of an H ii region at the location of the PN has been noted by Haffner (2001), who also mentions PG 1034+001 as a possible source for the ionizing radiation. Werner, Dreizler, & Wolff (1995) derived a spectroscopic distance for PG 1034+001 of 155±58 pc, and confirmation of the association would make Hewett 1 one of the closest PNs known (Napiwotzki 2001), the 2σ diameter corresponding to a physical size of 3.5–7.0 pc for the likely distance range of 100–200 pc. Again, Sh 2-216 provides the current benchmark, with a trigonometric distance of 130±5 pc (Harris et al. 1997) and a physical size of ≈3.5 pc. A parallax determination for PG 1034+001 would establish whether Hewett 1 is even closer.

Notwithstanding targeted searches (Werner et al. 1997), very few PNs are known to be associated with non-DA (hydrogen-poor) WDs. Hewett 1 may be the first PN to be discovered associated with a DO WD; although PG 0108+101 (Reynolds et al. 1987) and PG 0109+111 (Werner et al. 1997) have candidate nebulae, neither detection is regarded as secure. Since DO WDs are thought to evolve from PG 1159 stars (see Dreizler & Werner 1996 and references therein), it will be of interest to compare the properties of Hewett 1 both to the PNs associated with PG 1159 stars (Napiwotzki 1999) and theoretical models (Görny & Tylenda 2000). The derivation of a reliable age for the PN associated with PG 1034+001 will be of particular interest for constraining the timescales associated with the late stages of evolution of post–asymptotic giant branch stars and the origin of PG 1159 stars and helium-rich WDs.

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The SDSS Web site is located at http://www.sdss.org.