THE ASTROPHYSICAL JOURNAL, 321:L7–L10, 1987 October 1

PC 0910+5625: AN OPTICALLY SELECTED QUASAR WITH A REDSHIFT OF 4.04

MAARTEN SCHMIDT
Palomar Observatory, California Institute of Technology
DONALD P. SCHNEIDER[1]
Institute for Advanced Study
AND
JAMES E. GUNN[2]
Princeton University
Received 1987 June 15; accepted 1987 July 13

ABSTRACT

In this *Letter* we report the discovery of the second quasar with a redshift greater than 4. This object, which has an r magnitude of 21.0, was detected on a CCD grism survey. The spectrum of the quasar has strong, relatively narrow (but resolved) emission lines; there is a deep absorption trough ~ 100 Å wide on the blue wing of the Lyman-α line; and the continuum at wavelengths shorter than the absorption feature is far weaker than the level present redward of Lyman-α.

Subject headings: cosmology — quasars

After a decade of quiescence, the search for quasars with redshifts larger than 3.5 has become an extremely active field. In the past 5 yr, the largest known redshift has been raised from 3.78 (PKS 2000−330; Peterson *et al.* 1982) to 3.80 (1208+1011; Hazard, McMahan, and Sargent 1986), and most recently up to 4.01 (0046−293; Warren *et al.* 1987). These three quasars, like most of their high-redshift ($z > 3$) brethren, are relatively bright (m_R = 17.3, 17.5, and 19.2 for PKS 2000−330, 1208+1011, and 0046−293, respectively); surveys for low-luminosity ($m \approx 21$) high-redshift quasars have yielded far fewer objects than one would have expected based on extrapolation from lower redshifts (Koo and Kron 1980; Osmer 1982; Schmidt, Schneider, and Gunn 1986*a*). What is especially promising about the recent observations is that the three listed quasars were identified via different survey techniques: PKS 2000−330 from a radio catalog, 1208+1011 by objective prism survey plates, and 0046−293 from broad-band colors. For the past several years we have undertaken surveys to find faint, high-redshift quasars (Schmidt, Schneider, and Gunn 1986*a*, *b*, 1987). In this *Letter* we report the discovery of the second quasar with a redshift greater than 4.

The quasar was first noticed in a 4-Shooter (Gunn *et al.* 1987) transit grism survey performed in 1985 December (see Schmidt, Schneider, and Gunn 1986*a*, *b*, 1987 for descriptions of the observational and data analysis techniques). The survey was centered at declination +56°16′ (epoch 1985.9) and has a width of 8′.5. Intermittent clouds reduced the useful area of the survey to only 4.1 deg^2. In addition to transparency problems, the data also suffered from poor (2″.5) seeing; this resulted in a spectral resolution of 200 Å. In this survey each object was recorded by two of the four Texas Instruments 800 × 800 CCDs; at this declination the effective integration time was 62 s. Spectra covering a wavelength range of 4400–7500 Å of over 40,000 objects were extracted from the data and wavelength-calibrated and flux-calibrated. A search of this data base for emission lines yielded a sample of over 100 candidates. PC 0910+5625 was noted to have a strong line at ~ 6200 Å; this, combined with a sudden change in continuum level across the line, made it a prime candidate for a quasar with a redshift of ~ 4.1. Figure 1 (Plate L1) is a finding chart for PC 0910+5625, and the fully processed grism spectrum of the object is presented in Figure 2.

A moderate-resolution spectrum of the candidate was acquired on 1987 April 26 with the 4-Shooter spectrograph (Gunn *et al.* 1987) mounted at the Cassegrain focus of the Hale telescope. The seeing was excellent (~ 1″) during the exposure, but the sky conditions ranged from moderately clear to quite cloudy. A 1″.5 slit, 200 line mm^{-1} grating, and an 800 × 800 Texas Instruments CCD combined to form spectra from 4500 to 9000 Å at a resolution of 25 Å. The slit was oriented to minimize losses due to differential atmospheric dispersion. The wavelength scale was determined from an Ar-He-Ne arc; the rms error of a cubic fit to the lines was 0.7 Å. The relative flux calibration was set by observations of the F subdwarf standards of Oke and Gunn (1983). Figure 3 shows the result of this 3000 s integration.

The slit spectrum confirms the basic features of Figure 2: a strong emission feature at 6131 Å and a discontinuity in the continuum across the line. The emission line, as expected, is Lyman-α, and the extended wavelength coverage, resolution, and signal-to-noise ratio in the slit spectrum allows the iden-

[1]Guest Investigator, Palomar Observatory, California Institute of Technology.
[2]Visiting Associate, Palomar Observatory, California Institute of Technology.

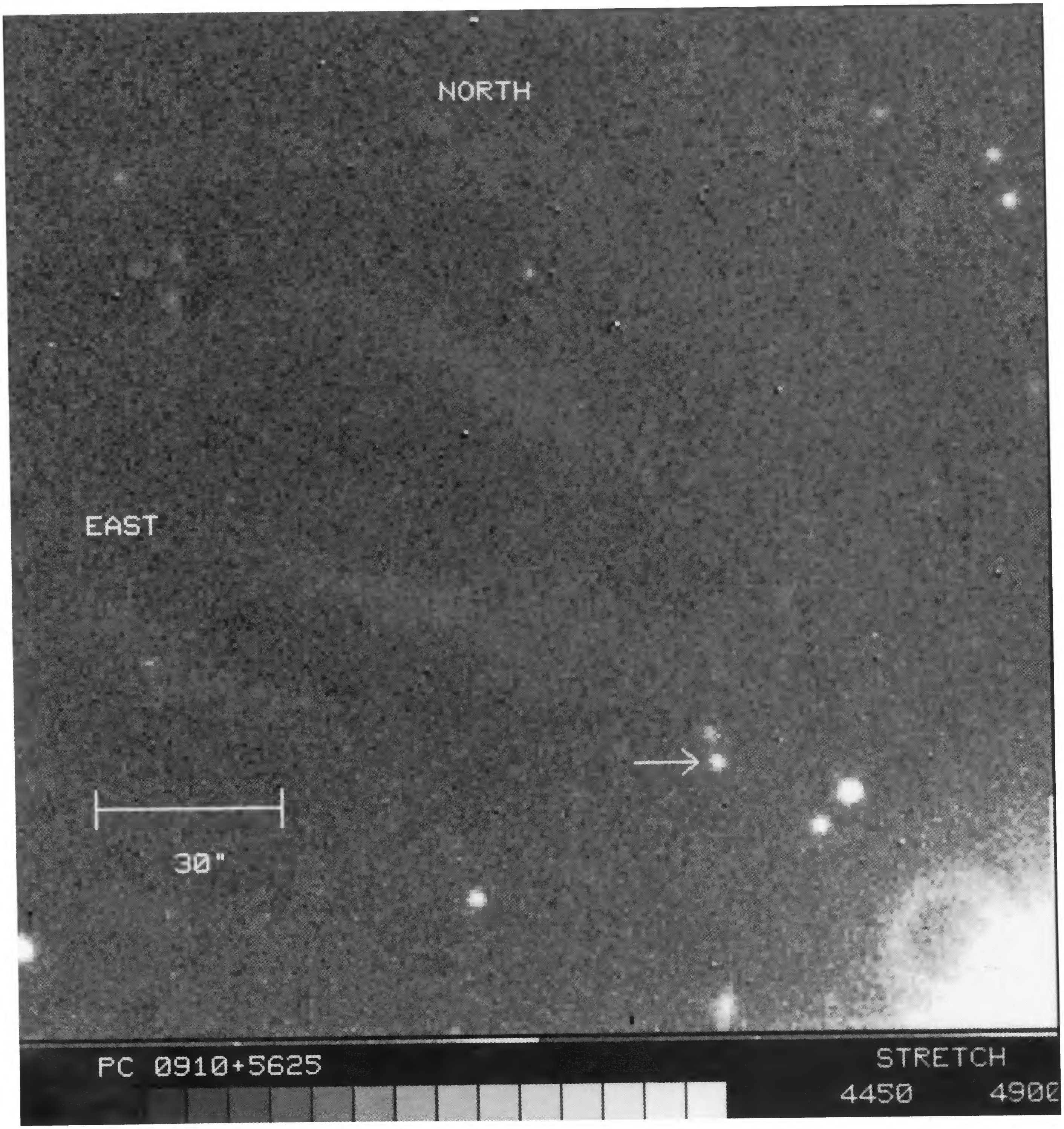

FIG. 1.—A finding chart for PC 0910+5625. North is up, east to the left, and the field is 168″ on a side. The picture is a 200 s exposure through the *r* filter of Thuan and Gunn (1976) taken with the 4-Shooter imaging system mounted on the Hale telescope.

SCHMIDT, SCHNEIDER, AND GUNN (*see* **321**, L7)

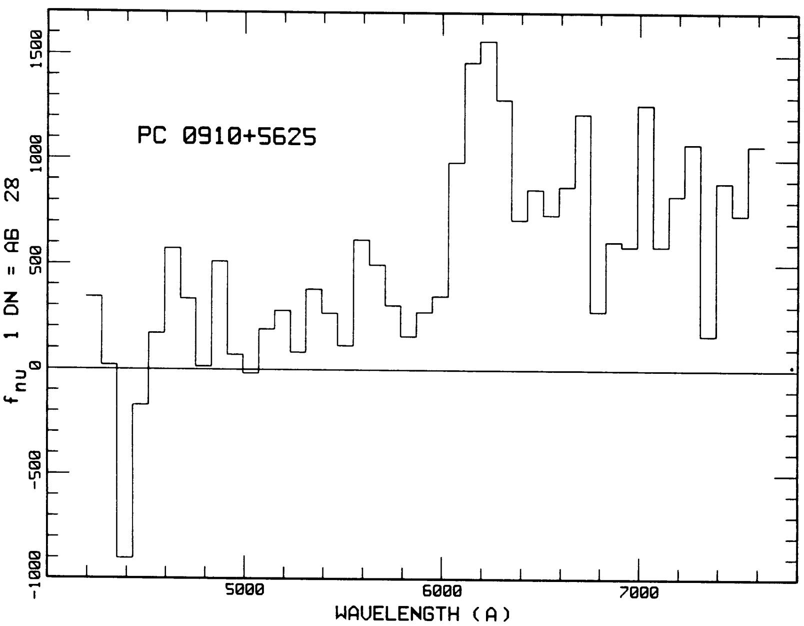

FIG. 2.—The 200 Å resolution 4-Shooter grism spectrum of PC 0910+5625 acquired in 1985 December. The effective exposure time was 62 s. The data are binned at 80 Å per pixel. On the vertical scale, 1 data number = AB magnitude 28 ($f_\nu = 2.29 \times 10^{-31}$ ergs s^{-1} cm^{-2} Hz^{-1}).

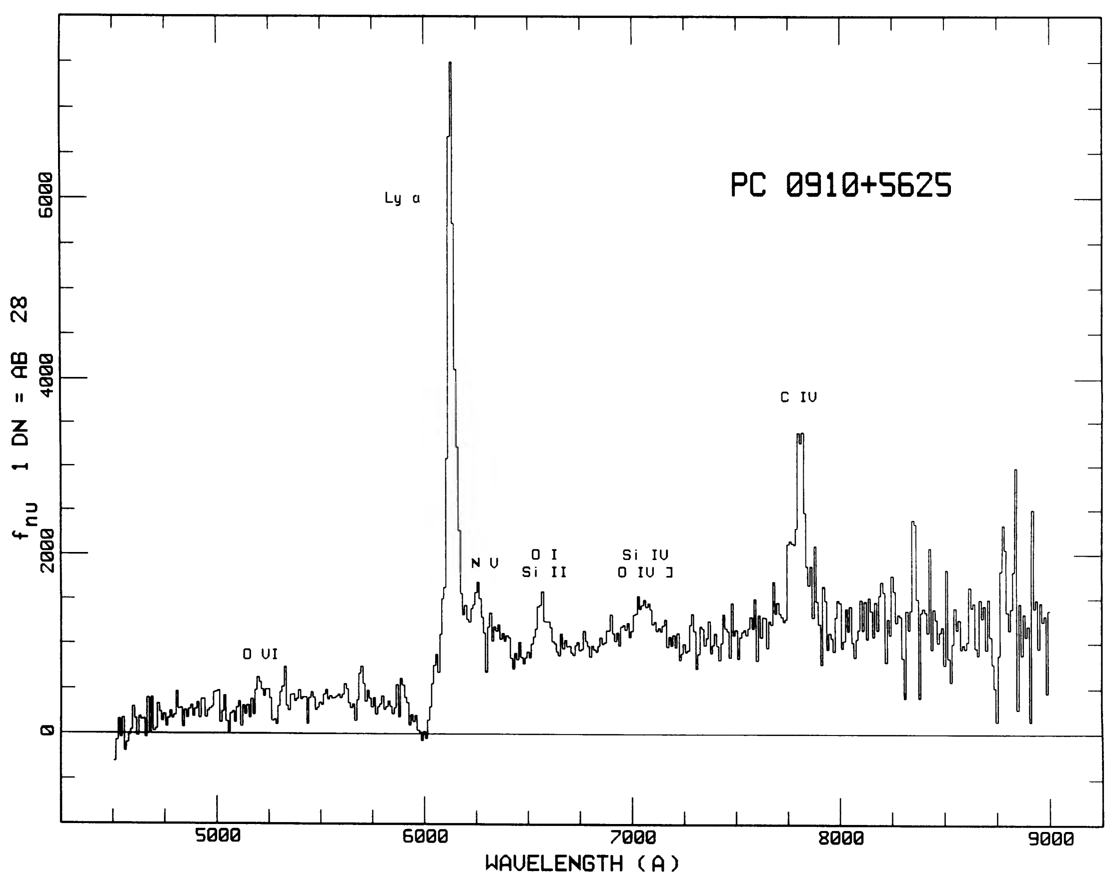

FIG. 3.—A 3000 s spectrum of PC 0910+5625 taken with the 4-Shooter spectrograph. The data are binned at 10 Å per pixel, and the resolution of the spectrum, taken through a 1''.5 slit, is 25 Å. The flux scale is only approximate. Prominent emission lines are labeled. Note the deep absorption trough on the blue wing of the Lyman-α line.

TABLE 1

SPECTROSCOPIC FEATURES IN PC 0910+5625

Line	λ_{vac} (Å)	λ_{air} (observed)	Redshift	Observed Equivalent Width (Å)	σ (Å)
O VI	1033.8	5213	4.044	44	17
Lyα (abs)	1215.7	5987	3.925	−78	26
Lyα (em)	1215.7	6131	4.045	210	12
Nv	1240.1	6251	4.042	23	14
O I, Si II	1306	6568	4.031	39	23
Si IV, O IV]	1402	7044	4.025	63	64
C IV	1549.1	7806	4.040	122	30

tification of five other emission lines. The wavelengths, strengths, and widths of these features are listed in Table 1.

The spectrum is qualitatively the same as that for other high-redshift quasars (compare Fig. 3 with spectra in Peterson *et al.* 1982, Sargent *et al.* 1986, and Warren *et al.* 1987). A striking feature of the spectrum of PC 0910+5625 is the width of the lines; they are resolved, but quite narrow (FWHM ≈ 30 Å). A very deep, wide absorption trough is present on the blue side of the Lyman-α line (the flux drops to zero in the center at this resolution), but the absorption does not appear to grossly disfigure the Lyman-α line (or at least the sharp emission core); the redshift derived from Lyman-α is only marginally larger than the C IV redshift. The spectrum extends down to the rest frame wavelength of 895 Å. The rest frame equivalent width of Lyman-α (42 ± 7 Å) is considerably smaller than the mean of nine high-redshift quasars found in another grism survey (90 Å; Schmidt, Schneider, and Gunn 1987), but this low value is probably caused by a combination of the unusual line shape (the entries in Table 1 are measured by fits of Gaussian line profiles to the data; Fig. 3 shows that there may be a broad component of the Lyman-α emission to the red that would not be included in the equivalent width measurement) and, because of the deep absorption feature at 6000 Å, the continuum measurement was made only on the red side of the Lyman-α line. A comparison with other $z \approx 4$ quasars reveals that the strengths of the Lyman-α and C IV lines in PC 0910+5625 are similar to the values measured in 1208+011 (Sargent *et al.* 1986) and 0046−293 (Warren *et al.* 1987).

The width and depth of the absorption feature make it a good candidate for a damped Lyman-α system (Wolfe *et al.* 1986). The rest frame equivalent width (16 Å) is typical of these systems; in fact, when investigated in detail, all features with $W > 13$ Å have proven to be damped Lyman-α (see Fig. 4 of Wolfe *et al.* 1986); it is possible, however, that this absorpion is a superposition of several features that cannot be separated at 25 Å resolution. If the trough in PC 0910+5625 is indeed damped Lyman-α, and, as seems likely, the damped systems are formed in galactic disks, it would suggest that such disks were formed before a redshift of 4.

TABLE 2

POSITION AND MAGNITUDES OF PC 0910+5625

Parameter	Value
Right ascension (1950.0)	$09^h10^m57^s.3$
Declination (1950.0)	+56°25′49″
Redshift	4.040 ± 0.005
g	22.29 ± 0.16
r	20.95 ± 0.05
M_B	−25.6

Photometry of the quasars in the g (5000 Å) and r (6500 Å) filters of the Thuan and Gunn (1976) system was acquired with the 4-Shooter on 1987 May 5 (the r frame was used to produce Fig. 1). The magnitudes listed in Table 2 are in good agreement with the grism data (Fig. 2). The flux calibration of the slit spectrum is uncertain because of marginal observing conditions. The equivalent absolute B magnitude (Schmidt and Green 1983) was calculated from the r measurement, assuming a spectrum with $f_\nu \propto \nu^{-0.5}$, $H_0 = 50$ km s^{-1} Mpc^{-1}, and $q_0 = 0.5$. There is a faint ($r = 21.6$) object located ∼ 6″ north of the quasar. Although the slit was not oriented to obtain a spectrum of the companion, the alignment was close enough so that a weak signal from the object appeared in the data; while we cannot precisely classify the spectrum, we can state that the companion lacks any strong emission lines.

This research was supported in part by National Science Foundation grants AST83-14134 and AST84-20352, NASA contract NAS5-29225, and the John D. and Catherine T. MacArthur Foundation. D. P. S. acknowledges the support of an Exxon fellowship.

REFERENCES

Gunn, J. E., *et al.* 1987, *Opt. Eng.*, in press.
Hazard, C., McMahon, R. G., and Sargent, W. L. W. 1986, *Nature*, **322**, 38.
Koo, D. C., and Kron, R. G. 1980, *Pub. A.S.P.*, **92**, 537.
Oke, J. B., and Gunn, J. E. 1982, *Pub. A.S.P.*, **94**, 586.
Osmer, P. S. 1982, *Ap. J.*, **253**, 28.
Peterson, B. A., Savage, A., Jauncey, D. L., and Wright, A. E. 1982, *Ap. J. (Letters)*, **260**, L27.

Sargent, W. L. W., Filippenko, A. V., Steidel, C. C., Hazard, C., and McMahon, R. G. 1986, *Nature*, **322**, 40.
Schmidt, M., and Green, R. F. 1983, *Ap. J.*, **269**, 352.
Schmidt, M., Schneider, D. P., and Gunn, J. E. 1986*a*, *Ap. J.*, **306**, 411.
______. 1986*b*, *Ap. J.*, **310**, 518.
______. 1987, *Ap. J. (Letters)*, **316**, L1.
Thuan, T. X., and Gunn, J. E. 1976, *Pub. A.S.P.*, **88**, 543.
Warren, S. J., Hewett, P. C., Irwin, M. J., McMahon, R. G., Bridgeland, M. T., Bunclark, P. S., and Kibblewhite, E. J. 1987, *Nature*, **325**, 131.
Wolfe, A. M., Turnshek, D. A., Smith, H. E., and Cohen, R. D. 1986, *Ap. J. Suppl.*, **61**, 249.

JAMES E. GUNN: Peyton Hall, Princeton University Observatory, Princeton, NJ 08544

MAARTEN SCHMIDT: 105-24 Robinson Hall of Astrophysics, California Institute of Technology, Pasadena, CA 91125

DONALD P. SCHNEIDER: Institute for Advanced Study, The School of Natural Sciences, Princeton, NJ 08540