NOTICE

FINAL TECHNICAL REPORT

for

NASA Grant No. NSG 5377

Entitled: "OBSERVATIONS OF INTERSTELLAR ZINC"

Submitted by

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA
UNIVERSITY OF CALIFORNIA, LOS ANGELES
DEPARTMENT OF ASTRONOMY
405 HILGARD AVENUE
LOS ANGELES, CALIFORNIA 90024

Period of Performance: June 1, 1979 - August 31, 1981

PRINCIPAL INVESTIGATOR:

Michael A. Jura, Professor
Department of Astronomy
Office Phone; (213) 825-4302

N81-31043

(NASA-CR-164711) OBSERVATIONS OF INTERSTELLAR ZINC Final Technical Report, 1 Jun. 1979 - 31 Aug. 1981 (California Univ.) 23 p HC A02/MF A01 CSCL 03A

G3/89 Unclas 27288

This work was funded to conduct IUE observations of interstellar zinc. The manuscript has been written with Dr. D. York of Princeton University and is currently in press in the Astrophysical Journal. A copy of the preprint is enclosed. When the paper appears in press, five copies will be sent of the reprint. The scientific accomplishments are listed in the Abstract of the manuscript.

There were no inventions developed on this grant.

OBSERVATIONS OF INTERSTELLAR ZINC

D.G. York

Princeton University Observatory

and

M. Jura

Department of Astronomy, UCLA

Received 1981 June 29;

ABSTRACT

We have performed IUE observations of interstellar zinc toward 10 stars. We find that zinc is at most only slightly depleted in the interstellar medium; its abundance may serve as a tracer of the true metallicity in the gas. The local interstellar medium has abundances that apparently are homogeneous to within a factor of two, when integrated over paths of about 500 pc, and this result is important for understanding the history of nucleosynthesis in the solar neighborhood. In an appendix we analyze the intrinsic errors in detecting weak interstellar lines and we suggest how this error limit may be lowered to 5 mÅ per target observation.

Subject headings: interstellar: abundances - ultraviolet: spectra

I. INTRODUCTION

Interstellar gas phase abundances have been measured in a wide variety of interstellar clouds (Spitzer and Jenkins 1975). Refractory elements, such as aluminum, are depleted by factors up to 1000, and it is generally assumed that this gas phase depletion results from the material being contained within interstellar grains (e.g., Morton 1975, Field 1974). However, a few elements, such as sulfur (Spitzer and Jenkins 1975) and chlorine (Jura and York 1978) may be only slightly depleted, and the gas phase abundances of these species may reflect their true abundances. Toward ζ Oph, Morton (1975) reported that zinc is undepleted. We have used IUE to observe Zn II, the dominant form of zinc, in additional lines of sight to determine whether this phenomenon is more widespread.

Since we in fact do find that zinc generally appears to be undepleted, our observations can be used to estimate or place limits on the variability of the true metallicity in the interstellar gas in the solar region. A particular application of such a study is to investigate the lines of sight where the deuterium abundance varies (Laurent, Vidal-Madjar and York 1979). If deuterium has a cosmological origin, if deuterium is destroyed by processing through stars, and if the present interstellar abundance of zinc is due to ever-increasing enrichment of gas processes through stars, we might expect an anticorrelation between the deuterium and zinc abundances. Therefore, our observations can in principle serve to test the assumption that deuterium has a cosmological origin and therefore to determine whether the deuterium abundance can be used to estimate the mean density of the universe (Rogerson and York 1973).

II. OBSERVATIONS

We have used the IUE in the short wavelength, high resolution mode (Boggess et al. 1978) to observe the zinc doublet near 2000 Å toward ten stars. We selected the stars on the basis that: i) they have been well observed with Copernicus to measure hydrogen column densities; ii) they have moderate amounts of reddening so that the zinc lines should be detectable but not saturated; iii) the stars are rapid rotators so we do not confuse stellar and interstellar lines. Our observations and reduction procedure did not follow standard IUE practice; we describe them in more detail in the Appendix.

In Table 1 we present our measurements of the equivalent widths. Unfortunately, both zinc lines are somewhat blended with broad stellar lines and it is difficult to determine accurately the continuum level. Therefore, in every case, we assume at least a 20% uncertainty in the equivalent width; in some cases our measurements are more uncertain and are so listed. Only toward 29 CMa and 30 CMa does there appear to be any blending between Zn II 2025.52 and Mg I 2025.81; even in these two lines of sight, the separation of the two spectral lines is not especially ambiguous. We conclude that our zinc abundances are not affected by the presence of line blends.

III. COLUMN DENSITIES AND ABUNDANCES

In the optically thin limit, we expect that W_λ (2025 Å) = $2W_\lambda$ (2062 Å) where W denotes the equivalent width. In this case, with the f values of Morton

(1975), the derivation of the column density is straightforward (e.g., Spitzer 1978), although this analysis presumes that there are no clouds with very narrow velocity dispersions in the line of sight (Nachman and Hobbs 1973). However, a basic difficulty we face in deriving column densities is in estimating the amount of saturation. Because we have at least 20% errors in each equivalent width, we can almost never exclude the possibility that there is some saturation.

To estimate a rigorous lower bound to the column density, we have used the measured equivalen width of the weaker Zn II line at 2062 Å and we assumed that the line lies on the linear portion of the curve of growth. The results of this procedure are listed in Table 2. Even in this case where we assume no saturation, we find an average zinc abundance of $(1.6 \pm 0.5) \times 10^{-8}$, while Ross and Aller (1976) have argued that the solar zinc abundance is $(2.8 \pm 0.8) \times 10^{-8}$. Therefore we can conservatively argue that zinc is usually not depleted by more than a factor of 2; it may generally be undepleted.

IV. DISCUSSION

Our first conclusion is that zinc is not depleted in the interstellar medium by more than a factor of 2. While there is no generally accepted model for the selective depletion of certain elements, our result can serve to constrain the possible models (Barlow 1978, Duly and Millar 1978). That is, depletion onto grains is not inevitable, but depends upon the surface chemistry of the grains.

Second, our result that zinc is not generally depleted indicates that the zinc abundance can serve as an approximate tracer of the true metallicity in different regions. It appears that our measurements of zinc agree with the view that the local interstellar medium is homogeneous to within a factor of 2 (Jura 1980). This result should serve to test any comprehensive model for galactic evolution (see Reeves 1972, Chevalier 1979).

Our data are not of high enough resolution to draw this conclusion for individual components, but rather to apply to integrated abundances over lines of sight of 100 to 500 pc, each of which has at least five interstellar components. Cowies and York (1978), Hobbs (1974), Ferlet et al. (1980) and Martin and York (1981) find evidence for larger variations in [Ar/N] and [Ar/S] from component to component.

Finally, we consider the possible correlation between zinc and deuterium abundances. We have observed five lines of sight in common with the study of Laurent, Vidal-Madjar and York (1979), and the result is shown in Figure 1. The errors are large and do not rule out an anticorrelation in Zn and D column densities. However, the data suggest that zinc and deuterium abundances are, if anything, correlated rather than anticorrelated. Our result, if true, is inconsistent with the hypothesis that deuterium has a cosmological origin, if elements heavier than carbon are produced by several generations of processing primordial gas through stars. However, our result disagrees with that of Penzias (1979) who finds an increase in deuterium abundance outward from the Galactic Center, as would be expected if there has been less stellar processing in the outer regions of the galaxy. It is important to obtain very precise data for those elements which generally show low depletion (N I, Lugger et al. 1978, Cl II, P II, Jura and York 1978) as well as of D I in the same line of sight, to provide more definitive results from this straightforward test of galactic evolution. This test should be valid on an integrated line-of-sight basis and need not require observations at the highest resolutions, except that higher resolution generally assures more precise column densities.

This work has been partly supported by NASA; both authors were guest investigators on the IUE Satellite. M.J. has been an Alfred P. Sloan Foundation Fellow.

APPENDIX

I. INTRODUCTION

To obtain abundances of elements in interstellar gas, high-precision equivalent widths are needed Since individual IUE spectra are generally not of sufficient precision for interstellar studies, we took several spectra of each star. In this Appendix, we quantify the behavior of noise in high-dispersion IUE spectra, discuss its possible origin and describe ways to improve future observations.

II. DATA ANALYSIS

A. Fixed-Pattern Noise

Other IUE observers (T.P. Snow, private communication and T.P. Stecher, private communication) have found that adding IUE spectra does not lead to the increase in signal-to-noise ratio expected if the noise were random; the presence of detector-induced, fixed-pattern noise seems likely. Our original goal was to remove this noise.

Because we suspected that there might be short-term drifts in the calibration of the instrument, we obtained calibration spectra with our own observing time soon after we performed our actual observations. The spectra within ± 500 km s^{-1} of each zinc line were reduced with standard IUE programs, and then averaged at Princeton. The observations were accumulated over five days in 1979, and a brief observation log is given in Table A1. For each star we give the number of spectra, the GMT interval for the observations, the IUE image numbers, the temperature, T, of the spectrograph as recorded in the observing log, and the noise amplitude attributed to microphonics in IUE Data Numbers (DN). The last item is discussed in detail later.

To analyze the data, we define the following quantities:

S = Average signal level of all points in a single spectrum;

$\overline{S}$ = Average signal for all spectra of one star;

R_s = Root mean square deviations of a single spectrum, i.e., a single IUE image, from a smooth curve fitted through the spectrum;

R_o = rms deviations of individual spectra with the mean of all spectra of that star;

R_A = rms deviations of the average spectrum of a star with a smooth curve fitted through the mean spectrum;

R'_A = Predicted value of R_A, assuming that the errors R_o are random in origin: $R'_A \equiv R_o/\sqrt{N}$, where N is the number of spectra available;

R_N = Residuals (rms) with respect to a smooth curve of the average spectrum of a given star divided by the spectrum of a standard star.

To compute the above quantities, each spectrum was fitted with a series of cubic splines so the curve was smooth and differentiable. The results for these different quantities for all our stars are given in Table A2. Tabulated are the star, the number of spectra, $\bar{S}$, the average value R_s/S, $R_A/\bar{S}$, $R'_A/\bar{S}$, and R_N. For R_N, we choose as a standard star HD 120315 (η UMa) because of its generally flat spectrum, free of undulations from stellar lines.

Sample spectra are shown in Figures A1 and A2. Visual inspection shows that the noise in a given spectral region is similar in the spectra of different stars. Note particularly the obvious features near - 200 km s^{-1} and - 20 km s^{-1} in the 2025 Å region and the general similarity from - 300 to - 500 km s^{-1} in the 2062 Å region. These fluctuations are presumably the fixed pattern discussed below.

The strongest argument for a noise source other than that which results from counting statistics or other random processes is based on the comparison of (R_s/S) and (R_o/S). The former is always greater than the latter by much more than a standard deviation. This indicates that the random noise in a single spectrum measured with respect to the mean of several spectra is less than the apparent noise in an individual spectrum measured with respect to a reasonably drawn mean. Evidently, at least one component of the noise reoccurs at the same wavelength(s) for all the spectra of the same star taken close together in time.

The absolute values of R_s/S indicate that 4% fluctuations, or a signal-to-noise ratio of 25:1, are normal in a single high-dispersion spectrum from IUE. The spectral resolution is nominally 0.15 Å for the Zn II lines, so the 1 σ detection limit is between 6 and 10 mA, depending upon the number of resolution elements incorporated into a line measurement. Detections at the 3 σ level are thus limited to lines with W > 20 mA. If the non-random noise could be removed, we expect that with five spectra 1 σ errors of 1.4% or 2 mA might be achievable. Here we have taken (R_o/S) as a measure of the random error (~ 3%) and divided by $\sqrt{5}$. Detailed predictions of the achievable error in each case we studied are listed as $R_A'/\overline{S}$ in Table A2.

If the pattern of non-random noise is constant with time in the IUE detectors, then dividing an average spectrum by the spectrum of a standard continuum source should remove the fixed pattern. To test this, we divided each spectrum by the average of HD 120315 after excluding the spectral regions of the interstellar absorption lines. If the pattern is fixed, and if both the stellar spectrum and the standard have 1.4% noise because each average contains 4 to 6 spectra, the final quotient should show rms noise of 2%. However, values of 3% are found. We conclude that while a fixed pattern of noise apparently exists, it is not constant with time.

Since the fixed pattern may change with time, we present in Table A3 the results of analyses using standard stars, for which data were obtained within a few hours of the main spectrum. Table A3 gives the star and standard star, the number of spectra of each, the mean time of observation, and three measures of the rms errors: R_N', R_N'', and R_N. R_N is taken from Table A2. R_N' is calculated, using the new standard star, like R_N. R_N'' is the predicted minimum error, assuming fixed pattern can be completely removed, but accounting for random errors in both spectra. The latter are the values R_A from Table A2.

It is apparent from Table A3 that the fixed pattern is nearly removed for HD 68273 (γ^2 Vel) when we used HD 66811 (ζ Pup) as a standard instead of HD 120315 (η UMa). For HD 24760, the residuals can be seen to be nearly as predicted for purely random noise for the 2025 Å spectrum. For HD 37128, use of a standard star spectrum obtained on the same day definitely improves the signal-to-noise, though ideal performance is not achieved. For HD 37742, no improvement is achieved. Reference to the temperatures in Table A1 shows that apparent shifts in fixed pattern are not uniquely related to temperature. Both HD 24760 and HD 37128 were observed at temperatures about 0.6 K above that found for the respective standards, yet for the former we obtain excellent results, while for the latter our ideal performance was not achieved. Spectra of HD 68273 and HD 37742 were obtained at the same temperature as the respective standards, yet one gives nearly ideal performance while the other has errors too large by a factor of 2. Comparison of two spectra of HD 36486 with spectra taken on the same day, and again with spectra obtained on a preceding day, show comparable errors. In both cases, ΔT was about 0.5 K.

B. Random Noise

Besides the fixed-pattern noise, there is random noise in our data. It presumably consists of photon noise, particle noise and microphonic noise. The particle background is negligible for our short exposures of bright stars. The microphonic noise is caused by capacitance changes between the target and mesh in the vidicon tubes as target vibrations are triggered, either by spacecraft vibrations or by the read-beam itself. The amplitude of the microphonics noise (recorded by the IUE staff for each exposure) is typically 2 DN for SWP exposures. Since an ideal exposure is about 200 DN/pixel, microphonics may account for errors of 1% or more in individual spectra. In this case, we find 4% errors to be typical (see R_s/N, Table A2), so photon noise is usually the dominant source of random noise. We note that only HD 37128 was observed under conditions giving no detectable microphonic noise (last column, Table A1). Table A2 shows that the residuals obtained are not much different from those found in other spectra.

III. SUMMARY

We have found that a significant fixed-pattern noise is present at 2025 Å and 2062 Å in IUE high-dispersion images made with the Short Wavelength Prime Camera. This fixed pattern shifts on time scales as short as one hour and it certainly drifts from day to day. Microphonics are not an important source of random noise, so long as the measured amplitude is less than 2 DN. Errors of 1 to 3% can be obtained using five spectra and a well-chose standard star.

Further improvement in IUE performance may be possible. We suggest that pattern recognition be used to derive the fixed-pattern noise for each image independently of any other image so that it will not be necessary to have standard star and target spectra obtained close together in time. This procedure is presently difficult because of the non-uniform illumination perpendicular to the orders of the Echellogram. However, trailed high-dispersion spectra would be better adapted to pattern recognition, and for bright stars such as those discussed here there would be the additional advantage of obtaining more photons/unit time. For bright stars such as those discussed here, an exposure takes only 6 seconds, but 40 minutes must elapse before the next exposure. Using trailed spectra, more photons are obtained in a given exposure. If the fixed pattern can be identified and removed, so the camera is nearly photon-limited, this procedure increases the observing efficiency by at least a factor of 3. (Trailing is not a useful technique at shorter wavelengths on either IUE camera because the echelle orders overlap.) We conclude that 1% rms errors might be achieved by averaging five spectra if the non-random noise discussed could be removed.

Table 1

Equivalent Widths of Zinc II Lines Toward Observed Stars

Star	W_λ (2062 Å) mÅ	W_λ (2025 Å)
ζ Pup	20 ± 4	31 ± 6
ε Ori	41 ± 9	41 ± 10
ε Per	32 ± 7	40 ± 8
γ Vel	9 ± 5	21 ± 6
κ Ori	31 ± 6	50 ± 10
ζ Ori	19 ± 6	40 ± 8
δ Ori	22 ± 6	31 ± 6
ι Ori	17 ± 10	20 ± 10
29 CMa	72 ± 8	134 ± 10
30 CMa	55 ± 9	146 ± 8

Table 2

Column Densities and Abundances of Zinc

Toward Observed Stars

Star	NH	N(Zn)	a(Zn)
ε Per	$3.2 \cdot 10^{20}$	$4.3 \cdot 10^{12}$	$1.3 \cdot 10^{-8}$
δ Ori	$1.7 \cdot 10^{20}$	$2.5 \cdot 10^{12}$	$1.5 \cdot 10^{-8}$
ι Ori	$1.4 \cdot 10^{20}$	$2.2 \cdot 10^{12}$	$1.6 \cdot 10^{-8}$
ε Ori	$2.8 \cdot 10^{20}$	$5.4 \cdot 10^{12}$	$1.9 \cdot 10^{-8}$
ζ Ori	$2.6 \cdot 10^{20}$	$2.5 \cdot 10^{12}$	$1.0 \cdot 10^{-8}$
κ Ori	$3.3 \cdot 10^{20}$	$4.1 \cdot 10^{12}$	$1.2 \cdot 10^{-8}$
29 CMa	$5.0 \cdot 10^{20}$	$9.5 \cdot 10^{12}$	$1.9 \cdot 10^{-8}$
30 CMa	$5.0 \cdot 10^{20}$	$7.2 \cdot 10^{12}$	$1.4 \cdot 10^{-8}$
ζ Pup	$0.97 \cdot 10^{20}$	$2.6 \cdot 10^{12}$	$2.7 \cdot 10^{-8}$
γ Vel	$0.6 \cdot 10^{20}$	$1.2 \cdot 10^{12}$	$2.0 \cdot 10^{-8}$

Table A1

Log of Observations

	GMT	Star	No. of Spectra	SWP Images	T(°K)	Noise (DN)
272	12:03-14:33	HD 68273	5	6672-6676	6.1(+.3,-.3)	2
272	08:30-10:29	HD 66811	5	6665-6669	5.9(+.2,-.1)	2
272	15:15-15:42	HD 36486	2	6677-6678	6.1(+0,-0)	2
		CAL	2	6670-6671		
273	08:07-09:27	HD 36486	4	6682-6685	5.5(+.3,-.4)	2
273		HD 37043	2	6688-6689	5.3(+.2,-.2)	2
273	13:01-15:11	HD 37742	6	6690-6695	5.4(+.1,-.3)	2
		CAL	2	6686-6687		
275	07:32-09:25	HD 24760	5	6707-6711	7.0(+.2,-.2)	2
275	12:26-13:41	HD 120315	4	6714-6717	6.3(+.2,-.2)	2
		CAL	2	6712-6713		
276	07:34-09:17	HD 37128	5	6724-6728	6.8(+0,-0)	0
276	11:22-13:38	HD 38771	6	6731-6736	6.3(+.2,-.2)	2
		CAL	2	6729-6730		
277	07:43-09:46	HD 57060	5	6740-6744	6.8(+.4,-.3)	2
277	11:55-13:25	HD 57061	4	6747-6750	6.8(+0,-0)	2

Table A2

Statistical Data on IUE Spectra

A. 2025 Å

Star	Number of spectra	$\overline{S}$	(R_s/S)	(R_o/S)	$R_A/\overline{S}$	$R'_A/\overline{S}$	R_N
120315	4	17.3	.026(.003)	.024	.024	.012	--
24760	5	22.3	.040(.003)	.027	.032	.012	.022
36486	6	22.3	.037(.005)	.026	.026	0.011	.031
37043	2						.029
37128	5	24.6	.033(.002)	.023	.020	.010	.042
37742	6	21.5	.034(.004)	.024	.023	.010	.027
38771	6	22.8	.038(.004)	.028	.025	.011	.036
57060	5	22.5	.037(.005)	.024	.025	.011	.027
57061	4	15.0	.040(.003)	.027	.030	.014	.023
66811	5	19.3	.037(.003)	.026	.024	.012	.025
68273	5	22.0	.037(.003)	.024	.026	.011	.026

B. 2062 Å

Star	Number of spectra	$\overline{S}$	(R_s/S)	(R_o/S)	$R_A/\overline{S}$	$R'_A/\overline{S}$	R_N
120315	4	16.0	.037(.003)	.028	.021	.014	--
24760	5	19.8	.044(.008)	.030	.031	.013	.038
36486	6	20.7	.038(.002)	.032	.022	.013	.030
37043	2						.022
37128	5	22.3	.044(.006)	.033	.020	.015	.029
37742	6	19.9	.043(.004)	.034	.025	.014	.026
38771	6	19.9	.049(.008)	.034	.021	.014	.024
57060	5	20.6	.036(.008)	.029	.021	.013	.027
57061	4	14.5	.048(.005)	.036	.032	.018	.030
66811	5	18.2	.042(.003)	.030	.025	.013	.029
68273	5	21.7	.039(.003)	.025	.026	.011	.035

Table A3

Comparisons of Spectra Taken at Different Times

	Spectrum	#	Day	Hr.		2025			2062	
					R_N'	R_N''	R_N	R_N'	R_N''	R_N
Spectrum	68273	5	272	10	.017	.016	.026	.019	.017	.035
Standard	66811	5	272	13						
Spectrum	37742	6	273	14	.028	.015	.027	.031	.019	.026
Standard	120315	4	273	09						
Spectrum	24760	5	275	08	.022	.017	.022	.038	.019	.038
Standard	120315	4	275	13						
Spectrum	37128	5	276	08	.025	.015	.042	.030	.021	.029
Standard	38771	6	276	12						
Spectrum	36486	2	272	15	.023	---	---	.036	---	---
Standard	36486	2	273	08^h						
Spectrum	36486	2	273	9^h	.025	---	---	.032	---	---
Standard	36486	2	273	8^h						

REFERENCES

Barlow, M.J. 1978, M.N.R.A.S., **183**, 417.

Boggess, A. *et al*. 1978, *Nature*, **275**, 372.

Chavalier, R. 1979, *Mem. Soc. Astr. Ital*., **58**, 65.

Duley, W.W., and Millar, T.J. 1978, *Ap. J*., **220**, 124.

Ferlet, R., Laurent, C., Vidal-Madjar, A., and York, D.G. 1980, *Ap. J*., **235**, 478.

Field, G.B. 1974, *Ap. J*., **187**, 453.

Jura, M. 1980, *Highlights in Astronomy*, **5**, 293.

Jura, M., and York, D.G. 1978, *Ap. J*., **219**, 861.

Laurent, C., Vidal-Madjar, A., and York, D.G. 1979, *Ap. J*., **229**, 923.

Lugger, P.M., York, D.G., Blanchard, T., and Morton, D.C. 1978, *Ap. J*., **224**, 1059.

Martin, E., and York, D.G. 1981, in preparation.

Morton, D.C. 1975, *Ap. J*., **197**, 85.

Nachman, P., and Hobbs, L.M. 1973, *Ap. J*., **182**, 481.

Penzias, A. 1979, *Ap. J*., **228**, 430.

Reeves, H. 1972, *Astr. and Ap*., **19**, 215.

Rogerson, J.B., and York, D.G. 1973, *Ap. J. (Letters)*, **186**, L95.

Ross, J.E., and Aller, L.H. 1976, *Science*, **191**, 1223.

Spitzer, L. 1978, *Physical Processes in the Interstellar Medium*. J. Wiley: New York.

Spitzer, L., and Jenkins, E.B. 1975, *Ann. Rev. Astr. and Ap*., **13**, 133.

FIGURE CAPTIONS

Figure 1. Plot of deuterium abundance versus zinc abundance for the lines of sight for which both quantities are available.

Figure A1. Spectrum in the vicinity of the 2062 Å Zn II lines toward γ^2 Vel and ζ Pup, respectively. The zero level is given by the standard IUE reduction procedure. The dotted line for the γ^2 Vel plot is the quotient of the γ^2 Vel and ζ Pup averaged spectra. Using the solid line through the points (a set of cubic splines), the errors used to compute the quantity R_N are determined. Quantitative comparisons of errors in the averaged γ^2 Vel plot and in the quotient (dotted line) are discussed in the text.

Figure A2. Spectrum in the vicinity of the 2025 Å Zn II lines toward ζ Pup and 29 CMa, respectively. The zero level is given by the standard IUE reduction procedure.

AUTHORS' ADDRESSES

M. Jura

Department of Astronomy

University of California, Los Angeles

405 Hilgard Ave.

Los Angeles, CA 90024

D.G. York

Department of Astrophysical Sciences

Princeton University

Peyton Hall

Princeton, NJ 0854~~0~~4