GODDARD GRANT

16 P.

COSMIC X-RAY PHYSICS

IN - 13090

Grant NAG 5-629

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SEMI-ANNUAL STATUS REPORT

to

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 1, 1986 - June 30, 1986

Submitted by

The Space Physics Group

W456040 9

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July 1986

(NASA-CR-177227) COSMIC X-RAY PHYSICS Semiannual Status Report, 1 Jan. - 30 Jun. 1986 (Wisconsin Univ.) 16 p CSCL 03B

N86-30624

Unclas

G3/93 42954

Introduction

This is our semi-annual progress report for NASA grant NAG5-629 "Cosmic X-ray Physics".

I. Very Soft X-ray Observations

We have completed the analysis of the beryllium-filtered data from Flight 17.020. These data are entirely consistent with a constant Be/B ratio of about 0.11 over the factor of 2 1/2 variation in absolute rates, although the low-rate end of the distribution is poorly represented in this sample (Figures 1-3). The close tracking of the Be and B band rates implies at least that the emission mechanisms are closely related, and in the context of equilibrium plasma emission models, the actual ratio observed is consistent with a unabsorbed single-temperature source near $10^{6.0}$ K, as shown in Figure 4. According to the most recent models, a single plasma with a temperature between $10^{5.9}$ K and $10^{6.1}$ K could provide all of the observed flux in the Be, B, and C bands. An older (but not necessarily less accurate!) version of these models would require about 7×10^{18} HI cm^{-2} of intervening absorption to reduce the Be band flux from a 10^6 K plasma to the observed value.

These results are currently in press (Bloch *et al*. 1986), and we have recently flown the experiment a second time (27.103). It was the only payload on this flight, and the targets were chosen to ensure a good sample of the low B band rate regions that were underrepresented on the first flight. The high-rate regions chosen were also in a different part of the sky than those from the first flight. The new data are not yet fully reduced, but preliminary results analagous to those of Figure 3 are shown in Figure 5. Once again, the data are a reasonable fit to a straight line, and there is no evidence for any change in behavior in the low-rate regions. Final calibration corrections have not yet been applied to these data.

The most straightforward conclusion that can be drawn from these new observations is that we should go to the simple-minded picture of a cavity surrounding the Sun, filled with $\sim 10^{6.0}$ K gas and very little else, and extending ~40 - 200 pc in various directions. Since any interstellar absorption that significantly affected the B or C band rates would produce a drastic change in the Be/B ratio (the effective absorption cross sections are a factor of seven different for the two bands), the observed anticorrelation of B band rate and HI column density must be due to variations in the extent of the cavity which leave more or less room for neutral hydrogen outside it. This necessitates a re-examination of blast wave models of the local cavity, which produce X-rays primarily near the walls, and favors a modification where the hot gas is considerably older and X-ray emission more uniformly distributed throughout the cavity.

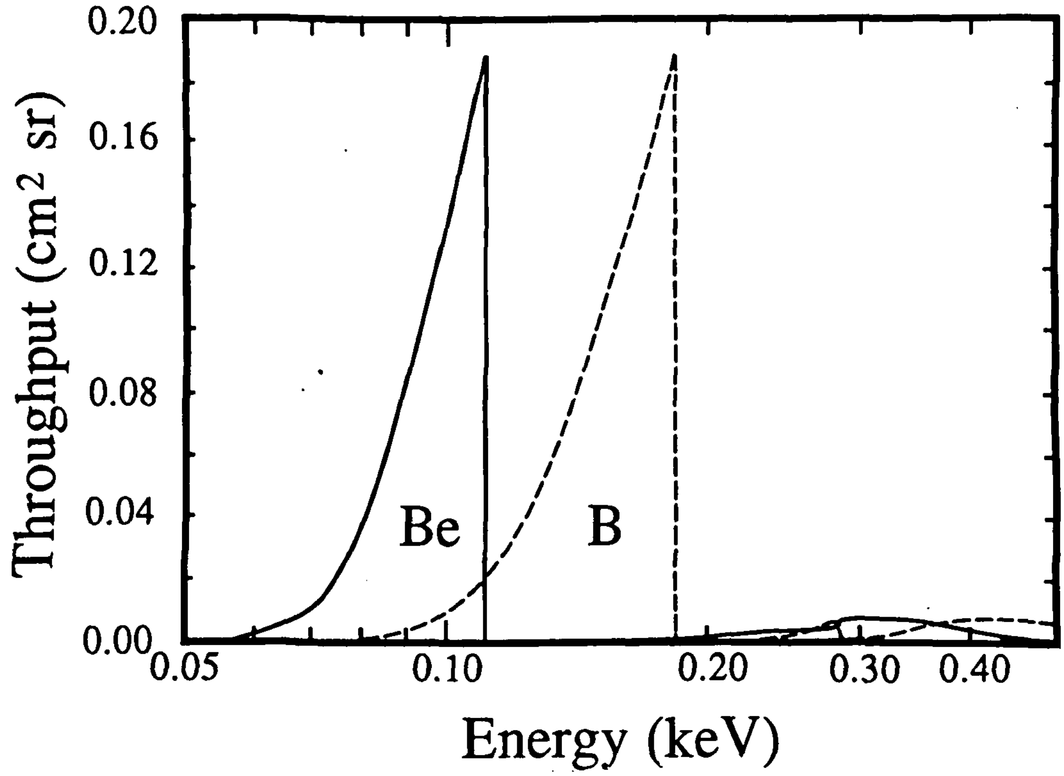

Fig. 1 .--Effective area-solid angle product as a function of photon energy for the Be band. The Wisconsin sky survey B band response, reduced by a factor of 0.086, is shown for comparison.

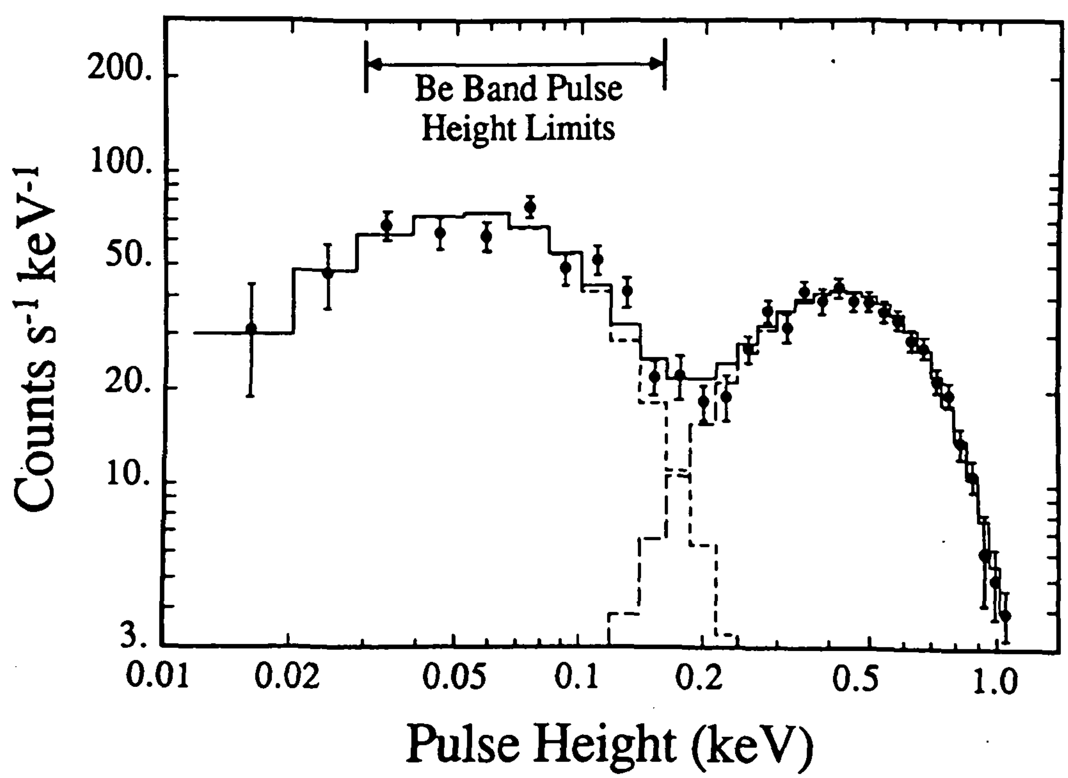

Fig. 2.--Pulse height distribution from the beryllium-filtered counter using data from all sky regions examined. The pulse height limits defining the Be band are indicated.

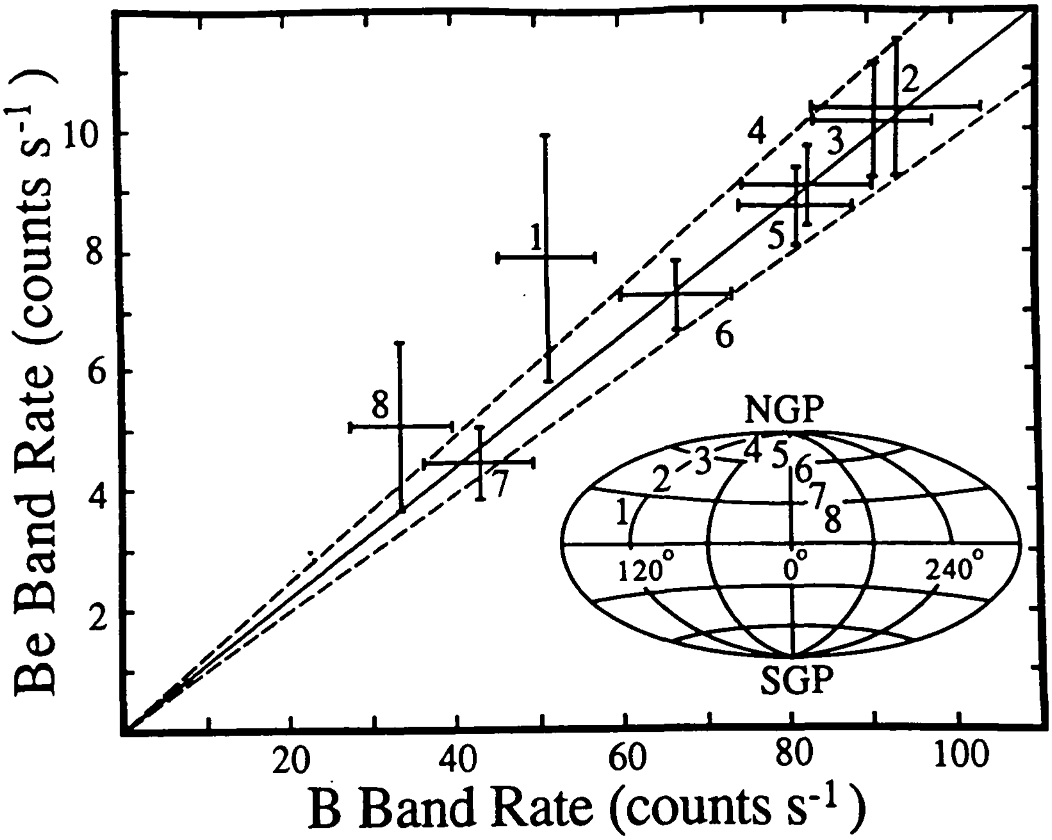

Fig. 3.--Observed Be band rates (this experiment) vs. B band rates from the Wisconsin sky survey. The solid line is the best fit slope. The range of Be to B band rate ratios consistent with the individual uncertainties of most of the observed points is enclosed by the dashed lines and corresponds to a 99% confidence interval if the ratio is assumed to be constant.

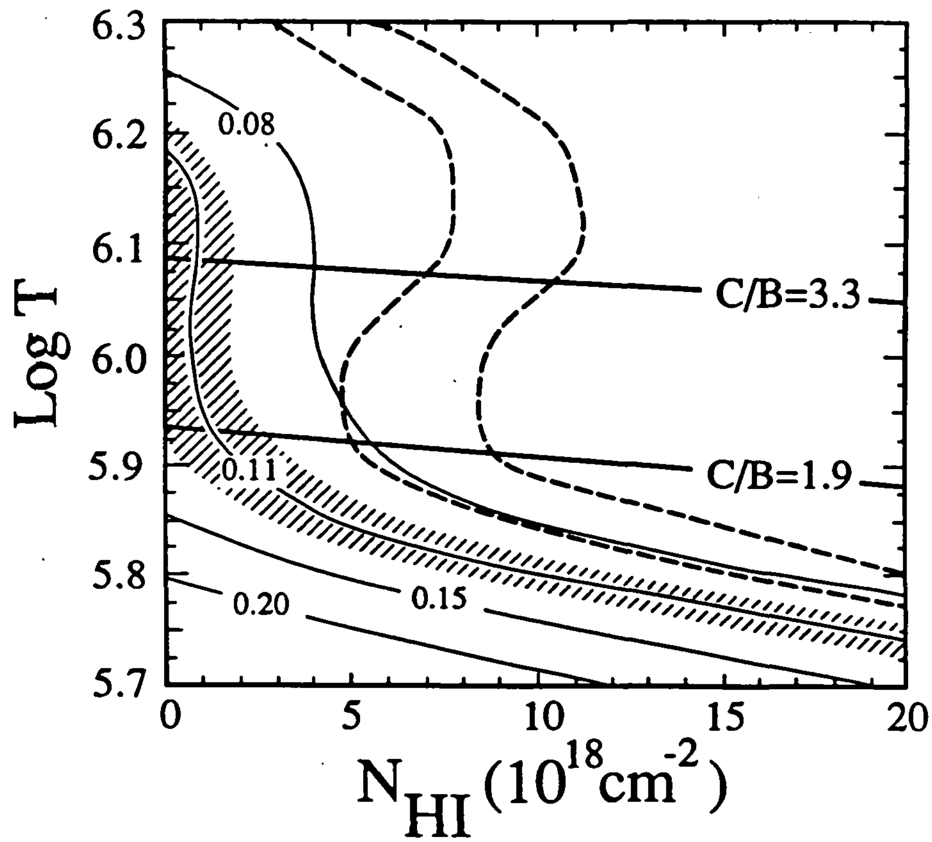

Fig. 4.--The light lines show combinations of plasma temperature and absorbing foreground column density which would give the indicated Be to B band counting rate ratios. The shaded region corresponds to the range of Be/B ratios enclosed by the dashed lines in Figure 3. Emission from an equilibrium plasma with solar abundances was assumed (Raymond and Smith 1984). The dashed lines in this Figure enclose an equivalent region for an earlier set of emission models (Raymond and Smith 1979). The heavy lines are for constant C to B band ratios of 3.3 and 1.9, which bracket the range of values observed in this part of the sky.

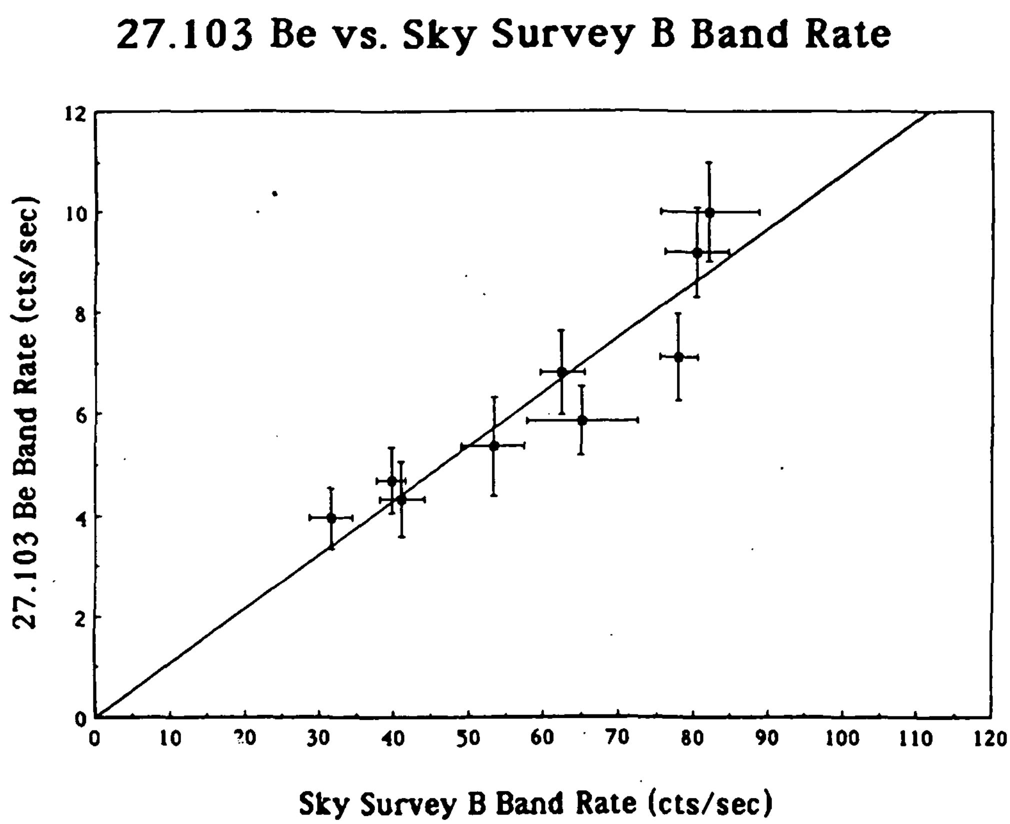

Fig. 5.--Preliminary data from the second flight. Observed Be band rates are plotted against B band rates for the same part of the sky from the all-sky survey maps, as in Figure 3. $\chi^2_\nu = 0.7$ for 8 degrees of freedom for the straight line fit.

II. Sky Survey Analysis

We are continuing with analyses of the data base provided by the Wisconsin diffuse X-ray sky survey. Steve Snowden is currently completing an investigation of the correlation of B and C band emission with individual velocity components of the neutral hydrogen. The HI components were identified by doing a gaussian deconvolution of the 21 cm profiles from the high-quality survey of Stark et al. which is essentially free of stray radiation. This analysis will be in Snowden's Ph. D. thesis. Combined with new constraints provided by the Be band observations, it has resulted in a multi-component model of the local interstellar medium and has inspired a theoretical re-examination of the source of X-rays in the "local bubble" (Cox and Snowden 1986). Cox reported on these results at the XXVI COSPAR meeting in Toulouse.

III. High Resolution Detector Development

High resolution spectroscopy of diffuse or extended sources is inherently difficult. Dispersive instruments (diffraction gratings and Bragg reflection crystals) have spectral resolving powers which are inversely proportional to the angular spread of X-rays accepted by the instrument. Reducing this acceptance angle to improve resolution also reduces the flux accepted from an extended source. The problem is minimized in optical "nebular spectrometers" by using very fast optics, typically f/1. This is impractical in the X-ray regime, where one must usually employ grazing incidence reflections.

The obvious solution to this problem is to use a solid state detector, which gives the energy of each incident photon regardless of arrival direction. The existing state of the art energy resolution for small Si(Li) detectors, however, is about 100 eV FWHM. This is not much better then proportional counter resolution below 1 keV, and is entirely inadequate for spectral line studies in this energy range. Fundamental statistical limitations on the operation of these detectors prevents improvements by large factors over current performance.

We have been working on a solid state detector operating on a different principle, which does not have the same inherent limitations. It is simply a microcalorimeter for single photons, where the photon energy is deduced from the measured temperature increase of the absorber. Fundamental resolution limits for a practical detector operating at 0.1 K seem to be about 1 eV FWHM. The best resolution obtained so far (with a relatively crude detector) is 33 eV FWHM, about a factor of five better than the current state of the art for Si(Li) detectors at this energy. We are reasonably sure that the resolution can be improved to better than 5 eV FWHM.

Development work on detectors of this type suitable for a general-purpose spectrometer on AXAF is being undertaken in collaboration with the X-ray group at Goddard Space Flight Center and is currently being supported under the AXAF definition phase program. However, we are continuing under this grant with aspects of the deveopment which are directly related to the eventual use of these detectors on a sounding rocket or SPARTAN mission.

Our goal is to make use of this promising new detector to obtain some valuable scientific results in the pre-AXAF era. A logical sequence would be:

1. Construct a sounding rocket payload with simple mechanical collimators which requires no fine pointing. This would be used to provide a check on the absolute calibration of DXS and to extend its wavelength coverage. At the same time, it would allow us to get valuable experience with the construction of a flight cryogenic system, and a realistic in-flight test.

2. With the cryogenics problems worked out and tested in 1., build a SPARTAN payload employing the light-weight aluminum foil mirror which has been developed at GSFC. This instrument would be able to make exceedingly interesting observations of many supernova remnants. The results should allow testing of the detailed models of SNR evolution that are currently being developed.

IV. 21 cm Observations

Both simple two-component models of the B and C band emission and more recent sophisticated models involving a distribution of cold clouds within the X-ray emitting material are most readily reconciled with X-ray observations if it is assumed that most of the cool material is clumped into clouds of average thickness $1\text{-}2 \times 10^{20}$ HI cm^{-2}. We have recently completed a series of 21 cm observations in collaboration with F. J. Lockman of N.R.A.O. which seems to rule out the existence of such structure. The 10' angular resolution data from the Green Bank 300 foot telescope have been analyzed, and a letter submitted to the Astrophysical Journal on the results. Jahoda has completed his Ph. D. Thesis on this topic.

V. Artificial Multilayers

We have recently published a paper describing our progress to date in understanding the effects of process parameter variation on the reflectivity of sputter-deposited tungsten-carbon multilayers. We have found that, at least for silicon substrates, thorough cleaning is essential; that sputter gas pressure markedly affects the quality of the LSM ("Layered Synthetic Microstructures"); that high substrate bias leads to a degradation in properties, whereas a low bias may be beneficial; that collection of electrons with anode rings appears to have little effect on grating quality; and that the quality of LSMs with small d-spacings is worse than that for those with larger spacings, reflecting the influence of surface roughness and layer thickness variation.

Transmission electron microscope measurements of our LSMs by a research group at Argonne National Laboratories indicates regularity of layer spacing within a single LSM as good as any. (No quantitative interpretation yet for this report.) Our most recent tests show repeatability of average layer spacing to better than ±1.5% within one run and better than ±3% from one run to another. Current investigations include the addition of a 500 Å carbon base layer to increase adhesion of the multilayer to the substrate and to reduce the effective surface roughness of the substrate, and increasing the number of layer pairs from the current 20 to 40, 60, 80, and 120 to see how well the model-predicted increases in reflectivity and resolution can be achieved in practice.

We are working in this area in collaboration with a group in the U.W. Materials Science Department which has an interest in these structures for use in microlithography. Our involvement is at a rather low level now, and consists largely of undergraduate student labor to manufacture the LSMs of interest to us, occasional small contributions to improvements in the apparatus, some technical direction, and testing of most of the completed LSMs using our low-energy X-ray diffractometer. We also developed the programs required for LSM modelling and performance analysis.

III. Theoretical Studies

The Hester, Raymond, and Cox collaboration on data presentation and a model for one extremely well-studied filament of the Cygnus Loop saw useful progress in manuscript preparation during a visit of Hester to Wisconsin during May. The paper will be a lovely discussion of the progress of a shock into a region with a density gradient along the front. Line spectra, surface brightness distribution, and line shapes are all addressed with considerable success.

The Cox and Franco collaboration on molecular cloud existance criteria was vigorously pursued but new calculations and insights came faster than could be digested during an intense period during March. The results are now in Franco's hands and two papers are envisioned for their presentation. A new twist is the application of the ideas to understanding gross properties of molecular cores of HI clouds.

The new students are now involved in interesting projects. Boulares' interests in the interaction between cosmic rays and the interstellar medium are now being applied to improve our understanding of the z distribution of various contributions to the interstellar pressure. Slavin is involved in a project to estimate the maximum contribution to the soft X-ray background and ionization rate of hydrogen around the solar system which could derive from a conduction boundary around the cloud in which the solar system is immersed. Having developed the capacity to do that problem he will be in a position to apply the techniques to modeling the emission properties of the hot gas bubbles created, according to Cox's ISM theory (Meudon paper listed in previous progress report), by individual supervovae.

Finally, Cox has been working with Snowden to develop a picture of the distribution of X-ray emissive material in the Local Bubble and to determine the processes that are important in understanding the origin of the cavity. In this study it has become clear that the recent supernova reheating of the gas (as needed in McKee, Ostriker, and Cowie views to date and developed by Cox and Anderson, and Edgar studies) is not necessarily required. The cavity itself appears to be about 2×10^7 years old.

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✓ Supported totally or in part by DXS contract NAS 5-26078

* Supported totally or in part by NASA grant NAG5-594

† Half-time position, funded 30% by this grant and 20% by the University.

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