EXTRAGALACTIC ASTRONOMY AND IUE

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The first thing to say is that IUE has been a great success and we should all congratulate the agencies in the U.S.A., Europe and the U.K. and the many scientists and engineers involved in the project on making it possible. In surveying what has been achieved so far, it is important to remember that we may well have IUE with us for a further 3 or even 5 years, meaning that it may be operating right up to the time of launch of Space Telescope. Undoubtedly, observations with IUE will pioneer many fields which will be explored in much more depth by the Space Telescope - there is no reason why IUE should not scoop some of the topics originally thought to be only the province of the Space Telescope.

It was always recognized that the study of extragalactic objects would be difficult with IUE. As Michael Penston expresses it, most astronomers don't try to do extragalactic astronomy with an 18-inch telescope. Nonetheless, many observers have used their observing time to make long exposures on faint objects and there is no question about the significance of the science which has been accomplished. My own experience has been entirely with quasars and radio galaxies and, now that many of the obvious bright objects have been observed, we have settled into a pattern of only attempting one object per 8 hour shift, switching between the long and short wavelength spectrographs in mid-shift. We then repeat the observations in the following shift. Our experience is that this procedure is valuable in distinguishing whether faint features are real or not. Because of the long projected life of IUE, we do not regard this as an extravagant use of time and it is to be hoped that many more observers will adopt this point of view.

I will touch on some aspects of the previous presentations, noting points which I find particularly interesting. I will deal first with normal galaxies and then the emission and absorption line spectra and continuum emission of active galaxies and quasars.

Normal galaxies. Dr. Bertola has indicated clearly the capabilities of IUE for studying normal galaxies. Apparently some galaxies have stellar populations which are little different from what is predicted from the

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optical spectrum whilst others show a strong excess in the far ultraviolet. The nature of this excess is bound to vary from galaxy to galaxy and what is required is a systematic study of a wide range of galaxies of different morphologies and intrinsic luminosities. Every galaxy denoted "peculiar" is surely worth studying because they always seem to involve star formation in some guise or other. Equally, one would like to verify quantitatively one's intuitive feeling that galaxies in which stars are forming are stronger UV emitters than those with old populations. A particularly interesting aspect of the study of the spectra of normal galaxies is whether or not it will be practicable to use their UV spectra to determine the redshifts of the very faint galaxies which will be studied by the Space Telescope. There will be problems in using the conventional methods of identifying the H and K lines of calcium and the 4000 Å break at redshifts greater than about 0.7. IUE observations can indicate what features may be usable in the spectra of normal galaxies in the rest wavelength range $1100 < \lambda < 3200$ Å. The spectrum of M87 shown by Dr. Bertola is rather encouraging from this point of view because of the strength of the emission at the shortest wavelengths observable. We shall have to wait and see.

Active galaxies and quasars - the emission lines. Many beautiful UV spectra of active galaxies and quasars have now been obtained. Except for the most nearby active galaxies, such as NGC1068, most of the objects for which good spectra have been obtained are broad line systems such as quasars, type I Seyferts and broad-line radio galaxies. We have tried to obtain spectra of the narrow line radio galaxies 3C 98 and Cygnus A but have had no success. In contrast, the broad-line radio galaxies and quasars have strong continua and prominent emission lines - examples include the radio galaxies 3C 382 and 3C 390.3.

Dr. Ulrich described the observations of 3C 390.3 and I would like to say a few more words about it because I believe it to be of particular significance in understanding the Ly α/Hβ ratio in active galaxies and quasars. The IUE observations of active galaxies and quasars have confirmed the anomalous Ly α/Hβ ratios suggested by ground-based observations of distant quasars, the sense being that this ratio is between 10 and 20 times smaller than the value predicted by recombination theory.

The spectrum of 3C 390.3 contains both narrow and broad-line components, the broad-line component dominating the Balmer line profiles. What makes this object of particular interest is that the line profiles of the two components are very different and readily separated (Ferland et al. 1979). Putting in a correction for extinction in our own Galaxy, we find that the Ly α/Hα ratio for the narrow line region has roughly the recombination value whilst the broad-line region has the typical "anomalous" ratio. We infer that the anomalies must be associated with the broad-line region rather than the narrow line region which is located further from the central source of continuum radiation.

Two arguments suggest that the anomalies are associated with elementary processes in the broad-line region. First, it seems that the fraction of the total energy lost by Lyman-α radiation in the broad-line regions is about 25% as expected in recombination models. This suggests that the cause of the anomaly is strengthening of the Balmer lines rather than suppression of Lyman-α. Second, if the Lyman-α radiation were suppressed by a factor of 10 by extinction, this energy should be reradiated in the low infrared waveband. There is no evidence of such emission in the spectrum of 3C 273.

We propose that the anomaly arises from collisional excitation of the Balmer series out of the n = 2 level of atomic hydrogen. We find that, for particle densities $n \sim 10^{10}$ cm^{-3} and using the excitation cross-sections of Krolik and McKee, (1978) we can account for the Ly α /Hα ratio. A problem with our interpretation is that the predicted ratio is rather temperature sensitive and if the Ly α/Hβ ratio turns out to be roughly a constant in the broad line region, one would have to find a reason why the broad-line regions are always heated to almost exactly the same temperature. We have now accumulated 10 hours of observation each of the short and long wavelength spectra of 3C 390.3 from which a more refined analysis will be made.

It is of obvious importance to extend analyses such as this to other objects. The problem with most quasars is that their line profiles are bell-shaped and it is not possible to separate them into distinct broad and narrow components. The beauty of 3C 390.3 is that it contains the normal narrow line spectrum which acts as a calibrator for the whole spectrum. We have tried to extend this analysis to other N-galaxies which are known to possess both broad and narrow line components but with little success because few of them are bright enough and some are inaccessible to IUE.

Other programmes of obvious importance are quantitative studies of the relative strengths of the emission lines and how they vary from one class of object to another. We have also observed variability in the broad-line component of 3C 382 and similar studies of other objects are of obvious significance.

Absorption lines. Dr. Boksenberg gave an excellent survey of the wide range of exciting astrophysics associated with studies of the absorption line spectra of quasars. Most of his presentation concentrated on 3C 273 and NGC4151 for which spectra of very high quality have been obtained. The variability of absorption features in the spectrum of NGC4151 on time-scales as short as a day will potentially lead to new understanding of the environments of galactic nuclei.

Of the quasars which have been observed so far, Dr. Boksenberg concentrated on 3C 273 which shows only absorption due to the interstellar gas in our own galaxy. It will be very interesting to hear of the results for other bright quasars. We now know that there are at least four distinct types of absorption features observed in the spectra of distant quasars and we would like to know which of these types are also present in the spectra of quasars at the present epoch. Are there hydrogen clouds forming a "cluster" around nearby quasars as is inferred to be the case for some distant quasars? Are there really no intergalactic clouds of neutral hydrogen at the present epoch? I'm sure some IUE observers already have data relevant to these questions and the answers will be very interesting.

A topic which we have heard little about is the intensity of the continuum radiation on the short wavelength side of the redshifted Lyman-α line. As is well known, this places very tight limits of the present density of intergalactic neutral hydrogen, $n_{HI} \lesssim 10^{-7}$ cm^{-3}. Observations of 3C 273 show little evidence for Lyman-α absorption but again one would like much more extensive observations of quasars of rather larger redshift so that the continuum beyond Ly-α is uncontaminated by geocoronal Lyman-α.

Continuum emission. The most exciting result in my view was what Dr. Boksenberg described as the "blue bump" in the continuum spectrum of 3C 273. I understand that similar features have been observed in other quasars. The continuum optical spectrum of 3C 273 has always been a problem because of the abrupt change in slope of the continuum at $\lambda \approx$ 2500 Å. It has been conventionally assumed that the polarisation and optical variability of the continuum of quasars mean that the emission is the radiation of ultrarelativistic electrons. The old problem with this hypothesis is that such processes cannot produce abrupt spectral breaks because the radiation of a single ultrarelativistic electron is broad-band. Convolving this spectrum with any reasonably sensible relativistic electron spectrum smooths out all features. The decomposition of the optical spectrum of 3C 273 into a "thermal" component associated with the bump and an underlying smooth continuum which may extend from infrared to X-ray wavelengths solves this problem. However, the bump itself produces other problems. They mostly hinge on whether the spectrum really possesses a bump rather than a monotomically varying intensity as a function of wavelength. If it does not have a real bump, for example, if the spectral index on the red side of the bump is $\alpha \approx$ 0, then there is no problem in attributing the radiation to the thermal bremsstrahlung of gas at temperature $\approx 2 \times 10^4$ K. However, if the spectrum mimics a black-body, which a superficial look at the data suggests, there are problems. Essentially, one must arrange physical conditions similar to the outer layers of a star to ensure the thermalisation of the initial radiation spectrum to a radiation temperature of $\approx 2 \times 10^4$ K. How this fits into the conventional picture of an accretion disc about a massive black hole is not clear to me.

Indirect evidence supporting the decomposition of the spectrum into two components comes from work which a number of UK astronomers have been trying to write up (Barr et al., in preparation). The X-ray emission from 3C 390.3 is variable and it is possible to make a first attempt at correlating this with optical variations over the period 1970 to 1979. Despite large variations in both wavebands, there is no correlation at all contrary to what might have been expected if the optical and X-ray emission had the same origin. If there is an underlying non-thermal continuum which extends from infrared to X-ray wavelengths, we would expect to observe correlated variations in the infrared and X-ray wavebands. There is not yet data to test this hypothesis.

The one confident prediction which can be made is that the "blue bump" is likely to spawn a major theoretical industry and it is to be hopedthat this will soon be fostered by further high quality observations.

References

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