Astronomy

Emission lines from galactic nuclei

from B.E.J. Pagel and M.G. Edmunds

QUASARS, radio galaxies, Seyfert galaxies and many other galaxies display a variety of emission-line spectra from their nuclei. These spectra have some features in common with the relatively well understood spectra of planetary nebulae, HII regions and supernova remnants, but there are also significant differences in line profiles and intensity ratios.

Even galaxies usually regarded as 'normal', such as the nearby spirals M51 and M81, have long been known to have nuclei in which a faint emission-line spectrum is superimposed on the underlying continuum and absorption lines of a stellar population. The development of linear digital detectors capable of high spatial and spectroscopic resolution at low light levels has revealed many more than these 'low-ionization nuclear emission-line regions' (acronym 'liners') which are characterized by an Hα line with broad wings and remarkably strong [NII] lines on either side. In 1981, T.M. Heckman, now at the University of Maryland, found at least 30 per cent of large spiral galaxies to have this type of emission; more recently W.C. Keel at the Lick Observatory, Santa Cruz, has shown that virtually all of them do, at least in those cases that are not dominated by some other kind of emission (*Astrophys. J.* **269**, 446; 1983). J.A. Baldwin and M.M. Phillips of Cerro Tololo Inter-American Observatory, Chile, and R. Terlevich of the Institute of Astronomy, University of Cambridge, showed in 1981 that the line intensity ratios in the various types of object — planetaries, HII regions, narrow-line components of Seyfert galaxies and liners — follow quite separate patterns indicating distinct excitation and ionization mechanisms in the galactic nuclei; but what are these mechanisms? This question was the main topic of a recent meeting*.

Quasars and Seyfert 1 galaxies, which have a smooth non-stellar continuum, broad hydrogen and helium lines and narrow forbidden lines, are strong X-ray sources and probably both the broad- and the narrow-line-emitting regions are photoionized by a hard spectrum which can be represented (in part, at least) by a power law $F_{\nu} \sim \nu^{1.5}$ or so. A similar photoionization mechanism applies to Seyfert 2 galaxies where narrow lines dominate the spectrum. The penetration of X rays into predominantly neutral zones adjoining ionized material nearer to the radiation source causes emission from neutral species such as [OI] and contributes emission to the hydrogen lines. For liners, which are often associated with compact radio sources, the situation is more ambiguous. Photoionization models had in the past failed to predict strong enough [OI] and [NII] and so people had turned to shock models similar to those which are successful in accounting for supernova remnants. However, improved photoionization models incorporating the effects of charge-exchange reactions between ionized and neutral atoms have now been shown by D. Péquignot (Observatoire de Meudon), G. Ferland (University of Kentucky) and H. Netzer (Tel Aviv University; *Astrophys. J.* **264**, 105; 1983) and by J. Halpern (Harvard Center for Astrophysics) and J.E. Steiner (Universidade de São Paulo; *Astrophys. J. Lett.* **269**, L37; 1983) to give an account of liner spectra as good as, and in some respects better than, that provided by the shock models, given the assumption of a spectral distribution similar to that in Seyferts but with a more diluted radiation field relative to the particle density.

A potentially crucial test — measurement of the electron temperature in the more ionized zone from the ratio of the weak and strong lines λλ4363 and 5007 of [OIII] — unfortunately gives ambiguous results because of the masking effect of the complex absorption spectrum of the stellar background. Several plausibility arguments (such as continuity with the less luminous Seyfert galaxies) now support the photoionization models, but M.A. Dopita (Mount Stromlo and Siding Spring Observatories, Australian National University) pointed out the potentially interesting consequences of very high-velocity shocks leading to X rays, and there were some reservations about the explanation of the various iron-line spectra ranging from FeII to [FeXIV]. Interesting information on the details of excitation mechanisms (and perhaps evidence of more exotic plasma processes) is likely to spring from the observations by Heckman and his colleagues of emission-line spectra that are spatially associated with jets of radio emission in or near active nuclei.

Various problems and possibilities are raised by the line profiles. In quasars the widths of lines (which measure the velocity field in regions where the lines are formed) are remarkably similar for species of widely differing excitation potential that might have been expected to be widely stratified in space, provoking G. Shields (University of Texas at Austin) to put forward an unconventional model in which the broad lines come from the surface of a rapidly rotating superstar or spinar excited by radiation from sources extended along the polar axis. On the other hand, A. Filippenko (Cal Tech) and J.A. Baldwin had studied cases of active galaxies in which the line widths were found to increase systematically with the theoretical critical density at which collisional de-excitation becomes equally probable with radiative de-excitation and therefore begins to quench the line, indicating a clear stratification of the velocity field with depth.

Another sidelight is cast on ionization mechanisms by studies of variability over a wide range of wavelengths, notably the systematic monitoring programme of the

*A workshop on 'Ionization mechanisms in emission-line nuclei of galaxies', was held at the Royal Greenwich Observatory, Herstmonceux, on 6–7 April 1983.

100 years ago

THE SUPPOSED HUMAN FOOTPRINTS RECENTLY FOUND IN NEVADA

DURING the past summer various accounts have been published of the discovery of human footprints in sandstone near Carson, Nevada. Many different kinds of tracks were found, some of which were made by an animal allied to the elephant; some resembled those of the horse and the deer; others were apparently made by a wolf. There were also tracks made by large birds.

The supposed human footprints are in six series, each with alternate right and left tracks. The stride is from two and a half to over three feet in extent. The individual footprints are from eighteen to twenty inches in length, and about eight inches wide. The distance between the line of right-hand and left-hand tracks, or the straddle, is eighteen to nineteen inches.

The form and general appearance of the supposed human tracks is shown in Fig. 2. The size of these footprints, and especially the width between the right and left series, are strong evidence that they were not made by men, as has been so generally supposed.

A more probable explanation is that the impressions are the tracks of a large sloth, either *Mylodon* or *Morotherium*, remains of which

Fig. 1. Left hind foot of *Mylodon Robustus* (after Owen).

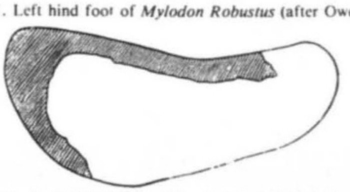

Fig. 2. Left footprint at Carson (after Harkness).

have been found in essentially the same horizon. In support of this view it may be said that the footprints are almost exactly what these animals would make if the hind feet covered the impressions of those in front. In size, in stride, and in width between the right and left series of impressions, the footprints agree closely with what we should expect *Mylodon* or *Morotherium* to make (Fig. 1).

The geological horizon of these interesting footprints is near the junction of the Pliocene and Quaternary.

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