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STARBURST AND ACTIVE GALACTIC NUCLEI

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RESUMEN. Los encuentros galácticos pueden inducir brotes de formación estelar y actividad nuclear en las galaxias, pero la conexión evolutiva no está clara. Los encuentros pueden depositar grandes masas de gas en la región nuclear de una galaxia, donde forma estrellas con gran eficiencia. El gas o las estrellas concentradas en unos cuantos parsecs en la región central pueden explicar la luminosidad nuclear y las líneas anchas de emisión.

ABSTRACT. Galactic encounters can induce starbursts and nuclear activity in galaxies, but the evolutionary connection is unclear. Encounters can deposit huge masses of gas in the nuclear region of a galaxy, where it forms stars with high efficiency. Gas or stars concentrated in the central few parsecs may explain the nuclear luminosity and the broad emission lines.

Key words: **GALAXIES-ACTIVE — QUASARS**

I. STARBURSTS IN GALAXIES

Starbursts occur in a variety of circumstances. Blue compact galaxies are undergoing intense star formation that has lasted only a small fraction of the Hubble time (Searle and Sargent 1972; Kunth, Thuan, and Trahn van Tahn 1986). These objects, with their strong emission lines and pristine composition, provide an opportunity for measuring the primordial abundance of helium (Pagel 1989, this volume). Scalo (1987) reviews starbursts in galaxies and argues that the Milky Way and other spirals undergo massive extranuclear starbursts.

Starbursts in galactic nuclei have been widely studied in recent years (Balzano 1983; Heckman 1987). Much information is contained in *Galactic and Extragalactic Star Formation* (Pudritz and Fich 1988), *Starbursts and Galaxy Evolution* (Thuan, Montemerle and Tran Thanh Van 1987) and *Star Formation in Galaxies* (Lonsdale 1986). Star formation and nuclear activity might be related in a variety of ways. Star formation may be a cause of nuclear activity, an effect of it, or a simultaneous but independent consequence of some triggering event.

Heckman (1987) concludes that Seyfert 2 galaxies have higher-than-average star formation rates, whereas Seyfert 1 galaxies do not. Shaw and de Robertis (1988) find that the star formation in starburst galaxies extends for hundreds or even thousands of parsecs from the nucleus. The gas appears to be rotationally supported in a disk aligned with the galactic disks. The emission lines appear to come from multitudes of individual giant H II regions of the kind normally found in galaxies. Shaw and de Robertis argue that the disk they observe is too large to collapse to the nucleus as suggested by Weedman (1983). Nevertheless, luminous IRAS galaxies suggest that encounters have deposited large quantities of gas in the nuclear regions, with massive star formation and nuclear activity both observed to result (Sanders et al. 1988). Balzano (1983) notes a high incidence of companion galaxies near starburst galaxies and AGN. Evidently galactic encounters are effective at causing both nuclear starbursts (Larson and Tinsley 1978) and AGN. Additional references include Dahari (1984, 1985), Bushouse (1986, 1987), Hutchings (1983), and Keel et al. (1986). The surveys indicate that the presence of a companion enhances by several times the probability of nuclear activity, although the incidence of activity is suppressed in strongly interacting systems. Lin, Pringle, and Rees (1988) argue theoretically that a tidal encounter can trigger a strong surge of accretion into the center of a marginally self-gravitating disk.

II. ENCOUNTERS, STARBURSTS, AND AGN

Evidence for a link between starbursts and AGN is provided by studies of highly luminous IRAS galaxies. Sanders et al. (1988) studied the infrared, optical, and CO emission of 10 galaxies with L_{FIR} (8-1000 μm) $\geq 10^{12}$ $L_\odot$. At these luminosities, and also for L > 10^{10} $L_\odot$, IRAS galaxies outnumber AGN and QSOs of comparable luminosity at Z ≤ 0.1 (Soifer et al. 1986). Defining IR luminosity classes moderate (10^{10} - 10^{11} $L_\odot$), high (10^{11} - 10^{12} $L_\odot$), and ultraluminous ($\geq 10^{12}$ $L_\odot$), Sanders et al. and Scoville (1988) note that the ultraluminous objects are strongly interacting, have an AGN type ionizing source, and have high star formation rates per unit mass of molecular gas. In contrast, the moderate luminosity objects are mostly isolated, with H II region type spectra, and more normal star formation efficiencies. The high luminosity objects are intermediate in all these properties.

The large numbers of ultraluminous IRAS galaxies encourage Sanders et al. to suggest that evolution from infrared galaxies to optical AGN is common. QSOs and Seyfert galaxies frequently have companions (e.g. Hutchings 1983; de Robertis 1985; Dahari 1984, 1985). The nuclear gas in an ultraluminous IRAS galaxy is indeed sufficient to fuel a QSO outburst. Sanders et al. (1988) derive masses of 0.5-1x10^{10} $M_\odot$ of H_2 from the CO luminosities of their 10 ultraluminous objects. Arp 220 has 9x10^9 $M_\odot$ of gas within a radius of 750 pc. This is 36 percent of the dynamical mass, suggesting self-gravitational instability that might concentrate some of the gas in still smaller regions around the nucleus. Here it may be well positioned to fuel a central black hole (Scoville and Norman 1988). The dispersal of the circumnuclear gas by the enshrouded active nucleus later allows the AGN to become visible. Sanders et al. (1988) note that a 10^{12} $L_\odot$ central luminosity will deposit enough radiative momentum to expel the ~10^{10} $M_\odot$ of gas in a few times 10^7 yr.

Some models do not invoke a supermassive black hole. Weedman (1983), noting the frequency of starburst nuclei (Balzano 1983), argued that the compact remnants of massive stars would provide a cluster of accretors. For neutron stars or stellar mass black holes, the efficiency of energy production could be comparable with that of a supermassive hole. In such a model, the strong variability of some AGN presumably results from instabilities in a "cauldron" in which the energy from individual stellar remnants is pooled (Arons, Kulsrud, and Ostriker 1975).

Terlevich and Melnick (1985) do not invoke accretion at all. Massive stars in the starburst cluster pass through an evolutionary phase of high effective temperature, ~10^5 K, as a result of mass loss (Maeder 1983). At an age of ~3 million years, the ionizing continuum of a cluster with such "WARMERS" resembles an $L_\nu \propto \nu^{-1.5}$ power law. Consequently, photoionization models of gas ionized by this continuum match the line intensities of Seyfert 2 narrow line regions and of LINERS as well as do models with a "nonthermal" power law. To explain Seyfert 1 activity, Terlevich and Melnick (1987) invoke young supernova remnants evolving in the dense interstellar medium. A typical bubble might have a radius of 30 light days and emit 10^{52} ergs over ~10^3 days. Typical line widths would be ~5000 km s^{-1}, in agreement with the observed broad lines.

III. FEEDING THE "MONSTER"

Black hole models for quasars (Rees 1984) involve holes of mass $M_8 = M/10^8$ $M_\odot \approx 1$ accreting at rates $\dot{M}_0 \equiv \dot{M}/1$ $M_\odot$ $yr^{-1} \approx 1$. These values are motivated by the Eddington limit, $L_E = (10^{46.1}$ erg $s^{-1})$ M_8 and the theoretical luminosity of an accretion disk, $L \approx 0.1 \dot{M}c^2 = (10^{45.8}$ erg $s^{-1})$ $\dot{M}_0$. Evidence for black holes in nearby galactic nuclei is reviewed by Dressler (1989). The search for a sufficient accretion source has frustrated theoretical efforts (Shields and Wheeler 1978). Alternatives involve tidal disruptions and stellar collisions in a dense nuclear star cluster, mass supplied by stellar evolution, and sudden dumping into the nucleus of gas from farther out in the galaxy.

A problem with stellar evolution is that, for a population ~10^{10} yr old, the stellar mass loss of an entire galaxy must somehow reach the nucleus. Nuclear starbursts mitigate this problem, because one can postulate that a massive star cluster is formed at any time, and vigorous mass loss during its youth fuels the brightest phase of AGN activity. In this spirit, Norman and Scoville (1988) proposed that a giant star burst in the inner 100 pc or so. Consisting of massive star clusters, this collection of stars undergoes rapid relaxation, so that ~4x10^9 $M_\odot$ of stars winds up in a core ~10 pc in radius. The mass lost by red giants is bound to the cluster and swallowed by the hole. The black hole luminosity, ~10^{-1} $\dot{M}c^2$, fades from an initial value $10^{13.5}$ $L_\odot$ to only 10^{11} $L_\odot$ at 3x10^9 yr. At all times, the accretion luminosity exceeds the stellar luminosity by roughly two orders of magnitude.

The postulated star cluster has a virial velocity of ~2000 km s^{-1}. If such clusters exist, one wonders why they have not been observed in galactic nuclei. However, such a cluster offers an interesting explanation of the broad emission lines. Scoville and Norman (1988) propose that the central "nonthermal" continuum photoionizes the stellar wind envelopes of red supergiants. The observed emission lines, arising from myriad such stars, are Doppler broadened by the stars' motion. The radius of the nuclear star cluster is chosen to give the correct line width. The emitting gas density is determined by the radius r_s in the stellar wind to which the gas is ionized. Let us assume a ballistic spherical flow at velocity $v_w \approx 10$ km s with mass lost rate $\dot{m}$. This is exposed to an ionizing flux ϕ_i =

$Q/4\pi R^2$, where $Q(H^o) = L_{UV}/\langle h\nu \rangle$ is the ionizing photon luminosity of the AGN. The gas is ionized to a point given by

$$\phi_i = \frac{1}{3} \alpha\, r_s\, [n(r_s)]^2 \tag{3.1}$$

(cf. Osterbrock 1989). Here $n = \dot{m}/(4\pi r^2 v_w m_H) = (10^{9.5}\ \mathrm{cm^{-3}})\ \dot{m}_{-5}\, r_{14}^{-2}$, where $\dot{m}_{-5} = \dot{m}/10^{-5}\ M_\odot\ \mathrm{yr^{-1}}$. This gives

$$n_s = (10^{8.2}\ \mathrm{cm^{-3}})\ \dot{m}_{-5}^{-1/3}\, \phi_{18}^{2/3}. \tag{3.2}$$

The ionization parameter is then

$$U \equiv \frac{\phi_i}{n_s c} = 10^{-0.7}\, \phi_{18}^{1/3}\, \dot{m}_{-5}^{1/3}. \tag{3.3}$$

Photoionization models generally imply $\phi_{18} \approx 1$ and $U \approx 10^{-2}$ (Ferland and Shields 1985). Thus, the wind model appears to give values of U higher than required. However, the medium may provide sufficient pressure to raise the density of the emitting gas and lower its ionization parameter. Shields (1989) has proposed a model in which the broad line region consists of the debris of tidally disrupted stars. These clouds eventually collide and are heated to near the virial temperature. The hot gas settles onto the hole to produce the ionizing luminosity. For emission-line clouds in pressure equilibrium, the observed values of U arise naturally. The same idea could be adapted to the red giant wind model, if the stellar mass loss is shocked to provide the medium. Indeed, the medium pressure should exceed the ionized stellar wind pressure at 10^4 K and the density of eqn. (3.2). Thus the medium pressure must modify the red giant wind in an important way.

IV. THE PROMISE OF STARBURST MODELS

Starburst models, or more generally, models involving sporadic events such as galactic encounters, offer hope for resolving earlier difficulties regarding the fuel supply for AGN. In addition to the role of stellar evolution described above, massive nuclear gas clouds or clumps of stars could enhance the orbital relaxation rate and thus the rate of tidal disruption of stars (Shields and Wheeler 1978). Such models are consistent with indications that AGN activity in a given galaxy is short lived. For example, Shields and Wheeler noted that the accretion rate needed to power NGC 1068, if sustained for a Hubble time, would build a black hole more massive than observations of the rotation curve allow. Such constraints surely can be improved by observations with a large telescope in space.

REFERENCES

Arons, J., Kulsrud, R. M., and Ostriker, J. P. 1975, *Ap. J.*, **198**, 687.
Balzano, V. 1983, *Ap. J.*, **268**, 602.
Bushouse, H. A. 1986, *Astr. J.*, **91**, 255.
_________ . 1987, *Ap. J.*, **320**, 49.
Dahari, O. A. 1984, *Astr. J.*, **89**, 966.
_________ . 1985, *Astr. J.*, **90**, 1772.
Dressler, A. 1989, in I.A.U. Symposium No. 134: *Active Galactic Nuclei*, eds. D. E. Osterbrock and J. S. Miller (Dordrecht: Kluwer).
Ferland, G. J., and Shields, G. A. 1985, in *Active Galactic Nuclei and Quasi-Stellar Objects*, ed. J. S. Miller (San Francisco: Univ. Science Books), p. 157.
Heckman, T. M. 1987, in*Starbursts and Galaxy Evolution*, eds. T. X. Thuan, T. Montmerle, and J. Tran Thanh Van (Gif sur Yvette, France: Editions Frontières), p. 381.
Hutchings, J. B. 1983, *P.A.S.P.*, **95**, 799.
Keel, W. C., Kennicutt, R. C., Hummel, E., and van der Hulst, J. M. 1985, *Astr. J.*, **90**, 708.
Kennicutt, R. C., Keed, W. C., van der Hulst, J. M., Hummel, E., and Roettiger, K. A. 1987, *Astr. J.*, **93**, 1011.
Kunth, D., Thuan, T. X., and Tran Thanh Van, J. 1986, eds., *Star Forming Dwarf Galaxies* (Paris: Editions Frontières).
Larson, R., and Tinsley, B. M. 1978, *Ap. J.* , **219**, 46.
Lin, D.N.C., Pringle, J. E., and Rees, M. J. 1988, *Ap. J.*, **328**, 103.
Lonsdale, C. J. 1986, ed., *Star Formation in Galaxies*, NASA Conference Publication 2466.
Maeder, A. 1983, *Astr. Ap.*, **120**, 113.
Norman, C., and Scoville, N. 1988, *Ap. J.*, **332**, 124.

Osterbrock, D. E. 1989, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei* (Mill Valley, CA: Univ. Science Books).

Pagel, B.E.J. 1989, *Rev. Mexicana de Astron. y Astrof.*, in press (this conference).

Pudritz, R. E., and Fich, M. 1988, eds., *Galactic and Extrogalactic Star Formation* (Dordrecht: Kluwer).

Rees, M. J. 1984, *Ann. Rev. Astr. Ap.*, **22**, 471.

Sanders, D. B., Soifer, B. T., Elias, J. H., Madore, B. F., Matthews, K., Neugebauer, G., and Scoville, N. Z. 1988, *Ap. J.*, **325**, 74.

Scalo, J. M. 1987, in *Evolution of Galaxies*, Proc. 10th Europ. Regional Astron. Meeting of the I.A.U., Vol. 4, ed. J. Palous (Prague: Astronomical Institute), p. 101.

Scoville, N. 1988, in *Galactic and Extragalactic Star Formation*, eds. R. E. Pudritz and M. Fich (Dordrecht: Kluwer), p. 541.

Scoville, N., and Norman, C. 1988, *Ap. J.*, **332**, 163.

Searle, L., and Sargent, W.L.W. 1972, *Ap. J.*, **173**, 25.

Shaw, R. A., and de Robertis, M. M. 1988, in *Active Galactic Nuclei*, eds. H. R. Miller and P. J. Wiita (New York: Springer Verlag), p. 49.

Shields, G. A. 1989, in I.A.U.Symposium No. 134: *Active Galactic Nuclei*, eds. D. E. Osterbrock and J. S. Miller (Dordrecht: Kluwer).

Shields, G. A., and Wheeler, J. C. 1978, *Ap. J.*, **222**, 667.

Soifer, B. T. *et al.* 1986, *Ap. J. (Letters)*, **303**, L41.

Terlevich, R., and Melnick, J. 1985, *M.N.R.A.S.*, **213**, 841.

__________. 1987, in *Starbursts and Galaxy Evolution*, eds. T. X. Thuan, T. Montmerle, and J. Tran Thanh Van (Gif sur Yvette, France: Editions Frontières), p. 393.

Thuan, T. X., Montmerle, T., and Tran Thanh Van, J. 1987, eds., in *Starbursts and Galaxy Evolution*, (Gif sur Yvette, France: Editions Frontières), p. 393.

Weedman, D. W. 1983, *Ap. J.*, **266**, 479.

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