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STARBURST AND AGN CONNECTIONS AND MODELS

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ABSTRACT

There is accumulating evidence for a strong link between nuclear starbursts and AGN. Molecular gas in the central regions of galaxies plays a critical role in fueling nuclear starburst activity and feeding central AGN. The dense molecular ISM is accreted to the nuclear regions by stellar bars and galactic interactions. Here we describe recent observational results for the OB star forming regions in M51 and the nuclear starburst in Arp 220 – both of which have approximately the same rate of star formation per unit mass of ISM. We suggest that the maximum efficiency for forming young stars is an Eddington-like limit imposed by the radiation pressure of newly formed stars acting on the interstellar dust. This limit corresponds to approximately 500 $L_\odot$ / $M_\odot$ for optically thick regions in which the radiation has been degraded to the NIR. Interestingly, we note that some of the same considerations can be important in AGN where the source of fuel is provided by stellar evolution mass-loss or ISM accretion. Most of the stellar mass-loss occurs from evolving red giant stars and whether their mass-loss can be accreted to a central AGN or not depends on the radiative opacity of the mass-loss material. The latter depends on whether the dust survives or is sublimated (due to radiative heating). This, in turn, is determined by the AGN luminosity and the distance of the mass-loss stars from the AGN. Several AGN phenomena such as the broad emission and absorption lines may arise in this stellar mass-loss material. The same radiation pressure limit to the accretion may arise if the AGN fuel is from the ISM since the ISM dust-to-gas ratio is the same as that of stellar mass-loss.

Key words : starbursts, active galactic nuclei, AGN, infrared galaxies

I. INTRODUCTION

OB star formation in galactic spiral arms is enhanced due to the concentration of giant molecular clouds resulting from orbit crowding in the spiral density wave. Similarly, in the luminous infrared galaxies, nuclear starbursts are fueled by extraordinarily large masses of gas and dust concentrated at radii of a few hundred pc by viscous accretion and the torques associated with galactic merging. In these two very different environments, dissipative gas dynamics play a critical role in setting the initial conditions for the local starbursts. In both instances, the star formation efficiency (as measured by the local luminosity to ISM-mass ratio) is remarkably similar. These facts suggest a degree of commonality between spiral arm star formation and nuclear starbursts despite the much greater extent (and therefore integrated output) of the latter.

In this contribution, I describe our recent high resolution study of HII region properties in M51 and review existing results for Arp 220. I find that in both cases, where the luminosity is generated by recently formed stars, there exists approximately the same luminosity to mass ratio ($\sim$500 $L_\odot$ /$M_\odot$) and I argue that this may be an upper limit imposed by self-regulation due to radiation pressure on dust exceeding the self-gravity of the star forming region. There is now abundant circumstantial evidence for an evolutionary link between nuclear starbursts and AGN and I point out how two of the most prominent characteristics of AGN (the broad emission and absorption lines) may actually arise from the AGN luminosity shining on the numerous red giant stars in a post-starburst population and that once again the pressure on dust is a critical rate-limiting consideration.

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II. HIGH-MASS STAR FORMATION – M51 HII REGIONS

M51 has been the focus of numerous ground based Hα studies (Kennicutt *et al.*1989; van der Hulst *et al.* 1988; Rand 1992; Petit *et al.* 1996; and Thilker *et al.* 2000) and these studies have contributed much of what is currently known regarding OB associations in other spiral galaxies. We have recently completed a comprehensive study of M51 comprised of HST (WFPC2 and NICMOS) imaging of the Hα and Pα emission lines (Scoville *et al.* 2001). The 0.1 — 0.2″ resolution available with HST corresponds to 4.6 — 9.3 pc. These sizes correspond to those of individual resolved Galactic HII regions (eg. the Orion Nebula). Related mm-CO interferometry has been presented in Aalto *et al.*(1999). The former probes the stellar disk, the dust, and the OB star formation while the latter

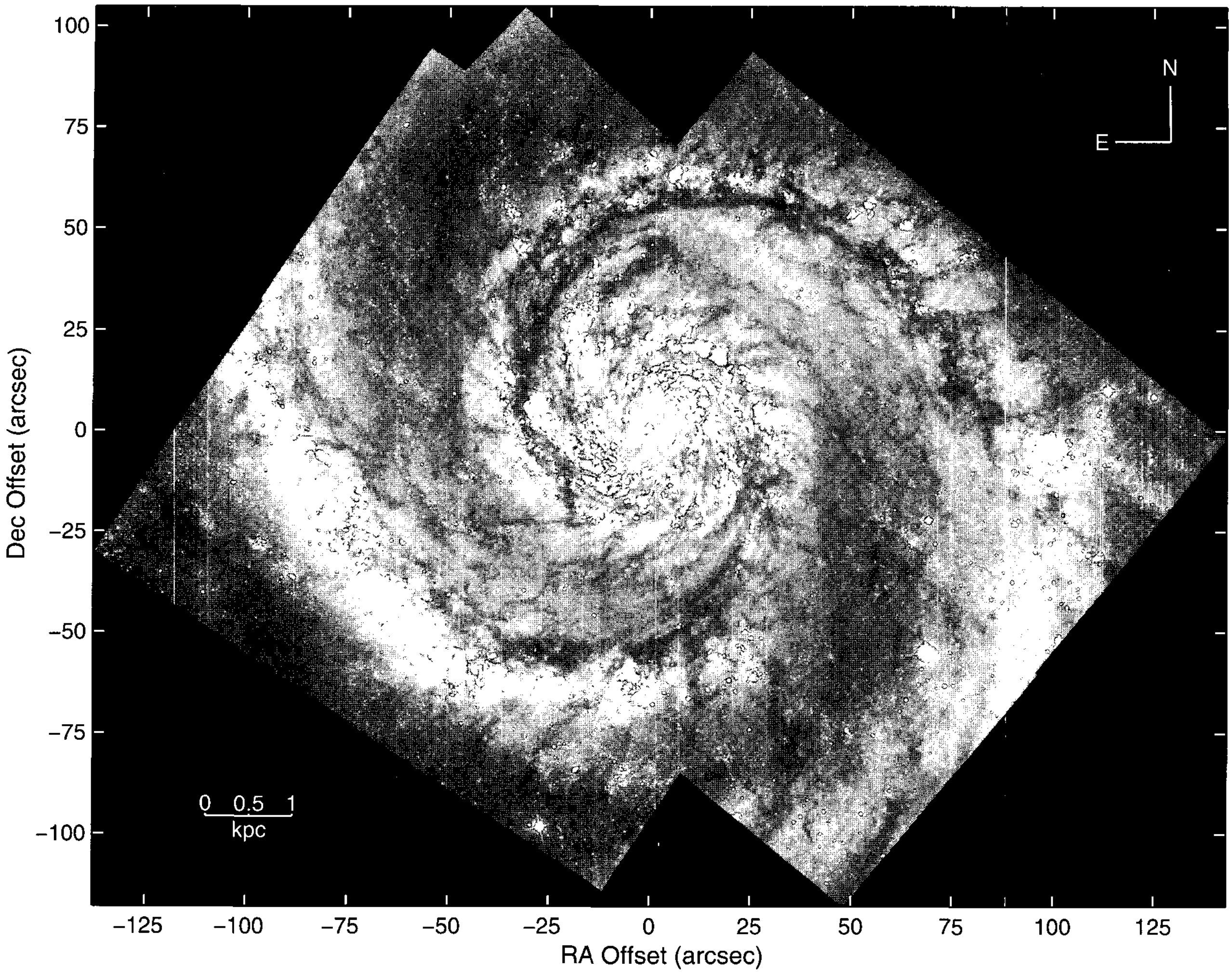

Fig. 1.— The full mosaic of WFPC2 Hα (continuum subtracted) images for the central 281×223″ of M51. The Hα emission is shown with the continuum V and B bands (Scoville *et al.*2001).

probes the dense, molecular ISM which is the birthsite of OB star clusters.

In Figure 1, the Hα emission is shown for the central disk of M51. Hα emission extends out 10″ from nucleus at PA $\sim$ -15° and bright, discrete Hα emission regions outline the spiral arms. The locations of bright Hα emission are closely associated with the dark dust lanes, but relative to the dust, the Hα is often displaced to the outside, or leading edge, of the arms. Although generally Pα shows the same emission regions, many of the arm HII regions have considerable reddening.

The *observed* (uncorrected for extinction) Hα luminosity functions differentiated between arm, interarm and nuclear areas are shown in Figure 2. To characterize the luminosity function, we express it as a truncated power law : in differential form,

$$\frac{d\ N(L_{H\alpha})}{d\ ln\ L_{H\alpha}} = N_{up}\left(\frac{L_{H\alpha}}{L_{up}}\right)^{\alpha}. \quad (1)$$

Over the luminosity range $L_{H\alpha} = 12 \rightarrow 500 \times 10^{36}$ ergs s^{-1}, logarithmic truncated power-law fits have exponents -0.72 ± 0.03, -0.95 ± 0.05, and -1.12 ± 0.11 for the arm, interarm and nuclear (excluding the nuclear jet) regions, respectively. McKee & Williams (1997) obtained a power law index for Galactic radio HII regions similar to that in M51.

An excellent match to the overall luminosity function power law index -1.01 is thus provided by $N(M_{cl})\ dM_{cl} \propto M_{cl}^{-2.01}$ with variations of the power law index = ±0.15 between arm and interarm regions. The derived power law index for the cluster mass spectrum is close to but not identical to that) of Galactic GMCs ($\Gamma \simeq -1.6$, Scoville & Sanders 1978).

The fitting results clearly show a *significant* trun-

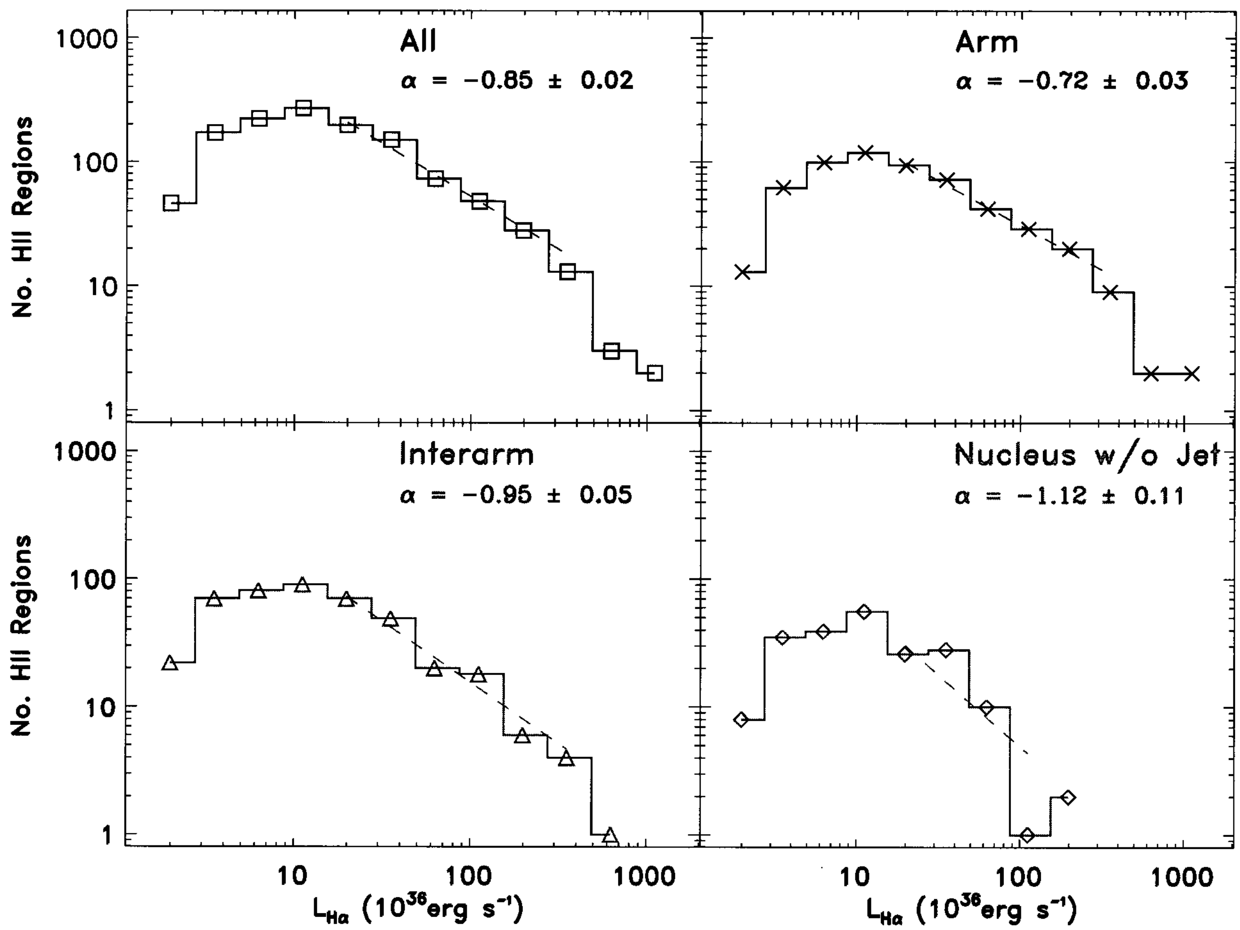

Fig. 2.— The observed Hα luminosity functions separated for arm, interarm and nuclear regions. Fits to logarithmically binned distributions are over the range $L_{H\alpha} = 12 \rightarrow 500 \times 10^{36}$ erg s^{-1}. The power-law fits to the high luminosity tail are also shown. A significant truncation of luminosity function occurs at $L_{up} \simeq 4 \times 10^{38}$ erg s^{-1}, corresponding to a maximum cluster mass of $7{\times}10^3$ $M_\odot$.

cation of the luminosity functions at $L_{up} \simeq 4 \times 10^{38}$ erg s^{-1}, strongly suggesting a physical or observational limitation to the maximum luminosity of the HII regions. The extinction-corrected Hα luminosities for an HII region sample with diameters $\leq$ 50 pc (which we argue is the maximum size which could be ionized by a single OB star cluster) imply maximum Lyman continuum emission rate of $Q_{LyC} = 7 \times 10^{50}$ s^{-1}. For a Salpeter IMF populated between 1 and 120 $M_\odot$, this corresponds to cluster mass of $7{\times}10^3$ $M_\odot$ and the mean cluster mass is $\sim 10^3$ $M_\odot$. Above approximately 10^3 $M_\odot$, the cluster contains a reasonable sampling of all stellar masses and the stellar population is said to be 'saturated' (cf. Oey & Clarke 1998). The Lyman continuum production rate grows linearly for further increases in the cluster mass. If the Salpeter IMF is extended down to 0.1 $M_\odot$, the total cluster mass estimate is increased by a factor of 2.5.

(a) OB Star Cluster Formation and the Upper 'Cutoff' of Cluster Mass

Since the parent molecular clouds are much more massive than the typical OB star clusters (few $\times 10^3$ $M_\odot$), one must ask : why don't the OB star clusters generally build up to much greater mass? The important role of radiation pressure in high-mass star formation has not been amply appreciated (except Elmegreen 1983) and we discuss here the feedback of radiation pressure on buildup of a stellar cluster in a molecular cloud core.

Initially, as the OB star cluster grows, it will contain only a few low-mass stars and the gas dynamics will be entirely determined by the self-gravity of the cloud core and cluster. Since we neglect rotational or magnetic stresses, this is clearly the **most favorable** situation for accretion and maximal growth of the cluster. On the other hand, as the cluster becomes more massive and populates the upper main sequence, the higher luminosity-to-mass ratio of high-mass stars will

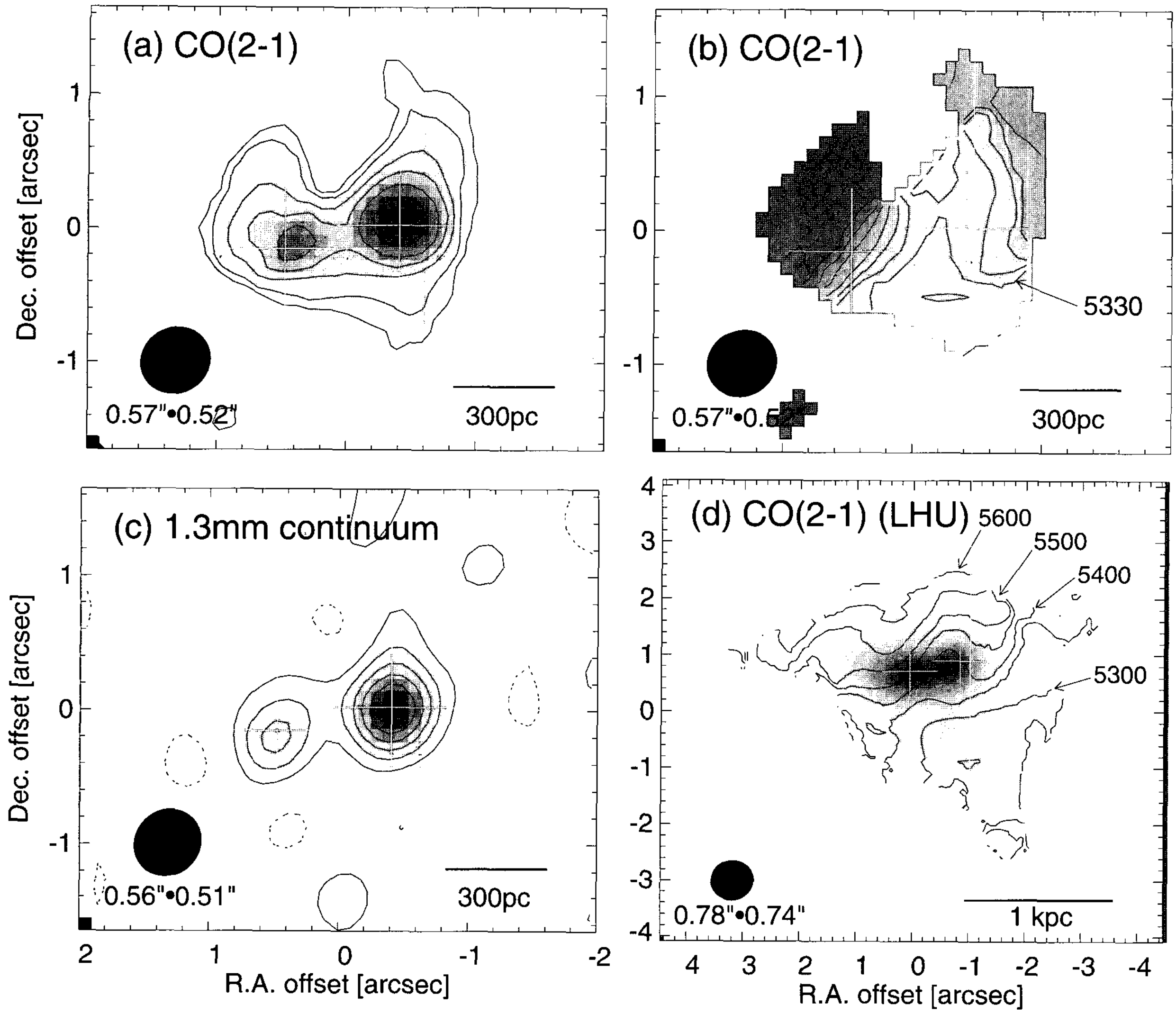

Fig. 3.— The merging nuclei of Arp 220 are shown in 0.5″resolution imaging of the CO(2–1) and dust continuum emission. These data clearly resolve the two nuclei and reveal for the first time counter-rotating disks in each nucleus. The panels show : a) continuum-subtracted CO(2–1) (using only high resolution data), b) the CO mean velocities, c) the 1.3 mm dust continnum, and d) the total CO emission including both low and high resolution interferometry (Sakamoto et al. 1999). Crosses indicate the 1.3 mm continuum positions of the nuclei.

result in increased radiation pressure on the surrounding dust — eventually terminating further accretion to the cloud core. The outward radiation pressure will dominate self-gravity at radius R when

$$\frac{L<\kappa>}{4\pi R^2 c} \geq \frac{GM_R}{R^2} \quad , \tag{2}$$

where $<\kappa>$ is the **effective** radiative absorption coefficient per unit mass.

Although the original stellar radiation is primarily UV and visible, the dust in the cloud core absorbs these photons and reradiates the luminosity in the infrared. The 'effective' absorption coefficient takes account of the fact that outside the radius where $A_V \sim 1$ mag, the luminosity is at longer wavelengths where the dust has a reduced absorption efficiency. For the standard ISM dust-to-gas ratio (Bohlin 1975), $A_V = 1$ mag corresponds to a column $N_H = 2\times10^{21}$ cm^{-2} and

$$<\kappa>= 312\ \frac{\lambda_V}{\lambda_{eff}(R)}\ cm^2 gr^{-1} \quad . \tag{3}$$

$\lambda_{eff}(R)$ is the absorption coefficient-weighted mean wavelength of the radiation field at radius R and for simplicity, we have adopted a λ^{-1} wavelength dependence for the absorption efficiency.

Combining Eq. 2 and 3, we find that the radiation pressure will exceed the gravity of the cluster stars when

$$(L/M)_{cl} \geq 42 \frac{\lambda_{eff}}{\lambda_V} \frac{L_\odot}{M_\odot} \quad . \qquad (4)$$

If $\lambda_{eff} \sim 3\ \mu$m, $\lambda_{eff}/\lambda_V \sim 10$. Thus, for clusters with luminosity-to-mass ratios exceeding $\sim 500\ L_\odot\ /\ M_\odot$, radiation pressure will halt further accretion. This luminosity-to-mass ratio is reached at about the point where the upper main sequence is first fully populated, i.e. a cluster with approximately 2000 $M_\odot$ distributed between 1 and 120 $M_\odot$.

III. ARP 220 – A 'PROTOTYPICAL' ULIG

Mm-wave imaging provides a unique capability to probe the starbursts in dusty ULIRG nuclei. More than 20 luminous ($\geq 10^{11} L_\odot$) infrared galaxies have now been imaged, primarily at OVRO and IRAM (Scoville, Sargent & Sanders 1991, Scoville, Yun & Bryant 1997, Downes & Solomon 1998, Bryant & Scoville 1999, Tacconi *et al.*1999). Virtually all display massive concentrations of molecular gas in the central few kpc.

Arp 220, at 77 Mpc, is one of the nearest and the best known ultra-luminous merging systems ($L_{8-1000\mu m}$ = 1.5×10^{12} $L_\odot$). Visual wavelength images reveal two faint tidal tails, indicating a recent tidal interaction (Joseph & Wright 1985), and high resolution ground-based radio and near-infrared imaging show a double nucleus (Baan & Haschick 1995, Graham *et al.*1990). The radio nuclei are separated by 0.″98 at P.A. $\sim 90°$ (Baan & Haschick 1995), corresponding to 350 pc. To power the energy output seen in the infrared by young stars requires a star formation rate of $\sim 10^2$ $M_\odot$ yr^{-1}. Arp 220 has been the subject of a number of OVRO and IRAM interferometer studies imaging in the 2.6 mm CO line (Scoville, Sargent & Sanders 1991), 3 mm HCN (Radford *et al.*1991), and 1.3 mm CO (Scoville, Yun, & Bryant 1997, Downes & Solomon 1998, Sakamoto *et al.*1999). The CO (2–1) line emission, mapped at 1″ resolution, showed two peaks separated by 0.9″, and an inclined disk of molecular gas (Scoville, Yun, & Bryant 1997, Downes & Solomon 1998). These peaks correspond well with the double nuclei seen in near-infrared and radio continuum images. The 0.5″ resolution CO and 1.3 mm continuum maps obtained recently by Sakamoto *et al.*(1999) using OVRO are displayed in Figure 3. These reveal **counter-rotating** disks of gas in each of the nuclei. The kinematic data clearly require very high mass concentrations in each nucleus, consistent with their being individual galactic nuclei. The fact that they are counter-rotating is consistent with the concept that more complete merging may be associated with counter-rotating precursor galaxies in which there can be greater angular momentum cancellation. The masses in each nucleus are apparently dominated by the molecular gas – a common finding of the ULIG galaxy studies (Bryant & Scoville 1999).

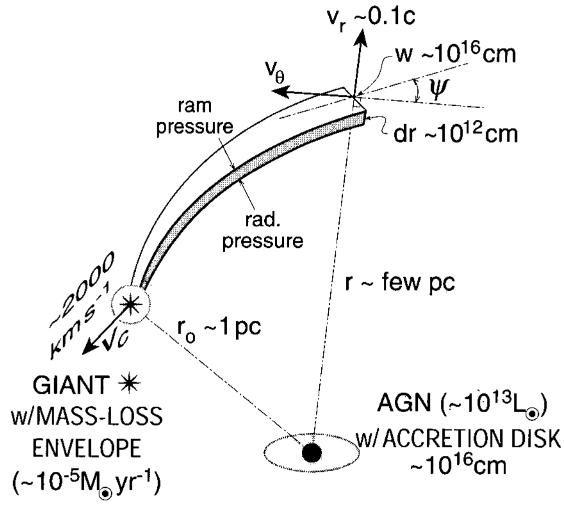

Fig. 4.— Schematic drawing of a stellar trail.

(a) Radiation-Pressure Limited Starbursts – similarities to M51

The total molecular gas content for Arp 220 is $9 \times 10^9 M_\odot$ based on the CO (2–1) emission and a CO-to-H_2 conversion ratio which is 0.45 times the Galactic value (Scoville, Yun & Bryant 1997). This enormous mass (approximately two times that of the total Galactic ISM) is contained entirely within R <1.5 kpc and approximately $5 \times 10^9 M_\odot$ is apparently concentrated in a thin disk in the nuclear region at radii $<\sim 250$ pc. The gas is probably collected in the center of the merging system as a result of torques associated with the encounter and the high dissipation in the gas. The inferred mean extinction through the disk in the center of Arp 220 is A_V = 1000–2000 mag (Scoville, Yun & Bryant 1997). For Arp 220, the central disk luminosity is approximately $2.5 \times 10^{12}\ L_\odot$, implying a luminosity to mass ratio of 500 $L_\odot\ /\ M_\odot$ which is **nearly identical to that of the most massive OB star clusters in M51**! In the ULIRG disks, the star formation may also be regulated by radiation pressure since a high star formation rate leads to higher luminosity and greater radiation pressure support of the disks in the vertical direction (and thus a reduced star formation rate). This is much the same situation as the OB star clusters forming in a molecular cloud core in as much as the ULIRG disks are probably self-gravitating and the radiation is once again due to the young, high mass stars. Although the geometry is planar in the case of the nuclear starburst disks (rather than spherical as in the case of the individual cloud core), both regions would be self-gravitating and the same numerical limit applies.

IV. AGN – STARBURST : OBSERVATIONAL CONNECTIONS

Evidence has also accumulated for an evolutionary link between merging ultra-luminous IR galaxies and UV/optical QSOs as suggested by Sanders *et al.*(1988) : similar local space densities for ULIRGs and QSOs; continuity of FIR SEDs smoothly transitioning between the two classes (Sanders *et al.*1988 & Neugebauer *et al.*1986); the occurrence of AGN-like emission lines (Veilleux *et al.*1999) and significant point-like nuclei (less than 0.2 ″ – Scoville *et al.*2000) in 30-40% of the ULIRGs ; and the association of both ULIRGs and some QSOs (MacKenty & Stockton 1984, Bahcal *et al.*1997) with galactic interactions. Whether the entire QSO population had precursor ULIRGs (implying that galactic merging is the predominant formation mechanism for AGNs) is not yet settled. Two possible scenarios linking the ULIRG and AGN phenomena are : 1) that the abundant ISM which fuels the starburst also feeds the central black hole accretion disk; or 2) the post starburst stellar population evolves rapidly with a high rate of mass-return to the ISM in the galactic nucleus – leading to sustained fueling of the black hole (e.g. Norman & Scoville 1988).

(a) Gas-Rich 'Spirals' as the Hosts of Luminous QSOs

We have recently completed a CO(1-0) line survey (Scoville *et al.* 2002) in a complete sample of 12 low redshift ($Z \leq 0.1$), optically bright QSOs (PG QSOs with $M_B \leq -23$ mag). Six new CO detections are reported here at levels exceeding 2 Jy km s^{-1}. Combined with three previously reported detections, we find that 9 of the 12 QSOs have abundant, dense ISMs characteristic of late type galaxies. In all 9 of the detected QSOs, the derived molecular gas masses are $M_{H2} \geq 1.6 \times 10^9$ $M_\odot$ and the largest is 10^{10} $M_\odot$ (PG 0050+124 – I Zw 1). In the sources not yet detected in CO, the upper limits on the gas masses are $\sim 10^9$ $M_\odot$ and thus we cannot rule out abundant ISMs even in these objects. Since our sample was chosen entirely on the basis of low redshift and the highest optical luminosity (i.e. not chosen for strong infrared emission), we conclude that *the majority of luminous, low redshift QSOs have gas-rich host galaxies and therefore cannot be normal elliptical galaxies.*

The molecular gas detections make it clear that the highest luminosity and, presumably most massive AGNs, are generally not in *normal* (ie. gas-poor) ellipticals. Quite plausibly, the same process (galactic merging) which can lead eventually to a relaxed bulge stellar population also deposits large masses of ISM in the galactic nuclei to feed and buildup massive AGN. The connection between bulge light and central black hole mass (Magourian *et al.*1998, Merritt & Ferrarese 2001) might then be circumstantial rather than causal if both the bulge stellar population and the build up of the central massive black holes are linked to galactic merging.

V. AGN – STARBURST : THEORETICAL CONSIDERATIONS

The largest potential source of fuel for active galactic nuclei (AGNs) and for the interstellar medium in active galaxies is the mass-loss which occurs from late type stars in the evolving population of the nuclear star cluster. For a galactic nucleus with mass $10^9 M_\odot$ in a young stellar population, approximately 20% of the initial stellar mass will be lost via red giant mass-loss winds within the first 2×10^8 years (Norman and Scoville 1988). In two papers (Scoville and Norman 1988, Scoville and Norman 1995), we have examined critically the fate of this mass-loss material – specifically to account for both the broad emission lines and the broad absorption lines seen in AGNs.

The physics of the dust shed by the stars in their stellar winds, particularly its evaporation, is critical to determining whether the mass-loss material accretes inwards to an accretion disk or is blown outwards by radiation pressure. This consideration leads naturally to a division of the central cluster environment into an inner zone (at $\lesssim$1 pc) where the dust is evaporated and the gas falls inwards and an outer zone ($r \geq 1$ pc) where the dust (and gas) survives and is driven outwards at high velocity by radiation pressure. In the outer zone the dust is highly charged and thus tightly coupled to the ionized gas through magnetic fields. The compression of these stellar mass-loss trails into thin, high density ribbons as shown in Figure (a) can be modelled numerically to predict the expected density and thickness along the line-of-sight to the central, UV-emitting accretion disk.

For standard grain opacities, the equilibrium temperature of the grains is given by (cf. Scoville and Norman 1995)

$$T_D(r) = 1800 \left(\left(\frac{L_{UV}}{5 \times 10^{12} L_\odot} \right) \left(\frac{1}{r_{pc}} \right)^2 \right)^{\frac{1}{5.6}} \text{ K.} \quad (1)$$

If the grains sublimate at 1800 K, then the closest distance for grain survival is

$$r_0 = \left(\frac{L_{UV}}{5 \times 10^{12} L_\odot} \right)^{\frac{1}{2}} \text{ pc}, \quad (2)$$

or approximately 1 pc from a central source of luminosity $5 \times 10^{12} L_\odot$. For a standard mix of gas and dust the outward terminal velocity of mass-loss debris is given by

$$v_\infty = 32000 \left(\frac{1 \text{ pc}}{r_0} \left(\frac{L_{UV}}{5 \times 10^{12} L_\odot} - \frac{M}{1.2 \times 10^{11} M_\odot} \right) \right)^{\frac{1}{2}}. \quad (3)$$

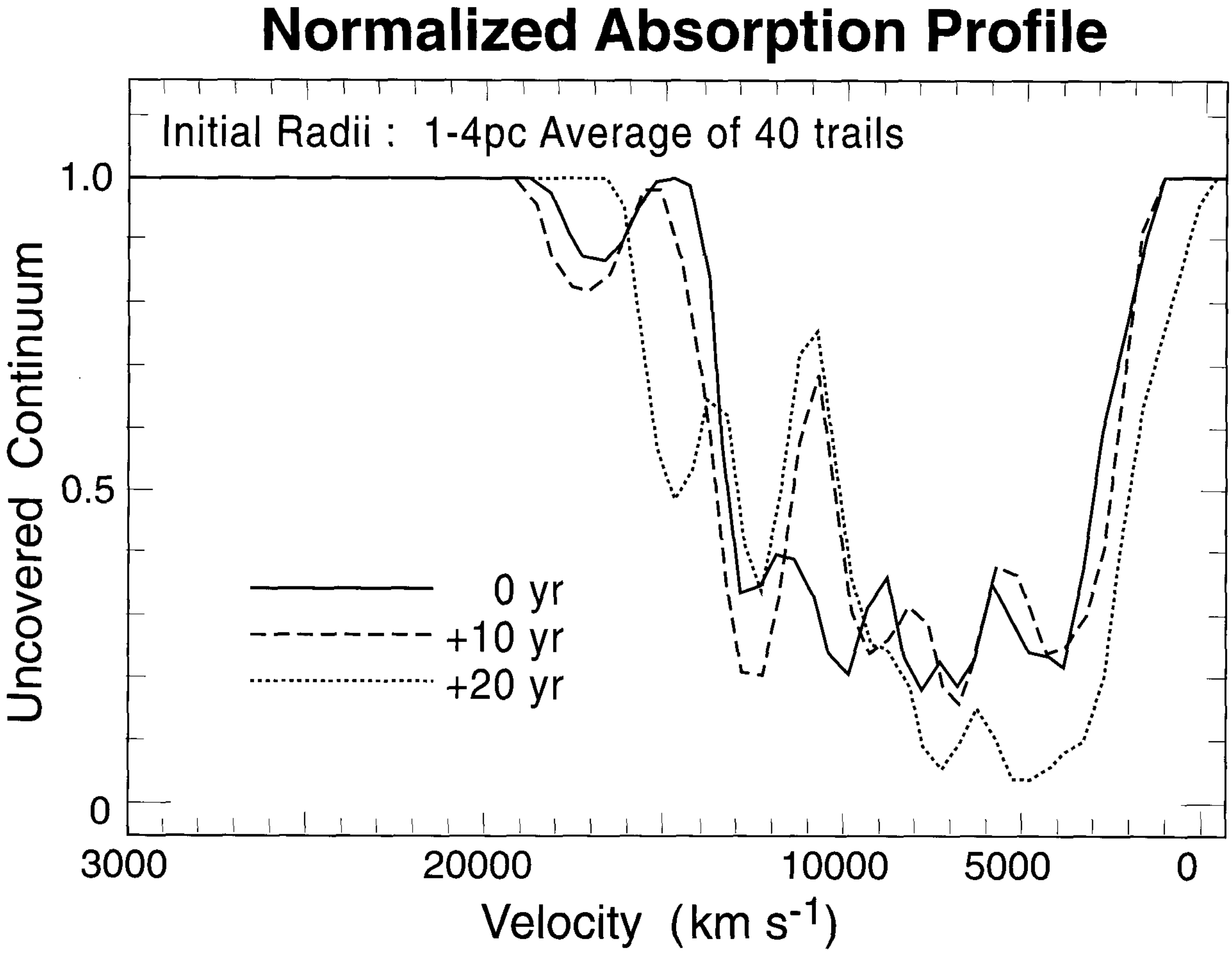

Fig. 5.— Absorption profile obtained by computing the covering factor for 40 trails crossing the accretion disk. Two additional curves are shown corresponding to the source stars having orbited an additional 10 and 20 yr (in the QSO rest frame.) The orientation of the orbital planes and the azimuthal phase angle of the stars were randomly chosen, and the stars were selected from a uniform distribution at 1-4 pc.

Since the maximum terminal velocity is achieved by grains originating at the smallest initial radius, the last two equations can be combined, yielding the maximum wind velocity as:

$$v_{max} = 32,000 \left(\frac{L_{UV}}{5\times 10^{12} L_\odot}\right)^{\frac{1}{4}} \text{km s}^{-1}. \qquad (4)$$

Thus for AGNs with luminosities in the range $10^{12} - 2.5 \times 10^{13}\ L_\odot$, the maximum velocities are in the range of 21,000-48,000 km s^{-1}, ie $\sim$ 0.1 c. This dependence of the maximum velocity on source luminosity is in approximate agreement with the observed correlation in BAL sources. For pure radiative acceleration in the resonance lines, neglecting ionization parameter considerations, the terminal velocity scales as $L^{1/2}$ and there is no maximum allowed velocity (Weymann et al 1985).

As the mass-loss debris is accelerated outwards, it is vital that the material be maintained at high density in order to avoid either grain destruction or ionization of the ionic gas to such a high state that there is no significant resonance line opacity. For the material lost by the giant stars in which the dust survives, the opacity in the radial direction due to dust will be substantially greater than unity. The interior face of this trail will therefore feel a greater radiation pressure force than the layers outside $\tau \geq 1$. This differential radiation pressure force in the radial direction across the stellar contrail will have the effect of compressing the trail in the radial direction and maintaining the density at greater than 10^9 cm^{-3}. The derived parameters agree well with those for the BAL clouds. Figure (a) shows schematically one of these trails.

Based on the numerical results for the evolution of individual trails (Scoville and Norman 1995), computed composite absorption line profiles produced by a population of mass-loss stars along the line-of-sight to a central, UV-emitting, accretion disk. In Figure 5 the computed absorption line profiles are shown for a collection of stars distributed at 1-4 pc radius for a case with 40 trails crossing in front of the accretion disk. When there is a larger number of crossing trails the absorption trough becomes filled in and exhibits a lumpier appearance. This figure also illustrates the temporal evolution of a single system in that the individual absorption line trails were allowed to move dynamically and the profiles were computed for three different epochs (0, 10 and 20 years in the rest frame of the QSO). An excellent test of this model would be the comparison with absorption line profiles monitored over similar time spans.

To account for a 1-10% covering factor in BAL QSOs, the red giant contrail model requires approximately $10^4 - 10^5$ giant stars within the central 10 pc for an isotropic distribution of star orbits. This requirement is consistent with the number of giant stars expected in a nuclear starburst cluster. In any case, one should expect the incidence of BAL phenomena to correlate with the age of the stellar population; specifically, in a young post-starburst AGN one expects a high number of red giant stars and BALs (cf. Norman & Scoville 1988). In addition, since the red giant mass-loss material will be enriched in heavy elements, it is expected that these absorption systems should show higher than solar metallicity.

Any model for the broad absorption lines must account for several key observational characteristics:

- The maximum terminal velocity is approximately 0.1 c or 30,000 km s^{-1} and this terminal velocity correlates weakly ($\sim L^{0.2}$) with the central source of velocity.
- A diversity of line profiles is observed with smooth broad and lumpy features in some sources and multiple and narrower absorptions seen in other sources (Turnsheck 1987, Turnsheck et al 1987, Foltz et al 1987, Korista et al 1996).
- Temporal variations in the line profile shapes. This is an observation which as yet has not been exploited but should be of great use with longer time span observations on individual objects.
- The apparently high metal abundances produced by the BALs (Korista et al 1996; although some of the apparent high metalicities may be questioned due to partial source-covering.

To some extent these observational characteristics may be accounted for or at least predictably modelled in the context of stellar mass-loss trails, and other models for the BALs must be subjected to such testable predictions.

It is interesting to note that the density required for tidal stability of a broad emission line cloud requires that such clouds must have extremely high internal densities – perhaps arguing for a stellar origin rather than interstellar. At 1 pc from a 10^9 $M_\odot$ black hole, the Roche limit density is 3×10^{11} cm^{-3}.

VI. CONCLUDING REMARKS

For HII regions in M51, the extinction-corrected luminosities imply maximum cluster mass $\leq$5000 $M_\odot$ (between 1 and 120 $M_\odot$). This maximum cluster mass may well be determined by radiation pressure terminating the gravitational accretion of gas and dust to the cloud cores once the central clusters have grown to a few thousand $M_\odot$. It turns out that much larger scale nuclear starburst such as that in Arp 220 have approximately the same empirical limit of 500 $L_\odot$ / $M_\odot$, suggesting that nuclear starburst activity may also be regulated by a balance of self-gravity and radiation pressure support. In AGN, accretion from either the ISM or from stellar mass-loss will also have the same radiation pressure limit (similar to an Eddington limit with dust rather than electron scattering) as long as the dust survives.

Interaction and merging play a fundamental role in the evolution of galaxies – producing the most luminous starburst galaxies and very likely luminous AGN. The dynamical effects of the interactions are most dramatic in the ISM since it is dissipative and has high filling factors. The torques and increased velocity dispersions due to the galactic encounters lead to rapid transport of the dense molecular ISM to the nuclear regions and high rates of cloud-cloud collisions. The shock-induced cloud compression might trigger formation of super starburst clusters in the regions of physical overlap of the galactic disks and in tidal bridges/tails. In many of the ultra-luminous IR galaxies, over 10^9 $M_\odot$ of H_2 gas is found at radii << 500 pc (comparable with the Galactic ISM mass, but within an area 50 times smaller). Within the central region, it now appears this gas dissipatively settles into a thin disk. These ultra-massive nuclear gas disks are presumably the sites of the nuclear starburst activity which may be regulated by a balance of self-gravity and radiation pressure support.

It is natural to think of evolutionary connections between starbursts and AGN in the sense of an ageing starburst leading to a luminous, optical AGN once the interstellar matter is dispersed or used up.

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