SECTION VIII

STARBURST ACTIVITY

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WARMERS on television! Terlevich with an Armenian TV crew.

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STARBURST MODELS FOR AGNs

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1. INTRODUCTION

A significant fraction of all spiral galaxies exhibit some type of "activity" in their nuclear regions as evidenced by the presence of emission lines in their optical spectrum (Keel, 1982; Cetty-Veron and Veron, 1985). It has become standard to classify emission-line galaxies into two main groups: "active" having Seyfert or Liner nuclei and "inactive", having Starburst or HII-region like nuclei. Two main classification criteria are used, one based in the widths (Khachikian and Weedman 1974) the other in the intensity ratios of the nuclear emission lines (Baldwin, Phillips and Terlevich, 1981).

It is now 20 years since the seminal first Byurakan Symposium on nuclear activity. Astronomers have accumulated an enormous body of data at all wavelengths from which is possible to infer details about the most interesting and fundamental aspect: the origin of the nuclear activity. There are two competing scenarios to explain nuclear activity: "Monster" models that assume nuclear activity to be powered by a compact powerhouse lodged in the nuclei of galaxies generally believed to be a spinar or an accretion disk circling a massive black hole (see Rees 1978, 1984 for references), and dense cluster or Starburst models first proposed by Shklovskii (1960) and more recently developed by Weedman (1983) and Terlevich and Melnick (1985), which postulate activity to be the consequence of one or several violent bursts of star formation (for a definition see Melnick, Terlevich and Eggleton 1985).

The causal connection between some form of violent star formation and Seyfert or radio galaxies has been recognized in the past by several authors (Shklovskii 1960, Field 1964, Pronik 1974, Adams and Weedman 1975, Harwit and Pacini 1975, McCrea 1976, Osterbrock 1978, Weedman 1983). Continuity or overlap of properties between "normal" and "active" galaxies has been reported repeatedly in radio, infrared and X-ray surveys of luminous galaxies (Condon et al 1982, Kriss et al. 1980, Fabbiano et al. 1982, Rieke and Lebofsky 1979, Lawrence et al. 1984).

Up to now this view where activity is the consequence of violent

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star formation in the nuclear region of galaxies has not been considered a serious contender to the "monster" scenario, basically because it failed to give satisfactory answers to the following fundamental questions:

1. Can the large luminosity of Seyfert galaxies and QSOs be provided by a starburst?

2. Can the emission line spectra of AGNs be explained by photoionization by young stars?

3. Why AGNs have broader forbidden emission lines than starbursts do?

4. Can the starburst scenario give an explanation for the broad permitted emission lines in type 2 Seyfert galaxies?

5. Can the starburst hypothesis explain the variability observed in AGNs?

6. Why the Hubble type distribution of galaxies with active nucleus is completely different to that of galaxies with starburst nucleus?

7. Can starbursts provide the observed radio luminosity? If so, can they produce the observed "jet-like" morphology observed in some AGNs?

8. Can the starburst scenario provide a non-thermal like optical continuum?

9. Can starburst provide the observed X-ray luminosity in AGNs?

Meanwhile, several new lines of evidence are somehow changing our interpretation of nuclear activity towards models involving some form of violent star formation. For instance: (1) IRAS discovery of hyper-luminous starburst galaxies with total luminosities of more than $10^{12}L_{\odot}$ rivaling those of QSOs (Wright et al. 1984, Houck et al. 1985, Allen et al. 1985). (2) Terlevich and Melnick (1985,TM85) proposal that the emission line spectrum of type 2 Seyferts and Liners is not associated with a non-thermal power source but rather with violent star formation at high metal abundances. (3) The detection of molecular hydrogen emission and water vapour mega-masers in active nuclei (Claussen et al. 1986, Heckman et al. 1986). (4) The discovery of Radio-supernovae hundreds of times more luminous than Cass A and associated with regions of star formation (Weiler et al. 1986 and references therein).

In this contribution we will re-discuss the Starburst scenario for nuclear activity and show that the Hubble type distribution of parent galaxies, the total luminosity, the radio and X-ray luminosities, the emission line ratios and line widths and the characteristics of the optical continuum of Seyfert 2 and Liners all agree with the predictions of the Starburst-Warmer model. The Hubble type distribution dichotomy arises naturally in the Starburst-Warmer scenario and is in fact rooted in the differences of metal abundance for galaxies of different Hubble type.

We will also show that the observed characteristics (ie, luminosity, line widths and variability time-scale) of the broad line region in AGNs seem consistent with being originated in supernova flashes and supernova remnants evolving in high density enviroment.

2. THE EVOLUTION OF STARBURSTS

Within the life span (3 to 20 Myrs) of a massive star ($10 < M < 100 M_{\odot}$) the Starburst-Warmer model predicts a substantial evolution in the emitted spectrum of the young stellar cluster and its associated HII region (TM85). It also predicts the existence of simple evolutionary sequences among active galaxies. In order to gain insight into the predictions of the scenario and compare them with observation, it is necessary to understand the evolution of massive stars and how this evolution may be influenced by environmental conditions.

i - The stellar phase

It is a well established observational and theoretical fact that, for a given mass, the most important parameter affecting the evolution of a massive star is the mass-loss rate. Evolutionary models incorporating the effects of mass loss have been computed by a large number of authors (see e.g. Chiosi, 1981 for a review). Without exception, all authors find essentially the same basic difference between conservative ($\dot{M}_{\odot}$=0) and mass-losing models found initially by Tanaka (1966) namely a change in the H and He-burning time scales and a blueward evolution when the products of nuclear burning reach the stellar surface (Stothers and Chin, 1979).

The common drawback of all non-conservative models is that the physics of mass loss is not completely understood and therefore, mass loss rates cannot be directly predicted even knowing the structure of the stellar interiors. This situation is partly compensated by a substantial improvement in the observations that have allowed accurate mass-loss rates to be determined for a significant number of nearby stars (see e.g. Conti and Garmany, 1983). Thus, stellar interior models incorporating the best observationally determined mass loss rates should provide a reliable picture of how massive stars evolve. Notice however that, in principle, this model should only apply to stars having mass loss rates similar to those of the stars that provide the empirical determination namely, stars in the solar vicinity. This restriction may be important in the present context and we will return to it at the end of this section.

Throughout this paper we will use the computations of Maeder (1986) that incorporate the most recent mass-loss rates as well as improvements in the basic input physics such as improved nuclear reaction rates and an accurate treatment of convective overshooting (see also Maeder 1985 for a description of the models). Maeder´s models give a consistent description of the evolution of massive stars. The observed lack of red supergiants with Log L > $5.8 L_{\odot}$, the surface

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chemical composition and isotope ratio in W-R stars, the evolutionary status and chemical composition of Hubble-Sandage variables and Eta Carina, all agree remarkably well with the theoretical predictions.

Very different evolutionary sequences are obtained from models of massive stars according to their initial masses and mass loss rates.

a) High mass-loss: Massive stars evolve initially towards the red (decreasing temperatures) but eventually the outer layers are peeled off by stellar winds leaving exposed the nuclear burning layers. Subsequently as was the case for the early Tanaka (1966) models, the stars evolve towards high temperatures and end their evolution as bare cores, near the He-ZAMS (Stothers and Chin, 1979) where they reach effective temperatures well in excess of 100,000K. Stars more massive than $60M_{\odot}$ spend most of their He-burning life at temperatures higher than those corresponding to the H-ZAMS. Stars less massive than this limit spend part of their He-burning life as red supergiants. However the mass loss in the red-supergiant phase completes the removal of the envelope and thus brings back the star to higher temperatures near the He-ZAMS also as a bare core. The evolutionary sequence is, according to Maeder:

O - Of - (Eta Car/H-S var) - WN - WC - WO - SNI

(see footnote)

for stars more massive than $60M_{\odot}$, and

O - BSG - RSG - WN - WC - WO - SNI

for stars with masses between $25M_{\odot}$ and $60M_{\odot}$.

b) Low mass-loss: In this case stellar-winds are not sufficiently strong to remove the envelopes. As a consequence, stars spend all of the He-burning time in the RSG branch. The evolutionary stages are,

O - BSG - RSG - YSG/Cepheids - RSG - SNII

Terlevich and Melnick (TM85) have computed evolutionary models for the emission line spectra of gaseous nebulae photoionized by coeval clusters of massive stars taking into account the effect of mass-loss in the stellar evolution. The ionizing spectrum of a starburst is dramatically affected by the presence of hot luminous massive stars near the He-ZAMS that have been called WARMERS by TM85 precisely because of this effect. These models show that when Warmers begin to

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The meaning of the symbols is : O = O star Of = Of star H-S var = Hubble Sandage variable BSG = Blue Supergiant star YSG = Yellow Supergiant star RSG = Red Supergiant star WN = Nitrogen series Wolf-Rayet WC = Carbon series Wolf-Rayet WO = Oxygen series Wolf-Rayet SNI and SNII = Supernovae of type I and II respectively

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appear in the cluster (i.e. after about 3 million years) the nebular spectrum changes in a very short time scale from a normal, low-excitation HII region (typical of nuclear starbursts) to a Seyfert or Liner spectrum. The theoretical predictions agree remarkably well with the observed line ratios in AGNs. Figure 1 reproduces one of the diagrams of TM85 where this "qualitative" change is clearly illustrated. TM85 concluded that the mere presence of strong high excitation narrow forbidden lines in the nuclear spectrum of an early type galaxy does not necessarily imply that photoionization is produced by a non-thermal source. Photoionization models of Starbursts with WARMERS give a very good description of all the observed line ratios in type 2 Seyfert and LINERS.

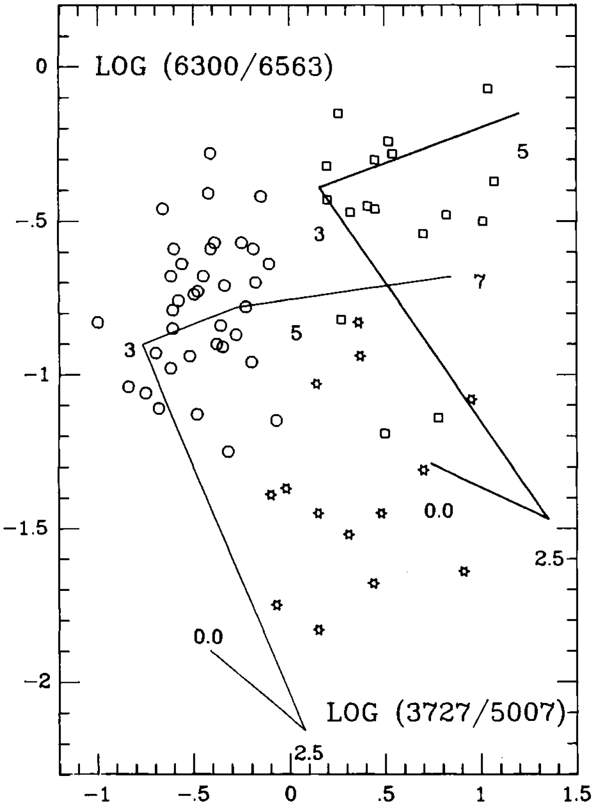

Fig. 1. The logarithmic intensity ratio [OII]3727Å/[OIII]5007Å versus the logarithmic intensity ratio [OI]6300Å/Hα. The stars correspond to starburst nuclei, squares to LINERs and circles to Seyfert galaxies.

ii - The supernova phase

TM85 paper was concerned with photoionization models using clusters of coeval stars. The evolution of the clusters was followed through all stages but did not include the supernova phase. The effect of a

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population of supernova remnants from massive progenitors evolving in a high-density medium is worth a detailed investigation. I will only present here some arguments as guidelines.

Both for high and low cases of mass-loss rate, observational considerations lead to the conclusion that massive stars end their evolution as supernova explosions that occur shortly after carbon ignition (Maeder and Lequeux, 1982).

Supernovae are expected to be of two different types depending on the progenitor´s mass:

I - Those coming from high mass-loss progenitors (WARMERS) will give rise to a shock that expands from a non-degenerate carbon-oxygen core into the high velocity and low density pre-supernova wind blown bubble. Given the composition and density of the medium into which the shock expands, this type of event will presumably look like a sub-luminous type I supernova (Chevalier 1971). The flash may last a few weeks and have total energies probably below 10^{49} ergs. (Woosley and Weaver 1982). Following Wheeler et al 1980 (WMS), at the time of explosion the surrounding wind blown bubble consists of stellar wind out to

$$R_l = 0.33 \text{ pc } n_4^{-3/10} \dot{M}_{-6}^{3/10} v_8^{1/10} t_6^{2/5}$$

where t is the life-time of the star, v is the wind velocity, M is the mass loss rate and n is the density of the medium. The density in the interior of this bubble is low and the supernova remnant sweeps up only a small amount of mass before encountering the dense interstellar medium at the edge of the bubble. As WMS pointed, this is likely to produce a rapid evolution phase with time-scales and luminosity depending on the density distribution. Thereafter, the evolution should follow the predictions of the pressure-driven snowplough with maximum luminosity,

$$L_{p\text{-}snow} = 0.8 \times 10^9 L_o \; n_6^{7/11} \; E_{51}^{9/11}$$

where E is the total energy of the supernova. In a high density enviroment a supernova remnant will deposit all the kinetic energy in a short time scale and reach very high luminosities. Most of the luminosity will be emitted in the UV/X-ray region of the spectrum (WMS).

II - Low mass-loss progenitors will give rise to classical type II supernovae. The supernova envelope will expand out in the dense stellar wind of the red giant pre-supernova star. This produces a fast shock propagating outwards into the stellar wind and a reverse shock moving backwards into the stellar envelope. Comptonized UV radiation is emitted by the outer shock while the inner emits mainly in the X-rays. This "flash" of energetic radiation lasts few weeks and emits 10^{49-50} ergs (see Chevalier 1982, Fransson 1982,1984). After this the supernova shell continues to expand until it reaches the edge of the wind blown bubble. The subsequent evolution of the supernova remnant will be similar to the one outlined above for SNIs.

iii - Abundance effects

It is widely accepted that stellar winds are mostly due to radiation pressure in metal lines and therefore that mass-loss rates should depend on chemical composition.

Evidence supporting this comes from studies of galaxies in the Local group. These studies indicate a strong correlation between the relative numbers of hot (WC) to cold (WN) WR stars and chemical composition. The ratio WC/WN seems to be a very steep function of the abundance (van der Hucht 1981), with hot WR stars outnumbering cold ones only in systems with abundance larger than solar.

We therefore expect that only those massive stars formed in metal rich (relative to solar) enviroment will eject their outer layers to reveal the hot bare core and become Warmers. In metal poor (relative to the solar value) starbursts, instead, massive stars will not be able to remove the outer layers and expose their core. In this case massive stars will end their evolution as Red Supergiants or late WN stars and will not reach the hot Warmer phase.

Consequently only in those systems where the metal abundance is solar or larger a burst will develop Seyfert or LINER characteristics. The emitted spectrum of metal poor starbursts will always look like a "normal" HII region starburst to develop Seyfert or Liner.

iv - Dust

Stars more massive than $60M_{\odot}$ experience during their evolution, strong mass loss in the post main sequence stage, near the De Jager instability region of the HR diagram. This is the Eta Carina/Hubble-Sandage-variable phase. During this time, large amounts of dust are synthesised out of the mass flow (Andriesse et al.1978). Wolf-Rayet stars and RSG are also known to have large rates of dust production (van der Hucht et al.1986). In the case of young clusters, we expect the dust production to be somehow related to the total mass loss rate. Large amounts of dust will be generated when the more massive stars are undergoing the Eta Car phase, between 2.7 and 3.7Myr. After this the dust production should steadily decline as the total mass loss from the cluster gets smaller.

3. THE HUBBLE TYPE DISTRIBUTION

There is a basic difference in the Hubble type distribution of galaxies that host emission line nuclei. As can be seen in fig 2, galaxies with "active" nuclei have Hubble types earlier than Sbc while those with "inactive" nuclei have Hubble types later than Sbc. This important behaviour, first reported by Heckmann et al. (1980) raises several important questions:

i - Why this dichotomy in the Hubble type distribution exists at all?

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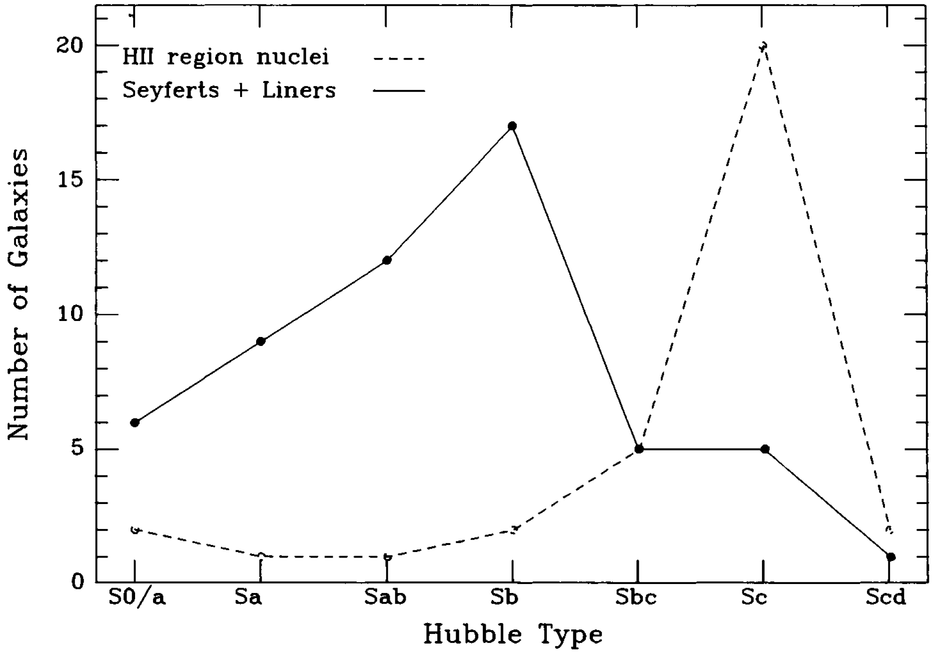

Fig. 2. The Hubble-type distribution of spiral galaxies with nuclear emission lines.

ii - How is it possible that while star formation is so common among nuclei in late type spirals it seems to be almost completely switched off at Sb only two Hubble types away from the peak of the distribution?

and conversely,

iii - How is it possible that, "monsters" being so common among early type galaxies, their formation seems completely inhibited at Sc, again only two Hubble types away from the maximum of the distribution?

There are several important intrinsic parameters in the bulges that do change with Hubble type. Hubble type is mainly defined by the disk to bulge (D/B) ratio, D/B is small for early type spirals and large for late type spirals. Simien and de Vaucouleurs have investigated the D/B distribution for a sample of bright spirals. They find that not only the D/B changes with Hubble type but also the total bulge luminosity. The bulge luminosity is roughly constant from S0 to Sb at about Mb=-19 (for H_0=100Km/s/Mpc), and drops sharply for later types.

Whitmore et al. (1979) found that the central velocity dispersion in spiral bulges is well correlated with the total bulge luminosity.

Cowley et al.(1982) reported a good correlation between line strength indices and bulge luminosity; particularly important is the relation between the Mg b index and bulge luminosity because this index can be calibrated in a metallicity scale relative to the sun (see Faber 1977).

Thus, from this evidence, we can conclude that the Hubble sequence is also a sequence of Bulge luminosity, Bulge velocity dispersion, Bulge size and Bulge metallicity.

The first corollary of these findings is that the empirical classification method of segregating "active" and "non-active" nuclei based in their emission-line widths is not sound and should be abandoned. The difference in the mean FWHM between "active" and "non-active" nuclei is probably a reflexion of their different Hubble type distribution. Thus, the classification method based in the FWHM of the emission lines is only an indirect way of dividing the sample into "active" and "non-active" nuclei; it probably has a large uncertainty and its use should be discouraged.

The second conclusion relates to the abundance distribution at the center of bulges. From the work of Cowley et al.(1982) and Faber (1977) the Mg b index can be calibrated in term of [Fe/H]. Although it is possible that the observed Mg b vs Luminosity relation in bulges is in fact a combination of age and abundance effects in the stellar population, nevertheless, it is still valid to take as a lower limit the abundances inferred by this method. Based on the strength of the Mg b index observed by Cowley et al. for galactic globular clusters, we estimate that Mg b is about 0.16mg for [Fe/H]=0.0 . When this value is translated into the relation between bulge luminosity and Mg b, it implies that a bulge has to be brighter than Mb=-18.0mg to have abundances larger than solar. This value corresponds to central FWHM of about 350Km/s and Hubble type Sbc.

Therefore galaxies with Hubble type earlier than Sbc have on average over-solar abundances in their central regions and broad lines (FWHM>350Km/s). Galaxies with Hubble type later than Sbc are on average underabundant in metals with respect to the sun and have narrow lines (FWHM<350Km/s).

We can now answer the questions raised at the start of the section. In section 2iii we pointed that only those bursts with over-solar abundances are expected to develop Seyfert or LINER characteristics, this will therefore correspond to spiral galaxies with Hubble type earlier than Sbc. Those bursts in galaxies with Hubble type later than Sbc are expected to look always as "normal" HII regions. The change in the Hubble type distribution at Sbc is associated with a sharp drop in the average spiral bulge luminosity and chemical composition beetwen Hubble types Sb and Sc.

4. VARIABILITY TIME SCALES AND TOTAL ENERGY

Variability studies are a very important way to discriminate between different models for active galactic nuclei. Two typical total energies and time scales are expected in the Starburst scenario during the Supernova phase:

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(a) Flares of about 10^{49-50} ergs and lasting for few weeks coming from those supernovae whose progenitor is a red supergiant (SNII)

(b) About 10^{+52} ergs total energy in longer term variations with time scales of order:

$$t \sim 1500 \text{ days } n_6^{-0.4}$$

and peak luminosity:

$$\text{Log } L/Lo \sim 9.0 + 0.64 \log n_6$$

associated with the supernova remnants.

WMS computed the luminosity of a 10^{52} erg/sec supernova ejecta expanding into a medium of uniform density n = 5 x 10^6 cm^{-3}. One year after the explosion reaches a peak luminosity of 10^9 solar luminosities. Thereafter, the luminosity evolves as the -11/7 power of the time, i.e. drops by a factor of two after 2.7 years or about 1,000 days.

These are exactly the time scales and total energies observed in highly variable Seyfert nuclei. Lyutyi (1977,1979) and Dibai and Lyutyi (1984) made extensive photometric observations of 16 galaxies since the late 1960s. They found that the optical variability contains two components: a rapid "flare" component with characteristic time scales of tens of days and typical total energies of few 10^{49} ergs. These flares have a typical rise time of 10 days and a decay of 40 days with average absolute magnitude of -18.4 in galaxies like NGC4151 and NGC1275. The flares are superposed on a slower component with variability time scale of several years and similar amplitude to the flare component. This implies total energies of about 10^{51} ergs.

Similar results can be found in recent studies of variability. The comprehensive IUE study of NGC4151 by Ulrich et al.(1984) reports variability in the broad CIV1550A with time scales of several weeks and luminosity in the variable component of CIV of about 2x10^{41}erg/sec, corresponding to total energies of about 5x10^{49}ergs. Another well studied Seyfert galaxy, NGC1566, was found to show variations of 1300 days duration and total energies of order 10^{51} ergs (Alloin et al. 1986).

One is led to conclude that the so-called "broad line region" in Seyfert galaxies is a superposition of several supernova flashes and supernova remnants evolving in the high density enviroment of the nuclear interstellar medium.

5. SUPERNOVA RATES AND RADIO AND X-RAY LUMINOSITIES

The Starburst scenario have been strongly criticized from the point of view of radio astronomy. Heckmann et al. (1983) raised objections regarding the observed morphology of the radio emission (jets, double lobes). Ulvestad (1982) concludes that the large number of massive stars needed to make the high supernova rates would radiate an amount of energy a factor of 10 in excess of the total luminosity observed in Seyfert galaxies. In estimating these rates Ulvestad used Rieke et al. (1980) starburst models with exponentially decaying star formation. These models overestimate respect to coeval models the total luminosity of a burst at a given supernova rate. Using Melnick, Terlevich and Eggleton (1985) models of the luminosity evolution of clusters of stars with instantaneous star formation, we estimated the bolometric and Hα luminosity of a cluster capable of producing one supernova per year. For a slope of the initial mass function similar to that of massive stars in the solar neigbourhood (Lequeux,1980) and an upper limit of $100M_\odot$ at t=0, the luminosities are $10^{11}L_\odot$ and 7×10^{42}erg/sec repectively at the time the first supernova with a massive progenitor explodes, and $3\times10^{10}L_\odot$ and 10^{42}erg/sec when the first type II supernova explodes. These luminosities are 3 and 10 times lower respectively than the value of $2.9\times10^{12}L_\odot$ per supernova used by Ulvestad. Figure 3 shows the relation between the supernova rate necessary to explain the radio emission (estimated using equation 8 from Ulvestad, 1982) and the expected supernova rate based in the above estimate of 1 supernova per $10^{11}L_\odot$ at the start of the supernova phase. The two rates are basically equal.

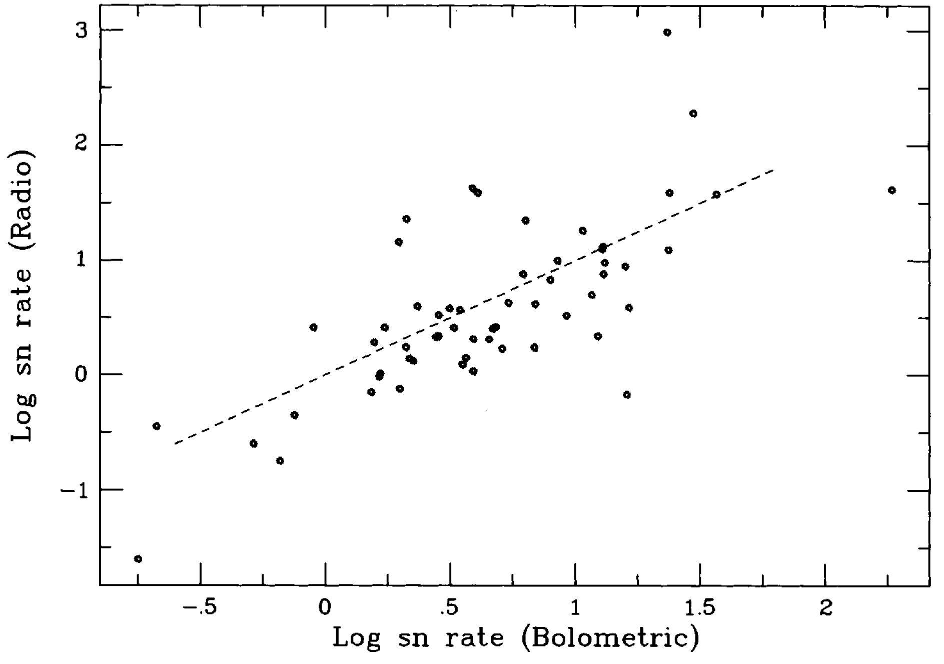

Fig. 3. The predicted (from 60-100μm luminosity) supernova rate versus the supernova rate necessary to explain the radio luminosity in AGNs.

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Regarding the morphology of the radio emission, it is useful to remark the conditions in the nucleus of an early type spiral. The gravitational potential will confine the central gaseous component to a relatively thin disk. The most massive stars will presumably form in the central parts of the disk. Wind from these stars will overlap and produce an extended bubble filled with hot gas. This bubble will extend further towards regions with steeper decreasing density gradients, this will presumably be along the rotation axis. The first supernovae will explode in this environment and the radially decreasing density gradient will accelerate the shock. If the remnant or remnants reach the edge of the disk a jet of matter should be ejected into the lower density outer regions. UV radiation from the central cluster should leak also in the same direction, illuminating therefore any background or foreground gas. This possibility provides some degree of collimation and explains the correlation observed between the major axis of linear radio sources and the major axis of the extended narrow line regions (Ulvestad, Wilson and Sramek 1981).

Let us now estimate the X-ray luminosities of a supernova remnant. As we saw above, most of the energy of the supernova remnant will be emitted in the extreme UV/X-ray part of the spectrum. The dust and gas that surrounds the remnant will absorb part of the optical and UV and reradiate it in the IR. The amount of reradiation will depend on the gas and dust geometry and column density. At short enough wavelength the optical depth decreases again, therefore X-rays with energies larger than about 1Kev will not be absorbed. According to WMS, the

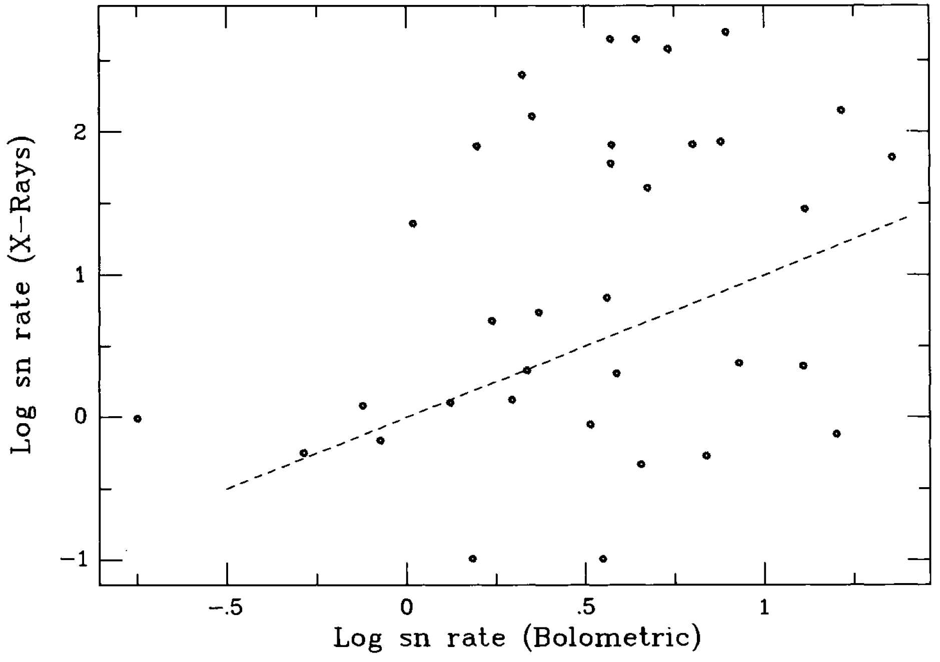

Fig. 4. The predicted (from 60-100μm luminosity) supernova rate versus the supernova rate necessary to explain the X-ray luminosity in AGNs.

hard X-ray (1 to 10Kev) luminosity of a supernova remnant with total energy $3x10^{51}$ergs expanding into a homogeneous medium of density $10^6 cm^{-3}$ is about 10^{42} erg/sec or about 25% of the total luminosity. Figure 4 shows the necessary rate to explain the hard X-ray emission in Seyfert galaxies compared with the expected rate from the total luminosity. Although there is a large scatter, the relation is consistent with equal rates in both axes.

6. THE UNDERLYING CONTINUUM

A fundamental discrepancy between the "monster" and Starburst scenario, is related to the origin of the underlying blue featureless continuum detected in all Seyfert galaxies and some LINERS. This relatively faint nonstellar continuum is difficult to study in detail because of substantial contamination from starlight even in nearby galaxies. Its spectral characteristics have not been unambiguously determined, rather most students have assumed them to be somehow similar to that of QSO´s (Koski 1978, Malkan and Filipenko 1983).
The general properties of the underlying continuum are:

a - It is featureless, i.e. it has no strong optical absorption lines.

b - It is well represented, at least in the optical range, by a power law dependence of the flux density on frequency.

c - It is unresolved, stellar-like.

The most effective way to separate the underlying continuum from the bulge stellar component is high or intermediate resolution spectroscopy of the most prominent stellar absorption features such as CaII H and K lines (3968, 3933 A), G-band (4303 A), MgIb line (5175 A), NaI doublets (5890,5896 A and (8193,8195 A) and the infrared CaII triplet (8498,8542,8662 A). All these lines are presumably absent in any non-stellar "monster" continuum and their strengths in normal stellar populations are relatively well known.

In the "classical" non-thermal case, all the stellar absorption features should be weaker than in normal galaxies by an amount that is wavelength dependent, since the underlying continuum is featureless and bluer than the old stellar population of spiral bulges. In the starburst-Warmer case instead, the blue continuum is originated in a reddened young cluster. The optical continuum in young regions of violent star formation is featureless to a high degree (see Kinmann and Davidson 1981, Rayo et al. 1982, Melnick et al. 1985). This is due to the fact that the optical spectra of a young cluster has relatively narrow absorption lines at the same wavelengths of the emission lines from the ionized gas. Relatively weak absorption is expected in CaII H and K, G-band, MgI triplet and NaId since these features are weak or absent in the O-B stars that are responsible for the optical continuum. On the contrary, the near IR CaII triplet being very dependent on the stellar gravity (Jones, Alloin and Jones 1984), it is expected to be stronger than in an old stellar population if the turn-off point of the

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cluster is below 50M⊙ (cluster age more than 3.7Myr). At this time the first luminous red supergiants appear and thereafter dominate the infrared light of the burst (Campbell and Terlevich 1984). Some dilution is expected during the supernova phase because part of the optical and near infrared continuum will be emitted by hot supernova remnants.

Terlevich, Diaz and Terlevich (1987) have recently obtained spectra in the near infrared covering the CaII triplet, of a number of Seyfert, LINER and normal galaxies. A large number of type 2 Seyfert galaxies with weak absorption lines at visible wavelengths were

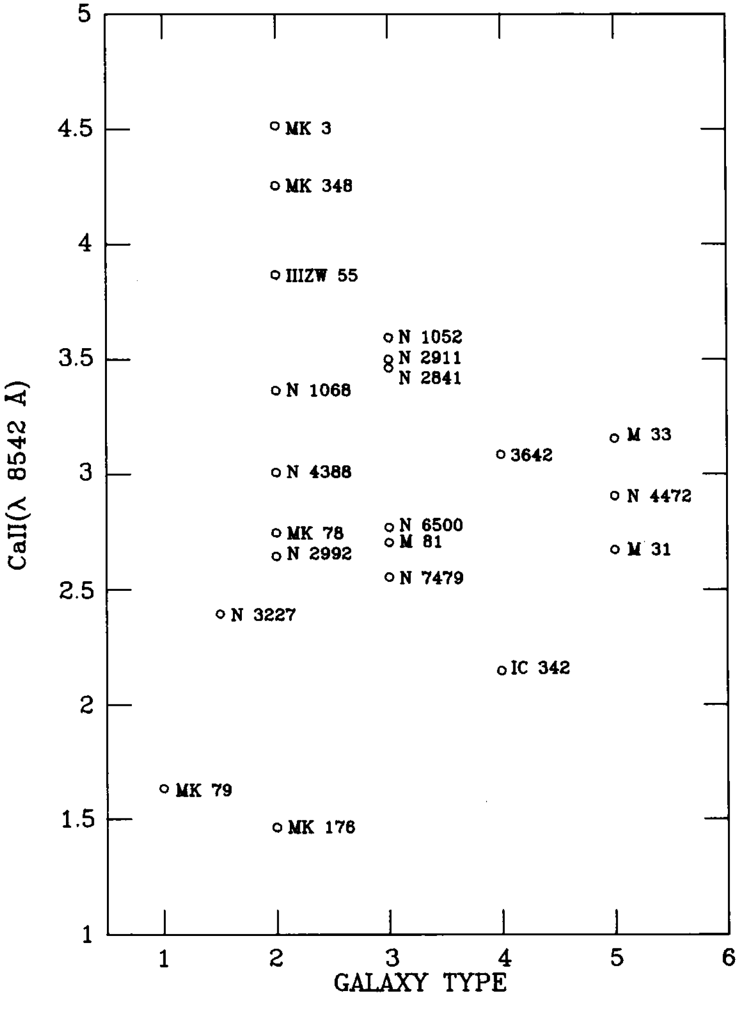

Fig. 5. The intensity of CaII 8542Å line versus galactic nuclear type assigned as follows: 1 = Seyfert 1; 1.5 = Seyfert 1.5; 2 = Seyfert 2; 3 = LINER; 4 = Starburst; 5 = Normal.

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included in the sample. Figure 5 shows distribution of the strength of the CaII 8542 A line versus galactic nuclear type. It can be seen from the diagram that not only no dilution was detected, but also that many type 2 Seyfert galaxies show CaII 8542 A equivalent widths larger than those in normal galaxies like NGC 4472, a luminous elliptical or M 31. Therefore, the underlying "featureless" continuum in (at least) some AGNs has strong near IR stellar absorptions indicative of a stellar population substantially younger than that found in normal early type galaxies.

Another property of the continuum in young bursts of star formation is that it is almost constant in flux density per unit frequency interval from 3000Å to 22000Å after corrections for reddening have been applied (Neugebauer et al. 1976). The presence of dust makes the continuum redder but preserves the power law shape.

Therefore an underlying "featureless" optical continuum that is well fitted by a power law is not only consistent but expected in the Starburst scenario.

But, can the unresolved or point-like light distribution of the continuum be originated in a Starburst?.

To answer this question, we can look at the properties of the nearest regions of violent star formation, 30-Dor in the LMC and NGC3603 in the Galaxy. The central part of 30-DOR consists of a compact cluster of luminous stars, one of these is in fact R136 whose brightest component, R136a, is believed to be an extremely compact cluster of massive stars. This central part that contains most of the stars with masses larger than $20M_\odot$ is what we will define as the CORE of the burst of star formation. About 2/3 of the total U.V. flux of 30-DOR is radiated from the central 7arcsec or 1.7pc (diameter), and about half of that flux comes from the central 1.5arcsec or .35pc(diameter) corresponding to R136 (Savage et al. 1983).

Recently Moffat and Seggewiss (1985) used CCD images to determine the core radius of the two nearest bursts of star formation, 30-DOR and NGC 3603. They concluded that the surface brightness distribution is nicely fitted by a King profile for over two orders of magnitude in radius. They determined that the core radius of 30-DOR is 0.26pc and that of NGC3603 is 0.026pc; both estimates are very close to the seeing radius and therefore the corrected core radii are even smaller.

Terlevich and Melnick (1981) and Terlevich (1982) found a good relation between the internal velocity dispersion and effective radius for young and old stellar clusters. This relation holds for globular clusters, starburst clusters and elliptical galaxies covering over 6 orders of magnitude in mass. These results imply constant surface density or constant surface brightness, if the mass-to-light ratio is constant. Using this fact, it is possible to scale up the core size of 30-DOR to the typical masses and luminosities expected for the larger bursts associated with "active" nuclei. TM85 estimated that a starburst of about $3x10^8M_\odot$ or about 40 times the mass (or Luminosity) of 30-DOR will be needed to explain the luminosity of a typical type 2 Seyfert. This cluster will therefore be about 6 times larger than 30-Dor and its predicted core radius is 2pc. This result is compatible with the best direct information on the size of a Seyfert nucleus. NGC

4151 was photographed with the Princeton Stratoscope II balloon telescope and found to have a diameter at half intensity of less than 7pc or 0.08 arcsec.

6. THE REDDENING AND THE 2200Å FEATURE

For the best observed Seyfert 2 galaxy, NGC 1068, Neugebauer et al. (1980) combined IUE, visual and IR observations of recombination lines and concluded that all the data was consistent with reddening by normal dust, i.e. galactic disk type dust, with E(B-V)=0.4mg. The only observation that was not consistent with this interpretation was that there was no evidence for an absorption feature at 2200A of the type seen in the Galaxy. This fact was also recognized by Malkan and Oke (1983). They found that in the two Seyfert 2 galaxies they studied (NGC1068 and Mk 3) the "non-stellar" continuum must be substantially reddened if it powers the large infrared emission observed, but in the case of NGC1068, this requires a reddening law with extremely weak 2200Å dip. This apparent weakness of the 2200Å ultra-violet band has been also reported in other AGNs. The more likely interpretation is that the dust composition in NGC1068 differs considerably from that of the galactic disk (Stein and Soifer 1983).

Weak 2200Å features have been observed in star forming regions as Orion, 30-DOR (Stein and Soifer 1983 and references therein) and also in the giant HII regions in M101 (Rosa 1980) and it is known as "anomalous extinction". The dust recently synthesized by Eta Carina also shows "anomalous extinction". If all massive stars ($M>60M_\odot$) go through a similar phase as is predicted by the models (Maeder 1983) just before becoming WARMERS, thus a large amount of dust will be produced. Obviously this dust will have an important role in the total extinction and reddening of the central region of the cluster. At least in a qualitative vein it is possible to predict that high metallicity starbursts will have large reddening and infrared excesses and extremely weak 2200A feature.

7. PUTTING ALL TOGETHER

The evolution of a starburst can be divided into four natural phases. The transitions between phases are given by: (a) the appearance of the first WARMER at about 2.8Myr, (b) the first RSG and SNI appear simultaneously at 4Myr and (c) the last WARMER and first SNII at around 8Myr.

The expected characteristics of these phases are:

Phase 1 0 to 2.8Myr
- All stars burning hydrogen
- Photoionization by normal O-B stars
- Optical continuum is a mixture of old red and young blue stars
- Normal reddening
- Radio emission mainly thermal
- No X-rays
- No variability

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Phase 2 2.8 to 3.8Myr
- Most massive stars ($120M_\odot > M > 60M_\odot$) are burning Helium near the He-ZAMS
- Photoionization by WARMERS and O-B stars
- Optical continuum is a mixture of old red and young blue stars
- Very large amounts of dust synthesised during Eta Car phase
- Radio emission mainly thermal
- No X-rays
- No variability

Phase 3 3.8 to 8Myr
- Most massive stars explode as SNI inside common wind blown bubble
- First RSG
- Optical continuum is a mixture of RG, RSG and BSG
- O-B stars are too cold to ionize the gas ($T_{eff} < 30,000K$)
- Photoionization by WARMERS and Supernova remnants
- Large amounts of dust from Wolf-Rayet stars and RSG
- Very reddened broad lines from supernova remnants
- No supernova X-ray/UV flashes
- Broad line variability; time-scale of tens of years
- Non-thermal radio from young SN
- Some X-rays from SNR

Phase 4 8 to 20Myr
- First SNII. Explosion inside small wind blown bubbles
- Optical continuum is a mixture of RG,RSG,BSG and SNR
- Photoionization by hot SNR, SN flashes and Warmers
- Small amount of dust
- Very broad emission lines
- Large variability in two time scales:
  1-Few weeks and total energy of about 10^{49-50}. SN events
  2-Few years and total energy of about 10^{51-52}. SN remnants
- Thermal X-ray emmision from SNR
- Non-thermal radio from SNR and SN

Quoted masses are the zero age main sequence values.

8. CONCLUSIONS

The main aim of this contribution was to show that a substantial part of the observed properties of active galactic nuclei are consistent if not expected in the Starburst-Warmer scenario.

We strongly believe that for at least a substantial fraction of nuclei currently classified as "active", the black-hole hypothesis is unnecessary. We also believe that such objects as BL-Lacs, classical Quasars and luminous radio galaxies are the best candidates for nuclear black holes. Detailed computations with improved evolutionary tracks and atmospheres, and including short-lived phases can substantially improve our understanding. Particularly important is the problem of the evolution of a supernova remnant in a high density environment.

QUESTIONS AND COMMENTS

A.V. Filippenko: This is a very interesting work and I certainly agree that some LINERs may be produced by your mechanism, but I doubt that most of them are. I have two questions: I - How do you account for the broad Hα emission (FWZI=5000Km/s) that Sargent and I are finding in a large fraction of LINERs? II - Since the Warmer phase lasts only for a few million years in a given starburst, whereas most early-type galaxies have LINER nuclei, you have to postulate some sort of continuously-operating bursts that form massive stars. Where are you going to get enough gas to accomplish this in the old bulge of an early type galaxy?

R. Terlevich: Regarding your first question, in our model typical LINERs are the low luminosity or low ionization parameter equivalent of Seyferts. We expect LINERs also to have supernova activity although with lower rate than Seyferts. Therefore some will show broad lines. To form a starburst that will evolve into a LINER as little as $3x10^5 M_\odot$ or as much as $3x10^7 M_\odot$ are needed depending on the initial mass function. The life-time of a burst is about 10^7yr and to explain the observed fraction of LINERs one burst every $4x10^7$ years is needed. This requires only $0.1 M_\odot$/yr to $1 M_\odot$/yr of fresh gas being accreted by the nuclear region. This is not a very high rate, Hubble types between Sa and Sb have total neutral hydrogen masses between 10^9 and $10^{10} M_\odot$.

T. Heckman: Given that (in your model) LINERs and Seyferts are the evolutionary aftermath of a Starburst, where are all the progenitors (normal HII regions photoionized by O main sequence stars) in the nuclei of early type galaxies.

R. Terlevich: I believe there is a classification problem. Most astronomers working in low luminosity activity have used the [NII]6584A to Hα ratio to segregate between LINERs and Starburst. This criterion is not as good as the [OI]6300A to Hα ratio but is used nevertheless mainly because [OI]6300A is very weak. To confidently assess about the percentage of starburst to LINERs in early type galaxies a high signal-to-noise survey of [OI]6300A is required.

R. Antonucci: I have two comments regarding the applicability of this mechanism to Seyfert 2s. In NGC1068 the non-stellar light is 16% polarized and wide Balmer lines are seen in polarized light. Also the polarized flux (scattered light) spectrum looks just like the spectra of Seyfert 1s and Quasars. If that´s not a coincidence then your model must explain them too, and of course their continua vary.

R. Terlevich: I would agree with you in principle. In our model objects like NGC1068 should be at the start of Phase 3 and we expect large amounts of dust recently formed and the first massive SNI to be present.

D. Alloin: The WARMERs approach to active galactic nuclei should

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explain too the variability properties of AGNs like: Few hours X-ray variations by factors of 2 to 3 and few days or weeks for the hard ionizing photons involving energies like 10^{50-51} ergs.

R. Terlevich: If you are referring to the variability of NGC1566, I believe that the 10^{51} ergs in 1200sec is perfectly compatible with being originated in a supernova remnant expanding in a high density medium. Regarding the X-ray variability in time scales of few hours I believe that poses a problem for ALL types of scenarios.

T. Tutukov: Can you please answer the following question: Is the high star formation rate the reason of the high metal content? or Is the high metal content the reason for the high star formation rate. Is it possible that both are consequences of some other common reason?

R. Terlevich: In principle there is no causal relation between the star formation rate and the abundance. But they will be correlated to other parameters like the gas mass fraction.

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