

WARMERS: MASSIVE STARS IN THE NUCLEI OF GALAXIES

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1. ACTIVE GALACTIC NUCLEI

A very small minority of all galaxies exhibit activity in their nuclear regions. The best known and most studied signature of nuclear activity is the presence of emission lines in the optical spectrum. In fact, active galaxies are classified as Seyferts, Liners or Starburst galaxies according to the strengths, widths and intensity ratios of their nuclear emission lines (figure 1).

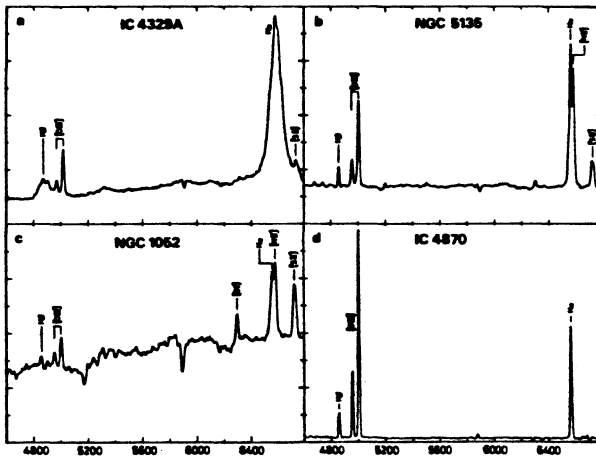


Figure 1:
Typical examples
of active
galaxies taken
from the Véron's
catalogue.
a) Seyfert 1
b) Seyfert 2
c) Liner
d) HII region.

There are two competing scenarios to explain nuclear activity: Starburst models, that postulate activity to be caused by one or several violent star formation events in the central regions of galaxies, and Nonthermal or Monster models that assume nuclear

activity to be powered by a compact nonthermal powerhouse (the Monster) lodged in the nuclei of galaxies. Whilst many of the properties of active galaxies are well explained by Starburst models, conventional starburst photoionization models fail to reproduce the morphology of the emission line spectra of Seyferts and Liners.

On the other hand, nonthermal power-law photoionization models fit reasonably well the observed spectra of active nuclei but fail to explain why some galactic nuclei harbor active star formation while others contain luminous nonthermal sources or why only a small fraction of all galaxies display nuclear activity.

2. STARBURSTS OR MONSTERS?

According to Heckman et al. (1983; A.J. 88, 1077) the starburst theory can be consistent with the optical, radio and X-ray observations of Seyferts and Liners only if,

a) Nuclear starbursts differ in several fundamental ways from extranuclear starbursts; and

b) The type of optical emission line spectrum produced by the nuclear starburst is strongly correlated with both the radio properties of the starburst and the nature of the parent galaxy.

While these two conditions are not inconsistent with observation they were regarded by Heckman et al. to be ad-hoc, to have neither empirical nor theoretical justification and therefore to argue strongly against the starburst scenario.

However, new developments in evolutionary theories for massive stars lend theoretical support to these two conditions. Here we will present the empirical evidence that is obtained by reanalyzing the observations of Seyferts and Liners in the light of these new theories.

3. WARMERS

The models presented by André Maeder in this Symposium predict that massive stars with strong mass-loss will spend a significant fraction of their He-burning phase to the left of the ZAMS on the HR diagram (figure 2). Thus, the ionizing spectrum of a young cluster of massive stars will be dramatically influenced by these extremely hot and luminous stars that we will refer to as WARMERS (observationally young Warmers may correspond to early WC and WO stars).

We have computed evolutionary models for the emission line spectra of constant density, spherically symmetric nebulae photoionized by coeval clusters of massive stars with solar-neighborhood IMF (Terlevich and Melnick, 1985, M.N. 213, 481).

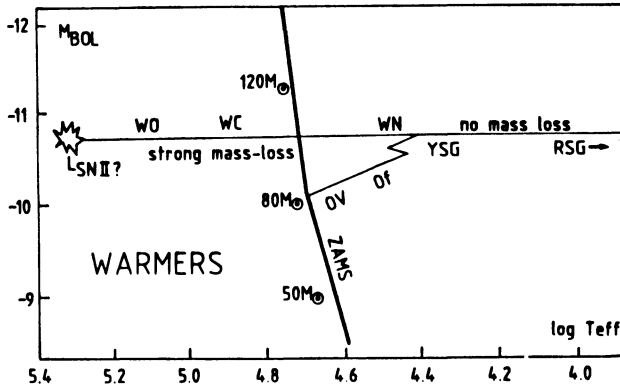


Figure 2: Schematic illustration of the effect of mass-loss on the evolution of massive stars.

Figure 3 presents some results from these models. After 2-3 million years, Warmers begin to appear in the cluster and the nebular spectrum suddenly changes from a normal, high excitation HII region (typical of extranuclear starbursts) to a Seyfert and/or Liner spectrum (figure 3).

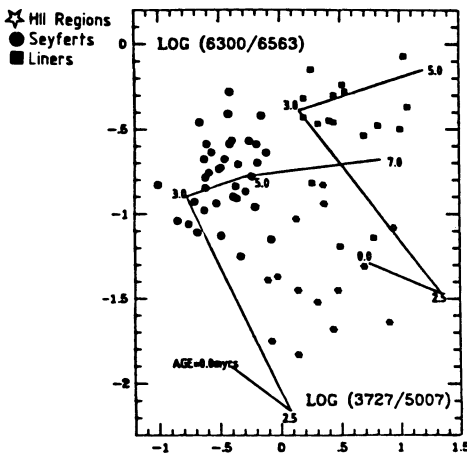


Figure 3: Starburst photoionization models with Warmers.

These models naturally explain the different types of active nuclei as an evolutionary sequence determined by the total mass of the ionizing cluster (or starburst) and the mass-loss rates of the ionizing stars. The models predict two parallel evolutionary sequences in the case of strong mass-loss,

Large Starbursts: HII regions → Seyferts → (Blue) Liners

Small Starbursts: HII regions → (Red) Liners.

If mass-loss is not strong, massive stars end their evolution as Red Supergiants or late WN stars but not as Warmers. Therefore metal poor starbursts will not be expected to develop Seyfert or Liner characteristics.

4. NUCLEAR VS. EXTRANUCLEAR STARBURSTS: MASS-LOSS

There is no complete theory of mass-loss but most theoretical scenarios predict a strong correlation between mass-loss rate and metallicity. There is substantial, albeit indirect, observational evidence for such a correlation (e.g. the dependence of Wolf-Rayet populations of parent galaxy composition). Most spiral galaxies show abundance gradients such that their nuclear regions are more metal rich. Thus, the Warmers models naturally explain the observed differences between nuclear and extranuclear starbursts as a metallicity effect through its influence on the stellar mass-loss rates.

In addition, for a given Hubble type extranuclear starbursts are on average considerably less massive than nuclear ones and therefore are not expected to contain very massive stars. For example, the most massive star in the Orion nebula has only $30 M_{\odot}$.

5. NUCLEAR ACTIVITY AND GALAXY MORPHOLOGY

Figure 4 presents a histogram of the frequency of different types of nuclear activity as a function of the Hubble type of the parent galaxy. This distribution was drawn from the volume-limited sample of Keel (1983; Ph.D. thesis UCSC) which contains 93 galaxies out of which 30 have HII-region nuclei and 52 have Liners and 5 Seyferts.

The histogram shows that HII-region nuclei occur predominantly in spiral galaxies with small bulges while Liners are mostly found in

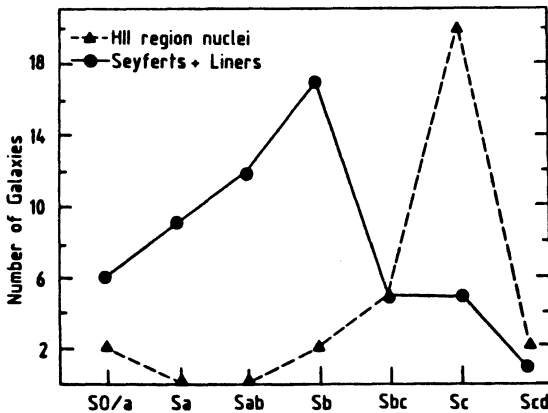


Figure 4: Distribution of nuclear morphology versus parent galaxy type.

early type spirals. The work of Cowley, Crampton and McClure (1982; Ap.J. 263, 1) shows that there is a good correlation between the luminosity of the bulge component of spiral galaxies and the chemical composition and/or the age of the stellar population such that

luminous bulges are metal rich and old. According to this work and the calibration of Hubble (or de Vaucouleurs) morphological type as a function of bulge luminosity by Simien and de Vaucouleurs (in IAU Symp. 100, p. 375) the bulges of spirals of de Vaucouleurs type 4 or Hubble type Sbc have approximately solar abundances.

Spirals later than Sbc have bulge abundances lower than solar while the bulges of early type spirals have over-solar metallicities. Thus, Warmer models explain the Hubble type distribution of galaxies with active nuclei as a metallicity effect.

EPILOGUE: THE UNDERLYING CONTINUUM

Starburst models with Warmers explain, at least as well as Monsters, the observational properties of active galaxies. For reasons of space we cannot discuss here any of these properties but one: The morphology of the optical continuum in Seyferts and Liners.

After deconvolving the bulge component, the (underlying) continuum of Seyfert nuclei is featureless and is roughly a power-law of slope 1. Since a power-law ionizing spectrum of approximately the same slope is used to fit the emission-line spectrum of active galaxies, the morphology of the optical continuum is generally considered to be one of the strongest lines of evidence in favor of the Monster hypothesis. This interpretation, however, fails to consider reddening. After correction for reddening the mean observed slope of the continuum is -1 , totally inconsistent with the ionizing power-law. On the other hand, the observed continuum of young, high excitation HII regions (figure 5) is also featureless and has the correct slope!

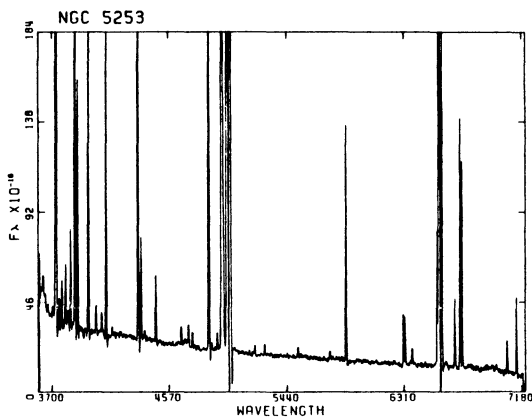


Figure 5: The featureless continuum of the nucleus of NGC 5253.

To conclude, although starburst models will certainly not fit the observations of all active galaxies, they explain the activity observed in the vast majority of spiral galaxies.