Diagnostics of composite starburst+Seyfert 2 nuclei: 
Hints on the starburst-AGN connection

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Abstract. We present a simple population synthesis scheme which recognizes composite starburst+Seyfert 2 nuclei from a few easy-to-obtain optical measurements. Composite systems seem to evolve towards less luminous Seyfert 2’s which do not harbor detectable circum-nuclear starbursts. We encourage applications of this cheap diagnostic tool to large samples of Seyfert 2’s, as well as its extension to other activity classes, in order to test and refine this evolutionary scenario.

1. Introduction

The nowadays popular expression “starburst-AGN connection” was to our knowledge first coined by Tim Heckman in a 1991 conference paper which dealt primarily with the then hot debate over the starburst model for AGN of Roberto Terlevich and collaborators. Since then, several groups have gathered unambiguous evidence that vigorous star-formation occurs in the inner few hundred pc of many AGNs (see Cid Fernandes et al. 2001a and references therein), flooding AGN papers with considerations about the effects of starbursts. This very volume contains several new reports of nuclei exhibiting both starburst and AGN properties (e.g. Colina et al., Levenson et al.) and of ways of diagnosing such composite systems (e.g. Kohno et al.). While these discoveries undoubtedly strengthen the long held suspicion that these two phenomena are intertwined in some fundamental way, in all fairness, we still do not know what this connection actually means! In a way, the situation was perhaps clearer 5–10 years ago,
when the discussion was polarized in terms of the pros and cons of the starburst model for AGN, a central theme of the La Palma meeting back in 1993 (Tenorio-Tagle 1994). Now that the focus has (ironically) drifted away from that debate (because of the overwhelming evidence that super-massive black-holes do exist, gathered since we last meet here in “la isla bonita”), there is not a well defined theoretical framework able to make good use of these new data. Now that we all recognize that the issue is not starburst or black-hole, the fundamental questions are (1) what role do starbursts play in defining the observed properties of AGN, and (2) what is the physics linking starbursts and AGN?

The kind of starburst-AGN connection which would do more justice to the term “connection” is one in which circum-nuclear star-formation somehow controls the accretion rate and/or vice-versa, via symbiotic/feedback processes, perhaps on the lines of the old models by Perry & Dyson (1985) and Norman & Scoville (1988). A more trivial and less causal connection would be one that links starbursts and AGNs by their common eating habits. Both starbursts and black-holes live on gas, so feeding the inner regions of galaxies (by the dynamical processes discussed in this meeting) may well lead to a simple genetic link between star-formation and nuclear activity, with either phenomenon proceeding essentially unaware of the concomitant occurrence of the other. These two extreme alternatives, which broadly outline “nurture or nature” perspectives on the starburst-AGN connection, respectively, are presently viable. By the time we next gather in La Palma we will surely have a clearer understanding of which of them is more relevant.

Observational clues on the nature of the starburst-AGN connection require the careful study of systems in which both phenomena co-exist. A critical first step is hence to devise ways of identifying such composite starburst+AGN nuclei. A second step is to characterize the basic parameters of both the starburst (e.g., its star-formation rate) and the AGN (say, its accretion rate), preferably for as large a number of systems as possible, so that one can address issues such as evolutionary effects, correlations between the starburst and AGN properties, the frequency of starbursts in AGNs and the role of the host galaxy (see Storchi-Bergmann’s contribution elsewhere in this volume). In these few pages we summarize some of our results concerning the first step, i.e., the diagnosis of compositeness. Our major “publicity” goal here is to convince the reader that we found relatively cheap ways of identifying composite systems and to encourage her/him to apply them to her/his data sets. We predict that such applications will substantially enlarge the current database of composite systems, thus providing plenty of raw material for more detailed studies, necessary to further our understanding of the starburst-AGN connection.

2. How to tell a starbursting from a “boring” Seyfert 2

AGNs are so complex and interesting by themselves that AGN-aunts have traditionally been reluctant to meddle in the business of stellar populations. The sentence “removing the starlight contribution”, present in so many papers since the late 70’s, epitomizes the historical view of stellar populations as an annoying pollution of AGN spectra. Most of the recent advances in the topic of the starburst-AGN connection stem from works which break this barrier by daring
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Figure 1. Results of the synthesis analysis, condensed into a ($x_{FC}, x_{INT}, x_{OLD}$) representation. Dotted lines trace lines of constant $x_{OLD}$. (a) Sources from our Seyfert 2 sample. Filled circles indicate composite systems, while empty circles indicate “boring” Seyfert 2’s. (b) Results for Starburst galaxies (stars), Narrow Line AGN (empty triangles), some of which are composites, and Mergers (filled squares).

to dissect this “pollution”, using it to characterize the stellar content within the central kpc of active galaxies. This lead to an outbreak of discoveries of starbursts around AGN, predominantly Seyfert 2’s, where the nuclear light-house is conveniently blocked from view, facilitating the study of circum-nuclear stellar populations. For instance, stellar wind lines in the UV, the WR bump and/or high order Balmer absorption lines, all signatures of recent or ongoing star-formation, were detected in 15 out of 35 Seyfert 2’s in our combined northern (Heckman et al. 1997; Gonzalez Delgado, Heckman, & Leitherer 2001) and southern (Cid Fernandes, Storchi-Bergmann, & Schmitt 1998; Storchi Bergmann, Cid Fernandes, & Schmitt 1998; Storchi-Bergmann et al. 2000) samples. Identifying these finger-prints of starbursts required high S/N data and years of hard work. But can we make it simpler? In other words, can we use these data to figure out a less expensive way of identifying composite starburst+Seyfert 2 systems?

The answer is yes! This answer was reached from an apparently hopeless method. We simply feed the population synthesis code of Cid Fernandes et al. (2001b; see also Schmitt, Storchi-Bergmann, & Cid Fernandes 1999 and Leão et al. in this volume) with the equivalent widths of Ca K, CN and the G-band absorption features, plus a couple of near-UV colors ($F_{3660}/F_{4020}$ and $F_{4510}/F_{4020}$). Very few observables to solve an acknowledgedly difficult problem (population synthesis), which, despite its “long and venerable history” (Worthey 1994), has something of a “bad reputation” (Searle 1986). Sure enough, we were not able to achieve a detailed description of the stellar populations in terms of all age and metallicity-related parameters in the code with so little information. However, we achieved excellent results by reducing the dimensionality of the problem to just 3 components: $x_{OLD}$, which is the total fraction of light due to stars of $10^9$
yr or more, $x_{INT}$, the fraction due to $10^8$ yr (post-starburst) populations, and $x_{FC}$, which congregates all stellar generations of age $\leq 10^7$ yr plus a power-law Featureless Continuum (FC), included to account for scattered light. While it is generally difficult to decide whether young stars or a genuine AGN FC dominate this last component (a historic problem which is still unsolved—see Storchi Bergmann et al. 2000), in practice the strongest FC’s are found in composites, for which young stars clearly dominate $x_{FC}$. The $x$-components, which we chose to normalize at the 4861 Å continuum, must add up to 100%, thus defining a plane in $(x_{OLD}, x_{INT}, x_{FC})$-space, so in practice the method provides a bi-parametric semi-empirical description of the data.

The results of this exercise are shown in Fig. 1a, where the synthetic proportions are projected in the $x_{FC}$-$x_{INT}$ plane. Our 15 certified composite systems are plotted as filled circles, whereas “boring” Seyfert 2’s (those where we have not detected signatures of circum-nuclear starburst activity) are shown as empty circles. Regardless of the actual meaning of the synthesis analysis, even the most skeptical reader must agree that the method provides an excellent empirical tool to separate composite from boring Seyfert 2’s! All composites but only one “pure” Seyfert 2 (NGC 1068, affected by its uniquely strong scattered light component) have $x_{OLD} < 75\%$ and thus $x_{INT} + x_{FC} > 25\%$, a threshold which can be equally well expressed by $W_{CaK} < 10$ Å. Also, all $x_{FC} > 30\%$ sources are composites. A remarkable fact about this diagram is that it does not use any of the information which was used to classify systems as composite (UV lines, the WR bump and/or high order Balmer lines). The synthesis picks out the composites simply by their diluted metal absorption bands and blue colors. As these data are relatively easy to obtain (all you need is a $S/N \sim 10$ optical spectrum), the method can be readily applied to large data sets, offering a cheap way to find many more composites. We have in fact verified that the method works for other samples, as illustrated in Fig. 1b (see Cid Fernandes et al. 2001a for details and for other handy properties of the synthesis parameters).

3. Evolution: Do composites end up as “boring” Seyfert 2’s?

Another remarkable fact about Fig. 1 is that our seemingly crude synthesis yields a good description of the evolutionary status of the circum-nuclear starbursts in composites. The youngest composites (those which exhibit O and/or WR star features, such as Mrk 477) are located in the bottom-right part of the plot (large $x_{FC}/x_{INT}$) whereas systems in a post-starburst phase (with pronounced high order Balmer absorption lines, such as ESO 362-G8) populate the top-left region, and nuclei which exhibit both characteristics (e.g., NGC 5135, NGC 7130) are located in between (top-right). The bottom-line here is that, more than a necessary evil, betting on a simple population synthesis analysis of Seyfert 2’s was not a bad idea after all!

The evolutionary path of a starburst in Fig. 1 would roughly follow a $x_{FC} \rightarrow x_{INT} \rightarrow x_{OLD}$ sequence as the burst ages and fades, converging to bottom-left of the plot, i.e., the region populated by “boring” Seyfert 2’s. This naturally suggests that “boring” Seyfert 2’s are the end point of composites! It must be stressed, however, that (at least some) “boring” Seyfert 2’s may well have faint but not necessarily old starbursts, which are naturally harder to detect against
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Figure 2. Far IR (60 + 100 µ) luminosity against \( W_{\text{CaK}} \), an empirical diagnostic of compositeness, for (a) the Seyfert 2 sample, and (b) Starburst and Merger galaxies. Symbols as in Fig. 1. A qualitative evolutionary arrow is sketched. Comparing the two panels we see that as a whole our Seyfert 2 sample is rather comparable to merger systems.

the dominant background of old bulge stars (quantified by their large \( x_{\text{OLD}} \)). In fact, we came to recognize that we know much less about the “boring” Seyfert 2’s than about the composite ones, which, somewhat paradoxically, makes “boring” Seyfert 2’s more interesting! Despite such caveats, such an evolutionary scenario seems compelling.

4. Composites are more luminous than “boring” Seyfert 2’s

Among the many interesting systematic differences we found between composite and “boring” Seyfert 2’s is that the former are significantly more luminous than the latter. This is illustrated in Fig. 2, where we see that composites are typically \( \sim 5 \) times more luminous in terms of their far IR emission than “boring” Seyfert 2’s. A more dramatic way of putting it is that above \( L_{\text{FIR}} = 2 \times 10^{10} \ L_\odot \), \( \sim 80\% \) of Seyfert 2’s in our sample are composites. Luminous Seyfert 2’s may therefore owe much of their luminosity output to circum-nuclear star-formation. Composites are also more luminous in the optical continuum and emission lines, a difference which is only exacerbated when reddening corrections are applied, since composites are also more optically extincted than “boring” Seyfert 2’s, consistent with the X-ray analysis of Levenson, Heckman & Weaver (2001). Intuitively, one expects younger things to be more luminous, so this tendency fits well in the evolutionary scenario outlined by the (luminosity-independent) synthesis analysis. We also find that “boring” Seyfert 2’s are weaker both in indices sensitive to starburst \( (L_{\text{FIR}}, L_{H\beta}) \) and AGN \( (L_{\text{[O III]}}) \) activity, indicating that more luminous AGN host correspondingly more luminous circum-nuclear starbursts! A more refined analysis may eventually translate this finding into something like a “star formation rate \( \propto \) accretion rate” relation.
5. Final remarks: Starbursts are here to stay

In our full comparative study of the properties of composite and “boring” Seyfert 2’s (which includes the analysis of reference samples of Starburst, active, merging and normal galaxies), we further identify the effects of circum-nuclear starbursts upon emission line equivalent widths, gas excitation indices, line profiles, near-UV surface brightness and central morphology. Whilst we still lack a clear understanding of whether circum-nuclear starbursts are indeed an integral part of the AGN phenomenon, there remains no doubt that they exist and play a major role in defining observable properties traditionally attributed solely to AGN. Like it or not, theorists have to deal with this fact. For instance, we find that typically 50% (and up to 80%) of the nuclear Hβ luminosity of composites is powered by massive stars! At the very least, this calls for a revision of classical photoionization models, which must mix a starburst and a harder ionizing source when modeling nuclear emission lines in Seyfert 2’s. Less starburst-phobic readers will see these results as further signals of a truly physical connection between star-formation and nuclear activity. Establishing how fundamental this connection is will require the extension of diagnostics such as the ones presented here to larger samples of Seyfert 2’s in order to derive statistically robust results, as well as a more panoramic view of starbursts in AGNs as a whole, from LINERs to QSOs. Slowly, but surely, we are putting together the pieces of this puzzle.

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