QUASARS, STARBURSTS, AND THE COSMIC ENERGY BUDGET

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Abstract

Observations in the far infrared are the best way to make an unbiased survey of active galaxies in the loosest sense - but separating the the true quasars from the surrounding starburst may be difficult. There is in fact much evidence to suggest that starburst and AGN activity are intimately connected, and FIRST will help us to explore this link. Since the last major FIRST conference in Grenoble, this issue has become even more central to modern astrophysics, with the realisation of the dominance of the FIR background, the discovery of high redshift SCUBA sources, and the emergence of the black hole mass deficit problem. What dominates the cosmic energy budget - nuclear fusion or accretion ?

Key words: Cosmology:observations - Quasars:X-rays - Galaxies:starburst - Galaxies:formation

1. Introduction

The FIRST mission will make important contributions to AGN studies in several ways. Broad-band colours could be measured for hundreds of selected AGN of various types, including AGN at much higher redshift than previously possible. Spectral energy distributions could be measured for dozens of objects. Blazar monitoring could be performed at sub-mm wavelengths, measuring changes in the real core, rather than pc-scale jets. Very large numbers of submm selected AGN will come from the anticipated survey programmes. The issues addressed by such studies include AGN dust models, the starburst/AGN ratio, and its variation with luminosity, redshift, radio power etc, and the question of when dust first formed.

The prospect for most of the above issues has not changed much since the last conference looking forward to FIRST, in Grenoble 1997. (Lawrence 1997). However the FIR emission from AGN has taken on a new cosmological perspective. First, submm surveys with SCUBA have discovered luminous objects at high redshift, and the old IRAS galaxy AGN versus starburst debate has taken on a new lease of life. Second, the FIR background has been discovered, and is seen to dominate the energetic output of galaxies over cosmic history. It seems to be a close call

whether nuclear fusion or accretion has produced more energy over the history of the universe. It is these questions that I concentrate on for the remainder of this review.

2. The AGN versus Starburst debate

A typical AGN emits most of its radiative energy in the ultraviolet, and perhaps only 10-20% in the IR. However, the FIR region seems to be the region of most disagreement. Fig. 1 shows a compilation made by James Manners for his PhD. From 10μm to 1000Å the agreement is excellent, but in the FIR the various studies seem to disagree quite markedly. The reason for this seems likely to be that the AGN samples used in the various studies cover characteristically different luminosity ranges, and that the relative FIR strength is a function of luminosity. (This is specifically claimed in the Green *et al.* 1992 study). This probably means that the FIR represents a distinct component that correlates only weakly with the true quasar emission. The natural guess for the origin of this component is that it represents a concurrent starburst.

There are a number of reasons for believing that the FIR emission (at 60μm and longward) of AGN is due to an accompanying starburst. (i) The correlations between 60μm luminosity, radio power, and CO emission show AGN and starforming galaxies occupying the same areas (e.g. Lawrence 1997 and references therein; Evans *et al.* 2001). (ii) The SEDs of AGN are the same shape as those of starforming regions longward of $60\ \mu$m - see Fig. 2. (iii) The FIR luminosity functions of AGN and starburst galaxies are closely similar in shape, but differ in amplitude by a factor of $\sim$25 (Lawrence 1997; Rowan-Robinson 2001). Taken at face value, the evidence seems to suggest that (a) all AGN are accompanied by a starburst, but that (b) one starburst out of twenty five is accompanied by an AGN.

The above analysis assumes that we know an AGN when we see it, and that we can tell the difference between an AGN and a starburst. However this may not be easy if the quasar component is obscured by a thick layer of gas and dust, in which case the energy of the AGN will emerge in the IR. Through the late 80s and early 90s the hot debate was whether the newly discovered ultra-luminous IRAS galaxies (ULIRGs) are starbursts or obscured AGN. Summaries of this debate are given in Sanders and Mirabel (1996), and Sanders (1999).
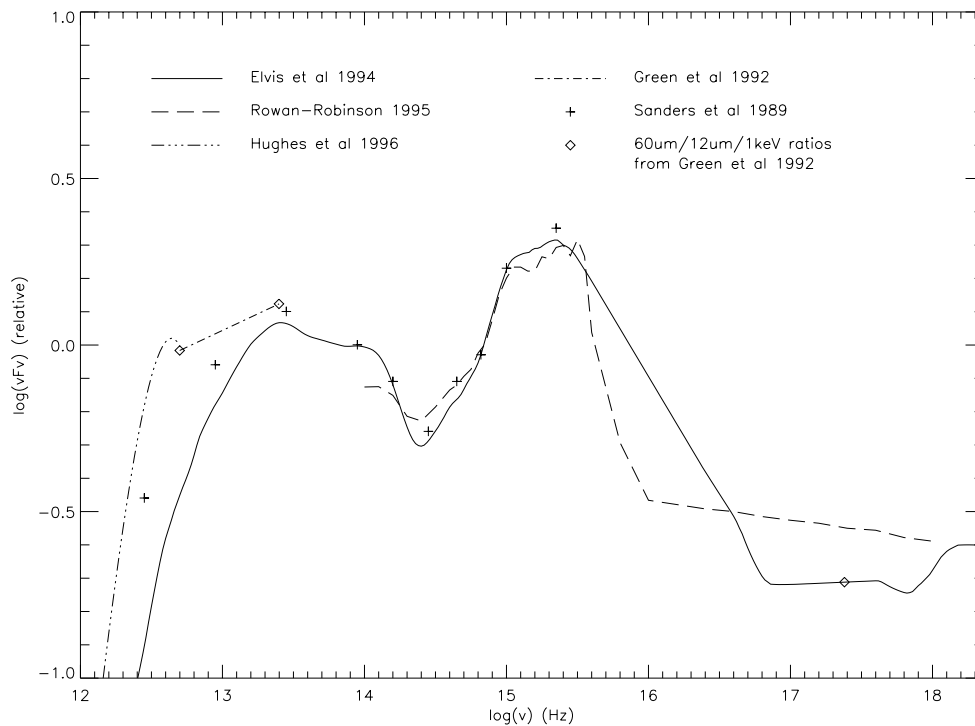
Figure 1. Mean Spectral Energy Distributions (SEDs), taken from various studies, as labelled in the diagram. From the PhD thesis of James Manners, in preparation.

On the one hand, ISO spectroscopy seems to confirm the majority of ULIRGs as being clearly star formation powered (Lutz *et al.* 1998; Genzel *et al.* 1998). On the other hand, searches for absorbed hard X-ray sources and weak broad lines can turn up unexpected AGN (Vignati *et al.* 1999; Veilleux *et al.* 1999), and it maybe that the AGN fraction keeps increasing towards the very highest IR luminosities (Veilleux *et al.* 1999). Finally of course it could well be many AGN are hidden behind columns of material that are *Compton thick* so that more or less nothing will get through directly.

The current best-bet AGN fraction is around 20% - in other words, for objects selected by FIR emission, which is pretty undiscriminating, the starbursts are about 5 times as common as AGN. This contrasts with the ratio of 25 or so mentioned above that we deduce from the IR luminosity function of known AGN selected by other means. The simplest interpretation is that obscured AGN are *five times as common* as naked AGN.

3. The missing quasars

The theme of obscured AGN pops up in several places. The idea that Type 2 AGN are in general obscured Type 1 AGN has of course been around for a long time (Rowan-Robinson 1977; Lawrence and Elvis 1982; Antonucci and Miller 1985; Barthel 1989). The relative space density of the two is hard to estimate as of course they have very different selection sensitivities to different methods. A survey by Lawrence (1991) found the Type-2/Type-1 ratio to vary from 1 to 10 in a variety of samples. Low frequency radio selection may be one of the safest selection methods, and interestingly this seems to show a ratio that changes dramatically with luminosity, and possibly also with cosmic epoch (Lawrence *et al.* 1991; Willott *et al.* 2001).

Then there is the idea that large numbers of obscured AGN are needed to explain the X-ray background (XRB; Setti and Woltjer 1989). Models producing a good fit to the XRB (.e.g. Comastri *et al.* 1995; Gilli *et al.* 2001) have three times as many absorbed as unabsorbed AGN, with a fairly flat distribution in N_H. However, studies of local Type 2 Seyferts by Beppo-Sax show that the flat N_H distribution carries on to ever larger columns, such that perhaps half of them are Compton thick (Risaliti *et al.* 1999). Overall then, indirect evidence from X-ray studies suggests that the obscured/unobscured ratio is ~ 6. At least some high redshift high luminosity obscured objects do exist (e.g. Norman *et al.* 2001); Chandra and XMM studies should soon tell us whether they are there in the right numbers.

The idea of hidden quasars has come up yet again through a third route. The current day accumulated mass density of relic black holes can be predicted by integrating the quasar light over all redshifts, and assuming they have been accreting at 10% efficiency (Soltan 1982; Chokshi and Turner 1992). Meanwhile, the prevalence of mas-
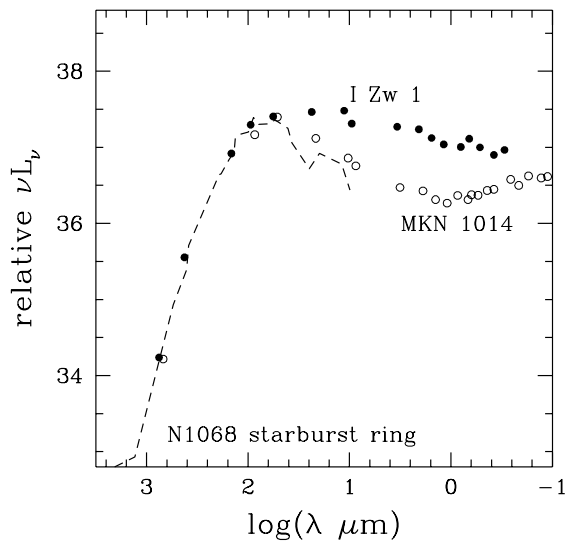
Figure 2. SEDs of two low-z quasars compared to the SED of the starburst ring in NGC 1068. Note that there is a variety of forms at short wavelengths, but everything looks the same at long wavelengths. Data for the quasars are from Hughes et al 1993 and references therein; data compilation for NGC 1068 is as in Lawrence et al 1994.
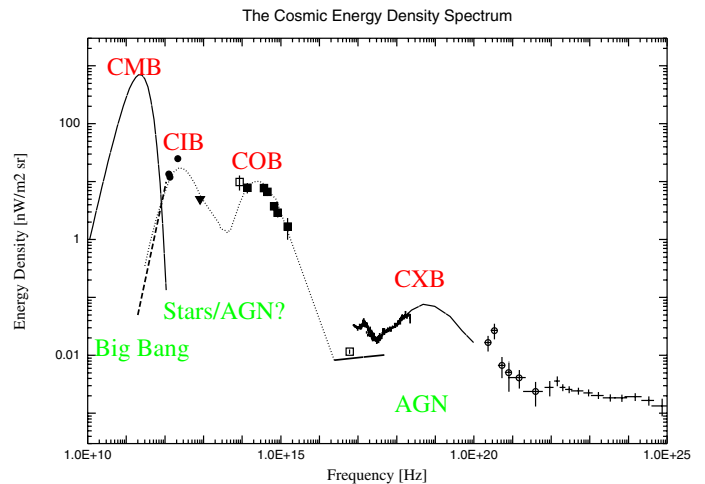

Figure 3. SED of the cosmic background light. This figure is taken from Hasinger (2000); the data references are given in that paper. Note that in the case of the optical background the data represents the integrated light, as there is no unresolved component. The dotted line shows one of the evolving starburst models of Dwek et al. 1998.

sive central dark objects in local galaxies (Magorrian *et al.* 1998) can be put together with the known density of starlight to produce an actual estimated black hole mass density, which turns out *an order of magnitude larger* than the density predicted from known quasars (Phinney 1997; Haehnelt, Ratarajan and Rees 1998). There may be a variety of reasons for this, but one of the most appealing is that the true number of quasars is an order of magnitude larger than we had always thought, in crude agreement with the argument from X-ray studies.

4. The FIR background

One of the most exciting results of the 1990s was the discovery from COBE data of the FIR-mm background light (Puget *et al.* 1996; Fixsen *et al.* 1998). The entire cosmic background light is shown in Fig. 3, which has been taken from Hasinger (2000). The thermal radiation energy of the universe, as represented in the CMB, dominates everything else. This aside, the IR and optical backgrounds combined are much larger than the XRB, which naively suggests that energy produced by stars is much more important than energy produced by accretion over the history of the universe. Within the optical-IR region, the νF_ν peak in the IR is a factor of two higher than that in the optical. This is very different from typical ordinary local galaxies, where the FIR peak is lower than the optical

peak by a factor of several, but not as IR dominated as ULIRGs, where the FIR peak is 100 times higher than the optical peak. (See for example, the range of SEDs in Fig. 2 of Sanders and Mirabel 1995.)

This speaks of a violent past for the cosmos. Today, although ULIRGs and AGN are fascinating, the local radiated energy density they produce is only a few percent of that produced by stars. Active objects are spectacular, but only a sideshow. In the past, active objects must have been much more common. Dwek *et al.* (1998) modelled the FIR-mm background by assuming it is made by a population of rapidly evolving starburst objects with an SED like that of ARP 220. But, if it is really true that obscured AGN outnumber naked AGN by a factor of several, is it possible that the FIR-mm background is after all made by AGN ? Figure 4 shows an attempt to model the mm to X-ray background this way, using a ratio of roughly 3 to 1 for absorbed to unabsorbed AGN (Manners, Almaini and Lawrence 2000; Manners *et al.* in preparation). The result is sensitive to the FIR SED assumed. The possibilities shown are those illustrated in Figure 1. The traditional "naked quasar" population makes a very small contribution to the FIR-mm background. Scaling the number of obscured quasars to explain the XRB, and using the most FIR-loud SED, about 5% of the FIR-mm is explained. Of course Compton-thick AGN will not contribute to the X-ray background. Scaling the number of obscured quasars from the local mass-deficit argument, perhaps 10-20% of the FIR-mm background could be reached.

From first principles, which process would we expect to dominate the energy budget of the cosmos - star formation or accretion onto black holes? A simple argument, due to G.Hasinger and elaborated in Fabian and Iwasawa

(1999) is as follows. The Magorrian *et al.* (1998) relation suggests that the local mass in (spheroid) stars is ~ 200 times that in nuclear black holes. However, energy generation per unit mass is ~ 20 times larger for accretion than for nuclear fusion. If 10% of the original stellar mass has been burnt, and all of the black hole mass has accumulated during accretion, then over cosmic history, the amounts of energy generated by accretion and fusion must be roughly equal. Beyond this heuristic argument, the ratio depends on several other factors, such as the relative mass in spheroids and disks, the fraction of stars which have completed their evolution, and how efficiently used stellar material is recycled (Fabian 2000). But it is clear that it may be a close run thing between accretion and fusion.

5. SCUBA SOURCES : STARBURSTS OR AGN ?

The FIR-mm dominated extragalactic light implies that active objects, and probably ULIRG-like starburst galaxies, must have been much more common in the past. This seems to have been directly borne out over the last few years by blank field submm surveys using the SCUBA instrument on the JCMT (Smail, Ivison, and Blain 1997; Hughes *et al.* 1998; Barger *et al.* 1998, 1999; Eales *et al.* 1999; Lilly *et al.* 1999; Blain *et al.* 1999; Scott *et al.* 2001; Fox *et al.* 2001). Making reliable identifications, and getting redshifts, has proved very difficult (and indeed I have suggested in Lawrence 2001 that perhaps a quarter or so of SCUBA sources could actually be very local Galactic dust clouds) but it seems clear that most SCUBA sources are ULIRG-analogues at redshifts greater than 1, and usually greater than 2. Hughes *et al.* derived an estimate of the star formation rate per unit volume at high redshift in the Hubble Deep Field and found it *larger* than that implied by the high-redshift Lyman break galaxies in the same volume. Optical estimates have since been revised upwards, so that the two estimates are now roughly similar - but coming from distinct populations. This means that in the youthful universe, as much star formation is going on in a handful of objects going BANG as in hundreds of galaxies with more modest activity, confirming directly the lesson drawn indirectly from the extragalactic background light.

Initially it was assumed that SCUBA sources are massive high-redshift starbursts, but once again one has to ask whether in fact they are obscured AGN. Almaini, Lawrence and Boyle (1999) calculated expected submm number counts for obscured AGN, scaling from XRB models. The results are sensitive to the assumed cosmology, but also to what is assumed about quasar evolution at $z > 2$, as most of the XRB is made at relatively modest redshifts ($z \sim 1$) whereas the submm sources are mostly at higher redshift. Overall however the XRB models predict that the fraction of SCUBA sources that are AGN should be around 5-20%.

6. SCUBA SOURCES IN X-RAYS

Observations in the submm, corresponding to the FIR at high redshift, should find both starbursts and AGN. The obvious way to to distinguish the populations is by spectroscopy. Optical identification and spectroscopy has proved very difficult. There are certainly no simple broadline AGN amongst the SCUBA sources to date. There are certainly some objects with rest-frame UV spectra similar to narrow-line radio galaxies, which are good candidates for obscured AGN (Ivison *et al.* 1998). Only a third or so of SCUBA sources have good IDs to date, and the spectroscopy is very patchy, but the available evidence is consistent with a fairly high AGN fraction, around 20% (Barger *et al.* 1999).

Another way to test the AGN hypothesis is to look for hard X-ray emission from SCUBA sources. Chandra observations in several fields are now deep enough that even if the SCUBA sources are highly absorbed objects similar to NGC 6240, they should be detected. Of course Compton-thick objects can escape the net, but if the scattered fraction is 1% or more, they will still be detected, so *most* AGN should be seen. Published results to date on various fields find the SCUBA source detection fraction to be 0/6, 2/3, 0/10, and 1/9 (Fabian *et al.* 2000; Bautz *et al.* 2000; Hornschemeier *et al.* 2000; Severgnini *et al.* 2000). The largest SCUBA survey to date is the 8 mJy survey being carried out by the UK submm consortium (Scott *et al.* 2001; Fox *et al.* 2001). Almaini *et al.* (in preparation) have a 75 ksec Chandra observation in one of the two main fields. The preliminary analysis finds X-ray detections for 1/17 SCUBA sources. The grand total to date then is X-ray detections for 4/45 SCUBA sources. At 10±5%, it is becoming clear that most SCUBA sources are starbursts and not AGN, but on the other hand that it really is true that most AGN are obscured.

7. CLOSING THOUGHTS

Evidence from the XRB, from the FIR-mm background, from high redshift SCUBA sources, and from local black hole searches seem to be telling a reasonably consistent story. The youthful universe was dominated by galaxies going BANG. Galaxies are still going BANG today, but they make little impact on the current day energy budget. Most of the bangs are massive bursts of star formation. In something like one starburst in ten, quasar-like activity is happening concurrently. It is not clear whether this an evolutionary process, with mergers leading to starbursts leading to quasars, as suggested by Sanders *et al.* 1988, or simply that a quasar is not always triggered. Of those quasars, something like four fifths are obscured by gas and dust. It remains possible that even the "starburst-only" objects contain a quasar, but one completely hidden by obscuring material - Compton thick and with no holes for light to escape and be scattered in our direction.
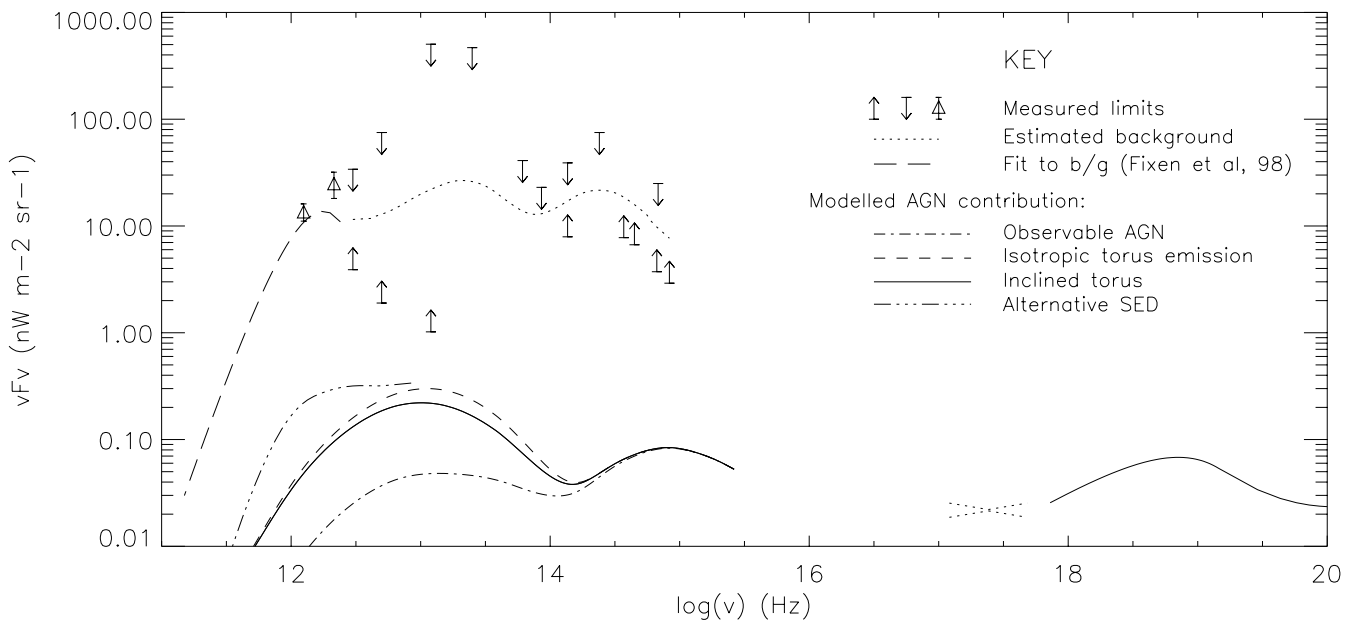
Figure 4. AGN contribution to the extragalactic light, making various assumptions about the AGN SED in the FIR, and how the obscuration and re-emission takes place. Taken from Manners, Almaini and Lawrence (2001).

A substantial fraction of the stars present today might well have been made in those early bangs, as opposed to being made in slow and steady subsequent star formation. It is tempting to identify these bangs as the catastrophic formation of galaxy spheroidal components, a challenge to standard hierarchical galaxy formation models. If this is correct, after the bang a luminous red quiescent galaxy should be left behind, and these should greatly outnumber the SCUBA sources at high redshift. This idea is testable by large area deep near infrared surveys.

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