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AGN WITH AKARI AND HERSCHEL

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ABSTRACT

AKARI and the subsequent Herschel Space Observatory have yielded tremendous advancement in our knowledge of the infrared-submillimeter properties of active galaxies and active galactic nuclei, AGN. This short review describes some highlights. Active galaxies are found to do what they are supposed to do: build up their stellar bodies while building up their central black holes.

Key words: Galaxies: active — Infrared: galaxies

1. THE STAR-FORMATION AND ACCRETION HISTORY OF THE UNIVERSE

A wide variety of large-area and deep-field studies in the optical and near-IR have taught us four important facts about galaxies and their cosmic evolution. Excellent, extensive review on the topic were published recently by Madau & Dickinson (2014) and Caputi (2014).

1. Early type galaxies occupy a concentrated high-mass, red color area of the color-mass diagram, the so-called red sequence. Their mass range is 10^{10} – 10^{11} $M_\odot$. Late type galaxies occupy a more extended area, the so-called blue cloud. They have a wider range in (blue-green) colors, and masses going down below $10^{9.5}$ $M_\odot$. The so-called green valley is a consequence of the red sequence and the blue cloud, hence is not a true locus of a certain population of galaxies. However, Schawinski et al. (2007) and Best & Heckman (2012) provide evidence that AGN preferably occur in this green valley, hence in mature galaxies with somewhat elevated recent star-formation. The effects are nevertheless modest: AGN hosts do not particularly stand out w.r.t. non-AGN hosts, neither in their morphology nor concerning the level of interaction with neighbours (Silverman et al., 2008; Cisternas et al., 2011; Kocevski et al., 2012). Internal secular processes and minor merging have played major roles in the past.
2. Very massive galaxies are in place early (Hopkins, 2004; Fontana et al., 2009); they most probably grow through continuous accretion of (cold) gas, and mergers with small satellites (e.g., Van Dokkum et al., 2010; Conselice et al., 2013).
3. As judged from studies in the optical and ultraviolet, taking the (uncertain!) obscuration into account, the star-formation rate as a function of cosmic epoch, SFR(z), declines rapidly since $z \sim 2$ (e.g., Schiminovich et al., 2005; Bouwens et al., 2011). Dust obscuration makes the study of cosmic evolution at $z \gtrsim 2$ rather opaque.
4. The star-formation rate in galaxies, or better its upper limit, is a function of galaxy mass, in the sense that the dominant star-forming galaxies lie along the so-called Main Sequence (e.g., Noeske et al., 2007).

The growth of the stellar bodies of galaxies has been mapped out, and is understood, out to $z \sim 2$, as far as the population of unobscured galaxies is concerned. As has become clear since surveys with ISO (e.g., Elbaz et al., 1999), dusty starburst systems occur frequently at high redshift, and they contribute significantly to the cosmic SFR. Deep-field studies with Spitzer have underlined the latter statement. In fact, beyond $z = 1$ the star-formation rate density, SFRD, occurs primarily in luminous and ultraluminous infrared galaxies, having luminosities between 10^{11} and 10^{12} $L_\odot$, and in excess of 10^{12} $L_\odot$, respectively, while being ultra-faint or invisible at uv-optical wavelengths. Many publications have dealt with these issues; we here mention Caputi et al. (2007) and Magnelli et al. (2009) in particular.

Well-established scaling relations have taught us that galaxy bulge formation must go in concert with central black hole formation, or in other words: the build-up of the stellar mass must go in concert with the growth of the central massive black hole (through AGN activity). Whereas the actual symbiotic occurrence is difficult to observe and/or quantify, the two processes must be coeval, or at least be interconnected. Deep X-ray and radio surveys have indeed revealed a widespread occurrence of nuclear accretion in the faint star-forming galaxy population (e.g., Alexander et al., 2008; Daddi et al., 2007; Guidetti et al., 2013). Hence, also active galaxies can be rich in dust. In fact, circumnuclear dust is a key ingredient of AGN unification models, unifying Type-1 (broad-lined) and Type-2 (narrow-lined) AGN. Hot dusty nuclei are for instance a common property of powerful 3C radio galaxies and quasars (e.g., Ogle et al., 2006), and the mid- and far-IR data provide useful constraints for unification models for these classes (e.g., Haas et al., 2008; Leipski et al., 2010). It is worth recalling Michael Rowan-Robinson[1] here, who wrote already in 1995, on the basis of IRAS data: "A QSO or Seyfert event appears to be inevitably accompanied by a starburst, but the reverse is not true" (Rowan-Robinson, 1995).

In summary, star-formation and active black hole accretion in galaxies are continuously ongoing processes, forming and shaping galaxies up to here and now. This short review paper deals with the increased understanding provided by the AKARI and Herschel space missions, of the symbiotic occurrence of accreting (active) nuclei in their star-forming – or even star-bursting – host galaxies. What follows is by no means a complete overview, but just a selection of important contributions (in the eye of this reviewer). Following up on Spitzer, AKARI and Herschel brought tremendous progress in our understanding of the global astrophysical processes, through SED (Spectral Energy Distribution) as well as spectroscopic studies.

2. AKARI STUDIES

AKARI carried out a number of programs dealing with starburst and active galaxies. Some highlights are the following.

2.1. *High redshift QSOs*

Using the IRC spectrograph, Oyabu et al. (2007, 2009) and Im (2010) investigate the properties of the Hα emission line in extreme redshift QSOs. The velocity dispersion of the broad-line clouds is used to infer the central (accreting) mass. No redshift evolution in the Hα properties was found; the measurements moreover allowed assessment of MBH masses out to these extreme redshifts ($z \sim 5-6$).

2.2. *AGN classification*

Hirata et al. (2014) combine AKARI with XMM survey data to refine the classification of AGN, and to uncover obscured AGN. Oyabu et al. (2011) use the all-sky survey to identify hidden AGN in infrared galaxies, on the basis of infrared colors.

2.3. *Deep field studies: star-formation and AGN*

White et al. (2010, 2012) examined the source counts in the AKARI NEP and SEP fields, and established a 1mJy upturn of star-forming galaxies. They uncovered a small fraction of AGN. DeSoto et al. (2014) study the FIR-properties as a function of the AGN radio-loudness; the radio-loudest AGN in the NEP field appear to have the highest level of host star-formation (Karouzos et al., 2014). The latter authors are also investigating the occurrence of negative feedback. Malek et al. (2014) describe the faint star-forming galaxy population uncovered in the AKARI Deep Field-South at 90 μm.

2.4. *LIRGs and ULIRGs*

Beautiful spectroscopic studies by Imanishi et al. (2010), and Lee et al. (2012) uncovered buried AGN in a good fraction of Luminous Infrared Galaxies, LIRGs, and Ultraluminous Infrared Galaxies, ULIRGs, out to $z \sim 0.4$. The AKARI IRC spectrograph demonstrated its unique capabilities in these studies, and WISE colors are found to provide additional conclusive information concerning the presence of buried AGN.

2.5. *Radio galaxies and submm galaxies*

IRC spectroscopy of high redshift radio galaxies is carried out by Sedgwick et al. (2013): broad Hα emission is measured in the infrared, indicating a broad emission

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line region, hence an optically obscured quasar. The authors also target distant submm galaxies, SMG, and find Hα emission.

3. Herschel studies

Roughly spoken, 25% of the total Herschel observing time of 23.000hrs was spent on global star-formation and AGN studies. Its three instruments HIFI, PACS, and SPIRE all contributed their share, in many dozens of Guaranteed and Open Time projects, in regular and Key science set-up. Some highlights are below.

3.1. High redshift luminosity function

The Herschel studies of the evolving luminosity functions of star-forming galaxies confirmed and extended the Spitzer studies in a beautiful way. The Gruppioni et al. (2013) studies went out to $z \sim 4$ and demonstrated again that whereas ULIRGs are exceptional objects locally, they represent the norm among massive star-forming galaxies at redshifts $z > 2$. Rodighiero et al. (2011) determined the $z \sim 2.5$ star-forming Main Sequence; it was found to be a function of redshift (e.g., Whitaker et al., 2012)

3.2. SF-AGN connection, at the low-intermediate level

Photometric surveys in deep Chandra fields indicated that AGN hosts have mildly elevated star-formation with respect to non-AGN hosts (e.g., Santini et al., 2012), but also that the effects are modest. Luminous AGN *can* have strong star-formation, but do not have to (Rosario et al. 2012). As judged from the extensive H-ATLAS program, the SFRs in QSO hosts are broadly luminosity dependent, which expresses the fact that both processes draw from the same gas influx (Serjeant et al., 2010). Mullaney et al. (2012) show that the *global* specific star-formation rate, sSFR increases with a factor 25–50, from $z \sim 0.1$ to $z \sim 2.5$, both for (X-ray selected) AGN and non-AGN.

3.3. SF-AGN connection, highest level (QSOs, QSRs, RGs)

Also from H-ATLAS, Kalfountzou et al. (2014) reported that radio-loud quasars display stronger star-formation than radio-quiet QSOs. Whether this represents positive feedback in the radio-loud class, or negative feedback in the radio-quiet class, remains an open issue. Extreme star-formation in ultra-powerful radio galaxies (but not in all) was reported by Barthel et al. (2012) and Drouart et al. (2014). Leipski et al. (2014) observed the same in extreme redshift ($z > 5$) QSOs. As these objects are hosted by very massive galaxies, the implied specific star-formation rates, sSFR, are nevertheless entirely cf. expectation (Mullaney et al., 2012, Rosario et al., 2013).

3.4. SLEDs: XDR and PDR

A beautiful SPIRE FTS spectrum revealed the spectral line energy distribution, SLED, of Mk231, a nearby prototypical AGN-starburst composite (Van der Werf et al., 2010). As expected, both an X-ray dominated region, XDR, and a photon dominated region, PDR, are needed to explain the variety of atomic, ionic, and molecular transitions. Using the same instrument, Spinoglio et al. (2012) spatially separated the nuclear XDR in the star-bursting Seyfert-2 galaxy NGC 1068 from its circum-nuclear PDR.

3.5. AGN gas outflows and feedback

Outflowing winds responsible for substantial gas loss from (star-forming) AGN hosts were reported by for instance Fischer et al. (2010), Sturm et al. (2011), and Veilleux et al. (2013). Whereas these observations were taken as evidence for negative AGN feedback (as demanded in ΛCDM scenario's) it remains to be seen if it is the AGN which drives the outflow, or the circum-nuclear star-formation itself (recall M 82!) The issue of AGN feedback remains a vexed question; little evidence so far has been found of powerful AGN shutting down ongoing host star-formation. The evidence presented by Page et al. (2012) has met with counterarguments (Harrison et al., 2012). As for radio-loud AGN *accreting efficiently, i.e., in the quasar mode*, there is in fact more evidence for positive than for negative feedback (Podigachoski et al., 2014).

4. CONCLUSIONS

Both AKARI and Herschel have contributed tremendously to our understanding of the growth of galaxies with and without actively accreting black holes. The high redshift universe represented a period of galactic fireworks – that is certain. No clear answers have been found yet regarding true causal astrophysical relationships between the growth of the stellar body in a galaxy and of its central black hole. The properties of the dust and gas in distant galaxies must be studied at a higher, more intricate level, in order to be able to address causal relationships, as well as the feeding mechanisms for the large- and small-scale growth. As such, there are high expectations for SPICA, ALMA, and JWST.

In 1963, Burbidge, Burbidge, and Sandage (Burbidge et al., 1963) wrote a seminal paper, which in the 1970s pulled me into astronomy, and in the world of quasars, radio galaxies and other spectacular, exotic objects. Now, five decades later, we understand that AGN, i.e., accreting black holes, are simply basic[2] ingredients of star-forming galaxies, throughout cosmic time. Nevertheless, I loved them, and still do.

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