HERSCHEL AND GALAXIES/AGN

Peter Barthel
Kapteyn Institute, Univ. of Groningen,
P.O. Box 800, NL–9700AV Groningen, The Netherlands

ABSTRACT

Herschel will represent a breakthrough in the study of nearby gas-rich and gas-poor galaxies, as it will for the first time permit imaging photometric and spectroscopic observations of their ISM in the FIR-submm wavelength range. The unprecedented sensitivity and angular resolution of Herschel will furthermore yield a breakthrough in our understanding of distant galaxies and AGN, as their gas and dust – both the ISM- and the AGN-related – will for the first time come within reach. Herschel will undoubtedly yield major discoveries concerning the cosmologically evolving gas and dust properties in galaxies, back to very early epochs.

Key words: HERSCHEL; Galaxies; Active Galaxies.

1. INTRODUCTION

Evidence is accumulating that star-formation in galaxies and the occurrence of accretion-driven activity in their nuclei are astrophysically connected processes. I’ll give three prime lines of reasoning.

1. The masses of the spheroidal components in galaxies grow together with their massive black holes (MBHs) – this is the well-known bulge – black hole correlation.

2. Nuclear accretion is often preceded by a phase of enhanced star-formation. We suspected this from age dating of the host galaxies of nearby Seyfert galaxies and QSO’s (e.g., González-Delgado et al. 2001, Canalizo & Stockton 2001), but a wonderful proof of the symbiosis has recently been obtained by Kauffmann et al. (2003), using SDSS data. A remarkable plot from this work is reproduced in Fig. 1: this emission line ratio diagram shows the normal star-forming galaxy population, from low mass (left) to high mass (bottom), with the "abnormal" populations of LINER and Seyfert galaxies branching off towards the top right. The Seyfert galaxies, having high [O III] luminosities, were often found to display young stellar populations, i.e., they are often post-starburst systems. This is the plot all extragalactic astronomers – the privileged Herschel users in particular – should be thinking about, concerning its origin and its cosmic evolution!

3. The resemblance of the cosmic star-formation history plot and the QSO space density plot, in particular the z ~ 2 peak, may not be a coincidence. Also the nature of the distant submm galaxies, most likely containing a substantial AGN-fraction (e.g., Frayer et al. 2004), supports an astrophysical link.

The following issues are also very relevant in this respect.

1. Given the fact that z > 6 QSOs are being found, and that they possess very massive black holes, the bulge – black hole correlation just mentioned implies that massive bulges must be in place, within a Gigayear after the Big Bang.

2. The emission line spectra of these z > 6 QSOs
differ little or nothing from the spectra of more recent QSOs: the abundances in the broad line gas are solar (or even super-solar). This is indicating that processed material is being accreted, and not pristine ISM gas.

3. As reported in several recent studies, molecular gas is sometimes found in distant AGN, both QSOs and radio galaxies, in staggering quantities: there is plenty of fuel for star-formation.

In summary, it was long known that the two phenomena can co-exist (e.g., NGC 1068!), but the study of this important star-formation–AGN connection evolving throughout cosmic time will be a major challenge for extragalactic astronomers in the coming decade. As will be illustrated below, Herschel (and ALMA) can and will play an important role in these investigations. Obviously this review cannot be complete but it will hopefully raise interest from outside the already impressively large Herschel communities.

2. THE LEGACY OF IRAS AND ISO (AND SPITZER)

As amply documented (e.g., Soifer et al. 1987), the all-sky IRAS mission opened the dusty universe, detecting dust radiation from many classes of extragalactic objects – both expected and unexpected – and classifying these dust properties. UltraLuminous InfraRed Galaxies, ULIRGs, emerged as an important class of obscured, gas-rich galaxies having their SEDs dominated by unusually strong far-infrared emission.

Following in its footsteps, the observatory mission ISO subsequently carried out more detailed investigations. ISO revealed the presence of cold dust (∼15 K) in galaxies, and established the unexpected fast decay of starbursts. Mid- and far-infrared luminosities, colors, and temperatures were obtained for many objects in the local and nearby (z < 0.1) universe. In nearby galaxies, ISO provided more insight in the physics of the star-forming regions, in particular the [CII] and [OI] cooling. ISO imaging of the warm dust in nearby galaxies proved to be a fine tool to address localized radiation properties. ISO revealed fascinating cases of obscured star-formation such as in the Antennae NGC 4038/4039. Moreover, the spectroscopic capabilities of ISO permitted great advance in our understanding of the gas properties of nearby dusty and gas-rich objects. The mid-infrared aromatic features were discovered, but also the absorption characteristics, as well as the diagnostic emission lines and the cooling lines in the mid- and far-IR. An excellent account of the ISO legacy can be found in Genzel & Cesarsky (2000). NASA’s Spitzer mission is currently continuing this work, at much improved sensitivity; impressive first results have appeared recently (ApJS Vol. 154 No.1 issue), and some highlights were reported at this meeting. Spitzer will surely bring great advancement in our understanding of the spectral energy distributions (SEDs) of nearby and distant galaxies, including the magnificent 2-D information resulting from its infrared camera.

Equally interesting results are to be awaited from ASTRO-F, the Japanese mission to be launched hopefully in 2005. ASTRO-F will operate a sensitive large field-of-view near- and mid-IR camera, and will in addition carry out an improved all-sky far-infrared survey, FIS, with a predicted yield of over 10⁷ extra-galactic far-infrared sources – a significant improvement with respect to IRAS. The ASTRO-F FIS data will undoubtedly be important for Herschel.

3. HERSCHEL EXPECTATIONS

Broadly speaking, Herschel will continue where its predecessors stopped. However, in addition to the fascinating achievements which one can foresee, Herschel will obviously make completely unexpected discoveries: the telescope will point at known (active) objects but in addition of course follow-up on its own discoveries. Herschel will extend the IRAS/ISO/Spitzer/ASTRO-F wavelength range into the submm, at much greater sensitivity, at considerably higher spatial resolution and at much higher spectral resolution. These qualifications will permit studying the mid- and far-infrared out to high redshifts. Given that at these wavelengths star-formation and nuclear activity – be it indirectly – are optimally revealed, Herschel will truly live up to its Cornerstone expectations. The paragraphs below summarize the key themes in this respect: dust and star-formation. In short, besides being the optimal far-IR spectrograph, Herschel will become the perfect SED-machine.

3.1. DUST: nearby and far

The optical–infrared SEDs for early and late type galaxies differ most significantly in the mid- and far-IR. Whereas the former are roughly flat (in the Fν representation), or show a modest peak around 2μm from stellar photospheric emission, the latter show a peak around 100μm, indicative of cool dust. Starburst galaxies such as M 82 show that peak more pronounced and at somewhat shorter wavelength (∼ 60 – 80μm), while the SEDs of ULIRGs – the champion FIR-emitters – are completely dominated by such a warm far-infrared peak, the latter contributing around 90% of the bolometric emission. The strength of this warm dust component is correlated with the optically thin synchrotron radio emission – this is the well known radio-FIR correlation (e.g., Condon 1992).

Far-infrared dust emission is also measured in active galaxies and AGN. The excess thermal emission in Seyfert-2 galaxy NGC 1068 is known since the 1970’s, but the systematic properties of this emission
in Seyfert galaxies had to await the IRAS survey. Using IRAS data, De Grijp et al. (1985) were able to show that the infrared color $\alpha_{60\mu m}^{25\mu m}$ provides a good AGN selector, that is to say: besides star-formation related warm dust, active galaxies are characterized with additional hot dust, which together yield relatively flatter infrared spectral indices. ISO data permitted more elaborate multi-component dust models, both for star-forming objects (e.g., Klaas et al. 1997) and active galaxies (e.g., Pérez García et al. (1998), Spinoglio et al. 2002). Moreover, the ISO spectrographs allowed us to examine the richness of the mid- and far-infrared spectra. These studies demonstrated the importance of the mid- and far-infrared wavelength range, assessing the relative and absolute strength of star-formation and nuclear activity, in a crude way, for nearby objects.

Similar SED analysis tools were applied in case of more distant, more powerful AGN, such as QSOs, radio galaxies, and radio-loud quasars. These studies were only moderately successful due to sensitivity constraints. Nevertheless, intriguing trends were reported such as the dusty nature of QSOs (e.g., Haas et al. 2003) and the star-formation connection (Van Bemmel & Barthel 2001). ISO photometry was also applied to test AGN unification schemes (Van Bemmel et al. 2000, Haas et al. 2004). Figure 2 illustrates the technique of multi-component dust model fitting, in the (high S/N) case of the nucleus of the Cygnus A radio galaxy. Recalling the substantial diffuse cold dust in galaxies, at least three components must be present in active galaxies. The hot circumnuclear torus dust however will display complicated aspect dependent optical thickness effects. The latest torus models (Van Bemmel & Dullemond 2003, Nenkova et al. 2002) cannot yet be properly tested with current SED data: high S/N SEDs for many classes of objects are eagerly awaited.

As mentioned already, the warm dust in galaxies draws from star-formation (and also from torus emission). A strong warm dust component can be inferred from infrared color-color plots and implies relatively strong star-formation activity. This is obviously true for ULIRGs, prime cases of starburst activity, but also QSOs (with an additional dust heating source, namely the AGN) can be put on such plots. Figure 3 indicates that indeed such star-forming AGN can be identified: age-dating using optical spectra of the circumnuclear populations in these QSOs (Canalizo & Stockton 2001) supports their post-starburst nature, cf. expectation. During the last few years evidence is growing that QSO host galaxies may be richer in star-formation fuel than initially thought (e.g., Evans et al. 2001, Scoville et al. 2003).

Herschel will address the symbiosis\(^1\) of MBH accretion activity and star-formation out to high z, using the PACS and SPIRE instruments. This symbiosis is manifested in the global FIR-submm spectral energy distributions as well as in the detailed FIR-submm spectral properties. Given its (one to two orders of magnitude) improved sensitivity w.r.t. previous mis-

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\(^1\)It is appropriate here to recall a result from SED modeling studies by M. Rowan-Robinson (1995): “a QSO or Seyfert event appears to be inevitably accompanied by a starburst”
3.2. STAR-FORMATION: present and past

ISO spectra have brought great advancement in our understanding of the star-formation process, both locally in the Milky Way and globally in nearby and low redshift galaxies. Spectra taken with the Spitzer IRS are currently refining this knowledge and extending the distance coverage. The improved angular resolution of Herschel nevertheless is eagerly awaited for investigations of the details of the star-formation process: PDR cooling, the mass function of Giant Molecular Clouds, the fragmentation, properties of Super Star Clusters, etc. Herschel’s HIFI instrument will explore the chemistry of starburst evolution and differentiation, in the Galaxy and in nearby galaxies. Template cooling line spectra containing the many CO, H₂O, and related lines will be obtained, and their application for distant star-forming objects will be investigated. The circumnuclear X-ray dominated regions (XDRs) in nearby active galaxies will be investigated, again yielding template spectra. PACS and SPIRE will make imaging studies of the molecular cloud complexes, both in continuum and line (including PAH) radiation. PACS will obtain imaging spectroscopy of star-forming regions, focussing on the detailed physics of Galactic PDRs and the star-formation–AGN interplay in nearby (active) galaxies.

Concerning cooling, a lot of work must be done. Cooling through [C II]λ158µ and [O I]λ63µ is not well understood, and the [C II] deficit in strongly star-forming galaxies and ULIRGs (e.g., Malhotra et al. 1997) has now been measured at extreme redshift (Bolatto et al. 2004).

Taking full advantage of the Herschel sensitivity, star-formation in early type galaxies will be investigated. Also the puzzling class of blue compact dwarfs will be studied: what is the origin of the low metallicity of these objects?

Herschel spectroscopic imaging observations may shed light on the driving force of nuclear activity: can we finally solve the bar issue, is there a direct physical link with circumnuclear star-formation? Also close to home, the details of the radio-FIR correlation, including the small-scale break-down can be studied using Herschel imaging. Such studies will refine the already impressive Spitzer studies (e.g., Gordon et al. 2004).

Concerning distant and powerful starburst galaxies such as HyLIRGs, submm galaxies, Lyman-break galaxies, and high z ellipticals, Herschel will undoubtedly quantify the level of star-formation and settle the question as to the presence of additional energy sources. With help from the negative K-correction, galaxies having star-formation rate \( \sim 10^2 \, M_\odot/\text{yr} \) can be observed out to \( z \sim 2 \), molecular or ionic cooling lines .... This will require tens of hours of integration but is not unfeasible.
whereas SFRs of order $10^3 \, M_\odot/yr$ can be traced out to much higher redshifts. Large Herschel Key Programs will be devoted to a census of the evolving starburst galaxy population, on the basis of data from the large-area Herschel photometric surveys. Indeed, these surveys will address the question "how do galaxies form?" Together with ALMA and other ground-based mm telescopes Herschel will determine the cosmologically evolving star-formation efficiency $SFE = L_{\text{FIR}}/L_{\text{gas}}$. Star-formation in very high redshift AGN, such as radio galaxies (e.g., Greve et al. 2004) and QSOs (e.g, Walter et al. 2003) will undoubtedly receive much Herschel attention.

4. SUMMARY

Star-formation and AGN activity were in the past at least one order of magnitude more prominent than they are now. Understanding these evolving phenomena and their interplay is a key theme of today's astrophysics. To obtain that understanding is the raison d'être of the Herschel Space Observatory. Herschel will deal with star and galaxy formation, throughout cosmic history, globally and in detail: MW, PDRs, GMCs, SSCs, BCDs, Es, LBGs, EROs, DRGs, SMGs, XDRs, QSOs, PRGs, LIRGs, ULIRGs and HyLIRGs,... ² you name it! These are exciting times and Herschel is going to make it even more exciting. Those who wish to join in the planning of Herschel studies are referred to the Herschel website http://www.rssd.esa.int/Herschel/

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