# Far-Infrared and Submillimeter Spectroscopy of Low to Moderate Redshift Normal and Active Galaxies

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Abstract. Broadband surveys with planned observatories such as SIRTF, ASTRO-F, NGST, Herschel, SMA, and ALMA will provide large samples of dust-enshrouded galaxies undergoing varying proportions of star formation and accretion onto supermassive black holes. Recent evidence suggests that the mass of supermassive central black holes are proportional to central velocity dispersions of their host galaxy bulges, but it is not yet known how these properties are evolutionarily connected. To trace the evolution of these components during the important luminous, dusty merger episodes as a function of redshift, sensitive mid- to far-infrared spectroscopic diagnostic observations from space will be necessary. The high sensitivity and spatial resolution of a large aperture, natural background limited far-infrared/submillimeter telescope such as SAFAIR will allow detection and identification of the far-infrared/submillimeter components of galaxies and of a multitude of rest-frame mid- to far-infrared recombination, fine-structure, and molecular lines toward dusty galactic nuclei. The line diagnostics beginning to be developed from ISO work will help determine important parameters such as the intrinsic spectral energy distribution, ionization parameters, metallicities, densities, extinction to the embedded energy sources, and ultimately the star-formation and accretion rates in these galaxies. Ultimately, the higher spatial resolution provided by a cold, far-infrared submillimeter interferometer is needed to view the distribution of structure in galaxies in order to unravel the as yet untold story of the evolution of galaxies over the lifetime of the Universe.

## 1. Science goals of Far-IR/Submillimeter Large Aperture and Interferometer Missions

Broadband imaging surveys in optical, near-infrared, and high energy bands will tell us how the number counts of different galaxy types vary as a function of photometric redshift and thus give us quantitative information on galaxy evolution. The missions of interest in this workshop must have the sensitivity and spatial resolution to uniquely detect and identify far-infrared and submillimeter galaxies (or protogalaxies) and the far-infrared and submillimeter emission components associated with the galaxies discovered in other bands. SAFAIR was conceived to be able to do this. Further, it will allow us to characterize the broadband distribution of the far-infrared and submillimeter emission and to carry out sensitive spectroscopy to determine in which types of cosmological sources these emission components trace accretion onto supermassive black holes and when they trace powerful bursts of star formation. These observations will help determine the relationship of the evolution of black holes to the evolution of galaxies. For example, do supermassive black holes evolve throughout normal galaxy evolution or is their evolution mediated mainly through collisions and mergers of galaxies?

2. Current understanding and puzzles

Interpretation of cosmological broadband and spectroscopic signatures is dependent on the thorough understanding of local ones. ISO observations have brought a clearer understanding of some infrared signatures, while adding further puzzles in the cases of others. Here, I highlight some of the ISO results on galaxies and the questions that they have raised.

Moorwood et al. (1996) were able to use the plethora of mid-infrared lines from highly ionized species from the visually obscured, Compton-thick active nucleus in the nearby Circinus galaxy to determine the shape of the ionizing spectrum including a strong UV bump, while Clavel et al. (1999) have found evidence for large differences in obscuration by dust that explain the different mid-infrared signatures in Seyfert 1 and 2 galaxies, consistent with unification theories of AGN. Mid-infrared diagnostics have been used to quantitatively ascertain the starburst and AGN contributions to the infrared luminosity of ultraluminous infrared galaxies (Genzel et al. 1998; Laurent et al. 2000). Based on the ISO determined Milky Way galactic center extinction law, Genzel et al. find that the ratio of ionizing photons to bolometric luminosity in ultraluminous galaxies is similar to that of starburst galaxies. Lutz (1999) has found that the extinction laws in these galaxies may differ systematically from each other, so the sensitivity of future missions must allow us to *measure* the extinction law towards these galaxies. If confirmed, these differences may shed light on the varied conditions in the interstellar media of these galaxies and will need to be used to derive the important diagnostic ratio of ionizing flux to bolometric luminosity.

Luhman et al. (1998; 2002) and Malhotra et al. (1997; 2001) have found unexpected weakness of the [CII]158μm and [OI]63μm luminosities of ultraluminous and lower luminosity warm galaxies, while the ratio of the [CII] and PAH feature luminosities is constant (Helou et al. 2001; Luhman et al. 2002), except in the important case of low metallicity galaxies (Madden 2001). Helou et al. suggest that this may indicate that both high radiation density and increased importance of large grains in warm galaxies may explain these phenomena, while Luhman et al. (2002) posit that the presence of dust-bounded ionized regions and the resulting excess infrared emission may be contaminating the PDR emission diagnostics. These explanations need not be in conflict! Fischer et al. (2001; these proceedings) have modeled fine-structure line diagnostics of high ionization parameter regions illuminated by AGN and starbursts that may be responsible for producing dust-bounded ionized regions and the observed weakness of fine-structure lines from ionized regions. Lastly, atomic and molecular absorption in lines of OH, $H_2O$, and [OI] can be used to constrain the intervening column densities towards and physical conditions in the far-infrared emission regions in these galaxies (for discussion on OH, see Smith, these proceedings).

The higher sensitivity and spatial resolution of observatories such as SIRTF, SOFIA, NGST, Herschel, SMA, and ALMA will propel these endeavors forward, paving the way for interpretation of these spectroscopic diagnostics in cosmological sources.

3. The need for natural-background limited sensitivity and high spatial resolution

Bock et al. (these proceedings) illustrate the dramatic improvement in sensitivity produced by cold, natural-background limited, space-borne spectrometers, while Bradford et al. (these proceedings) discuss a novel, lightweight, stackable spectrometer concept with no moving parts that can be used for redshift identification and other spectroscopic studies. A good illustration of the need for the high sensitivity that SAFAIR will provide, is the large scale spectroscopic survey suggested by Dudley et al. (these proceedings) to study the [CII]158μm deficiency break at ~ $10^{12}$ $L_\odot$ in luminous infrared galaxies. Such a survey is capable of statistically tracing metallicity evolution with redshift, if it occurs in infrared luminous galaxies, with a novel alternative possibility of its use as a *statistical* standard candle if the metallicity in such objects is similar to that found in the local universe.

The need for high spatial resolution cannot be overemphasized. The high spatial resolution of SAFAIR will be necessary to correctly associate far-infrared and submillimeter cosmological sources with those in other spectral bands. Further in the future, direct measurement constraints on the physical sizes of objects such as obscured AGN (10 mas ~ 3.7 pc at the distance of the nearest ultraluminous infrared galaxy) can be conclusive proof of their nature. Associated interferometric spectroscopic signatures can then be used as diagnostics of these types of objects at cosmological distances as long as the spatial resolution is high enough to prevent swamping of these features by emission from other structures within the same galaxy. Thus the high spatial resolution provided by a cold, far-infrared/submillimeter interferometer equipped with spectroscopic capability will be necessary in order to produce a detailed account of the evolution of galaxies over the lifetime of the Universe.

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