The Formation and Evolution of Galaxies V: Obscured Star Formation at High Redshifts

Program contacts: Marcia Rieke, Simon Lilly, James Graham, Jill Bechtold, Mike Fall, Massimo Stiavelli

Scientific category: DISTANT GALAXIES
Instruments: MIR/CAM, MIR/SPEC
Days of observation: 64

Abstract

The discovery by DIRBE of a 240 μm background and the subsequent resolution of some of this background into galaxies by ISO and groundbased observation with SCUBA suggests very strongly that a significant fraction of star formation at z $\sim$ 2-3 is obscured by dust. This proposal addresses studying such star formation by complementing short wavelength deep surveys with a longer wavelength survey with bands centered from 7 to 35 μm. The resulting database of objects observed from at least 1 to 35 μm will yield greatly refined star formation rates from z=1 to 3 and higher, and will permit a search for a population of heavily dust-enshrouded high-redshift objects, predicted in some models of galaxy formation, which have gone undetected in the optical/UV-selected samples.

The correction for extinction is controversial, while the first hints of a significant high-redshift population of IR-luminous galaxies are just emerging. SCUBA, and in the near future WIRE and SIRTF, will certainly discover members of this population. Dust extinction decreases with wavelength, and is about 25 times less at 2.2 μm than at 140 nm. For z=3-5 near-IR, reddening independent, measures of morphology and star formation rate (e.g., Pα) can be measured from 5-15 μm. In this wavelength range NGST is also exquisitely sensitive to 3.3 μm PAH emission, and can trace deeply extincted starformation to $z = 3.5$. The mid-IR also exploits tracers which are crucial to distinguish between star formation and AGN luminosity, including IR coronal lines (e.g., [SiVI], [SiVII], [SiIX], [SIX], and [CaVIII]), rotation-vibration emission of hot H_2, and emission from dust. By products of this program will include a measure of dust production rates with redshift and galaxy samples containing AGN and ULIRGS, some of which will be observed in the spectroscopic portion of this program.

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
DEEP HIGH LATITUDE FIELD	12 20	+30 00	34 at L	MIR/CAM R3	6
WIDE HIGH LATITUDE FIELD X 16	12 30	+32 00	33 at L	MIR/CAM R3	48
SELECTED GALAXIES X 50	12 30	+32 00	33 at L	MIR/SPEC R300	10
				Grand total days	64

Scientific Objectives

The broad goals of the galaxy formation and evolution program have been outlined in the first proposal for this program. The specific goal of this segment of the galaxy evolution program is the measurement of the mid-infrared output of high redshift galaxies. Such measurements will greatly reduce the uncertainties in star formation rates relative to rates deduced from rest frame UV-optical data alone, and will also trace the formation of dust in galaxies as a function of time, a simple measure of the increase in metallicity. This technique relies on the utility of mid-infrared fluxes at $\sim 10\mu m$ to provide an estimate of the bolometric luminosity of a galaxy (eg., Spinoglio and Malkan 1995). Figure 1 shows a Bruzual-Charlot model at an age of $1.3x10^8$ years with a metallicity of .004 solar and with no extinction or with $A_V = 2$. The sensitivity of NGST with two choices of mirror temperature is also plotted.

While only one third of the bolometric luminosity of local galaxies is radiated in the IR (Soifer & Neugebauer 1991), there is growing evidence that this fraction is increasing with redshift. The deepest counts available from IRAS at 60 μm (Hacking & Houck 1987), which correspond to an average redshift of about 0.2 (Ashby et al. 1996), already suggest some evolution of the IR emission in the universe. A deep survey with the ISO at 15 μm has discovered a few objects at z=0.5-1 with star formation rates much higher than deduced from the optical (Rowan-Robinson et al. 1997). These conclusions are reinforced by unexpectedly high far-IR and sub-mm source counts measured by ISO and the JMCT/SCUBA (Puget et al. 1997; Smail et al. 1997; Hughes et al. 1998). Using the areal number densities of galaxies detected by ISO at $15\mu m$, this NGST survey should detect more than 10^5 galaxies brighter than 30 nJy at 10 μm per 4'x4' field, nearly confusion limited but the large extrapolation in flux by over a factor of 1000 must be kept in mind.

Whether galaxies are assembled from smaller units via a succession of mergers or by the collapse of single large cloud, the role of starburst-like activity is apt to be significant. The correlation between galaxy-galaxy interactions and starbursts is well-established at low redshift (see references in Sanders and Mirabel 1996) with the most extreme mergers producing spectacular luminosities in the cases of Ultra-Luminous Infrared Galaxies. Much of this star formation is virtually invisble in the ultraviolet and optical or is observed through such a thick shroud of dust that extinction levels as deduced at optical wavelengths imply an optical depth of 1 because that is all the deeper one can see into the galaxy. Longer wavelength data, especially at mid-far infrared wavelengths are required to learn just how much energy has been absorbed and re-emitted by the obscuring dust.

At low redshifts a range of both morphological types and sizes of galaxies have much of their star formation obscured by dust. In some cases high levels of star formation occur in normal galaxies with no obvious triggers and may be hidden by more than 30 magnitudes of extinction in the the central kiloparsec. As discussed in Kennicutt 1998, the character of star formation in the central regions is different from disk star formation with the nuclear star formation process having much higher star formation efficiencies. The dependence of nuclear star formation on either morphological type or spiral structure is nil with the exception of a dependence on bars. Note that for many early-type spirals, the nuclear star formation is

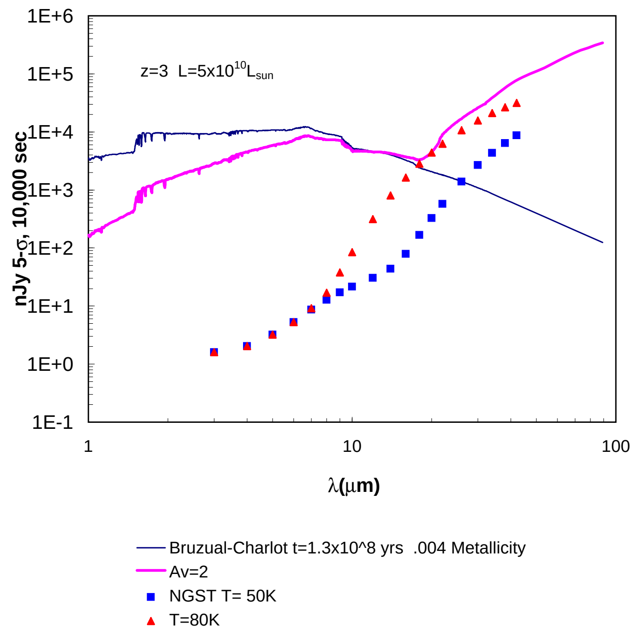

Figure 1: A Bruzual-Charlot model galaxy with and without dust extinction compared to the sensitivity of NGST.

comparable to the integrated disk star formaition so that nuclear starbursts are an essential piece of the puzzle for understanding these galaxies. The relationship of this nuclear star formation in nearby galaxies to star formation at early times, especially the formation of bulges and spheroids which may also represent star formation in a galaxy's central potential well is obviously not known now, but evidence from the Milky Way and the pattern of higher metallicity towards the centers of ellipticals and spiral bulges suggests that rapid, possbily burst-like star formation is important.

As higher redshift objects are observed, one expects that lower and lower metallicity regions will naturally predominate. At some point when the very first generation of stars are observed, no dust should be present simply because no C or Si is available from which to form dust. Current evidence for dust at high redshifts includes several observations in the rest-frame UV at z=3-5 which imply extinctions of ~ 0.9 at V (Trager et al. 1997, Sawicki and Yee 1998, Soifer et al. 1998, Armus et al. 1998). Particularly given the problems of estimating total dust amounts from extinction at very short wavelengths where observations will be dominated by the least heavily obscured regions, it seems highly probable that dust amounts corresponding to at least $A_V \sim 1$ will be present at $z \sim 5$ which be enough dust to not only complicate star formation rate estimates from UV-optical data alone, but will ensure the presence of mid-infrared emission from the UV-heated dust. This contention is

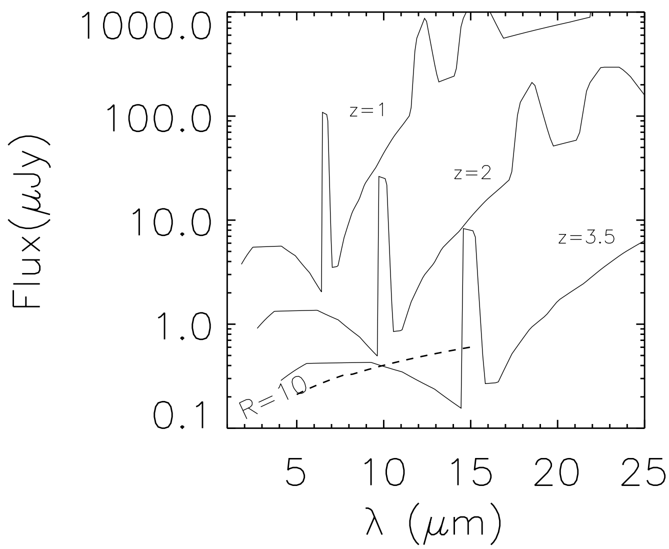

Figure 2: MIR spectra of an ultraluminous ($10^{12}\ L_{\odot}$) IR galaxy are plotted for $z = 1 - 3.5$ (Guiderdoni et al. 1997), representative of objects such as Arp 220. The most prominent feature is the 3.3 μm PAH emission band. The sensitivity of IFIRS, one possible configuration for a mid-ir spectrometer on NGST, in a 10^4 s exposure is shown. The full 5-15 μm band-pass is scanned, and the flux corresponding to SNR=10 is plotted for $R = 10$ spectral channels. $H_0 = 50$ km s^{-1} Mpc^{-1}, and $q_0 = 0.1$.

supported by the discovery of large amounts of dust ($A_V \sim 20$) in the nearby low-metallicity (1/40 of solar) dwarf galaxy SBS 0335-052 (Sauvage and Thuan 1998) which has a $12\mu m$ to B luminosity ratio of 2.2.

After the imaging surveys are analyzed, a sample of the most intriguing objects will be selected for further study. Low-resolution spectra will be used to look for spectral features which are indicative of either star formation (eg. PAH features) or hard UV sources via coronal lines such as [SiVI]. Figure 2 shows a low resolution spectrum including PAH dust emission which is usually strong in starbursts but weak in Seyfert galaxies.

References

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NGST Uniqueness/Relationship to Other Facilities

These observations utilize two unique characteristics of NGST. First, NGST will have greater sensitivity than SIRTF at 5-25 μm ($T_{mirror} \sim 100°K$) or to 40 μm for $T_{mirror} < 80°K$. These sensitivity levels correspond to a deeper look at star forming galaxies than either FIRST or the MMA will provide. At the same time, NGST can provide angular resolution higher than either SIRTF or FIRST and similar to that of the MMA. Thusthe combination of mid-infrared sensitivity and angular resolution that NGST provides will be unmatched in the foreseeable future and will allow unambigious identifications between MMA sources, mid-infrared sources, and optical-near infrared sources.

Observing Strategy

The observing strategy here closely parallels that of the 1-5 μm surveys where an ultra deep survey will cover a single 4'x4' field and a very deep survey will cover 16 4'x4' fields with both surveys executed using multiple filters. The same fields will be observed using $R \sim 3$ filters centered at 8, 16, 24, and 36 μm. The ultra deep survey limit will correspond to $L_{bol} \sim 10^9 L_\odot$ or about $1 M_\odot/yr$ at z $\sim$ 3 while the very deep survey will correspond to $\sim 5 M_\odot/yr$. These star formation rates were computed assuming a telescope mirror temperature of $80°K$ and will be lower if the mirror achieves the baseline temperature of $50°K$.

After completion of the imaging surveys, 50 sources for spectroscopic follow-up will be chosen.

Special Requirements

Precursor/Supporting Observations