Science Proposal Template #2

Determining the connection between black hole growth and star formation over cosmic time

1. Science aim/goal

With large statistical samples of galaxies, we will separate the SF and AGN emission based on robust MIR/FIR diagnostics to determine the cosmic SFRD and BHARD from the peak through Reionization.

2. Proposal

Scientific Importance:

There appears to be a rough correspondence in the shape of the Star Formation and Black Hole Accretion Rate Density (SFRD, BHARD) out to z~3 which, along with the local BH-stellar mass relation, implies some co-evolution in galactic and BH growth over the last ⅔ of the age of the Universe. It is not clear how this comes about, nor what even the shape of the SF or BH accretion history is for z > 3. This is a glaring gap in our basic understanding of galaxy evolution. Recent ALMA results show that the obscured SF continues to dominate in galaxies at z=1-3 down to stellar masses of 4e8 Msun (Dunlop+2016), and the deepest Herschel results suggest that the IR SFRD may only slowly decline to z~5 (Rowan-Robinson +16). Both of these results are highly uncertain, being based on handfuls of galaxies spread over a wide ranging parameter space. Since a great deal of the star formation and black hole growth in normal and massive galaxies occurs in dusty or highly obscured environments, the FIR Surveyor can uniquely unravel both, all the way back to Reionization.

While the stellar mass is the integral of the star formation rate of any galaxy over its lifetime, it tells us little about how galaxies actually grow. This growth depends on a large number of factors, such as halo mass, local environment, mergers, gas accretion, and the impact of feedback from starbursts and AGN. In the local Universe we see a strong dichotomy between cluster and field galaxies, but we do not understand how environment influences growth over cosmic time. The role of AGN activity in this picture is particularly uncertain, since only the brightest AGN are often studied, and the physics of the interaction of AGN and host galaxy is poorly understood. Accurately mapping the SFRD and BHARD with redshift at z > 3, and disentangling galaxy properties (environment, SSFR, AGN power, etc.) are crucial for understanding how galaxies evolve over time. With the FIR Surveyor, we can simultaneously measure the SFR and BH accretion rate using multiple diagnostics that are effective in even the dustiest or Compton Thick (CT) galaxies, generating samples over large areas that are immune to cosmic variance, and for the first time measuring the infrared properties of significant numbers of normal, low-luminosity galaxies in the early Universe.

Measurements Required:

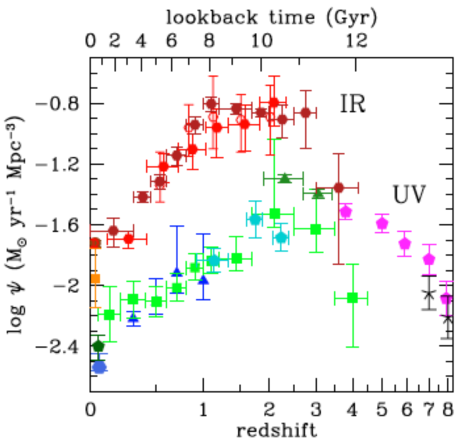
We will need to measure the bright FIR fine structure lines ([OIV], [NeII]) and PAH features to z~6-7. These features (fluxes, line ratios, EQW) provide SFR, BHAR, and redshifts. Line profiles are not required, but could provide, for the brightest sources, indications of high-velocity gas (broad line wings) or estimates of the BH mass. Large areas (tens of sq. degrees) are required to build up samples sufficient for binning sources in LIR, z, AGN fraction/power, and environment/merger stage. A large, low-res spectroscopic survey would provide redshifts, spectral classes (AGN, SB, composite) and SFR's of high-z galaxies with LIR < 1E12 Lsun for the first time. This survey would also allow discovery of extremely red or IR-only sources. Deep, follow-up spectroscopy at higher resolution (R~3000) of representative samples could be used to probe gas dynamics, molecular gas temperatures and masses, shock tracers, and more complete diagnostics of the ISM.

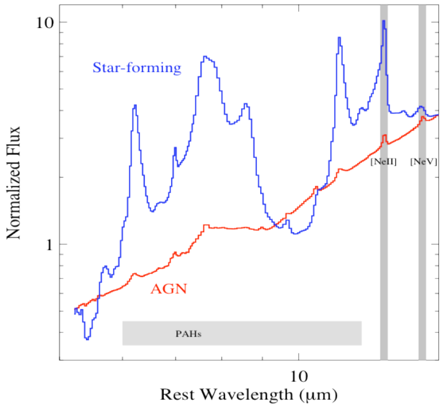
Uniqueness to 10 micron to few mm wavelength facility:

Only in the rest-frame mid and far-IR do we have access to diagnostics of the SFR, BHAR, neutral and ionized atomic gas, and the warm molecular gas and dust, in all sources including those that are highly obscured and/or CT. The sensitivity of a large, cold telescope in space with sufficient mapping speed can generate extremely large and unbiased samples of luminous and normal galaxies through Reionization.

Longevity/Durability:

The FIR Surveyor will uniquely measure key diagnostics of starbursts and AGN, as well as the warm atomic and molecular ISM in dusty galaxies to very high-z. JWST will be blind to most of the key MIR diagnostic features at z > 1 (except the 3.3 PAH and 6.2 PAH [visible until z~3]). JWST and ALMA cannot survey large areas (at most 1-few sq. deg.). Future x-ray facilities, e.g. Athena, will detect moderately obscured AGN at high redshifts, but will have great difficulty measuring the more extinguished black hole accretion to high redshifts and will not measure the SFR in composite systems. The FIR Surveyor can find and characterize the AGN and SB power in normal galaxies over large areas, defeating cosmic variance and producing a complete census of SF and BH growth through Reionization.





Left: Star Formation Rate Density vs. redshift from Madau & Dickinson (2014). While the light from most stars emerges in the IR at z < 3, the SFRD as traced in the FIR is virtually unknown for z > 3. The BHAR has a roughly similar shape and while luminous QSOs have been used to map the BHARD to higher redshift (Merloni & Heinz 2008, Aird +10), there is large uncertainty about the highly obscured and CT population – precisely that which can be probed with the FIRS (Delvecchio +14). ***Right:*** Average rest-frame mid-IR spectra of pure star forming galaxy (blue) and strong AGN (red), normalized at 15 microns. Gray regions highlight the diagnostic power of the [NeV]/[NeII] line ratio and the PAH feature strengths at separating AGN and star formation activity.

4. Performance Requirements

Parameter	**Unit**	**Required**	**Desired**	**Comments**
Wavelength/band	um	30-300	10-500	Key MIR SFR, BHAR diagnostics z=2-7
Number of targets		2E4	2E5	25-100 sources each in bins of z, LIR, merger fraction, density/environment
Survey area	deg.^{2}	10	100	Overcome cosmic variance, build large samples at z > 4, find rare objects.
Angular resolution	arcsec	5	2	Spectrally/spatially separate pairs/groups
Spectral resolution	l/Dl	100	500	Line and PAH detection
Bandwidth	dex	0.3	0.7	multiple spectral lines per band
Spectral line sensitivity	W m^{-2}	5E-21	1E-21	5-sigma, 1hr.
Field of Regard		½ sky	Full sky	Survey large areas, observe rare objects

5. Key References

Aird, et al. 2010, MNRAS 401, 2531; Armus, L., et al. 2007, ApJ, 656, 148; da Cunha, et al. 2013, ApJ, 766, 13; Delvecchio, I. et al. 2014, MNRAS, 439, 2736; Madau, P., & Dickinson, M., 2014, ARA&A, 52, 415; Merloni, A., & Heinz, S. 2008, MNRAS, 388, 1011. Rowan-Robinson, et al. 2016, (arXiv:1605.03937); Veilleux, S., et al. 2009, ApJS, 182, 628

6. Appendix: sensitivity estimates and other requirements (table notes)

The bright rest-frame MIR fine structure lines ([OIV], [NeII]) have ratios to the FIR continuum of 1E-4 to 1E-3, so about 5E-21 W m^{-2} for LIR = 1E12 Lsun at z=5-6, and about 1E-21 W m^{-2} for a LIRG at z=2-3. The 6.2 and 7.7 PAH features can be 1-4% FIR, or about 2E-20 W/m^2 at z=6 for LIR=1E11 Lsun. We need to measure line fluxes, ratios for F.S. lines, and flux and EQW for the PAH features in normal galaxies with LIR = 1E11 – 1E12 Lsun. The [OIV]/[NeII] and PAH EQW provide AGN fractions, the [NeII] flux a SFR, and the [OIV] flux (for AGN dominated sources), the BHAR. PAH fluxes can also provide SFR, but would need to check PAH/FIR against PDR deficits. Following Bethermin +12, assume ~500 ULIRGs per. sq. degree at z~4-5, ~100 per sq. degree at z~5-6, 50-100 per sq. degree at z~6-7, requiring tens of sq. degrees to generate >1E4 galaxies.