Science Proposal Template #1

Linking feedback to the growth of galaxies over the last 12 billion years

1. Science aim/goal

Measure the feedback from SNe and AGN on the molecular and atomic ISM in galaxies since z~3 - a key to galactic evolution and black hole growth.

2. Proposal

Scientific Importance:

Since a significant fraction of star formation and black hole growth occurs behind dust, our understanding of how and why galaxies evolve will remain incomplete until deep, wide area spectroscopic surveys in the FIR can be carried out from space. The number of high-redshift galaxies with high SNR spectra in the mid and far-IR from ISO, Spitzer and Herschel is extremely limited. The FIR Surveyor will uniquely measure black hole growth and star formation in dusty galaxies over more than 95% of cosmic history. The correlation of black hole and stellar mass and spectroscopic surveys at low-z have shown that most active galaxies are simultaneously making young stars and feeding their central black holes - they exhibit both starburst and AGN properties. Energetic feedback from AGN young stars and SNe have been modeled as key means of regulating galaxy and black hole growth over a wide range in mass, yet the existence and type of feedback as a function of redshift, luminosity, and environment, especially in dusty and/or massive galaxies, is poorly constrained. A spectroscopic survey with the FIR Surveyor will have an enormous impact on our understanding of galaxy/BH co-evolution, quantifying the ubiquity, duty cycle and basic physical properties of feedback on the ISM in AGN and starburst galaxies. When combined with detailed studies of low-z galaxies (see related Nearby Galaxies science case) it will be possible to map AGN and SB feedback over the last 12 Gyr.

Simulations suggest that feedback from AGN and/or powerful nuclear starbursts can heat and expel gas, affect the mass function of galaxies, and speed the evolution from blue disks to red ellipticals. While the hot, low-density atomic phase of galactic outflows have been studied in starburst galaxies at low-z, massive (100 Msun/yr), fast (1000 km/s) molecular outflows have only recently been detected in some of the nearest most luminous galaxies with Herschel, via blueshifted absorption profiles of OH and H_2O in the FIR. These winds have outflow rates comparable to the star-formation rates. Mid and far-IR spectroscopy provides a unique window on the physical conditions in the multi-phase ISM in galaxies experiencing powerful feedback. With the FIR Surveyor we can directly observe the role of feedback in quenching galaxies, derive the wind mass, kinetic energy and mass outflow rates, and correlate these with key galaxy properties (AGN or SB power, environment, mass, age, etc.).

Measurements Required:

We will measure the strength and velocity offset of any P-Cygni profiles in the FIR OH lines to estimate the speed and mass of the molecular outflow and correlate with AGN and SB strength (using the FIR flux and MIR diagnostics). Broad wings (1-few x 1000 km/s) on the MIR fine structure lines will indicate high-velocity ionized gas as well as the ionization mechanism in the different velocity components. The H2/PAH flux ratios will be compared to PDR models to isolate systems with strong H2, indicative of shock heating. Large samples are required because the feedback is expected to be “bursty” and dependent on the coupling of stellar and AGN power to the ISM (which will vary from galaxy to galaxy).

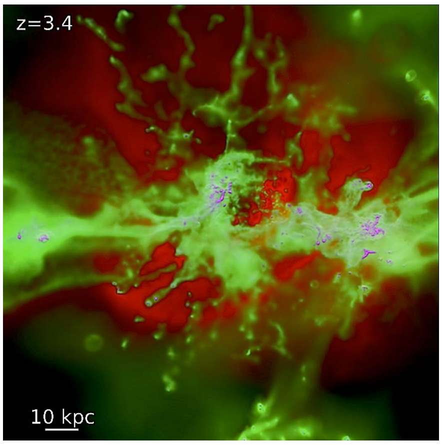
Uniqueness to 10 micron to few mm wavelength facility:

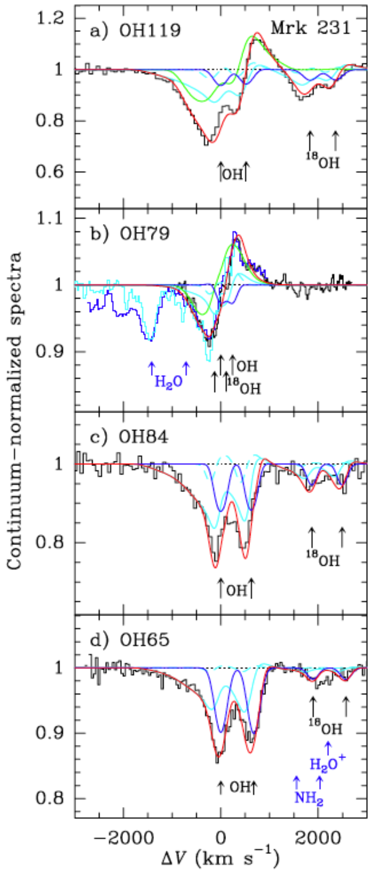
The mid and far-IR provide unique access to the neutral and ionized atomic gas, over a vast range of ionization and critical density ([NeII], [SiII], [OI], [OIII], [OIV], [NeV]), the warm molecular gas (rotational H2 lines), and the small and large dust grains (via PAH features, thermal continuum, and silicate absorption). In particular, the OH 79 and 119um ground-state doublets are visible to z ~ 4, while the MIR H2, PAH and FS lines are visible to z~10.

Longevity/Durability:

FIR Surveyor will uniquely measure key diagnostics of **both** starbursts and AGN, and probe the warm atomic and molecular ISM in galaxies over most of cosmic time. JWST cannot measure the FIR lines, and will be blind to the key

MIR diagnostic features at z > 1 (except the 3.3 PAH 6.2 PAH [to z~3]). ALMA can spatially resolve broad wings on CO lines in individual sources, but will never undertake a wide-area survey, and cannot constrain the multiphase atomic and molecular ISM central to these outflows.





Above: Representative simulation of a Milky Way galaxy at z=3.4 showing its feedback-driven, multi-phase structure in cold (< 1000K) gas (magenta), warm (10^4 – 10^6K) gas (green) and hot (10^6K) gas (red), from Hopkins +14. By z=0 this galaxy settles down to a spiral disk. ***Right***: Herschel/PACS OH spectra and fits of the molecular outflow in Mrk 231. Light blue is the high velocity outflow (1700 km s^{-1}) carrying 100 Msun yr^{-1} sr^{-1}, and red is the total fit to the spectrum (from Gonzalez-Alfonso +14). This is an example of a high-velocity, AGN-driven outflow in a local ULIRG seen in molecular gas.

4. Performance Requirements

Parameter	**Unit**	**Required**	**Desired**	**Comments**
Wavelength/band	um	20 - 300	10-500	F.S., dust and molecular abs. at z=1-4
Number of targets		2E3	2E4	100 sources in 10 z, LIR, AGN %, merger bins
Survey area	$deg.^2$	3	25	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	1000	5000	Matches line-widths, resolves P-cygni profiles
Bandwidth	dex	0.3	0.7	multiple spectral lines per band
Continuum Sensitivity	mJy	1	0.2	5-sigma, 1hr
Spectral line sensitivity	W m^{-2}	2E-21	5E-22	5-sigma, 1hr
Field of Regard		½ sky	Full sky	Survey large areas, observe rare objects

5. Key References: *Fischer, J., et al. 2010, A&A, 518, L41; Gonzalez-Alfonso, E., et al. 2014, A&A, 561, 27; Hopkins, P.F., et al. 2014, MNRAS, 445, 581; Leroy, A., et al. 2015, ApJ, 814, 83; Madau, P., & Dickinson, M., 2014, ARA&A, 52, 415; Sparre, M., et al. 2015, arXiv:1510.03869; Veilleux, S., et al. 2013, ApJ, 776, 27.*

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

The most useful diagnostic fine structure lines have widths of 200-300 km/s. Broad wings can be 1-few x 1000 km/s. P-Cygni profiles in fast outflows in the molecular lines (OH) need to be resolved at the ~100-200 km/s level to avoid blending, or R >1000. A ULIRG at z=3 should have a rest-frame 60 micron flux density of about 1-2 mJy (~2-3E-21 W m^{-2} line flux equivalent for R=1000 and 10% of the continuum). Scaling the FIR fine structure lines from local ULIRGs with AGN, [OIV]/FIR ~1E-4, so about 1-2E-20 W m^{-2} for LIR = 1E12 Lsun at z=2-3. Since we want to observe LIRGs at these epochs for the first time, we need to be able to detect lines at levels of 2E-21 W m^{-2}. From the Bethermin +12 models we expect ~1000 ULIRGs per sq. degree from 2 < z < 4, so need at least 5 sq. degrees to have enough sources to cover a range in LIR, z, AGN fraction, merger stage, especially since the the SF and feedback is expected to be bursty. The survey could be done in a two or three-tiered "wedding cake" manner, but would still require many thousands of sources at high spectral resolution to be effective.