1. Science aim/goal:
Characterize the mechanisms of feedback from AGN/star formation across the spectrum of galaxy masses and types and quantify the amount of material recycled/expelled from galaxies at z<1.

2. (i) Scientific Importance: Feedback is the action of radiative and mechanical processes, caused by accretion onto a SMBH and/or star formation, on the accretion and star formation processes themselves. Feedback on all scales is one of the key open questions in astrophysics. It is a fundamental ingredient in galaxy evolution, yet it is poorly understood and it constitutes a major unknown in galaxy evolution models. Among other things, feedback determines galaxy properties such as the galaxy mass function, the separation between blue and red galaxies, the existence of a main galaxy sequence, and the enrichment of the interstellar and circumgalactic medium. *A key goal is to characterize the mechanisms of feedback across the spectrum of galaxy masses and types, and quantify the amount and type of material ejected*. This requires observations with statistical power, not just case studies. The Far-IR provides a unique window to probe the energetics and the masses of major constituents of feedback-driven outflows, as well as uncovering hidden/dusty AGNs and nascent starbursts (see Appendix G).

(ii) Measurements Required:
Gas measurements in absorption: *Measure H_2O, [OI], and OH features in absorption against the source continuum, spectrally separating the outflowing gas to z<1.* Galaxy outflows have been traced in the diffuse ionized gas in nearby galaxies for decades. The cooler phases of these outflows, however, may dominate the mass budget. Far-infrared absorption features, which trace neutral and molecular material, are probes of this cool phase, first measured in a handful of nearby AGN and ultra-luminous infrared galaxies with Herschel. These unambiguously trace negative feedback on the cold molecular ISM (e.g., Sturm et al. 2011). When put together with similar measurements at $z \geq 1$, these observations will allow us to reconstruct the cosmic history of outflows. Details are in Appendix A.

Gas measurements in emission: *Map extraplanar H_2, HD, [CII] in emission with very good surface brightness sensitivity and some velocity resolution and obtain measurements of molecular ions to determine outflow driving mechanisms.* Outflows, or in general extra-planar gas, can be imaged in emission, in molecular or fine structure transitions (H_2 at 28 um, HD at 112, 56 um). Determination of sizes and velocities permits estimating mass outflow rates. [CII] 158 um emission in particular can be used effectively as a tracer of very low column density material (either neutral, molecular, or ionized) and it is predicted by simulations of galactic disk "fountains" (e.g., Walch et al. 2015; see Figure included). Details are in Appendix B.

Dust measurements: *Map extraplanar dust emission in continuum or PAH bands with very good surface brightness sensitivity.* The dust PAH or FIR continuum emission can be used to trace galactic outflows, where dust continuum is seen to trace the combined molecular and neutral atomic outflow very well (Veilleux et al. 2005, Leroy et al. 2015). Details in Appendix C.

(iii) Uniqueness to 10μm to few mm wavelength facility: The Far-IR has a unique potential to trace the bulk mass that is ejected, as well as to provide kinematic information. Mm-wave observations are highly complementary but cannot replace the Far-IR, since the accessible species and transitions are considerably more indirect (or in other ways limited).

(iv) Longevity/Durability: The gaps in our understanding of the physical processes that regulate galaxy growth are large, and although our knowledge has evolved over time, fundamental questions about galaxy evolution have remained open for several decades. It is easy to anticipate that they will be still with us 15 years from now. The overarching question is "how do galaxies grow and evolve through cosmic time?"

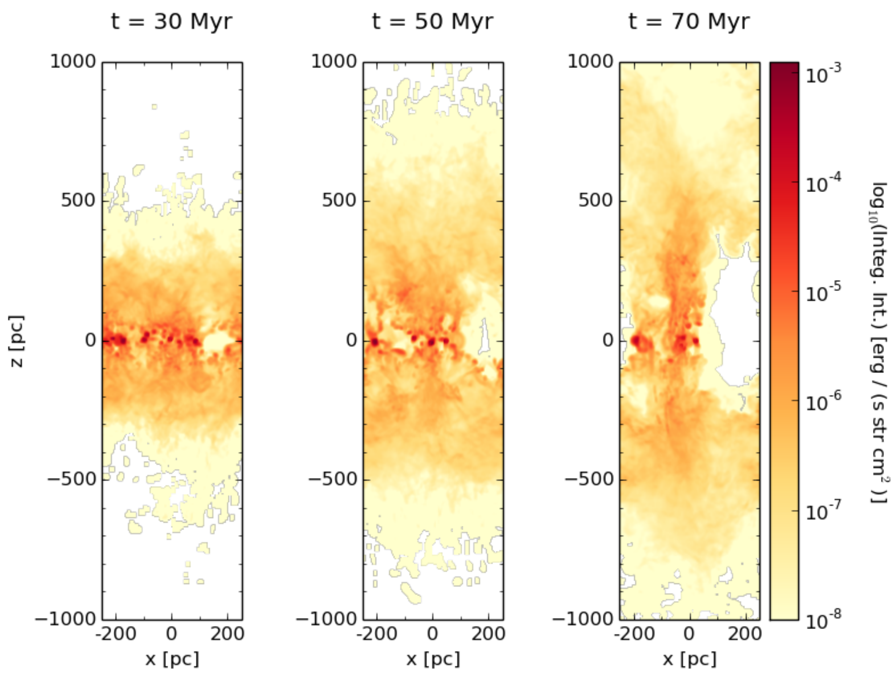
There is a lot of potential for complementarity with other facilities: study of the physical conditions in the PAHs with JWST or ELTs accessing the shorter wavelength spectral features, emission in molecules in galactic outflows detected by ALMA, study of reddening in the CGM of galaxies with WFIRST to trace dusty halos. SOFIA could test some techniques, but it does not have the sensitivity necessary for this type of work.

4. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	20-350	10-500	Accommodate PAH features and H_3O+ /OH+ at the long end
Number of targets		100s	1000	Goal is statistic characterization
Survey area	$deg.^2$	0.1	10	See Appendix F
Angular resolution	arcsec	5	2	At 158 um. 500 pc at 50 Mpc desired, 500 pc pc at 20 Mpc minimum
Spectral resolution	$\Delta\lambda/\lambda$	3,000	30,000	10 km/s desirable, 100 km/s usable. 30 km/s is a good compromise.
Bandwidth	km/s	1,500	4,000	Instantaneous bandwidth for spectral lines
Continuum Sensitivity (1 σ)	μJy	50?		At 160 um. See Appendix E
Spectral line sensitivity (1 σ)	W m^{-2}	1×10^{-21}	1×10^{-22}	Computed for [CII] in ~1 hr. See Appendix D
Dynamic range		500?		Limiting close to bright sources for faint extended emission mapping

5. Key references:

Veilleux, S., Cecil, G., & Bland-Hawthorn, J. 2005, ARAA, 43, 769



Extraplanar [CII] emission as a probe of outflow activity. Simulations of stellar feedback in a galaxy disk, showing star formation driving of galactic outflows visible in [CII] emission. The calculations use the SILCC simulations and include radiative transfer to compute [CII] emission (Franeck et al. in prep., Walch et al. 2015).

Appendix A

Observations of outflow p-Cygni profiles in FIR lines such as those of water (78 um), molecular hydrogen, [OI], and OH (79, 119 um), have proven to be key diagnostics for constraining the amount of molecular mass entrained in galactic outflows. These observations require spectrally resolving the outflowing gas, so they need R~3,000-10,000 to attain 100-30 km/s resolution. AGN-driven outflows are usually faster than SF-driven outflows, so some work on the former could be done even at lower resolution. Very high angular resolution is not required. Because absorption is observed against the continuum from SF/AGN, the beam size would ideally be matched to that of the continuum source, but this is unlikely to be a major limitation since there is always a coverage fraction that is not unity for the absorbing material. Conversely, sensitivity (thus collecting area) drives the requirement. It is mostly a pointed observation, so no mapping is necessary. This measurement can be done at z~0-1 (during the decline of cosmic SFR), to compare to absorption results at higher z and thus reconstruct the cosmic history of outflows.

Appendix B

Calculations for the CALISTO concept show that [CII] observations would be sensitive to surface densities of neutral gas of Σ_{gas}<0.05 M$_\odot$pc^{-2} at 100 K and n~10 cm^{-3} (i.e., very subcritical, n_{cr}~3000 cm^{-3}) for Solar abundances in 1000 seconds, or that same surface density of n_e~0.1 cm^{-3} ionized gas. In order to gather velocity information these observations would have R~3,000-10,000. In order to have good surface brightness (and surface density) sensitivity this type of imaging prefers a filled-aperture instrument. Information on spatial scales of ~0.25-1 kpc is desirable, implying ~5''-20'' at 10 Mpc. But to increase the number and variety of galaxies available we want to extend this to 50 Mpc. This is a mapping or imaging observation, so good mapping speed is desirable. Note that the same type of observation can be used to image gas trails that are remnants of interactions, for example, with orders of magnitude better mass sensitivity than is possible in HI with the VLA (see N(H) calculation in Appendix D).

Appendix C

As with the spectral lines, this type of work requires excellent surface brightness sensitivity, and favors good mapping/imaging capabilities. It does not require spectral capabilities except those needed to model the SED, although it may benefit from a complete spectrum if features can be identified. The use of PAH features would only require R~300-600, since those are intrinsically broad.

Appendix D

To target a sensitivity we can use as guidance the calculations shown in the Figure for [CII] emission in a galactic fountain, in the science case of mapping extended low level [CII] emission due to outflows. The off-plane emission is ~10^{-8} erg/s/cm^2/sr. To map that emission we should request a sensitivity at least an order of magnitude better, 10^{-9} erg/s/cm^2/sr = 10^{-12} W/m^2/sr. If we take a beam size of 5-6 arcsec, that corresponds to a beam solid angle $\Omega_b=10^{-9}$ sr. So the 1-sigma sensitivity required is approximately 1×10^{-21} W/m^2 at 158 um, in a spectral resolution element of ~30-100 km/s. We have not specified a time, but we would want to map ~0.1-1 sq deg during mission lifetime, multiplexing with other projects, which probably means this is a ~1hr (to ~10 minutes) wall-clock sensitivity depending on the degree of spatial multiplexing possible. By comparison PACS on Herschel was $1\text{-}2\times10^{-18}$ W/m^2 in 450s according to the manual. The corresponding N(H) column in the "high-temperature, high-density" limit would be ~3×10^{16} cm^{-2} for Galactic carbon abundance (C/H=1.6×10^{-4}). Assuming a perhaps more realistic density n_H~1 cm^{-3} and high temperature that would correspond to N(H)~4×10^{18} cm^{-2} (see for example Goldsmith et al. 2012 for the equations).

Appendix E

If we take the Planck Collaboration (2014) value of N(H)/τ_{160}~1.1×10^{25} cm^{-2} measured in the diffuse Galactic ISM as a guidance, a column density of N(H)~10^{18} cm^{-2} (as estimated in Appendix D) would have τ_{160}~10^{-7}. A black-body at 30 K with this optical depth would emit $S_\nu=10^{-7}\,B_\nu$(160 um, 30 K)=5×10^{-22} W/m^2/Hz/sr. Thus the equivalent sensitivity in continuum would be 50 μJy assuming $\Omega_b=10^{-9}$ sr. This is probably better than (or at least on the order of) the confusion limit at 160 um for that beam size. On the other hand, assuming a dust temperature of 100 K would bump this by a factor of 10.

Accounting for dust destruction we may require ~10 times better sensitivity. That is probably substantially better than the confusion limit at 160 um, so it may not make sense. In any case, the problem of bumping against the confusion makes the point that spectral lines are probably the way to go for detecting diffuse gas.

Appendix F

There are about 23,000 galaxies with optical diameters D_{25}>1 arcmin. The total area subtended is about 380 sq. deg, but most of it is in the biggest 50 objects. The rest of the galaxies subtend ~60 sq deg. It seems reasonable that surveying 100s-1000s would require 0.1-10 sq deg. This is a very simple minded calculation that should be done better.

Appendix G

Far-IR observations offer the means to uncover dust-hidden AGNs and nascent starbursts as the drivers of feedback. They do this through unique chemical probes. Highly ionized lines like [NeV] and [OIV] at ~25 um can directly probe hidden AGN, as shown by Spitzer observations, particularly with high surface-brightness sensitivity which can be used to probe scattered/reflected light.

Because of their relatively simple chemistry, hydrides can also be used as diagnostic of physical processes. Thanks to the full wavelength coverage achieved with the Herschel, new tracers of feedback processes have been identified: the series of ionized oxygen hydrides (OH^+, H_2O^+ and H_3O^+) are excellent tracers of the ionization rate, provided either by cosmic rays of powerful X ray sources. H_3O^+ (transitions between 300 and 150 um) is particularly interesting because a large number of inversion lines are accessible in the FIR, which can be used to reveal heavily buried active regions (Indriolo et al. 2015, Lis et al. 2014, Gonzalez-Alfonso et al. 2013, 2015). OH lines can be used in complement to trace the outflowing material. The best lines are those from rotationally excited levels, which probes the dense regions where the wind is launched. A good spectral resolution is needed to resolve the winds/outflows, of order 50-100 km/s for external galaxies. H_2O and vibrationally excited CO and HCN can also be used as Far-IR diagnostics.