Science aim: Study feedback on all scales in the cosmic web via ionized gas traced with the Sunayev-Zel'dovich effect.

Scientific Importance: Galaxy formation is highly inefficient---only ~10% of the baryons are incorporated into stars. Some form of feedback keeps the other 90% of the baryons in a gaseous phase known generically as the circumgalactic medium (CGM) which includes the intra-cluster medium in the more massive halos, but this process is not well understood. The Far-IR Surveyor can uniquely address this question by measuring the CGM content within dark matter halos and the filamentary structure of the cosmic web. Through the thermal and kinetic Sunyaev-Zel'dovich (SZ) effects (upscattering of CMB photons by hot electrons in ionized circumgalactic gas) the Far-IR Surveyor will measure the mass and thermal energy of the CGM from galactic to cluster scales and through cosmic time. This will provide unique constraints on feedback as a function of object type (normal/active galaxy, AGN, QSO, etc.), local environment and redshift. The large-scale dataset provided by the Surveyor will be very powerful for aggregate measurements. As an example, Planck has shown the ability to detect the stacked SZ signal in very small galaxy groups, even pushing down toward 10^{12} M_{sun} halos, the regime of single-galaxy halos (Figure left panel).

As pioneered with Planck, the approach is to correlate FIR Surveyor wide-field SZ (and CIB) measurements which probe baryon content with 3-D maps of dark matter. The dark matter distribution which will be available via multiple techniques: galaxy lensing from CMB Stage-IV will trace the overall dark matter distribution to z~1, and observations of the lensing of CMB anisotropies will extend mass measurements to z~5-10. The Far-IR Surveyor continuum bands between ~100 microns and ~1 mm will provide maps of both the SZ effect and the cosmic infrared background (CIB) (distinguishable from from one another via the multiple bands). The combination will reveal the relative distribution of gas and dark matter on all scales across the cosmic web, as well as the energy content in the CGM and the star formation rate, constraining models of gas flows driven by feedback and infall. The 2-D datasets can be first correlated with the lensing map (also effectively 2-D given the broad redshift kernel), but the most powerful analyses will be to incorporate galaxy survey data (wide-field surveys by WFIRST, LSST and *Euclid)* to provide redshift information. The SZ and CIB measurements can then be correlated in redshift bins, and / or stacked on particular objects of interest.

Example stacking measurements from *Planck* are shown in the figure panels. The right shows the aggregate SZ (hot gas) and CIB (dust) signal in 300,000 quasars binned in z to reveal evolution of the quasar hosts through cosmic time. The dust emission broadly follows the cosmic star formation trend: a rise at early times, a broad peak around z~2, and a decline thereafter. *We emphasize that while there will be rich datasets from the ground at the low frequencies, distinguishing the SZ, dust and the CIB was simply not possible without the high-frequency channels above 300 GHz on Planck: spaceborne far-IR measurements are essential.*

The Surveyor will be a huge advance over *Planck* in these measurements. By way of example, we suggest a strawman survey covering 20,000 square degrees in broad (~10%) bands ranging from 300 GHz to 3 THz. With the envisioned cameras (14 arcmin^2 on the 10m) 3000 hours yields map sensitivities several x to more than 10x better than *Planck, and* at much higher angular resolution (<1 arcmin vs. *Planck*'s best 5-10 arcmin beams). Even deeper surveys are possible over smaller survey areas. Moreover, the Surveyor will be better able to separate dust, cosmic infrared background (CIB) and SZ signals with more bands extending to higher frequencies. These are crucial advances because angular resolution and dust/CIB contamination were the primary limiting factors in the *Planck* analyses.

Measurements Required: We require broadband imaging over thousands square degrees with multiple bands in the 100μm - 1mm range. We will stack/bin SZ and lensing signals on large samples of pre-selected objects (e.g, WFIRST HLS) by object class to probe gas as a function of halo mass, and use cross correlations between SZ signal, the galaxy field and lensing maps to characterize the large-scale distributions of gas, galaxies and dark matter.

Uniqueness to 10µm to few mm wavelength facility: Coverage above 300 GHz (below 1mm) is required to measure the thermal and kinetic SZ effects, and distinguish both from the CIB and Galactic dust.

Longevity/Durability: The role of feedback in galaxy formation will remain a critical, outstanding question in the 2025-2030 timeframe. No other facility considered will have the capability of broadband imaging at these wavelengths over thousands of square degrees. The Far-IR Surveyor would be a powerful complement to WFIRST, LSST and *Euclid*, and also to ground-based millimeters surveys, e.g., CMB Stage IV, by extending their frequency coverage.

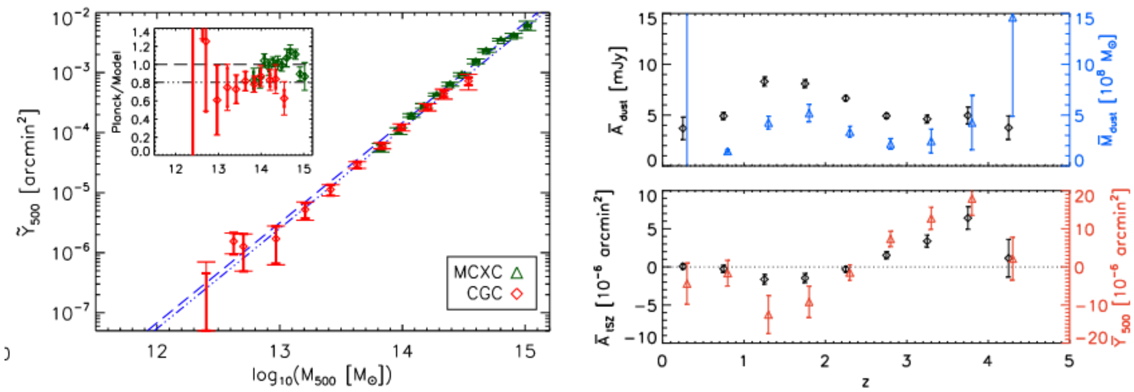

Figure: Example dust and SZ stacking measurements from Planck. *Left panel:* the SZ signal as a function of dark matter halo mass for central galaxies (red points). The measurement was made by binning on a sample of nearly 260,000 galaxies from the Sloan survey. The result demonstrates that the gas content (mass and thermal energy) follows the self-similar scaling law, $Y \sim M^{5/3}$, from the most massive clusters (green points) to very poor groups. The inset shows the ratio of this model to the measurements. The lower mass limit is set by dust contamination from the emission by the galaxies themselves, and would be improved substantially with the Surveyor. (Planck XI, 2013). *Right panel:* Dust (upper panel) and thermal SZ (lower panel) emission binned on ~300,000 BOSS QSOs as a function of redshift. Black points give the raw measurements on their respective left-hand scales, while the colored points give the dust mass and SZ signal on the right-hand scales. The SZ effect is clearly seen at $2.5<z<4$, showing the presence of hot gas in QSO dark matter host halos. By measuring the thermal energy of the gas, the SZ effect constrains feedback by the QSOs. Dust mass is a tracer of star formation rate, and the upper panel shows that QSO environments follow the cosmic trend with a peak near z=2. (Verdier et al 2016).

4. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	µm	300-1000	50-2000	
Number of targets		N/A	N/A	
Survey area	deg.^{2}	3000	20000	
Angular resolution	arcsec	60	30	At 1mm
Bandwidth	%	10	10	
Continuum Map Sensitivity (1 σ)	kJy/ster	100	10	

5. Key references: (Optional, at most three, reviews preferred)

Ade et al., 2013. *Planck Collaboration Int. results. XI. The gas content of dark matter halos: the Sunyaev-Zeldovich-stellar mass relation for locally brightest galaxies*, A&A 577, A52.

Verdier, L. et al. 2016. *Quasar Host Environments: the View from Planck*, A&A 588, A61