1 Science Plan

1.1 Scientific Justification

After 8 cycles, Spitzer’s legacy has yet to be established in the broadest tier of the standard wedding cake design of astronomical surveys—despite the breadth of science that such surveys have historically afforded. SWIRE (Lonsdale et al. 2003), the Spitzer Deep, Wide-Field Survey (Boötes; Ashby et al. 2009) and SERVS (Mauduit et al. 2012) each cover a number of ∼ 10 deg$^2$ fields, but they are small compared to the sizes needed to probe the rarest objects. Furthermore, while Cycle 8 saw the approval of wider fields with the SHELAs (Papovich et al. 2011) and the SPT-Spitzer Deep Field (SSDF; Stanford et al. 2011) surveys, the former field is too small for our proposed science and the latter is more focused in nature and lacks the ancillary data that is needed for our primary goals of using the luminosity function (QLF) and clustering of AGN as a constraint on models of galaxy evolution. WISE data, while covering the full sky, have insufficient depth for our science goals. As such, we seek to expand Spitzer’s legacy by observing a large, contiguous field with a plethora of multi-wavelength ancillary imaging and spectroscopy that will allow both our proposed AGN and broad ancillary science, in addition to providing a rich dataset accessible to the whole community.

A core goal of our project is to enable community-based science by rapidly making the fully cross-linked catalogs public, building on our experience with the (much larger) SDSS data releases.

We will first detail some high-impact AGN science projects and then briefly describe a host of other “survey” science (from the CMB to cool stars) that the same data will afford. Measurements of the clustering and luminosity function z > 3 AGNs can uniquely constrain the important issue of the nature of AGN “feedback”. As designed (see § 1.2), this program will also discover thousands of obscured quasars and > 30 quasars at z > 6. Given the rarity of high-z quasars (typical comoving space densities ∼ 10$^{-9}$ Mpc$^{-3}$), we require a survey volume at z > 3 of nearly an order of magnitude larger than that of existing Spitzer medium-deep survey fields. To achieve that goal, we propose the Spitzer-IRAC Equatorial Survey (SpIES), a 175 deg$^2$ survey to SWIRE depths (120s integration) in IRAC Channels 1 and 2 that will expand Spitzer’s scientific legacy in the large-area regime. Figure 1 shows how the proposed observations fit into the structure of existing wide-area surveys with Spitzer.

![Fig. 1: Comparison of deep-wide mid-IR fields. Depths are given as 5-σ, point sources at 4.5 μm according to the PET. These values are deeper than the 80% completeness limit, but provide a level playing field for comparison and are the appropriate numbers for point sources with a priori positions (e.g., quasar candidates). Herschel-ATLAS covers ∼ 600deg$^2$ but at a depth of 67 mJy at 110μm (> 1000 × brighter than our flux limit at 4.5μm for a type 1 quasar) and a resolution of ∼ 10′′ (Eales et al. 2010). WISE covers the whole sky (41k deg$^2$) but at a 4.6 μm 5-σ point source depth of only 110 μJy and a resolution of ∼ 6′′ (Wright et al. 2010).](image)
1.1.1 Field Selection

Multi-wavelength imaging and existing spectroscopy are extremely important to the survey nature of the proposed science. A number of possible areas of sky in could support a very large-area warm mission survey; however, an unparalleled combination of extensive spectroscopy and deep optical, near-IR (NIR), UV, X-ray, radio, and millimeter imaging strongly argues for placing our fields in the SDSS “Stripe 82” region, located on the Celestial Equator centered roughly on $\alpha = 0$ hrs (Fig. 3). The SDSS imaged this area of sky $\sim 80$ times over 8 years. The resulting coadded 5-band photometry reaches $\sim 2$ mag fainter than the SDSS main survey ($g \sim 24.5$, $i \sim 23.3$; 5$\sigma$ for point sources; Annis et al. 2011) with combined photometric calibration uncertainties at the 1% level (Ivezić et al. 2007), while the individual scans give detailed variability information. Additional imaging with CFHT exists for 170 deg$^2$ of Stripe 82 to a depth of $i = 23.5$ ($7\sigma$ for galaxies) with excellent seeing (median 0.6$''$), enabling deep lensing studies (Erben et al. 2012, in prep.). The Dark Energy Survey (DES) will probe this region to $i = 25.3$. Other multi-wavelength data are summarized in Figure 2 (which presents a comparison of SEDs to multi-wavelength flux limits) and in § 1.2.5 and Figure 3. Extensive spectroscopy of stars, galaxies and quasars has been conducted in Stripe 82 by the SDSS-I/II (Abazajian et al. 2009), SDSS-III/BOSS (Eisenstein et al. 2011), 2dF, 6dF, and AUS (e.g., Croom et al. 2004, 2009), WiggleZ (Glazebrook et al. 2007), VVDS (Le Févre et al. 2005), and Deep2 (Davis et al. 2007) projects. In all, there exist over 125,000 high-quality spectra in Stripe 82 for an average spectral density of over $400$ deg$^{-2}$. Indeed Stripe 82 is such a good choice that the SHELA survey (Papovich et al. 2011) already covers 28 deg$^2$ (to 3× deeper than our required depth) on Stripe 82 rather than using the main HETDEX field; thus 16% of our job has already been done.

Figure 2: Comparison of SEDs with the multi-wavelength flux limits in Stripe 82, normalized to the SpIES 4.5$\mu$m flux limit. Blue tickmarks indicate the main SDSS depth and the Stripe 82 depth. Cyan indicates the GALEX (2×MIS) depth. Green tick marks show the depth of the existing UKIDSS data and the ongoing VICS82 survey. The brown tick marks show the depth of our proposed IRAC observations. The SED of a $z = 0.5$ elliptical is shown as a dashed gray line (scaled to our flux limit at 4.5$\mu$m). The solid black and grey lines show a type 1 quasar SED at $z = 4$ and $z = 1$, respectively, showing good agreement between our proposed IRAC observations and the existing SDSS depth on Stripe 82. SpIES will be able to identify thousands of type 2 AGN to nearly the IRAC limits, because the IR and optical depths are well-matched for a type 2 AGN SED (shown with a dashed red line for a $L \simeq 10^{43}$ erg/s type 2 AGN at $z = 0.5$).
Figure 3: Multi-wavelength coverage of Stripe 82. Note that the scales on RA (x-axis) and Dec (y-axis) are quite different. Panel a: Every 1000th SDSS source, showing the density of sources with RA. The red boxes outline the proposed 175 deg$^2$ of the SpIES survey (which overlaps the deep CFHT area, although the extension to the CFHTW4 field to $\delta \approx 4.5^\circ$ at $\alpha \approx -27^\circ$ is not shown). We avoid the region of high stellar density on the left and high optical extinction on the right (see Panel g). The ecliptic is shown by the dashed blue line. The orange shaded region marks existing IRAC data from the SHELA survey. Panel b: IR coverage. Grey: existing public UKIDSS DR8 data (sparse sampled); the dashed box indicates the UKIDSS DXS area. Black: Existing targeted IRAC pointings (covering $\sim 2$ deg$^2$). Green: Herschel data from the HeLMS survey. Panel c shows coverage by the Wiggle-z spectroscopic survey (upward hashes), ACT coverage (downward hashes), and the CFHITLS W4 and VVDS 22hr fields (dotted and dashed boxes near $\alpha = -30^\circ$). Panel d: VLA coverage at 20 cm to 3–5× FIRST depth (FIRST data exist over the whole field). Panel e: GALEX coverage in the Medium Imaging Survey (blue), including regions covered twice as deep (green). Gaps largely indicate regions occupied by bright stars. Panel f: X-ray coverage, by the Chandra (green), XMM (red), and SWIFT (blue) satellites. Panel g: $i$-band Galactic extinction (Schlegel et al. 1998) as a function of RA.
Our goal of 175 deg$^2$, allows us to choose an optimal region from the 300 deg$^2$ available on Stripe 82. Excluding regions of high stellar density and Galactic extinction, we propose to carry out IRAC observations as indicated in the top panel of Figure 3 ($-40^\circ < RA < 40^\circ$) covering 160 deg$^2$ of Stripe 82, which results in the best use of ancillary imaging/spectroscopic data. As the CFHTLS (e.g., Veillet 2007) “W4” field overlaps significantly with Stripe 82 and also has similarly high-quality optical imaging/spectroscopy, we will extend our IRAC coverage to the rest of the W4 field, filling out another $\sim 15$ deg$^2$ for a total of 175 deg$^2$, 147 of which require new Spitzer observations. The deep optical-IR SpIES data will enable high precision photo-$z$’s, which are important for both AGN and CMB science. The Equatorial location also has the advantage of being accessible to all major observatories for ground-based follow-up observations.

1.1.2 Science Programs

A. Active Galactic Nuclei

The role of AGN feedback is one of the hottest topics in galaxy evolution today. A key goal of this proposal is a unique investigation to distinguish between feedback models. Feedback models predict how the dark matter halos hosting quasars grow as supermassive black holes evolve; this translates to different predictions for the amplitude of quasar clustering and quasar number density as a function of redshift and luminosity.

The models that we consider are those from Hopkins et al. (2007a), see Figures 4 (for clustering) and 5 (right, for the QLF). These predict similar observed clustering at $z < 2$, but diverge at higher redshifts and are similarly degenerate in the QLF at current survey limits. At $L \gg L^*$, all models predict that the population is dominated by the most extreme, biased systems, so if survey flux limits do not include $L^*$ quasars, the distinction between the models is erased. Figure 5 (left) shows the redshift evolution of $L^*$ using the QLF derived in Hopkins, Richards, & Hernquist (2007; HRH07), which predicts that $L^*$ gets fainter at $z > 2–3$, requiring deeper surveys to probe to this limit.

The three cases considered herein can be summarized as follows (and apply to the left, middle, and right panels respectively in Figure 4) and to the different curves in Figure 5. They are: (1) Extremely strong (efficient) feedback, where every high-redshift quasar is in “blowout” and about to shut down for a Hubble time (preventing any further BH growth). To be on the observed $M_{BH} - M_{halo}$ relation at $z=0$, the halos must have been very small and “caught up” at lower redshifts. (2) A more typical “standard” (inefficient) feedback model, in which the BH and halo are approximately co-eval and the quasars grow to $z \sim 2$ before shutting down. These systems have similar $z = 0$ masses when they shut down and would be increasingly biased at high-$z$; this scenario is equivalent to “pure density evolution” (which is ruled out at low-$z$, but not at high-$z$). (3) A “maximal growth” model in which high-$z$ quasars cannot regulate at all, and will continue to grow their BHs rapidly until $z = 2$ (when the global QLF turns over). To match the local $M_{BH} - M_{halo}$ relation, the BHs must already be in very massive halos, and spend the time at $z > 2$ “catching up” to the halo.

Clustering: In Figure 4 we contrast the clustering bias of these 3 models as a function of survey depth and redshift, demonstrating that they are degenerate in a survey like SDSS (dominated by quasars brighter than $20.2$ and $z < 2.5$) and also in current high-$z$ quasar investigations (e.g., Shen et al. 2007)—due to a lack of dynamic range in quasar luminosity. However, Hopkins et al. (2007a) note that extending the depth of quasar surveys to $i \sim 23$ will move further down the QLF, increasing the quasar density and allowing a smaller survey
to provide clustering constraints at SDSS-level accuracy—breaking the degeneracy between the models at high-z.

More recent work from the SDSS-III/BOSS spectroscopic quasar sample lacks sufficient faint \( z > 3 \) quasars to perform this measurement (Figure 5, left). This was recently confirmed by White et al. (2012), who found that quasar clustering measurements from the first half (2.5 out of 5 years) of BOSS were entirely consistent with earlier surveys, despite being more precise. Further, White et al. (2012) note that BOSS lacks sufficient dynamic range to constrain the expected—but as yet unobserved—luminosity dependence of quasar clustering at \( z > 2.5 \). In fact, the analysis of BOSS quasar clustering in White et al. (2012) contains insufficient redshift range to constrain quasar clustering for \( z > 2.8 \).

On the other hand, our proposed survey volume at \( z > 3 \), to our proposed flux limit, would give sufficient dynamic range to perform the necessary clustering measurements, enabling a powerful new discriminator of early feedback. Moreover, the deep, multi-wavelength SpIES imaging provides significantly accurate selection and photo-z’s to do what a spectroscopic survey cannot. The narrow geometry of the field is not an issue since 2° is always > 160 Mpc/h comoving at \( z > 3 \) (while we benefit on large scales from the contiguous nature of the field [as compared to SWIRE or SERVS]). As \( z > 3 \) quasars are rare, a significant signal requires a large area to achieve the necessary density of sources; a photometric survey substantially smaller or shallower than SpIES (or one with larger photo-z errors) would not be able to distinguish competing feedback prescriptions. In short, the large-area SpIES survey distinguishes the models in Fig. 4 at > 2 \( \sigma \) at both \( z = 3.5 \) and 4.5 (i.e. > 3 \( \sigma \) overall), providing an important and unique constraint on AGN feedback models.

**Quasar Luminosity Function (QLF):** As with clustering, the QLF is well-determined for bright quasars up until the “peak” epoch of \( z = 2–3 \) (above the dotted line in Fig. 5 (left) and leftward of the peak), but is much more poorly constrained for fainter and/or higher redshift quasars. In models in which (luminous) quasars are powered by infall triggered by galaxy mergers (e.g., Hopkins et al. 2006), quasars above the break luminosity (dotted line in Figure 5, left) are those accreting close to the Eddington limit and those below the break luminosity reflect the distribution of Eddington ratios among objects accreting much more slowly. Most of the mass accreted by supermassive black holes accumulates in quasars at the break luminosity in the QLF (because the lower luminosity quasars are growing too slowly and there are too few higher luminosity quasars). Sampling both populations is essential in order to determine the break luminosity accurately and to observe whether the proposed theoretical differences in accretion modes are correct.

Existing optical and mid-IR data fail to fully probe the QLF below the break luminosity and generally do not approach the break luminosity above \( z \sim 3.5 \). To confirm whether the break luminosity evolves with redshift, it is critical to obtain quasar samples that span a large redshift range—which requires a large-area survey at epochs prior to \( z \sim 2.5–3 \) when quasar activity peaked (e.g., HRH07; Siana et al. 2008; Glikman et al. 2011; Ikeda et al. 2011). The open squares in Figure 5 (right) indicate the dynamic range and uncertainty in the QLF that SpIES will obtain—aPath to properly distinguish between models (Figs 4 and 5 [right]).
Figure 4: Different feedback models make different predictions for quasar bias (as a measure of clustering strength). The models predict similar clustering at $z < 2$, as observed (points; see Lidz et al. 2006; Hopkins et al. 2007a), but the models diverge at high-$z$. We compare the current SDSS (dotted) and SpIES (dash-dot) flux limits and an infinitely deep survey (solid). Only a deep spectroscopic survey, or a survey with photometric redshifts comparable to those of SpIES, across a large range in luminosity, can distinguish competing feedback models. The models are Left: strong feedback, where every high-$z$ quasar is in 'blowout' mode, about to shut down for a Hubble time, Center: ‘standard’ feedback, in which the BH and halo are co-eval, and Right: a model in which high-$z$ quasars do not regulate their hosts at all, continuing to grow their BHs rapidly until $z = 2$. (From Hopkins et al. 2007a).

Figure 5: Left: All known quasars (light grey contours/points), including SDSS-III/BOSS. The dashed black line indicates the SpIES depth ($i \sim 23, f_{4.5\mu m} \sim 7\mu m$). The dotted black line shows $L^* (M^*_i)$ for quasars, illustrating the important parameter space gap that SpIES will fill. The shaded region indicates the region of focus for the proposed science. Right: Predicted QLF and uncertainties for the SpIES survey (green squares) compared to 3 models (black, red, cyan lines), following HRH07. The blue triangles show data from the much shallower and less complete SDSS survey. The top-left panel shows the luminosity function at $z = 2.4$. The other panels show the results at $z = 0.87, 2.40$, and $4.25$, after normalizing by a fiducial model to emphasize the model distinctions.
These data will also allow us to address the important question of the break luminosity ($L^*$) evolution itself, which is currently only weakly constrained. The dotted line in Figure 5 (left) is the estimate of the evolution of $L^*$ based on the combination of optical, IR, and X-ray surveys from HRH07, but is still poorly determined at high-$z$. While Fan et al. (2001) and Richards et al. (2006) find that the QLF slope flattens at high-$z$ (consistent with the popular cosmic downsizing scenarios), other work suggests that the slope might still be steep at $z \sim 6$ (Jiang et al. 2009; McGreer et al. 2012, in prep.); this discrepancy may simply reflect insufficient knowledge of the break luminosity at high-$z$. The SpIES data would allow a conclusive answer and would have a significant impact on our understanding on the growth of supermassive black holes and cosmic downsizing.

**The Highest Redshift Quasars:** At even higher redshifts ($z \sim 5$–9) the QLF is *wildly* uncertain (Fig. 6, left); one of the goals of SpIES is to measure it properly, directly probing the formation and evolution of the earliest supermassive black holes. The single IR-selected $z > 6$ quasar (Stern et al. 2007) suggests SpIES will discover $\sim 0.1$–84 $z > 6$ quasars (a huge uncertainty), and the Willott et al. (2010) results give $\sim 10$ at $6.5 < z < 7.5$. An area on order of 200 deg$^2$ is needed to pin down the $z > 6$ QLF as Jiang et al. (2008, 2009) predict $\sim 30$ quasars at $6 < z < 7$, and $\sim 1$–2 objects at $z > 8$ in SpIES, while the Hopkins et al. (2007a) model predicts several hundred $z > 5$ quasars in SpIES but only 1–3 at $z > 7$; see Figure 6.

These very high-$z$ quasars will be selected as optical and NIR ($i$ and $z$) dropouts, and will be separated from cool L, T and Y dwarf candidates based on a combination of their blue $J$–[3.6] and red [3.6]–[4.5] colors and/or lack of proper motions (Lang et al. 2008). These objects will provide ideal targets for deep NIR spectroscopy both from the ground and using JWST (e.g., Fan 2009) to study the history of reionization and metal enrichment.

**Obscured Quasars:** Until now our discussion has focused on unobscured (Type 1 AGNs); however, the majority of the AGN in the universe are optically obscured (e.g., Treister et al. 2004; Brandt & Hasinger 2005; Daddi et al. 2007; Reyes et al. 2008; Treister et al. 2009). This means that most black hole growth occurs in systems that look like inactive galaxies to optical surveys. This population must be discovered at infrared and/or X-ray wavelengths; such surveys are essential to an accurate census of cosmic black hole growth, as well as to understanding the role of AGN feedback in galaxy evolution. Only a few dozen obscured quasars are currently known at the peak of quasar activity at $z \sim 2$. Existing methods for selecting obscured quasars at these redshifts from IR data are limited by their optical faintness. The SpIES depths in the IRAC and SDSS bands are well-matched to the SEDs of obscured quasars (Fig. 2). The multi-color Bayesian algorithm mentioned above (Fig. 7, middle) is effective at selecting obscured quasars; we expect to detect more than 1000 $L_{\text{bol}} > 10^{45}$ erg/s type 2 quasars at redshifts $z < 1.5$ and more than 400 objects with $L_{\text{bol}} > 10^{45.5}$ erg/s at $1.5 < z < 2.0$. In short, SpIES will enable a many-fold increase over the number of all published $z \simeq 2$ obscured quasars, and will allow us to perform the same kinds of clustering and QLF analysis as describe above with this crucial population.
Figure 6: Left: Predictions of the cumulative number of quasars in the SpIES area for different high-redshift bins, following models from Hopkins et al. (2007a) and Jiang et al. (2009), which represent extrema in predictions for numbers of $z > 6$ quasars. They both involve extrapolations from existing data; their predictions at the SpIES depth are indicated with a vertical dashed line. Right: Volume within which SpIES, SWIRE and UKIDSS surveys can detect 1 Gyr Y dwarfs between 1 and 25 $M_{\text{Jup}}$. Sensitivity estimates are derived from synthetic photometry of Burrows et al. (2003) model spectra and 5σ detection limits at 2.3μm (UKIDSS) and 4.5μm (SpIES & SWIRE). Water, methane, and ammonia absorption shortward of 4.5μm makes SpIES 4.5μm imaging orders of magnitude more sensitive to Y dwarfs than the UKIDSS K band.

Figure 7: Left: Selection of AGNs based on MIR-only is biased against $3.5 < z < 5$ AGNs which are outside of the standard selection wedge (and degenerate with stars); red point are stars, blue/green are quasars, black are high-$z$ quasars. Middle: Distribution of point (blue) and extended (red) sources in IRAC (AB mag) and SDSS color space from SWIRE data. Green crosses are known type 1 quasars and open grey squares are known type 2 quasars. Using our multi-color Bayesian selection (Richards et al. 2009b), it is possible to select even those AGNs that are not outliers in this depiction. This combined MIR and optical selection is both less contaminated and more complete than the standard 2-D MIR-color wedges. T-dwarfs also have red $[3.6] - [4.5]$ colors, but can be distinguished from quasars using the deep optical photometry and astrometry in Stripe 82. Right: Relative fraction of known quasars matched to MIR data as a function of redshift. WISE data lacks the depth to reach the high-$z$ AGNs that SWIRE depth can; SpIES research SWIRE depth over a large contiguous area.
Selection & Photo-z’s: For our clustering and QLF science, we must be able to efficiently identify high-z quasars and determine accurate photometric redshifts for them. To this end we will rely on the Bayesian AGN selection algorithm developed by Richards et al. (2004,2009a) that is superior to traditional color cuts, taking advantage of not only colors but also the variability information uniquely afforded by Stripe 82 data (e.g., MacLeod et al. 2010). In short, both MIR-only and optical-only selection methods are very inefficient at the redshifts we require for our science. In our crucial redshift range $3.5 < z < 5$, MIR-only selection is hampered by the presence of Hα in Ch. 1, giving blue [3.6]-[4.5] colors degenerate with other objects (see Figure 7, left; Stern et al. 2007; Donley et al. 2008; Richards et al. 2009b) and optical-only selection has been shown to be biased towards those objects with Lyman limit absorption systems (Worseck & Prochaska 2011). However, by combining SWIRE-depth IRAC Channel 1 and Channel 2 data with deep optical data, these important objects can be cleanly selected (see Figure 7, middle; Richards et al. 2009b). Recently-taken IRAC pointings on 300 known $z > 2.2$ SDSS quasars (Fig. 3) provide the necessary training objects that enable us to find fainter high-z quasars in the full SpIES region (and existing SWIRE fields). The right-hand side of Figure 7 demonstrates that this science cannot be done with WISE-depth exposures: WISE data provide IR data primarily for $z < 2$ quasars with $i < 20$, whereas our targets have $z > 3$ and as faint as $i = 23.3$. Including obscured AGNs, we estimate that we will be able to select $> 1000$ AGN deg$^{-2}$ (as compared to 70 deg$^{-2}$ with WISE; Eisenhardt et al. 2011). The deep, seven-band SDSS+IRAC data enables accurate photometric redshifts of AGNs/quasars (e.g., Salvato et al. 2008; Richards et al. 2009b). Optical-only photometry gives photo-z’s accurate to $\Delta z \sim 0.3$, but in SpIES it will be $\Delta z \sim 0.1$ or better — more than adequate for our science goals.

B. Ancillary Science

While AGN science is the driver for this proposal, these data will also contribute significantly to CMB and cosmological investigations, as well as studies of the cool end of the stellar mass function.

CMB-related Science: Measurement of CMB fluctuations on scales smaller than probed by WMAP or Planck will lead to improved measurements of the primordial power spectrum index, constraints on the mass of the neutrino, and secondary effects due to the interaction of CMB photons with foreground objects, in particular gravitational lensing and the Sunyaev-Zel’dovich (1980; SZ) effect. ACT$^1$ (Swetz et al. 2011) is a millimeter telescope mapping the microwave sky at 148, 218, and 270 GHz (2.1, 1.4, and 1.1 mm) with $1' - 1.7'$ resolution, designed to address these scientific questions. ACT has already observed the entire SpIES region down to a noise level of 24 $\mu$K-arcmin and will begin releasing its maps in 2012.

The addition of of the SpIES IRAC observations will allow us to secure accurate photometric redshifts of galaxies and reliably select clusters at $z > 1$. Red galaxy SEDs peak at 3-5$\mu$m for $z > 1$, so clusters stand out particularly well in IRAC data. Through its observations of the SZ effect, ACT has already performed a cluster survey mass-limited to $1 \times 10^{15}$ $M_{\odot}$ (Marriage et al. 2010). Based on the noise levels in the 2010 maps, we predict of order 50 such clusters over the SpIES area with masses down to $5 \times 10^{14}$ $M_{\odot}$ and that $\sim 1/3$ of them will be at $z > 0.7$. SpIES observations will allow us to determine photometric redshifts and stellar masses for these clusters at all redshifts. Stacking of the more numerous lower-mass clusters selected from the IRAC data that are not individually detected in SZ will allow us to estimate the mass and pressure in these clusters (e.g., Hand et al. 2010). Furthermore, the

$^1$http://www.physics.princeton.edu/act/
cluster number density with redshift from this complete SZ+IRAC-selected massive cluster catalog will place strong constraints on $\sigma_8$ (e.g., Gladders et al. 2007; Vanderlinde et al. 2010) and modified gravity theories (Schaef er & Koyama 2008).

The galaxies in the IRAC data will have a median redshift of $\sim 1$ (Rowan-Robinson et al. 2008) and a surface density of $\sim 5 \times 10^4$ deg$^{-2}$. The large-scale structure traced by these galaxies provides the strongest contribution to the CMB gravitational lensing kernel; thus cross-correlating them with the ACT CMB signal will allow a $\sim 25\sigma$ measurement of the lensing of the CMB, much better than the $\sim 3\sigma$ detection of this effect by Smith et al. (2007). A massive neutrino species represents a relativistic, and therefore unclustered, form of dark matter, which would result in a weaker CMB lensing signal. Our planned combined measurement will be able to confirm or contradict the recent claims for sterile neutrinos masses of $\sim 1$ eV based on reactor and laboratory neutrino oscillation experiments (Mention et al. 2011).

Finally, ACT’s power spectrum measurement on small angular scales will be limited by confusion due to emission from foreground sub-mm galaxies (Das et al. 2010); these objects are not individually resolvable by ACT (Wang, Barger, & Cowie 2006), but will be detectable in the IRAC bands. Cross-correlating the SpIES catalogs with the ACT maps will reduce the contribution of the sources to the power spectrum by roughly an order of magnitude, see Figure 8. Removing this dominant source of confusion and systematic error will produce better constraints on the physics of inflation by measuring the running of the scalar spectral index and determine the duration of the epoch of reionization by detecting the Ostriker-Vishniac (1986) effect.

Figure 8: The angular auto and cross power spectra measured by ACT at 148GHz and 218GHz (Das et al. 2010), with the theoretical model for CMB, SZ, and point sources best-fit to the three spectra. The lensed CMB dominates at large scales, but falls exponentially due to Silk damping. The majority of power at $l > 3000$ (small scales) comes from extragalactic IR point sources (radio sources are sub-dominant). The infrared source emission, assumed to follow a power law, is dominated by Poisson power at small scale, but about 1/3 of the IR power at $l = 3000$ is attributed to clustered source emission. With SpIES we will be able to directly detect point sources, and thus subtract the Poisson power on small scales, thus measuring the small-scale CMB much more accurately. Even accounting for SED uncertainties from extrapolation, SpIES will significantly improve the subtraction of the foreground component. (From Dunkley et al. 2010).
SNe Hosts: Stripe 82 formed the basis for the SDSS-II Supernova Survey (Frieman et al. 2008) which resulted in over 500 spectroscopically-confirmed Type Ia supernovae (SNIa) and over 1500 photometrically classified SNIa (Sako et al. 2011). Recent research on SNIa indicates a strong correlation between their luminosity and host galaxy properties, which, if understood, would improve their effectiveness as standard candles in cosmology (Kelly et al. 2010; Lampeitl et al. 2010). The addition of IRAC mid-IR data for all the SDSS-II SN host galaxies would greatly improve the stellar population modeling of these galaxies (e.g., break degeneracies in the age and metallicities, stellar mass, and dust content of these host galaxies), allowing further exploration of correlations with the SN light curve data. Such work would greatly help the next generation of SN surveys (e.g., the Dark Energy Survey, which starts in late 2012, and will find thousands of SNIa for cosmology).

UV Luminous LBGs: The large SpIES survey area allows us to probe the most luminous end of the high redshift galaxies. In this field, we have selected a large sample of extreme UV luminous Lyman Break Galaxies (LBGs) \((L > 7L^*)\) at \(z \sim 3\). Our initial spectroscopic follow-up survey has revealed eleven highly UV luminous galaxies with \(r \sim 21-22.3\): more than 2 magnitudes brighter than typical LBGs in previous studies (Steidel et al. 2003). With \(L > 7L^*\) and star formation rate \((SFR) \sim 500 \text{M}_\odot \text{yr}^{-1}\), they are some of the rarest and most intensive star forming systems in the early Universe. The SpIES observations will allow us to improve our LBG selection to eliminate low redshift interlopers by using \(r-[3.6]\) and \([3.6] - [4.5]\) colors (Bian et al. 2012, in prep.). In the SpIES area, we expect to find about 50 highly UV luminous LBGs. The SpIES observations will probe the old stellar population to put a better constraint on the stellar mass of these galaxies. Combined with the SFR measured from dust corrected UV luminosity, we will be able to place these galaxies on the SFR vs. \(M_{\text{stellar}}\) plane (e.g. Daddi et al. 2007), and address key questions: What is the main mode of star formation in these ultra-luminous LBGs? What physical process triggers the extremely high star formation rate in these galaxies?

Brown Dwarfs and White Dwarfs: More locally, SpIES will measure mid-IR flux densities for the large number of well-characterized stars in Stripe 82 and enable the discovery of extremely faint, red objects. SpIES will provide 3.6 and 4.5\(\mu\)m flux densities for thousands of SDSS-selected white dwarfs, complementing the targeted Spitzer surveys of these objects (Farihi et al. 2008, 2010). These mid-IR observations will provide a test of the circumstellar accretion hypotheses for metal-rich white dwarfs, and assess the occurrence of brown dwarf companions to solar-mass stars. Furthermore, the SpIES 4.5\(\mu\)m imaging will be orders of magnitude more sensitive to Y dwarfs \((T < 500\text{K})\) than deep near-infrared surveys such as UKIDSS (Fig. 6, right), and SpIES covers a larger area, with extensive coverage at other wavelengths, than does SWIRE. Based on their Spitzer colors (Patten et al. 2006) and local dwarf density (Burgasser 2007; Metchev et al. 2008), SpIES should find \(\sim 400\) T dwarfs, including 30 late T dwarfs, and refine the substellar census, which currently includes \(\sim 450\) T dwarfs over the entire sky. The SpIES sample will (1) provide a measurement of the mass function and a potentially definitive measurement of the scale height of substellar objects, (2) yield kinematic information via their large proper motions, measured from the SDSS multi-epoch data (see Lang et al. 2008; Scholz et al. 2008), (3) find common-proper-motion faint companions to nearby main sequence stars and white dwarfs, and (4) provide the data to allow the selection of Y dwarfs.
1.2 Technical Plan

1.2.1 Observations

**Area/Depth:** Our solid angle requirement is driven by the need to accurately measure the quasar correlation function at high-\(z\) and on large scales, and to obtain a statistically significant sample of \(z > 3\) (and \(z > 5\)) quasars. As science productivity in a wide-angle survey is generally driven by the total number of objects detected, larger areas are favored over greater depth for sources like high-\(z\) quasars where the number counts rise slowly with depth. In a fixed amount of time the number of objects gained by going deeper does not make up for the area lost. In addition, we require sufficient depth to 1) measure the QLF below the break luminosity to \(z = 4\) (Fig 5), 2) cover sufficient dynamic range to determine the luminosity dependence of quasar clustering as a function of redshift (particularly \(z > 3\)), and 3) robustly identify AGNs at limits where optical data alone are highly contaminated. These requirements are met both by the depth of our SDSS imaging coadd (\(i = 23.3\)) and a SWIRE-like depth of 4.9\(\mu\)Jy at 3.6\(\mu\)m and \(\sim 7\mu\)Jy at 4.5\(\mu\)m (Figure 2).

In summary, to probe 1 dex fainter than \(L^*\) at \(z \sim 3\) and as faint as \(L^*\) at \(z \sim 4\) requires a magnitude limit \(i \sim 23.3\) (\(f_{4.5\mu m} \sim 7\mu Jy\)) and a volume of \(\sim 5\) Gpc\(^3\) (to have \(\sim 15\) quasars at \(M \sim -28\); Croom et al. 2009, Glikman et al. 2011); this volume out to \(z \sim 3\) corresponds to \(\sim 175\) deg\(^2\). Only with this depth and volume will SpIES have sufficient quasar numbers and dynamic range to accurately determine the high-luminosity QLF and clustering bias.

**Location:** SDSS Stripe 82 provides the best combination of existing, public, deep multi-wavelength data over the required area. Trimming out regions of high stellar density and optical extinction on Stripe 82, we cover the region \(320^\circ < \alpha < 40^\circ\), for \(-1.0^\circ < \delta < +1.0^\circ\). We also observe an additional \(\sim 15\) deg\(^2\) at \(\alpha \sim 330^\circ\) to cover the entire CFHTLS W4 field (\(\delta \sim +1\)). See the top panel of Figure 3 for a visual summary of our proposed coverage. The proposed contiguous area allows for maximum use of the large amount of existing ancillary data (§ 1.2.5). While this region crosses the ecliptic, contamination by asteroids is not a matter of significant concern: The proposed mapping strategy allows the identification of most asteroids by eliminating fast-moving objects. Furthermore, 50-80\% of the asteroids are expected to be identified with known objects.\(^2\) Finally, only about 0.2\% of the pixels are expected to be affected by asteroids on the ecliptic.

**Exposure Time:** Exposure times of less than 30s are inefficient in a large angle survey due to the appreciable overheads. At least two dithered exposures should be taken at each pointing position to account for pixel-to-pixel variations and allow cosmic ray rejection, and at least two epochs separated by a few hours are required to identify and reject asteroids as moving/“variable” objects. This suggests that the SWIRE large-area mapping strategy, namely two epochs at each pointing, with two dithered exposures of 30 seconds each, is the best for our survey.

For mapping to this depth (\(2 \times 2 \times 30 = 120s\)), the PET estimates 5\(\sigma\) depths of 4.9 and 7.2 \(\mu\)Jy in Channels 1 and 2, respectively, assuming a medium background (see below) and optimal point-source fitting. In practice, e.g., for the XFLS (Lacy et al. 2005), limits tend to be worse than this; however, with newer processing methods (e.g., Hora et al. 2008) and considering that most objects will be multiply detected at non-IRAC wavelengths, this estimate should be quite reasonable.

**Background:** At 3.6\(\mu\)m and 4.5\(\mu\)m the zodiacal background, even on the ecliptic, is a relatively minor issue. Our 5\(\sigma\) depth estimates above assumed nominal medium background

levels of 0.125 MJy/sr at 3.6μm and 0.366 MJy/sr at 4.5μm. The actual backgrounds over our survey area range between 0.09 and 0.23 MJy/sr at 3.6μm, yielding a S/N at 4.9μJy of 5.5–4.2 for point sources.

1.2.2 Scheduling Constraints

We are submitting a full set of AORs for this program. The scheduling constraints are tabulated below in a series of Stripe 82 observing windows, broken into three chunks. For each, we include the range of orientations, backgrounds and PSF S/N for Channel 1.

**Needs to be updated [Mark and Gordon]**

<table>
<thead>
<tr>
<th>Window</th>
<th>Orientation</th>
<th>Ch1Bkgrnd</th>
<th>Ch1SNR(@4.9μJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21h40m+0d Window</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011Jul08 - 2011Aug17</td>
<td>71-62</td>
<td>0.14-0.09</td>
<td>5.0-5.5</td>
</tr>
<tr>
<td>2011Dec20 - 2011Jan29</td>
<td>257-248</td>
<td>0.10-0.17</td>
<td>5.4-4.7</td>
</tr>
<tr>
<td>2012Jul15 - 2012Aug24</td>
<td>71-62</td>
<td>0.14-0.09</td>
<td>5.0-5.5</td>
</tr>
<tr>
<td>00h40m+0d Window</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011Aug20 - 2011Sep29</td>
<td>66-69</td>
<td>0.18-0.12</td>
<td>4.8-5.2</td>
</tr>
<tr>
<td>2012Feb02 - 2012Mar12</td>
<td>243-247</td>
<td>0.12-0.23</td>
<td>5.2-4.4</td>
</tr>
<tr>
<td>02h40m+0d Window</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011Sep19 - 2011Oct30</td>
<td>69-81</td>
<td>0.14-0.10</td>
<td>5.0-5.4</td>
</tr>
<tr>
<td>2012Mar01 - 2012Apr10</td>
<td>242-254</td>
<td>0.11-0.18</td>
<td>5.3-4.8</td>
</tr>
</tbody>
</table>

Apart from a ~ 7 week gap from 2011Oct30 to 2011Dec20, and a ~ 12 week gap from 2012Apr10–2012Jul15, Stripe 82 is visible continuously from July 2011 until the end of Cycle 8. At any epoch, about 1 hour of RA will be visible, so the ~ 12 weeks of total observing could be split into ~ 8 “mini campaigns” of about 1.5 weeks each. Further subdivision would allow for minimization of PA variation, so more fine-grained splitting could also be considered (e.g., 24 3.5-day campaigns).

Where the background is higher than average, we can follow the practice adopted by the S-COSMOS team of time-constraining our observations to the high solar elongation end of the visibility window to minimize the zodiacal background. We will cooperate with the schedulers to ensure our observations are taken optimally with minimal disruption to the overall telescope schedule. Should such a constraint prove to be too burdensome, it could be lifted without significant loss of data quality.

Each AOR duration is 24100s (6.7 hours). The area is covered with an 8 × 36 map with small cycling dither, 2x30s exposures per point and 280″ map offsets. Pairs of AORs, offset by 1/2 array spacing in row and column, are constrained using a “group within” constraint, requiring their execution within an 18 hour window (so the maximum “gap” is 18 – 2 × 6.7 = 4.6 hours, enough to slip in downlinks and calibrations, or small program AORs). The CFHTLS W4 requires additional AORs north of Stripe 82, which will use the same strategy as the main Stripe 82 AORs. The W4 AORs have durations of 4.9 hours each and are constrained to be executed within a 15 hour window. The total AOR durations are 1342 hours; we request another 8 hours for contingency, making our total request 1350hr.
1.2.3 Data Analysis Plan

We will follow the data reduction procedures developed for and tested on the XFLS (e.g., Lacy et al. 2005), SWIRE (e.g., Surace et al. 2005), and SERVS data sets; see also Hora et al. (2008). As with those surveys, the images will first be pre-processed at the SSC using the IRAC pipeline, which produces the Basic Calibrated Data (BCD) and the corresponding DCE masks. These images will have been corrected for dark current, linearity, flatness, and some image artifacts. In addition to the SSC’s pipeline products, which have been constantly improving, we will use tools developed for the XFLS and SWIRE to fix other data artifacts (e.g., muxstriping), following procedures similar to those detailed in Lacy et al. (2005).

Images will be produced in $2 \times 2 \text{deg}^2$ tiles with $2 \times$ oversampling of the native pixel scale, making them large but manageable. Image generation will be handled by a postdoc to be hired that will work under the guidance of PI Richards and Co-I Lacy (who is one of the world experts in this processing). At Drexel, Richards’ group will use these tiles to produce initial catalogs using both APEX and SExtractor (Bertin & Arnouts 1996). With large Beowulf and GPU clusters, Drexel’s facilities are more than adequate for this task. Scanning through the ecliptic will require extra care dealing with asteroids (e.g., Ryan et al. 2009). We will mask out regions of known/suspected asteroids ($\sim 0.2\%$ of pixels) before creating the catalogs. Co-I Ryan will consult in this effort (and lead the asteroid science effort with our serendipitous detections). The Drexel team will band-merge the IRAC catalogs with data at other wavebands and incorporate the results into the SDSS and NVO database frameworks.

We estimate the data volume to be 27Gb of imaging (44 tiles of 4 deg$^2$ at 580Mb each) and 2.5Gb of catalogs (about 50,000 sources deg$^{-2}$ at 256 bytes per object). Our planned delivery schedule is as follows:

Observations begin: August 2012
Observations end: September 2013
Prelim. delivery of sample data: August 2013
Delivery of final images: March 2014
Delivery of single-band catalogues: July 2014
Delivery of final band-merged IRAC/UKIDSS/SDSS/etc. catalogs: January 2015

The distribution of IRAC data and catalogs will follow a path similar to that of the Legacy surveys. We will deliver final images and band-merged IRAC catalogs to IRSA’s Spitzer Legacy repository, and to the SSC directly. The first data will be made public in mid-2013. All of the primary ancillary data sets (SDSS, UKIDSS, GALEX) are already public. We have allowed for some extra time in the schedule to produce final multi-wavelength band-merged catalogs.

Band-merged object catalogs will be made available in a VO-compliant format. Szalay’s group at JHU and the Drexel team will provide support for this work and for integrating the data into the SDSS database. While the dataset is quite large by Spitzer standards, it is small compared with the total SDSS dataset. Users will be able to access the data through either the SDSS or NVO web interfaces. In summary, PI Richards will lead the overall processing, with Co-I Lacy leading the initial data reduction and Co-I’s Strauss, Lupton, Szalay, and Spergel also playing key roles in data processing and distribution. Overall, this team has an excellent track record for timely public data releases.
1.2.4 Feasibility

Existing observations support the general technical feasibility of our proposed project. SWIRE has demonstrated the photometric depths that our proposed exposures will achieve, and has shown that confusion is not an issue at these limits. The XFLS, SWIRE, Boötes, and SERVS mapping have demonstrated that covering large areas, while challenging, is quite feasible. We are adopting the proven SWIRE mapping strategy of dithering and half-array offsets to minimize problems due to detector artifacts and asteroids. The visibility of our fields has been considered in detail and is supported by the full set of AORs (rather than generic examples that are allowed) that we have submitted with this proposal. Indeed, Co-I Mark Lacy, an IRAC science team member, has been integral to many of these issues at the SSC and has led the feasibility checking of the technical aspects of this proposal.

1.2.5 Provenance/Availability

Here we summarize the availability of the ancillary data in our proposed field (Fig. 3).

- SDSS multi-epoch $ugriz$ imaging over $300 \text{deg}^2$ to $g \sim 24$; all data public
- CFHT imaging in $160 \text{deg}^2$ of the SpIES region to $i = 23.5$ at 0.6" resolution
- SDSS-III imaging over contiguous $2000 \text{deg}^2$ centered on Stripe82
- UKIDSS $Y, J, H, K$ imaging to $K_{\text{AB}} = 20$; DR8 public
- VICS82 (VISTA-CFHT Stripe 82 survey) to $J = 22.4, K_{\text{s}} = 22$ (AB)
- Deep optical/NIR imaging over 1-10 $\text{deg}^2$: CFHTLS W4, VVDS 22hr and UKIDSS DXS
- ACT to 25$\mu$K-arcmin in the 2 mm band; ACTPOL data starting in Fall 2012
- 3$\times$ FIRST depth VLA data at 20 cm over $\sim 90 \text{deg}^2$ (Hodge et al. 2011)
- GALEX two-band UV to 2$\times$ MIS depth ($m_{\text{AB}} \sim 23.75$)
- XMM observations over $5 \text{deg}^2$ (PI: Meg Urry)
- SDSS spectroscopy of galaxies, stars, quasars over $300 \text{deg}^2$; all public.
- SDSS+2dF spectra of $z < 3$ quasars to $g = 21.85$ and LRGs to $i = 19.8$ over $190 \text{deg}^2$
- SDSS-III spectra of $z \sim 3$ quasars to $g = 22$ and LRGs to $i = 19.8$
- Wiggle-Z spectra (400 $\text{deg}^{-2}$) over $\sim 70 \text{deg}^2$; plus VVDS and DEEP2 spectra

On a longer timescale, additional surveys (Pan-STARRS, LSST, the Dark Energy Survey, the VISTA Hemisphere Survey, Subaru Hyper-Suprime Cam) will also be covering Stripe 82.
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Marriage, T., et al. 2010, arXiv1010.1065
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GTR: With the figures now embedded, this line must appear no later than the bottom of Page 14!!
In addition to the Science Plan, the following sections are required and have specified page limits:

2 Scheduling Profile of the Proposed Program

Mark and Gordon to update

SDSS Stripe 82 is a $120^\circ \times 2.5^\circ$ field along the Celestial Equator. The length of the field means that some part of it is nearly always visible to Spitzer. For the area that we propose to cover ($-40^\circ < \text{RA} < 40^\circ$), our field is visible continuously in Cycle 9 apart from an $\sim 7$ week gap in the Fall of 2011 and an $\sim 12$ week gap in the Spring of 2012. At any epoch, about 1 hour of RA will be visible. The $\sim$12 weeks of total observing could be split into $\sim$8 “mini campaigns” of $\sim$1.5 weeks each. Further subdivision could allow for minimization of PA variation (e.g., 24 3.5-day campaigns). The field is visible a factor of 2.6 times more than is needed to complete the observations, so scheduling should not be a significant issue.

Below we note the windows during which 3 blocks of Stripe 82 are observable during the course of the warm mission.

21h40m+0d Window
2011Jul08 - 2011Aug17
2011Dec20 - 2011Jan29
2012Jul15 - 2012Aug24

00h40m+0d Window
2011Aug20 - 2011Sep29
2012Feb02 - 2012Mar12

02h40m+0d Window
2011Sep19 - 2011Oct30
2012Mar01 - 2012Apr10

3 Brief Team Resume

PI: Gordon Richards (Assoc. Prof. of Physics, Drexel University; PhD Univ. of Chicago 2000); Alfred P. Sloan Research Fellowship (2007); multiwavelength quasar expert; co-deputy chair of the SDSS Quasar Working Group; PI of 4 Spitzer projects

Co-I: Mark Lacy (Scientist, NRAO; PhD, Cambridge 1993); former Spitzer Archive Scientist at the SSC. Interests include distant galaxies and dust obscured AGN/QSOs.

Co-I: David Spergel (Princeton; Chair of Dept. of Astrophysical Sciences); member of the ACT and WMAP teams; author of the most cited paper in ADS

Co-I: Michael Strauss (Professor, Princeton University; PhD Berkeley 1989); SDSS-III Survey Science Coordinator; author of papers on AGN demographics, type 2 quasars, brown dwarfs, and large-scale structure

Co-I: Scott Anderson (Professor and Chair, Astronomy Department, University of Washington; PhD Washington 1985); multiwavelength surveys and quasar studies.

Co-I: Niel Brandt (Professor, Penn State; PhD Cambridge 1996); extensive studies of active galaxies and extragalactic surveys at X-ray and other wavelengths; chair LSST AGN Science Collaboration
Co-I: Xiaohui Fan (Professor, Univ. of Arizona; PhD Princeton, 2000); expert on high-z quasars, cosmic reionization and brown dwarfs; co-deputy chair of the SDSS quasar working group; leads team that has discovered the majority of $z > 5$ quasars

Co-I: Karl Forster: (Caltech, GALEX SOC team lead; PhD Columbia 1998); member of the GALEX science team, AGN astrophysics.

Co-I: Eilat Glikman (NSF Postdoctoral Fellow, Yale University) dust-reddened quasars, quasar/galaxy co-evolution driven by galaxy mergers, quasar luminosity functions and low-luminosity quasars at $z \sim 4$.

Co-I: Philip Hopkins (Miller Fellow, UC Berkeley; PhD Harvard 2008); modeling and numerical simulations of galaxy formation, black hole growth, and AGN feedback

Co-I: Jack Hughes (Professor, Rutgers University); CMB, clusters, SNe

Co-I: Linhua Jiang (Postdoc, Arizona; PhD Arizona 2008); high-z QSOs and galaxies.

Co-I: Gillian Knapp (Professor, Princeton University): leader of SDSS photometric and spectroscopic pipeline development: papers on SDSS brown and white dwarfs.

Co-I: Jean-Paul Kneib (Research Scientist, Laboratoire d’Astrophysique de Marseille Observatoire Astronomique de Marseille-Provence); PI of CFHT imaging program on S82

Co-I: Yen-Ting Lin (Asst. Research Fellow, ASIAA, Taiwan; PhD Illinois 2005); galaxy formation and evolution, galaxy clusters, radio galaxies, VICS82 Co-PI

Co-I: Robert Lupton (Princeton University): Software/algorithms guru for SDSS, ACT, and LSST.

Co-I: Martin Makler (Assoc. Researcher, Brazilian Center for Physics Research; PhD CBPF 2001); PI of CFHT optical and IR programs on S82 (VICS82), co-coordinator of the DES Strong Lensing Working Group, [PI of SOAR Gravitational Arc Survey/SOGRAS, which imaged 50 cluster fields on S82]

Co-I: Peregrine McGehee (Staff Scientist, IPAC; PhD NMSU 2005); Planck Early Release Compact Source Catalog Lead; interstellar medium and galactic star formation.

Co-I: Felipe Menanteau (Research Scientist, Rutgers University; PhD Cambridge 2000); observational cosmology, SZ surveys, clusters of galaxies, formation and evolution of elliptical galaxies

Co-I: Adam Myers (Asst. Professor, Wyoming; PhD Durham 2004); pioneering work on clustering of photometric quasars; SDSS-III/BOSS Architect and External Participant

Co-I: Donald Schneider (Professor, Penn State); Extensive experience in quasar surveys; Chair of SDSS Quasar Working Group; SDSS-III Survey Coordinator; HET Scientist

Co-I J. Allyn Smith (Assoc. Prof., Interim Chair Physics & Astronomy Dept. Austin Peay State Univ.; PhD Florida Tech 1997); cool white dwarfs; survey calibration

Co-I: Alex Szalay (Professor, JHU); database guru; NVO Co-PI

Co-I: C. Megan Urry (Prof., Chair, Physics Dept., Yale University); actively accreting supermassive black holes, the co-evolution of AGNs with normal galaxies; PI of XMM Survey on Stripe 82

Co-Is: Steve Warren (Professor, Imperial College London); Paul Hewett (Professor, IoA, Cambridge); Richard McMahon (Reader, IoA, Cambridge); UKIDSS Survey Scientist and collaborators, bringing significant NIR expertise in addition to being AGN experts

Co-I: Nadia Zakamska (Asst. Prof. JHU; PhD Princeton 2005; *Spitzer* Fellow 2005-08); selection and multi-wavelength properties of type 2 quasars; AGN demographics

• Anderson, S. F. et al. 2007, “A Large, Uniform Sample of X-ray Emitting AGN from the ROSAT All-Sky and SDSS-DR5 Sample”, AJ, 133, 313
• Lacy, M. et al. 2007, “Optical Spectroscopy and X-ray Detections of Quasars/AGNs Selected in the Mid-IR from Two Spitzer Wide Area Surveys”, AJ, 133, 186
• Richards, G. T., et al. 2009a, “Efficient Photometric Selection of Quasars from the SDSS: II. 1,000,000 Quasars from DR6”, ApJS, 180, 67

4 Summary of Existing Programs

PI G. Richards is also PI of AR-1 program #3284, AR-3 program #30347, GO-5 program #50087, and GO-6 program #60139. The cycle-1 program sought to construct mean optical+IR quasar SEDs for SDSS quasars with public Spitzer-IRAC photometry. The analysis has been completed and published (Richards, Lacy, et al. 2006, ApJS, 166, 470). This paper has already been cited 182 times and is proving to be quite useful for planning of AGN-related Spitzer proposals. Results from the cycle 3 program were published as Richards et al. 2009, AJ, 137, 3884 and have been cited extensively herein. The cycle 5 program results have been presented in Deo et al. 2011, (ApJ, 729, 108, arXiv:1101.2855). The cycle 6 program data (on Stripe 82) have been fully processed and are included for public consumption in a paper recently submitted to ApJS (Krawczyk et al. 2012); we are using it to optimize the selection algorithms discussed herein.

Co-I M. Lacy is PI of the SERVS Exploration Science proposal, and is PI or technical contact on 13 other Spitzer proposals, resulting in four publications to date, with another paper in preparation. Data taking for SERVS is nearly complete, and four papers have

Co-I S. Anderson is a co-I on Spitzer programs #3221, #3284, and #30476. Publications for#3221 (PI: Fan) and #3284 (PI: Richards) are detailed in this section under entries for X. Fan and G. Richards, respectively. Initial results for #30476 (PI: Shemmer) appear as Lane et al. 2010, BAAS, 42, 372 (“The Optical to Mid-Infrared Spectral Energy distributions of Weak-Emission Line Quasars”; also, paper in prep).

Co-I W. N. Brandt; is a Co-I on 2 previous Spitzer proposals. Cycle-2 archival grant (PI: Steffen) was published as “Revealing the unresolved hard cosmic X-ray background using Spitzer”. Cycle-3 observing proposal (PI: Shemmer) was published as “Lineless quasars at high redshift: BL Lacs or a new class of unbeamed quasars?”.

Co-I X. Fan is the PI on five Spitzer projects in previous cycles and Co-I on another seven about quasars and brown dwarfs; GO-3198 (PI): all data analyzed and published in Jiang et al. (2007); GO-30402 (PI), GO-40356 (PI), GO-50390 (PI): all data from these programs analyzed and published in Jiang et al. (2010, Nature) and featured as a SSC press release. GO- 3221(PI): all data analyzed and published in Diamond-Stanic et al. (2009) and in Lane et al. (2011).

Co-I L. Jiang is PI of GO-70094 (no data taken yet) and TC of another three GO programs 30402, 40356, and 50681 (programs completed, two papers published).

Co-I G. Knapp is a member of the Spitzer-Taurus Legacy Survey Team, PI D.L. Padgett Co-I M. Strauss; GO-3163 (PI; Zakamska, Co-I) “Mid- and Far-Infrared Spectral Energy Distribution of type II Quasars from the Sloan Digital Sky Survey” . All Spitzer data reduced and analyzed. Supporting ground-based data obtained, reduced and analyzed. Results published in Zakamska et al. 2008, AJ, 136, 1607 and additional pub. in prep.


The following sections are required but do NOT have page limits.

5 Observation Summary Table

Our Spitzer-IRAC observations will tile 175 deg² along the celestial Equator (SDSS Stripe 82) bounded by $-40^\circ < RA < 40^\circ$ ($21^h40^m < RA < 2^h40^m$) over $-1.0^\circ < \text{Dec} < 1.0^\circ$. We include the area covered by the part of the CFHTLS W4 field that extends out of SDSS Stripe 82. See the top panel of Figure 3 for a visual description of the proposed area. We will use half-array offsets between two epochs, with two observations at each epoch for an integration time of 120s, yielding flux density limits of $\sim4.9$ and 7.2 $\mu$Jy in channels 1 and 2, respectively.
<table>
<thead>
<tr>
<th>Target Field</th>
<th>Position (J2000)</th>
<th>Flux Density</th>
<th>AOT/Int.</th>
<th>AOR Duration</th>
<th># of AORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stripe 82</td>
<td>21:20:00−01:00:00 to 02:40:00+01:00:00</td>
<td>4.25 µJy</td>
<td>IRAC 120</td>
<td>24063</td>
<td>238</td>
</tr>
<tr>
<td>CFHT W4</td>
<td>22:13:18 +01:19:00</td>
<td>4.25 µJy</td>
<td>IRAC 120</td>
<td>17433</td>
<td>26</td>
</tr>
</tbody>
</table>

There are \(~1342\) hours total in IRAC AORs and we are requesting a total of 1350 hours in order to account for scheduling inefficiencies.

6 Modification of the Proprietary Period

Consistent with the spirit of the Legacy programs in previous cycles, we waive the proprietary period.

7 Summary of Duplicate Observations

Some IRAC observations do exist in our region (e.g., \(~300\) pointings on known high-\(z\) quasars) and thus there will be some duplication. However, they are much smaller than our map sizes, so working around them will be inefficient and discrepant exposure times would pose problems for streamlining the data reduction process. Thus, it is generally better for the mapping strategy to perform the duplicate observations rather than trying to account for the small area of existing data. This is true both in terms of observing strategy and also data reduction (where imaging small areas to a different depth would complicate the reduction pipelines). However, we will work with the schedulers to minimize unnecessary overlap.

8 Summary of Scheduling Constraints/ToOs

Imposing some constraints to minimize zodiacal background (as done by the S-COSMOS team) is desirable and should be possible with minimal disruption of the overall telescope schedule.

AORs are paired with “group within” constraints with 18hr windows to ensure the first epoch follows fairly closely on the second.

There are no ToOs.