GEMINI OBSERVATORY

observing time request summary

Semester: 2012A | **Observing Mode:** queue | **UK Reference:** G/2011A/073

Instruments: GNIRS | **Time Awarded:** | **Gemini Reference:**

Thesis:
no

Band 3 Acceptable:
Yes

Title: **Physical properties of star-forming high-z galaxies discovered in the Herschel Astrophysical Terahertz Survey (H-ATLAS)**

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Loretta Dunne: University of Nottingham,
Steve Eales: University of Cardiff,
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Partner Submission Details *(multiple entries for joint proposals)*

				NTAC			
Partner	**Partner Lead Scientist**	**Time Requested**	**Minimum Time Requested**	**Reference Number**	**Reco-mmended Time**	**Minimum Time Reco-mmended**	**Rank**
Canada	Scott	4.0 hours	2.0 hours		0.0	0.0	
UK	Verma	10.0 hours	6.2 hours	G/2011A/073	0.0	0.0	
USA	Bussman	7.0 hours	3.0 hours		0.0	0.0	
	Total Time	*21.0 hours*					

Abstract *(199 words)*

We propose GNIRS spectroscopy of bright sub-mm galaxies (SMGs) discovered in the H-ATLAS survey that have been spectroscopically confirmed to lie at high-redshift and are strongly-lensed (5-30x) by a foreground galaxy. Luminous infrared galaxies are thought to dominate the z>1-2 galaxy population, and thus determining the physical properties of SMGs is important to obtain a complete picture of the extragalactic population at this

critical epoch where the star-formation and quasar activity are seen to peak. The amplification due to lensing allows us to probe typical SMGs at high-z that would otherwise be too faint to be studied in the NIR with current facilities. We have in hand a wealth ofmulti-wavelength follow-up on these sources including deep imaging (accurate positions and estimtes of the stellar masses) and measurements of CO transitions in the millimetre (redshifts and molecular gas masses)., but rest-frame optical spectra (that provide key diagnositcs of the physical properties) are currently lacking. The spectra will contain the nebular emission lines of H-alpha, Hbeta, [O II] and [O III] from which we will derive the rest-frame optical extinction, star-formation rates, masses, metallicities allowing us to characterise the properties of the SMGs and compare them to ostensibly related high-z populations.

Science Justification *(995 words)*

Sub-mm surveys have revealed a population of dust-obscured, high-z galaxies forming stars at a prodigious rate residing at an epoch when the bulk of the stellar mass in the Universe was formed. Sub-mm galaxies (SMGs) are thought to pin-point the most massive dark matter halos and may be the progenitors of massive elliptical galaxies seen at the present-day. Thus identifying and determining the nature of these galaxies provides strong constraints on the formation and early evolution of massive galaxies. The number-density of (U)LIRGs/SMGs is seen to sharply increase to z~1-2 [1] coinciding with the epoch where both star-formation and AGN activity in the Universe are prolific [2,3]. In order to obtain a complete understanding of the extragalactic population at this epoch, studies of SMGs must be placed on an equal footing with UV/optically selected galaxies.

Recently, studies of high-z galaxies in the "redshift desert" have dramatially improved out understanding of galaxy evolution [4-14] particularly in the near-infrared where bright UV and visible emission line tracers of star-forming regions are redshifted and where adaptive optics can deliver (near-)diffraction limited performance. These studies have constrained the properties of high-z galaxies including dynamical masses and metallicities, showing a diversity of kinematic signatures from mergers to ordered rotation and dispersion-dominated systems. These studies are focussed on z~2 galaxies selected by their rest-frame UV optical emission. Few SMGs have been similarly studied in as much detail [4,14,15,16] due to their faintness in the rest-frame optical therefore most SMGs would be missed by standard optical/UV selection techniques

Our recent demonstration that it is possible to efficiently select gravitationally lensed SMGs efficiently from wide area sub-mm surveys with Herschel (Negrello et al. [17]) has alleviated this imbalance. The amplification due to lensing allows fainter galaxies to be studied than would be normally possible in reasonable observing times and the magnification allows smaller scales within the SMGs to be resolved. Thus our unique sample of lensed SMGs are detectable with current 8m facilities in the near-infrared. Lensed SMGs are typical star-forming dusty galaxies with ULIRG like luminosities when corrected for the amplification due to lensing. Thus they are an ideal comparative sample of dusty galaxies to the z~2 galaxies selected solely on the basis of their optical/UV emission.

Our sample is derived from the Herschel Astrophysical Terahertz Large Area Survey (H-ATLAS), the shallowest but widest area extragalactic survey that is being carried out by Herschel as an Open Time Key Project [18]. By its completion, H-ATLAS will have mapped ~550 square degrees split over five independent fields at 110, 170, 250, 350 and 500um, down to a 5sigma detection limit of a few tens of mJy. Because of its areal coverage, H-ATLAS has the capacity to detect hundreds of thousands of galaxies well above the source confusion limit. This wide area naturally lends itself to the study of bright, extreme and rare objects including high-z galaxies that have had their flux boosted through strong gravitational lensing by a foreground source.

We have discovered >100 sources that are plausibly lensed and at high-z in H-ATLAS. These targets are subject to ongoing follow-up at various facilities, including spectroscopic confirmation from millimetre "z-machines" detecting multiple CO emission lines. These galaxies are lensed by a lower-z (z<0.9) foreground mass with predicted lensing magnification >~6-30 [17,19,20]. The lower-redshift foreground galaxies have 'red & dead' optical-NIR SEDs that cannot be reconciled with such strong FIR-mm emission. High resolution continuum and CO line millimetre interferometry follow-up show strcuture that is consistent with lensed images of the background SMG. The large sample of H-ATLAS lensed SMGs provides a target-pool with which a statistically significant study of the properties of SMGs can be made.

Thus, we propose to observe the strong nebular emission lines of [OII]3727, [OIII]5007 and Halpha+NII and HBeta in strongly-lensed galaxies with GNIRS in cross-dispersed mode. These emission lines will clearly standout against the continuum and absorption line dominated spectrum of the foreground lensing elliptical galaxy. Our proposed spectroscopy is designed to detect the emission lines with high-significance and does not need to reach the rest-frame UV/optical continuum of the lensed SMGs as this is already in-hand from our follow-up imaging (HST, Keck, VLT and Sptizer). From these ancillary data, we can derive the stellar ages and masses, as well as molecular gas masses and the associated dynamical mass from our extensive mm follow-up. The gas fractions will provide constraints on the evolutionary state of the SMGs. The proposed obervations will allow us to characterise key properties of SMGs and compare them to other ostensibly related poopulations at similar redshifts.

Specifically our goals are to determine:

Extinction: Using the ratio of Halpha and Hbeta to determine the Balmer derement & rest-frame optical extinction;

correct the line and continuum fluxes and derive extinction corrected star-formation rates and stellar masses and metallicities; use corrected SFRs and moelcular gas mass from our CO observations to derive star-formation efficiencies and compare to other high-z galaxies [4,5,13]

Dynamics: Using the derived line widths we will search for signatures of ordered rotation, dispersion-dominated systems and mergers; derive rotation curves (where appropriate) and determine dynamical masses; search for disk instabilities arising from high SFRs in systems with regular dynamics; compare these to the derived kinematics of the molecular gas

Metallicity: We will derive gas phase metallicities using the standard N2 and R23 estimators [21]. Combined with the mass estimates, we will be able to place these galaxies on the mass-metallicity relation that has been recently investigated by several authors [e.g. 4,21-23].

Excitation & Outflows: use nebular excitation diagnostics to determine whether the gas is predominantly starburst or AGN heated (e.g. BPT diagram [24]) ; search for kinematically- and spatially-broad [OIII] or Ha emission (outflow) or high-velocity gas close to an AGN if compact; if evident derive energetics of the outflow and determine if of SF or AGN origin [25]

Exisiting spectroscopic studies of SMGs have already demonstrated that SMGs properties can be determined using the rest-frame optical emission lines even in the presence of dust [13-16].

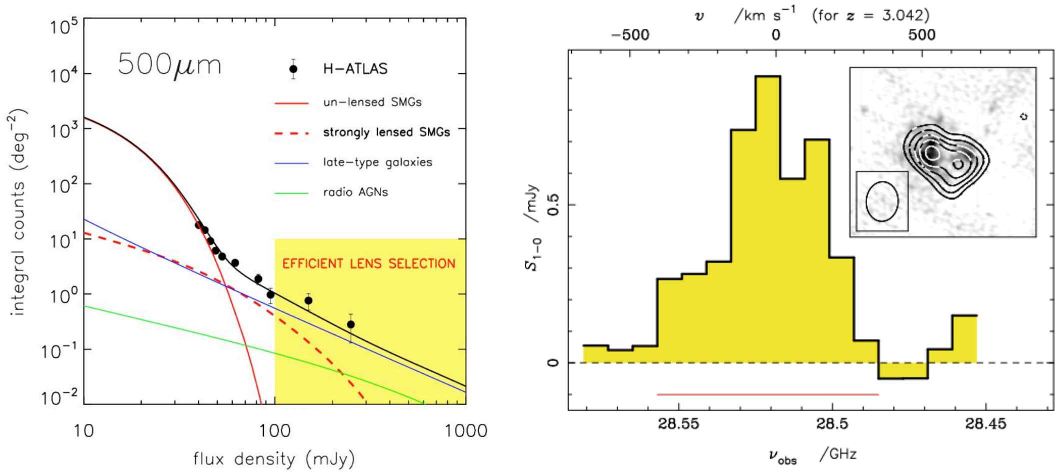

Figure1: *Left*: Predicted number counts of 250μm sources as a function of galaxy type [2]. The yellow box highlights the flux above which strongly lensed sources will be a major contributor to the bright sub-mm number counts, and unlensed SMGs are rare. Low-z late-type galaxies, and canonical radio sources are easily removed using out comprehensive multi-wavelength data sets. *Right*: EVLA observations of the ^{12}CO $J = 1 - 0$ line emission in SDP.81 taken from Valtchanov et al. MNRAS subm. The inset is an overlay f the 880μm continuum image of SDp.81 taken at the SMA [N10] with contours from the EVLA CO(1-0) emission integrated over -400 to 350 km/s. This source was originally confirmed using multiple CO lines using Z-Spec at the CSO with multiple CO lines detected (CO(7-6), CO(8-7), CO(9-8)) by Lupu et al. [11] and then subsequently confirmed with other facilities, as has been done for most of our lensed SMGs.

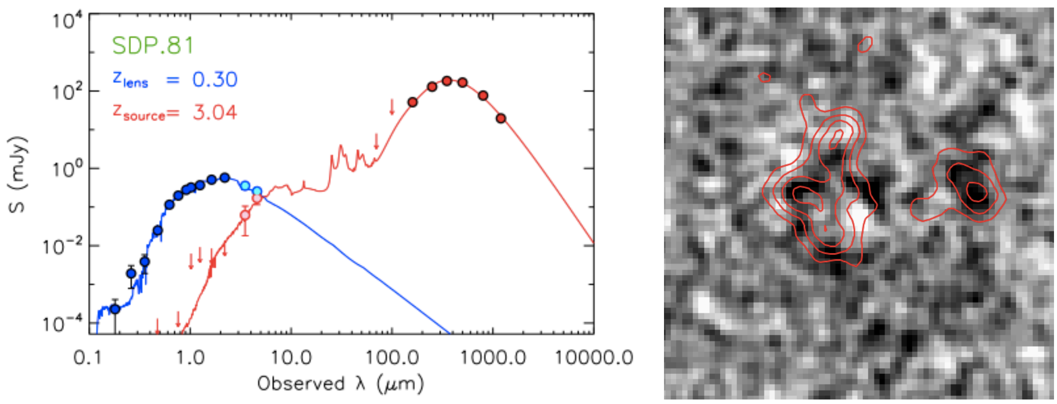

Figure 2: *Left* Spectral energy distribution derived for SDP.81. The Spitzer IRAC data has allowed emission fro the lensed background SMG to be decoupled form the emission of the foreground lens (Hopwood et al. 2010, [13]). *Right* A tentative detection of the observed frame K-band light from the high-z SMG. The foreground lens has been removed based on the mode used by Hopwood et al. (The image is best seen printed out). There is an excess of emission that matches the extent of the SMA emission very well (red contours, [2]). Emission lines from this source will be detectable to the depths requested in this survey.

REFERENCES:

[1] Magnelli et al. 09, A&A 518 L28 [2] Hopkins & Beacom 06, ApJ 651 142 [3] Wall et al. 05, A&A 434 133 [4] Förster Schreiber N., 2009, ApJ, 706, 1364 [5] Gnerucci et al. 2011, A&A, 528, 88 [6] Jones et al. 2010, MNRAS, 404, 1247 [7] Genzel et al. 2006, Nature, 442, 786 [8] Epinat et al. 2009, A&A, 504, 789 [9] Lemoine-Busserolle et al. 2010, MNRAS, 402, 229 [10] Law et al. 2009, ApJ, 697, 2057 [11] F?orster Schreiber et al. 2006, ApJ, 645, 1062 [12] Nesvadba et al. 2007, ApJ, 657, 725 [13] Tacconi L., et al., 2010, Nature, 463, 781 [14] Tecza M., et al. 2004, ApJ, 605, L109 [15] Swinbank, A.M, et al. 2006, ApJ, 371, 465 [16] Takata, et al. 2006, ApJ, 651, 713 [17] Negrello M., et al. 2010, Science, 330, 800 [18] Eales S., 2010, PASP, 122, 499 [19] Lupu R., et al. 2010, arXiv:1009.5983 [20] Frayer D., et al.2010, ApJ,762, L22 [21] Kewley L., et al. 2010, ApJ, 721, L48 [22] Law D., 2009, ApJ, 697, 2057 [23] Jones T., 2010, ApJ, 404, 1247 [24] Baldwin et al. 1981, PASP, 93, 5 [25] Alexander, D., et al. 2010, MNRAS, 402, 2211 [26] Swinbank A.M., et al.2004, ApJ, 617, 64 [27] Valtchanov, I, et al. 2011, MNRAS, 415, 3473

Technical Justification *(759 words)*

We propose GNIRS-XD spectroscopy of strongly-lensed SMGs selected from the H-ATLAS survey. All of the lenses have or will have high resolution millimetre imaging measurements (SMA or IRAM/PdBI) as well as imaging with HST (ongoing), Keck and VLT imaging. Each of these galaxies hasbeen spectroscopically confirmed to lie at high redshift through CO-line measurements with facilities such as the GBT and ZSpec. We propose to observe the redshifted optical lines of [OII]3727. [OIII]5007 and Halpha+NII. We have confirmed that these lines will lie in relatively OH-line free regions of the K-band.

The Ha survey of SMGs conducted by Swinbank et al. [26] showed that typical Ha derived star-formation rates of SMGs are typically 10x fainter than is suggested by the FIR luminosity. We use the median L(Ha)/L(FIR) ratio (~0.03%) for the SMGs detected by Swinbank to estimate our Ha fluxes. The HATLAS lensed SMGs have L(FIR)~>2e13 Lsol, at the redshift of our targets this gives a predicted integrated Halpha flux of 3e-19 W/m2.

We will use the widest slit (1") aligned to the distribution of the lensed images determined by our opt-MIR imaging data in-hand (HST, VLT and Spitzer) and ground-based millimetre follow-up (SMA, PdBI) . We choose to observe in cross-dispersed mode to obtain measurements of as many redshifted nebular lines as possible. Our sensitivity estimates are driven to detect Halpha with good SNR~13 (FWHM=350km/s at 2.2um). This SNR corresponds to the peak of the emission line, the integrated line flux will be closer to SNR~20. The proposed depth will also allow us to reach lines as faint as 3e-20 W/m2 with SNR~3. This depth is sufficient to observe OII and OIII that are typically 1-2x fainter than Halpha and to reach HBeta even if it is 10 times fainter than Halpha to determine the extinction correction (typically HBeta is 5 times fainter than Halpha in SMGs [16])

The time estimates are derived form the GNIRS ITC using:

Source point source 20mag @ K-band (irrelevant for the single line spectral template)

Single emission line: line at 2.2um, flux=3e-19 W/m2, FWHM=350km/s, continuum=3e-18W/m2/um

GNIRS: camera=0.15"/pix, FPU mask=1" slit, Grating=32l/mm, Central wavelength (irrelevant for XD), XD=yes

Read mode: very low background

Conditions: IQ=85, CC=70, WV=Any, SB=Any, Airmass=1.5

Exp: 12x300s 100% on source

For most sources we are able to nod-along-slit in the standard ABBA patter to remove the sky background. For these sources our time estimates are 3600s+10% (for readout & offsetting overheads) + 18 mins setup time giving a total of 1.4hrs per source

For sources that are more extended we need to offset to sky to make sure the off position is free from NIR emission. For these sources we will need to double the integration+overhead time to 7200s+10% + 18 mins setup time. This gives a total of 2.54 hrs per source

Some of our sources have nearby stars that can be used as tip/tilt star for observations with the LGS - considering the improved conditions for such observations (IQ=70, CC=50) and the improved PSF this would reach our SNR in only 6x300s+10% +24 mins setup = 1hr on source. Considering the demands on these very good observing conditions and for the LGS we have chosen to observe these sources in seeing limited mode to increase our chances of being observed. We intend to apply for NIFS follow-up in future semesters and will employ the LGS toobtain the highest resolution then. In 11A the NTAC felt that NIFS follow-up should be preceded by long-slit observations to establish line strengths and awarded us band 3 time to acquire this (GN-2011A-Q-79). Unfortunately none of the observations were carried out in 11A, hence we reapply for these observations to be carried out as well as adding more targets. We already have the phase II prepared for 6 of the sources proposed.

We propose to observe a sample of 15 SMGs to provie sufficient numbers with which we can determine trends from our derived properties within the SMG sample itself. Our minimum time request corresponds to our most well studied targets (8) for which we will make siginificant progress in establishing the properties of lensed SMGs.

We note that we will simultaneously obtain spectra of the foreground lens (0.3<z<0.8) in our GNIRS slit, but standard absoprtion line tracers fall in the optical for most of our targets. For our higher redshift ellipticals the Ca triplet will lie in regions of our proposed GNIRS spectra with good sensitivity and we will combine these data with thise from the proposed GMOS-S program to derive stellar velocity dispersions and the properties of the lensing galaxies.

Band 3 Information

Requested time in case of band 3 allocation: 21.0 hours

Minimum required time for a usable band 3 allocation: 11.0 hours

Use the following conditions for band 3 only:

Name	Image Quality	Sky Background	Water Vapor	Cloud Cover
Band 3 Observing Conditions	85 %	Any	Any	70 %

Band 3 Consideration Comments *(73 words)*
As the main program. The minimum corresponds to our 8 most well studied sources. The band 3 conditions use CC=70, if we find that our targets are not being observed we could relax this to CC=80 at phase 2 and observe only our brightest targets (5) in the same time requested (fewer sources to compensate for the compromised sensitivity). I leave this to the discretion of the NTAC/ITAC depending on the available conditions.

Observation Details

Observation	RA	Dec	Brightness	Total Time *(including overheads)*
G9.9	09:07:40.0	-00:42:0.0		1.4 hours
31501754(wfs)	9:07:14.761	-0:40:56.68	11.26 UCmag,9.892 Jmag,9.236 Kmag	separation 6.4
Observing conditions: GNIRS		resources: GNIRS		
G9.130	09:13:5.09	-00:53:42.77		1.4 hours
31502145(wfs)	9:12:48.346	-0:57:35.77	13.02 UCmag,12.127 Jmag,11.663 Kmag	separation 5.71
Observing conditions: GNIRS		resources: GNIRS		
G15.141	14:24:13.92	02:23:3.9		1.4 hours
32547251(wfs)	14:24:36.594	2:26:17.09	13.20 UCmag,12.045 Jmag,11.606 Kmag	separation 6.51
Observing conditions: GNIRS		resources: GNIRS		
G9.81	09:03:11.58	00:39:6.55		2.5 hours
32031580(wfs)	9:03:09.104	0:32:57.76	10.95 UCmag,10.256 Jmag,9.995 Kmag	separation 6.18
Observing conditions: GNIRS		resources: GNIRS		
G9.11	09:10:43.08	-00:03:23.05		1.4 hours
31681325(wfs)	9:10:37.21	-0:09:12.52	11.71 UCmag,10.624 Jmag,10.182 Kmag	separation 6.01
Observing conditions: GNIRS		resources: GNIRS		
G9.17	09:03:3.02	-1:41:26.94		1.4 hours
31162176(wfs)	9:02:39.511	-1:41:25.84	10.00 UCmag,8.343 Jmag,7.663 Kmag	separation 5.87
Observing conditions: GNIRS		resources: GNIRS		
G9v1.97	08:30:51.0	01:32:24.0		1.4 hours

32194426(wfs)	8:30:40.494	1:26:53.67	12.11 UCmag,11.473 Jmag,11.235 Kmag	separation 6.1
Observing conditions: GNIRS		resources: GNIRS		
G12v2.30	11:46:38.0	-00:11:32.0		2.5 hours
31688424(wfs)	11:46:16.143	-0:10:18.86	9.28 UCmag,8.300 Jmag,8.042 Kmag	separation 5.6
Observing conditions: GNIRS		resources: GNIRS		
G12v2.353	11:38:33.0	-00:17:35.0		1.4 hours
31688115(wfs)	11:38:21.425	-0:13:01.92	10.92 UCmag,10.051 Jmag,9.769 Kmag	separation 5.39
Observing conditions: GNIRS		resources: GNIRS		
G12v2.257	11:58:20.0	-1:37:53.0		1.4 hours
31170809(wfs)	11:58:34.133	-1:32:41.73	11.65 UCmag,10.520 Jmag,10.047 Kmag	separation 6.28
Observing conditions: GNIRS		resources: GNIRS		
G12v2.890	11:32:43.0	-00:51:8.0		1.4 hours
31508718(wfs)	11:33:07.583	-0:49:45.81	13.50 UCmag,12.678 Jmag,12.343 Kmag	separation 6.3
Observing conditions: GNIRS		resources: GNIRS		
G12v2.43	11:35:26.0	01:46:5.0		2.5 hours
32372062(wfs)	11:35:46.942	1:50:01.26	14.17 UCmag,13.070 Jmag,12.745 Kmag	separation 6.55
Observing conditions: GNIRS		resources: GNIRS		
G15v2.235	14:13:51.0	00:48:53.0		1.4 hours
32044566(wfs)	14:14:11.158	0:52:45.26	10.81 UCmag,10.003 Jmag,9.651 Kmag	separation 6.35
Observing conditions: GNIRS		resources: GNIRS		
G15v2.19	14:29:35.0	-00:28:36.0		1.4 hours
31694655(wfs)	14:29:26.404	-0:23:23.33	10.63 UCmag,9.724 Jmag,9.425 Kmag	separation 5.64
Observing conditions: GNIRS		resources: GNIRS		
NGP.NA.56	13:34:29.0	30:30:36.0		1.4 hours
42587143(wfs)	13:34:51.165	30:33:10.43	11.38 UCmag,10.396 Jmag,9.935 Kmag	separation 5.42
Observing conditions: GNIRS		resources: GNIRS		
NGP.NA.144	13:36:50.0	29:18:1.0		1.4 hours
42066085(wfs)	13:37:03.61	29:12:15.99	14.96 UCmag,13.989 Jmag,13.696 Kmag	separation 6.47
Observing conditions: GNIRS		resources: GNIRS		
NGP.NB.43	13:24:27.0	28:44:52.0		1.4 hours
41890780(wfs)	13:24:23.255	28:51:24.78	12.57 UCmag,11.448 Jmag,10.920	separation 6.6

			Kmag	
Observing conditions: GNIRS		resources: GNIRS		
NGP.NB.78	13:30:8.0	24:59:0.0		2.5 hours
40693930(wfs)	13:29:50.681	25:03:45.05	12.53 UCmag,11.389 Jmag,10.837 Kmag	separation 6.16
Observing conditions: GNIRS		resources: GNIRS		

Observing Conditions

Name	Image Quality	Sky Background	Water Vapor	Cloud Cover
Band 3 Observing Conditions	85 %	Any	Any	70 %
GNIRS	85 %	Any	Any	70 %

Resources

- Gemini North
  - GNIRS
    - Camera
      - short (0.15 arcsec)
    - Disperser
      - 32 l/mm grating
      - Cross-dispersing prism
    - Focal Plane Unit
      - 1.0 arcsec slit
    - Disperser order
      - XD (cross-dispersed X-K)

Scheduling Information

Scheduling constraints and non-usable dates

- (impossible):
- (optimal):
- (synchronous):

Additional Information

Keyword Category: extraGalactic
Keywords: Dynamics
Emission lines
Evolution
Gravitational lensing
IR-luminous galaxies
Starburst galaxies

Allocations:

Reference	Time	% Useful	Status of previous data
GN-2009B-C-206	2.0 nights	80%	Data is fully reduced and catalogues have been generated. These have been fused with the multi-wavelength SERVS cataogue and a paper is in preparation
GN-2011A-Q-79	8.4 hours	0%	None of the observations were executed in the queue

Publications:

- Negrello M., et al., 2010, Science in press: The Detection of a Population of Submillimeter Bright, Strongly Lensed Galaxies
- Frayer D., et al., 2010, ApJL submitted: ?GBT Zpectrometer CO (1-0) Observations of the Strongly-Lensed Submillimeter Galaxies from the Herschel ATLAS?
- Lupu R., et al., 2010, ApJ submitted: "?Measurements of CO redshifts with Z-Spec for lensed submillimeter galaxies discovered in the H-ATLAS survey"
- L. Leeuw et al., ?CARMA CO(2-1) and CO(3-2) imaging of lensed submillimeter galaxies discovered in the H-ATLAS survey?; in preparation.
- Smith et al., 2010, MNRAS, 404, 1089 "Herschel-ATLAS: counterparts from the UV--NIR in the science demonstration phase catalogue"
- Swinbank, A.M., et al. 2010, Nature, 464, 733 "Intense star formation within resolved compact regions in a galaxy at z = 2.3"
- Sturm, Verma et al, 2010, A&A, 518, L36: Herschel-PACS spectroscopy of IR-bright galaxies at high redshift
- Danielson A.L.R., Swinbank, A.M., Smail, I., et al. 2010, MNRAS, in press (arXiv:1008.3183): The properties of the interstellar medium within a star-forming galaxy at z = 2.3
- de Zotti G., Massardi M., Negrello M., Wall J., 2010, A&ARv, 18, 1: Radio and millimeter continuum surveys and their astrophysical implications
- Forster Schreiber N., inter alios, Verma A., et al., 2009, ApJ, 706, 1364: The SINS Survey: SINFONI Integral Field Spectroscopy of z ~ 2 Star-forming Galaxies
- Eales S., Dunne L. et al., 2010, PASP, 122, 499: The Herschel ATLAS
- Nesvadba N., Lehnert M., Davies R.I., Verma A., Eisenhauer F., 2008, A&A, 479, 67: Integral-field spectroscopy of a Lyman-break galaxy at z = 3.2: evidence for merging