The SCUBA2 Cosmology Legacy Survey - to coldly go where no man has gone before...
Outline

- Reasons for submm surveys
- A survey of SCUBA surveys
- SCUBA-2 Cosmology Legacy Survey
- 850 μm survey science
- 450 μm survey science
A clear view out to reionization
Much of cosmic star formation history is obscured

(Hughes et al., 1998)
A challenge to galaxy formation models

Integral under green curve would exceed local stellar mass estimates for normal IMF.
SCUBA surveys

- Many teams, many surveys
- Blank field surveys (confusion-limited)
- Gravitationally lensed surveys
- Few 100 SMGs detected
- Small field $\Rightarrow$ slow buildup of samples
Early surveys

- Clusters – Smail et al. (1997)
- HDF – Hughes et al. (1998)
- Canada-UK Deep Submm Survey (CUDSS) – Eales et al. (2000)
- Hawaii Flanking Fields survey – Barger et al. (1998)
- 8-mJy survey – Scott et al. (2002)
- 8-mJy IRAM Mambo follow-up – Greve et al. (2004)
- combined analysis of all SCUBA blank-field surveys – Scott et al. (2006)

+ enormous efforts in follow-up:
  IDs: K-band (Smail, Knudsen), radio (Ivison)
  redshifts: radio-submm (Carilli, Yun) and spectroscopic (Chapman)
A survey of SCUBA surveys

HDF

SHADES

8 mJy
The submillimetre universe

- Estimated background of sources >2 mJy is ≈ 9700 mJy/deg² so >20-30% of FIRB resolved

- Assuming most of these lie at $z \approx 2$: co-moving number density of objects forming $\approx 10^3 M_\odot$ of stars per year is $1-3 \cdot 10^{-5}$ Mpc⁻³

- Comparable to number density of 2-3 $L^*$ ellipticals today

(Coppin et al., 2006)
From SCUBA to SCUBA-2

- Field of view 8’×8’: 10× SCUBA
- SCUBA-2 brings rectangular array imaging to submm astronomy
- 8 arrays of 40×32 TES detectors – 4 arrays at 850 μm, 4 at 450 μm
- Fully sampled imaging at 850 μm
- Per pixel NEP 50 (220) mJy/√Hz at 850 (450) μm
SCUBA-2 type surveys

1 \text{ deg}^2 \text{ field, will be mapped to confusion limit in 23 hours by SCUBA-2 at 850 \text{ \mu m}}

(from Gastañaga et al.)

SCUBA-2 field-of-view
Legacy survey process

- Concept of legacy surveys proposed to JCMT board
- Legacy surveys can use both SCUBA-2 and HARP (16-pixel 350 GHz receiver)
- Call for proposals by the board – resulted in oversubscription of all assumed (usable) JCMT time in 2007-2009 time by factor 5.5
- International workshop in Leiden led to coordinated proposals
- Each proposal evaluated by a number of referees from outside the JCMT community
- Process overseen by the JCMT Survey Steering Group, which made a recommendation to the JCMT board, which was adopted
Outcome of the process

- Two sets of surveys: 2-year surveys and 5-year surveys
- Two-year plan approved; 5-year plan approved in principle, but new call for surveys after 2 years
- During this period, 55% of the available time on JCMT will go to the Legacy Surveys
- Surveys are overseen by the JCMT Survey Oversight Committee, which advises the JCMT board; teams will report every six months and must demonstrate progress, keeping up with the data stream, ability to produce a uniform dataset, etc.
- Data initially proprietary, but obligation to release reduced data
JCMT Legacy Surveys

- **Cosmology Legacy Survey** (most highly rated):
  - 490 hours band 1 (this is 90% of the expected available band 1 time!)
  - and 630 hours band 2/3

- **SCUBA-2 All-Sky Survey (SASSy)**: 500 hours band 4 to 150 mJy depth
  - (all-sky in 5 years)

- Debris disks – complete set of nearby stars
- Nearby galaxies survey – SCUBA-2 and HARP

- Gould’s Belt survey (2nd highly rated) – SCUBA-2 and HARP
- Galactic Plane survey – SCUBA-2 and HARP

- Spectral line survey – HARP only
Debris disk survey

- Few hundred nearby stars, mapped to the confusion limit at 850 μm
- Will likely produce very nice target set for adaptive optics observations of SMGs

Fomalhaut at 450μm

Holland et al. (2001)
SCUBA-2 Cosmology Legacy Survey

- 4 PIs: Jim Dunlop, Mark Halpern, Ian Smail, Paul van der Werf; + ≈ 100 co-I’s
- 2-year program:
  - large survey (20 deg²) at 850 μm,
  - deep survey at 450 μm (0.5 deg²)
- 5-year program:
  - large survey (50 deg²) at 850 μm,
  - deep survey at 450 μm (1.3 deg²)
- Time allocation for the 2-year program: 41 nights band 1 weather, 61 nights band 2/3
Survey properties

- Survey volumes are always very long in the radial direction.
- A deeper submm survey does not probe a larger volume, but fainter galaxies at all redshifts.
- JCMT/SCUBA-2 confusion limit at 850 µm is 0.8 mJy; to 3σ we resolve only ≈20% of background.
- Bright sources are typically 20 mJy ⇒ limited dynamic range in flux
- Wide 850 µm survey of only 1 layer

(from Andrew Blain)
Survey depths and widths (2-yr plan)

- Wide 850 μm survey: 20 deg$^2$ to $1\sigma = 0.7$ mJy.
  Comparable to a Schmidt plate to the depth of the SCUBA-HDF-N map.
  Expected to yield several $10^3$ sources at $>10\sigma$, several $10^4$ at $>3\sigma$.

- Deep 450 μm survey: 0.5 deg$^2$ to $1\sigma = 0.5$ mJy (expected confusion limit).
  Intended area of SHADES, to average over sufficient cosmic volume.
  Expected to yield several $10^2$ sources at $>10\sigma$, several $10^3$ at $>3\sigma$.

- Deep 850 μm survey: 0.5 deg$^2$ to $1\sigma = 0.15$ mJy (ignoring confusion).
  In parallel with 450 μm map, which will be used for deconvolution.
## Survey fields

- **850 μm survey:**

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Field selection (partly) driven by complementary data of the required depth; e.g., $K_{AB}=25$
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### Deep Imaging

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(FUV for Tadpole in field 1 is still missing)
Science case 850 μm survey

- Clustering of SMGs
- Relation with other populations through massive source stacking
- Extreme objects (>30 mJy) – how many? what are they?
- $10\sigma$ detections: easier identification, better photo-$z$
- Properties of host galaxies – stellar masses, $K$–$z$ diagram, growing AGN?
- New tests for semi-analytical models
- Rich source of follow-up by e.g., ALMA
Clustering and evolution

- Clustering signal even without any redshift information
- Photo-$z$’s $\Rightarrow$ clustering as function of $z$
- Assign halo masses to SMGs
- Same at all redshifts?
Relations between source populations

- Availability of very deep data from e.g., UDS and IRAC allows recovery of submm signal from a selected population.

- E.g.: Lyman Break Galaxies have no detectable submm emission even after massive source stacking, but Distant Red Galaxies (DRGs) do!

- Defined by $J_s - K_s > 2.3$, which brings the Balmer break between $J_s$ and $K_s$ for $z > 2$

- DRGs: massive galaxies with high SFRs; source density $3 \text{ arcmin}^{-2}$ for $K < 22.5$ is comparable to SMGs with $>0.8 \text{ mJy}$ at 850 μm (as estimated from lensing surveys).

- 1 unlensed DRG detected directly with SCUBA (5 mJy).
Rest-frame SEDs: Lyman break galaxies
Rest-frame SEDs: distant red galaxies
SCUBA observations of MS1054–03

M1383
S_{850} = 5 \text{ mJy}

(Knudsen, Van der Werf & Kneib 2007)

SCUBA-2 Cosmology Legacy Survey

NICTMOS
ACS
r_e = 1.26'' = 10.26 \text{ kpc}; H\alpha < 0.4''

(Toft et al., 2007; Van Starkenburg & Van der Werf, in prep.)
Stacking DRGs

DRGs, EROs

DRGs: $S_{850} = 1.11 \pm 0.28 \text{ mJy}$
$\approx 20\% \text{ of background}$

(Knudsen et al., 2005)

random positions
Cosmic backgrounds

- Microwave Background
- IR/Optical Background
- X-Ray Background
- Stars+BlackHoles
- Big Bang
- AGN


IRBG peaks at ≈200μm.
At 850μm, 30× lower
At 450μm, only 3× lower

Cosmic backgrounds

1mm 1μm 1nm
Science case 450μm survey

- Probe the IR/submm background close to its spectral peak

- Resolve $\approx 75\%$ of the 450μm background: new territory!

- Out to $z=3$: full census of ULIRGs in survey volume
- Out to $z=2$: full census of $>3 \times 10^{11} L_\odot$ galaxies
- Out to $z=1$: full census of $>2 \times 10^{11} L_\odot$ galaxies

- Connection to other populations without stacking

- Deconvolve confusion-limited 850μm map

- Evolution of IR/submm luminosity function, obscured star formation history
Elbaz diagram
A2218: SCUBA 850 μm

(Kneib et al. 2005)
A2218: SCUBA

850 µm

450 µm

SCUBA-2 Cosmology Legacy Survey
A2218: deep 850 µm map

(Knudsen et al. 2006)
Deep 850μm source counts

- Currently from gravitationally lensing cluster fields ⇒ small survey volumes, affected by cosmic variance
- Deconvolved deep 850μm map large enough to average out cosmic variance
- Several $10^3$ sources expected at >10σ down to 1.5 mJy (resolves ≈ 40% of 850 μm background)

(Knudsen, Van der Werf & Kneib, 2007)
Practical challenges at 450\(\mu\text{m}\)

- Even in excellent weather observing at 450\(\mu\text{m}\) is challenging.

- Special care needed in calibration – monitor conditions and take beammaps several times per night.

- Need to establish a rigorous observing protocol, since the data are going to be taken by many different persons (often not even member of the cosmology survey team).

- Surface accuracy of JCMT dish <22\(\mu\text{m}\) is needed; this needs to be monitored and maintained.

- Crucial requirement for 450\(\mu\text{m}\) survey depth and uniformity.
Conclusions and outlook

- 850 μm survey will produce statistically accurate results, and robust samples for easier follow-up.

- Clustering is a key application

- The 450μm survey is unique in probing lower SFRs

- Deep complementary data is essential

- Follow-up is crucial: deep radio, near-IR deployable IFUs, redshift machines using CO

- Numbers are still “low” ⇒ a next-generation instrument?