The Herschel Lensing Survey (HLS)

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Steward Observatory, University of Arizona
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<tr>
<th>E. Egami (PI)</th>
<th>B. Altieri</th>
<th>M. Dessauges-Zavadsky</th>
<th>M. Jauzac</th>
<th>J. Richard</th>
<th>M. Werner</th>
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<td>T. Jones</td>
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<td>M. Zamojski</td>
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<td>M. Swinbank</td>
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<td>S. Bussmann</td>
<td>D. Fadda</td>
<td>A. Omont</td>
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<td>Rujopakarn (Arizona)</td>
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Collaborators

- **SMA** (Giovanni Fazio, Mark Gurwell, Caitlin Casey...)
- **LABOCA Lensing Survey** (Axel Weiss)
- **CARMA** (Dominik Riechers)
- **GBT/Zpectrometer** (Andy Harris, Andrew Baker, Dave Frayer)
- **SCUBA2 Lensing Survey** (S2LS team)
- **CLASH team** (Marc Postman, Rychard Bouwens, Leonidas Moustakas, Piero Rosati...)
- **SPT team** (Dan Marrone, Joaquin Vieira, John Carlstrom...)
- **CODEX team** (Alexis Finoguenov, Eduardo Rozo...)
Outline

I. Motivation

II. What is Herschel Lensing Survey (HLS)?
   • HLS-deep & HLS-snapshot

III. Scientific Highlights
   (1) HLS-deep
       \( z=5.24 \) SMG (Rawle+13, arXiv:1310.4090)
   (2) HLS-snapshot
   (3) IR-bright cluster members

IV. Public data release (HLS DR1)
I. Motivation
Herschel $D=3\text{m}$

This is all for free!

$D=30\text{m}$!
The Bullet Cluster (Egami+10, Rex+10, etc.)

Optical+X-ray+WL

PACS 100μm

PACS 160μm

5σ ~ 24 mJy

5σ ~ 26 mJy

5σ ~ 32 mJy

~75x
II. What is HLS?
What was HLS?

<table>
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<tr>
<th>Cycle</th>
<th>Title</th>
<th>Tobs (hrs)</th>
<th>#clusters</th>
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<tbody>
<tr>
<td>HLS-deep I</td>
<td>&quot;The Herschel Lensing Survey&quot; Open-Time Key Program (OTKP)</td>
<td>318.2</td>
<td>44</td>
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</table>
What is HLS?

HLS-snapshot inspired by the discovery of the Eyelash galaxy at z=2.3 (Swinbank+10)
The Herschel Lensing Survey (HLS)

1. HLS-deep (366 hrs): Deep PACS (100/160 um) & SPIRE (250/350/500 um) imaging of 54 (→ 65) massive (i.e., X-ray-luminous) cluster cores (z~0.1-0.5) to detect and study Herschel sources below the confusion limit.

2. HLS-snapshot (52 hrs): Shallow SPIRE-only imaging of 527 massive cluster cores (z~0.1-1) to discover exceptionally bright (Speak≥100 mJy) cluster-lensed galaxies that will allow a variety of multi-wavelength observations.

Note: Field surveys (H-ATLAS, HerMES, SPT, ACT, etc.) → Galaxy-lensed systems
Cluster Samples

- **HLS-deep**: 54 clusters (HLS) \(\rightarrow\) +11 GT = 65
  - 54 well-studied massive clusters
  - Includes 23 CLASH clusters + 1 from GT (PI: Altieri)
    (1 missing: A1423)
  - Will eventually add 10 GT clusters
- **HLS-snapshot**: 527 clusters = 279 + 148 + 100
  - 279 ROSAT clusters (PI: Ebeling)
  - 148 SPT clusters (PI: Carlstrom)
  - 100 CODEX (ROSAT+SDSS) clusters (PI: Finoguenov)
III. Scientific Highlights
(I) HLS deep

Saintonge+13

Rawle+13, in prep

8/20 at z>2
Sklias+13 (arXiv:1310.2655) and poster

Zamojski poster

Schaerer poster

AGN
Super-bright z=5.2 galaxy-lensed SMG

Combes+12
Rawle+13
(arXiv: 1310.4090)

~200 mJy at 500um

Lensing galaxy at z=0.6

50 mJy at 1.3 mm!
(SMA Compact)

CO redshift → z=5.24
New Data
(Rawle+13; arXiv:1310.4090)

SMA [CII] 158um
SMA 1mm continuum
JVLA CO(1-0) 2.6mm

Compact+Extended+ Very Extended
305 GHz=984 um

C and DnC config
HyLIRG with a LIRG-like SED

Magnification $\mu = 8.9$

$L_{\text{FIR}} = 1.8 \times 10^{13} \, L_\odot$

$SFR_{\text{FIR}} = 2100 \, M_\odot/\text{yr}$
Complex Line Profile

→ Likely suggesting a merging system
Spatially Distinct Velocity Components

- VB (-860 to -590 km/s)
- B (-590 to -310 km/s)
- Rb (-310 to -30 km/s)
- Ra (-30 to +420 km/s)

[CII]

CO(1-0)
Spatial resolving z=5.2 galaxy!
L[CII]/L(FIR) similar to other z>4 galaxies. VB component shows an abnormally large ratio.
z=6.1 Quad system with submm emission? 
or 
SZ substructures?

From the LABOCA Lensing Survey (Boone+13)
(2) HLS-snapshot

4 examples at
z=2.0, 1.9, 4.7, and 1
HLS-snapshot bright sources allow easy CO redshift measurements.
Optically-Faint IR Arc at $z=2.0$  

Walth+13 in prep
MACS2043 at $z=2.04$

**Magellan/IMACS**
- i band

**LBT/LUCI**
- K band

**SMA**
- 870 um

**JVLA**
- CO(1-0)

**Continuum**

$I_{\text{vis}}$ & $I_{\text{obs}}$ \\
$\lambda_{\text{d}} / \mu$m & \\
300 & 250 & 200 & 150 & 100

$\lambda_{\text{d}}$ & \\
205 & 158 & 146 & 122 & 119

$v / \text{km s}^{-1}$ (for $z=2.04$)

-4000 & -2000 & 0 & 2000 & 4000

$I_{\text{vis}}$ & $I_{\text{obs}}$ \\
$\lambda_{\text{d}} / \mu$m & \\
88 & \\
4000 & 2000 & 0 & 2000 & 4000

**Ivison & George**
CO(1-0) ≠ Continuum

z=1.9 galaxy-lensed source from HLS-snapshot

Rujopakarn+13 in prep
Quintuply lensed $z=4.7$ galaxy (Egami+13, in prep)

$z(\text{CO})=4.69$

Two components separated by ~650 pc

Magnification factor $>130$ for A+B+C+D

$\Rightarrow L_{\text{IR}} < 5 \times 10^{11} \, \text{L}_\odot$
IRAC counterparts for the submm sources

Spitzer/IRAC 3.6 um

HST/WFC3 F140W
Triply lensed galaxy at $z \sim 1$
(3) IR-bright cluster galaxies

Cluster samples:
- Bullet cluster
- Abell 2744

Field samples (0.05 < z < 0.3):
- Bullet foreground
- A2744 foreground
- BBC03
- H10 (SDSS/Akari)
- H10 (GOODS-N/Herschel)

Observed wavelength [μm]

Normalized flux density

Two component fit to "normal" source
- warm fixed at $T_{\text{dust}}=41.0$ K
- cold best fit $T_{\text{dust}}=24.5$ K

Composite warm dust source (best fit $T_{\text{dust}}=41.0$ K)
Composite "normal" source (best fit $T_{\text{dust}}=28.5$ K)

$z > 0.9$ SPT clusters

Rawle+12; Rawle Poster
IV. HLS Data Release (DRI)

- HLS-deep 44 clusters (Original OTKP sample).
- Fully processed PACS and SPIRE images.
- Source catalogs with IRAC and/or MIPS priors will be released in ∼1 month.
- We plan to release all HLS-deep images (with source catalogs) and HLS-snapshot images by the end of 2013 with the survey paper (Egami et al. 2013, in prep).
From the HLS website
http://herschel.as.arizona.edu/hls
(or google “herschel lensing survey”)

Herschel Lensing Survey

Overview:
The Herschel Lensing Survey (HLS) is a large extensive imaging survey of massive galaxy clusters in the far-infrared and submillimeter using the Herschel Space Observatory. Its main scientific goals are the following:

1. To detect and study infrared/submillimeter galaxies that are below the nominal confusion limit of Herschel by taking advantage of the strong gravitational lensing power of massive galaxy clusters.
2. To discover exceptionally bright (S\text{peak}>100 \text{ mJy}) lensed infrared/submillimeter galaxies that will allow a variety of detailed multi-wavelength follow-up observations.
3. To examine infrared/submillimeter properties of galaxies in dense environment (i.e., cluster members).
4. To investigate the Sunyaev-Zel'dovich (SZ) effect through the detection of the increment signal.
There are three ways to download the images:

- Simple tarballs (the "Download" column in the table)

Each tarball contains the PACS (100/160 um) and SPIRE (250/350/500 um) images. PACS images come with coverage maps while SPIRE images come with coverage and uncertainty maps. All the HLS DR1 data are also available in one big tarball here: hls-deep1_dr1.tar.gz

- Rainbow Data Extractor pages (the "Rainbow" column in the table)

This interface allows downloads of individual images (use the link at the bottom of each page for a single tarball). In the future, these pages will provide additional files such as source catalogs and various ancillary data (e.g., Spitzer & WISE images).

- Rainbow Slicer interface (Click the "Rainbow Slicer (public)" tab on the left)

Rainbow Slicer allows the user to select images for downloads. It can also generate multi-wavelength postage-stamp images for a given sky position (N-BAND QUICKLOOK) or for a given set of source positions (N-SOURCE QUICKLOOK). The Rainbow Data Extractor pages described above are the outputs when "Select Filters = all".

README file provides more detailed information on the images provided here.

Note: We are still finalizing the processing of the Bullet cluster PACS data, which were obtained during the SDP period and require special treatment. These PACS images will be released shortly.

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<thead>
<tr>
<th>Cluster</th>
<th>Full / Alternate Name(s)</th>
<th>R.A.</th>
<th>Dec.</th>
<th>Redshift</th>
<th>Download</th>
<th>Rainbow</th>
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<td>+18d26m18.0s</td>
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Summary

• Gravitational lensing provides enormous gain in sensitivity for free.

• HLS-snapshot is picking up exceptionally bright lensed galaxies that can be studied in detail with pre-ALMA facilities.

• HLS-deep probes faint lensed galaxies that will require ALMA follow-ups (= strength of lensing cluster surveys).

• Submm/mm interferometers (especially ALMA) aided by lensing magnification resolve bright lensed galaxies into individual star-forming regions (HII regions, molecular clouds) ➔ Next frontier