Pushing SPICA to Its Limit: Probing IR-Luminous Galaxies at z~4-10

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Disclaimers….

- My knowledge of the SPICA instrumentation is limited, so there may be some big mistakes (please correct me if you spot any!).
- This presentation is simply a collection of my random thoughts rather than a decent feasibility study. My hope is to promote discussion among interested researchers by using this material as a starting point.
- I'm sure that many of the smart SPICA people already had similar thoughts, so please forgive me if nothing here is new…

Outline

I. Scientific motivation

II. Practical limitation/constraint

III. SPICA's competitive edge

IV. Strategies for z=4-10

  a) Broad-band imaging

  b) Spectro-imaging

  c) Spectroscopy

  d) Lensing cluster survey

V. Summary

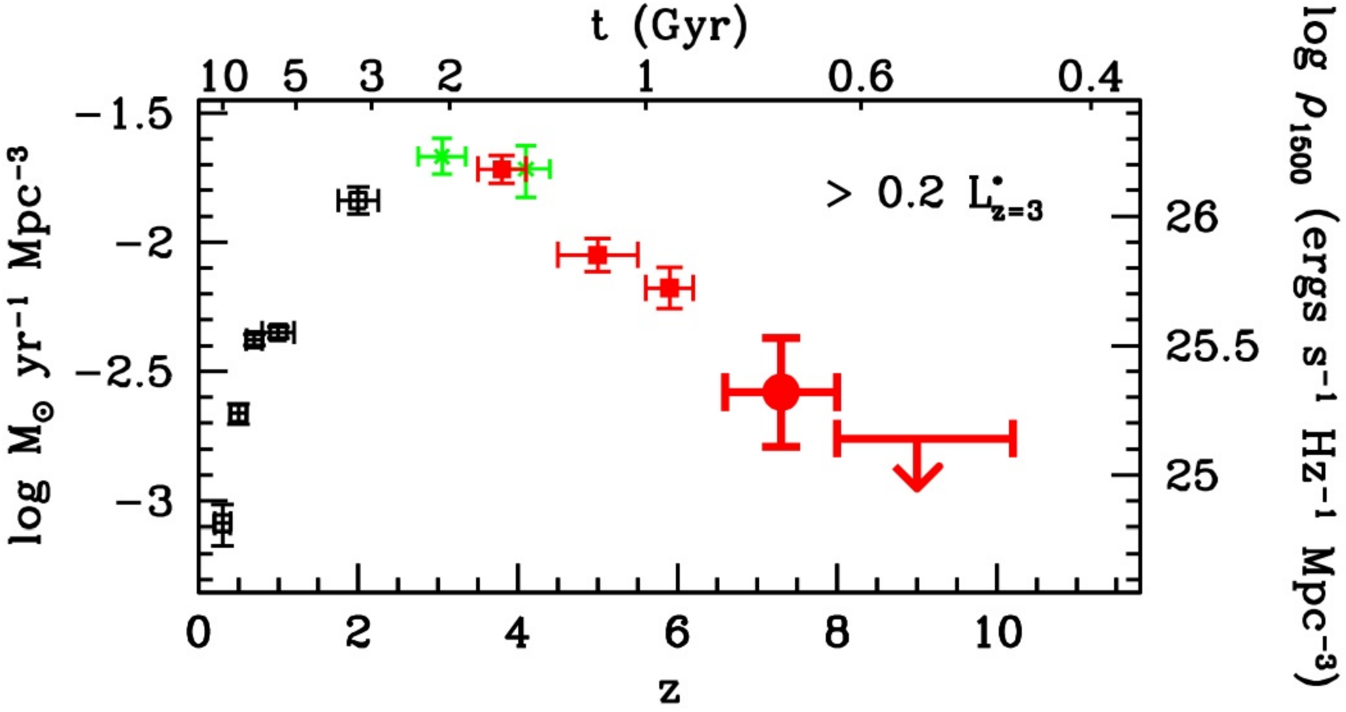
I. Scientific Motivation

- We now understand the properties/evolution of dust-obscured and unobscured galaxies up to z~4 reasonably well. SPICA will also do an excellent job at z<4.
- With LMT (CCAT), ALMA, and JWST, the next challenge will be to probe the dust-obscured (i.e., IR-luminous) population at z>4.
- Question: How can we use SPICA to explore the z>4 Universe?

Q1: Why z=4-10?

- z~4: Current upper redshift limit of extragalactic IR/submm/mm astronomy (excluding luminous AGNs/QSOs).
- z~10: Expected epoch of reionization. Also, strong negative K correction should allow submm/mm observations to detect IR-luminous galaxies up to z~10 easily.
- Unobscured galaxies are already studied up to z~7. Can we detect obscured population as well? (e.g., LBGs vs. SMGs analogy).

Tracing the Cosmic Star Formation History at 4<z<10



Bouwens et al. (2008)

Rest-frame UV-selected galaxies show a steep decline of star formation rate density from z~4 to 10. Is dust obscuration playing any role?

Q2: Why (rest-frame) mid-IR?

- Ground submm/mm observations will have no problem detecting galaxies up to z~10 (if they exist, that is). Also, submm/mm observations will directly measure the total IR luminosity (which is great!).
- However, submm/mm observations (and probably even JWST observations) will have difficulty characterizing the properties of detected galaxies (e.g., star-forming vs. AGN).

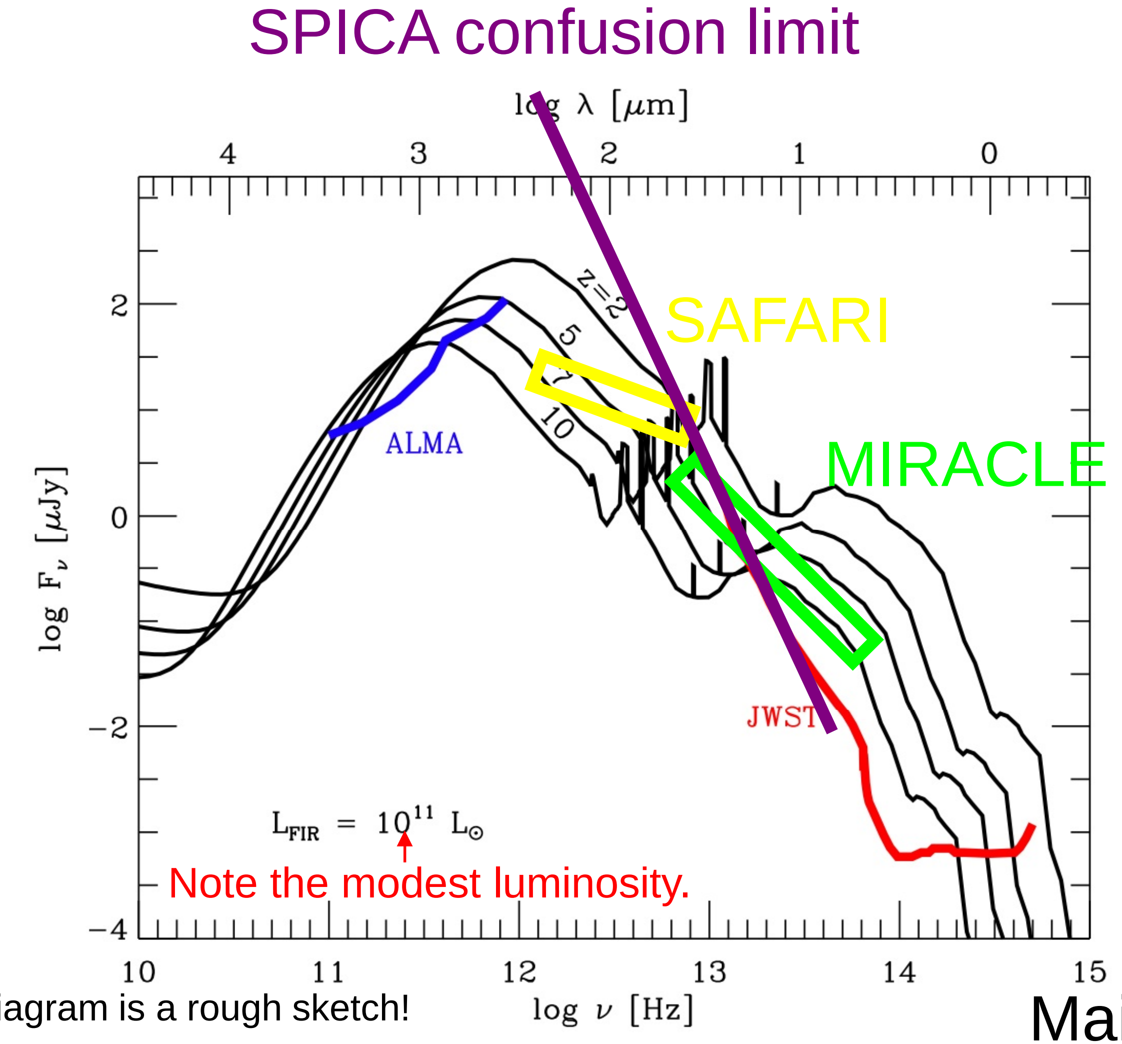
Q2: Continued…

- On the other hand, in the rest-frame mid-IR range, which is sampled by SPICA far-IR observations at z>4, we can employ various well-established diagnostic methods (e.g., Spitzer).

II. Practical Limitation/Constraint

- The main obstacle is the confusion limit over the SAFARI wavelength range. Herschel, *with the same telescope diameter (3.5m)*, can achieve confusion limit at z>100 um with broad-band imaging (PACS: 100/160 um; SPIRE: 250/350/500 um).
- (MIRACLE, on the other hand, will detect z=4-10 galaxies, maybe Hα emission line as well).
- Another constraint is competition. JWST can achieve better sensitivities at < 20 um.

Background-limited Sensitivity and Confusion limit



Warning: This diagram is a rough sketch!

Maiolino (2009)

III. SPICA’s Competitive Edge

- 20-100um coverage/depth
- Spectroscopic capabilities (can mitigate confusion limit)
- Timing (Herschel will be gone when ALMA & JWST start operating)
- Mapping speed?
- Efficiency? (Herschel does achieve confusion limit but observing efficiency is not great in some observing modes)

IV. Strategies for z=4-10

- Because of the cold large telescope, SPICA's background-limited performance will be superb. How can we exploit this excellent sensitivity to probe the z=4-10 Universe?
  - Broad-band imaging: Dig into the confusion noise with source deconvolution/deblending techniques.
  - Spectro-imaging/Spectroscopy: Go deeper than confusion-limited broad-band imaging.
  - Extra: Utilize powerful gravitational lensing effects.

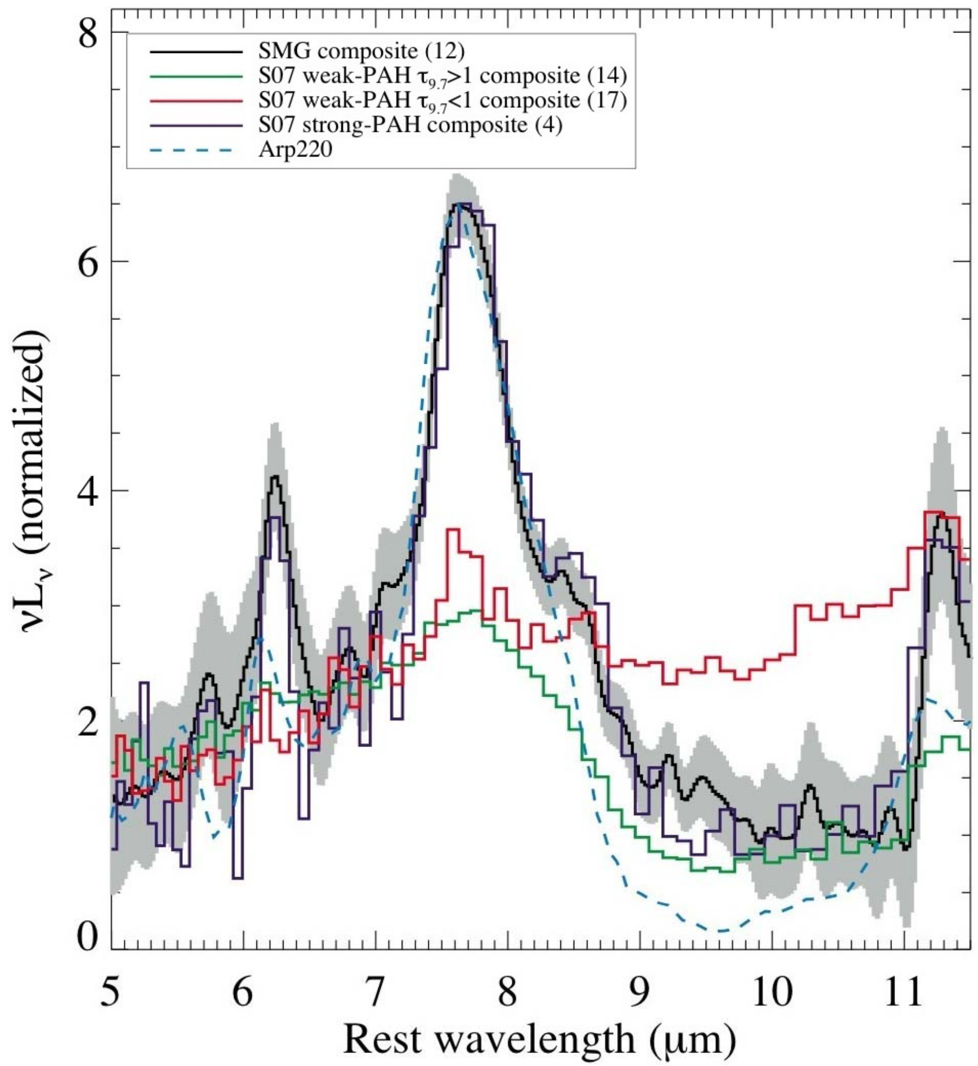
a) Broad-band Imaging

- This is tough… Herschel will already achieve confusion limit at > 100 um, and the limit will be the same for SPICA.
- BUT, with SPICA, there is a much larger gap between the confusion limit and background-limited sensitivity (σ(bkgd) a few orders of magnitude smaller).
- Will this allow us to dig deeper into the confusion noise with various deconvolution/deblending techniques?
  ➔ Needs detailed simulations.

b) Spectro-Imaging

- SAFARI offers spectro-imaging capability.
- Low-resolution specto-imaging observations targeting 7.7um PAH emission feature could significantly go deeper.
- 7.7um PAH luminosity of z~2 SMGs: ~5e10^{10} $L_{\odot}$ for the most luminous ones (Pope et al. 2008) ➔ Requires a flux sensitivity of ~10^{-19} Wm^{-2} to detect up to z~10 (but R~20…)
- Need to look for PAH on top of confused continuum sources, but confusion noise is spatially fixed, allowing clean background subtraction (well, in principle…).
- Will this work??

Strong 7.7 PAH with z~2 SMGs

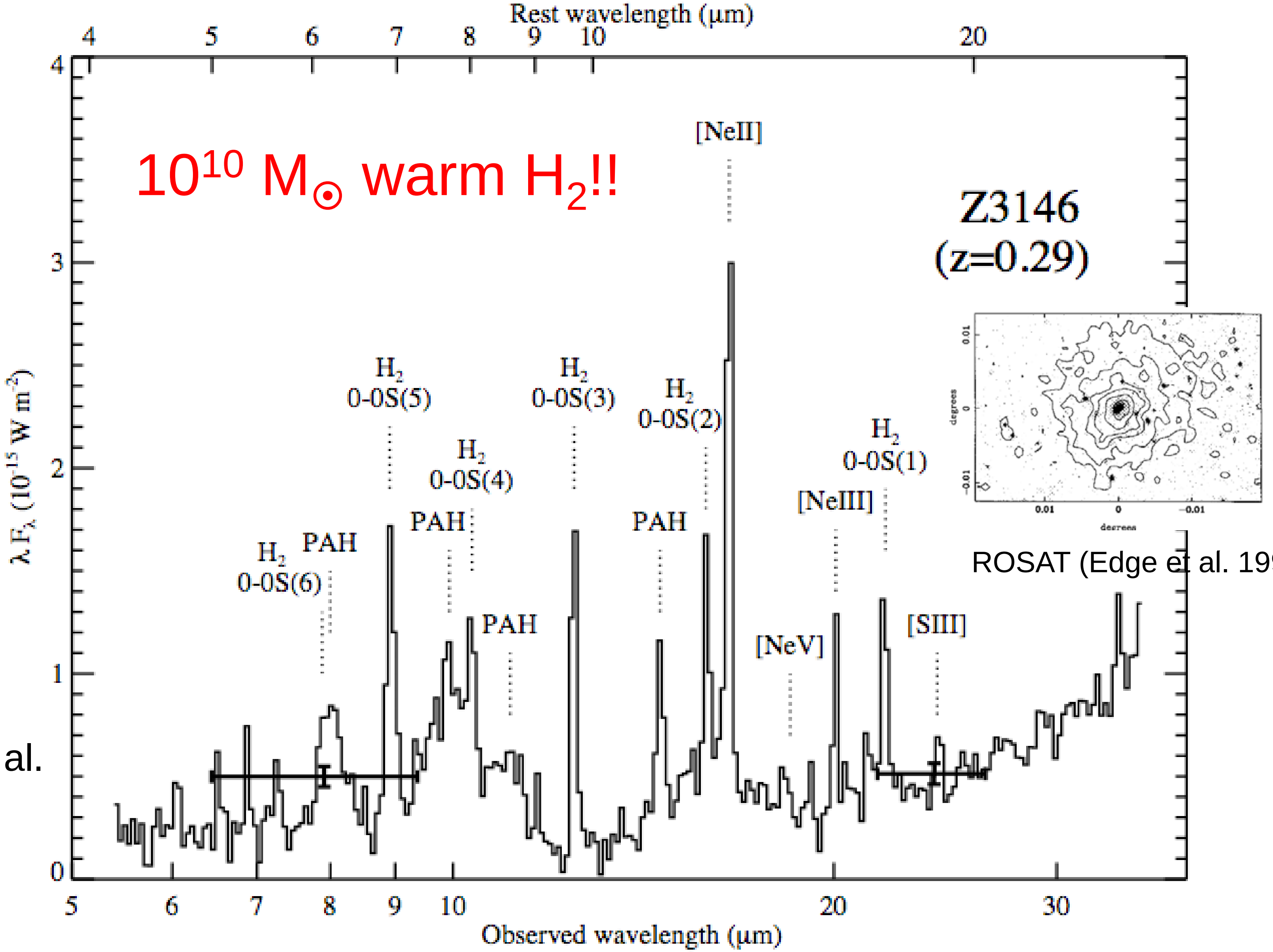


Pope et al. (2008)

c) Spectroscopy

- Zodi/cirrus-background limited spectrometer like BLISS (line flux sensitivity~10^{-20} Wm^{-2}) could detect bright (>3-4x10^9 $L_\odot$) fine-structure lines (e.g., [Ne II] 12.8um) and H_2 lines up to z~10.
- Galaxies with such strong [Ne II] and H_2 lines do exist in the nearby Universe (e.g., IR-luminous BCGs).

H_2 with SF - Z3146 BCG



ROSAT (Edge et al. 1994)

Egami et al. (2006)

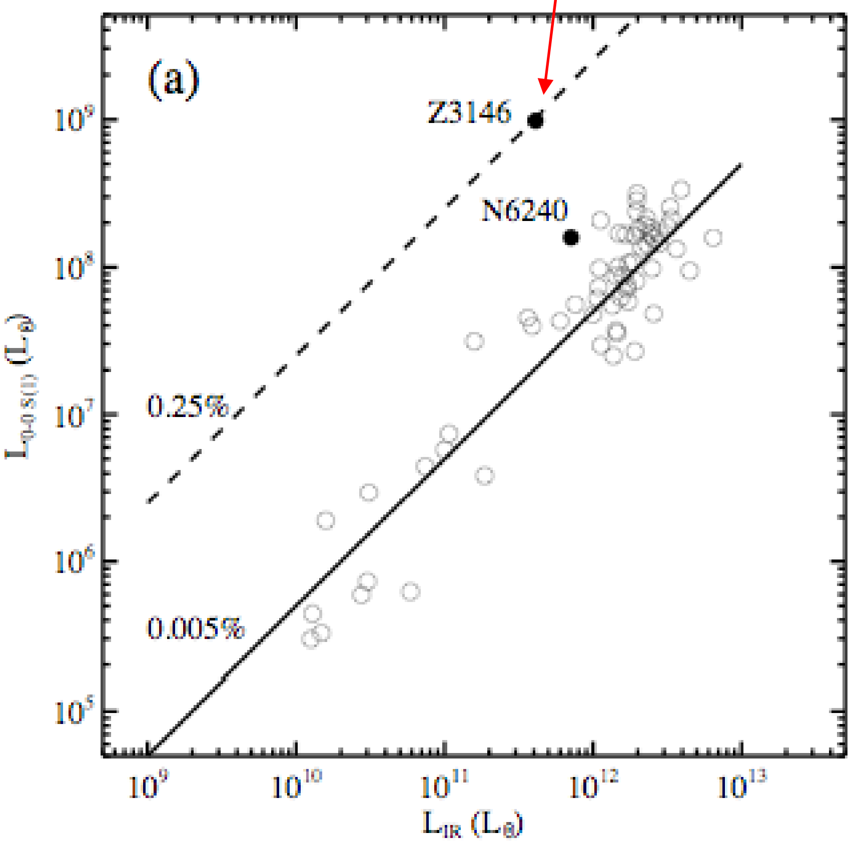
More Strong H_2 Emitters!

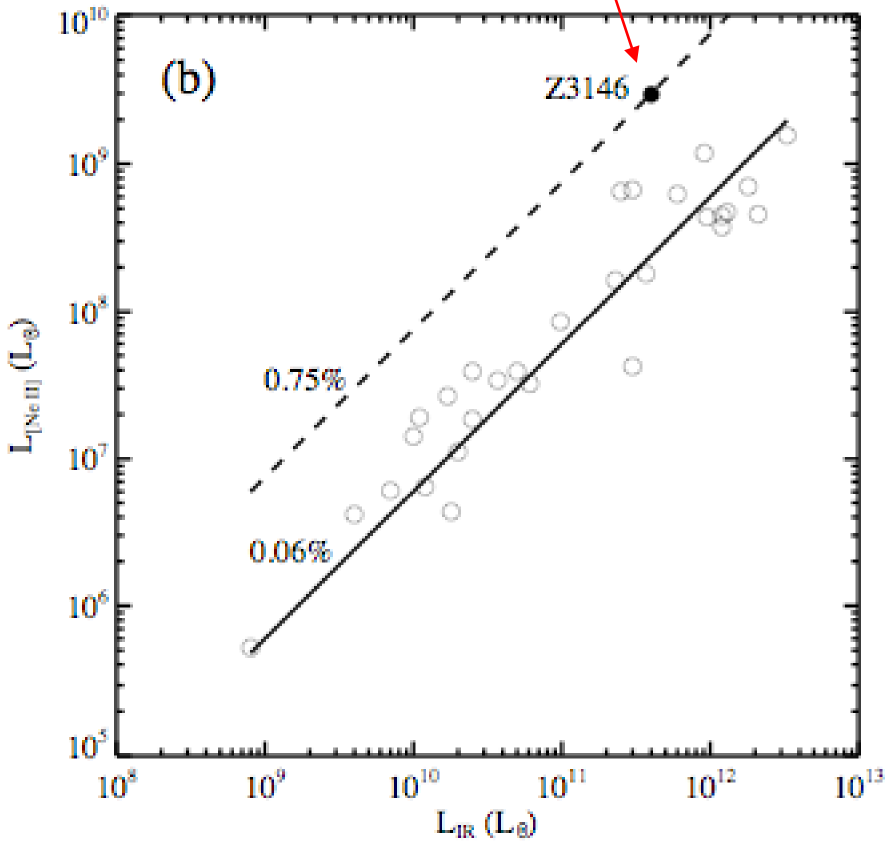
Egami et al. (2009, prep)

L(0-0 S(1)) vs. L(IR)

L([Ne II]) vs. L(IR)

Close to the BLISS detection limit at z~10.





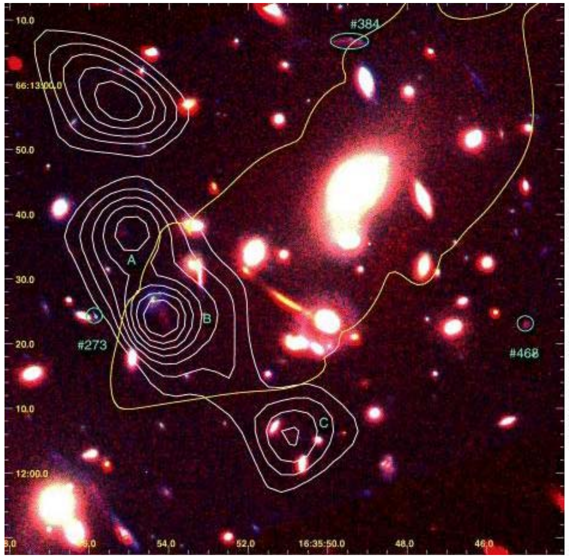
Excitation mechanism not understood but could be shocks associated with cluster cooling flows.

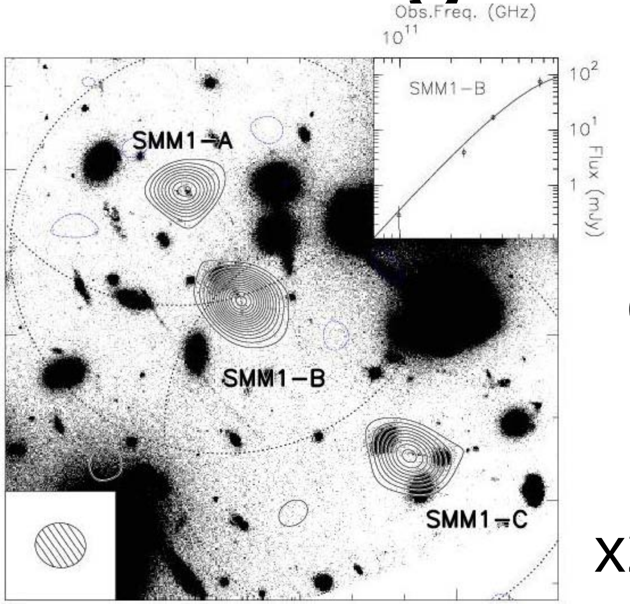
d) Lensing Cluster Surveys

- Increase the detection limit dramatically by taking advantage of the gravitational lensing power of massive galaxy clusters at z=0.1-0.5.
- A magnification factor of 10 translates into
  - x10 increase in sensitivity
  - X100 increase in observing time when background-limited
- Allows detections of sources well below confusion limit.
- However, survey volume is limited…

Triply-lensed z=2.5 IR galaxy

HST &
850 um

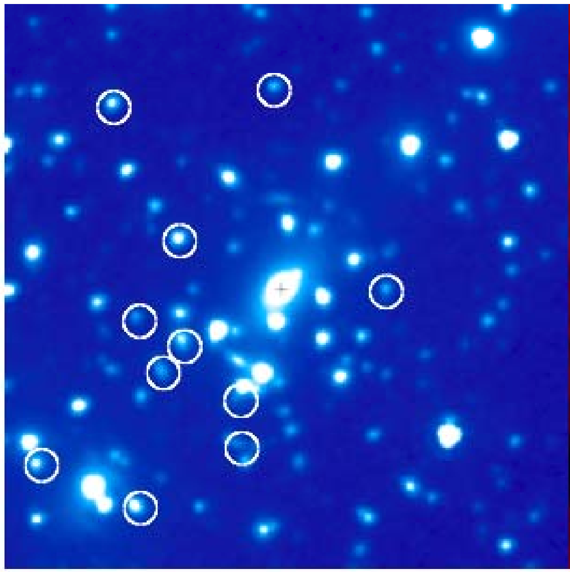




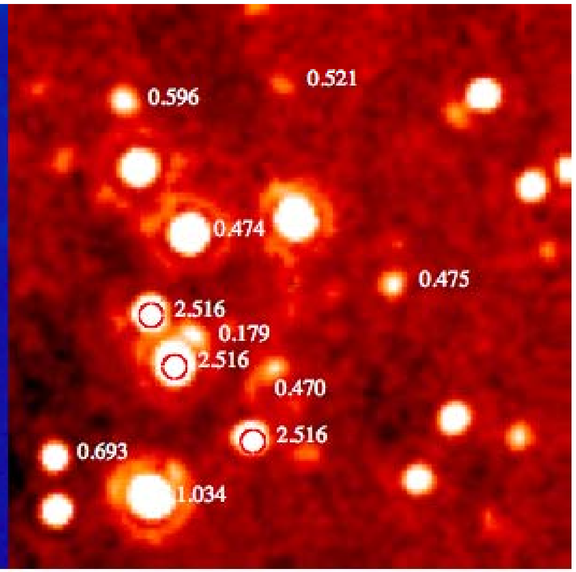
CO

x22 ➔
x480 gain
in obs time

IRAC 4.5 um



MIPS 24 um



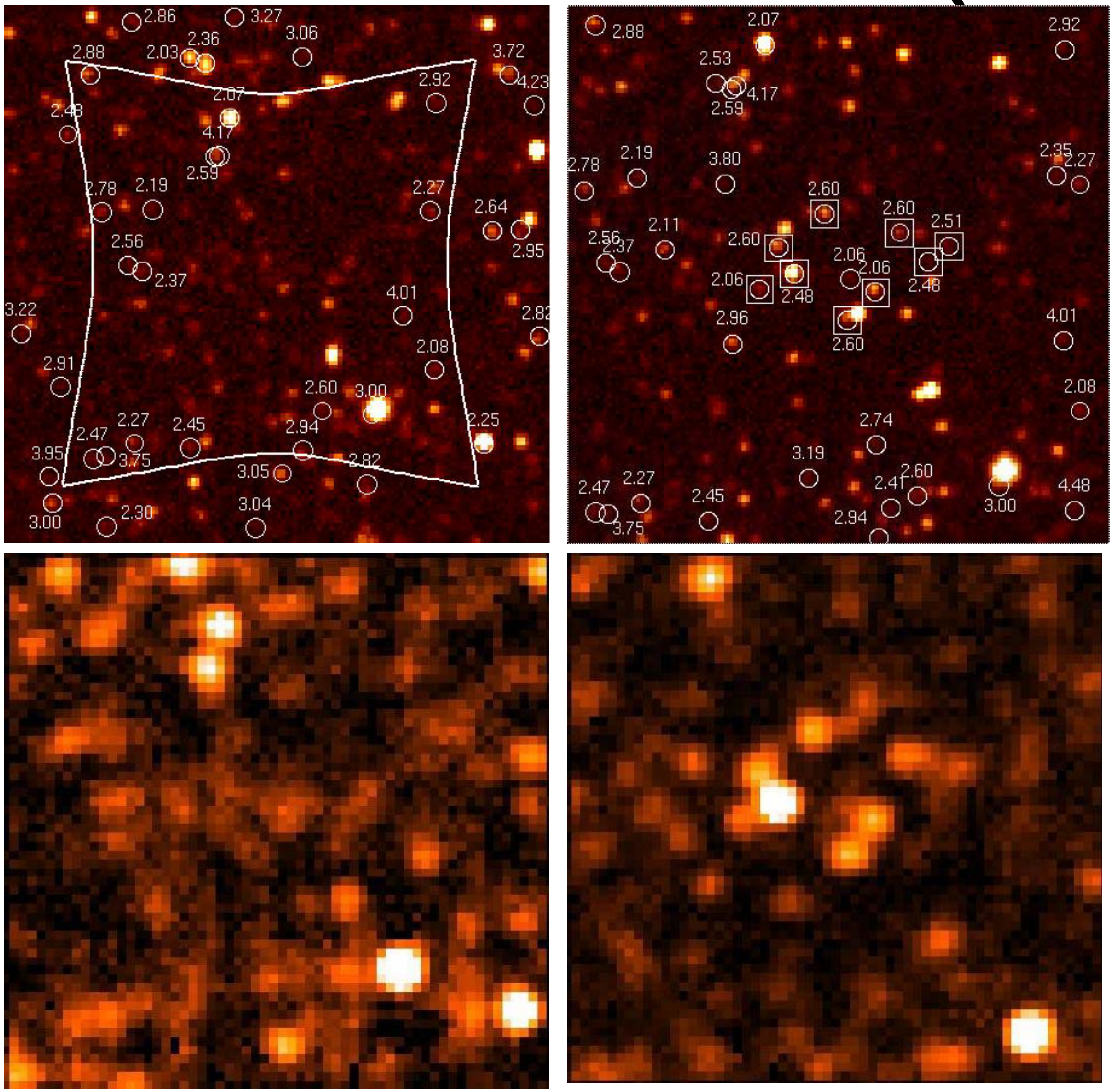
4.5 um

24um

Herschel Simulated Images of massive cluster cores (HLS)

PACS
100um

Without lensing



7'x7'

Squares
- m>5

With lensing

SPIRE
250um

Clusters act as transparent lens

Upcoming Surveys

- The Herschel Lensing Survey
  - – Herschel open-time key program
  - – PI: Egami, 292 hrs, ~40 clusters
  - – PACS 5hr/SPIRE 2hr per cluster (a bit inefficient)
- The IRAC Lensing Survey
  - – Spitzer warm mission science exploration program
  - – PI: Egami, 526 hrs, ~50 clusters
- The WFC3 Lensing Survey
  - – GO-17 program
  - – PI: Kneib, 43 orbits, 10 clusters
  - – GO-18 proposal planned to cover the whole Herschel/IRAC sample
- LMT, ALMA, JWST, etc. surveys in the future.

V. Summary

- Considering that the frontier of extragalactic IR/submm/mm astronomy will move into the z>4 regime in the near future, it is important to identify SPICA's strengths for z>4 studies.
- SPICA has a great potential to probe the z=4-10 Universe if,
  - deconvolution/deblending techniques will allow us to dig deeper into the confusion noise.
  - SAFARI/FTS low-resolution spectro-imaging achieves a flux sensitivity of $\sim 10^{-19}$ Wm^{-2} or below (targeting 7.7um PAH feature).
  - BLISS spectroscopy achieves a flux sensitivity of $\sim 10^{-20}$ Wm^{-2} or below (targeting fine-structure/H_2 lines).

Summary (continued)

- We know that there exist galaxies with $>10^{10}\ L_\odot$ 7.7um PAH features (e.g., z~2 SMGs) and $>10^{9} L_\odot$ [Ne II]/H2 lines (e.g., IR-luminous BCGs). SPICA has the potential to detect such galaxies up to z~10.
- The ultimate question is whether similarly luminous galaxies exist at z>4. However, this question, I believe, is the very reason why we want to explore the z=4-10 Universe with SPICA.