

May 21st, 2009, Joint Subaru-Gemini Science Conference
Kyoto University, Japan

*AzTEC/ASTE 1.1mm survey
of Submillimeter Galaxies:
Optical/Infrared Properties of Dusty
Extreme Starburst Populations in the
Early Universe*

Kohno Kotaro



東京大学
THE UNIVERSITY OF TOKYO

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*AzTEC/ASTE 1.1mm survey
of Submillimeter Galaxies:
collaboration with
SUBARU & GEMINI
toward the ALMA era*

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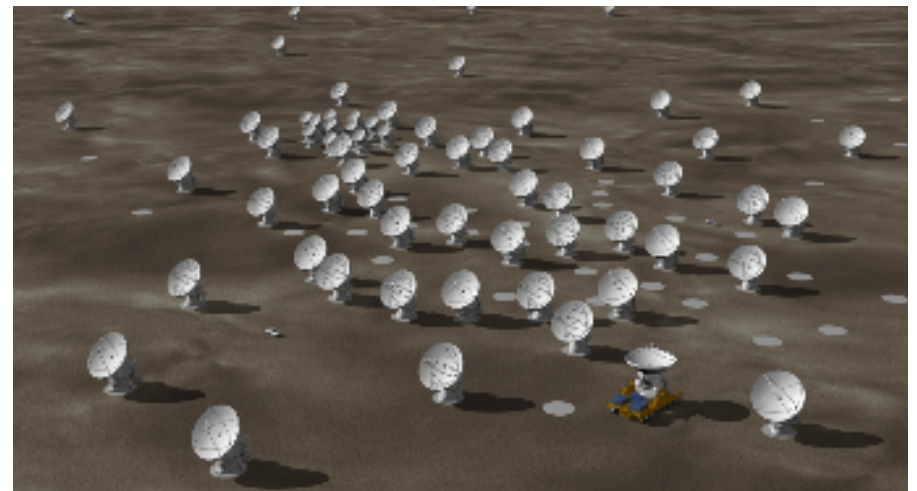
I am talking about ALMA because...

□ The 1st call for proposals of ALMA will be

October 2010

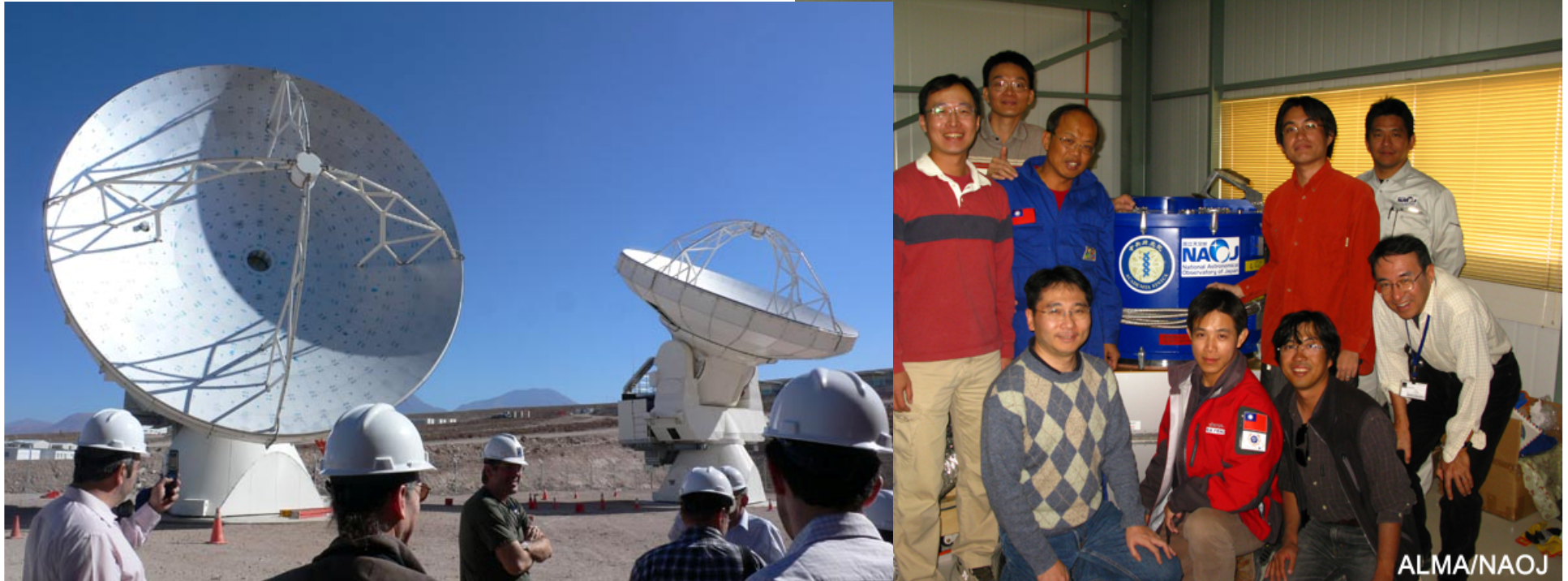
i.e., just 16 months later from now !
(for Early Science; at the earliest case)

Some of you just recall
an artistic drawing
like this, but..



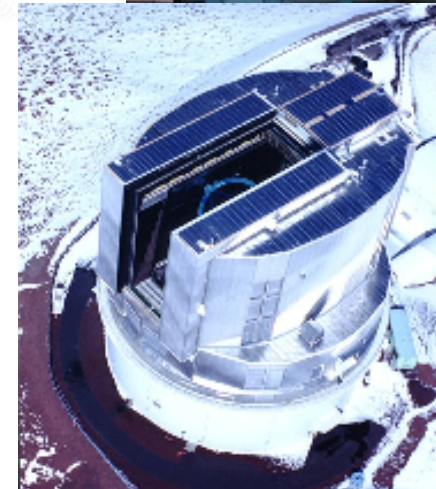
Our dream, ALMA, is a reality now

- ❑ 1st acceptance of 12m antenna (from Japan): December 19th, 2008
- ❑ 1st Front-end from ALMA East-Asia integration center: January 9th, 2009
- ❑ 1st astronomical fringe: April 30th, 2009



Toward the ALMA era

- ❑ Strong science cases based on our own sample for ALMA proposals
- ❑ Accelerate multi-wavelengths collaboration to strengthen the science cases !



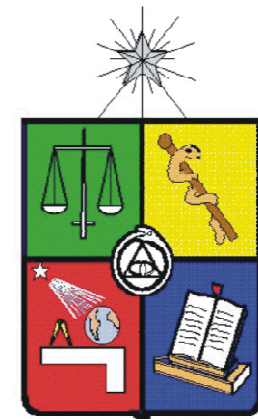
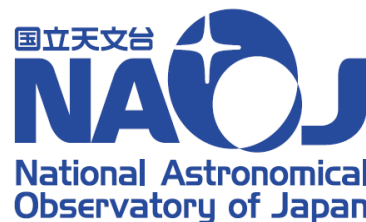
Outline of this talk

- Unprecedentedly wide and deep surveys of submillimeter galaxies (SMGs) @1.1mm
 - Using bolometer camera AzTEC mounted on submm telescope ASTE 10m in Chile
 - Area: $>2 \text{ deg}^2$; Sensitivity $\sim 0.5\text{-}1 \text{ mJy}$ (1σ)
 - Detections of ultra-bright SMGs
- Combined analysis of 1.1mm and optical/IR data: How fruitful they are
 - SSA 22, discovery of SMG cluster
- ALMA is coming! Access to Southern sky through GEMINI-S is attractive & crucial
 - ADF-S, a new unique deep field in southern sky

Collaborators



- Kohno, K. (ASTE Project director), Ezawa, H. (ASTE Project manager; NAOJ), Yamamoto, S. (ASTE Project scientist), Kawabe, R. (Director of NRO), Tamura, Y., Oshima, T., Tosaki, T., Sawada, T., Nakanishi, K., Takata, T., (NAOJ), Hatsukade, B., Ikarashi, S., Tsukagoshi, T. (Univ. of Tokyo), Tanaka, K. (Keio Univ.), Cortes, J., (JAO), Khan, S. (Univ. Catorica), Bronfman, L. (Univ. of Chile), & ASTE team
- Wilson, G.W., (PI. of AzTEC; UMASS), Aretxaga, I., Hughes, D.H., (INAOE), Yun, M.S., Austermann, J., Perera, T., Rand, J., Scott, K.S., Williams, C., (UMASS), & AzTEC team



0. What is ASTE?

Atacama Submillimeter Telescope Experiment

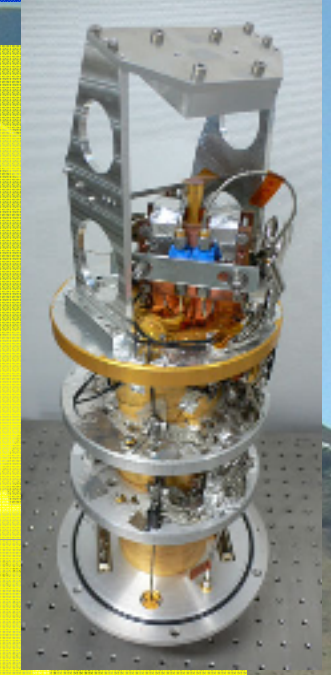
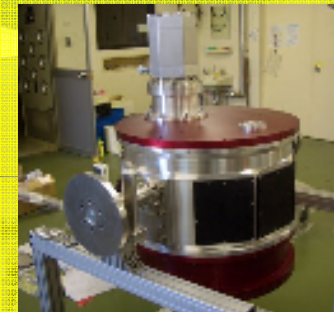
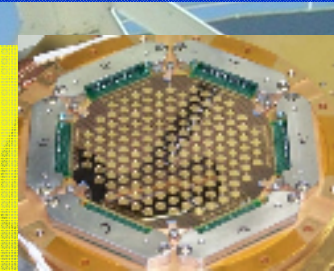
- Main reflector: D=10m
- Heterodyne spectroscopy :
350 GHz (CATS345)
490 GHz (ALAM Band-8 QM) [#]
- Continuum imaging:
1100 μm (AzTEC) *decommissioned
1100/850/450 μm [#]

#: under development

- Remote observations from Tokyo/Nobeyama
- Joint project among NAOJ and Universities

<http://www.das.uchile.cl/astechile/ASTEinicio.html>

<http://www.nro.nao.ac.jp/~aste/>



The ASTE site

- ❑ Located at alt. 4,860 m in the Atacama desert in Chile
- ❑ Many mm/submm/Infrared facilities are coming!

NANTEN2



ASTE



ACT



miniTAO/TAO



APEX



QUIET/CBI



2009 Digital
2009 Google
2009 DMaps
iv/Geosistemas SRL

Google

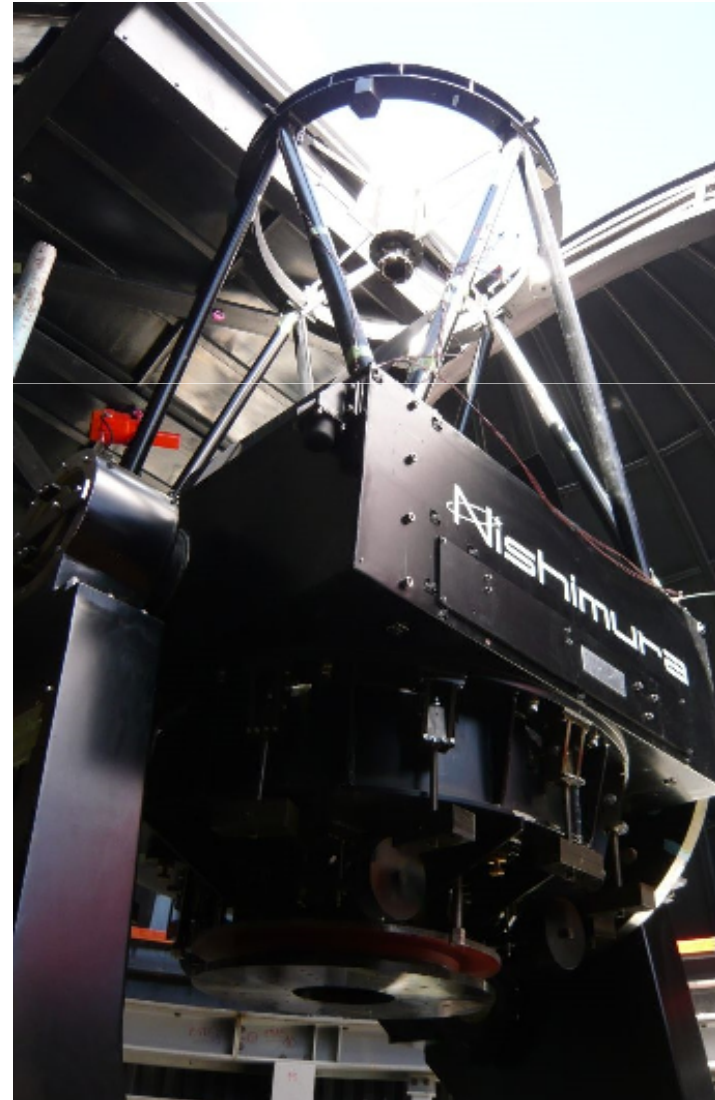
Current view of the ASTE site and the summit of Co. Chajnantor



Construction of Mini-TAO 1m telescope at the summit of Co. Chajnantor

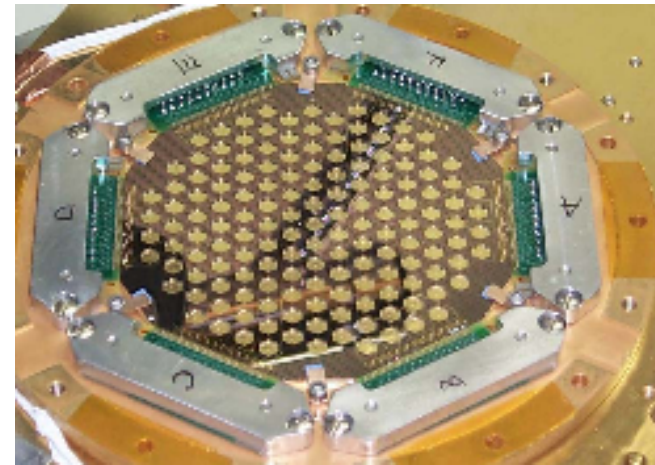
Since Feb. 2009

<http://www.ioa.s.u-tokyo.ac.jp/TAO/>
PI: Prof. Y. Yoshii (Univ. of Tokyo)



Engineering 1st light! (Mar. 22-23, 2009)





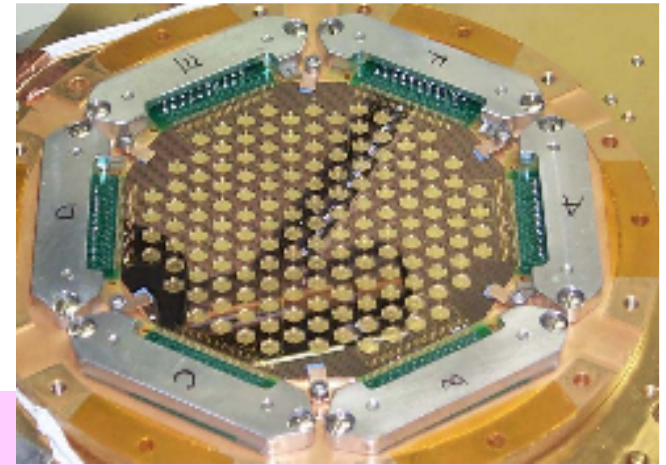
1. AzTEC-ASTE survey of SMGs

Motivations

A large portion of cosmic SF is hidden by dust! Mm/submm can probe by negative K corr.

1. Unveil hidden massive star-forming populations in the early universe → determine “true” cosmic star formation history
2. Clustering properties/LSS of SMGs → underlying dark matter distributions
 - Extreme starbursts in the biased environments
3. Comparison with other high- z populations
 - (LBGs, LAEs, LABs, DRGs, BzKs, ...) → an unified view of galaxy formation and evolution
4. Understand the FIR cosmic backgrounds
 - Only $\sim 10\%$ of CFIRB ($\lambda \sim 1\text{mm}$) is resolved into point sources so far. → constraint on galaxy formation in the very early epoch

AzTEC Camera on ASTE



- 144 pix Si_3N_4 micromesh
“spider-web” bolometers

- Wavelengths: **1100 μm**

- Spatial resolution: **28 arcsec @ ASTE 10m**

- Mapping speed: **10-30 arcmin² hr⁻¹ Jy⁻²**

→ x20 faster than SCUBA on JCMT !!

- Innovated atmospheric emission removal technique optimized for faint point sources (i.e., SMGs)
- Superb transmission of sky in Atacama

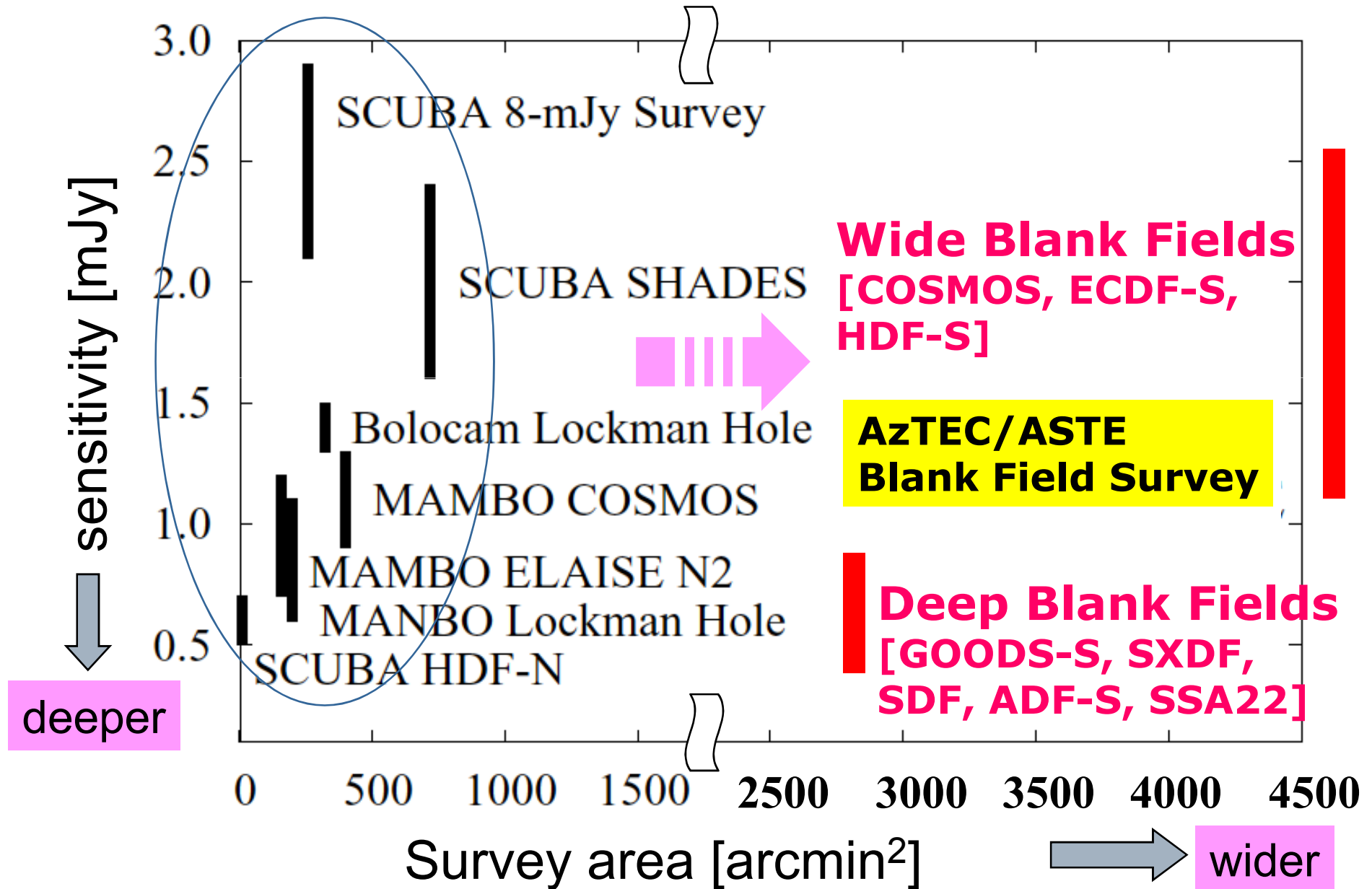
- Developed for LMT 50m; waiting for it

- Successful operation on JCMT (late 2005) just after decommissioning of SCUBA

<http://www.astro.umass.edu/aztec/>

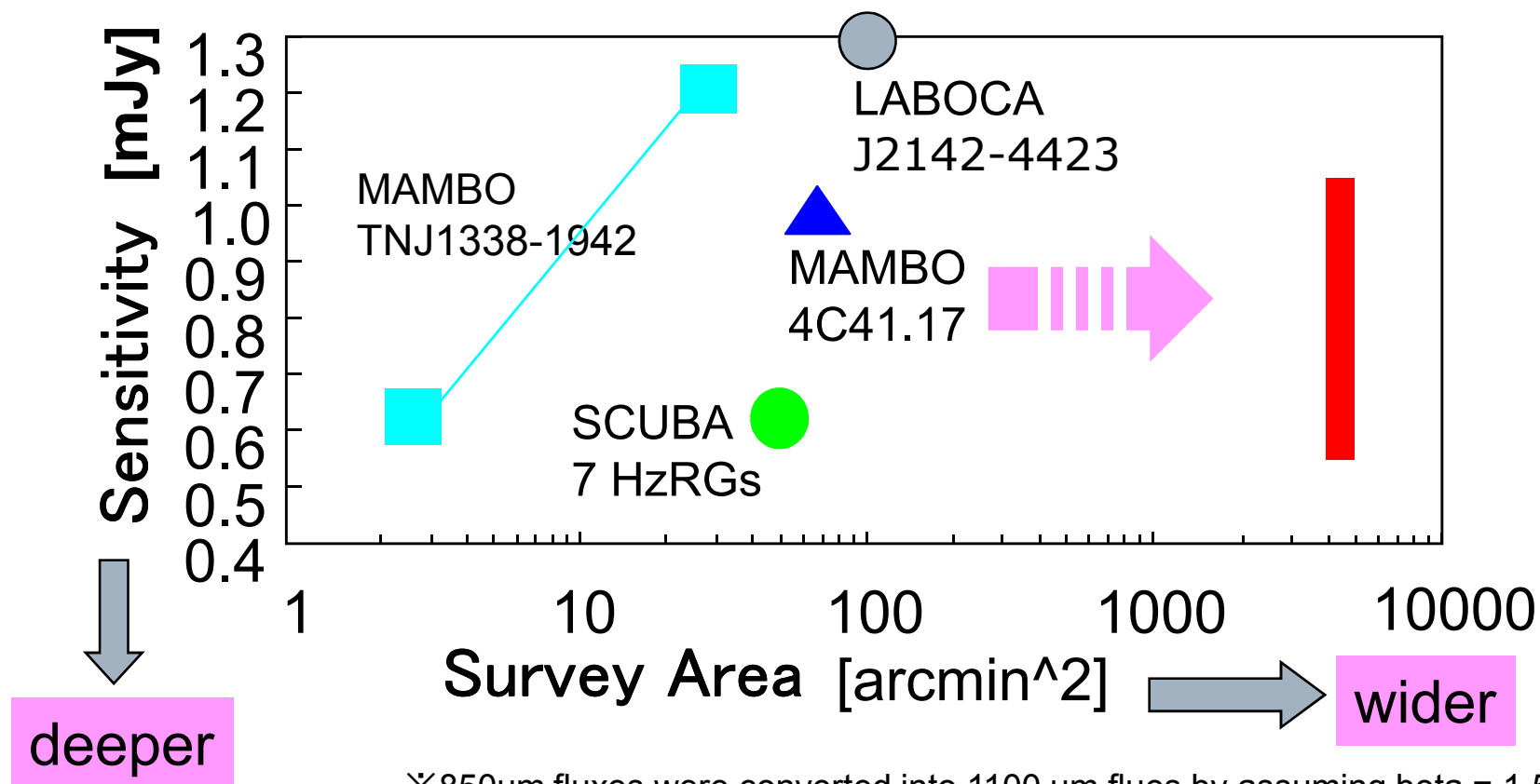
**PI. G. Wilson
(UMASS)**

AzTEC/ASTE Blank Field Survey

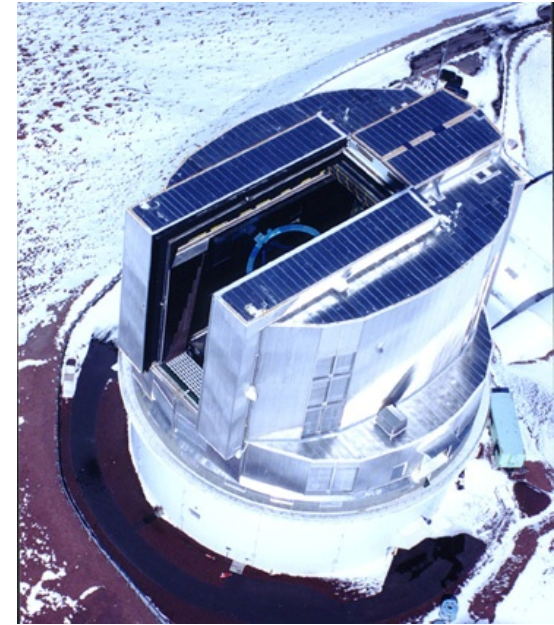


AzTEC-ASTE Biased Field Survey

High-z proto-cluster survey
[4C23.56, TNJ1338-1942,
... (~40 HzRGs/X-ray detected clusters)]



※850um fluxes were converted into 1100 um fluxes by assuming beta = 1.5



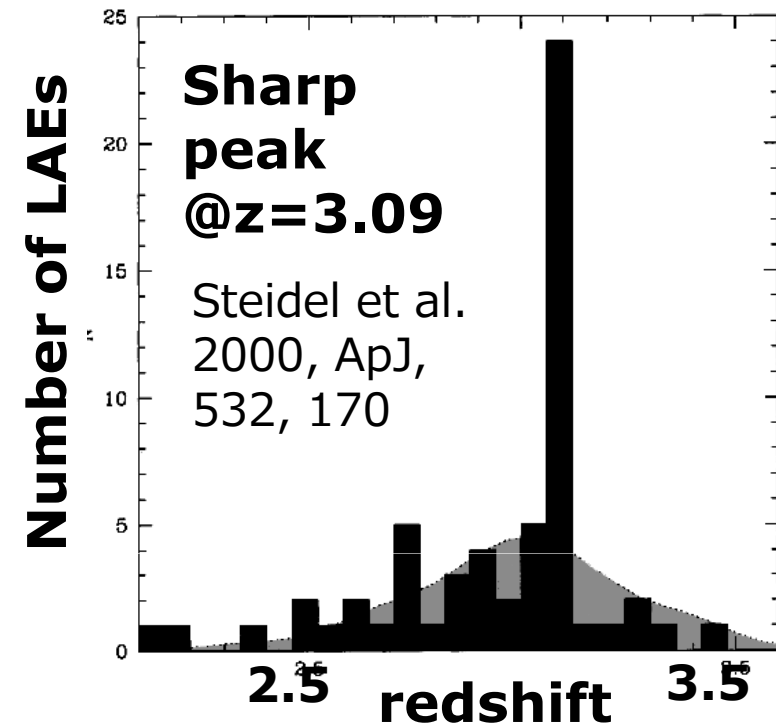
***2. Joint analysis
between AzTEC-ASTE
and SUBARU: SSA 22***

A difficulty of current SMG study

- How can we determine the distances (redshifts) of them?
 - Radio/mm/submm ID → optical spectroscopy
 - Direct spectroscopic determination with CO?
 - Either works, but very time consuming..
- Yoichi Tamura proposed an interesting new method:
- Taking a two point angular **cross-correlation** between SMGs and other population of galaxies with *known* redshift (in this case, LAEs)

SSA 22: a proto-cluster @ $z=3.1$

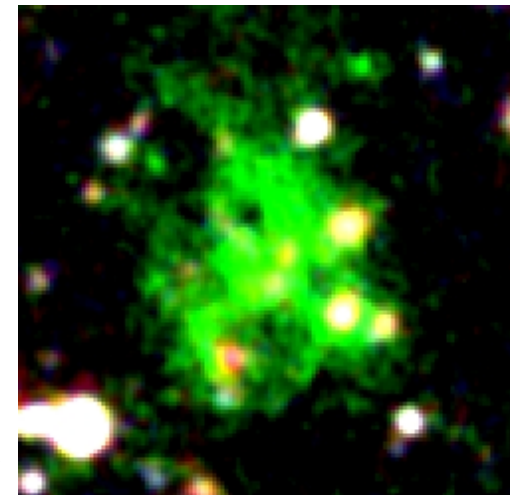
- Over density of LAEs around $z=3.1$
 - Steidel et al. 1998, 2000
- LLS of LAEs
 - Hayashino et al. 2004
 - Nakamura et al. 2007
- “Nest” of LABs
 - Matsuda et al. 2004
- No powerful AGN?
 - Comparison with other proto-cluster regions with powerful RGs



“LAB1”

**25” or
190 kpc**

Matsuda
et al. 2004

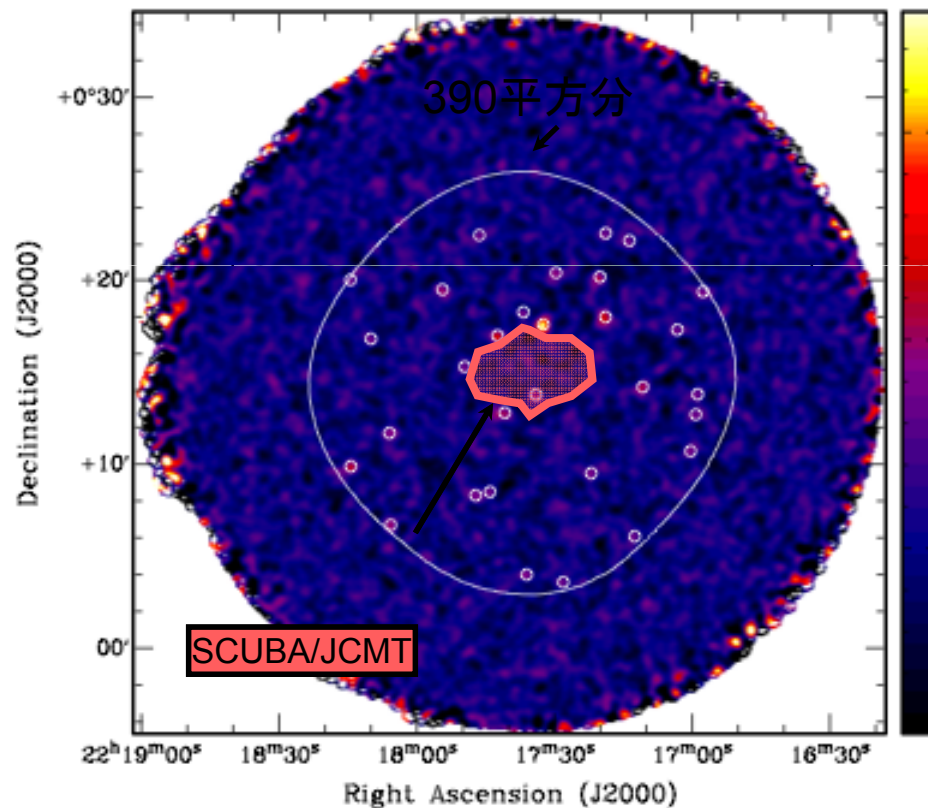


AzTEC/ASTE 1.1mm image of SSA22

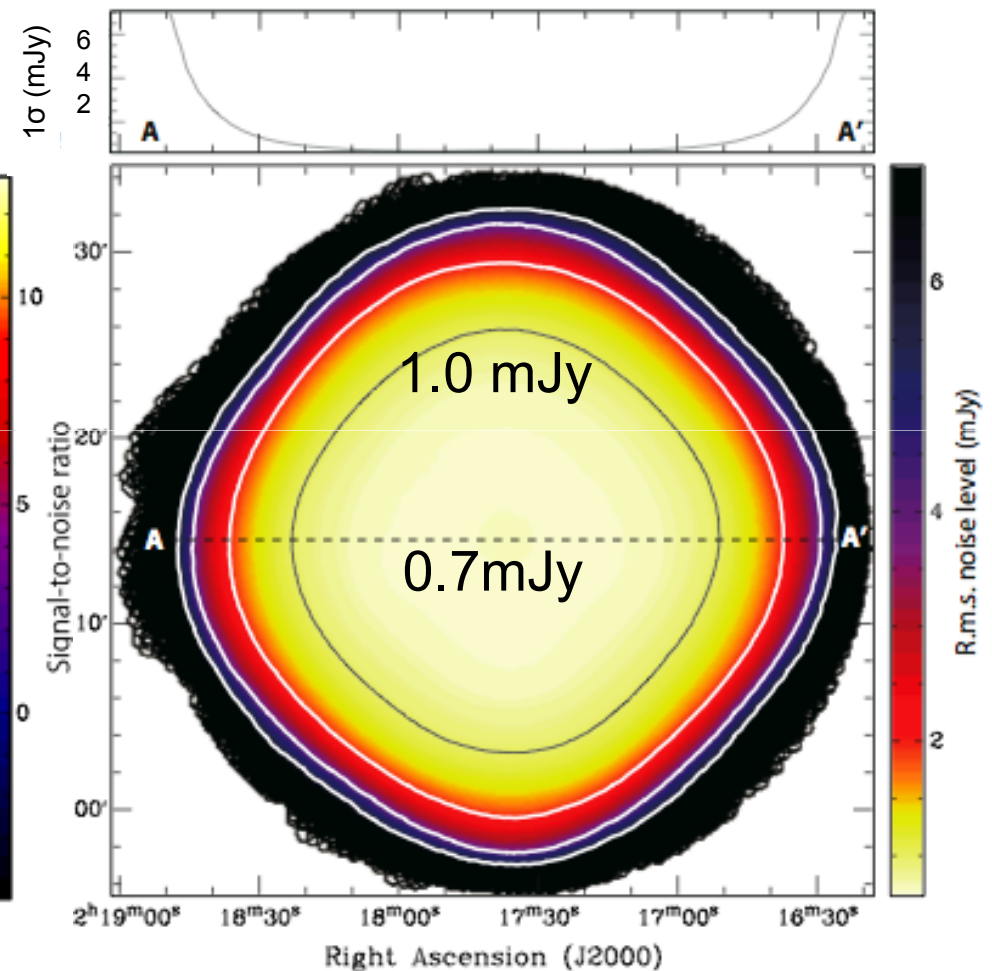
S/N map

✧ 30 robust sources ($S/N > 3.5$)

✧ $1 \text{ FTR} > 4 \times 10^{12} \text{ cm}^{-2}$



Noise map

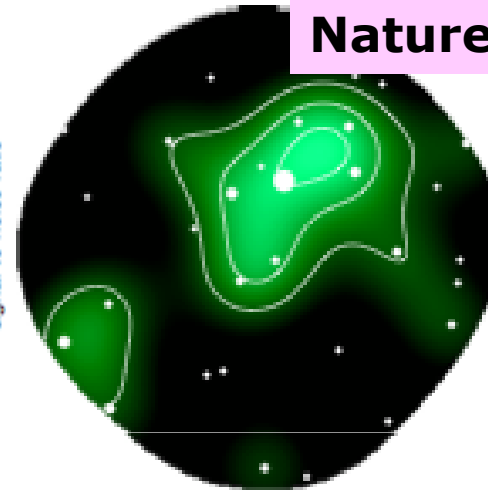
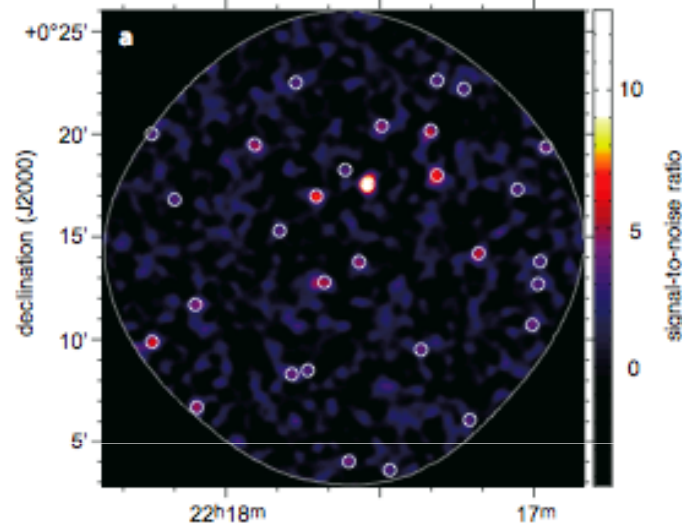


✧ The central uniform noise area ($\sigma < 1.0 \text{ mJy/b}$, 390 arcmin^2) is used for the following discussion

Clustering of SMGs toward the biased region traced by LAEs

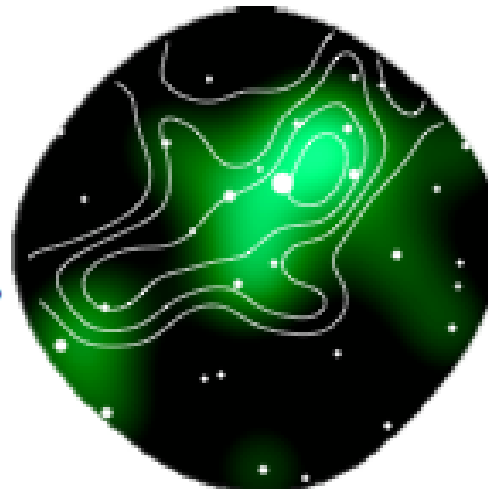
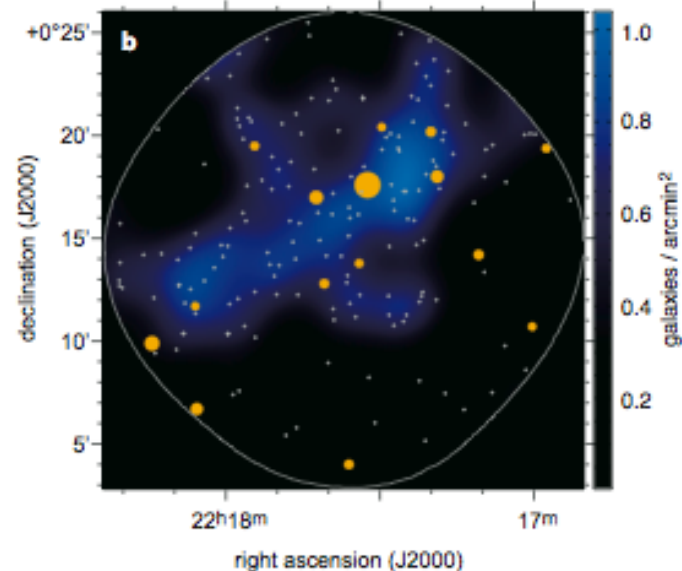
**Tamura et al., 2009,
Nature, 459, 61**

1.1mm image



Number density
contours of
bright SMGs

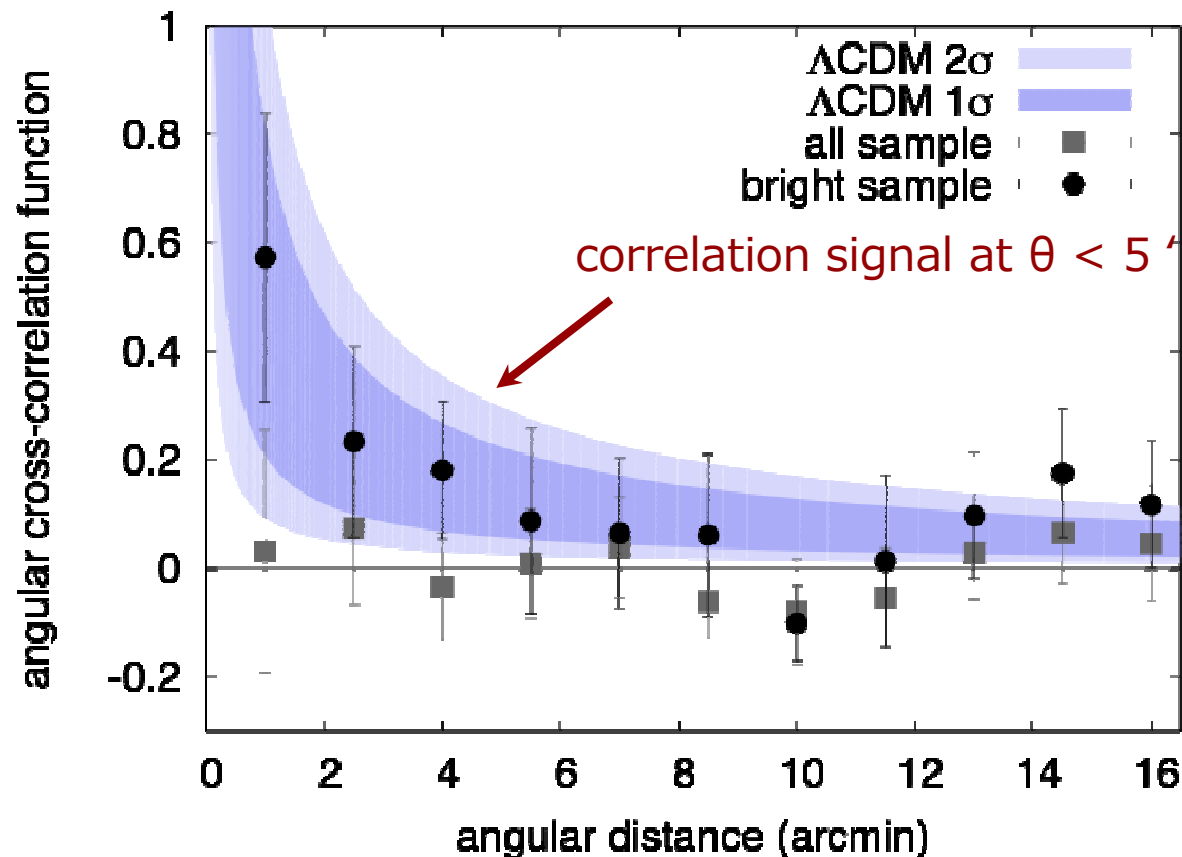
“Bright” SMG
on Ly α emitters



Color: Number
density of
bright SMGs
Contour:
Number density
of LAEs

Large-scale correlation of SMGs & LAEs

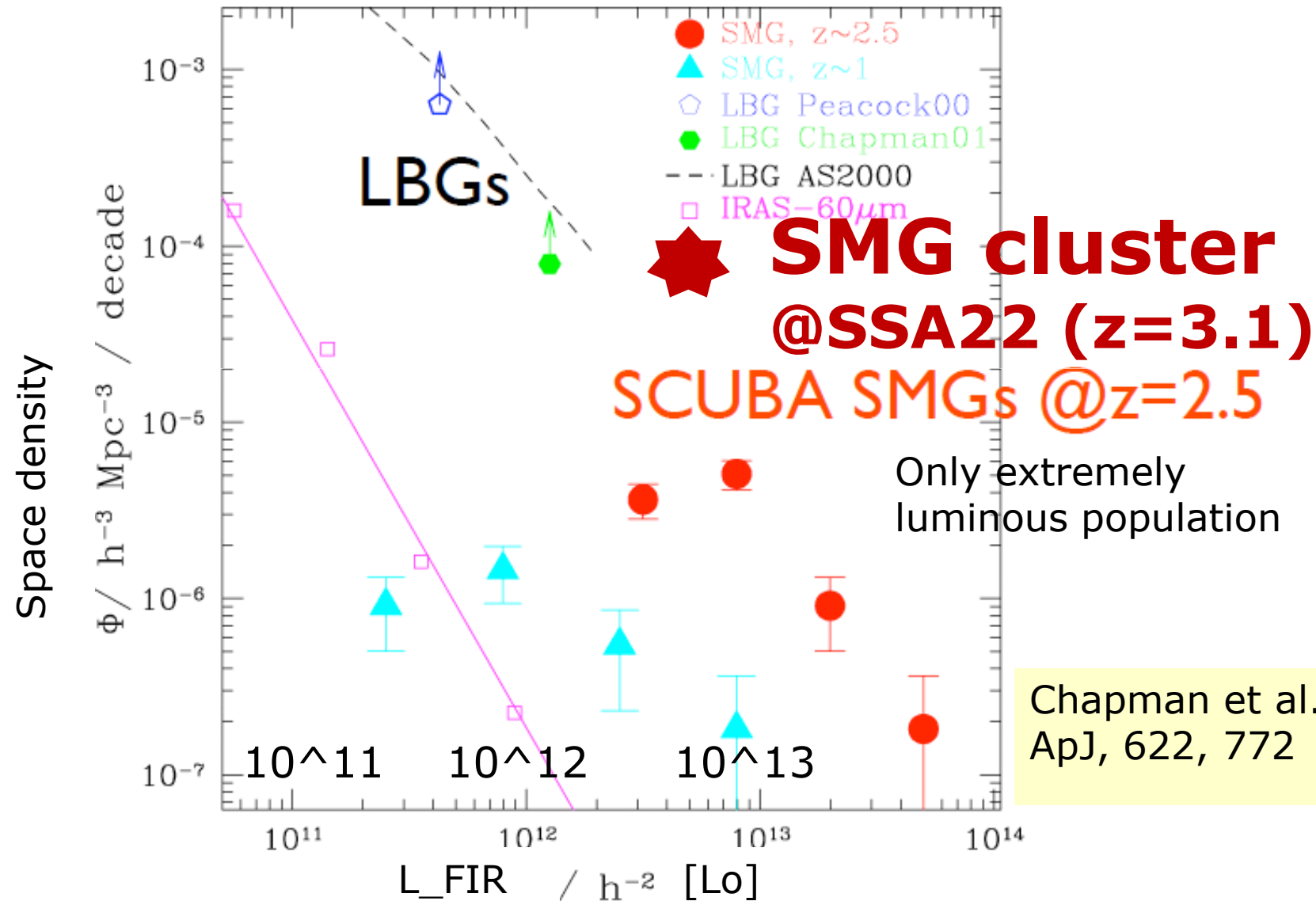
- 2-point angular cross-correlation between SMGs & LAEs
 - Landy & Szalay's estimator
 - probability of finding a source of the other population at distance θ
- Association with SMGs and LAEs is also reproduced by a simulation



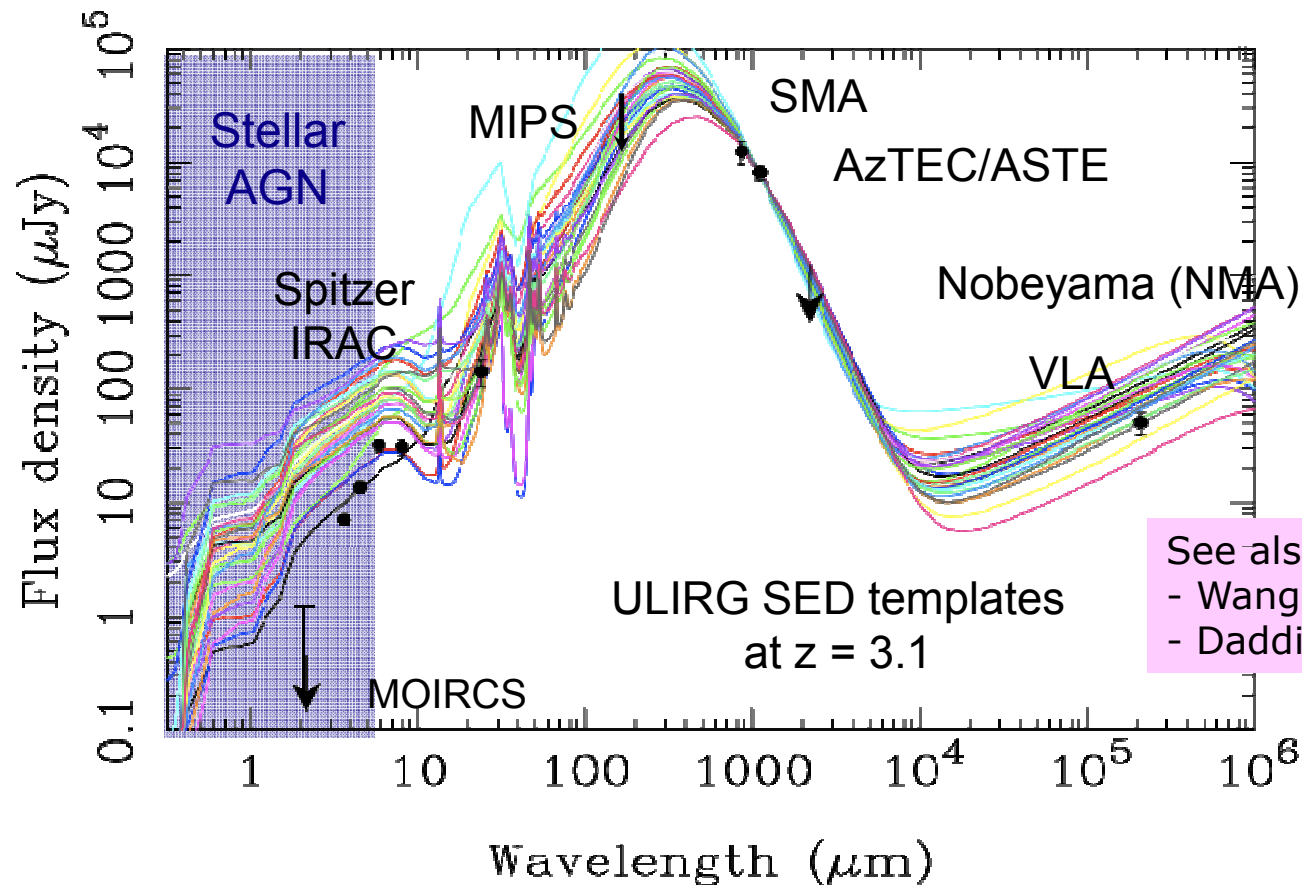
**Tamura et al., 2009,
Nature, 459, 61**

**Hirashita et al., 2009
Submitted to MNRAS**

"SMG cluster" of SSA22: enormous enhancement of space density



K-drop/extremely red SMG population



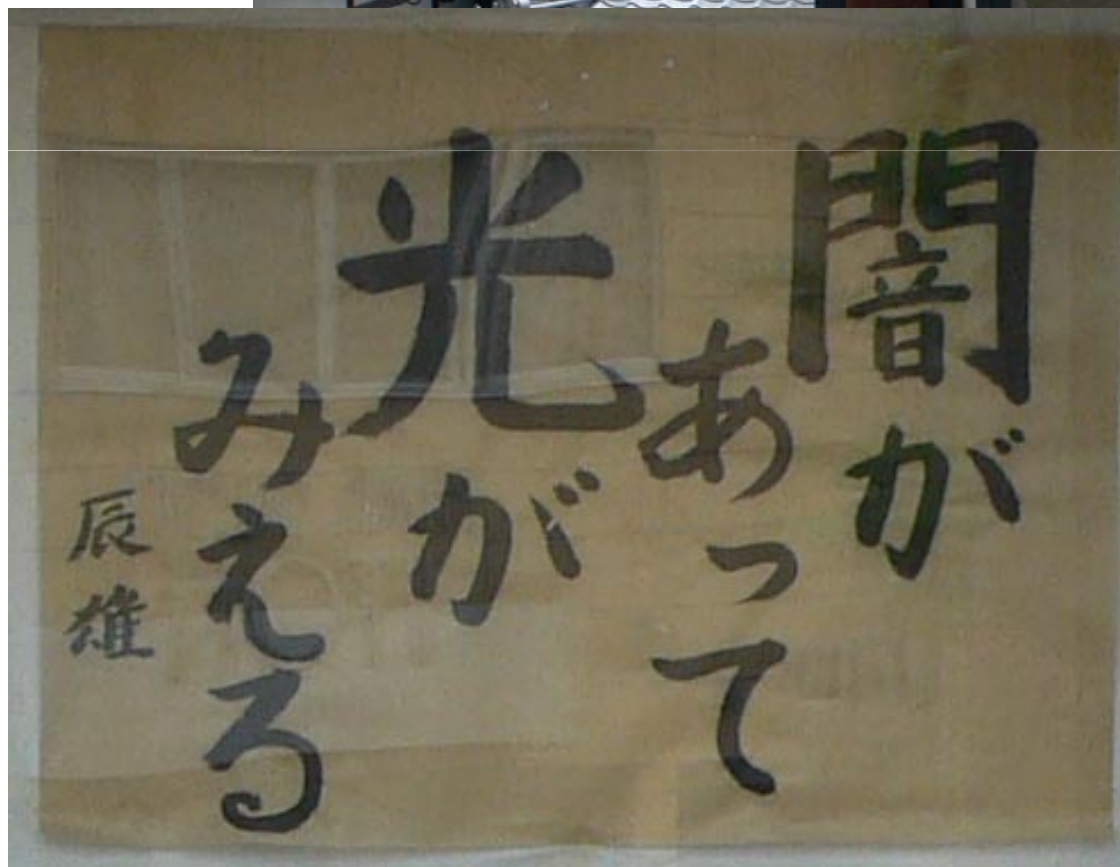
Y. Tamura
et al. 2009
in prep.

See also: GOODS 850-5/GN10
- Wang+ 2009, ApJ, 690, 319
- Daddi+ 2009, ApJ, 695, L176

- SED at $\lambda > 5\mu\text{m}$ is consistent with that at $z=3.1$
→ this source can be indeed associated with the large scale structure traced by LAEs
- Rapid decrease at short wavelengths ($\lambda < 5\mu\text{m}$)

This situation has been described as..

- Translation (?) "There is a darkness of K' band, whereas you find a brightness at the submillimeter wavelength there."



LETTERS

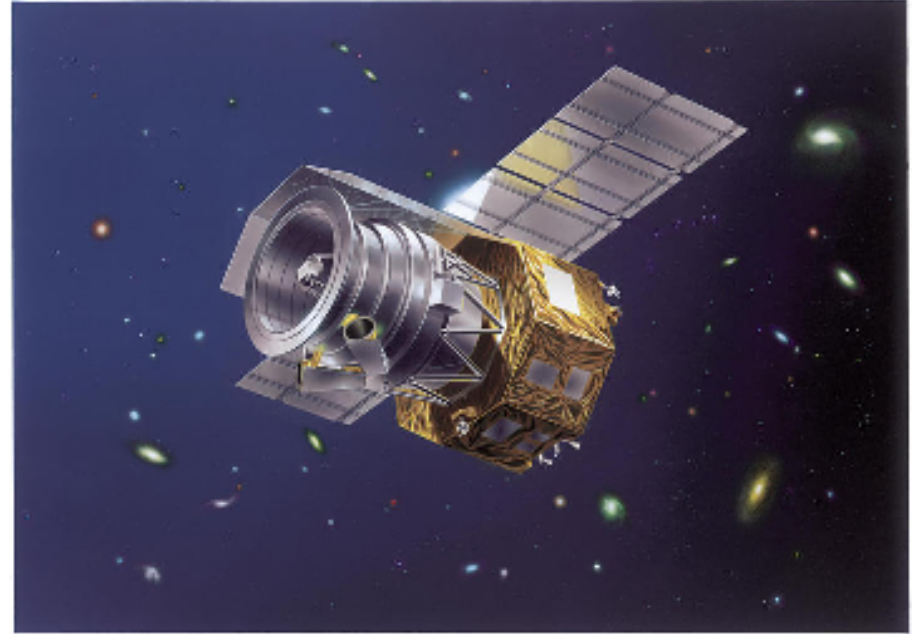
Spatial correlation between submillimetre and Lyman- α galaxies in the SSA 22 protocluster

Yoichi Tamura^{1,2}, Kotaro Kohno³, Kouichiro Nakanishi^{2,4}, Bunyo Hatsukade³, Daisuke Iono^{3,4}, Grant W. Wilson⁵, Min S. Yun⁵, Tadafumi Takata², Yuichi Matsuda², Tomoka Tosaki⁴, Hajime Ezawa⁴, Thushara A. Perera⁵, Kimberly S. Scott⁵, Jason E. Austermann⁵, David H. Hughes⁶, Itziar Aretxaga⁶, Aeree Chung⁵, Tai Oshima⁴, Nobuyuki Yamaguchi⁴, Kunihiro Tanaka⁴ & Ryohei Kawabe⁴

Lyman- α emitters are thought to be young, low-mass galaxies with ages of $\sim 10^8$ yr (refs 1, 2). An overdensity of them in one region of the sky (the SSA 22 field) traces out a filamentary structure in the early Universe at a redshift of $z \approx 3.1$ (equivalent to 15 per cent of the age of the Universe) and is believed to mark a forming protocluster^{3,4}. Galaxies that are bright at (sub)millimetre wavelengths are undergoing violent episodes of star formation^{5–8}, and there is evidence that they are preferentially associated with high-redshift radio galaxies⁹, so the question of whether they are also associated

limited in sensitivity and spatial coverage, they support the idea that SMGs are related to large-scale structure. To better understand the connection between the formation of massive galaxies and large-scale structure, we mapped the large-scale distribution of (sub)millimetre-bright, dusty starburst galaxies in the SSA 22 protocluster.

We carried out a wide-area (390-arcmin^2) survey of the SSA 22 field at $1,100\text{ }\mu\text{m}$ using the AzTEC camera¹³ mounted on the Atacama Submillimeter Telescope Experiment (ASTE)¹⁴, Chile (see also Supplementary Fig. 1). Our AzTEC map (Fig. 1a) which is more



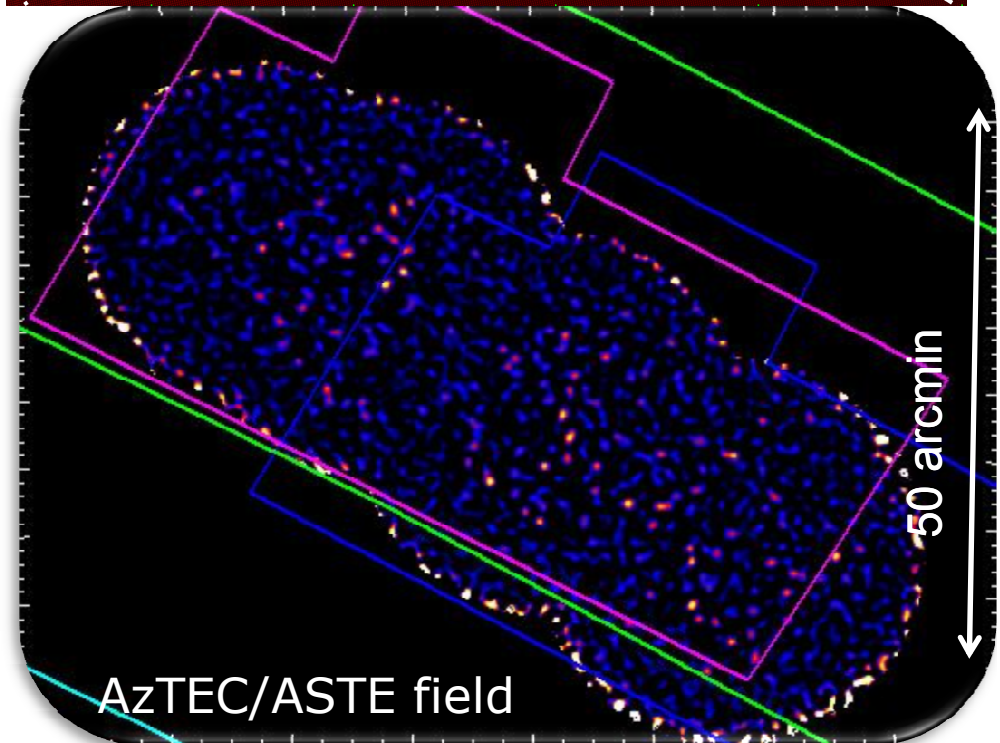
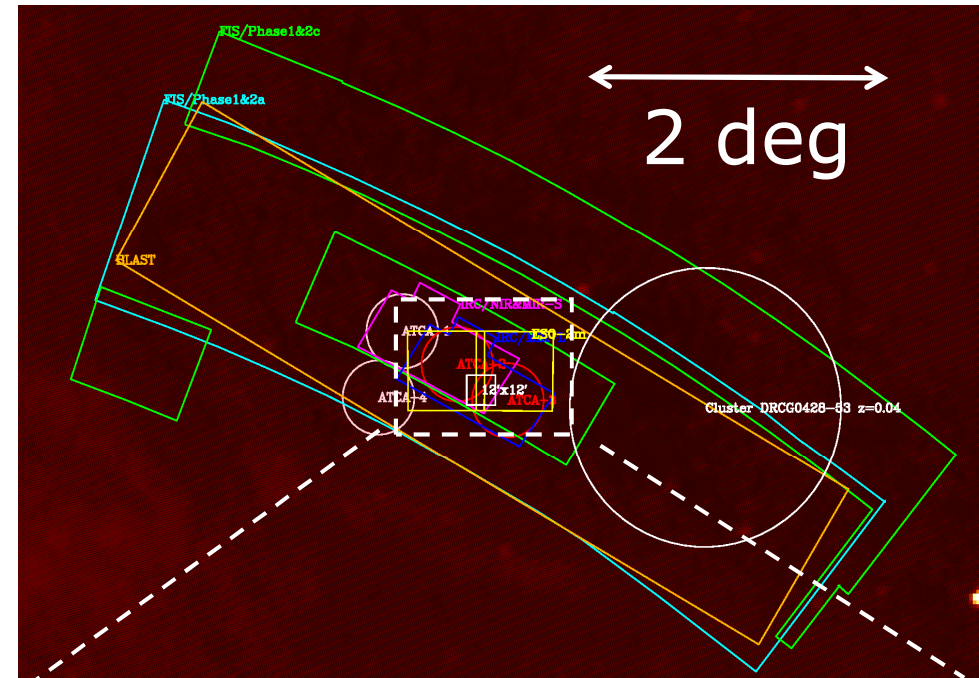
*3. Necessity of access to
Southern large telescopes:
AKARI Deep Field South*

ADF-S (SEP)

- the lowest cirrus emission
unique window to high-z
- multi-wavelengths data
 - AKARI/FIS, $\sim 12 \text{ deg}^2$ ($\sim 20 \text{ mJy @ } 90 \mu\text{m}$)
 - AKARI/IRC (NIR)

**See a poster presentation
by Mai Shirahata et al.**

- GALEX (UV)
- CTIO (B,V,R,I,Ks)
- Spitzer/MIPS
- BLAST (250,350,500 μm)
- Laboca/APEX (870 μm)
- AzTEC/ASTE (1100 μm)
- ATCA (20cm)



AzTEC/ASTE 1100 μ m image of ADF-S

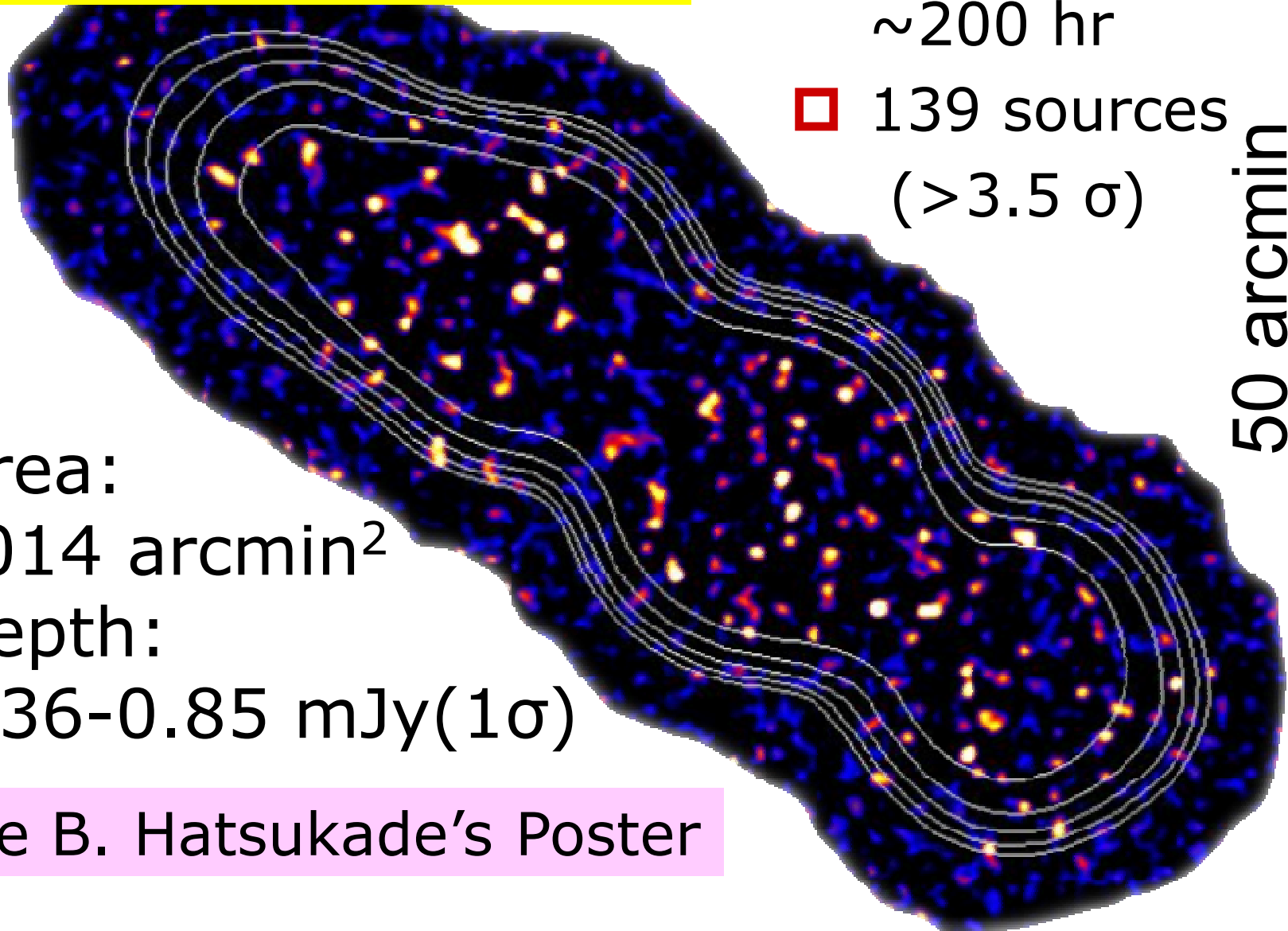
Widest & Deepest to date!

□ on-source:
 ~ 200 hr

□ 139 sources
($> 3.5 \sigma$)

- area:
1014 arcmin²
- depth:
0.36-0.85 mJy(1σ)

See B. Hatsukade's Poster



The issue: how to follow up?

□ Deep NIR imaging

$M(\text{gas/dust})$ from ALMA
 $M(*)$ from NIR (+ SFR)

- to access stellar component of SMGs
- to compare with NIR selected star forming galaxies (sBzK, DRGs, etc.)

✓ Currently we use ISPI/Blanco 4m, but ...



SDF/SXDF
accumulating
NIR data

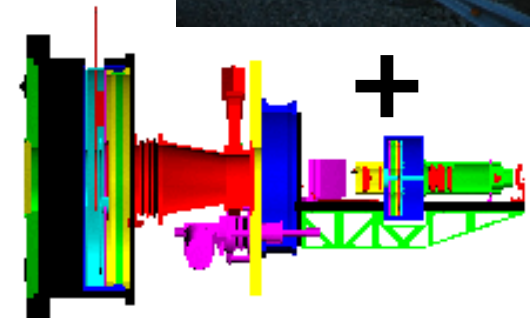
□ Sensitive NIR spectroscopy

- Redshift determination via H α /Ly α
- Line emitter search (H α /OII/etc.)

□ GEMINI-S with FLAMINGOS-2

will be a unique opportunity

Note that >20 pointings must be still required to cover entire AzTEC/ASTE field ($\sim 1000 \text{ arcmin}^2$) even with the wide coverage of FLAMINGOS2 ($7' \times 7'$)



Summary

- Unprecedentedly wide and deep surveys of submillimeter galaxies (SMGs) @1.1mm
 - Using AzTEC-on-ASTE in Chile
 - Unique sample of dusty high-z extreme starbursts
- Combined analysis of 1.1mm and optical/IR data: How fruitful they are
 - SSA 22, discovery of SMG cluster
 - Deep NIR observations will also be a key
- ALMA is coming! Access to Southern sky through GEMINI-S is attractive & crucial
 - ADF-S, a new unique deep field in southern sky
 - TAO will also join for Southern sky surveyer