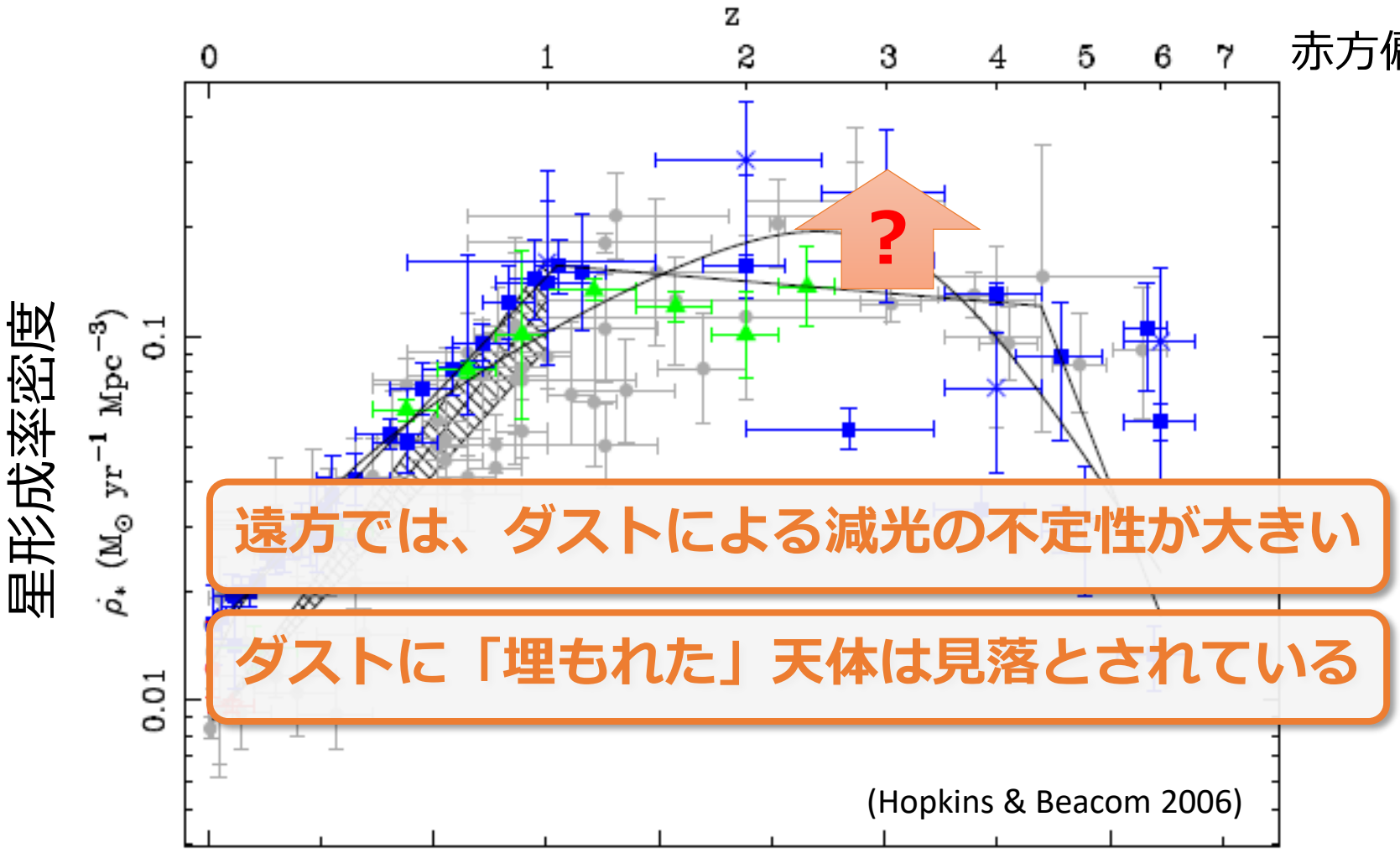
研究紹介

廿日出

広い観点からの目標
「宇宙星形成史の理解」



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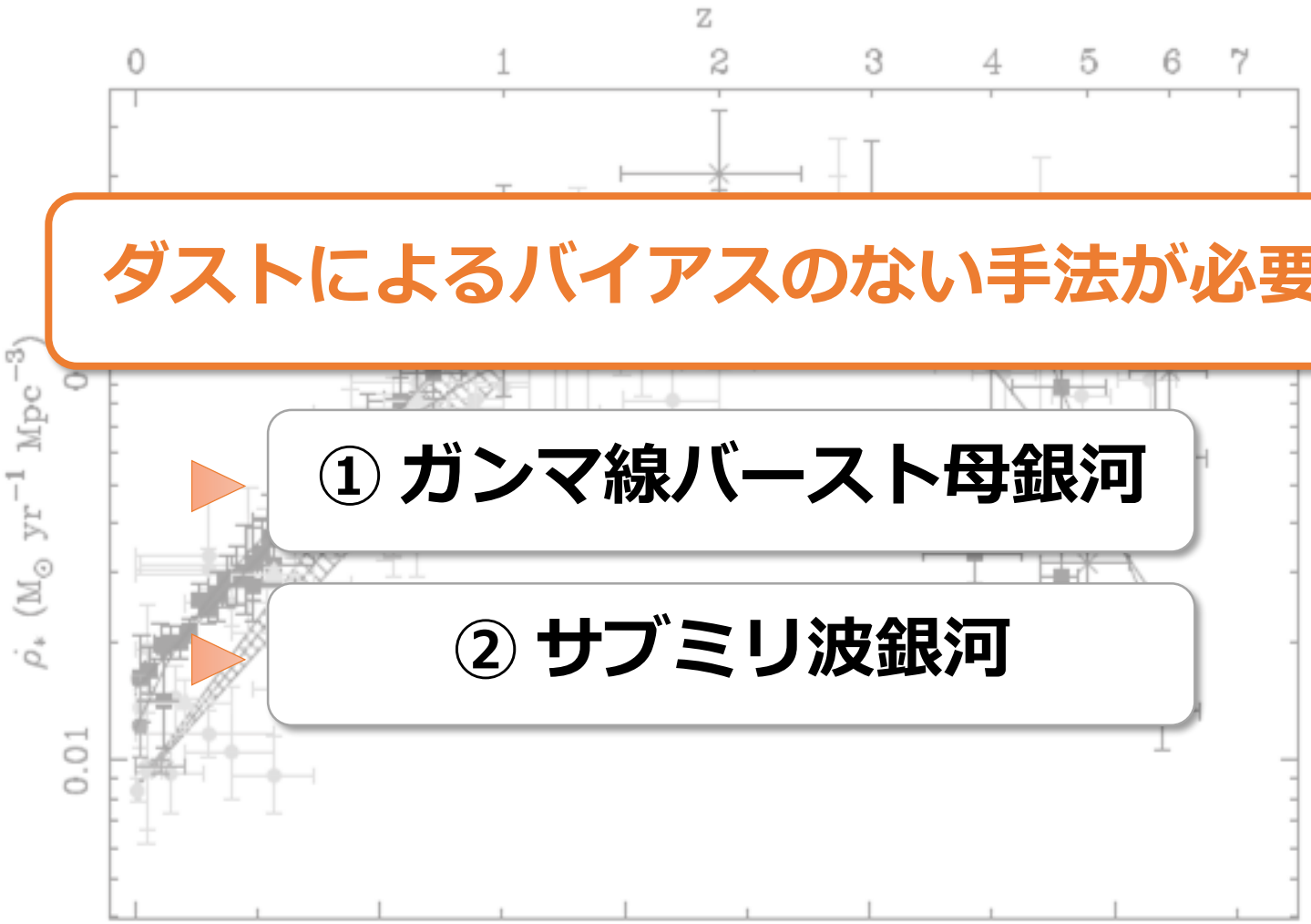
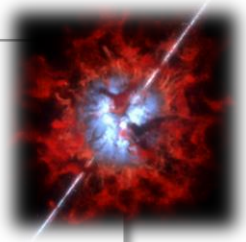


ダストによるバイアスのない手法が必要

- **① ガンマ線バースト母銀河**
- **② サブミリ波銀河**

① ガンマ線バースト母銀河

Long-duration Gamma-ray Burst (GRB)



- 大質量星の終末の大爆発に起因
  - ↳ 星形成活動と密接に関連
- 近傍(z=0.0085)から遠方(z>7, 8)まで検出可

遠方宇宙での星形成活動を探る新たなプローブ

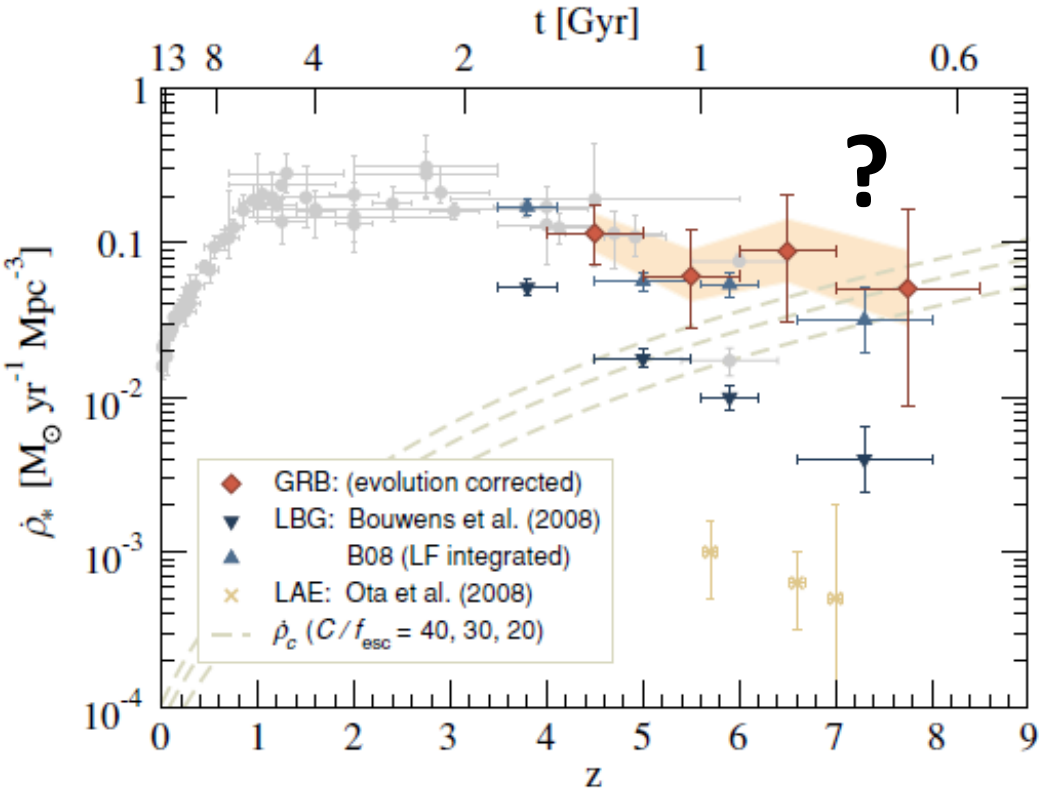
GRBの発生環境、母銀河における星形成活動の理解が必須

Long-duration GRBs: Probes of Star-forming Activity

LGRBs can be used as an ***unbiased*** tracer of star formation?

e.g., Perley+13, Greiner+15

➡ *Need to understand the properties of LGRB hosts*

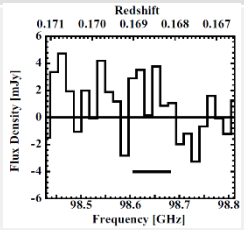
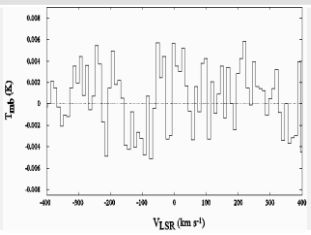
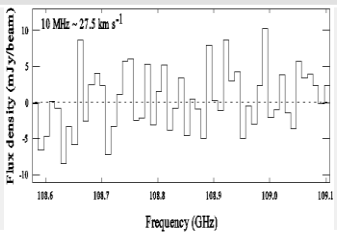
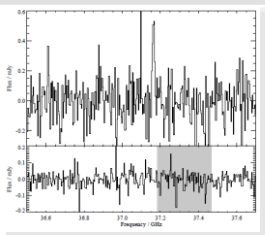


Robertson+11

分子ガス(星形成の材料)の観測

CO輝線強度 ＝ 分子ガス質量の指標

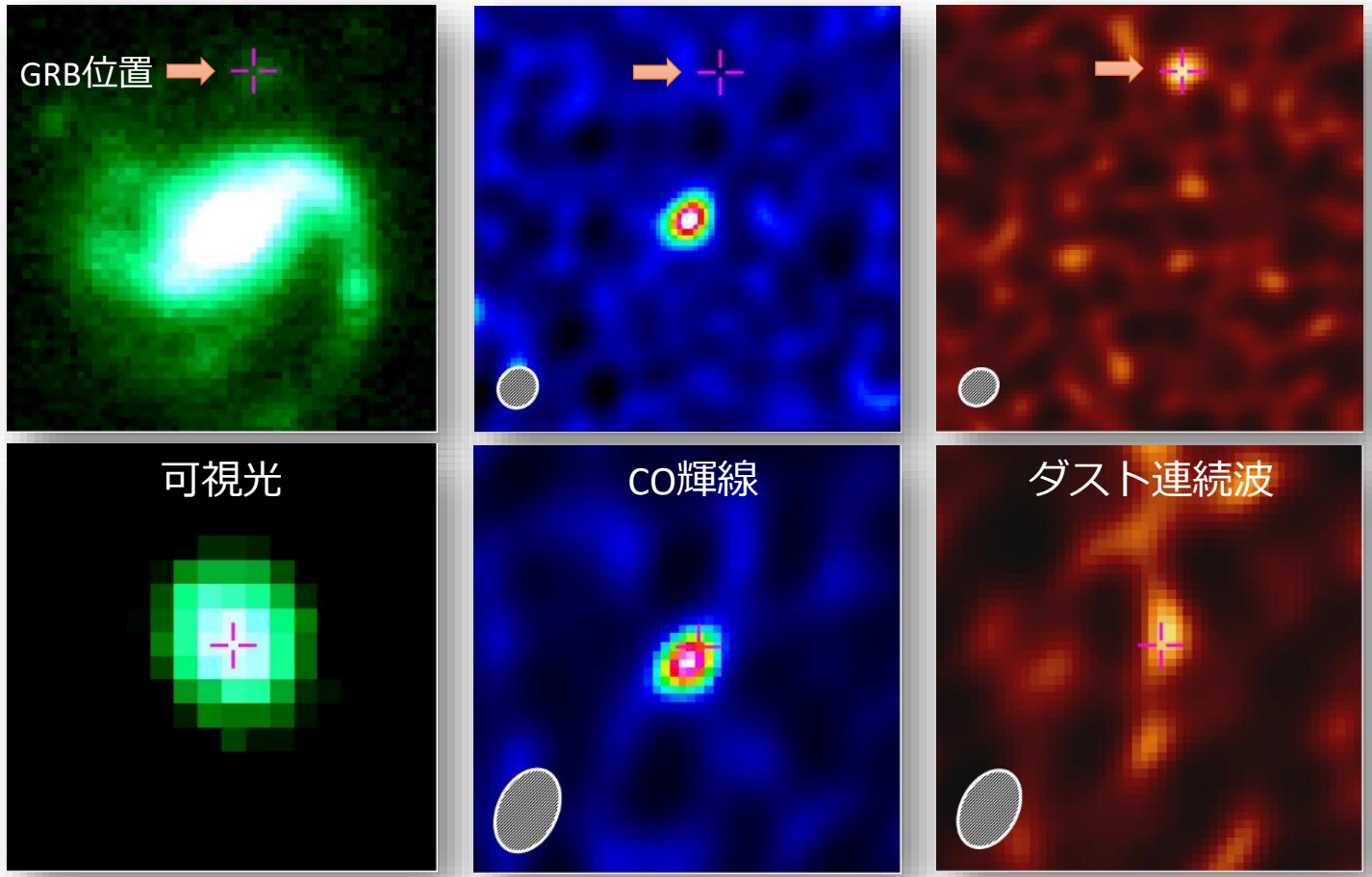
これまで検出された例はなかった

Telescope	NMA	ASTE	PdBI	ATCA
				
GRB Host	**GRB 030329**	**GRB 980425**	**GRB 000418**	**GRB 090423**
Date	**2003-2005**	**2005**	**2006-2007**	**2010**
Ref.	**Kohno+05 Endo+07**	***Hatsukade+07***	***Hatsukade+11***	**Stanway+11**
Spectra (non detection)				

ALMAによる観測

GRB母銀河における初の**CO輝線検出** (*Hatsukade+14*)

GRB020819B母銀河では分子ガスとダストの分布が**大きく異なる**



GRBの一般的な発生環境を探る

ALMA観測の結果 (Hatsukade+14)

GRB母銀河の分子ガス量を測定することに成功

➡ **分子ガスの観点から研究する新たな手法を開拓**

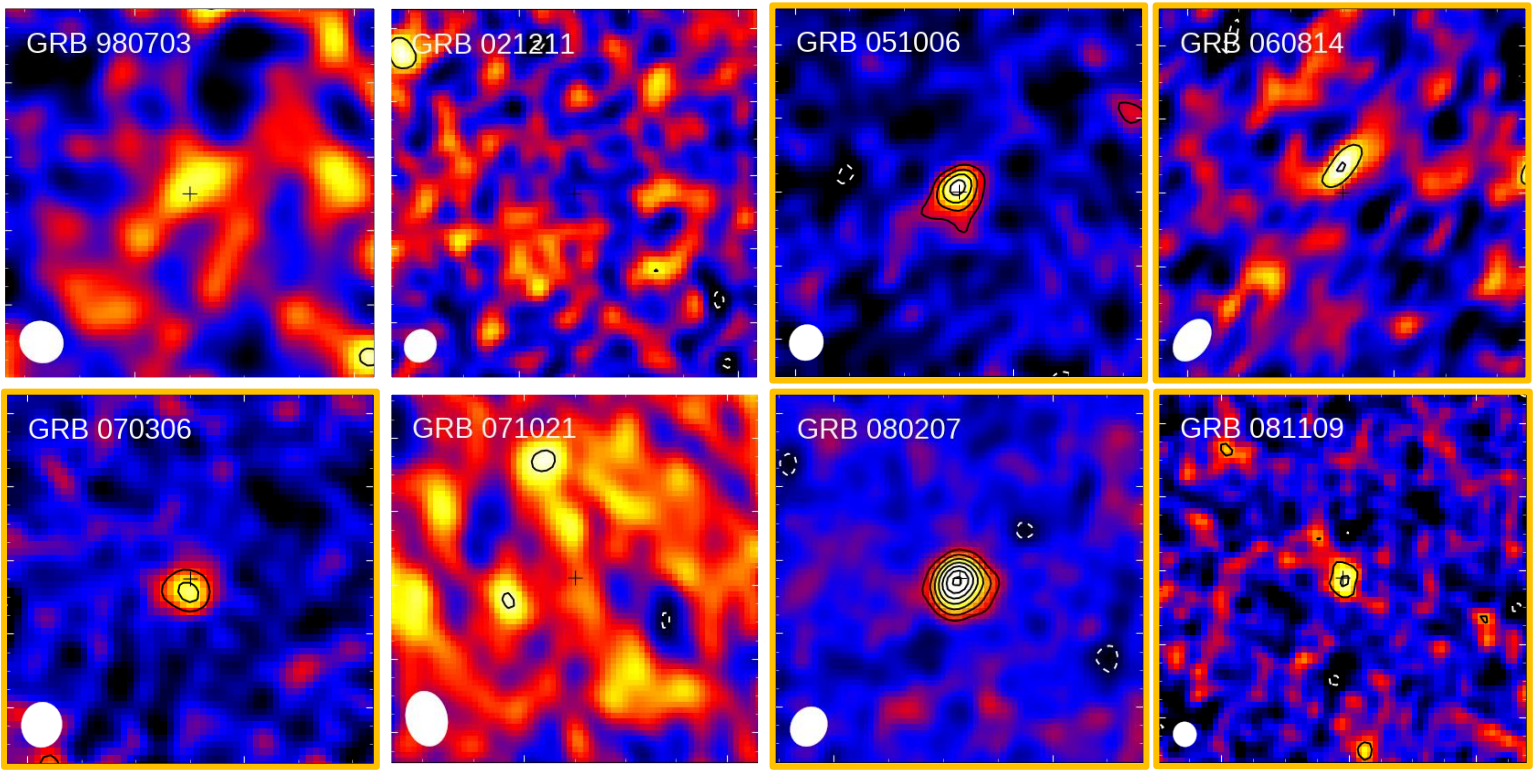
分子ガスとダストの空間分布が大きく異なる

➡ **GRBは特殊な環境で発生か？**

GRBが発生する一般的環境を探るには
他の母銀河での検証が必要

ALMA cycle 3

- 10 hosts were observed
- CO detection in 5 hosts (+ 1 tentative)
  - z = 1.0-2.1



Hatsukade+ (in prep.)

ALMA cycle 3

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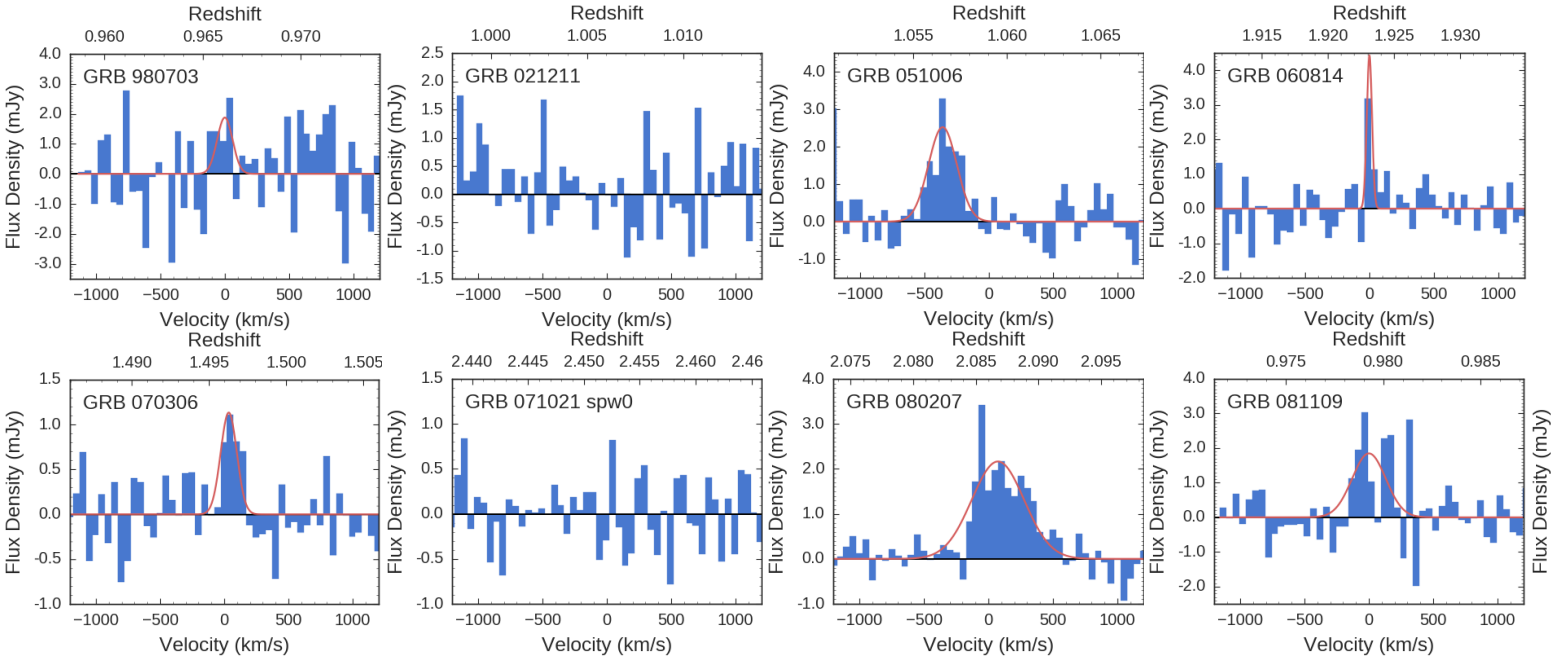
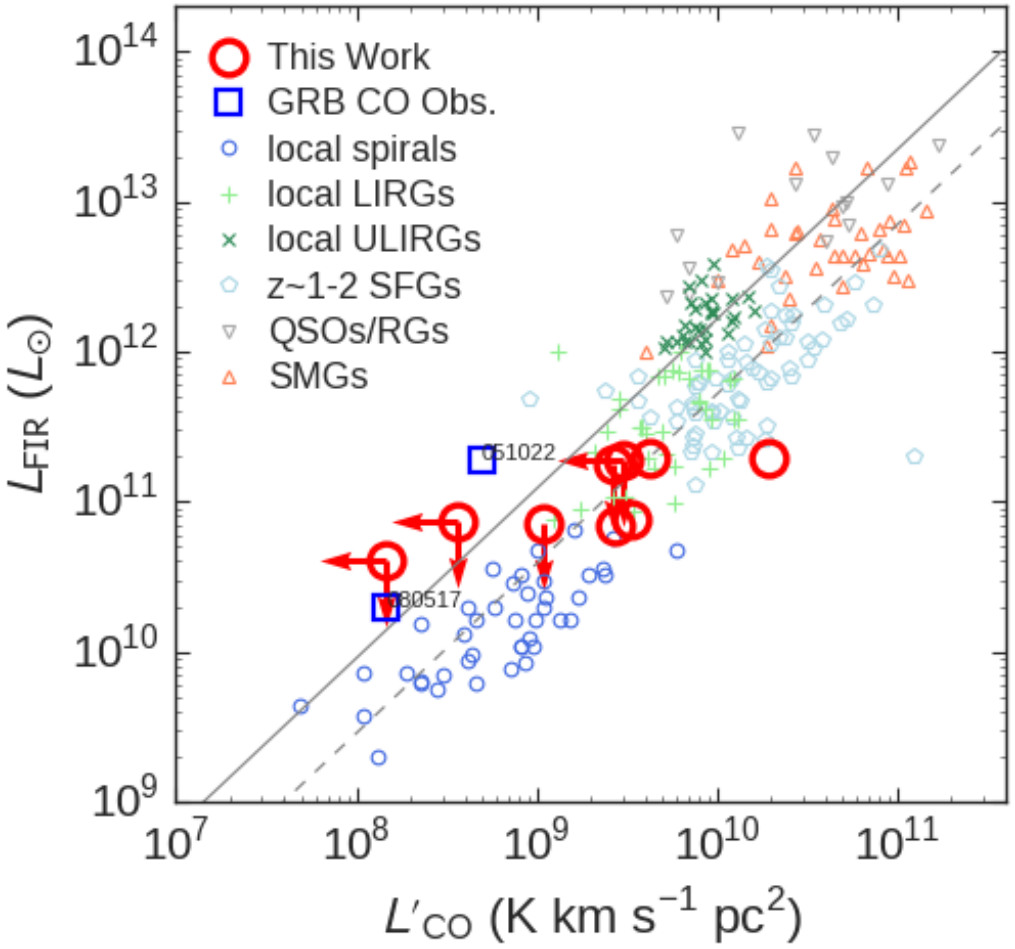


Hatsukade+ (in prep.)

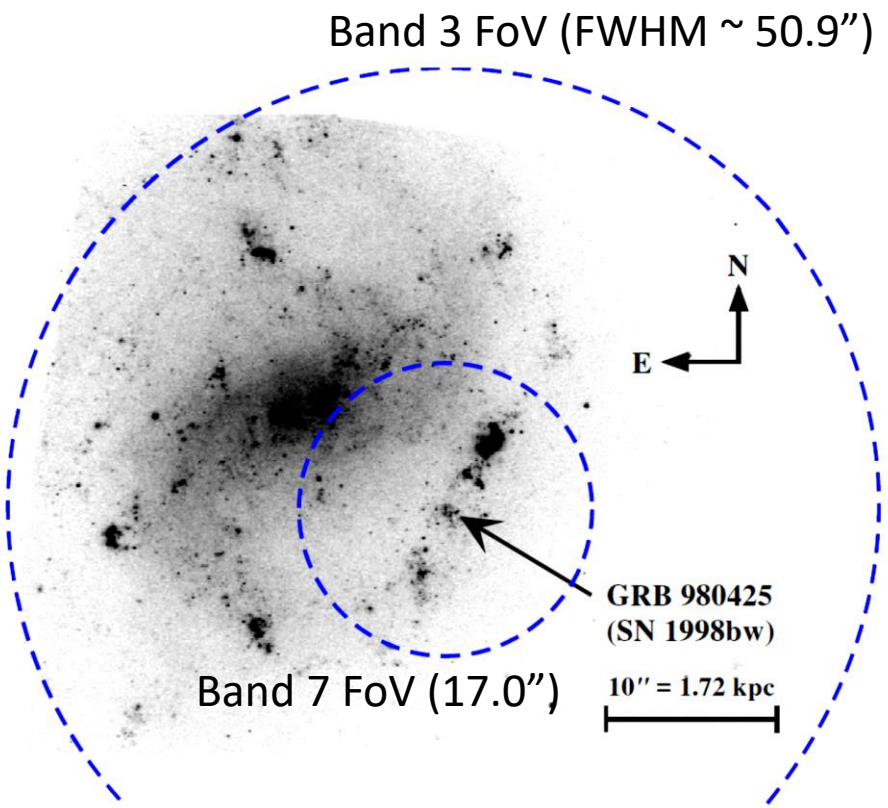
Star Formation Efficiency (SFE)

SFEs (L_{FIR}/L'_{CO}): comparable to normal SF galaxies at z ~ 1-2



Cycle 4: GRB 980425 Host

- GMC-scale molecular gas (5×10^5 Msun) with SN ≥ 5
- 0.59” resolution (100 pc)
- CO(1-0) at band 3
  - 1σ = 1.4 mJy, Δv = 5 km/s
- CO(3-2) at band 7
  - 1σ = 3.3 mJy, Δv = 5 km/s

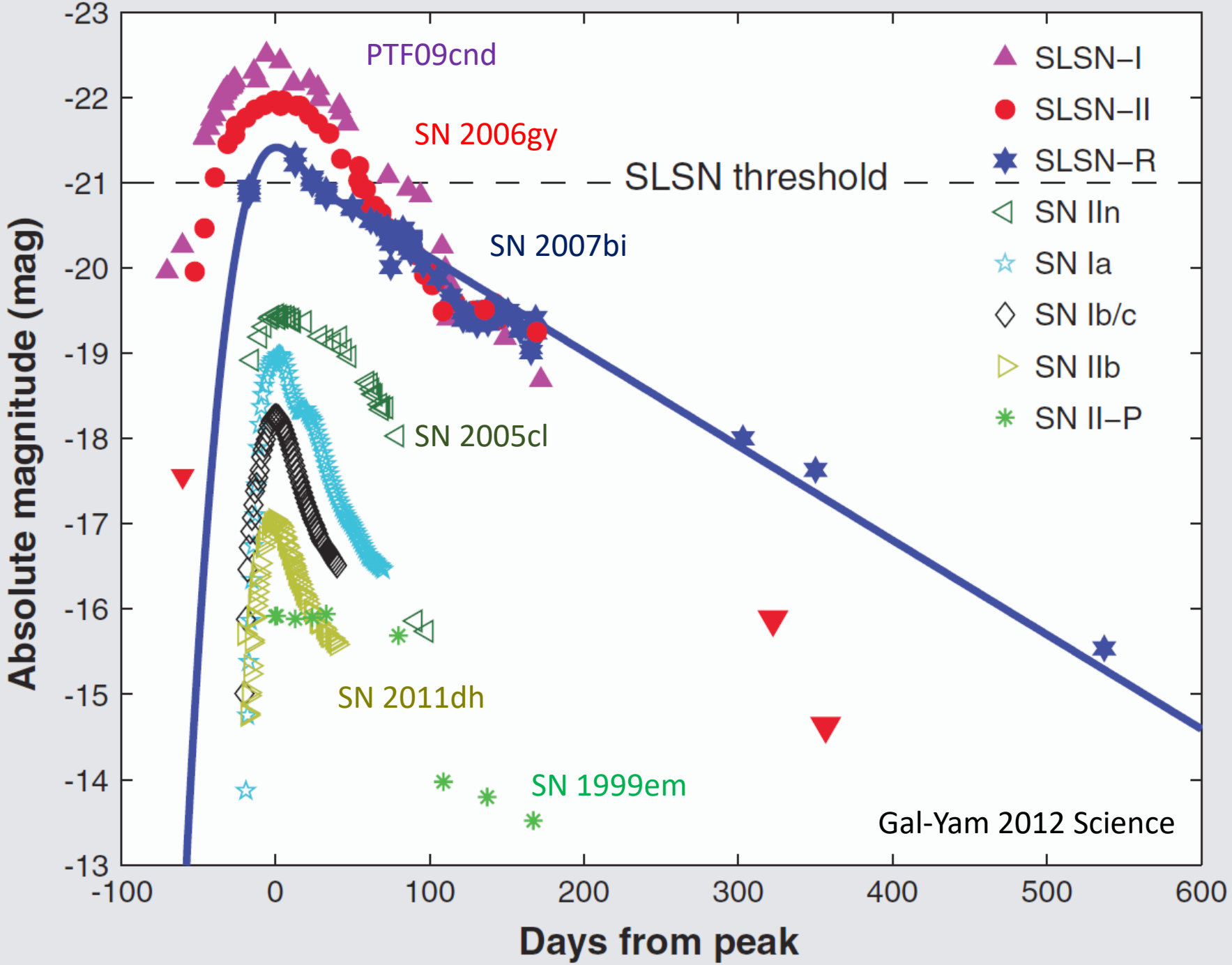


Super-luminous Supernovae (SLSNe)

- Very bright explosions, ~10-100 times brighter than ordinary Type Ia and core-collapse SNe
  - Gal-Yam 12
- Detected at high redshifts, up to z = 3.9
  - Cooke+12

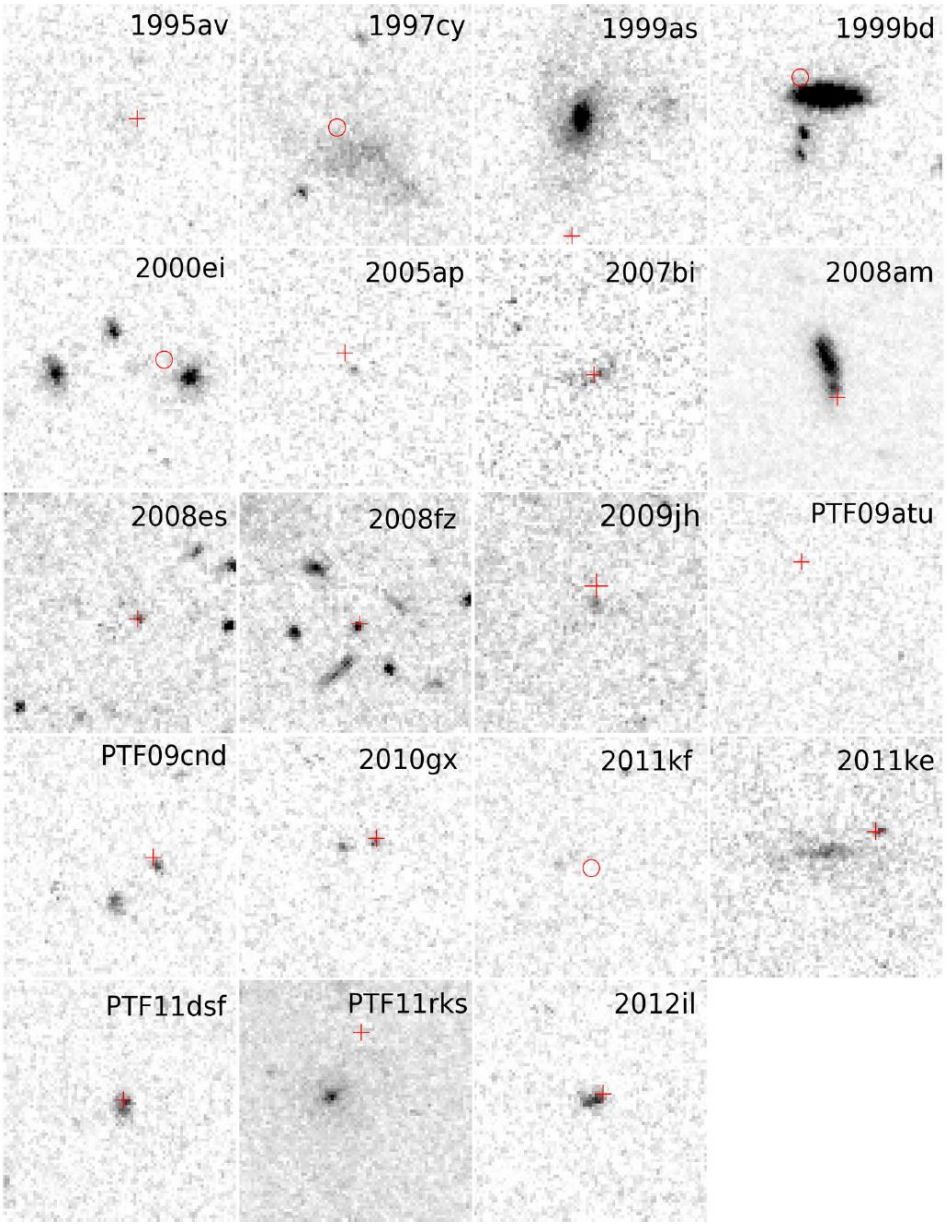
➔ powerful indicators of environments in the distant universe

- Classes
  - SLSN-I : hydrogen-poor in spectra
  - SLSN-II: hydrogen-rich in spectra
  - SLSN-R: a long light-curve tail powered by radioactive decay

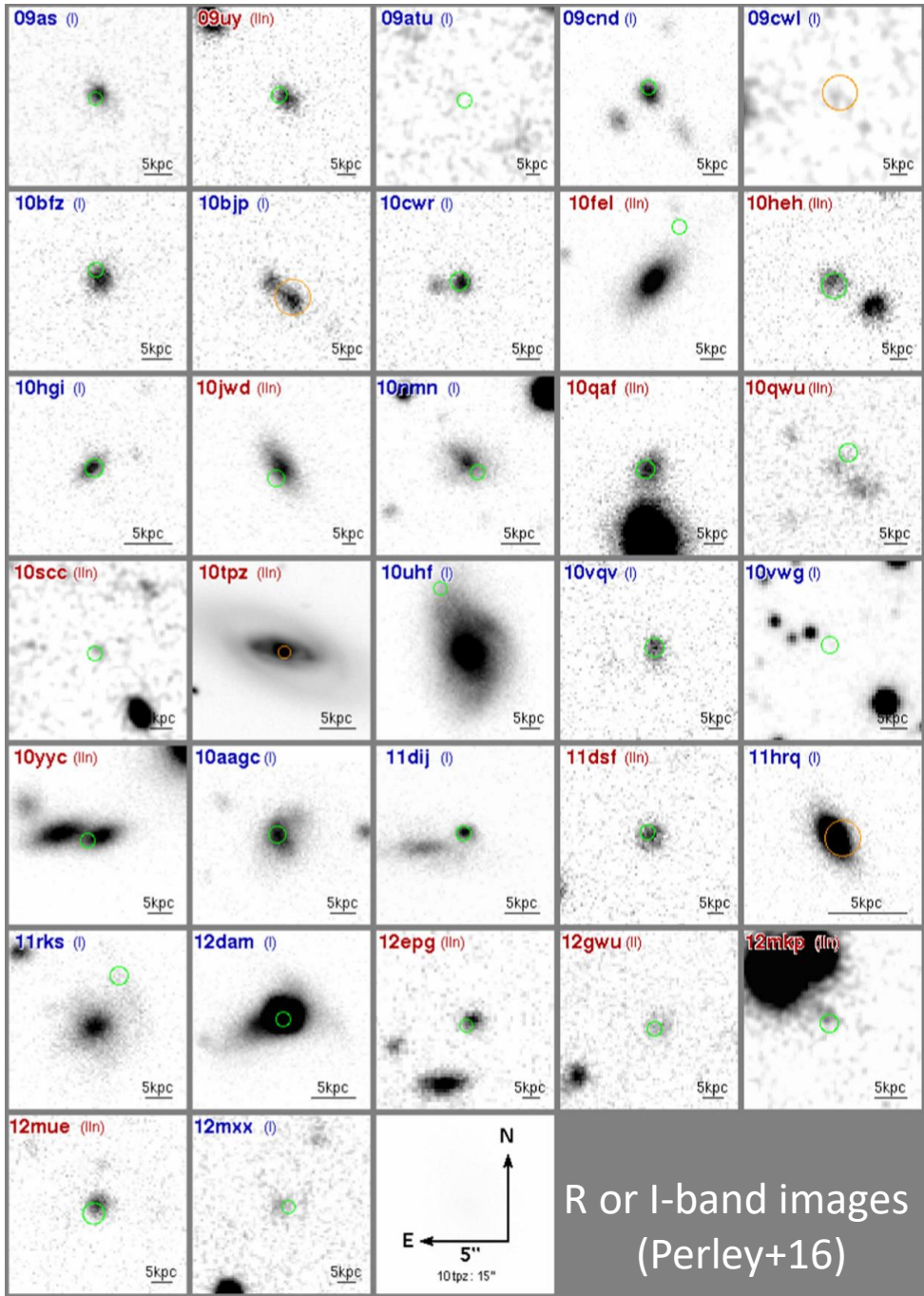

PTF09cnd
SN 2006gy
SLSN threshold
SN 2007bi
SN 2005cl
SN 2011dh
SN 1999em
SLSN–I
SLSN–II
SLSN–R
SN IIn
SN Ia
SN Ib/c
SN IIb
SN II–P
Gal-Yam 2012 Science
Absolute magnitude (mag)
Days from peak
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14
-13
-100
0
100
200
300
400
500
600

Host Galaxies

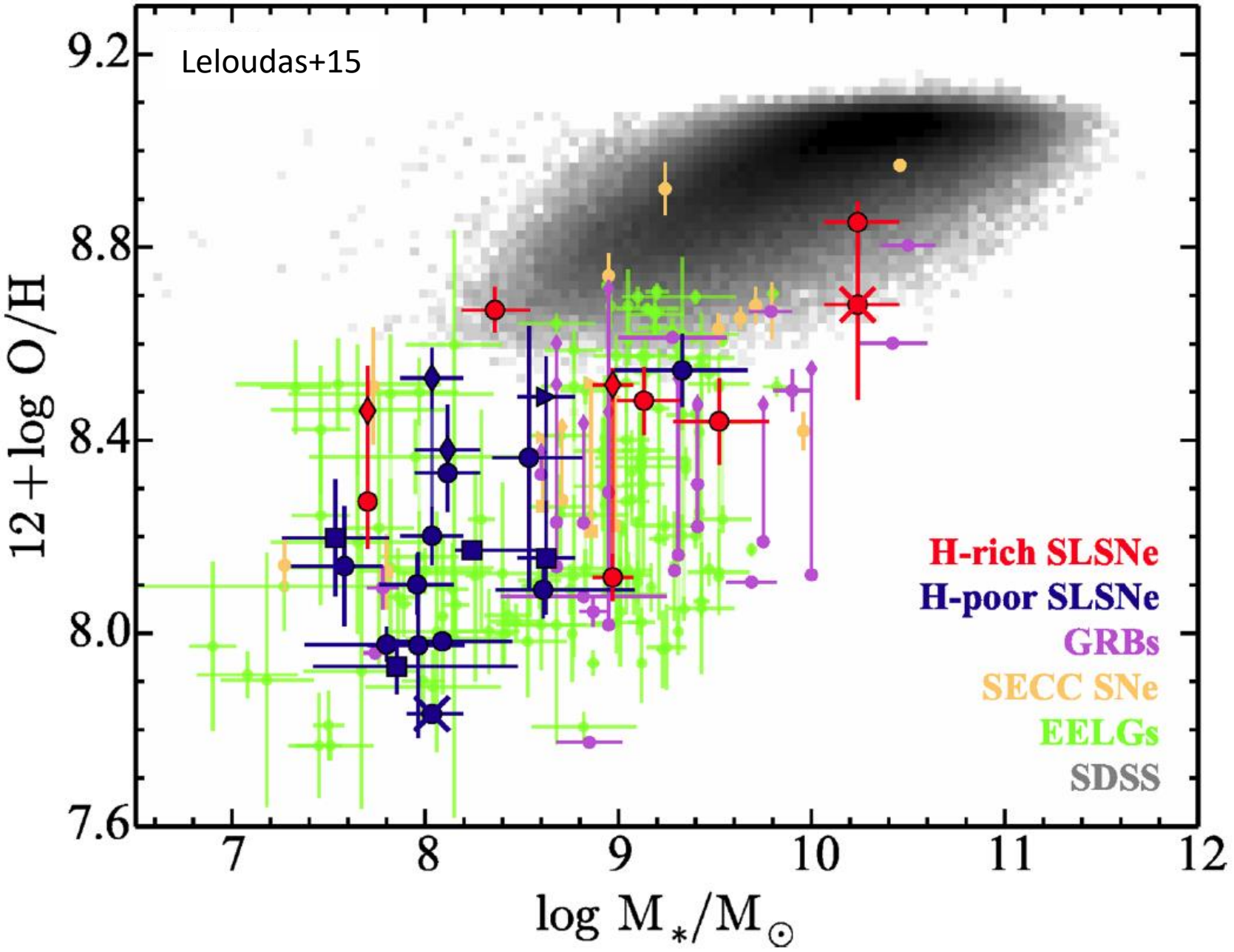
- SLSN-I hosts
  - low-luminosity, low stellar mass, and low SFR galaxies compared to local star-forming galaxies and the hosts of core-collapse SNe,
- SLSN-II hosts
  - show a larger range
    - e.g., Lunnan+14; Leloudas+15; Angus+16; Perley+16
- Comparison between SLSN-I and long-duration GRB hosts ➔ controversial issue
  - SLSN-I hosts have lower stellar mass and SFR
    - Leloudas+15; Angus+16
  - similar in terms of SFR, stellar mass, and specific SFR
    - Lunnan+14; Japelj+16
- SLSN-I occur in galaxies with strong nebular emission lines
  - common properties with Extreme Emission Line Galaxies (EELGs)
    - e.g., Leloudas+15; Perley+16



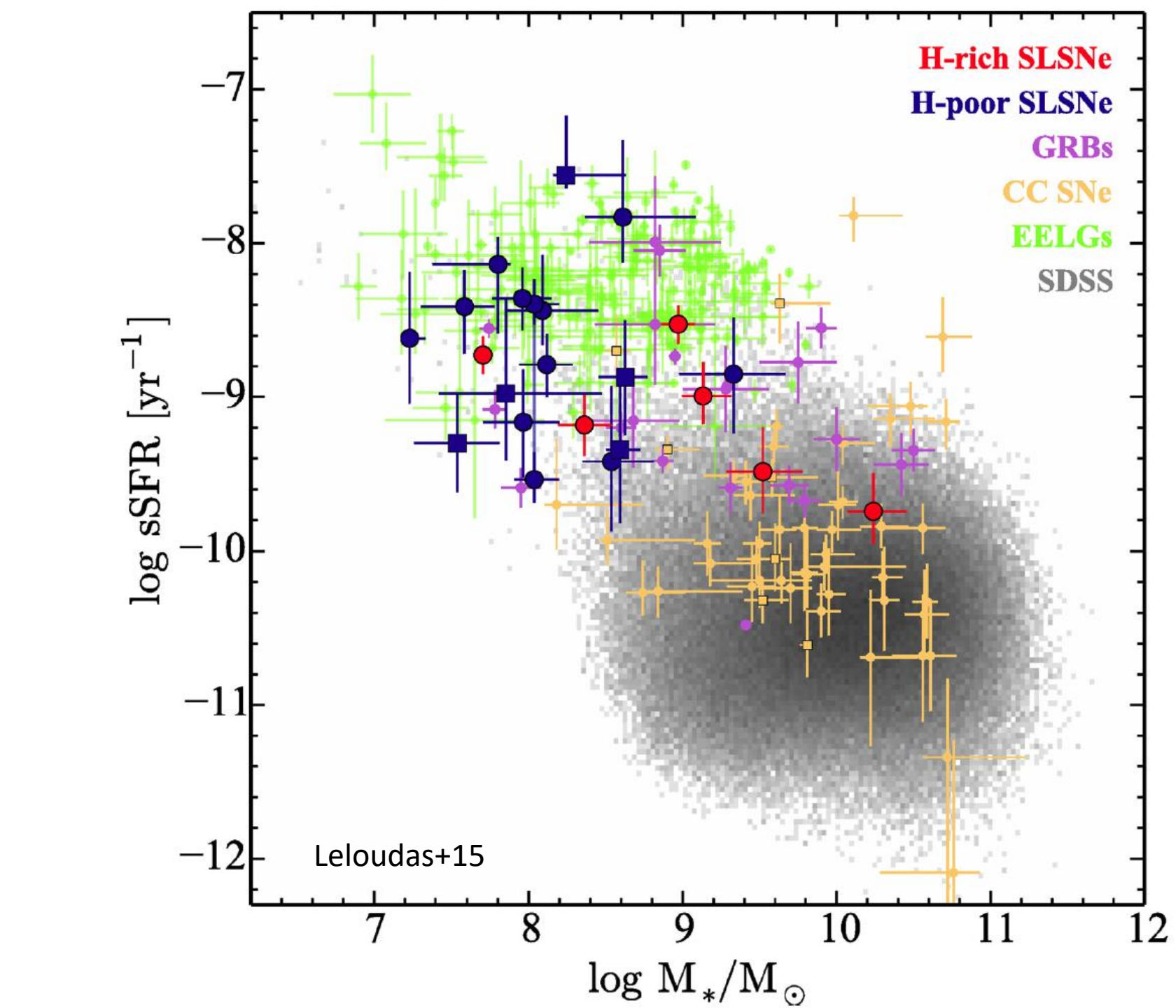
HST NIR images
(Angus+16)

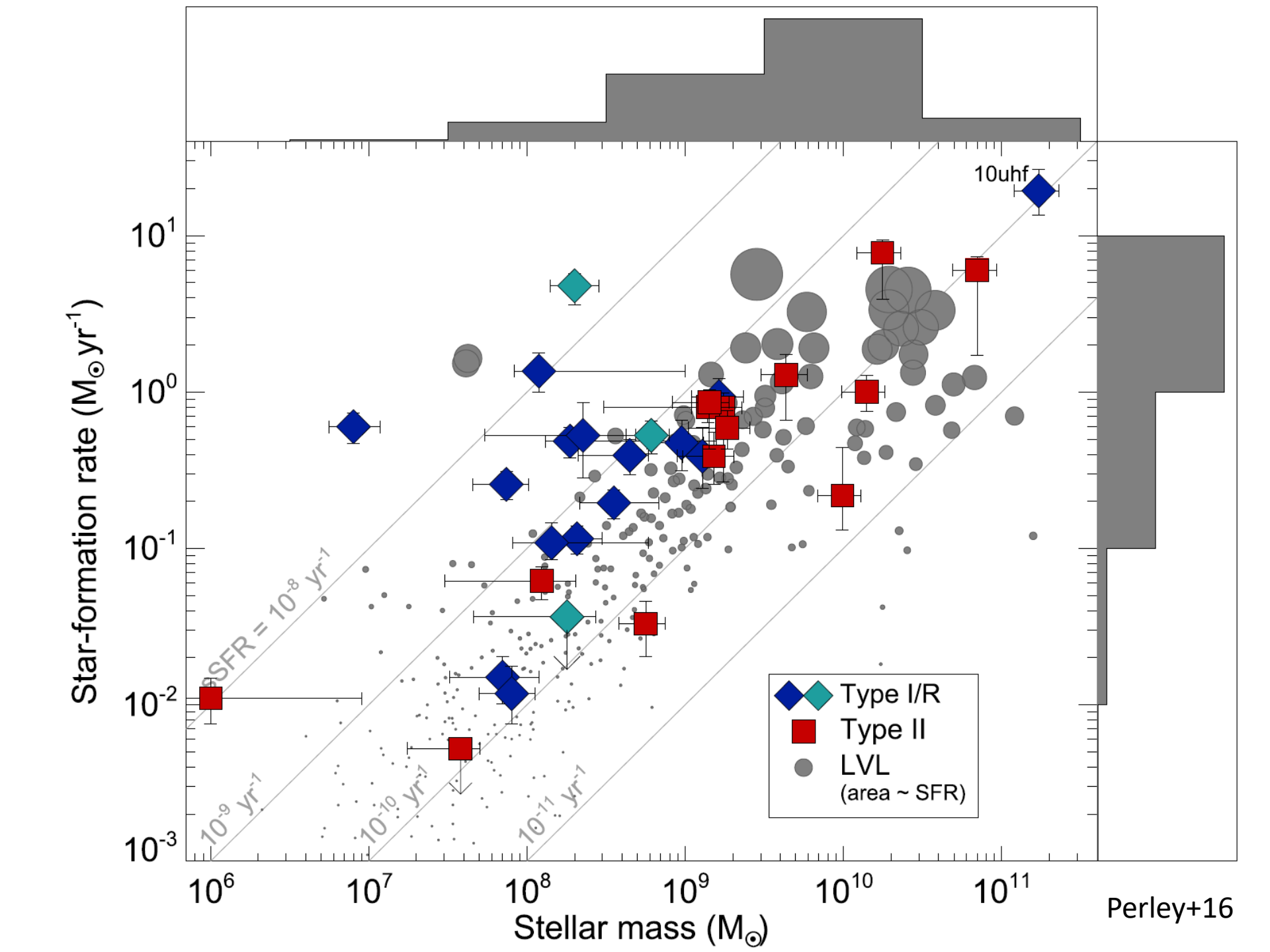


R or I-band images
(Perley+16)



- Extreme Emission Line Galaxies (EELGs): low-mass, metal-poor, intensively star-forming galaxies with strong nebular lines and a hard ionizing radiation field


H-rich SLSNe
H-poor SLSNe
GRBs
CC SNe
EELGs
SDSS
Leloudas+15
log sSFR [yr^{-1}]
log M$_*$/M$_\odot$
−7
−8
−9
−10
−11
−12
7
8
9
10
11
12

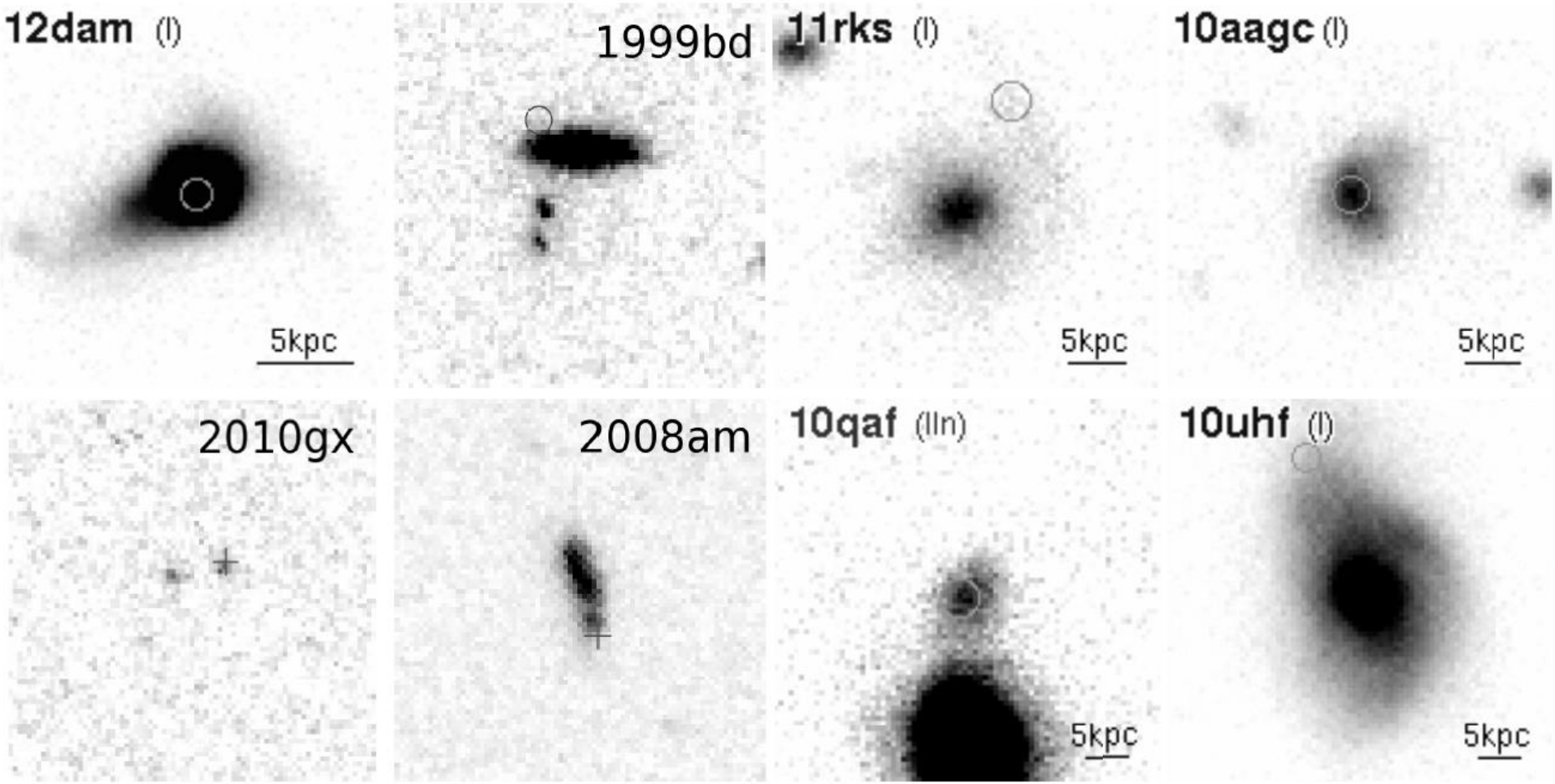

10uhf
Star-formation rate ($M_\odot yr^{-1}$)
Stellar mass ($M_\odot$)
SFR = 10^{-8} yr^{-1}
10^{-9} yr^{-1}
10^{-10} yr^{-1}
10^{-11} yr^{-1}
Type I/R
Type II
LVL
(area ~ SFR)
Perley+16

VLA Proposal 2017A

- 3 GHz continuum observations of 8 hosts at $z < 0.3$
- To examine whether there is significant dust-obscured star formation or not
  - ➔ allow us to derive true star forming activity
  - Studies of SLSN hosts have been made exclusively in UV/optical/NIR, which are sensitive to dust extinction

- 1. no significant obscured star formation
  - confirm the similarity between SLSN-I hosts and EELGs in M*-SSFR plane
  - ➔ support the idea that SLSN-I result from very first star exploding in a starburst, earlier than GRBs
- 2. significant obscured star formation
  - the hosts are starbursts
  - preferred by the progenitor model of dynamical interactions and collision of stars in dense young star clusters

VLA Targets

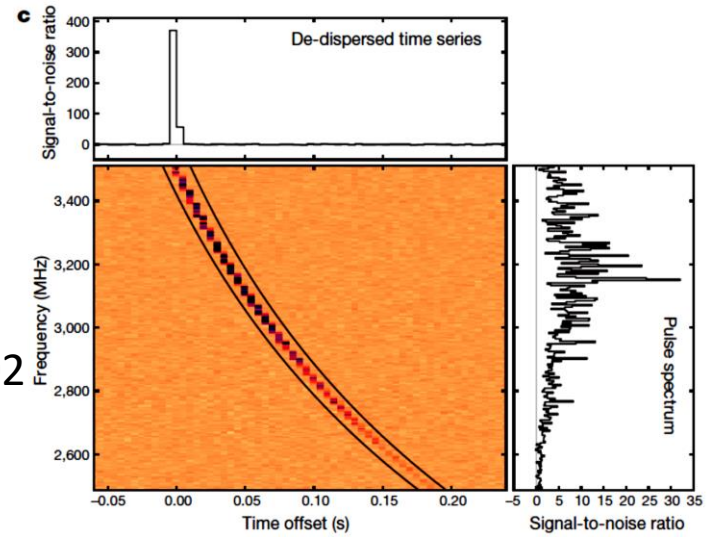


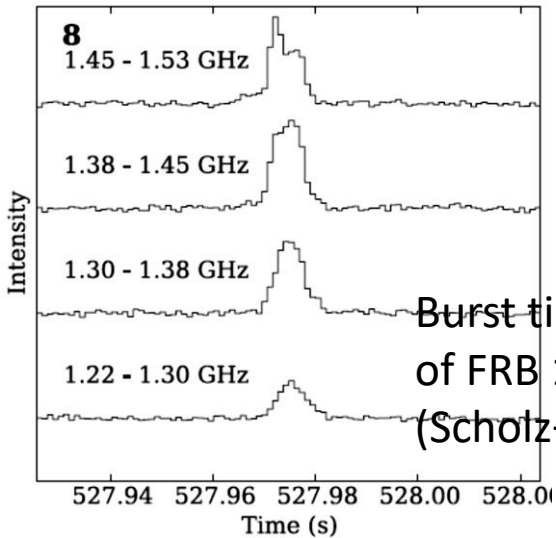
NIR images of the targets obtained by ground-based telescopes or HST (Angus+16; Perley+16). Circles and crosses represent SLSN positions. 10” x 10”

Fast Radio Burst (FRB)

- 継続時間が数ミリ秒の謎のフラッシュ現象
  - Parks, Arecibo, GBT
  - peak flux ~ 0.5-1 Jy at 1.4 GHz
  - dispersion measures (DMs) >~ 300 pc cm^-3
  - ➔ extragalactic origin?
    - SN? GRB? magnetar?

Time–frequency data of FRB 121102 (Chatterjee+17)

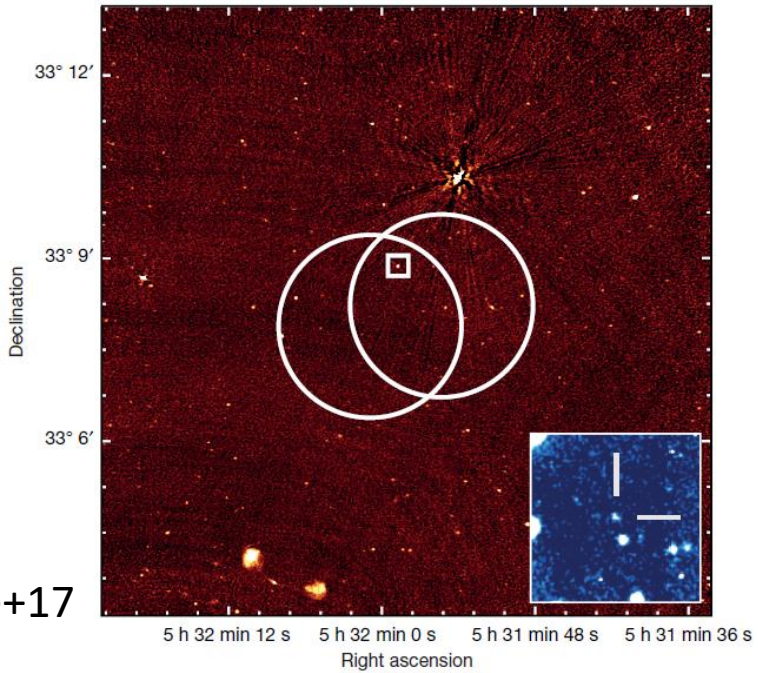




Burst time series of FRB 121102 (Scholz+16)

Host Galaxy of FRB 121102

- VLA detection of the repeating FRB 121102
- Host galaxy at z = 0.19273
  - dwarf, low-mass, low-metallicity galaxy
  - ➔ similar to long GRB hosts and SLSN hosts



Chatterjee+17

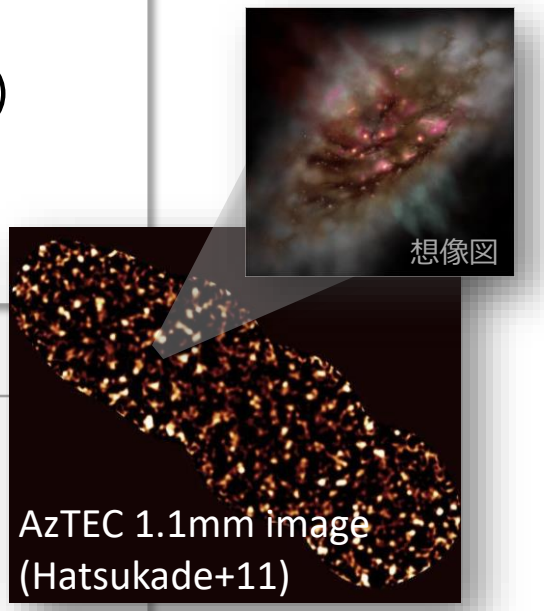
M* (Msun)	(4-7) x 10^7
SFR(Hα) (Msun/yr)	0.4
12+log[O/H]	<8.4 (3σ)

Tendulkar+17

② サブミリ波銀河

サブミリ波銀河：ミリ波・サブミリ波で明るい銀河

- ダストに厚く覆われた大規模星形成銀河
- FIR luminosity >$10^{12\text{-}13}$ Lsun（ダスト熱放射）
- 星形成率 ～数100-1000 Msun/yr
- 赤方偏移 z～1-4, z > 4, 5 のものも



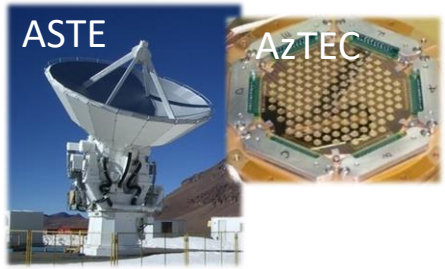
サブミリ波銀河の重要性

- ダストに隠された星形成銀河への寄与
- 遠赤外背景放射への寄与
- 近傍宇宙の大質量楕円銀河の祖先？

個数密度分布を調べることが重要な課題

ナンバーカウントの作成

ASTE望遠鏡搭載AzTECカメラによるサーベイ

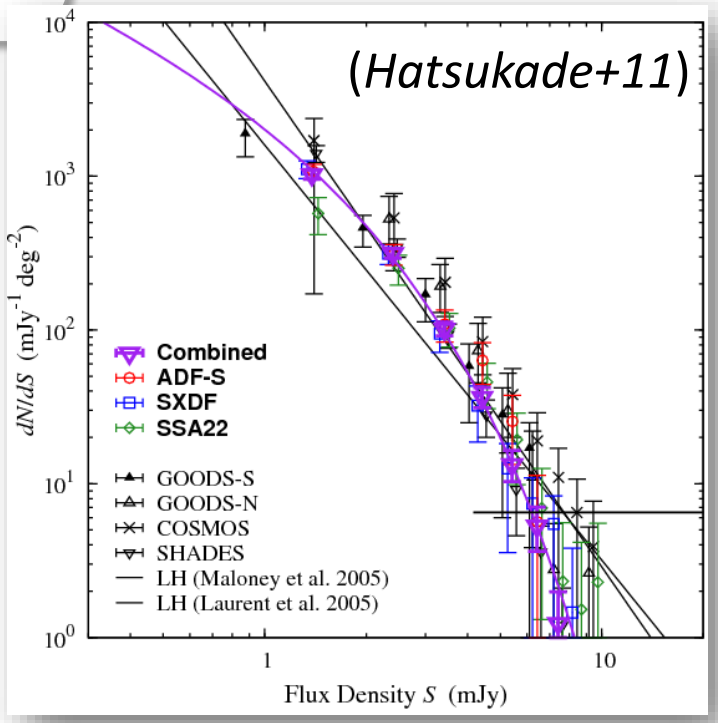


- 波長1.1mm
- サーベイ面積：3平方度以上
- 1000個以上のサブミリ波銀河を検出
  （850um-1.1mm帯で最多）

ナンバーカウント

- 1.1mmでの宇宙背景への寄与はおよそ**10%**

より暗い (<1mJy) ソースが大きく寄与



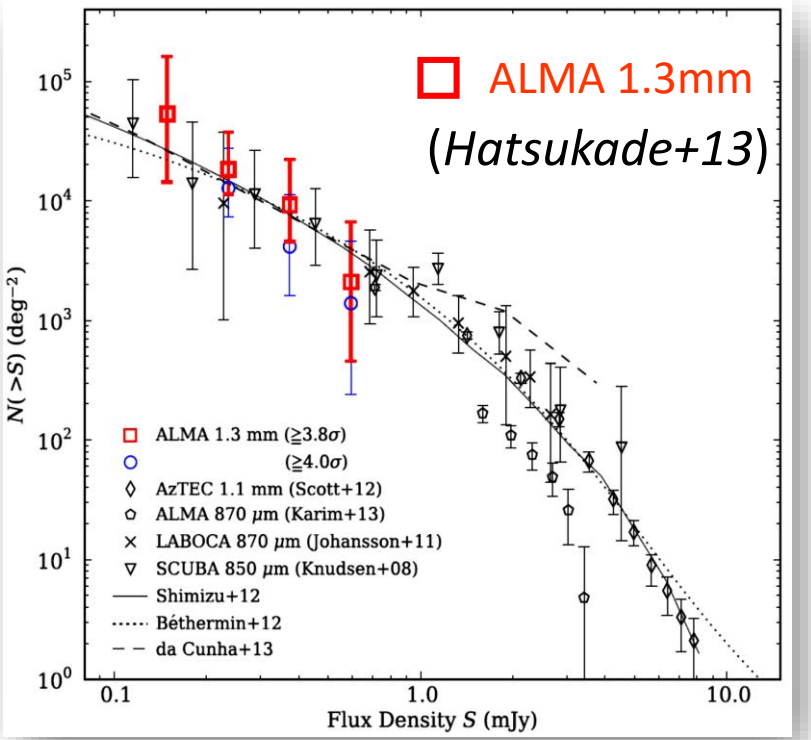
ナンバーカウント：Faint End

ALMAを用い、最も暗い部分のナンバーカウントを作成

- ALMA cycle 0にて、20個の遠方星形成銀河を観測
- 偶然に15個の暗いソースを検出 (AzTEC観測より一桁暗い)

暗いサブミリ波銀河

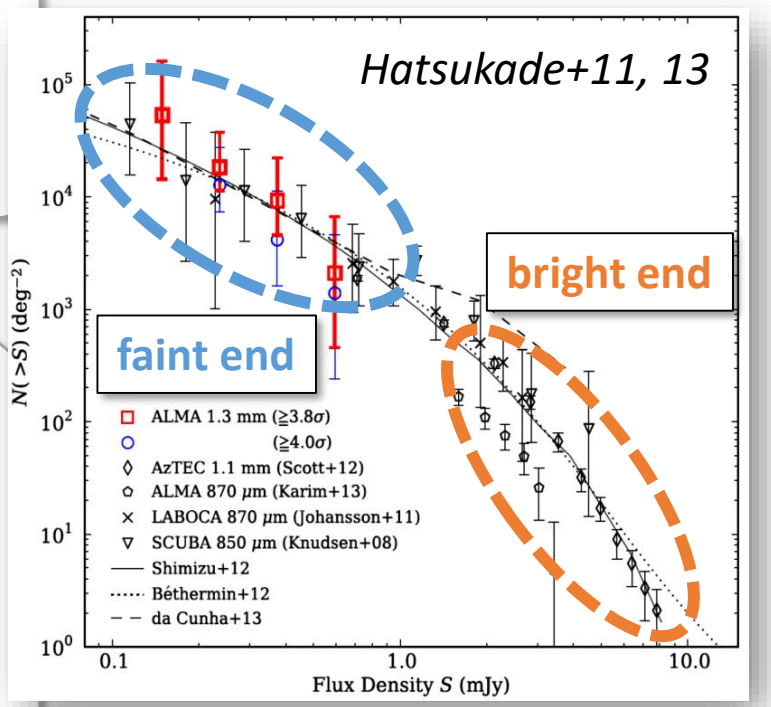
- 1.3mmでの宇宙背景への寄与はおよそ**80%**
- これまで見つかっていたサブミリ波銀河と比べると、より**一般的な星形成銀河に近い**



サブミリ波銀河ナンバーカウントの決定

ALMA・ASTE/AzTECを用いた観測

ナンバーカウントの faint end - bright end を統一的に理解



問題点

bright end

- 複数の銀河を一つとしてカウント？
- 重力レンズされた銀河の寄与

faint end

- サンプル数が少なく不定性大
- 星形成銀河周りで検出されたソースにはバイアス？

ALMA

bright end への制限

- AzTECで検出した明るい333個のサブミリ波銀河を高空間分解能観測 (1 arcsec)
- ALMA cycle 2, 3 (PI: Hatsukade)

→ **複数のソースが寄与しているか検証**

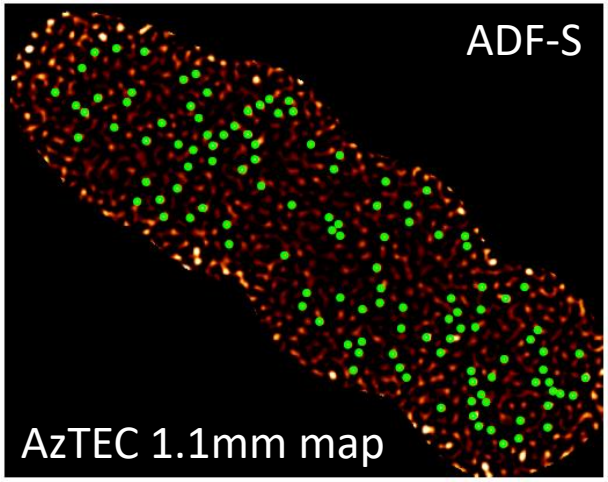
faint end への制限

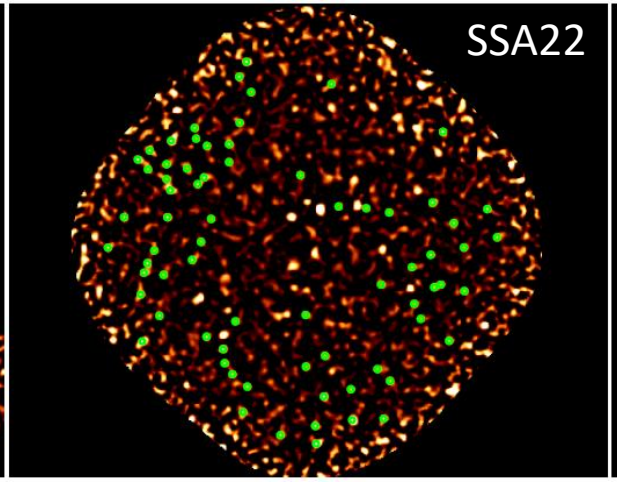
- SXDS 105” x 50” (PI: K. Kohno)
- GOODS-S 4.8’ x 4.8’ (PI: K. Kohno)

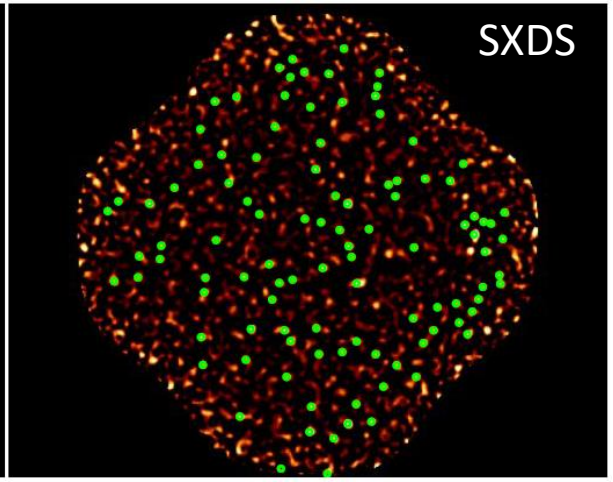
→ **一般領域での広視野探査により**
バイアスのないサンプルを取得

ALMA Observations of bright AzTEC Sources in ADFS/SXDS/SSA22

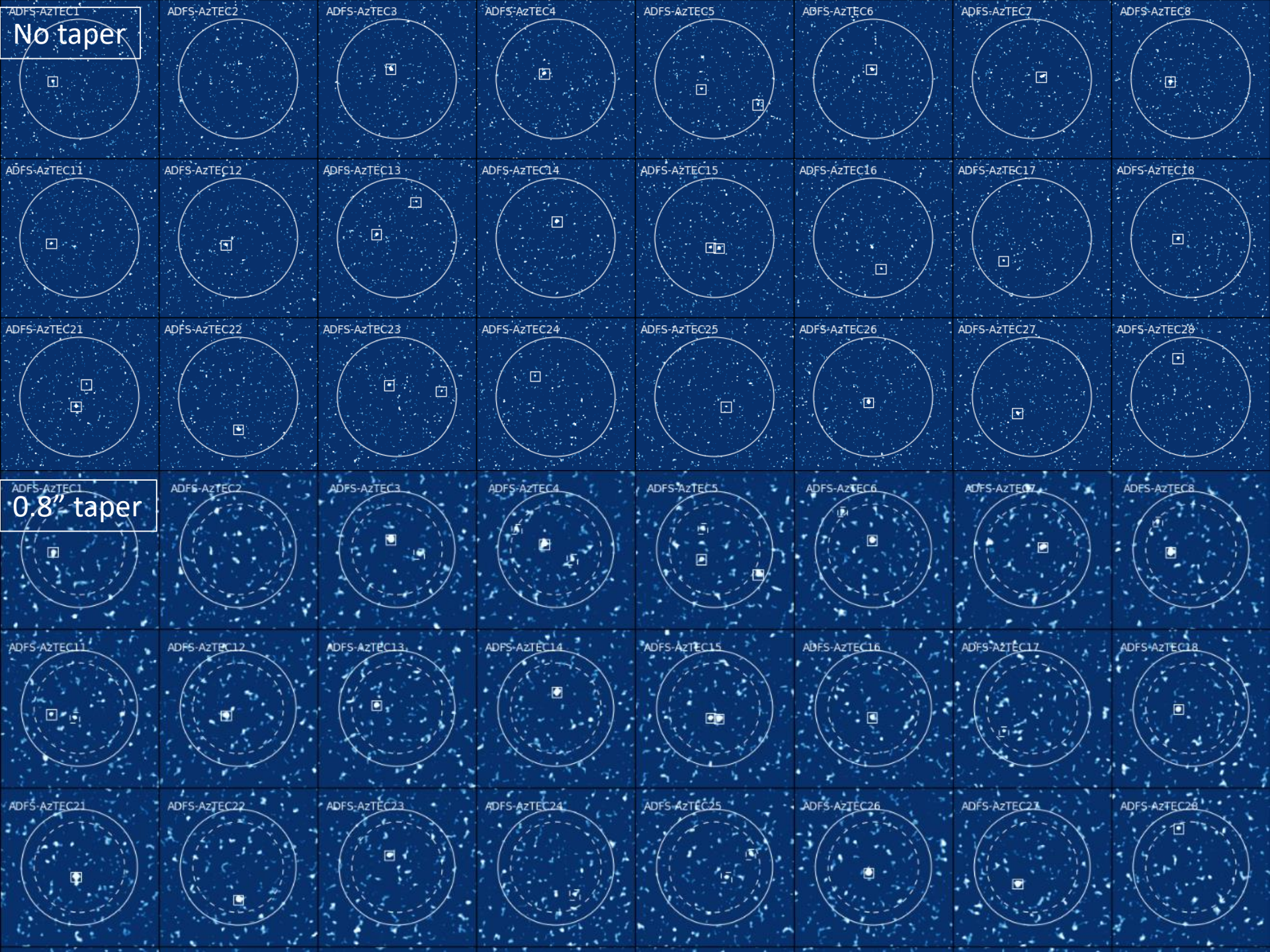
- cycle 2 & 3 (PI: B. Hatsukade)
- 333 sources
- Band 6 (1.1mm)
- proposed rms: 180 uJy



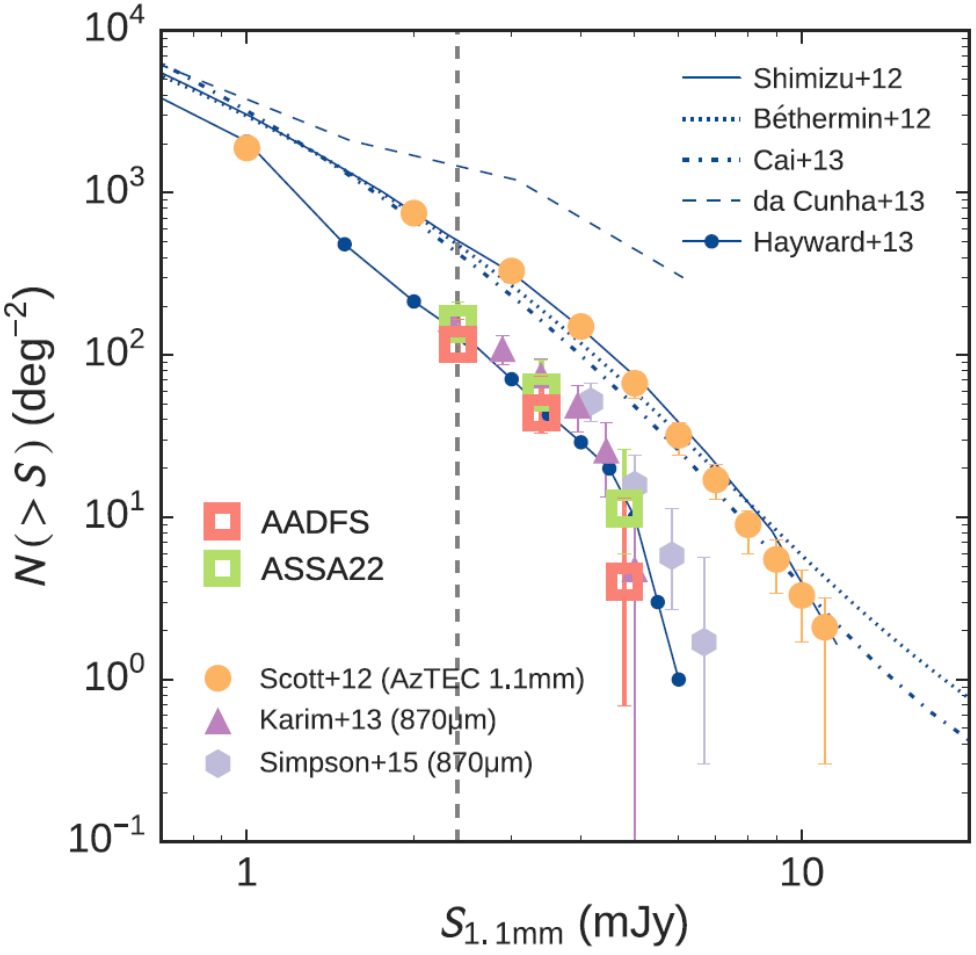


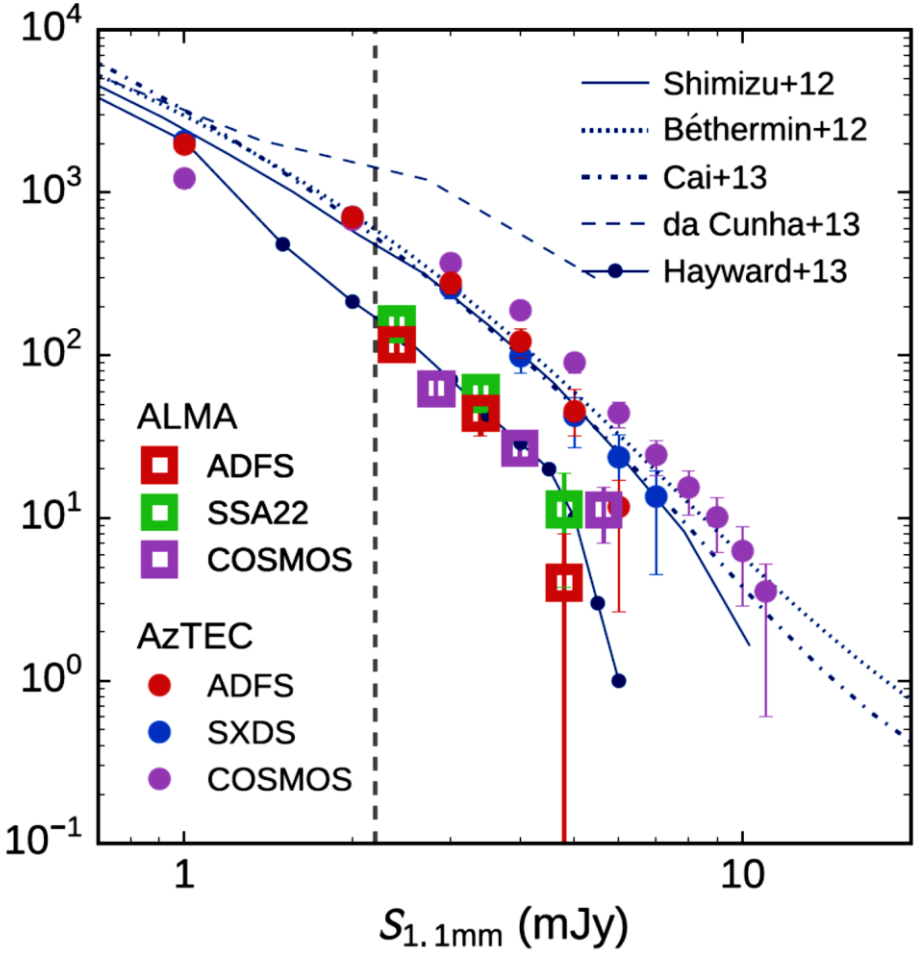


	Area (arcmin2)	rms (mJy/beam)	N (total)	N (>=2.4mJy)
ADF-S	909	0.38-0.80	233	100
SSA22	973	0.73-1.30	125	91
SXDS	954	0.52-0.92	280	142


No taper
ADFS-AzTEC1
ADFS-AzTEC2
ADFS-AzTEC3
ADFS-AzTEC4
ADFS-AzTEC5
ADFS-AzTEC6
ADFS-AzTEC7
ADFS-AzTEC8
ADFS-AzTEC11
ADFS-AzTEC12
ADFS-AzTEC13
ADFS-AzTEC14
ADFS-AzTEC15
ADFS-AzTEC16
ADFS-AzTEC17
ADFS-AzTEC18
ADFS-AzTEC21
ADFS-AzTEC22
ADFS-AzTEC23
ADFS-AzTEC24
ADFS-AzTEC25
ADFS-AzTEC26
ADFS-AzTEC27
ADFS-AzTEC28
0.8” taper
ADFS-AzTEC1
ADFS-AzTEC2
ADFS-AzTEC3
ADFS-AzTEC4
ADFS-AzTEC5
ADFS-AzTEC6
ADFS-AzTEC7
ADFS-AzTEC8
ADFS-AzTEC11
ADFS-AzTEC12
ADFS-AzTEC13
ADFS-AzTEC14
ADFS-AzTEC15
ADFS-AzTEC16
ADFS-AzTEC17
ADFS-AzTEC18
ADFS-AzTEC21
ADFS-AzTEC22
ADFS-AzTEC23
ADFS-AzTEC24
ADFS-AzTEC25
ADFS-AzTEC26
ADFS-AzTEC27
ADFS-AzTEC28

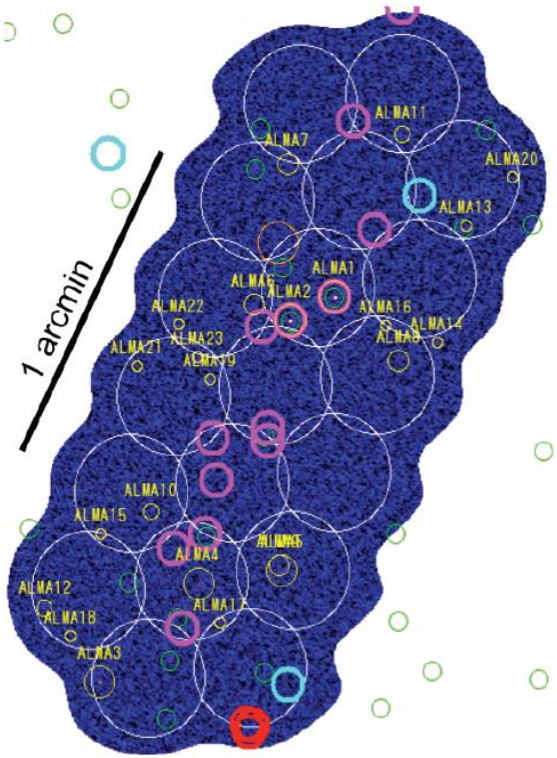
Number Counts





SXDS-ALMA Survey

- ALMA observations of a contiguous 105” x 50” (or 2 arcmin^2) window in the SXDF-UDS-CANDELS field
- PI: K. Kohno
- Band 6 (1.1 mm, 274 GHz)
- 19-point mosaic
- Total observing time: 3.6 hours
- Beam size: 0.53” x 0.41”
- Typical rms noise level: 55 uJy/beam
- Publications:
  - survey design, source catalog: Kohno+ in prep.
  - properties of Hα-selected galaxies: Tadaki+15
  - multi-wavelength analysis: Yamaguchi+ in prep., Wei-Hao+ in prep.

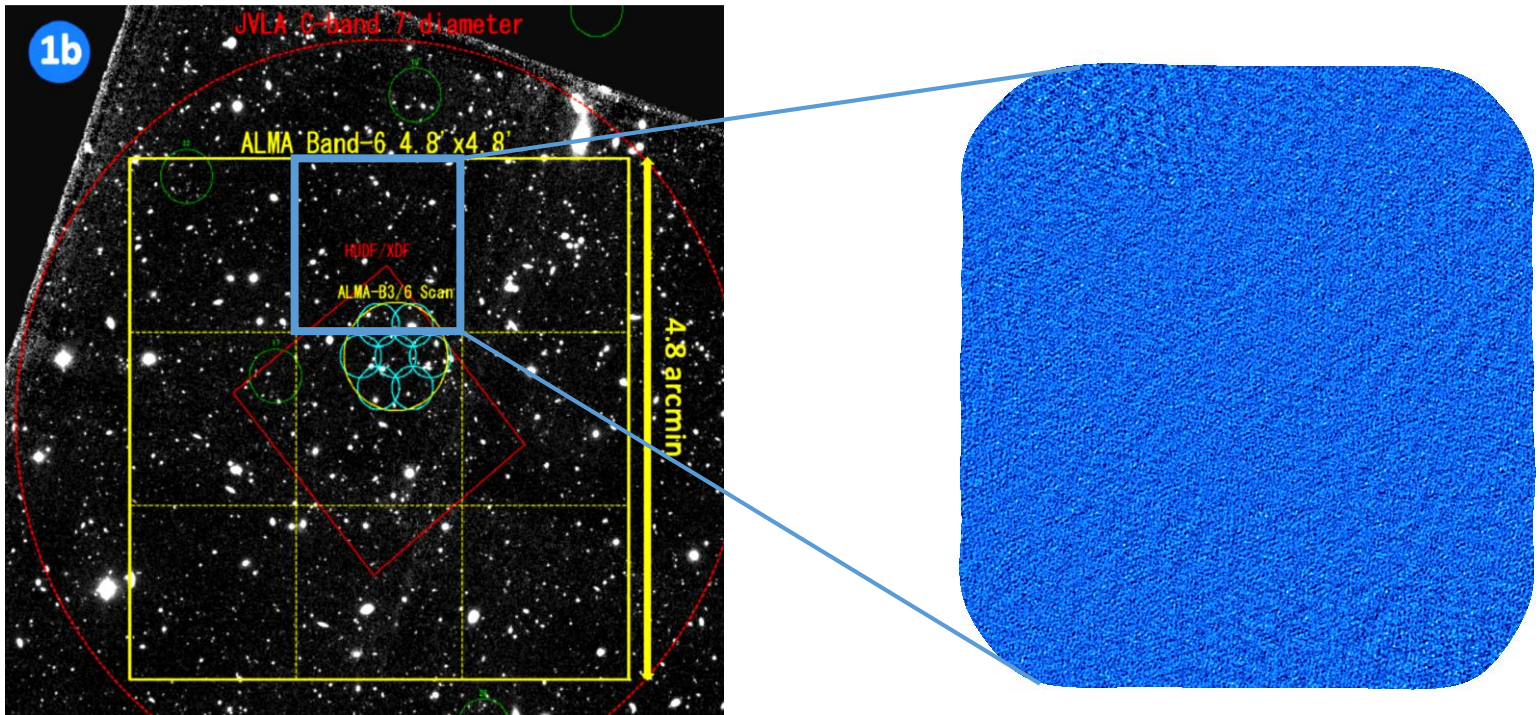


Kohno+15, IAU proc.
Kohno+ in prep.

GOODS-S-ALMA Survey

- ALMA cycle 4 (PI: K. Kohno)
  - survey area: 23 arcmin^2 (4.8’ x 4.8’)
    - x10 times wider than SXDF-ALMA
  - proposed depth: 60 uJy (1σ)
    - c.f., 55 uJy in SXDF-ALMA

➔ Expected number of detections ≈ 100-200 sources (≥4σ)???



GOODS-S-ALMA Survey: preliminary

- data of tune1-north (1.6’ x 1.6’)
  - rms ~ 110 uJy/b (taper 0.5”)
- expected number of sources (SN>5)
  - ~1-10